THE STOCHASTIC BACKGROUND

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Stochastic GW Background

- A stochastic background of gravitational waves has resulted from the superposition of a large number of independent unresolved sources from different stages in the evolution of the Universe.

- Cosmological (inflation, cosmic strings, phase transitions, PBHs) or astrophysical (since the beginning of stellar activity)

- Usually characterized by the energy density in GWs:

$$\Omega_{gw}(f) = \frac{f}{\rho_c} \frac{d\rho_{gw}(f)}{df}$$

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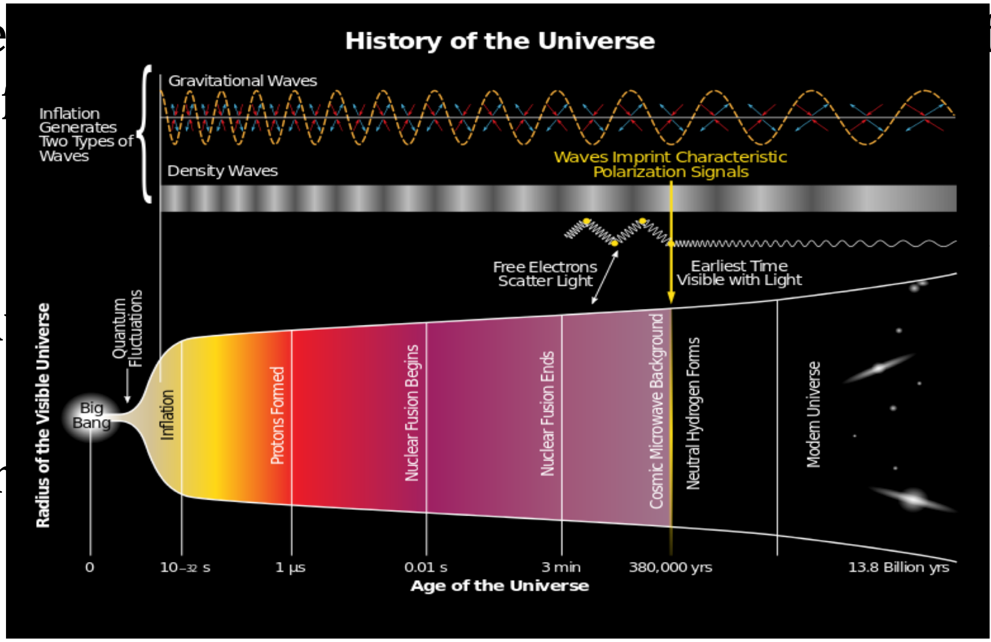


Stochastic GW background

= superposition of overlapping unresolved sources

Noise

Symphony of the Universe

Data Analysis Principle

Search for excess of coherence in the cross correlated data streams from multiple detectors with minimal assumptions on the morphology of the signal.

- Assume stationary, unpolarized, isotropic and Gaussian stochastic background.
- Cross correlate the output of detector pairs to eliminate the noise:

$$s_i = h_i + n_i$$

$$< s_1 s_2 > = < h_1 h_2 > + \underbrace{\cancel{< n_1 n_2 >}}_{0} + \underbrace{\cancel{< h_1 n_2 >}}_{0} + \underbrace{\cancel{< n_1 h_2 >}}_{0}$$

