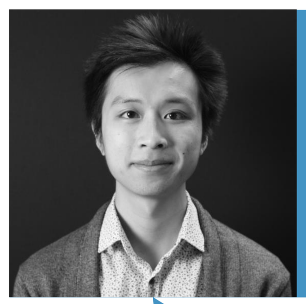
Estimating the Effects of Weak Gravitational Lensing on the Cosmic Microwave Background using Local Statistics



That's me!

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The cosmic microwave background and weak gravitational lensing

Why do we care about CMB lensing?

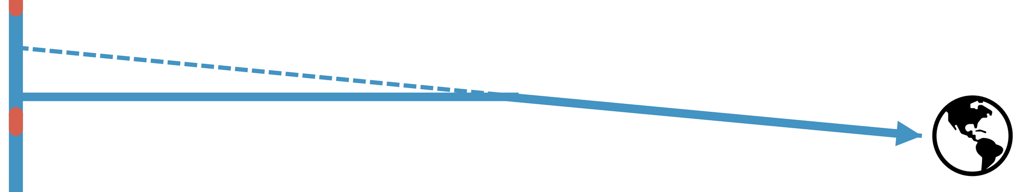
- Models of dark matter make predictions about the formation of compact structures.

Example:

- Their abundance sets the extent of lensing effects.
- The CMB travels through every compact structure since recombination.
- CMB lensing can be observed at all lines-of-sight.

How does lensing affect the CMB?

- Weak gravitational lensing re-maps the CMB temperature field with respect to the lensing potential (ψ).



- Features can be magnified or de-magnified.
- Statistically, lensing alters the distribution of anisotropies.
- Effects are dominant at small angular scales

Previously

- Detections have taken advantage of additional correlations introduced by CMB lensing.
- These methods are currently sub-optimal for determining the effects of lensing at small angular scales (< 3 arcmin).
  - High resolution CMB maps (20 arcseconds), and
  - Low noise levels (0.5 μK-arcmin) would be optimal.

Goals

- Construct an estimator for the effects of CMB lensing at < 3 arcmin.
- Characterize its ability to quantify lensing statistics at small scales in comparison to an all-sky average estimate.

Determining local lensing statistics in the cosmic microwave background

Estimator principles

- We will take advantage of the CMB temperature re-mapping. A first order Taylor expansion reveals:

$$T_{\text{lens}}(\hat{n}) = T_{\text{CMB}}(\hat{n}) + \vec{\nabla}\psi \cdot \vec{\nabla} T_{\text{CMB}}$$

Lensing potential

- And statistically (over the entire sky) at small scales:

$$\langle T^2_{\text{lens}} \rangle \sim \langle T^2_{\text{CMB}} \rangle + \left\langle \left|\vec{\nabla}\psi\right|^2 \right\rangle \left\langle \left|\vec{\nabla} T_{\text{CMB}}\right|^2 \right\rangle$$

We can observe these directly!

Can we do better than an all-sky average?

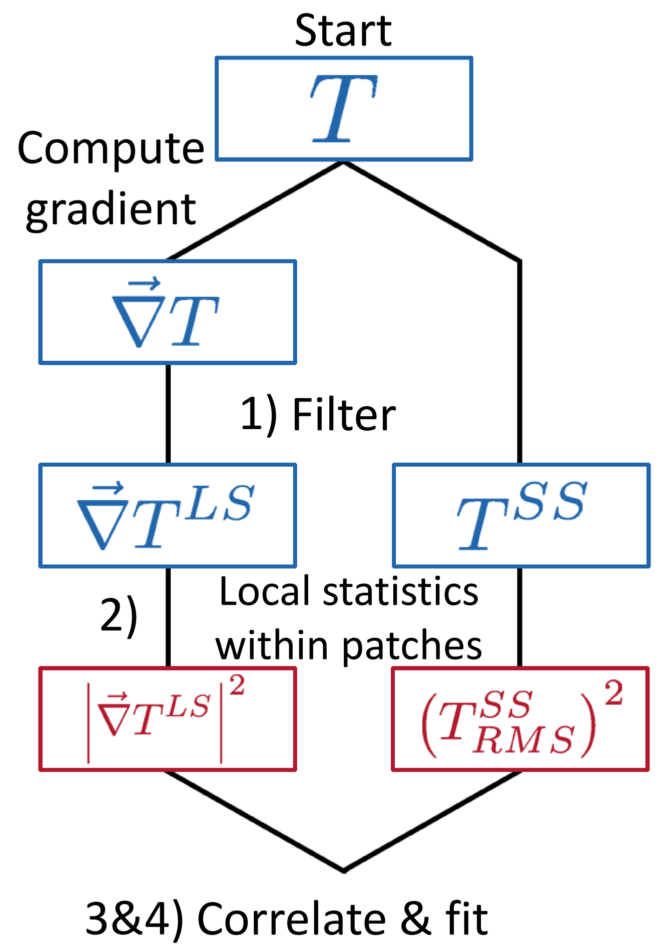
- We construct patches on the sky containing sub-pixels used to determine local lensing observables.
- A large sample of local measurements can out-perform an all-sky average.

