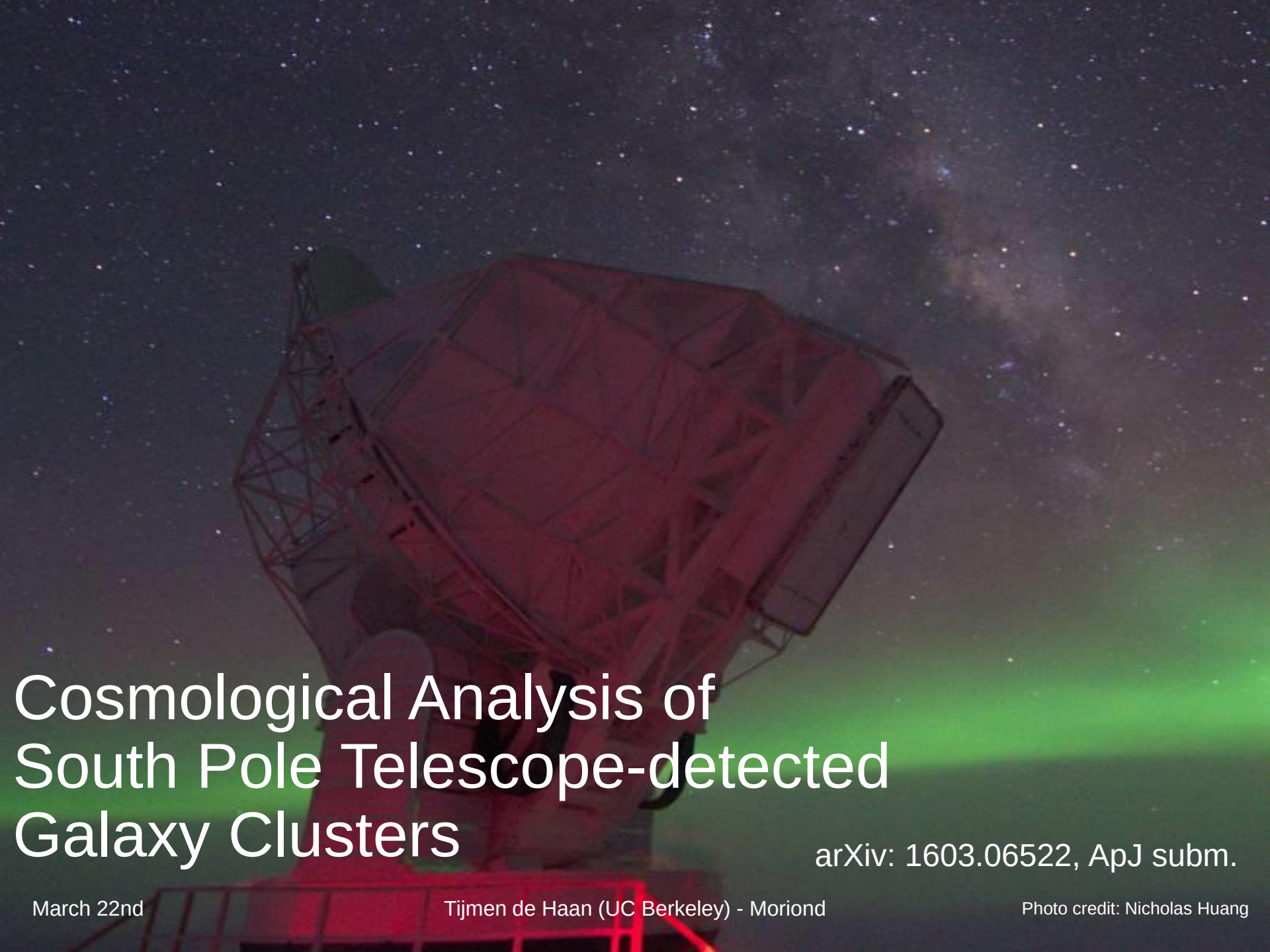


Cosmological Analysis of South Pole Telescope-detected Galaxy Clusters

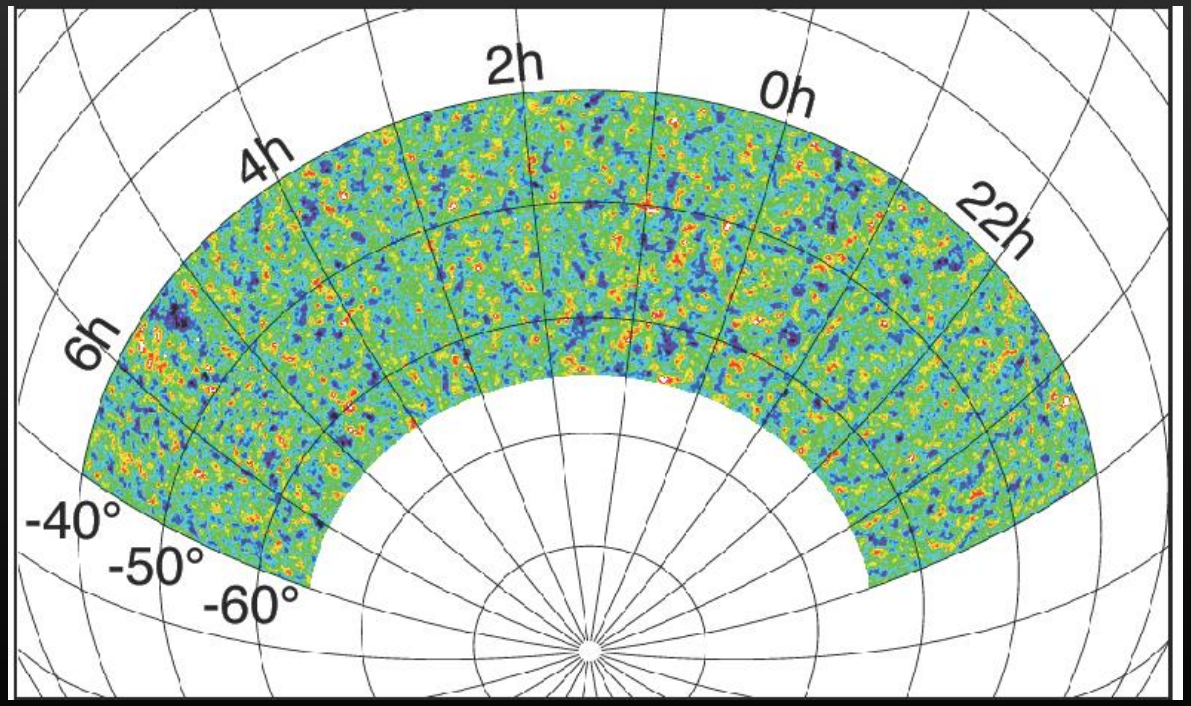
arXiv: 1603.06522, ApJ subm.

