The Atacama Cosmology Telescope (ACT):

Recent results and future prospects

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For the ACT collaboration

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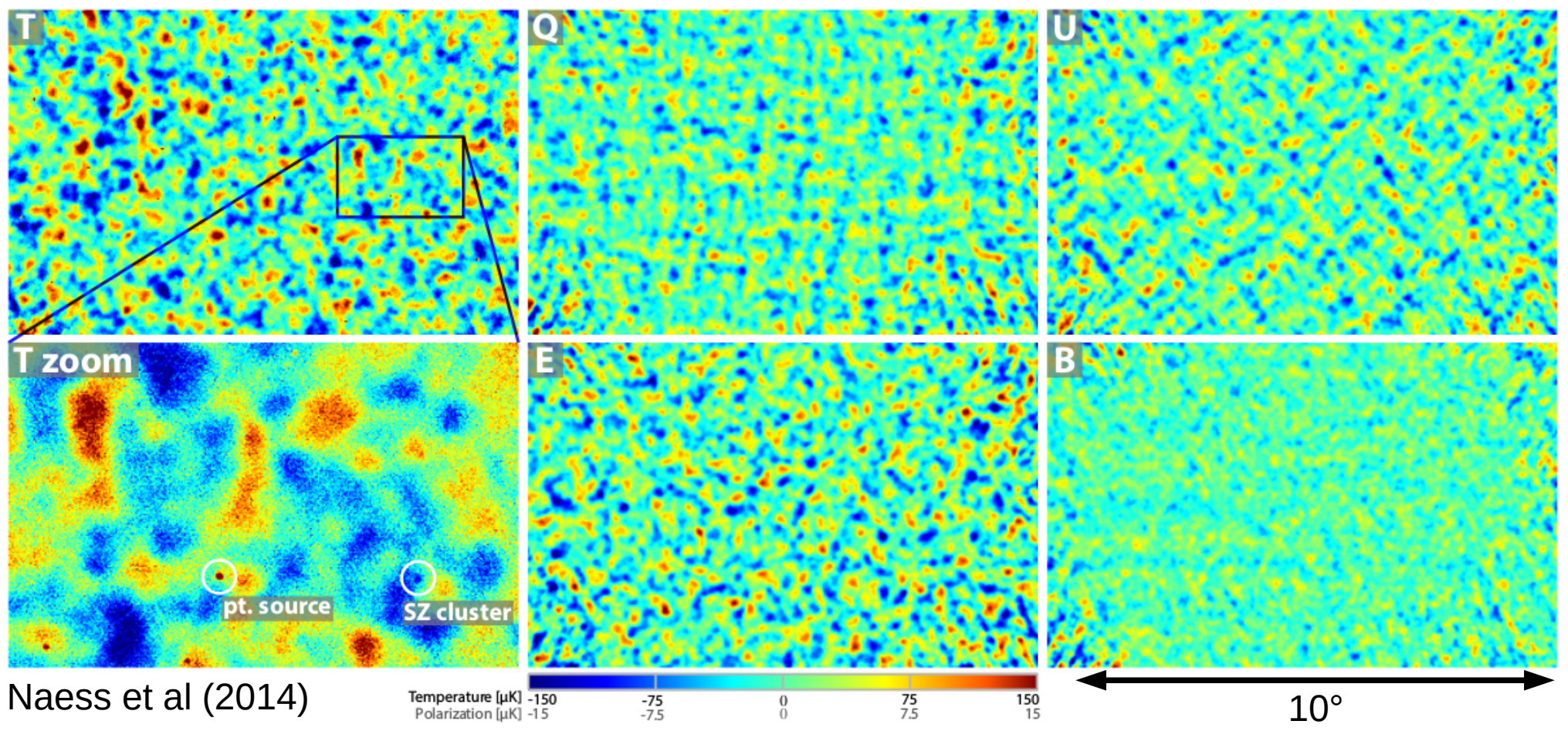
What does ACTPol do?

- ACTPol is a telescope, camera, and collaboration for measuring the intensity and polarization anisotropies of the CMB.
- The spectra and other statistics of the intensity and polarization maps encode important cosmological information.
- The maps also provide important samples of resolved objects (clusters, DSFGs).



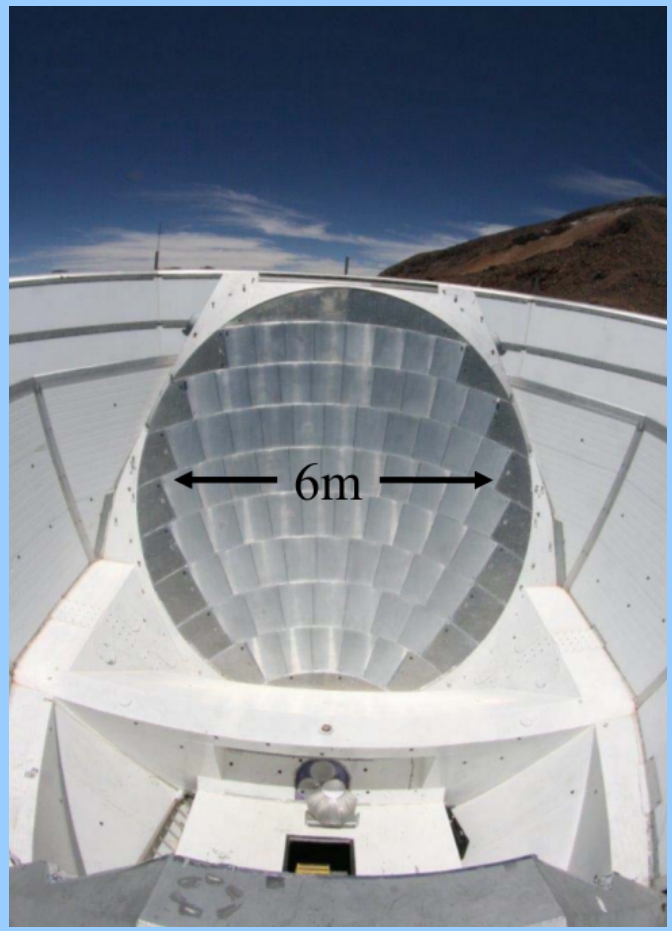
Naess et al (2014)

Cosmological content of the CMB

- ΛCDM and its extensions – T and E angular power spectra.
  - *Planck*: primary anisotropies of CMB intensity have been measured; ΛCDM is enough.
  - E-mode polarization contains a somewhat independent probe of ΛCDM parameters – an important consistency check.
  - Detailed measurements of E can be used to clean the T map (e.g., to measure kSZ) or to "delens" the B map.
- Inflation
  - Gravitational waves in very early universe would leave a signal in B-mode polarization at large angular scales → probes the energy scale of inflation.
- Neutrino properties and dark energy
  - Lensing of CMB by local structures:
    - creates correlations in the otherwise-Gaussian-random CMB temperature field.
    - converts polarization E-modes into polarization B-modes.
  - Galaxy cluster abundance is important probe of structure growth; CMB provides detection and mass proxy through the Sunyaev-Zeldovich effect.

Atacama Cosmology Telescope

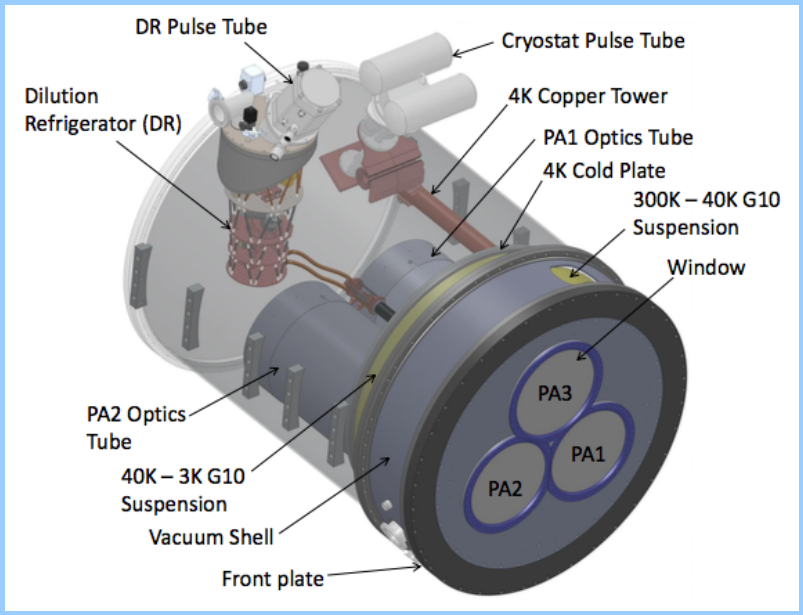
- Chilean desert, near ALMA site, at 5200m altitude.
- Latitude of 23° S gives access to much of Northern and Southern equatorial sky.
- 6m primary mirror → FWHM 1.3' at 150 GHz.



