Proceedings of the Conference

Evolution of Cosmic Objects through their Physical Activity

dedicated to
Viktor Ambartsumian's
100th anniversary

National Academy of Sciences of the Republic of Armenia
V.A. Ambartsumian Byurakan Astrophysical Observatory

Proceedings of the Conference

"Evolution of Cosmic Objects through their Physical Activity"

dedicated to Viktor Ambartsumian's 100th anniversary

15-18 September 2008
Yerevan - Byurakan, Armenia

Editors:
Haik Harutyunian, Areg Mickaelian, Yervant Terzian

Yerevan
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2010

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2010

Proceedings of the Conference "*Evolution of Cosmic Objects through their Physical Activity*", dedicated to Viktor Ambartsumian's 100th anniversary, *held on 15-18 September 2008 in Yerevan-Byurakan, Armenia*. ***Editors:*** Haik Harutyunian, Areg Mickaelian, Yervant Terzian. Yerevan: "Gitutyun" Publishing House of NAS RA, 2010, 355 pages, including figures.

The book presents papers of the Proceedings of the conference dedicated to Viktor Ambarstumian's 100 anniversary held in 2008 in Yerevan and Byurakan. It is divided into 5 parts related to the sessions held during the conference: *Stars and Nebulae*, *Pulsars / Neutron Stars*, *Activity in Galaxies*, *Cosmology*, *Light Scattering and Radiative Transfer*, and *Miscellanea*. All these fields reflect extremely productive results and achievements obtained by Viktor Ambarstumian during his long scientific life. Most of the authors have used Ambarstumian's ideas to obtain new results and give new interpretations on various cosmic phenomena, which come to prove the importance of Ambarstumian's works nowadays too. The book also includes a preface by the editors, the list of participants of the conference, report on the opening session at NAS RA, and author index at the end.

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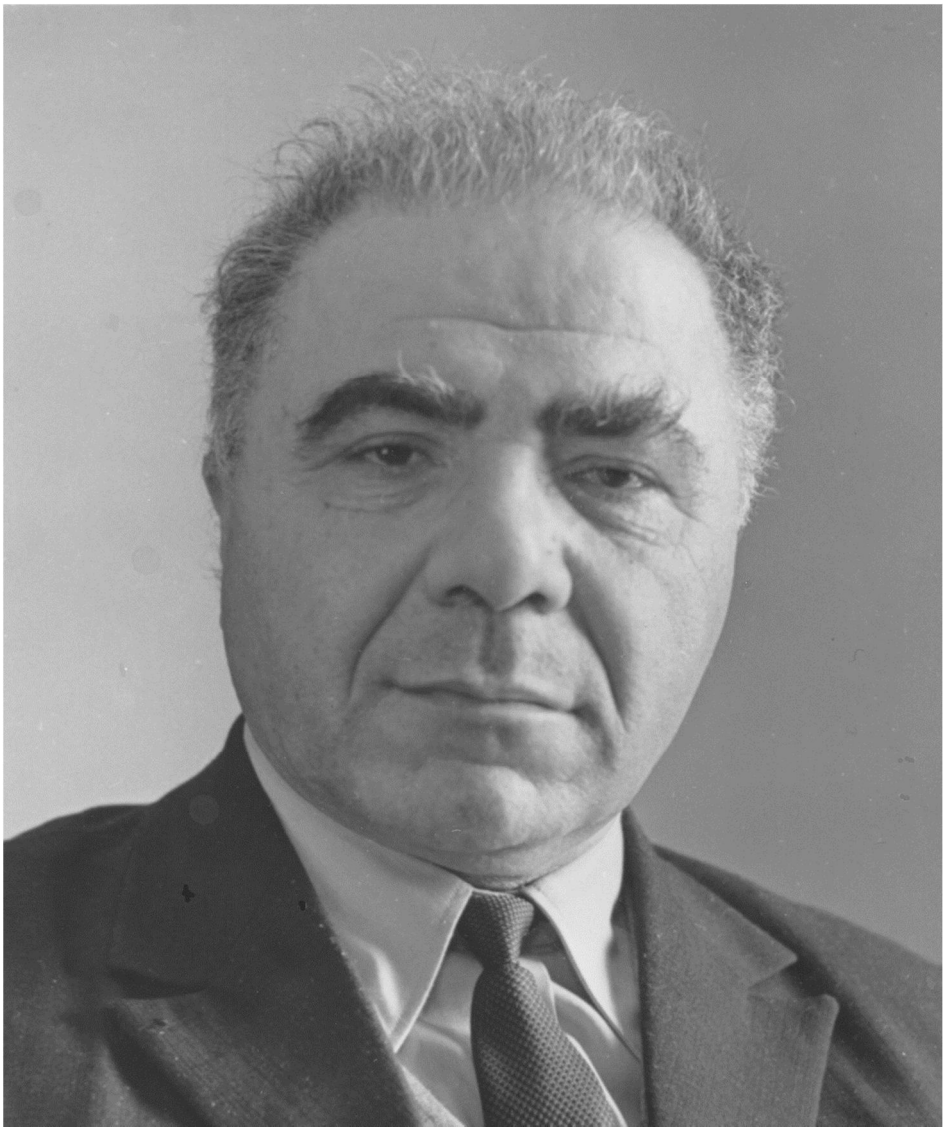


Viktor Ambartsumian
(1908-1996)

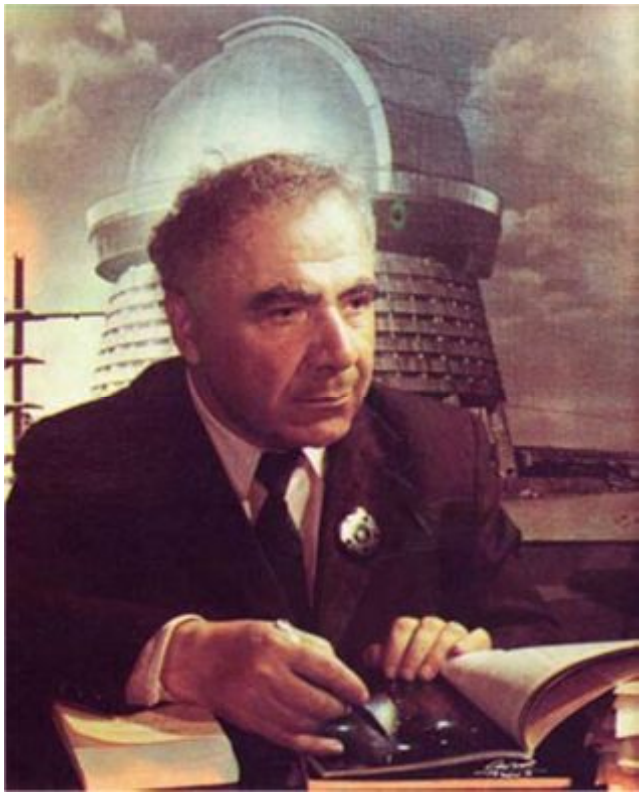
PREFACE

Victor Ambartsumian's scientific heritage is rather voluminous and diversified. His first scientific papers were devoted to some actual problems of mathematical and theoretical physics, the quantum field theory and the structure of atomic nuclei, the age of the Universe and radiation transfer theory, and other topics. These studies of the 30s and 40s of the last century had a theoretical nature, were highly mathematical, and pioneered new mathematical methods of analyses. Later on the elegant mathematical computations were substituted for studies of more physical problems. Of course, such a differentiation of the sphere of his scientific interests is rather arbitrary and all his scientific researches originated from physical problems but with mathematical rigor. Twenty years ago S. Chandrasekhar noted: "Academician Ambartsumian's realm does not divide astronomy and astrophysics into its conventional parts: theoretical and observational. He is an astronomer *par excellence*".

On the other hand, any historian of science could conclude that Ambartsumian had a special attitude towards unstable phenomena and he studied active processes taking place in various hierarchical levels of our universe during all his life. The phenomena of activity and instability of cosmic objects or their systems which are related to their structural, physical or other changes always hints at an evolutionary path to be found. Some of Ambartsumian's results based on the study of activity (instability) processes are widely known. One can recall his ideas on the beta-decay or studies concerning the instability of planetary nebulae or "evaporation" of star clusters etc. However, the astronomical community worldwide is much more aware about his studies of stellar associations and active galactic nuclei. The first series of investigations led him to show in the 40s of last century the existence of young stars and consequently the continuing nature of the star formation process. Undoubtedly that was a very important astronomical result but also it had much deeper philosophical significance than solving a particular astronomical problem. Later the concept of the activity of galactic nuclei, put forward in the mid 50s received a hostile reception from the astronomical community without any exception. He was alone in his fight to promote the idea of the AGNs. Of course, both physical intuition and scientific competence were needed for arriving at an extraordinary for that time conclusion on the activity of galactic nuclei. However, these purely scientific qualities might have been insufficient if he had not personal courage helping him forward in an openly distrustful

atmosphere.

Nowadays, after 50-60 years have elapsed, Ambartsumian's ideas both in the field of star formation studies and AGN investigations are among the most actively developing scientific topics. Yet, new generations of astronomers working in these fields do not even know Ambartsumian's name! The organizers of this meeting decided to dedicate this event to the active processes and their evolutionary significance indicating thus again the very important role Ambartsumian played in this area of research in revealing the evolutionary paths for cosmic objects. It is worth recalling his words on the activity phenomena in the galaxies: "These processes often reach such a large scale that they influence the appearance and integral parameters of the galaxies. Therefore the study of the nuclei and the study of the structure of galaxies with their evolutionary changes cannot be separated".



Nevertheless, the organizers of this meeting decided not to be very restrictive on the subject area of this conference. The meeting devoted to the centenary of a

great scientist cannot be limited in the frame of a very special subject only. That is why, many other reports not related to the activity phenomena have been accepted for the conference and are included in this volume as well.

87 scientists from 12 countries participated in the conference *"Evolution of cosmic objects through their physical activity"*. Many of them personally knew Ambartsumian and some have worked with him as well. The volume is divided into 6 Sections according to the sessions held during the conference: Stars and Nebulae, Pulsars / Neutron Stars, Activity in Galaxies, Cosmology, Light Scattering and Radiative Transfer, and Miscellanea.

Opening of V.A. Ambartsumian's bust in front of the main builing of the Byurakan Observatory. Haik Harutyunian, Gennadi Mesyats, Radik Martirosyan, V.A. Ambartsumian's sons Rafael and Ruben Ambartsumians.

However, the Centennial meetings and celebrations took place during the whole year in 2008 at the Byurakan Astrophysical Observatory in Byurakan, Armenia, and also in Yerevan at the Armenian National Academy of Sciences. Most of the important events were organized in September around Ambarstumian's birthday; there was a solemn meeting at the Armenian National Academy of Sciences on Sep 12, the international conference *"Evolution of cosmic objects through their physical activity"* on Sep 15-18, another conference *"Physics of compact objects"* on Sep 17-23 in Yerevan, opening of Ambartsumian's bust in the Byurakan Observatory and visit to his cemetery on Sep 18, a ceremonial meeting and concert at the Opera House in Yerevan on Sep 19 (with

participation of the President of Armenia, Prime-Minister, Catolicos, and many important guests), and the Second Byurakan International Summer School for young astronomers *"Practical Astrophysics"* on Sep 20-30. In addition, a book with memories about V.A. Ambartsumian (compiled by E.S. Parsamian) was presented and distributed to the guests during the registration of the participants of the meeting. A DVD with all available information about Ambartsumian (compiled by A.M. Mickaelian, edited by H.A. Harutyunian) was released and presented on Sep 15 as well. In addition, H.A. Harutyuniana and A.M. Mickaelian prepared a booklet about Ambartsumian's main scientific results and achievements; top 20 results entered this booklet together with some biographical data and other information and photographs.

Ceremonial meeting and concert at the Yerevan Opera House on September 19, 2008.

We would like to acknowledge support for organization of this conference by the Armenian Government, Armenain National Academy of Sciences (NAS RA), Byurakan Astrophysical Observatory (BAO), and the International Science and Technology Centre (ISTC).

Haik Harutyunian, Areg Mickaelian, Yervant Terzian
Editors

Byurakan, Armenia and Ithaca, New York, USA
August 2010

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CONTENTS

Session 3. ACTIVITY IN GALAXIES

Session 4. COSMOLOGY

Session 5. LIGHT SCATTERING AND RADIATIVE TRANSFER

Session 6. MISCELLANEA

LIST OF PARTICIPANTS

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OPENING SESSION

15 Sep 2008,
Armenian National Academy of Sciences, Yerevan

The official opening session of the conference took place on Sep 15 at the National Academy of Sciences in Yerevan. *Prof.* Radik Martirosyan, the President of NAS RA opened the session and welcomed the guests. His welcome address was followed by speeches by *Prof.* Jean-Claude Pecker (France), *Dr.* Bo Reipurth (USA), *Dr.* Natalia Shakht (Russia), *Prof.* Rolan Kiladze (Georgia) et al.

Prof. Radik Martirosyan, President of NAS RA, welcomes the participants of the conference.

Prof. E.V. Chubaryan (Armenia), *Prof.* J.-C. Pecker (France), and *Prof.* J. Narlikar (India) at the opening session.

At the end of the session, Areg Mickaelian presented the newly released DVD completely devoted to Viktor Ambartsumian and his activity (**Viktor Ambartsumian – 100, DVD, compiled by A.M. Mickaelian, edited by H.A. Harutyunian, Yerevan, 2008**). The DVD was compiled to have a full information concerning *Prof.* V.A. Ambartsumian collected together, including his biography, scientific results, achievements, publications, photos, videos, etc. Among the most important materials that are given for the first time are: a newly compiled chronological dates of Ambartsumian's life (330 items) and its statistics, an interactive CV, newly compiled list of 135 achievements and their statistics, a list of 20 most important scientific results by Ambartsumian (according to H.A. Harutyunyan and A.M. Mickaelian), list of 71 publications about Ambartsumian, most complete list of Ambartsumian's 610 publications

(including 225 original scientific papers) and statistics, PDF files of 237 original publications (including 18 books) and 37 translated ones, 433 photos describing Ambartsumian's life and activity, three video movies, a list of items named after Ambartsumian, etc. Most of the material is cross-translated and is available in English, Russian, and Armenian.

The book (**Viktor Ambartsumian – 100, compiled by E.S. Parsamian, 556 p., Yerevan 2008**) is a collection of memories and statements about V.A. Ambartsumian and is a result of 10 years work by *Prof.* E.S. Parsamian. 70 authors from various countries have contributed, included famous scientists such as Jan Oort, Subrahmanian Chandrasekhar, Geoffrey Burbidge, Adrian Blaauw, Halton Arp, Lodewijk Woltjer, Jean-Claude Pecker, Yervant Terzian, and many others. In addition, Ambartsumian's biography in three languages (Armenian, Russian, English) by Prof. L.V. Mirzoyan, a chronological list of his achievements, and a list of the most important publications are attached.

Session 1. STARS AND NEBULAE

V.A. Ambartsumian's contribution in the field:

For the first time the **amount of matter and masses of envelopes ejected due to the Novae and Supernovae explosions** was estimated. Presently known values of 0.00001 and 1 solar masses for Novae and Supernovae phenomena have been found, respectively (together with *N.A. Kozirev*, 1933).

Ref.: W.A. Ambarzumjan, N.A. Kosyrew – Uber die Massen der von den neuen Sternen ausgestossenen Gashullen (On the Masses of Envelopes thrown out by Novae) // *Zeitschrift fur Astrophysik, 7, 320-325, 1933 (in German).*

For the first time the **distribution function of stellar 3D velocities has been obtained only using radial velocities and coordinates** of stars. This problem has been reduced to the numerical inversion of the Radon transform. Four decades later the same mathematical scheme was applied for the construction and exploitation of computer tomography (1936).

Ref.: V.A. Ambartsumian – On the Derivation of the Frequency Function of Space Velocities of the Stars from the Observed Radial Velocities // *MNRAS, 96, 172-179, 1936.*

The **nature and patchy structure of the interstellar absorbing matter** (dust component of the Milky Way) was revealed and the **mean absorption of individual clouds was estimated** to be equal to 0.2 magnitudes (together with *Sh.G. Gordeladze*, 1938).

Ref.: V.A. Ambartsumian, Sh.G. Gordeladze – Problem of Diffuse Nebulae and Cosmic Absorption // *Bulletin of the Abastumani Astrophysical Observatory, 2, 37-68, 1938 (in English and Georgian).*

The **theory of the fluctuations in brightness of the Milky Way** was formulated. In the simplest form it asserts that the probability distribution of fluctuations in the brightness of the Milky Way is invariant to the location of the observer (1944).

Ref.: V.A. Ambartsumian – To the Theory of Fluctuation in the Brightness of the Milky Way // *Doklady USSR Acad. Sci., 44, 244-247, 1944 (in Russian).*

Discovery of stellar associations, groups of hot giants and T Tauri stars. It was shown for the first time that the star formation process continues at all stages of the evolution of our Galaxy, including the present one and that the star formation is a permanent process. A conclusion was drawn that **stars are formed** not individually, but **in groups** (1947).

Ref.: V.A. Ambartsumian – Evolution of Stars and Astrophysics // *Acad. Sci. ArmSSR, 39 p., Yerevan, 1948 (in Armenian).* V.A. Ambartsumian – Preliminary Data on O-Associations in the Galaxy // *Doklady USSR Acad. Sci., 68, 21-22, 1949 (in Russian).*

Theoretical prediction of the phenomenon of expansion of stellar associations. Revealing the importance of the stellar associations as dynamically unstable entities. Statistics of the Trapezium Orionis type systems and a **proof of disintegration of the young stellar systems** (together with *B.E. Markarian*, 1949-1951).

Ref.: V.A. Ambartsumian – Stellar Associations // *Astron. Zh., Vol. 26, No. 1, p. 3-9, 1949 (in Russian).* V.A. Ambartsumian, B.E. Markarian – Stellar Association around P Cygni // *Communications of the Byurakan Observatory, 2, 3-17, 1949 (in Russian).* V.A. Ambartsumian – On the Statistics of Trapezium type Multiple Systems // *Doklady Acad. Sci. ArmSSR, 13, 129-131, 1951 (in Russian).*

Statistical studies of the flare stars revealed their evolutionary status: a method for estimation of the total number of flare stars in a star system based on the number of the observed flares. The flare activity was shown to be the regular stage in the evolutionary path of the low luminosity and low mass late-type stars (1968).

Ref.: V.A. Ambartsumian – On the Statistics of Flare Objects // *Proc. symp. "Stars, Nebulae, Galaxies", devoted to the 60th anniversary of academician V.A. Ambartsumian, held in Byurakan, 16-19 Sep 1968. Acad. Sci. ArmSSR, 283-292, Yerevan, 1969 (in Russian).*

FUors and Early Stellar Evolution

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Abstract. Ambartsumian was among the first researchers who recognized the importance and uniqueness of FUors, the term he coined for the rare outburst sources of the FU Orionis type. A wealth of observational data and concomitant theoretical work has advanced our understanding of FUors in the intervening almost 40 years. These results are summarized in this brief review, with special emphasis on observations related to the binarity of FUors. It is argued that at least some FUors represent the transitions of young binaries from a wide to a close system, and are thus signposts of the formation of a spectroscopic binary. Finally, we discuss in some detail recent observations of V1647 Ori, the latest eruption to have been witnessed in a star forming region.

1. Ambartsumian and the FUors

In 1936 the faint irregular variable star FU Orionis, located in the small dark cloud B35 in the λ Orionis region (Fig.1), underwent a major eruption, increasing in brightness by about 6 magnitudes over a period of half a year (Wachmann 1954, Herbig 1966). In 1969 another faint star, LkHα 190 = V1057 Cyg, located in the NGC 7000 region in Cygnus, similarly brightened by about 5 magnitudes over the span of one year (Welin 1971). Spectra of the latter object before and after the eruption indicated a significant transformation from a T Tauri-type emission spectrum to that of an A-type spectrum in the blue spectral region and F-G0 in the red spectral range, with significant P Cygni profiles at the Hα and sodium lines, and with a strong lithium line (Herbig & Harlan 1971).

The above brief account basically summarizes the extremely limited information available on these two eruptive variables by 1971, when Victor Ambartsumian published a paper on the phenomenon (Ambartsumian 1971). In that paper, Ambartsumian coined the term FUor, by which the members of this class of eruptive variables have been known since. Given the dearth of observations available at the time, it is not surprising that Ambartsumian's ideas of the energy source for these eruptions no longer have relevance in light of all we have subsequently learned about FUors. However, Ambartsumian raised a general and very important point as follows:

The study of such phenomena that appear so infrequent, that get lost so easily among a welter of superficially similar facts, and that appear to be unsubstantial in a superficial examination, should not be neglected in an analysis of the observational data. Furthermore, their great infrequency may be responsible for an erroneous tendency to consider those objects in which the phenomena are observed to be exceptional objects, some sort of freaks of nature, and as such incapable of affecting general regularities in stellar evolution. Meanwhile, if some rapidly unfolding phenomenon occurs, say, only once during the lifetime of a star, that phenomenon will be observed extremely infrequently among the stars surrounding us, despite the fact that it may constitute a regular and even major stage in the evolution of all stars or, say, of stars having masses within a certain specified range.

As will become evident in the following discussion, FUors indeed represent rare but extremely important events in early stellar evolution, events that provide essential insight into the formation of low mass stars. Late in life, Ambartsumian summarized his views on early stellar evolution, emphasizing expansion of stellar associations, ejections from compact groups, and eruptions in young stars as important elements in the evolution of young stars (Ambartsumian & Mirzoyan 1982). It would undoubtedly have been satisfying to Ambartsumian to see that today some of these ideas are considered key elements in our understanding of at least some FUor eruptions.

2. FUors and FUor-like Objects

The breakthrough study of FUors appeared in 1977, when George Herbig's classical paper "Eruptive Phenomena in Early Stellar Evolution" was published, summarizing the key properties of FUors based on three cases, FU Ori, V1057 Cyg, and V1515 Cyg (Herbig 1977). A total of 10 objects are now known which show the characteristic spectroscopic features of FUors and for which evidence of a major eruption exists. Table 1 lists the 10 objects that are widely accepted as bona fide FUors today. Additionally, a number of objects have been found which share the same spectroscopic characteristics as FUors, but for which an eruption has not been witnessed, most commonly because it happened before major sky surveys were carried out. In analogy with the concepts of novae and nova-like objects, we call these latter objects for FUor-like objects (Reipurth et al. 2002a). Table 2 lists the objects which are today considered FUor-like objects.

The principal model to account for the characteristics of FUors is the accretion disk model (Hartmann & Kenyon 1985, 1996), in which strong accretion through a circumstellar disk heats up the disk, leading to excess optical/infrared emission from the disk, with shorter-wavelength emission arising in the inner parts of the disk, and longer-wavelength emission coming from regions further out in the disk. This readily explains the curious observation that FUors tend to have earlier spectral types in the blue spectral region than they do in the red and infrared. FUors commonly have considerable

luminosities, e.g., FU Orionis itself has L_{bol}=500$L_\odot$ (although there are puzzling exceptions like L1551 IRS5 and HH381 IRS with luminosities of only 15-25$L_\odot$). The observed luminosities indicate that almost all of the light we see from a FUor comes from the heated disk, thus "drowning" the light from the central star. This of course implies that one cannot determine the ages of FUors from their position in a theoretical HR-diagram (e.g., Baraffe et al. 2009). The accretion rates required to reproduce the observations may be as high as 10^{-4} $M_\odot$/yr, and if the average FUor outburst lasts about 100 years, then the star gains of the order of 10^{-2} $M_\odot$ in an eruption. Statistical arguments, albeit in the low-number statistics regime due to the rarity of FUors, suggest that a star undergoing FUor eruptions must suffer several such episodes (Herbig 1977). It is not evident, however, that *all* stars must pass through a FUor phase, but at least those that do will gain a significant amount of mass, perhaps as much as 10% of their total final mass.

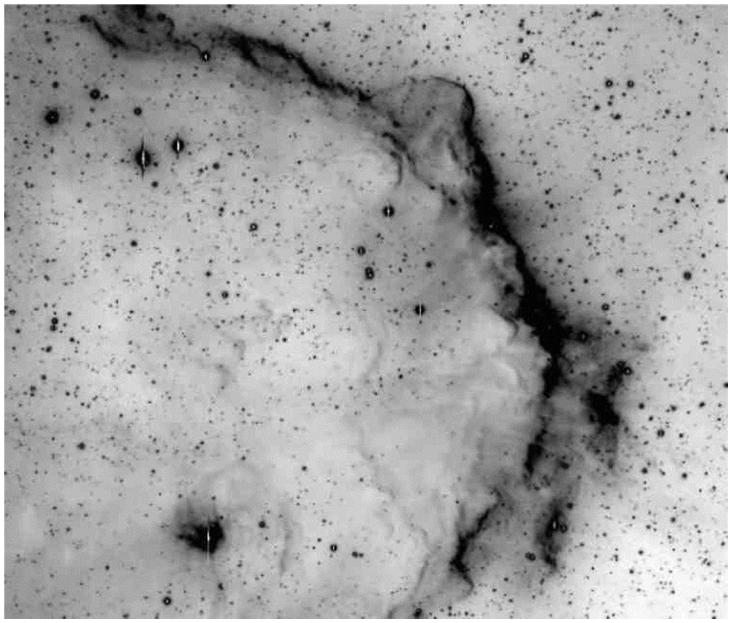

Fig. 1. FU Orionis erupted in 1936 in the small bright-rimmed cloud B35 in the λ Ori region. FU Ori is the bright nebulous star in the lower left corner. North is up and east is left in this Hα image obtained at the Subaru 8m telescope.

FUors have massive supersonic winds. Some FUors are associated withHerbig-Haro objects, but generally these winds are only observed as P Cygni profiles with deep high-velocity blueshifted absorption troughs in certain prominent lines such as the low Balmer lines, the Na I resonance lines, and the Ca II H & K lines (e.g., Herbig 2009). Time-series spectroscopy reveals such winds to be highly variable (e.g., Errico et al. 2003). Figure 2 shows a sequence of Hα line profiles of the FUor V1057 Cyg obtained by Herbig et al. (2003). Mass loss rates for FUors have been derived by comparing line

profiles with models of disk winds, and are found to be typically in the range 10^{-6} to 10^{-5} $M_{\odot}$ yr^{-1} (Croswell et al. 1987, Calvet et al. 1993, Hartmann & Calvet 1995).

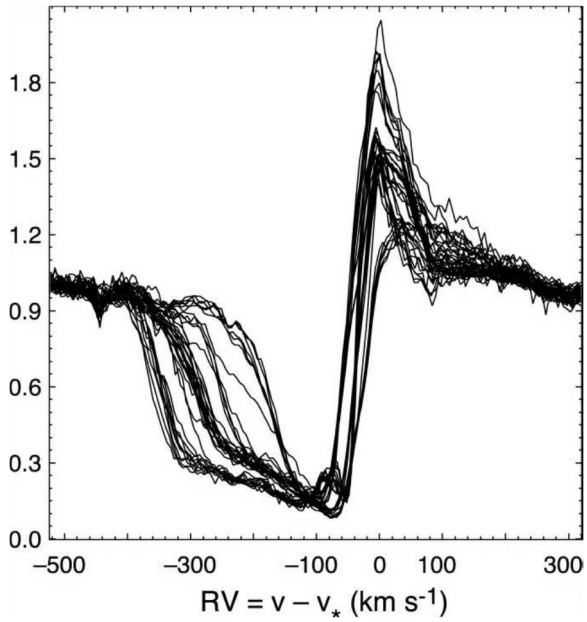

Fig. 2. The outflowing wind in FUors is highly variable, as seen in these Hα profiles of V1057 Cyg in the period 1996–2001 (Herbig et al. 2003).

New observing techniques have provided further insights into the FUor phenomenon. X-ray detections have been made of several FUors (e.g., Skinner et al. 2006, 2009), revealing a high-temperature X-ray plasma associated with magnetic processes. Also, interferometric observations have resolved the circumstellar environment of FUors on AU-scales (Malbet et al. 1998, Millan-Gabet et al. 2006, Quanz et al. 2006). The most detailed interferometric observations are presented by Malbet et al. (2005), who find that their data for FU Orionis are consistent with a disk accreting at a rate of ~6×10^{-5} $M_{\odot}$ yr^{-1} and a temperature distribution consistent with standard models; the inclination and position angle of the disk can also be obtained from these data. Finally, it should be mentioned that half of all known FUors or FUor-like objects are partially or fully embedded in molecular clouds, and thus progress in infrared techniques has enabled important new observations. High-resolution near-infrared spectroscopy probes the physical conditions in the inner disk regions (Greene et al. 2008), whereas mid-infrared spectra from Spitzer have revealed the presence of amorphous silicate grains and various molecular species (Green et al. 2006, Quanz et al. 2007). The infrared energy distributions have been plausibly interpreted as evidence for flared disks, and in some cases for the presence of a remnant infalling envelope (e.g., Zhu et al. 2008).

While the disk model has demonstrated great successes in interpreting the observations of FUors, certain discrepancies remain, indicating that refinements to the model still need to be done, as pointed out by, e.g., Herbig (1989), Herbig et al. (2003) and Petrov & Herbig (1992, 2008), who favor a model that involves a rapidly rotating low-gravity star. It is noteworthy that the massive accretion onto the central star expected by the accretion disk hypothesis may naturally lead to a fast rotating bloated star, and thus the differing views of Herbig vs. Hartmann & Kenyon may be merely different aspects of the same overall process. Another way to reconcile the differing review is to assume that the innermost part of the disk is puffed up and resembling a supergiant (Kravtsova et al. 2007).

Table 1. FUors for which an eruption has been observed.

Object	α_{2000}	δ_{2000}	Date of	Key Reference
V883 Ori	05:38:18.1	–07:02:26	< 1888	Strom & Strom (1993)
FU Ori	05:45:22.4	+09:04:12	1936	Herbig (1977)
V1647 Ori	05:46:13.1	–00:06:05	2003	Reipurth & Aspin (2004b)
V346 Nor	16:32:32.1	–44:55:31	-1980	Graham & Frogel (1985)
V1515 Cyg	20:23:48.0	+42:12:26	-1950	Herbig (1977)
HH381 IRS[a]	20:58:21.4	+52:29:27	1952 – 1989?	Reipurth & Aspin (1997)
V1057 Cyg	20:58:53.7	+44:15:29	1969	Herbig (1977)
V1735 Cyg	21:47:20.7	+47:32:04	1952 – 1965?	Elias (1978)
V733 Cep	22:53:33.3	+62:32:24	1953 – 1984?	Reipurth et al. (2007)
HH 629 IRS	21:00:25.4	+52:30:16	1999	Movsessian et al. (2006)

Table 2. FUor-like objects for which an eruption has not been observed.

Object	α_{2000}	δ_{2000}	Key Reference
RNO 1b/c	00:36:46.3	+63:28:54	Kenyon et al. (1993)
PP 13S	04:10:41.1	+38:07:53	Sandell & Aspin (1998)
L1551 IRS5	04:31:34.2	+18:08:05	Mundt et al. (1985)
Haro 5a/6a IRS	05:35:26.6	–05:03:56	Reipurth & Aspin (1997)
NGC2071 MM3	05:47:36.6	+00:20:06	Connelley & Greene (2010)
AR 6a/b	06:40:59.3	+09:35:52	Aspin & Reipurth (2003)
Z CMa	07:03:43.2	–11:33:06	Hartmann et al. (1989)
BBW 76	07:50:35.5	–33:06:24	Reipurth et al. (2002a)
Parsamian 21	19:29:00.7	+09:38:39	Staude & Neckel (1992)
HH 354 IRS	22:06:50.5	+59:02:47	Reipurth & Aspin (1997)

A number of ideas have been forwarded to explain the triggering of FUor outbursts, and they can be divided into three categories. The first involves a throttle mechanism that controls the passage of gas through the inner disk (e.g., Hartmann & Kenyon 1996). The disk receives gas from an infalling envelope, but it is not evident that the disk can transfer the gas inwards through the disk at precisely the same rate that it falls in, thus leading to material piling up in the disk, and eventually a re-adjustment that leads to an

eruption. The second is based on the assumption that the energy generated in a viscous disk must be balanced by radiative losses in order to remain in thermal equilibrium. When perturbations are applied to a disk that lead to higher disk temperatures then the disk may under some circumstances just radiate more and remain stable. But if the opacity of the gas in the disk rises sufficiently fast with temperature then heat becomes trapped within the disk and a runaway situation develops until the opacity dependence on temperature changes again. Such thermal instability models have been explored by many groups, including Bell & Lin (1994) and Armitage et al. (2001). Finally, the third mechanism to drive accretion involves a companion star in an eccentric orbit that perturbs the disk at periastron (e.g., Bonnell & Bastien 1992). Perturbations by a planet (Clarke et al. 2005) or with another member of a dense cluster (Pfalzner 2008) have also been considered.

In the following, we will explore a number of observations relevant to the third triggering mechanism involving a companion. However, it should be mentioned that there is no particular reason why all FUor outbursts necessarily must be triggered the same way. There are differences between the light curves of the known FUors, so one might envisage several different mechanisms at work leading to similar overall observational characteristics but with differences in their details. We tend to simplify the interpretation of a complex phenomenon by assuming that all observed cases can be explained in the same way. But it is worth recalling that the number of ways a disk can react to any instability are limited and in all cases will involve a brightening and subsequent decay. Thus, if based on an examination of limited data, it is then easy to fit all observed eruptions into a single favored interpretation. Unless we obtain far better and more complete observations (which requires more cases observed as early as possible after eruption) then we are not able to distinguish between the various triggering mechanisms, and we should be open to the possibility that they all may operate at different stages in the evolution of a young star, and even may co-exist in some eruptions.

3. Binary FUors and Unstable Multiple Systems

Among the 20 objects listed in Tables 1 and 2, which constitute the most complete summary of FUors and FUor-like objects currently available, a number of objects are known to be binaries. What is truly remarkable, however, is the presence of two binaries of which *both* components are FUor-like objects. These are RNO 1b/c (Kenyon et al. 1993) and AR 6a/b (Aspin & Reipurth 2003). Given the extreme rarity of FUors, the probability that two FUors should independently erupt simultaneously a few arcseconds from each other is negligible. In other words, what caused one component to erupt must also have caused the second component to erupt. This could easily be explained if the two FUor-like components had passed through a close periastron passage which triggered the outburst. However, the projected separations of these two binaries are ~5000 AU and ~2200 AU, respectively. It would take thousands of years for the companions to move to their present large separations, and there is currently no evidence that FUor eruptions last that long. This is called the timescale problem. Moreover, the eccentricity would have to be

larger than 0.998 to combine a periastron distance of around 10 AU (required to profoundly perturb the disks involved) with apastron distances of several thousand AU, and such extreme eccentricities in *wide* binaries are highly unlikely. The conclusion is that another dynamical mechanism is in play.

A solution to the abovementioned timescale problem can be found in the dynamical evolution of small multiple systems. Many stars are born in small triple systems in non-hierarchical configurations (e.g., Larson 1972), which subsequently decay, either into a binary with a distant companion, i.e. a hierarchical triple system, or into a binary and an unbound, escaping third member (e.g., Sterzik & Durisen 1998). Numerous studies have shown that the close binaries that form as a result of the escape of a third member usually are highly eccentric, with eccentricities exceeding 0.9 not being unusual. For parameters that are likely to hold among newly born multiple stars, decay times are of the order of several times 10^4 yr, that is, the stars are still surrounded by large amounts of circumstellar material (Reipurth 2000).

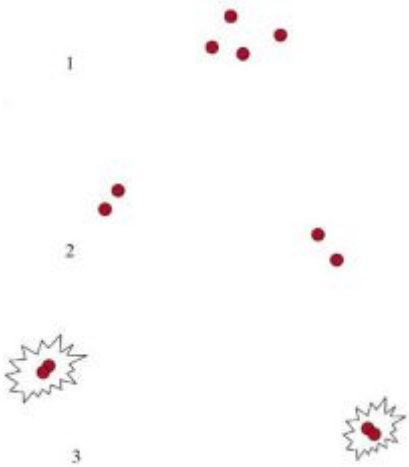

Fig. 3. The evolution of a newborn non-hierarchical quadruple system [1]. After evolving to a more stable hierarchical configuration [2], the individual binary pairs evolve viscously with their circumstellar disks, leading to increasingly closer periastron passages until the circumstellar disks violently interact, causing a series of FUor eruptions. The end result is a pair of binaries each surrounded by circumbinary disks [3].

Let us assume that each component of a pair of FUors is a close binary, i.e., that they altogether form a hierarchical quadruple system that, through dynamical interactions, was recently transformed from an unstable nonhierarchical system, following a close encounter among the components. This transformation implies that two close stellar pairs were formed that may either remain bound to each other or eventually will disperse as two independent close binaries (Fig. 3). Each of these binaries evolves with significant viscous

interactions, leading to angular momentum transfer and thus to rapid orbital shrinkage of the components (e.g., Artymowicz & Lubow 1996; Bate et al. 2002). As the components spiral in, they may trigger disk instabilities leading to (one or more) FUor eruptions (Bonnell & Bastien 1992, Clarke & Syer 1996, Reipurth & Aspin 2004a). This may explain the existence of close pairs of FUors.

The above scenario will of course be equally applicable to hierarchical triple systems, except that in this case only the binary would undergo a FUor eruption, with a normal T Tauri companion. In this context it is of interest that FU Ori itself has a companion with a separation of a few hundred AU (Wang et al. 2004, Reipurth & Aspin 2004a), and Malbet et al. (2005) found possible evidence for a close companion only ~10 AU from the FUor and in a highly eccentric orbit.

4. FUors, Herbig-Haro Jets, Brown Dwarfs, and Spectroscopic Binaries

The scenario outlined above links the FUor phenomenon to other phenomena of early stellar evolution that have not previously been associated with FUors.

As the components of the newborn binary spiral towards each other, some of the material culled from the individual circumstellar disks may settle into a circumbinary disk around the newly bound stellar pair. The small remaining and truncated circumstellar disks are fed from the circumbinary disk through gas streams, and this as well as other dynamical effects cause the binary orbit to shrink (Artymowicz & Lubow 1996). Gas streams, together with disk interactions at periastron, drive cyclic accretion modulated on an orbital timescale. As the stellar components gradually spiral toward each other, the increasingly frequent mass-loss events form chains of HH objects until eventually the binary has a semimajor axis of only ~10 AU, at which point the closely spaced shocked ejecta are produced on the 20-30 yr timescale observed in finely collimated jets. Thus, such HH flows can be read as a fossil record of the evolution of orbital motions of a binary, newly formed in a triple disintegration event, as it shrinks from a typical separation of 100 AU or more to 10 AU or less.

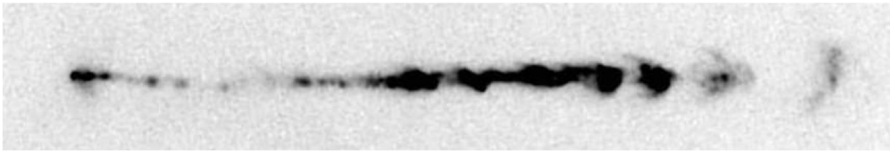

Fig. 4. The HH 34 jet is a fine example of a highly collimated Herbig-Haro jet. From Reipurth et al. (2002b).

At this point, the components are becoming so close that they, in combination with their eccentric orbits, begin to have difficulties maintaining stable circumstellar disks. This implies that the jet collimation mechanism, which is likely to involve magnetic fields

partly anchored in the disk (e.g., Shu et al. 1995), becomes increasingly ineffective. Although mass loss continues, and indeed sporadically increases greatly, it soon no longer can take the form of collimated jets. At the same time, the proximity of the two stars near periastron causes significant perturbations of the remaining disk material, leading to enhanced accretion (Bonnell & Bastien 1992; Clarke & Syer 1996), which we observe as FUor outbursts. In this view, at least some FUor outbursts will preferentially occur during a brief evolutionary phase in the formation of a close binary that is partly overlapping with and immediately following the formation of HH jets. In other words, the FUor phenomenon is in this scenario a signpost of the formation of a spectroscopic binary. Since approximately 18% of evolved stars are found to be spectroscopic binaries, the implication is that about a fifth of newborn stars should pass through this type of FUor outbursts.

Numerous simulations of the few body problem have shown that the resulting binary usually contains the two most massive members of the original multiple system (e.g., Valtonen & Mikkola 1991). In some cases, such ejection events may take place at such an early stage that the ejected member has not had time to accrete sufficient mass to eventually burn hydrogen. In other words, such stellar embryos will forever remain as brown dwarfs (Reipurth & Clarke 2001).

As outlined above, and recalling Ambartsumian's admonition quoted earlier, we find a surprising connection between FUors, Herbig-Haro jets, brown dwarfs, and the formation of spectroscopic binaries.

5. EXors and Other Young Eruptive Variables

There is another class of eruptive pre-main sequence stars, whose amplitudes can approach or equal those of the FUors. This class is known as the EXors (Herbig 1989), in obvious reference to the FUor class, or occasionally "subfuors". The four classical EXors are listed in Table 3, and are briefly discussed below to illustrate the common features and individual traits.

EX Lup. The prototype of the EXor class is the T Tauri star EX Lupi, an M0-type star with a rich emission-line spectrum exhibiting long periods of lowlevel variability interspersed with episodes of sometimes dramatic brightening (Herbig 2007). A famous such event occurred in 1955-56, during which the star brightened by about 5 magnitudes for a period of about a year (Herbig 1977). In the half century since then the star has flickered, with occasional minor flare-ups (Lehmann et al. 1995, Herbig et al. 2001), until very recently the star again went into a major year-long eruption (e.g., Kospal et al. 2008). In contrast to FUors, the spectra of EXors are very rich in emission lines, especially near minimum light. During outburst, a hot continuum floods the spectrum, diminishing the equivalent widths of the emission lines (Figure 5). At the

same time, redshifted absorption components appear at the stronger emission lines, indicating that the outbursts are accompanied by infall of material.

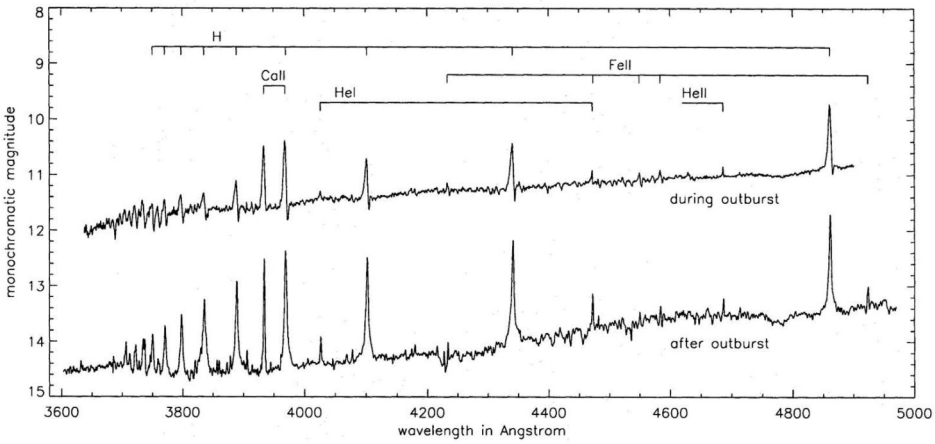

Fig. 5. The rich emission line spectrum of EX Lup in quiescence (bottom) and during an outburst (upper). During outburst a hot continuum "drowns" the photospheric spectrum and emission lines, and inverse P Cygni profiles appear.
From Lehmann et al. (1995).

V1118 Ori. Since its discovery in 1983, V1118 Ori has shown much activity, with at least four significant outbursts, in 1983-84 (Parsamian & Gasparian 1987), 1988-90 (Parsamian et al. 1993), 1997 (Garcia & Parsamian 2000), and 2005 (Garcia et al. 2006). The star is located just southwest of the Orion Trapezium. Low-dispersion optical spectra displaying a rich set of prominent emission lines are discussed by, e.g., Parsamian et al. (1996, 2002). High-dispersion spectra by Herbig (2008) show multiple deep blueshifted absorption lines at velocities of up to 200 km s^{-1}, indicating the presence of high-velocity outflow activity.Also, TiO bands suggest that the underlying star is an early M-star. Astonishingly, these high-resolution spectra revealed Li I 6707 in emission. Infrared spectroscopic studies suggest that the activity of this star is accretion driven, and that variable extinction does not contribute to the brightness variations (Lorenzetti et al. 2006, 2007, 2009). An optical image obtained by the Hubble Space Telescope has uncovered a slightly fainter companion with a separation of 0.18″ (Reipurth et al. 2007b); it is not known whether both stars are variable.

V1143 Ori. The photometric behavior of this star appears to be similarly erratic to V1118 Ori, although the existing light curves are more fragmentary (e.g., Gasparian et al. 1987, Parsamian et al. 1991). Spectroscopic observations of the star show a rich emission line spectrum both at minimum and near maximum light, with an underlying early M-type stellar spectrum (e.g., Peimbert et al. 1991, Herbig 2008).

NY Ori. This is the longest-known of the three classical EXors in the vicinity of the Orion Nebula (Herbig 1950). It is a difficult object to observe, because it is located only 5 arcseconds from the much brighter A-star V566 Ori, so observations are sparse. High-resolution optical spectra obtained by Herbig (2008) show a rich emission-line spectrum with an underlying K-type absorption spectrum. In some emission lines the presence of broad redshifted absorption components indicate infalling material.

The four stars discussed above are universally agreed to belong to the EXor class, hence the term 'classical' EXors. The characteristics of these 4 members can therefore be said to define the EXor phenomenon as we currently understand it. Other objects are known which are possible or even likely members of the EXor class, like UZ Tau E, VY Tau, DR Tau, and PV Cep (see Table 4), but where the observational material is not yet complete enough to make a firm classification. Similarly, there are young eruptive variables which sometimes are suggested to be FUors, but for which the evidence is controversial or incomplete, or the objects show peculiarities which suggest they may represent some other type of phenomenon; several such cases are also listed in Table 4. In the following, three of the objects in Table 4 are briefly discussed.

Table 3. Classical EXors.

Object	α_{2000}	δ_{2000}	Key Reference
V1118 Ori	05:34:44.8	-05:33:42	Herbig (2008)
NY Ori	05:35:35.8	-05:12:21	Herbig (2008)
V1143 Ori	05:38:03.9	-04:16:43	Herbig (2008)
EX Lupi	16:03:05.5	-40:18:25	Herbig (1977)

Table. 4. Other selected eruptive PMS variables.

Object	α_{2000}	δ_{2000}	Type	Key Reference
V512 Per	03:29:03.8	+31:16:04	EXor?	Eislöffel et al. (1991)
T Tau S	04:21:59.4	+19:32:06	EXor?	Kobayashi et al. (1994)
XZ Tau	04:31:40.1	+18:13:57	EXor?	Coffey et al. (2004)
UZ Tau E	04:32:43.0	+25:52:31	EXor?	Jensen et al. (2007)
VY Tau	04:39:17.4	+22:47:53	Pecul.	Herbig (1990)
L1415 IRS	04:41:35.9	+54:19:12	Pecul.	Stecklum et al. (2007)
DR Tau	04:47:06.2	+16:58:43	EXor?	Kenyon et al. (1994)
Re 50 IRS	05:40:27.7	–07:27:28	Pecul.	Reipurth & Bally (1986)
V1184 Tau	05:47:03.8	+21:00:36	Pecul.	Semkov et al. (2008)
OO Ser	18:29:49.3	+01:16:19	FUor?	Hodapp et al. (1996)
PV Cep	20:45:54.0	+67:57:39	EXor?	Cohen et al. (1981)
GM Cep	21:38:17.3	+57:31:23	EXor?	Sicilia-Aguilar et al. (2008)
V392 Cep	21:42:57.6	+66:04:26	EXor?	Miranda et al. (1994)
V350 Cep	21:42:59.9	+66:11:28	Pecul.	Herbig (2008)

Re 50 is a bright compact nebula in the L1641 cloud. This nebula appeared sometime between 1955 and 1979, and is associated with the embedded source IRAS 05380–0728, which drives a molecular outflow and, with a total luminosity of ~250 $L_\odot$, is one of the most luminous sources in the L1641 cloud (Reipurth & Bally 1986). The nebula reflects the light from the embedded source (Scarrott & Wolstencroft 1988), which is hidden by ~50 magnitudes of visual extinction (Casali 1991). Based mainly on the presence of an extreme P Cygni profile at Halpha with absorption from outflowing gas at velocities as high as 1000 km/sec it was suggested by Strom & Strom (1993) that Re 50 IRS is a FUor. However, infrared spectroscopy by Reipurth & Aspin (1997) showed a mostly featureless 2.0–2.5 μm spectrum, with no evidence for the broad CO absorption bands that are characteristic of FUors.

OO Ser is an infrared source deeply embedded in the Serpens molecular clouds. It was found by Hodapp et al. (1996) to have undergone a significant brightening in the K-band. Detailed infrared multi-wavelength photometry by Kóspál et al. (2007) indicates an outburst duration of at least 4 years, and possibly as long as 10 years. This is long for an EXor and short for a FUor, but until more detailed spectroscopic studies are available, which might offer further insight into the nature of the source, it is too early to consider this a new class of eruptive variables.

PV Cep is a faint star associated with a cometary nebula in a small molecular cloud (Gyulbudaghian & Magakian 1977, Movsessian et al. 2008). Interest in the object was raised by the discovery of a major change in the appearance of the nebula (Gyulbudaghian et al. 1977, Cohen et al. 1977), and subsequent monitoring revealed a very erratic variability of star and nebulosity with an amplitude of up to 5 magnitudes (Cohen et al. 1981). It was later found that PV Cep drives a giant bipolar Herbig-Haro flow (Reipurth et al. 1997, Gomez et al. 1997). In an infrared photometric/spectroscopic study of PV Cep, Lorenzetti et al. (2009) found that the brightness variations of the star are well accounted for simply by variable extinction, in contrast to the classicial EXors, in which accretion appears to be the main driver. PV Cep could therefore be something else than a bona fide EXor.

The considerable variety in behavior and spectral characteristics of the various eruptive objects listed in Tables 1–4 suggests that several physical mechanisms are likely to be at play. Detailed simultaneous spectroscopic and photometric observations would be very helpful to better understand the range of properties of these objects, and thus their underlying causes. We must recognize that our understanding of eruptive phenomena in early stellar evolution is still limited, and it is possible, and even likely, that as new eruptions are being discovered and studied with increasingly advanced techniques, then the criteria we use to accept objects as FUors or EXors may change or expand.

Fig. 6. An optical image of V1647 Ori and the associated McNeil's nebula. CCD image from the Gemini 8m telescope (Reipurth & Aspin 2004b).

5. The Puzzling Eruption of V1647 Ori

Until 2003, only two FUors had been witnessed to erupt, FU Ori in 1936 and V1057 Cyg in 1969. However, in 2003 a new outburst source, now known as V1647 Ori, was detected in the Orion B cloud near M 78 (McNeil 2004). It has been debated whether this source is truly a FUor, but recent studies appear to support such a classification. The importance of this event lies in the major developments that have taken place in instrumentation since the two previous FUor outbursts. These have allowed unprecedented insights into the physical processes underlying the eruption. Optical CCD and near-IR array development has given us highly sensitive detectors that, when combined with imagers and spectrographs, result in a wide range of spatial and spectral resolution observations. In addition, space-based observations have been made at wavelengths inaccessible from the ground, in particular in the mid- to far-IR and at X-ray wavelengths. From early 2004 to the present time, around 35 refereed papers have been published specifically on the V1647 Ori outburst. Below we summarize the results obtained and their relationship to FUor events.

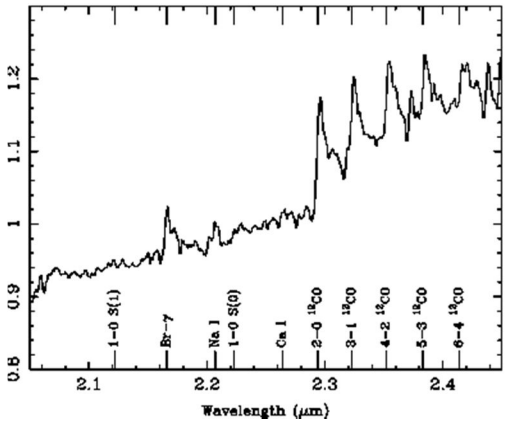

Fig. 7. A K-band spectrum of V1647 Ori shortly after the eruption commenced. From Reipurth & Aspin (2004b).

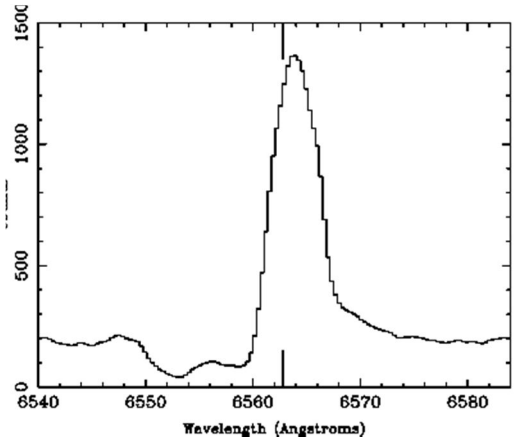

Fig. 8. The Hα line of V1647 Ori showed a dramatic P Cygni profile with an absorption trough extending about 600 km/sec shortly after the eruption commenced. From Reipurth & Aspin (2004b).

Prior to the 2003 outburst, V1647 Ori was known as a faint optical star associated with LMZ 12 (Lis, Menten, & Zylka 1999), a sub-mm/mm core, and it was also detected in the far-infrared as IRAS 05436–0007.

Soon after its discovery, V1647 Ori was observed by several researchers using optical and near-IR instrumentation (e.g., Reipurth & Aspin 2004b, Bricenõ et al. 2004, Vacca, Cushing, & Simon 2004, Walter et al. 2004). The results showed that the young star had undergone an extreme outburst and had risen in optical brightness by over five magnitudes (see Fig. 6 for an outburst image). Its optical spectrum showed a red continuum with strong Hα emission and blue-shifted absorption component producing a P Cygni profile. In the

near- IR, strong 2.3 μm emission bands from CO were observed together with Brγ and Na I emission (Fig. 7). It was noted in Reipurth & Aspin (2004b) that the near-IR photometric colors of V1647 Ori had changed from their pre-outburst (2MASS) values (they became bluer) and the change had been precisely along a reddening vector. New mid-IR and sub-mm/mm observations by Andrews, Rothberg, & Simon (2004) showed that the source had increased in bolometric luminosity by at least an order of magnitude during the eruption, yet the sub-mm/mm fluxes had been unaffected. Important space-based observations taken soon after the outburst were presented by Muzerolle et al. (2005, *Spitzer)* and Kastner et al. (2004, *Chandra).* The *Spitzer* observations showed V1647 Ori to be exceptionally bright from 3.6 to 70 μm and that a simple accretion disk model with tenuous envelope could explain the pre- and post-outburst spectral energy distribution. The *Chandra* observations showed a coincident X-ray eruption with an increase in X-ray flux of a factor ~50 which was associated with the enhanced accretion process.

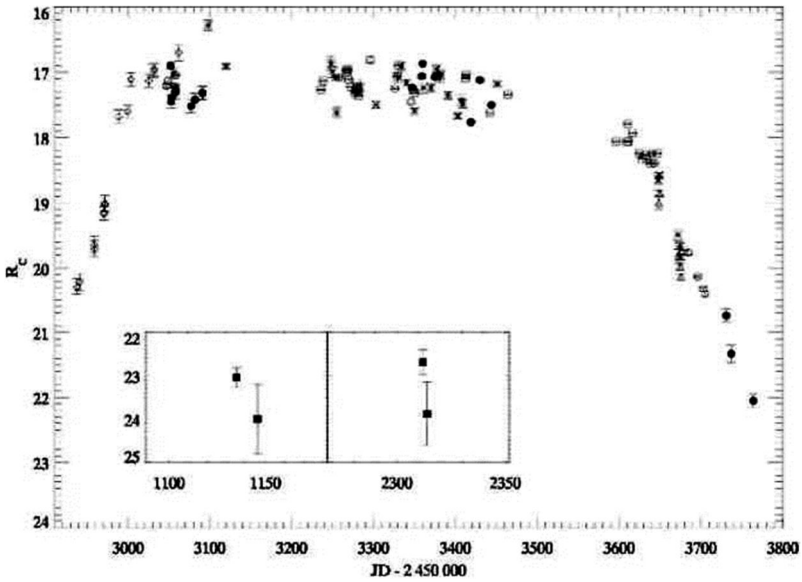

Fig. 9. Optical R-band lightcurve of V1647 Ori covering its 2003-2006 eruption. In 2008 the star erupted again. From Fedele et al. (2007).

The fading of V1647 Ori was tracked photometrically and spectroscopically, in the optical and near-IR, by a number of authors including Gibb et al. (2006), Ojha et al. (2006), Fedele et al. (2007), Acosta-Pulido et al. (2007), and Aspin & Reipurth (2009). A composite optical light-curve, from pre- to post-outburst (taken from Fedele et al. 2007) is shown in Fig. 8. During this period, both Halpha emission and absorption weakened, the near-IR CO bandheads faded away, as did V1647 Ori and McNeil's Nebula. About one year after V1647 Ori had returned to its pre-outburst optical

brightness, Aspin, Beck, & Reipurth (2008) reported followup observations showing that the star remained in a 'quiescent' state and suggesting that the best-fit spectral type was around M0, with a visual extinction of A_V =19 magnitudes, a K-band veiling of r_K=1.5, and a mass accretion rate at that time of 10^{-6} $M_\odot$ yr^{-1}. The latter was an order of magnitude lower than at the peak of the outburst. Surprisingly, V1647 Ori was observed to brighten again in late 2008. This re-occurrence was documented by Kun (2008) and Aspin et al. (2009). It was determined that this second eruption was not identical to the 2003 event but perhaps a continuation. In this scenario, the fading between the two eruptions would be mainly due to the reformation of dust obscuring the young star from direct view and along the line-of-sight from McNeil's Nebula. One further clue to the true nature of V1647 Ori was the spectral structure observed in high resolution near-IR data (R~18000) taken with NIRSPEC on the Keck II 10m telescope. These data were published in Aspin et al. (2009) and showed that V1647 Ori was almost identical in spectral structure to many other FUors (see Fig. 9) and totally dissimilar to other known young variable stars such as EXor variables. At the time of writing, V1647 Ori is still in an elevated, eruptive state.

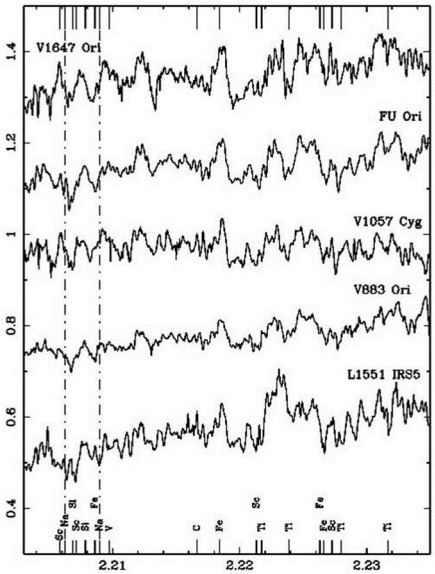

Fig. 10. High resolution infrared spectra around 2.22 μm showing the similarity between V1647 Ori and three other FUors or FUor-like objects.
From Aspin, Greene, & Reipurth (2009).

After the 2003 outburst occurred, it was noticed that McNeil's Nebula was present on a 1966 photograph of the region shown in Mallas & Kreimer's 1970 book on Messier objects. A detailed investigation of plates and films from this period by Aspin et al. (2006) showed that the 1966 outburst appeared very similar in amplitude and duration

to that occurring in 2003. Hence, V1647 Ori is known to have had two eruptions separated by around 40 years.

The evidence on the true nature of V1647 Ori therefore is somewhat contradictory. On the one hand, the magnitude of the event, the spectral energy distribution of the star, the extreme velocity structure in Hα, and its near-IR appearance at high spectral resolution, all point to V1647 Ori being a FUor. On the other hand, the short outburst timescale, its observed repetitive nature, and its strong near-IR emission spectrum during outburst, suggests it is more like an EXor. The great similarity of the high spectral resolution near-IR structure to many known FUors is particularly important and perhaps suggests that the boundary between FUors and other eruptive phenomena is not as well defined as one could hope.

6. Conclusions

As was surmised already by Ambartsumian (1971), the FUor phenomenon has emerged as an important element in our understanding of the evolution of stars towards the main sequence. The extraordinarily high accretion rates witnessed in these eruptions provide insights into disk physics that we cannot gain from the study of ordinary T Tauri stars. While there is still debate about the outburst mechanism, compelling observational evidence points to FUors being eccentric binary systems in which the components spiral together and transition from a wider binary with two circumstellar disks to a closer binary with a single circumbinary disk, triggering a sequence of eruptions during periastron passages. In this scenario, the FUor phenomenon is related to seemingly disparate phenomena like the birth of binaries, Herbig-Haro jets, and the formation of brown dwarfs, because they are all related aspects of the same underlying phenomenon, namely the evolution and break-up of small multiple systems of newborn stars. This brief overview of our current understanding of the FU Ori phenomenon cannot go into the many detailed observations available of FUors, nor do justice to the considerable theoretical work that has been done to understand these objects. For an up-to-date and in-depth discussion of the FUor phenomenon, the reader is referred to Chapter 9 in the new book *Accretion Processes in Star Formation* by Lee Hartmann (Hartmann 2009).

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Multi-Sided Studies of the Manifestations of Young Stellar Activity in Star Forming Regions

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Abstract. Byurakan observatory actively continues one of its traditional directions of research, namely studies of the early stages of the stellar evolution. We present recent results, obtained by the variety of the observational methods as in Byurakan so as in cooperation with other astronomical institutes. The main aims are search of new HH outflows and the further studies of their structure and sources. Special attention will be devoted to the compact and little-studied star formation region in Cyg OB7 association, where besides of a plentitude of HH flows, nebulae and YSOs, at least two new FU Ori type objects with registered recent outbursts were found.

1. Introduction.

In the end of 1940ies the volume of the observational evidences about the stellar formation and evolution was virtually nonexistent. Several authors like Joy (1945, 1949), Greenstein (1950), Herbig (1951) already found certain astronomical objects of unusual nature and made some suggestions about their probable youth. In the mean time ideas of Ambartsumian (1947, 1949, 1957) about the stellar associations and groupings of T Tauri stars were instrumental in the formation of the now generally accepted concept of recent galactic star formation. In one of the recent reviews about that early period of star formation exploration Bertout (2007) highlights the role of Byurakan's achievements in this direction of scientific exploration. Star formation and early evolution was defined and still remains on of the key research directions in the Byurakan Observatory.

Those early stage studies carried out in Byurakan laid the foundation of our understandings of young stars in stellar associations, Herbig-Haro objects (termed by

Ambartsumian, 1957), cometary nebulae and FU Ori type stars (or simply FUors, as they were called by Ambartsumian, 1971). One should emphasize that the first papers of Ambartsumian devoted to these objects are, of course, superseded by modern studies and the arguments included there no longer have relevance. But the main conclusions remain true, and that is the most important and even surprising result of these early works.

To illustrate this let us consider the so called cometary or comet-like nebulae. In his papers of 1950-ies Ambartsumian (1954, 1955) pointed to the several unusual characteristics of these nebulae: they have strange shapes, suggesting the existence of magnetic fields; in many cases they are too bright compared to their source stars; some of them show changes in morphology and brightness during years or even months; certain nebulae have very unusual spectra, different in significant details from that of the illuminating stars. All these features in that time naturally lead to the assumption about the existence of the non-thermal radiation in these objects. Now it is well-known that all listed above peculiarities are explained by the geometrical effects and by the existence of collimated outflows and dense circumstellar discs around the central stars of the cometary nebulae. However, the main conclusion made by Ambartsumian, remains as true as it was 50 years ago: cometary nebulae indeed are connected with very young stars and serve as a good indicator for the star forming activity.

Nearly the same can be said about the Herbig-Haro objects: although the ideas about their nature underwent great changes (initially they were regarded as extremely young stars, or stellar precursors), their relation with the extremely young stars, suggested half a century ago, presently is a fundamentally established fact. The modern understanding of this phenomenon as the extended collimated flows, ejected from the central stars, where individual HH objects represent only the local dense knots, was somewhat unexpected in 70ies, when the first reliable evidences of such flows were obtained. However, in the works of Ambartsumian the possibility of a directed matter ejection from the young stars was assumed more than once.

For many decades the observational possibilities of Byurakan observatory limited the observational studies of young stars, carried there, by surveys and searches of the variable and emission-line stars. The capabilities of the existing equipment for the detailed investigation of selected objects were adequate only for the brightest stars of PMS population. This situation drastically changed in the end of 90ies, when 2.6-m telescope was equipped with the first modern CCD camera.

2. Observational stellar formation studies in Byurakan

In this short review we cannot describe in detail all studies of young stars and their activity carried out in Byurakan. Therefore, we will concentrate on the work of our

group, which is engaged in the observational study of the stellar formation and early evolution during the last two decades. When new CCD spectral system was set in operation in 1997, several projects were immediately launched, which are in successful realization up to the present moment. In principle, these projects, described below, directly continue the tradition of the studies of non-stable astronomical phenomena, established in Byurakan by Ambartsumian. Most interesting objects were then studied with more powerful telescopes, including UKIRT 4m infrared telescope, 6-m telescope of SAO (Russia) and, lately, 8-m telescopes Subaru and Gemini North at Hawaii.

2.1. Searches of HH objects and YSOs

Several HH objects were discovered in Byurakan in the process of the slit spectroscopy of the selected interesting nebulae (e.g., Gyulbudaghian et al. 1977; Magakian 1983, 1984). However, the effectiveness of this method was low. The systematic searches started in 1997-1998, since the CCD system allowed using the simple and productive technique of the comparison of direct images taken with narrow-band filters (i.e. in the emission lines of Hα and [SII]) and in continuum. The results of this survey (which is still under way) were presented in a number of papers (see, for example, Magakian, Movsessian and Nikogossian, 2003, 2004; Movsessian et al., 2003); we show two typical fields, rich by HH objects and flows, in Fig.1 and 2.

In the last 10-12 years the total number of known HH objects remarkably increased. Some well-known and nearby dark clouds, like Taurus-Auriga and Orion, became thoroughly studied and mapped for HH objects and flows by various authors (see, e.g., huge survey of Perseus cloud by Walawender, Bally and Reipurth, 2005). Nevertheless, many areas still remain uncovered by searches. In any case, the important problem remains the selection of the most promising target fields. As such we chose the environments of compact reflection nebulae and cometary nebulae, because they are good signposts of the recent star formation. This approach proved its successfulness, drastically increasing the number of HH objects found in Byurakan.

Several more distant and large-extension HH flows, found in our survey, which increased thus the number of known star forming regions (SFR), should particularly be noted. We will return to this question below, in section 3. We will depict also new FU Ori type stars, found during our searches.

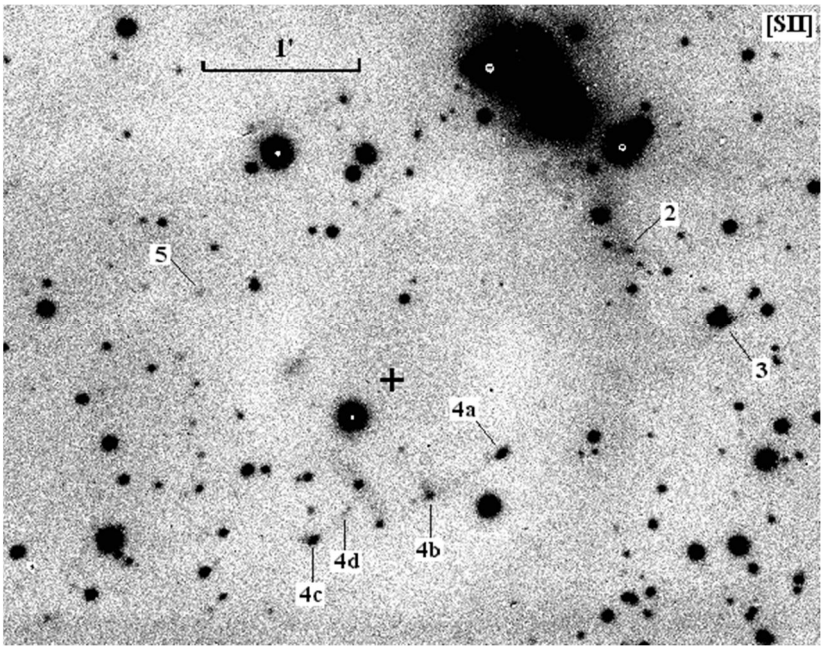

Fig.1. HH objects and flows (shown by numbers), found in the L1340 dark cloud. This image in [SII] emission lines is obtained at the 2.6-m Byurakan telescope (Magakian, Movsessian and Nikogossian, 2003).

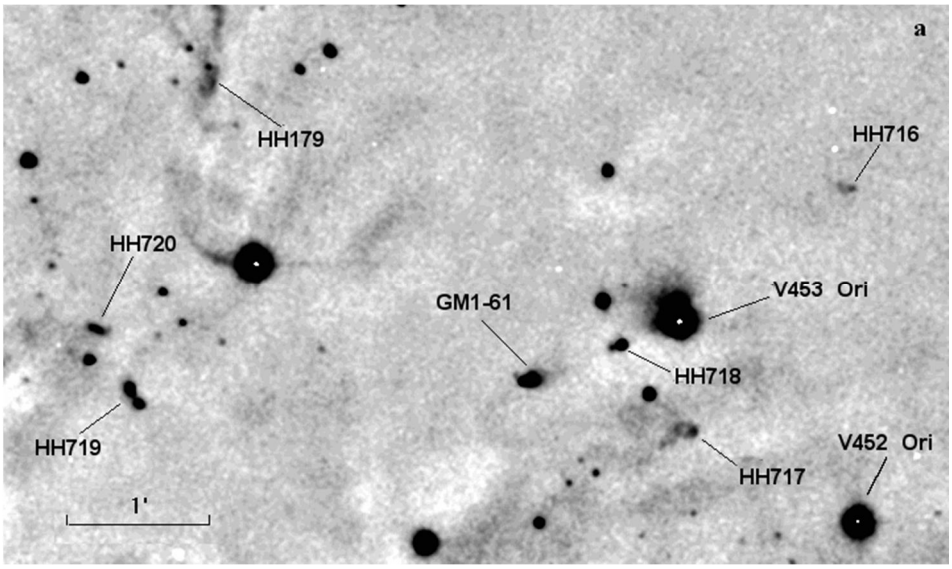

Fig.2. Compact field near the star V453 Ori, rich in HH objects and flows. This image in [SII] emission lines is obtained at the 2.6-m Byurakan telescope (Magakian, Movsessian and Nikogossian, 2004).

2.2. 2D spectroscopy of HH flows

Starting from the first findings, the physical characteristics of HH objects seemed controversial, giving cause for sophisticated speculations about their origin and inner structure. Even after the revealing the true nature of HH objects as shock waves in the flows, many interesting questions claimed attention and observational verification. We tried to face some of these questions, applying effective methods of 2D spectroscopy. Scanning Fabry-Perot interferometry of the selected flows was performed mainly at the SAO 6-m telescope, whereas small nebulae and knots were observed with the fiberless multi-pupil spectrograph VAGR, specially designed and built in Byurakan observatory just for these purposes (Movsessian et al., 2000).

Among our last achievements in this field we can mention the studies of so called "shocked cloudlets" (i.e. the rare cases when HH knot is actually the dense interstellar cloudlet, excited by the collimated flow from the source) in HH 319 and HH 43 systems (Magakian et al., 2002; Hovhannisyan et al., 2007), the finding of the interacting (probably colliding) flows in the HL Tau/XZ Tau system, where such collisions produce the chain of waves in the HL Tau jet and other effects (Movsessian et al., 2007) and the study of the inner structure and of the working surface of the HH 83 flow (Movsessian et al., 2009). In this last case we found the impressive kinematical and spatial separation between the bow shock and Mach disk inside the working surface of the flow. Some of these results are shown in Fig.3 and Fig.4.

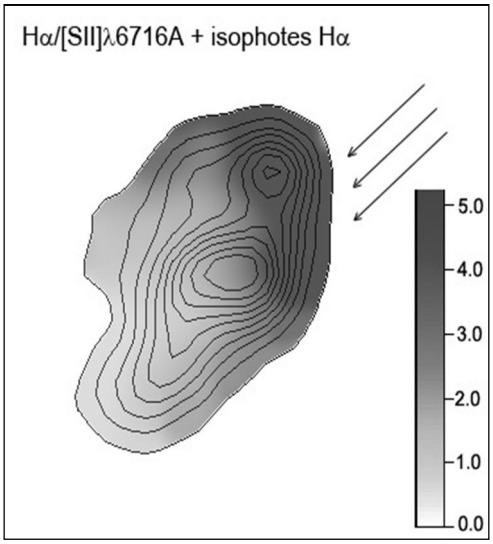

Fig.3. The distribution of the intensity ratio Hα/[SII] (which measures the excitation level) over HH 43 with intensity contours of the object in Hα line. The arrows indicate the direction of the flow from the exciting source HH 43-MMs1. Observations are done with multi-pupil spectrograph VAGR at the 2.6 m telescope in Byurakan (Hovhannisyan et al., 2007).

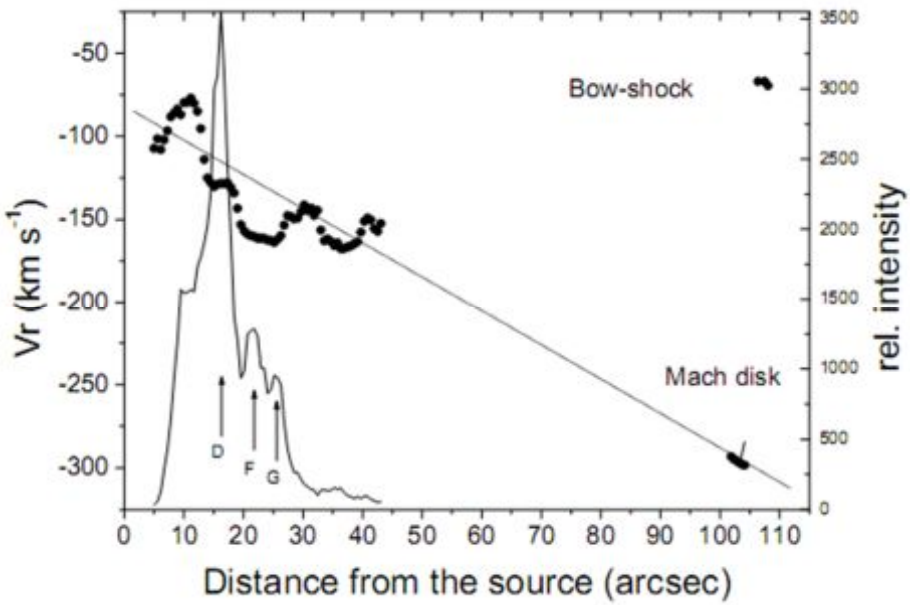

Fig.4. The heliocentric radial velocity distribution along the HH83 flow system, versus the angular distance from the source. The working surface of the flow is separated into Mach disk and bow-shock structures (see text). The plot of the intensity of Hα emission is superposed. The straight line extrapolates the jet velocity curve to the Mach disk. The internal velocity waves in the jet, which actually create the visible HH knots, also are obvious. These data are obtained with the scanning Fabry-Perot interferometer on the 6-m telescope (Movsessian et al., 2009).

2.3. Spectroscopy of the reflection nebulae in SFR

The importance of the spectral studies of reflection cometary nebulae is not obvious, because in principle their spectra should be identical to that of the illuminating star. However, that is not always true, as some spectral anomalies where detected even in the 40ies by Greenstein (1948) for the bright cometary nebulae NGC 2261 and NGC 6729. These spectral anomalies (which can be shortly described as the progressive strengthening and changes in radial velocities of certain absorption lines with the increase of the distance from the source star) became the subject of several studies and were successfully explained by Herbig (Jones and Herbig, 1982) as a result of the existence of anisotropic expanding stellar envelope around the central star, combined with the geometrically favorable projection of its spectrum on the walls of the cavity in the interstellar dust (which we see as the bright conic nebula). This opened an interesting possibility to analyze the structure of such envelopes by studying the spatial variations of the certain spectral features in the connected nebulae. After the successful reanalysis of the NGC 2261 spectrum, based on the observations with 6-m telescope, which allowed to find interesting new properties of the R Mon collimated flow

(Magakian and Movsessian, 1997; Movsessian, Magakian and Afanasiev, 2002) we continued the searches of similar anomalies in the spectra of other cometary nebulae. For these observations we also used the multi-pupil spectrograph on 2.6-m telescope, described above. As a result several other cases of the so called “spectral asymmetry” were found in such systems as RNO 129 (Movsessian and Magakian, 2004), PV Cep (Movsessian et al., 2008, shown on Fig.5) and FS Tau B systems (Movsessian et al., 2010).

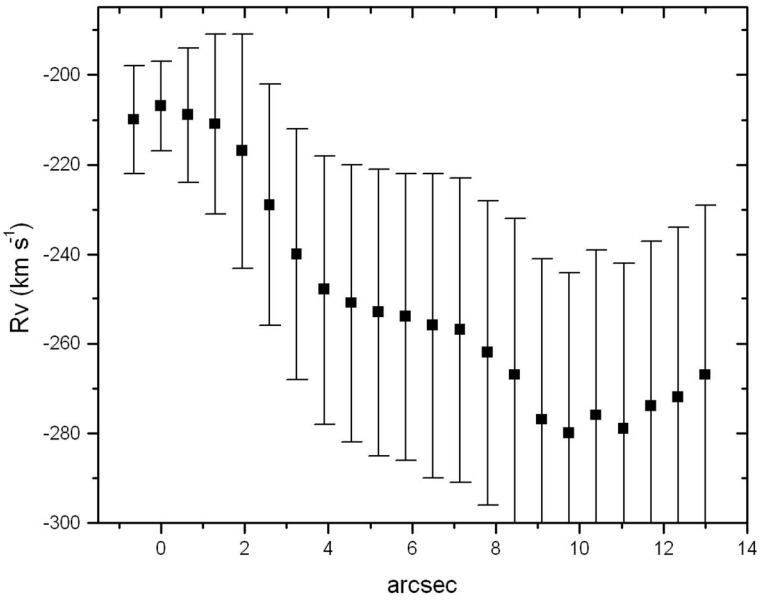

Fig.5. A plot of the radial velocity of the absorption component of the Hα line in the spectrum of the GM 1-29 nebula as a function of distance from the central star PV Cep (Movsessian et al., 2008). These results are based on the observations with multi-pupil spectrograph VAGR at the 2.6 m telescope in Byurakan.

We hope that this unusual method of the indirect study of PMS stars envelopes will be applied in future to the data obtained with the largest telescopes on the earth and in space because the special resolution is of the crucial importance here.

3. Searches and studies of distant (~1 kpc) SFRs

As already was mentioned in section 2.1, our searches of the star forming activity near the small reflection nebulae, just as was expected, revealed several more distant SFRs, which were poorly studied before or even not known at all (see, for example, Nikogossian, Magakian & Movsessian, 2007; Magakian, Movsessian and Nikogossian,

2008). In many cases they contain rather extended HH flows. Certain of these SFRs turned out to be most interesting fields which required special attention. In the course of the work the international consortiums were formed to study them in various wavelengths – from optics to radio. Below we will describe two such regions still actively studied by us.

3.1. GM1-64 (RNO53) and GM2-4 nebulae

These nebulae lay near the center of the molecular cloud KOY98 183.7-03.6 with a size of about 6 pc, and a distance of 1 - 2 kpc. This region attracted significant attention and has been studied in detail in the radio and IR ranges. In particular, the adjacent H_2O maser, a bipolar CO outflow and the bright IR source IRAS 05373+2349 associated with a high luminosity YSO object CPM 19 were discovered in this cloud.

Our optical studies revealed here 3 new HH objects and 12 emission line stars. The HH 940 object was particularly interesting because of its location nearby to CPM 19 / IRAS 05373+2349 source. Besides, we found the strong and unusual optical variability of CPM 19 source in the period of several years, as well as small and compact cluster of young stars, which surrounds this source (Nikogossian et al. 2009 & references therein).

Furthermore, the most interesting findings were made when this field was observed in near-IR at the 3.5 m telescope (Calar Alto, Spain). Several powerful and extended flows, seen mainly in molecular hydrogen lines, were discovered around CPM 19 and the compact IR stellar cluster, some of these stars are the most probable sources of these outflows. Other established outflow sources are the heavy reddened star in the center of GM2-4 nebula (IRS4 in Fig.7) and another strong IR source (IRS1 in Fig.7), found in the western border of the cloud.

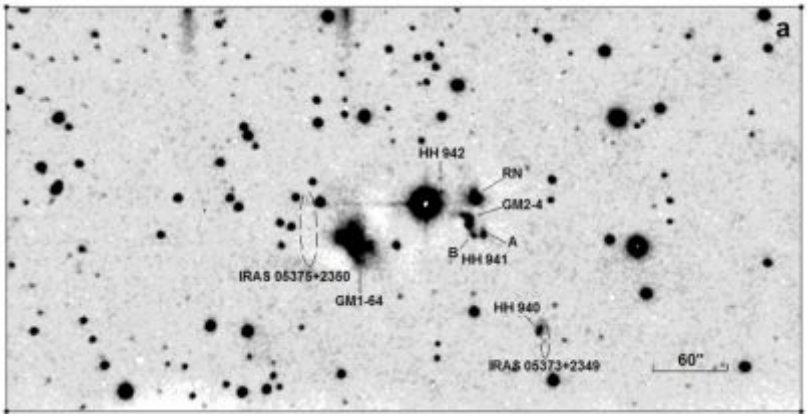

Fig.6. [SII] band image of the GM2-4 and GM1-64 region. Herbig-Haro objects and reflection nebulae, embedded in a giant molecular cloud [KOY98] 183.7-03.6, are marked. CPM 19 is a faint star just in the center of IRAS 05373+2340 source error ellipse.

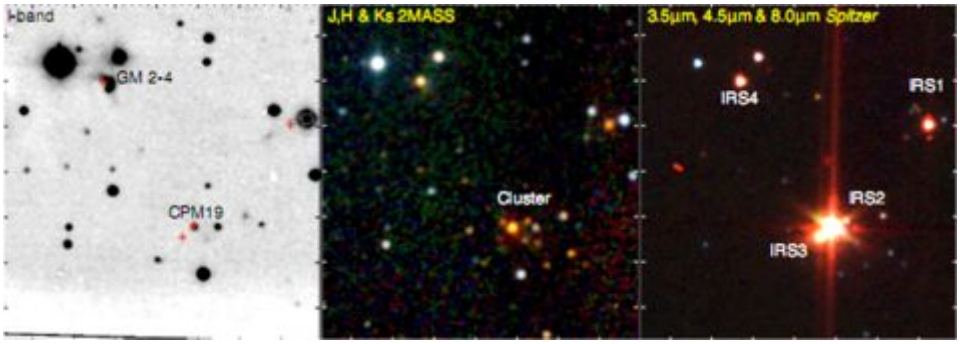

Fig.7. IR views of the region. Left panel is the I-band view where CPM19 and GM2-4 are marked along with the crosses indicating the positions of IRS1 to IRS4. Middle panel is the 2MASS false color composite view of the region. Note the cluster of faint IR stars around CPM 19. Right panel is Spitzer IRAC composite image of the region where the strong sources IRS1 to IRS4 are indicated.

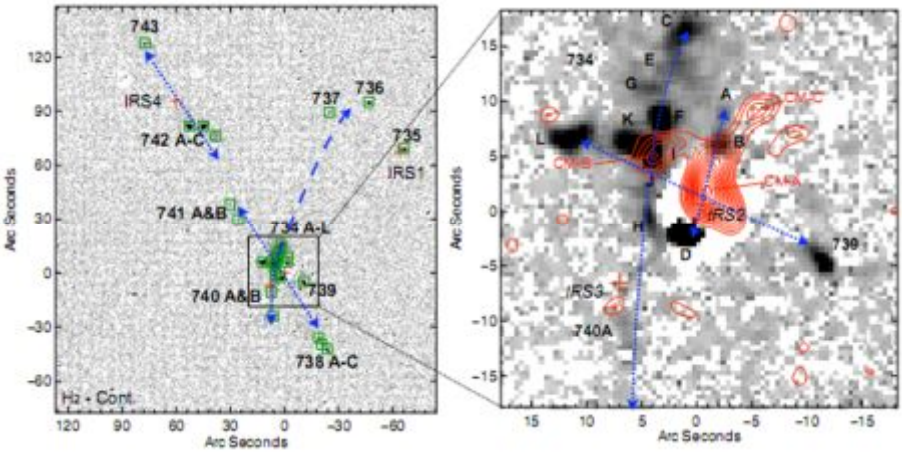

Fig.8. The scheme of possible outflows in the GM2-4 and GM1-64 region. Their extend and structure are shown with dotted and dashed-lines in the left panel in continuum subtracted H_2 line. The newly found molecular hydrogen emission-line Objects (MHOs) are numbered. Right panel is the magnified view of the main IRS2-IRS3 area overlaid with 3.6cm contours.

Some of these findings can be seen in Figs.6-8. Their full description will be presented in the paper of Khanzadyan et al. (2010, in preparation). But even now one can say that this cloud as whole as well as young objects in it, in the first place CPM 19 and IRS 4, deserve further attention. In particular radio-line observations in our possession confirmed the schematic representation of the flows presented in Fig.8. These data and further analysis on the region will be presented in one of our next publications.

3.2. L1003 cloud in Cyg OB7

This dark cloud lies in the northern border of large CygOB7 association, in the 800 pc distance. Strangely enough, for a long time it escaped the attention of observers. Only one sufficiently bright HH object (RNO 127 = HH 448) (Cohen, 1980) and several emission-line stars (Melikian et al. 1996), which were potentially part of a larger pre-main sequence (PMS) population, were found here.

When L1003 field was included in our survey, very soon it was found to contain not one, but numerous HH objects and cometary nebulae (Movsessian et al. 2003). Especially interesting was the discovery of a new FU Orionis eruptive variable star (Movsessian et al. 2006). Below we refer to it as 'The Braid Nebula star' due to the twisting double-spiral morphology of its associated refection nebula (Movsessian et al. 2003, 2006). The Braid Nebula star was also found to be the driving source of an extensive bipolar HH flow (Movsessian et al. 2006).

The area to the west of the Braid Nebula had previously been found to contain several interesting HH objects, including HH 381 and 382 (Devine, Reipurth and Bally, 1997). In their vicinities a double fan-shaped refection nebula, associated with an IRAS source (IRAS 20568+5217), is located. A NIR K-band spectrum of this point source, which coincides with a visible star at the center of the nebula (currently designated HH 381 IRS), obtained by Reipurth and Aspin (1997), showed it to be extremely similar to that of many known FUors. Further NIR spectroscopy by Aspin et al. (2009) showed that HH 381 IRS also possesses strong water vapor absorption features, again a common feature of other FUors. HH 381 IRS therefore also seems to be in an elevated FUor state and it is interesting to note that it is located within 30′ of the Braid Nebula star. Hence, two FUor-like objects are embedded in this one dark cloud.

In order to better understand the environment around the two FUor-like objects and study the outflows and jets present and their relationship to the young stellar objects, we initiated a multi-wavelength (optical to sub-mm/mm) study of a region of L1003 approximately 60′×30′ in size which included both the Braid Nebula star and HH 381 IRS. These investigations are still under way; several works are already published (Aspin et al. 2009; Magakian et al., 2010), others are in preparation. Here we will describe several highlights from this large volume of study.

Using the images, obtained with Suprime-Cam mosaic CCD system on the Subaru 8.2-m telescope, we confirmed all HH objects, previously found in this field, and discovered many others faint HH knots. The analysis of their morphology shows that at least 12 optical outflows exist in this region, some of them rather extended. Especially interesting is that the longest flows, with extent of more than several parsecs, are

produced by the above-mentioned FU Ori type stars. Besides, we were able to detect the jet (with about 1200 AU extension) in the immediate vicinities of HH381 IRS star, which confirms its current activity. Moreover, our analysis of the observational data from various sky surveys shows that the HH381 IRS star indeed rose in optical brightness about 30 years ago, thus confirming its FU Ori nature. For other hand, the existence of several small quasi-periodic bow-shocks with a kinematic inter-ejection timescale of about 1000 years in the both flows is suggestive of multiple ejections with similar occurrence timescales. To illustrate the aforementioned, we show the images of the both FUors and their related outflows in Figs. 9-11. Pay attention also to drastic changes in the morphology of both nebulae between I and K bands.

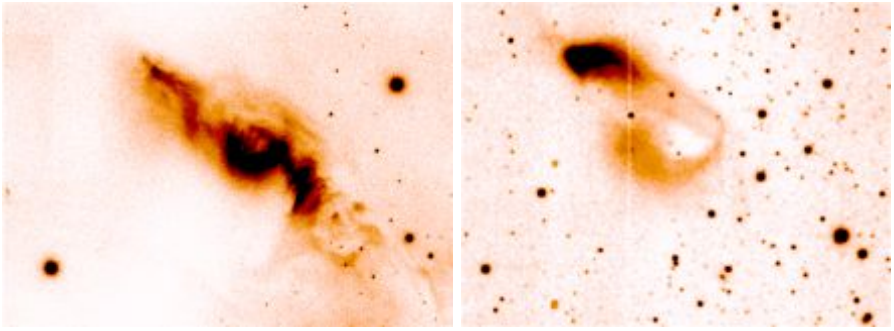

Fig.9. Braid Nebula reflects light from the brightened source in the apex (visible only in infrared range). Left panel: Subaru image (I band); right panel: UKIRT WFCAM image (K band); both are obtained in 2006.

