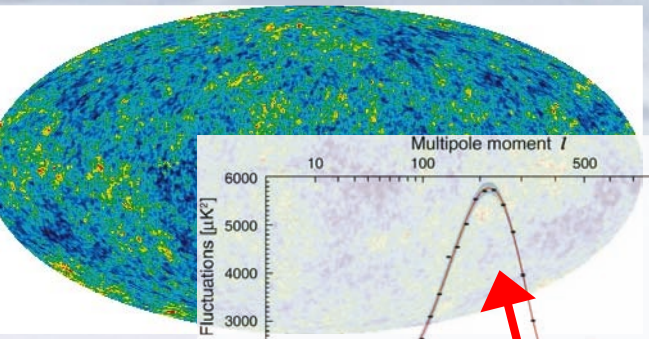
SPT SZ Observations

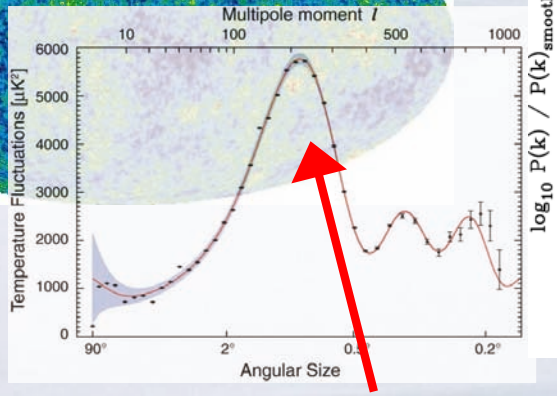
Christian Reichardt

UC Berkeley

Photo credit: J. Dana Hrubes

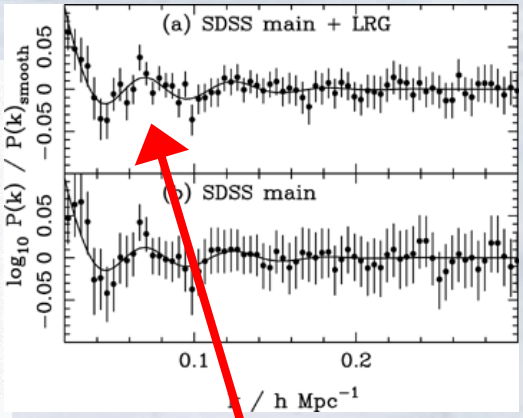
We Live in a Universe Dominated by Dark Energy



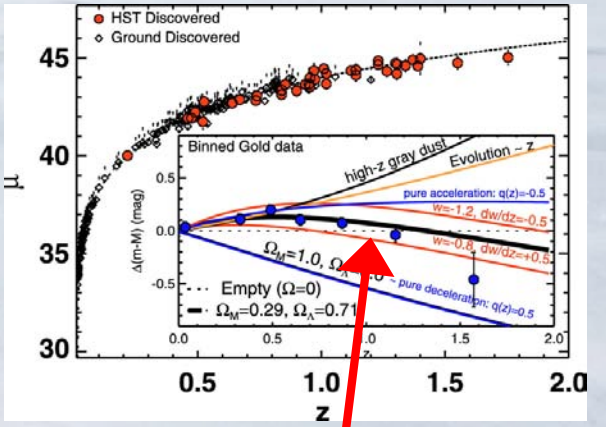


Komatsu et al 2008

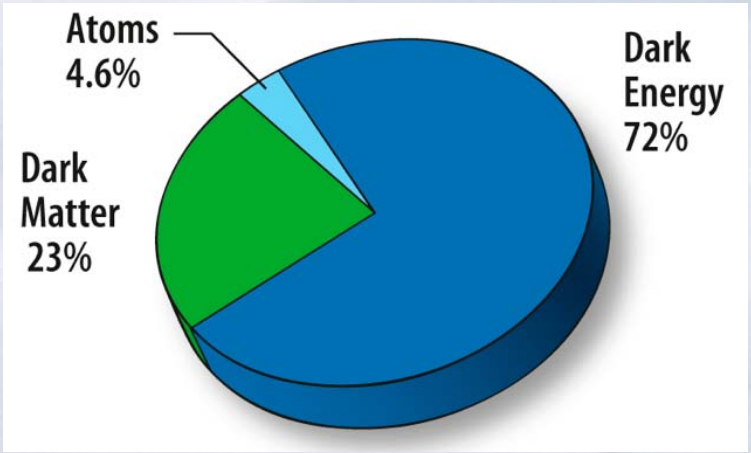
Percival et al 2007



Riess et al 2007



CMB + Large Scale Structure + SNe Ia



We live in a flat universe whose density is dominated dominated by dark energy

$\Omega_\Lambda = 0.721 \pm 0.015$

... but what is dark energy?

Dark Energy Constraints with Clusters of Galaxies

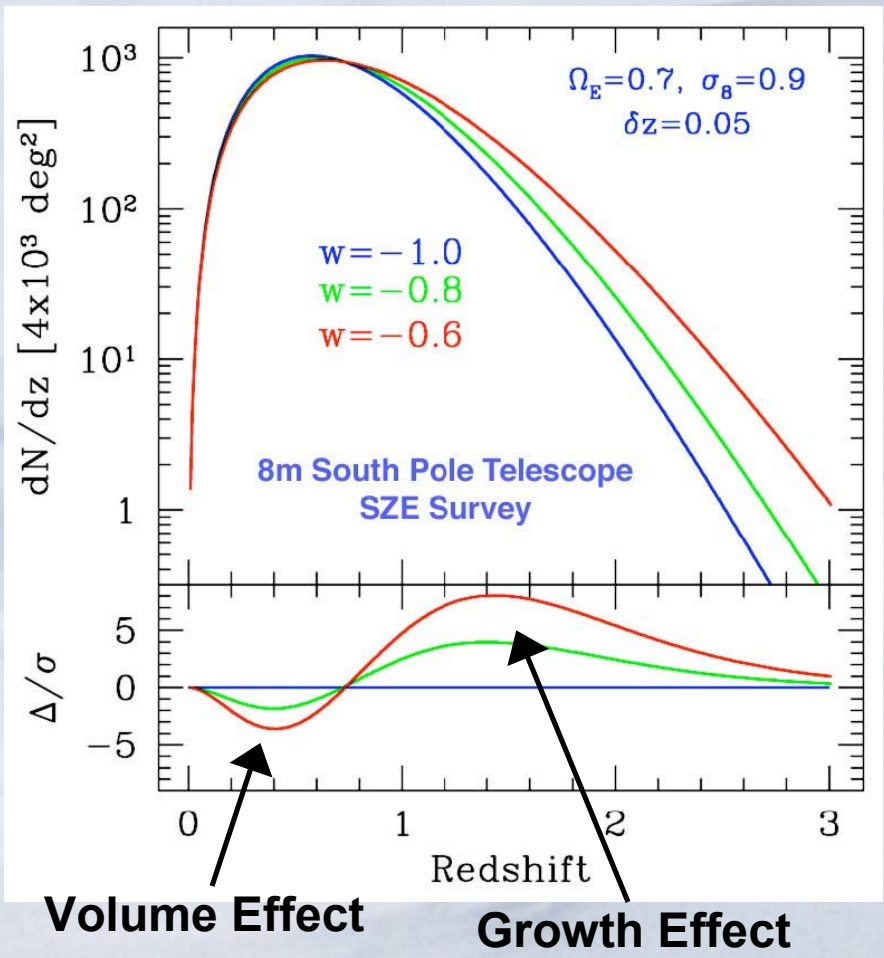
Cluster Abundance, dN/dz

$$\frac{dN}{d\Omega dz} = n(z)\frac{dV}{d\Omega dz}$$

Depends on:
Matter Power Spectrum, *P(k)*
Growth Rate of Structure, *D(z)*

Depends on:
Rate of Expansion, *H(z)*

Credit: Joe Mohr



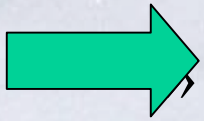
For fixed Ω_{DE} and less negative *w*:

1. Fewer clusters at low redshift, due to decreased volume surveyed
2. More clusters at high redshift, due to decreased growth rate

Requirements for an SZ cluster-finding machine

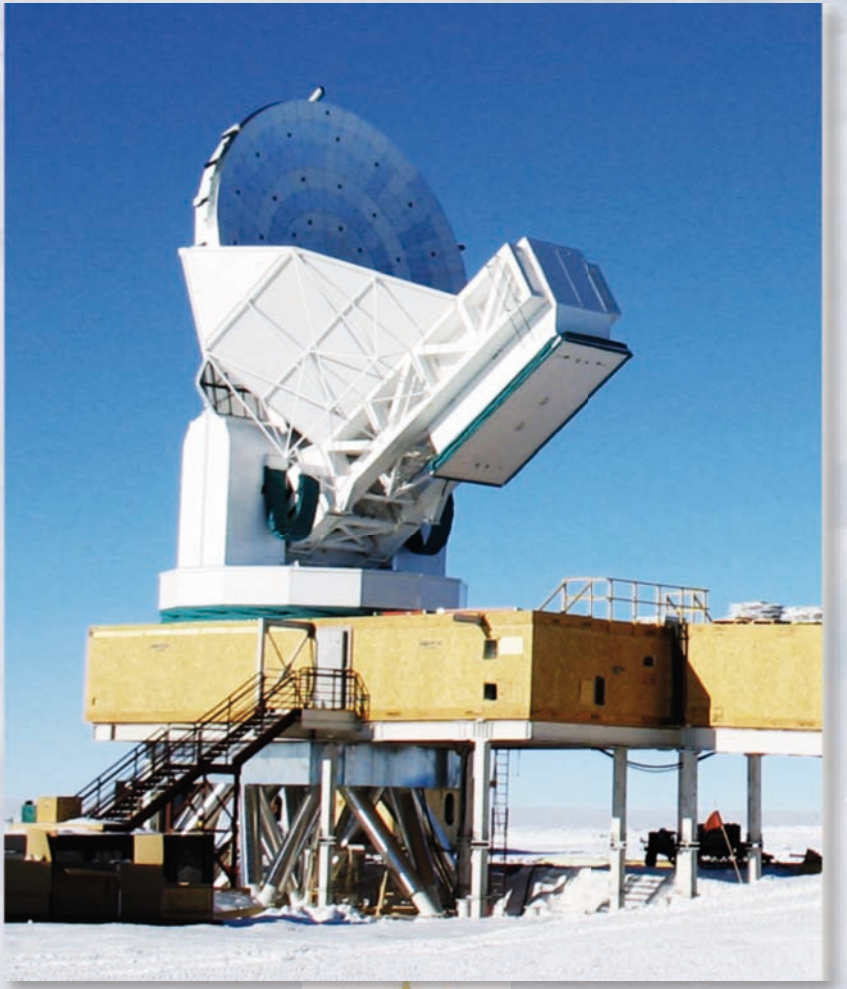
- **Resolution**
  - 1’ is well-matched to typical cluster size at these redshifts
  - At 150 GHz this means you need a 8-10 meter dish

- **Mapping Speed**
  - (# of elements) / noise^2
  - At 150 GHz (from the ground), bolometers have reached photon background limit to sensitivity
  - Previous SZ/CMB instruments have on the order of tens of pixels (e.g. – ACBAR =16, QUAD = 31 pixels, ...)



Need more background-limited detectors!!!

