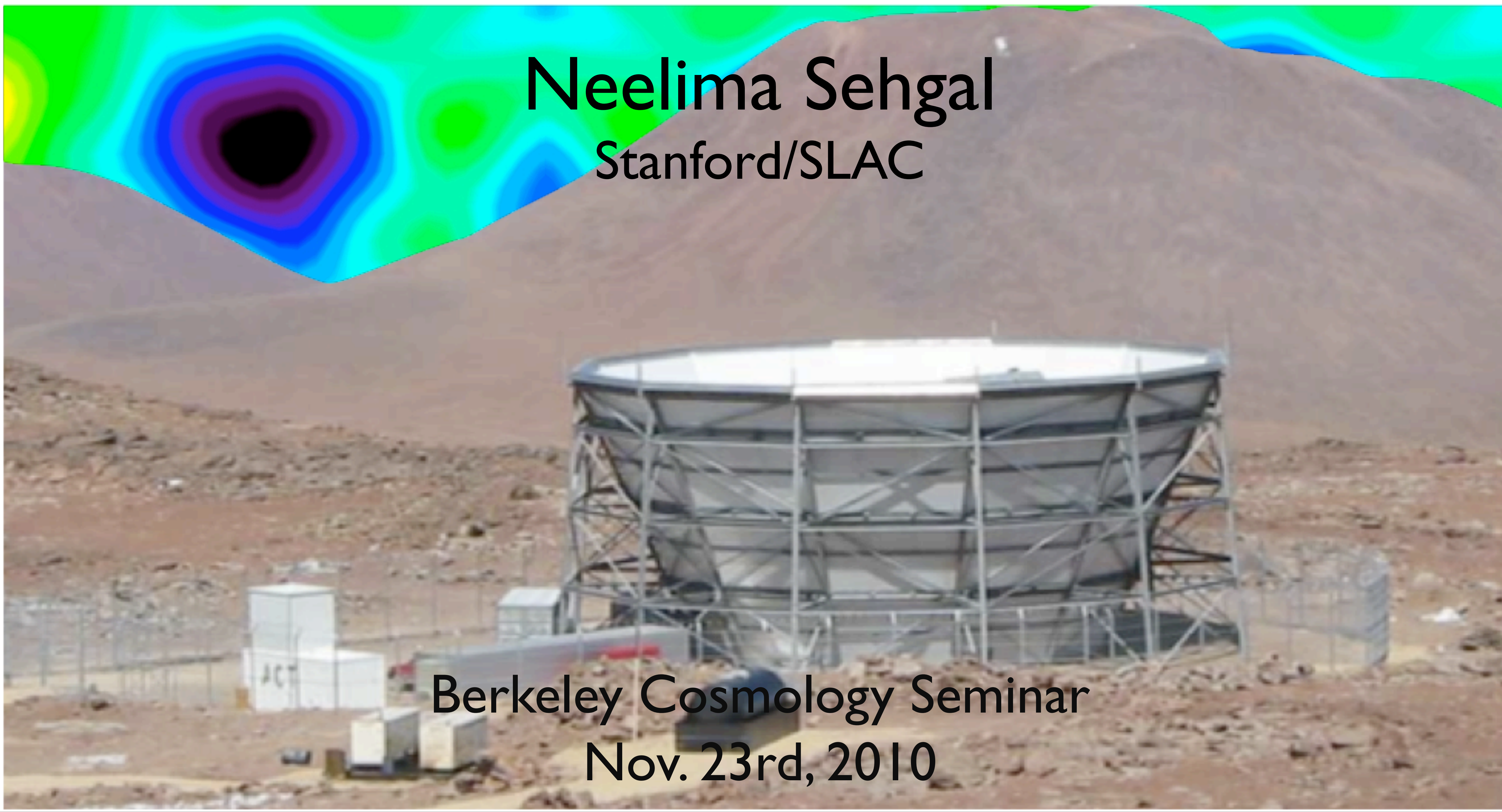
Cosmology Constraints from Sunyaev-Zel'dovich Galaxy Clusters Detected with the Atacama Cosmology Telescope



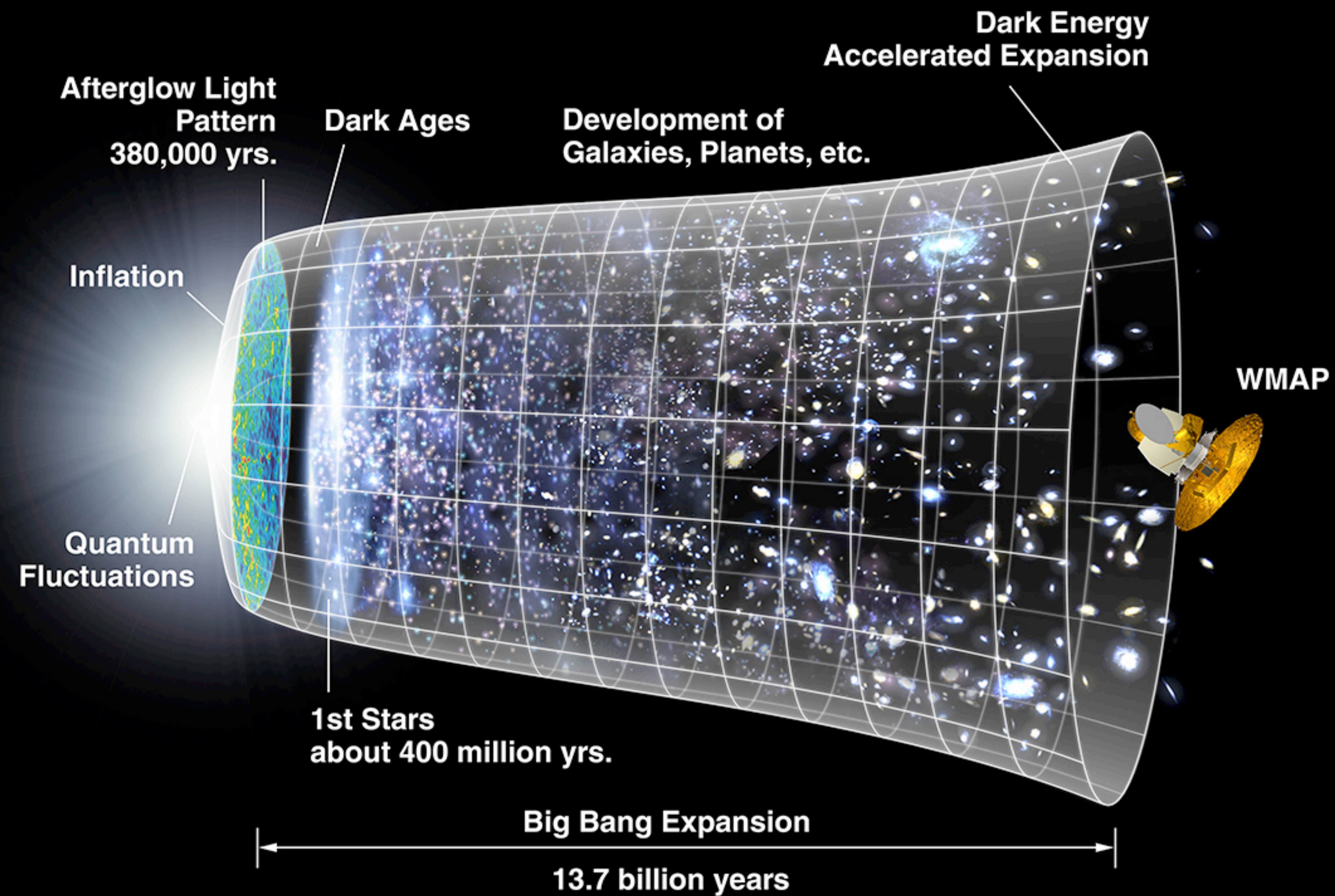
Neelima Sehgal
Stanford/SLAC

Berkeley Cosmology Seminar
Nov. 23rd, 2010

Overview

- SZ Cluster Surveys as an Important Cosmological Probe
- First Cosmology Constraints from Atacama Cosmology Telescope Cluster Sample
- Implications for Fundamental Physics and Astrophysics and Future Prospects

A STANDARD MODEL FOR COSMOLOGY

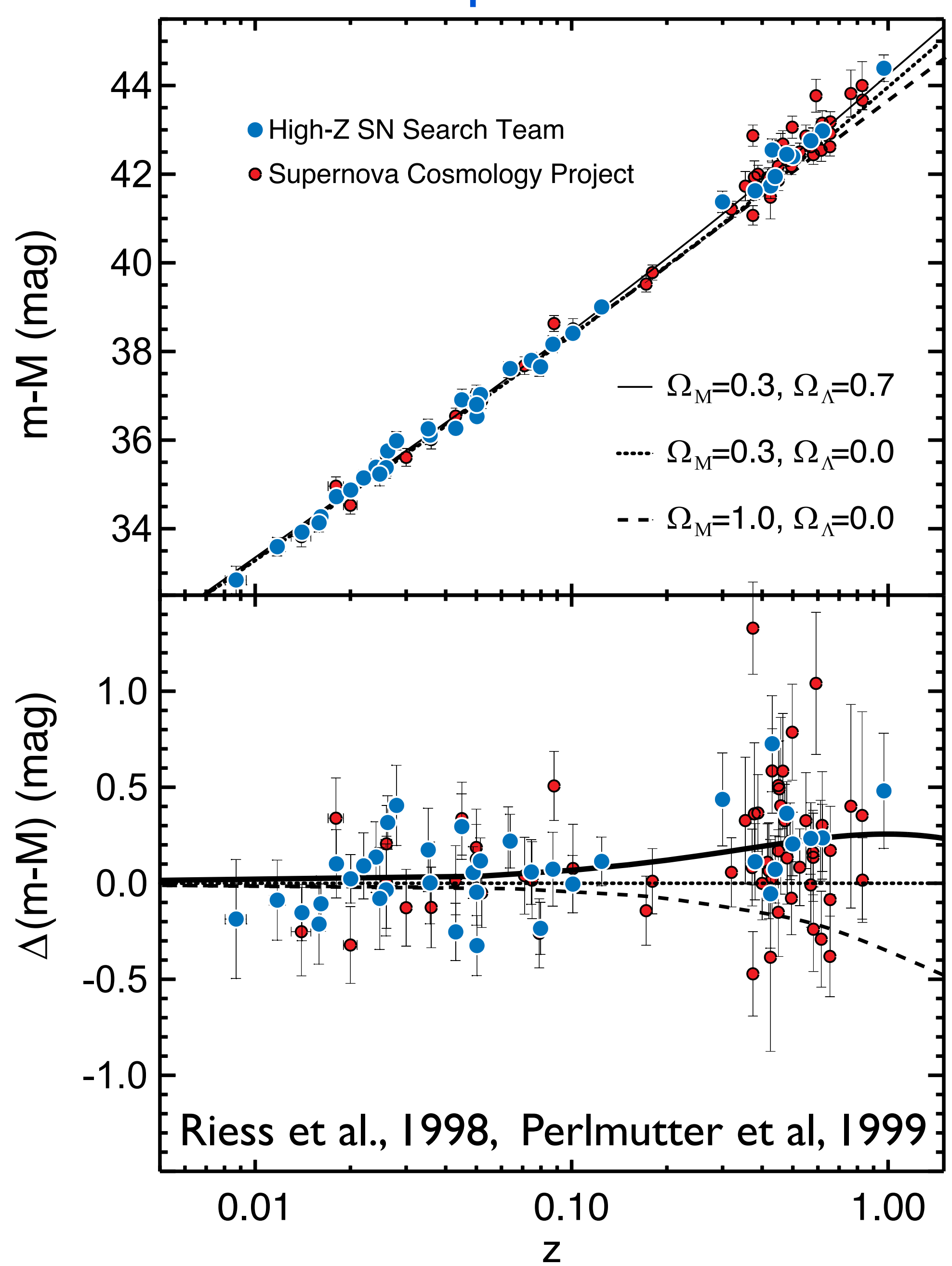


NASA/WMAP Science Team

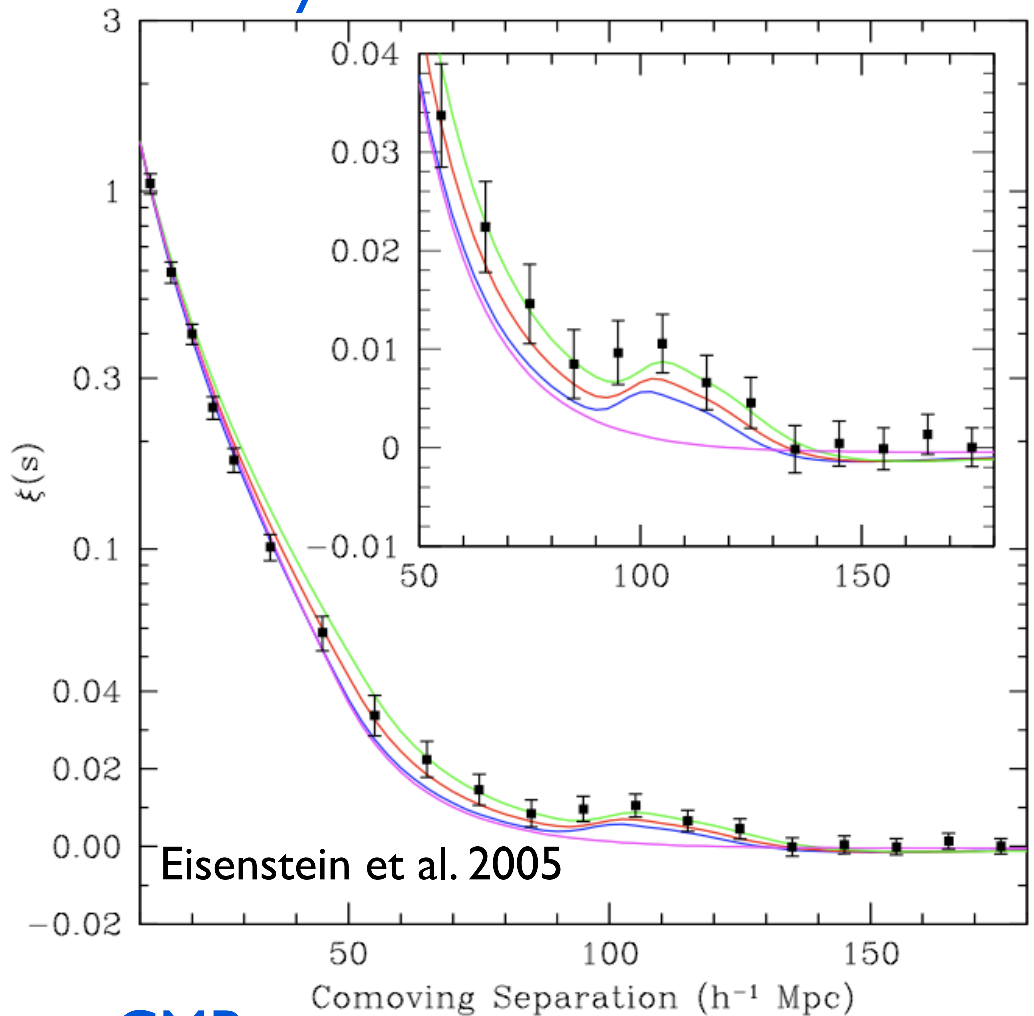
How do we Measure our Universe?

