Early warning of third generation gravitational wave detector for precessed compact binary merger

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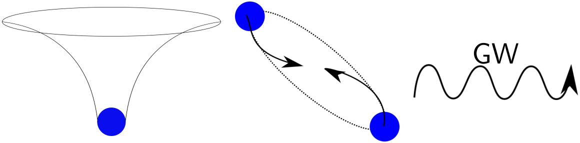
August 19, 2020

What is GW?

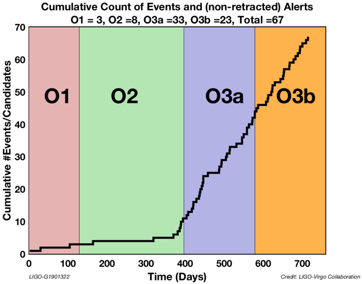
According to GR,...



Binary merger perturbs spacetime (GW)

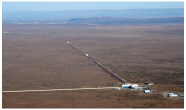
↓

Many GWs have been detected by detectors



@LIGO (twitter)

LIGO-Hanford



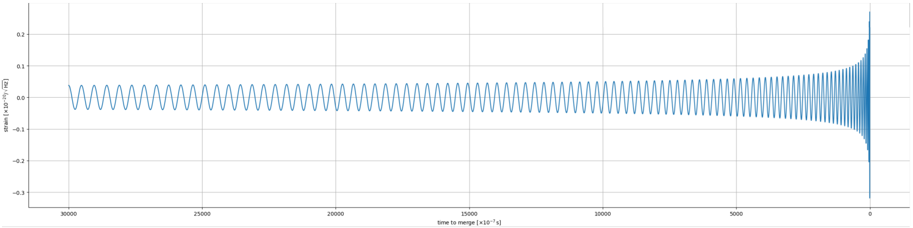
LIGO-Livingston

Virgo

KAGRA

(https://www.ligo.caltech.edu/)

Application: Early Warning



↑ EW ↑ so far

GW is emitted during the inspiral phase

→ GW can be detected before the merger

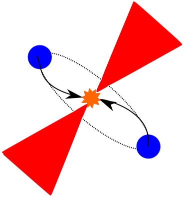
(∼O3, EW has not done yet, whereas O4∼, been planed.)

Why does Early Warning make us happy?

EW $\rightarrow$ The binary can be localized before the merger

$\rightarrow$ EM counterpart can be observed directly

Prompt Emission of sGRB

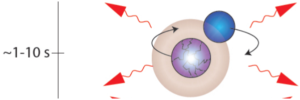


$\downarrow$

sGRB models

Resonant Shattering

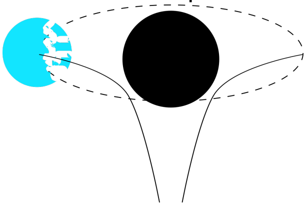
(http://www.physics.mcgill.ca/ dt-sang/TidalGRB.html)



$\downarrow$

EOS of NS

Tidal disruption



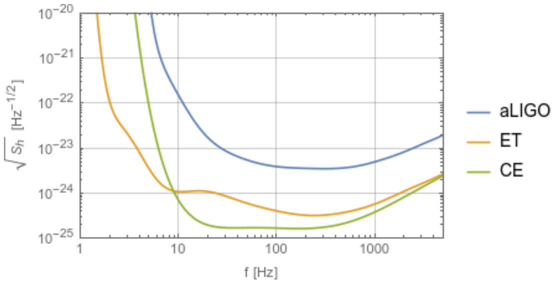
$\downarrow$

r-process nuclei

$\downarrow$

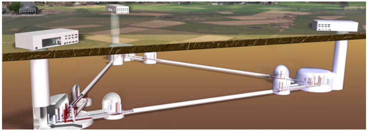
various physics, rich information (cf. multi-messenger astronomy)

3rd Generation detectors



Einstein Telescope

(https://www.aei.mpg.de/)



Cosmic Explorer

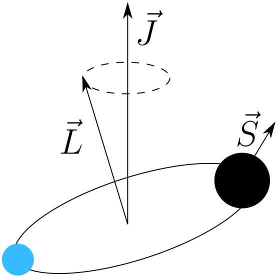
(https://gwic.ligo.org/)

→ 3G detectors are sensitive from ~ 1 Hz

→ Low frequencies become more important than so far

Properties of NSBH binary

Our target is NSBH (precession effect is larger than BNS)



- Time to merger $\sim$ 1 day
  $\rightarrow$ Doppler effect by Earth rotation
- Mass ratio $=$ 10
  $\rightarrow$ The orbital plane is precessing

$\downarrow$

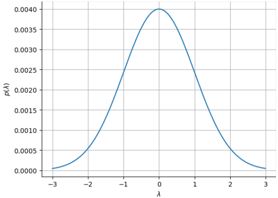
By considering those, parameter estimation should be improved.

