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Diffuse matter and cosmogony of stellar systems in researches by G.A. Shajn

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Abstract The main topic of long-term researches by G.A. Shajn is the nature of diffuse matter, its distribution in the Galaxy and extragalactic systems, interaction with the interstellar medium and hot stars, and the formation of emission and reflection nebulae and stars. Based on the analysis of experimental data, mainly photographic observations of nebulae in the Milky Way and extragalactic systems, he made conclusions and suggested well-founded hypotheses on a wide range of considered problems, including those related to cosmogony. The structure of nebulae, and their masses and sizes give reasons behind the conclusion that most of them are formed not in the process of ejection of matter from the stars, but rather they are objects which are born and evolve, and quite often are comprised of giant conglomerates of gas, dust and stars. The distribution of OB-type stars and nebulae in spiral branches points to their genetic relation and the fundamental role of the interstellar medium as the source of their formation. The structural features of nebulae are determined by the action of magnetohydrodynamic forces. Magnetic fields in a galaxy control the motion of diffuse gas-dust matter and ensure the maintenance of its spiral structure. These ideas continue being developed in modern directions of astrophysics.

Key words: galaxy — interstellar matter — diffuse nebulae — cosmogony

1 INTRODUCTION

An intensive study of interstellar matter, its properties and distribution in our Galaxy and extragalactic systems began in the middle of the 20th century and posed a number of problems concerning the origin of stars and stellar systems, and their stability and evolution (Ambartsumian 1933, 1949; Whipple 1946; Bok & Reilly 1947; Sharpless 1954). The first ideas and theories proposed in a number of works were based on the results from scanty observational data (von Weizsäcker 1951; Blaauw 1952; Sharpless & Osterbrock 1952; Oort 1954; Oort & Spitzer 1955). More extensive facts obtained by different methods were required for their verification and development.

Long-term investigations of nebulae in the Milky Way were carried out at the Crimean Astrophysical Observatory (CrAO) for about 20 years according to a program developed by G.A. Shajn.

Grigory Abramovich Shajn (1892–1956) is a famous astrophysicist, who is a member of the Academy of Sciences of the USSR and a number of astronomical societies. His scientific path began at the Pulkovo Astronomical Observatory in 1921; in 1925 he was sent to Simeiz Observatory, which under his leadership became the leading astrophysical observational base in the Soviet Union. Investigations of small planets and comets, the Sun, variable stars and galaxies were carried out there (Samus & Li 2018). Shajn was the initiator of the foundation of CrAO and its Director between 1944–1952. His bibliography contains about 150 works concerning different astronomical objects - meteors, comets, small planets, stars, nebulae and galaxies. His results on the rotation of stars, the features of spectra of long-period variables and the abundance of carbon isotopes in cold stars, as well as on the study of nebulae in the Milky Way and the interstellar medium, made contributions to the physics of stars and galaxies and determined the development of a number of directions in this field. Shajn's biography has been presented in articles by Pikel'Ner (1957), Struve (1958), and Chuvaev (1995). His scientific heritage was generalized in reviews published in different years (Pikel'Ner 1957; Struve 1958; Pronik 1998, 2005, 2008; Pronik & Sharipova 2003) and in proceedings of the memorial conference published in *Izv. Krym. Astrofiz. Obs. (BCrAO) v. 90, 1995*.

In the late 1930s, Shajn studied the distribution of matter in the Galaxy. He obtained an unexpected result which was named the "Shajn Paradox." Observations have shown the absence of a correlation between the reddening of stars and the brightness of the Milky Way. Stars with a small reddening were detected in dark areas, but in contrast, stars with a strong color excess were found in light areas (Shajn 1937). This fact found an explanation in the cloudy structure of the Milky Way, whose apparent brightness is associated with nearby clouds, at a distance of 100–150 pc from the Sun. Also Shajn & Dobronravin (1939) carried out a study of the continuous spectrum of the Milky Way.

