ON THE ORIGIN OF NEBULAE

V.A. Ambartsumian
President, Academy of Sciences Armenian S.S.R.
Yerevan, Armenian S.S.R., U.S.S.R.

With great pleasure and warm sympathy the author dedicates this paper to Academician J. Xanthakis.

1. Introductory Remarks

The origin and the evolution of stars has always attracted the attention of astrophysicists. The solution of this problem is considered by many of them as one of the main aims of their science. The theoreticians devoted to this problem their great efforts.

Much less attention has been paid to the problem of the origin and evolution of nebulae as individual objects. In the textbooks the nebulae are often considered in the chapters dedicated to "the interstellar matter". This indirectly makes an impression that a nebula is something deprived of individuality like a fluctuation of "internebular matter". Actually the nebulae are discrete objects and their mutual distances are as a rule much larger than their diameters. Therefore, one must assume that they are to some degree mutually independent.

It is true that some of the nebulae are dispersing with time in the surrounding space (for example the planetary nebulae). But this fact is related rather to their final fate than to their origin.

Even the superficial study of known facts concerning the galactic nebulae is sufficient to conclude that :

a) The observations give us much more direct and rich information on the dynamical changes and physical processes in them than in the case of the stars, where our hopes to obtain a modest amount of direct information on the internal structure from observations of neutrino fluxes at least for one star have not yet materialized.

b) The changes occurring in nebulae are in many cases closely connected with some turning points in the life of some stars. Therefore, any

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conclusion on the origin and evolution of nebulae can serve as valuable information on the evolution and perhaps even on the origin of stars.

With this connection between the two problems in mind we try to give here a short review of ideas on the origin of nebulae. Our aim is to attract the attention of readers to this more accessible side of the complex evolutionary processes taking place in the Galaxy.

2. The Case when the Nebula Is Connected with Only One Star

There are several classes of nebulae of more or less regular shape, where some kind of connection with a star is almost obvious. From the point of view of contemporary Astrophysics the solution of the problem of the origin for some of such classes of nebulae is almost trivial. Let us consider them :

a) During the outbursts of Novae we observe the formation of small expanding nebulae around them. The velocity of expansion is of the order of 1000 km s^{-1} and after some decades the expanding nebula disappears in the space surrounding the Nova. There is no doubt that the nebula is ejected from the star and consists of the material formerly belonging to the outer layers of the star. The mass ejected is usually of the order of 10^{-5} $M_\odot$.

b) The formation of a planetary nebula is the result of the ejection of external layers of its nucleus. This time the nebular object formed is much more massive having the mass between 0.01 $M_\odot$ and 0.1 $M_\odot$. The planetary nebulae also expand into surrounding space, but they are accessible to observers during the time of the order of 10^5 years. Apparently during the life of our Galaxy hundreds of millions planetaries have formed and dispersed in it.

c) The supernova remnants are nebulae originated from giant stellar explosions. Their initial masses are believed to be of the order of one solar mass. However, during their expansion the original mass often draws in the surrounding interstellar matter. Thus, the mass of the expanding shell can increase enormously. Thus, sometime the nebulae of large mass are formed.

d) It seems now quite certain that the cometary nebulae are formed from the matter ejected by variable stars which we observe in their "heads".

e) Some WR stars in our Galaxy are surrounded by nebulae of circular form like NGC 6888. Similar cases have been observed in LMC. The observational data related both to these stars and the surrounding nebulae suggest the formation of such nebulae from the matter and impulse ejected by WR stars in the same way as SNR are formed as consequence of SN outbursts.

Five cases considerated above cover all known classes of nebulae of more or less regular shape. We see that in all five cases the evolutionary transitions of matter between the dense stellar bodies and the rarified nebular state are going on in one way :

dense matter $\rightarrow$ diffuse matter.

3. Processes in Diffuse Nebulae

About 35 years ago, when we started the study of stellar associations we were much impressed by the fact that almost every OB association contains one or more large diffuse nebulae. From this it was concluded that the formation of groups of young stars must proceed simultaneously with the formation of nebulae since the very forms of nebulae were suggesting their instability and youth.

However, proceeding from the ideas of classical Cosmogony many theoreticians have hurried to conclude from the coexistence of young stars with nebulae in stellar associations that we witness in them the immediate transformation of nebular masses into young stars.

Various mechanisms of the so-called collapse have been proposed but at that time we needed more the observational data rather than elaborated models of condensation of matter.

The accumulation of necessary data has accelerated in the subsequent period as a result of the application of new observational methods (21 cm observations of HI, radio observations of molecules, infra-red observations, VLBI observations of fine details). A number of qualitatively new phenomena has been discovered. Among them :the compact HII regions deep in the cold and dark parts of nebulae, the OH and H_2O masers, hot regions of infra-red emission. It was shown that many optically bright emission nebulae which surround the groups of young OB-stars are expanding with considerable velocity. For example, in the Rosette nebulae around the cluster NGC 2244 the expansion velocity is of the order of 20 km s^{-1}. It was quite clear that such cases almost directly contradict to the idea of condensation.

