АСТРОФИЗИКА

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TRAPEZIUM TYPE MULTIPLE STARS - INSTABLE SYSTEMS

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The Trapezium type multiple stars are centers of star formation in stellar associations. Theoretical and observational studies showed that they are dynamically instable. Owing to special space configurations of components of the Trapezium type multiple stars are disintegrating completely or partly after some rotations around their centers. These stars have the main role in the origin and evolution of stars which consist of OB- and T- associations. According to observations of 15 Trapezium type multiple stars having the brightest star of OB-classes 14 are in expansion. The age of the Trapezium type multiple stars is of the order of $2 \cdot 10^6$ years. There are weighty arguments to assume that the majority of them are in the state of expansion having positive total energy.

1. *Introduction.* The existence of the Trapezium type multiple stars became known in 1949. Ambartsumian and Markarian [1] considering the structure of nuclei of OB-association around P Cygni established that almost all of them are dynamically instable. Owing to their specific structure they must be disintegrated after some rotations around their centers, for about some million years. Other nuclei of OB-stellar associations usually are also dynamically instable and disintegrated systems [2].

This unusual regularity of nuclei of OB-associations is one of the reasons of their disintegrating. It can be noted that the Trapezium type multiple stars are disintegrated earlier than OB-associations itself - 10^7 years [3].

The study of the Trapezium type multiple stars have very significant meaning for formation and development of stars. Unfortunately it is hard succeed to study T Tau type multiple stars of Trapezium type in T-associations.

In this article we consider the observational data concerning the Trapezium type multiple stars in detail to show their principle importance for stellar evolution.

2. *Theoretical consideration of the problem.* All multiple stars can be divided into two groups according their motions. The systems having at least three components with mutual space distances, comparatively not numerous, are the *Trapezium type*. Prototype of these systems is the Orion Trapezium system. All other multiple systems are the *ordinary* systems.

The Trapezium type multiple stars are practically clusters, but the number of components is smaller. In these two types of multiple stars: Trapezium and ordinary types, the motions are quite different. In ordinary systems the motions of components are Keplerian or quasi-Keplerian, i.e. almost periodic and they can exist for a very long time. Whereas in Trapezium type multiple stars motions of components are not periodic and after some rotations around the center of gravity they must be disintegrated completely or partly throwing out one or more members and transforming to ordinary systems [2].

For Trapezium type multiple stars one can use Ambartsumian's [4] (see, Chandrasekhar [5]) formula for disintegration of clusters. If used with N (number of components) equal to some units, R (radius of system) of the order of 10 000 AU and mean mass of stars of the order of solar mass, the time of disintegration comes out $2 \cdot 10^6$ years [4]. It is valid for the Trapezium type multiple stars with negative total energy.

It means that Trapezium type multiple stars are very instable and disintegrated even in the case when they have negative energy. In other cases they are disintegrated for much shorter time. The time of disintegration increases slowly with increase of number of components.

The observations show that the multiple stars exist in both associations and in general galactic star field. This is natural consequence of the shorter duration of the existence of Trapeziums. The Trapezium type multiple stars containing OB-stars are disintegrating before the disintegration of stellar associations and the ordinary type multiple stars have time to enter the general galactic star field.

3. *Direct observations of real Trapezium type systems*. The first paper devoted to the motions of stars in the Orion Trapezium was carried out by Parenago [6] who using observations of six components of the system showed that this system is really disintegrating system. He used all measurements of these components for 120 (1820-1940) years. In spite of some astronomers dispute Parenago's result, however all measurements used by him can not be rejected (see, for instance, [7]).

The list of the first Trapeziums consisting as brightest components of OB-stars has been published by Ambartsumian [2] in 1949.

In Aitken's [8] Catalogue of Double Stars there are many multiple stars including the Trapezium type multiple stars. Not all of them are real Trapeziums. Probability to be observed as Trapezium is ~0.1 [9] because of projection on the sky (Pseudotrapeziums).

In Table 1 the relative number of Trapeziums is presented according to Index-Catalogue of Visual Double Stars [10]. It consists of 412 Trapezium type multiple stars [11]. Table 1 shows that the Trapezium type multiple stars are observed among young stars (O-B2 and B2-B9) more frequently.

