

No Black Holes in NGC 6397

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ABSTRACT

Recently, Vitral & Mamon (2021) detected a central concentration of dark objects in the core-collapsed globular cluster NGC 6397, which could be interpreted as a subcluster of stellar-mass black holes. However, it is well established theoretically that any significant number of black holes in the cluster would provide strong dynamical heating and is fundamentally inconsistent with this cluster’s core-collapsed profile. Claims of intermediate-mass black holes in core-collapsed clusters should similarly be treated with suspicion, for reasons that have been understood theoretically for many decades. Instead, the central dark population in NGC 6397 is exactly accounted for by a compact subsystem of white dwarfs, as we demonstrate here by inspection of a previously published model that provides a good fit to this cluster. These central subclusters of heavy white dwarfs are in fact a generic feature of core-collapsed clusters, while central black hole subclusters are present in all *non*-collapsed clusters.

Globular clusters (GCs) are highly dynamic systems hosting a wide range of stellar phenomena, particularly involving compact objects. Recently, analyzing a heightened central velocity dispersion in NGC 6397, Vitral & Mamon (2021) detected a central dark population, which they suggested may be a subcluster of stellar-mass black holes (BHs) of total mass $10^3 M_{\odot}$ within the central 6 arcsec (0.07 pc). However, the presence of such a BH subcluster would contradict longstanding consensus from GC modeling that *any* substantial population of BHs within a cluster would provide enough dynamical heating to prevent core collapse and, instead, sustain a large, easily resolvable core (Merritt et al. 2004; Mackey et al. 2007; Wang et al. 2016; Kremer et al. 2019a). For lists of Galactic GCs that *are expected to retain a large population of BHs* at present, see Askar et al. (2018), Weatherford et al. (2020), and Shishkovsky et al. (2020).

No stellar-mass BH population in NGC 6397

Massive star evolution produces hundreds to thousands of BHs in typical GCs, most of which (unlike neutron stars) are initially retained (e.g., Kroupa 2001). These BHs quickly mass-segregate to the cluster core, assembling a dense central BH subsystem (e.g., Spitzer 1969; Kulkarni et al. 1993). Three-body encounters within this BH-dominated core produce many dynamically-hard BH binaries (e.g., Morscher et al. 2015), which then provide energy to passing stars through scattering interactions. This further hardens the binaries while heating the rest of the cluster (Breen & Hogg 2013). BHs undergoing these binary-mediated encounters receive significant recoil kicks that displace them away from the core (and eventually may eject them from the cluster altogether); they further heat the cluster through dynamical friction while sinking back to the core. Overall, the dynamics of BHs acts as a strong energy source in a process we call “BH burning” (for a review, see Kremer et al. 2019b). This process is well-understood and well-supported by a wide scientific consensus (Merritt et al. 2004; Mackey et al. 2007; Breen & Hogg 2013; Peuten et al. 2016; Wang et al. 2016; Chatterjee et al. 2017; Arca Sedda et al. 2018; Kremer et al. 2018; Kremer et al. 2019a; Antonini & Gieles 2020).

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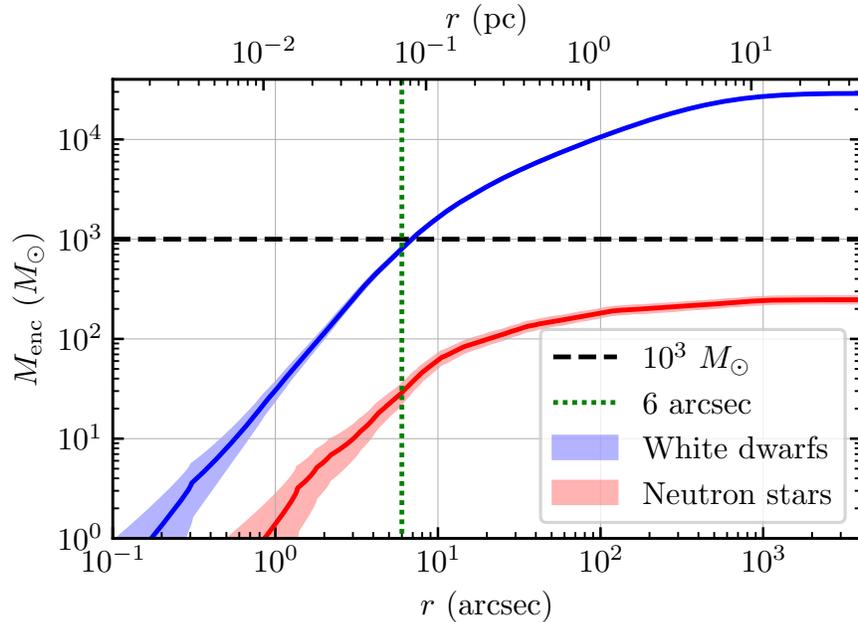