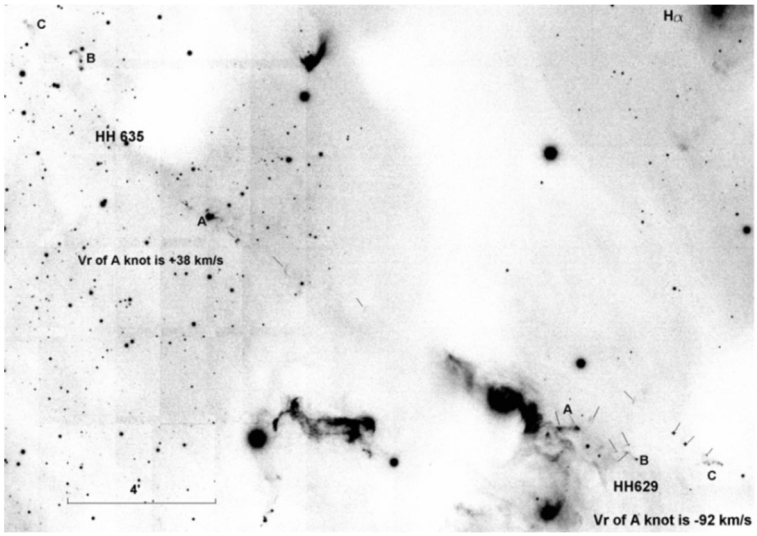

Fig.10. Braid Nebula outflow consists of many knots (marked by arrows on this Subaru image), which are grouped in HH 635 and HH 629. Note the parallel flow in the lower right corner. The bright knotty object in the lower part of the figure is HH 448.

Several other flows, found in L1003 field, are also of great interest. Some most impressive examples we present in Figs. 13-15. Their detail structure can become the subject of separate study. For example, HH 448 (which can be seen in Fig.10), being the brightest HH object in this cloud, has controversial morphological and kinematic characteristics, and its exciting source (or sources) remain still unknown. In any case, one can be sure that the PMS population of this cloud should be numerous. Our searches in NIR range revealed in L1003 many molecular hydrogen outflows (Khanzadyan et al., 2010, in preparation); partly they coincide with the optical flows, but some, even the giant ones, are visible only in H_2 emission. The results of mm/submm surveys show the existence of the even more extended molecular outflows (these data also soon will be prepared for publication). We hope that the joint analysis of this bulk of data will give us more or less full understanding of the star formation process in L1003 cloud. Its relatively distant location can be even favorable because allows to see the complete picture.

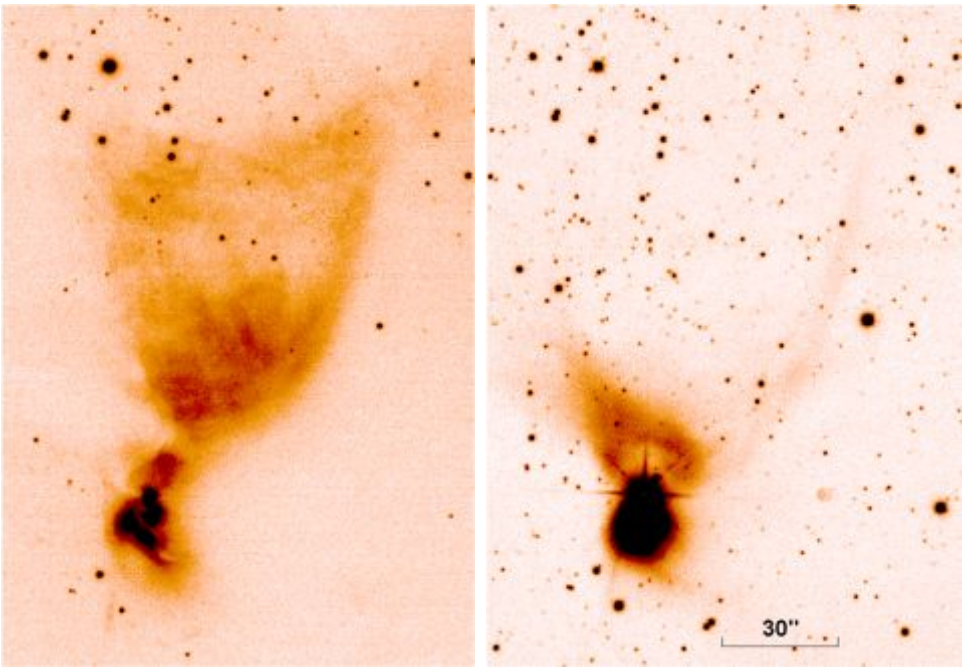

Fig.11. IRAS 20568+5217 (HH381 IRS) Nebula has typical hourglass shape. The central star is much brighter in infrared. Left panel: Subaru image (I band); right panel: UKIRT WFCAM image (K band); both are obtained in 2006.

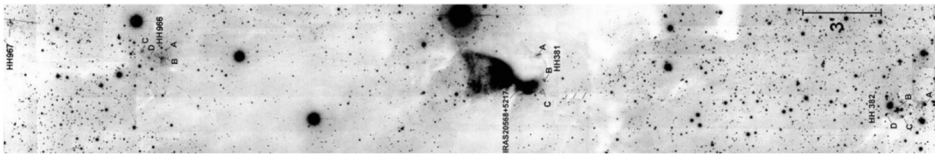

Fig.12. This figure (north is in left, east down) demonstrates the visible extent of HH 381 IRS outflow. Two groups of HH knots (HH966 in the left and HH 382 in the right side) denote the major terminal shocks of the optical flow. But it can be even longer in IR and radio range; note also the HH967 group in the leftmost edge, which also can extend the visible flow, if proved to be its part.

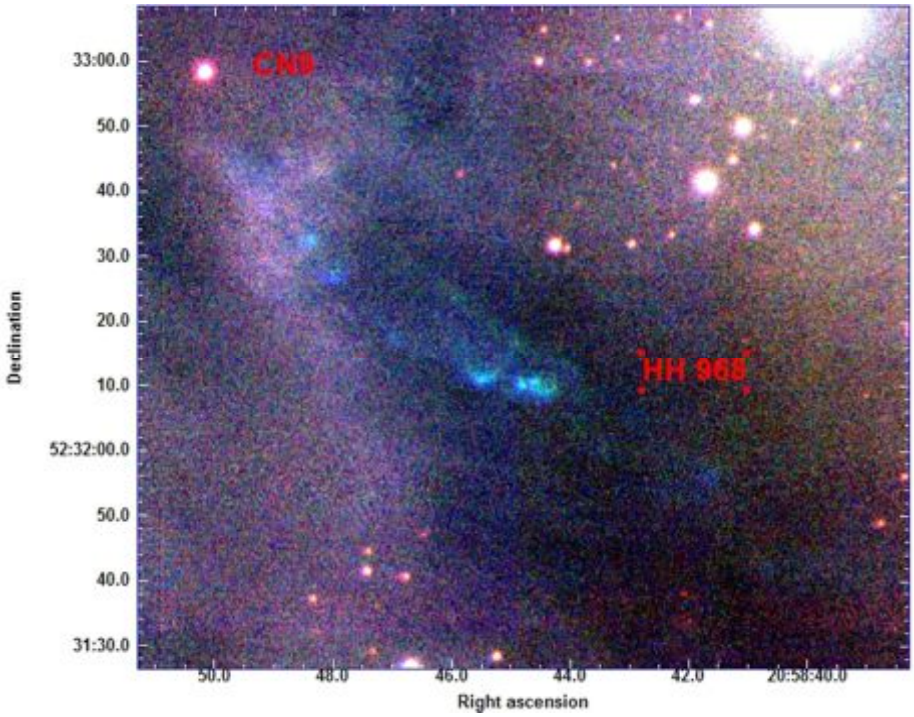

Fig.13. False color image of HH 968 flow, constructed from Subaru images in I (red), Hα (green) and [SII] (blue) bands. The very red star in upper left corner is the probable source. The full extent of this flow can be much larger and include other HH groups (see Magakian et al., 2010 for details).

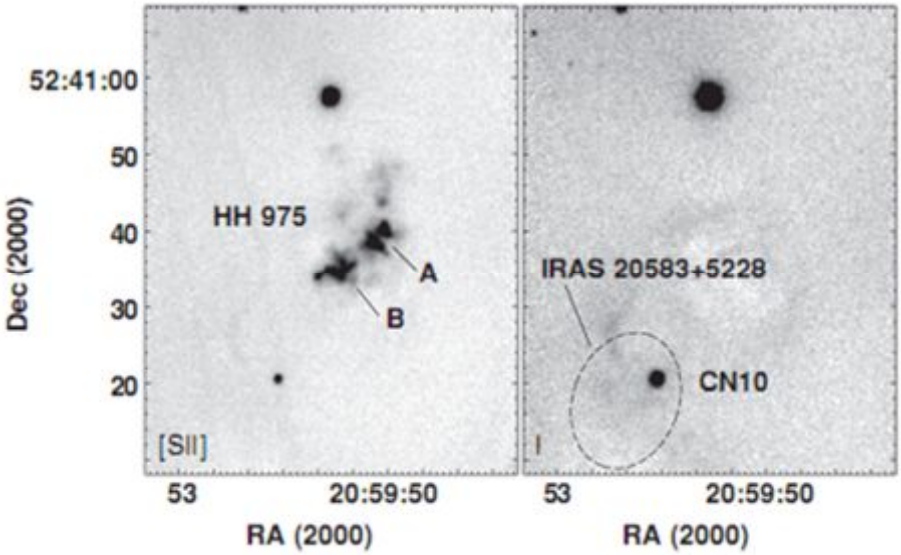

Fig.14. The HH 975 group. Left panel is [SII] image, right panel – image in I band (both obtained with Subaru telescope). The emission objects seem to be embedded in the very high extinction dust cloud. The faint star, probably related to IRAS 20583+5228, can be the exciting source of this group.

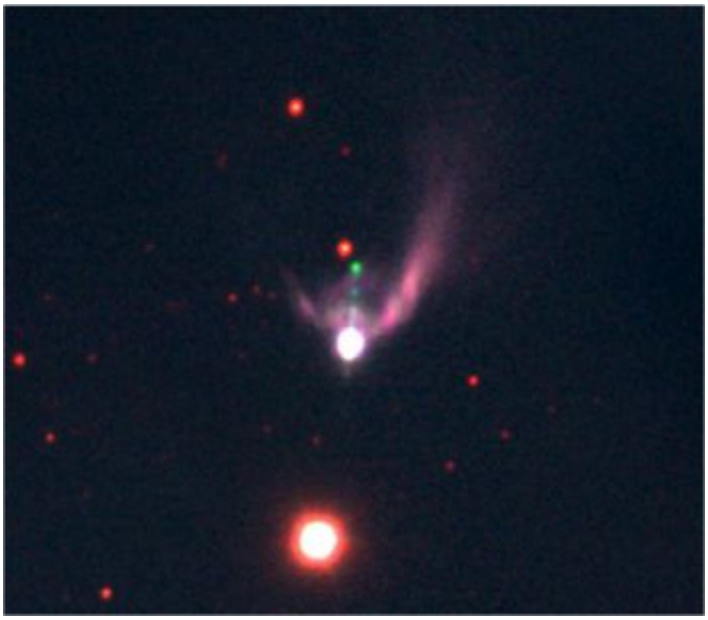

Fig.15. CN1 nebula and the knotty HH 632 flow are well seen in this false color image, constructed from Subaru images in I (red), Hα (green) and [SII] (blue) bands.

4. Conclusions

We can summarize the intermediate results of our work in the following way.

- New star formation regions were found.
- Their stellar content includes various interesting examples of YSO, among them two new representatives of the extremely rare class of FU Ori type objects, which were found in one SFR.
- Cygnus constellation seems very promising for the further searches of SFRs and FUors particularly (at least 5 are already found). In fact, such conclusion is not surprising, if we take into account that line of sight in this direction goes along with the spiral arm of Galaxy.
- Notwithstanding the present abundance of the many-sided studies of HH flows and individual knots, the detailed spectral analysis of these objects still allows to find the unusual examples of their structure and kinematics, important for the refining of the theoretical models.

There are other interesting and promising regions, for which we continue our studies. The limited volume of this presentation does not allow to describe them.

The main deduction which can be made on the base of the discussed above results is actually obvious. The concepts of Ambartsumian remain surprisingly fruitful for the searches and studies of stellar formation and activity in the early evolutional stage, even if our interpretation of such activity considerably changed in last thirty years.

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Colin Aspin (*Institute for Astronomy, University of Hawaii),*Tracy L. Beck (*Space Telescope Science Institute),*Tae-Soo Pyo (*Subaru Telescope, National Astronomical Observatory of Japan),* Chris J. Davis, Gerald M. Schieven (*Joint Astronomy Centre),* Michael D. Smith (*Centre for Astrophysics & Planetary Science, School of Physical Sciences, The University of Kent, Canterbury).* We are grateful to our collaborators for their support in preparing this presentation, in particular for the unpublished results.

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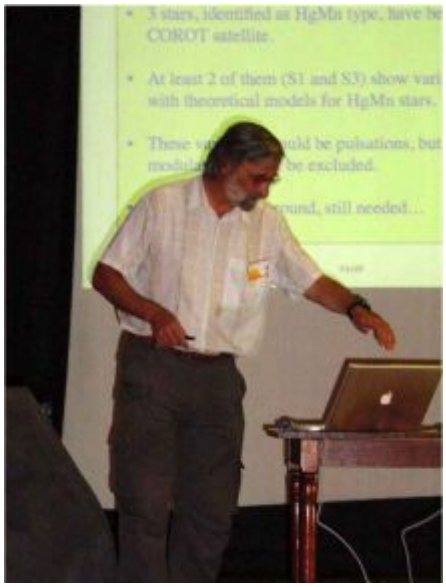
Will COROT satellite tell us whether HgMn stars pulsate or not?



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Contribution not available.

Gaseous Nebulae: Astrophysical Laboratories in the Sky

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Abstract. Planetary Nebulae are described as the product of the late evolution of intermediate mass stars. Several peculiar recent observations are related such as FLIERS and RINGS. The morphology and distance scale of these objects are also discussed.

1. Introduction.

In the last several decades, stellar evolution studies have indicated that stars in the mass range from about one to eight solar masses will eventually become planetary nebulae, expanding gaseous envelopes ejected from a central dying star. Four to five billion years from now, our Sun will also have the same fate.

In our galaxy we have been able to observe ~1500 planetary nebulae, although their total number is much higher. These objects range in size from ~0.04 to 0.7 pc and range in mass from ~0.2 to 3 solar masses. The expansion velocity of the nebulae is between 20 and 30 km/sec, and the lifetime of the visible nebulae is about 20 to 40 x 10^3 years.

The ionized gaseous envelopes surrounding the dying stars are rich in astrophysical processes. Bright emission lines are seen from such objects, as well as continuum radiation from the x-ray and ultraviolet spectrum and the infrared and radio spectrum. The bright nebular spectral lines were identified in the 1920s with the forbidden lines of ions like [O II] and [O III]. As early as 1933 V. A. Ambartsumian (1933) developed a radiative equilibrium theory of planetary nebulae and described the role of radiation pressure in these objects.

When stars evolve out of the Main Sequence and become AGB stars that develop planetary nebulae they have many things in common and undergo many of the same processes. The expanded giant stars usually have a radius of about 2 AU and a mass of one to a few solar masses. These stars have a mass loss rate which increases from 10^{-8} to 10^{-4} solar masses per year. First a slow wind develops, which creates an expanding

envelope that contains molecules including CO, CS, SiO, HCN, and dust particles. The lifetime of AGB stars is about 10^6 years, characterized by a Helium shell burning phase, and a thermal pulse phase. After 10^6 years, the core quickly collapses into a White Dwarf, and a fast wind compresses and ionizes the surrounding envelope to a thin radiating shell.

2. Unsolved Problems in Planetary Nebulae

Among the unsolved mysteries in planetary nebulae are the FLIERS (Fast Low Ionization Emission Regions), the symmetrical concentric shells around the nebulae (RINGS), the existence and role of magnetic fields in shaping the nebulae, and generally their distance scale in the galaxy.

(a) FLIERS are low ionization knots of small scale and are easily seen in the light of [N II] and tend to come in pairs equidistant from and on opposite sides of the central star, and mostly lie in the direction of the major axis of the nebulae (Hajian et al 1997, Balick et al 1998, Terzian and Hajian 2000). Kinematic studies have shown that such features have velocities directed away from the central star and these velocities are typically a few times larger than the expansion velocities of the nebulae. Figure 1 shows examples of FLIERS imaged with the Hubble Space Telescope (Balick et al 1998), NGC 3242, NGC 6826 and NGC 7009 are shown.

Figure 1. Examples of FLIERS in NGC 3242, NGC 6826 and NGC 7009.

Redman and Dyson (1999) have suggested that FLIERS originate from mass loaded supersonic collimated outflows, originating from the central star, and Dopita (1997) has suggested that they may be due to shocks in a photoionized medium. It still remains an open question on how FLIERS are formed, why they show a large N abundance, and what is the origin of the large Doppler velocities. It may be that the knots were pre existing large Jupiter like planets around the star and we are seeing the interaction of the stellar wind with the upper low density part of such planets (photoevaporation). Given that the FLIERS are mostly seen in the plane of the major axis of the nebulae, this may

be a possibility. However, it is unlikely that planets come in pairs and equidistant from one another at opposite sides.

(b) The Hubble Space Telescope observations of planetary nebulae have also provided unexpected images showing multiple faint symmetrical RINGS around the central stars. These are clearly concentric shells surrounding the central star and may be the result of episodic mass loss from the AGB star. The separation of these shells is only a few hundred to a thousand years (Teymouryan and Terzian 2008). It also appears that rings maintain their extremely symmetric structure for several thousand years. CRL 2688 has been modeled with as many as 13 rings, and NGC 6543 with 8. Figure 2 shows the concentric rings around NGC 6543 and CRL 2688.

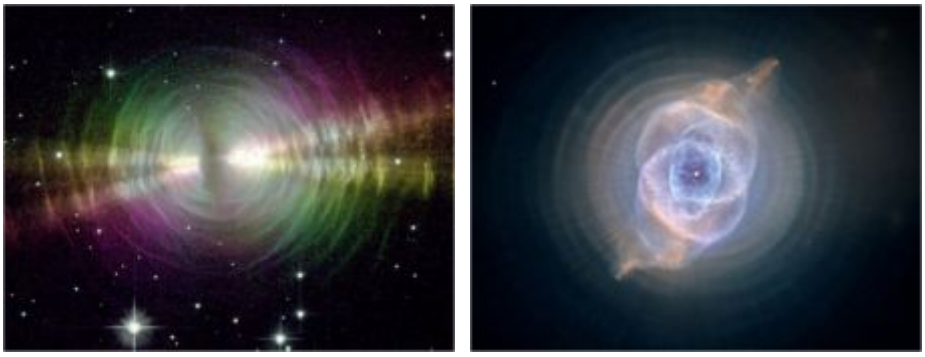

Figure 2. The RINGS around CRL 2688 and NGC 6543.

One of the most peculiar objects that shows symmetrical rings/rectangles surrounding it is the Red Rectangle nebula shown in Figure 3. Another is MWC 922 the Red Square shown in Figure 4. It is hard to envisage large scale celestial low density gaseous and dusty objects having such accurate symmetries with sharp angles at astronomical sizes. Most of the ring images show reflected light by dust particles, but in other cases the shells seem to be ionized showing Halpha, Hbeta and [O III] emission, particularly close to the centers.

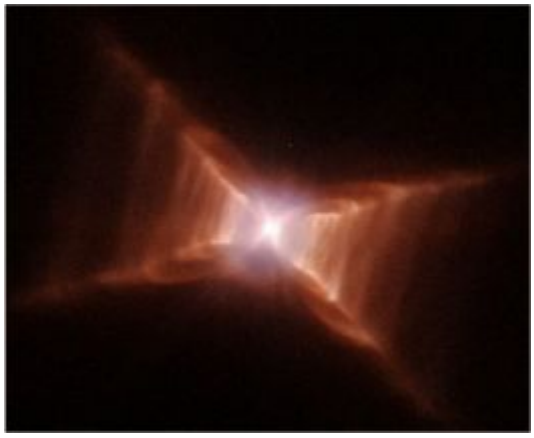

Figure 3. The Red Rectangle nebula (Cohen et al 2004).

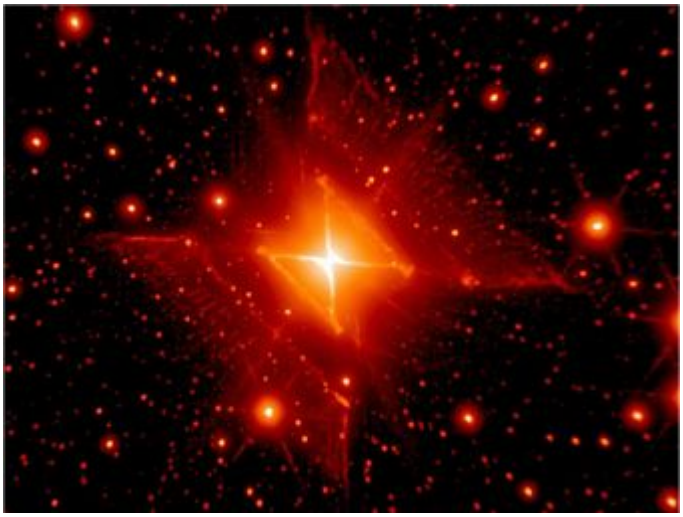

Figure 4. The Red Square nebula MWC 922 (Tuthill and Lloyd 2007).

The observed shells may be related to the stellar thermal pulses due to the 'Helium flash' phase of the star's evolution, however, these are predicted to occur with much longer time intervals compared to the measured separation of the rings in the planetary nebulae.

(c) Another unexplained aspect of planetary nebulae is their morphological appearance. Deep images of these objects reveal that in almost all cases we are seeing a bipolar morphological structure with a general mirror symmetry. Figure 5 shows examples of Mz3 and M2-9.

Figure 5. The bipolar nebulae Mz3 and M2-9.
http://antwrp.gsfc.nasa.gov/apod/archivepix.html.

In some cases the structures are complex and show small scale filamentary microstructure, collimated radial jets and multipolar bubbles (in addition to FLIERS and

RINGS). The physical reasons for shaping these nebulae are not clear, but dipole magnetic fields have been suggested (Gurzadyan 1997), and the gravitational effects of a secondary star in a compact binary stellar system, in shaping the nebula, have been investigated (Livio et al 1979, Soker and Harpaz 1992, Mastrodemos 1998). In addition, the effects of stellar rotation have been considered by Garcia-Segura et al (1999). However, no magnetic fields have been detected in planetary nebulae, and most stars do not have a close binary companion, and the rotational velocities of AGB stars are very low in order to have large effects on the structure of the nebulae.

(d) Another severe limitation to our knowledge of planetary nebulae is their distance scale. Various statistical attempts to determine distances to these objects have been shown to be very unreliable (Terzian 1993). Only recently measurements of expansion parallaxes of the nebulae using radio maps obtained with the Very Large Array (Hajian et al 1993, 1995, Hajian and Terzian 1996), and high resolution optical images obtained with the Hubble Space Telescope (Reed et al 1999, Terzian and Teymouryan 2005), have resulted in distance measurements of individual objects with accuracies of about 20%, compared to the large systematic errors in previous studies which were uncertain by factors of 2 , 3 or more.

The new distance calibration scale has resulted in an estimate of the total number of planetary nebulae in the galaxy to be about 45,000 resulting in a spatial density of ~150 per cubic kiloparsec, and a birthrate of ~1 per year. These estimates indicate that the total mass returned to the interstellar medium in the galaxy from planetary nebulae is of the order of 20 solar masses per 100 years. This number rivals the mass returned from supernova explosions and has significant implications on the chemical evolution of the galaxy.

Acknowledgments. Thanks are due to Bruce Balick and Arsen Hajian for informative discussions.

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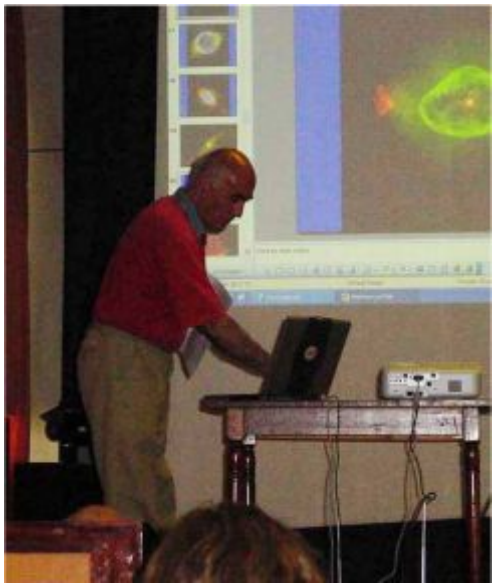
OB-Assocoations and Molecular Clouds



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Abstract. The discovery of existence of stellar associations was crucial in elucidation of star formation processes. Before the works of Ambartsumian the widespread idea was that the stars are born together and will die together, but Ambartsumian showed that the star formation processes are continuous events, which took place in the past, take place at present time and will take place in the future, in stellar associations. During last 30 years the connection of stellar associations with molecular clouds became obvious. Ambartsumian: "My opinion is that the future observations will show, that the stellar associations and expanding nebulae are forming together. I suppose that we must refuse the old idea of formation of stars out of diffuse matter and presume, that the diffuse matter as well as the stars are forming together as a result of disintegration of protostars".

The stellar associations are concentrated mainly in the disc of our Galaxy in the molecular ring R = (4 – 8) kpc. An OB-association is also present in the very center of our Galaxy – near the central object Sgr A*.

Still in 1937 Ambartsumian wrote [1]: "Investigation of above mentioned four types of objects shows the way in which the evolution of many stars takes place. These are explosions, accompanied by ejection of large amounts of material, and continuous outflow of matter".

1. Stellar Associations

Ambartsumian was the first [2, 3] who discovered the existence of stellar associations (in 1947). This idea was a consequence of generalization of observational facts. These facts were the following: in the sky there were several regions where the concentration of the stars of definite spectral types was very high comparing with the common stellar field (the groups of stars, containing the stars B0 or earlier, and also late type stars). In

the unit of volume of these groups there are several times more O – B2 type stars than in the common galactic field. OB-associations have one or several nuclei, which contain O-type galactic stellar clusters, stellar chains and Trapezium-like multiple systems. Trapezium-like multiple systems are rare systems with multiplicity (3 – 10), which have at least three stars, the distances between them are of the same order. In 1951 Ambartsumian gave the following definition: "The stellar systems are called O-associations if the O-B2 type stars partial stellar densities are exceeding the mean density of O-B2 stars subsystem so, that these deflections of mean density cannot be explained by accidental fluctuations, moreover there are representatives of one of the types O or B0.

O-associations have the following properties:

1. Their diameters are in the range between 30 and 200 pc.
2. They contain as nuclei O-type stellar clusters.
3. The stellar associations except the O-B2 type stars at the same time contain also B3 – B9 type stars and the stars of more later spectral types. However it is difficult to establish the number of stars of low luminosity, which are including in the association. In several associations WR-type stars are also including.
4. Trapezium-type multiple systems and stellar chains can be and often occur as nuclei of O-associations, at the same time with clusters.
5. Hot giants occur not only in the nuclei of the associations, but also outside of nuclei in the whole volume of the association.
6. There are weighty grounds to consider that O-associations are unstable systems".

Stellar associations are very young unstable formations, which are disintegrating. Ambartsumian suggested the following reasons for such a statement.

1. In the structure of associations there are young stars, O-type, WR-type, P Cyg type, super giants (and also cold super giants). O-type, WR-type and P Cyg type stars have very high luminosity and are unstable, they lose mass from the surface and cannot exist in such state for a long time: the upper limit of the O-type stars age is 10^7 – 10^8 years, of WR-type stars – 10^6 – 10^7 years, and for P Cyg type – 10^5 years. It means that the associations, which contain such unstable, still in their process of evolution objects, are also recently formed structures.
2. Stellar chains and Trapezium-like systems can not be stable configurations. They must disintegrate in a timescale not more than 10^7 years, moreover, as they exist, it means they are young and hence the stellar associations (which contain them) are also young.
3. Associations have sizes much more than the sizes of stellar clusters, and have stellar densities, lower than the stellar clusters have, and hence the influence of tidal forces of our Galaxy must start disintegration of the association. The tidal forces are the difference of attraction force on the opposite edges – closer and farther edges –of any

formation. After integration of Oort's formule $\Delta V_r = A\ r\ \sin 2(l - l_0)$ over two moments of time we have $\ln R_2/R_1 = A\ (t_2 - t_1)\ \sin 2(l - l_o)$. Hence the expansion of association will be the largest at $l - l_0 = 45^0$ and the time of doubling of sizes of association will be $t_2 - t_1 = 3{\cdot}10^7$ years. During this time the tidal force will cause noticeable elongation of association. In real associations we do not observe elongation. It means that there are other reasons which cause enlargement of associations in all directions. The only possible conclusion is that during their origin the members of associations received considerable velocities of removing away from the centre – about (5 – 10) km/s.

The discovery of small age of observed stellar associations has a great importance. It leads to the following conclusions:

1. The origin of stars takes place also at present time.
2. The stars are originating not separately, but by groups – in associations or their parts – nuclei.

Ambartsumian predicted that the velocity of enlargement of associations must be of the order of 10 km/s. If that value was more, say ~100 km/s, it would be noticed at once; if about 1 km/s, it would be not enough for disintegration of association, moreover, the tidal forces would make the shape of association rather elongated, but the elongation of associations is not observed. The predicted by Ambartsumian enlargement of associations was confirmed by observations of stellar velocities of stars, members of associations.

Ambartsumian suggested hypothesis that many stars (if not all), involving in the plane population of our Galaxy, were formed in the associations. The stars formed in the associations leave the associations and are involving in common galactic field, meanwhile the process of formation of new stars in the associations is continuing.

In the clusters and associations we have the influence of inner attractive forces, as well as perturbating tidal forces of our Galaxy. The latter are elongating and trying to destroy the systems. In the association the attraction is small comparing with tidal forces. The latter are increasing with enlargement of association. After a definite interval of time the change in velocity due to tidal forces, is comparing with the initial velocity of expansion. Simple calculation shows that the requested interval of time does not depend on the initial velocity of expansion and in the solar vicinity in the Galaxy has a value of the order of $15{\cdot}10^6$ years.

Due to their proper motions several expanding associations are already known: Pers OB2, Cep OB2, associations in Lac, Scorp et cet. The mean velocity of expansion in them is about 10 km/s.

OB-associations contain bright stars, so they are seen easily in near galaxies, mostly in spiral arms. The most rich with OB-associations are Sc and irregular galaxies.

In large associations there are several nuclei, which is in favor of existence in such associations of several star-forming centers. There are also stars belonging to associations out of these nuclei. The latter stars were formed in the nuclei which were already disintegrated. Taking these facts into account Ambartsumian suggested, that in the large associations we have several events of formation of tight stellar groups, these events occur in different time. Ambartsumian proposed that there are bodies in the associations out of which the stars are formed. These bodies are so named protostars.

Ambartsumian showed that the system of protostars can exist for a long time, if its sizes are ~40 pc, the number about 100 protostars, the mass of the system – about 60000 M_0. Such a system can exist about $2 \cdot 10^9$ year. The peculiar velocities of different nuclei in the association must be of the order of several km/s. The protostars are transforming into unstable nuclei of associations. During the disintegration of these nuclei the star members of nuclei receive more velocities – about 10 km/s, and overcoming the attraction of other stars of the nuclei and the association as a whole, are leaving the association and are embedded into general stellar field of the Galaxy. In each moment the association consists of protostars, nuclei of associations – stellar clusters, trapezium-like multiple systems and star chains, diffuse matter and stars, formed from already disintegrated nuclei. The association can exist for a long time, because in place of stars, leaving the association, will come new stars, forming from other protostars.

Except OB-associations there are also T-associations, containing T Tauri type variable stars. T Tauri type stars are irregular variable stars of second part of main sequence (G-K-M) with emission lines in the spectra. They are distributed, as noticed Ambartsumian, in the sky by groups. The well known are near Orion Nebula and in Taurus. Except T Tauri type stars in T-associations are also included non variable stars – sub giants and dwarfs (G-K-M), and Herbig A_e/B_e stars (which are very similar to T Tauri type stars).

2. Trapezium-Like Systems

Ambartsumian was the first who took attention on the existence in many OB-associations of multiple star systems in which the distances between the neighbour stars are rather similar [4, 5]. Such systems were called trapezium-like systems in analogy with Trapezium Orionis. In the range O-B2 the majority of multiple systems are of trapezium-type. The percentage decreases up to 10% for A and K stars, where is the majority of multiple systems. The stellar system with negative energy is disintegrating by throwing away of separate stars and afterwards the system is contracted, meanwhile the configuration of the system with positive energy is expanding, so the existence of wide systems(comparing with classical trapezium-type systems) is in favour of suggestion that the trapezium-like systems have positive energy. Ambartsumian also

gave estimation of the age of trapezium-like systems – not more than 10^6 years. In [4] the list of trapezium-like multiple systems is given. The more complete list of trapezium-like systems gave Salukvadze. It is possible to tell on the existence of physical connection between the members of trapezium-like systems only on the whole – a definite part of these systems are physically connected systems. The question of physical connection between the components of a multiple system is rather important. Salukvadze with coathours used several methods [6-9]. They made photometry of the components of multiple systems, they also obtained the radial velocities of components of trapezium-like systems. After arriving of new stellar catalogues they enlarged the list of multiple systems, there are already 637 systems.

The probability of existence of physical connection between the stars of a system is increasing, if all the components of a multiple system are of the same spectral class. During our searches of new trapezium-like systems we kept this condition for increasing the probability of physical connection.

It is interesting to discover more tight systems than the classical multiple systems. They are very young systems. Such systems is possible to discover among the objects embedded in molecular clouds. Such objects are invisible in optics, but seen in infrared and/or radio range. The sizes of such systems are in the range (0.01 – 0.1) pc. They are mainly consisting of late O and early B type stars. The estimates of their spectral classes were made by comparing their radio and IR brightness with their brightness in the visible part of spectrum. It is supposed that in molecular clouds a reradiation from visible part in IR and radio takes place: heating of dust and gas with further reradiation. The tight systems are rather young, and that is why in most cases the main star of tight systems is of type O – B2.

The classical multiple systems have sizes ~0.1 pc. It is interesting to consider systems which have wider sizes, say ~1 pc. Ambartsumian considered the existence of such wide systems and gave a list of 5 such systems, with sizes (0.3 – 0.6) pc, but the components were of different spectral classes. We decided to find wide systems, consisting of the stars of the same spectral class (mainly B). It is possible to find wide multiple systems also among the objects given in [10-12]. These are catalogues of stars connected with reflection nebulae (these objects are the members of so named R-associations, which are mainly parts of OB-associations). These systems are physical with high probability, because they are connected with reflection and dark nebulae. In [13] we found 10 multiple systems from the objects of latter catalogues. The components are mainly B type stars, the sizes are (0.4 – 1.5) pc, multiplicity 3 or 4. The mean difference between the magnitudes of faintest and brightest components is 1.9 in our list and 5.5 in the list of wide systems of Ambartsumian, so in our choice the stars are more similar in different qualities: magnitudes, spectral types. In the intermediate ejection from the nucleus of NGC5128 (Cen A) there are chains of blue stars [14, 15] (the spectra of several of them correspond to the spectra of B type supergiants). The

blue stars in the chains compose multiple systems with multiplicity of 3 or 4. The middle distance between the members is about 70 pc. The dimensions of these systems correspond rather to nuclei of superassociations, which have dimensions about 1 kpc.

Salukvadze was looking for trapezium-like systems containing T Tauri type stars [16]. His search was around already known T Tauri type stars, members of T-associations.

We have done a search on the PSS charts of Northern Hemisphere and also on ESO/SRJ charts of Southern Hemisphere of trapezium-like systems, consisting of low mass and low luminosity stars, in the regions containing dark clouds [17]. The following restrictions were imposed on the multiple systems.

1. All the distances between the members of multiple systems must be of the same order.
2. The difference between the magnitudes of member stars must be not more than 2^m.
3. The systems must be connected with dark clouds.

These restrictions must increase the probability of physical connection between the members of found multiple stars. Several dozens 0f such systems were found. Almost all the systems are connected with IRAS point sources and OB-associations.

3. Molecular Clouds and Stellar Associations

Since middle 70-es the molecular hydrogen became one of the main objects of investigation of physics of interstellar matter. The investigation of distribution of H_2 in the Galaxy gave discovery of new element of the structure of disc of our Galaxy – molecular ring – the region of high concentration of H_2 in the ring with radius R = (4 – 8) kpc. In this ring we have also high concentration of stellar associations, HII regions, pulsars, SN remnants, the sources of diffuse γ-radiation and synchrotron radiation.

It is now known, that OB-stars are born mainly in molecular clouds in star-forming regions, moreover during the formation of stars the molecular clouds are destroying partly or wholly [18]. After the destroy of molecular clouds radial systems of dark globules were forming.

Several radial systems of dark globules were carefully investigated and are well known: in Gum nebula, around λ Ori, in the Rosette nebula [19-22]. We decided to obtain new such systems, and for that reason looked through the PSS2 charts. During the search [23-25] about 20 new radial systems with HII regions were discovered. In the central parts of these systems mainly O-type stars are situated. In several cases there is no O-type star, visible in optics in the central parts of these systems, but there is a dark cloud in that region, and several infrared stars can be the candidates of O-type stars, situated

in the background of dark cloud. About 40% of globules of radial systems have embedded IRAS point sources. Out of 140 stars, connected with cometary nebulae, 100 are embedded in dark globules. Many HH objects are also embedded in dark globules.

4. The Central Body of Our Galaxy – Sgr A*

In the center of our Galaxy a massive object Sgr A* is situated [26-30]. In 3mm the sizes of this body are estimated as $1.4 \cdot 10^{13}$ cm, its mass is estimated as $2 \cdot 10^{6}$ $M_{\odot}$. In the vicinity of this object young blue very bright stars are situated, B type super giants. Some of them are very rich in He and the stellar wind is flowing away from them, the velocity of the wind reaches 1000 km/s. Such stars are very rare beyond the center of our Galaxy. These stars make chains, one of 6, the next of 4 stars. The mean distance between the stars in the chains is ~0.03 pc, it means that the chains are trapezium-like tight systems. These stars together with Sgr A* are situated in the cavity (~2.7 pc) inside the molecular cloud. The dimensions of that cloud are ~7.5 pc. This group of blue stars perhaps has blown away the former material of cavity around them, in the molecular cloud.

In [30] is mentioned that Sgr A* is emitting (4 – 6) orders less energy than we could anticipate if the accretion on the black hole takes place. If we agree with the point of view of Ambartsumian, than Sgr A* is one of super dense bodies, the decay of which originates new OB-associations. It is possible that one of such bodies near Sgr A* (or a part of Sgr A*) decayed in the past, as the result of this decay originating molecular clouds, chains of blue stars, and also late type super giants (the latter are also present in the cavity).

5. Conclusions

Discovery of stellar associations by Ambartsumian gave an impulse to many astronomers to begin the investigations of processes of star formation. In recent decades were the following objects were discovered: star-forming regions in molecular clouds, which are the early stage of stellar associations, radial systems of dark globules, which are parts of stellar associations. These works were done due to the discovery of molecular hydrogen in the galactic disc, in so named molecular ring.

During the last decades were continued also the works devoted to the investigation of discovered by Ambartsumian trapezium-like systems in stellar associations, in star-forming regions, in outer galaxies, and also in the centre of our Galaxy.

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On cosmic ray processing of ices in molecular clouds

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Abstract. We investigated theoretically the transformation of the energy dependence of the cosmic ray proton flux in the keV to GeV region when penetrating inside molecular clouds. Our computations suggest that energy losses of the cosmic ray particles by interaction with the matter of the molecular cloud are principally caused by the inelastic (electronic) interaction potential; the transformed energy distribution of energetic protons is determined mainly by the column density of the absorbing medium.

Up to now there are no detailed investigations on an energetic particle processing of various ices by ions, modeling the cosmic ray irradiation over the whole energy range from eV to GeV. Our studies on the ion induced conversion of ices include an examination of the linear energy transfer due to stopping processes, by which the input projectile loses its original energy to particles in the target. In particular, a cosmic ray irradiation dose up to $A_V = 50$ for icy methane is calculated and discussed. The results can be used to predict a radiation induced chemical conversion rate of simple chemical species to complex ones by means of forthcoming experimental data.

Keywords: *Cosmic rays – ionization of H_2 – molecular clouds – irradiation doses of ices*

1. Introduction

Dust grains inside dense interstellar clouds become coated with molecular ices. These ices are detected by infrared absorption spectroscopy against background stars. The ice composition is mainly H_2O, with significant contributions of CO, CO_2, CH_3OH, CH_4, NH_3 and other species. H_2O is formed on the surface of the grains by hydrogenation of O-atoms that collide with and stick to the grains, while CO arises from CO in the gas simply adhering to the surfaces. Other ice species, are of too low abundance in the gas phase to account for the observed ice composition, and must be formed by a chemical processing in the ice [1,2]. Such chemical processing requires the input of energy. For example, laboratory studies have shown that there are energy barriers to be overcome in the hydrogenation of CO to form CH_3OH and it is clear that these reactions will be entirely suppressed at the temperature of interstellar ices (~10 K) in the absence of non-thermal excitation. The formation of CO_2 is known from experiments to occur when solid mixtures of CO and H_2O are suitably energised. Thus, although several molecules known to exist in the ices are evidence of chemical processing, the mechanism by which

this occur is uncertain, and the chemical extent is unclear. Two sources of energy are available in interstellar clouds: energetic particles known as cosmic rays (CR) and ultraviolet (UV) radiation. CR particles coming from various galactic sources consist mostly of protons with a flux of 1-10 particles/cm^2/s, α-particles and electrons, but heavier particles such as C, N, O, Fe etc. nuclei with the abundance less than a few percent. are also present [1].

The energy spectrum outside of the clouds peaks at a few MeV, and extends to very high values with very low fluxes. It would be shown below that galactic cosmic rays (GCR) of MeV to GeV energies penetrate all but the very densest regions of interstellar clouds, up to a column density N_H of 10^{24} cm^2 and deposit a tiny fraction of their energy in material through which they pass. If the clouds are also regions of star formation, then a second source of energy is available from the intense radiation fields from young massive stars [1]. However, although UV photons do not penetrate into the deeper layers, CR particles can induce an ionization and destruction of H_2 in the interior of clouds. There have been extensive experimental studies of both mechanisms for processing interstellar ice analogues in the laboratory [1-4].

In this work it is investigated the transformation of the energy dependence of the CR proton flux in the keV to GeV region when penetrating inside molecular clouds ($N_H > 10^{21}$ cm^2). The physical characteristics of interstellar clouds such as temperature, pressure, radiation balance as well as energy deposition from CR particles and UV photons depend strongly on the state of hydrogen (H^+, H or H_2) [1]. Clouds with dominant H_2 hold average number densities of 10^3 cm^{-3} and temperatures of about 10 K [1]. The interior of these clouds are entirely blocked from the external UV photon field; recall that the column density along the line of sight, N (in cm^{-2}), is related to A_v (in mag) by $N = 2{\cdot}10^{21} {\cdot}A_v$ [2]. Ices are usually present in regions with $A_V \geq 3$ [2]. Here we present a numerical approach to compute the depth-dependent energetic spectral flux of the CR particles in a molecular cloud provided that the CR flux outside of the given cloud is known (section 2). We will investigate then the energy loss processes of these charged particles upon their penetration inside the cloud (section 3) and calculate the change in flux of the CR particles followed by irradiation of molecular ices (section 4).

2. The cosmic ray spectrum

In the diffuse interstellar medium (ISM), CR particles can propagate almost freely without losing a significant fraction of their kinetic energy to the matter in the cloud [5]. Very recently, Cooper et al. [5] compiled observational and model data of the CR particle flux in the very local ISM (Fig.1), which is the power-law extension of the CR spectrum to an intersection with the high-energy side of the plasma distribution. We would like to stress that the non-attenuated particle flux in [5] is remarkably different from the usually used model [6] (Fig. 1). The total proton flux in the energy range 1 eV–10 GeV calculated from the [5] is $7.4{\cdot}10^4$ particles/cm^2/s with an energy deposition

of $4.3 \cdot 10^9$ eV/cm^2/s. The authors of [6] obtained in the energy range from 1 MeV – 10 GeV 9.6 particles/cm^2/s and $3.1 \cdot 10^9$ eV/cm^2/s, respectively.

The interaction and hence energy loss processes of each charged particle with the matter of the molecular cloud depends primarily on the kinetic energy of the particles and the physical characteristics of the medium (density, spatial size, magnetic field) [1,2,4,7,8]. To quantify the energy loss of an ion while crossing a molecular cloud, we have to investigate the energy-dependence of the nuclear, ($S_n(E)$), and electronic, ($S_e(E)$), stopping power [9]. The total stopping power $S(E)$ is simply the sum of both contributions (Eq. 1). Since the units of the stopping powers are given in energy per length (r), we can also express the stopping power as the differential dE/dr. Here, we utilize the TRIM (**Tr**ansport of **I**ons in **M**atter) which is a part of SRIM (The **S**topping and **R**ange of **I**ons in **M**atter) code [9]. Note that at kinetic energies larger than several hundred MeV the energy loss of each charged particle is also determined by Bremsstrahlung, Cherenkov radiation, and nuclear reactions [9]. Here, we neglect these processes since the differential flux of the CR particles at these energies is at least 4 orders of magnitude lower than, for instance, in the MeV region [5]:

$$S(E) = S_n(E) + S_e(E) = dE/dr \qquad (1)$$

3. Energy loss and ranges of charged particles in molecular clouds

We will quantify now the energy loss and the penetration (range) of charged particles inside molecular clouds. Note that in this calculation we only focus on protons. To describe a particle penetration depth into a cloud, the projected mean range, R, is often used in collision dynamics. Compared to the actual path length, L, of a projectile, the projected range, i.e. the straight-line distance from implantation origin to the end point of the trajectory projected in the initial velocity vector, is always smaller. As the kinetic energy decreases, this difference becomes more pronounces. Here, significant angular deflections of the projectile via nuclear interaction happen to be eminent at energies of less than 1 keV/a.m.u [9] (a.m.u. is the atomic mass unit). For example, considering 1 MeV protons, we can provide [9] a crucial relationship between the mean free path, λ, i.e. the average distance between two collisions, of a CR proton, the ionization cross-section of H_2 σ(1 MeV), and the number density of H_2 (Eq. 2). For $\sigma(1\text{ MeV}) = 3 \cdot 10^{-17}$ cm^2 [9] and $n(H_2) = 10^3$ cm^{-3}, a 1 MeV proton has $\lambda \sim 3 \cdot 10^{13}$ cm.

$$\lambda \sim [\sigma(1\text{ MeV}) \cdot n(H_2)]^{-1} \qquad (2)$$

Obviously to slow down a proton from MeV to keV energies it needs about 10^4 collisions followed by ionizations. We computed the projected ranges as well as stopping powers of protons in H_2 gas with the SRIM code for a density of $8.9 \cdot 10^{-5}$ g/cm^3 [9]. SRIM does not allow a computation of the stopping powers at the low density of

interstellar clouds directly. Since the range is inversely proportional to the density of a medium, we can utilize Eq. (2) to scale the range R_1 of a proton of an energy E in a medium of a density ρ_1 to compute the range R_2 of the same proton with an identical energy E in a medium of a density ρ_2 via Eq. (3). Applying this procedure for clouds with $n(H_2) = 10^3$ cm^{-3}, we find that $R_2 \approx 2.7 \cdot 10^{16} \cdot R_1$. Since H_2 is the dominating component of these environments, our scaling procedure is well justified. For instance, applying this procedure to 1 MeV protons gives a computed range in the clouds of $2.6 \cdot 10^{17}$ cm. We conclude that protons with E <1 MeV can not penetrate inside clouds with $n(H_2) \sim 10^3$ cm^{-3} deeper than 0.1 pc; for E >1 MeV, the particles travel essentially straight paths through the cloud since deflections from their trajectories via nuclear interactions are negligible (recall that the nuclear interaction dominates at energies less than 1 keV); and the non-attenuated CR flux is changed due to the energy loss: this in turn slows the particles down and shifts the flux distribution from high values to lower:

$$R_1 \cdot \rho_1 = R_2 \cdot \rho_2 \qquad (3)$$

In a one-dimensional steady-state approximation, the proton flux inside a molecular cloud after shielding by a homogeneous layer, $F_{internal}(E)$ with a depth d and a density ρ_2 can be numerically computed from the stopping power for H_2 $S(E)$ given by SRIM and the initial, non-attenuated proton flux, $F(E)$ (Fig. 1). Accounting for Eq. (1), the energy-dependent energy loss of a particle with a kinetic energy E, $\Delta E(E)$, can be calculated via Eq. (4):

$$\Delta E(E) = S(E) \cdot d \cdot (\rho_2 / \rho_1) \qquad (4)$$

Considering energy conservation, we have to bear in mind that the external energy flux $Q_{external}(E)$ - in units of eV/cm^2/s - of the protons outside the molecular cloud (the non-attenuated energy flux) must be equal to the energy flux from the decelerated protons inside the cloud, $Q_{internal}(E)$, plus the energy flux given to the target atoms, $Q_{target}(E)$:

$$Q_{external}(E) = Q_{internal}(E) + Q_{target}(E) \qquad (5)$$

Here, the external energy flux $Q_{external}(E)$ can be computed as the product of the energy E and the non-attenuated flux $F(E)$ (Fig. 1) to:

$$Q_{external}(\mathrm{E}) = F(E) \cdot E \qquad (6)$$

Likewise, the internal energy flux presents the product of the energy E and the internal flux $F_{internal}(E)$ – the quantity we want to compute - to:

$$Q_{internal}(\mathrm{E}) = F_{internal}(E) \cdot E \qquad (7)$$

To calculate the energy flux transferred from particles of an energy E given to the target molecules (the H_2 gas inside the molecular cloud), we have to account for the following scenario.

For particles at a given energy E, the energy flux contributing from these particles is being *reduced* (they are actually slowed down from an energy E to lower energies) via interaction with the target gas by $F(E)\cdot\Delta E(E)$ (c.f. Eq. (4) for the definition of $\Delta E(E)$); likewise, particles of an energy E', which is higher than E, can be decelerated to the energy E; this process actually increases the energy flux for a given energy E by $F(E')\cdot\Delta E(E')$. Recall that p(E) presents a proton of the CR with a kinetic energy before (E) and after (E') the ionization process. In other words, a particle with an energy E' transverses a hydrogen column density $d\cdot\rho_2$ and exits with an energy E:

$$E = E' - \Delta E(E') \qquad (8)$$

Combining these relationships with equations (5–7) and plugging them into Eq. (4) gives us the tool to calculate $F_{internal}(E)$ via Eq. (9) from which we can extract then $F_{internal}(E)$:

$$F(E) \cdot E = F_{internal}(E) \cdot E + F(E)\cdot\Delta E(E) - F(E')\cdot\Delta E(E') \qquad (9)$$

$$n \cdot D_r = \int_{E_1}^{E_2} S(E) F(E) dE \quad , \; D = D_r \cdot t \; . \qquad (10)$$

We can now utilize these attenuated fluxes $F_{internal}(E)$ to investigate to what extent the CR protons process icy species. Integrating the fluxes over the energy-dependent ionization loss of given species $S(E)$, also available by SRIM, a simple procedure (Eq. (10)) finally yields the depth dependent irradiation dose rate D_r (in eV/a.m.u) and the dose, D (in eV) inside of molecular clouds.

4. Results and conclusion

Fig. 1 shows the results of our computations for a cloud model with the homogeneous concentration $n(H_2) = 10^3$ cm^{-3} and the size up to $A_V = 50$ mag. The corresponding CR internal flux and the depth-dependent dose for icy CH_4 in 10 Ma are also depicted in Fig. 1.

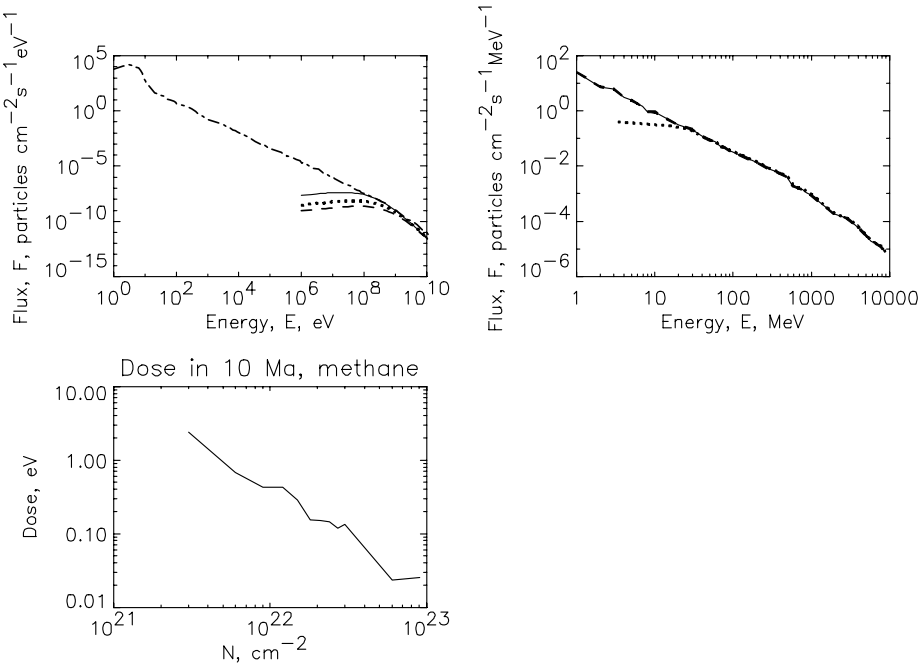

Fig. 1. Left: energy-dependent flux of the cosmic ray particles (protons) in the very local interstellar medium adapted from [5]. The peak in the spectrum arises from the plasma distribution in the very local interstellar medium. Dotted, dashed and dash-dotted lines show spectra given by [6] for three distinct parameter sets. Right: the transformed flux of [5] inside the cloud with $n = 10^3$ cm^{-3} at the edge of $A_V = 50$ mag (dotted lines). Bottom: the irradiation dose of icy methane (in eV/a.m.u.) during a minimal cloud's lifetime $t = 10$ million (Ma) years, on the base of the flux from [5].

Here, it is also worth mentioning that the CR flux – assumed similar in the solar neighborhood and at the edge of the non-attenuated cloud - is adequately transformed after shielding corrections inside the dense cloud. Doses for other icy species are close to that of for methane with an accuracy of a factor of 2-3 [7, 8].

Summarized, we have shown that the distribution of the CR particle flux inside a molecular cloud can be calculated if the energy loss of energetic protons – the principal constituent of the cosmic radiation field - in molecular hydrogen is known. The latter can be computed utilizing the SRIM program package and re-scaling the computed data to the actual number densities of the cold clouds. It is shown also that GCR in deeper layers of the clouds where ices are present ($N_H > 10^{22}$ cm^2 [2]) may irradiate ices up to amounts of absorbed energy, doses, no more than 0.1-0.5 eV per a.m.u. in $t = 10$ Ma (a minimal cloud's lifetime), which is much less than a threshold value of 10-100 eV/a.m.u. to initiate important radiation chemical transformations of simple ices to complex ones ([8]). It should be noted that the GCR flux decreases when penetrates

deeper than $N_H > 10^{21}$ cm^2 into the clouds followed with the doses decrease. Our model of the changes of the CR spectral fluxes in the eV-GeV range due to ionization energy loss of particles as they pass through a dense cloud probably need an additional source of CR ([8]).

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On a Mechanism of Stars' Flares

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Abstract. Flare mechanism for explanation of relatively high energetic of flares in low mass red dwarf flare stars and fast course of flare processes is represented. The investigation was made on the base of existing observations of flare stars and ones obtained in the Abastumani Astrophysical Observatory. Spectral and photometrical observational peculiarities revealed during flares of the stars led us to the represented mechanism of flares. Discussion of mechanisms generating course of flare processes in the red dwarf flare stars is being continuing during half a century but improved understanding about a flare mechanism and excess energy source, which is generated during flare processes, is not reached yet. Our investigation is attempting to some degree supplement this gap.

1. Introduction

A flare may have as thermal origin (hot spots) so non-thermal one (synchrotron mechanism, reversed Compton Effect). Not excluded that the above two types of mechanism are exist simultaneously in particular cases.

Flare stars are known from twenties of the last century. The flares of these kinds of stars in different spectral ranges including x-rays were observed using space telescopes during the latest years. But their essence is not clearly understood. The significant investigations of low mass cool stars are planned in coming 20 years' international ground-based and space projects (see: A Science Vision for European Astronomy and The Science Case for the European EXTREMLY LARGE TELESCOPE: The next step in mankind's quest for the Universe [1]).

Observations of flare stars are carried out in the Abastumani Observatory from 70-ies of the last century. Using the rich and unique observational material which was obtained by 70 cm meniscus telescope, the Catalog of Flare Stars in Orion Nebula Region was

compiled and published [2]. The catalog includes data about 491 flare stars and 694 flares of them and it represents rather rich data base for such kind of stars. The results of observations obtained in Abastumani (Georgia), Asiago (Italy), Byurakan (Armenia), La-Silla (Chile), Rojen (Bulgaria), Tonantzintla (Mexico), and Upsala (Sweden) are gathered in the catalog.

On the base of analysis of above data and new spectral observations of flare stars of solar vicinity, also after revealing an "unusual" flare of EM Cep an idea of flare course was born.

2. Diversity of flares

The revealed flares are different of kinds according their character of course, duration and energetic. They often characterized by complex structure, when powerful, complex flare is seen as a result of superposition of several "simple" flares (see for example: [3] and [4]). Combinations of different complex flares are shown on Fig.1 and Fig. 2.

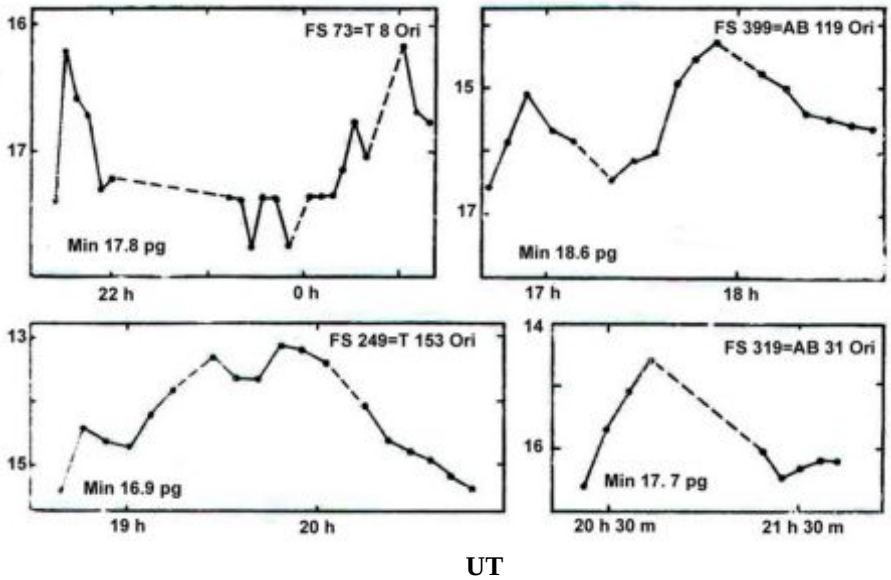

Fig. 1. Combination of flares: fast-slow, slow-slow and slow-fast [3].

Micro-flares too, being revealed during electro-photometrical observations of high mass stars are sometimes analogous with course of flares of red dwarf stars. A flare of the EM Cep ([5], [6]) is especially interesting. The flare was fixed in red spectral range of radiation while synchronous anti-flare was revealed in ultraviolet band.

Observations of red dwarf flare stars showed that at the initial stage of flare course a tendency of blue shift of spectral lines exists and widening of spectral lines is common at the later stages which may be explained by expansion of irradiative environment. During the widening of spectral lines the increase of equivalent widths of them exists which may be explained by gradually getting out of irradiation from inner layers during rarifying of irradiative expanding environment.

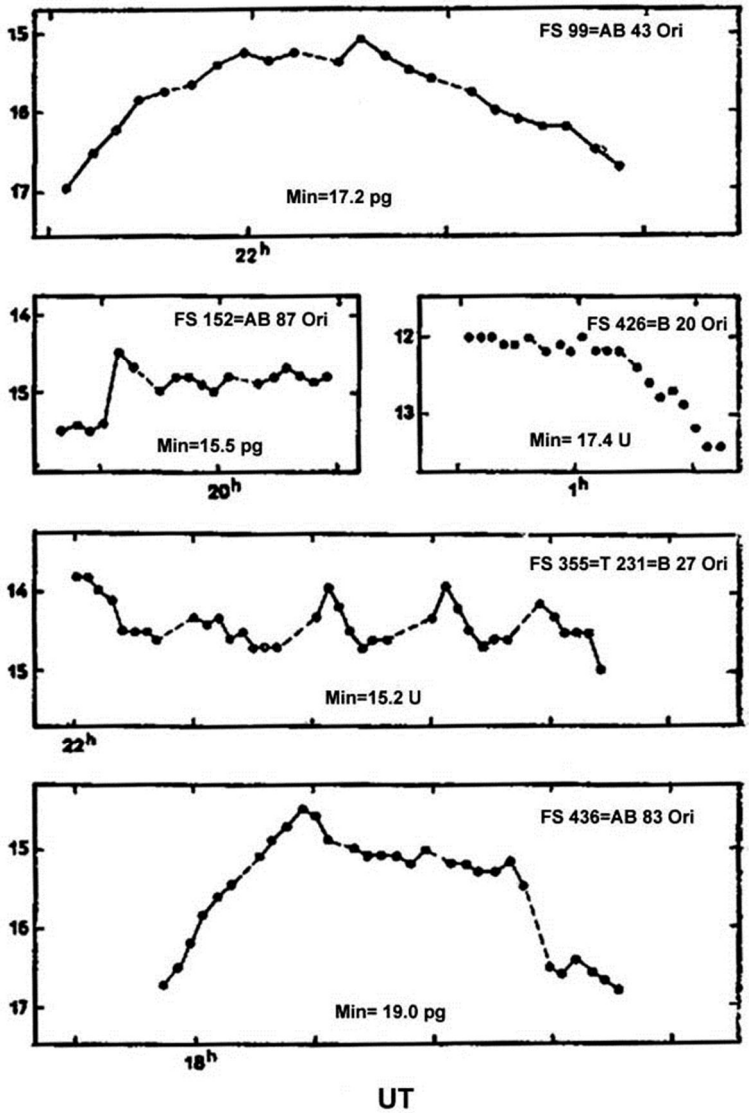

Fig. 2. Fuor-like brightness changes of flare stars [4].

3. Flare mechanism

High density and temperature expanding environment which has explosion character originates on the stellar disc. The geometrical sizes and location with respect of center of the stellar disc of such environment is significant for an observer, especially in case if the expansion of the environment is not spherically symmetric and it courses on the stellar limb. Tangential motion could not act on the dynamics of spectral lines. Radial motion of layers of the environment near center of the disc will provoke a different effect. Because this we have to expect events of different character during a flare of a star. We would like to represent common scenario for the case when the expanding hot dense environment exists near the center of stellar disc and expansion is almost spherically symmetric.

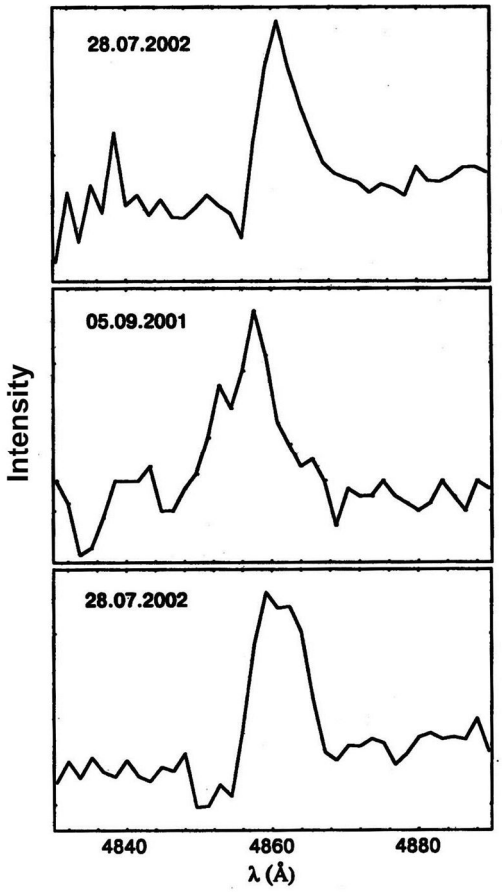

Fig. 3. Blue-shift of Hβ line profile during the observed flare of 05.09.2001 ([7]).

In such a case of explosion character expansion of the environment just at the moment of its appearing in upper layers of the star the temperature jump must revealed. This jump would be seen as excess energy flux in the continuum spectrum and also a blue

shift of continuum radiation must exist. This situation would exist until optical thickness of the environment would diminish sensibly and spectral lines would be arisen. These lines must be narrow on the initial stage and they must have also significant blue shift (Fig. 3), after that the red wing of the lines will begin shifting to the red range. This event would have an effect of the line widening. During this the temperature of the dense hot environment will gradually decreased and the expanding velocity of its layers maybe as increased so decreased which determines the character of widening of lines, but the temperature of the environment will decrease and because this the excess radiation flux gradually moves to the longer wavelength spectral region.

After the certain limit of the irradiating environment's density this environment gradually generates linear specter and continuous radiation will gradually interrupted. Spectral lines will be narrower at the initial stage than the next ones because the increase of sizes of expanding environment and decrease of the optical thickness will cause the increase of velocity difference and the spectral lines will widen. At the initial stage only radiation of the part of the environment moving toward the observer will registered and blue-shift of the spectral lines will revealed.

So if it would be possible a registration of flare of a star with high temporary and spectral resolution the above effects must be fixed as chronologically sequins. It would be possible to estimate chronological variations of metric and physical parameters of observed expanding environment having explosion character. On the bases of spectral observational statistical data of red dwarf flare stars it is possible the further checking and improving of the presented mechanism.

4. Conclusion

Even explosion character expansion of one hot dense environment which is formed on the stellar disc can inspire different events according to the geometrical location of this environment on the stellar disc and its physical parameters (temperature, mass, density, size, velocity of expansion, kind of symmetry of the expansion). Flare process would be much more complex if a few such kind of separate environment participates in the flare. We think that flares with complex structure of light variations must be result of combine action of some different areas (Fig. 1, [3]).

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Georgian delegation at Ambartsumian's centennial meeting:
Giorgi Javakhishvili, Nino Kochiashvili, Rezo Natsvlishvili

Observations of double and multiple stars by means of Pulkovo 26- inch refractor

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Contribution not available.

Multicolour Photometry of MR Ser

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Abstract. The multicolour photometry of magnetic cataclysmic variable (polar) MR Ser is presented. Observations were done with the help of 2.6 meter and 0.38 meter telescopes at Crimean Astrophysical Observatory (Ukraine) in UBVR-bands. Time of observations is 2006-2007 years. Color-Color and Color-Magnitude various diagrams were plotted and analyzed for our observations. During our observations MR Ser system was in 'bright' state.

We made attempt to determine constraint value of Tcol of the white dwarf in MR Ser system (Tcol - Color Temperature). Our result is in good agreement with the value, determined from far-ultraviolet spectroscopy carried on the Hubble Space Telescope.

Bright Stars with *Spitzer* 24 μm Excesses in Boötes and FLS

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Abstract. Optically bright stellar sources ($V<15^m$) with f_ν (24 μm) > 1 mJy are identified in a survey with the Multiband Imaging Photometer on *Spitzer* (MIPS) within 8.2 deg^2 of the NOAO Deep Wide-Field Survey region in Boötes (NDWFS) and within 5.5 deg^2 for the *Spitzer* Extra-Galactic First Look Survey (FLS). 128 stars are identified in Boötes and 140 in the FLS, and their photometry is given. Stars are classified using spectra from the Digitized First Byurakan Survey (DFBS), and (K–[24]) colors are determined using K magnitudes from the 2MASS survey to search for 24 μm excesses. In the combined sample of 268 stars, 26 have excesses with (K–[24]) > 0.2^m. The star with the greatest (K–[24]) excess is a variable star; the remaining 25 stars have 0.2 < (K–[24]) < 0.7 and are candidates for having debris disks. Using limits on absolute magnitude derived from proper motions, it is estimated that at least 12 of the stars with excesses are main sequence stars, and estimates derived from the distribution of apparent magnitudes indicate that 22 are main sequence stars. These estimates lead to the conclusion that between 5% and 10% of the main sequence field stars in these samples have hot debris disks. For comparison using the same (K–[24]) > 0.2 criterion for defining an excess, 5 of 69 bright, main sequence FGK field stars in a previous Spitzer survey show excesses.

1. Source Identification in Boötes and FLS fields

To identify sources within our previous studies of faint Boötes sources (e.g. Houck et al. 2005; Brand et al. 2006; Houck et al. 2007), we generated lists of Spitzer 24 μm sources which are identified with optical sources in the NDWFS within 2.0″. The NDWFS is

designed for the identification of very faint sources, to R ~ 26^m, and this identification criterion works well for faint, unresolved sources. Brighter, resolved galaxies and stars brighter than R ~ 16 may not be reliably identified in this way because of such problems as saturation of the source image or complex image structure. It is sometimes difficult, for example, to determine if saturated sources are stars or galaxies.

The magnitude cutoff of R < 17 is chosen to assure that all bright Galactic stars are included but to exclude quasars and unresolved galaxies which appear in increasing numbers for R > 17. In the Boötes survey area, there are 2853 sources with fν(24 μm) > 1 mJy. Of these, 308 sources have no optical counterpart in the merged catalog within 2.0″, and 281 sources have a counterpart identified which has R < 17. We used several steps to identify and classify these 589 sources. In the first step, DSS1 and DSS2 blue, red, and IR images were examined to classify the objects morphologically. Sources were also examined on the images of the Sloan Digital Sky Survey (SDSS; Adelman-McCarthy et al. 2008) for confirmation of the classification and to obtain SDSS r magnitudes.

The FLS survey catalog lists fν(24 μm) and R magnitudes for sources in an area of 5.5 deg^2 (Fadda et al. 2006). We used a similar strategy as in Boötes to examine all sources which could be bright stars. All sources in the catalog having fν(24 μm) > 1 mJy and with listed R < 17 or having no entry for R were examined individually on DSS and SDSS images to determine if they are bright Galactic stars, or galaxies.

R photometry for most bright stars in the Boötes and FLS surveys (R ≤ 15) is unreliable because images are saturated. As a result, our final selection of sources uses SDSS r mag. Inclusion of a source in our final list as a Galactic star requires r < 17, to omit the increasing number of quasars at fainter magnitudes.

Within Boötes, of the 589 sources selected for initial examination of their images, 439 were found to be galaxies bright enough for classification on either DSS or SDSS images, 16 were found to be sources too faint for classification on the DSS or SDSS (so with r >> 17), 6 were stellar objects with r > 17 (stars or QSOs), and 128 were determined to be stellar objects with r < 17. Despite using the r < 17 criterion for inclusion in the sample, all selected stars are actually r < 16. This is simply an empirical result; there are no stellar sources in the survey with 16.0 < r < 17.0, which confirms that our criterion of r < 17 assures inclusion of all bright Galactic stars. In the FLS area, there are 213 sources having fν(24 μm) > 1 mJy with an optical counterpart R < 17 and 87 sources with no optical counterpart. As for Boötes, our final selection of sources uses SDSS r magnitude < 17 to provide consistent photometry, which extends to brighter stars. 140 stellar sources in the FLS have been selected. As for Boötes, despite using the r < 17 criterion for inclusion in the sample, all stars are actually brighter; r < 15.5 for the

FLS stars. We restrict our analysis to sources having fν(24 μm) > 1 mJy to assure that the IR detections are of high precision, with S/N > 15.

For determining the spectral classification of sources in Boötes, we initially utilized the DFBS (Mickaelian et al. 2007), a low resolution objective prism survey of the sky originally used primarily to discover Markarian galaxies (the FLS field is not currently included within the DFBS). These classifications provided the initial indication that the great majority of these stars are of F, G, and K spectral types. The DFBS cannot provide luminosity classifications, and it is important to know which of the stars are main sequence (MS) stars. We estimate this by using available data on proper motions (PM) to estimate luminosity limits. The PM data are from Tycho-2 (when available) or USNO-B1.0 catalogs. This estimate uses 100 km/s as an upper limit for v_t to calculate the maximum distances and upper limits for luminosity. For example, a star with PM of 100 mas/yr should be at a distance less than 210 pc; for apparent $m_v = 15$, this requires absolute magnitude $M_v > 8.4$. Any star with $M_v > 4$ is assigned as MS (luminosity class V). This is a relaxed limit, so many stars without a confident assignment to class V may also be MS stars. Although the criterion for selecting bright stars uses SDSS r magnitudes, the highest accuracy optical magnitudes over the full range of brightness of these stars are the V magnitudes from the Tycho-2 catalog. In order to list a consistent spectral classification for both Boötes and FLS fields, we assign a final spectral class using the V–K colors of the stars compared to the relation between this color and spectral type shown by Gorlova et al. (2006). Spectral subclasses are not used after M0 (stars redder than V–K>4.5) because the relation is not well-calibrated.

2. Definition of Stars with 24 μm Excesses

The objective of our study is to identify excess IR continuum emission which exceeds that expected from the stellar photosphere. Determining the SED and temperature distribution of the material producing the IR excess requires detailed modeling of the stellar atmospheres and subsequent measures of the deviations from such a model at various wavelengths (e.g. Bryden et al. 2006). If the objective is only to identify stars with IR excesses, without determining in detail the spectrum of the excess, this identification can be done in a straightforward, empirical way with limited photometry. As shown in Gorlova et al. (2004), this can be done by comparing only NIR photometry (JHK) with fν(24 μm).

A simple method to seek 24 μm excesses in stars is to compare colors J-K with K-[24]. As pointed out by Gorlova et al. (2004), this method works because pure photospheric emission leads to K-[24] = 0, virtually independent of spectral type through type M. This constant color arises because both the K and [24] bands are on the Rayleigh-Jeans tail of the spectral energy distribution so that the color has little dependence on stellar temperature. Gorlova et al. (2004) compare (J-H) to the K-[24] colors in magnitude units. As in Gorlova et al. (2004), we define the magnitude at 24 μm by [24], with zero

magnitude of the MIPS 24 μm fluxes corresponding to 7300 mJy. Results for the Boötes stars and FLS stars are shown in Figure 1.

Gorlova et al. (2004) define stars with 24 μm excesses as those having (K-[24]) > 0.4 mag. Stars with no excesses above the photospheric continuum have (K-[24]) = 0.0 mag. This definition of a 24 μm excess arises by locating stars with a > 3σ excess at 24 μm compared to the flux expected from the photosphere, with the value of σ determined from the uncertainties of the 2MASS and MIPS photometry.

Because 3σ uncertainties in the Boötes and FLS data are ≤ 0.2 mJy, we identify those stars with (K-[24]) > 0.2 as stars with possible excesses. While in some cases, the observed excesses may arise because of sources being at the extremes of uncertainty, this definition of excess is justified by noting in Figure 1 that there is more extended dispersion of the points with (K-[24]) > 0.2 than for (K-[24]) < 0.2. Using this definition of excess, there are 13 such stars in Boötes and also 13 in the FLS.

The stars with IR excesses are identified in Figure 1 according to their listing in Boötes and FLS tables. The 26 IR excess stars are listed in Table 1. The most extreme source is no. 107 in Boötes, but this is a variable star so the observed excess is not attributed to a debris disk. This leaves 12 stars in Boötes and 13 in the FLS with 0.2 < (K-[24]) < 0.7, probable candidates for having debris disks.

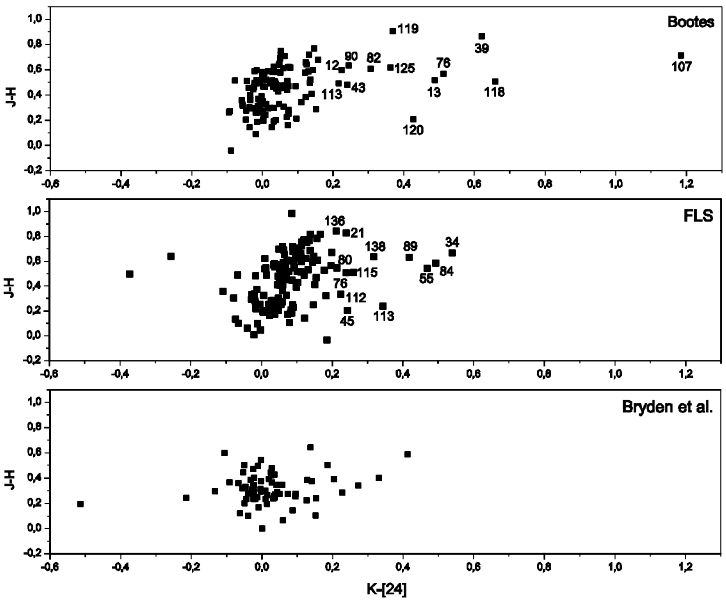

Fig. 1. J-H *vs.* K-[24] diagram for Boötes, FLS, and stars from Bryden et al. (2006) showing IR excess stars by individual numbers. IR excess is defined as K-[24]>0.2.

3. Characteristics of Stars with IR Excesses

Although 25 non-variable stars are identified with observed excesses, explaining the excesses as debris disks requires more information for each star. It is especially crucial to know which stars are MS stars, because giants with excesses can be explained by dust having been produced and ejected in the extended stellar atmosphere. Also, the presence of unresolved binary systems could lead to greater excesses (e.g. Trilling et al. 2007). Limits on luminosities determined by PMs are used to determine which stars are MS stars, as discussed above. Of the 25 (non-variable) stars identified with excesses, 12 are identified as MS based only on the PM criterion. Confirming estimates also derive by considering the magnitudes of the stars, as giants would be expected to appear systematically brighter. Really, most stars identified as showing excesses are among the faintest stars of a given spectral type (i.e. of a given (V–K) color). If we use only these magnitude trends as estimates of luminosity classes, we would deduce that all but the three bright stars mentioned above should be considered as MS stars, i.e. 22 out of 25. Using both the PM and magnitude criteria, therefore, we conclude that 12 to 22 out of 25 are MS stars.

Table 1. List of 26 IR excess stars identified from Boötes and FLS surveys defined as K-[24]>0.2.

No.	MIPS J2000	f_{24}	J	H	K	SDSS r	GSC V	V-K	K-[24]	Sp. type	PM	Com
	h m s d am as	mJy	mag	mag	Mag	mag	mag	mag	mag		mas	
b012	14 25 55.8 +33 04 26.5	1.746	9.983	9.386	9.275	11.682	11.91	2.64	0.222	M0	10	
b013	14 25 58.1 +34 31 33.6	1.585	10.376	9.859	9.650	13.050	13.36	3.71	0.492	K5V	328	
b039	14 28 50.5 +35 04 32.4	81.508	6.651	5.786	5.501	10.068	10.82	5.32	0.621	K5	19	
b043	14 29 18.3 +33 39 15.8	1.285	10.237	9.759	9.630	11.495	11.67	2.04	0.244	K5V	64	
b076	14 31 43.1 +32 14 32.8	2.014	10.261	9.693	9.413	14.254	14.39	4.98	0.515	M0V	197	
b082	14 32 49.1 +33 46 41.8	2.051	10.038	9.431	9.186	14.000	12.84	3.65	0.308	M0V	45	
b090	14 33 46.1 +33 34 54.2	3.429	9.352	8.717	8.564	11.553	12.23	3.67	0.244	M0V	40	
b107	14 35 24.3 +34 46 46.7	7.755	9.566	8.855	8.618	12.271	12.25	3.63	1.184	M5		var
b113	14 36 21.6 +34 40 11.4	1.280	10.236	9.745	9.606	11.858	11.89	2.28	0.216	M0		
b118	14 37 32.0 +35 39 50.6	1.837	10.287	9.780	9.655	14.460	12.24	2.59	0.657	K0V	27	
b119	14 37 32.0 +35 28 18.7	23.900	7.636	6.731	6.581	13.140	10.71	4.13	0.369	M0	13	
b120	14 37 37.0 +35 39 40.6	1.144	10.202	9.995	9.943	11.130	11.29	1.35	0.431	F5	17	
b125	14 38 23.1 +33 29 29.8	2.618	9.805	9.188	8.975	12.779	12.94	3.97	0.362	M0V	74	
f 022	17 10 56.0 +60 18 21.2	1.050	10.870	10.044	9.845	13.326	13.61	3.77	0.240	K5		
f035	17 12 56.7 +58 33 07.9	1.050	11.002	10.335	10.145	14.050	13.07	2.93	0.540	K0		
f046	17 15 10.6 +60 20 03.5	1.030	10.142	9.940	9.869	13.595	11.26	1.39	0.243	G0V	26	
f056	17 17 09.8 +59 24 09.3	1.060	10.851	10.309	10.064	14.310	14.43	4.37	0.469	K5V	301	
f077	17 21 20.8 +60 03 29.3	1.960	9.807	9.301	9.167	13.307	11.76	2.59	0.239	G5	13	X
f081	17 21 50.0 +60 26 06.2	2.190	9.704	9.160	9.021	13.616	11.52	2.50	0.214	K5	8	
f085	17 22 18.3 +59 50 03.8	1.510	10.577	9.993	9.704	14.140	14.55	4.85	0.493	G5V	109	
f090	17 22 42.9 +60 08 22.5	2.320	10.050	9.419	9.162	13.849	14.29	5.13	0.417	K5V	334	
f113	17 25 15.3 +58 35 08.2	1.220	10.019	9.686	9.667	13.578	11.21	1.54	0.225	K0		
f114	17 25 40.8 +59 15 31.3	1.310	10.006	9.768	9.709	10.338	10.51	0.80	0.344	F8	13	X
f116	17 25 49.5 +58 33 47.6	1.100	10.428	9.918	9.814	14.208	12.13	2.32	0.259	K5		
f137	17 27 30.5 +59 44 49.6	18.910	7.720	6.878	6.678	13.365	10.98	4.30	0.211	K5	10	
f139	17 28 23.5 +60 19 24.8	1.110	10.717	10.082	9.862	13.456	13.74	3.88	0.317	K5V	89	

The Boötes and FLS samples can be compared with the Bryden et al. (2006) study of FGK main-sequence field stars to determine the fraction of IR excesses that would be found with the same criterion used in Boötes and the FLS to define an excess. There are 5 of 69 stars (7%) with (K-[24]) > 0.2 mag.

To make comparisons of the Boötes and FLS samples with this result from Bryden et al. (2006), we need to know what fraction of all MS stars in the total Boötes/FLS sample have IR excesses, for comparison with the 7% number that arises from Bryden et al. (2006). A lower limit for the number of MS stars in Boötes/FLS derives from taking only those stars with MS classification deriving from PMs, which is 102 stars. If this is compared to the 12 stars with excesses and MS classification, the fraction of MS stars with excesses is 12%. If we simply take the total number of stars with excesses compared to the total in the sample, we have 25 of 268, or 9%. We can conclude that the fraction of MS field stars with IR excesses attributable to debris disks is ~ 10%, or a similar number to what was determined in Bryden et al. (2006).

4. Summary

The Surveys at high galactic latitude at 24 μm with the Spitzer MIPS instrument have been used in a serendipitous study of bright Galactic stars with detections at 24 μm. 268 stars with $V < 15^m$ and $f\nu(24\ \mu m) > 1$ mJy are identified within 14 deg^2 of the combined NDWFS Boötes and FLS fields. Using a comparison with fluxes from the 2MASS survey, it is found that 25 stars have excesses $0.2 < (K–[24]) < 0.7$ compared to the expected $(K–[24]) = 0.0^m$ for stellar photospheres. For MS stars, such excesses are attributed to hot debris disks. At least 12 of the 25 stars with excesses are identified as MS stars based on PMs; 22 of the 25 would be estimated as MS stars based only on distributions of apparent magnitude.

Depending on how many stars in the total sample are MS, the fraction of MS stars with debris disks in Boötes and FLS is ~ 10%. This is comparable to the 7% for the 5 of 69 bright FGK MS stars in Bryden et al. (2006), and is also comparable to the 9% fraction of 53 Pleiades FGK stars in Gorlova et al. (2006).

Although further observations of the individual stars are needed to determine possible sources of the excess other than hot debris disks, this study demonstrates the utility of combining Spitzer surveys with 2MASS data for bright stars to accumulate a meaningful sample of Galactic stars with 24 μm excesses. Such a statistical sample is essential to eventual understanding of debris disks associated with solar-like stars because such a small number of stars have as yet been surveyed for measures or limits on 24 μm excesses.

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Identification of Peculiar A-Stars. Analysis of the Equivalent Widths of the 2786-2810 Å Spectral Bands and the MgII 4481 Å Line for 137 A-Stars

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Abstract. The dependence of the equivalent widths of the 2786-2810 Å spectral bands and the MgII 4481 Å line on the basic parameters (Teff, log g and [M/H]) for 137 bright A-stars shows that 60 of them are candidate peculiar stars. Given the similar behaviour of W(2800) and W(4481), it can be assumed that 34 of the stars are chemically peculiar stars. The anomalous values of W(2800), W(4481), and [M/H] vary over wide limits for the rest of the stars, possibly because they are binary.

1. Introduction and observable material

For understanding the nature of peculiar A stars expansion and specification of their list are necessary. This paper is an attempt to identify new peculiar A-stars. This is done by analysing of the equivalent widths of the 2786-2810Å spectral bands as a function of the fundamental parameters of the stars for the cases of 137 bright A-stars. The 2786-2810Å band is chosen mainly because the MgII resonance lines (k 2795.5 and h 2802.7 Å) - the strongest spectral features observed in the spectra of any astronomical object, including the A-stars - fall within it. The intensities of these resonance lines, depend strongly on the magnesium content, as well as on the kinematic and physical characteristics of the object.

As observable material we use ultraviolet spectrum with the high resolution (~0.17Å) taken from the INES (IUE Newly Extracted Spectra) archive. For being more certain in our results, we have subjected to the analysis of homogeneous data Abt and Morell [1] of equivalent width line 4481MgII. The equivalent width of the 2786-2810 Å segment [W(2800) in the following] was defined as the area of the region within the interval 2786-2810 Å between the observed spectrum and the "local continuum," expressed in units of wavelength. The average values and standard deviations (in parentheses) of our measurements of *W*(2800) for all 137 program stars are given in table 1 Ohanesyan [2].

2. Analysis of the power in the 2786-2810 Å spectral bands and the MgII 4481 Å line

In order to obtain a real empirical relationship between *W*(2800), *W*(4481) and the major parameters of the stars, *Teff*, log *g*, and metallicity [*M/H*], the last also for all stars represented by uniform data, we used Moon's program [3] and the Strömgren ubvybeta photometric indices data from the catalogue of Hauck et al. [4]. Data of *Teff*, log *g*, and [*M/H*] also are given in Ohanesyan [2].

Figure 1 shows two graphs (a) and (b), whose abscissae are the same and correspond to *Teff* and the ordinate is the observed values of *W*(2800) with the standard deviations (error bars) and the values of equivalent width 4481MgII line data (Abt and Morrell [1]) for the 137 A-stars, respectively.

The appearance of the dependence of *W*(2800) and *W*(4481) on *Teff* is essentially the same in both graphs of Fig. 1 for all the groups of stars: first, most of the program and Am-stars are uniformly scattered on both sides of the smooth curve within ±3σ (1.6 Å) and (0.12 Å) on Fig1(a) and Fig1(b), respectively; second, the λBoo and Cp(4481wk) stars lie in regions with large deficits in *W*(2800) and *W*(4481), i.e., quite far from the empirical dependence of *W*(2800) and *W*(4481) on *Teff* calculated using Eqs.(1) and (2) (the smooth lines).

The dependence of the observed *W*(2800) and *W*(4481) on log g and [*M/H*] was studied by initially dividing the stars into 6 subgroups in the region of *Teff* from 7500 to 11000K. Within each subgroup no dependence of *W*(2800) and *W*(4481) on either log *g* or [*M/H*] was observed.

3. Results

Analysis the observed *W*(2800) and *W*(4481) with using Eqs.(1) and (2) for all 137A-stars allow yielded 60 stars for which the values of *W*(2800) and/or *W*(4481) deviate from Eqs. (1) and (2) by the corresponding ±3σ and more. Table 2 in Ohanesyan [2] is a list of these stars. These stars can be separated on two set: first set consists of 49 stars which were selected as candidate peculiar stars with a probability of greater than 99%. For these stars the differences Δ*W*(2800) {between the observed values of *W*(2800) and those calculated using Eq. (1)} and/or Δ*W*(4481) {between the observed values of *W*(4481) and those calculated using Eq. (2)} was ≥3σ. The first set included both isolated stars and stars in groups with certain physical and kinematic features: 7 CP(Ap) and 5 CB (chemically peculiar and close binary systems, respectively), 15 λBoo stars, 2 Vega type stars, 2 FHB, and 4 Am stars. With a few exceptions, the values of W(2800) and W(4481) for most of the stars are in deficit, and the stars themselves have the following characteristics: *Teff* below 9500 K, metal abundances in both deficit and

excess, as well as normal (solar); *V*sin*i* (the projection of the rotation velocity) [1,6] lies within a wide range from 10 to 300 km/s and there is a tendency for the rotation velocity to decrease as $|\Delta 2800\ W|$ and $|\Delta 4481\ W|$ increase. Similar behaviour of *W*(2800) and *W*(4481) among 34 stars of set 1 and the high percentage known of chemically peculiar among them suggest that all of them are chemically peculiar. The peculiar feature of the remaining 15 stars in first set shows up either as an anticorrelation between the values of Δ*W*(2800) and Δ*W*(4481) or as an anomalous equivalent width for one of the spectral features; in addition, [*M/H*] is anomalous for these stars.

