20 — ON THE ORIGIN OF STARS

BY

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Recent progress in the studies of stellar associations and particularly of the processes of their disintegration led to the conception that stars originate in groups in our Galaxy (1).

That stars in our Galaxy might originate in groups was indicated already by statistical data related to binaries, multiple star systems and open clusters. But only the detailed study of O- and T-associations made it clear, that a simultaneous origin of stars in groups is a general rule, at least in respect to stars forming flat and intermediate subsystems.

As long as stellar associations are systems with positive total energies, i.e. unstable and expanding systems, their lifetime must be rather short (of the order of 10^7 years for O-associations and of the order of 10^6 years for T-associations). As the age of our Galaxy is at least a thousand times greater the whole number of stellar associations having originated and got dissipated in the course of the lifetime of the Galaxy should be several times greater, than the number of associations existing now. The whole number of O-associations in the present Galaxy must be of the order of 10^4. Consequently, the number of O-associatoins which existed during the lifetime of our Galaxy should be of the order of 10^6. The number of T-associations which have originated and dissipated is accordingly of the order of 10^8. If we suggest that about a hundred stars originate in every association, we obtain as a lower limit of the number of stars having originated in O and T-associations, 10^8 and 10^{10}, correspondingly.

These values are closely approaching the total number of stars belonging to the O-F and G-K regions of the Main Sequence. As to faint M-type dwarfs it is not clear at all whether they also originate in T-associations, or in some other aggregates.

Observations of the proper motions, at least in some B and A-type clusters, show, on the other hand, that for them the virial theorem is approximately fulfilled. This is, without doubts, connected with their stability. The whole energy of such clusters is negative and their life-times are estimated to be equal to hundreds of millions and sometimes even billions of years. These clusters are doubtless groups of stars which have originated simultaneously. However, a mere comparison of statistical data concerning clusters and associations shows that there originates a much greater number of systems with positive, than with negative energies. A general theory of the origin of stars should, therefore, first of all afford an explanation of the origin of stellar groups with positive total energies.

It is reasonable to suggest that an expanding association of the ζ Per, or Cepheus II type formerly occupied a much lesser volume, than at present and were quite like the usual open O-clusters. The latter, as B. Markarjan (2) was able to show, are usually systems of positive energy and therefore of short life-time. Every O-cluster after dissipation, must remain a poor O-association for a relatively short time.

As to large stellar associations like the association in Cygnus, they consist of several O-clusters (nuclea of the association) and field-stars, which are evidently members of the already disintegrated O-clusters. It follows from all said above, that the problem of the origin and development of O associations is referred to the problem of the origin and development of O-clusters, having positive energies. The diameters of O-clusters are usually about 2-10 parsecs. The fact that their total energy is positive makes it possible to suggest that even at that, comparatively early stage of development, the members of these stellar groups are diverging. That means that at the moment of their origin their diameters were, consequently, still less, of the order of one or two parsecs, or even less.

A question arises how could an expanding stellar group of the order of two parsecs in diameter, have originated ? Could it not have originated directly from diffuse matter, i.e. out of a nebula, as a result of the appearance of several centres of gravitational condensation ? If such condensations are caused by gravitational instability, the answer should be negative, because a group originating as a result of gravitational instability must have negative total energy.

It is, however, possible that although the energy of such a stellar group is negative it begins to dissipate owing to the mechanism of mutual approaches. But in a dissipating system with a diameter of the order of 2 parsecs and a mass of the order of 500 $M_\odot$, the velocity of escape should be of the order of 1 km per sec. and the time of its decay up to 100 millions of years. This result does not correspond to the observed velocities for expanding clusters (IC 2602, for example).

Thus the only remaining possibility is to assume that clusters of the order of two parsecs in diameter have orinated as the result of a mere expansion of one or several groups of a still smaller diameter.

We know such close groups the diameters of which are of the order of 0,1 parsec. Such are the multiple systems of the Orion-Trapezium type. Many multiple systems of such kind are often contained in O-type clusters. For instance the multiple system of the Trapezium type ADS 13626 belongs to IC 4996, which is an O-type cluster. The Orion-Trapezium itself also belongs to an open cluster. Several O-type clusters contain two Trapezium systems (see the « Atlas of open stellar clusters of the Bjurakan Astronomical Observatory », 1952).

We have no reason to assume that the total energy of all the Trapezium type systems is negative. But even in the case of a negative energy, such a system should have an extremely short life-time of the order of one million of years. Under the influence of processes of exchange of energies at mutual approaches, the components of the Trapezium system should consequently acquire large kinetic energies and escape as this usually occurs in every cluster. But whereas in usual clusters this process proceeds slowly, in systems of the Trapezium type it should lead to a dissipation of the system during a period of time of about one million years. At the same time the velocity of escape might reach several kilometers per second. It is very probable, therefore, that O-type clusters are actually being formed from such more compact groups.

The shortness of the life-time of such compact groups of the Trapezium type indicates that they themselves should have been formed during a comparatively short interval of time from some other objects having different physical properties.

