

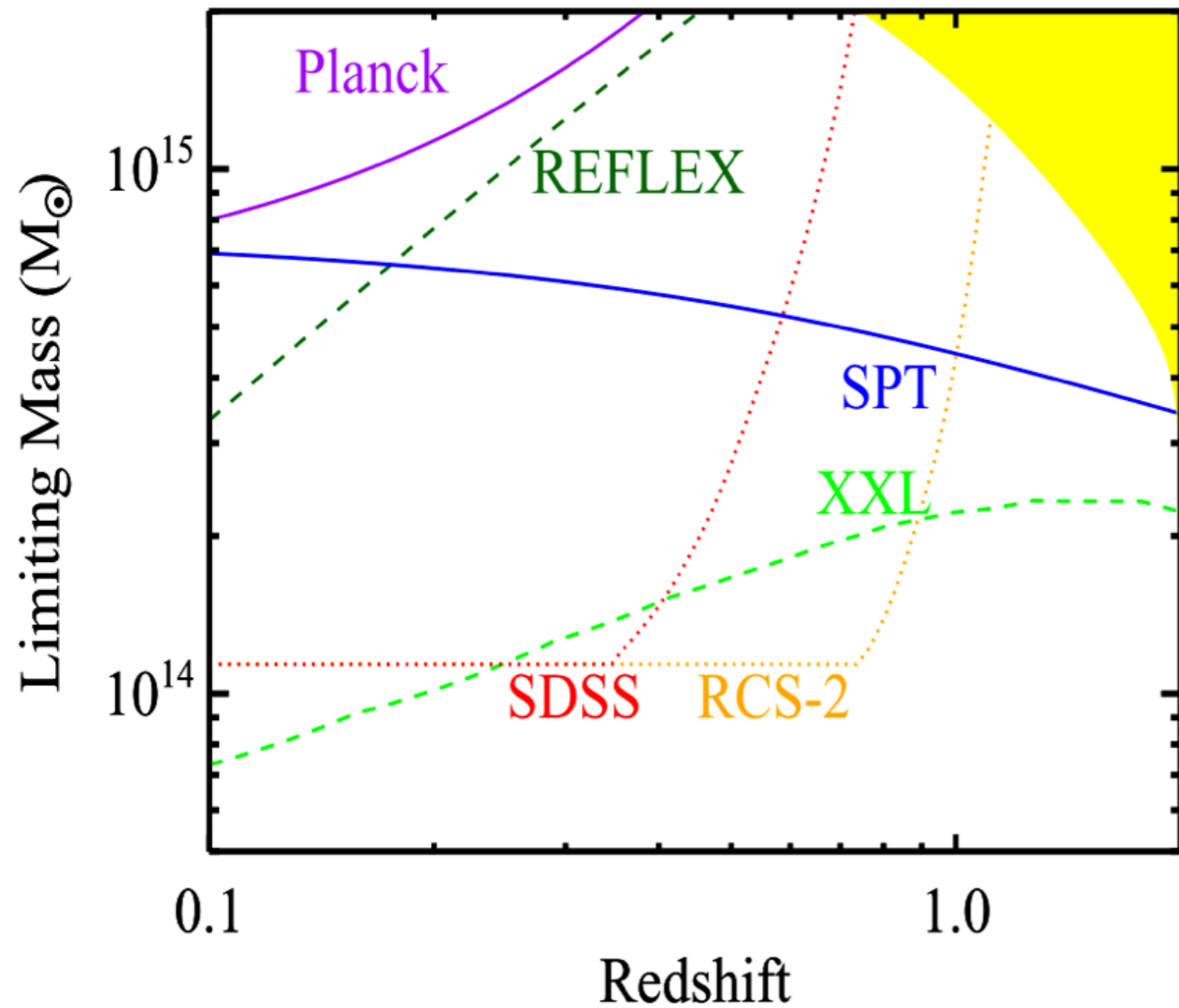
# Cluster Studies with SPT and DES



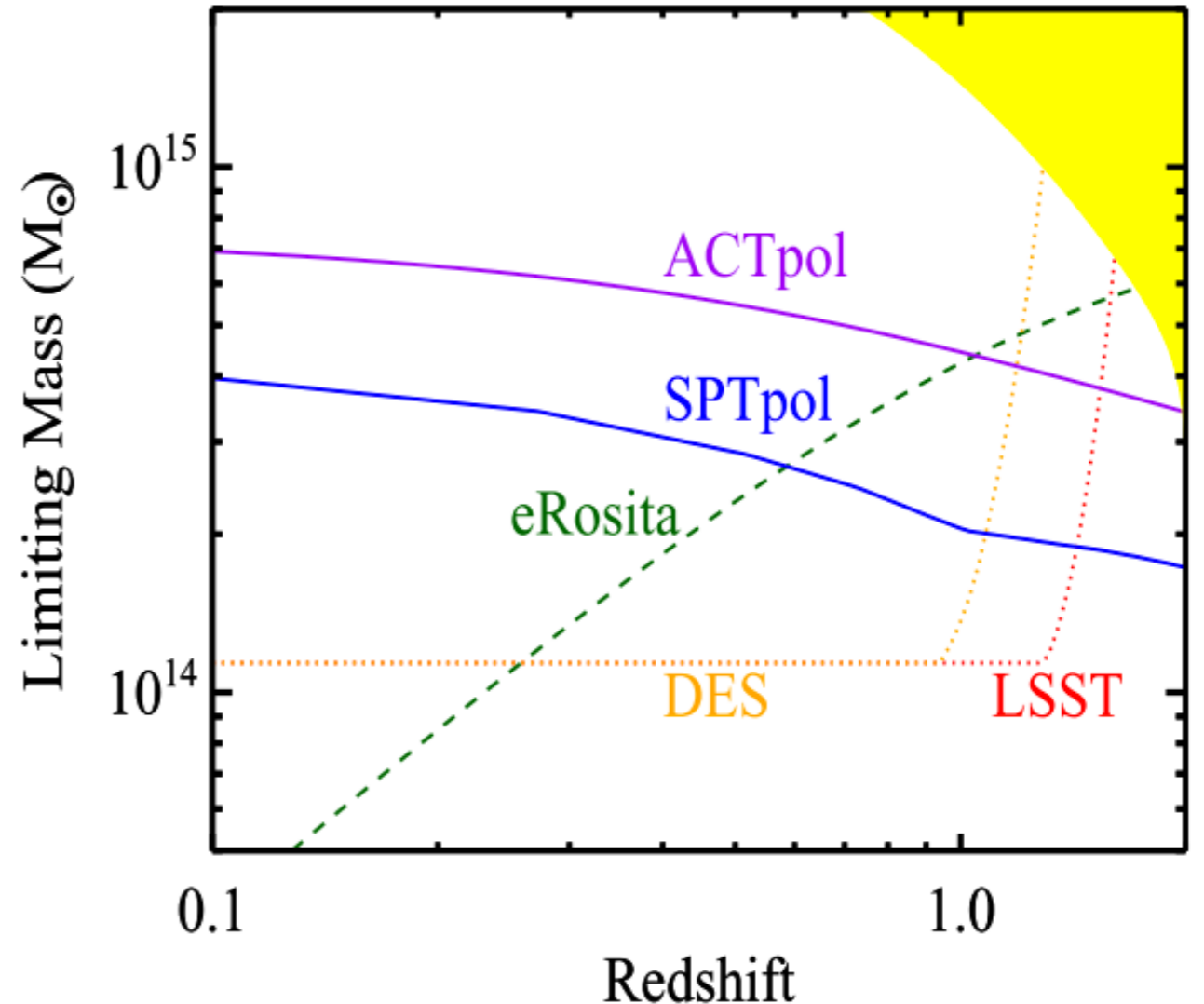
Lindsey Bleem  
Argonne National Laboratory  
Dec 9, 2014

Photo credit: Keith Vanderlinde

# 3 Approaches: Optical, X-ray, SZ



Current



Online/Near Future

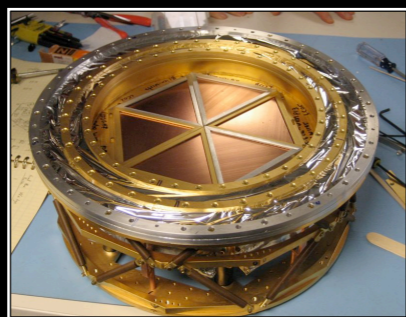
# The South Pole Telescope (SPT)

10-meter sub-mm quality wavelength telescope

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

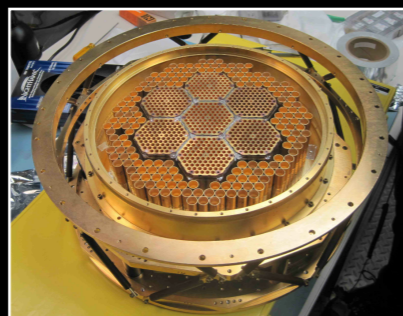
## 2007: SPT-SZ

960 detectors  
100, 150, 220 GHz



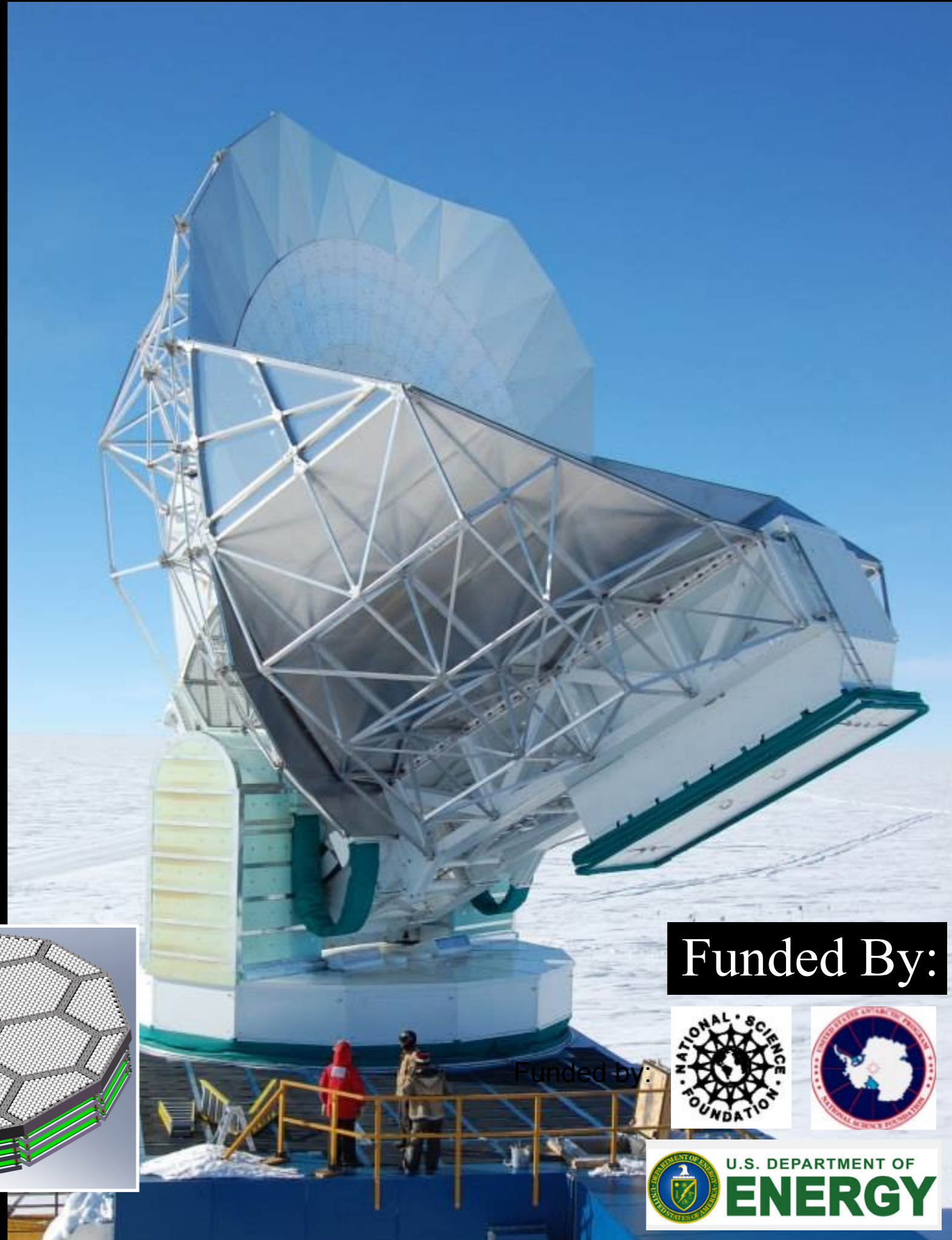
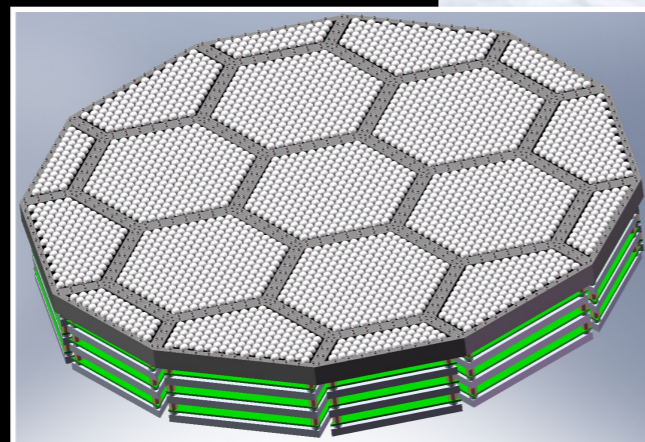
## 2012: SPTpol

1600 detectors  
100, 150 GHz  
*+Polarization*



## 2016: SPT-3G

~15,200 detectors  
100, 150, 220 GHz  
*+Polarization*



Funded By:



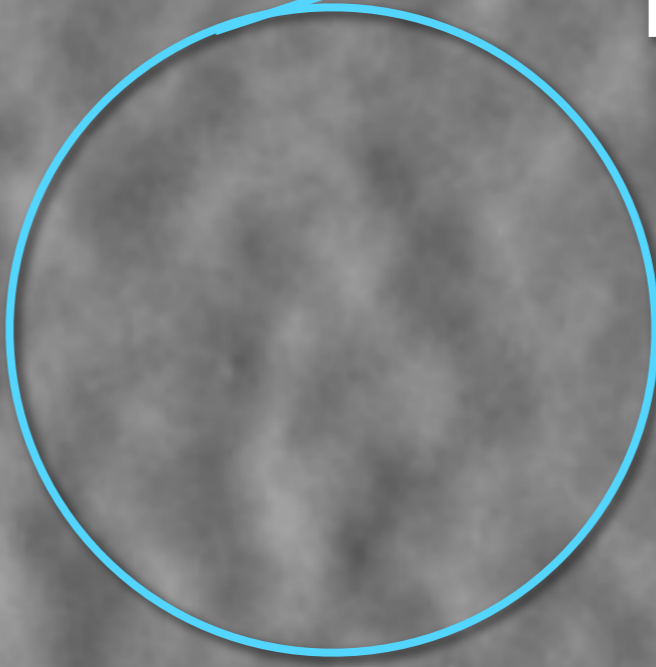
U.S. DEPARTMENT OF  
**ENERGY**

# Zoom in on an SPT map

50 deg<sup>2</sup> from  
2500 deg<sup>2</sup> survey

## CMB Anisotropy

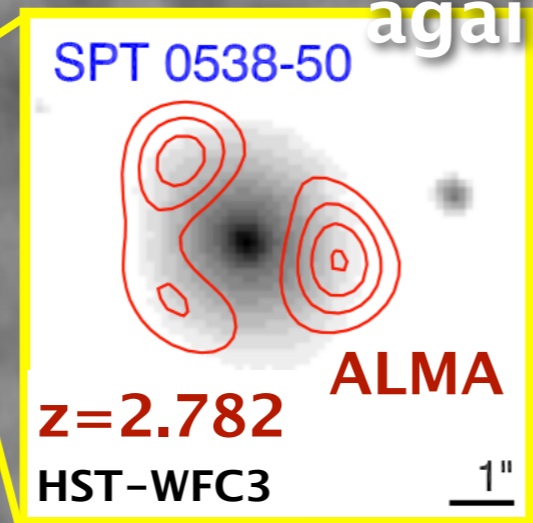
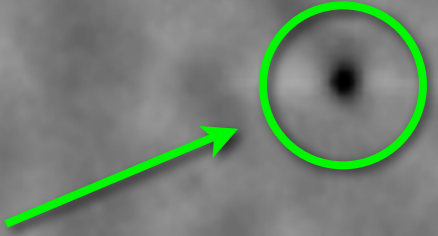
– Primordial and secondary anisotropy in the CMB



**Point Sources** – High-redshift dusty star forming galaxies and Active Galactic Nuclei



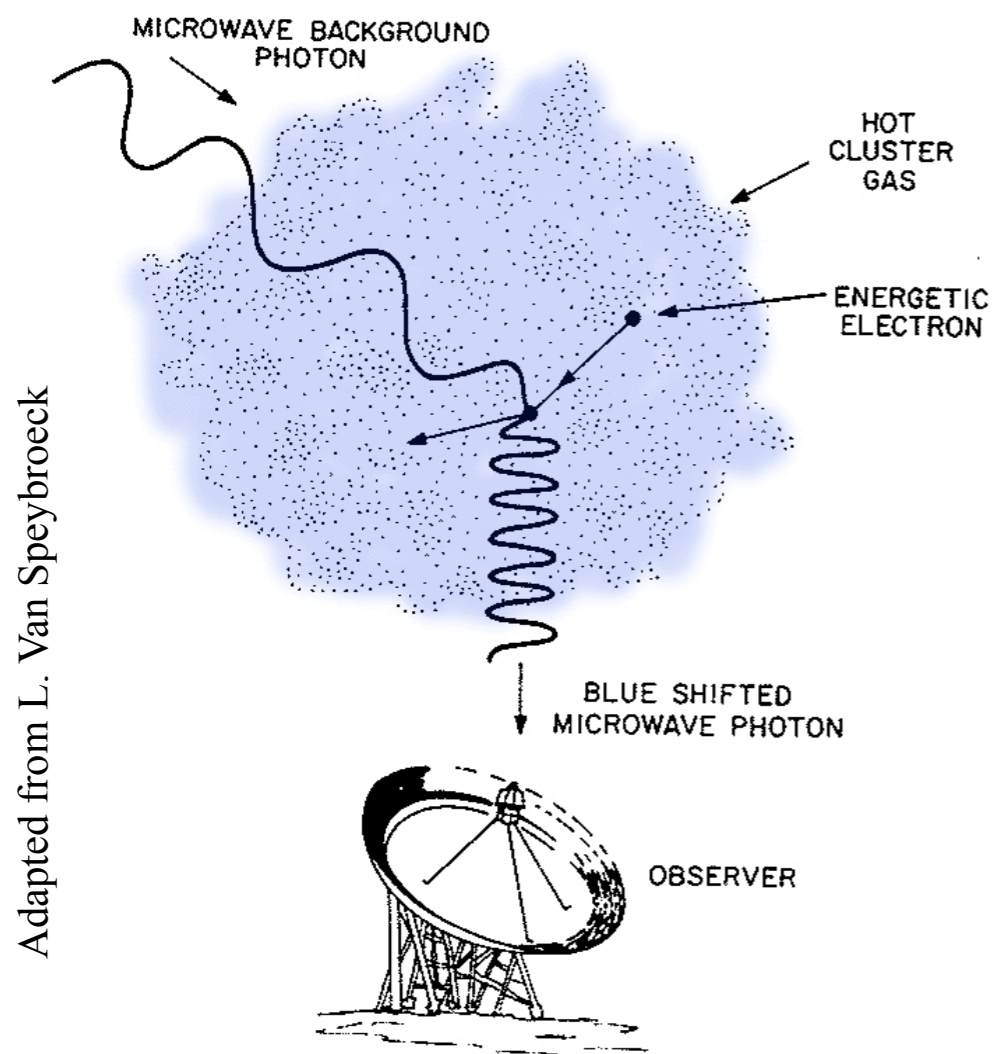
**Clusters** – High signal to noise SZ galaxy cluster detections as “shadows” against the CMB!



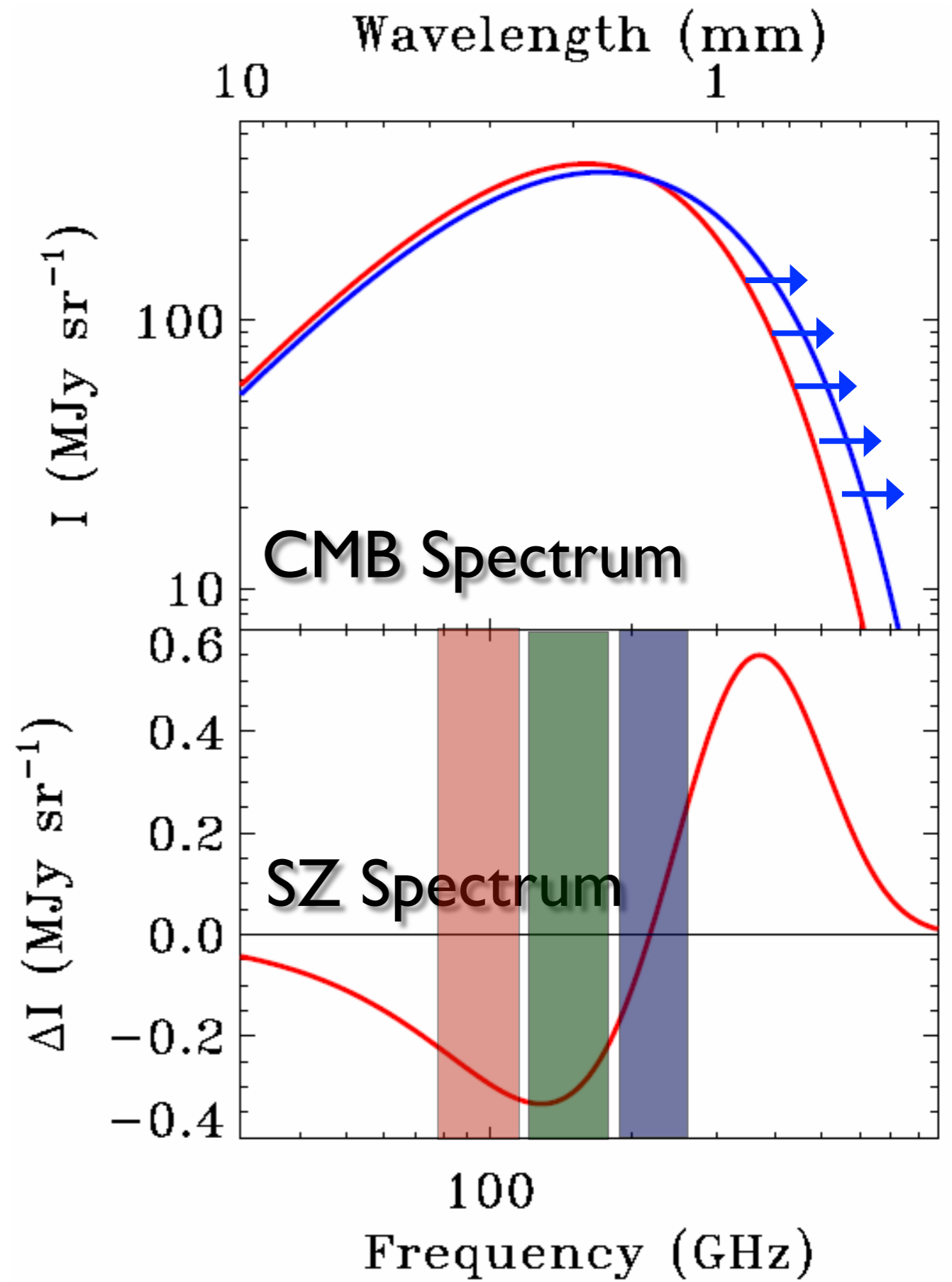
Cluster of Galaxies



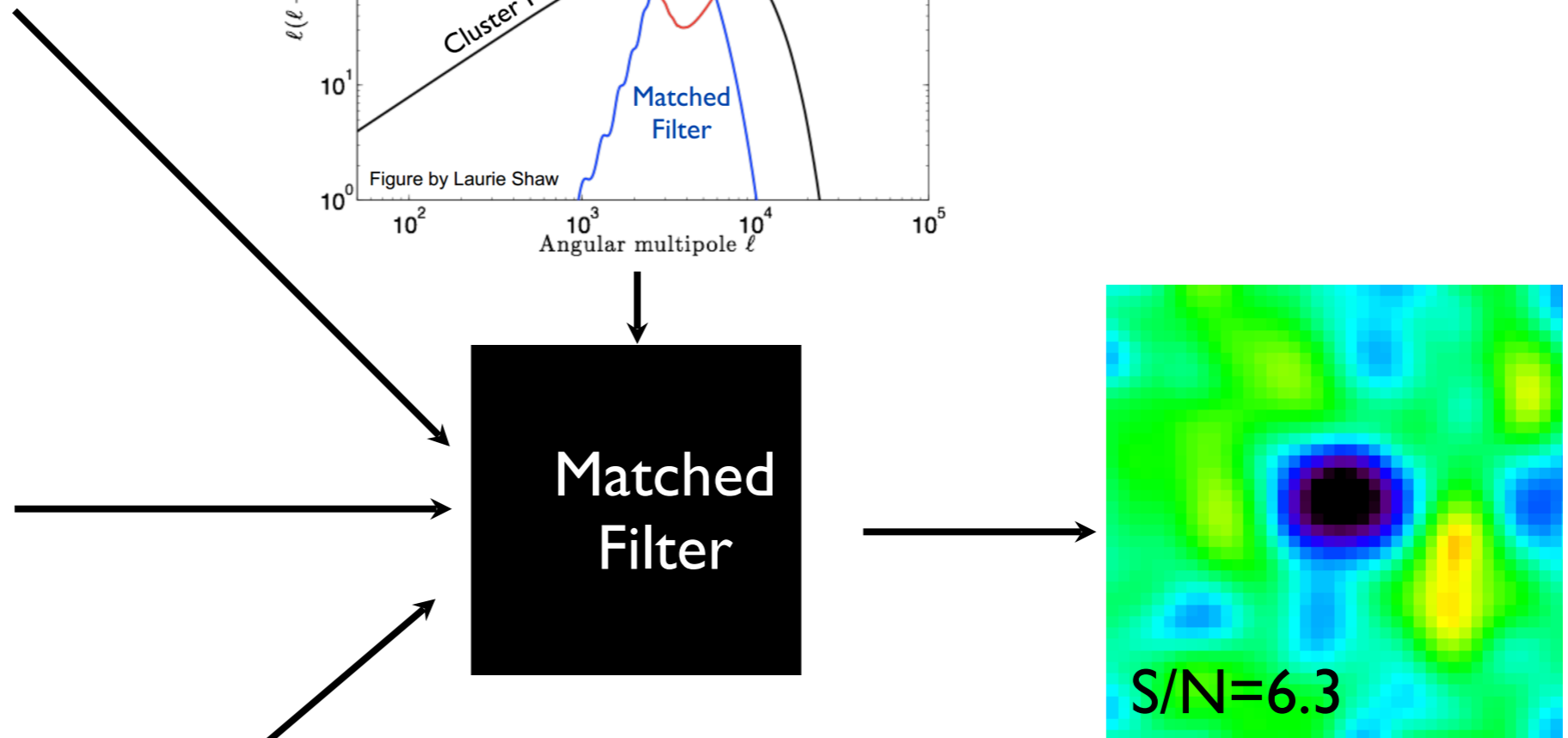
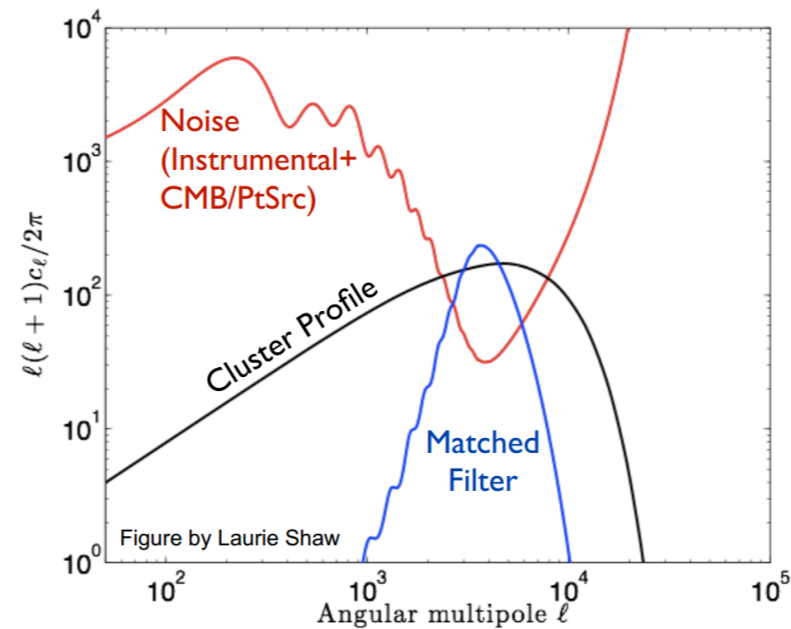
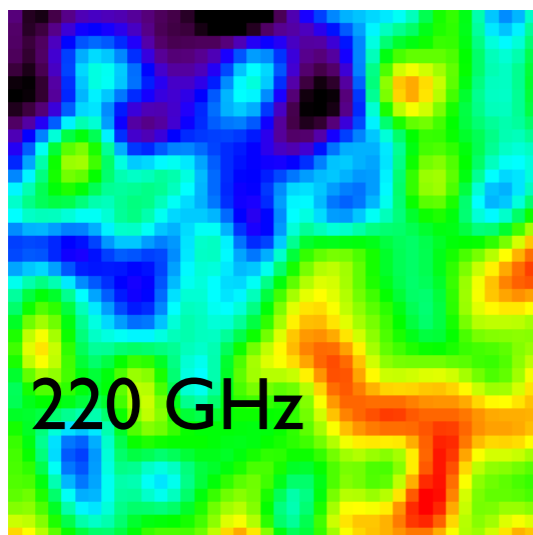
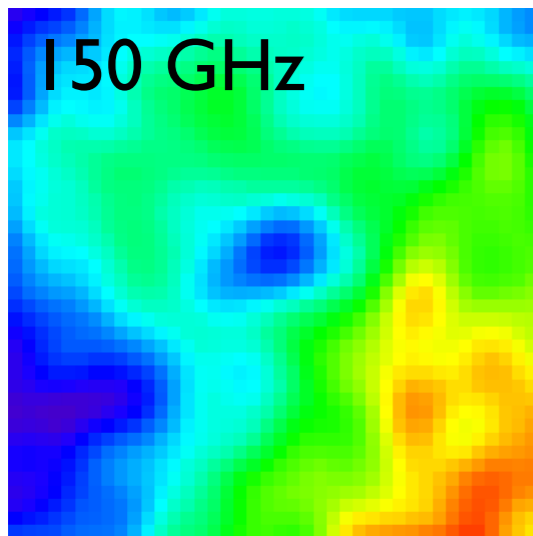
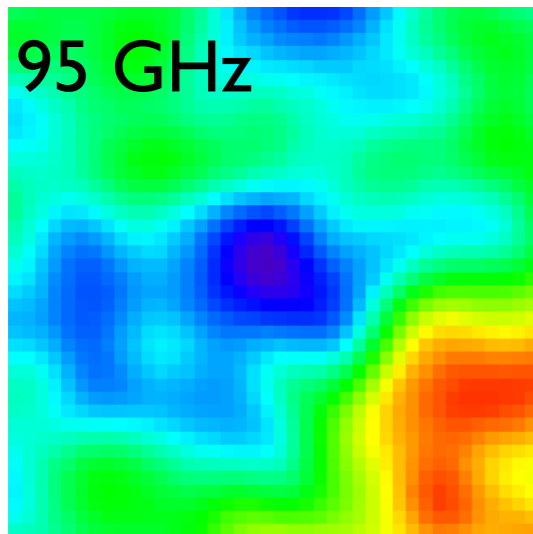
# The Sunyaev Zel'dovich (SZ) Effect



