Intermediate-Mass Black Holes

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Observational evidence.

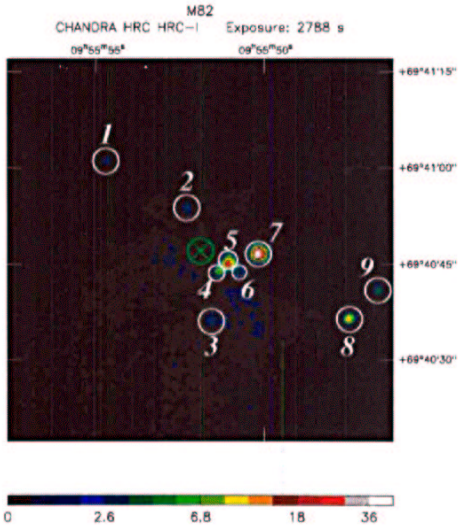
Dense stellar systems.

Detectability in globulars.

Implications for gravitational radiation.

Future observations and theory.

Matsumoto et al. (2000), M82



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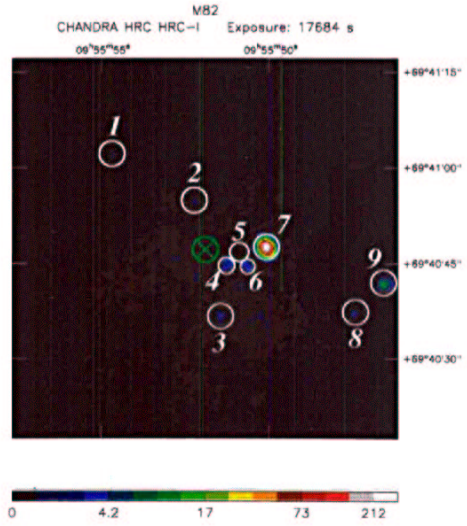


20 January 2000

Observations

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

$L < L_{\rm Edd} \Rightarrow M > L_{38} M_\odot \approx 10^{2-3}\, M_\odot$.

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

Motivation for Dense Stellar Systems

Will proceed assuming $M \sim 10^{2-3}\, M_\odot$.
- 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 $n \sim 10^{5-6}$ pc^{-3} and $M_{\rm tot} \sim 10^{5-6}\,M_\odot$?

- Mass segregation.
- Binary hardening, exchanges.

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

Evolved cluster, interactions of BH, NS.

- If $M_{\rm BH} < 10\,M_\odot$, recoil $\Rightarrow$ ejection.
- If $M_{\rm BH} > 50\,M_\odot$, inertia $\Rightarrow$ merger.

Binary-binary can leave stable triple.

- High inclinations $\Rightarrow$ Kozai resonance.
- Mergers? Miller & Hamilton 2002.

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, $M_{\rm compact} > M_{\rm MS}$.

Density or velocity cusp.

- But, wandering can be significant.
- $(\langle m \rangle / M)^{1/2} r_{\rm core} < GM/\sigma^2$.
- For σ=10 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: $f_{\rm bin} \sim 10^{-4}$ Hz.

Unknown eccentricity.

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

If $t_{\rm merge} > 10^6$ yr, S/N(LISA)=S/N($t_{\rm merge}$).

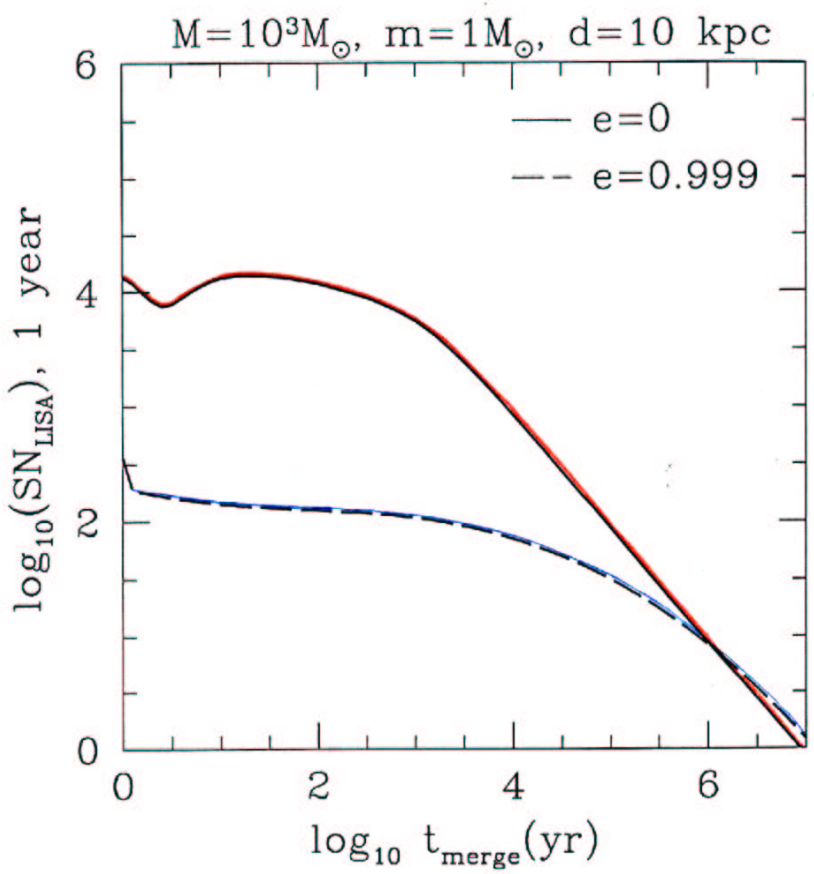
In 1 yr, detect ~few around Galaxy.

Also, ~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.