Gravitational Radiation from the Birth of Intermediate Mass Black Holes

M. Benacquista

Montana State University-Billings

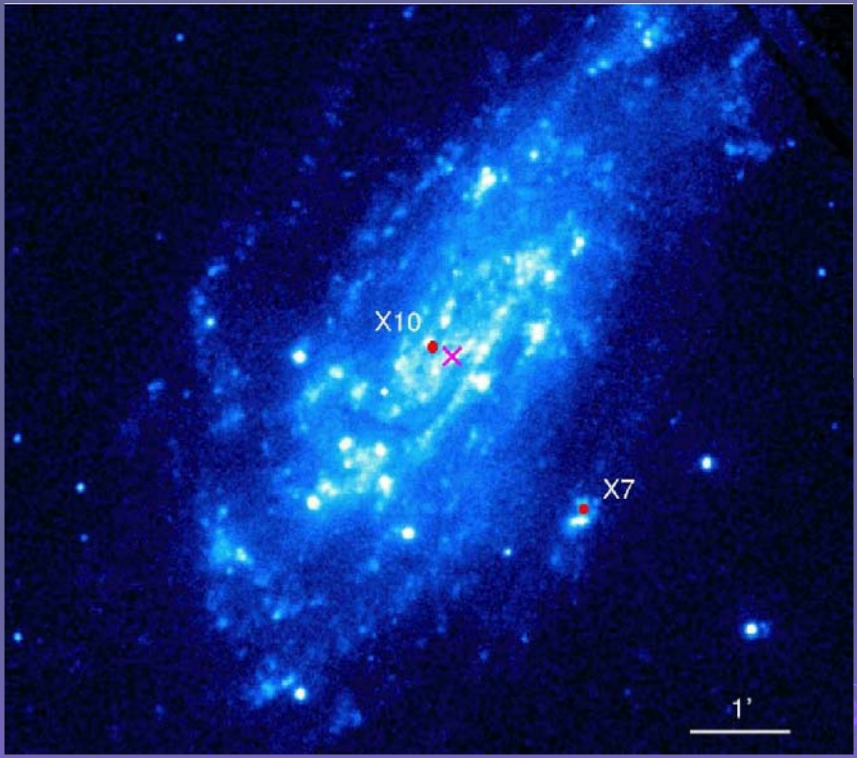
LIGO-G050026-00-Z

Basic Points

- Intermediate mass black holes are potential sources of gravitational waves in the low frequency regime.
- There are a number of formation scenarios which produce different signals.
- Detection can distinguish between some scenarios.
- Non-detection can also provide information about possible formation scenarios.

Observational Evidence

- Most compelling evidence are ultra-luminous x-ray sources (ULXs).
- Luminosity indicates $M > 100\ M_9$ if $L = L_{edd}$.
- Generally in starburst galaxies.
- May be less massive if x-rays are beamed.