Tijmen de Haan (UC Berkeley) - Moriond

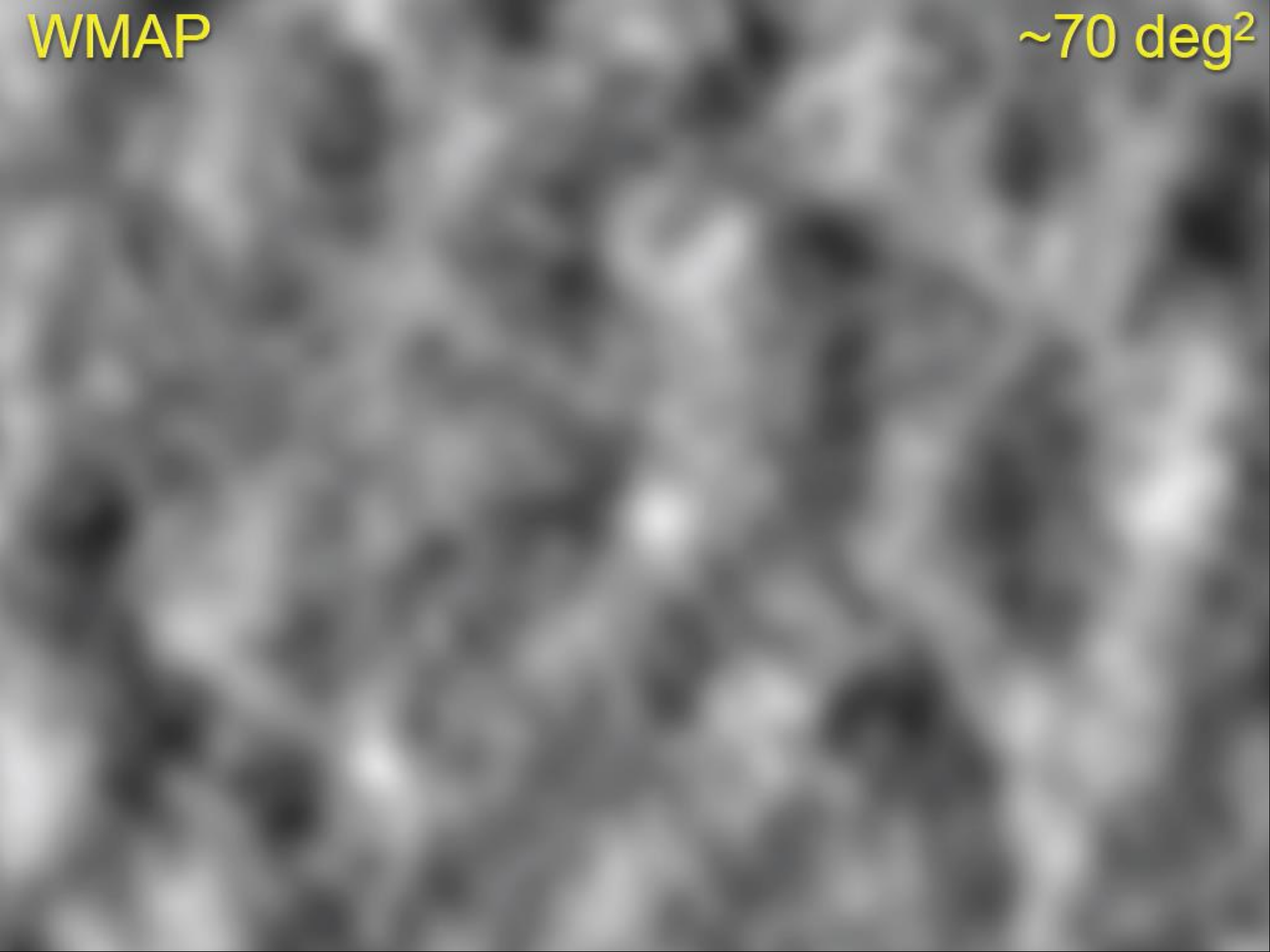
Photo credit: Nicholas Huang

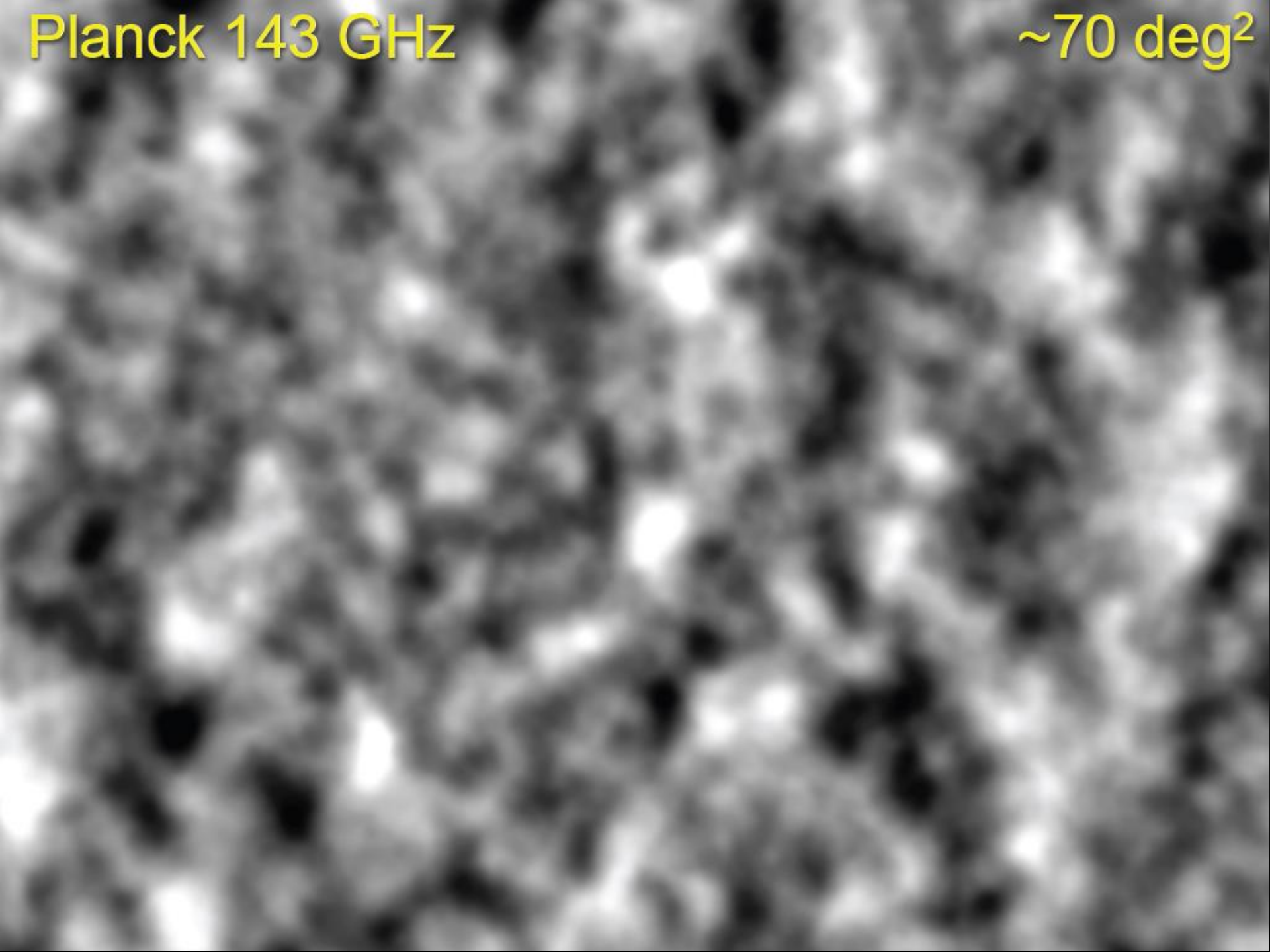
2500 square-degree SPT-SZ survey

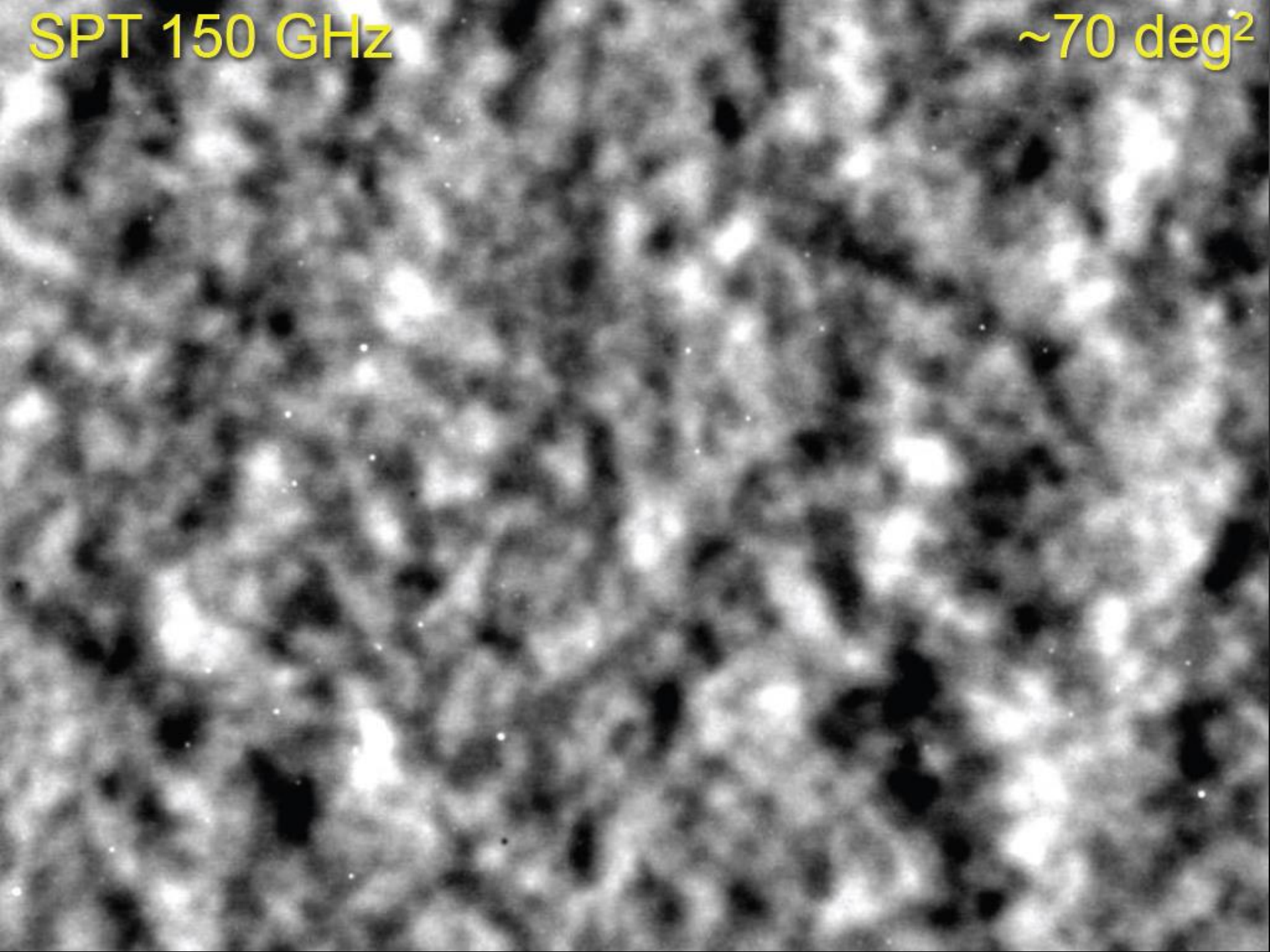
- 5 year survey (2007 to 2011)
- 95 GHz: 40 μK-arcmin
- 150 GHz: 18 μK-arcmin
- 220 GHz: 70 μK-arcmin

