

Title: Probing low redshifts with upcoming CMB surveys

Date: Apr 11, 2017 11:00 AM

URL: <http://pirsa.org/17040068>

Abstract: <p>A number of ground based CMB surveys that will survey large fractions of the sky to high sensitivity are currently in the planning stages. I will give an overview of what can be learned from these surveys about the Universe since recombination, focussing on gravitational lensing science. I will also discuss some new CMB observables that would be accessible with even more futuristic surveys.</p>

Probing low redshifts with upcoming CMB surveys

Alexander van Engelen (CITA, U. Toronto)

Perimeter, April 2017

Moore's law for CMB experiments

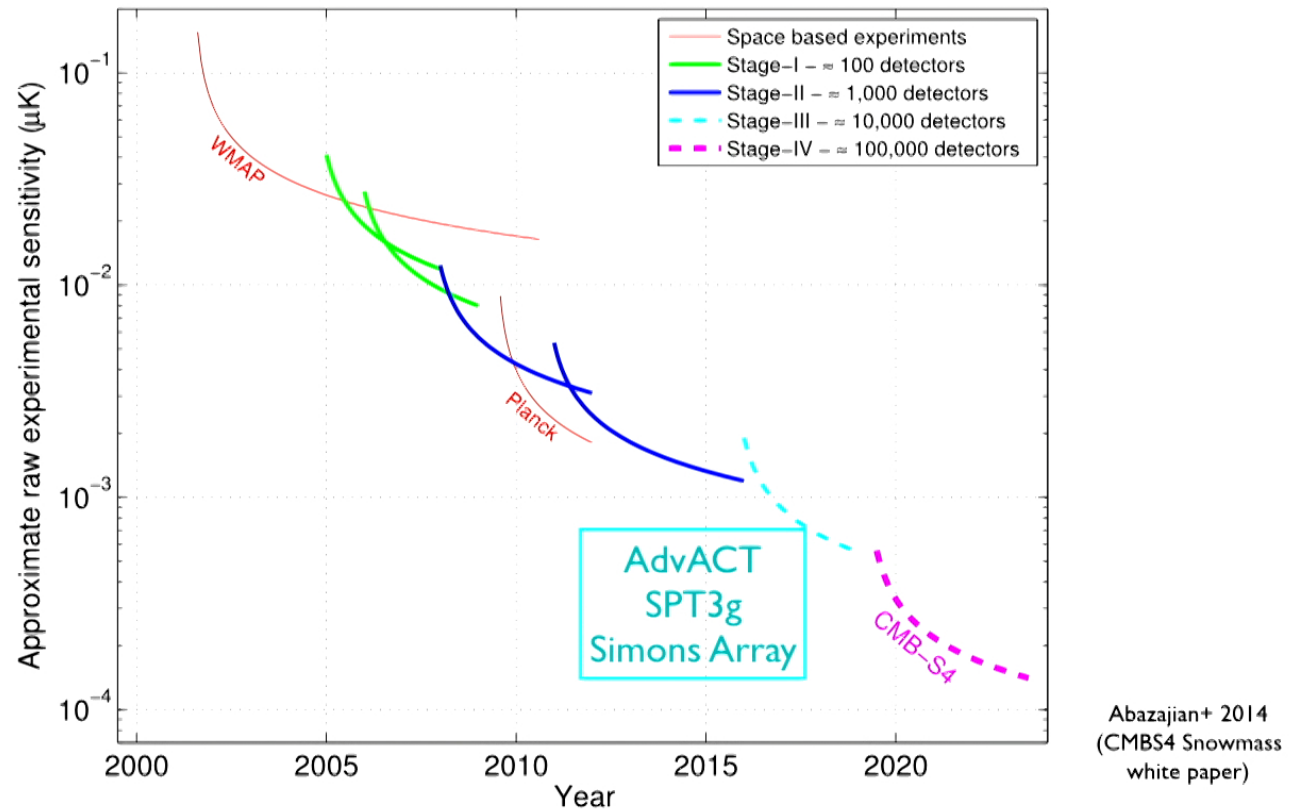


Figure 6. Plot illustrating the evolution of the raw sensitivity of CMB experiments, which scales as the total number of bolometers. Ground-based CMB experiments are classified into Stages with Stage II experiments having $O(1000)$ detectors, Stage III experiments having $O(10,000)$ detectors, and a Stage IV experiment (such as CMB-S4) having $O(100,000)$ detectors.



WMAP

high-pass filtered at $l = 200$

$\sim 30 \text{ deg}^2$

A grayscale map of the ACTPol region, showing a dense field of stars and galaxies. The map is high-pass filtered, resulting in a noisy appearance with bright spots and dark regions. The text "ACTPol" is overlaid in the top right corner in a bright cyan color. The text "high-pass filtered at l = 400" is overlaid in the bottom left corner in black. The text "~30 deg^2" is overlaid in the bottom right corner in black.

ACTPol

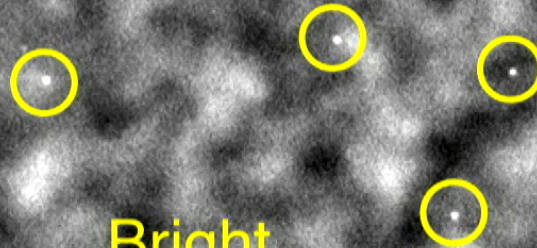
high-pass filtered at $l = 400$

~30 deg²



Galaxy
cluster

ACTPol

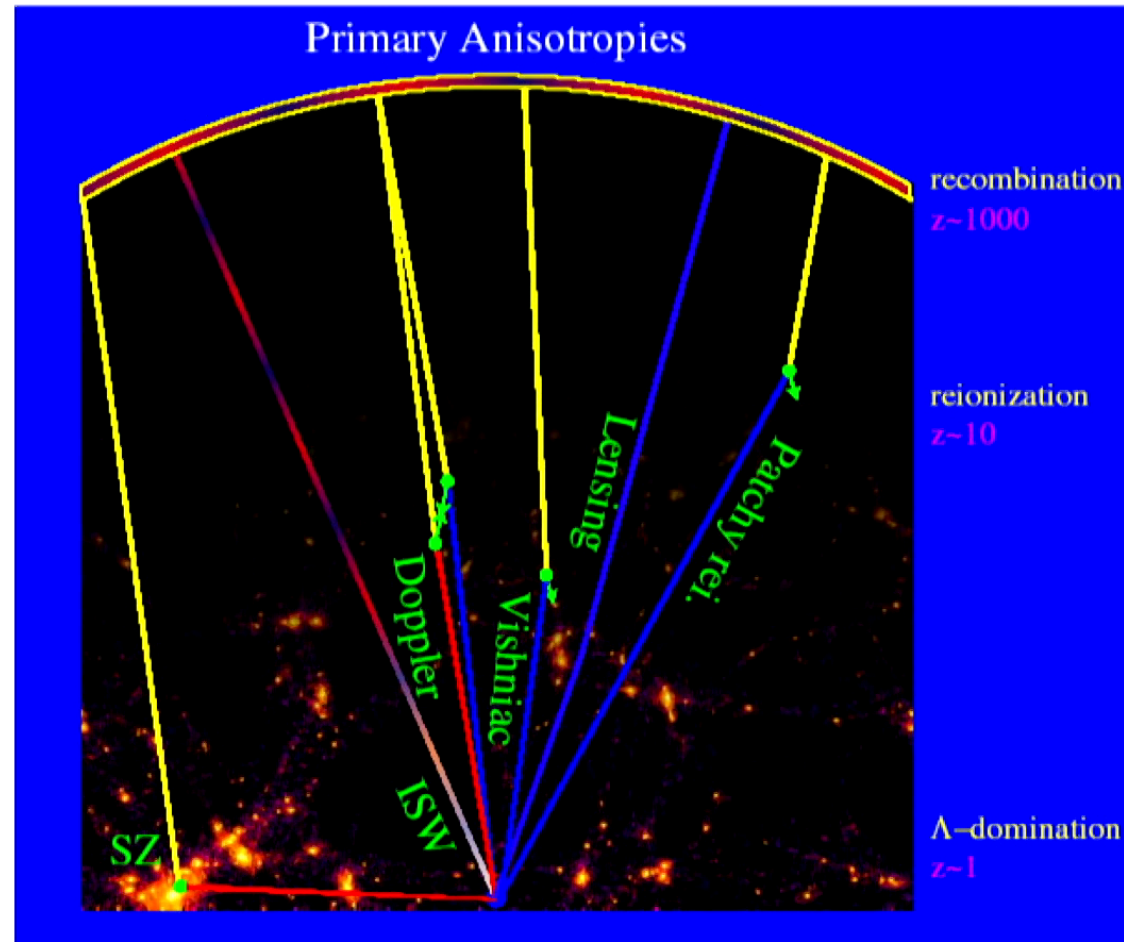


Bright
mm-wave galaxies

high-pass filtered at $l = 400$

$\sim 30 \text{ deg}^2$

The CMB as a backlight

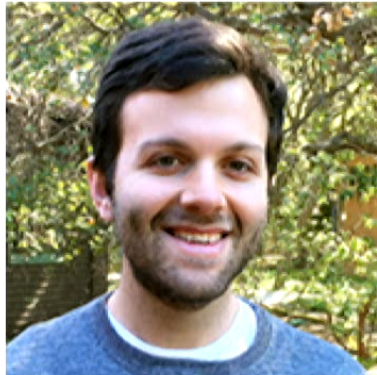


plus, emission in mm from dusty galaxies and AGN

Wayne Hu's website

Outline

Ongoing Analyses	ACTPol (2013-15)	~12-15 uK-arcmin	~10% of sky
Future data: Opportunities and Challenges	AdvACT (2016++)	~5-9 uK-arcmin	~40-50% of sky
	Simons Observatory (~2020++)	~few uK-arcmin	~40-50% of sky
	CMB-S4(~2024++)	~1 uK-arcmin	~40-50% of sky



Blake Sherwin
LBNL



Neelima Sehgal
Stony Brook

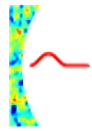


Mat Madhavacheril
Princeton

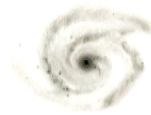
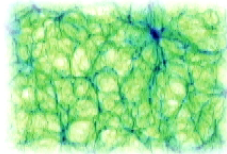


From pristine CMB to dirty data

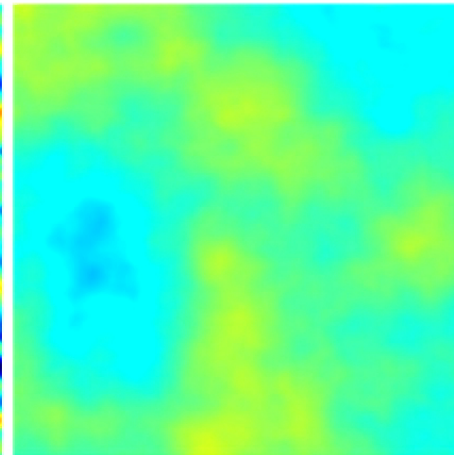
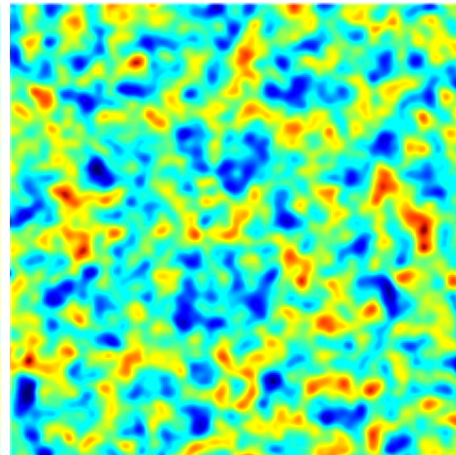
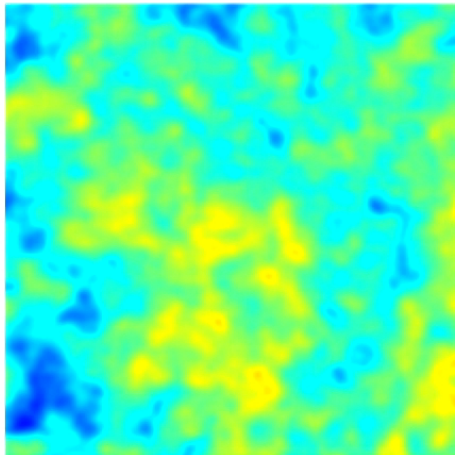
At the surface of last scattering



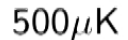
T



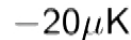
B



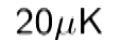
$-500\mu\text{K}$



$500\mu\text{K}$

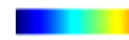


$-20\mu\text{K}$



$20\mu\text{K}$

$-1\mu\text{K}$

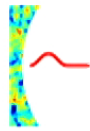


$1\mu\text{K}$

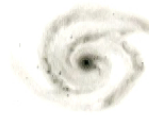
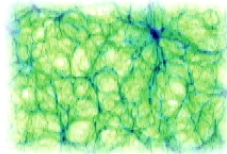
Image sequence credit: Sigurd Naess

From pristine CMB to dirty data

At the surface of last scattering



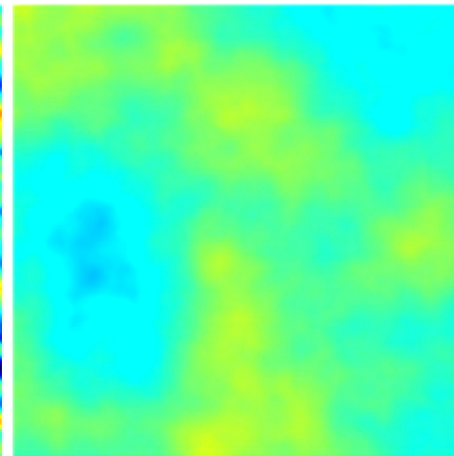
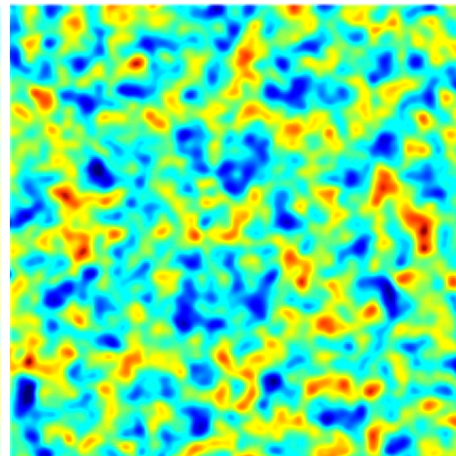
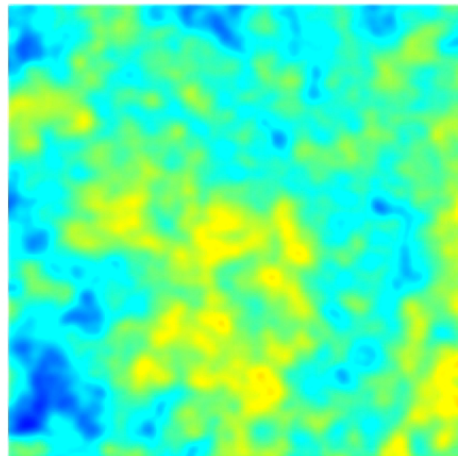
T