Reduction pipeline

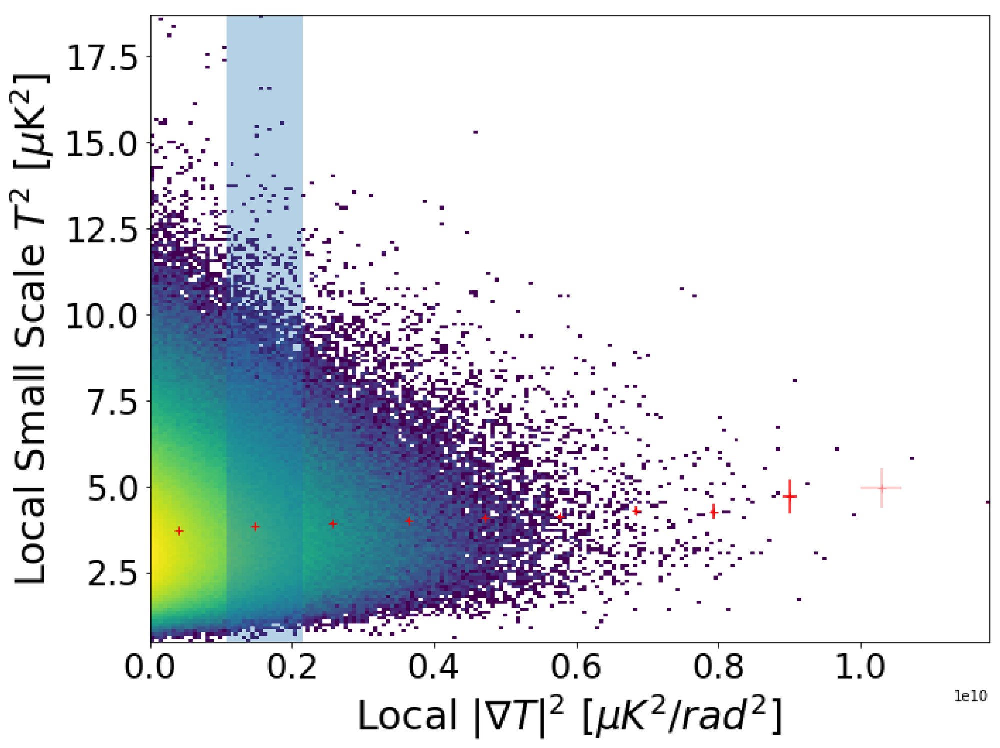
- Start with a CMB temperature map

Objectives:

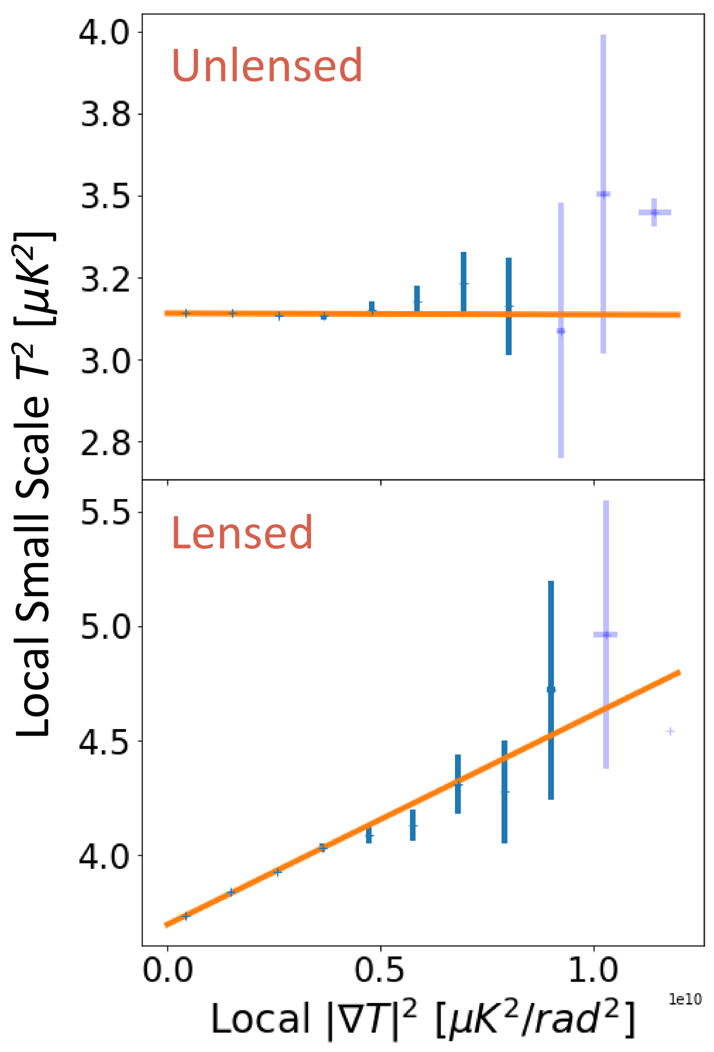
1) Filter maps to select for lensing effects.
2) Compute local statistics by grouping pixels into local patches.
3) Correlate gradient and temperature maps.
4) A linear relation reveals:
   - A slope (lensing deflection), and
   - An intercept (original CMB variations + non-lensing).



