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DATA ANALYSIS OF SPACE OBSERVATIONS OF GLOBULAR CLUSTERS

Annotation

We have performed an analysis of observational data on the apparent surface density of 81 globular clusters obtained within the framework of the GAIA DR2 space program and published in the work of de Boer et al (2019). We first studied the quality of GAIA DR2 observational data in comparison with similar data obtained by HST. Using our 3-parameter model, previously tested on the example of HST space observation data, we found the values of the parameter of star concentration to the center of the cluster. To do this, it was first necessary to divide the GAIA data into four groups and compare their quality from a number of physical considerations. We investigated the dependence of the concentration parameter of GCs found by us on the basic characteristics of these objects. The results obtained confirm the validity of the previous classification of GCs according to the degree of star concentration to the center of the cluster.

Keywords: globular clusters, visible surface densities, space observations, concentration parameter.

АНАЛИЗ ДАННЫХ КОСМИЧЕСКИХ НАБЛЮДЕНИЙ ШАРОВЫХ СКОПЛЕНИЙ ЗВЕЗД

Аннотация

Мы выполнили анализ данных наблюдений видимой поверхностной плотности 81 шарового скопления, полученных в рамках космической программы GAIA DR2 и опубликованных в работе de Boer et al (2019). Нами изучено качество данных наблюдений GAIA DR2, используя нашу 3-х параметрическую модель, апробированную ранее на примере космических данных наблюдений HST. С этой целью сначала потребовалось разделить данные GAIA на четыре группы и сравнить их качество из ряда физических соображений. Исследована зависимость найденных нами параметра концентрации ШС от основных характеристик этих объектов. На основе полученных нами резултатов, мы предлагаем классификацию ШС по степени концентрации звезд к центру скопления.

SHARSIMON YULDUZ TO‘DALARINING KOSMIK KUZATUV MA'LUMOTLARI TAHLILI

Annotatsiya

Biz GAIA DR2 kosmik dasturi doirasida olingan va de Boer et al. (2019) ishida nashr etilgan 81 ta sharsimon yulduz to’dalari (ShYT)ning ko'rinma sirt zichligi bo'yicha kuzatuv ma'lumotlarini tahlil qildik. Biz birinchi navbatda GAIA DR2 kuzatuv ma'lumotlarining sifatini HST tomonidan olingan shunga o'xshash ma'lumotlar bilan taqqoslab o'rgandik. Ilgari HST kosmik kuzatuv ma'lumotlari misolida sinovdan o'tgan 3 parametrli modelimizdan foydalanib, biz konsentratsiya parametrining to’da markazigacha bo'lgan qiymatlarini topdik. Buning uchun birinchi navbatda GAIA ma’lumotlarini to'rt guruhga bo'lish va ularning sifatini bir qator jismoniy jihatlardan solishtirish kerak edi. Biz topilgan ShYT larning kontsentratsiya parametrining ushbu ob'ektlarning asosiy xususiyatlariga bog'liqligini tekshirdik. Olingan natijalar klaster markaziga yulduz kontsentratsiyasi darajasi bo'yicha GK larning oldingi tasnifining to'g'riligini tasdiqlaydi.

Ключевые слова: шаровые скопления, видимые поверхностные плотности, космические наблюдения, параметр концентрации.