For G, K and M spectral classes the data repeat the data for A and F classes. Only for spectral class M the data are not sufficient for statistics.

Table 1

THE RELATIVE NUMBER OF REAL TRAPEZIUM TYPE MULTIPLE STARS IN INDEX-CATALOGUE OF VISUAL DOUBLE STARS [10]

Spectrum of brightest component	Total number of multiple stars	Probable number of real Trapeziums	Relative number of Trapeziums (%)
O-B2	59	34	58
B3-B9	190	31	16
A	394	25	6
F	309	13	4

Note: In column of probable Trapeziums about 10 % [9] are excluded as Pseudotrapeziums.

A strong tendency to contain O-type stars has been found by Sharpless [12] in Trapezium type multiple stars connected with emission nebulae. The result obtained here is new strong evidence in favour of the idea on the extreme dynamical instability of the Trapezium type multiple stars.

One of the authors (G.N.S.) gathered all astrometric material in order to measure the motions of components of Trapezium type multiple stars connected with OB-stars.

It turned out that only 15 Trapeziums connected with OB-stars have more than 5 measurements during last more than 100 years [11]. All astrometric data are obtained in Nice (France) and Naval (USA) Observatories. He used also some photographic observations obtained in Abastumani (Georgia) astrophysical observatory.

Based on these observations, the graphs of the dependence of mutual distances of components - time (epoch) of observation have been drawn. The astrometric material indicates an expansion of 14 Trapezium type multiple systems out of 15 studied.

Fig. 1 and 2 show the graphs for ADS 719 and ADS 2843.

The observational data are scanty for Trapeziums consisting of red dwarf stars (T Tau and flare stars). However, it can be used for estimations of their total energy.

For instance [14] the Trapezium type multiple systems are observed in "pure" T-associations.

The Trapezium type multiple stars found by Hambarian [15] in the Orion stellar association consist either of T Tau and flare stars exclusively or they medley. In agreement with the disintegration of the Trapeziums sizes (means), of the systems consisting of the T Tau stars seems to be smaller than those of the systems consisting of flare stars only [16].

Besides Hojaev [17] measured two systems of Trapezium type consisting of red dwarf stars (T Tau and flare) in Taurus Dark Clouds and found that they have apparently positive total energy.

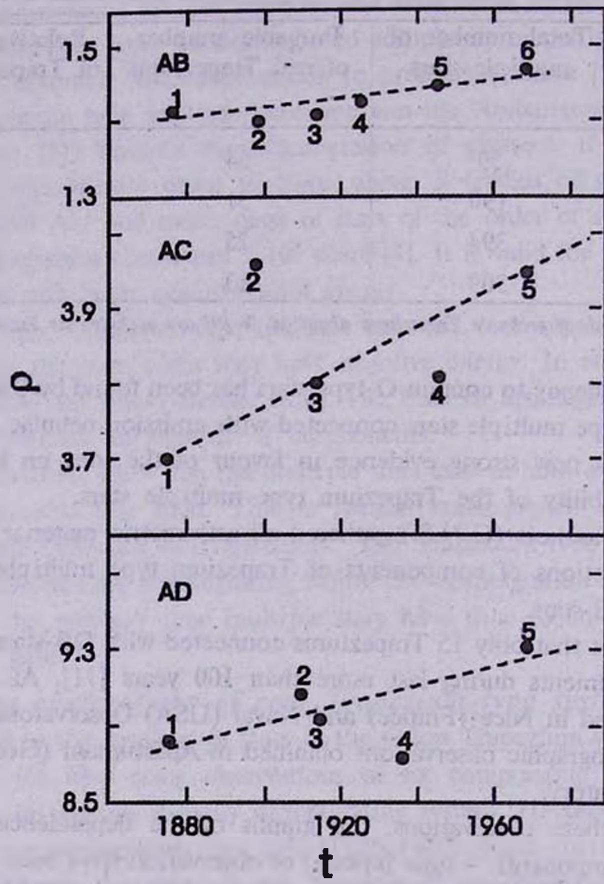

Fig. 1. Observed dependence (ρ, t) showing the expansion of the Trapezium type multiple system ADS 719, where ρ (in arcsec) is the angular distance from the main star and t is the time (epoch). After the paper [13].