Estimator characterization and outlook



Above: Distribution of local lensing statistics from patches of a simulated lensed CMB.



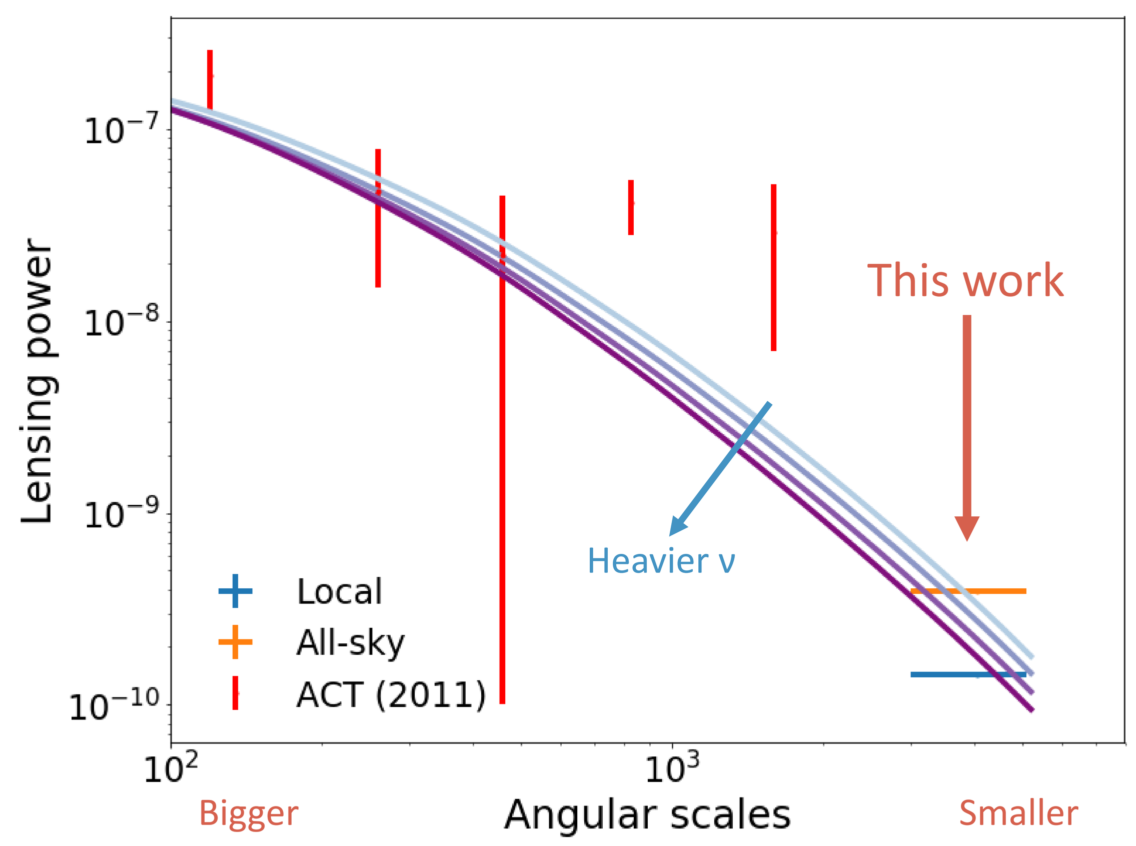
Left: Best fit lines for the binned distributions of local lensing statistics from unlensed and lensed simulated CMB temperature maps.

Current results

- The non-zero correlation for the lensed case is a **clear detection of lensing at small angular scales.**
- We find a **30σ detection** with realistic foregrounds and noise levels.

Future steps

- Further characterize the estimator by applying it to different simulated CMB maps.
- Apply local statistical estimators to other CMB secondaries such as the kinetic Sunyaev-Zel'dovich effect.



Above: Comparison of predicted lensing power from different neutrino masses.

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