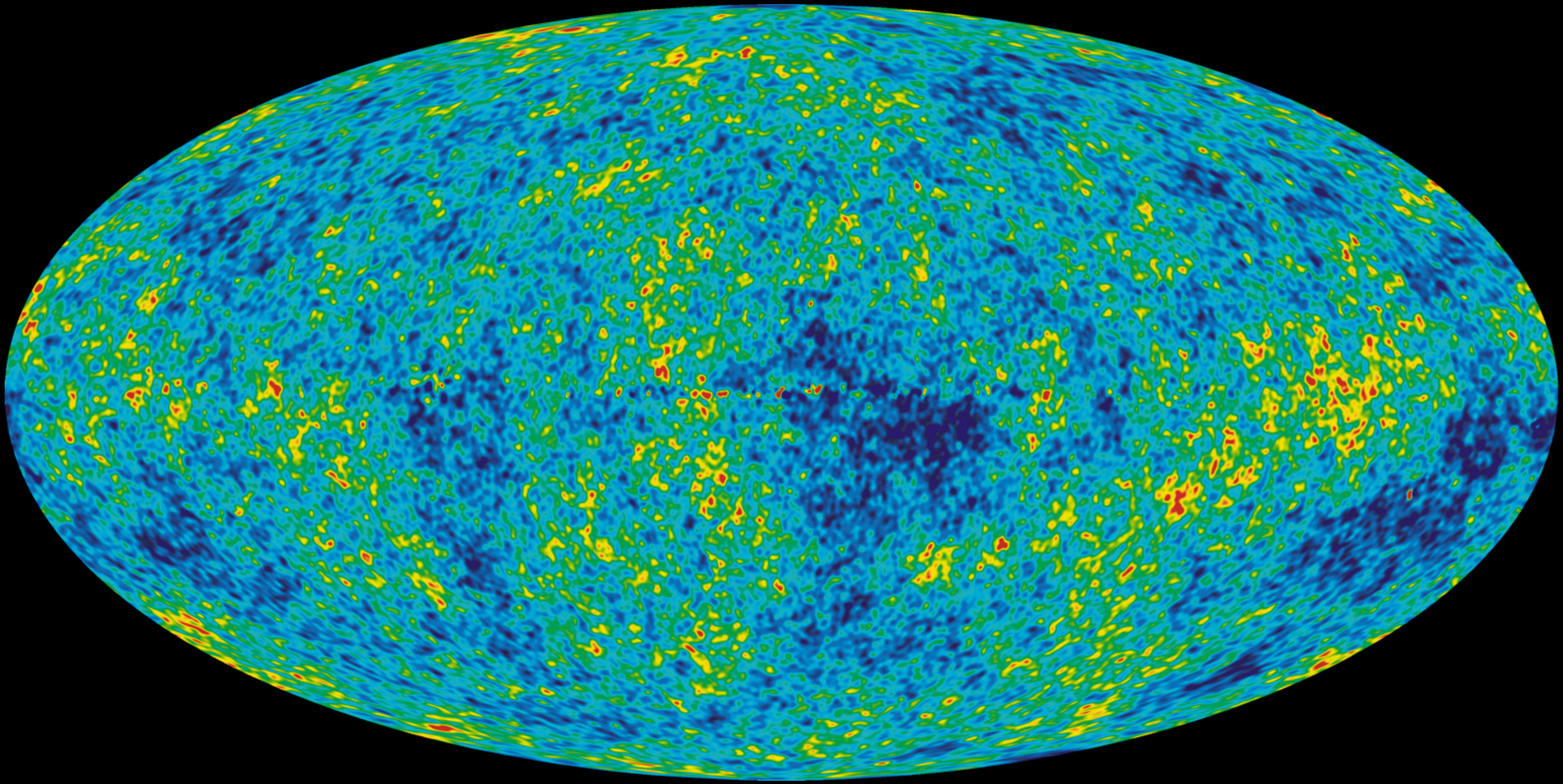
Measuring Primary CMB Bispectrum: The Role of the Clumpy Universe

Devdeep Sarkar
Center for Cosmology, UC Irvine

In collaboration with:
Paolo Serra (UCI), and Asantha Cooray (UCI).

Credit: NASA/WMAP Science Team



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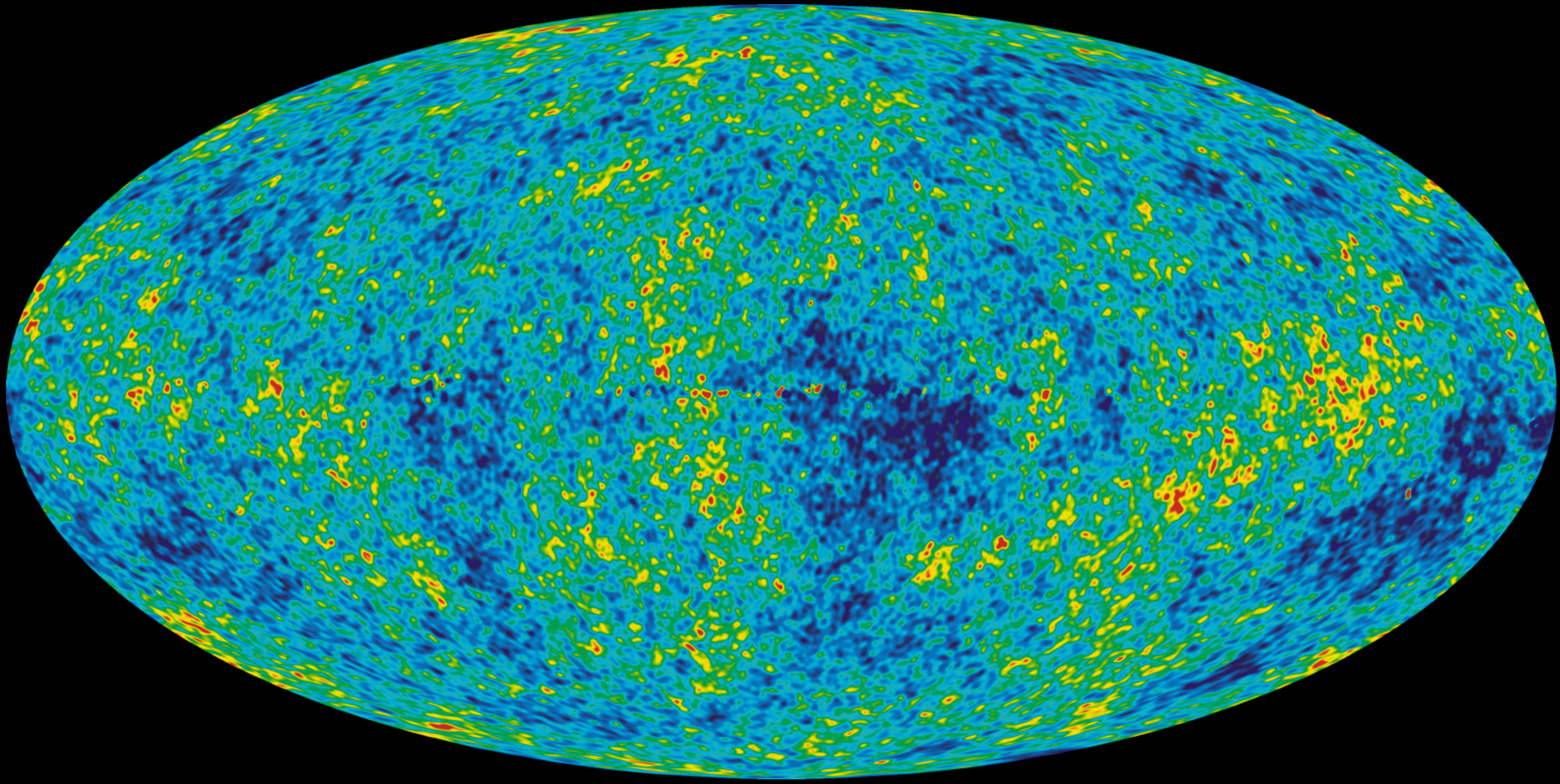
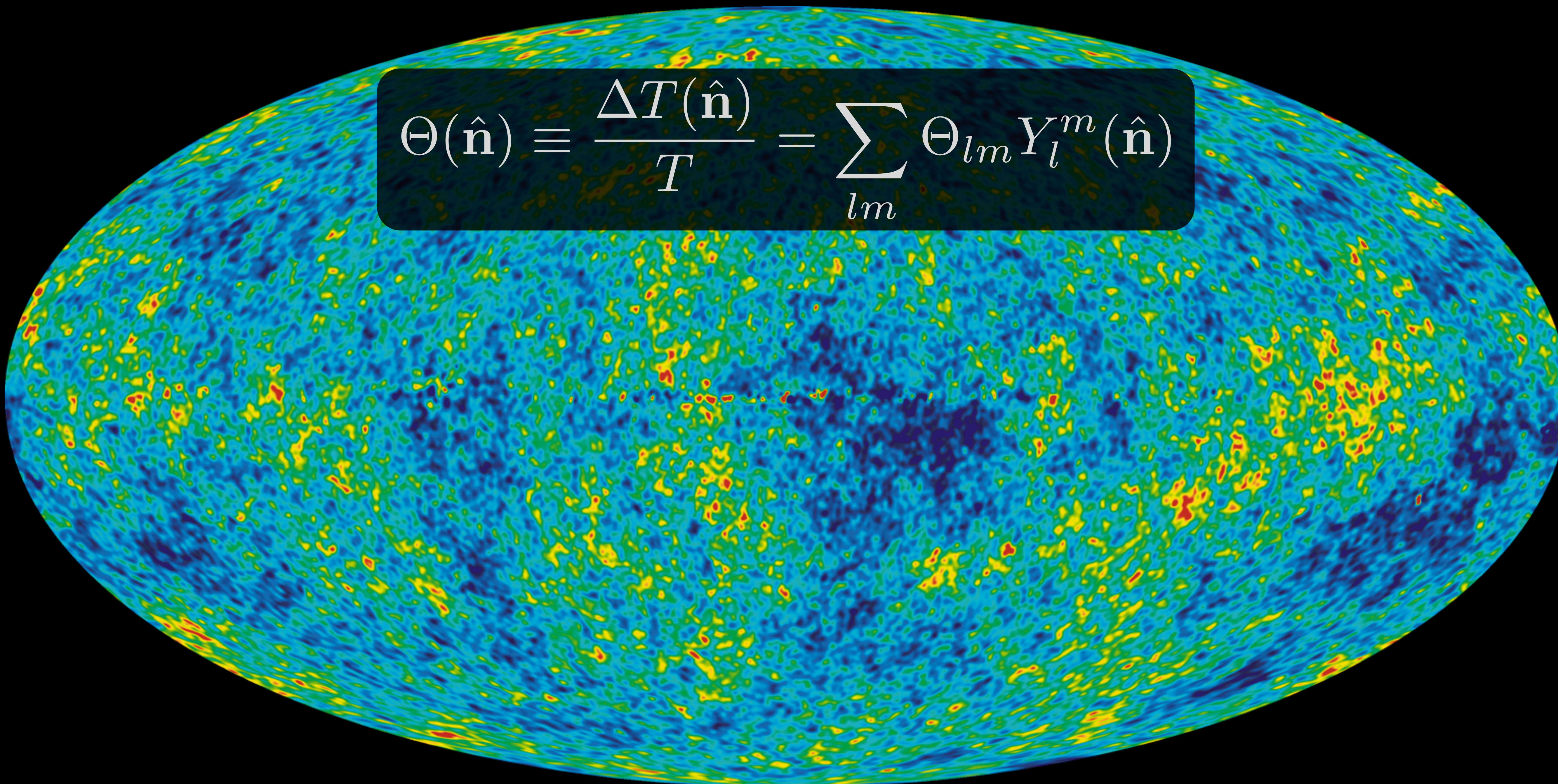


For a review on Inflation and CMB: D. Baumann and H. V. Peiris, arXiv:0810.3022

Credit: NASA/WMAP Science Team



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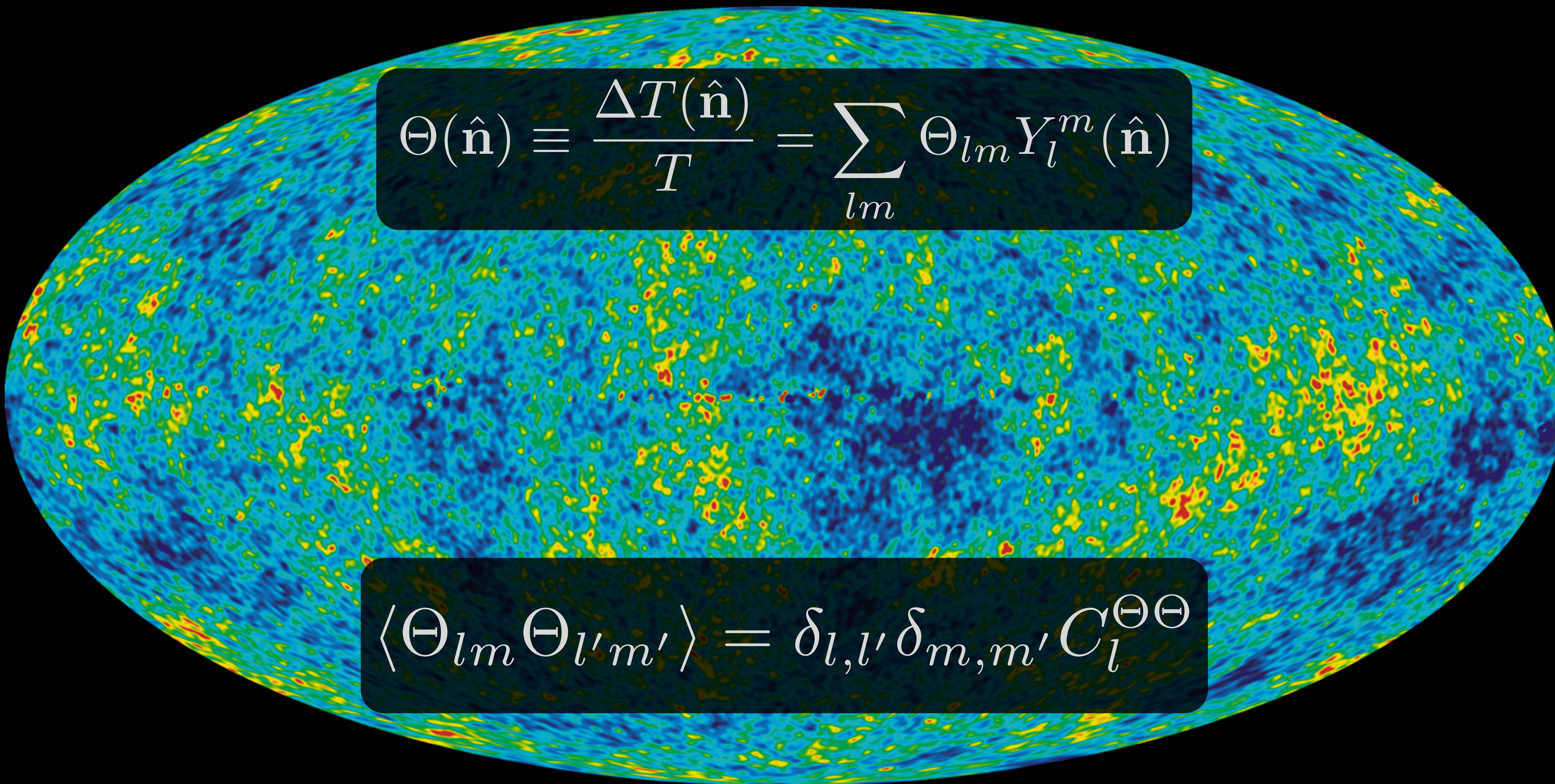

$$\Theta(\hat{\mathbf{n}}) \equiv \frac{\Delta T(\hat{\mathbf{n}})}{T} = \sum_{lm} \Theta_{lm} Y_l^m(\hat{\mathbf{n}})$$

$$\langle \Theta_{lm} \Theta_{l'm'} \rangle = \delta_{l,l'} \delta_{m,m'} C_l^{\Theta\Theta}$$

