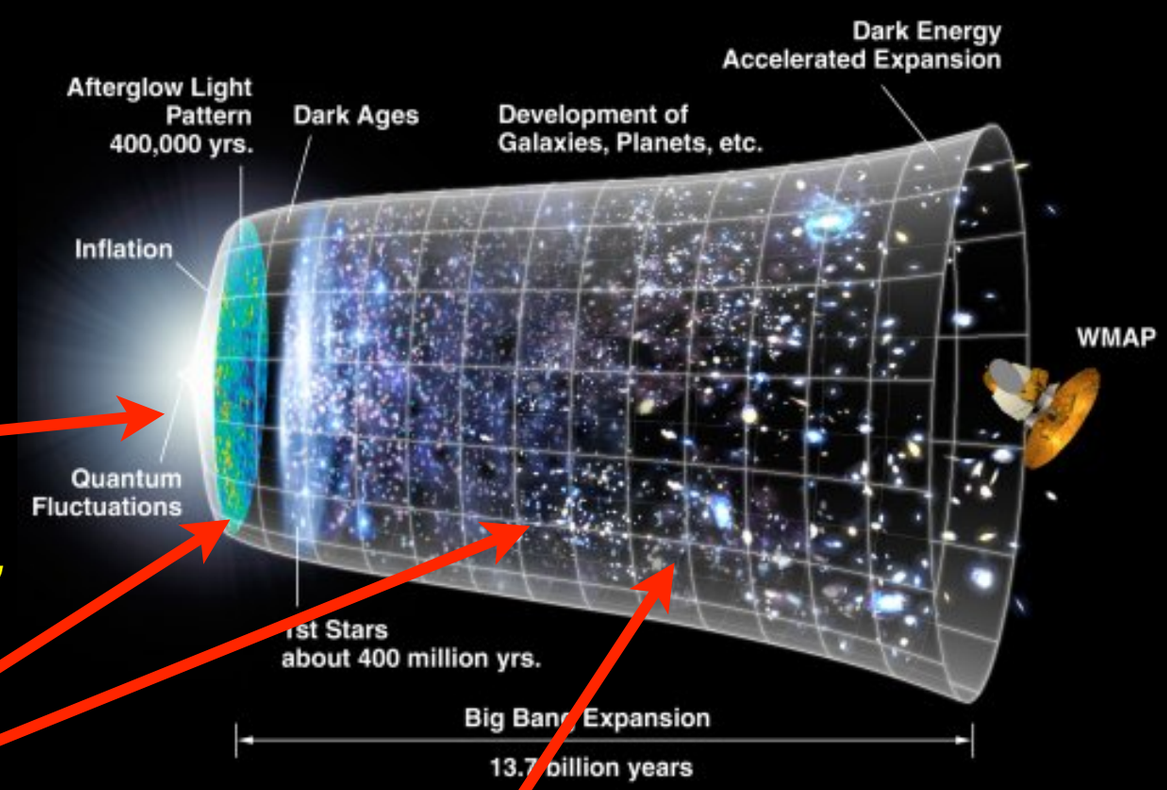
The South Pole Telescope (SPT)

Bradford Benson
Fermilab, U. Chicago
ICHEP August 6, 2016

CMB Measurements Probe Cosmology and Fundamental Physics



1) Inflation

- Spectral index of fluctuations
- Non-Gaussianity
- ***Energy-scale of Inflation (10^{16} GeV)***, *from B-mode polarization*

2) Neutrinos

- Measure the relativistic energy density of the Universe, and any ***"Dark Radiation"*** (e.g., Sterile Neutrinos)
- ***Sum of the neutrino masses***, through their impact on the growth of structure, CMB lensing and clusters of galaxies

3) Dark Energy

- "Early" dark energy
- Clusters of galaxies
- Tests of General Relativity

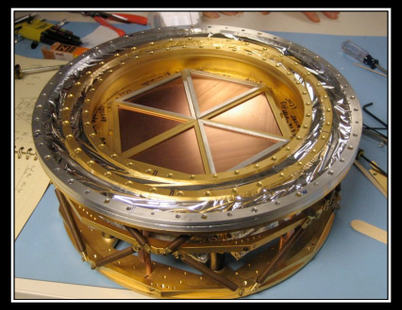
graphic from NASA/WMAP

The South Pole Telescope (SPT)

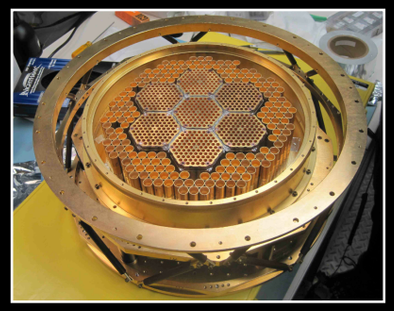
10-meter sub-mm quality wavelength telescope

100, **150**, **220** GHz and
1.6, **1.2**, **1.0** arcmin resolution

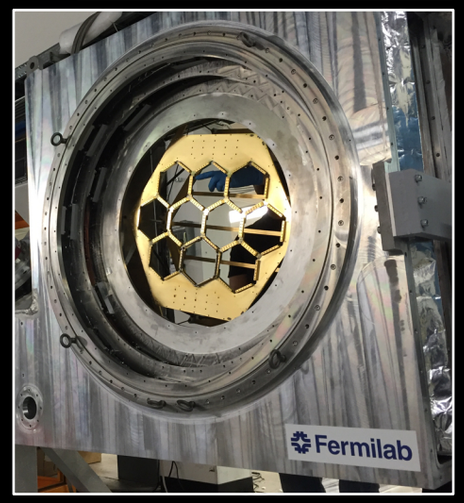
2007: SPT-SZ
960 detectors
100,150,220 GHz

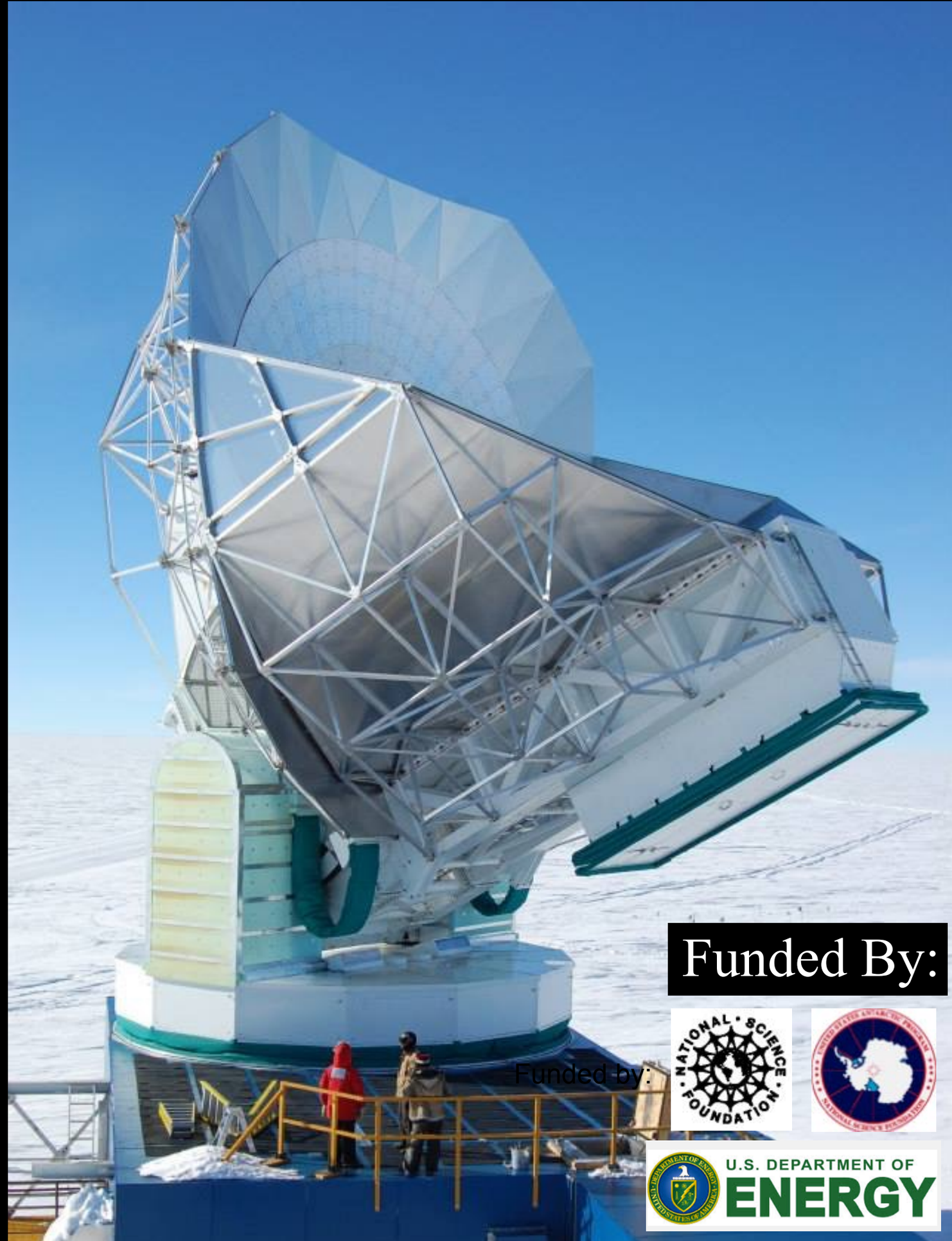


2012: SPTpol
1600 detectors
100,150 GHz
+Polarization



2016: SPT-3G
~16,200 detectors
100,150,220 GHz
+Polarization





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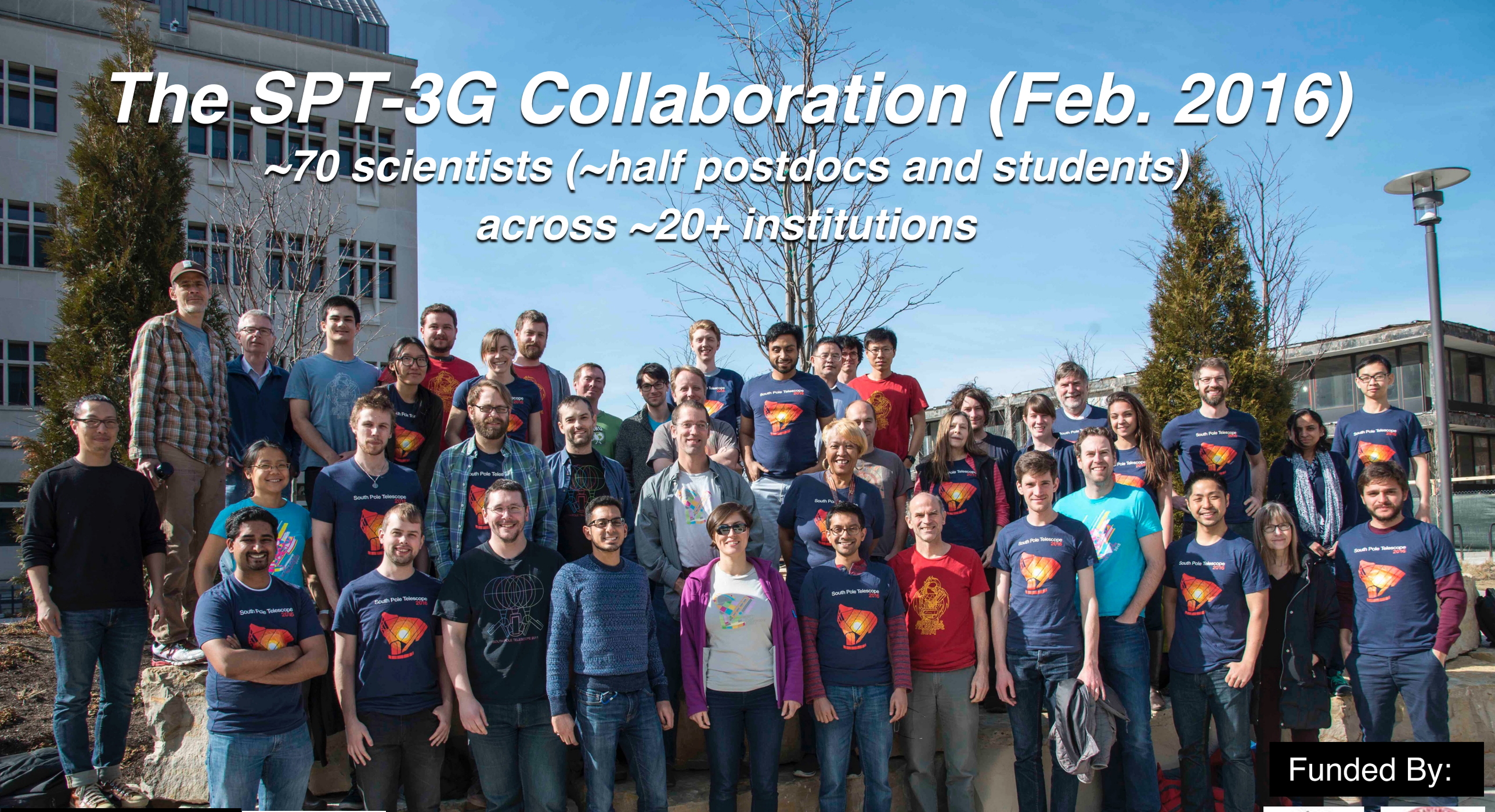
U.S. DEPARTMENT OF ENERGY