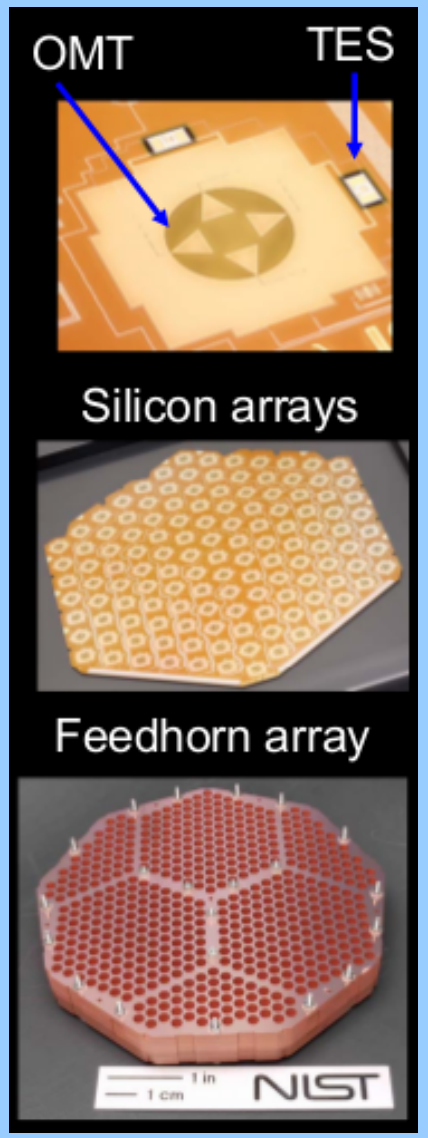
The ACT epochs of observation

- **MBAC**, 2007-2010:
  - ~3000 bolometers @300mK.
  - 148, 218, 277 GHz.
  - Intensity only.
  - 950 deg^2 total survey area
- **ACTPol**, 2013-2015:
  - ~2500 bolometers @100mK.
  - 146 GHz and 146/90 GHz.
  - Polarization sensitive
  - Deep fields of ~70 deg^2 + wider fields from 600 – 1600 deg^2.
- **Advanced ACTPol**, 2016+:
  - ~6000 bolometers @100mK.
  - Polarization; 5 bands; f_{sky} ~50%
  - More on this later.

