The Black Hole–Stellar Mass Relation in the Dwarf-galaxy Regime with Gaia-Sausage/Enceladus and ω Centauri

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ABSTRACT

The discovery of fast moving stars in Milky Way's most massive globular cluster, ω Centauri (ω Cen), has provided strong evidence for an intermediate-mass black hole (IMBH) inside of it. However, ω Cen is known to be the stripped nuclear star cluster (NSC) of an ancient, now-destroyed, dwarf galaxy. The best candidate to be the original host progenitor of ω Cen is the tidally disrupted dwarf Gaia-Sausage/Enceladus (GSE), a former Milky Way satellite as massive as the Large Magellanic Cloud. I compare $\omega \text{Cen/GSE}$ with other central BH hosts and place it within the broader context of BH-galaxy (co)evolution. The IMBH of ω Cen/GSE follows the scaling relation between central BH mass and host stellar mass $(M_{BH}-M_{\star})$ extrapolated from local massive galaxies $(M_{\star} \gtrsim 10^{10} \, \mathrm{M}_{\odot})$. Therefore, the IMBH of ω Cen/GSE suggests that this relation extends to the dwarf-galaxy regime. I verify that ω Cen (GSE), as well as other NSCs with candidate IMBHs and ultracompact dwarf galaxies, also follow the $M_{BH}-\sigma_{\star}$ relation with stellar velocity dispersion. Under the assumption of a direct collapse BH, $\omega \text{Cen/GSE's IMBH}$ would require a low initial mass ($\leq 10,000 \,\mathrm{M}_{\odot}$) and almost no accretion over \sim 3 Gyr, which could be the extreme opposite of high-z galaxies with overmassive BHs such as GN-z11. If $\omega \text{Cen/GSE's IMBH}$ formed from a Population III supernova remnant, then it could indicate that both light and heavy seeding mechanisms of central BH formation are at play. Other stripped NSCs and dwarf galaxies could help further populate the $M_{BH}-M_{\star}$ and $M_{BH}-\sigma_{\star}$ relations in the low-mass regime and constraint IMBH demographics and their formation channels.

Keywords: Intermediate-mass black holes; Dwarf galaxies; Star clusters

1. INTRODUCTION

Understanding the early assembly of supermassive black holes (BHs) and their coevolution with their host galaxies is a major goal in Astrophysics (Kormendy & Ho 2013; Inayoshi et al. 2020; Fan et al. 2023). Given a certain seeding mechanism, either Population III supernovae explosions or direct collapse (Volonteri et al. 2008;

Just recently, Häberle et al. (2024) has provided strong evidence for the existence of an IMBH ($M_{BH} \gtrsim 8200\,\mathrm{M}_{\odot}$) in ω Centauri (ω Cen), the most massive MW globular cluster (e.g., Baumgardt & Hilker 2018); see Noyola et al. (2008) for an earlier proposition. These authors identified a collection of fast moving stars with tangential velocities well above the cluster escape ve-

Gaia-sausage-Enceladus

THE 'SAUSAGE' GLOBULAR CLUSTERS

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ABSTRACT

The Gaia Sausage is an elongated structure in velocity space discovered by Belokurov et al. (2018) using the kinematics of metal-rich halo stars. It was created by a massive dwarf galaxy ($\sim 5 \times 10^{10} M_{\odot}$) on a strongly radial orbit that merged with the Milky Way at a redshift $z \lesssim 3$. We search for the associated Sausage Globular Clusters by analysing the structure of 91 Milky Way globular clusters (GCs) in action space using the Gaia Data Release 2 catalogue, complemented with Hubble Space Telescope proper motions. There is a characteristic energy $E_{\rm crit}$ which separates the in situ objects, such as the bulge/disc clusters, from the accreted objects, such as the young halo clusters. There are 15 old halo GCs that have $E > E_{\rm crit}$. Eight of the high energy, old halo GCs are strongly clumped in azimuthal and vertical action, yet strung out like beads on a chain at extreme radial action. They are very radially anisotropic ($\beta \sim 0.95$) and move on orbits that are all highly eccentric ($e \gtrsim 0.80$). They also form a track in the age-metallicity plane distinct from the bulk of the Milky Way GCs and compatible with a dwarf spheroidal origin. These properties are consistent with GCs associated with the merger event that gave rise to the Gaia Sausage.

