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Eliminating ISW-Lensing bias in the estimation of the local form primordial non-Gaussianity

In collaboration with Eiichiro Komatsu (MPA) and Aditya Rotti (IUCAA)

Outlines

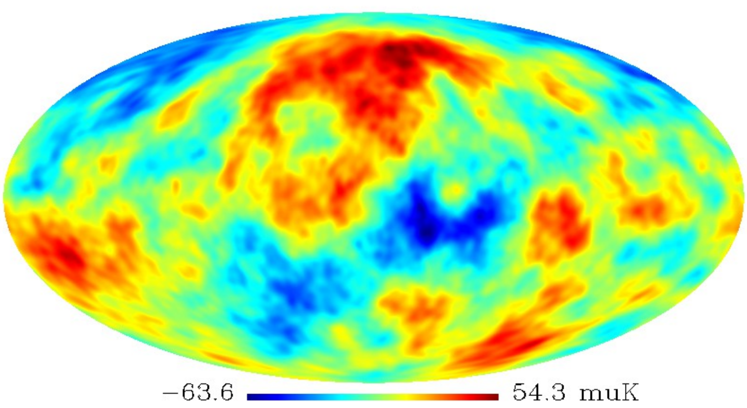
- Integrated Sachs Wolfe (ISW) effect in CMB anisotropy
- Lensing of CMB anisotropy
- Bispectrum of the ISW and lensing
- The effect on the primordial non-Gaussianity estimation
- Debiasing the ISW-lensing effect in the fNL estimation
- Summary and prospects

Integrated Sachs-Wolfe effect

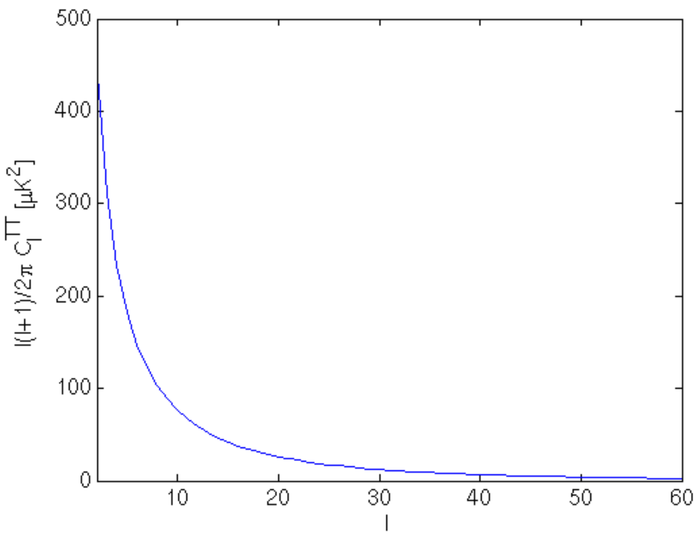
Time-varying potential leads to integrated Sachs-Wolfe effect

$$T_{\mathrm{ISW}}(\hat{\boldsymbol{n}}) = \int_0^{\chi_*} d\chi\, \dot{\Psi}(\chi\hat{\boldsymbol{n}}; \eta_0 - \chi)$$

Present conformal time — Comoving distance



Simulated ISW map



CMB power spectrum due to ISW

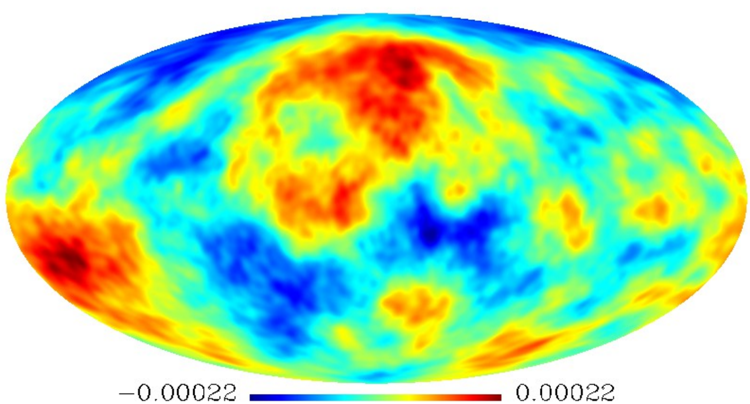
With the recent dominance of dark energy, ISW are produced at low redshift and large angular scales.