During World War II, the 1 m telescope at Simeiz Observatory was demounted, and after the war the spectral investigations could not be continued. Shajn decided to choose a direction of research in which small instruments could be used to obtain actual results relevant to physics of the interstellar medium and to the cosmogony of stellar systems (Shajn & Gaze 1951). He saw the development of questions of cosmogony in the solution of problems relating to the physical nature of nebulae, the diversity of their physical characteristics, their distribution in a galaxy, and the interaction between interstellar matter and stars. Later, the important part of this program became a study of magnetic fields and their role in maintaining the structure of nebulae and spiral arms of galaxies.

The systematic survey of nebulae was started by G.A. Shajn in 1949, together with V.F. Gaze, and within two years they obtained images of nebulae in the Milky Way in the belt of galactic latitude limited to $\pm 10°$ (Shajn & Gaze 1951). In terms of galactic longitude, the observations covered the Milky Way from Sagittarius to Monoceros. These researches were based on experimental data obtained by Shajn together with colleagues in CrAO. Shajn used high-speed cameras (F:1.4) with diameters of 450 mm and 640 mm for photography and narrow-band filters that extracted strong emission lines and narrow bands in the continuum. This method of observation with an appropriate choice of exposure made it possible to obtain unique images of nebulae, with many details that were invisible in early images of already known nebulae, and to discover new nebulae.

Shajn presented results obtained during the first two years in his report at the VIII General Assembly of the International Astronomical Union (IAU) in 1952 in Rome (Shajn & Gaze 1954a). These studies were recognized as being important, and it was decided to create a new catalog of gas nebulae. For this aim, a Sub-Commission of the IAU was organized and V.F. Gaze actively participated in it until 1953.

Vera Fedorovna Gaze (or V.Th. Hase 1899–1954) was a researcher at CrAO. She was the author of about 40 papers in the field of minor planets, stellar spectroscopy and spent her last years studying diffuse nebulae and the structure of our Galaxy (Shajn 1955a).

In 1955, Shajn and Gaze published a catalog (Gaze & Shajn 1955), compiled on the basis of four lists of nebulae prepared in 1950–1954. The new catalog included 286 nebulae; objects discovered in the Simeiz Observatory are designated in it by the letter "S" (Simeiz). This catalog and the one published by Sharpless (1953) provided complete information about the locations of nebulae near the galactic plane. Photos of 48 bright nebulae were published in the Atlas of Diffuse Nebulae (Shajn & Gaze 1952).

To solve some tasks, observations of several nebulae were carried out with the nebular spectrograph at the Simeiz Observatory (Pikel'Ner 1954); polaroids (Shajn et al. 1955b) and results in the radio range were used also (Shklovsky & Shajn 1955).

Wide-field photographic observations and observations with an objective prism were acquired starting in 1950 in a specified band of the Milky Way in 13 selected areas with size $10° \times 10°$ to study absorption at different distances, determine the connection between nebulae and hot stars and also to identify regions of star formation. These works were continued until 1967; reviews of the results are presented by Pronik (1998, 2005) and Pronik & Sharipova (2003). The obtained photographic material is preserved in the archives of CrAO (Bondar 1999; Shlyapnikov et al. 2015; Shlyapnikov et al. 2017), at the International Center in Sofia (Bulgaria) and in a digital version in the Virtual Observatory of CrAO (*http://www.craocrimea.ru/ãas/Projects/SPPOSS.html*).

Investigations of diffuse nebulae were performed by Shajn in the last years of his life and he could not summarize them into a monograph. He presented some of the results in the report which was delivered to IAU Symposium No.6 (Shajn 1958a). Besides the above catalog and the Atlas of Diffuse Nebulae, he published more than 40 articles in which he extensively analyzed the images of nebulae and discussed hypotheses and conclusions about the nature and development of nebulae and galactic systems.

This brief review contains the main results and conclusions published by Shajn in his papers and in a series of works with co-authors on the following topics: the structure of diffuse nebulae, their physical parameters, the relationship with OB-type stars, the distribution of nebulae in the Galaxy, its magnetic field and the interstellar medium.