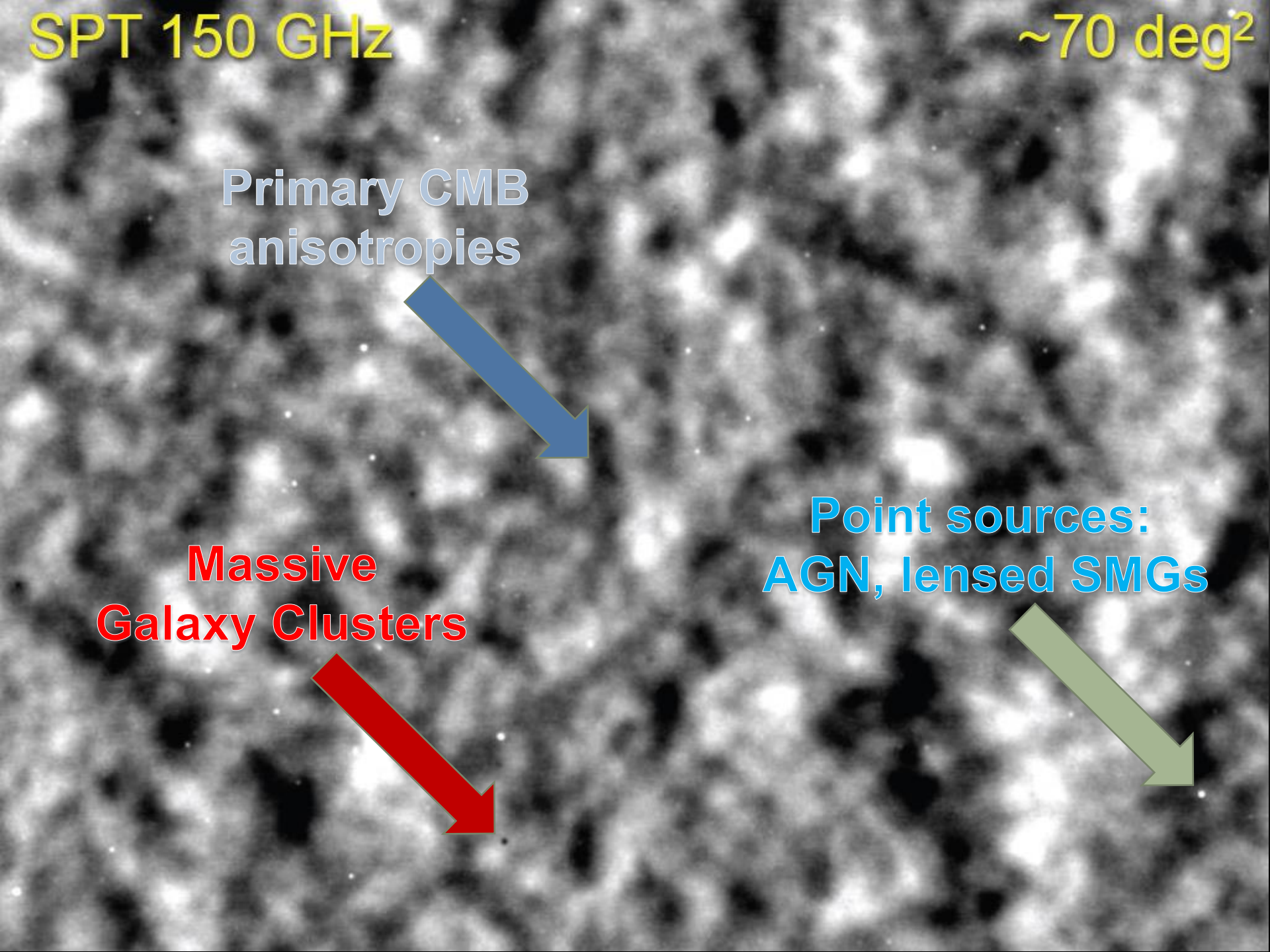


Stephen Padin
Zak Staniszewski
Keith Vanderlinde
Dana Hrubes
Erik Shirokoff
Ross Williamson
Daniel Luong-Van


WMAP
~70 deg²

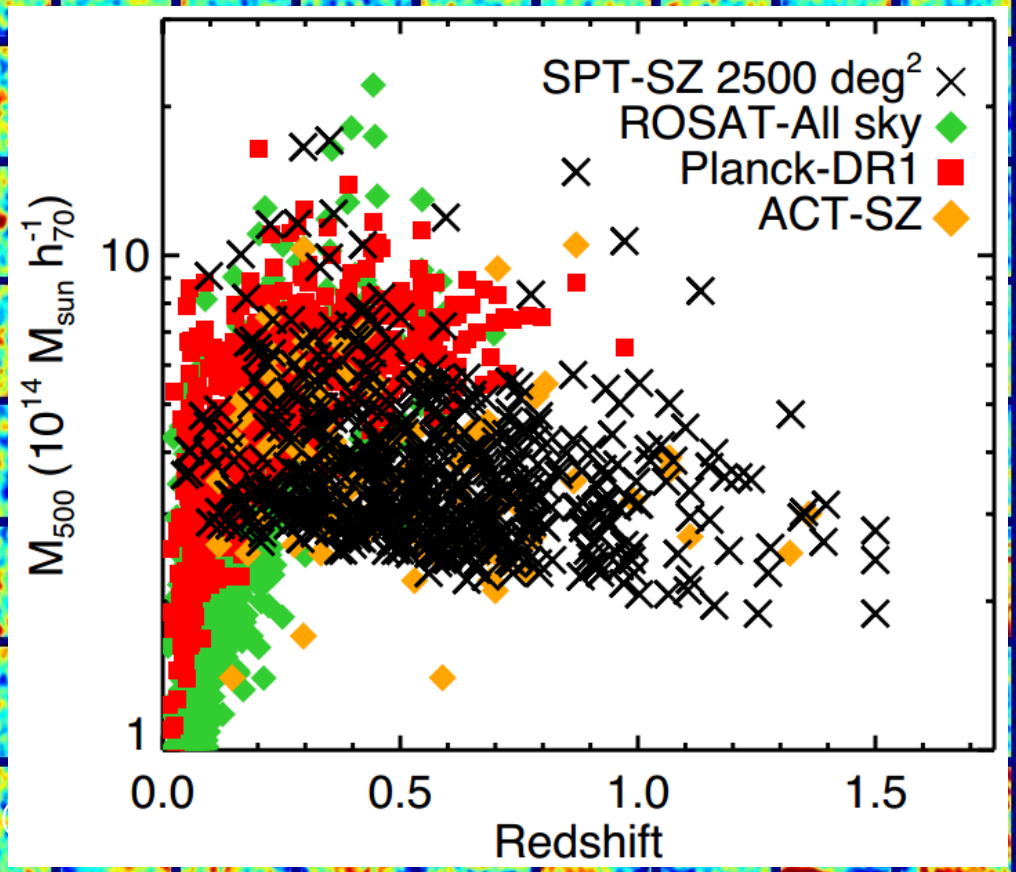

Planck 143 GHz
~70 deg²


SPT 150 GHz
~70 deg²


SPT 150 GHz
~70 deg²
Primary CMB anisotropies
Massive Galaxy Clusters
Point sources: AGN, lensed SMGs

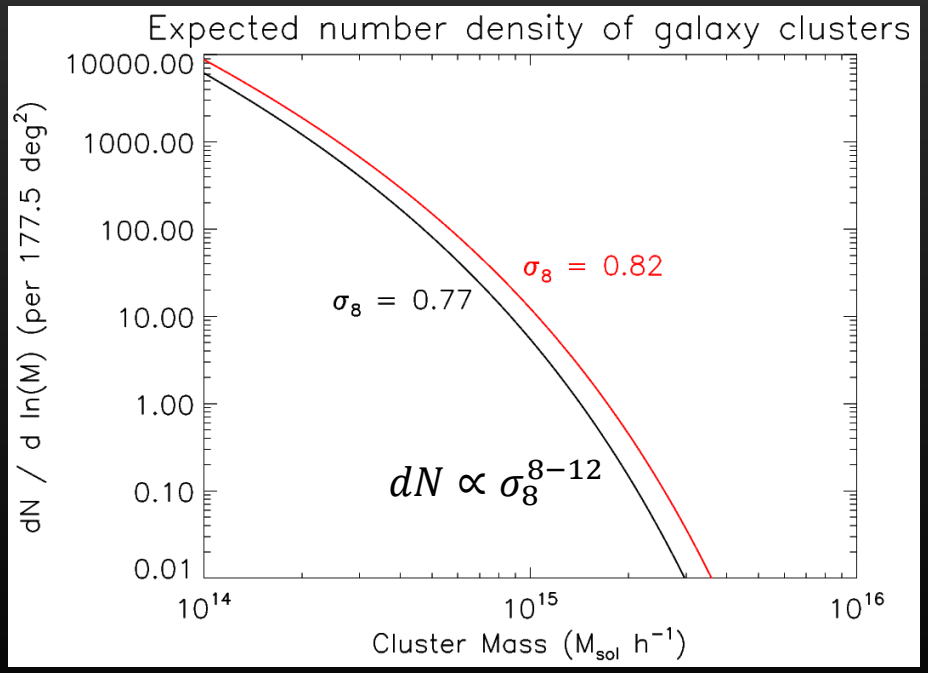
Cluster Catalog

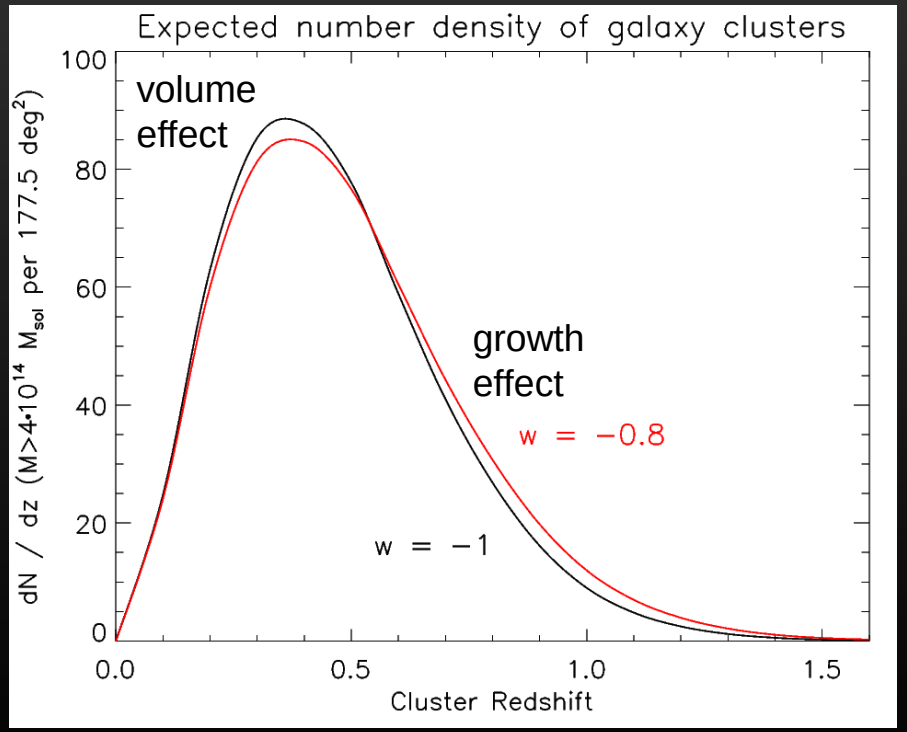
~400 clusters in cosmology sample (detected at >5σ)



