DOUBLE GLOBULAR CLUSTERS IN THE GALAXY?

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Abstract. Four pairs of 'visual double' star clusters with the lowest mass-to-luminosity ratio have been selected among globular clusters of our Galaxy. By taking into accounts the effects of dynamical friction and compressive gravitational shocks, we conclude that the probability for the pairs to be gravitationally bound is very low.

1. Introduction

There are double stars and double galaxies. But are there double star clusters? This question is not trivial, because double star systems, like double stars, contain very important information about the physical properties and the dynamical histories of the systems.

The existence of double open clusters in our Galaxy is evident (Denoyelle *et al.*, 1990). A few years ago a discussion was begun on the existence of multiple open clusters, including double ones (Barkhatova and Pavlovskaya, 1981; Barkhatova *et al.*, 1981). The systems were found, but very often the age of the systems does not exceed their dynamical time (= crossing time), thus leaving open the problem of stability of the systems. In any case, the systems attract our attention from the point of view of the genesis of the young stellar aggregates and of the origin of the larges star-forming objects – i.e., star complexes (Efremov, 1982, 1984).

The existence of binary star clusters in the Large Magellanic Cloud has been recently suggested by Hatzidimitriou and Bhatia (1988) and Bhatia and Hatzidimitriou (1988). If we take into account the age and the stellar population of the clusters, they are similar to the open clusters of our Galaxy. A statistical study of the close pairs of clusters (center-to-center separation smaller than 18 pc) in the LMC, leads to the conclusion that projection effects cannot account for a significant number of such pairs. Photometric observations of some of these clusters, the spectral properties of their stars, and the surface density profiles of the pairs, showed that clusters belonging to the same pair often have very similar ages and are, probably, physically associated (Kontizas *et al.*, 1989).

The problem of binarity of globular clustes is also important. If the result of the search of double clusters will be positive, we will obtain a new method to measure the mass of globular clusters. If not – this will give us additional material for the present picture of the origin and evolution of globular clusters.

As an example of 'visual double' globular cluster the pair M10/M12

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(NGC 6254/6218) was discussed a few times (Buonanno *et al.*, 1973). These clusters are extraordinary alike: they have very similar luminosities, diameters, degree of concentration, and metallicity. The angular distance between the clusters in 3.3° and their spatial separation is about 0.8 kpc (data by Thomas, 1989). There are other pairs of globular clustes, as it will be shown, which are not so similar for what physical parameters are concerned, even though they are considerably closer.

2. Dynamical Characteristics of Candidate 'Double Clusters'

In an attempt to investigate the binarity of globular cluster pairs, we undertook a dynamical study of the most probable candidate pairs selected from the Kukarkin (1974) catalogue. All possible combinations of the clusters into pairs were considered, and the minimum dynamical mass of the pairs was calculated by means of two independent methods:

(1) from the energy equation

$$M_1 = \frac{\Delta v_r^2 \Delta R}{2G}, \tag{1}$$

(2) from the tidal stability criterion (Spitzer, 1987)

$$M_2 = A M_G \left(\frac{\Delta R}{R}\right)^3, \tag{2}$$

where M_1 and M_2 are the minimum total mass of the pair; ΔR, the spatial separation of the clusters forming the pair; R, the distance of the barycenter of the pair from the galactic center; M_G, the mass of the Galaxy inside R; Δv_r, the radial velocity differences between the clusters; G, the gravitational constant; and the constant A depends on the mass distribution in the Galaxy and on the shape of the clusters orbit.

For this calculations we assumed a simple model of the Galaxy, with constant rotational velocity:

$$M_G = 10^{10} M_\odot \left(\frac{R}{1\ \text{kpc}}\right). \tag{3}$$

In this model the minimum value of the constant in Equation (2) is $A = 1$ (Rastorguev and Surdin, 1978). Taking into account the low accuracy in evaluating the distances, we can put low limits on the mass of the pairs by means of substituting ΔR with $\Delta R_{\min} = D \sin \alpha$, where D is the mean distance of the pair from the Sun, and α is angular separation between the clusters forming the pair. The resulting equations for the minimum masses are:

$$M_1 = \frac{\Delta v_r^2 D \sin \alpha}{2G}, \tag{4}$$

$$M_2 = 10^{10}\,M_\odot \left(\frac{R}{1\ \text{kpc}}\right)\left(\frac{D \sin\alpha}{R}\right)^3 . \tag{5}$$

It is obvious that the absolute low limit of the total mass is also the maximum value for the two: i.e.,

$$M_{\min} = \max\{M_1, M_2\} . \tag{6}$$

If we use coordinates and velocities of the globular clusters, compiled in Thomas (1989) catalogue, we calculated the values of M_1, M_2, and $M_{\min}$ for all combinations of galactic globular clusters in pairs. Distance to the galactic center was assumed to be $R_0 = 10$ kpc. Data for four pairs with minimum mass-to-luminosity ratio smaller than $10^4\ M_\odot/L_\odot$ are presented in Table I. In a previous publication (Surdin, 1988) due to a computer error was also included a fifth pair – NGC 6749/6760.