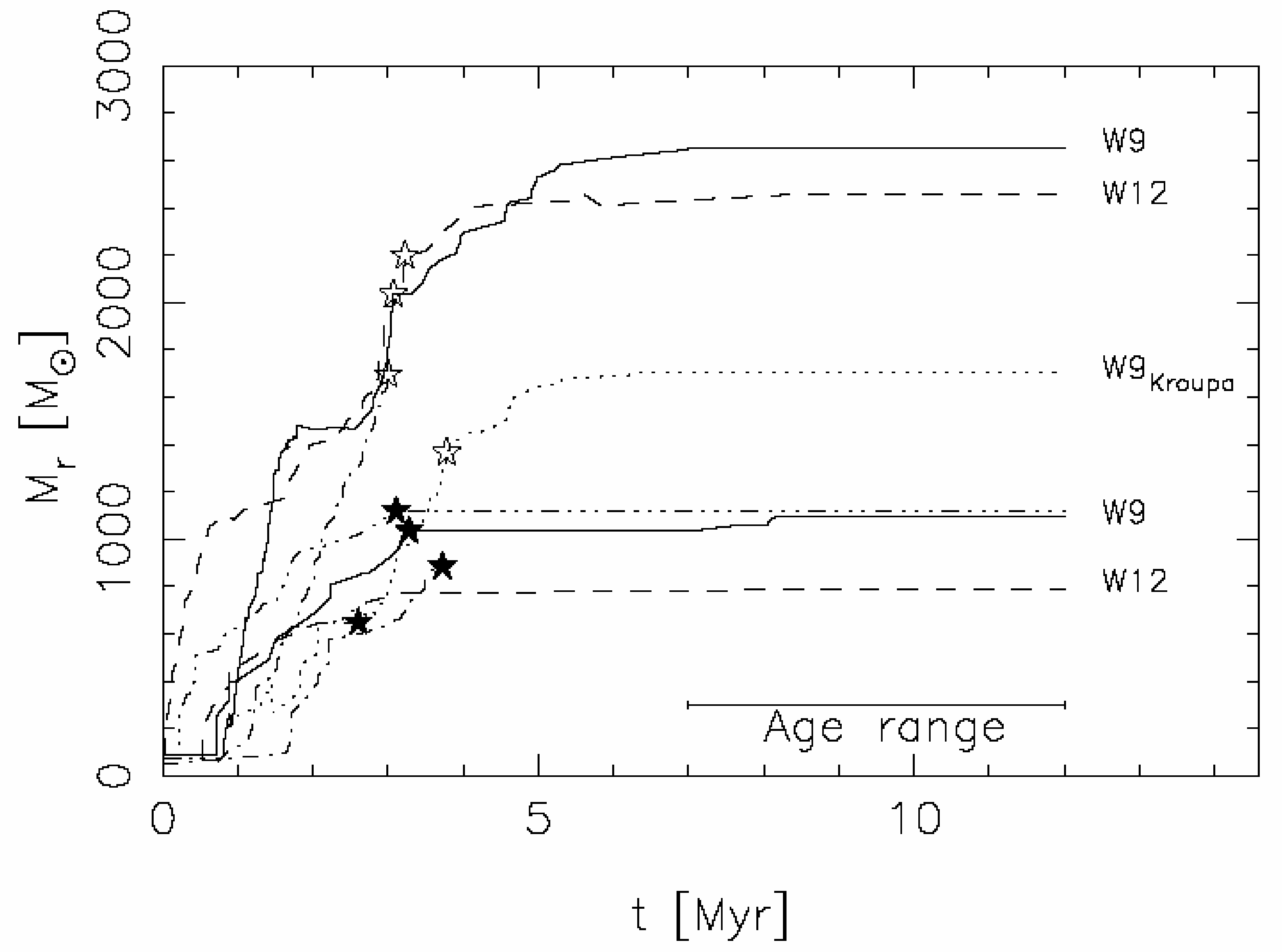
- NGC 4559 (Cropper, *et al.* 2004)

Formation Scenarios

- Massive Population III stars
  - Low stellar winds.
  - Appear as halo objects pass through gas in disk.
- Globular cluster formation
  - Old halo objects
  - Grow through accretion and inspiral
- Young dense stellar clusters
  - Recent formation
  - Young disk/bulge objects
- See van der Marel (astro-ph/0302101) for a good review