E



B



$-500\mu\text{K}$  $500\mu\text{K}$ $-20\mu\text{K}$  $20\mu\text{K}$


$-1\mu\text{K}$  $1\mu\text{K}$

Image sequence credit: Sigurd Naess

From pristine CMB to dirty data

Lensing by large-scale structure

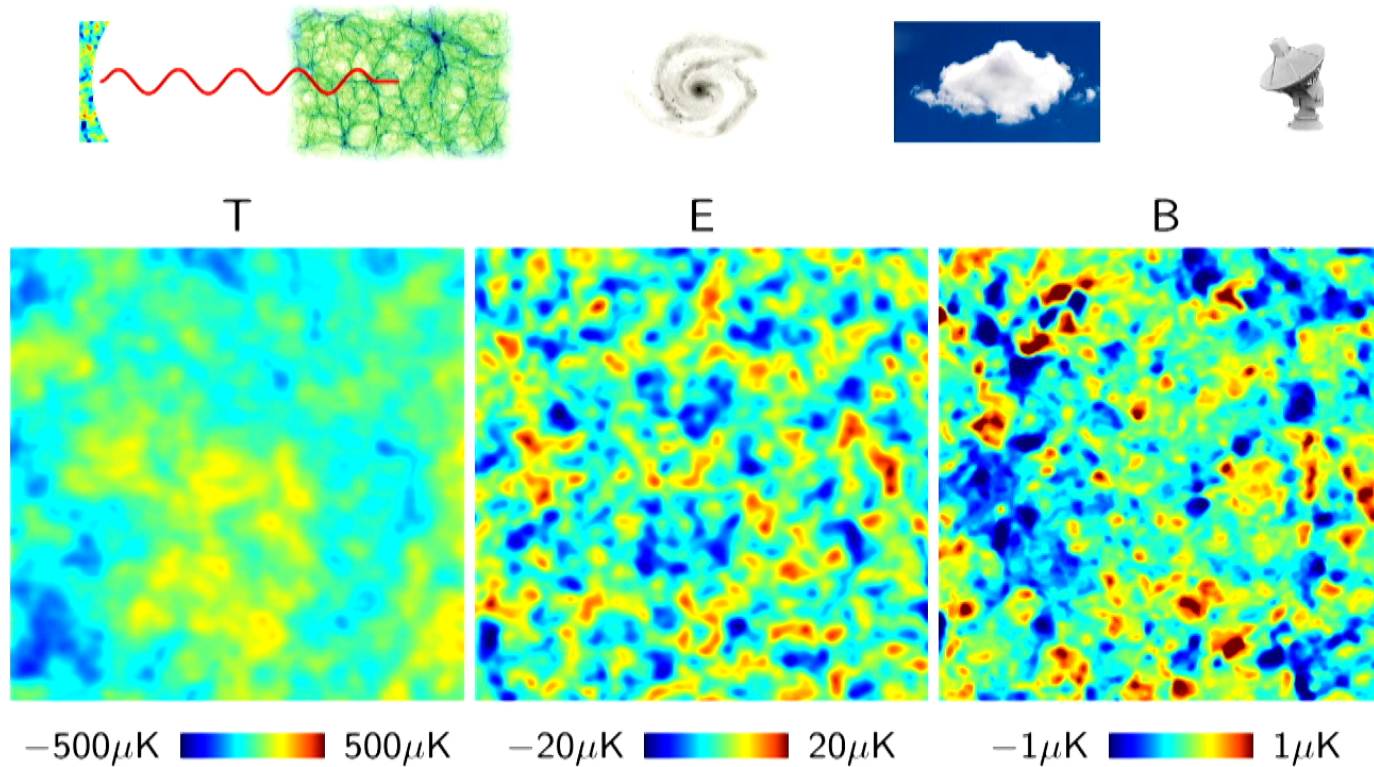
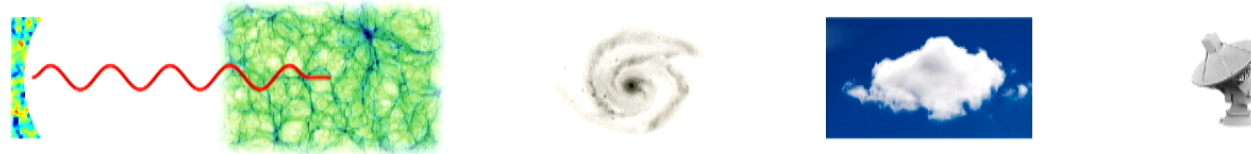


Image sequence credit: Sigurd Naess

From pristine CMB to dirty data

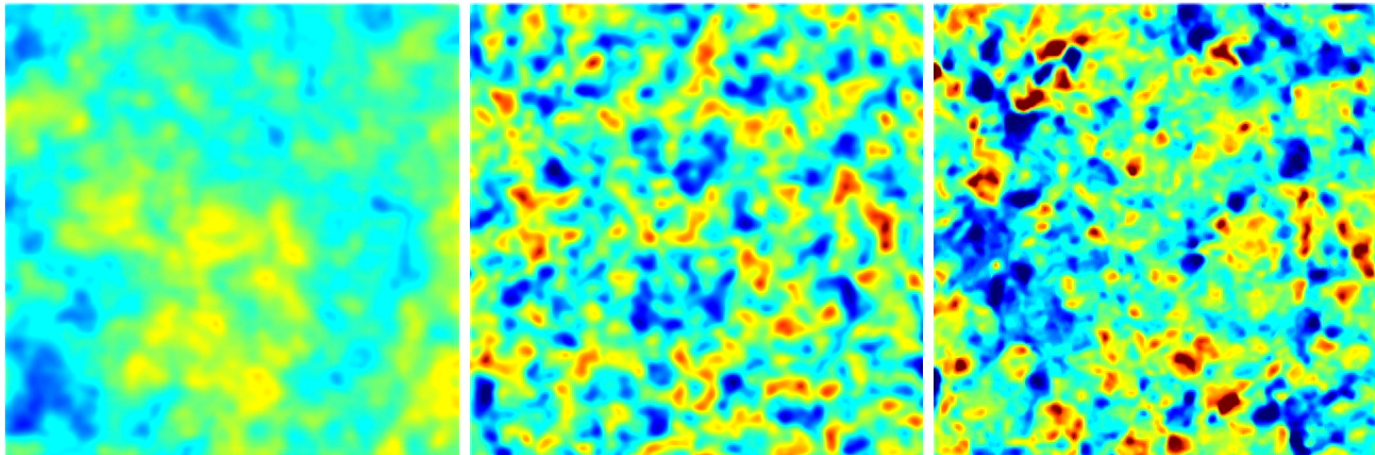
Lensing by large-scale structure



T

E

B



$-500\mu\text{K}$  $500\mu\text{K}$ $-20\mu\text{K}$  $20\mu\text{K}$


$-1\mu\text{K}$  $1\mu\text{K}$

Image sequence credit: Sigurd Naess

From pristine CMB to dirty data

Faraday rotation

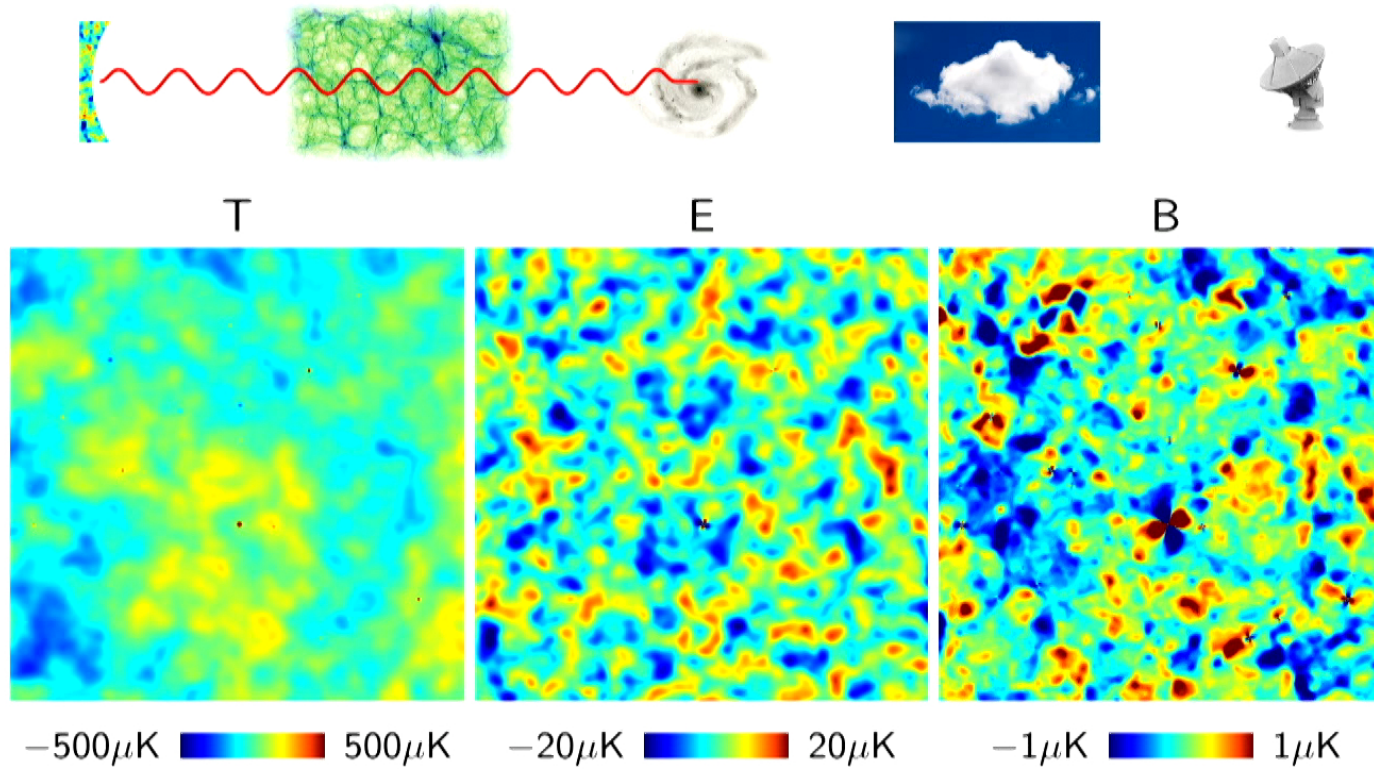


Image sequence credit: Sigurd Naess

From pristine CMB to dirty data

Galactic dust, synchrotron, etc

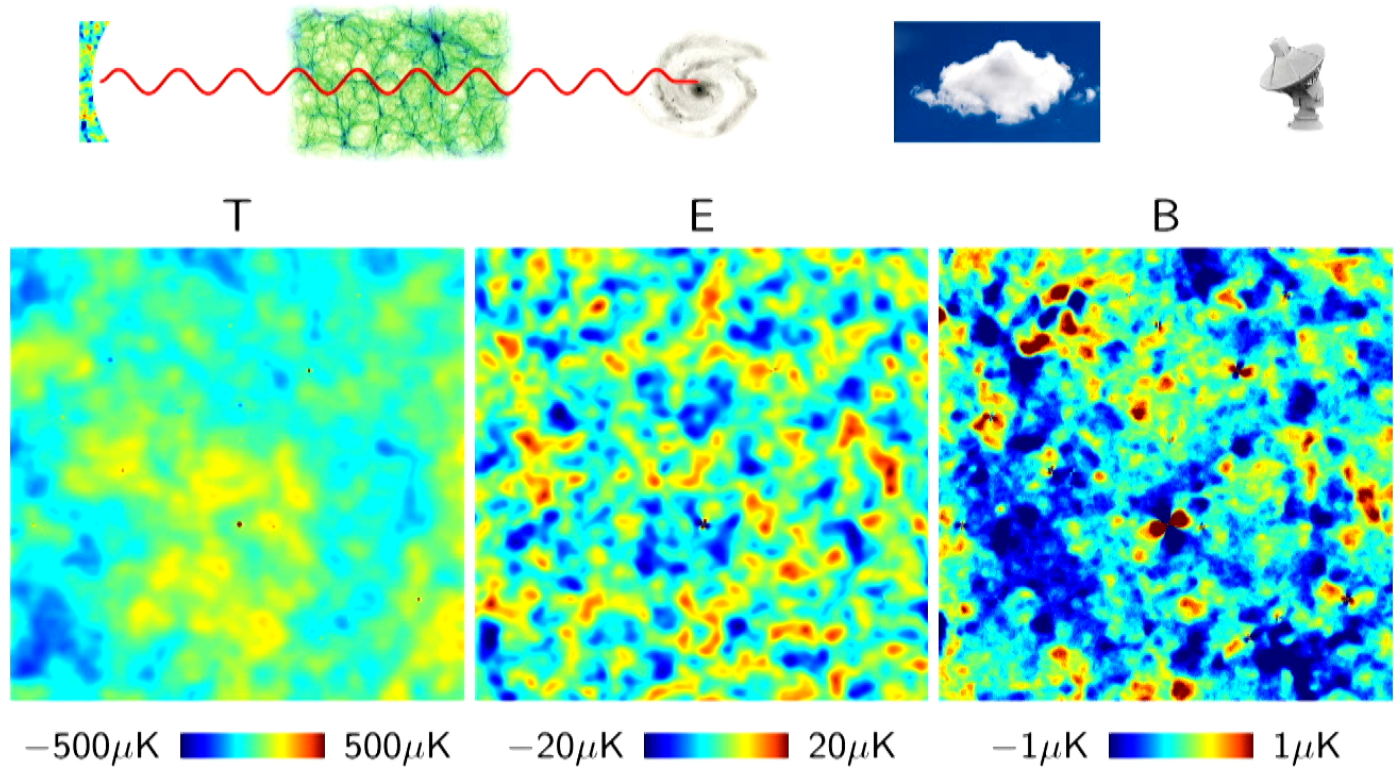


Image sequence credit: Sigurd Naess

From pristine CMB to dirty data

Atmospheric emission

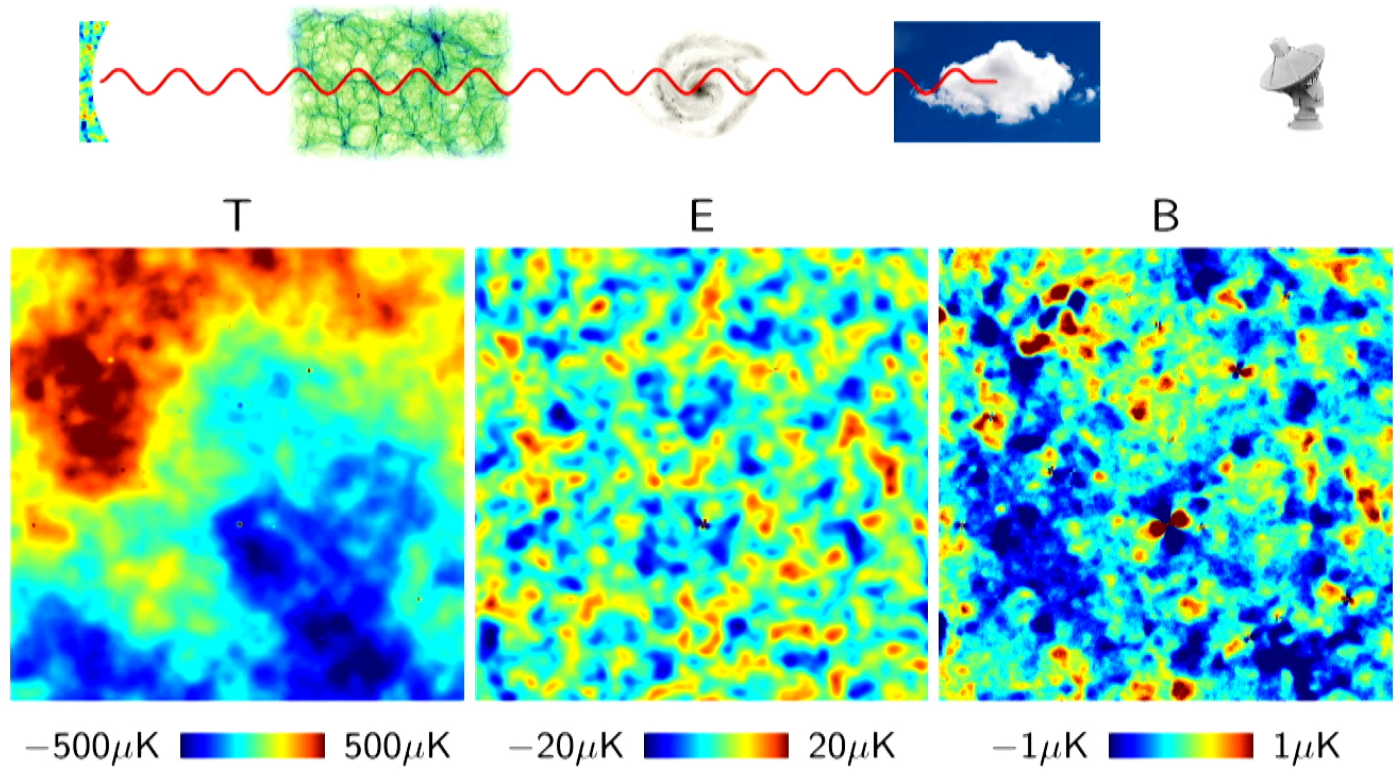


Image sequence credit: Sigurd Naess

From pristine CMB to dirty data

Absolute polarization offset (1° example)