The South Pole Telescope (SPT)



Sub-millimeter Wavelength Telescope:

- 10 meter telescope (1' FWHM beam at 150 GHz)
- Off-axis Gregorian optics design
- 20 microns RMS surface accuracy
- 1 arc-second pointing
- Fast scanning (up to 4 deg/sec in azimuth)

SZ receiver:

- 1 sq. deg FOV
- ~960 background limited pixels
- Observe in 3 bands between 95-220 GHz simultaneously with a modular focal plane

Funded by NSF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UNIVERSITY OF ILLINOIS
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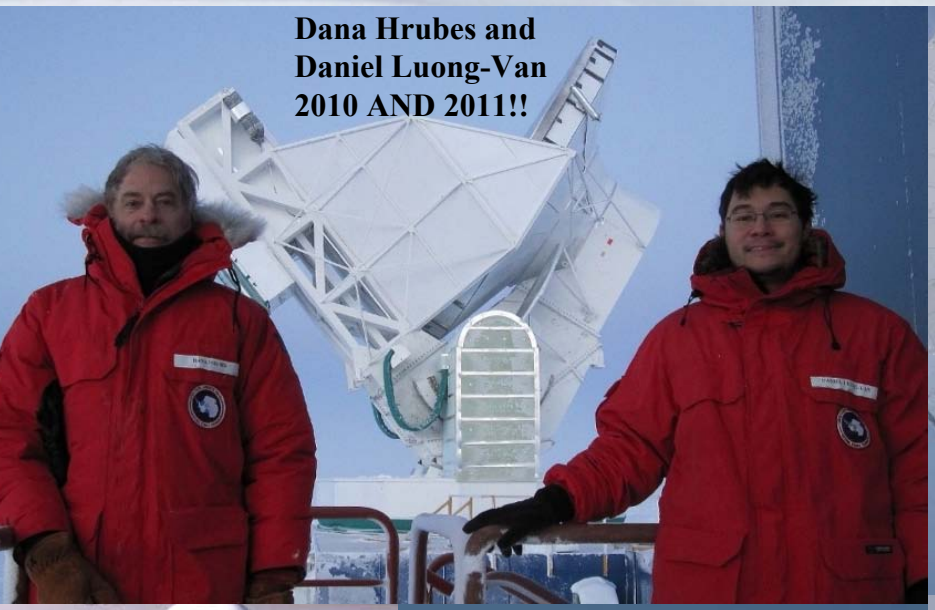
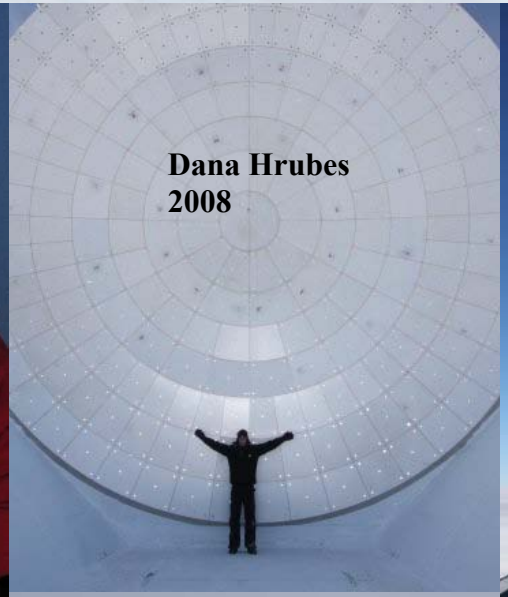
SPT Collaboration

SPT Heroes Gallery


Dana Hrubes and
Daniel Luong-Van
2010 AND 2011!!


Dana Hrubes
2008


Keith Vanderlinde
2008

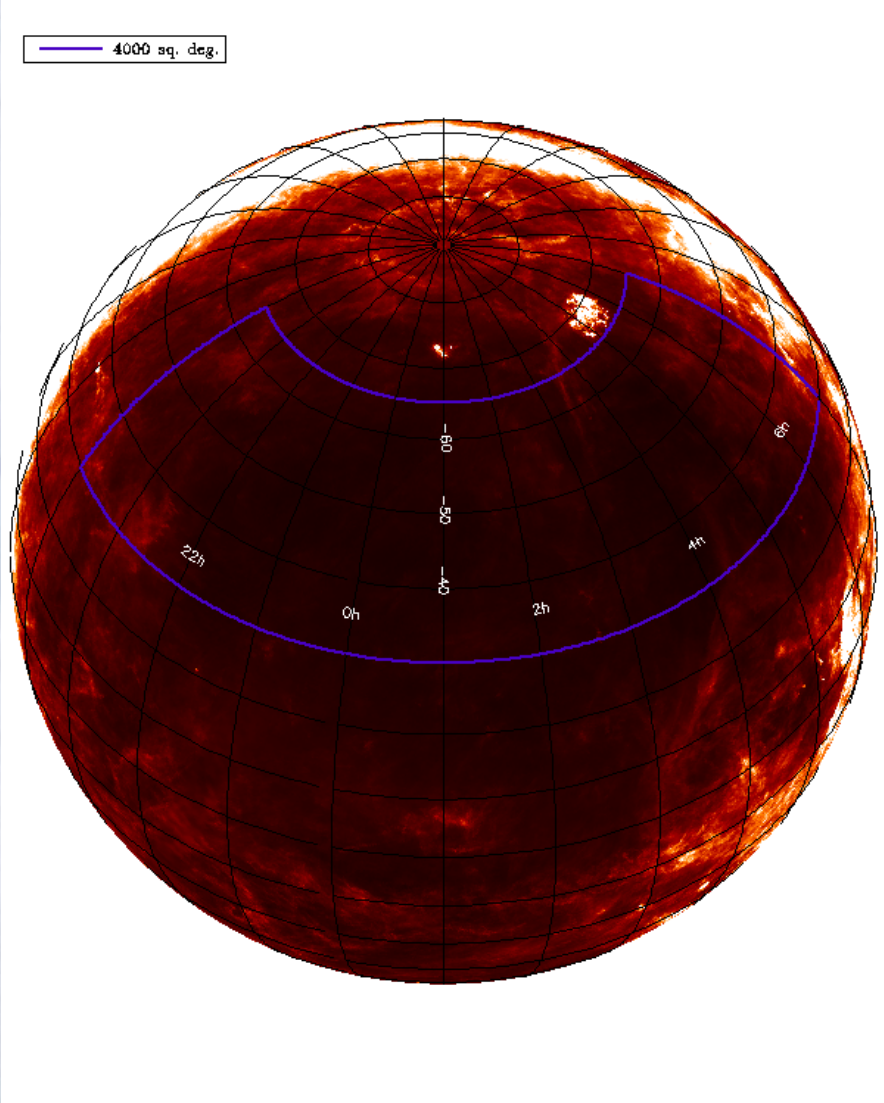

Steve Padin
2007


Zak Staniszewski
2007


Ross Williamson and
Erik Shirokoff
2009

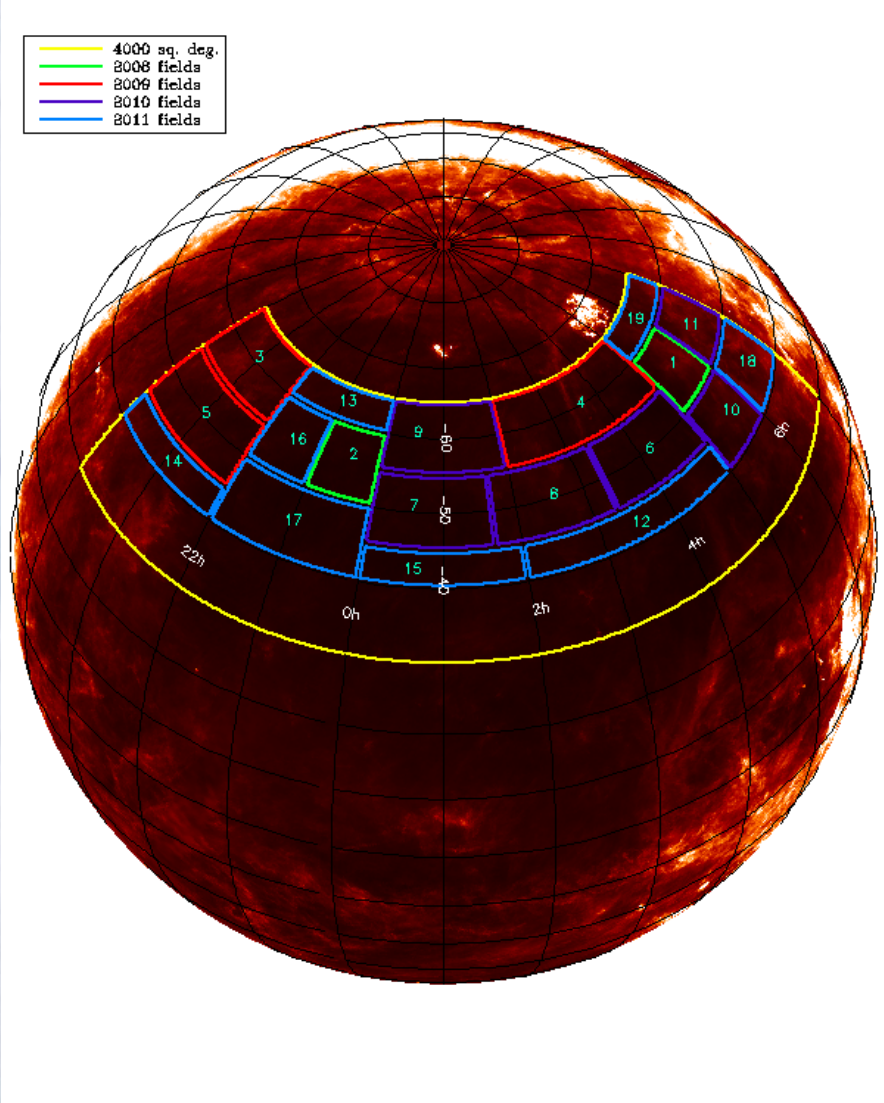
The Survey

- Limited to Southern Celestial Hemisphere.
- Galactic dust emission drives to 20h < RA < 7h.
- Atmospheric emission drives to observing elevations > 30deg.
- Leaves us ~4000 contiguous square degrees.