YoDeC Formation Scenario

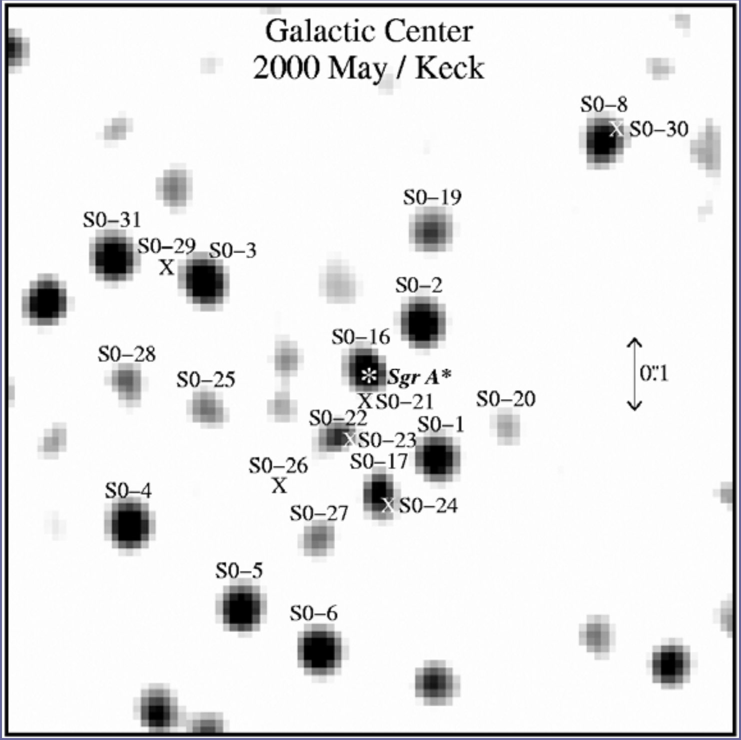
- Born in young dense stellar clusters.
- Mass segregation brings massive stars to the core prior to their evolution off the main sequence.
- Run-away collisions build up a massive (~1000M_9) main-sequence star.
- Star collapses to form IMBH.
- Mass of final IMBH depends upon mass loss.
- Gürkan, Freitag, & Rasio, ApJ 604, p.632 (2004)
- Portegies Zwart & McMillan, ApJ 576, p. 899 (2002)

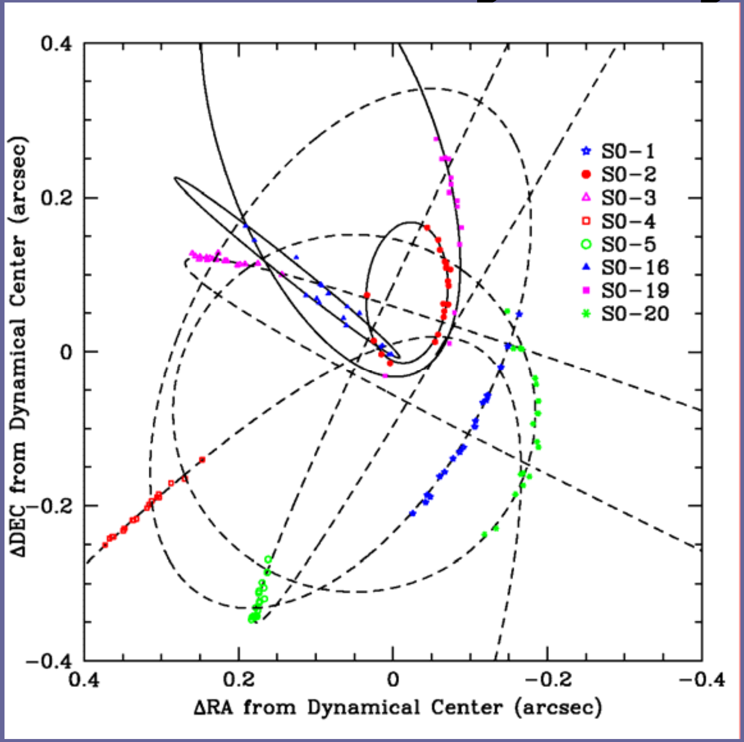


3000
2000
1000
0
M_r [$M_\odot$]
W9
W12
W9 Kroupa
W9
W12
Age range
0
5
10
t [Myr]

