The astrophysical SGWB as a cosmological probe: challenges and opportunities with next-generation interferometers

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- OSB Div 3 -

SISSA

ET EINSTEIN TELESCOPE

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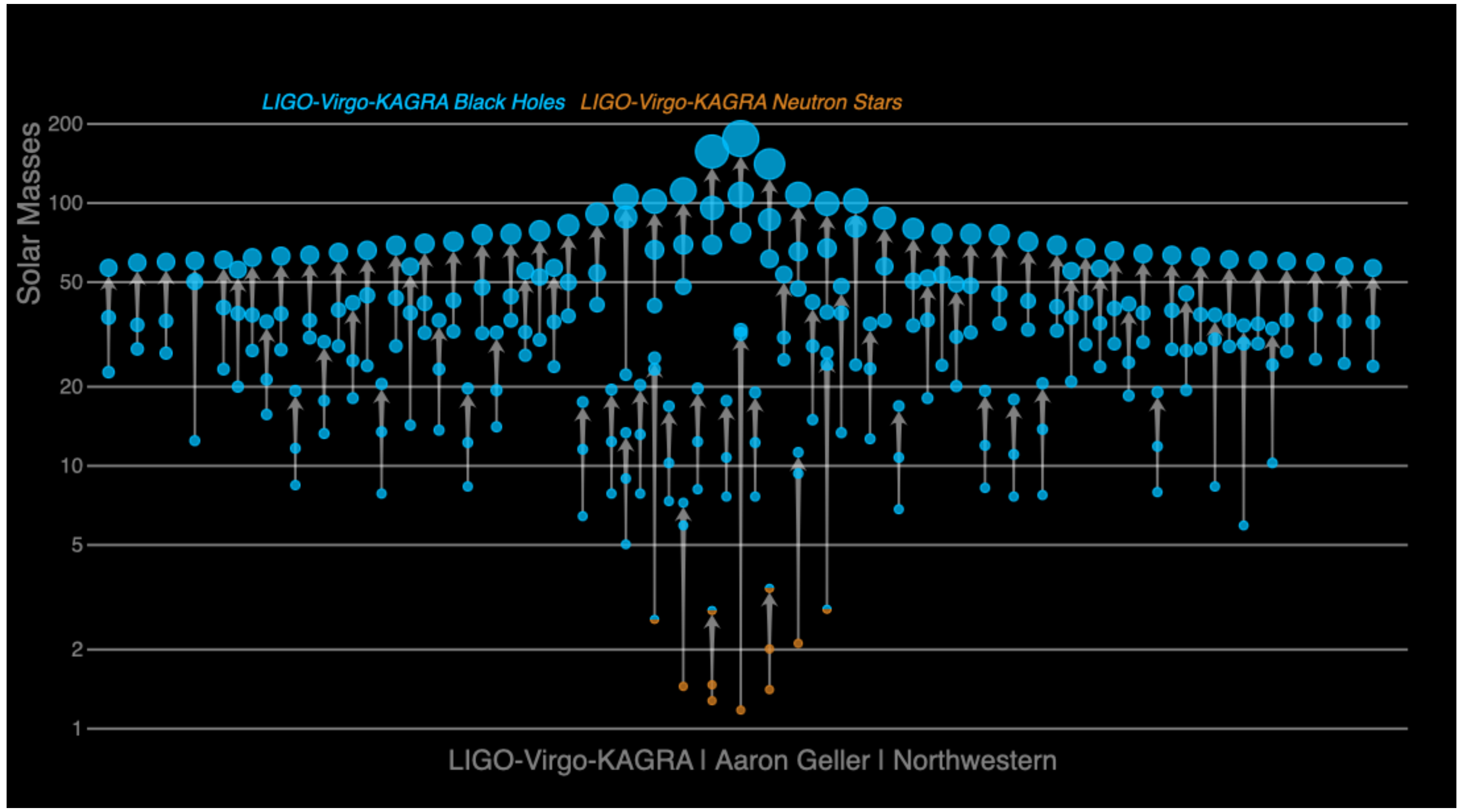
SGWB from merging stellar compact binaries