Introduction. To date, 157 globular clusters (GCs) of stars have been identified, but far from all of them have been observed for surface density using space telescopes. Initially, ground-based methods of photographic astrometry and stellar astronomy were used to determine the structural parameters of GCs (see, for example, [1, 2-4]. Since the number density towards the center of GCs increases rapidly, it is difficult for ground-based telescopes to analyze their central region (for details see, for example, [5]) and CCD observations are necessary. In rare cases, several deep observations of the surface density of specific GCs were carried out [6]. As of today, one can note the observational data on the surface density for 26 GCs, carried out within the framework of the HST space program and published [7], as well as data from the GAIA DR2 space program processed [8]. Nuritdinov et al. (2022) [9] found values of the degree of concentration parameter for these 26 GCs and for the first time proposed a classification of GCs that solves the problem of Shepley-Sawyer (1927) [1]. Naturally, the question arises: how much can the values of the degree of concentration parameter differ for other GCs? Unfortunately, there are no data for other GCs within the framework of the HST program. That is why it is necessary to analyze and calculate the concentration parameter for 81 GCs provided by the GAIA DR2 Space Program [8]. Despite the fact that the quality of these data is somewhat inferior to HST data, we have studied each GC in sufficient detail. An analysis of the quality of the observational data and the behavior of the surface density for 81 GCs shows the need to divide them into four groups (see Section 2 below). It turned out that only for one of them it makes sense to determine the values of the GC concentration degree parameter and the corresponding empirical formulas for the dependence of this parameter on the main physical characteristics of the clusters. The values of correlation coefficients between the concentration parameter and individual physical characteristics obtained from observations were found, including with the mass of GCs, absolute magnitude, King’s parameter [10] and GC index of richness (IR) [11]. During the analysis of the problem, the main differences between GAIA DR2 and HST observational data were studied in detail.

Analysis of GCs observation data within the GAIA DR2 program. Observational data on the surface density of GCs obtained by space telescopes within two programs (GAIA DR2 and HST) differ significantly in quality from each other. Below we will try to indicate these differences one by one. Let’s start with the fact that 20 GCs were observed by both GAIA DR2 and HST. The surface density profiles of most of these GCs obtained from different space telescopes clearly differ in star concentration, data uniformity and smoothness of apparent surface density. It is known that the concentration of stars in globular clusters increases uniformly towards the center. However, 7 out of 81 globular clusters observed by GAIA DR2 (TER 8, NGC 7492, PAL 12, PAL 1, NGC 6218, NGC 6362, NGC 6496) have very uneven density profiles towards the center, while these unevennesses are almost absent in observational data obtained within HST. This can be seen on the example of NGC 7492 (fig. 1). This situation creates serious difficulties in analyzing such GCs.

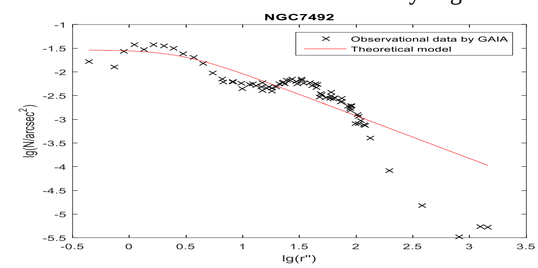

Fig. 1. Observational data for NGC 7492 on GAIA DR2.

Further, we note that out of the remaining 74 GCs in 16 cases (IC 4499, NGC 288, NGC 5024, NGC 5053, NGC 5139, NGC 5466, NGC 5897, NGC 6101, NGC 6121, NGC 6144, NGC 6235, NGC 6254, NGC 6366, NGC 6809, PAL 11, PAL 14), the central part has a complex and physically unexplainable picture of the density profile. In addition, most GCs have density profiles that start not from the center but most often from a value of $lg(r'') \sim -0{,}5$. We see this on the example of NGC 6934 (fig. 2). The density profiles of the above-mentioned 16 GCs start at a distance of $lg(r'') \sim +0.4$ from the center. We can see this on the example of NGC 6254 (fig.3). Density fluctuations in the central region and on the periphery (fig.3) also create difficulties in calculating the degree of concentration. The fact is that the absence of a density value in the center seriously affects the value of the concentration parameter.

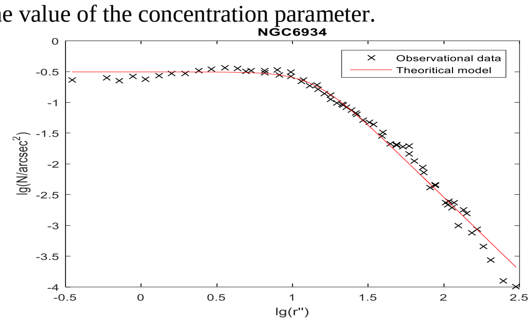

Fig. 2. Peculiarities in the density drop in the central region and at the periphery for NGC 6934.

