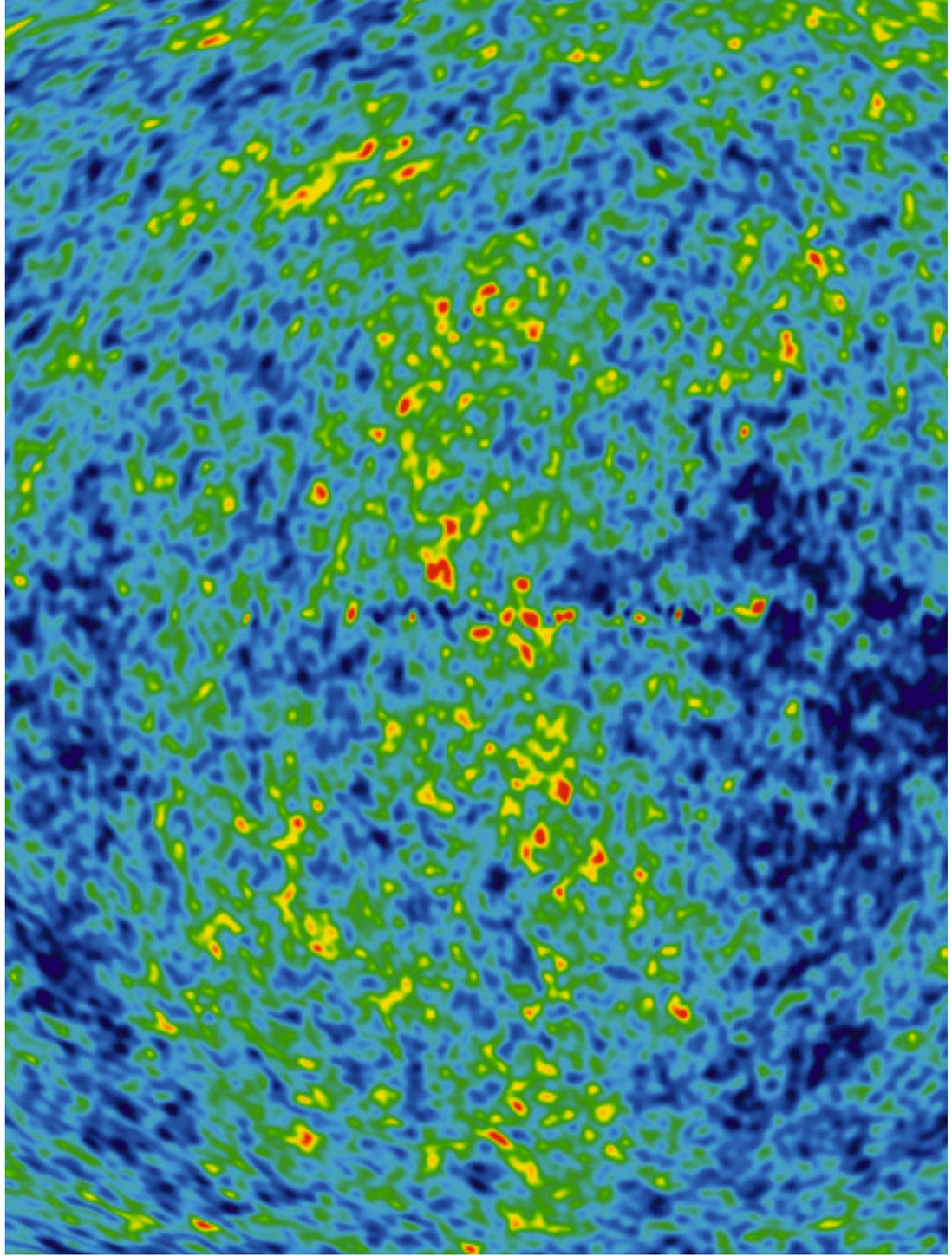


OPTIMAL ESTIMATORS FOR CLUSTER MASSES USING CMB LENSING FOR CMB S4

Sayan Saha

[Final year PhD Student at IISER Pune]

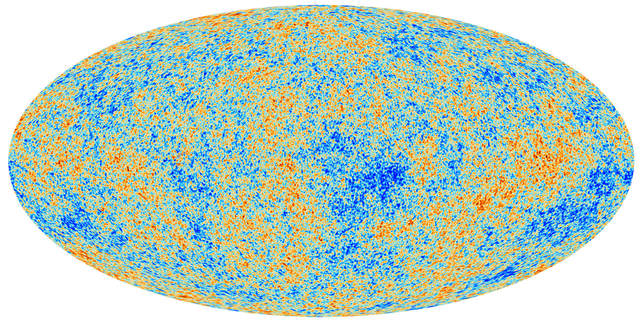
CMB-S4 Spring Collaboration Meeting, JSAC Talk

27 March 2024

PROLOGUE!

PROLOGUE!

- CMB tells us about the primordial universe



Credit: ESA, Planck

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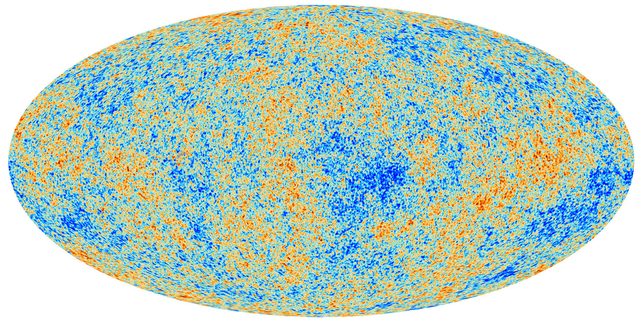
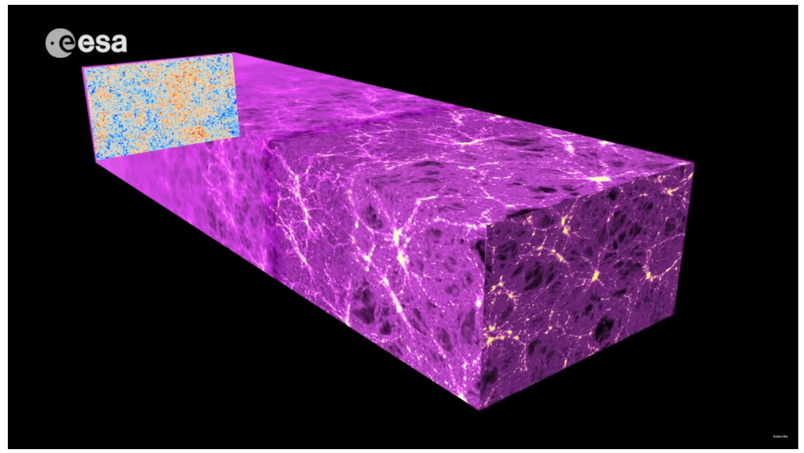


Credit: ESA, Planck

- CMB also tells us about the Late-time Universe through weak lensing



Credit: ESA YouTube Channel

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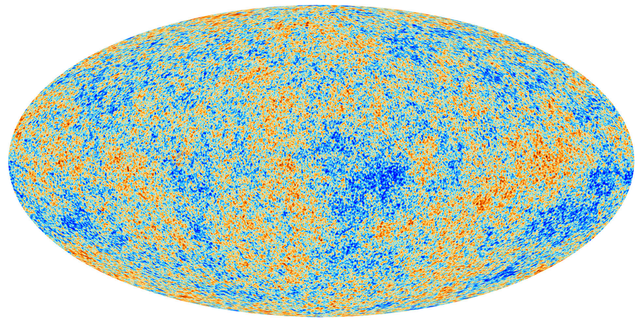