$\downarrow$

goal

Estimate how much EW is improved by Doppler & precession effect

Fisher analysis



Assuming: The probability density function is Gaussian in the neighborhood of the true parameters $\{\lambda_i\}_i$

$$p(\{\lambda_i\}_i) \propto \exp\left[-\frac{1}{2}\Delta\lambda_i F_{ij} \Delta\lambda_j\right]$$

$$F_{ij} := \int_{f_{\rm min}}^{f_{\rm max}} \mathrm{d}f \, \frac{\partial h(f,\lambda)}{\partial \lambda_i} \frac{\partial h^*(f,\lambda)}{\partial \lambda_j}\bigg|_{\lambda=\lambda_{\rm true}}$$

$$\downarrow$$

$$\sigma_{ij}^2 \geq F_{ij}^{-1} \text{ is known}$$

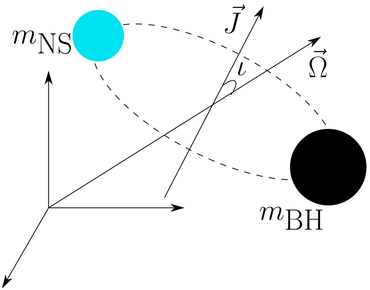
$$\text{e.g. } \Delta\Omega \sim \sqrt{\det F_{ij}^{-1}\Big|_{i,j=\theta,\phi}}$$

Setting

m_{BH}	m_{NS}	χ_{BH}	χ_{NS}	z
14	1.4	0.5	0	0.1

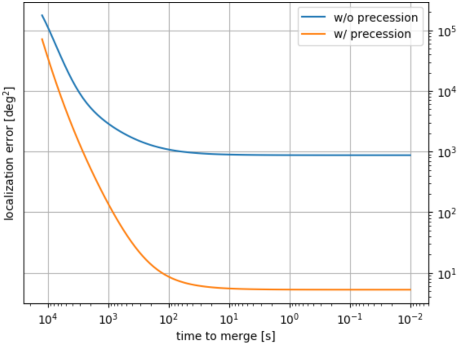
200 sources are randomly sampled under

$$\theta_s \in [0, \pi)$$
$$\phi_s \in [0, 2\pi)$$
$$\psi \in [0, 2\pi)$$
$$\cos\iota \in [-1, +1]$$
$$\vec{L} \perp \vec{S}$$

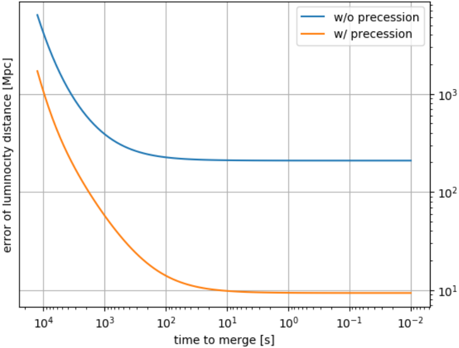


Einstein Telescope at Virgo

$\Delta\Omega$ [deg^2]



Δd_L [Mpc]



if $\Delta\Omega = 1000\,\mathrm{deg}^2$

↓

1000 s earlier

if $\Delta d_L = 200\,\mathrm{Mpc}$

↓

3000 s earlier

↓

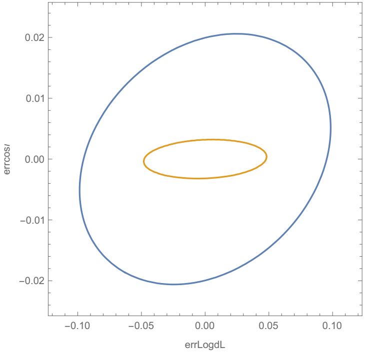
much improved

(At the end, $2 \times 10^3\,\mathrm{Mpc}^3 \rightarrow$ Including 20 galaxies)

Why is the EW much improved?

$$\tilde{h}(f) \sim \left(\frac{1+\cos^2\iota}{2} F_+ + \mathrm{i} \cos\iota F_\times \right) \frac{M_c^2}{d_L} (\pi M_c f)^{-7/6} \exp\left[-\mathrm{i} \frac{3}{128} (\pi M_c f)^{-5/3} \right]$$

- if no precessing
  - → The amplitude is estimated
  - → Since $\cos\iota$ is constant, $\cos\iota$ degenerates with d_L.
- if precessing
  - → $\cos\iota$ is varying
  - → the degeneracy is broken



without/with precession

Summary

- The constructions of third generation detectors are planed
- NSBH can be observed for $\sim 1\,\mathrm{day}$
- Doppler & precession effect can be considered
- We estimated the performance of Early Warning for the above setting
- The precession brakes the degeneracy between the luminosity distance & the inclination

$\rightarrow$ Early Warning is much improved