STELLAR ASSOCIATIONS

Existence in the Galaxy of stellar associations is established. An association is a system of stars which have common origin, and are of much lower spatial concentration than that of the general stellar field of the Galaxy, where the associations are imbedded. The most important examples of associations are the groups of variable dwarf stars of T Tauri type and the groups of supergiants of O and B types.

Associations consisting of supergiants often have in their center a usual star cluster, the associations nucleus.

By all indications, the giant clusters in the Great Magellanic Nebulae are stellar associations .

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Until recently, only two types of "small" stellar systems were studied within our Galaxy: the open and the globular clusters. The magnitude orders of gravitional interaction energy for the open clusters and for many visual double stars are the same. This speaks for the proximity of their nature. However the author has established recently [1], that along with open and globular clusters, we have within our Galaxy still another type of stellar systems – the stellar association. They are of outstanding interest from the viewpoint of problems of stellar evolution. In the present paper we consider some examples of stellar associations and discuss their types and properties.

Examples of stellar association .

1) A group of vaiable stars of T Tauri type and the associated stars in Taurus and Auriga.

It is well known that the stars of Tauri type are restricted to certain parts of the sky. In particular, eight such stars form an isolated group in the constellations of Taurus and Auriga within a solid angle of $12^\circ \times 12^\circ$.

The distance order being 100 parsec,this means that the diameter of the group is 25 parsec by order. Joy has discovered within the same domain a series of dwarf stars whose spectra possess bright lines. This indicates their probable interrelation with the stars of T-Tauri type. At this point we stress two important facts:

a) compactness of this group of stars can not be explained as accidental. Obviously we deal with a single system.

b) the density of this system of stars is low to the extent, that direct observation could never identify it to be a cluster, even in case it was situated several times nearer to us.

Discovery of this association became possible exclusively because its stars belong to a definite class of variable stars. An important characteristic of this system is its low spatial density.

Even if the system of 7-8 stars of T Tauri type is complemented by 40 dwarfs with bright lines, we obtain a spatial density which is much lower than that of Galactical stellar field where the association is imbedded. This circumstance remains in force even after we attach to the system some dwarfs lacking bright lines (they are several times more in number, than dwarfs possessing bright lines).

According to well known dinamical criteria this means that the system we consider is unstable and is going to be destroyed under tidal influence of the general gravitational field of the Galaxy. We are compelled to think that the system consists of stars diverging in the space.

Possible relations between the stars of the system and both luminous and dark interstellar matter also deserve attention.

2) Kukarkin and Parenago catalog of variable stars in a small region centered at $\alpha = 18^h40$: $\delta = 9°0'$ indicates eight stars of T Tauri type (or by the catalog terminology— of RW Auriga type). Three of them have a question mark, which refers to the type of variability. We represent the list of these stars.

name		α	δ	*stellar magnitude*	*type*
$V637$	Ophiuchus	$18^h31^m59^s$	$+9°51'.1$	$13^m.6 - 16^m.0$	T Taurus
$V681$	Ophiuchus	32 34	$+9°06'.1$	$14^m.2 - 15^m.4$	T Taurus ?
$V643$	Ophiuchus	32 34	$+6°16'.7$	$13^m6 - 15^m.6$	T Taurus ?
$V645$	Ophiuchus	33 02	$+11°47'.1$	$14^m.6 - 15^m.6$	T Taurus ?
$V476$	Aquila	43 57	$+7°02'.3$	$13^m.3 - 14^m.2$	T Taurus
$V480$	Aquila	45 43	$+7°00'.7$	$14^m0 - 16^m.0$	T Taurus
$V489$	Aquila	50 55	$+11°56'.3$	$13^m.1 - 14^m.8$	T Taurus
$V490$	Aquila	53 49	$+12°51'.1$	$14^m.1 - 15^m.5$	T Taurus

The stars are situated in a small, $6° \times 7°$ region, not far from Galactic equator. Even if we neglect three stars, whose types need confirmation, the remaining five stars of T Tauri type still produce concentration, which cannot be accidental. We deal with members of a system of stars. Average maximal brightnesses of the variables for this system is $3 - 4^m$ less than that for the association in Taurus. Apparently, this is an evidence of greater distance to the association in Aquila and Ophiuchus.