Measures of the Expansion Rate

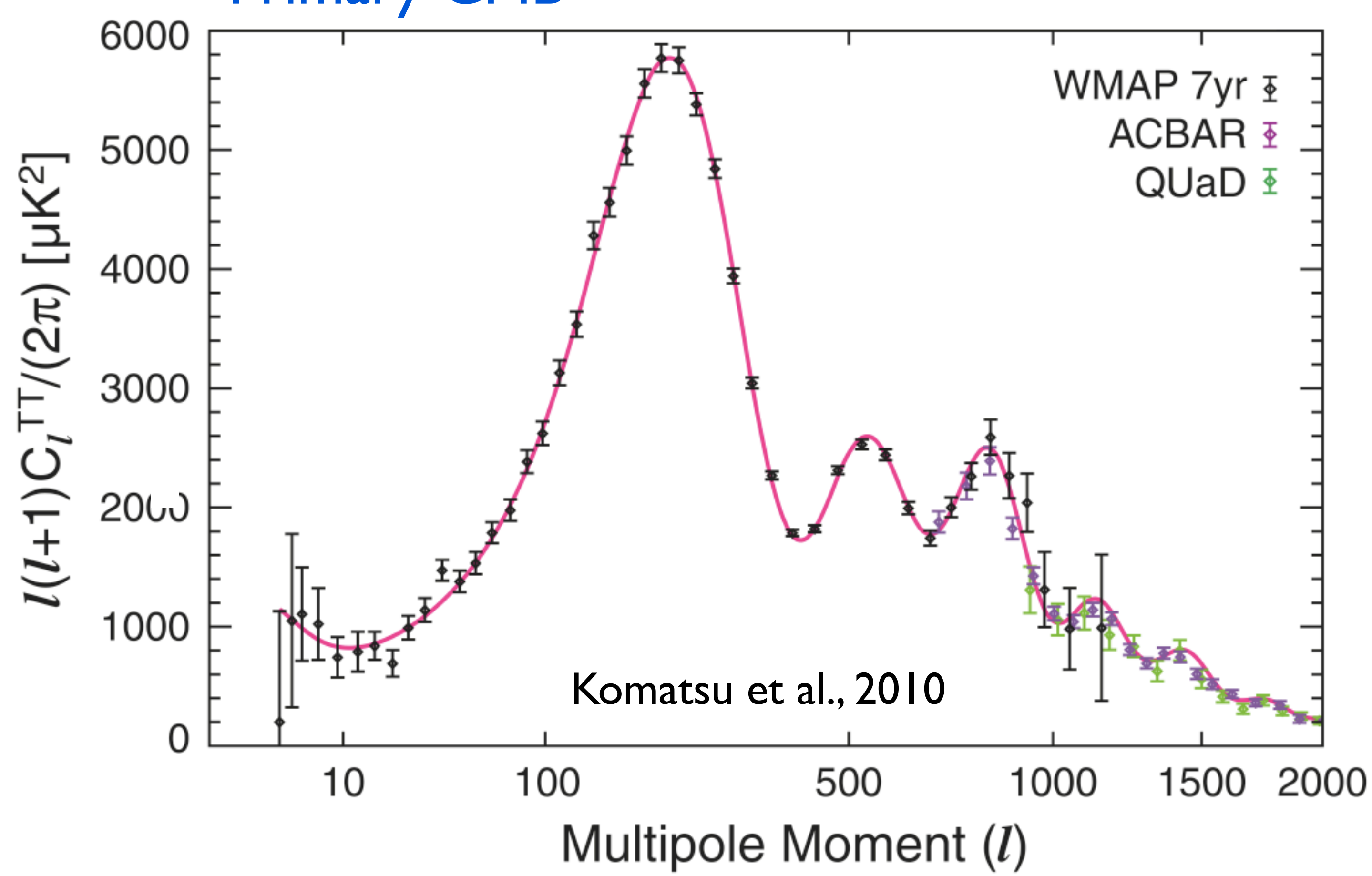
Supernovae



Baryon Acoustic Oscillations



Primary CMB

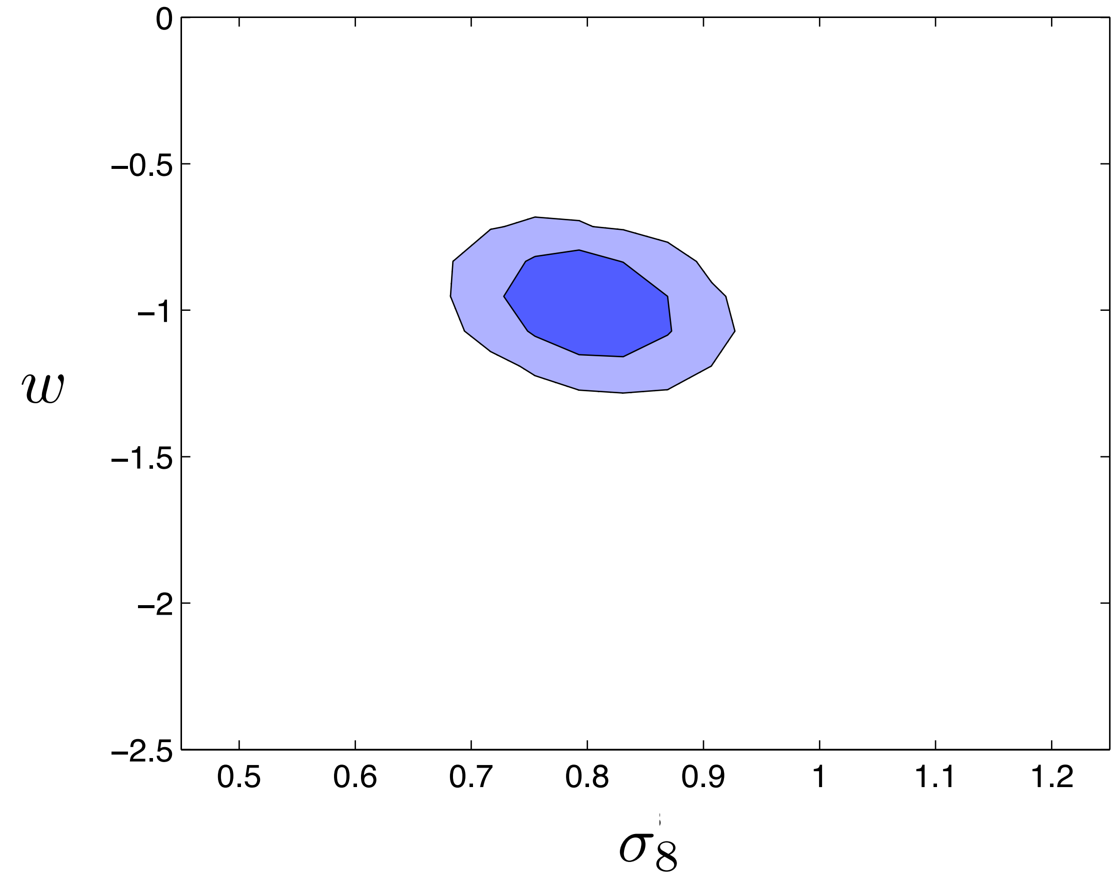


Cosmological Parameters

WMAP, BAO, and SN provide rulers to measure the Universe's expansion rate

From the expansion rate we can determine the Universe's age, baryon content, dark matter content, dark energy content, and other parameters

WMAP 7 + BAO + SN



Two very interesting parameters are:

$w = p/\rho$ = equation of state of dark energy

σ_8 = rms mass density fluctuations in 8 h^{-1} Mpc spheres today

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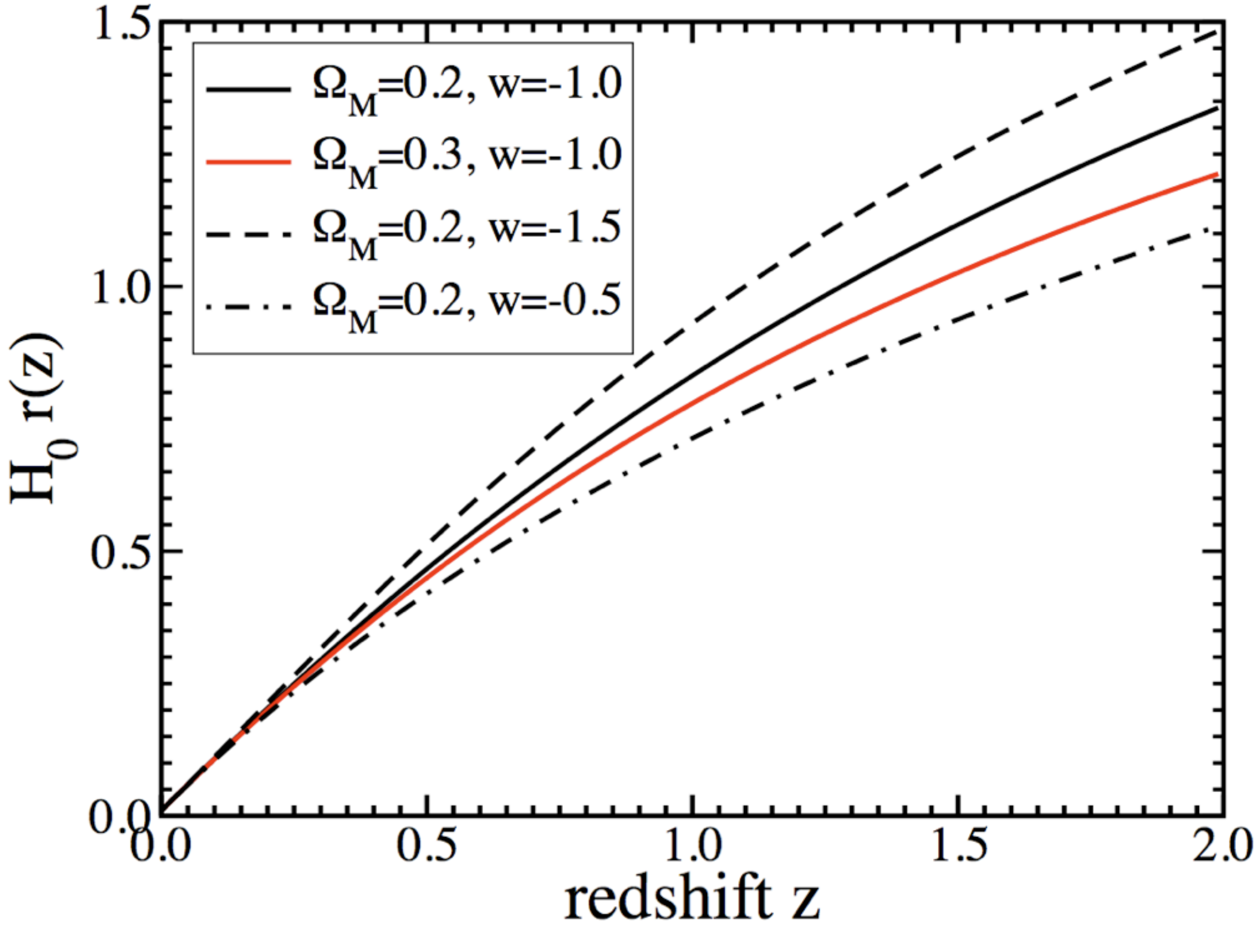
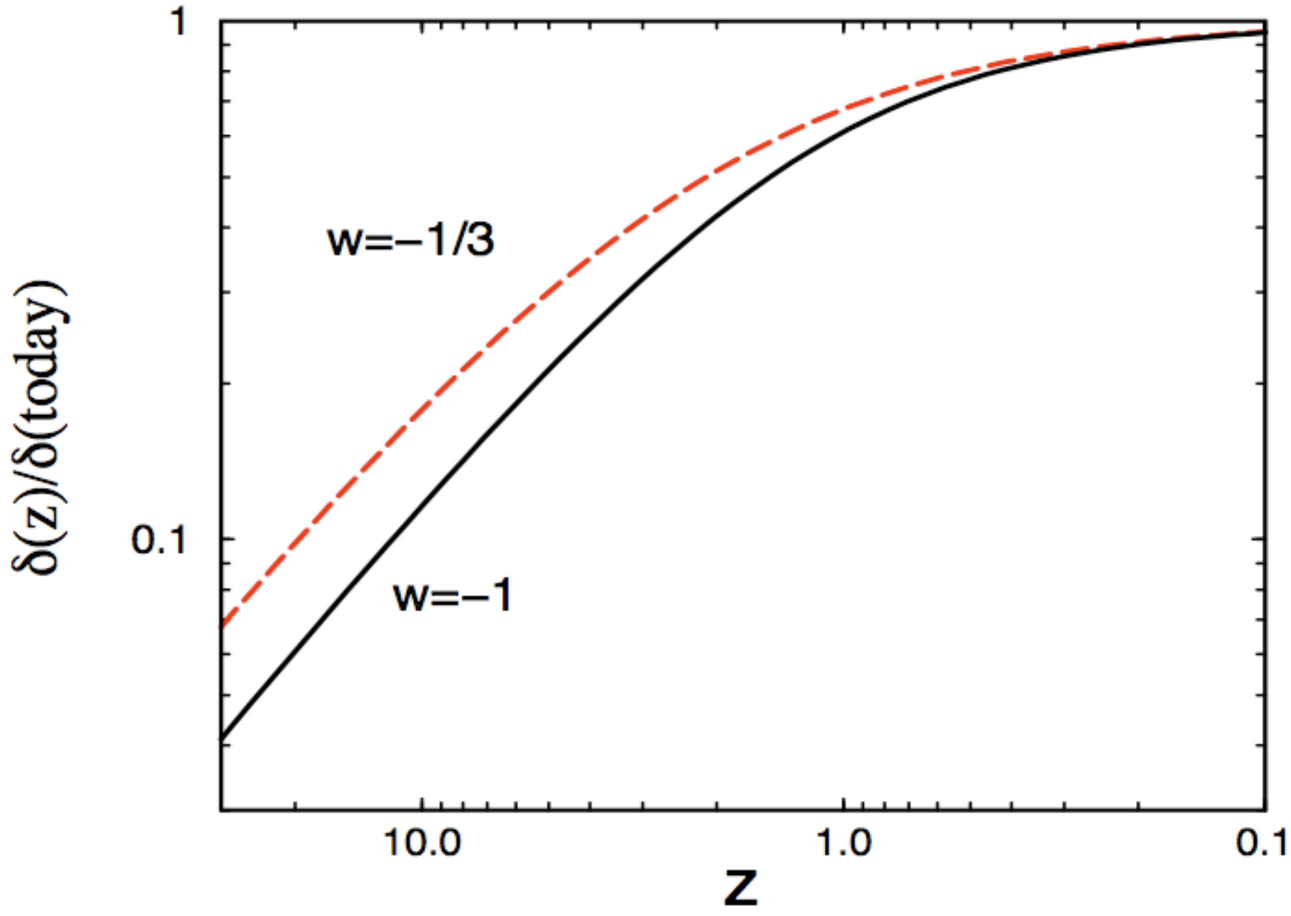
Two Different Types of Probes of Cosmology

