The Quest for the Gravitational-Wave Stochastic Background with LIGO/Virgo

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GW Stochastic Background

- The stochastic background of gravitational waves is superposition of a large number of independent unresolved sources.

  - Many overlaps (independent of the detectors)

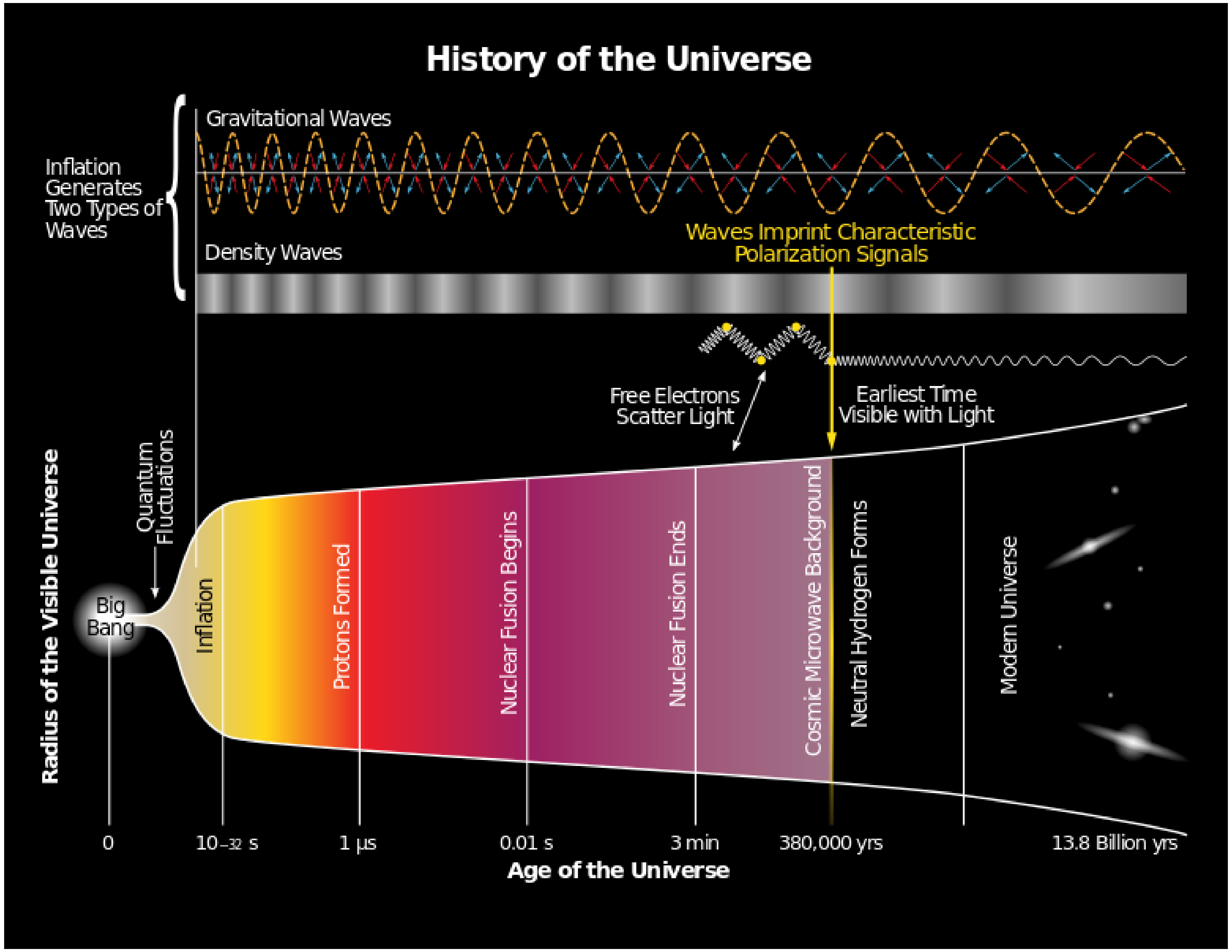
  - Below the sensitivity (depend on the detectors)

- The energy density spectrum is described by the dimensionless quantity:

