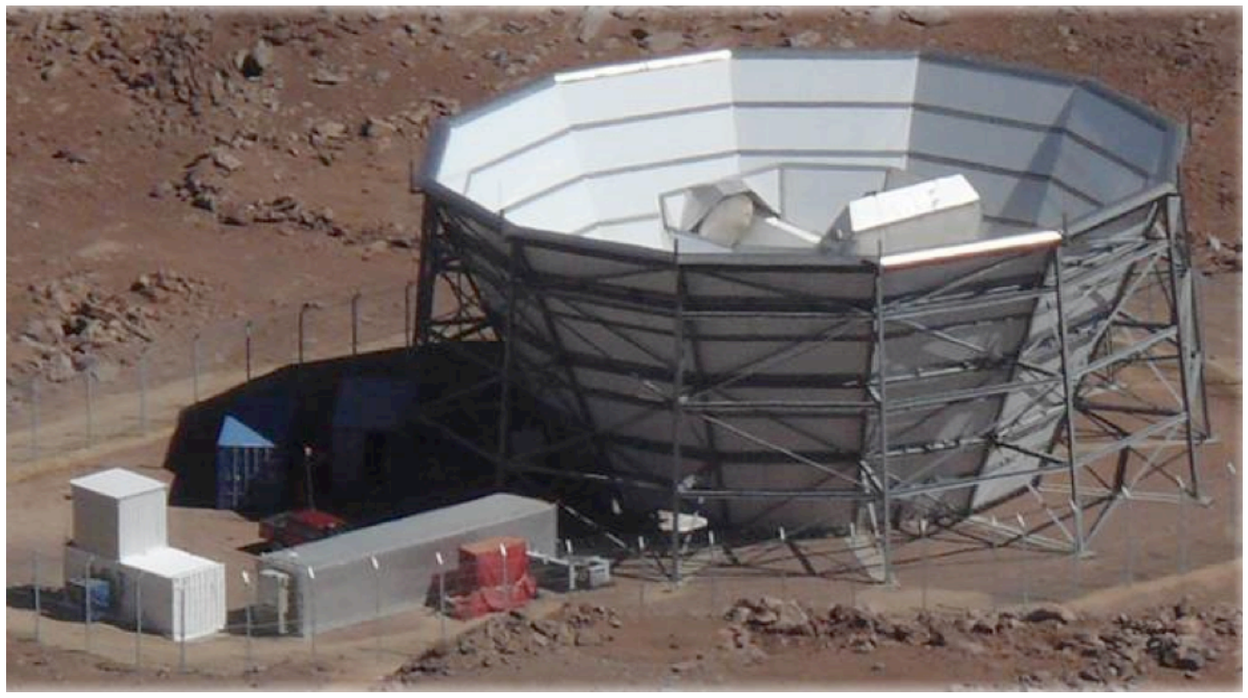
The
ATACAMA COSMOLOGY TELESCOPE:
PRELIMINARY RESULTS



SUDEEP DAS

Berkeley Center for Cosmological Physics
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L. Infante [4]
K.D. Irwin [11]
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R. Jimenez [19]
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J. Klein [2]
A. Kosowsky [9]
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Y.T. Lin [22,1,4]
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D. Marsden [2]
K. Martocci [23,6]
P. Mauskopf [3]
F. Menanteau [18]
K. Moodley [14]
H. Moseley [10]
B. Netterfield [24]
M.D. Niemack [11,6]
M.R. Nolta [8]
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B. Reid [19,1]
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O. Stryzak [6]
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E. Switzer [23,6]
R. Thornton [26,2]
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[28] University of Massachusetts, Amherst (USA)
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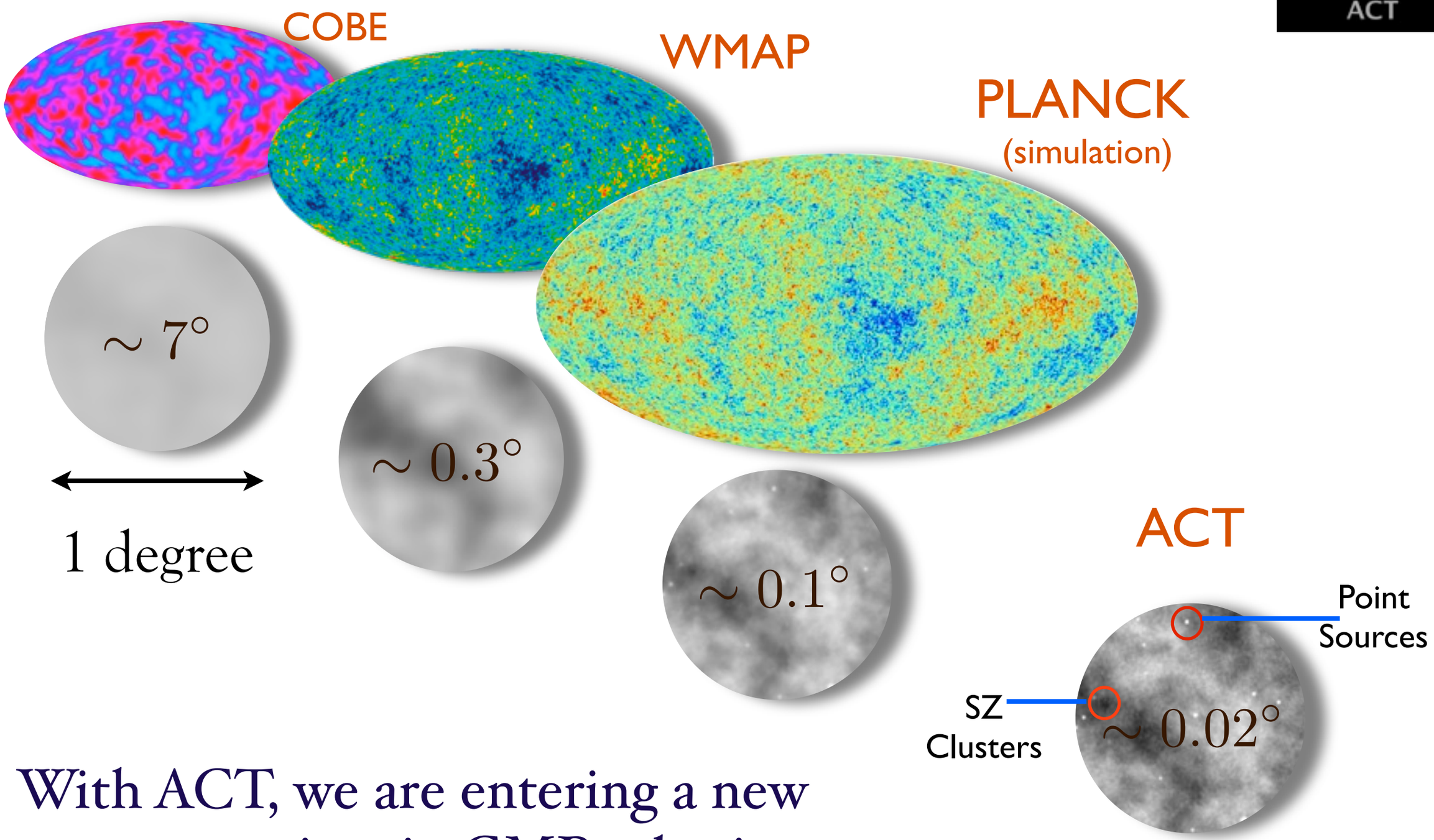
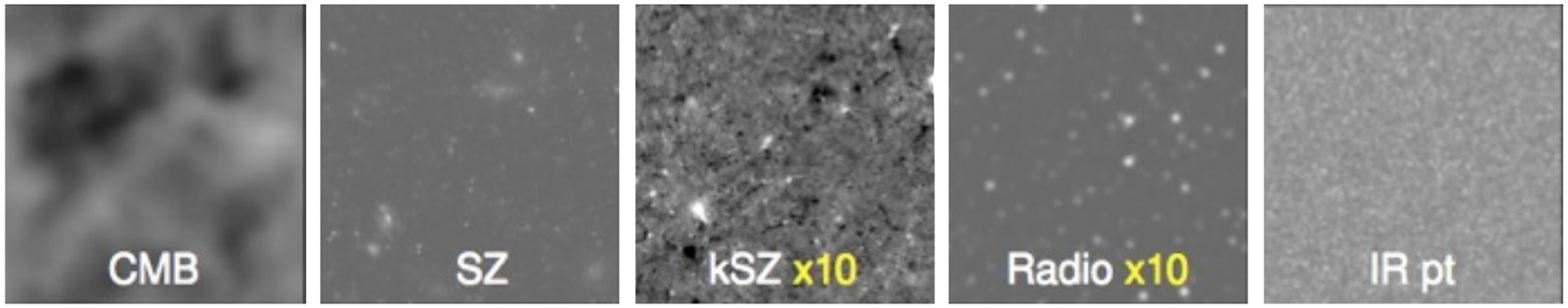
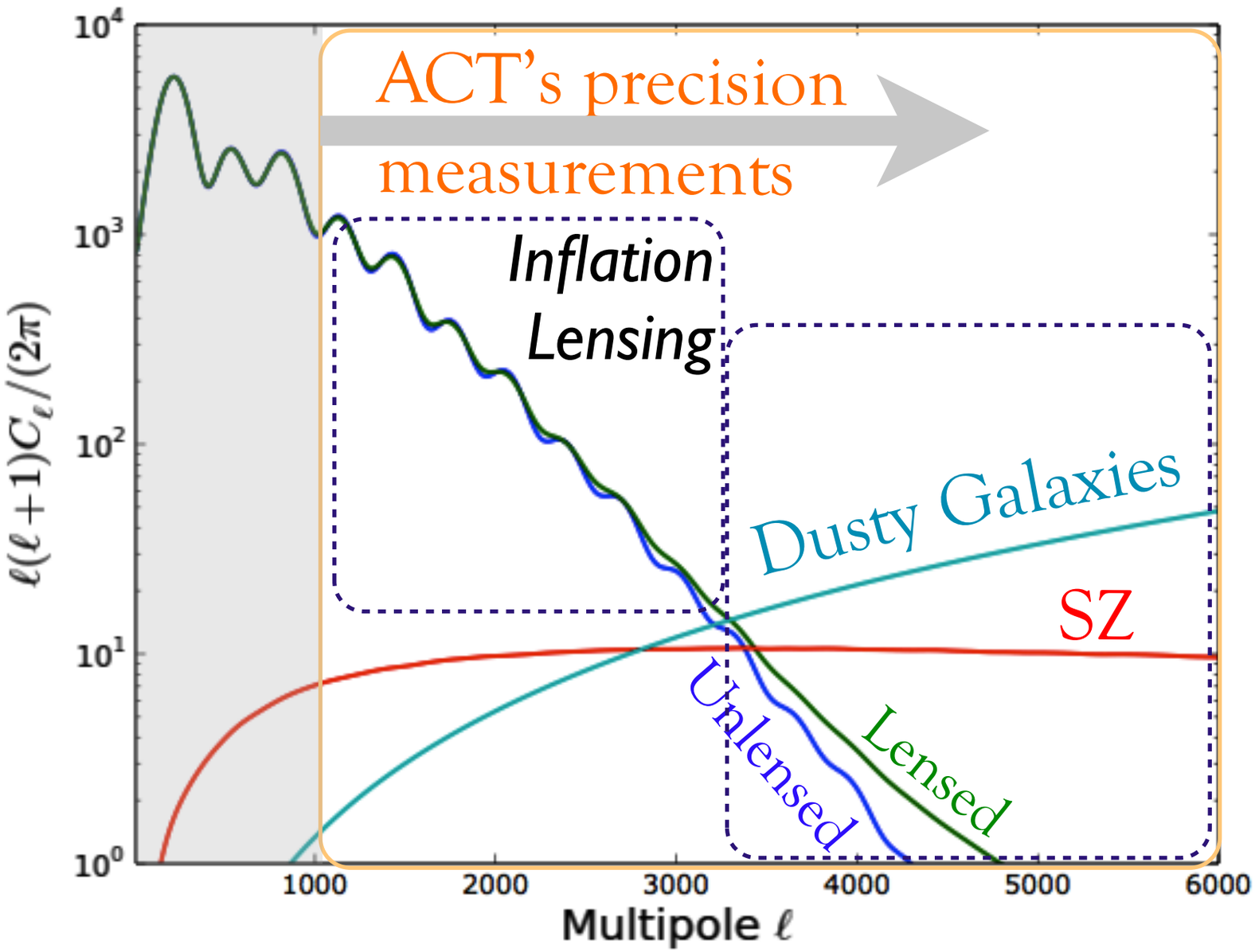
SCIENCE



With ACT, we are entering a new regime in CMB physics.

