COSMOS

Cosmic Orbital and Suborbital Microwave ObservationS

The Early Universe

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The Inflationary Paradigm

Inflation (i.e.a period of accelerated expansion in the early Universe driven by the potential energy of a suitable scalar field, dubbed the “inflaton”) is nowadays considered as the standard (only) paradigm to describe the Early Universe and solve some fundamental shortcomings of the hot Big Bang model (horizon, flatness, generation of perturbations).

Inflation provides the only self-consistent mechanism able to explain the generation of the primordial seeds that have subsequently given rise to CMB temperature anisotropies and polarization and (via gravitatonal instability) to all the cosmic structures we observe today.

Inflation is firmly rooted in modern theories of unification in particle physics, even though the nature of the inflation (the scalar field which drove the inflationary expansion) and the energy scale of inflation

SVT decomposition and the generation of primordial fluctuations

Cosmological perturbations can be divided into scalar, vector and tensor modes, according to their transformation rules w.r.t. to coordinate transformations of the background 3-space.

Scalar modes describe (in the simplest case) energy density perturbations, which lead to CMB anisotropies and seed cosmic structure formation.

Vector (vortical) modes are usually not generated and if present ijn the initial conditions tend to decay with time, owing to the Kelvin's circulation theorem. Second-order contributions (see Mollerach, Harari & Matarrese 2004; Fidler et al. 2014 too small to be detectable in CMB B-mode polarization).

Tensor modes represent gravitational waves. Their production via quantum oscillations of the vacuum state of the gravitational field is a genuine prediction of cosmic inflation.

The primordial stochastic background of gravitational waves and the tensor-to-scalar ratio

Tensor modes (GW) represent the smoking-gun proof of inflation. However, some models predict too small an amplitude of GW to allow (indirect) detectability via CMB B-mode polarization. In some of these cases, small-scale power can be large enough for these backgrounds to be directly detectable by e.g. LISA.

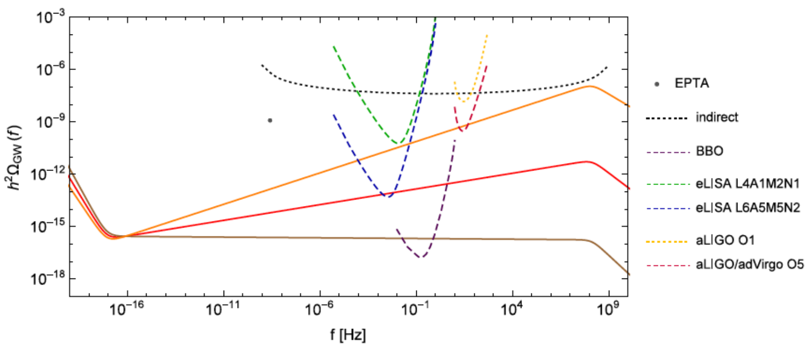
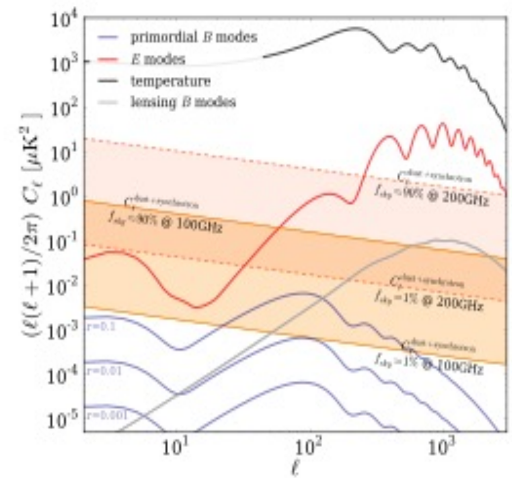


Figure 9: GW spectral energy-density for different values of n_T are shown with solid lines: $n_T = -r/8$ (brown), $n_T = 0.18$ (red) and $n_T = 0.36$ (orange). The r value is fixed at $r_{0.05} = 0.07$. It is assumed also $T_R = 10^{16}$ GeV. Short-dashed lines are current bounds related to: aLIGO data, O1:2015-16 observing run (yellow) [403], combined analysis of Planck data, BAO and BBN measurements which provides an integral bound $\Omega_{GW} < 3.8 \times 10^{-6}$ (black) [378]; see [276] for the manner of employing this limit. The gray dot corresponds to the bound provided by EPTA [398], which assumes $n_T = 0$; see [276] for comments about this choice. Long-dashed lines are expected power-law integrated sensitivity curves for the following experiments: BBO (violet) [193, 409], eLISA configuration L6A5M5N2 (blue) [410], eLISA configuration L4A1M2N1 (green) [410], aLIGO-adVirgo, O5:2020-22 observing run (magenta) [403]. Plotted upper bounds and expected sensitivity curves are obtained by the method provided by [409] (see also [2]), assuming a power-law signal. The mentioned eLISA configurations are described in [28].