ACTPol receiver

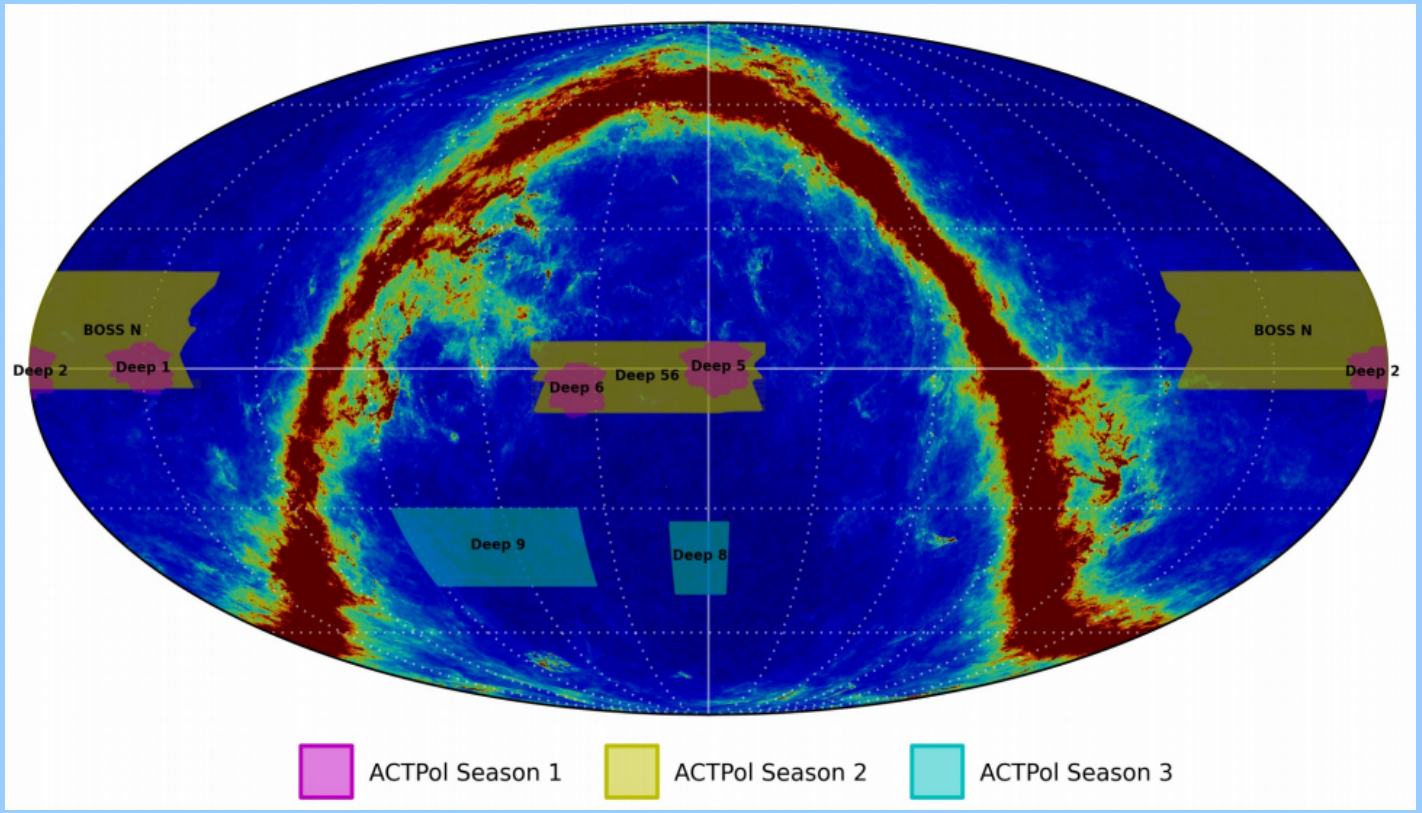


Thornton et al – arXiv:1605.06569



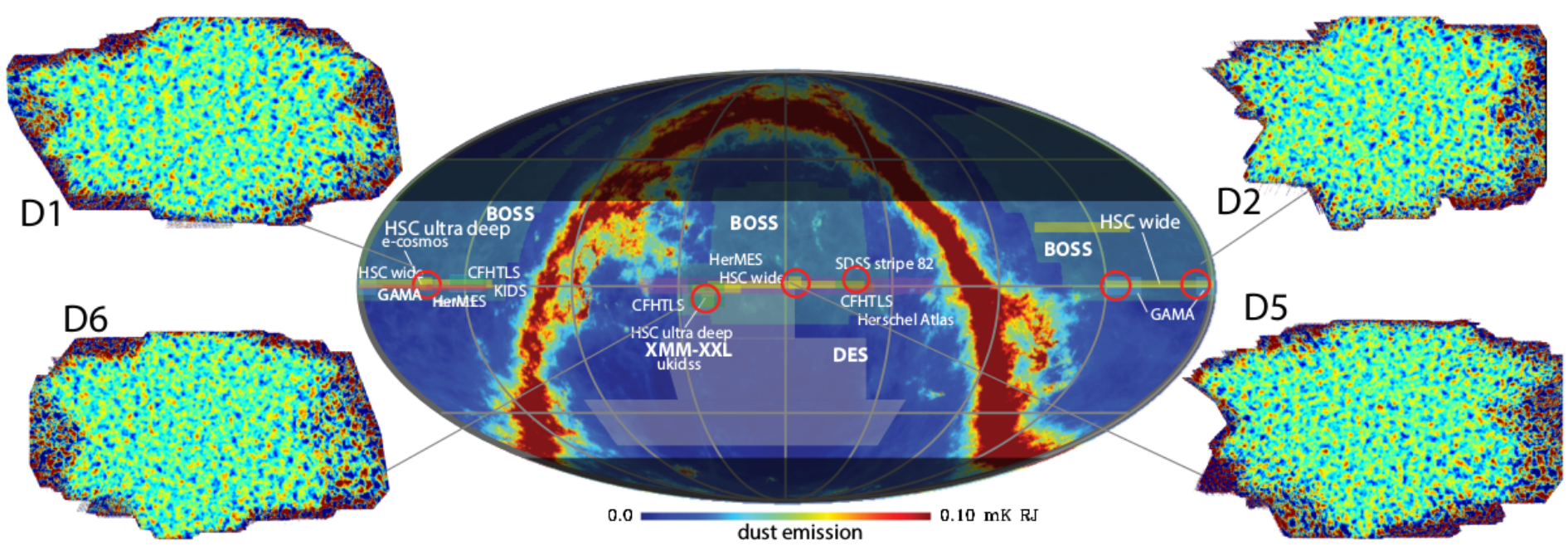
ACTPol observations, 2013-2015

- Season 1 (2013):
  - 1 array; 4 deep fields (~65 deg^2 each) on equator.
- Season 2 (2014):
  - 2 arrays @ 146 GHz. Fill in region from 0h to 3h; observe 12h (BOSS N) during daytime.
- Season 3 (2015):
  - 2 arrays @ 146 GHz + 1 multichroic array at 90/146 GHz.
  - Significant nighttime depth on BOSS N *and* D56 (0h) fields.



ACTPol season 1 results

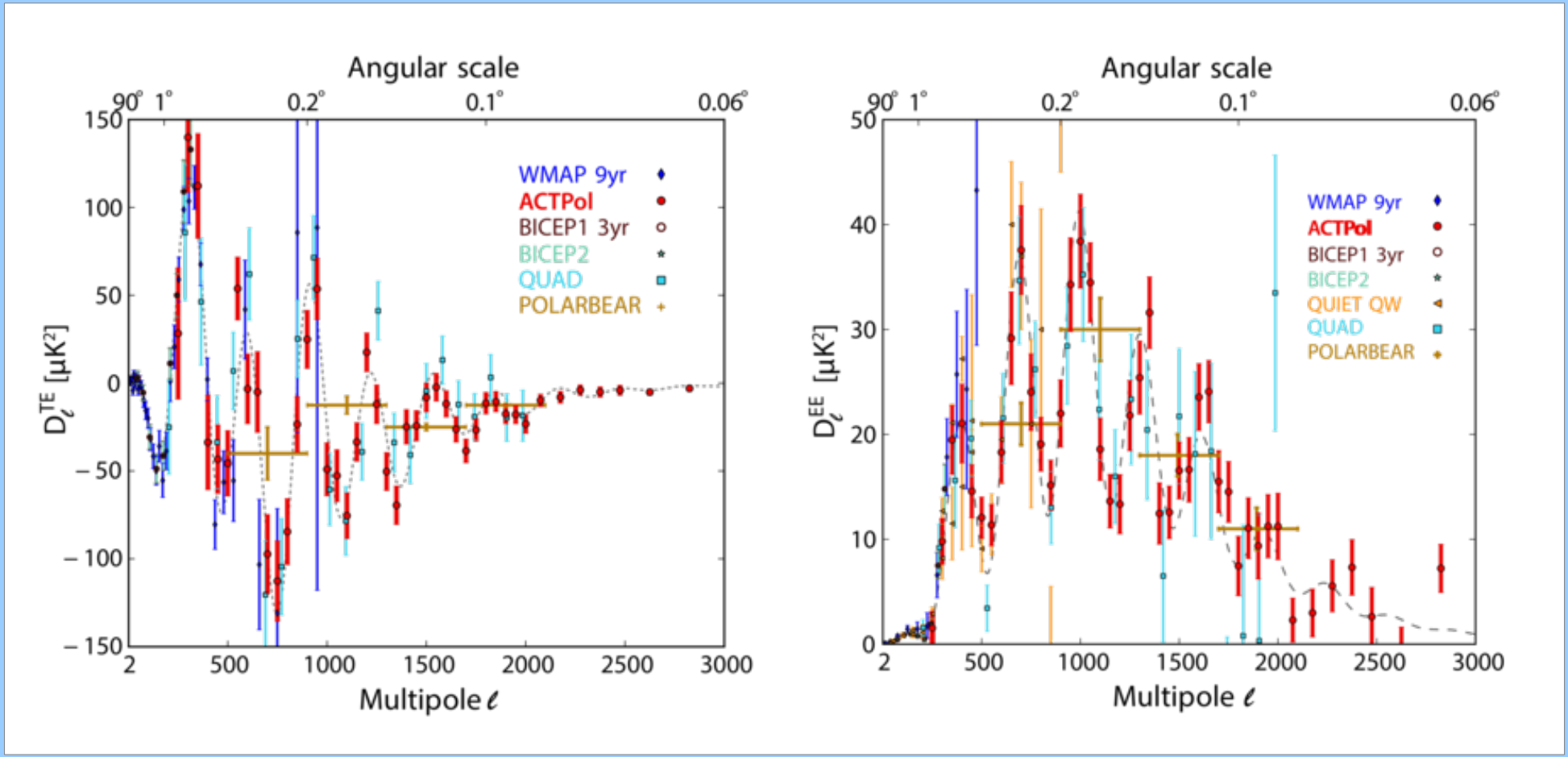
- 3 months of observations with 1 detector array at 146 GHz; about 5% of total data.



Naess et al (2014) – JCAP; arXiv:1405.5524

ACTPol season 1 results

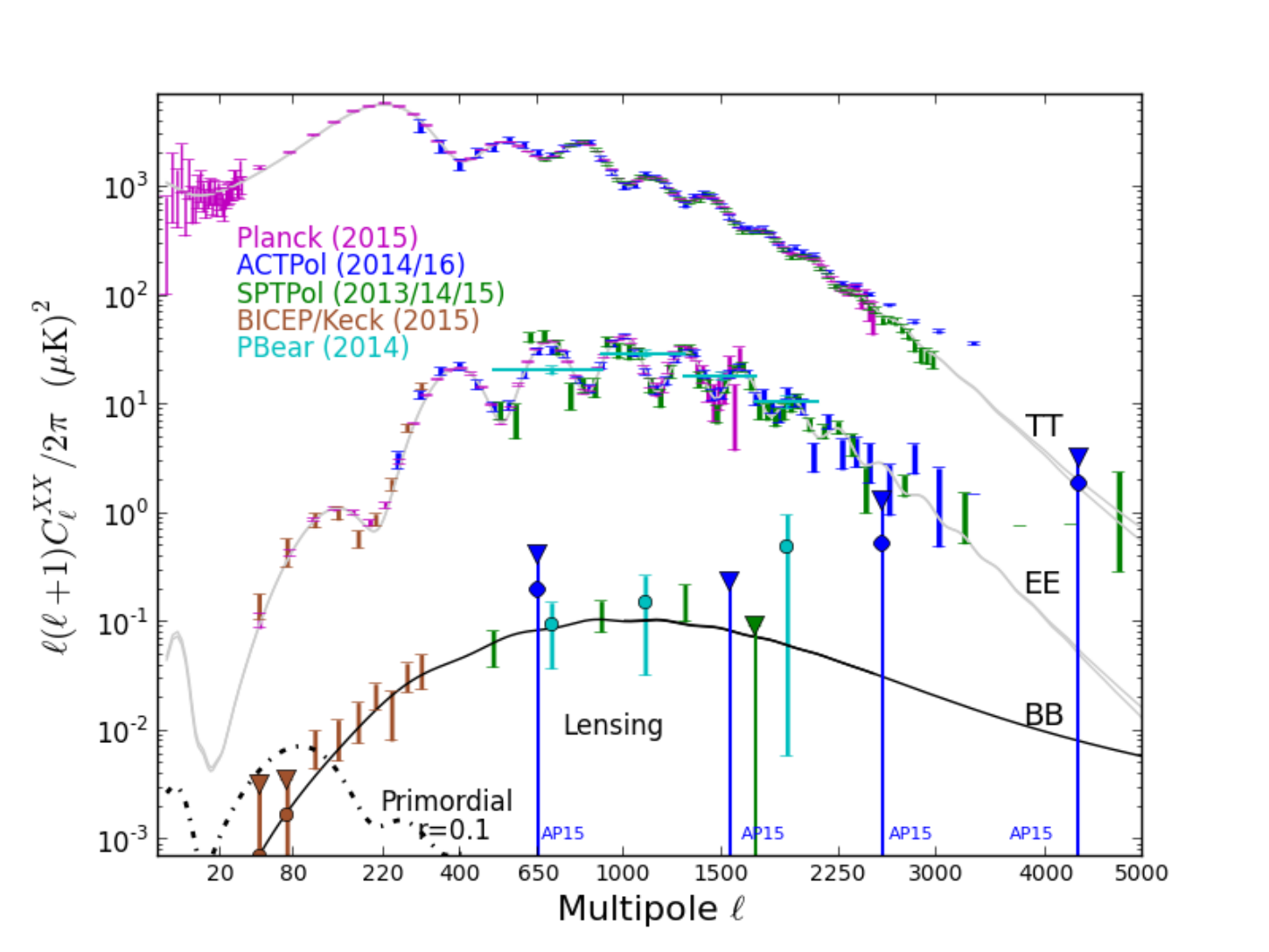
- T,E,B spectra (TE and EE shown below).
- Consistent with *Planck* cosmological parameters.