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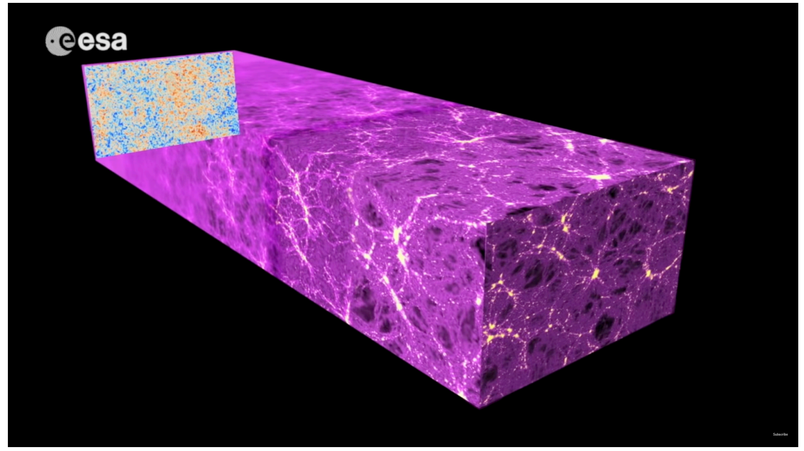


Credit: ESA YouTube Channel

TO PROBE CLUSTERS

PUBLICATION AND THE COLLABORATORS

Cluster profiles from beyond-the-QE CMB lensing mass maps

Sayan Saha,[1,2,3,*] Louis Legrand,[1,4,†] and Julien Carron[1,‡]

[1] *Université de Genève, Département de Physique Théorique et CAP, 24 Quai Ansermet, CH-1211 Genève 4, Switzerland*
[2] *Department of Physics, Indian Institute of Science Education and Research, Pune 411008, India*
[3] *Raman Research Institute, C. V. Raman Avenue, Sadashivanagar, Bengaluru 560080, India*
[4] *Instituto de Física Teórica da Universidade Estadual Paulista and ICTP South American Institute for Fundamental Research, R. Dr. Bento Teobaldo Ferraz, 271, Bloco II, Barra-Funda - São Paulo/SP, Brasil*

Clusters of galaxies, being the largest collapsed structures in the universe, offer valuable insights into the nature of cosmic evolution. Precise calibration of the mass of clusters can be obtained by extracting their gravitational lensing signal on the Cosmic Microwave Background (CMB) fluctuations. We extend and test here the performance achieved on cluster scales by the parameter-free, maximum a posteriori (MAP) CMB lensing reconstruction method, which has been shown to be optimal in the broader context of CMB lensing mass map and power spectrum estimation. In the context of cluster lensing, the lensing signal of other large-scale structures acts as an additional source of noise. We show here that by delensing the CMB fluctuations around each and every cluster, this noise variance is reduced according to expectations. We also demonstrate that the well-known bias in the temperature quadratic estimator in this regime, sourced by the strong non-Gaussianity of the signal, is almost entirely mitigated without any scale cuts. Being statistically speaking an optimal and blind lensing mass map reconstruction, the MAP estimator is a promising tool for the calibration of the masses of clusters.

Julien Carron

Louis Legrand

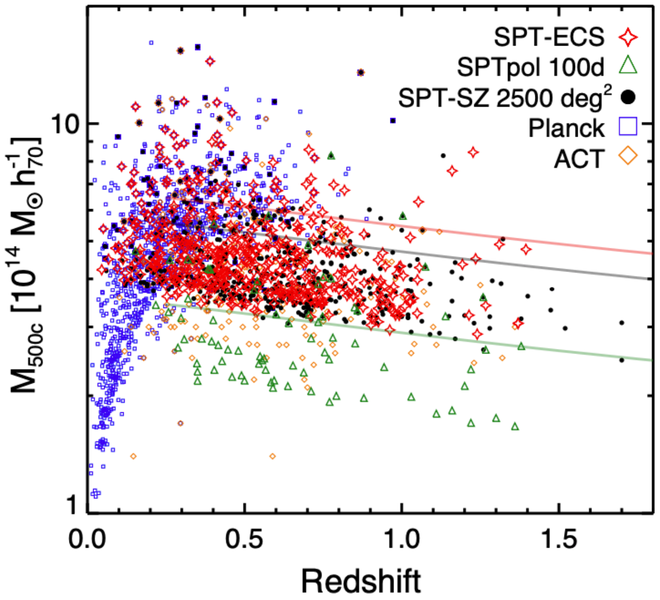
arXiv: 2307.11711,
JCAP 01 (2024) 024

MOTIVATION BEHIND COSMOLOGY WITH CLUSTERS

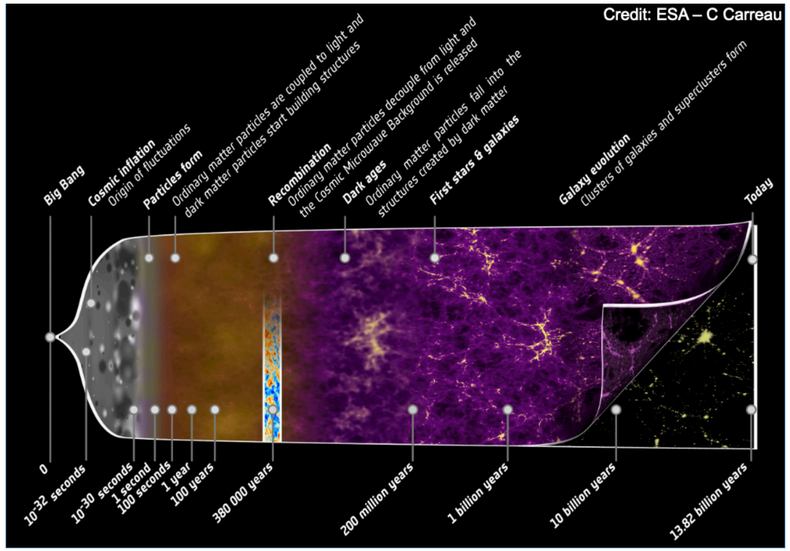
- Cluster abundances Cosmology

$$\left(\frac{dN}{dMdVdz}\right) \longrightarrow$$

COSMOLOGICAL CONSTRAINTS



Bleem et al. (2020) [SPTPol]



- This history sets bounds on how small and how large a collapsed object can be.
- Uncertainties in cluster mass measurements affects our understanding of the cosmic expansion history

HOW MASS OF CLUSTERS COMES TO THE PICTURE?

