Exploring cosmological gravitational wave backgrounds through the synergy of LISA and ET

Debika Chowdhury

Indian Institute of Astrophysics, Bengaluru

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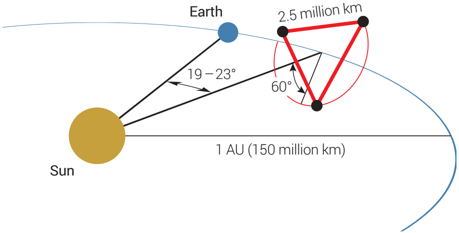
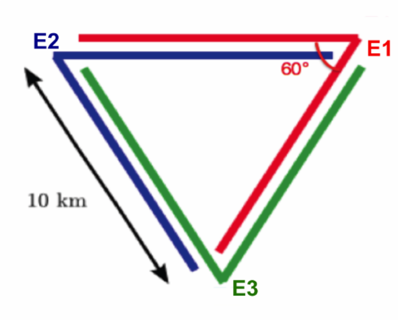
LISA and ET

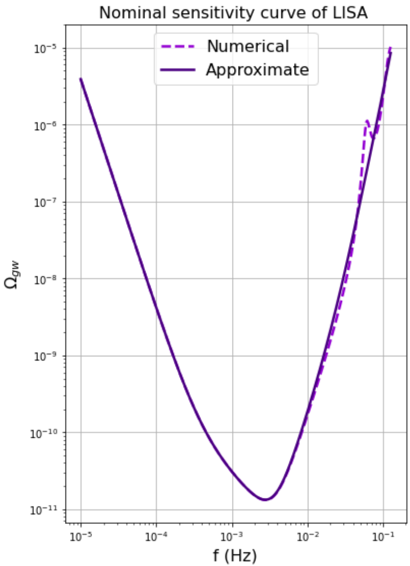


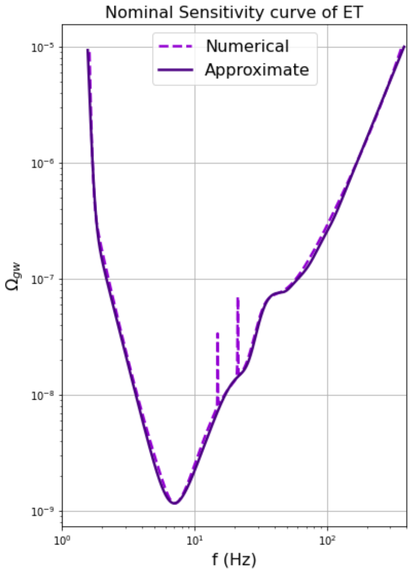


Schematic configurations of LISA[1] (left) and ET[2] (right).

[1] Image from: J. Baker *et al.*, arXiv: 1907.06482 [astro-ph.IM] (2019).
[2] Image from: T. Regimbau *et al.*, Phys. Rev. D **86**, 122001 (2012).

Nominal sensitivity curves[3]





[3] R. Flauger *et al.*, JCAP **01**, 059 (2021); S. Hild *et al.*, Class. Quant. Grav. **28**, 094013 (2011).

Combined SNR

Our aim is to estimate the optimal signal-to-noise ratio (SNR) for detecting a stochastic GW signal with the two instruments LISA and ET working together.

The square of the total SNR is the sum of the squares of the individual SNRs[4]:

$$\begin{aligned} \mathrm{SNR}_{\mathrm{tot}} &= \sqrt{T \int_0^\infty df \left[\frac{\Omega^2_{\mathrm{GW}}(f)}{\Sigma^2_{\mathrm{LISA}}(f)} + \frac{\Omega^2_{\mathrm{GW}}(f)}{\Sigma^2_{\mathrm{ET}}(f)} \right]} \\ &= \sqrt{\mathrm{SNR}^2_{\mathrm{LISA}} + \mathrm{SNR}^2_{\mathrm{ET}}}. \end{aligned}$$

The two detectors together can reach higher values of SNR.