SCIENCE


CMB
SZ
kSZ x10
Radio x10
IR pt

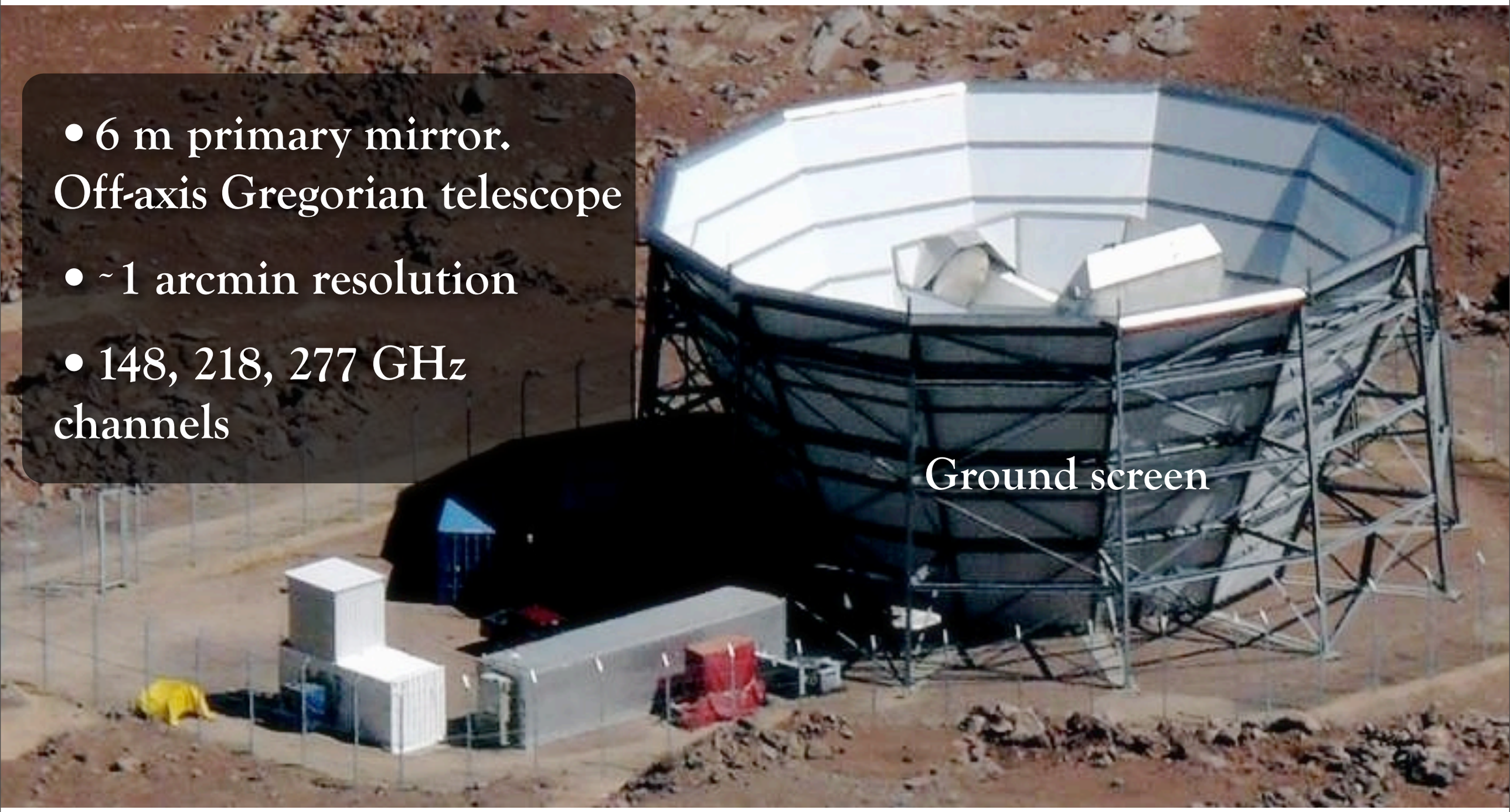

ACT's precision measurements
Inflation
Lensing
Dusty Galaxies
SZ
Unlensed
Lensed
10^4
10^3
10^2
10^1
10^0
$\ell(\ell+1)C_\ell/(2\pi)$
1000
2000
3000
4000
5000
6000
Multipole ℓ

THE TELESCOPE

THE TELESCOPE:
LOCATION

- 5200 meters (17,000 ft)
- "High and dry": 0.49 mm median Precipitable Water Vapor (PWV).
- Latitude 23 degrees South - good for cross-linked observations.

THE TELESCOPE:
DESIGN

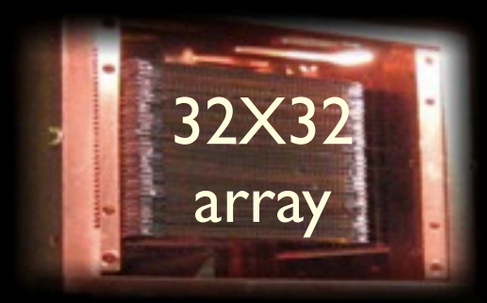


- 6 m primary mirror. Off-axis Gregorian telescope
- ~1 arcmin resolution
- 148, 218, 277 GHz channels

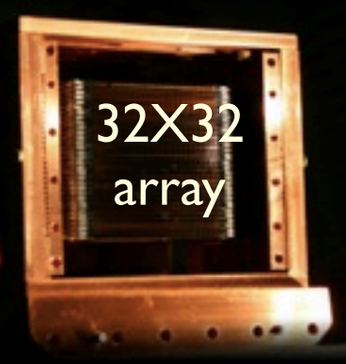
THE TELESCOPE:

DETECTORS + OPTICS

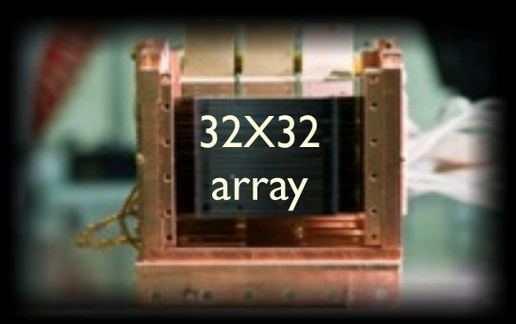
Transition Edge Sensors



148 GHz

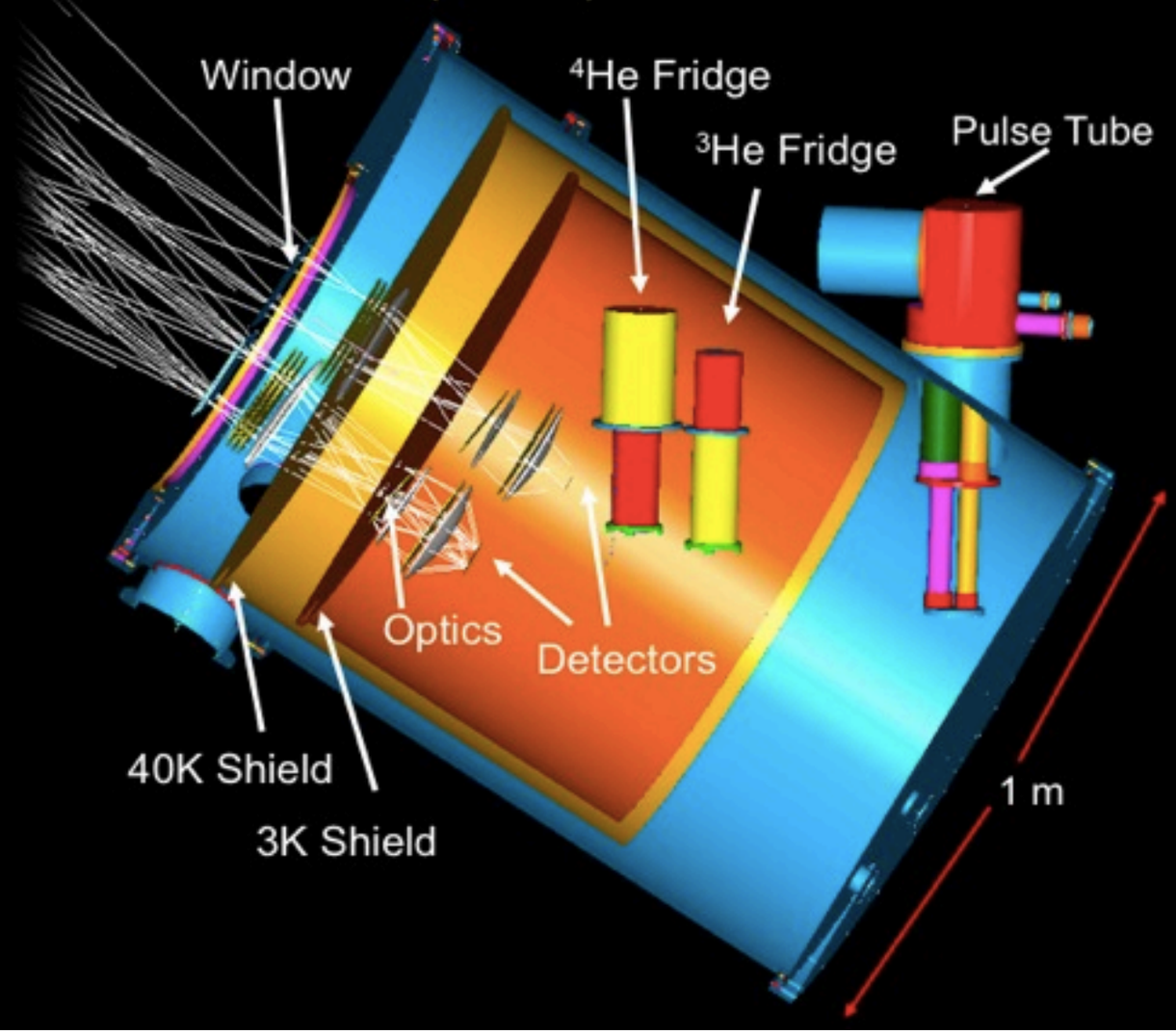


218 GHz

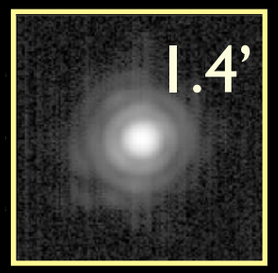


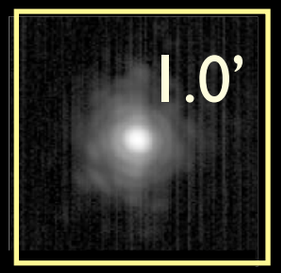
277 GHz

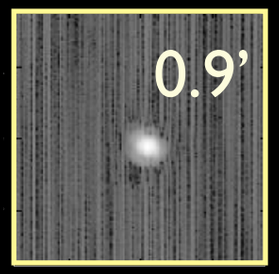
The Millimeter Bolometric Array Camera (MBAC)



Beams





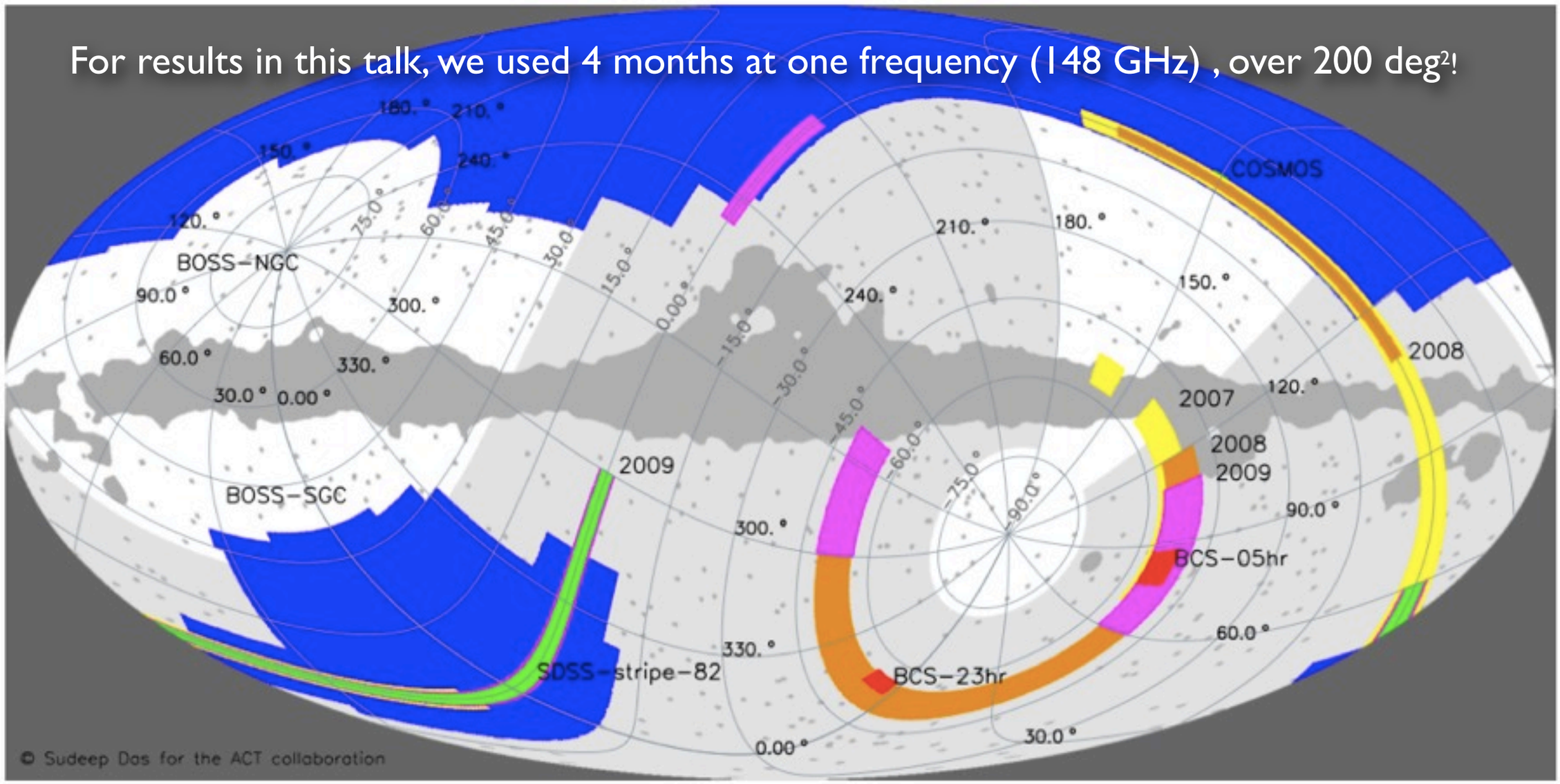


THE OBSERVATIONS:

