Title: Large Scale Structure from ACT: The Atacama Cosmology Telescope

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Abstract: TBA

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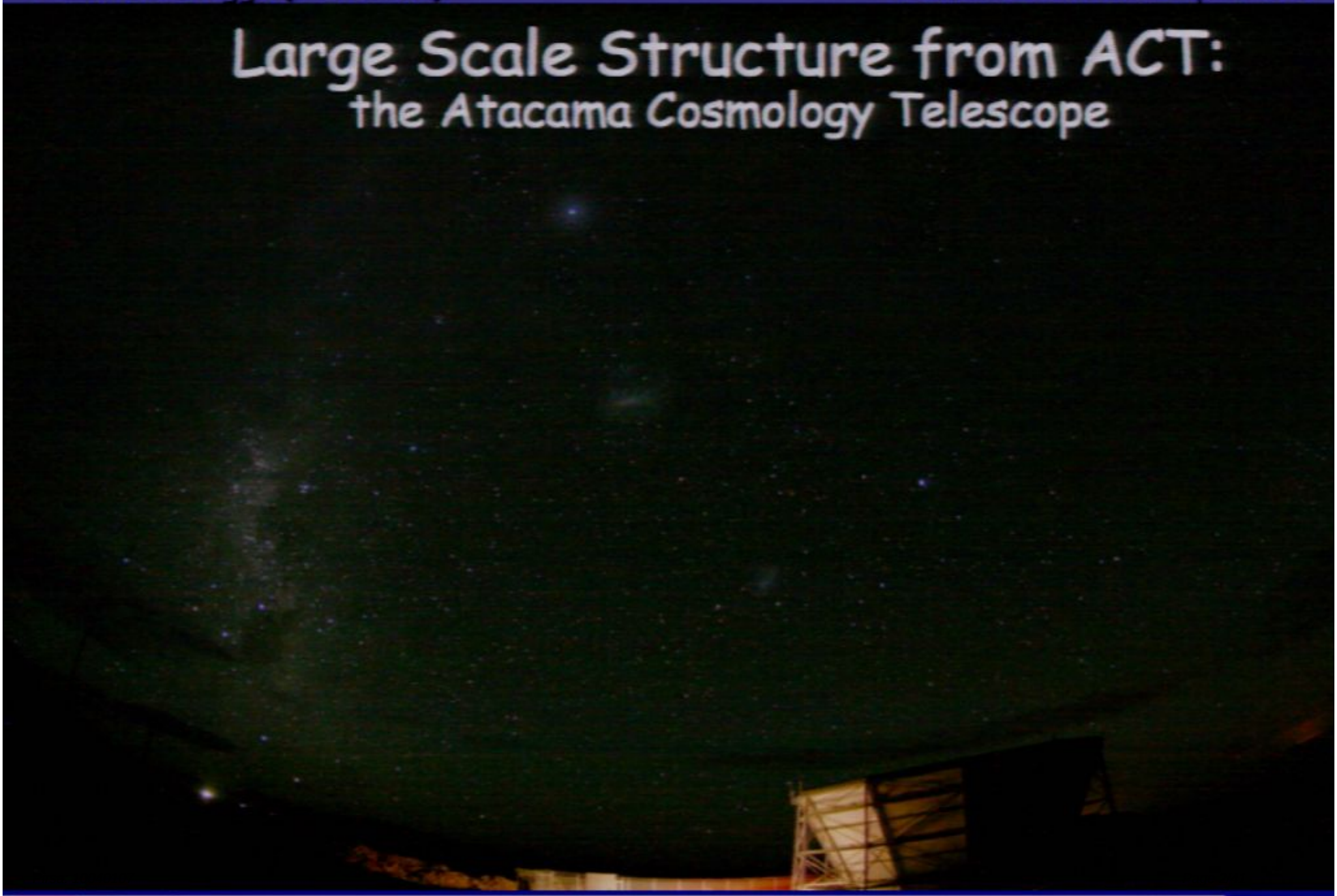
the Atacama Cosmology Telescope



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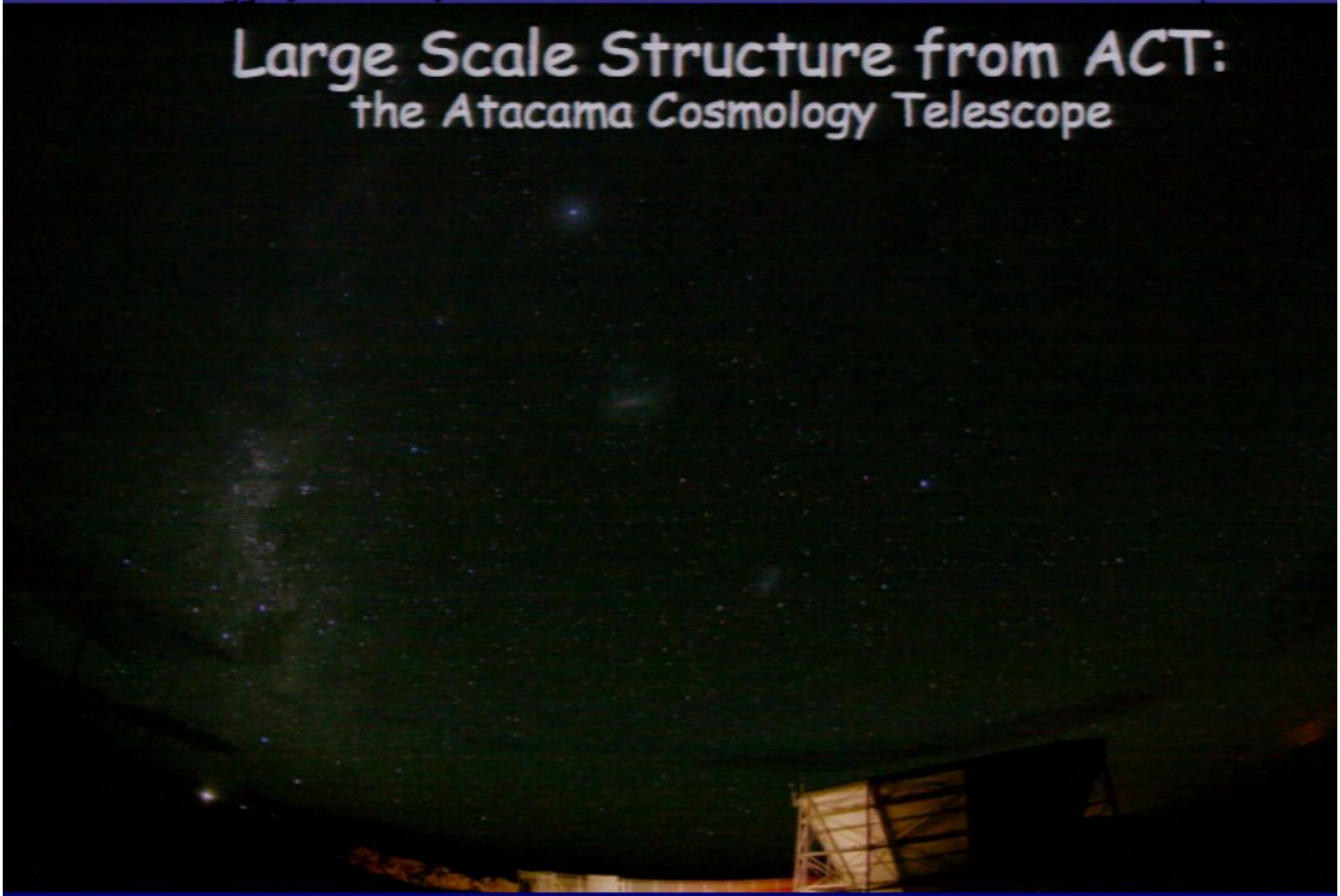

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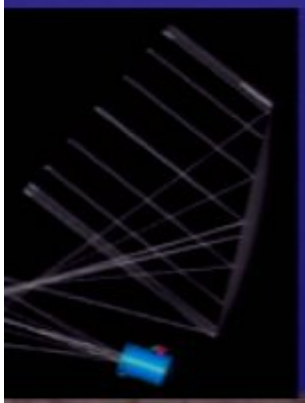
ACT

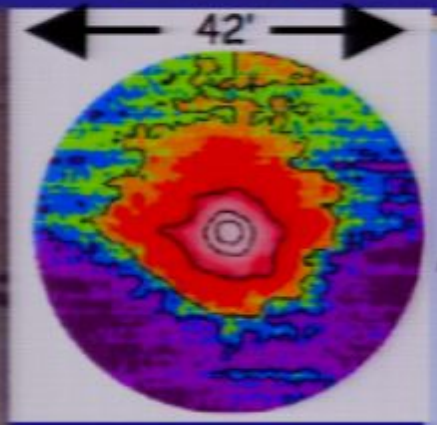


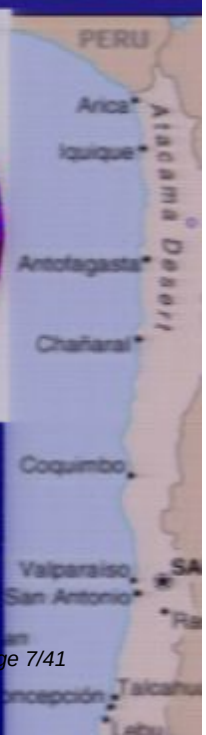
6m off-axis Gregorian telescope

Located at 5200 m (0.5 mm PWV)

3 arrays of 1024 TES bolometers each

148 GHz, 218 GHz, 277 GHz





148 GHz:

1.4' resolution

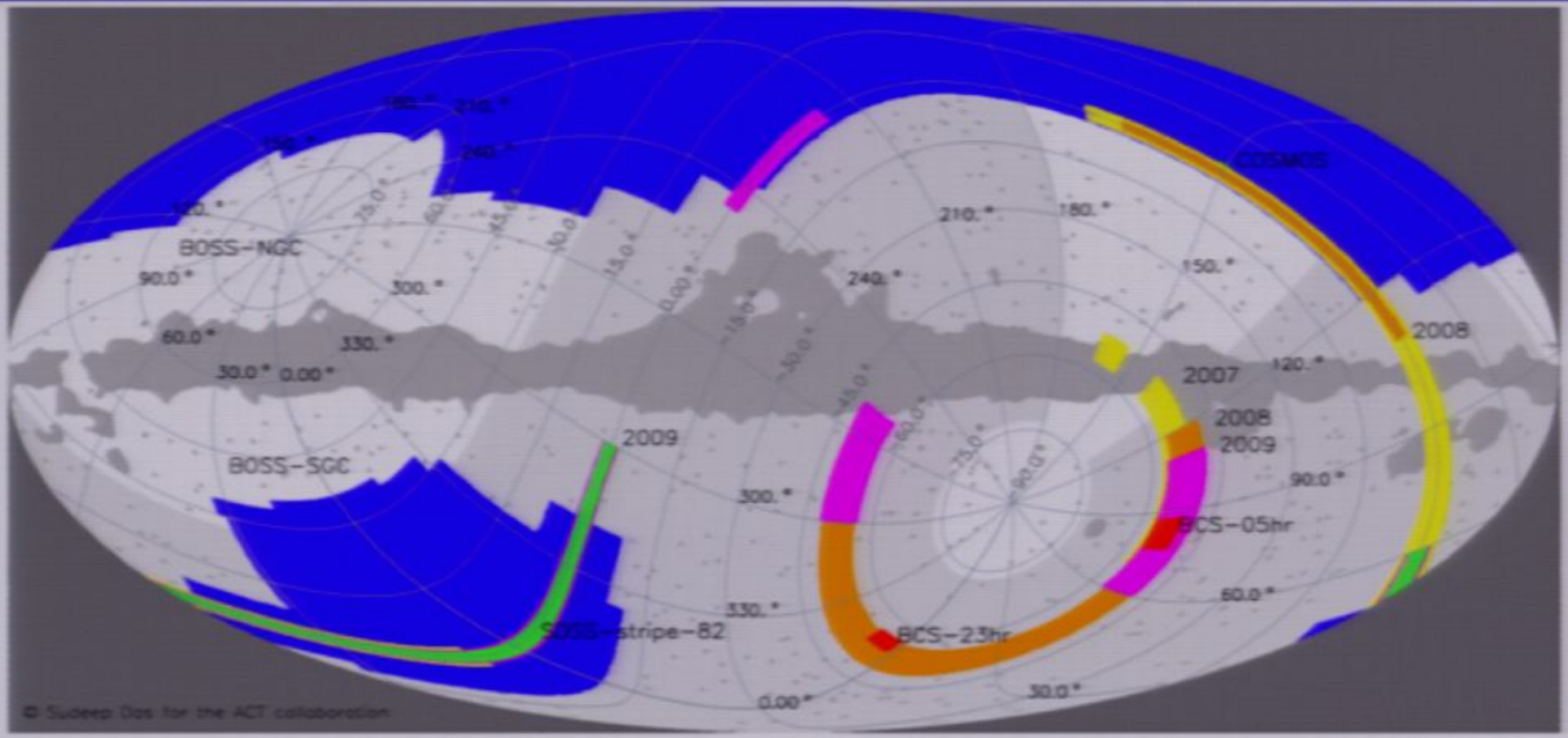
30 uK-rt(s)

$f_{knee} \sim 84$ Hz

ACT Coverage

ACT has taken 14 months of data at 3 frequencies already, over ~1300 deg^2.

wler et al, 2010 power spectrum uses 4 months, half-time, at one frequency (148 GHz) , over 200 deg^2



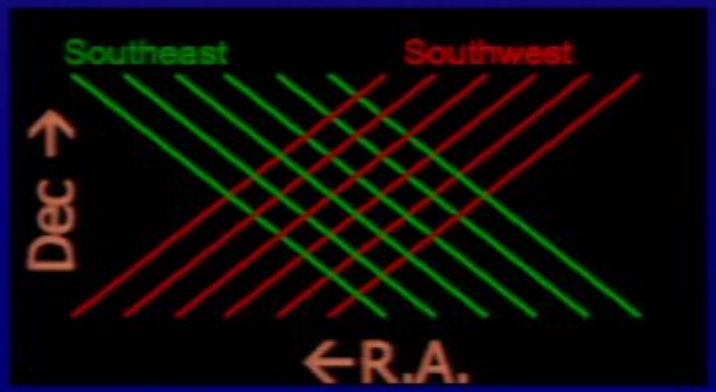
2007	2009	Stripe 82	BCS
2008	ACT Range	BOSS	Masked

Making CMB Maps

The emergence of structure manifests itself as non-Gaussian features in a map, with both compact and diffuse components.