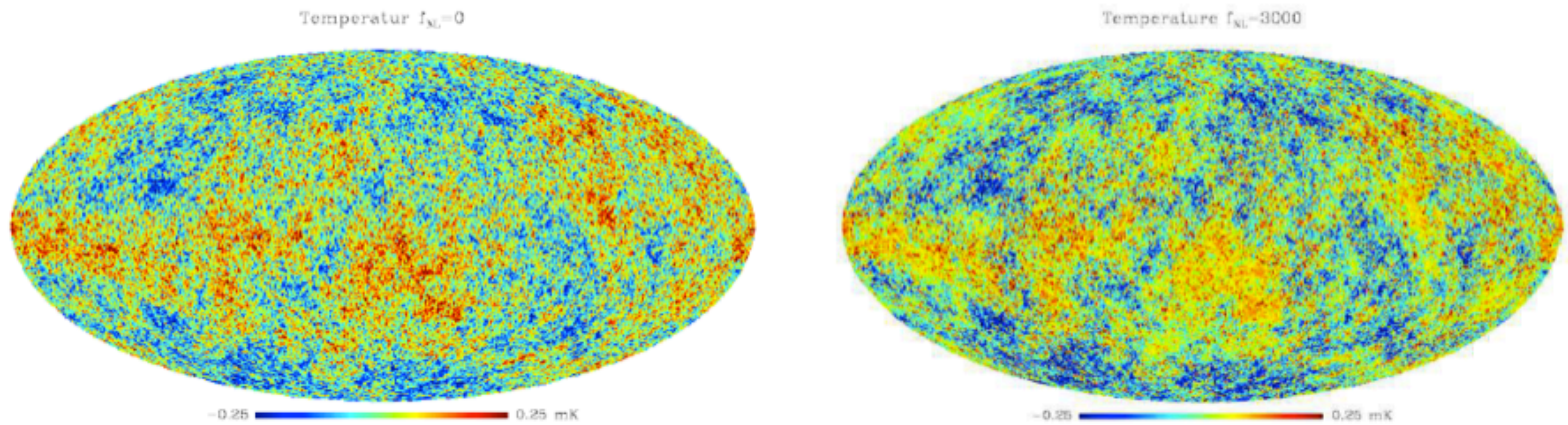


Comparison of diffuse astrophysical foregrounds amplitudes with cosmological signals, including the primordial and lensed B-modes. The sensitivity to the primordial signal is limited by the galactic emissions and the gravitational lensing (figure t taken from Errand et al. (2016)).

The primordial stochastic background of gravitational waves and the tensor-to-scalar ratio

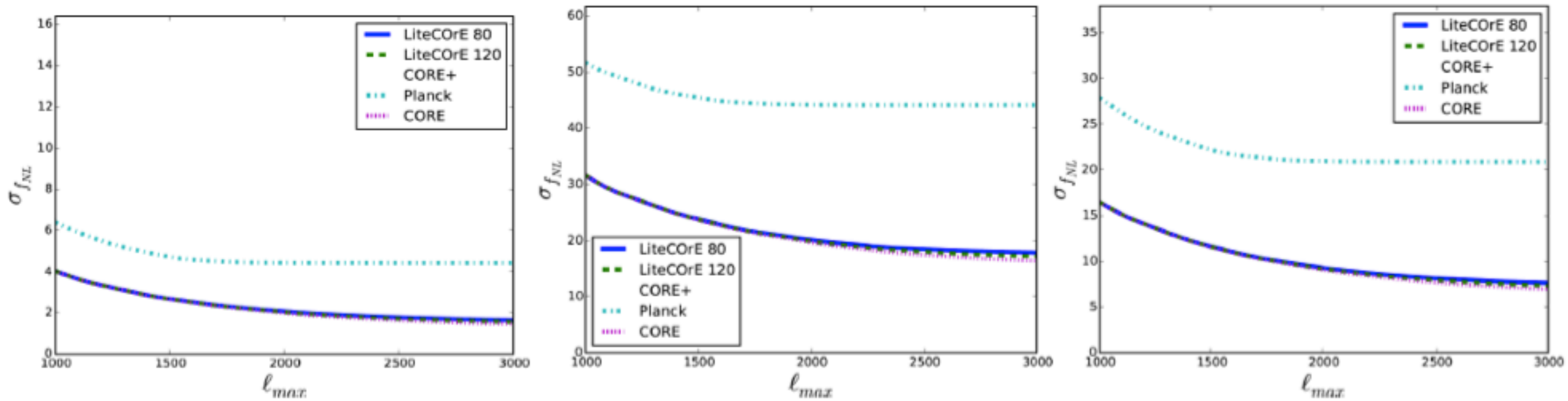
1. The search for PNG signatures in the tensor modes can be crucial in determining the *nature* of the gravitational-wave signal. Various inflation models for non-vanishing 3-point functions involving tensor-tensor-tensor or mixed correlators (such as TSS) carry signatures of new physics, e.g. parity breaking interactions in the gravity sector (Maldacena & Pimentel 2011; Shiraishi 2011). These primordial correlators determine bispectra involving T and B, such as, e.g., <BBB> or <BTT> etc.. With the improvement of B measurements such correlators can give better constraints on tensor PNG w.r.t to <TTT> correlators only (Meerburg et al. 2016).
2. There exists cosmological consistency relations that involve these higher-order correlators, that if observationally disproved would rule out *entire classes* of inflationary models (Bordin et al. 2016).

