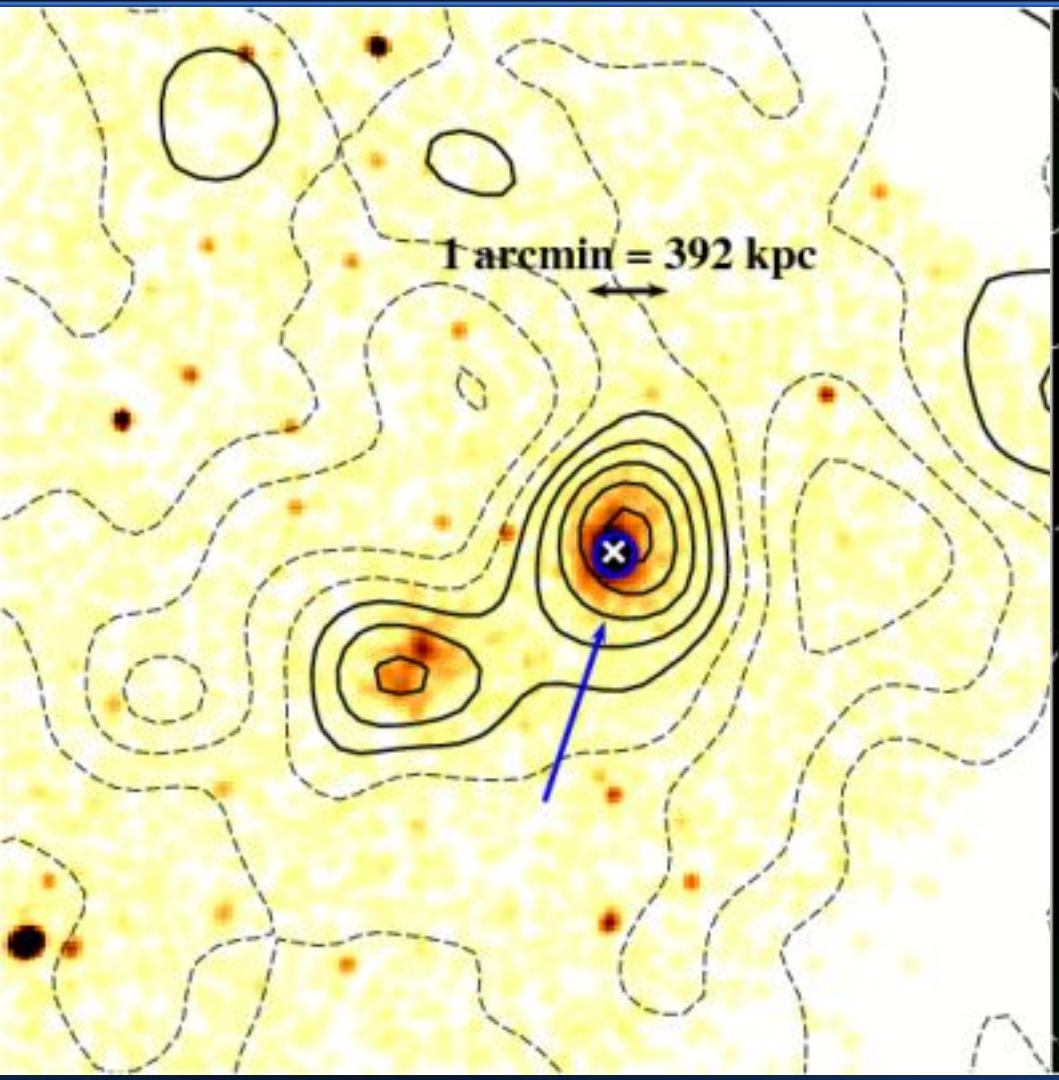
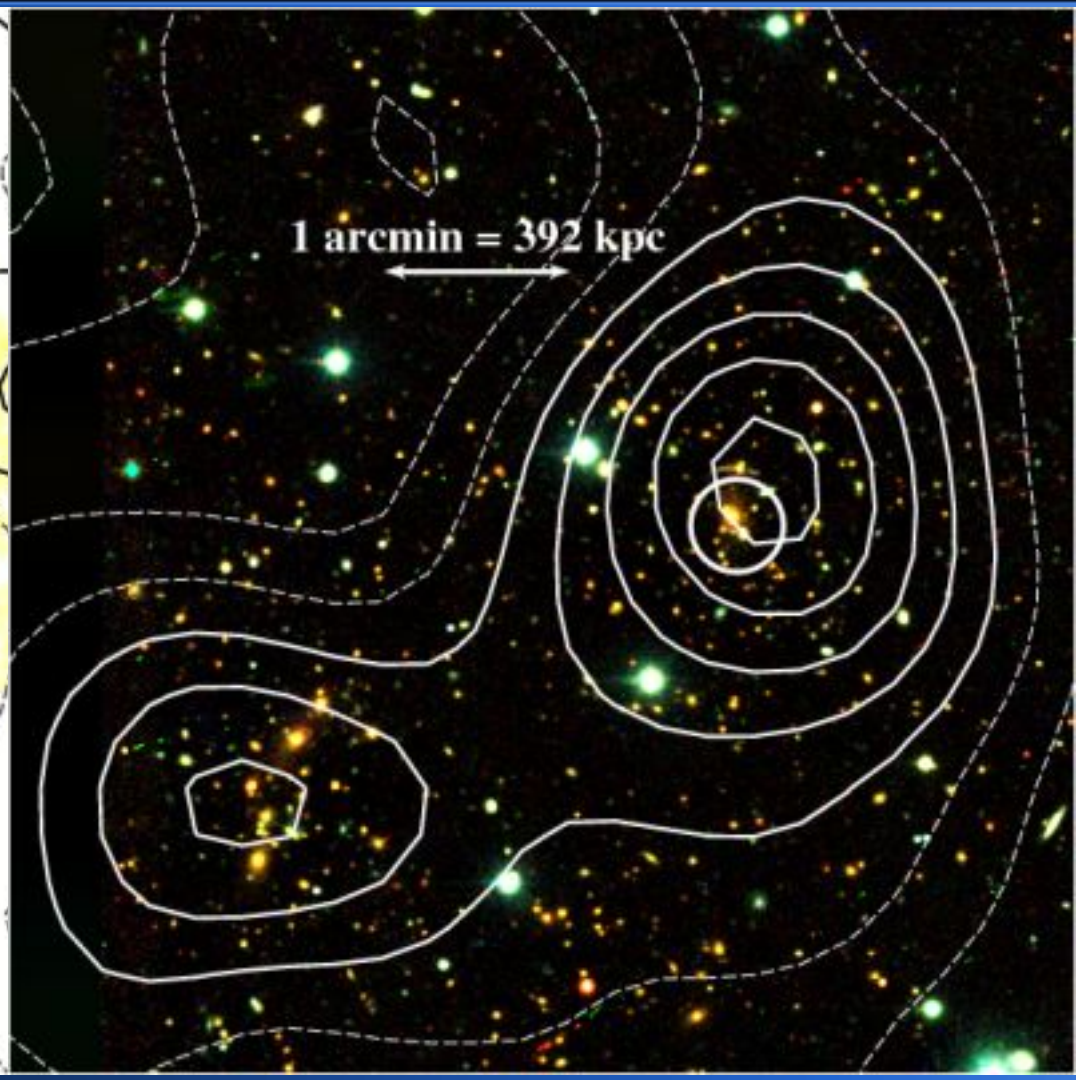
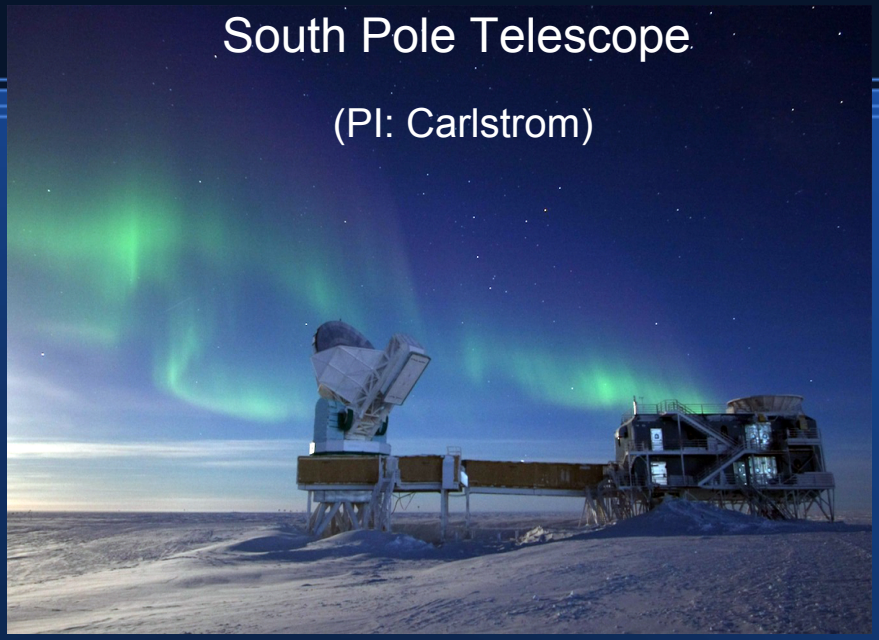
X-ray properties of SZ selected clusters from the South Pole Telescope