Lensing of CMB anisotropy by large-scale structure

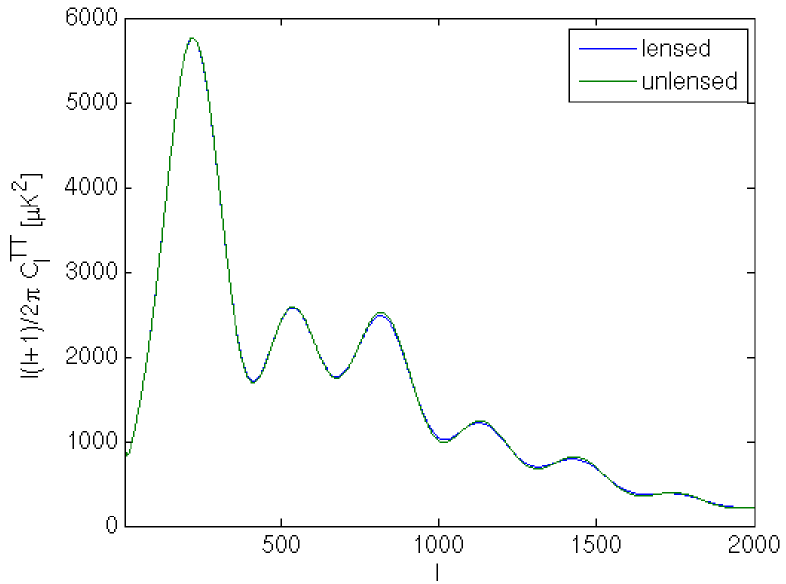
$$\tilde{T}(\hat{\boldsymbol{n}}) = T(\hat{\boldsymbol{n}} + \nabla\psi) \approx T(\hat{\boldsymbol{n}}) + \nabla T(\hat{\boldsymbol{n}}) \cdot \nabla\psi$$

$$\psi(\hat{\boldsymbol{n}}) = -2\int_0^{\chi_*} d\chi\, \Psi(\chi\hat{\boldsymbol{n}}; \eta_0 - \chi)\frac{\chi^* - \chi}{\chi^*\chi}$$

Projected lensing potential



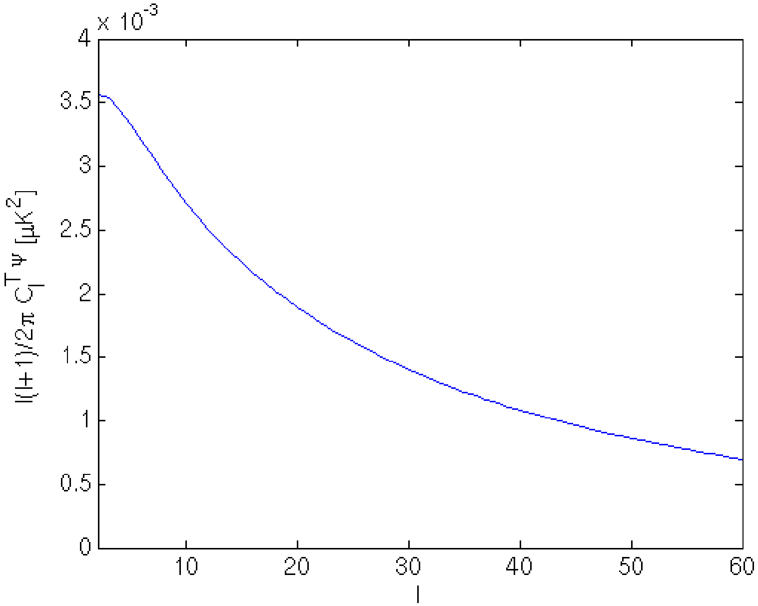
Simulated lensing potential map



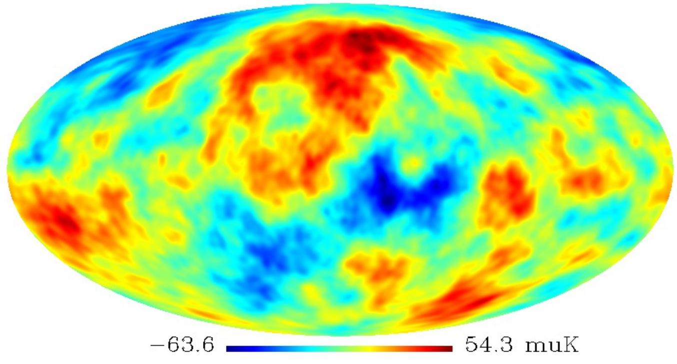
Lensing effect is more important at high multipoles.