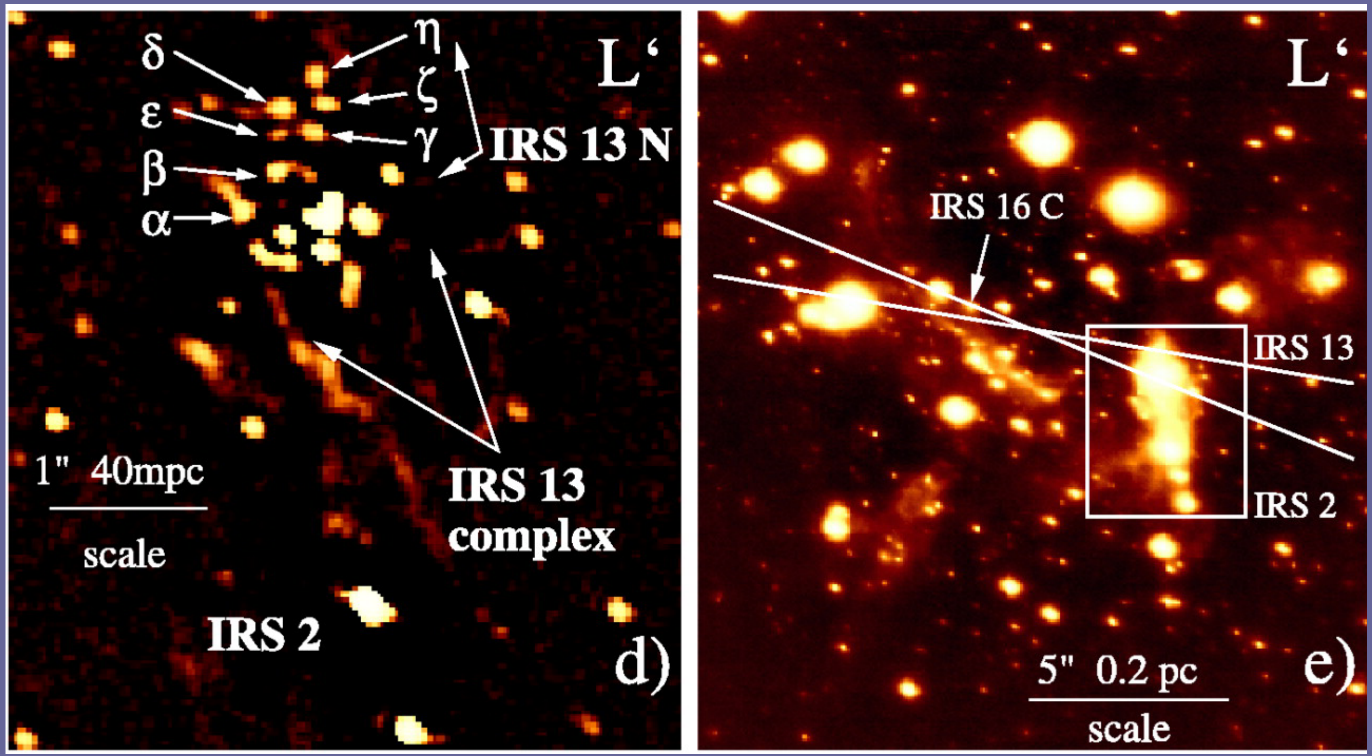
Westerlund 1 in infrared

Observational Evidence: Milky Way





- Cluster of kinematically distinct stars around galactic center (Ghez *et al.* 2003)
- Hot photospheres indicate young ≤ 10 Myr stars.
- Difficult to form *in situ*.
- Diffusion time too long unless cluster is accompanied by IMBH (Hansen & Milosavljevic 2003)



- Infrared observations of the Galactic Center show small cluster of hot objects
- ~ 0.13 lyr in diameter
- Young O type or Wolf-Rayet stars ≤ 10^7 yrs old
- Maillard *et al.* (2004) estimate a central mass of ~ 1300 M_9. (On the basis of 2 stars)

Birth Rates

- Crude estimate of birth rates:
  - Two clusters in the Milky Way with age < 10 Myr.
  - ULX's seen in many young dense clusters in other galaxies.
  - Assume we are not viewing at a special time.
  - Not all IMBH's are in clusters brought to the center of the galaxy.
  - Not all extragalactic IMBH's are accreting (and therefore seen as ULX's)
- Birth rate of ~ $10^{-6} - 10^{-7}$ per yr per MWEG.
  - Comparable to NS-NS inspiral birth rates.