- The gravitational lensing signature is directly sensitive to the mass of clusters.

galaxy cluster SMACS 0723
Credits: NASA, ESA, CSA, and STScI

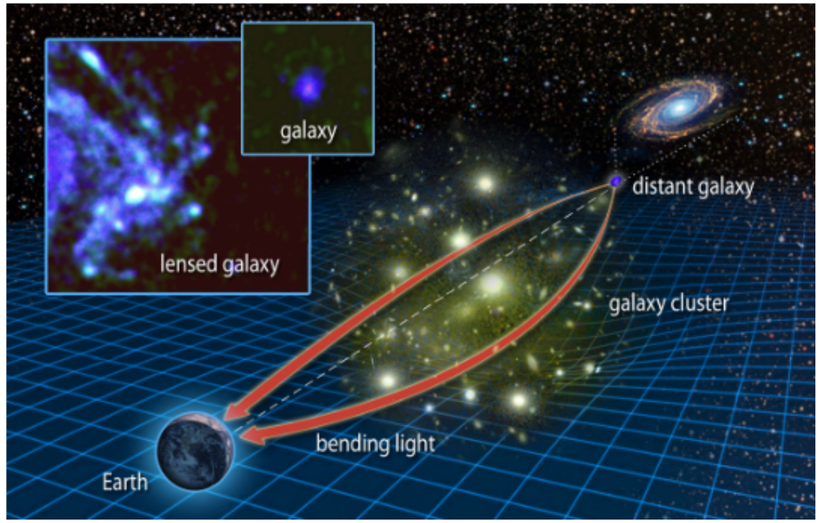


Image credit: Karen Teramura

- The mass profile of the clusters can be studied through:

1. Strong Lensing distortions of Galaxies
2. Weak Lensing distortions of Galaxies
3. CMB Lensing by the galaxy clusters

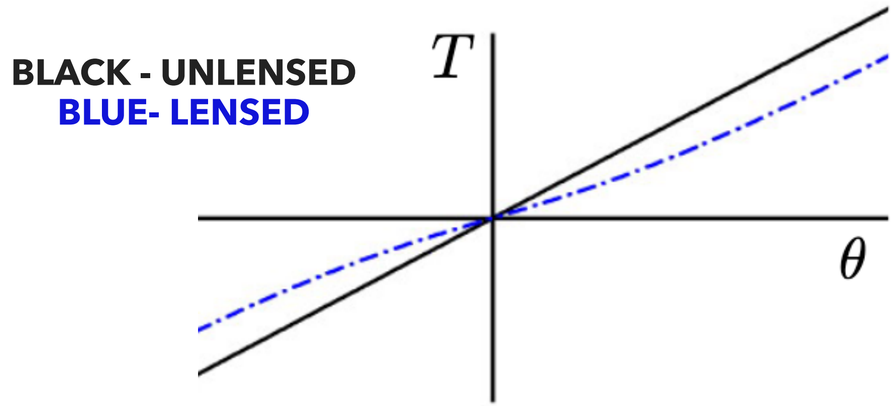
CMB LENSING BY GALAXY CLUSTERS

- The lensing of CMB conserves the surface brightness.

  So if CMB is uniform, the lensing cannot be detected.

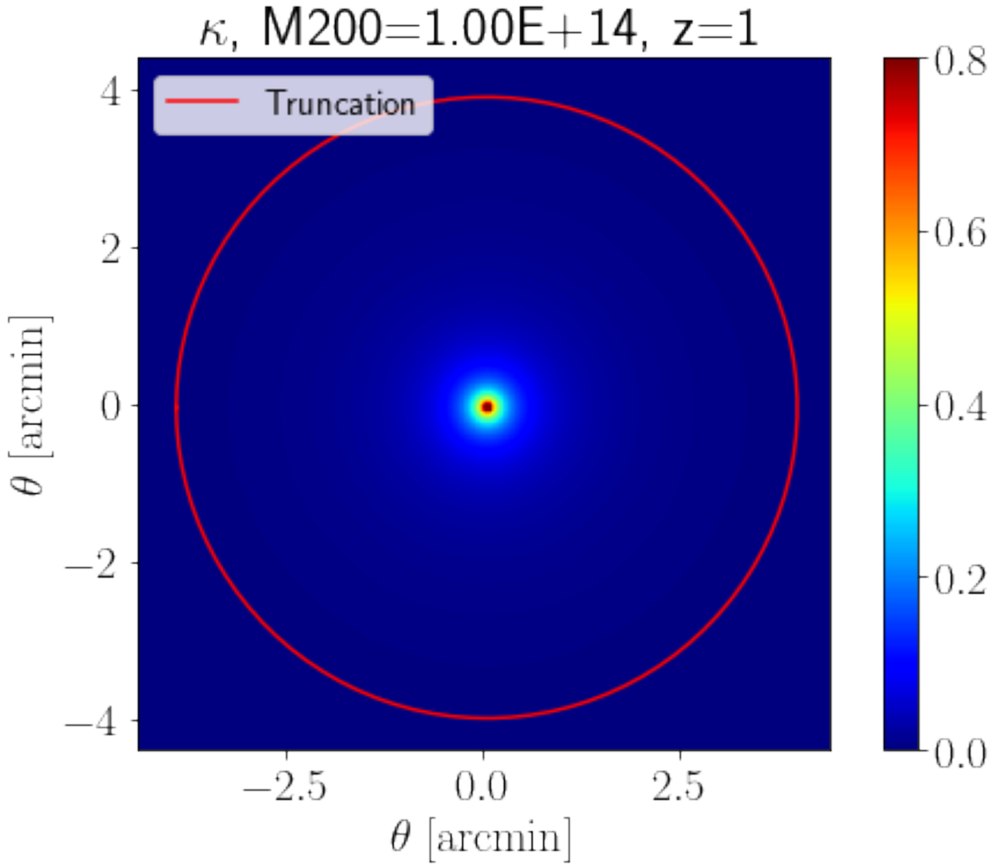
  Lensing can only be detected if there is anisotropies

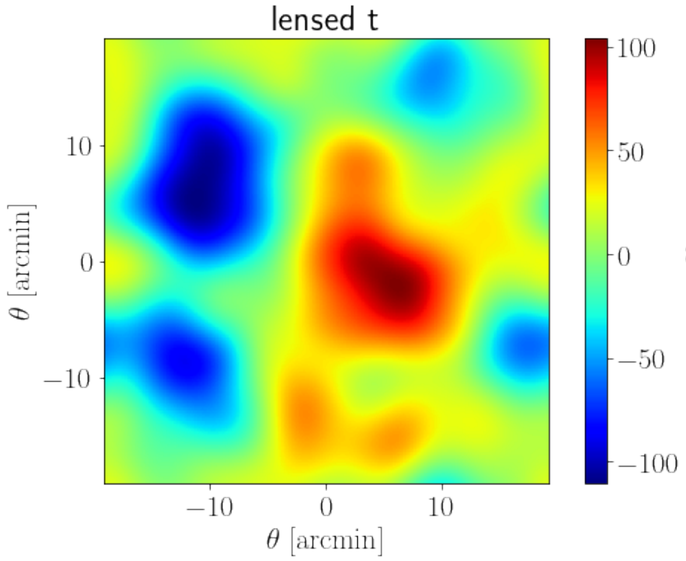
- In case of a 1D CMB gradient that is lensed by a cluster

