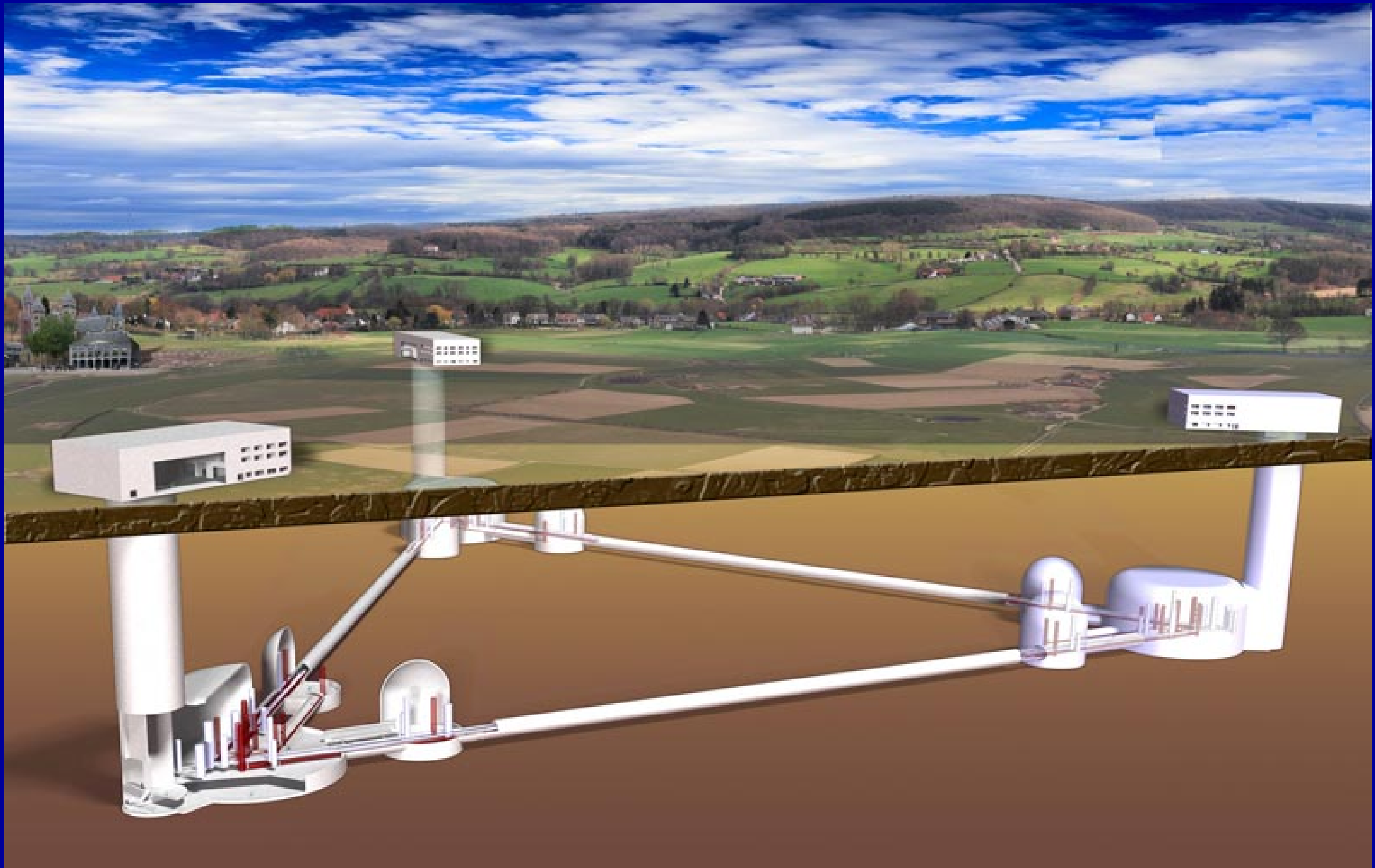
GW sources from a few Hz to a few kHz

Cole Miller, University of Maryland



Outline

- The most massive white dwarfs
- Long lead times for telescopes
- Nonzero eccentricities?
- Intermediate-mass black holes
- High freq: NS masses, radii, and modes
- High freq: SN bursts