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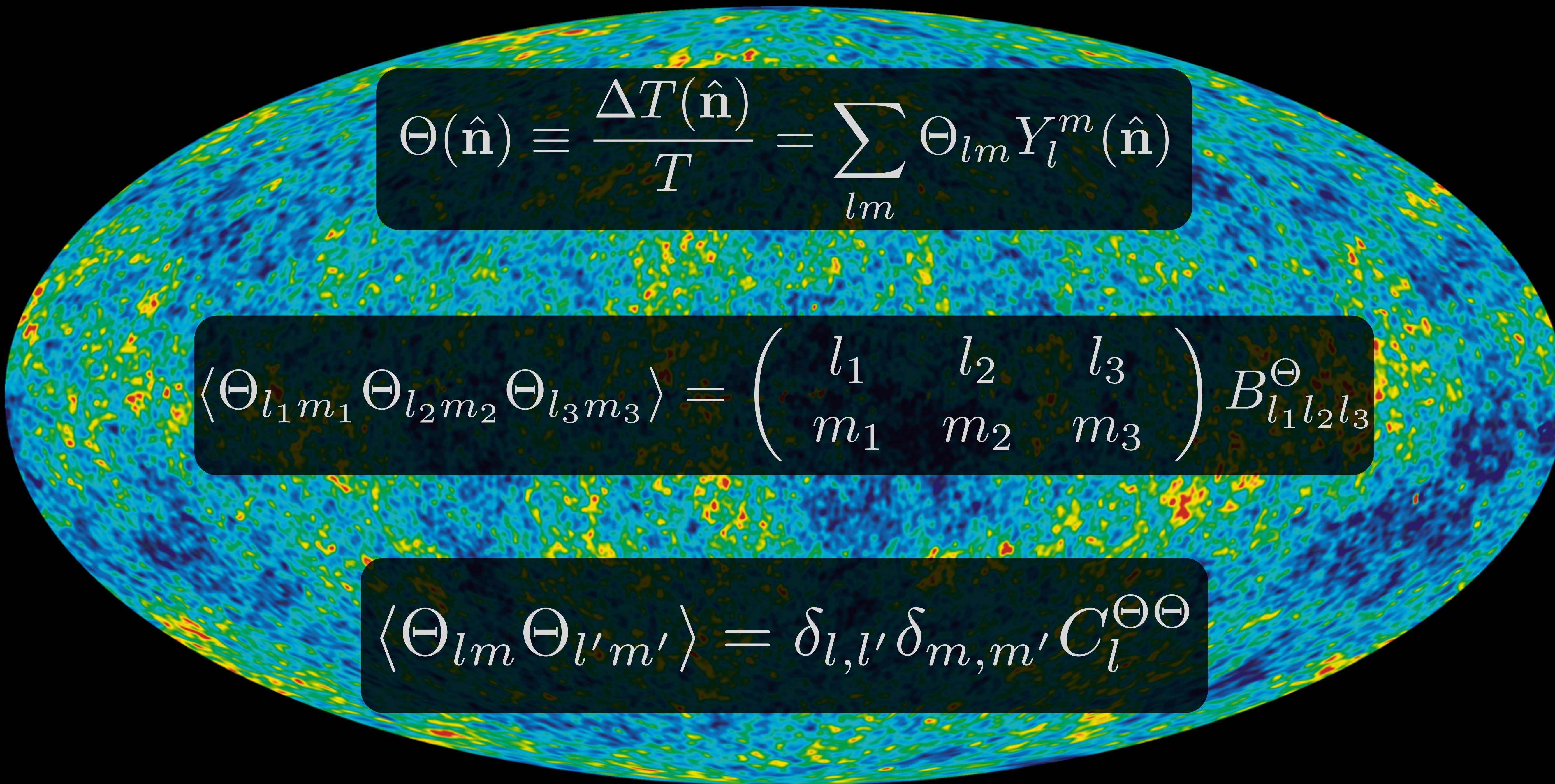

$$\Theta(\hat{\mathbf{n}}) \equiv \frac{\Delta T(\hat{\mathbf{n}})}{T} = \sum_{lm} \Theta_{lm} Y_l^m(\hat{\mathbf{n}})$$

$$\langle \Theta_{l_1 m_1} \Theta_{l_2 m_2} \Theta_{l_3 m_3} \rangle = \begin{pmatrix} l_1 & l_2 & l_3 \\ m_1 & m_2 & m_3 \end{pmatrix} B^{\Theta}_{l_1 l_2 l_3}$$

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For a review on Inflation and CMB: D. Baumann and H. V. Peiris, arXiv:0810.3022

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

$$\frac{\Delta T(\mathbf{x})}{T} \sim \Phi(\mathbf{x})$$

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

Non-Linear Coupling Parameter

Measurement of non-Gaussian CMB anisotropies can potentially constrain non-linearity, "slow-rollness", and "adiabaticity" in inflation.

Primordial non-Gaussianity

→ Primary CMB Bispectrum

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)

PRL **100,** 181301 (2008) PHYSICAL REVIEW LETTERS week ending 9 MAY 2008

Evidence of Primordial Non-Gaussianity (f_{NL}) in the Wilkinson Microwave Anisotropy Probe 3-Year Data at 2.8σ

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*

(Received 7 December 2007; revised manuscript received 6 March 2008; published 7 May 2008)

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 $\ell_{\max} = 750$ we find $27 < f_{\mathrm{NL}} < 147$ (95% C.L.). This amounts to a rejection of $f_{\mathrm{NL}} = 0$ at 2.8σ, disfavoring canonical single-field slow-roll inflation. The signal is robust to variations in $l_{\max}$, 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 2.5σ to be conservative.

FIVE-YEAR WILKINSON MICROWAVE ANISOTROPY PROBE (WMAP[1]) OBSERVATIONS: COSMOLOGICAL INTERPRETATION

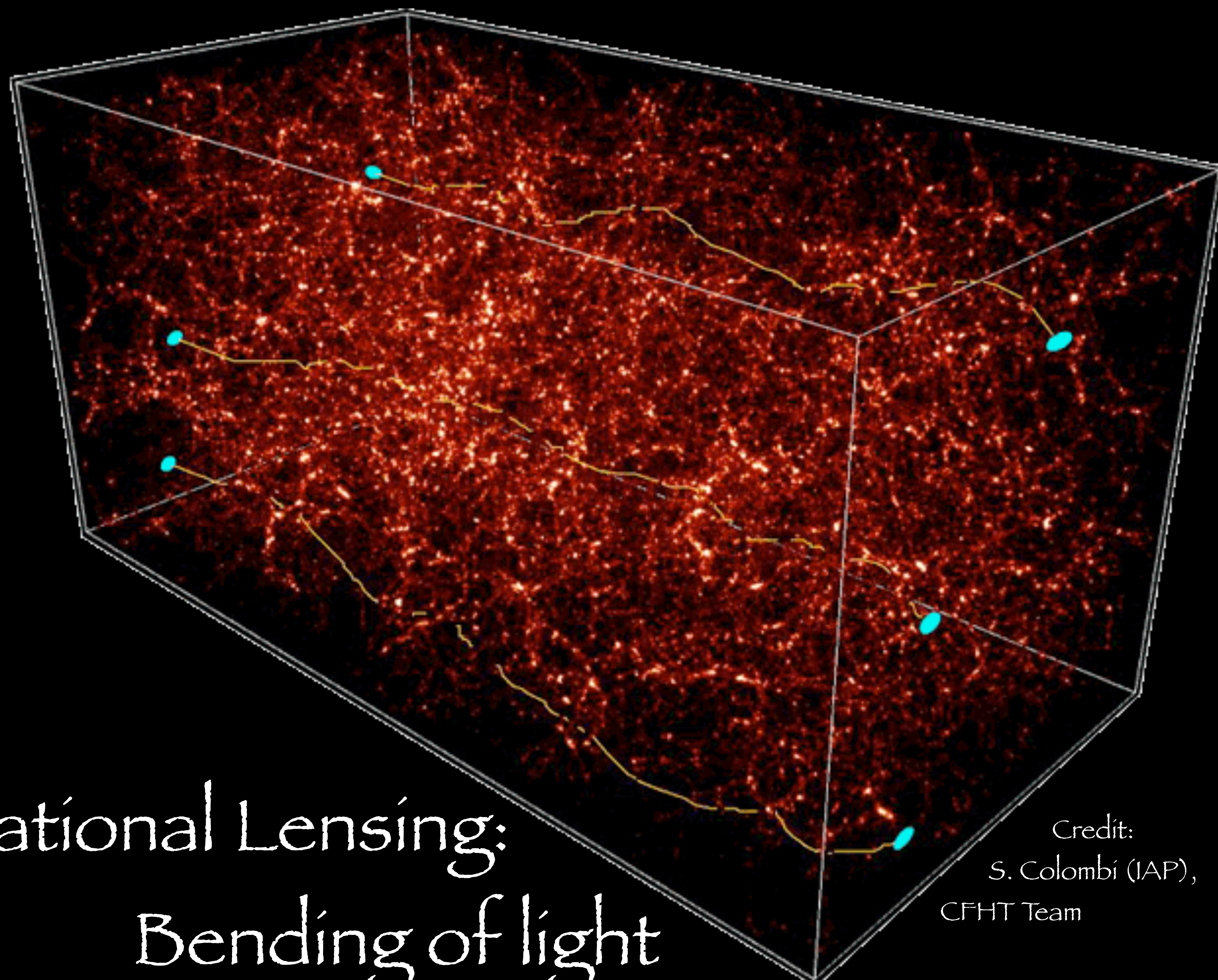
E. Komatsu [1], J. Dunkley [2,3,4], M. R. Nolta [5], C. L. Bennett [6], B. Gold [6], G. Hinshaw [7], N. Jarosik [2], D. Larson [6], M. Limon [8] L. Page [2], D. N. Spergel [3,9], M. Halpern [10], R. S. Hill [11], A. Kogut [7], S. S. Meyer [12], G. S. Tucker [13], J. L. Weiland [10], E. Wollack [7], and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

Submitted to the Astrophysical Journal Supplement Series

ABSTRACT

$$-9 < f_{NL}^{local} < 111 \text{ and } -151 < f_{NL}^{equil} < 253 (95\% \, CL)$$

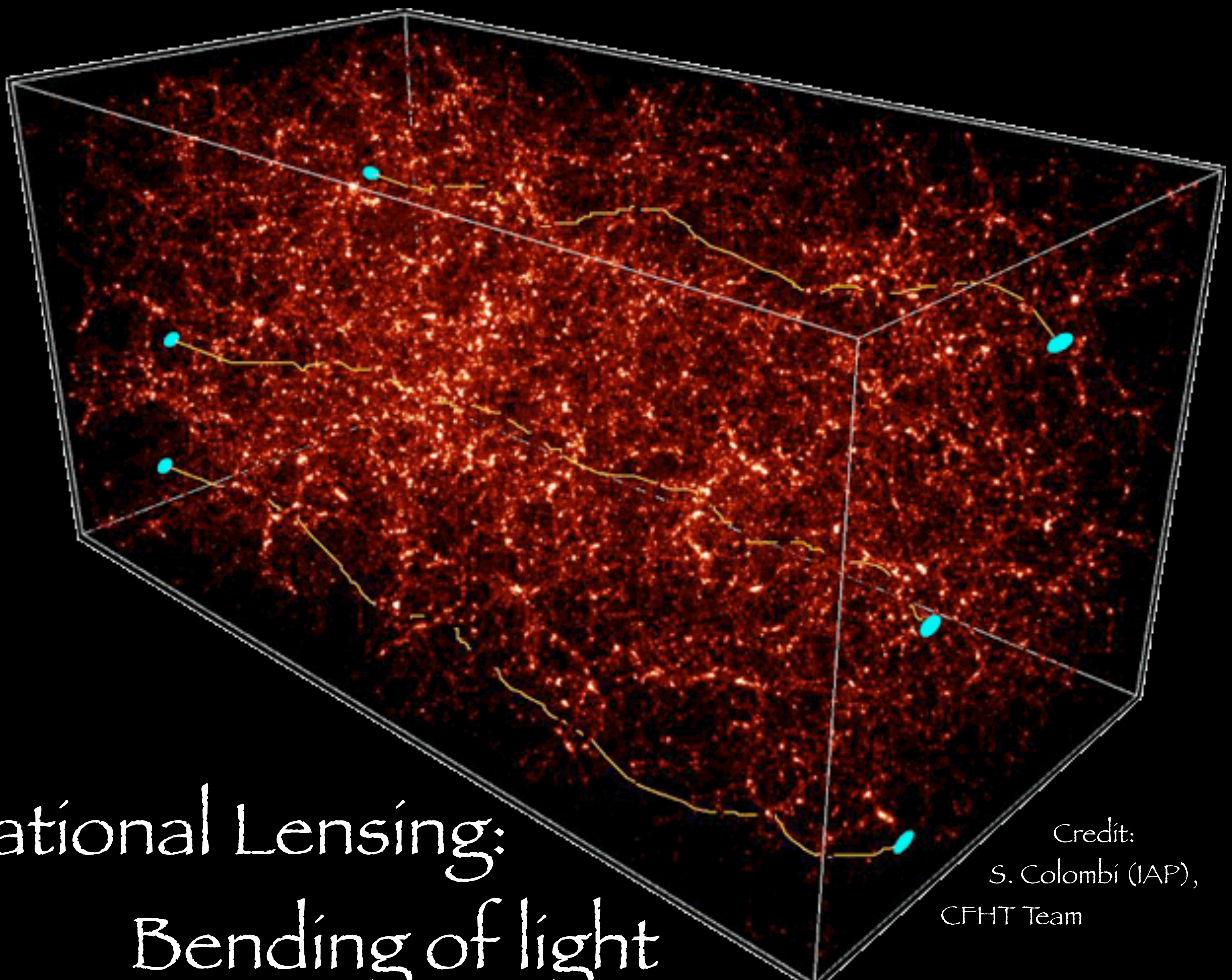
Journey Through the "Clumpy" Universe



Weak Gravitational Lensing: Bending of light

Credit: S. Colombi (IAP), CFHT Team

Journey Through the "Clumpy" Universe



Weak

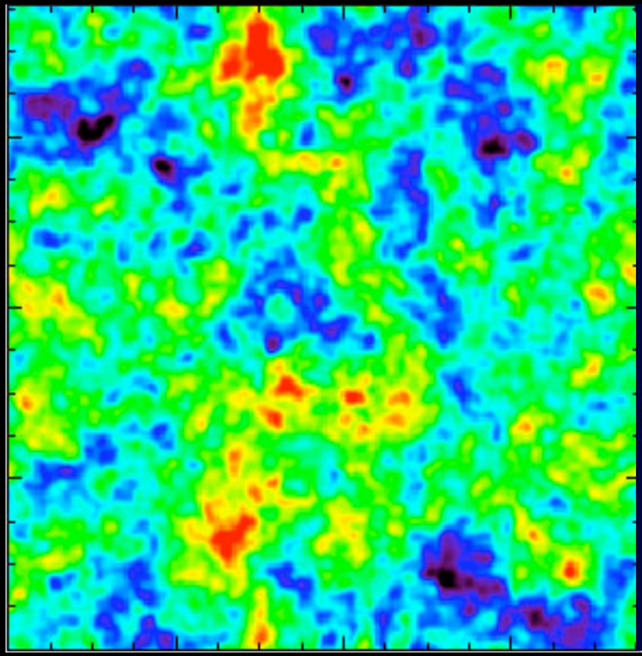
Gravitational Lensing:

Bending of light

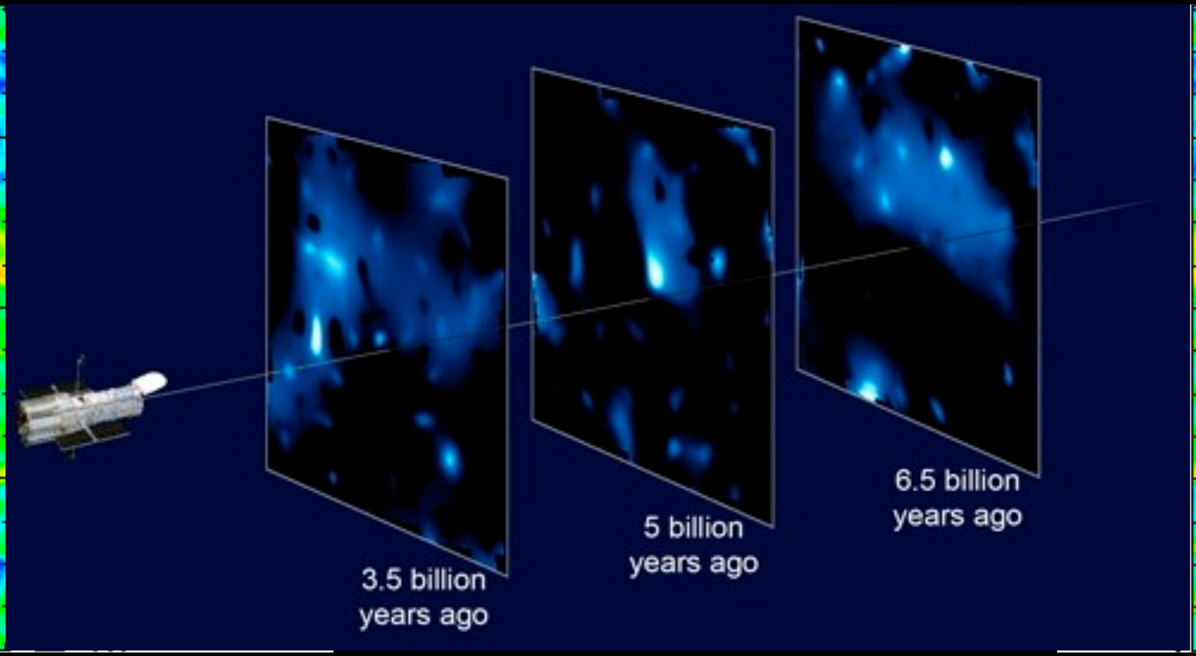
Credit:
S. Colombi (IAP),
CFHT Team

Antony Lewis and Anthony Challinor, Phys.Rept. 429, 1 (2006)