Expansion rate



Growth of Structure



Frieman, Turner, Huterer, ARA&A 2008

Expansion rate probes (e.g. CMB, SN Ia, BAO) suggest ΛCDM Universe
ΛCDM makes definitive prediction of structure growth
Look for deviations from this prediction

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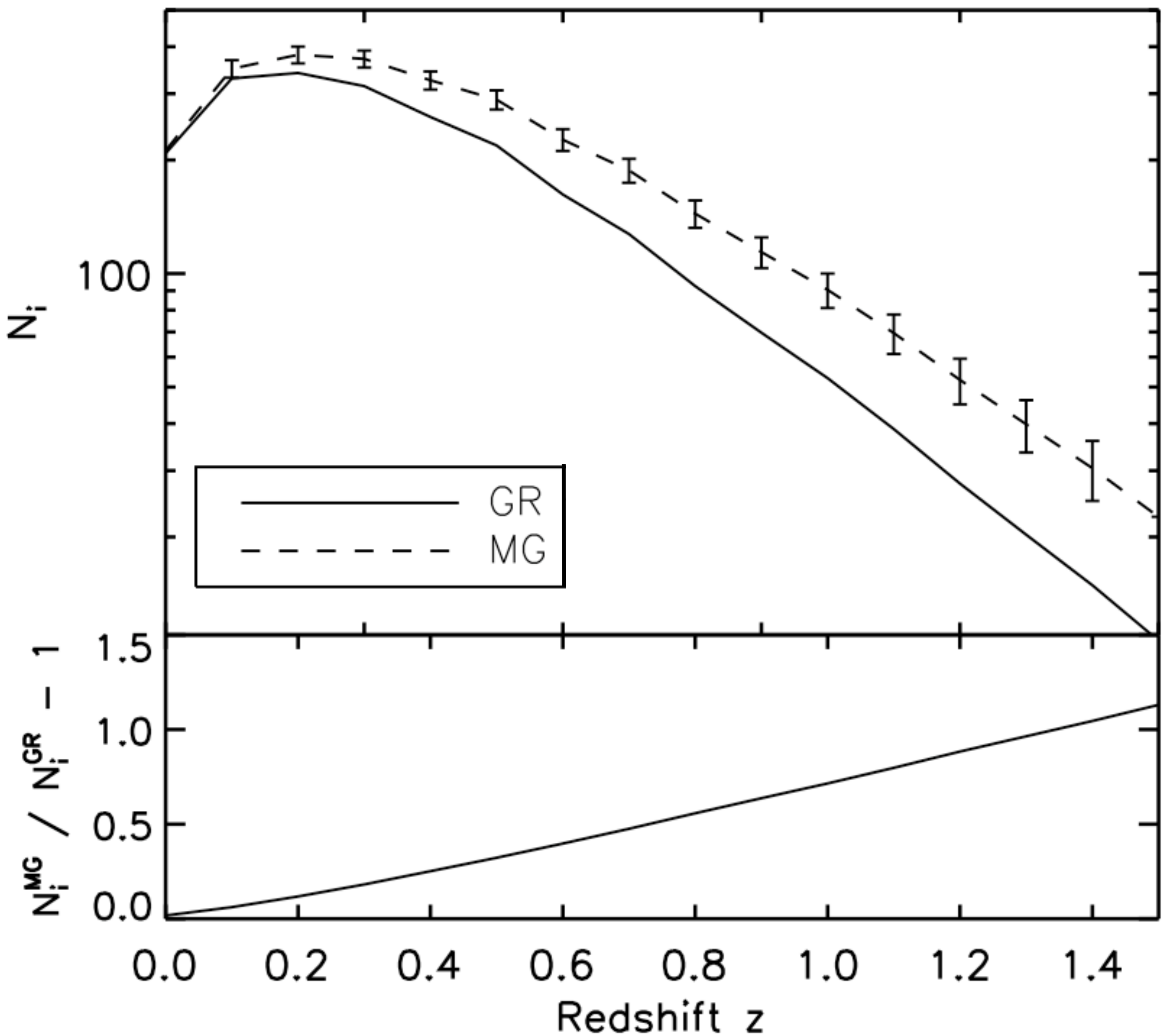
Learning about Dark Energy

One idea about the nature of dark energy is that it is indicating a breakdown of GR on large scales

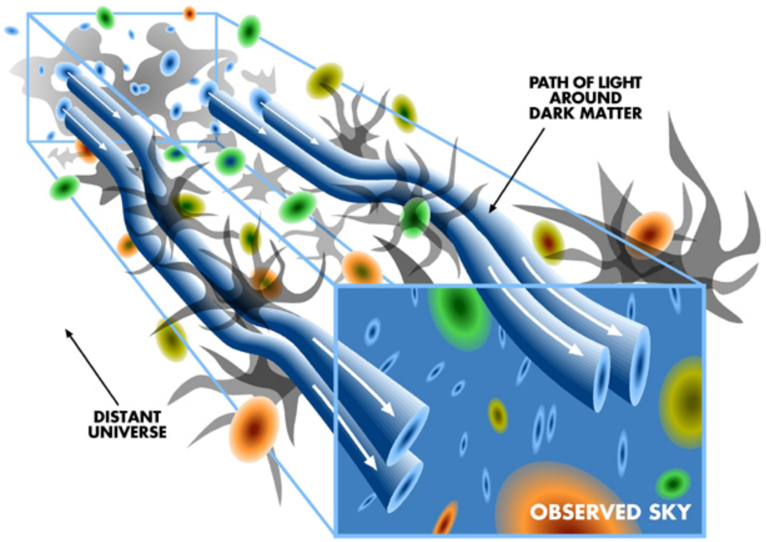
An alternative model to GR can give the same expansion rate but different growth of structure



Shapiro, Dodelson, Hoyle, Samushia, Flaugher (1004.4810)

