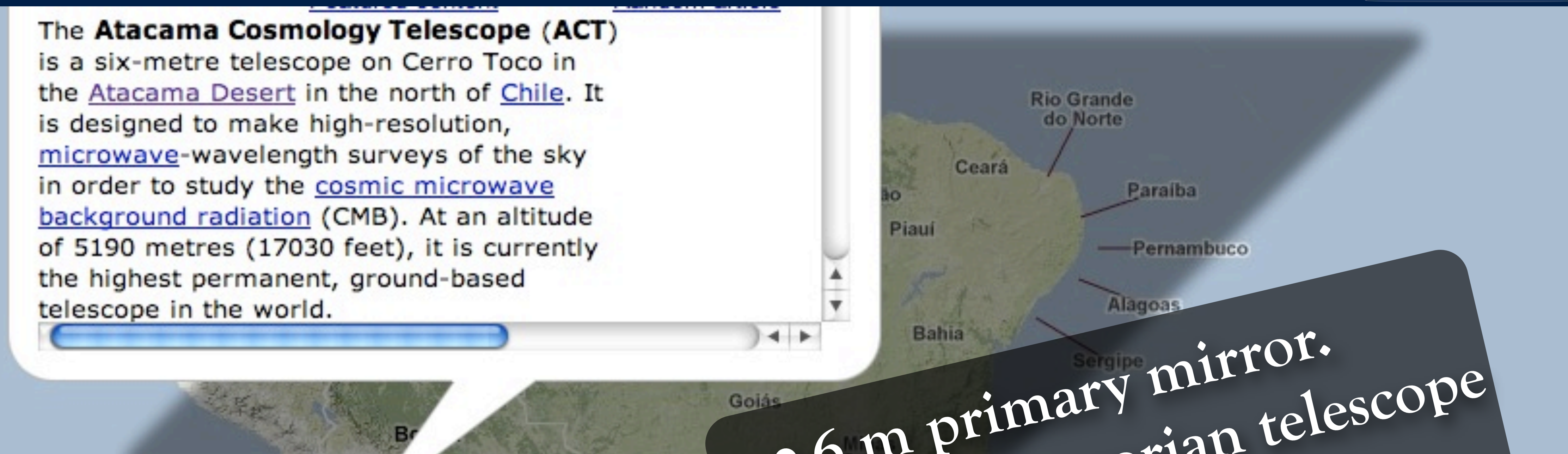
A SHARPER IMAGE OF THE CMB
WITH THE ATACAMA COSMOLOGY TELESCOPE

Sudeep Das

Berkeley Center for Cosmological Physics

The Telescope



- 6 m primary mirror. Off-axis Gregorian telescope
- ~1 arcmin resolution
- 148, 218, 277 GHz channels
- 3000 detector elements

Swetz et al. (2010)

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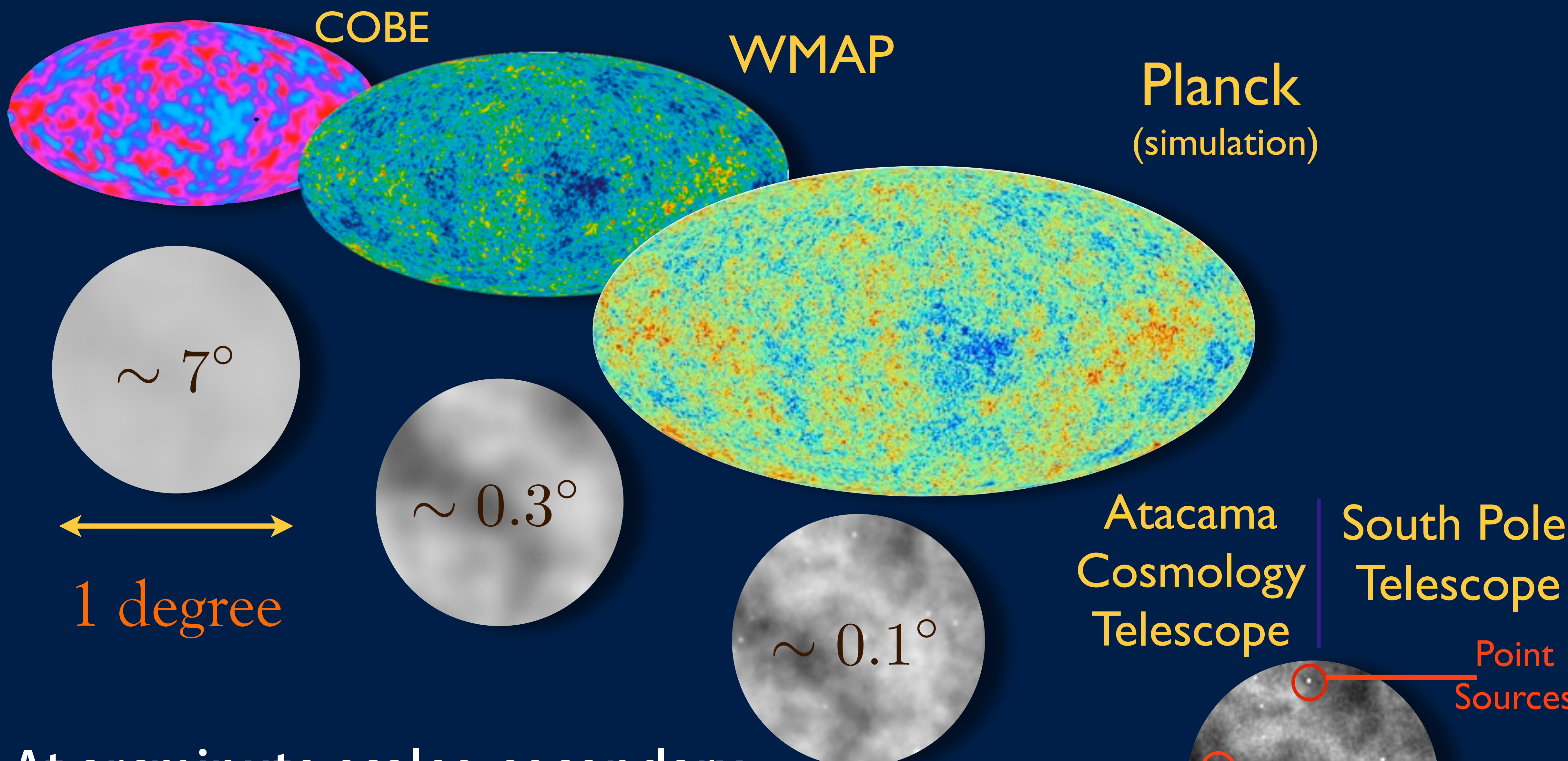
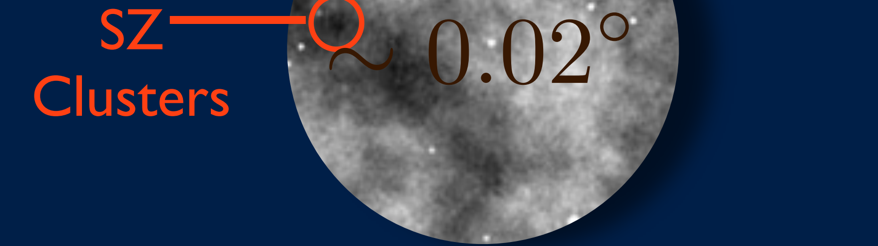
New view of the CMB





At arcminute scales, secondary anisotropies become important and bring us in contact with astrophysics.

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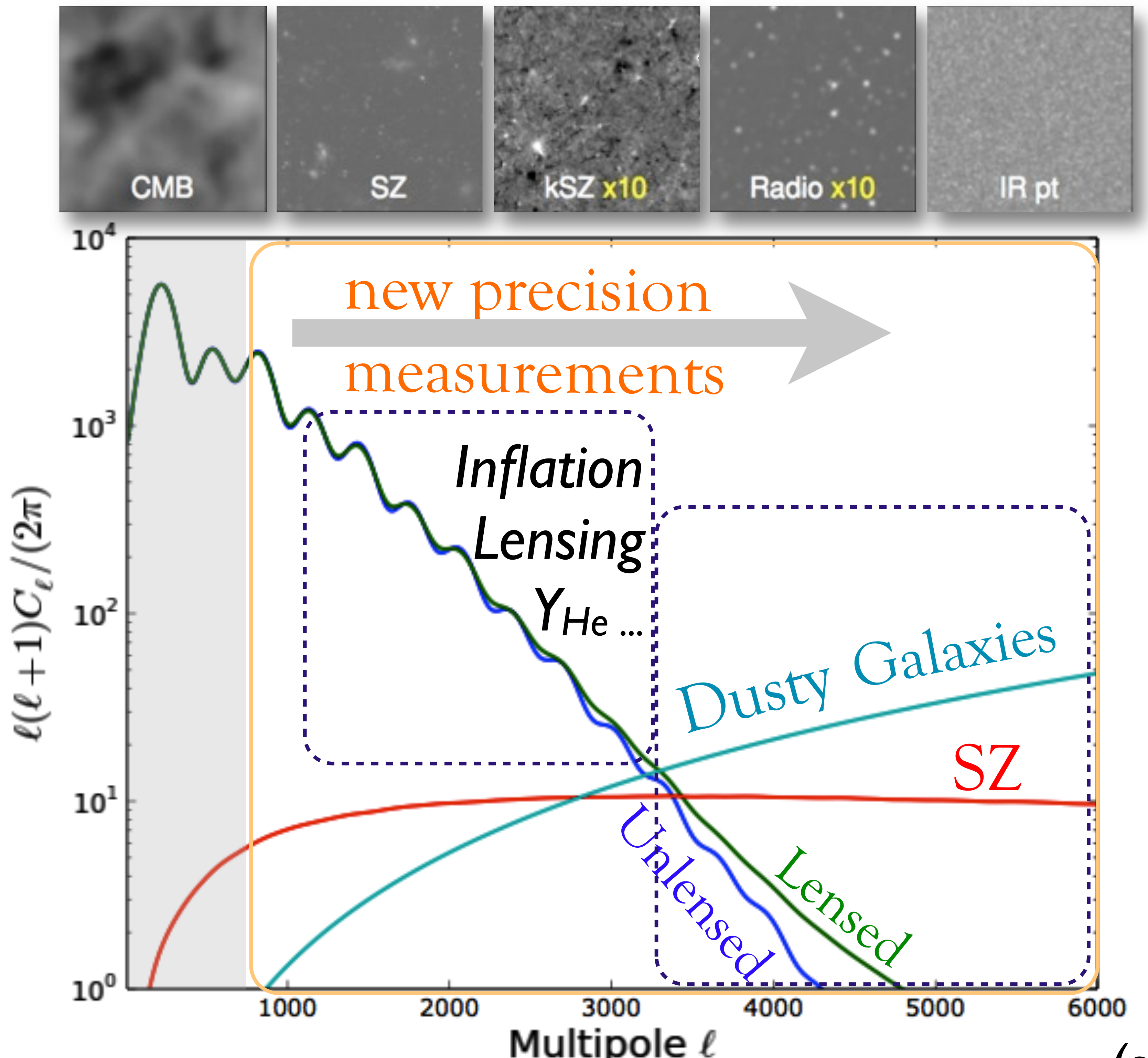
New view of the CMB



Higher order peaks give leverage on cosmology.