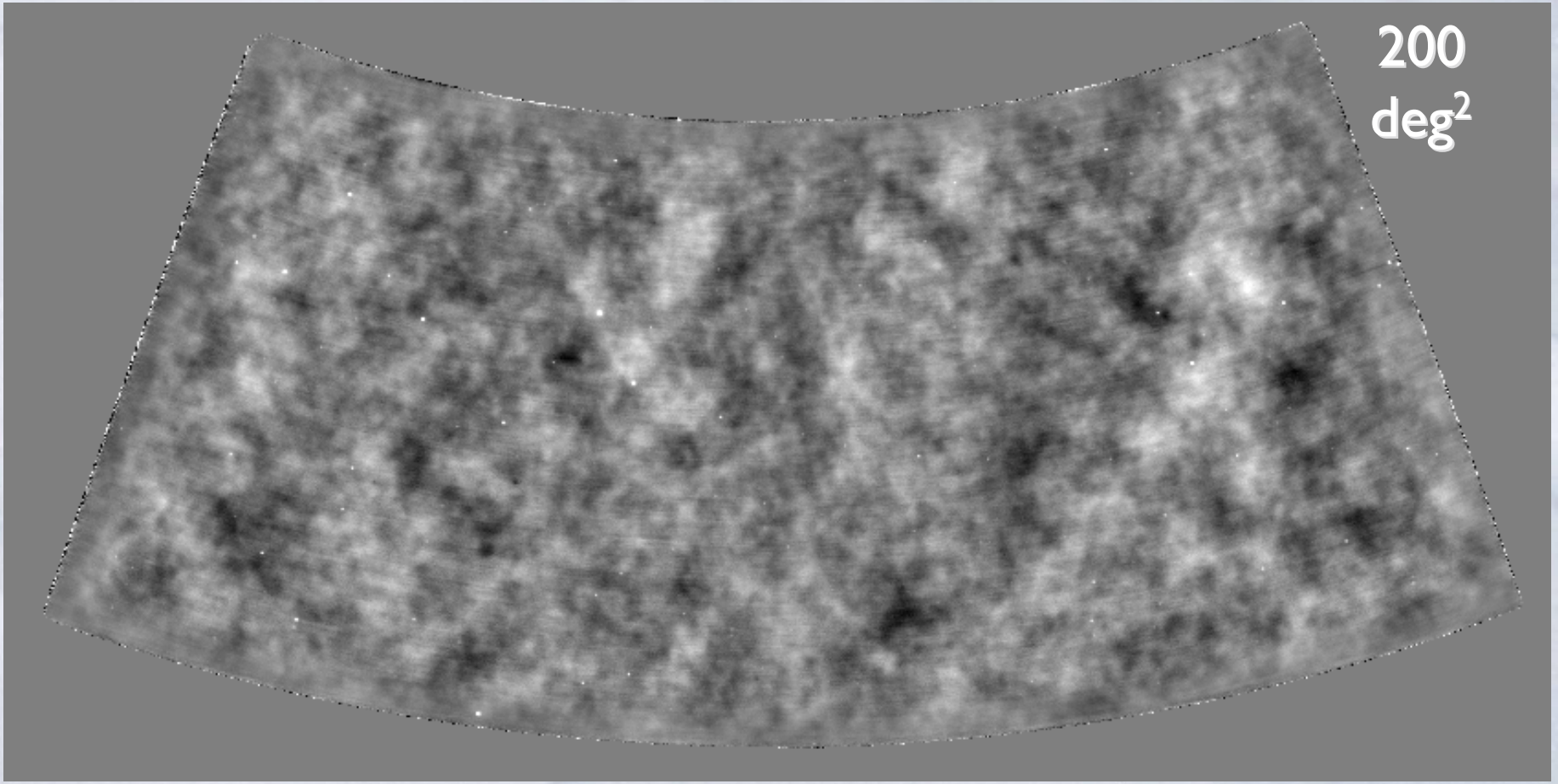


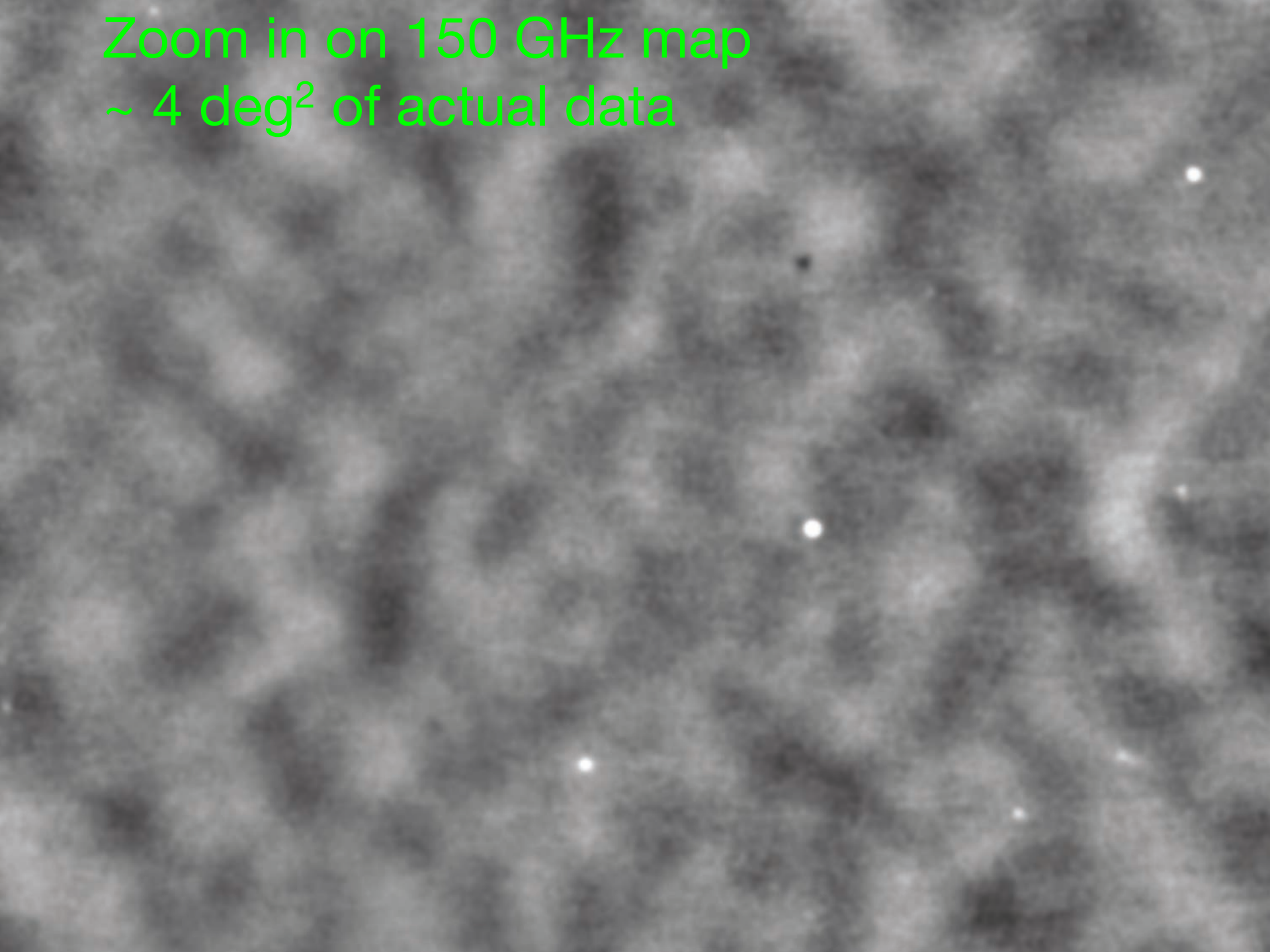
The Survey

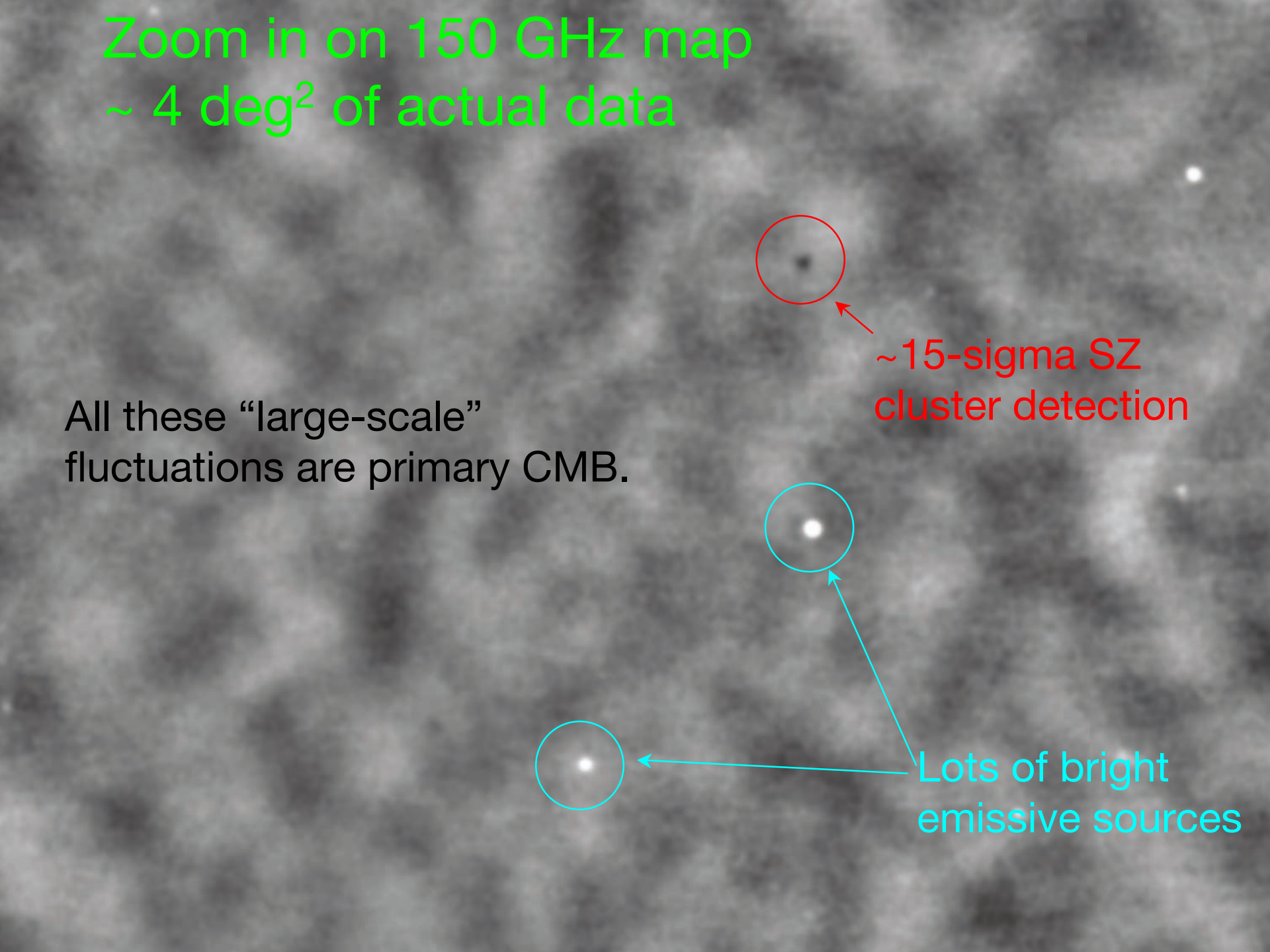
- So far have mapped ~1500 square degrees to survey depth.
- Full survey will be ~2500 square degrees - finishes in 2011. (concentrate on higher-latitude / more-negative-dec regions)



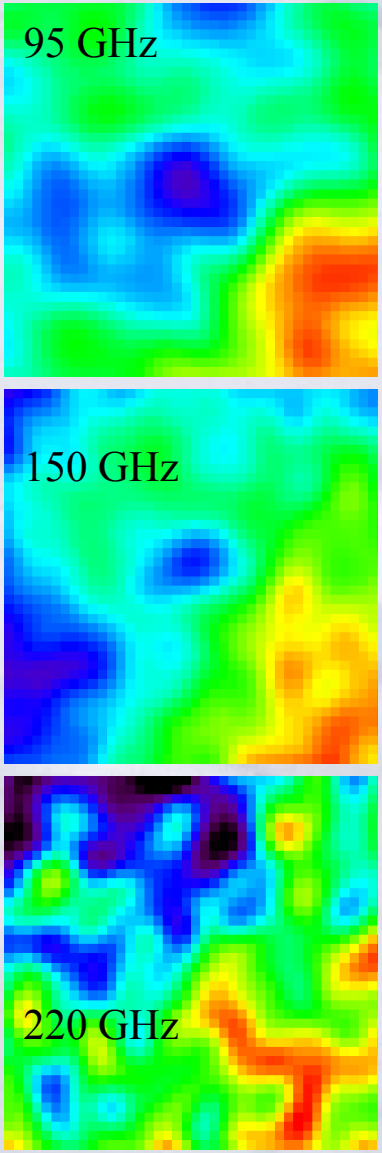
SPT map



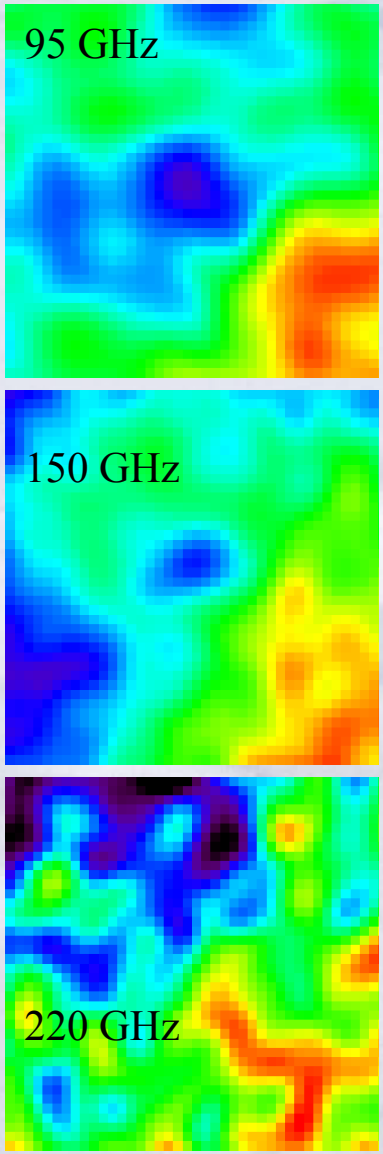

Zoom in on 150 GHz map
~ 4 deg^2 of actual data


Zoom in on 150 GHz map
~ 4 deg^2 of actual data
~15-sigma SZ
cluster detection
All these “large-scale”
fluctuations are primary CMB.
Lots of bright
emissive sources