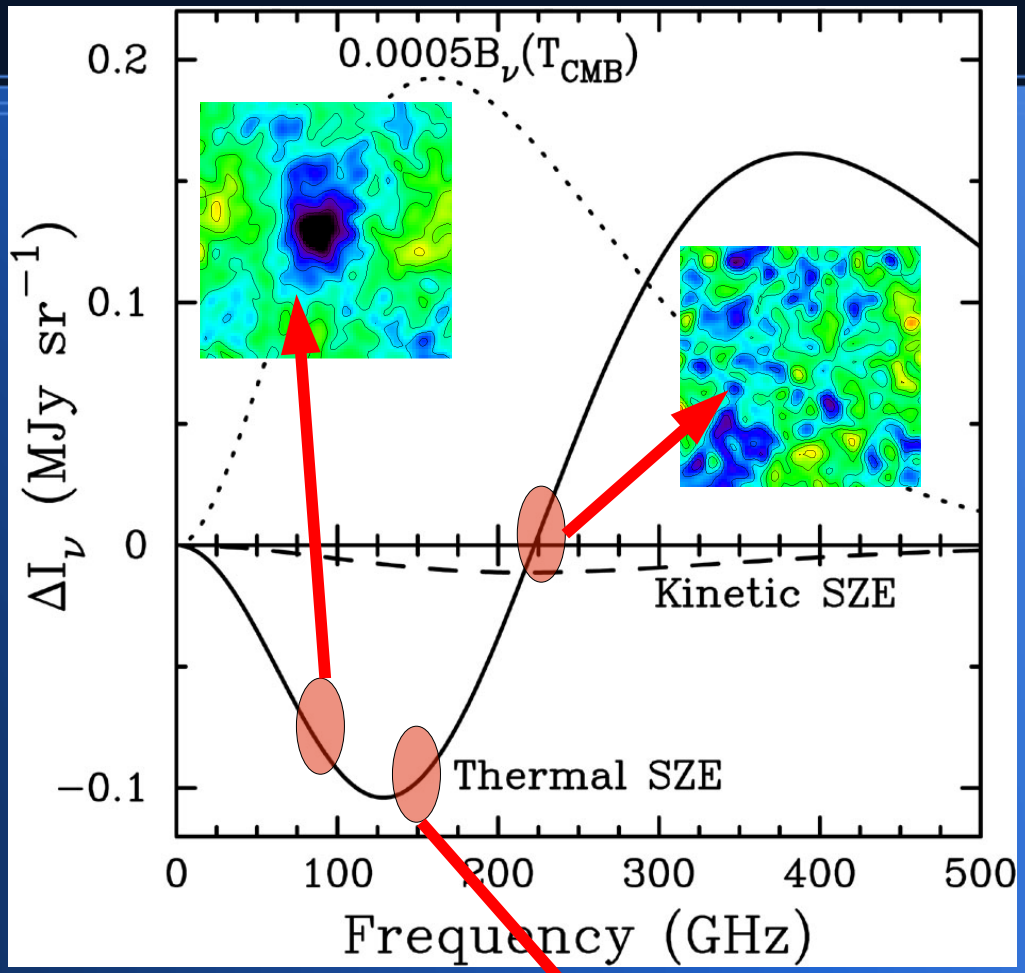


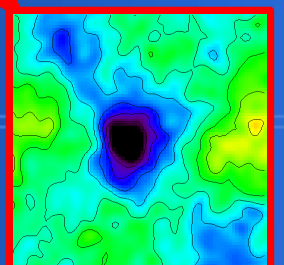


The SZ effect with SPT



- 10m telescope at the South Pole
- Dry, high alt (2800m)
- Observes the CMB at 100, 150 and 220 GHz
- Spatial resolution ~1 arcmin





Kavli Institute for Cosmological Physics AT THE UNIVERSITY OF CHICAGO
Berkeley University of California
Case Western Reserve University
The University of Chicago
UC Davis University of California
Astronomy
University of Illinois at Urbana-Champaign
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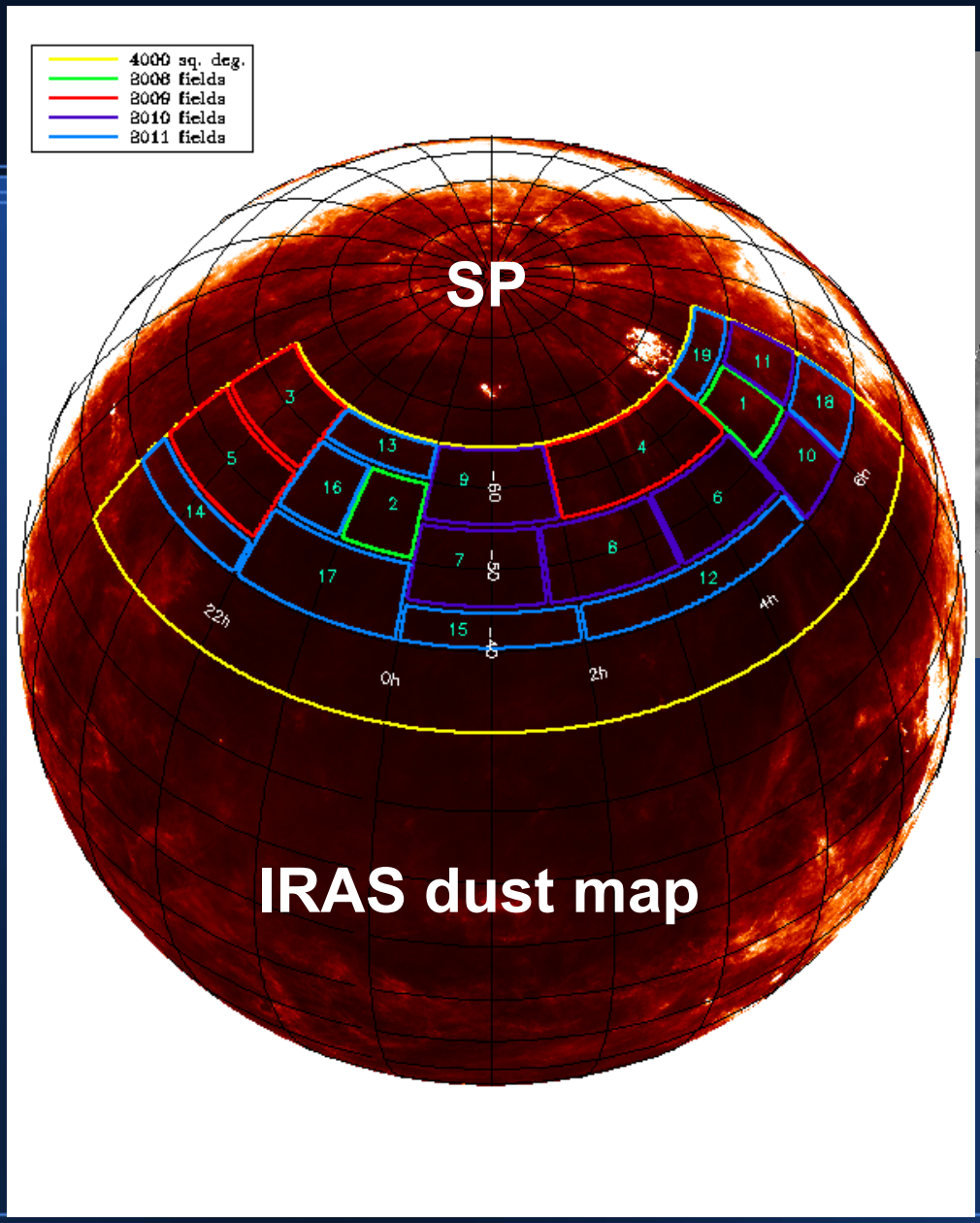
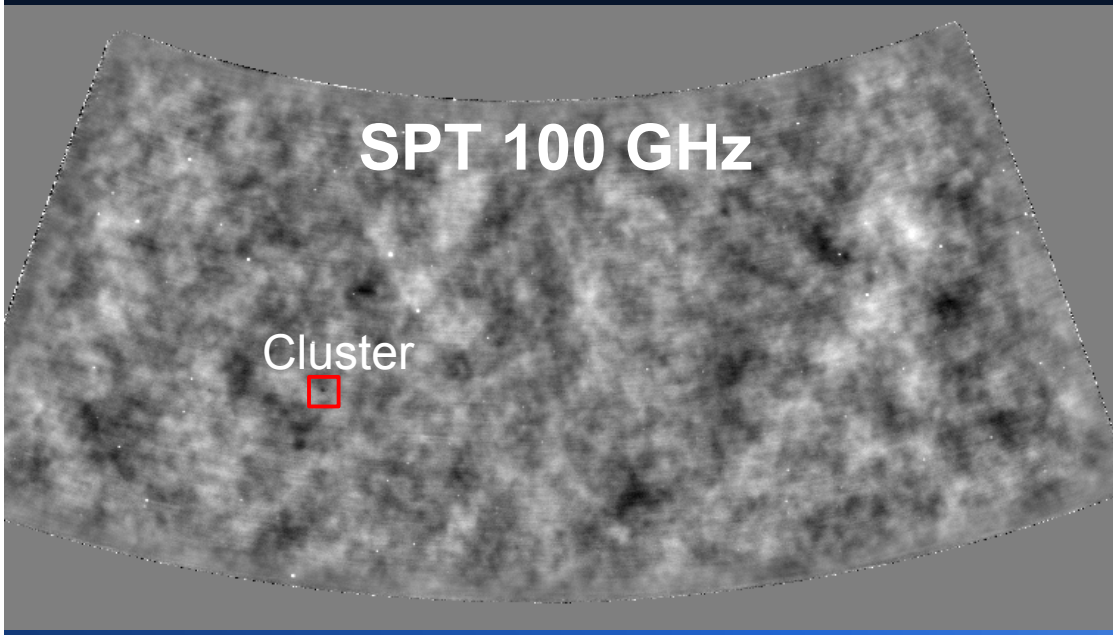
Harvard-Smithsonian Center for Astrophysics
Cardiff University
Prifysgol Caerdydd
Colorado University of Colorado at Boulder
Berkeley Lab