Ringdown Waveforms

- Strongly damped sinusoid
- Central frequency: $f \approx 32\ \mathrm{Hz} \times \left(1 - 0.63(1-\hat{a})^{0.3}\right)\left(\frac{1000\ \mathrm{M}_9}{M}\right)$
- Quality factor: $Q \approx 2(1-\hat{a})^{-0.45}$

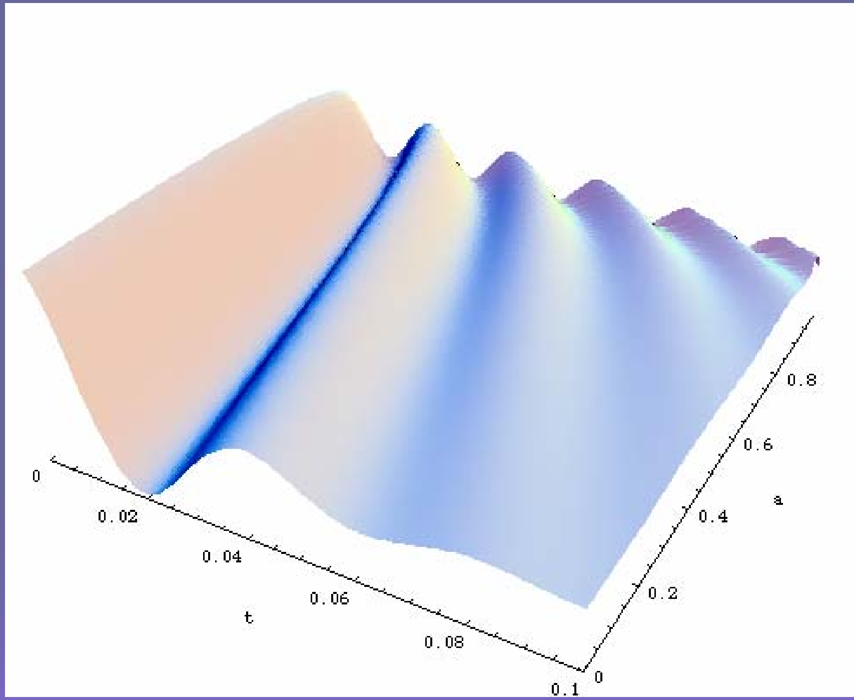
- Angle averaged strain amplitude:

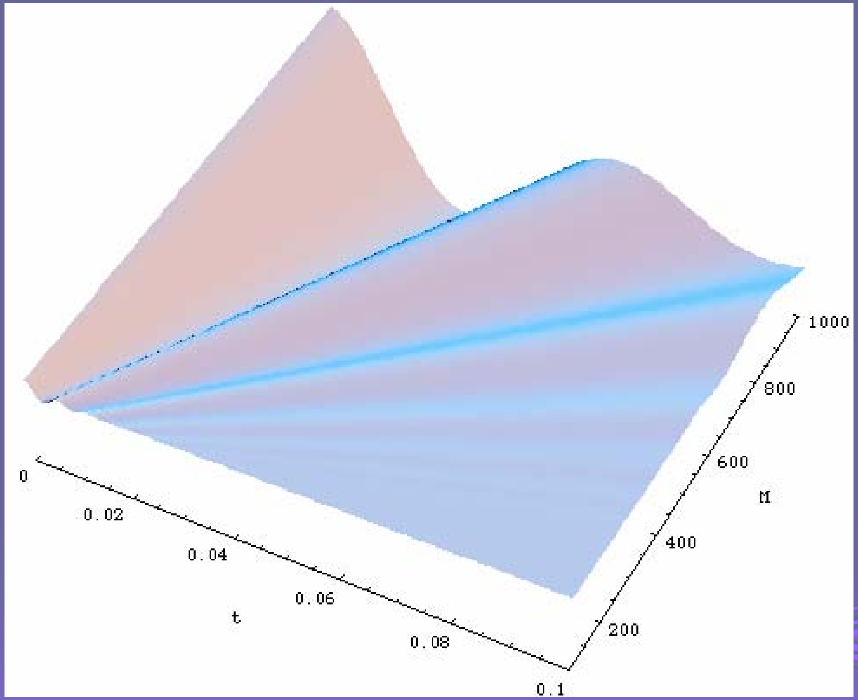
$$h(t) = Aq(t)$$

$$q(t) = \sqrt{2\pi}\, e^{-\pi f t/Q} \cos(2\pi f t)$$

$$A \approx 2.415 \times 10^{-21} Q^{-1/2} \left[1 - 0.63(1-\hat{a})^{0.3}\right]^{-1/2} \left(\frac{\mathrm{Mpc}}{r}\right)\left(\frac{M}{\mathrm{M}_9}\right)\left(\frac{\varepsilon}{0.01}\right)^{1/2}$$

Effect of spin and mass on waveform



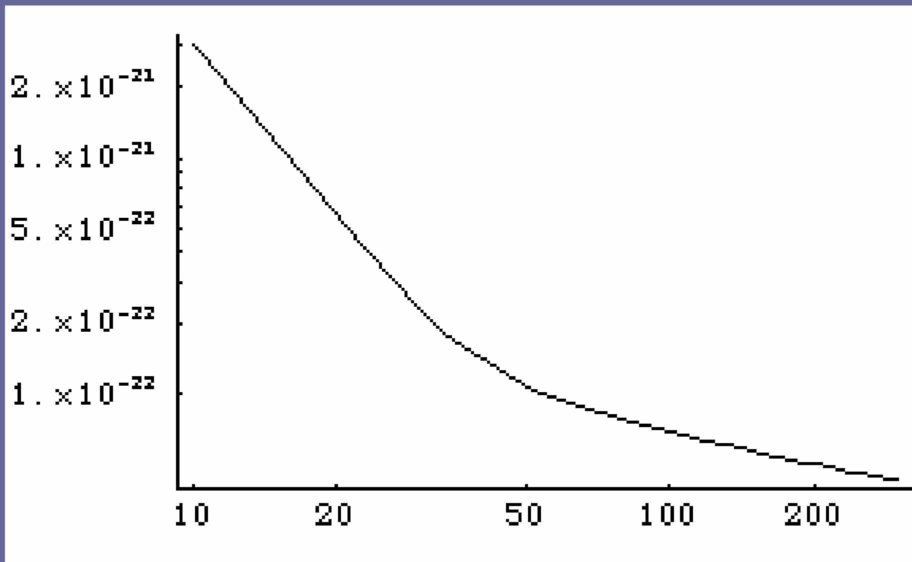


- Vary â with M = 500 M_9.
- Vary M with â = 0.5.