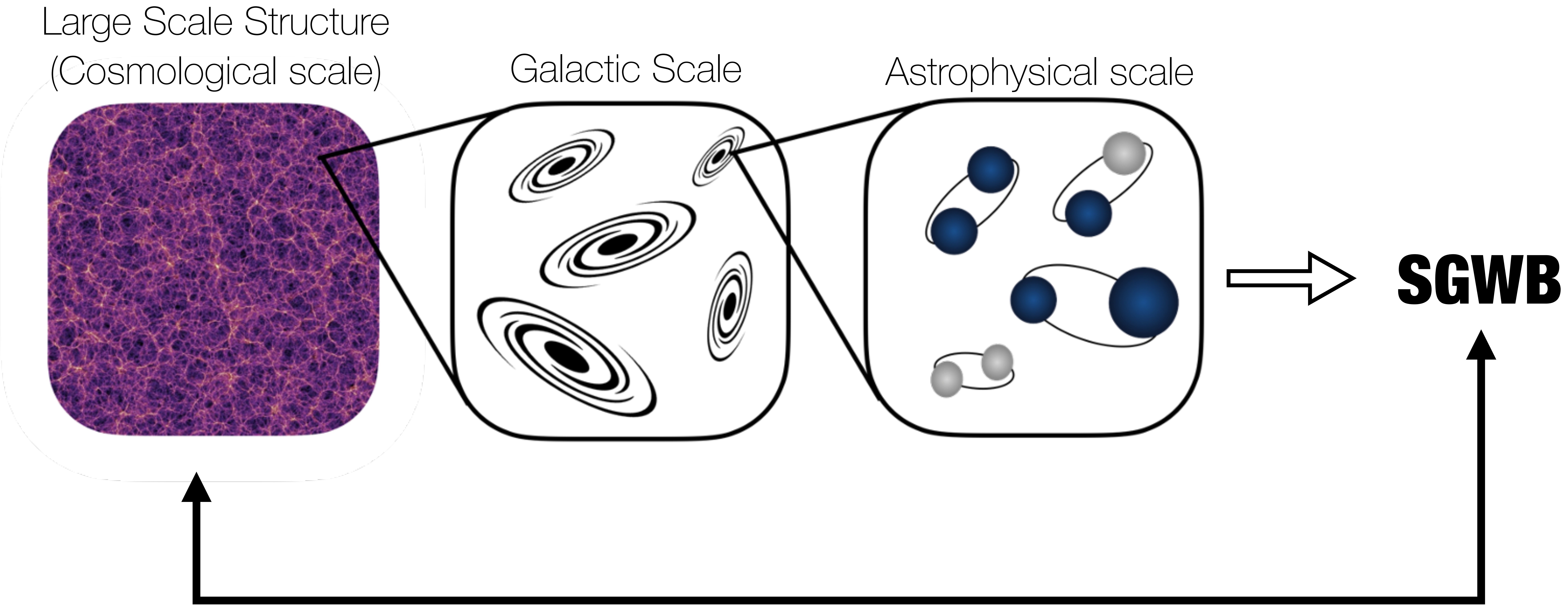


Incoherent superposition of all the unresolved GW signals produced by merging stellar compact binaries

Why is it worth studying?

1) Dominant contribution in the 10 Hz-1 kHz band
2) Generated by all merging binaries since the beginning of stellar activity
3) Powerful astrophysical probe: many processes involved, at different time and spatial scales
4) Powerful cosmological probe: tracer of the Large-Scale Structure

A tracer of the Large-Scale Structure



The anisotropies of the SGWB reflect those of the underlying dark matter distribution!

The isotropic energy density parameter

$$\Omega_{\rm gw}(f,\hat{n}) = \frac{1}{\rho_c}\frac{d^3\rho_{\rm gw}(f,\hat{n})}{d\ln f\, d^2\Omega} = \frac{\bar{\Omega}_{\rm gw}(f)}{4\pi} + \delta\Omega_{\rm gw}(f,\hat{n})$$

$$\bar{\Omega}_{\rm gw} = \frac{8\pi G f_o}{3H_0^3 c^2}\int dz \int d\mathcal{M}_c \frac{R_{\rm merge}(\mathcal{M}_c, z)}{(1+z)\, h(z)} \frac{dE}{df}(f_e(z)\,|\,\mathcal{M}_c) \int_0^{\bar{\rho}} d\rho\, P_\rho(\rho\,|\,\mathcal{M}_c, z)$$

See e.g. Regimbau, Res. Astron. Astrophys. **11** (2011) 369

Intrinsic merging rate

per unit comoving volume and per unit chirp mass

From Boco+19, Boco+20

Energy spectrum

of the signal emitted by a merging binary with a given chirp mass at a given redshift

From Ajith+07

Distribution of sky-averaged signal-to-noise ratio ρ

for a given detector at given chirp mass and redshift

From e.g. Taylor & Gair 2012

Merging rates

Stellar term — Galactic term

$$R_{\rm merge}(t) = \int dt_d \int dZ \, \frac{dN}{dM_{\rm SFR}\, d\mathcal{M}_c\, dt_d}(Z) \; \frac{d\dot{M}_{\rm SFR}}{dVdZ}(t - t_d)$$