Naess et al (2014)

Recent CMB spectrum measurements

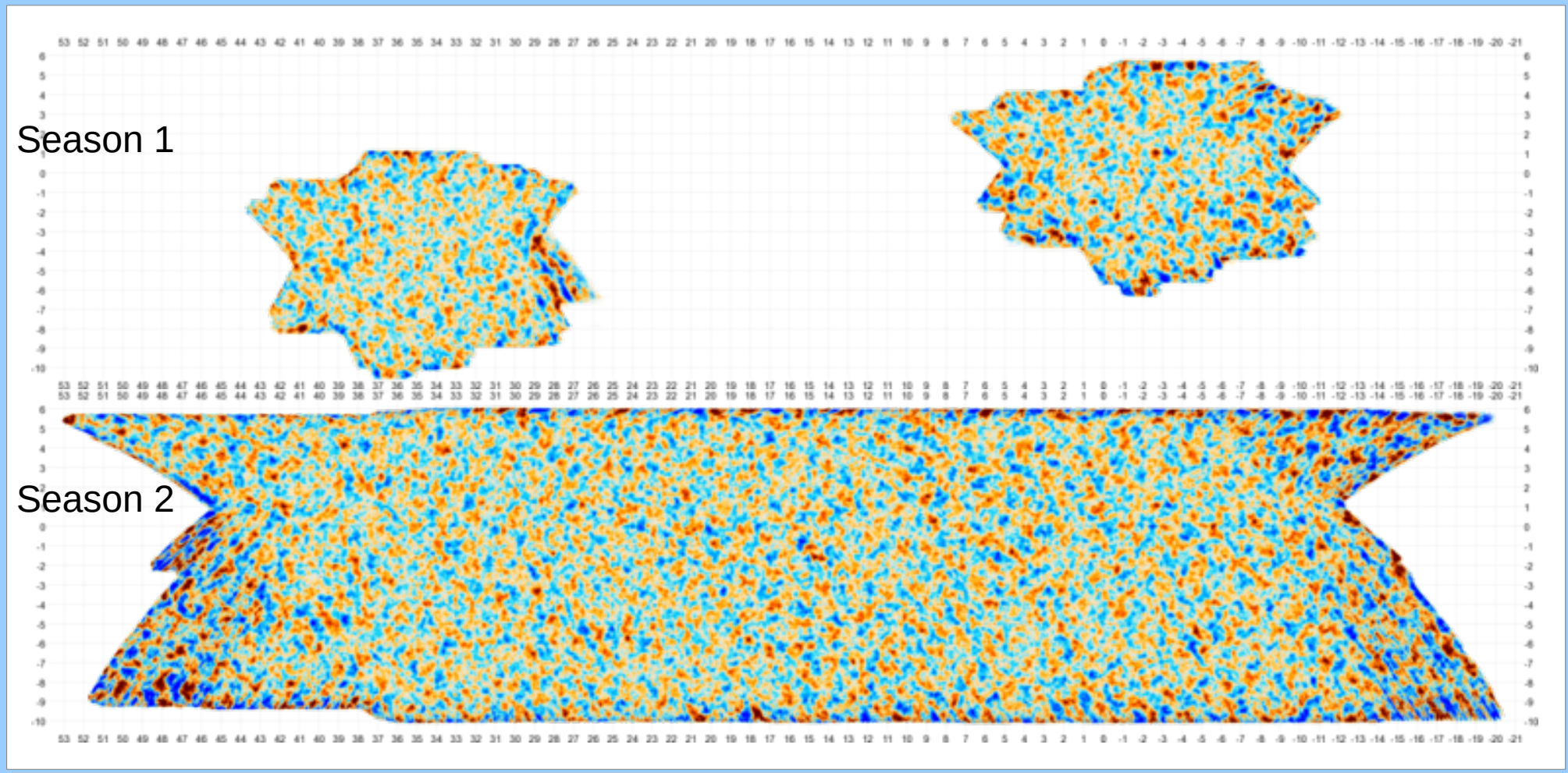
- *Planck* provides strong baseline… but not cosmic variance limited.
- Ground-based groups measuring lensing B modes and constraining tensor/scalar ratio.



