Title: New probes of fundamental physics: Utilising small-scale signatures in the Universe.

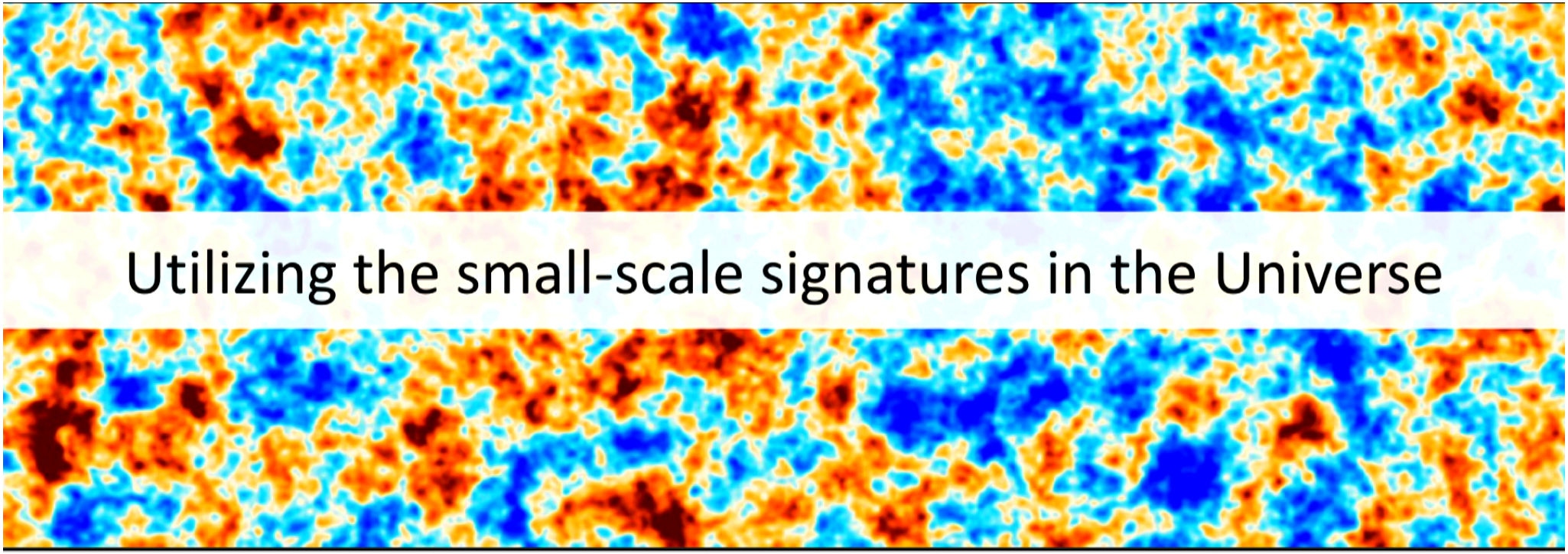
Speakers: Selim Hotinli

Series: Cosmology & Gravitation

Date: November 05, 2019 - 3:00 PM

URL: http://pirsa.org/19110056

Abstract: The influx of new and high-quality cosmological data from upcoming cosmic microwave background (CMB) and large-scale structure surveys will provide unique and exciting opportunities to study the fundamental constituents of the Universe in the upcoming few years. In particular, measurements of second-order effects in the CMB will become observationally significant for the fist time as surveys will achieve the necessary precision. Such second-order effects include weak gravitational lensing by large-scale structure; the integrated Sachs-Wolfe and Rees-Sciama effects, which describe the redshift effect on CMB photons due to evolving gravitational potentials along the line of sight; and the Sunyaev-Zel'dovich effect where CMB photons Compton scatter with free electrons in galaxy clusters and the intergalactic medium. In parallel, surveys of the 21cm hydrogen line will achieve sufficient accuracy for cosmological inference. In this talk I will describe how these new cosmological probes provide opportunities to study old fundamental problems. I will focus on two new probes: the moving lens effect on the CMB (Hotinli 2019, PRL) and the velocity acoustic oscillations (`so-called' VAOs) in the 21cm hydrogen. I will describe how these observables can be utilised to constrain a class of early Universe models.



Utilizing the small-scale signatures in the Universe

Selim Hotinli

05/11/2019
Perimeter

Imperial College
London

Early universe

Global fits of BSM models
Testing Higgs Inflation and axion dark matter models with global fits. GAMBIT collaboration, *In prep*

Phenomenology of many field inflation + reheating
arXiv:1710.08913 (PRD)

Blue-tilted isocurvature
w/ Kamionkowski, Tenkanen and others
In prep

Compensated isocurvature
w/ Kamionkowski, Johnson, Martens
arXiv:1908.08953 (PRD)

Late time effects

CMB weak lensing/delensing
w/ Green, Meyers, van Engelen
In prep

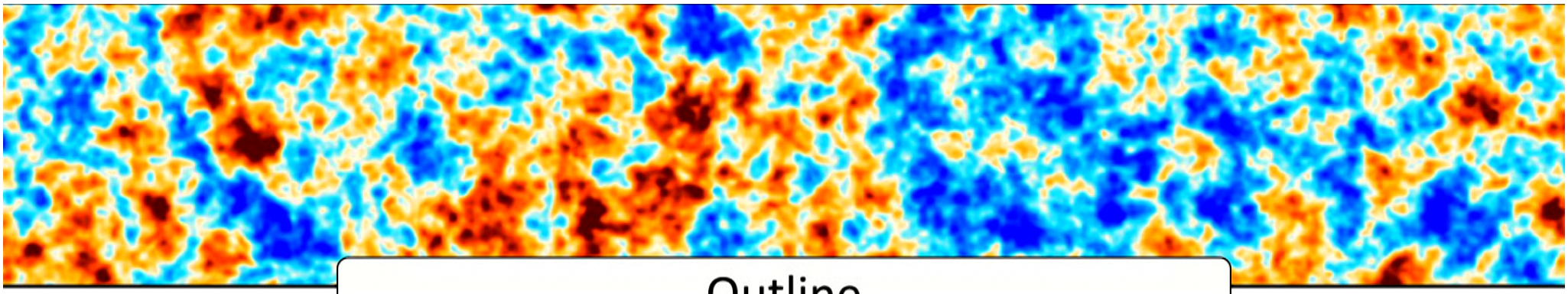
The moving lens effect
w/ Dalal, Johnson, Meyers, Smith, Jaffe, v Engelen, Munchmeyer, Martens,
arXiv:1812.03167 (PRL)
++In prep

21cm VAO features
w/ Kamionkowski, *In prep*

Anisotropy of the GWB
w/ Kamionkowski, Jaffe
arXiv:1904.05348 (OJA)
++In prep

Statistical anisotropy

Recent works



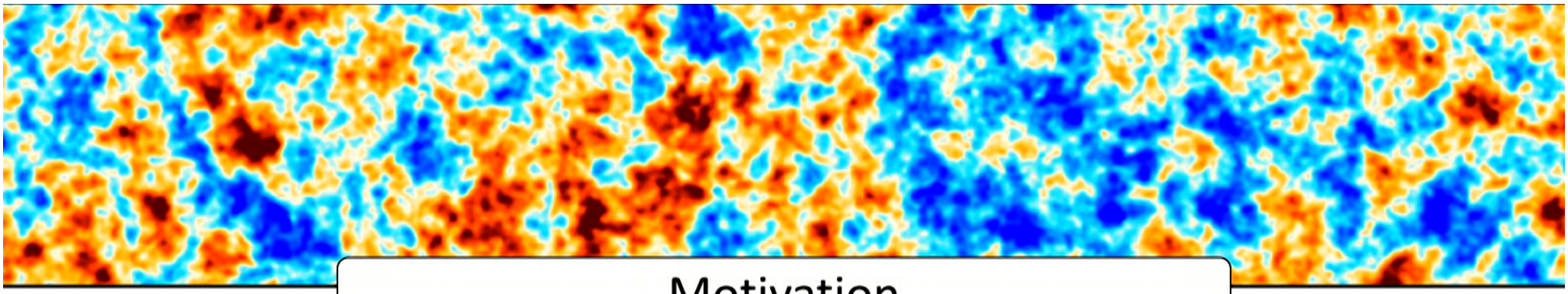
Outline

Probing fundamental physics beyond the LCDM

- Motivation
- Future directions
- CMB secondaries
  - The moving lens effect
- Beyond the standard LCDM
  - Case study: Primordial compensated isocurvature

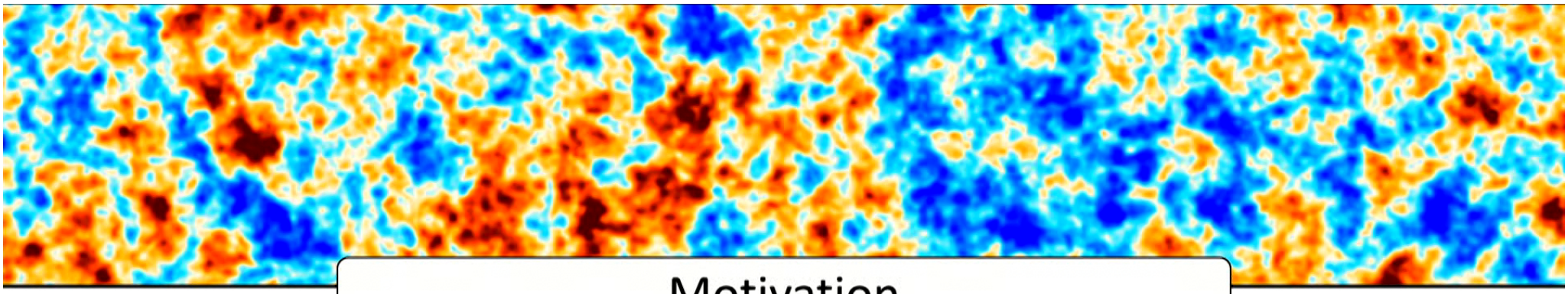
LSS + CMB

the *next* high-significance detection!



Motivation

- So far with e.g. WMAP, PLANCK, BOSS, DES,...:
  - Standard cosmological paradigm (**LCDM**) well understood, constraints on matter & baryon densities, curvature, age etc… *and* constraints on initial fluctuations: gaussian, close to scale-invariant, adiabatic...



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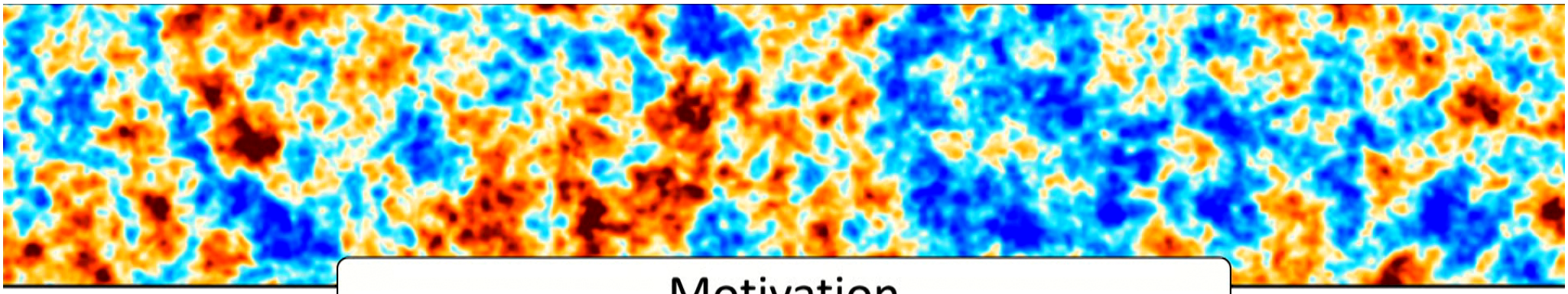
- *Remaining questions*, SO, DESI, CMB-S4, LSST,...:
  - Growth of structure: neutrinos & dark photons, dark energy, modified gravity
  - Inflation (what seeds fluctuations?)
  - Dark matter



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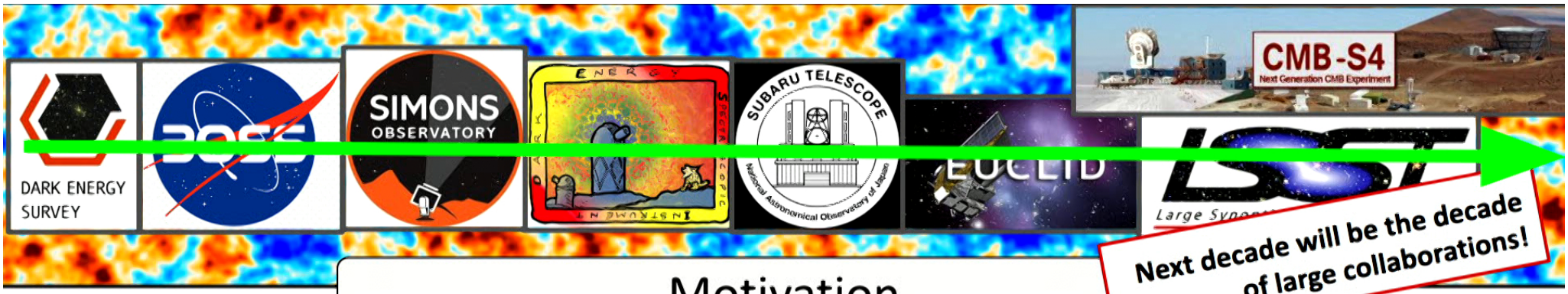

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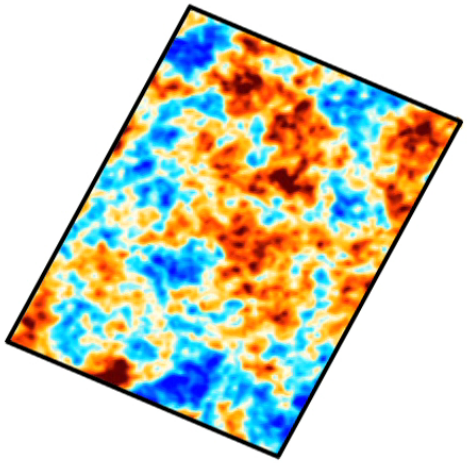
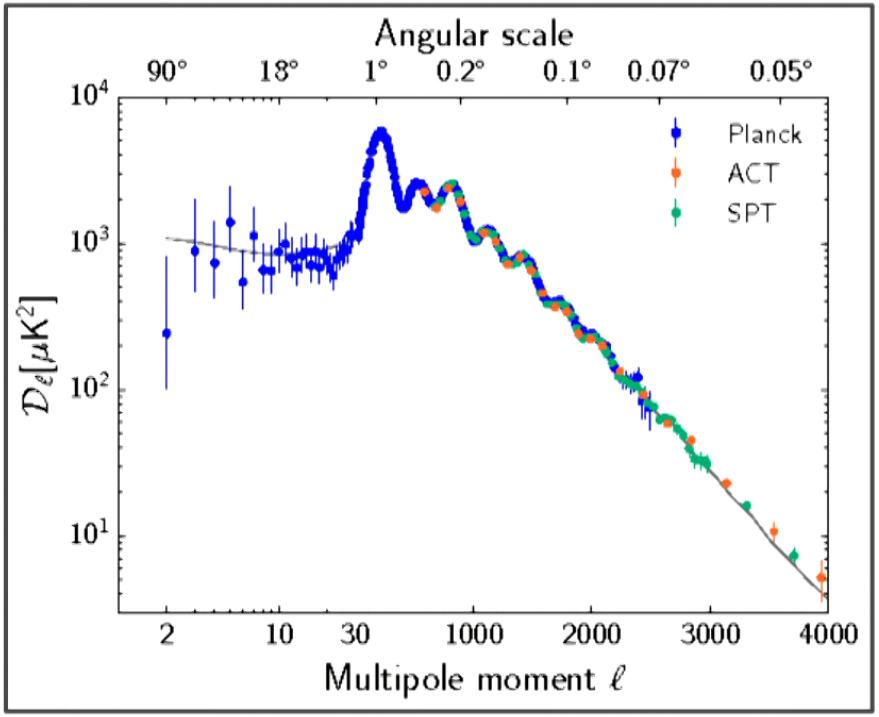
Future Directions