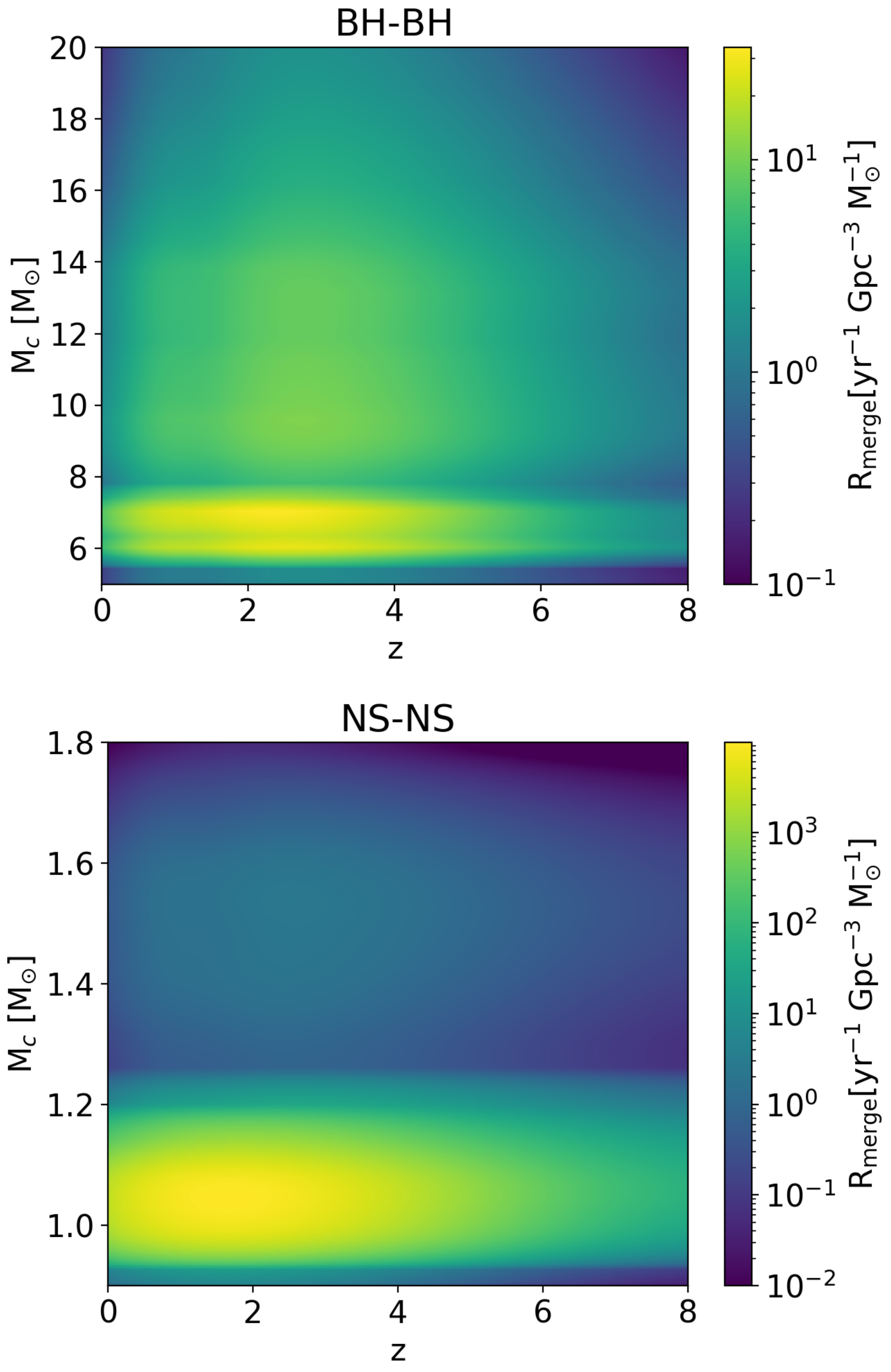
Boco et al. 2019, 2021

Properties of the binary compact objects population based on stellar dynamics, stellar evolution and binary population synthesis codes

SISSA RU: Dr Mario Spera, Prof Enrico Barausse, Prof. Alessandro Bressan, Cristiano Ugolini, Cecilia Sgalletta, Francesco Addari, Mattia Mencagli

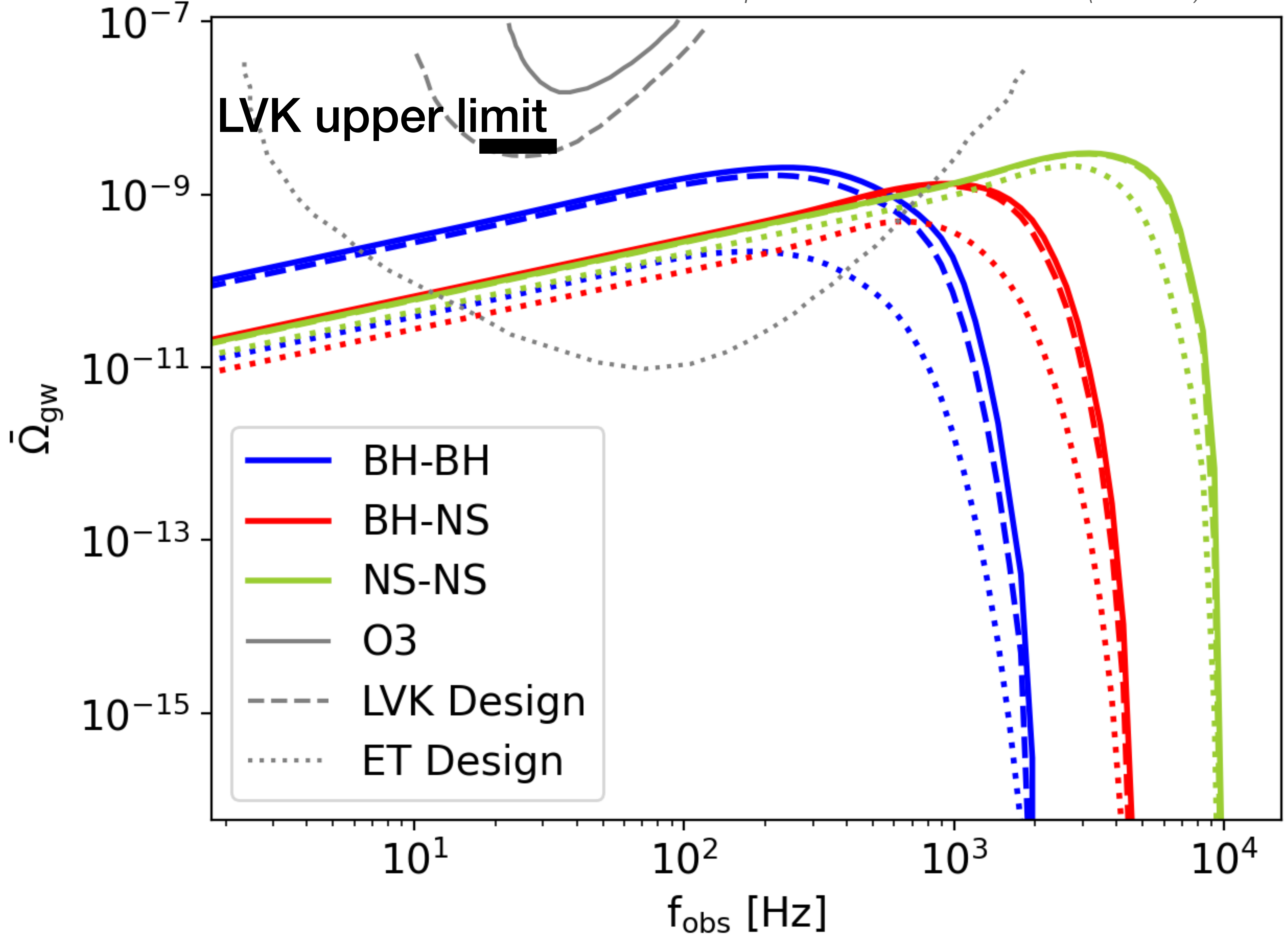
Link between the population of merging binaries and their galactic hosts across cosmic time