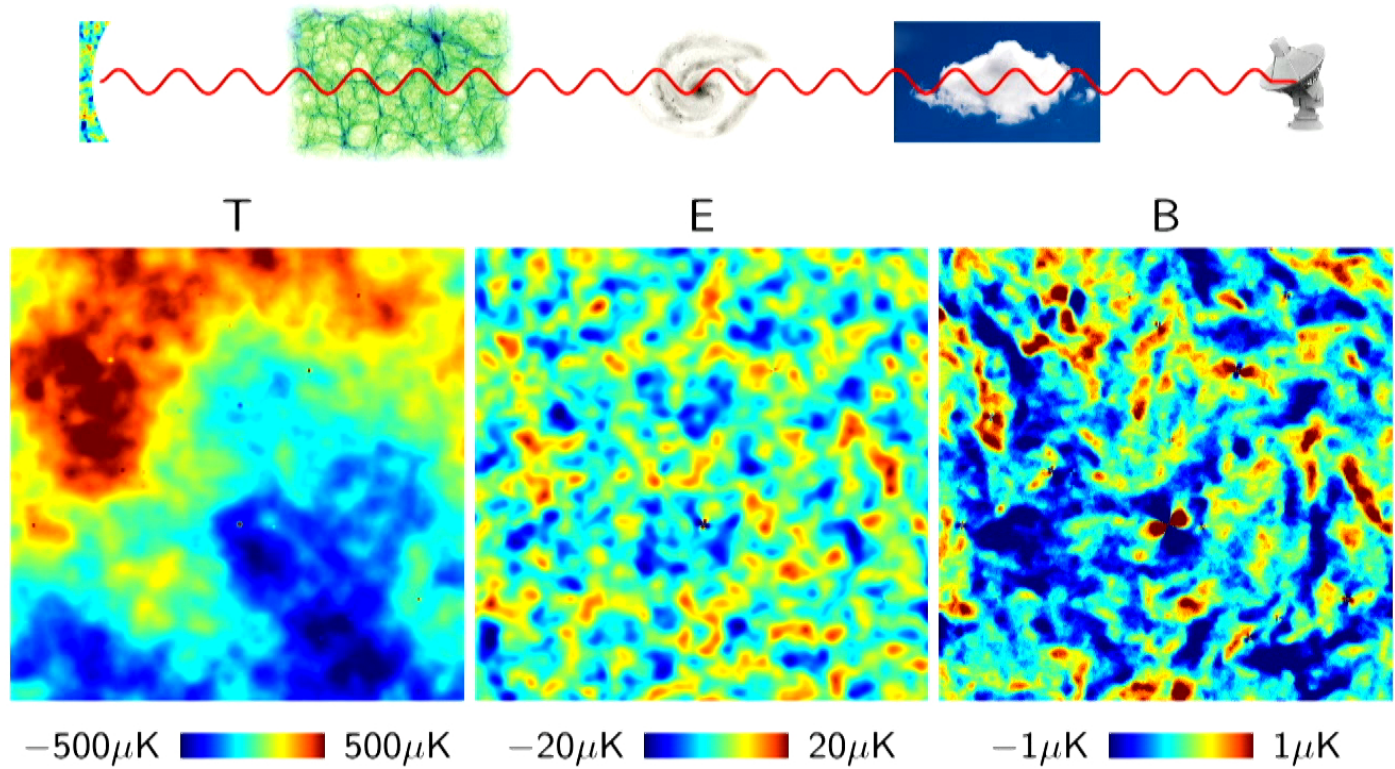


Image sequence credit: Sigurd Naess

From pristine CMB to dirty data

Detector noise

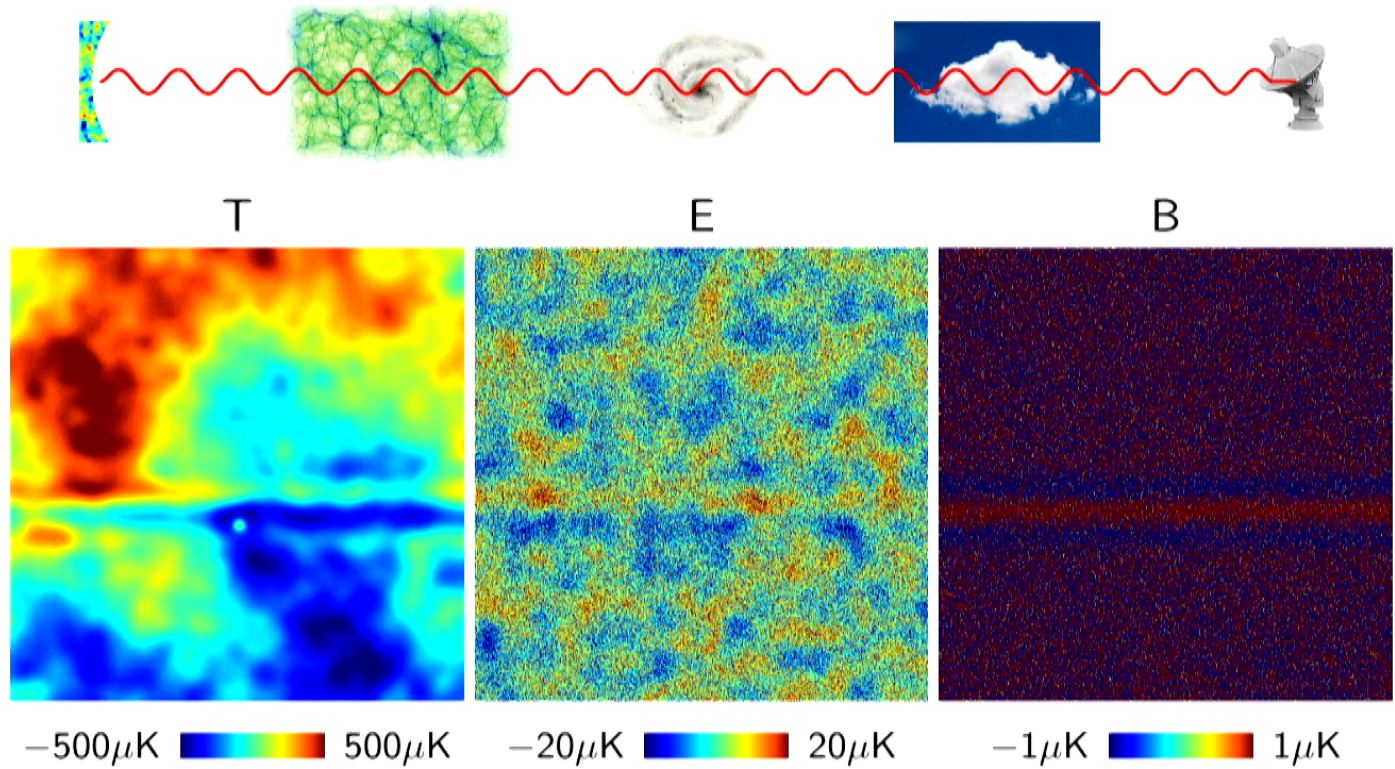
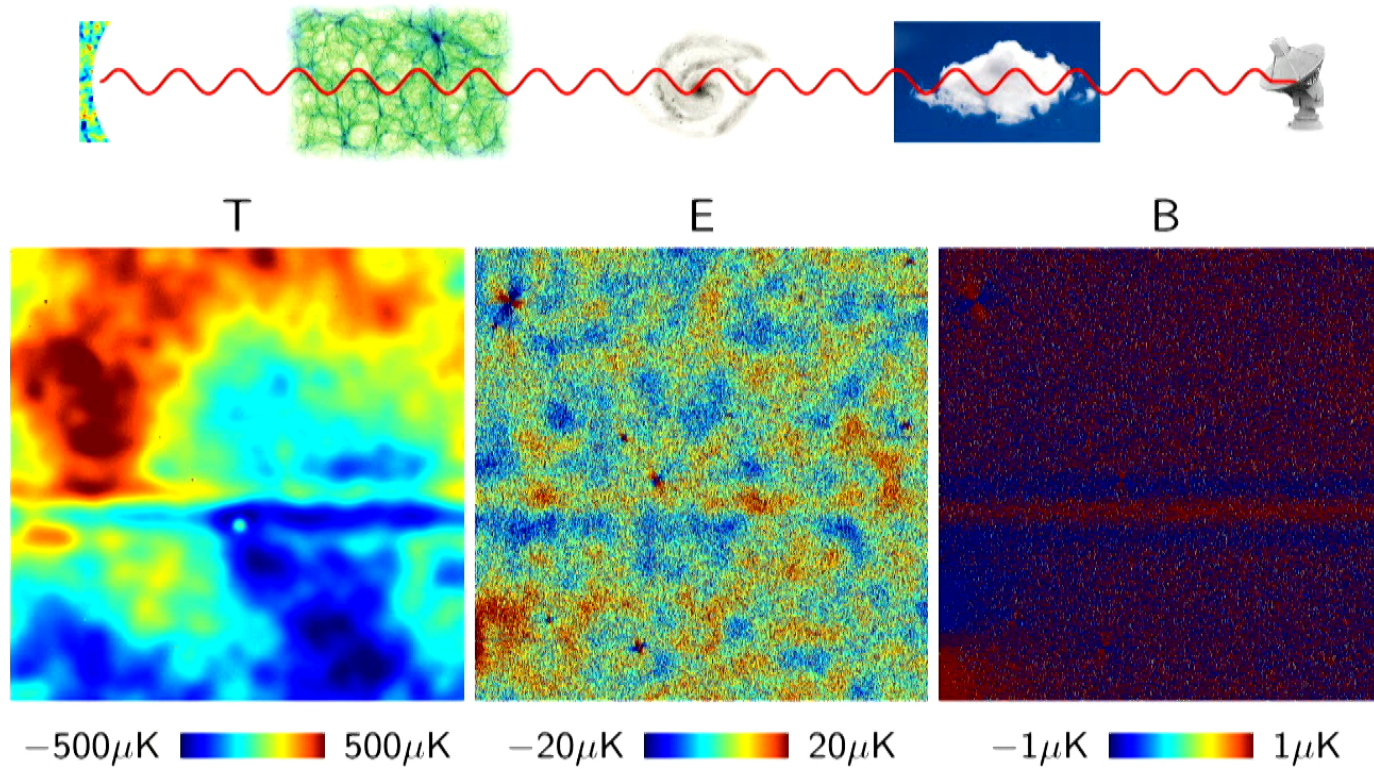


Image sequence credit: Sigurd Naess

From pristine CMB to dirty data

Glitches






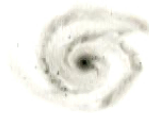
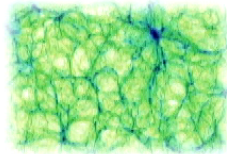
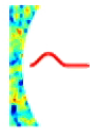
$-500\mu\text{K}$  $500\mu\text{K}$ $-20\mu\text{K}$  $20\mu\text{K}$ $-1\mu\text{K}$  $1\mu\text{K}$

Image sequence credit: Sigurd Naess

From pristine CMB to dirty data

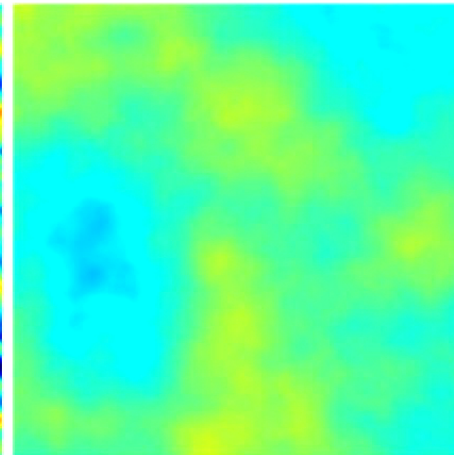
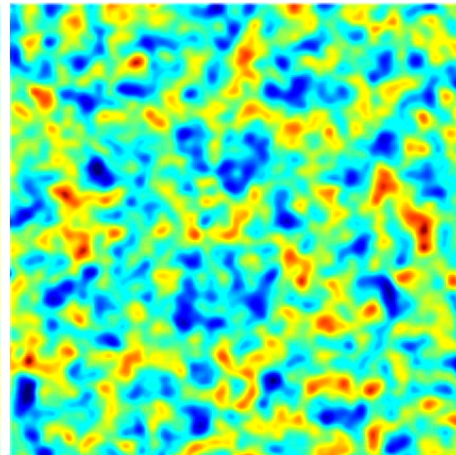
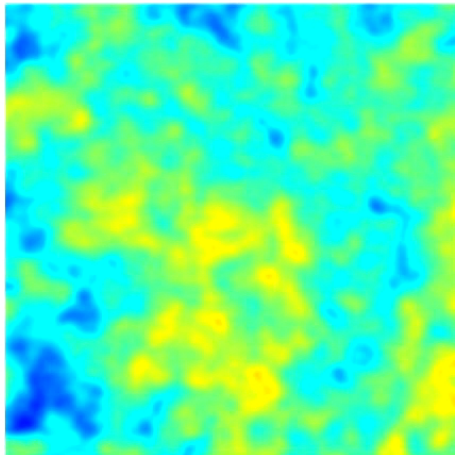
At the surface of last scattering