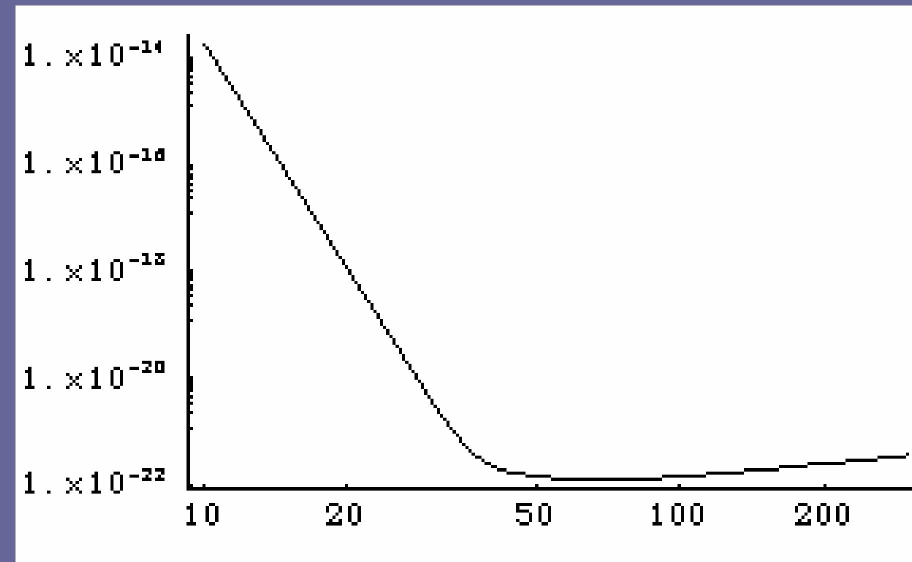
Detection Strategy

- Ringdown can be mimicked by transient noise.
- Coincidence is necessary for detection.
- Use Virgo as a trigger, use LIGO for coincidence.
- Use 3-detector coincidence timing to determine position(s).
- Optical search for starburst galaxy with young dense clusters.