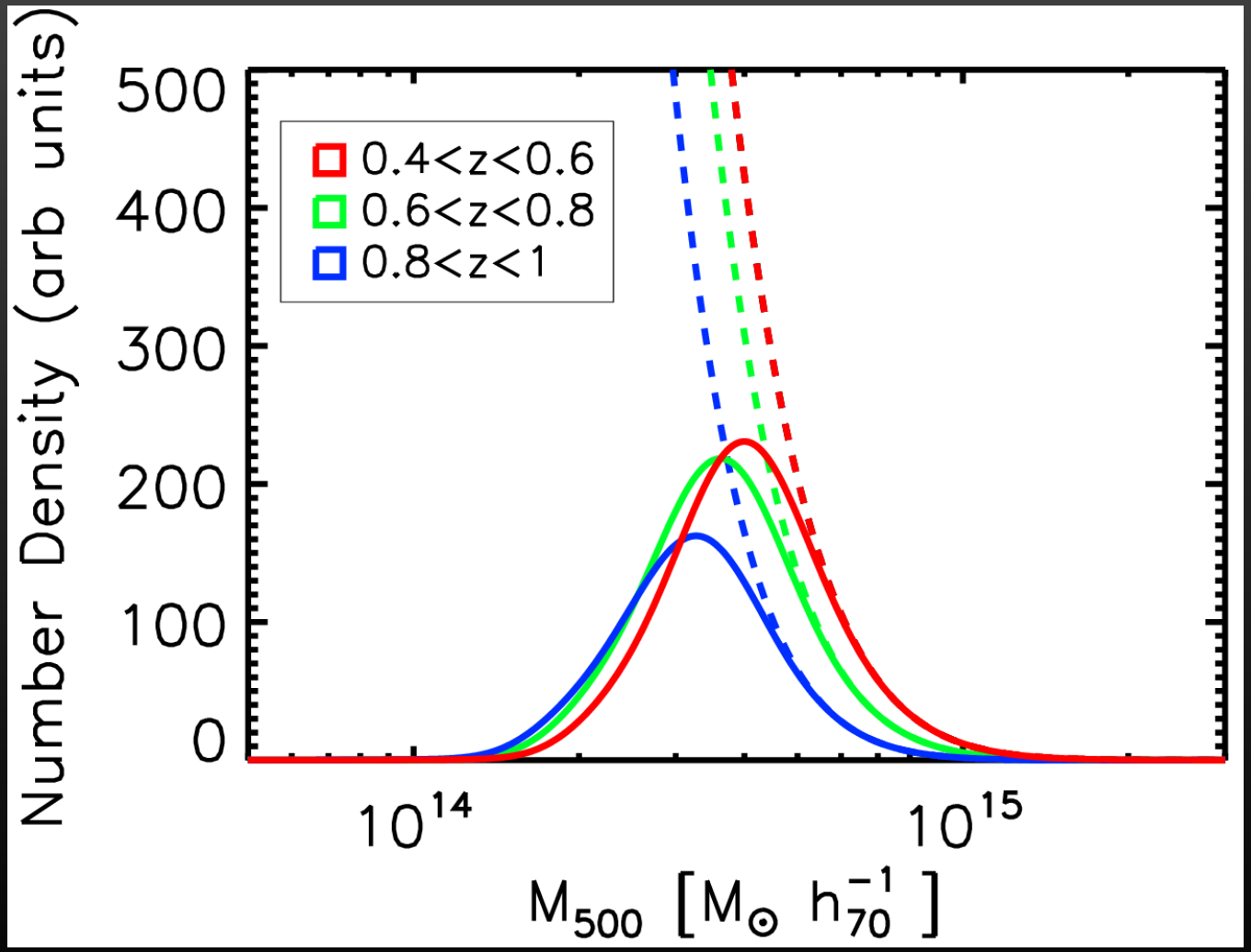
Counting Galaxy Clusters

- Abundance as a function of mass and redshift (“mass function”) is robustly predicted from N-body simulations
- Mass function is extremely sensitive to cosmological parameters
  - ΛCDM $\sigma_8(\Omega_M/0.27)^{0.3}$
  - Dark energy (w, w_a)
  - Neutrino Mass $\sum m_\nu$



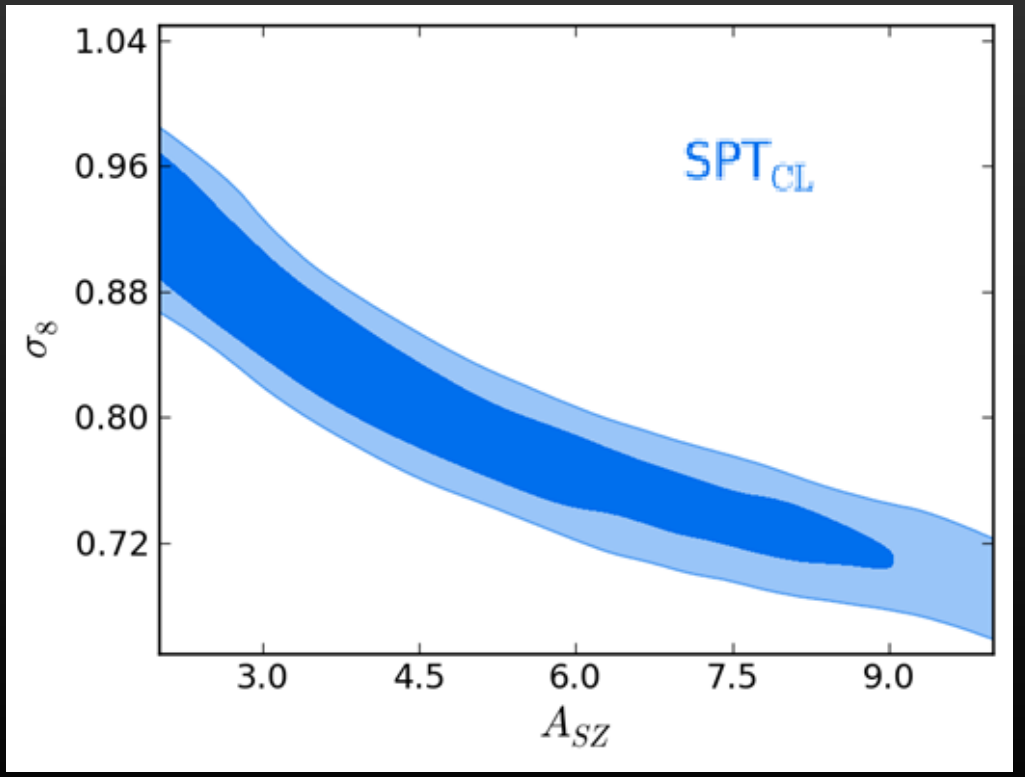


Selection Function



Mass Scale of the SPT-SZ Sample

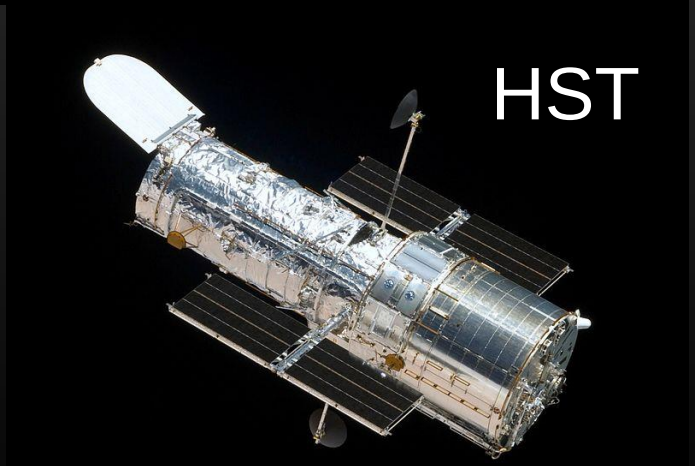
- Statistical (Poisson) uncertainties are very good
  - Error on measured number counts: $1/\sqrt{400}$
  - Implies 0.5% on σ_8 (compare to 2% Planck measurement of 0.829 ± 0.14 in ΛCDM)
  - Ability to break degeneracies in extensions to ΛCDM
- Systematics limited ->
- We assume a 30% error on SZ normalization from cosmo-OWLS simulations
- Dominates uncertainties on cosmological parameters
- Need for determining the mass scale from multi-wavelength follow-up



Multi-wavelength mass measurements

http://www.iras.ucalgary.ca/satellites/Xray/index.html

http://obs.carnegiescience.edu/Magellan



http://spaceflight.nasa.gov/gallery/images/shuttle/sts-119/hires/s125e011848.jpg

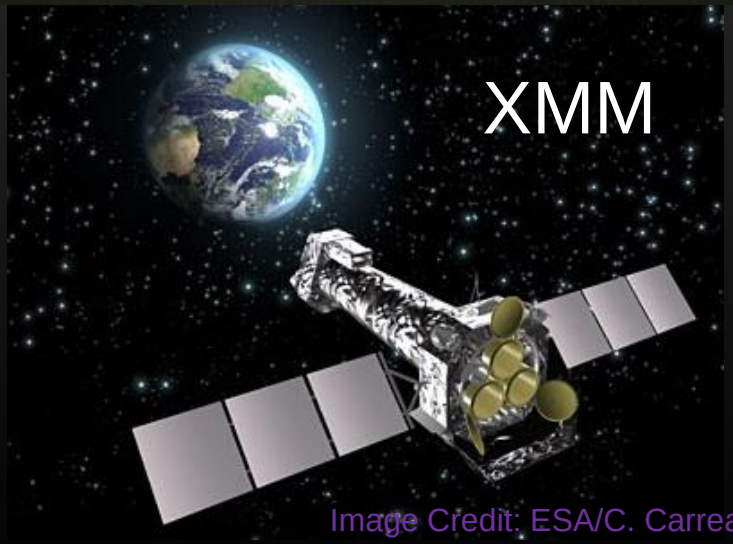
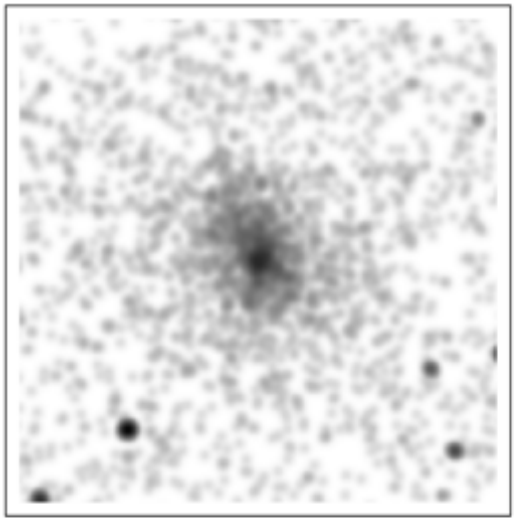