T

E

B



$-500\mu\text{K}$  $500\mu\text{K}$

$-20\mu\text{K}$  $20\mu\text{K}$


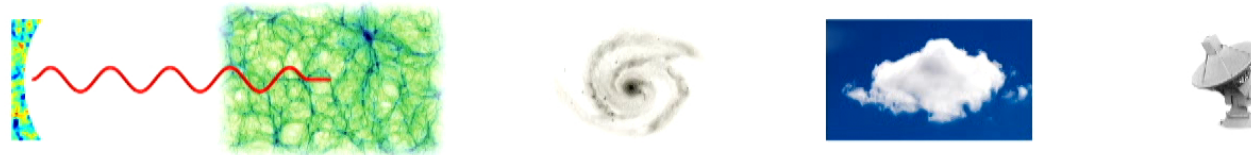
$-1\mu\text{K}$  $1\mu\text{K}$

Image sequence credit: Sigurd Naess

From pristine CMB to dirty data

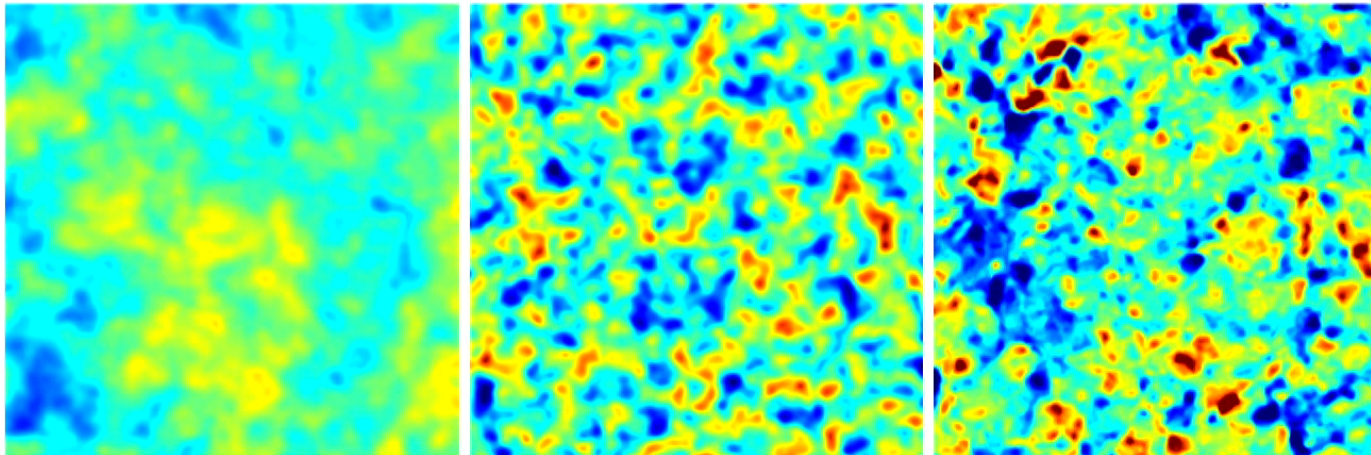
Lensing by large-scale structure



T

E

B



$-500\mu\text{K}$  $500\mu\text{K}$ $-20\mu\text{K}$  $20\mu\text{K}$


$-1\mu\text{K}$  $1\mu\text{K}$

Image sequence credit: Sigurd Naess

From pristine CMB to dirty data

Detector noise

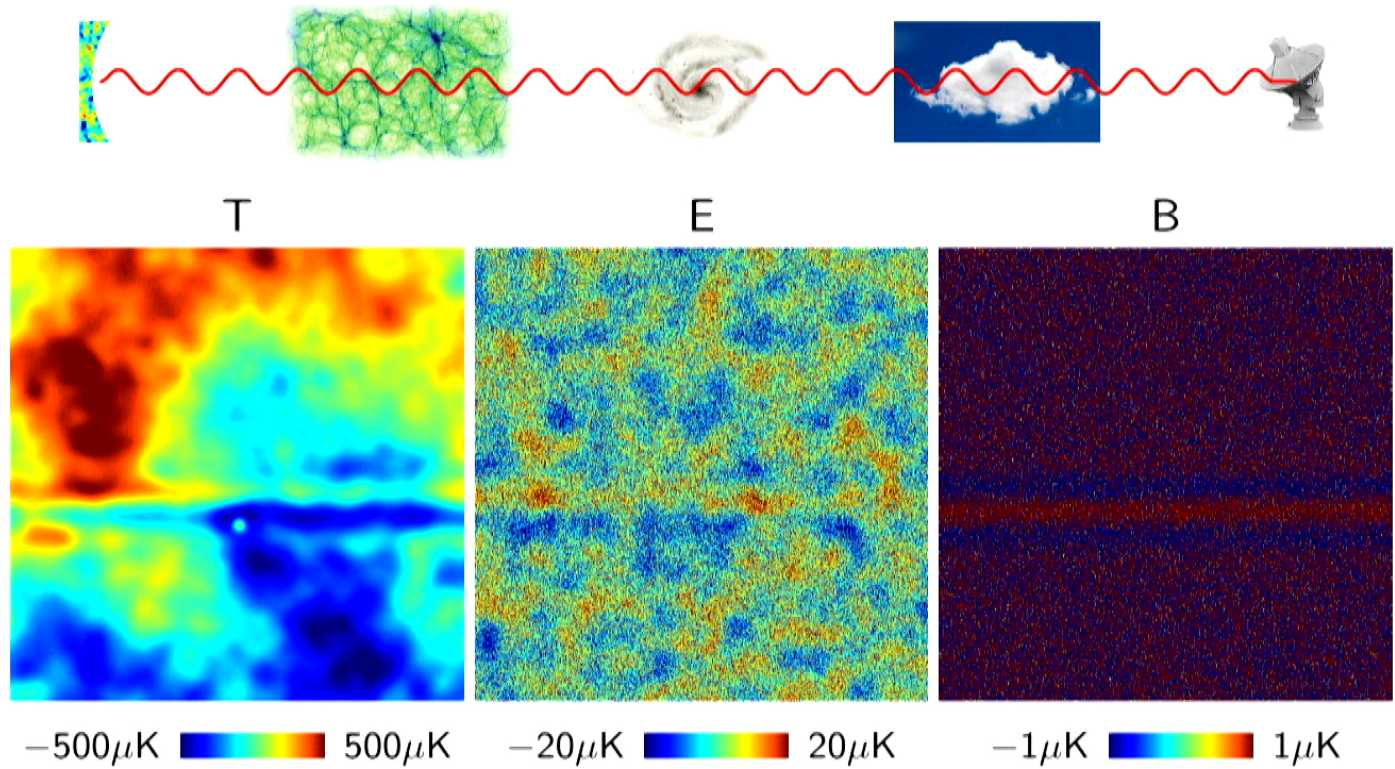
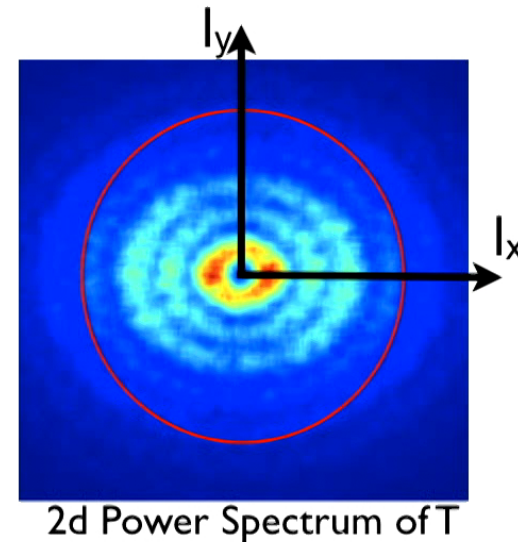


Image sequence credit: Sigurd Naess

Effect of lensing: breaking statistical isotropy

- CMB still locally Gaussian
- but power spectrum locally *distorted*

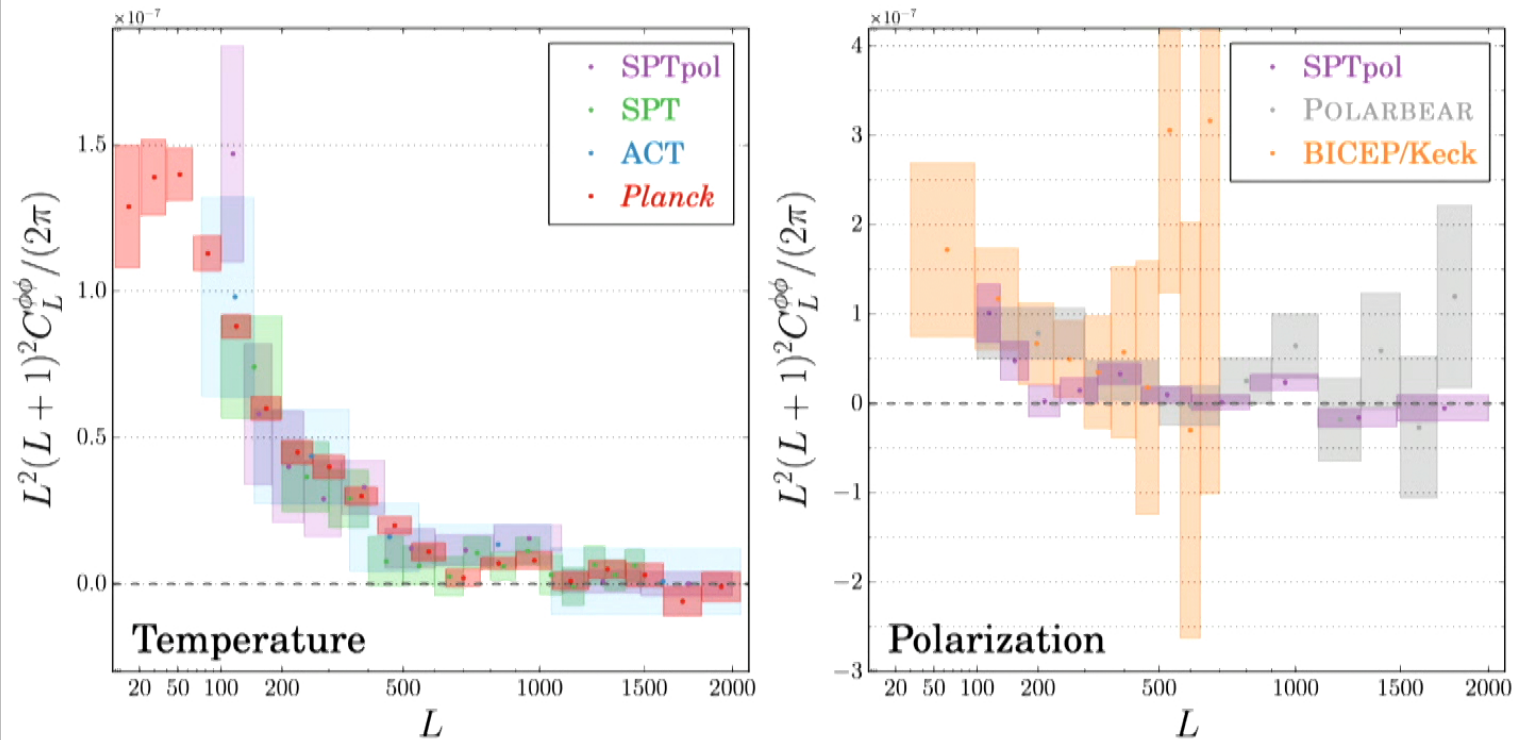
e.g. shear: 



Bucher+ 2011

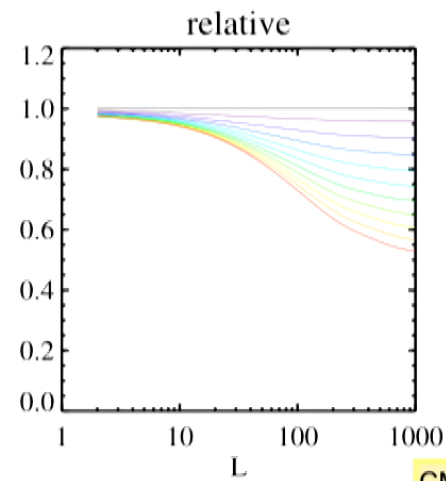
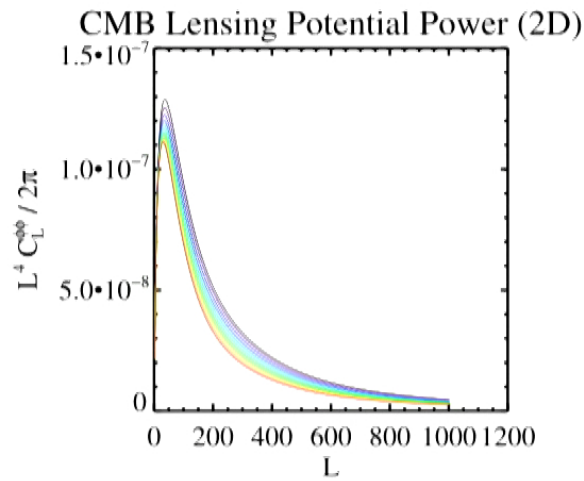
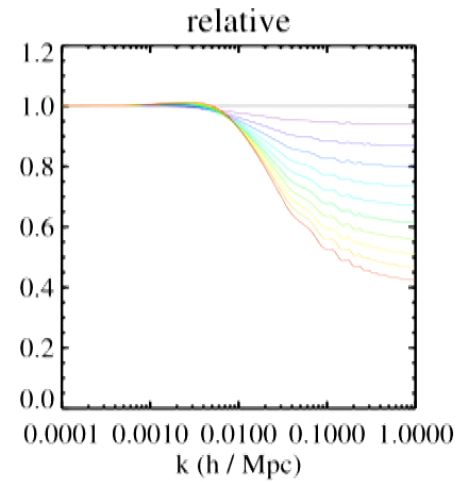
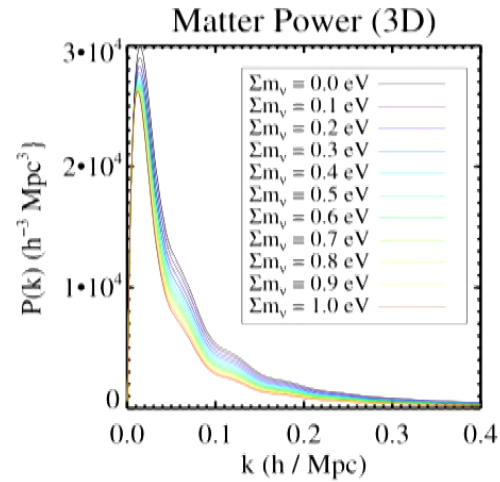
- Use this for reconstructions (Hu 2001, Hu&Okamoto 2001)

CMB lensing auto spectrum measurements c. 2016



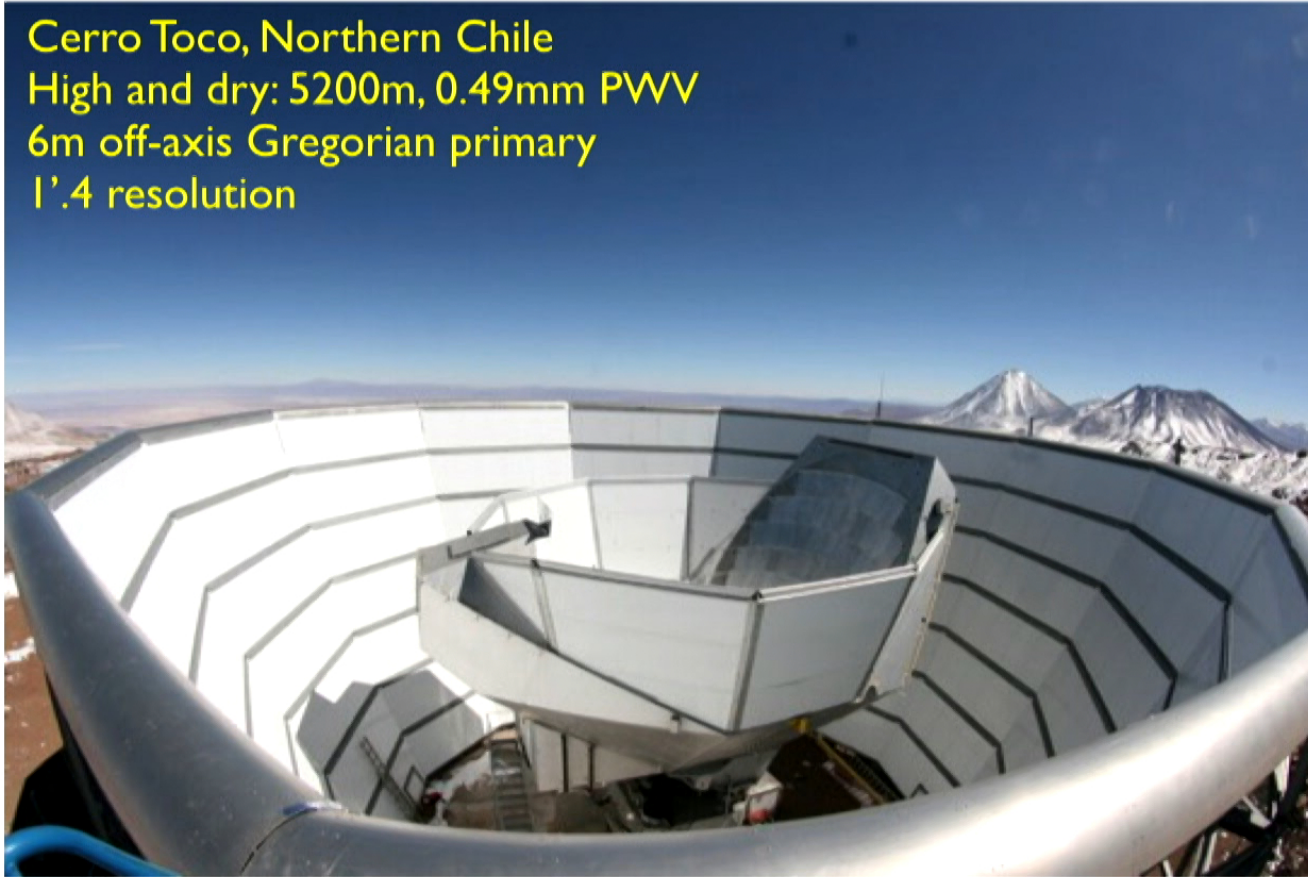
CMB-S4 Science Book

Σm_ν of 0.1 eV \longleftrightarrow 5% in $C_l^{\phi\phi}$

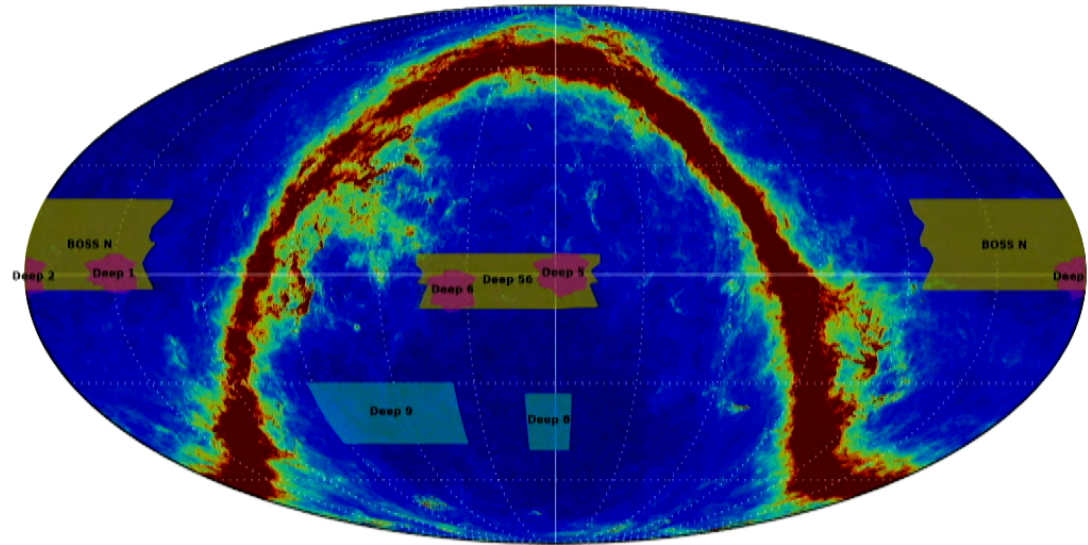


Atacama Cosmology Telescope

Cerro Toco, Northern Chile
High and dry: 5200m, 0.49mm PWV
6m off-axis Gregorian primary
1'.4 resolution