Figure 1. The enclosed mass of white dwarfs and neutron stars versus projected radius for the best-fitting NGC 6397 model (Rui et al. 2021) found in the CMC Cluster Catalog (Kremer et al. 2020). Solid curves bounded by shaded regions indicate the expectation value and spread from all possible projections. In contrast to black holes, white dwarfs are a natural and obvious “dark” population contributing $10^3 M_{\odot}$ (black dashed line) within 6 arcsec (green dotted line) of the cluster center, in concordance with a recent analysis of NGC 6397 data by Vitral & Mamon (2021). Not shown here are black holes, as this model for NGC 6397 contains only a single remaining black hole, of mass $17.4 M_{\odot}$.

The energy generated by BH burning inflates the cluster and supports it against gravothermal contraction. Hence, clusters that retain sizable BH populations today exhibit large core radii with flat central surface brightness profiles (well fit by King models) and reduced mass segregation in the luminous stellar populations (e.g., Chatterjee et al. 2017; Weatherford et al. 2018, 2020; Kremer et al. 2020). BH burning is so powerful that star clusters exceeding a critical mass fraction in BHs may even evolve towards 100% BH clusters, after ejecting their entire luminous stellar populations (Weatherford et al. 2021; Gieles et al. 2021). Importantly, a star cluster will only evolve towards a traditional “core-collapsed” surface brightness profile after almost all BHs have been ejected. Since NGC 6397 is core-collapsed, it should therefore be expected to have retained very few, if any, BHs at present (the model illustrated in Fig. 1 contains just one BH).

While direct probes of the BH population are sparse (binary counts from X-ray/radio and/or radial-velocity measurements are instructive but typically small; e.g., Strader et al. 2012; Giesers et al. 2018), indirect probes such as the degree of mass segregation are powerful when combined with careful modeling. Along these lines, Weatherford et al. (2020) leverage a known anti-correlation between clusters’ observable mass segregation and BH populations to place, at 95% (67%) confidence, restrictive upper limits of 16 (8) BHs with total mass less than $420 M_{\odot}$ ($200 M_{\odot}$) in NGC 6397 at present. This eliminates BHs as a plausible explanation for the central dark population in this cluster.

No IMBHs in core-collapsed clusters

For similar reasons, claims of intermediate-mass BHs (IMBHs) at the centers of core-collapsed GCs (e.g., Gerssen et al. 2002; Kamann et al. 2016; Perera et al. 2017) have not withstood follow-up studies and are almost certainly incorrect (e.g., McNamara et al. 2003; Murphy et al. 2011; Kirsten & Vlemmings 2012; Gieles et al. 2018; Tremou et al. 2018). Like stellar-mass BHs, an IMBH would provide a central dynamical heat source which would act to inflate the cluster core significantly (Shapiro 1977; Marchant & Shapiro 1980; Heggie et al. 2007). Clusters with IMBHs are expected to resemble standard King models except within the small radius of influence of the IMBH (Baumgardt et al. 2005). Searches for IMBHs in core-collapsed clusters in pursuit of the theorized cusp in the surface density are

therefore misguided. On the contrary, such searches should focus on clusters which have *not* undergone core collapse, where a stronger case for an IMBH might be made.

The alternative: a massive subsystem of white dwarfs

In Fig. 1, we illustrate a GC model that closely fits NGC 6397’s surface brightness and velocity dispersion profiles. The initial cluster contained $N = 4 \times 10^5$ stars and was relatively compact (virial radius $r_v = 1$ pc). The present-day model agrees quite well with many observations, including numbers of cataclysmic variables, millisecond pulsars, and low-mass X-ray binaries (Rui et al. 2021). The model belongs to a large, recently released model grid, the **CMC Cluster Catalog**, designed to broadly probe the space of realistic Milky Way GCs without any directed attempt to fit any particular cluster (Kremer et al. 2020).

The best-fitting model from this grid for NGC 6397 possesses only a single stellar-mass BH. However, it contains close to $10^3 M_\odot$ in white dwarfs within the central 6 arcsec (see Fig. 1), neatly and completely accounting for the dark population detected by Vitral & Mamon (2021). In our model, the white dwarf population is dominated by heavy white dwarfs with a mean mass $\approx 1 M_\odot$; most of these are carbon-oxygen white dwarfs (86%), with a sizable minority of oxygen-neon white dwarfs (14%). Crucially, both the lack of stellar-mass BHs and the presence of a centrally concentrated white dwarf population are generic, robust features expected in all core-collapsed GCs, rather than esoteric predictions expected to apply only to NGC 6397 (see, e.g., Kremer et al. 2020, where this result was demonstrated generally). We will further explore the implications of these white dwarf subsystems in core-collapsed clusters in a forthcoming work (Kremer et al. in prep.).

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