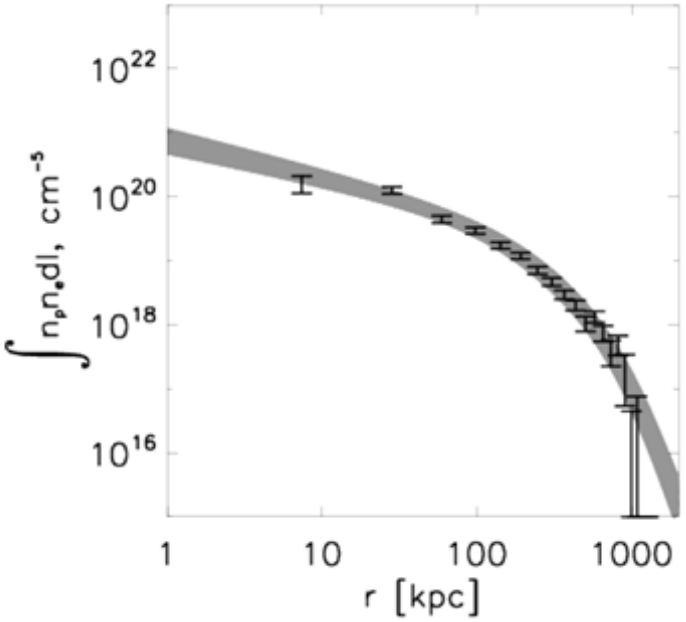
Image Credit: ESA/C. Carreau

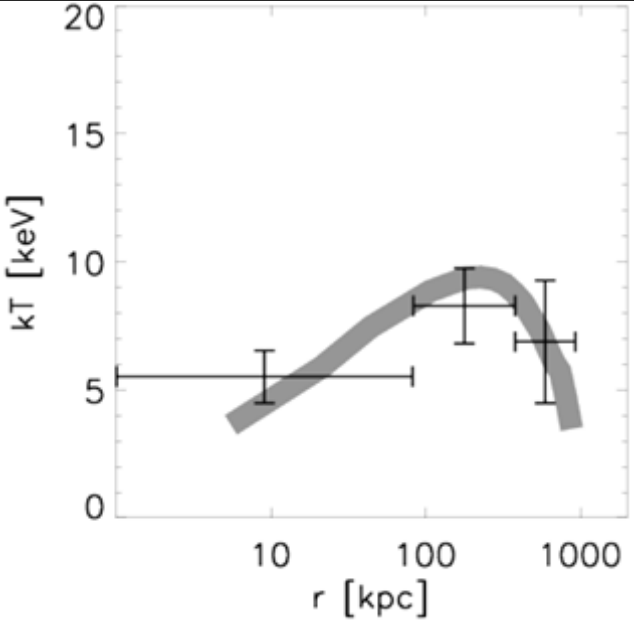
Chandra Observations

- Awarded 3.2 Ms of Chandra time
- ~90 clusters observed @ ~2k photons
- $Y_X = T_X \times M_{gas}$
- $Y_X - M$ relation determined through hydrostatic mass estimates at low redshift



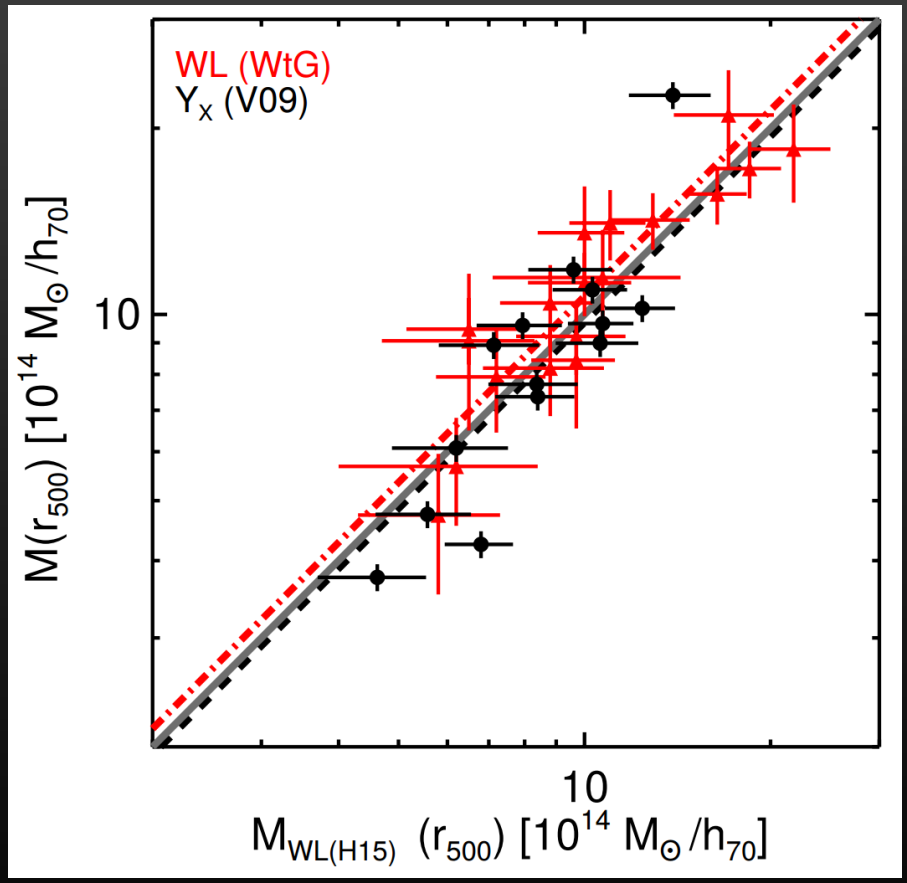
SPT−CLJ2222−4834





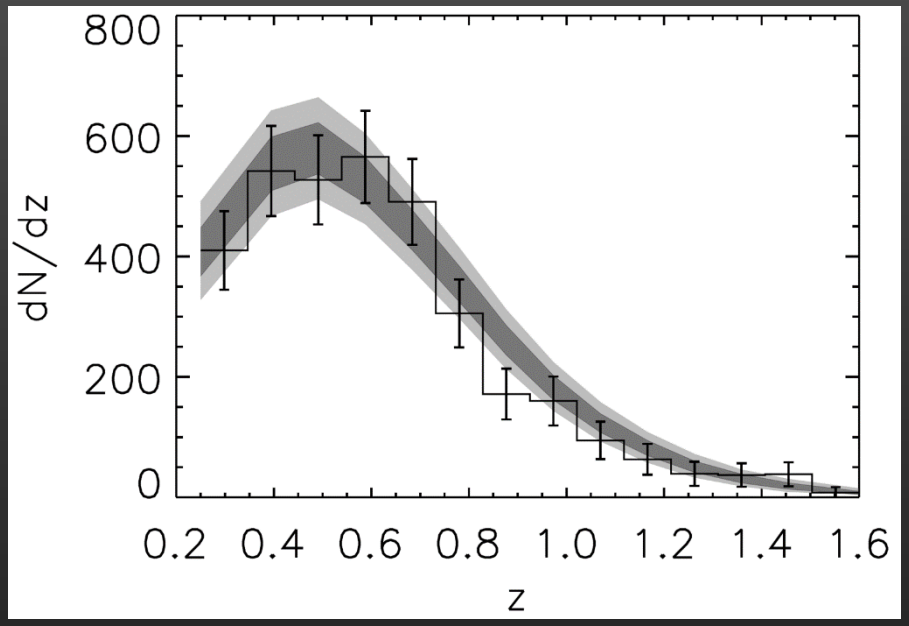
Determining the Mass Scale

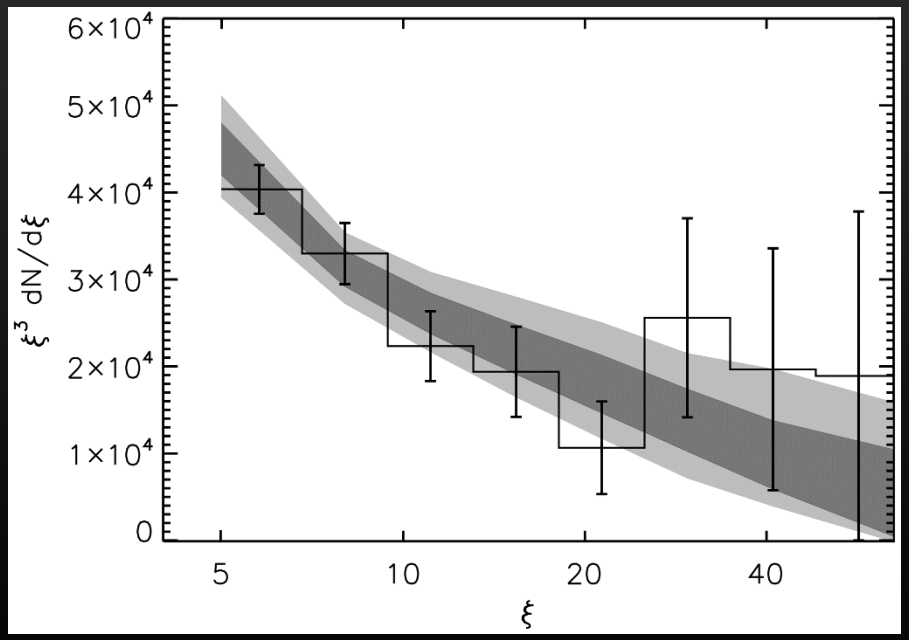
- Unlike previous SPT cluster cosmology results, we now rely purely on weak lensing observations
  - “hydrostatic mass bias” calibrates out
- Weak lensing data from Canadian Cluster Comparison Project (CCCP) and Weighing the Giants (WtG)



