Primordial Gravitational waves Challenges for Future Detectors

Shuxun Tian, Philip Jones, Jing Wang, Charlie Hoy, Ryan Cutter

Motivation

Gravitational waves act as the time machine that allows us to see through the entire history of the universe. Unlike the CMB photons, inflationary gravitational waves will carry information about **time periods prior to recombination**.

The detections of the stochastic background of inflationary gravitational waves will therefore have **profound implications for the physics of the early universe** and the high energy physics that is not accessible by particle accelerators.

Introduction

In cosmology it is useful to work with the **gravitational wave spectrum** Ω_{GW}, defined as [3]:

$$\Omega_{\mathrm{GW}}(f) = \frac{f}{\rho_c}\frac{\mathrm{d}\rho_{\mathrm{GW}}}{\mathrm{d}f} \quad (1)$$

This is related to the usual strain $h(f)$ by the equation:

$$h_{100}^2\Omega_{\mathrm{GW}} = \frac{2\pi^2 f^2}{3\left(100\mathrm{kms}^{-1}\mathrm{Mpc}^{-1}\right)^2}|h(f)|^2 \quad (2)$$

Note the f^2 dependence; detectors operating at lower frequencies are much more sensitive to the inflationary signal. The current inflationary gravitational wave spectrum predicted by slow-roll models is shown below, with a peak at $f \approx 10^{-18}Hz$. This is far below the range of any existing or planned detector. Instead, the long tail of $h^2\Omega_{\mathrm{GW}} \sim 10^{-15}$ is the region of interest, however reaching the sensitivity required to detect this tail poses many challenges for future experiments. For reference, LIGO can currently probe to about $\Omega_{\mathrm{GW}} = 10^{-9}$.

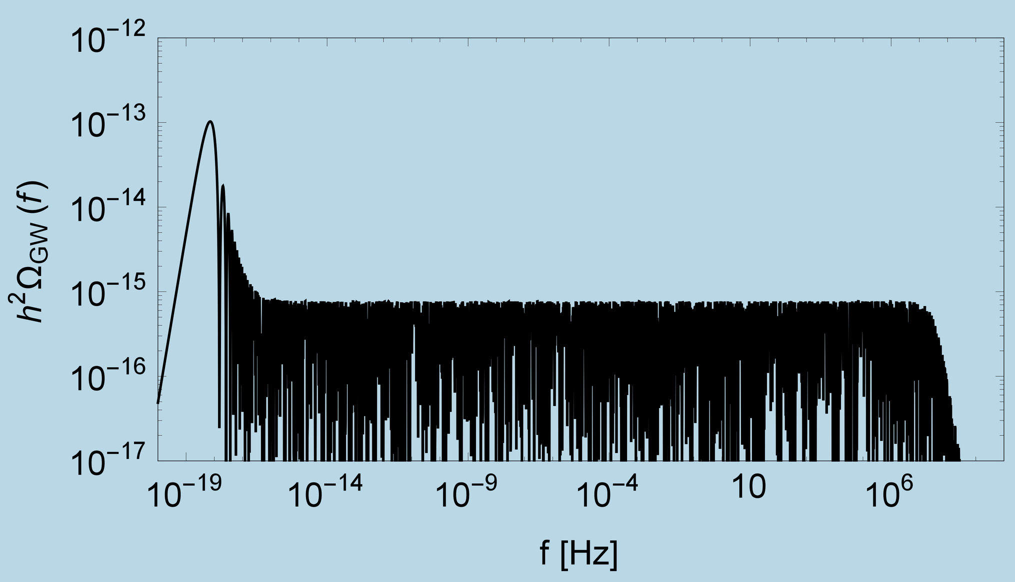

Figure 1: Primordial gravitational wave energy density spectrum predicted by current models of slow-roll inflation. [2]

References

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Constraining Cosmology

Studying the current inflationary gravitational wave spectrum will give insight into the dynamics of the slow roll inflation model. It will provide answers concerning the duration of inflation and energy scale of reheating, both important stages which shape the universe today.

Energy Scale of Reheating: The energy scale of reheating can be measured from the highest frequency of the primordial gravitational wave spectrum. Isolating this energy scale will give details concerning when known matter was created.