Some ACT features for mapmaking:

- Large ground screens (co-moving & fixed)
- Scan entire telescope rapidly in azimuth (~1 deg/s) at constant elevation
- Observe patches in east and west for crosslinking
- Use all 1024 detectors in each band at once; each 32x32 array is 22' x 2
- Solve simultaneously for celestial map and nuisance terms



Mapmaking

(in praise of SciNet)

aximum Likelihood Map:

mestream is $d = Pm + n_t$ with noise covariance $N = \langle nn' \rangle$.

aximum likelihood estimate for the map m is m' :

$$P^T N^{-1} P) m' = P N^{-1} d$$

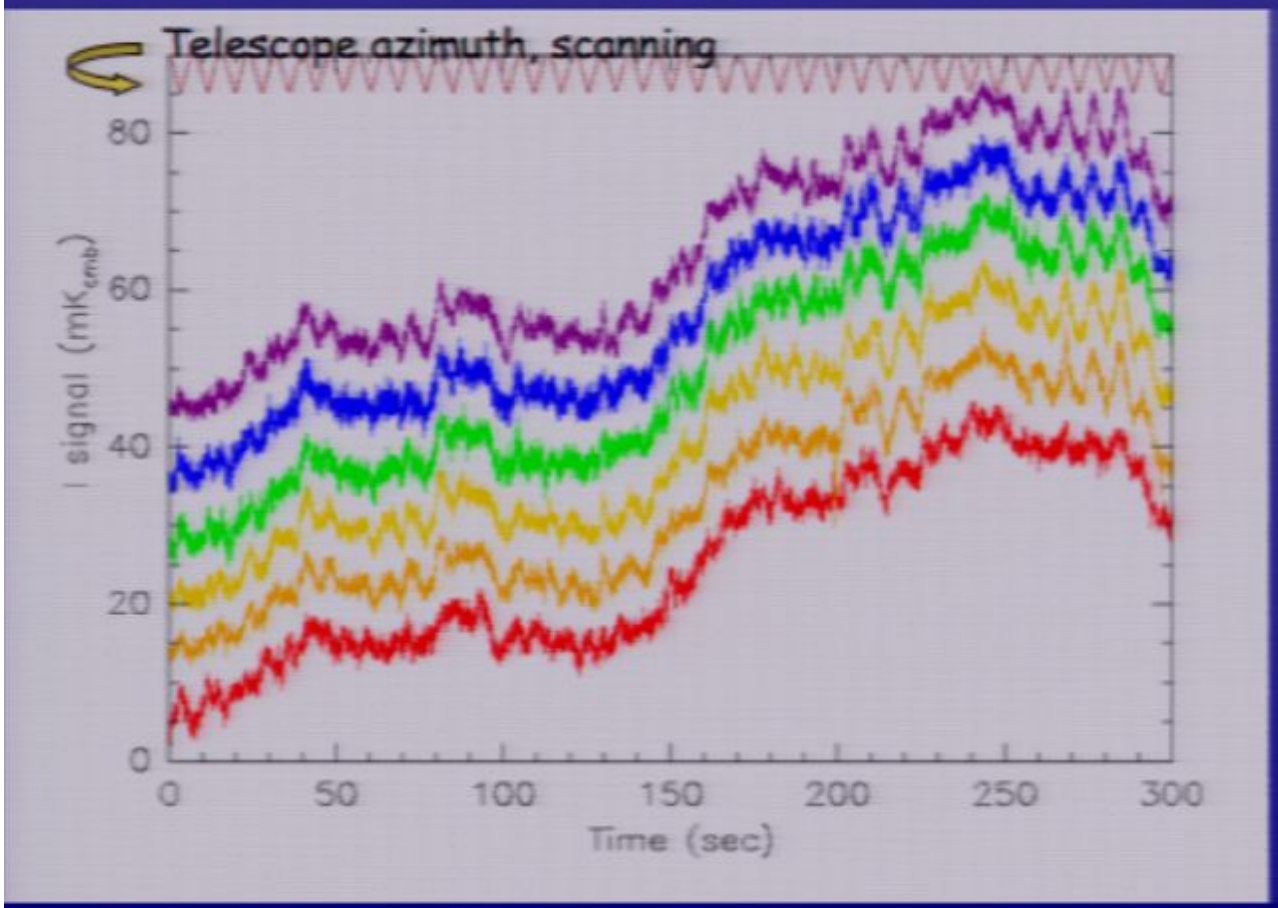
se PCG method to iteratively solve for m'

Data rate = 200 GB/night (3000 detectors, 10 hrs/night, 400 Hz sampling).
ACT southern strip from 2008 for 148 GHz ~ 3.2 TB
Final map ~ 200 MB --> compression by 16,000

Fully parallel map making code runs on UToronto SciNet cluster.
30,000 2.53 GHz Nehalem cores, 8 cores, 16 GB/node.
Takes ~10 CPU yrs for one season of data for 1000 iterations.

Nuisance Terms?

Raw timestreams for 6 detectors over 5 minutes: atmosphere in common



Whilst solving for the sky map, also solve for 10 most significant eigenmodes of the ~1000 detectors at each instant.

Removes atmosphere common mode and gradients, detector correlations along vertical rows, scan-synchronous effects, etc.

Every 10 mins, remove mean and slope from each detector; no other timestream processing needed.

ACT Map Zoom-in:

Unbiased estimate of all modes from *ell* ~ 100 - 10000

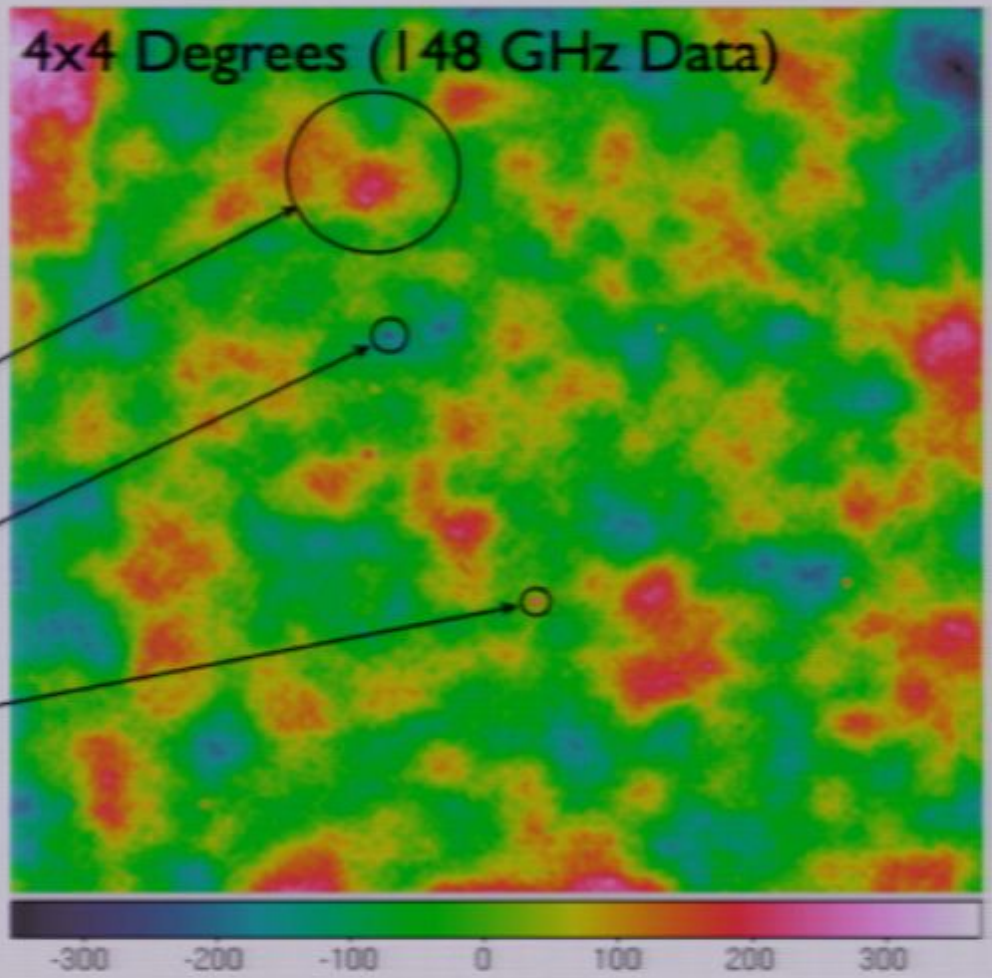
Atmosphere: 2 deg
(Filtered Here)

CMB: 1 deg

Clusters*: (>1.4')-4'

Sources*: 1.4'