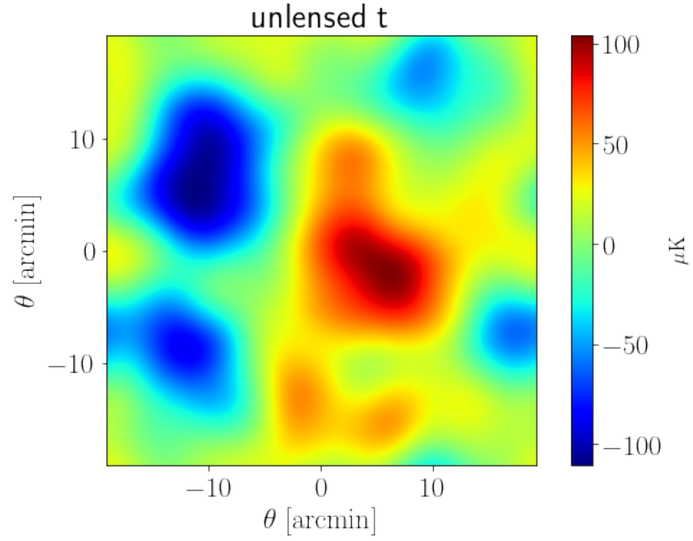


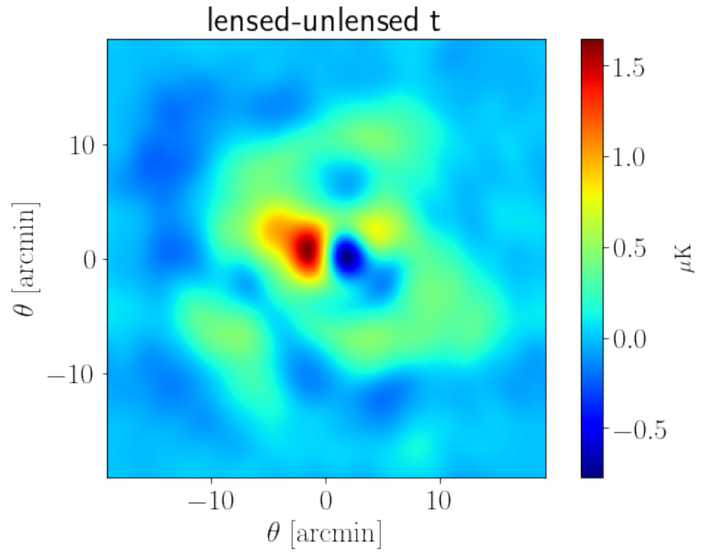
Seljak & Zaldarriaga 2001

CMB LENSING BY NFW PROFILE



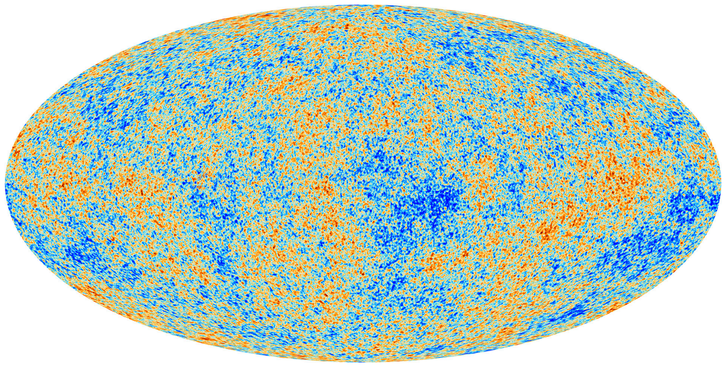






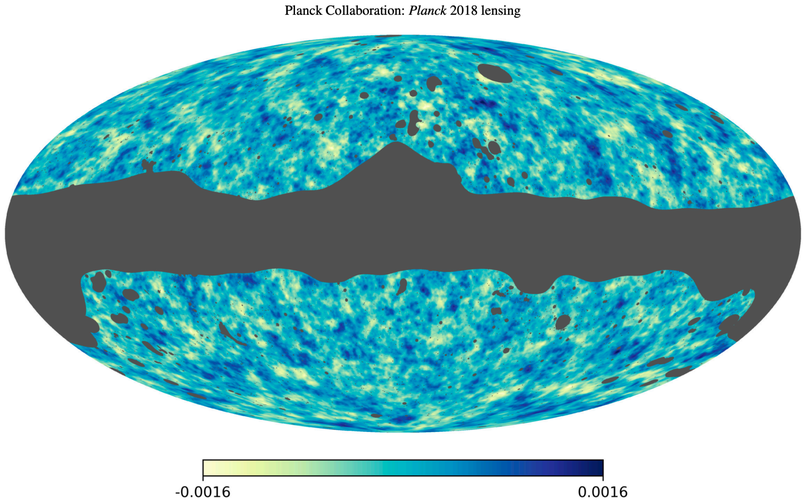
Lensit

QUADRATIC ESTIMATOR (QE)?



Observed CMB Map

QE



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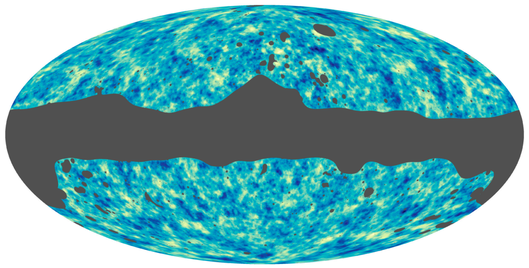
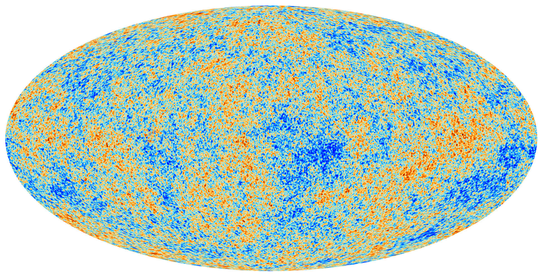
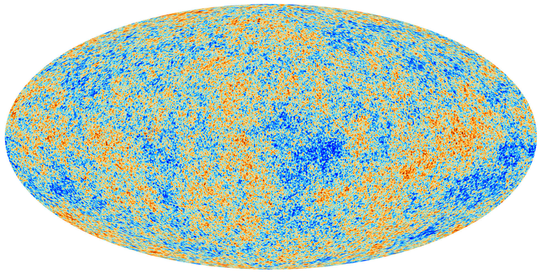


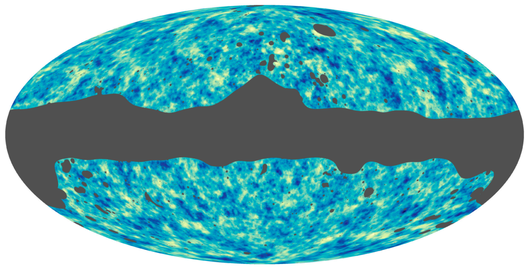
$$\hat{\alpha}^{QE}(\hat{n}) \propto \bar{X}(\hat{n}) \times \nabla X^{WF}(\hat{n})$$



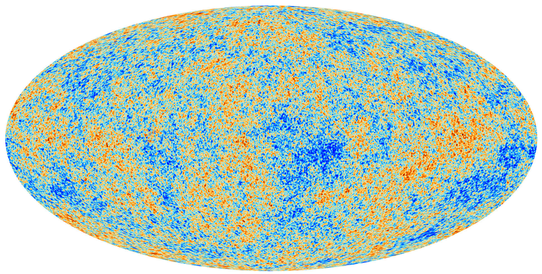


QUADRATIC ESTIMATOR (QE)?