From L. Page

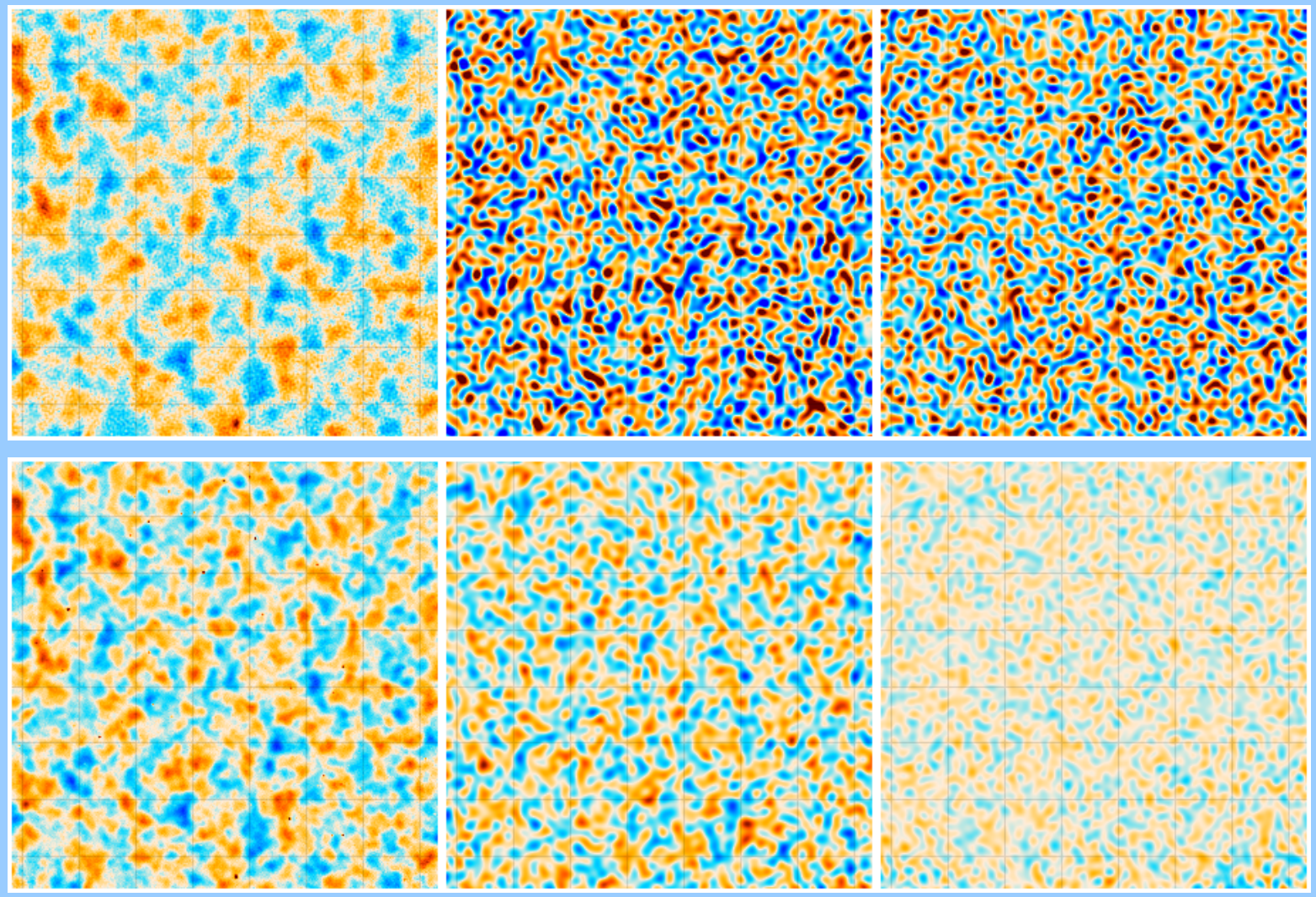
ACTPol – next steps: Season 2 maps

- Season 2 (2014) observations: fill in region between RA=0h and RA=3h deep fields.
- Intensity and polarization maps now in null-test phase.



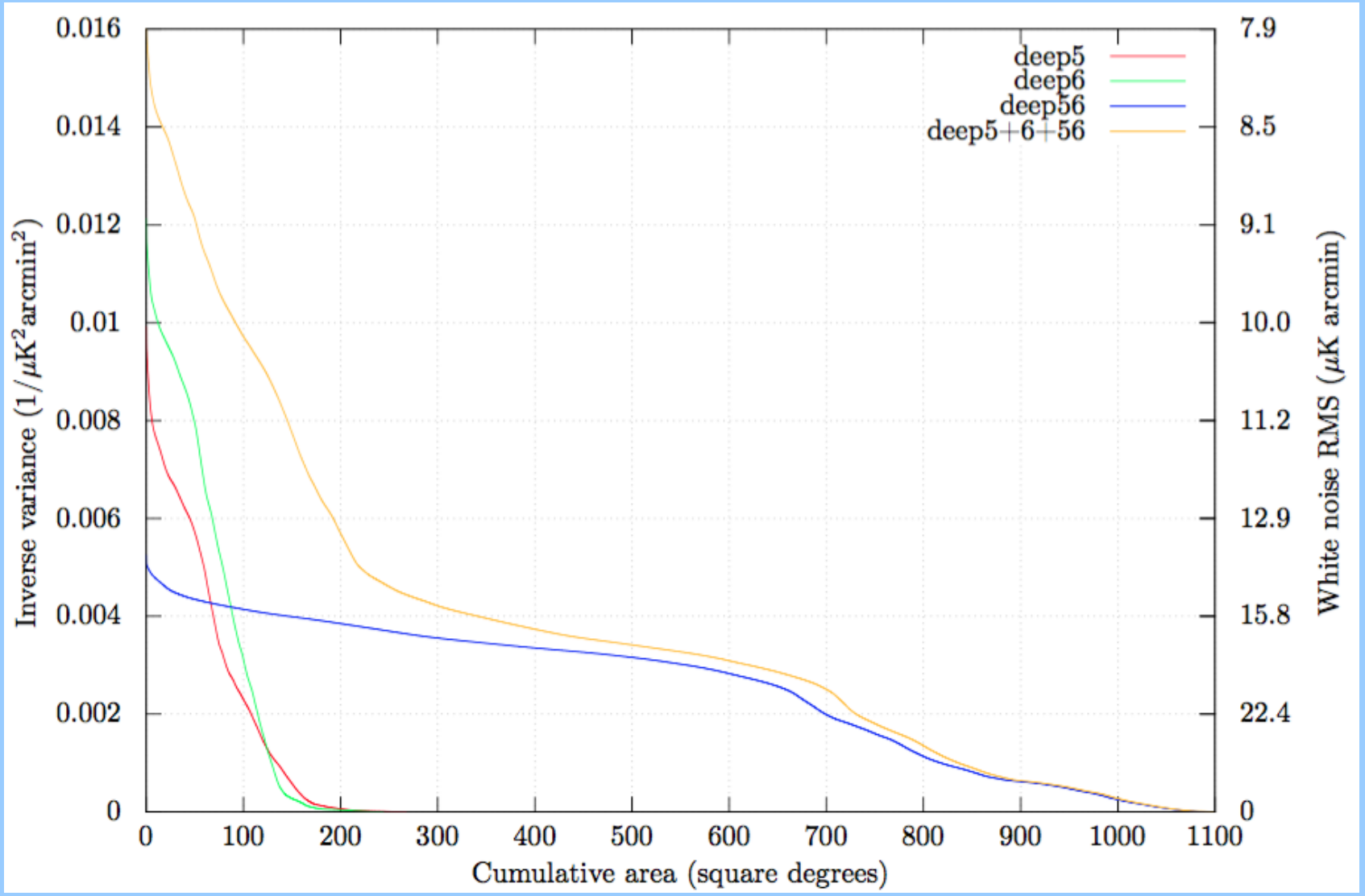
ACTPol – next steps: Season 2 maps

- Zoom in on one of deepest regions in S1+S2 dataset and compare to *Planck.*
  - Colorscale for T: ±250 μK; for E,B: ±25 μK.
  - All data high-pass filtered at ell=200. Polarization low-pass at ell=1900.



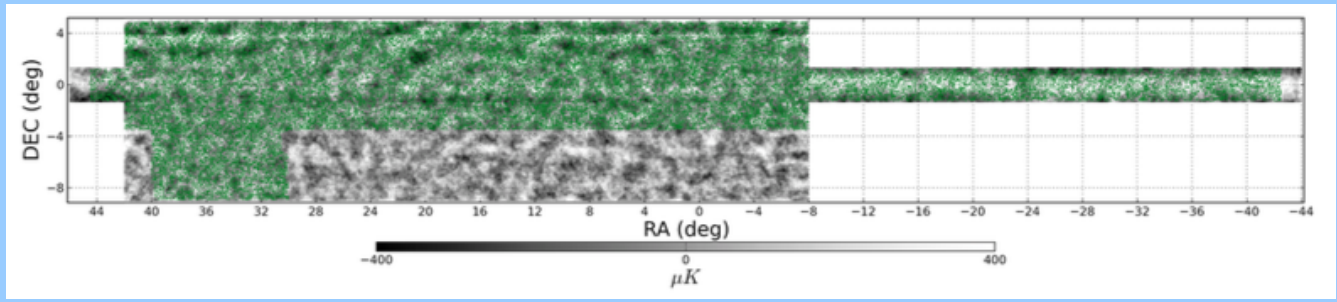
ACTPol – next steps: Season 2 maps

- Season1 + Season2 nighttime data – (15% of all data to Dec. 2015)
  - Deep regions complemented by wider coverage for total of ~700 deg^2.