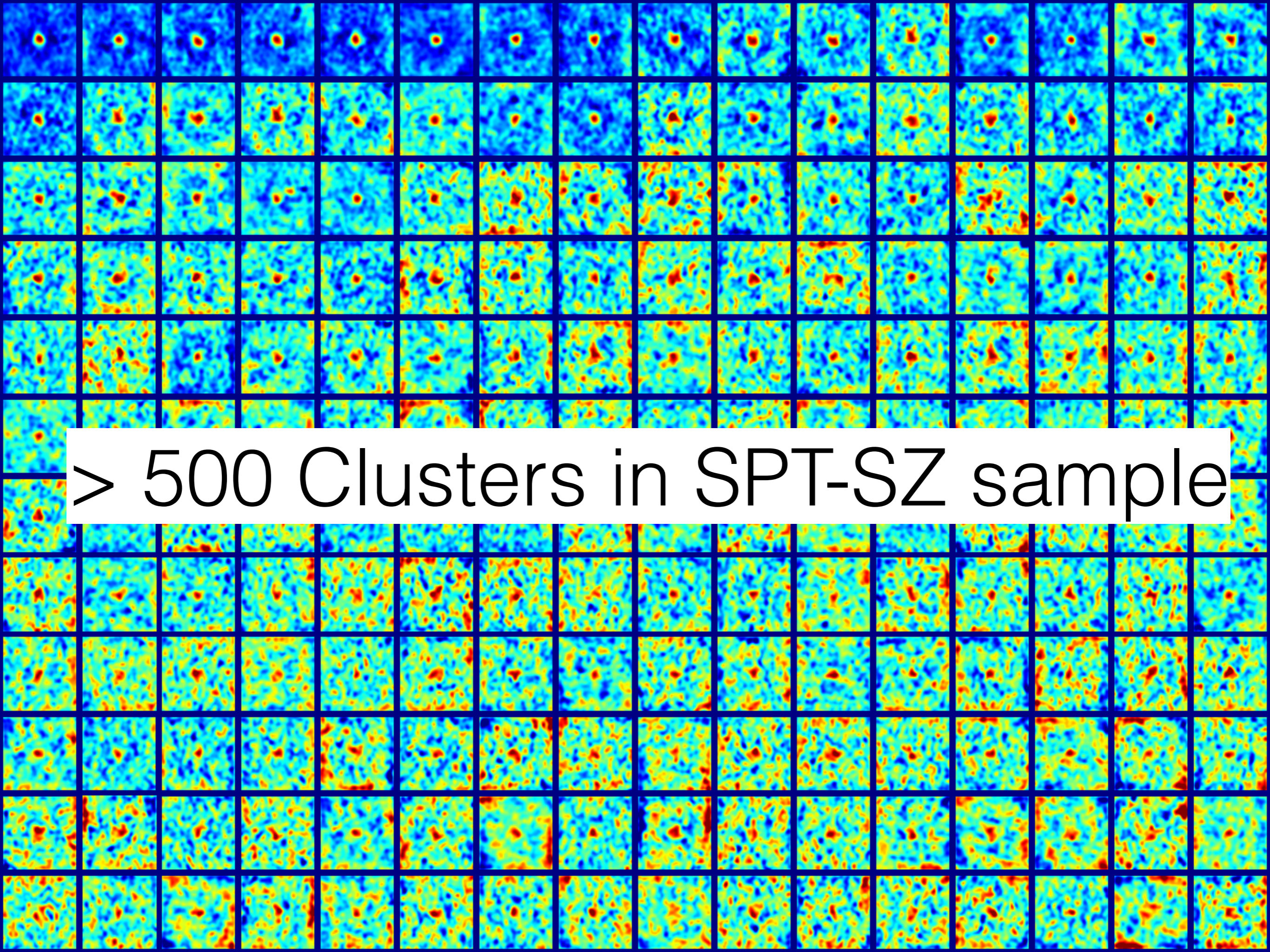
Towards a massive cluster,  
 $\sim 1\%$  of CMB photons scatter  
off of intra-cluster gas



# Finding Clusters in the SPT Survey



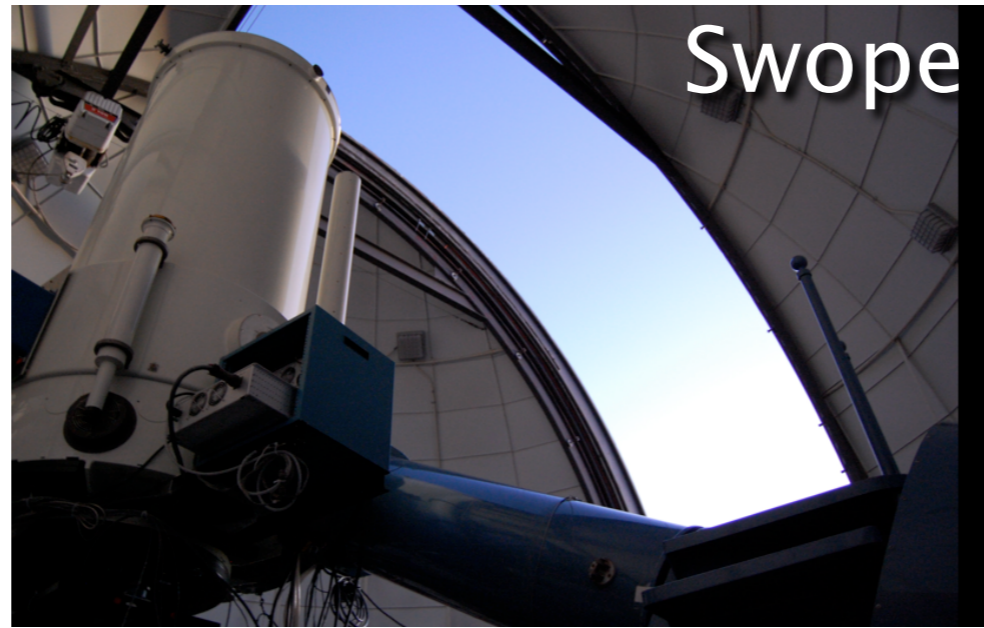
- Matched-filter multi-frequency cluster finder (Melin et al. 2006)