However, later, when it was shown that nebulae in OB associations contain large cold clouds of H_2 and other molecules and that the velocity gradients in them are as a rule very small, the trend of scientific opinion turned again in favour of the process on condensation. And the discovery of compact HII regions inside the molecular clouds has been considered as the direct proof of the process of collapse within the molecular clouds.

The truth is that the discovery of compact HII regions in such clouds is the direct evidence only of star formation going on in them but not the direct evidence of collapse processes.

4. Infra-Red Sources in Diffuse Nebulae

According to the classification of Rowan-Robinson (1979) all diffuse nebulae belong to one of two following classes :

a) Cold nebulae without appreciable radiation in the infra-red region 1-20 μm and,

b) the clouds which have infra-red source (IRS) (or sources) in them. The average masses of clouds of this second type are much higher than the average mass of a cold cloud. The clouds of the second type as a rule are situated in OB-associations.

Very often the presence of IRS coincides with the presence of a compact HII region. In these cases there is quite natural explanation of the origin of IR radiation. The dust in the cloud absorbs completely the radiation of the OB star (stars) and is heated to the temperatures of several hundred degrees.

However, there are cases when the cloud contains an IRS without the radio-continuum. As is known such a continuum is an inevitable consequence of the presence of the HII-region.

These cases were considered by adherents of the collapse-hypotheses just as places where the collapse of the surrounding molecular cloud has produced a very young star which is still accreting the material infalling from the cloud. The best example of such IRS is the Kleinman-Low source with its infra-red maximum IRc_2. It was assumed that at such an early stage of the formation of the star the absorption of the Ly-continuum by infalling dust is sufficiently strong to prevent the formation of a HII region.

The observations have shown that in both cases (the presence or absence of compact HII region) the source is accompanied by a maser or by a group of masers (in the molecular lines of OH or H_2O). They have been explained as consequence of pumping of gases by infra-red radiation of the source.

At the end of the seventies many theoreticians were convinced that the further detailed study of the objects like Kleinman-Low-region in Orion will result in the clear picture of collapse-processes in molecular clouds and of the formation of "cocoon stars".

5. New Observational Data

During the last three years new observational data have been obtained which completely changed the situation described above.

a) The measurements with sufficient angular resolution of the profiles of the CO radio-lines in the IRS of the type described above (ten of arcseconds) have shown the Doppler-broadening of the order of 80 km s^{-1}. This means that the velocities relative to the centre of mass of the object are of the order of 40 km s^{-1}. In the case of the infall of material to the condensation of the mass of the order of 10^3 $M_\odot$ the velocities expected can hardly exceed 10 km s^{-1}. This alone is sufficient to deny the picture of the gravitational contraction.

In the case of the Kleinman-Low nebulae the profiles look like the superposition of two profiles : one of high velocity flow (plateau about 100 km s^{-1} wide) and another of low velocity flow (40 km s^{-1} wide).

b) In each case dispersion of radial velocities of H_2O masers in and around of such IRS is in good general agreement with the wide of CO profiles of the infrared region. This apparently is an evidence of close connection between the system of H_2O masers and molecular flow producing the line broadening. The masers are immersed in the flow.

c) As a result of a series of very accurate VLBI observations of the positions and the determination of the proper motions of H_2O masers it was established that the system of masers in and around Kleinman-Low infrared region in Orion nebula is expanding (Genzel et al., 1981). The center of expansion was determined with considerable accuracy and coincides within the errors of determination with the infra-red source IRc_2.

There are two groups of masers in expansion. One with expansion velocity of 18 km s^{-1} and the second with velocities higher than 40 km s^{-1}. This is in fairly good agreement both with the dispersion of radial velocities of masers and with the profiles of CO lines.

A more complicated picture of tangential motions has been obtained from the similar study of proper motions of H_2O masers in W51-Main. Here the number of H_2O masers is larger and the general pattern deviates from the picture of radial expansion. However, the whole region is in vigorous motions and there is no doubt that the large velocities again are caused by processes of outflow. In any case the collapse-model seems quite impossible.

6. The Estimate of the Ejected Mass

In the case of the outflow in Orion Molecular Cloud it was estimated by Genzel et al. (1981) that the intensity of ejection of mass is of the order of 10^{-3} $M_{\odot}$ per year. At the same time the duration of outflow as is inferred from the size of KL nebula is not shorter than 2.10^3 years. Therefore, the total mass ejected from the central body during the outflow must be larger than 2 $M_{\odot}$.