The SPT-3G Collaboration (Feb. 2016)

~70 scientists (~half postdocs and students) across ~20+ institutions



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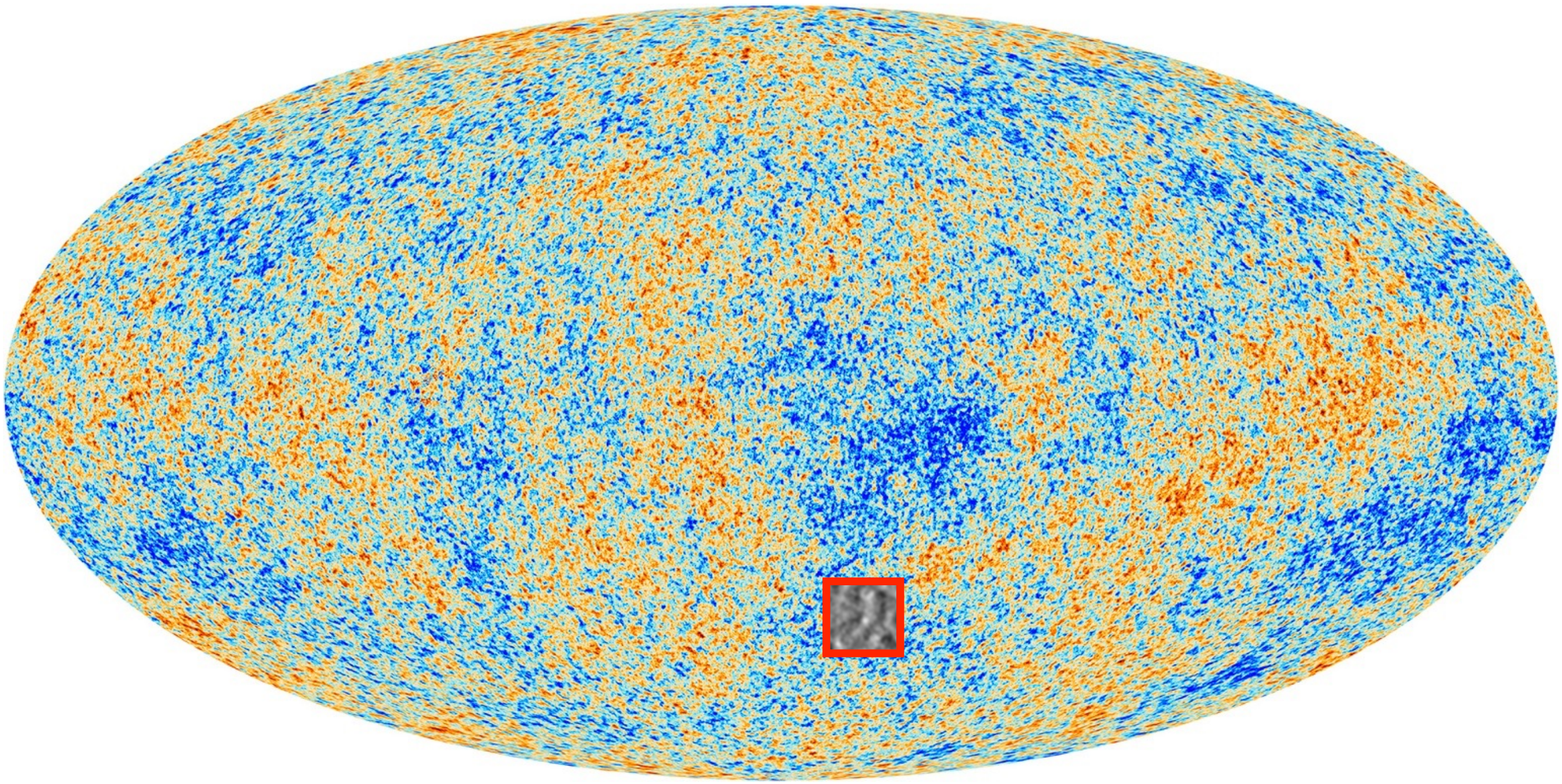
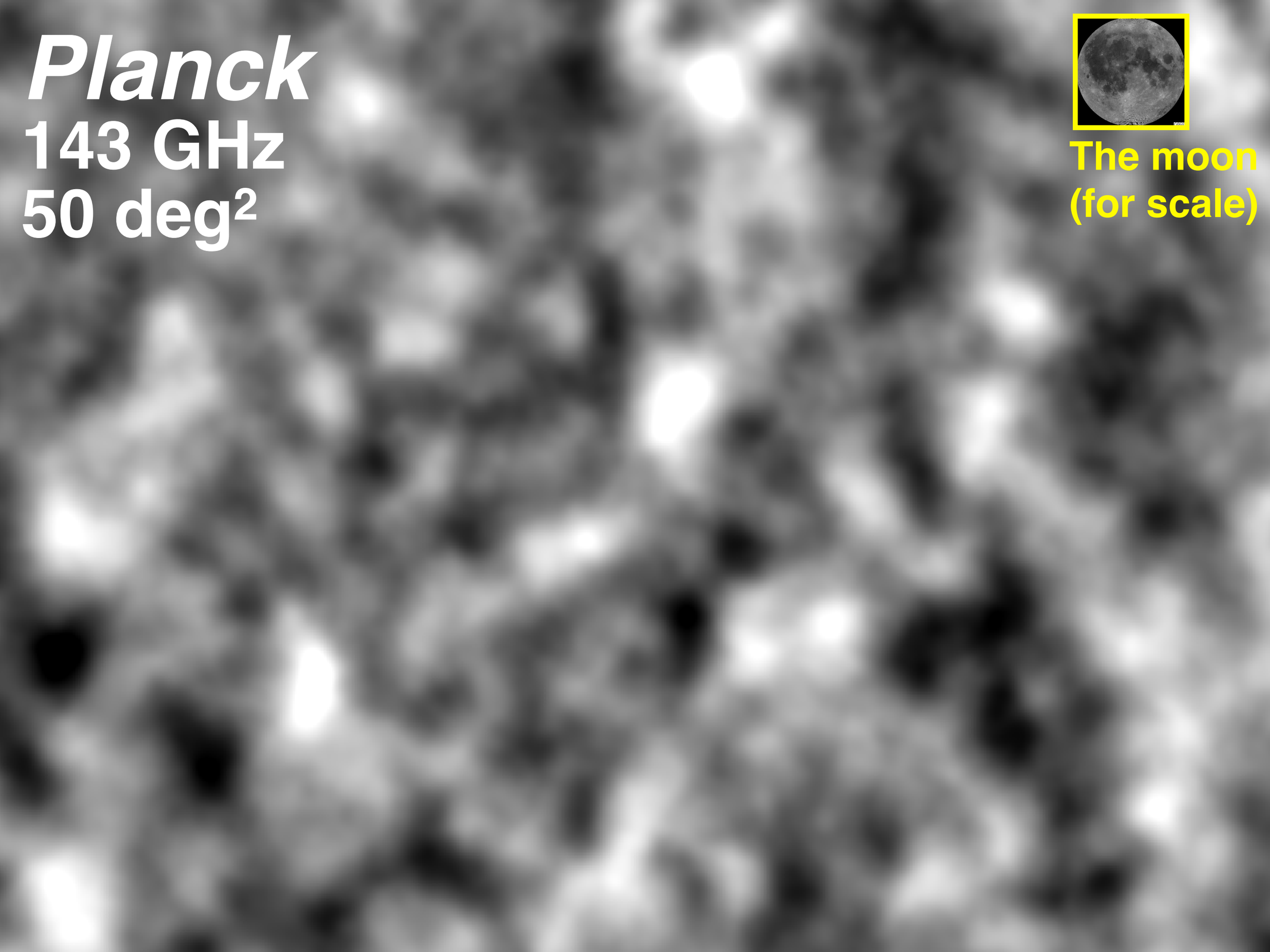
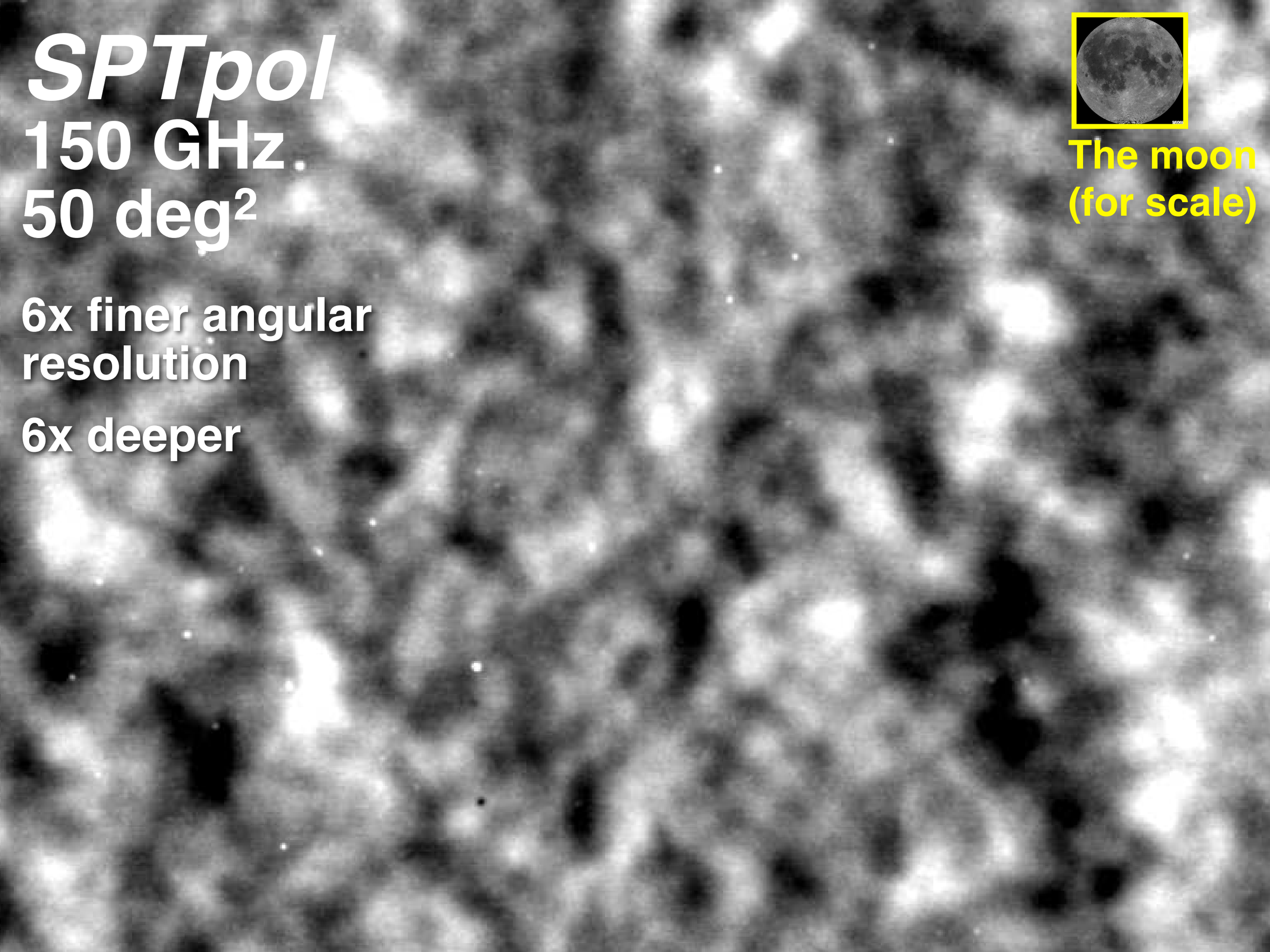
2013: Planck