Correlation between ISW and lensing potential

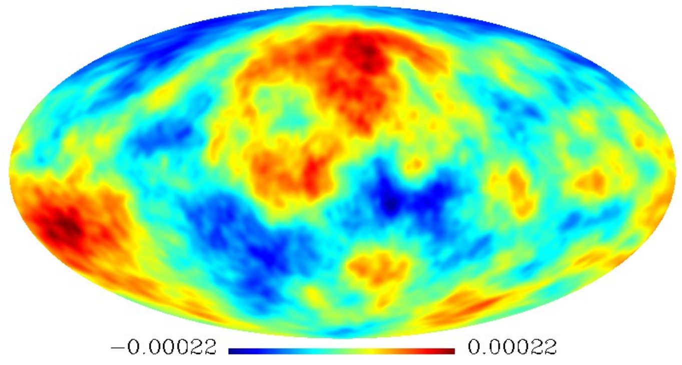
Due to the similarity of the integral kernel, there exists non-negligible correlation between ISW and lensing potential.



High correlation (>0.9) at low multipoles



Simulated ISW

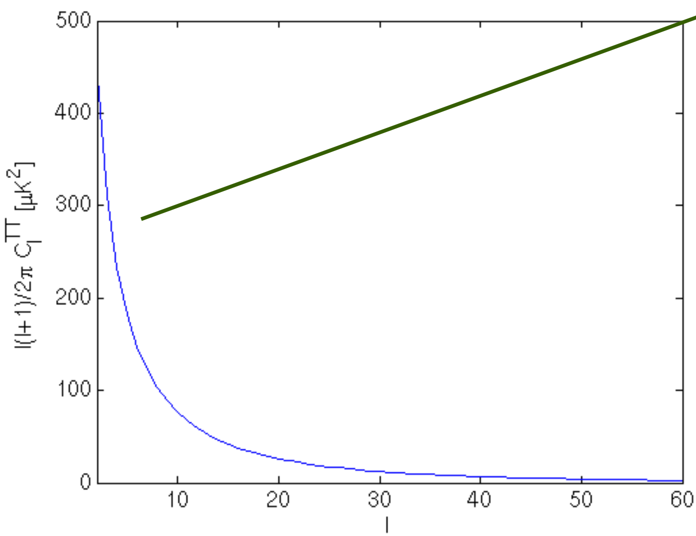


Simulated lensing potential

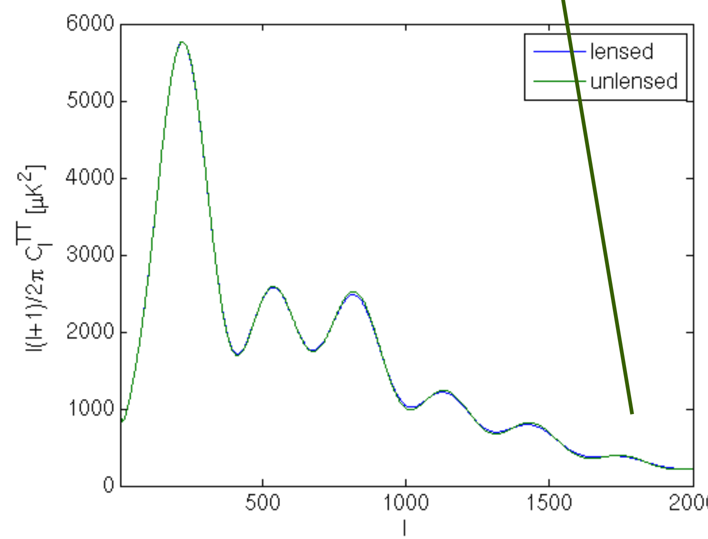
ISW and Lensing bispectrum

Lewis, Challinor, Hanson 2011