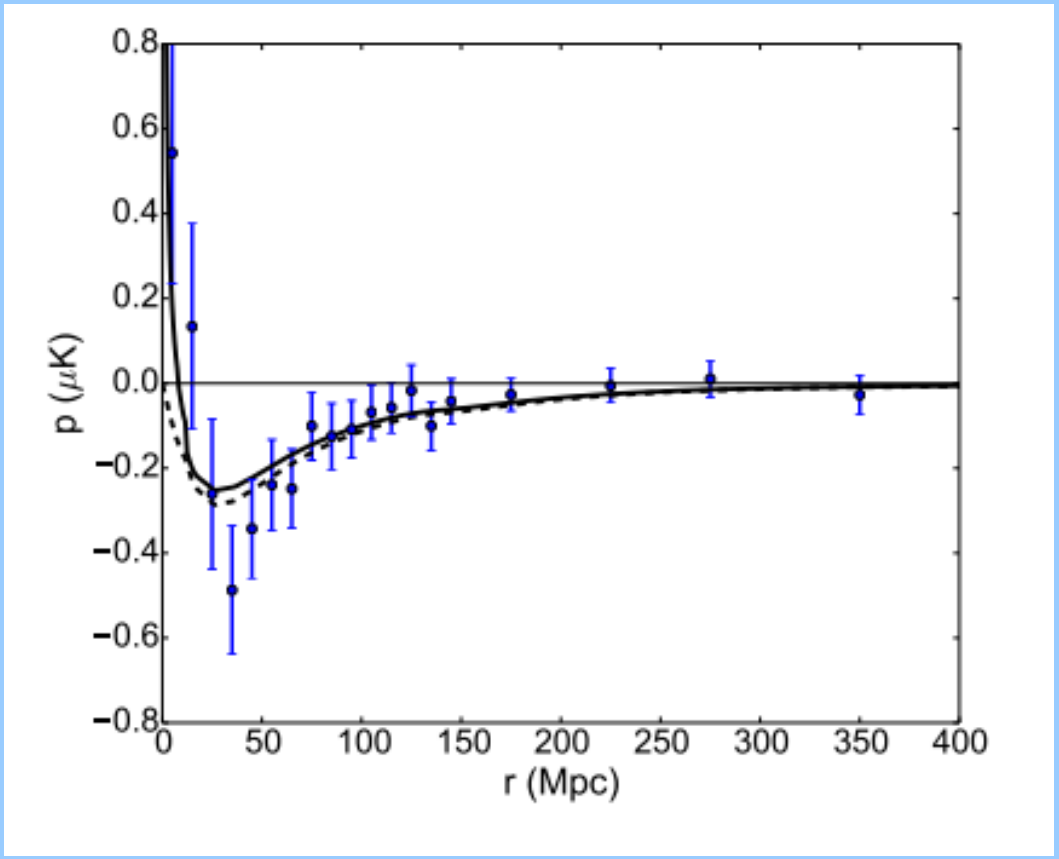


ACTPol: kSZ study on season 1+2 maps

- Kinetic Sunyaev-Zeldovich effect – new detection using ACTPol S1+S2 data and BOSS DR11 LSS sample. (De Bernardis et al, arXiv:1607.02139).



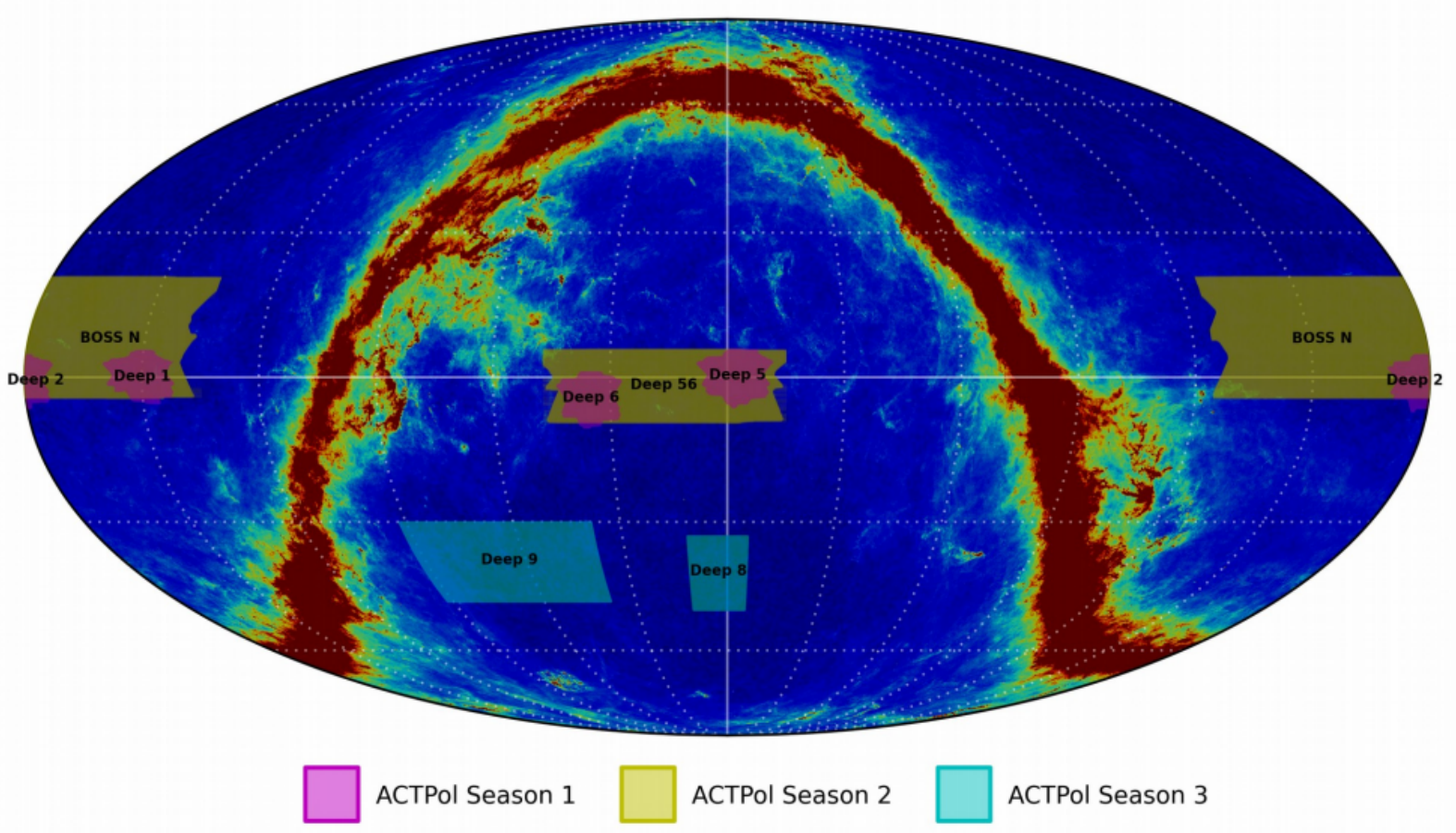
- Use 50000 galaxies from BOSS; identify pairs and subtract ACTPol signal. Bin in galaxy separation.
- This is a measure of the mean pair-wise momentum as a function of separation.
- Detection significance of 3.6 to 4.1 depending on luminosity cut.



- ACTPol Season 3 (2015) data will add substantially to this result...

ACTPol – next steps: season 3 maps

- Moving to our Season 3 (2015) data:
  - More nighttime depth on deep56 field (RA 00h-03h).
  - But even more depth on RA 12h field – BOSS North; ~1600 deg^2 ← very significant for lensing and kSZ studies.
  - 90 GHz data from multichroic array.
  - First data with continuously rotating Half-Wave Plate.



Continuously rotating warm Half-wave Plate

- Spinning HWP modulates polarization information to frequencies above atmospheric 1/f knee.
- Significant suppression demonstrated by ABS experiment
- ACTPol: preliminary HWP data (Sapphire and meta-material construction) acquired in 2015 and early 2016 and under analysis.

Broadband HWP installed on ACTPol receiver.