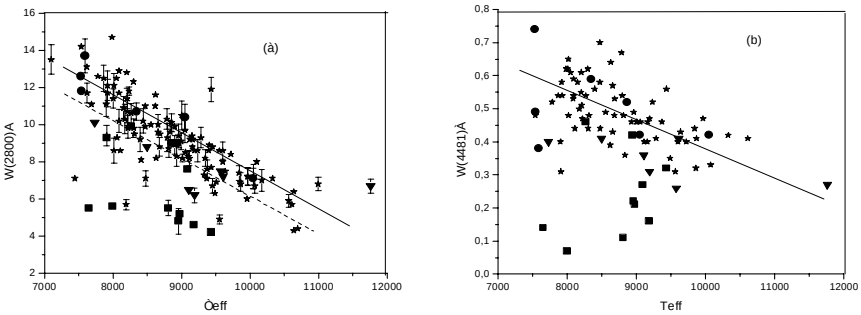

Fig. 1. (a) dependence between observable values W (2800) with bars standard deviations and Teff for 137 A-stars are showed. Continuous line is empirical dependence between W(2800) and Teff for 24 standard-stars with solar metallicity. A functional kind of this dependence is the following: W(2800) = 14.6 - (Teff-6500)/500, standard deviation σ = 0.45 Å (1).
In the former of shaped line are shown the similar dependence received by Solano and Paunzen [5] by data INES archive for 15 standard stars whith functional kind difference from (1) only free member, they have equal to 13.
(b) distribution of values of equivalent width W(4481) [1] depending on Teff. Continuous line is empirical dependence between W(4481) and Teff, received for the same standard - stars. A functional kind of this dependence is the following: W(4481) = 1.3 – 0.9xTeff, standard deviation σ = 0.04 Å (2). Stars on both diagrams are represented by symbols: program - asterisks, Lambda Boo (λ Boo) - squares, Cp (4481MgIIwk) – triangles and Am – circles.

Second set contains 11 stars whose peculiarity is based on a deficit/excess in estimates for [*M/H*], obtained difference method, while their Δ*W*(2800) and Δ*W*(4481) lie within the limits of ±3σ. The stars in the second set also include chemically peculiar stars: two λ Boo, one CP, and one Am.

4. Discussion

Out of the 137 program stars, therefore, 60 have anomalous values of W(2800), and/or W(4481), and/or [M/H]. The values of W(2800) and W(4481) are observed to be in deficit for 34 and 21 of these stars, respectively, and in excess for 3 and 3, respectively.

Figure 2a, which shows the variation of $\Delta W(2800)$ with $\Delta W(4481)$ for all 60 peculiar A-stars provides a clear representation of the differences in mechanism responsible for the observed peculiarities of the stars in sets 1 and 2. The stars in set 2 lie in a region bounded by the dotted lines (a shaded rectangle), while the stars in set 1 lie outside of this region. It can be seen in this figure that practically all peculiar (λBoo and Cp) stars lie in the region where the variations $\Delta W(4481)$ and $\Delta W(2800)$ are mutually proportional.

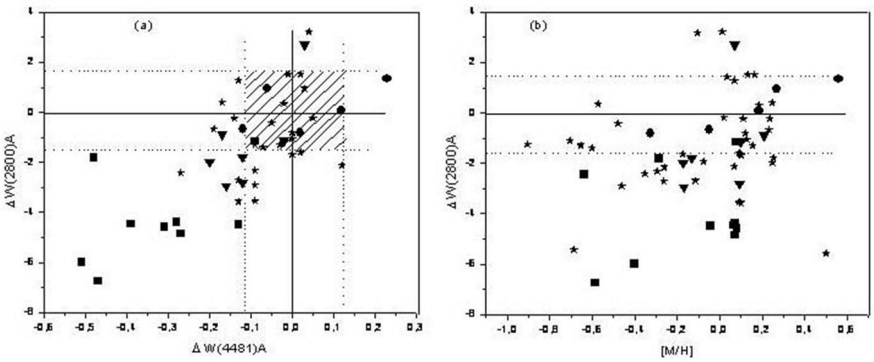

Fig. 2. (a) The relationship between ΔW (2800)Å and $\Delta W(4481)$Å, the differences between the observed values of $W(2800)$ and $W(4481)$ and the corresponding calculated values according to Eqs. (1) and (2). The smooth lines correspond to the level at which there is no difference and the dotted lines, to a difference at a level of ±1.6 Å and ±0.12 Å, respectively for $W(2800)$ and $W(4481)$.
(b) The relationship between ΔW (2800) Å, the difference between observed value of $W(2800)$ and the value calculated using Eq. (1), and [*M/H*]. The smooth line corresponds to the level at which there is no difference and the dotted lines, to a difference at a level of ±1.6 Å. The notations for the stars are as in Fig. 1.

Figure 2b is a plot of $\Delta W(2800)$ (for $\Delta W(4481$ it is similar) as a function of the [*M/H*] for all 60 stars. It can be seen from this graph that stars with a large deficit of $W(2800)$ can lie in regions with a large deficit or with a normal abundance [*M/H*] and, conversely, stars with a deficit in [*M/H*] may not manifest distinctive behaviour of $W(2800)$. This behaviour of $\Delta W(2800)$ as a function of [*M/H*] may reflect peculiar (chemical, physical, and kinematic) features of the stars.

Of the 60 candidate peculiar stars, 26 (15 from set 1 and 11 from set 2) have nonunique parameters $\Delta W(2800)$, $\Delta W(4481)$, and [*M/H*]. The lack of agreement between the

estimates of the metallicity obtained by different methods, as well as the large scatter in the data on the other parameters (*Teff*, *V*sin*i*, galactic coordinates) may be real and reflect the variety of physical and/or kinematic conditions in the atmospheres of these 60 stars. There were no theories proposed to explain the high attenuation of the metal lines in the spectra of λBoo stars. All these things allow us to appeal to a known fact: the probable cause of the things that are not understood in the behaviour of most of the parameters of these stars lies in their multiplicity. Our data for stars with a broader representation of peculiar groups do actually confirm this result. In fact, on one hand, of the 36 stars we found with spectral peculiarities, 10 (28%) are members of multiple systems and, on the other, of the 137 program stars, 38 are binaries, of which 14 (37%) manifest anomalous values of *W*(2800) and/or *W*(4481). An intense, comprehensive study of the 137 candidate λBoo stars has led Farragiana et al. [7] to conclude that more than 17% (perhaps 38%) of the stars in this group have a composite spectrum. Are these numbers coincidences or a reflection of reality? If so, than one in three binary stars should have an anomalous value of *W*(2800), while one in three stars with an anomalous value of *W*(2800) should be binary.

Thus, the main result of the present studies is the discovery of 32 new candidate peculiar stars. The possible reasons for the observed peculiarities may be linked to an anomalous abundance of elements in the stars' atmospheres and/or to multiplicity of the objects. Clarifying the physical or kinetic nature of the anomalous cases of *W*(2800) will require a thorough qualitative and quantitative analysis of all the lines within the confines of the 2786-2810 Å spectral feature, as well as of other resonance lines in the visible and ultraviolet. These studies are in processes.

5. Conclusions

The equivalent widths of the 2786-2810 Å spectral band and the MgII 4481 Å line for 137 bright A-stars have been analyzed using high resolution UV spectra from the INES archive and the data of Abt and Morrell [1]. An empirical relationship between the equivalent width of these features and the effective temperature has been developed for the standard stars. Using the functional form of these relationships, we have identified 49 +11 peculiar stars, for which the values of all or one of the parameters W(2800), W(4481), and/or [M/H] are in deficit/excess for their spectral classes. The deficit and excess of W(2800) and/or W(4481) are detected for the first time for 31 and 4, respectively, of the program stars. Stars with an anomalous behaviour in W(2800) and/or W(4481) are widely represented. These include λBoo stars, stars with a faint MgII 4481 Å line, shell, variable, and binary stars, etc. Using the example of a large group of stars with a metal deficit (13 λBoo stars and 6 Cp stars with a faint MgII 4481 Å line) the prospects for using this method to identify peculiar A-stars has been demonstrated. Using the example of a large group of stars with a metal deficit (13 λBoo

stars and 6 Cp stars with a faint MgII 4481 Å line) the prospects for using this method to identify peculiar A-stars has been demonstrated.

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Session 2. PULSARS / NEUTRON STARS

V.A. Ambartsumian's contribution in the field:

Showed the **nonthermal nature of the continuous emission** observed in the spectra of non-stable stars and put forward an idea about new possible sources of stellar energy, the **hypothesis of the superdense protostellar matter** (1954). This hypothesis bears V. Ambartsumian's name.

Ref.: V.A. Ambartsumian – The Phenomenon of the Continuous Emission and Sources of Stellar Energy // *Communications of the Byurakan Observatory, 13, 1-36, 1954 (in Russian).*

Theoretical studies of the hypothetical superdense degenerate protostellar matter: **development of principles of the theory of baryonic stars**, which allowed a detailed research of physical conditions in superdense stellar conditions in the frame enabled by the modern knowledge of physics. These researches later on allowed increasing the Chandrasekhar limit of stellar masses (together with *G.S. Saakyan*, 1960-1961).

Ref.: V.A. Ambartsumian, G.S. Saakyan – The Degenerate Superdense Gas of Elementary Particles // *Soviet Astronomy, Vol. 4, No. 2, p. 187-201, 1960.* V.A. Ambartsumian, G.S. Saakyan – On Equilibrium Configurations of Superdense Degenerate Gas Masses // *Soviet Astronomy, 5, 601-610, 1962.* V.A. Ambartsumian, G.S. Saakyan – Internal Structure of Hyperon Configurations of Stellar Masses // *Soviet Astronomy, 5, 779-784, 1962.*

Victor Hambartsumian's Best Hypothesis

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I began to work with V. Hambartsumian and his colleague G. Sahakian since my student years. In particular, they thanked me in one of their papers, where it was shown for the first time that the bound energy can be positive in curved space (!). They thanked me, the mere student, for carrying out the calculations. It is to be noted that to carry the calculations out one had to integrate a system of non-linear equations on the computers of those years (computers were just getting into use).

His and G. Sahakian's pioneering works aroused great interest for developing and elaborating the theory of super dense celestial objects, the White dwarfs and the so called "hyperon stars». The latter are the part of the smallest stars (with radius of the order of ~ 10 km), and which are commonly known under the name of neutron stars. Their theoretical investigation started in 30th of the last century but then was stopped for about 20 years. In 50th of the last century, V. Hambartsumian and G. Sahakian started that investigation anew.

As far as I know, the fact that V. Hambartsumian undertook this investigation, firstly had nothing to do with the investigation of the neutron stars, but was connected to the hypothesis of his that the galaxy core could be consisted of super dense matter. To establish theoretically the validity of this hypothesis one must have shown that there could exist a celestial object having a mass of the order of a galaxy and density of a nucleus. To solve this problem one must have known such different brunches of physics as the contemporary theories of the nucleus and elementary particles, statistical physics and theory of gravitation. We could find out the validity of V. Hambartsumian's hypothesis applying these three branches of physics. It is to be noted that V. Hambartsumian had offered his hypothesis taking into account the observed activity of galaxy cores. It seemed natural to him that this activity is due to the huge density of the core matter. But how could one prove that? It had to be found out by theoretical investigations.

Statistical physics is the only field of the above-mentioned brunches that, more or less, is completed as a science and it seems to be most reliable. The other two brunches that were to be used for developing an activity theory, hadn't been studied properly yet.

Indeed, physicists neither had been of the same opinion on the ideas of matter state in the case of nuclear or higher densities, nor on the question which gravitation theory ought to be chosen for these densities. First, in the case of nuclear and higher densities,

it is impossible to investigate experimentally the matter properties, for we can't have such densities in laboratories. Of course, it is known that hadrons combine at huge densities, and the matter is consisted of quarks in this case. Nevertheless, we don't know much about quarks as they never are in a free state; consequently, it is impossible to carry out direct measurements to find out their properties. We know very little about the interaction of matter particles in the case of densities higher than that of a nucleus. To carry out astrophysical investigations one must know the state equation, $P = P(\rho, T)$, where P is pressure, ρ is density, and T is temperature. But if density exceeds the nuclear density a few times we know noting about the state equation. The situation is as difficult as this if one is to choose a gravitation theory. We now use Einstein's gravitation theory, but we don't know whether this theory applies to the case, or no. The situation is especially dramatic, because the gravitation forces are only attractive, therefore, they can lead to collapses of celestial bodies. It isn't known when this collapse stops, and if it doesn't stop, the density will infinitely increase, which we don't understand. According to Einstein's theory, this process leads to a hole, and information from it will reach us for the infinite time, that is, we will never know what is in the hole. When we say we don't know what is in a hole, we don't mean that we can't give any scientific answer to the question. Perhaps holes are results of limitedness of Einstein's gravitation theory? By the way, Hambartsumian understood these difficulties well and he had never been fascinated of this doubtful result of Einstein's theory.

Thus, the two of the three brunches of theoretical physics can't confirm Hambartsumian's hypothesis, for they contain great uncertainties in themselves. Hence, it is no to-day's task confirming Hambartsumian's hypothesis theoretically. Hambartsumian's ideas were thus much far ahead of his time that the present physics doesn't give possibility to check them.

Anyhow, the investigations connected to this hypothesis allowed to elucidate the internal structure and other properties of celestial super dense objects. These investigations become a base on which a whole relativistic astrophysical direction was founded, which is known under the name of neutron star or "pulsar" investigations. These investigations have gone on for about 50 years now, and though Hambartsumian's hypothesis hasn't been theoretically confirmed yet, nevertheless, the investigations have been continued at various scientific centres of the world. The popularity of these investigations is due to the fact that radio astronomers discovered the neutron and hyperon stars in our Galaxy, which had been theoretically predicted. Hewish was the first who discovered a pulsar in 1968, and he got a Nobel Prize for that. Immediately after the discovery of the pulsars, the American scientist Gold offered a hypothesis, according to which a pulsar is a rotating neutron star possessing huge magnetic field. The magnetic field on the surface of such star reaches 10^{12} G. These

magnetic fields are the largest magnetic fields ever observed in nature, because even the magnetic fields of magnetic stars don't exceed a few million Gauss.

To stress V. Hambartsumian's works importance it is enough to note that one of the authors of Soviet hydrogen bomb, Ya. B. Zeldovich had often been in Yerevan and Byurakan, aiming at meetings with Victor Hambartsumian and Gurgen Sahakian to discuss these new works with them. Later he grouped some scientists in Moscow, which group was to become one of well-known scientific groups in the world. So mighty was V. Hambartsumian's authority among the soviet astronomers that he was chosen for founding the journal of *Astrophysics*. That meant that Hambartsumian was the number one astrophysicist in the Soviet Union. *Astrophysics* was an all Union journal that was first published in 1965, and V. Hambartsumian had been its editor for many years. It is enough to note that Ya. B. Zeldovitch had been its deputy editor on theory until his death (1987). The editorial board included the best astronomers of the Soviet Union. Since independence of Armenia the journal has gone on coming out as an international journal, and the author of this paper is its editor now. This means that the astrophysical school founded by Hambartsumian in Armenia is so mighty that it goes on working and being appreciated by the astronomers of the world, particularly, by those of Russia.

A few words about the scientific success of the astrophysical theoretical school founded by V. Hambartsumian and G. Sahakian. I mean the results of the investigations of neutron stars and pulsars. First in the frame of this theme a doctoral thesis was defended (G. Sahakian) still in 60th of the last century, and at the beginning of 70th a few theses were defended (Yu. Vardanyan, D. Sedrakian and E. Chubaryan), too. In the result of these works, the internal structures of super dense celestial objects (White dwarfs, neutron stars and pulsars) were completely investigated; dependences of such star integral parameters – as mass, radius, compression, quadruple momentum and the maximum speed – on the star's central density and angular momentum were calculated both by Newton's and Einstein's gravitation theories. In particular, Einstein's equations for cylindrical symmetry were integrated for the first time. A new method was offered for calculation of the internal structure and external gravitational field of rotating super dense stars in the frame of Einstein's theory. I think, the most important result was the curve expressing the dependence of a super dense object on its central density, which was obtained both for spherical and rotating stars. The main result that followed from that curve stated that like White dwarfs the masses of neutron stars are limited from above. By the way, this result for the White dwarfs had been obtained by Chandrasekhar long ago, and he got a Nobel Prize for that work. Unfortunately, the analogous result obtained by V. Hambartsumian and G. Sahakian for the neutron stars for the first time was never awarded in such a manner. I also consider important the fact that the maximum of a neutron star mass – I would call it *the Hambartsumian-Sahakian-Vardanian (HSV) limit* – is higher than that of Chandrasekhar's for White dwarfs. It means that if a star evolution passes on to contracting, then the neutron star masses must be greater than the Chandrasekhar's limit, being in the range:

$1{,}4M_0 \le M \le 2M_0$. It seems this result doesn't contradict the observations. The calculations of neutron star internal structures for various state equations were repeated by many scientific groups in the world and those calculations only confirmed the main result. Why is the limitedness of mass of super dense star very important for astrophysics? The reason is that ordinary stars lose their thermal energy when evolving, and so they also lose their thermal pressure, which has been balancing against the gravitation and, consequently must contract. In the case of comparatively small densities, $\rho \le 10^{13}$ g/cm^3, the role of thermal pressure plays the pressure of the degenerated electron gas, and in the case of higher densities, $\rho \ge 10^{14}$, the pressure of the degenerated neutron gas. In the first case, the resulted celestial equilibrium object is called a *White dwarf*, and in the second case it is called a *neutron star*. If a star evolution goes on with mass conservation, then the above-mentioned evolution is possible if the star mass is less than two Sun masses. But what happens to those contracting stars whose masses exceed the HSV limit? Let's note that the number of such stars is very large in our Galaxy. According to Einstein's general theory of relativity and a result followed from it – obtained by Schwarzschild – such stars must contract to the gravitational radius and then become so called *Black holes*. Thus, existence of a Black hole follows from: Einstein's theory, mass conservation assumption and – the most important thing – limitedness of mass of the super dense objects, which, as we said, was the result of the Armenian physicists. Let's note that if a star evolution goes on with such explosion that the masses of the remnants won't exceed the HSV limit, then no Black hole is originated. Such are, for instance, the explosions of super novas, which result nebulae and pulsars, that is, a neutron star, as for example, the Crab and Vela. Probably Black holes can be in central parts of galaxies (the core). Let's note that the average densities of Black holes decreases if the object's mass increases, and so it is possible that in Black holes, having masses of the order of a galaxy mass, the density is in the range of 10^{-4}-10^{-8}g/cm^3. The adherents of existence of Black holes, taking this fact into account, contend that one ought to look for them in central parts of galaxies. This is the reason that many consider that a galaxy centre can be a Black hole. On this occasion I would like to mention that as soon as a Black hole is formed, its internal matter permanently contracts, according to Einstein's theory. This permanent increase of a Black hole's internal density leads to the situation when we won't know the matter and, consequently, can't say anything about the future of this process, especially as this future is just fantastic, the matter piles up in one point! The particularity of this origin appears in the theory, and this particularity is more dreadful than the seemingly "particular point" of Schwarzschild. These difficulties make the astronomers of the world divide into two groups. One group – the adherents of Einstein's theory – thinks that the existence of Black holes is an irrefutable fact, and they even contend that our Galaxy centre is a Black hole. The other part of astrophysicists – to which, I think, V. Hambartsumian belonged and I am one of them too – thinks that the existence of Black holes hasn't been proved yet. Moreover, they think that their theoretical prediction perhaps shows certain deficiency of the theory

itself. I think that if V. Hambartsumian had spoken on this, he would have especially mentioned one important peculiarity. If Black holes had existed, then the matter falling on them could have been a source of powerful radiation, and in some cases it could have explained the galaxy centres' activity. But this activity is rather a restrained one. What makes some of them split into parts? How can this be understood in the frame of the theory of Black holes?

V. Hambartsumian was both the author of the galaxy core activity hypothesis and then the author of discussions of the observed data. This hypothesis was one of the best of his, which lately was conformed by the experiment. As Hambartsumian had been contending and as the observations showed, this activity wasn't usual and wasn't like the activity of Markarian galaxies, for instance, which could have been explained by the radiation of the matter falling on Black holes. The first activity is much more by its scales and energy amount. In the case of that activity, the galaxy cores split into parts, or they erupt matter, which has mass of the order of a galaxy mass. Such phenomena can't be explained by the theory of Black holes.

V. Hambartsumian thought that the investigation of such huge-scale processes is most important, even if they can't be explained by the knowledge of to-day. He thought it important to look for such a theory, which could overcome the crisis or show a way out of it, instead of being carried away with doubtful theories that perhaps might explain galaxy's not strongly expressed activities. One mustn't forget that such activity can be the consequence of a mightier one.

Since 1970 the investigation of super dense objects in the school of the Armenian astrophysicists went on in two directions. The investigators of one direction in Byurakan, as well as at the Chair of Theoretical Physics, Yerevan State University, tried to get out of the frame of Einstein's theory of gravitation, including new gravitation theories. They aimed at showing by calculations that it is possible to enlarge the HSV limit of super dense objects, which could have justified Hambartsumian's hypothesis about super dense cores of galaxies. Unfortunately, those efforts didn't give any positive result. It was found that masses of super dense celestial objects are always limited if we stay in the frame of modern theoretical physics.

The followers of the other direction formed two separate groups, one at the Department of Radiophysics (under Yu. Vardanyan), the other at the General Physics Chair (under D. Sedrakian), Department of Physics, both in Yerevan State University, went on with their investigations of new phases in the internal structure of neutron stars, of finding out of new physical phenomena in neutron stars and of explaining of some peculiarities of pulsar behavior. These works were aroused by the discovery of pulsars, in 1968, and the quick piling of observation data on them. The new found data brought forth a number of new problems for the theorist astrophysicists. Let's mention some of them: explanation of radio radiation, investigation of observable phenomena due to rotation

dynamics of pulsars, discovery of X-ray and γ-ray radiation mechanisms, arousing the powerful magnetic fields and explanation of their connection with the radio radiation, and so on. Let's add to these the investigation of new phases of matter in neutron stars, such as, for instance, the quark phase, and the investigation of quark stars. A great army of theorists works to get the answers to these problems, and the two mentioned groups of Yerevan State University have their proper place among them. Let's mention that it's going to be 40 years in the nearest future since the pulsars were discovered, but only a small part of these problems got more or less satisfactory answers. Let me mention some results obtained by my group for the last 30 years. We managed to find out a powerful magnetic field generation mechanism in neutron stars. This mechanism is based on super fluidity of neutrons and superconductivity of protons. Some interesting results are obtained connected with this problem, namely, with rotation properties of super fluid matter and magnetic properties of superconductive matter. In particular, a new physical effect is obtained, the "entrainment effect" in interaction of two super fluid condensates. A theory is worked out to explain an interesting phenomenon of pulsar rotation dynamics. It follows from the observations that the angular velocity secular decrease of some pulsars is broken from time to time by its sudden increase and following relaxation. This phenomenon is called *glitch*. We worked out a theory that can explain this phenomenon. This theory explains the observation data better than the theories offered by other groups in the world, because those theories have serious difficulties. In the last few years we studied the gravitational radiation expected from White dwarfs and neutron stars. The results of these studies would help the researchers looking for gravitational waves for choosing sections of the heaven and frequencies for their research. It is to be noted that the discovery of gravitational waves is so important that the discoverers shall get a Nobel Prize for that. At the end, let's mention that presently our group works on the problem of elaborating a new mechanism of pulsar's radio radiation.

Yu. Vardanyan and his followers carried out interesting works in the field of quark star study. New variants of the gravitational theory have been studied at the Chair of Theoretical Physics. It is to be mentioned that the first chairman of this chair, G. Sahakian, who was V. Hambartsumian's colleague and my teacher, devoted the last years of his life to discovering of new mechanisms of radio, X-ray and γ-ray radiation.

Summing up this brief list of works carried out in Armenia, we can assert that in the result of V. Hambartsumian's and G. Sahakyan's pioneering works the so called new *Hyperon* (neutron) stars were discovered. After 10 years of these works these stars were observed in our Galaxy and they were called pulsars. More than 1700 pulsars have been observed in our Galaxy up to now. This is the reason that that the investigation of this problem offered by V. Hambartsumian goes on not only in the school of Armenian theoretical astrophysics, but also in many astrophysical centres spread all over the world.

Dedicating thus modest paper to the 100th birth anniversary of my beloved teacher V. Hambartsumian, I would like to finish it with words that I and E. Parsamian wrote on the occasion of his 80th birth anniversary, when he was still alive.

"We think that nature is built in such a manner that a nation, collecting the abilities of all its members, piles them up in its very few representatives only. These chosen and highly gifted men carry great responsibility – to materialize that gift with their definite achievements which they gain by their work and life, in the name and for the glory of the nation, which begets them. to-day, we have all right to say that our beloved teacher justified the demands of his nation, indeed, and due to his great scientific discoveries he is the best example to be followed by the talented representatives of our future generations".

Scenarios for GCRT J1745-3009

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Abstract. I discuss several scenarios to explain properties of the radio transient source GCR J1745-3009. Namely, a highly magnetized neutron star on the propeller or georotator stage, a transient propeller, and an ejector in a binary system are discussed. Simple populational estimates favor the transient propeller model.

1. Introduction

Enigmatic radio source GCRT J1745-3009 was discovered in a dedicated search for transients in the galactic center region few years ago (Hyman et al. 2005; see a recent review in Ray et al. 2008). Since that time three periods of activity have been observed. During the first (the discovery one) the source demonstrated five bursts with duration about ten minutes and flux about 1 Jy. Bursts followed each other with a period about 77 minutes. During the second period just one burst was detected (Hyman et al. 2006). The event was similar to those detected before. Finally, during the last known period of activity again just one burst was detected (Hyman et al. 2007). It was weaker (~ 0.05 Jy) and shorter (about 2 minutes) than previous ones. No counterparts have been found in any other range.

Several models have been proposed (see the list and references in Hyman et al. 2007): a brown dwarf or a cool star, a binary neutron star (NS), a white dwarf, a nulling pulsar, a precessing pulsar. Here I discuss several other possibilities related to not that popular phenomena which happen when a NS passes through some elusive evolutionary stages. Some of them turn out not to be very likely to explain properties of GCRT J1745-3009, others are more promising. I focus on situations when magnetic field lines of a NS become opened for a short period of time, which corresponds to a burst, with possible repetition with the 77-min period, or on situations when an observer can periodically observe opened field lines.

2. A highly magnetized NS at the propeller or georotator stage

During its evolution a NS normally passes through several evolutionary stages (see, for example, Lipunov 1992): Ejector, Propeller, Accretor, Georotator. Radio pulsar activity corresponds to the early phases of the Ejector stage. At which stage a NS appears depends on relation between several critical radii: the gravitational capture radius - $R_Q = 2GM/v^2$, light cylinder radius - $R_{LC} = c/\omega$, Alfven radius - R_A, corotation radius - R_{co} =

$(GM/UJ^2)^1$^, and the so-called Shvartsman radius - i?sh (for all details see, for example, Lipunov 1992).

In some cases one can expect a more tricky situation due to a high level of asymmetry of a system, or due to rapid changes of parameters of surrounding medium. Let us consider a highly magnetized NS (HB-NS) with $B \sim 10^{15}$ G and velocity 200 km s^{-1}. Let us assume that its spin period is 77 minutes (such long periods are possible for HB-NSs due to a rapid spin-down related to a fall-back disc around a NS, see de Luca et al. 2006). In normal interstellar medium (ISM) such an object would be on the Propeller stage (Shvartsman 1970, Illarionov & Sunyaev 1975), but on an unusual one, as $R_Q < R_A$- SO, it is an analogue of the Georotator stage (Lipunov (1992) in Ch.6 calls it "a non-gravitating propeller"), but with the reversed relation between R_m and R_A-
Here we are interested in the case $R_G, R_{CO} < R_A < R$\- At the magneto-spheric boundary gravity is not important, as on the Georotator stage (Rutledge 2001 calls it the MAGAC stage, Toropina et al. 2001 - magnetic plow). Accretion is impossible as $R_A > R_m$- Several possibilities interesting in the context of transient radio emission observation can exist.
Variant la. For some combinations of spin, velocity and magnetic dipole vectors, due to the ram pressure of the ISM the magnetosphere can obtain a long "tail" similar to the magnetotail of the Earth. This tail can go beyond the light cylinder. Obviously, rotation is not important for the tail formation if spin and velocity are perfectly aligned. For perfect alignment the "tail" does not go beyond the light cylinder as it is parallel to the spin axis.

Variant lb. The back (respect to the flow) part of the magnetosphere is not only elongated, but is also widened. For low density of the ISM the magneto-spheric boundary can approach the light cylinder. Again, relative orientations of the three vectors are important. For example, for the perfect alignment one can apply the analytic solution developed for the Earth magnetosphere (Zhigulev, Romishevsky 1959, see also Lipunov 1992, Ch. 4). In this case the size of the magnetosphere in the direction perpendicular to spin and velocity approaches 2 • i?A on the back side. So, if the density of the surrounding medium is low (which is not unexpected due to formation of a kind of an "atmosphere" around the magnetosphere due to propeller action), then the magnetospheric boundary can reach the light cylinder.

Effectively, in both variants there is a region of opened field lines which can result in detectable radio emission. It is easy to obtain periodicity with the spin period. Changes in the ISM properties, sporadic accretion from a fall-back disc or an asteroid belt can result in transient behaviour.

As the magnetospheric boudary approaches the light cylinder, the velocity of its rotation is close to the velocity of light. This is called a "relativistic propeller" (Lipunov 1992,

Ch. 6). Such relativistic non-gravitating propeller can be a possible explanation for the GCRT.

Variant lc. Romanova et al. (2001) and Toropina et al. (2001) presented numerical studies of the Georotator stage. At this stage they observe reconnec-tion in the magnetotail a NS. For the non-rotating case they provide an estimate of the total energy:

$$E = 10^{28} B_{15} n^{1/2} v_{2}oo \text{ erg} \qquad (1)$$

For two limiting cases duration of an event is $t_{rec} = 10^5 B_{15}^{1/3} n^{-1/6} v_{200}^{-4/3}$ sec for high matter density, and $t_{rec} = 74 B_{15}^{1/3} n^{-1/6} v_{200}^{-1/3}$ sec - for low density. Few minutes periodicity observed in the case of GCRT is well within this interval. However, energy is too low to explain an event at further than few tens of parsec, even of all energy goes into radio emission at *v* ~ 330 MHz.

3. Transient propeller

Several authors discussed the following possibility. If on the Propeller stage cooling in the matter around the rotating magnetosphere is efficient enough (for example, synchrotron emission of thermal electrons on the magnetic field frozen in plasma can be important, the main problem here is that the frequency of the synchrotron emission can be smaller than the plasma frequency for large magnetospheric radius), than not a static atmosphere, but a dense envelope with growing mass is formed on top of the magnetospheric boundary (see the references and discussion in Lipunov 1992).

The radius of the boundary starts to be determined by the balance between the magnetic field and the weight of the envelope: $\wedge^2/8irR^6 = GM_shM/4irR^4$.

As the mass of the shell, M_sh, grows the radius of the magnetosphere decreases till it reaches the corotation radius. Then the whole envelope collapses to the NS. At this moment an X-ray and a radio bursts can be expected. The duration of a burst can be estimated as: Atb = -Rco/^g = *P/2-^2ir*, vg - the free-fall velocity.

Variant 2a. An isolated NS. In this case the 77-minute period should be associated with the interval between two successive episodes of an envelope collapse. This time can be estimated as:

$$\Delta t = M_{sh}/\dot{M} = 10^8 \mu_{30}^2 P^{-4/3} \rho_{-24}^{-1} v_{100}^3 \text{ s.} \qquad (2)$$

A 77 minute spin period would lead for some parameters to 77 minute interval between successive collapses. Then, then crossing time (the free-fall time) would be about *2TT* times smaller, as it is roughly observed for GCRT J1745-3009.

Variant 2b. A NS in a binary. Of course, the regime with a collapsing envelope can be reached also in a binary system. There the accretion rate can be much higher than for an isolated NS, so the 77-minute periodicity can be reached for shorter periods (or, for higher magnetic fields).

4. Ejector in a binary system

In a binary system when a NS is on the Ejector stage and the companion is a normal (hydrogen burning) star several situations can appear in which a transient radio source can appear.

Variant 3a. Superejector.
It can happen that a companion starts to fill its Roche lobe when a NS is still very rapidly rotating. In this case the so-called Superejector stage can be set on. "Super" stands for superEddington accretion rate (Lipunov 1992) (here, the accretion rate is used just in terms of properties of the matter flow from the normal star; of course, no accretion on the surface of a NS is going on). This stage is possible for very rapid rotators: P_{SE} < 11 msec/i_3Q .

On this stage a NS is surrounded by a cavern produced by the radio pulsar emission. Due to a sudden decrease of the accretion rate the cavern can open, so a radio burst can be observed. The stage is not well studied, so it is difficult to make predictions about periodicity in such outbursts.

Variant 3b. Pulsating cavern. The case of an Ejector in a binary for non-critical accretion rates was studied by Lipunov and Prokhorov (1984).

At this stage i?sh > *RG*- NO dense envelope is formed, and the cavern boundary is define by the stellar wind pressure and pulsar wind (and radiation) pressure.

Let us estimate the characteristic time scale for cavern pulsations following the general line presented by Lipunov and Prokhorov (1984). One can start with an equation of the pressure equilibrium:

$$\frac{\dot{M}V_{\rm w}}{4\pi R_0^2}\cos^2\psi + P_{\rm g} = \frac{L_{\rm m}}{4\pi R^2 c}\cos^2\chi + \frac{\delta L_{\rm m} t}{3V}. \qquad (3)$$

The first term on the left side represents the ram pressure of the stellar wind. Here $M = aLo/(V_w c)$ - is mass loss by the normal star. V_w - stellar wind velocity. P_g - is gas pressure, in an isothermal flow one can use $P_g = ARQ$. *RQ* and *R* are distances from the normal star and a NS to a point on the cavern, respectively. *ri*\> and \ are angles between the normal to the cavern surface

and vectors R_Q and R, respectively. On the right side the first term shows the pressure due to the relativistic wind from a NS. L_m - is the NS luminosity, which can be estimated, for example, with the magneto-dipole formula. If the cavern is closed then *6 = 1*, otherwise it is zero. The term with *6* appears as radiation and particles are collected inside the cavern during the time interval when the cavern is closed. The volume, *V*, can be roughly estimated as (4/3)7rii^3_, where *R*- is the distance towards the back end of the cavern on the line connecting the star and the NS.

It is necessary to estimate the critical time, tbr when the cavern becomes opened. At the critical point corresponding to _R_ the first term on the left side is zero. For the gas pressure I use $A = kMT^* j(2irV_w m_p)$, $Ro = a$ + _R_, *a* - is the semi-major axis of the binary system, *k* - the Boltzmann constant.

The critical radius of the cavern can be estimated from $P_g = L_m/(4irR?\_c)$ when *6 = 0*. Then one can estimate tbr from $P_g = L^t^/SV$ (in this case it is assumed that two terms on the right side of eq. 3 are of the same order):

$$t_{br} = (R_{Sh}/c)\,(1/(\sqrt{k_*} - (R_{Sh}/a))), \qquad (4)$$

here fc* = $4irA/(MV_w)$. This time interval can be equal to 77 minutes for some parameters of a NS and a binary system.

Variant 3c. Floating cavern. This case corresponds to i?sh < R_G- A dense envelope is formed, which defines the boundary. Lipunov and Prokhorov (1984) discussed a possibility that a cavern around a NS in a binary can become detached from the system, and "sail" away carried by the stellar wind. This happens when an expanding cavern reaches the R_Q.
In this case (Lipunov, Prokhorov 1984) the duration of the burst is:

$$\Delta t_b = R_G/c \approx 9\,(v/50\,\mathrm{km/s})^{-2}\mathrm{min} \qquad (5)$$

Clearly, only a very slow wind can produce a long burst. The interval between bursts is: $\Delta t = (a/R_{Sh})^2 R_G$/c. Here *a* is slightly larger than *Rsh*, so it is easy to have At few times larger than Δt_b

5. Populational aspects

If the GCRT is a typical representative of its class, then one can conclude that there are no more sources of this type in the direction of the search as the source was detected significantly above the threshold and observations are long in comparison with the duty cycle of the source.

If the source is close, then one can expect to find weaker bursts from other slightly further objects, unless we are extremely lucky to have a rare source close to us. So, the GCRT is most probably located close to the center of our Galaxy. Basing on the coverage of the galactic plane and the bulge by the observations which resulted in the detection, one can expect to have ~ 100-1000 such sources in the Galaxy (for isotropic emission, if emission is beamed, then the number of sources can be higher).

The GCRT can be an isolated NS. There are ~ 10^9 NSs in the Galaxy, their birth rate is ~ 1/50 yr^{-1}. If the GCRT stage is something typical to most of NSs, then the duration of the stage should be about 10^3 years. This is very short time scale for any stage of a normal NS evolution. So, one needs to proceed assuming that just a fraction of NSs pass through this stage of activity.

HB-NSs are assumed to represent few percents of the total population, may be slightly more. If a typical HB-NS at some stage of its evolution demonstrate an GCRT-type activity, then the duration of such stage should be about 10^5 yrs. HB-NSs are known to evolve rapidly, i.e. their spin-down scale is very short in their young years. They are expected to reach relatively quickly the ultimate stage of their evolution (Accretor or Georotator). When they reach such a stage it is difficult to associate such short timescale as 10^5 yrs with such objects. An intermediate stage for normal field NSs - the Propeller stage or its modifications - are, however, promising from the populational point of view, as for this stage the timescale about 10^5 yrs is typical.

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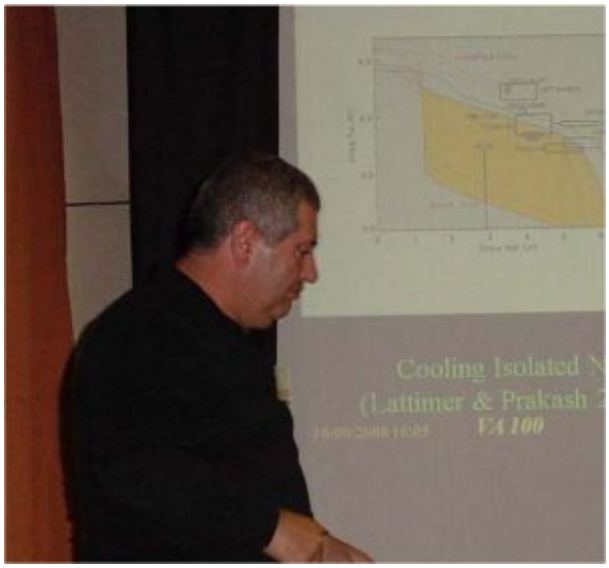
On the evolutionary status of Isolated Neutron Stars



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Abstract. ROSAT has discovered a new group of isolated neutron stars that are characterized by a soft black-body like spectra (kT ~ 40-120 eV), apparent absence of radio emission and no association with supernova remnants. So far only seven such sources are known. They exhibit X-ray pulsations with relatively long periods of the order of 10 sec. Two very different mechanisms may be envisaged to explain their properties. The neutron stars may be old and re-heated by accretion from the ISM in which case their population properties could provide information on past stellar formation and secular magnetic field decay. Alternatively, this group may be made of relatively young cooling neutron stars possibly descendant from magnetars and/or linked with recently discovered Repeating Radio Transients (RRATS). We review the last observational results and show how they can shed light on the evolutionary path of these objects within the whole class of isolated neutron stars.

1. Introduction

Pulsars are observed as celestial objects where the emission is in the form of highly periodic pulses. They are generally believed to be rotating and highly magnetized neutron stars. This combination of strong magnetic fields and fast rotation generates huge voltages across the star and in its magnetosphere, leading to the formation of ultra-relativistic beams of electrons and positrons and ultimately to beamed radiation at wavelengths that range from low radio frequencies to high-energy gamma rays. These beams sweep across the sky as the star rotates so that an observer who happens to lie in the path of a beam sees one pulse per revolution of the star.

The overwhelming majority of the 10^8-10^9 neutron stars (NSs) present in the Galaxy (supernova rate 1-3 per century) should be virtually undetectable using current observational means. Young cooling neutron stars might emit thermal X-rays during the first ~ 10^6yr and their pulsed radio emission will reveal them up to ages of ~ 10^8yr. So-called recycled millisecond pulsars are old objects but their previous accreting binary phase may have altered their physical properties in particular the magnetic field strength. In this context, the possibility that a sizeable fraction of the entire 'fossil' population is re-heated by accretion from interstellar medium and becomes detectable in the EUV / X-ray domain is exciting. This could allow an observational study of old neutron stars and give access to information on past stellar formation, heating and cooling mechanisms and magnetic field decay. This idea was first proposed by Ostriker, Rees & Silk (1970). Early population synthesis models (Treves & Colpi (1991), Blaes & Madau (1993), see also Popov et al. (2006)) predicted that a rather large number (2000-5000) of ROSAT all-sky survey (RASS) sources could be accreting isolated NS (INS), initiating several optical identification campaigns. In this paper we describe the general observational properties of the INSs discovered by ROSAT, and further investigated by XMM-Newton and Chandra, discuss the possible X-ray powering mechanisms, evolutionary link with other types of NSs based on the observational characteristics, i.e. spectral energy distribution, magnetic field strength and kinematic properties.

2. General Properties

One of the most intriguing results of the ROSAT All Sky Survey has been the detection of seven close by NSs, with particular characteristics (X-ray Dim Isolated Neutron Stars (XDINSs), often called also the Magnificent Seven/M7, see Haberl 2007; Van Kerkwijk & Kaplan 2007, for reviews). These sources stand apart with respect to other known classes of isolated NSs detected at X-ray energies. Their X-ray spectrum is close to a blackbody, and no evidence of radio emission has been reported so far despite deep searches have been performed (e.g. Kondratiev et al. 2008). They are likely to be endowed with relatively strong magnetic fields, $B \approx 10^{13}$–10^{14} G, as inferred from X-ray timing measurements and observations of broad spectral lines (equivalent width ≈ 10–100 eV, likely due to proton cyclotron and/or bound-free, bound-bound transitions in H, H-like and He-like atoms). This points toward a possible evolutionary link between XDINSs, "magnetars" (Anomalous X-ray Pulsars (AXPs) and Soft Gamma-Repeaters (SGRs); see Mereghetti 2008, for a review), and some of the recently discovered rotating radio transients (RRATs; McLaughlin et al. 2006, 2007, see also Heyl & Kulkarni 1998 and Popov, Turolla & Possenti 2006 for a discussion).

Detailed multi-wavelength studies of XDINSs are fundamental for tracking their evolutionary history, and for shedding light on their thermal and magnetic surface properties. While the XDINSs have similar spectral properties in X-rays, in the optical

the paucity of multi-band observations prevents a clear spectral characterization. For the XDINSs with a certified counterpart (Table 1, see also e.g. Kaplan 2008, for a recent review) the optical emission lies typically by a factor ~3-10, or more, above the extrapolation of the X-ray blackbody into the optical/UV band. However, while the optical flux closely follows a Rayleigh-Jeans distribution in RX J1856.5-3754, possible deviations from a blackbody behavior have been reported for RX J0720.4-3125 and RX J1605.3+3249 (Kaplan et al. 2003; Motch et al. 2003, 2005; Zane et al. 2006). Thus, whether the optical emission from XDINSs is produced by regions of the star surface at a lower temperature (e.g. Pons et al. 2002) or by other mechanisms, such as non-thermal emission from particles in the star magnetosphere or reprocessing of the surface radiation by an optically thin (to X-rays) hydrogen layer surrounding the star (Motch et al. 2003; Zane et al. 2004; Ho et al. 2007; Hambaryan et al. 2009), is still under debate.

Table 1. Observed properties of the seven Isolated Neutron Stars.

ROSAT Source	PSPC cts/s	kT eV	N_H $10^{20}cm^{-2}$	P Sec	$\dot{P}$ 10^{-14} [s s^{-1}]	m_B	Proper motion mas yr^{-1}	Distan. [pc]	$L^{(1)}$ 10^{32} ergs s^{-1}
RX J1856.5-3754	3.64	62	0.8	7.06	3	25.2	332	178	1.9
RX J0720.4-3125	1.69	85-95	1.0	8.39	7	26.1	108	360	8.5
RX J1605.3+3249	0.88	93	0.8			27.2	155	390	9.7
RX J0806.4-4123	0.33	92	1.1	11.37		>24		250	9.2
RX J1308.6+2127	0.29	102	1.8	10.31	11	28.4	223		14.0
RX J2143.0+0654	0.23	102	3.6	9.44	4	27.4		430	14.0
RX J0420.0-5022	0.12	45	2.1	3.45		26.6		345	0.53

1) Assuming NS radius 10km

3. Relation to the Pulsar Population

The data presented in Table 1 shows that XDINSs, as re-heated old NSs owing to the accretion from the ISM, can be easily ruled out for further consideration, because accretion cannot be considered as an effective powering mechanism for X-ray emission. Indeed, average persistent X-ray luminosity of magnetized, slow rotating INS (Ikhsanov & Biermann, 2007) due to the accretion from ISM is unlikely to exceed $4x10^{26}$ ergs sec^{-1} which is a few orders of magnitude lower than estimated ones of XDINSs. Similarly, they cannot be considered also as a rotation-powered pulsar owing to the slow rotation[1].

[1] Rotation-powered pulsars are rapidly rotating neutron stars, that gain their power of electromagnetic radiation from the loss of rotational energy, i.e. L ~

$$\dot{E} = \frac{d}{dt}\left(\frac{1}{2}I\omega^2\right) = I\omega\dot{\omega} = 4\pi^2 I\frac{\dot{P}}{P^3}.$$

The position in the P vs. $\dot{P}$ diagram (Figure 1) occupied by those sources suggests the general evolutionary status of the INSs. The matter is that young pulsars (associated with SNRs, indicated by stars in Figure 1) occupy either the left or right upper parts of the diagram and during their evolution they are moving to the right-down and there is no efficient way to increase the magnetic field strength during time. The estimated ages of XDINSs on the base of either the spin down rate or from NS cooling curves are of the order of ~1Myr, which indicates that they are relatively young. Long, similar rotational periods, ages and large magnetic fields of XDINSs mimic on the evolutionary link between them and AXPs.

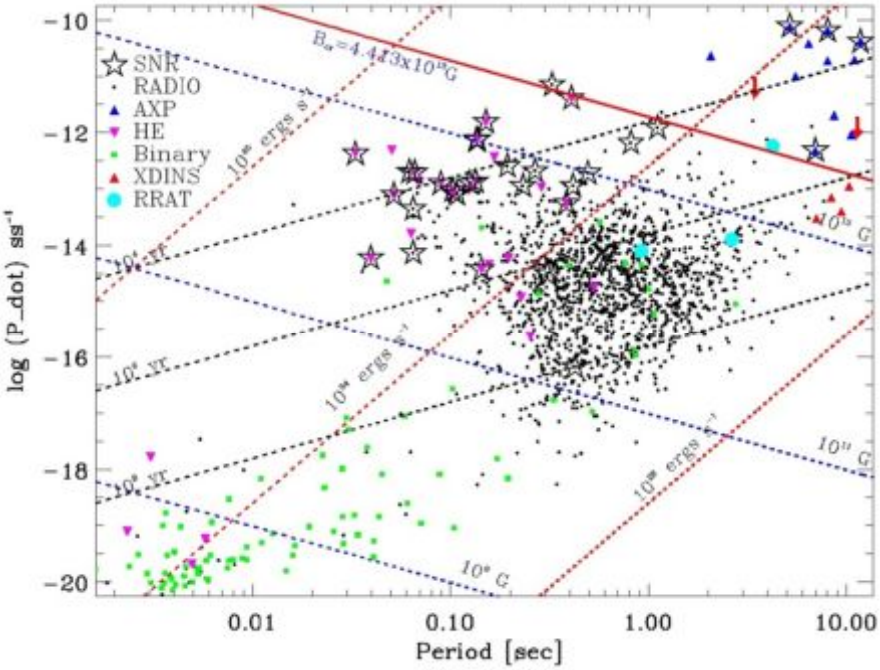

Fig. 1. Pulsar period derivative versus pulsar period for all known Galactic pulsars (the ATNF Pulsar Catalogue, http://www.atnf.csiro.au/research/pulsar/psrcat). Pulsars in several different flavors, distinguished by different period ranges and/or pulse emission properties, are indicated by different colors and symbols. Lines of constant characteristic age, $t_c = P/(2\dot{P})$, surface dipole magnetic field, $B_s \sim (P\dot{P})^{1/2}$, spin-down luminosity, $\dot{E} \sim \dot{P}/P^3$, are shown. The small group of radio-quiet, XDINs are depicted by red color triangles (upper right part).

The origin of the magnetic fields in neutron stars, and the physical differences between magnetars and strongly magnetized pulsars are still under vigorous debate. It has been suggested that the properties of the progenitors of neutron stars (the massive OB stars), such as rotation, magnetic fields and mass, may play an important role in the

outcome of core collapse leading to Type II supernovae. Therefore, knowing the magnetic properties of the progenitor OB stars would be an important asset for constraining models of stellar evolution leading to the birth of a neutron star. There are some testimonies on the magnetic properties of main-sequence magnetic massive OB stars. Namely, Petit et al. (2008) reported on the detection of two new massive magnetic stars in the Orion Nebula Cluster: Par 1772 (HD 36982) and NU Ori (HD 37061), for which the estimated dipole polar magnetic field strengths are 1150±250 and 620±200 G , respectively.

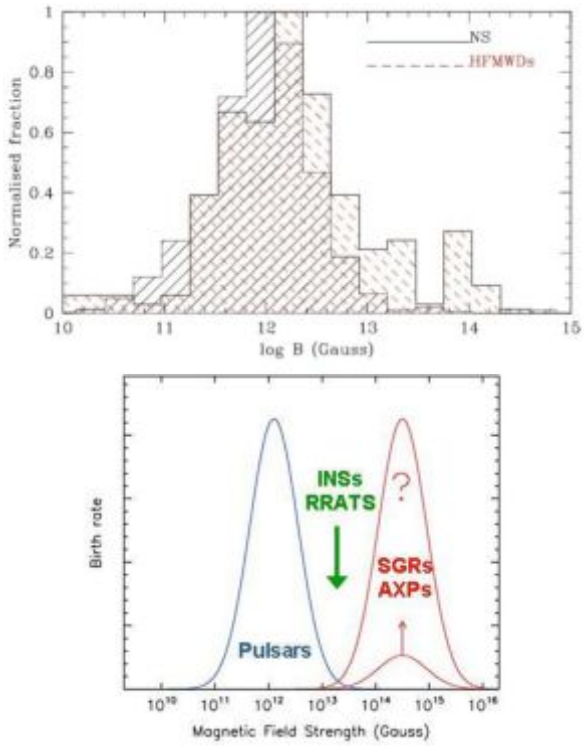

Fig. 2. Left: Black histogram (solid line): Magnetic field distribution of NSs. Red histogram (dashed line): Field distribution of High Field Magnetic White Dwarfs when their radii are shrunk to that of typical NS radius of ~10^6 cm (Petit et al. 2008). Right: Evolutionary considerations (e.g. AXPs→INSs, RRATs)

As already mentioned above XDINSs have large magnetic fields. If magnetic flux conservation during the birth of the NS is assumed then a progenitor must also possess a relative strong magnetic field, ie. ~1kG (Spitkovsky, 2008). Thus, magnetic OB-stars (Figure 2) can be considered as progenitors for XDINS. In order to identify most plausible progenitors, i.e. most probable birth places of XDINSs we have traced them back in time using kinematic characteristics (Table 1 and Figure 3). In some cases we

were able to identify a stellar association/cluster which can be considered as a probable birth place of an XDINS (Figure 3).

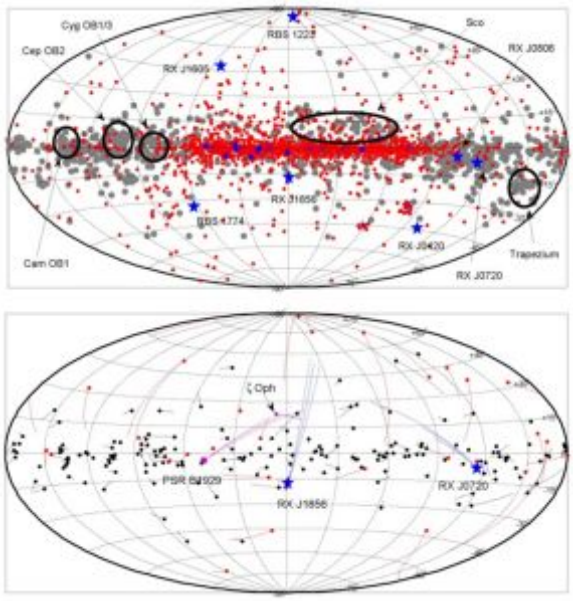

Fig. 3. Left: Distribution of pulsars in the galactic coordinate system. Red dots – radio pulsars taken from the ATNF Pulsar database, blue asterices – AXPs, blue diamonds – RRATs, blue stars – M7. OB stars (up to B2.5) are plotted as grey dots to indicate their distribution on the sky. Right: Runaway stars and pulsars. Black dots and lines indicate runaway stars, red ones pulsars from the ATNF database for which both proper motion and parallaxes are available. They are traced back for 2 Myr (pulsars with zero radial velocity). The dots mark their current positions. The M7 members RX J1856.5-3754 and RX J0720.4-3125 are plotted as blue stars and lines and with error bars (assuming a radial velocity of zero). As well is plotted the suggested pulsar/runaway pair PSR B1929/ζOph which were suggested to have been at the same position in Upper Sco about 1 Myr ago (for a radial velocity of the pulsar of 200 km/s).

Yet another evolutionary link of XDINSs to the sporadically emitting RRATs may serve similar spin and X-ray spectral characteristics (Rea et al., 2008).

Thus, all above mentioned properties of XDINS allow us to consider them as relative young (~1Myr), cooling isolated NSs and generated by magnetic OB stars.

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The Parkes Pulsar Timing Array (PPTA)

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Abstract. The detection and study of gravitational waves from astrophysical sources is a major goal of current astrophysics. Precise timing observations of a sample of millisecond pulsars widely distributed on the sky have the potential to detect gravitational waves at nanohertz frequencies. Potential sources of such waves include binary super-massive black holes in the cores of galaxies, relic radiation from the inflationary era and oscillations of cosmic strings. The Parkes Pulsar Timing Array (PPTA) is an implementation of such a system in which 20 millisecond pulsars have been observed using the Parkes radio telescope at three frequencies at intervals of two – three weeks for more than three years. To date, analysis of these data has been used to limit the gravitational wave background in our Galaxy and to constrain some models for its generation.

Gravothermal Star Clusters - Theory and Computer Modelling

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Abstract. In the George Darwin lecture, delivered to the British Royal Astronomical Society in 1960 by Viktor A. Ambartsumian he wrote on the evolution of stellar systems that it can be described by the ``dynamic evolution of a gravitating gas'' complemented by ``a statistical description of the changes in the physical states of stars''. This talk will show how this physical concept has inspired theoretical modeling of star clusters in the following decades up to the present day.

The application of principles of thermodynamics shows, as Ambartsumian argued in his 1960 lecture, that there is no stable state of equilibrium of a gravitating star cluster. The trend to local thermodynamic equilibrium is always disturbed by escaping stars (Ambartsumian), as well as by gravothermal and gravogyro instabilities, as it was detected later. Here the state-of-the-art of modeling the evolution of dense stellar systems based on principles of thermodynamics and statistical mechanics (Fokker-Planck approximation) will be reviewed. Recent progress including rotation and internal correlations (primordial binaries) is presented.

The models have also very successfully been used to study dense star clusters around massive black holes in galactic nuclei and even (in a few cases) relativistic supermassive dense objects in centres of galaxies (here again briefly touching one of the many research fields of V.A. Ambartsumian).

For the modern present time of high-speed supercomputing, where we are tackling direct N-body simulations of star clusters, we will show that such direct modeling supports and proves the concept of the statistical models based on the Fokker-Planck theory, and that both theoretical concepts and direct computer simulations are necessary to support each other and make scientific progress in the study of star cluster evolution.

Gamma-ray Bursts: Past, Present and Future

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Abstract. A review of cosmic gamma-ray bursts is presented. Milestones of history of gamma-bursts since its discovery, current understandings of the phenomenon and future missions are discussed. In particular optical properties and observations of burst sources are emphasizing.

Superdense stars containing strange quark matter

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Abstract. In pioneer work of V.A.Ambartsumian and G.S. Sahakian [1] it has been shown that degenerated nuclear plasma may contain, besides neutrons, protons and electrons, also strange baryons – hyperons. In [2] G.S. Sahakian and Yu.L. Vartanian for the first time have shown that taking into account the interaction between baryons makes possible the existence of hyperons in the central regions of stable neutron stars.

A new interest towards strange nuclear plasma has arisen when Witten [3] supposed, that quark-electron plasma with a strangeness - 1 per baryon may be absolutely stable state of cold superdense matter.

Possible implications for quark phase transition inside superdense stars are studied, based on the series of calculated models. The stars considered were pure quark stars (or strange stars) and hybrid stars consisting of a quark matter core with a nuclear matter crust around.

The detailed analysis of the parameters of calculated configurations, useful for comparison with neutron star observables, is carried out. Such comparison might help to test the used equations of state for superdense matter.

The observational consequences are affected very much by the features of the process of star restructuring, when phase transition occurs in the interior of a star. Possible observational tests are discussed to distinguish between the ordinary neutron stars, strange stars and superdense hybrid stars.

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Key words: strange stars, hadron-quark phase transition, neutron stars with a quark core

1. Introduction

The investigations of the superdense nuclear matter are performed on the intersection of a number of branches of modern theoretical physics, namely: elementary particles physics and nuclear physics, many-particle physics and statistical physics, and in connection with the astrophysical applications - relativistic theory of gravitation and theoretical astrophysics. After the discovery of pulsars, which are identified with the neutron stars, this field of science became one of the most actual not only in theoretical physics, but also in observational astronomy.

A new interest toward this field arose during the last period in connection with the theoretical investigations of the possibility of phase transition in nuclear plasma to the state, containing strange quark matter. It was shown, that such phase transitions might result in the existence of entirely new type of superdense stars - strange stars, - together with neutron stars.

Theoretical studies of superdense matter commenced in Armenia at the beginning of the 1960s, prior to the discovery of pulsars. The cosmogonical ideas of academician Victor Ambartsumian were stimulus for these investigations [1-3]. Armenian researchers have participated in the fundamental studies of the nuclear matter properties at superhigh densities. Of particular importance was that G.S. Sahakian, in collaboration with Yu.L.Vartanian, showed that taking into account the interaction between baryons makes possible the existence of hyperons in the central regions of stable neutron stars and increases the maximum mass of such stars up to $1.6 M_\odot$ [4,5]. These and subsequent results have paved the way for numerous studies. Armenian researchers have investigated many related problems, such as the inner structure, cooling, pulsations, and stability of superdense stellar objects, and properties of gravitational radiation from flattened pulsating white dwarfs and neutron stars. The results of these investigations have received wide exposure in papers on gravitation and relativistic astrophysics [e.g., 6-10].

In recent years, we have focused on phase transitions in superdense nuclear plasma to strange quark matter, and possible astrophysical applications of such transitions [11-17]. Our research is based on the "bag" model for infinite homogeneous quark matter developed at the Massachusetts Institute of Technology (MIT) [18]. Due to complexities in the theory of strong interactions, this model includes a number of physical constants that cannot be determined by laboratory investigations. Therefore, comparison of observations of superdense stars (e.g., the mass, radius, moment of inertia, redshift, or time of cooling) with the results of different theoretical models is very important for the physics of elementary particles. Examples of such investigations are in [12].

2. Strange stars

For some allowable values of the physical constants of the bag model, quark matter can be self-bound. This means that in such matter the binding energy per baryon is greater than it is in iron nuclei [19]. If this possibility occurs in nature, then the so-called strange quark stars may exist. The inner structure and integral parameters of strange stars were obtained in [20-23, 12]. At the surface of strange stars the density of matter decreases abruptly from ~10^{15} g/cm^3 to a much smaller value (of at least 10^8 g/cm^3, given that a normal crust is likely required to explain the properties of thermonuclear X-ray bursts). In the high-density region, the positive charge excess of strange quark matter is compensated by electrons. At the boundary between strange matter and normal matter, the strange matter ends suddenly, over strong interaction scales of a few fermis. In contrast, the electrons are not affected by the strong interaction, and hence can extend several hundreds fermis from the strange star surface. This produces a net outward-directed electric field at the surface, estimated to be 10^{17}volt/cm, which can support a crust of degenerate electrons and atomic nuclei. An investigation of such models has been performed in [20,17]. In particular, it has been shown that when the mass of a strange quark core decreases to 0.013 $M_\text{ł}$, the total mass of the star reaches one solar mass and a radius of 2500km. Such models are usually called strange dwarfs.

The radius of strange stars increases with the increase of their mass. Density in the center of star only two times more than one on the surface even for configurations with mass of 1.44$M_\text{ł}$. Self-bound quark matter may exist in form of strange stars with arbitrarily small sizes. Quite narrow intervals for values of their gravitational redshift from the star surface (0.29÷0.31) and minimum period of rotation (0.7÷0.75) obtained [12] might be used for identification of possible candidates for strange stars.

If in Nature a non-self-bound variant of quark matter is realized, neutron stars with a quark core may exist [21, 11, 13, 22-24]. During the construction of models of superdense stellar objects whose matter is subject to phase transition, it is usually assumed that two phases of star matter are spatially separated along the radius. In this case we have a two-layer star with a jump in density, and strange quark matter at the surface of a quark core is in thermodynamical equilibrium with the nuclear matter of the crust, which consists of degenerate neutrons, electrons and atomic nuclei (we call this Aen nuclear matter). Such a crust can in principle extend to radii of ~2000 km for very low-mass configurations. Accretion on the surface of such objects can result in two consecutive transitions to denser configurations, with an energy release similar to a supernova explosion [13, 14].

3. Neutron stars with a strange quark core

If the energy per baryon in strange quark phase has a positive minimum, a thermodynamic equilibrium between the quark matter and the baryon component may

take place that is realized in neutron stars with a quark core. The series of the models of neutron stars with a strange quark core were constructed, based on the extensive set of calculated realistic equations of state (EoS-s) of superdense matter with a quark phase transition [15].Some characteristic configurations of calculated series were also presented, and their thorough investigation was carried out [28].Integral and structural parameters for models of calculated series of superdense layer stellar configurations were presented. Among the basic parameters are the calculated stellar radius R, gravitational mass *M*, rest mass M_0, proper mass M_P, the mass and radius of the strange quark core M_{core} and R_{core}, respectively,relativistic moment of inertia I and gravitational redshift from the surface of the star Z_S.

The values of relativistic parameter of density jump λ determine the stability ranges of layer models on the curve of the dependence of star mass *M* on central pressure P_C [28]. In models of EoS-s with $\lambda < 3/2$ a kink (fracture) on the $M(P_C)$ curve without the change of derivative sign appears at the beginning of formation of quark-phase core at the center of the star (the transition to a quark phase does not cause instability). In the opposite case $(\lambda > 3/2)$ at the threshold of formation of quark-phase core a descending branch on the $M(P_C)$ curve occurs, which configurations are unstable (the so-called instability of configurations with small-mass cores); so, the local toothlike maximum (kink) arises on the $M(P_C)$ curve.

We have revealed [13-14, 28-29] that for some models of EoS a formation of the new local maximum on the stable branch of star mass - central pressure curve is possible. This maximum arises besides the appearance of sharp fracture on the mentioned curve, which is characteristic for models of layer stars with $\lambda > 3/2$ and corresponds to the beginning of formation of a new phase core (see fig.1, configurations *a, b, c*). Such a new local maximum is discovered in the mass range of about $M \cong 0.08$ M☉ in some models, as well as at $M \cong 0.82$ M☉ in others. The configuration *a* corresponds to a point of stability loss in the low-mass range on the $M(P_C)$ curve. These configurations have no quark core. Configurations *b* denote the models of neutron stars with the central pressure corresponding to the threshold for formation of a quark core. Configurations *c*, *d* and *e* describe this new local maximum, and configuration *c* describes the minimum after the kink attributable to the formation of quark phase. The branch *ab* represents stable neutron stars without a quark core, and *cd* – stable configurations having small quark core.

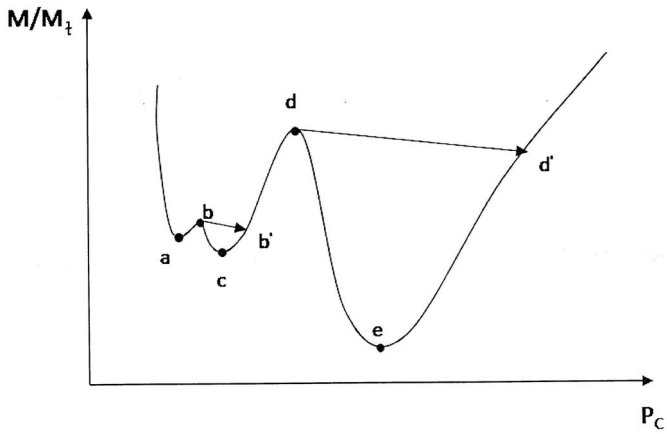

Fig. 1. Schematic arrangement of characteristic configurations.

For the first time such models were obtained and calculated in [13, 14]. The appearance of the second local maximum provides the possible existence of a new family of stable equilibrium stellar configurations - the neutron stars with a strange quark core with interesting distinctive features. In particular, the configurations of this new additional stable branch have radii exceeding a thousand kilometers. For such equations of state accretion onto a neutron star will lead to two successive catastrophic transitions to a quark-core neutron star; as a result, there will be two successive energy releases [14, 29].

Thus, we revealed for some models with a transition parameter $\lambda > 3/2$ a new stable branch of superdense configurations with a small quark core ($M_{core} \cong (0.004 \div 0.03)$ M☉) on the $M(P_C)$ curve. Stable equilibrium layer neutron stars, located in these ranges, are characterized also by unusually large values of stellar radius (from $R \approx 1300\,km$ to $R \approx 2700\,km$ for different equations of state). The possibility of existence of the new additional range of stability allows for these EoS-s the transition from configuration b to more dense model through the two restructuring in case of matter accretion on the star: first to a configuration of branch cd , and then - to the main ascending branch of stable neutron stars with a strange quark core (see fig.1). As a result, there will be two successive energy releases with $\approx 10^{51}$erg.

4. Conclusion

Thus, our research is concerned with studies of various theoretical models and calculations of integral parameters of superdense stars, based on these models, and possible observable manifestations of these parameters. Our focus is on reducing the uncertainties present in theoretical models by means of comparing the phenomena

occurring in superdense celestial bodies and in their close environment with observations. In particular, several of our papers are devoted to the choice, in this way, of realistic equations of state of matter for neutron stars from the theoretically determined equations. As a result of this, it will be possible to narrow in on the properties of quark matter and to reduce the uncertainties of the theory for quark matter MIT bag model.

We have investigated the observational manifestations of superdense stars containing strange quark matter, and their possible distinction from white dwarfs and ordinary neutron stars. As has already been mentioned, a quark core in the star ensures the existence of an extended Aen-crust. The radius and mass of such stars are very similar to those of ordinary white dwarfs. However, their inner structures are distinct. For example, in Aen-matter a superfluid state is possible, changing the cooling rate of the star, and the star may have a strong magnetic field [27].

A phase transition in degenerate matter can change the stellar mass-central density (central pressure) dependence. Just such a situation occurs for the phase transition from baryonic to quark matter. In this case, together with a number of new results, we have found that the formation of a quark core in the star interior can ensure the existence of stable stars with an extended Aen-crust [13, 14]. The masses of such stars can reach ~0.1$M_{\text{ł}}$. We find that the essential part of the stellar mass is composed of Aen-matter, in contrast to what was found for previous equations of state. The properties of Aen-matter are essentially different from those of white dwarf matter. In Aen-matter, the superfluid state of neutrons can be realized [27], and there may be a new source of energy [26]. In Aen-matter neutron-rich giant atomic nuclei with an atomic mass of A~2000 can exist. Despite the external similarity of such stars and white dwarfs (e.g., their radius and mass), their observational manifestations will differ strongly. It has been shown that during accretion of matter on such stars, two successive supernova-like explosions are possible [14]. This fact may serve as a way to discover such objects.

On the Hertzsprung-Russell diagram there is a vacant region between the white dwarf and neutron star branches. This intermediate range could be filled in by the so-called strange dwarfs [25, 17] or the stars with a strange quark core and extended crust of Aen nuclear matter (atomic nuclei, degenerate electrons and neutrons).

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Peculiarities of gravitational wave radiation of sources in medium frequency band

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Contribution not available.

Hyperflares of SGRs as an engine for millisecond extragalactic radio bursts

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Abstract. We propose that the strong millisecond extragalactic radio burst (mERB) discovered by Lorimer et al. (2007) may be related to a hyperflare from an extragalactic soft gamma-ray repeater. The expected rate of such hyperflares, ~ 20 - 100 d^{-1} Gpc^{-3}, is in good correspondence with the value estimated by Lorimer et al. The possible mechanism of radio emission can be related to the tearing mode instability in the magnetar magnetosphere as discussed by Lyutikov (2002), and can produce the radio flux corresponding to the observed ~ 30 Jy from the mERB using a simple scaling of the burst energy.

1. Introduction

Progress in observational technique in radio astronomy made it possible to detect single millisecond scale bursts (Cordes & McLaughlin 2003). Recently Lorimer et al. (2007) reported a serendipitous discovery of a strong nonthermal millisecond radio burst with peculiar properties.

The radio flux at 1.4 GHz is 30 ± 10 Jy, the duration of the event is shorter than 5 msec and its dispersion measure (DM) is 375 cm^{-3} pc suggesting the extragalactic nature of the source at a distance of < 1 Gpc. No host galaxy up to the 18th B-magnitude has been found implying a distance limit of > 600 Mpc for a Milky Way-like host. Such a distance implies a radio energy release in the burst of ~10^{40} ergs with a brightness temperature of ~10^{34} K. The total rate of such bursts is estimated to be around 90 d^{-1} Gpc^{-3}, which is much lower than the core-collapse supernova (SN) rate ~1000 d^{-1} Gpc^{-3}, but well in excess of the gamma-ray burst (GRB) rate ~4 d^{-1} Gpc^{-3}, and the expected rate of binary neutron star coalescences ~2 d^{-1} Gpc^{-3}.

The short time scale means the origin in a compact region < 1500 km (in the non-relativistic case), suggesting neutron stars as the most probable sources of mERBs. Lorimer et al. (2007) discuss several possible known sources of the strong millisecond radio bursts, including rotating radio transients (RRATs) and giant pulses from radio pulsars, but none of them appear to be energetic enough.

Here we propose to discuss another possibility that the strong mERB could be associated with hyperflares (HFs) of extragalactic soft gamma-ray repeaters.

2. MERBs from SGRs

Is it possible that the mERB is related to an extragalactic HFs of SGRs? To address this question, we first note that the inferred rate of mERBs is similar to the rate of HFs of SGRs obtained from searches for SGR flares in close-by galaxies and the Virgo cluster. Popov & Stern (2006) argue that the rate of HFs is ~10^{-3} yr^{-1} per a Milky Way-like galaxy. Lazzati, Ghirlanda & Ghisellini (2005) give slightly less stringent limit for the rate of HFs: < 1/130 yr^{-1}. Considering low statistics, however, here we use a more conservative estimate 0.001-0.003 per year per a Milky Way-like galaxy. This is ~10-50 times smaller than the galactic rate of SN, so from the SN rate ~1000 d^{-1} Gpc^{-3} we estimate the expected rate of SGR HFs to be ~20-100 d^{-1} Gpc^{-3} in good correspondence with the rate of mERBs obtained by Lorimer et al. (2007).

The possible mechanism of a prompt intense radio burst from SGR flares was discussed by Lyutikov (2002) (see also Lyutikov 2006). He proposed that a ~10 msec radio burst can be generated in the magnetar magnetosphere due to the tearing mode instability, following the similarity between solar flares and SGR bursts (in solar flares radio bursts accompany X-ray flares). For galactic SGRs with X-ray luminosity 10^{36} - 10^{39} erg s^{-1} and 10 kpc distance he estimated a possible radio flux at ~1 GHz of about 1 – 1000 Jy. Guided by these values, for a HF with peak gamma-ray luminosity of L = 10^{47} erg s^{-1} (as observed in the Dec. 27 2004 HF from SGR 1806-20) and 600 Mpc we obtain a radio flux of ~30 Jy, in correspondence with observations by Lorimer et al. (2007).

The millisecond time scale of the mERB is consistent with an event in a magnetar magnetosphere. For example, the light curve of the Dec. 27, 2004 event (see Fig. 1b in Palmer et al. 2005) shows a few features with the duration of a few milliseconds at the initial stage. The raising part of the main spike of the Dec 27, 2004 HF is also about 5 msec. The time scale of the radio burst produced by the discussed mechanism can be much smaller than 5 msec, since the crossing time of Alfven waves in internal parts of the NS magnetosphere is just $t_A \sim R_{NS}/c \sim 30\mu sec$ (see discussion in Lyutikov 2006). We note here that Lorimer et al. (2007) actually stress that the observed burst could indeed be much shorter than 5 msec.

In addition to strong HF, SGRs show less intensive and more frequent giant flares (GFs). Their galactic rate is estimated to be about 0.05-0.02 yr^{-1}, similar to the SN rate (Woods & Thompson (2006). Because of low statistics it is unknown if GFs and HFs from SGRs form continuous luminosity distribution. If they do, then mERB energy distribution should follow the same power law $dN/dE \sim E^{-\gamma}$ with the index $\gamma \approx 1.6$-1.7 (Gogus et al. 1999). But then, as noted by Lorimer et al. (2007) one would expect to see more weaker mERBs, which is apparently not the case. If one assumes that these events belong to different classes without bursts of intermediate energies, it is possible to explain why the first detected mERB was about two orders of magnitude above the threshold. If GFs can also produce mRBs with energies scaling similar to X-ray – soft-γ

bursts, as proposed by Lyutikov (2002), then they are too dim (or rare, if they come from much smaller volume corresponding to smaller distancies) to be detected in a search like the one performed by Lorimer et al. (2007). If the HF which produced the mERB was followed by usual (weak) bursts with energies < 10^{41} erg s^{-1}, as it is assumed to be typical for GFs and the HFs, then these events would produce too dim radio bursts (0.03 mJy according to the scaling suggested by Lyutikov 2002) to be detected.

3. Discussion

SGRs are assumed to be young (< 10^4 yrs) neutron stars, so extragalactic flares are expected to be related to galaxies with high star formation rate (Popov & Stern 2006). Potentially, this can give a hint about possible properties of the host galaxy of the mERB discovered by Lorimer et al. (2007). For example, the possible host galaxy can be rather dim in the optical due to dust; not necessarily it should be a Milky Way-like galaxy, it can be a smaller irregular galaxy with active star formation. In this case it can lie closer than the 600 Mpc distance as inferred from the optical limit. Intrinsic DM can also be higher in star forming galaxies. So it would be interesting to use the Spitzer space telescope to search for the host galaxy of this event in the infrared.

Unfortunately, there is no much hope to find many mERBs in dedicated searches for activity of extragalactic SGRs, as HFs are very rare events. Radio monitoring of galaxies even with extremely high rate of star formation appears to be not very promising in the sence of looking for more mERBs. For example, even in the “SN factories” discussed in Popov, Stern (2006) with the star formation rate about two orders of magnitude as high as in the Milky Way, we can expect to have only few extragalactic giant flares per year (from their distances of tens Mpc the scaling discussed by Lyutikov 2002 would yield detectable GFs-related radio bursts). Nevertheless, when performing archive searches for more mERB candidates it can be useful to check first directions with large integrated star formation rate along the line of sight. To find more mERBs related to SGR HFs this could be more promising than the direct search in programs like STARE and FLIRT, because mERBs can have no counterparts in other wavelengths.

To our knowledge, nobody was able to test directly the prediction by Lyutikov (2002) by observing galactic SGRs and/or AXPs exactly during bursts in radio with msec time resolution. Recently, some observations of AXPs have been reported (Burgay et al. 2006; Crawford, Hessels & Kaspi 2007). These authors put strong limits on the integrated pulsed emission and RRAT-like bursts of several AXPs, however, nothing can be said about mRB during X/γ bursts.

Lorimer et al. (2007) note that no gamma-ray burst was detected at the moment of the mERB (August 24, 2001). In the case of a HF from the distance ~600 Mpc it is not surprising.

For example, BATSE could detect events like the Dec. 27, 2004 flare only from a distance of ~30-40 Mpc (Hurley et al. 2005; Popov & Stern 2006). SWIFT can detect HFs from larger distances (~70 Mpc, Hurley et al. 2005), which is still much lower than 600 Mpc.

Some other exotic possibilities, like deconfinement inside a compact object leading to a quark star formation and complete reconfiguration of the magnetic field, can be discussed. Most of them are also expected to be accompanied by a SN-like or/and a GRB-like event.

4. Conclusions

We conclude that the rate of HFs of SGRs of several tens per day within 1 Gpc volume is similar to the inferred rate of mERBs. The time scale, the absence of counterparts at other wavelengths, as well as the non-observation of the host galaxy up to the 18th B-magnitude, are consistent with the HF hypothesis. The physical mechanism of the radio burst can be related to the tearing mode instability, as proposed by Lyutikov (2002). New observations are decisive to check if extragalactic binary neutron star mergings or hyperflares from SGRs underly mERBs.

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Session 3. ACTIVITY IN GALAXIES

V.A. Ambartsumian's contribution in the field:

The hypothesis on the activity of galactic nuclei was proclaimed. The various forms of activity were presented as different manifestations of the same phenomenon of activity. The evolutionary significance of the activity in the galactic nuclei was emphasized and a further hypothesis was suggested on the ejection of new galaxies from the active galactic nuclei. The hypothesis on the superdense protostellar matter was engaged to explain the observational data (1956). This hypothesis bears V. Ambartsumian's name.

Ref.: V.A. Ambartsumian – On the Nature of Radio Sources // *Proc. Fifth conference on Problems of Cosmogony: "Radioastronomy", held on 9-12 Mar 1955. Acad. Sci. USSR, 413-416, Moscow, 1956 (in Russian).* V.A. Ambartsumian – On Multiple Galaxies // *Izvestiya Acad. Sci. ArmSSR, Ser. Phys.-Math., Nat. and Tech. Sci., 9, 23-43, 1956 (in Russian).*

V.A. Ambartsumian and the Activity of Galactic Nuclei

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Abstract. We present Ambartsumian's impact on development of understanding of activity of galactic nuclei; from his early ideas to modern interpretation of the AGN unified scheme. It is shown that he was the first (in mid-1950s) to understand that central regions of galaxies contained huge sources of energy and played decisive role in origin and evolution of galaxies. This approach allowed predicting new types of active galaxies, e.g., QSOs discovered in 1963. We show that Ambartsumian's idea to unify all at that time available observed phenomena (radio galaxies, Seyferts, blue companions of galaxies, jets) supposed to be connected to the central regions of galaxies was in fact the beginning of the unified scheme of AGN (formally introduced much later in 1985), which at present reliably explains various manifestations of the same physical model. Moreover, the artificial contradiction between Ambartsumian's hypothesis about superdense matter in the centers of AGN and today's SMBH model is in fact the same approach with different further modifications, as the principal idea in both models is that super massive body in the centre of AGN is responsible for the huge amounts of the emitted energy. New understanding on various phenomena connected to the activity of galaxies is presented.

Keywords: activity of galactic nuclei, unified scheme, jets

1. Introduction: Ambartsumian's Concept of Intrinsic Activity of Cosmic Objects

The concept of physical activity of cosmic objects is evidently one of the key ideas playing an essential role in the evolution theories. In a very wide sphere of Ambartsumian's scientific interests this concept shows up frequently since the very beginning of his career. However, even the followers of Ambartsumian do not consider his activity paradigm comprehensively distinguishing active galactic nuclei from the huge variety of active phenomena in cosmic objects. This approach undoubtedly

detracts from his scientific merit and makes his activity paradigm strangulated. In this report an attempt is made to analyze Ambartsumian's work from a more general point of view and to search for the roots of his activity concept in his earlier papers. We limit ourselves to a systematic examination of Ambartsumian's legacy in order to identify the grounds which ultimately led him to a nonstandard conclusion regarding the physical activity of galactic nuclei and the vital importance of active processes in the evolution of cosmic objects and particularly galaxies.

For a short period of time a model of atomic nuclei was adopted according which those consisted of protons and electrons. Well known radioactivity phenomenon of beta decay seemed to be a good proof for such a structure. Given the fairy obvious contradictions between this model and the experimental data Ambartsumian and Ivanenko (1930a) proposed a new interpretation. They insisted on that no free electron could exist in the atomic nuclei and "the whole phenomenon is completely analogous to the emission of photons by an atom, i.e., the electron, like a photon (quantum of light) has no individuality inside the nucleus prior to its ejection" (Ambartsumian & Ivanenko 1930a). This idea was undoubtedly fundamental, as a natural extension and application of their pioneering idea enunciated earlier about the possibility of the creation and annihilation of individual elementary particles with nonzero rest masses (Ambartsumian & Ivanenko 1930b). For his further work on the objects' activity the most significant conclusion he arrived at was one sounding as follows. Physical processes are possible when physical object is active in a way such that it is capable of ejecting another object that did not exist within the original object before ejection. No doubt that this conclusion was utterly new and suggested the existence of new mechanisms for the formation of cosmic objects belonging to different hierarchical levels of the universe.

The next step that appears to have played an important role in establishing Ambartsumian's concept of a close link between the physical activity of objects and their evolution was a study of the effect of radiation pressure from a central star on the dynamics of planetary nebulae (Ambartsumian 1933). Here he proved that, because of radiation pressure, these gaseous formations could not exist for more than a hundred thousand years unless there was an additional supply of new gas. It was first proved in the above paper that these nebulae are formed as a result of an outflow of matter from a star, i.e., a more rarefied object is formed from a denser object. In the customary sense this result already provided a basis for the development of a more general concept, to the effect that decay and scattering characterize the direction of at least some part of the processes observed in our Galaxy. This result merited more attention, since it was fully consistent with the second law of thermodynamics.

Ambartsumian reached an analogous conclusion in analyses of a group of visual binary stars in the galaxy (Ambartsumian 1930) and of open stellar clusters (Ambartsumian 1938). He showed that star pairs decay on encountering field stars at a much greater rate than new pairs could be formed in random three-body encounters of individual stars.

This meant that in our epoch there is a rise in the relative number of individual stars in the common family of field stars in our Galaxy (Ambartsumian 1930). Using the principles of stellar dynamics, Ambartsumian found that open stellar clusters loss ever more stars with time (Ambartsumian 1938). This takes place because of energy exchange through which some stars gain enough energy to escape from the cluster. This phenomenon, known as the evaporation of clusters, also indicates that the decay and scattering processes observed in our galaxy actually do have a general character and play a major role in the evolution of individual objects and of systems of them.

One of the important stages in the development of Ambartsumian's paradigm of the physical activity preceding the concept of activity of galactic nuclei was study of stellar associations in our Galaxy during the 1940s (Ambartsumian 1947). The principal result of these studies was a proof of the dynamic instability of these systems and, therefore, a possibility of estimating their age. Based on these estimates, he demonstrated the existence of young stars in our Galaxy. These results could be formulated in a more general form as follows: *in our epoch stars of all ages can be found within a finite volume of space* (Harutyunian 2003). In this case, a finite volume is understood to mean individual galaxies (such as our own).

2. Activity of galactic nuclei. First vision

Ambartsumian formulated the basic principles which subsequently became a cornerstone for his concept of active phenomena in galaxies in the paper (Ambartsumian 1955). First of all he paid attention to the known observational fact that galaxies form part of clusters or groups more markedly than stars do. Based on the known facts and an analysis of analogous situations in the world of stars, he showed that under the current conditions of metagalaxy these systems are either preserved or are in the process of decay. In any case they cannot be enriched at the expense of galaxies formed independently of them. In the same paper he concluded also that the percent of the multiple galaxies in a given cluster of galaxies is many times greater than the calculated amount that should be observed under thermodynamic equilibrium. He arrived at a conclusion that *the components of a given binary or multiple galaxy, or even of a given cluster of galaxies, have been formed together* (Ambartsumian 1955; 1956).

In his first papers on this problem he concluded also that percentage of multiple Orion Trapezium-type systems is very high, and they constitute at least half of all multiple galaxies. Moreover, such a situation allowed him propose that *some of Trapezium-type multiple galaxies have a positive energy, i.e., they are groups which decay immediately after their creation* (Ambartsumian 1956).

Thus, this study of multiple systems of galaxies led for the first time to the conclusion that the components of the mentioned systems in past might have been a unitary object

which subsequently has been broken into independent parts, roughly in the same way as in the process of decay of superheavy atomic nuclei. The main difference is in space-time scales – while a process in the microscopic worlds occurs almost in a flash, in the world of galaxies we observe only frozen "stop frames" of this phenomenon.

If the nowadays multiple galaxies are considered to be a result of huge decay processes, one might search for the earlier phases of this phenomenon. In early 50s of the last century Ambartsumian gave much attention to radiogalaxies, firstly interpreted as the result of a random collision between two previously independent galaxies (Baade & Minkowski 1954). Among the first extragalactic radio sources were radio galaxies CygA and CenA (NGC 5128). Already at that time Ambartsumian emphasized very essential circumstance that radio galaxies belong to a small class of supergiants, most powerful ones of which coincide with the cD galaxies (Morgan & Lesh 1965) occupying central positions in clusters of galaxies. On the other hand a collision of two galaxies of lower absolute brightness should be much more probable, but no such "collisions" had been observed. Based on similar probabilistic estimates Ambartsumian suggested that the signs of binary and complicated structure observed in radio galaxies are not evidence of collision at all, but of breakup of galaxies or their nuclei or ejection from the nucleus.

In any case it was utterly evident that the relative predominance of supergiants among the radio galaxies represents some great difficulties for the collision hypothesis, because it led to "*an artificial assumption of an extremely strong dependence of the excited radio emission on the mass of the colliding galaxies*".

At the very beginning of the new concept formation Ambartsumian made the first rough classification of various activity exhibitions. Widely known today and studied in detail the galaxy M87 was the only extragalactic object with known jet emanating from its nucleus. Ambartsumian was sure that such a phenomenon could not be unique, and he emphasized the importance of searching for analogous formations in other galaxies (Ambartsumian & Shahbazian 1957). Moreover, the shape of the M87 jet with its condensations and sparser parts had been giving a hint that the sparse parts would disappear in time and only the bluer knots or condensations would remain without any hint at a connection with the maternal galaxy. Undoubtedly it increases the significance of searching for blue satellites around galaxies which could have been lost their apparent connection with giving them birth galaxies. "*Of course, in this case we cannot be certain that we are dealing with the fact of ejection. Furthermore, the question of a physical relationship between a satellite of this sort an elliptical galaxy requires further study, especially since, as our searches have shown, faint individual galaxies with a negative color index do surely exist*" (Ambartsumian & Shahbazian 1957).

As galaxies with M87-like peculiarities the binary galaxy NGC 3561 as well as the galaxy IC 1181 and other galaxies found in the Palomar charts have been mentioned

(Ambartsumian & Shahbazian 1957; 1958). It is worthy of note that both of the two mentioned galaxies appeared to be extremely interesting objects included later on in the Arp's Atlas of Peculiar Galaxies (Arp 1966). One of the small elliptical satellites to the south of the NGC 3561 is called in the literature "*the Ambartsumian knot*".

Returning once again to a prototype of galaxies with a distinct jet, i.e., to M87, we note that Ambartsumian did not believe that the jet consists exceptionally of relativistic electrons. "*These condensations probably do contain a vast number of relativistic electrons. But it is difficult to refute the proposition that, besides relativistic plasma, these knots also incorporate a substantial number of ordinary matter. In particular, they probably contain relativistic electron sources*" (Ambartsumian 1961a). It is remarkable, that at the beginning of our century about four decades later the closest to the nucleus knot in the jet of M87 has increased its brightness by a factor of 90 (Madrid 2009) during about six years. From where and how came the explosion energy is not completely clear yet. However, it is clear that relativistic electrons could not increase their radiation energy without any other matter containing huge amount of intrinsic energy.

3. Development of the activity concept

During first two-three years Ambartsumian formulated his concept on the formation and evolution of galaxies completely. However, that was appeared in its final version in when Ambartsumian presented a talk at the XI Solvay Conference in Brussels (Ambartsumian 1958a; 1958b). This paper is a nice example of systematic discussion of observational facts and the step by step construction of a new concept. The author has examined all the known for that time observational data – the tendency of galaxies to form groups and clusters, the deviation from dissociative equilibrium in the nowadays population of galactic systems, the phenomenon of radio galaxies, jets from the nuclei of galaxies, blue satellites etc. In this paper he added some new ideas as well. The significance of filaments joining the components of double and triple studied by Zwicky (1956) has been emphasized to show that they could develop during the mutual separation of initially joined components.

Two more additional bases are used in the Solvey talk for arguing the main ideas of the new concept. First of those is devoted to the examination of the interstellar gas. All the researchers more or less familiar to Ambartsumian's concept on the cosmic objects formation and activity forms are aware of the central idea rejecting the star formation from gas and dust. In this paper he again touches upon this issue and brings a number of arguments in favor of the idea that most likely the stars and gas originate jointly from prestellar matter. This principal idea originated in early 30s was accompanying him up to the end of his life (see, one of the last papers dedicated to this issue; Ambartsumian 1982).

The second one is connected with another his old result (Ambarzumian 1935) according to which the enormous difference in the velocity distributions of type I and II stellar populations excludes the possibility of evolutionary transitions from one type to the other. As another argument in favor of the fundamental difference between the types of stellar populations, Ambartsumian points out the fact that a substantial portion of a type II population passes through an RR Lyr stage, while there are no variables of this type in a plane subsystem.