3) A group of stars of type O and B, as well as of red supergiants around double open cluster χ and h of Perseus. This system was studied by Bidelman. Observations live no doubt about the

existence of a group of supergiants of early and late types, which surrounds χ and h Perseus clusters. The double cluster is the nucleus of this association .

The system diameter is 170 parsecs by order. While the diameter of both χ and h Perseus clusters is 10 parsecs by order (or 7 parsecs by Osterhoff). A characteristic feature of the system is the presence of a number of B type stars with bright lines. In particular, there are at least five stars of P Cygni type (HD 12953, 13841, 14134, 14143 and 14818). Even if we accept that the association as a whole contains tens of thousands of stars, yet its mean density will be less than that of Galactic field. Doubtless, the stars of the association diverge in the space. It should be noted however that the nuclei χ and h of Perseus which are usual open clusters, are perhaps stable and their decay necessarily should follow the patterns common for open clusters.

4) The open cluster $NGC6231$ is surrounded by a group of supergiants of O and B types. The study of radial velocities by Struve [4] shows that all these supergiants, together with the cluster form a single stellar association . Its distance from us is about 1000 parsecs. The association diameter almost five times exceeds the cluster diameter and is about 30 parsecs. Remarkably the association includes two Wolf–Rayet stars and two stars of P Cygni type.

It is self evident that the possibility of accidental concentration of these stars around the cluster is out of question. In this case we again have to accept, that average density of the association is low in comparison with density of galactic field. The association is unstable, although the nucleus ($NGC6231$ open cluster) probably is stable.

5) $NGC1910$ system in Great Magellanic cloud is of peculiar interest. It is a large group of supergiants of early types where some stars belong to P Cygni type, including the famous S Doradus. Diameter of this system is about 70 parsecs i.e. many times larger than the sizes of common Gallactic clusters.

6) Stellar association in Captein area SA 8 (around $\alpha = 1^h00^m,\ \delta = +60°10'$). The association is a group of weak stars of O and B types, occupying a region of 2.5 degrees in diameter. The association includes a Wolf–Rayet star and two stars of B type with bright lines. Apparently, at least 23 members of this association belong to BO type. We note that the association is situated in a region poor in bright stars of B type (brighter than $8^m.0$) Judjing from visible stellar magnitudes of stars of early types, this association is situated at a distance not less than 2000 parsecs. This suggests a diameter about 100 parsecs. This extremely interesting distant association was discovered in Burakan observatory in 1948 using Bergedorf catalog. Association nucleus is the open cluster $NGC381$, $7'$ or not less than 4 parsec in diameter.

Basic characteristics of stellar associations

The above facts suggest the following general conclusions about stellar associations :

1) The associations are systems with average densities small in comparison with density of Gallactical field. However, if we take partial concentrations of stars of separate spectral types,

then associations are sharply distinguishable, owing to abundance in them of stars of comparatively rare types. In some cases we deal with supergiants of O and B types, in others — with stars of T Tauri type. Owing to their low density, the associations cannot be stationary in the sense of stellar dynamics. Unlike globular and open clusters, associations are nonsteady systems. Obviously members of associations diverge in space, and will eventually dissolve among the field stars.

2) Associations always contain stars, which continuously emit matter. In three of the above six examples we find stars of P Cygni type. In the examples 4, 6 stars of Wolf–Rayet type are present. In the first two examples variable stars of T Tauri type are present, whose spectral bright lines possess absorbtion components on the violet side, i.e. they show the same peculiarity, as the bright lines in spectra of stars of P Cygni type. A natural conclusion is that these stars also continuously emit matter.

3) In some cases the associations have nuclei looking as open stellar clusters.

