Intermediate-mass black hole incubators

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Stellar black hole clusters from starbursts

→ star clusters formed during starburst periods as massive as $10^{5-7}\,M_\odot$ (Weidner et al. 2004)

→ total mass of the evolved stellar black holes $M_{\rm BH} \gtrsim 10^4\,M_\odot$ regardless of the stellar initial mass function of the cluster

→ massive stars/black holes dynamically mass-segregate at the cluster centres, low-mass stars in the outskirts

→ outskirts stripped by the galactic tides in galactic nuclei, dark star clusters are formed (Banerjee & Kroupa 2011)

→ starburst period ≈ 1 Gyr ago reported for the Milky Way (Nogueras-Lara et al. 2020)

Gas accretion onto the black hole clusters

→ black hole clusters accrete the gas from their momentary surroundings

→ Bondi-Hoyle-Lyttleton accretion rate applicable to compact clusters (Kaaz et al. 2019):

$$\frac{{\rm d}M_{\rm BH}}{{\rm d}t} \approx 4\pi\rho_{\rm g}\frac{(GM_{\rm BH})^2}{\left(v^2+c_{\rm s}^2\right)^{3/2}}\,,$$

where $\rho_{\rm g}$ is the gas mass density, v the velocity of the cluster relative to the gas, $c_{\rm s}$ the speed of sound and G the gravitational constant

→ relative velocities small for clusters comoving with the gas in the twisted ring of clouds in the central molecular zone of the Milky Way

→ for $\rho_{\rm g} = 250\,M_\odot\ {\rm pc}^{-3}$ (corresponds to $\approx 10^4$ particles per cm^3), $v = 10$ km/s $\gg c_{\rm s}$ and $M_{\rm BH} = 10^4\,M_\odot$, the cluster accretes $M_{\rm g} = 10^4\,M_\odot$ of gas in ≈ 2 Myr

→ stellar feedback not significant with massive stars having evolved to black holes and lighter stars having been stripped by the galactic tides

Black hole cluster collapse to an intermediate-mass black hole

→ black holes subject to the friction on the gas, their cluster shrinks

→ at $t = t_{\rm rel}$, the gravitational wave emission by the accelerating black holes starts to dominate

→ the cluster almost instantly collapses into an intermediate-mass black hole (Kroupa et al. 2020)

→ $t_{\rm rel} \approx 2$ Myr for a cluster of 10^3 equal-mass black holes with $m_{\rm BH} = 10\,M_\odot$ whose initial radius is $R_0 = 0.1$ pc and the total gas mass within the cluster $M_{\rm g} = 10^4\,M_\odot$ (see Figure)

→ five intermediate-mass black hole candidates reported in the central molecular zone of the Milky Way (Maillard et al. 2004, Oka et al. 2016, Tsuboi et al. 2017, Takekawa et al. 2019a,b, 2020, Peißker et al. 2024)

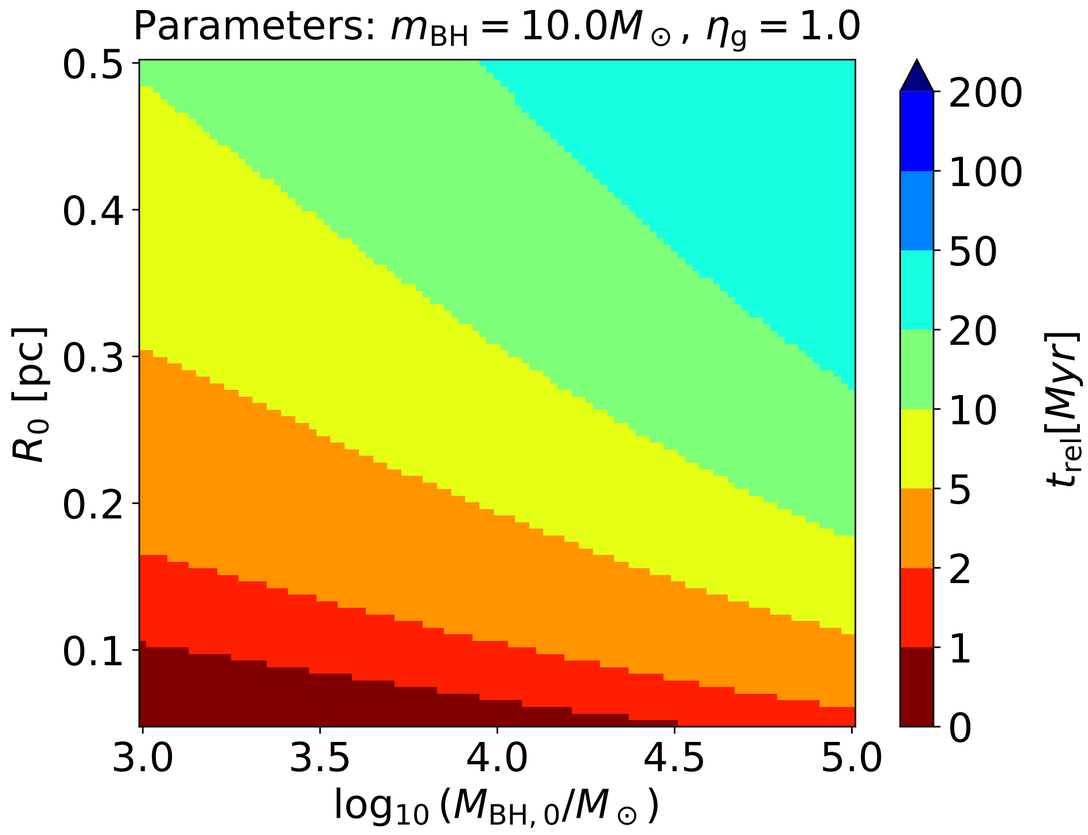

Figure: The time $t_{\rm rel}$ when the gravitational wave emission starts to dominate the evolution of the black hole orbits in their cluster for various combinations of the cluster mass $M_{\rm BH}$ and initial radius R_0. In all cases, the mass of the individual stellar black holes is set to $m_{\rm BH} = 10\,M_\odot$ and the total mass of the gas within the cluster to $M_{\rm g} = \eta_{\rm g} M_{\rm BH}$ with $\eta_{\rm g} = 1.0$. The plot has been taken from Haas et al. (2026).

References and acknowledgments

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