The division of the populations into two types according to their mechanism of formation is of fundamental significance. Ambartsumian was fully aware of its great importance and several times returned to this theme. In his talk at a session of the Royal Astronomical Society in London he notes that "*of course we must always keep in mind that the assumption that spiral arms and systems of spherical clusters originate directly from the nucleus of a given galaxy will encounter difficulties relating to the conservation of mass and the conservation of angular momentum. Perhaps these difficulties are an indication that the relationship between the nucleus and the process of forming the arms and spherical clusters is not very simple*" (Ambartsumian 1961b). At the end he adds: "*as we go deeper into the essence of the problem of the evolution of galaxies, the importance of a single fact, emphasized many years ago by Kukarkin, becomes ever more evident. This is the fact that paths for development of flat and spherical subsystems of stars in the galaxy are independent of one another*" (Ambartsumian 1961b).

The division of the populations into two types according to their mechanism of formation is of fundamental significance. This question was examined in more detail in two invited talks given at the IAU Symposium #15 *"Problems of Extragalactic Research"* in 1961 in Santa Barbara, CA, USA (Ambartsumian 1962) and at the IAU XI General Assembly in 1961 in Berkeley, CA, USA (Ambartsumian 1966). Undoubtedly, the existence of two type populations should be considered very carefully for comprehending the differences of the physical mechanisms responsible for their formation. The absence of gas in the halo of galaxies, as well as, at least, in the great majority of galaxies belonging to the early types is often invoked as an argument for a cutoff of star formation of type II population.

However, this problem has not found yet any self-consistent solution and no an adequate explanation has been given for all the differences between physical properties of these two populations. And for exact physical separation of these two types of stars (two types of populations) one needs to make a comparative analyze for all their appearances in various hierarchical levels. One of the striking observational regularities consists in a fact that the objects composed of type II population and having spheroidal forms (early type galaxies, globular clusters in galaxies) make spheroidal systems of higher hierarchical levels by their turn. Indeed, Globular cluster systems belong to the halos in host galaxy forming spherical structure and early type galaxies are more

numerous in regular clusters of galaxies and make concentrated to the cluster center subsystem in any cluster.

4. Forms of galactic activity and the modern Unified Scheme

Historically the first discovery of any kind of activity (from modern point of view) in galaxies was reported by Grote Reber in 1939, when he discovered Cygnus A as a radio source. Radio emission detected from our Galaxy and nearby bright galaxies (Andromedae, etc.) was believed to be common phenomenon, however, Cygnus A was a distant galaxy and the fact to be among the brightest radio sources in the sky was unexpected. Later on, Carl Seyfert (Seyfert 1943) observed emission-lines in the spectra of some spiral galaxies ("extragalactic nebulae"), including NGC 4151, NGC 1068, NGC 3516, NGC 7469, etc. Especially surprising were broad emission lines (or broad wings of lines) that were not observed in the spectra of the galactic nebulae. In 1940s, after the completion of the 3rd Cambridge radio survey (3C catalog) some radio sources were firstly identified with extragalactic objects: some galaxies were named radio galaxies. Hey, Parsons and Phillips (Hey et al. 1946) discovered variations in the intensity of galactic noise from the direction of the constellation of Cygnus, with a period of about one minute-suggesting that this particular radiation has its origin in a discrete source, Cygnus A (3C 405). Several other radio galaxies (Per A = NGC 1275, etc.) were detected that seemed to have double structure. These objects emited huge amounts of energy attributed to the collisions of two galaxies (Baade & Minkowski 1954). In the optical wavelengths, using three-color filter technique, 44 blue galaxies were found by Haro (1956), some of them showing emission lines in their spectra ([OII] λ3727 doublet, etc.). However, altogether very few observational facts were known in the middle of 1950s related to peculiar radiation from galaxies.

Since the beginning of 1950s, Ambartsumian carefully analyzed all accumulated data on emission-line galaxies, radio galaxies, blue components around giant galaxies (Ambarstumian & Shahbazian 1957), Haro's blue galaxies, etc. and came to a conclusion that all these different manifestations (various forms of activity) related to the same physical phenomenon, namely activity of the galactic nuclei. It was not straightforward and obvious, as the data were very few and each seemed to have independent explanation. Moreover, blue-UV emission of some nearby galaxies obviously came from their spiral arms and was explained by a large number of hot stars. Thus, a **hypothesis on the activity of galactic nuclei** was proclaimed by Ambarstumian (1955; 1956). The evolutionary significance of the activity in the galactic nuclei was emphasized and a further hypothesis was suggested on the ejection of new galaxies from the active galactic nuclei. The hypothesis on the superdense protostellar matter was engaged to explain the observational data. According to Ambarstumian, forms of activity could be rather different: emission of gas from the central part of the galaxy having velocities up to several hundreds of km/sec, emission of fluxes of relativistic particles originating high-energy particles (forming radio halos around the nuclei), eruptive outbursts of gas matter, eruptive outbursts of relativistic

plasma, outbursts of blue concentrations having absolute luminosities typical of dwarf galaxies, etc.

A comparative analysis of all these observational data shows that independent on their apparent differences, all these phenomena have a common physical nature. Ambartsumian came to such conclusion at the very beginning of investigations, however, during many years (1960s-1980s), all types of revealed AGN were regarded as different kinds of objects, probably with different mechanisms of radiation. Moreover, all historical classifications (Seyfert 1 and 2, radio galaxy, QSO, LINER, BL Lac objects, etc.) supported an idea to explain them separately and then (if possible) try to find similarities or links between these classes.

The theoretical study of the numerous observational evidences of various sorts of physical instability in galaxies led Ambartsumian to a fundamental conclusion that in processes of origin and evolution of galaxies, the role of the central small in their sizes condensations, the nuclei of galaxies, is huge. He justified an essentially new understanding that all observational evidences of the instability of galaxies are a consequence of activity of the galactic nuclei. Further on he established that to various degrees of activity of nuclei of galaxies correspond various manifestations by the form and power in structure and radiation of galaxies.

In 1985, Antonucci and Miller published a paper *"Spectropolarimetry and the nature of NGC 1068"* (a classical Seyfert 2 type showing only narrow emission lines) (Antonucci & Miller 1985). The polarized flux plot revealed the presence of very highly polarized, very broad symmetric Balmer lines and also permitted Fe II closely resembling the flux spectra of Seyfert type I nuclei. This line emission indicated that both polarizations were due to scattering, probably by free electrons which must be cooler than a million K. A model was suggested in which the continuum source and broad line clouds were located inside a thick disk, with electrons above and below the disk scattering continuum and broad-line photons into the line of sight. All of the narrow lines, including the narrow Balmer lines, had similar low polarizations, unrelated to that of the continuum. Further studies strengthened such a geometrical understanding of the difference between the AGN, so that each type (the classification) depended on the observed angle (**Fig. 1**).

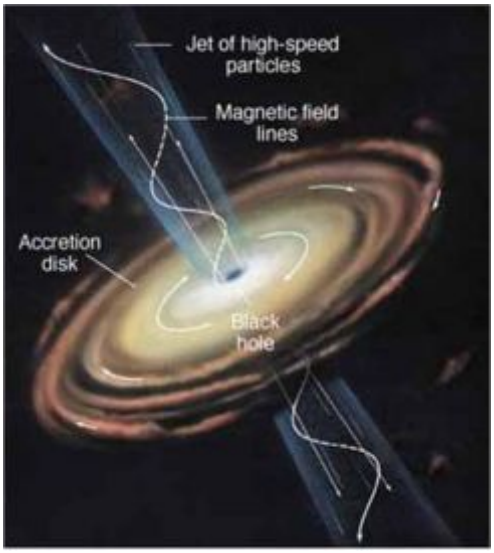

Fig. 1. Explanation of the AGN phenomenon according to the unified scheme.

Seyfert 1s are normal spiral or E galaxies with a compact, starlike nucleus and a nuclear emission line spectrum characterized by broad (a few thousands km s^{-1}) permitted lines and narrow (a few hundreds km s^{-1}) high excitation lines. Seyfert 2s have a narrow emission line spectrum like the Seyfert 1s, but they are lacking both the compact nucleus and the broad emission lines. Quasars (or QSOs) are high luminosity Seyfert 1 nuclei ($M_B < -24$); their luminosity is so high that the host galaxy is difficult to detect. Seyferts and QSOs contain a compact nuclear continuum source ionizing a broad line region, surrounded by an optically thick torus of dust. Depending on the orientation of this torus with respect to the line of sight, the central object is seen or hidden; when it is hidden, we see only the narrow, extended emission line region; the galaxy is a Seyfert 2. As mentioned, the major breakthrough in understanding the connection between Seyfert 1s and 2s was the discovery by Antonucci & Miller (1985) of a "hidden" broad line region (BLR) in the Seyfert 2 NGC 1068.

Many spiral galaxies contain a starburst in their central region. Spectra of narrow line Seyferts and starbursts are easily distinguished by their main emission line ratios. But diagnostic diagrams built with these emission line ratios reveal a third type of emission line spectra called LINER (Low Ionization Nuclear Emission line Region). Some of these objects are most probably low luminosity AGNs; others must be related to the cooling flow phenomenon occuring in clusters of galaxies or are produced in the collision and merging of gas rich galaxies.

Seyferts and QSOs can be radio loud or radio quiet. Radio loud objects are always hosted by an E galaxy. Most radio galaxies have a double lobe structure; the high radio

luminosity sources have edge-brightened lobes; they are called FR II radio sources (for Fanaroff-Riley type II). The low luminosity sources are called FR Is. FR II radio galaxies have the nuclear emission line spectrum of Seyferts; when they have broad emission lines they are called Broad Line Radio Galaxies (BLRGs); when they have the emission line spectrum of a Seyfert 2, they are called Narrow Line Radio Galaxies (NLRGs). All radio quasars have FR II morphology. FR Is have a weak low excitation emission line spectrum, similar to LINERs or no detectable emission at all.

The lobes of radio galaxies (FR Is and FR IIs) are powered by a relativistic jet; when the angle between the jet axis and the line of sight is small, the jet is Doppler boosted by a large factor and the whole spectrum (from radio to γ-ray) is dominated by a compact, highly polarized, highly variable, superluminal, almost featureless continuum. These objects are called blazars; they are divided into two subclasses: the Highly Polarized Quasars (HPQs) which show broad emission lines, and the BL Lacertae objects (BLLs) with no or weak broad emission lines. The parent population of the HPQs is made of the FR IIs, while the parent population of the BLLs is made of the FR Is. **Fig. 2** is a schematic diagram of an FR II galaxy showing how the appearance changes with the viewing angle.

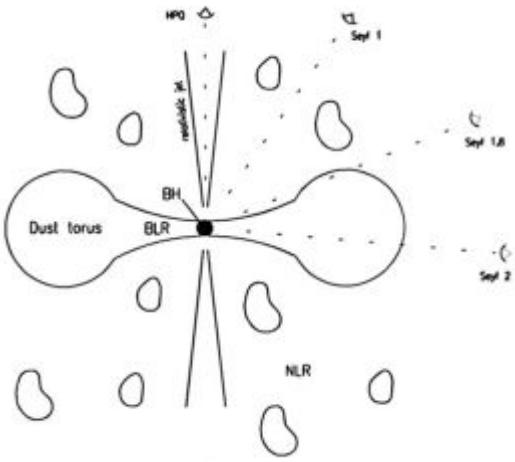

Fig. 2. Schematic diagram of FR II active nuclei showing how the appearance can change from NLRG (Seyfert 2) to BLRG (Seyfert 1) to HPQ with changing viewing angle.

This is, very schematically, the generally accepted Unified Scheme of AGNs. Thus, all kinds of AGN now are put in the same scheme and are regarded as a common phenomenon; an approach developed by Ambarstumian since the middle of 1950s!

5. Central source of energy and its activity: a supermassive dense matter or a supermassive accreting black hole?

As mentioned, Ambarstumian considered the existence of a supermassive dense matter in the center of stars and galaxies that was responsible for their activity and evolution (Ambartsumian 1954; 1958b). However, there in fact was no any developed model to describe this hypothesis, beside some attempts to build superdense stellar configurations (Ambartsumian & Sahakian 1960; 1961a; 1961b). Observational evidences, particularly the huge amounts of energy emitted from the central parts of galaxies, insist on existence of a powerful source and until now this puzzle is not yet finally solved. There are in fact two opposite understanding on the phenomena of star formation, cosmogony in general, and activity of the galactic nuclei; classic approach and Ambartsumian (or Byurakan) one. It is important to anyway understand, how much these two "opposite" approaches contradict each other and how much they are related.

At present, the most popular explanation for the AGN powerhouse involves accretion of gas onto a SuperMassive, perhaps spinning Black Hole (SMBH). Different regimes of accretion have been invoked to constitute the basis of a unified picture of AGNs. The predictions of the theory are that rotationally supported thin disks would form at lower accretion rates ($M<M_{Edd}$), while supercritical ($M>M_{Edd}$) accretion flows are expected to form thick disks supported by radiation pressure. A very subcritical flow may not be able to cool and, instead of forming a thin disk, it puffs up giving rise to an ion torus supported by gas, rather than radiation, pressure (Abramowicz et al. 1987; Narayan et al. 1999). The formation of the torus is crucial to support the unified model of AGN. Further studies strengthened such an understanding of the AGN energy sources. However, there still are many difficulties and the discovery of new objects with new properties encounter challenges in their explanation in frame of the general scheme.

It is believed that most gE galaxies possess a nuclear BH with a mass in excess of 10^8 M_o. Bondi accretion from the interstellar medium might then be expected to produce quasar-like luminosities from the nuclei of most gE galaxies. It is a puzzle that such luminosities are not observed (Fabian & Canizares 1995). Motivated by this problem, Fabian & Rees (1995) have suggested that the final stages of accretion in these objects occur in an Advection Dominated Accretion Flow (ADAF) with a small radiative efficiency. ADAFs occur when the local cooling time-scale becomes longer than the accretion time-scale so that most of the dissipatively liberated energy is advected inward with the accreting gas and lost into the BH. The viscous heating is assumed to affect mainly the ions, while the radiation is produced primarily by the electrons; as the ions transfer only a small fraction of their energy to the electrons via Coulomb collisions, the radiative efficiency of an ADAF is much less than the total energy released during accretion. The result is that the ion temperature becomes almost virial ($T\sim10^{12}K$) which causes the flow to have a nearly spherical morphology; the electron temperature is determined by a balance between heating due to collisions with the ions

and inverse Compton cooling and reaches $T_e \sim 10^9$-$10^{9.5}$K. This happens for accretion rates below $M_{crit} \sim \alpha^2 M_{Edd}$, where α is the viscosity parameter and M_{Edd} is the accretion rate corresponding to the Eddington limit. If $\alpha = 0.1$ then advection can dominate the flow if the accretion proceeds at less than 1% of the Eddington rate. For such low accretion rates, the expected luminosity scales as M^2 rather than M and the luminosity of the system falls well below the luminosity which is normally expected from accretion (Narayan et al. 1999; Mahadevan 1999). It is often assumed that there is, in these objects, an outer region extending outward from about 3 000 Schwarzschild radii where the accretion flow is in the form of a standard geometrically thin disk (Narayan et al. 1999).

The entire spectrum of an ADAF is completely determined by the mass of the BH and by the value of the transition radius out of which the disk is thin; it is very characteristic: a $\nu^{1/3}$ slope in the radio regime, a submillimeter-to-X-ray Compton spectrum, and a hard-X-ray-to-γ-ray Bremsstrahlung spectrum (Mahadevan 1997).

The radio emission is due to cyclo-synchrotron radiation from hot electrons in the equipartition magnetic field; it should be isotropic. In the absence of a radio jet, the expected core radio luminosity is relatively low and roughly proportional to the mass of the central BH; the 5 GHz ADAF luminosity is L (= νL_ν) $< 10^{38}$ erg s^{-1} for $M_{BH} < 10^9$ M_o; however, some level of jet activity not directly associated with the ADAF seems to be present in most sources and the observed radio emission can be considerably larger (Fabian & Rees 1995; Yi & Boughn 1999). Di Matteo et al. (1999) have shown that the high frequency radio emission of the nucleus of the gE galaxies for which the mass of the central BH has been estimated is significantly lower than predicted by the ADAF model, suggesting not only that there is no radio jet in these objects but also that that the radio emission due to the ADAF is being suppressed.

Ambartsumian's theoretical consideration of observational data about the known forms of activity of the galactic nuclei gave serious bases to admit that activity of nuclei was caused not by stars and not by diffuse matter containing in them. They could not explain, at least, such observed forms of nuclear activity, which were connected with allocation of enormous amounts of energy and eruptions of unusually big masses of matter. Hence, it is necessary to consider that in corresponding nuclei there are bodies of at present unknown nature, which contain very big stocks of matter and have huge energy. In other words, it is necessary to consider, that in galactic nuclei physical conditions of matter are extremely unusual and strongly differ from the conditions observed in other parts of the Universe. In particular, in some bodies containing in nuclei of galaxies, the matter density should be extremely high. Only in this case the nuclei can provide the continuous outflow of matter or emissions and eruptions of the big masses from the nuclei, phenomena revealed by observations in some galaxies. These reasons also have formed a basis for working out of new important understanding

that the galactic nuclei are sources of huge amounts of matter and energy, which then give rise to formation around them galaxies or systems of galaxies and supply them with energy of the observed non-stationary motions. Ambartsumian showed that the results of studies of non-stationary systems of galaxies and various forms of display of nuclear activity of separate galaxies represent huge scientific interest not only for discovery of the laws of the origin of stars and stellar systems of various scales, but also for detection and research of while unknown states of matter, including the proto-stellar ones. And the results received by Ambartsumian in this area are in a full consent with understanding of the theory of stellar associations already mentioned earlier that matter development in the Galaxy has a certain orientation from denser states to less dense ones. One could believe that the search for such forms and states of matter in the central parts of galaxies led some astrophysicists to find the model of SMBH as such, though not completely explaining many aspects.

There are of course principle differences in the classical and Ambartsumian's approaches to the explanation of AGN energy sources. Ambartsumain believed that the source of energy was inner; it is emitted from the central engine and was directly connected to the nature of the central dense matter. The unified scheme and related accreting SMBH theory attributes the energy to the accretion on SMBH, which is in fact a physical process related to the environment of the central source. But there also are similarities between the classical and Ambartsumian's approaches. Ambartsumian's suggestion that there existed a supermassive dense body in the center of galaxies is now well accepted and SMBH could be one of the possible models of such matter. It is obvious that Ambartsumian's idea on the activity of galaxies based on the energy sources hidden in the central parts of galaxies (nuclei) is modified to fit known physical theories, which Ambartsumian himself didn't find unambiguous.

6. Accelerated Hubble expansion of the Universe. An unrecorded source for activity energy

It seems to be very interesting that Ambartsumian has especially emphasized the huge importance of different ways for types I and II populations' formation. The different space distribution of these two types – flat or disk shaped for the former and spherical or isotropic for the latter – gives a hint for understanding their formation scenarios. One can connect type II objects formation with the accelerated expansion of the Universe, provided that this extremely slow process takes place also for the scales of cosmic objects. It is obvious that the case of non-rotating spherical or ellipsoidal objects is easier for considering if compared with objects possessing of a considerable angular momentum. Let us first consider an object with a mass M and radius R with a spherical distribution of matter density in it, which does not rotate and therefore does not possess an angular momentum of any significance.

The potential energy of this object is given by the relation

$$U = -k_U G \frac{M^2}{R}, \qquad (1)$$

where the coefficient k_U depends on the density distribution and for practical cases is close to unity. If such an object expands, for instance, according to the Hubble law (Harutyunian 1995), then one can calculate the change of the potential energy due to expansion of the object. To be more precise one should call this process delayed expansion of the objects compared with the space or "space scale frozen in the matter". It does mean that owing to gravitational or other forces expansion is happening more hampered than in the free space. In any case, the work to be done to expand the abovementioned spherical object in the period Δt amounts to

$$U_{add} = k_U G \frac{\varepsilon \Delta t M^2}{R(1+\varepsilon \Delta t)}, \qquad (2)$$

where ε is the rate of expansion for the unit time and unit length amounting $\varepsilon = 7.65 \times 10^{-11}$ year^{-1} for Hubble's constant $H = 75$ km/sec per Mpc.

From (2) one can find that during the period Δt the object accumulates certain amount of energy which is sufficient for providing an escape velocity for an object of a mass

$$\Delta M_{ej} = k_u \varepsilon \Delta t M \ . \qquad (3)$$

According the nowadays estimates the masses of clusters of galaxies amounts to $10^{14} \div 10^{15}$ solar mass. If this was the mass of the protocluster at the beginning of its formation one can find from the formula (3) that the amount of energy accumulated in 10^7 years would be enough for ejecting a bundle of matter amounting up to $10^{11} \div 10^{12}$ solar masses. It is the mass of our Galaxy which is considered to be a giant galaxy. This mechanism could provide energy supply for ejections of huge masses from galaxies which proposed to call Ambartsumian events by Burbidge (2004).

It is remarkable, that the expression (3) depends only on the time interval Δt and the initial mass *M*. It does mean that any initial "proto-object" (proto-cluster, proto-galaxy, etc), speaking in the language of statistics, would eject bundles of matter of higher mass at the beginning of the process. If this inference is applied to any protocluster one should arrive at a conclusion that the first galaxies formed owing to such ejection effects would be of higher masses if compared with latter ones.

From this viewpoint one might find interesting and very actual the studies of cD galaxies which have been found only in the centers of some regular clusters of galaxies and never in the field (Matthews et al. 1964; Morgan & Lesh 1965). Their physical properties are definitely specific and different from other giant elliptical and this difference makes them a subject of very intensive investigations and sources of building

various cosmogonic scenarios. These galaxies have elliptical “main body” surrounded by large low brightness and shallow stellar halo, more luminous ones having shallower brightness profiles. The *“main bodies” of cD galaxies have approximately the same luminosity irrespectively of the halo richness* although the luminosity of latter one correlates with the luminosity of the hosting cluster.

It has been shown (Schneider et al. 1983; Hoessel & Schneider 1985) that about half of the brightest cluster member galaxies (BCMs - mainly cD galaxies) in a large sample of Abell clusters are multiple-nucleus systems, considerably more than would be expected from chance projections if the clusters have cores. Moreover, it appeared that many of the secondary nuclei move too quickly to be gravitationally bound to the galaxy core (Tonry 1984; 1985; Hoessel et al. 1985). These observational evidences have a high significance from the viewpoint of Ambartsumian’s events and should be considered very carefully.

The well established correlation between envelope luminosities and parent cluster luminosities (Oemler 1976; Schombert 1988) suggests that similar (or the same) processes might be responsible for both. Such a correlation might be obvious if the cluster galaxies had been formed as a result of matter ejection from the maternal protocluster which have accumulated tidal debris of the ejected matter resulted owing to tidal interactions between maternal object and escaping matter bundles. More objects had been ejected more debris are accumulated in the stellar envelope of the maternal object.

The remarkably narrow specter of luminosities of the “main bodies” of cD galaxies which makes them practical candidates of “space candles” (see, for example, Sandage 1976; Sandage et al. 1976) brings up more new issues for discussion. First of all it remains unexplained how could happen that in completely different physical conditions where the density of galaxies varies more than a factor of twenty the “main bodies” have similar luminosities. Formula (3) and the general paradigm of Ambartsumian’s approach make this issue more transparent. The larger maternal objects eject more matter bundles forming a bigger envelope and a richer cluster during the period of their lifetime than smaller ones. Moreover, both the bigger and smaller maternal bodies inevitably will tend to the same limit which we observe as “main bodies” of the cD galaxies.

We would like to pay attention to one more observational fact that BCGs (Brightest Cluster Galaxies, a considerable part of which are cD galaxies) follow a different relation between luminosity and velocity dispersion than less massive elliptical galaxies, namely, the velocity dispersion increases less steeply with luminosity than predicted by the standard Faber-Jackson relation (Oegerle & Hoessel 1991; Lauer et al. 2006; von der Linden et al. 2007). One might explain this breach of the Faber-Jackson relation if takes into account that not the real velocity dispersion of these galaxies is involved for

deriving the mentioned relation. Actually one should consider the velocity dispersion of the cluster instead of the one central galaxy if we accept that all the galaxies are the daughter objects of the central one.

7. Concluding Remarks

The idea on the activity of galactic nuclei was based on previous results, on the more general concept of high importance of physical activity for evolution of cosmic objects belonging to all the hierarchical levels of the Universe. In mid 50s of the last century he was using only the observational facts available for that time. Nevertheless, he managed to describe all the forms of activity studied and classified during fifty years after his pioneering researches. This was a result of his striking analytical skills and physical intuition which have been manifested many times during his scientific career. It might be easily checked comparing the observational evidences of activity listed by Ambartsumian in his first papers with observational manifestations enumerated for the *modern Unified Scheme*.

On the other hand, Ambartsumian's paradigm differs from predominant models created for interpretation of activity of galactic nuclei. The main difference in the first place consists in the energy sources. It is not secret that all the models and scenarios describing an activity engine providing the necessary amounts of energy involve its primary release during big bang. No energy of other origin can be pointed out in the theories based on the big bang hypothesis. That is why all the galactic nuclei are accepted a priori to present black holes of various masses surrounded with an accretion disk which transforms certain part of disk's potential energy gained owing to primary explosion into kinetic energy and radiation.

In Ambartsumian's understanding of activity sources of energy were located in the objects exhibiting energy release but no any external physical mechanisms were involved for energy production. Actually such a difference has very profound physical consequences. And the most important one is the continuity of energy production according to Ambartsumian's approach. In the conventional cosmologies resulted from the big bang hypothesis there was single act of energy (matter, space, time) production and after that one may find only acts of energy transformation but no its production. In contrary, Ambartsumias approach requests energy sources which provide the necessary amounts of additional energy inherent for any active phenomenon and process.

In mid 50s and up to the end of last century no any renewable energy sources were known to be mentioned for this end. However, the accelerated Hubble expansion observed for all the length scales papered to be very appropriate mechanism for such a purpose. Evidently, the "physical vacuum" expands much easier in the absence of any obstacle attractive forces. Physical objects are consisted of baryonic matter and gravitational forces hamper the expansion process. Therefore physical situation arise when the *spatial scale is frozen in the matter* and the expansion is delayed within the object. More massive is the object, more is the delay in its evolution. External changes in the spatial scale accumulate potential energy within

the object which depends on the mass of the object and the time period of accumulation (see the relation (3)). This way seems to be very perspective for interpretation of energetic phenomena connected with activity processes in the objects belonging to various hierarchical levels and needs further investigations.

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Magnetic Fields and Outflows from AGN Disks

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Abstract

Activity of the nuclei of galaxies involving disk accretion to black holes is thought to be due to (1) a small-scale turbulent magnetic field in the disk (due to the magneto-rotational instability or MRI) which gives a large viscosity enhancing accretion, and (2) a large-scale magnetic field which gives rise to matter outflows and/or electromagnetic jets from the disk which also enhances accretion. An important problem with this picture is that the enhanced viscosity is accompanied by an enhanced magnetic diffusivity which acts to prevent the build up of a significant large-scale field. Recent work has pointed out that the disk's surface layers are non-turbulent and thus highly conducting (or non-diffusive) because the MRI is suppressed high in the disk where the magnetic and radiation pressures are larger than the thermal pressure. Here, we calculate the vertical (z) profiles of the stationary accretion flows (with radial and azimuthal components), and the profiles of the large-scale, magnetic field taking into account the turbulent viscosity and diffusivity due to the MRI and the fact that the turbulence vanishes at the surface of the disk. We derive a sixth-order differential equation for the radial flow velocity $v_r(z)$ which depends mainly on the midplane thermal to magnetic pressure ratio $\beta > 1$ and the Prandtl number of the turbulence P = viscosity/diffusivity. Boundary conditions at the disk surface take into account a possible magnetic wind or jet and allow for a surface current in the highly conducting surface layer. The stationary solutions we find indicate that a weak ($\beta > 1$) large-scale field does not di use away as suggested by earlier work.

1. Introduction

Professor Viktor A. Ambartsumian recognized already in the 1950's, well before most other scientists, the importance of the activity in galactic nuclei, the high energies involved, and the ejections on enormous scales (cf. Ambartsumian 1980). Now it is commonly thought that the activity is in many cases due to accretion to a massive black hole. Activity may also come from star burst events. The present contribution has to do with the formation of winds and jets owing to small and large scale magnetic field.

Early work on disk accretion to a black hole argued that a large-scale poloidal magnetic field originating from say the interstellar medium, would be dragged inward and greatly compressed near the black hole by the accreting plasma (Bisnovatyi-Kogan & Ruzmaikin 1974, 1976; see Figure 1) and that this would be important for the formation of jets (Lovelace 1976). Later, the importance of a weak small-scale magnetic field within the disk was recognized as the source of the turbulent viscosity of disk owing to the magneto-rotational instability (MRI; Balbus & Hawley 1991). Analysis of the di usion and advection of a large-scale field in a disk with a turbulent viscosity comparable to the turbulent magnetic di usivity (as suggested by MRI simulations) indicated that a weak large-scale field would di use outward rapidly (van Ballego oijen 1989; Lubow, Papaloizou, & Pringle 1994; Lovelace, Romanova, & Newman 1994, 1997). This has led to the suggestion that special conditions (nonaxisymmetry) are required for the field to be advected inward (Spruit & Uzdensky 2005). Recently, Bisnovatyi-Kogan and Lovelace (2007) pointed out that the disk's surface layers are highly conducting (or non-di usive) because the MRI is suppressed in this region where the magnetic energy-density is larger than the thermal energy-density. Rothstein and Lovelace (2008) analyzed this problem in further detail and discussed the connections with global and shearing box magnetohydrodynamic (MHD) simulations of the MRI.

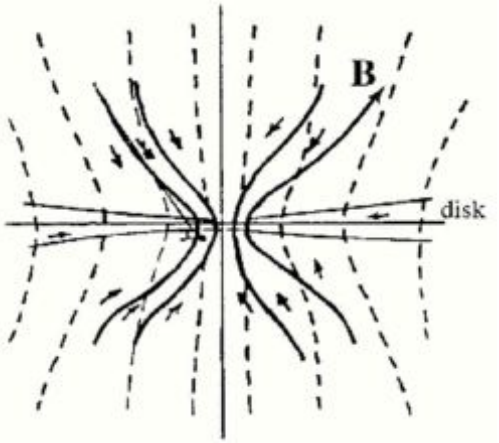

Fig. 1. Sketch of the poloidal magnetic field threading an accretion disk (from Bisnovatyi-Kogan & Ruzmaikin 1976). The field strength increases with decreasing radius owing to ux freezing in the conducting disk matter.

Here we calculate the profiles through the disk of stationary accretion ows (with radial and azimuthal components), and the profiles of a large-scale, weak magnetic field taking into account the turbulent viscosity and di usivity due to the MRI (in an -description) and the fact that the turbulence vanishes at the surface of the disk. A full explanation of this work will be given elsewhere (Lovelace, Rothstein, & Bisnovatyi-Kogan 2008). Related calculations of the disk structure were done earlier by Konigl (1989), Li (1995), Ogilvie and Livio (2001) but without taking into account the absence of turbulence at the disk's surface. Recent work calls into question the -description of the MRI turbulence in accretion disks and develops a closure model which fits shearing box simulation results (Pessah, Chan, & Psaltis 2008). Analysis of this more complicated mo del is deferred a future study.

2. Theory

We consider the non-ideal magnetohydrodynamics of a thin axisymmetric, viscous, resistive disk threaded by a large-scale dipole-symmetry magnetic field $\vec{B}$. We use a cylindrical $B(r,\phi,z)$ inertial coordinate system in which the time-averaged magnetic field is $\vec{B} = B_r\hat{r} + B_\phi\hat{\phi} + B_z\hat{z}$, and the time –averaged flow velocity is $\vec{v} = v_r\hat{r} + v_\phi\hat{\phi} + v_z\hat{z}$. The main equations are

$$\rho\frac{d\vec{v}}{dt} = -\nabla p + \rho\vec{g} + \frac{1}{c}\vec{J}\times\vec{B} + \vec{F}^{\nu}, \tag{1}$$

$$\frac{\partial\vec{B}}{\partial t} = \nabla\times(\vec{v}\times\vec{B}) - \nabla\times(\eta\nabla\times\vec{B}). \tag{2}$$

These equations are supplemented by the continuity equation, by $\nabla\times\vec{B} = 4\pi\vec{J}/c$, and by $\nabla\cdot\vec{B} = 0$. Here, is the magnetic diffusivity, $\vec{F}^{\nu} = -\nabla\cdot T^{\nu}$ is the viscous force with $T^{\nu}_{jk} = -\rho\nu(\partial v_j/\partial x_k + \partial v_k/\partial x_j - (2/3)\delta_{jk}\nabla\cdot\vec{v})$ (in Cartesian coordinates), and ν is the kinematic viscosity.

We assume that both the viscosity and the diffusivity are due to magneto-rotational (MRI) turbulence in the disk so that

$$\nu = P\eta = \alpha\frac{c_{s0}^2}{\Omega_K}g(z), \tag{3}$$

where P is the magnetic Prandtl number of the turbulence assumed a constant of order unity, $\alpha \le 1$ is the dimensionless Shakura-Sunyaev (1973) parameter, c_{s0} is the midplane isothermal sound speed, $\Omega_K \equiv \left(GM/r^3\right)^{1/2}$ is the Keplerian angular velocity of the disk, and *M* is the mass of the central object. The function $g(z)$ accounts for the

absence of turbulence in the surface layer of the disk (Bisnovatyi-Kogan & Lovelace 2007; Rothstein & Lovelace 2008). In the body of the disk $g = 1$, whereas at the surface of the disk, at say z_S , g tends over a short distance to a very small value $\sim 10^{-8}$, effectively zero, which is the ratio of the Spitzer diffusivity of the disk's surface layer to the turbulent diffusivity of the body of the disk.

We consider stationary solutions of equations (1) and (2) for a weak large-scale magnetic field. These can be greatly simplified for thin disks where the disk half-thickness, of the order of $h \equiv c_{s0} / \Omega_K$, is much less than r. Thus we have the small parameter $\varepsilon = h / r = c_{s0} / v_K << 1$. In the following we use the dimensionless height $\zeta \equiv z / h$. The three magnetic field components are assumed to be of comparable magnitude on the disk's surface, but $B_r = 0 = B_\phi$ on the midplane. On the other hand the axial magnetic field changes by only a small amount going from the midplane to the surface, $\Delta B_z \sim \varepsilon B_r << B_z$ (from $\nabla \cdot \vec{B} = 0$) so that $B_z \approx const$ inside the disk. As a consequence, the $\partial B_j / \partial r$ terms in the magnetic force in equation (1) can all be dropped in favor of the $\partial B_j / \partial z$ terms (with $j = r, \phi$). The velocity components are assumed to satisfy $v_z^2 << c_{s0}^2$ and $v_r^2 << v_\phi^2$. Consequently, $v_\phi(r,z)$ is close in value to the Keplerian value $v_K(r) \equiv (GM/r)^{1/2}$. Thus, $\partial v_\phi / \partial r = -(1/2)(v_\phi / r)$ to a good approximation.

With these assumptions, the radial component of equation (1) gives

$$\frac{\partial b_r}{\partial \zeta} = \frac{\beta \tilde{\rho}}{\varepsilon}\left(1 - k_p \varepsilon^2 - u_\phi^2\right) + \alpha^2 \beta \frac{\partial}{\partial \zeta}\left(\tilde{\rho} g \frac{\partial u_r}{\partial \zeta}\right), \qquad (4)$$

where $\tilde{\rho} \equiv \rho(r,z) / \rho_0$ with $\rho_0 \equiv \rho(r, z = 0)$. The midplane plasma beta is $\beta \equiv 4\pi \rho_0 c_{s0}^2 / B_0^2$, where $k_p \equiv -\partial \ln p / \partial \ln r$ is assumed of order unity and $p = \rho c_s^2$. Note that $\beta = c_{s0}^2 / v_{A0}^2$, where $v_{A0} = B_0 / (4\pi\rho_0)^{1/2}$ is the midplane Alfven velocity. The rough condition for MRI instability and the asso ciated turbulence in the disk is $\beta > 1$ (Balbus & Hawley 1991). In the following we assume $\beta > 1$, which we refer to as a weak magnetic field. We normalize the field components by $B_0 \equiv B_z(r, z = 0)$, with $b_r = B_r / B_0$, $b_\phi = B_\phi / B_0$, and $b_z = B_z / B_0 \approx 1$. Also, $u_\phi \equiv v_\phi(r,z) / v_K(r)$ and the accretion speed $u_r \equiv -v_r / (\alpha C_{s0})$. For the

assumed dipole field symmetry, b_r and b_ϕ are odd functions of ζ whereas u_r and u_ϕ are even functions.

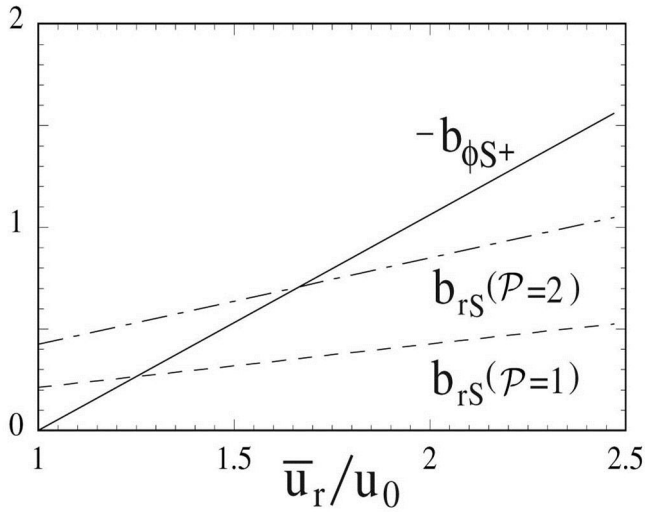

Fig. 2. Radial and toroidal field components (normalized to B_z) at the disk's surface as a function of the average accretion speed $\overline{u}_r$ (normalized by the viscous accretion speed u_0). For this plot $\beta = 100$ and Prandtl numbers P = 1 and 2. Note that $b_{\phi S+}$ is given by equation (5) and is independent of P and b_{rS} is given by equation (6).

In a similar way one can derive an equation for $\partial b_\phi / \partial \zeta$ b from the toroidal component of Eq. 1. The z-component of Eq. 1 corresponds to hydrostatic equilibrium for $\beta > 1$. Equations for $\partial u_\phi / \partial \zeta$ and $\partial b_r / \partial \zeta$ follow from Eq. 2.

Integration of the $\partial b_\phi / \partial \zeta$ equation from $\zeta = 0$ (where $b_\phi = 0$ and $\partial u_\phi / \partial \zeta = 0$) to the exterior of the disk (ζ_{S+} where $g = 0$) gives the average accretion speed,

$$u_r = u_0 - \frac{2b_{\phi S+}}{\alpha\beta\tilde{\Sigma}}, \qquad (5)$$

which is the sum of a viscous contribution, $u_0 \equiv 3\varepsilon k_\nu$ (with $k_\nu \equiv \partial \ln(\rho c_S^2 r^2 / h) / \partial \ln(r) > 0$ of order unity), and a magnetic contribution ($\propto b_{\phi S+}$) due to the loss of angular momentum from the surface of the disk where

necessarily $b_{\phi S+} \leq 0$ (Lovelace, Romanova, & Newman 1994). Here $\bar{u}_r \equiv \int_0^{\zeta_s} d\zeta \tilde{\rho} u_r / \tilde{\Sigma}$, $\tilde{\Sigma} \equiv \int_0^{\zeta_s} d\zeta \tilde{\rho}$, and the $S+$ subscript indicates evaluation outside the disk. A similar integration of the $\partial b_r / \partial \zeta$ equation implies that

$$b_{rS} = P \zeta_S \langle u_r \rangle, \tag{6}$$

where $\langle .. \rangle = \int d\zeta (..) / \zeta_S$.

The equations for u_r, u_ϕ, b_r and b_ϕ can be combined to give a single equation for $u_r(\zeta)$,

$$\begin{aligned}
&\alpha^4 \beta^2 \frac{\partial^2}{\partial \zeta^2}\left(g \frac{\partial}{\partial \zeta}\left(\tilde{\rho} g \frac{\partial}{\partial \zeta}\left(\frac{1}{\tilde{\rho}} \frac{\partial}{\partial \zeta}\left(\tilde{\rho} g \frac{\partial u_r}{\partial \zeta} \right)\right)\right)\right) \\
&\quad - \alpha^2 \beta P \frac{\partial^2}{\partial \zeta^2}\left(g \frac{\partial}{\partial \zeta}\left(\tilde{\rho} g \frac{\partial}{\partial \zeta}\left(\frac{u_r}{\tilde{\rho} g} \right)\right)\right) \\
&\quad - \alpha^2 \beta P \frac{\partial^2}{\partial \zeta^2}\left(\frac{1}{\tilde{\rho}} \frac{\partial}{\partial \zeta}\left(\tilde{\rho} g \frac{\partial u_r}{\partial \zeta} \right)\right) \\
&+ \alpha^2 \beta^2 \frac{\partial^2}{\partial \zeta^2}\left(\tilde{\rho} g (u_r - g u_0 \right) + P^2 \frac{\partial^2}{\partial \zeta^2}\left(\frac{u_r}{\tilde{\rho} g} \right) + 3 \beta P^2 \frac{u_r}{g} = 0
\end{aligned} \tag{7}$$

This equation is integrated from $\zeta = 0$ out to the surface of the disk ζ_S where the boundary conditions apply. Because u_r is an even function of ζ, only $u_r(0)$, $u_r''(0)$, and $u_r^{iv}(0)$ need to be adjusted in order to satisfy the boundary conditions at the disk surface (Lovelace et al. 2008).

Note that the value of $b_{\phi S+} \leq 0$ 0 is not fixed by the solution for the field/flow inside the disk. Its value can be determined by matching the calculated surface fields b_{rS} and $b_{\phi S+}$ onto an external magnetic wind or jet solution. Stability of the wind or jet solution to current driven kinking is predicted to limit the ratio of the toroidal to axial magnetic field components at the disk's surface $\left| b_{\phi S+} \right|$ to values $\leq \mathrm{O}(2\pi r / L_z)$ (Hsu & Bellan

2002; Nakamura, Li, & Li 2007), where L_z is the length-scale of field divergence of the wind or jet at the disk surface. From known wind and jet solutions we estimate $2\pi r / L_z \approx \pi$ (Lovelace, Berk, & Contopoulos 1991; Ustyugova et al. 1999; Ustyugova et al. 2000; Lovelace et al. 2002).

The quantity $\bar{u}_r / u_0 - 1 = 2\left|b_{\phi S+}\right| / (\alpha\beta\tilde{\Sigma}u_0)$ is the faction of the accretion power going into the jets or winds (Lovelace et al. 1994). For the mentioned upper limit on $\left|b_{\phi S+}\right|$, we find $\bar{u}_r / u_0 - 1 \leq \mathrm{O}/\left[2\pi / (\alpha\beta\tilde{\Sigma}u_0)\right]$. From equation (6) we have $b_{rS} = (P\zeta_S u_0)(\langle u_r \rangle / u_0)$. Therefore, for $\beta >> 1$ and $\langle u_r \rangle \approx u_0$, we have $b_{rS} \approx P\zeta_S u_0$.

The matching of internal and external field/ flow solutions has been carried out by Königle (1989) and Li (1995) for the case of self-similar $\left[B_z(r,0) \sim r^{-5/4}\right]$ magnetocentrifugally outflows from the disk's surface. These out ows occur under conditions where the poloidal field lines at the disk's surface are tipped relative to the rotation axis by more than 30° which corresponds to $b_{rS} > 3^{-1/2} \approx 0.577$ (Blandford & Payne 1982). The outflows typically carry a significant mass flux. For the internal field/flow solutions discussed in §4 with $\beta >> 1$, we conclude that b_{rS} is sufficiently large for magnetocentrifugal outflows only for turbulent magnetic Prandtl numbers, $P > 2.7$. Shu and collaborators (e.g., Cai et al. 2008, and references therein) have developed detailed 'X-wind' models which depend on the disk having Prandtl numbers larger than unity.

For Prandtl numbers say $P \leq 2.7$, the values of b_{rS} are too small for there to be a magnetocentrifugal outflow. In this case there is an outflow of electromagnetic energy and angular momentum from the disk (with little mass outflow) in the form of a magnetically dominated or 'Poynting flux jet' (Lovelace, Wang, & Sulkanen 1987; Lovelace, et al. 2002) also referred to as a 'magnetic tower jet' (Lynden-Bell 1996, 2003). MHD simulations have established the occurrence of Poynting- flux jets under different conditions (Ustyugova et al. 2000, 2006; Kato, Kudoh, & Shibata 2002; Kato 2007). Laboratory experiments have allowed the generation of magnetically dominated jets (Hsu & Bellan 2002; Lebedev et al.2005).

Figure 2 shows the dependences of the surface field components on the accretions speed for $\alpha = 0.1$ and $\beta = 100$.

Figures 3 and 4 show a sample solution of Eq. 7 for $\varepsilon = 0.05$, $\alpha = 0.1$, $\beta = 100$, and $P = 1$ where we find $\bar{u}_r / u_0 = 1.30$, $b_{\phi S+} = 0.321$, and $b_{rS} = 0.276$. For this solution both the density $\rho(\zeta)$ and $g(\zeta)$ are take to be step functions going to zero at $\zeta_m = \sqrt{2}$ (see Lovelace et al. 2008). Note that the solution has a 'channel' structure with the midplane region of the disk fowing radially outward and the regions closer to the disk's surfaces fowing radially inward.

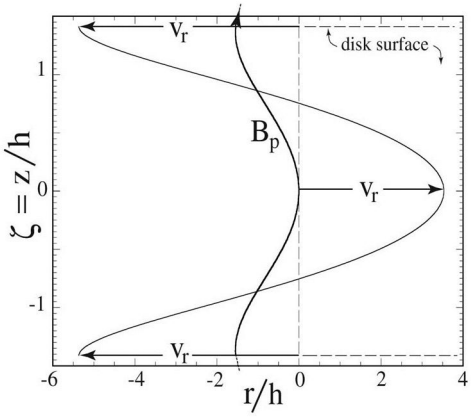

Fig. 3. Radial flow speed $v_r = -u_r$ (normalized to αc_{s0}) as a function of $\zeta = z/h$ and a sample poloidal (B_r, B_z) magnetic field line for $\beta = 10^{-2}$ and $P = 1$.

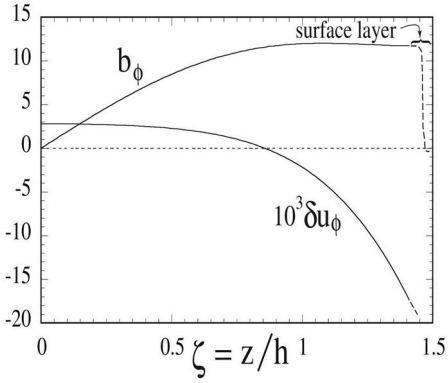

Fig. 4. Toroidal magnetic field $b_\phi = B_\phi / B_z$ and toroidal velocity $\delta u_\phi = (v_\phi - v_K)/v_K$ (with v_K the Keplerian velocity) for the case where $\beta = 100$ and $P = 1$. The jump in the toroidal magnetic field at the disk's surface is shown by the dashed line.

3. Conclusions

A study is made of stationary axisymmetric accretion flows $\left[v_r(z), v_\phi(z), v_z \approx 0\right]$ and the large-scale, weak magnetic field $\left[B_r(z), B_\phi(z), B_z \approx const\right]$ taking into account the turbulent viscosity and diffusivity due to the MRI and the fact that the turbulence vanishes at the surface of the disk as discussed by Bisnovayi-Kogan & Lovelace (2007) and Rothestein & Lovelace (2008). We derive a sixth-order differential equation for the radial flow velocity $v_r(z)$ which depends mainly on the ratio of the midplane thermal to magnetic pressures $\beta > 1$ > 1 and the Prandtl number of the turbulence $P =$ viscosity/diffusivity. Boundary conditions at the disk's surfaces take into account the outflow of angular momentum to magnetic winds or jets and allow for a surface current flow in the highly conducting surface layers. In general we find that there is a radial surface current but no toroidal surface current. Stability of the winds or jets will limit the ratio of the toroidal to axial field at the disk's surface $\left|b_{\phi S+}\right|$ to values $\leq \pi$. The stationary solutions we find indicate that a weak ($\beta >> 1$), large-scale field does not diffuse away as suggested by earlier work (e.g., Lubow et al. 1994) which assumed $b_{rS} \geq 3^{-1/2}$.

The flow/field solutions found here in a viscous/diffusive disk and are different from the exponentially growing channel flow solutions found by Goodman and Xu (1994) for an MRI in an ideal MHD unstable shearing box. Channel solutions in viscous/diffusive disks were found earlier by Ogilvie & Livio (2001) and by Salmeron, Königl, & Wardle (2007) for conditions different from those considered here. In general we find that the magnitude of the toroidal magnetic field component inside the disk is much larger than the other field components. The fact that the viscous accretion speed is very small, $\sim \alpha\varepsilon c_{s0}$, means that even a small large-scale field can significantly influence the accretion flow. We find that Prandtl numbers larger than a critical value estimated to be 2.7 are needed in order for there to be magnetocentrifugal outflows from the disk's surface. For smaller P , electromagnetic outflows are predicted. Owing to the stability condition, $\left|b_{\phi S+}\right| \leq \pi$, the fraction of the accretion power going into magnetic outflows or jets is $\leq \text{const}\,\beta^{-1} \sim B_z^2$.

Analysis of the time-dependent accretion of the large-scale B field is clearly needed to study the amplification of the field and build up of magnetic flux in the inner region of the disk. One method is to use global 3D MHD simulations (Igumenshchev et al. 2003; Hirose et al. 2004; De Villiers et al. 2005; Hawley & Krolik 2006; McKinney & Narayan 2007; Igumenshchev 2008), but this has the difficulty of resolving the very thin highly conducting surface layers of the disk. Another method is to generalize the approach of Lovelace et al. (1994) taking into account the results of the present work.

This is possible because the radial accretion time ($r/|\bar{u}_r|$) is typically much longer than the viscous diffusion time across the disk (h^2/ν).

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The Lyman Alpha Universe

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Abstract: I intend to review the basic physics and processes that drive the visibility of the Lyα line since it is presumably the most powerful tool for exploring the far reaches of the Universe. Local galaxies investigations from space instruments are reviewed and lessons from these studies help to understand the high redshift galaxies.

1. Introduction

Victor Ambartsumian ideas that energetic phenomena were conspicuous signatures of formation and galaxy evolution mechanisms led him to open new windows in observational astronomy. Due to his wide view and constant support, his collaborators – as for instance B. Markarian and M. Kazarian – explored the very near UV (in fact the "blue" as reached from ground based telescopes). UV is indeed a wonderful opportunity in the electromagnetic window allowing to trace back exotic physical phenomena where bursts of star formation have conspicuous signatures.

Indeed, all galaxies with ongoing massive star formation (somewhat loosely called "starbursts" hereafter) and emitting intense UV radiation produce an ionising flux (i.e. energy at > 13.6 eV) and will thus "intrinsically" emit a copious number of Lyα photons at their source.

Reprocessing around 1/3 of the ionizing energy of the most massive stars, the Lyman-alpha emission line (Lyα) enables the detection of evolving galaxies from the far reaches of the observable universe. Already in the sixties it was recognised that Lyα could be important for searches of primeval galaxies (e.g. Partridge & Peebles 1967). Even more, at (very) low metallicities the Lyα line is expected to be strong if not dominant for several reasons: an increasing ionising flux from stellar populations, thus Lyα can become the dominant cooling line when few metals are present and an

increased emissivity due to collisional excitation in a nebula with higher temperature. As a result, up to ~ 10% of the bolometric luminosity may be emitted in Lyα, rendering the line potentially detectable out to the highest redshifts.

In any case, it is interesting to note that most of the observational features predicted nowadays for "Pop III galaxies" were anticipated by early calculations, such as Partridge & Peebles' (1967), including of course the now famous Lyman-break galaxies (hereafter LBGs).

Therefore and thanks to its high restframe equivalent width (see Schaerer 2004) and convenient rest wavelength in the ultraviolet (121.6nm) Lyα is accessible to optical ground-based facilities in the redshift range $2 \leq z \leq 7$. This prospect triggered various searches for distant Lyα emitters, which remained, however, basically unsuccessful until the 1990s, for reasons discussed below.

Later on, exploitation of Lyα as a method of galaxy selection has allowed large samples of high-z galaxies to be assembled (e.g. Gronwall et al. 2007; Ouchi et al. 2008), and the discovery of candidate galaxies at extreme redshifts (e.g. Stark et al. 2007). In principle Lyα can also be used to probe the ionization fraction during the final stages of re-ionization (Malhotra & Rhoads 2004; Dijkstra et al. 2007), cosmic star-formation rates (Hu et al. 1998; Kudritzki et al. 2000; Ajiki et 2003), large scale structure (Venemans et al. 2002; Ouchi et al. 2005), and to identify potential host of population III star formation (Malhotra & Rhoads 2002; Nagao et al. 2007).

2. Local Starbursts

2-1. The IUE era

The early attempt to study Lyα emission from the International Ultraviolet Explorer (IUE) found that Ly emission was present in some metal-poor galaxy studied (Meier & Terlevich 1981). Subsequent studies of larger samples (Charlot & Fall 1993) confirm a weak correlation of Lyα and the metallicity of the gas; not an unpredicted result given that the dust content generally correlates with metallicity. However, corrections for dust were found not to reconcile the Lyα/Hβ line ratio with those expected from recombination theory (Giavalisco et al. 1996) and it became clear from these early studies that some other processes must be at work. Indeed, resonant scattering of Lyα in HI had long been studied theoretically (Osterbrock, 1962; Harrington 1974). The sub-recombination line ratios and low WLyα can be explained by multiple resonant scatterings locally trapping Lyα photons, redirecting them and causing them to traverse much greater integrated path lengths than non-resonant continuum or emission lines. Thus, even minute quantities of dust may result in significant or complete attenuation of Lyα (Neufeld 1990). This will remain the basic fact underlying most of the discussion throughout this paper.

2-2. HST results

2-2-1. Spectroscopy:

While from the absence of correlations between different measurements of extinction, Giavalisco et al. (1996) suggested that an inhomogeneous ISM geometry must be another determining factor; no quantification of this effect was presented or proposed. More detailed observations of local starbursts have since provided new important pieces of information we will now briefly summarise.

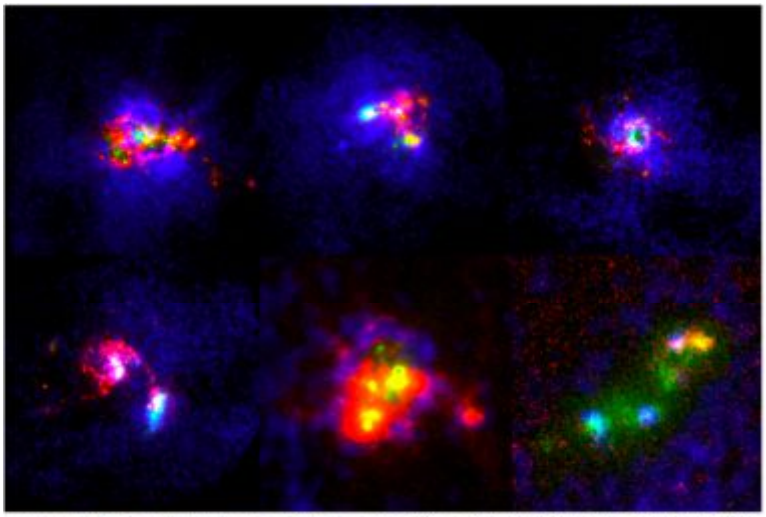
First the superior spectral and spatial resolution of ultraviolet (UV) spectrographs on the Hubble Space Telescope (HST) has allowed new insight into the formation process of Lyα.
Rapidly dust as a sole explanation was ruled out by the HST observations of I Zw 18 and SBS 0335-052, the most metal-poor starbursts known, which show NO Lyα emission, actually even a damped Lyα absorption profile (Kunth et al. 1994, Thuan & Izotov 1997). However, we now know (from ISO and Spitzer) that these objects contain also non-negligible amounts of dust (Thuan et al. 1999, Wu et al. 2007), although it is not clear if and how it is related to the line emitting regions, in particular spatially. On the other hand Lequeux et al. (1995) have found strong Lyα emission in a much more metal- and dust-rich starburst Haro 2.

Further HST Goddard High Resolution Spectrograph (GHRS) spectroscopy of eight gas-rich irregular galaxies by Kunth et al. (1998) indicated yet another, and most likely the dominant, parameter governing Lyα emission: neutral gas kinematics.

Indeed the presence of neutral gas outflows is clearly evidenced in 4 starbursts with Lyα in emission (P-Cygni profiles), whereas other starbursts with broad damped Lyα absorption do not show ANY velocity shifts between the ionised emitting gas and the neutral ISM traced by O I or Si II. The metallicities of these objects range from 12 + log(O/H) ~ 8.0 to solar, their extinction is $E_{B-V} \sim 0.1–0.55$. Further spectroscopic 2-D studies using the STIS onboard of the HST of Lyα and related properties in nearby starbursts have been carried out with integral field spectroscopy (optical) to analyse at high spatial resolution the distribution and properties of relevant parameters i.e. the young stellar populations, their UV slope (a measurement of the extinction), the ionised gas, and the resulting Lyα emission, absorption and the local line profile (e.g. Mas-Hesse et al. 2003). An “unifying” scenario to explain the observed diversity of Lyα profiles in terms of an evolutionary sequence of starburst driven super-shells/superwind has been presented by Tenorio-Tagle et al. (1999) and has been confronted with these local observations in a very qualitative way.

2-2-2. Imaging:

The resonant scattering phenomenon may cause Lyα photons to travel and to be emitted far from their production sites hence to be spatially uncorrelated with non-resonant radiation (Hα or continuum photons). UV-targeted spectroscopic studies may therefore miss a significant fraction of the Lyα emission if scattered away from the aperture. Ionised holes in the ISM may also allow the escape of Lyα photons in a spatially limited region, and transmissions may vary greatly on small scales across a starburst region. These considerations have motivated a Lyα imaging survey using the Advanced Camera for Survey (ACS) on board the Hubble Space Telescope (HST) for a hand-picked sample of six nearby star-forming galaxies, with the aim of exploring a range of relevant parameters. Preliminary results have been presented in Kunth et al. (2003), and more detailed studies on ESO 338-04 (Hayes et al. 2005) and Haro 11 (Hayes et al. 2007). Emission and absorption were found on very small scales in central regions of the starburst while absorption is observed in front of many of the brightest UV sources. As a service to the community the processed data on the "Centre de Données astronomiques de Strasbourg" (CDS) by Östlin et al. (2008, see image 1).



Lyman-alpha imaging of local starbursts. From left to right and from top to bottom:ESO 338-04, Haro 11, IRAS 08+65, NGC 6090, SBS 0335-052, Tol 65. Lya is in Blue, Halpha in red and FUV(1500 A) in green. FoV is 15"x15" except for SBS 0335-053 (5"x5") and Tol 65 (7.5"x7.5"). North is up and East to the left.

Figure 1. Mosaic of Lyα local galaxies (Östlin et al. 2008)

Besides Lyα, images have been acquired in Hα and six continuum band passes between 1500A and the I-band, enabling not only a comparison between Lyα and Hα, but also detailed modelling of the stellar population and dust.

These studies found that emission and absorption varied on small scales in the central starburst regions, exhibiting very little correlation with the morphology probed by stellar continuum observations. Damped Lyα absorption was found in front of many UV-bright, young star clusters that must be significant sources of ionizing photons. Using Hα, it was found that Lyα does emerge from central regions at surface brightness well below the value predicted by recombination theory. In contrast, large low surface brightness Lyα halos were found surrounding the central regions where typically Lyα/Hα ratios and equivalent widths exceed those predicted for recombination. Furthermore, modelling of the stellar population revealed that Lyα appears to emerge from regions either too old to produce ionizing photons and/or too dusty to permit the transfer of Lyα. Synthesis of these results points to the resonant scattering process being highly significant in the morphological structure.

It should be noted that these HST imaging observations are the only ones in existence that allow the comparison of Lyα with Hα and stellar continuum and that they have a physical resolution, in the most distant case, 2 orders of magnitude better than that attainable at high-z under the best observing conditions. The details of the continuum subtraction methodology can be found in Hayes et al. (2008).

As we stressed above, in front of the star forming regions strong variations are found in both the Lyα images and equivalent width maps, ranging between absorption and emission. This phenomenon is seen on scales ranging between the smallest (0.1″, corresponding to a physical sizes ranging between 20 and 60 pc) up to sizes an order of magnitude larger. Large variations of Lyα equivalent width from the regions of peak UV and Hα surface brightness have been found. There is no apparent characteristic size over which these variations are seen. That is, the Lyα flux or WLyα may be radically different, e.g. switching from absorption to emission, even on the smallest possible scales. This supports the model in which Lyα may escape through favorable paths in a porous and inhomogeneous ISM. However, it is also clear that this is not the main mechanism by which Lyα photons escape galaxies, because the net emission, if any, is always dominated by diffuse emission from regions with low UV and Lyα surface brightness.

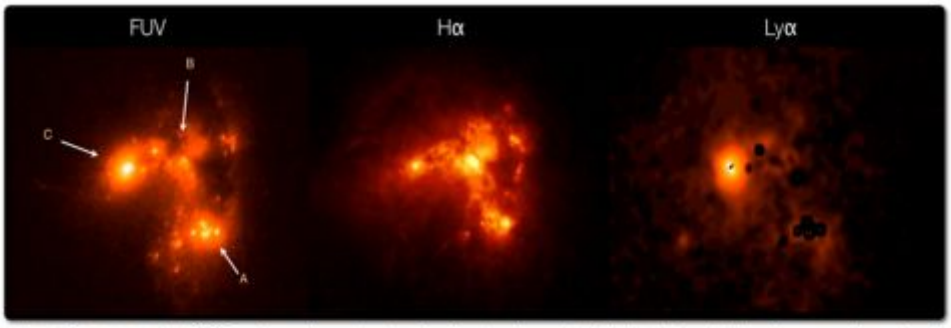
The fractional contribution to the total Lyα and Hα emission as a function of UV surface brightness shows a systematic offset between Hα and FUV which can be expected: the ionisation boundary must be extended away from clusters, where UV surface brightness is lower and may be resolved in the images. Moreover, stellar mechanical feedback may blow out the ionized ISM in shells and filaments, further decoupling the nebular and stellar components.

Lyα is in general further (as compared to Hα) offset towards lower FUV surface brightness levels, demonstrating the importance of additional scatterings affecting Lyα.

The only object that does not show a systematic offset between FUV and Hα surface brightness is SBS 0335–052. Mas-Hesse et al. (2003) suggested that the damped Lyα absorption profile in this galaxy is due to the youth of the starburst episode (WHα = 1500A) hence insufficient time has elapsed to generate a strong wind and accelerate the surrounding HI. The fact that we observe Hα and FUV emission from SBS 0335–052 to be rather tightly correlated could also be a reflection of this fact, and is consistent with the interpretation. The Lyα line, on the other hand, almost completely mirrors that of the FUV, and is seen only in strong absorption in the central regions.

Strong emitting galaxies, such as Haro 11 and ESO 338–04 show strong and systematic offsets between the surface brightnesses where the bulk of the Hα and Lyα emerge.

Clear signatures of diffuse Lyα emission, above the level of the background residuals is seen in both Haro 11 (see image 2) and ESO 338–04 at radial distances from the central star-forming region of around 3 and 1.5 kpc, respectively.



Haro 11 as seen by HST -- A complex emission structure is observed in the far UV and Hα, whereas only one knot shows Lyα in emission. The resonant scattering of Lyα photons on hydrogen atoms makes their escape more complex and less predictable than non-resonant radiation. This effect also produces the low surface brightness emission observed across the galaxy body.

Figure 2. Haro 11 (Hayes, M., Östlin, G., Atek, H., et al. 2007, MNRAS, 382, 1465)

Another interesting case is ESO 350-IG038, where Kunth et al. (2003) report two young star forming knots (B and C) with similar, high extinction, one showing Lyα emission the other not! Hence all these observations confirm that dust absorption cannot be the only dominant mechanism here. Based on the observed Hα velocity field, it is suggested that kinematics is an important factor for the observed differences between the two regions.

The properties of the neutral gas (density, kinematics, and covering factor) thus determine the shape of the profile and the equivalent width of the line, while the amount of dust drives only its intensity. The implication is that feedback from the massive stars via ionization and the creation of super bubbles and galactic-scale outflows lead to the

large variety of Lyα profiles. The escape of Lyα photons depends critically on the column density of the neutral gas and dust, the morphology of the super shells, and the kinematics of the medium. Since these effects can be highly stochastic, theoretical predictions for the Lyα strength are quite uncertain, and empirical guidelines are called for.

2-3. Global properties:

2-3-1. Lyα escape fraction and dust

The escape fraction may be a strong function of the chosen aperture. It may well increase whenever deeper data is obtained (down to fainter levels). Five out of six cases are found to be net Lyα emitters with escape fractions in the range 3 to 14 percent. From the sixth galaxy (SBS 0335– 052), we do detect some Lyα emission outside the central starburst region from resonant scattering.

However, also at faint levels is the net integrated Lyα flux negative. It is possible that more Lyα could have been detected with deeper observations allowing toprobe greater radii. The escape fractions should in this respect be seen as lower limits. On the other hand, some galaxies may contain star forming regions that are so dusty that not even any Hα escapes in which case the actual escape fractions would be lower.

2-3-2. Comparing EWs

Comparing WLyα or the escape fractions with other parameters yields almost no obvious trends but none should bear in mind that no statistical sample of local galaxies is by now available. That said, an anti-correlation of WLyα and WHα is found among these few cases (Östlin et al. 2008) that is indeed interesting as it seems to be rather tight although this trend is not seen in the Lyα escape fraction, with or without dust correction. From the Starburst 99 models, the lowest globally measured WHα corresponds to an age of around 6 Myrs and in the studies of Tenorio-Tagle et al. (1999) and Mas-Hesse et al. (2003) it is concluded that at the youngest times, Lyα may be expected in absorption, followed by an emission phase when the mechanical energy return from star formation has accelerated the ambient medium. How the expected equivalent widths of Lyα and Hα co-evolve is difficult to predict, and instantaneous burst assumption is certainly an over simplification when dealing with global properties. Nevertheless, what is seen may be a direct consequence of evolution.

3. Conclusions from imaging studies of local galaxies

We retain the following empirical results from nearby starbursts on Lyα:

- W (Lyα) and Lyα/Hβ are often smaller than the case B prediction.
- A variety of morphologies is found ranging from overall absorption to net emission.
- Outflows are ubiquitous.
- No clear correlation of Lyα with metallicity, dust, and other parameters is found.
- Strong variations of Lyα are observed within a galaxy ranging from general absorption to emission. Absorption and emission in individual targets are found to vary and intercombine on scales down to the resolution limit of the telescope. Lyα features show only minor correlation the stellar morphology and emission and absorption vary unpredictably.
- A Lyα scattering "halo" is often observed. Typically Lyα emission is seen on large scales surrounding the central star forming regions in the form of low surface brightness halos. Moreover, Lyα is found to be more spatially extended than Hα and appears to emerge almost preferentially at low FUV surface brightnesses. At fainter isophotal levels, Lyα is typically seen in emission, with fluxes and equivalent widths greater than those that would be predicted from recombination theory.
- Observed Lyα escape fractions range from below 0 (absorber) to about 14%. After correction for internal dust extinction, emitters are found to to have escape fractions in the range 13 to 40%.
- Although any trends found from such a small hand picked sample must be viewed with caution, the anti-correlation between the equivalent widths of Lyα and Hα is suggesting that Lyα escape is regulated by feedback, i.e. the development of wind blown bubbles and ISM flows that allow the photons to avoid the resonant trapping by static HI.
- The above statements point directly to one conclusion: the phenomenon of resonant scattering is observed to be extremely important in the regulation of Lyα emission, and radiative transfer of Lyα photons in star-forming galaxies.
- Some local investigated galaxies have far ultraviolet luminosities comparable to some objects being studied through their Lyα emission at the highest redshifts. Given the low escape fractions and complex resonant scattering phenomenon under observation here, care should be executed in interpretation of high-z survey data as we shall see below.

4. Model calculations: factors driving the visibility of the Lyα line

Many parameters being at work, their precise order of importance remains unclear and may well vary among objects. This is why in parallel quantitative modelling including known constraints (stars, emitting gas, HI, dust plus kinematics) with 3D radiation transfer model have been performed.

Lyα being a resonance line becomes optically thick at HI column densities of 10^{13} cm^{-2}. Thus in essentially all galaxies, Lyα undergoes a complex radiative transport, in which many parameters play a role. In particular, dust physics, the H I density, geometry, and

kinematics all matter and they may have distinctive role depending of each particular galaxy (because of its morphology, star formation rate, inclination towards the observer etc.).

Overall, the fate of Lyα photons emitted in a galaxy can be one of the following:

1) scattering until escape forming thus an extended Lyα "halo";
2) destruction by dust; or
3) destruction through 2 photons emission.

However, this last process is only possible in the ionised region.

Tenorio-Tagle et al. (1999), Mas-Hesse et al. (2003) have qualitatively and observationally shown how the variety of Lyα profiles are mostly driven by the expansion of a super-bubble of neutral gas and the properties of the ISM (HI column density and dust content). Ahn (2004) and Verhamme et al. (2006) have examined the formation of P-Cygni profiles from Lyman break-type galaxies, finding secondary emission peaks redwards of the P Cygni emission feature resulting from one or more backscattering in the expanding neutral medium. Hansen & Peng Oh (2006) utilized the original idea of Neufeld (1991) to investigate the effects of a multi-phase ISM. For their models in which dust is embedded in dense HI clouds Lyα photons can in fact preferentially avoid dusty regions and escape having experienced lower total dust optical depths than non-resonant photons. Thus equivalent widths may be artificially boosted, potentially causing ordinary star-forming objects to appear as more exotic systems.

More cosmological-oriented simulations (Tasitsiomi, 2006) have been carried out, although the effects of dust remain to be treated. The simulations are currently able to deal with arbitrary intrinsic emission characteristics, hydrogen density, velocity fields and dust distributions (Verhamme et al. 2006), and to consistently reproduce the Lyα profiles observed in $z \sim 3$ LBGs (Verhamme et al. 2007; Schaerer & Verhamme 2008).

The resonant decoupling of Lyα from non-resonant radiation leads also to an ubiquitous diffuse halo with low surface brightness. It represents the bulk of the Lyα emission and extends to regions at several kpc from emitting regions, which cannot be reached by Hα or continuum radiation yielding high $EW_{\mathrm{Ly\alpha}}$. Because of the radiative transfer complexity of the Lyα line, star formation rates (SFR) measured using Lyα differ from SFRs derived using other indicators (from UV for instance), and fail to recover the total SFR (UV + IR), even when corrected for dust obscuration, preventing any determination of the intrinsic star formation rate. We therefore propose a more realistic calibration of the SFR when information on Lyα only is available (which is usually the

case for high-redshift surveys), which accounts for dust attenuation and resonant scattering phenomenon by means of the Lyα escape fraction (Atek et al.2008).

5. Distant Lyα emitters

High-redshift galaxies exhibit similarities with local Lyman Alpha emitters (hereafter LAEs). At 2.5 < z < 5.2, about half of the galaxies show Lyα in emission (Steidel et al. 1999; Rhoads et al. 2000; Frye, Broadhurst, & Benitez 2002). At the same time, the Lyα line is asymmetric, displaying an extension toward larger wavelengths. The blue ‘‘ edge ’’ of the line could be described as showing a P-Cygni profile, and the centroid of the line is redshifted by several hundred km s-1 with respect to the metallic absorption lines. This is consistent with gas outflows, breakout of the gas bubble produced by the star-forming region, and results in the escape of Lyα emission (Shapley et al.2003).

Most of the distant known LAEs have been found through narrow-band imaging with the SUBARU telescope, thanks to its wide field imaging capabilities (Taniguchi et al. 2005, Kashikawa et al. 2006, Hu et al. 2004, Hu & Cowie 2006). The current record-holder as the most distant galaxy with a spectroscopically confirmed redshift 6.96 is by Iye et al. (2006). Lyα emitters emitters between z = 8.7 and 10.2 were recently proposed by Stark et al. (2007) using blind long-slit observations along the critical lines in lensing clusters. LAEs have also been used with SUBARU to trace large scale structures at z = 5.7 thanks to the large field of view (Ouchi et al. 2005).

Overall, quite little is known about the properties of observationally selected LAEs, their nature and their relation to other galaxy types (LBG and others), since most of them – especially the most distant ones – are detected in very few bands, i.e. their SEDs is poorly constrained.

The morphology of the highest-z LAEs is generally compact, indicating ionised gas with spatial extension of ∼ 2–4 kpc or less (e.g. Taniguchi et al. 2005, Pirzkal et al. 2006).

Although showing SF rates (SFR) of typically 2 to 50 $M_\odot$ yr^{-1}, the SFR density of LAEs is only 1/4th of that of LBGs at all redshifts. Further studies will be necessary to properly understand the connections between LBG and LAE and the evolution of these populations with redshift. Analysing the properties of LBGs and LAEs at $z \sim 3$ (Verhamme et al. (2008) have shown that there is a clear overlap between these two populations : ∼20−25% of the LBGs of Shapley et al. (2003) – those with $EW(\mathrm{Ly}\alpha)_{\mathrm{rest}}$ $_{\mathrm{obs}}$ > 20 Å – correspond to LAEs brighter than R_{AB} = 25.5 mag. The remaining ∼77% of the statistically complete LAE population from Gronwall et al. (2007) are fainter in the continuum than the LBGs. Radiation transfer, dust effects, and changes in the

stellar/ionising properties should also explain the increase of the LAE/LBG ratio, and a higher percentage of LBGs with strong Lyα emission with increasing redshift.

6. Summary

Dust is not the only driver for the transfer of the Lyα photons. Kinematics, gas density and geometrical effects must play a role. A huge scattered halo is found in most local LAEs. Locally some super-recombination values are observed (boosting effects). The average escape fraction is low (less than 20%). Standard dust correction fails to retrieve the standard recombination values. Lyα is now used for redshift determination for the majority of the targets at high redshift. This is rather important for more than half of the high z galaxies detected by various techniques show Lyα. It is crucial to consider that Lyα should still be a competitive tool in the future for the exploration of the distant universe but interpreting its physics is not straightforward.

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A walk across the Local Universe

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Contribution not available.

Optical and IR Monitoring of Some Blazars

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The term "galactic activity" is inseparably linked with the name of Victor Ambartsumian. He was the first who paid attention to this topic. There are many manifestations of activity but photometric and polarization variability is probably the most prominent. Because of different time scales of variability the monitoring is an important method of investigation of active galactic nuclei.

Optical monitoring of AGNs was started at the Observational Station of St.-Petersburg University in 60th of last century with two half-meter telescopes. With one of these photometric observations (mainly in B band) were done photographically, with the second the polarimetric observations were obtained with electrophotometer-polarimeter using photomultiplier. These observations were interrupted in 1991. After some years they were recommended in the fall of 90th with CCD photometer-polarimeter at 70-cm telescope of Crimean Observatory (BVRI bands) and with IR camera (JHK bands) with 1.1-m telescope placed in Campo Imperatore (Italy). Here some interesting results obtained using monitoring data will be presented.

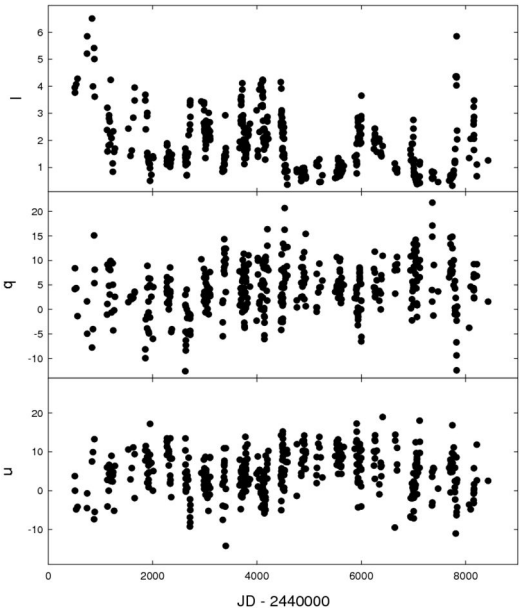

Fig.1. The results of optical monitoring of BL Lac in 1968-1991.

Fig.1 gives the results of optical photometric and polarimetric monitoring of BL Lac. Here I is the flux in mJy in *B* band, q and u are relative Stokes parameters in %. We use these sets for investigation of periodicity. The existence of periodicity is crucial for some models of AGNs. The results of such investigations are contradictory. Up to now all such investigations deals with photometric variability only. We have *completely independent* sets of photometric and polarimetric data. We use the method of Deeming for unequally spaced data.

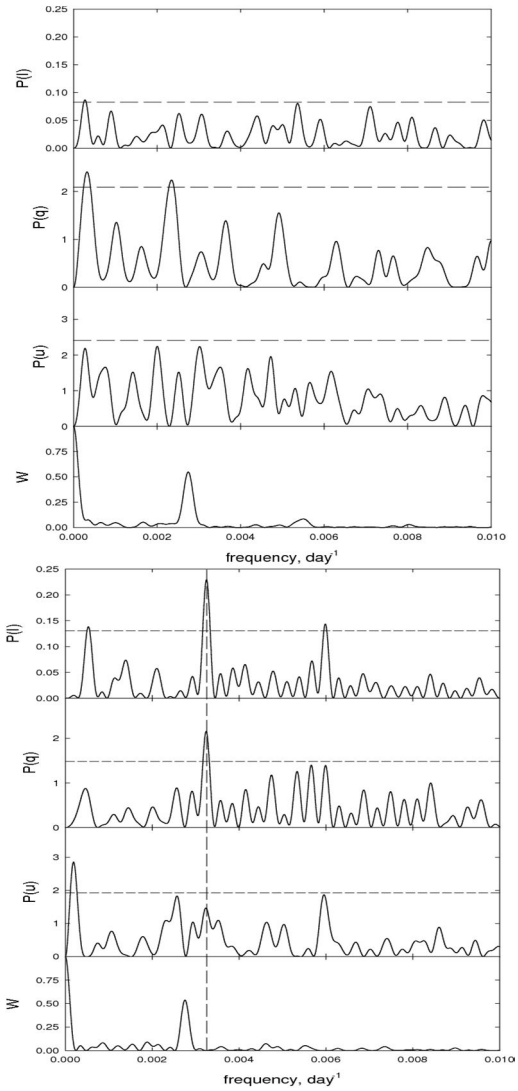

Fig.2. The power spectra and spectral window for 1968-1979.(left) and 1980-1991 (right).

In Fig.2 (left) the power spectra and spectral window are given for the first half of sets (1968-1979). There are no prominent details in the spectra. The situation changes radically when the power spectra are constructed for the second part of the data (1980-1991) These are given in Fig.2 (right).. Here we see maxima on the two upper panels at significance level <5% at the *same frequency* corresponding to period of 308 days. We stress that two sets are completely independent. So this may be considered as serious argument for the reality of period found.

To verify that the maxima are not related to the temporal spacing of the observations we have constructed a number of simulated sets. Each set has the same temporal spacing, fluxes and Stokes parameters as the observed data, but the values of flux I and q,u are randomly mixed. We analyzed the simulated sets for a periodicity in the same manner as the actual data. All simulated spectra have no prominent details. This confirms the reality of period found. Fig.3. gives the variations with phase for the period of 308^d. In two upper panels the systematic behavior is well seen.

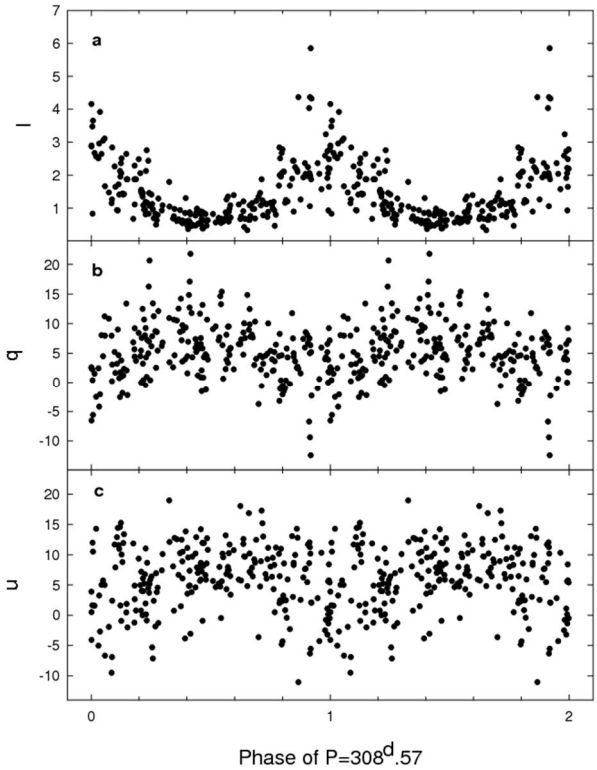

Fig.3.Variations with phase for a period of 308 days.

Thus we ascertain that the behavior of BL Lac in the optical region is intrinsically different in 1968-1979 and 1980-1991. In the first time interval there was no

periodicity, in the second one there was periodic component with P = 308 days, Our results show that *periodic variations may exist for a long time interval covering a number cycles and then disappear*. This can explain the discrepant results obtained by different authors who have analyzed for periodicity different parts of the light curve of the same object. For more details see Hagen-Thorn et al. (2002).

The sources responsible for variability are placed in the nearest neighborhood of the central engine and understanding their nature might give a way to the solution of the problem of nuclear activity in general. Unfortunately, these sources are not optically resolved and their flux is not observed directly without the confusion of some flux from underlying galaxy, accretion disk and other continuum and emission line contributors. The extraction of the radiation of the variable source is not a simple task because the fluxes of other contributors may be estimated only indirectly.

It is crucial for modeling activity to know a temporal development of spectral energy distribution (SED) of the variable source. Unreal taking into account other contributors leads to the wrong conclusions about the behavior of the source. Therefore, it is very important to derive some information on SED of variable source from observations directly, *before* taking into account other contributors. In what follows we consider one such possibility. We show how information on temporal development of SED of the variable source may be obtained from multicolor photometric observations of variability *without knowledge of its contribution to the total flux*. For detailed description of the method see Hagen-Thorn & Marchenko (1999).

Let us suppose that the variability within some time interval is due to a *single variable source*. If the variability is caused only by its flux variation but relative SED remains unchanged, then in the *n*-dimensional flux space $\{F_1,\ldots,F_n\}$ (*n* is the number of spectral bands used) the observational points must lie on a “straight line”. The direction tangents of the line are the flux ratios of the variable source determined by its SED. With small caveats, the opposite is also true: If the observational data points lie on straight line in this space the SED of the variable component do not change and direction tangents of the line give the flux ratios for variable source, i.e. its SED.

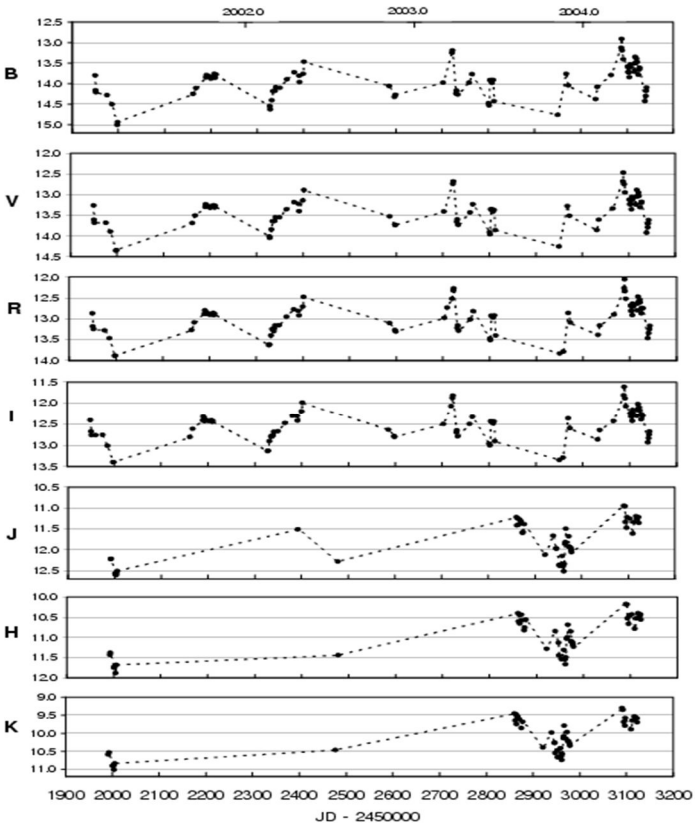

Fig.4. The results of monitoring of the blazer S5 0716+714 in 2001-2004.

Thus, the study of the behavior in flux space permit to answer the question *whether SED of the variable source responsible for variability at time interval under consideration is unchanged* and if yes, to find its SED *without preliminary correcting the data for contribution of constant component.* This rules out all possible mistakes connected with incorrect separation of constant and variable components.

Fig.4 presents the results of monitoring of the blazar S5 0716+714 which we shall analyze. The flux-flux diagrams are given in Fig.5. We see that the observational points lie on straight lines quite well pointing to the constancy of the SED of the variable source. This SED is given in Fig.6 showing that it is of power law with spectral index equal to -1.12. (of synchrotron origin).

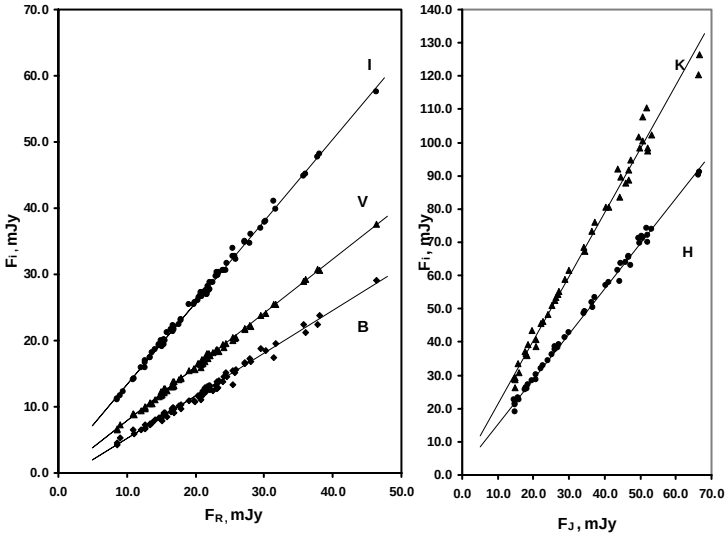

Fig. 5. Flux-flux diagrams

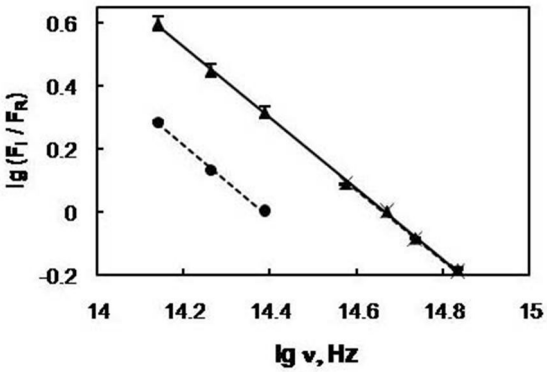

Fig. 6. Spectrum of the variable source.

Within some of the nights we have observed intraday variability (IDV). In our opinion, up to now the source of IDV has not been localized. For example, it has been suggested that this variability is due to outbursts in the accretion disk. The SED of the variable component is essential for such hypothesizing, and our observations provide relevant information in connection to this. Fig.7. gives the flux-flux diagrams for IDV (points). The straight lines are taken from Fig.5. From Fig.7 we see that points located along the lines, i.e. the SED of the source responsible for IDV is the same as for slowly varying component. suggesting the presence of a single variable source, with the IDV simply reflecting fluctuations of its flux. For details of this investigation see Hagen-Thorn et al. (2006).

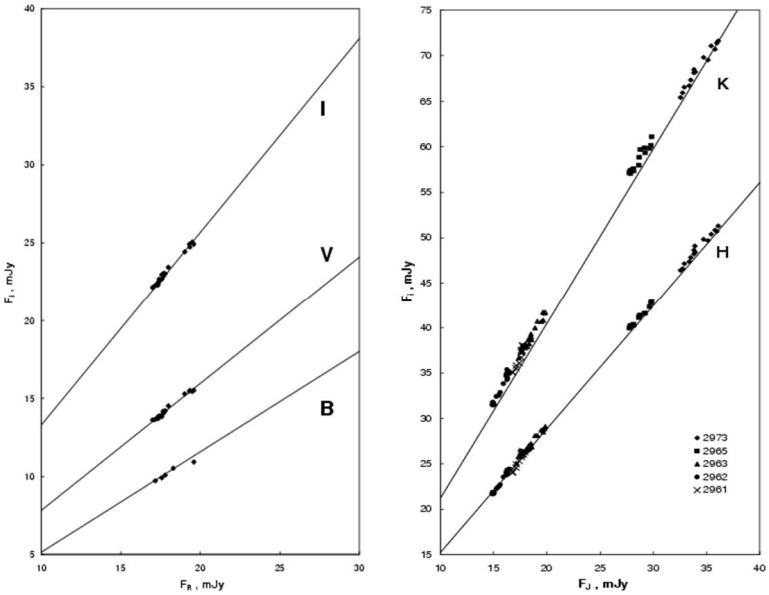

Fig.7. Flux-flux diagrams for IDV (points); the straight lines are taken from Fig.5.

The main results of our investigations of color variability may be formulated as follows:

1. In many cases the photometric behavior of AGN on different time scales and in different spectral ranges may be explained by the existence of a single variable source which has variable flux but unchanged SED.
2. The SEDs are well represented by the spectrum of homogeneous synchrotron source.
3. The color characteristics of the source responsible for IDV permit to suggest that IDV is simply fluctuations of the flux of slowly varying component.