$$\mathrm{W}_{gw}(f) = \frac{d r_{gw}(f)}{r_c d(\ln f)}$$

- Of both cosmological and astrophysical origin

GW Stochastic Background



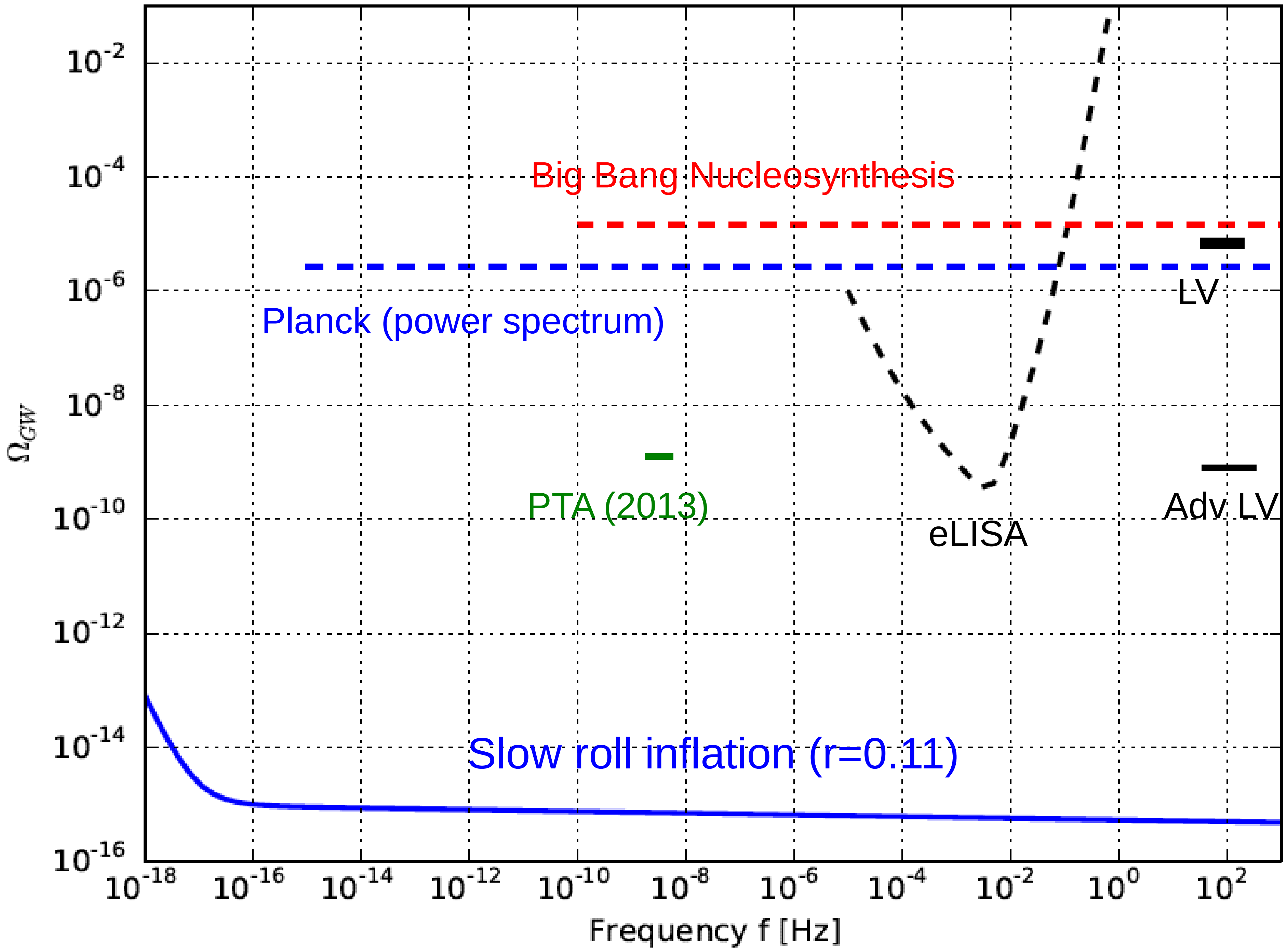
Cosmological Background

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

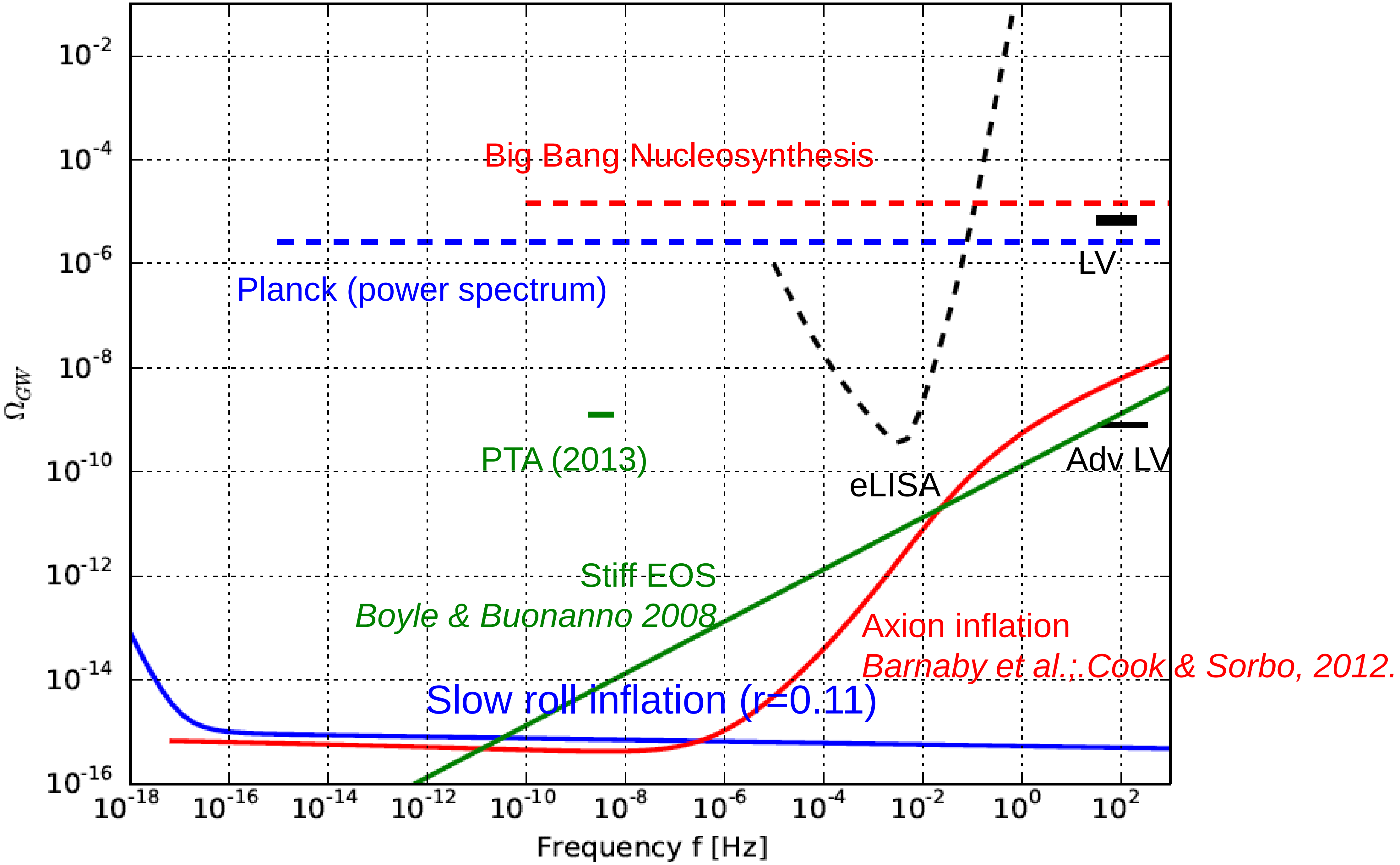
- The amplification of vacuum fluctuations during inflation, as well as on additional GW radiation produced in the final stages of inflation (for example in preheating models or models of axion inflation).

