THE BISPECTRUM OF REDSHIFTED 21-CM FLUCTUATIONS FROM THE DARK AGES

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We present the three-point statistics of the 21 cm brightness-temperature fluctuations from the absorption regime, analytically computing and numerically evaluating the bispectrum down to a few arcsecond angular scales. Measuring the bispectrum of the 21 cm anisotropies allows in principle to quantify the degree of non-Gaussianity of the dark matter density field at very high redshift. We find that low-frequency radio experiments with arcmin angular resolution can easily detect non-Gaussianity produced by non-linear gravity with high signal-to-noise ratio. The bispectrum thus provides a unique test of the gravitational instability scenario for structure formation, and can be used to measure the cosmological parameters. According to our calculations, detecting the signature of primordial non-Gaussianity produced during or right after an inflationary period is more challenging but still possible.

1 Introduction

During the dark ages (the time between recombination and the formation of the first stars), the cosmic microwave background (CMB) is coupled to atoms of neutral hydrogen through spin-flip 21-cm transitions. Due to the resonant nature of the interaction, neutral hydrogen at redshift z imprints a signature at a wavelength of $21.12\,(1+z)$ cm in the CMB. The brightness temperature of the CMB at radio wavelengths thus probes the three-dimensional neutral hydrogen distribution at $30 < z < 100$. This accurately traces dark-matter inhomogeneities down to the Jeans length (~ 10 comoving pc corresponding to angular separations of $\sim 10^{-2}$ arcsec). On smaller scales, the finite pressure of the gas keeps the baryons uniformly distributed. Brightness-temperature fluctuations in the redshifted 21-cm background from the cosmic dark ages can thus be used to determine the statistical properties of density fluctuations in the early Universe.

In Pillepich et al. 2007 [1], we focused on the three-point statistics. We first derived the most general expansion of brightness-temperature fluctuations up to second order in terms of all the possible sources of spatial anisotropies. We then computed the angular bispectrum of brightness-temperature fluctuations generated prior to the epoch of hydrogen reionization.

2 Aims

Measuring the bispectrum of fluctuations in the 21-cm background will ultimately allow to quantify the degree of non-Gaussianity (NG) of the density field at high-redshift. Such a non-Gaussianity has two possible origins: non-linearity due to the usual Newtonian gravitational