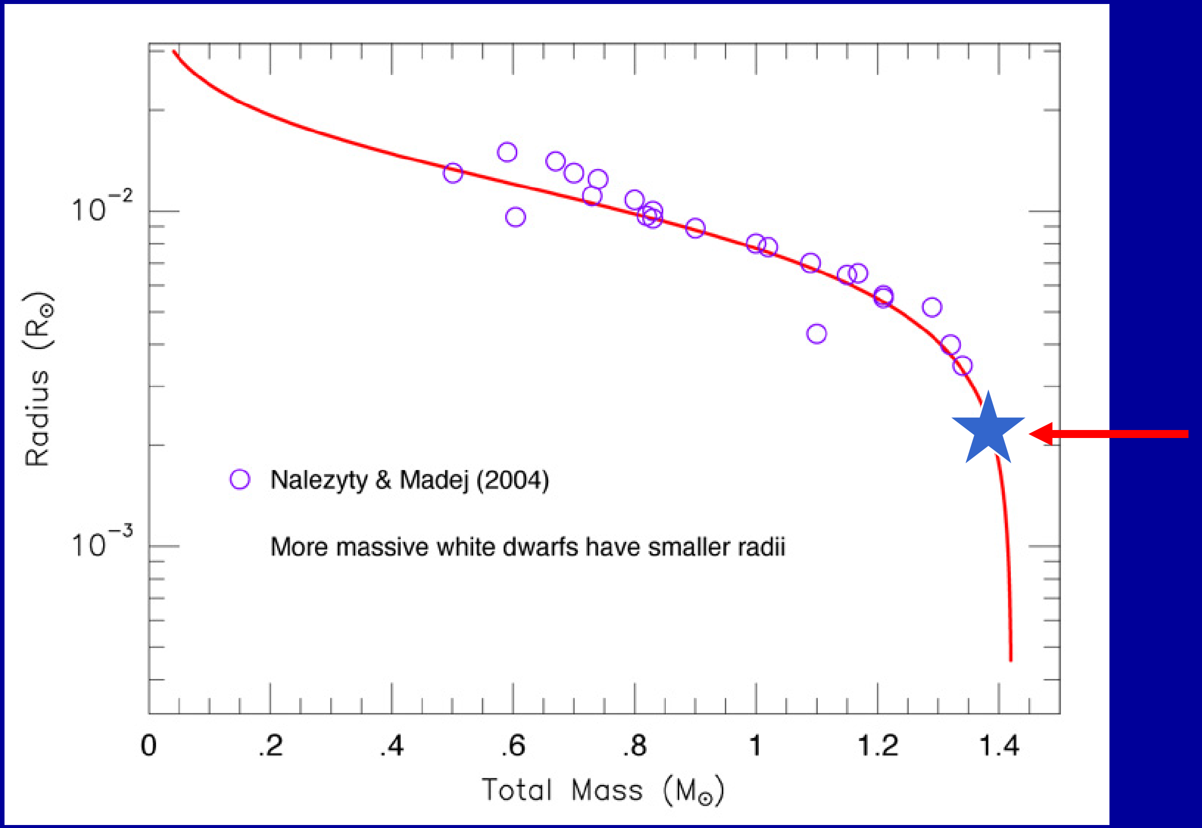
Frequency of Waves

Object of average density ρ has maximum frequency ~$(G\rho)^{1/2}$ for gravitationally bound object

- True for orbit, rotation, or full-body pulsation
- Neutron star: ~1200-2000 Hz
- White dwarf: up to ~1 Hz (but see later)

The Most Massive WD

- ~$10^{8\text{-}9}$ WD binaries in Milky Way
- Even small fraction with M~1.4 M_{sun} gives large number; new category of sources



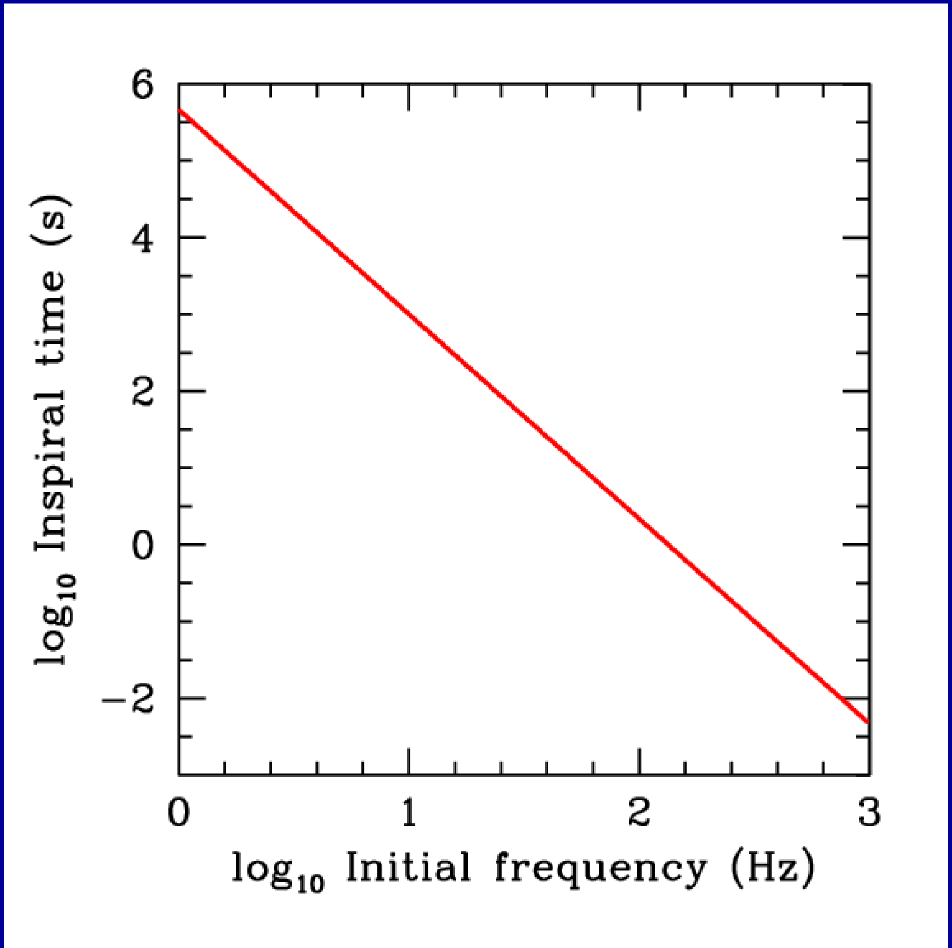
http://cococubed.asu.edu/images/coldwd/mass_radius_web.jpg