- Going beyond the primary CMB





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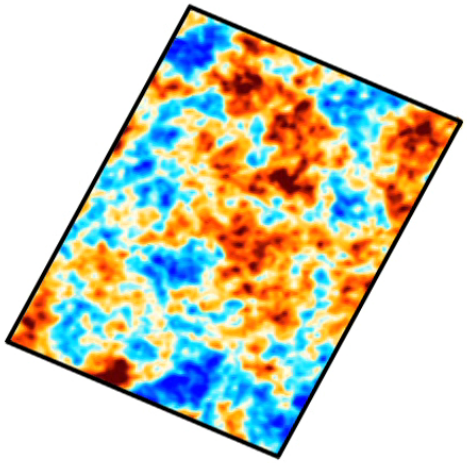
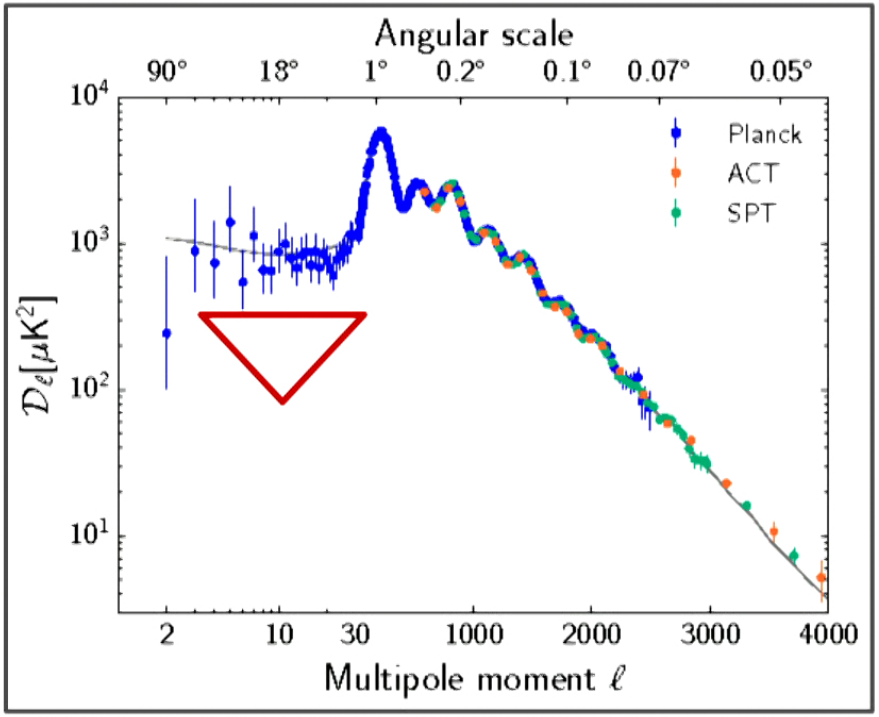
Future Directions

- Going beyond the primary CMB
  - Goal: Getting *new* large scale modes

equivalence: $\delta \sim \nabla^2 \Psi \, , \dot{\Psi}$





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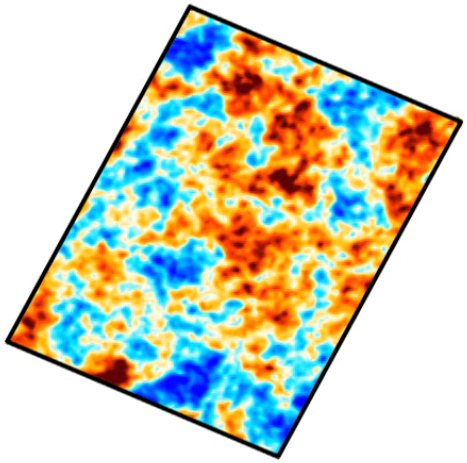
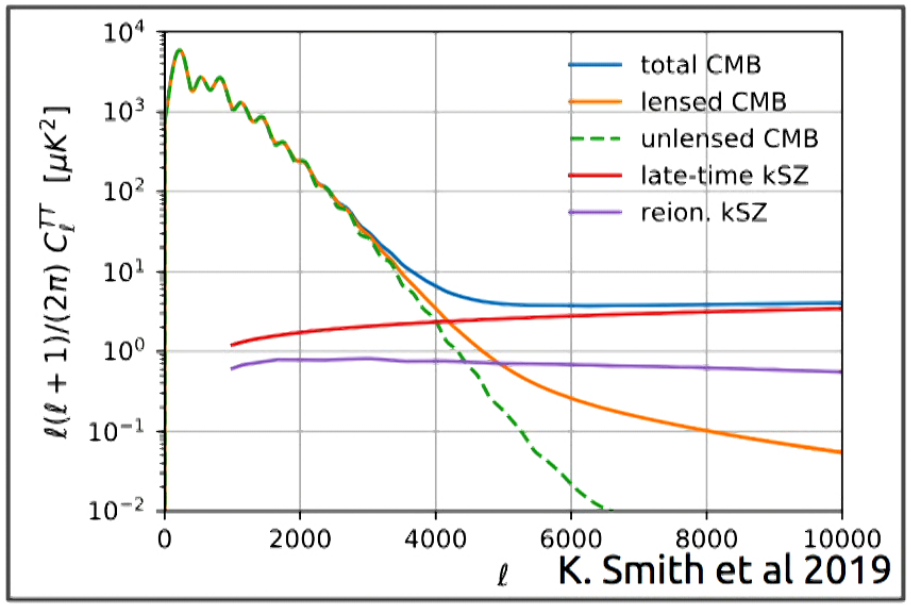
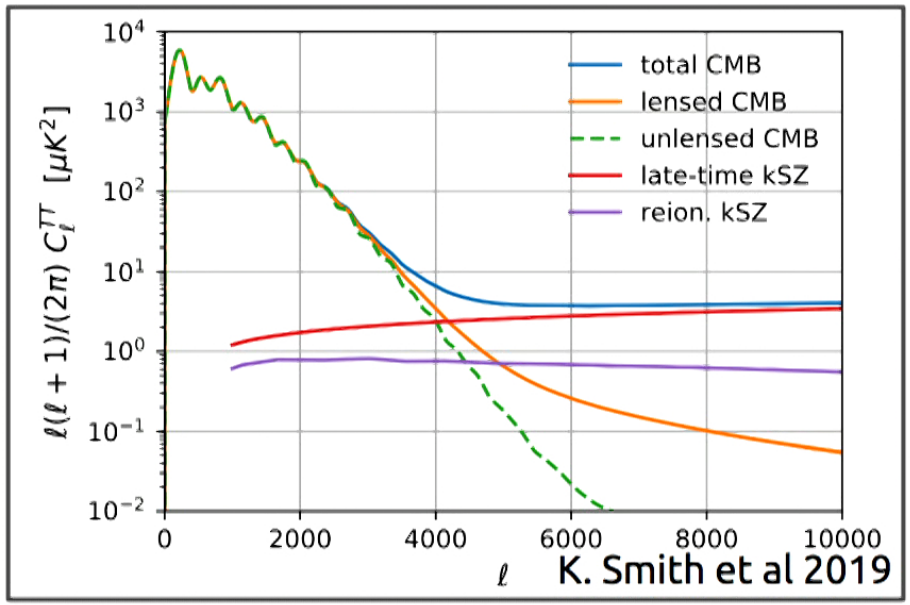




Future Directions

- Going beyond the primary CMB
  - Goal: Getting *new* large scale modes
  - Upcoming opportunity: Observation of *very small-scale* fluctuations
- Isolating fundamental signatures
  - Goal: *Effectively* searching for fundamental physics



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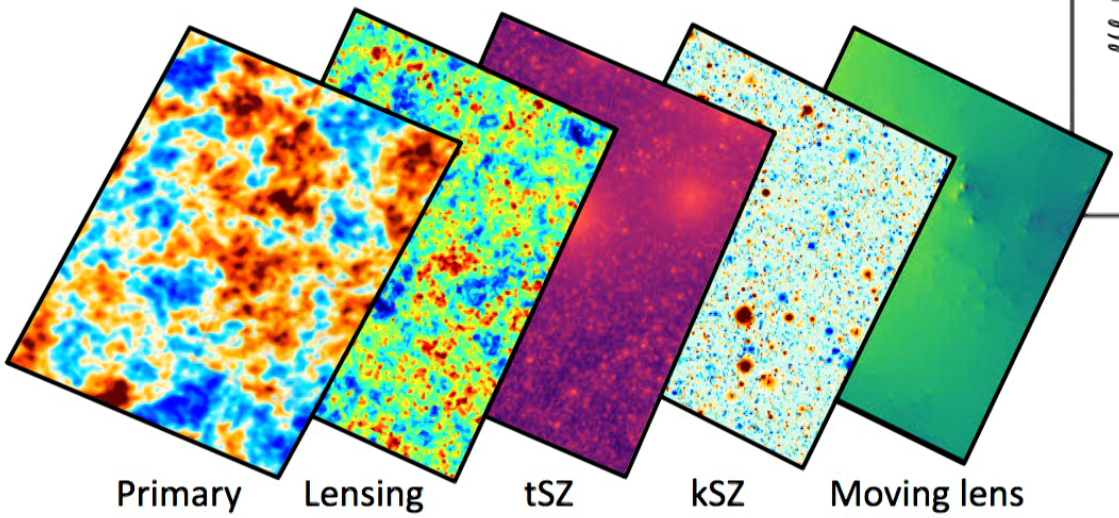

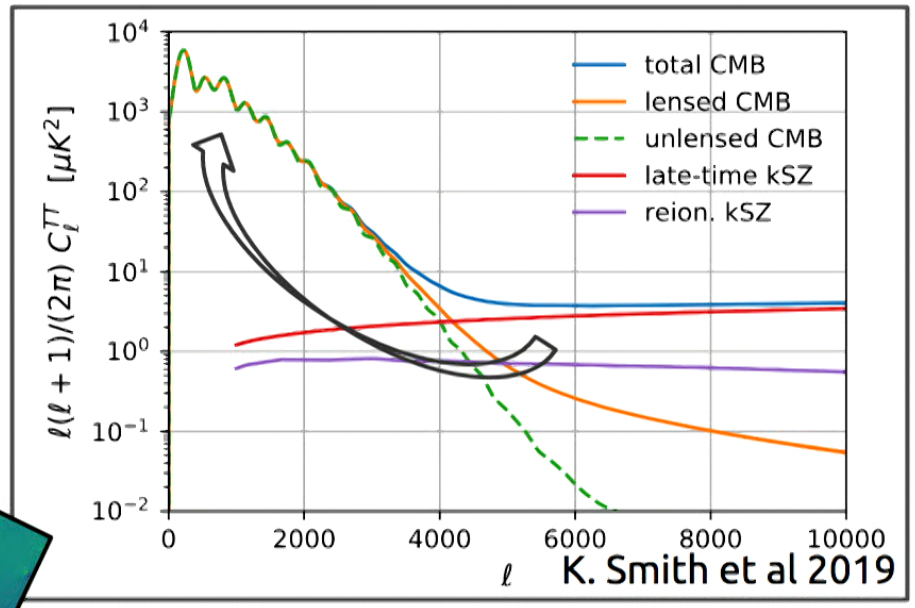

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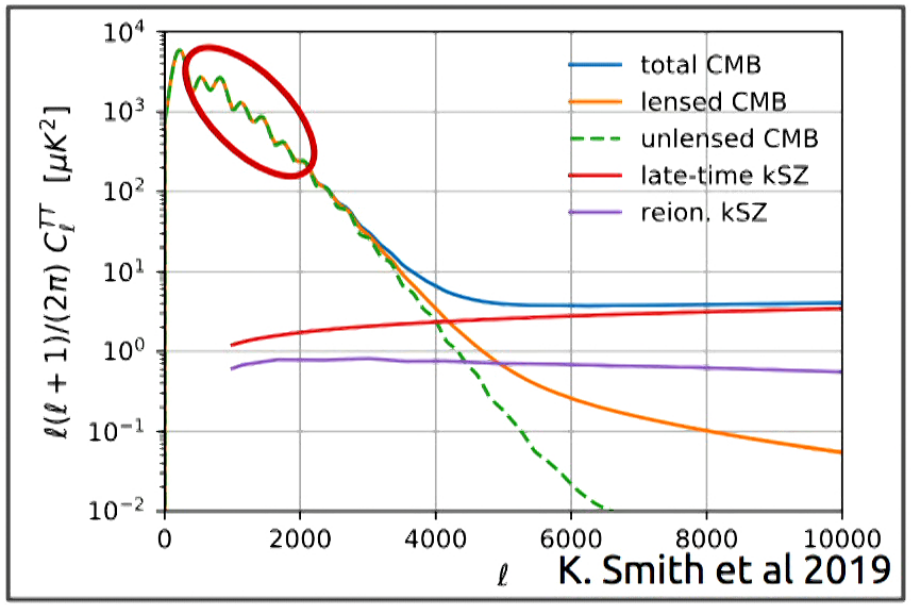
    e.g. on the morphology of BAO feature



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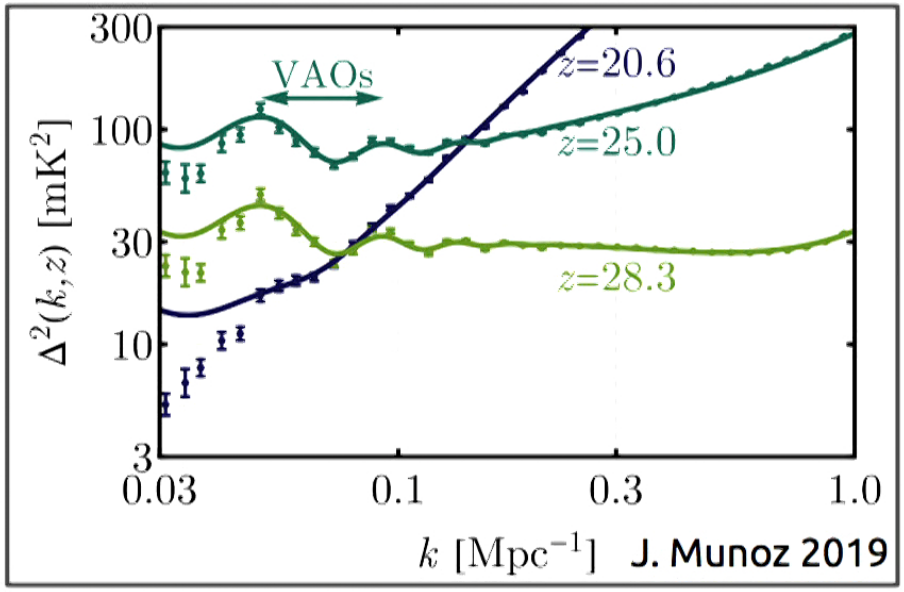
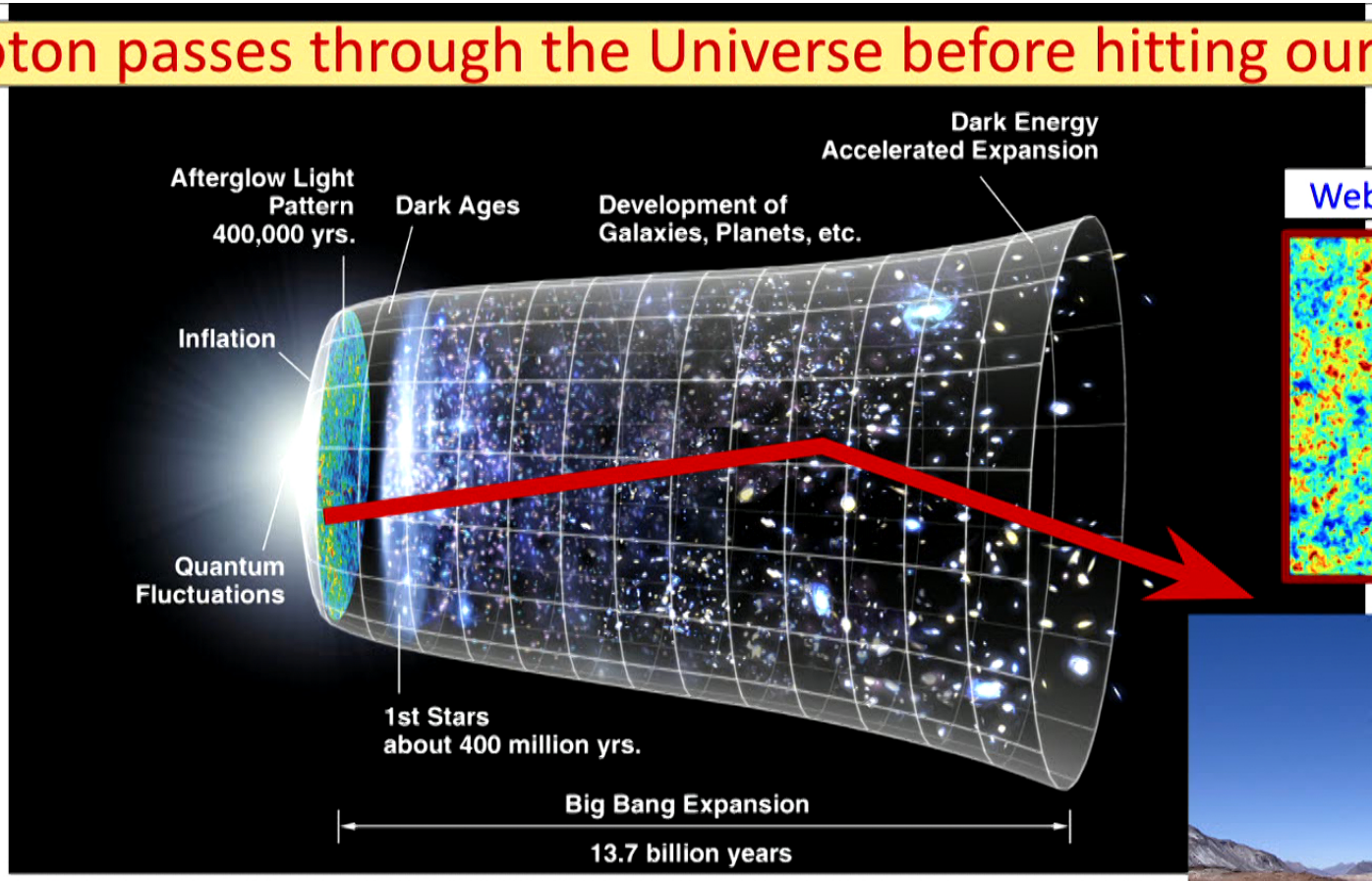
- Isolating fundamental signatures
  - Goal: *Effectively* searching for fundamental physics: *e.g.* on the morphology of BAO feature
  - Upcoming opportunity: Observations of acoustic oscillations on the 21cm-hydrogen line.