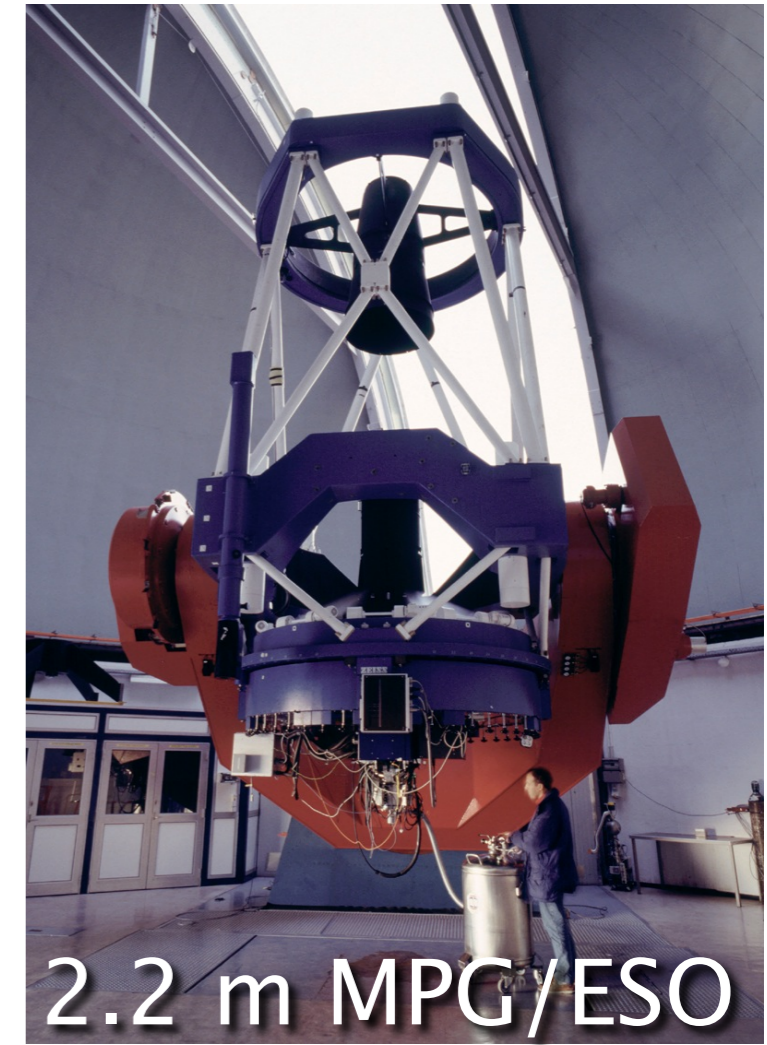
> 500 Clusters in SPT-SZ sample



Spitzer

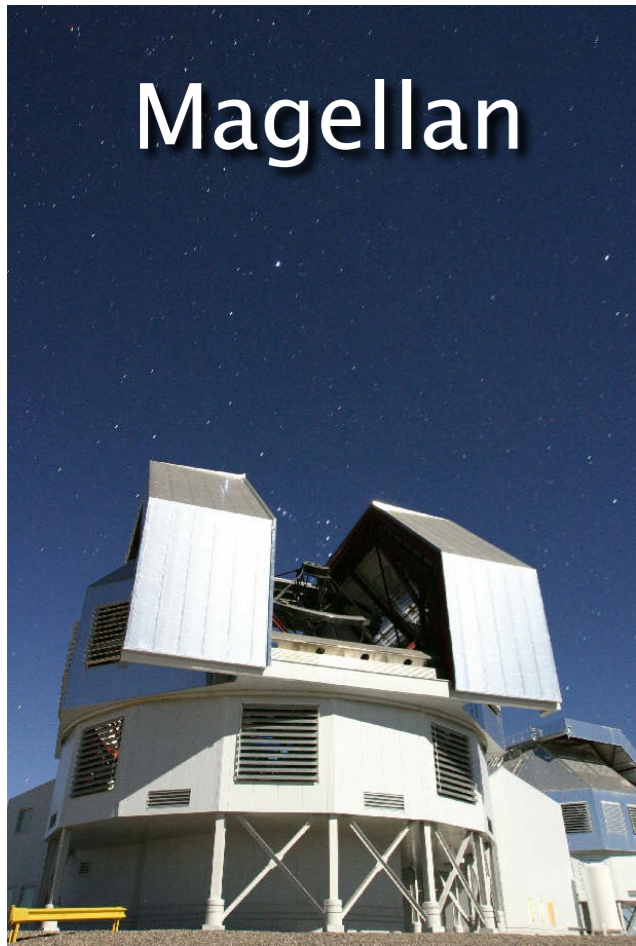


Swope



2.2 m MPG/ESO

# Multiple-facility Imaging Campaign for Cluster Confirmation



Magellan



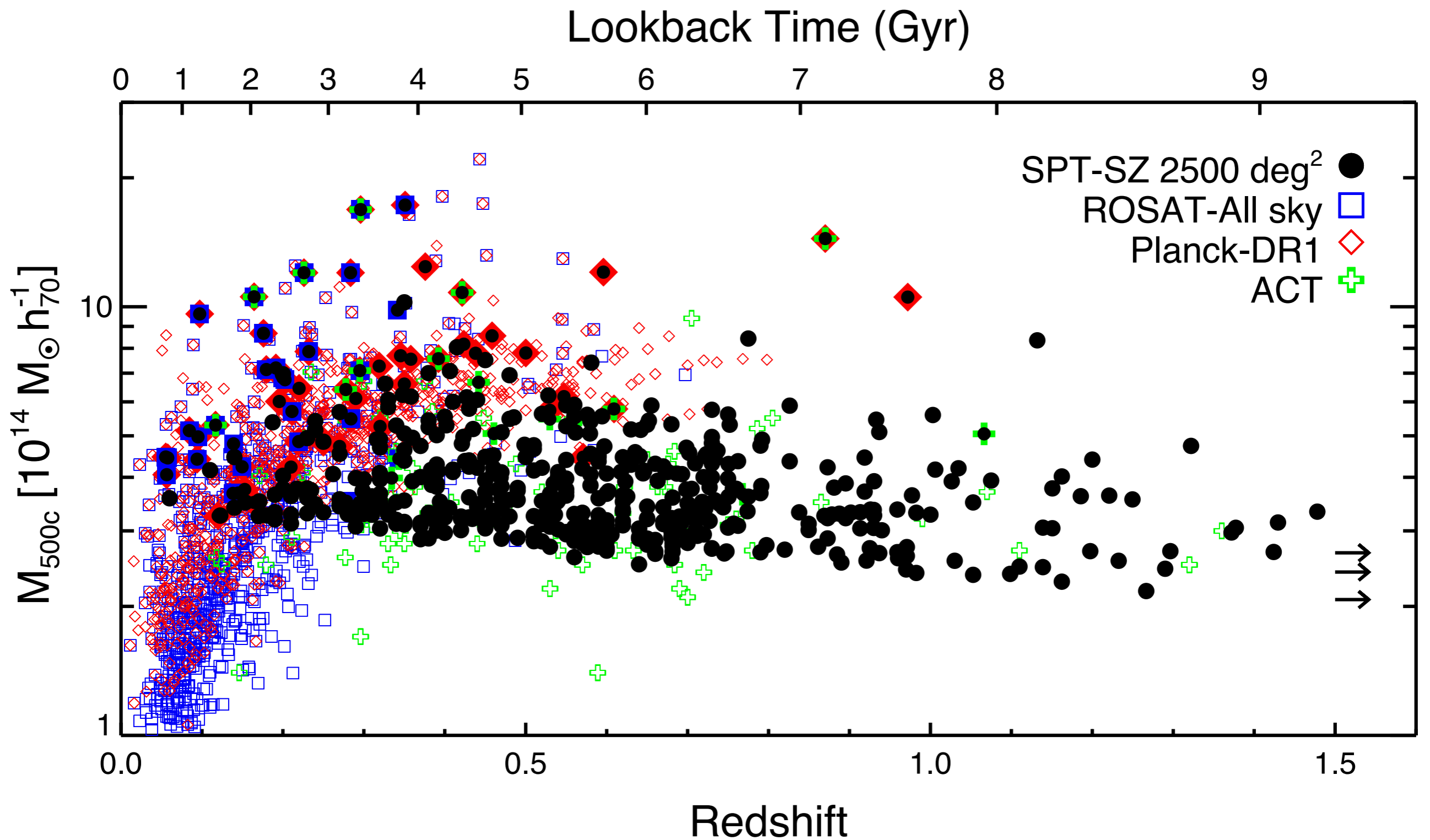
Blanco



NTT

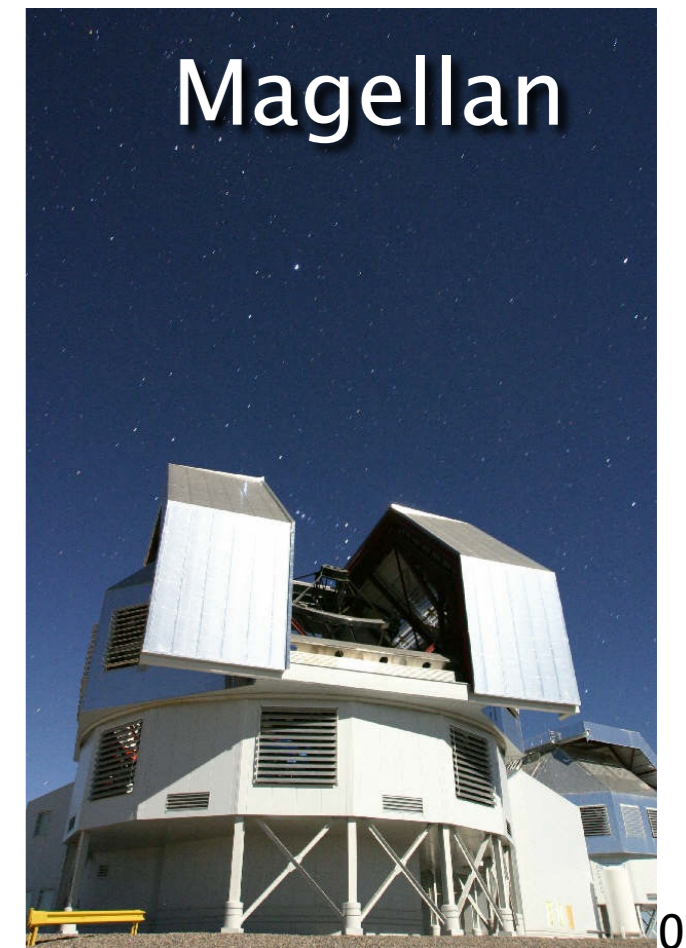
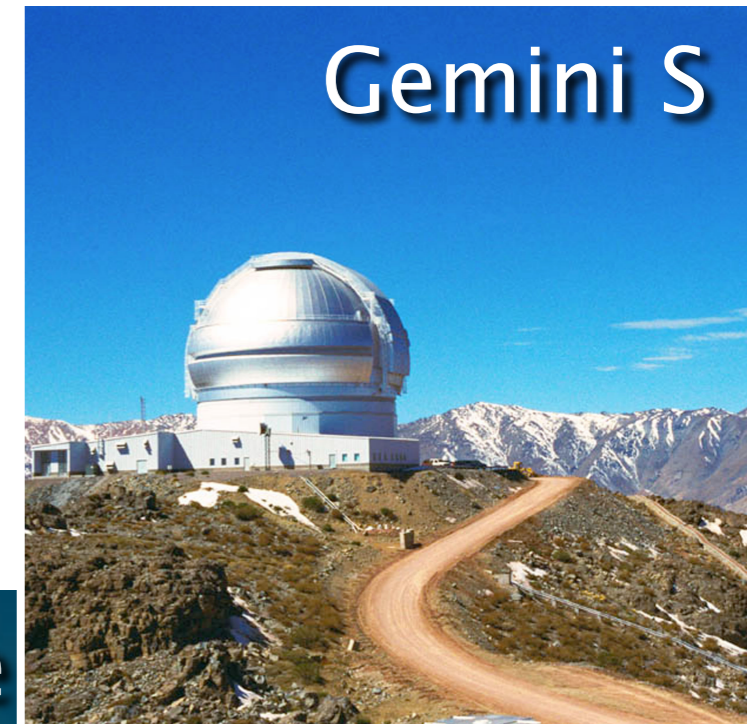


# *The 2500 deg<sup>2</sup> SPT-SZ Cluster Sample:*



# Multi-wavelength Follow-up campaign

1. **X-ray** with Chandra & XMM
2. **Weak lensing** from Magellan ( $0.3 < z < 0.6$ ) and HST ( $z > 0.6$ )
3. **Spectroscopic Data** from NOAO 3-year survey on Gemini ( $0.3 < z < 0.8$ ); VLT & Magellan at ( $z > 0.8$  (Ruel et al. 2013))
4. **NIR Data** (*Spitzer*, NEWFIRM, Magellan/FOURSTAR)  
~300 clusters