Stellar associations in Great Magellanic Cloud

Great Magellanic Cloud is very rich with open clusters. Remarkably, clusters of Great Cloud in some cases have rather big sizes (several dozens of parsecs) [5]. The most striking is the example of $NGC1910$. The curve representing distribution of the open clusters in Great Cloud according to their diameters has a minimum, which divides all open clusters in two groups: a) clusters with diameters greater than twenty parsecs and b) clusters with diameters less than twenty parsecs. This alone makes us suspect, that we deal with objects of two different types and scales. Presence of P Cygni stars in some clusters of the first group leads to an idea that those are objects of stellar associations type existing within our Galaxy, while the objects of another group are common open clusters.

The following consideration reduces this hypothesis to an almost certainity. Suppose we observe our Galaxy from some external system, say from Great Magellanic cloud. Then the association around χ and h Perseus will contrast sharply with the surrounding background, due to existence of great number of supergiants in the association . Observing the same system from inside the Galaxy we face the fact that the stars of low luminocity, which are at far shorter distances than the association, are projected upon the latter. Both the members of association and the projected stars will have visual magnitude of the same order and therefore the former will be lost among the latter.

An observer in Great Magellanic Cloud would conceive the association as a cluster of supergiants having a diameter of 170 parsecs. The χ and h Perseus clusters would appear to him as mere condensations in this magnificent system. On the other hand the system $NGC1910$ if transfered from the Great Cloud into the Galaxy, and placed at the locus of χ and h Perseus would be observed as a typical association , i.e. it will not form a visible condensation of stars. Only separate study of stars of early spectral types could betray its existence. Thus it seems that all giant systems in the Great Magellan Cloud (about 15 in number) are in fact stellar associations , whose characteristic features were described in the previous section.

Kinematics of stellar associations

The interaction forces between the stars in an associations are small as compared with the tidal action of the general force field of the Galaxy. Therefore at least for peripherical members of associations , the interaction forces can be neglected.

Considering the dynamics of stars of an associations under Galactic force field, it should be noted, that the differential effect of Galactic rotation implies growth of distances between members of the association .

For a pair of stars distance r apart, the growth rate of r due to Galactic rotation is expressed via well known Oort coefficient A as follows:

$$\frac{dr}{dt} = Ar \sin 2(l - l_0).$$

Accordingly, for the radius R of the system at given galactic longitude l we have

$$\frac{dR}{dt} = AR \sin 2(l - l_0).$$

For the radii R_1, R_2 at two epochs t_1, t_2 this implies

$$\ln R_2/\,R_1 = A(t_2 - t_1) \sin 2(l - l_0).$$

This formula says, that for $l - l_0 = 45^\circ$, a distence will be doubled after a period of $4 \cdot 10^7$ years.

Our derivation was based on the assumption, that all stars in the association follow circular orbits around Galactic center. Real orbits can of course be different. However, if we exclude too high relative speeds within an association , the radius dublication period will always have this order of magnitude.

Other possible causes of expansion can only support our conclusion, that *each individual association came into existence rather recently; it consists of stars which diverge from some primary volume where they have originated.*

However the differential effect of the Galactic rotation can produce expansion solely within the Galactical plane. If this was the only cause of expansion, then the associations would very soon acquire highly flattened shapes.

It should be stated, that the rate of possible expansion of an association due to differences in the periods of oscilatory movements of its members along Z axis should be much lower.

The reason for this lies in the asymptotical independence of the oscilation periods and the amplitudes, for smaller values of amplitudes. Recall, that for a star at the hight z above the Galactic plane

$$\frac{d^2z}{dt^2} = -2\pi G \int_{-z}^{z} \rho(z)\, dz,$$

where $\rho(u)$ is the Galactic density at height u.

For smaller values of z this reduces to

$$\frac{d^2z}{dt^2} = -2\pi G\rho(0)\,z$$

i.e. we have harmonic oscilations with period and amplitude mutually independent.

Since the associations which we observe are situated at low Galactic latitudes, their stars necessarily have almost equal oscilation periods in z coordinate.

Therefore the effect we consider is rather small as compared with the effect of differential rotation. Meanwhile observations do not show any considerable flatness in systems of the above examples. This compells us to think that there must be another cause of expansion, which prevails over Galactical rotation. We can suppose that the stars of the association have left the initial volume where they have formed, with certain velocities in different directions.