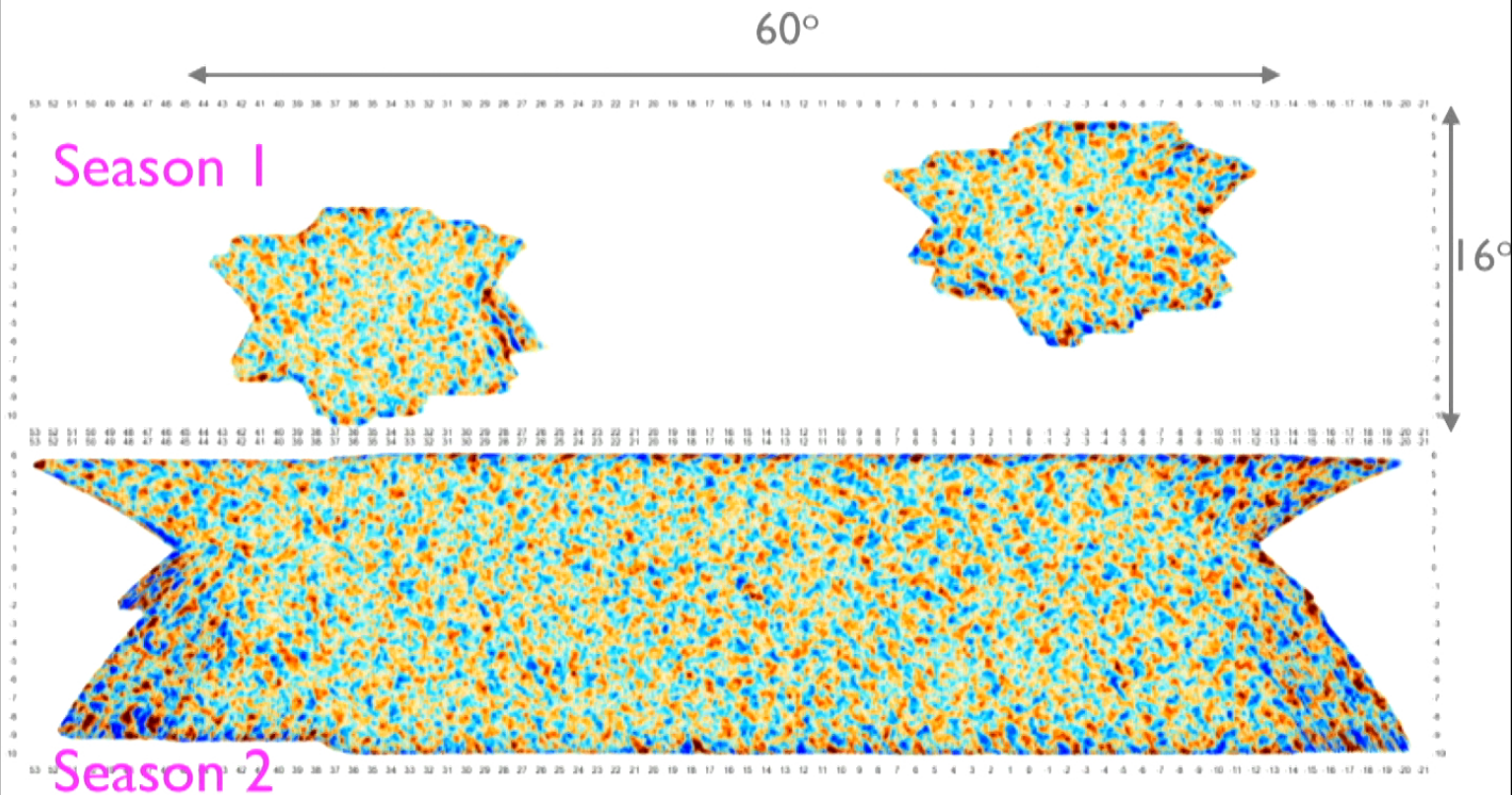


ACTPol Survey



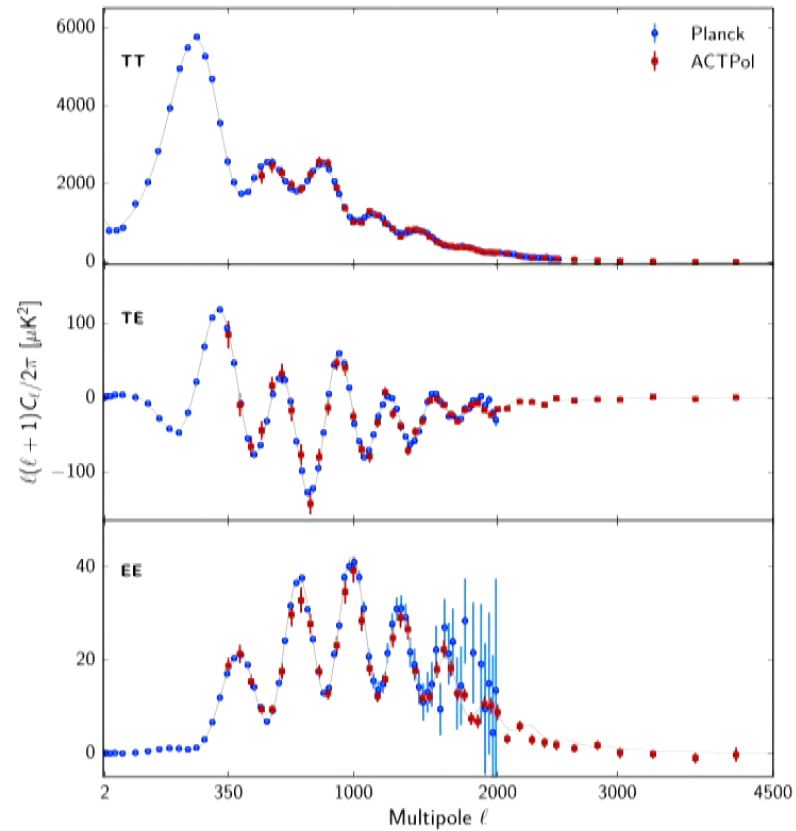
- Season 1 (Oct-Dec 2013)
 - Four deep fields, one 150 GHz array
- Season 2 (2014)
 - Wide fields, two 150 GHz arrays
- Season 3 (2015)
 - Wide fields + south, two 150 arrays + 90/150 array

ACTPol Temperature maps



Season 1: Naess+ JCAP, arXiv:1405.5524
Season 2: Louis+, arXiv:arXiv:1610.02360

ACTPol Season 1+2



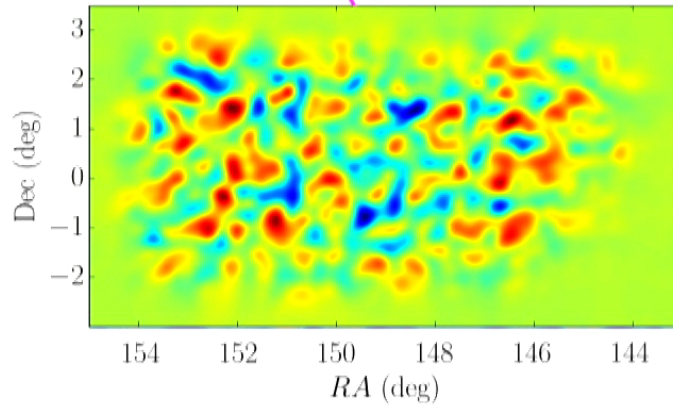
Season 1: Naess+ JCAP, arXiv:1405.5524
Season 2: Louis+, arXiv:arXiv:1610.02360

ACTPol: some science results

kSZ	velocity-weighted (spec-z) stack of ACTPol on BOSS-CMASS galaxies	3.2σ	Schaan+ 2016 arXiv:1510.06442
kSZ	pairwise momentum statistic on BOSS spec-z galaxies	$3.6-4.1\sigma$	de Bernardis+ 2016 arXiv:1607.02139
CMB Halo lensing	Stack of lensing reconstructions on BOSS CMASS galaxies	3.6σ	Madhavacheril+ arxiv:1411.07999

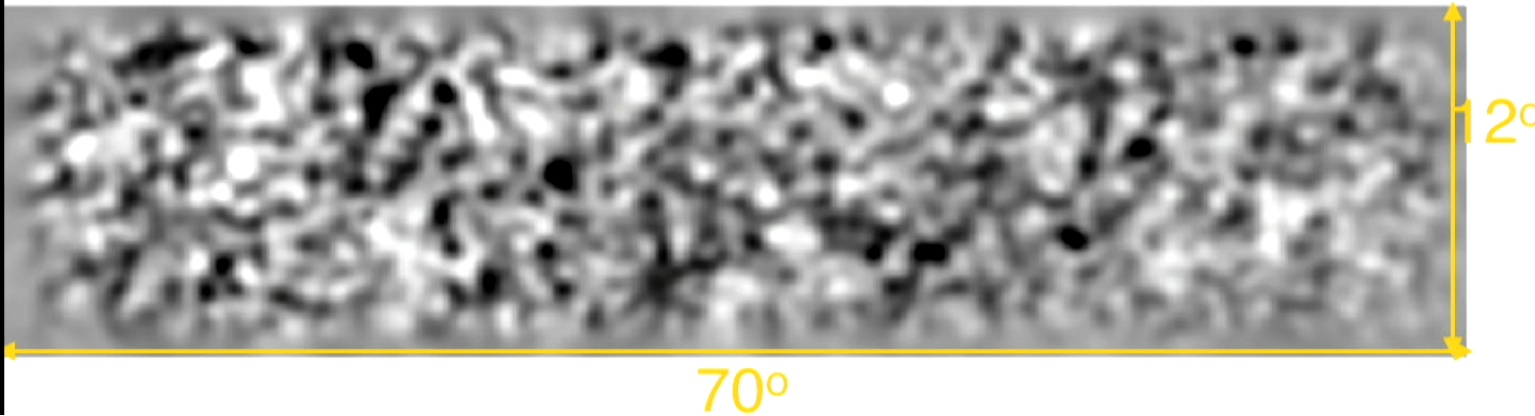
ACTPol lensing convergence maps

Season 1 (one of three)



Allison+ 2016
MNRAS, arXiv:1502.06456

Season 2 (preliminary)



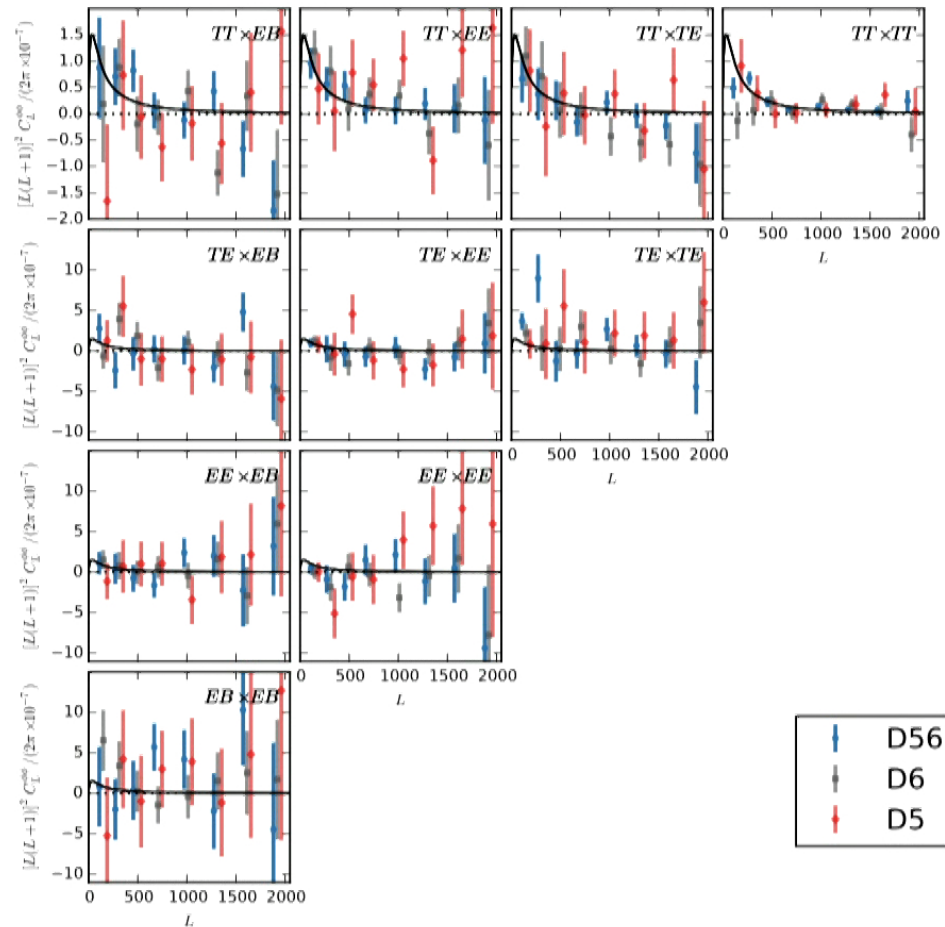
ACTPol Season 1+2

Sherwin, AVE, Sehgal, Madhavacheril++ (ACTPol Collab.) 2016

3 patches

TT, TE, EE, EB

Temperature
(TTxTT)
dominates
for now



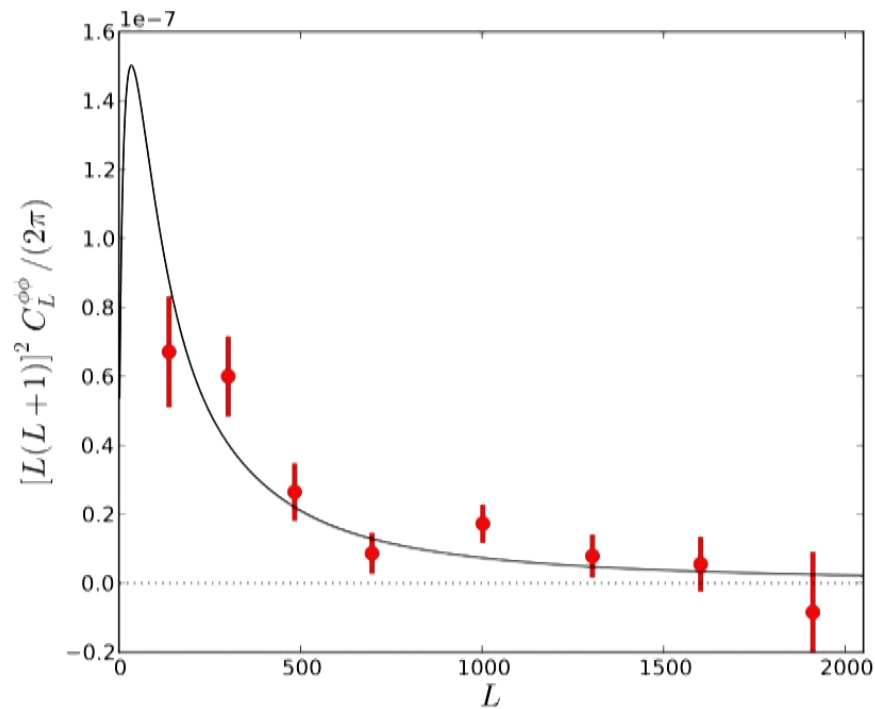
ACTPol Season 1+2

Sherwin, AVE, Sehgal, Madhavacheril++ (ACTPol Collab.) 2016

10% of all data
taken

20% of all
nighttime data

7σ detection
(15%)