Three suggestions might be advanced in this connection :

a. a compact Trapezium type system originates directly as a result of gravitational instability of some dense nebula.

b. Owing to gravitational instability there arises in the nebula at first one condensation of a large mass, which thereupon divides into several parts, as a result of instability.

c. The system has originated from an object differing in nature from the usual nebulae and stars. In this case such object should be of an extremely large mass. As all known large masses of matter (of the order of the mass of the Sun and greater) are usually forming stars or nebulae, we must assume this pre-stellar state of matter to have somewhat unusual properties. It could be, for example, if the prestellar matter should possess a very high density. As a result of disintegration its separate parts - newly formed stars, acquired considerable kinetic energies.

We shall call the object from which a stellar group is originating a protostar. According to the discussion above this should either be a diffuse mass of an extremely small volume, less than 0,1 parsecs in diameter, or a very dense, or even superdense body. In the second case, which seems to us to be the most probable, we should take into account that contrary to stars, protostars do not radiate any appreciable amount of energy, at least in the visible part of the spectrum. This means that they are deviating greatly from the mass-luminosity relation. Therefore the matter in its prestellar state has quite different properties than the ordinary stellar matter.

All suggestions mentioned above concerning the origin of expanding stellar groups find their counterpart and even their confirmation in the works by G.A. Shajn and V.F. Hase on diffuse nebulae of peripheric structure ([3]). Some of these nebulae, as for instance the filamentary nebula NGC 6960-6992 in Cygnus show direct indications of expansion. Others, as for example the large diffuse nebula around the O-type cluster NGC 2244 and the large nebula on the photo N° 1 of the Atlas of Nebulae of the Crimean Astrophysical Observatory, are of such a form, that its expansion from a much smaller volume is a quite obvious and natural explanation. In the last two cases the peripheric nebulae are situated with a sufficient symmetry around the groups of hot giants. This permits to suggest a simultaneous expansion of the stellar group and the diffuse nebula, connected with this group.

Shajn and Hase are, therefore, inclined to conclude that such cases represent a simultaneous origin of a star-group together with a diffuse nebula.

It has been already pointed out that a number of large O-associations contain several star clusters and besides some-field-stars which can be considered as a result of a decay of formerly existing clusters. Thus, large stellar associations are the result of a disintegration of several protostars. Such are the large associations in Orion and Cygnus. Such large O-associations contain several diffuse nebulae, often isolated one from another. It should, obviously, be considered that they originated simultaneously with different stellar groups, from various protostars and at different times.

Attention should be paid also to the extremely great diversity of types of relation between diffuse nebulae and young stellar groups. There exist groups of young stars which are not connected with diffuse nebulae of any considerable brightness. We may mention for instance the stellar association around χ and h Perseus. The existence of diffuse nebulae (which are usually considered as dust nebulae, but in reality contain besides dust also gas) which are not connected with any group of hot stars, is well known. A majority of new data have recently been accumulated, indicating that such nebulae are often connected with more or less compact T-associations. We may admit that in some cases of disintegration of a protostar there arises a stellar group only, in some other cases — only a nebula, though, usually we have the origin of a stellar group together with a diffuse nebula.

A similar condition is encountered in the question of the simultaneous or separate origin of a group of hot giants and of a group of T-Tauri type stars. Doubtless, the group of stars of the T-Tauri type around the Trapezium of Orion and around S Monocerotis have originated in conjunction with corresponding groups of giants. Nevertheless groups of T-Tauri type stars, not connected with giants, are also observed. As an example we may mention the T-association in Taurus.

Different cases when the origin of groups of giants is not accompanied by the formation of T-Tauri type dwarfs, are, obviously, also possible.

Let us discuss now from the above mentioned point of view a fact related to the association in Perseus II, located around ζ Per. As it was shown by Blaauw, this association consists of an expanding group of hot giants. It contains, however, extended masses of diffuse matter. It is interesting to note that a small stellar cluster, which is projected nor far from o Perseus is deeply involved into these diffuse masses. It seems natural to admit that stars of this cluster are the result of condensations of the diffuse matter around it. It seems that in this case we have a direct proof of the origin of stars from a diffuse nebula. But an altogether different interpretation is also possible. It may be admitted, that the diffuse nebula and the cluster around o Perseus originated at different times in the same Perseus II association, as the result of the disintegration of two different protostars.

As long as it is highly probable that the matter of protostars is in a condition different from the state of matter in stars, we are unable to follow theoretically the process of the origin of stellar groups and diffuse nebulae. But it seems to us that a further study of the observational data related to stellar associations and diffuse nebulae might be of a great assistance in the study of the physical nature of the protostars.

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DISCUSSION
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Von Hoerner. — Has Prof. Ambartsumian given a mechanism which condenses or creates the initial dense clouds ? For I think it is even more difficult to say how interstellar matter makes a very dense cloud than how it further condenses into stars.

Kourganoff. — Non, Ambartsumian n'indique aucun mécanisme physique concernant la création des proto-étoiles. D'ailleurs Ambartsumian ne dit pas que les proto-étoiles proviennent de la condensation de la matière interstellaire.

Schatzman. — Dans la discussion du Congrès de Rome (à paraître dans les Proceedings of the I.A.U.), Ambartsumian donne de très vagues suggestions sur l'état de la matière dans l'état pré-stellaire.