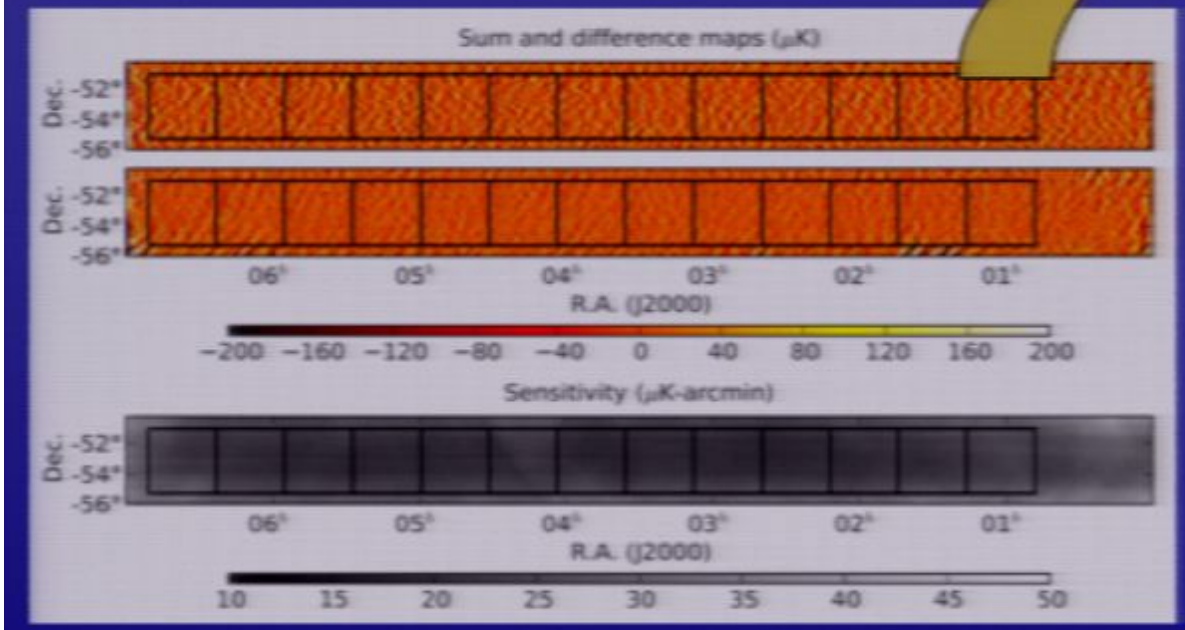
* Minimum size set by beam



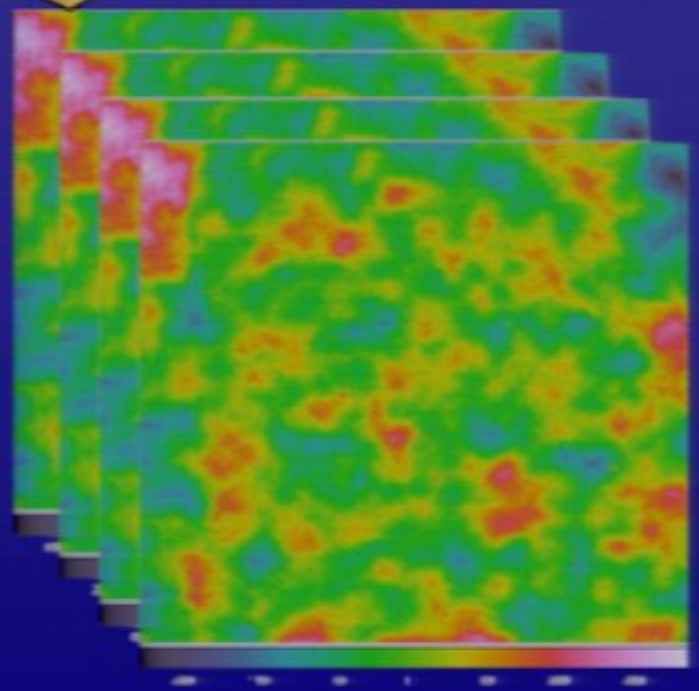
Slide courtesy of T. Marriage

Data for First ACT Power Spectrum

Fowler et al, 2010



Four map estimates made o
this Southern strip, each
using 1/4 of the timestrea



CROSS-SPECTRA USED: NO NOISE BIAS

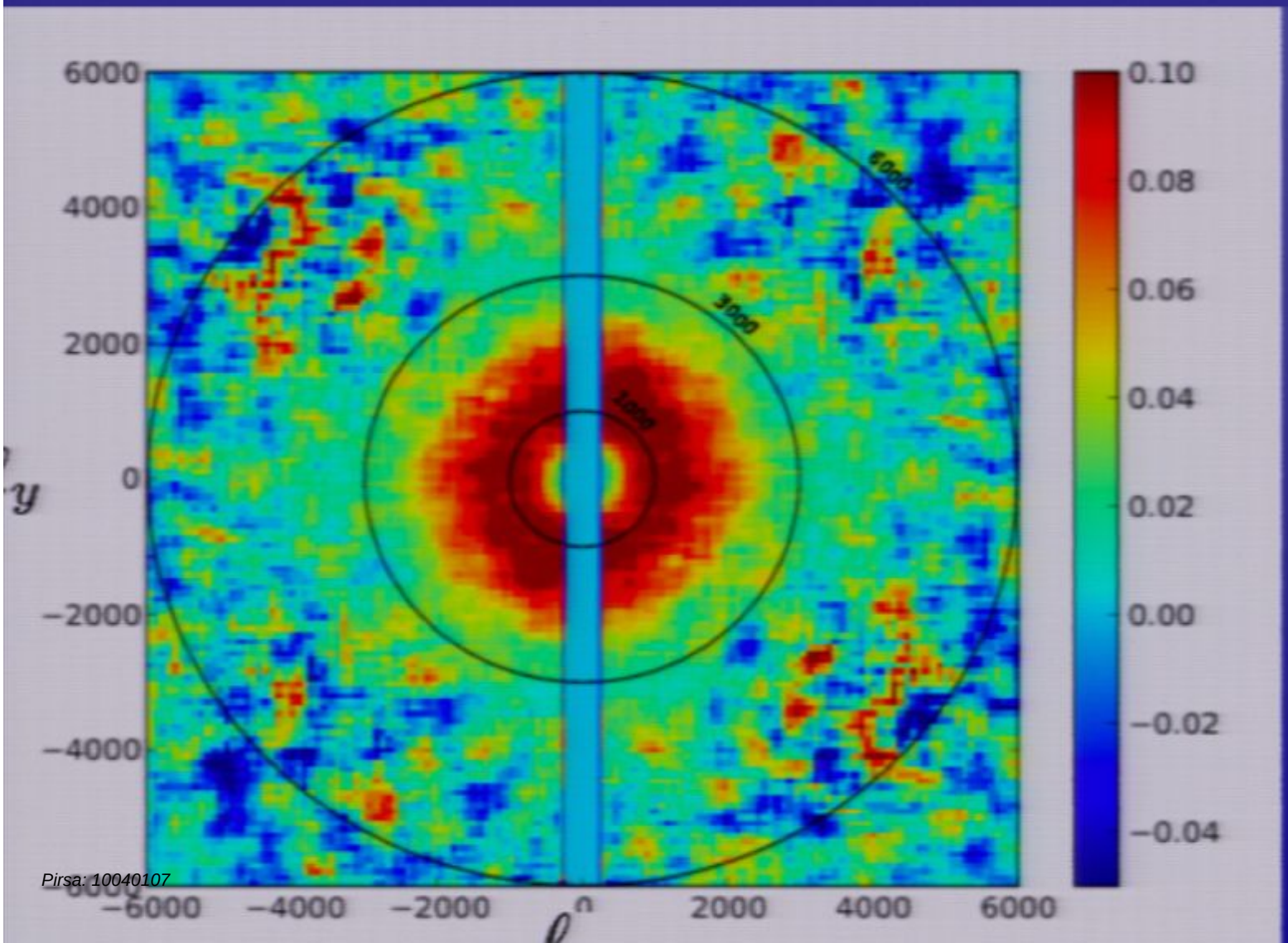
Map divided into 13 4°x4° patches; 6 cross-spectra calculated in each patch via adaptive multitaper approach (Das, Hajian, Spergel 2008)

Weighted mean of cross spectra reported

Scatter among patches estimates errors; verified analytically

ACT 2d Cross Power Spectrum

Fowler et al 2010

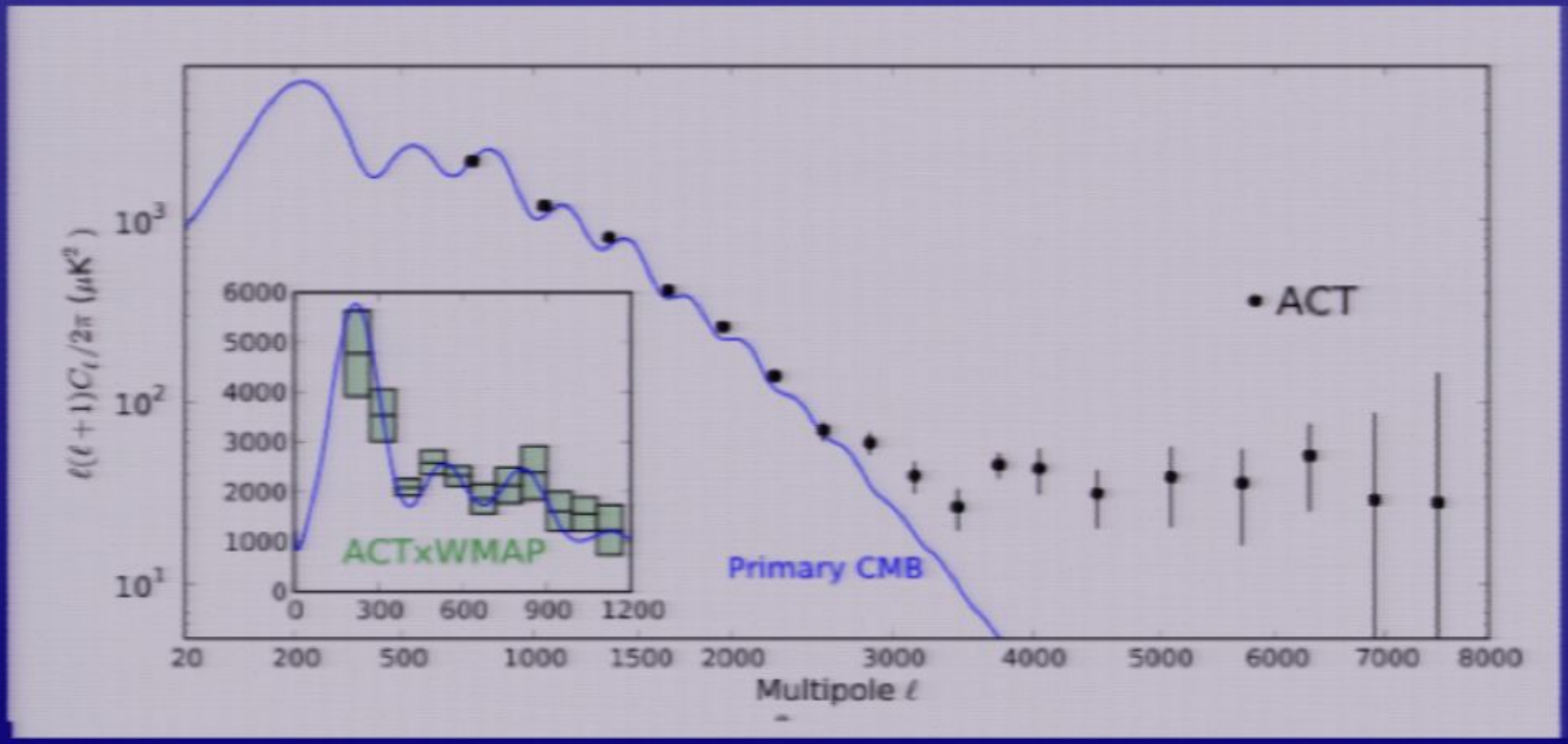


Multiplied by a factor of ℓ to emphasize angular variations: isotropic!