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Testing the Possibility of Galaxy Ejection

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Abstract. We analyzed 377 ACO clusters to obtain shape of the structures. The covariance ellipse method was used to ellipticity determination. We discuss the shape of two samples: the first one contains all galaxies in the magnitude range m_3, $m_3 + 3^m$ and the second sample contains only 20 brightest galaxies. Statistical test shows the difference in the ellipticity distribution in those two samples. The counts of galaxies located in 12 sectors of the circles 30° for two samples were performed. We found that the location of 20 brightest galaxies in the cluster is different that the distribution of all galaxies in the same structure. These results are not in contradiction with the naïve predictions coming from the Ambartsumian idea.

Keywords: galaxy structures; properties, origin

1. Introduction

In cosmology there are several scenarios of galaxy structures origin. Usually it is assumed that galaxies were formed through the gravitational instability. Totally different point view was expressed by V. A. Ambartsumian. He pointed out that the explosions in massive central galaxies (or protogalaxies) led to the formation of structures. The ejected from primordial, superdense body object can be a seed of further ejections of galaxies [2-5].

This picture is incorporated in so called explosive scenraio of galaxy origin [8], as well as in the formation of galaxies in the quasi-steady state theory in cyclic Universe [9]. The opinion that galaxies are ejected from QSO is widely spread in astronomical community [12].

We are trying to test Ambartsumian hypothesis. There are no clear predictions of theoretical considerations which can be compared with observations. This is the main difficulty, so we compare our data with a somewhat naive picture arising from the Ambartsumian's idea. If the first objects were ejected from the primordial body, one can expect that properties of the whole galaxy clusters and the brighter one should be different. We compared the structure shape and location of galaxies in 377 clusters dividing the sample into two groups. One of them contain all objects, the second one only 20 brightest galaxies.

2. Observational data

We used Abell [1] clusters with galactic latitude |b|>40° and Richness Class≥1 and redshift z<=0.2 [10] to determine catalogues of galaxies. The area covering 2x2 Mpc (h=0.75, q_0=0.5) was extracted from DSS [11]. Using FOCAS packages to DSS we obtained catalogues of galaxies. We analyzed only galaxies in the magnitude range m_3, m_3+3^m, where m_3 is the magnitude of the third brightest galaxy. To reduce the star/galaxy separation errors the photographic plates were additionally visually inspected in doubious cases.

Each catalogue contains information about right ascension and declination of galaxies, coordinates x and y on the photographic plate, instrumental magnitude m, area of object, galaxy ellipticity and position angle of the major axis of the galaxy image. The equatorial coordinates of galaxies for the epoch 2000 have been computed from the rectangular coordinates of DSS scans [11].

We divided our data into two subsamples: the first one containing all galaxies, denoted as A, and the second one denoted as B composed of 20 brightest galaxies.

3. Method of analysis

We used covariance ellipse method to obtain galaxy cluster shape. This method was adopted to the galaxy cluster ellipticity and position angle determination by Carter & Metcalfe [7]. The contour of an ellipse in two dimensional distribution of points is determined from the first five moments of the observed distribution:

$$M_{10} = \frac{1}{N}\sum_i x_i$$

$$M_{01} = \frac{1}{N}\sum_i y_i$$

$$M_{20} = \frac{1}{N}\sum_i x_i^2 - \left(\frac{1}{N}\sum_i x_i\right)^2$$

$$M_{02} = \frac{1}{N}\sum_i y_i^2 - \left(\frac{1}{N}\sum_i y_i\right)^2$$

$$M_{11} = \frac{1}{N}\sum_i x_i y_i - \frac{1}{N^2}\sum_i x_i \sum_i y_i$$

where x_i and y_i denote the coordinates of *i-th galaxy*. The centroid of the contour is: $x_0=M_{10}$, $y_0=M_{01}$, this is mean of galaxy coordinates. The semi - principal axes are the solution λ_u and λ_v of the quadratic equation:

$$\left(M_{20} - \lambda^2\right)\left(M_{02} - \lambda^2\right) - M_{11}^2 = 0,$$

the eigenvalues of the matrix of moments of the distribution. The cluster ellipticity is given by:

$$e = 1 - \sqrt{\frac{1-\varepsilon}{1+\varepsilon}}$$

where

$$\varepsilon = \frac{\sqrt{\left(M_{20} - M_{02}\right)^2 + 4M_{11}^2}}{M_{20} + M_{02}}$$

The position angle of the major axis is defined as:

$$tg\,2\theta = \frac{2M_{11}}{M_{20} - M_{02}}$$

4. Analysis

The structure ellipticity changes with distance from the cluster centre. We calculate its value in circular rings changing diameter from 0.5Mpc to 1.5Mpc with the step 0.25Mpc. The same procedure was performed for both samples A and B.

Applying Kolmogorov – Smirnov test we checked the similarity of the ellipticity distributions for samples A and B.
At the significance level α=0.01 the critical value of the Kolmogorov – Smirnov test is λ_α =1.627. Table 1 presents the obtained λ values for independent comparisons of samples A and B in the case of four investigated distance ranges.

The statistical analysis shows that the distribution of all galaxies in the galaxy clusters is different from the distribution of brighter objects. The distribution of brighter objects is more elongated that the distribution of all galaxies in the same regions. The mean ellipticities at the distance range from 0.5 till 0.75 Mpc are: 0.143 +/- 0.0215 and 0.297+/- 0.0116, from 0.75 till 1.0 Mpc are: 0.1005 +/- 0.1659 and 0.234 +/- 0.0188, from 1.0 till 1.25 Mpc: 0.1005 +/- 0.0549 and 0.237 +/- 0.0025, from 1.25 till 1.5 Mpc: 0.1004 +/- 0.0457 and 0.3 +/- 1.325 for the sample A and B respectively.

Table 1. The values of λ statistics for the comparison of samples A and B.

Distance range	0.5-0.75Mpc	0.75-1.0Mpc	1.0-1.25Mpc	1.25-1.5Mpc
λ value	1.405	2.556	3.544	1.977

We also investigate the distribution of galaxies in 377 ACO clusters counting the number of galaxies in circular sectors with 30° width. This analysis was performed using both the coordinate x, y system connected with the photographic plate and the coordinate system connected with the galaxy cluster (the cluster major axis were used as new basic line determining angles 0° and 180°).

In both coordinate systems the distributions of galaxies in sample A and B are isotropic which was statistically confirmed using K-S test. We extracted the sample containing only BM type I clusters (Fig.1 lower panel). In the x, y coordinate system both distributions, *i.e.* containing all galaxies and 20 brightest ones were isotropic. This is not the case of counts performed in the coordinate system connected with the galaxy cluster (Fig.2), were distributions are anisotropic. We observe the excess of galaxies in the sectors between 285° and 345° as well as in bins covering angles from 105° to 165°. For B sample only one maximum in the last sector was noted. Such result point out the connection with the cluster itself.

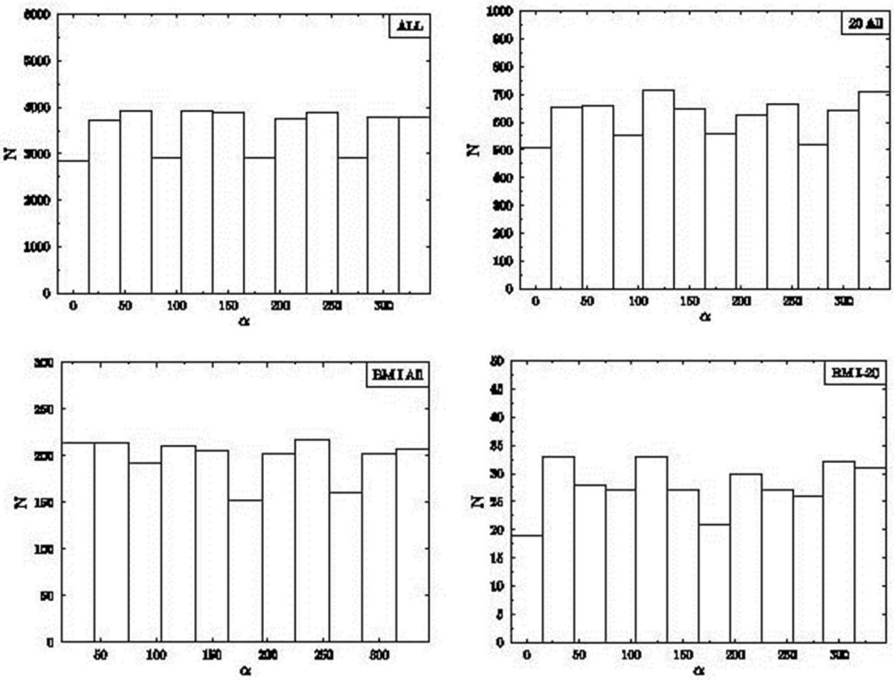

Fig. 1. The distribution of all galaxies in 12 equal area sectors in 377 clusters (x, y coordinate system) (upper left panel) and the brightest galaxies in these clusters (upper right panel), as well in BM I type clusters (all galaxies – lower left panel) and the brightest ones (lower right panel).

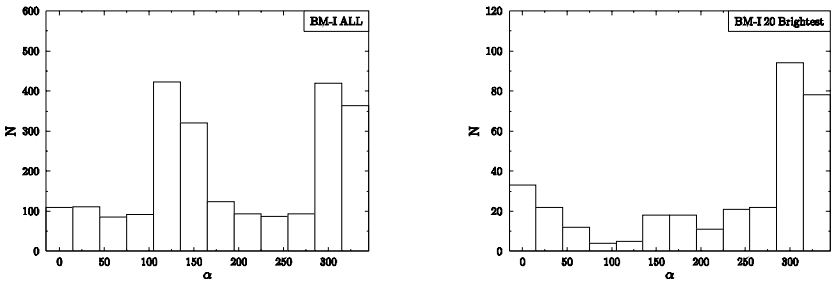

Fig. 2. The distribution of galaxies in BM type I clusters of samples A and B counted in the coordinate system connected with the galaxy cluster major axes

5. Conclusions

The ellipticity of structures determined using the 20 brightest galaxies in clusters is different that these for structures containing all galaxies [6]. We found that the location of galaxies in bins is isotropic. Considering the division of clusters according to their morphological types we found that only in the case of BM type I the anisotropy is

observed. Galaxies tend to locate along the cluster major axis. Such behavior of galaxies can be explained by the special role of cD galaxies. It was pointed out [13] that just cD galaxies can be regarded as progenitors of all cluster galaxies. In the picture of consecutive ejections of galaxies from that formed earlier *i.e.* brighter the change of the overall cluster shape should change. The structure ellipticity should be more sperical with time. This is the observed picture. However, such effect can occur in other scenarios of galaxy origin.

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Properties of Galaxy Clusters and the Ejection Picture of Galaxy Formation

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1. Introduction

Historically it was assumed that galaxy clusters can be described by radial profiles for the galaxy- and the gas-components which are approximated by an isothermal model with a hydrostatic equilibrium. The clusters were considered as relaxed structures. It was assumed that both the galaxies and the intracluster medium are related to the potential well of the cluster in the same way. Dark matter, gas and galaxies should show the same behaviour. In principle, the observations of all these three components should lead to equivalent distributions.

Recent investigations showed that this isothermal picture for galaxy clusters is not valid. Rather the results reveal a great richness of cluster structures and various relations between optical and X-ray structures. For some time past galaxy clusters are not recognized as simple relaxed structures.

The existence of different optical and X-ray structures in a considerable number of clusters should be discussed in connection with the deduced percentage of clusters with observed substructures: 40 % (Geller and Beers 1982), 70 - 80 % (Baier 1983), 35 % (Webster et al. 1988), 30 % (Jones and Forman 1990, Briel et al. 1991), 26 % (Rhee et al. 1991), 45 % (Jones and Forman 1992), 75 % (Burns et al. 1994), 85 % (Bird 1994a,b) and ~ 100 % (Baier 1997).

According to a first rough inspection galaxy clusters should be divided into the following main classes (Baier et al. 1996): (1) single and not relaxed clusters without any global strong X-ray emission (e.g. Abell 569, Abell 576, Abell 779, Abell 2162, Abell 2634, Abell 2666); (2) double clusters without any pronounced X-ray emission (e.g. Abell 1904); (3) double clusters with different optical and X-ray emission distributions (e.g. Abell 98, Abell 754, Abell 1589, Abell 1644, Abell 1736, Abell 2255, Abell 2256); (4) "concentrated clusters" with strong and extended X-ray emission and

pronounced apparent cooling flows but nevertheless with substructures (e.g. Abell 85, Abell 426, Abell 1795, Abell 2199, Abell 2670).

After our investigation of cluster structures (Baier 1997) we disbelieve the existence of real relaxed galaxy clusters. There are two opposite concepts for the formation and evolution of cosmic objects as for instance galaxies and clusters of galaxies. The first concept implies the "accretion scenario" or "merger scenario", respectively, according to which cosmic objects (e.g. galaxies) are formed by condensation or accretion of surrounding material and the already existing cosmic structures (e.g. groups and clusters of galaxies) may grow by the accretion of outlying galaxies and groups. According to Miller and Owen (2003) in *some cases*, bona fide clusters themselves can merge.

The clear evidence of activities in galaxies over the scale of clusters very often is cited as evidence for the merger scenario. But according to Miller and Owen (2003) the effect of cluster-cluster mergers on activity and star formation in individual galaxies is less certain because the various theoretical models produce differing conclusions resulting from a large range in environmental parameters. Therefore we have to consider the merger scenario as one thinkable scenario for the cluster formation but not as last resort. Rather we should consider different possibilities for the development of substructures.

2. Formation of new galaxies by ejections

A new concept implies the so-called "ejection scenario" according to which new cosmic objects (e.g. galaxies) are formed by ejections from already existing objects according to the ideas of Ambartsumian (1958, 1965), Alfven (1983), Arp et al. (1987, 1990, 1998) and Hoyle et al. (1993). Probably this ejection scenario may explain many observed cluster properties much better. Such properties are:

- the general appearance of galaxy clusters according to the Rood – Sastry classification (cD, B, L, F, C),
- the existence of X-ray luminous and very massive galaxy clusters at large red-shifts,
- the existence of fainter galaxies in the immediate neighbourhood of the so-called parent galaxies (cD- and D-galaxies) in the cluster centres as for instance "bound populations" and "multiple nuclei",
- the correlation between the orientations of central dominant galaxies and of the general distributions of galaxies in clusters (alignments),
- the activities of many central cluster galaxies (cD-galaxies),
- the connection of galaxy clusters with radio galaxies, quasars and further active extragalactic objects,
- the redshift differences (velocity offsets) between cD-Galaxies and the rest of the cluster population,

- the existence of filamentary structures in (some) galaxy clusters,
- ghost cavities in galaxy clusters,
- giant radio-rings (halos) and radio relicts in (some) galaxy clusters,
- cosmic gamma-ray bursts,
- the existence of fossile galaxy clusters,
- differences between galaxy- and X-ray distributions in many clusters,
- the so-called beta-problem,
- the existence of substructures in (nearly) all galaxy clusters.

In this connection the new observational results (e.g. activities in galaxies, ejections from galaxies, material bridges between galaxies with different redshifts, an excess of quasistellar objects (QSOs) near bright galaxies, associations between peculiar galaxies and radio sources, luminous arcs around dominant cluster galaxies, aligned objects in clusters, groups of active galaxies in clusters, elongated clusters and filaments of galaxies in clusters, elongated X-ray structures and X-ray material emerged from dominant galaxies in clusters and many others as discussed in Arp (1987, 1998) and Arp et al. (1990) have exceptional meaning.

There is every indication that new cosmic structures – above all galaxies – seem to be generated not by condensations or merging of already existing building blocks but by creation in little big bangs in a kind of a cascade process from already existing objects as it was proposed by Hoyle et al. (1993) within the scope of the quasi-steady state cosmological model (QSSCM). If this assumption is right, we should await such creation processes most frequently in galaxy clusters.

There are clear hints for strong activities in the central regions of clusters (Hydra A, Perseus, A 2052, A 2597) according to McNamara et al. 2001: The X-ray emitting gas in the central regions near the CDG is bright and irregular structured. These structures are associated with powerful radio sources at least in the first three cases. The radio sources or the CDGs appear to have pushed aside the gas, leaving low surface brightness “ghost cavities” in the gas of the central cluster regions. Further on there is a growing number of cavities found near giant elliptical galaxies, groups of galaxies and central dominant cluster galaxies (Finoguenov & Jones 2000, Vrtilek et al. 2000, Schindler et al. 2001).

Apart from that there are discoveries of giant, radio-emitting rings and segments around an increasing number of galaxy clusters (e.g. A 1656, A 2256, A 3376). Until now these structures are believed to be the result of shock waves caused by violent collisions or mergers of galaxy groups or clusters. We would like to bring up the question if these structures could be explained by the just discussed activity in cluster centres in connection with the more general concept of creations in little big bangs according to the QSSCM.

Therefore it is our aim to investigate the galaxy distribution in clusters as accurately as possible and to look for hints of activities of all kinds related to the cusps of the number density distribution of galaxies.

3. Investigation of the galaxy- distribution with the Voronoi-tesselation

In a new project the galaxy distribution in clusters is investigated by the help of the Voronoi-tesselation (VT).

A Voronoi-diagram is a special kind of decomposition of the metric space determined by distances to a specified discrete set of objects in the space, e.g., by a discrete set of points. For instance, we have a set of points s in the plaine, which are the Voronoi-sites. Each point has a Voronoi-cell V(s) consisting of all points closer to s than to any other site (Fig.1). The segments of the Voronoi-diagram are all the points in the plane that are equidistant to two sites. The Voronoi-nodes are the points equidistant to three (ore more) sites.

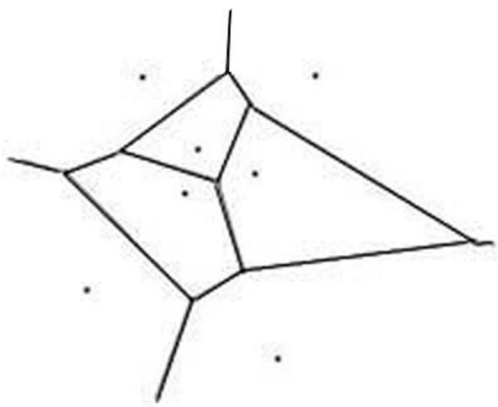

Fig. 1. Voronoi-tesselation

The practical realisation of the VT for the investigation of the galaxy distribution in cluster fields is as follows. Normally we start to count galaxies in a cluster field of roughly 1 degree by 1 degree (exactly 64' x 64') and a matrix of 64 x 64 quadratic counting cells of the dimension 1'. If we have more than one galaxy in any of the cells, all the cells are bisected. This process is continued until we have either one either zero objects in every of the cells of a matrix M_n with the dimension n x n (generally n is between 1024 and 4096). Then every empty field is allocated to one of the galaxies G_i (i = 1 … K) in the whole area with the smallest distance. As a result we get K areas of a size A_i and a number density of $D_i = 1/A_i$. This value of the number density is allocated

to every cell connected with the actual galaxy G_i. The result is the Matrix M_n with the highest possible resolution, which is converted to a picture. Therewith we have the possibility of the processing and presentation of the data with the data- and picture-reduction system MIDAS of the **E**uropean **S**outhern **O**bservatory.

First results of our investigation are discussed for A 2256, which is one of the most frequently investigated and discussed galaxy clusters. From previous investigations (Baier & Mai 1978, Geller & Beers 1982, Oegerle et. al. 1987, Fabricant et al. 1989, McMillan et al. 1989, Briel et al. 1991, Henry et al. 1993, Davies & Mushotzky, Bridle & Fomalont 1976, 1978, Miller et al. 2003, Clarke & Ensslin 2006 and Berrington et al. 2002) the cluster seems to show a central elongated optical structure with a position angle of roughly 120° (Figs. 2 and 3) or even two central density peaks (Fig. 7) and a substructure in the NW-region as well as a double X-ray distribution which is distinguished from the optical distribution. The orientation of the elongated (double) X-ray structure is between 65° (Briel et al. 1991) and 60° (Davies & Mushotzky 1993). Additionally we found a global optical cluster orientation of roughly 45° – 50° (Figs. 7,8) in agreement with Oegerle et al. (1987).

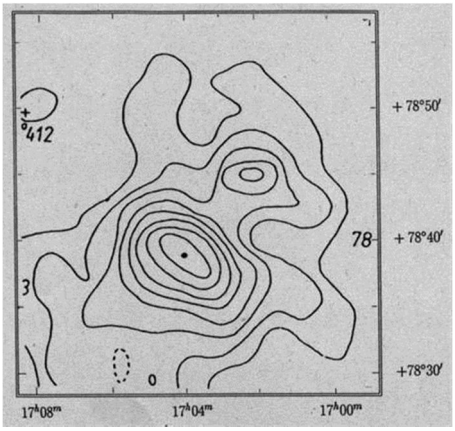

Fig. 2. Galaxy distribution in A 2256 according to Baier and Mai (1978)

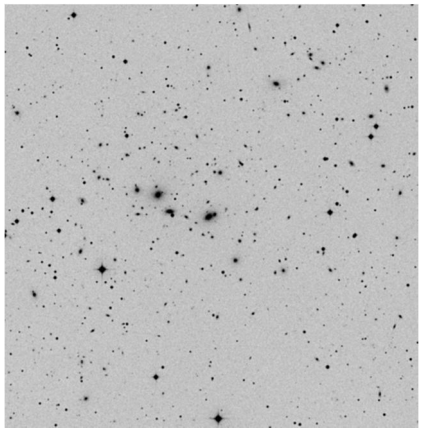

Fig. 3. The central region of the galaxy cluster A 2256 (20´ x 20´) centered at alpha = 17^h 03^m 33^s; delta = 78° 37´ 50´´. Picture form the SuperCOSMOS Sky Surveys

The double X-ray structure (Briel et al. 1991) was interpreted in the sense of a merger scenario, whereby the difference between the X-ray and the optical structure was not discussed in detail. For a particular discussion of the situation having regard to the investigation by Miller et al. (2003) we refer
to a future paper (Baier et al. 2009).

For the moment we consider the “central group” of the cluster including the BCG presented in Fig. 3. Miller et al. (2003) pointed out that the fairly strong radio source J170448+783829 in the neighbourhood of the brightest cluster galaxy is approximately in the centre of the cluster halo source. Furthermore the most western object in this group is a triple system including the tailed radio galaxy J170330+783755 with AGN-properties (Fig. 4).

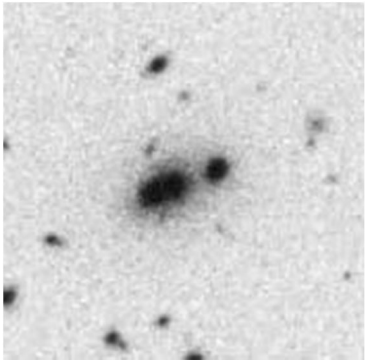

Fig. 4. The triple system with the tailed radio galaxy J170330+783755 (furthest right); Picture from the SuperCOSMOS Sky Surveys

This linear system contains another radio galaxy in the middle, has an orientation of 65° and is in the middle between the both X-ray structures found by Davies and Mushotzky (Fig. 5).

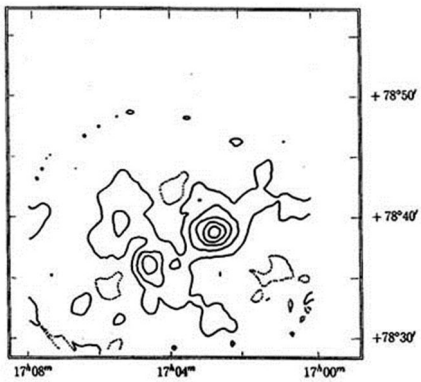

Fig. 5. X-ray substructure in A 2256 (Davies & Mushotzky 1993)

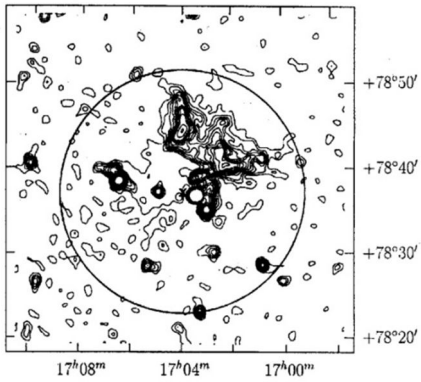

Fig. 6. Radio-emission of A 2256 (Bridle & Fomalont 1976)

It is interestingly that there are further galaxies with symptoms of activity in this region. In addition the material emitting the radio radiation (Fig.6) seems to stream from that central region through a bottleneck into the north western cluster region and spreads out

there. According to Brentjes (2008) relic radio sources could be produced by active galactic nuclei. Besides the number-density distribution shows a bridge between the central region and the north western subcluster (Fig.7) as well as a broad and sustained distribution to the SE. From all these indications we conclude that it is worthwhile to discuss alternative possibilities for the formation of substructures in galaxy clusters. Maybe the galaxy clusters and groups could be the places in the universe where the new matter is generated according to the ideas of Ambartsumian (1958,1965), Alfven (1983), Arp et al. (1987, 1990, 1998) and Hoyle et al. (1993). A detailed discussion of A 2256 and future work on the basis of a representative sample of galaxy clusters are in progress.

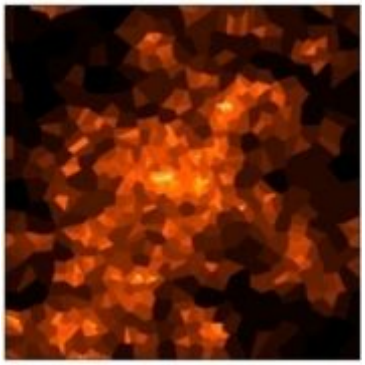

Fig. 7. Galaxy distribution in A2256 determined with the Voronoi-tessellation. Field: 30´ x 30´; Data from SuperCOSMOS Sky Surveys; m_{Rlim} = 20 mag

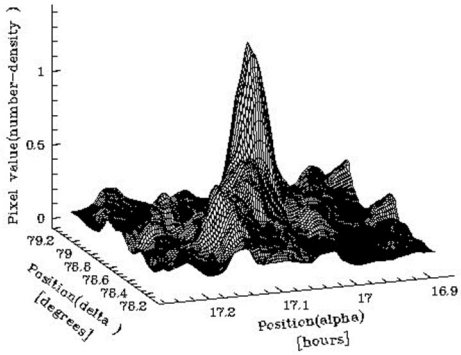

Fig. 8. Three-dimensional presentation of the galaxy-distribution in A 2256 determined with the Voronoi-tesselation. Field: 1° x 1° For furher details see Fig. 7.

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Apparent discordant redshift QSO-galaxy associations

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Abstract. An "exotic" idea proposed by Viktor Ambartsumian was that new galaxies are formed through the ejection from older active galaxies. Galaxies beget galaxies, instead of the standard scenario in which galaxies stem from the evolution of the seeds derived from fluctuations in the initial density field. This idea is in some way contained in the speculative proposal that some or all QSOs might be objects ejected by nearby galaxies, and that their redshift is not cosmological (Arp, G./M. Burbidge and others).

I will discuss some of the arguments for and against this scenario; in particular, I shall talk about the existence of real physical connections in apparently discordant QSO-galaxy redshift associations. On the one hand, there are many statistical correlations of high-redshift QSOs and nearby galaxies that cannot yet be explained in terms of gravitational lensing, biases, or selection effects; and some particular configurations have very low probabilities of being a projection of background objects. Our understanding of QSOs in general is also far from complete. On the other hand, some cases which were claimed to be anomalous in the past have found an explanation in standard terms. As an example, I will show some cases of our own research into this type: statistics of ULXs around nearby galaxies, and the Flesch & Hardcastle candidate QSOs catalog analysis. My own conclusion is neutral.

1. The problem and the observations that give rise to it

Viktor A. Ambartsumian suggested the idea that new galaxies are formed through ejection from older active galaxies (Ambartsumian 1958). This idea has had a certain continuity in the research carried out over the last 40 years based on the hypothesis that some extragalactic objects, and in particular high redshift QSOs, might be associated with low redshift galaxies, thus providing a non-cosmological explanation for the redshift in QSOs (e.g., Arp 1987, 2003; Narlikar 1989; Burbidge 2001; Bell 2002a,b, 2006, 2007; López-Corredoira & Gutiérrez 2006a); that is, a redshift produced by a mechanism different from the expansion of the Universe or the Doppler effect. Ambarsumian never accepted the idea of non-cosmological redshifts; however, the scenario of QSOs ejected by galaxies is a common theme of the Armenian astrophysicist and in proposals of discordant QSO-galaxy redshift associations.

There are plenty of statistical analyses (e.g., Chu et al. 1984; Zhu & Chu 1995; Burbidge et al. 1985; Burbidge 1996, 2001; Harutyunian & Nikogossian 2000; Benítez et al. 2001; Gaztañaga 2003; Nollenberg & Williams 2005; Bukhmastova 2007)

showing an excess of high redshift sources near low redshift galaxies, positive and very significant cross-correlations between surveys of galaxies and QSOs, an excess of pairs of QSOs with very different redshifts, etc. An excess of QSOs near the minor axes of nearby parent galaxies has also been observed (López-Corredoira & Gutiérrez 2007); however, the discovered excess for position angles lower than 45 degrees is significant only at the 3.5-σ level (3.9-σ for z_{QSO}>0.5) with the QSOs of the SDSS-3rd release (López-Corredoira & Gutiérrez 2007) and somewhat lower [2.2-σ (2.5-σ for z_{QSO}>0.5)] with the SDSS-5th release.

There are plenty of individual cases of galaxies with an excess of QSOs with high redshifts near the center of nearby galaxies, mostly AGN. In some cases, the QSOs are only a few arcseconds away from the center of the galaxies. Examples are NGC 613, NGC 1068, NGC 1097, NGC 3079, NGC 3842, NGC 6212, NGC 7319 (separation galaxy/QSO: 8”), 2237+0305 (separation galaxy/QSO 0.3”), 3C 343.1 (separation galaxy/QSO: 0.25”), NEQ3 (see Fig. 1/left; a QSO-“narrow emission line galaxy” pair separated 2.8” from another emission line galaxy with a second redshift, and all of them lying along the minor axis of an apparently distorted lenticular galaxy at ~17” with a third redshift), etc. In some cases there are even filaments/bridges/arms apparently connecting objects with different redshift: in NGC 4319+Mrk 205, Mrk273, QSO1327-206, NGC 3067+3C232 (in the radio), NGC 622, NGC 3628 (in X-ray and radio), NEQ3 (Fig. 1/left), etc. The probability of chance projections of background/foreground objects within a short distance of a galaxy or onto the filament is as low as 10^{-8}, or even lower. The alignment of sources with different redshifts also suggests that they may have a common origin, and that the direction of alignment is the direction of ejection. This happens with some configurations of QSOs around 1130+106, 3C212, NGC 4258, NGC 2639, NGC 4235, NGC 5985, GC 0248+430 (Fig. 1/right), etc. Other proofs presented in favor of the QSO/galaxies association with different redshift is that no absorption lines were found in QSOs corresponding to foreground galaxies (e.g. PKS 0454+036, PHL 1226), or distortions in the morphology of isolated galaxies.

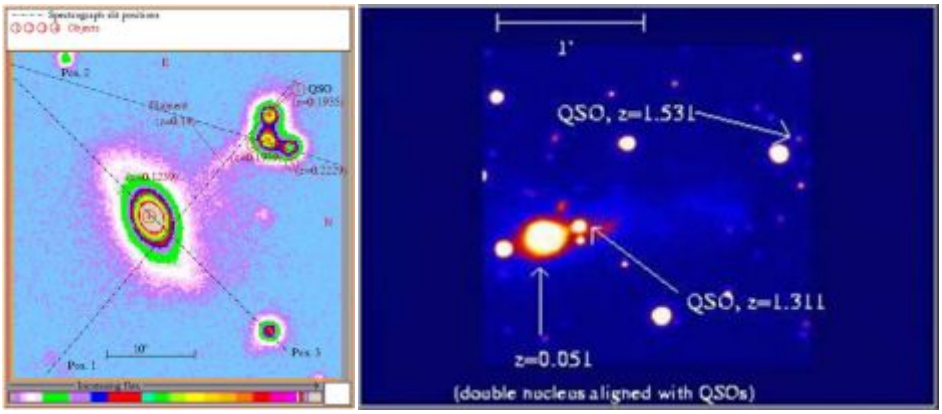

Fig. 1. Left: NEQ3; Sloan r' band, taken on the 2.6 m NOT (La Palma, Spain); reproduction of Fig. 1 of Gutiérrez & López-Corredoira (2004). Right: GC 0248+430, a galaxy with two nuclei, and two QSOs, all of them aligned (±5 degrees); Sloan r' band, taken on the 2.6 m NOT; reproduction of Fig. 6 of López-Corredoira & Gutiérrez (2006a).

The non-cosmological redshift hypothesis also affects galaxies differently from QSOs. Cases such as NGC 7603, AM 2004-295, AM 2052-221, NGC 1232, VV172, NEQ3, NGC 450/UGC 807, etc. present statistical anomalies also suggesting that the redshift of some galaxies different from QSOs might have non-cosmological redshifts. Not all supporters of the non-cosmological redshift agree with this idea; for instance, Arp claims that galaxies might have non-cosmological redshift because they derive from an evolution of ejected QSOs, while G. Burbidge only defends the non-cosmological redshifts in QSOs. In this paper, except for this paragraph, I shall talk only about anomalies in QSOs.

2. Probabilities of being background QSOs

There are two possible interpretations of these data: either QSOs with different redshifts are objects with different distances and the configurations are due to chance, or there are non-cosmological redshifts, and QSOs with different redshifts are at the same distance. The first position, the standard one, defends the hypothesis that in all cases the main galaxy is surrounded by background QSOs. The idea is quite straightforward. The position of anomalous redshifts is not naive enough to deny this possibility, and this might be the case in some examples. However, the question is not whether such a fortuitous projection is "possible" but whether it is "probable".

For the calculation of this probability *P*, it is normally assumed that the background/foreground objects in a small area are distributed according to a Poissonian distribution with the average density in any line of sight. There may be some clustering

of QSOs, but this does not essentially affect the numbers. A conspiracy in which a given line of sight crosses several clusters of QSOs at different redshifts is not justified because the increase in probability due to the increase in density along lines of sight with clusters is compensated for by the additional factor to be multiplied by the present amount P to take into account the probability of finding clusters in the line of sight. On average, in any arbitrary line of sight in the sky, the probability will be given anyway by the Poissonian calculation of P with the average density of QSOs in the sky (see further details in subsection 5.3.1 of López-Corredoira & Gutiérrez 2004).

A much more important matter concerns the consideration of the number of events in the whole sky. Of course, there may be many objects that are quite peculiar but we must consider the global probability in the whole sky multiplying by the number of galaxies or QSOs as in the anomalous case. For instance, if we found an NGC galaxy of magnitude m_g with a very low probability P_0 of being surrounded by N QSOs up to some magnitude and angular distance, we must calculate the global probability P, multiplying it by the number of NGC galaxies (around eight thousand; or somewhat larger if we considered the southern hemisphere), or at least the galaxies in the whole sky up to magnitude m_g.

It is said that one should not carry out a calculation of the probability for a configuration of objects known a priori (for instance, that they form a certain geometrical figure) because, in some way, all possible configurations are peculiar and unique. That is right so long as we speak about random configurations that do not indicate anything special. For example, if the Orion constellation is observed and we want to calculate the chance of its stars being projected in that exact configuration, we will get a null probability (tending towards zero as the allowed error in the position of the stars with respect the given configuration goes to zero), but the calculation of this probability is worthless because we have selected a particular configuration observed a priori. Therefore, the statistics to be carried out should not be about the geometrical figure drawn by the sources, unless that geometrical configuration is representative of a physical process in an alternative theory (for instance, aligned sources might be representative of the ejection of sources by a parent source).

In this last sense, I think that much of the statistics already published is valid and indicates the reality of some kind of statistical anomaly. It would be useful to look out for physical representations indicating peculiarities beyond mere uniqueness. I disagree with the claim that all attempts to calculate probabilities of unexpected anomalies are a posteriori and whose validity may therefore be rejected. Some astrophysicists, when looking at the images of the controversial objects, argue along the lines that the anomalous distributions of QSOs are curious, but that since they were observed their probability is 1 and there is therefore nothing special about them. According to this argument, everything is possible in a Poissonian distribution and nothing should

surprise us. But I believe that statistics is something more serious than the postmodern rebuff that anything is possible.

We think that this anti-statistical position, this way of rejecting the validity of the calculated probabilities, is equivalent to the scepticism that those unfamiliar with mathematics express when we discuss the low probability of winning the lottery. They continue to bet regardless with hope that, however low the probability, somebody is sure to win so why not me. Typically they are unaware of how low some probabilities are and make no distinction between a case such as $P \sim 10^{-2}$, which is a low but certainly makes a win possible from time to time, and the case $P \sim 10^{-7}$, which virtually ensures no wins during seven lifetimes of daily betting. Small numbers, like the huge numbers prevalent in astronomy, are not easily assimilated. Of course, somebody wins the lottery but this is because the number of players multiplied by the probability of winning of each player is a number not much lower than one; otherwise, nobody would ever be likely to win.

Even worse, imagine that a person wins the lottery four consecutive times with only one bet each time. If we did not believe in miracles, we might think that this person had cheated. We might carry out some statistical calculations and show how improbable it was that he/she could have won by chance. Somebody might say about these calculations that they are not valid because they were carried out a posteriori (after the person won the lottery four consecutive times). We would not agree because there is an alternative explanation (he/she is cheating; and this explanation could be thought of before the facts) and the event of winning the lottery four consecutive times, apart from being very peculiar among the random possibilities, would be an indication to support this hypothesis.

For our cases, we have facts (higher concentration of QSOs, alignments, QSOs projected onto filaments) which suggest that an alternative (a priori) theory claiming that galaxies/QSOs may be ejected by galaxies better represents the observations. The measured probabilities are not to form triangles or any shape observed a priori only because it was observed. The peculiarity that is analysed is not comparable with the previous example of Orion because we have in mind a physical representation rather than a given distribution of sources. The difference from the Orion problem is that the peculiarity of Orion is not associated with any peculiar physical representation to be explained by an alternative theory. The question is as follows: what is the probability, P, that the apparent fact be the fruit of a random projection of sources at different distances? In other words, what is the probability, P, that the standard theory can explain the observed facts without aiming at alternative scenarios?

There is some a posteriori information used normally in the calculations: for instance the maximum magnitude or distance of the QSOs according to what we have observed in our particular case. It is in this sense an a posteriori calculation, we are calculating

the most pessimistic case (the lowest probability). Because of this, the values of *P* might be slightly underestimated (by a factor not higher than 10-100) with respect to an a priori calculation without any information on magnitudes or radii, but values of *P* lower than ~10^{-4} should in any case be considered as statistically anomalous. In order to make a fairer estimate of the probability, we could calculate $P^*=2^n P$, where *n* is the number of parameters on which *P* depends. For instance, when we observe a source with magnitude 19 and we calculate $P(m<19)$ we are putting the limiting magnitude exactly at the observed number; a fairer calculation would be $P^*(m<(19+x))$ such that a source with magnitude 19 is a typical average source in the range $m<(19+x)$, i.e. roughly that half of the sources with $m<(19+x)$ have $m<19$ and the other half have $19<m<(19+x)$. This is equivalent to calculating $P^*(m<(19+x))=2\ P(m<19)$ and for the correction we can multiply by a factor two for any independent parameter. Values of P* lower than around 10^{-3} should be considered as statistically anomalous.

3. Gravitational lensing

An explanation for anomalous redshift systems might be found in principle if we considered some kind of gravitational lensing by the foreground object. However, the effect on the enhancement of the probability produced by an individual galaxy is small. In order to increase by at least an order of magnitude in *P* per object, i.e. an average enhancement of ~10 in density for each of the QSOs, we would need an average magnification of around 20,000 (López-Corredoira & Gutiérrez 2004, sect. 5.3.2). This is so because the enhancement in the source counts increases because of the flux increase of each source but decreases owing to the area distortion, which reduces the number counts by losing the sources within a given area (Wu 1996). A magnification of 2×10^4 is extremely high and impossible to achieve by a galaxy lens. The highest known values are up to a factor ~30 (Ellis et al. 2001) for background objects apparently close to the central parts of massive clusters. Moreover, a single galaxy would only produce a significant magnification at very close distances (a few arcseconds) from the center. The possibility of multiple gravitational microlenses within the galaxy (Paczynski 1986) does not work either (Burbidge et al. 2005, sect. 5; López-Corredoira & Gutiérrez 2006, sect. 8).

Weak gravitational lensing by dark matter has also been proposed as the cause of the statistical correlations between low and high redshift objects, but this seems to be insufficient to explain them (Kovner 1989; Zhu et al. 1997; Burbidge et al. 1997; Burbidge 2001; Benítez et al. 2001; Gaztañaga 2003; Jain et al. 2003; Nollenberg & Williams 2005; Tang & Zhang 2005) and cannot work at all for the correlations with the brightest and nearest galaxies; López-Corredoira & Gutiérrez (2007) have shown that gravitational lensing is not the solution for the possible minor axis excess of QSOs. Scranton et al. (2005) have claimed that the small amplitude correlation between QSOs and galaxies from the SDSS survey is due to weak gravitational lensing but this does not explain the most general case with bright nearby galaxies. Komberg & Pilipenko

(2008) suggested the existence of a large number of globular or proto-globular clusters in the intergalactic medium of clusters of galaxies as an explanation of the correlations, a hypothesis which is awaiting testing. In principle, it seems there are many field galaxies with an excess of surrounding QSOs. Further research is in any case necessary in some of these aspects.

4. Are all QSOs with anomalies really QSOs?

Even more important than thinking about gravitational lensing or discussing the probabilities of background projections is being sure that the identification of QSOs and their redshifts is correct. For instance, cases like 3C 343.1 (Arp et al. 2004a), if we believe that they are indeed a radio galaxy at z=0.34 and a radio QSO at z=0.75 separated by 0.25", are really spectacular, but are we sure of the correct identification of the sources?

An example: Burbidge et al. (2003) suggested that many of the ultraluminous compact X-ray sources (ULXs) found in the main bodies of galaxies are "local" QSOs, or BL Lac objects, with high intrinsic redshifts in the process of being ejected from those galaxies. Certainly, there is an overdensity of these X-ray sources near galaxies but, before claiming a case of anomalous redshift, we have to be sure that they are indeed QSOs with different redshifts. Arp et al. (2004b) took some spectra of ULXs and saw that some of them are QSOs but others were not. López-Corredoira & Gutiérrez (2006b) have shown that >50% of ULXs are effectively QSOs but, except for few cases which are anomalous for other reasons (e.g., NGC 3628, NGC 4319), the probability of these QSOs being background objects is significant, while the cases with ULXs over the expected background were not QSOs. Therefore, there are not enough statistical anomalies to claim that some ULXs are non-cosmological redshift QSOs.

Another example: Flesch & Hardcastle (2004) published a catalog of candidate QSOs (with a probability >40% of being QSOs) derived from the correlation of radio and X-ray sources with blue point-like optical objects. In this catalog, there is an overdensity of QSO candidates in fields near galaxies and for bright sources. However, López-Corredoira et al. (2008) showed that the probabilites of being QSOs were overestimated for bright objects and near galaxies. Therefore, again, there are in principle no reasons to think about statistical anomalies in this catalog.

5. Discussion

Some of the examples of apparent associations of QSOs and galaxies with different redshifts may be just fortuitous cases in which background objects are close to the main galaxy, although the statistical mean correlations remain to be explained, and some lone objects have a very low probability of being a projection of background objects. Nevertheless, these very low probabilities (down to 10^{-8} or even lower, assuming

correct calculations) are not extremely low and, if the anomaly is real, one wonders why we do not find very clear anomalous cases with probabilities as low as 10^{-20}. Gravitational lensing seems not to be a solution yet, although further research is required, and the aim that the probabilities be calculated a posteriori is not in general an appropriate answer for avoiding or forgetting the problem.

There are also other aspects of QSOs that are not well understood within the cosmological redshift assumption, and which could find an explanation within a non-cosmological redshift hypothesis (López-Corredoira & Gutiérrez 2006a, sect. 9): the extremely high luminosity of QSOs at high redshift and the absence of bright QSOs at low redshift, periodicity of redshifts, their age and metallicity and the lack of evolution signs, superluminal motions, spectral features in the emission and absorption lines that are not well understood, the mechanism of triggering activity, the fact that Faraday rotation does not increase with redshift, etc.

There are two possibilities: either all cases of associations are lucky coincidences with a higher probability than expected for some still unknown reason, or there are at least some few cases of non-cosmological redshifts. If we accepted that some objects (maybe not all of them) with different redshifts had the distance of the main galaxy, there might be some truth in those models (Burbidge 1999; Arp 1999a,b, 2001; Bell 2002a,b) in which QSOs and other types of galaxies are ejected by a parent galaxy, as proposed by Ambartsumian (1958). In these models, galaxies beget galaxies, not all the galaxies would be made from initial density fluctuations in a Big Bang Universe. For the explanation of the intrinsic redshift, there are several alternative hypotheses (reviews at Narlikar 1989; López-Corredoira 2003, sect. 2.1; 2006).

In my opinion, we must consider the question as an open problem to be solved. I maintain a neutral position, neither in favor of nor against non-cosmological redshifts. The debate has lasted a very long time, around 40 years, and it would be time to consider making a last effort to finish with the problem. However, the scientific community does not seem very interested in solving the problem because most researchers consider it already solved. Supporters of the standard dogma of all redshifts being cosmological do not want to discuss the problem. Every time it is mentioned they just smile or talk about “a posteriori” calculations, manipulations of data, crackpot ideas, without even reading any paper on the theme. The Arp-Burbidge hypothesis has become a topic in which everybody has an opinion without having read the papers or knowing the details of the problem, because some leading cosmologists have said it is bogus. This means that it is very difficult to make any progress in this field, as is usual when a researcher is away from the mainstream (López-Corredoira & Castro-Perelman, eds., 2008). On the other hand, the main supporters of the hypothesis of non-cosmological redshifts continue to produce tens of analyses of cases in favor of their ideas without too much care, pictures without rigorous statistical calculations in many cases, or with wrong identifications, underestimated probabilities, biases, use of

incomplete surveys for statistics, etc., in many other cases. There are, however, many papers in which no objections are found in the arguments and they present quite controversial objects, but due to the bad reputation of the topic, the community simply ignores them. In this panorama, it would be difficult for the problem to be solved soon. Mainstream cosmologists are waiting for the death of the main leaders of the heterodox idea (mainly Arp and the couple Burbidge) to declare the idea as definitively dead. However, as in the case of Ambartsumian, some challenging ideas could survive or even be revived after some time if we leave open problems without a clear solution. Therefore, I would recommend that the community either finds good arguments against the Arp-Burbidge hypothesis, or that it allows their ideas to cohabit within the possible speculative hypotheses in cosmological scenarios.

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Redshifts by coherent optics: Stromgren sphere of SNR1987A

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Abstract. The very large and the "anomalous" redshifts are observed in regions where atomic hydrogen is detected by its Lyman lines. Several coherent Raman scattering by the hyperfine structure of levels 2S or 2P may combine into a parametric effect which transfers energy between light modes, shifting the frequencies without any blurring of the images and the spectra. The temperature of a mode is deduced from its luminance by Planck-Nernst law; to obey thermodynamics, the hottest modes, usually light, are cooled, redshifted, while the cold ones, usually radio, thermal radiation, are blueshifted. Another coherent effect is superradiance which appears in regions where long paths in partly ionized hydrogen are available, in particular in the transition zone between a Stromgren sphere and unexcited atomic hydrogen. It appears that the brightest ring of SNR 1987A is the image and has the spectrum of a Stromgren sphere; the broad, strongly redshifted Lyman alpha spectrum of the internal ring cannot obey Hubble's law because the distance of SNR1987A was measured accurately by photon echoes; it results from coherent scattering. The spectra of the quasars, in particular the periodicities of the redshifts are accurately explained; other effects such the "anomalous acceleration" of Pioneer 10 and 11 probes, the proximity effect, the frequency shifts of the extreme UV lines of the Sun result from coherent scattering in atomic hydrogen too.

Investigation of rapid profile variability in the broad hydrogen lines of AGNs

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Abstract. We report the new results of high sampling rate spectral monitoring of the radio galaxy 3C390.3 and the Seyfert galaxy Markarian 6 carried out at the 2.6-m telescope of BAO. We have observed narrow, small-amplitude, but significant profile changes in the broad Hα and Hβ emission lines on time scale of hours. Variability on time scales shorter than the light crossing time of the BLR can be used to test different kinematical models of broad emission line region of AGNs. Obtained results may indicate the response of rotating emitting gas (an accretion disk) with macroturbulence to a light pulse from a central source.

On the formation and evolution of extended extragalactic radio sources. Implications for the Fanaroff-Riley Dichotomy

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1. Introduction

Magnetic fields have an important role in the dynamics evolution and radiation of extragalactic radio sources. In all known theories of formation of extragalactic radio sources are suggested some configuration of magnetic field for host galaxy and the mechanism of synchrotron radiation of relativistic plasma. For example in most known Blandford Znajek (1977) mechanism is supposed the existence of large angular momentum and strong magnetic field, parallel to the rotation axes of the Kerr black hole. Relativistic particles are moving along the magnetic lines and radiating in this field. Luhmann (1979) suggests an alternative interpretation of the morphology of extragalactic radio sources what concerns the possibility that the emission arises from the belts of trapped in dipolar magnetic field electrons, encircling the parent galaxy in the same manner as the Van Allen belts encircle the Earth. In (Andreasyan 1984) we have suggested a mechanism of the formation and evolution of extragalactic radio sources in framework of the cosmological conception of V.Ambartsumian (Ambartsumian 1966). This mechanism was as a hybrid of Blandford Znajek and Luhmann mechanisms. We suggest that the magnetic field of the host galaxy or AGN has a dipole configuration, with dipole axes parallel to the rotation axes or minor axes of host elliptical galaxy. Extragalactic radio sources are formed from relativistic plasma clouds, ejected from the central part of the optical galaxy and moving in its large-scale, dipole magnetic field. In the frame of suggested mechanism the well-known Fanaroff-Ryley Dichotomy (Fanaroff & Ryley 1974) finds a very simple physical explanation.

2. The mechanism of formation and evolution of extragalactic radio sources

The main suggestion is the dipole configuration of magnetic field of galaxy, with dipole axes parallel to the rotation axes of host elliptical galaxy. There are some observational evidences that large-scale galactic magnetic fields can have dipolar configuration as in NGC4631 (Dumke et al. 1995), or in the halo of our Galaxy (Andreasyan & Macarov 1989, Han et al.1997). The magnetic fields of dipole configuration can be formed and evaluate, for example, in the result of Biermann battery effect (Biermann 1950), in Active Galactic Nucleus (Lesch et all., 1989; Andreasyan 1996). Partly in (Andreasyan

1996) for the evolution of dipolar magnetic field we suggest a model of AGN in agreement with the cosmological conception of V.Ambartsumian. In agreement with this model from the nucleus of Active galaxy there is a permanent ejection of hot plasma, which expands in the fast rotating gaseous medium of the central part of galaxy. Because of the large differences between scattering time of electrons and protons in every point of rotating medium the rotation velocity of these particles will be different. In the result of forming of circular electric currents in the central part of Active galaxies evaluates dipolar magnetic fields. There are a lot of observational evidences of existence of the large amount of neutral and ionized gas in the host elliptical galaxies (for example Morganti et al.2003a, Andreasyan et.al.2008), and outflows in Radio galaxies (Morganti et al.2003b).

We suggest also that the extragalactic radio sources are formed from relativistic plasma clouds, ejected from the central part of the optical galaxy and moving in large-scale dipolar magnetic field of parent galaxy. The behaviors of relativistic plasma cloud, ejected in the direction of the dipole axis, depends on the ratio Q of the kinetic energy density of the plasma to the magnetic field energy density,

i) If the ratio Q is greater than unity (Q>1), the clouds of charged particles, expanding, travels large distances from the optical galaxy, carrying with them the magnetic field lines, as it takes place in many well known models. In this case we expect to observe the more elongated radio images (Fig.1). The directions of the major axes of the radio images will be close to those of the minor or rotation axes of the optical galaxies. The magnetic field will be mainly parallel to the radio axes. It can be formed also radio lobes and hot spots near their outer edges, and also magnetic canals directed from the AGN to the lobs, which can assist for the formation of good collimated jets in case of the secondary permanent ejection of plasma lower energy density. Similar features we observe in extragalactic radio sources of FRII classes (Fanaroff & Riley 1974).

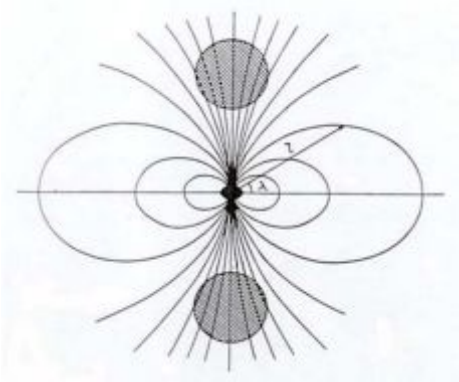


Fig. 1. The ratio Q is greater than unity (Q>1).

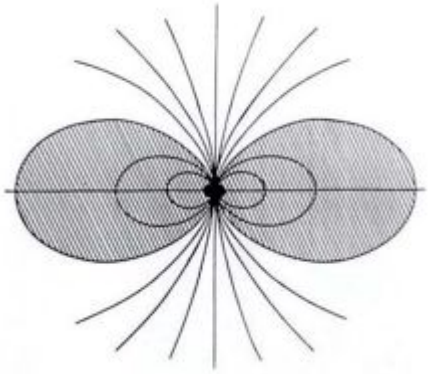


Fig. 2. The ratio Q is less than unity (Q<1)

ii) If the ratio Q of energy densities is less than unity (Q<1), the charged particles will move along the field lines of the dipole magnetic field of the galaxy. In the younger

radio sources along the dipole axes, will be observed the long, jet like features with relatively large opening angles, like to the jets classified as FRI type.

After some time, moving along the field lines of the dipole, the charged relativistic particles will be trapped in a magnetic field, in result of which all particles will execute oscillations and drift in a plane perpendicular to the dipole axis, as it takes place in the Van Allen belts of the Earth (Fig.2). In this case will be formed less elongated radio sources with the radio axes correlated with optical major axes. Also we will observe mainly the edge darkened FRI type. As it was shown, in this case it can be formed two type radio sources; the relatively older Van Allen belts type sources, perpendicular to the dipole axes, and the younger jet like radio sources along the dipole axes. These two types of extragalactic radio sources can be classified as edge darkened FRI type, though they have different radio orientations relatively to parent galaxies. It must be noted that such two types of relatively older and younger radio sources with different orientations can be observed near the same optical galaxy. Then we will observe misalignments of radio sources of different size scale, as in Appl et al. (1996), or the X shape radio sources (see for example Cheung 2007).

In this reason parallel to the well known Fanaroff-Riley classification we bring a simple classification of extragalactic radio sources by the elongation parameter K, which is the ratio of the largest dimension of the radio image to the perpendicular dimension. In the case when the charged relativistic particles will be trapped in a dipolar magnetic field, the largest value of the parameter K can be obtained from the equation of the line of force of the dipole field. This ratio is near to 2.5.
Thus, one can introduce a quantitative criterion for separating the extragalactic radio sources by their elongation parameter. That is $K>2.5$ for the case of $Q>1$ (FRII type), and for younger jet like radio sources of FRI type in case of $Q<1$, and $K<2.5$ for the relatively older Van Allen belts type sources in case of $Q<1$. As it will be seen in the next paragraphs there are certain correlations between FR and our classifications of extragalactic radio sources, though there are some differences. The statistical analyses of observational data were done parallel for the FR and K classification.

3. The Fanaroff-Riley Dichotomy of extragalactic radio sources

The Fanaroff-Riley (1974) classification of extragalactic radio sources was done using the morphology features, the edge darkened-FRI, and edge brightened, relatively more luminous FRII types. Probably one can wait some other morphological and physical differences between the different FR classes of extragalactic radio sources. The study of Fanaroff-Riley (FR) Dichotomy is very important for understanding and choosing of the mechanism of their formation and evolution. The FR Dichotomy is studying now very intensively, and there are found many other observational differences between the physical properties of these two morphological classes: in the total luminosity, in radio core powers, in ratio of core to lobe radio power, in the relationships between emission-

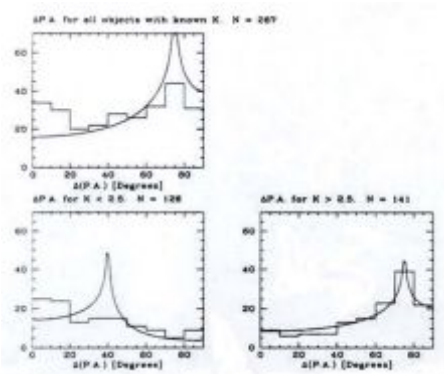
line luminosity and radio power etc (Zirbel & Baum 1995; Gopal-Krishna & Wiita 2000; et cetra). From the mechanism of formation of extragalactic radio sources, discussed above, it is clear that there can be a lot of other differences between different classes of extragalactic radio sources. Here we bring some other observational differences between the different FR types as well as between the types classified by the elongation parameter K.

4. Observational data

For this study we have used data for 267 nearby radio galaxies identified with elliptical galaxies brighter than 18th magnitude (sample1) (Andreasyan & Sol, 1999), and 280 extragalactic radio sources with known position angles between the integrated intrinsic radio polarization and radio axes (sample 2) (Andreasyan et all., 2002). For nearby radio sources, we have data: on the position angles of the optical images (oPA) of elliptical galaxies, found mainly from the Palomar maps, the position angles of radio image (rPA), angles between optical and radio axes (dPA), and FR classes taken from the literature. The radio galaxies were also classified as a function of their elongation parameter K using the published radio maps. The analyses of our data confirms the existence of a significant correlation between the Fanaroff-Riley classification and classification in terms of the elongation of radio images.

5. The correlation of radio axis with the optical axis in nearby radio galaxies

Data from sample of 267 nearby radio galaxies were used to construct histograms separately for radio galaxies classified by elongation (Fig.3) and for radio galaxies with FR classes (Fig4). On the figures the difference between the radio and optical position angles (dPA) is laid out along the horizontal axis and the number of radio galaxies along the vertical axis.



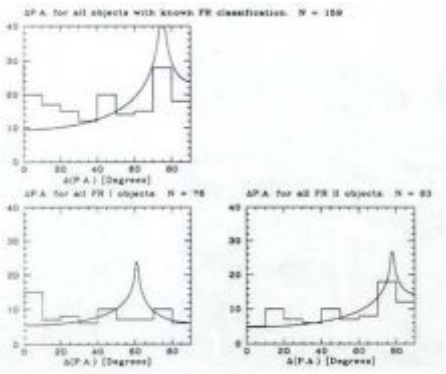


Fig. 3. The distribution of (dPA) for K classes. **Fig. 4.** The distribution of (dPA) for FR classes.

On the histograms we bring also the expected distribution of dPA. The continuous lines

show the best fits obtained from primary distributions of intrinsic angles, described by a delta-function, taking into account the orientation effect. The fit of observed histograms of these relative orientations have been done using the method developed by Appl et al. (1996).

So we found, that more elongated and FRII type radio galaxies are directed as minor axes or rotation axes of host galaxies, while the less elongated and FRI ones are directed perpendicular to these axes. This result is in a good agreement with conclusions of paragraph 2. The weaker correlation for radio sources of FRI type can be explained by our mechanism. As it was shown, if Q<1 It can be formatted two type radio sources; the relatively older Van Allen belts type sources (with K<2.5), and the younger jet like radio sources along the dipole axes (with K>2.5). These two type of extragalactic radio sources are classified as edge darkened FRI type, though they have different radio orientations relatively to parent galaxies

6. The ellipticity of elliptical galaxies identified with the different types of extragalactic radio sources

In the Sample1 we have data of the ellipticity (E) of 154 optical elliptical galaxies. For all of them we have the elongation parameters K and for 95 - the Fanaroff-Riley classes. We use this data to study the distribution of ellipticities of parent optical galaxies for different FR types and for different classes of our K classification (Fig.5).

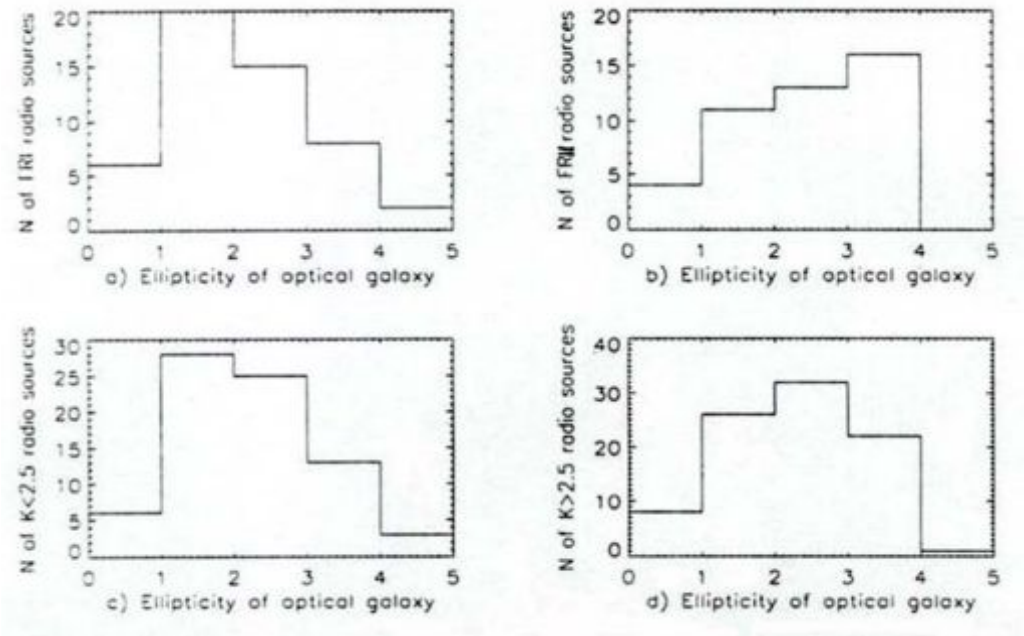
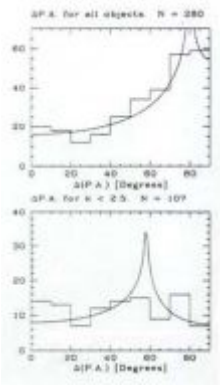


Fig. 5. The ellipticities of optical parent galaxies for different FR types and for different classes of K classification.

From the Fig.5 it is clear that the host elliptical galaxies of less elongated extragalactic radio sources and radio sources of FRI type have less ellipticity (E ~1 to2) than these of radio sources of large elongation and radio galaxies FRII type (E ~3 to 4).

7. The correlation of the radio polarization angle with the radio axes of extragalactic radio sources

We study the distribution of angles Δ(PA) between the integrated intrinsic radio polarization (perpendicular to intrinsic magnetic field's direction) and the major axes of 280 extragalactic radio sources (sample 2) for different types of radio sources, classified by their elongation (Fig.6), and FR classification (Fig.7). The histograms of angles between radio and polarization axes are shown here.



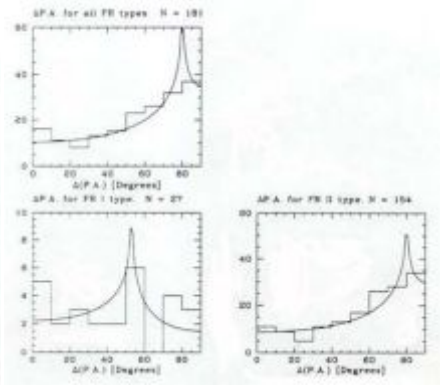


Fig. 6. The distribution of Δ(PA) for K classes. **Fig. 7.** The distribution of Δ(PA) for FR classes.

The fit of the observed histograms of relative orientations also have been done using the method developed by Appl et al. (1996), taking into consideration the projection effects. The continuous line shows the best fits obtained from primary distributions of intrinsic angles described by a delta-function. This describes rather well the case of elongated and FRII sources, which suggests that their intrinsic integrated polarization is perpendicular to their intrinsic major radio axes. Conversely the less elongated and FRI radio sources do not show any specific intrinsic angle and cannot be fitted by such a simple scenario.

Magnetic fields in optically thin synchrotron radio sources are perpendicular to the polarization electric vector. So the main result of this study is that integrated magnetic fields can be described as intrinsically aligned with major radio axes for elongated and FRII radio sources, while they appear not correlated at all with radio axes for stocky and FRI radio sources.

8. Conclusions

The results, obtained above from the analyses of observational data are in good agreement with the suggested mechanism of formation of extragalactic radio sources. Almost all main properties of extragalactic radio sources can be qualitatively explained in terms of mentioned scenario, varying the parameter Q and the environment of radio sources.

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Synchro-self-Compton mechanism of radiation of jets of AGN with ultra- and moderate relativistic electrons

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1. Introduction

The problem of galactic nuclei activity plays a great role in scientific works of V.A.Ambartsumian. He often pointed out on the importance of studying this problem. It is not surprising that the conference in his memory is devoted to it.

Now great attention is paid to active galactic nuclei (AGN). They are observed practically in all spectral ranges from radio to TeV. Radio jets now can be observed in optics and UV. Multiple coordinated observations permit to make more precise models of jets and other objects connected with galaxy activity. Nevertheless many questions remain unsolved.

It is synchro-self-Compton mechanism that is accepted as the basic mechanism of radiation of jets. According this mechanism, relativistic electrons in weak magnetic field radiate soft photons which then are scattered by the same electrons. As a result photons are transfered to more hard regions up to X-rays and gamma-rays. A bump arises in spectrum and its appearance is not possible to explain without Compton scattering which transfers the electron energy to photons. There are several models of the sources of the energy of electron gas but it is not a problem of our work.

The synchro-self-Compton mechanism is widely applied when observations of AGN are interpreted (for example, in [1, 2, 3]). As a rule the theory of synchrotron radiation is applied, i.e., the radiation of ultra-relativistic electrons [4]. The theory of Compton scattering is developed in detail and energies of electrons and photons can be arbitrary (the review is given in [5]).

The theory of cyclo-synchrotron radiation is based on the Schott formula [6]. This formula defines the power of radiation in separate lines if radiating electron is rotating in the plane which is perpendicular to magnetic field. The generalization to the case of movement along a spiral was made by several authors starting with basic works [8, 7**Error! Reference source not found.**]. Many other physicists and astrophysicists developed the theory for the possibility of its application to astrophysical objects (the reviews are in the books [9, 10]).

In this note we first show that the generalization of the Schott formula to the case of spiral movement can be made using simple physical considerations. Then we obtain rather simple expression for the emissivity of electrons with given energy and for emission coefficient of the unit volume, i.e., averaged on the momentum distribution of electrons which is assumed to be axial to the magnetic field.

As a rule the electrons are assumed to be ultrarelativistic with energies much more then mc^2 so used formulas are not applicable to the cases when they are only of order mc^2. We give the general formulas.

2. Radiation of an electron rotating on the circle

Let an electron rotate in homogeneous magnetic field $H\vec{e}$, where a unit vector $\vec{e} = (0,0,1)$, with the velocity $\beta_{\mathrm{e}} c$ in a plane perpendicular to the field. Then angular frequency of its rotation is $\omega_{\mathrm{e}} = \dfrac{\omega_*}{\gamma_{\mathrm{e}}}$, where cyclotron frequency $\omega_* = \dfrac{eH}{mc}$ and the Lorents factor $\gamma_{\mathrm{e}} = \dfrac{1}{\sqrt{1-\beta_{\mathrm{e}}^2}}$. The radius of the circle (the Larmor radius) is expressed in terms of introduced variables: $R_* = c\beta_{\mathrm{e}}/\omega_{\mathrm{e}}$.

The spectrum of such an electron consists of equidistant lines with frequencies $l\omega_{\mathrm{e}}$, where $l = 1,2,...$ is the number of the line. Let

$$\vec{n}_{\mathrm{e}} = (\sin\theta_{\mathrm{e}}\cos\varphi, \sin\theta_{\mathrm{e}}\sin\varphi, \cos\theta_{\mathrm{e}}) \qquad (1)$$

be an unit vector with spherical coordinates θ_{e} (a polar angle) and φ (an azimuth). The power of energy in unit frequency in the direction of this unit vector is defined by well known Schott formula (see for example [11]):

$$W_l^{\mathrm{e}} = \frac{e^2}{c} l^2 w_l^{\mathrm{e}}, \qquad (2)$$

where

$$w_l^{\mathrm{e}} = \cot^2\theta_{\mathrm{e}} J_l^2(Z_l^{\mathrm{e}}) + \beta_{\mathrm{e}}^2 J_l'^2(Z_l^{\mathrm{e}}), \quad Z_l^{\mathrm{e}} = l\beta_{\mathrm{e}}\sin\theta_{\mathrm{e}}, \quad (3)$$

and $J_l(Z)$ is the Bessel function.

According to the Schott formula the power of radiation in lines depends on the direction but their frequencies do not depend on the direction. The wave vector of the photons in

the line l is equal to $\square\vec{\kappa}_l^{\mathrm{e}} = \kappa_l^{\mathrm{e}}\vec{n}_{\mathrm{e}}$, where the wave number is $\square\kappa_l^{\mathrm{e}} = \dfrac{\omega}{c}$. We introduce four-dimensional photon wave vector

$$\underline{\kappa}_l^{\mathrm{e}} = \{\kappa_l^{\mathrm{e}}, \vec{\kappa}_l^{\mathrm{e}}\}. \qquad (4)$$

The Schott formula can be rewritten in relativistic way in terms of momentum emitted by an electron in the angular frequency $c\kappa_l^{\mathrm{e}}$ into solid angle $\mathrm{d}^2 n_{\mathrm{e}} = \sin\theta_{\mathrm{e}}\mathrm{d}\theta_{\mathrm{e}}\mathrm{d}\varphi$ near the direction of the vector $\vec{n}_{\mathrm{e}}$:

$$\mathrm{d}^2\underline{P}_l^{\mathrm{e}} = e^2 c\frac{(\kappa_l^{\mathrm{e}})^2}{\omega_{\mathrm{e}}^2}\underline{\kappa}_l^{\mathrm{e}}\frac{w_l^{\mathrm{e}}}{l}\mathrm{d}^2 n_{\mathrm{e}} = \frac{W_l^{\mathrm{e}}}{c}\omega_{\mathrm{e}}\{1, \vec{n}_{\mathrm{e}}\}\mathrm{d}^2 n_{\mathrm{e}}. \qquad (5)$$

3. Movement along the spiral

If there is a component of the electron velocity along the field $\beta_{\parallel}c\vec{e}$, then by the Lorents transform with such a speed we can transport into the frame of reference where the electron is rotating in the plane on the circle. For each electron such a frame will be its own. In this frame the relations of the previous point are fulfilled. We mark the quantities in this frame with index e.

The Lorents factor for the electron velocity along the field is $\gamma_{\parallel} = \dfrac{1}{\sqrt{1-\beta_{\parallel}^2}}$. Its speed perpendicular to the field is $c\beta_{\perp} = c\dfrac{\beta_{\mathrm{e}}}{\gamma_{\parallel}}$ and the full speed is $c\beta = c\sqrt{\beta_{\parallel}^2 + \beta_{\perp}^2}$.

The frequency of rotation of the electron is $\omega = \dfrac{\omega_{\mathrm{e}}}{\gamma_{\parallel}} = \dfrac{\omega_*}{\gamma_{\mathrm{e}}\gamma_{\parallel}} = \dfrac{\omega_*}{\gamma}$, where the complete Lorents factor $\gamma = \dfrac{1}{\sqrt{1-\beta^2}} = \gamma_{\mathrm{e}}\gamma_{\parallel}$ is a product of the factors of two movements which are perpendicular. The electron moves along the spiral with the step $2\pi c\dfrac{\beta_{\parallel}}{\omega} = 2\pi c\gamma_{\parallel}\gamma_{\mathrm{e}}\dfrac{\beta_{\parallel}}{\omega_*}$ and the radius $R_* = c\beta_{\mathrm{e}}\gamma_{\mathrm{e}}/\omega_{\mathrm{e}}$, not depending on $\beta_{\parallel}$.

We introduce three and four-dimensional wave-vectors and wave-number of photons in the line l:

$$\vec{\kappa}_l = \kappa_l\vec{n}, \quad \underline{\kappa}_l = \{\kappa_l, \vec{\kappa}_l\}, \quad \vec{n} = (\sin\theta\cos\varphi, \sin\theta\sin\varphi, \cos\theta). \qquad (6)$$

The azimuth of the direction of radiation is the same in both frames. Wave-numbers of radiated photons are connected with the Doppler effect and the directions - with the aberration law.

4. Radiation of an electron moving along the spiral

For generalization of the formula (2) for the case of spiral movement it is not necessary to find the Fourier transform of the electric field strength created by the electron as it is made when the Schott formula is deduced. It is sufficient to write a formula for relativistic covariant quantity which contains only relativistic values and if $\beta_{\|} = 0$ the formula have to go to the Schott formula. Such a quantity is the emitted momentum.
With the Doppler and aberration laws we easy find the generalizations of the values (3):

$$w_l = \gamma_{\|}^2 \left[\frac{(\cos\theta - \beta_{\|})^2}{\sin^2\theta} J_l^2(Z_l) + \beta_{\perp}^2 J_l'^2(Z_l) \right], \quad Z_l = l\beta_{\mathrm{e}} \sin\theta_{\mathrm{e}} = l\beta_{\perp} \frac{\sin\theta}{1-\beta_{\|}\cos\theta}. \quad (7)$$

Relativistic expression for emitted momentum in the line l in the direction $\vec{n}$ into solid angle $\mathrm{d}^2 n = \sin\theta \mathrm{d}\theta \mathrm{d}\varphi$ with the wave number κ_l is the direct generalization of the equation (5):

$$\mathrm{d}^2 \underline{P}_l = e^2 c \frac{(\kappa_l)^2}{\omega_{\mathrm{e}}^2} \underline{\kappa}_l \frac{w_l}{l} \mathrm{d}^2 n. \quad (8)$$

Since the product $(\kappa_l)^2 \mathrm{d}^2 n$ is a relativistic invariant and $\underline{\kappa}_l$ is a four-vector proportional to the four-momentum of the photon then $\mathrm{d}^2 \underline{P}_l$ is a four-dimensional momentum. If $\beta_{\|} = 0$ the formula (8) transforms to (5).
The formula (8) can be rewritten in the form of the second expression in (5):

$$\mathrm{d}^2 \underline{P}_l = \frac{W_l}{c} \frac{\omega}{1-\beta_{\|}\cos\theta} \{1, \vec{n}\} \mathrm{d}^2 n. \quad (9)$$

Here the energy in the line calculated on the unit emitted frequency is introduced because the distance between the neighbouring lines is equal $c\frac{\kappa_l}{l} = \frac{\omega}{1-\beta_{\|}\cos\theta}$.
The expression for these energy is a generalization of the Schott formula (2)

$$W_l = \frac{e^2}{c} l^2 \frac{w_l}{(1-\beta_{\|}\cos\theta)^2} \quad (10)$$

and returns to it when $\beta_{\parallel} = 0$.

The full momentum in the line l

$$\underline{P}_l = \int \mathrm{d}^2 \underline{P}_l = e^2 c \int \frac{(\kappa_l)^2}{\omega_{\mathrm{e}}^2} \underline{\kappa}_l \frac{w_l}{l} \mathrm{d}^2 n = e^2 c \int \frac{(\kappa_l^{\mathrm{e}})^2}{\omega_{\mathrm{e}}^2} \underline{\kappa}_l^{\mathrm{e}} \frac{w_l^{\mathrm{e}}}{l} \mathrm{d}^2 n_{\mathrm{e}} \quad (11)$$

does not depend of the frame system in which the integrals are calculated.

5. The source frame

Let in definite place of some object the local magnetic field H and the ensamble of electrons are given. Let us introduce the local frame system with the axis of applicats in the direction of the field. We choose the origin of the coordinates in such a way that the mean momentum of the electrons be equal to zero. This system we call the source frame.

Let us introduce the notations for dimensionless momenta $z_{\perp} = \gamma\beta_{\perp}$, $z_{\parallel} = \gamma\beta_{\parallel}$ and for pitch-angle α with the definitions $\beta_{\parallel} = \beta\cos\alpha$, $\beta_{\perp} = \beta\sin\alpha$.

The local distribution of the electron momenta is characterized by the function $\tilde{f}_{\mathrm{e}}(z_{\perp}, z_{\parallel}) = f_{\mathrm{e}}(\gamma, \alpha)$. If the distribution is isotropic this function depends on the energy γ only: $f_{\mathrm{e}}(\gamma)$. The distribution function in the source frame is normalized with the condition

$$2\pi \int_{-\infty}^{\infty} \mathrm{d}z_{\parallel} \int_0^{\infty} \tilde{f}_{\mathrm{e}}(z_{\perp}, z_{\parallel}) z_{\perp} \mathrm{d}z_{\perp} = 2\pi \int_0^{\pi} \sin\alpha \mathrm{d}\alpha \int_1^{\infty} \gamma z \mathrm{d}\gamma f_{\mathrm{e}}(\gamma, \alpha) = 1, \quad (12)$$

where $z = \sqrt{z_{\perp}^2 + z_{\parallel}^2} = \sqrt{\gamma^2 - 1}$. If the distribution function depends only on energy the integral on the pitch-angle is replaced by 2. The number density of the electrons is denoted as N_{e}.

6. The emission in the source frame

Let us fix not only the direction of radiation but its frequency as well. Then the wave-vector $\vec{\kappa}_l$ of the photons emitted in the source frame in the line l will be fixed. Let us represent the integral (11) as a triple integral on the momenta of photons:

$$\underline{P}_l = \frac{e^2 c}{\omega_{\mathrm{e}}^2} \int \kappa_l^2 \underline{\kappa}_l \frac{w_l}{l} \mathrm{d}^2 n = \frac{e^2 c}{\omega_{\mathrm{e}}^2} \int \mathrm{d}^3\kappa \underline{\kappa} \frac{w_l}{l} \delta(\kappa - \kappa_l) = \frac{e^2}{\omega_*} \int \frac{\mathrm{d}^3\kappa}{\kappa} \underline{u}_l. \quad (13)$$

Here the four-dimensional dimensionless vector

$$\underline{u}_l = \{u_l^0, \vec{u}_l\} = \frac{c\gamma_e^2}{\omega_*}\kappa\underline{\kappa}\frac{w_l}{l}\delta(\kappa-\kappa_l) = \frac{c\gamma_e^2}{\omega_*}\kappa_l\underline{\kappa}_l\frac{w_l}{l}\delta(\kappa-\kappa_l). \qquad (14)$$

The full momentum emitted by the ensemble of electrons in the unit volume can be calculated in the source frame as

$$\overline{\underline{P}}_l = 2\pi N_e\int_{-\infty}^{\infty}\mathrm{d}z_\parallel\int_0^\infty z_\perp\mathrm{d}z_\perp\,\tilde{f}_e(z_\perp, z_\parallel)\underline{P}_l = 2\pi N_e\int_0^\pi\sin\alpha\mathrm{d}\alpha\int_1^\infty z\gamma\mathrm{d}\gamma f_e(\gamma,\alpha)\underline{P}_l. \quad (15)$$

Using the second expression for this momentum and changing the order of integration we get

$$\overline{\underline{P}}_l = \{\overline{P}_l^0, \overline{\vec{P}}_l\} = 2\pi N_e\frac{e^2}{\omega_*}\int\frac{\mathrm{d}^3\kappa}{\kappa}\int_1^\infty z\gamma\mathrm{d}\gamma\int_0^\pi\sin\alpha\mathrm{d}\alpha f_e(\gamma,\alpha)\underline{u}_l. \quad (16)$$

In the astrophysical works the ordinary frequency ν (not angular ω) is used so in the following we use the notation $\nu_* = \omega_*/2\pi = \dfrac{eH}{2\pi mc}$. We will use also the frequency of radiation

$$\nu = \frac{c}{2\pi}\kappa, \quad \kappa = \frac{2\pi}{c}\nu. \qquad (17)$$

The basic characteristic of emitting electrons is considered to be their emissivity, i.e., the energy emitted in the unit time into the unit solid angle in the unit interval of frequency. To find this value for the electrons of given energy we have to represent the time component of the momentum (16) as

$$\overline{P}_l^0 = 2\pi N_e\int_0^\pi\sin\alpha\mathrm{d}\alpha\int_1^\infty z\gamma\mathrm{d}\gamma f_e(\gamma,\alpha)\int_0^\infty\mathrm{d}\nu\int\mathrm{d}^2 n\,\varepsilon_{l,\nu}(\alpha,\theta,\gamma)\frac{T}{c}, \quad (18)$$

where $T = \gamma/\nu_*$ is a time during which the electron passes one step of the spiral (the period of radiation). The speed of light in the denominator transfers the energy into the zeroth component of the momentum. Thus the well known furmula is obtained [4]

$$\varepsilon_{l,\nu}(\alpha,\theta,\gamma) = 2\pi\frac{e^2}{c}\frac{\nu}{\gamma}u_l^0 = 2\pi\frac{e^2}{c}\nu^2(1-\beta\cos\alpha\cos\theta)\times$$
$$\times\left[\left(\frac{\cos\theta-\beta\cos\alpha}{\sin\theta}\right)^2 J_l^2(Z)+\beta^2\sin^2\alpha J_l'^2(Z)\right]\delta\left(\nu-\frac{l\nu_*}{\gamma(1-\beta\cos\alpha\cos\theta)}\right).$$

Here

$$Z = l\frac{\beta\sin\alpha\sin\theta}{1-\beta\cos\alpha\cos\theta} = \frac{\nu}{\nu_*}\gamma\beta\sin\alpha\sin\theta. \qquad (20)$$

7. The integral on the pitch-angle

The delta-function permits to calculate an integral on some variable. We choose the pitch-angle.

Denoting the dimensionless frequency (in the units of cyclotron frequency) of radiation emitted by electron and received by the observer in the line l as $\tilde{\nu} = c\kappa/\omega_* = \nu/\nu_*$, let us distinguish the pitch-angle in the argument of the delta-function:

$$\delta(\kappa-\kappa_l)=c\frac{1-\beta_\parallel\cos\theta}{\omega_*\tilde{\nu}\beta\,|\cos\theta|}\delta\left(\cos\alpha-\frac{\gamma-\zeta_l}{z\cos\theta}\right)=c\frac{\zeta_l}{\omega_*\tilde{\nu}z\,|\cos\theta|}\delta\left(\cos\alpha-\frac{\gamma-\zeta_l}{z\cos\theta}\right), \qquad (21)$$

where

$$\zeta_l = \frac{l}{\tilde{\nu}} = l\frac{\omega_*}{c\kappa}. \qquad (22)$$

The value of the pitch-angle is defined by its cosine in the argument of the delta-function. Calculation of the integral on α gives

$$\int_0^\pi \sin\alpha\,\mathrm{d}\alpha\,\delta(\kappa-\kappa_l) = \frac{c\zeta_l}{\omega_*\tilde{\nu}z\,|\cos\theta|}. \qquad (23)$$

The integral of the delta-function is non-zero only if the following inequality holds:

$$\left|\frac{1-\zeta_l/\gamma}{\cos\theta}\right| \le \beta \text{ or } \sin^2\theta\gamma^2 - 2\zeta_l\gamma + \zeta_l^2 + \cos^2\theta \le 0. \qquad (24)$$

So the quantity γ must be between the roots of the quadratic function in the left side of the second inequality in (24): $\gamma_-(\zeta_l,\theta) \le \gamma \le \gamma_+(\zeta_l,\theta)$, where

$$\gamma_\pm(\zeta,\theta) = \frac{\zeta_l \pm |\cos\theta|\sqrt{\zeta_l^2-\sin^2\theta}}{\sin^2\theta}. \qquad (25)$$

It is clear that the following condition must be fulfilled

$$\zeta_l = \frac{l}{\tilde{\nu}} \ge \sin\theta, \quad l \ge \tilde{\nu}\sin\theta. \qquad (26)$$

This condition sets the limitations on the values of wave-number κ of emitted photon and on the number of line l if the magnetic field is given. The averaging on the pitch-angle yields

$$\underline{\bar{u}}_l = \frac{1}{2}\int_0^{\pi} \sin\alpha \mathrm{d}\alpha\, \underline{u}_l = \frac{c}{\omega_*}\gamma_{\mathrm{e}}^2 \frac{w_l}{2l}\frac{\kappa\underline{\kappa}c\zeta_l}{\omega_*\tilde{\nu}z|\cos\theta|} = \frac{c^2}{\omega_*^2}\frac{\gamma_{\mathrm{e}}^2}{2}\frac{\kappa\underline{\kappa}w_l}{\tilde{\nu}^2 z|\cos\theta|} = \frac{\gamma_{\mathrm{e}}^2}{2z|\cos\theta|}\frac{\underline{\kappa}}{\kappa}w_l. \quad (27)$$

Substituting the expression for w_l, taking in attention the relation $\gamma = \gamma_{\mathrm{e}}\gamma_{\parallel}$ and equality $\kappa = \omega_*\tilde{\nu}/c$, we get

$$\underline{\bar{u}}_l = \frac{\gamma^2}{2z|\cos\theta|}\frac{\underline{\kappa}}{\kappa}\left[\left(\frac{\cos\theta - \beta_{\parallel}}{\sin\theta}\right)^2 J_l(Z_l) + \beta_{\perp}^2 J_l'^2(Z_l)\right]. \quad (28)$$

If we express the variables presented in this formula in terms of γ and substitute the value of the pitch-angle we find the final expression $\underline{\bar{u}}_l = \frac{\underline{\kappa}}{\kappa}\bar{u}_l = \{1, \vec{n}\}\bar{u}_l$, where $\bar{u}_l = \bar{u}_l^0$ and

$$\bar{u}_l = \frac{1}{2z|\cos^3\theta|}\left[\left(\frac{\zeta_l - \gamma\sin^2\theta}{\sin\theta}\right)^2 J_l^2(Z_l) + [z^2\cos^2\theta - (\gamma - \zeta_l)^2]J_l'^2(Z_l)\right]. \quad (29)$$

Averaging over the distribution of the electron momenta gives the integral

$$\langle\bar{u}\rangle_l = 2\pi\int_0^{\pi}\sin\alpha\mathrm{d}\alpha\int_1^{\infty} z\gamma\mathrm{d}\gamma f_{\mathrm{e}}(\gamma,\alpha)u_l = 4\pi\int_{\gamma_-(\varsigma_l,\theta)}^{\gamma_+(\varsigma_l,\theta)} z\gamma\mathrm{d}\gamma f_{\mathrm{e}}(\gamma,\alpha)\bar{u}_l, \quad (30)$$

where α enters into the argument of distribution function only and is defined with the value of its cosine in (21).

8. The full radiation

We can find the full radiation into all directions. For this we must integrate (30) on the angle θ because nothing depends on the azimuth. The integral must be calculated numerically.

If the distribution function is isotropic $f_{\mathrm{e}}(\gamma,\alpha) = f_{\mathrm{e}}(\gamma)$ only the energy is emitted. The integral on directions can be calculated with the arbitrary distribution function but for this we must change the order of integration. To define the limits of integration on θ with fixed ζ_l and γ it is necessary to solve inequality (24) on θ.

Then averaging the emissivity (19) on the pitch-angle, on the energy and integration on direction leads to expression

$$2\pi\int_0^{\pi}\sin\theta\mathrm{d}\theta\, 2\pi\int_0^{\pi}\sin\alpha\mathrm{d}\alpha\int_1^{\infty}z\gamma\mathrm{d}\gamma f_{\mathrm{e}}(\gamma)\varepsilon_{l,\nu}(\alpha,\theta,\gamma) =$$
$$= 4\pi\int_{(\zeta_l+1/\zeta_l)/2}^{\infty}z\gamma\mathrm{d}\gamma f_{\mathrm{e}}(\gamma)2\pi\int_{|\gamma-\zeta_l|/z}^{1}\mathrm{d}\eta\,\bar{u}_l = 4\pi\int_{(\zeta_l+1/\zeta_l)/2}^{\infty}z\gamma\mathrm{d}\gamma f_{\mathrm{e}}(\gamma)\varepsilon_{l,\nu}(\gamma). \quad (31)$$

Thus

$$\varepsilon_{l,\nu}(\gamma) = 2\pi^2\frac{e^2}{c}\frac{\nu}{z\gamma}I_l(\gamma,\tilde{\nu}), \quad (32)$$

where the integral on directions

$$I_l(\gamma,\tilde{\nu}) = \int_{|\gamma-\zeta_l|/z}^{1}\frac{\mathrm{d}\eta}{\eta^3}\left[\frac{(\zeta_l-\gamma+\gamma\eta^2)^2}{1-\eta^2}J_l^2(Z)+(2\gamma\zeta_l-\zeta_l^2-\gamma^2+z^2\eta^2)J_l'^2(Z)\right], \quad (33)$$

$\zeta_l = l/\tilde{\nu}$, and the argument of the Bessel functions

$$Z = \tilde{\nu}\frac{\sqrt{1-\eta^2}}{\eta}\sqrt{2\gamma\zeta_l-\zeta_l^2-\gamma^2+z^2\eta^2}. \quad (34)$$

This integral is calculated numerically.

9. The spectrum of monoenergetic electrons

Let us find the spectrum of radiation if the energy of electrons γ is fixed. With the fixed number of line the electron energy must obey the inequality $\gamma \geq \frac{1}{2}\left(\zeta_l+\frac{1}{\zeta_l}\right) = \frac{1}{2}\left(\frac{l}{\tilde{\nu}}+\frac{\tilde{\nu}}{l}\right)$. Various lines can contribute into radiation of given frequency. From presented inequality the limits of variation on the number of lines must be found: $\tilde{\nu}/(\gamma+z) \leq l \leq \tilde{\nu}(\gamma+z)$. The full radiation is calculated as a sum

$$\varepsilon_\nu(\gamma) = 2\pi^2\frac{e^2}{c}\nu_*\frac{\tilde{\nu}}{z\gamma}\bar{I}(\gamma,\tilde{\nu}), \quad \bar{I}(\gamma,\tilde{\nu}) = \sum_{l=\tilde{\nu}/(\gamma+z)}^{\tilde{\nu}(\gamma+z)} I_l(\gamma,\tilde{\nu}). \quad (35)$$

The formula obtained is valid for arbitrary energy of electrons. When the energies are large the summation on l can be replaced by integration with possible correction with the aid of the Euler - Maclaurin formula.