COVERAGE

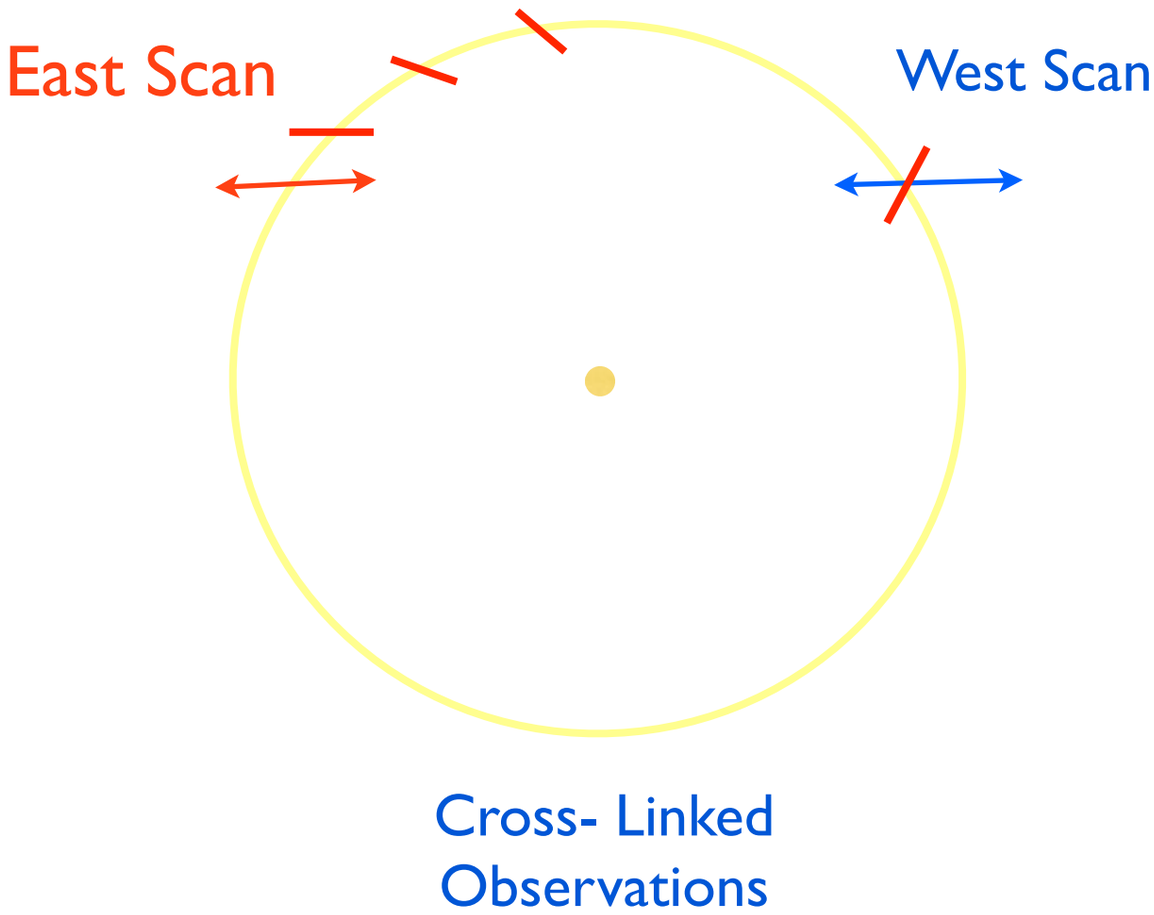
ACT has taken 12 months of data at 3 frequencies already, over ~1300 deg^2. !

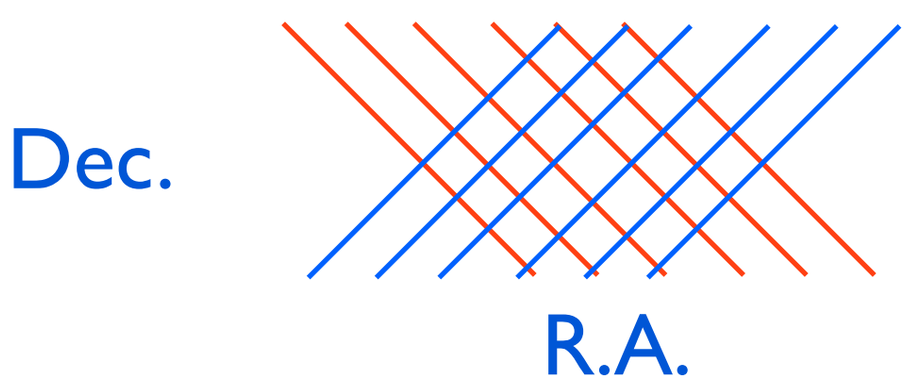
For results in this talk, we used 4 months at one frequency (148 GHz) , over 200 deg^2!



2007	2009	Stripe 82	BCS
2008	ACT Range	BOSS	Masked

THE OBSERVING STRATEGY

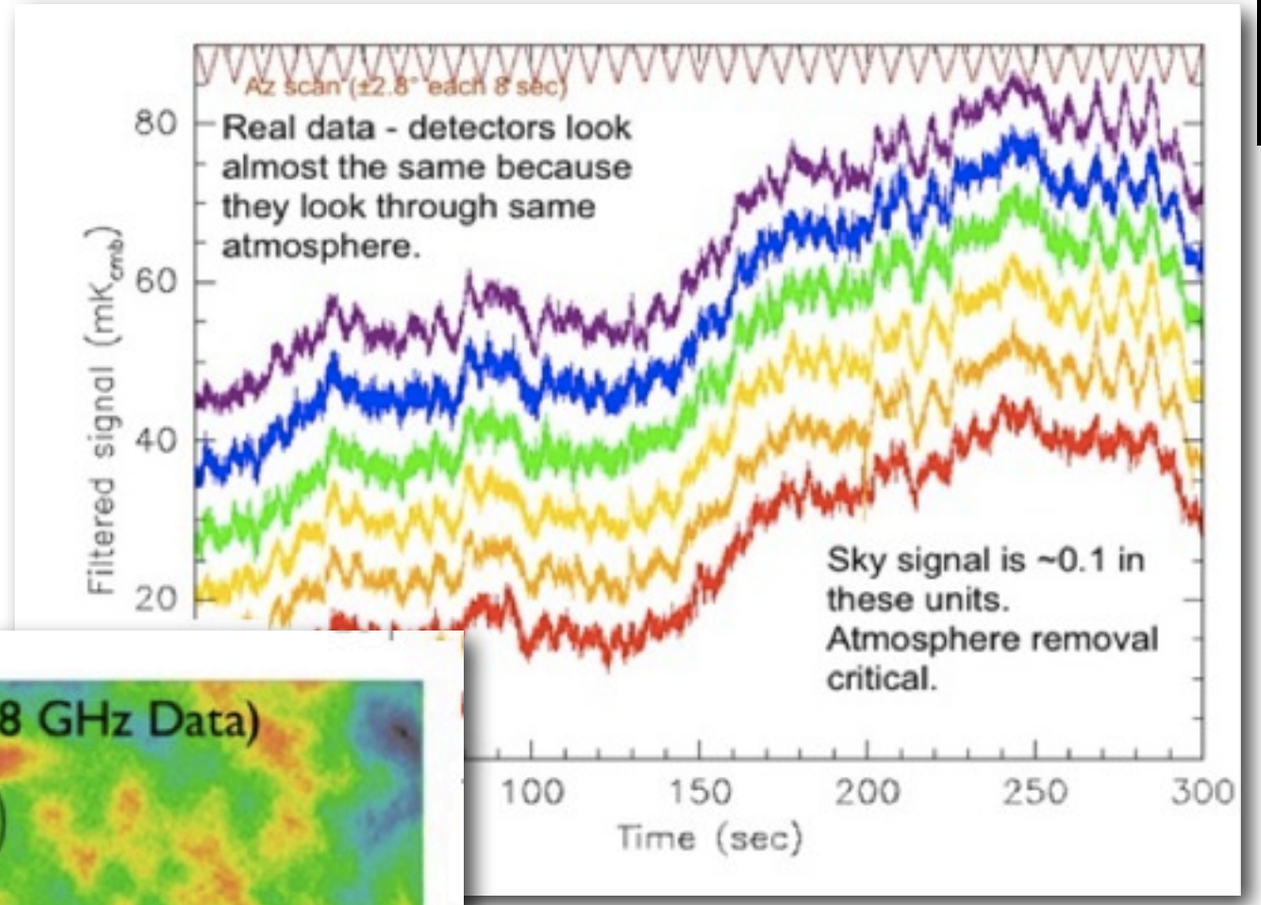


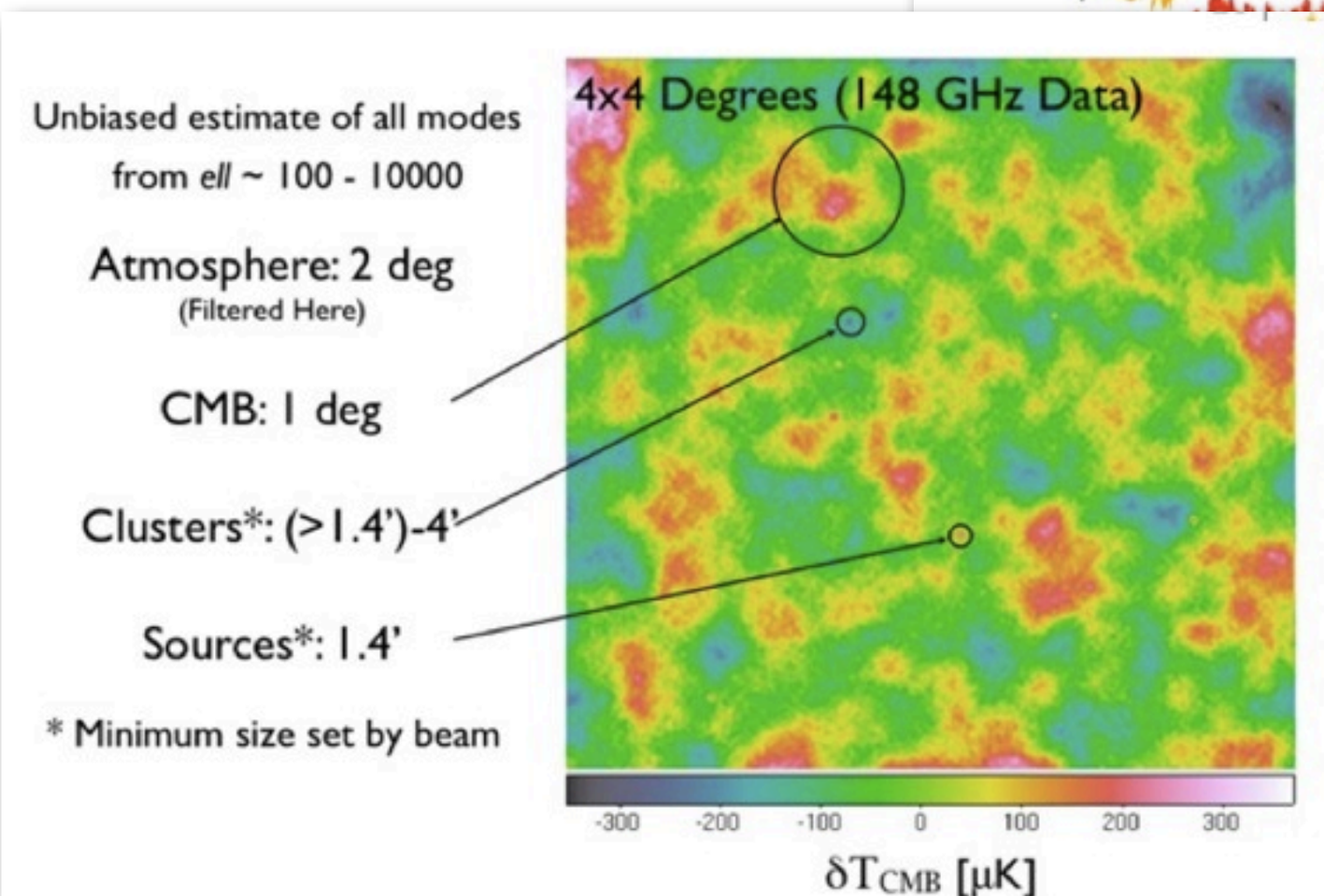


- Observe mainly during the night (20:00 to 09:30 local time)
- Scan at fixed elevation, 6 degree/8 seconds azimuthal chop.
- Observe facing South East before mid-night m South West afterwards to catch the same region at different angles.
- Spend 10 min per night observing planets - for beams, calibration and pointing