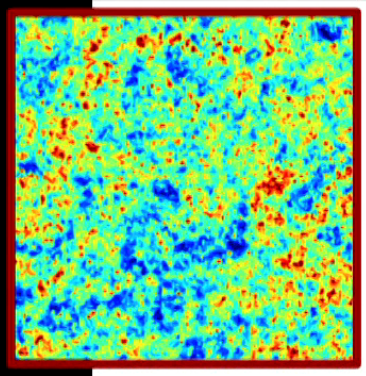


Will come back later

A CMB photon passes through the Universe before hitting our satellites



Websky, Alvarez et al.



- Gets deflected by gravitational potential: **Gravitational lensing**.
- Scatters on baryons: **thermal/kinematic Sunyaev Zel'dovich effects**.
- Gets redshifted due to *evolving* potentials: **Sachs-Wolfe effect, Rees-Sciama effect,...**

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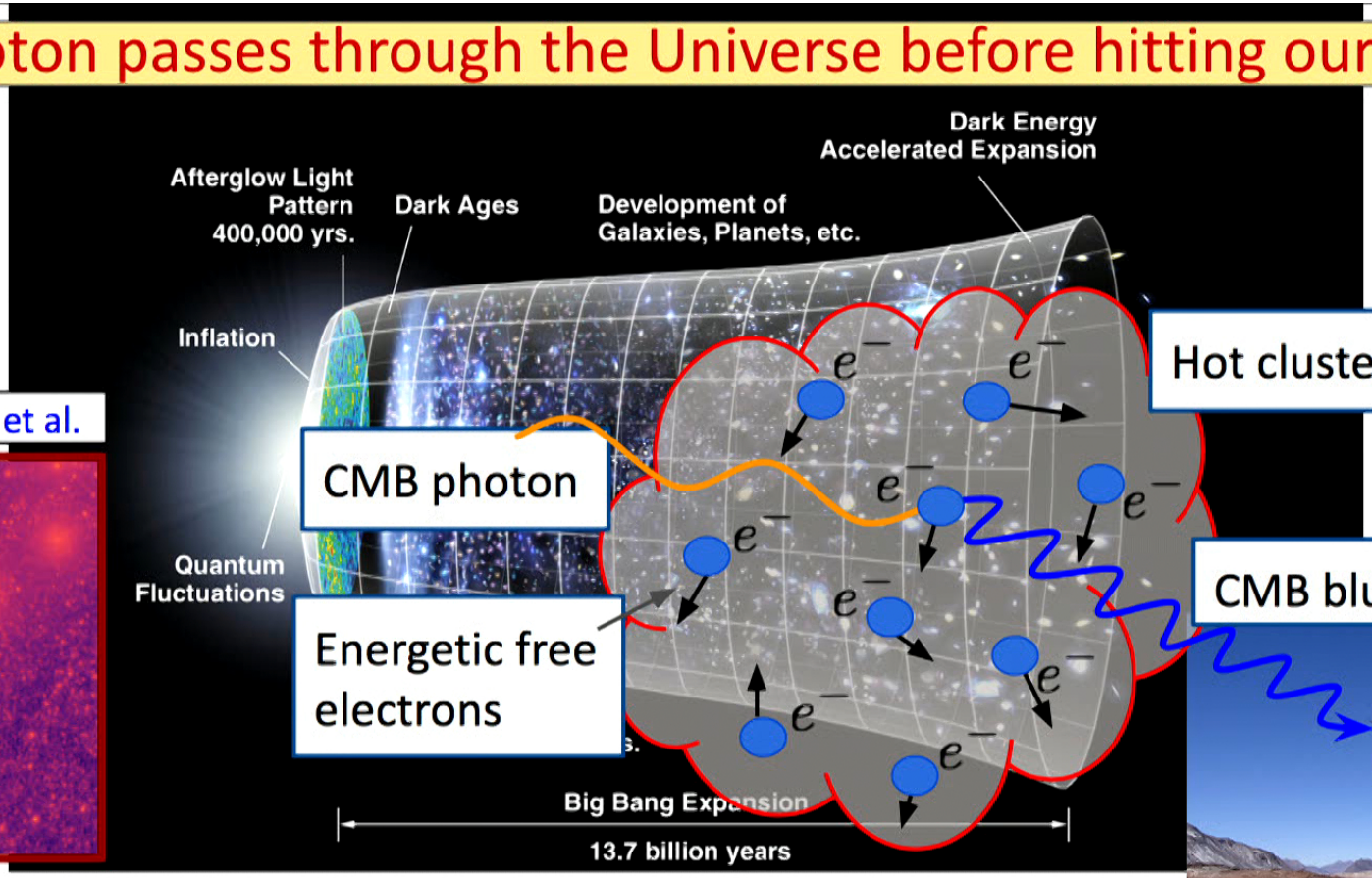

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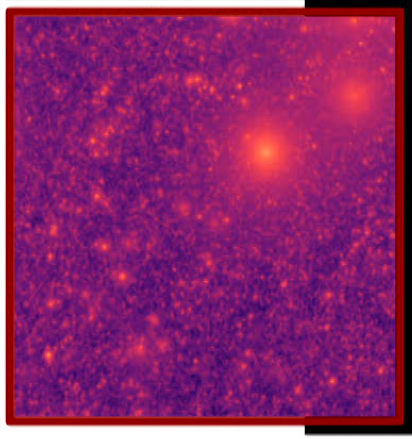

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kinetic Sunyaev Zel'dovich (kSZ) effect:

CITA/Websky, Alvares, 2016

$$\frac{\Delta T_{\rm kSZ}(\hat{\mathbf{n}})}{T_{\rm CMB}} \sim \int {\rm d}\chi e^{-\tau(z)} v_r \delta_e(\hat{\mathbf{n}}, \chi)$$

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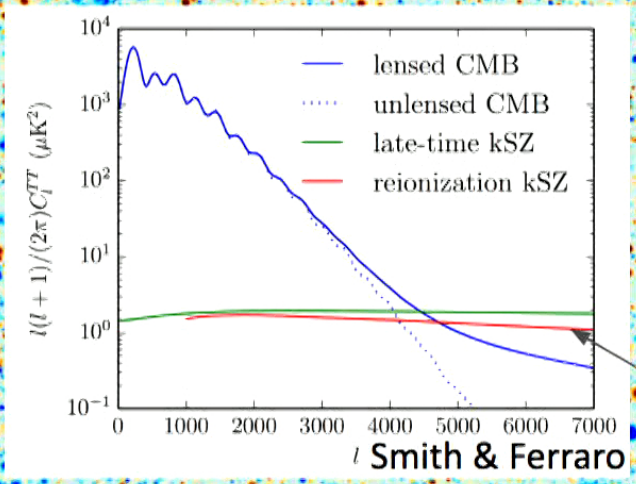
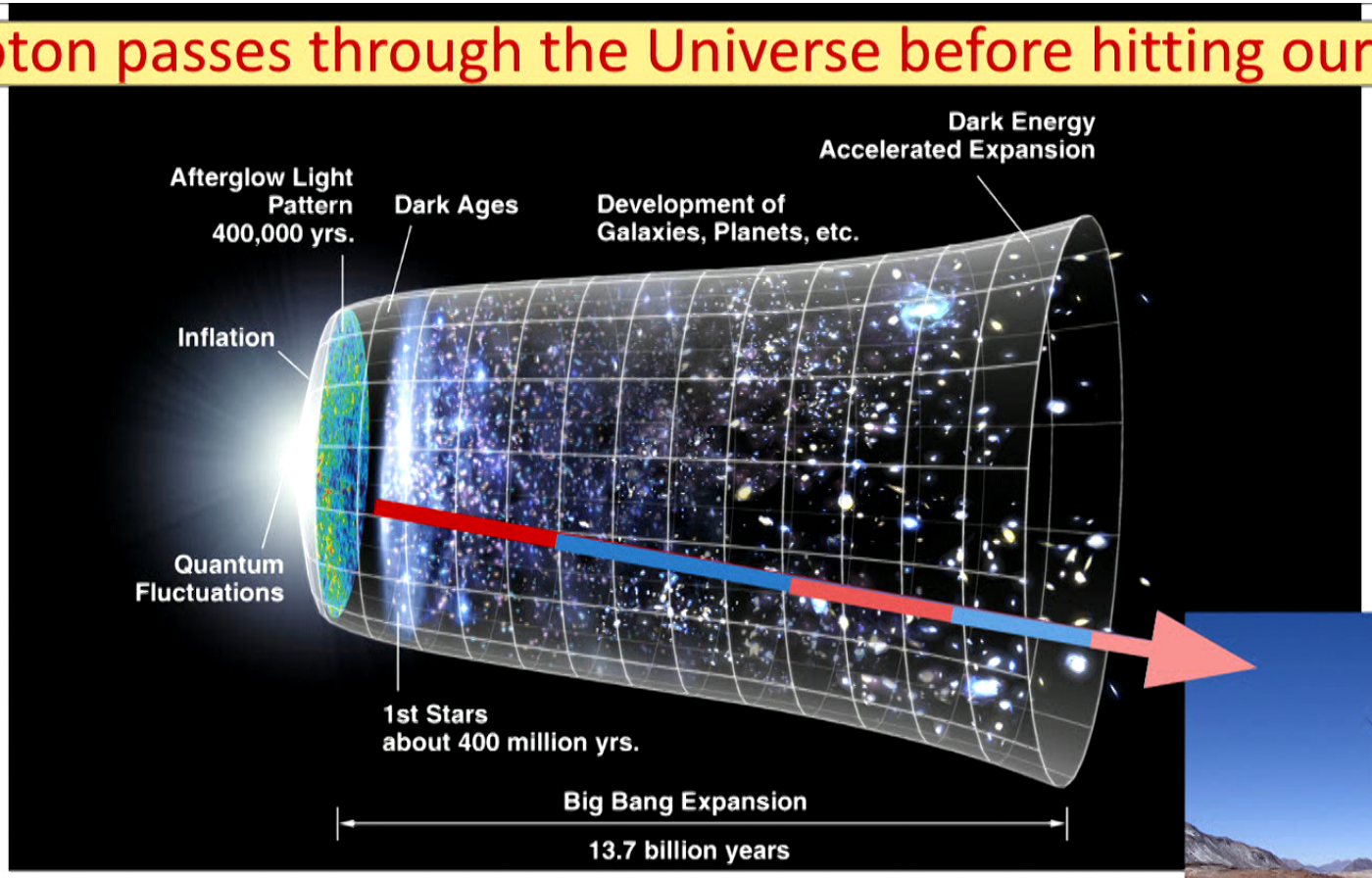


at small scales, CMB is mostly kSZ.

A CMB photon passes through the Universe before hitting our satellites



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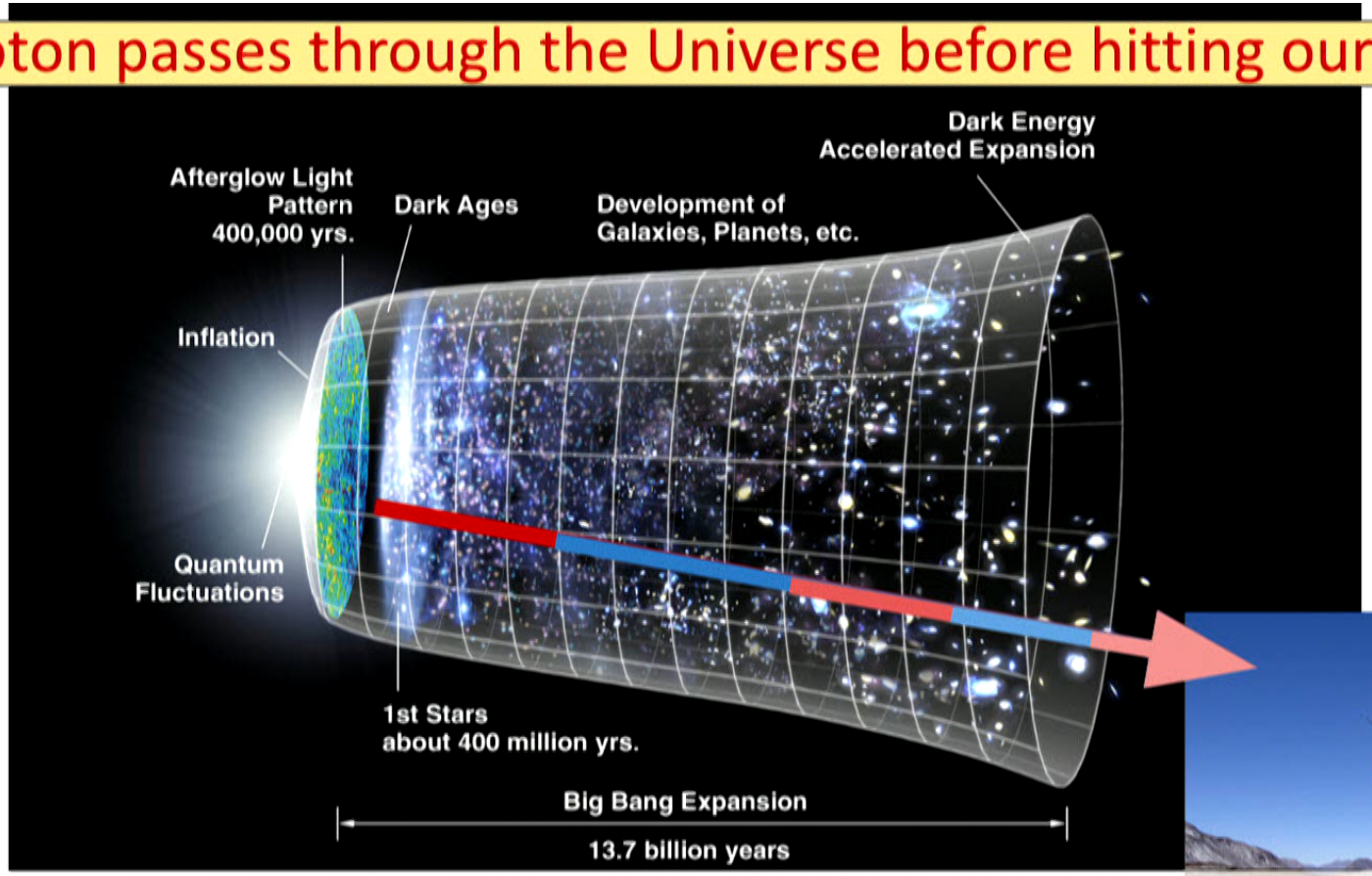

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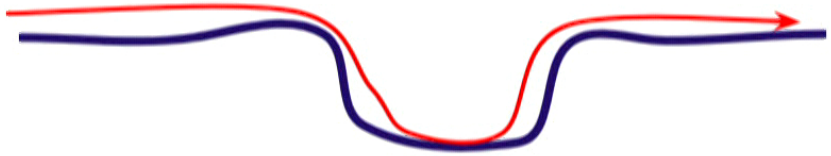

The moving lens effect:

PRL, arXiv: 1812.03167

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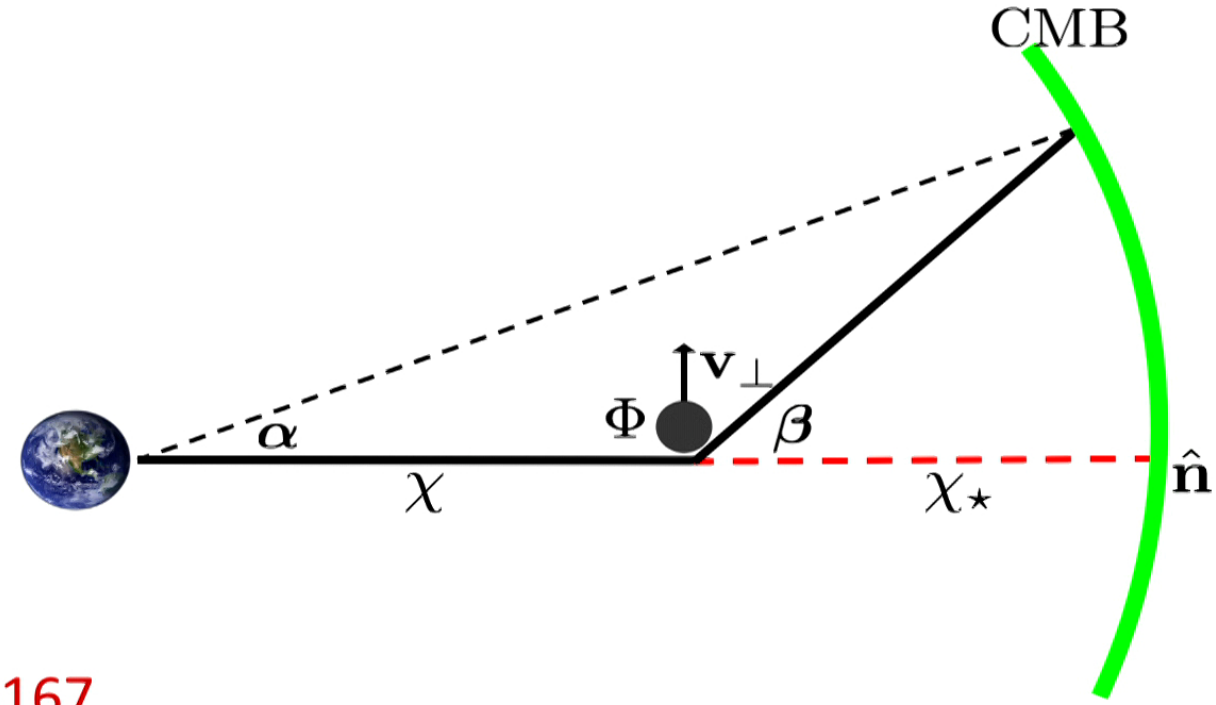

