Detecting Inflationary Gravitational Waves by Realizing Removal of Lensing Contaminants in Cosmic Microwave Background B-modes

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I present my recent efforts on establishing methodology for removing lensing noise (delensing) to detect primordial gravitational waves (GWs) from cosmic microwave background (CMB). One of the promising cosmological probes in the next decades is the twisting pattern in the CMB polarization map (B-modes) which will be a unique way to explore the early universe through GWs. In this poster, I show successful delensing algorithm which works even in practical situations for the Simons Observatory such as the presence of inhomogeneous noise and masking. The expected constraints on the amplitude of the primordial GWs by delensing would be improved by a nearly factor 2 compared to that without delensing.

Simons Observatory (early 2020s)

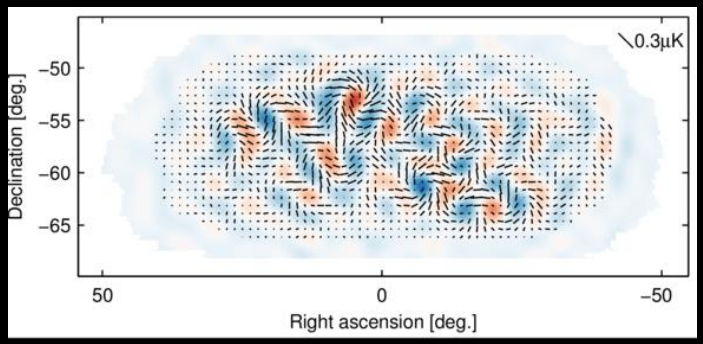
(2020s)

- Inflation is a quasi-exponential expansion at the very early stage of the Universe to solve the problems in the initial condition (singularity, horizon, flatness, etc)
  (e.g. Starobinsky '79, Guth '81, Sato '81, Linde '81)
- Quantum vacuum fluctuations during inflation give the initial condition for all the structures in the Universe we can observe (galaxies, CMB, etc)
- However, the presence of primordial GWs, one of the important predictions of inflation, is not yet tested

One of the main goals in ongoing/future CMB experiments is to detect inflationary GWs

Probing Inflationary GWs from Large-Scale B-modes

- GWs impart a characteristic twisting pattern in polarization map, the so-called B-modes

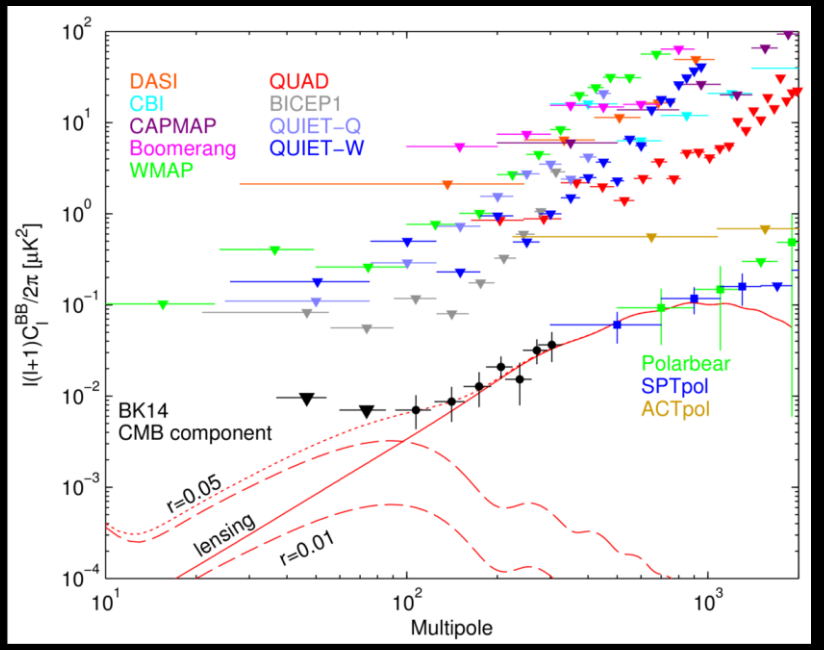


(BICEP2/Keck Collaboration 2016)