2 STRUCTURE OF NEBULAE

The structural features of nebulae were studied from the images obtained in the hydrogen line H_α with different exposures at a scale of $\sim 4'$. The distribution of matter, its concentration in individual light and dark details, and position relative to ionizing stars were taken into account. In addition to the known types of nebulae, Shajn and Gaze identified two new types. One of them was named filamentary nebulae. This type includes nebulae similar to the nebula Simeiz 147 in Auriga described by Shajn and Gaze in 1951 (Shajn & Gaze 1952e; Shajn 1955d). Nebulae in which gaseous matter is concentrated at a distance from the center were named peripheral (Shajn & Gaze 1953b). Extensive low-luminosity nebulae known as hydrogen fields were also identified (Shajn & Gaze 1952b, 1954a).

Peripheral nebulae are different in structure and look like extended gaseous clouds, arcs or rings at some distance from one or a group of O–B0 stars located in the central region of the nebula. They are similar to planetary nebulae in this aspect, but are brighter and more massive. The list prepared by Shajn & Gaze (1953d) includes 20 nebulae of this type in our Galaxy and eight in extragalactic systems. Taking into account that only the brightest nebulae were considered, they concluded that this type of nebula is rather numerous in our and other galaxies.

Their new result is that nebulae are not amorphous and stationary objects. Obvious details in nebulae – rings, stripes, segments, streams, filaments, branches – point to not only morphological differences (Shajn 1958b), they show that nebulae are objects with complex dynamics manifesting turbulent motion, collisions and interactions between individual fragments and layers. The characteristic features of different types of nebulae, including planetary and reflection nebulae (like that associated with the Pleiades for example), are filaments and layers. Filaments in nebulae have different shapes, sizes and brightness, they may be found both at an edge and inside a nebula, and in some nebulae they have a preferential direction. The outward motion of matter in nebulae leads to the dissipation of matter and the formation of low-density and low-luminosity clouds around them. The scattering of matter causes uneven edges of the nebula, blurring of boundaries, arising from the low luminosity matter around the main nebula, and even the appearance of separate parts.

Shajn revealed that a characteristic feature of nebulae is the uneven distribution of brightness in them, except for hydrogen fields. This unevenness is caused by their structure, stratification, and by the presence of very small dark nebulae, globules and more significant dark formations, which are closely associated with and related to the origin and evolution of the nebula, its physical state, dynamics and interaction with the interstellar medium. Nebulae include gaseous and solid particles, however, the number of dust particles is extremely small in gaseous nebulae (Shajn et al. 1954, 1955a). Shajn was the first to find the relative abundance of dust in diffuse nebulae.

3 PARAMETERS THAT DESCRIBE NEBULAE

To study the origin of nebulae and to solve the question about the relation with embedded stars, Shajn determined the sizes, masses and densities of nebulae. To estimate mass and density, it is necessary to know the linear sizes and shape of the nebula, and its surface brightness covering 1 square arcsecond. Calculations of these parameters were made for several bright nebulae; their surface brightness in the H_α line was converted into absolute values, in $\mathrm{erg\,cm^{-2}\,s^{-1}}$ (Shajn & Gaze 1952d). Besides nebulae in the Galaxy, he studied extragalactic systems M33, M31, M101 and NGC 6822, and found that most bright nebulae in these have masses of $M_\mathrm{n} < 10\,M_\odot$ (Shajn & Gaze 1953e).

Small nebulae are comparable in mass to the Sun or less, and filaments are formations with masses of $0.01\,M_\odot$. Massive nebulae have $M_\mathrm{n} > 10^3\,M_\odot$ and they are not numerous in our Galaxy. Giant massive gaseous or gas-dust clouds with masses of $10^4 - 10^5\,M_\odot$ were detected in extragalactic nebulae. Masses of nebulae have been determined with an accuracy of 15%–30%. These values represent aggregate errors, involving errors arising from the measurement method, features associated with the structure of the nebula and also errors in determining sizes of nebulae and distances to them. However, even with large errors, one can confirm confidently that the mass of matter contained in a nebula exceeds the mass of hot stars in it.

