The bispectrum of redshifted 21-cm fluctuations from the dark ages

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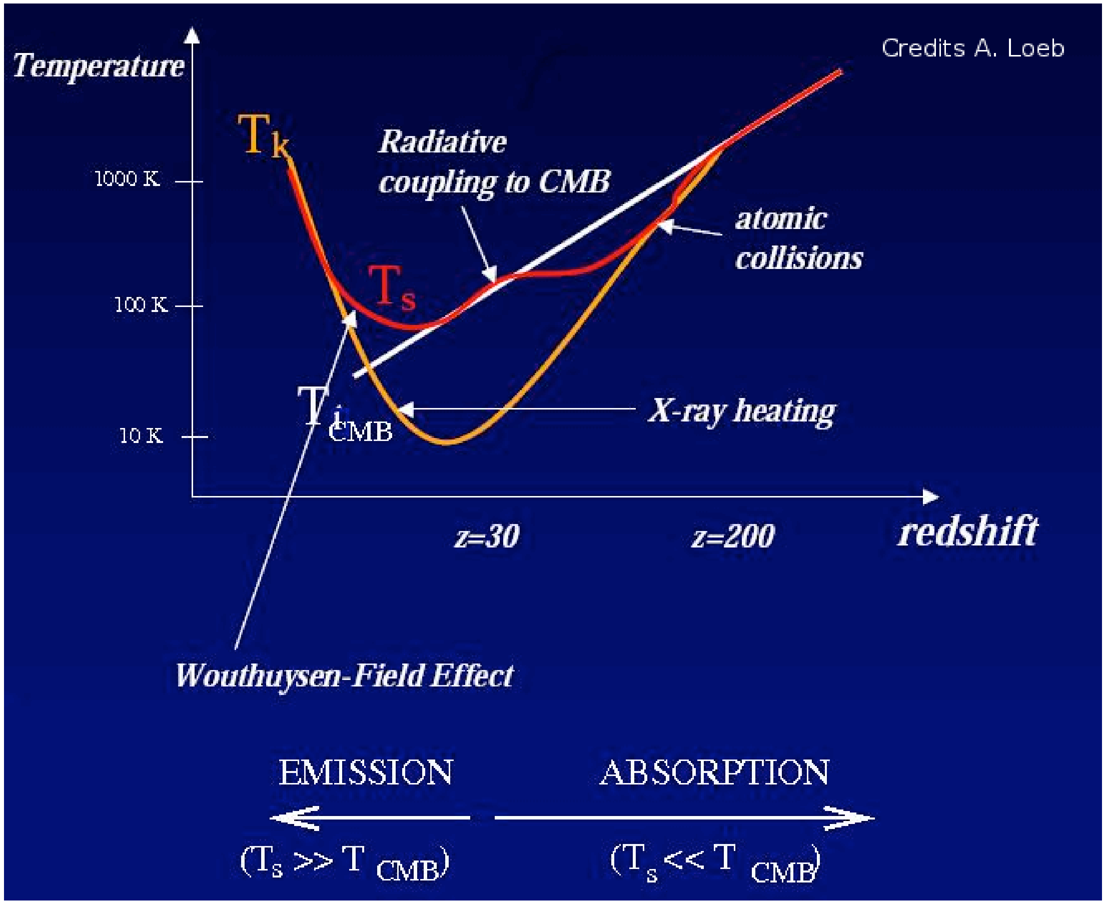
The 21 cm line in Cosmology

DETECTION OF THE REDSHIFTED 21cm LINE $\Longrightarrow$ PRESENCE OF NEUTRAL HYDROGEN AT HIGH REDSHIFTS (AFTER HYDROGEN RECOMBINATION)



$$T_{21}(\vec{r},\nu) \cong \frac{T_S - T_{CMB}}{(1+z)}\tau_{21} \qquad \tau_{21} = \frac{3c^3\hbar A_{10} n_{HI}}{16 k_B \nu_{21}^2 T_S \left(\frac{\partial v_r}{\partial r}\right)}$$

(Brightness temperature) (Optical depth)

The largest data set in the sky

$$\lambda_{OBS} = 21\mathrm{cm}(1+z) \Longleftrightarrow \text{distance}$$

$$\Downarrow$$

slices of the universe at different redshifts z

Other and related positive aspects:

- CMB: $2D$ picture of the universe at z_{LS};
  21 cm: ($2D \times z$-dimension) information;

- CMB: very small scales limited by *Silk Damping*
  21 cm: very small scales limited by the much smaller *Jeans Length*;

- for 21 cm IN ABSORPTION ($30 \lesssim z \lesssim 200$):
  21 cm signal simply shaped by gravity, adiabatic expansion and well-known atomic physics;

$\Rightarrow$ STUDYING THE PRIMORDIAL FIELD:

- CHARACTERIZATION OF THE STATISTICAL PROPERTIES
- PARAMETERIZATION OF NON-GAUSSIANITY

Non-Gaussianity

NON-GAUSSIANITY AS KEY OBSERVABLE TO DISCRIMINATE AMONG COMPETING SCENARIOS FOR THE GENERATION OF COSMOLOGICAL PERTURBATIONS

A stochastic field $f(\vec{x})$ is said to be Gaussian if the real part and the imaginary parts of its Fourier modes $\tilde{f}(\vec{k})$ are mutually independent and Gaussian distributed with variance given by the power spectrum $P(k)$.

