Constraining inflationary physics with primordial gravitational waves at small scales

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Abstract. Any inflationary model predicts the production of a stochastic gravitational-wave background. Experiments of direct gravitational-wave detection at small scales represent a promising way of extracting several exciting information encoded in such a primordial signal.

1. Theoretical picture: information carried by inflationary gravitational waves

Any inflationary model predicts the production of a stochastic gravitational wave (GW) background which turns out to represent an exciting window on the physics of the early universe; see [1] for a recent review and refs. therein.

Inflationary GWs from quantum fluctuations: because of quantum fluctuations of the gravitational field the production of a GW background takes place during inflation. In many cases, the corresponding GW power spectrum turns out to be well described by a power-law:

$$P_T(k) = A_T(k_*) \left(\frac{k}{k_*}\right)^{n_T},$$

(1)

with $A_T(k_*)$ the amplitude at at chosen pivot scale k_*, and n_T the spectral index. Such a stochastic GW background represents a smoking gun for the cosmic inflationary model and carries unique information about such a stage of the universe. For example, according to single-field slow-roll inflation, the GW amplitude reflects the energy scale of the inflationary mechanism, while n_T measures the deviation with respect to a de-Sitter background.

Inflationary GWs from classical production: quantum fluctuations of the gravitational field are not the only mechanism by which GWs can be generated during inflation. The presence of further fields besides the gravitational one, gives rise to source terms in the GW equation of motion. Depending on the efficiency of the source, this mechanism can provide significant extra contributions to the inflationary GW background.

Quantum and classical GW contributions carry different information about the inflationary process: the first reflects the properties of the underling theory of gravity, while the latter the features of the involved fields. Therefore, inflationary GWs represent a promising way of discriminating among the variety of inflationary models; see tab.2 of [1].

Inflationary consistency relation: Single-field slow-roll inflation predicts a consistency relation between the tensor-to-scalar ratio r and the GW spectral index: $r = -8n_T$. However, several inflationary models are expected to violate such an equality, making it a powerful test for single-field slow-roll inflation, see tab.3 of [1]. Clearly, in order to test such a consistency relation, GW measurements on different scales are required.

2. Observational prospects and the role of experiments at small scales

Modeling the evolution of the universe, the inflationary GW spectral-energy density expected to fill the universe at the present time can be calculated [2]. The obtained GW background turns out to reflect the primordial amplitude and spectral index and to carry the imprints of the history of the universe it underwent. Notice that the resulting GW spectrum covers a wide range of frequencies: from $f \sim 10^{-16}$Hz, up to $f \sim 10^3$Hz or more, i.e. the range of the so-called small scales ($f = k/2\pi a$). Figure 1 provides an updated overview of the sensitivity curves for current and future experiments of direct GW detection at small scales.
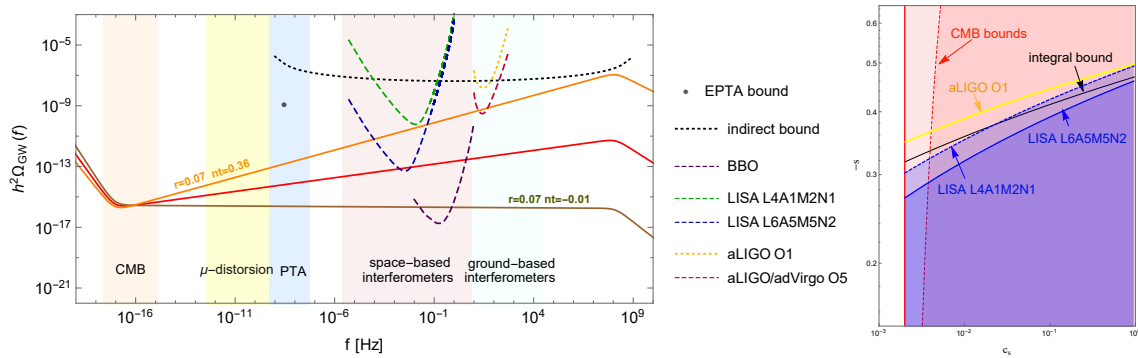

Figure 1. Left (taken from [1] *with kind permission of Società Italiana di Fisica* ©): current bounds and sensitivity curves of direct GW detection experiments. The three lines represent possible inflationary signals with $r = 0.07$ at $k = 0.05$Mpc^{-1} and different n_t values. Right (taken from [3]): constraints on the parameter-space $c_s - s$ of a specific inflationary model (see main text).

Such experiments are expected to provide new constraints on the GW parameters. In particular, LISA [4] should significantly improve current bounds obtained by limits on the integral amount of GW [5] and by aLIGO O1 [6] (see also [7]).

More precisely, the combination of current CMB measurements and the data from experiments at small scales will provide new constraints on the GW spectral index and then new significant hints in the direction of testing the inflationary consistency relation. Moreover, the new bounds on GW features provided by upcoming detectors at small scales could be translated into limits on the parameter-space of specific inflationary models (see [3], w.r.t. LISA). For example, if scalar *spectator* fields are present during inflation [3] (and refs. therein), they can give rise to a significant, classical GW production. The amplitude and the spectral index of such an extra contribution turns out to depend on the propagation speed of the scalar perturbation of the spectator field c_s, and to its variation with respect to time s, respectively. Expected limits on the parameter space $c_s - s$ are shown in fig.1.

In conclusion, experiments of GW detection represents a promising way of probing inflationary physics. In particular, experiments related to GW at small scales are expected to provide new information with respect to CMB experiments and to give new hints with respect to the test of the inflationary consistency relation.

Acknowledgments

References

[1] Guzzetti M C, Bartolo N, Liguori M and Matarrese S 2016 *Riv. Nuovo Cim.* **39** 399–495 (*Preprint* 1605.01615)
[2] Watanabe Y and Komatsu E 2006 *Phys. Rev.* **D73** 123515 (*Preprint* astro-ph/0604176)
[3] Bartolo N *et al.* 2016 *JCAP* **1612** 026 (*Preprint* 1610.06481)
[4] Seoane P A *et al.* (eLISA) 2013 (*Preprint* 1305.5720)
[5] Pagano L, Salvati L and Melchiorri A 2016 *Phys. Lett.* **B760** 823–825 (*Preprint* 1508.02393)
[6] Abbott B P *et al.* (Virgo, LIGO Scientific) 2016 *Phys. Rev. Lett.* **116** 131102 (*Preprint* 1602.03847)
[7] Abbott B P *et al.* (Virgo, LIGO Scientific) 2016 (*Preprint* 1612.02029)