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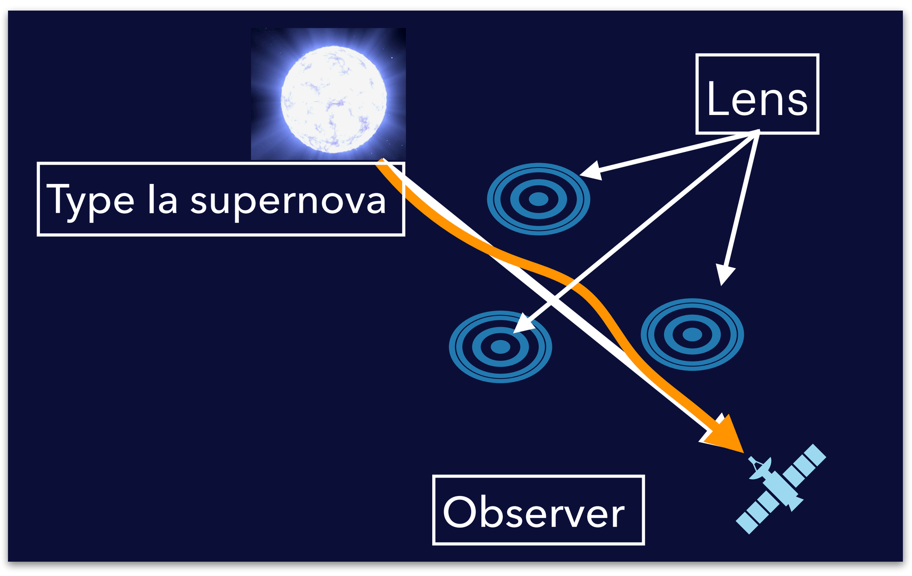
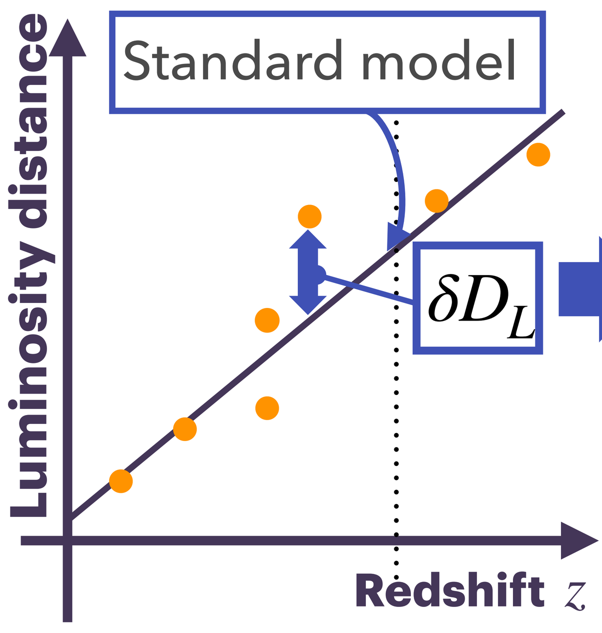
Measuring lensing convergence dispersion using auto-correlation of gravitational wave sources & cross-correlation between GW sources and galaxies

Introduction

Cosmology using the lensing convergence dispersion $\langle\kappa^2\rangle$ with Type A Supernova



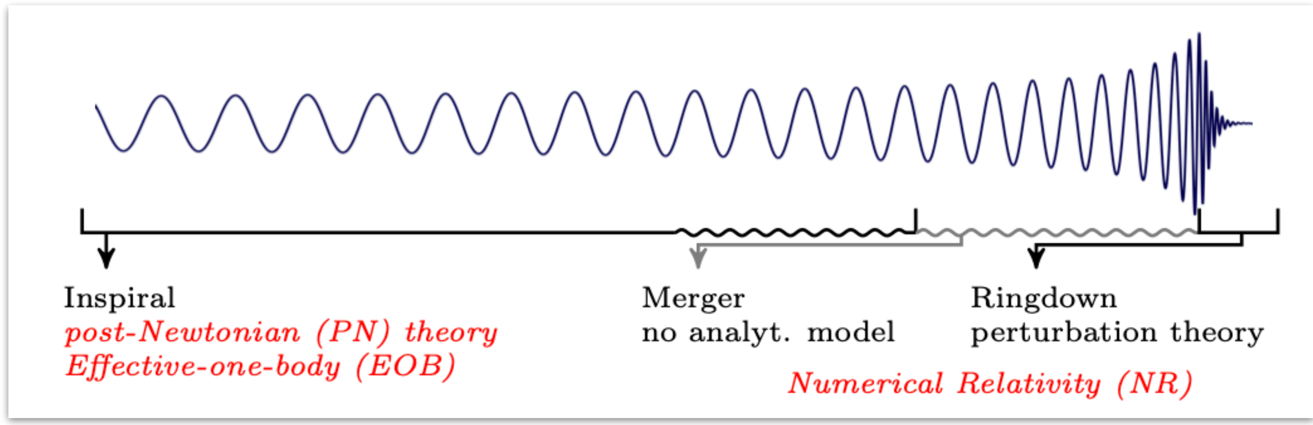


→ $\langle\kappa^2\rangle$ → **Information about small-scale matter density field.** →