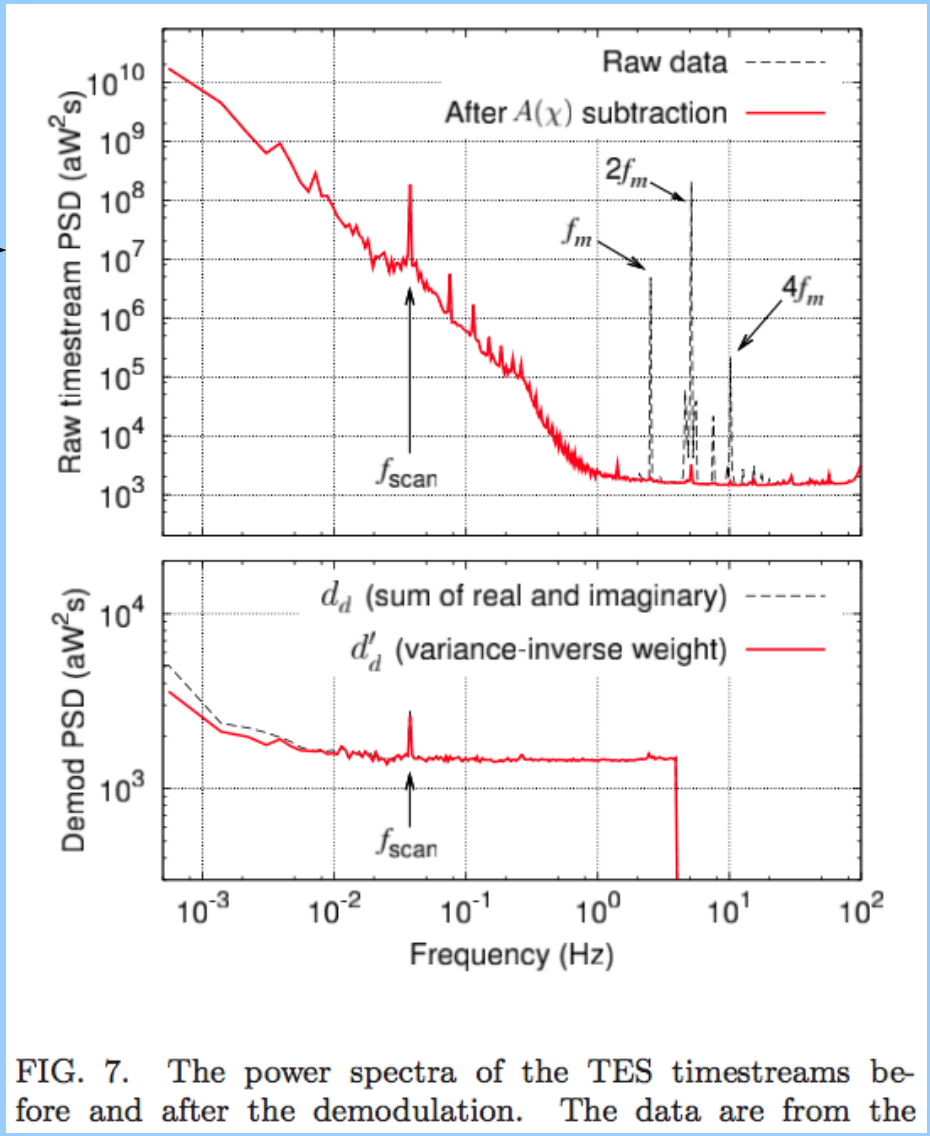


FIG. 7. The power spectra of the TES timestreams before and after the demodulation. The data are from the

ABS - Kusaka et al (2014)

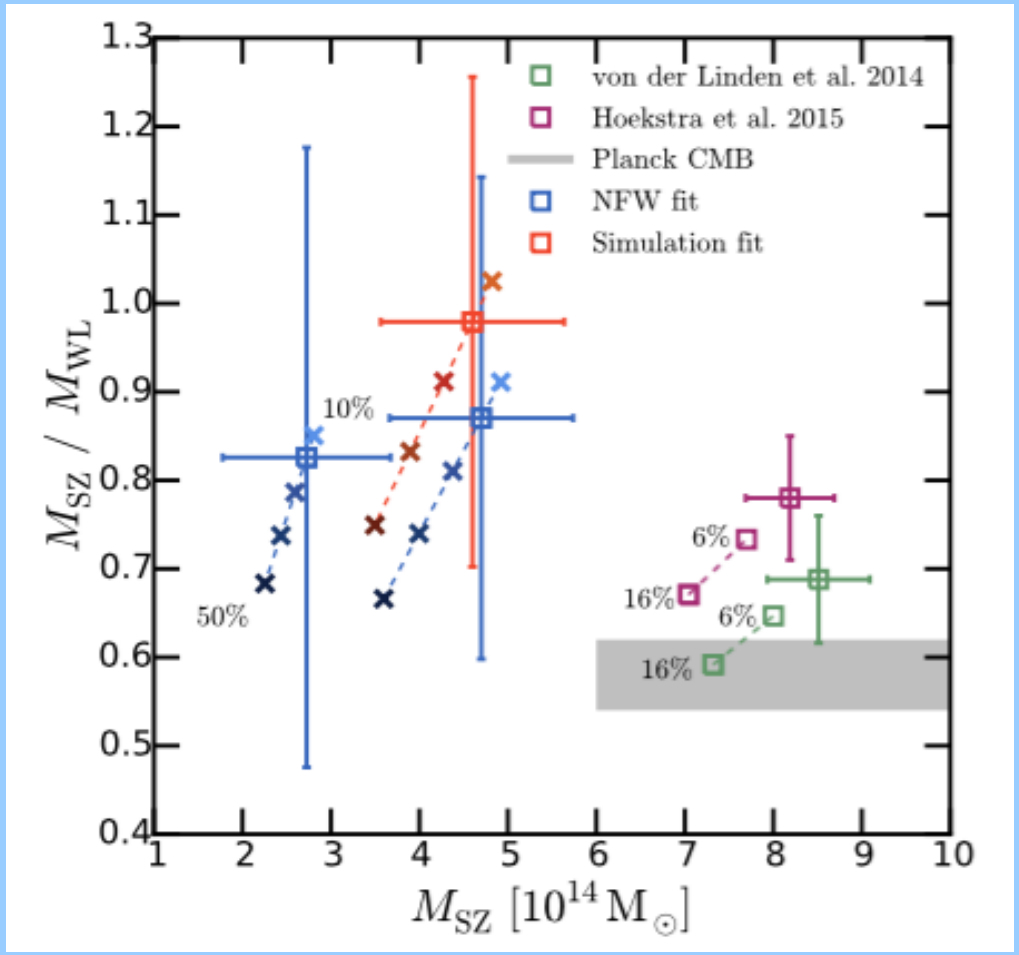
Galaxy cluster cosmology – mass calibration

- Mass calibration is the main systematic limiting cosmological constraints from galaxy clusters.
- ACT preliminary study – follow up a complete ACT sample of clusters in CFHT's "CS82" weak lensing map to compare WL and SZ masses (Battaglia et al, 2016).

$M_{WL} = (4.8 \pm 0.8) \times 10^{14}\ M_{\odot}$

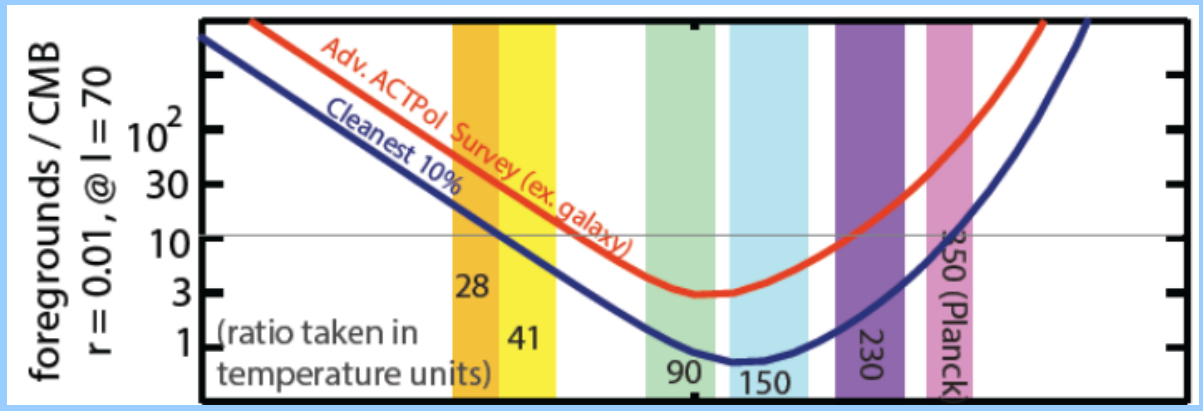
$M_{SZ} = (4.7 \pm 1.0) \times 10^{14}\ M_{\odot}$

- Attention to sample selection and other systematic biases is extremely important.
- Pre-cursor to what can be done with upcoming Hyper Suprime-cam (HSC) surveys.



