# Discovery and studies of stellar associations. The Key to Understanding Star Evolution

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**Abstract**

The review presents works carried out in BAO in the period 1947-70. It tells about the history and significance of one of the greatest discoveries of the twentieth century - stellar associations. Among the fundamental works of Ambartsumian and BAO studies of stellar associations occupy a special place. Their discovery radically changed the existing theories of star formation and evolution and "revived" the slowly dying (as previously assumed) Universe. The discovery of stellar associations proved that star formation occurs in our era. Ambartsumian's ideas clarified the existing and somewhat confusing theory of stellar evolution and gradually became one of the generally accepted directions of the theory of stellar evolution. For more than 75 years, scientists from the BAO and many observatories around the world have been studying stellar associations, but surprises and discoveries are not exhausted. Metaphorically, one can say that for a long time astronomers will follow the path illuminated by stellar associations.

***Keywords:*** *stellar association, evolution*

## 1. Introduction

Over the 75-year history of the Byurakan Astrophysical Observatory (BAO), various scientific studies in the field of astrophysics have been carried out, many of which have gained great recognition in the former Soviet Union and the world. The first cycle of works - the discovery and study of stellar associations - stands apart among them. It was these works that brought the BAO world fame, and the director of the observatory, Victor Ambartsumian, rightfully took an honourable place among the greatest scientists of the 20th century. According to many scientists and experts in science, it is these works are the most significant contribution of Ambartsumian and BAO to world science.

On October 27, 1947, at the General Meeting of the Academy of Sciences of the USSR, Ambartsumian presented a report "Modern astrophysics and cosmogony", a revised version of which was published by the publishing house of the Academy of Sciences of Armenia under the title "Evolution of stars and astrophysics". In this work, Ambartsumian established and substantiated the existence of a new type of stellar system - stellar associations. In the subsequent works of Ambartsumian (1949-1959), the main ideas of this work were developed and presented to a wider circle of scientists.

The author of this review was faced with the difficulty task of presenting the achievements of the BAO in this area since they were repeatedly presented in the books and excellent articles of Ambartsumian, Mirzoyan and other famous scientists. The author was always interested in the question of why for the first article, among all possible attractive titles, Ambartsumian chose exactly this ("Evolution of stars and astrophysics"), changing the title of the report? The key change was the introduction of the phrase "evolution of stars". Maybe it meant that the main results of this work will impact the theory of evolution of stars and Ambartsumian wanted to emphasize it? Therefore, it was decided to present these achievements in light of the development of the ideas of the theory of stellar evolution.

The review presents the works carried out in BAO in the period 1947-70, which are of a more general and fundamental nature. The articles after 1970 are mainly devoted to individual associations or young non-stable stars and stellar systems that are part of associations. There are many high-quality works among them, which deserve separate consideration.

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## 2. Some historical remarks on the stellar evolution theory

In all areas of science (social, biology, etc.), evolutionary problems are the most attractive. Naturally, astronomy is no exception. The evolution of stars became the subject of fundamental research after the appearance of the H-R diagram. In 1911, Danish astronomer Hertzsprung published a diagram of the absolute luminosity of stars in the Pleiades and Hyades star clusters, versus their spectral type or effective temperature. In 1914 American astronomer Russell published a similar diagram for feld stars, and such plots are now known as Hertzsprung-Russell (H-R) diagrams. The H-R diagram, together with the theory of radiative equilibrium in stars (Schwarzschild K., Eddington), has become an important tool for understanding and interpreting stellar evolution.

The somewhat bizarre view of the diagram (Jeans used the geographic names of the world map to describe the diagram) shows the existence of clearly separated groups of stars with possible connections between them. It became obvious that any theory of evolution must be self-consistent with the H-R diagram.

Sometimes a joint analysis of the accumulated data and H-R diagram led to interesting results, such as Russell's brilliant hypothesis about the jump-like changes of stars in the process of evolution. According to Russell (1914) "...It is conceivable that at some particular epoch in a star's history there might be so rapid an evolution of energy - for example, of a radioactive nature - that it temporarily surpassed the loss by radiation and led to an expansion against gravity; but this would be, at most, a passing stage in its career, and it would still be true in the long run that the order of increasing density is the order of advancing evolution."

It must be admitted that at the beginning of the 20th century, there were no prerequisites for the development of the theory of evolution due to the lack of high-quality observational data on the distances, masses, luminosity, temperature, etc. of stars. But the main problems were associated with the lack of exact estimates of the age of stars/star systems and ignorance of the source of radiation energy of stars.