- the presence of primordial black holes (PBH) (Zumalacárregui & Seljak 2018)
- the mass of the neutrino (Hada & Futamase 2016 Agrawal,Okumura & Futamase 2019)
- small-scale cosmological density power spectrum (Ben-Dayan & Takahashi 2016)

Can we constrain the lensing convergence dispersion from GW observation?

Direct measurement of luminosity distance from GW



Ohme 2012

$$\dot{f}(t) \propto M_z^{5/3} f^{11/3} \quad h_{+\times}(t) \propto \frac{M_z^{5/3} f^{2/3}}{D_L}$$

$$(M_z \equiv (1+z)M_c)$$

M_c : chirp mass
$h_+, h_\times$: strain of plus mode, cross mode
$f, \dot{f}$: frequency, frequency evolution

The luminosity distance can be measured directly and accurately from the gravitational wave waveform.

$\delta D_L / D_L \lesssim 1\,\%$! (Holz 2005)

Challenges in obtaining redshift information

- No redshift information from gravitational waveform
- BH-BH merger has no EM counterpart
- Wide error area → Large-scale follow-up

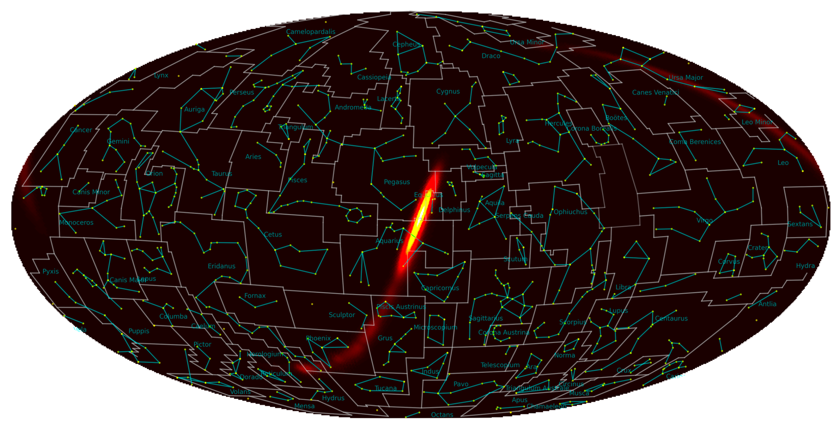


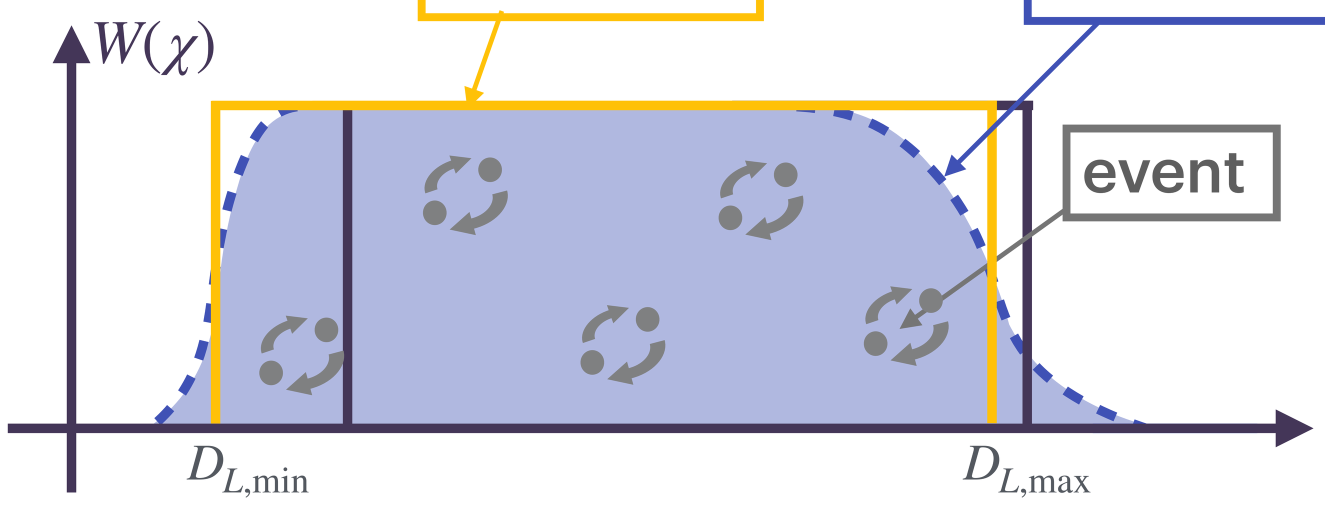
Fig: The error area of GW from BH-BH merger (S240530a) https://gracedb.ligo.org/superevents/S240530a/