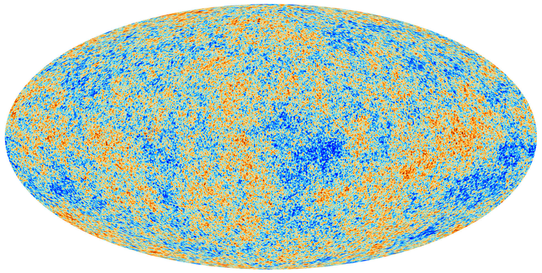
GRADIENT OF THE UNLENSED FIELD



$$\propto$$



$$\times$$



$$\hat{\alpha}^{QE}(\hat{n}) \qquad \bar{X}(\hat{n}) \qquad \nabla X^{WF}(\hat{n})$$

SMALL-SCALE FILTERED ANISOTROPY

MAXIMUM-A-POSTERIORI (MAP) ESTIMATOR

- The Maximum a Posterior (MAP) Estimator by Carron et al 2017
- We maximize the log posterior:

$$\ln p(\phi \,|\, X^{dat}) = \ln p(X^{dat} \,|\, \phi) - \frac{1}{2} \sum_L \frac{\phi_L^2}{C_L^{\phi\phi}}$$

- Using Gradients:

$$g_\phi = \frac{\delta \ln p(X^{dat} \,|\, \phi)}{\delta \phi} = g^{QD} - g^{MF} + g^{PR}$$

- We use these gradients iteratively to reach the maximum to get $\hat{\phi}_{MAP}$

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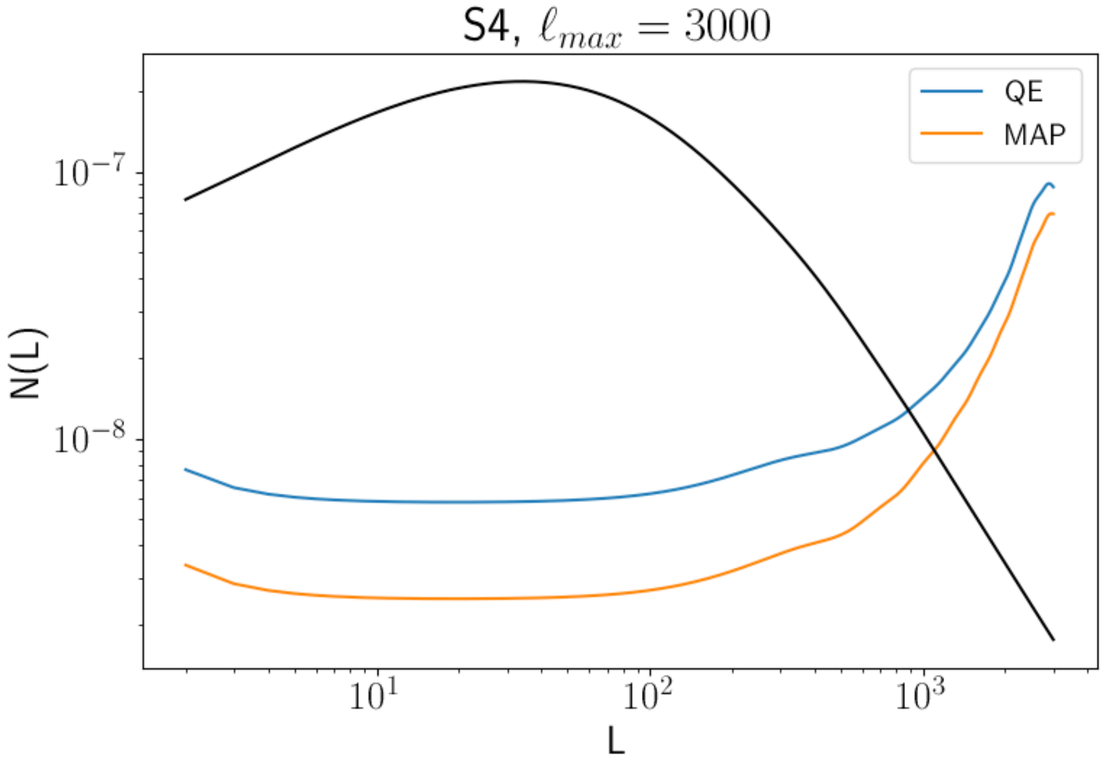

$\Delta_T = \Delta_P/\sqrt{2} = 1\mu K$-arcmin
Beam = 1 arcmin

LIKE CLEANING SMUDGES OFF THE GLASS

LIKE CLEANING SMUDGES OFF THE GLASS

QE MAP

ESTIMATOR OF MASS

$$\hat{\kappa}_0 = \frac{\int d^2\overrightarrow{L} \; \frac{\kappa^t(\overrightarrow{L})\hat{\kappa}(\overrightarrow{L})}{N_{\vec{L}}}}{\int d^2\overrightarrow{L} \; \frac{|\kappa^t(\overrightarrow{L})|^2}{N_{\vec{L}}}}$$

ESTIMATOR OF MASS

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$\hat{\kappa}_l$ = convergence estimated from data