In the scheme of Russell (1914), evolution proceeds in the direction of "red giants - blue giants - red dwarfs". This scheme was consistent with Lockyer (1899, 1902) idea that stars reach their maximum luminosity by the middle of their life, as well as the generally accepted idea that a star contracts as a result of evolution ("... of all the propositions, more or less debatable, which may be made regarding stellar evolution, there is probably none that would command more general acceptance than this—that as a star grows older it contracts." - Russell (1914)). It follows from this scheme that the observed differences between the stars are because they are at different stages (different ages) of their development.

On the contrary, in the Jeans evolution scheme, it was suggested that the overwhelming majority of stars have almost the same age. According to Jeans (1929) "... There is rather distinct evidence of a special birth of stars at about the time when our Sun was born, and this leads naturally to the conjecture that the galactic system was born out of a spiral nebula whose main activity in producing stars centred around that epoch". Consequently, the observed differences between stars are associated with different initial conditions for star formation.

In both schemes, there are very vague ideas about the absolute age of stars and the rate of evolution, as well as a clearly predictable and sad future, described by Jeans in a "theatrical" (literally and figuratively) manner - "... perhaps the main drama of the Universe is over, and our fate is simply watch the unwanted ends of the lighted candles go out on an empty stage".

An important step in understanding the evolution of stars was revelation of Bethe (1939) that thermonuclear reactions, particularly the combustion of hydrogen, are the source of stellar energy. It seemed that this discovery could also solve the basic problems of stellar evolution. According to Gamow (1939) "... we can say that, due to the application of our present knowledge of nuclear physics, the problem of stellar energy sources and the main features of stellar evolution can be considered at present as practically solved".

Gamow developed his theory of evolution reasonably criticized by Lyttleton & Hoyle (1940). According to them "... **It has been customary during recent years for investigators on stellar evolution to devote attention to internal constitution with little or no regard for the dynamical features.** It appears that Prof. Gamow has followed essentially in this tradition and therefore confined his article to the modifications effected by the introduction of modern nuclear theory".

The importance of considering the dynamical characteristics of stars in the problems of evolution was accurately emphasized by Russell 20 years earlier. According to Russell (1919) studies of Galactic systems "... lead up to a single ultimate problem, which may be defined as the representation of the present positions and motions of the stars as a stage in the history of a dynamical system (whether in a steady state or not) and the deduction of the presumable history of the system in the past and the future. Among the subsidiary


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problems connected with this are (a) the existence, character, distribution and gravitational influence of possible dark or absorbing matter in space; **(b) the relation between the age or evolutionary stage of a star and its position and motion within the galactic systems. The latter connects the problems of stellar and galactic evolution in such a way that any notable advance in the solution of one is likely to be of aid in that of the other, while an unfounded assumption regarding either will probably confuse the discussion of both."**

Hoyle and Lyttleton also rightly criticized Gamow's views about the ages of stars and star formation in our era. In turn, Gamow (1940) suggested that the mechanism of accretion of interstellar matter onto stars proposed by Hoyle and Lyttleton could not contribute significantly to the luminosity of the giant stars[1] Ironically, these prominent scientists, as it turned out, were closer to the truth in their critics of each other than in their works on this topic. In particular, according to Hoyle's theory of accretion, the formation whole of stars in the Galaxy took place in the distant past, and all hot giants are also old stars.

Thus, Hoyle and his co-authors tried to solve one of two main problems associated with hot giant stars - the determination of the source of his high luminosity over a long time scale. Another problem was the existence of groups of O stars (or helium stars, as they were then called), investigated by Kapteyn (1914, 1918a,b,c). Given the rareness of such stars, it is unlikely that such groups could have formed accidentally.

Both problems found a brilliant solution in the works of Ambartsumian on stellar associations. Using his original approach (which he called "observational") to solving scientific problems, he considered these problems in conjunction with other characteristics of stars and their systems, in particular, with dynamical and kinematical ones. This led him to the discovery of stellar associations as a new type of star cluster, in which star formation processes are going at the present epoch. Ambartsumian approach to the problems of evolution was in complete harmony with Russell approach cited above. This approach sets them apart from other great astronomers of the time. Ambartsumian's ideas clarified the existing and somewhat confusing theory of stellar evolution and gradually became one of the generally accepted mainstreams of the theory of stellar evolution.

## 3. Discovery of associations, their main characteristics

A stellar association is a spatial group of stars belonging to a certain physical type (relatively rare). The partial density of such stars (concentration per unit area of the celestial sphere) in the association is high, but it is less than the average density of whole of stars in a given region of the celestial sphere. As a result, the stars - members of the association are practically not connected with each other by the force of gravity, but experience the gravitational influence of other stars in this region, as a result of which the association disintegrates. Its constituent stars are scattered among the field stars. The calculation of the association disintegration time led to the conclusion that it does not exceed several million years.