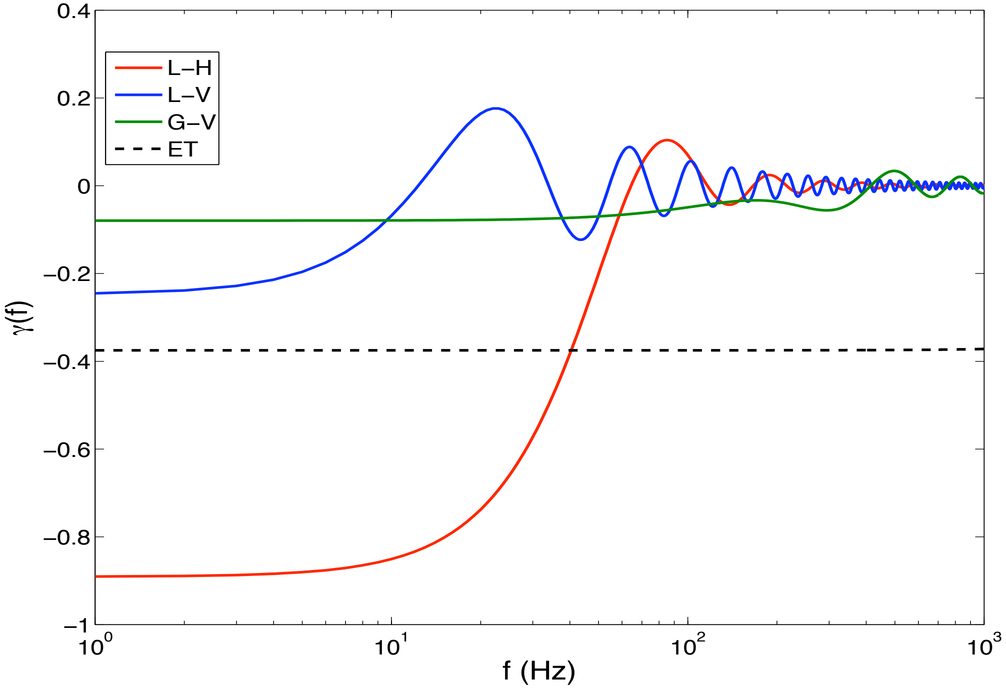
Cross Correlation Statistics

- Standard CC statistics (Allen & Romano, 1999, PRD, 59, 102001)
- Frequency domain cross product: $Y = \int \tilde{s}_1^*(f)\tilde{Q}(f)\tilde{s}_2(f)df$
- optimal filter: $\tilde{Q}(f) \propto \dfrac{\gamma(f)\Omega_{gw}(f)}{f^3 P_1(f)P_2(f)}$ with $\Omega_{gw}(f) \equiv \Omega_0 f^{\alpha}$
- in the limit noise >> GW signal

$$\mathrm{Mean}(Y) = \Omega_0 T,\ \mathrm{Var}(Y) \equiv \sigma^2 \propto T,\ \mathrm{SNR} \propto \sqrt{T}$$

Overlap Reduction Function

Loss of sensitivity due to the separation and the relative orientation of the detectors.