SISSA RU: Prof. Andrea Lapi, Dr Lumen Boco, Francesco Gabrielli



Results for the isotropic SGWB

Capurri et al JCAP11(2021)032



INSTRUMENTS:

- LIGO/Virgo/KAGRA
- Einstein Telescope

SIGNALS:

- Solid lines = **total SGWB**
- Dashed/dotted lines = **residual SGWB**

DETECTION PROSPECTS:

- LVK: $\bar{\Omega}_{gw} < 3.4 \cdot 10^{-9}$ at 25 Hz
- ET: detection expected, complementary to large population of resolved events

Theoretical modelling of SGWB anisotropies

Angular power spectrum
of the anisotropies

$$C_\ell = \frac{2}{\pi} \int \frac{dk}{k} P(k) \left[\frac{\delta\Omega_\ell(k)}{\bar{\Omega}_{\rm gw}/4\pi} \right]^2$$

P(k) primordial matter power spectrum

Relativistic angular fluctuation of the SGWB energy density

Other works modelling the SGWB anisotropies:
Cusin et al 2017, 2018, 2019
Jenkins et al. 2018a, 2018b
Bertacca ed al 2020

The relativistic fluctuation $\delta\Omega_\ell(k)$:

1) Contains all density, velocity, lensing and gravity effects
2) Depends on 3 main ingredients:

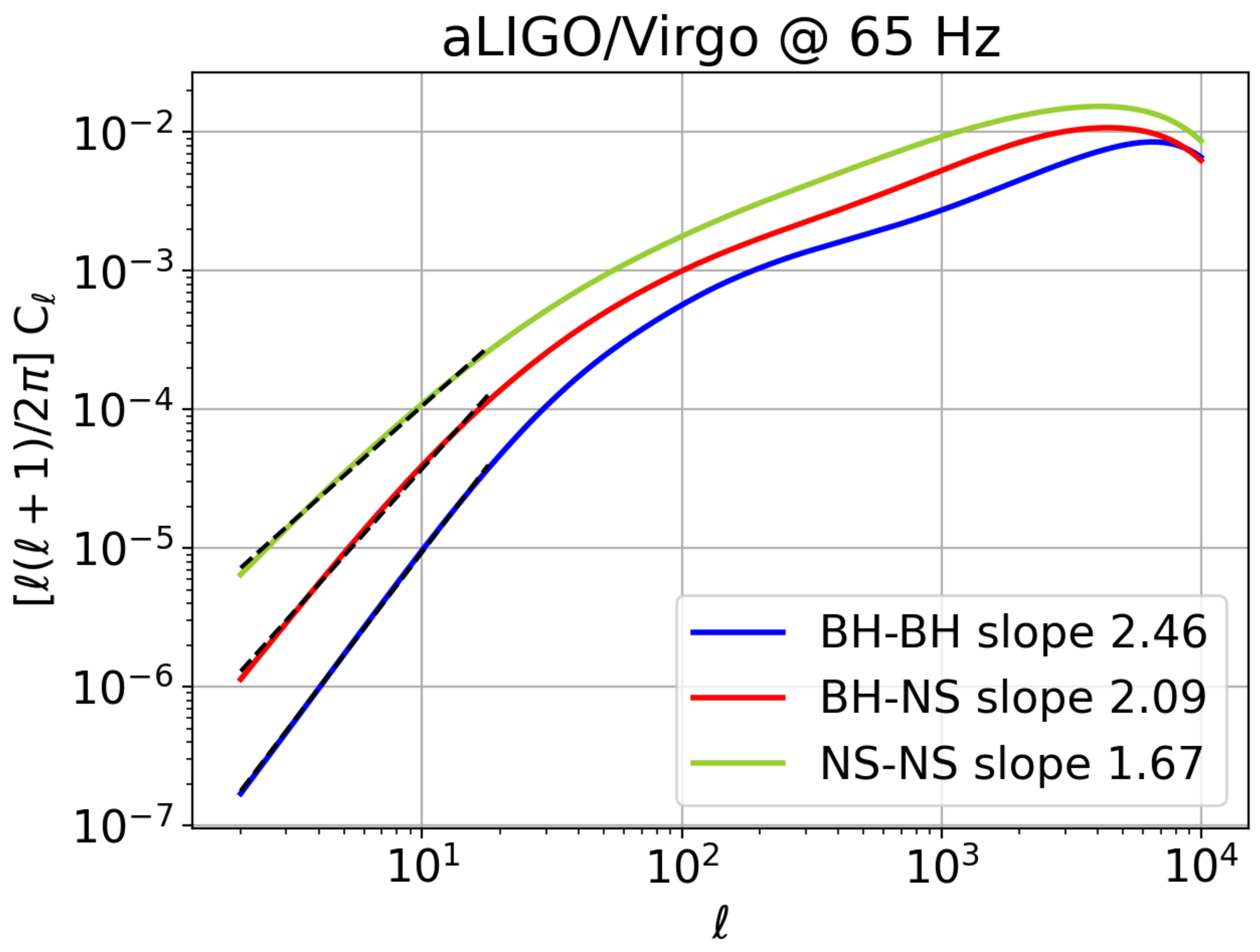
a) Redshift distribution
b) Bias
c) Magnification bias