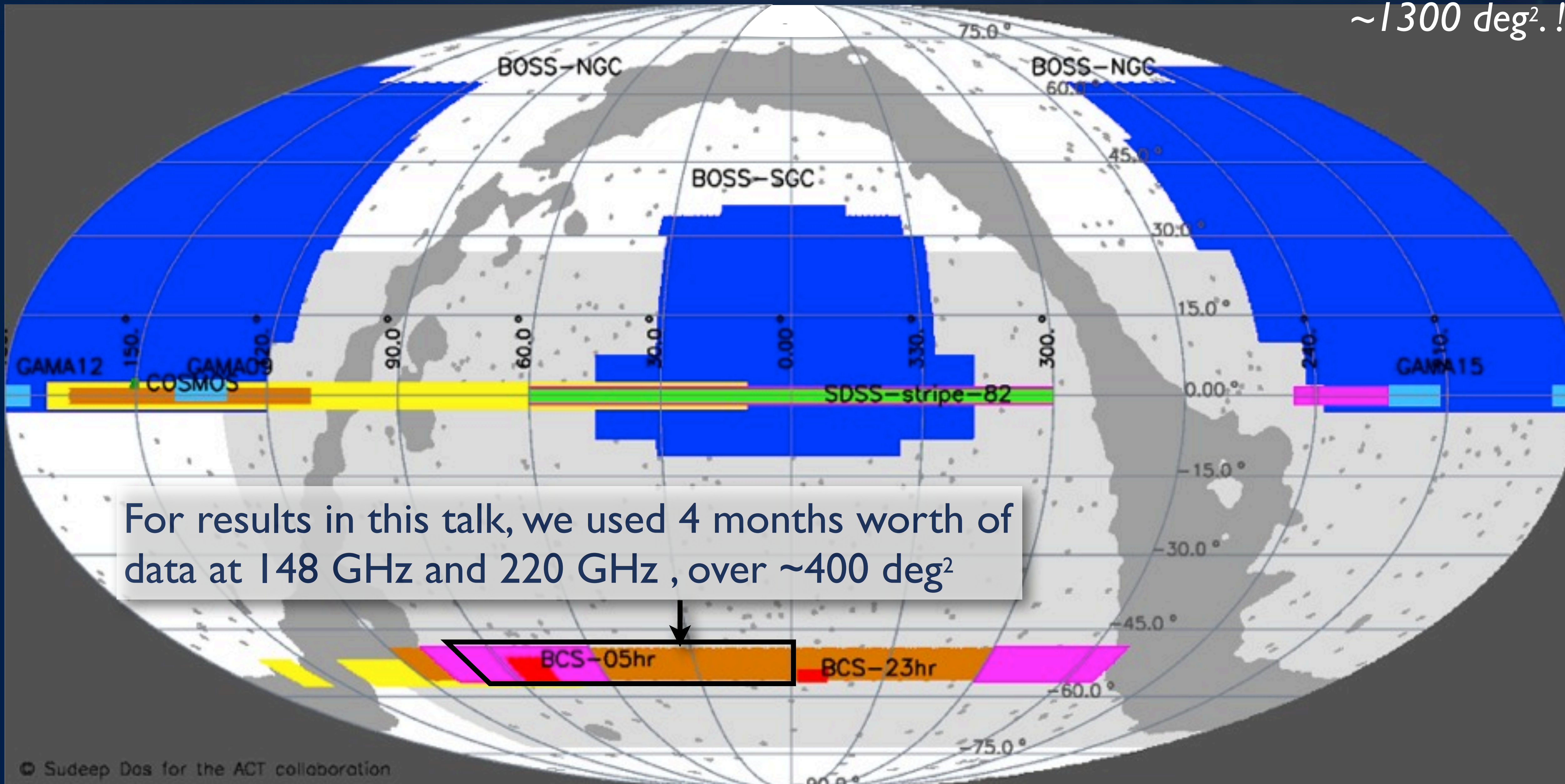
Secondary anisotropies (SZ, lensing) lets us probe geometry, growth, reionization, etc ...

Dusty galaxies give a window into high-z galaxy clustering and evolution.

(see, e.g. Galli et al. 2010)

Observations

ACT has taken 18 months of data at 3 frequencies already, over ~1300 deg². !



For results in this talk, we used 4 months worth of data at 148 GHz and 220 GHz , over ~400 deg²

2007	2008	2009	Stripe 82	
BCS	BOSS	GAMA	ACT Range	Mask

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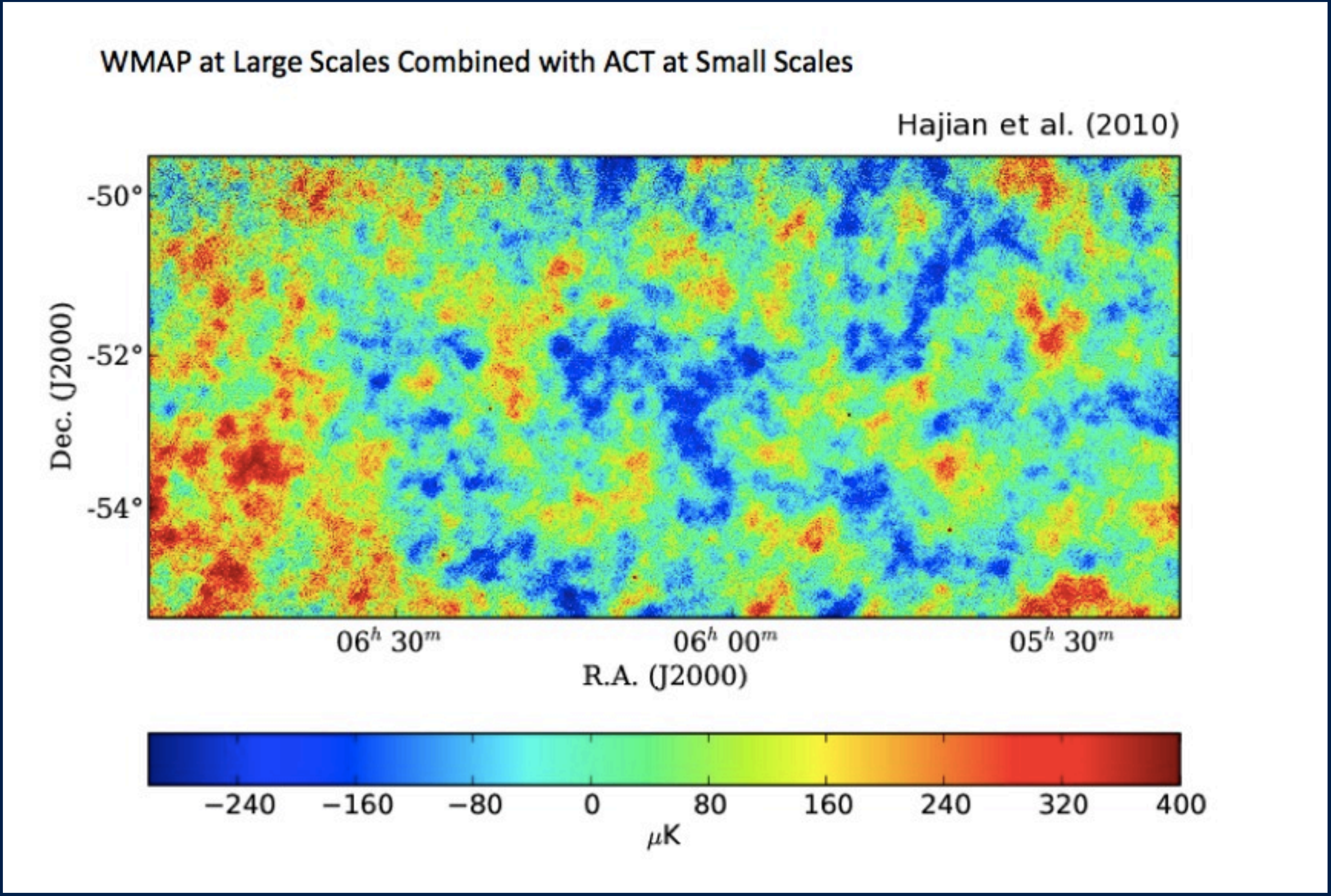
Maps