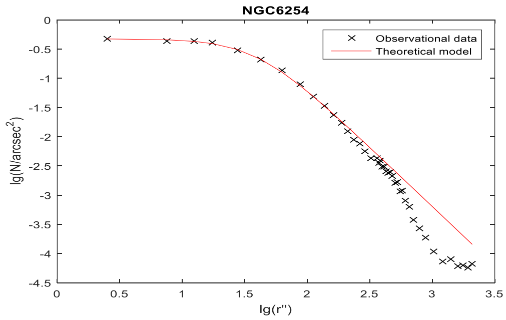

Fig. 3. Peculiarities in the density drop in the central region and at the periphery for NGC 5024.

Note that although the density profiles of GCs obtained by HST sometimes have relatively few observation points compared to the GAIA data, but on the other hand the concentration in the first case increases uniformly towards the center, while in the second case non-uniformity is observed both in distance from the center and in the value of the surface density itself. These differences are shown on the example of NGC 6809 (fig. 4).

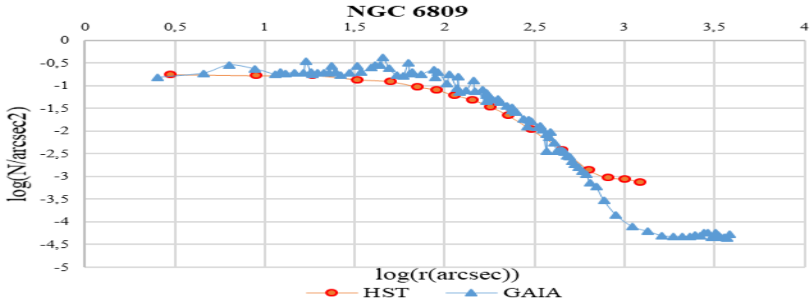

Fig. 4. Comparison of density profiles of NGC 6809 obtained by HST (circles) and GAIA (triangles) space telescopes.

The features shown in figs. 1-4 cause serious problems when calculating the concentration parameter of GCs.

Thus, we are forced to divide clusters into 4 groups:

1) clusters observed by GAIA and HST (there are 20 of them);
2) clusters with oscillating density profiles in central regions (there are 17 GCs);
3) clusters with weak concentration in the central region or with concentration towards the periphery, and the density profile only satisfies requirements on some sections (12 GCs);
4) clusters for which the observed density profile is uniform and smooth everywhere, especially in the central region (there are only 32 of them).

As can be seen, only those clusters that are included in the last group deserve to determine the values of the concentration parameter for them.

Determination of the concentration parameter from GAIA DR2 observational data. As noted above, Nuritdinov et al. in their work [9] analyzed the degree of concentration in 26 GCs, the observational data of which are given in the work of [7]. For this purpose, in [9] the King model $(\sigma \sim [1 + r^2/r_0^2]^{-1})$ was first generalized in the following form:

$$\sigma(r,\gamma,r_0,\sigma_0) = \sigma_0 \left[1 + \left(\frac{r}{r_0}\right)^2\right]^{-\gamma}. \qquad (1)$$

Here γ, r_0 and σ_0 are free parameters, γ is the degree of star concentration towards the center of the cluster, r_0 is the core radius of the cluster, σ_0 is the surface density at the center of the GC. The authors [9] calculated the above-mentioned free parameters for 26 GCs and found good correlations between these quantities and the observed main parameters of clusters.

As a logical continuation of the work of [9], we calculated free parameters of GCs based on model (1) using data for surface density in a sample of 32 GCs noted in the previous section of this article. The chi-square minimization method was used to calculate parameters:

$$\chi^2 = \sum_n \frac{\left|\sigma_{obs}^{(n)} - \sigma(r_n,\sigma_0,r_0,\gamma)\right|^2}{\sigma(r_n,\sigma_0,r_0,\gamma)} \qquad (2)$$

The calculated free parameters and their uncertainties are given in Table 1.