$$\langle \tilde{a}_{l_1 m_1} \tilde{a}_{l_2 m_2} \tilde{a}_{l_3 m_3} \rangle \approx \frac{1}{2} \begin{pmatrix} l_1 & l_2 & l_3 \\ m_1 & m_2 & m_3 \end{pmatrix} \begin{pmatrix} l_1 & l_2 & l_3 \\ 0 & 0 & 0 \end{pmatrix} \left(\left(l_2(l_2+1) + l_3(l_3+1) - l_1(l_1+1) \right) C^{T\psi}_{l_2} \tilde{C}^{TT}_{l_3} + 5\, perm \right)$$

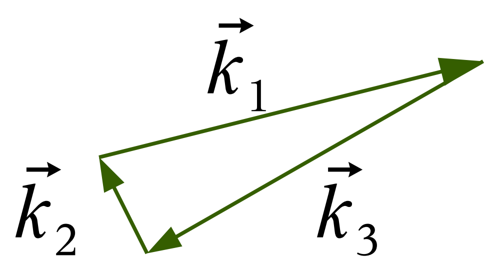


Low l



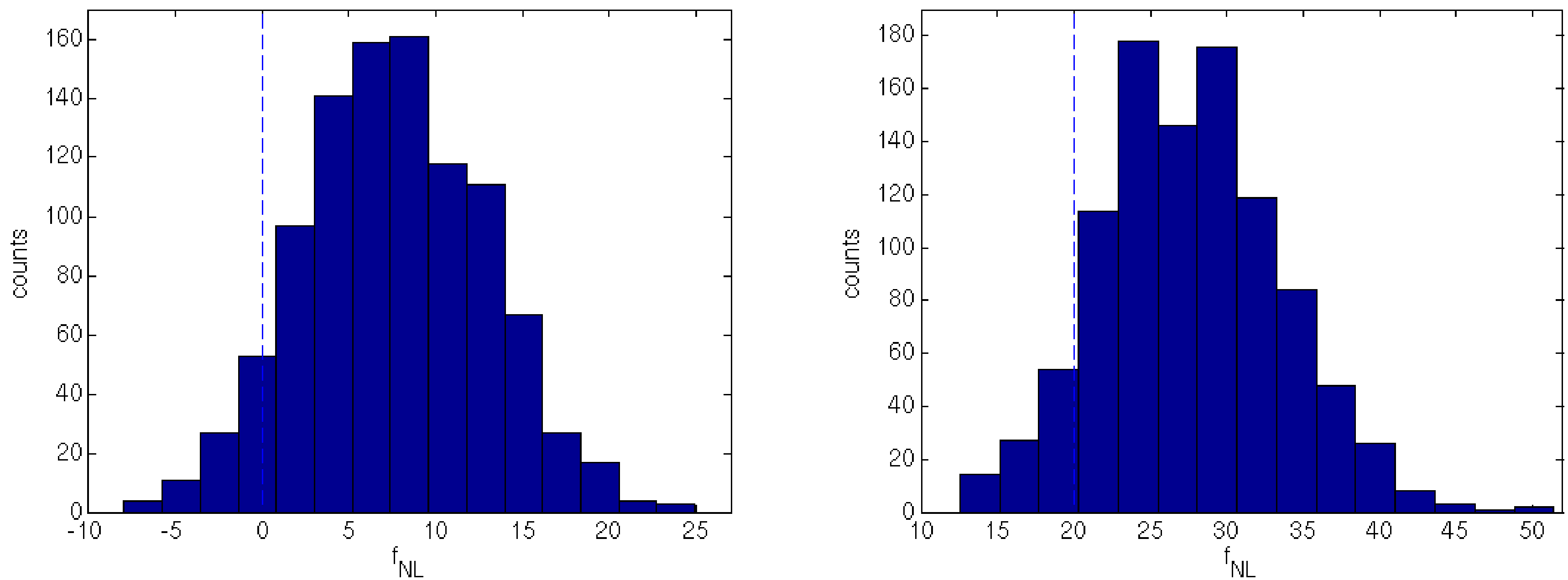
High l

Configuration of the local form primordial non-Gaussianity!!



