Weak Lensing of the Primary CMB Bispectrum

Devdeep Sarkar
Center for Cosmology, UC Irvine

in collaboration with:
Asantha Cooray and Paolo Serra

UC Irvine TASC 2008 Oct 24, 2008
\[ \Theta(\hat{n}) \equiv \frac{\Delta T(\hat{n})}{T} = \sum_{lm} \Theta_{lm} Y_{lm}^m(\hat{n}) \]
\[ \Theta(\hat{n}) \equiv \frac{\Delta T(\hat{n})}{T} = \sum_{lm} \Theta_{lm} Y_l^m(\hat{n}) \]

\[ \langle \Theta_{lm} \Theta_{l'm'} \rangle = \delta_{l,l'} \delta_{m,m'} C_l^{\Theta \Theta} \]
\[ \Theta(\hat{n}) \equiv \frac{\Delta T(\hat{n})}{T} = \sum_{lm} \Theta_{lm} Y_l^m(\hat{n}) \]

\[ \langle \Theta_{l_1 m_1} \Theta_{l_2 m_2} \Theta_{l_3 m_3} \rangle = \left( \begin{array}{ccc} l_1 & l_2 & l_3 \\ m_1 & m_2 & m_3 \end{array} \right) B_{l_1 l_2 l_3}^{\Theta \Theta} \]

\[ \langle \Theta_{lm} \Theta_{l'm'} \rangle = \delta_{l,l'} \delta_{m,m'} C_l^{\Theta \Theta} \]
Primordial non-Gaussianity

Primary CMB Bispectrum
Primordial non-Gaussianity

Primary CMB Bispectrum

Gaussian Quantum Fluctuation

Non-Gaussian Inflation Fluctuation

Non-Gaussian Curvature Perturbation

Non-Gaussian CMB Anisotropy
Primordial non-Gaussianity

Primary CMB Bispectrum

\[
\frac{\Delta T(x)}{T} \sim \Phi(x)
\]

\[
\Phi(x) = \Phi_L(x) + f_{NL} \left[ \Phi_L^2(x) - \langle \Phi_L^2(x) \rangle \right]
\]

Non-Linear Coupling Parameter

Measurement of non-Gaussian CMB anisotropies can potentially constrain non-linearity, “slow-rollness”, and “adiabaticity” in inflation.
Primordial non-Gaussianity

Non-Gaussianity from the simplest inflation model is very small:

\[ f_{NL} \sim 0.01 - 1 \]

Much higher level of primordial non-Gaussianity is predicted by:

- Models with Multiple Scalar Fields
- Non-Adiabatic Fluctuations
- Features in the Inflation Potential
- Non-Canonical Kinetic Terms
- ...

Review: N. Bartolo, E. Komatsu, S. Matarrese, and A. Riotto, Phys. Rep. 402, 103 (2004)
Evidence of Primordial Non-Gaussianity ($f_{NL}$) in the Wilkinson Microwave Anisotropy Probe 3-Year Data at $2.8\sigma$

Amit P. S. Yadav$^1$ and Benjamin D. Wandelt$^{1,2}$

$^1$Department of Astronomy, University of Illinois at Urbana-Champaign, 1002 W. Green Street, Urbana, Illinois 61801, USA
$^2$Department of Physics, University of Illinois at Urbana-Champaign, 1110 W. Green Street, Urbana, Illinois 61801, USA

We present evidence for primordial non-Gaussianity of the local type ($f_{NL}$) in the temperature anisotropy of the cosmic microwave background. Analyzing the bispectrum of the Wilkinson Microwave Anisotropy Probe 3-year data up to $\ell_{\text{max}} = 750$ we find $27 < f_{NL} < 147$ (95% C.L.). This amounts to a rejection of $f_{NL} = 0$ at $2.8\sigma$, disfavoring canonical single-field slow-roll inflation. The signal is robust to variations in $\ell_{\text{max}}$, frequency and masks. No known foreground, instrument systematic, or secondary anisotropy explains it. We explore the impact of several analysis choices on the quoted significance and find $2.5\sigma$ to be conservative.

FIVE-YEAR WILKINSON MICROWAVE ANISOTROPY PROBE (WMAP$^1$) OBSERVATIONS: COSMOLOGICAL INTERPRETATION

E. Komatsu$^1$, J. Dunkley$^{2,3,4}$, M. R. Nolta$^5$, C. L. Bennett$^6$, B. Gold$^6$, G. Hinshaw$^7$, N. Jarosik$^2$, D. Larson$^6$, M. Limon$^8$, L. Page$^2$, D. N. Spergel$^{3,9}$, M. Halpern$^{10}$, R. S. Hill$^{11}$, A. Kogut$^7$, S. S. Meyer$^{12}$, G. S. Tucker$^{13}$, J. L. Weiland$^{10}$, E. Wollack$^7$, and E. L. Wright$^{14}$