The sizes of nebulae also span wide ranges – from compact nebulae with radii that are fractions of a parsec to giant clouds with $R = 8 - 60$ pc. Filaments exceed a length of 1–4 pc, but their width and thickness are fractions of a parsec. The density of protons in a nebula is higher than in the interstellar medium – from 10 to 100 or more per 1 cm^3, and in filaments it becomes very high, exceeding 10^3 protons per 1 cm^3.

Thus, the obtained results show that the ejection of matter from stars or their destruction leads to the appearance of some types of low-mass nebulae, but these processes cannot cause the formation of massive nebulae.

4 CONNECTION WITH HOT WR- AND OB-STARS

Over three years of investigations, Shajn & Gaze (1953a) obtained images of 300 nebulae and performed statistical analysis of this material, as well as 536 Wolf-Rayet (WR) stars and O–B1 stars, to determine the correspondence between locations of nebulae and stars, and to consider the question about their random or genetic connection. Hot stars in the investigated galactic belt turned out to be located mainly in localized regions of nebulae, but maxima in their concentration did not always coincide. In some areas there are deviations from this relationship, for example, the region around OB-associations in Perseus has no gaseous nebulae.

The brightest and most isolated nebulae are related to hot stars, and this connection increases with increasing temperature of the star – from B1- (19%) to O- and WR-stars (56% of the considered stars among these types are associated with the emission nebulae).

Among bright, massive nebulae, about 85% are associated not with one, but with a group of O-stars and multiple systems. Stars of later spectral types – B2–B5 stars – are associated with gas-dust and dust nebulae (Shajn et al. 1955a). Diffuse nebulae (peripheral, compact spherical) in which O-B1 stars are located near their central part and provide their illumination, are genetically related to these hot stars. The question about a random or genetic relation is solved ambiguously if an ionizing star is at the edge of a nebula, or if the nebula is extensive, but the position or number of stars is insufficient for its illumination, and also if there are no hot stars in the nebula. In these cases, other mechanisms of luminosity must be considered.

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Shajn noted that such conclusion may be made for a bright and massive gaseous nebula. Concerning the vast but faint hydrogen fields extending up to several dozen parsecs, one may to say that some of them are associated with O–B0 stars definitely, but in more cases these stars could not be detected simply. Investigating the role of hydrogen fields in cosmogony of stars represents a future task.

5 DISTRIBUTION OF NEBULAE IN THE GALAXY

The discovery of several hundred nebulae, penetrating the Galaxy at depths up to 2–3 kpc, means that gas and gas-dust nebulae are numerous in the Galaxy and extragalactic systems (Shajn 1958b). The distribution of nebulae is not random. Groups of nebulae, probably related genetically, are concentrated in the spiral arms of galaxies almost along their entire length. A group involves several nebulae located approximately at the same distance from us. Shajn identified 21 groups of nebulae in our Galaxy (Shajn & Gaze 1953d; Shajn 1954, 1956a), with the largest of them being in Orion, Sagittarius and Cygnus; their extension reaches several hundred parsecs. At the same time, there are fields with a small number of nebulae or which are devoid of nebulae, for example, in the regions of Aquila and Perseus (Shajn & Gaze 1953a, 1954a).

In the spiral arms, a non-uniform distribution of nebulae is observed with significant fluctuations in concentration of gas-dust matter on a scale of 150–300 pc or more. Along with the bright emission nebulae, which were found in nearby extragalactic objects, many nebulae exist on medium or small scales. Shajn concluded that the characteristic feature of spiral galaxies is the presence of a large number of gaseous nebulae. However, the spiral arms include conglomerates of gas, dust and stars. The dust is found in both reflection and emission nebulae, including planetary ones. A dark nebula can penetrate or surround a diffuse nebula, and dust can be concentrated in the form of filaments and globules, or other dark structures (Shajn & Gaze 1953a; Shajn et al. 1954, 1955a).

