



CORRELATION BETWEEN CONCENTRATION PARAMETER AND BLACK HOLE SUBSYSTEMS IN GLOBULAR CLUSTERS

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This study aims to statistically analyze the correlation between concentration parameters derived from HST observations and the physical parameters of BHSs provided by numerical simulations and observational catalogs.

ABSTRACT

The dynamical evolution of globular clusters (GCs) is closely tied to the presence of black holes (BHs) in their centers. The concentration parameter, which measures the degree of stellar density toward the core, serves as a key diagnostic of a GC's dynamical state. Understanding the correlation between this parameter and the physical characteristics of black hole subsystems (BHSs) is essential for tracing the evolutionary pathways of GCs. Observations and simulations over the past decades have demonstrated that both stellar-mass and intermediate-mass black holes (IMBHs) may significantly influence cluster dynamics (Gebhardt et al. 2005; Noyola et al. 2008; Arca Sedda et al. 2018). The discovery of BH candidates in Milky Way and extragalactic clusters (e.g., Maccarone et al. 2007; Strader et al. 2012) has challenged earlier assumptions that stellar-mass BHs cannot be retained within GCs due to dynamical ejection

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For this research, surface brightness profiles of 26 GCs obtained from HST observations (Miocchi et al. 2013) were fitted using the King model to derive central concentration parameters via simplex and chi-squared minimization techniques. The derived parameters were then compared with the BHS characteristics from Weatherford et al. (2020) and the MOCCA Survey Database (Askar et al. 2018). Twelve clusters overlapped between

these datasets, allowing a detailed comparison. Statistically significant correlations were found between the concentration parameter (c) and the relative mass ($M_{\text{BHS}}/M_{\text{cluster}}$) as well as the relative number of BHs ($N_{\text{BHS}}/N_{\text{cluster}}$). The trends suggest that more centrally concentrated clusters tend to host more massive and numerous black holes. Further analysis of GC models indicates that the density, size, and total mass of BHSs correlate with observable cluster parameters such as luminosity, core radius, and velocity dispersion. These results are consistent with theoretical expectations that black hole subsystems dynamically heat cluster cores, thereby preventing core collapse.

Miocchi et al. (2013) presented observational data on the apparent surface density of 26 globular clusters by HST. Based on this observation, Nuritdinov et al. (2021) calculated the concentration parameter toward the center using the (1) model for each cluster. Two methods were used to calculate the concentration parameter: simplex and chi-square. The same values were found in both methods. Based on the King model ($\sigma \sim \left(1 + \frac{r}{r^*}\right)^2$) in the analysis of observational data on the surface density of GCs, Nuritdinov et al. proposed the following model:

$$\sigma(r, \gamma, r^*, \sigma_0) = \sigma_0 \left(1 + \left(\frac{r}{r^*}\right)^2\right)^{-\gamma} \quad (1)$$

Here, γ , r^* and σ_0 are free parameters,

γ — is the concentration of stars towards the center of the GC,

r^* — is the value associated with the cluster core radius r_c ,

σ_0 — is the apparent density at the center.

When using the simplex method, the free parameters are found by minimizing the function (2).

$$F(\gamma, r^*, \sigma_0) = \sum_k \left[\sigma(r, \gamma, r^*, \sigma_0) - \sigma_{obs}^{(k)} \right]^2 \quad (2)$$

Good correlations were found between the concentration parameter and other physical parameters (M_V , D_g , $\lg M$, c , IR) for 26 GCs. Therefore, here we will focus on the results of the calculation by the χ^2 method

$$\chi^2 = \sum \frac{\left| \sigma_{obs}^{(k)} - \sigma(r, \gamma, r^*, \sigma_0) \right|}{\sigma(r, \gamma, r^*, \sigma_0)}$$

Weatherford (2020) gives the values of the physical parameters of BHSs for 50 GCs. We will consider the connections between these parameters and the concentration parameter. For 12 of the 26 GCs given in Miocchi, BHS parameters are given in Weatherford. In particular, the concentration parameter correlates with the relative mass ($M_{\text{BH}}/M_{\text{cluster}}$) and the relative number ($N_{\text{BH}}/N_{\text{cluster}}$) of BH in the GC. At Weatherford, the given physical parameters of BHSs are found in two ways based on mass segregation. The first one, Δr_{50}^{ij} , is the difference in median distance from the cluster center between Pop_i and Pop_j . Second, ΔA^{ij} is the difference in the area under the cumulative radial distribution of the two populations (Weatherford et al. 2020). Weatherford states that using the latter of Δ_A and Δ_{r50} is compliant. Our results are also consistent with this conclusion, finding a better correlation with the parameters found in the second method (Δ_{r50}).

$$cc_{\text{relative mass}}=0.58, \quad cc_{\text{relative number}}=0.56,$$

In the first method, a smaller correlation is found

$C_{\text{relative mass}}=0.70$, $CC_{\text{relative number}}=0.75$.

The presence of numerous stellar-mass BHs and potentially IMBHs plays a fundamental role in the long-term evolution of GCs. Recent N-body simulations (Morscher et al. 2015; Askar et al. 2018) confirm that several hundred BHs can be retained over gigayear timescales, influencing both the structural and kinematic properties of the cluster. The established correlation between concentration parameter and BHS mass demonstrates that internal cluster dynamics are strongly governed by the gravitational influence of these compact objects. This connection provides an indirect observational tool for identifying clusters with rich BHS populations. Additionally, the findings contribute to the broader question of how IMBHs form and evolve within dense stellar systems.

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