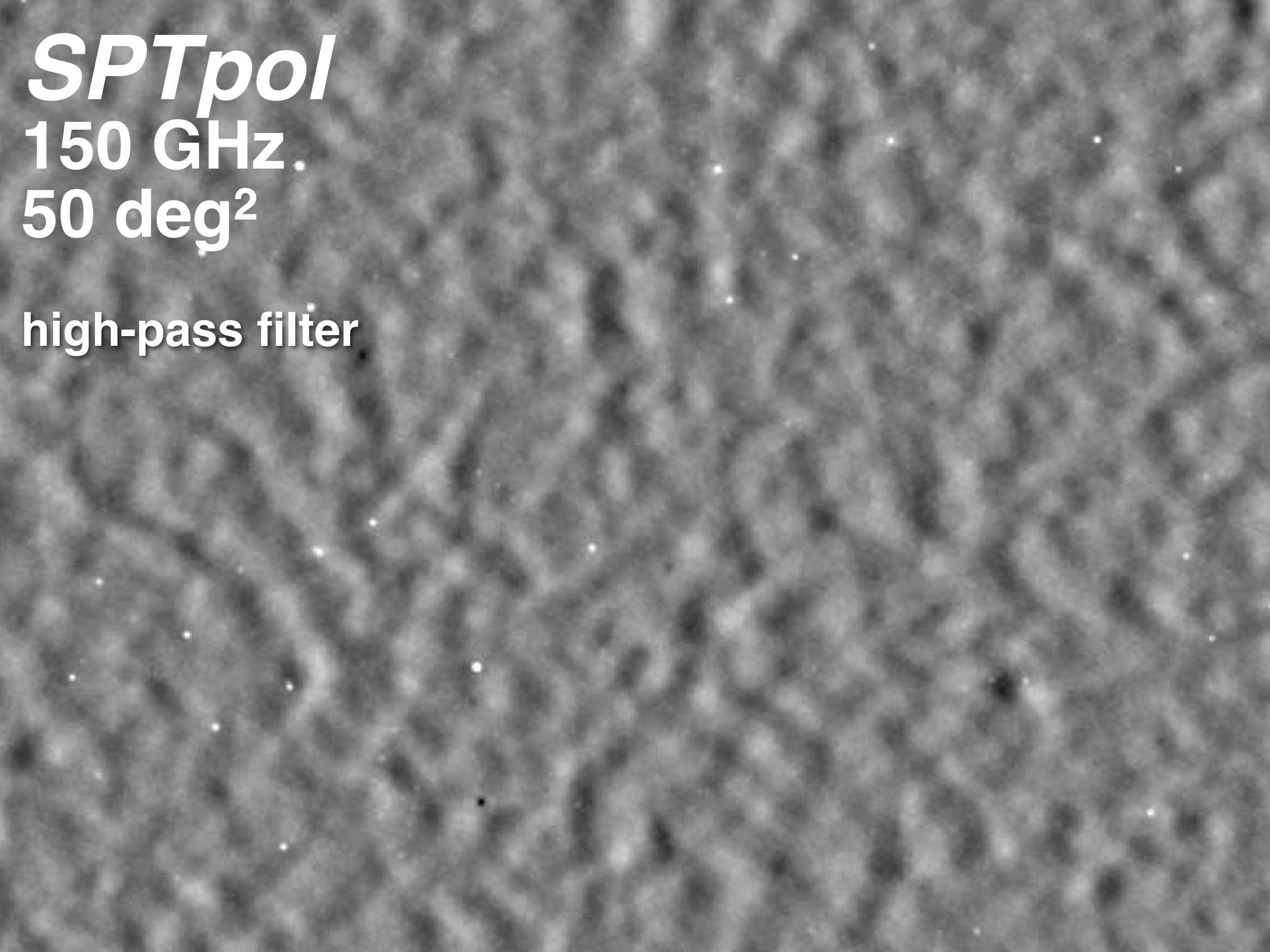
30μK RMS fluctuations on 3 K background

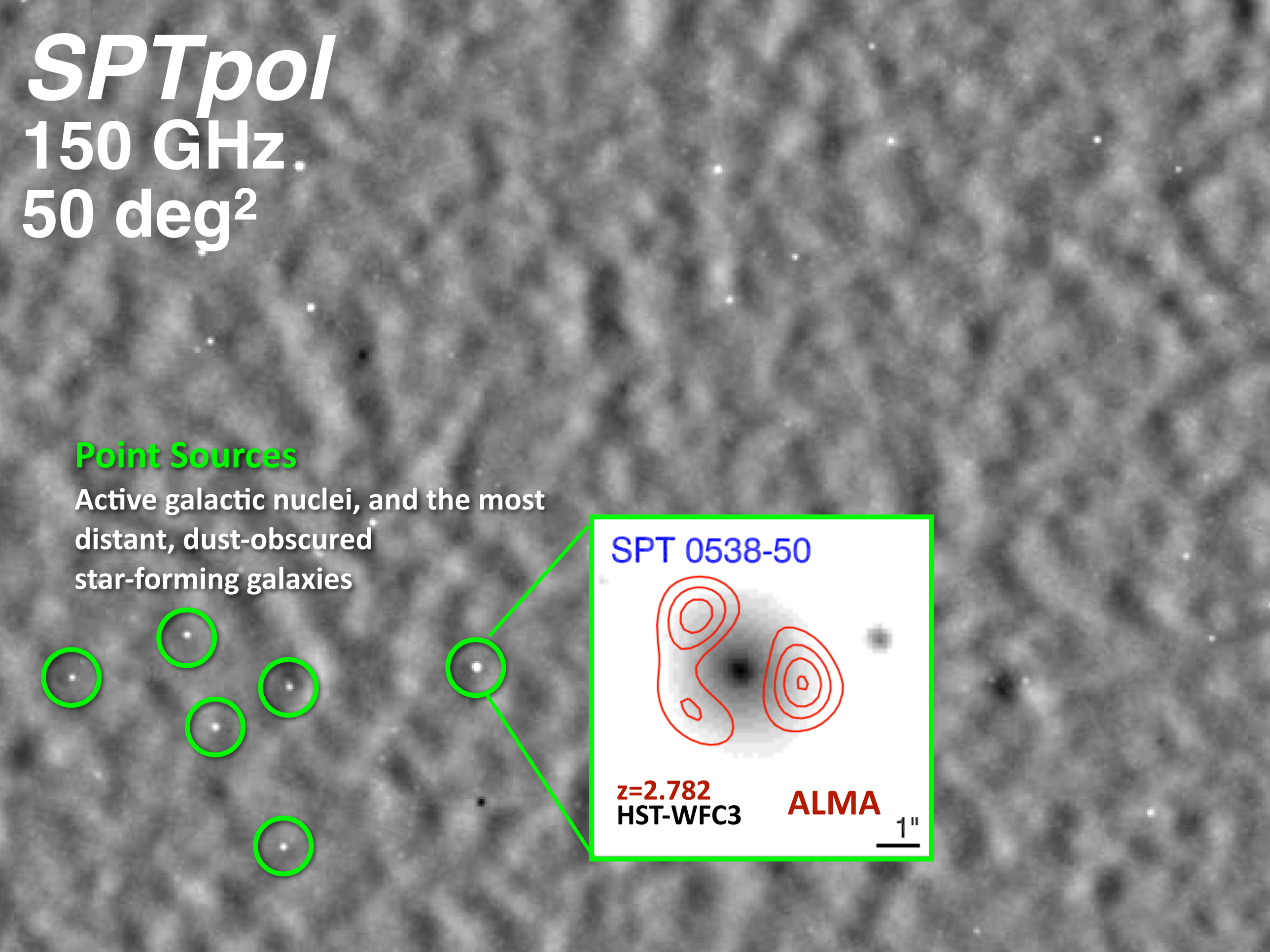


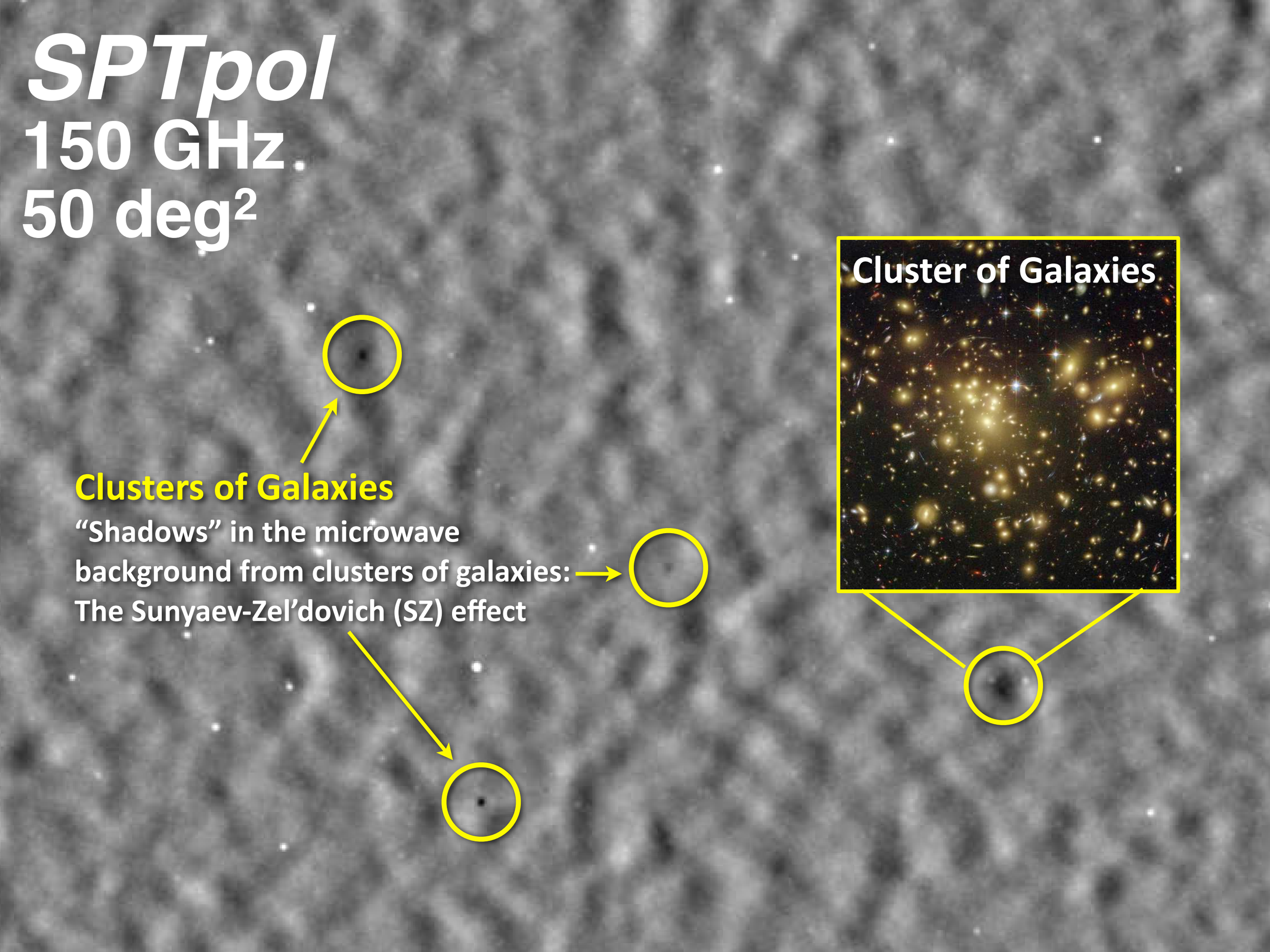
Credit: ESA (Planck)


Planck
143 GHz
50 deg²
The moon
(for scale)

