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New empirical dependences for globular cluster systems

I.U. Tadjibaev*, S.N. Nuritdinov

Physical faculty, National University of Uzbekistan, Vuzgorodok, Tashkent, 100174, Uzbekistan

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The work presents results of a statistical analysis of our new compiled catalog of 441 globular cluster systems (GCS) of different types of Hubble galaxies. New empirical dependences are revealed between basic physical parameters of GCS and their parental galaxies for the main morphological types of galaxies of the Hubble sequence. Concrete dependences of the absolute magnitude on the morphological type code for S and SB-galaxies are also found.

Keywords: Galaxies, globular cluster systems, empirical dependences

1. Globular star clusters are most unique objects in the Universe and in the problem of comparing two scenarios of the origin of galaxies: a cascade fragmentation and the hierarchical clustering. Moreover, according to modern observations, almost all types of galaxies of the Hubble tuning fork contain some globular cluster systems (GCS) in varying degrees. Many works have been published on the results of the search, processing observational data of individual galaxies and compiling their list in the world literature. Thus the first list of GCS, comprising 60 systems, was published in 1991 by Harris (1991). In the work of Ashman and Zepf (1998) this list was brought up to 82 systems, in the next work (Tadjibaev et al. (2013)) – up to 252 systems, and in the following work (Harris et al. (2013)) their number reached confidently about 400 objects after exclusion of some repetitions. However the electronic catalog of Harris et al. (2013), as distinct from our compiled catalog of 441 GCS (Nuritdinov et al. (2014)), does not contain the data on metallicity at all. The data of the electronic catalog of Harris et al. (2013) have not been processed up to now.

We note that up to our papers (Nuritdinov and Tadjibaev (2014); Nuritdinov et al. (2014); Tadjibaev et al. (2015)) in the literature there was no analysis of available quite extensive observational data; no reliable empirical dependence between their basic physical parameters for elliptical and spiral galaxies have been found, and a classification of GCS was absent. So up to now there are no attempts to define some kinematic and dynamic parameters of these systems and a reliable theory of the origin and evolution within the frames of reference of the early collapse of galaxies.

*Email: ikram@mail.ru

In the work of Nuritdinov and Tadjibaev (2014) analysis of the observational data and the search for empirical dependences were performed on the basis of our compiled catalog (Tadjibaev et al. (2013)) of 252 GCS. At that time because of insufficiency of the data for statistical processing GCS of spiral, irregular and dwarf galaxies, the study of Nuritdinov and Tadjibaev (2014) was carried out only for the elliptical and lenticular galaxies. Therefore, we had significantly expanded our compiled catalog both horizontally and vertically and the latest data were published in the work of Nuritdinov et al. (2014). In the work of Tadjibaev et al. (2015) for the first time we were able to perform the analysis of observational data for the spiral and dwarf galaxies. However, within our compiled catalog of Nuritdinov et al. (2014) of 441 GCS, this work for elliptical, lenticular, and irregular galaxies has not been implemented so far. Below we briefly give the main results of the statistical analysis of the new catalog for all types of galaxies.

2. From the point of view of the physics of GCS, it is important to determine a dependence of their metallicity on the absolute magnitude of the parental galaxy.

Our analysis of observational data on certain types of galaxies has shown that the metallicity is linearly dependent on the absolute magnitude of the parental galaxy:

$$[Fe/H] = -2.91\,(\pm 0.42) - 0.09\,(\pm 0.02)\,M_V \qquad \text{(for E galaxies)}, \tag{1}$$

$$[Fe/H] = -4.22\,(\pm 0.79) - 0.16\,(\pm 0.04)\,M_V \qquad \text{(for S0 galaxies)}. \tag{2}$$

It should be noted that for lenticular galaxies dependence on metallicity of GCS on M_V was interesting primarily for the authors of the work of Kundu and Whitmore (2001). These authors found a dependence that is close to dependence (2).

However, for a relatively precise definition of analogous dependences for spiral and dwarf galaxies today we have a shortage of observational data about metallicity of GCS. Despite this, we have tried to assess these dependences and found that,

$$[Fe/H] \approx -8.84\,(\pm 2.43) - 0.36\,(\pm 0.11)\,M_V \qquad \text{(for S galaxies)}, \tag{3}$$

$$[Fe/H] \approx -3.93\,(\pm 0.25) - 0.15\,(\pm 0.01)\,M_V \qquad \text{(for dE galaxies)}. \tag{4}$$

And for irregular galaxies the determination of the dependence of the GCS metallicity on the absolute magnitude of the parental galaxies is not possible yet because of the insufficiency of observational data.

So the dependences found by us have show that if the absolute magnitude of the parental galaxy is brighter then the metallicity of GCS increases by an average. Errors in the determination of the coefficients of these dependences are quite acceptable.

