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Abstract

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ON THE CONTINUOUS FORMATION OF STARS IN O-ASSOCIATIONS

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According to the theory of stellar associations developed by V. A. Ambartsumian ([1], [2]), the stars of the flat subsystems of the Galaxy are formed in these systems. As a result of expansion and the subsequent disintegration of stellar associations, the stars being formed subsequently enter the general galactic field. At any moment in the life of an association, a definite distribution of stars should therefore be observed around its nuclei, determined by the dependence, existing up to that moment, of the intensity of star formation on time.

The presence of several nuclei in individual associations distorts the expected distribution within the volume of the associations, while the small number of O—B stars, the most characteristic members of O-associations, makes it difficult to derive the distribution of the partial stellar density around the nuclei of stellar associations.

In the author' s work ([3]), after a formal transformation of the totality of all O—B1 stars into a single one-nucleus association by superposing the subsystems around the nuclei upon one another, a law was derived for the distribution of stellar density within such a superposition of stellar associations from the density distribution in projection on the celestial sphere. It turned out that the partial density ρ of O—B1 stars decreases in proportion to r^3—the third power of the distance from the center of the summed system. The law obtained, $\rho \sim r^{-3}$, makes it possible to draw certain conclusions about the intensity and rates of development of stars in stellar associations.

If the Galaxy is regarded as stationary during the time of disintegration of a single association, then the flux of stars from the center of the constructed summed association must satisfy the condition of stationarity

$$\rho r^2 V = \text{const},$$

where V is the velocity of removal of stars from the nuclei. If, in addition, it is assumed that V in the summed association does not depend on r, then for the distribution of the summed stellar density around the nuclei one obtains the law

$$\rho \sim r^{-2}.$$

This law is valid for the entire set of stars produced by the nuclei. In cases where consideration is limited only to a certain class of stars, as in our case, one must take into account the influence of the process of stellar aging—their transition into later spectral classes.

The departure of stars from the set under consideration as a result of their aging with increasing distance from the generating nuclei leads to a steeper decrease of stellar density than in the law r^{-2}. From the deviation of the observed law from the expected r^{-2} one may judge the rates of development of stars in stellar associations.

There are, however, other factors that increase the deviation. For example, among the nuclei of stellar associations there may exist comparatively stable multiple stars and star clusters, which do not disintegrate immediately on the cosmic time scale. For this reason the stellar density must decrease more rapidly. The influence of this factor on the law of distribution of stellar density around the nuclei cannot at present be even approximately estimated. It may be assumed, however, that it is insignificant. A much more effective factor is the existence of a dependence of the velocity V on the distance r, which we shall consider in more detail.

The non-simultaneity of the departure of stars from the nuclei of associations, and possibly also from an individual nucleus, and the existence of a considerable dispersion in the velocities of departing stars (^4) should lead to a definite dependence of the mean expansion velocity on the distance from the nuclei.

Qualitatively this is confirmed by Table 1, compiled from the data of (^4) and containing material on the aggregate of O—B0.5 stars with known radial velocities, transformed into a single-nucleus association. It gives: the mean distance from the nucleus $\bar{r}$; the number of stars N; the mean residual radial velocity (absolute value) $|\bar{V}_r|$, freed from the differential effect of Galactic rotation and from the K-effect.

Table 1

$\bar{r}$, kpc	N	$\lvert\bar{V}_r\rvert$, km/sec	t, years
0.05	67	9.3	$2.7 \cdot 10^6$
0.20	85	10.4	$9.6 \cdot 10^6$
0.45	81	13.3	$1.7 \cdot 10^7$
0.80	42	15.4	$2.6 \cdot 10^7$
1.25	21	19.1	$3.3 \cdot 10^7$
2.40	28	22.1	$5.4 \cdot 10^7$

With the aid of $|\bar{V}_r|$ the mean expansion velocity of associations is determined by the formula (^5)

$$\bar{V} = 2|\bar{V}_r|.$$

Figure 1

Figure 1: Figure 1

Table 1 presents the "mean age" of the stars, determined from the relation

$$t = \left(\frac{\bar{r}}{\bar{V}}\right) \simeq \frac{\bar{r}}{\bar{V}} = \frac{\bar{r}}{2|\bar{V}_r|}.$$

It should be emphasized that the data of Table 1 can be regarded only as qualitatively confirming the expected behavior of the expansion velocity and of the "mean age" of the stars as a function of distance from the nuclei. Quantitatively, they contain a number of unaccounted-for systematic errors that lead to a distortion of the true values of $\bar{r}$, $\bar{V}$, and t, in particular to a considerable overestimate of the first two (the dispersion of absolute magnitudes, nonstationary motions of the nuclei and associations in the Galaxy, gravitational braking, etc.).

