Intermediate-Mass Black Holes and Gravitational Radiation

Cole Miller, University of Maryland

IMBH in stellar clusters.

Rates and scenarios for interactions.

Amplitudes and eccentricities.

Information from 0.1–10 Hz.

Summary and future work.

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Intermediate-Mass Black Holes

Hypothetical population with $M \sim 10^{2-4}\, M_\odot$.

Too large for stellar evolution.

Evidence is strong, but not conclusive.

Kinematic evidence in globulars.

Evidence for $\sim 10^{3-4} M_\odot$ BH in M15, G1?

BH may not be needed.

Analyses of other clusters ongoing.

Bright X-ray sources in several galaxies.

Bright, variable, off-center.

If quasi-isotropic, $M > 10^{2-3}\, M_\odot$.

If beamed, could have $M \sim 10\, M_\odot$.

Several strong cases for $M > 100\, M_\odot$.

Many candidates in dense stellar clusters.

Types of Interactions

Mass segregation causes massive objects to sink to the center of a dense stellar cluster.

Binaries, BH, neutron stars.

Three-body interactions tend to tighten hard binaries.

Gradual hardening can cause merger.

Inspiral time: $\sim 10^{6-7}$ yr.

Initial $e \sim 0.9 - 0.99$ (Gultekin).

Direct two-body capture by gravitational radiation.

Plunge orbits.

Pericenter $\sim$few$\times 10^2\,M$.

Inspiral time: $\lesssim 10^5$ yr.

Initial eccentricity: $e \sim 1 - 10^{-5}$.

Rates of Interactions

Event rates depend on number density of IMBH, types of interactions.

Average number density of globulars: $\sim 2\ \mathrm{Mpc}^{-3}$.

Energy release, merger mass affect LIGO-II detection rate.

- $E/M = 0.1$, up to $\sim 10^3\ \mathrm{yr}^{-1}$.
- More realistic 0.01-0.02, tens per year.

What about at other frequencies? Assume:

- 10% of globulars have 1000 $M_\odot$ BH.
- Average 10^8 yr between mergers with 10 $M_\odot$.
- Observe for one year.

Compute h, e for three-body, two-body scenarios.

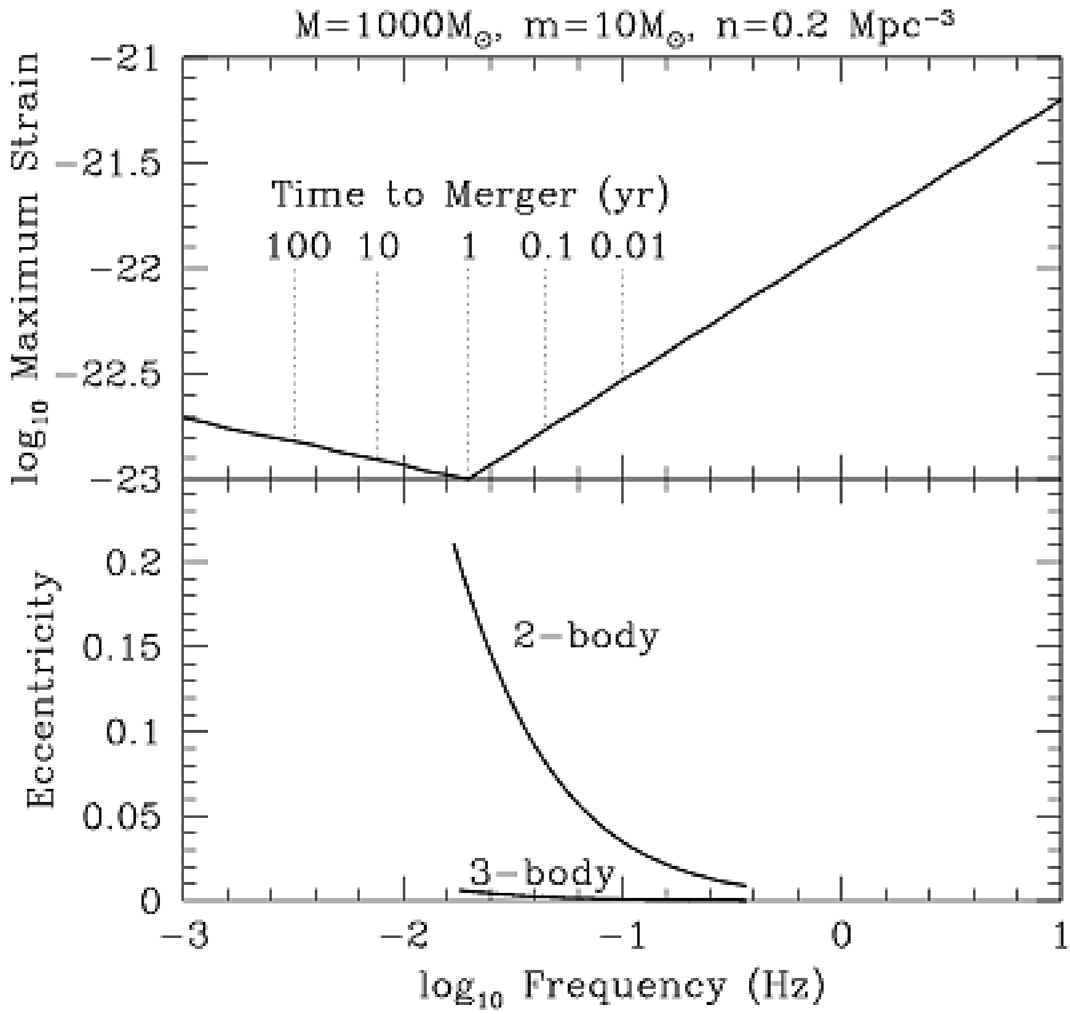

Fig. 1.— Typical strains and eccentricities versus frequency, for two-body and three-body scenarios in globular clusters. We consider a $10^3\,M_\odot$ black hole in a binary with a $10\,M_\odot$ black hole, and that there are on average 0.2 globular clusters per Mpc^3 with such a black hole in the center. In a year's observation, binaries less than a year to merger will be seen at their event rate, implying that typically the closest one will be $\sim$ 500 Mpc away. In this realm, higher frequencies lead to larger observed strains. In the same 500 Mpc radius volume there are numerous binaries with longer times to merger than 1 yr, with the number increasing as the time to merger increases. Therefore, for a given $\tau_{\rm merge} > 1$ yr, the typical distance to the closest such binary decreases as $\tau_{\rm merge}$ increases, with the result that the strain observed from the closest such binary increases with increasing $\tau_{\rm merge}$ and decreasing frequency.

Information in the 0.1-10 Hz Range

Inspiral, merger, ringdown for 1000 $M_\odot$ BH.

Pericenter precession

- For 2-body inspiral, $e \gtrsim 0.05$ at 0.1 Hz.
- Above 1 Hz, essentially circular.

Lense-Thirring precession.

- Orbits will be at random angles.
- $a/M \sim 0.1$ expected.

Orbital decay.

If EM counterpart (e.g., Virgo Cluster), get distance or do self-consistency check.

Summary and Future Work

Active field, but lots to do!

Observational: masses, number density.

- How common are IMBH?
- What is their mass distribution?
- In detail, what are their environments?

Theoretical: spins, eccentricities.

- What are most common encounters?
- What is distribution of e, a/M?

In general, speculative but promising sources.