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ANALYSIS OF OBSERVATIONAL DATA OF GLOBULAR CLUSTERS WITHIN THE FRAMEWORK OF GAIA DR2 (+25 CLUSTERS)

Annotation

Globular clusters (GCs) are important systems for understanding stellar dynamics and Galactic structure through their observable surface number density profiles. In our previous study, we analyzed the apparent number density of 81 GCs using Gaia DR2 data. Building upon this, we present an analysis of 25 additional GCs, whose density profiles were provided by de Boer et al. (2020). Using the King model and least squares fitting, we calculated the structural parameters – Including the concentration parameter (β), core radius (r_0), and central surface density (σ_0) - for 15 of these clusters. The remaining 10 clusters were excluded due to non-standard profiles or insufficient central concentration.
Key words: globular clusters, structural parameters, number density, cosmic observations.

АНАЛИЗ НАБЛЮДАТЕЛЬНЫХ ДАННЫХ ШАРОВЫХ СКОПЛЕНИЙ В РАМКАХ GAIA DR2 (+25 СКОПЛЕНИЙ)

Аннотация

Шаровые скопления (ШС) представляют собой важные системы для изучения звёздной динамики и структуры Галактики благодаря их наблюдаемым профилям поверхностной числовой плотности. В нашем предыдущем исследовании мы проанализировали видимую числовую плотность 81 ШС, используя данные Gaia DR2. В настоящей работе мы представляем анализ дополнительных 25 ШС, профили плотности которых были предоставлены de Boer и др. (2020). С помощью модели Кинга и метода наименьших квадратов мы рассчитали структурные параметры - включая параметр концентрации (β), радиус ядра (r_0) и центральную поверхностную плотность (σ_0) - для 15 из этих скоплений. Оставшиеся 10 скоплений были исключены из-за нестандартных профилей или недостаточной центральной концентрации.
Ключевые слова: шаровые скопления, структурные параметры, числовая плотность, космические наблюдения

GAIA DR2 DOIRASIDA SHARSIMON YULDUZ TO‘DALARI KUZATUV MA’LUMOTLARINING TAHLILI (+25 TO‘DA)

Annotatsiya

Sharsimon yulduz to‘dalari (ShYT) - yulduzlar dinamikasi va Galaktika tuzilishini o‘rganishda muhim tizimlar bo‘lib, ularning ko‘rinma sirt son zichligi profillari orqali tahlil qilinadi. Oldingi tadqiqotimizda biz Gaia DR2 ma’lumotlaridan foydalangan holda 81 ta ShYTning ko‘rinma son zichligini tahlil qilgan edik. Ushbu ishda de Boer va boshqalar (2020) tomonidan taqdim etilgan qo‘shimcha 25 ta to‘daning zichlik profillari asosida tahlil o‘tkazdik. King modeli va kichik kvadratlar usuli yordamida ushbu to‘dalarning 15 tasi uchun strukturaviy parametrlar — konsentratsiya parametri (β), yadro radiusi (r_0) va markaziy sirt zichligi (σ_0) - hisoblab chiqildi. Qolgan 10 ta to‘da esa nostandart profillarga yoki markaziy konsentratsiyaning yetarli emasligiga ko‘ra tahlildan chiqarib tashlandi.
Kalit so‘zlar: sharsimon yulduz to‘dalari, strukturaviy parametrlar, sirt zichligi, kosmik kuzatuvlar.

Introduction. GCs are dense, gravitationally bound systems of old stars that orbit the halos of galaxies. They serve as key astrophysical laboratories for studying stellar evolution, galactic formation, and dark matter distribution. One of the fundamental observable properties of GCs is their apparent surface density profile, which quantifies the projected surface density of stars as a function of angular distance from the cluster center. This parameter is essential for understanding the structural and dynamical properties of GCs, including mass segregation, core collapse, and the potential presence of central black holes [1, 2].