Finding Clusters in the SPT Survey



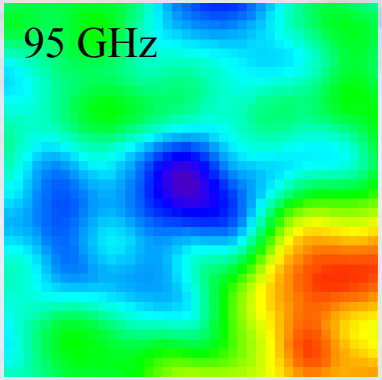
Finding Clusters in the SPT Survey

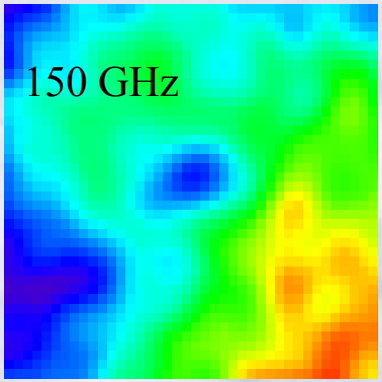


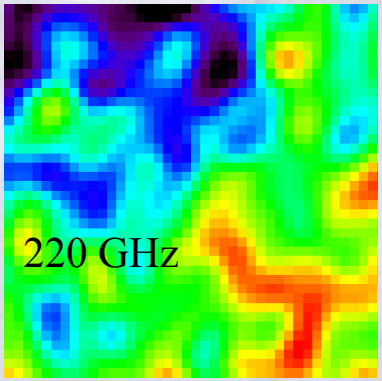
Matched Filter

(Not really a black box; we understand it quite well.)

Finding Clusters in the SPT Survey







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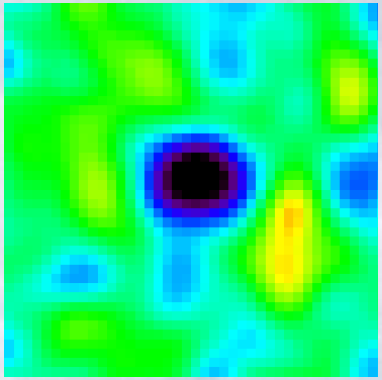


S/N ~ 6.3 (lots of guys like this in every field)

SPT has found hundreds of new clusters!

Observing year	Area surveyed (square degrees)	Candidates above 4.5 sigma	Candidates above 4.5 sigma w/redshifts
2008	~200	~40	~30
2009	~600	~190	~150
2010 (full-depth & analyzed)	~600	~170	~80
TOTAL	~1400	~400	~260

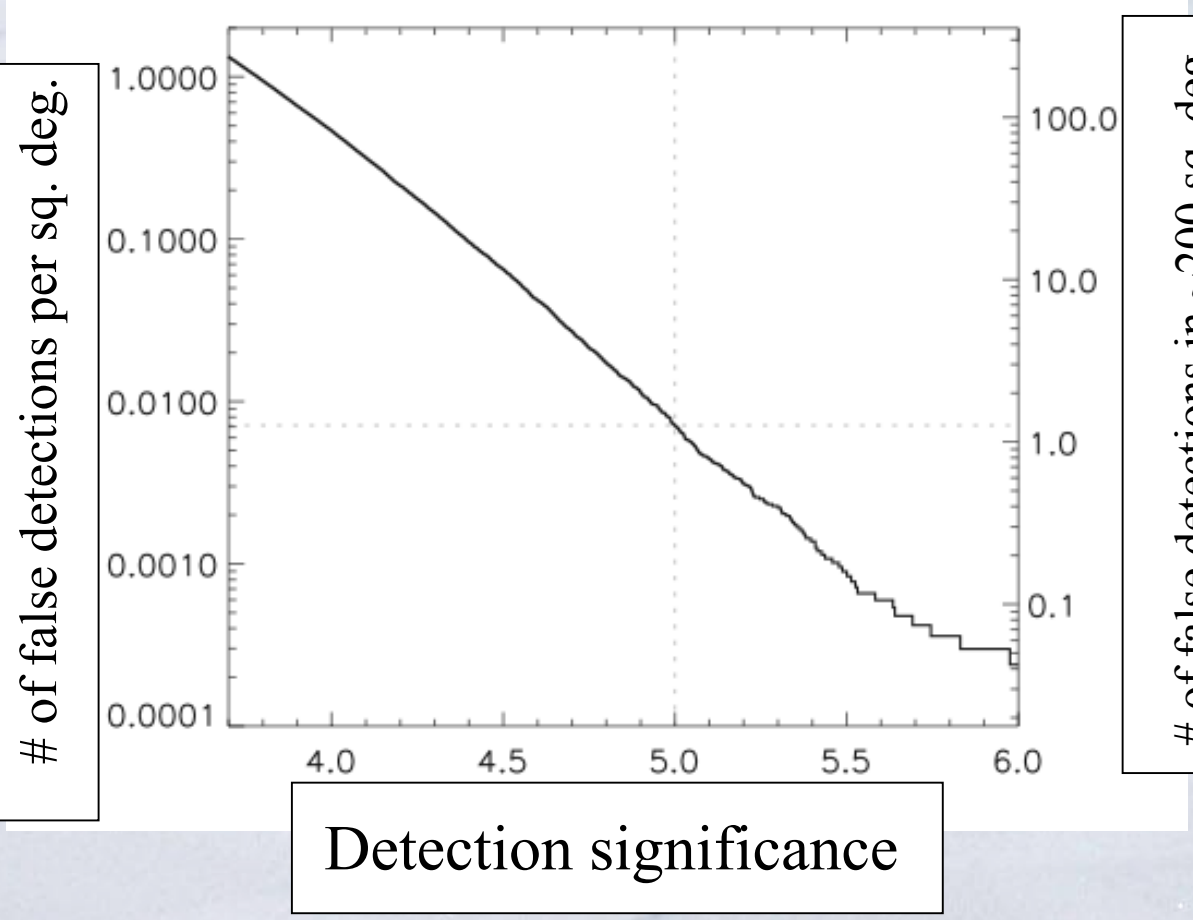
Vanderlinde et al. 2010: 21 clusters from the first 200 deg^2

Williamson et al., 2011: 26 most massive clusters from the complete 2500 deg^2 survey region

Scaling of actual counts predicts O(750) candidates for complete survey!

C. Reichardt, *SPT SZ Observations*, Planck conference, January 11, 2011

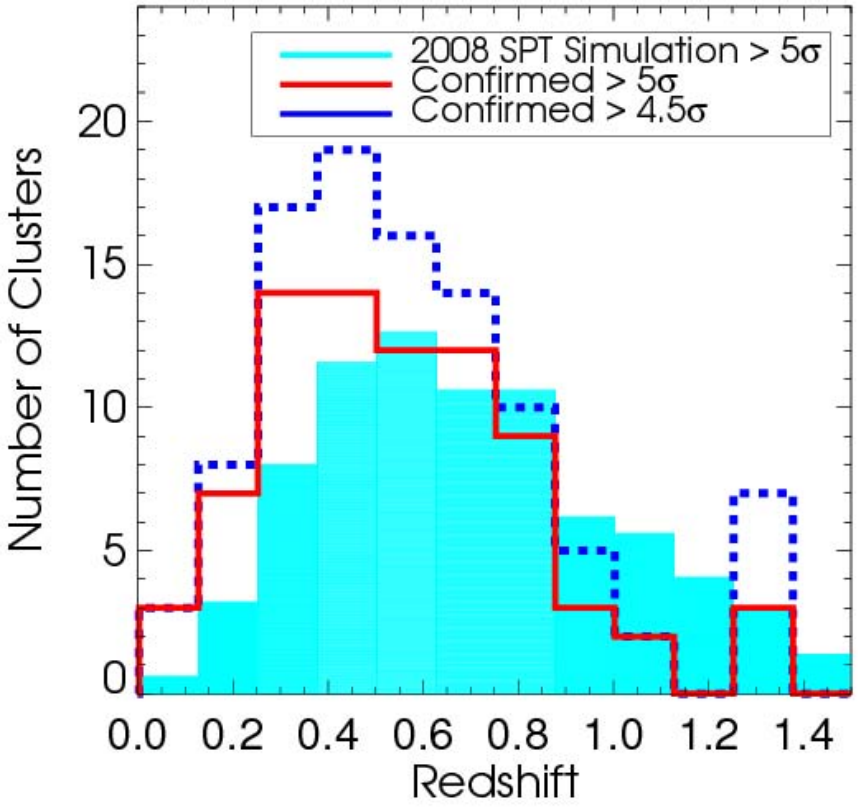
SPT cluster detections are robust



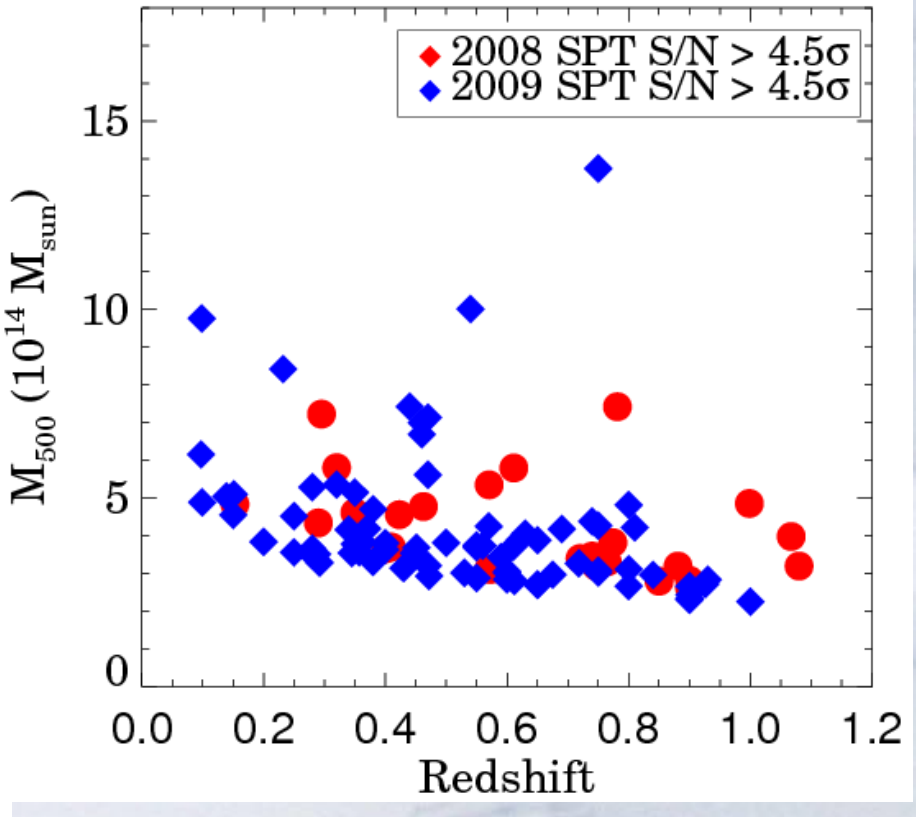
- Simulations predict ~10 false positives above S/N=5 in entire survey (~100 above S/N=4.5).
- Borne out by optical/IR/x-ray follow-up of first catalog (only 1 spurious detection out of 22 in first ~200 sq. deg.)