GAUSSIAN FIELD:
2-point correlation function
NON-GAUSSIAN FIELD:
higher-order correlation functions.

$< f(\vec{x}_1) \cdot f(\vec{x}_2) > \overset{F}{\leftrightarrow}$ power spectrum
(variance)

$< f(\vec{x}_1) \cdot f(\vec{x}_2) \cdot f(\vec{x}_3) > \overset{F}{\leftrightarrow}$ Bispectrum
(skewness)

...

$\Downarrow$

STATISTICAL TOOLS OF SEARCHING FOR NON-GAUSSIANITY ARE THE 3 AND 4-POINT CORRELATION FUNCTIONS IN HARMONIC OR FOURIER SPACE.

Non-Gaussianity

Theoretical prediction from Inflationary models and incidental spurious sources

+

measurements

$\Downarrow$

constraints for weak non-Gaussianity in the data

Phenomenological parameterization of the level of non-Gaussianity:

$$\Phi = \Phi_L + f_{NL} \cdot (\Phi_L)^2$$

CURRENT LIMITS FROM THE CMB DATA:

Experiments	f_{NL} from bispectrum
COBE	$\mid f_{NL} \mid < 1500(68\%)$
MAXIMA	$\mid f_{NL} \mid < 950(68\%)$
WMAP (1^{st} year)	$-58 < f_{NL} < 134(95\%)$
WMAP (3^{rd} year)	$-54 < f_{NL} < 114(95\%)$

21cm anisotropies and non-Gaussianity

Fluctuations in the 21-cm brightness temperatures trace irregularities in the gas-density distribution:

$$\begin{aligned}
\Delta T_{21}(\mathbf{r}, z) &= T_{21}(\mathbf{r}, z) - T_{21}^{(0)}(z) = \\
&= f_1(z)\left(\delta^{(1)}(\mathbf{r}, z) + \frac{1}{2}\,\delta^{(2)}(\mathbf{r}, z)\right) + f_2(z)\;\delta^{(1)}(\mathbf{r}, z)^2 + \\
&+ f_3(z)\int d^3\mathbf{x_1}\int d^3\mathbf{x_2}\;\mathcal{G}_2(\mathbf{x_1}, \mathbf{x_2}, z)\,\delta^{(1)}(\mathbf{r}+\mathbf{x_1}, z)\,\delta^{(1)}(\mathbf{r}+\mathbf{x_2}, z)
\end{aligned}$$

$$\Downarrow$$

THE 21 CM BACKGROUND PROVIDES A POTENTIAL TEST-BED FOR PRIMORDIAL NON-GAUSSIANITY!

observed non-Gaussianity

=

primordial + by gravity + astrophysical + ...

At different redshifts, different ratios among the contributions:

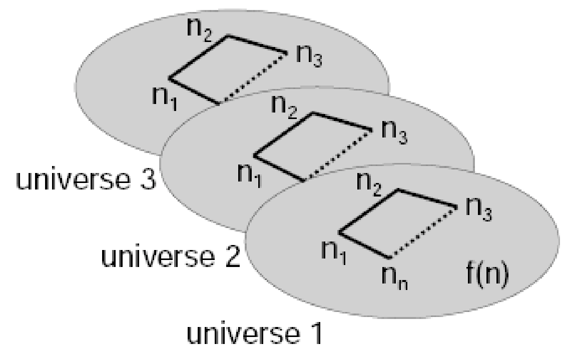
AT HIGH REDSHIFT ($30 \lesssim z \lesssim 200$), NO ASTROPHYSICAL CONTRIBUTIONS AND NON-GAUSSIANITY GENERATED BY GRAVITY STILL NEGLIGIBLE WITH RESPECT TO THE COSMOLOGICAL ONE.