SPT survey





- First clusters detected from an SZ survey, presented in Vandelinde et al. 2010, 21 clusters ~180 deg^2
- First cosmological constraints presented
- SPT will cover ~2500 deg^2 by Nov 2011
- Goal to constrain cosmological pars through measurement of cluster mass function
- 15 clusters with X-ray data from ~180 deg2

Optical follow-up

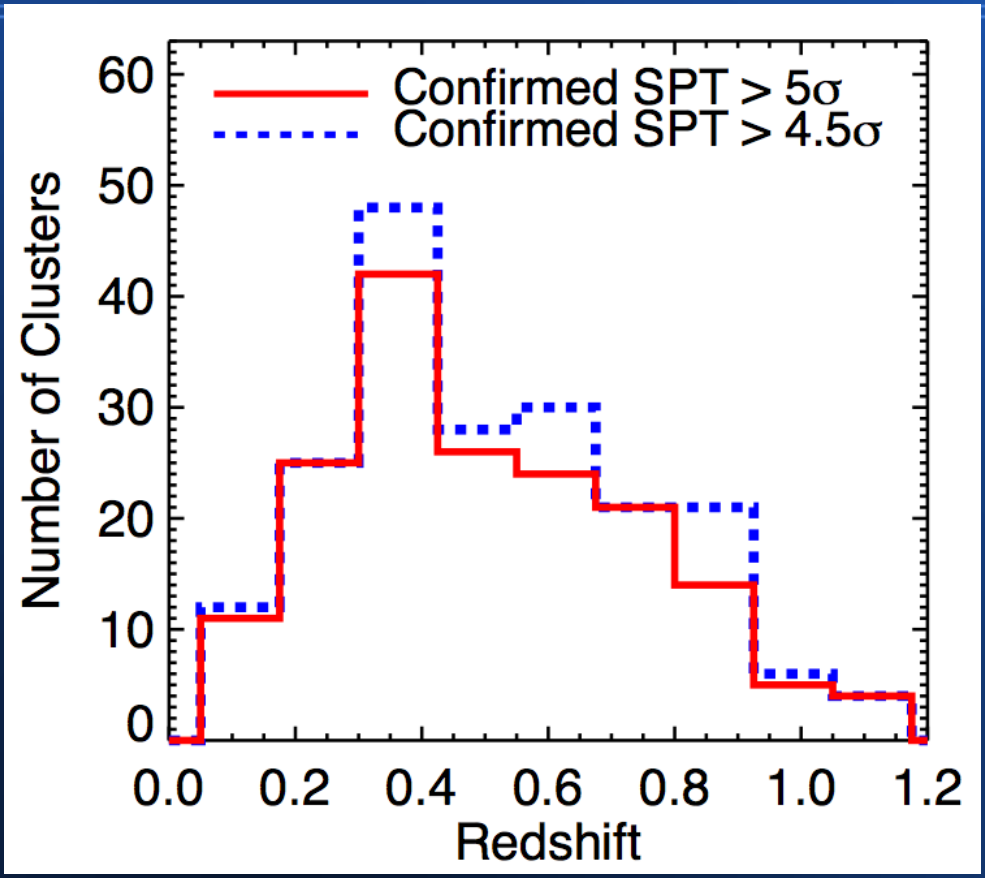
- End of 2010, 1500 deg^2 observed, ~240 clusters with optical confirmation
- Increased focal plane sensitivity, telescope efficiency
- ~95% purity at S/N > 5

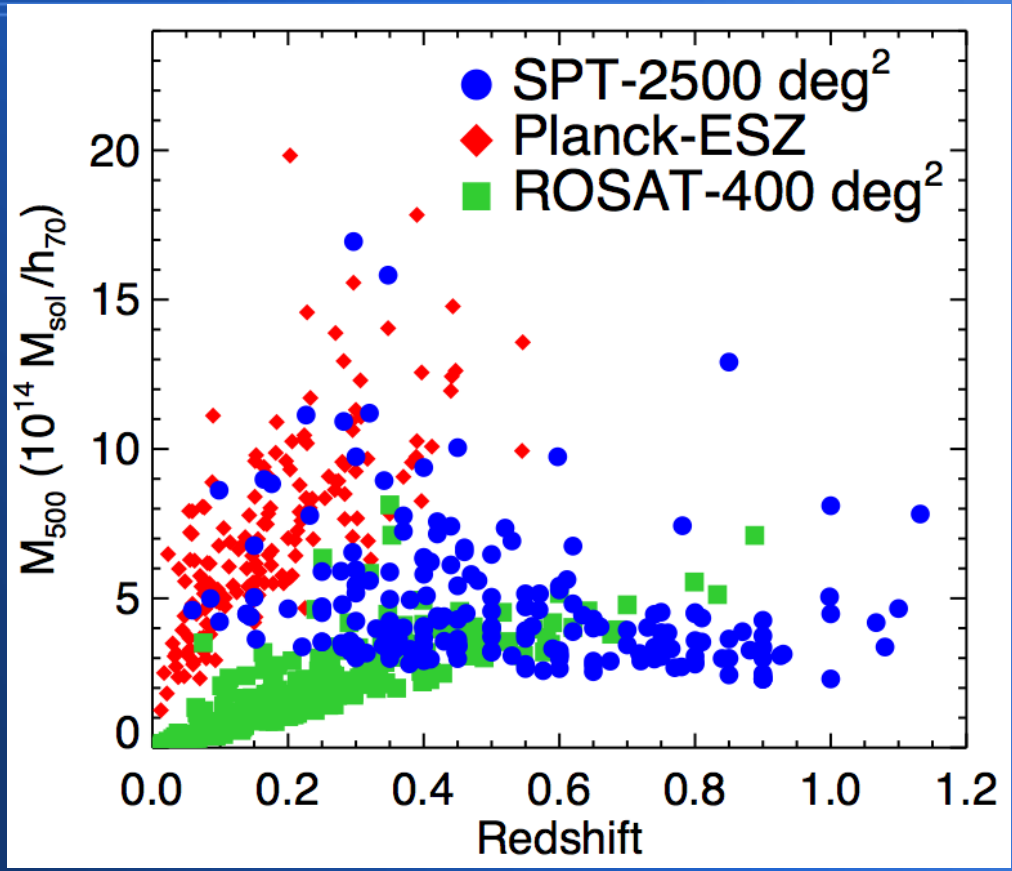
Observed	Candidates >5σ	Followed up >5σ
2008	22	19
2009	98	98
2010	172	122
2011	more...	
So far..	292	239

Expect 440 clusters at this threshold

- Several stage optical confirmation
- DSS
- SWOPE (0.9m)
- Blanco MOSAIC (4m)
- Magellan (6.5m)
- Spitzer (z>0.6)