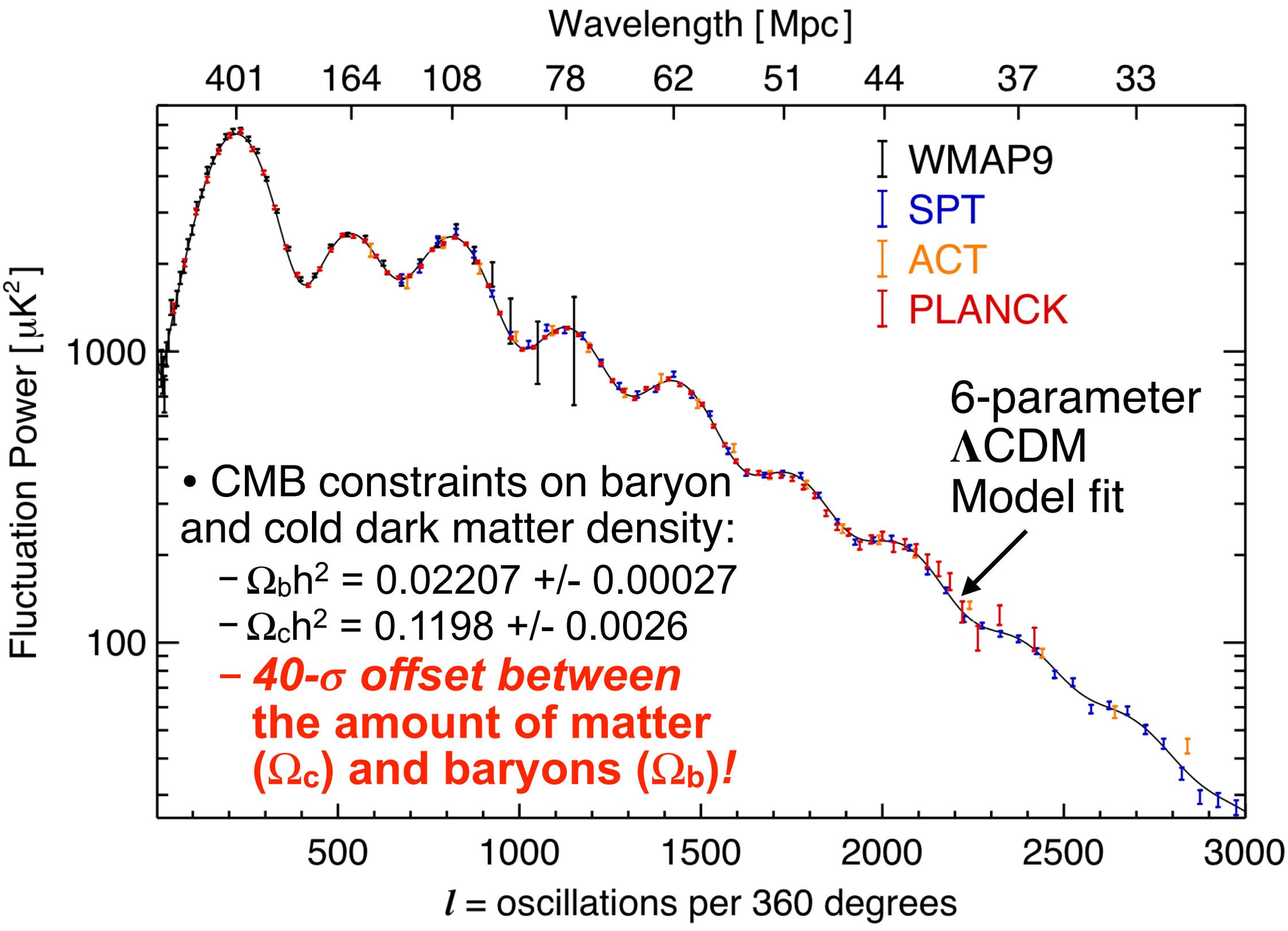

SPTpol
150 GHz
50 deg²
6x finer angular resolution
6x deeper
The moon (for scale)


SPTpol
150 GHz
50 deg²
high-pass filter


SPTpol
150 GHz
50 deg²
Point Sources
Active galactic nuclei, and the most distant, dust-obscured star-forming galaxies
SPT 0538-50
z=2.782
HST-WFC3
ALMA
1"

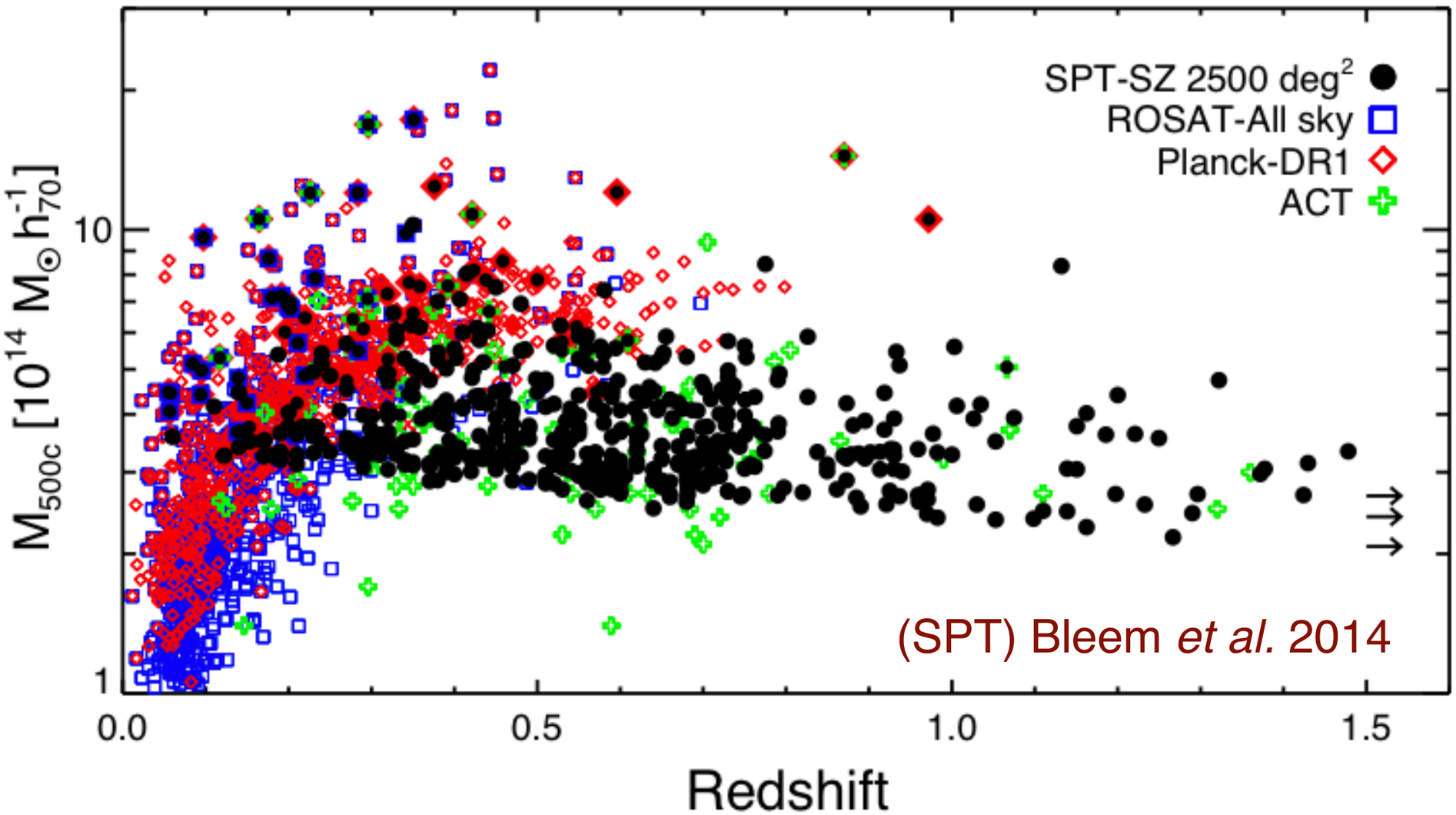

SPTpol
150 GHz
50 deg²
Cluster of Galaxies
Clusters of Galaxies
"Shadows" in the microwave
background from clusters of galaxies:
The Sunyaev-Zel'dovich (SZ) effect

The CMB implies a Universe dominated by dark matter and dark energy (ΛCDM model)



- CMB constraints on baryon and cold dark matter density:
  - $\Omega_b h^2$ = 0.02207 +/- 0.00027
  - $\Omega_c h^2$ = 0.1198 +/- 0.0026
  - ***40-σ offset between* the amount of matter (Ω_c) and baryons (Ω_b)!**

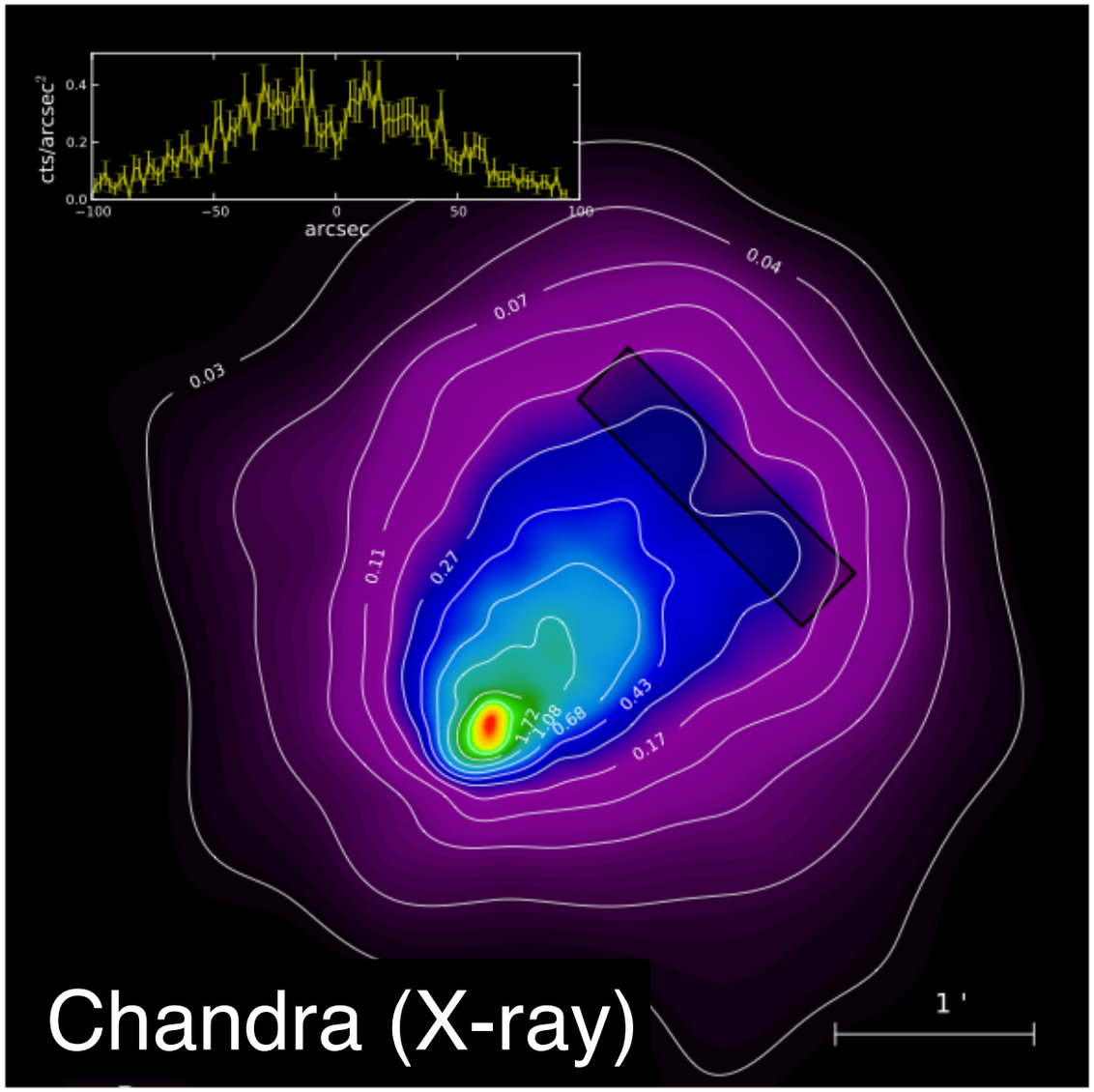
Dark Energy and Sunyaev-Zel'dovich (SZ) Effect Discovered Clusters