Who Cares About Massive WD?

- Precise maximum mass depends on composition, other properties
- Massive WD (in binaries with normal stars) possible Type Ia SNe progenitors
- Mergers would be spectacular but short-lived EM events
  How much lead time do we have?

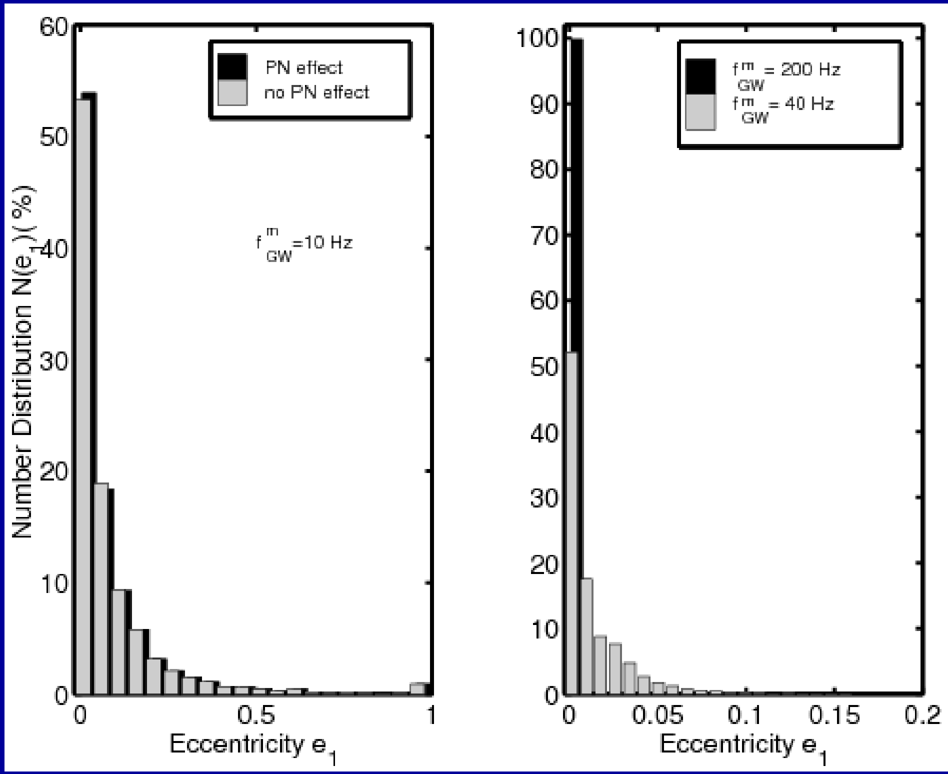
Advance Warning of Merger

- EM counterparts to mergers: lots of info!
  Precise localization
  Nature of transients
- Time to merger scales as $f_{init}^{-8/3}$
- At 3 Hz, could be identified hours in advance
- Key: how soon could GW be localized?
  Rotation of Earth?



Nonzero Eccentricities?

- Usually, think of binary GW as circular
  ~true for >10 Hz or field binaries
- Dynamical interactions can change, e.g., Kozai in dense systems
  Eccentric Kozai
- e~1/f for e<<1
- Low freq important for inferring dynamic origin