SPT Cluster Properties

SPT Redshift Histogram (July 2010)

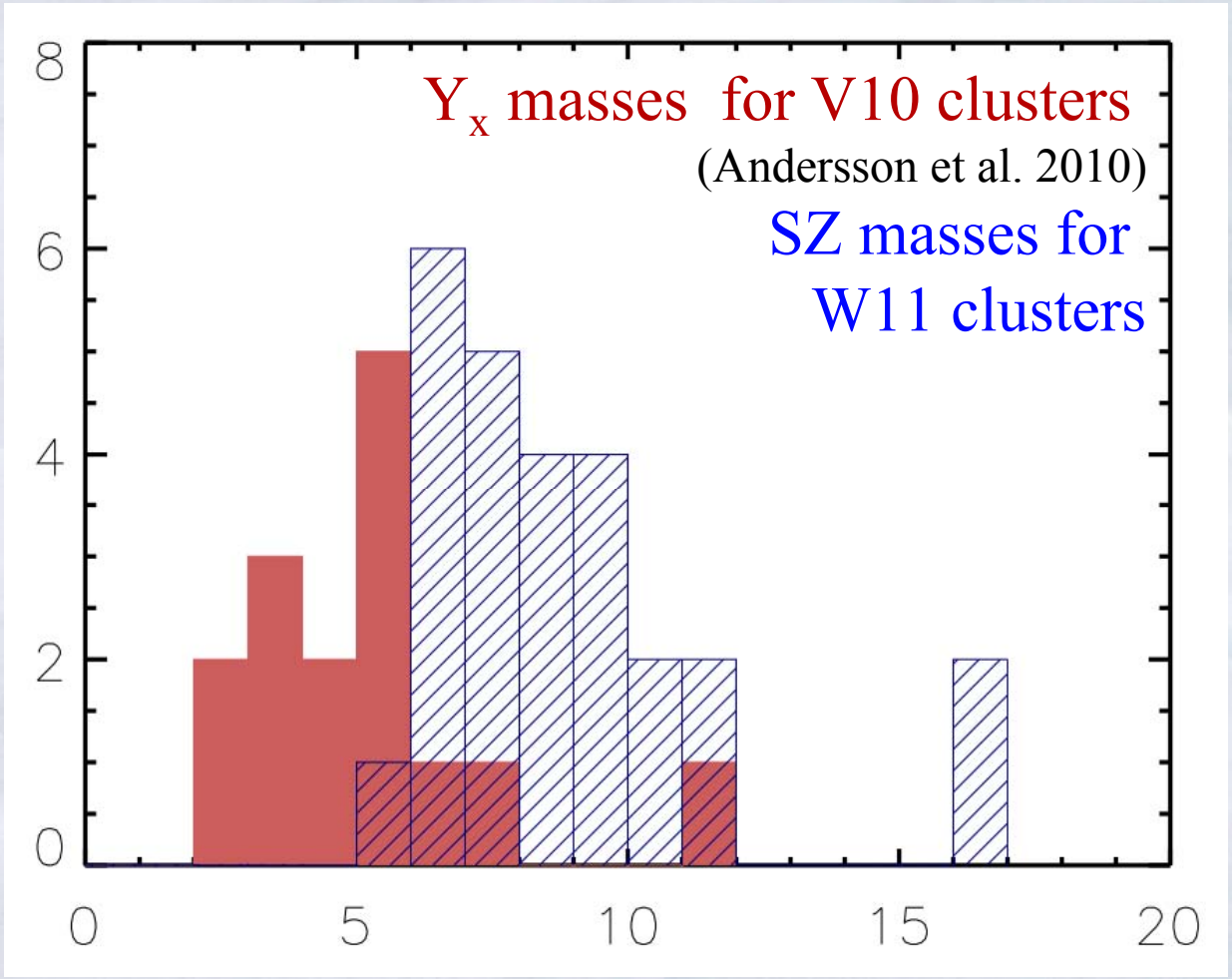


SZ Mass vs Redshift



- SPT clusters are high redshift ($z \sim 0.6$)
- Mass threshold flat (or falling) with redshift

SPT clusters are all massive



All optically confirmed SPT clusters with x-ray measurements show strong signal and temperatures consistent with massive clusters ($\geq 2 \times 10^{14}$ solar masses).

The most significant clusters are even more massive:

($\geq 5 \times 10^{14}$ solar masses).

Take-Home Message #1

SPT has already discovered hundreds of cluster candidates, the vast majority of which correspond to real, massive clusters.

Cosmology with SPT clusters I: Vanderlinde et al., 2010

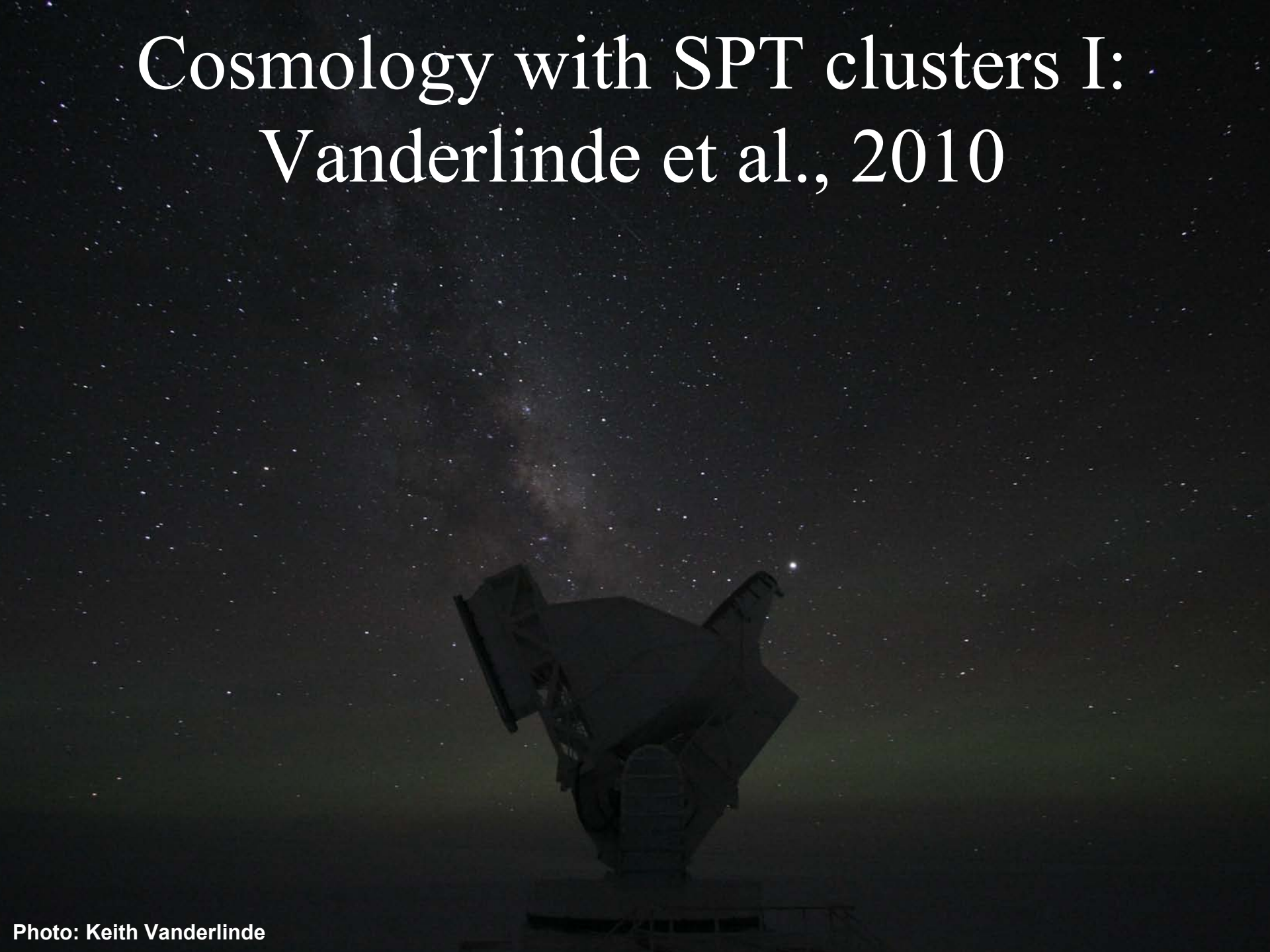


Photo: Keith Vanderlinde

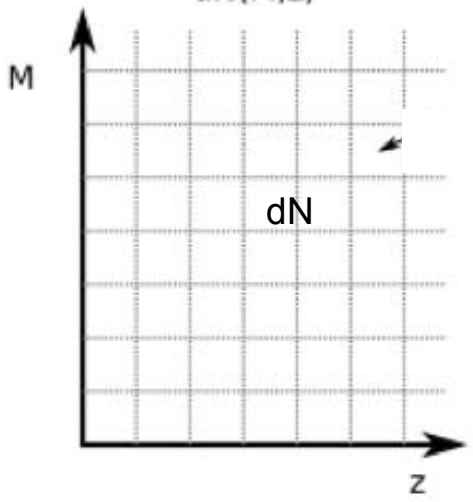
Cosmology to Expected Number Counts

Cosmology

Tinker et al. 2008
Mass functions

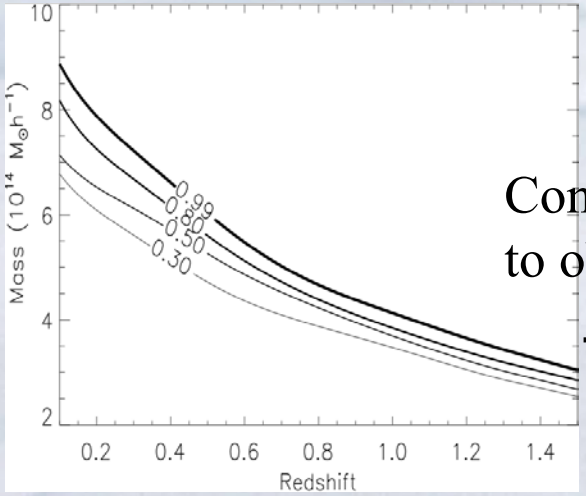
- Generate expected SPT number counts from cosmological parameter sets

Theory Curves
dN(M,z)