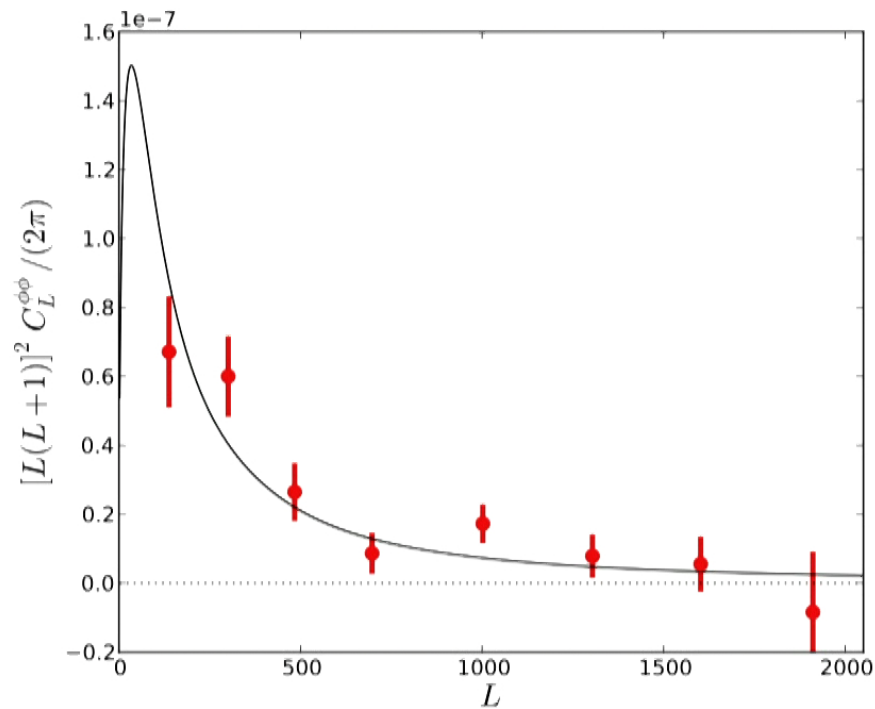
ACTPol Season 1+2

Sherwin, AVE, Sehgal, Madhavacheril++ (ACTPol Collab.) 2016

10% of all data
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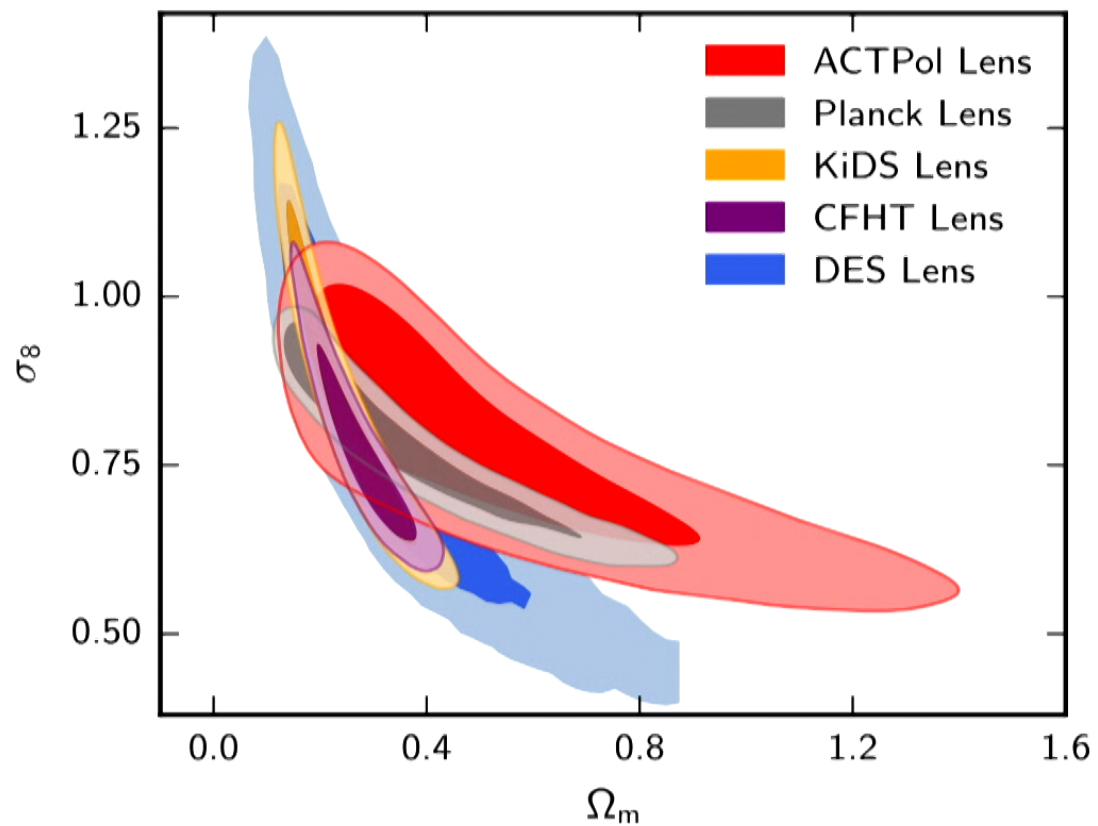
20% of all
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7σ detection
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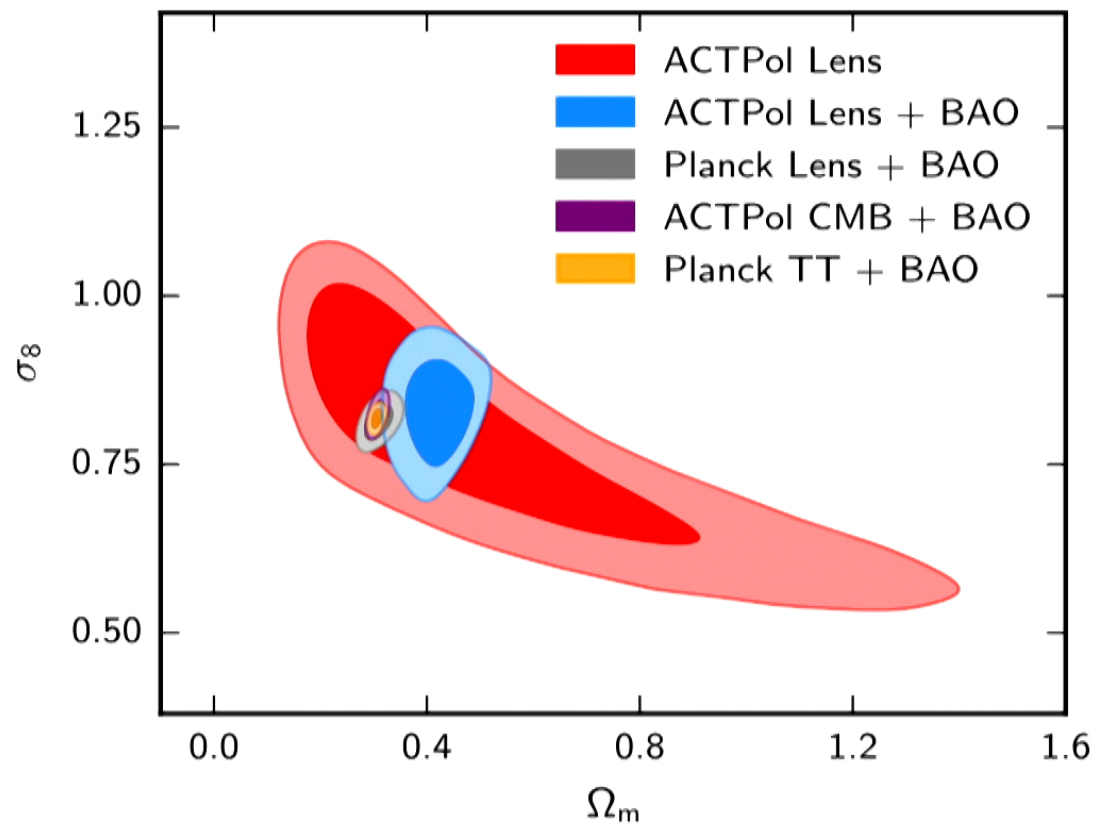
ACTPol Season 1+2

Sherwin, AVE, Sehgal, Madhavacheril++ (ACTPol Collab.) 2016



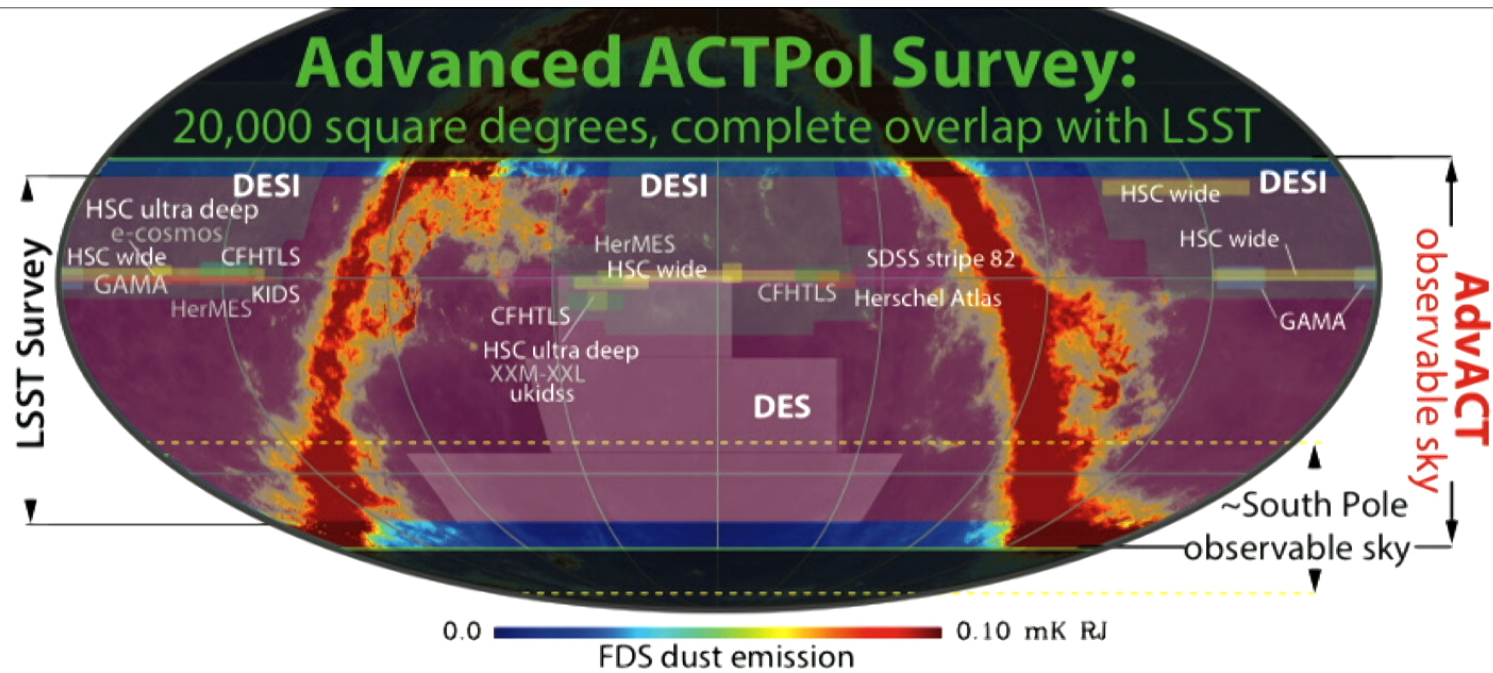
ACTPol Season 1+2

Sherwin, AVE, Sehgal, Madhavacheril++ (ACTPol Collab.) 2016



Outline

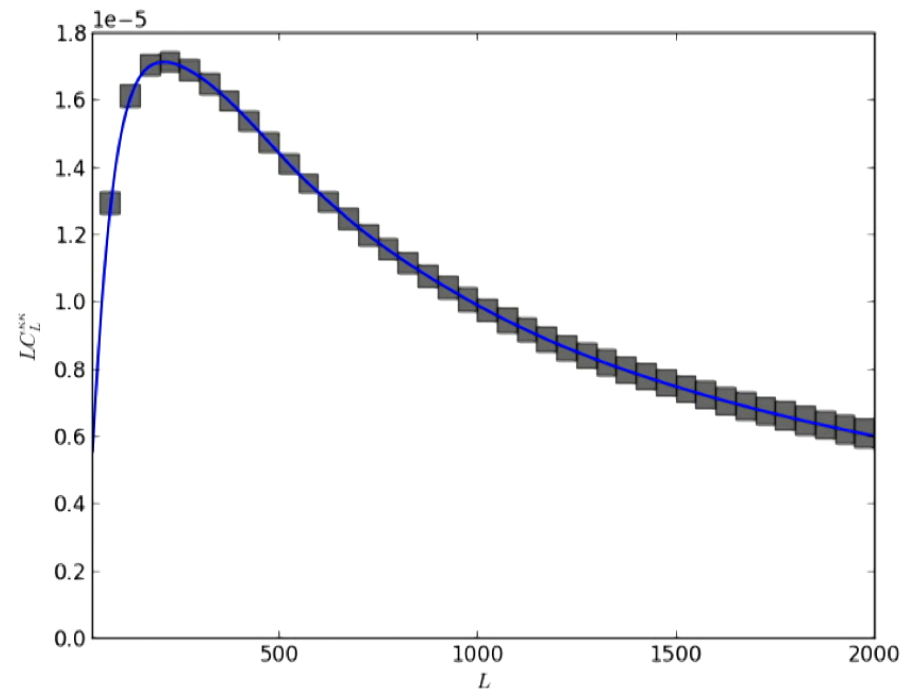
Ongoing Analyses	ACTPol (2013-15)	~12-15 uK-arcmin	~10% of sky
Future data: Opportunities and Challenges	AdvACT (2016++)	~5-9 uK-arcmin	~40-50% of sky
	Simons Observatory (~2020++)	~few uK-arcmin	~40-50% of sky
	CMB-S4(~2024++)	~1 uK-arcmin	~40-50% of sky



- Half the sky
- 5 frequencies
- Ongoing (begun 2016)
- Followed by Simons Observatory

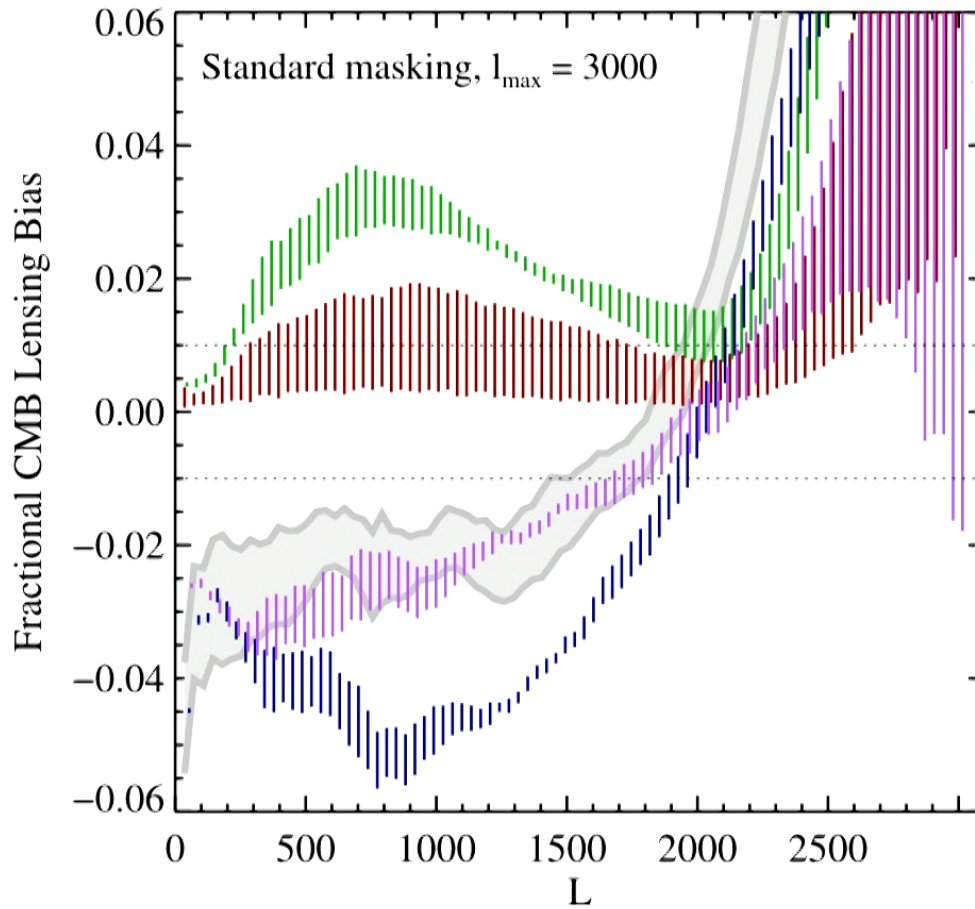
Stage 3 - AdvACT

- $\sim 220\sigma$ lensing
- Neutrino mass to 0.04 eV with BOSS



from Blake Sherwin

Contamination in temperature-based lensing: foreground non-Gaussianity at 150 GHz