Inflation Duration: The interval between the highest and lowest frequency gives the duration of inflation. The duration has important consequences for the flatness problem, monopole problem, and the horizon problem.

Polarisation: Inflation theory predicts that the amplitude of the two polarisations $(h_+, h_\times)$ are equal. This is an important part of testing our current understanding of the early universe. Given LISA's ability to distinguish between the two polarisations, observation of the inflationary signal could help further inflationary theory.

Echoes of an Ancient Universe: Primordial gravitational waves are predicted to follow a particular power law relying on the variable n_T. Depending on where the signal lies, or if the background is detected will inform us on the nature of inflation. The power law is as follows:

$$P_T(k) = A_T\left(\frac{k}{k_*}\right)^{n_T+\frac{1}{2}\frac{\mathrm{d}n_T}{\mathrm{d}\ln k}\ln\left(\frac{k}{k_*}\right)+\ldots} \quad (3)$$

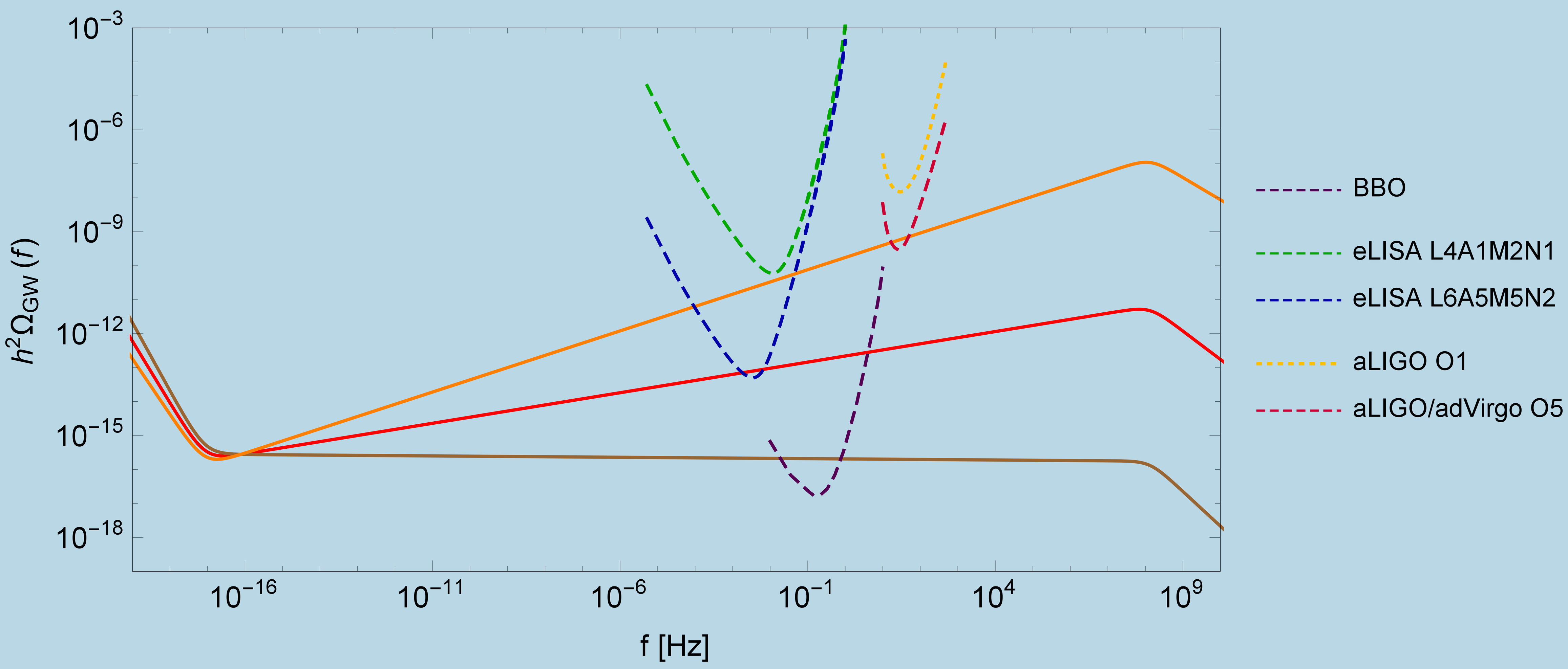

Figure 2: GW spectral energy-density for different values of n_T are shown with solid lines, with the value predicted by slow-roll inflation models shown in brown.[2]

Solutions

Figures 1 and 2 highlight that aLIGO and LISA will not be able to detect gravitational waves from inflation due to a lack of sensitivity, if current inflationary models are correct. Null results will put constraints on the value of n_T, providing information on the equation of state for slow roll inflation. In order to directly detect primordial gravitational waves, modifications must be made to the existing experiments.