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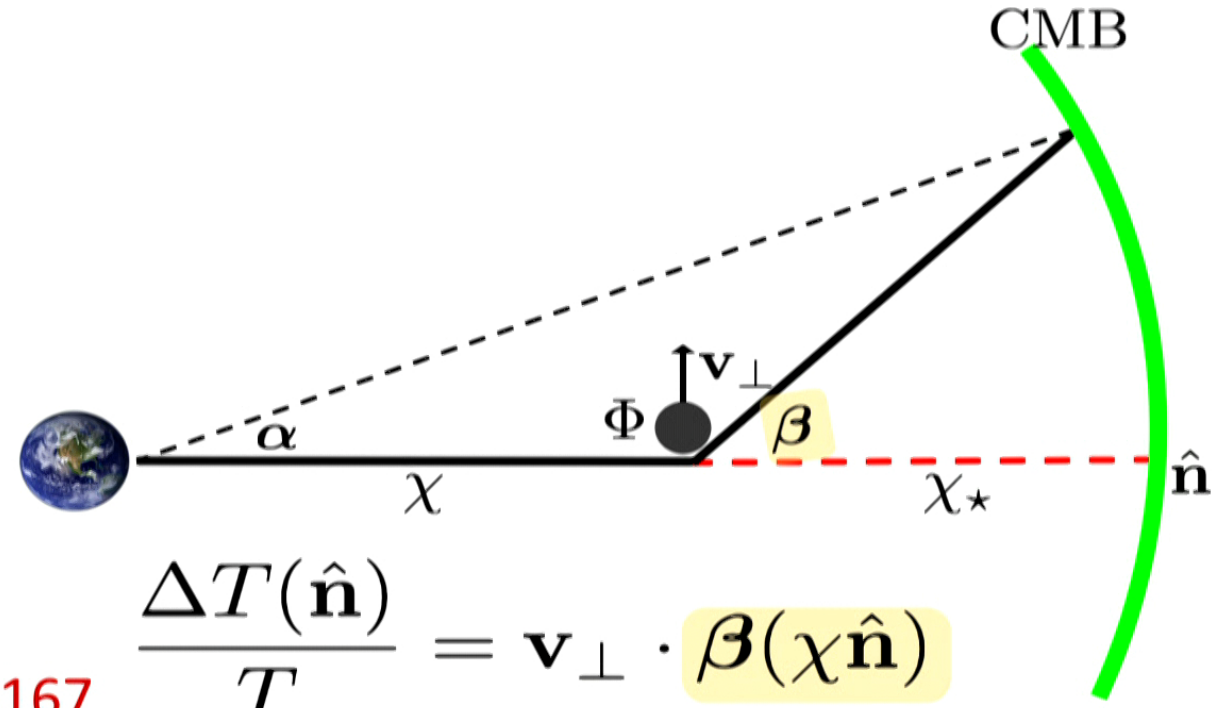

$$\frac{\Delta T(\hat{\mathbf{n}})}{T} = \mathbf{v}_\perp \cdot \boldsymbol{\beta}(\chi\hat{\mathbf{n}})$$

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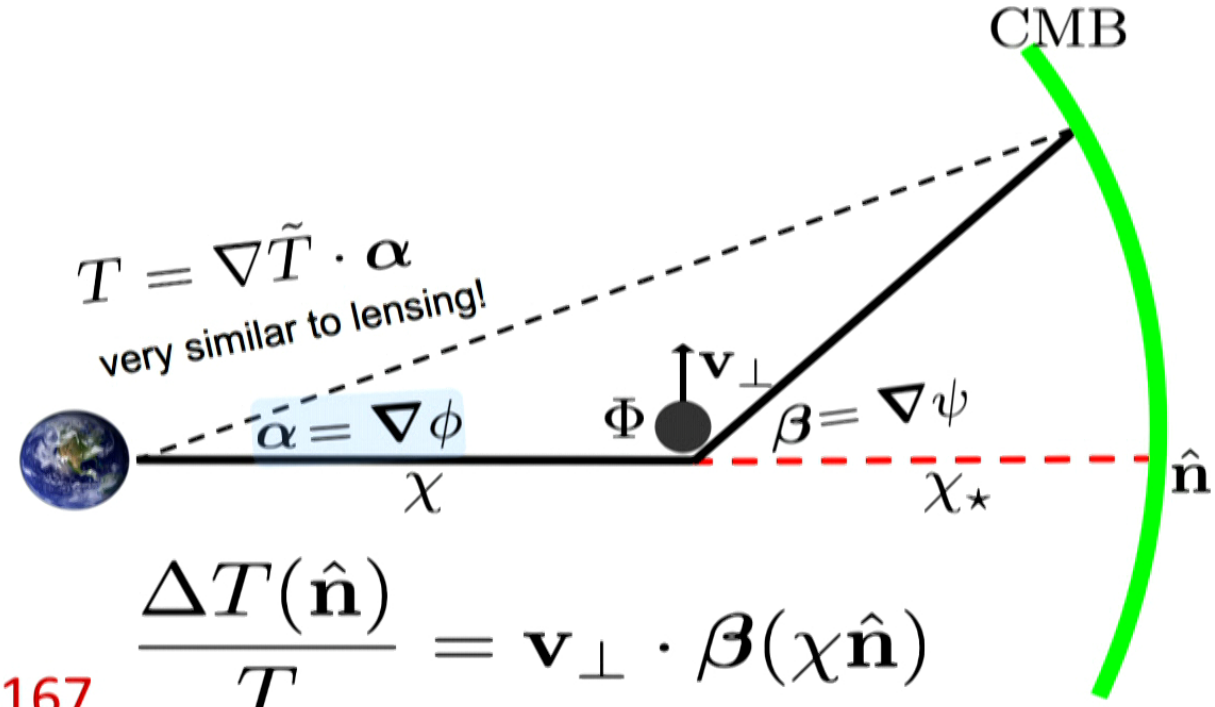

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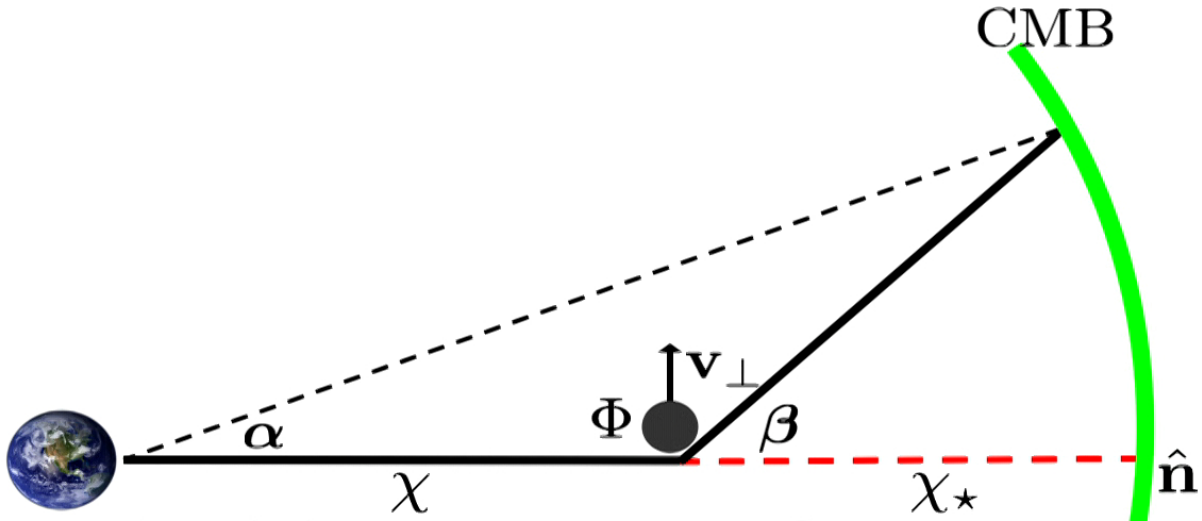

$$\left.\frac{\Delta T(\hat{\mathrm{n}})}{T_{\mathrm{CMB}}}\right|_{\mathrm{ISW}} = -2\int_{\mathrm{e}}^{\mathrm{o}} \mathrm{d}\tau\, \dot{\Phi}$$

and analogous to ISW

PRL, arXiv: 1812.03167

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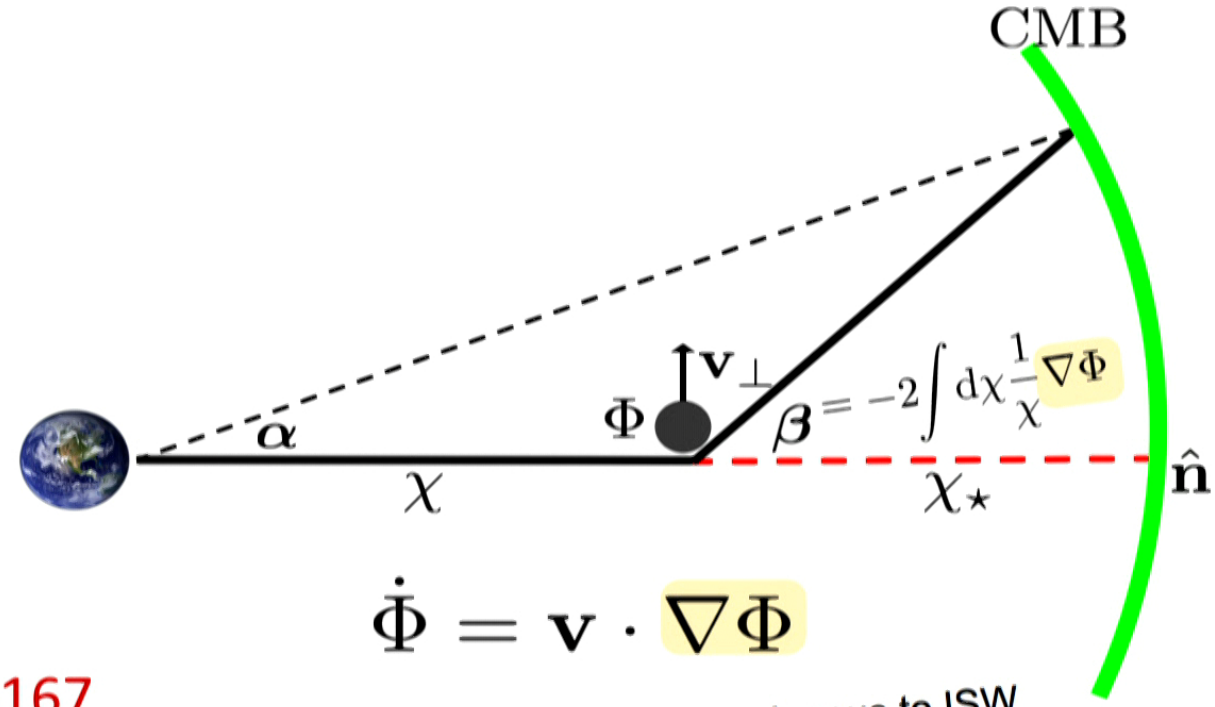

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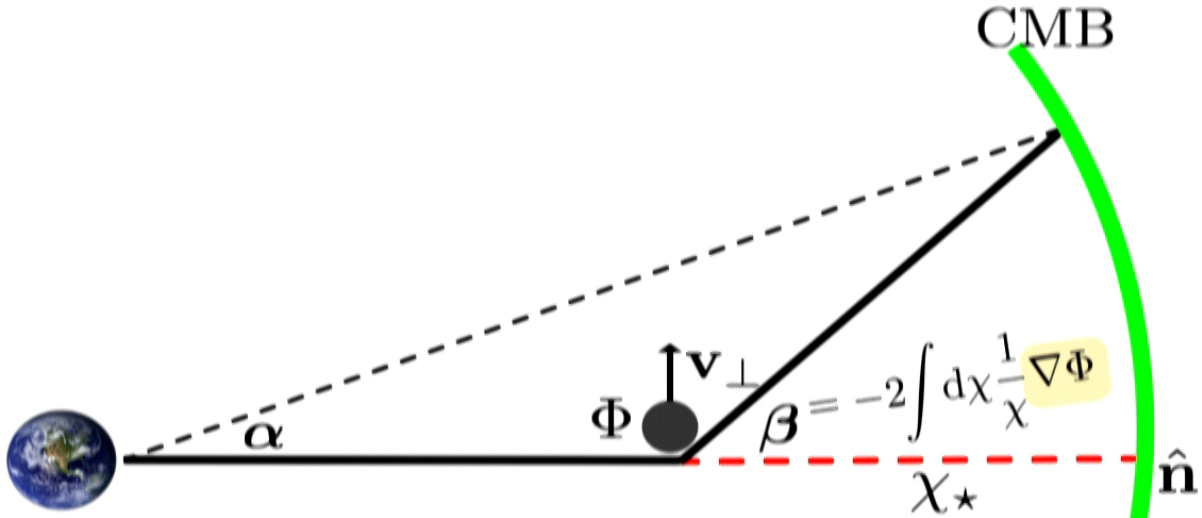

$$\frac{\Delta T}{T_{\rm CMB}} = -2\int \mathrm{d}\tau\ \mathbf{v}_\perp \cdot \nabla_\perp \Phi$$

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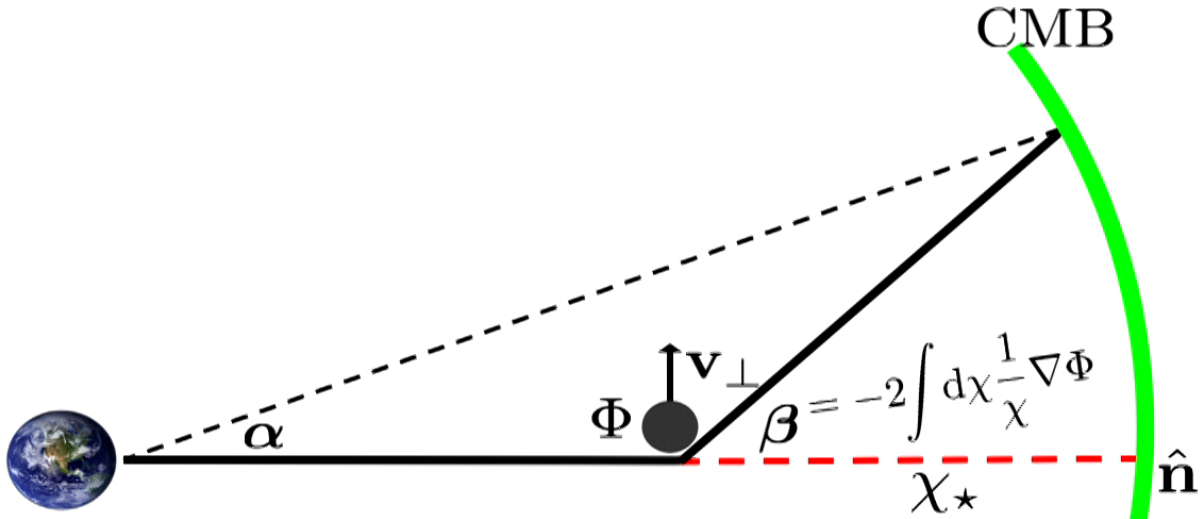

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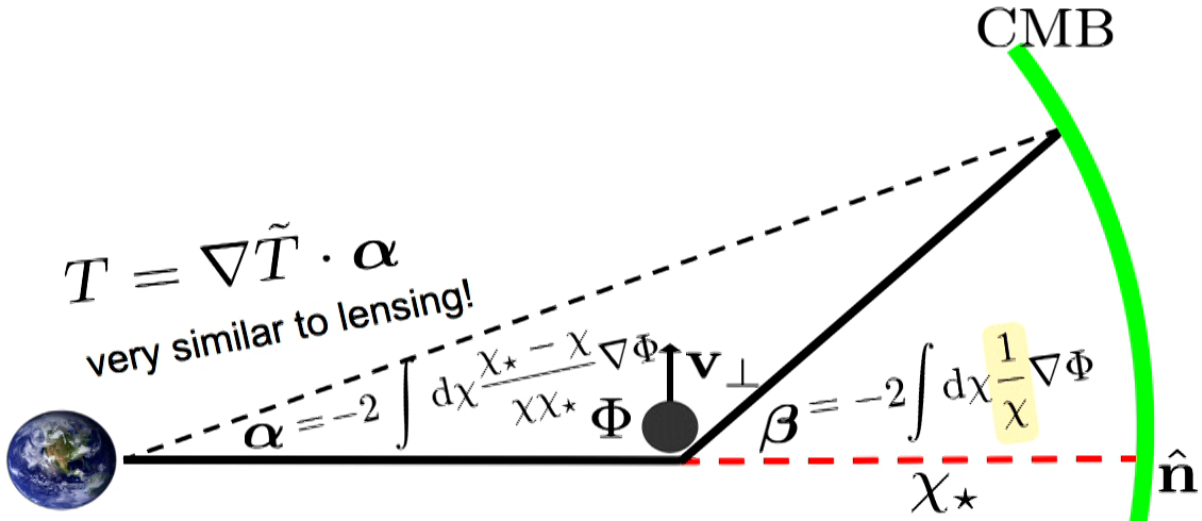

