THE QUEST FOR THE SGWB IN TERRESTRIAL INTERFEROMETERS

Tania Regimbau

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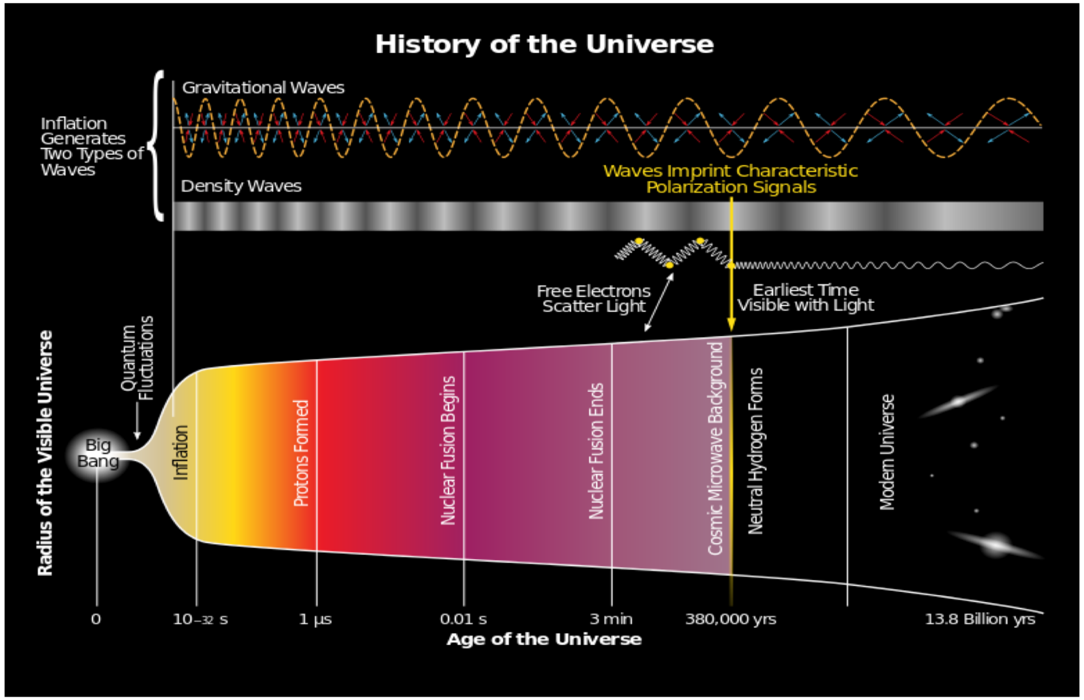
Stochastic GW background (SGWB)

A stochastic background of gravitational waves has resulted from the superposition of a large number of independent unresolved sources.

- Cosmological (signature of the early Universe)
- Astrophysical (since the beginning of stellar activity)



Cosmological background

- Unique window on the very early stages of the Universe and on the physical laws that apply at the highest energy scales (potentially up to the Grand Unified Theory (GUT) scale 10^{16} GeV).

- Results from the amplification of vacuum metric fluctuations during inflation (see arXiv:1610.06481)

- Active sources could have enhanced GW production at the end of inflation (particle production, reheating, spectator fields, primordial black holes)

- Other models include cosmic phase transitions, topological defects (cosmic (super)strings)

Characterizing the SGWB

Assuming the background is Gaussian, stationary, isotropic and unpolarized (by analogy with the CMB), it can be completely characterized by the dimensionless spectral energy density parameter :