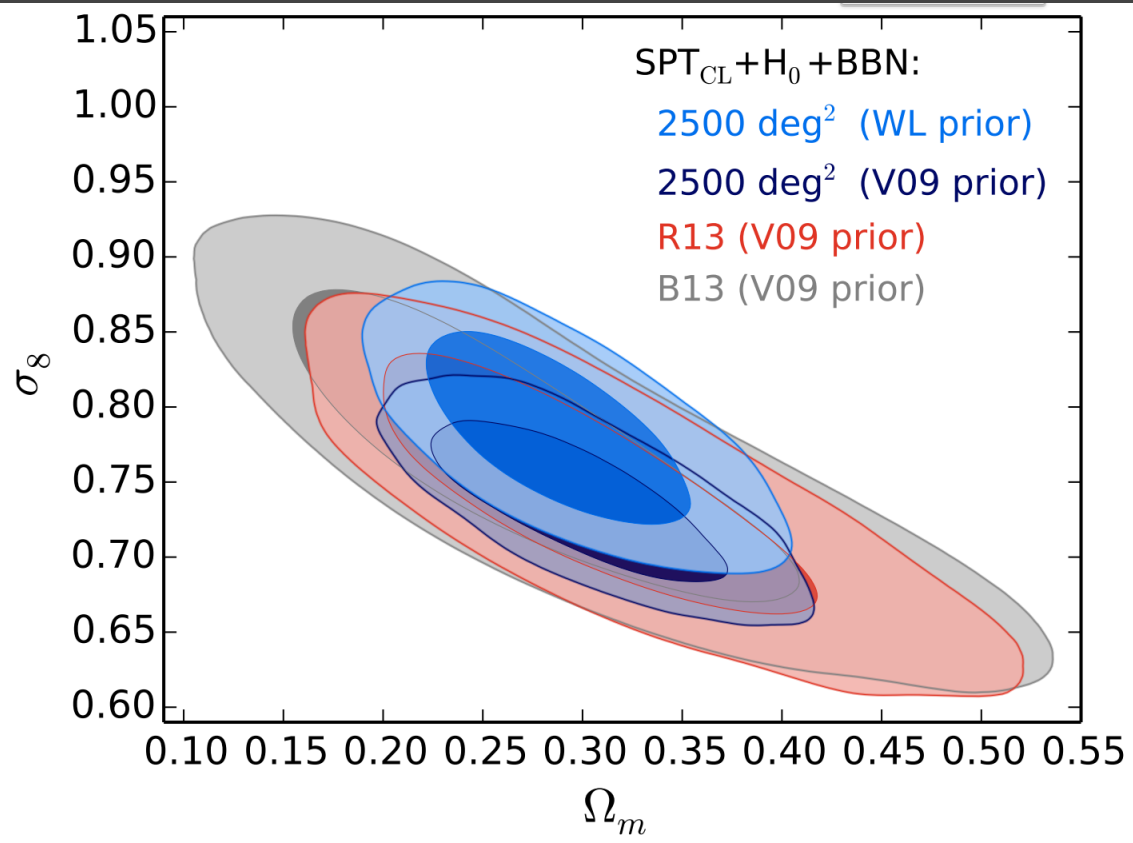
Cosmological Analysis

- Explore cosmological parameter space using CosmoMC+cluster module
- Marginalize over nuisance parameters
  - Scaling of SZ signal with cluster mass & evolution with mass, redshift
  - Scaling of X-ray signal with cluster mass & evolution with mass, redshift
  - Intrinsic scatter in the scaling relations, including correlations
  - For SPT-SZ+Chandra, that's 9 nuisance parameters
- Bayesian likelihood code, fully taking into account selection effects, self-consistently and efficiently incorporating any number of mass proxies, including correlations





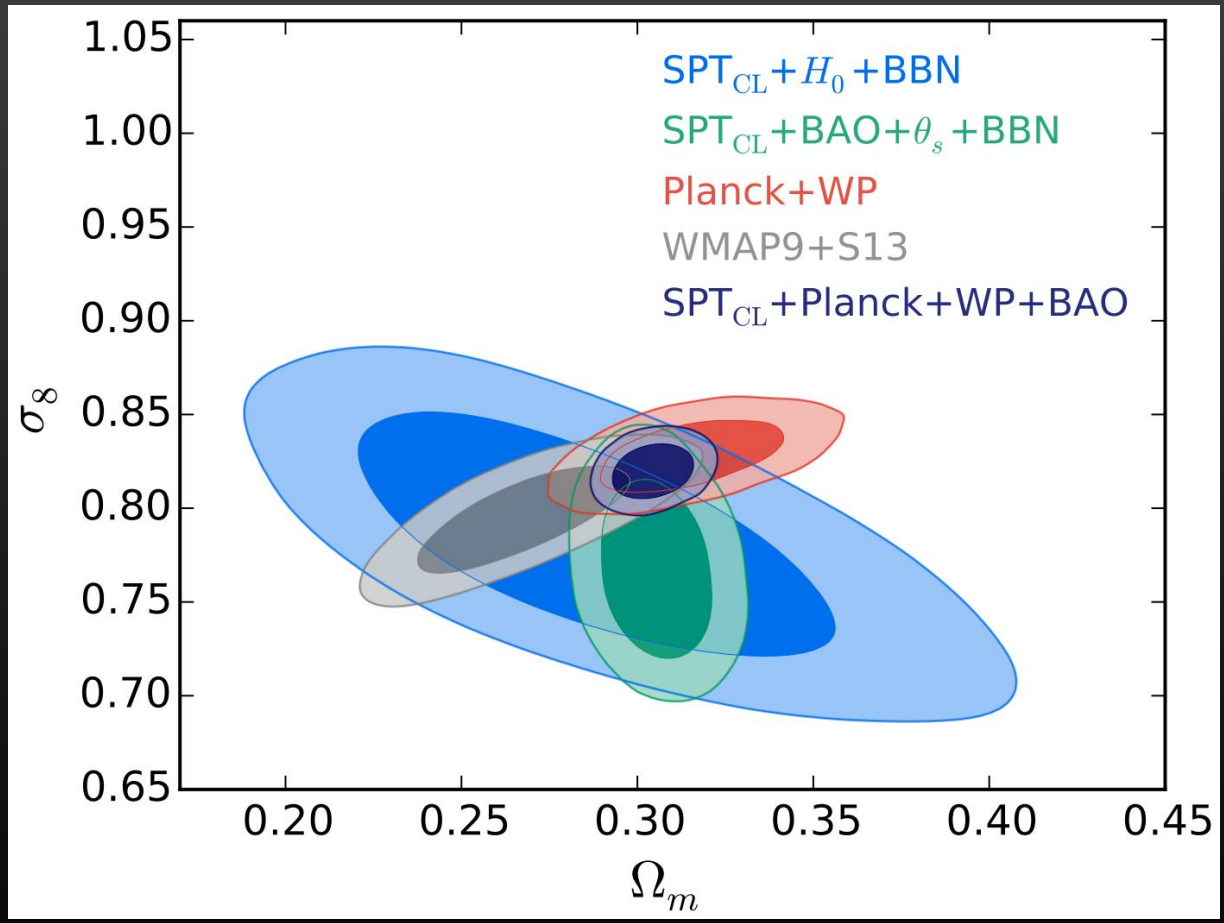
Evolution of SPT Cluster Cosmology



- 178->720->2568 square degrees of the SPT-SZ survey
- 18->100->377 clusters
- 14->14->82 clusters with high-quality Chandra Y_X
- Revisited mass scale relying purely on weak lensing