- Other models include phase transitions, cosmic (super)string models, and string theory pre-Big Bang models.

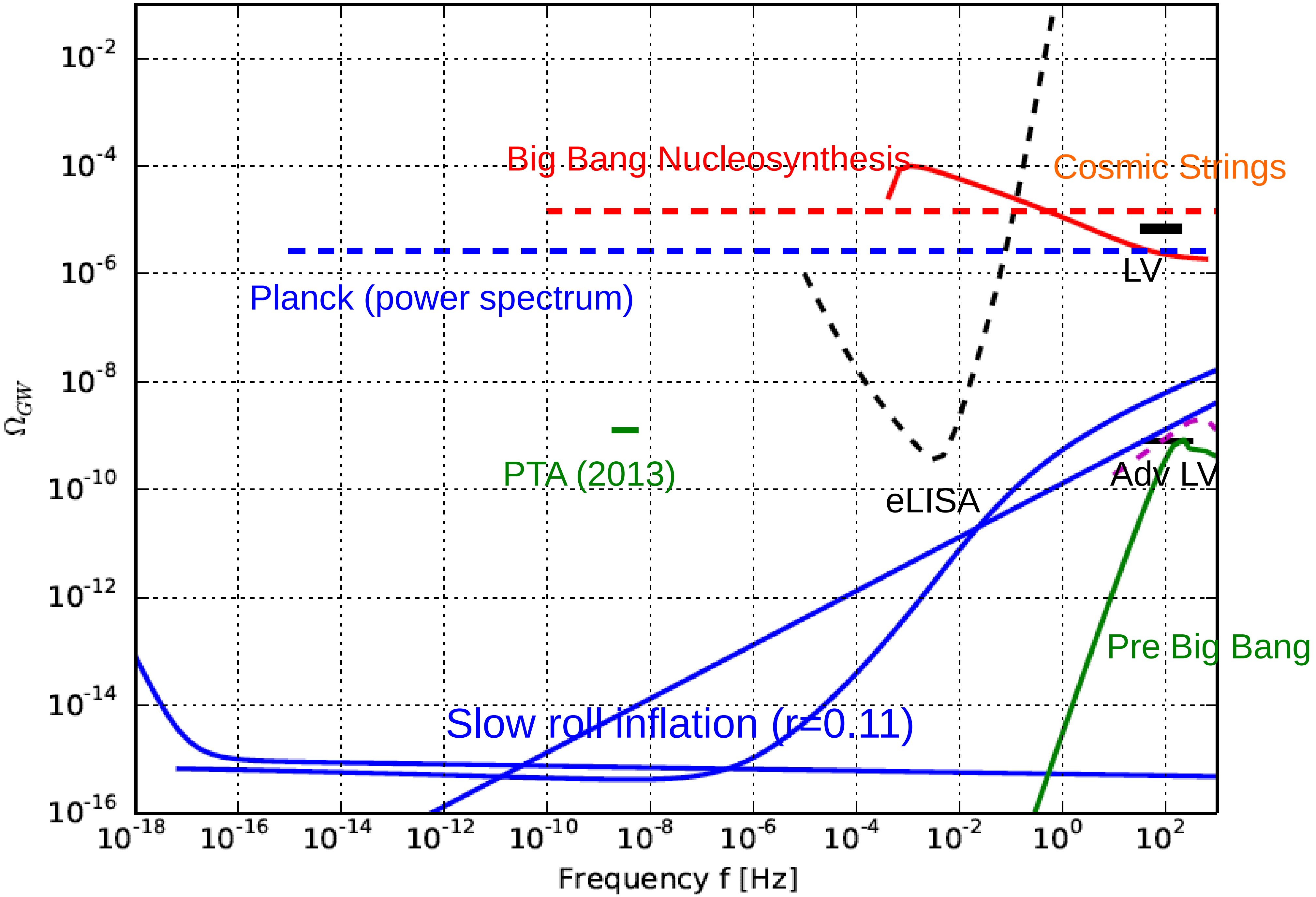
Observational Bounds



Predictions: Background from inflation



Predictions: Other Cosmological Backgrounds



Astrophysical Backgrounds

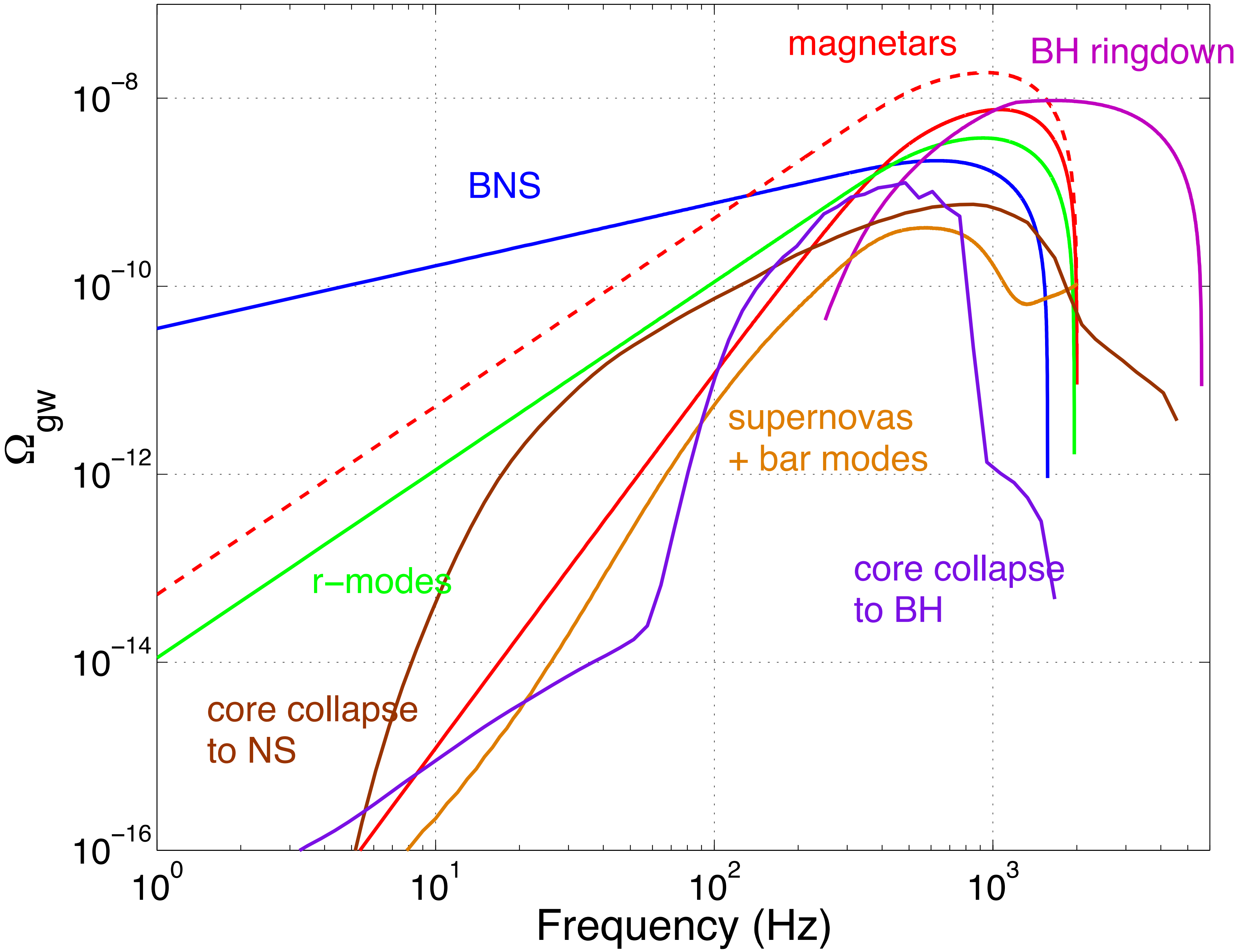
- The spectrum depends on the rate and the individual spectral properties

$$\Omega_{gw}(f)=\frac{8\pi G}{3c^3H_0^2}fF(f)\simeq\frac{8\pi G}{3c^3H_0^2}f\int_{z_h}^{z_{\max}}\frac{dR(z)}{dz}\frac{d\bar{E}}{df_e}(f(1+z))\frac{dz}{4\pi r(z)^2}$$

- Carry lots of information about the star formation history, the metallicity evolution, the average source parameters.
- But can be a noise for the cosmological background