Primordial non-Gaussianity



Simulations of CMB temperature maps, including primordial NG conditions of the local type. Left panel, f_{NL}=0 (G map). Right panel, same seed, f_{NL}=3000. The very large value is chosen to make differences visible by eye. Current bound f_{NL}<10 (Planck 95% C.L.). Future goal, f_{NL}=1. From Liguori et al. (2007).

Primordial non-Gaussianity



Forecasts of expected f_{NL} error bars (68% C.L.) using different designs for future proposed CMB satellite missions, in comparison with Planck. From left to right: local, equilateral and orthogonal shape. From Finelli et al. (2016).

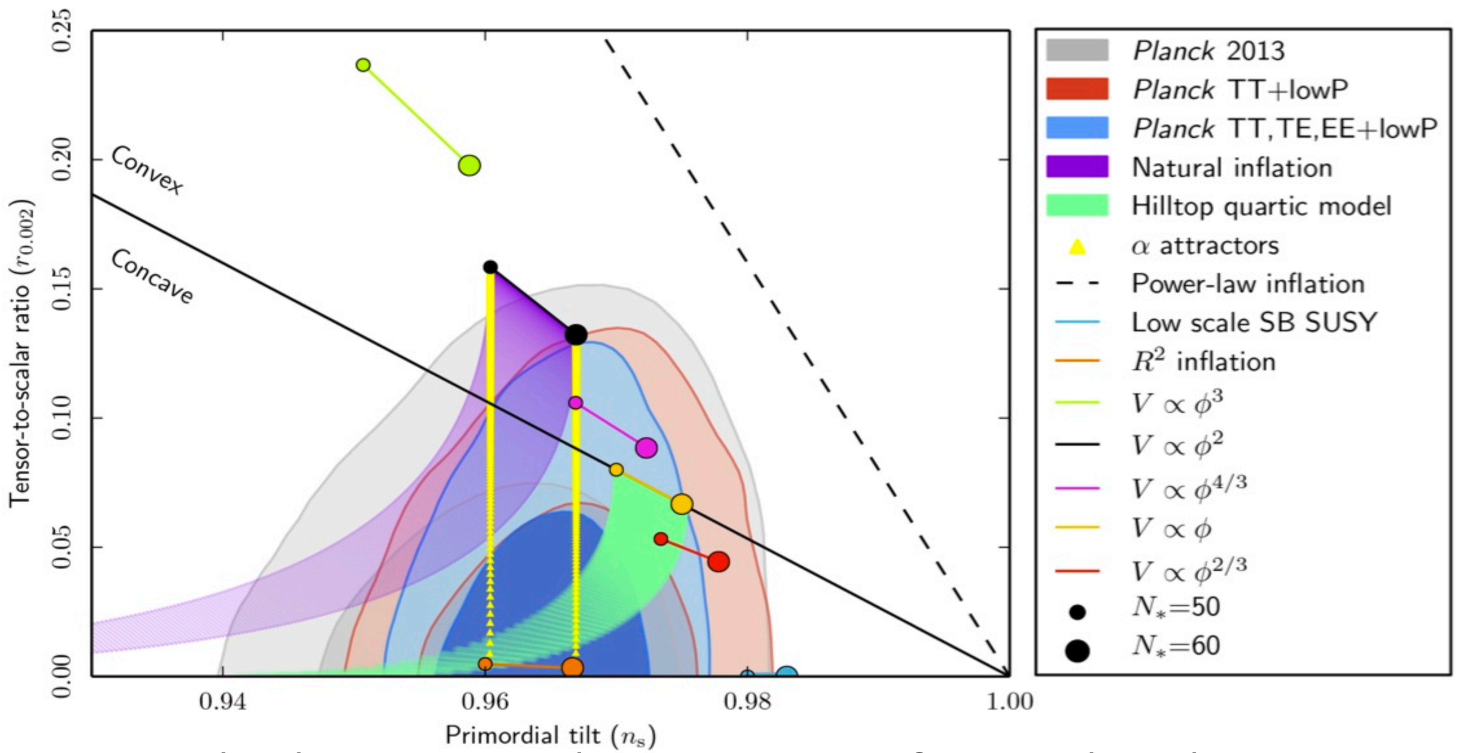
Primordial non-Gaussianity

The way to proceed for local NG requires looking at other observables. Fascinating prospects are provided by CMB spectral distortions (e.g. Pajer & Zaldarriaga 2012, Bartolo et al. 2016) and by full-sky CIB measurements (Tucci et al. 2016).

Spectral distortions promise, in principle, massive improvements in local f_{NL} sensitivity, ~2-3 orders of magnitudes, but such improvements are futuristic in that they require high signal-to-noise ratio measurements of distortion *anisotropies*. Nevertheless, interesting results are already achievable in the near future for NG models which predict deviations from an exact scale-invariant local shape, or enhancement of the signal in the squeezed limit.

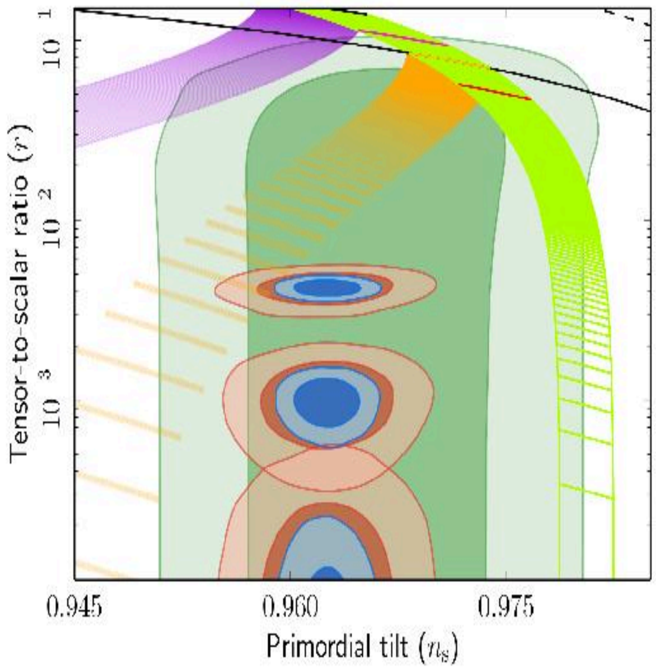