$|\ell_x|<270$ cut b/c contaminated with scan synchronous signals

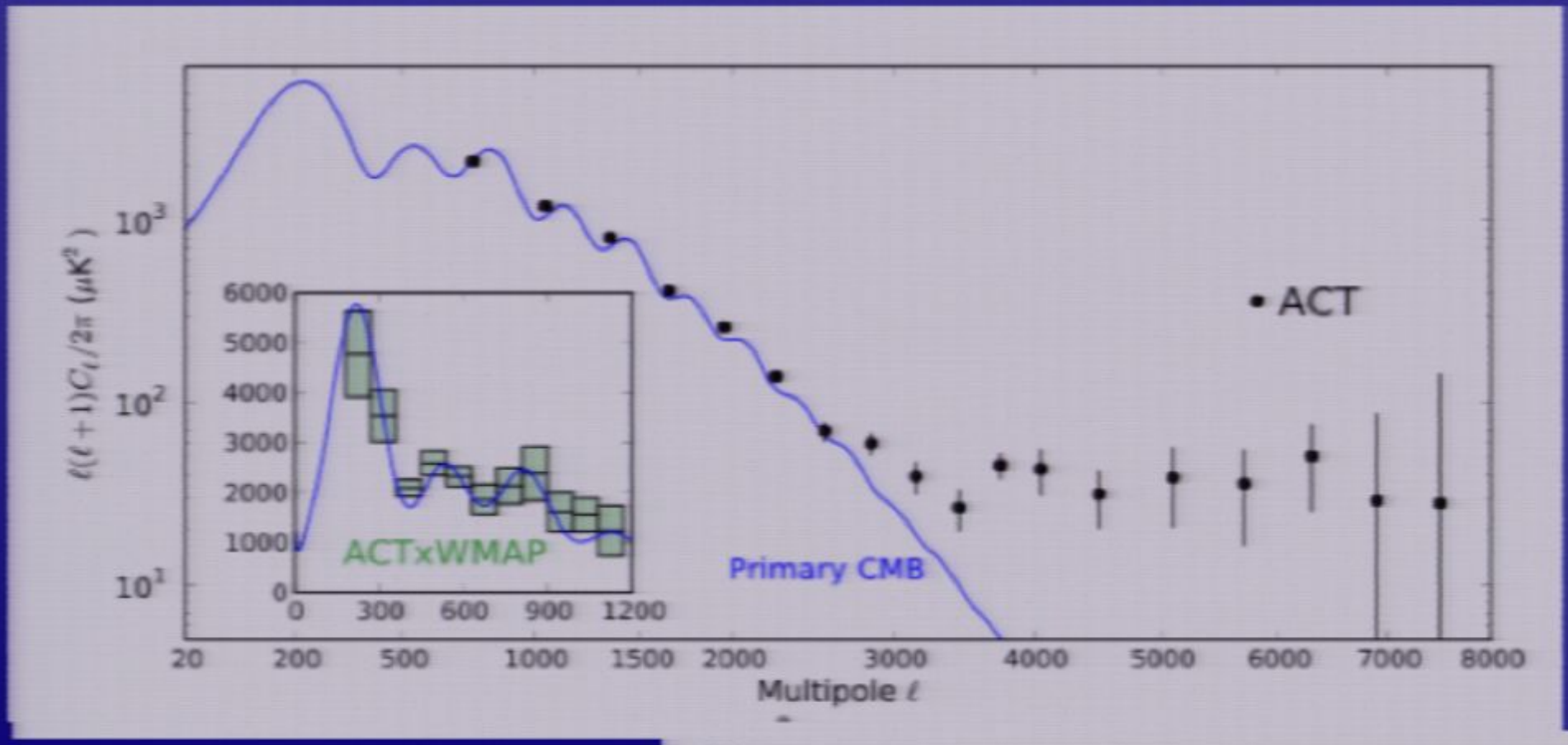
ACT Power Spectrum

Fowler et al, 2010

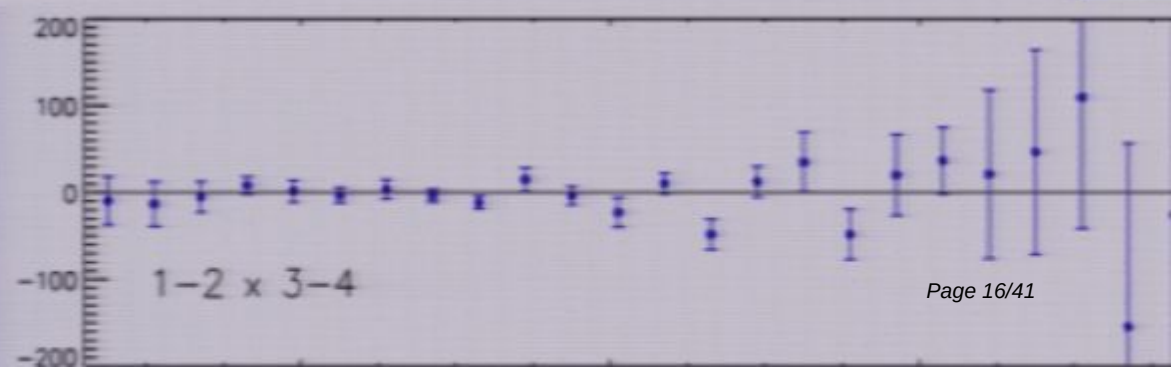


ACT Power Spectrum

Fowler et al, 2010

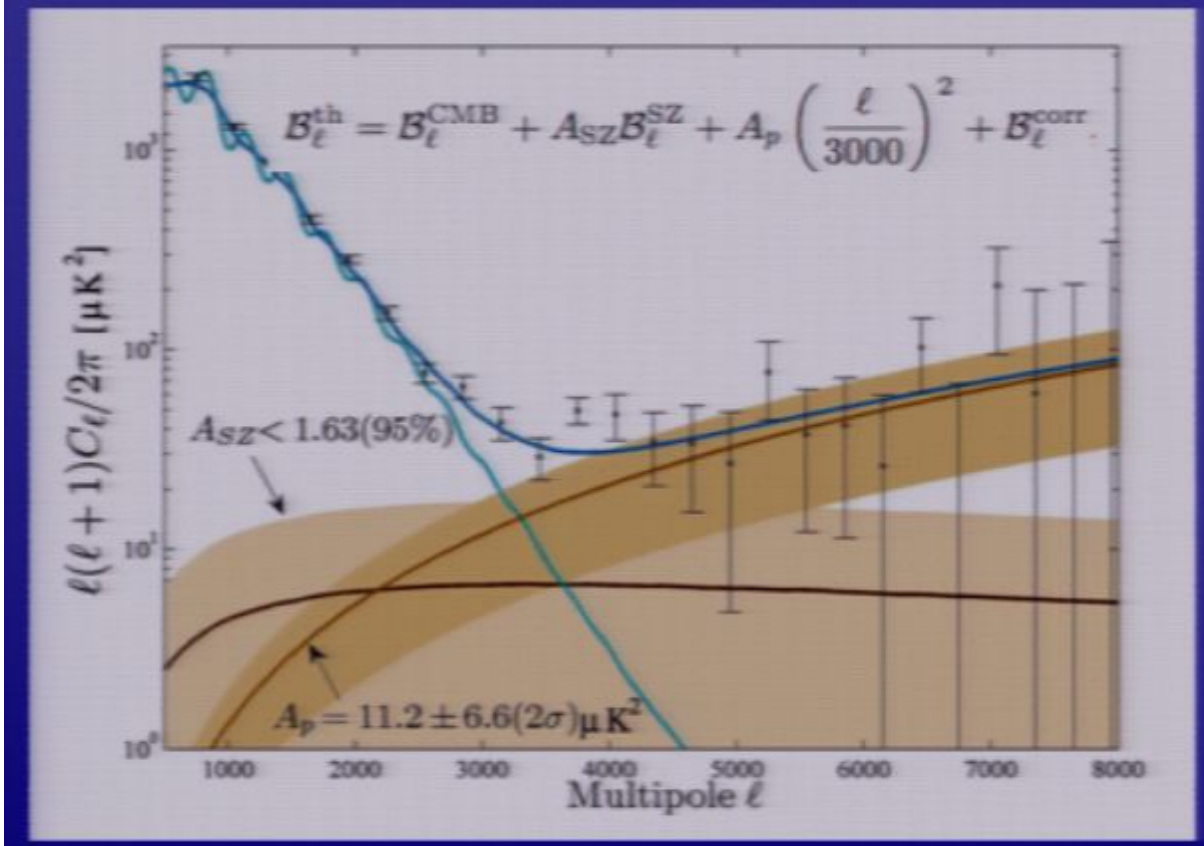


One of 3 null test spectra from differencing pairs of the four submaps



Fitting ACT Power Spectrum

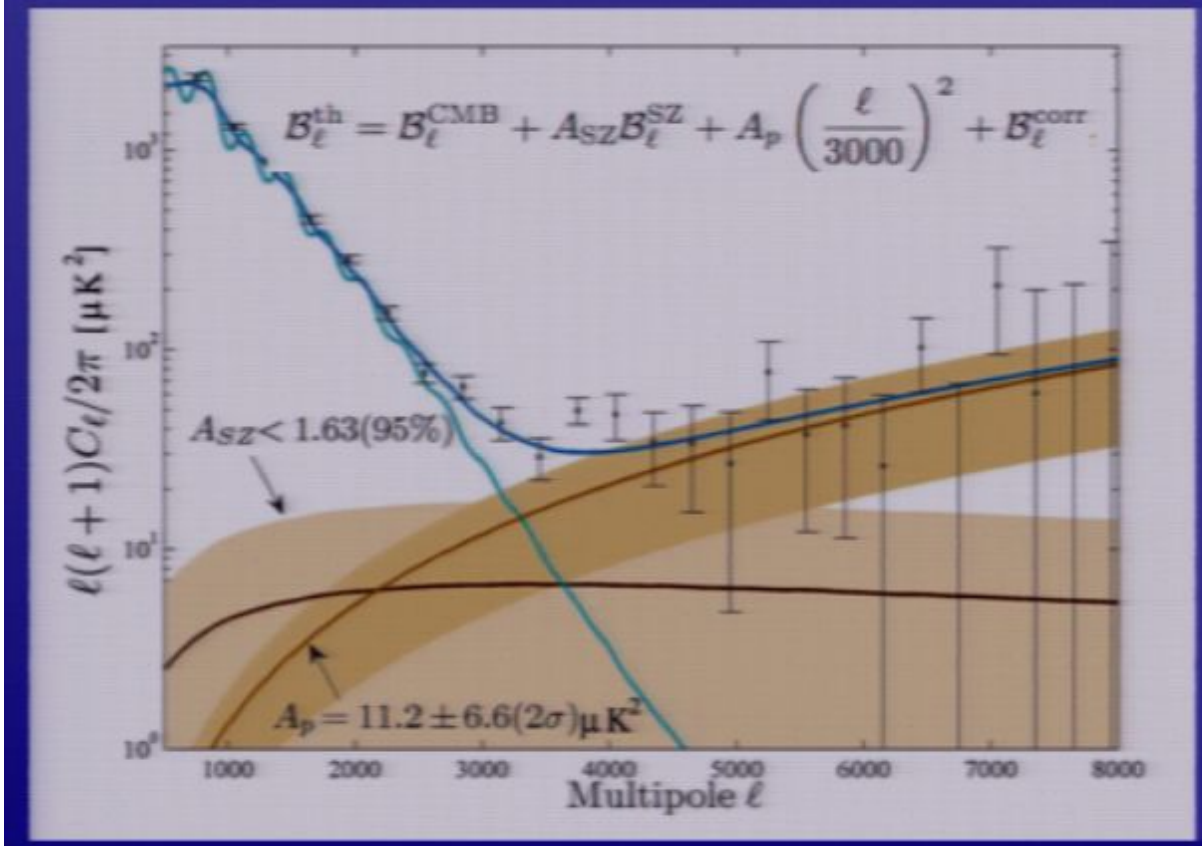
Fowler et al, 2010



A_{SZ}
< 1.63
< 1.36

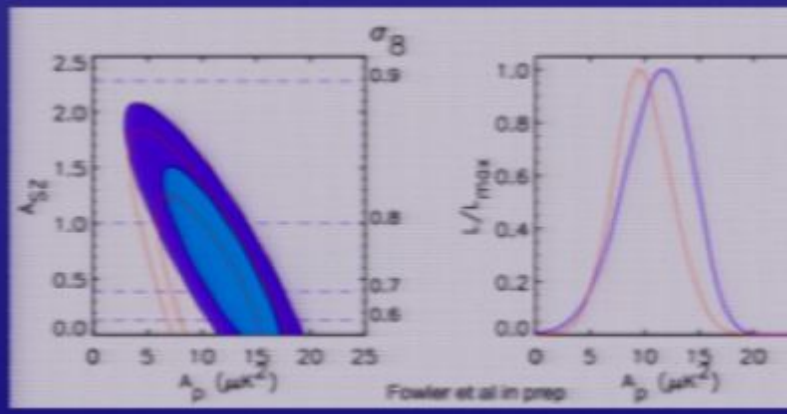
Fitting ACT Power Spectrum

Fowler et al, 2010



Uncorrelated point sources (blue)

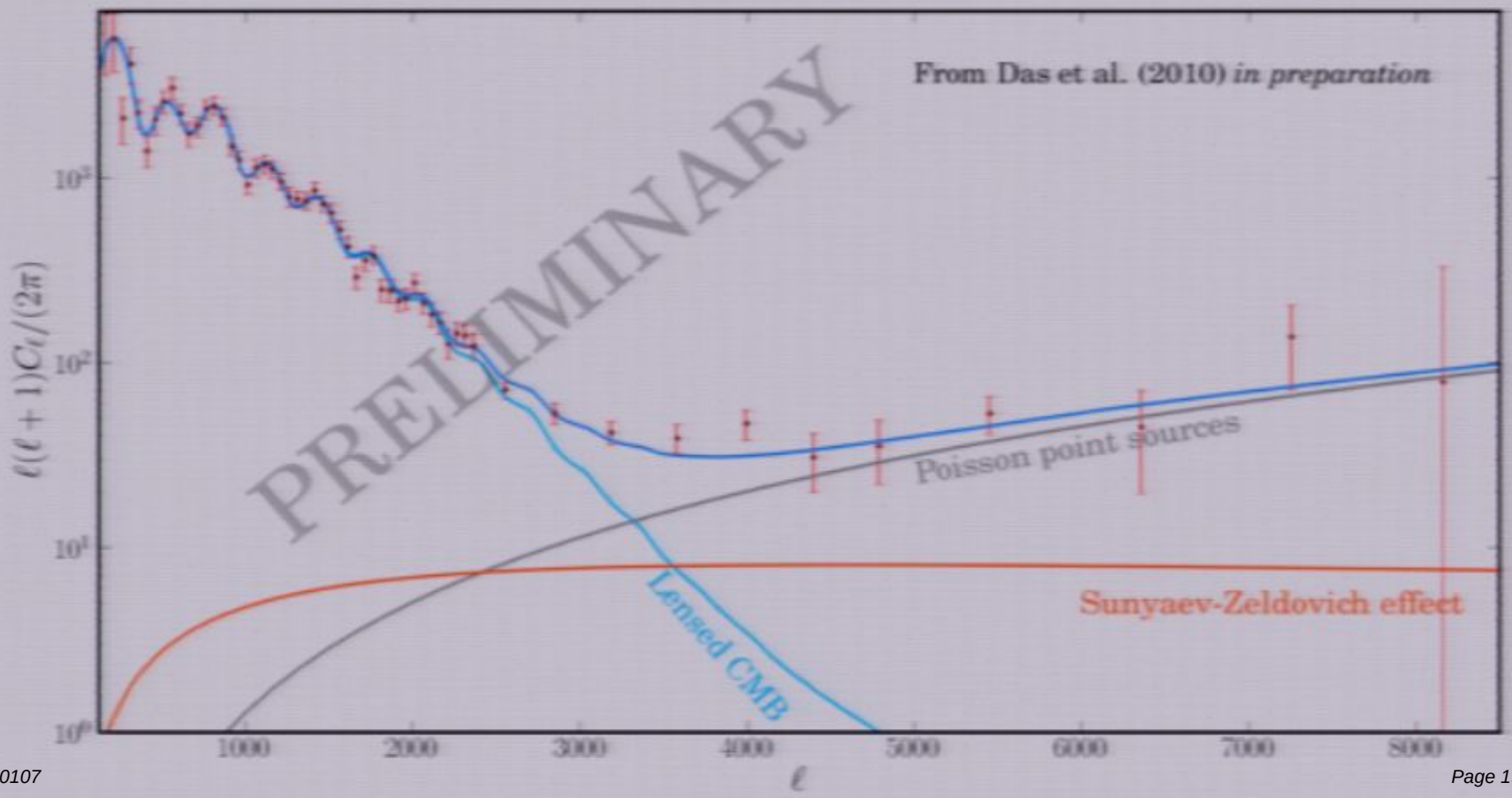
Including some correlated point sources (red)



