IMAGINING THE FUTURE:
GRAVITATIONAL WAVE ASTRONOMY

The Interplay Between Gravitational Wave Astronomy and X-Ray/UV/optical Astronomy in the Year 2024

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What do X-ray astronomers talk about in their secret meetings?

- Solar Corona + Stellar Coronae
- Isolated Neutron Stars
- Interacting Binaries Especially ultracompact ones
- Supernova Remnants and Supernovae Type Ia
- The Hot Interstellar Medium
- Starburst Galaxies
- Active Galactic Nuclei and Quasars

Supermassive binaries, tidal disruptions...

Capabilities of imaginary instruments

- Positional resolution (avoids confusion):
  - locate individual nearby binaries and galaxies
- Wide range of frequencies: 1 Hz - 0.1 mHz
  - WD mergers → Type Ia SNe
  - short-period CVs → system properties
  - tidal disruptions (1 Hz)
  - long period SMBHs (1 nHz)
- High sensitivity:
  - $h < 10^{-25}$ (merging WDs @ Virgo)
- Several operating modes:
  - continuous monitoring → post facto study
  - “pointed” observations → specific systems

Case Study 1: Merging White Dwarfs as Progenitors of Type Ia Supernovae

$M_1 = M_2 = 0.7\ M_\odot \Rightarrow$ Chirp mass: $\mathcal{M} = 0.4\ M_\odot$

Period just before merging: $P \sim 1$ sec

$$h \approx 2 \times 10^{-24} \left(\frac{d}{20\ \mathrm{Mpc}}\right)^{-1} \left(\frac{P}{1\ \mathrm{sec}}\right)^{-2/3}$$

Long before merging (in LISA band...):

$P \sim 10$ -100 sec $\Rightarrow h < 10^{-24}$ - 10^{-25}

$$\tau_{GR} = 43 \left(\frac{\mathcal{M}}{0.4\ \mathrm{M}_\odot}\right)^{-5/3} \left(\frac{P}{10\ \mathrm{sec}}\right)^{8/3} \mathrm{days}$$

Perhaps we can even predict Type Ia supernovae...

Case Study II: Ultracompact Double Degenerates and Short Period CVs

Orbital angular momentum: $J \propto \mathcal{M}^{5/3}\, P \propto h\, P^{5/3}\, d$

Mass transfer is driven by angular momentum loss via gravitational radiation:

$$-\frac{dJ}{dt} \propto \mathcal{M}^{10/3}\, P^{-7/3} \propto h^2\, P^{-28/9}\, d^2$$

Thus we can get mass transfer rates via:

$$\left|\frac{\dot{M}_2}{M_2}\right| \approx \left|\frac{\dot{J}}{J}\right| \propto h\, P^{-11/3}\, d$$

The Holy Grail: Mass Transfer Rates

ACCRETION DISK THEORY

Direct comparison with spectra

Winds and other outflows

Angular momentum transport in the disk

Can we measure these things?

- Periods are a piece of cake
- Distances can be measured by parallax up to 100 pc. In 20 years we may be able to measure parallaxes to much more distant objects with space-based, optical interferometers, such as the TPF.
- The strain could be measured even by LISA, if only it had the positional resolution, since

$$h = 2.5 \times 10^{-22} \left(\frac{\mathcal{M}}{\mathrm{M}_\odot}\right)^{5/3} \left(\frac{P}{1\ \mathrm{hr}}\right)^{-2/3} \left(\frac{d}{1\ \mathrm{kpc}}\right)^{-1}$$

FOR THOSE WITH A VIVID IMAGINATION...

30m-class optical telescopes + Constellation X

Optical (or X-ray) spectroscopy allows us to measure the mass ratio of the binary, if we can detect the orbital motion of both components. Thus, we may be able to measure component masses from the chirp mass, since

$$\mathcal{M} = \left[\frac{(M_1 M_2)^3}{M_1 + M_2}\right]^{1/5} = M_1 \left(\frac{q^3}{1+q}\right)^{1/5}$$

And some halucinations...

- Supermassive bimary black holes in neraby galaxies (z~0.1).
  - Close enough for tidal interaction but too far away for imminent merger.
  - $M_1 = 10^8\ M_\odot$, $M_2 = 10^6\ M_\odot$, $P = 10$ years

    $h \sim 10^{-19}$ but $f \sim 30$ nHz
- Tidal disruption of a star by a supermassive black hole in a nearby galaxy.
  - very brief X-ray flash (duration ~ weeks)
  - non-periodic gravitational wave signal
  - f ~ □Hz

In the year 2024: Hopefully Strong Interactions

- Hey Mike, LISA-XIV has detected another binary white dwarf about to merge! We predict a Type Ia supernova on January 21 at 3:16 pm
- That's Brilliant, Sam! We will get the Constellation-Z X-ray Observatory on it.

The End

Many thanks to Tamara Bogdanovic
for tips and movies.

Inspirational Papers:

- Nelemans et al. 2001, A&A, 375, 890
- Faulkner 1971, ApJ, 170, L99
- Taam et al. 1980, ApJ, 239, 1017