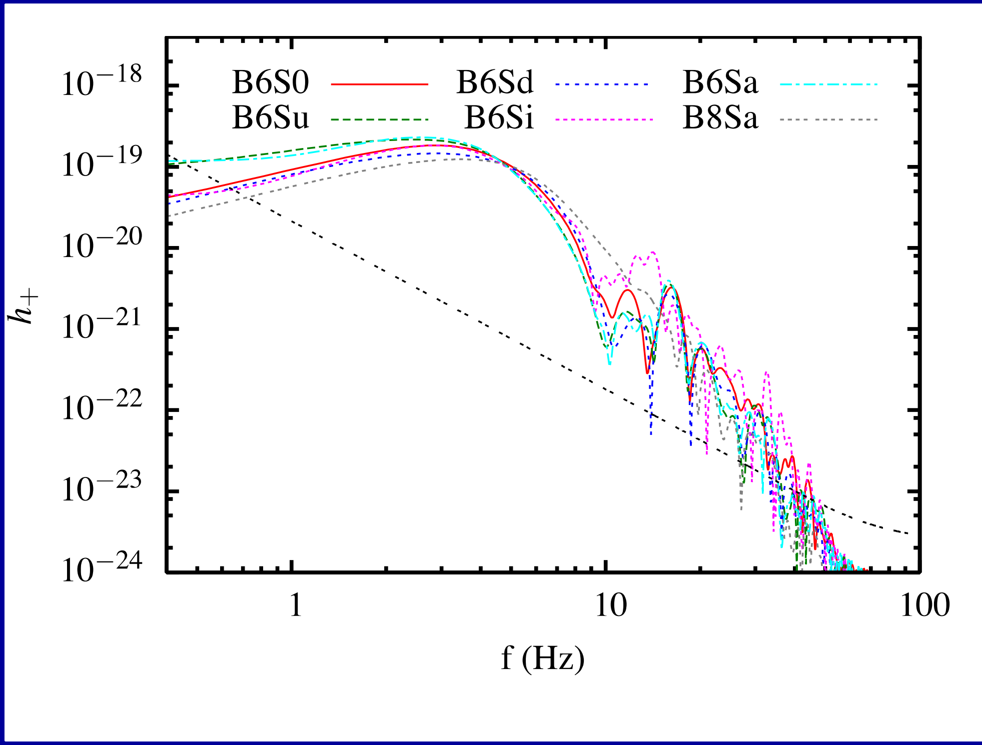


L. Wen 2002
Following Miller & Hamilton 2002

Plunges into IMBHs

Haas et al. 2012

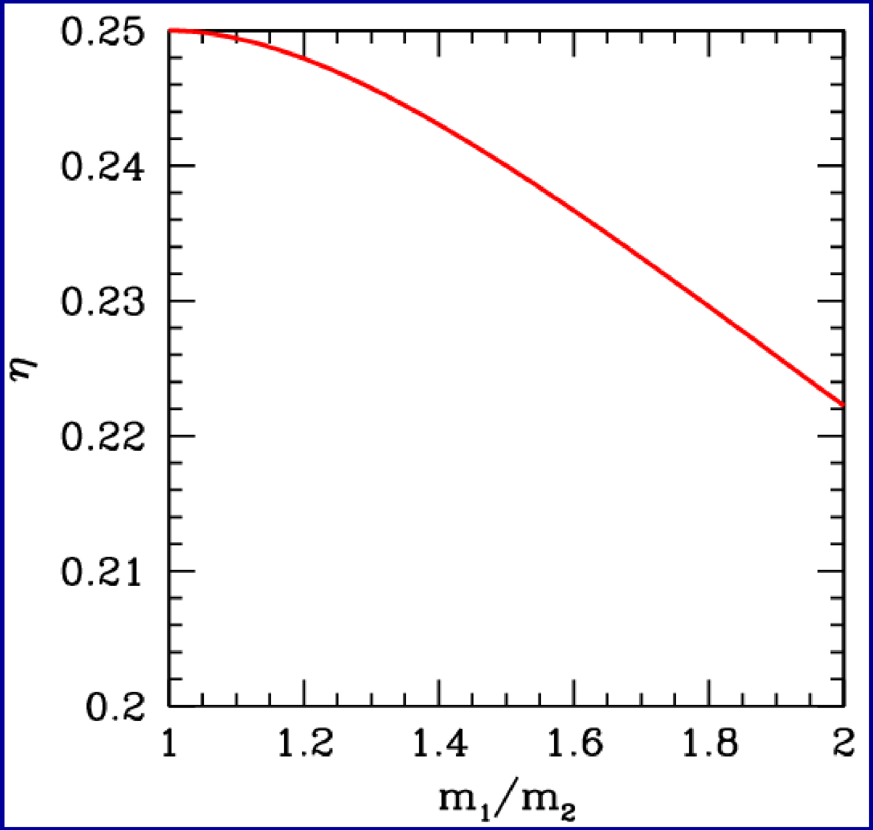
- You can get some leakage to higher freq with plunge
- WD disrupted but bulk moves along same trajectory
- Evidence of IMBH? This, or IMBH-IMBH, could be first direct proof



10^3 M_{sun} BH, 1 M_{sun} WD, penetration factors of 6 and 8; assume 20 kpc for distance of source