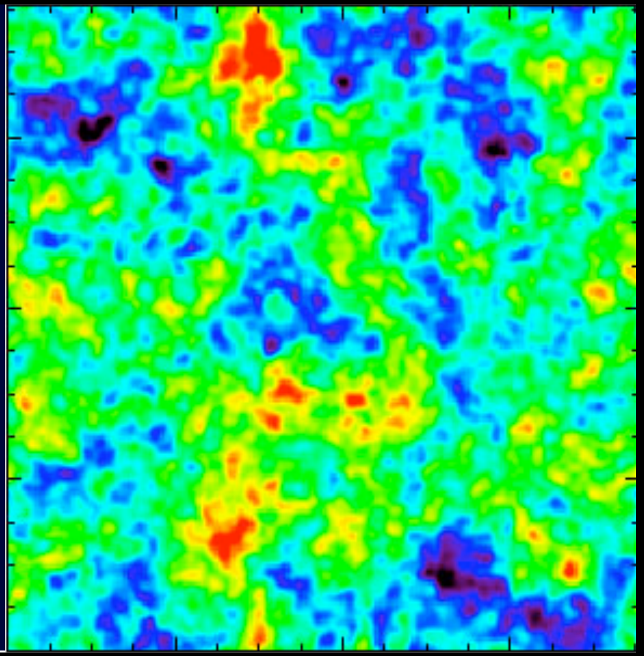
Weak Lensing of the Primary Bispectrum



Credit: Vale, Amblard, White (2004)



NASA, ESA, and R. Massey (CalTech)



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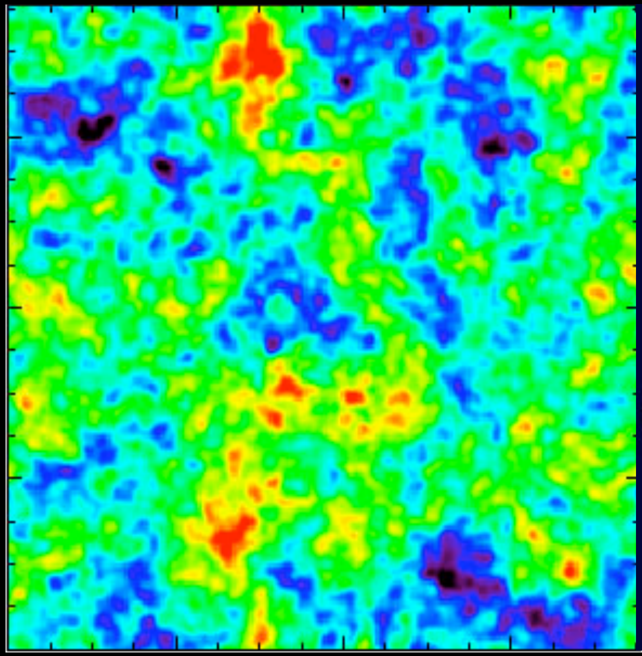

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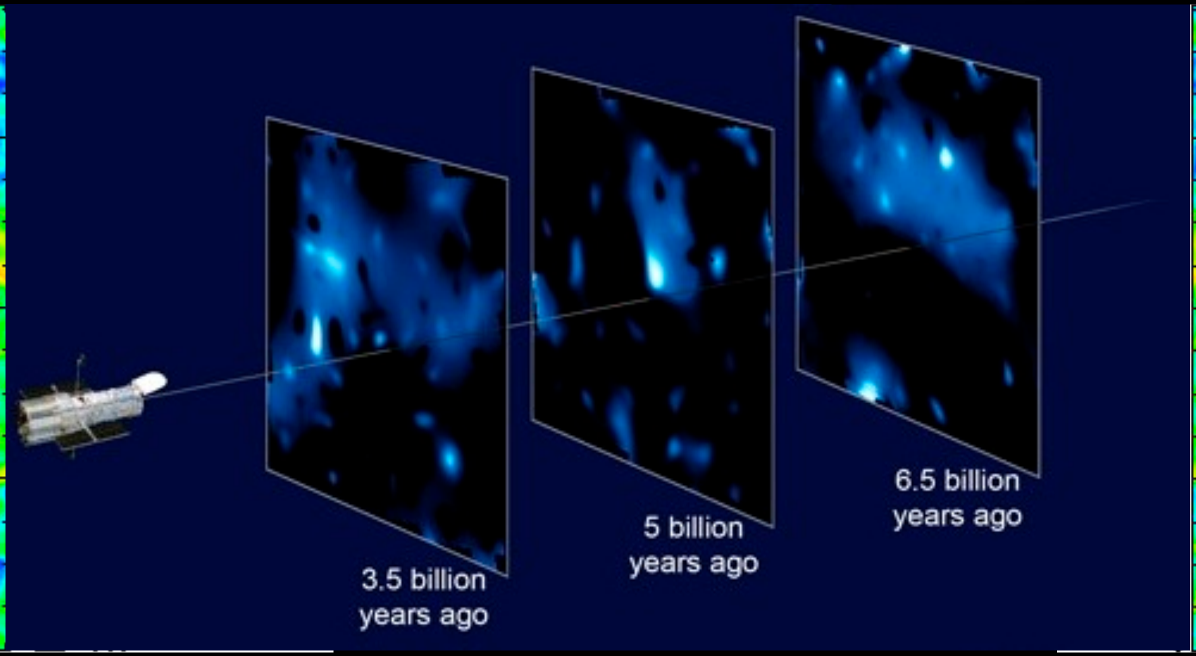

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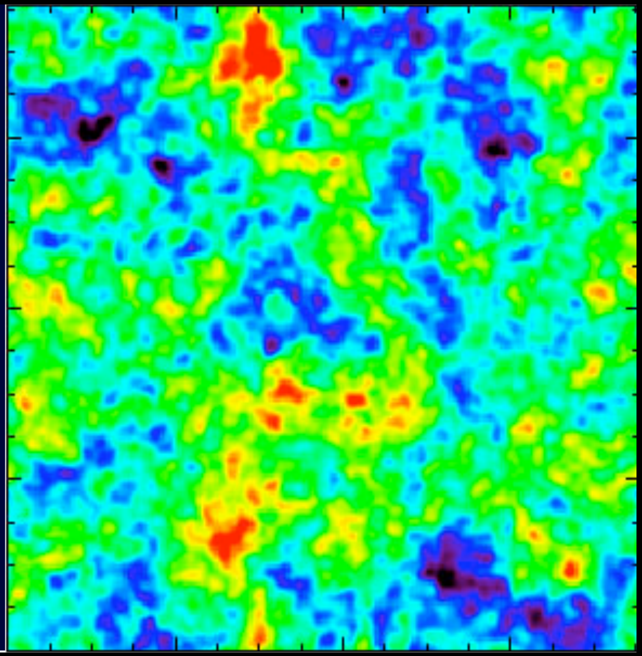

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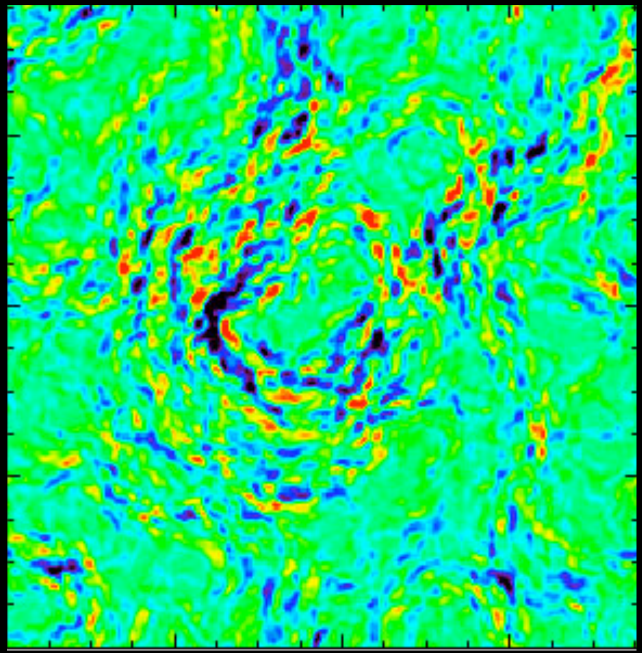

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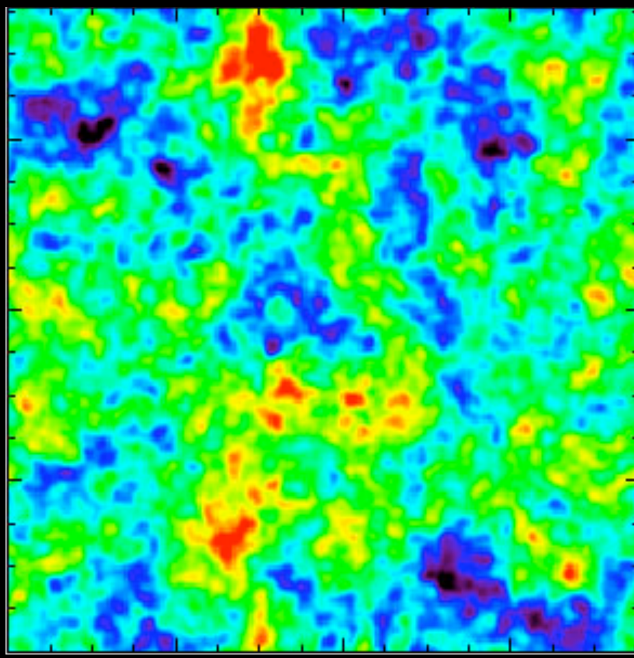

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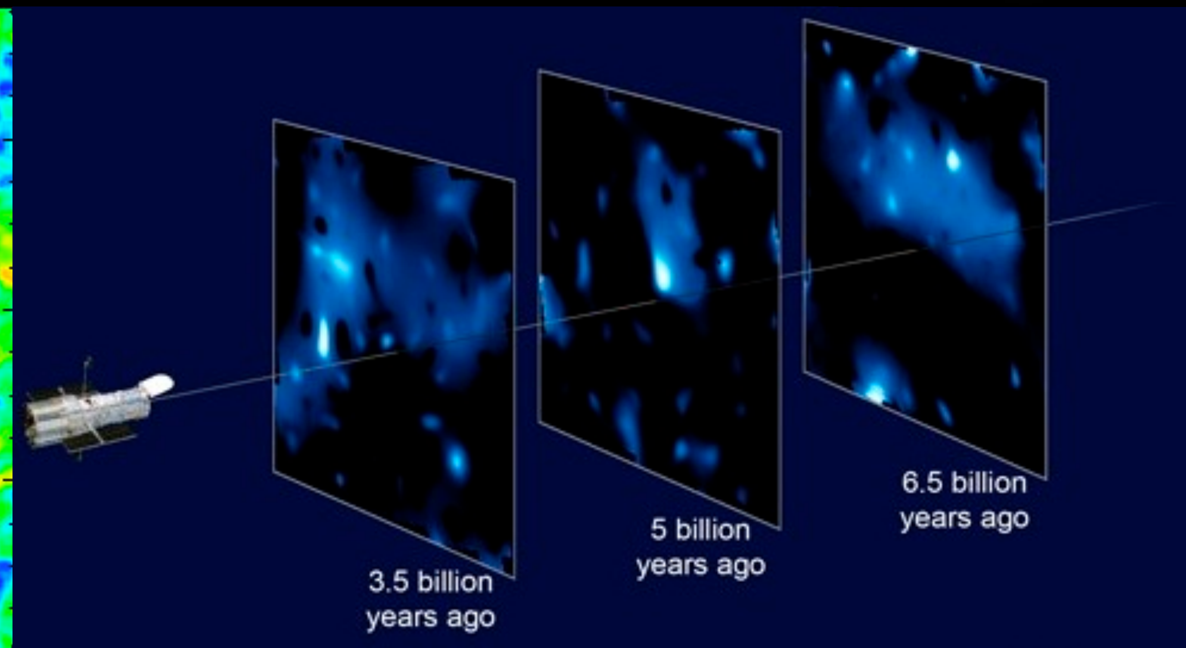

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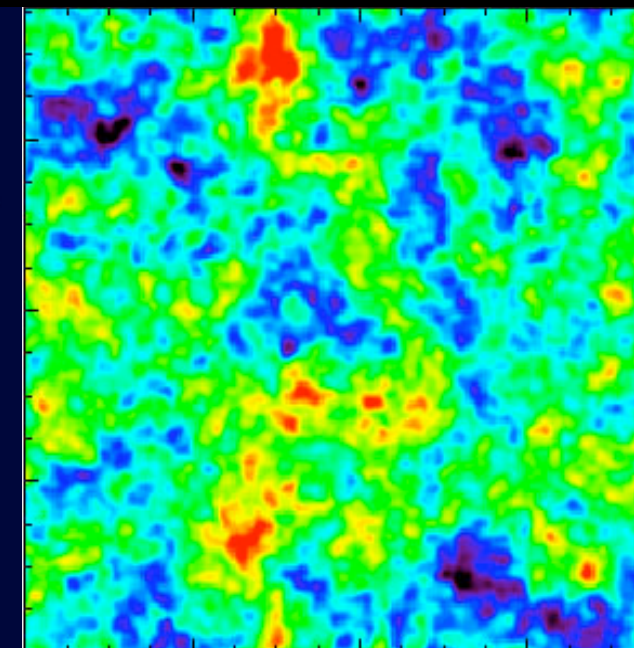
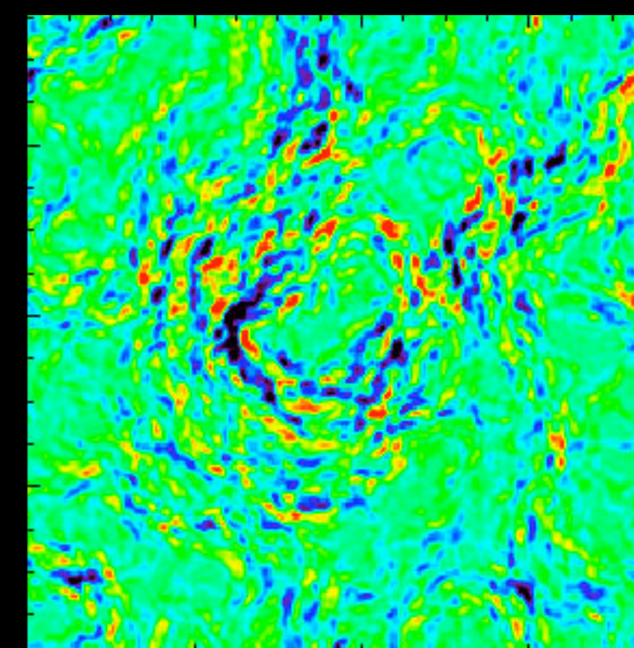
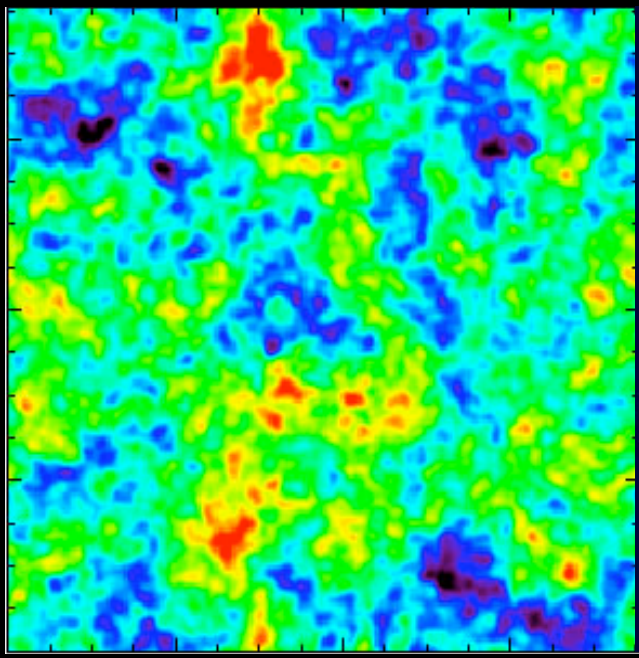


Credit: Vale, Amblard, White (2004)

$$\tilde{\Theta}(\hat{\mathbf{n}}) = \Theta\left[\hat{\mathbf{n}} + \hat{\alpha}\right]$$