- May have different statistical properties : non continuous, non-Gaussian, non isotropic

Predictions: Astrophysical Backgrounds

From different authors (see Regimbau, RAA, 11, 369 (2011)



Data Analysis Principle

- 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

- Energy density in GWs:

$$\mathrm{W}_{gw}(f)=\frac{d\,r_{gw}(f)}{r_c\,d(\ln f)}\approx f^3S(f)$$

- Standard CC statistic (Allen & Romano, 1999, PRD, 59, 102001)

\- Frequency domain cross product: $Y=\int\tilde{s}_1^*(f)\tilde{Q}(f)\tilde{s}_2(f)df$

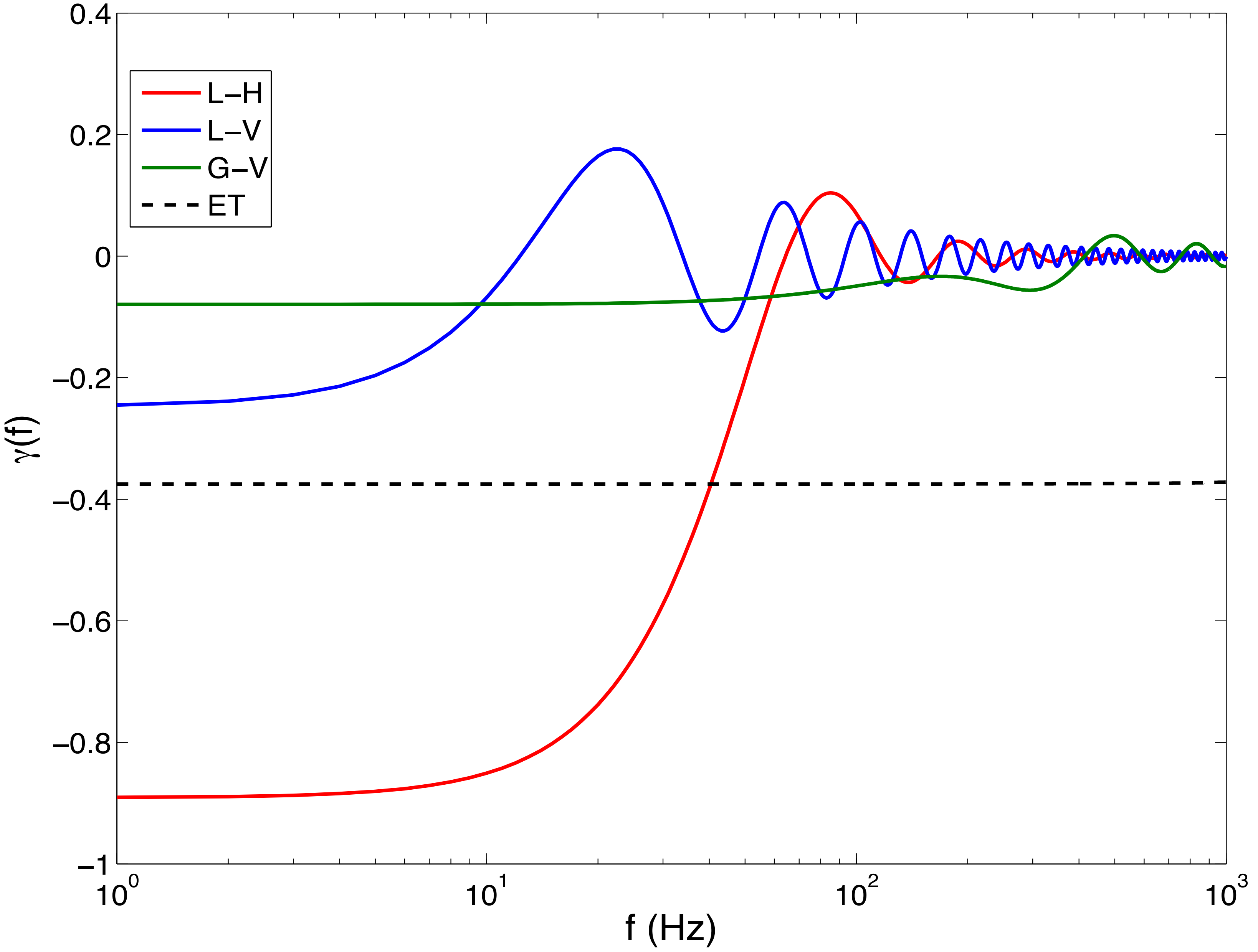
\- optimal filter: $\tilde{Q}(f)\propto\frac{\gamma(f)\Omega_{gw}(f)}{f^3P_1(f)P_2(f)}$ with $\Omega_{gw}(f)\equiv\Omega_0f^\alpha$