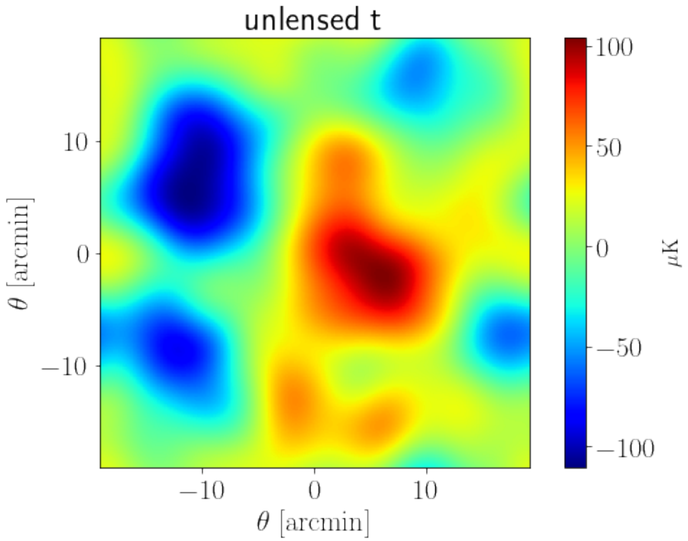
N_l = Noise of the estimation

$= C_l^{\kappa\kappa} + N_0^{\kappa} + N_1^{\kappa}$

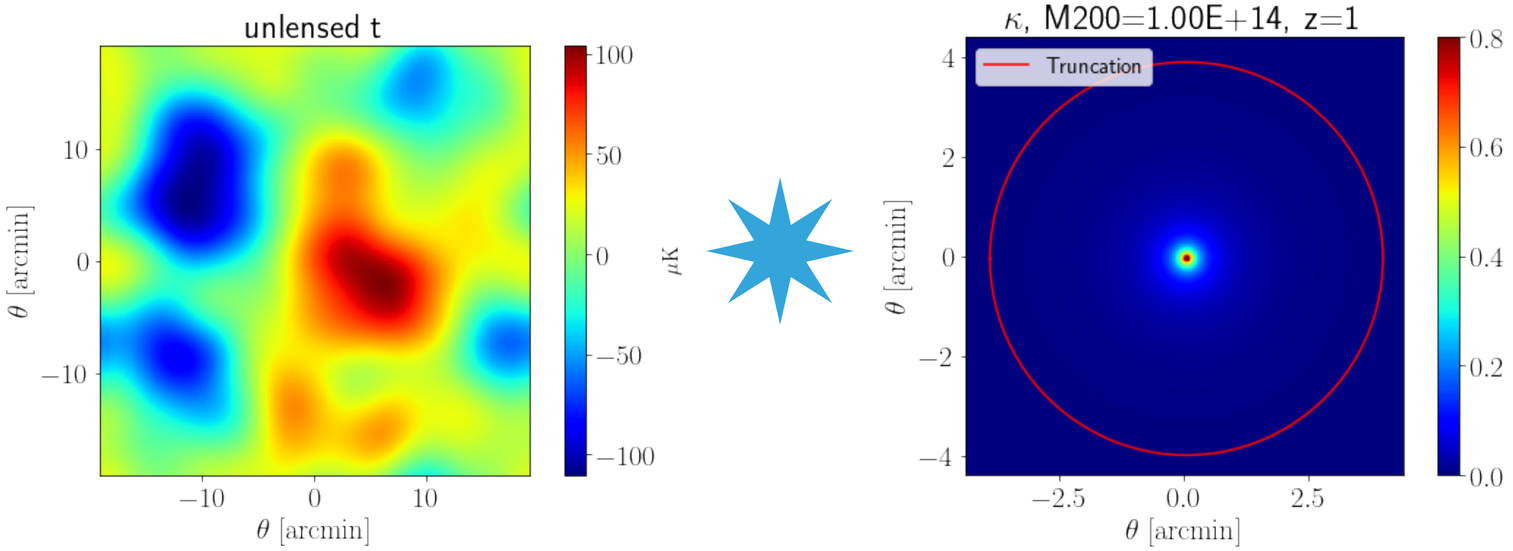
You can use any estimator you want

QE, or MAP

BIAS IN TEMPERATURE QE



BIAS IN TEMPERATURE QE



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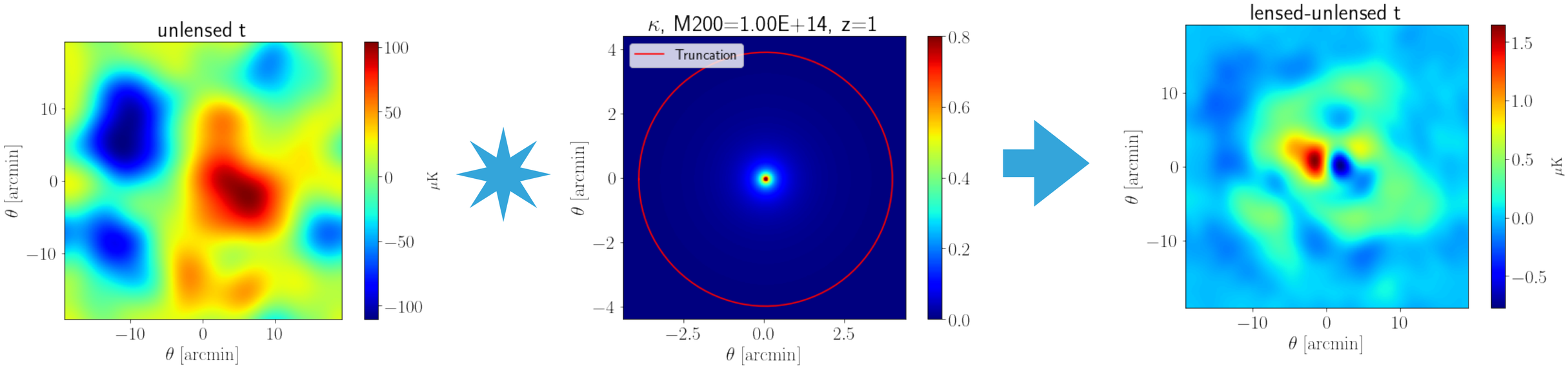

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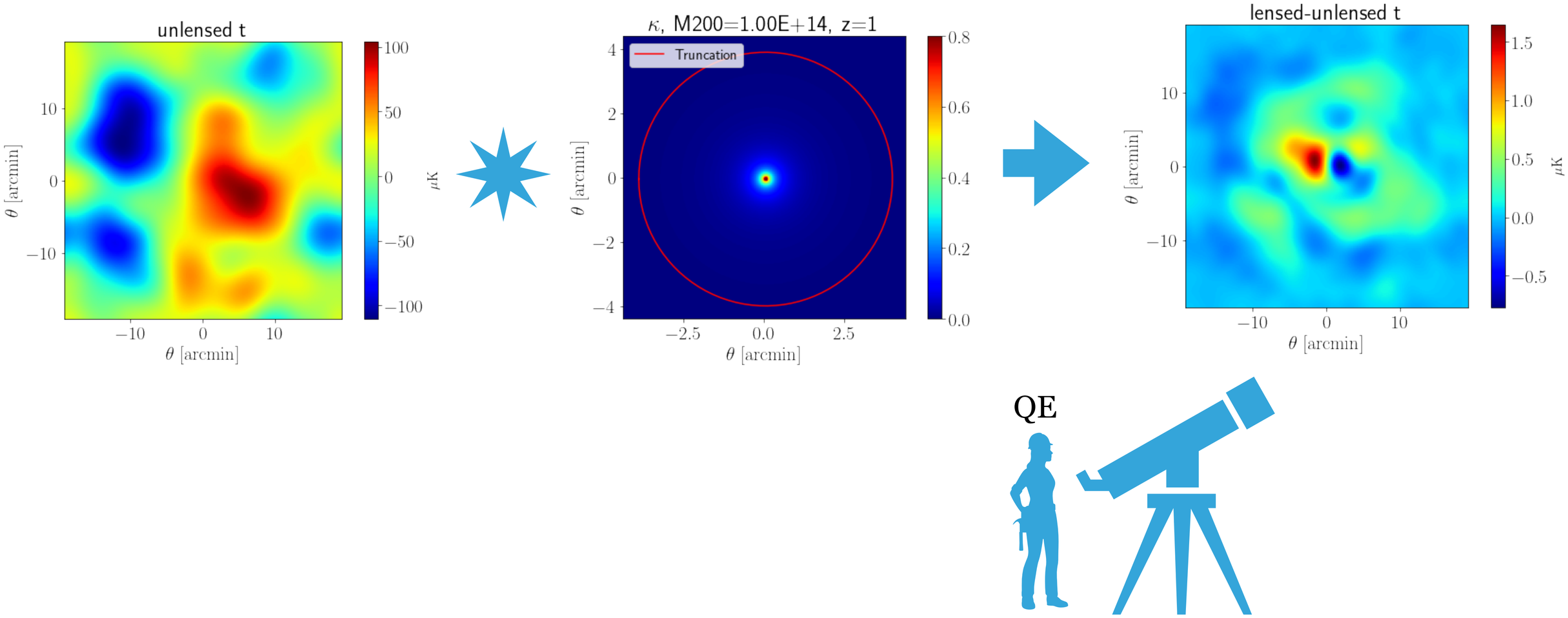