Weak Lensing of the Primary Bispectrum



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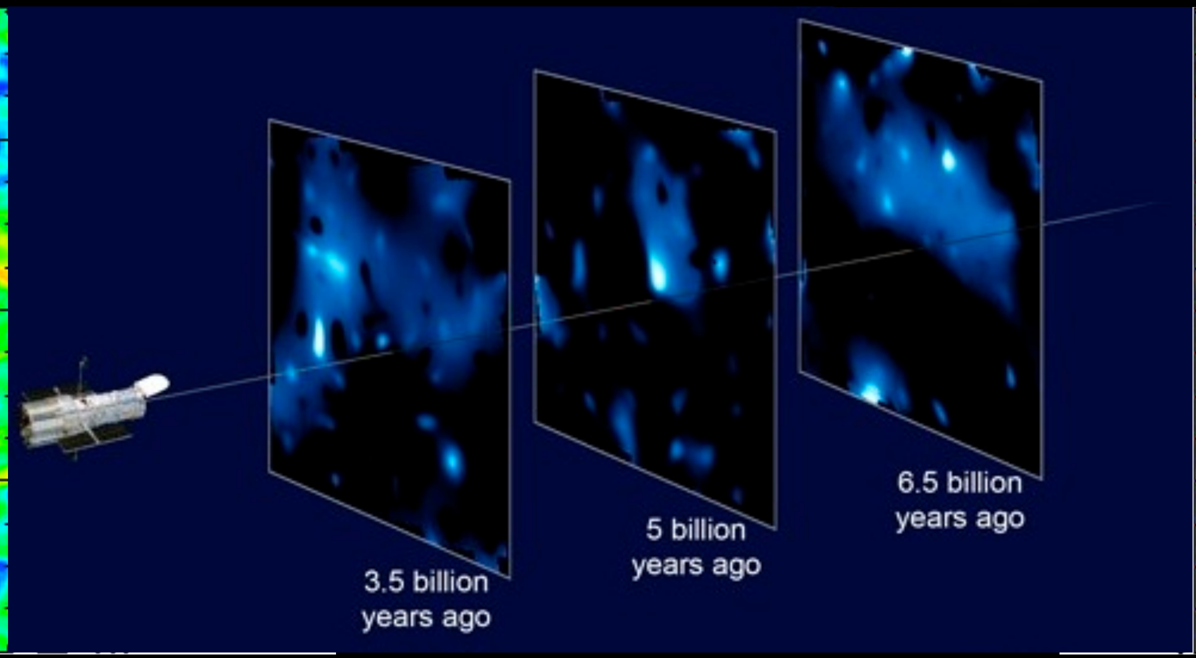

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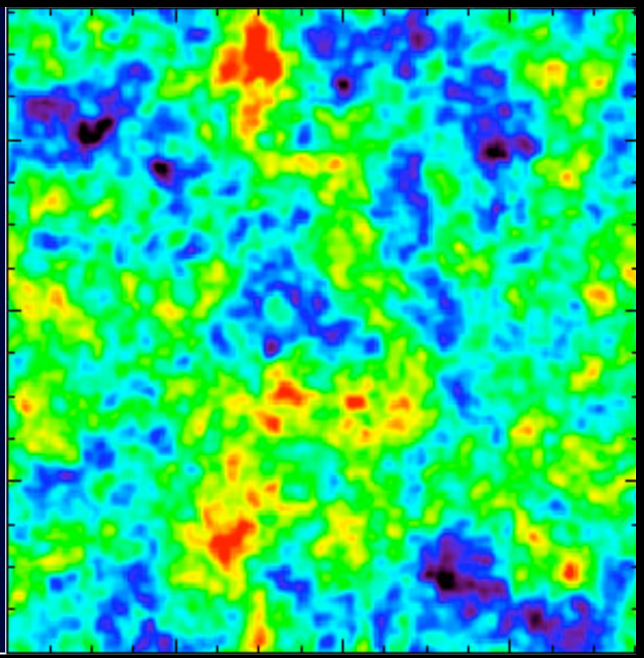
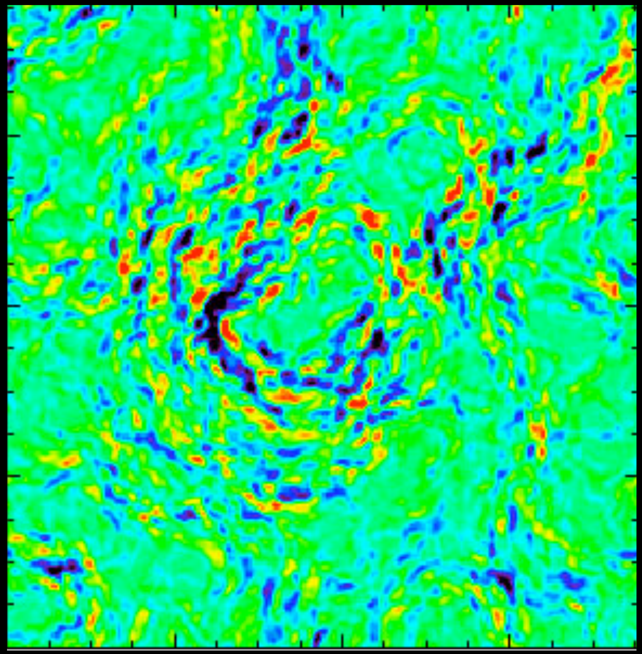


Credit: Vale, Amblard, White (2004)

$$\tilde{\Theta}(\hat{\mathbf{n}}) = \Theta\left[\hat{\mathbf{n}} + \hat{\alpha}\right]$$
$$= \Theta\left[\hat{\mathbf{n}} + \nabla\phi(\hat{\mathbf{n}})\right]$$



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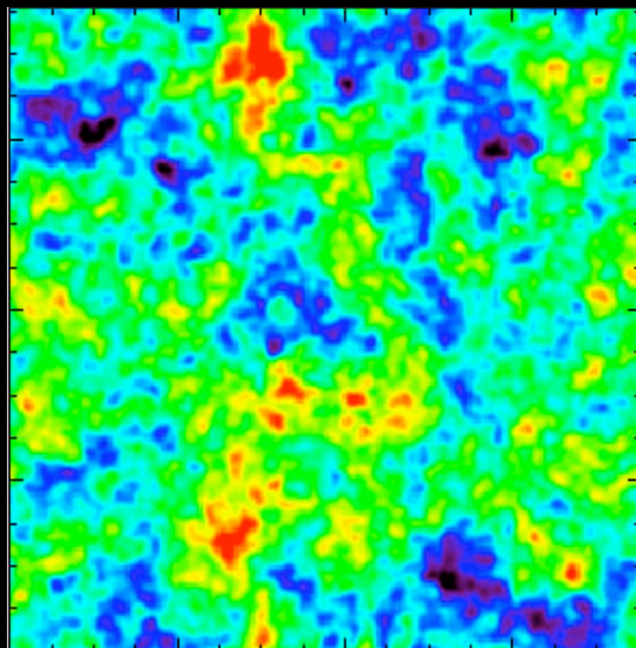
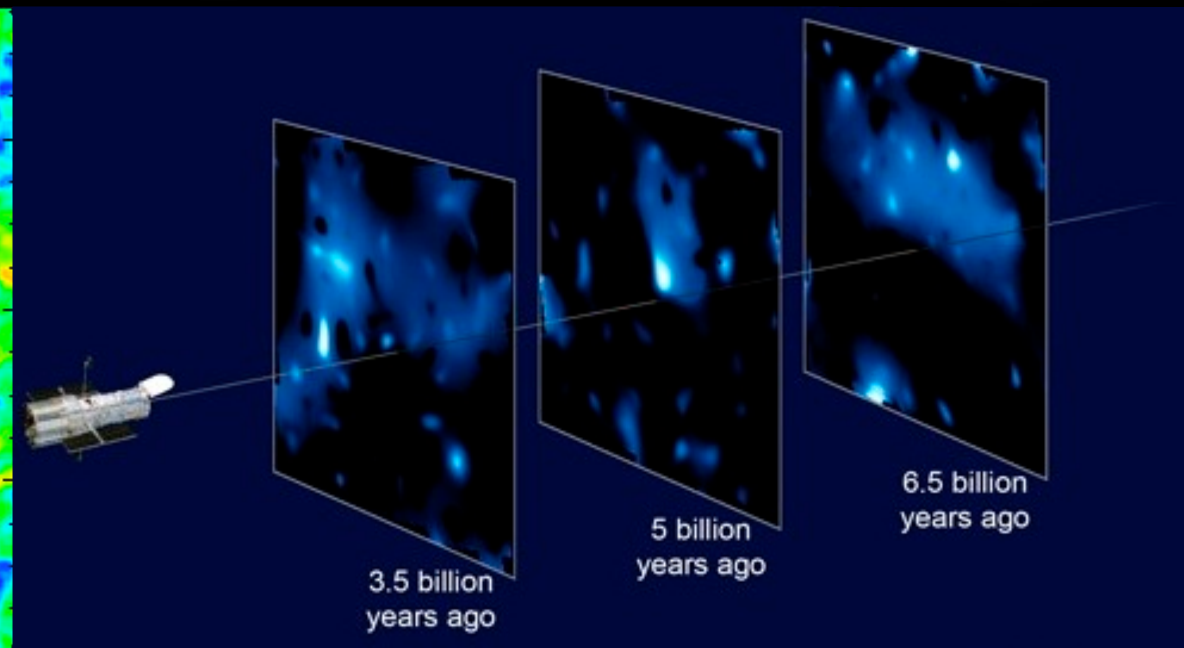


Credit: Vale, Amblard, White (2004)



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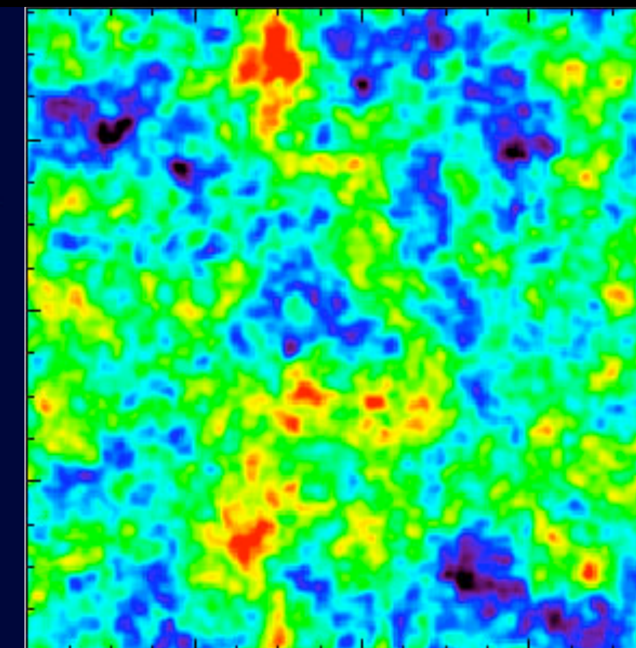
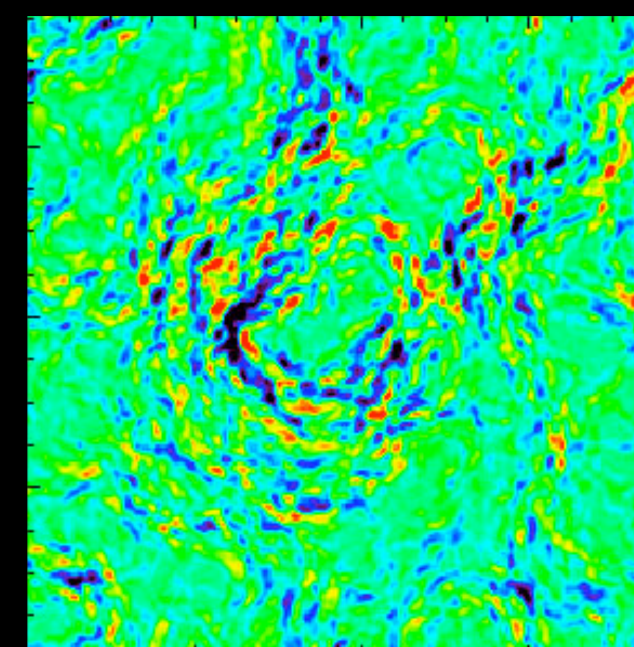


Credit: Vale, Amblard, White (2004)

$$
\begin{aligned}
\tilde{\Theta}(\hat{\mathbf{n}}) &= \Theta\left[\hat{\mathbf{n}} + \hat{\alpha}\right] \\
&= \Theta\left[\hat{\mathbf{n}} + \nabla\phi(\hat{\mathbf{n}})\right] \\
&\approx \Theta(\hat{\mathbf{n}}) + \nabla_i\phi(\hat{\mathbf{n}})\nabla^i\Theta(\hat{\mathbf{n}}) \\
&\qquad + \frac{1}{2}\nabla_i\phi(\hat{\mathbf{n}})\nabla_j\phi(\hat{\mathbf{n}})\nabla^i\nabla^j\Theta(\hat{\mathbf{n}})
\end{aligned}
$$



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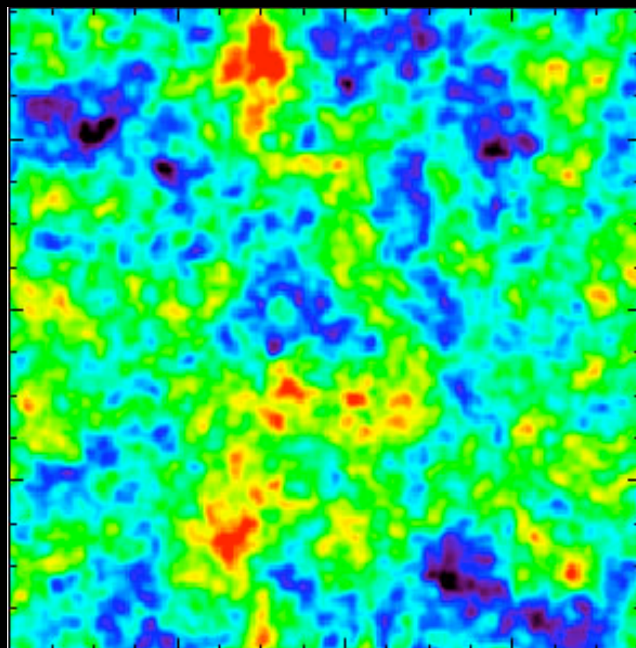

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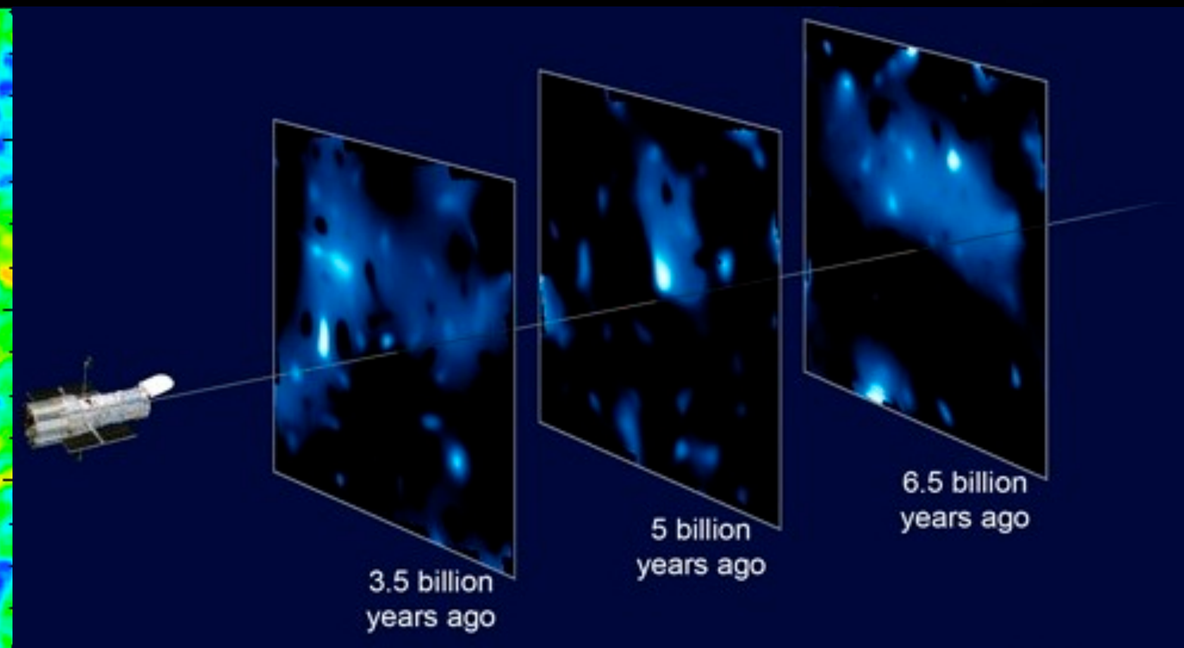

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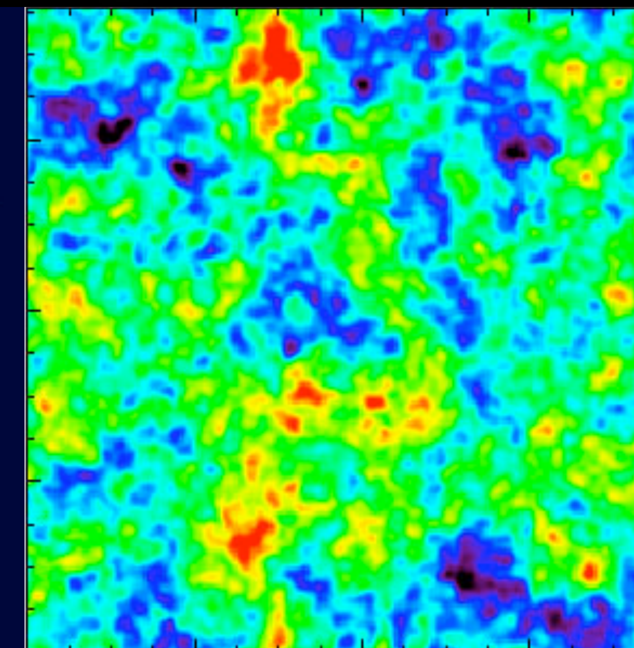