Table 1. Values of free parameters of GC and errors in their determination.

GC name	γ	$\Delta\gamma$	r_0	Δr_0	σ_0	$\Delta\sigma_0$
NGC 104	0,97	0,15	22,03	4,01	7,37	0,40
NGC 288	1,24	0,50	85,30	35,01	0,14	0,01
NGC 362	0,82	0,11	7,88	1,26	13,63	0,56
NGC 1851	1,26	0,68	5,39	2,75	23,52	2,08
NGC 1904	1,02	0,40	8,65	4,67	4,38	1,20
NGC 2808	0,87	0,06	12,51	1,05	11,90	0,28
NGC 4590	1,32	0,44	43,17	13,64	0,63	0,06
NGC 5024	1,07	0,31	23,93	8,98	0,37	0,05
NGC 5272	1,12	0,67	25,24	17,69	1,55	0,41
NGC 5286	1,24	0,38	18,38	5,10	1,48	0,07
NGC 5466	1,50	0,60	107,18	44,30	0,02	0,002
NGC 5694	0,93	0,14	3,34	0,63	1,25	0,06
NGC 5824	0,94	0,09	3,25	0,49	6,65	0,44
NGC 5904	0,73	0,25	16,32	8,62	2,22	0,41
NGC 6093	1,01	0,23	7,44	2,17	6,94	0,99
NGC 6101	1,61	0,62	79,53	30,30	0,06	0,01
NGC 6144	0,64	0,14	25,73	12,94	0,03	0,01
NGC 6171	1,30	0,44	36,32	10,81	0,30	0,02

NGC 6205	1,12	0,30	45,29	13,66	1,81	0,15
NGC 6229	1,16	0,61	9,10	5,09	0,72	0,16
NGC 6254	1,10	0,50	40,95	24,15	0,52	0,15
NGC 6266	0,61	0,07	5,70	1,17	2,98	0,24
NGC 6273	0,92	0,13	22,36	3,61	1,22	0,08
NGC 6341	1,17	0,63	16,58	10,35	2,49	0,73
NGC 6356	0,81	0,07	10,67	1,09	0,20	0,01
NGC 6388	0,63	0,08	4,35	0,95	2,15	0,17
NGC 6496	1,73	0,80	70,00	29,91	0,03	0,01
NGC 6569	1,36	0,30	24,61	4,97	0,08	0,01
NGC 6626	0,93	0,18	12,13	2,49	0,57	0,03
NGC 6656	1,17	0,34	80,92	23,29	0,19	0,01
NGC 6715	0,91	0,06	5,35	0,42	4,40	0,09
NGC 7089	0,99	0,46	14,00	8,34	4,60	1,36

As can be seen from Table 1, the errors in determining the values of the free parameters of model (1) are quite acceptable.

We also looked for a correlation between the parameter γ and the main physical characteristics of GCs. In this case, obviously, only 32 GCs given in Table 1 were considered. Next, we calculated the corresponding correlation coefficients and found empirical dependencies of γ on the main physical characteristics taken from the catalogs of Harris [12] and Baumgardt [13].

The dependence between γ and absolute magnitude M_V. The correlation coefficient between these quantities is 0,70. The corresponding empirical formula has the form

$$\gamma = 0{,}21(\pm 0{,}04)M_V + 2{,}87(\pm 0{,}33), \tag{3}$$

or vice versa

$$M_V = 2{,}30(\pm 0{,}43)\gamma - 10{,}86(\pm 0{,}47). \tag{4}$$

Dependence of the parameter γ on the King parameter "c". Here the correlation coefficient is very good and equal to $-0{,}77$. The empirical relationship looks like this

$$\gamma = -0{,}61(\pm 0{,}09)c + 2{,}04(\pm 0{,}15), \tag{5}$$

and vice versa

$$c = -0{,}96(\pm 0{,}15)\gamma + 2{,}59(\pm 0{,}16). \tag{6}$$

The dependence between γ and the mass of GCs. The correlation coefficient is also good and equal to $-0{,}71$. Empirical formula:

$$\gamma = -0{,}49(\pm 0{,}09)lg\frac{\mathcal{M}}{\mathcal{M}_\odot} + 3{,}81(\pm 0{,}49), \tag{7}$$

and vice versa

$$lg\frac{\mathcal{M}}{\mathcal{M}_\odot} = -1{,}04(\pm 0{,}19)\gamma + 6{,}66(\pm 0{,}21). \tag{8}$$