\- in the limit noise >>GW signal

$$\mathrm{Mean}(Y)=\mathrm{W}_0T,\ \mathrm{Var}(Y)\equiv s^2\propto T,\ \mathrm{SNR}\propto\sqrt{T}$$

Overlap Reduction Function

$$\gamma_{ij}(f) = \frac{5\sin^2(\alpha)}{8\pi}\int d\hat{k}\, e^{i2\pi f\hat{k}\Delta\vec{x}_{ij}/c}\left(F_+^i F_\times^j + F_+^i F_\times^j\right)$$



Background from CBC

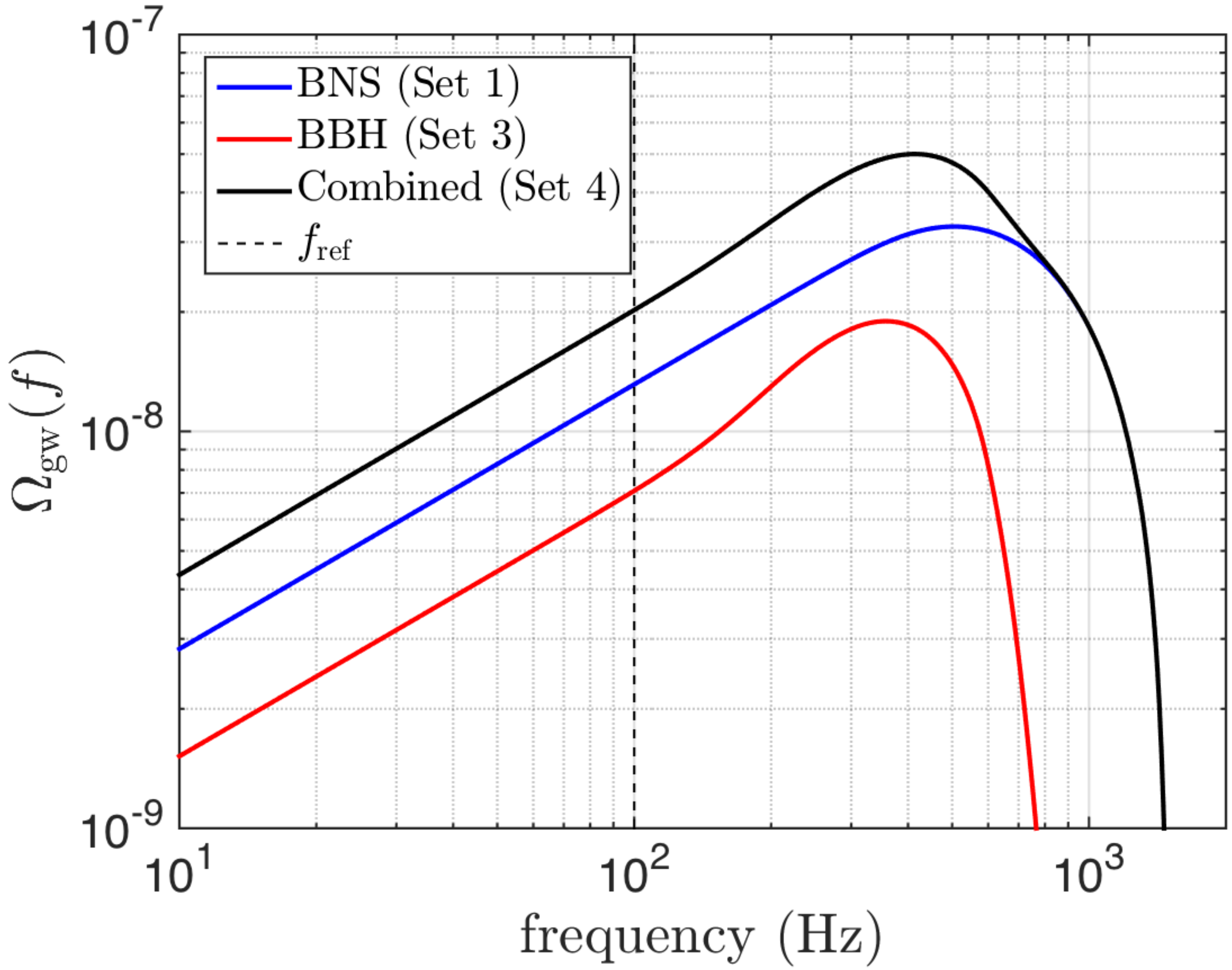
- The background from compact binary coalescences has a realistic chance to be detected with Advanced LIGO/VIRGO detectors (ALV) after a few years of observations.