# Dark Energy Survey (DES) and SPT

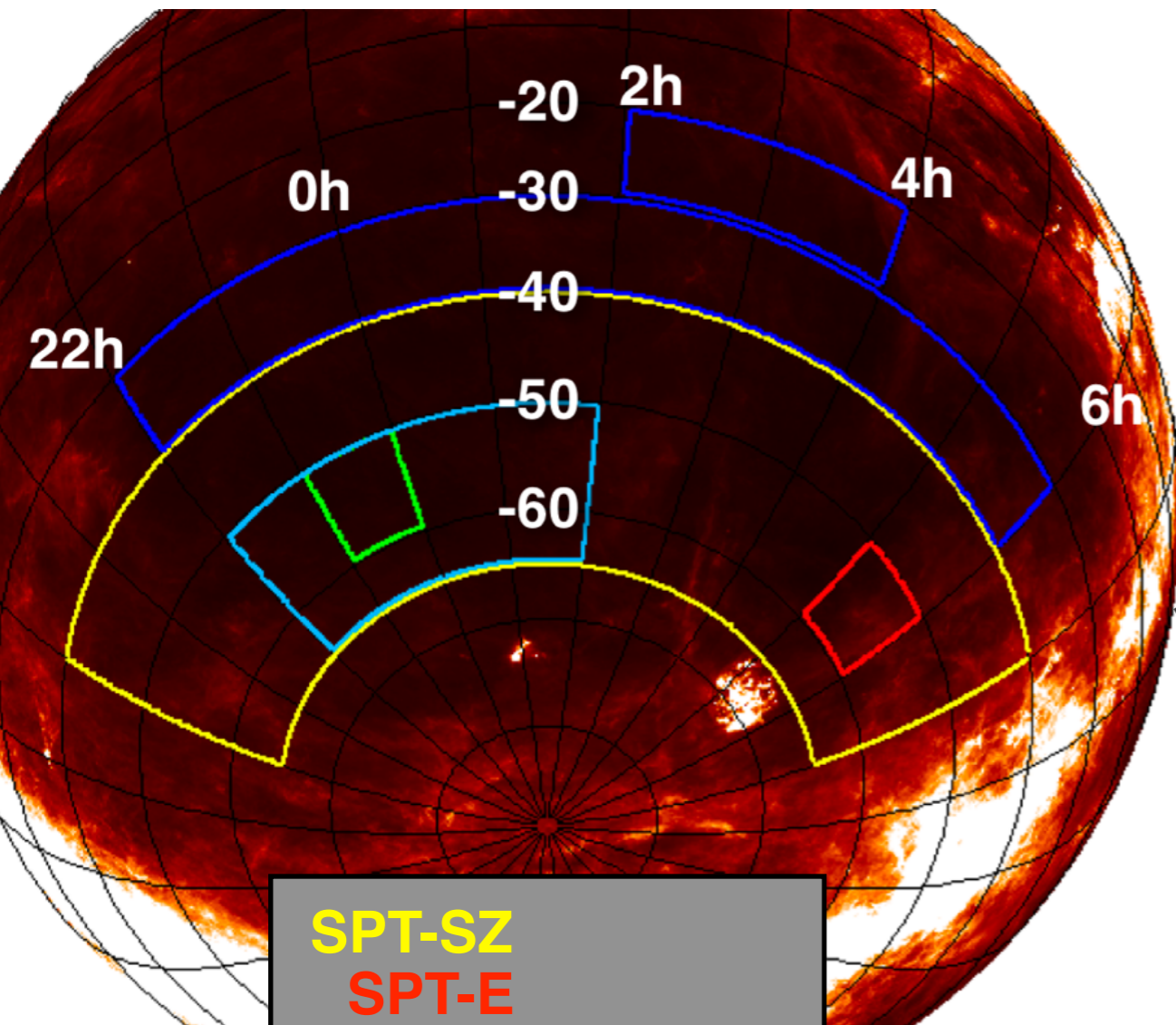


Image credit: Roger Smith/NOAO/AURA/NSF

Blanco 4m. Cerro Tololo, Chile

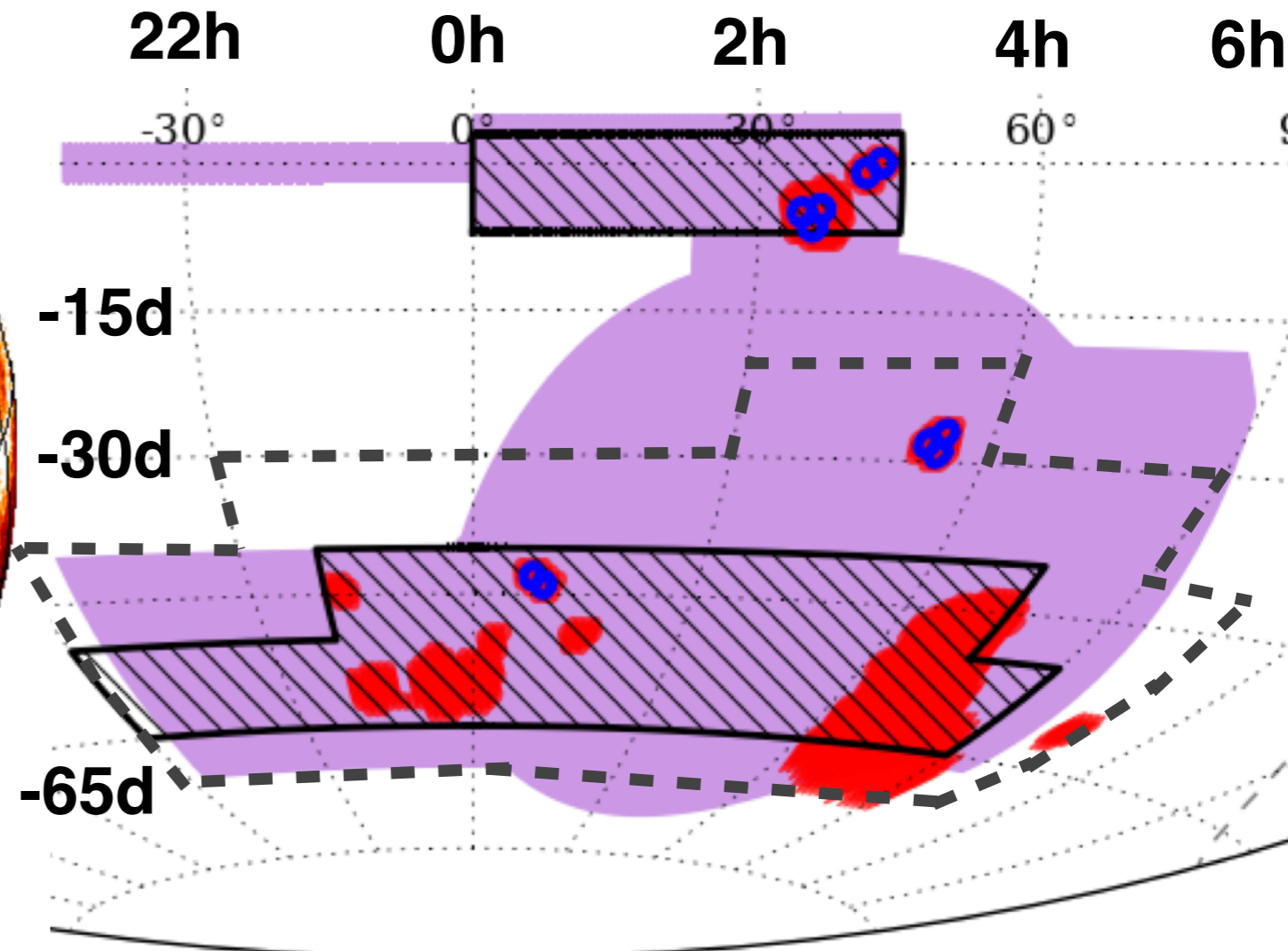
- Wide field ( $2.2 \text{ deg}^2$ ) optical camera for 4-meter Blanco telescope (Chile)
- **Optical survey (2012-2016) to cover  $\sim 5000 \text{ deg}^2$  which will detect  $\sim 100,000$  clusters out to  $z \sim 1$**
- Multiple probes of dark energy (cluster survey, weak lensing, BAO, SN)
- Coordinated to overlap with SPT

# SPT Footprints



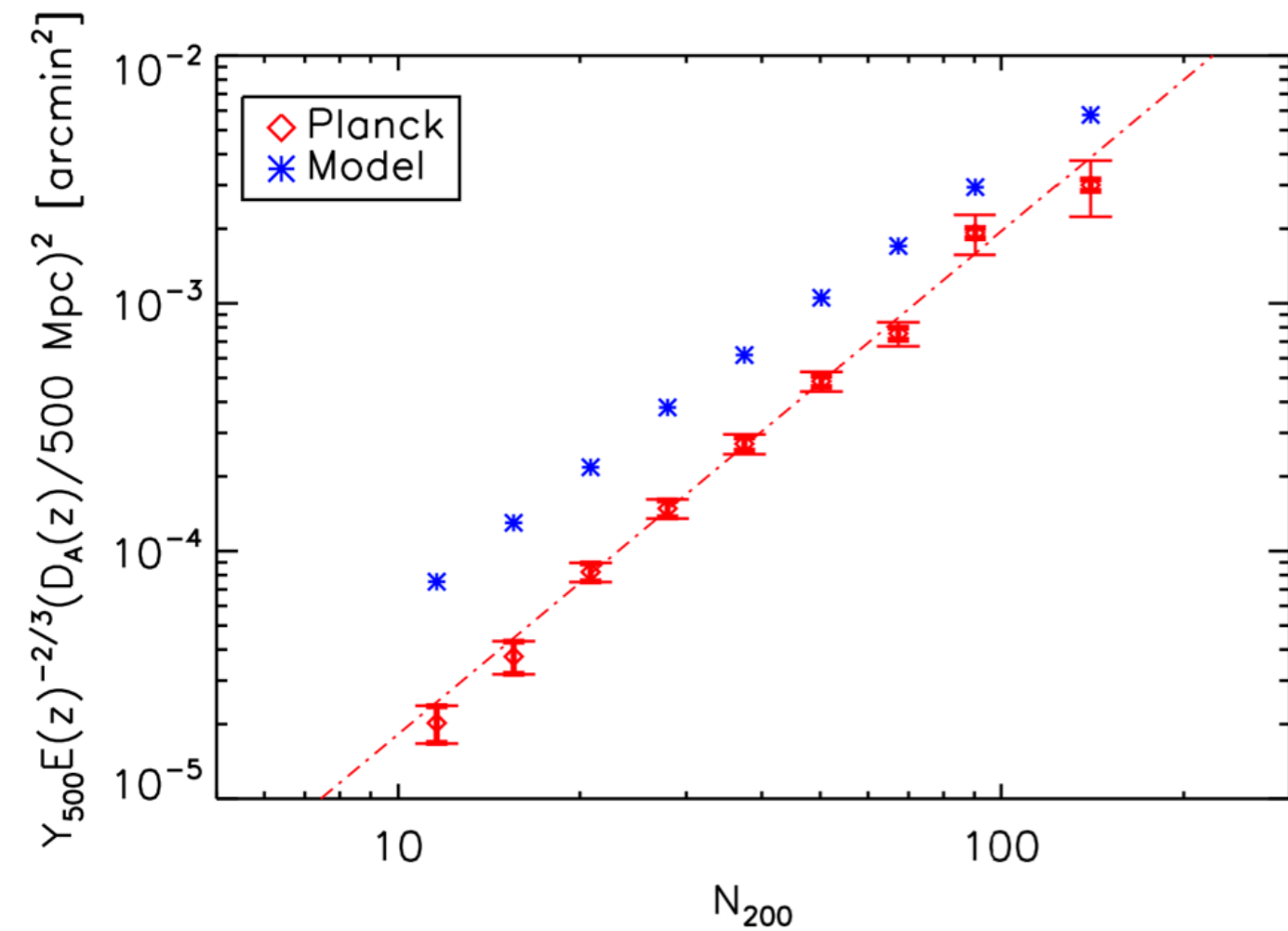
**SPT-SZ**  
**SPT-E**  
**SPT-W**  
 (SPTpol 2012)  
**SPTpol**  
**SPTpol-Summer**

# DES Footprint SPT Footprint

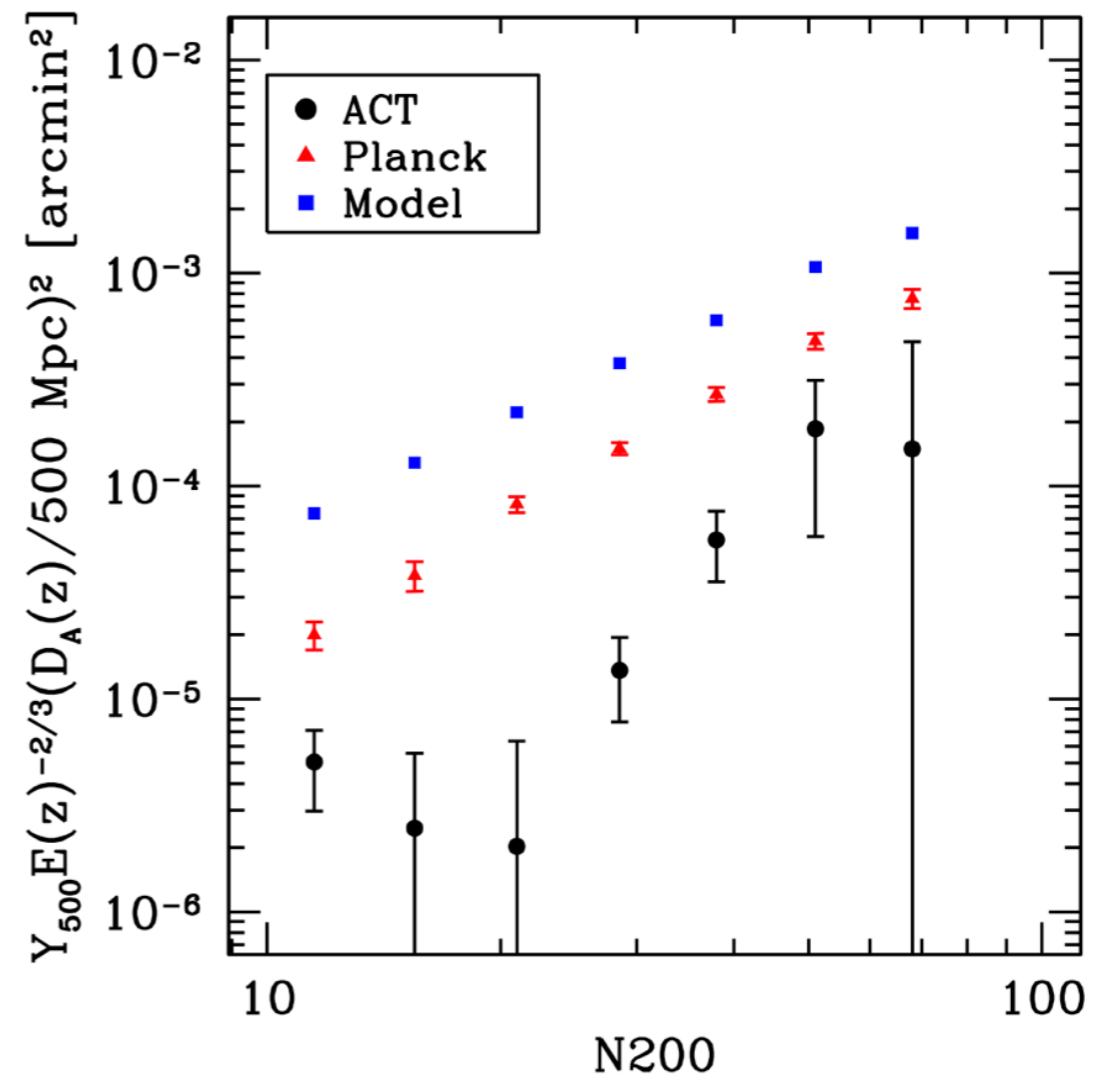


Survey	Area (deg <sup>2</sup> )	150 GHz Depth (uK-arcmin)	Bands (GHz)	Status
<b>SPT-SZ</b>	2500	17	90, 150, 220	<b>Complete</b>
<b>SPT-E</b>	100	13	90, 150, 220	<b>Complete</b>
<b>SPT-W</b>	100	6	90, 150, 220	<b>Complete</b>
<b>SPTpol</b>	500	6	90, 150	<i>In Progress</i>
<b>SPTpol-Summer</b>	1250	29	90, 150	<b>Complete</b>
<b>SPT-3G</b>	2500	2	90, 150, 220	<i>2016 Start</i>

# Comparisons across wavelengths provide powerful checks on mass calibration and systematics control



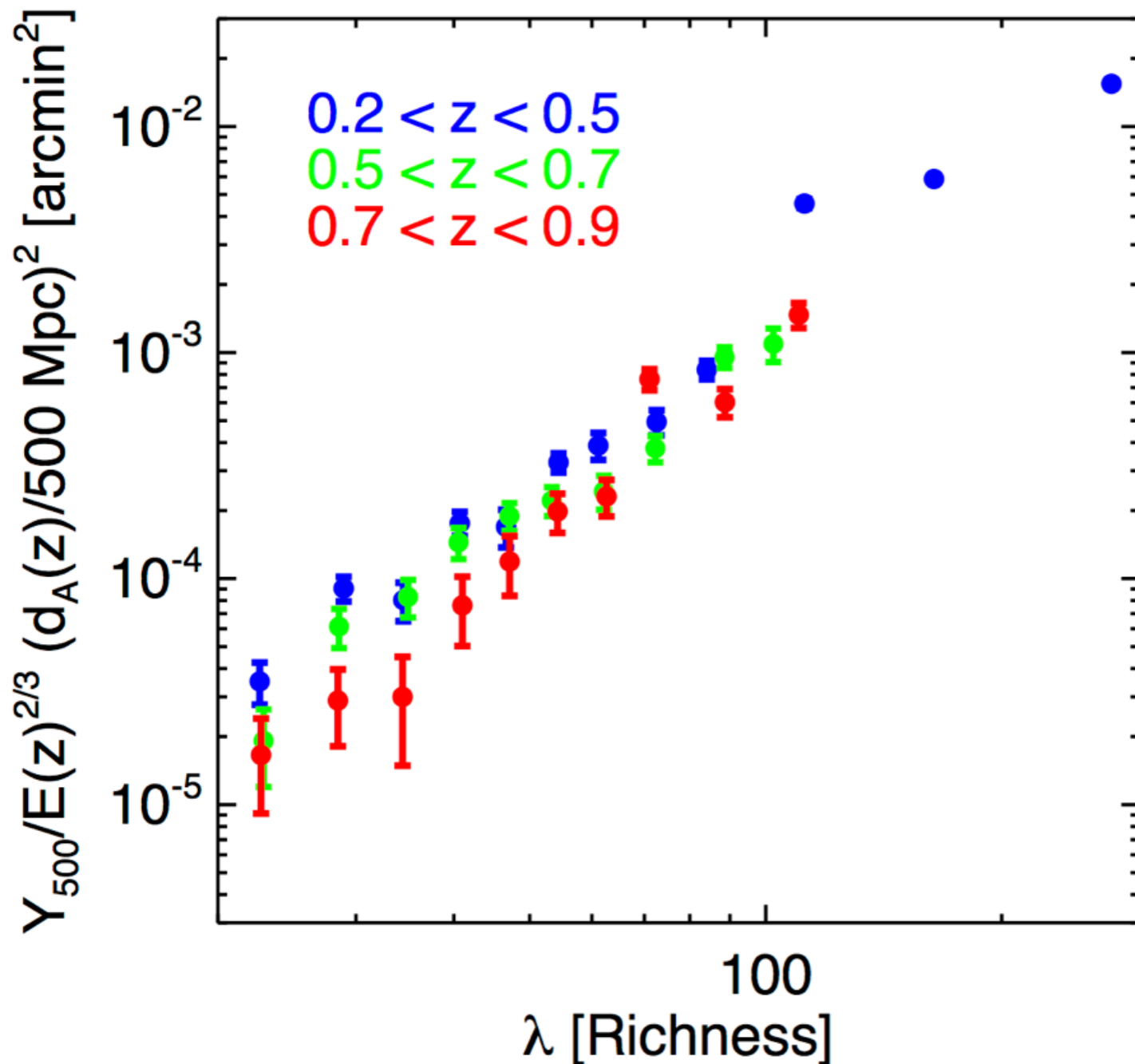
Planck Collaboration,  
Planck2011-5.2c



Sehgal et al 2013  
(1205.2369)