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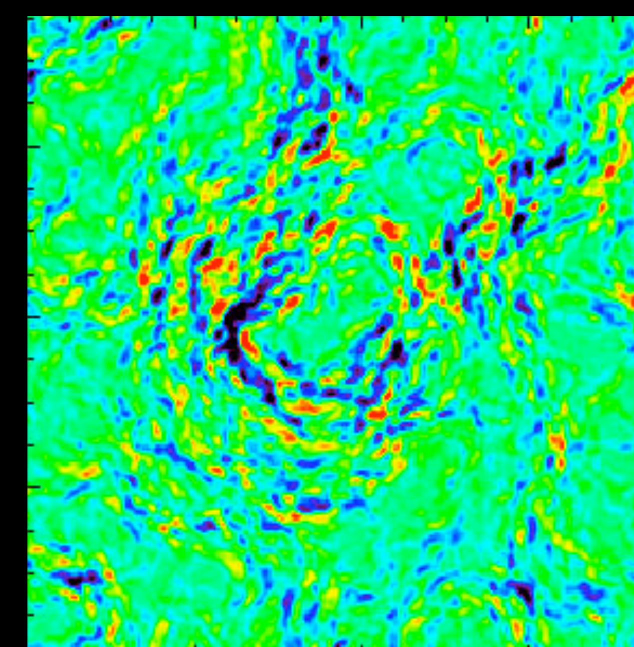
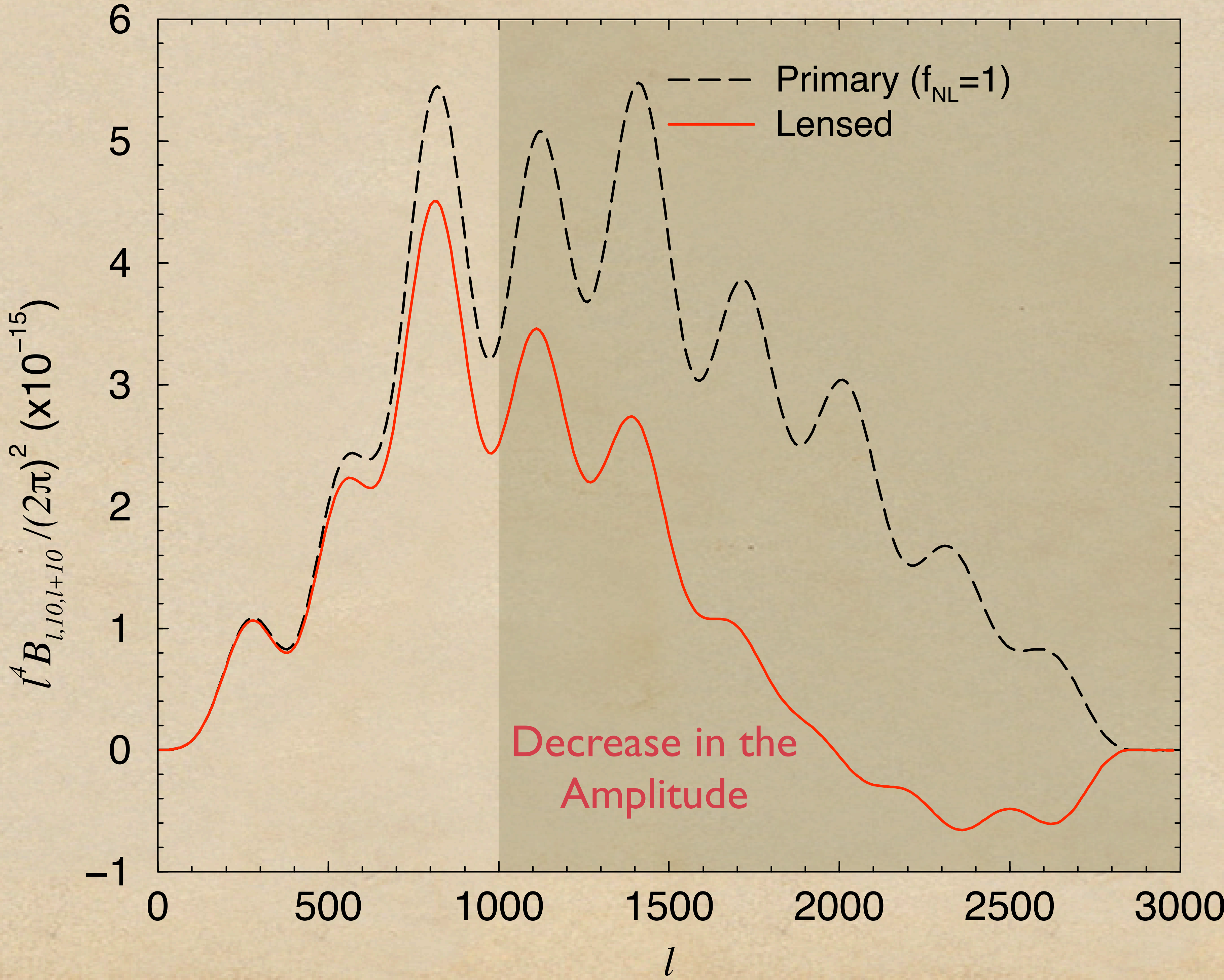


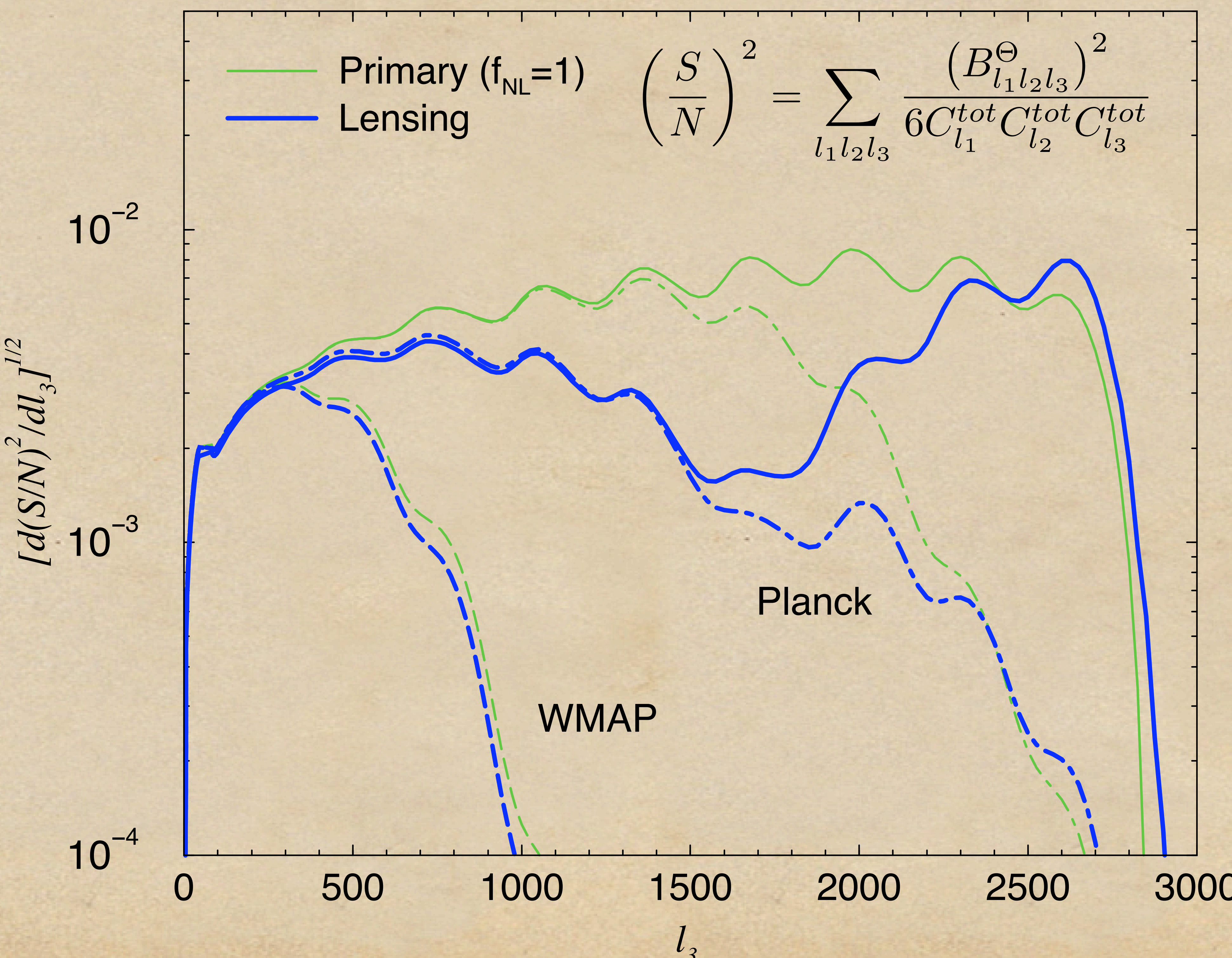
$$
\tilde{B}^{\Theta}_{l_1 l_2 l_3} = \sum_{m_1 m_2 m_3} \begin{pmatrix} l_1 & l_2 & l_3 \\ m_1 & m_2 & m_3 \end{pmatrix} \langle \tilde{\Theta}_{l_1 m_1} \tilde{\Theta}_{l_2 m_2} \tilde{\Theta}_{l_3 m_3} \rangle
$$

The Effect of Lensing on the Bispectrum



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

Reduction in the S/N due to Lensing



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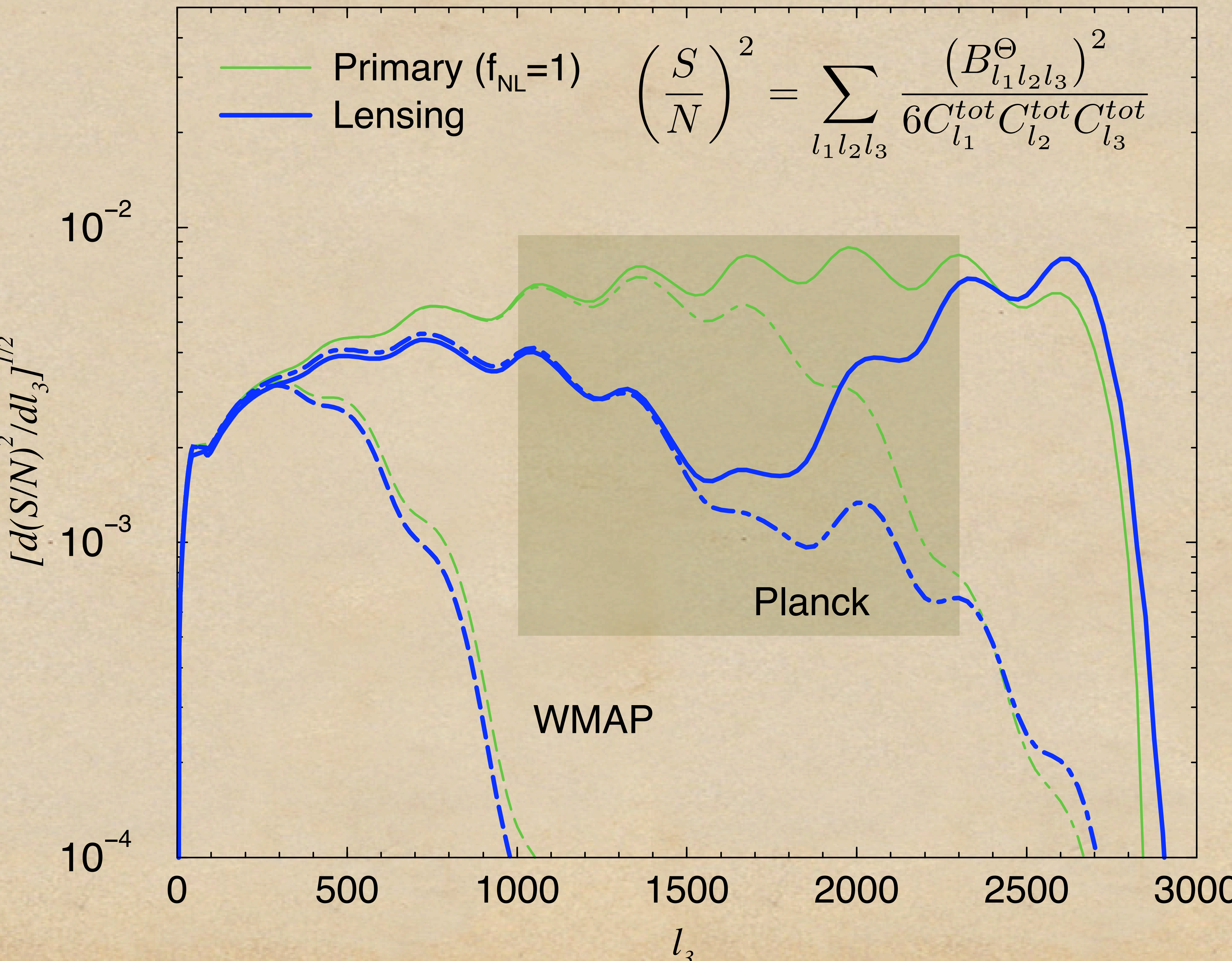
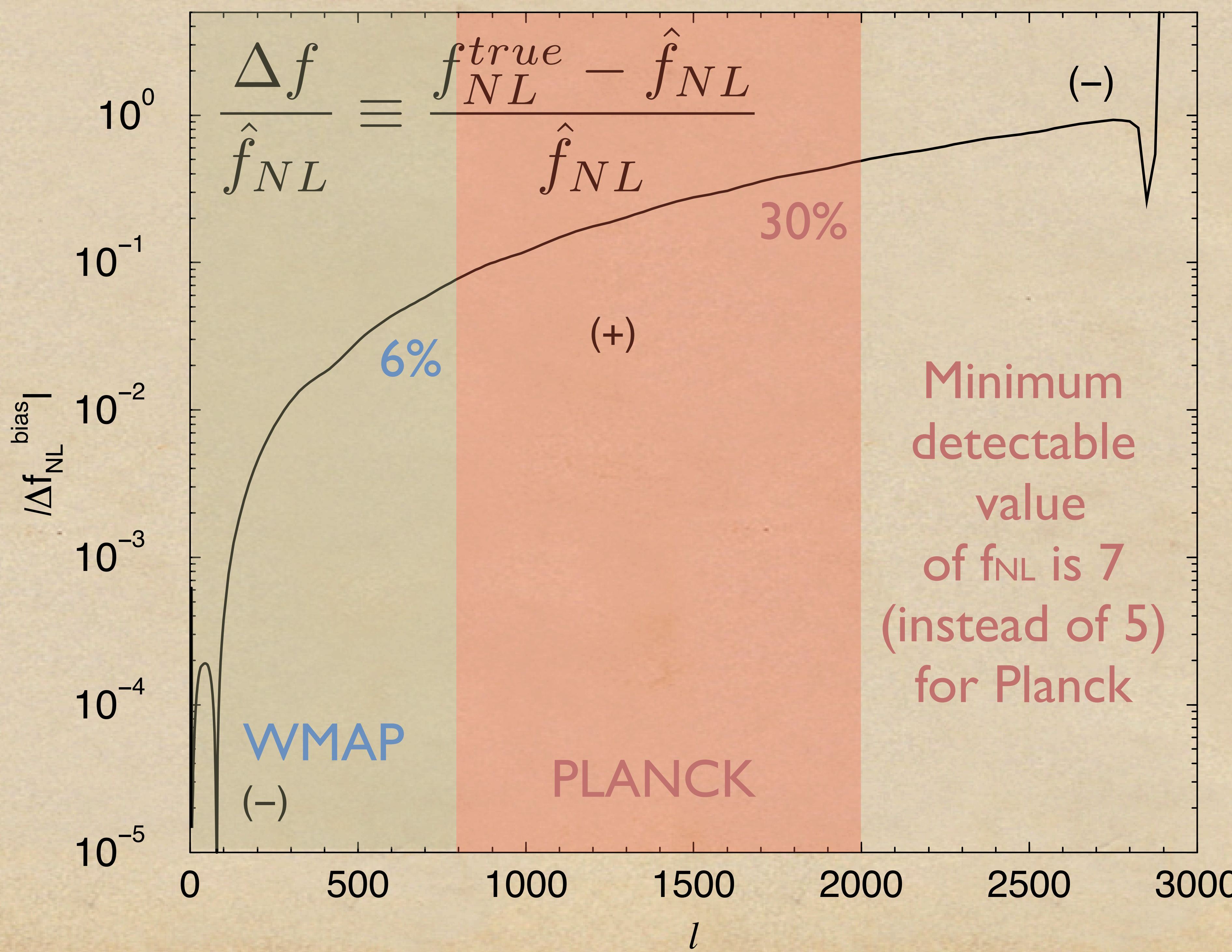