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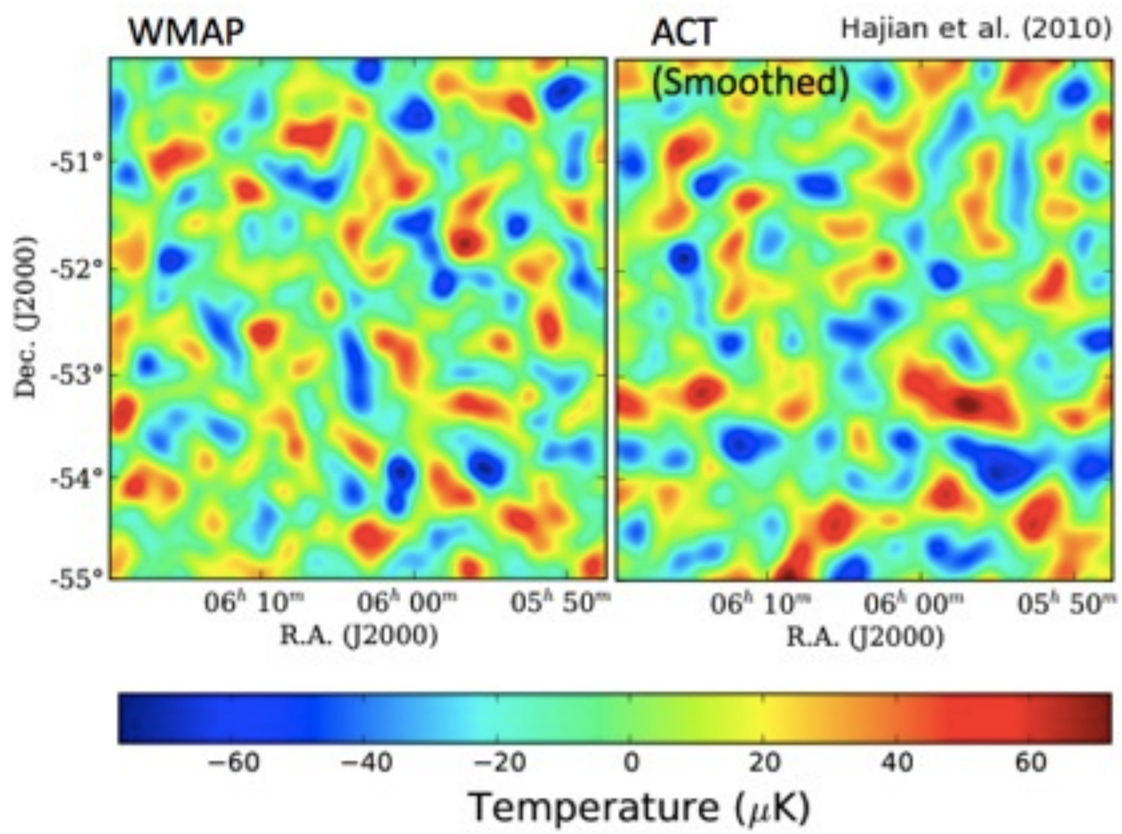
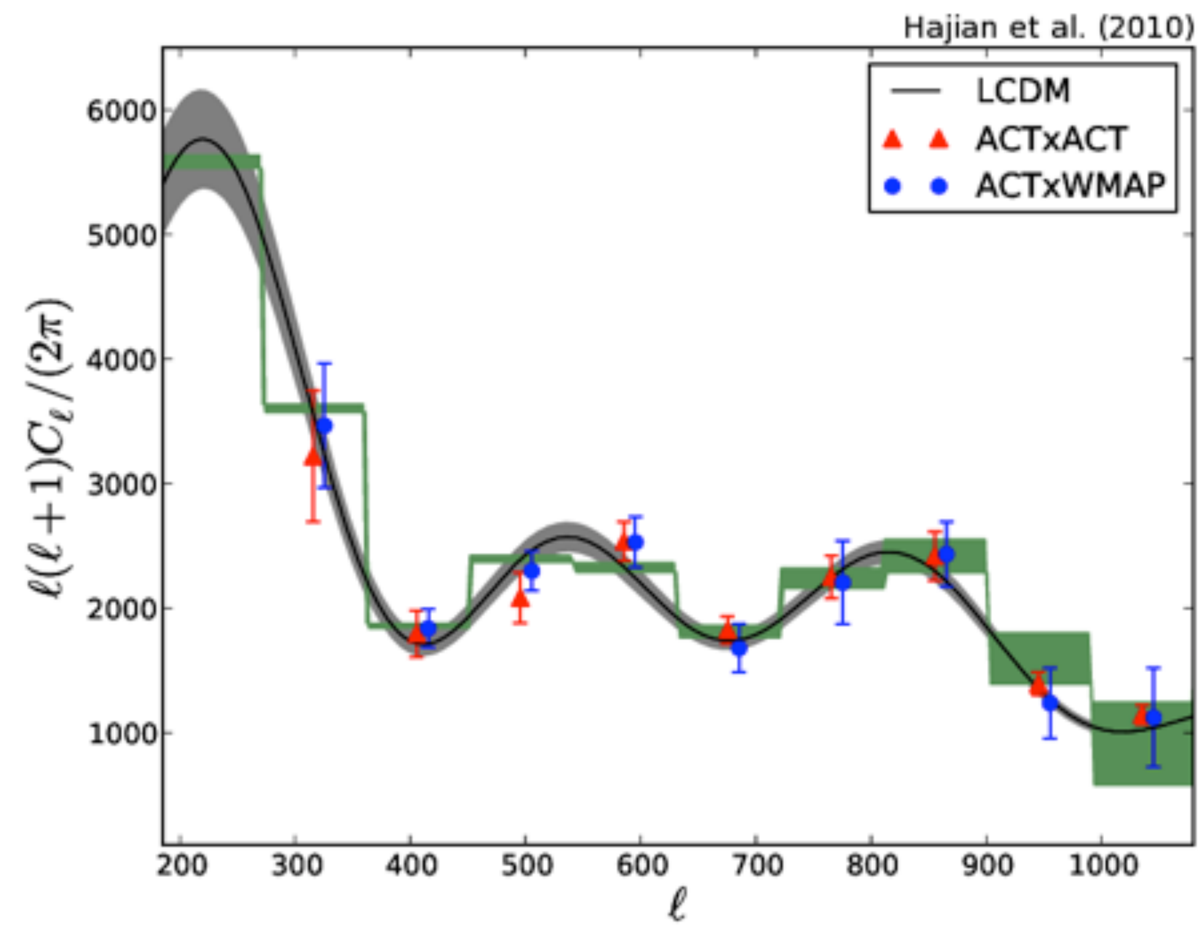
WMAP and ACT



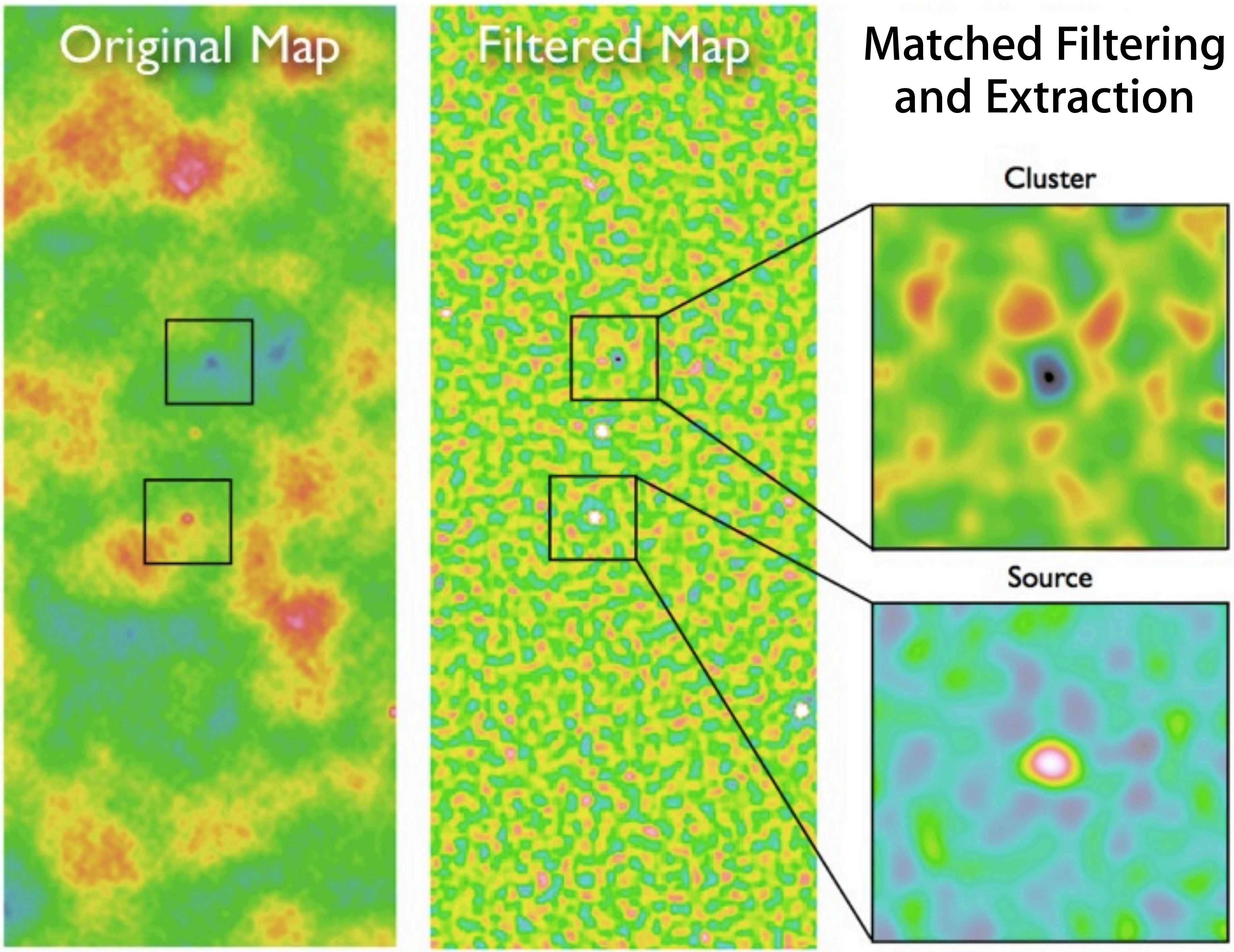


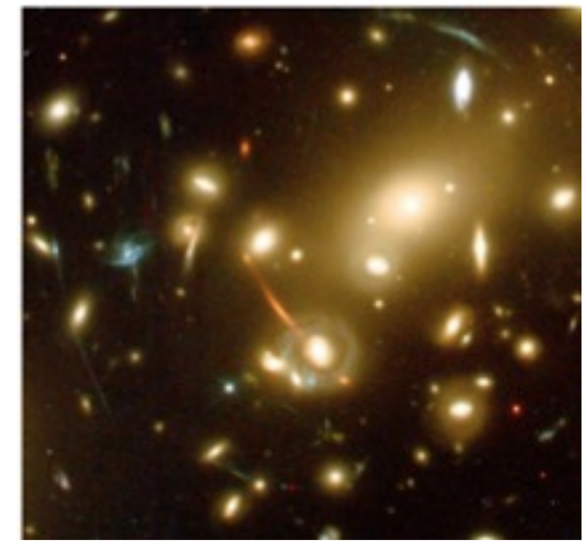
- ACT sees the same hot and cold spots as WMAP, but at a much higher angular resolution.
- We cross-correlate ACT maps with WMAP maps to estimate the absolute calibration for the ACT maps.
- For our148 GHz maps, we achieve a 2% calibration uncertainty.

Hajian et al. (2010)

