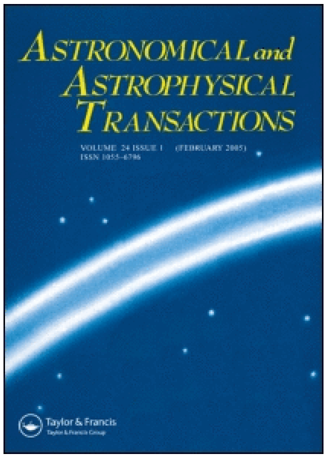

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RESEARCH ON DIFFUSE NEBULAE AND INTERSTELLAR MATTER

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The history and the results of an investigation on diffuse nebulae and the stars connected with them obtained at the Fessenkov Astrophysical Institute are given briefly.

Keywords: Reflection, diffuse nebulae, stars connected with nebulae

1 INTRODUCTION

At the end of 1950 at the observatory of the Astrophysical Institute of the Academy of Sciences of Kazakh SSR, photographic observations using a new 50 cm those times large light-gathering power (1 : 2.4) Maksutov telescope, which at that time had a high light-gathering power (Rozhkovskij, 1955) commenced. The instruments optics enabled excellent photographic images of stars with a field of view of 25 deg^2 to be received. The successful design of the instrument, developed by B.K. Ionissiani at the State Optical Institute of the Academy of Sciences of USSR, and the favourable astronomical conditions in the Zailijskoe Alatau foothills provided astronomers at the Astrophysical Institute and other astronomical establishments of the country with an opportunity to carry out many new observations and research on various astronomical objects. So, for the last few decades, astronomers at the Astrophysical Institute have created a unique collection of photographs (more than 7000) of nebulae, comets, clusters of stars and other objects obtained with various filters, frequently with exposures of an hour or longer. Also, for quantitative estimations of object brightness and definitions of stellar magnitudes the collection contains a few hundred auxiliary photographs. In total, this collection represents an original history of astronomical events in the sky above Zailijskoe Alatau for the past few decades.

It is necessary to mention that, at the beginning of this history (i.e. 50 years ago), the new telescope for the first time gave astronomers (and not only those at Kazakhstan) the opportunity to study the structure and physical properties of diffuse galactic nebulae. These objects had previously been almost inaccessible for observations. The excellent optics of the telescope allowed photographs of these gas and dust clouds to be obtained with many details

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of filamentary structure, inclusions absorbing light (e.g. globules and channels) and light fringes; sometimes these images were incredibly detailed. At this time, not much was known about the physical and dynamic processes behind this variety of structures. This motivated astronomers at the Astrophysical Institute to observe and study the physical processes in nebulae for many years. This was based on the ideas and guidance of the academician V. G. Fessenkov (1951, 1955), who shared a constant interest in the problems of the origin and evolution of celestial objects, and in particular the problems of star formation.

In the first 50 years of the Astrophysical Institute, the available data testified that many hundreds of emission nebulae are the origin of young O–BO stars. The research by Shajn *et al.* (1954) allowed them to conclude that because of the mass and gas-and-dust composition of nebulae, they are a suitable medium for the formation of stars. The idea suggested by V. A. Ambarzumian that stellar associations undoubtedly resulted in the group formation of stars, in our Galaxy. These and many other data caused Fessenkov to propose the idea that nebulae are recent (on a space–time scale) centres of star formation from initial diffuse gas-and-dust matter. It was supposed that the stars formed or their groups can be found as a result of their connection with features of the structural details of nebulae (Fessenkov, 1951).

The problem required many photographs to be obtained with various structures of the nebulae using different filters and other auxiliary snapshots, allowing a quantitative estimate of the brightness of the objects and the nearest stars up to magnitude 18. It is impossible to count the number of silent hours, usually in the evening that Fessenkov devoted to the analysis of the sets of photographs, assessing and sketching the most interesting details. He constantly checked and specified the reliability of the most detailed picture of the structural phenomena and the features showing the complexity and variety of the physical factors acting on the gas-and-dust matter of objects.