A. Cooray, D. Sarkar, and P. Serra; Phys. Rev. D, 77, 123006 (2008)

Bias in the non-Gaussian Parameter



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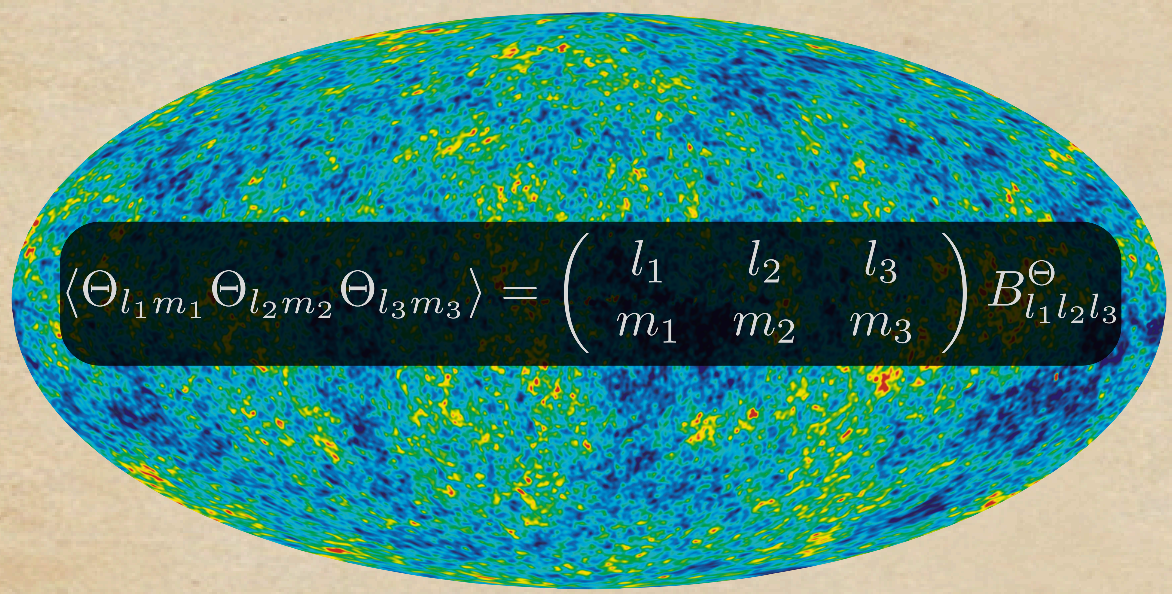
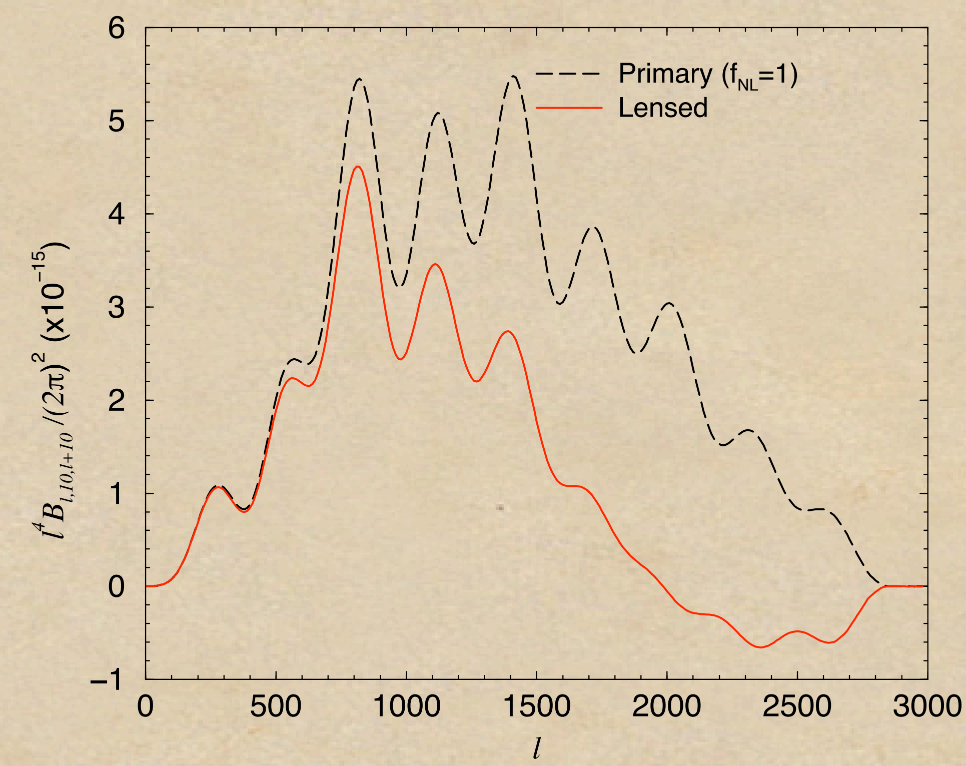
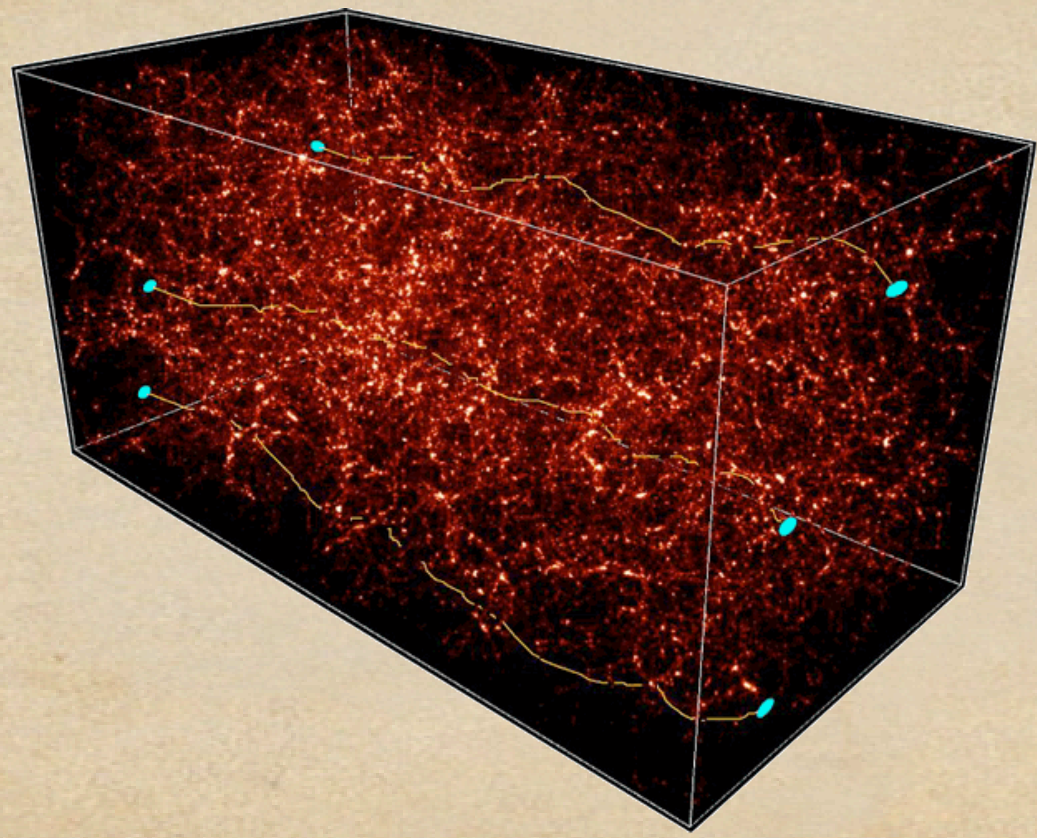
IoA, Cambridge   Astrophysics Talk   Jan 28, 2009

Summary







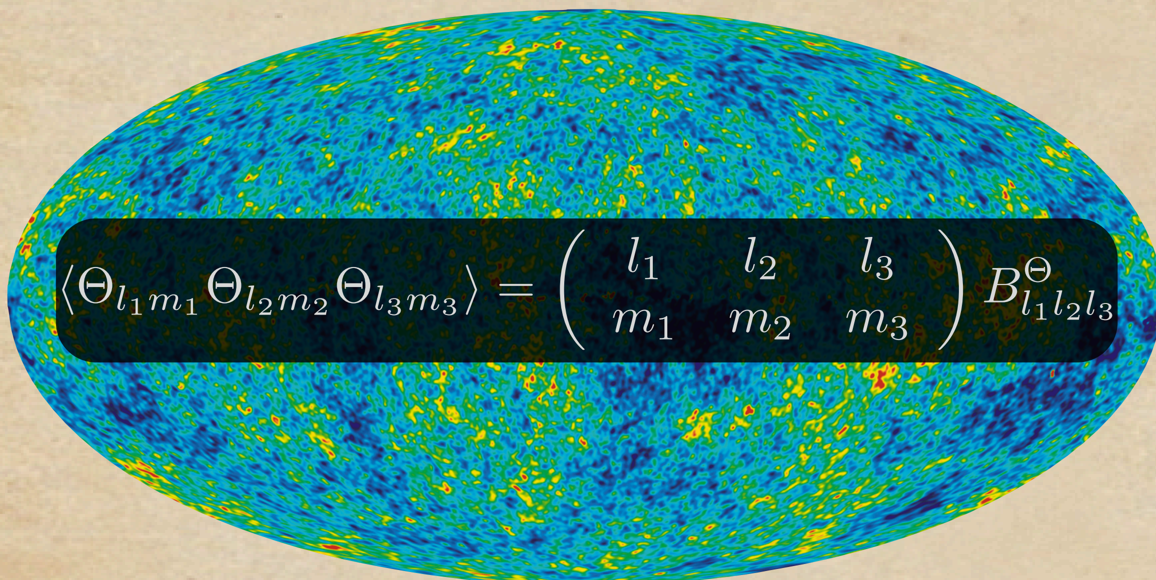
6% Bias for WMAP

30% Bias for Planck

Minimum f_{NL} 7

DSARKAR.ORG

Summary



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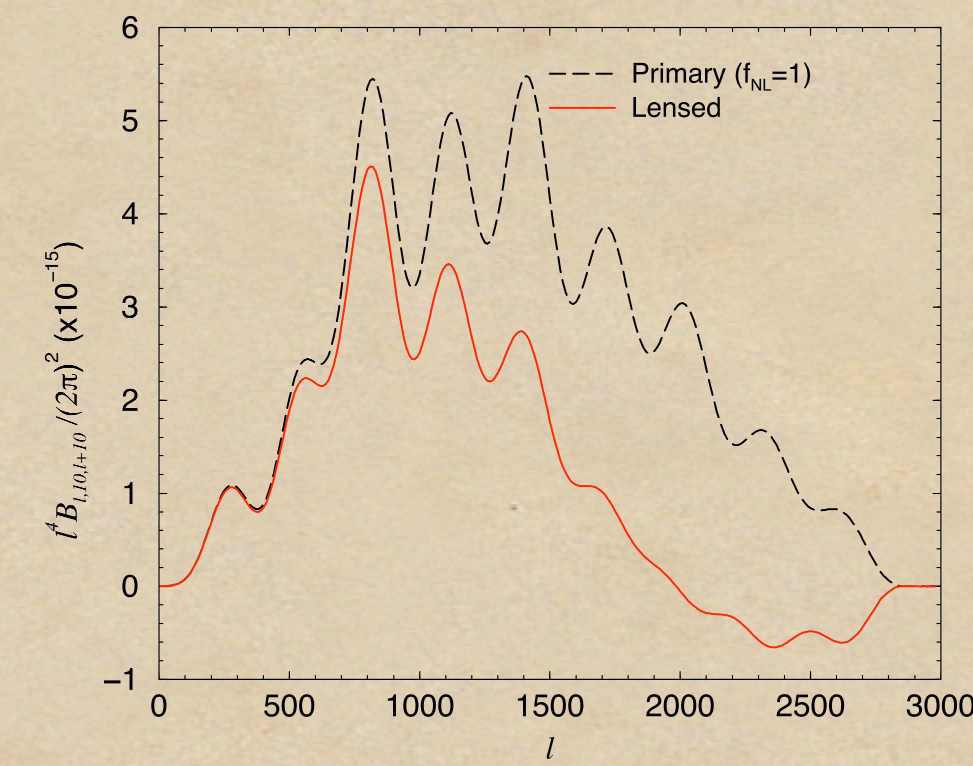

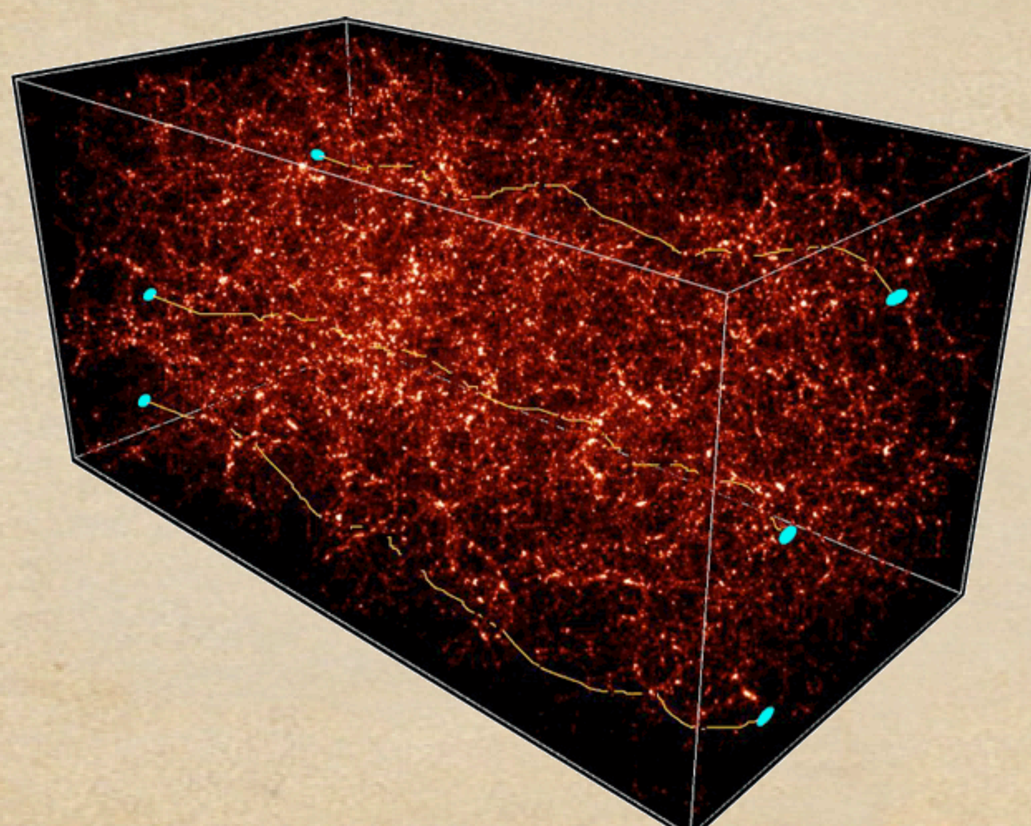

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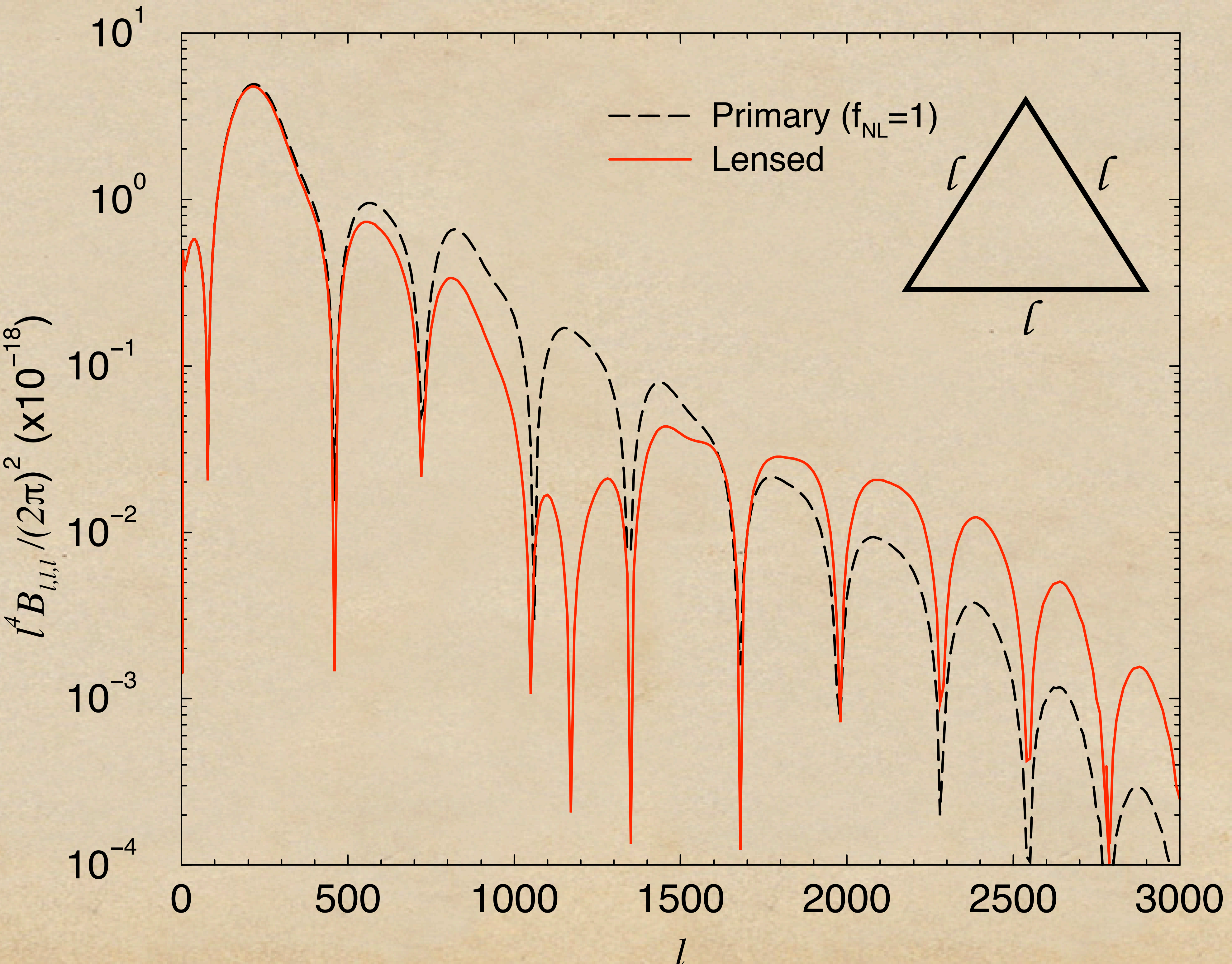
XTRA SLIDES