- So far, the GW amplitudes characterized by a parameter, r, have been constrained by multiple CMB polarization measurements

$$r < 0.072\ (2\sigma)$$

(BICEP2/Keck Collaboration 2018)



(BICEP2/Keck Collaboration 2016)

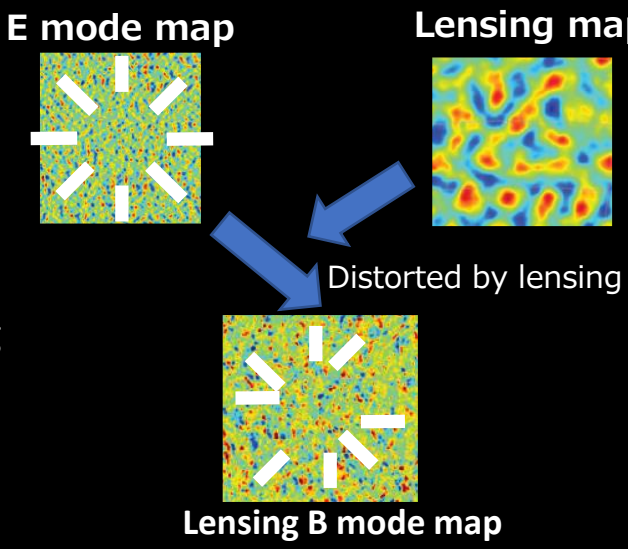
Problem: lensing also produces B-modes which becomes a noise for inflationary GW searches

- Lensing noise already limits the constraints on primordial GWs in ongoing experiments
- Mitigating lensing B mode contaminants will be important to improve sensitivity to primordial GWs in ongoing/future CMB experiments
- In Simons Observatory, ~60-70% of lensing should be removed for a nearly factor of 2 improvement on error on r

Delensing

Lensing B-modes & delensing

- During propagation of CMB photons, lensing distorts polarization patterns and part of E-modes are converted into B-modes which we observe as lensing B-modes.
- Therefore, for given E-modes and lensing maps, we can estimate lensing B-modes by distorting observed E-modes and lensing map measured within CMB experiments, with appropriate Wiener filtering
- This process, delensing, reduces scatter from lensing B-modes and improve constraint on the amplitude of GWs, r

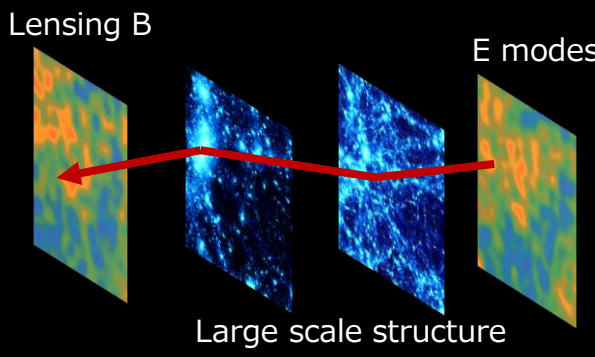


Multi-Tracer Delensing

- In addition to CMB data, external data such as galaxy clustering can be also used to estimate lensing map

  Galaxy number density ≃ matter density fluctuations ≃ gravitational potential

- Mass tracers at higher redshifts are better to efficiently remove lensing since the lensing effect on CMB occurred mostly at high redshifts