At that time for the astronomers of the world a diffuse galactic nebulae looked like the original *terra incognito* with respect to a number of the physical properties. Therefore many outstanding astronomers (B. Bok, G. A. Shajn, O. Struve, A. Tackerey, etc.) studied their photographs in a search for the key to understanding the physical factors responsible for the glow and structure of objects. Fessenkov succeeded in transferring to his employees his own passion for similar problems. So, at the Astrophysical Institute a small group of the astronomers specializing in the field of physics of nebulae and interstellar matter and in adjacent domains of astrophysics was created.

2 THE INVESTIGATION OF THE DIFFUSE AND REFLECTION NEBULAE

In 1951 on the basis of study of a number of nebulae, Fessenkov and Rozhkovskij noted the formation of stars from nebulae by disintegration of their dense filamentary structures into lumps of gas and dust matter. These lumps under favourable physical and dynamic conditions can further be condensed into a star state, forming young stars. In this way in some nebulae rows or a chains of stars arise, which reproduce the form of their primogenitor: a filament of nebula. Fessenkov and his co-workers published a number of papers on the basis of their observations of this phenomenon giving many reasons (Fessenkov, 1955) for it.

At the beginning of 1951, studying structures known to be filamentary nebulae in the Cygnus constellation (Loop Nebula), Fessenkov and Rozhkovskij found evidence of this mechanism of the formation of stars in the number of star chains that were undoubtedly spatially associated with filaments of nebulae. From photometric research the fact that stars belong to the yellow subgiants was established. These observations and their interpretation have attracted great interest from both domestic and foreign astronomers. These data became the subject of intense discussion, during which all the observed data and the various theoretical situations from the fields of star evolution and cosmogony, and in particular the well-known Jeans criterion about the gravitational collapse of fragments of primary matter of gas-and-dust filaments were considered. A detailed and interesting discussion of all these questions was given by Fessenkov (1956).

In 1953 with the assistance of the Astrophysical Institute of the USSR Academy of Sciences the *Atlas of Gas and Dust Nebulae* (Fessenkov and Rozhkovskij, 1953), containing many photographs of nebulae and separate photographs of interesting details.

The photographs obtained in two spectral ranges opened up a panorama of structures of objects formed by a radiating ionized gas and simultaneously allowed the dust scattering of the light of stars to be revealed. In the *Atlas* it is possible also to see nebulae for the first time obtained by Shajn *et al.* (1954). Generalized sketches of the very fine details of several photographs were drawn by Fessenkov. The Atlas certainly contained information which was new and useful to astronomers, together with references available in the literature. Simultaneously it stimulated interest in the study of nebulae. Also it illustrated the high quality of the Maksutov optical system and promoted development and production of astronomical optics.

In the 1950s and the next few decades, observers, using a Maksutov telescope, developed and improved the application of various methods of observations. They also designed new instruments and devices, which were necessary to perform scientific tasks and to organize observations within the framework of the All-Union programmes (photographing many regions of the sky to search for asteroids lost in military years, to carry out astrometry and photometry of the artificial Earth satellites, etc.). For example, in 1954 the Maksutov telescope began to be applied to the study of the polarizing properties of nebulae. The technique of polarimetric observations was constantly improved and subsequently been used in the automatic polarigraph, allowing various programmes of photographic polarimetric observations to be realized.

The complex of reflection nebulae were of interest to photometric polarimetric observations and necessary to reach some statistical conclusions; the formation of the reflection nebulae in the Galaxy was attributed to a causal arrangement of stars (nuclei of nebulae) near dust clouds. The luminescence, structure and other properties of 120 reflection nebulae, and their relation to objects with isolated absorbing clouds of the Galaxy, were studied on the basis of photographic observations using a Maksutov telescope. A set of phenomena indicating a physical and, perhaps, genetic connection between the nuclei of nebulae and the afore-mentioned clouds was revealed. However, the fact that nuclei belong to the certain clouds that absorb light in a not haphazard way was confirmed by observations of interstellar polarization of many nuclei with a 1 m telescope. Phenomena indicating the influence of local magetic fields on the polarizing properties of nuclei and the structure of clouds were found. A list of reflection nebulae (Rozhkovskij and Kurchakov, 1968) was published in which many new data for more than hundred objects were given. The obvious tendency of nebulae to unite and to form separate groups, probably connected with the general formation with many other young objects gravitating to absorbing clouds was pointed out (Rozhkovskij, 1960; Pavlova, 1990).