X

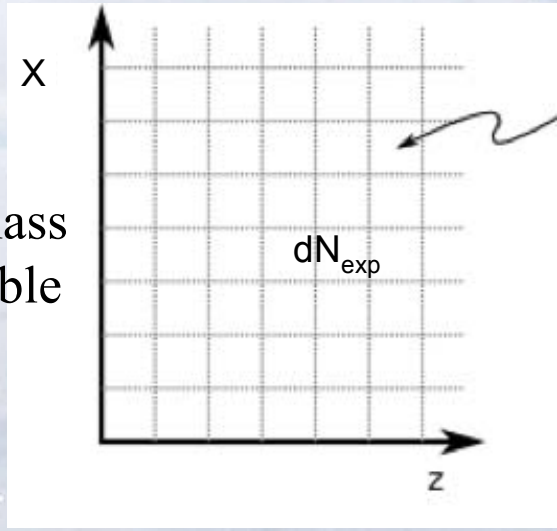
Selection Function



Convert mass to observable

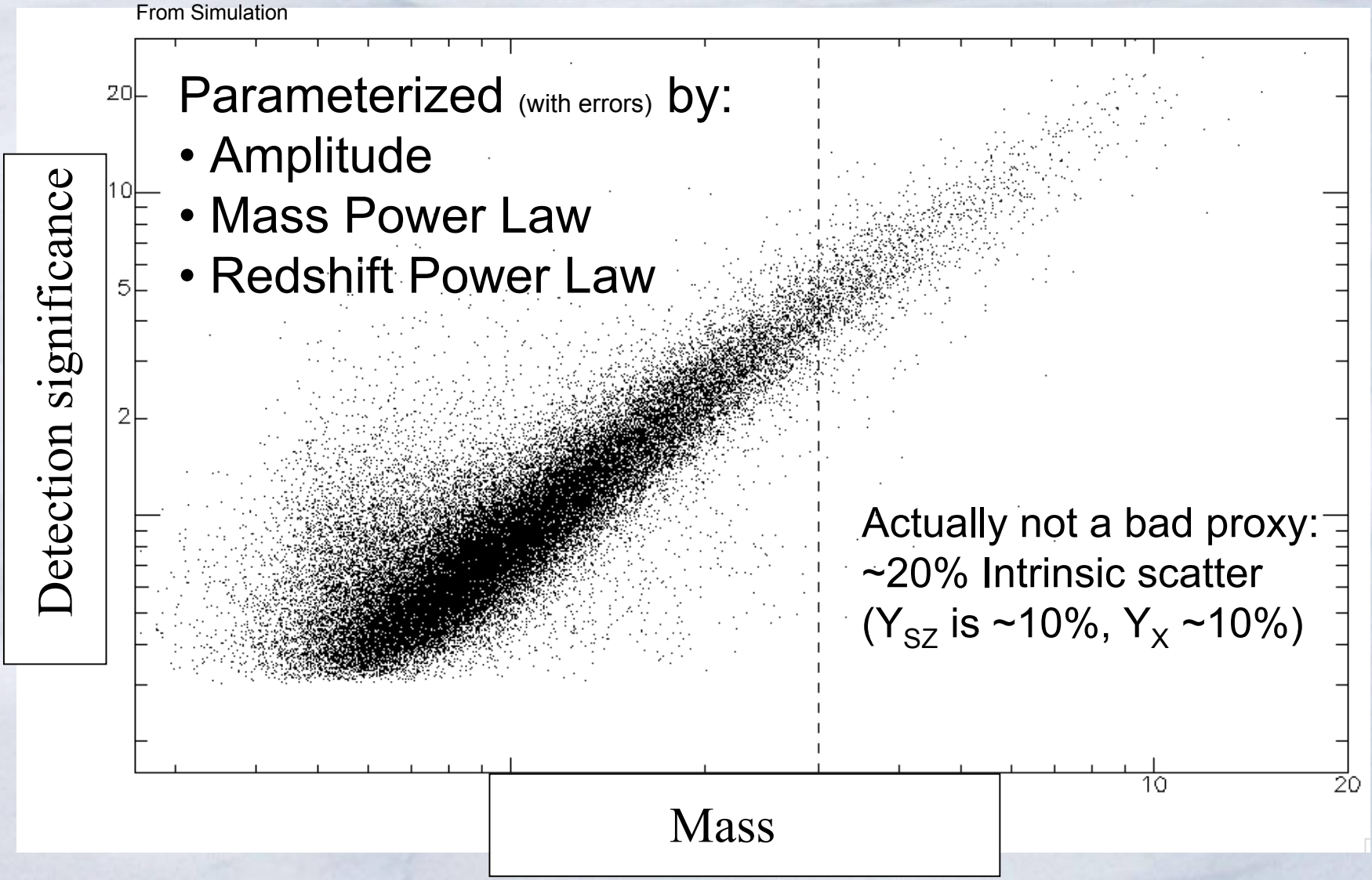
Compare to data

X

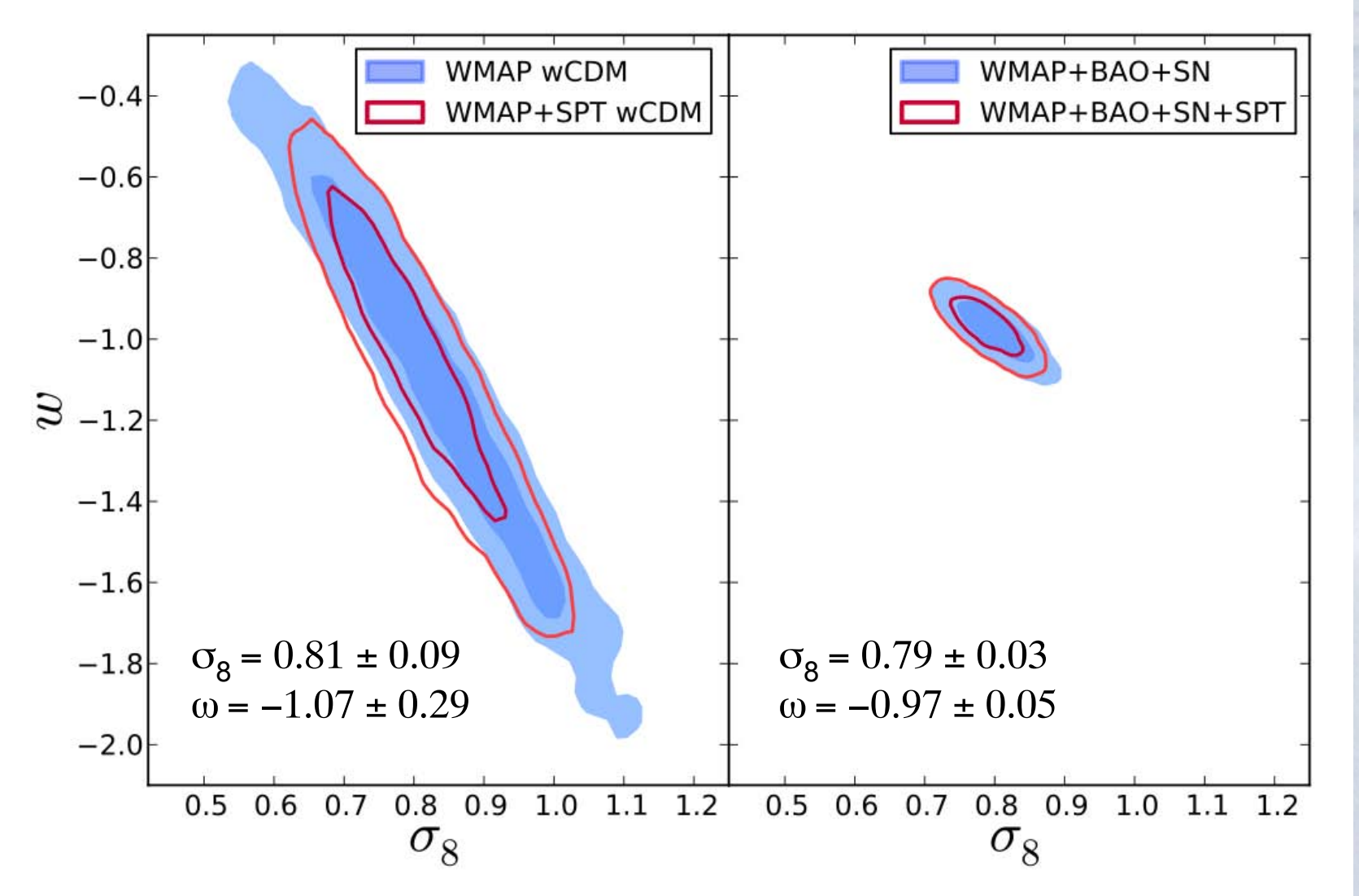


Mass Proxy?

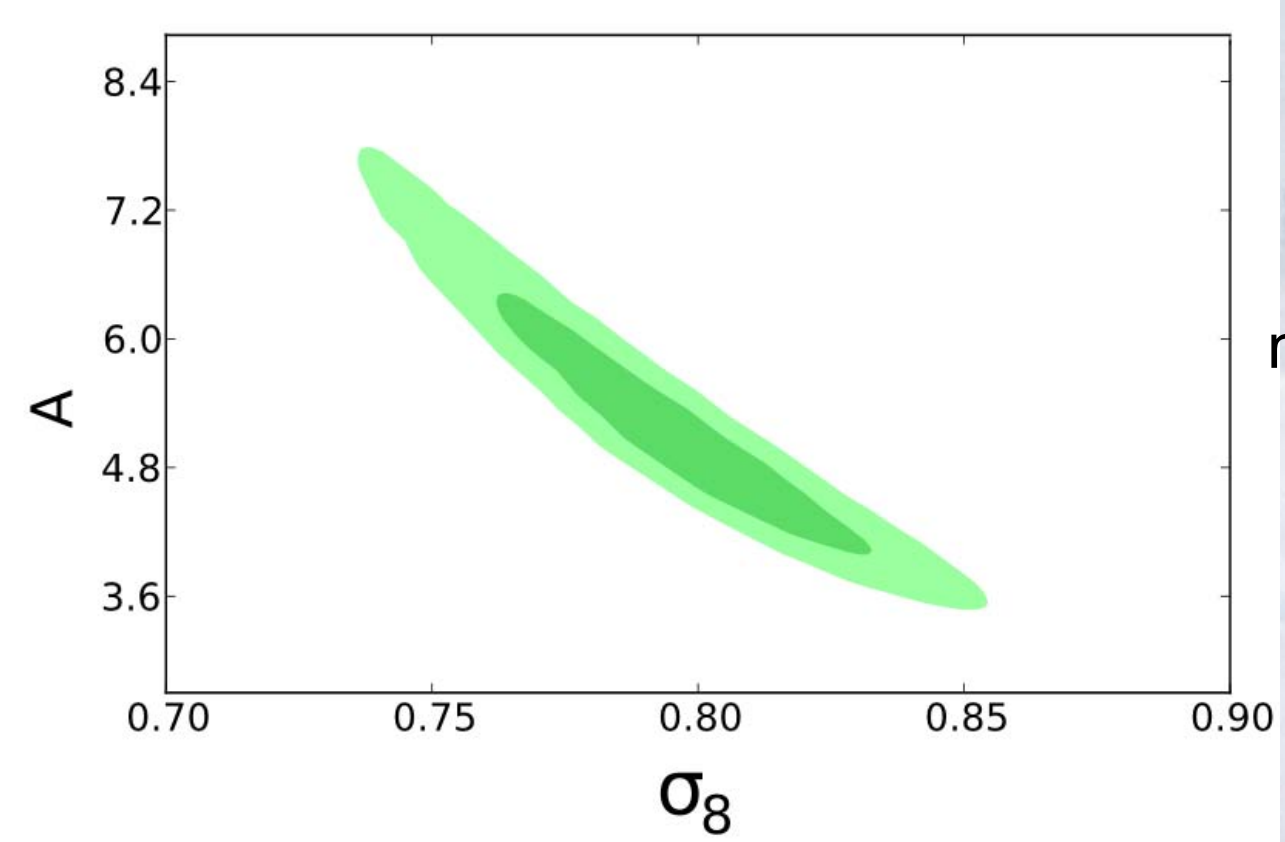
Just use detection significance!