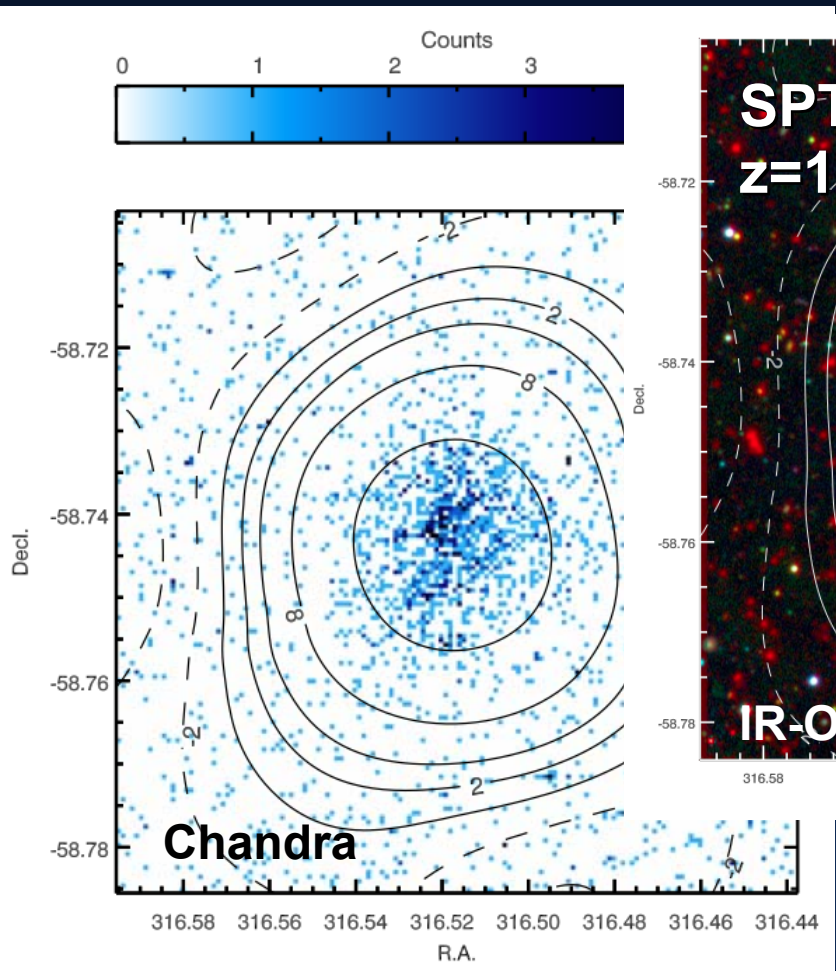
SPT cluster sample

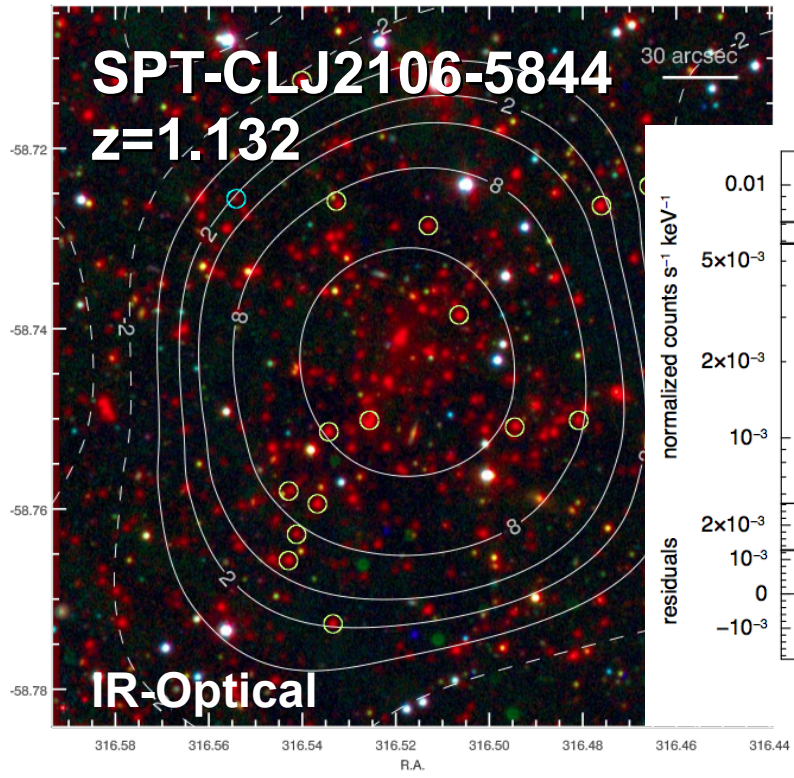


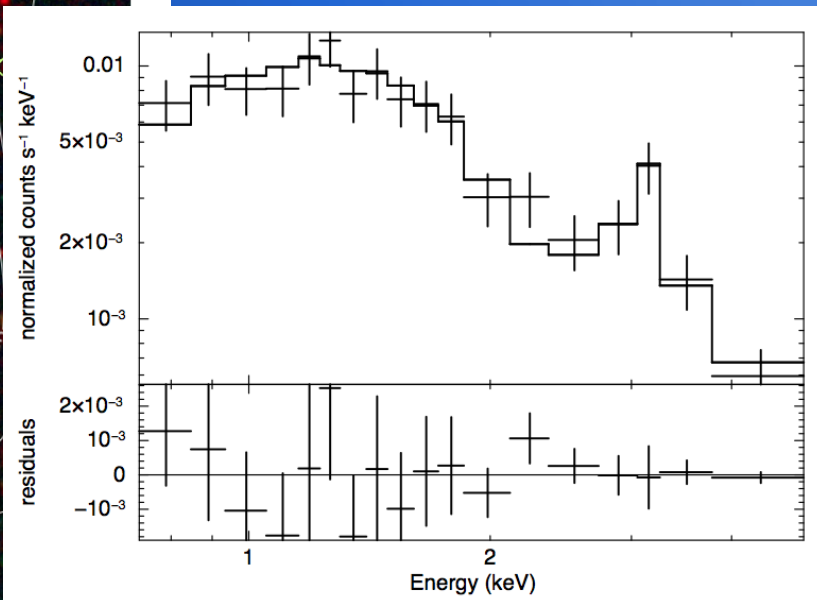


~80% new discoveries
Average redshift z~0.55

Most massive cluster at z>1







- Significant central dip in kT, 11→6 keV
- High Metallicity = 1.4+-0.6 Z_o
- M_{200} = 1.3 10^{15} M_o (Combined X-ray/SZ)

Foley et al. 2011

Mass Calibration

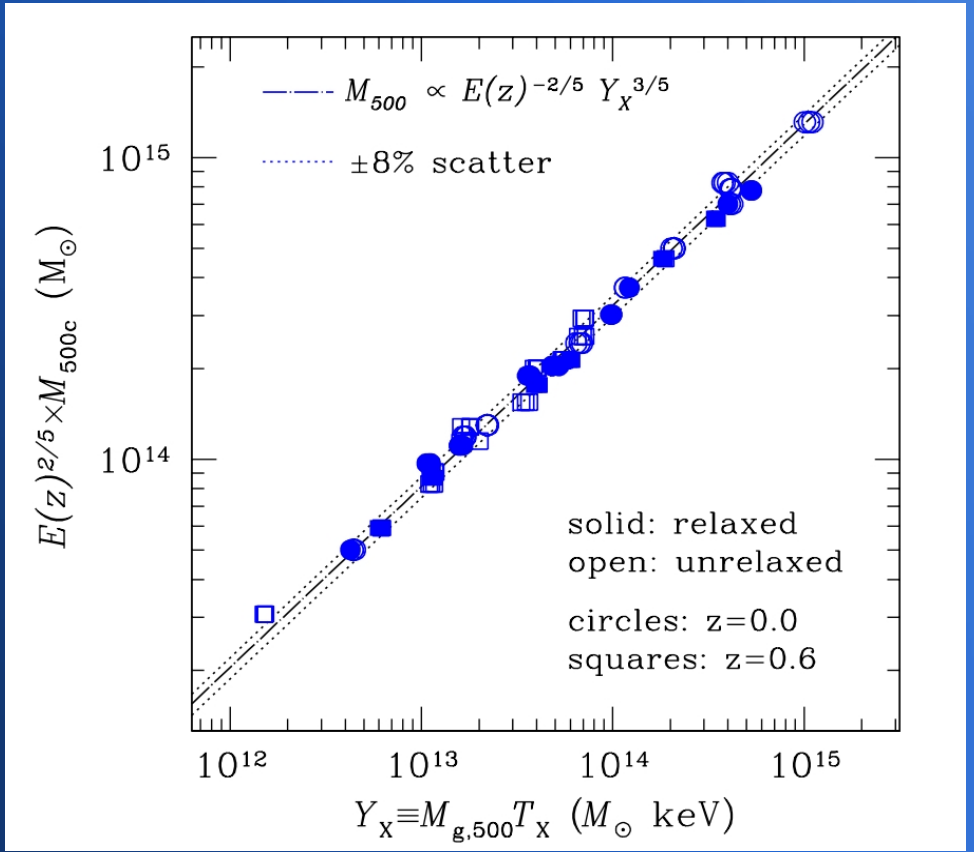
- First cosmological constraints are limited by ~25% mass calibration
- Need precise, unbiased masses
  - X-ray: Chandra and XMM
  - WL: Magellan and HST
  - Dynamical masses: Gemini and VLT

Mass Calibration

- First cosmological constraints are limited by ~25% mass calibration
- Need precise, unbiased masses
  - **X-ray: Chandra and XMM**
    - **Have ~45 approved cluster obs total**
  - WL: Magellan and HST
  - Dynamical masses: Gemini and VLT

Y_X, mass proxy

- $Y_X = M_{gas} T_X$
- X-ray mass proxy Y_X has low scatter
- Simulations find < 8%
- Confirmed by observations
- X-ray ~equiv of Y_{SZ}



Kravtsov et al. 2006

1st SPT X-ray follow-up program

- 15 highest S/N clusters from 2008 catalog (Vanderlinde et al. 2010)
- Obtain 1500 source cts for ~15% *kT*
- Estimate cluster mass via X-ray calibrated Y_X-M_{500} relation
- Observation with both Chandra and XMM
- Results → Andersson et al. 2010, arXiv 1006.3068
- X-ray follow-up for z~0.7 clusters is very expensive →

