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Exploring resonances in binary inspiral using gravitational waves

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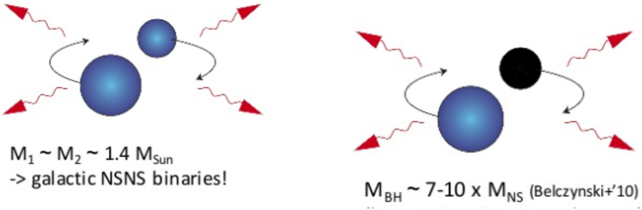
Introduction

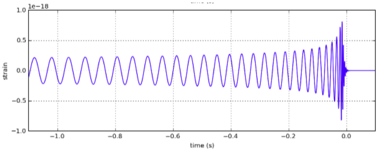


- Binary system emits gravitational waves, as a result orbital frequency increases
- When gravitational frequency matches with resonance frequencies of the neutron star, orbital energy dissipated
  - inspiral speeds up
  - visible in gravitational waves signal
  - can be measured in principle

Gravitational wave signal

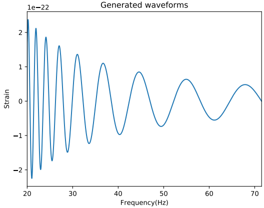
- Gravitational waves signal seen in the detector

$$h(t) = A(t)Cos(\phi(t))$$



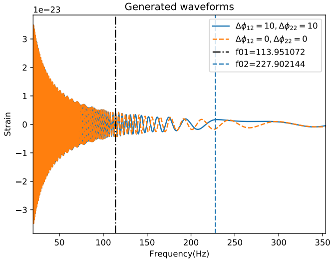
- Fourier transform of it

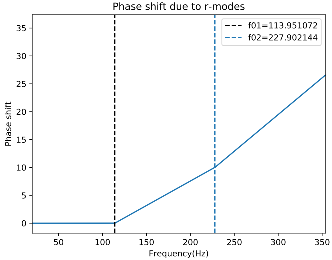
$$\tilde{h}(f) = A(f)e^{i\psi(f)}$$



Effect of r-modes in neutron star blackhole binary

- R-modes causes phase shift in orbital phase of binary





- r-modes resonances provide information about interior structure of neutron star
- Can effect of r-modes resonances can be measured ?

R-modes

- When neutron star spins then it has r-modes oscillations
- r-modes oscillation frequencies

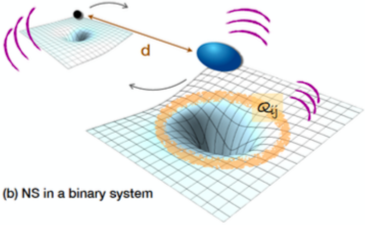
$$\omega_{lm} = \frac{2m}{l(l+1)}\Omega_{\mathrm{rot}}$$

  Ω_{rot} is spin frequency of neutron star
- Effect of r-modes can be seen during binary inspiral of binary neutron star or neutron star blackhole binary
- When orbital frequency matches with r-modes frequency during binary inspiral it causes phase shift

$$\psi(f) = \begin{cases} \psi_0(f) + (\frac{f}{f_{lm}} - 1)\Delta\phi_{lm}, & f \geq f_{lm}. \\ \psi_0(f), & f < f_{lm}. \end{cases} \tag{1}$$

Neutron star

Neutron star characterized by



- Mass M, moment of inertia I
- Dimesionless spin χ
- Tidal Deformability λ It grows as the neutron star get close with other binary object
- R-modes frequencies f_{lm}

R-modes

- For l = 2, m = 1 and l = 2, m = 2 modes

$$f_{22} = \frac{2}{2\pi 3}\Omega_{\rm rot} \qquad f_{21} = \frac{1}{2\pi 3}\Omega_{\rm rot}$$

- $\Omega_{\rm rot}$ does not enter waveform directly

$$\chi = \frac{S}{M^2} = \frac{I\Omega_{\rm rot}}{M^2}$$

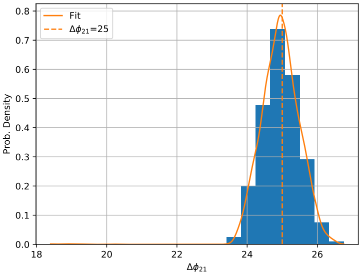
  where χ is dimensionless spin I is moment of inertia, M is mass of neutron star S is angular momentum
- Moment of inertia I depends on tidal deformability λ through universal relation