Parameter Constraints



Parameter Constraints

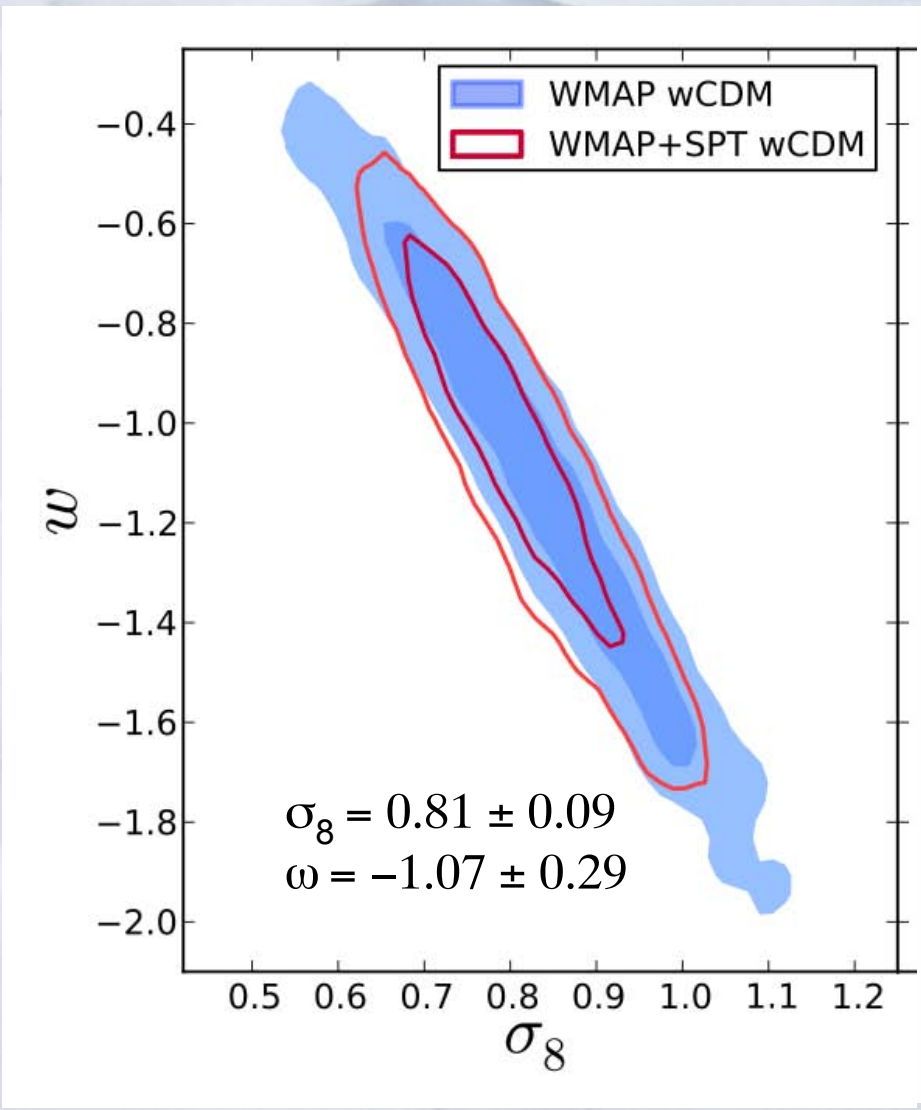


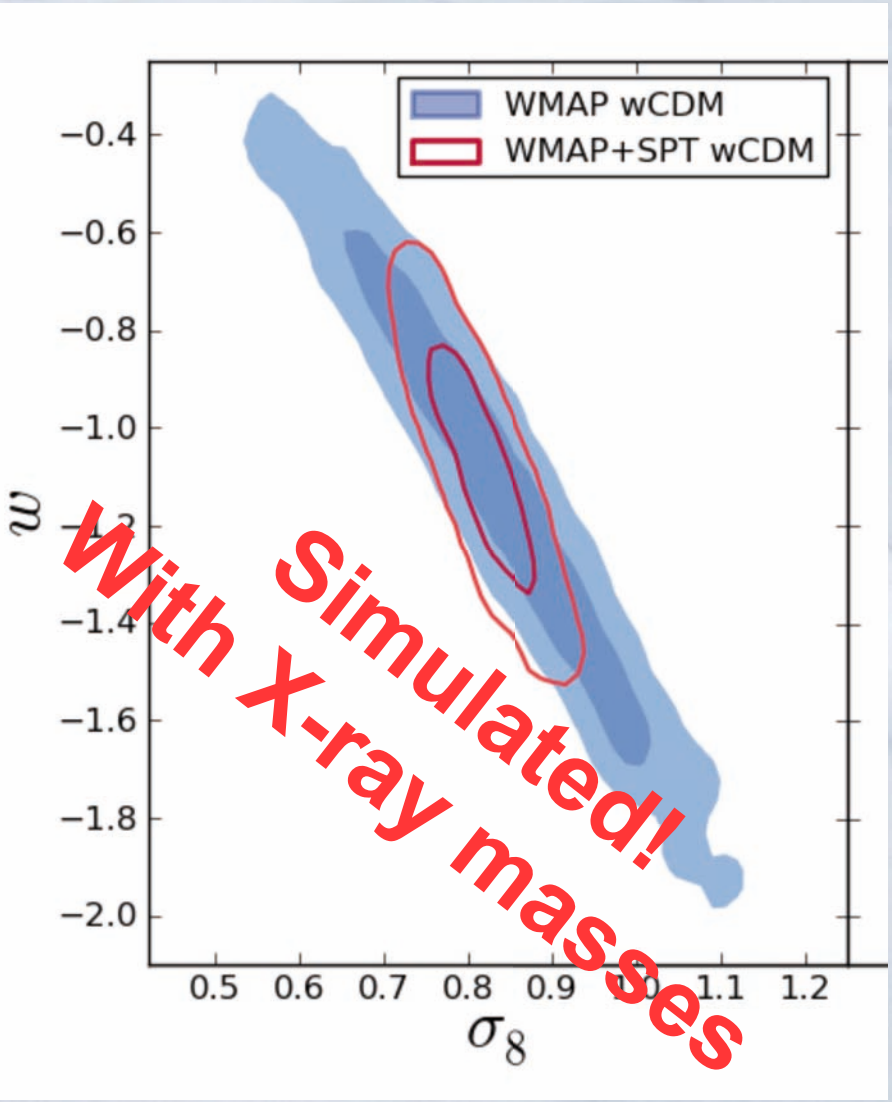
Amplitude of SZ-mass scaling relation is almost perfectly degenerate with σ_8.

Need scaling relation calibration!
X-ray? Weak Lensing?

C. Reichardt, *SPT SZ Observations*, Planck conference, January 11, 2011

Parameter Constraints





C. Reichardt, *SPT SZ Observations*, Planck conference, January 11, 2011

Cosmology with SPT clusters II: Testing ΛCDM

Williamson et al., 2011

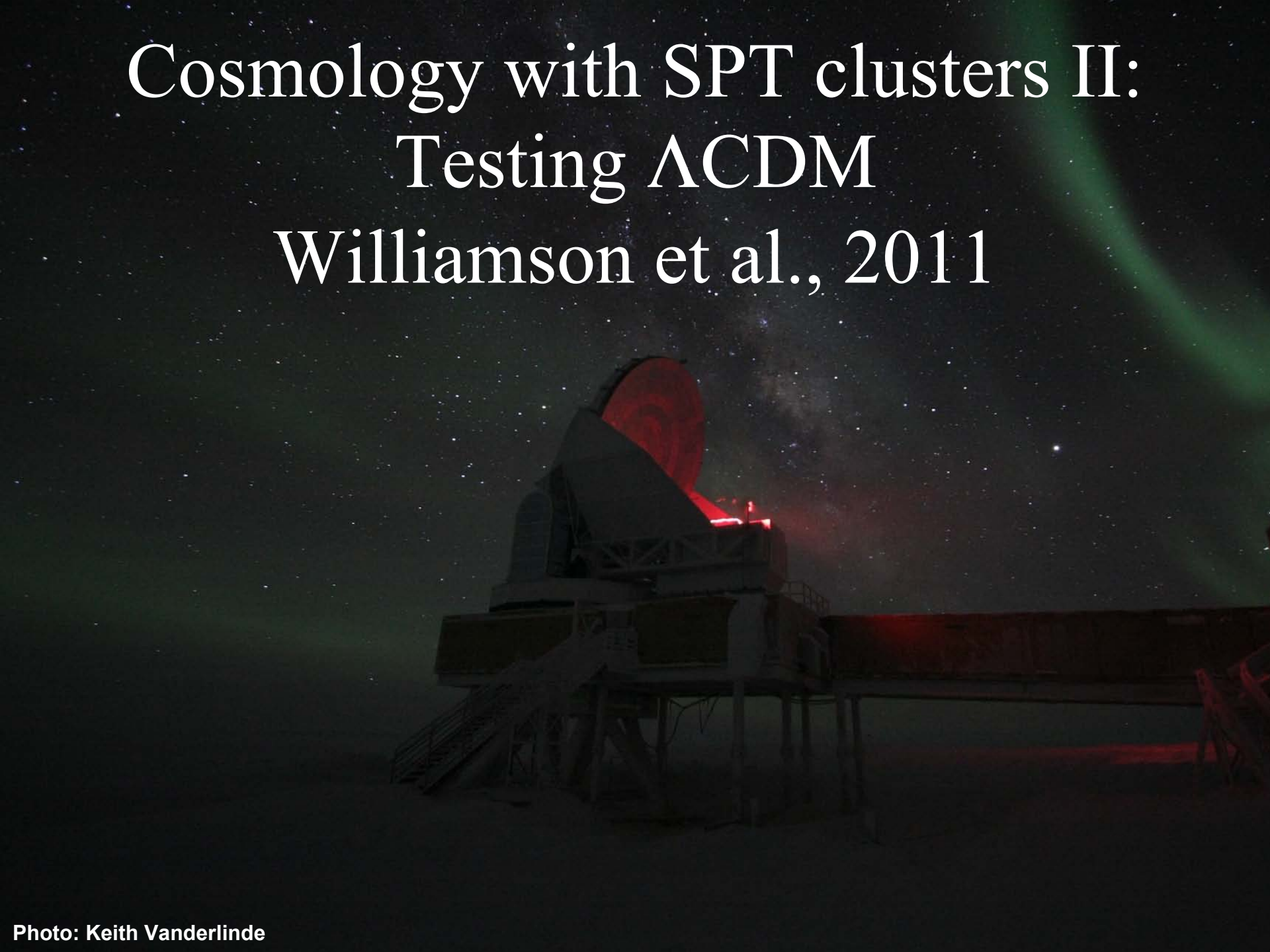
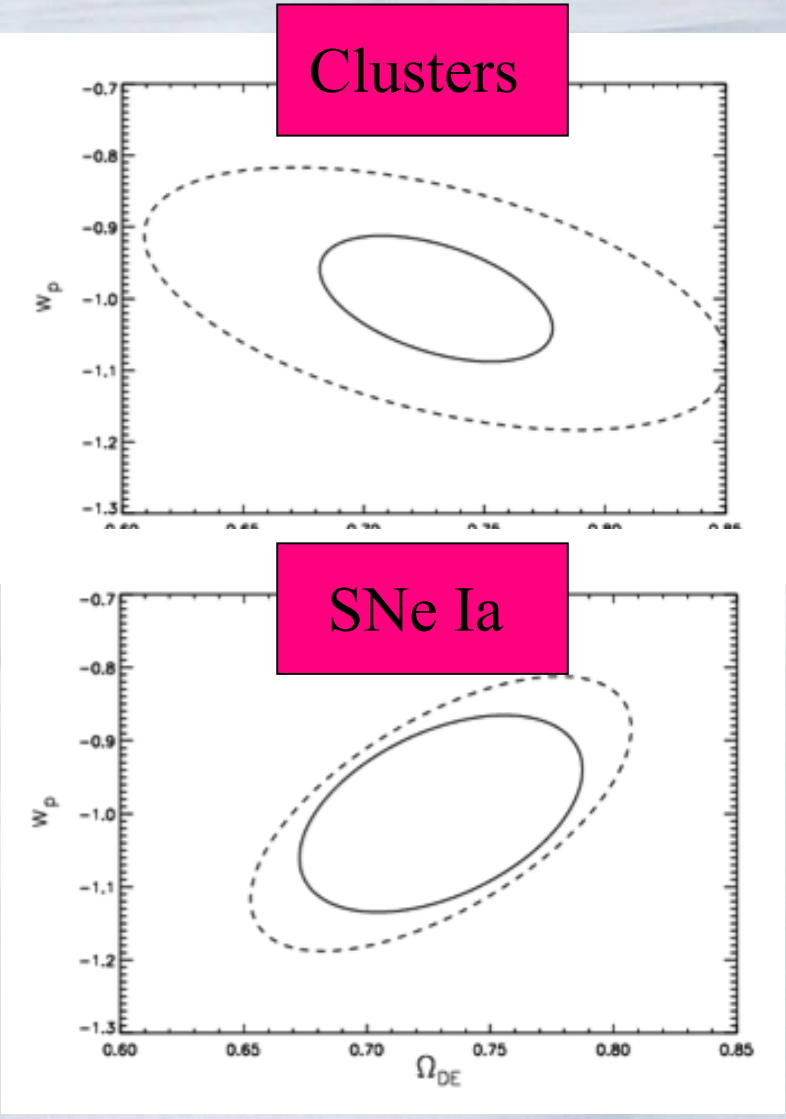


