Intermediate-Mass Black Holes

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Observational evidence.

Dense stellar systems.

Detectability in globulars.

Implications for gravitational radiation.

Future observations and theory.
Observations

Odd point sources seen in several galaxies:
  X-ray flux ⇒ $L_{\text{iso}} > 10^{40}$ erg s$^{-1}$
  Off-center, strongly variable ⇒ BH.

$L < L_{\text{Edd}} ⇒ M > L_{38} M_\odot ≈ 10^{2-3} M_\odot$.

Dynamical friction implies $M < 10^{5-6} M_\odot$.
  New class of black hole?

Associated with star-forming regions.
  One source in superbubble.

Velocity cusps in globulars, $M ≈ 10^{3-4} M_\odot$.
  Some $L > 10^{39}$ erg s$^{-1}$ sources in extragalactic globulars.

Motivation for Dense Stellar Systems

Will proceed assuming $M ≈ 10^{2-3} M_\odot$.
  Might be beamed, super-Eddington.
  Beaming not favored (He II nebula).
  Binary measurements would clinch.

What is the source of the accreting matter?

Not Bondi-Hoyle; rate is too low.
  Even in MC, $L < 10^{36} M_3^2$ erg s$^{-1}$.
  Must be accreting from binary.

Where did companion come from?
  Co-evolution? No, BH too massive.
  Captured? Need high stellar density.

Thus, dense stellar clusters.
Dynamics of Dense Stellar Systems

What processes go on when \( n \approx 10^{5-6} \text{ pc}^{-3} \) and \( M_{\text{tot}} \approx 10^{5-6} M_\odot \)?
- Mass segregation.
- Binary hardening, exchanges.

In young cluster, direct collisions (Portegies Zwart & McMillan).

Evolved cluster, interactions of BH, NS.
- If \( M_{\text{BH}} < 10 M_\odot \), recoil \( \Rightarrow \) ejection.
- If \( M_{\text{BH}} > 50 M_\odot \), inertia \( \Rightarrow \) merger.

Binary-binary can leave stable triple.
- High inclinations \( \Rightarrow \) Kozai resonance.

Detection of IMBH in Globulars

If many globulars have \( 10^{2-4} M_\odot \) BH, how could we see them?
- Accretion from main sequence stars?
  - Exchanges favor more massive objects.
  - In globulars, \( M_{\text{compact}} > M_{\text{MS}} \).
- Density or velocity cusp.
  - But, wandering can be significant.
  - \( (\langle m \rangle/M)^{1/2} r_{\text{core}} < GM/\sigma^2 \).
  - For \( \sigma=10 \text{ km s}^{-1} \), need \( M > 500 M_\odot \).

Radiation from Bondi accretion?
- Uncertain efficiency, \( \dot{M} \), preheating.

Gravitational radiation.
Gravitational Radiation

If this model is correct, many $\sim 10^3 \, M_\odot$ BH exist in globulars.

What are the properties of these sources?
After last encounter: $f_{\text{bin}} \sim 10^{-4}$ Hz.
Unknown eccentricity.

Mass supply, $M/\dot{M}$ limit rates.

If $t_{\text{merge}} > 10^6$ yr, $S/N(\text{LISA}) = S/N(t_{\text{merge}})$.
In 1 yr, detect $\sim$few around Galaxy.
Also, $\sim$few detectable in Virgo.
May be usable as distance measure.

Final merger detectable with LIGO-II.
If 10% of clusters have $100 \, M_\odot$ BH, 10-100 visible mergers per year.
Future Work

(A. Wilson): nature of companion should evolve with age of young star cluster.

Variation in globular sources around ellipticals?

Binary companion plus period would clinch mass range (Liu & Bregman 2002).

Theoretical work, e.g.:
  Four-body dynamics.
  High mass ratio encounters (Gultekin).
  Waveforms for 100:1, 1000:1 inspirals.