Contribution ID: **21** Type: **Talk**

The Steady State Population of Intermediate-Mass Black Holes Near a Supermassive Black Hole

Tuesday, 24 October 2023 14:45 (15 minutes)

With the onset of next generation gravitational interferometers, we find ourselves in an era where we can peer into cosmic time and see the influence of mergers on the growth of supermassive black holes (SMBH). Here, we investigate properties of a cluster of intermediate-mass black holes surrounding a supermassive black hole. A model first proposed by Ebisuzaki et al. (2001) and for which Portegies Zwart et al. (2006) argue that such a population can exist in the core of the Milky Way.

We simulate clusters of equal-mass intermediate-mass black holes ($m_{\mathrm{IMBH}} = 10^3\ M_{sun}$) initialised in a shell between $0.15 \leq r$ [pc] ≤ 0.25 centred about a supermassive black hole. We explore the influence of the cluster population and supermassive black hole mass (exploring the values $M_{\mathrm{SMBH}} = 4 \times 10^5\ M_{sun,\ 4\times10^6\ M_{sun}}$ and $4 \times 10^7\ M_{sun}$) on the IMBH ejection rate and escape velocity.

For $M_{\mathrm{SMBH}} = 4 \times 10^6\ M_{sun}$, we use both a Newtonian and post-Newtonian formalism, going up to the 2.5th order, including cross-terms. We run 40 and 60 simulations per cluster population for either formalism respectively. For the other two SMBH-mass configurations, we model the system taking into account relativistic effects. In the case of $M_{\mathrm{SMBH}} = 4 \times 10^5\ M_{\odot}$, 30 simulations are run per population. For $M_{\mathrm{SMBH}} = 4 \times 10^7\ M_{\odot}$ we run 10 simulations per population. The simulations end once a black hole escapes the cluster, a merger occurs, or the system has evolved till 100 Myr.

We find that clusters evolved with the post-Newtonian formalism lose their intermediate-mass black holes quicker than those evolved under Newtonian gravity. Lowest-mass SMBHs predominantly experience ejections. Increasing the supermassive black holes causes the merger rate to increase. Although relativistic effects allow for lower eccentricity mergers, all merging binaries have e
$gtrsim 0.97$ when measured $1 - 2$ kyr before the merging event.

Most of the strongest gravitational wave signals originate from merging IMBHs that form a binary with the SMBH and eventually merge. Weaker and more frequent signals are expected from gravitational wave radiation emitted in a fly-by.

Both processes are suppressed in the non-relativistic calculations. In these simulations, the IMBHs tend to stall in the vicinity of the SMBH, after which they usually eject via the sling shot mechanism. For all configurations, no IMBH-IMBH binaries were detected.

In our post-Newtonian calculations, when it comes to SMBH-IMBH binary systems emitting strong gravitational wave signals, 11.4% of them are detected as gravitational wave capture binaries, while the remaining 86.6% are in-cluster merging binaries.

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Session Classification: Astrophysics & Cosmology

Track Classification: Astrophysics & Cosmology