CMB Polarization-assisted Correction for the Integrated Sachs-Wolfe Effect

Guo Chin Liu, Kin-Wan Ng and Ue-Li Pen

Abstract

Integrated Sachs-Wolfe (ISW) effect can be estimated by cross-correlating Cosmic Microwave Background (CMB) sky with large-scale structure. The cross-correlation signal has positive power on large angular scales and can be used to study dark energy. However, a significant noise is resulted from spurious cross-correlation of the CMB anisotropies generated from the recombination and reionization epochs. Using information of CMB polarization to suppress the spurious correlation is proposed.

Integrated Sachs-Wolfe Effect

As CMB photons propagate through a gravitational potential generated by large scale structures in the expanding Universe, the photons undergo an energy shift[1]. It produces temperature perturbations

$$\frac{\delta T(\hat{n})}{T_0} = -2\int_0^{\eta_{dec}} d\eta \frac{d\Phi}{d\eta}(\eta\hat{n}).$$

η Conformal time

Φ Gravitational potential

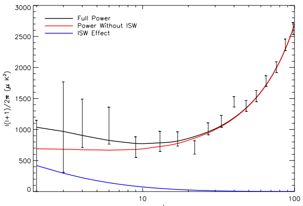


Figure. 1. Power spectra of temperature anisotropies. We show the full power (black), power without ISW effect (red) and power for late ISW (Blue) only. The error bars come from WMAP 7-year results. The ISW effect manifests itself on large angular scales because the CMB temperature fluctuations are dominantly induced by gravitational potential at large scales.

Integrated Sachs-Wolfe Effect and Dark Energy

In a matter-dominated universe, the gravitational potential stays a constant, so the CMB temperature fluctuations are not generated. However, the existence of a spatial curvature or dark energy results in a time-varying gravitational potential, thus producing a time-integrated temperature fluctuations of the CMB. Therefore, the detection of the late-time ISW effect in a flat universe can be regarded as direct dynamical evidence for dark energy.

Cross-correlation between CMB and matter

A positive large-scale correlation signal may occur by correlating the CMB sky with the local matter distribution as a result of the ISW effect. This idea was first explored by Crittenden and Turok[2] (1996). And first detection is claimed by Bought and Crittenden[3] (2004), who use the CMB data from WMAP and large scale structure from the X-ray background and distribution of radio galaxies.

Problem of the cross-correlation

A significant uncertainty in the cross-correlation is coming from the spurious correlation of matter distribution with the primary CMB anisotropies generated from the recombination and reionization epochs. It plays a role like the cosmic variance in observations of the low multipoles of the CMB anisotropy that have only a few independent modes. This spurious correlation obscures the measurement of the true correlation that we are interested in and indeed weakens the constraint on the dark energy component.

Purpose of the work

CMB polarization is also generated when the primary anisotropies are scattered by free electrons in the early universe. Using the fact that the ISW effect occurs at relatively late times, the information imprinted on the CMB polarization may give an opportunity to separate the ISW effect from the primary anisotropies.

Method and formulae

We assume the relation between E-mode polarization E and temperature T

$$E_l^{NOISW} = a_l T_l^{NOISW} + n_l, \qquad (1)$$

where the n_l plays a role like "noise" and a_l quantifies the amount of correlation between E polarization and temperature anisotropies. Then we estimate the temperature after the E-mode corrected temperature anisotropies as

$$\tilde{T}_l = T_l - \frac{E_l}{a_l} \approx T_l - \frac{E_l^{NOISW}}{a_l} \times \frac{\langle TT\rangle_l}{\langle TT\rangle_l + n_l^2/a_l^2}.$$

We cross-correlate and auto-correlate eq. (1) then obtain

$$\langle TE\rangle_l^{NOISW} = a_l \langle TT\rangle_l^{NOISW}$$
$$\langle EE\rangle_l^{NOISW} = a_l^2 \langle TT\rangle_l^{NOISW} + n_l^2$$

We can then calculate the sets n_l and a_l using these equations, given the power spectra C_{Tl}, C_{El} and C_{Cl}.

Reference

1. Sachs, R. K., & Wolfe, A. M. 1967, ApJ, 147, 73
2. Crittenden, R. G., & Turok, N. 1996, PRL, 76, 575
3. Boughn, S. P., & Crittenden, R. G. 2004, Nature, 427, 45

Test of the subtraction

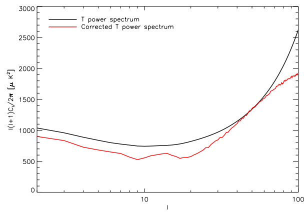


Figure 2. Power spectrum of the CMB temperature anisotropies after the correction by the E-mode polarization (Red) and total power spectrum (Black). Using information polarization, we can filter out the part of the signal coming from the early universe.

Application to WMAP and NVSS data

CMB data:

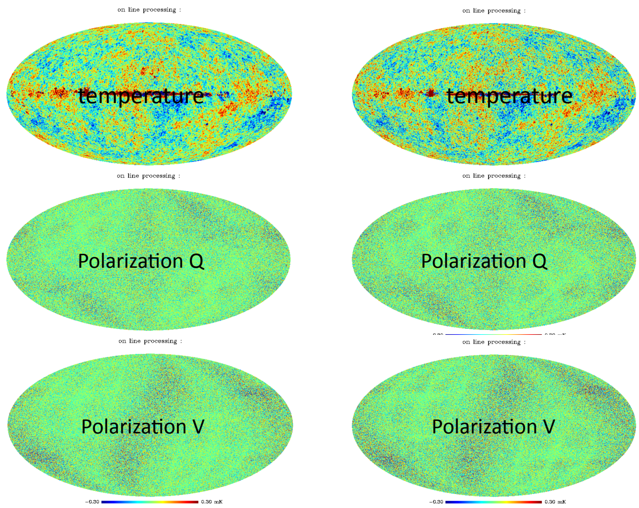
WMAP Coadded 7-year data.

Foreground reduced I, Q, U maps

Frequency: Q (41 GHz) and V (61 GHz) bands

Q band

V band

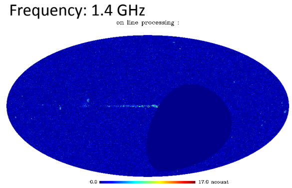


Matter tracer:

NRAO VLA Sky Survey

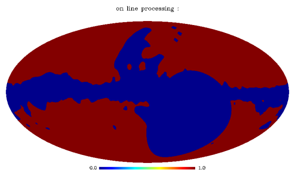
Sky covering: north of -40 dec

Frequency: 1.4 GHz



Mask:

CMB polarization analysis mask + NVSS blank sky



Results

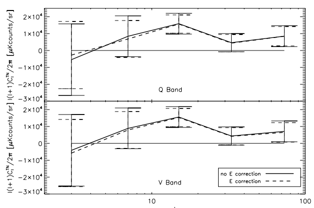


Figure 3. Cross-correlation of WMAP and NVSS for Q and V frequency bands. The error bars are calculated by cross-correlated 500 simulated CMB skys with NVSS catalog. Using E-polarization, the error bars and signal of cross-correlation are changed.

Using the E-mode correction, we found

1. The errors are improved by 6%, 9,5%, 12.3%, 4.9% and 7.3% for the five bins.
2. The detection of the correlation signal is improved. The χ^2 values are increased from 9.8 to 11.7 for Q band and 9.0 to 10.6 for V band.