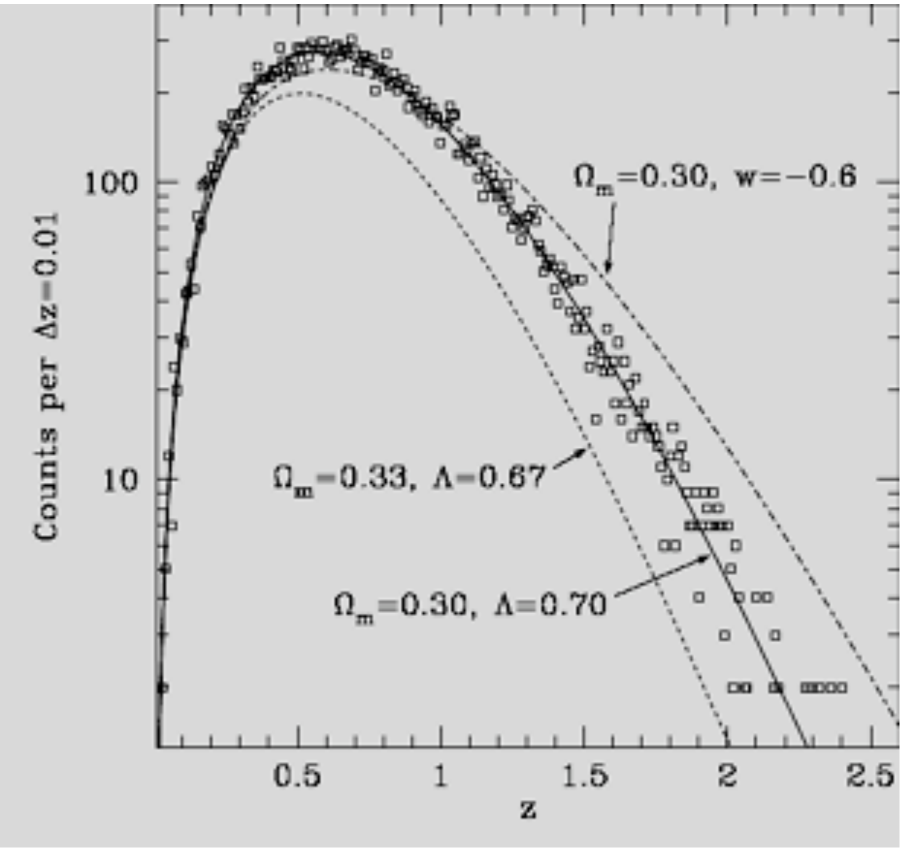
Measures of the Growth of Structure

Weak lensing



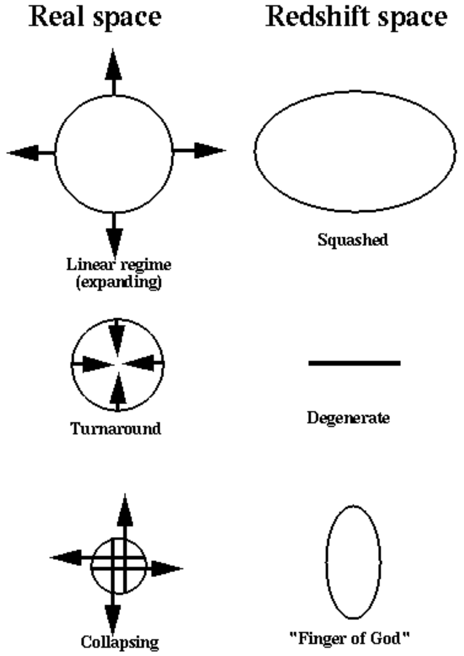
LSST website

Cluster Abundance



SPT website

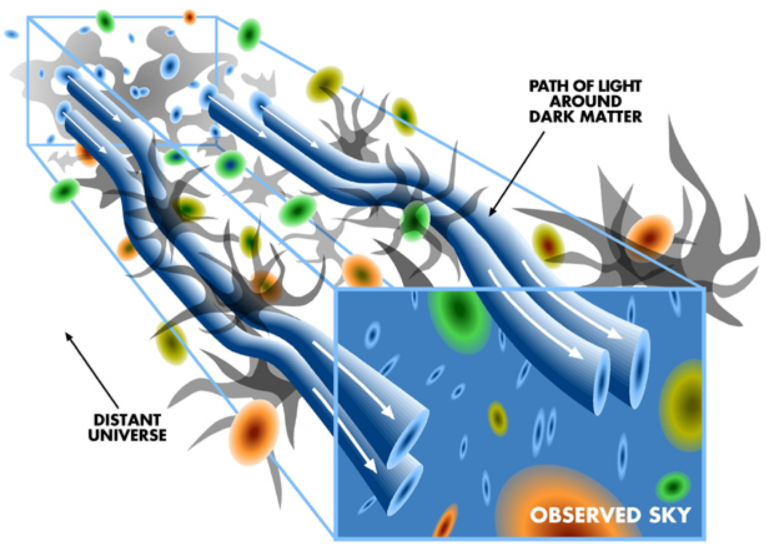
Red-shift space distortions



W. Keel

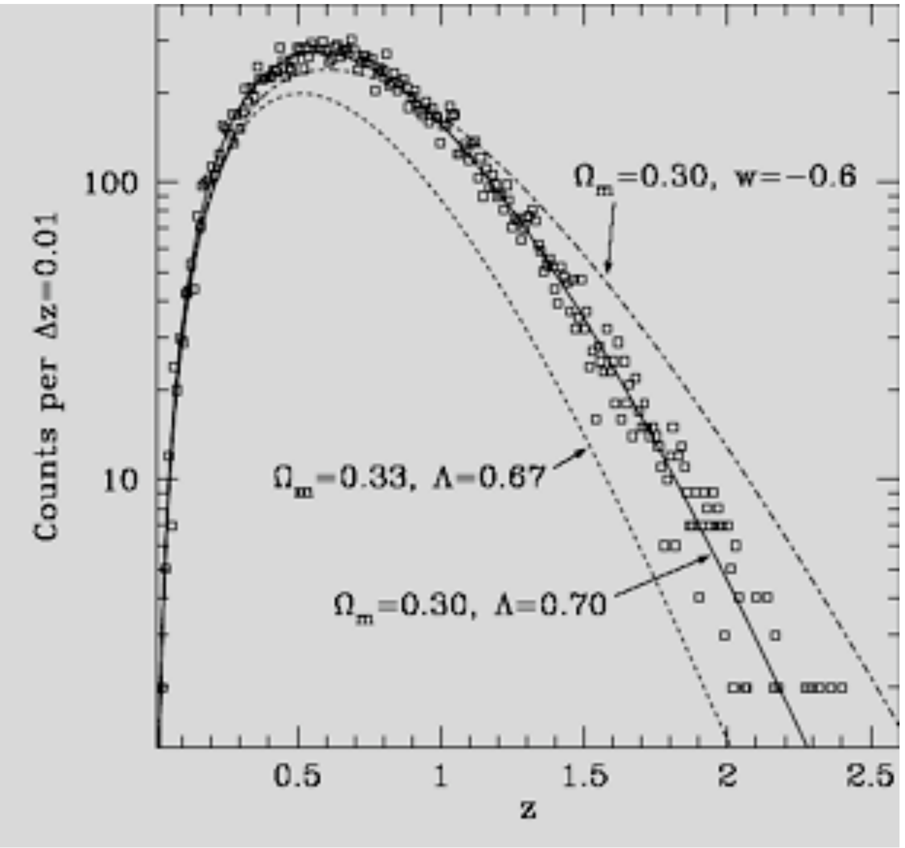
Measures of the Growth of Structure

Weak lensing



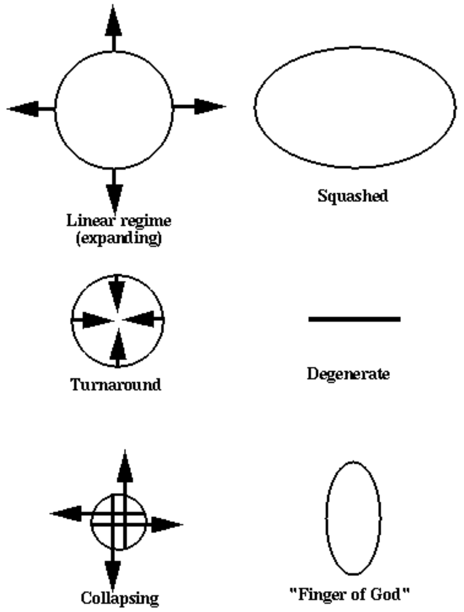
LSST website

Cluster Abundance



X-ray Optical CMB

Red-shift space distortions



W. Keel

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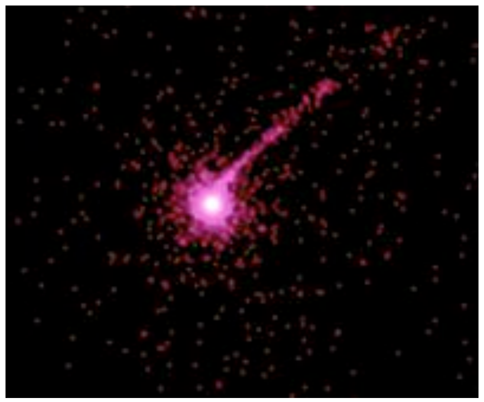
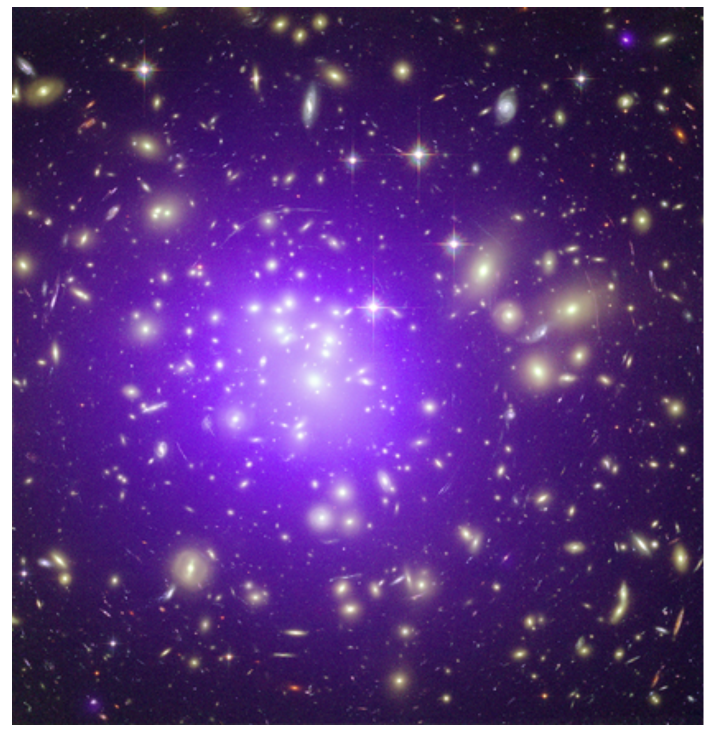
Measuring Cluster Abundance with the CMB



Radio & IR galaxies



Galaxy Cluster

z=1089
13.7 Gyr

z~2-5
10-12 Gyr

z~0.01-2
1-10 Gyr

today

Using the CMB as a backlight, study structure as it was forming
Structure formation tells us about Dark Energy

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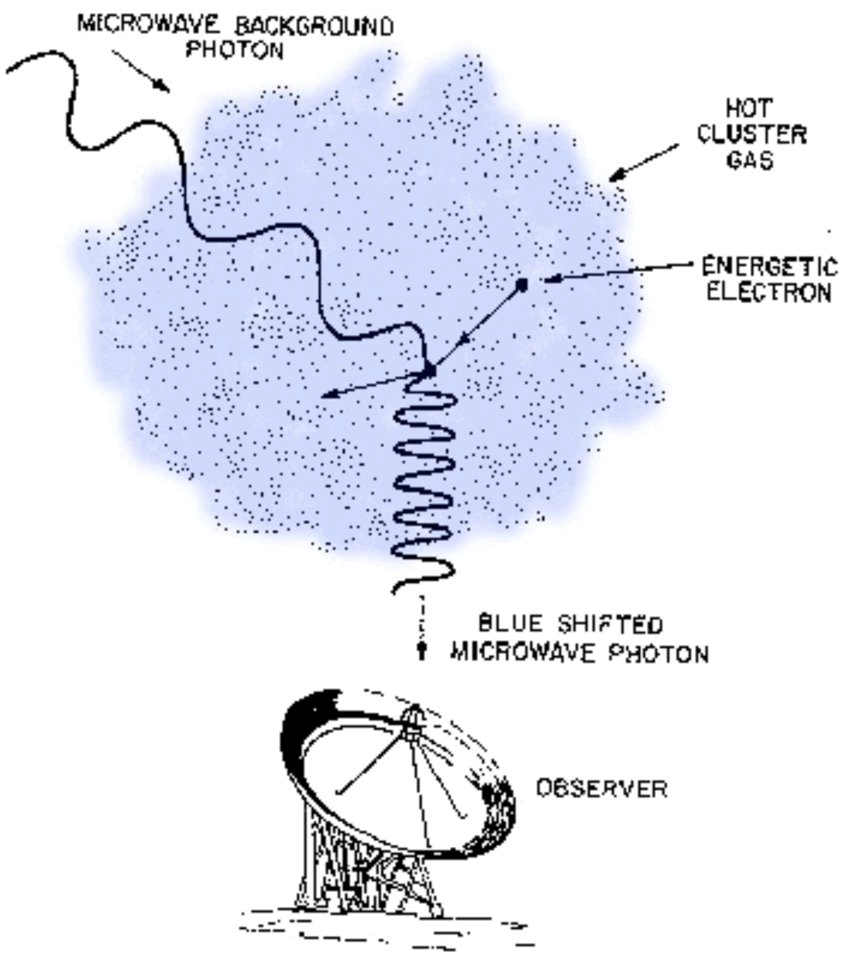
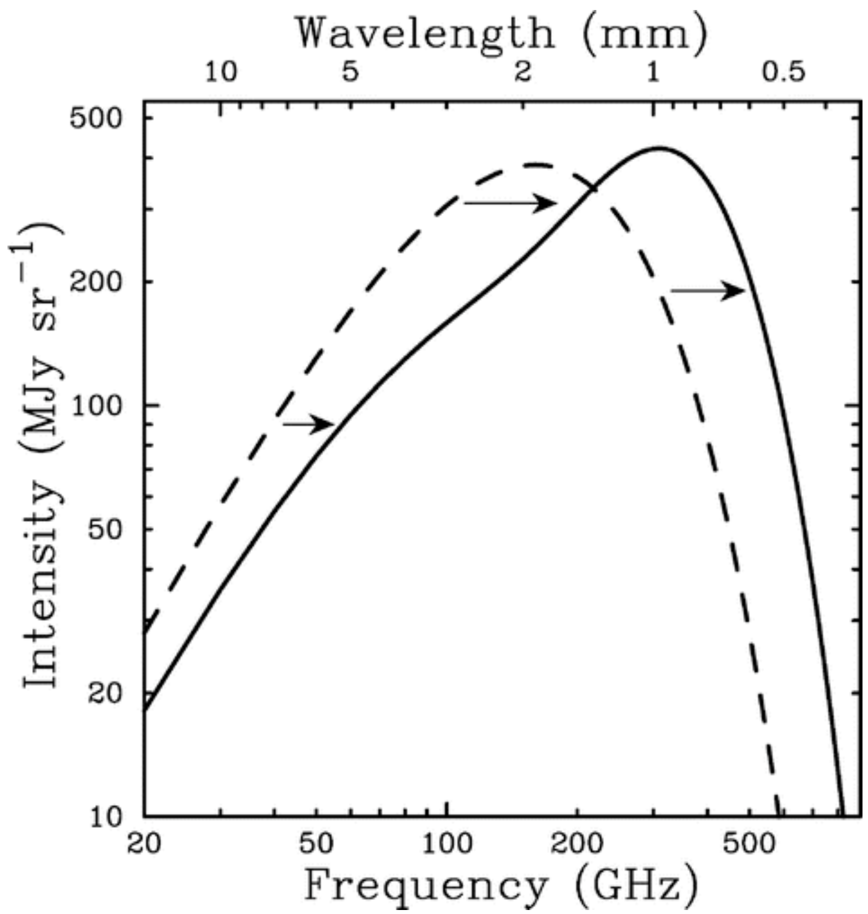
Sunyaev-Zel'dovich (SZ) Effect

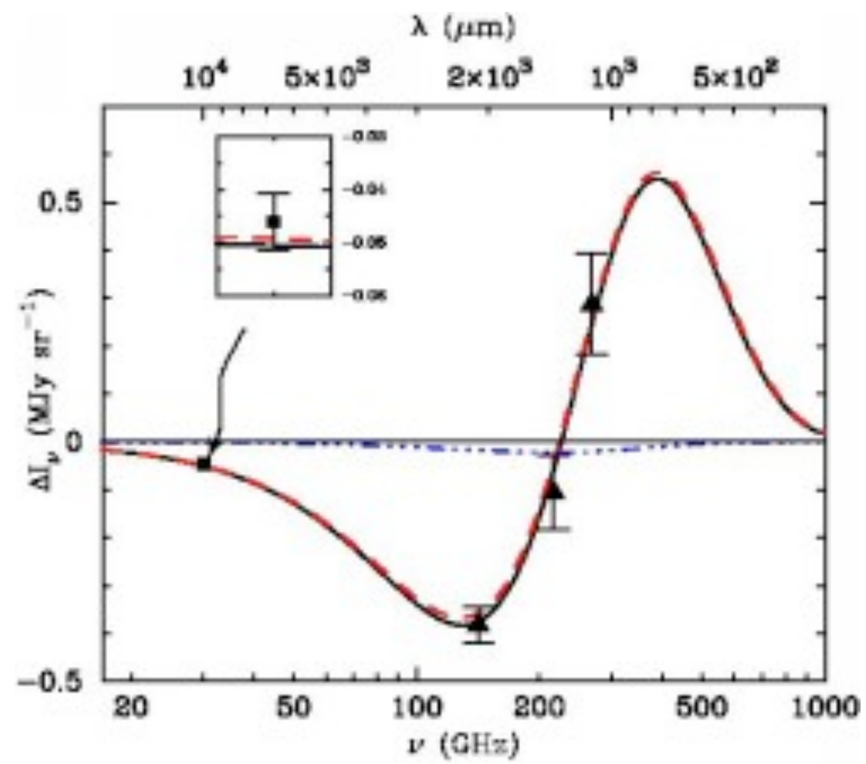
SZ signal is a fluctuation in the primary CMB caused by CMB photons getting upscattered by the hot gas in galaxy clusters