A_{SZ}	$A_p(\ell = 3000)$ μK^2	C_p $10^{-5}\mu K^2$	C_p $Jy^2 sr^{-1}$
< 1.63	11.2 ± 3.3	0.784 ± 0.23	1.22 ± 0.3
< 1.36	9.7 ± 2.8	0.68 ± 0.2	1.05 ± 0.3

Extragalactic point sources below 17 mJy detection limit: radio galaxies & dusty star-forming IR galaxies

Preliminary Next Generation ACT Power Spectrum



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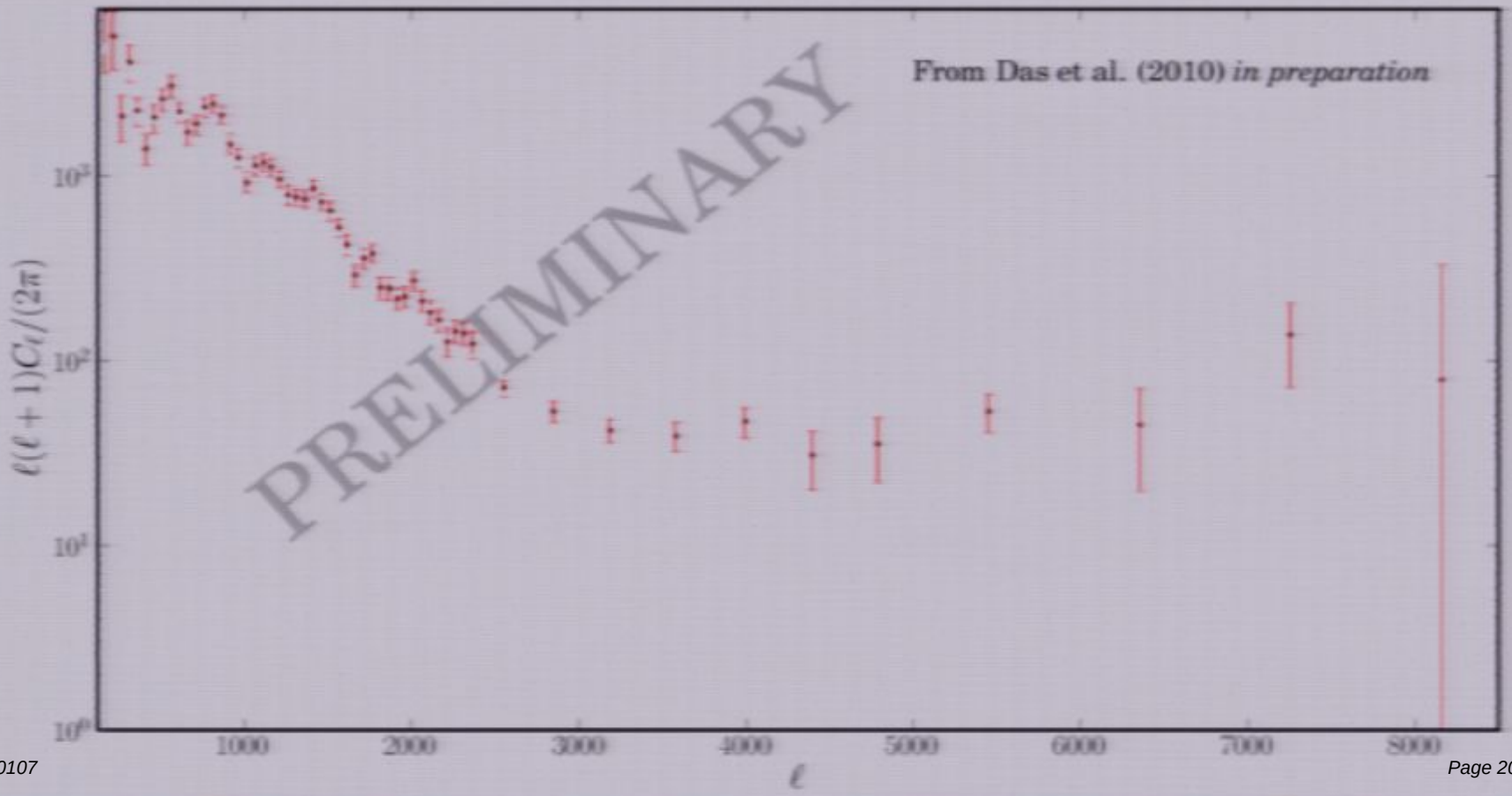

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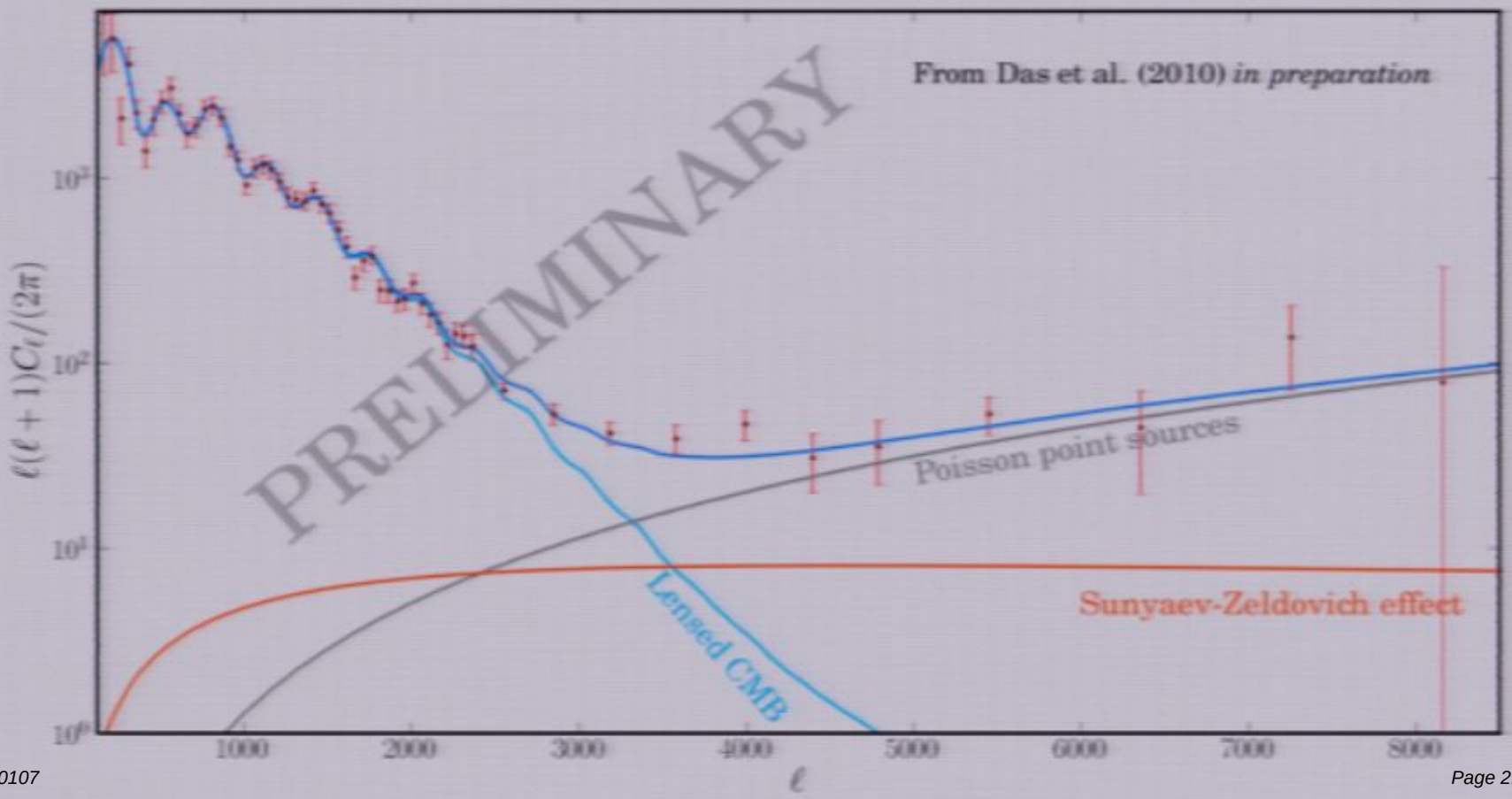