Probably, for the first time in the USSR the present author successfully applied a Monte Carlo method for modelling the process of radiation transfer in spherical nebulae, illuminated by single stars (or their set) and located in a field of isotropic radiation (Kurchakov and Matjagin, 1968; Kurchakov, 1970).

From observations of reflection nebulae and the luminescence of high-latitude clouds of interstellar matter the average values of interstellar grains were determined to be less than of the order of 10^{-5} cm. From similar observations and model calculations, completely independent estimations of the albedo values of dust grains is important for the physics of interstellar matter. It was established that their values were obtained, which were less than 0.7 and, most likely, are in the range 0.4–0.6. These data are consistent with the results of other albedo switching extra-atmospheric definitions published by Kurchakov (1966), Rozhkovskij and Kurchakov (1968), Rozhkovskij (1971) and Desert *et al.* (1990). At high-mountain stations of the Astrophysical Institute (Coronal and Assy) surface photometry of an extensive Milky Way strip (Zavarzin, 1975) was performed using a high-speed electrophotometer. The importance of similar observations in research on space and geophysical glows of the night sky is well known. Data on the high-mountain observations were utilized in various model computer calculations approximating the property of a common field of diffuse radiation of the Galaxy and its local sources in the form of clouds (Rozhkovskij, 1969; Matjagin and Rozhkovskij, 1972; Rozhkovskij and Matjagin, 1972; Rozhkovskij and Gabdullin, 1979). Alongside the photometry, the polarizing properties of nebulae were studied also. The first experiments have shown how polarimetry can be used to determine the presence of dust in nebulae such as (C+E), the spectral properties and the nature of primary light sources scattered by internal dust (Rozhkovskij, 1955; Dzhakusheva, 1971, 1979; Dzhakusheva and Gabdullin, 1978; Rozhkovskij *et al.*, 1962).

Original pictures of the glow of the Orion, Horseshoe and Trifid Nebulae were obtained from detailed filter observations of brightness and polarization of many areas of these objects containing internal dust. The observable glow of areas included the recombination glow of gas weakened by dust and scattered and partially polarized by a dust, the recombination glow of total gas nebula and, finally the light of the central star that had been scattered and partially polarized by a dust. These features are most typical for the Orion Nebula, in which, from Astrophysical Institute observations, the internal dust in the areas is capable (up to 30%) of polarizing the radiation in the Hα line (Dzhakusheva and Gabdullin, 1978). The study of physical processes in such objects is a difficult task, which follows from the extensive literature devoted to the properties nebulae and the interpretation of properties by various models.

In a number of Astrophysical Institute studies, some methods of quantitative estimations of the contents and properties of dust in reflection and emission nebulae are considered. It is established that a considerable number of objects is seen in the structure, which at least, do not contradict using the spatial model consisting of spheres containing a homogeneous astmosphere and luminous ionized gas for the observed data. Such simplifications are natural from the viewpoint of real features of investigated objects. Taking into account multiple scattering, diagrams and highly simple analytical ratios connecting the observable integrated brightness to the properties of light scattering by grains, optical depth and albedo of dust atmosphere are obtained in this way, quantitative data for the dust contents in young emission nebulae were determined in agreement with other published studies of internal dust based on application of modern observation facilities (Fessenkov, 1955; Rozhkovskij, 1962, 1989, 1990).