Adapted from L. Van Speybroeck



Abell 2163



Redshift independent

Amplitude of fluctuation (Y) $\propto$ cluster mass

Carlstrom et al., ARA&A vol 40, pg 643, 2002

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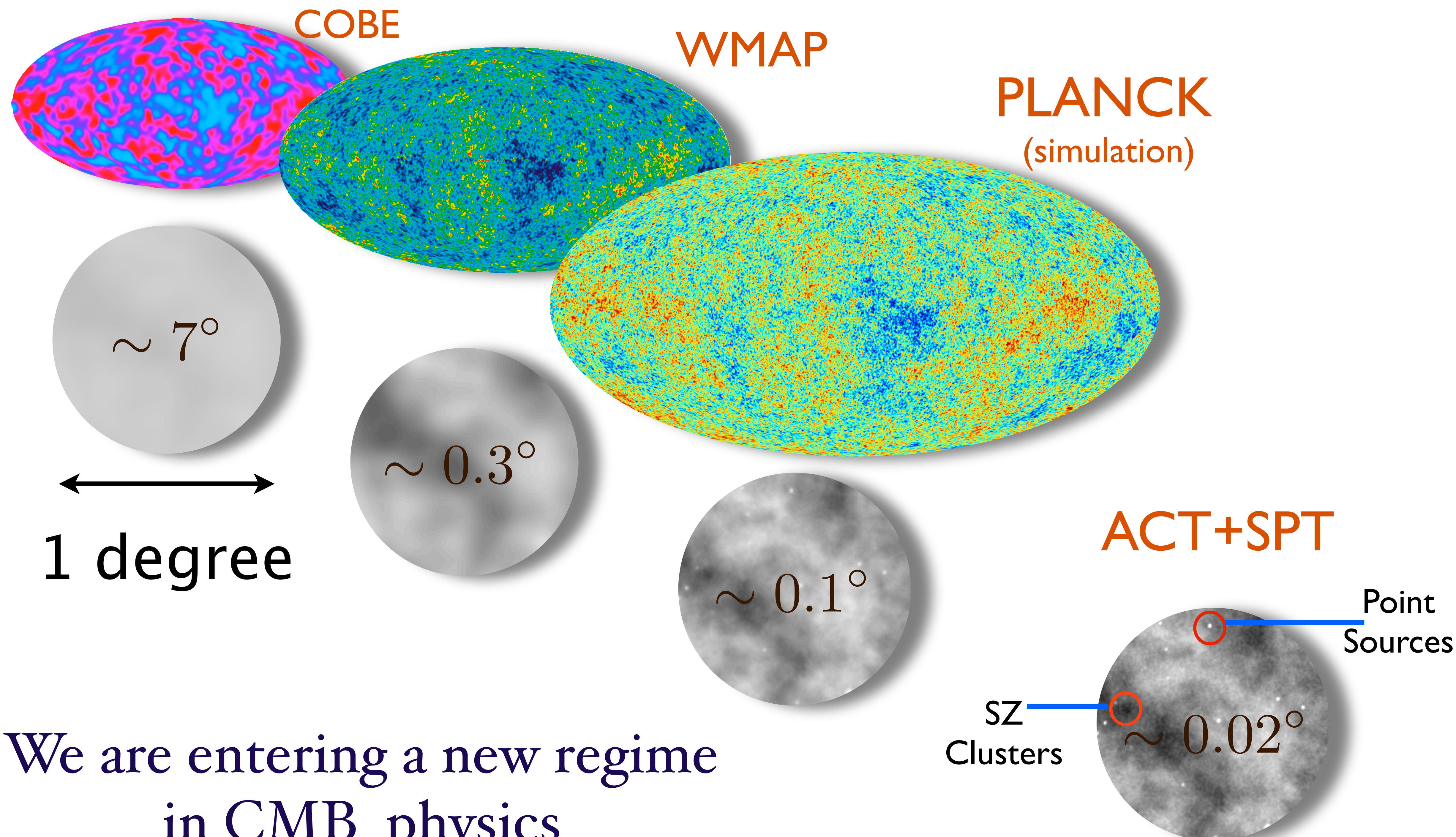
New Generation of Microwave Observations



We are entering a new regime in CMB physics

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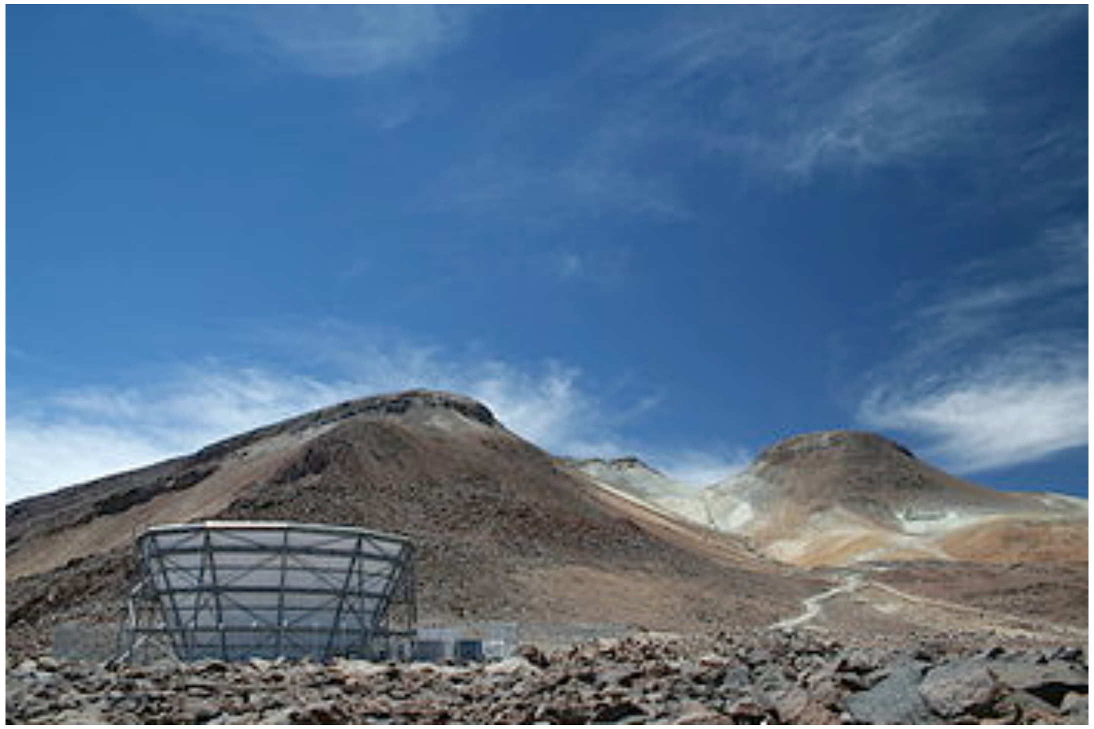
ACT and SPT



Atacama Cosmology Telescope (ACT)
in the Atacama desert in Chile.

South Pole Telescope (SPT)
at the South Pole.

Main institutions:
Princeton, U. Penn, Rutgers, NIST, GSFC,
U. of Toronto, U. of British Columbia,
U. of KwaZulu-Natal, U. Catolica, Oxford

Main institutions:
U. of Chicago, U.C. Berkeley, Case
Western, C.U. Boulder, Harvard-CfA,
Jet Propulsion Lab, U.C. Davis, McGill

Overview

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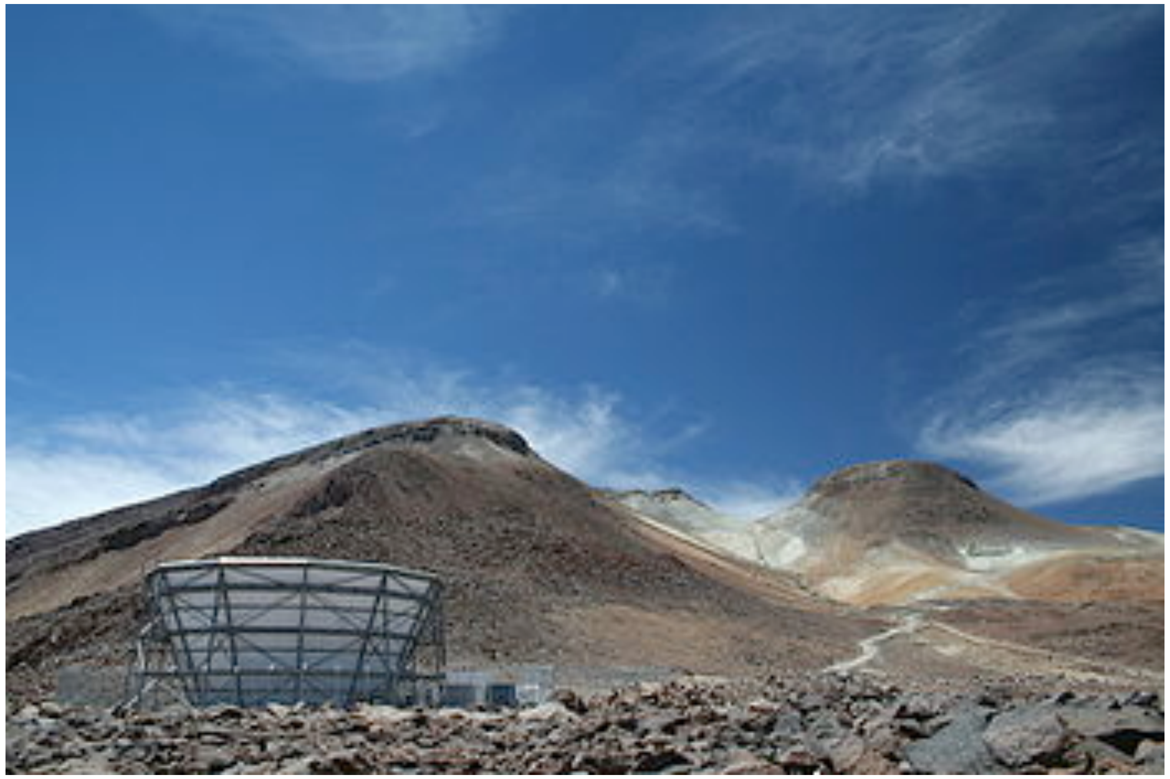
- First Cosmology Constraints from Atacama Cosmology Telescope Cluster Sample
- Implications for Fundamental Physics and Astrophysics and Future Prospects

Atacama Cosmology Telescope

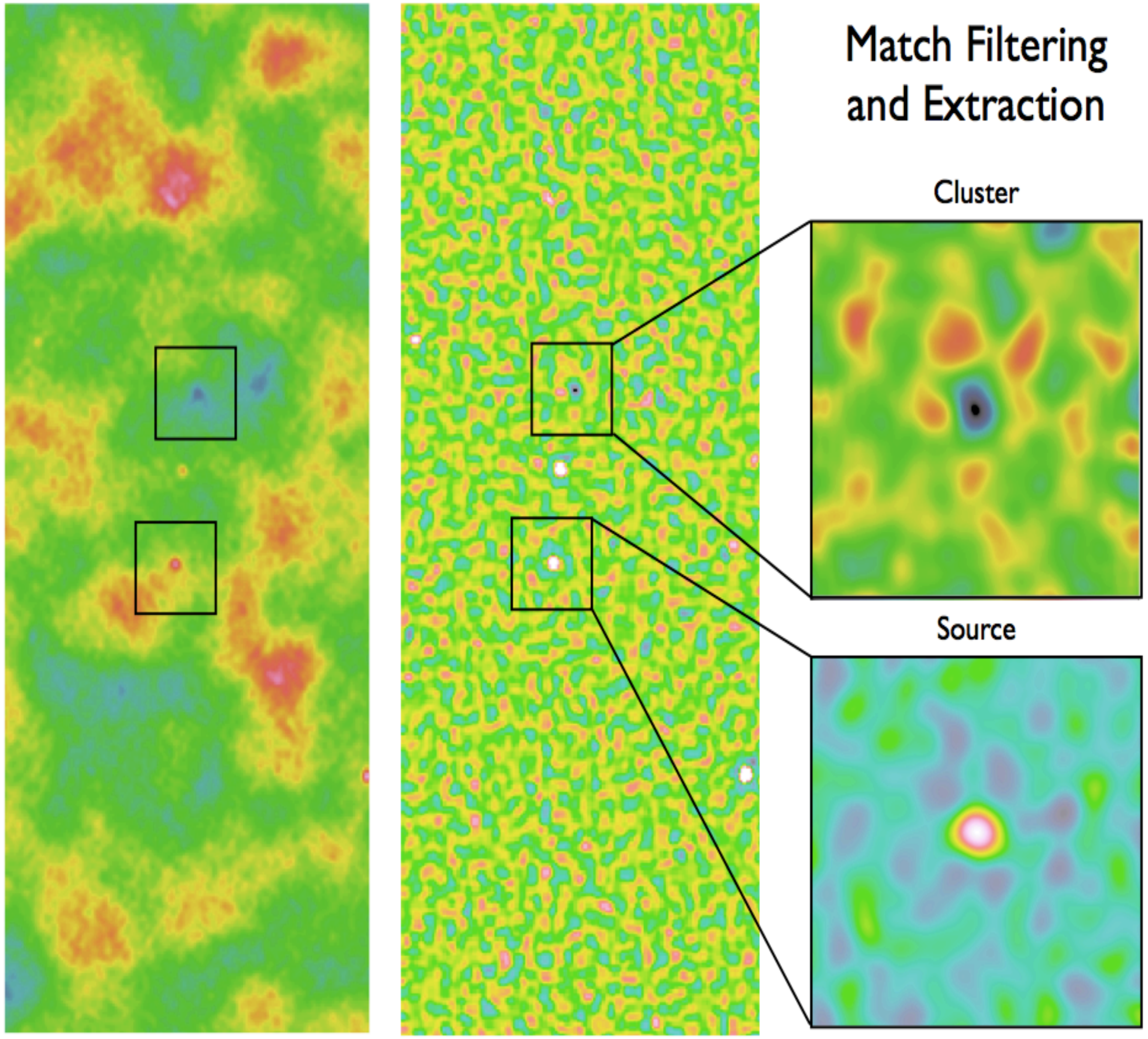


Atacama Cosmology Telescope (ACT) in the Atacama desert in Chile.