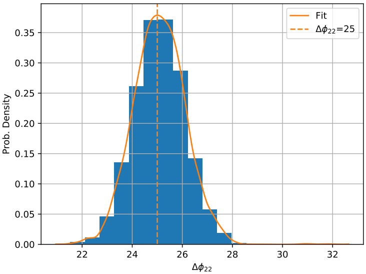
$$f_{22} = \frac{2}{2\pi 3}\frac{\chi M^2}{I(\lambda)} \qquad f_{21} = \frac{1}{2\pi 3}\frac{\chi M^2}{I(\lambda)}$$

- Parameters are to be measured $\Delta\phi_{21}$ and $\Delta\phi_{22}$

Results with simulated signal

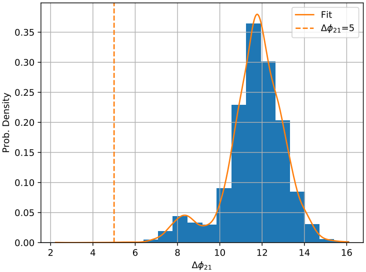
- For neutron star blackhole binary system
- $M_{blackhole} = 10\ M_{\odot}$, $M_{neutron-star} = 1.2\ M_{\odot}$
- $\lambda_{blackhole} = 0$, $\lambda_{neutron-star} = 1000$, $\chi_{neutron-star} = 0.1$
- Values for $\Delta\phi_{21} = 25$, $\Delta\phi_{22} = 25$ in simulated signal, signal to noise ratio $= 34.22$
- Measurement results of parameters in terms of probability distribution

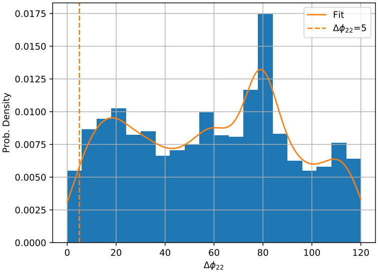




Results with simulated signal

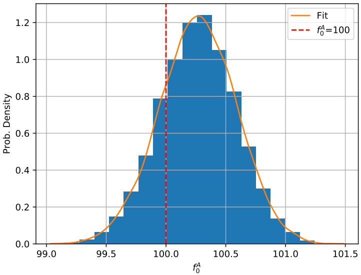
- $M_{blackhole} = 10\ M_\odot$, $M_{neutron-star} = 1.2\ M_\odot$
- $\lambda_{blackhole} = 0$, $\lambda_{neutron-star} = 1000$, $\chi_{neutron-star} = 0.1$
- Values for $\Delta\phi_{21} = 5$, $\Delta\phi_{22} = 5$ in simulated signal, signal to noise ratio $= 34.22$
- Measurement results of parameters in terms of probability distribution

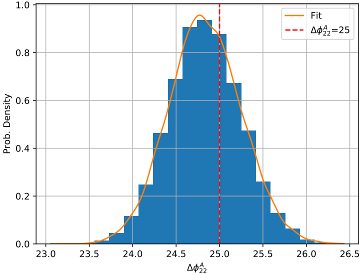




Binary neutron star system

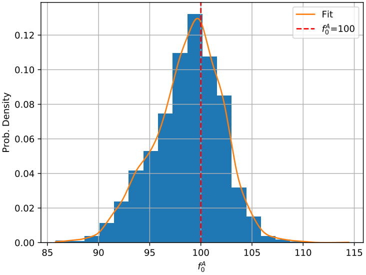
- For binary neutron star system where f_0 and $\Delta\phi$ are sampling parameters
- Values for $\Delta\phi = 25$, $f_0 = 100$Hz in simulated signal, signal to noise ratio $= 55.30$
- Measurement results of parameters in terms of probability distribution

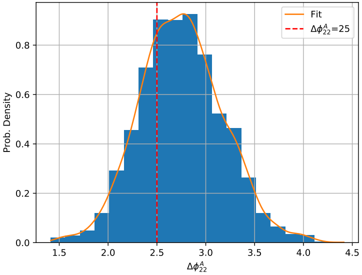




Binary neutron star system

- Values for $\Delta\phi = 2.5$, $f_0 = 100$Hz in simulated signal, Network signal to noise ratio = 55.30
- Measurement results of parameters in terms of probability distribution





Conclusion and future work

- Assessed the detectability of resonant r-modes in neutron star blackhole binary and binary neutron star with 2nd generation detectors
- Induced phase shifts of a few radians may be measurable
- Next step : search for r-modes in GW170817 binary neutron star event
- Measuring r-modes provide information about interior of neutron star

Thank you !