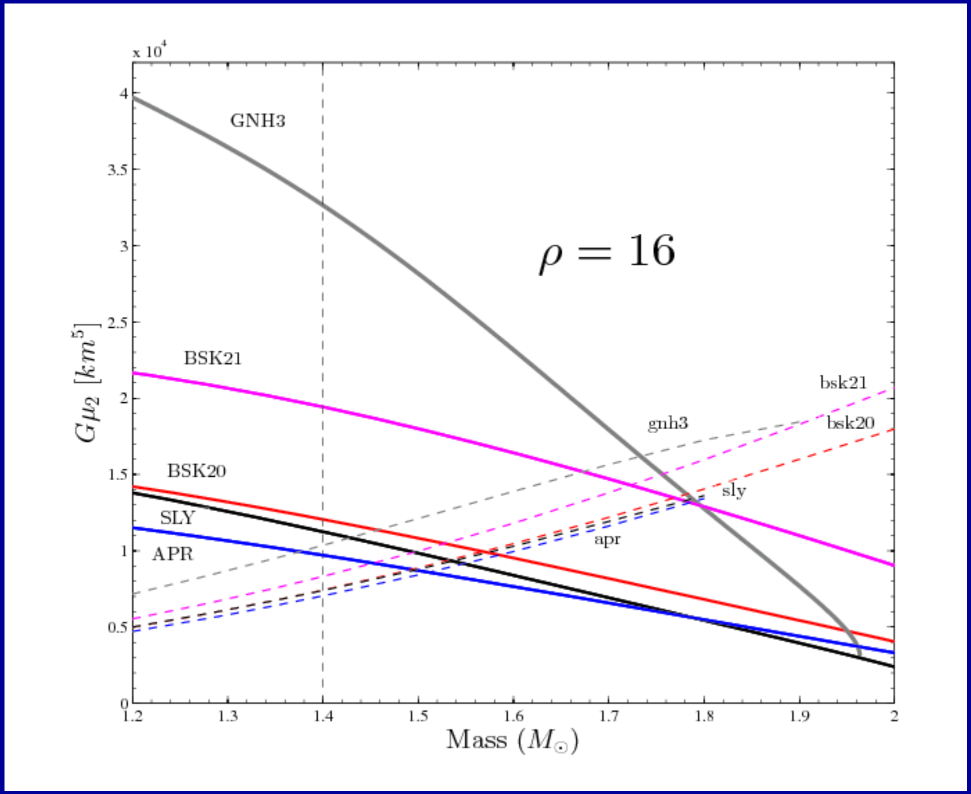
NS and BH masses

- Chirp mass is easy: $df/dt \sim \eta M^{5/3} f^{11/3}$
- Getting both masses requires symmetric mass ratio $\eta = m_1 m_2 / M^2$
- Need higher-order, high freq effects in GW
- aLIGO/Virgo at SNR=15: $\Delta\eta \sim 0.007$
- Bad for NS-NS; okay for NS-BH, but better high-freq sensitivity is a must!



NS Radius: Phase Accumulation

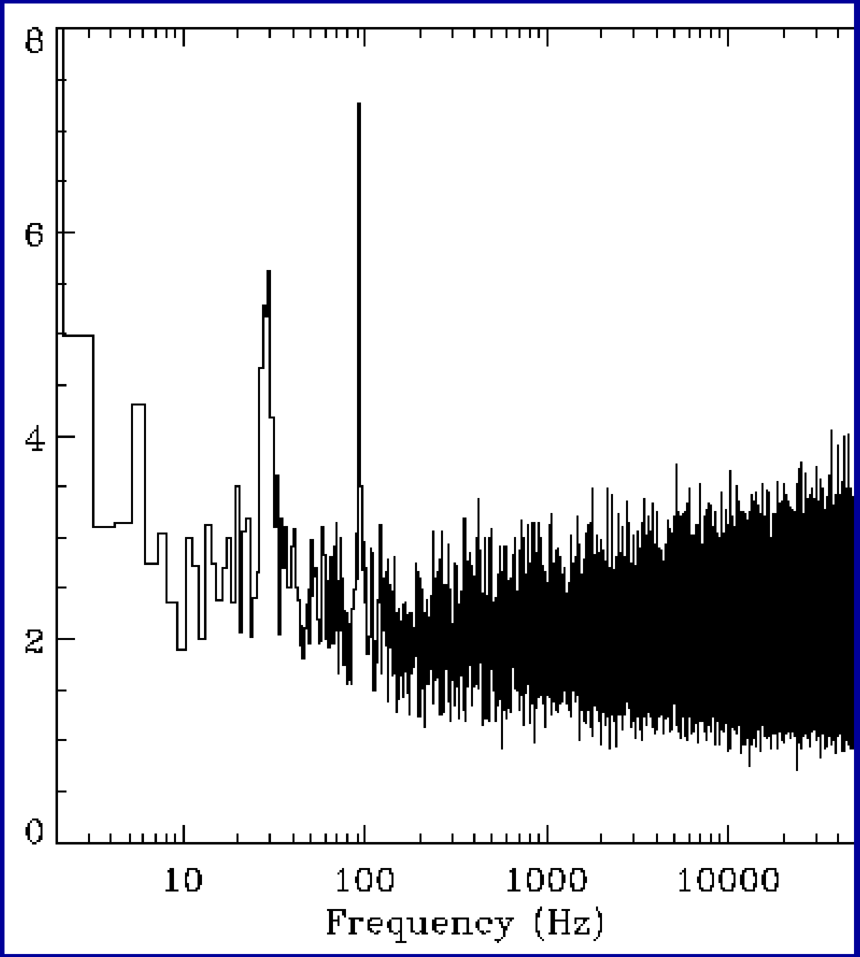
- Radius: key EOS unknown
- Deviation from point mass: accumulated tidal effects
- For aLIGO, can measure tidal param; SNR>30 can distinguish EOS, barely
- Higher sensitivity at high frequencies would allow fairly precise measurement of tidal parameter, hence radius