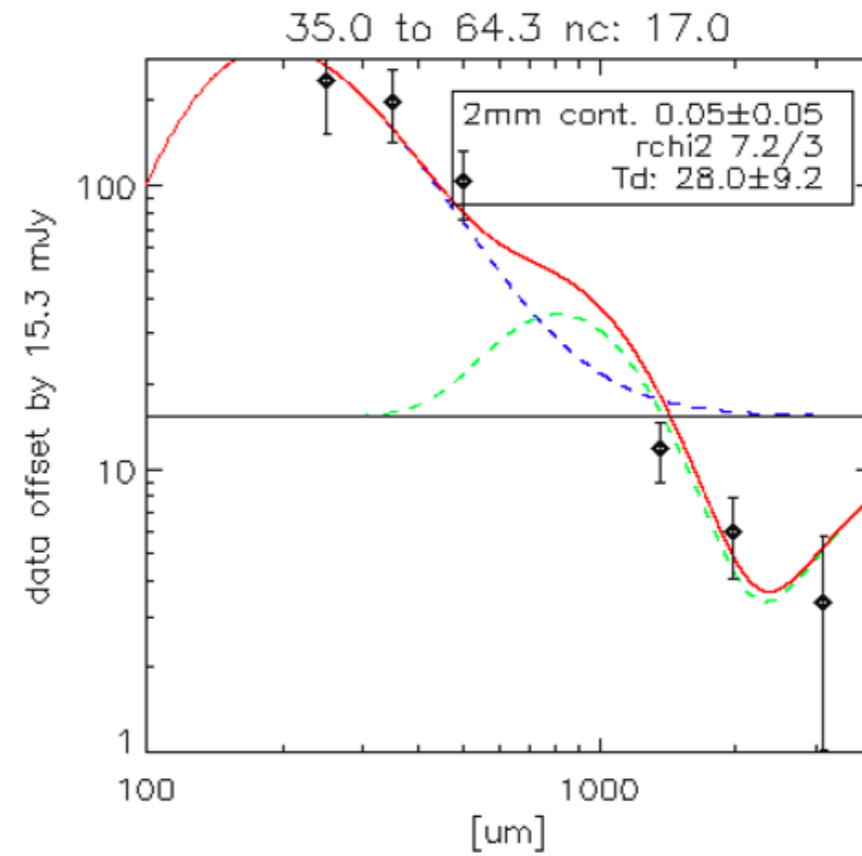
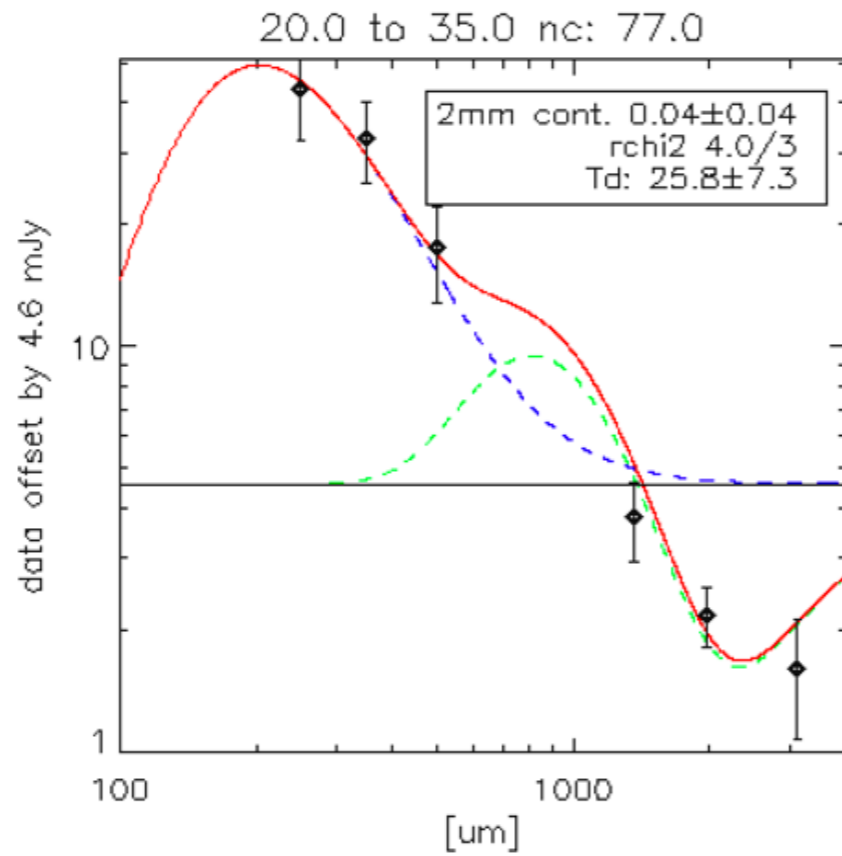
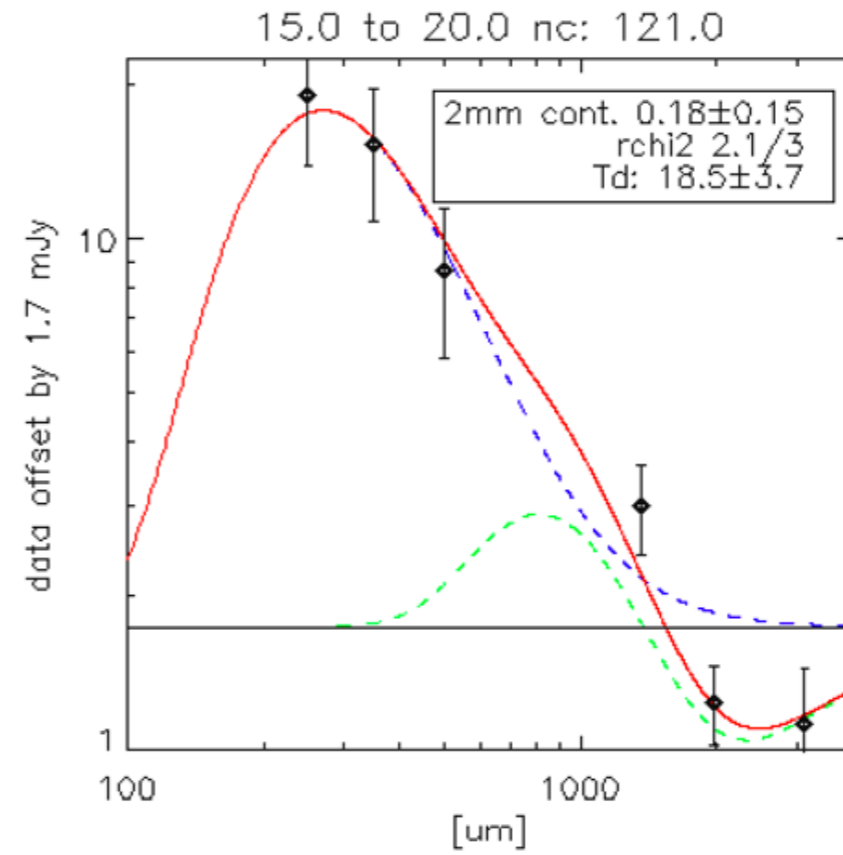
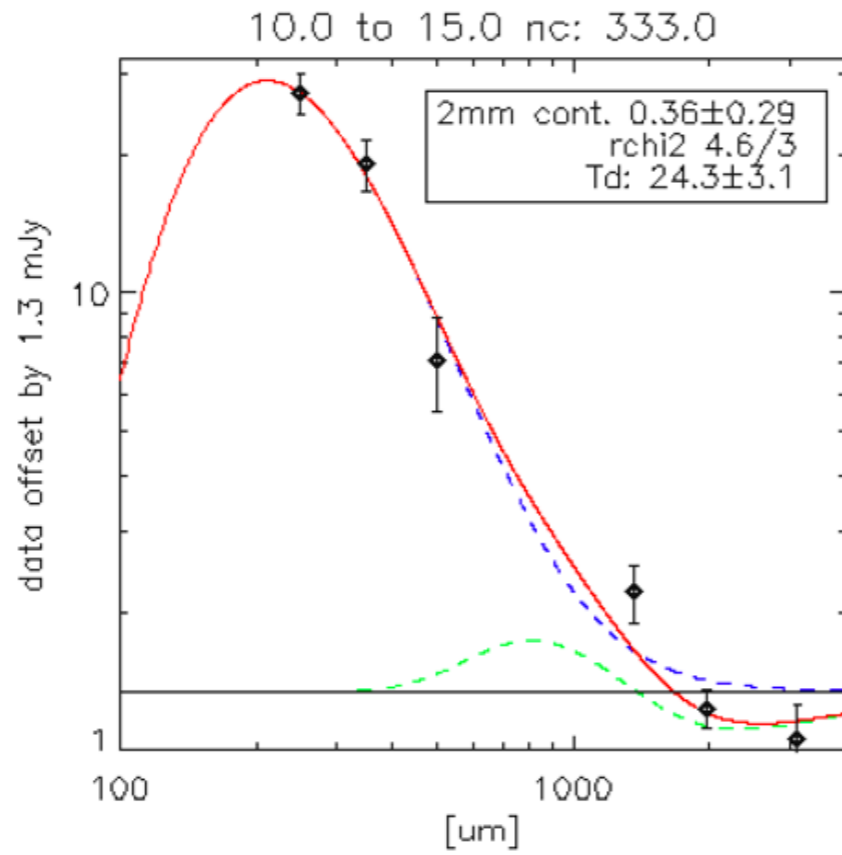
# *The SZ signal from DES (optically-selected) clusters*

## SZ Flux vs Optical Richness

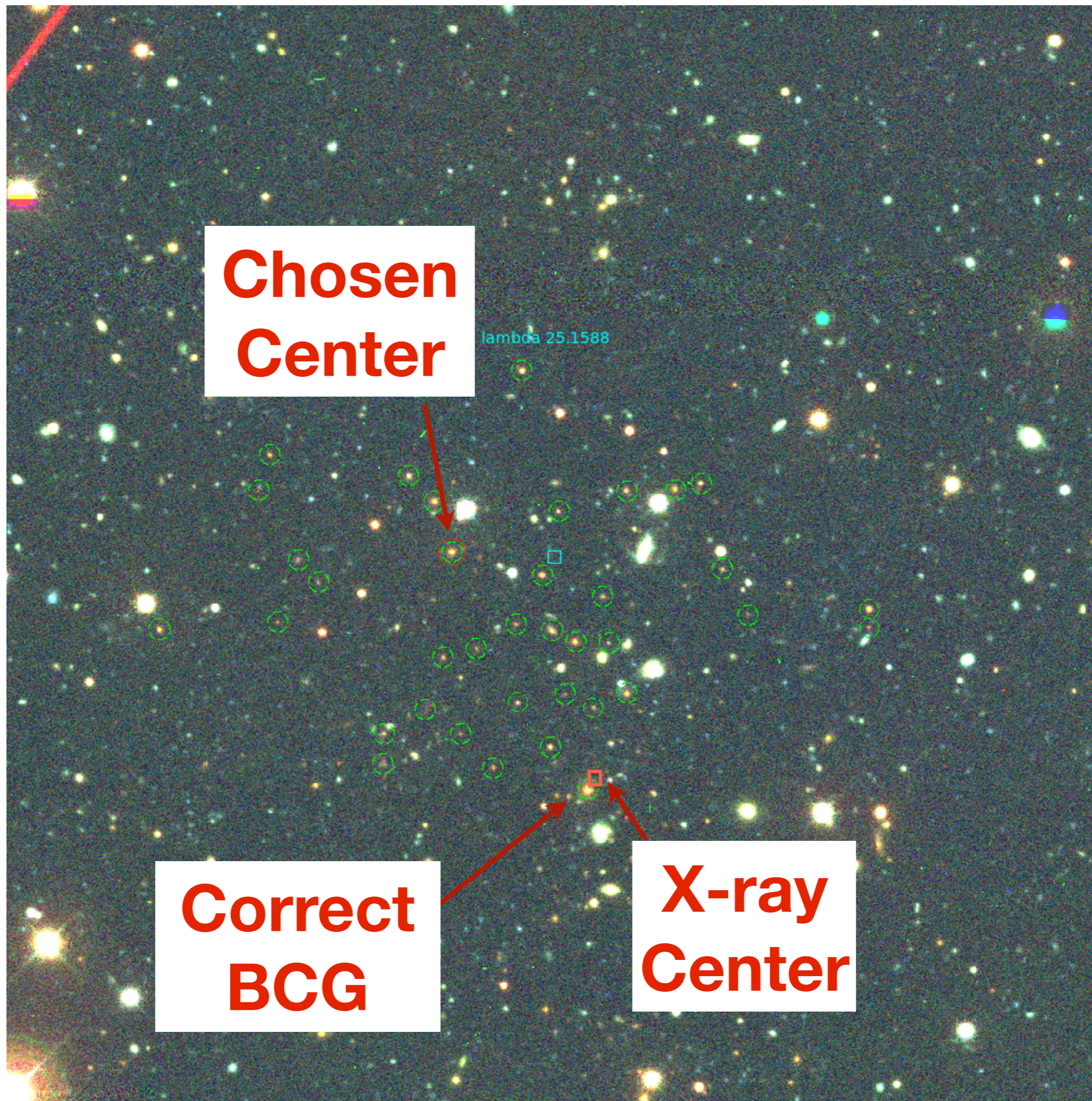


- Stack of SPT-SZ data on  $\sim 600$  optically selected clusters from first 150 deg<sup>2</sup> of early DES
- Strong correlation in multiple richness and redshift bins from  $0.2 < z < 0.9$
- Provides early calibration of DES optical richness (i.e., number of galaxies per cluster) for cluster mass  $> 10^{14} \text{ Msun}$