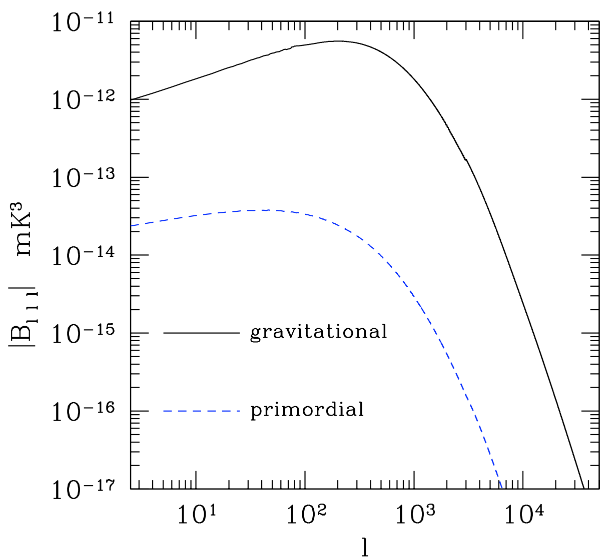
Angular Bispectra at z=50

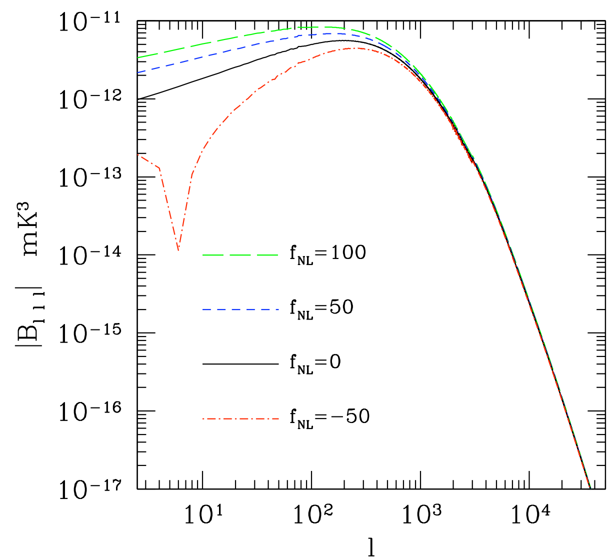
$$B^{21}_{\ell_1\ell_2\ell_3} = B^{\rm L}_{\ell_1\ell_2\ell_3} + f_{\rm NL}\; B^{\rm NL}_{\ell_1\ell_2\ell_3}$$

2D STATISTICS:

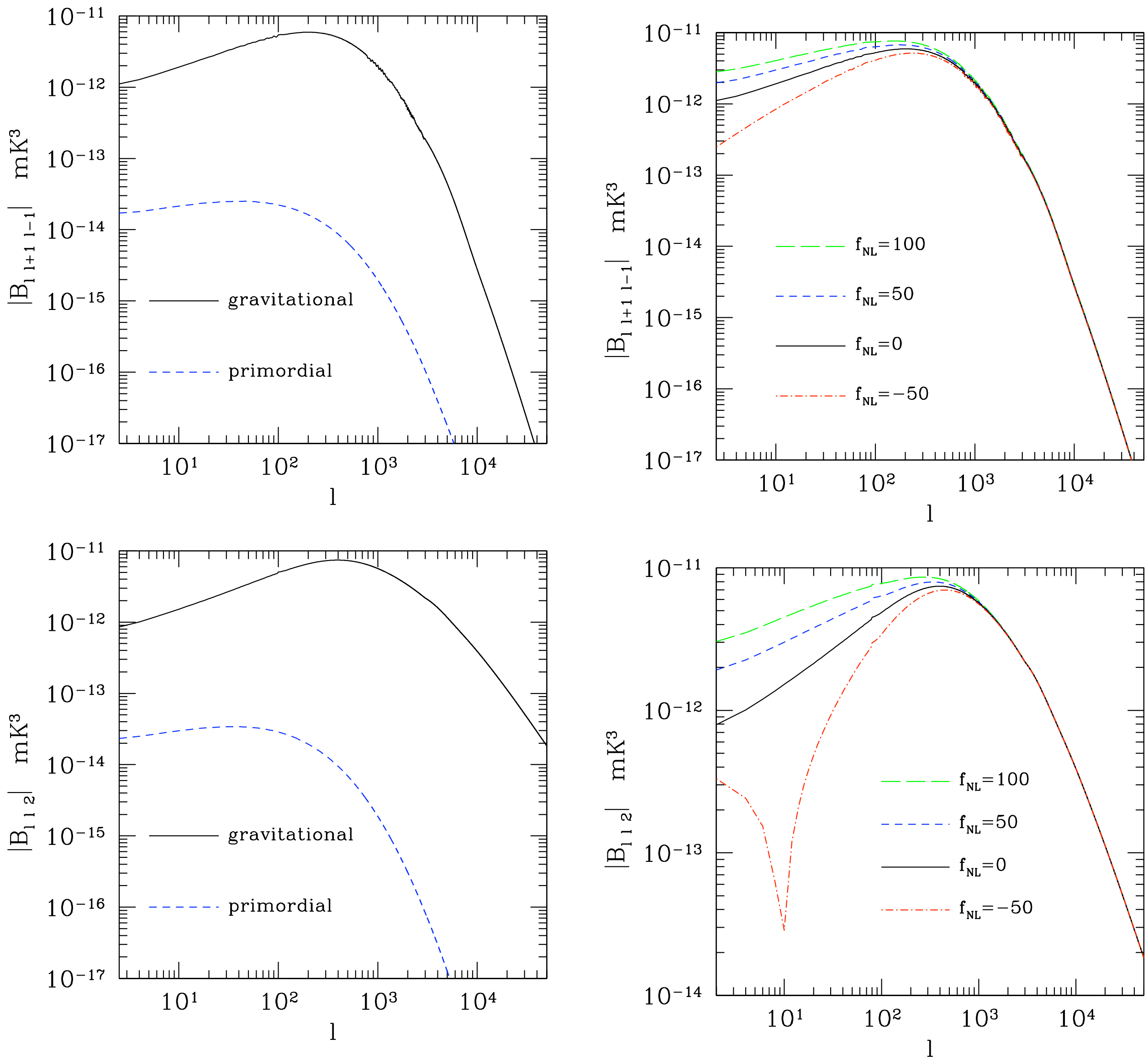
- angular power spectrum: $\langle a_{\ell m} a_{\ell m}\rangle = C_\ell$
- angular bispectrum: $\langle a_{\ell_1 m_1} a_{\ell_2 m_2} a_{\ell_3 m_3}\rangle = \begin{pmatrix} \ell_1 & \ell_2 & \ell_3 \\ m_1 & m_2 & m_3 \end{pmatrix} B_{\ell_1\ell_2\ell_3}$