In the 1970s, observations of stars in reflection nebulae were carried out in two parallel directions by spectrophotometry and electropolarimetry. To define the status of the nuclei reflection nebulae, which at the time was not absolutely clear, their continuum spectrum was investigated. On the basis of many observations obtained with Maksutov telescopes with objective prisms, in the observatories at Alma-Ata and Abastumani, the following results were noted. Firstly, in the spectra of stars of reflection nebulae, attributes related to different spectral subclasses were found. This is also characteristic for young stars, which are included into the list of nuclei of reflection nebulae. Secondly, features in the energy distribution of continuum spectra of nuclei of reflection nebulae can be attributed to the variation in local interstellar absorption, which is caused by the properties of the dust of the cloud, in which the reflection nebulae are located. For eight areas of reflections associations the average curve of selective interstellar absorption were determined in the wavelength range 3700–6700 Å. As a whole, the absorption curves are close to the average curve of interstellar absorption; however, in a number of cases there is a deviation from it connected with the specific properties of the dust near the forming objects (Pavlova, 1977). Polarimetric research on reflection nebulae at the Institute for a long time was mainly centred on photographic methods. The first observations were performed to find out the nature of filamentary nebulae. The data on interstellar polarization available at that time satisfied well models of aligned particles oriented by a magnetic field in such a manner that the large axis of particles was perpendicular to the magnetic force lines. However, the role of magnetic fields in the formation of the stretched nebulae structures was not clear. The first photographic observations of nebulae polarization and theoretical calculations have shown that the standard Davis–Greenstein mechanism was not sensitive enough both for orientation of the particles and for geometrical location of filaments relative to an illuminating star (Kurchakov, 1967). More acceptable for this purpose were the observations of polarization of star radiation, where light passes through filaments. Such observations were possible, when in the 1970s the AZT-8 telescope was equipped with an electrophotometer–polarimeter. Observations of a number of reflection nebulae stars with a filamentary structure have shown that in such cases, when the filamentary structure of nebulae has a regular character, there is a precise connection between the plane of polarization of the star's light and the direction of filaments. By using a model of the aligned particles and the Davis–Greenstein orientation mechanism, this is direct proof that the particles are oriented along the large axes perpendicular to filaments (Kurchkov, 1973). As a result it became clear that the research on the polarization of the radiation of stars in nebulae and dark clouds can give information about magnetic fields. In the 1980s the observations were continued on the Assy–Turgen plateau where the 1 m Zeiss telescope became operational. At this time the electropolarimeter had become advanced and was automated with the help of the Planet-3 computer (Kurchakov and Rspaev, 1985). 75 stars in reflection associations were measured within the framework of star research in dark clouds. These data were used to establish a correlation between the orientation of the polarization plane and the different scale structures of interstellar matter. The colour parameters of polarization allowed the properties of grains to be defined more precisely. The method of polarizing maps, where the directions of matter structures and the orientation of the polarization vectors of star radiation are identified, allows the local magnetic fields to be allocated (Pavlova and Rspaev, 1986; Pavlova, 1987). Data on our observations of the polarization of star radiation and data from other catalogues were used to define 'intrinsic' polarization of young stars to study the magnetic fields in star envelopes. As an example, for 14 stars, it was shown that the orientation of intrinsic polarization is connected to the plane of a disc envelope or with a jet direction. The variability of the observed polarization depends on the different contributions to the radiation of two orthogonal structures: disc and a jet. The wave dependence $P(\lambda)$ specifies which has the greater influence on dust matter, a disc or a gas in a jet.

3 RESEARCH ON SPECTRA OF EMISSION NEBULAE

Spectral observations of diffuse nebulae were possible after installation at the Astrophysical Institute of the AZT-8 telescope, equipped with a spectrograph designed by E. K. Denissyjuk. The first review of 98 diffuse nebula spectra was published in 1972 (Glushkov *et al.*, 1972). For the majority of nebulae the relative intensities of lines were obtained, and for some the intensity of the Hα line in absolute units for the central area was determined. Furthermore this review formed the basis for research on other separate interesting objects.