The dependence of the parameter γ on Kukarkin's "index of richness". We found a good correlation equal to $-0{,}71$. Empirical formula:

$$\gamma = -1{,}01(\pm 0{,}18)IR + 1{,}69(\pm 0{,}12), \tag{9}$$

or if expressed through

$$IR = -0{,}50(\pm 0{,}09)\gamma + 1{,}15(\pm 0{,}10). \tag{10}$$

For reference, we note that the values of the index are given in the article [11].

Conclusion. Analysis and comparison of observational data on the apparent surface density of GCs obtained by the GAIA DR2 and HST space programs have been performed. It is noted that the quality of the GAIA observational data is somewhat inferior to the HST data. Therefore, we were forced to create a normal sample from the GAIA DR2 observational data. Using a 3-parameter model (1) and applying the chi-square minimization method, we found the values of the GC concentration parameter. The correlation coefficients of the concentration parameter γ with the main physical characteristics of GCs (M_V, $lg\mathcal{M}$, c, IR) were calculated and the corresponding empirical formulas for dependence were found. These results were determined for 32 GCs observed within GAIA DR2. The found values of γ are in the interval (0,61; 1,73), which shows the validity of our previous GC classification, developed by us based on the results of the analysis of HST observational data.

REFERENCES

1. Shapley H., Sawyer H.B., Harvard Obs. Bull., Volume 849, 11 (1927).
2. Grillmair Carl J. et al., Globular Clusters with Tidal Tails: Deep Two-Color Star Counts, The Astronomical Journal, Volume 109, February 1995.
3. Lehmann I., Scholz R.D., Tidal radii of the globular clusters M 5, M 12, M 13, M 15, M 53, NGC 5053 and NGC 5466 from automated star counts, Astron. Astrophys., Volume 320, 776–782, 1997.

4. Testa V. et al., Use of DPOSS data to study globular cluster halos: an application to M 92, arXiv:astro-ph/0002280v1, 14 Feb 2000.
5. Carballo-Bello Julio A. et al., Outer density profiles of 19 Galactic globular clusters from deep and wide-field imaging, Mon. Not. R. Astron. Soc., Volume 419, 14–28, 2012.
6. Di Cecco A. et al., On the density profile of the globular cluster M92, arXiv:1302.1714v1 [astro-ph.SR], 7 Feb 2013.
7. Miocchi P. et al., Star count density profiles and structural parameters of 26 galactic globular clusters, The Astrophysical Journal, Volume 774, 151 (16pp), 2013.
8. de Boer T.J.L. et al., Globular cluster number density profiles using Gaia DR2, arXiv:1901.08072v2 [astro-ph.GA], 5 Mar 2019.
9. Nuritdinov S.N. et al., To the Globular Cluster Classification Problem. Calculating the Concentration of Stars for 26 Clusters, ISSN 1063-7737, 2021.
10. King Ivan R., The structure of star clusters. III. Some simple dynamical models, Astronomical Journal, Volume 71, p. 64, 1966.
11. Kukarkin B.V., The concentration classes of globular clusters, Sov. Astron., Volume 15, 89-94, 1971.
12. Harris William E., A New Catalog of Globular Clusters in the Milky Way, arXiv:1012.3224 [astro-ph.GA], 15 Dec 2010.
13. Baumgardt H., Hilker M., A catalogue of masses, structural parameters and velocity dispersion profiles of 112 Milky Way globular clusters, arxiv.org/abs/1804.08359v2, 23 Apr 2018.