  Thanks to lots of Chandra GTO data + GO programs

First X-ray study of SZ selected sample

z=0.29

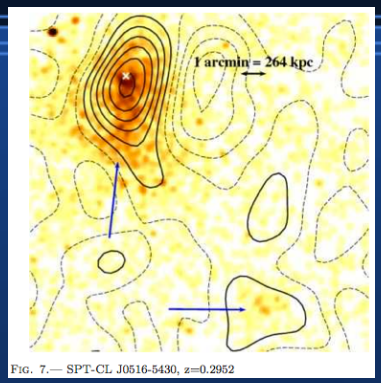


FIG. 7.— SPT-CL J0516-5430, z=0.2952

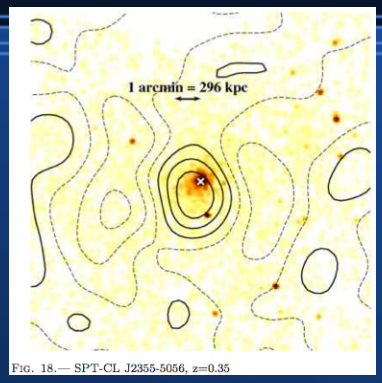


FIG. 18.— SPT-CL J2355-5056, z=0.35

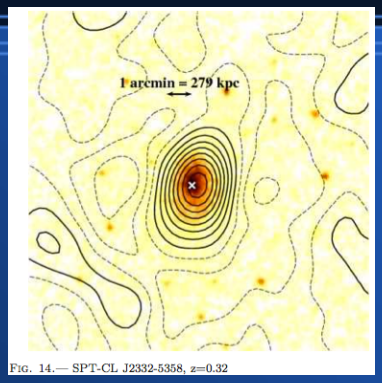


FIG. 14.— SPT-CL J2332-5358, z=0.32

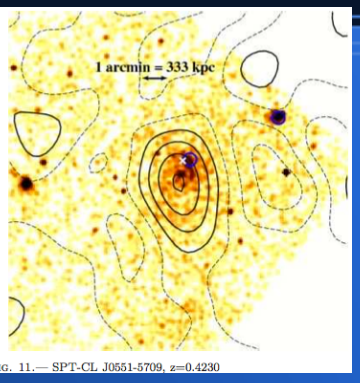


FIG. 11.— SPT-CL J0551-5709, z=0.4230

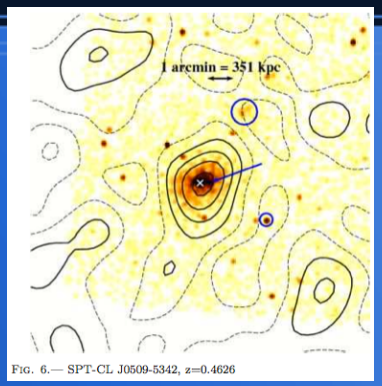


FIG. 6.— SPT-CL J0509-5342, z=0.4626

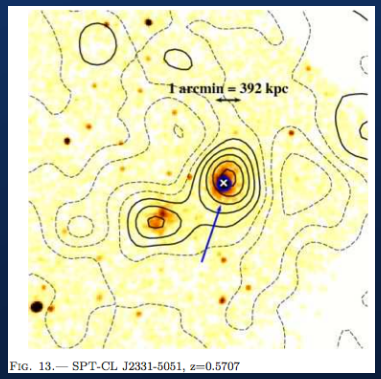


FIG. 13.— SPT-CL J2331-5051, z=0.5707

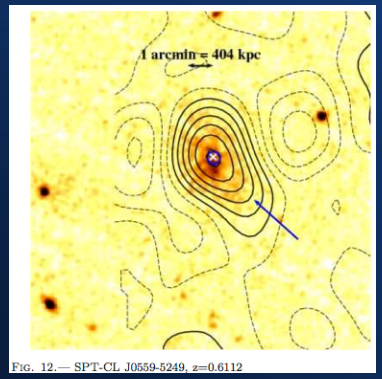


FIG. 12.— SPT-CL J0559-5249, z=0.6112

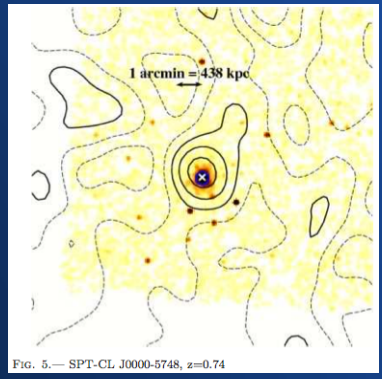


FIG. 5.— SPT-CL J0000-5748, z=0.74

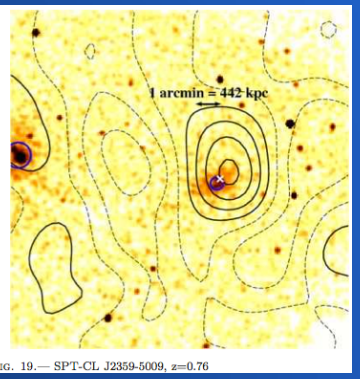


FIG. 19.— SPT-CL J2359-5009, z=0.76

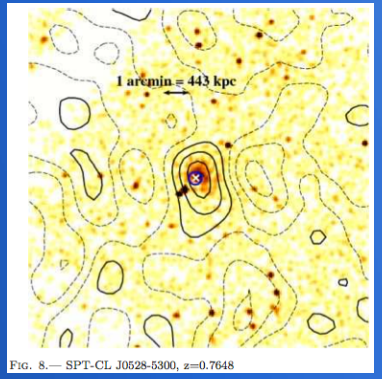


FIG. 8.— SPT-CL J0528-5300, z=0.7648