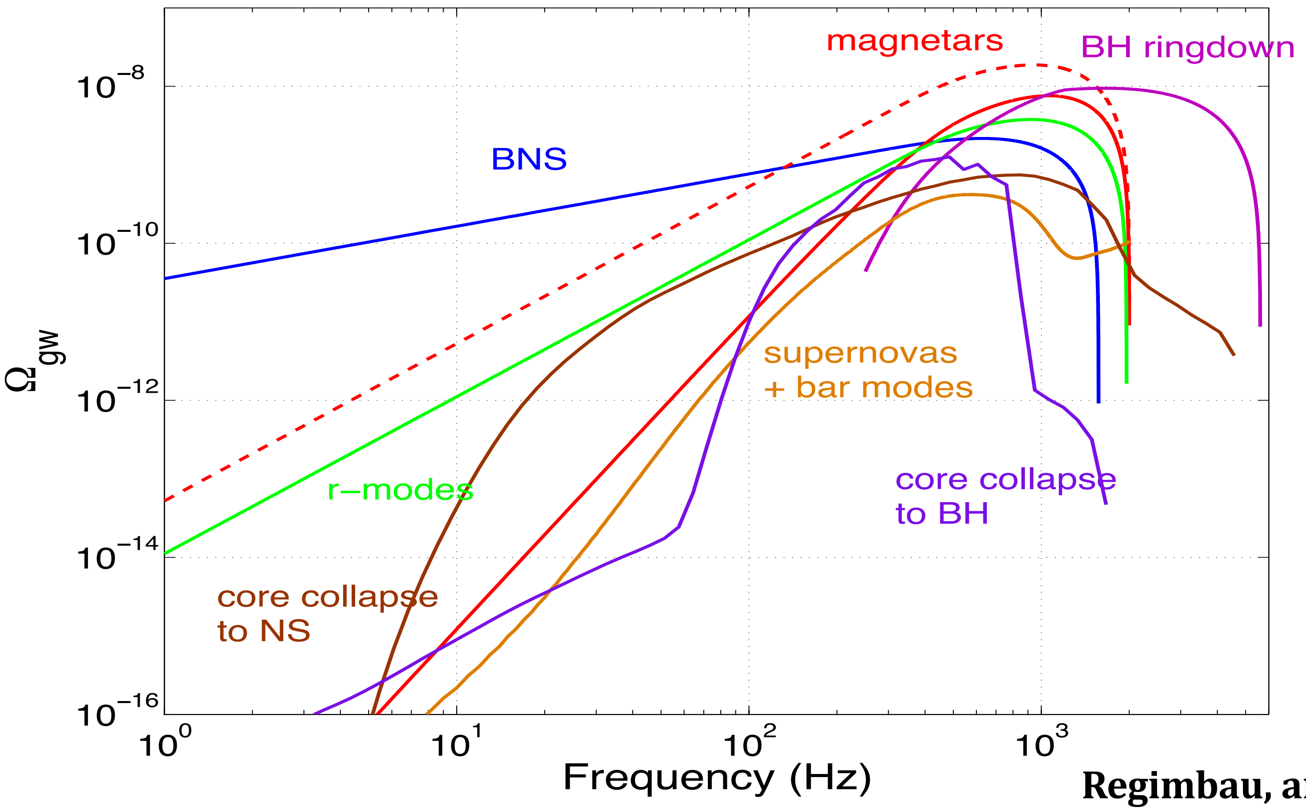


Time delay

$$\gamma(f) = \frac{5}{8\pi} \sum_{A=\{+,\times\}} \int e^{2\pi i f \hat{\Omega}\Delta\vec{x}/c} F_1^A(\hat{\Omega}) F_2^A(\hat{\Omega}) d\Omega$$

Detector response

Astrophysical Backgrounds



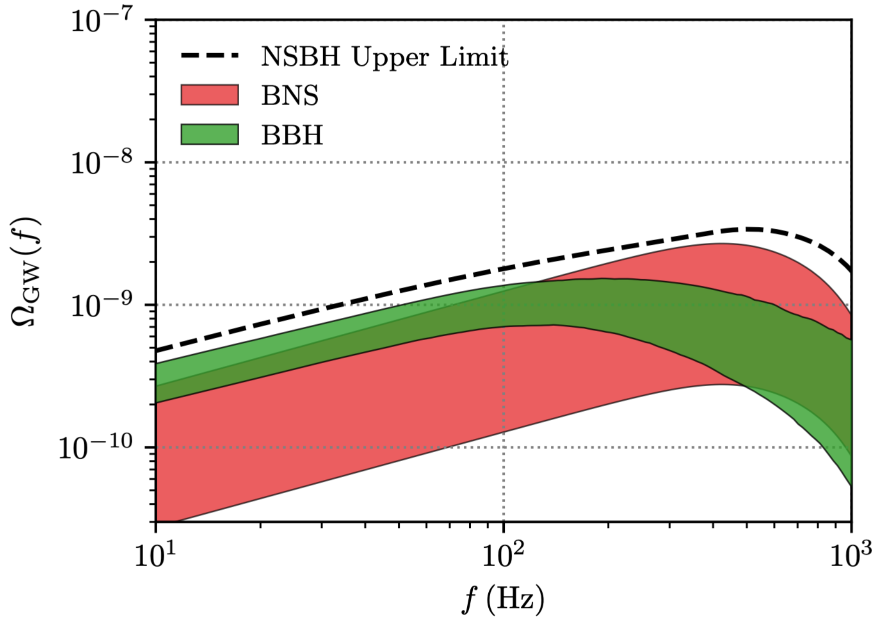
Regimbau, arXiv:1101.2762

Background from CBCs

- LIGO and Virgo have already observed 50 BBHs and 2 BNSs in O1/O2/O3a.
- The events we detect now are close and loud individual sources. Many more sources at larger distances contribute to create a stochastic background.
- Using mass distributions and local rates derived from observations, we are able model to the GW background from BBHs and BNSs.
- Other predictions based on population models (Dvorkins, Périgois …)
- The detection of this background could be the next milestone for LIGO/Virgo.