23 clusters detected
~50% are new

Marriage et al. 2010 - SZ Cluster Sample
Menanteau et al. 2010 - Optical/X-ray Analysis
Sehgal et al. 2010 - Cosmology Constraints

455 square degrees surveyed in 2008 at 148 GHz



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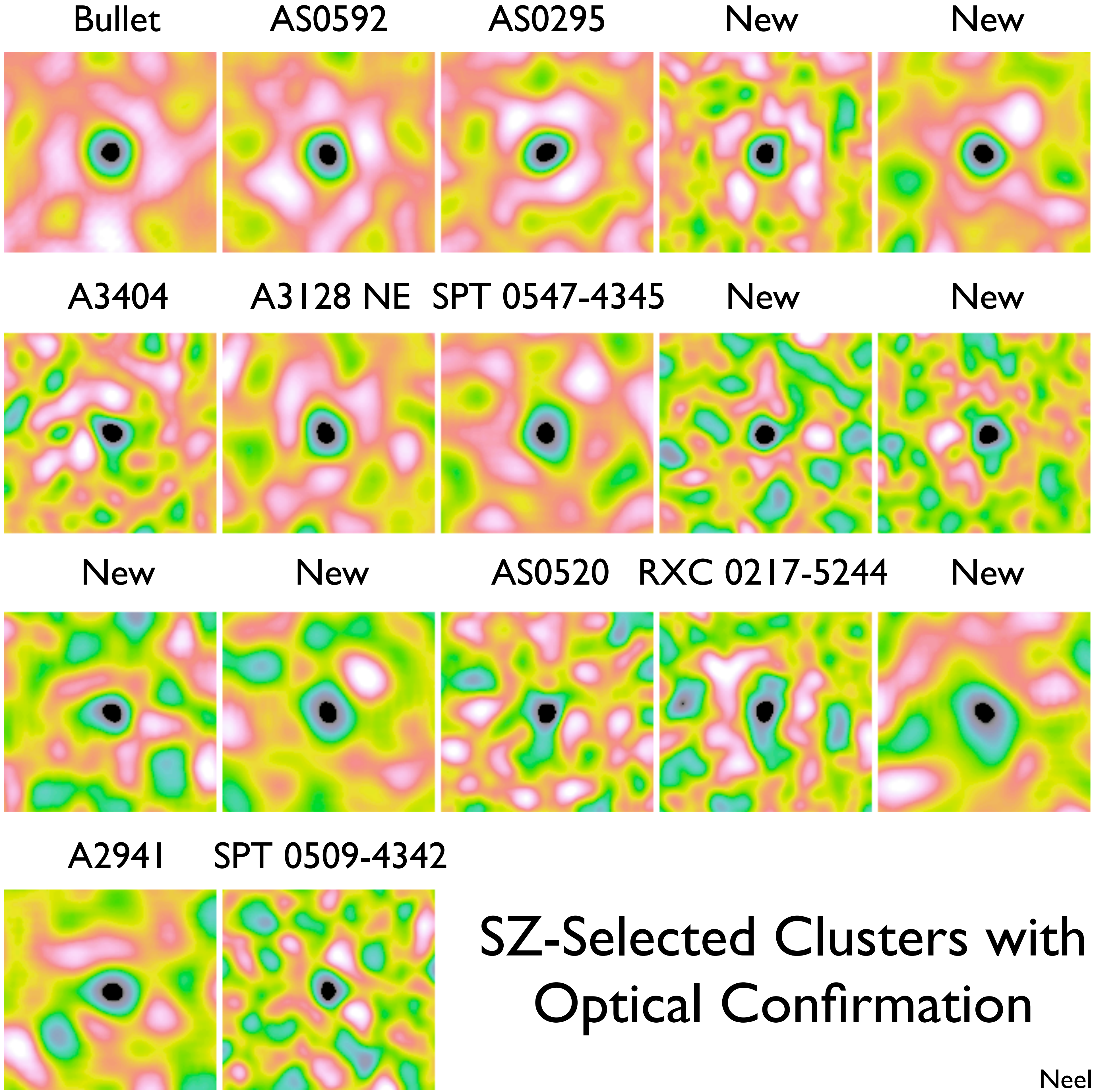

148 GHz
2008
Data

New
Cluster
Fraction:
50 %

SZ-Selected Clusters with Optical Confirmation

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ACT High-Significance Cluster Sample

9 clusters detected at greater than 5σ

From 455 square degrees observed at 148 GHz in 2008

ACT CLUSTER CATALOG FOR HIGH-SIGNIFICANCE CLUSTERS FROM THE 2008 OBSERVING SEASON

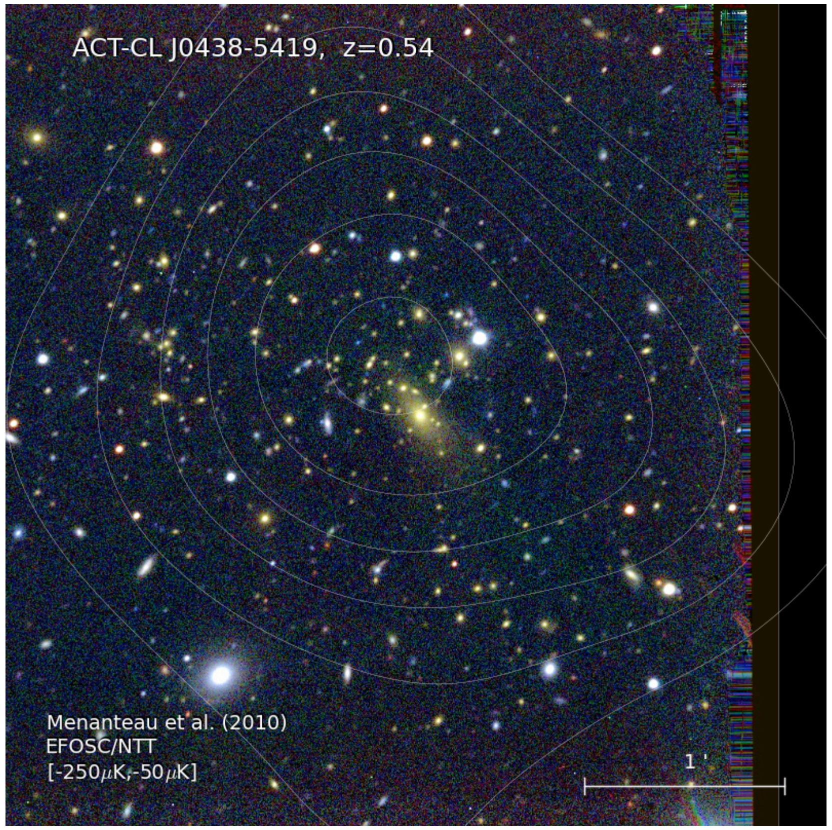
ACT Descriptor	R.A.	decl.	$yT_{CMB}(\mu K)^{\dagger}$	Redshift	Other Name
ACT-CL J0645–5413	06:45:30	–54:13:39	340 ± 60	0.167[a]	Abell 3404
ACT-CL J0638–5358	06:38:46	–53:58:45	540 ± 60	0.222[a]	Abell S0592
ACT-CL J0658–5557	06:58:30	–55:57:04	560 ± 60	0.296[b]	1ES0657–558(Bullet)
ACT-CL J0245–5302	02:45:33	–53:02:04	475 ± 60	0.300[c]	Abell S0295
ACT-CL J0330–5227	03:30:54	–52:28:04	380 ± 60	0.440[d]	Abell 3128(NE)
ACT-CL J0438–5419	04:38:19	–54:19:05	420 ± 60	0.54 ± 0.05[e]	New
ACT-CL J0616–5227	06:16:36	–52:27:35	360 ± 60	0.71 ± 0.10[e]	New
ACT-CL J0102–4915	01:02:53	–49:15:19	490 ± 60	0.75 ± 0.04[e]	New
ACT-CL J0546–5345	05:46:37	–53:45:32	310 ± 60	1.066[f]	SPT-CL 0547–5345

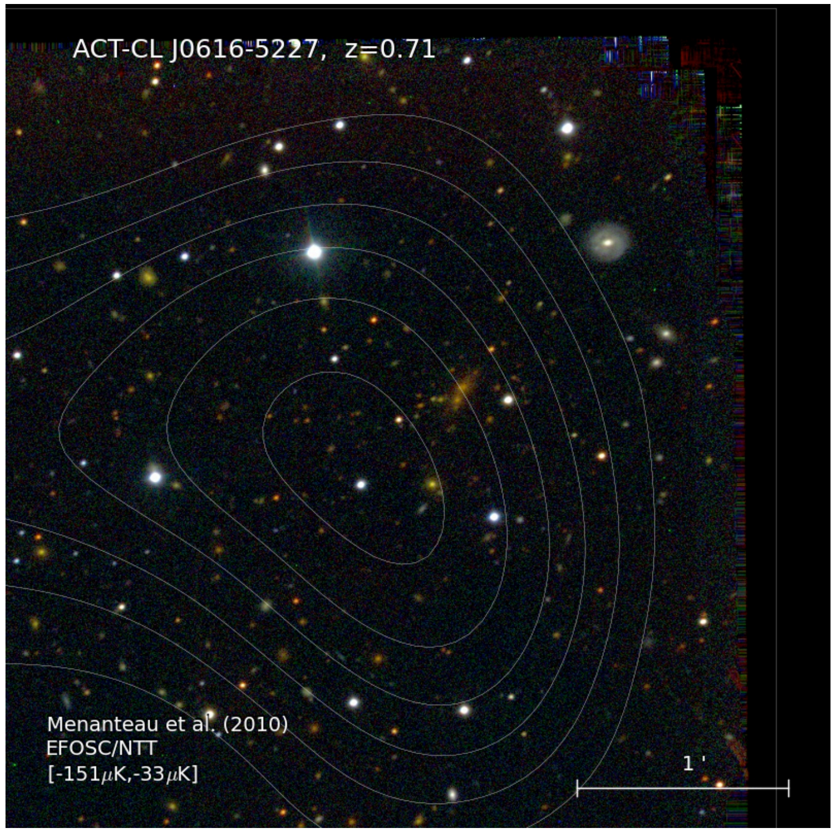
Clusters with $z > 0.5$ have been discovered with SZ

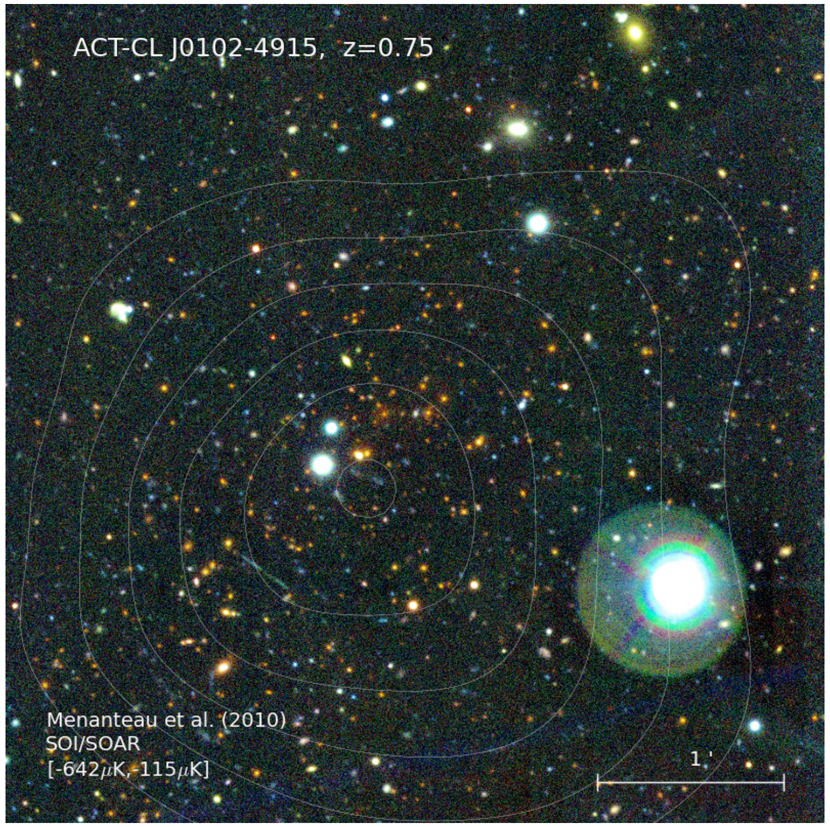
6 out of 9 clusters have spectroscopic redshifts now