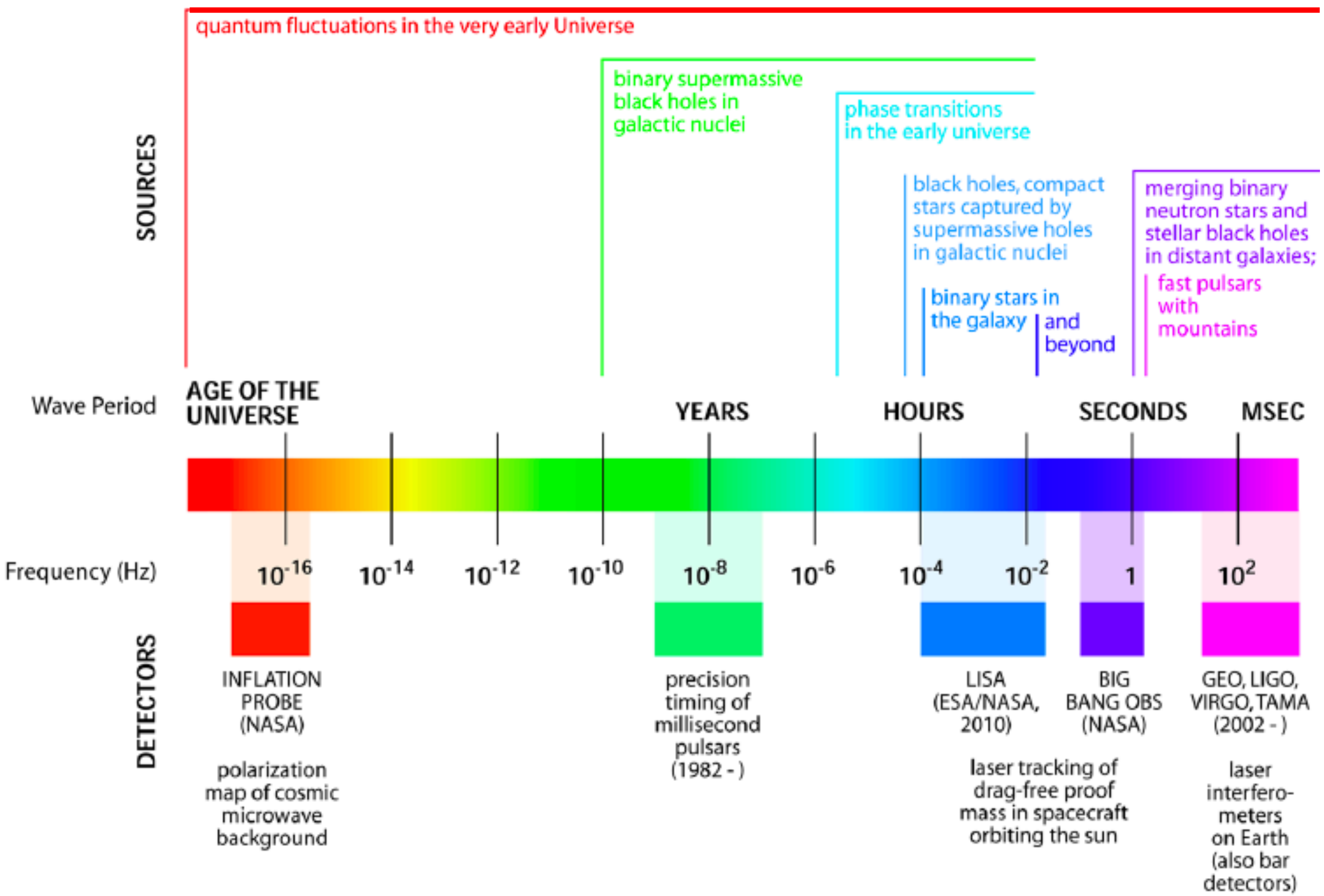
$$\Omega_{gw}(f) = \frac{f}{\rho_c}\frac{d\rho_{gw}}{df}$$