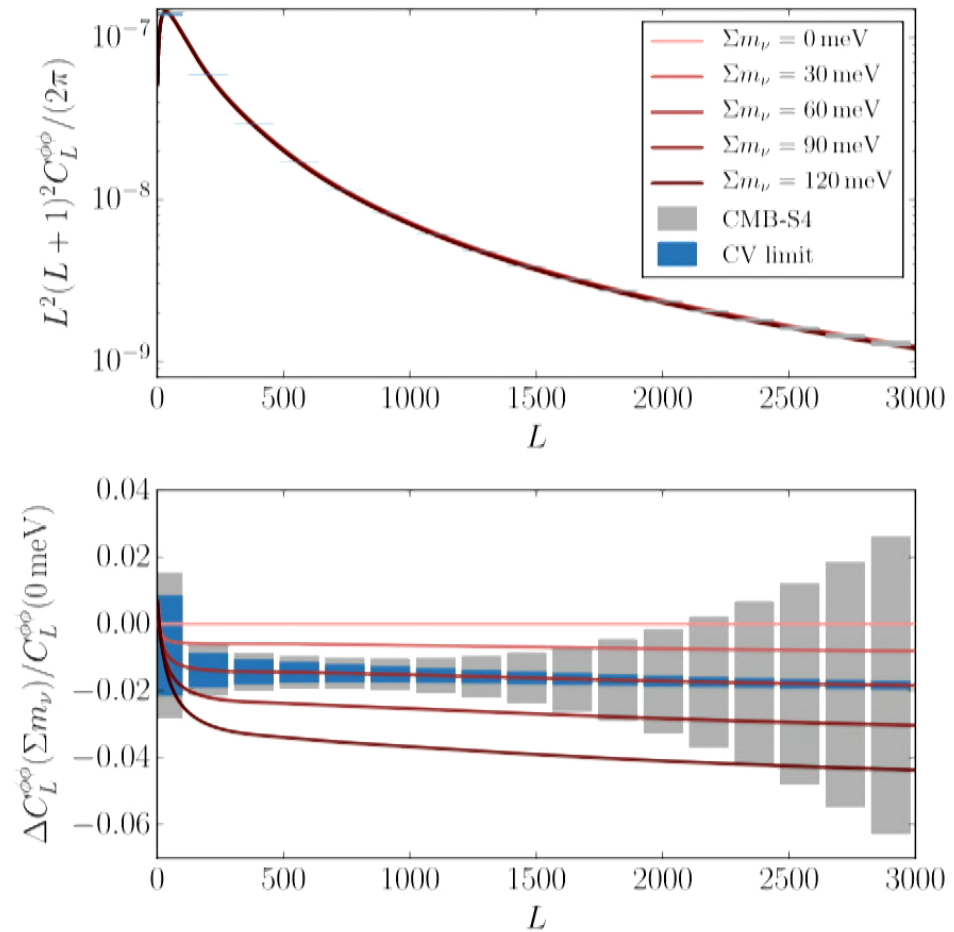
tSZ-tSZ-tSZ-tSZ
CIB-CIB-CIB-CIB

total
CIB-CIB- ϕ
tSZ-tSZ- ϕ

van Engelen+ 2014
ApJ, arXiv:1310.7023

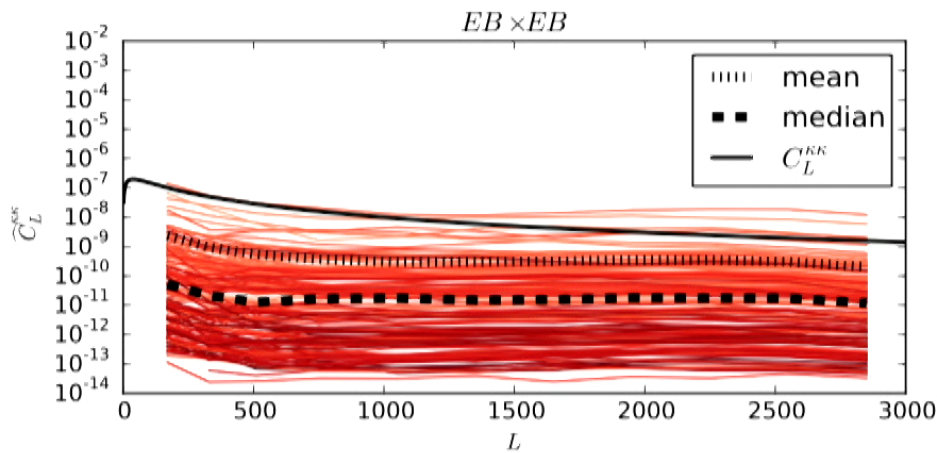
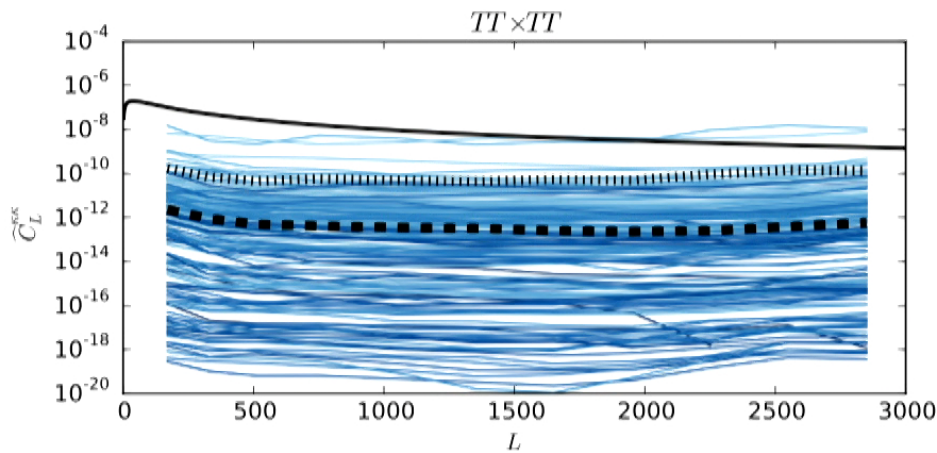
Stage 4 - CMB-S4

- Polarization dominates
- $\sim 500\sigma$ lensing on 20k sq. deg.
- Neutrino mass to 0.02 eV with DESI BAO



CMB-S4 Science Book

Contamination in polarization-based lensing: dust/synch. non-Gaussianity

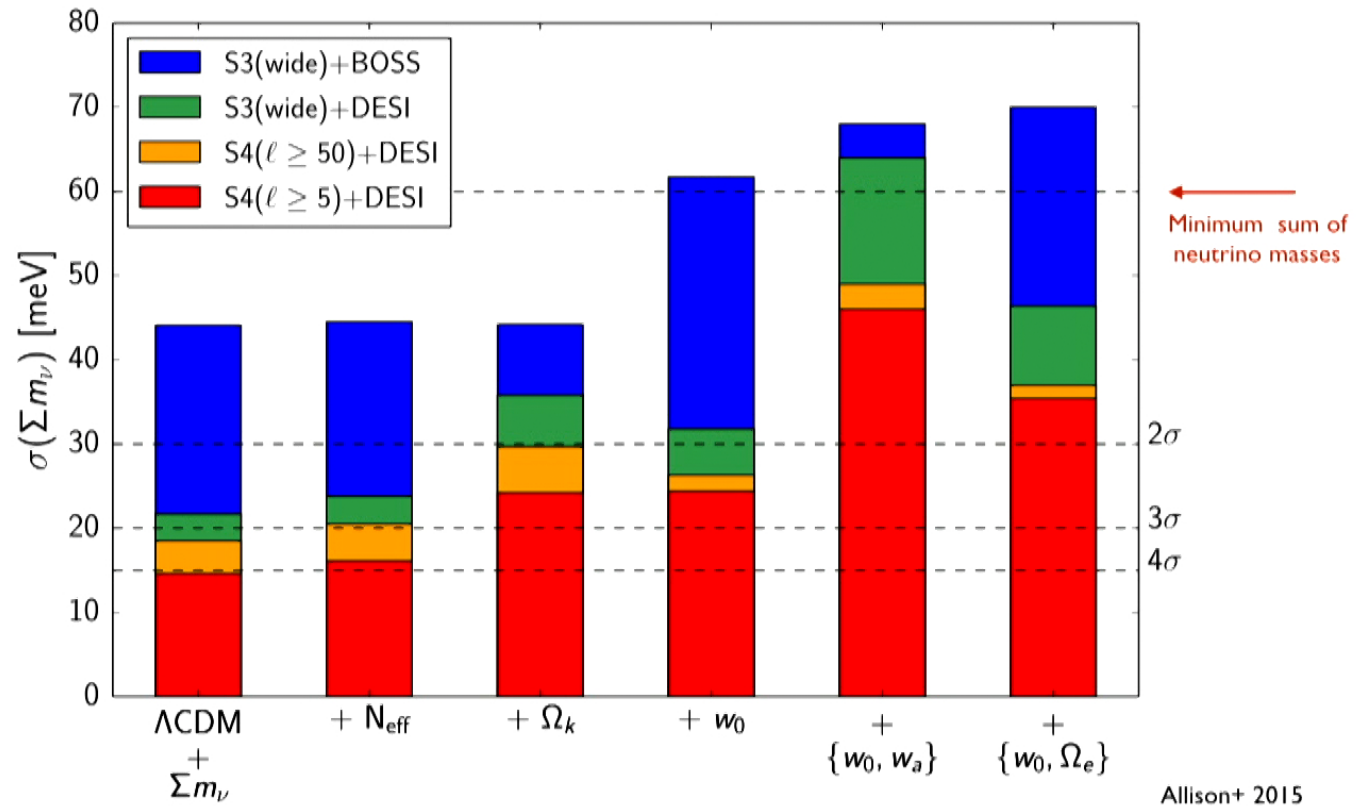


50% of the sky

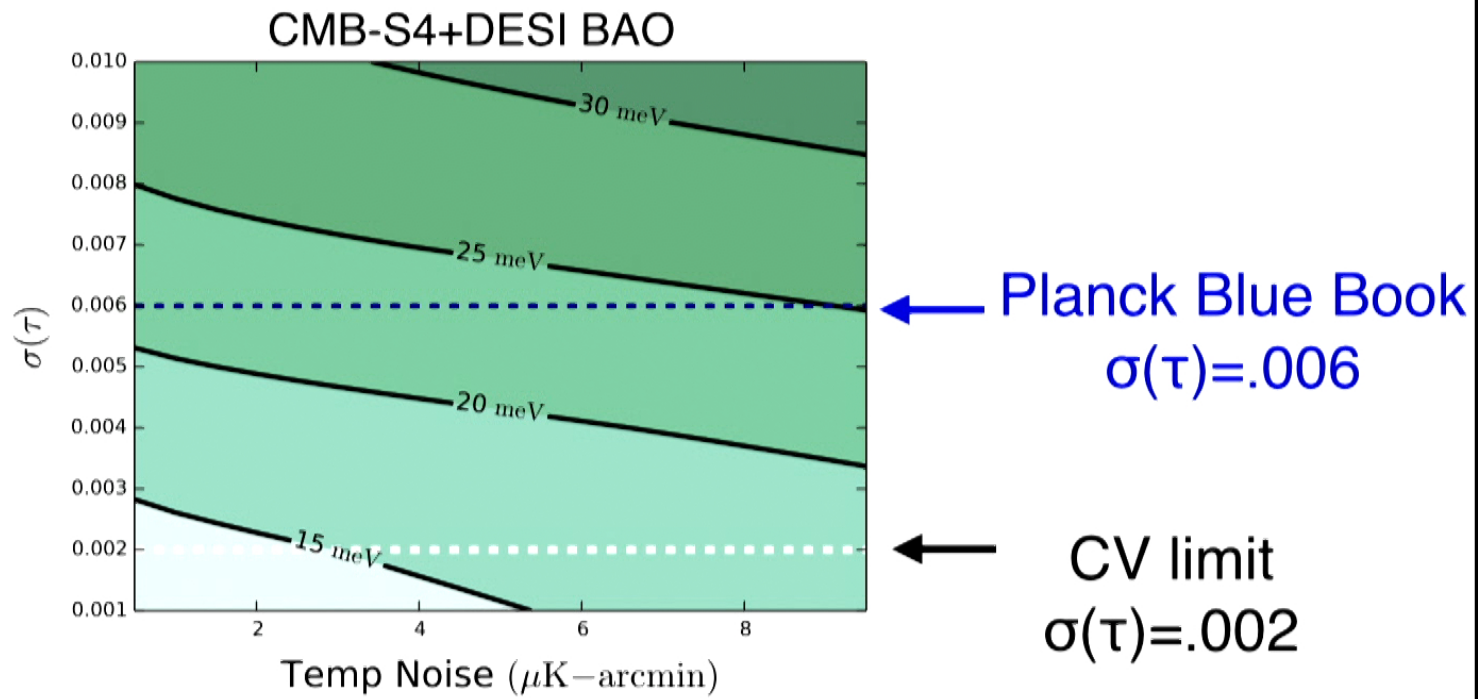
- Simulations with turbulent magnetic fields (van Syngel +)
- One frequency, scaled to 150 GHz
- In progress for other models

AVE++ in prep.

● S3 / S4 Neutrino Sensitivity



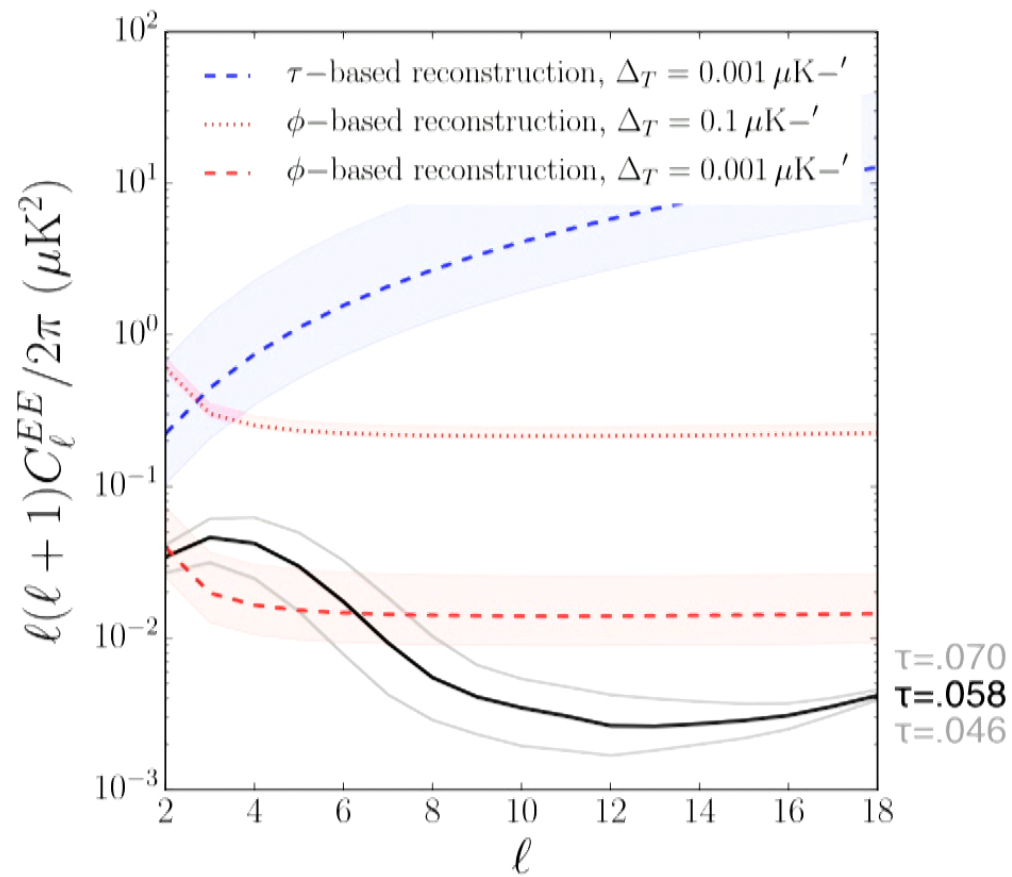
- Neutrino mass from S4 will be **tau-limited**