Smallest Scales: Point Sources & Clusters

Matched Filtering and Extraction

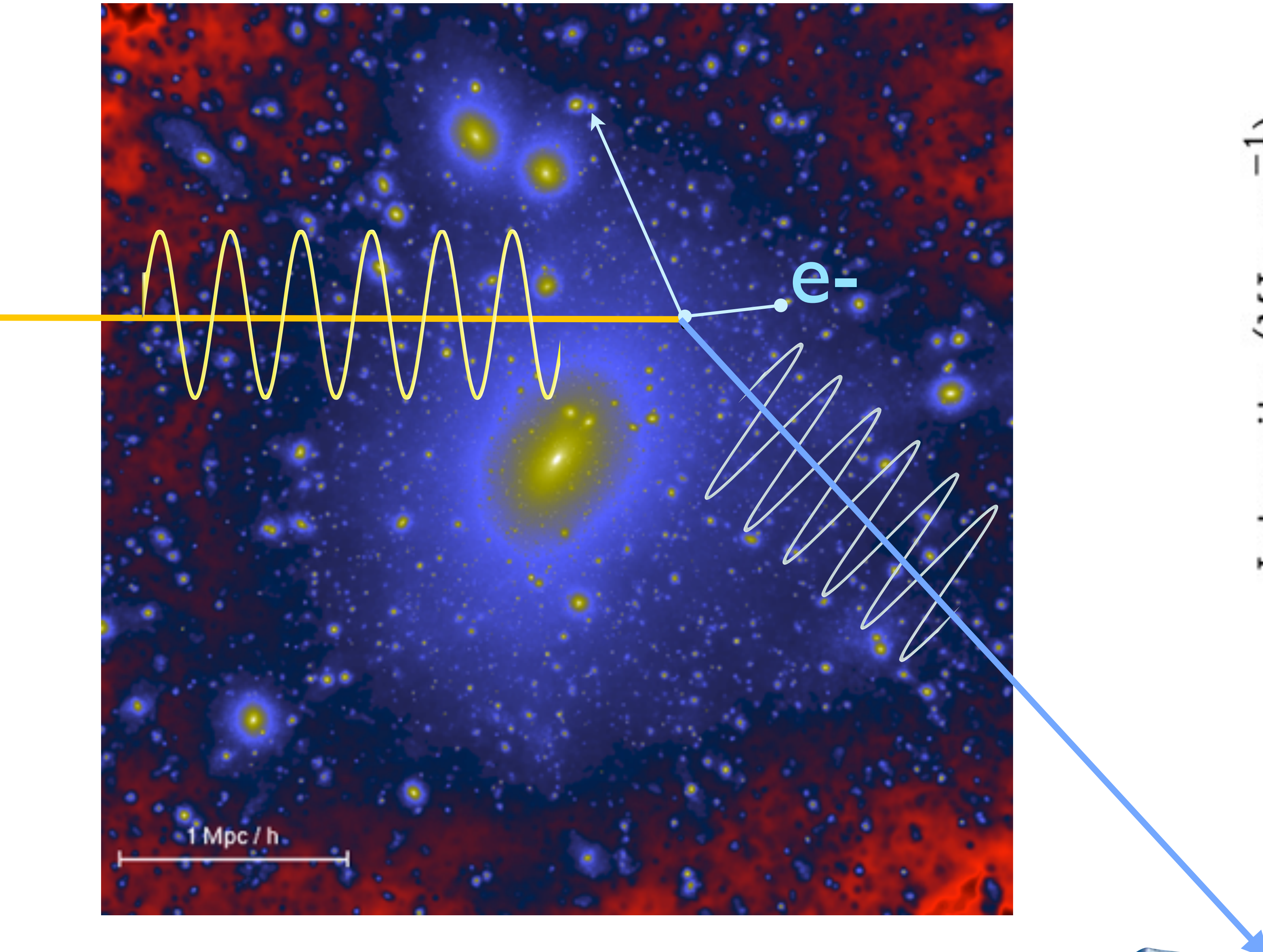


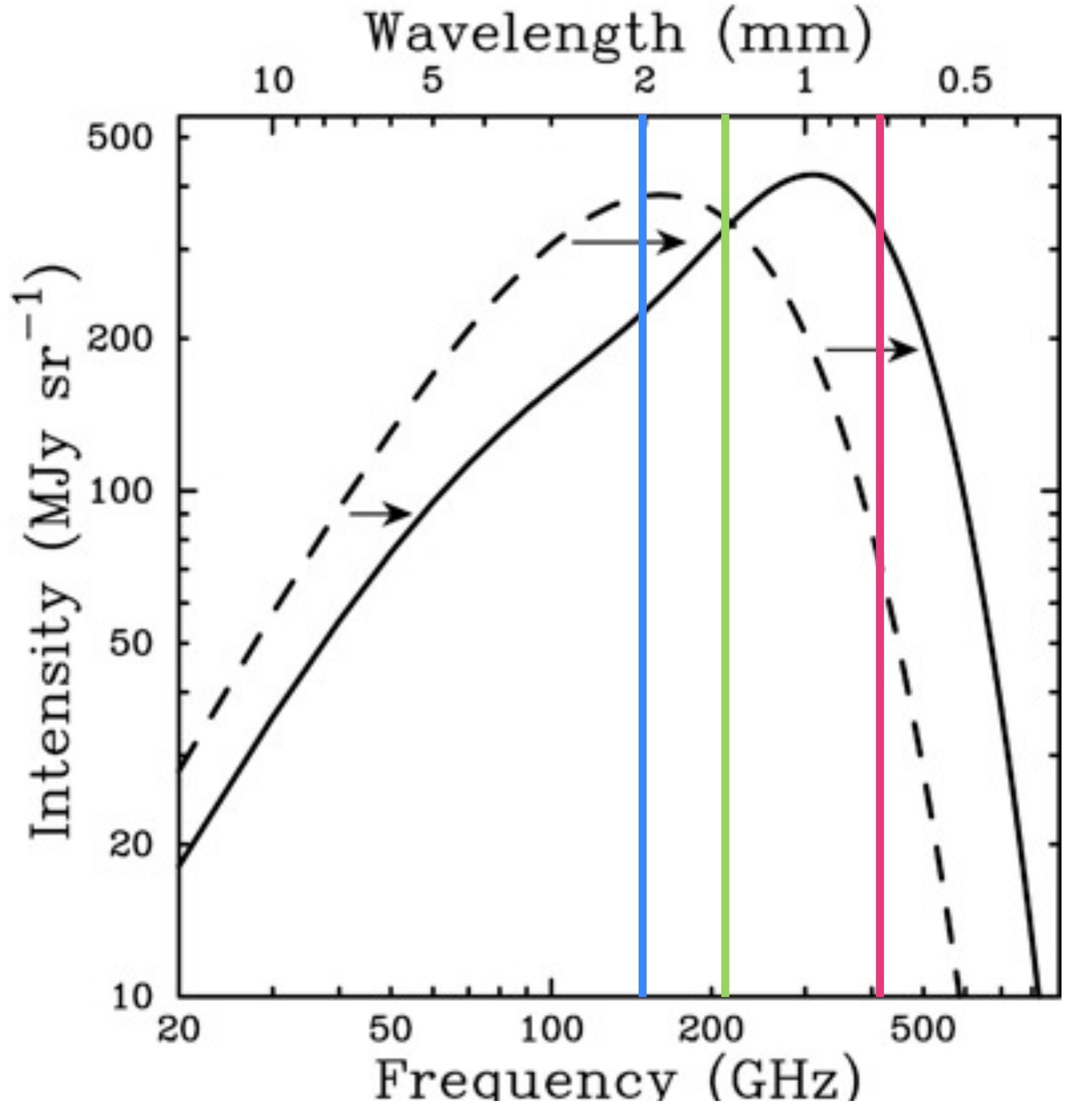


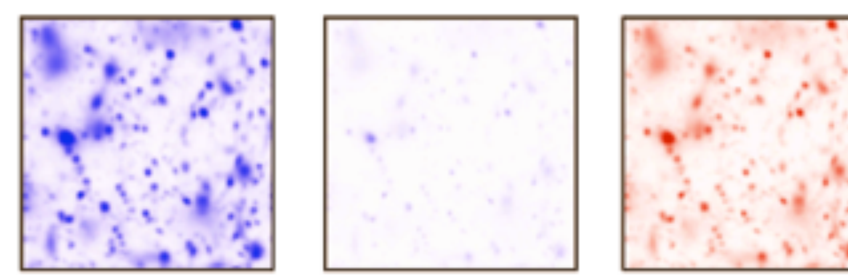
Flat Sprectrum Radio Sources

Cen A, LABOCA

The Sunyaev-Zeldovich Effect



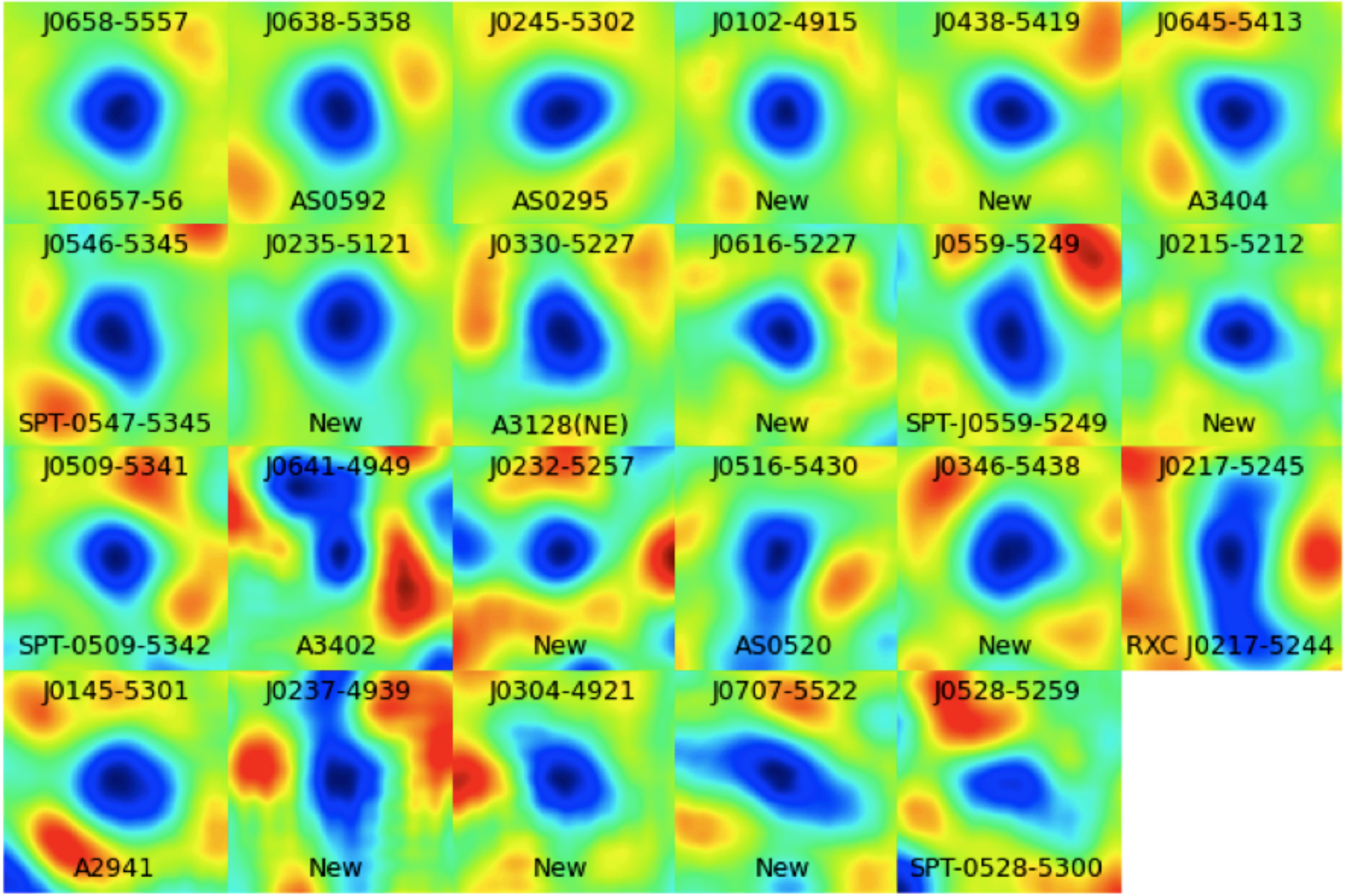




150 GHz decrement | 220 GHz null | 280 GHz increment

see, e.g., Carlstrom et al. (2002)
Reese (2003)

Galaxy Clusters @ 148 GHz



Marriage et al. (2010b)

See, also, Vanderlinde et al. (2010)