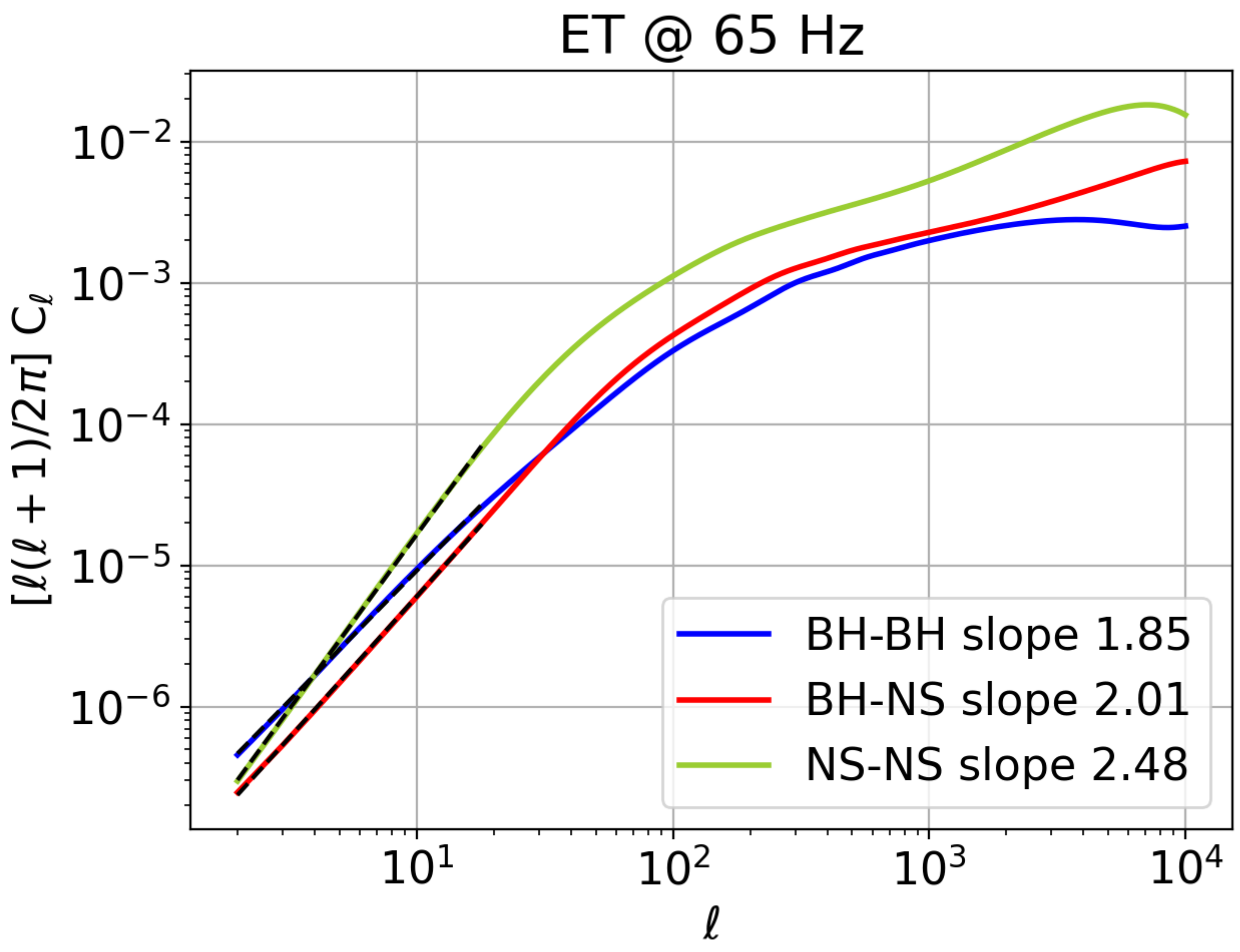
⇩

CLASS
The Cosmic Linear Anisotropy Solving System
Lesgourgues, 2011

Results for the angular power spectrum

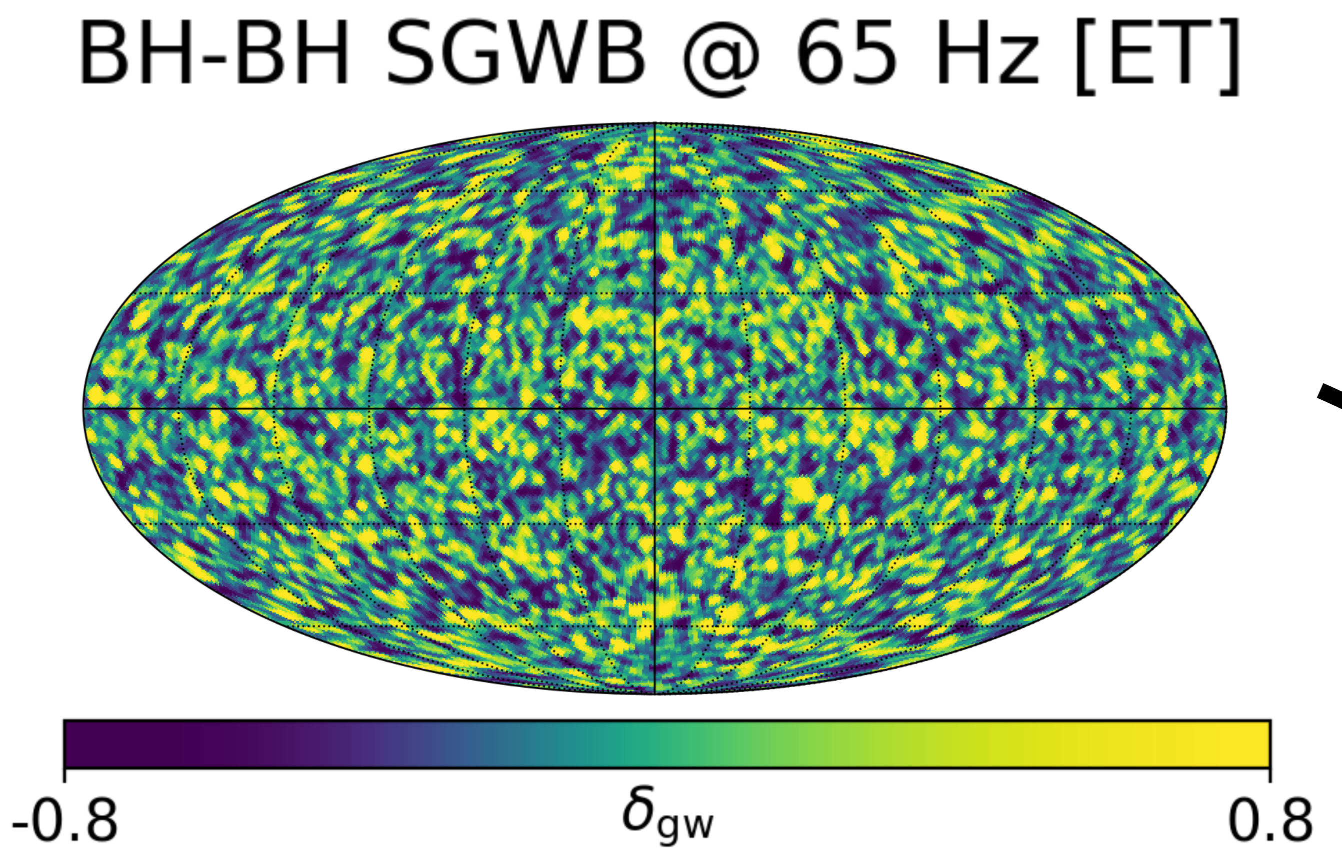
Residual SGWB: only unresolved events, detector dependent