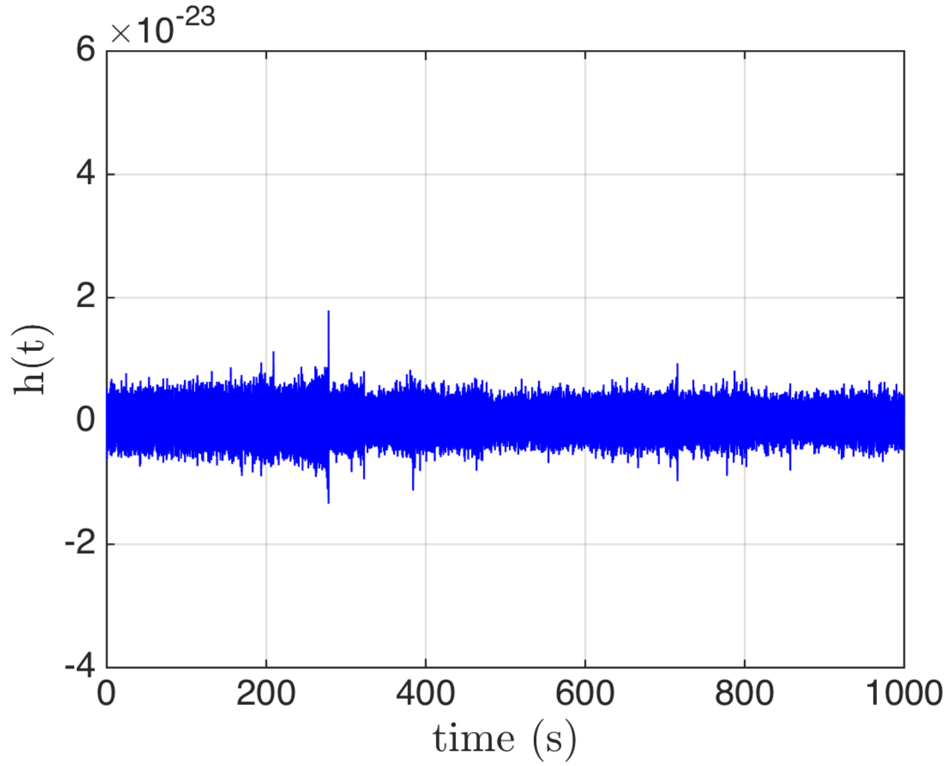
- Mock Data Challenges for ALV and Einstein Telescope (ET) have shown that this background could be detected with no bias using the CC statistics even if it is non-continuous and non-Gaussian.

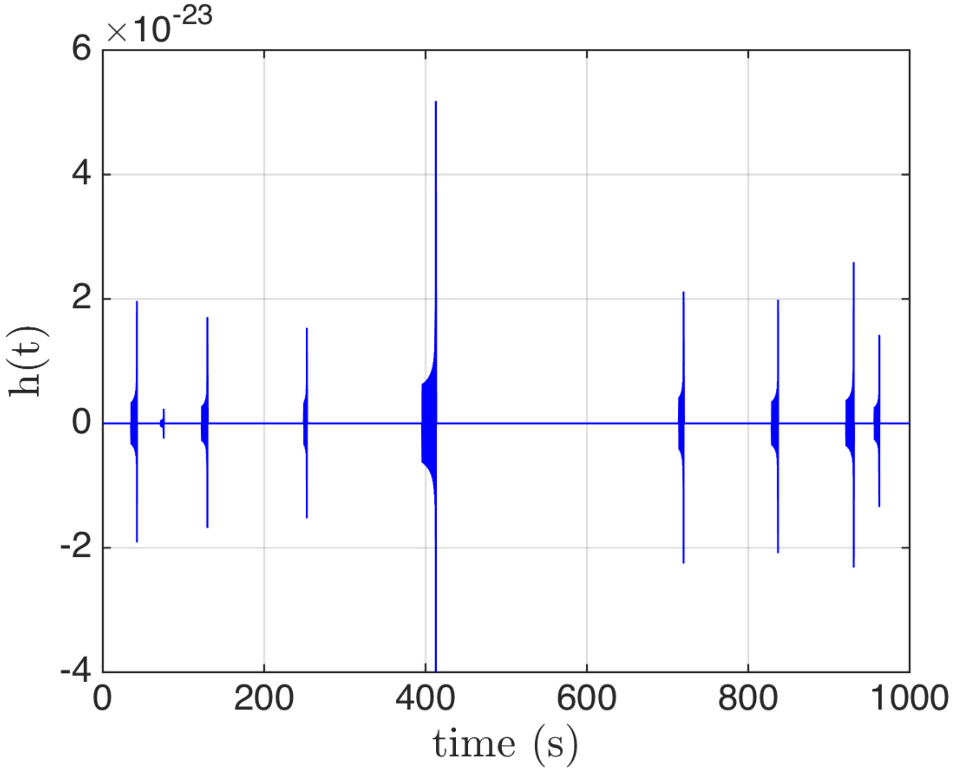
- With ET, the residual background is not isotropic (the best located and oriented sources individual sources a have a larger SNR if they are directly overhead). A correction to the overlap reduction function must be applied.