THE ANALYSIS:
DATA TO MAPS

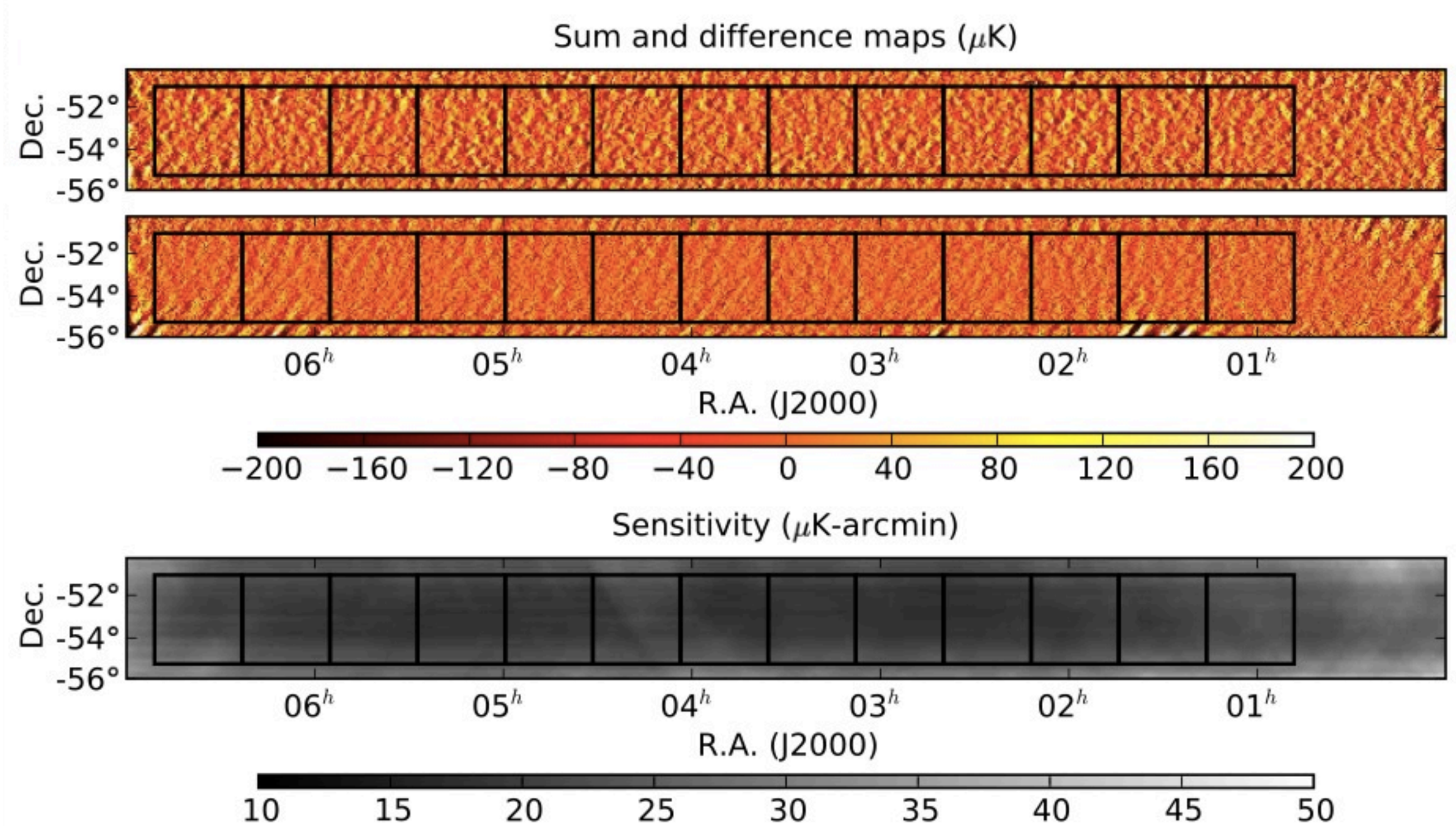
Solve for the maximum-likelihood map: true representation of the sky. Gain back modes suppressed by filtering. Iterate until maps converge and transfer function is unity.



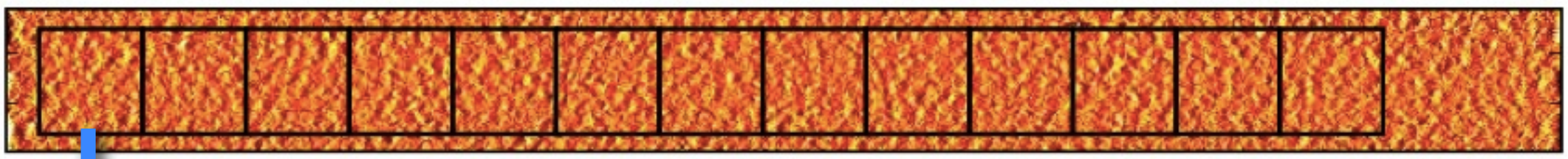


Data set is enormous. 3000 detectors, ~10 hours CMB/night, 400 hz sampling rate, 4 bytes/sample = ~200 GB/night. We have written fully parallel map making code. Runs on UToronto SciNet cluster. 30,000 2.53 GHz Nehalem cores, 8 cores, 16 GB/node. Takes ~100,000 CPU hours for one season of data.

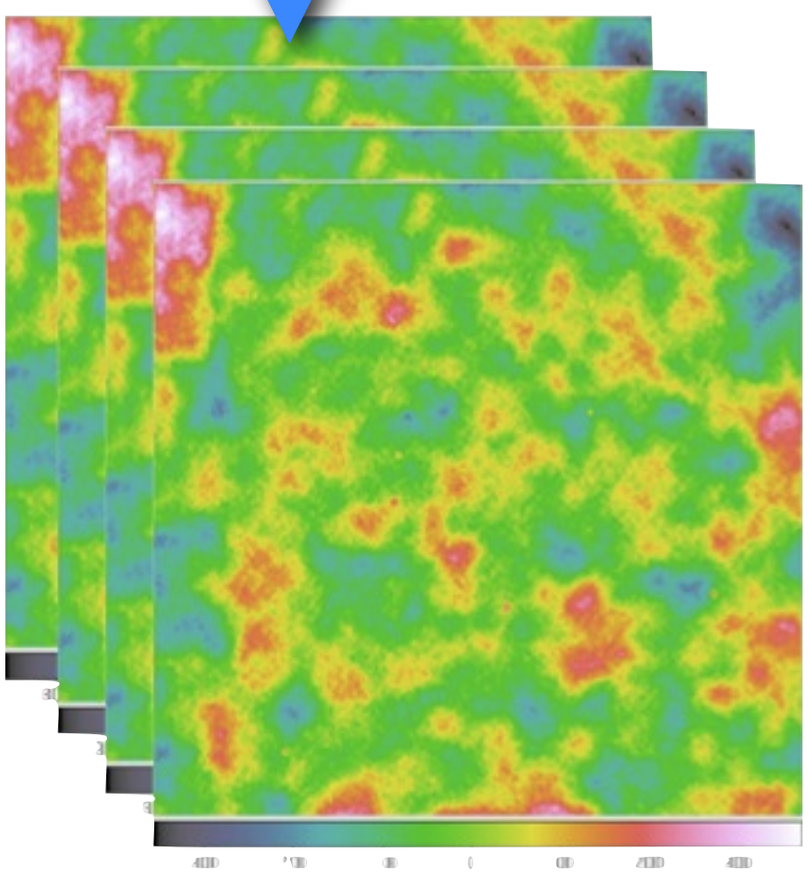
MAPS


Sum and difference maps (μK)
Dec.
-52°
-54°
-56°
06h
05h
04h
03h
02h
01h
R.A. (J2000)
−200 −160 −120 −80 −40 0 40 80 120 160 200
Sensitivity (μK-arcmin)
10 15 20 25 30 35 40 45 50

MAPS TO SPECTRA

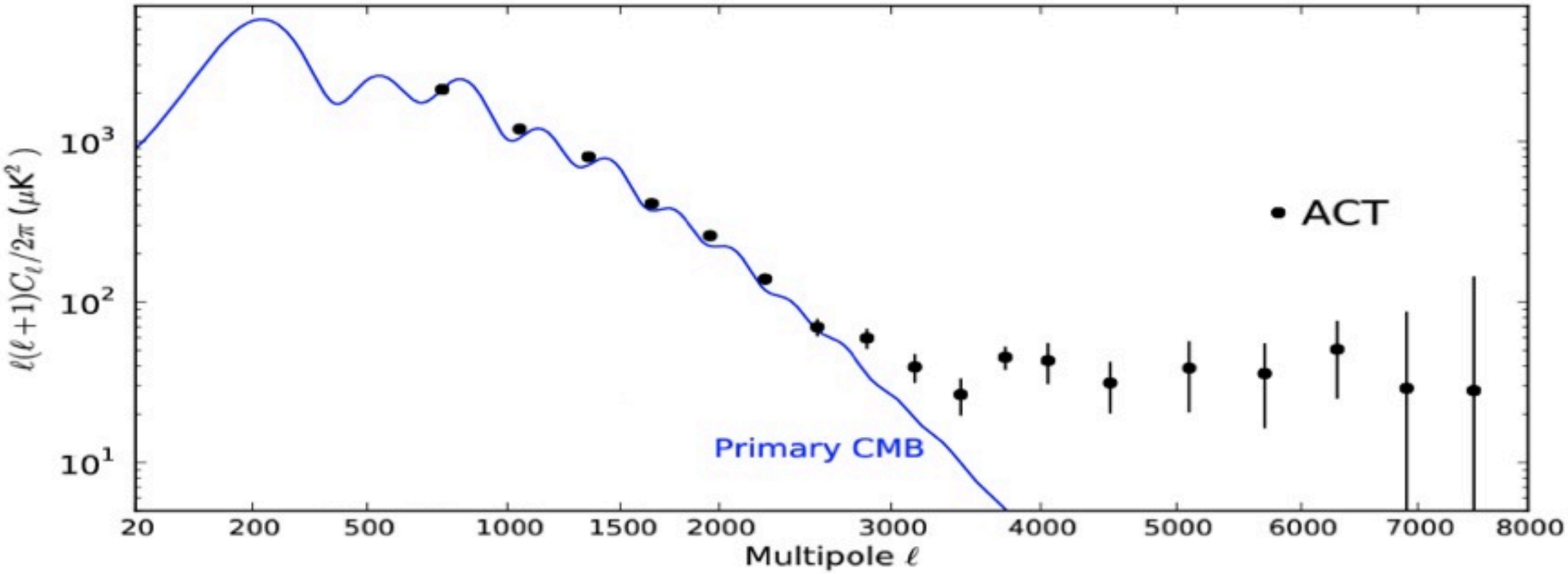


We use a cross-spectrum based estimator - no noise bias

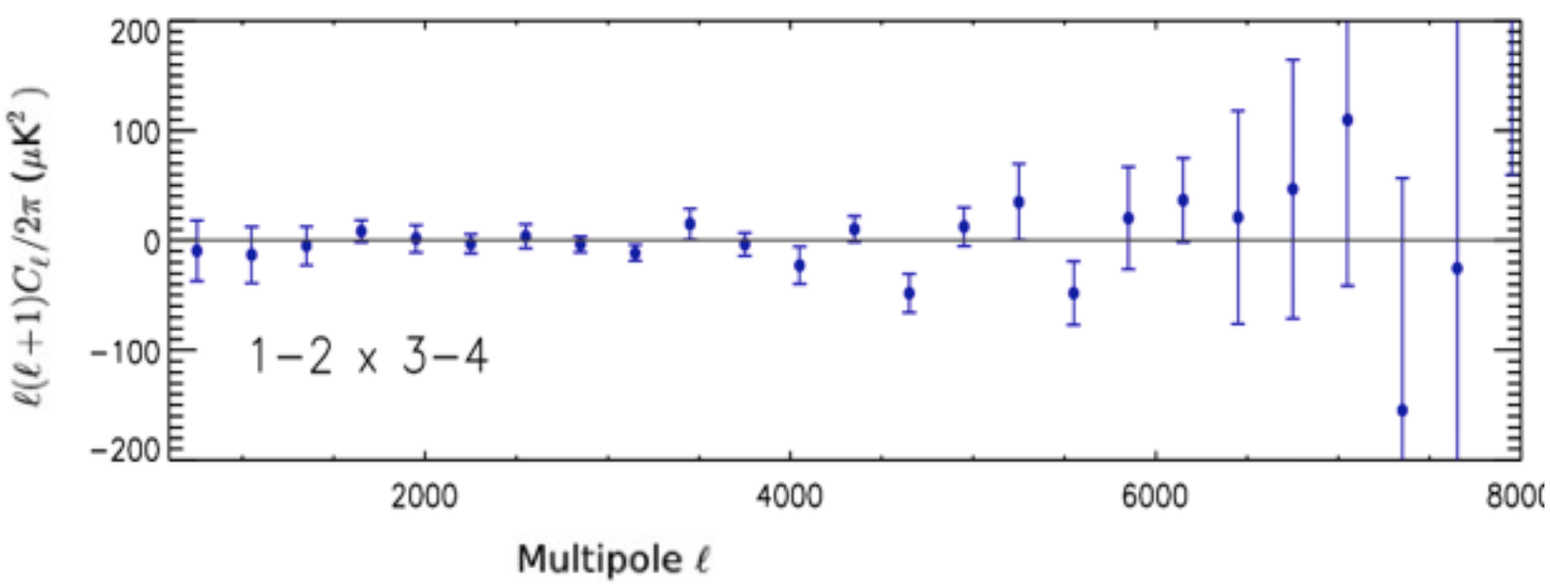


- For each of 13 patches, we have 4 submaps for each quarter of the season.
- Take cross-spectra between the submaps using the adaptive multitaper method (*Das, Hajian, Spergel 2008*).
- Take the weighted mean of the cross-spectra to report the final spectrum.
- Use scatter between patches to report error bars (verified analytically).

