CMB lensing-Galaxy 相互相関を用いた Primordial Non-Gaussianity への制限

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Overview

• The primordial non-Gaussianity (NG) affects the clustering of dark matter halo through the **scale-dependent bias**.

• **Recent results** : ***Obs***ervations & ***For***ecasts (1σ error)

Obs. $f_{NL} = 53 \pm 25$ & $f_{NL} = 47 \pm 21$: from NVSS & SDSS DR6 QSOs data (Xia et al. 2010)

For. $\Delta f_{NL} \sim$ 1-5 : cluster counts for DES-like survey (Cunha et al. 2010)

For. $\Delta f_{NL} \sim$ few : CMB Bispectrum with ideal CM experiment

• CMB lensing is a powerful tool to explore the large scale structure, which can get matter distribution without uncertainty of bias.

• Cross correlation between galaxy & CMB lensing can be break some degeneracy of NG and bias.

1.Scale-dependent bias (Dale et al. 2008, Slosar et al. 2008)

Deviations from Gaussian initial conditions are commonly parameterized in terms of the dimensionless f_{NL} parameter

Primordial non-Gaussianity (NG) of the local type

$$\Phi = \phi + f_{\rm NL}(\phi^2 - \langle\phi^2\rangle)$$ (Komatsu & Spergel 2001)

The effect of the primordial NG of the local type is seen in the clustering of halos through a scale-dependent bias

Galaxy power spectrum

Gaussianity　non-Gaussianity

$$P_g(k) = b_0^2 P(k) \rightarrow [b_0 + \Delta b(k)]^2 P(k)$$

$$\Delta b(k) = \frac{3(b_0 - 1) f_{\rm NL} \Omega_m H_0^2 \delta_c}{D(z) k^2 T(k)}$$

b_0 : linear bias
P(k) : matter power spectrum
D(z) : growth factor
T(k) : transfer function

• Primordial NG of the local type gives rise to a strong scale-dependent bias on large scales ($\propto k^{-2}$), while the bias is roughly constant in the Gaussian case.

2.Galaxy-CMB lensing cross correlation signal

• The cross correlations between the CMB and the galaxy are well known as providing additional information other than their respective autocorrelation.

• We introduce the cross correlation between the CMB lensing and the galaxy angular distribution to estimate errors in constraining cosmological parameters.

cross correlation angular power spectrum

$$C_l^{\psi g} = \frac{2}{\pi}\int k^2 dk P(k) \Delta_l^{\psi}(k) \Delta_l^{g}(k)$$

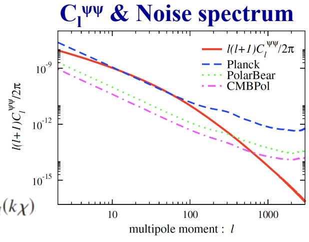
galaxy distribution (counts)

$$\Delta_l^g(k) = \int dz \frac{dN}{dz} b(k,z) T(k) D(z) j_l(k\chi)$$

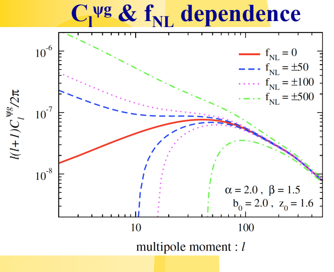
CMB lensing potential

$$\Delta_l^{\psi}(k) = -2\int_0^{\chi_*} d\chi T_{\Psi}(k; \eta_0 - \chi)\left(\frac{\chi_* - \chi}{\chi_* \chi}\right) j_l(k\chi)$$

$C_l^{\psi\psi}$ & Noise spectrum



$C_l^{\psi g}$ & f_{NL} dependence



• Lensing potential ψ can be reconstructed from lensed T, E ,B. (Hu & Okamoto 2002)

• Planck is not sensitive to CMB lensing so much.

• NG rises the power on large scale

• For the high-z and highly biased objects, the effect of NG appears more pronouncedly.

3.Fisher Information Matrix (Tegmark et al. 1997)

• Fisher matrix

$$F_{ij} = \sum_{l=2}^{l_{\rm max}} \sum_{XX',YY'} \frac{\partial C_l^{XX'}}{\partial \theta_i} ({\rm Cov}_l^{-1})_{XX'YY'} \frac{\partial C_l^{YY'}}{\partial \theta_j}$$

Cov_l : Covariance matrix (XX',YY' ∈ TT, EE, TE, ψψ, Tψ, gg, Tg, ψg)

To include ψg, we calculate Cov_l as

Ex.

$${\rm Cov}_{l\,TTTT} = \frac{2}{(2l+1) f_{\rm sky}}\left[(C_l^{TT})^2 + \frac{2(C_l^{TE})^2[C_l^{\psi\psi}(C_l^{Tg})^2 + C_l^{gg}(C_l^{T\psi})^2 - 2C_l^{T\psi}C_l^{Tg}C_l^{\psi g}]}{[(C_l^{\psi g})^2 - C_l^{\psi\psi}C_l^{gg}]}\right]$$

$${\rm Cov}_{l\,\psi g\psi g} = \frac{2}{(2l+1) f_{\rm sky}}\left[\frac{1}{2}[(C_l^{\psi g})^2 + C_l^{\psi\psi}C_l^{gg}]\right]$$