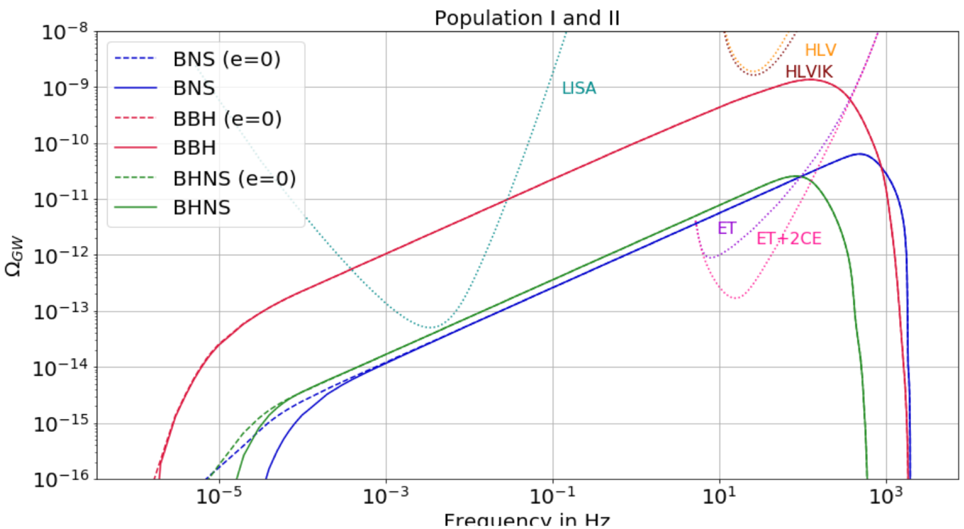
Predictions from LVK

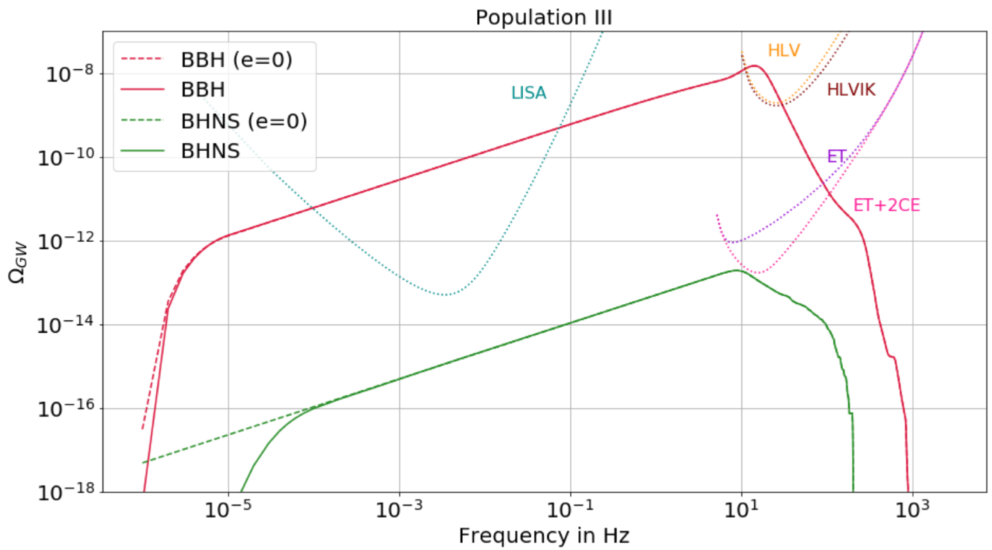
Detected after a few years of observation at design sensitivity by 2G detectors