Keywords: galaxies: kinematics and dynamics — galaxies: structure

Gaia-Sausage/Enceladus (далее- GSE) — результат major merger?

This 'sausage' in the velocity space is probably due to relatively metal-rich stars compared to the Galaxy halo (with metallicities $Z \approx Z/10$), which have also large velocity anisotropy. (Belokurov et al.,2018) Helmi et al.,2018: "We conclude that the halo near the Sun is strongly dominated by a single structure of accreted origin"

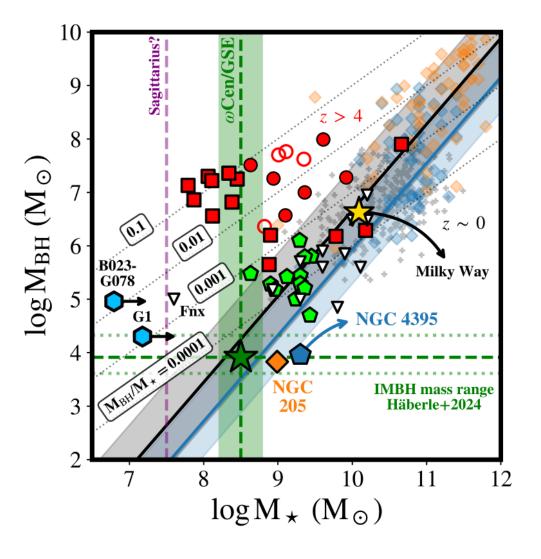
For GSE, Callingham et al. (2022) finds $log (M*/M\odot) = 8.5 \pm 0.3$.

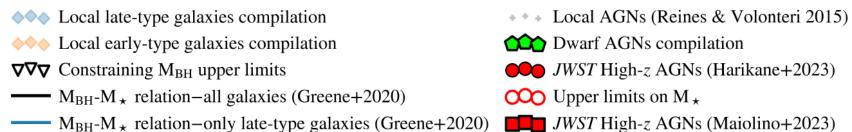
• Существование IMBH ($100 \lesssim MBH/M\odot < 10^5$) —нерешенная проблема. Just recently, H"aberle et al. (2024) has provided strong evidence for the existence of an IMBH (MBH $\gtrsim 8200M\odot$) in ω Centauri (ω Cen), the most massive MW globular cluster .



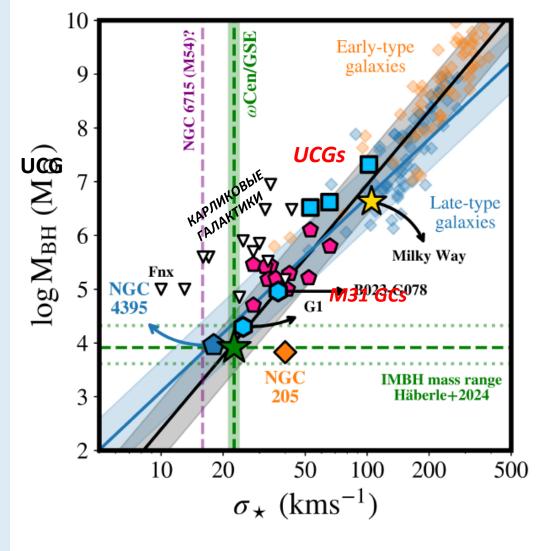
К чему стремится автор?

- ω Cen has similar kinematics to GSE's stellar population (Massari et al. 2019; Callingham et al. 2022). Hence, GSE is the best candidate, out of known accreted dwarfs, to be the original host galaxy of ω Cen. Therefore, the discovery of a central BH in ω Cen provides the unique opportunity to extend well-known scaling relations, such as between MBH and host M*.
- GSE is the best candidate to be the original host galaxy of ωCen. Цель работы проверить эту гипотезу.