TABLE I

Dynamical properties of the 'visual double' globular clusters

Pair (NGC)	6218/6254	6266/6304	6522/6528	6553/6626
D, kpc	4.9	6.0	6.7	5.7
R, kpc	6.2	4.1	3.3	4.4
ΔR, kpc	0.8	0.4	0.2	0.4
α, deg	3.3	3.0	0.27	3.6
$\Delta R_{\min}$, kpc	0.28	0.31	0.032	0.36
Δv_r, km s^{-1}	119	15	171	32
M_1, $10^6\ M_\odot$	440	77	100	41
M_2, $10^6\ M_\odot$	5.7	18	0.03	24
$M_{\min}$, $10^6\ M_\odot$	440	18	100	41
$M_{\min}/L_V$, $M_\odot/L_\odot$	2000	54	1000	200
t_{df}, 10^8 yr	2	20	2	9
t_{sh}, 10^8 yr	100	1	3000	2

3. Can the Mass of Globular Clusters Be so Large?

As we can see, minimum pair's mass $M_{\min}$ is considerably larger than what is generally accepted for the mass of single globular clusters, which are usually obtained by means of radial velocity dispersion measurements of the stars in the cluster and giving mass-to-luminosity ratio in the central region of the globular clusters $M/L = (1–3)\ M_\odot/L_\odot$ (Illingworth, 1976). For our hypothetical double clusters we obtain $M/L \sim 10^2–10^3$. This value is of the same order of the mass-to-luminosity ratio for galaxies and clusters of galaxies with dark matter (Fukugita, 1990). By analogy we could assume that also globular clustes have extended dark halos. Actually, the vlaue of M/L is measured usually within the half-mass radius r_h of the cluster. For the pairs selected in Table I, the ratio of $\Delta R_{\min}$ to the sum of the radii r_h is from 11 to 74. Consequently, for the least concentrated distribution of dark matter $\rho(r)$ = const., which in principle is not forbidden, we may obtain in the inner parts of the clusters ($r < r_h$) a ratio $M/L \sim 1$ without contradicting the observations. Moreover, there is a method to measure the total mass of star cluster from their gravitational effect on the movements of field stars. Up to now, the method was used only for the globular cluster ω Cen and led to a very interesting result: $M/L \sim 10^2$ (Naumova and Ogorodnikov, 1974; Antonov *et al.*, 1975; Naumova, 1975). However, we must note that the reliability of the value is very low, so far as the accuracy of observational material obviously does not correspond to the requirements of the method. In any case, observational tests do not prohibit the existence of large missing mass inside the cluster's haloes and, consequently, they also do not exclude the existence of gravitationally bound pairs of globular clusters.

4. Dynamical Evolution of Double Clusters

Two main factors of dynamical evolution of double globular clusters will be considered: dynamical friction (Tremaine *et al.*, 1975; Surdin and Charikov, 1977) and compressive gravitational shocks, that is gravitational perturbations resulting from the passage of a double cluster through the galactic disk (Ostriker *et al.*, 1972; Surdin, 1979). For single star cluster exist also one more important factor of dynamical evolution, namely, the escape of stars. But in the case of double cluster systems this factor can be neglected, because the dissipation time for so massive star systems in the Galaxy is very long (Surdin, 1978).

Under the action of dynamical friction the massive object looses its orbital momentum and falls down into the galactic center. If M is the mass of the object, R is the initial value of the apogalactic distance, and the initial eccentricity of the orbit is $e = 0.5$–0.7 (typical value for globular clusters (Rastorguev and Surdin, 1978)) then the time of fall is

$$t_{df} = 2 \times 10^7 \left(\frac{R}{1\ \text{kpc}}\right)^2 \left(\frac{M}{10^8\, M_\odot}\right)^{-1} \text{yr}\,. \tag{7}$$

The time for $M = M_{\min}$ is given in the 12th line of Table I.

Under the action of compressive shocks double cluster must be destroyed. The characteristic time of the destruction may be computed on the impulsive approximation if we assume, that $\Delta R_{\min}$ is the mean random projected distance between clusters

$$t_{sh} = \frac{GMPv_z^2}{4\Delta R_{\min}^3 g_m^2}\,, \tag{8}$$

where M is the total mass of the double system; P, the galactocentric orbital period of the system; v_z, z-velocity when the system is approaching the galactic plane; and g_m, the maximum value of the gravitational z-acceleration due to the galactic disk. We may assume that in the case of thin disk

$$g_m = 2\pi G\sigma\,, \tag{9}$$

where σ is the surface density of the disk. In this case, for the exponential model of the disk (van der Kruit, 1987; Gould, 1990)

$$\sigma = 370 \exp(-R/5\,\text{kpc}) M_\odot\,\text{pc}^{-2}\,, \tag{10}$$

from Equations (3), (8), (9), and (10) we obtain

$$t_{sh} = 7 \times 10^5 \left(\frac{M}{10^8\,M_\odot}\right)\left(\frac{\Delta R_{\min}}{1\,\text{kpc}}\right)^{-3}\left(\frac{R}{1\,\text{kpc}}\right)\exp\left(\frac{R}{2.5\,\text{kpc}}\right)\text{yr}\,. \tag{11}$$

The time for $M = M_{\min}$ is given in the 13th line of Table I.

5. Conclusions

As one can see from Table I, cooperative evolutionary effect produced by dynamical friction and compressive gravitational shocks lead to very short evolutionary time ($\leq 2 \times 10^8$ yr) for massive double clusters. Therefore, we believe that 'visual double' globular clusters are not gravitationally bound and, consequently, that there are no physical double clusters among the old star clusters of our Galaxy. All double clusters in LMC are very young. This is, probably, a common property for the systems of star clusters and is connected with their dynamical evolution.

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