Apparent number density is derived from star counts within concentric annuli centered on the cluster core. Observations are typically performed using high-resolution photometry from both ground-based telescopes and space missions such as the Hubble Space Telescope (HST). To mitigate foreground/background contamination and photometric incompleteness, statistical decontamination techniques and completeness corrections are applied [3]. Modern surveys, including Gaia and the HST UV Legacy Survey of GCs, provide extensive astrometric and photometric datasets that allow astronomers to generate precise surface density profiles for numerous clusters [4]. These profiles are often fitted using empirical King models or more advanced dynamical models such as Wilson or Elson–Fall–Freeman profiles [5]. Empirical studies have revealed that the surface number density profiles of GCs exhibit a central concentration of stars, a characteristic core radius, and a steep decline in the outer halo. The core radius indicates the region of nearly constant stellar density, while the tidal radius reflects the outer boundary set by the Galactic tidal field.

For core-collapsed clusters such as NGC 6397 and M15, observations reveal a steep power-law rise in the central density, deviating from classical King profiles [6]. In contrast, low-concentration clusters like Palomar 5 show extended tidal features and lower central densities, reflecting their dynamically younger state and susceptibility to tidal stripping [7]. Furthermore, multi-band observations indicate that faint main-sequence stars exhibit broader distributions compared to bright giants, reflecting mass segregation due to two-body relaxation. This behavior, confirmed in clusters such as 47 Tuc and Omega Centauri, suggests advanced internal dynamical evolution [8].

In our previous work [9] we analyzed apparent number density of 81 GCs observed by GAIA DR2. In 2020, de Boer et al. announced the addition of number density observations for 25 clusters [10]. In this work, we calculate concentration parameter values for these clusters.

1.Extra number density observations of GAIA DR2

De Boer et al. (2019) initially presented apparent surface density profiles obtained by GAIA DR2 for 81 GCs [10]. These authors subsequently presented surface density observational data for an additional 25 GCs (GC names Arp 2, E 3, NGC 4372, NGC 6287, NGC 6304, NGC 6316, NGC 6342, NGC 6356, NGC 6441, NGC 6517, NGC 6535, NGC 6558, NGC 6638, NGC 6642, Pal 5, IC 1257, NGC 4833, Pal 2, NGC 6535, Pal 15, Pyxis, Rup 106, Terzan 3, Terzan 7). In our initial work [9], we analyzed the surface density profiles of 81 clusters and determined the values of the concentration parameter for them. As a logical continuation of this work, we analyze the surface density observation profiles of an additional 25 GCs and determine the values of the concentration parameter for them using the King model using the least squares method (1). Typically, the stellar concentration in GCs increases uniformly towards the center (in the case of NGC 6642 in Fig. 1).