We are interested in SGW spectra enhanced within the broad frequency band:

$$10^{-5}\,\mathrm{Hz} \leq f \leq 445\,\mathrm{Hz}.$$

[4] T. L. Smith and R. R. Caldwell, Phys. Rev. D **100**, 104055 (2019); J. D. Romano and N. J. Cornish, Living Rev. Rel. **20**, 2 (2017).

Power-law integrated sensitivity (PLS) curves

GW spectra of a power-law form are assumed:

$$\Omega_{\rm GW}(f) = \Omega_\beta \left(\frac{f}{f_*}\right)^\beta .$$

For a set of β and some choice of f_*, the following amplitude is evaluated:

$$\Omega_\beta = \frac{\rm SNR}{\sqrt{2T}} \left[\int_{f_{\rm min}}^{f_{\rm max}} {\rm d}f \, \frac{(f/f_*)^{2\beta}}{\Sigma^2(f)}\right]^{-1/2} .$$

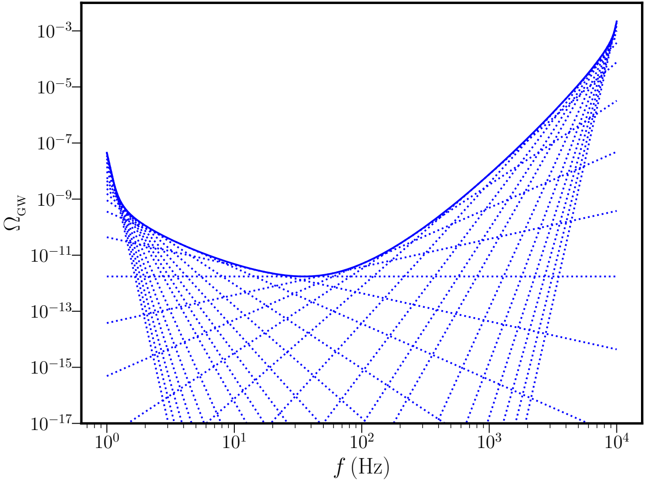
For each pair (β, Ω_β), $\Omega_{\rm GW}(f)$ is plotted against f.

The resulting envelope of the family of such curves is the PLS curve[5]:

$$\Omega_{\rm GW}^{\rm PLS}(f) = \max_\beta \left[\Omega_\beta \left(\frac{f}{f_*}\right)^\beta\right] .$$

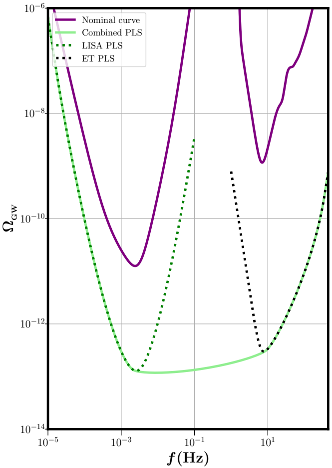
[5] E. Thrane and J. D. Romano, Phys. Rev. D **88**, 124032 (2013).