6 MAGNETIC FIELDS IN THE INTERSTELLAR MEDIUM AND NEBULAE

In searching for an understanding of the inner processes in nebulae, Shajn (Shajn & Gaze 1954a,b) confronted difficulties in explaining structural features of nebulae, their elongation and preferential orientation only by action of hydrodynamic processes, tidal interactions and differential rotation of the Galaxy. He believed these difficulties can be overcome if one hypothesizes there is an interaction between hydrodynamic and electromagnetic phenomena. The discovery of polarization of stellar light in 1949 by Hiltner (1949), Hall (1949) and Dombrowskiy (1949) indicated the presence of a magnetic field of order of 10^{-5} G permeating the interstellar medium. Taking into account that gaseous and dust nebulae are an electrically conductive medium in which non-stationary motions occur, Shajn & Gaze (1951) made a working assumption that there are inner magnetic fields in nebulae.

In a series of papers in 1952–1955, Shajn considered arguments to confirm and develop the offered hypothesis. He paid attention to the fact that dark and some emission nebulae are elongated over distances up to several parsecs and the orientations of nebulae and filaments in them are the same (Shajn & Gaze 1952c). A certain direction of elongation is observed not only in some nebulae, but it is a characteristic feature in some wide regions. A comparison of the observed elongation with polarization data in this region has shown that nebulae are elongated in the direction coincident with the plane of polarization (Shajn 1955c). Based on these facts, Shajn concluded that the magnetic field influences matter in a nebula, having the ability to dissipate it and move it outward, decelerate it in the direction perpendicular to the lines of force and allows movement along these lines.

According to calculations, the velocity of macroscopic motions is 1–2 $\mathrm{km\,s^{-1}}$ in dust nebulae and 10–15 $\mathrm{km\,s^{-1}}$ in emission ones, and the external magnetic field is able to stretch a nebula up to 20–30 pc during 10^7 and 10^6 years, respectively. In diffuse nebulae, the elongation of globules and the motion of matter between them are also explained by the influence of magnetic fields. Scattered matter is oriented along the lines of force, even if a nebula is decaying.

As follows from polarization measurements at low galactic latitudes ($< 10°$), the elongation of nebulae as well as filaments in them is almost parallel to the galactic equator and coincides with the direction of the external regular magnetic field. In higher latitudes, the nebulae are elongated at a significant angle to the galactic equator, which points to the action of the local magnetic field in the region where they are located (Shajn 1956d).

Shajn has shown that the magnetic field in the interstellar medium, and dynamic and other physical processes in it, are connected (Shajn 1955c, 1956b,c, 1957). Turbulent motions inside the nebula lead to an increase of the inner magnetic field; at the same time this field is inhomogeneous due to fluctuations in density. Magnetic field lines frozen into the nebula matter thicken in high-density regions. The presence of an irregular magnetic field (up to 10^{-4} G) allows one to interpret the concentration of matter and the brightness increase in the central part of some nebulae (for example, the Crab Nebula, IC 1805 and NGC 1976 (the Orion Nebula)).

Shajn's assumptions about the existence of magnetic fields in nebulae and galaxies found independent evidence in works by Pikel'ner and Shklovsky. Pikel'Ner (1953) showed that the magnetic field maintains cosmic rays in the halo and disk. Shklovsky (1953) explained the radiation of the Crab Nebula in the radio and optical spectrum by emission of relativistic electrons in the magnetic field. He discussed this mechanism within the problem of cosmic ray generation during an outburst of supernovae and novae.

In the 1950s, the Crab Nebula was a puzzling object. It is a remnant of a supernova, SN 1054, discovered by Chinese astronomers, and it was studied intensively by different methods. Measurements of the polarization in different parts of the Crab Nebula (Shajn et al. 1955b) have shown that the magnetic field in the amorphous central part is more regular than at the periphery. Polarization in the nebula is caused not by absorption inside or outside the nebula, but due to magnetic bremsstrahlung radiation of relativistic electrons, that produces both continuous emission and polarization The role of the magnetic field and cosmic rays in generating optical and radio emission from the Crab Nebula and in the secular acceleration of its filaments was shown by Pikel'Ner (1956, 1964) within magnetohydrodynamics developed in his theoretical works.