# SZ contamination studies

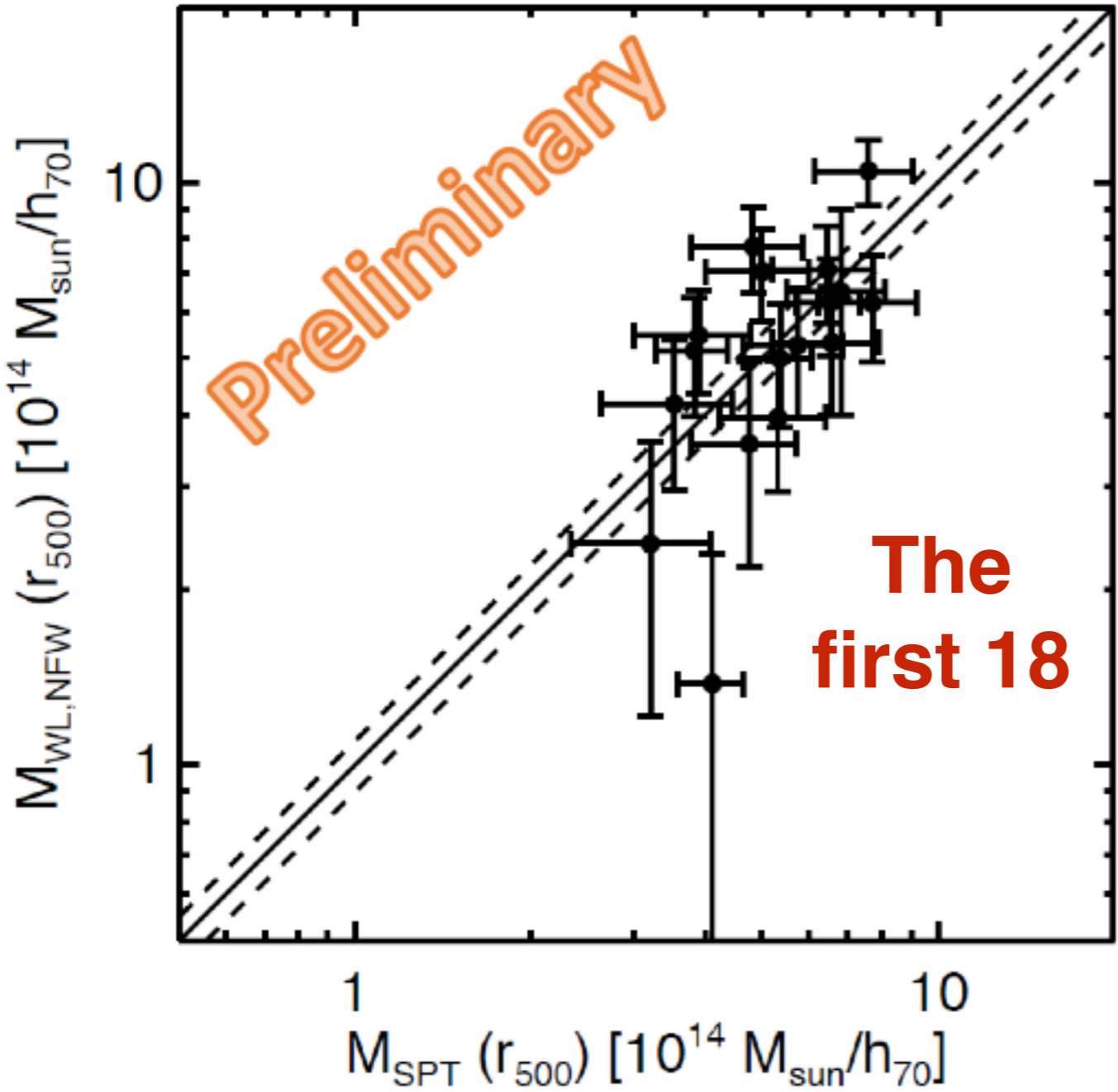


# Other Systematics





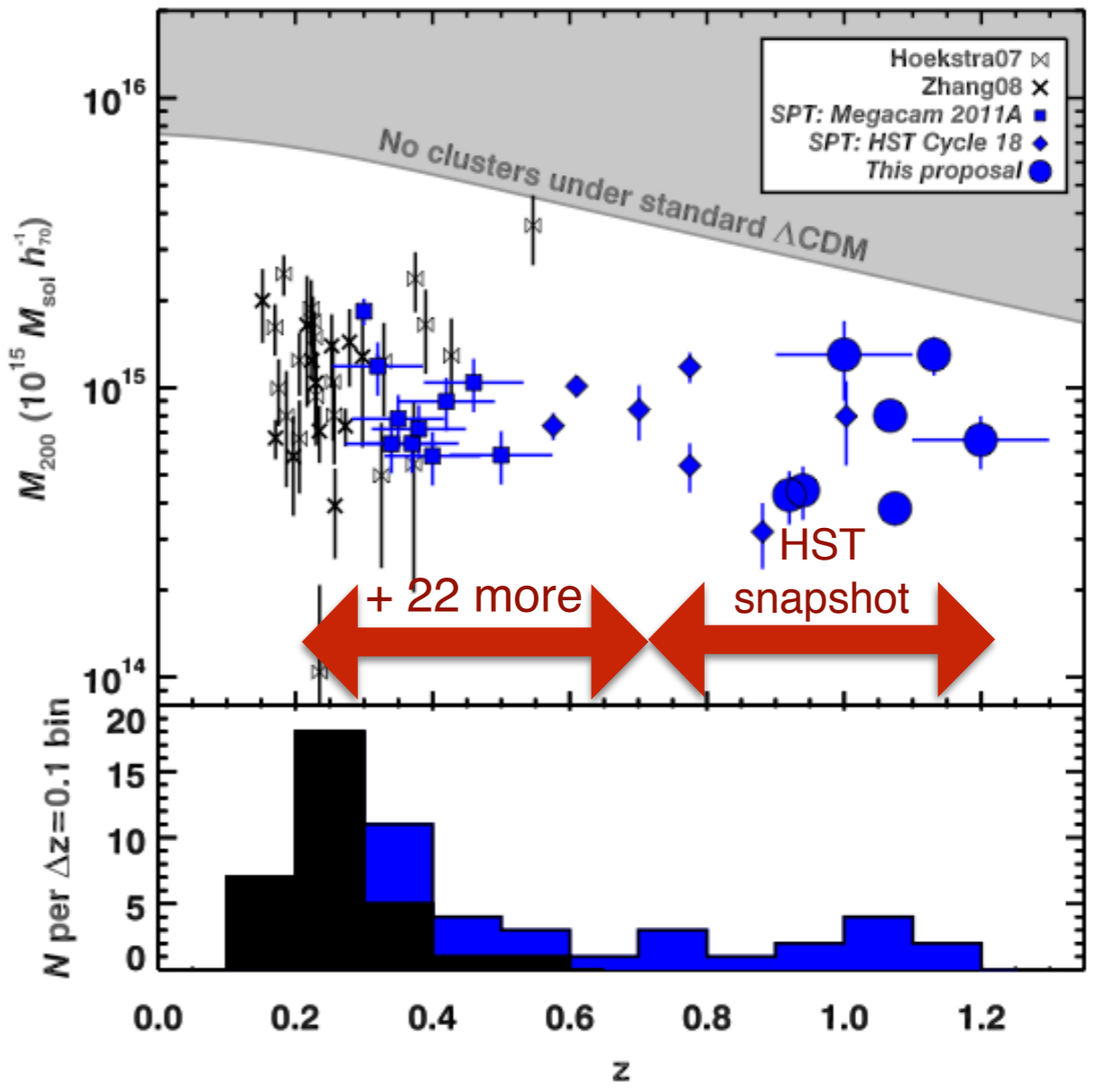
# Coming Soon: Weak Lensing Mass Calibration



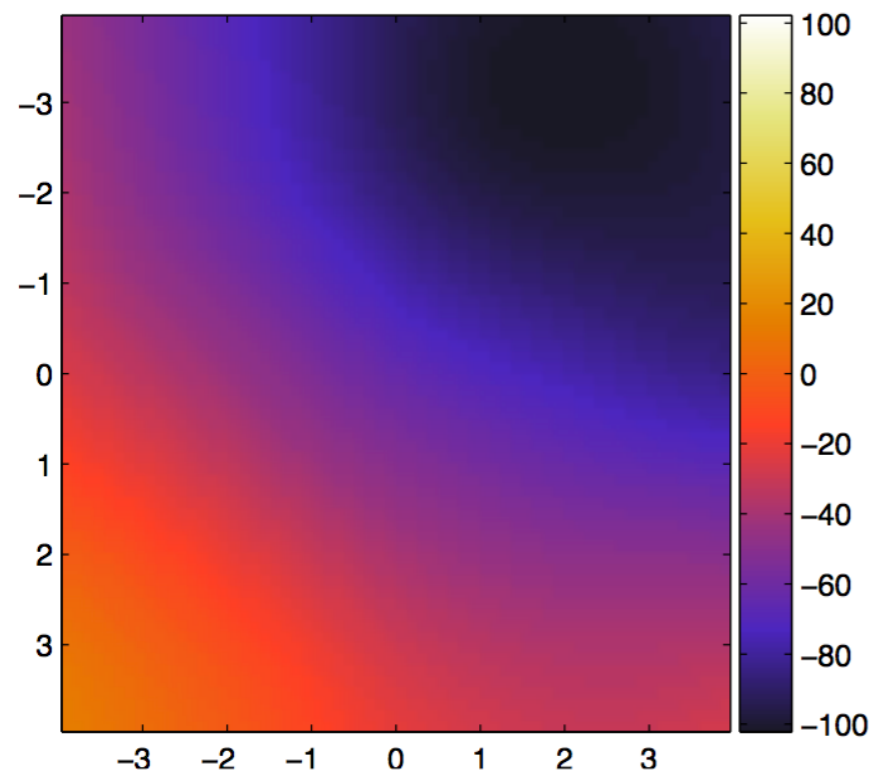
The first 18

Dietrich et al. (in prep)

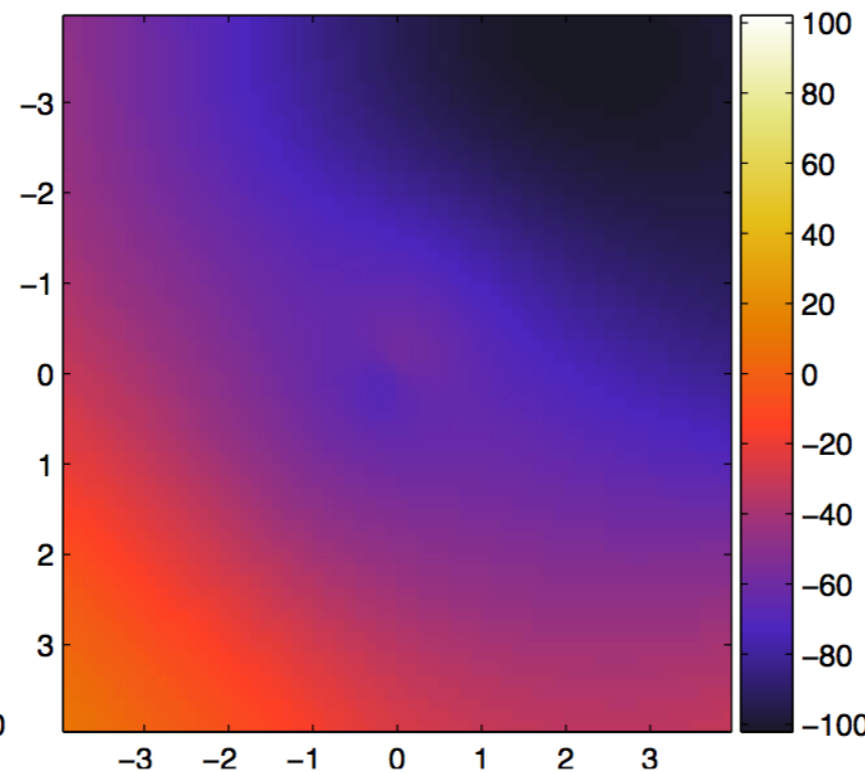
## Weak Lensing Sample



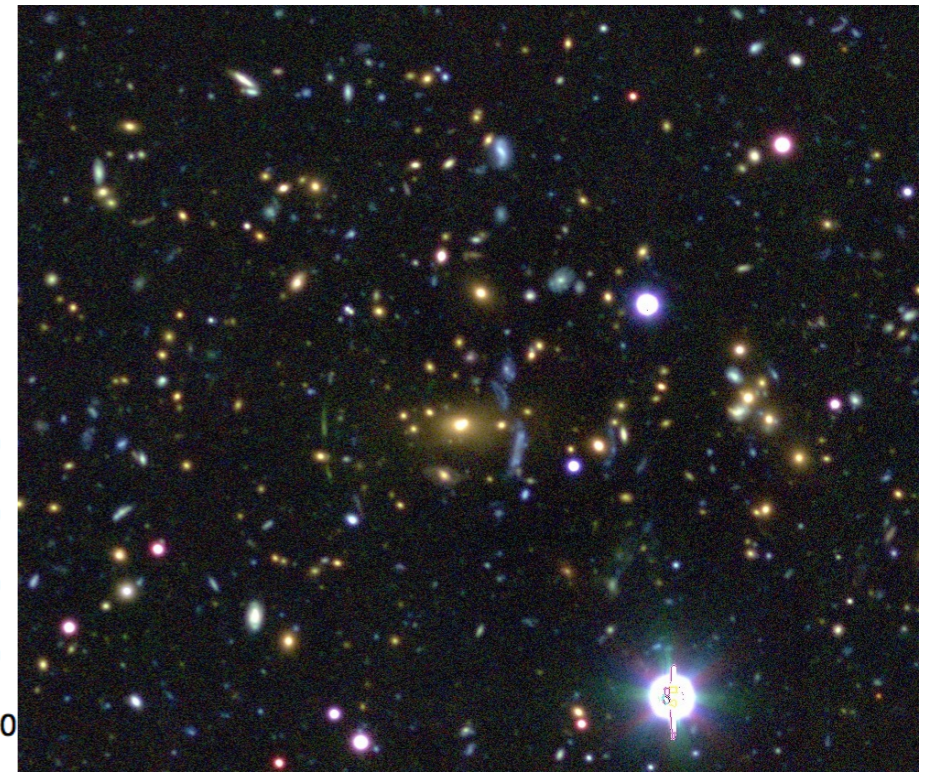
Weak Lensing is the “Gold” standard for cluster mass-calibration.