energy density in GWs

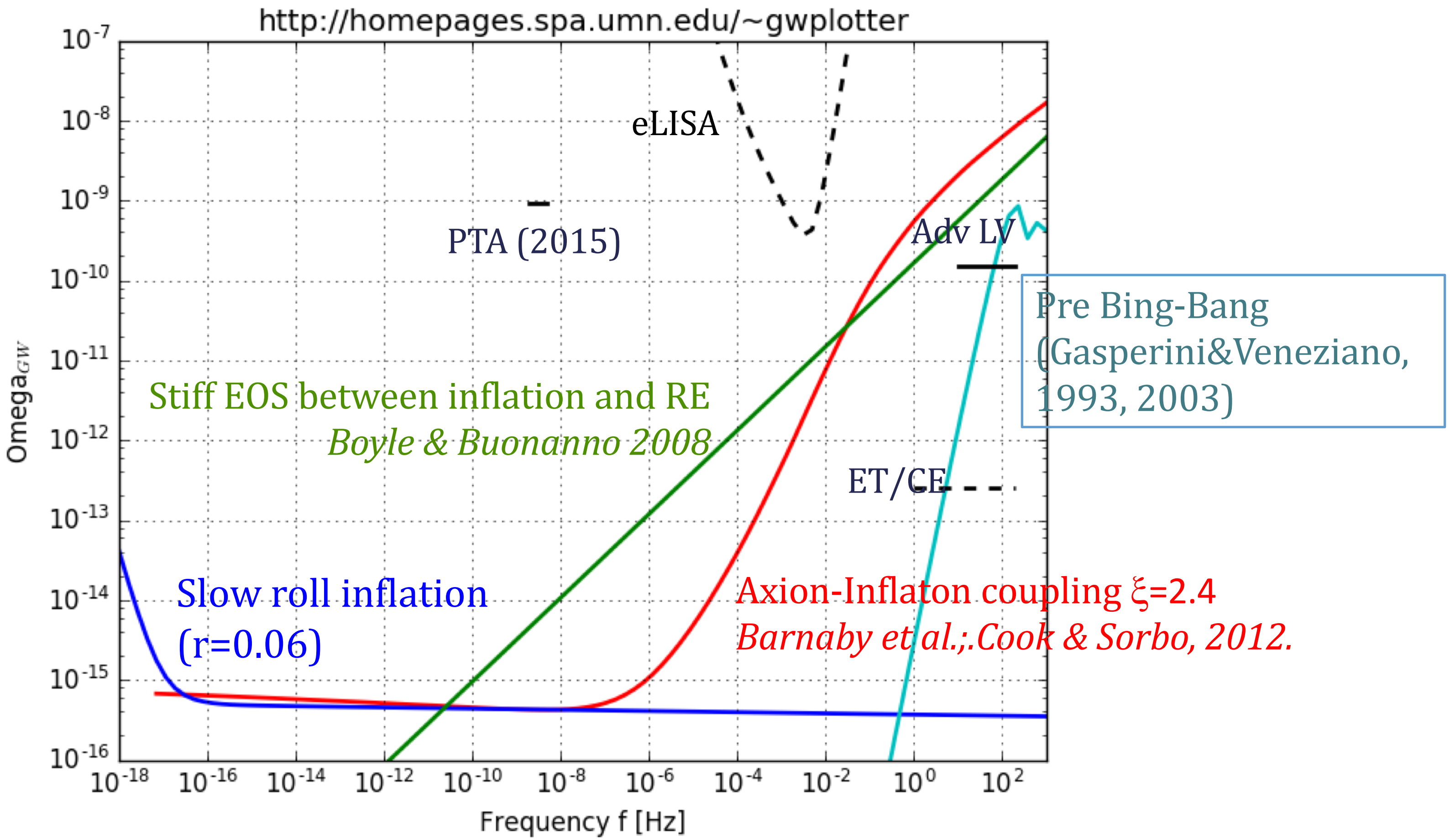
closure energy density

with $\rho_c = \frac{3H_0^2c^2}{8\pi G}$

THE GRAVITATIONAL WAVE SPECTRUM



Background from inflation



Astrophysical Backgrounds

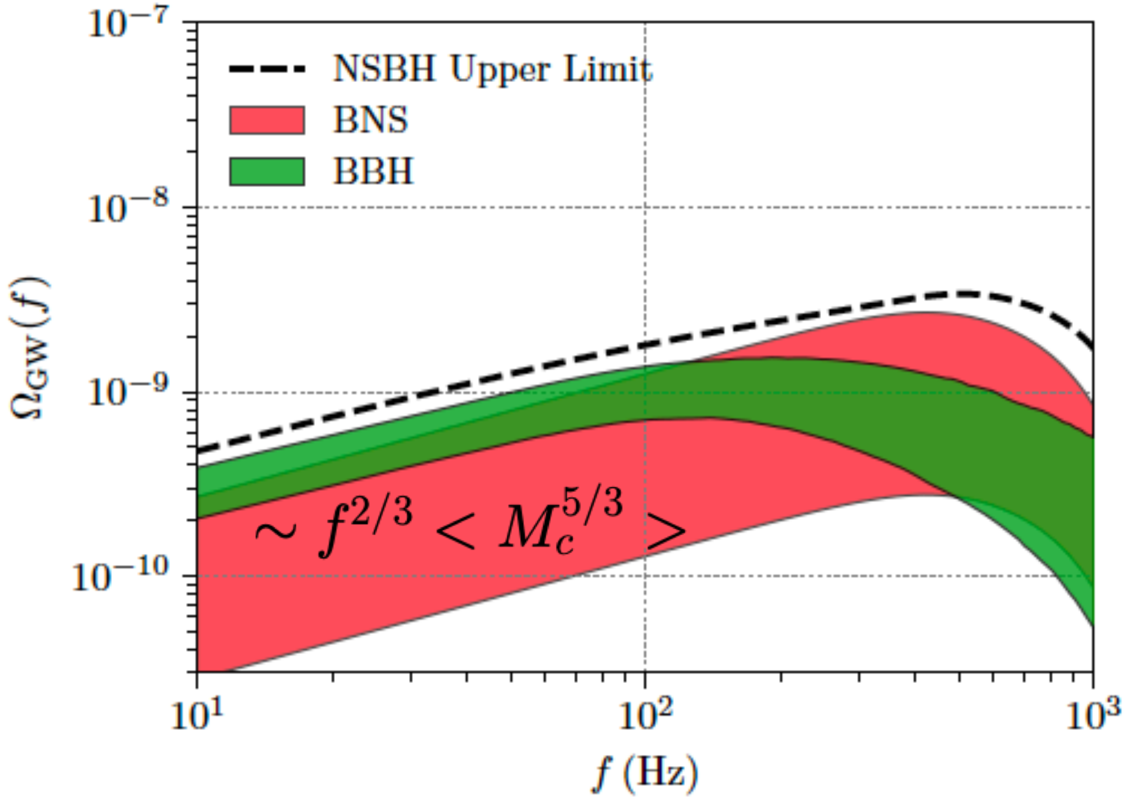
- Foreground for the cosmological background