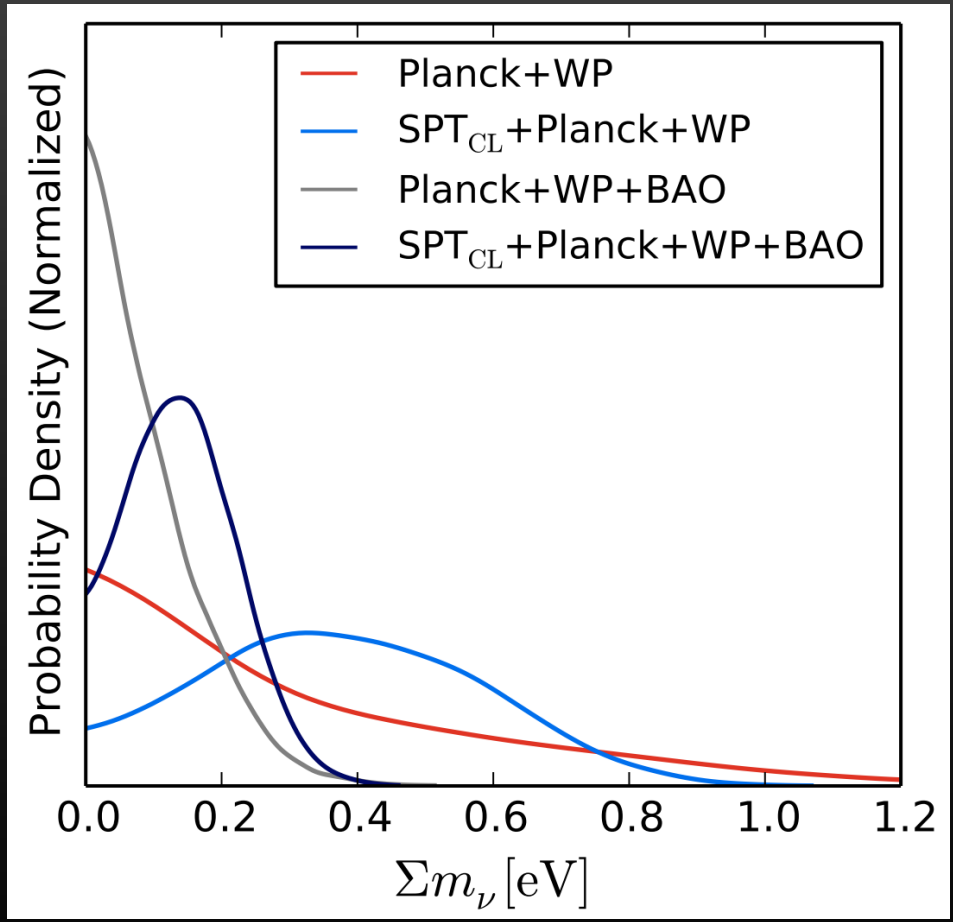
ΛCDM Results

- Consistent with ΛCDM parameters from CMB power spectrum measurements



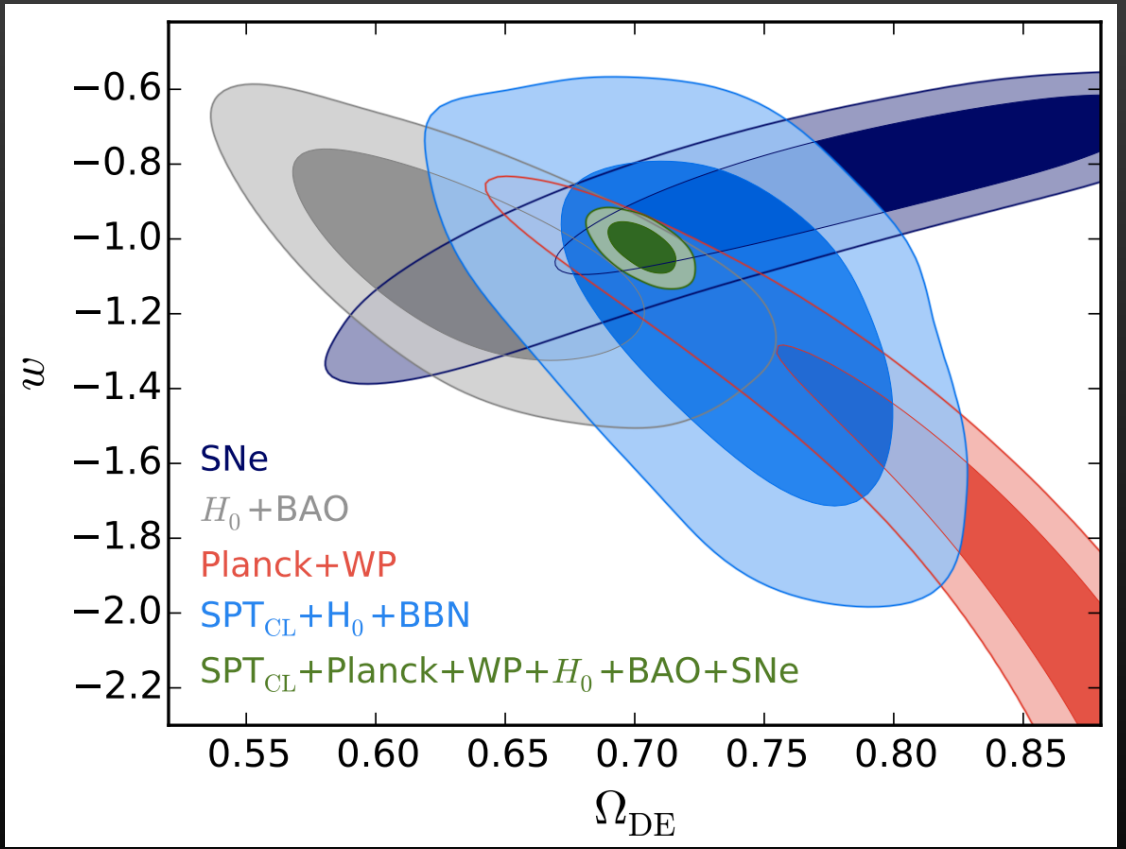
Constraints on the Species-summed Neutrino Mass

- Addition of cluster count information causes the posterior to peak at positive values
- Consistent with minimal allowed value of $\Sigma m_\nu = 0.06$ eV from atmospheric neutrino oscillation experiments



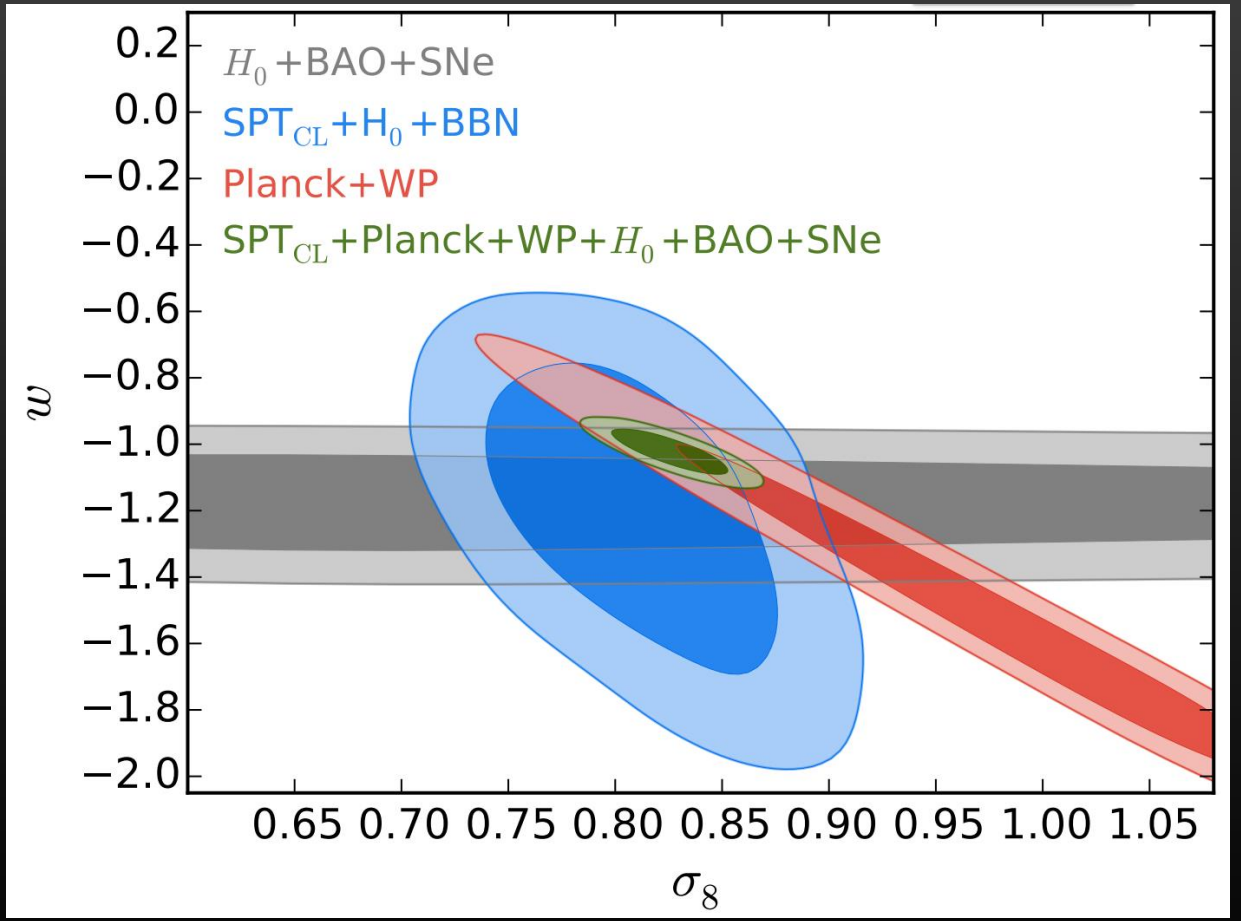
Dark Energy

- Consistent with other probes
- Clusters are a growth-based probe, providing a powerful complementary probe of dark energy
- Consistent with ΛCDM where $w = -1$

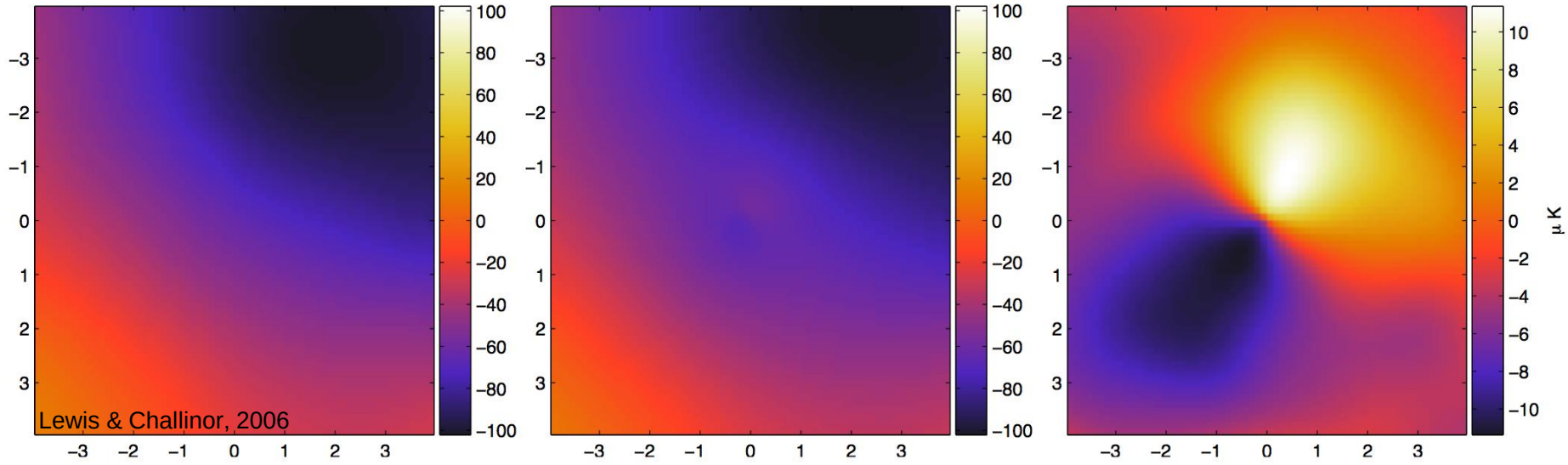


Dark Energy

- When adding to other datasets, cluster counts improve w constraint primarily by breaking σ_8 - w degeneracy