Plotting the envelope

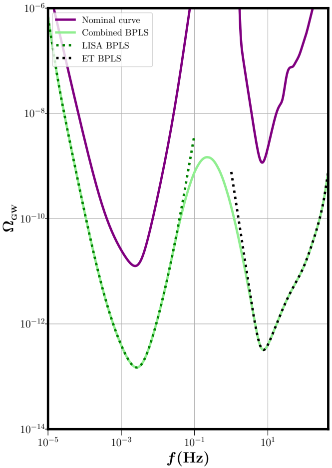


PLS for ET

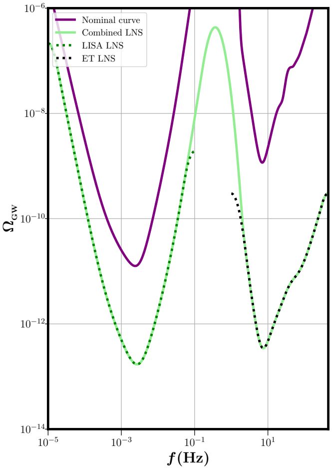
Integrated sensitivity curves



Power-law

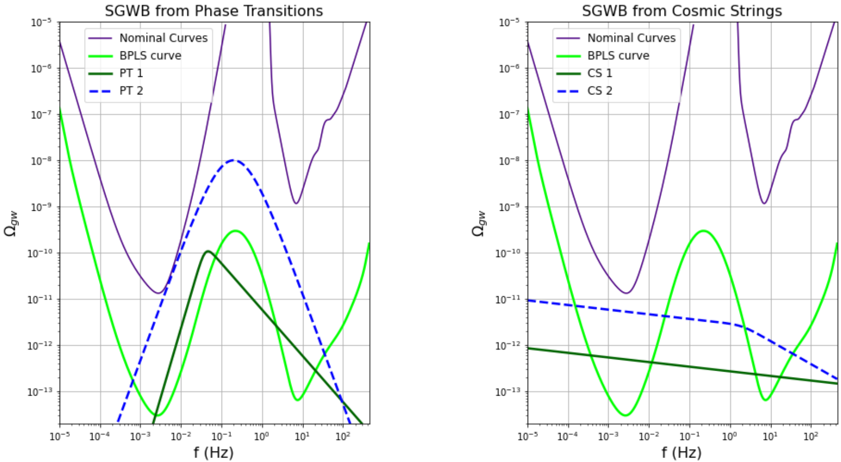


Broken power-law



Lognormal

Power-law (PL) and broken power-law (BPL) signals

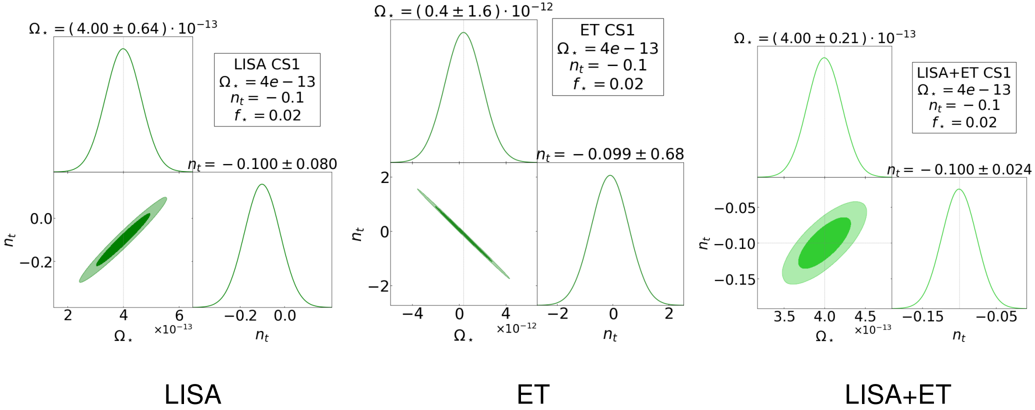


A BPL signal can be parameterized as[6]:

$$\Omega_{\rm GW}(f) = \Omega_\star \left(\frac{f}{f_\star}\right)^{n_1} \left[\frac{1}{2} + \frac{1}{2}\left(\frac{f}{f_\star}\right)^{\sigma}\right]^{\frac{n_2-n_1}{\sigma}} .$$

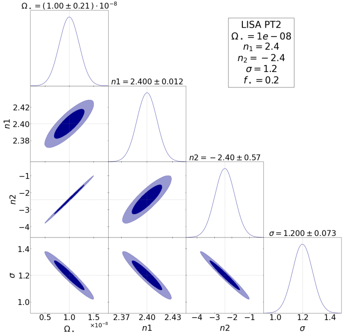
[6] LISA Cosmology Working Group, JCAP **10**, 020 (2024).