- Formed by astrophysical sources that cannot be resolved individually. The level decreases as the sensitivity increases.

- Dominated by compact binary coalescences in the band of LVK.

- May have different statistical properties compared to the cosmological background: non continuous, non-Gaussian, non isotropic

Estimate from Detected Sources



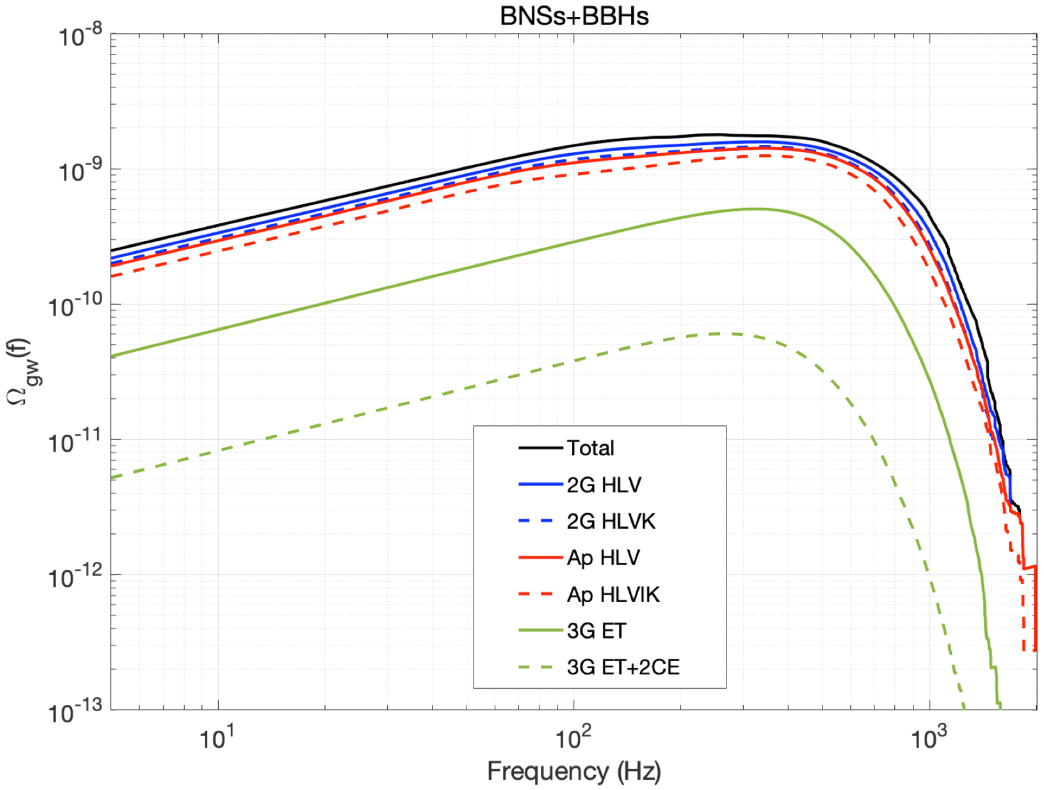
$$\Omega_{BNS}(25\,\mathrm{Hz}) = 2.1^{+2.9}_{-1.6} \times 10^{-10}$$