Ambartsumian established the existence of associations of two types - O and T, the main stellar population of which consists of objects located at diametrically opposite ends of the H-R diagram - OB giant and T Tau type (red dwarf) stars, respectively. Ambartsumian was the first to establish that class O giants are born in groups - apparently, together with stars of lesser luminosity. The latter circumstance is confirmed by the fact that some of the O-associations contain many T Tau stars. Ambartsumian also noted the connection of T-associations with diffuse gaseous nebulae. This observational fact subsequently played a significant role in the development of theoretical concepts of stellar formations.

Analysis of relatively scarce data has led him to the conclusion that "... stellar associations (and some clusters) are young systems of stars that somehow formed in our Galaxy, but did not form by combining previously independent stars. Consequently, stars belonging to associations and clusters did not exist before the appearance of the corresponding associations and clusters. On the other hand, these systems themselves are, by definition, composed of stars. We come to the inevitable conclusion that stars in open clusters (associations) are formed during the formation of this cluster (associations)". From this, Ambartsumian made two conclusions, which are very important not only for astrophysics but also for the whole of natural science:

(i) Star formation in the Galaxy continues even now, in our epoch.

[1]Later Ambartsumian (1954c, after the discovery of stellar associations) criticized Hoyle's theory of accretion for the same reason and noted that the very existence of stellar associations and their expansion refutes the theory of accretion (Ambartsumian, 1954b).


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(ii) Stars are born in groups.

This was a refutation of the concept of the simultaneous origin of stars in the Galaxy. This work became a basis for astronomical studies of the evolution of stars and stellar systems by observing their development. This unorthodox view found support from various sides, including studies of the source of stellar (nuclear) energy and the study of the relative motions of the stars in the associations:

1) Based on the dynamic characteristics of associations, Ambartsumian pointed out that many associations cannot be bound by their own gravity and, therefore, must be in a state of expansion. He estimated their ages to be of the order of $10^7$ years. For the O and B stars, ages of the same order had previously been estimated based on the luminosity and the energy sources, for instance, by Unsöld (1948). It is important to note that the "age" of a star, determined in this way, is actually an estimate of the duration of the evolutionary stage at which the star is at a given moment. Such estimates do not take into account the relation between the age / evolutionary stage of a star and its position and motion in galactic systems (see Russell's note above). Ignoring this circumstance sometimes can lead to erroneous conclusions, as in Gamow's theory of red giants.

2) Dynamical studies, such as those of Bok (1934) and Mineur (1939), have shown that clusters in the vicinity of the Sun with densities below about $0.1 M_\odot/pc^3$ are unstable. For densities an order of magnitude lower, their movements are governed by the gravitational field of the Galaxy, and not by the gravity of the members of the group themselves. It is important to note here that the disintegration of clusters because of the tidal effect (discussed these articles) leads to a change in the primary, presumably spherical shape of the cluster. Due to differential rotation, the clusters elongates and loses their spherical shape, which is not observed in the case of O-associations. It was this fact that allowed Ambartsumian to suggest that, in addition to the tidal mechanism, there is an internal mechanism of radially symmetric expansion of the association, which dominates over the tidal one and allows the association to retain a spherical shape. For such domination, the expansion rate must be of the order of $5 \div 10$ km/s.

3) The theoretical prediction (in 1947-49) of Ambartsumian about the dynamic instability of stellar associations and their expansion was confirmed as a result of an analysis of the motions (both tangential and radial) of stars carried out in Leiden (Blaauw, 1952, 1964, 1978) and Byurakan (Mirzoyan, 1966, Mirzoyan & Mnatsakanyan, 1970) observatories. Modern astrometric studies with the space observatories *HIPPARCOS* and *GAIA* have confirmed the results obtained on the dynamic instability of associations.

The study of associations and the analysis of observational facts (huge positive energy of associations and their expansion, the initially small volume of the region of formation, etc.) led Ambartsumian to an unconventional point of view on the origin and decay of stellar associations. He suggested that stars were formed from superdense bodies - a hitherto unknown state of matter, which contradicted the generally accepted view that star formation occurs due to the gradual compression of an interstellar gas cloud.

Ambartsumian views stimulated his opponents to develop their theories of the origin of associations and their expansion. Oort (1952, 1954), Opik (1953), and Zwicky (1953) suggested their own mechanisms of formation and expansion of stellar associations, based on the traditional view. In the modern theory of the formation of associations and their following expansion, some elements of all these mechanisms are included, but the basic idea is more close to Zwicky view.

## 4. Some important results of the early stage studies (1947-70)

The study of associations in the BAO can be conditionally divided into two stages: before 1970 and after it. Until 1970, articles were devoted to the fundamental problems of a) the formation and decay/expansion of associations, b) star formation in associations, c) the place and role of associations in the theory of evolution, etc. These works were carried out by a surprisingly small number of astronomers - the first disciples of Ambartsumian, who later became internationally recognized scientists. Among them were future academicians Markarian, Mirzoyan and Gurzadian.