• Marginalized 1σ error : $\sigma(\theta_i) = \sqrt{(F^{-1})_{ii}}$

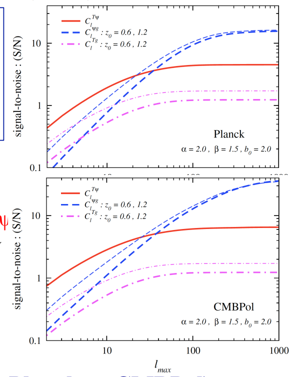
4.Result: Signal to Noise

• Compare the S/N of some cross-correlations

$$\left(\frac{S}{N}\right)^2 = f_{\rm sky}\sum_{2}^{l_{\rm max}}(2l+1)\frac{(C_l^{XY})^2}{(C_l^{XY})^2 + (C_l^{XX} + N_l^{XX})(C_l^{YY} + N_l^{YY})}$$

Survey parameters

• f_{sky} : sky coverage
for galaxy survey ($C_l^{gg}, C_l^{Tg}, C_l^{\psi g}$) - $f_{sky} = 0.10$
for CMB ($C_l^{TT}, C_l^{EE}, C_l^{TE}, C_l^{\psi\psi}, C_l^{T\psi}$) - $f_{sky} = 0.65$
• $N_g = 10^6$: total number of galaxies



• S/N does not increase in high-l_{max}.
=> dominated by noise in small scale region

• For high-l_{max}, ψg get larger S/N than Tg or Tψ

• ψg will get larger S/N by future CMB survey which is more sensitive to CMB lensing (e.g. CMBPol).

• ψg can be an important observation value !!

5.Result: Parameter forecast (for Planck or CMBPol)

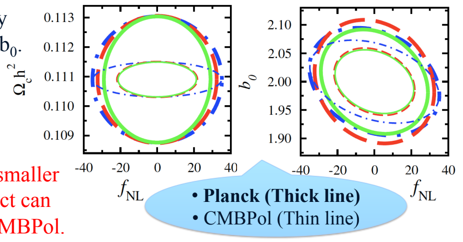
To see the contribution of ψg for construing NG, compare the 3 cases.

• Case I : $C_l^{TT}, C_l^{EE}, C_l^{TE}, C_l^{\psi\psi}, C_l^{T\psi}, C_l^{gg}$, ~~$C_l^{Tg}$~~, ~~$C_l^{\psi g}$~~ (without $C_l^{Tg}, C_l^{\psi g}$)
• Case II : $C_l^{TT}, C_l^{EE}, C_l^{TE}, C_l^{\psi\psi}$, ~~$C_l^{T\psi}$~~, C_l^{gg}, ~~C_l^{Tg}~~, $C_l^{\psi g}$ (without $C_l^{Tg}, C_l^{T\psi}$)
• Case III: $C_l^{TT}, C_l^{EE}, C_l^{TE}, C_l^{\psi\psi}, C_l^{T\psi}, C_l^{gg}, C_l^{Tg}, C_l^{\psi g}$ (full)

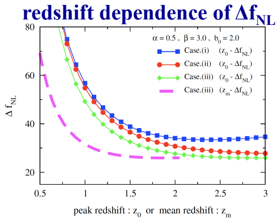
• f_{NL} degenerates especially with linear bias parameter b_0.

• However, f_{NL} does not degenerate with other cosmological parameters so much.

• The error of f_{NL} become smaller by including ψg. This aspect can be seen more clearly for CMBPol.



redshift dependence of Δf_{NL}



• The error of f_{NL} depends extensively on the peak redshift of the galaxy distribution z_0 for small z_0.
=> the effect of NG become large with z_0.

• For large z_0, the cange of Δf_{NL} is small.
=> the amplitude of the matter density is small.

for HSC-like survey

HSC: Hyper-Suprime Cam (Subaru Telescope)

Assuming finite observation time, survey parameters are related as below.

$$z_{\rm m} = 0.9\left(\frac{t_{\rm exp}}{30\ \ {\rm min}}\right)^{0.067}$$

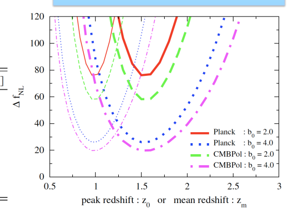
$$n_L = 35\left(\frac{t_{\rm exp}}{30\ \ {\rm min}}\right)^{0.44}\ [{\rm deg}^{-2}]$$

$${\rm area} = \pi\left(\frac{\text{field of view}}{2}\right)^2 \frac{T_{\rm total}}{1.1 \times t_{\rm exp} + t_{\rm op}}$$

(Yamamoto et al. 2007)

Survey parameters

z_0	f_{sky}	n_L [deg^{-2}]
1.0	0.41	0.8
1.3	0.39	4.7
1.4	0.34	7.6
1.5	0.26	12.0
1.6	0.16	18.3
1.7	0.09	27.2
1.9	0.02	56.5
2.2	0.002	148.1

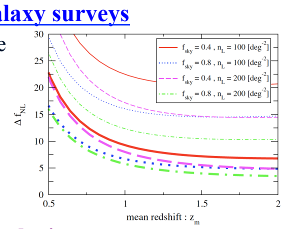


for future wide field galaxy surveys

Future galaxy surveys will be able to observe the wider field and more objects.
=> get larger f_{sky} & N_g (or n_L) .

• Some combinations of the survey parameters (f_{sky}, n_L & z_0) achieve $\Delta f_{NL} < 5$.

• This results are competitive to the CMB Bispectrum or Trispectrum constraints.



6.Summary & Conclusion

• Cross correlation ψg plays an important role to break some degeneracy between f_{NL} and b_0, and to constrain on f_{NL} more tightly.

• It is competitive constraint on f_{NL} CMB higher-order correlation (Bispectrum, Trispectrum, etc…) with ideal CMB observation.

• The constraint through the scale-dependent bias is sensitive only to the local-type NG. For the constraints on the other NG models, we must consider higher-order correlation.