LVK collaboration, arXiv:2101.12130

Possible extra contribution from Pop III

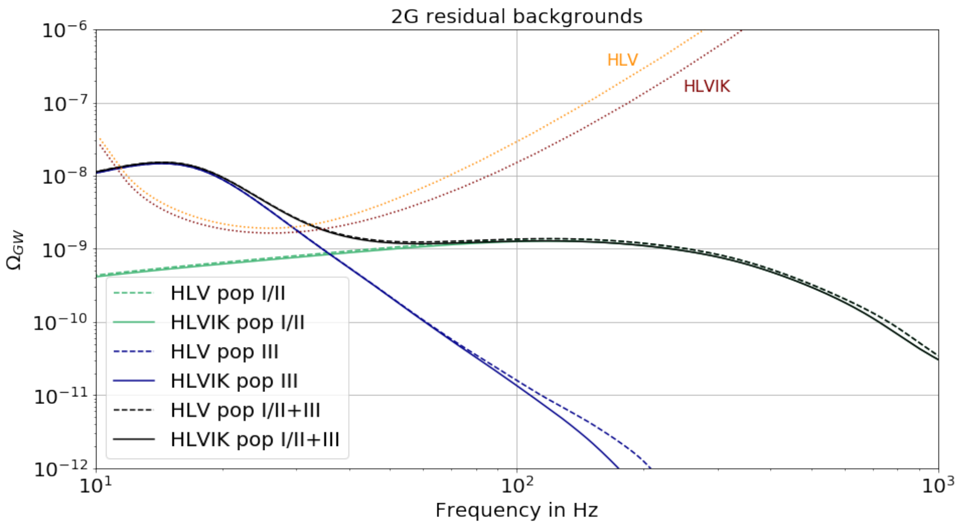


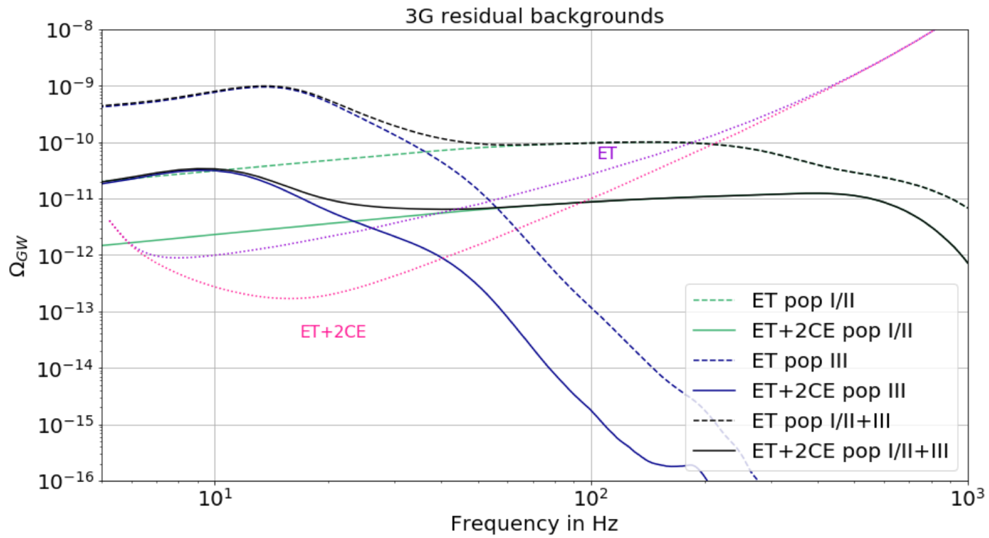


Perigois et al. (starTrack): arXiv:2101.12130

Residual background in 2G and 3G

The background from CBCs is not continuous/Gaussian and sources are separated in the parameter space (see Meacher et al. arXiv:1511.01592)