Cluster Follow-up

Optical Observations with Blanco, NTT and SOAR

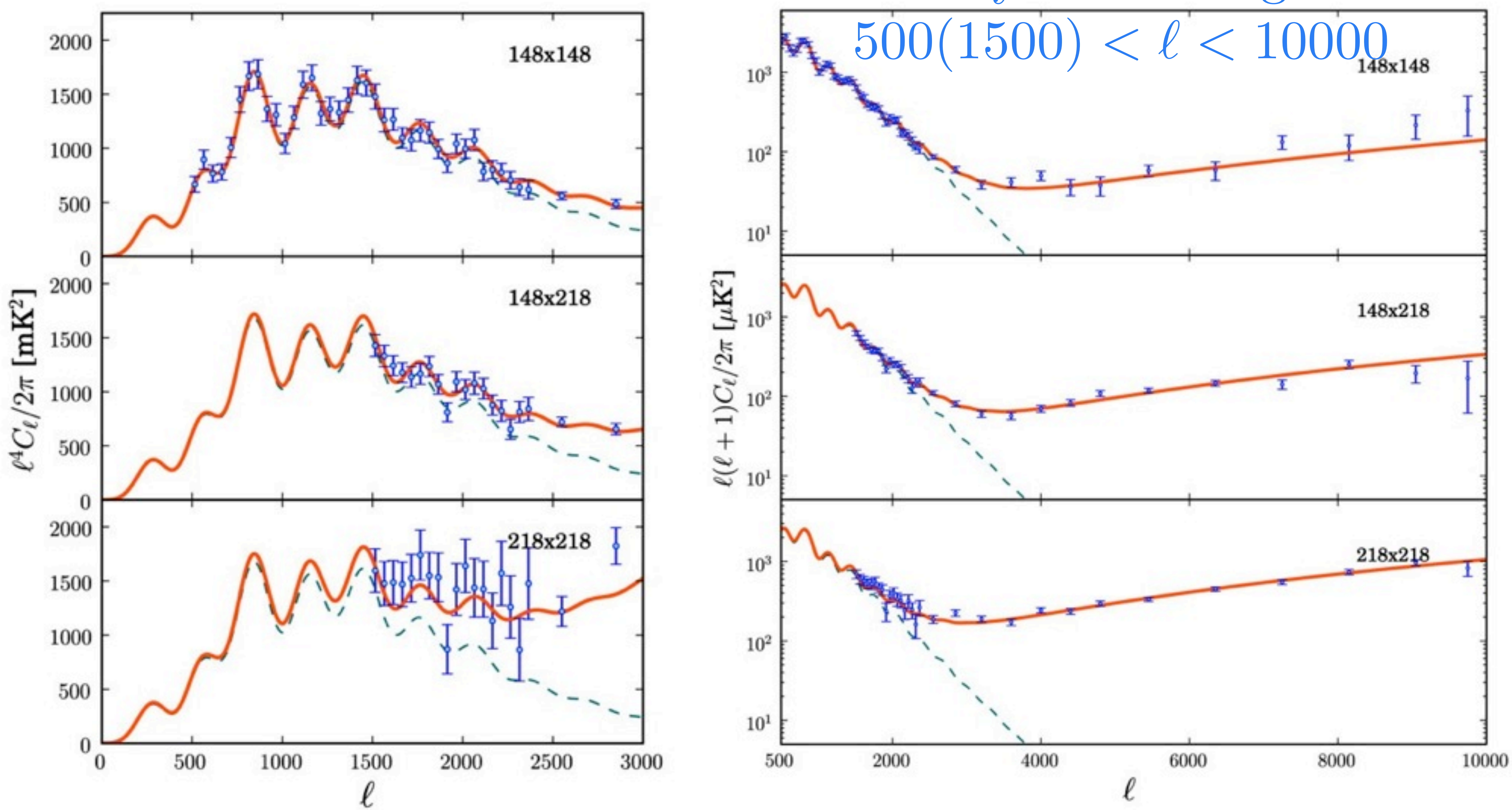
Menanteau et al. (2010)

See, also, High et al. (2010)

Multifrequency Power Spectra

Zoom in with ℓ^4 scaling

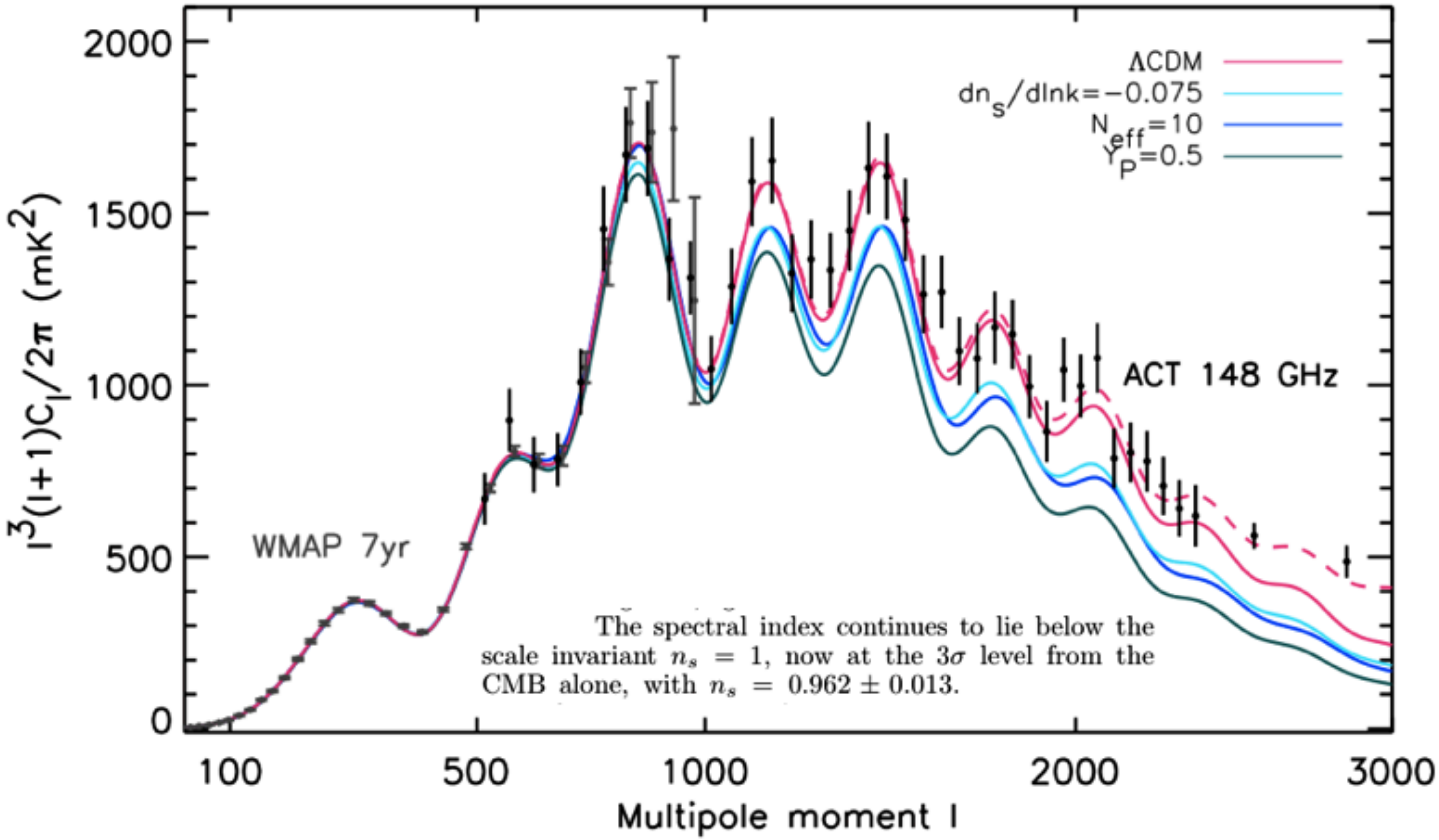
Full dynamic range $500(1500) < \ell < 10000$



Das et al. (2010)

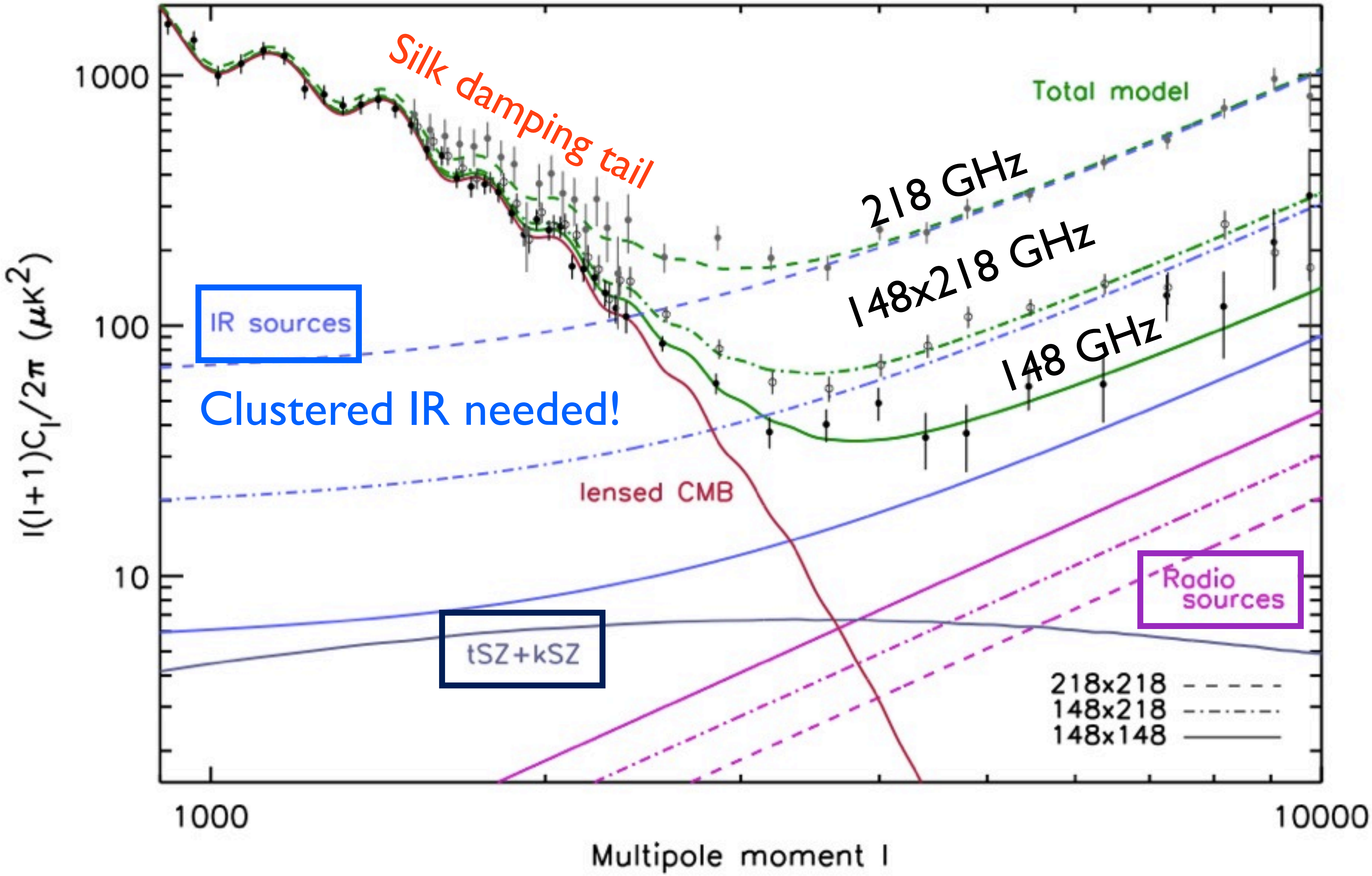
The "low-multipole" parameters

- The low-multipole spectra (l<3000 @148 GHz and l<2000 @218 GHz) are in excellent agreement with the 6-parameter ΛCDM model.
- The higher order peaks provide new constraints on beyond-ΛCDM parameters.