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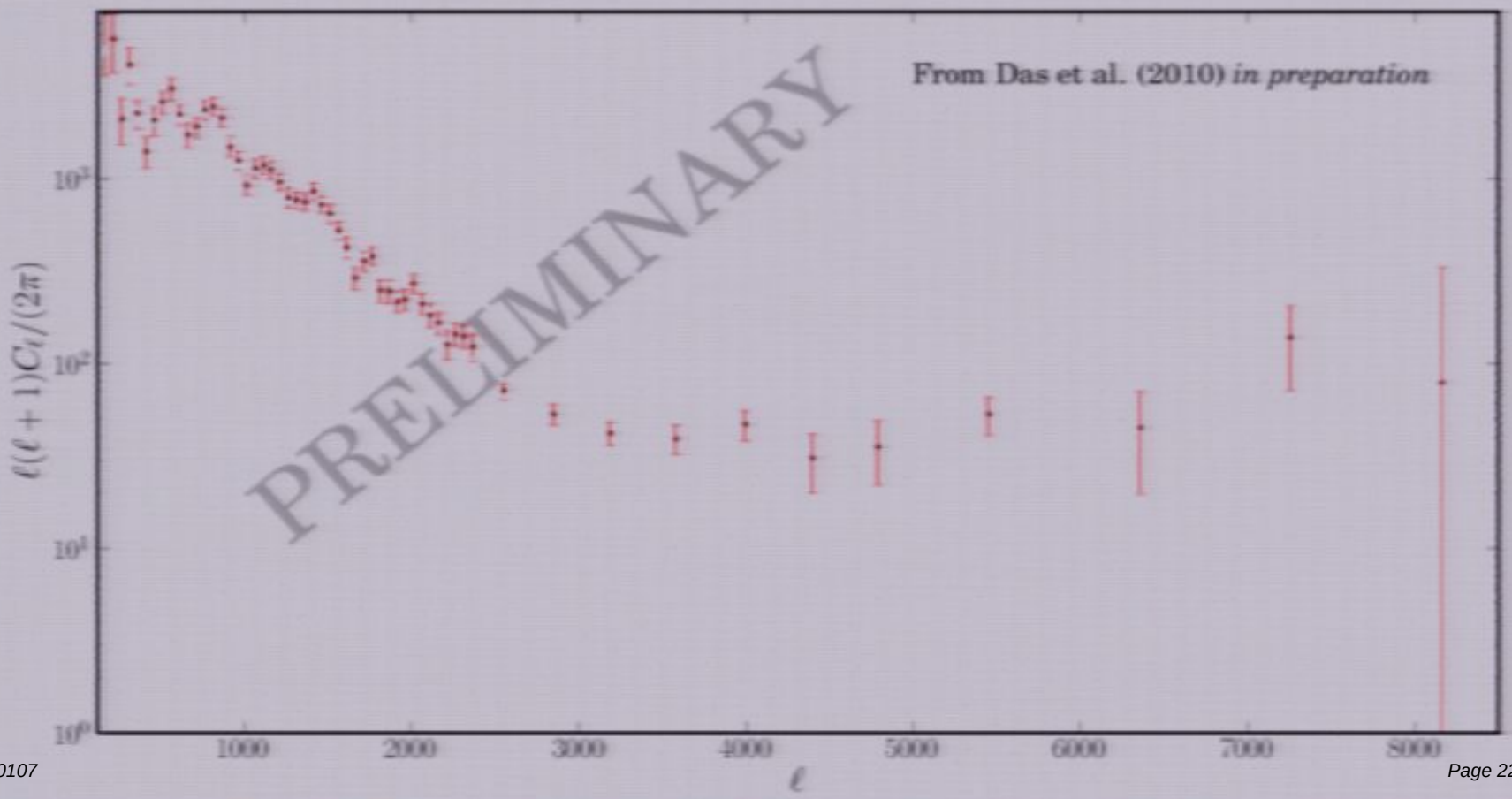
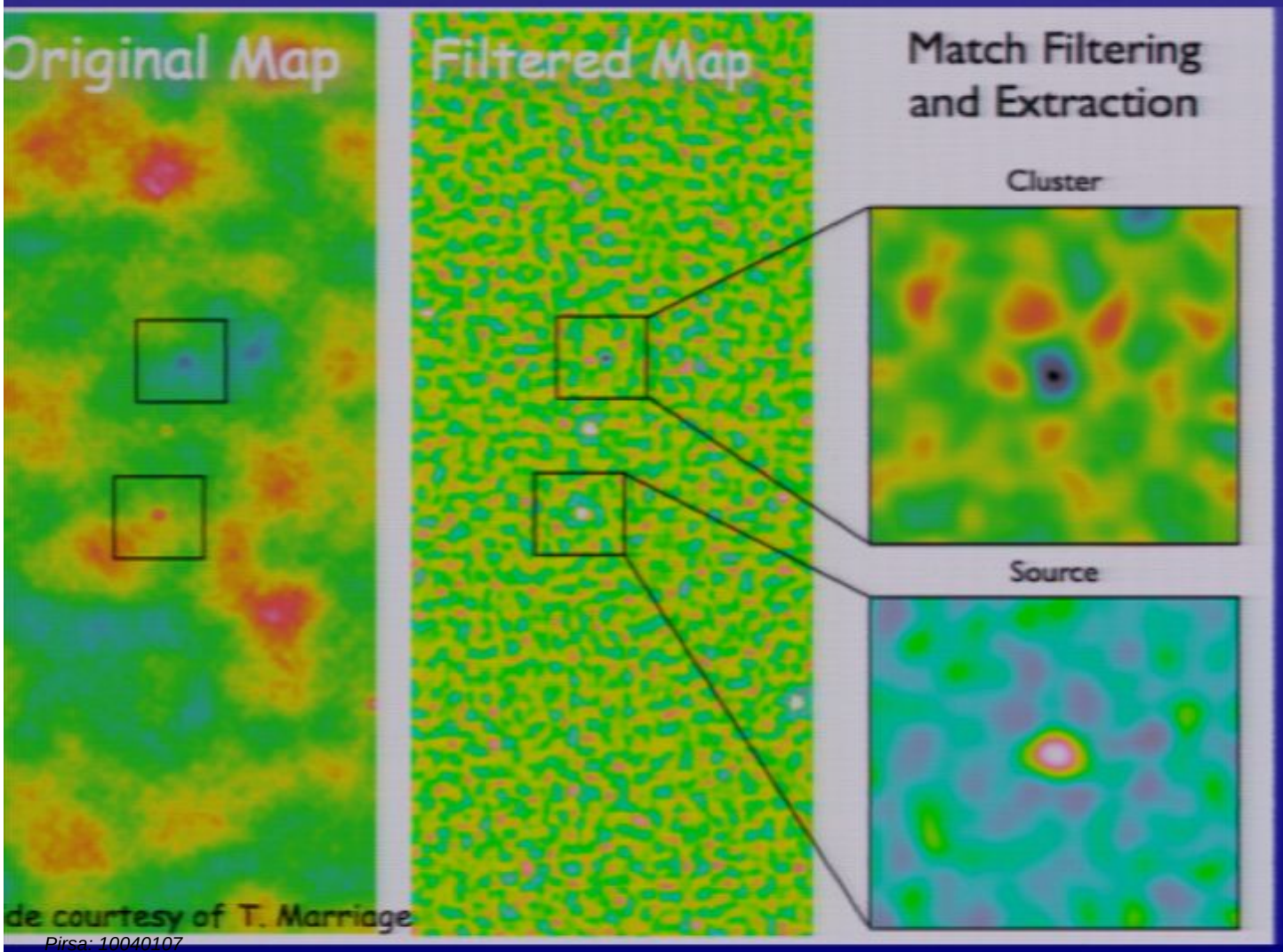


Recovering Clusters & Point Sources from ACT 148 GHz Map

Marriage et al I, in preparation; Marriage et al II, in preparation



Point source case

Real Space:

$$T(x) = T_0 b(x) + T_{bg}(x)$$

Pt src

beam

Fourier Space, Matched Filter:

$$\Theta(k) = b^*(k)/|T_{bg}(k)|$$

Apply additional normalization so each pixel of the filtered map in real space is an estimate of T_0

Recovering Clusters & Point Sources from ACT 148 GHz Map

Marriage et al I, in preparation; Marriage et al II, in preparation

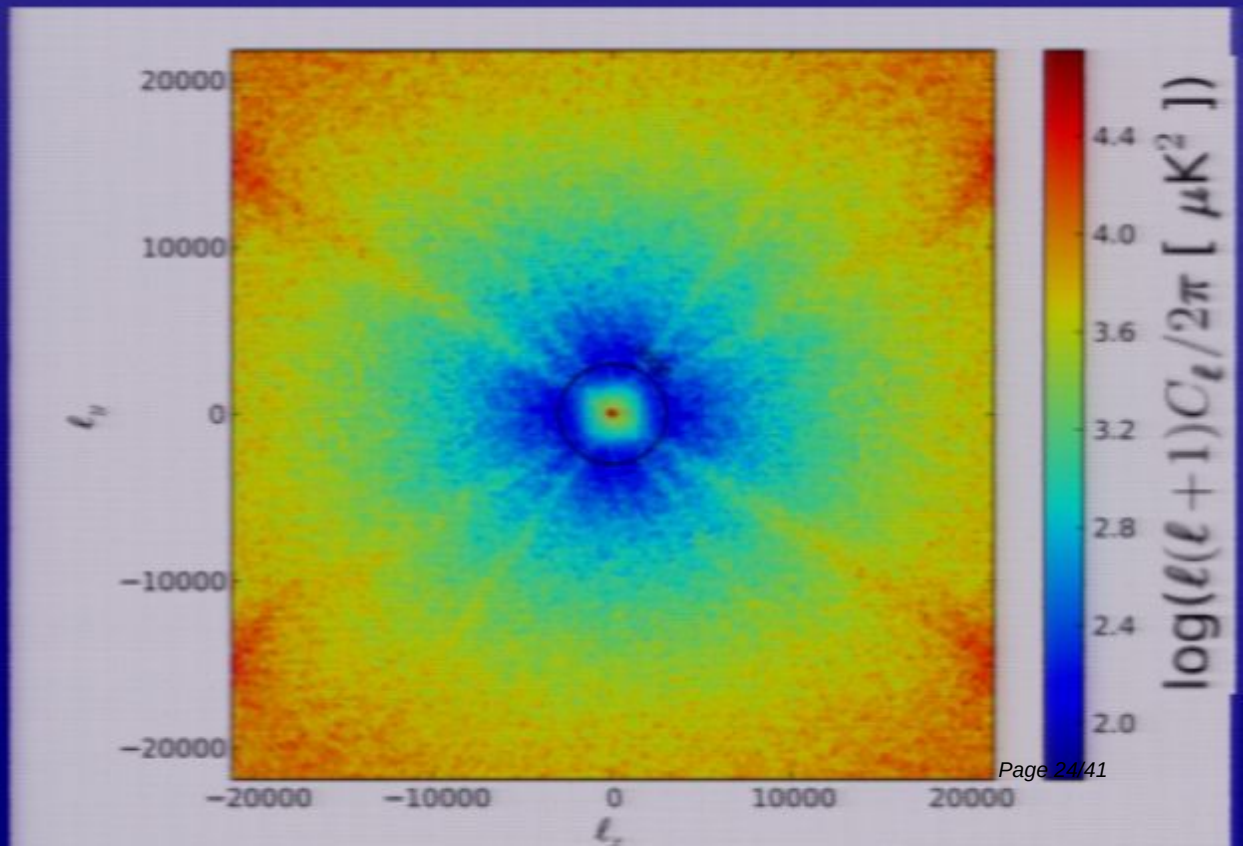
ourier Space,
latched Filter:

$(k) = b^*(k)/|T_{bg}(k)|^2$

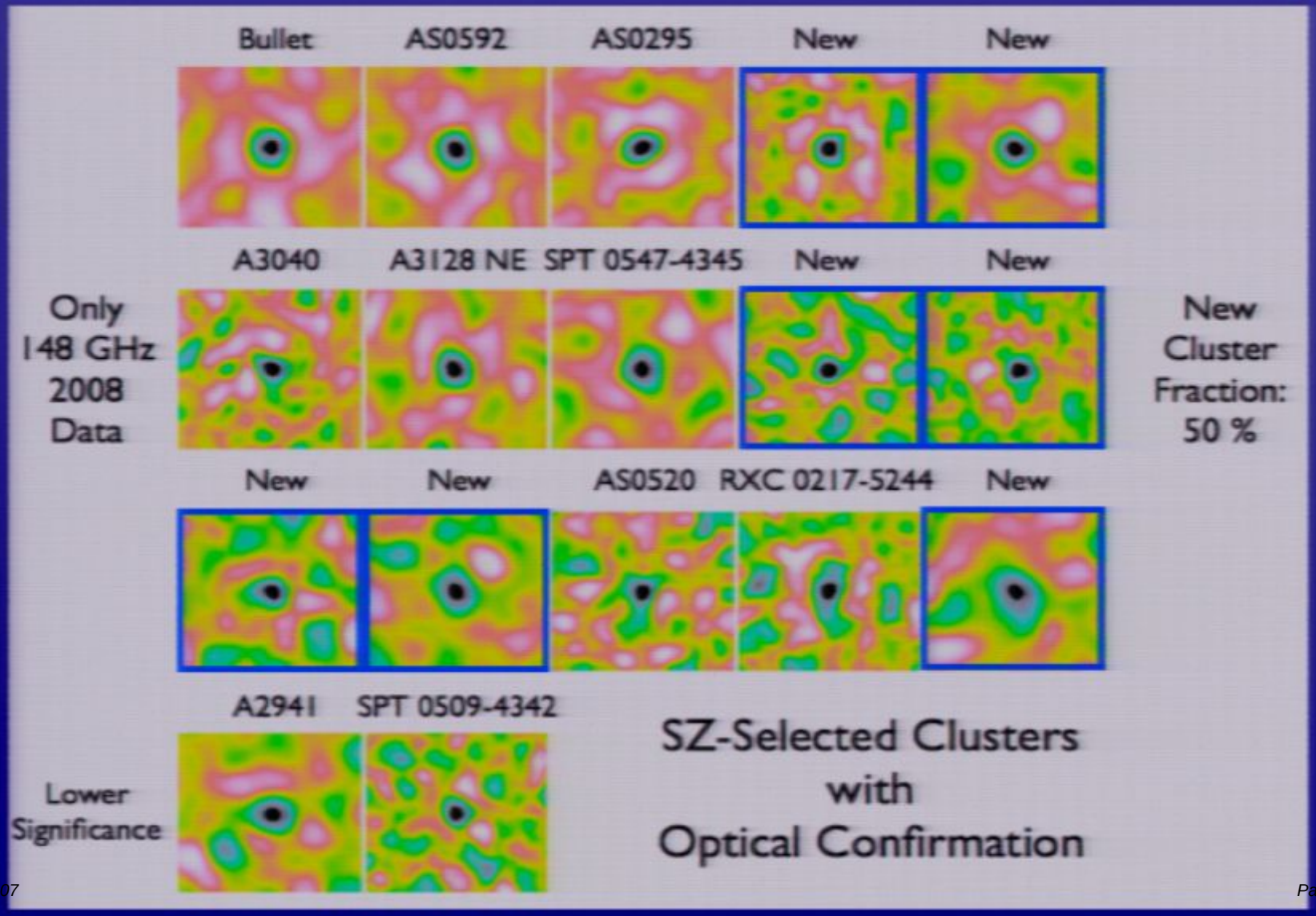
$T_{bg}(k)$ includes the CMB, undetected sources, and unresolved SZ , from the fit to the ACT power spectrum.

$T_{bg}(k)$ also includes an estimate of the noise using the full 2d autospectrum of a null map (from two half-season maps).

Cluster and point source finding proceeds from the maximum likelihood maps!