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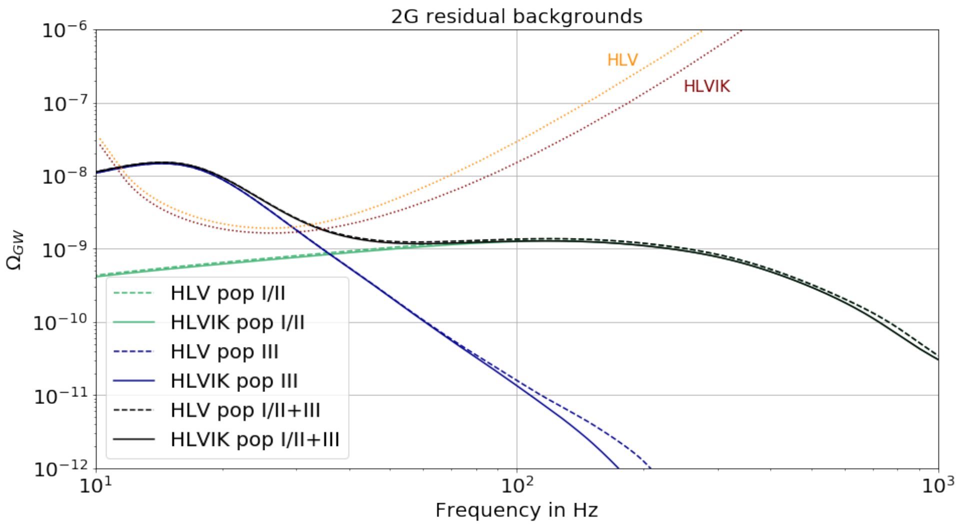
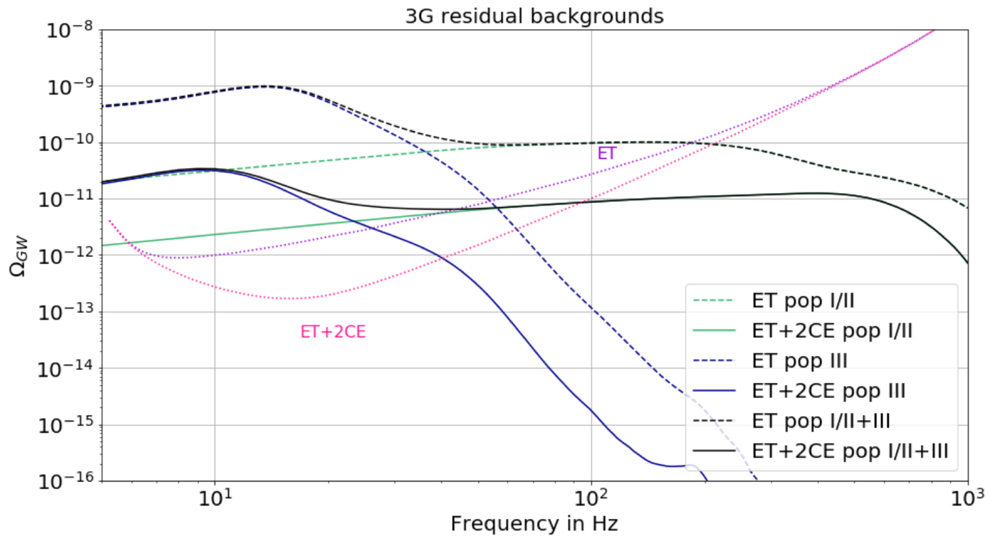
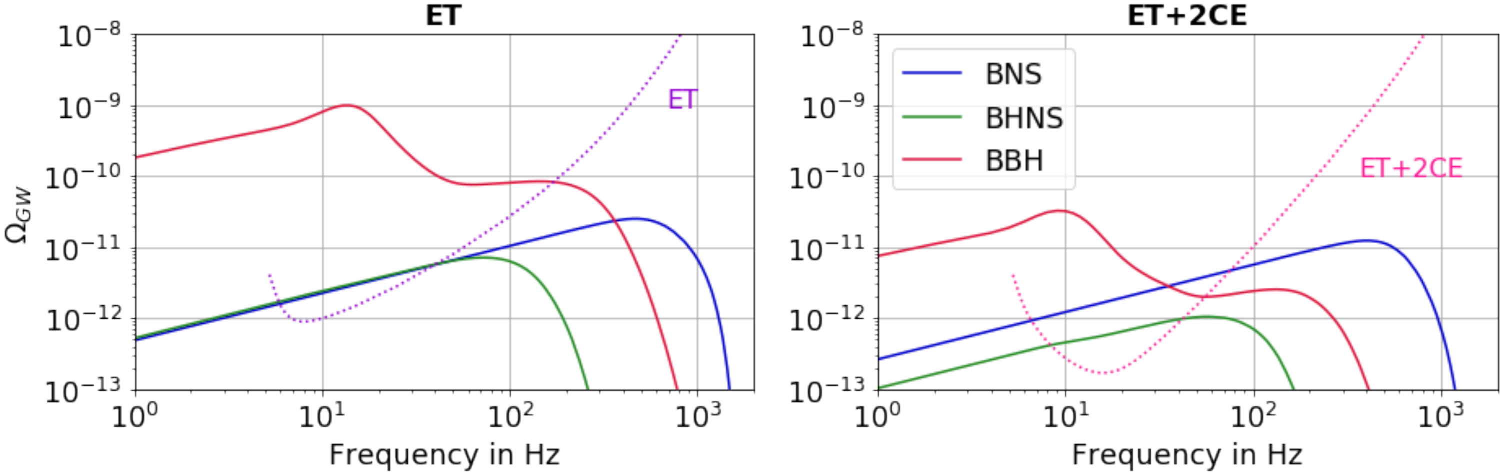




Perigois et al. (starTrack): arXiv:2101.12130

Detection



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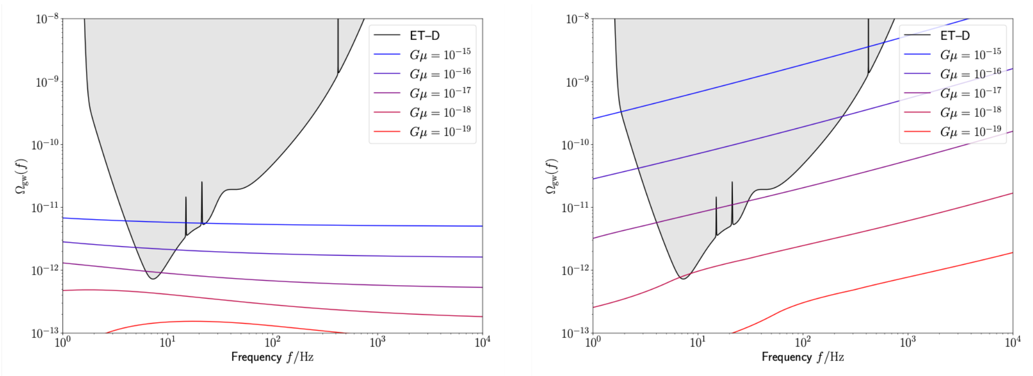
	HLV	HLVIK	ET	ET+2CE	LISA
pop I/II	0.8	1.1	60	0.02	62
pop III.	7.2	8.6	1481	334	1587
Total	7.2	8.7	1482	334	1588