It can be added that some Trapeziums are observed which consist of other very young objects: IR sources, Herbig-Haro objects and cometary nebulae and so on (see, for instance, [18]).

4. *Trapezium type multiple stars indicating on expansion*. In agreement with the disintegration of Trapeziums it is interesting to consider of the sign of total energy. However, this kind of study demands data (distances, masses and velocities) of all components in the given multiple system, which are unknown in overwhelming majority of cases.

For this reason we used 412 Trapezium type multiple stars of which 0.1

were Psevdotrapezium. They consist of 1303 stars [10].

It is natural to think that the components of relatively lower mass may be observed, in average, in farther distances from the center of gravity than others, independent from the sign of total energy.

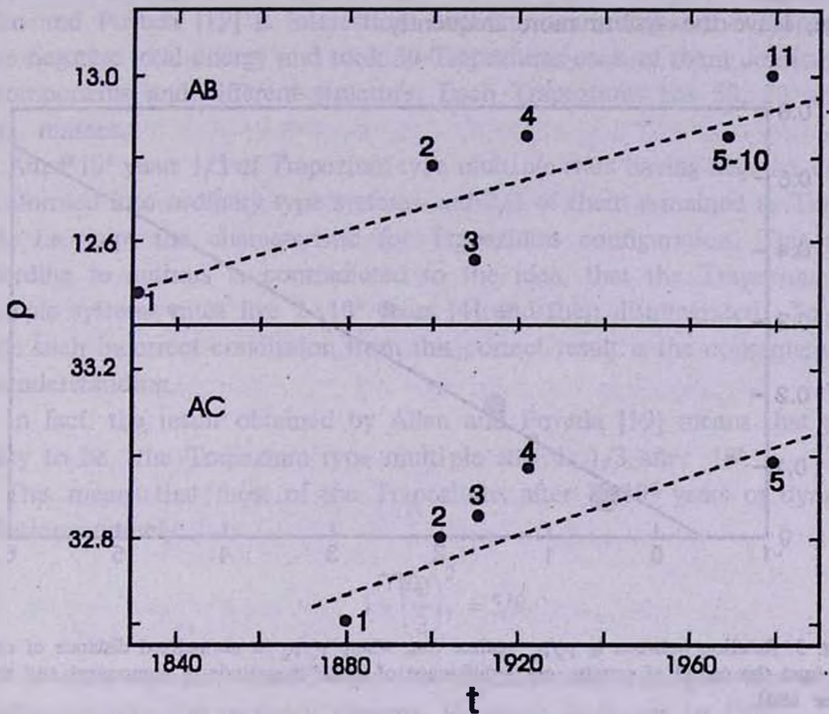

Fig. 2. Observed dependence (ρ, t) showing the expansion of the Trapezium type multiple system ADS 2843, where ρ (in arcsec) is the angular distance from the main star and t is the time (epoch). After the paper [13].

Therefore, from this point of view the relation between masses of components and their distances from the center of gravity in a given system can be considered as some additional argument to the mentioned problem.

For this purpose we have constructed relation between differences of stellar magnitudes of components and main star against normalized distances of components from the gravity center. Normalization is achieved by dividing distances of components by the distance of main star from the center of gravity or dividing by the median of all mutual distances of components. Thus constructed relation is presented in Fig. 3.

Of course the observational selection effects which are present in Trapeziums' list [8] (fainter is component smaller is searching radius around main star) can significantly change observed picture and taking into account this fact may only improve observed relationship.

It should be noted that considered dependence is observed for different subsets of Trapeziums (spectral class, brightness of main star) without significant variations.

Thus, it may be concluded that the fainter the farther is the component from the gravity center. Therefore, components of relatively lower mass, in average, leave the system more frequently.