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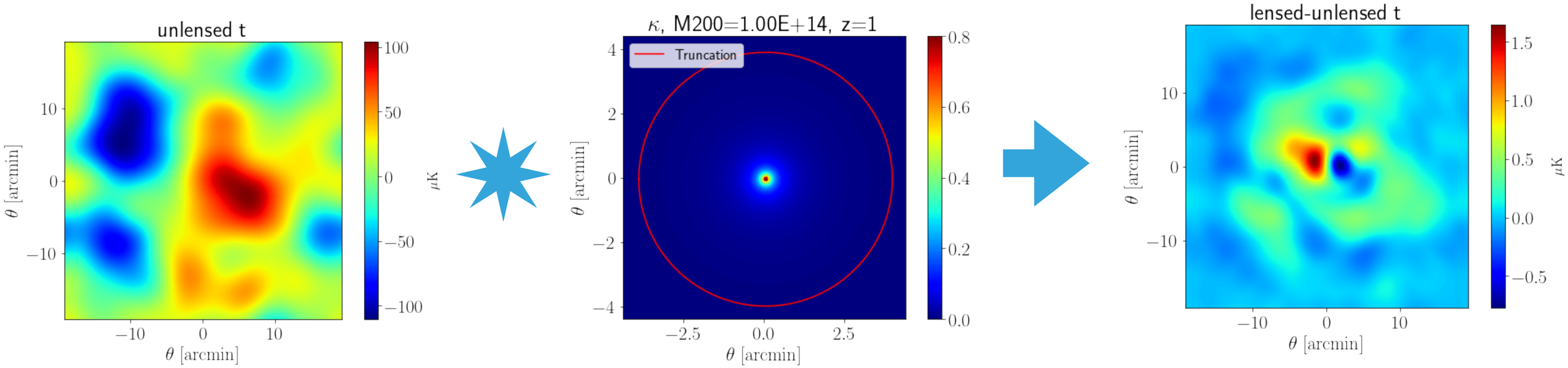

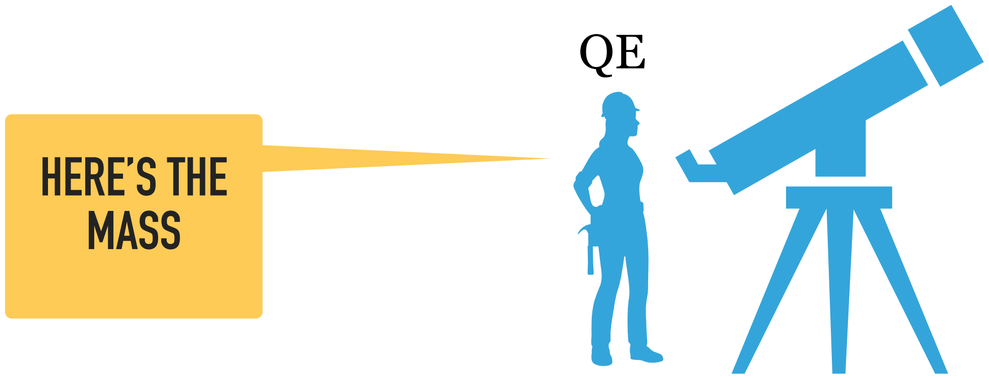

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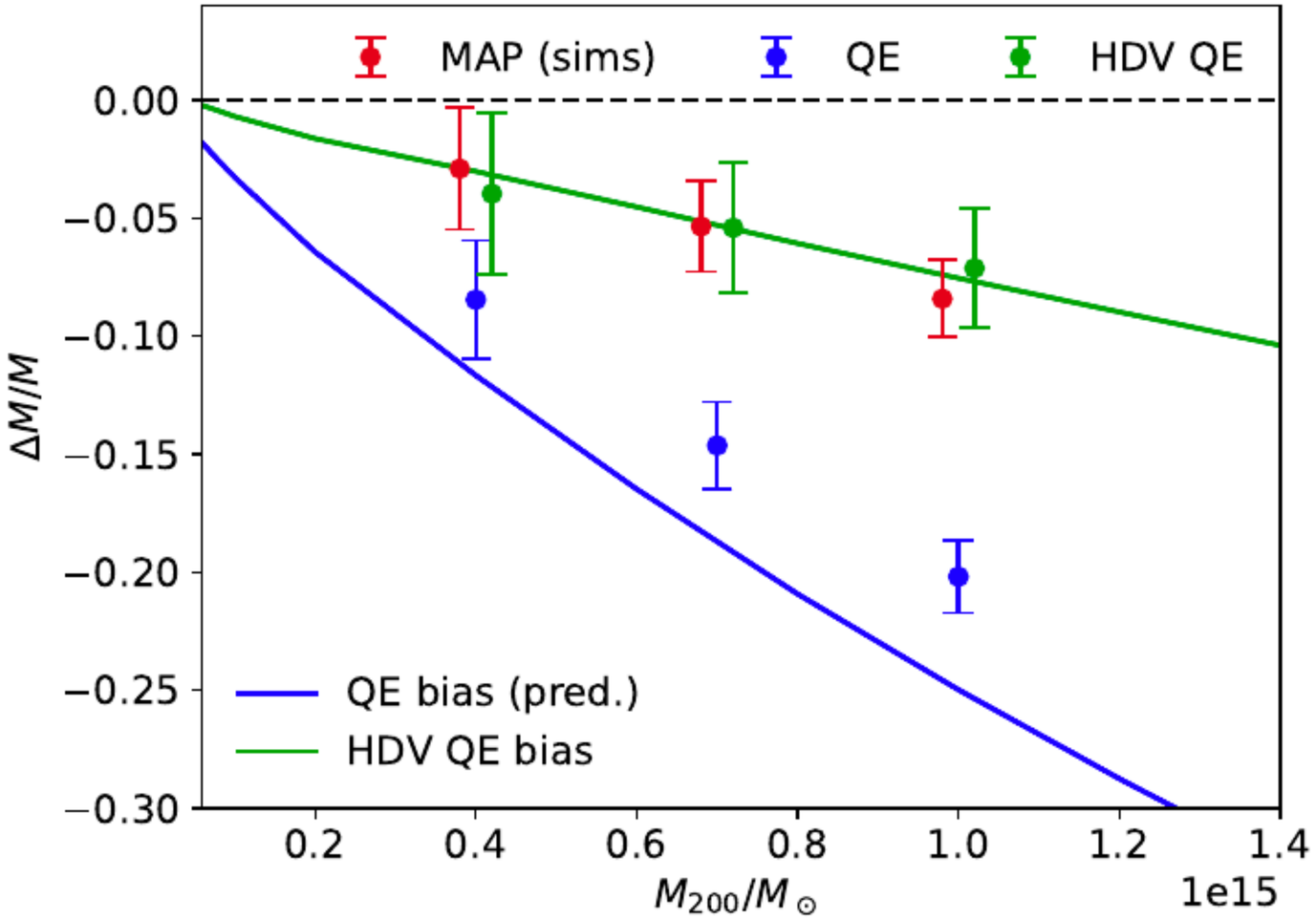
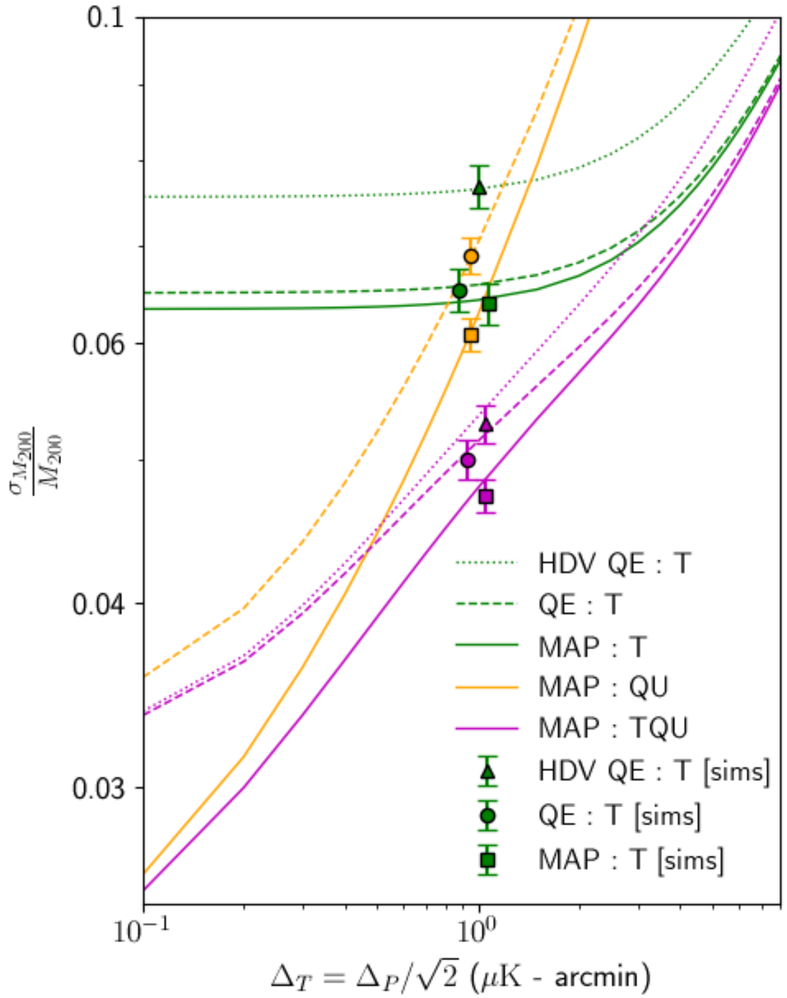