It is challenging to derive redshift information from black hole gravitational waves.

Aims

To develop methods for extracting the lensing convergence dispersion from GW of BBH without relying on redshift information.

Method



$$W(D_L) = \frac{1}{N_{GW}} \frac{dN_{GW}}{dD_L} \quad (D_{L,\min} < D_{L,\mathrm{obs}} < D_{L,\max})$$

auto-correlation power spectrum

original term, dispersion term, translation term

$$C^{\mathrm{ww}}(\ell) = C^{\mathrm{ss}}(\ell) + C^{\mathrm{st}}(\ell) + C^{\mathrm{su}}(\ell) + C^{\mathrm{tt}}(\ell)$$

$\langle\kappa^2\rangle$

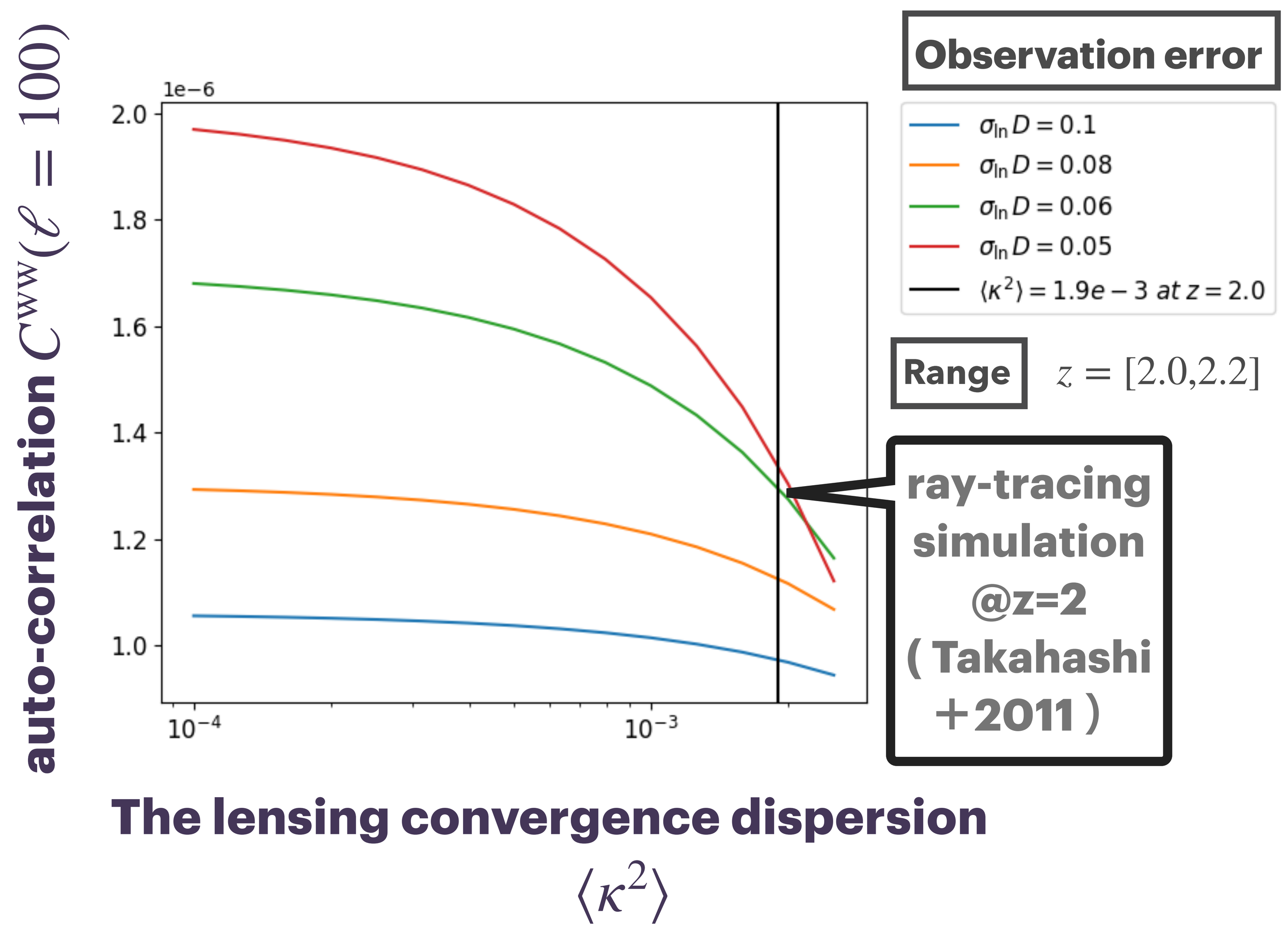
cross-correlation power spectrum

$$C^{\mathrm{wg}}(\ell) = C^{\mathrm{sg}}(\ell) + C^{\mathrm{tg}}(\ell) + C^{\mathrm{ug}}(\ell)$$