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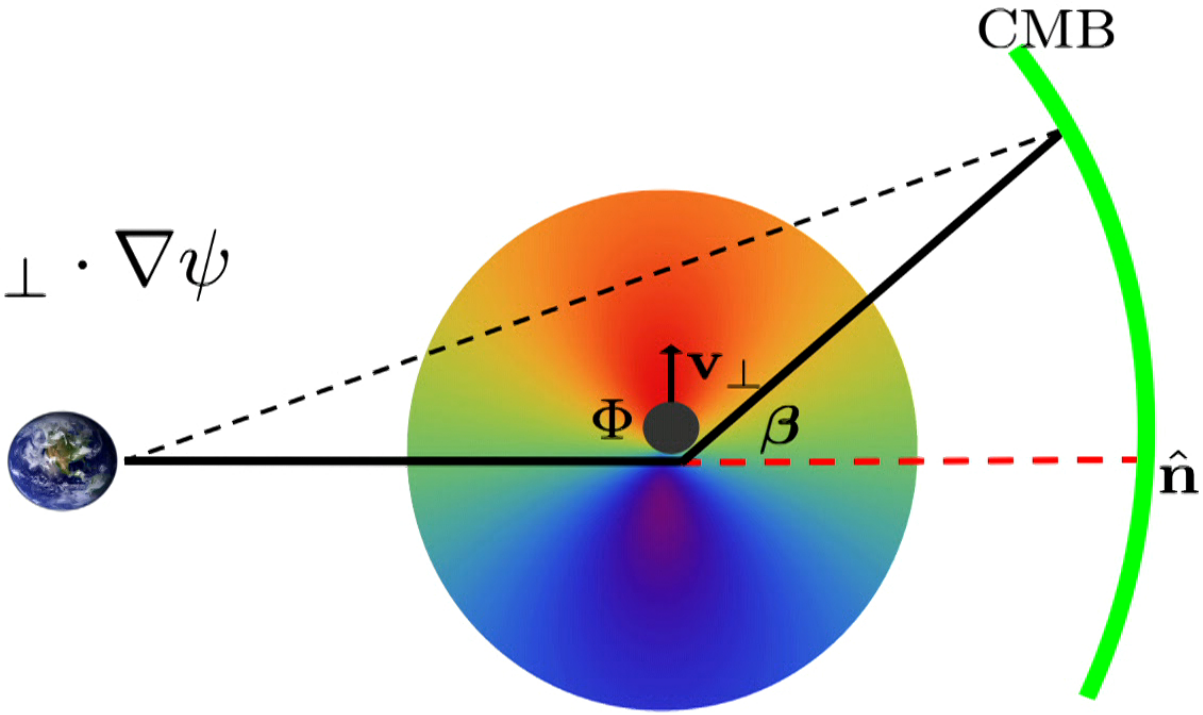
$$\frac{\Delta T(\hat{\mathbf{n}})}{T_{\rm CMB}} = \mathbf{v}_\perp \cdot \nabla\psi$$



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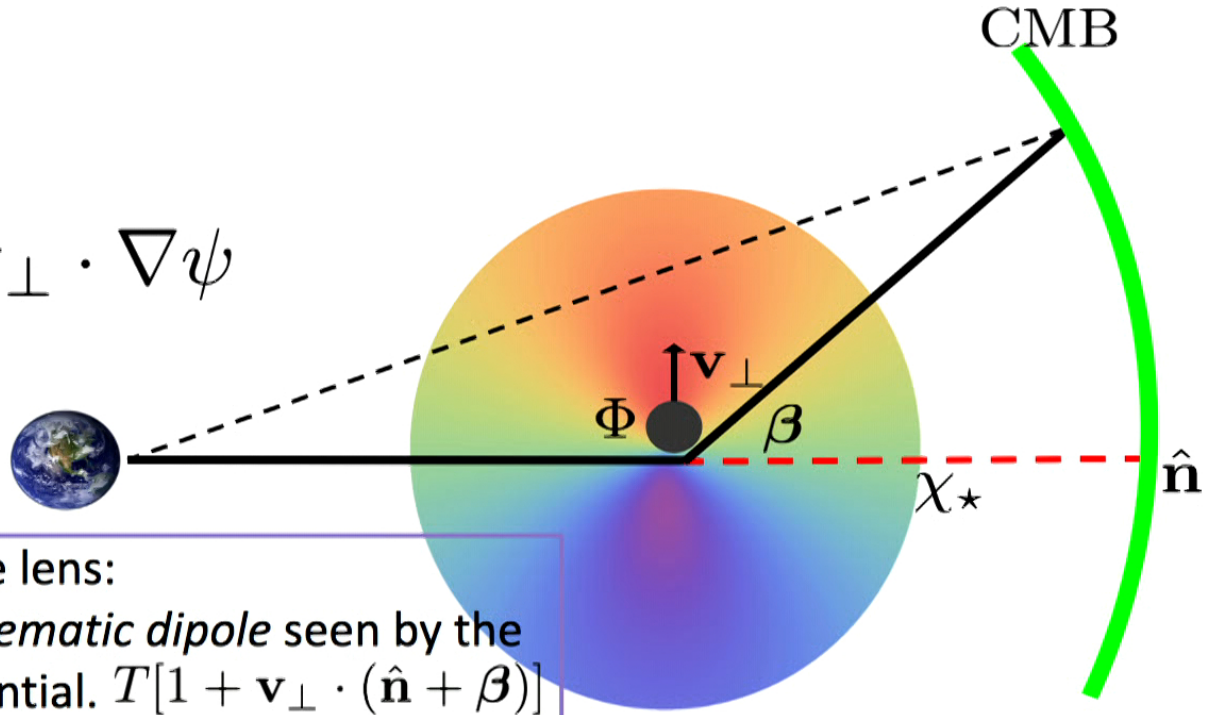
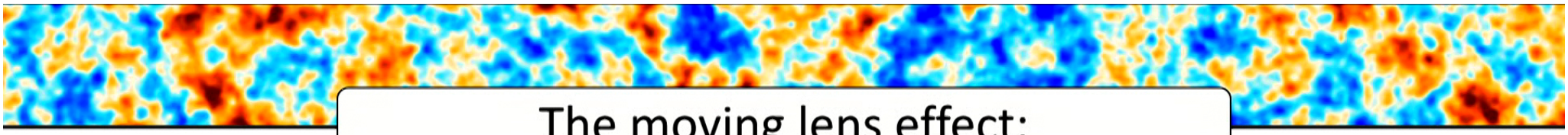


In the rest frame of the lens:

- Lensing of the *kinematic dipole* seen by the gravitational potential. $T[1 + \mathbf{v}_\perp \cdot (\hat{\mathbf{n}} + \boldsymbol{\beta})]$



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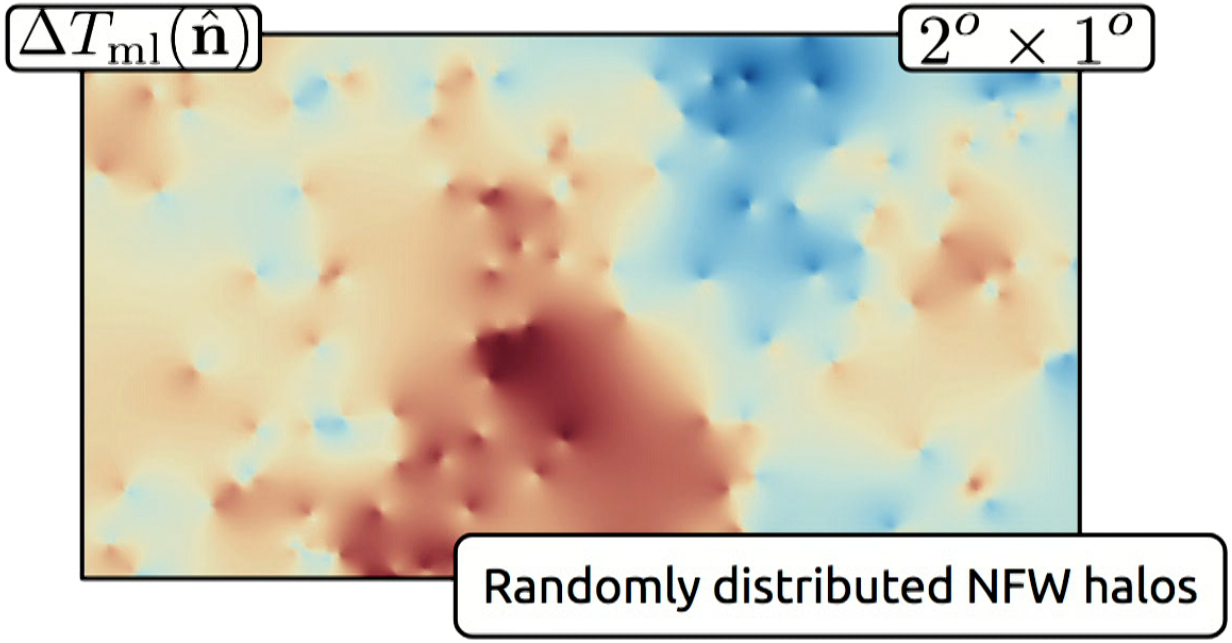

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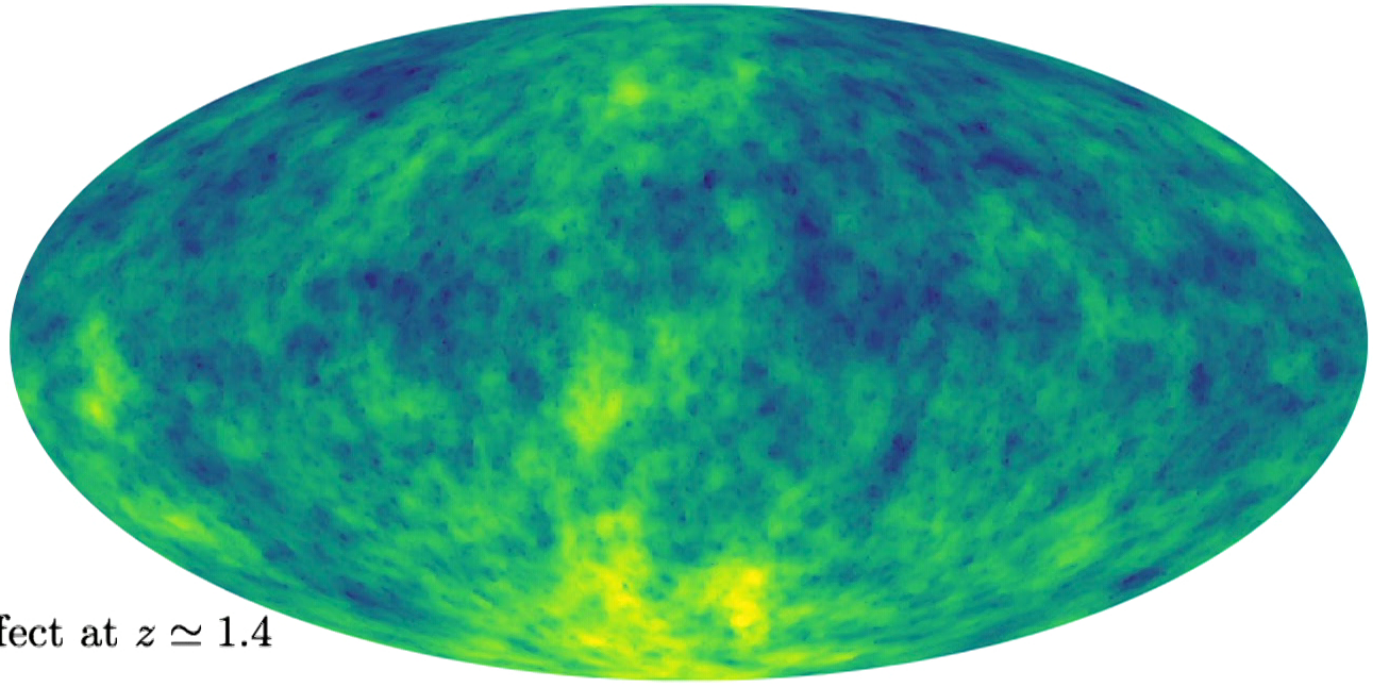


Moving lens effect at $z \simeq 1.4$

The moving lens effect:

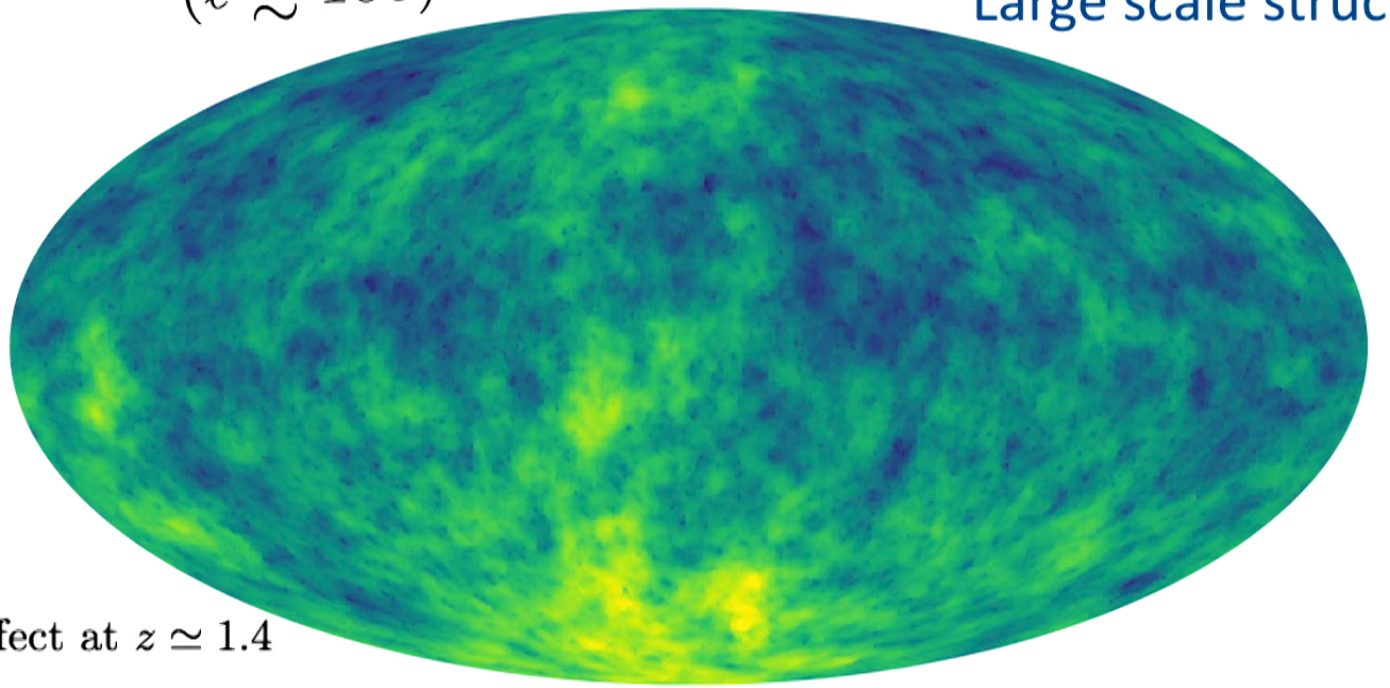
quadratic estimator:

CMB $(\ell \gtrsim 2000)$

$$\hat{\mathbf{v}}_\perp \propto \langle T \psi \rangle$$

$(\ell \lesssim 100)$

Large scale structure



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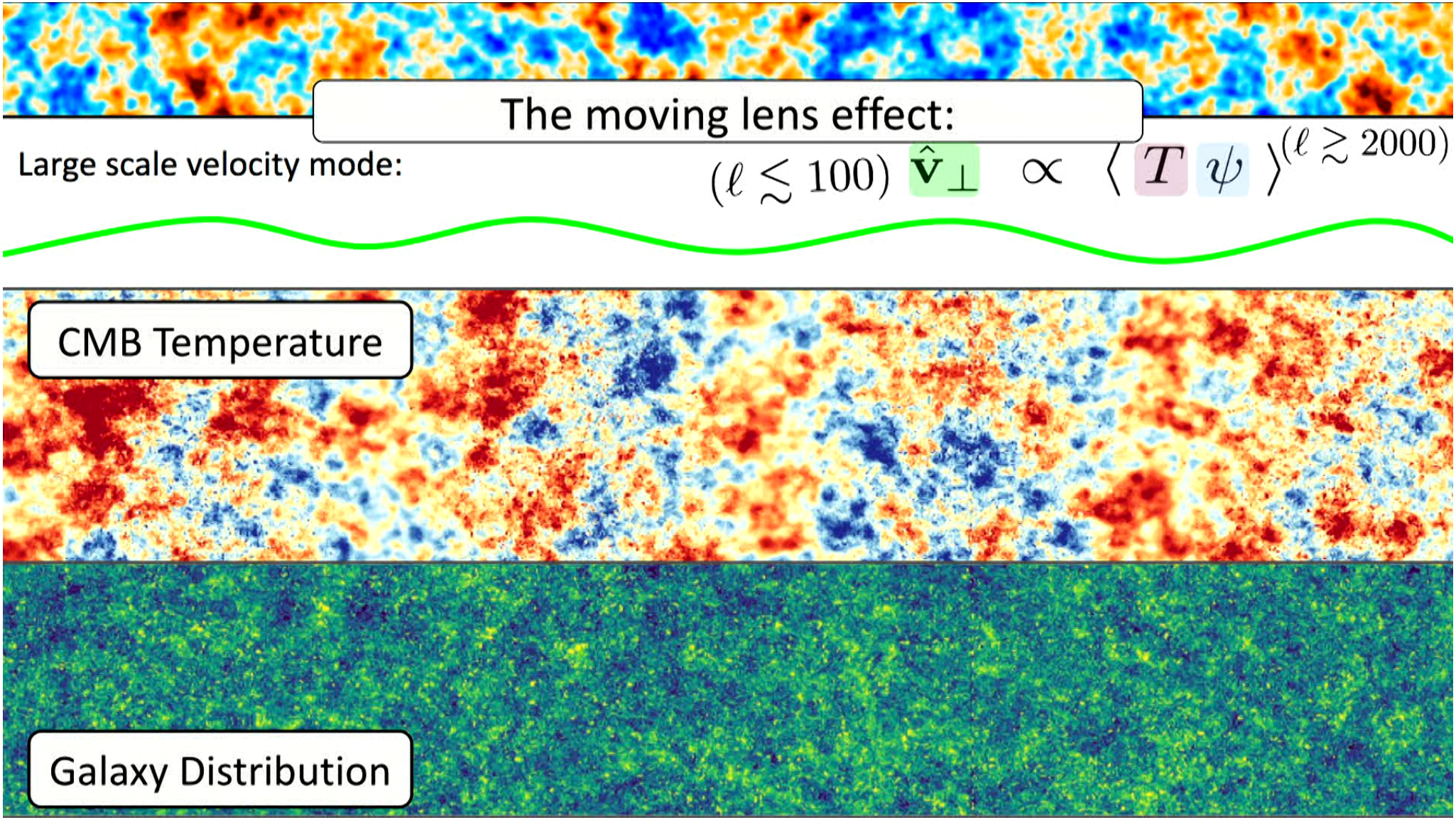
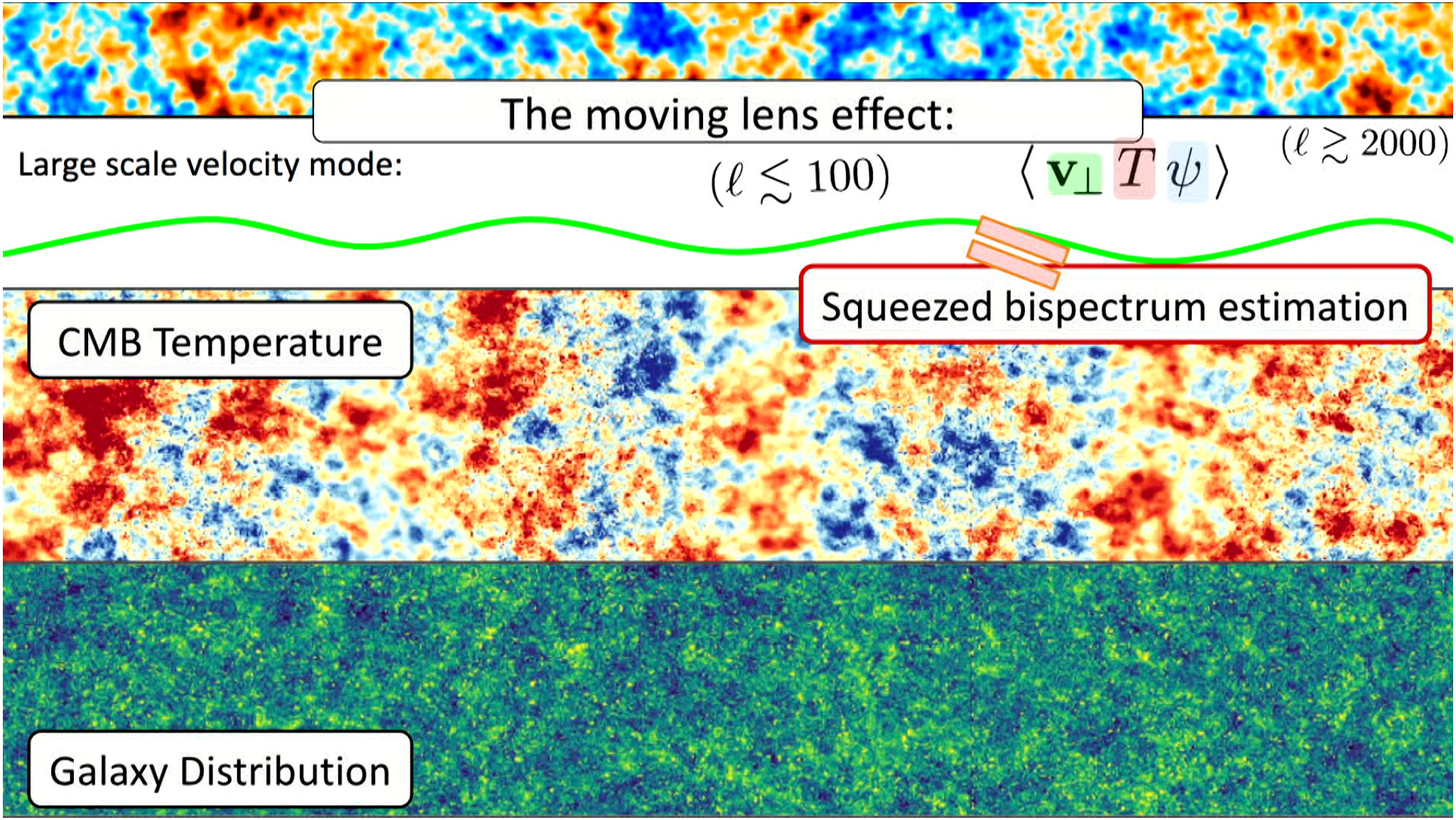
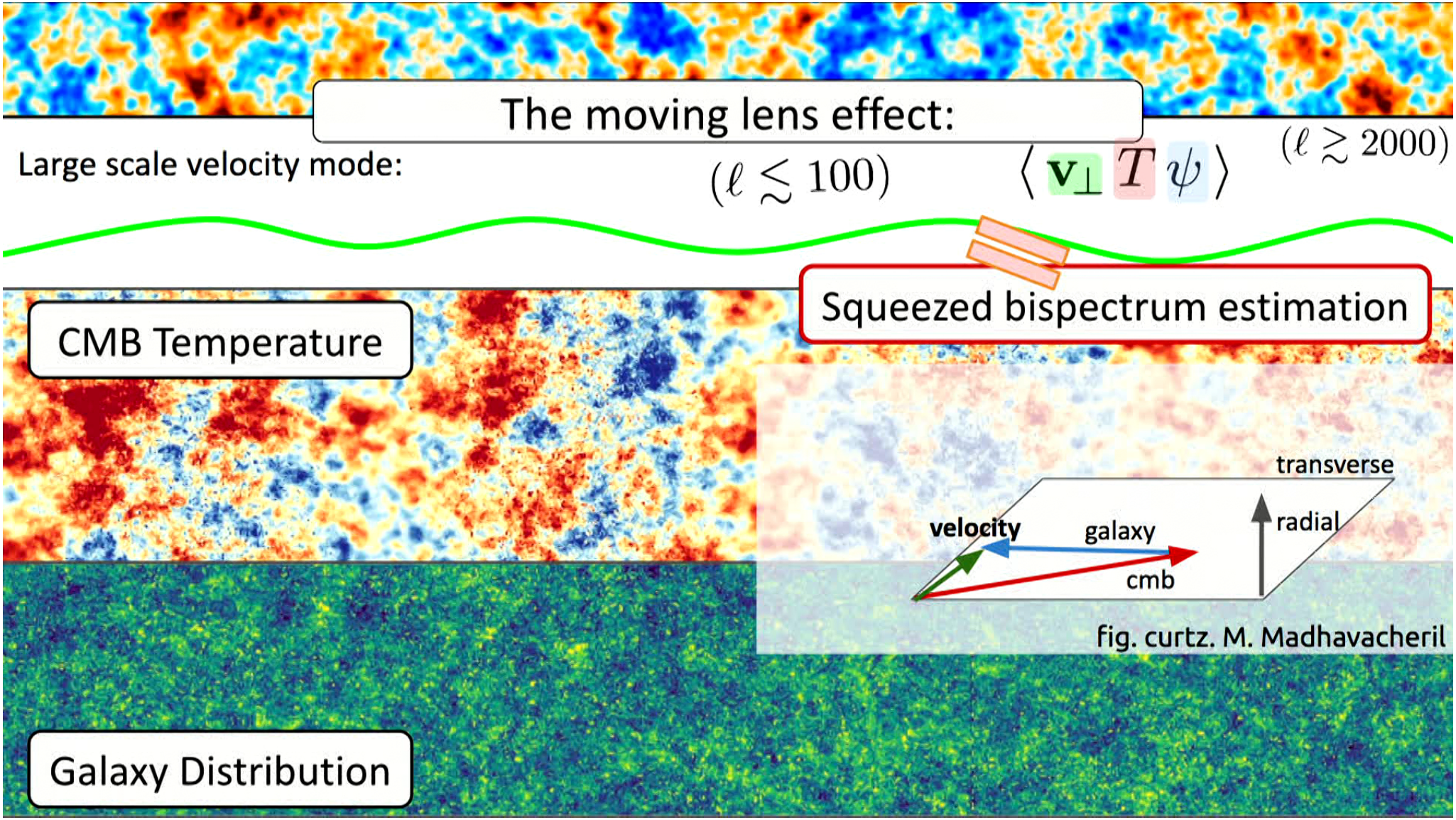

The moving lens effect:
Large scale velocity mode:
$(\ell \lesssim 100)\ \hat{\mathbf{v}}_\perp \propto \langle T\ \psi \rangle^{(\ell \gtrsim 2000)}$
CMB Temperature
Galaxy Distribution


The moving lens effect:
Large scale velocity mode:
$(\ell \lesssim 100)$
$\langle \mathbf{v}_\perp T \psi \rangle$
$(\ell \gtrsim 2000)$
Squeezed bispectrum estimation
CMB Temperature
Galaxy Distribution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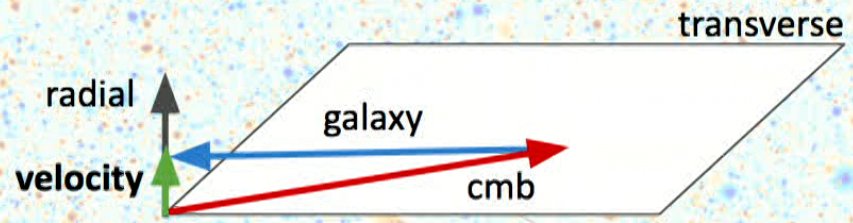
transverse
radial
velocity
galaxy
cmb
fig. curtz. M. Madhavacheril

The moving lens effect:

kinematic Sunyaev Zel'dovich (kSZ) effect:

CITA/Skymaps, Alvares, 2016

$$\frac{\Delta T_{\rm kSZ}(\hat{\mathbf{n}})}{T_{\rm CMB}} \sim \int {\rm d}\chi e^{-\tau(z)} v_r \delta_e(\hat{\mathbf{n}}, \chi)$$



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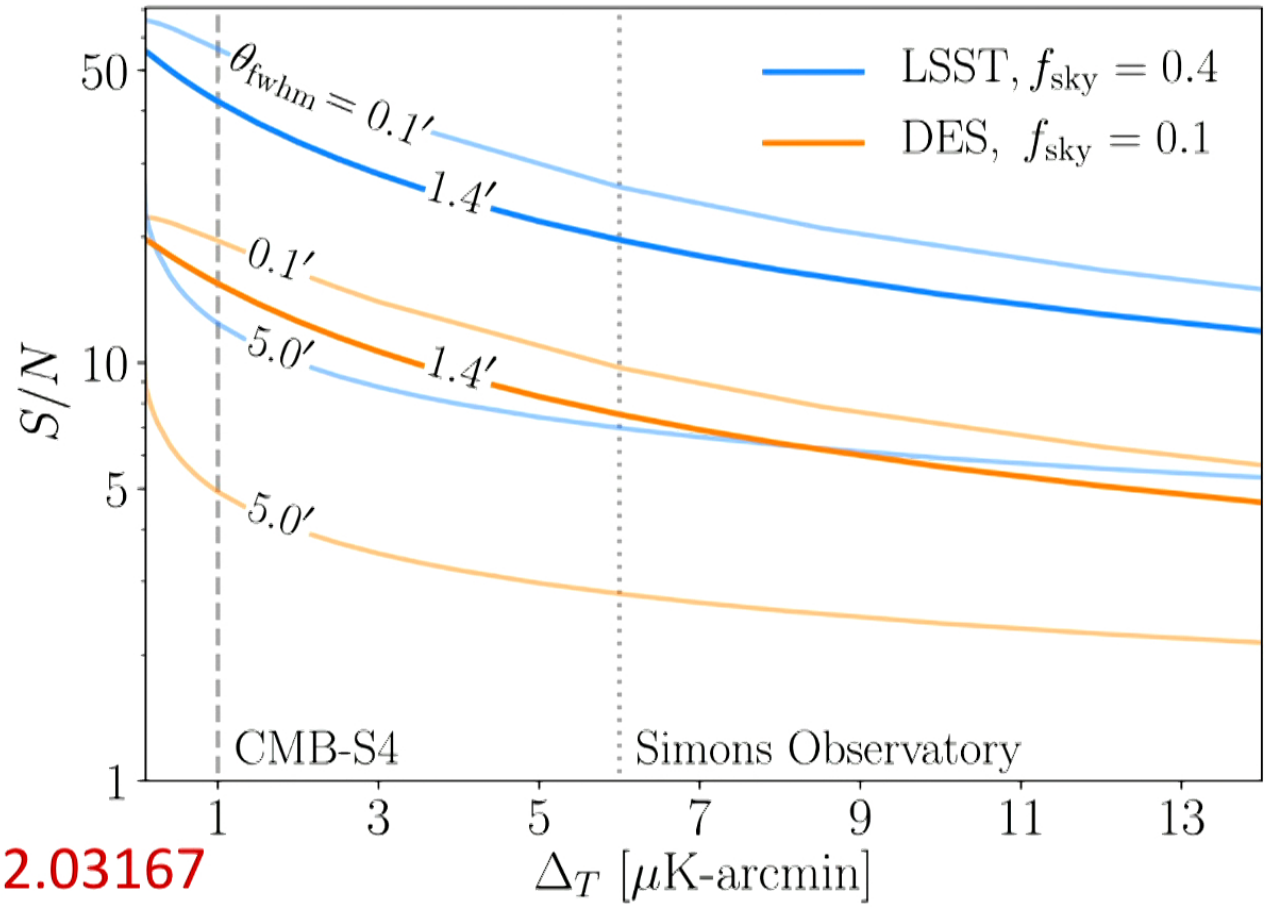

PRL, arXiv: 1812.03167

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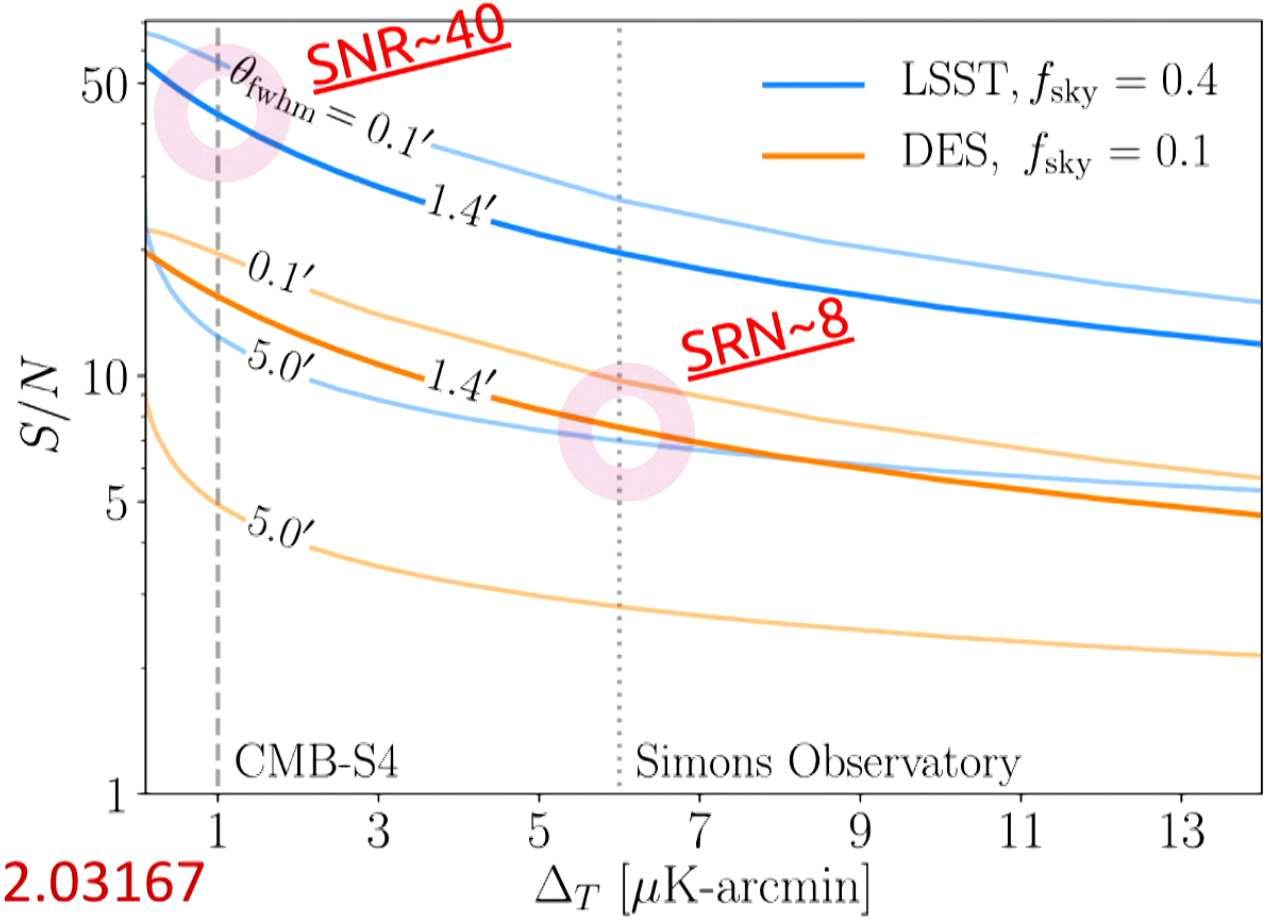