Photo: Keith Vanderlinde

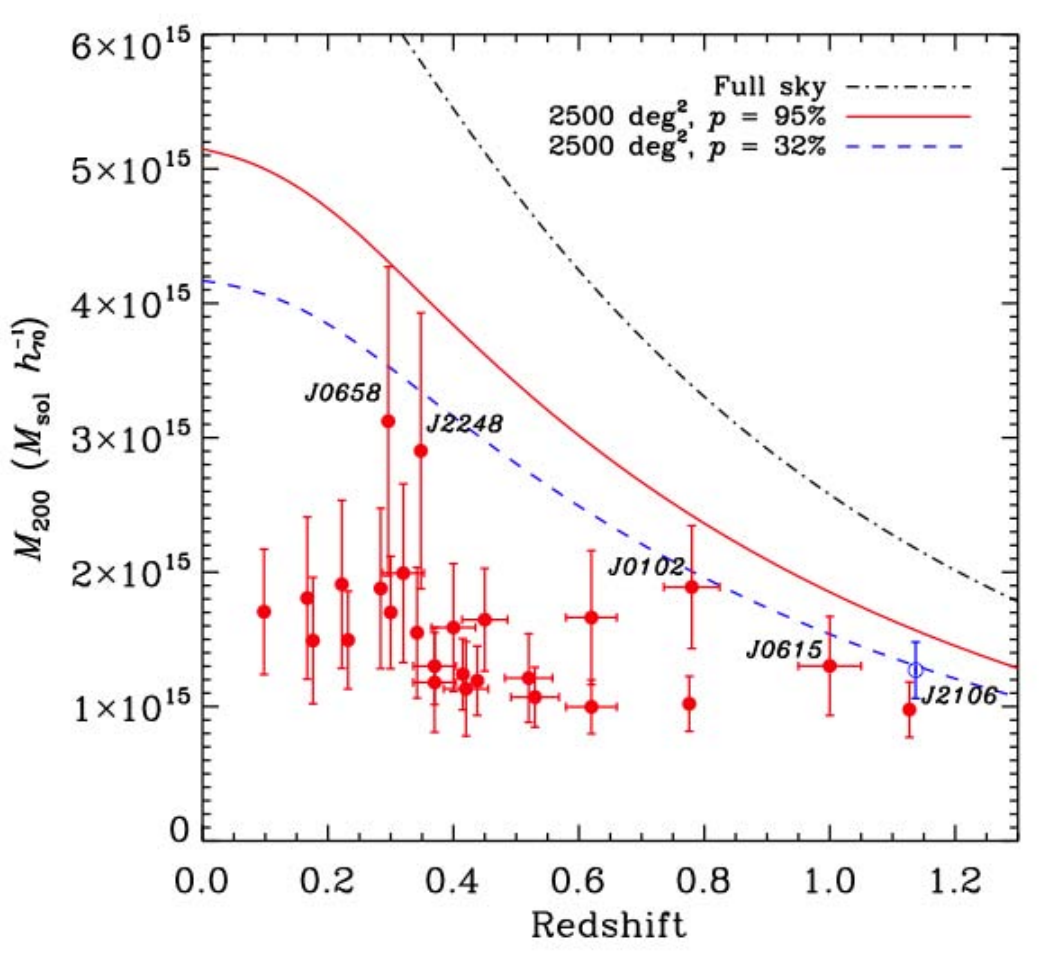
Testing the model

Look for inconsistencies between growth-based measurements and distance-based measurements (or poor fit to LCDM).

- evidence for modified gravity, non-Gaussian initial conditions, ?



Ruling out LCDM

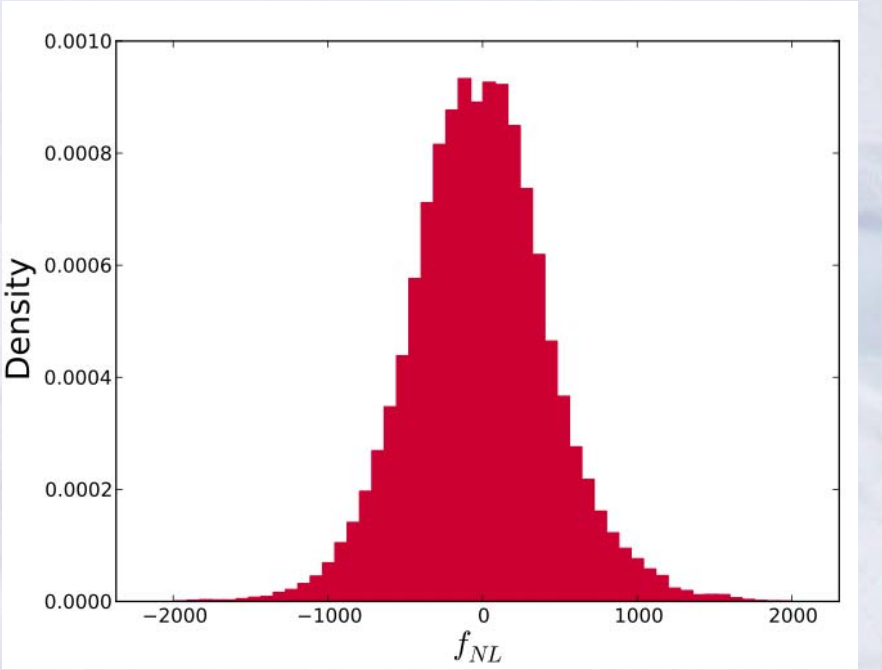


Mortonson et al. 2010 presented a formula for addressing whether a single massive cluster is in tension with LCDM.

The most significant SPT clusters are **not** in tension.

The highest redshift cluster rules out 32% of LCDM parameter space (at 95% CL).

Non-gaussian initial conditions



- We explore f_{nl} constraints from the most massive SPT clusters.
- Find no preference for non-Gaussianity.
  - $f_{nl} = 20 \pm 450$

Cosmology with SPT clusters III: Scaling relations

Photo: Keith Vanderlinde

Cosmology with SPT clusters III:

Distinguishing between cosmology and evolution in the SZ-mass scaling relation requires precise and unbiased mass calibration AT ALL REDSHIFTS.

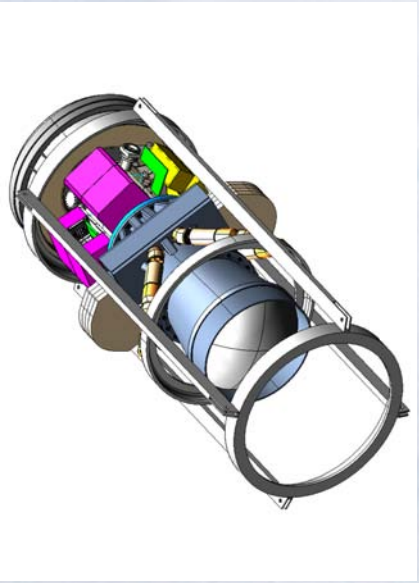
- multi-wavelength mass calibration campaign, including:
- x-ray with Chandra and XMM (all redshifts)
- weak lensing at from Magellan (low/mid-z) and HST (high-z)
- dynamical masses from Gemini, VLT, hopefully HST

Cosmology with SPT clusters III:

Distinguishing between cosmology and evolution in the SZ-mass scaling relation requires precise and unbiased mass calibration AT ALL REDSHIFTS.

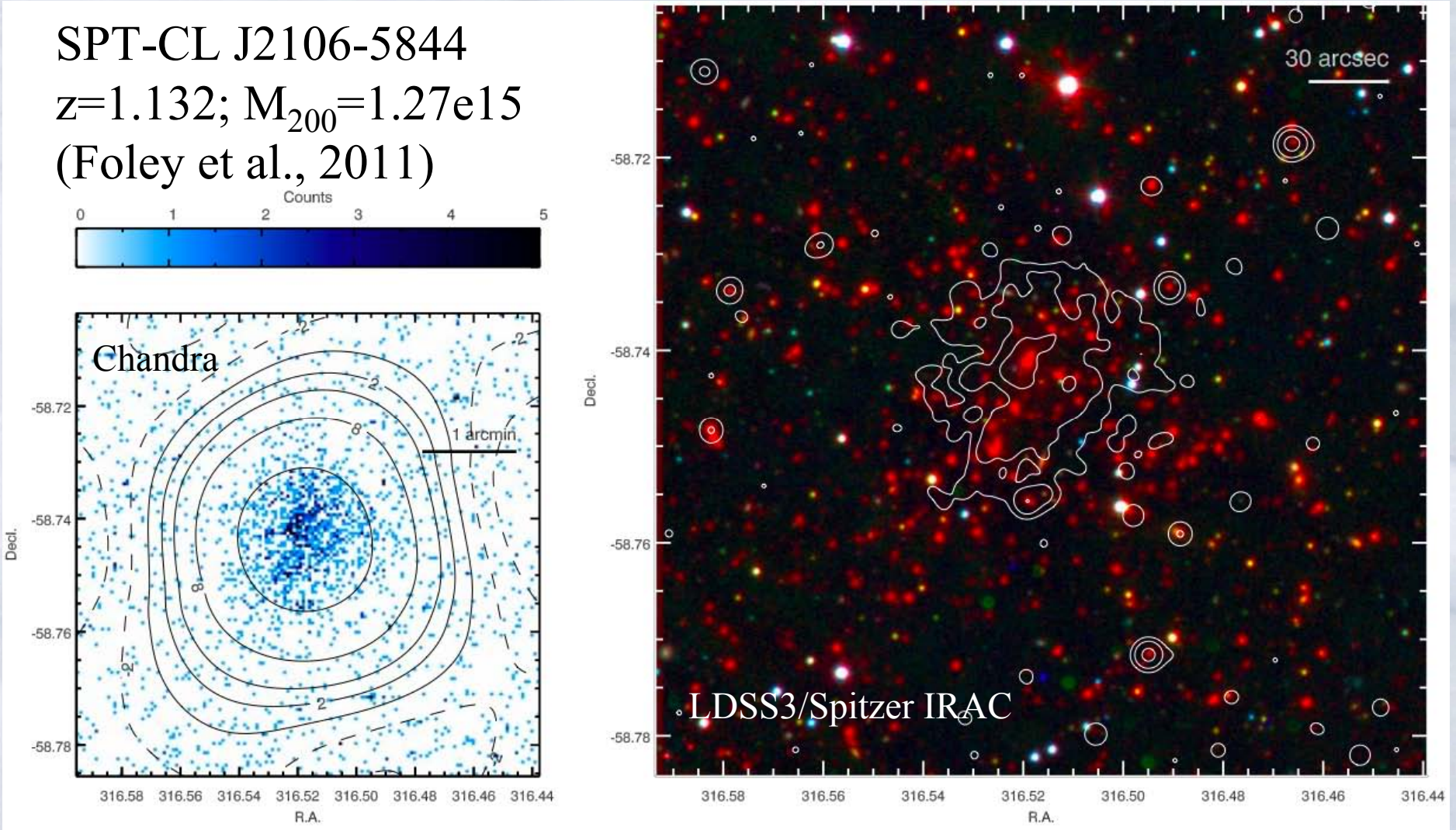
- multi-wavelength mass calibration campaign, including:

- SOON: Deep optical, weak-lensing-quality data from DES



Example of the followup program

SPT-CL J2106-5844
z=1.132; M_{200}=1.27e15
(Foley et al., 2011)



X-ray with SZ contours

Optical/IR with X-ray contours

Take-Home Message #2

In the near future, SPT will deliver a catalog of O(750) cluster candidates, with accurate, unbiased mass calibration at all redshifts, to constrain cosmological models.

Thanks!

Photo credit: Keith Vanderlinde