The ACT Power Spectrum

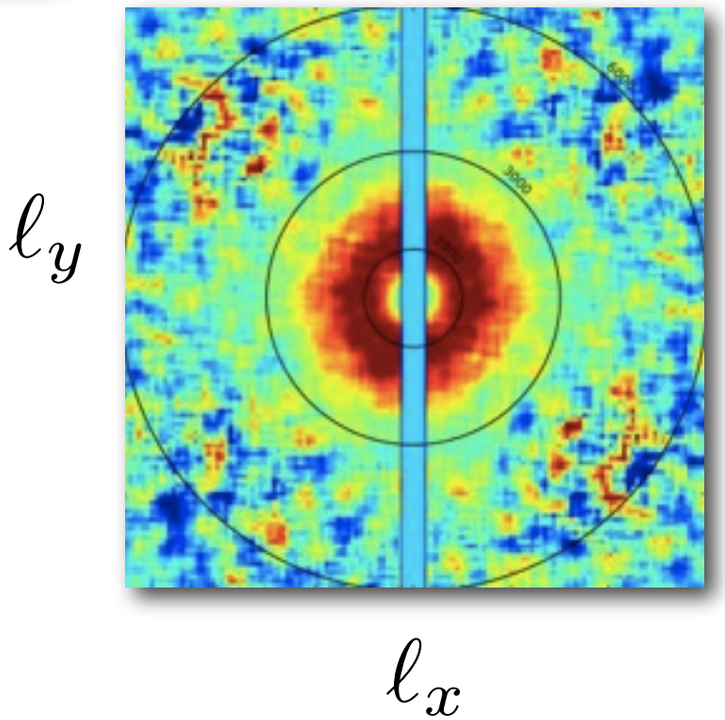


One of 3 Jacknives from 4 submaps

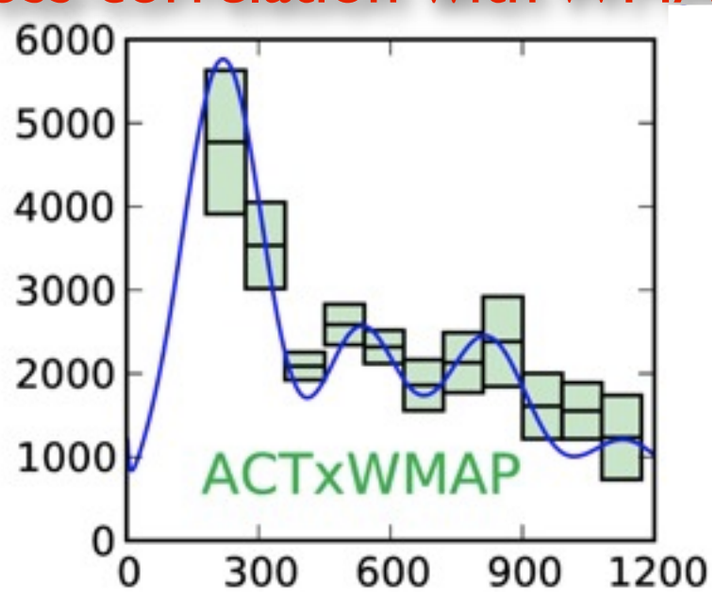


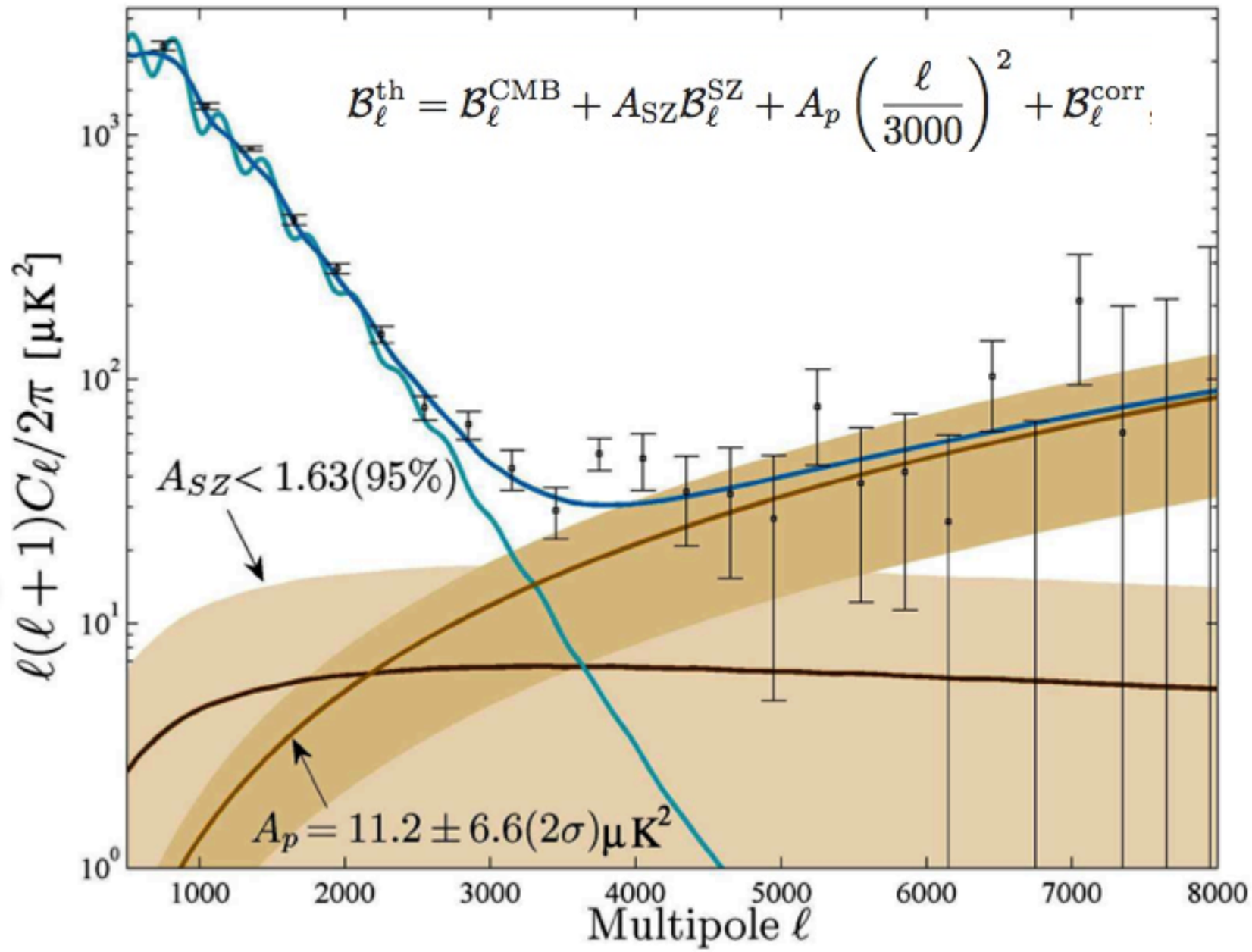
The Power Spectrum

2D power spectrum is isotropic!



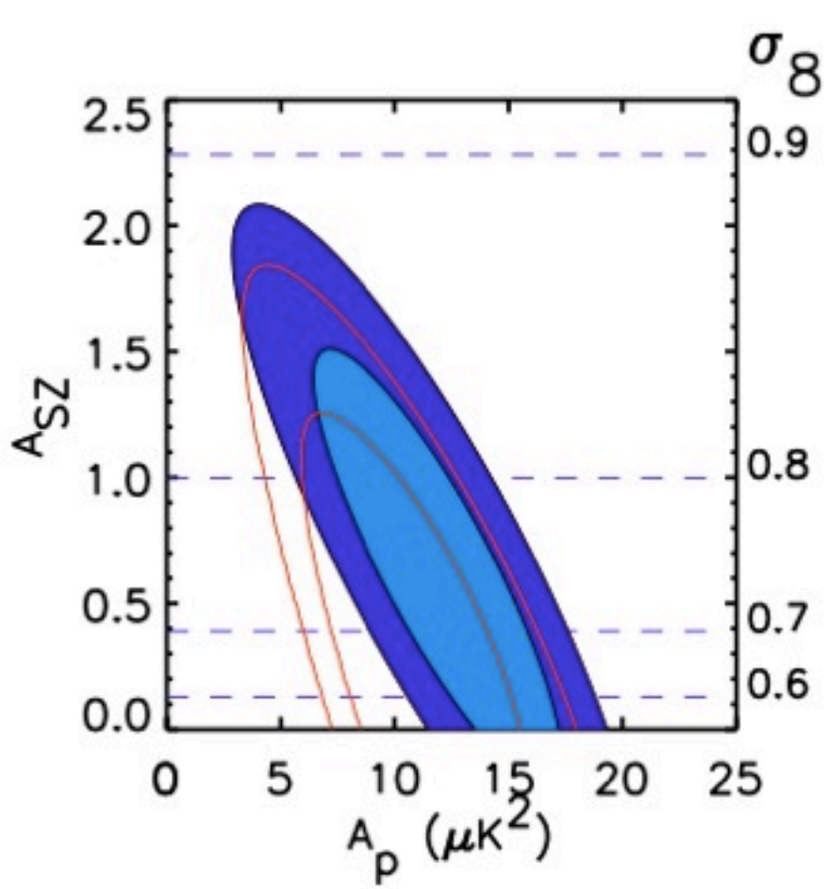
Cross-correlation with WMAP

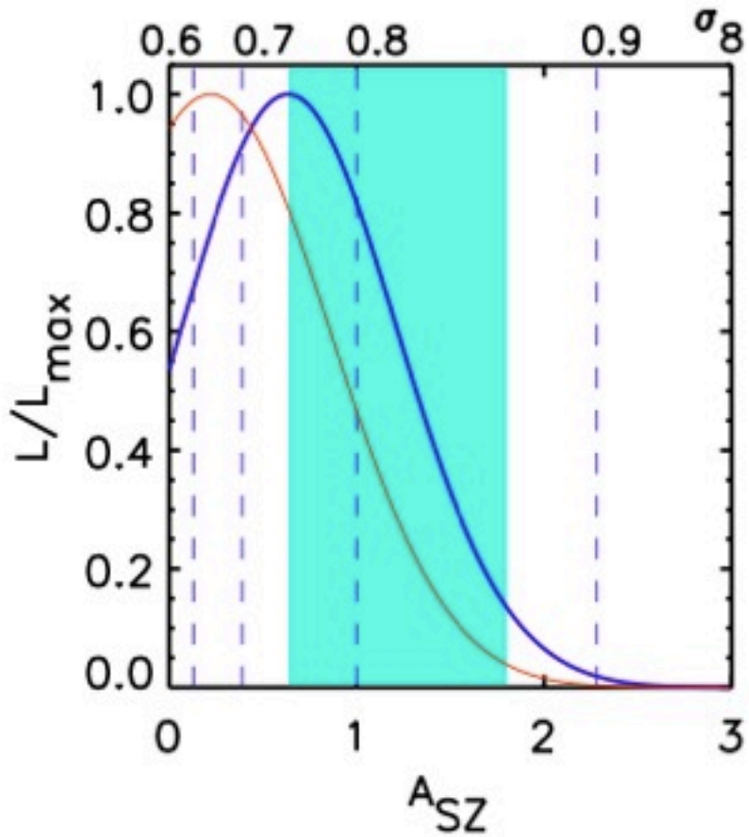




The SZ Power

$$\mathcal{B}_\ell^{\rm th} = \mathcal{B}_\ell^{\rm CMB} + A_{\rm SZ}\mathcal{B}_\ell^{\rm SZ} + A_p\left(\frac{\ell}{3000}\right)^2 + \mathcal{B}_\ell^{\rm corr}$$





A_{SZ}: Scale factor applied to our SZ template (kSZ+tSZ) with σ_8 = 0.8.

$\sigma_8^{\rm SZ}$	$A_{\rm SZ}$	
< 0.86	< 1.63	(no correlated IR PS)
< 0.84	< 1.36	(correlated IR PS)

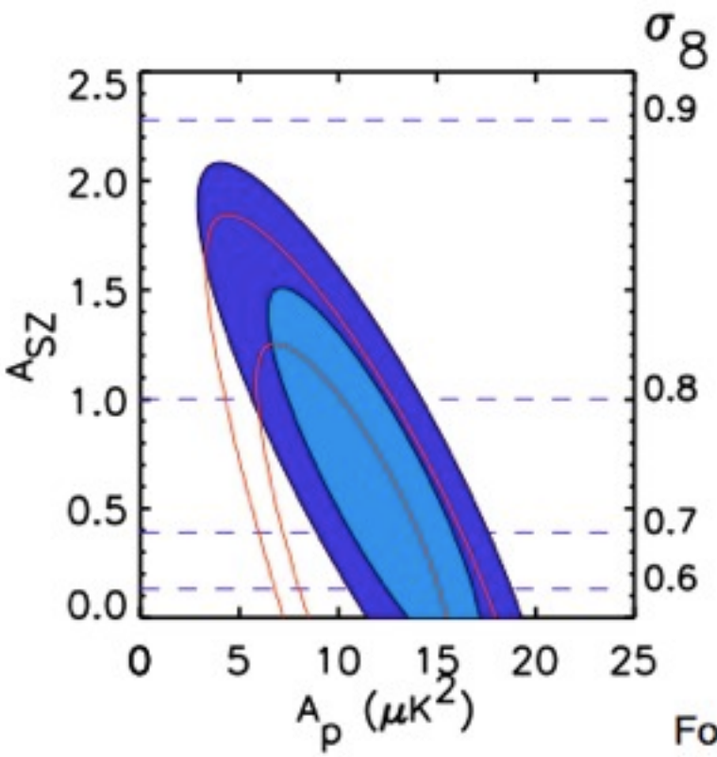
- SZ template depends on gas model, and may be degenerate with a correlated dusty galaxy component.!
- With 220 (and 270) GHz data we should be able to break degeneracies.
- Also, higher point correlation functions will help separate SZ from extragalactic point sources.

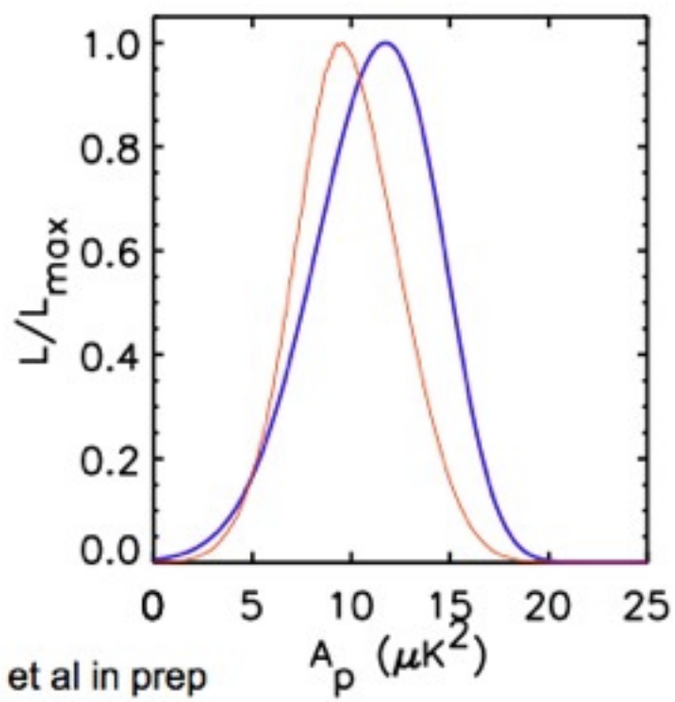
No indication of an SZ excess!