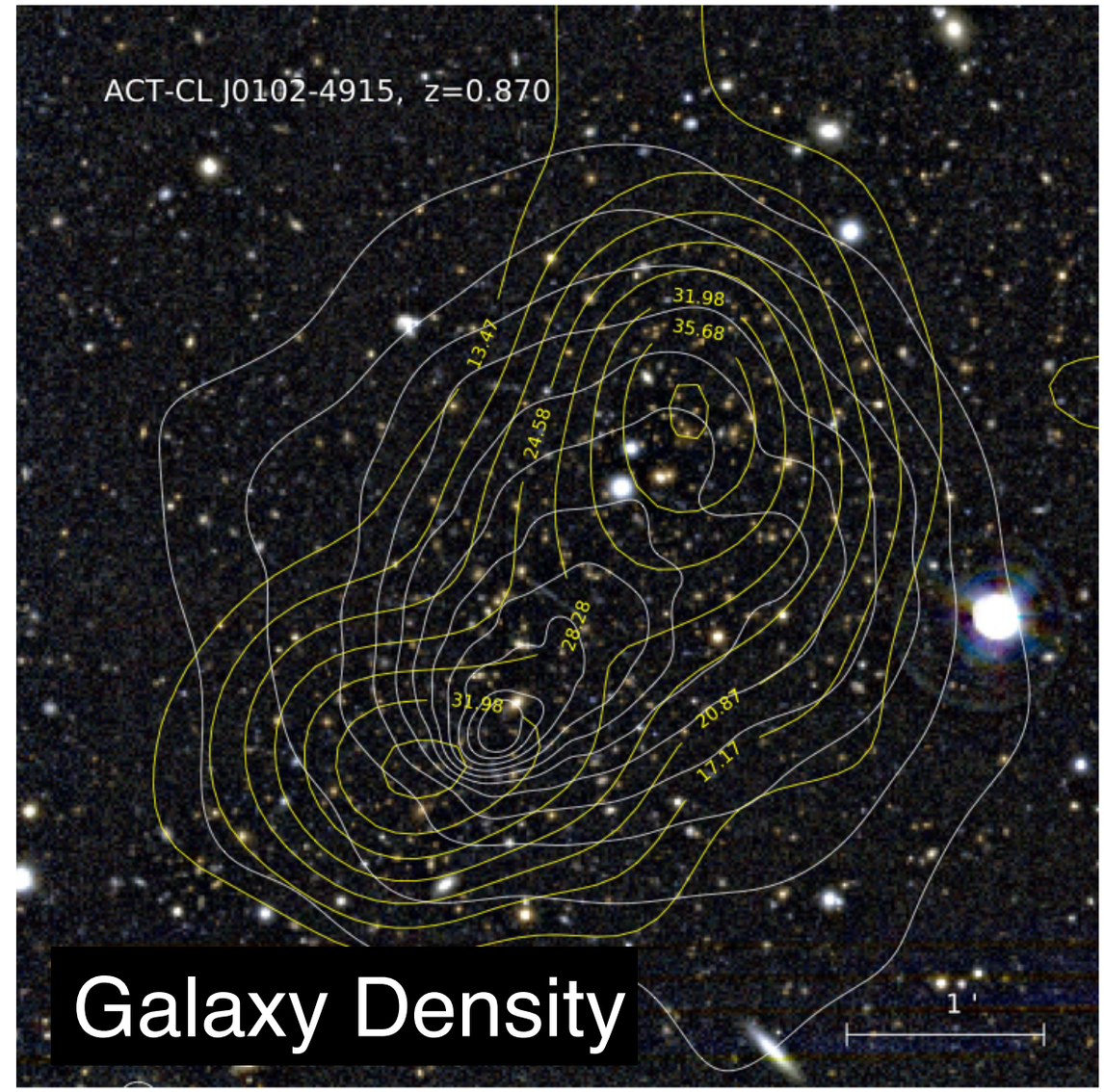


- First SZ-discovered clusters found in 2008 (SPT, Staniszewski+2008), now >1000 SZ-identified clusters
- SZ uniquely provide "clean" samples of the most massive, high-redshift clusters of galaxies

ACT-CL/SPT-CL J0102-4915: "El-Gordo"

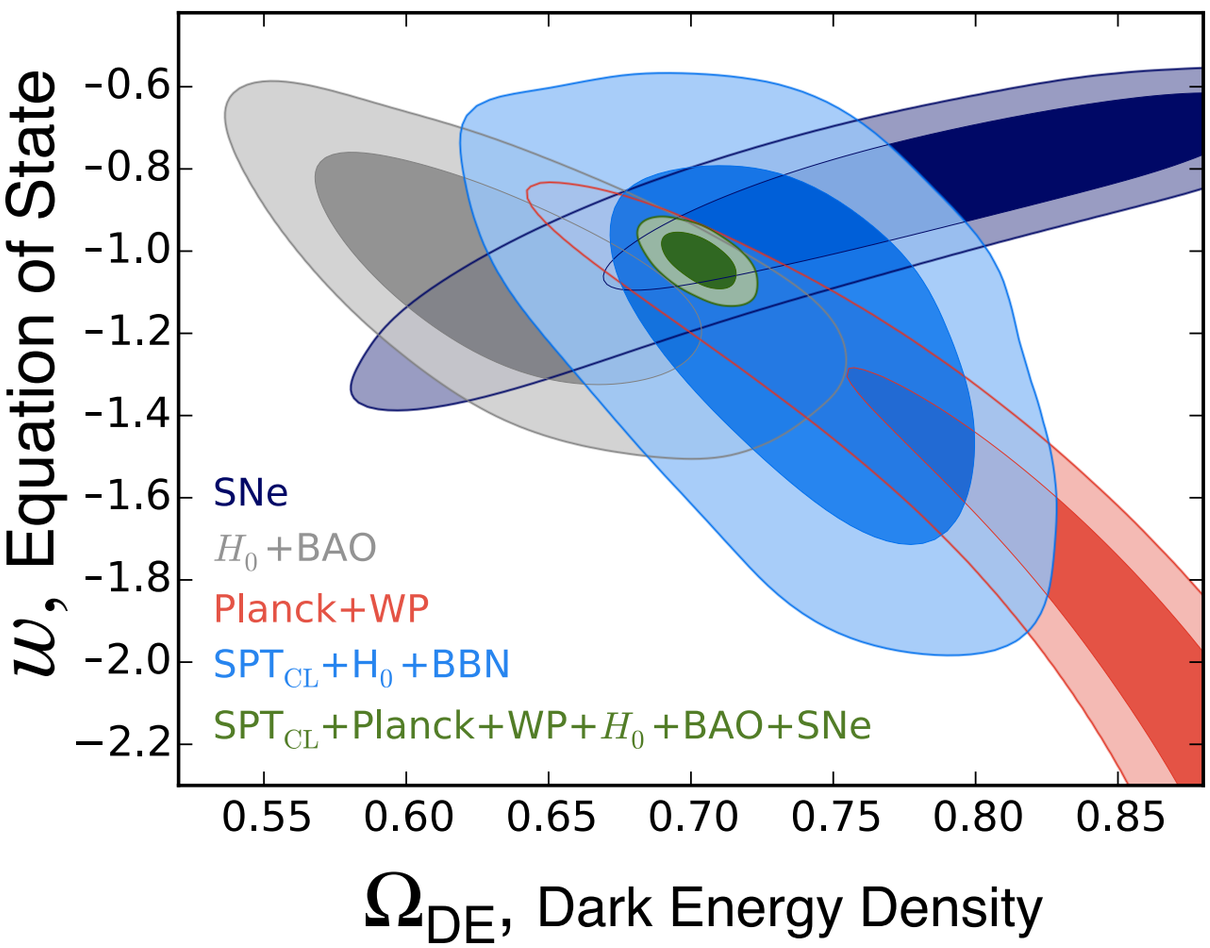
"Rarest" cluster in universe; At z=0.87 with mass, M_{200}, ~ 3 x 10^{15} M_{sun}, above this mass and redshift only 1 cluster expected in Universe.

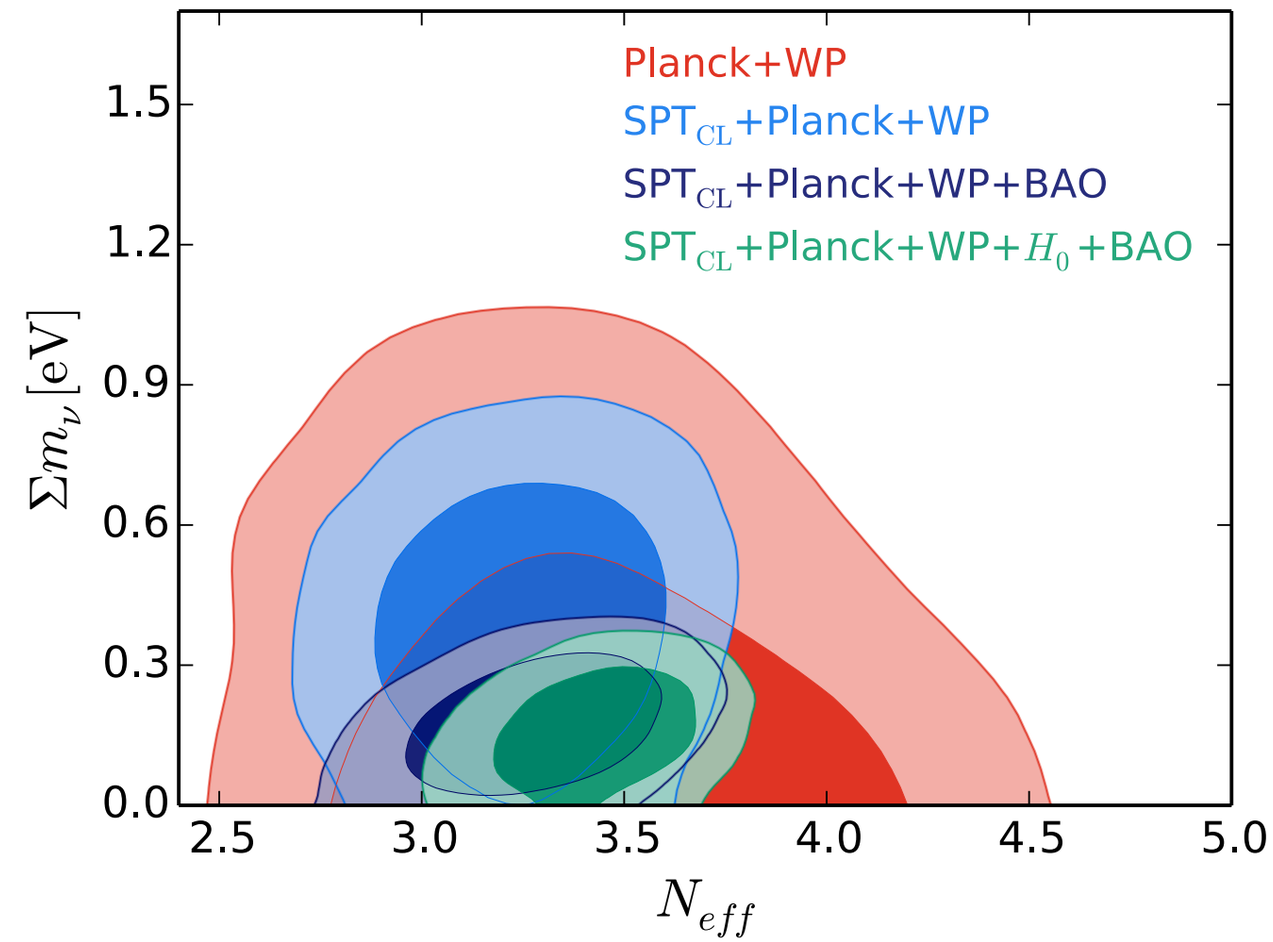




(ACT) Menanteau et al. (2011), (SPT) Williamson et al. (2011), (SPT) Stalder et al. 2013