Adv LIGO/VIRGO Mock Data Challenge

Meacher et al. 2015

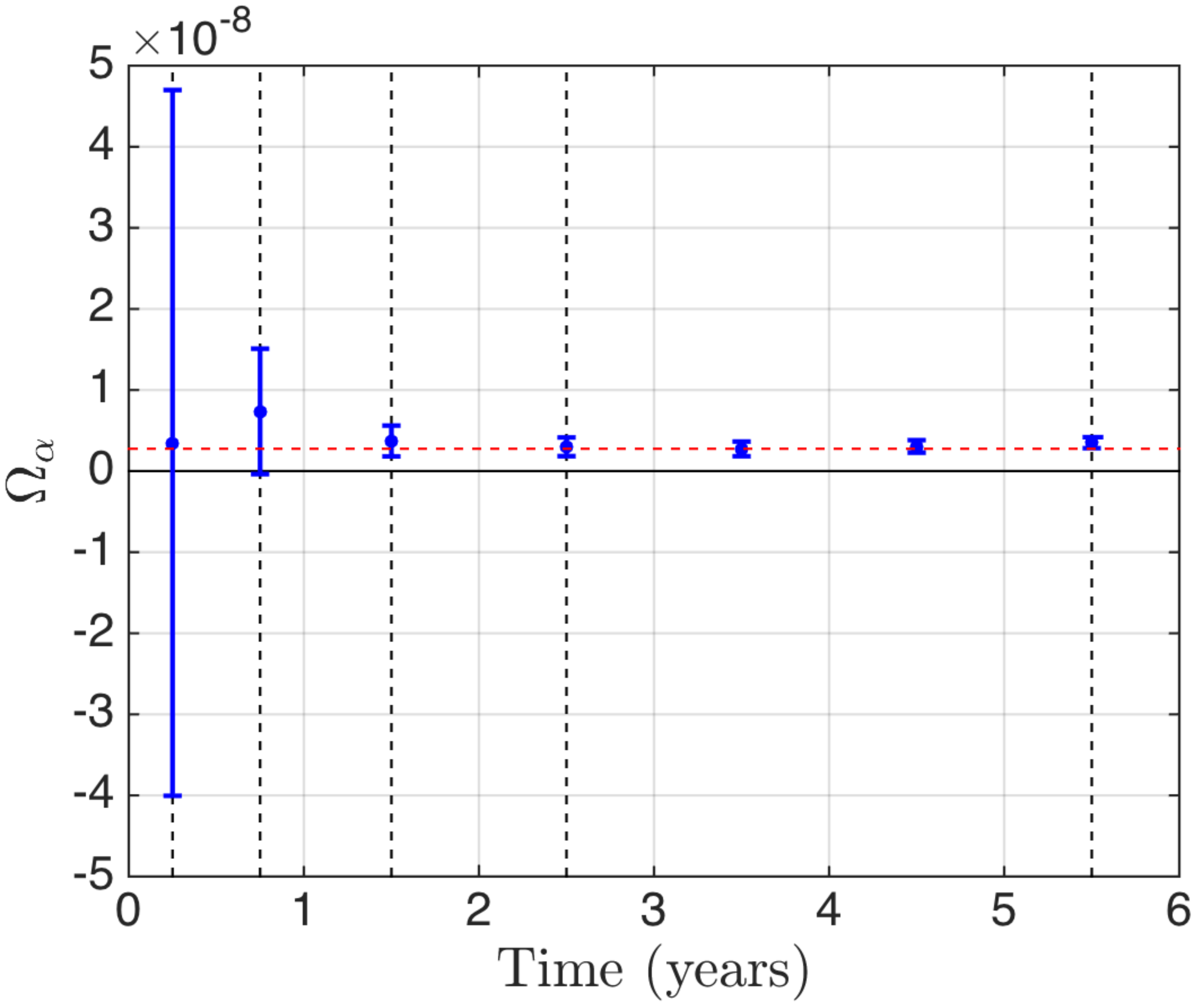


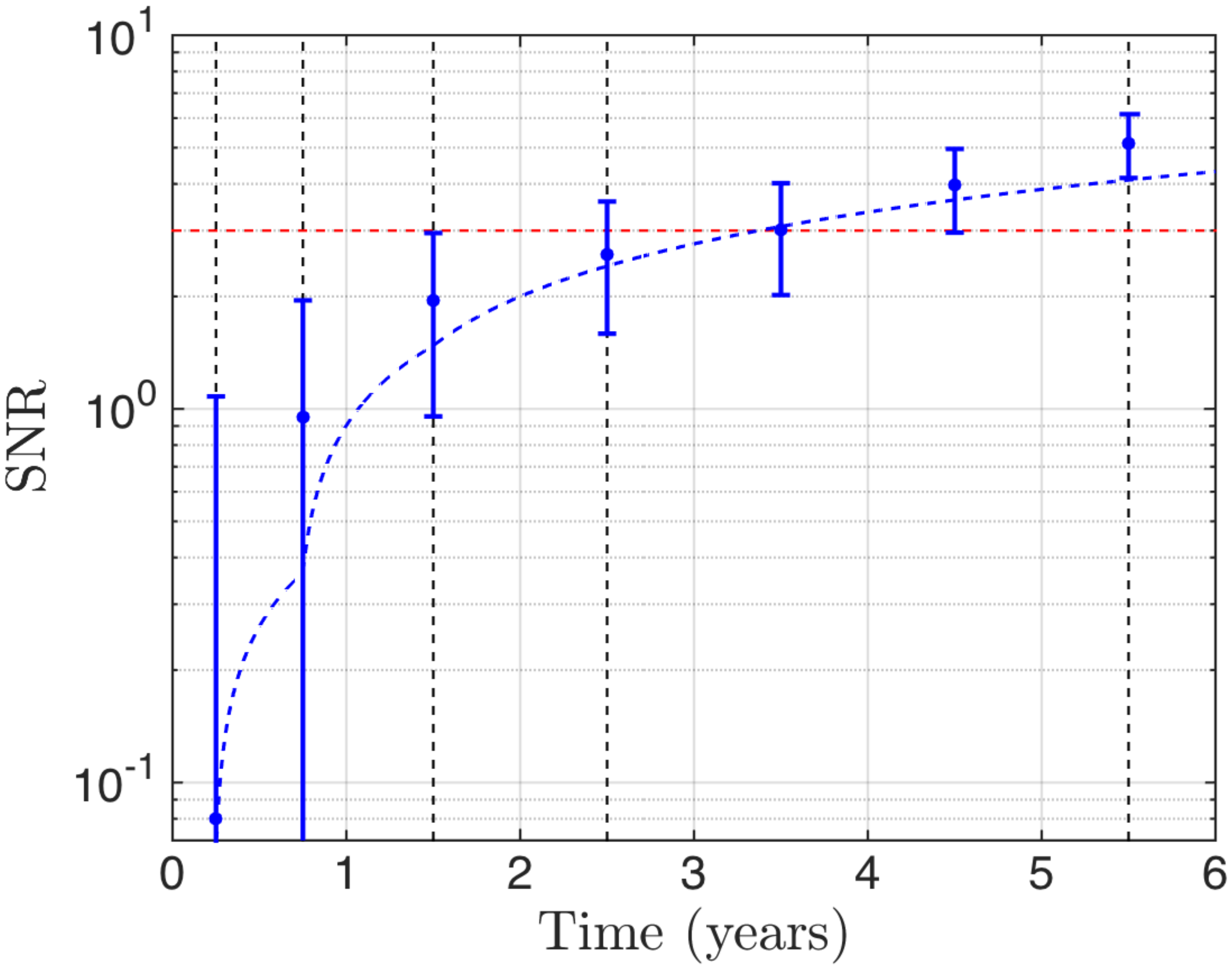




ALV Mock Data Challenge

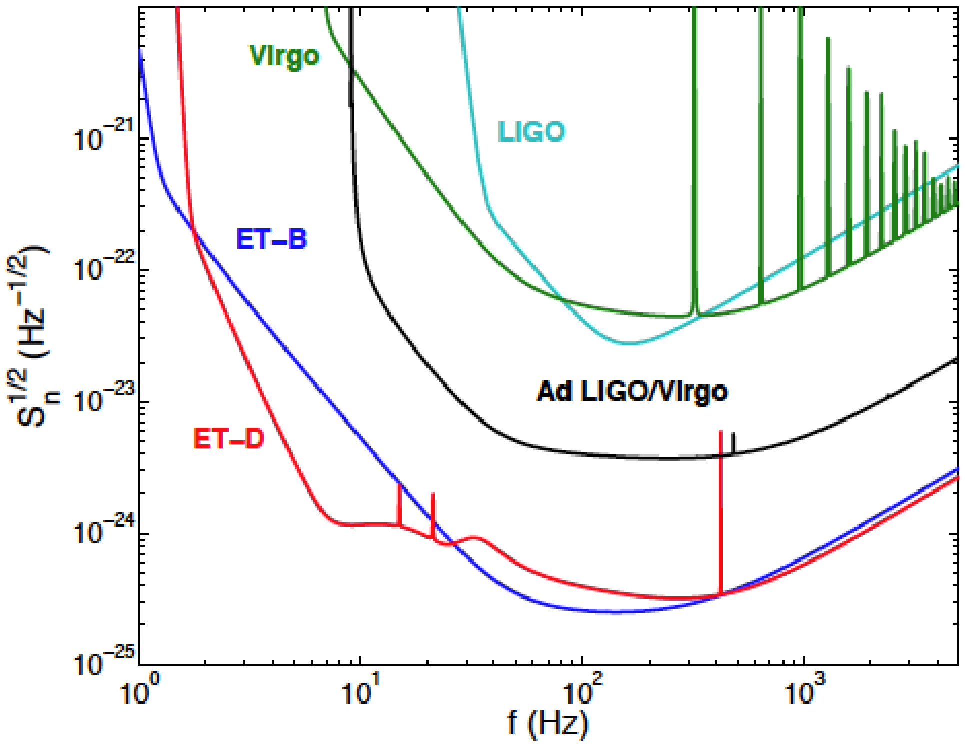
Meacher et al. 2015



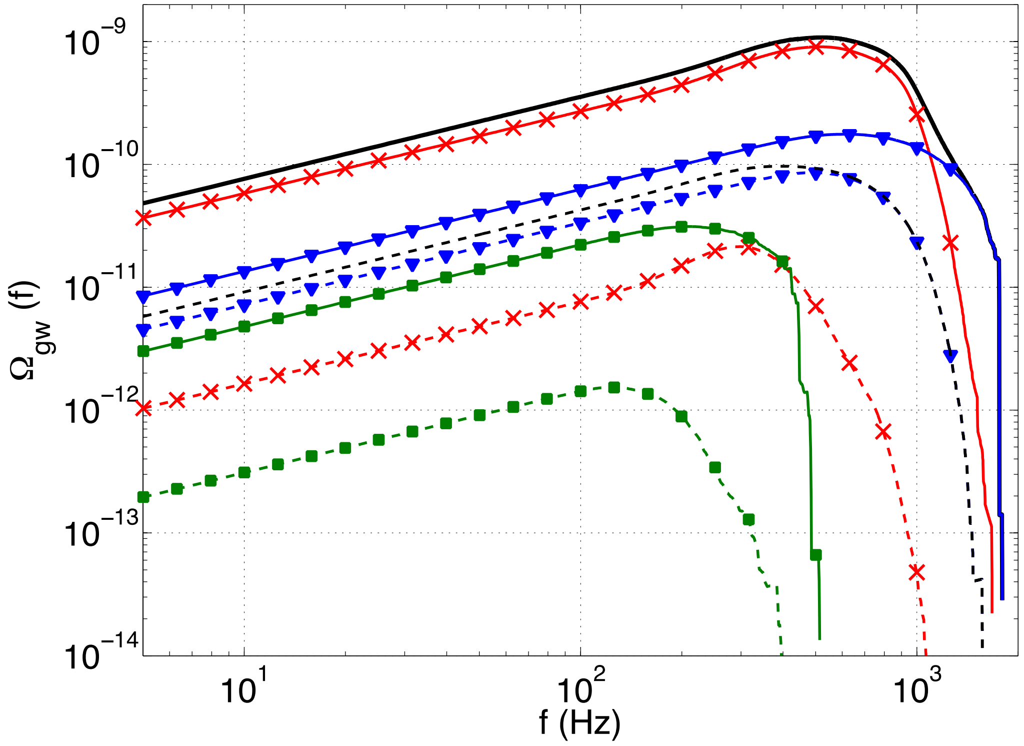


Einstein Telescope Mock Data Challenge

- Third generation detector under designed study
- Sensitivity ten times better
- BNS detected up to z=4
- The residual background is not isotropic
- Need to use a discrete non overlap reduction function
- Using a average value the bacground can be estimated with the standard CC statistic with precision better than 1%.



Regimbau, Meacher and Coughlin, 2014



Conclusion

- Many models of SGWB can potentially be detected by the next generation of LIGO/Virgo detectors

- The cosmological background is a unique way to probe the very early Universe

- Astrophysical sources may create a foreground but can also provide very valuable informations

- The background from compact binary coalescences has a realistic chance to be detected after a few years of observation