Remove the astrophysical background

- Observe the cosmological/astrophysical backgrounds below



Cosmic Strings from Maggiore et al. arXiv: 1912.02622

- Performed mock data challenges to test waveform subtraction methods

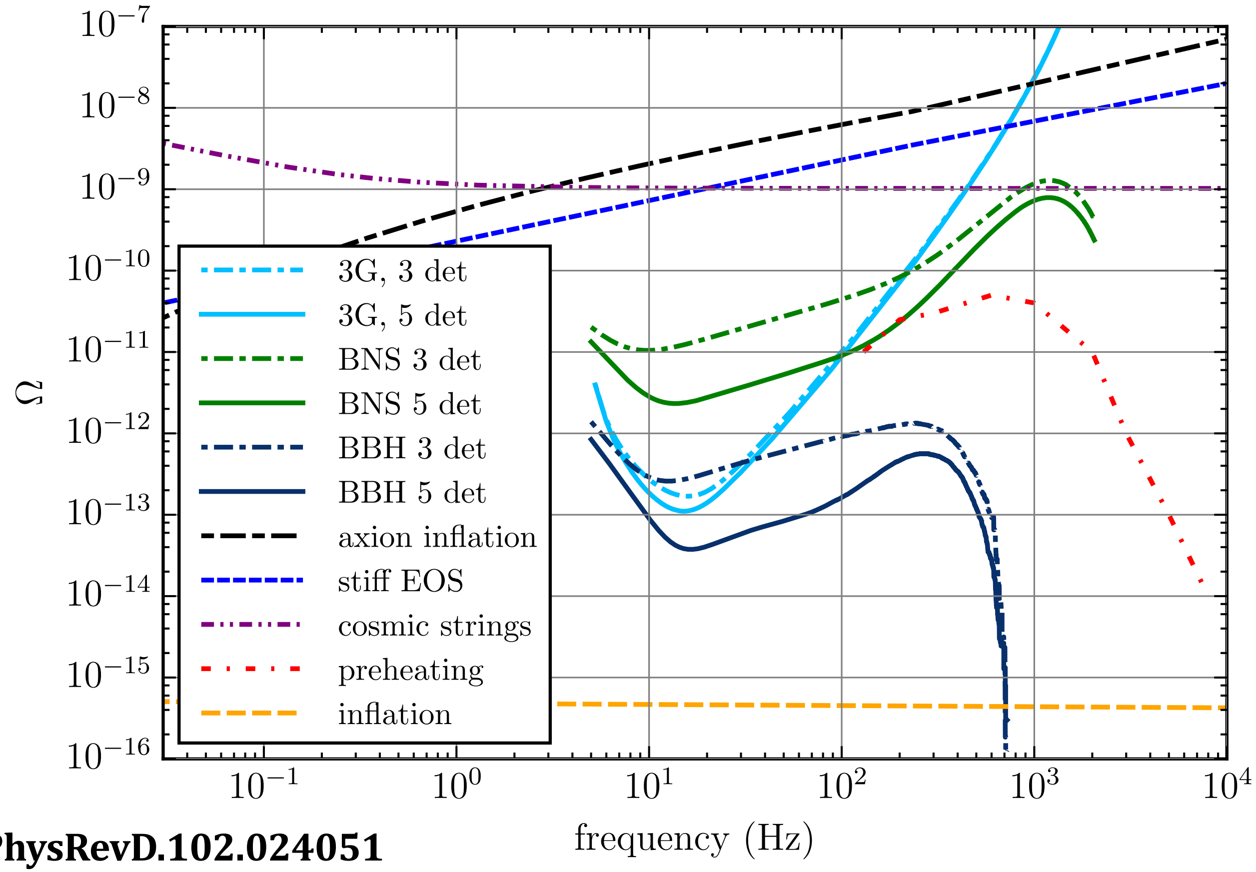
Error on recovered parameters

$$\Omega_{\rm GW} = \Omega_{\text{cbc, rec}} + \Omega_{\text{error}} + \Omega_{\text{cbc, unres}} + \Omega_{\text{cosmo}} + \Omega_{\text{astro, }\imath}$$