Power-law (CS) Fisher analysis

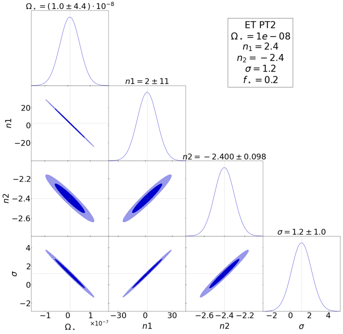


By operating together, LISA and ET can measure these parameters with better accuracy.

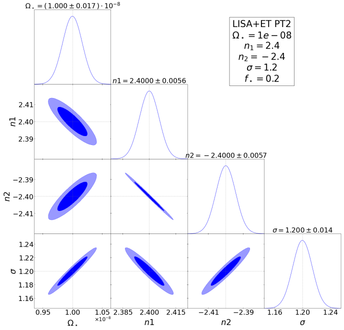
Broken power-law (PT) Fisher analysis



LISA



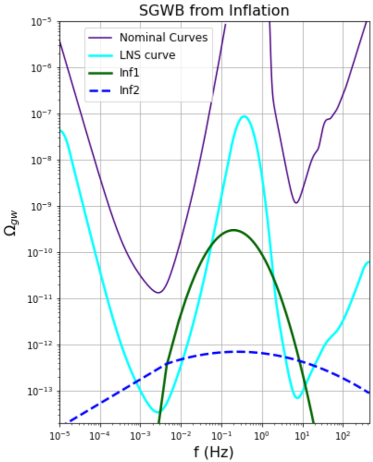
ET



LISA+ET

By operating together, LISA and ET can measure these parameters with an accuracy of $\sim 10\%$.

Lognormal signal

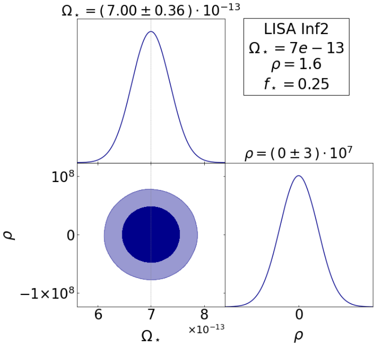


A lognormal signal can be parameterized as[7]:

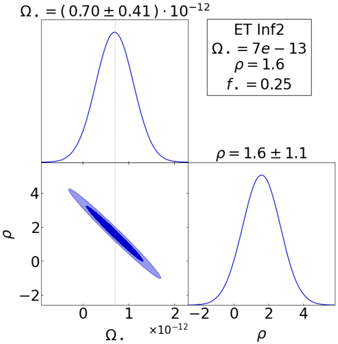
$$\Omega_{\rm GW} = \Omega_\star \exp\left[-\frac{\ln^2(f/f_\star)}{2\rho^2}\right].$$

[7] R. Namba *et al.*, JCAP **01**, 041 (2016).

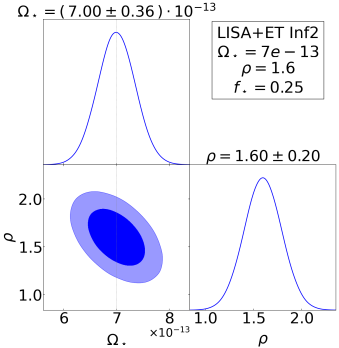
Lognormal (inflation) Fisher analysis



LISA



ET



LISA+ET

By operating together, LISA and ET can measure these parameters with better accuracy.

Summary

- LISA and ET will be operational approximately around the same time.
- We are interested in a stochastic gravitational wave background that is characterized by a spectrum spanning a wide range of frequencies.
- We have investigated the consequences of using synergies between LISA and ET for improved detection of such a GW background.
- We have illustrated this effect using several examples of early-universe scenarios that lead to GW signals with different frequency profiles.

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Thank you!