CMB-S4 science book

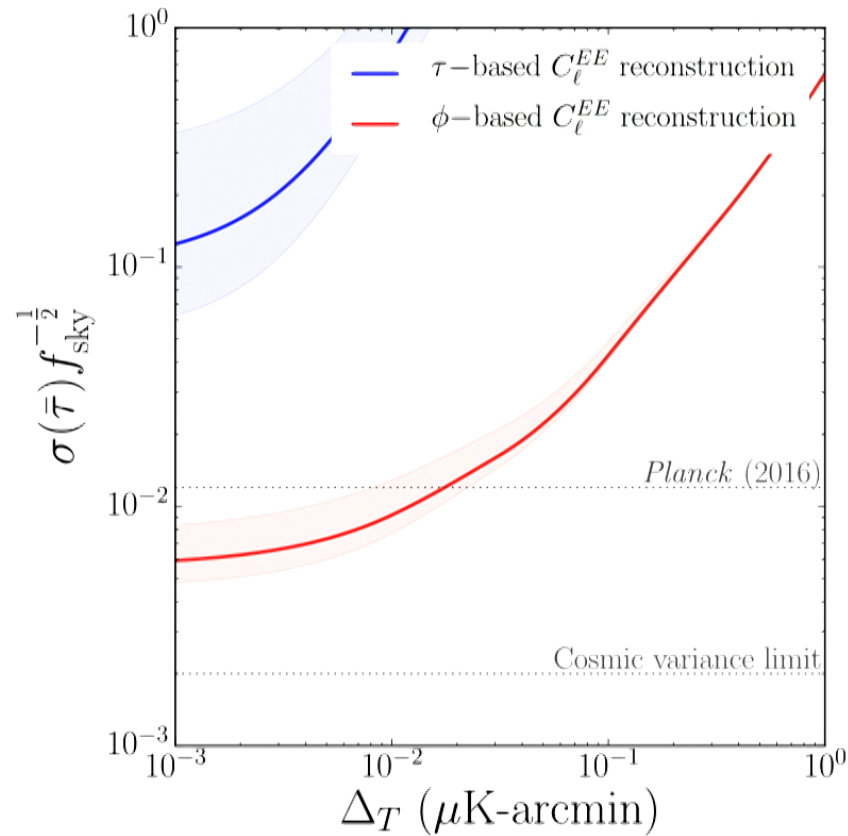
E-mode reconstruction

Meerburg, Meyers, Smith, AVE 2017
1701.06992



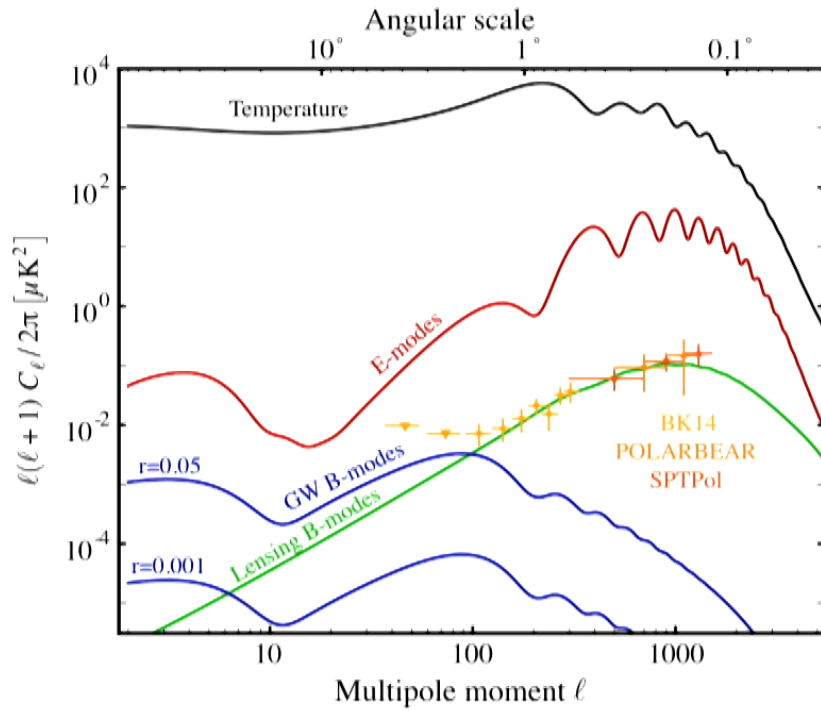
E-mode reconstruction

Meerburg, Meyers, Smith, AVE 2017
1701.06992



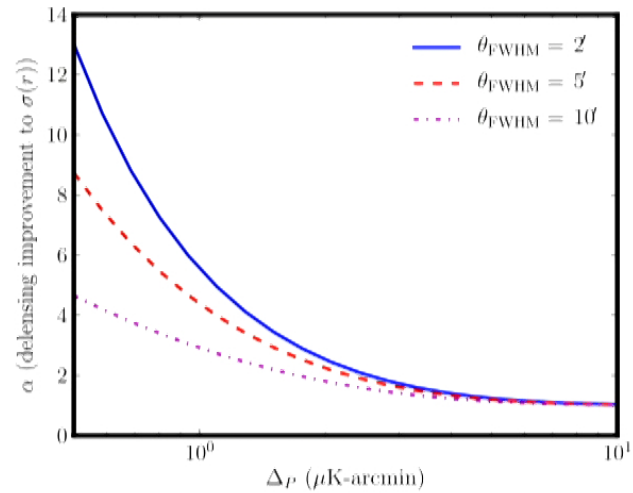
Also: temperature
dipole reconstruction

CMB Delensing



CMB-S4 Science Book

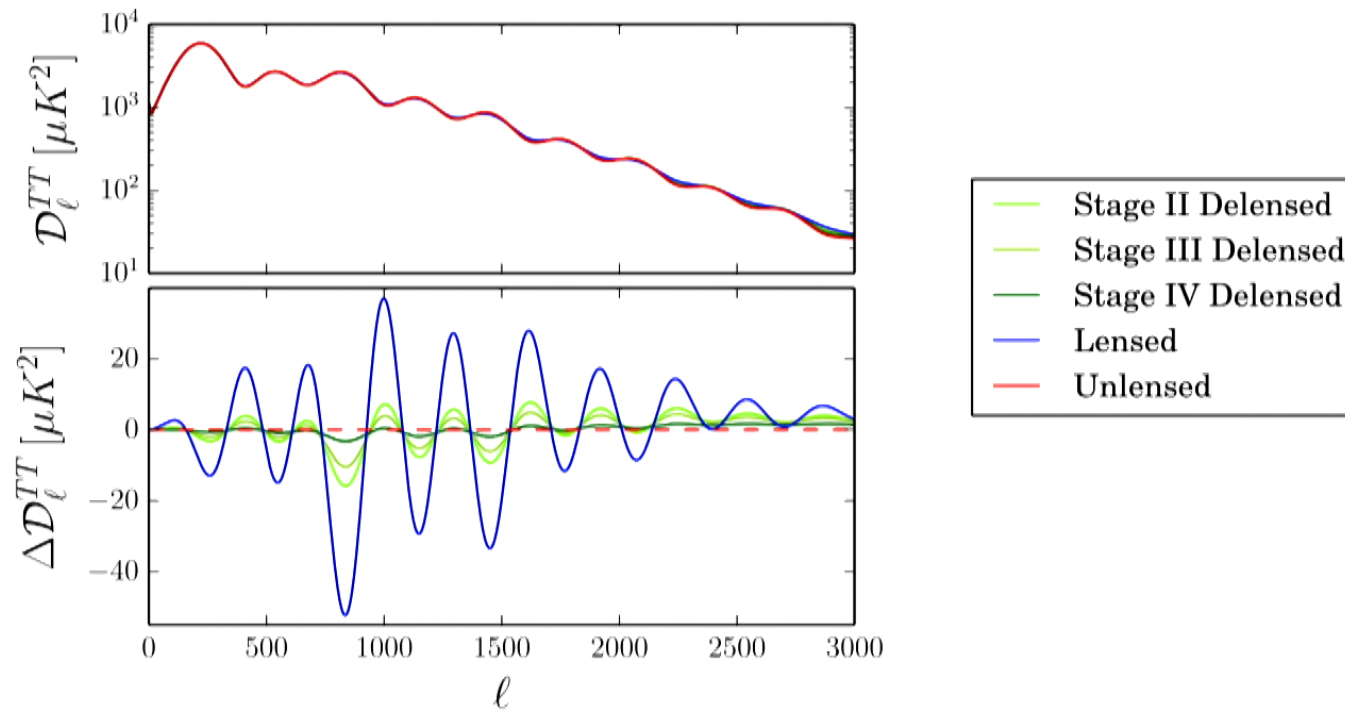
Crucial for B-mode science



Smith++ 2010

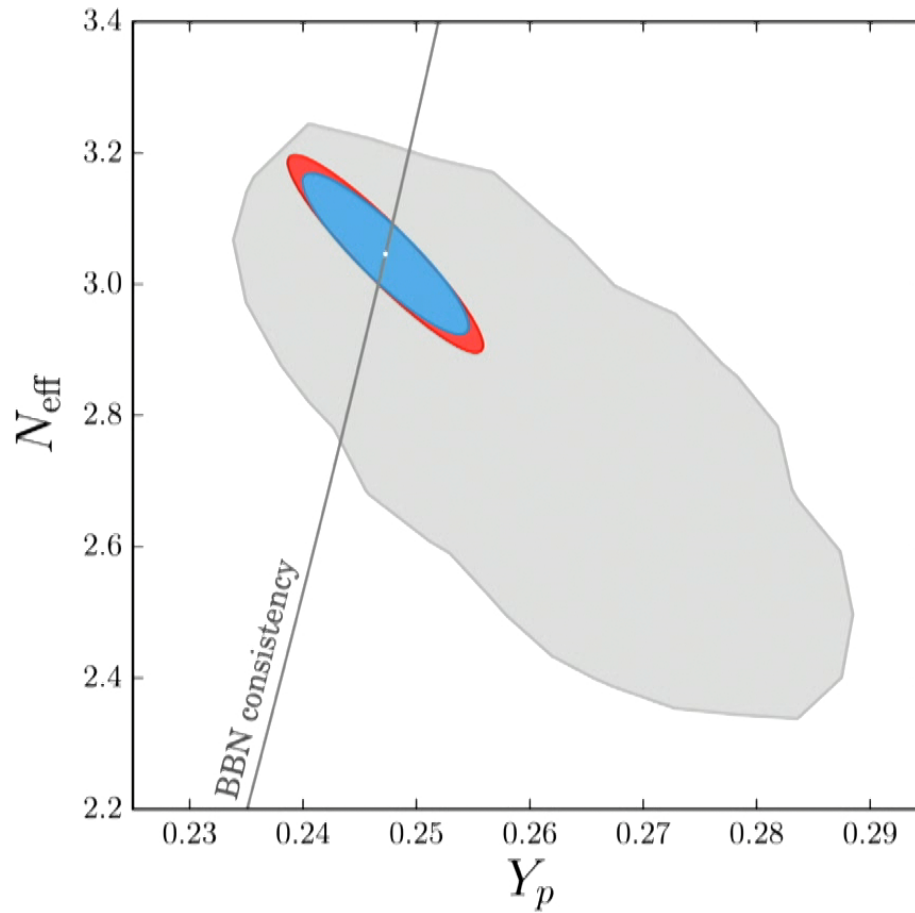
CMB Delensing Beyond the B-modes

Green, Meyers, AVE 2016
arXiv:1609.08143



CMB Delensing Beyond the B-modes

Green, Meyers, AVE 2016
arXiv:1609.08143



Planck-2015 + BAO
CMB-S4 + DESI
CMB-S4 (delensed) + DESI

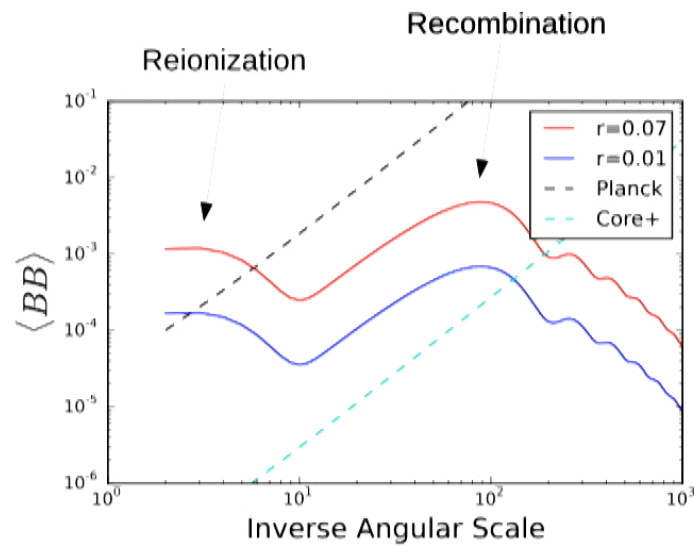
$\langle B\omega \rangle$

Sheere, AVE, Meerburg, Meyers 2016

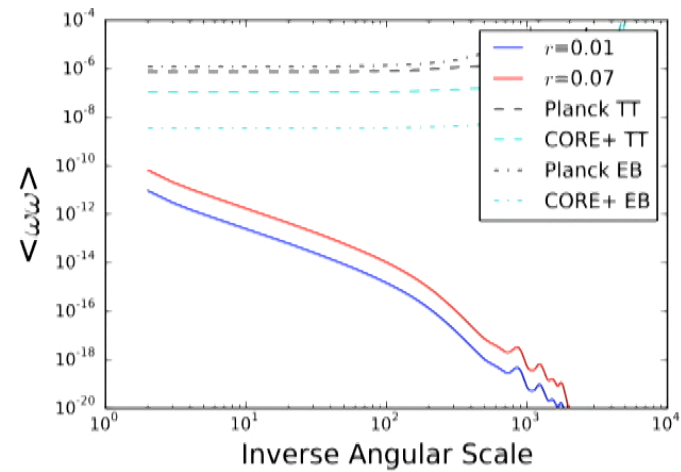
1610.09365

$$\langle hh \rangle \rightarrow \langle BB \rangle$$

$$\langle hh \rangle \rightarrow \langle \omega\omega \rangle$$



(sourced only by tensors on large scales)

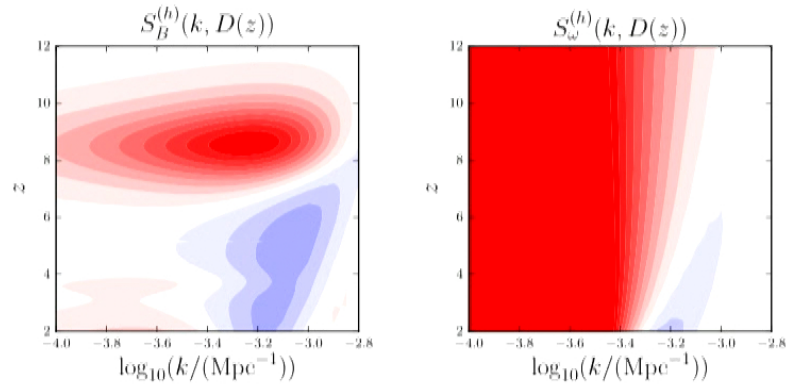


$\langle B\omega \rangle$

Sheere, AVE, Meerburg, Meyers 2016

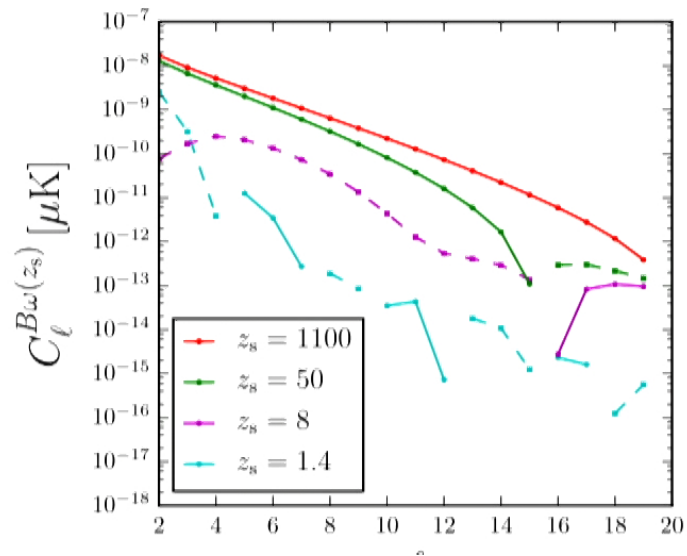
1610.09365

B, ω source functions



$$\langle hh \rangle \rightarrow \langle B\omega \rangle$$

for $z_s \sim 1-2$:
see Dodelson 2010,
Chisari, Dvorkin, Schmidt 2013

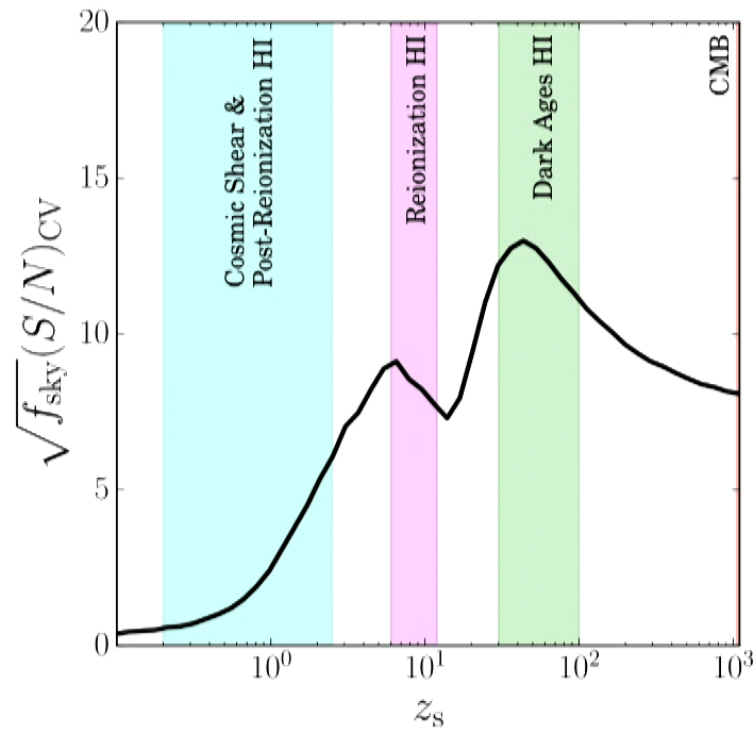


$\langle B\omega \rangle$

Sheere, AVE, Meerburg, Meyers 2016

1610.09365

Detectability per z_s slice (no-noise limit)



With noise: very
hard to detect.
Dark ages wins

Summary

- ACTPol lensing at 7σ using 12% of data
- To come: AdvACTPol, Simons Observatory, CMB-S4
 hundreds of sigmas
- Challenges: extragal. foregrounds (T), gal. foregrounds (Pol.)
- Challenges: Tau limited. E-mode reconstruction idea.
- Application: Delensing of T, E, B.
- Application: $\langle B\omega \rangle$ as a cross-check on tensors.