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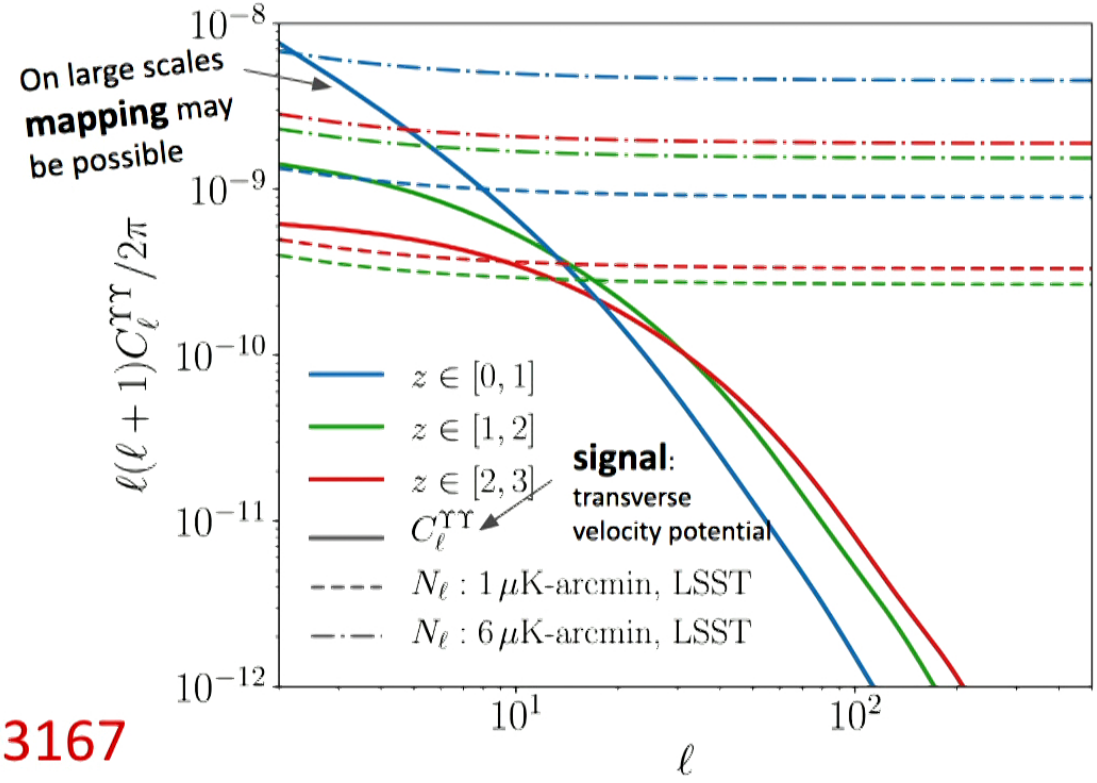

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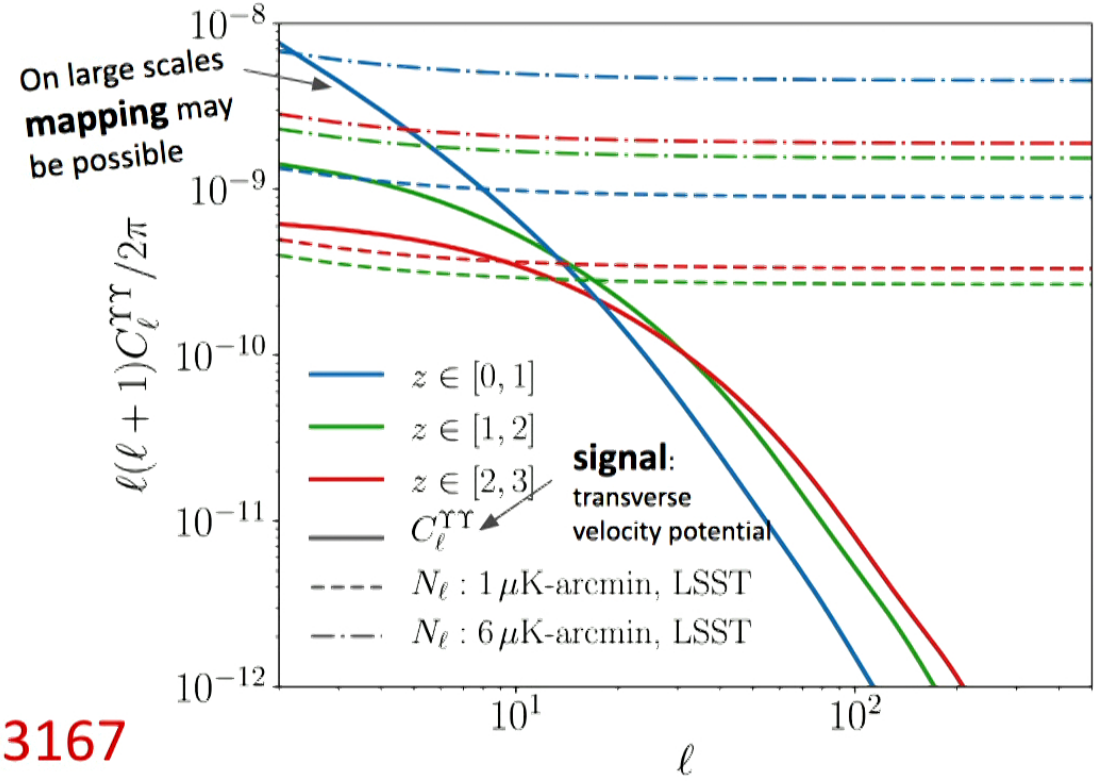

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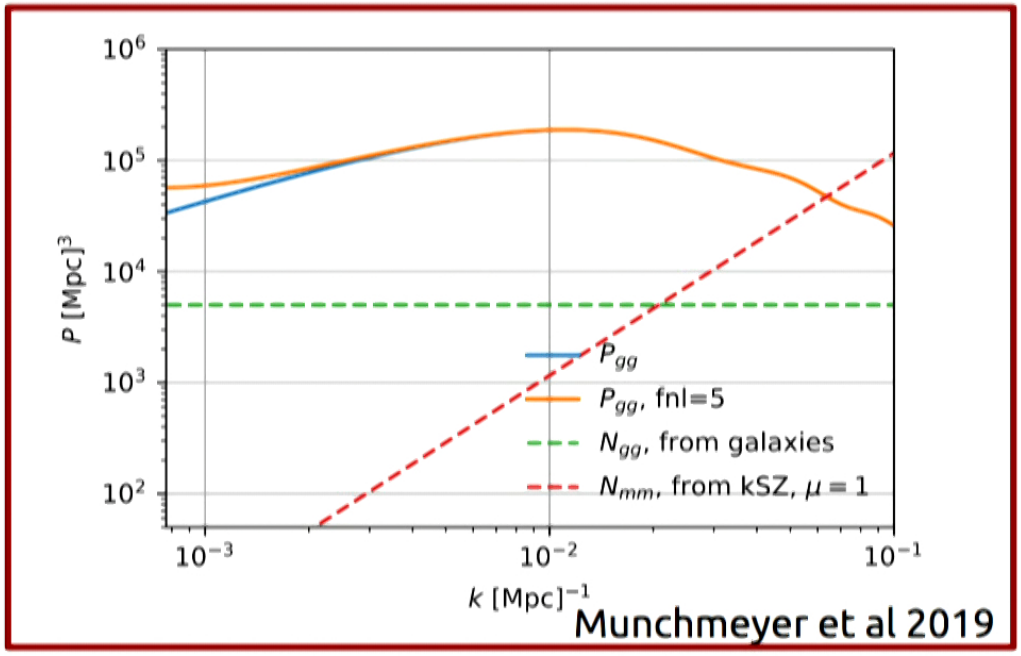
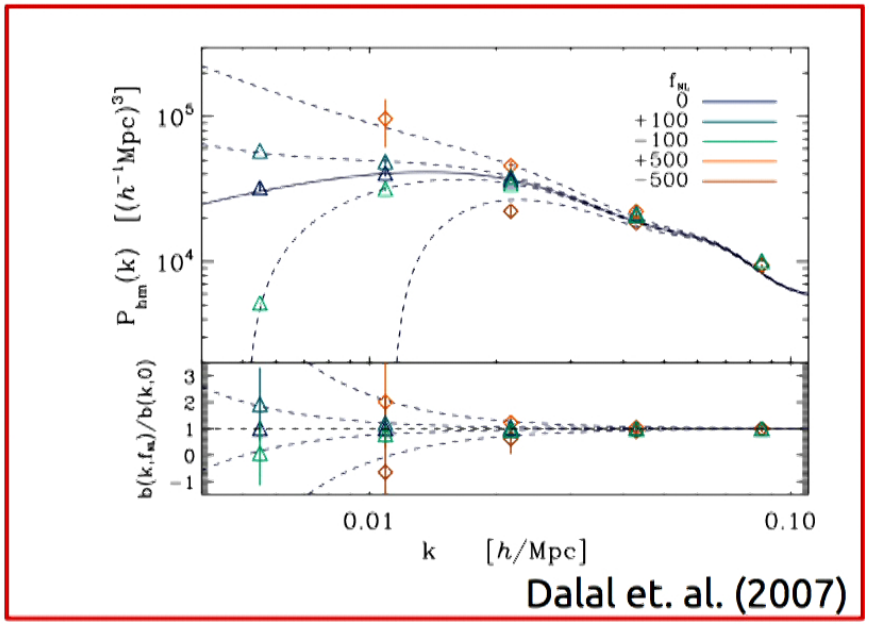


Probes of fundamental physics

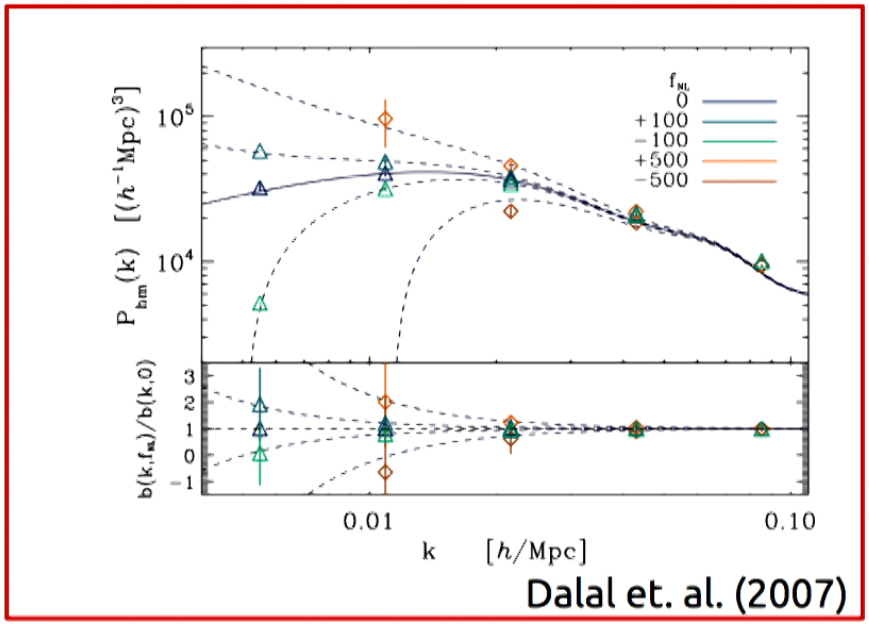


Dalal et. al. (2007)

$$\delta_h = b\,\delta$$

Probes of fundamental physics

Primordial non-Gaussianity leads to a scale dependent **bias**



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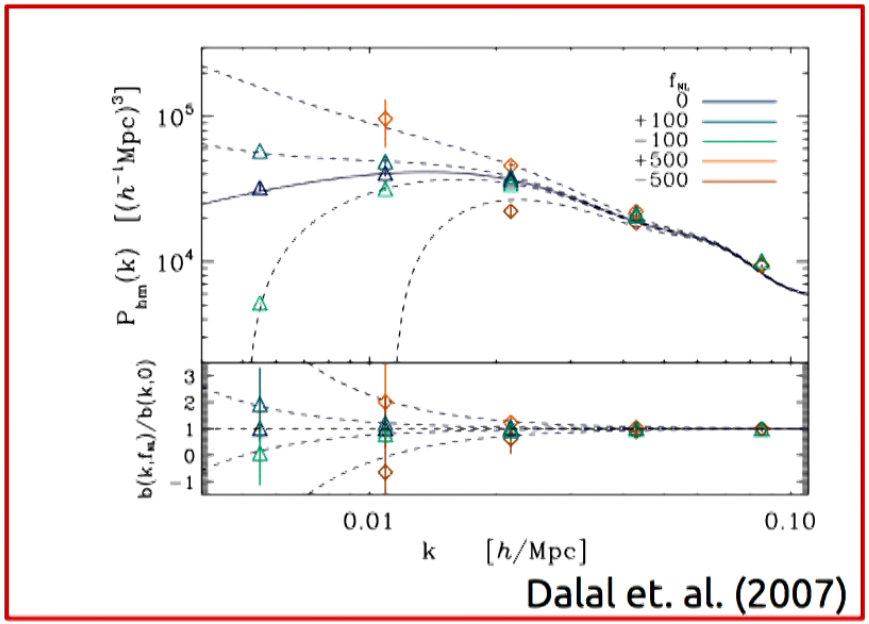

Dalal et. al. (2007)

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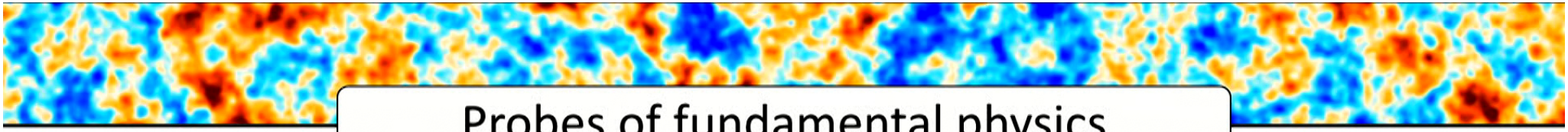
The ***relative*** bias of two tracers will then pick up scale dependence.
This can be used to constrain **local non-Gaussianity!**

Sample-variance cancellation, Seljak (2008)

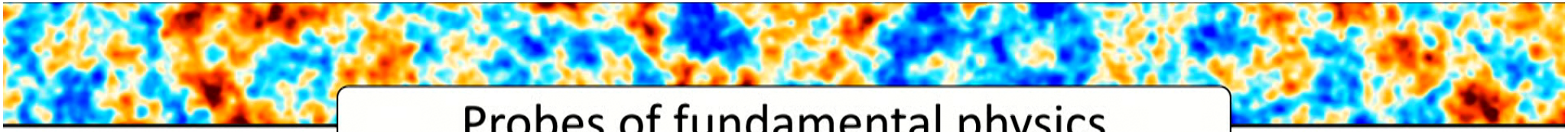


Probes of fundamental physics

General motivation for primordial isocurvature:

Weinberg 2003

- Field equations for cosmological perturbations always have an adiabatic solution.
- Theories of the early Universe which have one degree of freedom, such as single field inflation, naturally predict purely adiabatic fluctuations.
- Theories with multiple degrees of freedom can source isocurvature (entropy) perturbations



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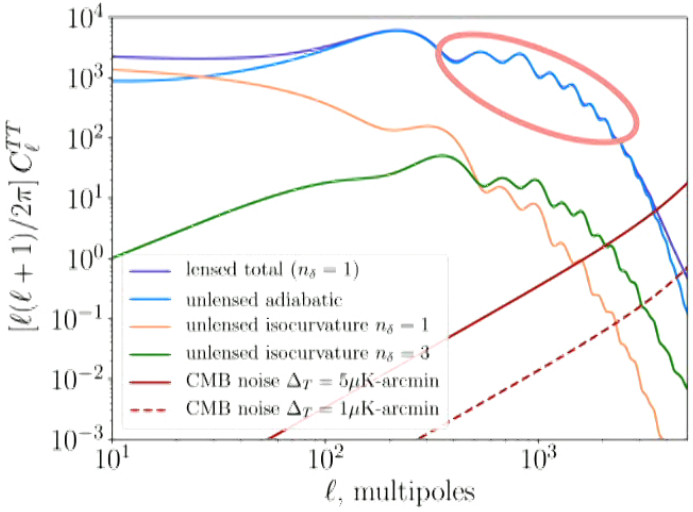