Extragalactic Point Source Power

$$\mathcal{B}_\ell^{\rm th} = \mathcal{B}_\ell^{\rm CMB} + A_{\rm SZ}\mathcal{B}_\ell^{\rm SZ} + A_p\left(\frac{\ell}{3000}\right)^2 + \mathcal{B}_\ell^{\rm corr}$$

$$\mathcal{B}_\ell^{\rm corr} = A_c\left(\frac{\ell}{3000}\right)$$





Fowler et al in prep

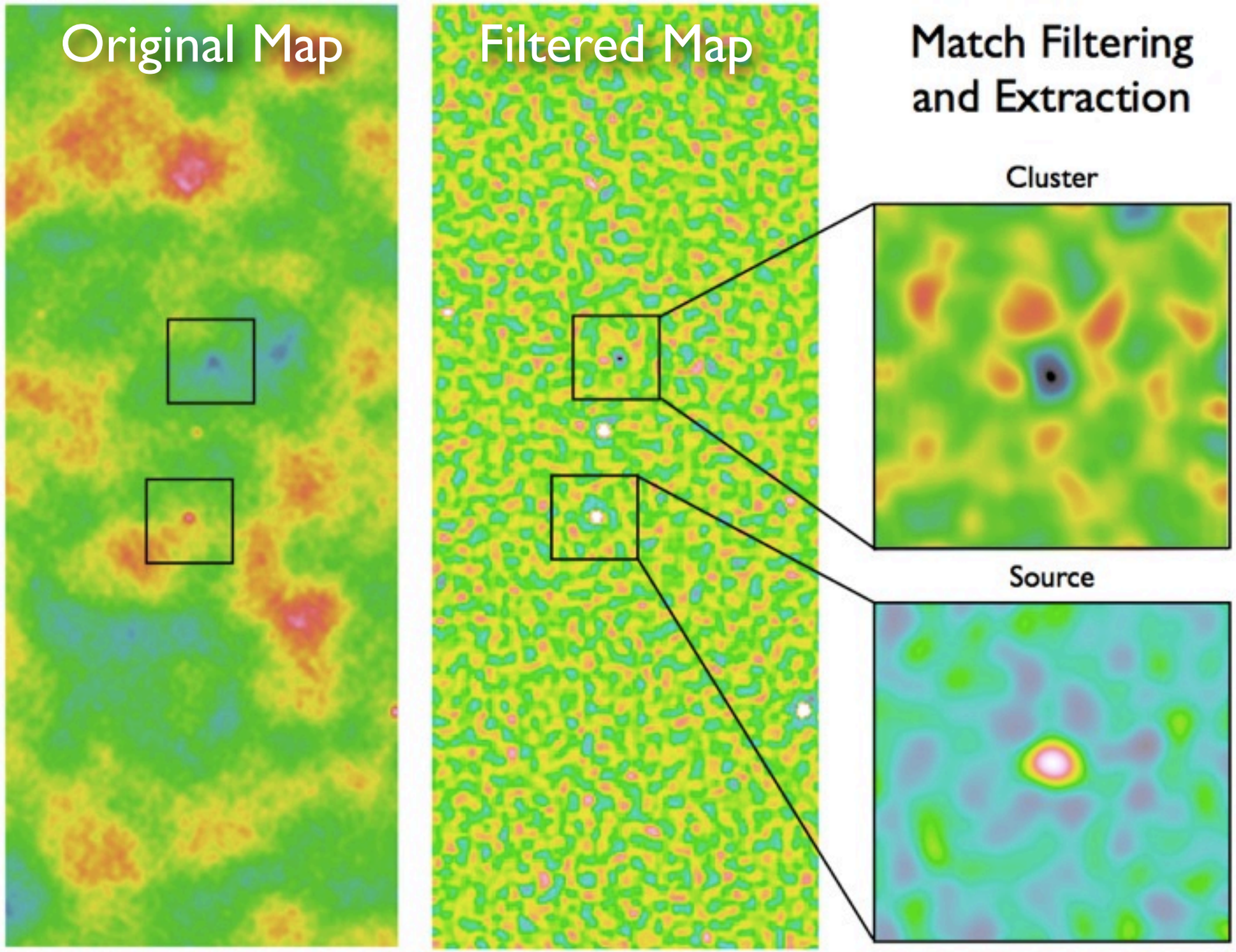
$A_p(\ell = 3000)$ μK^2	C_p $10^{-5}\mu K^2$	C_p $\mathrm{Jy^2 sr^{-1}}$
11.2 ± 3.3	0.784 ± 0.23	1.22 ± 0.36
9.7 ± 2.8	0.68 ± 0.2	1.05 ± 0.3

Two populations at 148 GHz below 17 mJy detection limit.

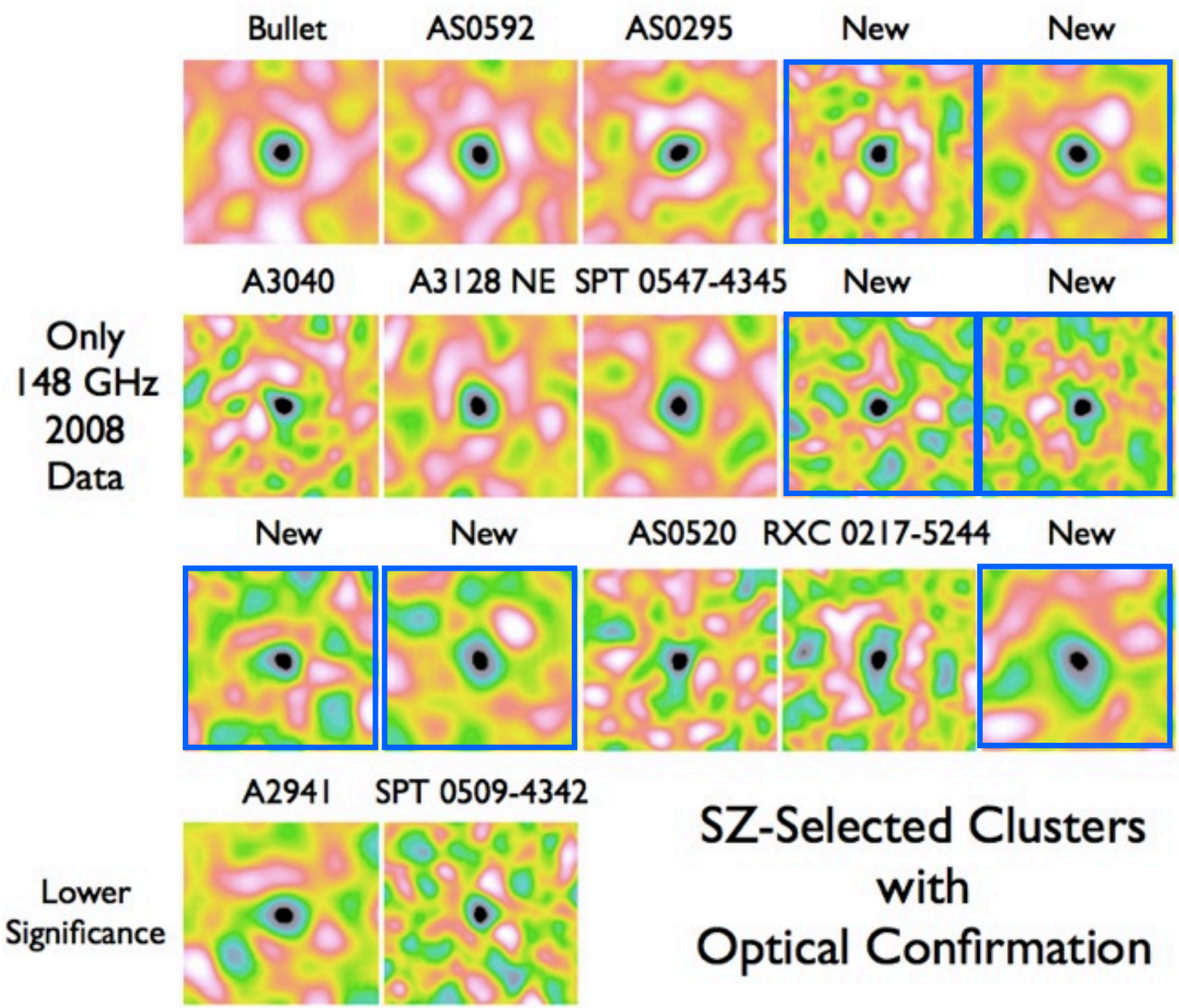
1. Radio galaxies: A_p = 4 - 7 μK^2 at ℓ =3000, C_p = 0.3 - 0.5 x 10^{-5} μK^2
From number counts, matches Toffalatti model.

2. Infra-red dusty galaxies: Also A_p = 4 – 7 μK^2. Can compare to SCUBA at 353 GHz and BLAST at 600 GHz (2.7± 0.2 x 10^3 Jy^2/sr). Spectral index α = 2.9-3.1.

Detecting SZ clusters and point sources



SZ CLUSTERS

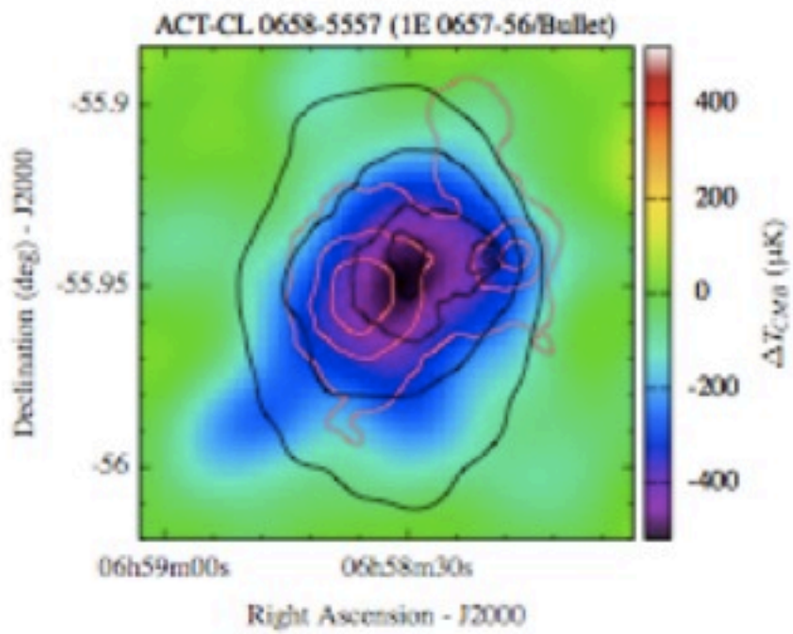


Followup Program:

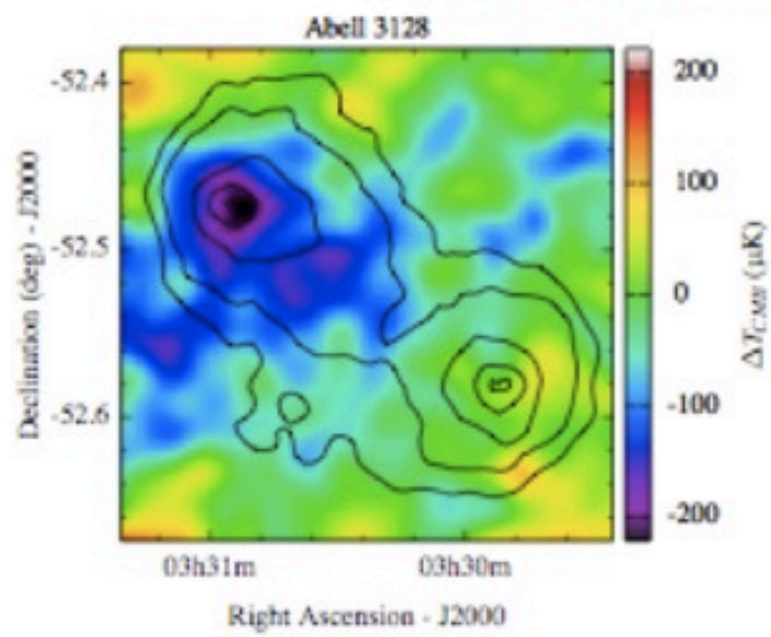
- ○ XMM observations approved
- ○ VLT/Gemini spectroscopy and deep imaging
- ○ SALT spectroscopy later this year
- ○ Chandra and HST proposals planned