The expected bias on the local form fNL estimation

	1 sigma	ISW-lensing bias
Planck-like observation	~5	~8
Cosmic Variance limited observation	~2	~20



fNL estimation from 1000 Planck-like lensed simulations with the assumed fNL=0 (left) and fNL=20 (right)

I. Debiasing fNL estimation

Subtracting the theoretical prediction of ISW-lensing bias from the fNL value estimated from real data

$$a_{l_1 m_1} a_{l_2 m_2} a_{l_3 m_3} - \langle a_{l_1 m_1} a_{l_2 m_2} a_{l_3 m_3} \rangle_{\mathrm{ISW,\,lensing}}$$

- Requires very solid understanding on the statistical properties of ISW and Lensing sources
- Realization-specific fluctuation of the ISW-lensing bispectrum

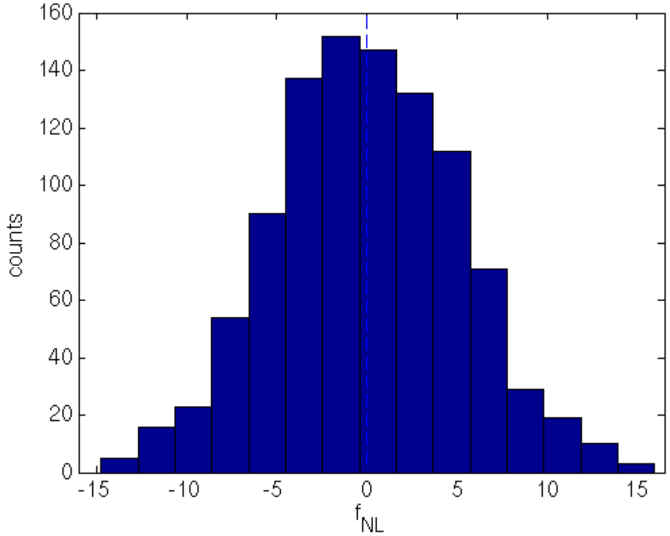
Planck-like observation	No ISW-lensing	ISW-lensing
1 sigma	~5	~5.3

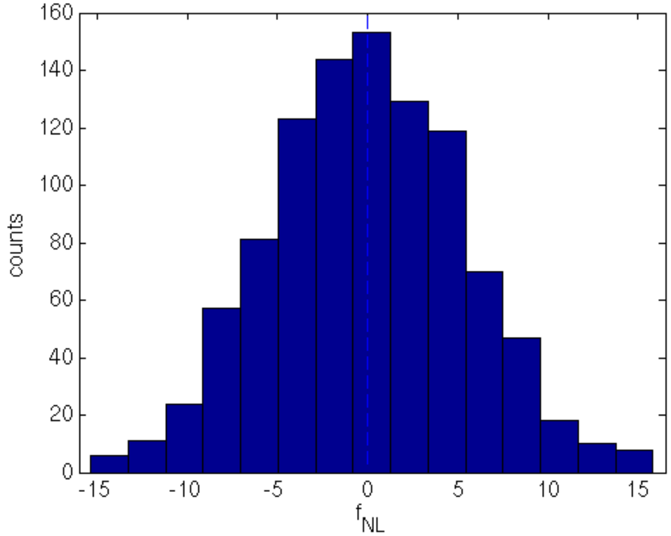
II. Debiasing fNL estimation

Subtracting a realization-specific bias (JK, Rotti, Komatsu in preparation).

$$\sum_{m_1 m_2 m_3} \begin{pmatrix} l_1 & l_2 & l_3 \\ m_1 & m_2 & m_3 \end{pmatrix} a_{l_1 m_1} a_{l_2 m_2} a_{l_3 m_3} - \frac{1}{2} \begin{pmatrix} l_1 & l_2 & l_3 \\ 0 & 0 & 0 \end{pmatrix} \left(\left(l_2(l_2+1) + l_3(l_3+1) - l_1(l_1+1) \right) C_{l_1}^{T\psi} \tilde{C}_{l_3}^{TT} + 5\,perm \right)$$