Higher Power: While increasing laser power increases the sensitivity in strain of a detector, it also increases the frequency at which the detector is most sensitive. This then reduces the sensitivity to gravitational waves from inflation. Reducing power does not improve sensitivity either with current detectors, as seismic noise dominates at lower frequencies.

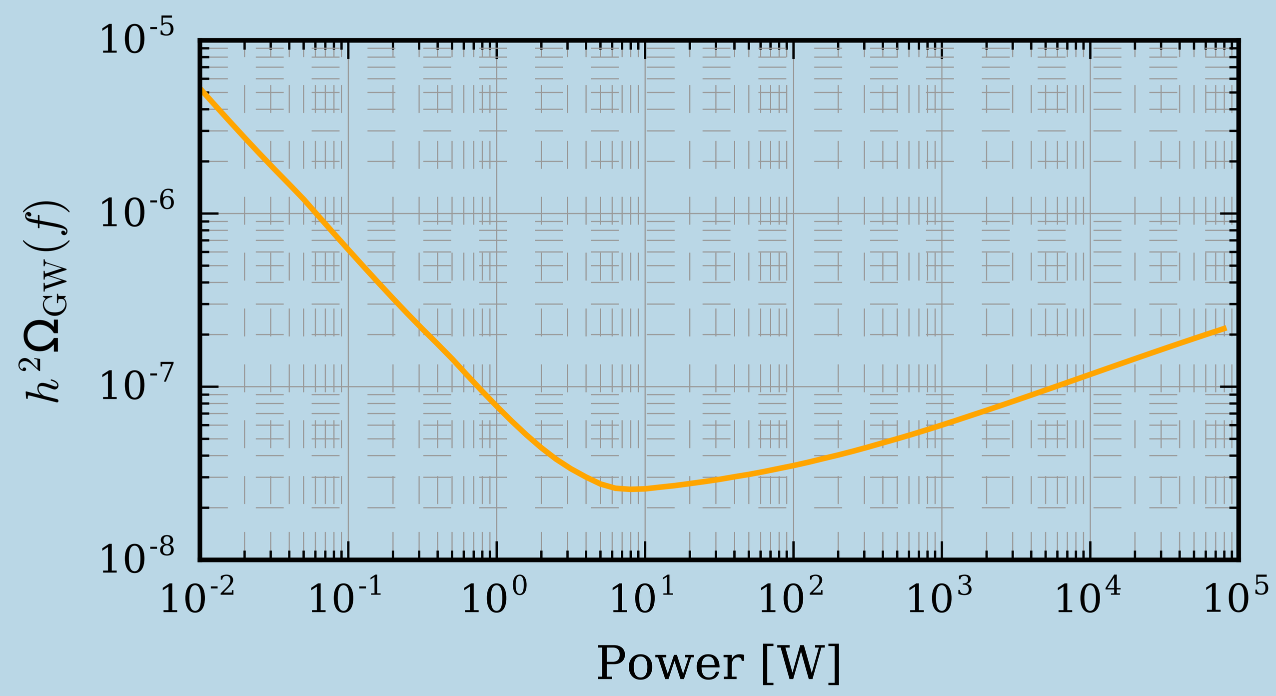

Figure 3: The maximum sensitivity of LIGO as a function of laser power. As can be seen, simply changing the power cannot let LIGO detect inflationary gravitational waves.

Continuous Observation: While Figure 2 seems to show that even eLISA won't be able to detect gravitational waves from inflation if current models are correct, they are a continuous source, and so long-term observation may provide this possibility. This is because the effective amplitude of a signal improves roughly as the square-root of observation time.