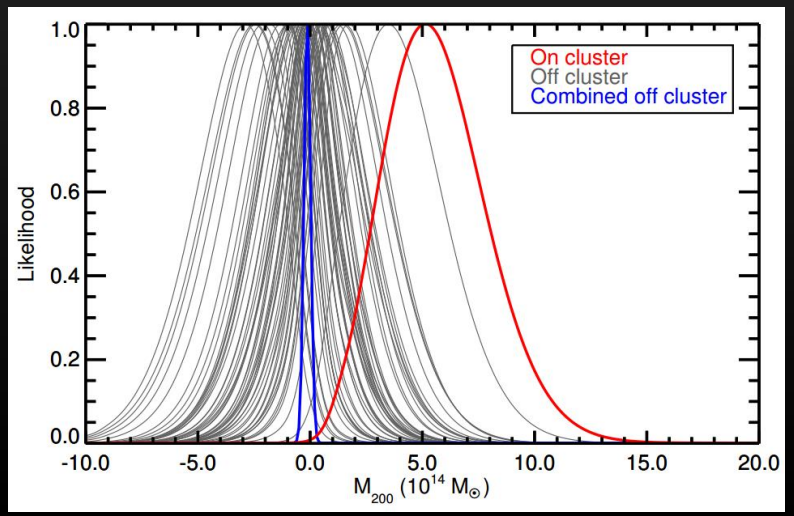
Cluster Weak Lensing of the CMB

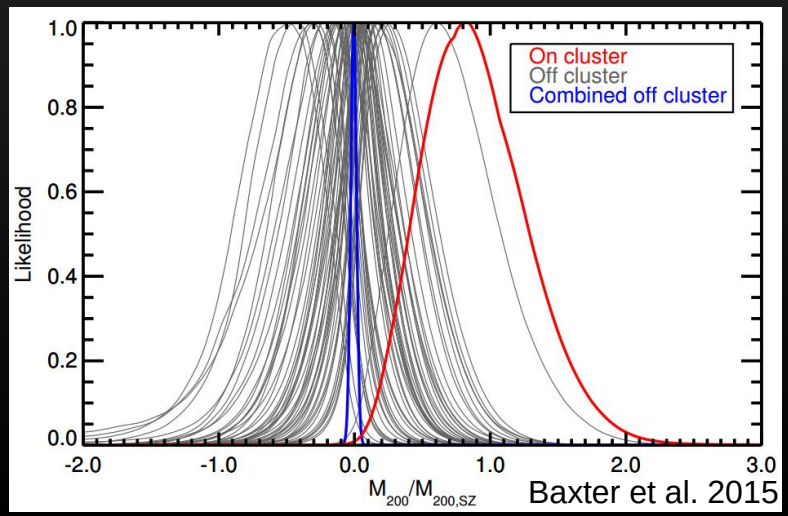


Unlensed CMB

Lensed CMB

Difference

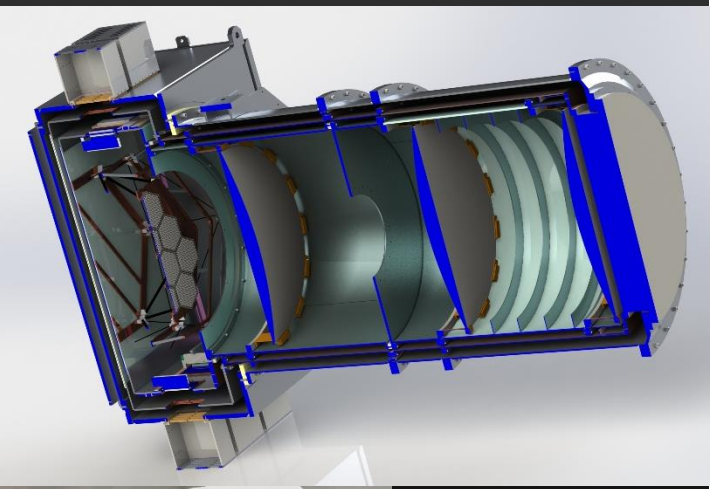


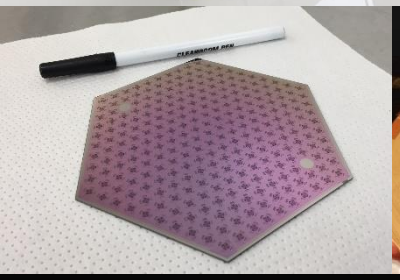


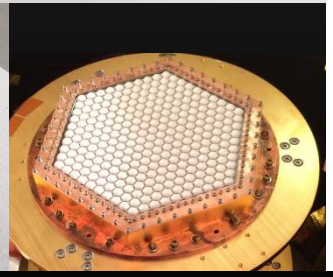
Baxter et al. 2015

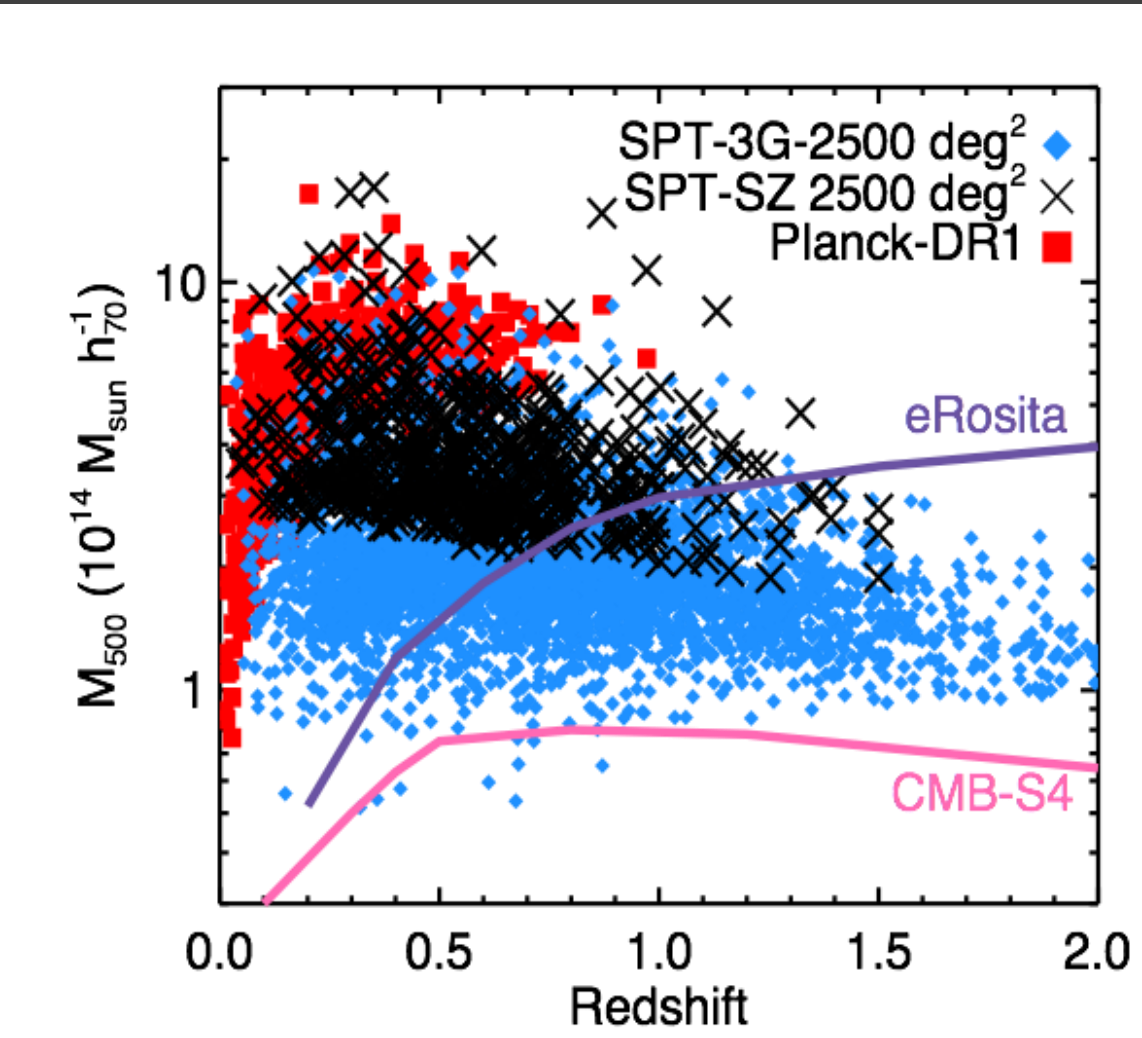
SPT-3G

- ~10,000 clusters
- Lower mass threshold implies the sample will go out to much higher redshift
- Powerful constraints on the mass scale from CMB cluster lensing
- Deploying at the end of this year









Summary

- 2500 square degree SPT-SZ sample ~400 clusters, spanning 0.1<z<1.5
- Chandra Y_X mass calibration, recalibrated using optical weak lensing
- ΛCDM constraints on σ_8 and Ω_m consistent with CMB measurements
- Neutrino mass constraints $\Sigma m_\nu = 0.14 \pm 0.08$ eV consistent with minimum allowed value
- Dark energy constraints from cluster counts alone
- Exciting future ahead with SPT-3G which will find ~10,000 clusters and will be able to weigh in on the mass scale with CMB cluster lensing