CIB based NG studies will require full-sky CMB space missions, with very large frequency coverage. This is the same requirement as for the study of polarization B-modes, which will be the main target of such a mission. The CIB is therefore a very promising observable to improve our understanding of primordial NG in the not so far future.

Constraints on the inflationary models



Marginalized joint 68% and 95% CL regions for n_S and r at k = 0.002 Mpc^{-1} from Planck, compared to the theoretical predictions of selected inflationary models. Note that the marginalized joint 68% and 95% CL regions have been obtained by assuming $dn_S/d \ln k = 0$.

Constraints on the inflationary models



Marginalized 68% and 95% CL 2D marginalized forecast regions for n_s, vs r for CORE-M5 (blue) and LiteBIRD (red). Three reference cosmologies are considered: a value for the tensor-to-scalar ratio consistent with the R^2 model ($r \approx 0.0042$), $r=10^{-3}$ and a third case in which the level of primordial gravitational waves is undetectably small (i.e., $r=0$). The green contours showing the 68% and 95% CL for Planck 2015 TT + low P data combined with the BKP joint cross-correlation are also displayed for comparison. We show the predictions for natural inflation (purple band), the hilltop quartic model (orange discrete band) and power law chaotic (light green discrete band) models, accounting for representative uncertainties in the post-inflationary era with $47 < N_* < 57$. These inflationary models consistent with the current data can be ruled out by CORE-M5. Note the logarithmic scale on the y-axis and that the pivot scale considered here is $k_* = 0.05\ \mathrm{Mpc}^{-1}$.