INTERESTING SZ CLUSTERS

from Hincks et al. 2009

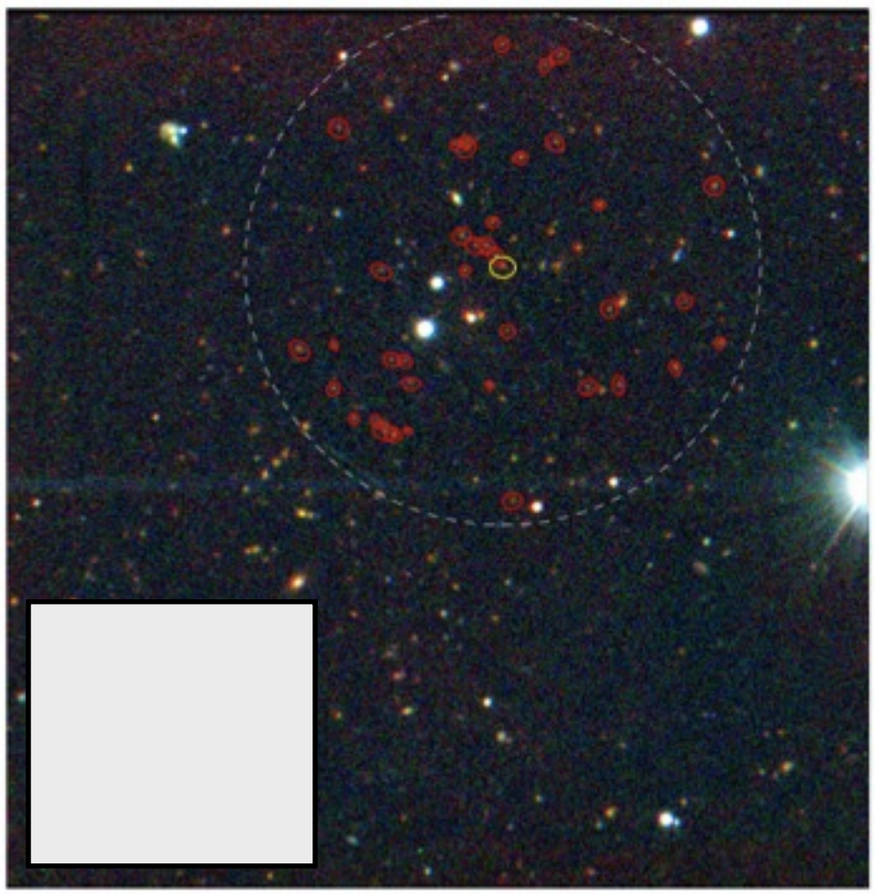


ACT map of the "Bullet" cluster with X-ray and WL shear contours

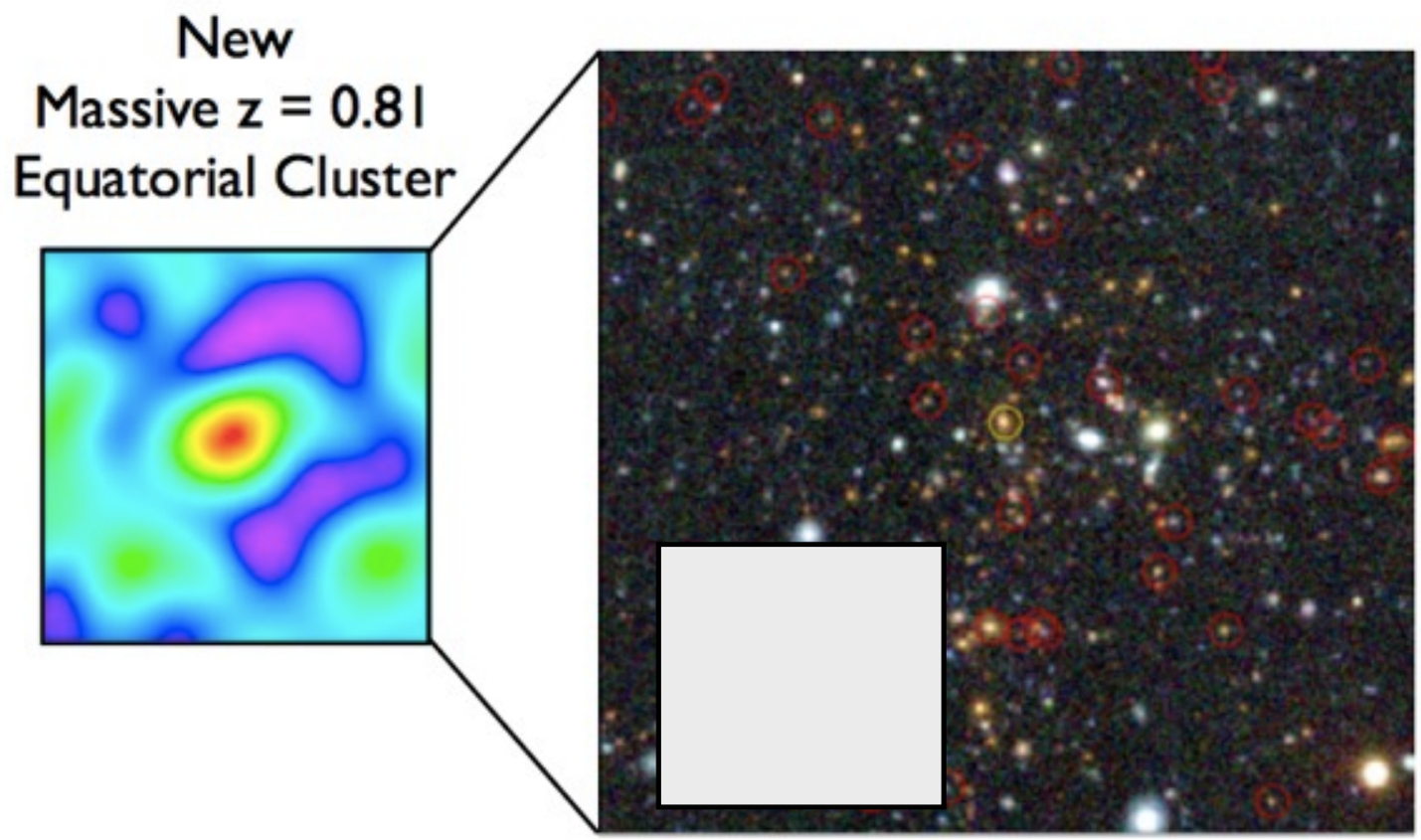


ACT map of Abell 3128 with X-ray contours Note double cluster in X-rays, but only one component in SZ – due to mass threshold

HIGH Z MASSIVE CLUSTERS!