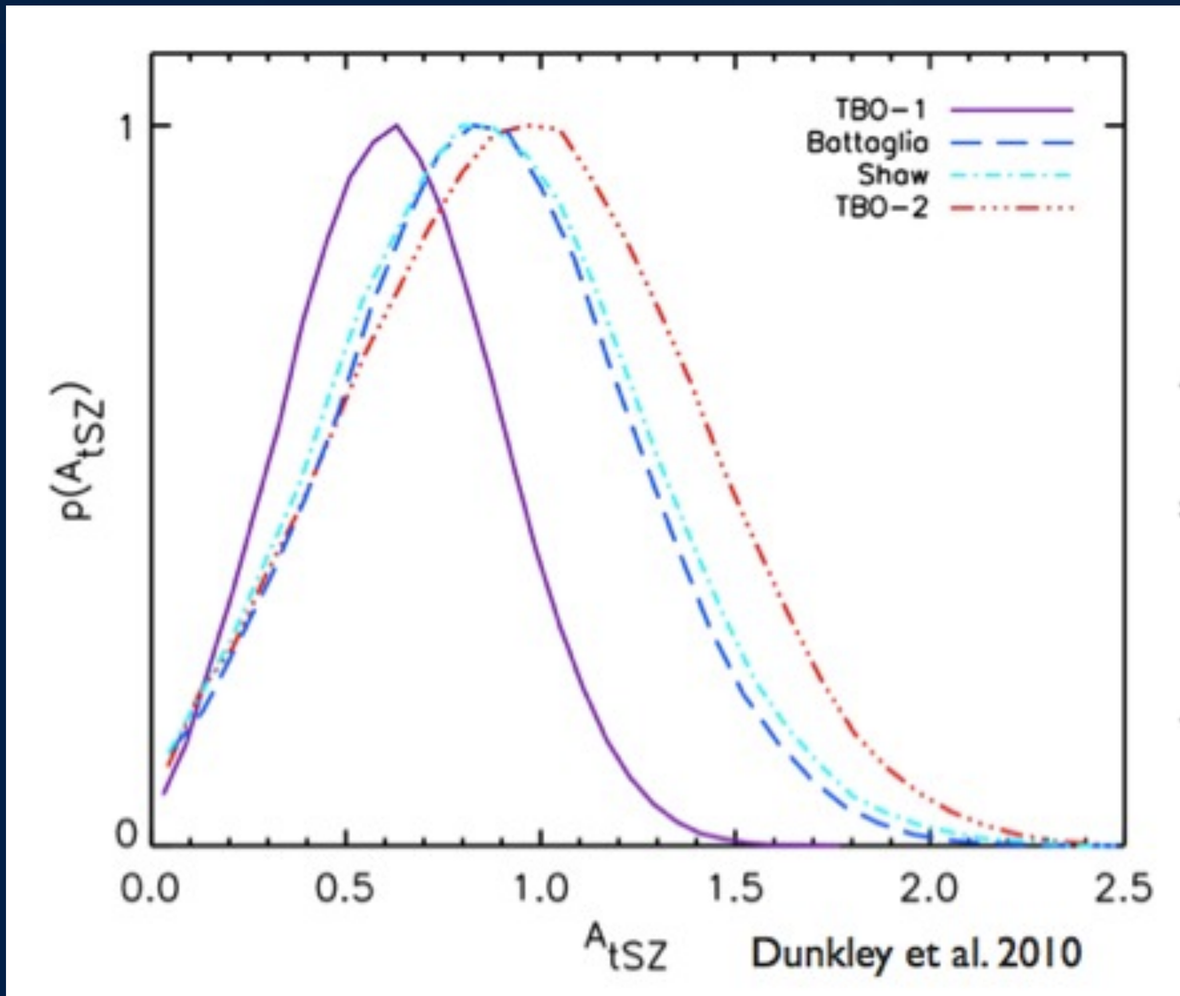
Dunkley et al. (2010)

Interpreting The Spectra



Dunkley et al. (2010)

SUNYAEV-ZEL'DOVICH POWER



- An SZ component is required at 95% confidence.
- Observed SZ power is consistent with SPT.
- Various SZ models were considered --- the power at l=3000 is independent of the template.
- Kinetic SZ upper limit < 8 μK^2 at l=3000.

Template[a]	A_{tSZ}[b]	$\mathcal{B}_{3000}^{SZ}$[c] (μK^2)	$\sigma_8^{SZ,7}$ $0.8 \times (A_{tSZ}^{1/7})$	$\sigma_8^{SZ,9}$ $0.8 \times (A_{tSZ}^{1/9})$
TBO-1	0.62 ± 0.26	6.8 ± 2.9	0.74 ± 0.05	0.75 ± 0.04
TBO-2	0.96 ± 0.43	6.7 ± 3.0	0.78 ± 0.05	0.79 ± 0.04
Battaglia	0.85 ± 0.36	6.8 ± 2.9	0.77 ± 0.05	0.78 ± 0.04
Shaw	0.87 ± 0.39	6.8 ± 3.0	0.77 ± 0.05	0.78 ± 0.04

Dunkley et al. (2010); see also Hall et al. (2010)

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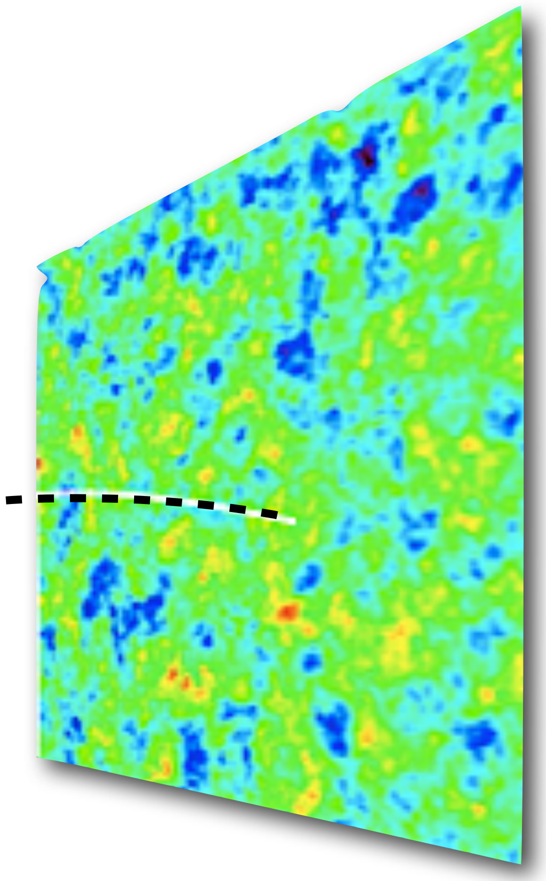
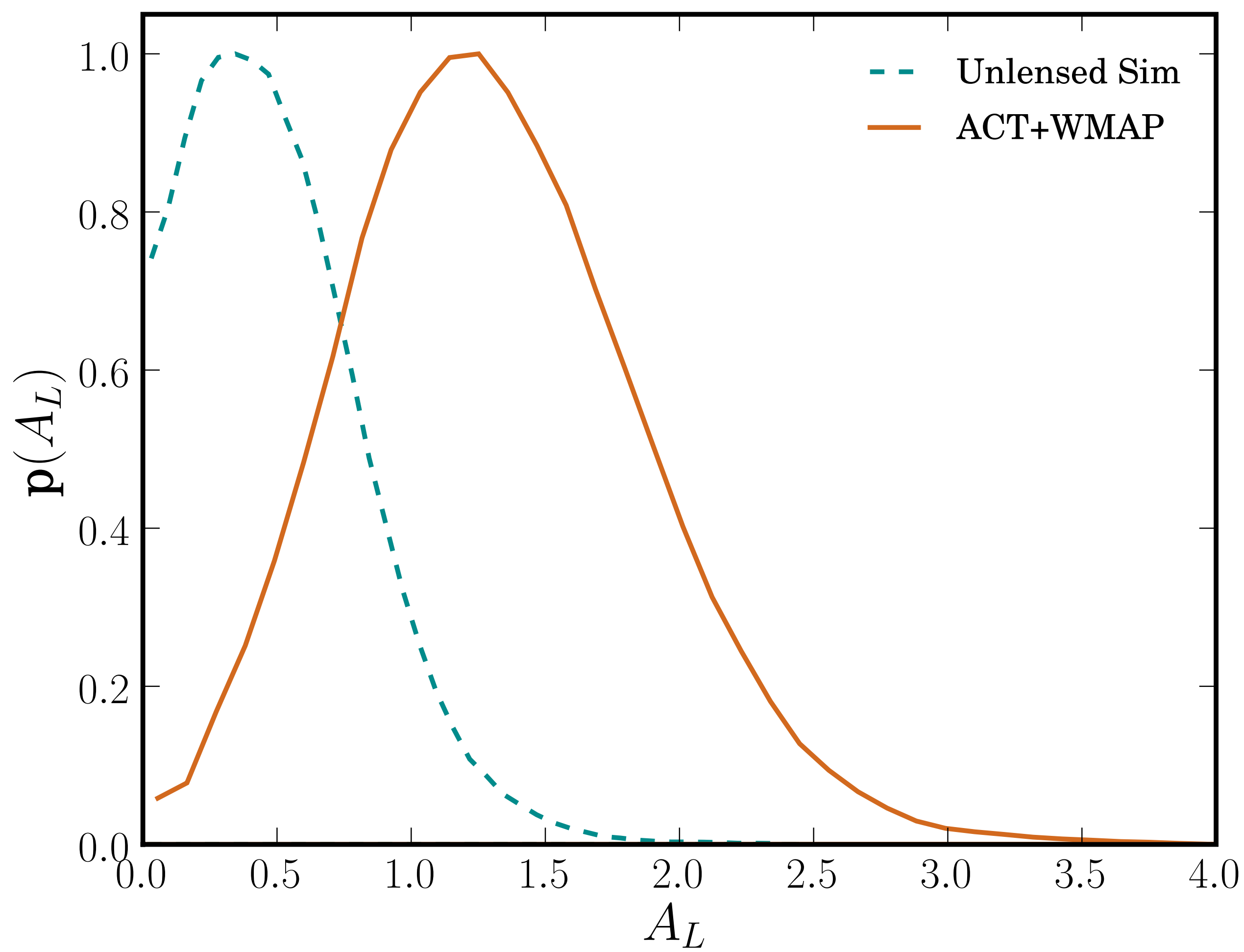
Intervening large-scale potentials deflect CMB photons and distort the CMB.

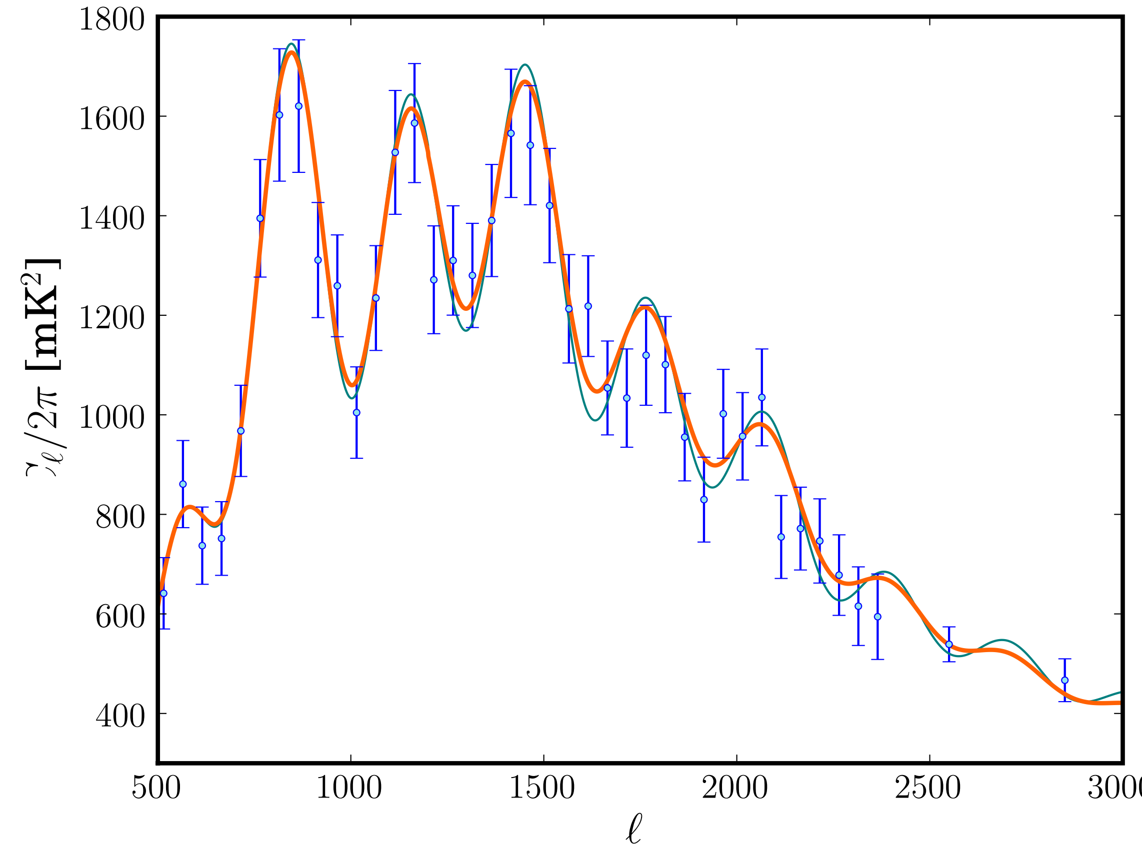


The RMS deflection is about 2.7 arcmins, but the deflections are coherent on degree scales.