The discovery of associations and group nature of star formation made it possible to directly study the nature and cosmogonic role of double and multiple stars, stellar chains, Trapezium-type systems, star


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clusters, gaseous and cometary nebulae, non-stable stars, are stars, emission stars, globules, FUors and EXors, YSO etc. After 1970, the overwhelming majority of articles are devoted to these objects - members of associations. Drastically has increased the number of astronomers involved in these works, as well as published articles. The beginning of these works was laid in the works of Ambartsumian, in particular, in the work "Multiple systems of Trapezium type", which is an impeccable example of solving statistical problems. This article does not review these works. They deserve separate consideration.

Therefore, some important works of the first period are presented here to get a complete picture of the research of this period (1947-70).

In the 50s, Markarian, together with Ambartsumian, actively participated in the study of associations. It is worth noting his work on identifying associations between groups of OB (Markarian, 1951-52) stars and creating the first catalogue of OB stars. The first lists of O - associations were published by Markarian (1951), Morgan et al. (1953), and Code & Houck (1958). Because the nomenclatures used in these lists were differed each from other, Commission 37 (Star Clusters and Associations) of the International Astronomical Union, at the 1961 Berkeley Meetings, recommended the use of the Markarian nomenclature.

Another cycle of his works (1950-59) is devoted to the study of open stellar O-clusters in O-associations, in particular, their dynamic state and possible paths of evolution. The possible genetic relationships of associations and clusters were also considered.

In the sixties, Mirzoyan, another famous Armenian astrophysicist, actively joined the research of the associations. An interesting method for estimation of development rates of OB stars in stellar associations was proposed by him Mirzoyan (1961, 1964, 1965). Since the number of OB stars in individual associations is small, to increase the statistical reliability, he built one "synthetic association" from known associations and introduced the concept of the ageing function, which is actually the law of the change in the stream of stars with increasing distance from the nucleus of the "synthetic association" as a result ageing and rate gradient. Thus, thanks to this function, it is possible to estimate the rate of ageing of stars in associations.

Later, the velocity distribution of O-B stars in a "synthetic association" has been investigated by Mirzoyan & Mnatsakanyan (1970). They presented a method for the determination of the mean velocity of stars in spherically symmetric systems at different distances from the centre, using their residual radial velocities and the distribution projected on the celestial sphere and applied this method to the synthetic association. It was shown that the dependence of the mean space velocity of the stars on the distance from the centre of the system is a linearly increasing function. This can be regarded as another important evidence for the expansion of associations and their dynamical instability.

## 5. A brief chronology of the results of early studies of stellar associations

1) 1947-1949 Discovering of stellar associations - Ambartsumian

2) 1949-1950 Early studies of stellar association and connected stellar clusters and star groups - Ambartsumian, Markarian

3) 1950 - Ambartsumian and Markarian for the "... for the discovery and study of a new type of stellar systems (stellar associations), presented in a series of articles published in the journals: "Communication of the Byurakan Observatory", "Reports of the Academy of Sciences of the Armenian SSR", and "Soviet Astronomical Journal" (e.g. Ambartsumian, 1949, 1950, Ambartsumian & Markarian, 1949)" were awarded by the Soviet State prize[2].

4) 1951-52 - The first lists of O - associations were published by Markarian.

5) 1954 - Statistical study of multiple systems of Trapezium type - Ambartsumian.

6) 1950-54 - Studies of O type open clusters, their evolution and relation to host O association - Markarian.

7) 1961-1970 - Continuous formation and rates of development of stars in stellar associations: synthetic association, ageing function. Confirmation of expansion by analysis of radial motion - Mirzoyan; Mirzoyan and Mnatsakanian.

[2]https://ru.wikipedia.org/wiki/


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# 6. Conclusion

The review presents works carried out in BAO in the period 1947-70. It tells about the history and significance of one of the greatest discoveries of the twentieth century - stellar associations. Among the fundamental works of Ambartsumian and BAO studies of stellar associations occupy a special place. Their discovery radically changed the existing theories of star formation and evolution and "revived" the slowly dying (as previously assumed) Universe. The discovery of stellar associations proved that star formation occurs in our era. Ambartsumian's ideas clarified the existing and somewhat confusing theory of stellar evolution and gradually became one of the generally accepted directions of the theory of stellar evolution. For more than 75 years, scientists from the BAO and many observatories around the world have been studying stellar associations, but surprises and discoveries are not exhausted. Metaphorically, one can say that for a long time astronomers will follow the path illuminated by stellar associations.

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