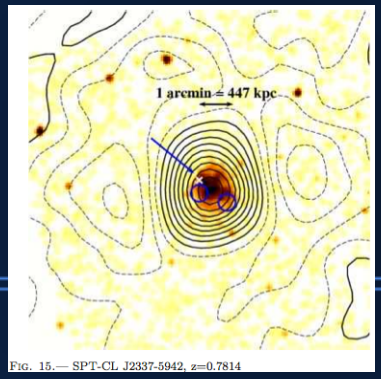


FIG. 15.— SPT-CL J2337-5942, z=0.7814

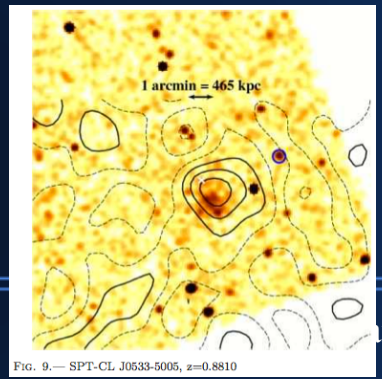


FIG. 9.— SPT-CL J0533-5005, z=0.8810

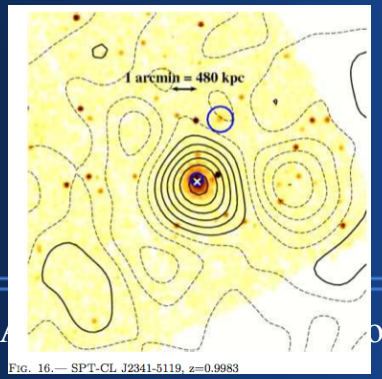


FIG. 16.— SPT-CL J2341-5119, z=0.9983

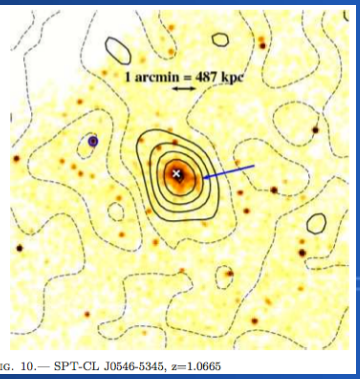


FIG. 10.— SPT-CL J0546-5345, z=1.0665

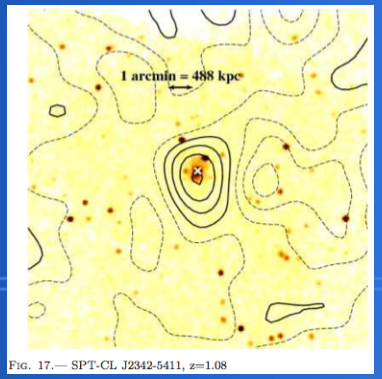
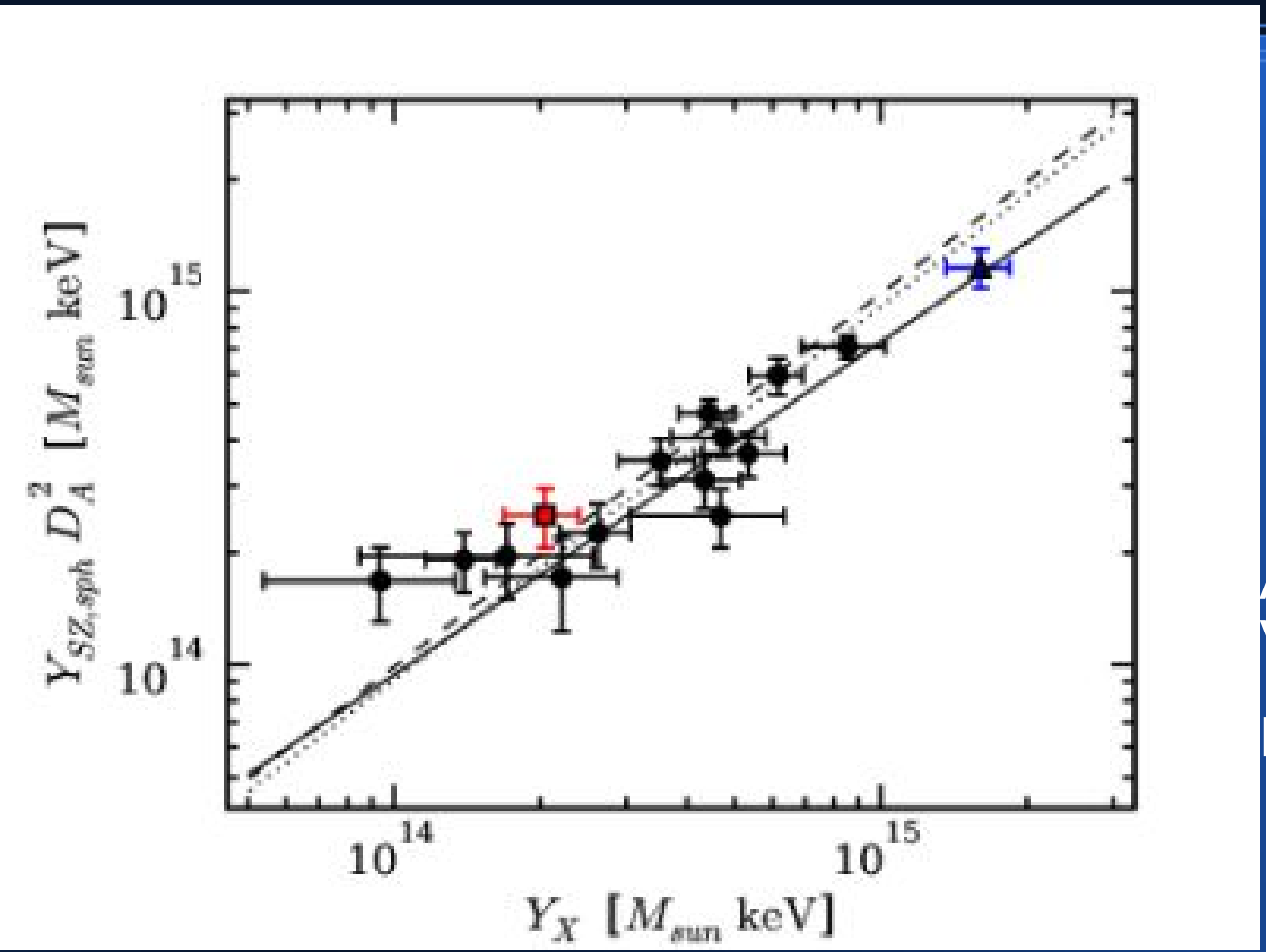


FIG. 17.— SPT-CL J2342-5411, z=1.08

Andersson et al. 2010

z=1.08

Y_{sz}-Y_x relation



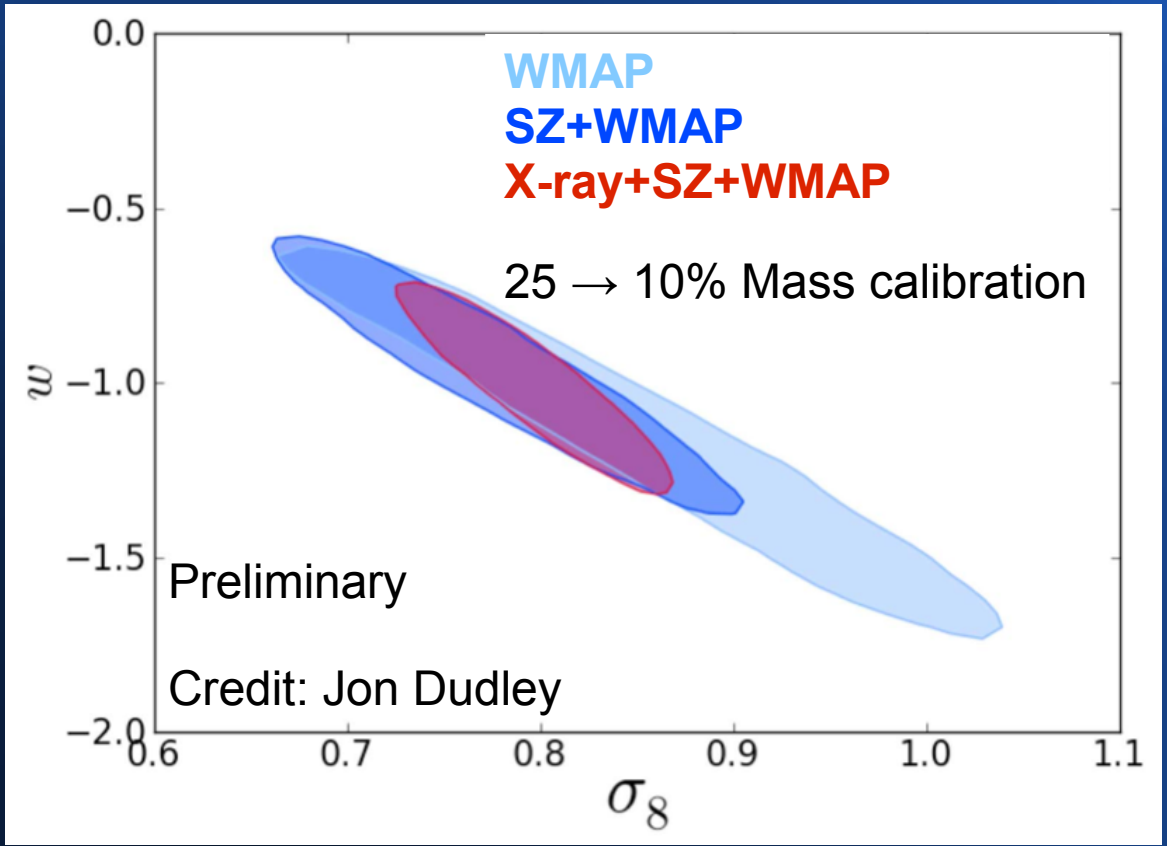
- Slope consistent with expected =1
- Normalization implies Y_{SZ}=0.82+-0.07 Y_X
- Expected Y_{SZ}/Y_X ratios from different gas models

Arnaud+09	0.924
Vikhlinin+06	~0.91

Measuring T_{mg}/T_X

SPT + X-ray follow-up cosmological constraints

Developing a full MCMC to jointly fit scaling relations and cosmology



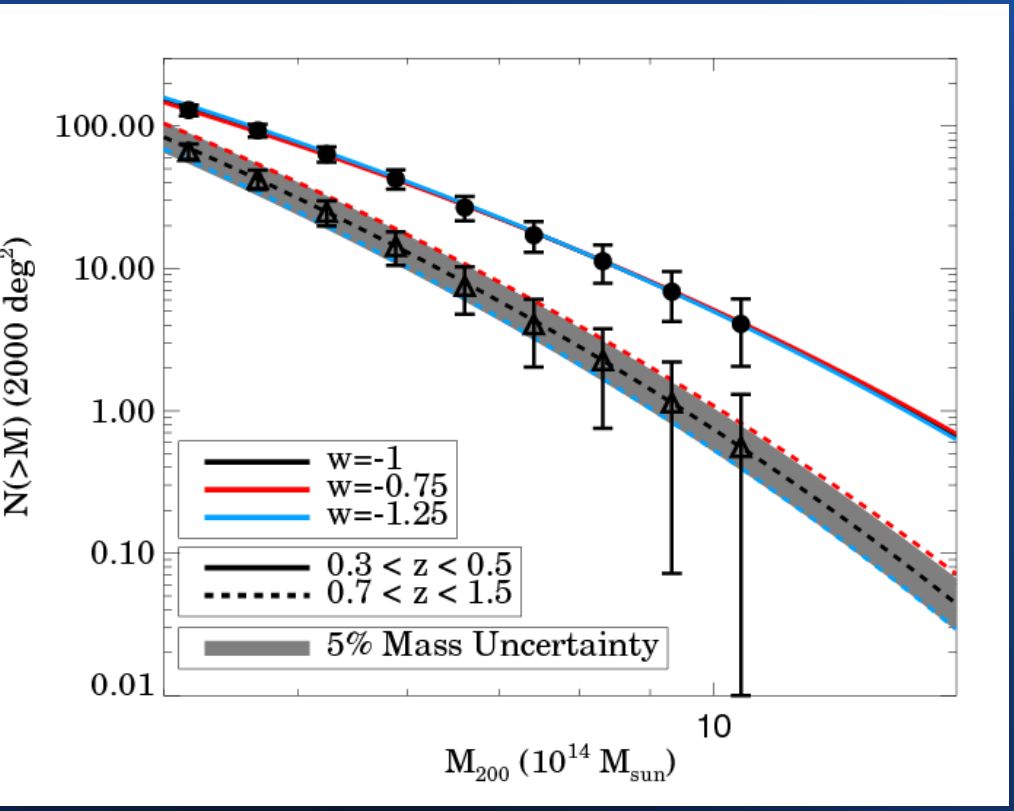
Benson et al. in prep.