$$\Omega_{BBH}(25\,\mathrm{Hz}) = 5.0^{+1.7}_{-1.4} \times 10^{-10}.$$

arXiv:2101.12130

Residual background

For CBCs the background decreases as the sensitivity of the detectors increases



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:

$$s_i = h_i + n_i$$

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

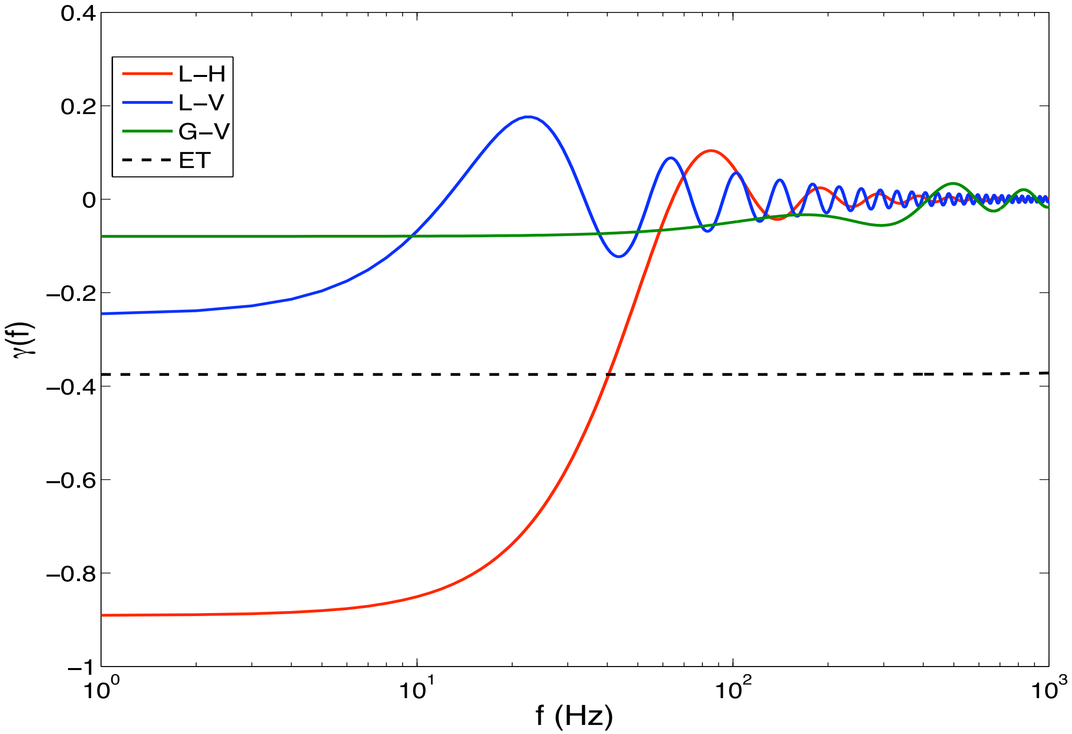
Cross Correlation Statistics

- 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: $\tilde{Q}(f) \propto \frac{\gamma(f)\Omega_{gw}(f)}{f^3 P_1(f) P_2(f)}$ with $\Omega_{gw}(f) \equiv \Omega_0 f^{\alpha}$
- in the limit noise >> GW signal

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

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

Constraints on the GW energy density from LVK

- No evidence for a stochastic background (cosmological or astrophysical).

- But set upper limits on the total energy density:

from CBCs

	Uniform prior			Log-uniform prior		
α	O3	O2 [43]	Improvement	O3	O2 [43]	Improvement
0	1.7×10^{-8}	6.0×10^{-8}	3.6	5.8×10^{-9}	3.5×10^{-8}	6.0
2/3	1.2×10^{-8}	4.8×10^{-8}	4.0	3.4×10^{-9}	3.0×10^{-8}	8.8
3	1.3×10^{-9}	7.9×10^{-9}	5.9	3.9×10^{-10}	5.1×10^{-9}	13.1
Marg.	2.7×10^{-8}	1.1×10^{-7}	4.1	6.6×10^{-9}	3.4×10^{-8}	5.1

arXiv:2101.12130

Directional searches

- relax assumption of isotropy and generalize to arbitrary angular distribution.