Estimated from our CMB sky





- Unbiased
- Lower variance
- Model-independent

Planck-like instrument noise	Lensing with no reconstruction noise	Lensing with reconstruction noise
Average of simulations (#1000)	0.01 +- 5.1	-0.004+- 5.4

III. Debiasing fNL estimation

Introducting a substraction term
(Mead, Lewis, King 2010)

$$\hat{a}_{lm} = a_{lm} - \frac{C_l^{T\psi}}{C_l^{\psi\psi}} \psi$$

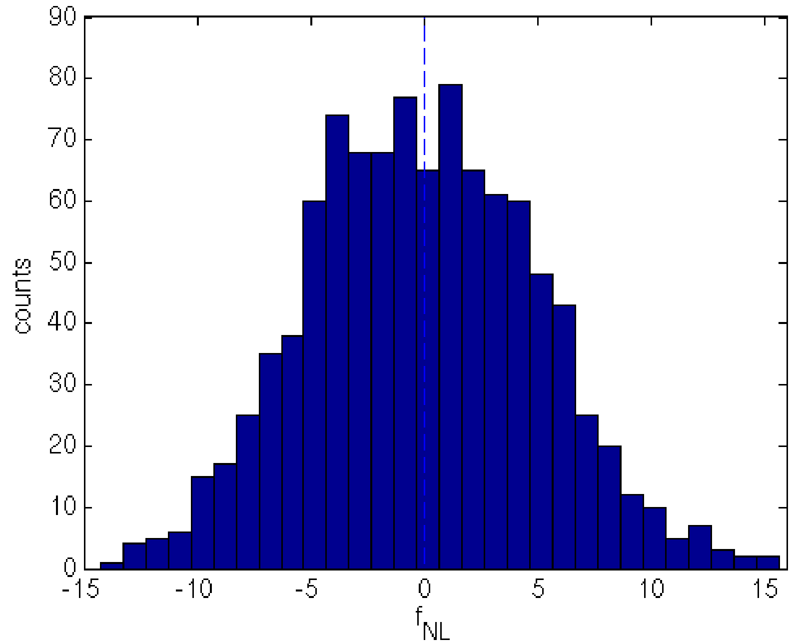
$$\langle \hat{a}_{l_1 m_1} \hat{a}_{l_2 m_2} \hat{a}_{l_3 m_3} \rangle = \langle a_{l_1 m_1} a_{l_2 m_2} a_{l_3 m_3} \rangle_{\mathrm{prim}}$$

$$\mathrm{Var}[\hat{a}_{l_1 m_1} \hat{a}_{l_2 m_2} \hat{a}_{l_3 m_3}] \approx \left(C_{l_1} - \frac{\left(C^{T\psi}\right)_{l_1}^2}{C_{l_1}^{\psi\psi}} \right) \left(C_{l_2} - \frac{\left(C^{T\psi}\right)_{l_2}^2}{C_{l_2}^{\psi\psi}} \right) \left(C_{l_3} - \frac{\left(C^{T\psi}\right)_{l_3}^2}{C_{l_3}^{\psi\psi}} \right)$$

- Unbiased and lower variance

III. Debiasing fNL estimation

When used with external lensing survey of low noise (e.g. Euclid), 1 sigma error is significantly reduced ~5 from ~5.3



fNL estimation from the bispectrum with the subtraction term.

When used with lensing potential reconstructed from CMB data by a quadratic estimator, there is reconstruction error bias (4 point correlation of CMB). However, this effect is well understood, and may be subtracted with better theoretical confidence than ISW-lensing bias.

Summary and prospects

- Coupling between Integrated Sachs Wolfe effect and lensing produces non-negligible bias in the fNL local form non-Gaussianity: ~8 (Planck) and ~ 20 (Cosmic variance limited observation).
- With the future CMB survey, ISW-lensing bias is more and more important, and should be properly taken into account.
- Removing the bias is possible, either by subtracting the ensemble average of the bias. Provided the lensing potential reconstructed from CMB itself or external lensing survey is available, we may remove the realization-specific bias in a model independent way.