Submitted to the Astrophysical Journal Supplement Series

ABSTRACT

$-9 < f_{NL}^{\text{local}} < 111$ and $-151 < f_{NL}^{\text{equil}} < 253$ (95% CL)
Journey Through the “Clumpy” Universe

Weak Gravitational Lensing: Bending of light

Credit: S. Colombi (IAP), CFHT Team
Weak Lensing of the Primary Bispectrum

Credit: Vale, Amblard, White (2004)

NASA, ESA, and R. Massey (CalTech)

Credit: Vale, Amblard, White (2004)
\[ \tilde{\Theta}(\hat{n}) = \Theta[\hat{n} + \hat{\alpha}] \]
\[ = \Theta[\hat{n} + \nabla \phi(\hat{n})] \]
\[ \approx \Theta(\hat{n}) + \nabla_i \phi(\hat{n}) \nabla^i \Theta(\hat{n}) \]
\[ + \frac{1}{2} \nabla_i \phi(\hat{n}) \nabla_j \phi(\hat{n}) \nabla^i \nabla^j \Theta(\hat{n}) \]
\[ \tilde{\Theta}(\hat{n}) = \Theta[\hat{n} + \hat{\alpha}] \\
= \Theta[\hat{n} + \nabla \phi(\hat{n})] \\
\approx \Theta(\hat{n}) + \nabla_i \phi(\hat{n}) \nabla^i \Theta(\hat{n}) \\
+ \frac{1}{2} \nabla_i \phi(\hat{n}) \nabla_j \phi(\hat{n}) \nabla^i \nabla^j \Theta(\hat{n}) \]

\[ \tilde{B}_{l_1 l_2 l_3}^\Theta = \sum_{m_1 m_2 m_3} \left( \begin{array}{ccc}
l_1 & l_2 & l_3 \\
m_1 & m_2 & m_3 \end{array} \right) \langle \tilde{\Theta}_{l_1 m_1} \tilde{\Theta}_{l_2 m_2} \tilde{\Theta}_{l_3 m_3} \rangle \]
The Effect of Lensing on the Bispectrum

A. Cooray, D. Sarkar, and P. Serra; Phys. Rev. D, 77, 123006 (2008)

Decrease in the Amplitude
Reduction in the S/N due to Lensing

\[ \left( \frac{S}{N} \right)^2 = \sum_{l_1 l_2 l_3} \frac{(B_{l_1 l_2 l_3}^{\theta})^2}{6 C_{l_1}^{tot} C_{l_2}^{tot} C_{l_3}^{tot}} \]
Reduction in the S/N due to Lensing

\[
\left( \frac{S}{N} \right)^2 = \sum_{l_1 l_2 l_3} \frac{(B_{l_1 l_2 l_3}^{\Theta})^2}{6 C_{l_1}^{tot} C_{l_2}^{tot} C_{l_3}^{tot}}
\]

- Primary \((f_{NL}=1)\)
- Lensing

\[
[\frac{d(S/N)^2}{dl_3}]^2
\]

\(l_3\)
Bias in the non-Gaussian Parameter

\[ \frac{\Delta f}{\hat{f}_{NL}} \equiv \frac{f_{true}}{\hat{f}_{NL}} - \hat{f}_{NL} \]

\[ |\Delta f_{NL}| \]

\[ l \]

A. Cooray, D. Sarkar, and P. Serra; Phys. Rev. D, 77, 123006 (2008)
Bias in the non-Gaussian Parameter

\[
\frac{\Delta f}{\hat{f}_{NL}} \equiv \frac{f_{true}^{NL} - \hat{f}_{NL}}{\hat{f}_{NL}} 
\]

WMAP

6%
Bias in the non-Gaussian Parameter

\[ \frac{\Delta f}{\hat{f}_{NL}} \equiv \frac{f_{true}^{NL} - \hat{f}_{NL}}{\hat{f}_{NL}} \]

Will you please explain the significance of the PLANCK and WMAP regions labeled in the diagram? Why are they marked with specific percentages (+) and (-)?
Bias in the non-Gaussian Parameter

\[ \frac{\Delta f}{\hat{f}_{NL}} = \frac{f_{true}^{NL} - \hat{f}_{NL}}{\hat{f}_{NL}} \]

Minimum detectable value of \( f_{NL} \) is 7 (instead of 5) for Planck

A. Cooray, D. Sarkar, and P. Serra; Phys. Rev. D, 77, 123006 (2008)
Bias in the non-Gaussian Parameter

\[
\frac{\Delta f}{\hat{f}_{NL}} = \frac{f_{true}^{NL} - \hat{f}_{NL}}{\hat{f}_{NL}}
\]

Minimum detectable value of \(f_{NL}\) is 7 (instead of 5) for Planck

\[\Delta f_{NL}\]

WMAP

PLANCK

6%

(+)

30%

(−)

dsarkar.org