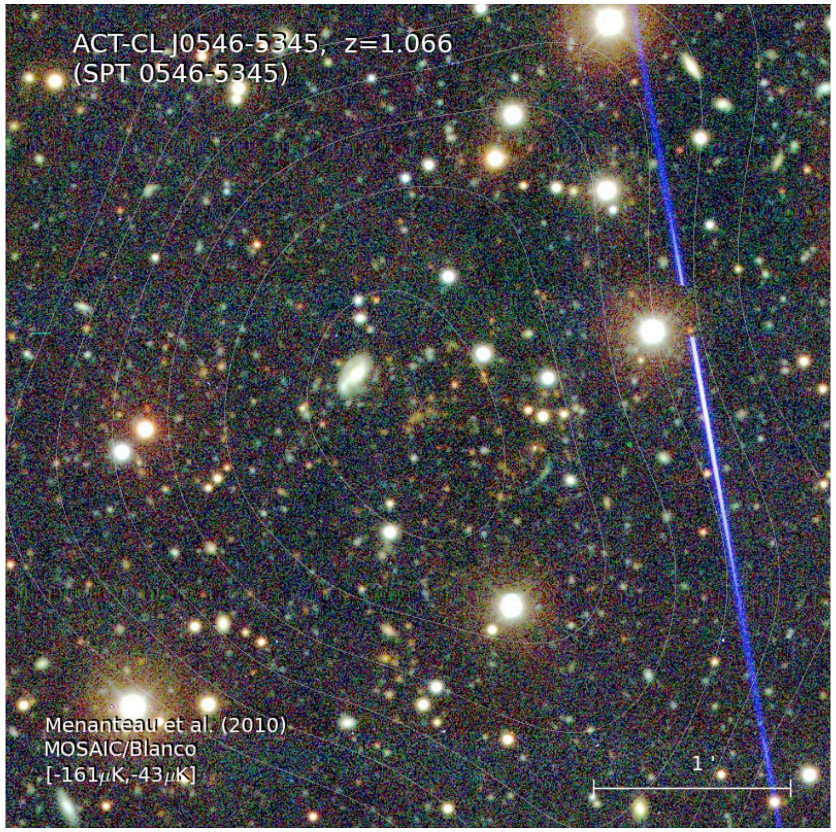
Sehgal et al., 2010, arXiv:1010.1025

High-z Clusters Discovered with SZ

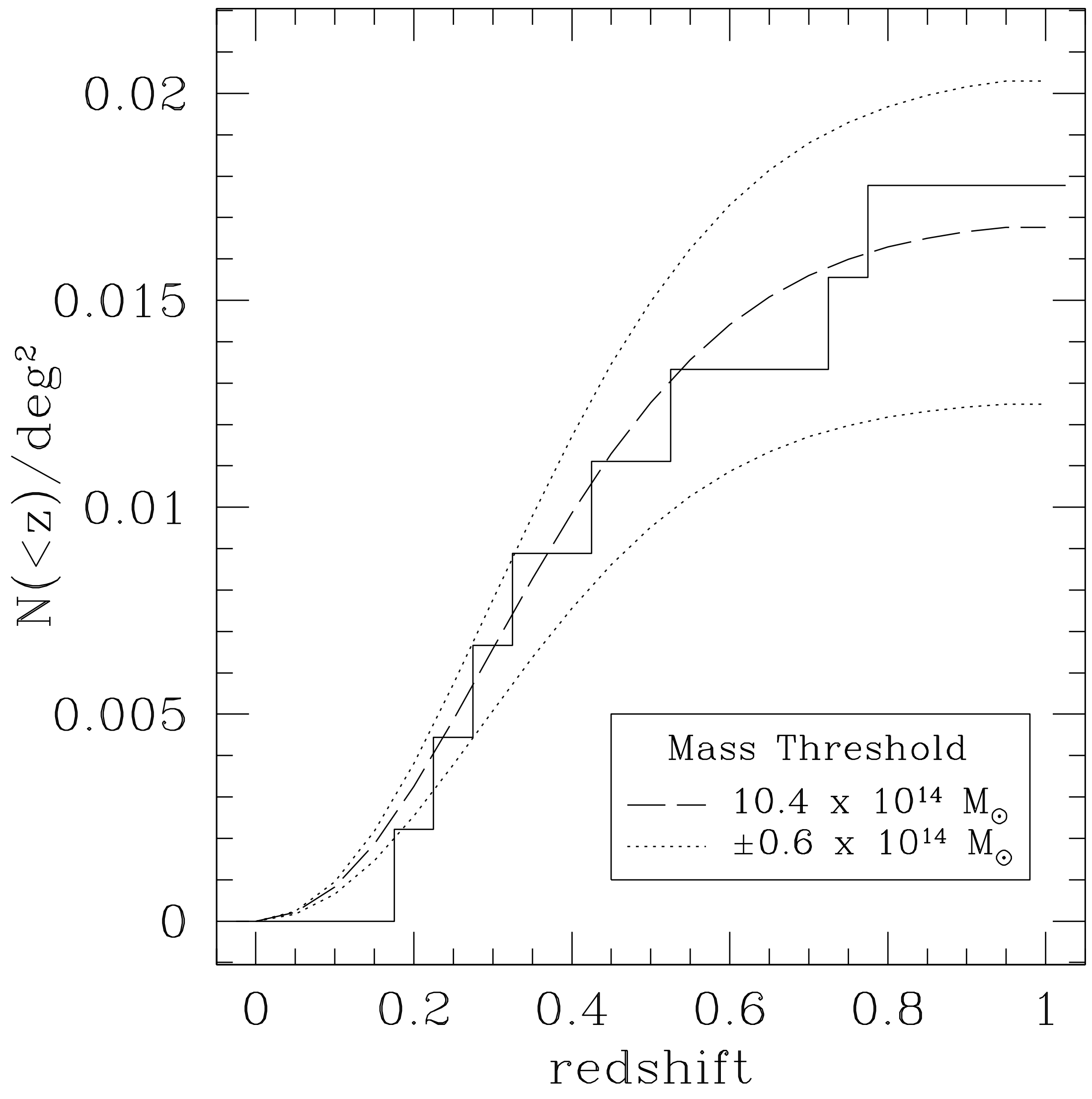








Redshift Distribution of Sample



Consistent with a mass threshold cut
(just sanity check)

Cosmology from Cluster Sample

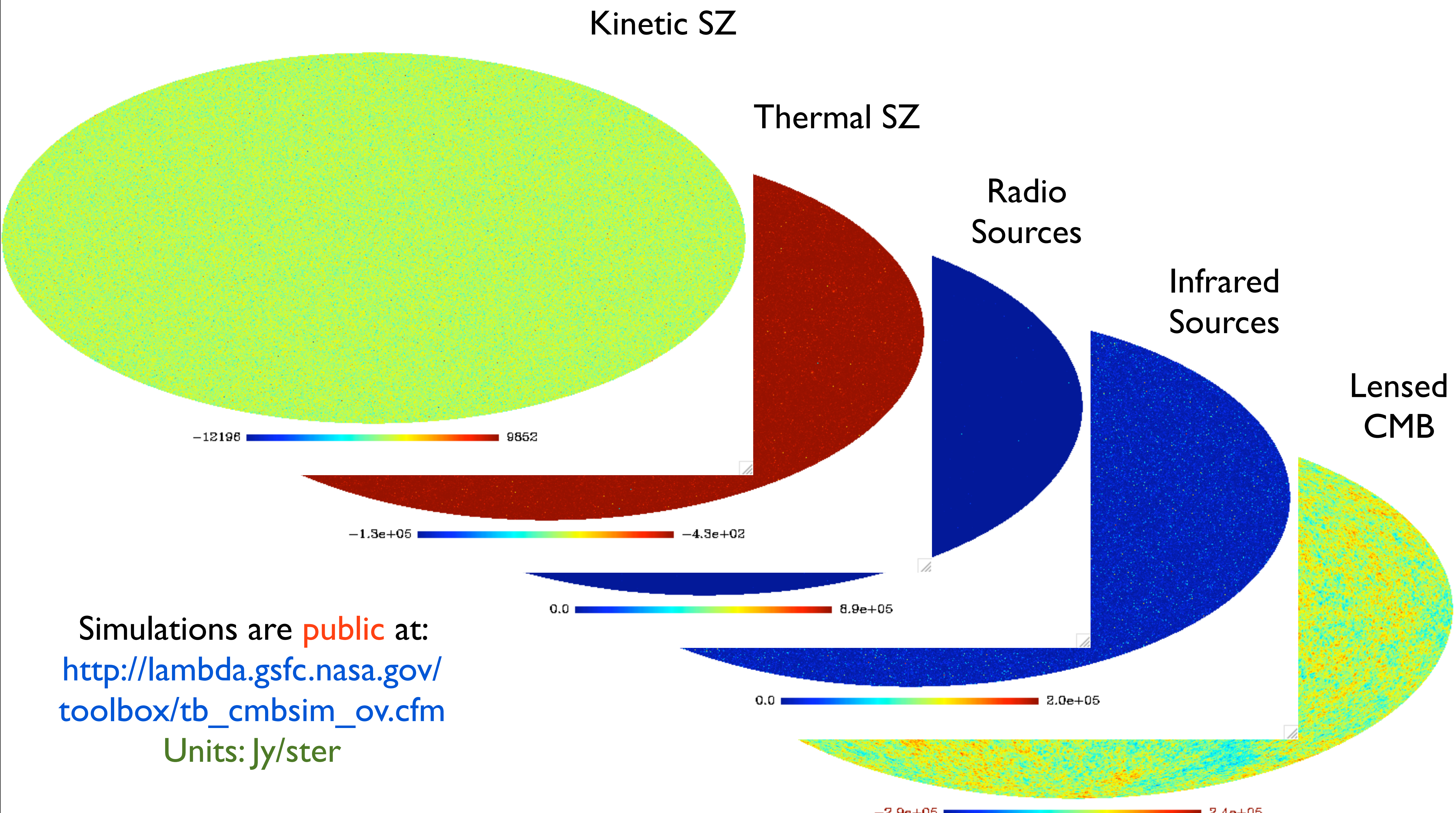
For cosmology we need:

1.) Completeness of Sample - are we missing clusters?

2.) Relation between SZ signal and mass

We answer these questions with simulations

Simulations of the Microwave Sky



Simulations are public at:
http://lambda.gsfc.nasa.gov/toolbox/tb_cmbsim_ov.cfm
Units: Jy/ster

"Simulations of the Microwave Sky"
N. Sehgal, P. Bode, S. Das, C. Hernandez-Monteagudo, K. Huffenberger, Y.-T. Lin, J. P. Ostriker, and H. Trac, 2010, ApJ, 709

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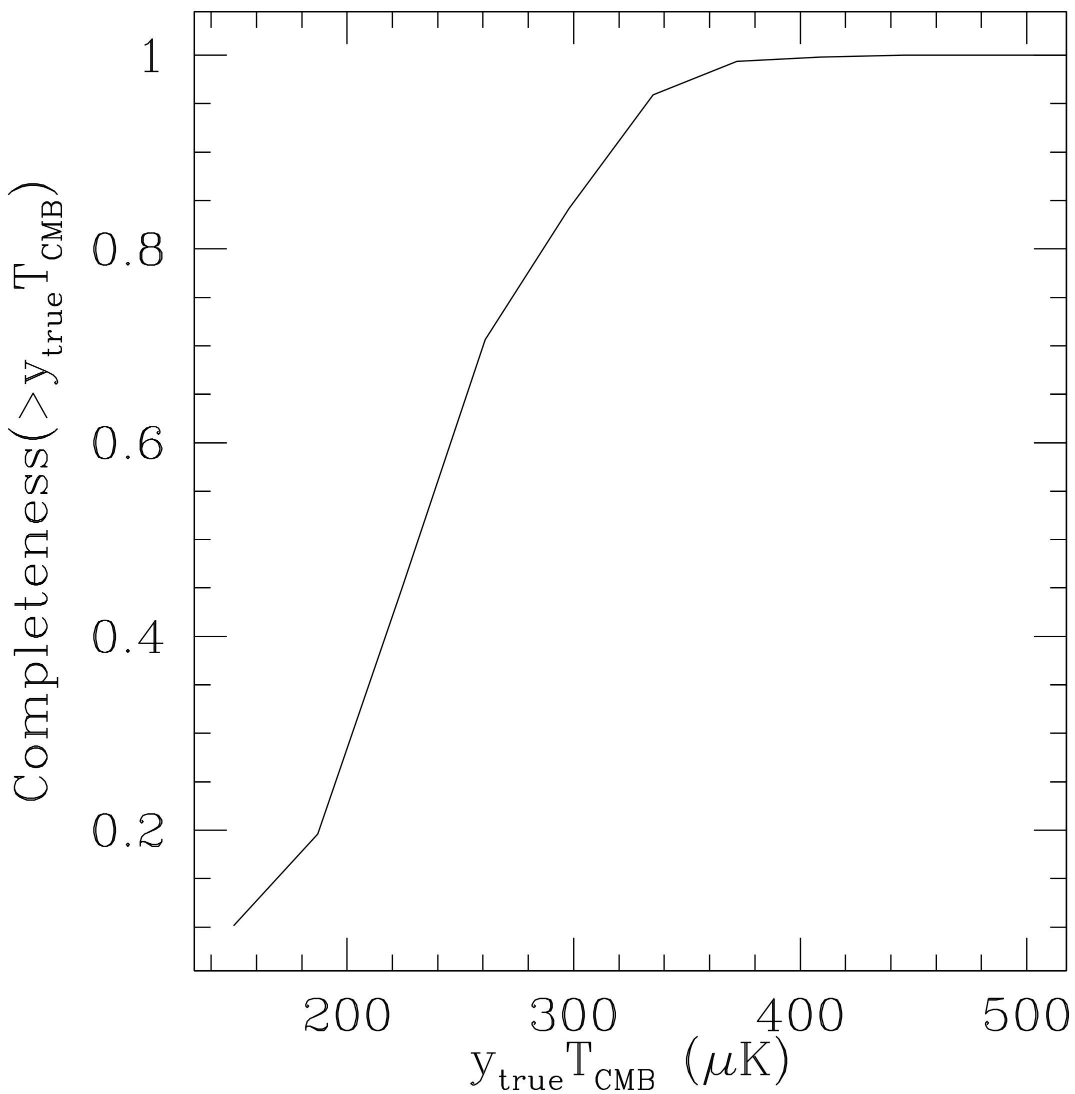
Selection Function of Sample