Lensing smoothes acoustic peaks

$$C_\ell^{\phi\phi} \rightarrow A_L C_\ell^{\phi\phi}$$





- Test for lensing in spectrum by marginalizing over (unphysical) parameter A_L, scaling lensing potential. [Calabrese et al 2008]

- Expect A_L=1, and unlensed has A_L=0. See lensing at almost 3σ level.

- Find $A_L = 1.3 \pm 0.5^{+1.2}_{-1.0}$ (68, 95% CL)

Das et al. (2010)

Why Study CMB Lensing?

CMB lensing can be fully described via the deflection field:

$$\Theta(\hat{n}) = \tilde{\Theta}(\hat{n} + \nabla\phi)$$

Lensed | Unlensed | Deflection Field

$$\phi = -2\int \frac{d_A(\eta_0 - \eta)}{d_A(\eta)d_A(\eta_0)} \Phi(\eta\hat{n}, \eta)$$

Effective Lensing Potential | Geometry | Matter potential

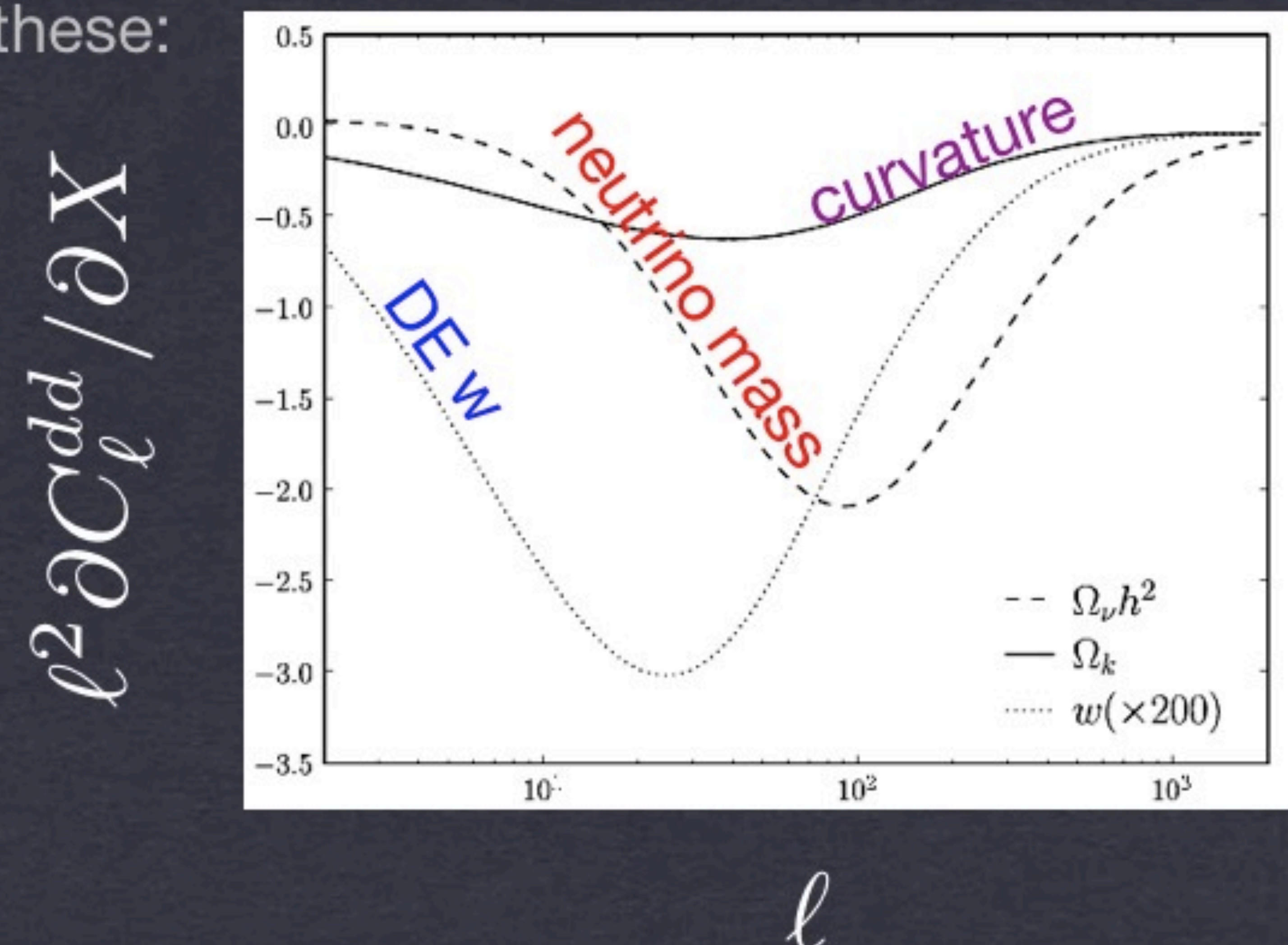
Affected by parameters that affect distance scales and growth of structure in the late universe.

For high lensed (clusters, galaxies) CMB is the only source !

Breaking Degeneracies

The primary CMB can be kept nearly unchanged under variations of neutrino mass, dark energy equation of state or curvature. But the deflection field cares about these:

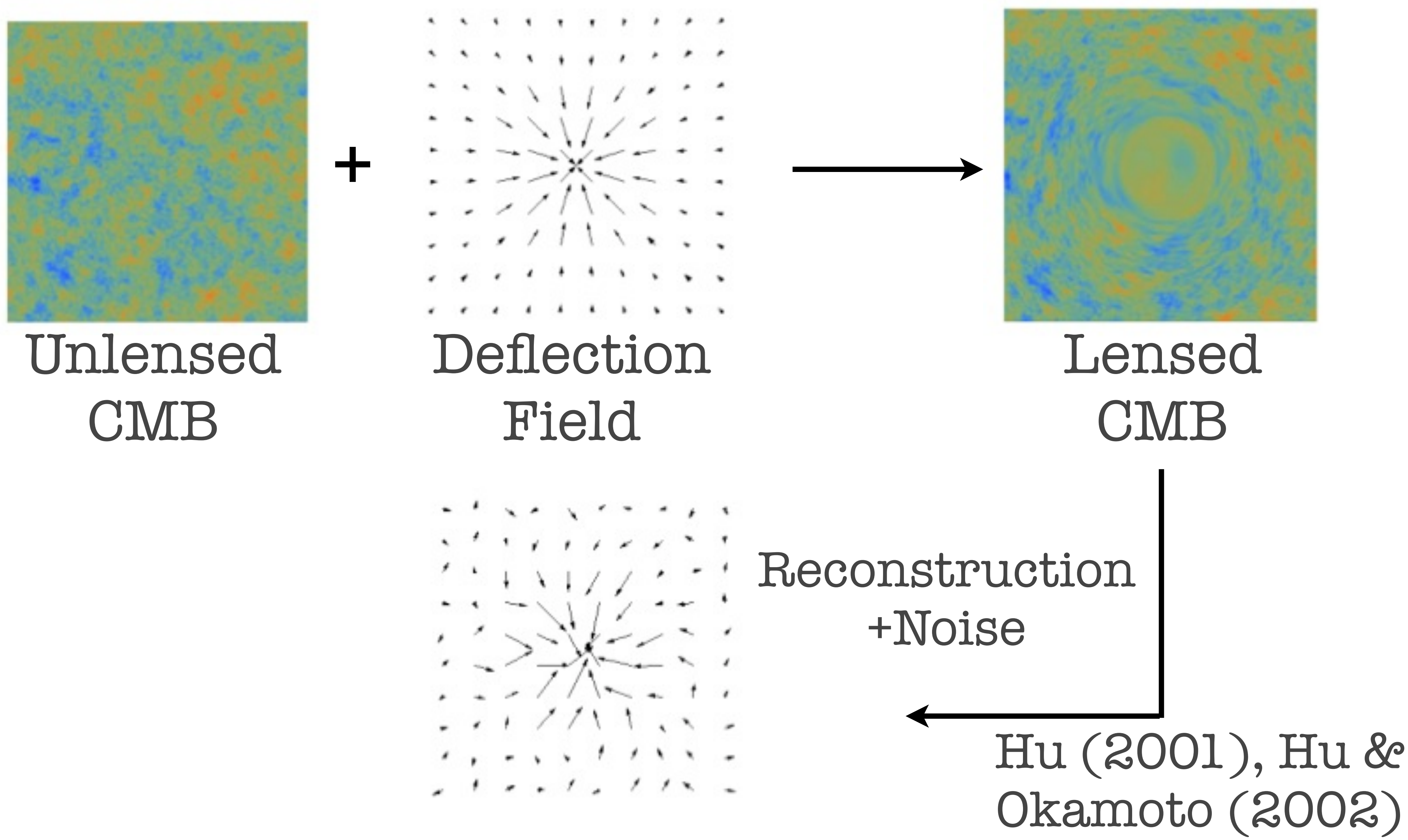
Lensing breaks the angular diameter distance degeneracy!