Damour et al., arXiv:1203.4352

NS Modes

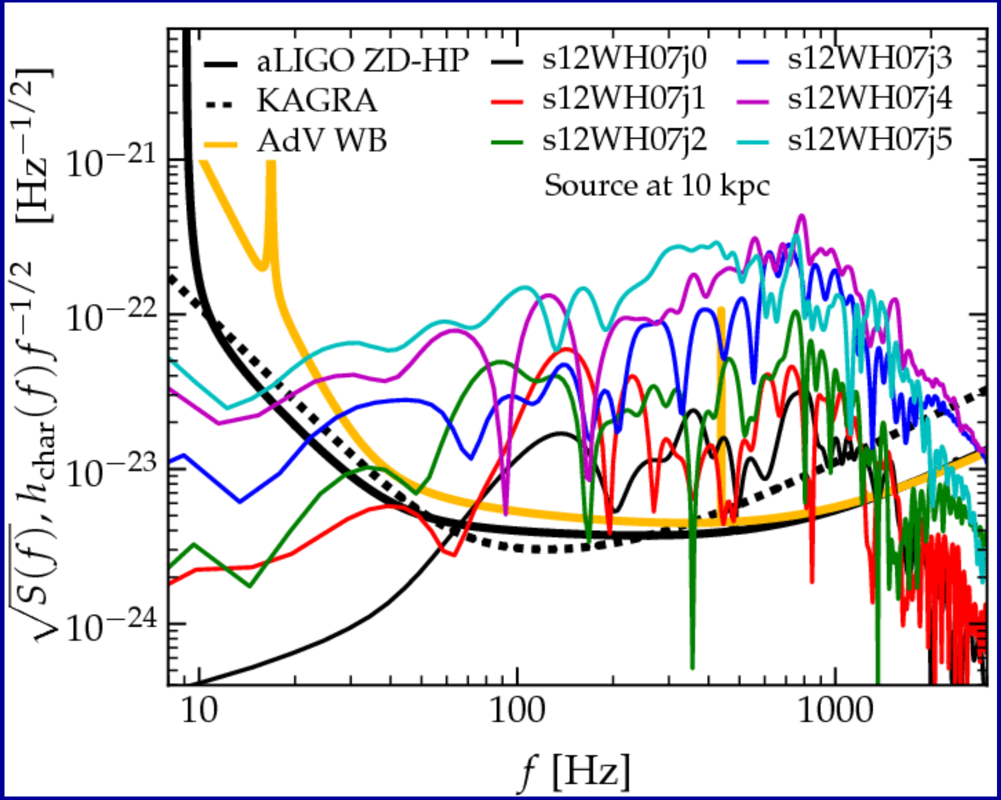
- NS seismology could tell us a lot!
- Indeed, QPOs have been seen
- But...
- Crust has ~1% of M, I; very weak GW
- If detectable, need huge, transient perturbation at main body freq: ~2000 Hz



QPOs from SGR 1806-20 superburst
Strohmayer 2007

GW from Supernovae

- >~10% chance for MW SN (~10 kpc) in decade
- Much uncertainty about mechanism!
- GW (+ν) will give invaluable info
- High freq are key



Ott et al. 2012

Conclusions

- The ~few Hz range contains qualitatively new sources: heavy WD and IMBH
- Long lead time will allow pointing of large telescopes if the direction can be established to within a few degrees
- The ~few kHz range gives us prospects of unique measurements of NS radius, many measurements of NS mass, and new insights about supernovae