$$\Omega_{\rm GW}(f) \equiv \frac{f}{\rho_c}\frac{d\rho_{\rm GW}}{df} = \frac{2\pi^2}{3H_0^2} f^3 H(f) \int_{S^2} d\hat{\Omega}\,\mathcal{P}(\hat{\Omega})$$

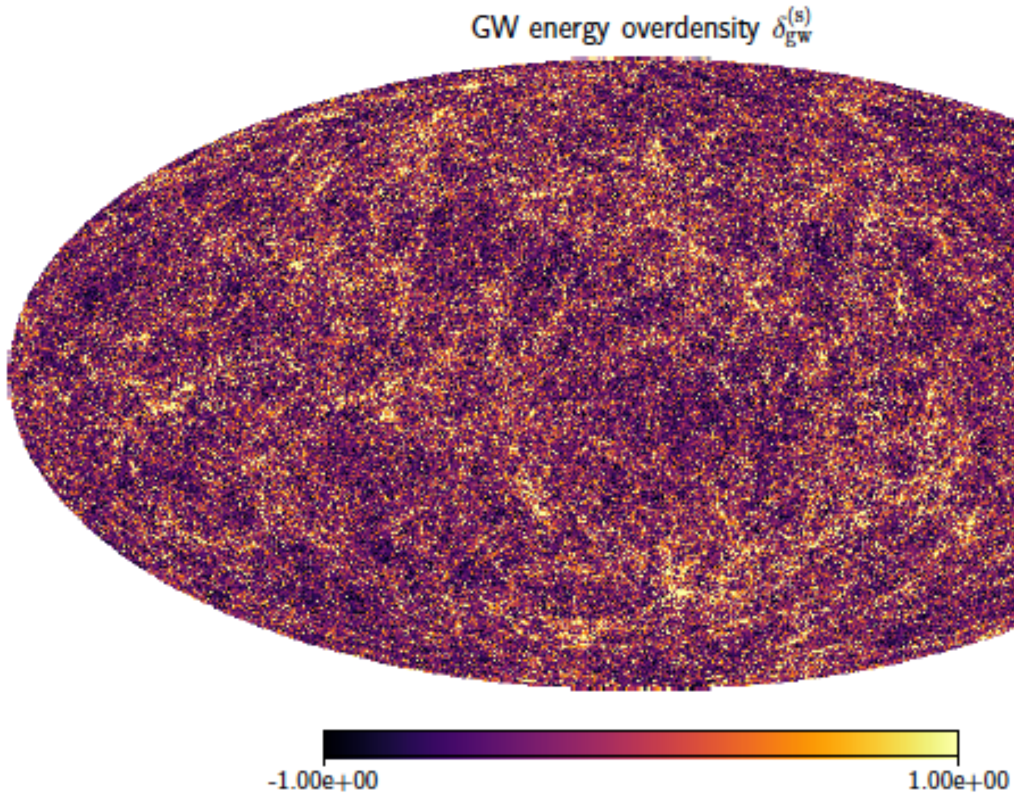
$$\mathcal{P}(\hat{\Omega}) = \mathcal{P}_\alpha \mathbf{e}_\alpha(\hat{\Omega})$$

- by applying appropriate time varying delays between detectors it is possible to map the angular power distribution in a pixel or spherical harmonic basis

radiometer analysis for point-like sources: $\mathcal{P}(\hat{\Omega}) \equiv \eta(\hat{\Omega}_0)\delta^2(\hat{\Omega}, \hat{\Omega}_0)$

spherical harmonic decomposition : $\mathcal{P}(\hat{\Omega}) \equiv \sum_{lm} \mathcal{P}_{lm} Y_{lm}(\hat{\Omega})$

Anisotropies from Compact Binary Mergers



arXiv:1802.06046

Conclusion

- The SGWB is the grail of GW astronomy and can be probed by different experiments in different frequency ranges.
- The background from slow roll inflation is out of reach for terrestrial interferometers, but extra contributions are predicted in some theories of inflation.
- An astrophysical foreground is expected to mask the cosmological background and needs to be removed (Regimbau et al., PhysRevLett.118.151105; Sachdev et al. PhRvD.102b4051S).
- More work is needed to understand how to combine constraints at different frequencies