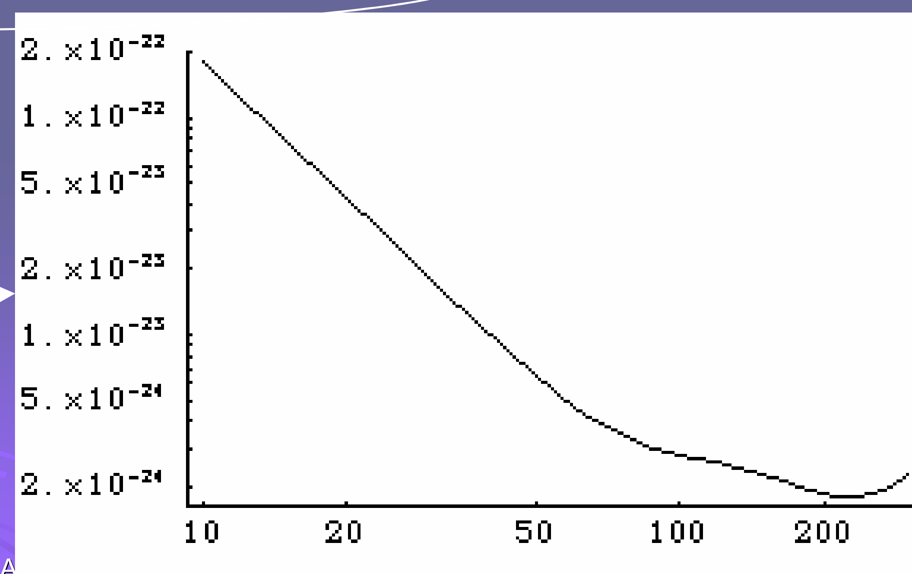
Noise Curves



Virgo



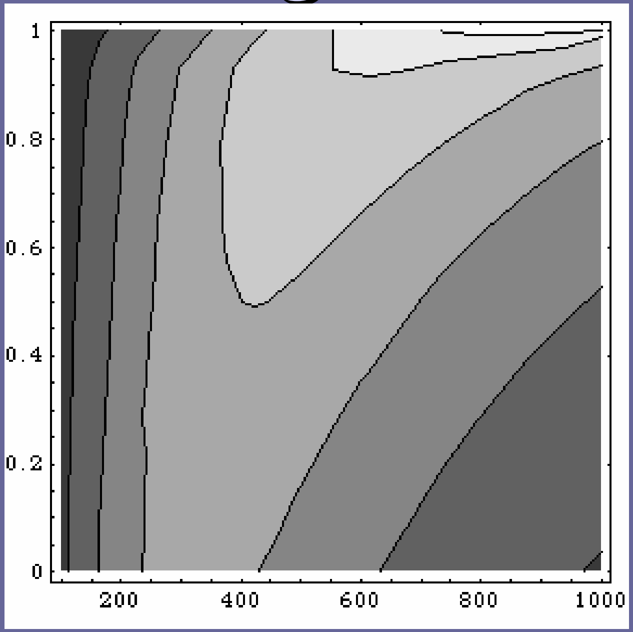
LIGO



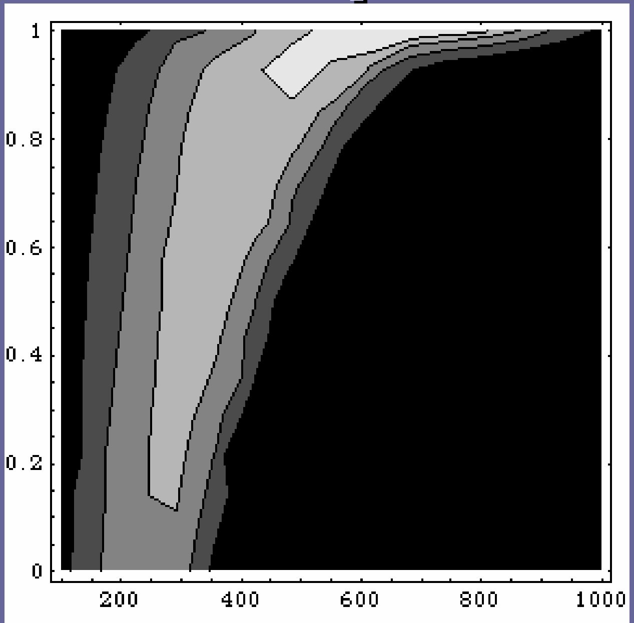
Advanced LIGO

Signal-to-noise at 15 Mpc

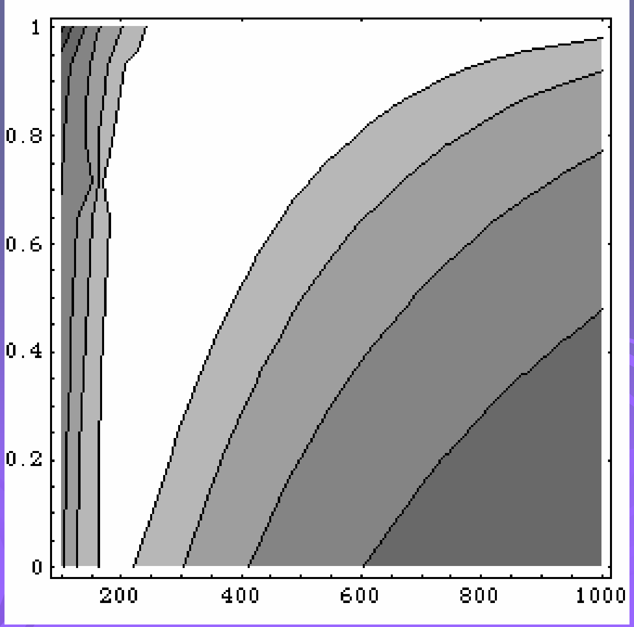
Virgo



LIGO I



Advanced LIGO



- Assume efficiency $\varepsilon = 10^{-4}$
- Virgo and LIGO I signal-to-noise contours 2 – 14.
- Adv. LIGO contours $\times$ 10

Benefits of Low f Detectors

- Ringdown frequency is near the low end of detector sensitivity bands.
- How to distinguish between ringdown following birth from ringdown following coalescence?
- Assume $R_{ISCO} = 3R_S$, then highest inspiral frequency is:
  $f \sim 4.4$ Hz $(10^3\ M_{9}/M)$
- Lower frequency detection may allow observation of inspiral phase to distinguish inspiral events from births.
- LISA may also observe the inspiral phase.

Conclusions

- If this mechanism occurs, LIGO I and Virgo can detect the birth of ~ 200 - 300 M_9 IMBHs out to 15 Mpc.
- Detection would indicate high mass loss rates.
- If high spins are favored, mass range extends up to ~ 500 M_9.
- Advanced LIGO will be sensitive to higher mass and lower spin IMBHs and may provide information about the birth rate and population statistics.
- Low frequency detectors can improve population statistics.