Amplitude of Gravitational Waves

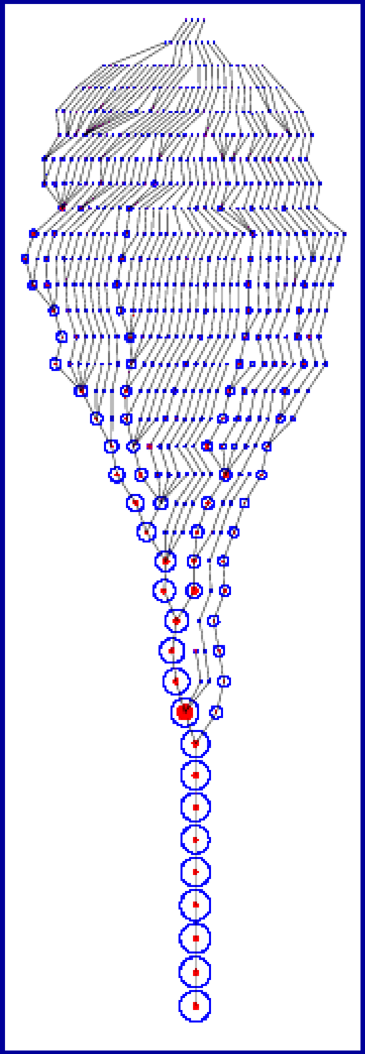
Binary of reduced mass μ, total mass M.
At luminosity distance d, frequency f_{GW},
dimensionless strain amplitude is

$$h=3\times10^{-23}\,(f_{GW}/1\text{Hz})^{2/3}(M_{ch}/10\,M_{sun})^{5/3}(100\text{Mpc}/d)$$

where $M_{ch}^{5/3}=\mu M^{2/3}$ defines the "chirp mass".

Context and Connections of IMBH

- In z~5-30 universe, seeds for SMBH
- In local universe, probes of star cluster dynamics
- Potentially unique sources of gravitational waves (ground and space)



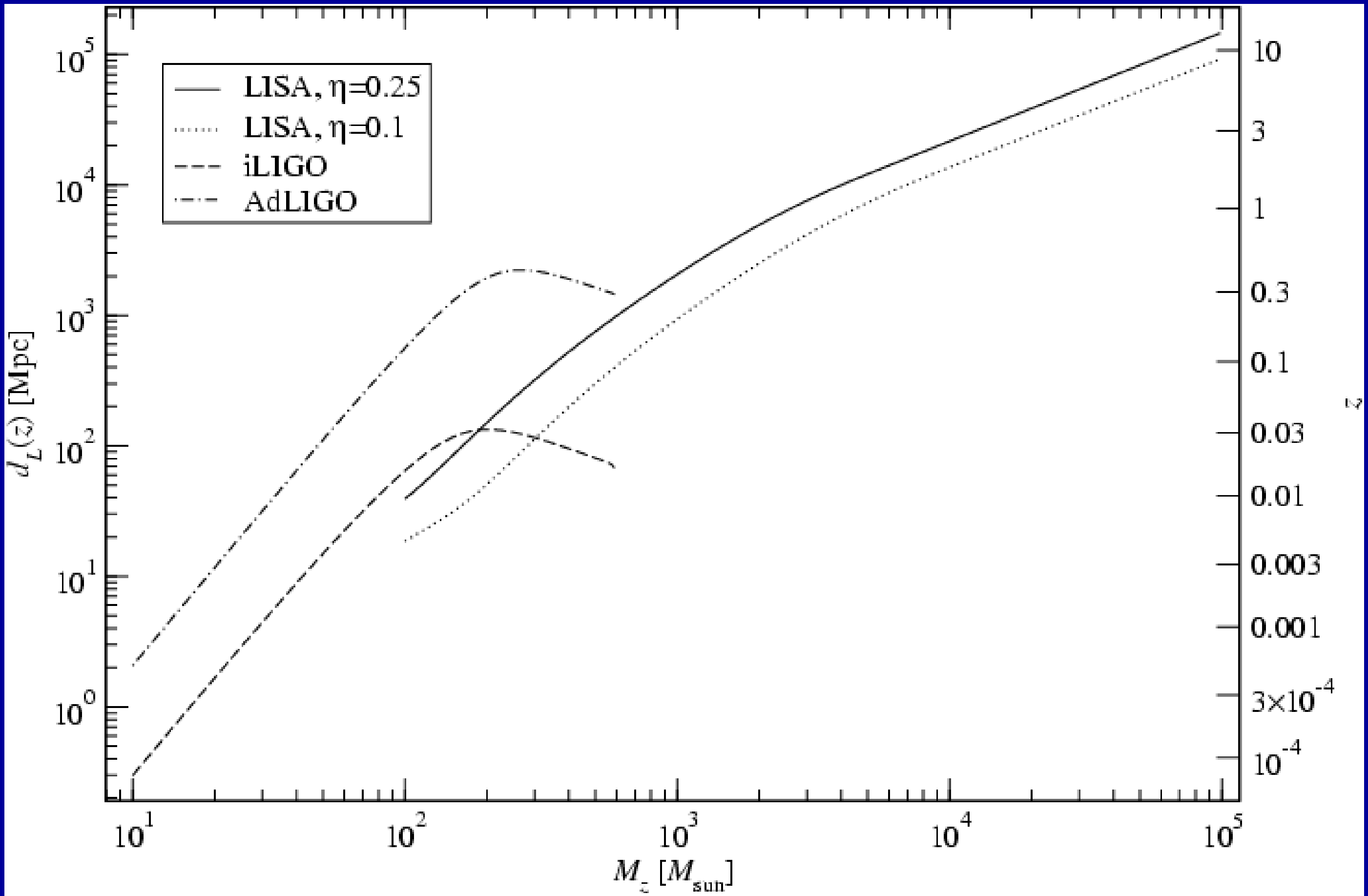
Wechsler et al. 2002

Why Are We Not Sure?