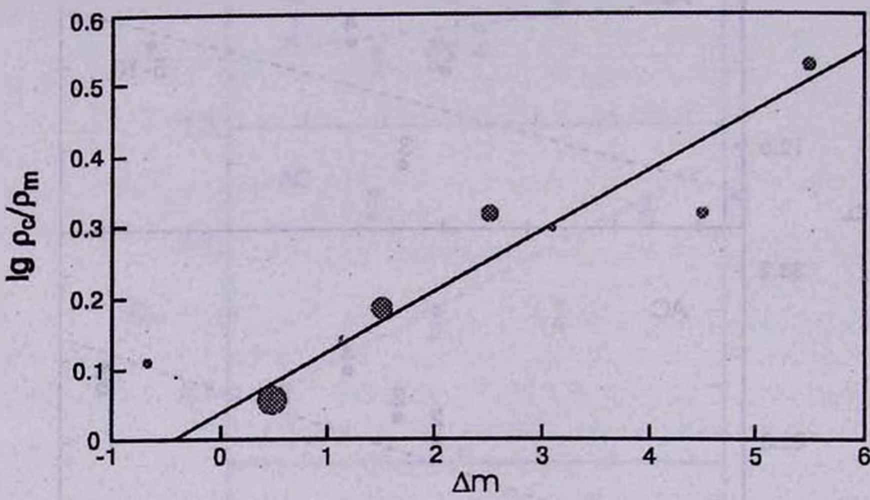

Fig. 3. Relation between lg ρ_c/ρ_m against Δm, where ρ_c/ρ_m is normalized distance of component from the center of gravity, Δm - difference of stellar magnitude of component and main star (see text).

Ambartsumian [2] paid attention that the Trapezium type multiple stars evolve and as consequence their sizes increase. He considers the region near to cluster NGC 6871 where there are at least five Trapezium type systems.

These Trapezium type multiple stars have 4-6 members and as the brightest B2-B5 stars. Their maximal sizes are 61 000 - 117 000 AU, if the association is found on the distance of 1500 pc. It means that they are formed from more compact Trapeziums. On the other hand by the forms they are similar to usual compact Trapeziums. All five systems are about ten times larger, than systems consisting Ambartsumian's [2] list.

In the case when expansion of these Trapeziums are the consequence of their disintegrations as result of encounters of stars with time the forms of Trapeziums must be changed considerably. However, unchanged forms of these Trapeziums may be explained only if one assumes that the Trapeziums have positive total energy and their components have enough kinetic energy in order to move off from the places of origin almost directly.

This is weighty evidance in favour of extreme instability of the Trapezium type multiple stars, which are living not more than some million years.

5. *Dynamical evolution of the Trapezium type systems*. It is significant to follow the dynamical evolutions of real Trapeziums. From this point of view it is important to see results on the research of the dynamical evolution of Trapeziums, with computers. In this sense the investigation of Allen and Poveda [19] is interesting. Authors assumed that the Trapeziums have negative total energy and took 30 Trapeziums each of them consisting of 6 components and different structure. Each Trapeziums has 50, 20 and 15 solar masses.

After 10^6 years 1/3 of Trapezium type multiple stars having negative energy transformed into ordinary type systems and 2/3 of them remained as Trapeziums, i.e. kept the characteristic for Trapeziums configuration. This result according to authors is contradicted to the idea, that the Trapezium type multiple systems must live $2 \cdot 10^6$ years [4] and then disintegrated. To conclude such incorrect conclusion from this correct result is the consequence of misunderstanding.

In fact, the result obtained by Allen and Poveda [19] means that probability to be the Trapezium type multiple star is 1/3 after 10^6.

This means that most of the Trapeziums after $2 \cdot 10^6$ years of dynmical evolution, namely

$$1-\left(\frac{2}{3}\right)^2 = 5/9$$

part of their sample, should lose the characteristic configuration and be transformed into the ordinary systems. However, it is not so [20].

It means that the mean age of Trapezium type multiple stars, studied by Allen and Poveda [19] is of the order of $2 \cdot 10^6$ years. This result is in remarkable agreement with the predicted age of such Trapeziums.

6. *Stellar systems with positive total energy*. In 1955 just after the division of multiple stars into two groups: Trapezium and ordinary types Ambartsumian [21] for the first time considered the systems having the positive total energy. Such systems are observed among nuclea of stellar associations, especially among Trapezium type multiple stars.