These initial velocities had to be not less than 1km/sec. In the countary case the effect of differential rotation should be evident for associations , whose sizes are several dozens parsecs. On the other hand they should be less then 10 km/sec, for greater initial velocities would have reflected in the distribution of radial velocities at present epoch, for instance in the association around NGC6231.

If the distance from center of association increases at a rate of 5km/sec, then the differential effect of Galactic rotation will fail to dominate until the sizes of the association reach several hundred parsecs. But such sizes would mean complete dissolution of the association among the field stars, i.e. the end of the association .

Consequently flattening of the associations would not be observed. Therefore the expansion velocities of 5km/sec by order are most likely. We come to the conclusion, that T Tauri type stars in the association in Taurus – Auriga were expelled from a primary volume several millions years ago, and the stars of the association around χ Perseus 10- 20 millions years ago, etc.

Expansion of an association begins without delay after the birth of its star members, since the assumption that the system spent considerable time in a stationary state before the expansion began contradicts stellar dynamics. This implies that the age of stars in the associations is measured by millions or at most by tens of millions of years.

This estimate is in good agreement with the fact, that in associations we find stars of P Cygni, Walf–Rayet or T Tauri type. A star can not remain in P Cygni state more than one or two million years, as determined by high emission rate of matter. On the other hand P Cygni stars possess not only maximal luminocities among the known stars, but also, probably, maximal masses as well. If other states, which correspond to greater or equal masses, exist, then their life length should be rather short, for such masses are extremely rare. But P Cygni type stars could not develope from stars possessing lesser masses. Consequently they should be ranked among the youngest stars.

Number of stellar associations in Galaxy

At present it is difficult to give a definite answer to the question concerning the number of stellar associations in the Galaxy. Associations, containing supergiants of early type, can be discovered on rather great distances (about 2000–3000 parsecs). Therefore a considerable fraction of them can be observed. Probably such observable associations are several dozens in number. This means that the total number of such associations in the Galaxy is of the order of one hundred. As for associations consisting of T Tauri type stars and other dwarfs with bright spectral lines, we know at present only two.

However both lie at rather short distances. In a ball of 100 parsecs radius there is one such association . This suggests that in the Galaxy they number in thousands.

Assume that this number is 10000 say. Also take into account that these associations remain detectable for a period of several million years. Then we have to conclude that in order to keep their present level, at least one association consisting of T Tauri type stars should be generated in 1000 years on the average.

The question of formation of stars

Some astronomers have been putting forward a hypothesis that all stars in the Galaxy have been born simultaneously or almost simultaneously several billions years ago i.e. together with formation of our Galaxy. The above facts bring this hypothesis to a collapse. The birth of stellar associations and formation of stars within the latter from some other form of matter goes on contineously almost before our eyes. The number of associations consisting of T Tauri type stars which emerge during the lifetime of an association is of the order of ten thousand. For the time being we do not know the mean number of stars born within an association for we can identify only the brightest members. However it seems reasonable that this number equals at least several hundreds.

This means that at least billion of stars in our Galaxy were formed as a result of development of stellar associations from some other objects which remain unknoun to us.

Possible other types of associations

It is highly probable that the system of B and O type stars in Orion together with Trapezium make up as a single giant association whose diameter exceeds 100 parsecs. The stars of Trapezium and the connected open star cluster apparently form the nucleus of this association . The presence of a giant diffuse nebula makes this system especially interesting and deserving thorough study. The moving cluster of Ursus Major is a system of 32 members more than 200 parsec in diameter.

The nucleus of this system is a subgroup of 11 stars nine parsec in diameter. However the system lacks direct indications of young age of the entering stars. Probably this small system is a remnant of a formerly rich association . The sun is situated in the interior of this system, but fails to be a member.

Conclusions

This article establishes the existence in the Galaxy of a great number of stellar associations, i.e. stellar systems of low density, unstable and dispersing in the Galactical space. The great role of stellar associations in the questions of the development of stars is evident. Therefore they deserve most thorough study.

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