In the theory of synchrotron radiation of ultra-relativistic electrons for $\varepsilon_\nu(\gamma)$ the following expression is found ([12])

$$I_{\mathrm{as}}(\gamma,\tilde{\nu}) = \frac{\sqrt{3}}{\pi}\frac{\gamma z}{\tilde{\nu}}\frac{x}{5}\left[(2+3x^2)K_{1/3}^2(x)+xK_{1/3}(x)K_{2/3}(x)-3x^2K_{2/3}^2(x)\right]. \quad (36)$$

where $x = \tilde{\nu}/(3\gamma^2)$ and $K_\nu(x)$ is the modified Bessel function. It can be demonstrated that with the high energies the function $\bar{I}(\gamma,\tilde{\nu})$ tends to $I_{as}(\gamma,\tilde{\nu})$.

Note that the quantity $\varepsilon_\nu(\gamma)$ was calculated in [13] and [14]. In the former delta-function was reduced with the integration over small intervals of the frequency whereas in the latter it was modeled with some finite function. In both case the double integral (on α and on θ) had to be calculated. In our formula (32) the single integration is required only.

Fig. 1 gives the the sum of integrals (35) for $\beta = 0.866$ ($\gamma = 1.99982$, $z = 1.73185$). Since this value is not ultrarelativistic the asymptotic is close to function only when frequency is large and only as mean values.

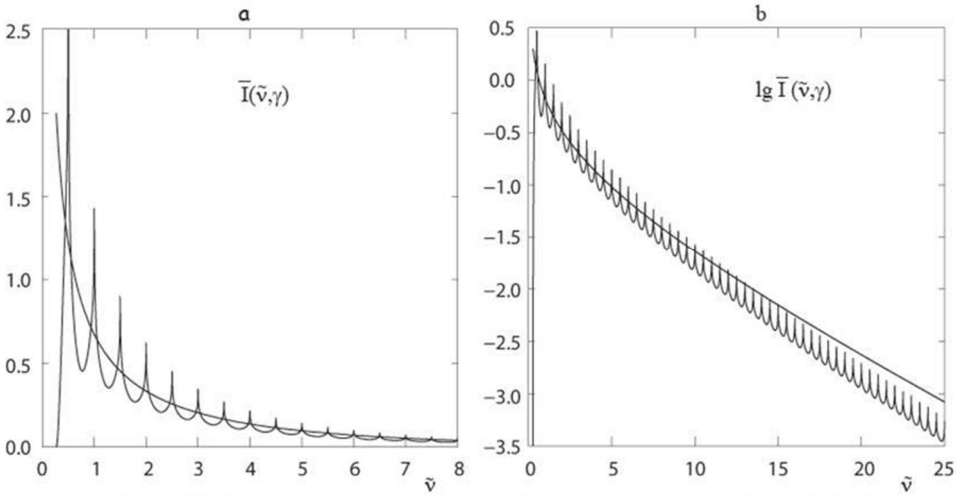

Fig. 1. The sum Ī (ν, γ) (a), its decimal logarithmus (b) for β=0.866 and ultrarelativistic limit.

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A comprehensive study of Shahbazian compact groups of galaxies

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Our research work is concerned with the investigation of Shahbazian compact groups of galaxies (SHCGs). The main goal of our program is to study the physical nature of these groups, their past and future evolutionary histories. The subject of joint research is the photometric, spectroscopic and morphological investigations of the galaxies in SHCGs for an understanding their properties (the morphology, dynamics, chemical abundance as well as evolution effects).

For this propose it is necessary to know the photometric data, i.e. B, V, R apparent magnitudes of member galaxies, radial velocities, velocity dispersion, mass-to-luminosity ratio, crossing times, metallicity.

CCD photometric and spectroscopic observations of the galaxies in SHCGs have been taken out with the 2.6 m telescope at the Byurakan Astrophysical Observatory during 1998-2000.

The data reduction procedure was made using the MIDAS, IRIS, SIPL programmes at the IAA.

Photometric data through the B, V, R filters were obtained at the prime focus of the Byurakan 2.6 m telescope using the THOMSON TH 7896 CCD with 1060 x 1028 pixels. The pixel size of 19 micron gives a scale of 0".51 per pixel. (With binning a scale is 1".02 per pixel).

The photometric calibration was performed with the B, V, R CCD magnitudes of standard stars in the field of the globular cluster NGC 7006. The exposures for the Shahbazian compact groups were 120 seconds in V, R colour bands and 240 seconds in B band, respectively. A series of the same exposures in the each colour band were obtained for the standard stars field at the same night.

The image cleaning, dark and bias subtraction, cosmic ray removal, flat fielding, and the final calibration were performed using the ESO-MIDAS software package.

The aperture photometry has been carried out for 60 galaxies in the following five groups: Sh 18 (V, R), Sh 19 (B,V,R), Sh 20 (V, R), Sh 181 (V, R) and Sh 130 (B, V, R). CCD B, V, R magnitudes were obtained for 16 galaxies in Sh 19 and Sh 130. The remaining 44 galaxies have been measured in V, R colour bands. For some galaxies isophotal photometry has been made using the program SIPL.

Spectroscopic observations have been taken out with the prime focus grism-spectrograph at the Byurakan 2.6 m telescope using the same Thomson CCD with area 500 x 1060 pixels. The pixel size of 19 micron gives a scale of 0".51 per pixel. The slit dimensions are 2" x 250". The reciprocal dispersion is 2.7 A per pixel. These observations cover the wavelength range from 4300 A to 7000 A. The exposure times for spectra of galaxies varied from 900 sec to 3000 sec.

The individual frames were first bias and dark corrected, cosmic ray removed, sky subtracted, flat-fielded and wavelength calibrated. The wavelength calibration was achieved by frequent exposures to an internal He-Ne-Ar lamp. The resulting spectra of the member galaxies usually show characteristics of K-type stars with absorbtion features of the H beta, MgIb, NaID and H alpha lines, which were used for the determination of the redshift.

The redshifts have been measured for 30 galaxies in the above-mentioned five groups.

A typical Shahbazian compact group is a relatively isolated association of five to fifteen galaxies within a small sky area of a few arcminutes across (Shahbazian 1973). These compact groups predominantly consist of early-type galaxies, elliptical and lenticular ones. This fact was also established in our earlier works (e. g. del Olmo, 1988; del Olmo and Moles, 1991; Amirkhanian et al. 1988, 1991). The number of late-type galaxies, i. e. spirals and irregulars in these systems seems to be very small. On the contrary for the Hickson compact groups at least half of the member galaxies (~50%) are spirals (e. g. Hickson, 1997). Hence it appears that the Shahbazian groups look like the central regions of rich clusters of galaxies. That is why the finding of an emission-line population with broad –line AGNs in SHCGs (del Olmo and Moles 1991; Tiersch et al. 1999; Amirkhanian et al. 2002, 2007) was unexpected. According our preliminary data about 7-10 % of member galaxies in SHCGs are emission-line galaxies. Some compact groups contain a high fraction of galaxies with morphological or kinematical pecularities and starburst or AGN activity.

Possibly, because of their large distances ($0.04 < z < 0.16$) with respect to the Hickson groups (z median ~ 0.03) SHCGs are intermediate in physical properties between classical compact groups (i. e. Hickson groups, Rose groups, south compact groups) and rich clusters of galaxies.

The detail results of these investigations will be published in our subsequent papers.

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The integral field (3D) spectroscopy of two candidates to polar-ring galaxies UGC 4385 and UGC 4261

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Abstract. We present new results of the study of the structure and kinematics of two peculiar galaxies UGC 4385 and UGC 4261 supposed to be the polar-ring galaxies on the basis of their previous photometric and long-slit spectroscopy investigation. New information about structure and kinematics of gaseous components was obtained using modern observing techniques such as integral field (3D) spectroscopy. Detailed analysis of the data confirmed that investigated objects have complicated multicomponent structure.

The analysis of the spectral data of some candidates to the polar-ring galaxies (PRG) was held. The observations of galaxies were carried out on the 6-m telescope of the Special Astrophysical Observatory of Russian Academy of Sciences using Interferometer Fabry-Perot (IFP) in emission line Hα. For both galaxies the brightness distribution in the Hα-line and in the continuum near Hα, the velocity and velocity dispersion fields of ionized gas were constructed.

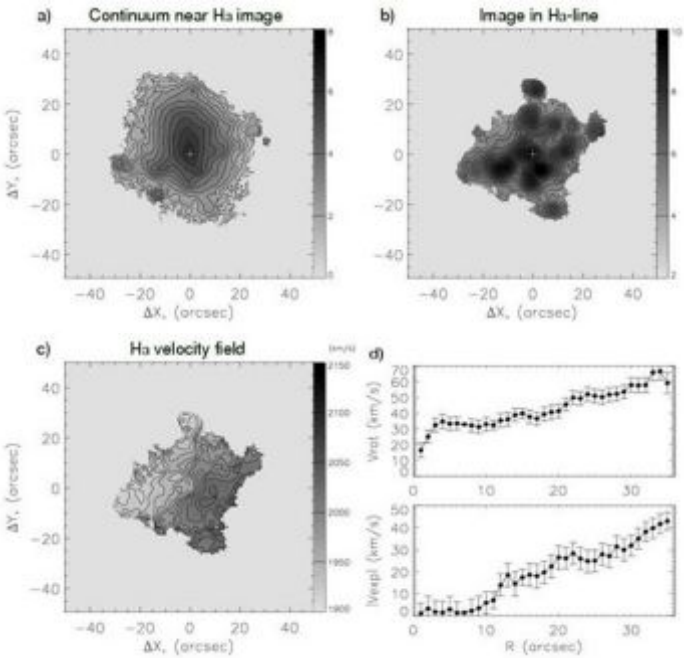

Fig. 1. UGC 4385.

UGC 4385. Data obtained using IFP (fig.1) confirmed the complex structure of UGC 4385: the presence of two kinematically distinct components with approximately perpendicular rotation planes. The infrared image in K_s-band revealed two bright condensations with spectra resembling galactic nucleus's ones, the southern condensation coincides with the optical center of UGC 4385. The main body of this object is, probably, the late-type spiral galaxy with PA about 0° strong inclined to the plane of the sky. The center of ring-like structure is the northern K_s condensation and its velocity field can be presented by the model of circular rotation with the expansion. Perhaps, we observe two galaxies in the stage of head-on collision. The distortion of the object's shape, the twist of the dynamic axis relative to the photometric one, complicated color distribution, the enhanced nuclear activity and other features suggest an ongoing interaction.

UGC 4261. UGC 4261 was added to the candidates to the polar-ring galaxies on the basis of peculiar morphology (fig.2): the irregular central body is surrounded along its minor axis by a large-scale structure resembling an open ring. In the continuum and Hα images we can see two bright condensations. The analysis of the velocity field using the method of "tilted rings" was

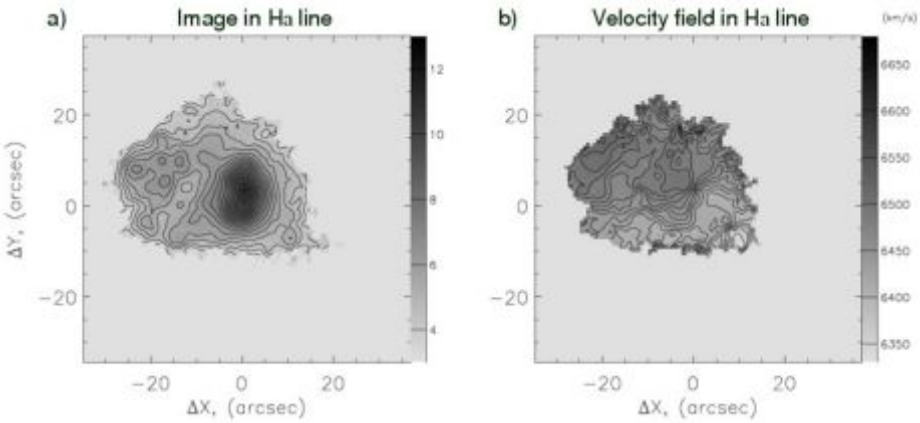

Fig. 2. UGC 4261.

held, and the rotation curve of the subsystem (fig.3) with the center in southern condensation was constructed. This rotation curve may be fitted by exponential disk (h = 3.6 kpc) and spherical isothermal halo (ρ_0 = 0.001 M_{sun}/pc^3, R_c = 7.2 kpc). It seems UGC 4261 is the pair of interacting galaxies. The interaction can explain observed morphological features like tidal tails.

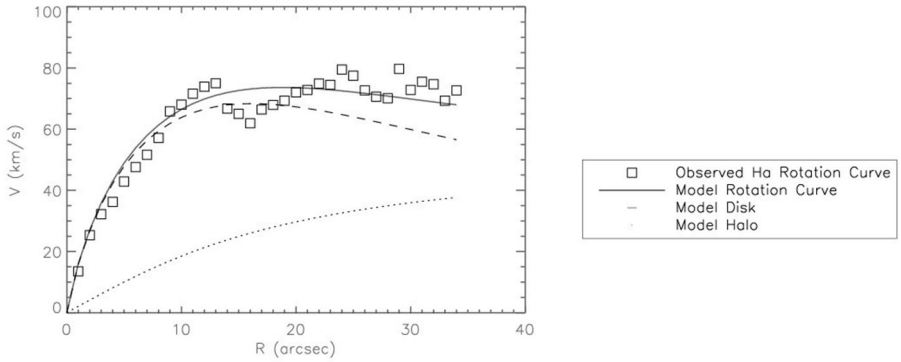

Fig. 3. The observed and model rotation curves of UGC 4261.

Infrared and Optical Study of Faint IRAS-FSC Sources

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Abstract. Extragalactic sources from the IRAS Faint Source Catalog (FSC) which have the optically faintest magnitudes (E>18) were selected by spatial coincidence with a source in the FIRST radio survey, and 28 of these sources have been observed with the Infrared Spectrograph on *Spitzer* (IRS). The sources luminosities encompass the range from local ULIRGs to the most luminous sources discovered by *Spitzer* at z~2. Detectable PAH features are found in 15 of the sources (54%), and measurable silicate absorption are present in 19 sources (68%); both PAH emission and silicate absorption are present in 11 sources. PAH luminosities are used to determine the SB fraction of bolometric luminosity, and model predictions for a dusty torus are used to determine the AGN fraction of luminosity in all sources based on νL_ν (5.5 μm). The ratio of infrared to radio flux, defined as $q=\log[f_\nu(25\ \mu m)]/[f_\nu(1.4\ Ghz)]$, does not distinguish between AGN and SB for these sources.

1. Sample Selection

We first cross-correlated the IRAS-FSC (Moshir et al. 1990) sources with the FIRST catalog (White et al. 1997), using FSC sources listed as real detections rather than upper limits at both 25 μm and 60 μm (sources with quality flags 2 or 3). 2,310 sources were associated to within 3 times the FSC 1σ positional uncertainty (ranging from 15″ to 90″ for individual sources). Images from the DSS2 were then examined for the 2,310 fields to determine an optical identification at the radio source position. Of the 2,310 sources, 1,944 can be identified with bright or medium brightness galaxies (photographic $E \leq 16^m$), and 225 are fainter galaxies ($16^m \leq E \leq 21^m$). The remaining 141 sources are identified with bright Galactic stars or have no optically identifiable galaxy; the latter could be either spurious sources or cirrus sources. The best available optical photometry for the entire FSC sample is the Minnesota APS catalog (Cabanela et al. 2003), which gives photographic O and E magnitudes. The final sample we select is defined by having E > 18, yielding 31 sources, ~ 1% of all sources common between FSC and FIRST.

2. IRS Observations and Analysis

We have obtained IRS low-resolution spectra for 24 of these 31 sources, and additional 4 have been observed in other *Spitzer* programs. Our new observations were made with

the IRS Short Low module in orders 1 and 2 (SL1 and SL2) and with the Long Low module in orders 1 and 2 (LL1 and LL2), described in Houck et al. (2004). These give low resolution spectral coverage from ~5 μm to ~35 μm. Background subtraction for spectra was done using co-added background images that added both nod positions having the source in the other slit. Starting with v15 of the SSC basic calibrated data (BCD), spectra were extracted using the SMART analysis package (Higdon et al. 2004). Extractions were done with an average width of 4 pixels (perpendicular to dispersion; width varies with wavelength because of varying spatial resolution), then we correct fluxes by using Markarian 231 as a standard source and extracting it with both 8 pixel and 4 pixel windows. Final spectra were boxcar smoothed to the approximate resolution of the different IRS modules (0.2 μm for SL1 and SL2, 0.3 μm for LL2, and 0.4 μm for LL1).

Fluxes and equivalent widths (EWs) for the 6.2 μm and 11.3 μm PAH features are measured using the single Gaussian line fit routine within SMART. For the 6.2 μm PAH line, the fitting is between 5.5 μm and 6.9 μm; for the 11.3 μm line, fitting is between 10.4 μm and 12.2 μm. The fitting procedure we use applies a linear fit for the continuum and a Gaussian fit for the line between the selected wavelengths.

The depth of the 9.7 μm silicate absorption feature is measured using the continuum fitting technique described by Spoon et al. (2007). The average spectrum of the 19 sources showing silicate absorption is compared to the spectrum of Markarian 231 in Figure 1.

3. Results and Discussion

One of the sources is a blazar (Perry et al. 1978) with observed IRS flux at 25 μm smaller by a factor of 30 than when observed by IRAS. The source met the criteria for definition of the sample and so was observed too. As a result of the unexpectedly low flux, the IRS spectrum is very noisy and shows no measurable features.

The ordering spectra by $\nu L\nu$(5.5 μm) showed, that sources with the strongest PAH features and weakest silicate absorption are among the lowest luminosity sources. Sources of intermediate luminosity generally show conspicuous silicate absorption and weak PAH features. Finally, the highest luminosity sources have the weakest silicate absorption and the weakest PAH features.

As a comparison standard throughout, we use the thoroughly studied ULIRG Markarian 231 because its mid infrared spectrum (Weedman et al. 2005; Armus et al. 2007) is similar in shape to many other absorbed sources. In Figure 1, we show this similarity by comparing the average spectrum of all the FSC sources having silicate absorption to the spectrum of Markarian 231. The average absorption depth is similar to that of

Markarian 231, for which the silicate optical depth of -0.7 corresponds to maximum extinction by the silicate feature of ~ 50% of the continuum flux.

The distribution of continuum luminosities for the FSC sources is shown in Figure 2, based on $\nu L\nu(5.5\ \mu m)$. This parameter is chosen for comparison to the large samples of ULIRGs, Sy1, Sy2, and QSOs summarized in Hao et al. (2007). All of these sources previously observed with the IRS have $\log[\nu L\nu(5.5\ \mu m)] < 46.1$, and the median ULIRG luminosity is $\log[\nu L\nu(5.5\ \mu m)] = 44.4$. The luminosity limit of these previously observed sources is exceeded by 3 of the FSC sources. The most luminous obscured sources at z ~ 2 (Houck et al. 2005; Yan et al. 2007) have $\log[\nu L\nu(5.5\ \mu m)] < 46.6$ (Polletta et al. 2008), and this extreme luminosity is matched by one of the FSC sources. The median luminosity of the FSC sources is $\log[\nu L\nu(5.5\ \mu m)] = 44.8$. These results indicate, therefore, that the FSC sample encompasses a luminosity range which includes typical ULIRGs and extends to the most luminous sources discovered by *Spitzer*.

Figure 2 compares the FSC sample and the ULIRG samples in 25 μm flux and redshift (using the *Spitzer* IRS $f\nu(25\ \mu m)$ for the FSC sources and the IRAS $f\nu(25\ \mu m)$ for the ULIRG sources). The FSC sample extends to higher redshifts than the previously published ULIRG samples which have IRS spectra. The maximum redshift of the FSC sample is 0.93 with median redshift of 0.25 whereas the ULIRG samples tabulated by Imanishi et al. (2007) and Farrah et al. (2007) have maximum z of 0.26. The combined dataset extends over a range of nearly 1000 in $f\nu(25\ \mu m)$.

The ratio of MIR to optical or NIR flux is a measure of domination of a source by dust absorption and dust continuum luminosity. In general, very dusty sources will have ratios enhanced both by increased extinction of shorter wavelengths and increased dust continuum at longer wavelengths, although detailed understanding of individual sources requires modeling of the dust absorption and emission contributions (e.g. Marshall et al. 2007). For comparing fluxes at different wavelengths we have used the 2MASS survey (Skrutskie et al. 2006) which encompasses all sources in the ULIRG samples and most sources in our FSC sample with NIR J, H, K photometry. The median for the combined ULIRG samples is $f\nu(25\ \mu m)/f\nu(J) = 2.42$ and is the same for the FSC sample, counting limits. The similarity in $f\nu(25\ \mu m)/f\nu(J)$ indicates that the FSC sample does not select in favor of sources with a greater dust content compared to the ULIRG samples.

One major objective of previous ULIRG studies has been to determine the relative contributions of starbursts (SBs) and AGN to the total luminosity of a source. A division of luminosity between SB and AGN at rest frame ~ 6 μm can be determined by the strength of the PAH features compared to the continuum, as measured by the equivalent width (EW) of the PAH features (Genzel et al. 1998; Laurent et al. 2000; Imanishi et al. 2007; Farrah et al. 2007; Desai et al. 2007). Pure SBs with no indicators of AGN at any wavelength have rest frame EW(6.2 μm) > 0.45 (Brandl et al. 2006). Smaller equivalent widths correspond to an increasing continuum, assumed to be caused

by an AGN. Very few ULIRGS have such strong PAH features; only 2 of 49 in Imanishi et al. (2007) and 8 of 107 in Desai et al. (2007), which indicates a substantial AGN contribution to the continuum at 6 μm. The distribution of PAH strength for the FSC sample is shown in Figure 2; only one of 28 sources has 6.2 μm EW> 0.45 and only three have EW > 0.2. These results indicate that, as in the ULIRG samples, the near-infrared continuum is generally much stronger relative to the PAH feature than in pure SBs. It is also seen in Figure 2 that the most luminous sources at rest frame 5.5 μm in the FSC sample are sources with the smallest PAH EW. The simplest interpretation of these results is that the most luminous near-infrared sources are dominated by AGN power.

How the luminosity divides in the near-infrared between AGN and SBs is not necessarily the same as the separation of SB and AGN power for bolometric luminosities. Many efforts have been made to separate the bolometric contributions within ULIRGs of AGN and SBs by assuming templates for the total AGN spectrum and the total SB spectrum (e.g. Farrah et al. 2003). But the assumed templates can be incorrect if, for example, there is cooler dust outside of the dusty torus which is also heated by the AGN, or if SBs are deeply buried in optically thick clouds that produce hotter dust (e.g. Levenson et al. 2007; Imanishi et al. 2007; Polletta et al. 2007). The templates may be examples of observed sources, but the intrinsic nature of the template sources may not be fully understood. It is desirable, therefore, to determine an estimate of AGN and SB contributions which is independent of template assumptions.

For the rest frame parameters $\nu L\nu$(5.5 μm) and L(6.2 μm), which are measured for our sources, empirical determinations relate these parameters to the bolometric luminosities of obscured AGN [Lir(AGN)] and of SBs [Lir(SB)]. For local SBs (Brandl et al. 2006) and high redshift sub-mm galaxies which are SBs (Pope et al. 2008), an empirical relation has been found to be log[Lir(SB)] = log[L(6.2 μm)]+ 2.7±0.1; L(6.2 μm) is the total luminosity of the 6.2 μm PAH feature, after subtracting the underlying continuum.

For AGN, it is assumed that the infrared continuum associated with the AGN arises from warm dust within a torus surrounding the accretion region. Using the clumpy torus model of Hönig et al. (2006), empirical fits to overall SEDs in Polletta et al. (2007) give log[L_{ir}(AGN)] = log[νL_ν(6.0 μm)] + 0.32±0.06. We make a nominal modification to this by transforming νL_ν(5.5 μm) to νL_ν(6.0 μm) using Markarian 231 because of its similarity to the average spectrum of our absorbed sources in Figure 1. With this correction, we have log[L_{ir}(AGN)] = log[$\nu L\nu$(5.5 μm)] + 0.33±0.06. We adopt this relation as applying to a “pure” AGN, with no contribution to IR luminosity from any source other than the torus heated by the AGN. These two relations for deriving L_{ir}(SB) and L_{ir}(AGN) are used to determine the SB and AGN luminosities for the FSC sources. We find that sources divide equally between those dominated by AGN luminosity and those by SB luminosity. The median luminosity in the sample attributed to AGN, log

L*ir*(AGN) ~ 45.2, is the same as that attributed to SBs, log L*ir*(SB), although AGN sources reach to higher luminosities.

Because this FSC sample was selected with the requirement of a FIRST radio detection (White et al. 1997), all sources have 1.4 GHz detections. We defined the parameter as q = log[*fv*(25 μm)/*fv*(1.4 GHz)] in the observed frame. For determining q, sources are assumed to be unresolved so the peak *fv*(1.4 GHz) is used. Larger values of q correspond to relatively weaker radio sources. The median value of q for the FSC sample is 1.25, which is larger than the median of q = 0.8 for faint *Spitzer* First Look Survey (FLS) sources detected at both 24 μm and 1.4 GHz (Appleton et al. 2004), which is the q value expected from previously known radio-infrared correlations for SBs (Condon et al. 1982). The median q is even less, q = 0.4, for faint sources in the *Spitzer* FLS, which have IRS spectra and z > 1 in Weedman et al. (2006). Some of these differences may be redshift effects. For example, Markarian 231 has q = 1.6 but, if at z = 2, would have q = 0.6. Our results do not indicate that the value of q can be used as a discriminant between SB and AGN sources. A median q of ~ 1.3 is found both for the SB sources that have PAH features and for the remaining sources dominated by AGN. Also, the range of q is similar for both categories of sources. All of the values of q for the FSC sources are much larger than in radio-loud AGN or quasars, for which q < -1 at any redshift (Higdon et al. 2005). The radio data, therefore, do not indicate any evidence of radio-loud AGN among the FSC sources.

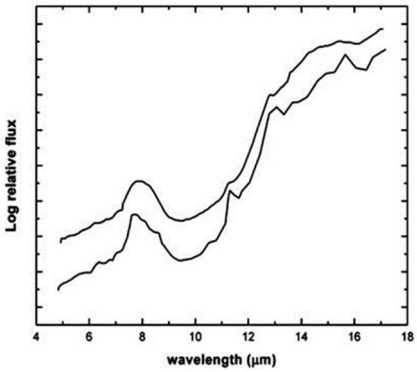

Fig. 1. Comparison of Mrk. 231 (top) with average of the 19 FSC galaxies with measured silicate absorption (bottom), arbitrarily normalized.

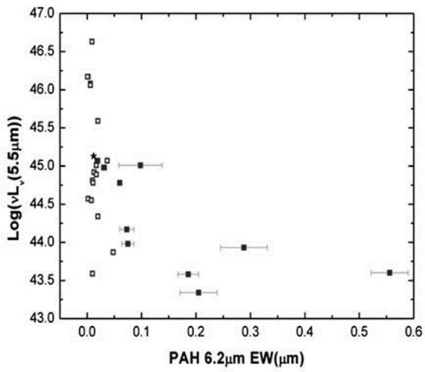

Fig. 2. Comparison of luminosities and PAH strengths for FSC sources; filled squares are sources with PAH detections and open squares show PAH upper limits for sources without PAH detections. The star indicates Mrk 231. Error bars show uncertainties in PAH EWs.

4. Summary

The IRAS-FSC was used to select the 31 optically faintest FSC sources which are also identified in the FIRST radio survey, representing the optically faintest 1% of IRAS extragalactic sources. 28 of these sources have been observed with the IRS on *Spitzer*.

This FSC sample reaches to higher redshifts and higher luminosities than the IRAS discovered ULIRG samples observed spectroscopically with *Spitzer*, and overlaps the luminosity range of *Spitzer*-discovered 24 μm sources at z $\sim$ 2. The FSC sources have $0.12 < z < 1.0$ and luminosities $43.3 < \log[\nu L\nu(5.5\ \mu\mathrm{m})] < 46.7$. 15 of the sources have detectable PAH features, and 19 have measurable silicate absorption. Median properties of the sample having silicate absorption are very similar to the ULIRG Markarian 231 in silicate strength, continuum luminosity, ratio $f\nu(25\ \mu\mathrm{m})/f\nu(\mathrm{J})$, and relative radio luminosity.

PAH luminosities are used to determine the SB luminosity within each source, and predictions from dusty torus models are used to determine the AGN luminosity. Sources have similar bolometric luminosities arising from SBs and from AGN and are equally divided between sources dominated by SBs and sources dominated by AGN. The ratio of infrared to radio flux is not a measure of whether sources are dominated in the infrared by SB or AGN luminosity.

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Relationship of Galaxies from the Second Byurakan Survey to Zwicky Clusters

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1. Introduction

Galaxy evolution in different systems depends of its environmen. In particular, galaxy-galaxy interactions can induce nuclear activity and/or enhanced star formation in the central region of a galaxy. Despite some contradictory results, observations in general support this idea. A higher rate of nuclear activity or enhanced star formation have been detected in interacting galaxies and in close pairs of galaxies (e.g. [1, 2]), and an enhanced number of active galaxies has been found in extreme environments of compact groups (e.g. [3-5]). Studies of the number of components around active and non-active galaxies have reported contradictory results.

As a result of the high scientific interest in such a fundamental topic as galaxy evolution, there have been many studies trying to understand the effect of the environment on the evolution of the galaxies. The results obtained, even contradictory, add new details in understanding of the problem. Given the complex nature of these interactions, many more are needed to disentangle the effects and achieve a clear understanding of the processes involved. One method to study this problem is to look at the spatial distribution of active and star forming galaxies collected in specific catalogues of these objects.

Now we presented data for all Second Byurakan Survey (SBS) galaxies located within the contours of Zwicky clusters, discusses the data and reports the results of a statistical investigation on the relationship between SBS galaxies and Zwicky clusters.

2. Expected and observed frequency of SBS galaxies in Zwicky clusters

The overlap in sky coverage of the SBS [24] and Zwicky [25] (CGCG) surveys is approximately 990 sq. degrees. In this common area, excluding already studied Markarian galaxies [21, 22], there are 1677 SBS galaxies and 1392 of them have redshifts. If we restrict the volume of space to consider only objects with $z < 0.050$ (near-distance class of Zwicky), this reduces the number of galaxies with known redshifts to 900 (65% of 1392). In this volume there is no any compact cluster and there

are 21 open and 16 medium compact clusters with the area coverage shown in Table 1. This table also shows the number of observed SBS galaxies compared to the expected random number of SBS galaxies in the field of these clusters assuming a Poisson distribution. In the last column of Table 1 the numbers of real and probable members of clusters to the numbers of the SBS galaxies which are projected on the clusters are presented. As seen in Table 1, the observed numbers of SBS galaxies associated with open Zwicky clusters about 16%, and associated with medium compact clusters about 72% higher that expected from a random distribution. This means that in studied volume SBS galaxies do not avoid open and medium compact Zwicky clusters and about 4.5 times often prefer medium compact systems.

Of 218 SBS galaxies coinciding with "near open" Zwicky clusters 47 (22%) are members of 12 clusters. Of 240 SBS galaxies, 47 (20%) are observed in 6 near medium compact clusters.

SBS galaxies are sometimes members of foreground or background groups of galaxies instead of being associated with the main cluster. SBS galaxies (20% of 218) which coincide with 9 foreground or background groups of 7 open clusters, and 28 galaxies (12% of 240) coinciding with 6 foreground or background groups of 4 medium-compact clusters. 39 SBS galaxies (about 4% of total 900) which are probable members of 14 Zwicky clusters but cannot be confirmed because there is either no independent measurement of the cluster redshift using another galaxy, or the difference in velocities between the cluster and SBS galaxy is in the 2000 – 4000 km/s range. Finally, there are real projection cases for SBS galaxies on the Zwicky clusters. 75 galaxies (34% of 218) which are projected on 11 open clusters, 19 galaxies (8% of 240) on 5 medium compact clusters.

It is clear from these that SBS galaxies participate in the clustering of galaxies with an over-density in cluster fields and an under-density in the field when compared to a random distribution. It is interesting to note that SBS galaxies coincide with medium compact clusters with greater probability (92%) that with open ones (65%), which is similar to that found for Markarian [21, 22] and Seyfert [6] galaxies.

3. Conclusions

The conclusion of this study may be summarized as follows:

1. SBS galaxies participate in the tendency of galaxies to cluster and do not avoid any type of Zwicky clusters.
2. SBS galaxies appear in medium compact clusters with greater probability than with open ones.
3. SBS galaxies follow the well established morphology-density relation. Earlier morphological type, higher luminosity, larger linear size and redder SBS galaxies

prefer to be discovered in the cluster with higher compactness or more compact regions of the clusters.

4. The number distribution of SBS galaxies in Zwicky open clusters probably follows the distribution of normal galaxies.
5. The number distribution of SBS galaxies in medium compact and compact clusters shows two-maxima structure.

Table 1. Predicted and Observed Numbers of SBS Galaxies in Zwicky Clusters.

System type	Area Sq. deg.	Number of SBS galaxies		
		Expected	Observed	Cluster Members /Nonmembers
Open	207	188±14	218	142/75
Medium-compact	154	140±12	240	221/19
All near clusters	361	328±18	458	363/94
Field	629	572±24	442	n/a

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Three Pairs of Galaxies with Ultraviolet Excess

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Abstract. The results of the morphological and the spectral investigation of galaxies with UV excess NN 65,66; 92,96; 135,136 from Kazaryan list (Kazarian, 1979a, 1979b) are presented. The morphological investigation of galaxies bases on the observations on primary focus of 2.6 m telescope of Byurakan Astrophysical Observatory (Armenia} (Yeghiazaryan, 1983). The spectra were obtained by 2.6 m telescope Crimean Observatory (Ukraine) and 6m telescope of Special Astrophysical Observatory (Russia) (Yeghiazaryan, 1989a, 1989b). It is shown, that there are three physical different morphological types and activity level galaxies among Kazarian's list of galaxies with UV excess. The relative intensities of the strong emission and forbidden lines of the bright nuclear and compact HII regions of galaxies are estimated.

X-ray Properties of OH Megamaser Galaxies

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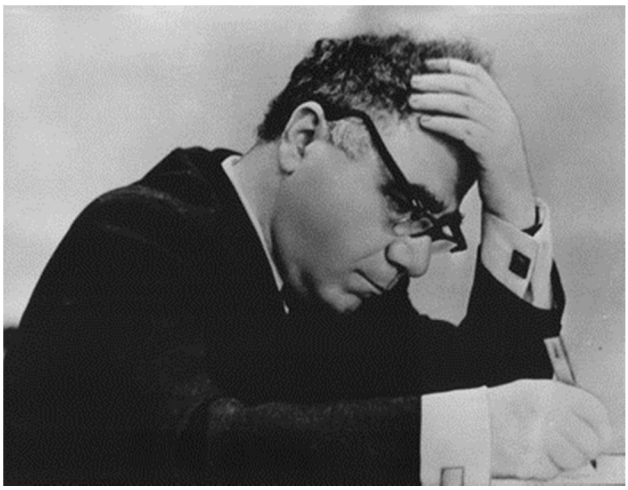
Abstract. The properties of OH megamaser galaxies in the X-ray region are discussed. Observational data from the X-ray satellites are presented. Based on a sample of OH megamaser galaxies it is shown that the X-ray and OH emission are closely coupled. The results of this study indicate that in OH megamaser galaxies an active nucleus, X-ray heating of molecules, and saturation of the maser emission can play an important role.

Session 4. COSMOLOGY



V.A. Ambartsumian's contribution in the field:

Using the statistical studies of wide binaries it was shown for the first time that those did not obey the dissociative equilibrium conditions. The same studies allowed arrive at a conclusion that the **components of binaries had been formed jointly.** Moreover, the observed distribution put an **upper limit for the Galaxy age, 10 billion years.** This proved incorrectness of the generally accepted estimate of the age of our Galaxy obtained by James Jeans (so-called "long scale", 10^{13} years) was shown and a new estimate of its age was given (so-called "short scale") (1936-1937).

Ref.: V.A. Ambartsumian – Double Stars and the Cosmogonic Time-Scale // *Nature, 137, 537, 1936.* V.A. Ambartsumian – On the Statistics of Double Stars // *Astron. Zh., 14, 207-219, 1937 (in Russian).*

Cosmology and Mini-Creation Events

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1. Introduction

The most perceptive astronomer in recent history was Viktor Ambartsumian the famous Armenian theorist. Starting in the 1950s and 1960s (Ambartsumian, 1965) he stressed the role of explosions in the universe arguing that the associations of galaxies (groups, clusters, etc.) showed a tendency to expand with far larger kinetic energy than is expected by assuming that the gravitational virial condition holds.

Here we take up the issue emphasized by Ambartsumian that there apparently exist phenomena in nuclei of galaxies where matter seems to appear with large kinetic energy of motion directed outwards. Later we will also include other phenomena that share the same property, namely explosive creation of matter and energy. We shall refer to such events as *mini-creation* events (MCEs, hereafter).

Since these phenomena appear on the extragalactic scale and involve quasi-stellar objects, active galaxies, powerful radio sources and clusters and groups of galaxies at all redshifts, we believe they must have an intimate connection with cosmology. Indeed, if one looks at standard cosmology, there too the paradigm centers around the 'big bang' which is itself an explosive creation of matter and energy. In the big bang scenario the origin of all of the phenomena is ultimately attributed to a single origin in the very early universe. No connection has been considered by the standard cosmologists between this primordial event and the MCEs that Ambartsumian talked about. In fact, the QSOs and AGN are commonly ascribed to supermassive black holes as 'prime movers'. In this interpretation the only connection with cosmology is that it must be argued that the central black holes are a result of the processes of galaxy formation in the early universe. So far no rationale for such an outcome is given in standard cosmology.

We first show that the dynamics of the universe is governed by the frequency and power of the MCEs, and there is a two-way feedback between the two. That is, the universe expands when there is a large MCE activity and contracts when the activity is switched off. Likewise, the MCE activity is large when the density of the universe is relatively large and negligible when the density is relatively small. In short, the universe oscillates

between states of finite maximum and minimum densities as do the creation phases in the MCEs.

This was the model proposed by Hoyle, Burbidge and Narlikar (1993) and called the *quasi-steady state cosmology* (QSSC in brief). The model was motivated partly by Ambartsumian's ideas and partly by the growing number of explosive phenomena that are being discovered in extragalactic astronomy. We first discuss the cosmological model and then turn to the various phenomena which are beginning to help us understand the basic cosmogony. Then we discuss and look at the phenomena themselves in the framework of this cosmology.

2. The QSSC Model

The mathematical framework for our cosmological model has been discussed by Hoyle, Burbidge and Narlikar (1995; HBN hereafter), and we outline briefly its salient features. To begin with, it is a theory that is derived from an action principle based on Mach's Principle, and assumes that the inertia of matter owes its origin to other matter in the universe. This leads to a theoretical framework wider than general relativity as it includes terms relating to inertia and creation of matter.

Thus the equations of general relativity are replaced in the above theory by

$$R_{ik} - \frac{1}{2} g_{ik} R + \lambda g_{ik} = 8\pi G \left[T_{ik} - f \left(C_i C_k - \frac{1}{4} g_{ik} C^i C_i \right) \right], \qquad (1)$$

with the coupling constant f defined as

$$f = \frac{2}{3\tau^2}. \qquad (2)$$

[We have taken the speed of light c = 1.] Here $\tau = \hbar / m_P$ is the characteristic life time of a Planck particle with mass $m_P = \sqrt{3\hbar / 8\pi G}$. The gradient of *C* with respect to spacetime coordinates $x^i \, (i = 0,1,2,3)$ is denoted by Cj. Although the above equation defines f in terms of the fundamental constants it is convenient to keep its identity on the right hand side of Einstein's equations since there we can compare the C-field energy tensor directly with the matter tensor. Note that because of positive f, the C-field has *negative* kinetic energy. Also, the constant λ is *negative* in this theory.

The question now arises of why astrophysical observation suggests that the creation of matter occurs in some places but not in others. For creation to occur at the points $A_0, B_0, \ldots$ it is necessary classically that the action should not change (i.e. it should remain stationary) with respect to small changes in the spacetime positions of these points, which can be shown to require

$$C_i(A_0)C^i(A_0) = C_i(B_0)C^i(B_0) = \ldots = m_P^2. \qquad (3)$$

This is in general not the case: in general the magnitude of $C_i(X)C^i(X)$ is much less that m_P^2. However, as one approaches closer and closer to the surface of a massive compact body $C_i(X)C^i(X)$ is increased by a general relativistic time dilatation factor, whereas m_P^2 stays fixed. For a Schwarzschild-type solution around an object of mass M, this factor at distance R from the centre is

$$\gamma = \left(1 - \frac{2GM}{R}\right)^{-1}. \qquad (4)$$

This suggests that we should look for regions of strong gravitational field such as those near collapsed massive objects. In general relativistic astrophysics such objects are none other than black holes, formed from gravitational collapse. Theorems by Penrose, Hawking and others (see Hawking and Ellis 1973) have shown that provided certain positive energy conditions are met, a compact object undergoes gravitational collapse to a spacetime singularity. Such objects become black holes before the singularity is reached. However, in the present case, the negative energy of the C-field intervenes in such a way as to violate the above energy conditions. What happens to such a collapsing object containing a C-field apart from ordinary matter? We argue that such an object does not become a black hole. Instead, the collapse of the object is halted and the object bounces back, thanks to the effect of the C-field. We will refer to such an object as a compact massive object (CMO) or a near-black hole (NBH). For a model of *NBH* see Narlikar et al. (2007).

It is worth stressing here that even in classical general relativity, the external observer never lives long enough to observe the collapsing object enter the horizon. Thus all claims to have observed black holes in X-ray sources or galactic nuclei really establish the existence of compact massive objects, and as such they are consistent with the NBH concept. A spinning NBH, for example can be approximated by the Kerr solution limited to region outside the horizon (- in an NBH there is no horizon). In cases where *C* has not gone to the level of creation of matter, an NBH will behave very much like a Kerr black hole.

The theory would profit most from a quantum description of the creation process. The difficulty, however, is that Planck particles are defined as those for which the Compton wavelength and the gravitational radius are essentially the same, which means that, unlike other quantum processes, flat spacetime cannot be used in the formulation of the theory. A qualitative discussion would go somewhat like this. A gravitational disturbance is necessarily involved and the ideal location for triggering creation is that near a CMO. The C-field boson far away from a compact object of mass M may not be energetic enough to trigger the creation of a Planck particle. However, on falling into the strong gravitational field of a sufficiently compact object, the boson energy is multiplied by a large 7- factor, for a local Schwarzschild metric.

Bosons then multiply up in a cascade, one makes two, two makes four, ..., as in the discharge of a laser, with particle production multiplying up similarly and with negative pressure effects ultimately blowing the system apart. This is the explosive event that we earlier referred to as a *mini-creation event* (MCE). Unlike the big bang, however, the dynamics of this phenomenon is *well defined and non-singular*. For a detailed discussion of the role of a NBH as well as the mode of its formation, see Hoyle et al. (2000), (HBN hereafter) p. 244-249.

While still qualitative, we shall show that this view agrees well with the empirical facts of observational astrophysics. For, as mentioned in the previous section, we do see several explosive phenomena in the universe, such as jets from radio sources, gamma ray bursts, X-ray bursters, QSOs and active galactic nuclei, etc. Generally it is assumed that a black hole plays the lead role in such an event by somehow converting a fraction of its huge gravita tional energy into large kinetic energy of the 'burst' kind. In actuality, we do not see infailing matter that is the signature of a black hole. Rather we see outgoing matter and radiation, which agrees very well with the explosive picture presented above.

The qualitative picture described above is too difficult and complex to admit an exact solution of the field equations (1). The problem is analogous to that in standard cosmology where a universe with inhomogeneity on the scale of galaxies, clusters, superclusters, etc., as well as containing dark matter and radiation is impossible to describe exactly by a general relativistic solution. In such a case one starts with simplified approximations as in models of Friedmann and Lemaitre and then puts in specific details as perturbation.

In the same spirit we approach the above cosmology by a mathematical idealization of a homogeneous and isotropic universe in which there are regularly phased epochs when the MCEs were active and matter creation took place while between two consecutive epochs there was no creation (-the MCEs lying dormant). We will refer to these two situations as creative and non-creative modes. In the homogeneous universe assumed

here the C-field will be a function of cosmic time only. We will be interested in the matter-dominated analogues of the standard models since, as we shall see, the analogue of the radiation-dominated state never arises except locally in each MCE where, however, it remains less intense than the C-field. In this approximation, the increase or decrease of the scale factor $S(t)$ of the universe indicates an average smoothed out effect of the MCEs as they are turned on or off. The following discussion is based on the work of Sachs, et al. (1996).

We write the field equations (1) for the Robertson-Walker line element with $S(t)$ as scale factor and k as curvature parameter and for matter in the form of dust, when they reduce to essentially two independent equations :

$$2\frac{\ddot{S}}{S}+\frac{\dot{S}^2+k}{S^2}=3\lambda+2\pi Gf\dot{C}^2, \tag{5}$$

$$\frac{3(\dot{S}^2+k)}{S^2}=3\lambda+8\pi G\rho-6\pi Gf\dot{C}^2, \tag{6}$$

where we have set the speed of light c = 1 and the density of dust is given by ρ. From these equations we get the conservation law in the form of an identity:

$$\frac{d}{dS}\left\{S^3(3\lambda+8\pi G\rho-6\pi Gf\dot{C}^2\right\}=3S^3\left\{3\lambda+2\pi Gf\dot{C}^2\right\}. \tag{7}$$

This law incorporates "creative" as well as "non-creative" modes.

The creative mode has $T^{ik}_{;k}\neq 0$ and the right hand of (7) non-zero. The non-creative mode has $T^{ik}_{;k}=0$. The old steady state theory arises as a special case of the creative mode.

The quasi-steady state cosmology is described by a combination of the creative and the non-creative modes. For this the general procedure to be followed is to look for a composite solution of the form

$$S(t)=\exp\left(\frac{t}{P}\right)\left\{1+\eta\cos\frac{2\pi t}{Q}\right\}, \tag{8}$$

wherein $P >> Q$. Thus over a period Q the universe is essentially in a non-creative mode. However, at regular instances separated by the period Q it has injection of new

matter at such a rate as to preserve an average rate of creation over period P. It is most likely that these epochs of creation are those of the minimum value of the scale factor during oscillation, because then the level of the C-field background is the highest. There is a sharp drop at a typical minimum but the $S(t)$ is a continuous curve with a zero derivative at $S = S_{\min}$.

Suppose that matter creation takes place at the minimum value of $S = S_{\min}$, and that N particles are created per unit volume with mass m_0. Then the extra density added at this epoch in the creative mode is

$$\Delta\rho = m_0 N . \tag{9}$$

After one cycle the volume of thespace expands by a factor exp $(3Q/P)$ and to restore the density to its original value we should have

$$(\rho + \Delta\rho)e^{-3Q/P} = \rho \text{, i.e.,} \quad \Delta\rho/\rho \cong 3Q/P . \tag{10}$$

The C-field strength likewise takes a jump at creation and declines over the following cycle by the factor $\exp(-4Q/P)$. Thus the requirement of "steady state" from cycle to cycle tells us that the change in the strength of $\dot{C}^2$ must be

$$\Delta\dot{C}^2 = \frac{4Q}{P}\dot{C}^2 . \tag{11}$$

The above result is seen to be consistent with (10) when we take note of the conservation law (7). A little manipulation of this equation gives us

$$\frac{3}{4}\frac{1}{S^4}\frac{d}{dS}\left(f\dot{C}^2 S^4\right) = \frac{1}{S^3}\frac{d}{dS}\left(\rho S^3\right). \tag{12}$$

However, the right hand side is the rate of creation of matter per unit volume. Since from (10) and (11) we have

$$\frac{\Delta\dot{C}^2}{\dot{C}^2} = \frac{4}{3}\frac{\Delta\rho}{\rho} . \tag{13}$$

and from (5) and (6) we have $\rho = f\dot{C}^2$, we see that (13) is deducible from (10) and (11).

To summarize, we find that the composite solution properly reflects the quasi-steady state character of the cosmology in that while each cycle of duration Q is exactly a repeat of the preceding one, over a long time scale the universe expands with the de Sitter expansion factor $\exp(t/P)$. The two time scales P and Q of the model thus turn out to be related to the coupling constants and the parameters λ, f, G, η of the field equations. Further progress in the theoretical problem can be made after we understand the quantum theory of creation by the C-field.

These solutions contain sufficient number of arbitrary constants to assure us that they are generic, once we make the simplification that the universe obeys the Weyl postulate and the cosmological principle. The composite solution can be seen as an illustration of how a non-creative mode can be joined with the creative mode. More possibilities may exist of combining the two within the given framework. We have, however, followed the simplicity argument (also used in the standard big bang cosmology) to limit our present choice to the composite solution described here.

Coming next to a physical interpretation of these mathematical solutions, we can visualize the above model in terms of the following values of its parameters:

$$P = 20Q, \qquad Q = 5\times 10^{10}\, yrs, \qquad \eta = 0.811,$$
$$\lambda = -0.358\times 10^{-56}\,(cm)^{-2}.$$

To fix ideas, we have taken the maximum redshift observable in the present cycle, $z_{\max} = 5$. This set of parameters has been used in recent papers on the QSSC (Narlikar, et al. 2002, 2003, 2006). For this model the ratio of maximum to minimum scale factor in any oscillation is around 9.6.

These parametric values are not uniquely chosen; they are rather indicative of the magnitudes that may describe the real universe. For example, $z_{\max}$ could be as high as 10 without placing any strain on the model. The various observational tests seek to place constraints on these values. Can the above model quantified by the above parameters cope with such tests? If it does we will know that the QSSC provides a realistic and viable alternative to the big bang.

3. The Radiation Background

As far as the origin and nature of the CMBR is concerned we use a fact that is always ignored by standard cosmologists. If we suppose that most of the ^4He found in our own and external galaxies (about 24% of the hydrogen by mass) was synthesized by

hydrogen burning in stars, the energy released amounts to about 4.37×10^{-13} erg cm^{-3}. This is almost exactly equal to the energy density of the microwave background radiation with T = 2.74°K. For standard cosmologists this has to be dismissed as a coincidence, but for us it is a powerful argument in favor of the hypothesis that the microwave radiation at the level detected is relic starlight from previous oscillations in the QSSC which has been thermalized (Hoyle, et al. 1994). Of course, this coincidence loses its significance in the standard big bang cosmology where the CMBR temperature is epoch-dependent.

It is then natural to suppose that the other light isotopes, namely D, ^{3}He, ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B and ^{11}B were produced by stellar processes. It has been shown (cf. Burbidge and Hoyle, 1998) that both spallation and stellar flares (for ^{2}D) on the surfaces of stars can explain the measured abundances. Thus *all* of the isotopes are ultimately a result of stellar nucleosynthesis (Burbidge et al. 1957; Burbidge and Hoyle 1998).

This option raises a problem, however. If we simply extrapolate our understanding of stellar nucleosynthesis, we will find it hard to explain the relatively low metallicity of stars in our Galaxy. This is still an unsolved problem. We believe but have not yet established that it may be that the initial mass function of the stars where the elements are made is dominated by stars which are only able to eject the outer shells while all of the heavy elements are contained in the cores which simply collapse into black holes. Using theory we can construct a mass function which will lead to the right answer (we think) but it has not yet been done. But of course our handwaving in this area is no better than all of the speculations that are being made in the conventional approach when it comes to the "first" stars.

The theory succeeds in relating the intensity and temperature of CMBR to the stellar burning activity in each cycle, the result emphasizing the causal relationship between the radiation background and nuclear abundances. But, how is the background thermalized? The metallic whisker shaped grains condensed from supernova ejecta have been shown to effectively thermalize the relic starlight (Hoyle et al., 1994, 2000). It has also been demonstrated that inhoniogeneities on the observed scale result from the thermalized radiation from clusters, groups of galaxies etc. thermalized at the minimum of the last oscillation (Narlikar et al., 2003). By using a toy model for these sources, it has been shown that the resulting angular power spectrum has a satisfactory fit to the data compiled by Podariu et al (2001) for the band power spectrum of the CMBR temperature inhoniogeneities. Extending that work further it has been shown by Narlikar et al. (2007), that the model is also consistent with the first- and third- year observations of the Wilkinson Microwave Anisotropy Probe (WMAP) (Page et al. 2003; Spergel et al. 2006).

We mention in passing that recent work (Wickramasinghe 2005) indicates that small traces of polarization would be expected in the CMBR wherever it passes through optically thin clouds of iron whiskers. These whiskers being partially aligned along the intracluster magnetic fields will yield a weak signal of polarization on the scale of clusters or smaller ojects.

It should be noted that the small scale anisotropics do not constitute as crucial a test for the QSSC model as they do for standard cosmology. Our general belief is that the universe is inhomogeneous on the scales of galaxy-cluster-supercluster and the QSSC model cannot make detailed claims of how these would result in the anisotropy of CMBR. In this respect, the standard model subject to all its assumptions (dark matter, inflation, dark energy, etc.) makes much more focussed predictions of CMBR anisotropy.

It is worth commenting on another issue of an astrophysical nature. The typical QSSC cycle has a lifetime long enough for most stars of masses exceeding $\sim 0.5 - 0.7 M_{\odot}$ to have burnt out. Thus stars from previous cycles will be mostly extinct as radiators of energy. Their masses will continue, however, to exert a gravitational influence on visible matter. The so-called dark matter seen in the outer reaches of galaxies and within clusters may very well be made up, at least in part, of these stellar remnants.

To what extent does this interpretation tally with observations? Clearly, in the big bang cosmology the time scales are not long enough to allow such an interpretation. Nor does that cosmology permit dark matter to be baryonic to such an extent. The constraints on baryonic dark matter in standard cosmology come from (i) the origin and abundance of deuterium and (ii) considerations of large scale structure. The latter constraint further requires the nonbaryonic matter to be cold. In the QSSC, as has been shown before, these constraints are not relevant. For other observational issues completely handled by the QSSC, see Hoyle et al. (2000).

4. Explosive Cosmogony

4.1. Groups and clusters of galaxies

We have already stated that it was Ambartsumian (1965) who first pointed out that the simplest interpretation of many physical systems of galaxies ranging from very small groups to large clusters is that they are expanding and coming apart. Since most of the observations are of systems at comparatively small redshifts it is clear that this takes place at the current epoch, and while we do not have direct evidence of the situation at large redshifts, it is most likely a general phenomenon.

Why has this effect been so widely ignored? The answer to this is clearly related to the beliefs of earlier generations of cosmologists. From an historical point of view, the first physical clusters were identified in the 1920s, and it was Zwicky, and later others who supposed that they must be stable systems. By measuring individual redshifts of a number of the galaxies in such a cluster it is possible to get a measurement of the line-of-sight random motions. For stability the virial condition $2E_K + \Omega = 0$ needs to be satisfied where E_K and Ω are the average values of the kinetic energy and potential energy of the cluster members. Extensive spectroscopic studies from the 1950s onward showed that nearly always the kinetic energy of the visible matter far exceeds the potential energy apparent from the visible parts of the galaxies. Many clusters have structures which suggest they are stable and relaxed. Thus it was deduced that in these clusters there must be enough dark matter present to stabilize them. This was, originally, one of the first pieces of evidence for the existence of dark matter.

The other argument was concerned with the ages of the galaxies. Until fairly recently it has been argued that all galaxies have stellar populations which include stars which are very old, with ages on the order of H_0^{-1}, i.e. that they are all as old as the classic big bang universe. However we now know that young galaxies with ages $<< H_0^{-1}$ do exist. But the major point made by Ambartsumian was, and is, that there are large numbers of clusters of galaxies, and many small groups, which are physically connected but clearly from their forms and their relative velocities, appear to be unstable.

In this situation the use of the virial theorem is totally inappropriate. It is worthwhile pointing out that if the virial theorem holds the random motions of the galaxies should follow a steady state distribution such as

$$F(v) \propto \exp\left[-\frac{v^2}{2\sigma^2}\right]. \qquad (14)$$

So far there is no observational demonstration that this is indeed the case. The conclusion drawn from $2E_K + \Omega > 0$ as based on visible components only should rather be that the clusters are manifestly *not* in dynamical equilibrium.

Modern evidence concerning the masses of clusters has been obtained from x-ray studies, the Sunyaev-Zeldovich effect, and gravitational lensing (cf. Fabian 1994; Carlstrom et al. 2002; Fort and Mellier 1994 and many other papers). All of these studies of rich clusters of galaxies show that large amounts of matter in the form of hot gas and/or dark matter must be present. However, evidence of enough matter to bind small or irregular clusters has not been found in general, and these are the types of

configurations which Ambartsumian was originally considering. A system such as the Hercules Cluster is in this category. Also the very compact groups of galaxies (cf. Hickson 1997) have been a subject of debate for many years since a significant fraction of them (~ 40%) contain one galaxy with a redshift very different from the others. Many statistical studies of these have been made, the orthodox view being that such galaxies must be "interlopers"; foreground or background galaxies. Otherwise they either have anomalous redshifts, or are exploding away from the other galaxies.

We also have the problem of interacting galaxies, briefly referred to earlier in Section 1. In modern times it has been generally supposed that when two galaxies are clearly in interaction they must be coming together (merging) and never coming apart. There are valid ways of deciding whether or not mergers are, or have occurred. The clearest way to show that they are coming together is to look for tidal tails (Toomre and Toomre 1972), or, if they are very closely interwoven, to look for two centers, or two counter rotating systems. For some objects this evidence does exist, and mergers are well established. But to assume that merging is occurring in all cases is unreasonable: there may well be systems where we are seeing the ejection of one galaxy from another as Ambartsumian proposed. Thus when the virial condition is not satisfied, and the systems are highly irregular and appear to be coming apart, then perhaps they *are* coming apart, and never have been separate. Here we are clearly departing from the standard point of view.

If one assumes that clusters may not be bound, their overall astrophysics changes from that of bound 'steady' clusters. Issues like the nature of intra-cluster medium, the role of the halo, generation of x-rays will require a new approach in the case where clusters are expanding. Further, the ejection of new matter provides additional inputs to the dynamics of the system. For example, the energy of ejection will play a role in heating the intracluster gas. This important investigation still needs to be carried out. However, a preliminary discussion may be found in Hoyle, et al. (2000), Chapter 20.

4.2. Explosions in individual galaxies

By the early 1960s it had become clear that very large energy outbursts are taking place in the nuclei of galaxies.

The first evidence came from the discovery of powerful radio sources and the realization that the nuclei of the galaxies which they were identified with, had given rise to at least 10^{59} - 10^{61} ergs largely in the form of relativistic (Gev) particles and magnetic flux which had been ejected to distances of > 100 kpc from the region of production.

A second line of evidence comes from the classical Seyfert galaxies which have very bright star-like nuclei which show very blue continua, and highly excited gas which has random motions > 3000 Km sec^{-1}, and must be escaping from the nucleus. We know

that the gas is being ejected because we see it through absorption in optical and X-ray spectra of Seyfert nuclei, and the wavelengths of the absorption lines are shifted to the blue of the main emission. The speeds observed are very large compared with the escape velocity. Early data were described by Burbidge et al. (1963).

In the decades since then it has been shown that many active nuclei are giving rise to x-rays, and to relativistic jets, detected in the most detail as high frequency radio waves. A very large fraction of all of the energy which is detected in the compact sources is non-thermal in origin, and is likely to be incoherent synchrotron radiation or Compton radiation.

Early in the discussion of the origin of these very large energies it was concluded that the only possible energy sources are gravitational energy associated with the collapse of a large mass, and the ejection of a small fraction of the energy, or we are indeed seeing mass and energy being created in the nuclei (cf. Hoyle, Fowler, Burbidge and Burbidge 1964).

Of course the most conservative explanation is that the energy arises from matter falling into massive black holes with an efficiency of conversion of gravitational energy to whatever is seen, of order 10%. This is the argument that has been generally advanced and widely accepted (cf. Rees 1984).

Why do we believe that this is not the correct explanation? After all, there is good evidence that many nearby galaxies (most of which are not active) contain collapsed supermassive objects in their centers with masses in the range 10^6 - 10^8 $M_\odot$.

The major difficulty is associated with the efficiency with which gravitational energy can be converted into very fast moving gas and relativistic particles, a problem that has haunted us for more than forty years (Burbidge and Burbidge 1965). In our view the efficiency factor is not 10% but close to 0.1% - 1%. The reasons why the efficiency factor is very small are the following. If the energy could be converted directly the efficiency might be as high as ~ 8%, or even higher from a Kerr rotating black hole. But this energy will appear outside the Schwarzschild radius as the classical equivalent of gravitons. This energy has to be used to heat an accretion disk or generate a corona in a classical AGN, or generate very high energy particles which can propagate outward in a radio source, then heat gas which gives rise to shock waves, which accelerate particles, which in turn radiate by the synchrotron process. Thermodynamics tells us that the efficiency at each of these stages is < 10%. If there are 3 to 4 stages the overall efficiency is ~ 10^{-3} – 10^{-4}. This is borne out by the measured efficiency by which relativistic beams are generated in particle accelerators on earth, and by the efficiency associated with the activity in the center of M87. (cf. Churasov et al. 2002).

If these arguments are not accepted, and gravitational energy is still claimed to be the only reasonable source, another problem appears.

For the most luminous sources, powerful radio sources and distant QSOs the masses involved must be much greater than the typical values used by the black hole-accretion disk theorists. If one uses the formula for Eddington luminosity (cf. for details pages 109-111, 408-409 of Kembhavi & Narlikar 1999) one arrives at black hole masses of the order 10^8 M_Θ on the basis of perfect efficiency of energy conversion. An efficiency of < 0.01 would drive the mass up a hundred fold at least, i.e. to 10^{10} M_Θ or greater. So far there is no direct evidence in any galaxy for such large dark masses. The largest masses which have been reliably estimated are about 10^9 M©.

In general it is necessary to explain where the bulk of the energy released which is not in the relativistic particle beams, is to be found. A possible explanation is that it is much of this energy which heats the diffuse gas in active galaxies giving rise to the extended X-ray emission in clusters and galaxies.

An even harder problem is to explain how the massive black holes in galaxies were formed in the first place. Were they formed before the galaxies or later? In the standard model both scenarios have been tried, but no satisfactory answer has been found.

In our model the energy comes with creation in the very strong gravitational fields very close to the central NBH, where the process can be much more efficient than can be expected in the tortuous chain envisaged in the classical gravitational picture.

Would very massive galaxies result if the universe allows indefinitely large time for galaxy formation? In the present case two effects intervene to make massive galaxies rather rare. The first one is geometrical. Because of steady long-term expansion, the distance between two galaxies formed, say, *n* cycles ago, would have increased by a factor ~ $\exp\left(n\frac{Q}{P}\right)$, and their density decreased by the factor ~ $\exp\left(-3n\frac{Q}{P}\right)$. For $n >> 1$, we expect the chance of finding such galaxies very small.

The second reason working against the growth of mass in a region comes from the negative energy and pressure of the C-field. As the mass grows through creation, the C-field also mounts and its repulsive effect ultimately causes enough instability for the mass to break up. Thus the large mass grows smaller by ejecting its broken parts.

What is ejected in an MCE? Are the ejecta more in the form of particles or radiation or coherent objects? All three are produced. For a discussion of the mechanism leading to ejection of coherent objects, see Hoyle, et al. (2000), Chapter 18.

4.3. Quasi-Stellar Objects

In the early 1960s QSOs were discovered as star-like objects with large red-shifts. Very early on, continuity arguments led to the general conclusion that they are very similar to the classical Seyfert glaxies, i.e. they are the nuclei of galaxies at much greater distances. However, also quite early in the investigations, it became clear that a good case could also be made for supposing that they are more likely to be compact objects *ejected* from comparatively local, low redshift active galaxies (Hoyle and Burbidge 1966). This conclusion has generated considerable controversy.

However, if this is accepted, it provides direct evidence that in the creation process active galaxies are able to eject compact sources with large intrinsic redshifts. What was not predicted was the existence of intrinsic redshifts. They present us with an unsolved problem, but one which must be closely connected to the creation process. A remarkable aspect of this problem is that the intrinsic redshifts show very clear peaks in their distribution with the first peak at z = 0.061 and with a periodicity of the form $\Delta \log(1+z) = 0.089$ (cf. Karlsson 1971, Burbidge and Napier 2001). The periodicity is in the intrinsic redshift component *(zi),* and in order to single out that component, either the cosmological redshift component z_c must be very small i.e., the sources must be very close to us, or it must be known and corrected for by using the relation $(1+z_{obs}) = (1+z_c)(1+z_i)$.

It is admitted that the evidence from gravitational lensing provides an overall consistent picture for the standard cosmological hypothesis. The evidence on quasars of larger redshift being lensed by a galaxy of lower redshift, together with the time delay in the radiation found in the two lensed images can be explained by this hypothesis. This type of evidence needs to be looked at afresh if the claim is made that quasars are much closer than their redshift-distances. In such cases, the lensing models can be 'scaled' down but the time-delay will have to be checked for lower values. To our knowledge no such exercise has been carried out to date.

4.4. Gamma Ray Bursts

One of the most remarkable phenomena discovered in recent years relate to very short lived (< minutes) bursts of high energy photons (7-ray and x-ray) which can apparently occur anywhere in the sky, and which sometimes can be identified with a very faint optical and/or radio source, an afterglow, which may fade with time. Sometimes a very faint object remains. The first optical observation in which a redshift could be measured led to the conclusion that those sources are extragalactic. Using the redshifts as distance indicators this has led to the conclusion that the energies emitted lie in the range 10^{50} - 10^{54} ergs, with most of them > 10^{53} ergs, if the explosions take place isotropically. If

energies involving single stars are invoked the energies can be reduced if beaming is present. The most recent observations have suggested that the events are due to forms of supernovae which are beamed. In the usual interpretation it is assumed that the redshifts which have been measured for the gamma ray bursts are cosmological (cf Bloom et al. 2001). However in a recent study using all (more than 30) gamma-ray bursts (GRBs) with measured redshifts it was shown that the redshift distribution strongly suggests that they are closely related to QSOs with the same intrinsic redshift peaks (Burbidge 2003, 2004). Also an analysis of the positions of all of the GRBs for which we have positions (about 150) shows that a number of them are very near to already identified QSOs (Burbidge 2003). All of this suggests that the GRBs are due to explosions of objects (perhaps *in* QSOs) which have themselves been ejected following a creation process from active galaxies. In general they have slightly greater cosmological redshifts and thus are further away (< 500 Mpc) than the galaxies from which most of bright QSOs are ejected. While we do not claim that this hypothesis is generally accepted, Bloom (2003) has shown that there are peculiarities in the redshift distribution interpreted in the conventional way. More observations may clarify this situation.

5. Concluding Remarks

The oscillating universe in the QSSC, together with a long-term expansion, driven by a population of mini-creation events provides the missing dynamical connection between cosmology and the 'local' explosive phenomena. The QSSC additionally fulfills the roles normally expected of a cosmological theory, namely (i) it provides an explanation of the cosmic microwave background with temperature, spectrum and inhomogeneities related to astro-physical processes (Narlikar et al. 2003), (ii) it offers a purely stellar-based interpretation of all observed nuclei *(including* light ones) (Burbidge et al. 1957; Burbidge and Hoyle 1998), (iii) it generates baryonic dark matter as part of stellar evolution (Hoyle et al. 1994), (iv) it accounts for the extra dimming of distant supernovae *without* having recourse to dark energy (Narlikar, Vishwakarma and Burbidge 2002; Vishwakarma and Narlikar 2005), and (v) it also suggests a possible role of MCEs in the overall scenario of structure formation (Nayeri et al. 1999). For limitations of time I have not described (iv) and (v).

The last mentioned work shows that preferential creation of new matter near existing concentrations of mass can lead to growth of clustering. A toy model based on million-body simulations demonstrates this effect and leads to clustering with a 2-point correlation function with index close to — 1.8. Because of repulsive effect of the C-field, it is felt that this process may be more important than gravitational clustering. However, we need to demonstrate this through simulations like those in our toy model, *together with* gravitational clustering.

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organizers for giving me this opportunity. The work presented here was done largely in collaboration with Geoffrey Burbidge, who would have very much liked to attend this meeting but could not because of health reasons. This presentation may be considered as a reflection of his ideas as well.

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The Local Contribution to the Microwave Background Radiation (MBR)

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Abstract. In the early fifties, from the early theories of the big bang universe, Gamow, Alpher & Herman have predicted the existence of a "cosmological" microwave background radiation, corresponding to a black body of a few Kelvins. When, in 1964, Penzias & Wilson, observed a radiation at 2.7 K, the scientific world concluded quickly it was a proof, a final proof, of the big bang type cosmologies. But it should be realized that, in the beginning of the XX-th century, several authors, from Guillaume to Eddington, have predicted the same thing in a static Universe. We have redone the calculations of Eddington, and based them on the recent and very accurate photometric results from the satellite Hipparcos. In the absence of any expansion, of any big bang type behaviour, we compute the local temperature induced by the reradiation by local matter of stellar radiation, and we found it to be in excellent agreement with the observations. This result, completed by a careful discussion, could lead to a dramatic revision of the classical cosmological concepts.

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Quantum effects in higher-dimensional cosmologies

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Abstract. Vacuum energy density and stresses are investigated for a scalar field with general curvature coupling parameter in de Sitter spacetime with an arbitrary number of toroidally compactified spatial dimensions. The corresponding expectation values are presented in the form of the sum of the vacuum expectation values in uncompactified dS spacetime and the part induced by the non-trivial topology. In the early stages of the cosmological evolution the topological parts dominate. In this limit the behavior of the Casimir densities does not depend on the curvature coupling parameter and coincides with that for a conformally coupled massless field. At late stages of the cosmological expansion the expectation values are dominated by the part corresponding to uncompactified dS spacetime. The vanishing of the topological parts is monotonic or oscillatory in dependence of the mass and the curvature coupling parameter of the field.

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1. Introduction

Many of high-energy theories of fundamental physics are formulated in higher-dimensional spacetimes. In particular, the idea of extra dimensions has been extensively used in supergravity and superstring theories. It is commonly assumed that the extra dimensions are compactified. From an inflationary point of view universes with compact spatial dimensions, under certain conditions, should be considered a rule rather than an exception [1]. The models of a compact universe with non-trivial topology may play an important role by providing proper initial conditions for inflation. As it was argued in Refs. [2], there are many reasons to expect that in string theory the most natural topology for the universe is that of a flat compact three-manifold.

In topologically non-trivial spaces the periodicity conditions imposed on possible field configurations change the spectrum of the vacuum fluctuations and lead to the Casimir-type contributions to the vacuum expectation values of physical observables. In the Kaluza-Klein-type models the Casimir effect has been used as a stabilization mechanism for moduli fields which parametrize the size and the shape of the extra dimensions. The Casimir energy can also serve as a model for dark energy needed for the explanation of the present accelerated expansion of the universe (see Refs. [3]) and references therein). In the present talk, based on Refs. [4, 5], we describe the effects of the toroidal compactification of spatial dimensions in dS spacetime on the properties of

quantum vacuum for a scalar field with general curvature coupling parameter. The one-loop quantum effects for a fermionic field on background of dS spacetime with spatial topology $R^p \times (S^1)^q$ are studied in Refs. [6, 7].

The paper is organized as follows. In the next section we describe the background geometry and present the complete set of eigenfunctions. In section 3 these eigenfunctions are used to evaluate the mode-sum for the vacuum expectation value of the energy-momentum tensor. The main results are summarized in section 4.

2. Background geometry and the eigenfunctions

As a background geometry we consider $(D+1)$-dimensional de Sitter spacetime (dS_{D+1}) generated by a positive cosmological constant Λ. In planar (inflationary) coordinates the corresponding line element has the form

$$ds^2 = dt^2 - e^{2t/\alpha} \sum_{l=1}^{D} (dz^l)^2 , \qquad (1)$$

with the parameter $\alpha^2 = D(D-1)/(2\Lambda)$. We will assume that the spatial coordinate $z^l, l = p+1,...,D$, is compactified to S^1, of the length L_l: $0 \le z^l \le L_l$,and for the other coordinates we have $-\infty < z^l < +\infty$, $l = 1,...,p$. Hence, we consider the spatial topology $R^p \times (S^1)^q$, where $q = D - p$.

This paper is concerned with the scalar vacuum densities induced by the non-trivial spatial topology. We will consider a free scalar field with curvature coupling parameter ξ. The corresponding field equation has the form

$$(\nabla_l \nabla^l + m^2 + \xi R)\varphi = 0 , \qquad (2)$$

where $R = D(D+1)/\alpha^2$ is the Ricci scalar for dS_{D+1} and ξ is the curvature coupling parameter. Let $z_p = (z^1,...,z^p)$ and $z_q = (z^{p+1},...,z^D)$ the position vectors along the uncompactified and compactified dimensions respectively. We have the following boundary condition along the compactified dimensions

$$\varphi(t, z_p, z_q + L_l e_l) = \pm\varphi(t, z_p, z_q) , \qquad (3)$$

where $l = p+1,...,D$, upper/lower sign corresponds to untwisted/twisted scalar field, and e_l is the unit vector along the direction of the coordinate z^l.

In order to evaluate the vacuum expectation value (VEV) of the the energy-momentum tensor we will use the direct mode-summation procedure assuming that the field is

prepared in the Bunch-Davies vacuum state. The corresponding eigenfunctions have the form

$$\varphi_\sigma(x) = \left[\frac{e^{i(\nu-\nu^*)\pi/2}\eta^D}{2^{p+2}\pi^{p-1}V_q\alpha^{D-1}}\right]^{1/2} H_\nu^{(1)}(k\eta)e^{ik_p\cdot z_p + ik_q\cdot z_q},\ \eta = \alpha e^{-t/\alpha}, \qquad (4)$$

where $H_\nu^{(1)}(x)$ is the Hankel function of the order

$$\nu = \left[D^2/4 - D(D+1)\xi - m^2\alpha^2\right]^{1/2}, \qquad (5)$$

$V_q = L_{p+1},..., L_D$ is the volume of the compactified subspace, and

$$k_p = (k_1,...,k_p), \qquad k_q = (k_{p+1},...,k_D), \qquad k = \sqrt{k_p^2 + l_q^2},$$

$$k_l = 2\pi(n_l + g_l)/L_l,\ n_l = 0,\pm1,\pm2,...., \qquad l = p+1,...,D. \qquad (6)$$

In (6), $g_l = 0$ for untwisted scalar and $g_l = 1/2$ for twisted scalar field.

3. Vacuum energy-momentum tensor

In this section we investigate the VEV for the energy-momentum tensor of a scalar field in dS_{D+1} with toroidally compactified q -dimensional subspace. This quantity acts as a source of gravity in the semiclassical Einstein equations and plays an important role in modeling self-consistent dynamics involving the gravitational field. Having the complete set of eigenfunctions we can evaluate the vacuum energy-momentum tensor by using the mode-sum formula $\langle T_{ik}\rangle_{p.q} = \sum_\sigma T_{ik}\{\varphi_\sigma(x)\varphi_\sigma^*(x)\}$, where the bilinear form $T_{lk}\{f,g\}$ is determined by the form of the classical energy-momentum tensor for a scalar field. In the problem under consideration the set of quantum numbers σ is specified to (k_p, n_q) with $n_q = (n_{p+1},..., n_{D)}$. Substituting the eigenfunctions (4) into mode-sum (\ref%{EMTsum}) and applying to the series over n_{p+1} the Abel-Plana summation formula (see, for example, Ref. [8]), we find the following recurrence relation for the VEV of the energy-momentum tensor%

$$\langle T_i^k\rangle_{p.q} = \langle T_i^k\rangle_{p+1.q-1} + \Delta_{p+1}\langle T_i^k\rangle_{p.q}. \qquad (7)$$

Here $\langle T_i^k\rangle_{p+1.q-1}$ is the part corresponding to dS spacetime with $p+1$ uncompactified and $q-1$ toroidally compactified dimensions and $\Delta_{p+1}\langle T_i^k\rangle_{p.q}$ is induced by the compactness along the z^{p+1} - direction. For the corresponding energy density one has

$$\Delta_{p+1}\langle T_0^0\rangle_{p.q} = \frac{2\eta^D L_{p+1}}{(2\pi)^{(p+3)/2}V_q\alpha^{D+1}}\sum_{n=1}^{\infty}(\pm 1)^n \sum_{n_{q-1}=-\infty}^{\infty}\int_0^{\infty}dx$$

$$\times\frac{xF_\nu^{(0)}(x\eta)}{(nL_{p+1})^{p-1}} f_{(p-1)/2}(nL_{p+1}\sqrt{x^2+k_{n_{q-1}}^2}), \qquad (8)$$

with the notations $n_{q-1}=(n_{p+2},...,n_D)$, $f_\mu(y)=y^\mu K_\mu(y)$, $K_\mu(y)$ is the MacDonald function and

$$F_\nu^{(0)} = y^2\left[I'_{-\nu}(y)+I'_\nu(y)\right]K'_\nu(y)+D(1/2-2\xi)y\left[I_{-\nu}(y)+I_\nu(y)\right]K_\nu(y)$$

$$+\left[I_{-\nu}(y)+I_\nu(y)\right]K_\nu(y)(\nu^2+2m^2\alpha^2-y^2), \qquad (9)$$

In Eq. (8), the upper/lower sign corresponds to untwisted/twisted scalar field. The vacuum stresses are presented in the form (no summation over i

$$\Delta_{p+1}\langle T_i^i\rangle_{p.q} = A_{pq} - \frac{4\eta^{D+2}L_{p+1}}{(2\pi)^{(p+3)/2}V_q\alpha^{D+1}}\sum_{n=1}^{\infty}(\pm 1)^n \sum_{n_{q-1}=-\infty}^{\infty}\int_0^{\infty}dxxK_\nu(x\eta)$$

$$\times\frac{I_{-\nu}(x\eta)+I_\nu(x\eta)}{(nL_{p+1})^{p-1}} f_p^{(i)}(nL_{p+1}\sqrt{x^2+k_{n_{q-1}}^2}), \qquad (10)$$

where we have introduced the notations

$$f_p^{(i)}(y) = f_{(p+1)/2}(y),\ i=1,...,p,$$

$$f_p^{(p+1)}(y) = -y^2 f_{(p-1)/2}(y) - pf_{(p+1)/2}(y), \qquad (11)$$

$$f_p(y) = (nL_{p+1}k_i)^2 f_{(p-1)/2}(y),\ i=p+2,...,D.$$

The first term on the right of Eq. (10) is given by

$$A_{pq} = \frac{2\eta^D L_{p+1}}{(2\pi)^{(p+3)/2}V_q\alpha^{D+1}}\sum_{n=1}^{\infty}(\pm 1)^n \sum_{n_{q-1}=-\infty}^{\infty}\int_0^{\infty}dx\frac{xF_\nu(x\eta)}{(nL_{p+1})^{p-1}}$$

$$\times f_{(p-1)/2}^{(i)}(nL_{p+1}\sqrt{x^2+k_{n_{q-1}}^2}), \qquad (12)$$

with the notation

$$F_\nu(y) = \left[2(D+1)\xi - D/2\right]y(\left[I_{-\nu}(y)+I_\nu(y)\right]K_\nu(y))' + (4\xi-1)y^2K'_\nu(y)$$

$$\times\left[I'_{-\nu}(y)+I'_\nu(y)\right]+\left[I_{-\nu}(y)+I_\nu(y)\right]K_\nu(y)\left[(4\xi-1)(y^2+\nu^2\right]. \qquad (13)$$

As it is seen from the obtained formulae, the topological parts in the VEVs are time-dependent and, hence, the local dS symmetry is broken by them. By taking into account the relation between the conformal and synchronous time coordinates, we see that the VEV of the energy-momentum tensor is a function of the combinations

$L_l/\eta = L_l e^{t/\alpha}/\alpha$, which is the comoving length of the compactified dimension measured in units of the dS curvature scale.

The recurring application of formula (7) allows us to write the VEV in the form

$$\left\langle T_i^k \right\rangle_{p.q} = \left\langle T_i^k \right\rangle_{dS} + \left\langle T_i^k \right\rangle_c, \qquad \left\langle T_i^k \right\rangle_c = \sum_{i=1}^{q} \Delta_{D-l+1} \left\langle T_i^k \right\rangle_{D-l,l}, \tag{14}$$

where the part corresponding to uncompactified dS spacetime, $\left\langle T_i^k \right\rangle_{dS}$, is explicitly decomposed. The part $\left\langle T_i^k \right\rangle_c$ is induced by the comactness of the q-dimensional subspace. This part is finite and the renormalization is needed for the uncompactified dS part only. We could expect this result, since the local geometry is not changed by the toroidal compactification.

For a conformally coupled massless scalar field $\nu = 1/2$ and we find (no summation over i)

$$\Delta_{p+1} \left\langle T_i^i \right\rangle_{p.q} = \frac{2(\eta/\alpha)^{D+1}}{(2\pi)^{p/2+1} V_{q-1}} \sum_{n=1}^{\infty} (\pm 1)^n \sum_{n_{q-1}=-\infty}^{\infty} \frac{g_p^{(i)}(nL_{p+1} k_{n_{q-1}})}{(nL_{p+1})^{p+2}}, \tag{15}$$

with the notations

$$\begin{aligned} &g_p^{(0)}(y) = g_p^{(i)}(y) = f_{p/2+1}(y), \qquad i = 1,\ldots,p, \\ &g_p^{(p+1)}(y) = -(p+1) f_{p/2+1}(y) - y^2 f_{p/2}(y), \\ &g_p^{(i)}(y) = (nL_{p+1} k_i)^2 f_{p/2}(y), \qquad i = p+2,\ldots,D. \end{aligned} \tag{16}$$

In this case the topological part in the VEV of the energy-momentum tensor is traceless and the trace anomaly is contained in the uncompactified dS part only. Formula (15) could be obtained from the corresponding result in $D+1$-dimensional Minkowski spacetime with spatial topology $R^p \times (S^1)^q$, taking into account that two problems are conformally related: $\Delta_{p+1} \left\langle T_i^k \right\rangle_{p.q} = \Delta_{p+1} \left\langle T_i^k \right\rangle_{p,q}^{(M)} \Big/ \alpha^{D+1}(\eta)$, where $\alpha(\eta) = \alpha/\eta$ is the scale factor. This relation is valid for any conformally flat bulk. The similar formula takes place for the total topological part $\left\langle T_i^k \right\rangle_c$. Note that, in this case the expressions for $\Delta_{p+1} \left\langle T_i^k \right\rangle_{p,q}$ are obtained from the formulae for

$\Delta_{p+1}\langle T_i^k\rangle_{p,q}^{(M)}$ replacing the lengths L_l of the compactified dimensions by the comoving lengths $\alpha L_l/\eta$, $l=p,...,D$.

Now we turn to the investigation of the topological part in the VEV of the energy-momentum tensor in the asymptotic regions of the ratio L_{p+1}/η. For small values of this ratio, $L_{p+1}/\eta << 1$, to the leading order $\Delta_{p+1}\langle T_i^k\rangle_{p,q}$ coincides with the corresponding result for a conformally coupled massless field, given by (15). For fixed value of the ratio L_{p+1}/α, this limit corresponds to $t\to-\infty$ and the topological part $\langle T_i^k\rangle_c$ behaves like $\exp[-(D+1)t/\alpha]$. By taking into account that the part $\langle T_i^k\rangle_{dS}$ is time independent, from here we conclude that in the early stages of the cosmological expansion the topological part dominates in the VEV of the energy-momentum tensor. In particular, in this limit the total energy density is negative.

For small values of the ratio η/L_{p+1}, we introduce a new integration variable $y=L_{p+1}x$ and expand the integrand by using the formulae for the modified Bessel functions for small arguments. For real values of the parameter ν we find

$$\Delta_{p+1}\langle T_0^0\rangle_{p.q} \approx \frac{2^\nu D[D/2-\nu+2\xi(2\nu-D-1)]}{(2\pi)^{(p+3)/2}L_{p+1}^{-q}V_q\alpha^{D+1}}\Gamma(\nu)\left(\frac{\eta}{L_{p+1}}\right)^{D-2\nu}$$
$$\times\sum_{n=1}^{\infty}(\pm1)^n\sum_{n_{q-1}=-\infty}^{\infty}\frac{f_{(p+1)/2-\nu}(nL_{p+1}k_{n_{q-1}})}{n^{(p+1)/2-\nu}}. \qquad (17)$$

In particular, this quantity is positive for a minimally coupled scalar field and for a conformally coupled massive scalar field. For a conformally coupled massless scalar the coefficient in (17) vanishes. For the vacuum stresses the second term on the right of formula (10) is suppressed with respect to the first term given by $(\eta/L_{p+1})^2$ for $i=1,...,p+1$, and by the factor $(\eta k_i)^2$ for $i=p+2,...,D$. As a result, to the leading order we have the relation (no summation over i) $\Delta_{p+1}\langle T_i^i\rangle_{p,q}\approx(2\nu/D)\Delta_{p+1}\langle T_0^0\rangle_{p,q}$, $\eta/L_{p+1}<<1$, between the energy density and stresses, $i=1,...,D$. The coefficient in this relation does not depend on p and, hence, it takes place for the total topological part of the VEV as well. Hence, in the limit

under consideration the topological parts in the vacuum stresses are isotropic. Note that this limit corresponds to late times in terms of synchronous time coordinate t, $(\alpha / L_{p+1})e^{-t/\alpha} << 1$, and the topological part in the VEV is suppressed by the factor $\exp[-(D-2\nu)t/\alpha]$. For a conformally coupled massless scalar field the coefficient of the leading term vanishes and the topological parts are suppressed by the factor $\exp[-(D+1)t/\alpha]$. As the uncompactified dS part is constant, it dominates the topological part at the late stages of the cosmological evolution.

For small values of the ratio η / L_{p+1} and for purely imaginary ν, the energy density behaves like

$$\Delta_{p+1}\langle T_0^0\rangle_{p,q} \approx \frac{4De^{-Dt/\alpha}B}{(2\pi)^{(p+3)/2}\alpha L_{p+1}^p V_q}\sin\left[2|\nu|t/\alpha + 2|\nu|\ln\left(L_{p+1}/\alpha\right)+\phi_0\right], \quad (18)$$

where the parameters B and ϕ_0 are defined by the relation

$$Be^{i\phi_0} = 2^{i|\nu|}\left[|\nu|(1/2-2\xi)+i(D/4-(D+1)\xi)\right]\Gamma(i|\nu|)$$
$$\times\sum_{n=1}^{\infty}(\pm 1)^n\sum_{n_{q-1}=-\infty}^{\infty} n^{2i|\nu|-p-1} f_{(p+1)/2-i|\nu|}(nL_{p+1}k_{n_{q-1}}). \quad (19)$$

In the same limit, the main contribution into the vacuum stresses comes from the term $A_{p,q}$ in (12) and one has (no summation over i

$$\Delta_{p+1}\langle T_i^i\rangle_{p,q} \approx \frac{8|\nu|e^{-Dt/\alpha}B}{(2\pi)^{(p+3)/2}\alpha L_{p+1}^{p+1}V_{q-1}}\cos\left[2|\nu|t/\alpha + 2|\nu|\ln\left(L_{p+1}/\alpha\right)+\phi_0\right]. \quad (20)$$

Hence, in the case under consideration at late stages of the cosmological evolution the topological part is suppressed by the factor $\exp[-Dt/\alpha]$ and the damping of the corresponding VEV has an oscillatory nature.

4. Conclusion

Motivated by the fact that dS spacetime naturally arises in a number of contexts, in the present paper we consider the Casimir densities for a massive scalar field in $D+1$ -dimensional dS spacetime having the spatial topology $R^p \times (S^1)^q$. Both cases of the periodicity and antiperiodicity conditions along the compactified dimensions are discussed. We have derived a recurrence relation which presents the vacuum energy-momentum tensor for the dS_{D+1} with topology $R^p \times (S^1)^q$ in the form of the sum of

the energy-momentum tensor for the topology $R^{p+1} \times (S^1)^{q-1}$ and the additional part induced by the compactness of the $(p+1)$th spatial dimension. The repeated application of the recurrence formula allows us to present the expectation value of the energy-momentum tensor as the sum of the uncompactified dS and topological parts. Since the toroidal compactification does not change the local geometry, in this way the renormalization of the energy-momentum tensor is reduced to that for uncompactified dS_{D+1}.

At early stages of the cosmological expansion, corresponding to $t \to -\infty$, the vacuum energy-momentum tensor coincides with the corresponding quantity for a conformally coupled massless field and the topological part behaves like $e^{-(D+1)t/\alpha}$. In this limit the topological part dominates in the VEV. At late stages of the cosmological expansion, $t \to +\infty$, the behavior of the topological part depends on the value of ν. For real values of this parameter the leading term in the corresponding asymptotic expansion is given by formula (17) and the vacuum stresses are isotropic. In this limit the topological part is suppressed by the factor $e^{-(D-2\nu)t/\alpha}$. In the same limit and for pure imaginary values of the parameter ν the asymptotic behavior of the topological part in the VEV of the energy-momentum tensor is described by formulae (18), (20) and the topological terms oscillate with the amplitude going to the zero as $e^{-Dt/\alpha}$ for $t \to +\infty$

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Might Quantum Symmetry Breakdown Cause Supermassive Proto-Matter according to Ambartsumyan's Prediction

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In recent papers we have predicted a heuristic hypothesis about domination of Bose-Einstein statistics over the Fermi-Dirac one at the beginning stage of the creation of quantum statistics. The mass and radius of spherical-symmetric configurations consisted of baryon-antibaryon pairs and $W^{\pm}, Z^{0}$ bosons, have been calculated. The sharp increase of the thermodynamic pressure during gravitational self-compressing process (caused by spontaneous breakdown of quantum symmetry resulted the transition from the Bose statistics into Fermi one) may be considered as a thermodynamic phase transition. The likelihood of so-called "Local Cosmological Bang" or "Cosmological Small Bang" phenomenon which followed perhaps the Big Bang, is very close to one. This phenomenon is considered to be a candidate for induced process of gravitational collapsing stimulated by the powerful shock wave, which may be generated due to the abrupt appearance of the Pauli Exclusion Principle. It might involve enormous interior mass of the configuration, supporting the Black Holes formation in the scale of broad masses within $10^{4} \div 5\times 10^{6} M_{\square}$.