Unlensed  
CMB



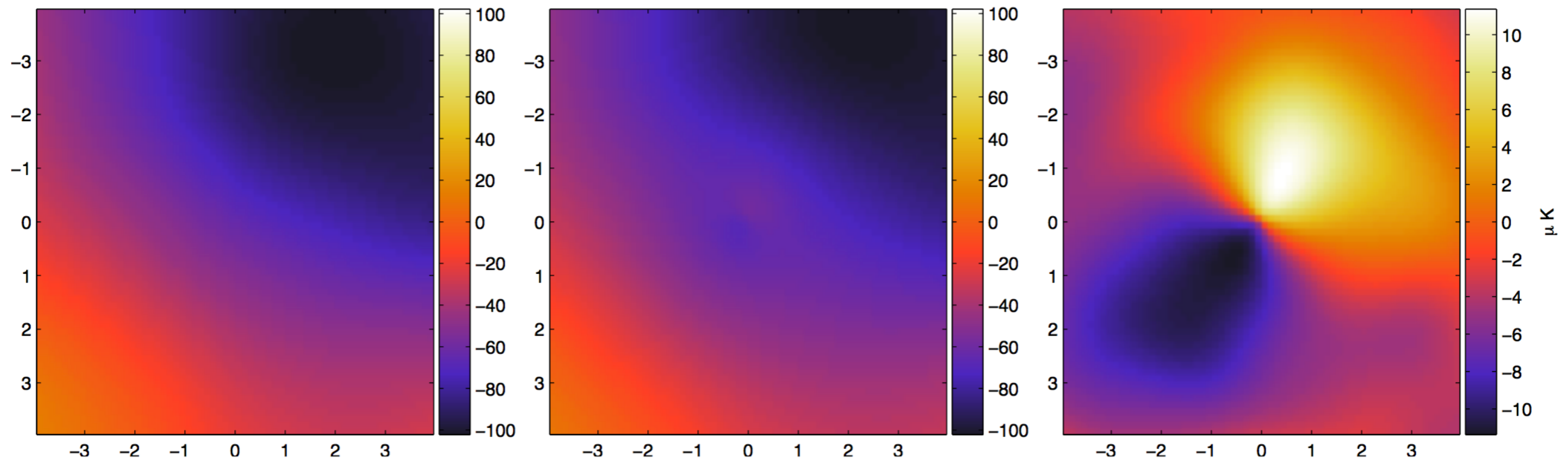
Lensed  
CMB



$M_{200} \sim 1e15 M_{\odot}$

Lewis & Challinor, 2006

Weak Lensing is the “Gold” standard for cluster mass-calibration.



Unlensed  
CMB

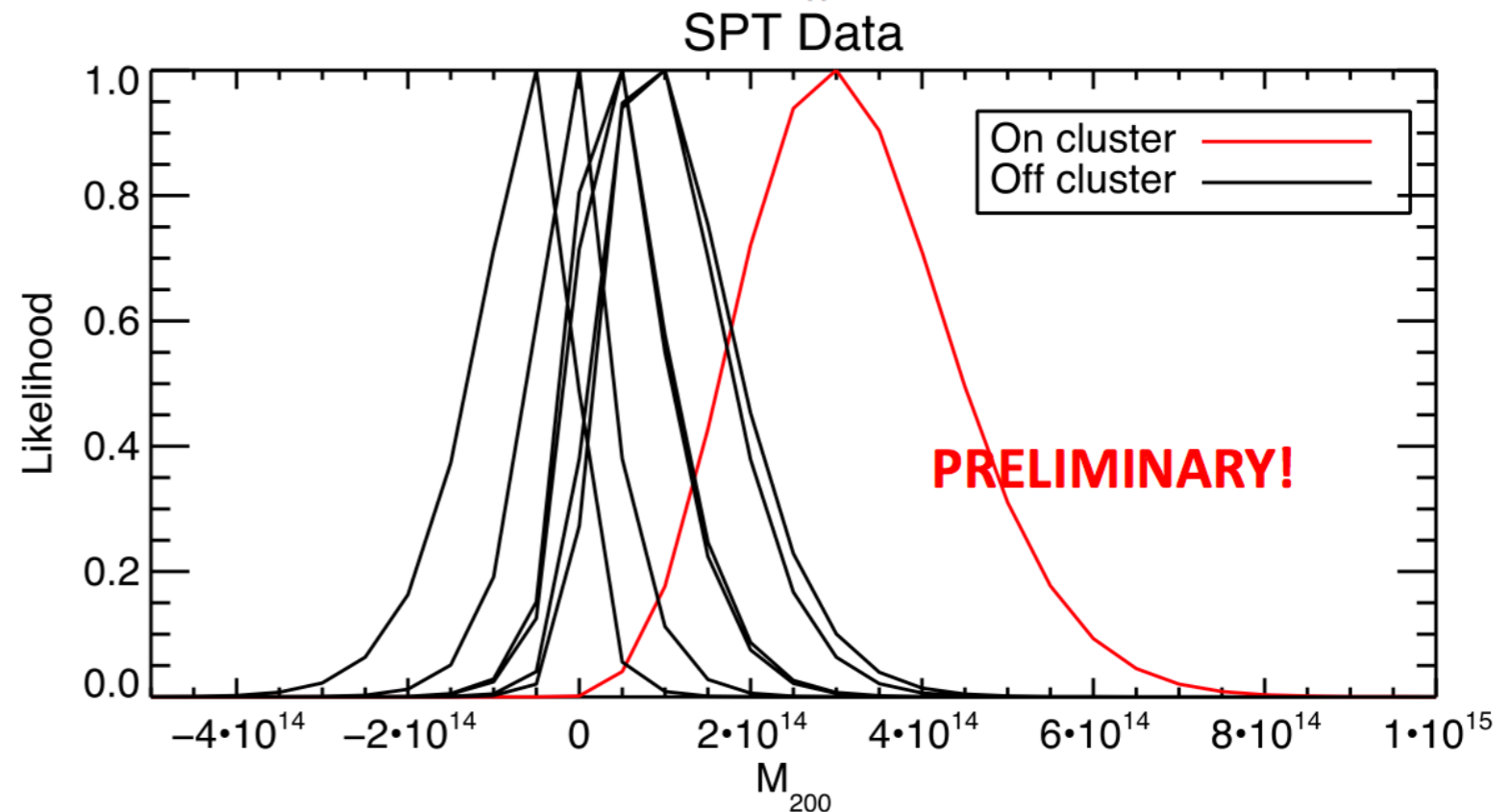
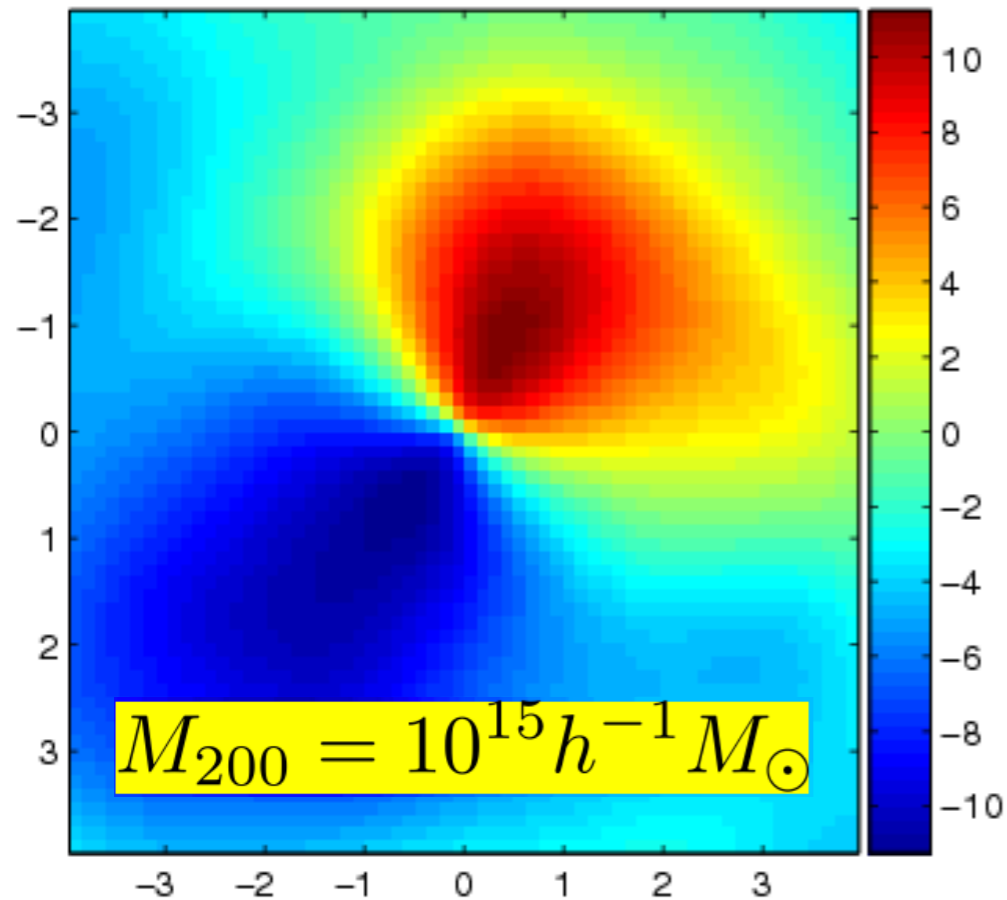
Lensed  
CMB

Difference

Lewis & Challinor, 2006

# CMB Cluster Lensing with SPT-SZ

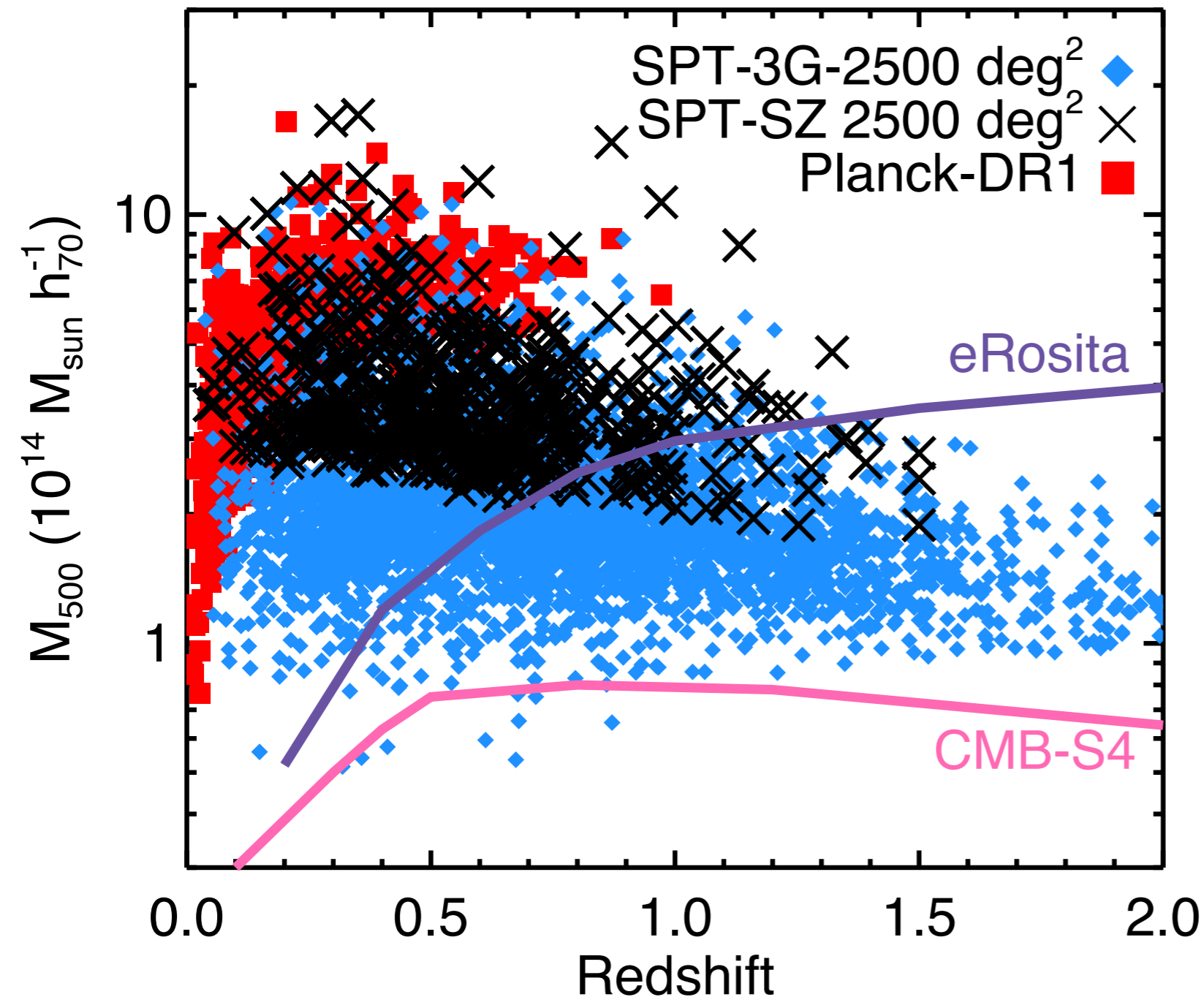
Lensed-Unlensed



A  $\sim$ few  $\mu\text{K}$  “dimple” in the CMB caused by lensing of a  $\sim 10^{15}$  solar mass cluster

A  $3.0\text{-}\sigma$  detection of CMB lensing using  $\sim 500$  clusters measured by SPT-SZ (Baxter 2014, *PhD thesis*)

# Snapshot of Upcoming SZ/X-ray Cluster Surveys



- SPT-3G (starting 2016) will survey 2500 deg<sup>2</sup> to a level 10x deeper than SPT-SZ survey (also Adv. ACTpol!)
- >10x increase in number of clusters over SPT-SZ
  - 4000 clusters at 99% purity threshold
- **3%** stacked mass calibration (full sample)
- **5-10%** Mass constraints on  $z > 1$  clusters from CMB Lensing!

\* eRosita 50 cts threshold  
(Pillepich et al 2012)