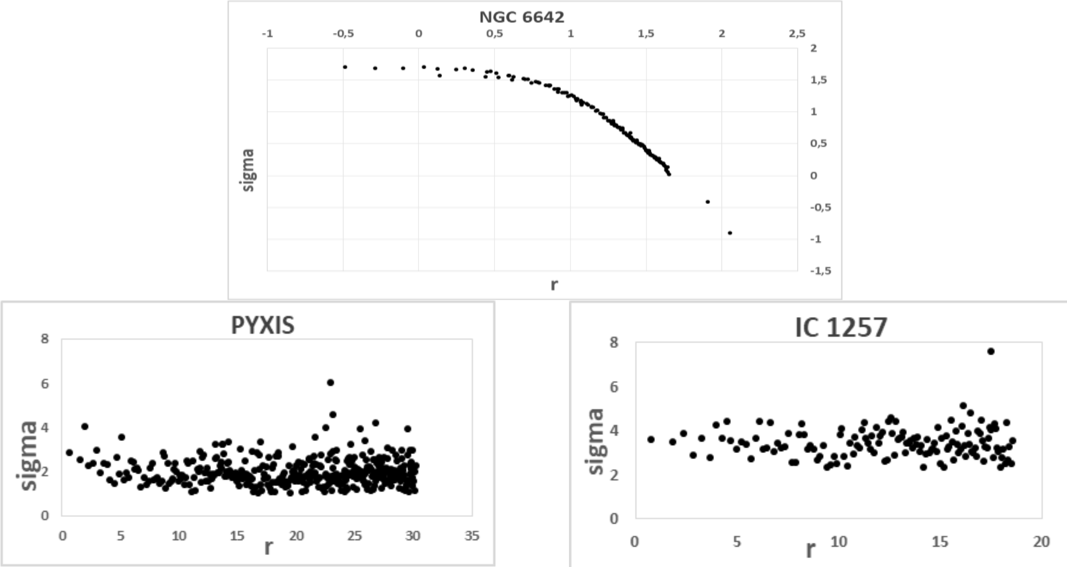

Fig. 1. Apparent number density profiles of GCs from GAIA DR2.

2.However, these additional clusters are mostly very young (3-5 Gyr) and non-standard clusters. For example, the surface density profiles of IC 1257, NGC 4833, Pal 2, NGC 6535, Pal 15, Pyxis, Rup 106, Terzan 3, Terzan 7 do not show a uniform increase in the concentration of stars towards the center (Fig. 2. In the case of Pyxis and IC 1257). Therefore, it is not possible to determine the values of the concentration parameter for these clusters. Based on this, we calculate the values of the concentration parameter for 15 clusters (Arp 2, E 3, NGC 4372, NGC 6287, NGC 6304, NGC 6316, NGC 6342, NGC 6356, NGC 6441, NGC 6517, NGC 6535, NGC 6558, NGC 6638, NGC 6642, Pal 5).

3.Calculating concentration parameter

We use the surface density observations of 25 additional clusters provided by De Boer et al. (2019) [11] to determine the values of the concentration parameter of these clusters. To do this, we use the following generalized model using the King model [12], which is widely used to analyze surface density observations of spherical objects (1).

$$\sigma = \sigma_0 (1 + (\frac{r}{r_0})^2)^{-\beta} \qquad (1)$$

here, β, σ_0 and r_0 are structural parameters. β – concentration parameter, which represents increasing rate of stellar density towards the center of the cluster. σ_0 – central stellar concentration of the cluster. r_0- central radius, which represents the profile sharp deviation from the horizon.

To calculate the value of the concentration parameter (β) in this model, we use the method of least squares (2):

$$\chi^2 = \Sigma_n \frac{\left|\sigma_{obs}^{(n)} - \sigma(r_{n,}\sigma_{0,}r_{0,}\beta\right|^2}{\sigma(r_{n,}\sigma_{0,}r_{0,}\beta} \qquad (2)$$

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

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

Nº	GC name	β	Δ β	ε (%)	r_0	Δ r_0	ε (%)	σ_0	Δ σ_0	ε (%)
	Arp 2	**0,77**	0,12	*16,00*	**47,74**	14,32	*30,00*	**0,01**	0,00	*20,00*
	E 3	**1,30**	0,71	*55,00*	**62,66**	35,32	*56,00*	**0,01**	0,00	*40,00*
	NGC 4372	**1,37**	0,81	*59,00*	**62,42**	53,01	*85,00*	**0,20**	0,07	*35,00*
	NGC 6287	**0,49**	0,08	*16,00*	**2,66**	1,17	*44,00*	**4,88**	1,22	*25,00*
	NGC 6304	**0,63**	0,16	*25,00*	**7,78**	3,31	*43,00*	**29,32**	4,29	*15,00*