Smith, Cooray, Das, Dore et al., CMBPOL Lensing White Paper (2009)

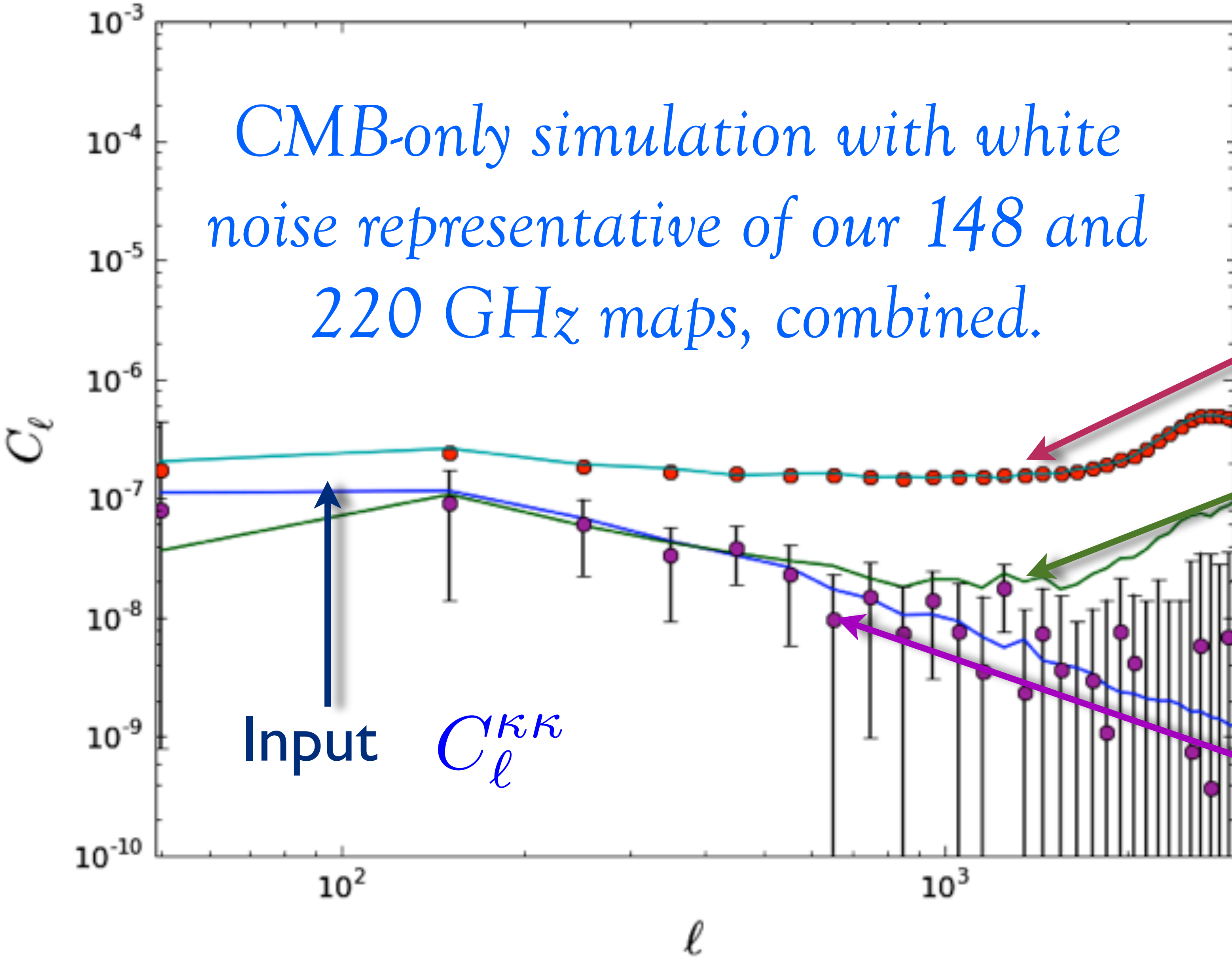
Lensing Reconstruction

Given only the lensed CMB sky, can we estimate the deflection field?



ONGOING SEARCH FOR LENSING

Work done with Blake Sherwin, Princeton



Observable: PS of the reconstructed map:

$$C_\ell^{\kappa\kappa} + N_\ell^{\kappa\kappa}$$

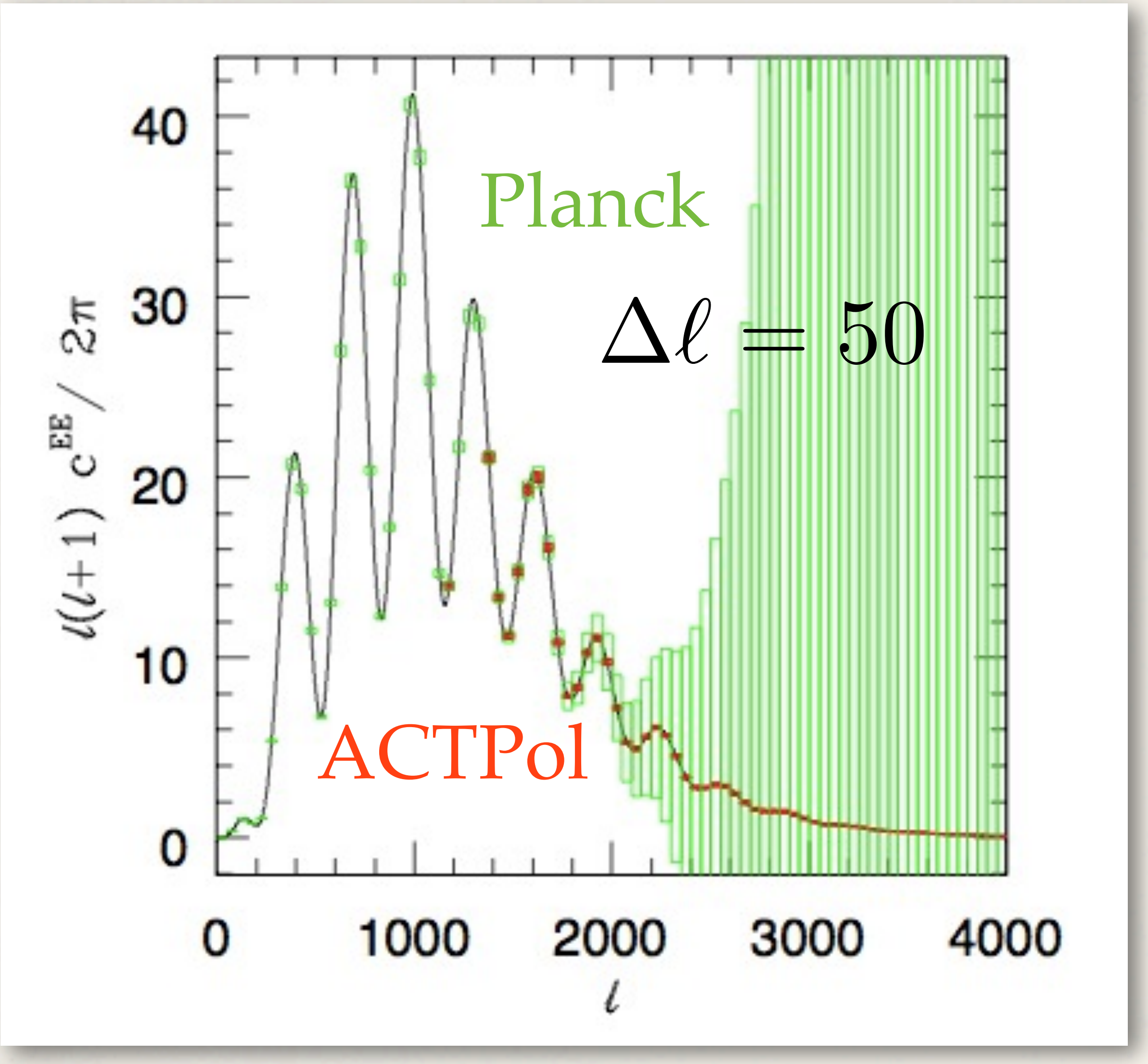
After subtracting noise-bias model, $N_\ell^{\kappa\kappa}$

After subtracting residual apodization bias.

Note that such a measurement will be an independent measurement of σ_8 at an effective z ~ 3

ACTPol: Adding Polarization to ACT

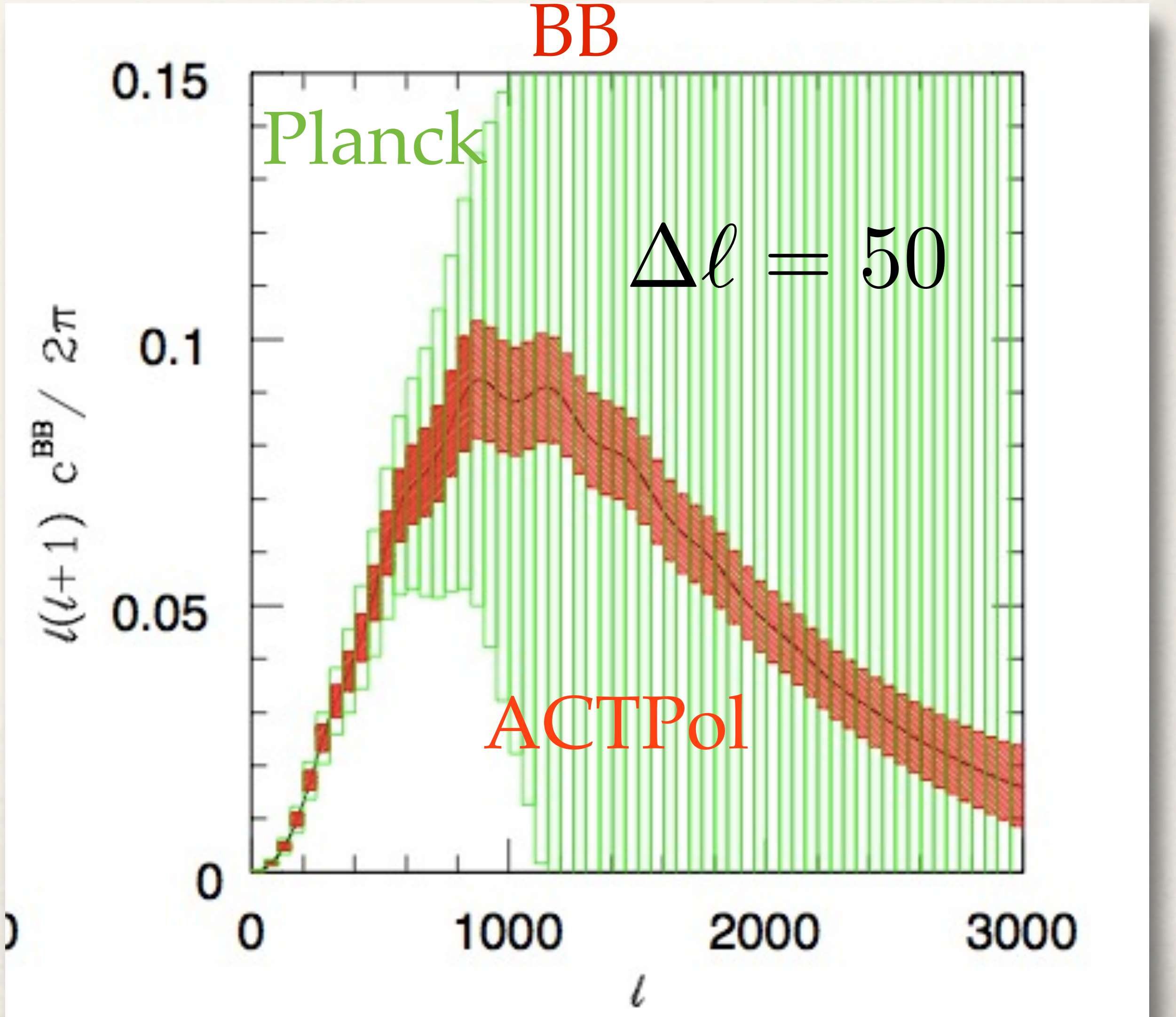
EE



ACTPol will make precise measurements of the high-l polarization spectrum.

For BB, the high-l spectrum comes primarily from lensing of E-modes.

BB



ACTPOL is funded !

See Niemack et al (2010)