Kourganoff. — Ambartsumian a toujours été très réticent sur la nature physique des proto-étoiles et leur rôle dans l'évolution stellaire. Dans le mémoire présenté au Colloque de Liège, Ambartsumian va beaucoup plus loin dans ce sens que dans toutes ses précédentes publications.

Gratton. — I should like to know how Ambartsumian obtained the total number of associations of our Galaxy. A very small change in the underlying assumptions might alter easily the estimated number by a factor ten or even a hundred.

Kourganoff. — Ambartsumian considère qu'il est actuellement encore difficile de chiffrer avec précision le nombre d'associations dans la Galaxie. Cependant les associations O, du fait qu'elles contiennent des supergéantes « visibles » à une distance de l'ordre de 2000 à 3000 parsecs doivent être observables en grande proportion. Le nombre d'associations O actuellement connues se chiffre par quelques dizaines (exactement 19 sûres et 6 « probables », d'après une publication de 1952, par Markarian). Ambartsumian en déduit qu'on peut estimer le nombre total d'associations O à un chiffre de l'ordre de cent.

En ce qui concerne les « associations T », Holopoff, un autre élève d'Ambartsumian trouve qu'il y en a en moyenne une dans un « cercle » de l'ordre de 100 parsecs », à une distance très faible (car on ne les voit pas de loin). Ambartsumian en déduit qu'il doit y en avoir un nombre de l'ordre de 1000. Nous voyons donc qu'il s'agit dans l'esprit d'Ambartsumian d'estimations tout à fait « quasi-qualitatives », qui sont d'ailleurs les seules auxquelles on peut se livrer pour le moment.

GRATTON. — In Ambartsumian's work I do not see any reference to the very remarkable observations of stars involved in nebular filaments by Fessenkov and Rosskowsky. The beautiful reproductions of their plates in the Russian Astronomical Journal impressed me very much.

— A ce sujet, MM. Kourganoff et Schatzman ont signalé que les nouvelles observations de Fehrenbach à l'Observatoire de Haute-Provence, ont jeté quelque doute sur l'interprétation avancée par Fessenkov et Rosskowsky.

GRATTON. — I have the impression that the importance of the sequences found by Parenago and Massewitch in the mass-luminosity diagram has been overstressed. I have been myself working on the mass-luminosity law since several years and I am convinced that at present the number of stellar masses individually known with reasonable accuracy is not larger than, say, fifty. The Russian colleagues were certainly somewhat too optimistic concerning the observational material available at present.

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KOURGANOFF. — Je remercie Mr. Vandekerkhove pour sa très intéressante communication. Je tiens seulement à attirer son attention sur le fait que le sens de l'évolution qu'il nous propose va entièrement à l'encontre de la conception selon laquelle les objets qui constituent les sous-systèmes sphériques sont beaucoup plus vieux que ceux qui constituent les sous-systèmes plats,.

VON WEIZSÄCKER. — If the component of smaller mass contains relatively more heavy elements, this would correspond to the composition of planets : Jupiter probably contains more heavy elements than the subgiants, and the Earth more than Jupiter. Perhaps planets accrete hydrogen from the nebula in which they were formed, thereby approaching the composition of ordinary stars.

ÖPIK. — The abnormal position of the subgiants in the H-R diagram is easily explained by rejecting homology and considering that a star which has acquired a core with more metals, will have both a greater luminosity (by 1-2 mag) and a greater radius, placing it more or less where it is found in the H-R diagram. Thus, difference in composition will necessarily lead to differences in structure where the solution is to be found.

Ten Bruggencate. — It seems to me very dangerous to draw a conclusion on stellar evolution by comparing a nebula with a velocity shift of 66000 km/sec, which belongs to a nebular cluster, and a nebula without appreciable velocity shift, which is an isolated nebula. We know from the work of Baade and Spitzer that isolated nebulae and cluster nebulae may have quite a different history. The computations of Mr. Vandekerkhove may be considerably influenced by this fact.

Gratton. — I do not know how the observers have selected their material but it seems likely that in each cluster, they would give preference to the nebulae of greater surface luminosity. This would produce a strong observational selection which might alter completely any conclusion on stellar evolution which might be drawn from a comparison of nebulae of different velocities and distances.

Schatzman. — Je m'étonne que Struve n'ait pas considéré comme une interprétation possible les changements de structure. Néanmoins, l'introduction d'un changement de structure se fait avec au moins deux paramètres supplémentaires, alors que Struve a réussi à établir une relation à un seul paramètre L (M, λ), R (M, λ) pour les sous-géantes. L'explication avec un changement de structure ne serait complète que si elle établissait la raison de l'existence d'une relation entre les paramètres supplémentaires de structure.

Cowling. — (Conclusion of Part II). The mechanisms responsible for stellar energy are now known with some confidence, though I do not think the last word has been said. On the other hand, the study of stellar evolution has only just begun. Our knowledge of the mechanisms of energy generation must materially assist in studying evolution.

PARTIE III

ABONDANCE DES ÉLÉMENTS DANS LES ASTRES