To develop our understanding about the creation of cosmic matter in the early stage of the Universe we made an attempt to advance a hypothetic model of quantum symmetry breakdown resulting the transition from the Bose statistics into Fermi one. For the first quasi-qualitative/quasi-quantitative investigation of accumulation of large cosmic scales masses we will start from the case of structural bosons, consisted mainly from proton and antiproton (number of neutron-antineutron, as well as electron-positron pairs are negligible). The spatial scale of quantum-electrodynamics phenomena, especially for $\gamma + \gamma \leftrightarrows p + \tilde{p}$ process, has the same order value as the proton's Compton wavelength: $\lambda_p = \hbar / m_p c \approx 2.1\times 10^{-14} cm$. The physical approach of structural boson's "point-or-elementary" assumption will maintain its descriptive strength until the scattering amplitude of these structural bosons will exceed their own size by several times. This corresponds to the upper limit of pairs concentration $n_{p\tilde{p}} \approx 1.9\times 10^{39} cm^{-3}$. For mentioned densities and supposed temperatures of the Universe $T \square 2\times 10^{9} \div 10^{10} K^{0}$ at the beginning stage of Matter Era the proton-antiproton superdense degenerate

plasma moderately reaches its relativistic bound and for the BEC temperature is obtained $T_0 \approx 4.6 \times 10^{12} K^0$.

The spherical-symmetric configuration of proton-antiproton pairs (so called hypothetical Micro-Universe) may be qualitatively described in presumption of convective stability (the process of gravitational pressing is assumed to be isothermal), then the equations of thermodynamic and hydrodynamic equilibrium without relativistic corrections (the photonic pressure is negligible in comparison with the BEC one) yield the following radial dependences of pressure (left) and mass (right) for mainly proton-antiproton (solid line) and in addition also $W^{\pm}$, Z^0 bosonic (dashed line) configurations:

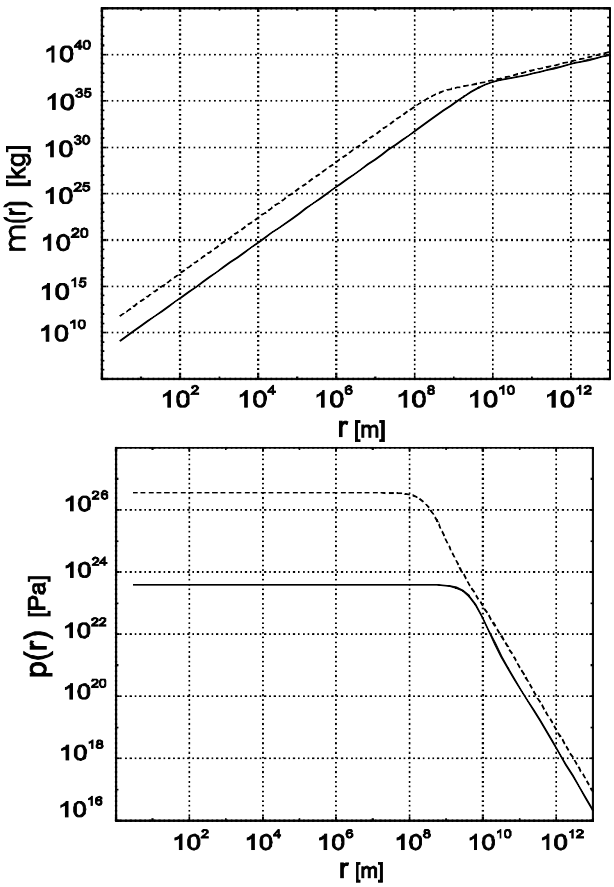

Fig. 1.

It is realistic, that beside the structural bosons – proton-antiproton pairs, at the generation of cosmic matter in the scope of proposed model one should probably take

into account also the principal existence of elementary bosons, namely $W^{\pm}$ and Z^{0}. As these gauge bosons are almost 100 times as massive as the proton, so they may have significant contribution in the pressure and mass accumulation (dashed lines). Although these bosons have a very short-life time, they may be engaged in the phenomenon of BEC. These issues require an additional theoretical investigation to constitute the following problems: might the elementary bosons become stable particles at the extra high densities? The possibility of this exotic phenomenon, i.e. production of elementary Bose-particles after the breakdown of supersymmetry and separation of fundamental interactions requires an additional discussion in following aspect: might the intermediate carriers of weak interaction appear and be stabilized in superdense plasma? Alternatively, might they play a significant role in the phenomenon of mass generation and further accumulation of the matter until galactic masses? At last, the most important issue: might the Bose-condensate of elementary bosons $W^{\pm}$ and Z^{0} be responsible for the phenomena of Dark Matter?

Up to critical density $n_{p\bar{p}} \approx 1.9 \times 10^{39} cm^{-3}$ the proton-antiproton pair do not "sense" own inner structure and may be considered as "point-or-elementary" boson. The weak dependence of pressure and temperature on the radius evidences that within the BEC state approximation the matter responds extremely weak on external pressure and in the result the gravitational pressing may accumulate huge masses within the cosmic scales. In this intermediate state, such hypothetical configuration of proton-antiproton degenerate plasma appears within extremely non-stable state. Actually, because of scattering of pairs on each other, at the critical value of density this state should fail due to the breakdown of structural Bose-pairs. So, this unstable state will be transferred from Bose-Einstein statistics to Fermi-Dirac one and in the result the pressure of the fermions system will increase significantly, in accordance with the Pauli Exclusion Principle. One can obtain the corresponding jump of pressure in the phase transition stipulated by the phenomenon of quantum mechanical symmetry breakdown: $P_{F-D} / P_{BEC} \approx 2.3 \times 10^{11}$.

It is physically obvious, that the possibility of generation of large-scale configurations in principle does not except just in one local cosmic space-time scales. Furthermore, this hypothesis and corresponding physical model, as well as its astrophysical applications might have cosmological consequences both within relatively small- and large-scales cosmic structures. Note that after predicted Cosmological Small Bang (CSB) at the beginning stage of Matter Era the "islands" of similar configurations of degenerate matter might be accumulated, which might form then various stable cosmic objects. It is physically obvious that these objects principally might correlate in groups, clusters, or even associations.

May the predicted CSB be a candidate for the "generator" of galactic-scale masses? This physical question requires additional analysis in the scope of considered hypothesis and corresponding astrophysical model. Besides, the considered problems require further investigation of the discussed analytical model and development of the main ideas presented here in the scope of general relativity. In addition, it is essential to take into consideration the various empiric equations for BEC which might be more realistic from the cosmological point of view.

As is seen from the graphic for pressure, in the result of gravitational pressing the pressure of the matter remains constant from the centre of the spherical-symmetric configuration up to the distance $R_0 \approx 10^{11} cm$, then decreases close to the exterior bound $R \approx 10^{15} cm$. That is the density of the baryon-antibaryon relativistic plasma achieves its critical value $n_{cr} \approx 1.9 \times 10^{39} cm^{-3}$ in the volume $V_0 = (4\pi/3) R_0^3 \approx 4.2 \times 10^{33} cm^3$ where the decay of the Bose condensate occurs. In the result the change of symmetry of the quantum statistics takes place and, consequently, the Bose-matter turns to the Fermi one. Such abrupt variation of quantum statistics will increase the initial pressure of Bose condensate from the initial value $1.26 \times 10^{24} Pa$ till the $3.36 \times 10^{35} Pa$, i.e. the growing of the matter pressure will be about $\Delta P \approx 3.36 \times 10^{35} Pa$. As far as this process can be considered in the constant volume then the amount of produced energy at this phase transition is:

$$\Delta E = V_0 \Delta P = \frac{4\pi}{3} R_0{}^3 \Delta P \approx 1.4 \times 10^{70} erg . \qquad (1)$$

Let us compare the energy of the initial proton-antiproton Bose-condensate, confined in the centre of considering configuration within the volume $V_0 \approx 4.2 \times 10^{33} cm^3$ with the total energy of Fermi gas of protons and antiprotons, produced in the same volume because of the phase transition. As it was mentioned in the previous paper [1], the initial temperature in the Bose-condensate state has been assumed $T \approx 10^{10} K^0$. Note that a more actual physical condition corresponds to constant temperature during the whole process of gravitational pressing. Indeed, since this phase transition from Bose to Fermi statistics occurs during the extremely short while (practically instantaneously) related to any relaxation times of plasma, then the temperature of the latter can not be varied considerably at such quantum phase transition.

Hence, in the scope of assumed model we obtain the amount of internal energy of the initial Bose-condensate consisted of baryon-antibaryon pairs:

$$E_{BEC} = 0.128 m_{p\tilde{p}}^{3/2} \hbar^{-3} V T^{5/2} \approx 2.21 \times 10^{63} erg . \qquad (2)$$

The resulting after the phase transition total energy of produced proton and antiproton Fermi gases is given by the expression

$$E_{F-D} = \frac{3}{4}(3\pi^2)^{1/3}\hbar c V\left(\frac{N}{V}\right)^{4/3} \approx 7,23\cdot 10^{69} erg\ . \qquad (3)$$

As is seen from the expressions (2) and (3), the produced in the result of CSB energy of the Fermi system on more than 6 orders exceeds the initial proton-antiproton Bose-condensate interior energy.

At the standard approach a very realistic question may arise: what is the source of the additional energy reservoir, providing the phase transition from Bose to Fermi statistics? For this goal let us consider the possible sources for the energy accumulation in the above stated inner volume of configuration.

The calculation of rotational energy of proton-antiproton pair is made in assumption that each of these pairs is an analogue of two-atom molecule. At the values of a proton-antiproton pair size considering in the paper [1], for the quantity of the moment of inertia we obtain $I \approx 7.4\times 10^{-52} g\cdot cm^2$. In the expression for the rotational energy $\varepsilon^{rot} = \frac{\hbar^2 K(K+1)}{2I}$ one can assume $K=1$, because the energy of rotational quantum $\varepsilon^{rot}_{\min} = \frac{\hbar^2}{2I} \approx 7.5\times 10^{-4} erg$ is quite larger than the energy of thermal quantum $k_B T \approx 1.38\times 10^{-6} erg$ at the temperature $T \approx 10^{10} K^0$. Therefore, for a system consisted of $N_{p\tilde{p}} \approx 3\times 10^{61}$ number of proton-antiproton pairs, the total rotational energy can be estimated as:

$$E^{rot}_{p\tilde{p}} = N_{p\tilde{p}}\frac{\hbar^2}{2I} \approx 2.25\times 10^{58} erg\ . \qquad (4)$$

The calculation of vibrational energy of baryon-antibaryon pairs may be done qualitatively using an experimental data of hydrogen molecule, according to which the quantum of vibrational energy about 70 times exceeds the quantum of rotational energy. Consequently,

$$E^{vib}_{p\tilde{p}} = 70E^{rot} \approx 1.6\times 10^{60} erg\ . \qquad (5)$$

At last, if one assumes the solid rotation for a spherical configuration as a whole body, we can also estimate the supremum of the rotational energy at the homogeneous distribution of the matter (numerical simulation for the mass with an inhomogeneous-decreasing distribution of the matter gives at least on 1 order smaller quantity):

$$E_{rot} \approx 6\times 10^{67} erg\ . \qquad (6)$$

The presented estimations of (4)-(6) confirm the infeasibility of energies provided by any well-known physical source for provision of necessary energy (1), which might realize the phase transition from Bose- to Fermi-statistics. So non of considered mechanisms might provide the required energies of the predicted CSB.

On the other hand, it is physically obvious, that such an abrupt change of the quantum plasma characteristics in the period, corresponding to CSB will lead also to the abrupt variation of its electromagnetic properties in the time, namely the dielectric permittivity. The latter will influence crucially on the frequencies of the quanta, propagating trough such matter with sharp nonstationary dielectric permittivity [2]. In these circumstances there is an undetermined parameter in considering issue - the while of the change of quantum symmetry. For the latter it is most reasonable to construct the minimal time scale in nonstationary processes trough the fundamental physical constants (namely the Planck's scales). Hence, for the minimal while for the fundamental quantum transition from the Bose statistics into Fermi one may be taken the Planck's time-scale:

$$t_{Pl} = (\hbar G/c^5)^{1/2} . \qquad (7)$$

Then arising from the principle of uncertainty $\Delta\varepsilon_1 \Delta t \leq \hbar$ for such transition process with $\Delta t \sim t_{Pl}$ one can estimate the energy change of the proton-antiproton matter after the decay on a system of free protons and antiprotons at the change of quantum statistics (energy change by the decay of one pair):

$$\Delta\varepsilon_1 \sim \frac{\hbar}{(\hbar G/c^5)^{1/2}} \approx 1.85 \times 10^{16} erg. \qquad (8)$$

Since the number of proton-antiproton pairs in the core of a configuration $V_0 \approx 4.2\times10^{33} cm^3$ is about $N_{p\bar{p}} \approx 3\times10^{61}$, then the total energy change of the initial Bose-condensate as a consequence of the phase transition of the quantum plasma from Bose- to Fermi-statistics reads:

$$\Delta E = N_{p\bar{p}} \Delta\varepsilon_1 \approx 5.55\times10^{77} erg . \qquad (9)$$

In comparison with (3) this energy exceeds on 7 orders the necessary energy required for CSB.

Because of the latter a shock wave is formed on the surface of the constant pressure sphere with the radius $R_0 \approx 10^{11} cm$. This shock-wave will propagate as to the centre of the configuration, as well as to the external surface. The effects arising because of the shock-wave propagating towards the configuration surface require a special consideration and will be studied in a separate paper. Note only that this shock wave of enormous strength will also break the Bose-condensate within the outer layer, where the main mass of the configuration is concentrated, nearly $M_{crust} \approx 10^{10} M_{\odot}$. Further

this cosmic plasma consisted mainly from baryons and leptons would be involved within the process of the celestial objects formation. Here let us note briefly about a consequence of the shock-wave action propagating to the centre of the configuration. Due to its enormous pressure this shock-wave will stimulate the gravitational collapsing, in the result of which it is possible the formation of Black Hole (BH) in the centre of the configuration. The mass of such BH just corresponds to the mass of the initial matter in the Bose-condensate within the volume $V_0 \approx 4.2 \times 10^{33} cm^3$. If one considers only proton-antiproton initial Bose-condensate, then from the solid line of the configuration mass graphic for the expected BH mass one can obtain $M_0 \approx 10^{38} g \approx 5 \times 10^4 M_\odot$. Meanwhile, if one includes also $W^\pm$, Z^0 bosonic-condensate, then from the dashed line of the configuration mass graphic for the expected Black Hole mass one can obtain $M_0 \approx 10^{40} g \approx 5 \times 10^6 M_\odot$. Both estimations of this speculative study are in good agreement with astronomical observational data, related to the BH with intermediate masses.

Resuming let us note as well that such huge energy corresponding to formula (9) will be a power source for understanding the physical mechanism of phenomenon of extra-high energy Gamma bursts, detected from the active galactic nucleus.

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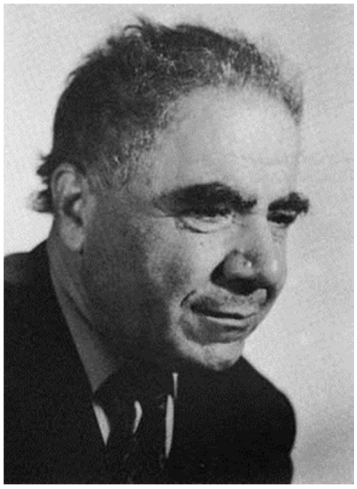
Session 5. LIGHT SCATTERING AND RADIATIVE TRANSFER



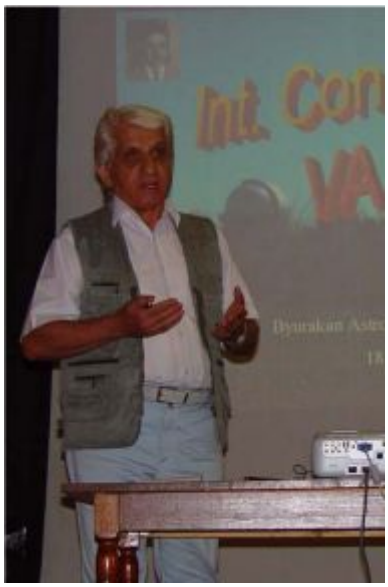
V.A. Ambartsumian's contribution in the field:

For the first time the **influence of the light pressure on the planetary nebulae (PN) dynamics** was studied. A new result on the **expansion and dissipation of PN** owing to light pressure. Shown that the age of PN could not exceed 100000 years if no continuous outflow existed from the central star. A new evolutionary paradigm on formation of objects from denser matter was formulated (1932).
Ref.: V.A. Ambartsumian – The Radiative Equilibrium of a Planetary Nebula // *MNRAS, 93, 50-61, 1932.*

New method (Ambartsumian's method) **for determination of the planetary nebulae's central stars surface temperature** giving the probabilistic definition of short wave energetic photons transformation into less energetic ones. This definition led to the radiative equilibrium determination (1932).
Ref.: V.A. Ambartsumian – On the Temperatures of the Nuclei of Planetary Nebulae // *Poulkovo Observatory Circular, 4, 8-12, 1932.*

Development of light scattering theory in turbid medium, **theory of Invariance (Ambartsumian's principle of invariance)**. A very simple physical reasoning that the reflection properties of the semi-infinite plane-parallel medium do not change if a very thin layer of the same physical properties is added (1941). Corresponding function was named Ambartsumian's φ function.
Ref.: V.A. Ambartsumian – The Scattering of Light in a Turbid Medium // *Journal of Physics, 5, 93, 1941.*

Ambartsumian's Methods in the Radiative Transfer Theory



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1. Introduction

An important place in the scientific heritage of Ambartsumian occupy his remarkable works in the theory of radiative transfer. I consider it an honor to tell at this anniversary conference on the methods proposed by him, their further development, the witness and participant of which to a certain degree was I.

Appearing in the beginning of the past century the works of Schuster, Schwarzschild, Milne and Eddington laid down a basis of the theory of stellar atmospheres. The study of the equation of radiation transfer and its solutions in various forms occupied important place in it. Of course, there were investigated first of all the simplest and therefore the rough models, in which the medium is assumed to be plane-parallel, stationary, homogeneous and purely absorbing. The last assumption substantially simplifies the problem of finding the field of radiation in the atmosphere, since in this case the state of the radiating gas obeys the equilibrium laws of Saha and Boltzmann with the local values of temperature and density. In this approximation, referred to as the approximation of LTE (local thermodynamic equilibrium), the source function, appeared in the transfer equation, is given by the Kirchhoff-Planck laws. The situation changes drastically, when one takes into account the scattering of radiation, which is of particular importance in the problem of the spectral lines formation in the atmosphere. Now the state of the radiating gas depends not only on the local values of thermodynamic parameters, but also on the field of radiation at a particular point, what establishes coupling between different volumes inside the atmosphere. The equation of radiation transfer in this case is integrodifferential and its solution encounters, in general, great difficulties.

In spite of the rough assumptions, the first works in this direction contributed in many respects to the physical understanding of the studied processes and stimulated progress of the theory. The most important articles in this field were assembled by Menzel [1]. The approach, which was developed in them and became classical, consisted in finding

the source function as a function of the depth in atmosphere, which, in its turn, made it possible to determine the field of radiation within it. In the simplest cases of isotropic and monochromatic scattering the problem is reduced mathematically to the solution of an integral equation of Fredholm's type with the kernel being the exponential integral depended on the modulus of a difference of the arguments (see below the equation (14)). Its solution allows, in particular, to determine the intensity of the radiation emerging from the atmosphere, i.e., the quantity, directly measured in observations. This was the state of the theory in 40-s of the past century, when the first works of Ambartsumian appeared in the field.

In contrast to the conventional approach described above, Ambartsumian proposed the new method, named by him ‘the principle of invariance’, which allowed to find the outgoing intensity without preliminary determination of the light regime at all depths. As it writes Ambartsumian [2], "… the theory in this case is constructed not on the integration of local processes, but on the properties of invariance". By principle of invariance, Ambartsumian implies such transformation of the initial atmosphere, which does not influence the global optical characteristics of the medium [2-5]. Such definition obviously suggests that the term "principle of invariance" can be used only in singular. Being applied the principle significantly facilitates the solution of the radiation transfer problems, revealing from the very beginning the structure of the desired solutions what is, in its turn, a great help in finding the field of radiation inside the atmosphere. The further progress showed that the principle of invariance is a special case of the more general variational principle, connected with the translational transformation of the optical depth (see below, §3, and also [6]). The application of this principle makes it possible to derive for different quantities in different problems the large number of important relationships, which sometimes are possible to write immediately, on the basis of simple physical and/or probabilistic considerations. Such relationships, which follow from the principle of invariance, can be called *the invariance relations*.

As a result of his studies in 1941-1947 in the theory of radiative transfer, Ambartsumian proposed also another rather efficient method, named by him the method of addition of layers [7] (see also [8]). It gives response to the question, how the global optical characteristics of the absorbing and scattering media (coefficients of reflection and transmission) are added during their joining. It is obvious that this sufficiently general posing of the question appears naturally, if we abandon the requirement that the optical properties of the medium would remain unchanged during adding to it of a new layer. The obtained relationships reveal the functional form of optical characteristics of the composite atmosphere, moreover, which is important, all parameters and functions, which describe elementary processes, play the role of arbitrary parameters. The small work published in the war years in Izv. AN of ArmSSR, devoted to the method of addition of layers, served as starting point for appearance of the new directions in the transfer theory, which have use not only in astrophysics, but also in some other

branches of physics. The method gives a key to the solution of the transfer problems for inhomogeneous atmospheres, and on the other hand, it was basis for the so-called method of invariant imbedding developed abroad.

Both for the principle of invariance and for the method of addition of layers developed by Ambartsumian are characteristic mathematical elegance, originality of approach, simplicity and clarity of reasoning. As in other branches of astrophysics, Ambartsumian finds the unordinary methods of solution of very complex and important problems. One of the founders of the theory of stellar atmospheres A.Milne wrote in this connection: "I have never imagined that the theory of radiative transfer could have attained the level of development and beauty which it had achieved in the hands of Ambartsumian".

The goal of this report is to give a general idea on Ambartsumian's methods, their importance and further development. I attempt to make it understandable for anyone who is not expert in the radiative transfer theory. From the vast volume of results obtained in the field by other authors, I shall mention only those, which, in my opinion, expose the essence and importance of Ambatsumian's methods to a greater extent.

2. The principle of invariance

Ambartsumian formulated the invariance principle for the first time in treating the problem of diffuse reflection of light from a semi-infinite atmosphere [3,4]. Considerations underwent the principle are based on the apparent fact that the addition to this medium a layer of infinitesimal optical thickness $\Delta\tau$, possessing the same properties as the original one, must not change its reflectivity. This thesis was referred by Ambartsumian to as the principle of invariance. This implies that the total contribution of processes relevant to the added layer will be equal to zero.

In the 3D problem the reflectance of a medium is characterized by the reflection function $\rho(\eta,\varsigma)$, where ς and η are respectively the cosines of the angles of incidence and reflection. It is introduced in such a way that the quantity $r(\eta,\varsigma)=(1/2)\rho(\eta,\varsigma)\varsigma$ defines the intensity of radiation diffusely reflected from a medium in the direction η, if the latter is illuminated at an angle $\arccos\varsigma$ by a flux of parallel rays equaled to π. Let us assume that the probability of the photon re-radiation during the elementary act of scattering is λ. The possible processes taking place in the layer $\Delta\tau$ are schematically depicted in the Fig.1.

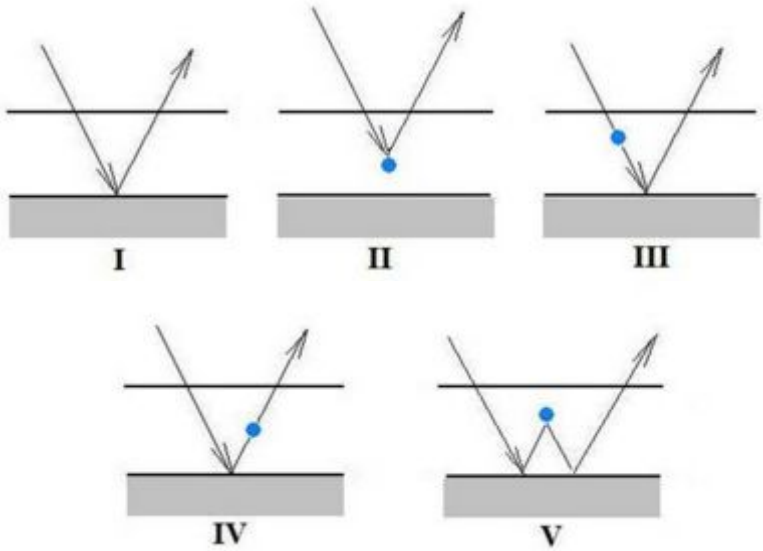

Fig. 1. Five possible realizations of the radiation transport through the layer $\Delta\tau$.

I. Incident radiation passes the additional layer without scattering, and then is reflected, again, with no scattering on the way out. The expression for the contribution of this process is

$$\left(1-\frac{\Delta\tau}{\eta}\right)r(\eta,\varsigma)\left(1-\frac{\Delta\tau}{\varsigma}\right)$$

II. The radiation is reflected by the additional layer. The contribution of this process is

$$\frac{\lambda}{4}\frac{\Delta\tau}{\eta}.$$

III. The incident radiation is scattered by the layer toward the medium and partially reflected by it. The proper intensity is

$$\frac{\lambda}{2}\Delta\tau\int_0^1 r(\eta,\eta')\frac{d\eta'}{\eta'}.$$

IV. Incident radiation passes the additional layer with no scattering, reflected by the medium and then it is scattered by the layer in a given direction. The contribution relevant to this process is

$$\frac{\lambda}{2}\frac{\Delta\tau}{\eta}\int_0^1 r(\eta',\varsigma)d\eta'.$$

V. The last possibility is due to double reflection (so-called threefold process). The radiation first reflected by the medium, then it is scattered backward by the additional layer, and finally it is again reflected by the medium. For this process we have

$$\lambda\Delta\tau\int_0^1 r(\eta,\eta'')\frac{d\eta''}{\eta''}\int_0^1 r(\eta',\varsigma)d\eta'.$$

Contribution of the all other possible processes is quantities of the higher order of smallness with respect to $\Delta\tau$ and may be ignored. Then the condition of invariance of the reflection function for the semi-infinite atmosphere can be written in the form

$$(\eta+\varsigma)\rho(\eta,\varsigma)=\frac{\lambda}{2}\varphi(\eta)\varphi(\varsigma), \tag{1}$$

where the function

$$\varphi(\eta)=1+\eta\int_0^1 \rho(\eta,\eta')d\eta' \tag{2}$$

is referred to as the Ambartsumian φ - function. The last two equations implies that the function φ satisfies the following functional equation

$$\varphi(\eta)=1+\frac{\lambda}{2}\eta\int_0^1 \frac{\varphi(\eta)\varphi(\eta')}{\eta+\eta'}d\eta', \tag{3}$$

usually called the Ambartsumian equation. We see from (1) that the reflectance $\rho(\eta,\varsigma)$ is expressed through a function of one variable and is a symmetrical function of its arguments. The quantity $\eta\rho(\eta,\varsigma)d\eta$ possesses a probabilistic meaning, namely, it gives the probability that the quantum incident on the medium in the direction ς, will be reflected by it in the directional interval η, $\eta+d\eta$.

In the same paper [3] Ambartsumian applies the principle of invariance for solving the problem of diffuse reflection and transmission for the medium of finite optical thickness. In this case the layer of infinitesimal optical thickness $\Delta\tau$ is added to one of boundaries while such layer is subtracted from the opposite side. For the reflectance

$\rho(\eta,\varsigma)$ and transmittance $\sigma(\eta,\varsigma)$ this results (for convenience of the further discussion we adopt here somewhat different notations)

$$\rho(\eta,\varsigma)=\frac{\lambda}{2}\frac{\varphi(\eta)\varphi(\varsigma)-\psi(\eta)\psi(\varsigma)}{\eta+\varsigma},$$

$$\sigma(\eta,\varsigma)=\frac{\lambda}{2}\frac{\psi(\eta)\varphi(\varsigma)-\varphi(\eta)\psi(\varsigma)}{\eta-\varsigma}. \qquad (4)$$

The auxiliary functions $\varphi(\eta)$ and $\psi(\eta)$ are determined from the following system of functional equations

$$\varphi(\eta)=1+\frac{\lambda}{2}\eta\int_0^1\frac{\varphi(\eta)\varphi(\eta')-\psi(\eta)\psi(\eta')}{\eta+\eta'}d\eta', \qquad (5)$$

$$\psi(\eta)=\mathrm{e}^{-\frac{\tau_0}{\eta}}+\frac{\lambda}{2}\eta\int_0^1\frac{\psi(\eta)\varphi(\eta')-\varphi(\eta)\psi(\eta')}{\eta-\eta'}d\eta', \qquad (6)$$

where τ_0 is the optical thickness of the medium. These functions also called the Ambartsumian functions. It is clear that the reflectance and transmittance as well as the functions $\varphi(\eta)$ and $\psi(\eta)$ depend also on optical thickness of the medium, nevertheless, for brevity, τ_0 is not indicated explicitly among arguments.

The results, obtained by Ambartsumian in this fundamental work stand out by their elegance and clarity. As has already been indicated, the starting point for determination of the intensity of radiation outgoing from the medium is here not the equation of transfer, which allows finding the required quantity only after the regime of radiation is found for all depths in the atmosphere. It is obvious that, in view of the linearity of problem, the knowledge of the functions of reflection and transmission makes it possible to determine the intensity of the outgoing radiation for any flux falling on the medium. On the other hand, formulas (1) and (4) give solution not only of one particular problem of diffuse reflection (for the semi-infinite medium) or the problem of diffuse reflection and transmission (for the finite medium). In fact they make it possible to reveal the structure of the global optical characteristics of medium, as such, expressing in this case the unknown quantities through the functions of one variable. Approach itself in many respects contributed to derivation of a number of important relations connecting with each other different characteristics of the radiation field, in the problems of the radiative transfer theory most frequently encountered in the

astrophysical applications. Some of them follow directly from the property of invariance. Such relationships were obtained in the different time by a number of authors (see, for example, [6, 9-18]).

It should be noted that the relations (1) -(3) were obtained by Ambartsumian earlier by another method in considering the scattering of light by the atmospheres of planets [19]. The way, chosen in the mentioned work, consists in formal differentiation of the initial integral equation for the source function over the optical depth. From a purely mathematical point of view the way proposed is of large importance, since it shows, how the solution of the integral equation of the Fredholm type with the difference kernel can be reduced to the solution of functional equation. In this work he obtained another important result in treating the energy distribution over the solar disk. It was shown that the limb-darkening law of the Sun is given by the function $\varphi(\eta)$ with $\lambda = 1$, namely, $I(\eta)/I(0) = \varphi(\eta)$ (see also [20]), where $I(\eta)$ - the intensity of radiation, observed at a certain angular distance from the center of the disk, whose cosine is η.

The exact analytical expression for the function $\varphi(\eta)$ in the case of conservative scattering was obtained earlier by Hopf ([21], p.105) in considering the Milne problem. An explicit expression was derived also for the general case $\lambda \neq 1$ (see [22])

$$\varphi(\eta) = \exp\left\{-\frac{\eta}{\pi}\int_0^\infty \ln\left(1-\lambda\frac{\operatorname{arctg} u}{u}\right)\frac{du}{1+\eta^2u^2}\right\}. \tag{7}$$

Numerical calculations of the function $\varphi(\eta)$ were performed by Ambartsumian in [19] by using the iteration method to the equation

$$\varphi(\eta) = \left(\sqrt{1-\lambda} + \frac{\lambda}{2}\int_0^1 \frac{\eta'\varphi(\eta')}{\eta+\eta'}d\eta'\right)^{-1}, \tag{8}$$

Later many authors turned to the problem of determination of this function. A simple expression for approximate calculations of the function $\varphi(\eta)$ was obtained in [9] with use of the Wick – Chandrasekhar method of discrete ordinates, which approximate the integral of an arbitrary function by a sum of discrete values of this function

$$\varphi(\eta) = \frac{\prod_{i=1}^{n}(1+\eta/\eta_i)}{\prod_{\alpha=1}^{n}(1+k_\alpha\eta)}, \tag{9}$$

where n is the order of approximation, η_i are zeros of the Legendre polynomials of the order n. The quantities k_α are the roots of the so-called characteristic equation

$$1 = \frac{\lambda}{2}\sum_{j=1}^{n}\frac{a_j}{1-k^2\eta_j^2}, \tag{10}$$

and the constants a_j are the weights of the Gauss-Legendre quadrature formula.

The idea on the invariant property of the global optical characteristics of the scattering and absorbing atmosphere with respect to the layer addition was employed by Ambartsumian in the problem of the radiation diffusion through the optically thick medium [23,24]. This means that the relative angular distribution of the intensity of radiation transmitted through such medium remains unchanged as a result of the mentioned transformation. Arguments typical to the invariance procedure accounting for the elementary processes in the additional layer allows to write for the transmitted intensity in the case of isotropic scattering

$$I(\eta) = C\frac{\varphi(\eta)}{1-k\eta}, \tag{11}$$

where C is a certain constant and k is determined from the equation

$$\frac{\lambda}{2}\int_0^1 \frac{\varphi(\eta)}{1-k\eta}d\eta = 1. \tag{12}$$

In the conservative case $(\lambda = 1)$ equation (12) yields $k = 0$ so that

$$I(\eta) = C\varphi(\eta). \tag{13}$$

Thus, the function $\varphi(\eta)$ admits an alternative physical interpretation, which concerns the angular distribution of the intensity of radiation transmitted through the optically thick atmosphere in the absence of true absorption. It is noteworthy that this simple formula remains be valid for the two-term indicatrix $x(\gamma)=1+x_1\cos\gamma$ for arbitrary x_1.

In various astrophysical problems one encounters, as it is known, the necessity to find the radiation field within the medium. An important advantage of the invariance principle is that the knowledge of the intensities of radiation outgoing from a medium facilitates the solution of this problem essentially (see, e.g., [25-27]). For instance, the problem of determination of the radiation field in a semi-infinite atmosphere illuminated by a beam of parallel rays at angle of $\arccos\varsigma$ is reduced, as it is known well, to the solution of the following integral equation

$$S(\tau,\varsigma)=\frac{\lambda}{2}\int_0^\infty \mathrm{Ei}\left(|\tau-\tau'|\right)S(\tau',\varsigma)\,d\tau'+\frac{\lambda}{4}e^{-\frac{\tau}{\varsigma}} \tag{14}$$

for the source function. Being applied the invariance principle makes it possible to reduce the solution of this Fredholm-type integral equation to the solution of the following Volterra-type equation for auxiliary function $\Phi(\tau)$ related with the resolvent function of equation (14)

$$\Phi(\tau)=L(\tau)+\int_0^\tau L(\tau-\tau')\Phi(\tau')\,d\tau', \tag{15}$$

where

$$L(\tau)=\frac{\lambda}{2}\int_0^1 \varphi(\varsigma)e^{-\frac{\tau}{\varsigma}}\frac{d\varsigma}{\varsigma}. \tag{16}$$

An explicit expression for the function $\Phi(\tau)$ was obtained in [28].

For illustration, we limited our consideration by the simplest case of monochromatic scattering, though the picture we described and conclusions remain valid for the much more general statement of the transfer problem. From the pure mathematical point of view, Ambartsumian's principle of invariance may be considered as a way reducing the boundary-value problem usually formulated for the source function to the solution of the initial-value or Cauchy problem.

The first works on the principle of invariance concern the monochromatic and isotropic scattering. It was apparent, however, that the principle may also be applied under much more general assumptions on the elementary act of scattering. That is why as early as in the paper [29] Ambartsumian handles the problem of diffuse reflection of light from a semi-infinite plane-parallel atmosphere for anisotropic scattering with arbitrary phase function. It is noteworthy that here he employs the expansion of the phase function $x(\gamma)$ (γ is the angle of scattering) in a series of Legendre polynomials which was suggested earlier by him in [30,31]

$$x(\gamma)=\sum_{i=0}^{\infty} x_i P_i(\cos\gamma). \tag{17}$$

or with use of the summation theorem for spherical functions

$$x(\eta,\eta',\varphi-\varphi')=\sum_{m=0}^{\infty}\cos m(\varphi-\varphi')\sum_{i=m}^{\infty} c_{im}P_i^m(\eta)P_i^m(\eta'), \tag{18}$$

where the constants c_{im} are expressed through the coefficients x_i. Then an expansion similar to (18) holds for the reflection function

$$\rho(\eta,\eta',\varphi-\varphi')=\sum_{m=0}^{\infty}\rho_m(\eta,\eta')\cos m(\varphi-\varphi'). \tag{19}$$

Now the solution of the problem is written by means of the functions $\varphi_i^m(\eta)$

$$\rho_m(\eta,\eta')=\frac{\lambda}{4}\sum_{i=m}^{\infty}(-1)^{i+m}c_{im}\frac{\varphi_i^m(\eta)\varphi_i^m(\eta')}{\eta+\eta'}, \tag{20}$$

which are determined from the following set of functional equations

$$\varphi_i^m(\eta)=P_i^m(\eta)+2\frac{(-1)^{i+m}}{2-\delta_{0m}}\int_0^1\rho_m(\eta,\eta')P_i^m(\eta')d\eta', \tag{21}$$

where δ_{km} is the Kroneker symbol.

To illustrate the obtained results, Ambartsumian treats in the same paper two special cases: the scattering with two-term and the Releigh phase functions, which are of astrophysical importance.

These results were developed in future by many authors. For instance, in the mentioned two special cases Chandrasekhar sought the requisite function in the form different from (19) which reduces the problem to solution of the following type of equations (see. [9])

$$H(\eta) = 1 + \eta \int_0^1 \frac{H(\eta) H(\eta')}{\eta + \eta'} \Psi(\eta') d\eta' . \qquad (22)$$

It is easy to see that Eq. (22) differs from (3) only by the so-called characteristic function $\Psi(\eta)$ appearing in integral term and representing the polynomial of the even degree. Here we are making use of the notation $H(\eta)$ introduced by Chandrasekhar for Ambartsumian's function. Similarly, for the functions φ and ψ in the case of finite medium, he introduced notations *X* and *Y*, which are in use mainly in the foreign literature (see [9]).

It is apparent that the invariance principle formulated by Ambartsumian is sufficiently general as far as its applicability does not depend on the initial assumptions concerning the elementary event of scattering, geometry of a medium, etc. It is well known that the multiple scattering of the line radiation in various astrophysical media undergoes redistribution over frequencies and directions. The transfer problem arisen in the general case of partial redistribution is similar in many respects to that for anisotropic scattering handled by Ambartsumian in [29]. This analogy is especially discernible when we use the bilinear expansions of redistribution functions [32,20,33].

Ambartsumian's principle of invariance played an important role in the theory of radiation transfer. Its application turned out especially efficient in treating the relatively more complicated problems of the theory. It was offered an idea that the transfer theory can be made to rest on the principle of invariance, the equation of transfer then being a law derived from the principle [11]. During future progress of the theory the possibility of this approach became apparent. Moreover, in some cases its application turned out more preferable. The advantage of such an approach is stipulated by strong intuitive content of the principle of invariance and existence of profound connection with intrinsic physical features of the problem at hand: symmetry properties, boundary and initial conditions etc. Besides, the connection between the principles of invariance and the laws of conservation is well known in physics. In view of the importance of this question, let us examine it in more detail in the case of the problem of radiation transfer in the plane-parallel atmosphere [6].

3. The variational formalism

Let us introduce, for convenience, the function $P(\tau,\eta,\mu)$ that characterizes the probability of the photon exit from the atmosphere in the direction μ, if it was originally moving at depth τ with the directional cosine η (the angles are referenced from outward normal direction). The transfer equations for this quantity may be written in the form

$$\pm\eta\frac{\mathrm{d}P(\tau,\pm\eta,\mu)}{\mathrm{d}\tau}=-P(\tau,\pm\eta,\mu)+\frac{\lambda}{2}\int_{-1}^{1}P(\tau,\eta',\mu)\mathrm{d}\eta'. \qquad (24)$$

From equations (24) one can easily obtain

$$\eta^2\frac{\mathrm{d}^2\Phi}{\mathrm{d}\tau^2}=-\Phi(\tau,\eta,\mu)-\lambda\int_{0}^{1}\Phi(\tau,\eta',\mu)\mathrm{d}\eta', \qquad (25)$$

where we introduced notation $\Phi(\tau,\eta,\mu)=P(\tau,+\eta,\mu)+P(\tau,-\eta,\mu)$.

One may readily check the self-adjointness of this equation so that the variational formulation is admitted [34,35]. Derivation of the conservation laws is based on the Noeter theorem [36] and its generalization to the case of integral-differential equations given in [37]. The Lagrangian density L corresponding to equation (25) was obtained in [38]

$$L(\Phi,\Phi',\tau,\eta,\mu)=\Phi^2+(\eta\Phi')^2-2\Phi U, \qquad (26)$$

where

$$U(\tau,\mu)=\frac{\lambda}{2}\int_{0}^{1}\Phi(\tau,\eta',\mu)\mathrm{d}\eta'. \qquad (27)$$

In accordance with [37] the Euler-Lagrange equation has a form

$$\frac{\partial L}{\partial\Phi}-\frac{\mathrm{d}}{\mathrm{d}\tau}\frac{\partial L}{\partial\Phi'}+\lambda\int_{0}^{1}\frac{\partial L}{\partial U}\mathrm{d}\eta'=0. \qquad (28)$$

One will make sure that insertion of the Lagrangian (26) into (28) yields the transfer equation (25).

It is important that both the transfer equation (25) and the Lagrangian density (26) do not depend explicitly on τ, or stated differently, they are form-invariant under infinitesimal transformation

$$\tau \to \tau' = \tau + \delta\tau\,, \quad \eta = \eta'\,, \quad \mu = \mu'\,, \tag{29}$$

where the quantity $\delta\tau$ is allowed to be an arbitrary infinitesimal function of τ. This implies that the transformation (29), i.e. translation of the optical depth, is the symmetry transformation for the system (24) and suggests a certain conservation law as follows

$$\int_0^1 \left[L - \frac{\partial L}{\partial \Phi}\Phi' \right] \mathrm{d}\eta = \mathrm{const}\,, \tag{30}$$

which in view of (26) takes a form

$$\int_0^1 \left[\Phi^2(\tau,\eta,\mu) - \eta^2 \Phi'^2(\tau,\eta,\mu) - 2U(\tau,\mu)\Phi(\tau,\eta,\mu) \right] \mathrm{d}\eta = \mathrm{const}\,, \tag{31}$$

or

$$\int_0^1 P(\tau,\varsigma,\mu) P(\tau,-\varsigma,\mu)\,\mathrm{d}\varsigma = \frac{\lambda}{4}\left(\int_{-1}^1 P(\tau,\varsigma,\mu)\,\mathrm{d}\varsigma \right)^2 + \mathrm{const}\,. \tag{32}$$

This relation is, in essence, a prototype of the Q – integral obtained by Rybicki in [39]. In this paper he came out with the suggestion that there exist some connection between the mentioned integral and the invariance principle, however, this connection was not established there.

The above considerations imply that by its content the integral (32) is an analog of the momentum conservation law in mechanics and is due to the axes translation transformation.

For semi-infinite atmosphere $P(\tau,\pm\varsigma,\mu) \to 0$ as $\tau \to \infty$ so that $\mathrm{const} = 0$. More general relation for this case may be derived if we treat to problems differing with each other by the value of the parameter μ

$$\int_0^1 P(\tau,\varsigma,\mu)P(\tau,-\varsigma,\mu')\mathrm{d}\varsigma = \frac{\lambda}{2}\left(\int_{-1}^{1} P(\tau,\varsigma,\mu)\mathrm{d}\varsigma\right)\left(\int_{-1}^{1} P(\tau,\varsigma,\mu')\mathrm{d}\varsigma\right). \quad (33)$$

For the first time this equation was obtained in [17] by two different ways particularly on the base of non-complicated physical reasoning. It was also shown there that by letting $\tau = 0$ in (33) we are led to the Eq. (1) obtained by Ambartsumian on the base of the principle of invariance formulated by him. This type of equations is called bilinear (see [39], as well as [6,17], [40]). The integral (33) may obviously be considered as a generalization of Ambartsumian's equation (1) over all depths. It holds everywhere where λ does not vary with depth.

The variational formalism allows not only to elucidate the physical meaning of invariance principle but enables one to derive along with many known results a great number of new relations of great importance for the theory and applications. It allows also finding out some statistical characteristics of the diffusion process in the atmosphere ([17,41]).

Some of previously obtained relations possess a rather evident physical or/and probabilistic meaning and, as it was pointed out, were written immediately on the base of simple considerations. However, all of them are consequences of the one and the same variational principle (or invariance principle), which reflects the invariance with respect to the translational transformation of the optical depth, so that these cannot be regarded as principles of invariance as it is often the case.

The variational formalism allows one to derive quadratic and bilinear integrals for different frequently occurring astrophysical problems of the transfer of radiation in a homogeneous atmosphere. As it was shown in [6], there exists a group of problems, which can be reduced to the source-free problem. This group includes the Milne's problem, the problem of diffuse reflection (and transmission in the case of the atmosphere of finite optical thickness) as well as the problems with exponential and polynomial laws for the distribution of internal energy sources. An important special case of the last type of problems is the problem of the radiative transfer in an isothermal atmosphere (i.e. in atmosphere with homogeneous distribution of internal sources). At least three features characterize this group of problems. First of all, the invariance principle implies bilinear relations connecting the solutions of the listed problems. Secondly, if the problem can be formulated for finite atmosphere then the principle allows connecting its solution with that of the proper problem for a semi-infinite atmosphere. Finally, an important feature of this group of problems is the fact that the knowledge of Ambartsumian's φ-function reduces their solutions to the Volterra-type equation for the source function with the following kernel function

$$L(\tau)=\frac{\lambda}{2}\int_0^1 \varphi(\eta)\mathrm{e}^{-\frac{\tau}{\eta}}\mathrm{d}\eta \qquad (34)$$

(see [6]).

In conclusion, it must be noted an attempt to apply the invariance principle to the inhomogeneous atmospheres [42]. In this case one introduces a new parameter appearing in truncating the inhomogeneous atmosphere as it is predicted by the theory of composite variational principles [43].

4. The method of addition of layers

As it was pointed out, the key condition in formulating the invariance principle was the requirement to keep the global optical characteristics of the initial medium intact in its transformation when adding or substracting another layer. If this condition is abandoned, the natural question arising is to establish the rule, which the given characteristics must obey in this transformation. The answer to this question has been given by Ambartsumian in his milestone work [7] (see also [8]), in which he proposed a method known as the method of addition of layers. This work is highly important since, as we will be convinced below, many methods proposed later on by different authors are based somehow or other on its results.

It is noteworthy that the idea of addition of layers was first used by Stokes [44] in studying the optical properties of the system of parallel glass plates. From subsequent works in different branches of science we point out the paper [45] in which the differential equations were derived for the reflection and transmission coefficients of a medium of finite optical thickness (see below Eqs. (39), (42)).

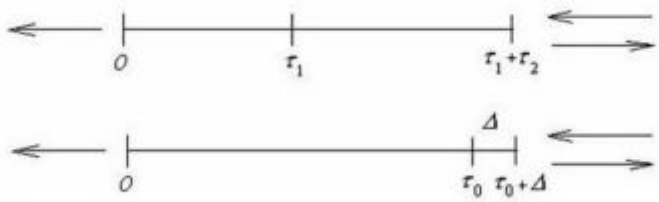

Fig. 2. Transfer of radiation through an atmosphere composed of two components.

In the abovementioned paper [7] Ambartsumian considers a composite homogeneous scattering and absorbing atmosphere of optical thickness τ_0, formed by an addition of two media with thicknesses τ_1 and τ_2 (see Fig.2). Simple arguments used by him for one-dimensional problem allow deriving functional equations relating the transmission and reflection coefficients of the composite atmosphere (q, r) with those for each component

$$q(\tau_1+\tau_2)=\frac{q(\tau_1)q(\tau_2)}{1-r(\tau_1)r(\tau_2)}, \tag{35}$$

$$r(\tau_1+\tau_2)=r(\tau_2)+\frac{r(\tau_1)q^2(\tau_2)}{1-r(\tau_1)r(\tau_2)}. \tag{36}$$

These relations are referred to as the laws of addition for the transmission and reflection coefficients. Note that the quantities q, r have a probabilistic meaning and may be correspondingly interpreted as the probabilities of the transmission and reflection of a photon incident on the medium.

Replacing τ_2 by the infinitesimal Δ (Fig.2, below) and passing to the limit when $\Delta \to 0$, we will have

$$\frac{\mathrm{d}q}{\mathrm{d}\tau_0}=-\left(1-\frac{\lambda}{2}\right)q(\tau_0)+\frac{\lambda}{2}q(\tau_0)r(\tau_0), \tag{37}$$

$$\frac{\mathrm{d}r}{\mathrm{d}\tau_0}=\frac{\lambda}{2}-(2-\lambda)r(\tau_0)+\frac{\lambda}{2}r^2(\tau_0). \tag{38}$$

The system of non-linear differential equations we obtain satisfies the initial conditions $q(0)=1$, $r(0)=0$. Its solution is:

$$r(\tau_0)=r_0\frac{1-\mathrm{e}^{-2k\tau_0}}{1-r_0^2\mathrm{e}^{-2k\tau_0}}, \qquad q(\tau_0)=\left(1-r_0^2\right)\frac{\mathrm{e}^{-k\tau_0}}{1-r_0^2\mathrm{e}^{-2k\tau_0}}, \tag{39}$$

where $k=(\lambda/4)\left(1-r_0^2\right)/r_0$, and r_0 is the coefficient of reflection from a semi-infinite atmosphere. Later the idea developed in this paper was employed by Ambartsumian in treating the more general problem of the transfer of radiation in the one-dimensional anisotropic medium [46].

Thus, for the first time in these papers it was treated the addition of layers of arbitrary optical thickness and established relations between the global optical properties of the composite atmosphere and characteristics of components. Thanks to its generality, these relations became a base for various modifications and stimulated the development of new methods in the radiative transfer theory. Some results obtained in the field are, in essence, nothing but elaboration of some special cases of the law of the layers addition.

For instance, taking as one of the layers semi-infinite atmosphere and for another a layer of infinitesimal optical thickness, we are led to the problem considered above, for which the invariance principle was formulated. When the infinitesimal layer is added to a finite layer, the requisite optical characteristics are found as the functions of optical thickness. Thus, the problem becomes 'imbedded' in a family of similar problems differing by the value of optical thickness. The generalization of this approach to the three-dimensional case was given by Chandrasekhar in [9]. It underlies the method of 'invariant imbedding' developed by Bellman and his co-authors [47,48]).

Finally, the method of addition of layers plays an important role in solving the problems of radiation transfer in inhomogeneous atmospheres. In this case the medium is divided into a number of layers in such a way as each of them can be regarded as homogeneous and the addition formulas (38), (39) are repeatedly applied (see, e.g., [49,18,50]). It is noteworthy that in the course of derivation of requisite optical parameters the fluxes appearing at the interfaces between adjacent layers are eliminated. Accordingly, in each application of the addition formulas one deals only with the intensities at the boundaries of the composite atmosphere. This is pointed out in some papers [51-53] in which Ambartsumian's addition formulas are treated in the case when the component layers are allowed to be inhomogeneous. In this works the law of addition of layers is called "the star product".

As it was shown in the works [50,54], in the case of isotropic, but inhomogeneous atmosphere, it comes into force, the so called, law of polarity, which consists in the fact that now the medium is characterized not by two, but three global optical parameters – by one coefficient of transmission and by two coefficients of reflection (for each of two boundaries). If such atmospheres are added, instead of (38), (39) we obtain

$$q(\tau_1+\tau_2)=\frac{q(\tau_1)q(\tau_2)}{1-r(\tau_1)\overline{r}(\tau_2)}, \tag{41}$$

$$r(\tau_1+\tau_2)=r(\tau_2)+\frac{r(\tau_1)q^2(\tau_2)}{1-r(\tau_1)\overline{r}(\tau_2)}, \tag{42}$$

where $\overline{r}$ is the reflection coefficient from the appropriate layer for the side, opposite to the direction of incident radiation (in Fig.2 - to the left). In writing the formulas (41), (42) we take into account that $q=\overline{q}$. The addition formula for $\overline{r}(\tau_1+\tau_2)$ is obtained from (42) by the simple transposition of indices.

In the works [7,46] Ambartsumian paid attention to the summation rule of the quantity, inverse to the coefficient of transmission. Subsequently it was used also in other

branches of physics [55,56]. In the latter from these works it was shown that the nonlinear system of equations of type (39), (40) for the inhomogeneous atmosphere can be reduced to the solution of the system of ordinary linear differential equations, if we besides the value $P(\tau_0)=1/q(\tau_0)$ introduce the function $S(\tau_0)=r(\tau_0)/q(\tau_0)$. In the case of atmosphere, in which the scattering coefficient depends on depth, this gives (see [50,54])

$$\frac{\mathrm{d}P}{\mathrm{d}\tau_0}=\left[1-\frac{\lambda(\tau_0)}{2}\right]P(\tau_0)-\frac{\lambda(\tau_0)}{2}S(\tau_0), \tag{43}$$

$$\frac{\mathrm{d}S}{\mathrm{d}\tau_0}=\frac{\lambda(\tau_0)}{2}P(\tau_0)-\left[1-\frac{\lambda(\tau_0)}{2}\right]S(\tau_0), \tag{44}$$

with initial conditions $P(0)=1$, $S(0)=0$. It was shown in these works that the functions P and S may be determined from separate equations followed from Eqs.(43),(44),

$$\frac{\mathrm{d}^2P}{\mathrm{d}\tau_0^2}-\frac{\lambda'}{\lambda}\frac{\mathrm{d}P}{\mathrm{d}\tau_0}-\left(1-\lambda+\frac{\lambda'}{\lambda}\right)P(\tau_0)=0, \tag{45}$$

$$\frac{\mathrm{d}^2S}{\mathrm{d}\tau_0^2}-\frac{\lambda'}{\lambda}\frac{\mathrm{d}S}{\mathrm{d}\tau_0}+\left(1-\lambda+\frac{\lambda'}{\lambda}\right)S(\tau_0)=0 \tag{46}$$

with initial conditions $P(0)=1$, $P'(0)=1-\frac{\lambda(0)}{2}$ and $S(0)=0$, $S'(0)=\frac{\lambda(0)}{2}$.

If the explicit form of the function $\lambda(\tau_0)$ is known, the system of Eqs. (43),(44) (or Eqs. (45),(46)) is easy to solve with use of one of the computational schemes, which exist for the Cauchy problem for the linear differential equations. In some special cases the Eqs. (45),(46) are converted into equations of known types, whose solutions are written explicitly in terms of elementary and special functions. The knowledge of functions P and S, and consequently also of the coefficients of reflection and transmission, for the family of atmospheres with different optical thicknesses allows to

determine easily the field of radiation within any medium of the fixed thickness, without solving any new equations. It is obvious that the described approach is suitable also in treating the three-dimensional problem, in which, however, the role of $P(\tau_0) = 1/q(\tau_0)$ will play the operator $q^{-1}(\tau_0)$.

5. Conclusion

Ambartsumian's methods played large role in the progress of the radiative transfer theory. Possessing the deep physical content, the principle of invariance and the method of addition of layers proved to be extremely flexible in the applications and effective in numerical calculations. They successfully were employed not only in astrophysics, but also in other branches of physics (neutrons transport theory, the theory of gases so forth.) and mathematics (differential equations, the theory of branching processes, stochastic geometry, dynamic programming), stimulating in this case the appearance of new methods. In the astrophysics the benefit from the application of Ambartsumian's methods occurred the more imposing, the more complex were the problems (anisotropic scattering, scattering with the partial redistribution of radiation in the frequencies and the directions, Compton scattering on the free electrons, non-stationary problems, the transfer of radiation in the media with the complex geometry, etc.) in question. At the same time, Ambartsumian noted that his methods are only techniques for solving the difficult problems of theoretical astrophysics and therefore can fruitfully be developed in close cooperation with other approaches and methods [2]. In our view, Ambartsumian's methods will continue to be developed, enlarging simultaneously the sphere of their applications.

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On one method in the radiative transfer theory

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Abstract. The author presents the main concepts allowing to develop a system for analytical solution of standard problems of radiative transfer theory. These solutions, found with the use of Ambartsumian's Principle of Invariance (API) and Sobolev's Probabilistic Interpretation (SPI) for the processes of radiation diffusion, are extremely compact and can be easily used for numeric calculations. A unified structural form of integral representations is given for various problems of radiative transfer theory in semi-infinite medium and in a finite layer. A descriptive block-diagram is given, representing solution stages for standard problems. It is shown that for the solution of semi-infinite medium problems Ambartsumian's function $\varphi(\eta)$ (or rather, $1/\varphi(\eta)$), plays a fundamental role, and for a finite layer "alternative" functions $a(\eta,\tau)$ and $b(\eta,\tau)$ play a similar role. It is also shown that any characteristics of the radiation field can be found by the solution of a single linear integral equation, followed by one or two quadratures and algebraic operations.

Examination of problems of interaction of emission with matter plays an important role in theoretical astrophysics. They are described by transfer equation which is obtained from physical considerations. In order to overcome the mathematical difficulties, a number of simplification assumptions are to be taken to obtain functional equations which can yield at least a numerical solution. Along with these assumptions appears a set of so-called boundary-value problems of different degree of complexity, which describe the process of multiple scattering of radiation. For a long time the standard approach to investigation of these problems was to start from the transfer equation (and balance equations) obtained for the particular problem under consideration and making an attempt to solve it with the use of known analytical or numerical methods.

In 40-es Ambatsumian [1] found a non-standard approach for resolution of the problems of transfer theory, which was named Ambatsumian‘s Principle of Infariance [API] or method of addition of layers. With this method it is possible to find solutions of certain theoretical problems, by-passing the transfer equation. It uses simple and obvious

reasoning which quickly yields us to the goal. The standard method trough the use of transfer equations would, naturally, yield the same results, but requires significantly larger mathematical efforts and importantly, the formal approach is not as obvious. The ideas of the API were further developed by Chandrasekar [2], Bellman [3] and others. In most general form they are described in the works of Pikichyan [4] and Rogovtsov [5]. It is worth mentioning that the ideas of the API are especially easy to apply when considering stochastically distributed nature of the processes of radiance diffusion. Such probabilistic interpretation (SPI) of transfer processes has been revealed by Sobolev [6].

Systematic application of these ideas (i.e. API and SPI) allowed us to significantly simplify the solution of a number of transfer theory problems. All kinds of analitical integrations on the optical depth played an important role in this process. For an extremely wide rane of problems source functions can be represented as a superposition of exponents (of optical depth) thus allowing to find closed form solutions for certain problems or obtain qualitatively new equations or expressions. As it was mentioned above, the same analitical results may also be derived by the formal approach, by using rather cumbersome mathematical tools. For example, explicit integral expression for the resolvent of a finite layer was obtained, with the use of methods of complex variable functions, in works of Mallikin (see, for example, [7,8]) and Rogovtsov and Samson [9]. We need to mention, however, that we obtain similar expressions instantly, on the base of simple physical considerations; at that, the final formulas are more efficient from the point of view of numerical calculations. To a significant degree this is fue to an adequate selection of auxiliary functions which are common for all standard problems of this class.

We mainly limited our consideration by the problems of isotropic scattering of monochromatic radiation in homogeneous plane-parallel media, understanding that generalization of the obtained results on more complex cases can be obtained almost automatically. For example, such automatic generalization takes place during full frequency redistribution, as it was shown by Ivanov [10], as well as for single-index azimuth harmonics or „pseudovalues“ (Chandrasekar’s terminology) during anisotropic scattering [2] , [11, 12].

By application of API and SPI, along with co-workers, we were able to separate angular variables when considering transfer theory problems in semi-infinite medium and in a finite layer, irradiated by parallel beams, or containing isotropic single-directional (for a finite layer Green function this was obtained by Pikichian [13]) primary sources of energy [14,15,16]. At that we introduced auxiliary functions $F, \tilde{F}$ (for semi-infinite medium) and $f, \tilde{f}$ (for a finite layer). The meaning of these functions are descending and ascending, respectively, intensities in scattering medium, on the boundary of which ($\tau = 0$) there is an isotropic primary energy source. These functions turned very useful afterwards. With the help of analytical integration (by optical depth) in [16, 17] were

already obtained certain qualitatively new results. Logical continuation of this approach, by shifting our interest towards investigation of problems in a finite layer, we obtained the results described in [18, 19, 20, 21], as well as some yet not published results. We would also like to point out that in [18] we introduce functions $a(\eta,\tau)$ and $b(\eta,\tau)$, which are alternative to Ambartsumian's functions $\varphi(\eta,\tau)$ and $\psi(\eta,\tau)$, and are closely associated with them, and in [20] there appear «basis» functions $u^{+}(\eta,\tau)$ and $u^{-}(\eta,\tau)$, through which, by only using quadratures, we can find any characteristics of the diffused radiation field in a finite layer. The functions themselves satisfy to quickly-convergent linear nonsingular integral equations and require only preliminary knowledge of Ambartsoumian's function for semi-infinite medium - $\varphi(\eta)$. We would like to point it out one more time that we will not need to solve any integral equations once these functions are obtained.

"Basis" functions satisfy to the following separate equations:

$$u^{\pm}(\eta,\tau) = 1 \pm \frac{\lambda}{2}\eta \int_0^1 \frac{g(\mu,\tau)}{\mu+\eta} u^{\pm}(\mu,\tau)\, d\mu \quad , \qquad (1)$$

with the following definitions:

$$g(\mu,\tau) = e^{-\frac{\tau}{\mu}}/R(\mu)\varphi^2(\mu) \;\; ; \;\; R(\mu) = \left(\frac{\lambda\pi\mu}{2}\right)^2 + \left(1 - \frac{\lambda}{2}\mu ln\frac{1+\mu}{1-\mu}\right)^2 \;\; ,$$

and λ- is the probability of survival for a quantum during an elementary act of scattering. We also need to mention that in case of numeric solutions of the equations (1) by the method of successive approximation these basis functions are obtained simultaneously, i.e. in fact, we are only solving one integral equation.

Explicit expressions of solutions for many problems of the transfer theory may be written in the following general form:

$$X(x) = g_X + CM_X\left(x;\frac{1}{k}\right) + \frac{\lambda}{2}\int_0^1 \frac{M_X(x;\mu)}{\mu R(\mu)} d\mu \quad , \qquad (2)$$

and for the rest, in the form of certain algebraic combinations composed from similar expressions. In the expression (2): X – is the solution of desired problem, $x = \{\tau,\tau^*,\eta,\zeta\ldots\}$ – setup of arguments, k - is the root of characteristical expression $\frac{\lambda}{2k} ln\frac{1+k}{1-k} = 1$, $C = \frac{k(1-k^2)}{k^2-1+\lambda}$, $R(\mu)$ – is the elementary function as described above, and g_X and M_X – are known functions, characteristic for this problem.

For example, for Ambartsumian's problem – $\varphi(\eta,\tau)$ and for Sobolev's resolvent function – $\Phi(\tau,\tau_0)$, we have, respectively, the following:

$$g_\varphi = 1 \;\; ; \qquad M_\varphi(\tau,\eta;\mu) = a(\mu,\tau)e^{-\frac{\tau}{\eta}}A(\tau,-\eta,\mu) - b(\mu,\tau)A(\tau,\eta,\mu)$$

and $g_\Phi = 0$; $M_\Phi(\tau,\tau_0;\mu) = a(\mu,\tau_0)e^{-\frac{\tau}{\mu}} - b(\mu,\tau_0)e^{-\frac{\tau_0-\tau}{\mu}}$, where $a(\mu,\tau)$ and $b(\mu,\tau)$ – are the alternative functions, and - $A(\tau,\eta,\mu) = \eta\mu\frac{e^{-\frac{\tau}{\mu}}-e^{-\frac{\tau}{\eta}}}{\mu-\eta}$.

In summary we would like to present a block-diagram for resolution of standard problems (from Ambartsumian's problem to Green function) of the transfer theory in semi-infinite medium and in a finite layer. It clearly shows which values can be found with what and with how much effort. Simple arrows imply the need for solely algebraic operations; double arrows signify simple integration by angular variable (like in (2)), and triple – solution of an integral expression (1).

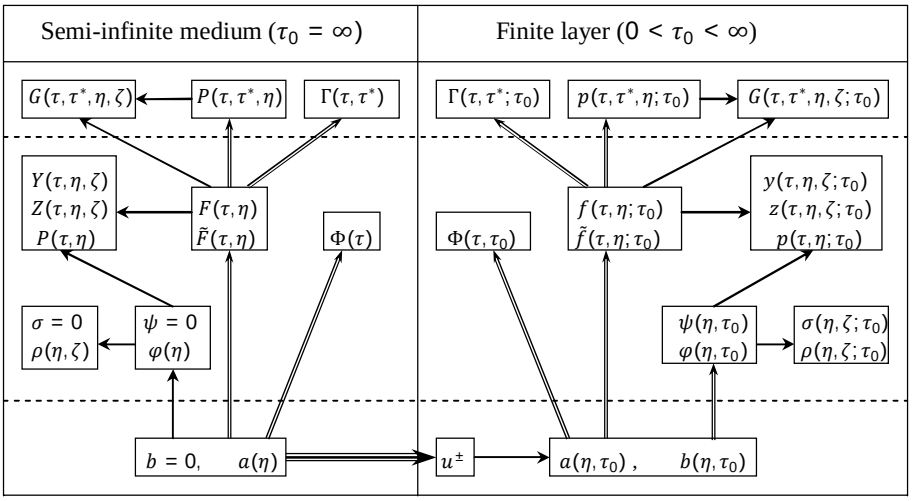

Fig. 1.

Most of the functions presented in blocks are well-known. For example G - is the Green function, P and p – are corresponding to them source functions, Γ and Φ – are the resolvent and resolvent function, Y,Z and y,z – are superficial Green functions, $P(\tau,\eta)$ and $p(\tau,\eta;\tau_0)$ – are probabilities of yielding Sobolev's quantum, ρ and σ – are reflection and transmission coefficients, $F,\tilde{F}$ and $f,\tilde{f}$ – are auxiliary functions introduced in [14] and [15]. Functions in the lower part of the diagram are the primary functions, i.e. reciprocal variable of Ambarsoumian's function, basis and alternative functions. For semi-infinite medium basis functions are equal to one, second alternative function is equal to zero, and first, because of Ambartsumian's nonlinear equation coinsides with $a(\eta,\infty) = 1/\varphi(\eta)$ $(= a(\eta))$.

On this diagram we can see one more time the fundamental nature of Ambartsumian's function - $\varphi(\eta)$ for a semi-infinite medium; with its help can also be resolved many problems for the finite layer. Therefore solution of virtually any problems of the transfer

theory should be started from this function (or its modifications). It also follows from here that for the problems of a finite layer functions $a(\mu,\tau)$ and $b(\mu,\tau)$ are playing the same role as functions $1/\varphi(\eta)$ in the problems of semi-infinite medium.

Due to the property of reciprocity of optical phenomena all values given on the block-diagram, except $u^{\pm}$ and $a(\eta,\tau)$, $b(\eta,\tau)$ have dual physical and dual probablistic essence. For example, function $f(\tau,\eta;\tau_0)$ gives, on one hand, the angular distribution of descending intensity in a finite layer, on the upper boundary ($\tau = 0$) of which there is a flat isotropic primary energy source. On the other hand, it gives the of source function on the upper boundary of the medium, containing a mono-directional primary source on the depth τ. In probabilistic interpretation it represents the probability that a quantum, which was initially moving on the depth τ in the direction $\cos^{-1}\eta$ (to the upper boundary) in a finite layer τ_0, will be absorbed in the upper near-border layer and, on the other hand, gives the probability that an isotropically radiated quantum on the upper boundary, as a result of diffusion, will be moving on the depth τ at the angle $\cos^{-1}\eta$.

Summarizing all of the above we may state that with the use of described method it is possible to find the main characteristics of the radiation field (up to Green's function) in a semi-infinite medium and in a finite layer with the help of one or two integrations by the angular variable, if we take Ambartsumian's function $\varphi(\eta)$ or alternative functions $a(\eta,\tau)$ and $b(\eta,\tau)$ as the initial (known) functions, respectively, for a semi-infinite medium and a finite layer. In both cases there is no problem in finding the initial functions, since there are good algorithms for numerical obtaining of Ambartsumian's function (saying nothing of its explicit expressions), and obtaining of alternative functions amounts to numeric solution of the quickly converging expression (1), without singularities.

In conclusion I would like to earnestly thank the administration of the Byurakan Astrophysical Observatory and the Organizational Committee of the Conference dedicated to 100th Anniversary of Academician V.A.Ambartsumian for the opportunity to present this work.

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The light scattering by moving dust in the neighbourhoods of young stars

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Abstract. The scattering of the photospheric radiation in the inner parts of an accretion disk, in a dust sublimation zone is considered. For T Tauri stars (TTSs) this zone is located at the distances of about several stellar radii and takes place in a large-scale (about of hundred and more kilometers per second) motion of the matter. In such a medium light scattering by the dust particles leads to a shift of the frequency of the scattered radiation due to the Doppler effect. An influence of this effect on the absorption spectrum of TTSs is considered using classical results of the radiative transfer theory.

New opportunities in non-linear radiative transfer based on Ambartsumian's Principle of Invariance

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Abstract. The advantages of using ***Ambartsumian's Concept of Invariance*** and the new opportunities gained through its use are considered in comparison with classical ***Boltzmann's Kinetic Equations*** approach. It is shown that all major simplifications attained in resolution of linear radiative transfer problems can be efficiently extended on respective non-linear problems. In particular, new expressions of ***partial*** and ***full invariance*** are found for one-dimensional non-linear problems of reflection/transmission along with determination of the internal radiation field in a layer with finite thickness when its both boundaries are irradiated by intensive beams of radiation. A new important for the general theory feature of ***equivalence*** is found between the two differential operators (Boltzmann's and Ambartsumian's) in spite of their entirely different physical nature. The results have also been extended onto the important for astrophysical purposes case of polychromatic scattering.

1. Introduction

Problems of radiative transfer were initially formulated for astrophysical purposes by Schwarzschild and Schuster. Modern radiative transfer theory is an important part of theoretical astrophysics. The main goal of transfer theory is solution of radiative transfer equation for different astrophysical situations dealing with multiple interactions between radiation and matter.

The radiative transfer equation is a linearized form of Boltzmann's kinetic equation for photon gases. In one-dimensional (stick-model) case, when outer fluxes j_1 and j_2 fall on the two boundaries of a slab, the intensity of radiation field $I^{\pm}(l) \equiv I_L^{\pm}(l, j_1, j_2)$ on geometrical depth $l \in [0, L]$ satisfies to Boltzmann's kinetic equation:

$$\pm \frac{\partial I^{\pm}(l)}{\partial l} = \alpha(I^{\pm}, I^{\mp}) \qquad (1)\,; \qquad\qquad I^{+}(0) = j_1 \quad , \quad I^{-}(L) = j_2 \quad . \qquad (2)$$

α - is Boltzmann's integral of "collisions" which, for the linear case, has the following form:

$$\alpha\left(I^{\pm}, I^{\mp}\right) = -k \cdot I^{\pm} + \frac{\lambda}{2} \cdot k \cdot (I^{+} + I^{-}) \quad . \qquad (3)$$

Here k and λ - are known parameters of the medium - absorption coefficient and "albedo" of single scattering. Equation (1), with boundary conditions (2), is a two point boundary-value problem. Emergent intensities u_L and v_L in this problem

$$u_L(j_1, j_2) \equiv I^+(L) \ , \ v_L(j_1, j_2) \equiv I^-(0) \qquad (4)$$

can only be determined after solution of the internal field problem over all depths $l \in [0, L]$, since differentiation over depth l is present in (1). Let us call this consideration "Boltzmann's approach".

2. Ambartsumian's achievements and the purpose of present reoprt

In 1942-1948 Ambartsumian [1-7] introduced a new methodology of the "principle of invariance" (see, e.g., [8]) in radiative transfer theory. Without consideration of the **internal** radiation field he immediately obtained a solution for the problem of **emergent** intensities. For better understanding of Ambartsumyan's achievements we may represent them as **three** consecutive steps, or **levels of simplification**, of the same initial problem (1)–(2). Each of these levels alone is capable of fully resolving the emerging intensities, by solely relying on certain "invariance" properties of the problem, leaving out the procedure (1)-(2). Due to linearity of the problem, emergent intensities could be presented through reflection- R and transmission- T coefficients:

$$u = j_1 \cdot T + j_2 \cdot R \qquad (5) \ ; \qquad v = j_1 \cdot R + j_2 \cdot T \ . \qquad (6)$$

As the **first step** Ambartsumian [5,6] formulates the "method of addition of layers" for values R and T. When reflection and transmission coefficients R_A, T_A and R_B, T_B of two separate layers with respective thicknesses "A" and "B" are known, then coefficients R_{A+B}, T_{A+B} of the unified layer "$A + B$" can be determined in the closed form:

$$R_{A+B} = R_A + S \cdot T_A \qquad (7) \ ; \qquad T_{A+B} = P \cdot T_B \ , \qquad (8)$$

where auxiliary functions S and P satisfy to the system

$$\begin{cases} S = P \cdot R_B \ , \\ P = T_A + S \cdot R_A \ . \end{cases} \qquad (9)$$

The **second step** of Ambartsumian's achievements [5] in linear case in the stick-model scheme appears in the form of differential equations of invariant imbedding

$$\begin{cases} \frac{\partial T}{\partial L} = \frac{k}{2} \cdot T \cdot (\lambda \cdot R + \lambda - 2) \\ \frac{\partial R}{\partial L} = \frac{\lambda}{2} \cdot k \cdot T^2 \end{cases} \qquad (10) \ ; \qquad R = 0 \ , \ T = 1 \ \text{ for } \ L = 0 \ . \qquad (11)$$

First level of simplification, represented by "adding equations" (7)-(9), allows to start from certain initial thickness of the "finite slab", for which the problem is already solved, gradually thickening (recursive adding, or "doubling" procedure) by finite steps until we achieve a solution of the problem for the desired thickness (see, e.g., [9]). The

second level brings the two-point boundary-value problem (1)-(2) of Boltzmann's kinetic equation to solution of the Cauchy initial-value problems directly for coefficients R and T, i.e. to the problem only with initial conditions. This type of equations are now [10, 11] well known as differential equations of "invariant imbedding". Both methods are perspective for a broad range of applications in modern science and technology. During the **third** step of simplification transmission coefficient T is expressed explicitly through the reflection coefficient R, by only using elementary operations, without differentiation over slab thickness [5]:

$$T^2 = R^2 + \frac{2}{\lambda} \cdot (\lambda - 2) \cdot R + 1 \ . \qquad (12)$$

Thickness in (12) is just a fixed parameter. Hence there is no need to find the whole family of transmission functions over the range of thicknesses $[0, L]$ for determination of T for each fixed value of L, as opposed to (10).

The first two steps of simplification (finite layer addition procedures and invariant imbedding) only express **particular** properties of invariance, because recursion and differentiation procedures over the thickness occur in corresponding equations. In the **third** step slab thickness only appears as a **fixed** parameter. This is due to **combination of all** particular properties of invariance, being a property of **complete invariance**.

In 1964 Ambartsumian [12] has also developed (see also [13]) the "principle of invariance" approach for resolution of nonlinear problems of radiative transfer. As the **first step** he formulated basic expressions of "non-linear addition" of layers:

$$v_{A+B}(j_1, j_2) = v_A(j_1, S) \qquad (13)\ ; \qquad \begin{cases} S = v_B(P, j_2) \\ P = u_A(j_1, S) \end{cases} \ . \qquad (14)$$

These expressions give the emergent intensity v_{A+B} in the case when fluxes j_1 and j_2 fall on the boundaries of the system "*A*+*B*" and properties u_A, u_B and v_A, v_B of separate slabs "*A*" and "*B*" are initially known.

As the **second step** of simplification of the problem of determination of $v_L\ (j_1, j_2)$ Ambartsumian [12] derived differential equation of invariant imbedding (17) by tending the thickness of a slab "A" to the "infinitely small" value Δ and using the following two expansions

$$v_\Delta(x, y) = y + \alpha(y, x) \cdot \Delta + O(\Delta^2) \ (15); \qquad u_\Delta(x, y) = x + \alpha(x, y) \cdot \Delta + O(\Delta^2), \ (16)$$

$$\frac{\partial v_L}{\partial L} = \alpha(j_1, v_L) \cdot \frac{\partial v_L}{\partial j_1} + \alpha(v_L, j_1) \ . \qquad (17)$$

In comparison with the linear case the novelty here is differentiation procedure by falling radiation flux j_1, which is exactly due to **non**-linearity of the problem. Through substitution of $L = \infty$, $\frac{\partial v_L}{\partial L} = 0$, $j_1 \equiv j$, $v_L(j_1, j_2) \equiv v_\infty(j,)$ into (17), we get to the particular case of semi-infinite medium:

$$\alpha(j, v_\infty) \cdot \frac{\partial v_\infty}{\partial j} + \alpha(v_\infty, j) = 0 \quad , \tag{18}$$

Ambartsumian [12, 13] also derived an analytical solution of the problem (18). The same problem for three-level atoms then analytically solved in [14,15]. Unlike (17), equation (18) is an expression of **complete invariance**, since it lacks any differentiation procedures by the spatial variable. The non-linear internal field problem for semi-infinite medium is analytically solved in [16] and some analogies with renormalization group are also considering there.

We can see that a **third level** of simplification is already achieved for the case of semi-infinite medium through (18). However the possibility of achieving the **third level** for a **finite** layer **has not been considered** by Ambartsumian. Moreover, he never considered the issue of finding the value of u_L. Most probably, the reason for this is the following: in linear transfer problem the functions of two variables $u_L(j_1, j_2)$ and $v_L(j_1, j_2)$ are directly expressed through two simpler and independent from each other auxiliary values of one variable $\mathrm{R}(j)$ and $T(j)$. In the nonlinear case, however, this is not possible due to lack of representations (5)-(6), and hence we have to refer directly to the equations of the two-variable values which we are looking up: $u_L(j_1, j_2)$ and $v_L(j_1, j_2)$. However geometric considerations of the problem from physical standpoint, as considered by Ambartsumian, dictated the expression of symmetry

$$u_L(j_1, j_2) = v_L(j_2, j_1) \, , \tag{19}$$

and if we take this into account in (17) we would derive a similar equation for $u_L(j_1, j_2)$:

$$\frac{\partial u_L}{\partial L} = \alpha(j_2, u_L) \cdot \frac{\partial u_L}{\partial j_2} + \alpha(u_L, j_2) \, . \tag{20}$$

Evidently, there was no need to consider (20) beside equation (17) , since finding the value of v_L from the latter was already sufficient for also obtaining u_L through symmetry of (19). Therefore at first glance it may seem that equation (17) already achieves complete simplification of the problem and separate consideration of value u_L in the frames of same geometrical scheme (13)-(14), through the analogy (13), would not add any significant results. It is however important to point out that thickness of layer in (17) and (18) is not a fixed parameter, and therefore each particular value of thickness "L_0" requires calculation of a whole **family** of values $v_L(j_1, j_2)$ **for all** values of the "immersion" parameter $L \in [0, L_0]$. This means that in the non-linear problem of a finite slab, as distinguished from the linear case (see formula (12)), **third level** of simplification has not been achieved yet.

The purpose of our report is to point at the very broad and yet undeveloped opportunities of Ambartsumian's principle of invariance in the sphere of **nonlinear** problems of radiation transfer theory, as well as other applications of Boltzmann's kinetic equation. We partially reported the results quoted below in [17]. We will first produce the expressions of invariance implementing the **third level** of simplification of the abovementioned nonlinear problem of finding the radiation emerging from a slab of **finite** thickness. We will then extend the results to nonlinear problem of finding the **internal field** of radiation in the slab. We will draw equations to implement **all three levels** of its simplification, and will then compare the «traditional» method of Boltzmann's kinetic equation with the new Ambartsumian's «invariance» approach. At that, we will first reveal the common features for both approaches, showing certain «equivalence», and will then point at their principal differences. Extending the results to the practical, from the point of view of astrophysical applications, case of multilevel atom – the nonlinear problem of polychromatic scattering, we will point out the universal nature of this approach and will show how fruitful Ambartsumian's principle of invariance can be for further analysis of complex and important problems of astrophysics.

3. Complete invariance in problem of emerging radiation from a finite slab

Let us pay attention to the fact that the procedure of deriving (17) (as well as the procedure of transition from it to (18) through the use of symmetry (19)) from physical standpoint denotes change of radiation intensity v_L (or u_L) emerging from the given boundary of layer through infinitely small variation of the location **of this same** boundary. If, in the frames of same geometric scheme, we make a transition to finding the field - u_L (or v_L) then evidently we will have to deal with the **opposite**, in relation to the varied, boundary of the layer. At that, naturally, we will achieve new, differing from (18), equation of invariant imbedding, since geometric picture of the procedure of boundary variation itself has changed. Indeed, points of observation and variation of medium in the second case - u_L, belong to **different** boundaries of the layer, whereas in the case of - v_L these boundaries were **coinciding**. The analogy for equation (13) for u_L will be

$$u_{A+B}(j_1, j_2) = u_B(P, j_2) \quad . \tag{21}$$

Applying here the solution of system (14) while $A \equiv \Delta \to 0$, we would result in a new equation of invariant imbedding

$$\frac{\partial u_L}{\partial L} = \alpha(j_1, v_L) \cdot \frac{\partial u_L}{\partial j_1} \quad . \tag{22}$$

We can see in (22) that, as distinguished from (20), the second, "free" from differentiation, summand of the right part is missing, and the differentiation procedure

is conducted by the left-handed flux j_1. Considering (19) from (22) we can find a similar equation for v_L (this transition procedure is equivalent to substitution into (13) $B \equiv \Delta \to 0$). Still within the frames of the **<u>second level</u>** of simplification of the problem of finding u_L and v_L, we may combine (19), (22) and derive a new closed-form system of quasilinear equations of invariant imbedding "without the right part":

$$\begin{cases} \frac{\partial u_L}{\partial L} - \alpha(j_1, v_L) \cdot \frac{\partial u_L}{\partial j_1} = 0 \\ \frac{\partial v_L}{\partial L} - \alpha(j_2, u_L) \cdot \frac{\partial v_L}{\partial j_2} = 0 \end{cases} . \tag{23}$$

Excluding the elements containing the procedure of differentiation by L from (17), (20) and (23) for determination of the same intensities we will derive, finally, the system of **<u>complete invariance:</u>**

$$\begin{cases} \alpha(j_1, v_L) \cdot \frac{\partial u_L}{\partial j_1} - \alpha(j_2, u_L) \cdot \frac{\partial u_L}{\partial j_2} = +\alpha(u_L, j_2) \\ \alpha(j_1, v_L) \cdot \frac{\partial v_L}{\partial j_1} - \alpha(j_2, u_L) \cdot \frac{\partial v_L}{\partial j_2} = -\alpha(v_L, j_1) \end{cases} , \tag{24}$$

which represents **<u>third level</u>** of simplification for the nonlinear problem of finite slab. Significance of the equations of complete invariance (24), from physical standpoint, corresponds to the procedure of adding of an additional layer with thickness $\Delta \to 0$ to one boundary of the initial medium, with simultaneous removal of a similar layer from its opposite boundary. This fundamental operation of invariance has been first introduced by Ambartsumian [2] when he considered the **<u>linear</u>** problem of transfer of a layer of finite optical thickness, therefore it is appropriate to call the main result, that was obtained from utilization of this same procedure in the **<u>non-linear case</u>** – **<u>the equation of complete invariance</u>**, and the new differential operators emerging at that, also by his name. It is notable that the system of **<u>Ambartsumian's complete invariance</u>** (24):

1) describes the problem of emerging intensities without involving any characteristics of the internal fields,
2) thickness of layer is a fixed factor in it,
3) it represents an initial-valu problem through falling intensities.

The first two points were also present in the linear problem, and the third one is exactly a result of the **<u>non</u>**-linear nature of the problem.

4. Internal field of radiation in non-linear transfer problem.

Ambartsumian's principle of invariance may be formulated in the following way [17] for the internal field problem of radiation: intensity $I_{A+B}(l, j_1, j_2)$ in geometric depth $l \in A$ of the unified layer "$A + B$ ", while irradiating its boundaries from right and left

by fluxes j_1 and j_2 respectively, is **identical** to intensity $I_A(l, j_1, S)$ in its isolated part "A", the left boundary of which is still irradiated by flux j_1, and the right one – by the resulting flux S, which established on the ajoint boundary of layers "A" and "B"

$$I_{A+B}(l, j_1, j_2) = I_A(l, j_1, S) \qquad (25)$$

In other words, intensity of internal field is **invariant** to the procedure of "dissection" of the "isolated" part "B" from the initial system "$A + B$" simultaneously with change of boundary condition j_2 into S.

Similar reasoning for $I_{A+B}(A + l, j_1, j_2)$, while $l \in B$ would result in

$$I_{A+B}(A + l, j_1, j_2) = I_B(l, P, j_2) \qquad (26)$$

The values P and S are still defined by system (14). It is also easy to compose the most common expression of invariance, when layer "B" is "immersed" into the system "$A + B + C$". By mentally "dissecting" the middle finite layer "B" from the three-layered medium "$A + B + C$", while $l \in B$, using same reasoning we will instantly derive

$$I_{A+B+C}(A + l, j_1, j_2) = I_B(l, P_1, S_2) \qquad (27)$$

Here P and S are "right-" and "left-handed" resulting fluxes on left – index "1", and right - index "2", boundaries of layer "B". They are defined according to the system

$$\begin{cases} P_1 = v_A(j_1, S_1) \\ S_2 = u_C(P_2, j_2) \\ S_1 = u_B(P_1, S_2) \\ P_2 = v_B(P_1, S_2) \end{cases} \qquad (28)$$

In particular, while $A \equiv 0$, $B \equiv A$, $C \equiv B$, (27) turns into (25), and when $C \equiv 0$ - into (26).