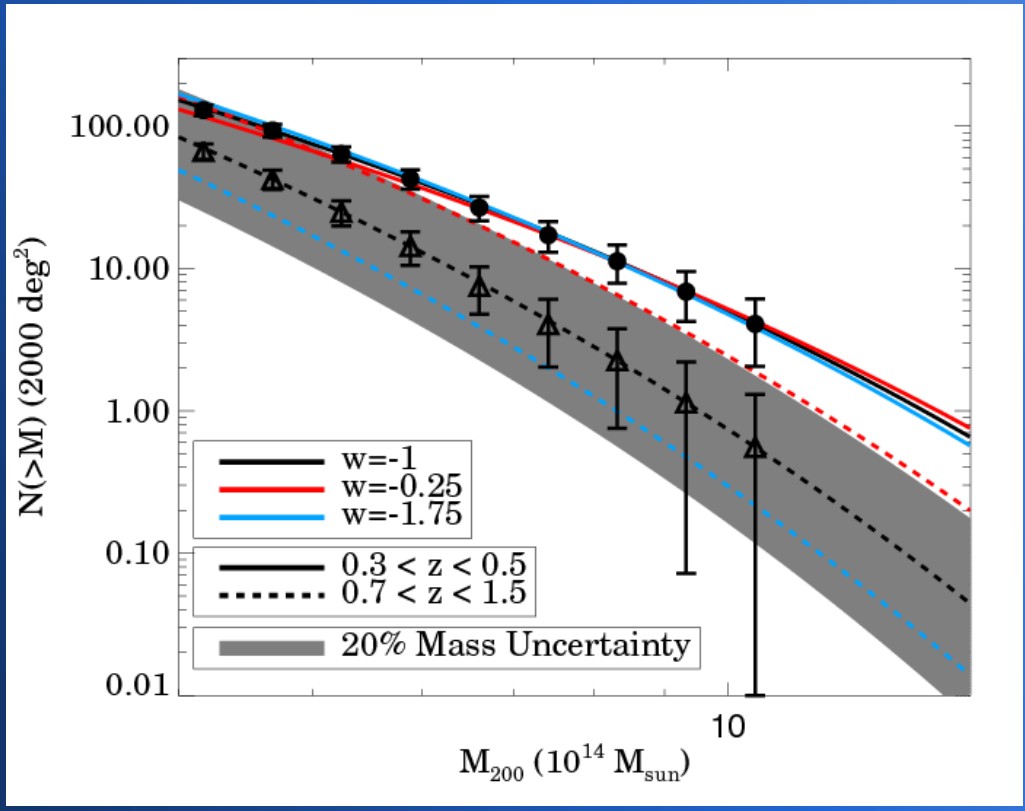
- *w* constraints improved by ~30%
- σ_8 by ~50%
- Constraints based on just 21 clusters with 15 having (limited) X-ray follow-up
- Full SPT survey will have ~450 clusters
- Separate XMM proposals to constrain low-z and high-z mass-observable norm.

Summary

- First X-ray follow-up of SZ selected sample
- X-ray mass calibration gives mass-SZ scaling consistent with expected relations
- Improves cosmological constraints of SPT
- SZ and X-ray integrated pressure agree well
- Multi-wavelength observations crucial for mass calibration to improve cosmological constraints