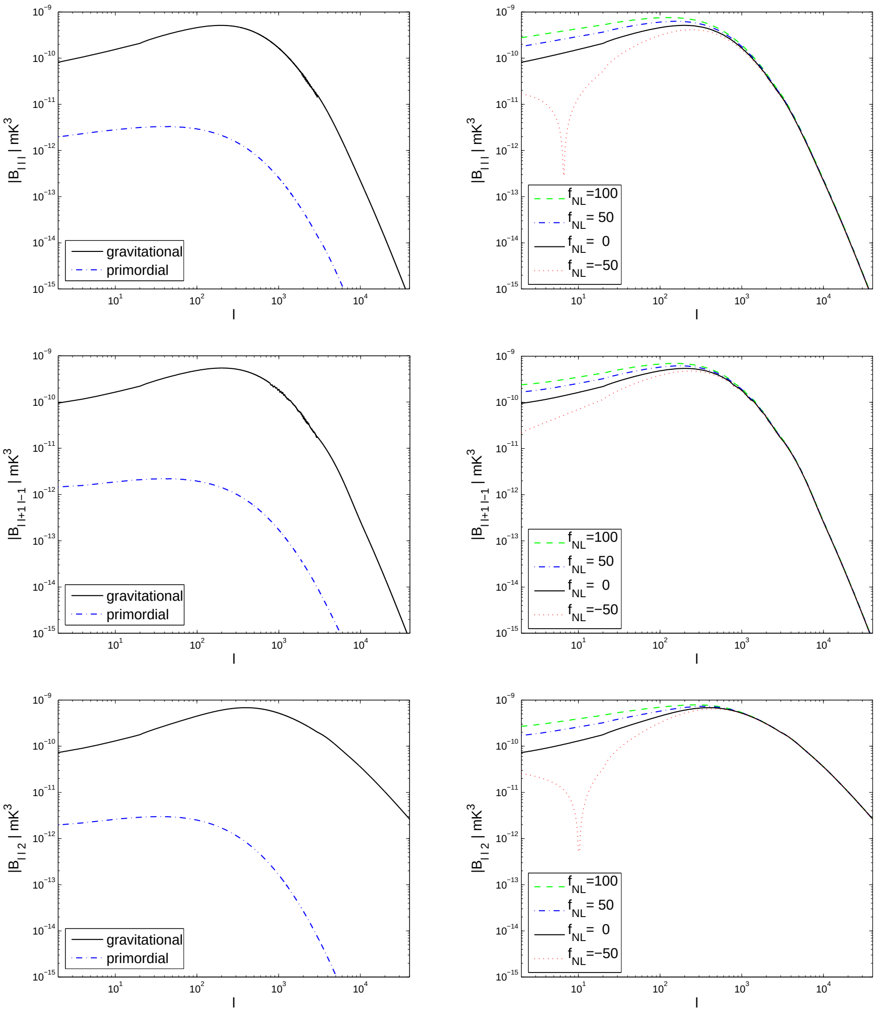

Figure 1: The bispectrum of 21-cm anisotropies B_{ℓ_1,ℓ_2,ℓ_3} measured by an ideal experiment with 0.1 MHz bandwidth centered around $z = 50$. We consider here, from top to bottom, equilateral ($\ell_1 = \ell_1 = \ell_3$), quasi-equilateral ($\ell_2 = \ell_1 + 1, \ell_2 = \ell_1 - 1$) and squeezed ($\ell_2 = \ell_1, \ell_3 = 2$) configurations. In the left panels, the contributions of non-linear gravity (solid) and of primordial non-Gaussianity (with $f_{\rm NL} = 1$; dashed) are compared. The right panels show the total bispectrum for different values of the non-linearity parameter.

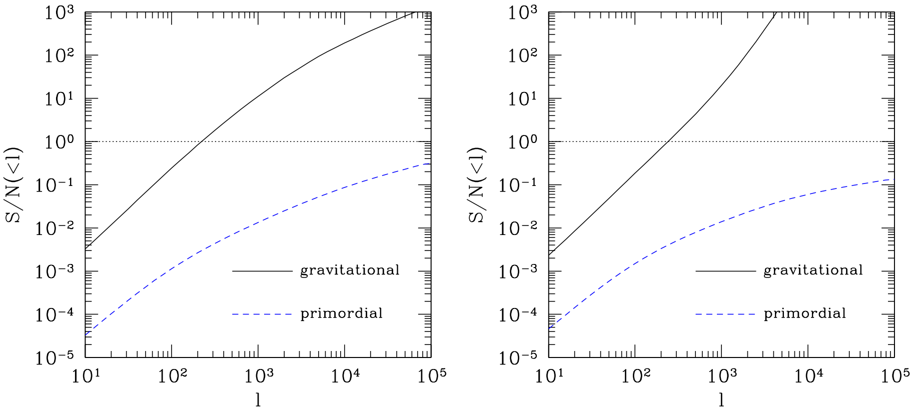

Figure 2: Cumulative signal-to-noise ratio for the measurement of the bispectrum of 21-cm anisotropies using modes up to a maximum value of ℓ. Solid lines refer to non-Gaussianity generated by gravity while dashed lines indicate the primordial signal with $f_{\rm NL} = 1$. These quantities have been computed using the signal-to-noise ratio per mode of the quasi-equilateral configuration (left).

instability and non-Gaussianity which is intrinsic in the mechanism generating the primordial seeds, i.e. arising during or immediately after inflation. The latter contributions to non-Gaussianity are usually expressed through a *non-linearity parameter* $f_{\rm NL}$ which measures the strength of quadratic terms in the *primordial* gravitational potential[3]. The most stringent limits on $f_{\rm NL}$ are based on the analysis of CMB anisotropies from five-year WMAP data (Komatsu et al. 2008 [2]) and give $-9 < f_{\rm NL} < 111$ (2σ confidence level). The high-resolution observations of CMB anisotropies by the *Planck* satellite should reduce the 2σ detection threshold to $|f_{\rm NL}| \sim 10$.

Searches for primordial NG based on the large-scale structure of the Universe where the relevant observables probe the density field (e.g. three-point statistics of the galaxy distribution) are plagued with two problems. First, the density field is related to the gravitational potential through the Poisson equation so that its Fourier modes weigh the non-gaussian contributions with extra k^{-2} terms and only the largest scales may keep memory of primordial NG. Moreover, the ratio of Newtonian non-linear terms to intrinsical non-gaussian terms roughly scales like $(1+z)^{-1}$, so that non-gaussian signatures in the local Universe are easily masked by the effects of gravitational instability. In this sense, the 21-cm background at large redhifts appears as an extremely promising dataset to search for primordial NG able to provide constraints on $f_{\rm NL}$ which can be complementary and possibly competitive with those based on CMB anisotropies.

3 Results

Using second order perturbation theory, we have computed analytically and evaluated numerically the angular bispectrum of 21-cm fluctuations redshifted from $z \sim 50$, down to a few arcsecond angular scales ($\ell \simeq 10^5$). Figure 1 shows that the angular bispectrum of brightness-temperature fluctuations is dominated by the contribution due to non-linear gravity (with the possible exception of the largest angular scales). The residual dependence on the amount of primordial NG is small but still measurable.

Our signal-to-noise analysis for an ideal experiment (full sky, limited only by cosmic variance, with perfect foreground subtraction) indicates that studies of the 21 cm bispectrum can provide a unique test of the gravitational instability scenario for structure formation, as low-frequency radio experiments with arcmin angular resolution can easily detect the NG produced by the evolution of non-linear gravity with signal-to-noise ratio of order 100 (see Figure 2).

On the other hand, detecting the signature of primordial NG is much more challenging but still possible. An ideal experiment limited only by cosmic variance and with an angular resolution of few arcsec has the potential to detect primordial NG with a non-linearity parameter $f_{\rm NL} \sim 1$. The combined use of tomographic techniques and optimal estimators can then be used to test the origin of the perturbations that seeded structure formation in the Universe.

References

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