Dark Energy and Sunyaev-Zel'dovich (SZ) Effect Discovered Clusters



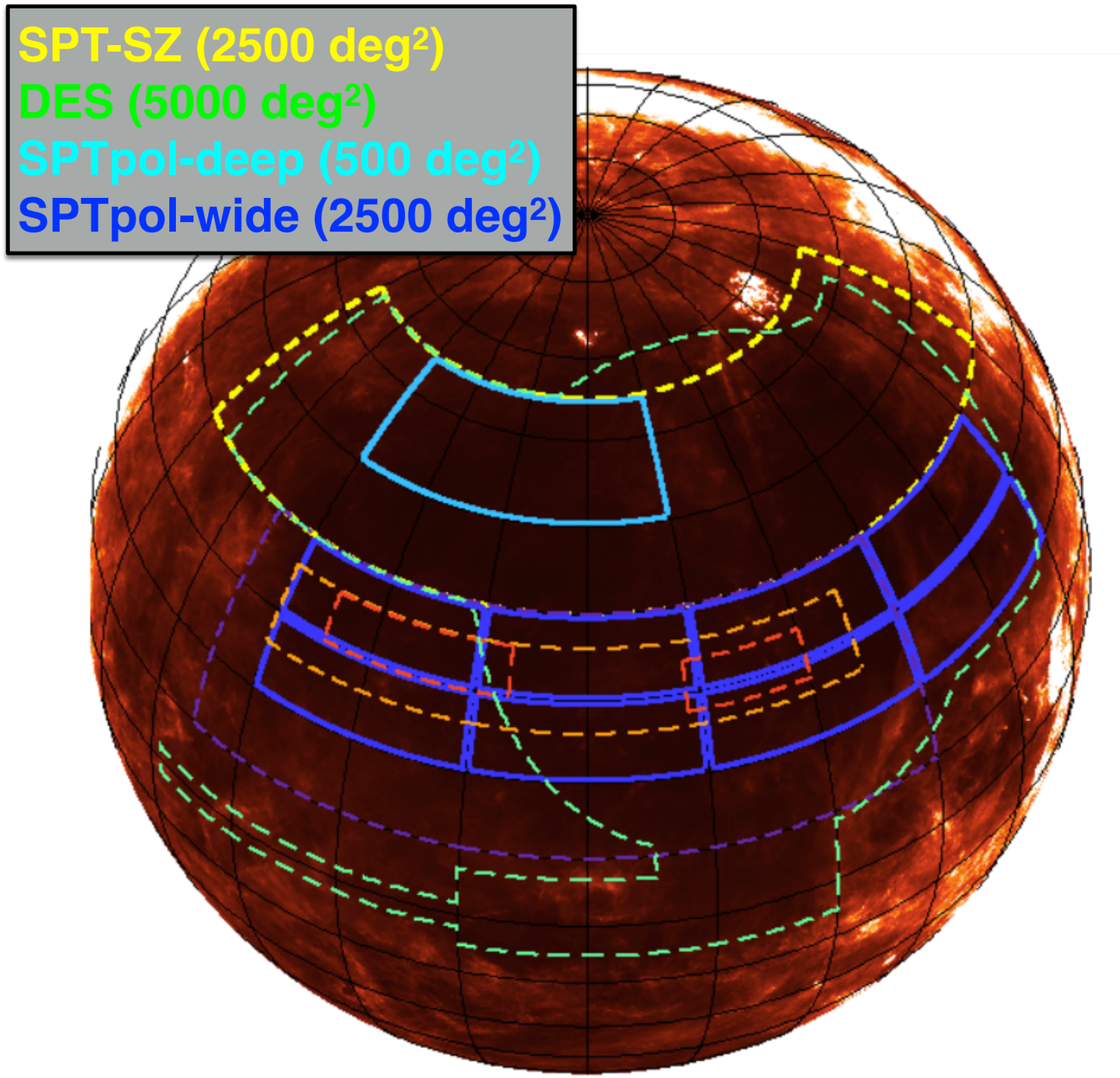


- Clusters provide complementary constraints to other DE probes (BAO, SNe)
- Combined constraint on DE equation of state w = -1.02 +/- 0.04

- Clusters measure structure growth
- Combined cosmological constraint on sum of the neutrino masses of 0.14 +/- 0.08 eV

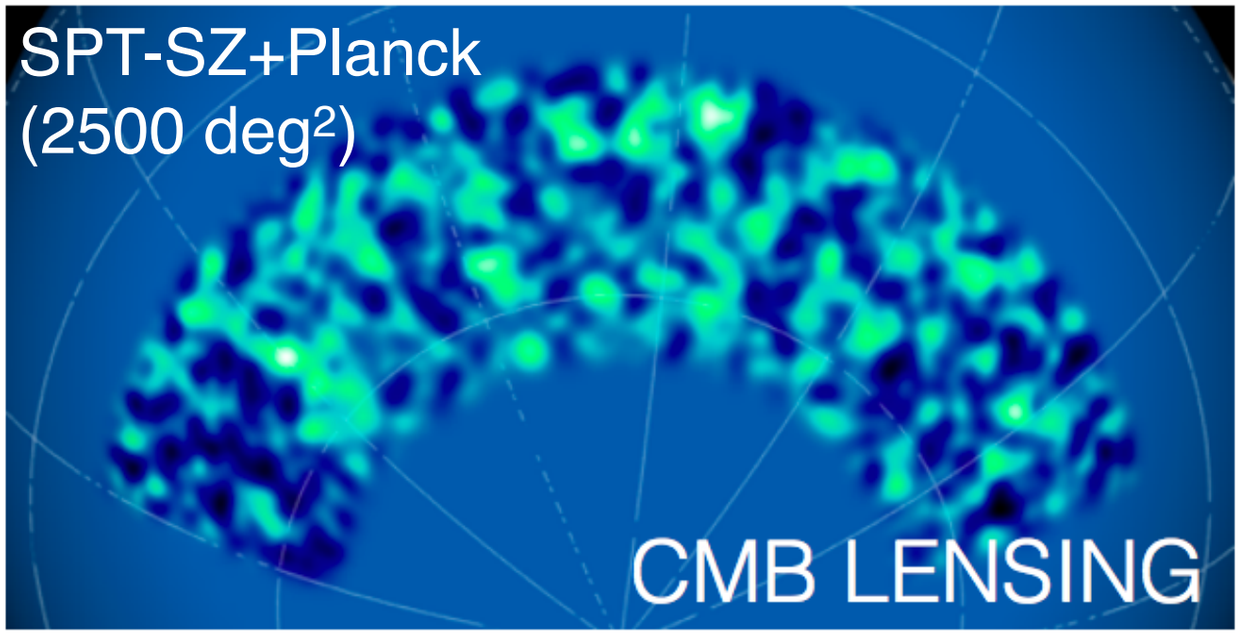
(SPT) de Haan *et al.* 2016

Synergy with Dark Energy Survey (DES)

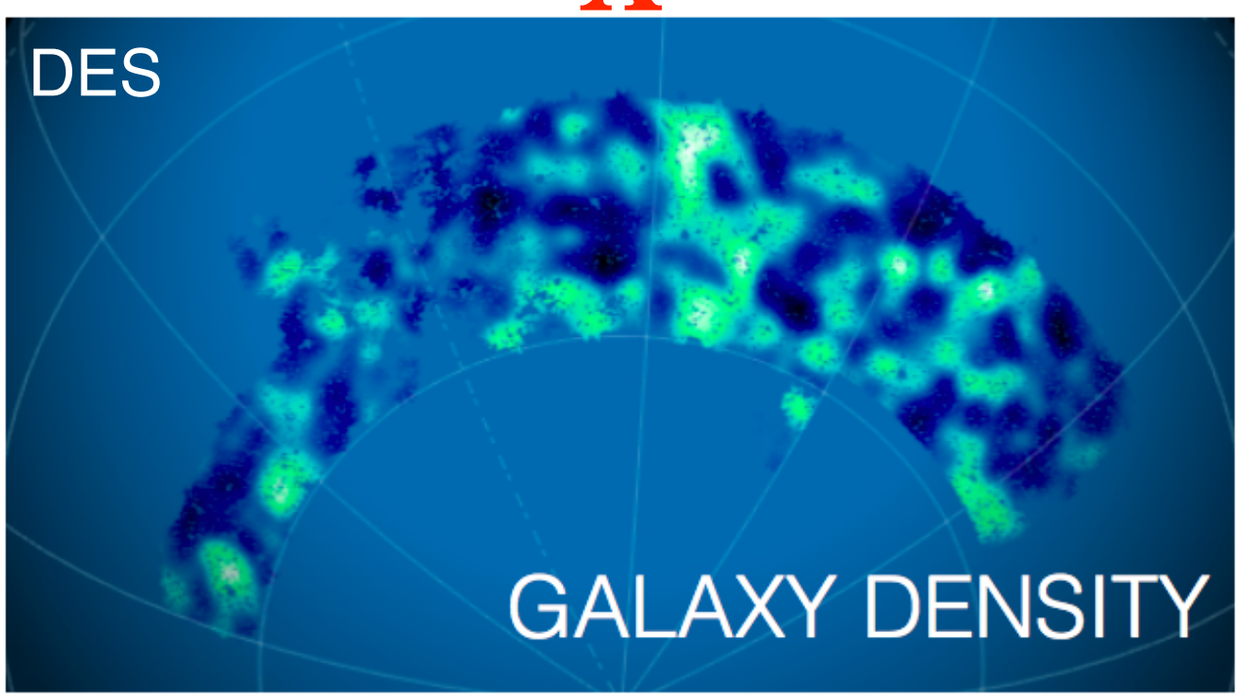


- DES originally motivated as optical follow-up survey for SPT
- 4000 deg² of overlap between SPT and DES surveys.
- Strong synergy between CMB and Optical surveys (e.g., SPT+DES, CMB-S4+LSST).
- Cross correlation of observables can contain additional information, control systematics:
  - CMB lensing
  - SZ maps
  - Galaxy and cluster density
  - Optical lensing

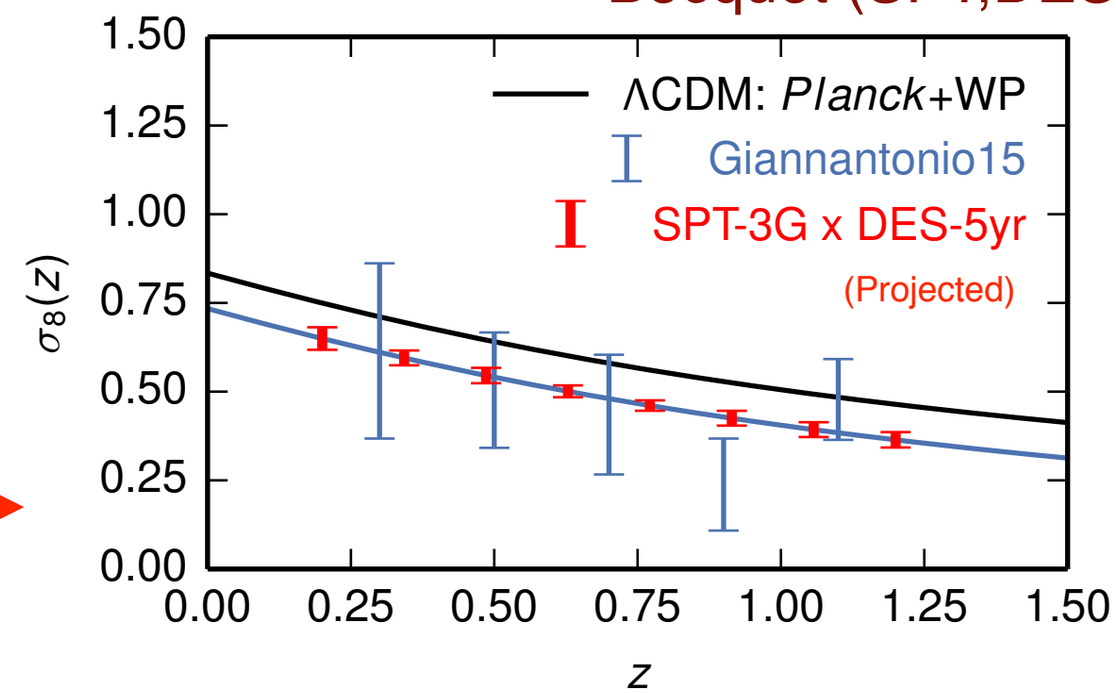
Synergy with Dark Energy Survey (DES)



X



Bocquet (SPT,DES)

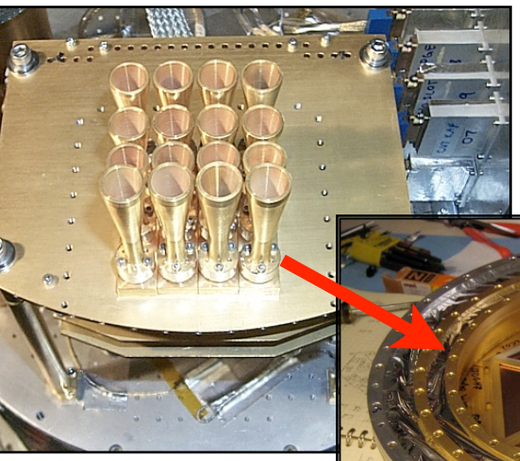


- Cross correlation of CMB lensing and galaxy density can probe evolution of structure (i.e., $\sigma_8(z)$)
- ***Powerful test of the physics of dark energy and general relativity***

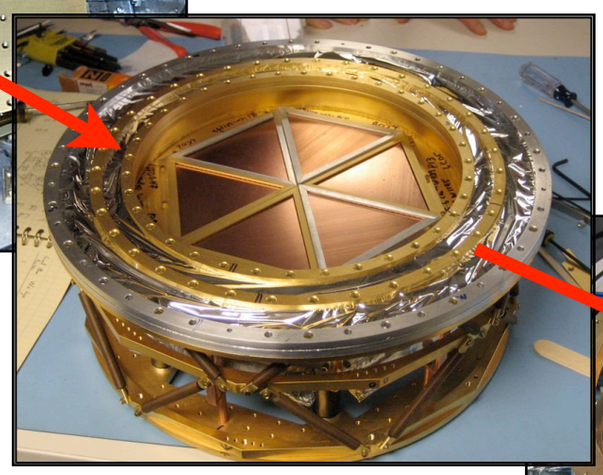
Omuri, Simard, Chown, Holder (SPT,DES)