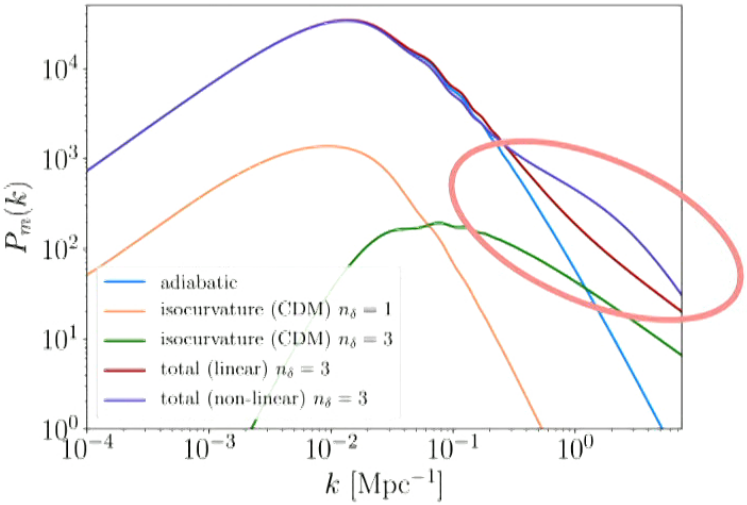

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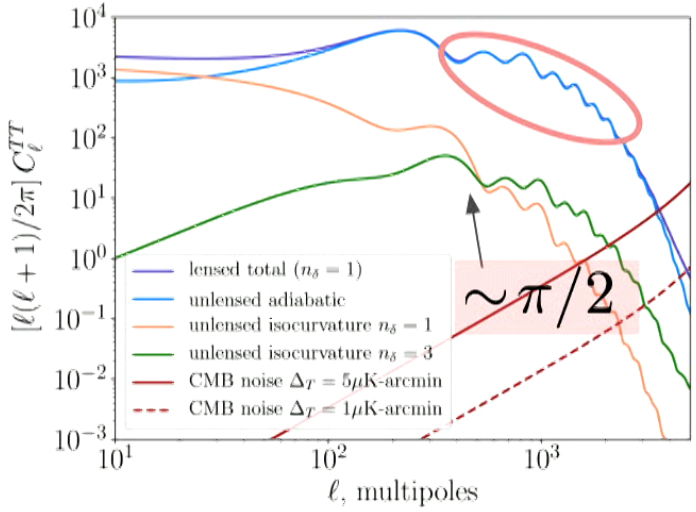

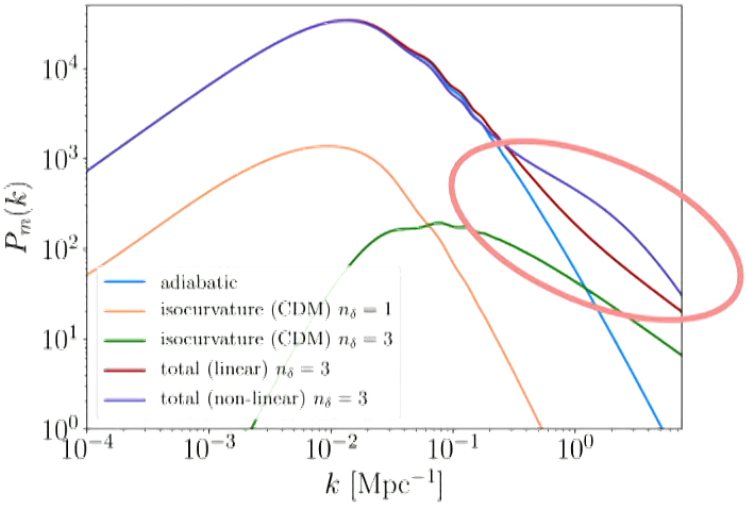

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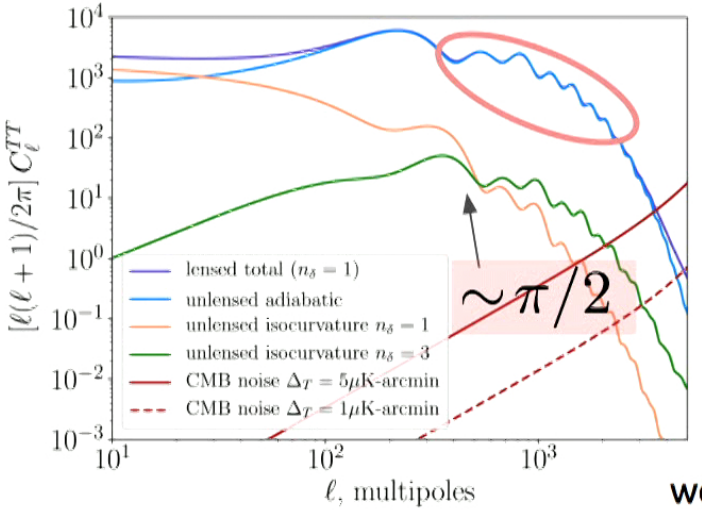
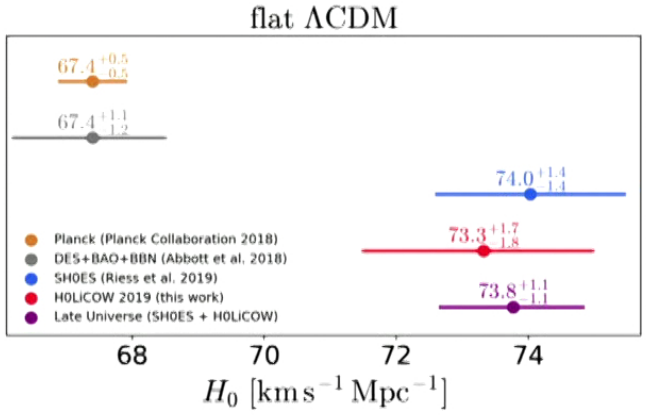
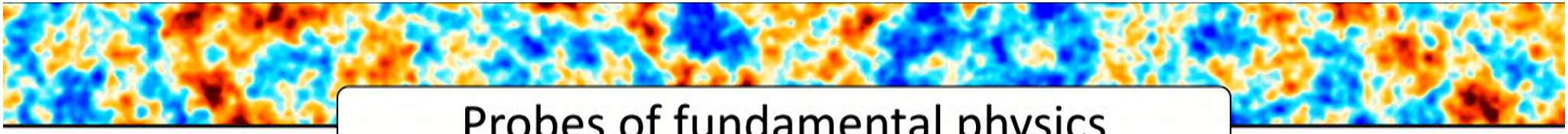




work with Tenkanen, Kamionkowski, and others



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Primordial non-Gaussianity leads to a scale dependent **bias**

Primordial isocurvature can <u>also</u> lead to a scale dependent **bias**

<u>Compensated</u> isocurvature perturbations (CIPs)

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baryons, CDM, neutrinos

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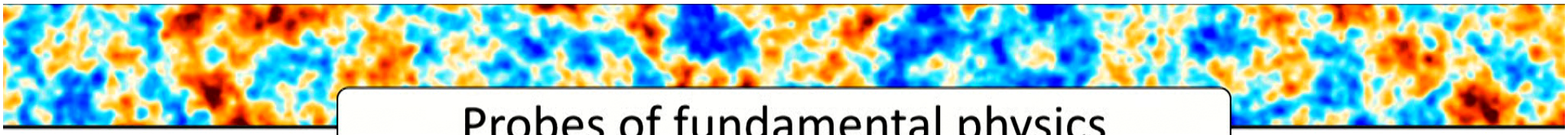

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Galaxy-bias

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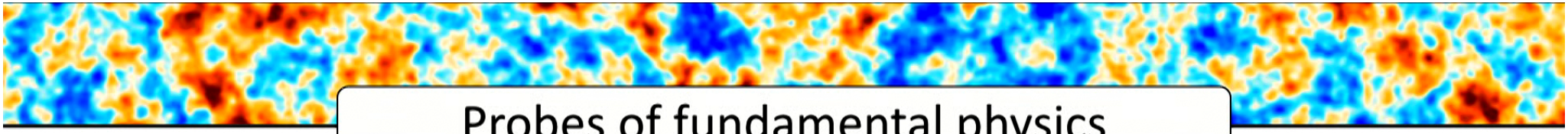

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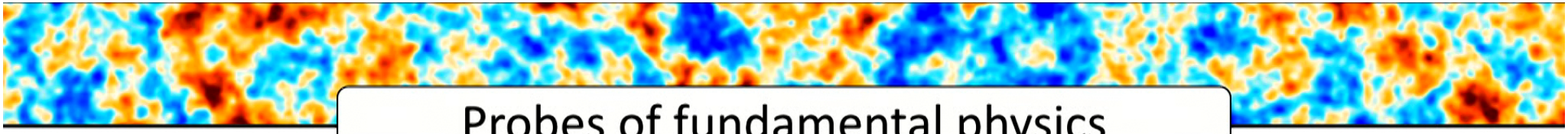
Current (future) constraints from CMB:

$$\sigma(A) \sim 500 \ (10)$$

Future constraints from **moving lens**:

$$\sigma(A) \sim 5$$



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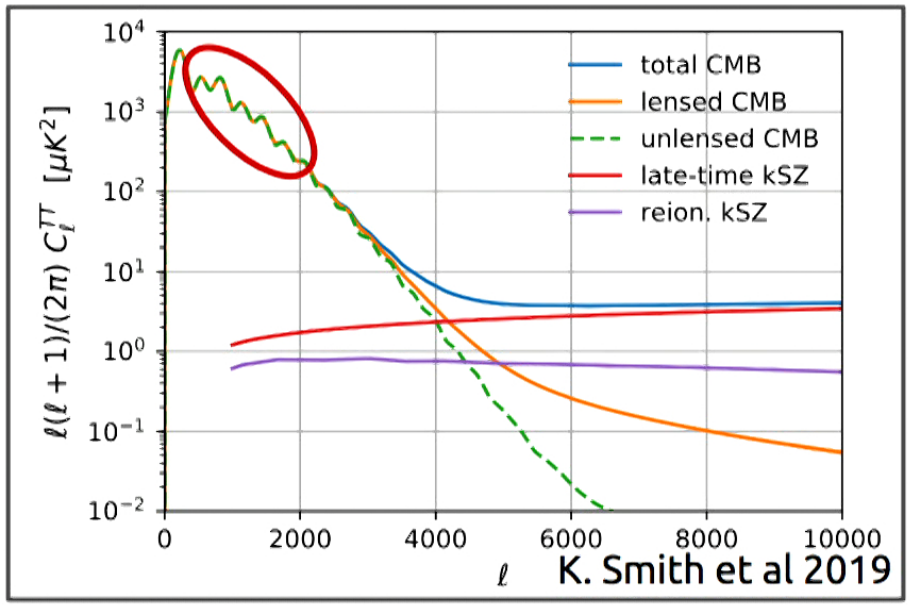
  - Goal: *Effectively* searching for fundamental physics:

e.g. on the morphology of BAO feature



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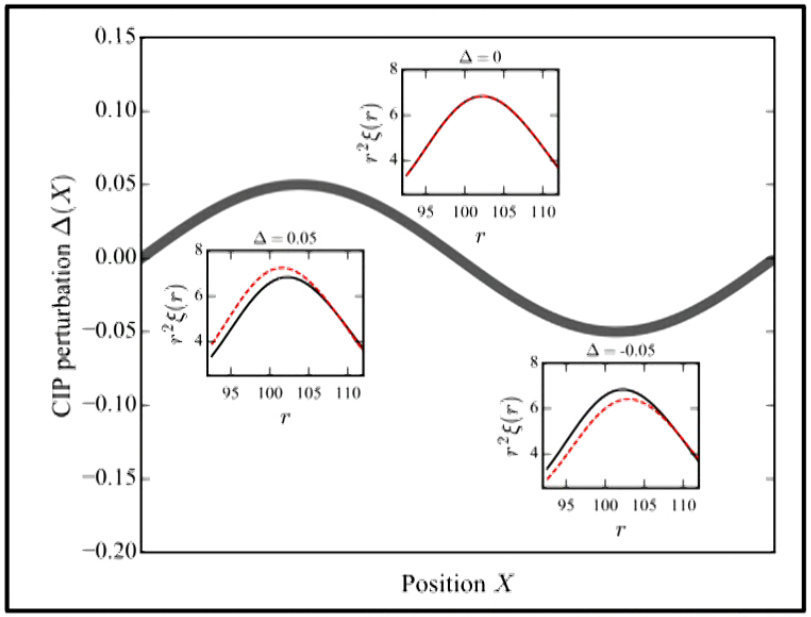

Heinrich and Schmittfull

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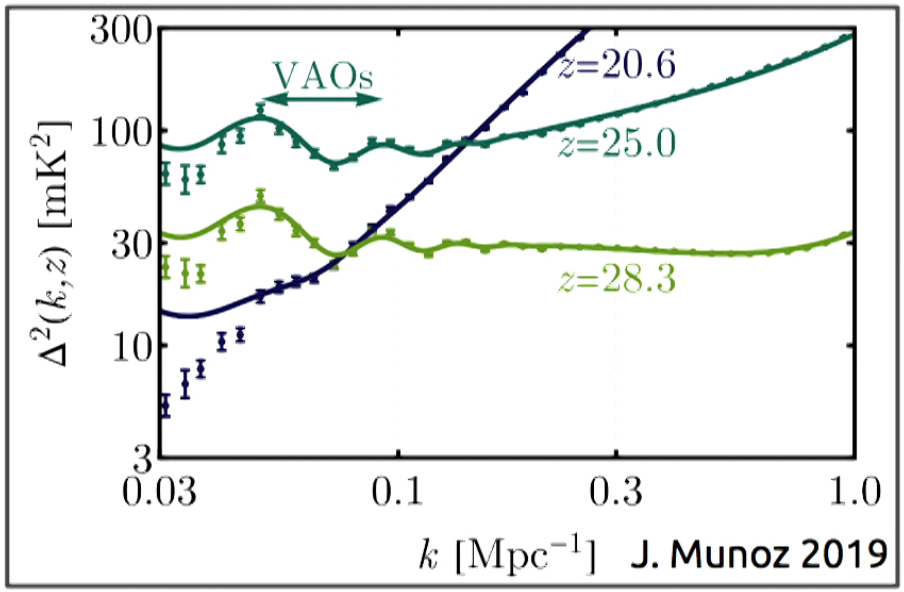

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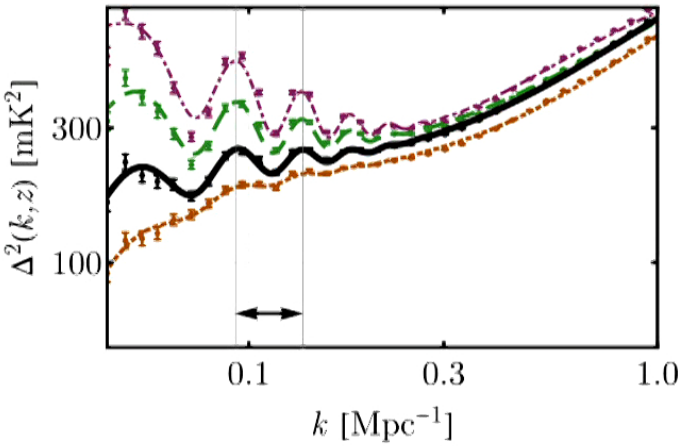
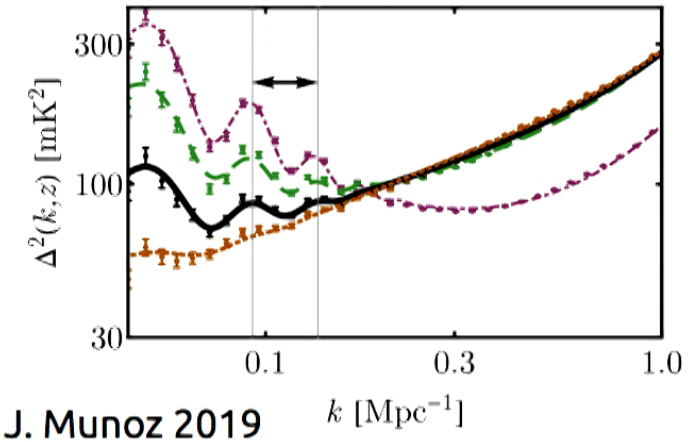
Peak locations and the VAO scale is a robust observable against the model uncertainties on baryonic feedback





J. Munoz 2019

Conclusions

- New and high quality data imminent from the CMB and galaxy surveys.
- Surveys of the 21cm hydrogen-line will achieve sufficient accuracy for cosmological inference.

These provide unique and exciting opportunities to study the fundamental constituents of the Universe!

- The large-scale cosmological fluctuations locally re-distribute the small-scale power in density fluctuations and induce small-scale statistical anisotropies.
- These large-scale cosmological observables are in turn extremely valuable for cosmological inference, as they are often protected from non-linear effects.

- The large relative velocities induced acoustic oscillations (`so-called' VAOs) in the 21cm hydrogen which can be used as a tool for constraining primordial isocurvature perturbations and other signatures beyond the standard LCDM paradigm.

Thanks!