The first important conclusion from these observations is that the Orion Molecular Cloud-1 is gaining the mass from the body situated at IRc_2.

We don't know the exact value of the total mass of Orion Molecular Cloud-1 (OMC-1). The value of 10^3 $M_{\odot}$ seems to be of the right order of magnitude. Comparing the gain from the outflow observed in the region of KL nebulae with this mass of OMC-1 we see that the relative increase of the mass of the nebula is relatively small - about 10^{-3} of the present mass of OMC-1.

If however the phenomenon of outflow is recurrent such gains can play an important role in the formation of the mass of OMC-1. Let us consider the evidences in favour of recurrence.

7. The Recurrence of Ejections

According to Downes et al. (1981) some of the properties observed in OMC-1 and W51-Main (wide molecular lines, the presence of masers) are typical for molecular clouds with infrared sources within them. Therefore, it is very probable that the observations of the molecular lines in such clouds with great angular resulution as well as the determination of the proper motions of their H_2O masers will reveal in them the similar kinematical pattern. And, since the majority of OB associations contain the diffuse nebulae with infrared core, this means that during most part of the life of OB-associations the similar phenomena of ejections persist in them.

Since the life-time of an OB-association is of the order of 10^7 years we can assume with some confidence that during 5.10^6 years the enrichment of the clouds belonging to the association is continuing. Of course the centre of the outflow can change its place and the ejection processes will happen from different bodies. But the total gain of mass by the clouds in the association during its lifetime can reach 10^4 $M_\odot$.

Thus, we can assume that the ejections from some unknown sources similar to that we observe in OMC-1 can play essential if not decisive part in the buildup of the clouds under consideration.

Of course we don't know what kind of stars or other dense bodies are the sources of ejections of such large masses. But we know that side by side with outflow phenomena in KL-like regions the ejection occurs from the WR and O stars we observe in associations. The quantity of matter ejected per year by an O star is at least two orders of magnitude lower than in the case of KL-region but the duration of ejection is longer. It is necessary to take into account that usually there are several O-stars simultaneously in an O-association. Nevertheless, it is quite possible that the total input of O and B stars into the mass of nebula is smaller than from outflows of KL-type. Another source of nebular mass is the large quantity of T Tauri variables. It may happen that their integral input is larger than the total input of OB stars. It is known that observations made with IUE have shown that the large part of T Tauri stars show P Cygni type absorption components and never the redshifted absorption. And it may well happen that their input can be larger than expected.

Our conclusion is that solely from observational grounds we can assume that large nebulae in OB-associations are in the process of growth. They are feeded by masses ejected from dense bodies present there.

Is there any need for other agents producing the nebulae? We cannot give a definitive answer to this question. However, the unified picture of the origin of all nebulae in the Galaxy from masses ejected by dense bodies seems now more attractive than ever.

8. The Common Origin of Stars and Nebulae

The purpose of this article was to show that we can try to follow the origin of diffuse nebulae without the speculative assumptions and remaining on purely observational grounds. The possibility of such approach is connected with the fact that each nebula is transparent for some of the frequencies we are able to use for observations. In the case of some nebulae of regular shape the optical observations alone provide the necessary data. Now the radio observations in frequencies of molecular lines give the solution for diffuse nebulae. The VLBI measurements of masers provide us with delicate data on the internal kinematics of nebulae in the regions of most recent star formation. But we cannot obtain similar data on the internal structure and dynamical processes in stars which are in the process of formation.

However, even the partial solution of the problem of the origin of nebulae contains very important information on the origin of the stars. First and the most important information is the total absence of collapse phenomena in nebulae. Instead, there are phenomena of the ejection and vigorous motions of large quantities of material taking place in the regions of star formation. Therefore it is clear that both the processes of formation of stars and nebulae are going on together. The idea of their common origin now seems very probable.

During our studies of OB associations we have expressed the opinion that the process of star formation in associations proceeds in small groups. The Trapezium of Orion is one of such groups. Perhaps θ^2 Orion is an example of an older group. Since the Kleinman-Low nebula is very near to these multiple stars it seems that we observe here the simultaneous process of the formation of a new stellar group and of ejection of nebular mass from some very massive body. It may happen also that first the nebular matter is ejected and then the stars are formed.

In both cases some body should exist from which the material of stars and of the ejected diffuse material is produced. Thus, we return to the idea of protostars (Ambartsumian, 1948).

In the middle of this century the idea of massive protostars (inaccessible as yet for observers) has found little sympathy among the theoreticians who prefer to continue to produce the models of gravitational collapse. The whole generation has been nourished by construction of these models. Though the idea of collapse has produced large numbers of PhD-s working on the models on condensation it was almost fruitless in explaining how the stars have been formed.

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