Evolution of CMB Focal Planes

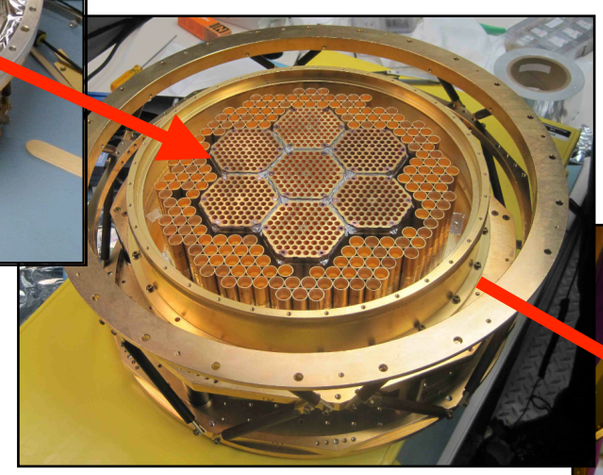
2001: ACBAR
16 detectors



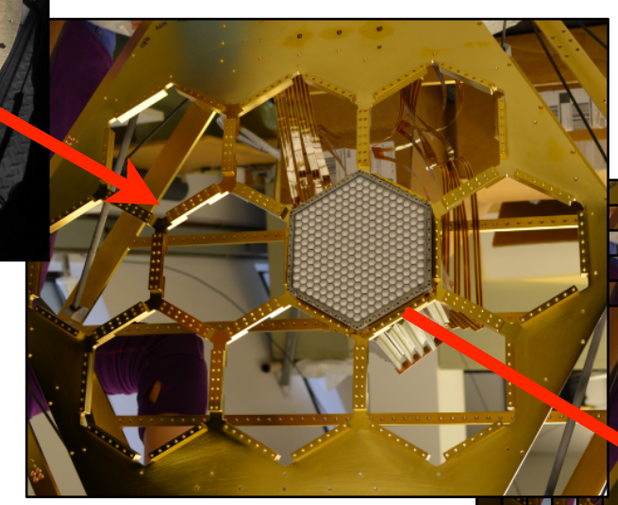
2007: SPT
960 detectors



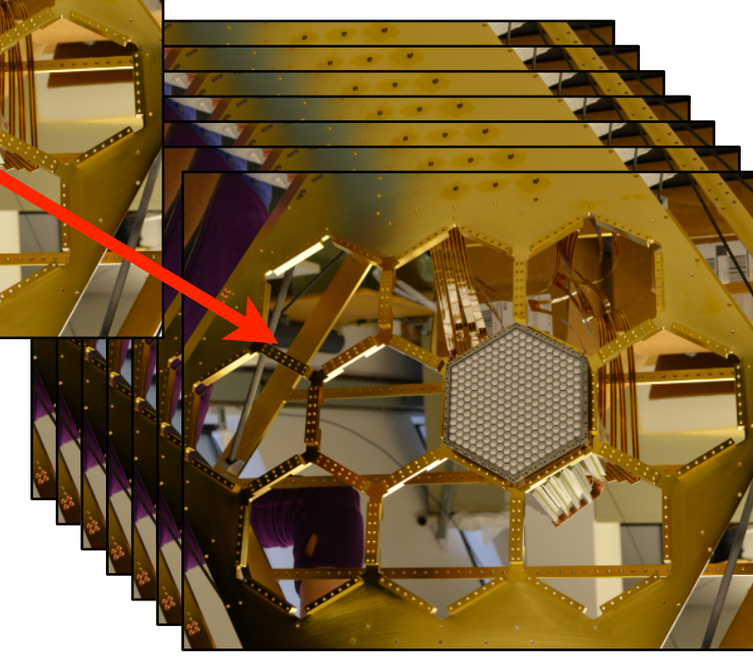
Stage-2
2012: SPTpol
~1600 detectors



Stage-3
2016: SPT-3G
~16,000 detectors



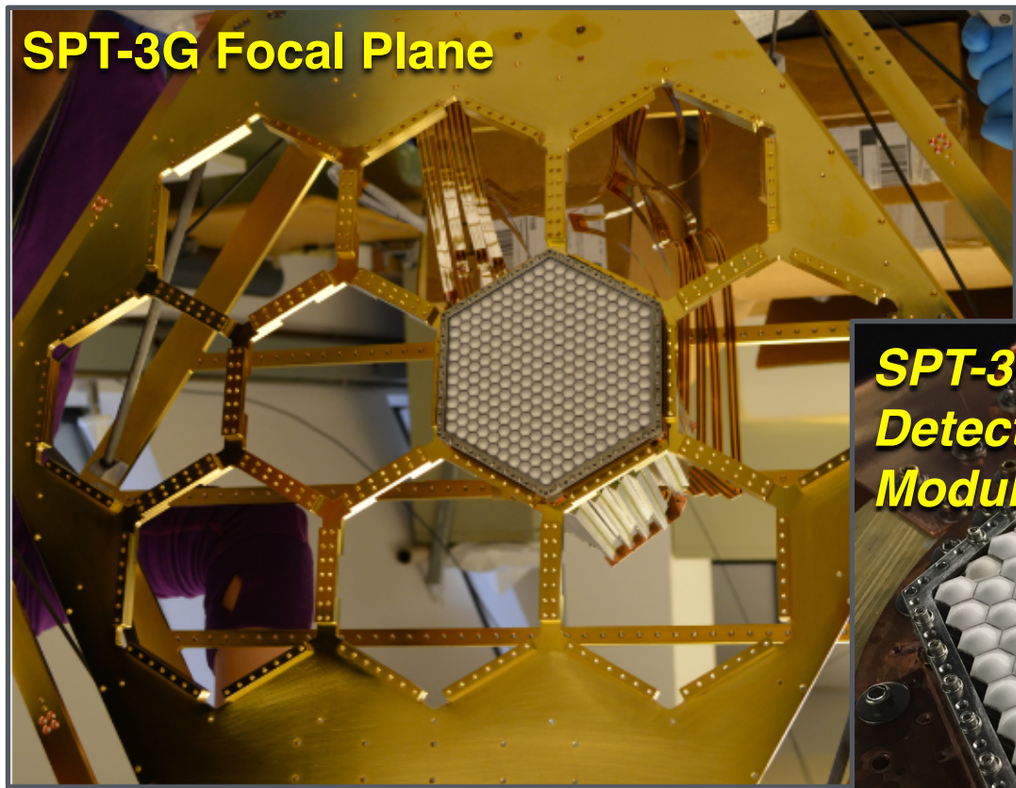
Stage-4
2020?: CMB-S4
500,000 detectors

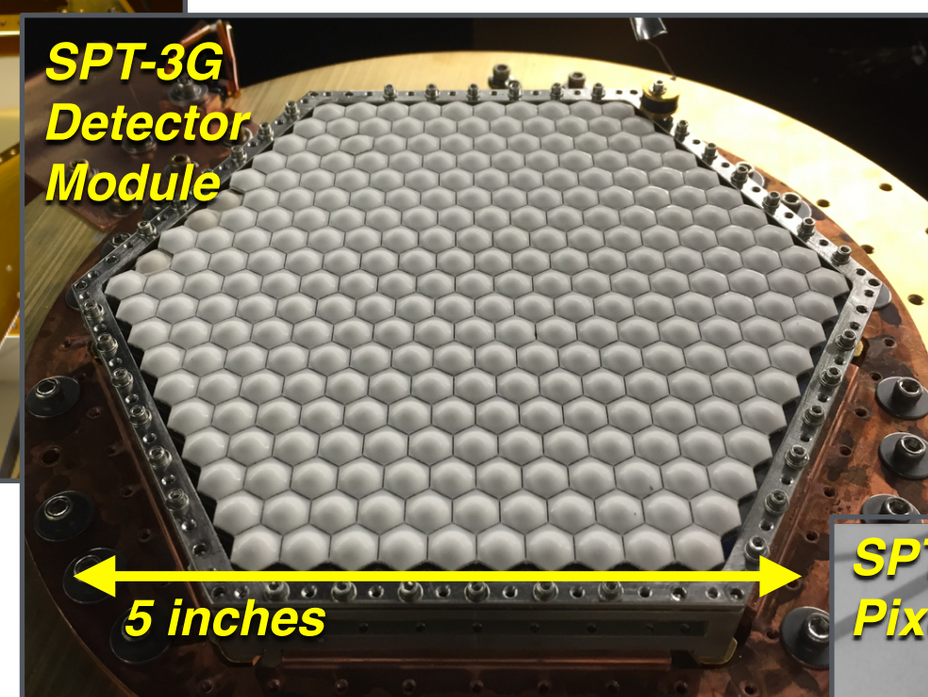


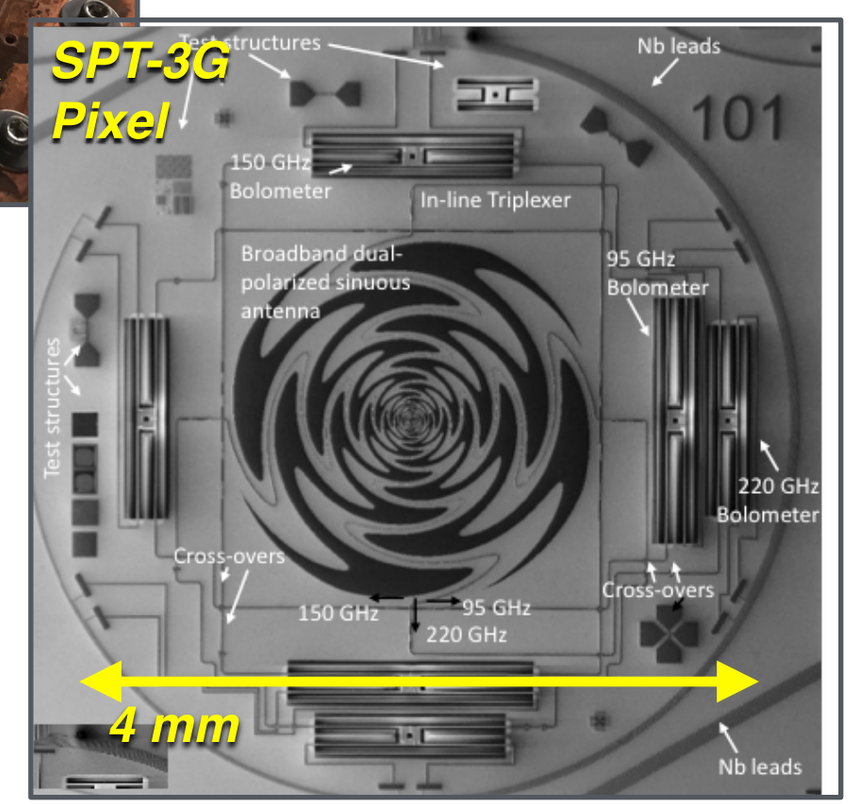
CMB Stage-4 Experiment
Described in Snowmass CF5:
Neutrinos: arxiv:1309.5383
Inflation: arxiv:1309.5381

Detector sensitivity has been limited by photon "shot" noise for last ~15 years; further improvements are made only by making ***more detectors!***