The foundation of the existance of stellar systems having positive total energy follows from observations. The abundance of multiple stars of Trapezium type in stellar associations indicate that majority of them must have positive total energy.

Instable of O-clusters could not evolve into the clusters of types B or A, do not containing OB-stars and are very rich (by Markarian classifications [22,23]).

If we assume that O-clusters are found in stable state the number of stars can not increase with time. The enrichment of star clusters owing to stars of general galactic star field is impossible. It means that O-clusters must integrate in a very short time.

This fact gives weighty foundation to assume that the majority of O-clusters have the positive total energy and must disintegrate in general galactic star field for some million years.

The Trapeziums considered by Allen and Poveda [19] have negative total energies. However, the discussion of the problem showed that there are reasons to assume that majority of the Trapeziums have positive total energies [21].

Up to now we deal with Trapeziums consisting of OB-stars. Observations indicate that there are numerous Trapeziums in "pure" T-associations, where there are no OB-stars. Owing to brightness OB-stars are found in more favourable conditions than red dwarf stars.

Unfortunately, the determinations of total energy for Trapezium type multiple stars, especially red dwarf stars are very incorrect on the basis of observations.

Nevertheless, it seems that among the Trapezium type multiple stars consisting of the T Tau type and flare stars detected by Hambarian [15,16] in the Orion and Hojaev [17] in Taurus Dark Clouds there are systems with positive total energy.

The estimations obtained for Trapeziums with negative total energies are valid if their energies are really so. But for Trapeziums having positive total energies the time of their disintegration must be considerably shorter [21].

Trapezium type multiple stars are observed in very young stellar systems - stellar associations. All associations (OB- and "pure" T-) show abundance of Trapeziums. Multiple stars observed in general galactic star field are usually of the ordinary type. This regularity is natural consequence of the fact that stars are formed in stellar associations.

However, the Trapeziums are disintegrating systems for a short time compared with multiple stars of ordinary type. Therefore Trapeziums are disintegrating before the disintegration of "maternal" associations and could not reach general galactic star field, whereas the ordinary type multiple stars had the time before disintegration of "maternal" associations to reach galactic field.

This regularity is direct indication that the stars are formed in groups and components of any physical systems, beginning with double stars, have common origin.

7. Conclusion. The new type of stellar systems - the Trapezium type multiple stars are discussed on the light of astronomical observations.

The idea of Trapezium originated in the Byurakan Observatory and one of authors (G.N.S.) from the Abastumani Observatory took active participation in the investigations of Trapeziums. Special interest presents his unique study of the expansions of 14 Trapeziums among 15 ones.

The significant results concerning the origin and evolution of Trapeziums are the inner peculiarity of star formation process. Their role in group formation of stars is very significant.

It seems that majority of the Trapeziums have positive total energy. Especially the data obtained in the Orion and Taurus Dark Clouds showed that Trapeziums have positive total energy. Discovery of stellar associations and their study were arguments to pick out the Trapezium type multiple stars [13,24] and confirmed the group character of starformation.They stimulated the investigations of the Trapezium type systems.

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КРАТНЫЕ СИСТЕМЫ ТИПА ТРАПЕЦИИ - НЕСТАЦИОНАРНЫЕ СИСТЕМЫ

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Кратные звезды типа Трапеции являются центрами звездообразованиия в звездных ассоциациях. Теоретическое и наблюдательное рассмотрение вопроса показывает, что они динамически неустойчивы. Из-за особой пространственной конфигурации компонентов, кратные звезды типа Трапеции распадаются полностью или частично после нескольких оборотов вокруг центра масс. Эти системы играют главную роль в образовании и эволюции звезд, входящих в ОВ- и Т- ассоциаций. Согласно наблюдениям 15 кратных звезд типа Трапеции, имеющих как главную компоненту ОВ звезды, находятся в состоянии расширения. Возраст кратных звезд типа Трапеции по порядку величины $2 \cdot 10^6$ лет. Есть веские основания предполагать, что большинство из них находятся в состоянии расширения, имеющих положительные полные энергии.

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