New Massive z=0.81 cluster in the Southern Strip

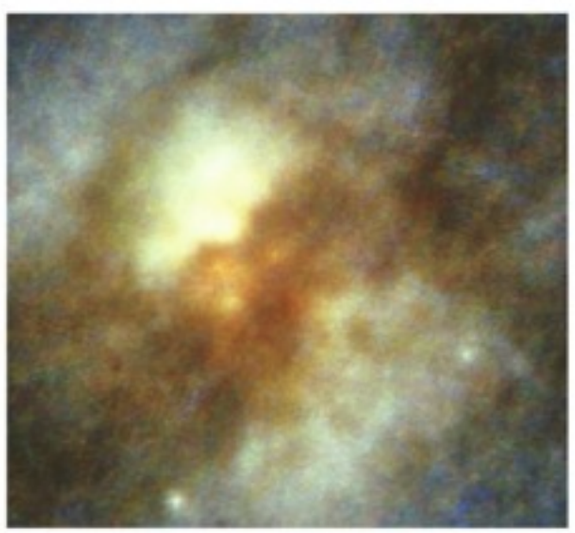


POINT SOURCE POPULATIONS

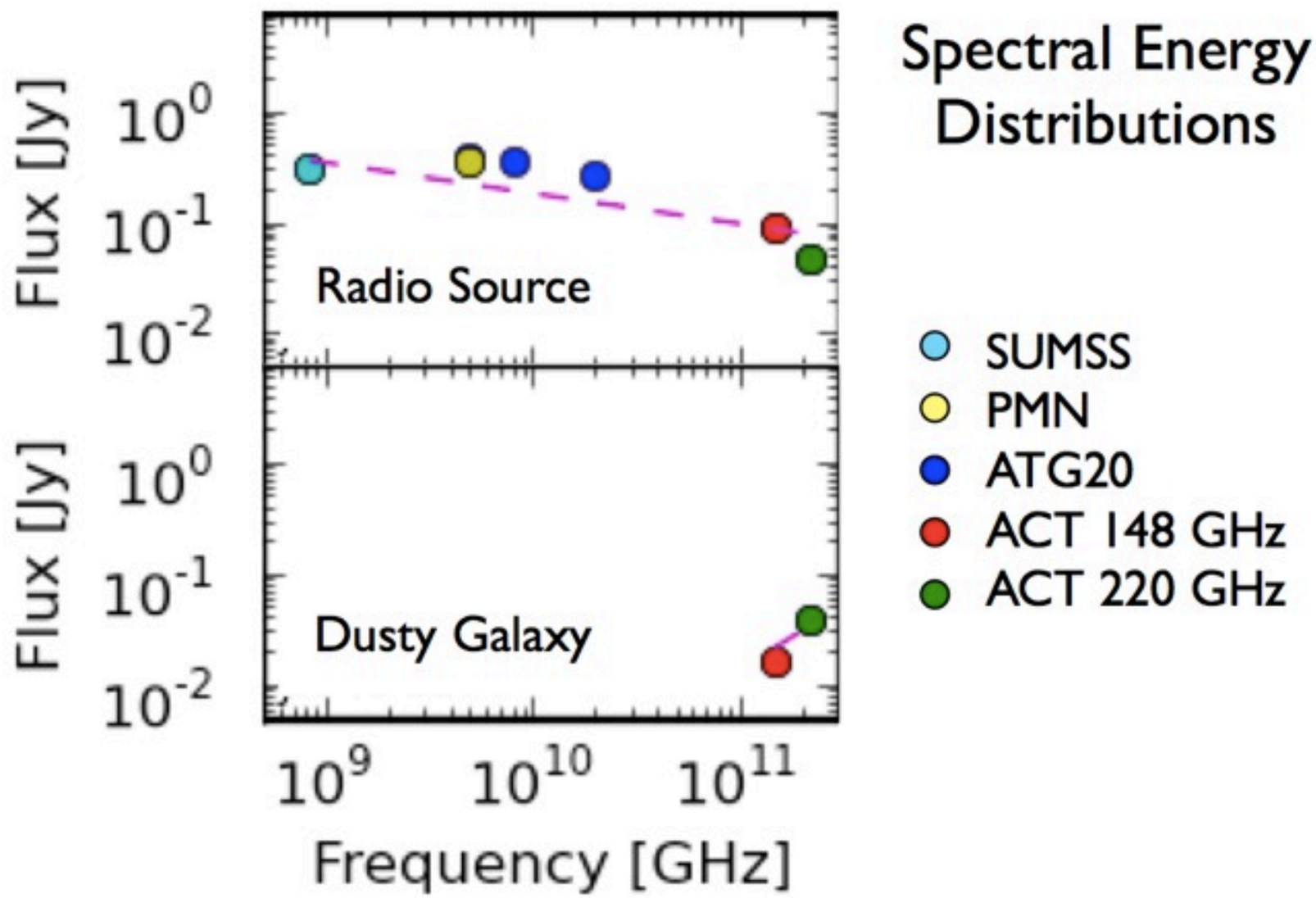
Flat Sprectrum Radio Sources

Cen A, LABOCA

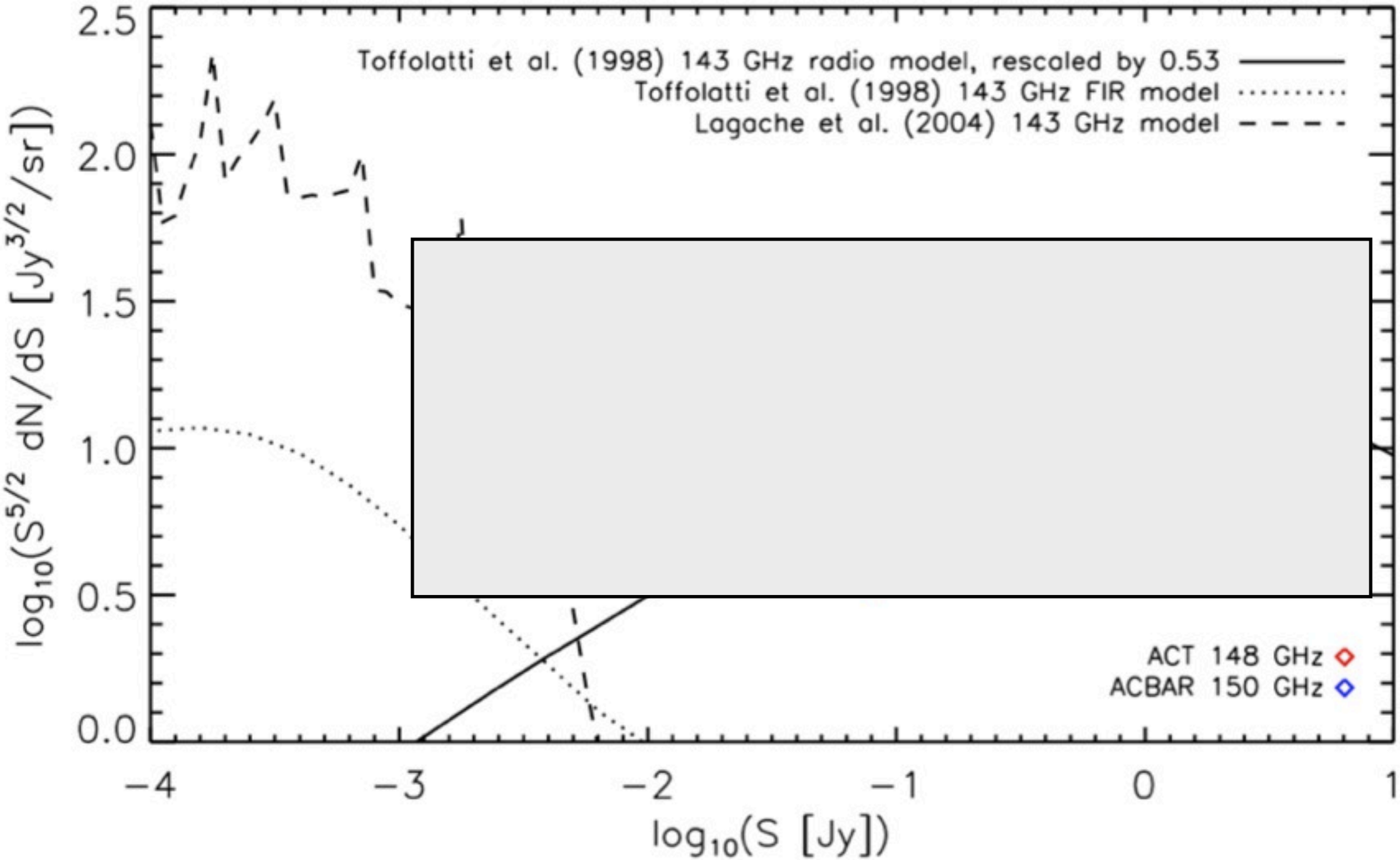
Dusty, Starbursting Galaxies



ARP 220, HST

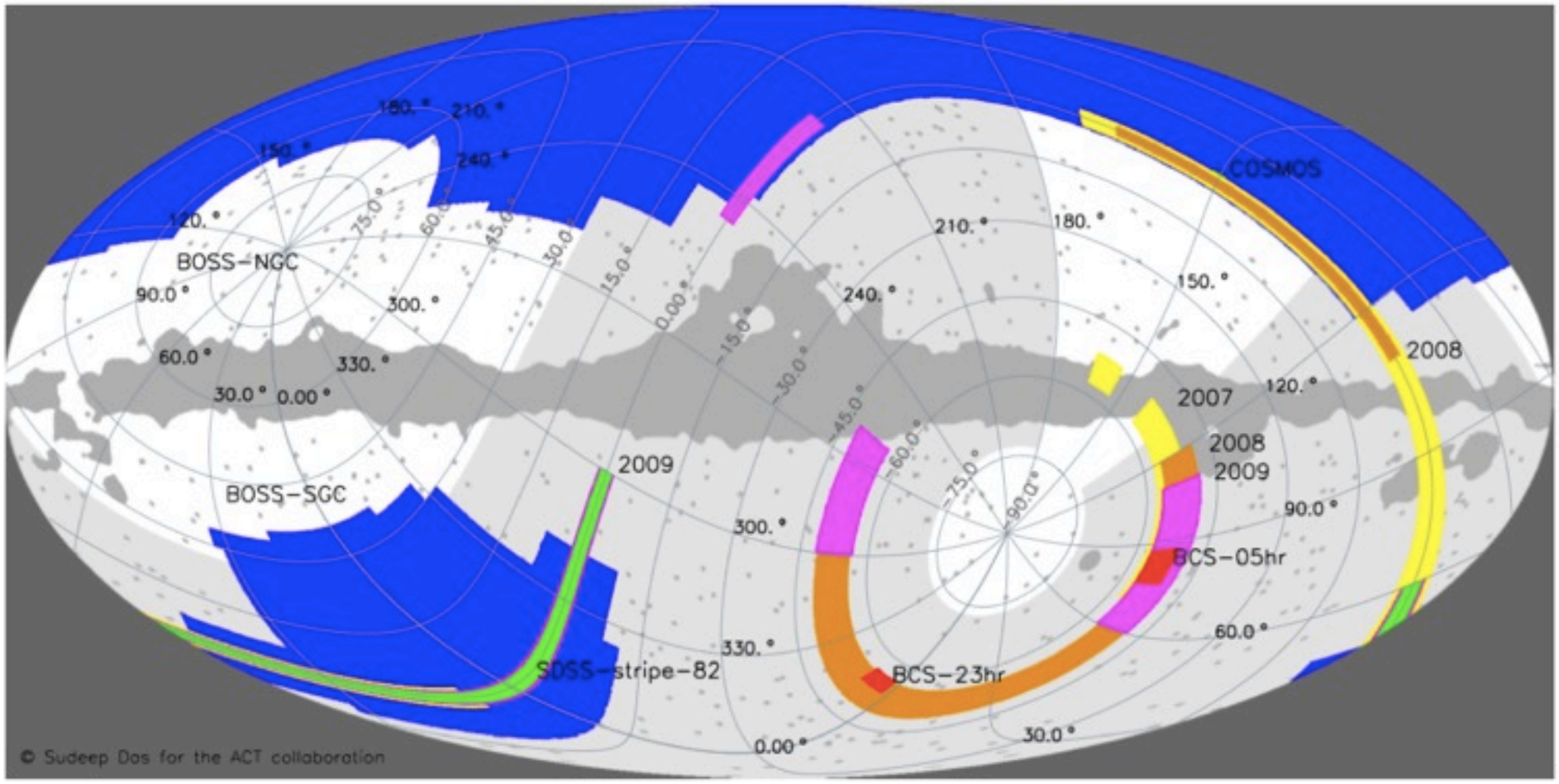


Point Source Model



FUTURE PLANS

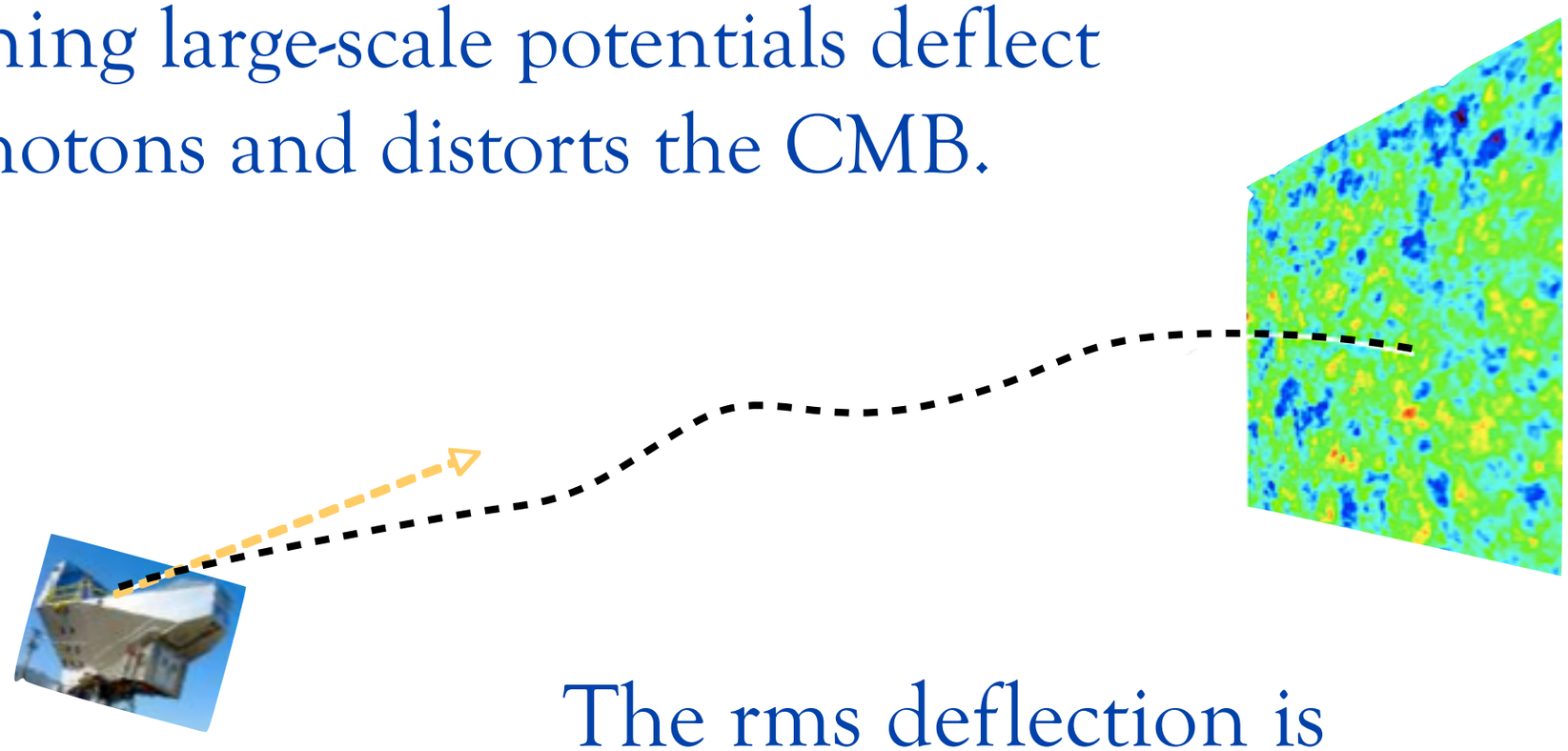
This is only the beginning !



- ACT has taken 12 months of data at 3 frequencies already, over ~1300 deg^2.
- We have shown 4 months at 1 frequency, over 200 deg^2
- Mapmaking and power spectrum pipeline are now in place for extended analysis of the full data set.
- Explore Silk damping regime of power spectrum with multi-frequency analysis.

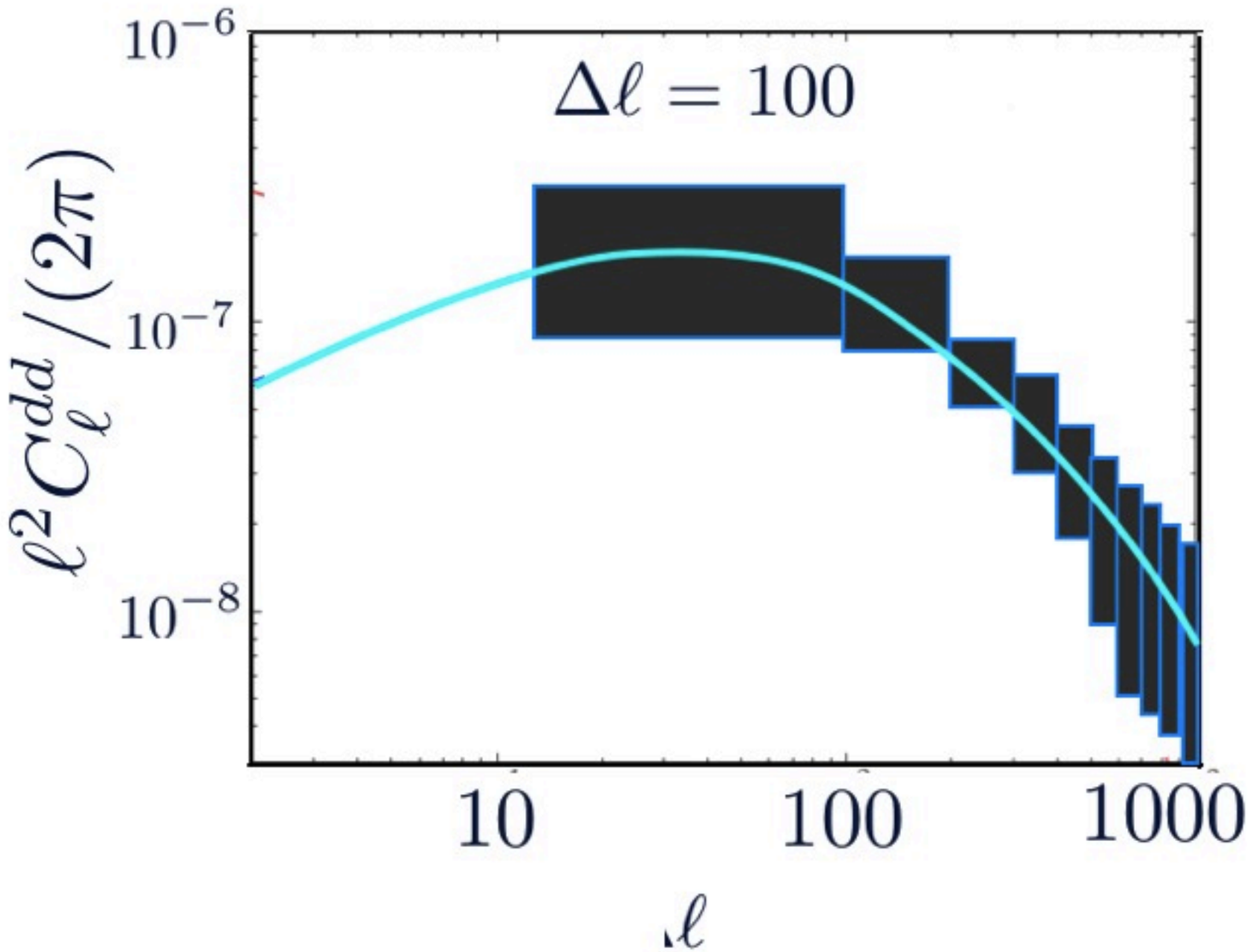
Gravitational Lensing

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



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

We hope to have a ~6 sigma internal detection from season 1



Deflection field auto-spectrum :

Measurement of σ_8. Neutrino mass, Dark Energy, curvature.

Cross-correlations:

Matter-Infrared Galaxies
Matter - Radio Sources
Matter- SZ clusters
Matter- Lyman-alpha
Matter - weak lensing.
Matter - galaxy counts

Next Step: ACTPOL

2010-2015 – measure temperature and polarization of CMB to arcminute scales over ~4000 deg^2, plus deep regions over ~300 deg^2.

Measure primordial polarized spectrum (~17% pol) to l=3500. Low foreground contamination.

- Test inflation: spectral index, running index, isocurvature fraction, cosmic strings
- Probe early universe: number of relativistic species, primordial abundances.

Measure lensing deflection field: distortion of CMB by large-scale structure

- sensitive to early dark energy, unique probe at z = 2-3 and ideal for cross-correlations.
- geometry of the universe
- neutrino mass (0.07 eV limits).

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

Lensed Unlensed Deflection Field

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

Geometry Matter potential