SPT-3G: A New Camera for the SPT

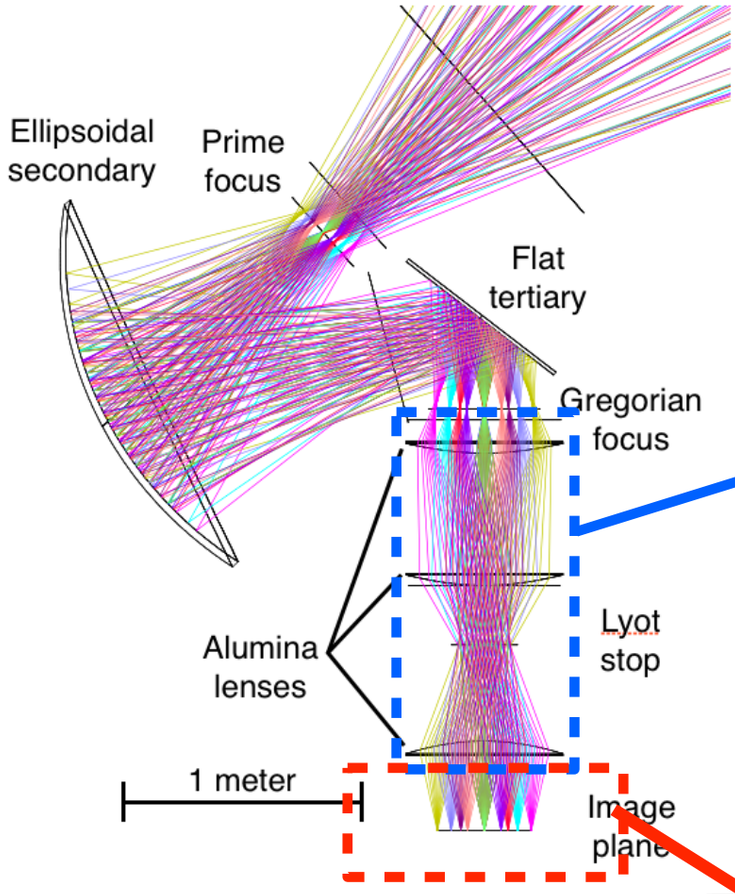


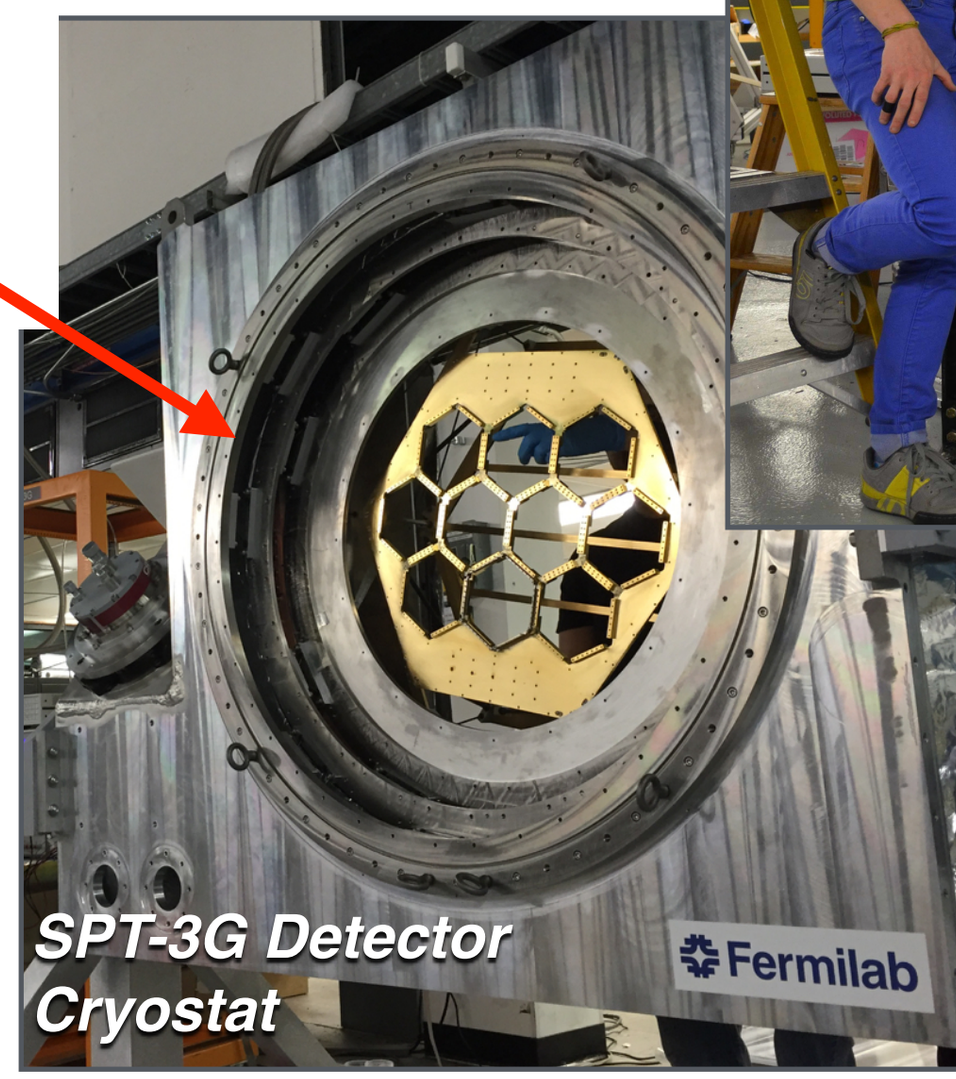




- ***To deploy in Dec. 2016!***
- 16,260 transition edge sensor (TES) bolometers at 250 mK
- Using lenslet coupled, 3-band (95, 150, 220 GHz) sinuous antenna coupled TES detector design from UCB (Suzuki et al, 1210.8256)
- 4-year survey (2017-2020) to cover 2500 deg^2

SPT-3G: A New Camera for the SPT

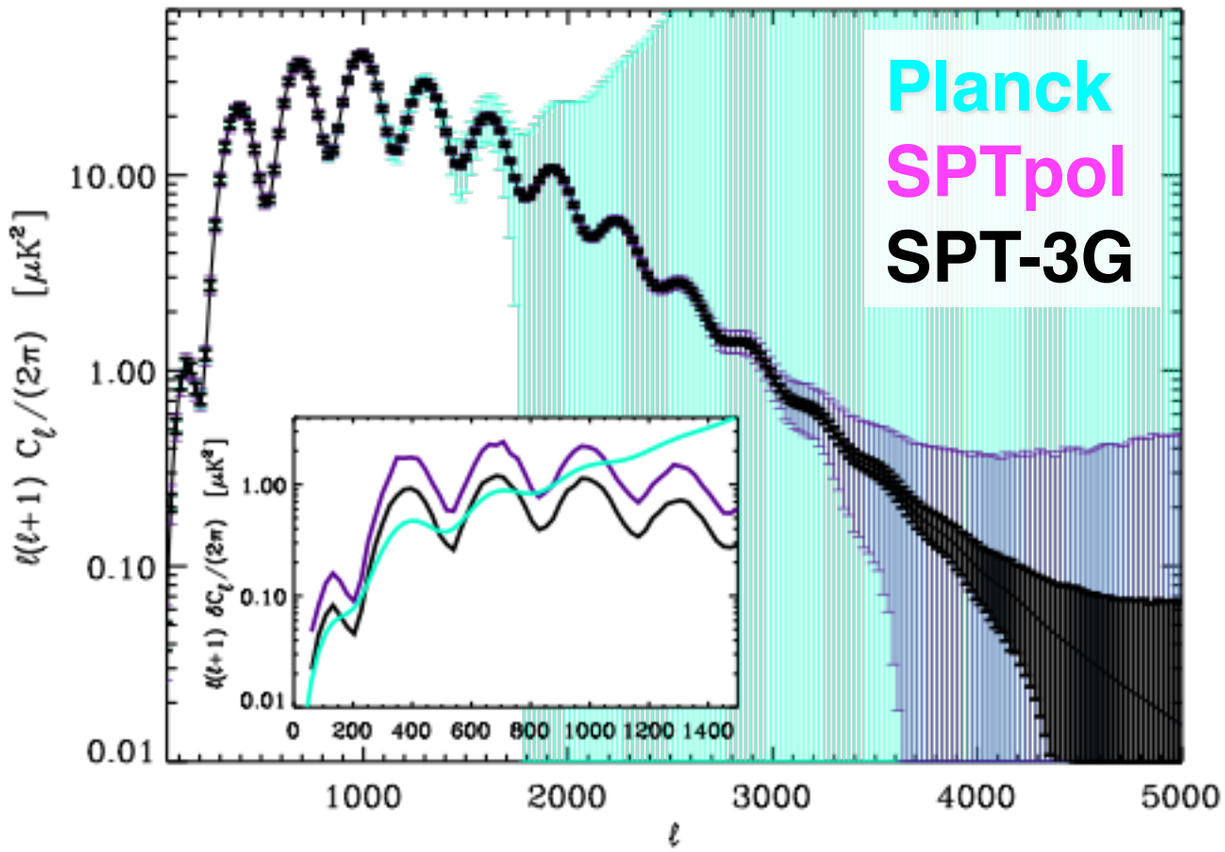




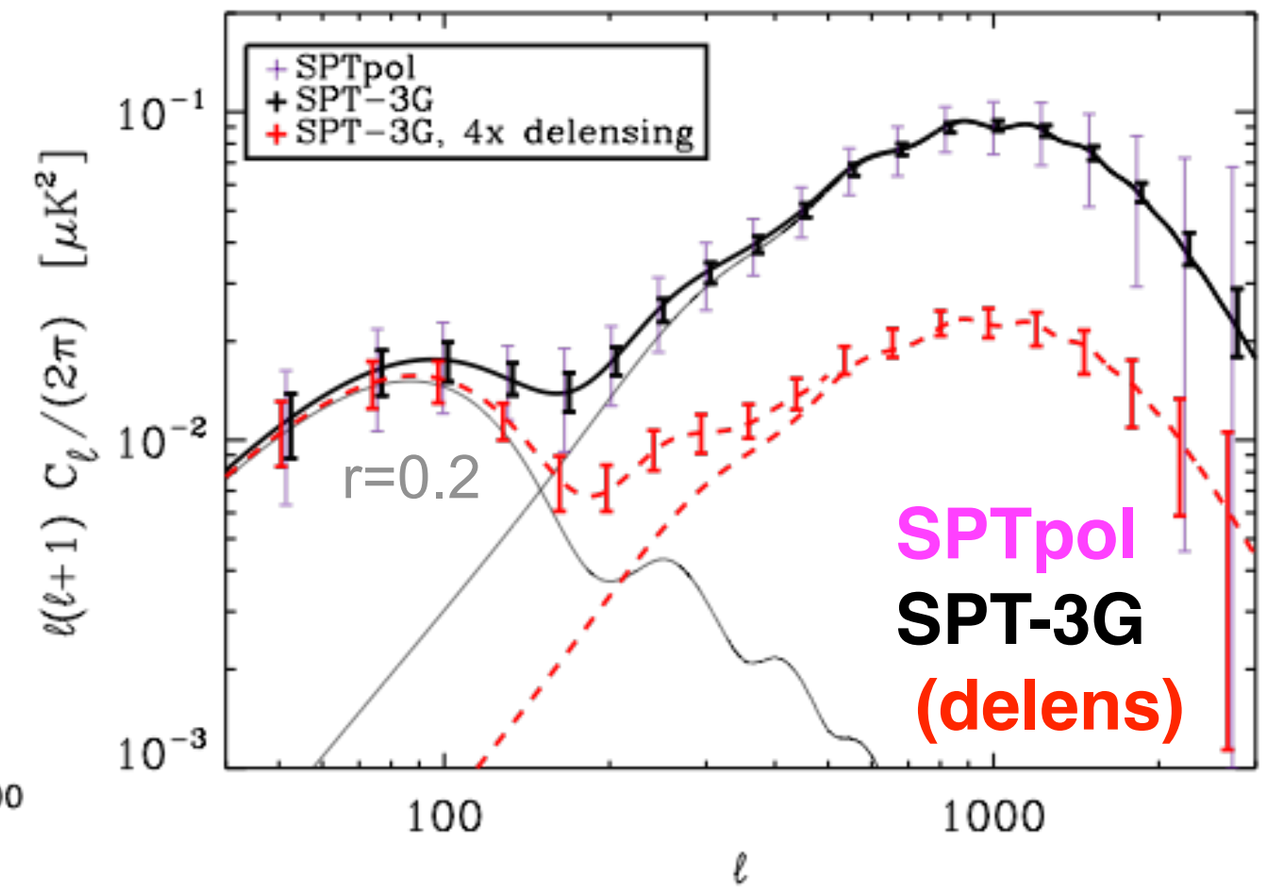
- ***Camera Cryostat Integration at Fermilab***
- *Alumina Lenses cooled to 4 K in Optics Cryostat*
- *Detectors cooled to 250 mK in SPT-3G Cryostat*

SPT-3G Survey (2017-2020)

EE-Spectrum



BB-Spectrum



SPT-3G Survey:

- 4-year survey, over 2500 deg^2 sky area:
- 150-σ detection of CMB lensing,
- Detect 10,000 clusters via the Sunyaev-Zel'dovich (SZ) effect,
- Constrain cosmology (see table)
- Overlap with BICEP/KECK survey, to provide CMB "de-lensing" to improve "r" constraints

(with Planck priors)	SPT-3G (2019)
$\sigma(r)$	**0.011**
$\sigma(N_{eff})$	**0.058**
$\sigma(\Sigma m_\nu)$	**0.061 eV***

Benson et al 2014
* Includes BOSS prior

Summary

- *High-angular resolution and depth of SPT-SZ, SPTpol data has provided new constraints on CMB power spectrum, CMB lensing, abundance of massive clusters.*
- *Strong synergies between optical and CMB surveys probing structure growth (e.g, DES+SPT).*
- *SPT-3G to deploy in Dec. 2016, and will improve SPT mapping speed by an order of magnitude.*
- *SPT data has provided new constraints on dark energy, neutrino mass; future measurements will provide new, powerful test of LCDM paradigm*