CLUSTER MASS CONSTRAINTS



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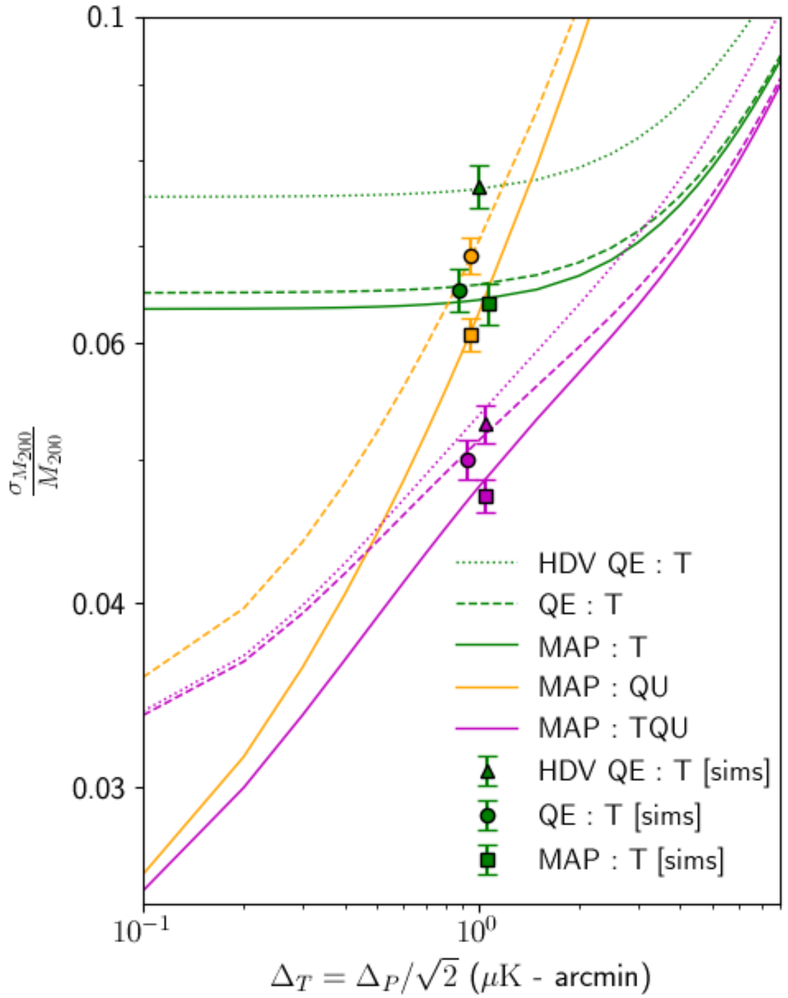

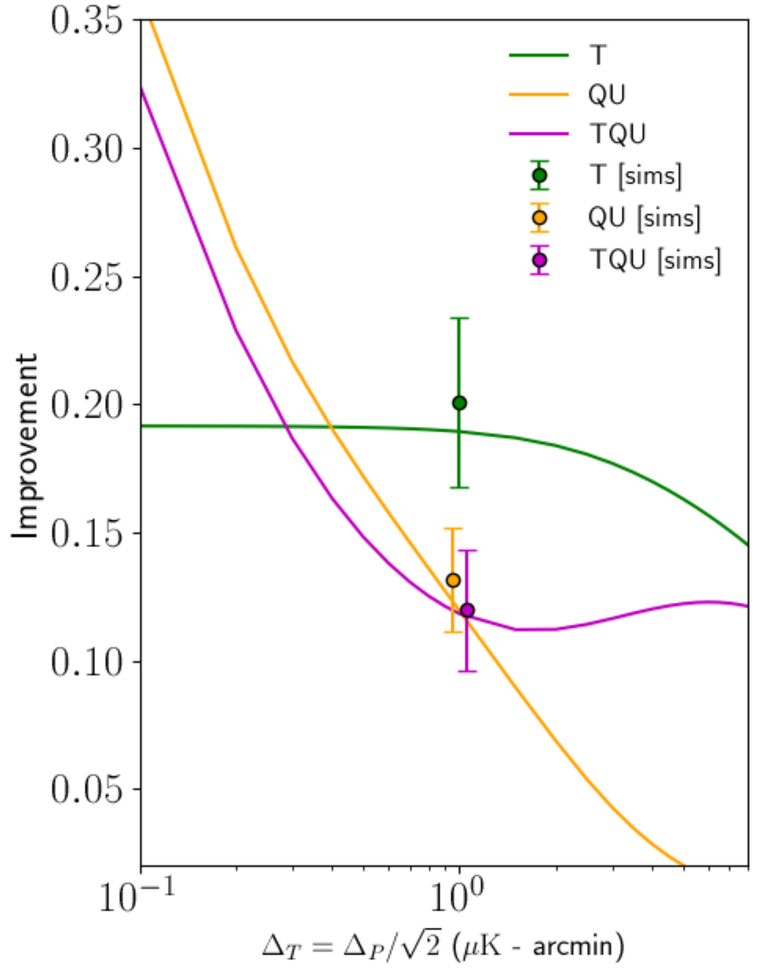

RESEARCH GOALS

- Using weights to the clusters while stacking according to the strength of gradient
- Implementation on curved sky (full and partial)
- Robustness against contaminations of tSZ and kSZ
- Robustness against systematics
- Implementations on Websky Simulations

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https://github.com/carronj/LensIt

sayan.saha@students.iiserpune.ac.in