

Research Summary

Hongbo Cai

Supervisor: Arthur Kosowsky

Department of Physics and Astronomy, University of Pittsburgh

I. LENSING RECONSTRUCTION ON THE CURVED SKY

Cosmic Microwave Background(CMB) photons are gravitationally lensed by the large scale mass distribution. We can use a first order perturbation to describe this effect which is called weak gravitational lensing of CMB. CMB temperature map(T) and polarization map(E,B) are distorted by (what is gravitational lensing) Weak gravitational lensing for the microwave background anisotropies (dark matter) in the projected gravitational potential (primordial gravitational waves)

There are several aspects where we see weak gravitational lensing effects on CMB. 1.Weak gravitational lensing modulates CMB temperature and polarization power spectra(2 point power spectrum). Statistical anisotropy is induced. 2.Lensing of CMB fields produces higher-order correlations between the multipole moments. Off-diagonal mode-coupling between map harmonics can be seen. The off-diagonal mode coupling is proportional to lensing potential.[1] 3.It generates B-mode polarization signal which confuses the signal from primordial gravitational waves.[2]

The lensing signal can help separate primordial gravitational waves(delensing) which can generate B-mode before the last scattering surface. It can also be used to help constrain cosmological parameters and lensing mass distribution. Thus, it is important to study weak gravitational lensing of CMB.

To obtain projected gravitational potential(lensing potential) and therefore the projected mass, we can take quadratic combinations of CMB fields. This process is called lensing reconstruction which is a story of measuring lensing.

I will outline

Since lensing is most sensitive to the projected potential at $L < 10^2$ or several degrees on the sky, we need consider the curvature of the sky.

In the section, I will present how to treat consistently the effect of gravitational lensing on CMB temperature and polarization maps by constructing the full sky quadratic estimators

of lensing potential and their noise. And I will introduce the simulation of lensed I will give preliminary results of my calculation

Deriving the full sky minimum variance quadratic estimators of lensing potential from CMB temperature and polarization fields.

My work of this part is mainly about: I am a member of both ACT and Simons

II. BIAS TO CMB LENSING RECONSTRUCTION FROM TEMPERATURE ANISOTROPIES DUE TO REIONIZATION KSZ

In this work, I am investigating a bias to CMB lensing reconstruction from temperature anisotropies due to the reionization kSZ effect. kSZ effect is short for kinematic Sunyaev-Zel'dovich effect, which is the Doppler shift of CMB photons induced by Compton-scattering off moving electrons.[3] The kSZ signal has its own intrinsic non-Gaussianity and its correlation with CMB lensing field is non-zero.[4]. The kSZ signal can bring bias to CMB lensing field. Plus, the kSZ effect preserves the blackbody spectrum of CMB which means it cannot be removed by multifrequency separation techniques.[5]

kSZ anisotropies can be produced when there are large fluctuation in electron density. There are two epochs when they can be produced: 1.a “late-time” contribution from redshifts $z < 3$ when inhomogeneities are large due to gravitational growth of structure 2. earlier during the epoch of reionization when hydrogen gets ionized again by the ultraviolet radiation of the first structures and the fluctuation electron density are caused by the fluctuations in the ionization fraction.[3] [6]

1.understand terms and calculations[3] [6] 2.why the ksz signal due to fluctuations in the ionization fraction during reionization can cause a detectable squeezed limit trispectrum.[4]

Next generation ground-based CMB experiments

? Compton scattering and Thomson scattering: Thomson scattering is the elastic scattering of electromagnetic radiation by a free charged particle, as described by classical electromagnetism. It is the low-energy limit of Compton scattering: the particle's kinetic energy and photon frequency do not change as a result of the scattering. This limit is valid as long as the photon energy is much smaller than the mass energy of the particle: , or equivalently, if the wavelength of the light is much greater than the Compton wavelength of the particle.

Reionization: At a redshift of about 10, hydrogen gets ionized again by the ultraviolet

radiation of the first structures kSZ:

tSZ effect: CMB photons interact with electrons that have high energies due to their temperature
 kSZ effect kSZ anisotropies: are produced in cosmological epochs during which there are large fluctuations in the electron density. ? (physical image) “kSZ” is used to refer to any blackbody temperature fluctuation arising from bulk motion integrated along the line of sight, including the Doppler effect.

? We refer to the Doppler effect as responsible for large-angle kSZ anisotropies. ? bulk velocity

To lowest order (in both optical depth and velocity), the kSZ effect produced only temperature anisotropies, not polarization anisotropies.

late-time kSZ: are present in galaxies and clusters due to the non-linear growth of structure
 reionization kSZ: fluctuations in the electron density field are due to fluctuations in the ionization fraction, are also expected to be correlated with the matter density field and hence with CMB lensing.

? non-linear growth of structure ? separation of “late-time” ksz and “reionization ksz”
 ? addition of “reionization ksz” map and “temperature” map ? how do I tell the difference between “late-time” kSZ and “reionization” kSZ?

? model of reionization kSZ ? CMB unlensed and lensed simulations ? websky reionization kSZ simulation and late-time kSZ(Dr.Trac might ask about this)

CMB-S3 and CMB-S4 lensing for a Stage 4 CMB experiment Their results have neglected the kSZ signal from reionization. kSZ signal due to fluctuations in the ionization fraction during reionization can bring a detectable bias(squeezed limit trispectrum) I am working on simulating the bias to lensing reconstruction from reionization kSZ effect.

As a member of both the Atacama Cosmology Telescope (ACT) and the Simons Observatory (SO), I am actively involved in the research and analysis projects in the collaborations. A short summary of each of my involvements is listed below.

Future

[1] Wayne Hu and Takemi Okamoto. Mass reconstruction with cmb polarization. *Astrophys. J.*, 574:566–574, 2002. doi:10.1086/341110.

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- [4] Kendrick M. Smith and Simone Ferraro. Detecting Patchy Reionization in the Cosmic Microwave Background. *Phys. Rev. Lett.*, 119(2):021301, 2017. doi:10.1103/PhysRevLett.119.021301.
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- [6] Marcelo A. Alvarez. The Kinetic Sunyaev–Zel’dovich Effect From Reionization: Simulated Full-sky Maps at Arcminute Resolution. *Astrophys. J.*, 824(2):118, 2016. doi:10.3847/0004-637X/824/2/118.