Some ACT SZ Clusters

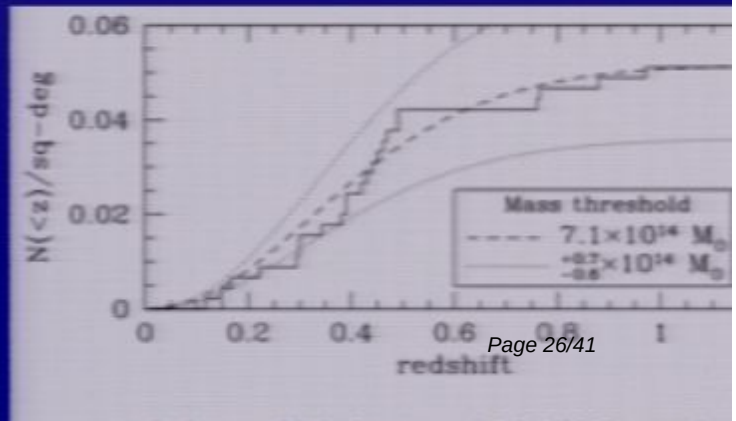


ACT SZ Cluster Follow-up

Optical Follow-up -- Testing purity of the ACT sample

- 4 nights at NTT (EFOCS), 4 nights at SOAR (SOI)
  + 2 nights at Blanco (MOSAIC) lost to bad weather
- g,r,i imaging; expected r magnitude 24.5
- 23 confirmed clusters from 450 deg^2 of ACT Southern strip (superset of data used for Fowler et al, 2010 power spectrum)

Menanteau et al, in preparation



New Clusters from the NTT Run

Menentau et al, in preparation

ACT SZ Cluster Follow-up

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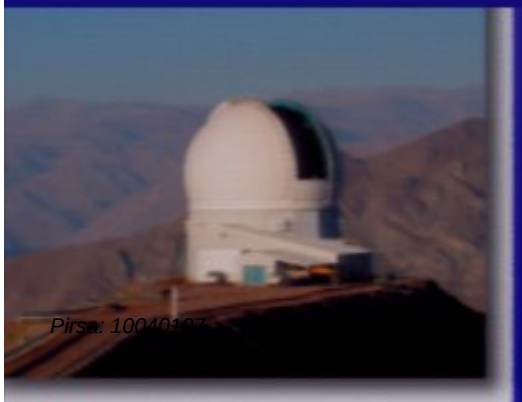
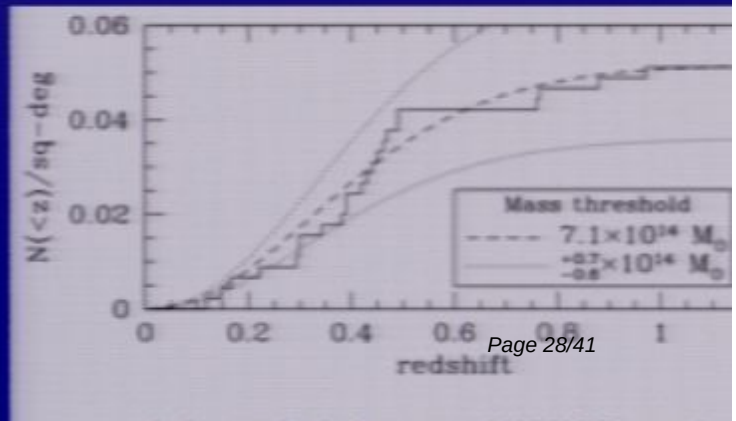
- 4 nights at NTT (EFOCS), 4 nights at SOAR (SOI)
  + 2 nights at Blanco (MOSAIC) lost to bad weather
- g,r,i imaging; expected r magnitude 24.5
- 23 confirmed clusters from 450 deg^2 of ACT Southern strip (superset of data used for Fowler et al, 2010 power spectrum)



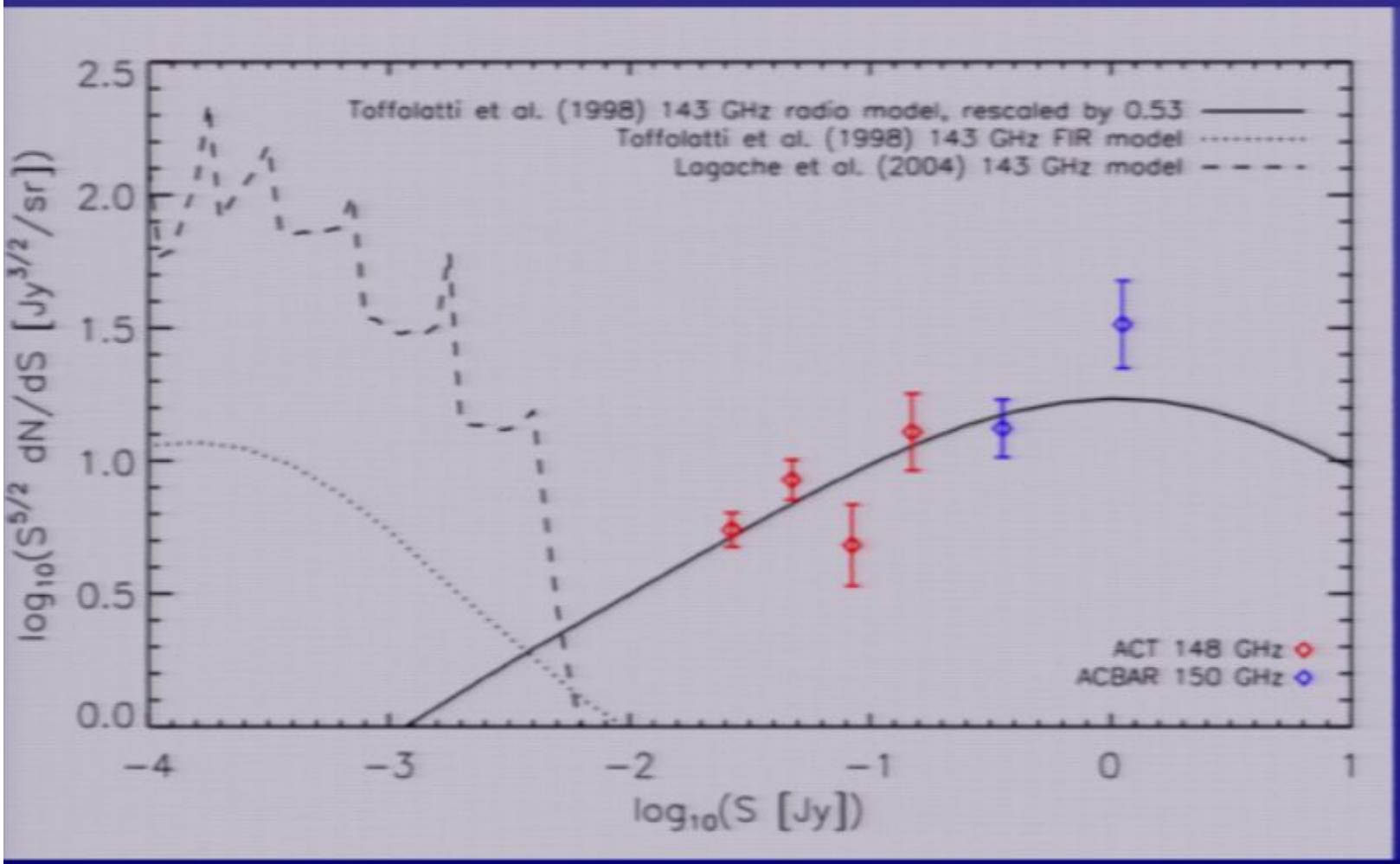
Menanteau et al, in preparation



New Clusters from the NTT Run

Menentau et al, in preparation

Preliminary Differential Source Counts

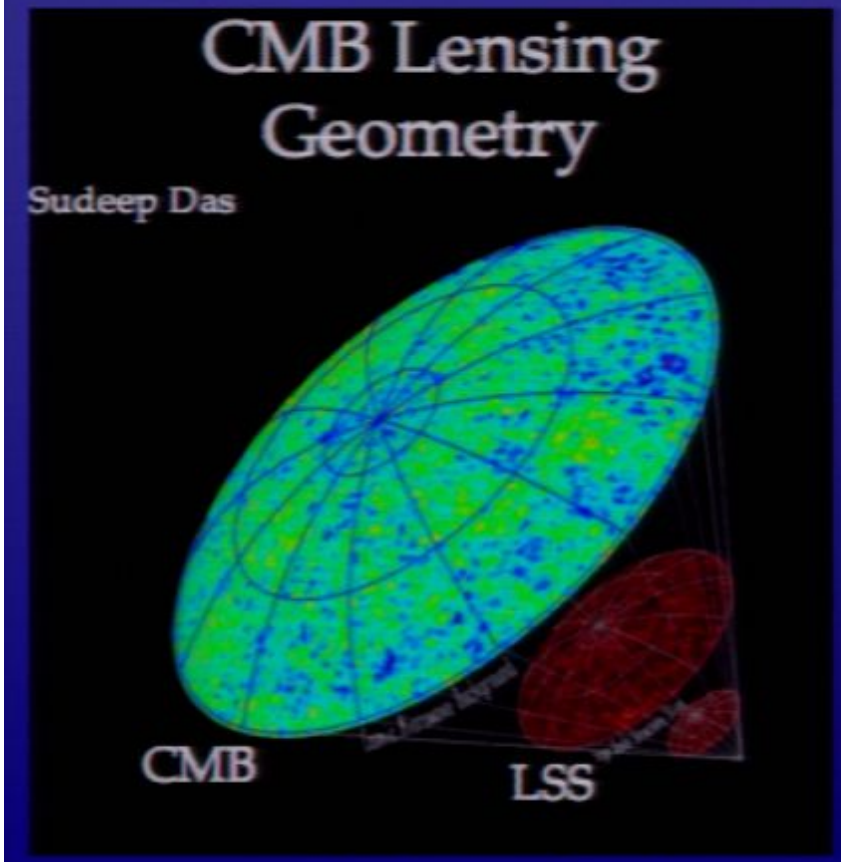


More definitiv
plots will be
forthcoming i
Marriage et a
in preparation

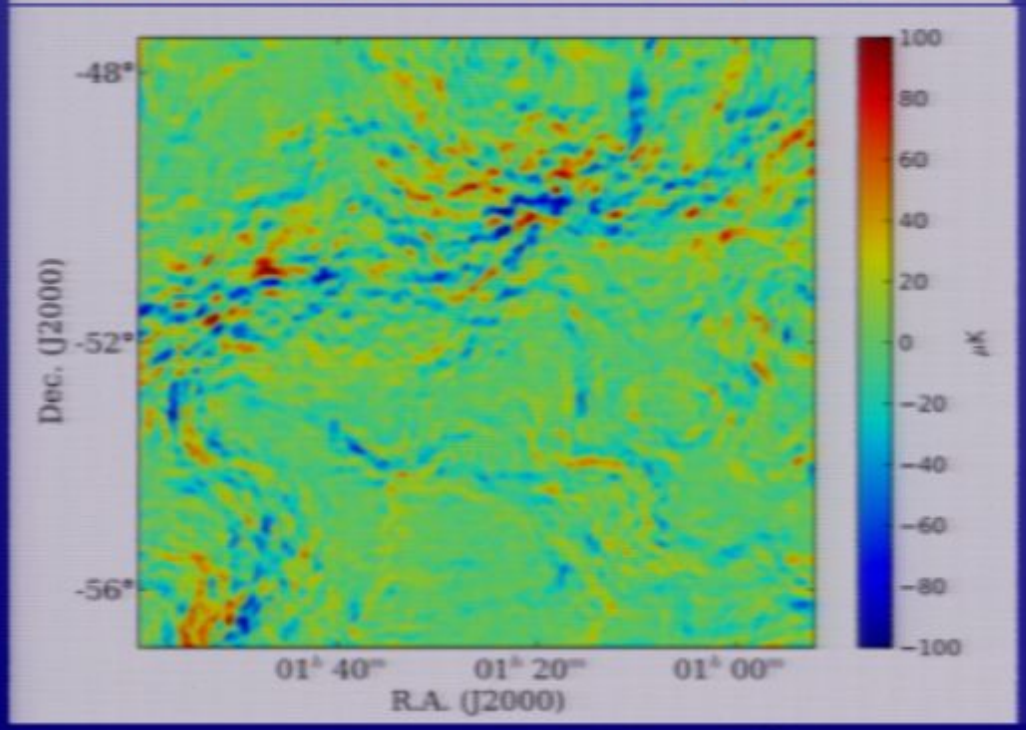
ue to the ACT flux limit (~17 mJy), resolved ACT
oint source counts are dominated by radio sources

Gravitational Lensing

(Simulation on hemisphere, Das & Bode 2007)
(Full 148 GHz Sky Simulations, Sehgal et al 2010)