- Stellar-mass (5-20 M_{sun}) and supermassive (10^6-10^{10} M_{sun}) BH are established with certainty
- Why not IMBH (10^2-10^4 M_{sun})?
- Lack of dynamical evidence
  Too rare for easy binary observations
  Too light for easy radius of influence obs
- Attempts being made, but settle for indirect observations in the meantime

IMBH-IMBH Visibility

- ~1000 M_{sun} binary visible to z~1.
- Reasonable rates: few tens per year at >1 Hz
- Unique probe of dense cluster star formation

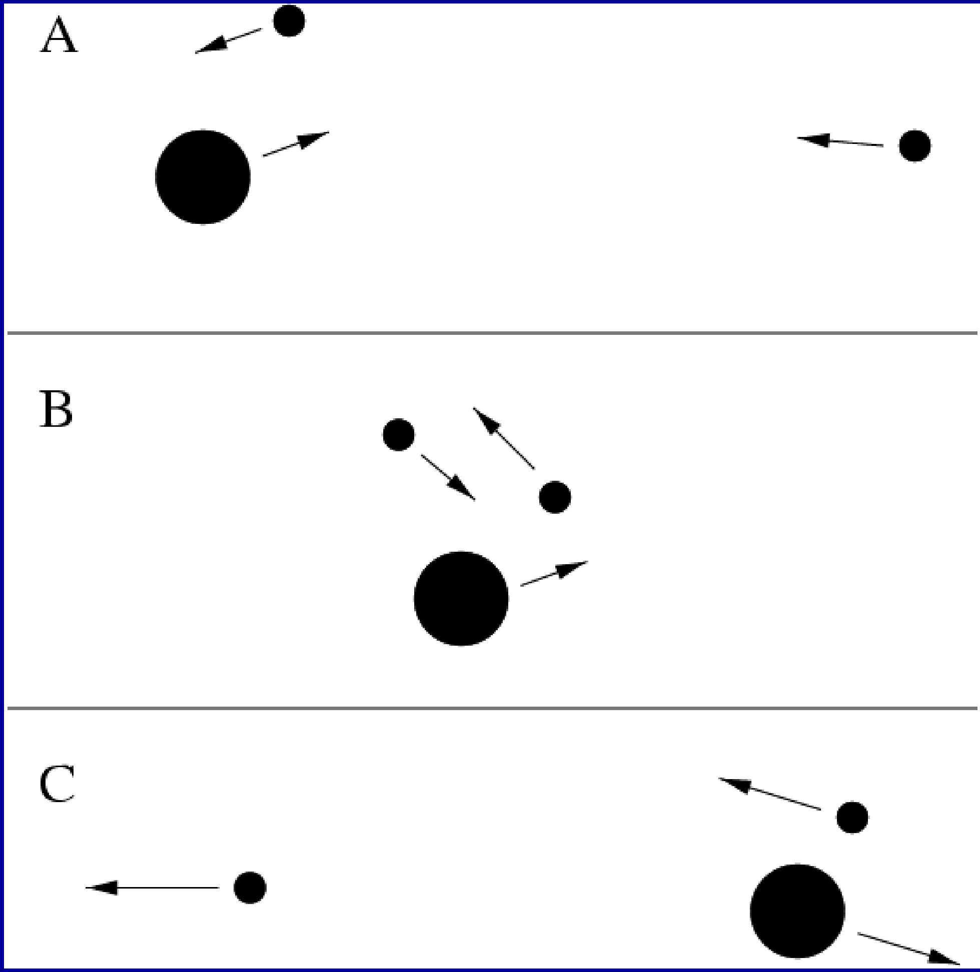


Fregeau et al. 2006

Formation of IMBHs

- Problem: ~10^3 M_{sun} too much from normal star!
- Population III stars
  Low Z; weak winds
- **Collisions or mergers**
  Needs dense clusters
  Young: collisions
  Old: three-body

Issue: ejections by 3-body or GW recoil. If M_{init}>300 M_{sun}, seems safe.



Open Question: Mass Function?

- Period, radial velocity of companion would give lower mass limit
  One example would establish IMBH
- Issue: unique identification
  Nearest ULX are few Mpc away!
  Even O, B stars are ~24th mag
- Maybe He II 4686A emission lines?
  Some candidates being pursued