In the frame of magnetohydrodynamics, the structure of nebulae associated with supernovae, including the orientation of arcs and filaments in them, exhibits a distribution pattern of the magnetic field from the progenitor star. This field affects the initial conditions of the ejecting stellar envelope and to some extent determines the currently observed distribution of the gas matter.

However, as noticed by Shajn (1955b, 1958a), the inner magnetic field, dominant in some nebulae, does not provide stability. This follows from the fact that fragmentation, dissipation and destruction are typical for many of them. The interstellar magnetic field has a significant effect on the distribution of diffuse matter along the spiral arms of the Galaxy and, by preventing the scattering of gas-dust clouds, maintains the stability of the structure of the Galaxy and extragalactic systems. As follows from a study of the magnetic field in the solar vicinity, the direction of the galactic regular magnetic field is subject to fluctuations on the order of 1000 pc (Shajn 1957).

Shajn's conclusions about magnetohydrodynamic processes in diffuse nebulae and the interstellar medium have been confirmed and developed in theoretical works by Pikel'Ner (1961, 1966, 1968, 1970), Kaplan & Pikel'Ner (1970); Kaplan & Pikelner (1974) and others.

Solomon Borisovich Pikel'ner (Pikelner 1921–1975) began to study the nature of nebulae and physical processes in the interstellar medium together with Shajn. He considered the problems of radiation from nebulae, turbulent motion, and influence of different kinds of instabilities in the medium and in the magnetic field on radiation and features related to the structure of nebulae, in particular, in the Crab Nebula. He created a new branch in astrophysics – physics of cosmic plasma, in which physical processes associated with different astrophysical objects and in the interstellar medium are studied within the influence of their magnetic field.

7 COSMOGONY OF DIFFUSE AND DUST NEBULAE

In the relationship between stars and nebulae, a different nature of their relationship may be traced, depending on the position of stars and nebula mass. The matter ejected by a star can be a cause for the formation of only certain types of low-mass nebulae. In bright massive nebulae, stars or groups of hot OB stars located in the central region of nebulae that provide their illumination are related genetically. But Shajn notes that this relationship, following from the statistics describing the distribution of stars and nebulae, is more deep and complex (Shajn & Gaze 1953a; Shajn 1955b). There is a reason to suppose that in a region where groups of hot stars have been formed, simultaneously the gas nebulae arise and, hence, nebulae and stars are formed in the same epoch, perhaps from one source, and then they evolve in their own ways.

In evolution of nebulae, the interaction of solid particles and gas should be taken into account, i.e. the initial density of the medium and consequent concentration of particles, which varies in time. During $10^6 - 10^7$ years, the dust component in a gaseous nebula increases and this nebula becomes a gas-dust nebula (Shajn et al. 1954, 1955a). The offered qualitative explanation is possible or probable, but when considering this problem it becomes obvious that nebulae are evolving objects which participate together with stars in an exchange of matter with the surrounding interstellar medium. These motions play a dominant role in the formation of both nebulae and stars.

From the point of view of the fundamental contribution of diffuse matter, one should consider the dynamics and evolution of giant diffuse nebulae, where complex interactions of stars, ionized gas and dust should occur. In such systems, objects of various ages exist simultaneously, including O-associations and the youngest multiple stars of the Trapezium type (Shajn 1955e). Diffuse matter and associated bright stars are concentrated in the spiral arms of galaxies (Shajn & Gaze 1953b). In the cosmogonic aspect, the entire gas population of a spiral branch can be considered as a whole higher-order system. At the same time, fluctuations at different scales are observed in the spiral branches, and extended systems of nebulae may be identified, as well as regions with small concentrations or with a total absence of nebulae. Systems of nebulae refer to young objects. They are detected along the entire spiral, thus the spiral branch as a whole displays a young formation (Shajn & Gaze 1954c; Shajn 1958b,a).

The magnetic field contributes to the elongation of nebula matter and its motion along the spiral arms, preventing scattering. A spiral branch can be regarded as a directed cosmic gas flow, with thickenings and knots, where genetically related groups of nebulae are concentrated. Such groups are very extensive, reaching hundreds of parsecs or more (Shajn & Gaze 1952c, 1953c, 1954a; Shajn 1955c,d).