CMB Bispectrum of the equilateral case



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

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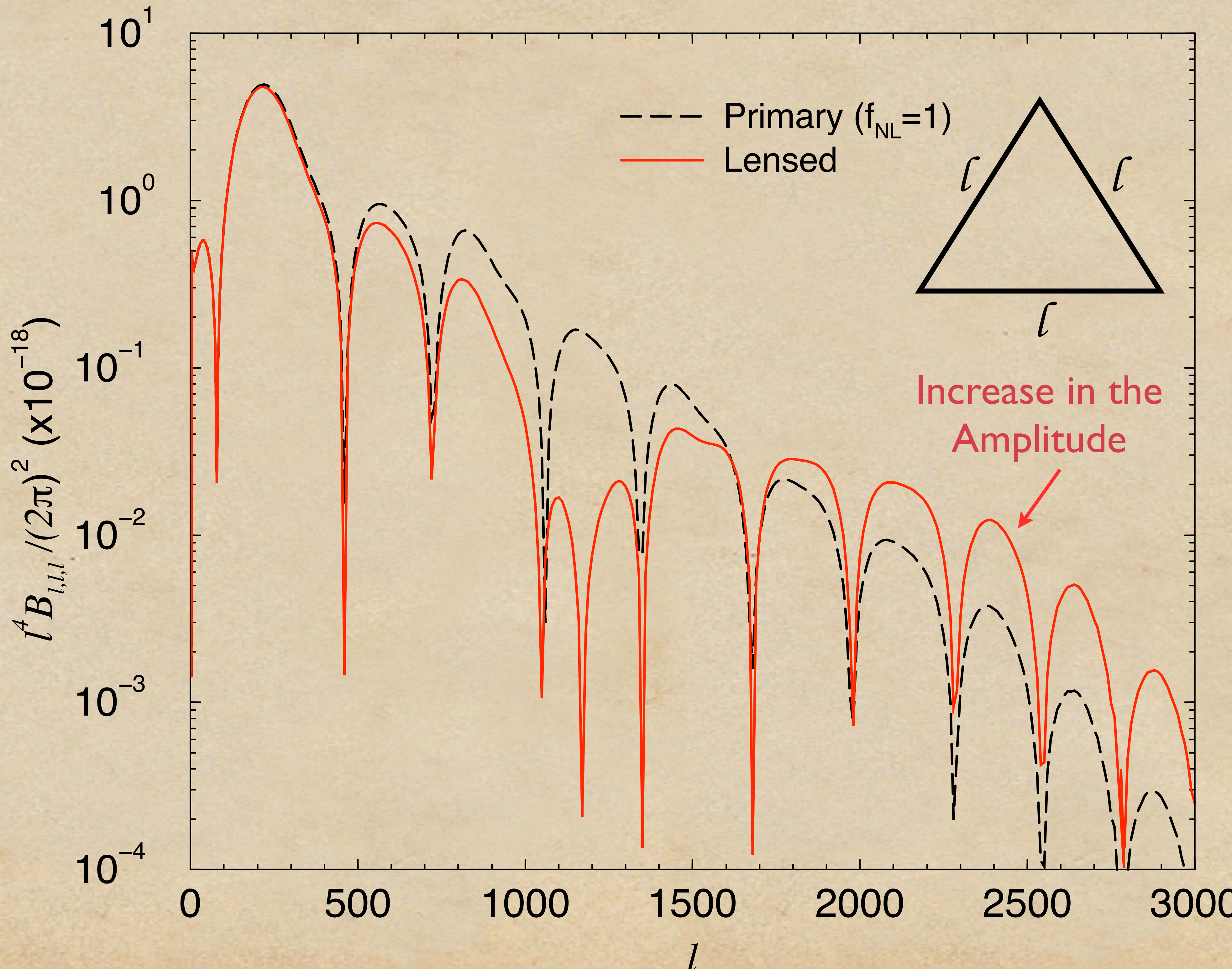

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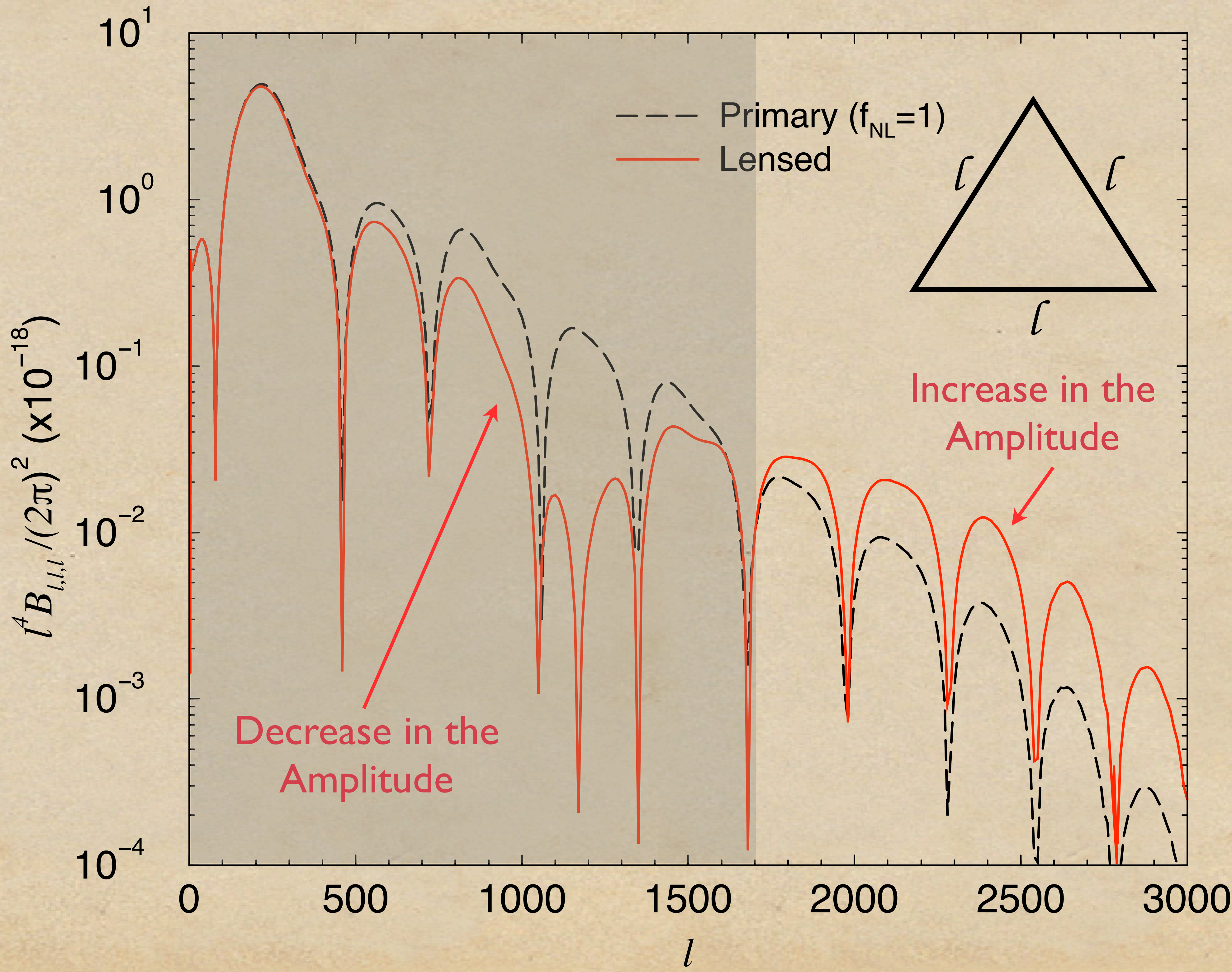
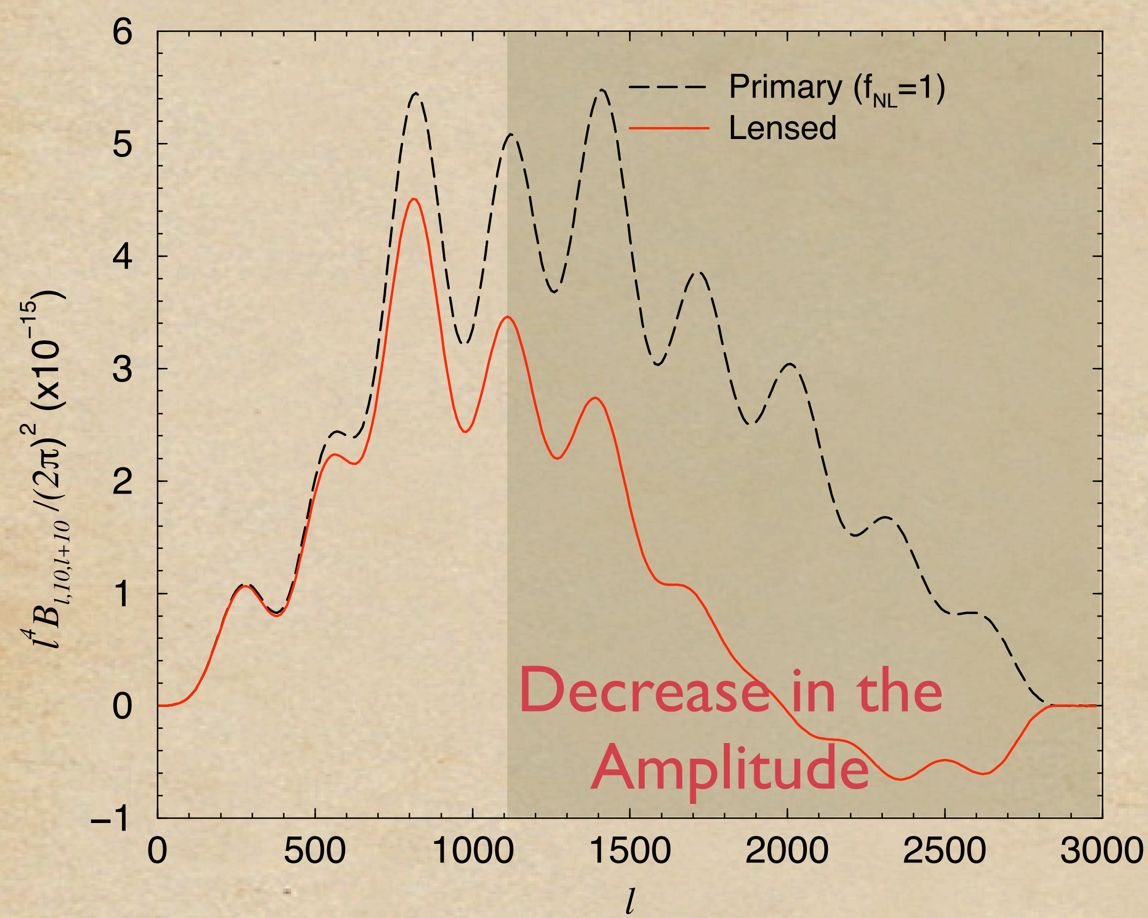
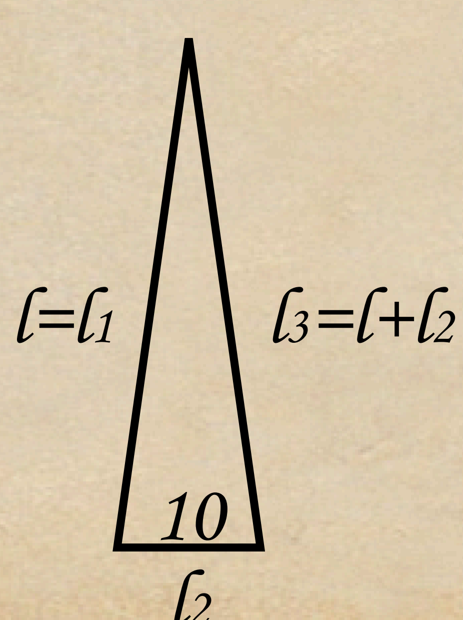


A. Cooray, D. Sarkar, and P. Serra; Phys. Rev. D, 77, 123006 (2008)

CMB Bispectrum of the squeezed case(s)





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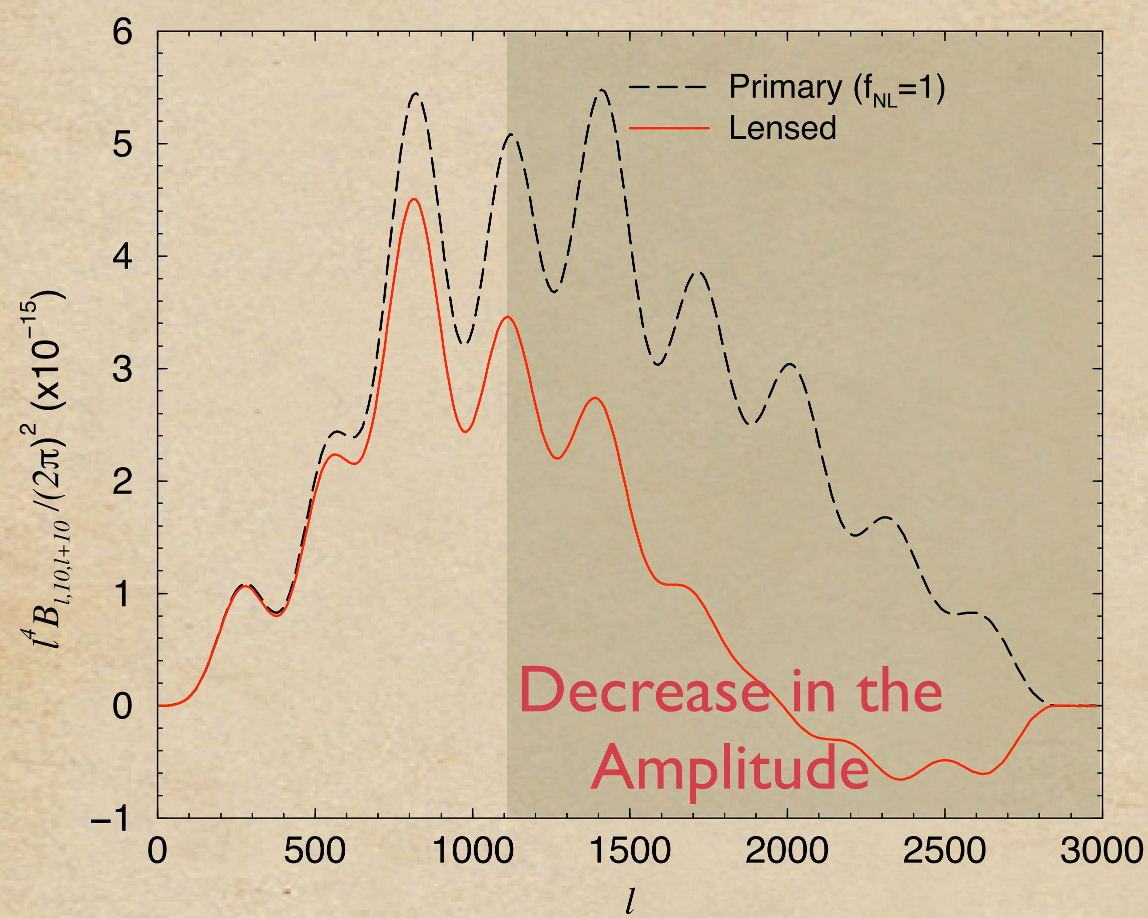