Difference between lensed and unlensed CMB in 10°x10° patch

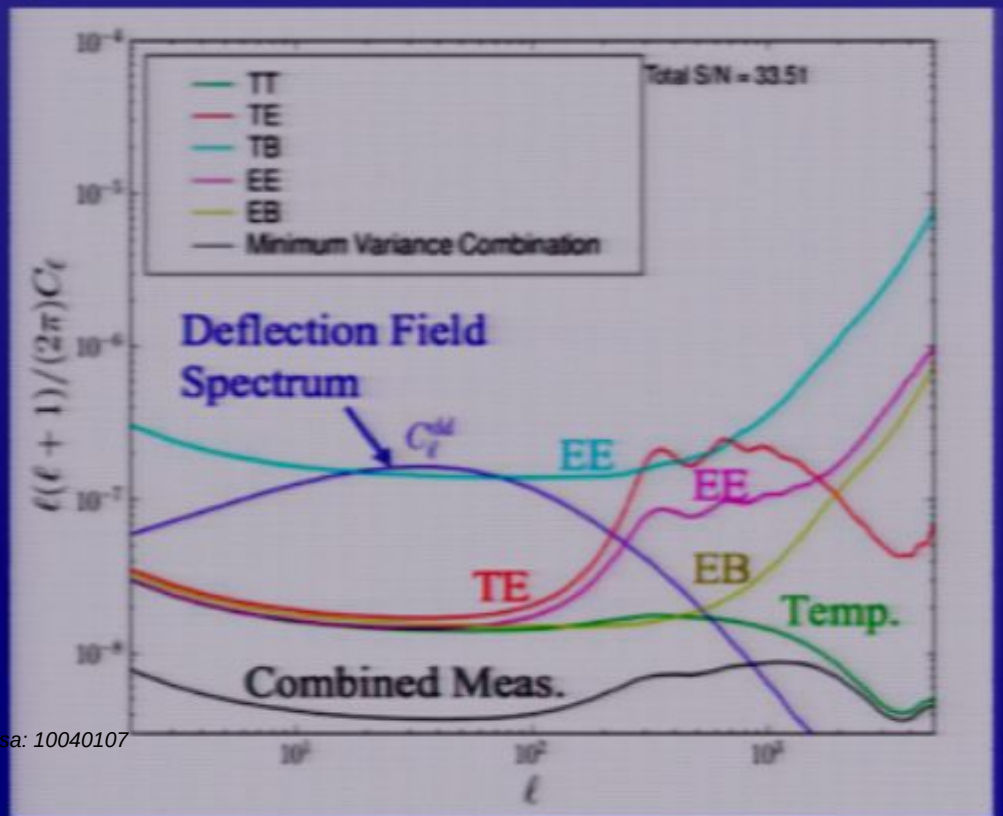


Typical 3' shift, but convergence spectrum peaks at l = 50: large & small scales coupled (non Gaussian)!

More on observing methods: Das, Hajian & Spergel 2008

Gravitational Lensing of the CMB: Mapping Large Scale Cosmic Shear

- CMB-only detection of lensing expected from extant ACT map
- Lensing rotates CMB polarization E-modes into B-modes at small angular scales
- ACTPol is a new receiver proposed for ACT with 5x the current sensitivity at 150 GHz, and with polarization sensitivity



Plot assumes one array* of 640 feedhorns with TES-OMT-coupled bolometers from NIST for one season on ACT, with 1.5' resolution on a 100 deg^2 survey area; map noise would then be 1.7μK-arcmin

*three are planned

Forecast Σm_ν to 0.07 eV

(not all systematics modeled yet)

Gravitational Lensing of the CMB: Mapping Large Scale Cosmic Shear

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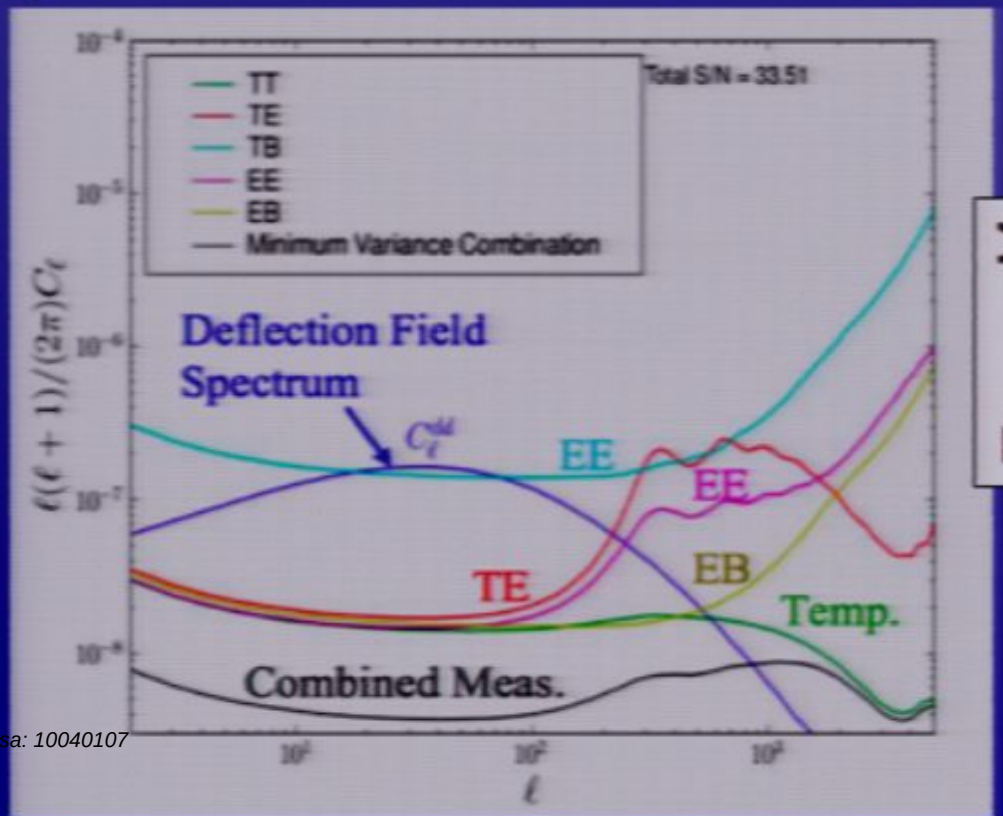
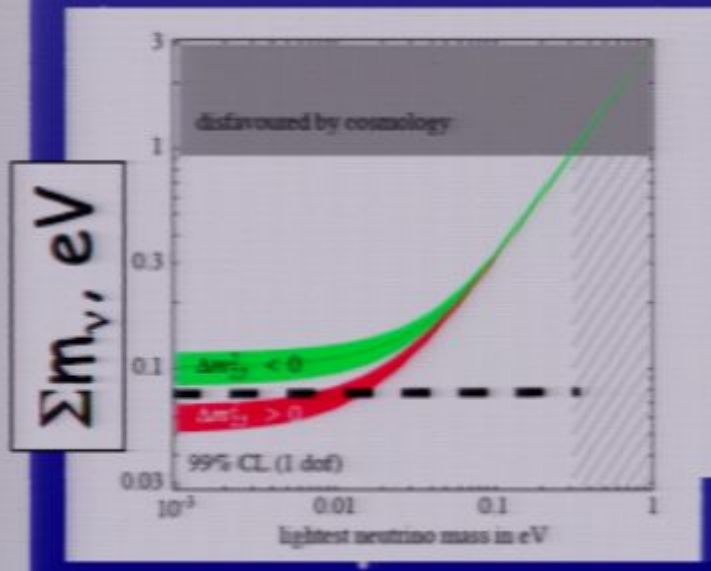


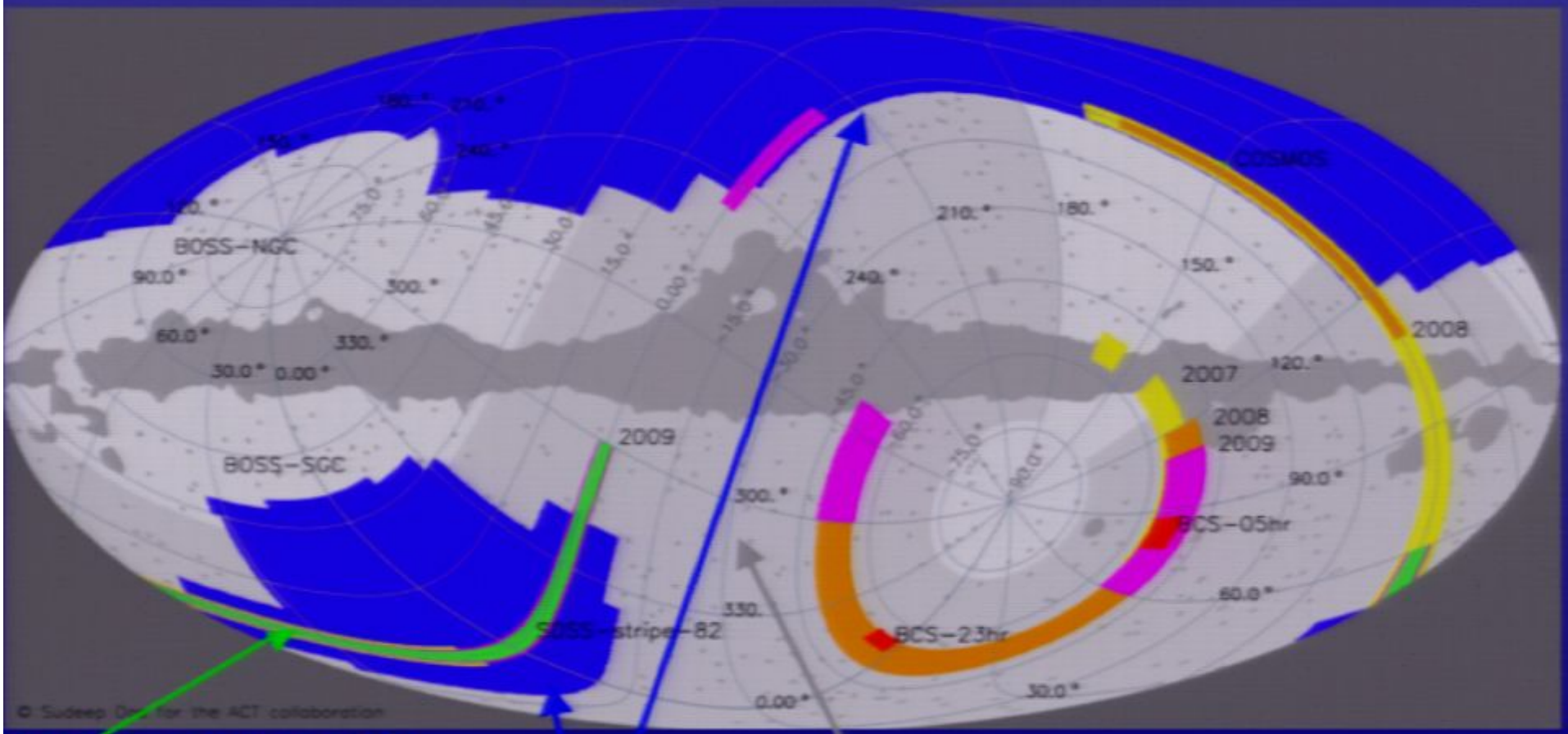


Could rule out the inverted mass hierarchy OR measure finite Σm_ν

Forecast Σm_ν to 0.07 eV

(not all systematics modeled yet)

Cross-Correlation Science with ACT



DSS stripe 82

Region viewable by ACT (in gray):

Overlaps with N. hemisphere telescope region

BOSS

BOSS Overview

SDSS-III's Baryon Oscillation Spectroscopic Survey (BOSS)

- 10,000 square degrees
- Spectroscopic z of 1.5 million galaxies to $z = 0.7$
- Lyman-α forests of 160,000 quasars at redshifts $2.2 < z < 3$
- Fall 2009 - Spring 2014

Benefits of Overlapping BOSS

- Permits ACT cluster identifications
- Permits cross-correlation of CMB lensing field to LRGs --> P(k, z)
- Permits calibration of the mass-gas relationship in the Ly α forest --> probing structure at high z via cross-correlation to CMB lensing (Vallinotto et al. 2009)
- Permits correlation of kSZ & galaxies with S/N ~ 20 to search for missing baryons (Ho, Dedeo & Spergel 2009)
- Permits measurement of the bias, b(a), of galaxies tracing the BAO --> D(a) (Acquaviva, Hajian, Spergel & Das 2008)

Near-term Prospects for ACT

- Analysis of 218 GHz and 277 GHz data in Southern strip to improve parameter estimation and increase cluster sample purity
- Analysis of equatorial strip data in all bands to begin rich cross-correlation science
- Construction of ACTPol receiver (funding permitting, but we've been working on the detectors and the optics designs already)


THE END

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THE END

No Signal

VGA-1