subtracted

undetected

Remove the astrophysical background

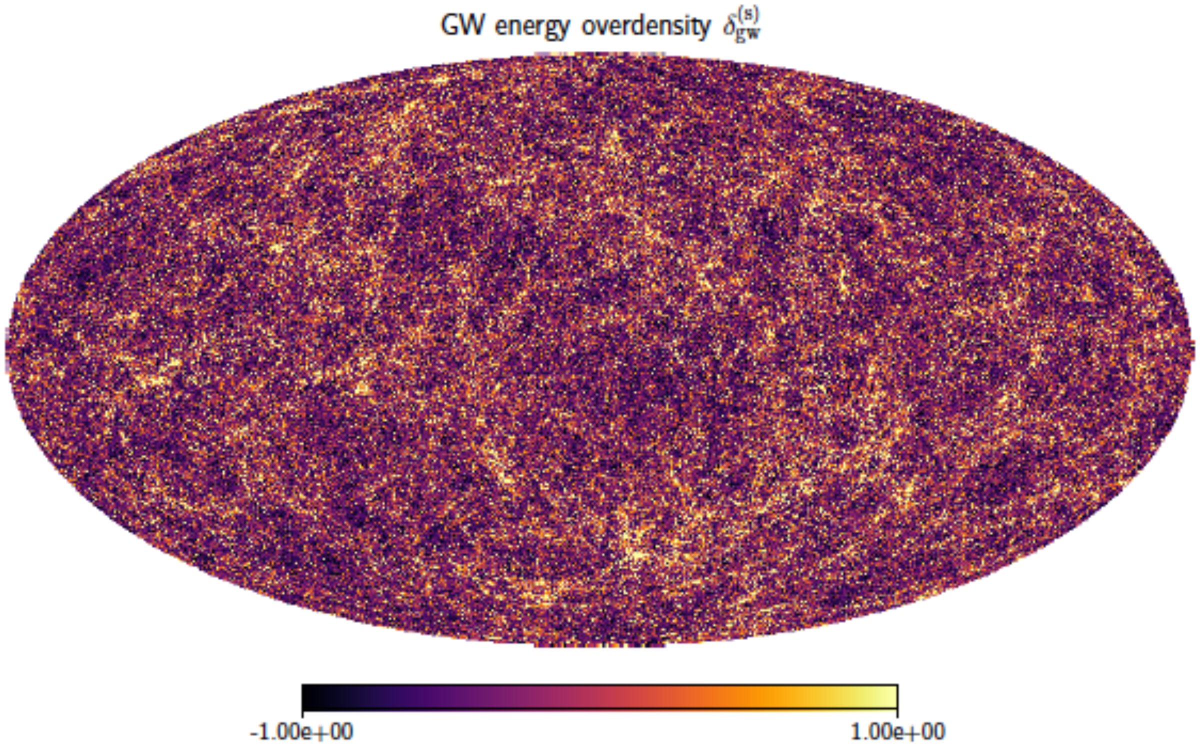


Sachdev et al., PhysRevD.102.024051

Conclusion

- The background from CBCs has a good chance to be detected in the next years.
- With ET the goal wil be to subtract it to recover the cosmological backgrounds
- Probe the anisotropy of the GWB (Cusin et al., Jenkins et al.)
- Remove correlated noise (i.e magnetic noise)
- Search for GWB with null stream

Anisotropies for the CBC background



Jenkins & Sakellariadou, arXiv:1802.06046

Background from CBCs

Energy density in GWs for a population k (BBH, BNS or BH-NS)

$$\Omega_{GW}(f,\theta_k) = \frac{f}{\rho_c}\int d\theta_k P(\theta_k)\int_0^{10} dz R_m^k(z,\theta_k)\frac{\frac{dE_{gw}}{df}(\theta_k, f(1+z))}{4\pi r^2(z)}$$

Rate

Spectral properties of individual sources

with distribution $P(\theta_k)$ in the parameter space $\theta_k=(m_1,m_2,\chi_{eff})$