Fig. 1. Laws of distribution of stellar density: **1** –observed ($\rho \sim r^{-3}$), **2** – $\rho \sim r^{-2}$, and **3** –observed, corrected for the velocity gradient ($V_{400} = 2V_{25}$)

It is easy to see that the observed variation of the velocity V with distance r increases the deviation of the law of distribution of stellar density around the nuclei from the law r^{-2}. The measure of the increase is determined by the velocity gradient.

Figure 1 presents the observed law of distribution of stellar density r^{-3} (1) and the law r^{-2} (2). The straight line 3 passing between them represents the intermediate case, when the law r^{-3} is freed from the influence of the velocity gradient. It corresponds to such a velocity gradient that the mean velocity at a distance of 400 pc from the nuclei (V_{400}) is twice the mean velocity at a distance of 25 pc (V_{25}). In all three cases the stellar density at a distance of 25 pc was taken to be the same.

Taking the velocity gradient into account, the stationarity condition is written in the form

$$\rho(r) r^2 V(r) = f(r).$$

With the aid of this condition, if one neglects the influence on the distribution of stellar density of the presence of comparatively stable nuclei in stellar

associations, one can estimate the fraction of stars, among all stars of a given class that have left a sphere of radius r_0 around the nuclei, which reaches a distance r while remaining in the class under consideration.

Obviously, this fraction is determined by the relation

$$D(r, r_0) = \frac{f(r)}{f(r_0)} = \frac{\rho(r) r^2 V(r)}{\rho(r_0) r_0^2 V(r_0)}.$$

Table 2 gives the results of calculating $D(r, r_0)$ for two cases: $r_0 = 10$ pc and $r_0 = 25$ pc, for the observed law of the distribution of stellar density around the nuclei $\rho(r) \sim r^{-3}$, both with and without allowance for the effect of the velocity gradient ($V = \text{const}$). The subscripts on the mean expansion velocity V continue to indicate the corresponding distances. For $r_0 < 10$ pc such calculations apparently have no physical meaning, since as $r \to 0$ the stellar density increases without bound for any n in the law $\rho(r) \sim r^{-n}$.

Table 2

r, pc	$D(r, 10)$ $V =$ const	$D(r, 10)$ $V_{400} = 2V_{10}$	$D(r, 10)$ $V_{400} = 3V_{10}$	$D(r, 25)$ $V =$ const	$D(r, 25)$ $V_{400} = 2V_{25}$	$D(r, 25)$ $V_{400} = 3V_{25}$
10	1.00	1.00	1.00	–	–	–
25	0.40	0.50	0.58	1.00	1.00	1.00
75	0.13	0.22	0.29	0.33	0.44	0.51
125	0.08	0.15	0.22	0.20	0.30	0.38
225	0.04	0.10	0.15	0.11	0.19	0.27
400	0.03	0.06	0.11	0.06	0.13	0.19

The data of Table 2 permit a rough estimate of the rates of evolution of O—B1 stars. For example, one may assume that the "mean age" of a star of a given class is determined by the time interval required for the aging of half of all stars of this class—that is, for their leaving the class. Then, from the data of Table 2, this "mean age" can be determined for O—B1 stars. Indeed, for permissible velocity gradients, on average half of all O—B1 stars that have left a sphere of radius 10 pc reach a distance of 25 pc after becoming older (Table 2), while half of the stars that have left a sphere of radius 25 pc "age" approximately out to 75 pc. Thus, the "half-life" corresponds to the time in which a star traverses a distance of 15 pc in the first case and 50 pc in the second.

If, in a rough approximation, one assumes that the velocity of motion is about 5 km/sec in the first case and approximately one and a half times greater in the second case, then for the "half-life" one obtains values of, respectively, $3 \cdot 10^6$ years and $7 \cdot 10^6$ years. These estimates agree well with other independent estimates of the ages of O—B0 stars ([6,7]). As for the B0—B1 stars included in our consideration, analogous estimates can be obtained using the data of the last rows of Table 2. They turn out, as was to be expected, to be on average almost an order of magnitude larger ($2 \cdot 10^7$—$5 \cdot 10^7$ years).

In conclusion, it should be noted that the discussion presented above supports the idea of the continuous formation of stars in stellar associations, at least during the period of formation and development of present-day stellar associations in the Galaxy. At the same time, it shows that the observational data are in agreement with the conclusions of the theory of stellar associations concerning the expansion and subsequent disintegration of these systems.

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Note: Figure translations are in progress. See original paper for figures.