Angular Bispectra at z=50

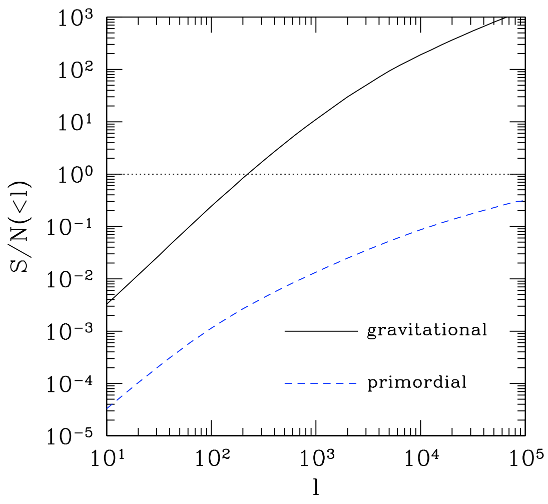


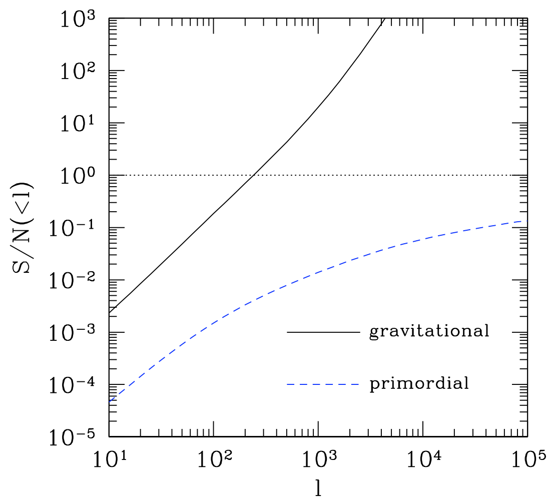
Signal to Noise

Is the expected signal detectable by future radio experiments?

Assumptions:

- ideal, full-sky experiment
- measurements just limited by cosmic variance
- perfect subtraction of foregrounds





- Experiment with arcmin-scale resolution $\Rightarrow$ gravitational non-gaussianity with $(S/N) \sim 100$
- Experiment with arcmin-scale resolution $\Rightarrow$ primordial non-gaussianity with $(S/N) \sim 0.1 f_{\rm NL}$

Conclusions

- Primordial non-Gaussianity imprints a strong signature in the bispectrum of the 21 cm background.
- For the simple parameterization of non-Gaussianity in terms of a constant $f_{\rm NL}$, this is particularly evident at low l.
- Future low-frequency experiments can easily test the gravitational instability scenario.
- Detecting the signature of primordial non-Gaussianity is more challenging: few arcsec resolution is needed for detecting non-Gaussianity with $f_{\rm NL} \sim 1$.
- We are currently evaluating the constraining power of a full three-dimensional analysis.