Advanced ACTPol: 2016+

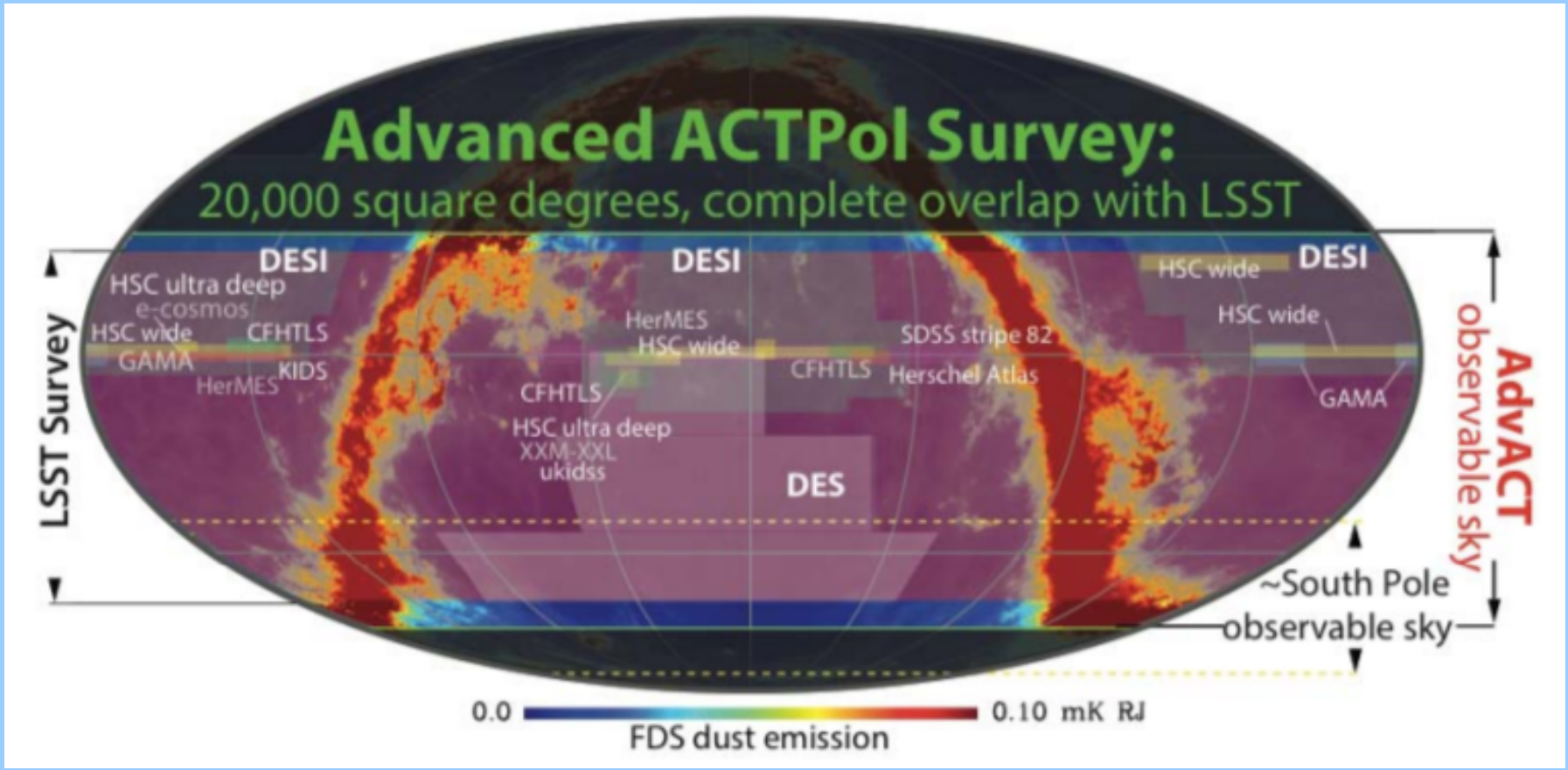
- Next phase of ACT observations:
  - Map half the sky, in 5 bands, over the next 5 years.
  - Aim for *Planck*-like noise in temperature, but also in polarization, and at higher resolution.



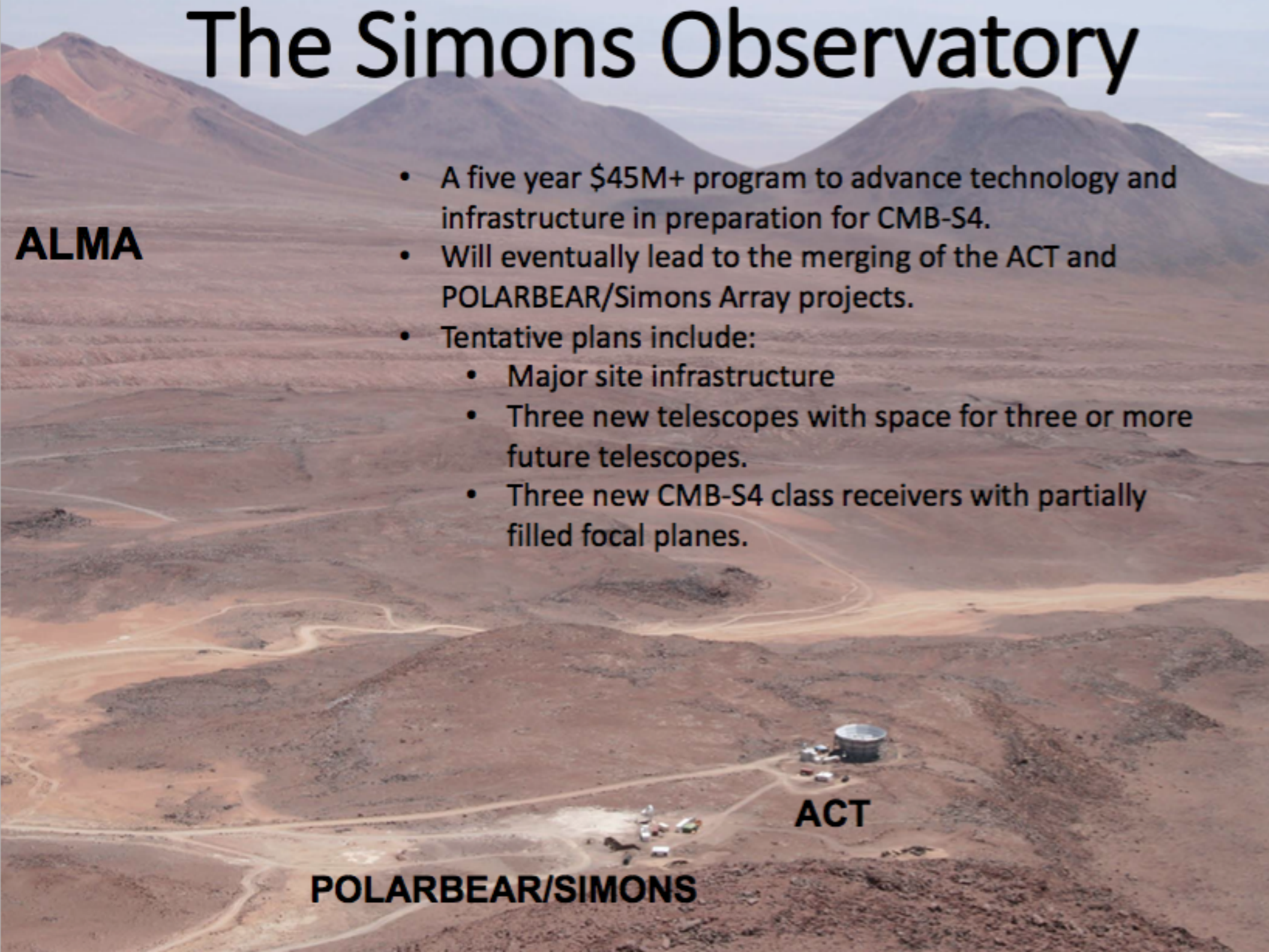
Detector Array	Center Freq. [GHz]	Width [GHz]	# TES –	Projected Map Noise [μK-arcmin]	beam size [arcmin]
LF	28	6	88	80	7.1
LF	41	19	88	70	4.8
MF	90	39	1712	8	2.2
MF/HF	150	41	2718	7	1.4
HF	230	100	1006	25	0.9

Advanced ACTPol: 2016+

- Next phase of ACT observations:
  - Map half the sky, in 5 bands, over the next 5 years.
  - Aim for *Planck*-like noise in temperature, but also in polarization, and at higher resolution.
- Upgrades:
  - Multi-chroic detectors and improved readout to double detector density (~6000).
  - HWP for atmospheric suppression.



The Simons Observatory



- A five year $45M+ program to advance technology and infrastructure in preparation for CMB-S4.
- Will eventually lead to the merging of the ACT and POLARBEAR/Simons Array projects.
- Tentative plans include:
  - Major site infrastructure
  - Three new telescopes with space for three or more future telescopes.
  - Three new CMB-S4 class receivers with partially filled focal planes.