	NGC 6316	**1,62**	0,49	*30,00*	**15,32**	3,62	*24,00*	**42,38**	1,95	*5,00*
	NGC 6342	**0,54**	0,05	*9,00*	**1,89**	0,38	*20,00*	**9,83**	0,50	*5,00*
	NGC 6356	**0,81**	0,07	*9,00*	**10,67**	1,09	*10,00*	**0,20**	0,01	*5,00*
	NGC 6441	**0,97**	0,07	*7,00*	**7,54**	0,80	*11,00*	**47,16**	2,03	*4,00*
	NGC 6517	**0,75**	0,05	*7,00*	**3,25**	0,35	*11,00*	**8,01**	0,23	*3,00*
	NGC 6535	**2,71**	1,83	*68,00*	**37,08**	17,99	*49,00*	**1,87**	0,26	*14,00*
	NGC 6558	**0,66**	0,08	*12,00*	**1,66**	0,30	*18,00*	**1,31**	0,09	*7,00*
	NGC 6638	**4,05**	1,79	*44,00*	**35,03**	8,79	*25,00*	**0,23**	0,01	*4,00*
	NGC 6642	**1,38**	0,57	*41,00*	**6,97**	2,23	*32,00*	**0,30**	0,02	*7,00*
	Pal 5	**0,49**	0,05	*10,00*	**64,42**	12,45	*19,00*	**0,00**	0,00	*10,00*
	IC 1257	-	-	-	-	-	-	-	-	-
	NGC 4833	-	-	-	-	-	-	-	-	-
	Pal 2	-	-	-	-	-	-	-	-	-
	NGC 6535	-	-	-	-	-	-	-	-	-
	Pal 15	-	-	-	-	-	-	-	-	-
	Pyxis	-	-	-	-	-	-	-	-	-
	Rup 106	-	-	-	-	-	-	-	-	-
	Terzan 3	-	-	-	-	-	-	-	-	-
	Terzan 7	-	-	-	-	-	-	-	-	-
	Terzan 12	-	-	-	-	-	-	-	-	-

The given dataset presents structural parameters of 15 GCs, including the concentration slope (β), core radius (r_0), and central surface density (σ_0), along with their associated uncertainties. The β parameter reflects the steepness of the surface density profile, with higher values indicating a more centrally concentrated system. Among the clusters, NGC 6638 exhibits the highest β value (4.05), implying a very steep density drop-off from the center, while clusters such as NGC 6287 and Pal 5 show the lowest β values (0.49), indicating shallower profiles and more diffuse structures. The majority of clusters have β values ranging from approximately 0.6 to 1.6, which is typical for GCs that possess a dense core and gradually decreasing stellar density toward the outskirts.

Core radius (r_0), which indicates the region over which the central surface density remains roughly constant, also varies significantly across the sample. Clusters like Pal 5 and E 3 have very large core radii (64.42 and 62.66 respectively), suggesting extended low-density cores, possibly as a result of tidal stripping or advanced dynamical evolution. In contrast, clusters such as NGC 6558 and NGC 6342 possess very compact cores, with r_0 values below 2 pc, reflecting strong central concentrations of stars.

The central surface density (σ_0) values further distinguish the structural diversity among these clusters. High central densities are observed in clusters like NGC 6441 (47.16) and NGC 6316 (42.38), indicating dense stellar cores that may be dynamically evolved. On the other hand, extremely low σ_0 values are seen in Pal 5 (0.00), E 3 (0.01), and NGC 6638 (0.23), suggesting diffuse cores or possibly observational incompleteness. Uncertainty levels (given as ε%) vary widely. Some clusters, such as NGC 6356 and NGC 6441, exhibit low percentage errors (<10%), indicating high confidence in the observational data and model fitting. In contrast, other clusters, including E 3 and NGC 6535, show very large uncertainties (up to 68%), suggesting limitations in data quality or complications due to irregular structures.

4.Conclusion. In this study, we extended our previous analysis of GC structural properties by incorporating newly available surface number density profiles for 25 additional clusters from Gaia DR2. Using the King model and least squares fitting, we successfully derived concentration parameters (β), core radii (r_0), and central surface densities (σ_0) for 15 of these clusters. The results reveal significant structural diversity among the analyzed systems, with some clusters displaying high central concentration and compact cores (e.g., NGC 6638, NGC 6316), while others exhibit diffuse, extended profiles (e.g., Pal 5, E 3). Notably, a subset of the clusters—particularly younger or dynamically disrupted systems such as Pyxis and IC 1257—could not be reliably modeled due to irregular or non-monotonic density profiles. These findings emphasize the complexity of GC evolution and the importance of accurate density measurements in tracing internal dynamics and environmental effects. Future work incorporating kinematic data and multi-band photometry may help to refine these structural parameters and further constrain models of GC formation and disruption in the Galactic halo.

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