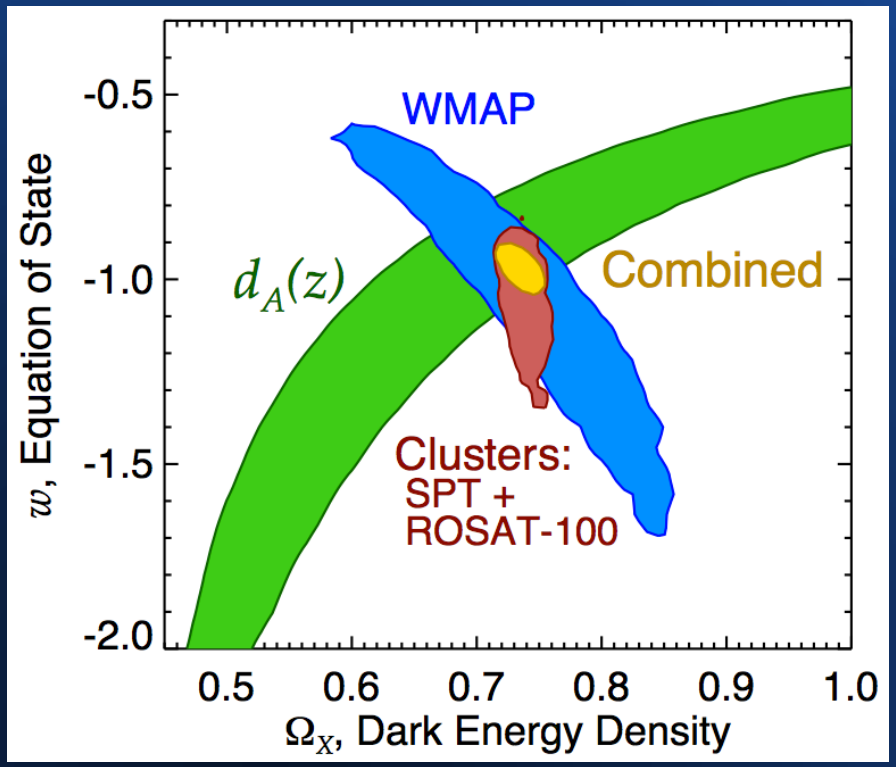
Mass function evolution



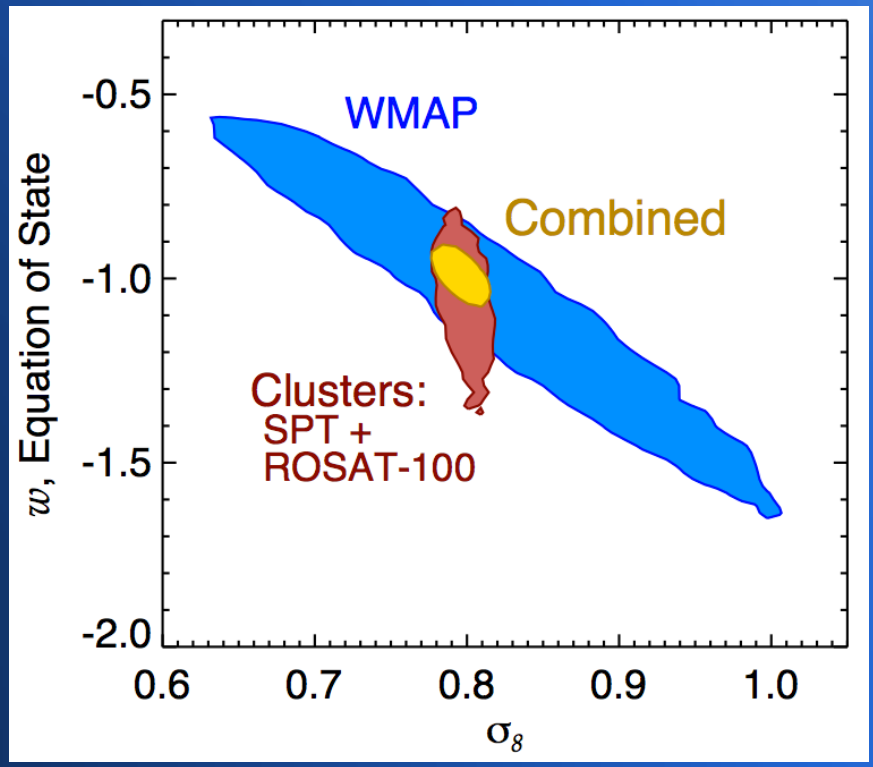


Projected constraints

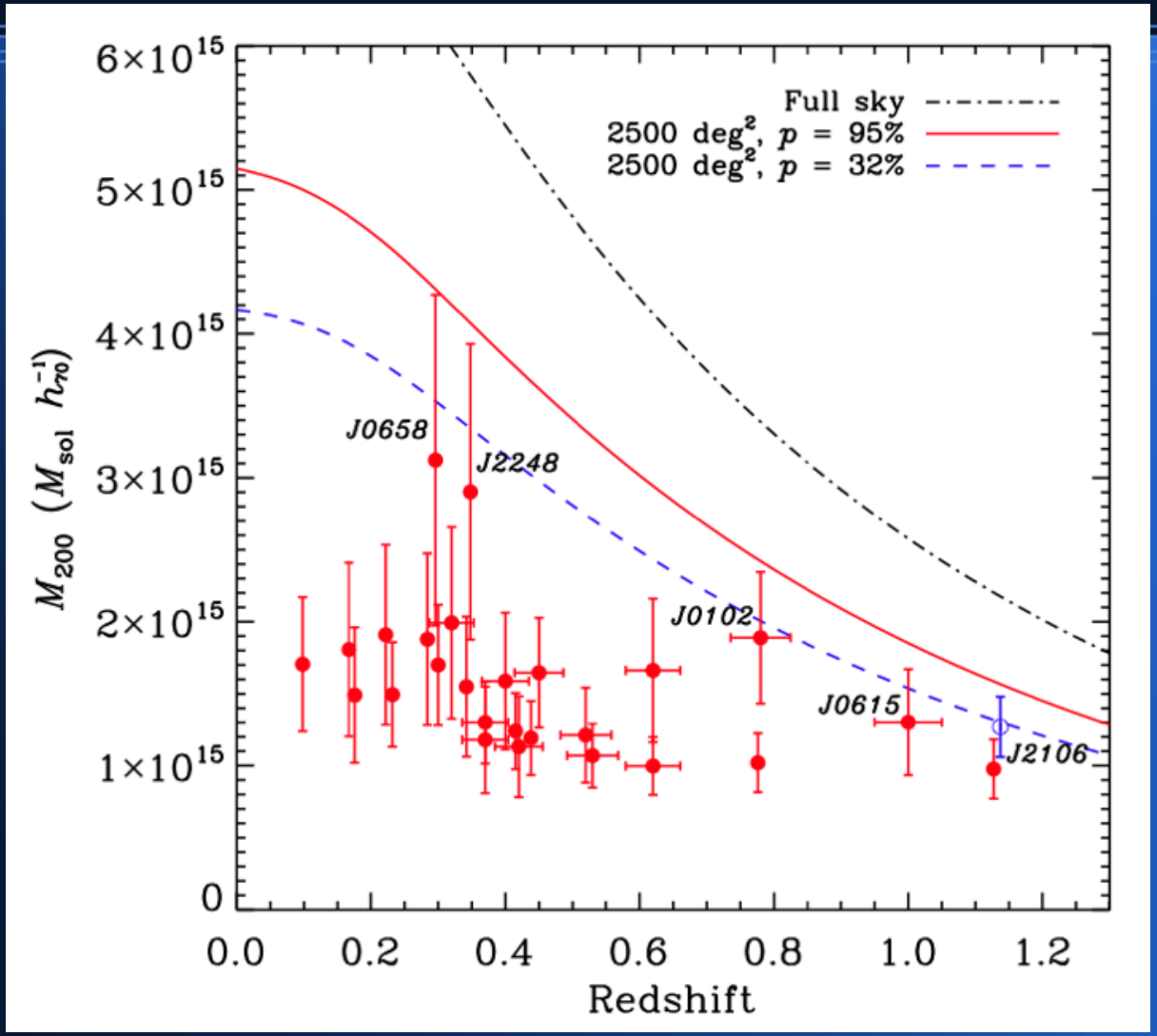
- With 5% mass cal, 10% on evolution z=0-1



+- 4.6% on w



LCDM has a problem?



Cluster modeling → Y_X

- Data depth allows for ~1 *kT* measurement
  - No hydrostatic masses
- Model gas density using surface brightness in 0.7-2. keV band
  - Low *kT* dependence
- Can fit variety of cluster morphologies

$$n_e n_p = n_0^2 \frac{(r/r_c)^{-\alpha}}{(1+r^2/r_c^2)^{3\beta-\alpha/2}} \frac{1}{(1+r^\gamma/r_s^\gamma)^{e/\gamma}}$$

Vikhlinin et al. 2006

Spherical Y_{SZ} via deprojection

- Vanderlinde et al. 2010, analysis extended
- Spatially filter SPT maps using information from X-ray gas density profile + “universal” temperature profile (also Arnaud+09 pressure)

$$T(r) = T_0 \frac{(x/0.045)^{1.9} + 0.45}{(x/0.045)^{1.9} + 1} \frac{1}{(1 + (x/0.6)^2)^{0.45}}$$

Vikhlinin et al. 2006

- De-project Y_{SZ} using these same profiles

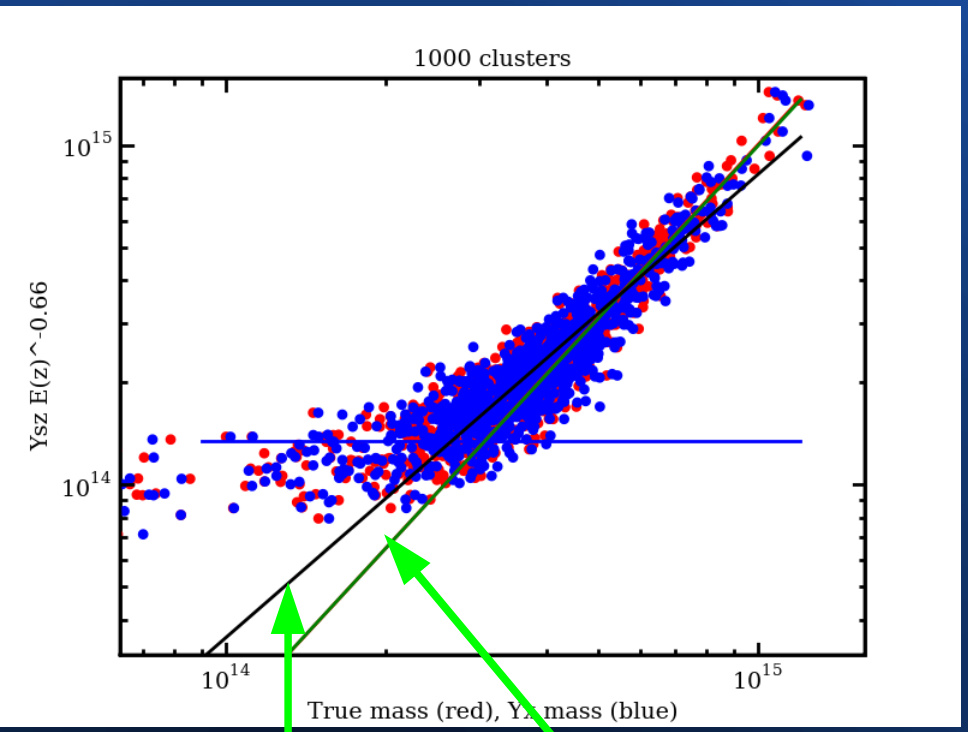
SZ selection effect

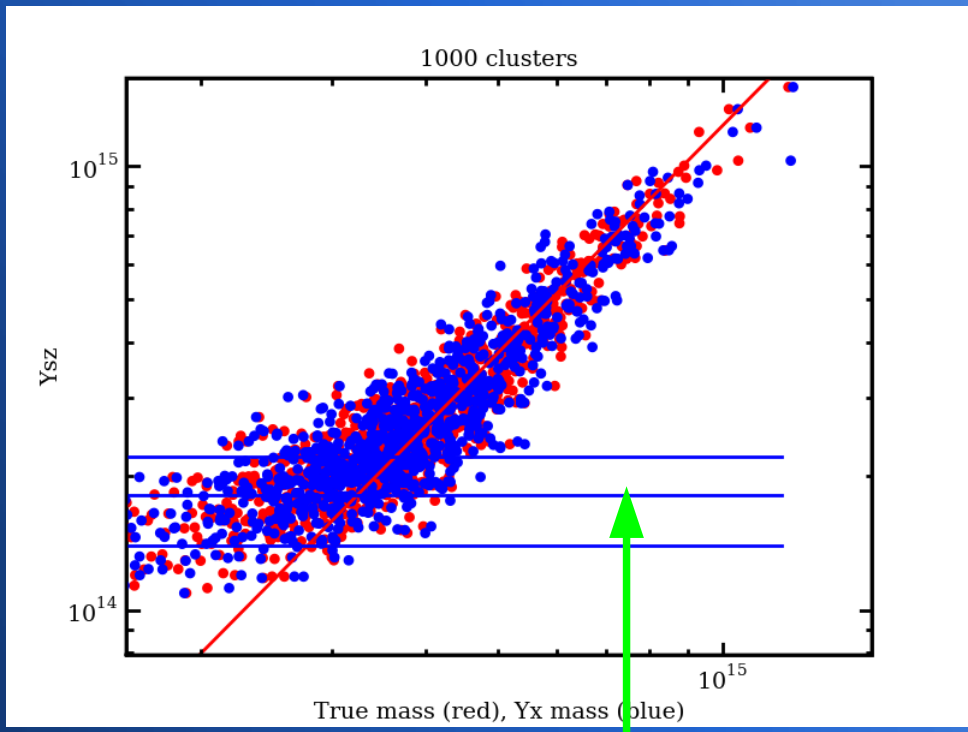
- SZ selection impacts scaling relations
- Selection is applied by truncating probability of Ysz given M and renormalizing
- Here, the \xi=5.5 cut is modeled as an errorfunction in Ysz

$$P_{sel}(\ln Y_{SZ}) = \frac{1}{2}\left(1 + erf\left(\frac{\ln Y_{SZ} - \ln Y_{SZ,\xi-cut}}{\sqrt{2\sigma^2_{\ln Ysz-\ln\xi}}}\right)\right)$$

SZ selection effect

1000 mock clusters drawn from a mass function





Fit without selection cut applied

Input scaling relation and best fit

Cut threshold, \xi=5.5