In subsequent years this research proceeded actively; more than 2000 spectra for 150 various nebulae were obtained, and some general relationships in the spectra of nebulae were revealed, exciting stars of which have the spectral classes B2–O5. It is found that the H II zones can be confidently allocated in nebulae, if the spectral class (Sp) of a exciting star is no later than B2.5. These studies allowed the criterion of Sp estimation of stars to be established, using the intensity ratios of emission lines, which is especially important for nebulae, in which absorption is high. Therefore the detection of and research on exciting stars in an optical range are practically impossible.

For a number of nebulae the dependence of the electronic temperatures (T_e) on the ratio of the Hα line intensity to the [N II] line intensity were determined. It appeared that T_e of nebulae with a large dust content are approximately 1000 degree below the electronic temperature of nebulae with a weak continnum spectrum at same Sp of the exciting star. For a number of nebulae the dependence of the electronic density (N_e) on the ratio of line intensities of the [S II] doublet were determined, and also the value of the absolute flow in the Hα line. It is found that in many cases N_e ([S II]) exceeds by a factor of 5–10 N_e value found for the Hα line, which provides evidence about the high nebula narrowness. The most important result of nebulae spectrophotometry is the detection of compact H II areas in the optical range (Glushkov, 1995). For the period 1971–1989, 21 compact area were found; their nature was further confirmed by infrared (IR) and radio observations. One of the most interesting results of this research was spectral observations of S106 (M1-19) nebula (Karjagina and Glushkov, 1971). The small nebula (about 1$'$.5) (one of the most interesting areas of star formation) was investigated in detail in the optical, IR and radio ranges. It was established that the nebula is connected with a huge molecular cloud and two maser sources. The exciting star is characterized by unusually large absorption A_V of magnitude 21, is surrounded by a powerful molecular disc and is the centre of one of most compact (radius about 0.55 pc) star cluster from approximately 100 stars which have been obtained in the IR range. In particular the M17 (Omega) nebula was investigated in detail; from 390 areas, more than 200 spectra were obtained. The values of electronic density for [S II] lines were determined, some compact H II areas were found and analysis of the nebula ionized structure was carried out (Glushkov *et al.*, 1978; Glushkov, 1998). In 1974 the extraordinary compact H II area S235A, connected with the extended area S235, was discovered (Glushkov *et al.*, 1974). Comparison of optical data with radio and IR observations, which were obtained in other observatories, allowed a conclusion to be made about the presence of strong star winds from exciting stars in compact H II areas.

Thus, a large amount of research material on more than 150 nebulae was obtained; T_e, N_e and, on occasion, the radial velocity and the absorption, were determined. Comparison with IR and radio observations allowed the places of star formation to be studied in more detail.

4 CONCLUSION

In the last few years the range of star research connected with nebulae has been essentially extended. A large amount of observational material on the photometry and polarimetry of Herbig Ae-Be (HAEBE) stars and T Tau stars has been obtained by Kardopolov and Rspaev. The addition of polarizing observations to electrophotometry for the young nonstationary stars T Tau and HAEBE essentially helps to reveal the mechanisms of the interaction of stars with their circumstellar dust envelopes. During the process of observations it was found that the main reason for brightness change of stars is most probably the variable circumstellar extinction, which is caused by density changes in the line of sight. For cold young stars such as T Tau, apparently, other mechanisms of brightness variability (e.g. surface activity or a non-stationary accretion) play a more appreciable role. For almost all stars selected for observations, the correlation (direct or inverse) between the degree of polarization and the photometric variability is investigated. The line variability in the spectra of the stars HAEBE and T Tau is well known. The line intensity and their structure can change from night to night. There is a large variety of theoretical studies explaining both the spectral and the photometric features of these stars. In each such case a qualitative picture of the observable phenomena is given, but a model that is capable of explaining all the dynamics of the observable features of a star is preferable. With this purpose in mind, it was decided to carry out monitoring the stars HAEBE and T Tau at the Assy observatory with the help of a 1 m telescope and a spectrograph, equipped with a charge-coupled device matrix. Such observations were begun at the end of 2000 and are proceeding now.

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