Based on the age of diffuse nebulae and the spatial velocity of $10\,\mathrm{km\,s^{-1}}$, it follows that they were born not far from the place where they are currently, i.e. at a distance of several hundred parsecs. But since gas nebulae are visible along an entire spiral branch, it means that they originated along the entire arm simultaneously. In any case, it cannot be assumed that they were formed in some central region and then spread along a spiral. Shajn noted that only the first steps had been made in understanding the formation of gas-stellar complexes, and for a complete investigation of this problem, the study of neutral hydrogen clouds in galaxies must be involved. During the time that nebulae exist as a result of their scattering along spiral branches, large masses of neutral hydrogen might be expected to accumulate. Significant masses of it were detected from radio observations at a wavelength of 21 cm, but this does not mean that neutral hydrogen is the final product. The initial conditions for the formation of nebulae and stars may be created in cool clouds of neutral gas (Shajn 1954, 1958a; Shajn & Gaze 1954c).

8 CONCLUSIONS

The high-quality images of previously known and newly identified nebulae in the belt of the Milky Way derived by G.A. Shajn and V.F. Gaze have demonstrated the structural diversity of these objects and allows one to put forward a number of hypotheses to explain their nature and origin. In works by Shajn, it has been shown for the first time that nebulae are not amorphous formations, but have a certain structure and evolve on a time scale of 10^7 years. A characteristic feature of nebulae is the presence of filaments oriented in a certain direction determined by the magnetic field in the given region.

Regarding the problem of the origin of stars and nebulae, Shajn believed that the fact that some low-mass nebulae have arisen due to ejections from stars or a supernova burst cannot be excluded, but in general the interstellar medium and conditions in it have a dominant role in the formation of both objects. This conclusion is based on the one obtained by Shajn and the results show that masses of many nebulae are larger than the total masses of ionizing stars. A comprehensive study of images of nebulae led Shajn to the discovery that, in a similar way to the stars in OB-associations, emission nebulae were born in groups and in the same places as OB-associations. This is indicated their genetic connection. Based on this, he came to the conclusion that stars and nebulae have arisen in the same region and possibly from one source. They should be studied as objects which belong to one system, especially at the early stage of development. This was a new approach to the question of whether stars originate from nebulae or vice versa.

Shajn found that diffuse nebulae contain dust and he made the first estimation of its relative content. He established that in emission and reflection nebulae there is a connection between the gaseous and dust matter. This is caused by the motion of nebulae relative to each other and in the interstellar medium, as well as by physical processes of condensation and evaporation, which lead to the formation of dust grains from gaseous particles and vice versa. The interstellar medium, enriched with stellar matter and scattered diffuse matter, is the material involved in the formation of stars and nebulae. In the absence of such cyclical exchange during the time that the Galaxy has existed, the amount of scattered matter should be 100 times larger than the currently observed concentration in diffuse nebulae.

Methods applied by Shajn to study nebulae made it possible to carry out not only qualitative analysis, but also to obtain quantitative estimates of parameters of nebulae, to estimate the distance to them and to represent their distribution as objects which belong to spiral arms of a galaxy.

Shajn came to the conclusion that when studying nebulae, the interstellar medium and the structure of a galaxy, it is necessary to take into account the existence of magnetic fields, internal and external, i.e. on the basis of magnetohydrodynamic processes. The magnetic field allows retention of the scattered matter in the region of spiral arms and thus maintains the stability of the structure of our Galaxy and spiral and irregular extragalactic systems.

In addition to the results presented here, Shajn considered questions about the nature of luminosity of different types of nebulae, the formation of HII and HI fields, and sources of radio emission. The tasks formulated by Shajn and developed in his methods have proved to be productive in studying questions on cosmogony. The whole body of his works on this topic had a significant impact on the subsequent works of Pikel'ner, Kaplan and other astrophysicists, founders of the physics of the interstellar medium, cosmic gas dynamics and extragalactic astronomy.

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