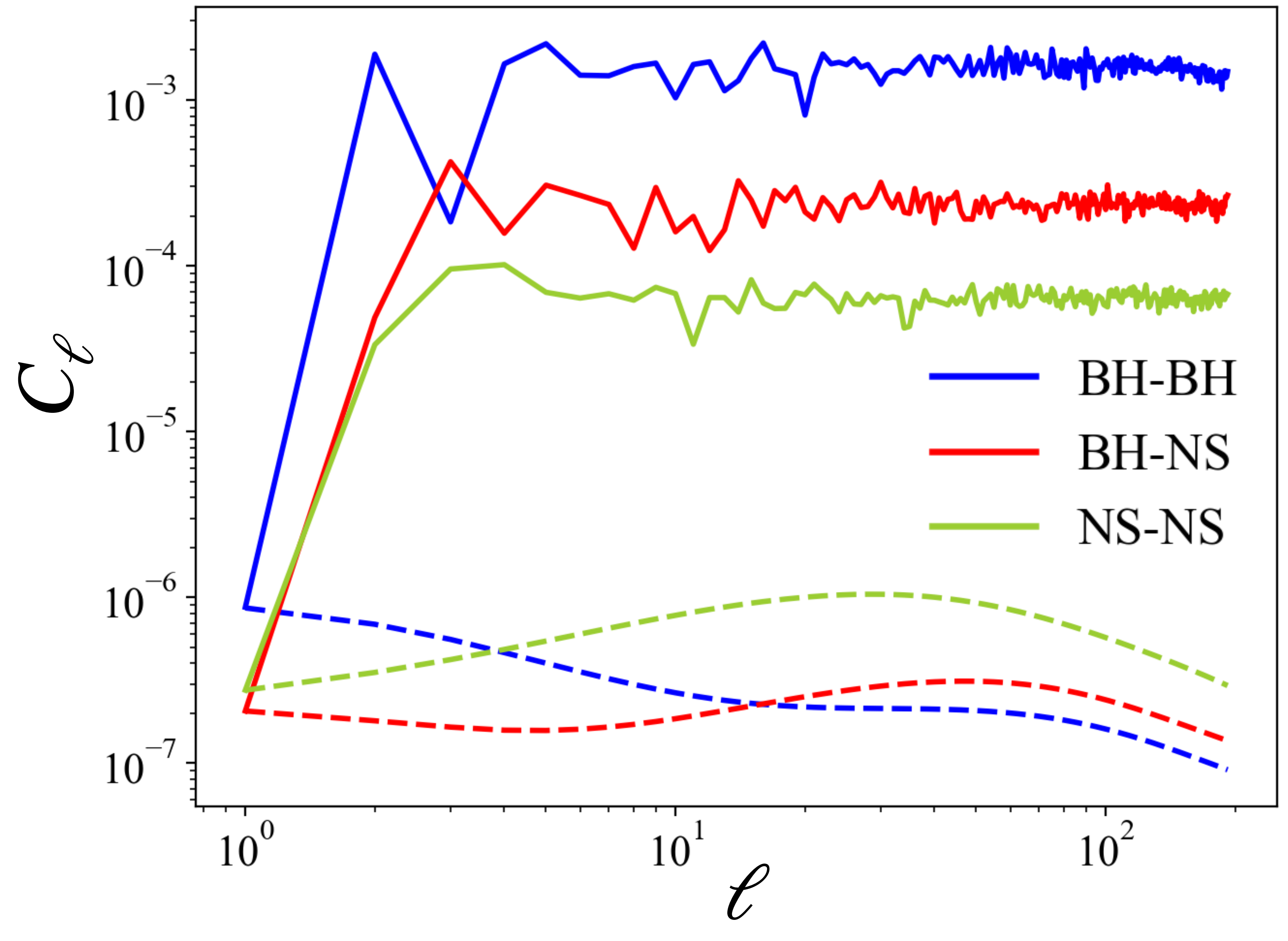




Are these signals detectable?