→ **Relation between $\langle\kappa^2\rangle$ and $C^{\mathrm{ww}}(\ell)$**

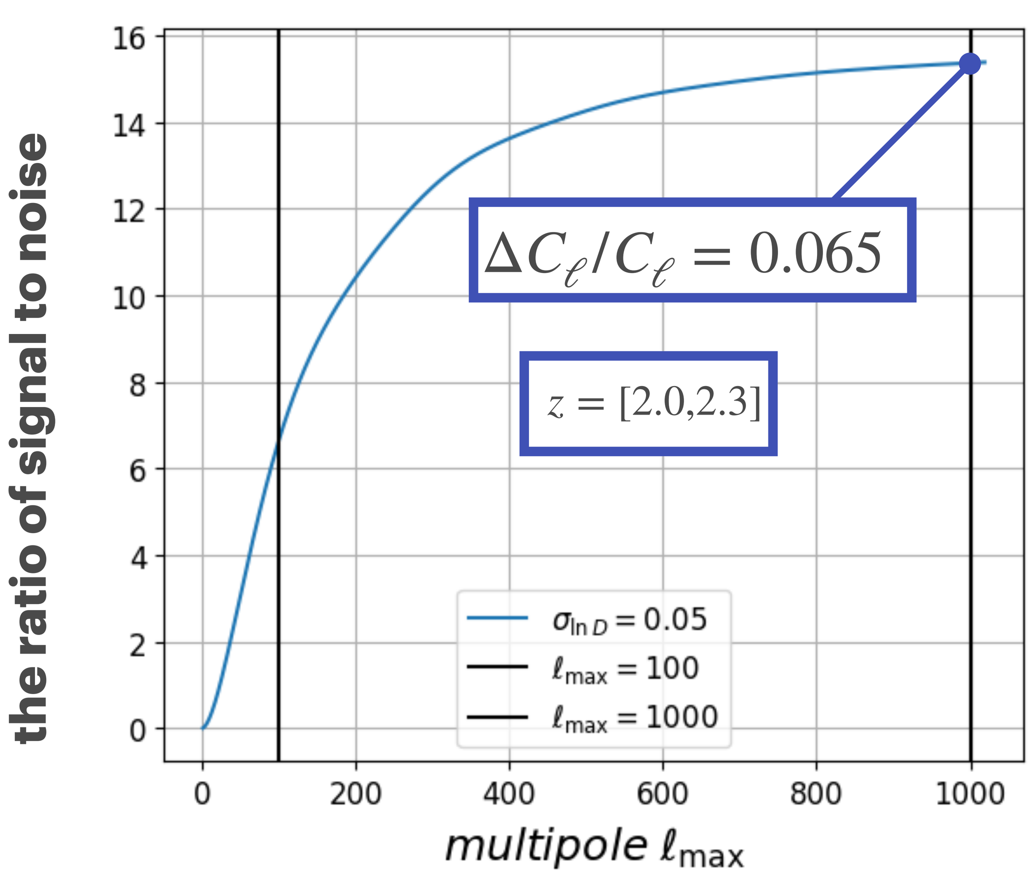
Result

Relation between $\langle\kappa^2\rangle$ and $C^{\mathrm{ww}}(\ell)$



anti-correlation between $C^{\mathrm{ww}}(\ell)$ and $\langle\kappa^2\rangle$

Signal to noise ratio



$$\Delta\langle\kappa^2\rangle / \langle\kappa^2\rangle \sim 0.30$$

Take Home Message !

- The lensing convergence dispersion contains a wealth of cosmological information.
- It is challenging to derive redshift from black hole gravitational waves.
- The anti-correlation between $C^{\mathrm{ww}}(\ell)$ and $\langle\kappa^2\rangle$ enables us to measure $\langle\kappa^2\rangle$ from GW without depending on redshift.