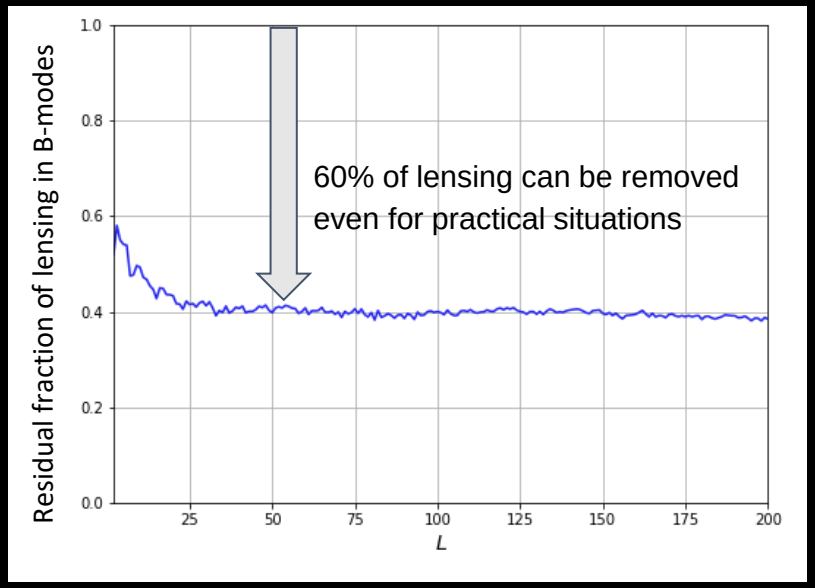


The concept of delensing is simple but multiple issues exist in practice, such as mode-mixing induced by masking, inhomogeneous instrumental noise, astrophysical uncertainties in mass tracers

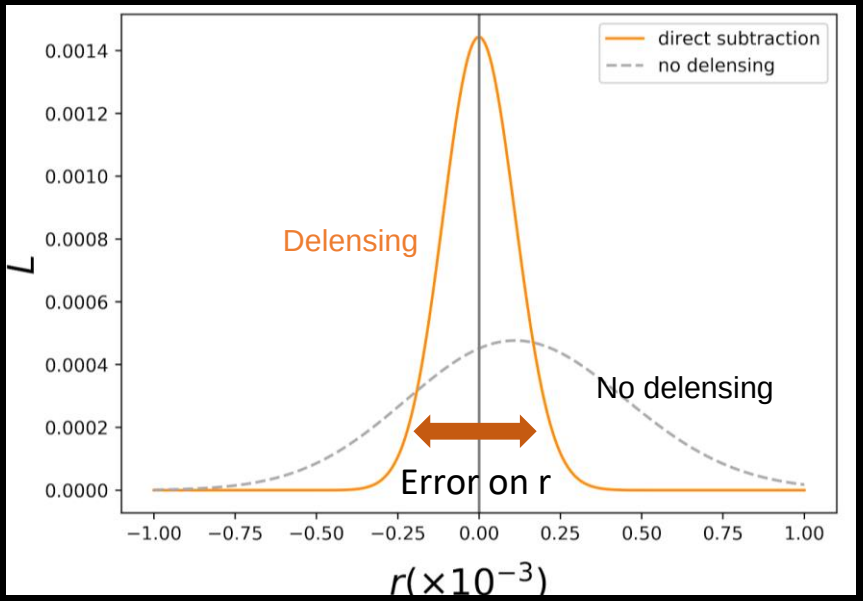
Development of Delensing Algorithm for Simons Observatory

- We have developed a delensing methodology for Simons Observatory which utilizes CMB, galaxy surveys and cosmic infrared background (CIB) and mitigates masking effect/instrumental noise inhomogeneities

<u>Our SO delensing pipeline gives close to idealized performance</u>



* This can be improved to 63% for the goal sensitivity



Credit: Naomi Robertson

- Bias from residual galactic dust in CIB negligible, assuming multifrequency cleaning is applied to E-modes, and that from CIB higher-order correlations is also negligible after masking point sources

by Anton Baleato

- Uncertainties in mass-tracers can be further constrained by auto/cross spectra
- Our methodology can be extended to a space mission, LiteBIRD