From the expressions of invariance (25)-(26), (14)-(15), with alternately vanishing B, A, l to $\Delta \to 0$, by using (16) for $I_L^{\pm}(l, j_1, j_2)$ we may derive three equations

$$\frac{\partial I_L^{\pm}}{\partial L} + \frac{\partial I_L^{\pm}}{\partial l} = \alpha(j_1, v_L) \cdot \frac{\partial I_L^{\pm}}{\partial j_1}, \qquad \frac{\partial I_L^{\pm}}{\partial L} = \alpha(j_2, u_L) \cdot \frac{\partial I_L^{\pm}}{\partial j_2}, \qquad \pm \frac{\partial I_L^{\pm}}{\partial l} = \alpha\left(I_L^{\pm}, I_L^{\mp}\right) \qquad (29)$$

The first two of these expressions are new – these are differential equations of invariant imbedding for the intensity of **internal** field, while third one is the well-known classical Boltzmann's equation (1). Expressions (25)-(28) and (29) represent, in the above mentioned sense, **first and second levels** of simplification, respectively, of the nonlinear problem of **internal** field of radiation in a finite slab. **Third** level of simplification can be easily obtained through combination of the equations (29). Excluding derivatives by thickness and depth, we will come to the equations of **Ambartsumian's complete invariance** in the form of quasilinear system [17]:

$$\alpha(j_1, v_L) \cdot \frac{\partial I_L^{\pm}}{\partial j_1} - \alpha(j_2, u_L) \cdot \frac{\partial I_L^{\pm}}{\partial j_2} = \pm\alpha\left(I_L^{\pm}, I_L^{\mp}\right) \qquad (30)$$

We should remember, however, that the purpose of conditional representation of three differing from each other "invariance" procedures for resolution of the same problem (1)-(2) in the form of its three "regular steps of simplification" was to accentuate the characteristic features for each of them, compare them with each other and with the "traditional" approach of kinetic equations. **First level** of simplification allows to replace calculation of the initial boundary problem (1)-(2) by algorithms of precise recurrent "nonlinear" addition (or ,in particular, doubling) of arbitrary "initial" layers before developing the required system. It is evident that, similar to the linear case, depending on interest and capacity of particular situation under investigation, any layer can be mentally imagined as a "system" of certain "given" components - "sub layers", and further, based on "addition formulas", compose an appropriate particular algorithm for calculation of these very "sub layers", as well as the whole "system". For the problem of emerging intensities, at that, we have the formulas (13)-(14), (21), and for the internal field – expressions (25)-(28). The **second stage** – two-point boundary-value problem (1)-(2), is replaced by a simpler problem with initial conditions – Cauchy problem. As against the linear case, however, here we have the procedure of differentiation by values of j_1, j_2 of falling external radiation. With the help of partial invariance expressions the emerging intensities can be found in two independent ways: by solving one of the two separate quasilinear differential equations of invariant imbedding (17) and (20), or by solving the system (23). Through introduction of operator designations

$$\hat{D} = \frac{\partial}{\partial L} \ , \quad \hat{B} = \frac{\partial}{\partial l} \ , \quad \hat{\mathrm{E}}_1 \equiv \alpha(j_1, v_L) \cdot \frac{\partial}{\partial j_1} \ , \quad \hat{\mathrm{E}}_2 \equiv \alpha(j_2, u_L) \cdot \frac{\partial}{\partial j_2} \qquad (31)$$

they can be written in a more compact form:

$$\left(\hat{D} - \hat{\mathrm{E}}_1\right) v_L = \alpha(v_L, j_1) \ (32); \ \left(\hat{D} - \hat{\mathrm{E}}_2\right) u_L = \alpha(u_L, j_2) \ (33); \ \begin{cases} \left(\hat{D} - \hat{\mathrm{E}}_1\right) u_L = 0 \\ \left(\hat{D} - \hat{\mathrm{E}}_2\right) v_L = 0 \end{cases} \ (34)$$

The expressions of partial invariance (29), which describe the inner field, will take the following form:

$$\left(\hat{D} + \hat{B} - \hat{\mathrm{E}}_1\right) I_L^{\pm} = 0 \ ., \quad \left(\hat{D} - \hat{\mathrm{E}}_2\right) I_L^{\pm} = 0 \ , \quad \hat{B} I_L^{\pm} = \pm\alpha\left(I_L^{\pm}, I_L^{\mp}\right) \ . \qquad (35)$$

The unknown value $I_L^{\pm}(l, j_1, j_2)$ too can be found in two ways: either by resolving one of the two separate uniform linear equations of invariant imbedding

$$\left(\hat{D} - \hat{\mathrm{E}}_2\right) I_L^{\pm} = 0 \quad (36) \ ; \quad \text{since} \quad I_L^{\pm}(l, j_1, j_2) = I_L^{\mp}(L - l, j_2, j_1) \ , \quad (37)$$

or with the help of the system

$$\left(\hat{D} - \hat{\mathrm{E}}_1\right) I_L^{\pm} = \mp\alpha\left(I_L^{\pm}, I_L^{\mp}\right) \ , \qquad (38)$$

which is derived from (35) through substitution of the third equation into the first one. **Third** stage of simplification can be easily written in compact form through introduction of **Ambartsumian's operator of complete invariance:**

$$\widehat{\mathrm{A}} \equiv \widehat{\mathrm{E}}_1 - \widehat{\mathrm{E}}_2 = \alpha(j_1, v_L) \cdot \frac{\partial}{\partial j_1} - \alpha(j_2, u_L) \cdot \frac{\partial}{\partial j_2} \quad . \qquad (39)$$

Herewith systems (24) and (30), which describe output intensities and the internal field, will take up the following forms:

$$\begin{cases} \hat{A}u_L = +\alpha(u_L, j_2) \\ \hat{A}v_L = -\alpha(v_L, j_1) \end{cases} \quad (40)\,; \qquad \hat{A}I_L^{\pm} = \pm\alpha\left(I_L^{\pm}, I_L^{\mp}\right) \quad . \qquad (41)$$

Mutual comparison of expressions (32)-(34) and (36), (38), as well as (40) and (41) reveals new and quite important features:

1) differential operators of invariant imbedding $\left(\widehat{D} - \widehat{\mathrm{E}}_1\right)$, $\left(\widehat{D} - \widehat{\mathrm{E}}_2\right)$ and the operator of complete invariance $\hat{A}$, depending on u_L ,v_L, **<u>retain</u>** their form during transition from the problem of **<u>emerging</u>** intensities to a more complex problem of **<u>internal</u>** field;
2) as distinct from $\left(\widehat{D} - \widehat{\mathrm{E}}_1\right)$ and $\left(\widehat{D} - \widehat{\mathrm{E}}_2\right)$, thickness of layer is only a **<u>fixed</u>** parameter in the operator of complete invariance $\hat{A}$, and
3) differentiation procedure is only carried out by the parameters j_1 and j_2 of external **<u>two-sided</u>** influence.

Since operators $\widehat{\mathrm{E}}_1$ and $\widehat{\mathrm{E}}_2$ depend on the values u_L and v_L, then it follows from (36), (38), (39) and (41) that, as against the traditional approach of kinetic equations (1)-(2), the internal field can only be found here after determination of emerging from the medium radiation, i.e. after solution of the **<u>outer problem</u>**. Therefore we are gradually **<u>separating</u>** the solution of a simpler outer problem u_L ,v_L from more complex inner problem - $I_L^{\pm}$. Herewith during resolution of the outer problem we compose also the operators of **<u>Ambartsumian's partial and complete invariance</u>** for the internal problem.

Using expressions of invariance (14) which link $I_L^{+}(l, j_1, j_2)$ and $I_L^{-}(l, j_1, j_2)$ with each other while $A \equiv l,\ B \equiv L - l$

$$\begin{cases} I_L^{+} = u_l(\,j_1\,, I_L^{-}) \\ I_L^{-} = v_{L-l}(\,I_L^{+}\,,\ j_2\,) \end{cases} , \qquad (42)$$

allows us, on one hand, to calculate $I_L^{\pm}$ directly, while remaining in the frames of **<u>first</u>** level of simplification, through solution of system (42), and on the other hand, to even further simplify the above mentioned systems of **<u>second and third</u>** level (1) ≡ (third from (29) and (35)) and (38), (30) **≡** (41) by bringing them to **<u>separate</u>** equations of Cauchy problems **<u>separately for «forwards» and «backwards»</u>** going intensities:

$$\hat{B}I_L^{+} = +\alpha\left(I_L^{+}, v_{L-l}(\,I_L^{+}\,,\ j_2\,)\right), \qquad \hat{B}I_L^{-} = -\alpha\left(I_L^{-}, u_l(\,j_1\,, I_L^{-})\right)\ ; \qquad (43)$$

$$\left(\widehat{D} - \widehat{\mathrm{E}}_1\right)I_L^{+} = -\alpha\left(I_L^{+}, v_{L-l}(\,I_L^{+}\,,\ j_2\,)\right)\ , \quad \left(\widehat{D} - \widehat{\mathrm{E}}_1\right)I_L^{-} = +\alpha\left(I_L^{-}, u_l(\,j_1\,, I_L^{-})\right)\ ; \qquad (44)$$

$$\hat{A}I_L^{+} = +\alpha\left(I_L^{+}, v_{L-l}(\,I_L^{+}\,,\ j_2\,)\right)\ , \qquad \hat{A}I_L^{-} = -\alpha\left(I_L^{-}, u_l(\,j_1\,, I_L^{-})\right)\ . \qquad (45)$$

This helps to achieve additional simplification. Evidently, it is more efficient in (45) in comparison with (43)-(44), since in (45) both spatial variables L, l are playing the role of fixed parameters. In **linear** problem of transfer using the second expression of (42) with the same purpose, as a linear analogue of the first expression in (43), was presented in [18] (see also [19]).

5. Initial conditions for operators of invariance

The above noted differential equations with operators of **partial** invariance $(\widehat{D} - \widehat{\mathrm{E}}_1)$, $(\widehat{D} - \widehat{\mathrm{E}}_2)$ and **complete** invariance $\hat{A}$ require formulation of appropriate initial conditions. They can be easily chosen from (2), (4) and depending on the particular situation from physical standpoint. For the external problem, for example, we have

$$u_L(j_1, j_2)|_{L=0} \equiv j_1, \quad v_L(j_1, j_2)|_{L=0} \equiv j_2; \quad u_L(0,0) = v_L(0,0) = 0 \text{ while } \forall\, L > 0 \quad (46)$$

$$u_L(0, j) = v_L(j, 0) \equiv R_L(j)\,, \quad u_L(j, 0) = v_L(0, j) \equiv T_L(j)\,, \quad (47)$$

where $R_L(j)$ and $T_L(j)$ are functions of nonlinear reflection and transmission of radiation by layer with thickness L during its **illumination from one side** by the flux j. To find these "auxiliary" functions of one variable from (20) and (22) we have

$$\frac{\partial R_L(j)}{\partial L} = \alpha(j, R_L) \cdot \frac{\partial R_L(j)}{\partial j} + \alpha(R_L, j) \quad (48); \qquad \frac{\partial T_L(j)}{\partial L} = \alpha(j, R_L) \cdot \frac{\partial T_L(j)}{\partial j}\,, \quad (49)$$

$$\text{at that,} \quad R_L(0) = T_L(0) = 0\,,\ \forall\, L > 0\,; \quad R_L(j)|_{L=0} \equiv 0\ ,\ \ T_L(j)|_{L=0} \equiv j. \quad (50)$$

For the internal problem too, we can easily select appropriate initial conditions through the following expressions

$$I_L^{\pm}(l, 0,0) = 0 \ \text{ at } \ \forall\, L > 0\,; \ \ I_L^{-}(l, j_1, j_2)|_{l=0} \equiv v_L(j_1, j_2),\ I_L^{+}(l, j_1, j_2)|_{l=L} \equiv u_L(j_1, j_2);$$

$$I_L^{+}(l, j, 0) = I_L^{-}(L - l, 0, j) \equiv Y_L(l, j), \quad I_L^{-}(l, j, 0) = I_L^{+}(L - l, 0, j) \equiv Z_L(l, j). \quad (51)$$

Here the values $Y_L(l, j)$ and $Z_L(l, j)$ represent intensities of "forwards" and "backwards" going radiation on the depth l, during irradiation of the layer from the "zero" boundary side by flux j. They can be derived from the above noted expressions for $I_L^{\pm}(l, j_1, j_2)$, taking into consideration (51) and $Y_L(L, j) = T_L(j)$, $Z_L(0, j) = R_L(j)$.

6. Equivalence and differences of "classical" and "invariance" representations of transfer processes

Comparing (35) and (41) we can see that right parts of Boltzmann's kinetic equation and the Ambartsumian's equation of complete invariance are identical and equal to "integral of collisions", i.e.

$$\hat{B} I_L^{\pm} = \pm\alpha\left(I_L^{\pm}, I_L^{\mp}\right) = \hat{A} I_L^{\pm}\,, \quad \text{from here} \quad \hat{A} = \hat{B}\,. \quad (52)$$

Consequently, from this equality of their right parts we can derive a new and very important property of some "**equivalency**" or "**parity**" of differential operators of Boltzmann - $\hat{B}$, and Ambartsumian - $\hat{A}$. However, although these operators are equivalent in the above mentioned sense, their physical essence is principally different. Indeed, Boltzmann's operator - $\hat{B} = \frac{\partial}{\partial l}$ finds the intensity of the field at a given depth - l through preliminary analysis of the internal mode of radiation through the **whole** layer $[0, L]$, while fixing the values of falling external fluxes j_1, j_2, whereas Ambartsumian's operator - $\hat{A} = \alpha(j_1, v_L) \cdot \frac{\partial}{\partial j_1} - \alpha(j_2, u_L) \cdot \frac{\partial}{\partial j_2}$, in the contrary, "watches" over field changes only at a **fixed** depth – l while **growing** the falling external fluxes j_1, j_2 from "zero" to their current values, taking into consideration thereat the precalculated properties of reflection-transmission - u_L, v_L for the investigated medium. We would like to stress it one more time here that appearing of new, differential (on falling radiation) operator of complete invariance - $\hat{A}$ is exactly due to **nonlinearity** of considered problems.

There is no doubt that the equivalency property for two completely different representations of the same problem by operators of **principally different** physical nature, drawn out from this simple model of one-dimensional medium, opens new possibilities for the development of the **general theory** of **physical kinetics** problems [20]. As distinguished from Boltzmann's traditional approach, Ambartsumian's operator:

1) separates the **external** problem from the more labor-intensive **internal** problem, thus simplifying the first by its independent consideration from the second, and the second – by using information about the already found solution of the first; At that,
2) instead of the two-point Boltzmann's **boundary-value** problem, formulates separate "external" and "internal" problems with **initial** conditions (initial-value problems) – Cauchy-type problems. Moreover,
3) provides an additional opportunity for simplification of the problems through **separate** finding of the "**forwards**" and "**backwards**" going internal fields.

7. Nonlinear problem of polychromatic scattering

Hereinabove we considered the single-frequency case which corresponds to nonlinear problem of two-level atom. However the problems of multilevel atoms are very important for astrophysical applications, when diffusion of radiation is accompanied by processes of nonlinear energy exchange between different atomic levels. Let us suppose that from the "left" and "right" of a layer with geometric thickness L are falling the fluxes of multifrequency radiation $j_1^+, \dots, j_n^+$ and $j_1^-, \dots, j_n^-$ respectively, and we need to find the outgoing through the "left" and "right" boundaries intensities

$v_k(j_1^+,\dots,j_n^+\,;\,j_1^-,\dots,j_n^-)$ and $u_k(j_1^+,\dots,j_n^+\,;\,j_1^-,\dots,j_n^-)$, as well as the values of "forwards" and "backwards" going intensities $I_k^{\pm}(l\,;\,j_1^+,\dots,j_n^+\,;\,j_1^-,\dots,j_n^-)$ of the internal field on the depth l for each of the frequencies numbered $k = 1,\dots,n$. Let us show that the above noted results can be generalized quite easily onto these complex problems of nonlinear polychromatic scattering. Utilization of the principle of invariance for the multifrequency case would bring up the following expressions for Ambartsumian's operator of complete invariance and the equations of complete invariance for respective intensities:

$$\hat{A} = \sum_{m=1}^{n}\left[\alpha_m(j_1^+,\dots,j_n^+\,;\,v_1,\dots,v_n)\cdot\frac{\partial}{\partial j_m^+} - \alpha_m(j_1^-,\dots,j_n^-\,;\,u_1,\dots,u_n)\cdot\frac{\partial}{\partial j_m^-}\right], \quad (53)$$

$$\begin{cases}\hat{A}u_k(j_1^+,\dots,j_n^+\,;\,j_1^-,\dots,j_n^-) = +\alpha_k(u_1,\dots,u_n\,;\,j_1^-,\dots,j_n^-)\\ \hat{A}v_k(j_1^+,\dots,j_n^+\,;\,j_1^-,\dots,j_n^-) = -\alpha_k(v_1,\dots,v_n\,;j_1^+,\dots,j_n^+)\end{cases}, \quad (54)$$

$$\hat{A}I_k^{\pm}(l\,;\,j_1^+,\dots,j_n^+\,;\,j_1^-,\dots,j_n^-) = \pm\alpha\left(I_1^{\pm},\dots,I_n^{\pm}\,;\,I_1^{\mp},\dots,I_n^{\mp}\right). \quad (55)$$

Taking into consideration the analogies of expressions (42)

$$\begin{cases} I_k^+(l\,;\,j_1^+,\dots,j_n^+\,;\,j_1^-,\dots,j_n^-) = u_k^{(l)}(j_1^+,\dots,j_n^+\,;\,I_1^-,\dots,I_n^-)\\ I_k^-(l\,;\,j_1^+,\dots,j_n^+\,;\,j_1^-,\dots,j_n^-) = v_k^{(L-l)}(I_1^+,\dots,I_n^+\,;\,j_1^-,\dots,j_n^-)\end{cases} \quad (56)$$

we will benefit from same additional simplification possibilities as in the single-frequency case (formulas (43) - (45)). In the expressions (56) we had to directly indicate the changed thicknesses of layers through the use of "upper indices" of values u_k and v_k. It is evident that the initial conditions which we discussed in section "5", as well as the equations (32)-(34), (36), (38), (43)-(44), can also be carried over easily into the multifrequency case.The non-linear problem of diffuse reflection from semi-infinite medium for a three-level atom, through analogies (18), was analytically solved in [14, 15]. In [21-23], an algorithm of approximate calculation of non-linear problem of diffuse reflection-transmission of radiation by a layer of finite thickness was used on the basis of the method of linear addition of layers, and it was numerically realized for the case of four-level atom with continua. We also feel it appropriate to mention here works [24-28] as examples of analytical consideration of non-linear problems through the use of other methods.

8. Conclusion

In this report we were trying to show that, through the use of Ambartsumian's principle of invariance, the achievements of well-developed problems of linear transfer can be efficiently extended onto the sphere of nonlinear problems of the transfer theory which is poorly explored because of its complexity but very practical from the point of view of astrophysical applications, as well as to other applications of Boltzmann's kinetic equation. By mentioning "new opportunities" in the title we implied the achievements of Ambartsumian's "invariance concept" or "invariance approach" which allows, by

using a physically transparent and mathematically elegant yet plain and simple methods for **direct** simplification of resolution of complex problems, which otherwise would require **cumbersome and unpredictable** efforts if using the traditional approach through the use of Boltzmann's kinetic equations. Below we are listing the main advantages of using the “invariance” methods:

1) Through the use of the “method of addition of layers” can be composed **precise algorithms** for calculation of external and internal fields through recurrent growth of layers up to their earlier designated thicknesses.
2) The problem of emerging from medium radiation can be resolved **without defining** any characteristics describing the internal field in the medium.
3) By using characteristics of emerging from medium radiation, internal field can be determined at every given depth, **independently** from other depths.
4) Transfer problems for **“forwards”** and **“backwards”** going fields can be resolved **separately** from each other.
5) Both operators of partial and complete invariance **maintain** their shape during transition from problems of emerging radiation to problems of finding the internal field.
6) Radiation field under **two-sided** external radiation of the medium can be found as the solution of Cauchy problem by fluxes falling from the outside. We use the earlier found solutions for medium radiated from **one side** as the initial conditions. At that, all spatial variables are only playing the role of fixed parameters.
7) Boltzmann’s and Ambartsumian’s operators, which serve to absolutely different purposes, are equivalent to each other. First sets the **two-point boundary-value problem** on the spatial variable while maintaining fixed values for the external influence parameters on the medium. The second, in the contrary, formulates **Cauchy problem** by parameters of external influence while maintaining a fixed value for spatial variable.

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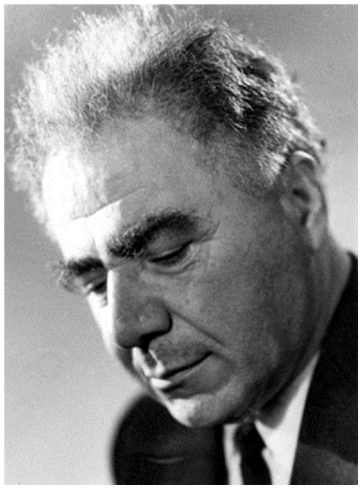
Session 6. MISCELLANEA



V.A. Ambartsumian's contributions in other fields:

For the first time **the problem of finding the differential equation corresponding to the known family of eigenvalues** was solved. A **problem inverse to Sturm-Liuville's problem was** formulated, which later became a starting point for an entire field of analogical class inverse problems (1929).
Ref.: W.A. Ambarzumjan – Uber eine Frage der Eigenwerttheorie (On a Problem of the Theory of Eigenvalues) // *Zeitschrift fur Physik, 53, 690-695, 1929 (in German).*

An idea that not only the quanta of the electromagnetic field, photons, but also **other particles (including particles having nonzero rest mass) may be born and disappear as a result of their interaction with other particles** (this idea lays in the basis of modern physics of the elementary particles and quantum field theory) (together with *D.D. Ivanenko*, 1930).
Ref.: W.A. Ambarzumjan, D.D. Iwanenko – Eine quantentheoretische Bemerkung zur einheitlichen Feldtheorie (A Quantum-Theoretical Remark on the Uniform Field Theory) // *Doklady USSR Acad. Sci., Ser. A, 3, 45-49, 1930 (in German).*

The **impossibility of existence of free electrons in the atomic nuclei** was proved. It was shown that **only electrically uncharged elementary particles of approximately proton mass could exist together with protons in nuclei.** In years James Chadwick discovered neutron (with *D.D. Ivanenko*, 1930).
Ref.: V.A. Ambartsoumian, D.D. Ivanenko – Les electrons inobservables et les rayons β // *Compte rendu hebdomadaire des seances de l'Academie des sciences de Paris, 190, 582-584, 1930 (in French).*

Explosions by Primary Proto-stellar Ambartsumian Objects are Local Bounces of Gravitational Collapses onto Local Rotation

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Abstract. Gravitational collapse in process of the stellar formation as well as in the cosmological models in the frame of the Newtonian and general relativistic treatments is considered. The centrifugal forces acting between particles rotating randomly around each other are shown to be able to reverse gravitational collapse. The concept of local rotation is highlighted (it violates the requirements of Penrose-Hawking theorems). Mechanisms of gravitational instabilities are discussed.

Viktor Hambartzumian's revolutionary conceptions and the paradigm of "crazy ideas"

Robert DJIDJIAN
Israel

Contribution not available.

Extrasolar planets and Their Parent Stars

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Abstract: Extrasolar planetas (exoplanets), or planets orbiting stars other than our own Sun, are a relatively new field of the astronomical and planetary sciences. After the discovery of Pluto in 1930, planet-finding activities appeared to have reached an end for the foreseeable future. Several brown dwarfs have been discovered between 1930 and 1993 orbiting other solar-type star. Brown dwarfs (or "failed stars") are low-mass celestial objects ($M \geq 10M_{JUP}$) that formed by stellar processes but did not obtain the critical mass required to sustain hydrogen burning within their core. Other claims for planetary detections were also made during the period 1944 – 1970 but were never verified or were later shown to be false, produced by timing artifacts or instrumentation errors. The first confirmed detection of an extrasolar planet occurred in 1992 when two bodies were found to be orbiting the millisecond pulsar PSR 1257+12 (Wolszczan and Frail, 1992). The first detection of an extrasolar planet orbiting a solar-type star occurred in 1994 with the claim of a Jupiter–type planet orbiting 51 Pegasi (Mayor and Queloz, 1995). As of January 2010, we currently know of 429 planets orbiting solar-type stars The vast majority of these detections have occurred via the radial velocity method (Udry & Santos 2007), although other methods such as that of transiting photometry and microlensing may become increasingly important in future planet searches as we seek to detect terrestrial-sized planetary bodies and utilize space- based observing programs.

1. Introduction

The problem of the existence of other worlds has been present in human history for millennia. Recently astronomers found that planets do exist and are common outside the Solar System. Based on the detection statistics of the current planet search programs, Marcy and Butler (1998) estimated that the Milky Way could be "home" to up to 10 billion planets. The major milestone in the search for extrasolar planets was the discovery in 1995 of 51 Peg b, the first extrasolar planet found to orbit a Sun-like star (Mayor & Queloz 1995). This planet named 51 Peg b orbits at 0.052 AU from its parent star, a striking characteristic when compared to the giant planets in the Solar

System, which all orbit beyond 5 AU. This proximity has been a major surprise and a serious challenge to planet formation theories. The discovery of now more than 400 extra-solar planets opened a wide range of questions regarding the understanding of the mechanisms of planetary formation and evolution.

Astrometry is the oldest search method for extrasolar planets. It dates back at least to statements made by William Herschel in the late 18th century who claimed that an *unseen companion* was affecting the position of the star he cataloged as 70 Ophiuci.

The method consists of precisely measuring a star's position in the sky and observing the ways in which that position changes over time. If the star has a planet, then the gravitational influence of the planet will cause the star itself to move in a tiny circular or elliptical orbit around the common center of mass. Because the motion of the star is so small, this method has not yet been very productive at detecting exoplanets. Five different techniques have contributed to these discoveries: timing (9 planets detected), Doppler spectroscopy (399 planets), photometric transits (69 planets), microlensing (10 planets), and direct imaging (11 objects with a mass possibly below 20 M_{Jup}). These observational techniques have considerably improved in recent years and Doppler spectroscopy, which has contributed the bulk of the discoveries so far, now allows the detection of planets with only twice the mass of the Earth (Mayor et al. 2009). The radial-velocity method is based on the fact that a star with a planet will move in its own small orbit in response to the planet's gravity. Our goal is to measure variations in the radial velocity variations of the star with respect to Earth. Since the probability of detecting a planetary signal depends essentially on the value of the velocity semi-amplitude, a simple expression indicates that Doppler measurements favour the detection of planetary systems with massive and short-period planets. Applied to the Solar System, we shall find that Jupiter induces on the Sun a radial-velocity perturbation with a semi-amplitude of 12.5 m s^{-1}, while the Earth induces a perturbation with a semi-amplitude of 9 cm s^{-1}. Obviously, obtaining radial velocities at this level of precision is nontrivial.

Planet formation theory has made rapid progress too. To meet the challenge posed by the most amazing properties of the newly found planets, two different formation models have emerged: core accretion and disk instability. In the disk instability model, giant planets form by direct fragmentation of the protoplanetary disk (Durisen et al. 2007). Quantitative predictions based on the disk instability scenario are still uncertain because the numerical simulations are challenging and involve complex physical processes. According to the core accretion model, dust grains coagulate to form planetesimals, which then accumulate and build planetary cores. Planetary cores reaching the critical mass of 5-15 $M_{\oplus}$ before the dissipation of the gaseous protoplanetary disk subsequently accrete large amounts of nebular gas and form giant planets (Lissauer & Stevenson 2007). The remaining solid cores merge through giant impacts to form terrestrial planets (Nagasawa et al. 2007). Core accretion theory is now developed enough to allow for

detailed calculations, predictions of chemical make up, and explicit comparisons with the observed population of extrasolar planets are possible.

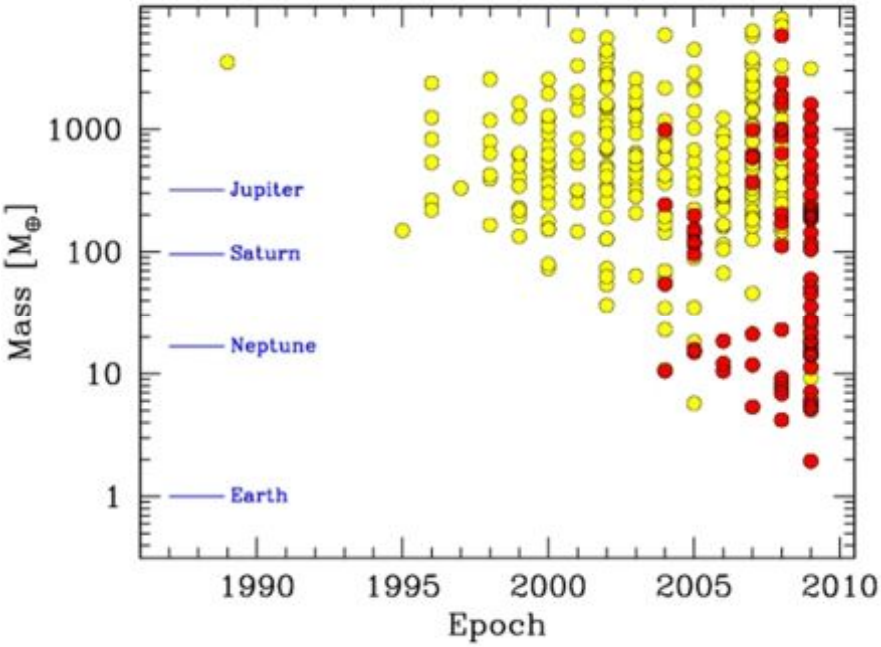

Fig 1. *The planet mass as a function of the year of discovery. Red dots denote planets discovered with HARPS since 2004. Only planets discovered using the radial velocity method are displayed. Most of the known planets have been discovered using this method.*

2. High-precision Doppler measurements: requirements and limitations.

High-precision measurements are difficult to achieve. A measurement error of 1 m s^{-1} corresponds to $\Delta\lambda/\lambda_0 = 3 \times 10^{-9}$ on the detector of a typical spectrograph (R ~ 100,000), this wavelength shift translates into a linear displacement of about 3×10^{-4} resolution element. Although attaining this precision is feasible by averaging over many spectral lines, experience shows that unless one takes special measures, errors in Doppler measurements are much greater than the above values and are usually systematic. Doppler measurements made with spectrometers or classical spectrographs rarely achieve standard errors better than ~200 m s^{-1}. In order to achieve the high Doppler precision for the detection of exoplanets, several sources of systematic errors must be considered.

An important source of errors is related to the motion of the photocenter at the spectrograph slit. The slit width of a spectrograph in Doppler units is typically a few km s^{-1}. This means that large errors will occur if the photocenter moves away from the slit center. In practice, photocenter motions due to guiding errors, seeing fluctuations, and atmospheric refraction usually amount to 10^{-1} slit widths. This problem can be solved with an optical fiber (often with the addition of a scrambling device), which is used to convey and scramble the starlight from the telescope to the spectrograph. Even more important source of errors comes from the variations of air refractive index and thermomechanical flexures. Negligible variations of barometric pressure and temperature may modify the refractive index of air near the grating and cause spurious wavelength shifts similar to Doppler shifts. Wavelength shifts are also produced by mechanical instabilities and thermal relaxation. For the CORALIE Spectrograph (Swiss 1.2m Leonard Euler telescope in La Silla, Chile), a temperature change of 1 K produces a net velocity drift of 90 m s^{-1}, while a pressure change of 1 mbar produces a net velocity drift of 300 ms^{-1}. A partial solution to this problem is a vacuum chamber, which allows stabilizing and controlling the entire spectrograph in temperature and pressure. However, small wavelength shifts cannot be fully avoided. Perhaps the only way to deal with this problem is to use a simultaneous wavelength calibration to monitor – and then correct for – these “instrumental drifts”. Radial velocities must be corrected to the Solar System barycenter. To obtain accurate barycentric radial velocities, one needs precise Solar System ephemeris. One also needs to know the photon weighted midpoint of each observation to better than 30 s. These requirements show that the trick to making high-precision Doppler measurements is to record the wavelength reference spectrum simultaneously with the stellar spectrum and to scramble the starlight before sending it to the spectrograph.

The secret to making high-precision Doppler measurements is to record the wavelength reference spectrum simultaneously with the stellar spectrum and to efficiently scramble the starlight before sending it to the spectrograph. Two techniques have been developed to achieve this. Both these techniques use a cross-dispersed Echelle spectrograph and handle instrumental drifts by means of a simultaneous wavelength calibration. However, they entirely differ in their approach and design. The simultaneous reference technique involves the use of two optical fibers to feed the spectrograph: the so-called object fiber, which records the starlight, and the reference fiber which records the light from a wavelength reference source. The simultaneous reference technique was pioneered on the ELODIE spectrograph, and up to now all the spectrographs based on this technique have used as reference source a thorium-argon (ThAr) lamp. This method is known as *the simultaneous thorium technique*. We stress that this technique can achieve high radial-velocity precision only if implemented on fiber-fed spectrographs with high mechanical and thermal stability. The role of optical fibers equipped with a scrambling device is to reduce instabilities in illumination and variations of instrumental profile. The thermal stabilization, on the other hand, keeps the optical paths of the two beams very similar within the spectrograph. Radial velocities are traditionally obtained

by numerically cross-correlating the observed spectra with box-shaped, binary (0 and 1 values) templates called masks (Baranne et al. 1996; Pepe et al. 2002). Construction of the cross-correlation function (CCF) is achieved by shifting the velocity of the mask by increasing amounts over a window nearly centred on the radial velocity of the star. Stabilized spectrographs searching for planets using the simultaneous thorium technique include ELODIE (1.93-m Telescope, Haute-Provence, France), CORALIE (Leonard Euler Telescope, La Silla, Chile), HARPS (3.6-m ESO Telescope, La Silla, Chile), and SOPHIE (1.93-m Telescope, Haute-Provence, France). The radial-velocity precision has considerably improved from ELODIE to HARPS and currently it is better than 1 m s^{-1}. Recently Mayor et al. (2009) reported a planet around GJ 571 with only two times the Earth mass.

The second calibration technique is based on gas cells. The idea of this technique is to pass the starlight through a cell containing an absorbing medium (the reference source) before entry into the spectrograph. Absorption lines from the reference source will be superimposed on the stellar spectrum, providing a wavelength scale that carries the same instrumental shifts and distortions as the stellar spectrum. Since the gas cell is at rest relative to the telescope, spurious instrumental shifts are measured by the wavelength shift of the reference lines. The reference spectrum also provides the instrumental profile and its variations at each position on the detector. Currently, all planet search programs based on this simple technique use an iodine cell and the technique is commonly cited as the *iodine cell technique*. This technique is easily implemented on any existing slit spectrograph. However, it implies a complicated Doppler analysis. Echelle spectrographs equipped with an iodine cell and used for planet searches include UCLES (AAT, Siding Spring, Australia), HRS (HET, Davis Mountains, USA), HAMILTON (Shane/CAT, Lick, USA), HIRES (KECK, Mauna Kea, USA) and UVES (VLT, Paranal, Chile). This technique has long demonstrated a precision of 3 m s^{-1} (Butler et al. 1996), which have not much improved since then.

Astrophysical limitations on Doppler spectroscopy are different. The most important limitations are related to stellar activity and sun-like oscillations. It has been known for many years that magnetic phenomena at the surface of solar-type stars induce radial-velocity variations through the temporal and spatial evolution of spots and convective inhomogeneities. Variations in line asymmetry caused by starspots are modulated by the rotational period of the star and can easily mimic a planetary signal. The radial-velocity perturbations related to stellar activity are called “stellar jitter”. Stellar jitter cannot be modelled in detail but we know that it depends on stellar activity, effective temperature, and projected rotational velocity (Saar et al. 1998; Santos et al. 2000b; Wright 2005). Maximal values of stellar jitter are 5 ms^{-1} for slowly rotating, chromospherically quiet G-K dwarfs (Santos et al. 2000b; Wright 2005) and 50 ms^{-1} for F5-M2 active young dwarfs (Paulson et al. 2004). For this reason high-precision Doppler planet searches select their targets among old, inactive and slowly rotating stars. Solar-type oscillations create problems as well. It is well known that the Sun oscillates in many low amplitude

modes simultaneously. These modes are characterized by a maximum amplitude 20 cms^{-1} and a period between 3 and 15 minutes. The interference of different modes can produce radial velocity variations up to 10 times the typical amplitude values (10-50 cms^{-1}) on time scales of minutes. An adequate observing strategy is required in order to minimise the impact of this effect on the search for low-mass planets.

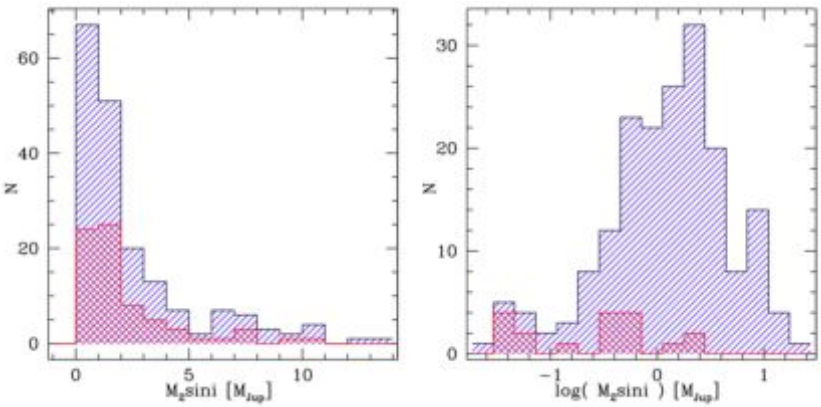

Fig 2. *Distribution of planet minimum masses in linear (left) and logarithmic (right) scales. The double-hatched histogram represents the planets detected with CORALIE (left) or with HARPS (right).*

3. Statistical Properties of Exoplanets

The number of planetary companions detected through Doppler spectroscopy has increased dramatically since 1995, providing a unique observational material to characterize the properties of planets and their host stars. These data have been used to study the distributions of planet properties and to quantify the frequency of giant planets among different populations of stars (Udry & Santos 2007). Obviously these statistical features hide fossil records of planet formation and evolution processes. In fact, core accretion models are able to generate synthetic planet populations, which can be compared with the observed sample of extrasolar planets (Ida & Lin 2004a; Alibert et al. 2005).

The most important radial velocity planet search programs, which have most significantly contributed to the present discoveries, are: the ELODIE Planet Search (330 G-K dwarfs; Perrier et al. 2003), the CORALIE Planet Search (1650 G-K dwarfs; Udry et al. 2000), the Anglo Australian Planet Search (230 F-G-K-M stars; Tinney et al. 2005), the California and Carnegie Planet Search (1100 F-G-K-M dwarfs; Marcy et al. 2005b) and the HARPS Planet Search (1500 G-K-M dwarfs; Mayor et al. 2003).

Omitting the N2K and ELODIE2 “metallicity-biased” surveys (2000 F-G-K dwarfs; Fischer et al. 2005, 1200 G-K dwarfs; da Silva et al. 2006), these planet search programs together monitor about 3000 F-G-K dwarfs in the solar neighbourhood.

At present, true occurrence rates are available for the ELODIE and for the Keck programs. Results from the ELODIE survey indicate that the fraction of stars with a planet more massive than 0.5 M_{Jup} is 0.7 ± 0.5% for P < 5 days (a < 0.06 AU) and 7.3 ± 1.5% for P < 3900 days (a < 4.8 AU) (Naef et al. 2005). For the same mass and period ranges, the Keck survey provides 0.65±0.40% and 8.6±1.3% (Cumming et al. 2008). We stress that according to planet formation models, giant planets reside preferentially beyond 3 AU, while low-mass planets dominate those populations (Ida & Lin 2004a). Taking into account the selection effects in Doppler spectroscopy, some authors have estimated (Mordasini et al. 2007) that the ELODIE and Keck programs could detect only about 6 % of the overall planet population around solar type stars.

The distribution of minimum masses (Doppler spectroscopy does not yield the true mass of planetary companions but only the product m_p sin i, which is a lower limit on the planet mass) is shown in Fig. 2. While most of the detected planets have minimum masses below 5 M_{Jup}, there is a long tail towards minimum masses exceeding 10 M_{Jup}. There is a scarcity of companions with masses between 10 and 100 M_{Jup} (Zucker & Mazeh 2001) for orbital periods less than a decade. This gap is called the brown dwarf desert and it suggests that extra solar planets and stellar companions belong to two distinctv populations, which formed through two different mechanisms. Some overlap seems to exist between 10 and 20 M_{Jup}. Obviously the low-mass side of the minimum mass distribution is strongly affected by selection effects below the mass of Saturn (0.3 M_{Jup}). Nevertheless, it seems that the distribution is turning upwards near 0.1 M_{Jup}.

The period-eccentricity diagram is shown for both extrasolar planets and stellar binaries with solar-type primaries (Fig 3). Apparently, the known extrasolar planets have on average larger eccentricities compared with those of Jupiter and Saturn (0.048 and 0.056, respectively). Planets with periods below 5 days tend to have small eccentricities due to tidal dissipation (e.g. Rasio et al. 1996). Tidal circularization becomes ineffective at longer periods and planetary eccentricities then span almost all the allowable range with a median value of 0.29. These high planetary eccentricities are very puzzling since formation in a disk is thought to yield almost circular orbits.

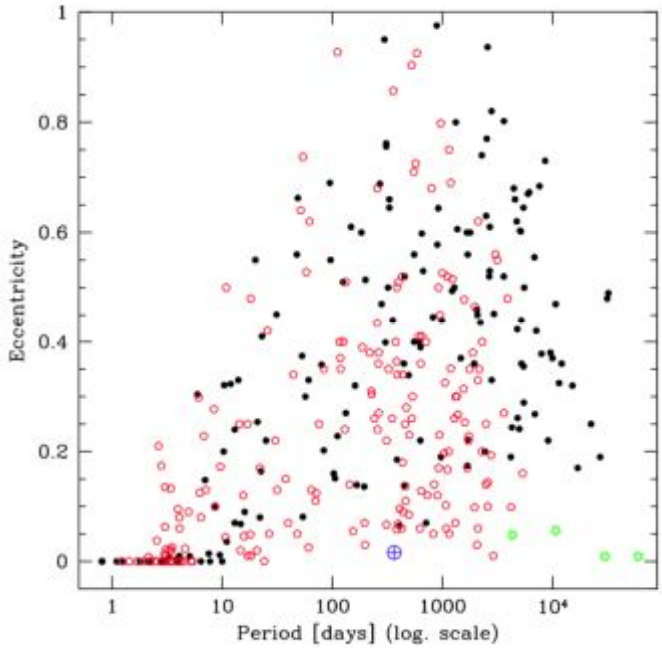

Fig 3. *Period-eccentricity diagram for extrasolar planets (open pentagons) and for stellar companions to solar-type stars (black dots). The Earth and the four giant planets of the Solar System are also indicated (Earth and starry symbols at the bottom).*

The period distribution is shown in Fig. 4. At short periods, there is a small excess of planets with periods between 2 and 5 days. This local peak is accounted by "hot Jupiters" like 51Peg b. The detection of Jovian planets with such a small orbital periods has been a major "shock" for many astronomers since classical theory of solar system formation predicted that giant planets would form beyond a few AU. In situ formation of hot Jupiters is very difficult (Bodenheimer et al. 2000) and their detection have posed a serious challenge to planet formation theories. According to the revised models, short-period giant planets likely formed far from their parent star beyond 2-3 AU and then migrated inwards due to the tidal interaction with the gaseous disk (e.g. Lin et al. 1996; Ida & Lin 2004a; Mordasini et al. 2007; Armitage 2007). The origin and even the existence of the pile-up of planetary companions with periods close to 3 days are still being debated. Many, if not all, hot Jupiters have undergone migration within a gaseous disk. Some of them have stopped at small radii while others have plunged into their star (Israelian et al. 2001). Different mechanisms have been proposed to stop orbital migration and to park giant planets on close orbits: Roche lobe overflow (e.g. Trilling et al. 1998; Gu et al. 2003). tidal interactions with the rotating host star (e.g. Trilling et al. 1998) or the existence of a central cavity in the disk (e.g. Lin et al. 1996; Kuchner & Lecar 2002).

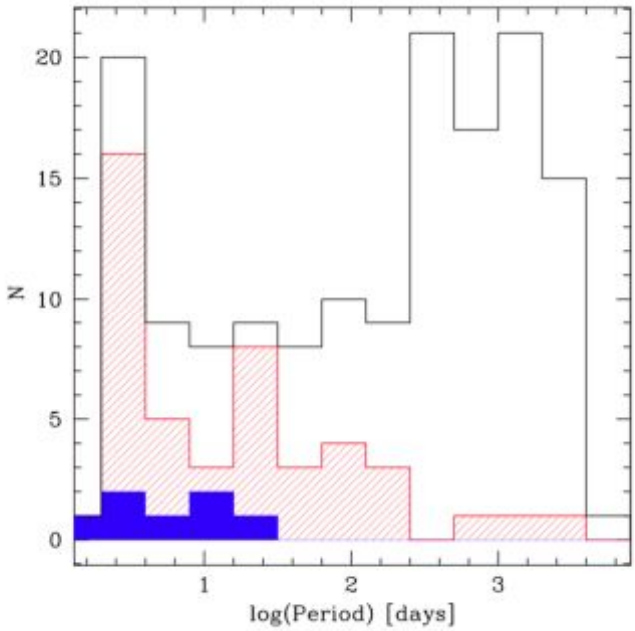

Fig. 4. *Period distribution for extrasolar planets. The hatched histogram represents light planets with mp sini* ≤ 0.75 M_{Jup}, *while the filled histogram represents Neptune-mass planets with mp sin i* ≤ 21 $M_{\oplus}$.

The number of planets with long periods between ~5 and 250 days remains constant and then increases abruptly. However, let us note that the time baseline of ongoing planet search programs is still too short to tell whether the period distribution remains flat between 300 days to 4 years, or increases continuously beyond 250 days. Current data clearly indicate the existence of a large population of giant planets with periods above 5 years, which we are just beginning to detect. Obviously the main limitation at the moment for the detection of solar system analogs is not the Doppler precision but the duration of the surveys. A lot more solar system analogs will be discovered during next 2-5 years.

4. Planet host stars

Since the planet formation is a by-product of star formation, some stellar properties could provide invaluable information about the conditions in protoplanetary disks and/or protostellar clouds leading to planet formation.

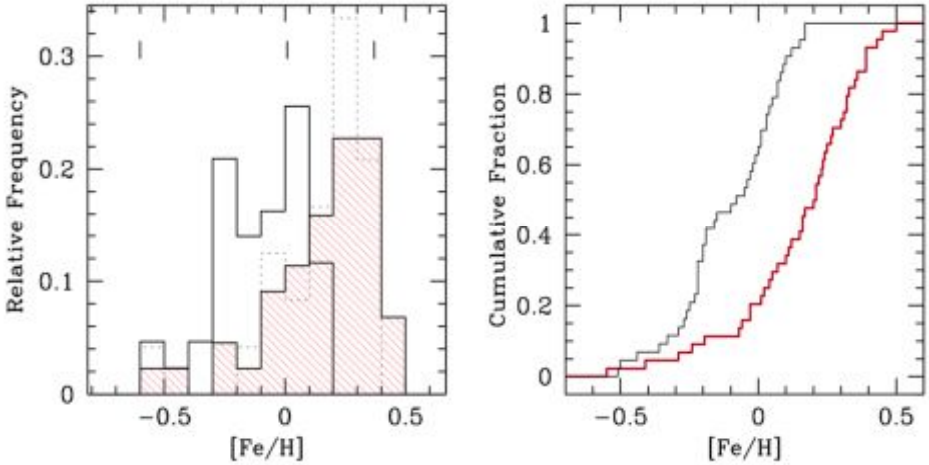

Fig 5. *Left: distribution of stars with planets (shaded histogram) compared with the distribution of field dwarfs presented in this paper (empty histogram). The dashed histogram represents the planet host sample if we consider only stars forming part of the CORALIE survey (see text for details). The vertical lines represent stars with brown dwarf candidate companions having minimum masses between 10 and 20 MJup. Right: The cumulative functions of both samples. A Kolmogorov–Smirnov test shows the probability of the stars' being part of the same sample is around 10−7.* (from Santos et al. 2001).

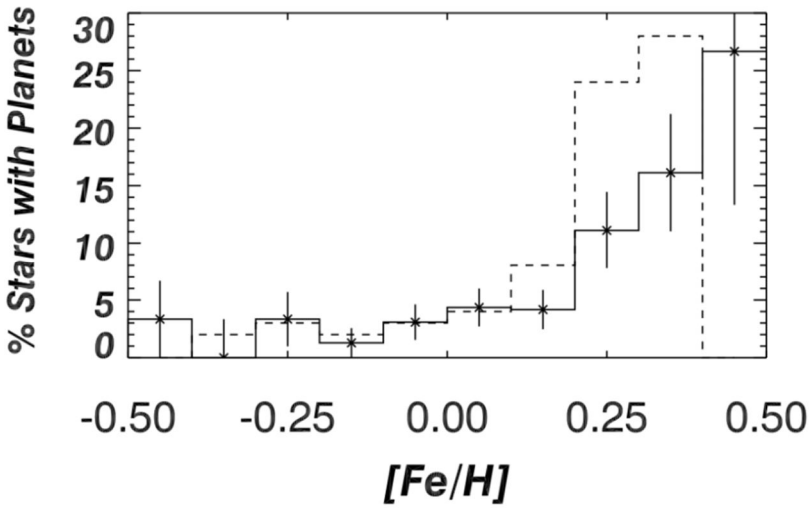

Fig. 6. *Percentage of planet-host stars as a function of stellar metallicity. The dashed line shows the results from Santos et al. (2004) and the solid line shows the results from Fischer & Valenti (2005).*

5. Iron

The first strong link established between the planetary com- panions and their host stars is the fact that planet-harbouring stars are on average more metal-rich with respect to field stars. This idea has been put forward by Gonzalez (1997), while the first clear evidence (Fig. 5) has been published by Santos, Israelian & Mayor (2001). Further studies have been confirming this result as new planet host candidates have been discovered (e.g. Gonzalez et al. 2001; Laws et al. 2003; Santos et al. 2003, 2004a, 2005; Fischer & Valenti 2005). This characteristic led to the suggestion that gas giant planet formation is favored by high stellar metallicity (Santos, Israelian & Mayor 2000, 2001, 2004, Santos et al. 2005), so that planetary systems would be more likely to form out of metal-enriched primordial clouds. Alternatively, the metallic excess in these stars may be attributed to the pollution by the late ingestion of planetary material (Laughlin 2000, Gonzalez et al. 2001). Several results supporting the "self-pollution" scenario were published. Murray & Chaboyer (2002) concluded that stochastic pollution by $\sim 5M_{\oplus}$ of iron-rich material, together with selection effects and high intrinsic metallicity, may explain the observed metallicities in planet-harbouring stars. Israelian et al. (2001, 2003) proposed the ^{6}Li –test and found evidence for a planet (planets or planetary material) having been engulfed by the discovery of a significant amount of ^{6}Li in the stellar atmosphere of the parent star HD 82943. However, the amount of accreted matter was not enough to explain the global stellar metallicity. Ingestion of planetary material may also explain the lithium and iron enhancement found by Gonzalez (1998) and Laws & Gonzalez (2001) in the primary component of the binary system 16 Cyg. However, most studies today suggest that a primordial origin is much likelier to explain the metallicity excess in planet host stars. Pinsonneault et al. (2001) ruled out the "self-pollution" hypothesis since the iron excess did not show the expected T_{eff} dependence. Nevertheless, some different premises proposed by Vauclair (2004) might invalidate their argument. An additional point in favour of the primodial scenario is the fact that the frequency of planets is a rising function of [Fe/H] (see Fig.6 and Santos et al. 2001, 2004a). This idea would support the classical CIA (core-instability accretion) model where some 10-15 $M_{\oplus}$ masses of planetesimals condense into a rocky core (Ida & Lin 2004b; Benz et al. 2006). Disk instability being apparently insensitive to metallicity (Boss 2002), the metal rich nature of planet-host stars is commonly considered as a major evidence that most of the giant planets we observe today formed through core accretion. Three possible explanations have been put forward to understand the metallicity correlation: (1) an enhanced metallicity in the protoplanetary disk could favour to planet formation, (2) the infall of metal-rich planetary material onto the host stars could have enriched their outer layers, or (3) there might be an "orbital period bias" due to the dependence of migration rates on metallicity (Livio & Pringle 2003) or to the inward shift of the optimum region for giant planet formation in metal-poor stars (Pinotti et al. 2005). The abundance analyses of elements other than iron may give clues to this open question.

6. Volatiles, refractory and heavy elements

Abundances of different elements may provide clue for checking various planet formation, and even planet migration, hypothesis. Volatiles are known to condense into solid grains at relatively low temperatures, and are expected to behave differently compared to the refractory, which condense at high temperature. If the star accreted a considerable amount of planetary material, then high temperatures near the star would favor the addition of refractory elements over volatiles (which are locked in giant planets) and a trend in abundance versus condensation temperatures may appear (Smith et al. 2001). If the infall of large amounts of rocky planetary material was the main cause of the metallicity excess in planet host stars, as the "self-pollution" scenario claims, an overabundance of refractory elements with respect to volatiles should be observed. This would imply an increasing trend of abundance ratios [X/H] with the elemental condensation temperature T_C. However, the engulfment of a whole planet (or the rapid infall of planetary material) may avoid the evaporation of volatile elements before being inside the star, leading to no peculiar trends of the stellar abundances with T_C. Smith, Cunha, & Lazzaro (2001) reported that a small subset of 30 stars with planets exhibited an increasing [X/H] trend with T_C and concluded that this trend pointed to the accretion of chemically fractionated solid material into the outer convective layers of these solar-type stars. Takeda et al. (2001) also searched for a correlation between chemical abundances and T_C. However, they found that all volatile and refractory elements behave quite similarly in a homogeneously analyzed set of 14 planet-harbouring stars and 4 field stars. Sadakane et al. (2002) confirmed this result in 12 planet host stars, supporting a likelier primordial origin for the metal enhancement. Unfortunately, more results for planet-harbouring stars and an homogeneous comparison with field stars were needed to perform a more convincing test. Ecuvillon et al. (2006) studied the [*X*/H] trends as function of the elemental condensation temperature T_C in 88 planet host stars and in a volume-limited comparison sample of 33 dwarfs without detected planetary companions. These authors gathered homogeneous abundance results for many volatile and refractory elements spanning a wide range of T_C , from a few dozens to several hundreds kelvin. They investigated possible anomalous trends of planet hosts with respect to comparison sample stars in order to detect evidence of possible pollution events. No significant differences are found in the behaviour of stars with and without planets (Fig. 7). This result is in agreement with a "primordial" origin of the metal excess in planet host stars. However, a subgroup of 5 planet host and one comparison sample stars stands out for having particularly high [*X*/H] vs. T_C slopes.

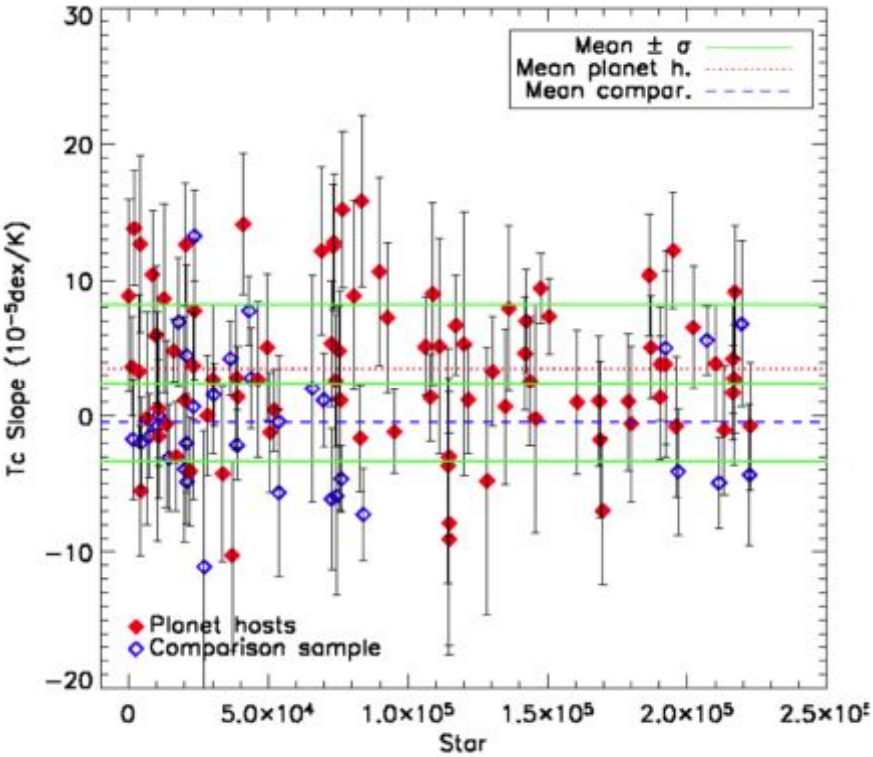

Fig 7. *Slopes derived from [X/H] vs. TC for all the planet host (filled symbols) and comparison sample (open symbols) stars. The solid lines represent the average slope of the two samples, and the average slope ± one standard deviation. The dotted and dashed lines indicate the average slope of stars with and without planets, respectively* (from Ecuvillon et al. 2006).

The number of detailed abundance studies at [Fe/H]>0 is very limited and exoplanet hosts can help to explore this regime. Some of the trends obtained in these studies may be linked with the presence of giant planets. According to Santos, Israelian and Mayor (2004), more than 25% of stars with [Fe/H] >0.3 host giant planets. The possibility that all metal-rich stars host giant planetary systems cannot be ruled out. Thus, it is almost impossible to compare stars with and without planets in the high [Fe/H] tail of the distribution. The relative frequency of stars with planets increases with [Fe/H], but there is a sharp cutoff once the metallicity reaches about 0.4 dex. It is hard to believe that Nature could somehow tune the pollution process (i.e. self enrichment) in planet hosts by not allowing them to have [Fe/H] > 0.5. Most probably, the cutoff represents a rough upper limit to metallicities in the solar neibourhood. If [Fe/H] ~ 0.4 represents the "present day" state of Galactic chemical evolution, then certain trends should appear for all other chemical species. How then can we disentangle the abundance anomalies produced by the presence of planets? Results from Bodaghee et al. (2003), Gilli et al.

(2005), Nave et al. (2009) clearly demonstrate that the excess in metallicity observed for planet host stars is widespread and not unique to iron (e.g. Israelian 2008). In general, the abundance distributions of planet host stars are high [Fe/H] extensions to the curves traced by the field dwarfs without planets. The most precise distributions published so far are those by Nave et al. (2009) based on the HARPS sample of stars with and without detected planets. No significant differences are found in the regions of overlap. However, although some differences for certain elements are subtle (and may even be negligible), they are certainly intriguing enough to merit additional studies.

7. Light elements Li and Be

Light elements are very important tracers of the internal structure and history of solar-type stars and therefore they can help to distinguish between different planet formation theories (Sandquist et al. 2002; Santos et al. 2002, 2004b; Israelian et al. 2004, 2009, Israelian 2008). The light elements Li and Be are important tracers of the internal structure and pre-main sequence evolution of solar type stars since they provide information regarding the redistribution and mixing of matter within a star. Studies of Be and Li complement each other as Li is depleted at much lower temperatures than Be. By measuring Li and Be in stars hosting planets we can obtain crucial information about the mixing, diffusion and angular momentum history of the stars. Accretion of planets and planetesimals, stellar activity and tidal interactions in star-planets systems may largely modify the surface abundances of the light elements.

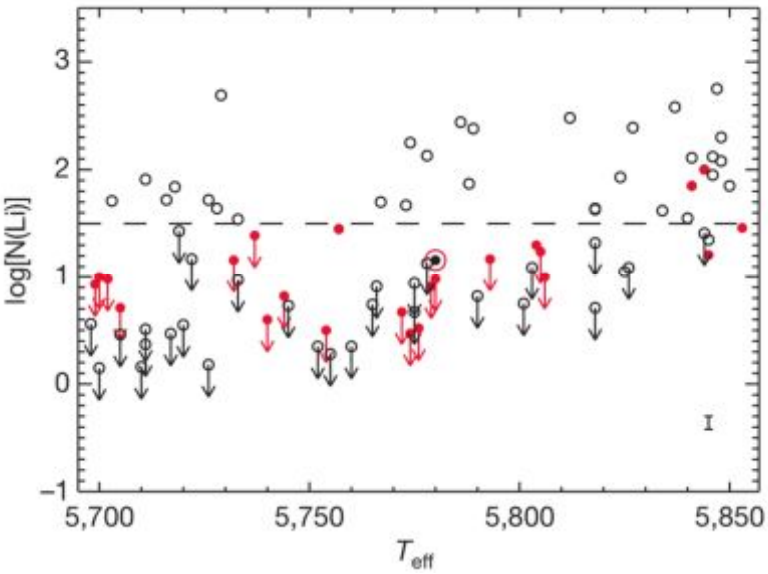

Fig 8. *Lithium abundances plotted against effective temperature in solar-analogue stars with (red dots) and without (empty circles) detected planets. The red circle with the black point at its centre indicates the Sun. From Israelian et al. (2009, Nature, 462, 189).*

Gonzalez & Laws (2000) presented a direct comparison of Li abundances among planet-harbouring stars with field stars without planets and proposed that the former have less Li. However, in a critical analysis of this problem Ryan (2000) concludes that planet hosts and field stars have similar Li abundances. Given the larger number of planet-harbouring stars, Israelian et al. (2004) reinvestigated the Li problem and looked for various statistical trends. When the Li abundances of planet host stars are compared with the 157 field stars, they find that the Li abundance distributions in the two samples are different. There is a possible excess of Li depletion in planet hosts having effective temperatures in the range 5600–5850 K, whereas they found no significant differences for stars with temperatures in the range 5850–6350 K. But why is the difference only seen in stars with effective temperatures in the range 5600–5850 K ? Given the depth of the surface convection zone, we expect that any effect on the Li abundance will be more apparent in solar-type stars. Lower mass stars have deeper convective zones and destroy Li more efficiently, so we can often only set upper limits to the abundance. However, the convective layers of stars more massive than the Sun do not reach the lithium-burning layer and therefore these stars generally preserve a large fraction of their original Li. Therefore, it seems that solar-type stars are the best targets for investigating any possible (and maybe marginal) effects of planets on the evolution of the stellar atmospheric abundance of Li.

More recently Israelian et al. (2009) obtained Li abundances from high resolution, high signal-to-noise (S/N) spectra for a sample of 451 stars in the HARPS high precision (better than 1 m/s) radial velocity exoplanet survey spanning the effective temperature range between 4900 and 6500 K. They found that the planet-bearing solar analog stars in the temperature range 5700-5850 K have less than 1 % of the primordial Li abundance, while about 50 % of the solar analogues without detected planets have on average 10 times more Li. The presence of planets may increase the amount of mixing and deepen the convective zone to such an extent that the Li can be burned. Thus, Lithium is the only chemical element, which behaves in a different way in planet host stars. It was argued that the Sun is “Lithium poor” because of the presence of planets in the system.

A unique opportunity for testing the planet and/or planetesimal accretion scenario is offered by a ^{6}Li–test proposed by Israelian et al. (2001). This approach is based on looking for an element that should not appear in the atmosphere of a normal solar-type star, but would be present in a star that has accreted planetary matter. Nuclear reactions destroy the ^{6}Li and ^{7}Li isotopes in stellar interiors at temperatures of 2×10^{6} (^{6}Li) and 2.5×10^{6} K (^{7}Li). Furthermore, convection cleans the upper atmosphere of Li nuclei by transporting them to deeper and hotter layers where they are rapidly destroyed. Young solar-type stars are entirely convective and most of the primordial Li nuclei are burned in their interiors in a mere few million years. However, many solar-type stars preserve a large fraction of their initial atmospheric ^{7}Li nuclei. According to standard models (Forestini 1994), at a given metallicity there is a mass range where ^{6}Li, but not ^{7}Li, is

destroyed. These models predict that no ^{6}Li can survive pre-MS mixing in metal-rich solar-type stars. The detection of ^{6}Li in HD82943 (Israelian et al. 2001, 2003) is convincing observational evidence that stars may accrete planetary material, or even entire planets, during their main sequence evolution. Other explanations of this phenomenon such as stellar flares or surface spots have been ruled out (Israelian et al. 2001). Sandquist et al. (2002) have recently proposed that ^{6}Li can be used to distinguish between different giant planet formation theories. Slow accretion of planetesimals was invoked in order to explain the [Fe/H] distribution in planet-harbouring stars. Murray & Chaboyer (2002) concluded that an average of 6.5$M_\oplus$ of iron must be added to the planet- harbouring stars in order to explain the mass–metallicity and age–metallicity relations. Accretion of 6.5 $M_\oplus$ of planetesimals of iron during early MS evolution will strongly modify ^{7}Li abundances in these stars. Moreover, given the depth of the convection zone in stars with Teff > 5900 K, a large amount of the added ^{6}Li may avoid destruction via mixing. Accretion of a chondritic matter with 6.5$M_\oplus$ of iron by a star with T_{eff}=6100 K and with a convection zone mass 10^{-3} $M_\odot$ will rise its ^{7}Li abundance from log N(Li)=2.7 to 3.2 while the isotopic ratio will become f(^{6}Li) = 0.06. This will create a detectable ^{6}Li absorption feature with an equivalent width (EW) ~4 mA. This feature can be measured even if it is blended with the line at 6708.025 A because the latter is expected to appear with an EW < 2 mA in these type of stars (no matter which kind of element/line is responsible for this absorption).

Santos et al. (2002, 2004c) derived beryllium abundances for a large sample of planet host and “single” stars aimed at studying in detail the effects of the presence of planets on the structure and evolution of the associated stars. Their preliminary results suggest that theoretical models may have to be revised for stars with Teff < 5500 K. Santos et al. (2002) found several Be depleted stars at 5200 K which current models cannot explain. A comparison between planet-hosting stars and “single” stars (although very few in their analysis) shows no clear difference between two populations.

Ecuvillon et al. (2007) presented detailed study on the kinematics of metal-rich stars with and without planets, and their relation to the Hyades, Sirius and Hercules dynamical streams in the solar neighbourhood. Accurate kinematics have been derived for all the stars belonging to the CORALIE planet search survey. They found that the planet-host targets show a kinematic behaviour similar to that of the metal-rich comparison subsample, rather than to that of the comparison sample as a whole, thus supporting a primordial origin for the metal excess observed in stars with known planetary companions. According to the scenarios proposed as an explanation for the dynamical streams, systems with giant planets could have formed more easily in metal-rich inner.

8. Strange worlds…

Many extrasolar planetary systems are abnormal in key cosmochemical ratios. Several systems are found to have C/O ratios at or above unity or Mg/Si ratios almost a factor of two higher than in our Solar System. If these ratios are primordial, established in the giant molecular cloud from which these systems subsequently formed, then the chemistry of the planet building material and ultimately any planets within these systems will be drastically different to that of our own Solar System. Dynamical simulations have shown that several systems contain a region of orbital space in which small mass bodies could potentially exist for long periods of time (e.g. Raymond and Barnes 2005; Asghari et al. 2004). Others have gone one step further and simulated actual terrestrial planet formation within these systems (e.g. Raymond et al. 2005; Mandell et al. 2007). Based on these simulations, terrestrial planets have been found to form in a wide variety of dynamical systems, indicating that they are indeed likely to exist in the majority of known extrasolar planetary systems. Raymond et al. (2006) has modeled terrestrial planet formation within specific systems and found that terrestrial planets could form in one of the systems simulated (55 Cancri), while small bodies comparable to asteroid sized objects would be stable in another (HD 38529). Studies have also suggested that a significant portion of these planets will reside in the habitable zone of their stellar system (Mandell et al., 2007).

However, no previous studies have considered the chemical composition of these potential planets. Given the wide variety of host star compositions observed, it is likely that terrestrial planets will display a similar variety of compositions. Of particular interest are those systems with exceptionally high C/O values. Such systems will contain C-based species such as SiC, TiC and graphite as the main planet forming material, therefore producing C-rich planets unlike anything we have previously observed. These variations will have drastic implications on a wide variety of planetary properties, including planetary processes (such as volcanism and tectonics), our ability to detect and observe extrasolar terrestrial planets and their ability to host life (as we currently know it). While the detection of a true Earth analog extrasolar terrestrial planet remains the main goal of extrasolar planetary searches, the potential diversity in planetary compositions is a fascinating aspect of planetary studies. For the first time, dynamical formation and chemical composition simulations have been undertaken for nine known extrasolar planetary systems, varying in both their dynamics and chemical compositions (Bond 2008).

9. Conclusions and Future Prospects

Doppler spectroscopy has reached neither its instrumental nor its astrophysical limits. Applying an adequate strategy on carefully selected targets could allow to average out stellar noise down to 10-20 cm s^{-1} on short and intermediate time scales for some dozens of stars. The next generation of HARPS-type instruments aiming at a Doppler

precision of 10-20 cms^{-1} (HARPS-North in La Palma, the VLT-ESPRESSO project) should therefore be able to detect Earth-mass planets in short-period orbits, and to characterize some of these planets up to periods of ∼1 year. Ultra-stable spectrographs aiming at a Doppler precision of 1 cm s−1 should be technically feasible. If stellar noise permits, such instruments would allow the detection and the precise characterization of Earth twins. CODEX on E-ELT will be the natural progression towards ultra-stable high precision spectroscopy, which so successfully started with HARPS for 4m class telescopes and will hopefully soon reach the 10m class with ESPRESSO. Due to the impressive progress in calibration techniques based on recent advances in laser technology like the Laser Frequency Comb, ESPRESSO should reach a Doppler precision of 10 cm/s with resolving power R>150 000 at one UT for relatively bright objects, and 1 m/s with R∼40 000 in the 4-UT mode for fainter objects. CODEX is designed to be in a class of its own in this respect and should reach 2 cm/s with a goal of 1 cm/s. CODEX will thereby be nevertheless optimized for throughput and thus be more efficient than *e.g.* UVES despite its ambitious precision and stability goals..

The observations discussed in this review provide a large and growing database with which planet formation theories can be tested. By combining observed properties of protoplanetary disks, models of planet formation and evolution, and observational selection effects, theorists now generate in a self-consistent way synthetic planet populations, which can be compared with observations. Recent models based on the core accretion idea successfully reproduce two important observational features: the mass distribution and the planet metallicity correlation. Although much remains to be understood about planet formation, these new theoretical achievements reinforce the idea that most of the known planets formed through core accretion. To progress in our understanding of planet formation and to appreciate the significance of our Earth, we must detect a wide range of planetary systems, including planets and host stars both similar and dissimilar to our own. Much work needs to be done in next 1-2 decades to detect the population of Earth-twins. However, it seems we have reached now the "know how" phase of this long road.

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Variation of Embedding Dimension as one of the Chaotic Characteristics of Solar and Geomagnetic Activity Indices

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Abstract. Solar and geomagnetic activity as one of the natural chaotic systems has unavoidable effects on earth, climate, satellites and space missions. Space weather is a term which generally refers to the dynamic, highly variable conditions in the geospace environment. This includes conditions on the sun, in the interplanetary medium, and in the magnetosphere-ionosphere-thermosphere system. Rapid changes in the near-Earth space environment can affect the performance and reliability of both spacecraft and ground-based systems. This can imply major problems due to communication, navigation, and reconnaissance satellite operational anomalies. One of the most important tools for eliciting the chaotic trends is the "Embedding Dimension". In this paper, the variation of Embedding Dimension for solar and geomagnetic activity indices especially during a well-known Coronal Mass Ejection (CME) is considered. This storm is the major magnetic storm on 13 March 1989, which shuts down the power supply system in Quebec, Canada. The method of this paper is based on the fact that the reconstructed dynamics of an attractor should be a smooth map, i.e. with no self intersection in the reconstructed attractor. It is shown that the Embedding Dimension (and other chaotic characteristics) of some solar and geomagnetic activity indices during these storms vary rapidly.

Keywords: Space weather, chaos, embedding dimension, one step ahead prediction error, solar activity indices, geomagnetic activity indices.

1. Introduction

"Space weather", concerns the daily varying space plasmas of the Sun, the Earth and their vicinity. We are living in the vicinity of a star, the Sun. Recently, there has been so much progress made in solar hot plasma eruptions, Earth geomagnetic storms and sub-storms, and solar-geomagnetic connections that the time is now ripe to put all related and global aspects together into a field of space weather. On the other hand, technological progress in 21st century has made human life increasingly dependent on satellites. There has been a rapidly increasing reliance on spacecraft systems to meet modern human needs for information transfer and remote sensing (Baker, 2000). As human presence in space is in an explosive phase, it is expected that the impact of these effects will be quite significant in this and the next few solar cycles (Vassilidiadis, 2000; Mirmomeni, et al., 2006; mirmomeni et al., 2007). In addition, modern satellite systems and subsystems appear to show an increasing susceptibility to effects of the space weather (Baker, 2000). In other words, space weather is a phenomenon which is caused by radiation and atomic particles emitted by the sun and the stars. It not only affects the functioning of technical systems in space and on Earth, but may also endanger human health and life (Hill et al., 2000; Carlowicz, Lopez, 2002). The effects of this phenomenon are many and varied: they include electronic failures (Dorman, 2005; Love et al., 2000), immediate and long term hazards to astronauts and aircraft crews (Garrett and Hoffman, 2000; Jokiaho, 2004; Defise et al., 2005), changes in electrostatic charging of satellites (Lai, 1996; Lai, 1999; Baker, 2000), interruptions in telecommunications and navigational systems (Boteler, et al., 1998; Stanislawska, 2003; Kikuchi, 2003), and power transmission failures (Kappenman, 1999; Pirjola, 2000; Daglis et al., 2004) and disruption to rail traffic (Label and Barth, 2000; Pirjola, 2003). Space weather is thus a lot more than the impressive auroras at high latitudes, with which we are all familiar and risk hazards due to space weather exotic phenomena pose serious threat motivating rapid search for accurate analyzing, modeling, and prediction methods (Turner, 2000; Bothmer, 2004). Among the various conditions that affect space weather, the sun-driven phenomena dominate the others. Origin of many space weather changes is the solar activity which varies in an almost eleven year period, called solar cycle. The solar cycle consists of a period of activity, the solar maximum, and a period of quiet, the solar minimum.

It is shown that the cyclic solar activity has chaotic characteristics especially during storm time which depicts the difficulties in long-term prediction of solar activity indices (Stefanski, 2000;

Gholipour et al., 2006; Mirmomeni et al., 2007). It has to be said that, deterministic chaos appears in different fields of science like physics, biomedical, and engineering (Kocarev et al., 2006; Ruelle, 1978). The main idea of chaotic time series analysis is that a complex system can be described by a strange attractor in the phase space (Mirmomeni, Lucas, 2007). The first step of chaotic time series analysis is the reconstruction of the equivalent attractor's state space. State space reconstruction can be described by embedding the time series in a vector space. The embedding theorem is proposed by Takens (Taken, 1981; Sauer et al., 1991). However, it has to be said that Takens' theorem is valid for indefinite noise free data only and does not address the calculation of embedding dimension and lag time. In addition, it is of little practical relevance since it suggests a sufficient condition based on the dimension of the attractor's manifold, which is not known a priori. There are many publications concerning the estimation of suitable embedding dimension from chaotic time series. They can be summarized in three main categories as follow.

The first approach is based on the fact that the original attractor lies on a smooth manifold. This condition is checked by different methods by many researchers. The most famous work seems to be the method of False Nearest Neighbours (FNN) developed in (Kennel et al., 1992). The second approach for estimating the embedding dimension is based on Singular Value Decomposition (SVD) which is proposed in (Broomhead and King, 1986; Cao, 1997). The main idea of this approach is to obtain a base for the embedding space in such a way that the attractor can be modelled by an invariant geometry in a subspace with fixed dimension. It has to be said that, many researchers doubt in the quality of this method in eliciting the characteristics of nonlinear time series because the SVD essentially is a linear approach with firm theoretic base. (Mess et al., 1987; Fraser, 1989; Bian and Ning, 2004; and Meng et al., 2007). The third approach is based on considering an invariant on the attractor such as correlation dimension (Grassberger, and Procaccia, 1983), successive values of embedding dimension and convergent values. The typical problems of this method are its computation time, its poor performance for short time series, and its sensitivity to noise (Meng et al., 2007).

In this paper, it is tried to elicit the chaotic trends of solar and geomagnetic activity indices especially during storm time. Eliciting the variation of chaotic trends is the first step for modeling such complex and chaotic phenomena. To achieve this, there are some quantitative measures included fractal dimension, entropy and Lyapunov exponents (LEs) (Sano, M, Sawada, 1985; Chen et al., 2006; Liu et al., 2006; and Serletis et al., 2007).

In this paper, the variation of embedding dimension from some solar activity indices especially during storm time based on polynomial models is considered. This method has been used in many applications by several researchers for example in (Ataei et al., 2003; Ataei et al., 2004; Bian and Ning, 2004; and Meng et al., 2007) and the

performance of this method in estimating the optimal embedding dimension even for noisy chaotic dynamics is great (Meng et al., 2007). In addition, this method is applicable to short time series as well and its performance for estimating embedding dimension of noisy chaotic dynamic is good (Bian and Ning, 2004; and Meng et al., 2007). In this method a general polynomial autoregressive model (Landau et al., 1989; Isermann, 1991; Ljung, 1998; and Nelles, 2001), is considered to locally fit the given data. The order of this model is the same as the dimension of the reconstructed state space. The reconstructed dynamics should be a smooth map, i.e. with no self-intersection in the reconstructed attractor. This property is checked by the evaluation of the one step ahead prediction error of the fitted model for different orders and various degrees of nonlinearity in the polynomials. The minimum embedding dimension is determined as the order with which the level of the prediction error decreases abruptly. It is shown that this approach has the capability of adaptively computing embedding dimension of uncertain or time varying chaotic dynamical systems (Ataei et al., 2004). Therefore, it is useful to apply this adaptive estimation method to elicit the variation of ED for some solar activity indices. To show the variation of ED of solar activity indices, a well-known storm is considered. This storm occurred on 13 March 1989 which causes a black out about nine hours in Quebec, Canada. In this paper, ED of a solar activity and a geomagnetic activity index is estimated via proposed adaptive approach: Sunspot number and Disturbance Storm Time (Dst). It is shown that the embedding dimension (and chaotic characteristics) of these solar and geomagnetic activity indices during these storms vary rapidly. The remaining sections of this paper are structured as follows: the main idea of the method for estimating the minimum embedding dimension is presented in Section 2. Model based procedure for estimation of the embedding dimension is presented in Section 3. Section 4 is devoted to describe the performance of the proposed method in eliciting the variation of chaotic characteristics of solar activity indices especially during storm time by estimating minimum embedding dimension of solar activity indices. The last section contains the concluding remarks.

2. Model based estimation of the embedding dimension

In this section, the basic idea and the procedure of the model based method for estimating the embedding dimension is presented. Let the original attractor of the system exists in an *m*-dimensional smooth manifold, *M*. The dynamical behavior of the system is not known a priori and only a sequence of measurements is available as follows,

$$y(t + t_s), y(t + 2t_s), \ldots, y(t + Nt_s) = y_i, y_2, \ldots, y_N \qquad (1)$$

where t_s is the sampling time and *Nis* the total number of measurement.

An embedding is a smooth map from the manifold Mto space *Um* such a way that its image be a smooth sub-manifold of *U*. It has to be said that this map is a

diffeomorphism between *M* and its image. By using *Method of Delays,* which is based on Takens' theorem, the embedding space is reconstructed by *d* (greater than *2m)* sequential values of measurements as:

$$[y(k-(d-l)_n.t_s),y(k-(d-2)_n.t_s),...,y(k-n.t_s),y(k)] \qquad (2)$$

where $n.t_s$ is the lag time and the dimension of the reconstructed space, *d* is called the embedding dimension (its optimal value is looked for).

The attractor of the well reconstructed phase space is equivalent to the original attractor and should be expressed as a smooth map. The state equations of the reconstructed dynamics are considered as:

$$x\_\{k+l)=f\_(x\_(k)) \qquad (3)$$

where /_(.) is a continuously differentiable function to the state vector *x(k).* In many practical situations, the structure of the underlying dynamical system is unknown. Depending on the objectives, there are different theories which are suitable for special analysis of nonlinear systems. In this paper, in order to model the reconstructed state space, the vector (2) after normalization, is considered as the state vectors.

$$\underline{x}(k)=\begin{bmatrix} x_1(k) \\ x_2(k) \\ \vdots \\ x_d(k) \end{bmatrix}=\begin{bmatrix} y(k-(d-1)) \\ y(k-(d-2)) \\ \vdots \\ y(k) \end{bmatrix} \qquad (4)$$

To derive the state equations, a function *g(.)* is estimated by polynomial modeling as follows:

$$y(k+\backslash) = g(x\_(k)) \qquad (5)$$

A canonical state space representation of the system is obtained as follows:

$$\underline{x}(k+1)=\begin{bmatrix} y(k-d+2) \\ y(k-d+3) \\ \vdots \\ y(k+1) \end{bmatrix}=\begin{bmatrix} x_2(k) \\ x_3(k) \\ \vdots \\ g(\underline{x}(k)) \end{bmatrix} \qquad (6)$$

Thus, the order of polynomial model *g(.)* will also be *d*. Therefore, the optimal embedding dimension and the suitable order of the polynomial model have the same value.

3. Model based procedure for estimation of the embedding dimension

The procedure for estimation of the embedding dimension of chaotic time series consists of 7 steps as follows:

1. The first step is devoted to preprocessing. The data has to be normalized. In addition, long-term trends or seasonal effects have to be omitted in this step.
2. Some definite ranges for embedding dimension and degree of nonlinearity of the polynomial models have to be chosen such as

$$D = \{1, 2, \ldots, d_{\max}\}, \quad N_p = \{1, 2, \ldots, n_{\max}\} \tag{7}$$

3. For each $d_i \in D$ construct the delayed vector as

$$\underline{x}(k) = \begin{bmatrix} y(k-(d_i-1)) \\ y(k-(d_i-2)) \\ \vdots \\ y(k) \end{bmatrix} \tag{8}$$

For each delayed vector (8), find r nearest neighbors which r should be greater than m as defined in (10) (Ataei et al., 2003; Ataei et al., 2004).

The following polynomial autoregressive model (Isermann, 1991; Ljung, 1998) is fitted to the set of neighbors found in the last step by well-known Least Square (LS) technique (Isermann, 1991; Ljung, 1998; andNelles, 2001).

$$\begin{aligned} y(k+1) = \theta_0 &+ \sum_{i=0} \theta_{1i} y(k-i) + \sum_{i=0} \sum_{j=i} \theta_{2ij} y(k-i) y(k-j) + \sum_{i=0} \sum_{j=i} \sum_{p=j} \theta_{3ijp} y(k-i) y(k-j) y(k-p) \\ &\cdots + \sum_{i=0}^{d_i-1} \sum_{j=i}^{d_i-1} \cdots \sum_{v=u}^{d_i-1} \theta_{n,ijp\cdots uv} y(k-i) y(k-j) y(k-u) y(k-v) \end{aligned} \tag{9}$$

The initial values of parameters in vector 0 which should be tuned by least square technique are chosen randomly. For the model order d_t and degree of nonlinearity n the number of parameters in vector 0 that should be estimated to identify the underlying model is:6. The mean square of prediction errors is computed as:

$$\sigma = \sqrt{\frac{1}{N} \sum_{k=1}^{N} e_k^2} = \sqrt{\frac{1}{N} \sum_{k=1}^{N} \left(\hat{x}(k) - x(k)\right)^2} \tag{11}$$

where N is the total number of points and e_k is the one step ahead prediction error.

7. The one step ahead prediction error should be calculated for all embedding dimension and degree of nonlinearity of the polynomial models by above procedure (the full range

of *D* and *Np).* The value of *d* which the level of *o* is reduced to a low value and will stay thereafter is considered as the minimum embedding dimension.

As it said before, this method presented in this paper has the following advantages, it is (1) applicable to a short time series, (2) stable to noise, (3) computationally efficient (typically, the analysis of a 500-point time series takes just a few seconds on a desktop computer), and (4) without any purposely introduced parameters (Bian and Ning, 2004; Meng et al., 2007).

4. Analysis

This Section is devoted to elicit the variation of embedding dimension of some solar activity indices such as sunspot number (SSN) as a good measure of solar activity and disturbance storm time (Dst.) as an important measure for predicting magnetic storms. The well-known storm that is considered in this section is a major magnetic storm on 13 March 1989 which causes a nine hours black out in Quebec, Canada. The solar and geomagnetic activity indices are used from "OMNI 2" data set contains the hourly mean values of the interplanetary magnetic field (IMF) and solar wind plasma parameters measured by various spacecraft near the Earth's orbit, as well as geomagnetic and solar activity indices, and energetic proton fluxes. This data set was created at NSSDC in 2003 as a successor to the OMNI data set first created in the mid-1970's. A detailed discussion of the creation OMNI 2 is at http://nssdc.gsfc.nasa.gov/omniweb/. The proposed method for estimating the embedding dimension or suitable order of model based on local polynomial modeling is implemented to these solar activity indices as some chaotic time series. For these time series, the developed general program of polynomial modeling is applied for various *d* and «, and *o* is computed for all the cases in a look up table. After that, based on the discussions in sections 2 and 3, the optimum embedding dimension is selected for these time series in each step.

Fig. 1 shows the daily average of Dst. index during 1989. The drop off during March depicts the major magnetic storm which caused the black out in Quebec.

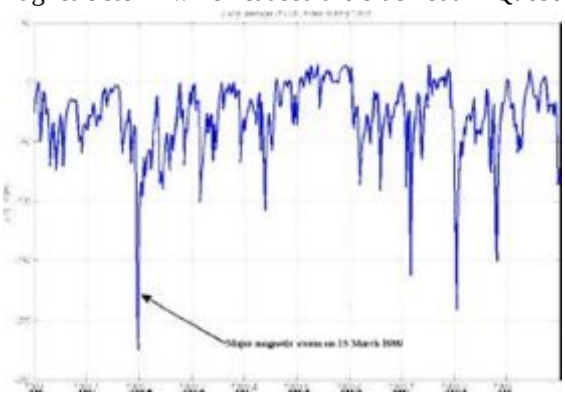

Fig. 1. Daily average of Dst. index during 1989.

Fig. 2 shows the variation of the minimum embedding dimension of Dst. index during 1988 and 1989. It is obvious that the variation of ED is large and there is an obvious pattern before storm beginning. Fig. 3 shows the variation of the one step ahead prediction error calculated for the estimated embedding dimension and degree of nonlinearity of the polynomial models by above procedure during storm on March 1989. It is obvious that the one step ahead prediction error increases rapidly before storm and during the storm time.

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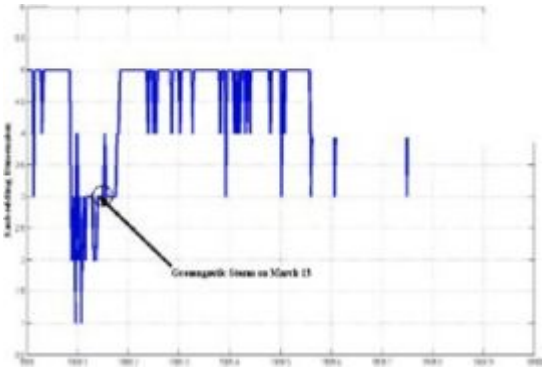

Fig. 2. Variation of the minimum embedding dimension of Dst. index during 1989.

Again, for SSN Index, the developed general program of polynomial modeling is applied to estimate the minimum embedding dimension of this chaotic dynamic. Fig. 4 shows the hourly SSN index during 1989. It is obvious that during major magnetic storm which caused the black out in Quebec, the sunspot number index is high.

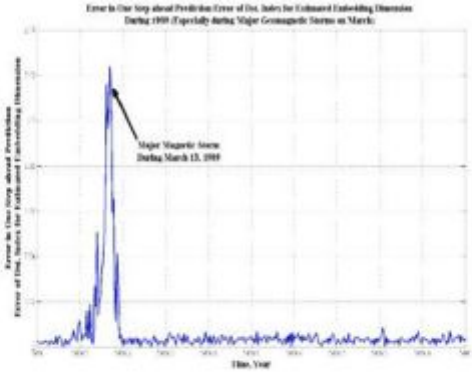

Fig. 3. Variation of one step ahead prediction error calculated for the estimated embedding dimension and degree of nonlinearity of the polynomial models of Dst. index during storm on March 1989. Daily Sunspot Number during 1989.

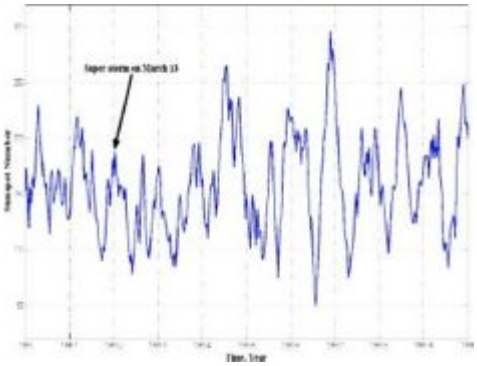

Fig. 4. Daily average SSN index during 1989.

Fig. 5 shows the variation of the ED of SSN index during 1988 and 1989. It is obvious that the variation of ED is not as large as the variation of ED of Dst. index but it has to be said that there is an obvious pattern before storm beginning for this index too. Fig. 6 shows the variation of the one step ahead prediction error for estimated embedding dimension of SSN index during storm on March 1989. It is obvious that the one step ahead error increases rapidly during this storm. In addition, it seems that there were some sub-storms in late 1989 and the sun was active during that period.

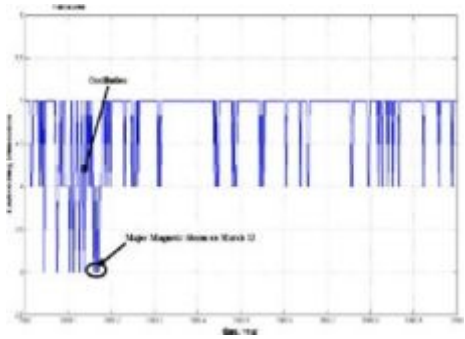

Fig. 5. Variation of the minimum embedding dimension of SSN index in 1988 & 1989.

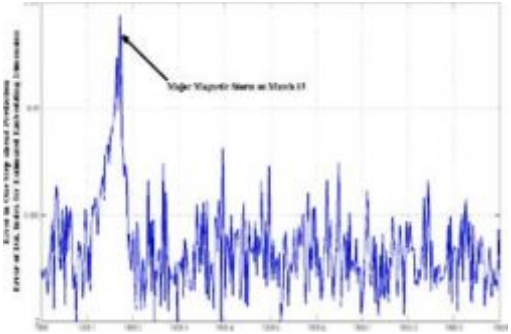

Fig. 6. Variation of one step ahead prediction error calculated for the estimated embedding dimension and degree of nonlinearity of the polynomial models of SSN index during storm on March 1989.

5. Discussion and Conclusions

In this paper, it is tried to elicit the variation of chaotic trends of solar and geomagnetic activity indices such as sunspot number and Dst. indices during storm time by estimating the minimum embedding dimension via an improved estimation method based on polynomial modelling. A well-known storm is considered in this paper: the major magnetic storm which caused the nine hours black out in Quebec, Canada on 13 March 1989. Analysis depicts the variation of ED of these solar activity indices during these storms. The ED of these solar activity indices begins to vary in such a way that an obvious pattern can be detected about 10 steps sooner before storm begins. Therefore, it is meaningful to use the variation of ED for alarming systems against space weather hazards.

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Power of imaging surveys: Scientific goals of the reconstruction of 1-m Byurakan Schmidt Telescope

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Abstract. Surveys performed with Schmidt telescopes had a great impact on the development of astronomy. Basic idea of 1m reconstruction – to continue Markarian's method of SED AGN classification, extrapolating it on deeper magnitude limits and wider redshift range using modern CCD detector and classification software. To realize this we plan to install a 4k x 4k CCD detector in telescope focus and equip it with 18 medium-band filters ~ 300 A FWHM. Filters will homogeneously cover entire optical spectral range from 3300 - 10000 AA. Methodically we plan to reach ABmag=23m with S/N~10 in 30-40 min in medium-band filters in UV and near the peak of detector quantum efficiency and in 160-180 min for near infrared filters.

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Jean-Claude Pecker and Elma Parsamian

Jayant Narlikar and Yervant Terzian summarizing the meeting results

Georges Alecian, Arthur Nikoghossian and Armen Gyulbudaghian

At the meeting: Jayant Narlikar making comments

Ruben Ambartsumian and Areg Mickaelian

Artashes Petrosian and Norair Melikian

Nina Ivanova and Rolan Kiladze

Meeting banquet at the Byurakan Observatory garden

Jean-Claude Pecker with the registration team

AUTHOR INDEX