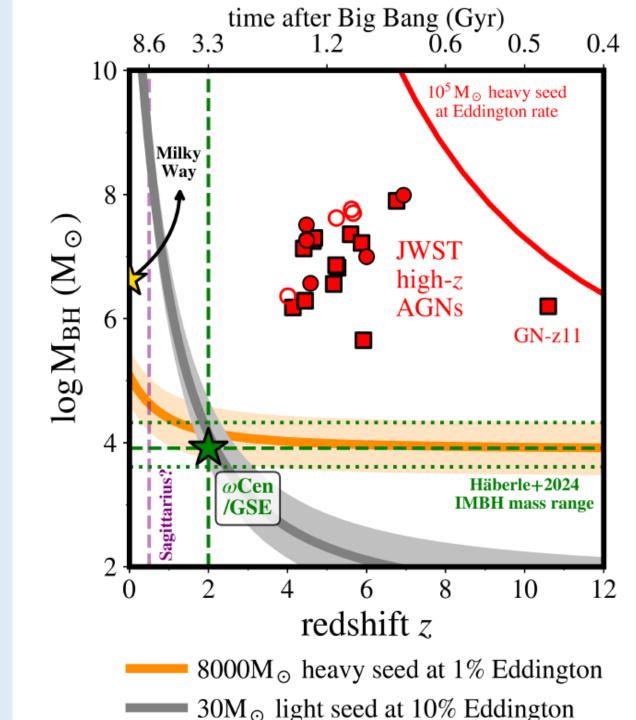


Since both NSCs and UCDs alike follow the MBH– $\sigma*$ relation, the $\sigma*$ in these low-mass systems can be compared to those in the bulges of local massive galaxies.



- Ultracompact galaxies with central BHs
- Dwarf AGNs (Baldassare+2020)
- ◆◆◆ Local late-type galaxies compilation
- ♦♦♦ Local early-type galaxies compilation
- ${\bf \nabla} {\bf \nabla} {\bf \nabla}$ Constraining M_{BH} upper limits
- M_{BH}-M_★ relation—all galaxies (Greene+2020)

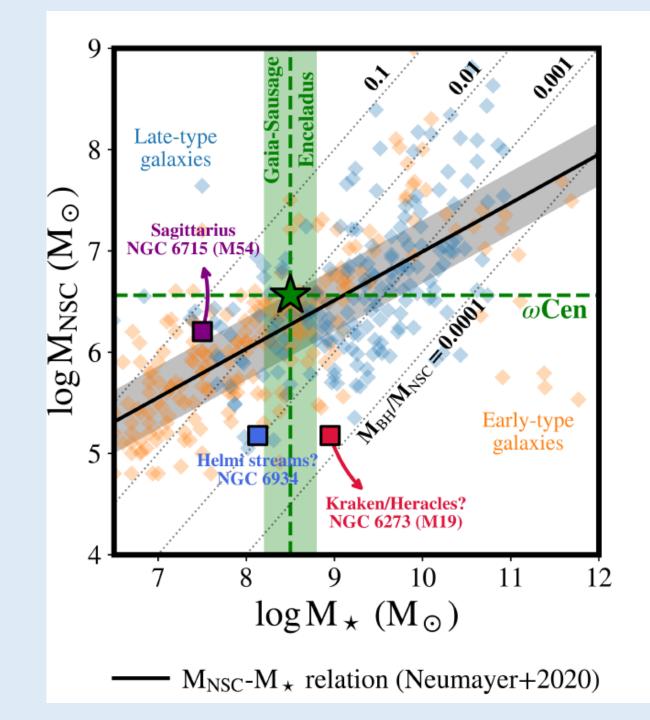
- Две модели роста Mbh (по расчетам Fan et al.,2023):
- Heavy seed: Эддингтон.аккреция на 10⁵ М⊙ (вверху), и
 light seed (аккреция на остатки Рор-III) (внизу).
- z=2 соответствует времени прекращения SF для GSE.



Какие шаровые скопления могут, как и ωCen, оказаться nuclear stellar clusters?

Кандидаты для программы поиска черных дыр в шаровых скоплениях: M54 (связь с Sag dSph) M19 (связь с Kraken/Heraclrs stream) N6934 (связь с Helmi stream).

Два последних – либо не NSCs, либо потеряли большую часть массы.



Основные выводы

- Существует единая зависимость «масса ВН масса или дисперсия скоростей балджа» для нормальных галактик, ультракомпактных галактик и шаровых скоплений, содержащих ВН промежуточных масс.
- This suggests that this scaling relation might extend to GSE-mass, i.e., S/LMC-mass galaxies. Hence, since there are many Local Group satellite that could host central IMBHs.
- Maccy IMBH в ωCen можно объяснить в моделях как сжатия, так и аккреции, но в последнем случае начальная масса должна быть небольшой и расти очень медленно.
- Sagittarius dSph could be a compelling target since it is relatively close and it also hosts the NSC M54.