3. Analysis of the dependence of the absolute magnitude of the parental galaxy on the number of globular clusters has shown an increase in the number of clusters in the system of the absolute magnitude. We have found the logarithmic dependence between these parameters for different types of galaxies separately: for elliptical galaxies

$$\lg N_{GC} = -4.48\,(\pm 0.22) - 0.35\,(\pm 0.01)\,M_V, \tag{5}$$

and for lenticular galaxies

$$\lg\, N_{GC} = -6.27\,(\pm 0.50) - 0.42\,(\pm 0.03)\,M_V. \tag{6}$$

It is obvious that for spiral, irregular and dwarf galaxies the values of their absolute magnitude must be also correlated with the number of globular clusters in the system. There is a reasonable dependence of the absolute magnitude on the number of globular clusters in the GCS for spiral, irregular and dwarf galaxy types. Calculation of this statistical dependence has given following results:

$$\lg N_{GC} = -3.43\,(\pm 0.46) - 0.27\,(\pm 0.02)\,M_V \qquad \text{(for S galaxies)}, \tag{7}$$

$$\lg N_{GC} = -2.79\,(\pm 0.34) - 0.24\,(\pm 0.02)\,M_V \qquad \text{(for dE galaxies)}, \tag{8}$$

$$\lg\ N_{GC} = -2.365\ (\pm 0.706)\ - 0.195\ (\pm 0.045)\ M_V \qquad \text{(for Irr galaxies)}. \tag{9}$$

From these dependences we can say confidently that every time the greater the number of clusters in GCS, the brighter the absolute magnitude of the parental galaxy is.

4. We also analyzed statistical dependences of the number of elliptical galaxies with the given value of compression n on the degree of compression. Simultaneously by means of the method of least squares, we found the following empirical dependence of N on compression of elliptical galaxies n:

$$N = 39.04\ (\pm 4.03) - 3.95\,(\pm 0.80)\ n. \tag{10}$$

We are also interested in the dependence of the number of dwarf elliptical galaxies on the degree of compression:

$$N = 15.21\,(\pm 2.97) - 1.38\,(\pm 0.59)\,n. \tag{11}$$

As can be seen, in both cases ((10) and (11)) the number of elliptical galaxies decreases with increase of their degree of compression within the context of the linear law.

It is clearly seen that with increase in compression of elliptical galaxy the logarithm of the average number of clusters in them decreases in the average. By means of the method of least squares we found this dependence in the following form:

$$\lg < N_{GC} > \ = 3.83\ (\pm 0.14) - 0.23\,(\pm 0.03)\ n. \tag{12}$$

Analysis of data on spiral galaxies has shown that GCS are contained at first glance in almost all types of S galaxies, and about 50% of these objects present the galaxies as Sb, Sc, SBb and Sbc. In contrast, spiral galaxies such as Sd, Sdm, Sm, SBa, SBab, SBcd and SBdm contain almost no GCS, or contain within the errors of their identification. In order to identify the degree of richness of clusters in GCS in the galaxy type we have considered the distribution of the average number of types of objects in the system. From here we conclude that for normal spiral galaxies with increasing degree of twist of the spiral arms, the average number of globular clusters in them is clearly increased gradually:

$$\lg < N_{GC} >= 2.95\,(\pm 0.25) - 0.24\,(\pm 0.06)\,T_n, \tag{13}$$

where T_n is the value of the morphological type code of the normal spiral galaxy according to the HyperLeda. This effect may be connected with the discovery that

for clusters, the case of wide-open spiral arms differs from the case of tightly twisted aims. We are still not able to determine the dependence of $< N_{GC} >$ on the value of morphological type code of spiral galaxies with bar (SB) with sufficient accuracy.

Further, we tried to obtain the dependence of the absolute magnitude M_V on the value of the morphological type code T for all spiral galaxies in general. So we get the following result:

$$M_V = -22.00\,(\pm 0.50) + 0.50\,(\pm 0.09)\,T. \tag{14}$$

Here, although the coefficient in front of T has not the desired error but the law (14) is quite clear. This dependence should be defined for normal and barred galaxies separately. So we obtained the following respectively:

$$M_V = -22.57\,(\pm 0.62) + 0.61\,(\pm 0.13)\,T \qquad \text{(for S galaxies)}, \tag{15}$$

$$M_V = -20.84\,(\pm 0.89) + 0.35\,(\pm 0.14)\,T \qquad \text{(for SB galaxies)}. \tag{16}$$

As it can be clearly seen, these dependences for the S and SB galaxies differ in the coefficients significantly.

We should note that here all the dependences for spiral galaxies are found by us for the first time, but according to the analysis of specific values and determination of the necessary dependencies, unfortunately, there is still some dissatisfaction about the values of individual magnitudes for many GCS of spiral galaxies, since it is clear that they are found from approximate observations.

5. In this study, we performed the following:

(a) We implemented a statistical analysis of our compiled catalog of 441 GCS.

(b) New empirical linear dependences are found between the GCS metallicity and the absolute magnitude of parental galaxy for the cases of elliptical, lenticular, spiral and dwarf galaxies.

(c) New logarithmic dependences are obtained between the number of globular clusters in the system on the absolute magnitude for elliptical, lenticular, spiral, dwarf and irregular galaxies.

(d) Concrete dependences are found of the absolute magnitude on the morphological type code for S and SB galaxies.

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