Two crucial issues: shot noise and detector noise

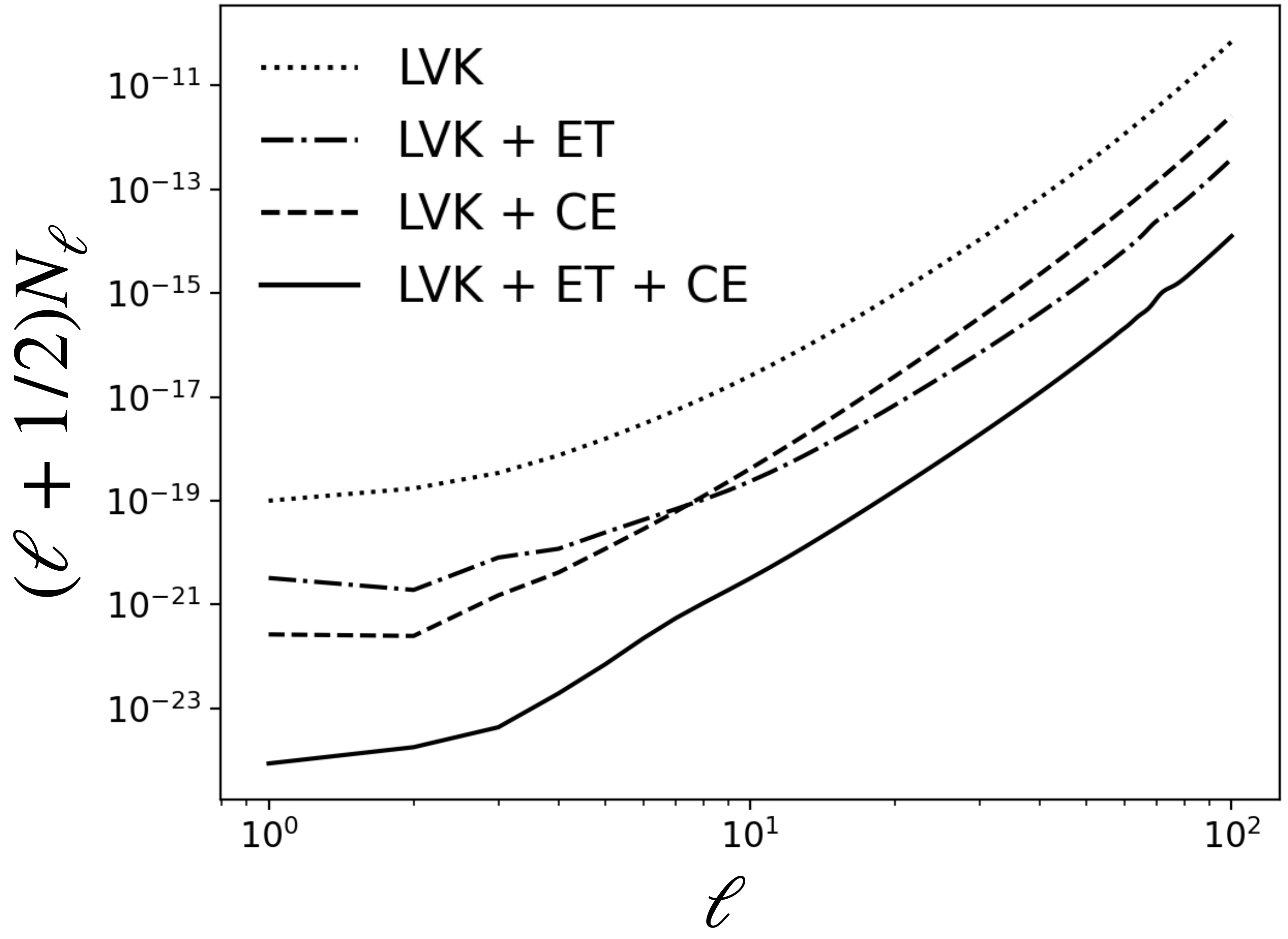




Public software **schNell**

Alonso et al. 2020

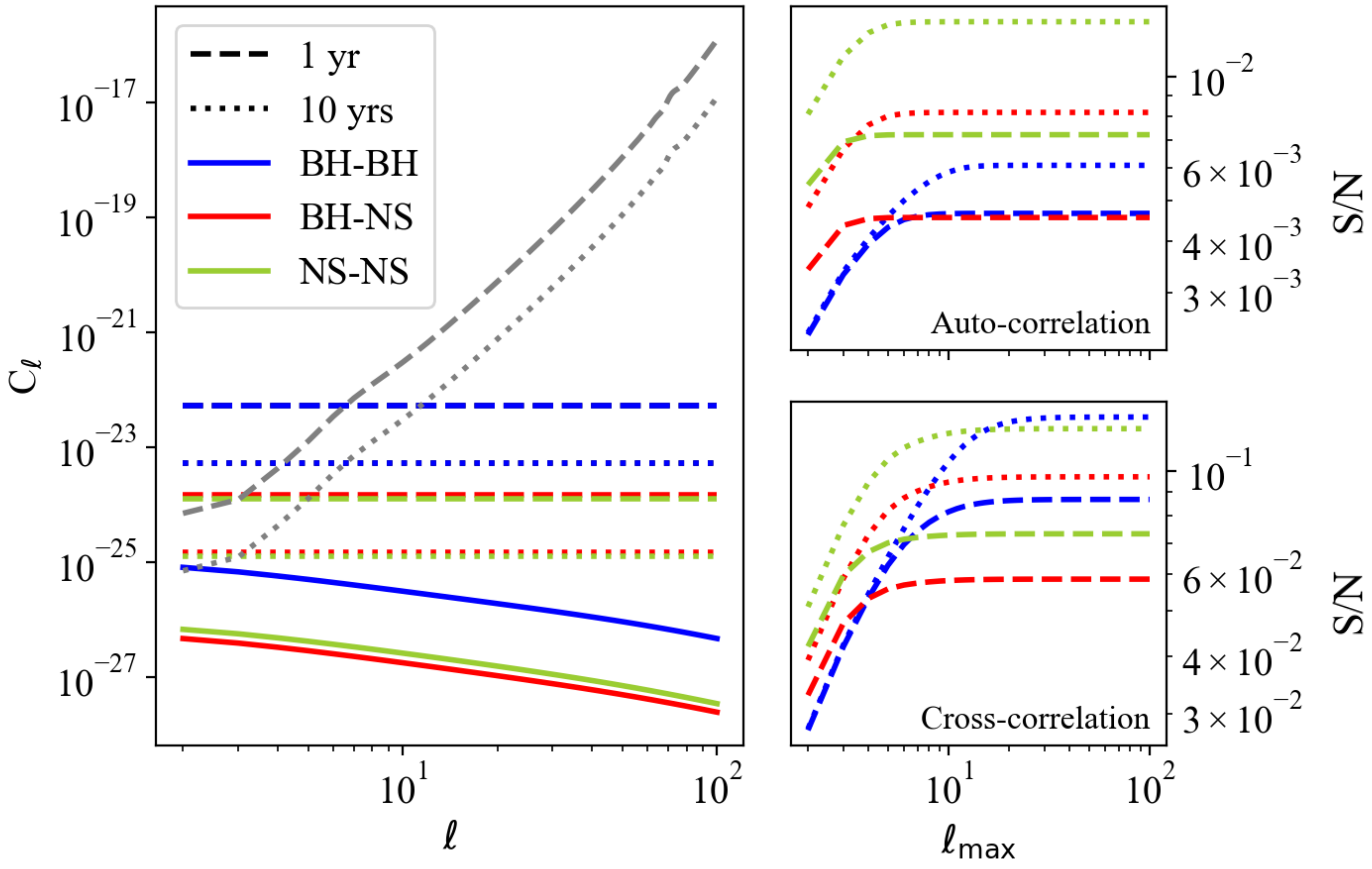
Angular power spectrum of the instrumental noise for interferometer networks mapping SGWB



Detection prospects with ground-based detectors

Comparison signal vs noises

Signal-to-noise ratio



Capurri et al, Universe **2022**, 8(3), 160

Detector network:

- LIGO Hanford, LIGO Livingston
- Virgo
- KAGRA
- Einstein Telescope
- Cosmic Explorer

Cross-correlation with other cosmic fields enhances the S/N…
…but not enough!

Summary and outlook

- The SGWB by merging stellar compact binaries is a powerful astrophysical and cosmological probe
- ET will be able to measure the isotropic SGWB energy density
- The detection of the SGWB anisotropies is more challenging due to the shot noise and the instrumental noise
- Cross-correlation with other cosmic fields enhances the S/N

Future perspective

- Refine detection prospects considering improved data analysis techniques (already in contact with ISB)
- Focus on the physics we can constrain with the first multipoles (and monopole too!)

Thank you so much for your attention!

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