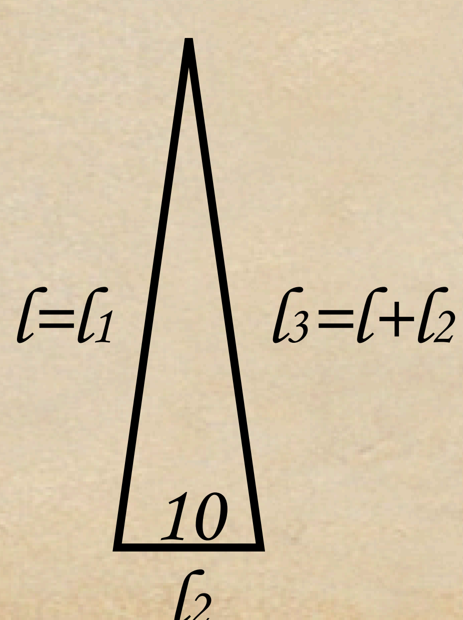

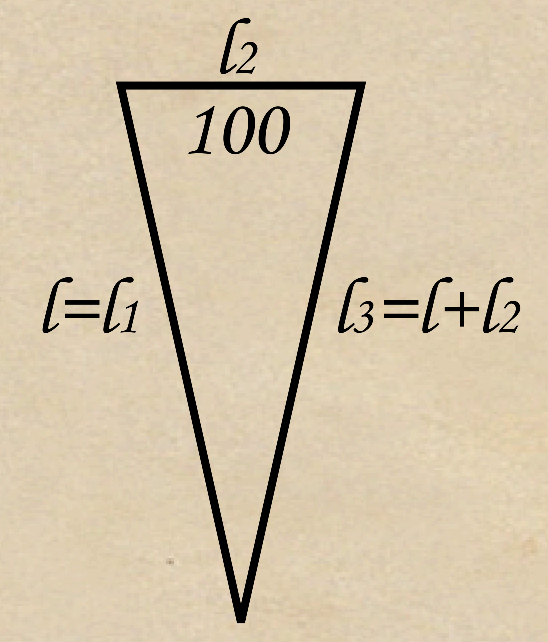

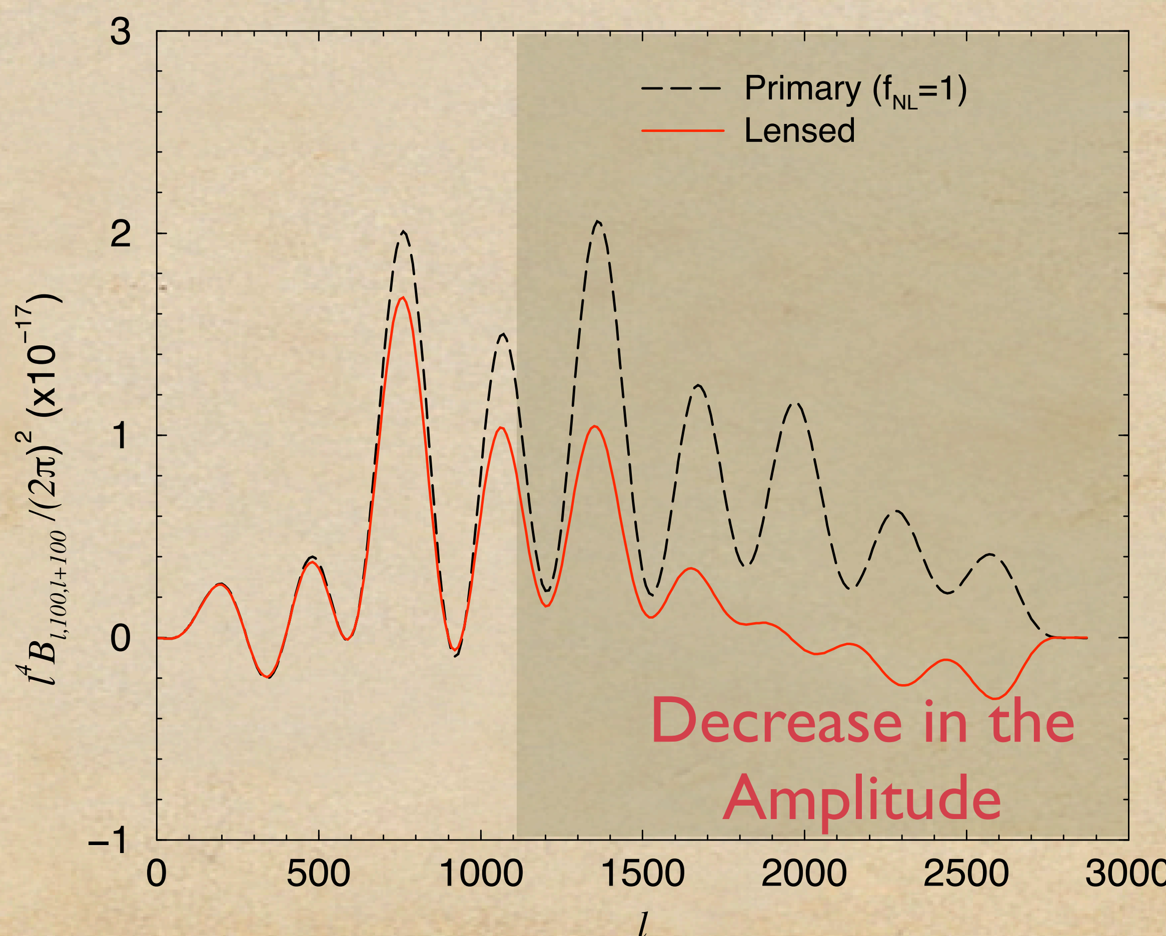

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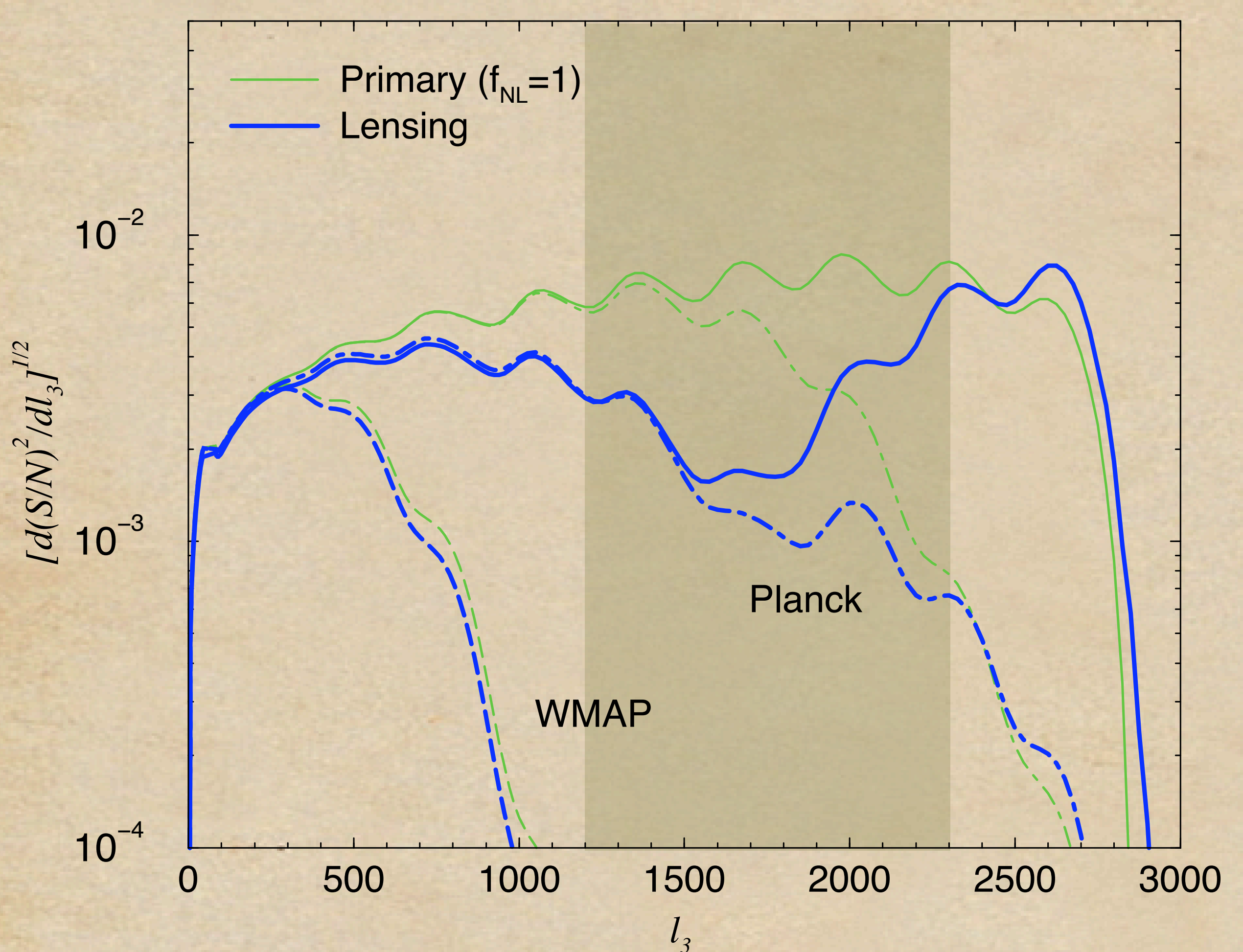
Reduction in the S/N due to Lensing



$$\left(\frac{S}{N}\right)^2 = \sum_{l_1 l_2 l_3} \frac{\left(B^{\Theta}_{l_1 l_2 l_3}\right)^2}{6 C^{tot}_{l_1} C^{tot}_{l_2} C^{tot}_{l_3}}$$

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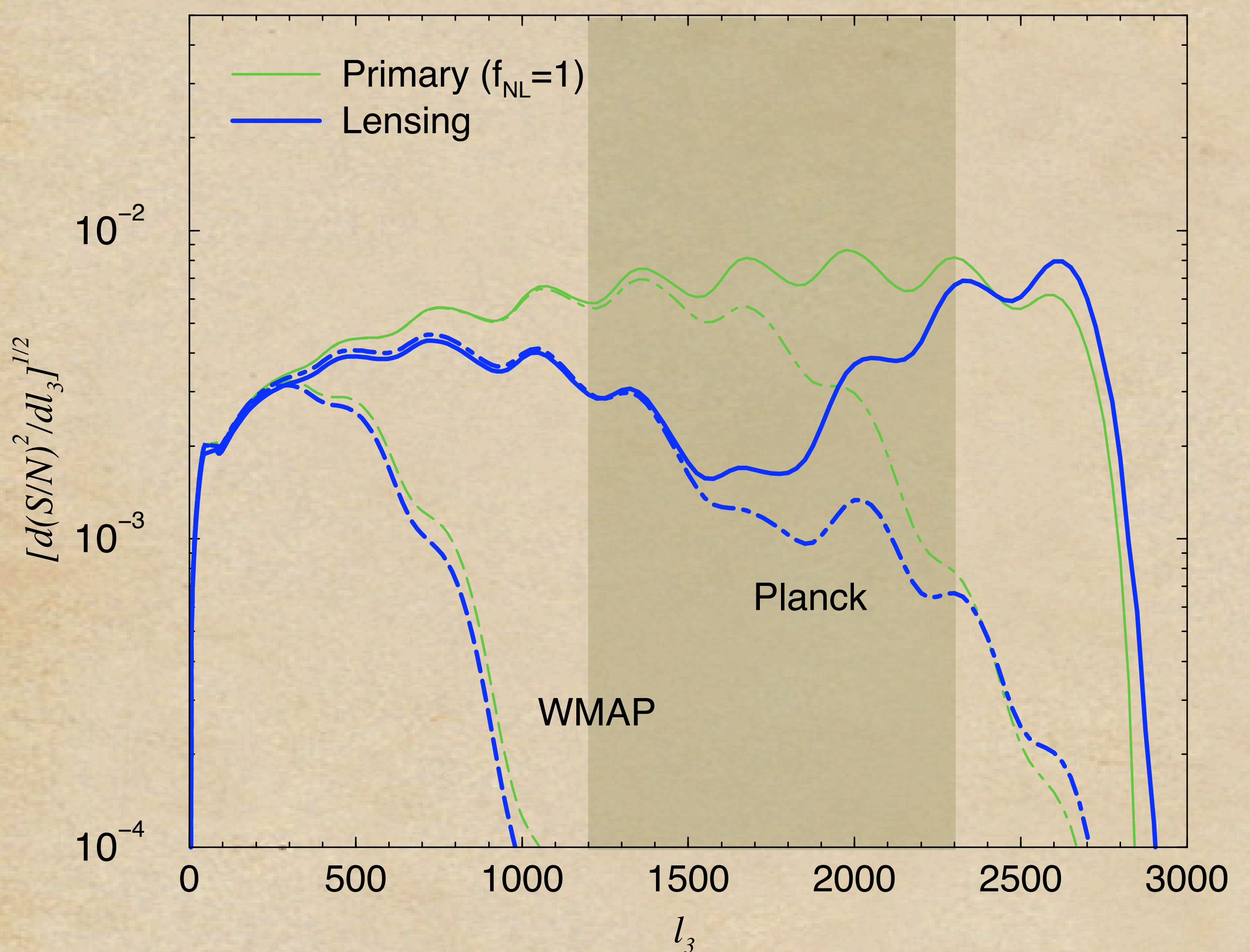
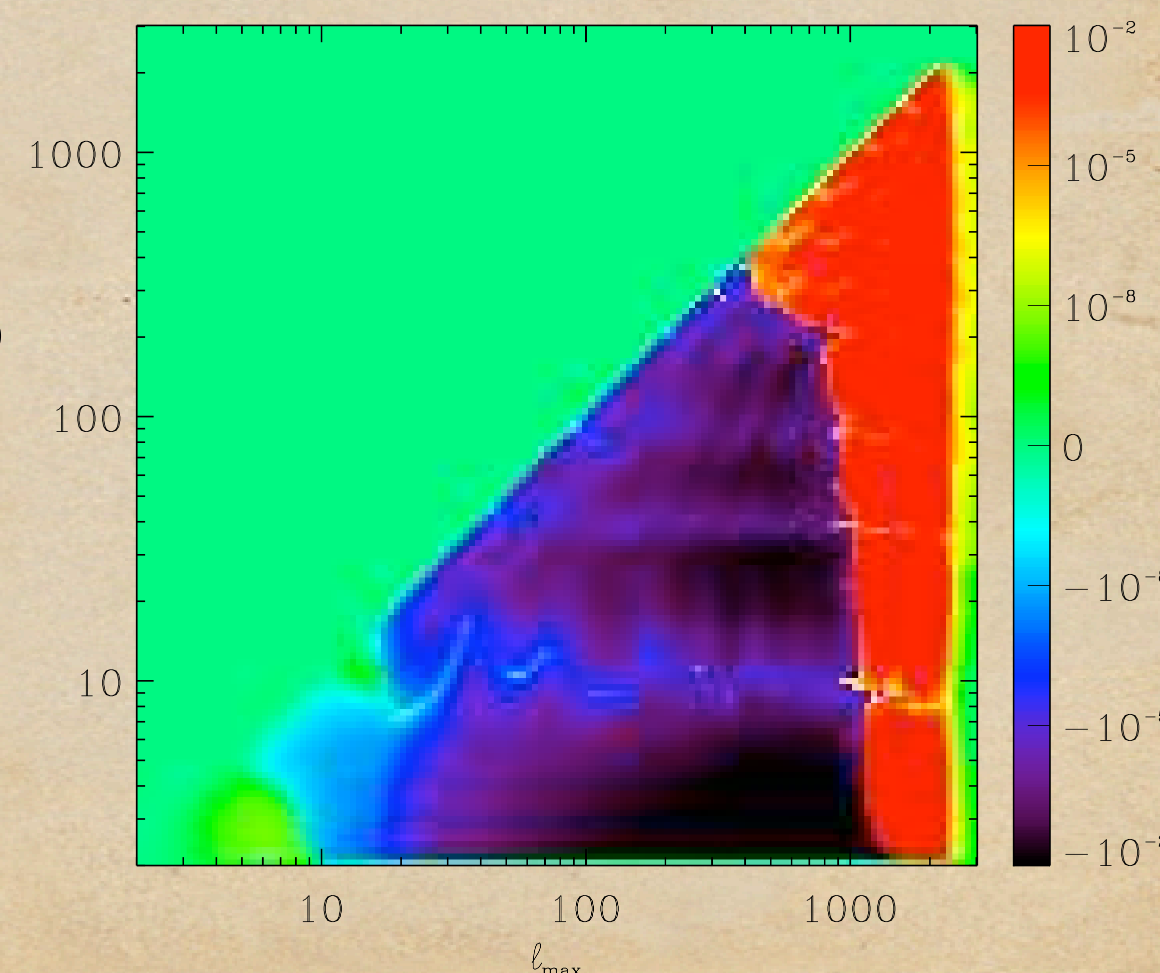
Reduction in the S/N due to Lensing



$$\frac{d\left[\left(\frac{S}{N}\right)^2_{lensed} - \left(\frac{S}{N}\right)^2_{unlensed}\right]}{d\log l_{max} d\log l_{min}}$$



$$\left(\frac{S}{N}\right)^2 = \sum_{l_1 l_2 l_3} \frac{\left(B^{\Theta}_{l_1 l_2 l_3}\right)^2}{6 C^{tot}_{l_1} C^{tot}_{l_2} C^{tot}_{l_3}}$$

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