SZ signal of each cluster is measured in μK within a fixed aperture of 0.5 arcmin



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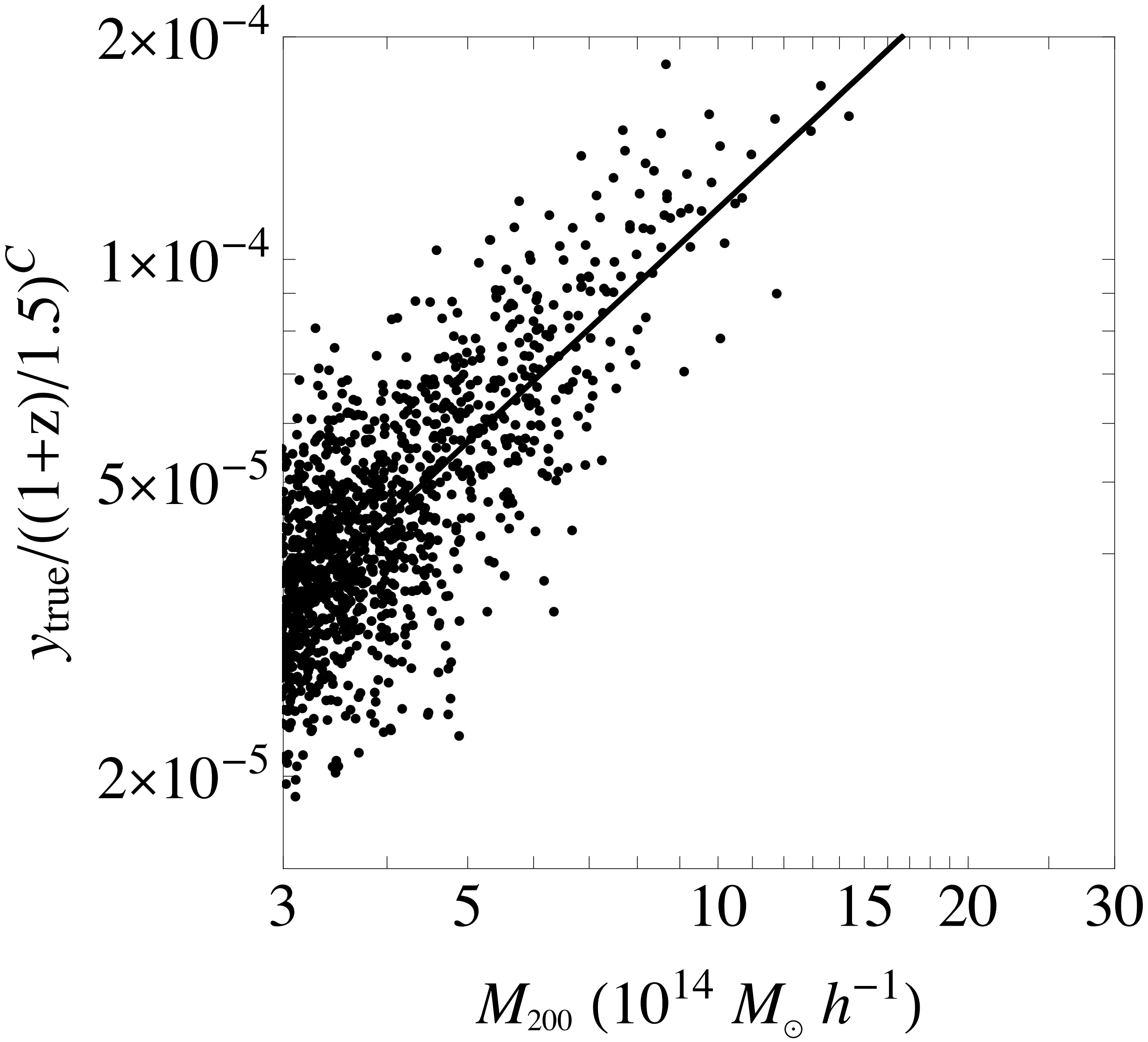
Scaling Relation Between SZ Signal and Mass



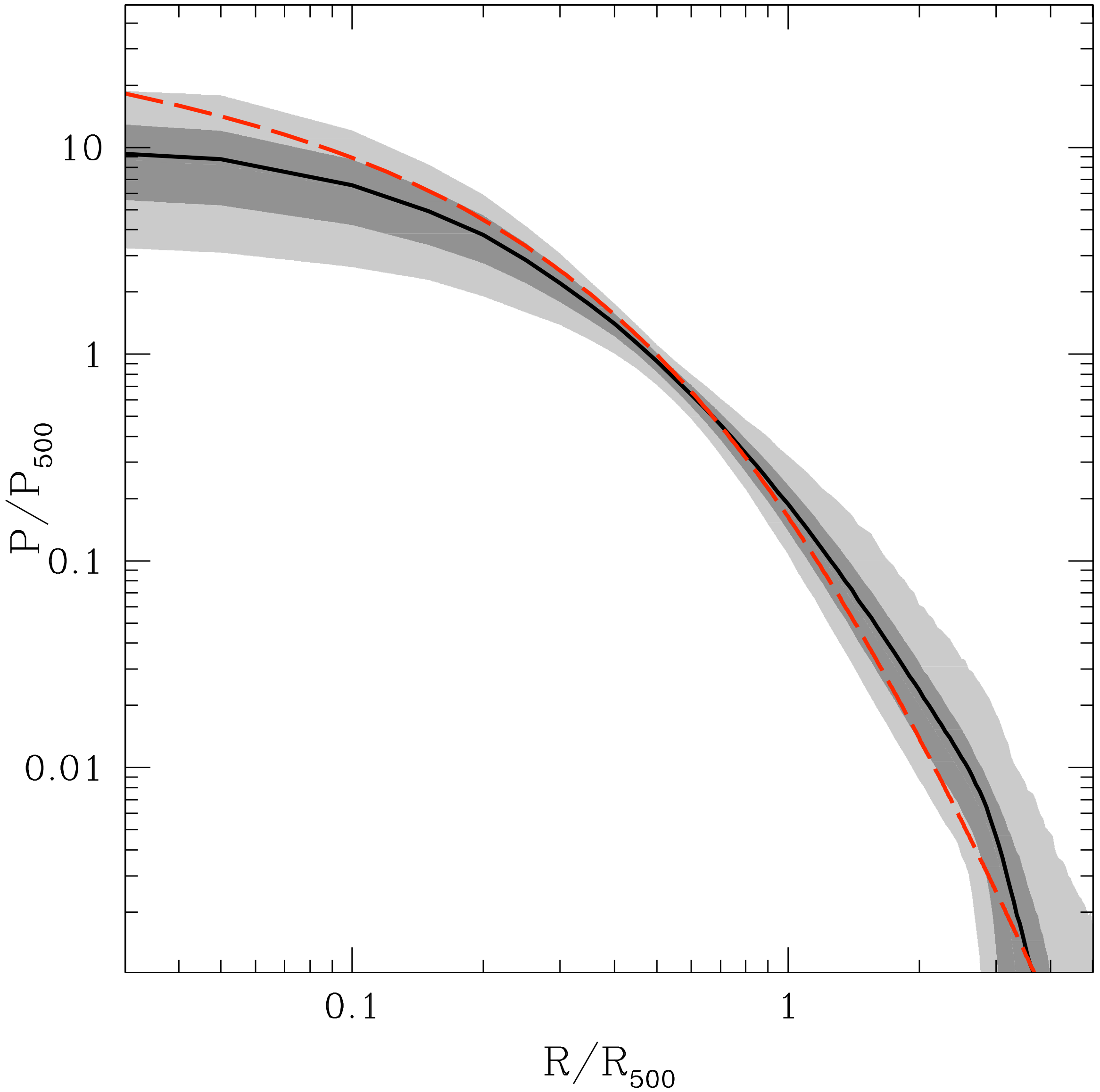
Gas model based on Bode, Ostriker, and Vikhlinin, ApJ 2009

This will be the fiducial relation

Y-M relation from simulations

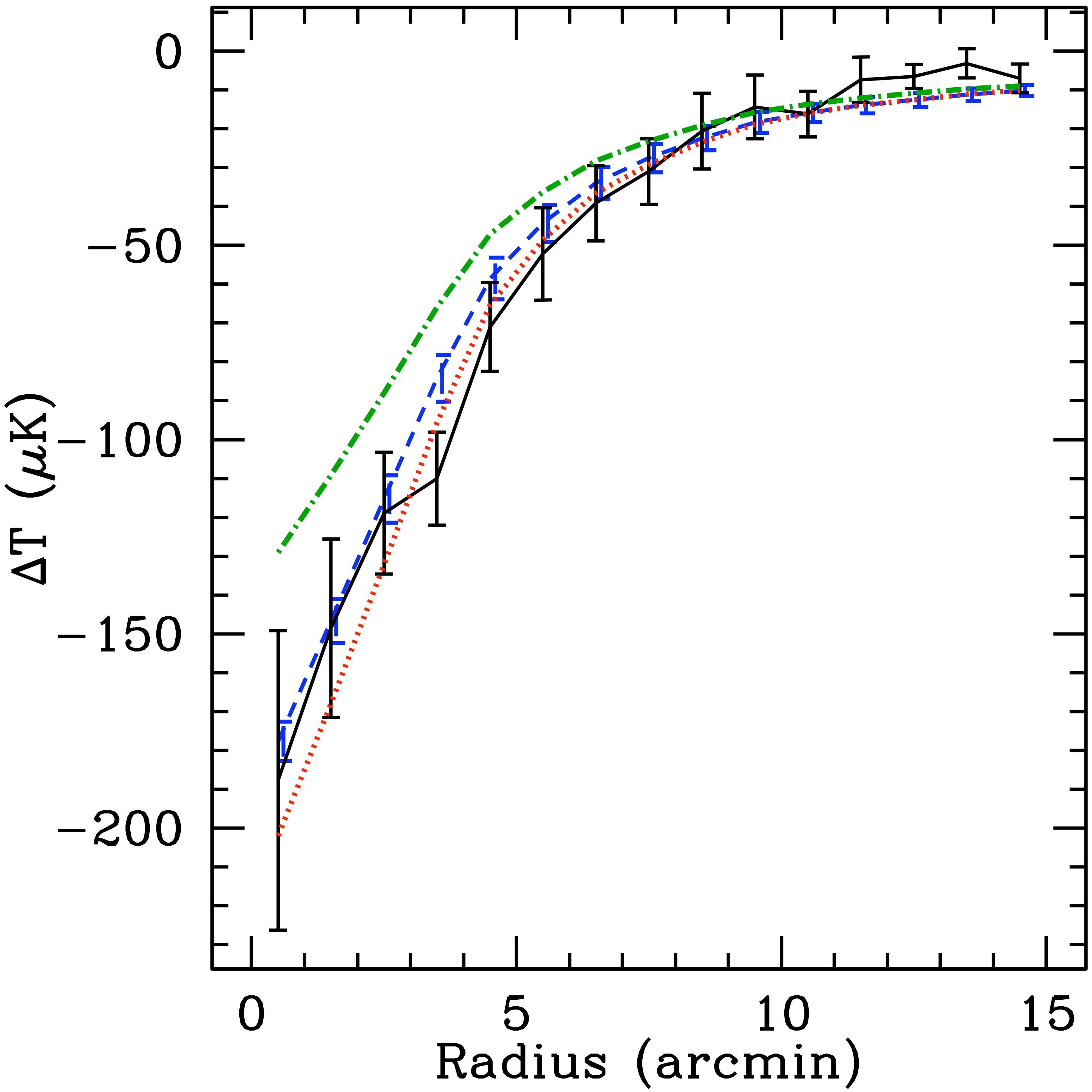
Sims are from Sehgal et al. 2010

Gas Model Calibrated by X-ray Observations



Comparison of sims (black) to X-ray data of Arnaud et al. 2010 (red)

Stacking the High-Significance SZ Clusters



Data (9 clusters)
Sim fiducial model
Sim nonthermal model
Sim adiabatic model

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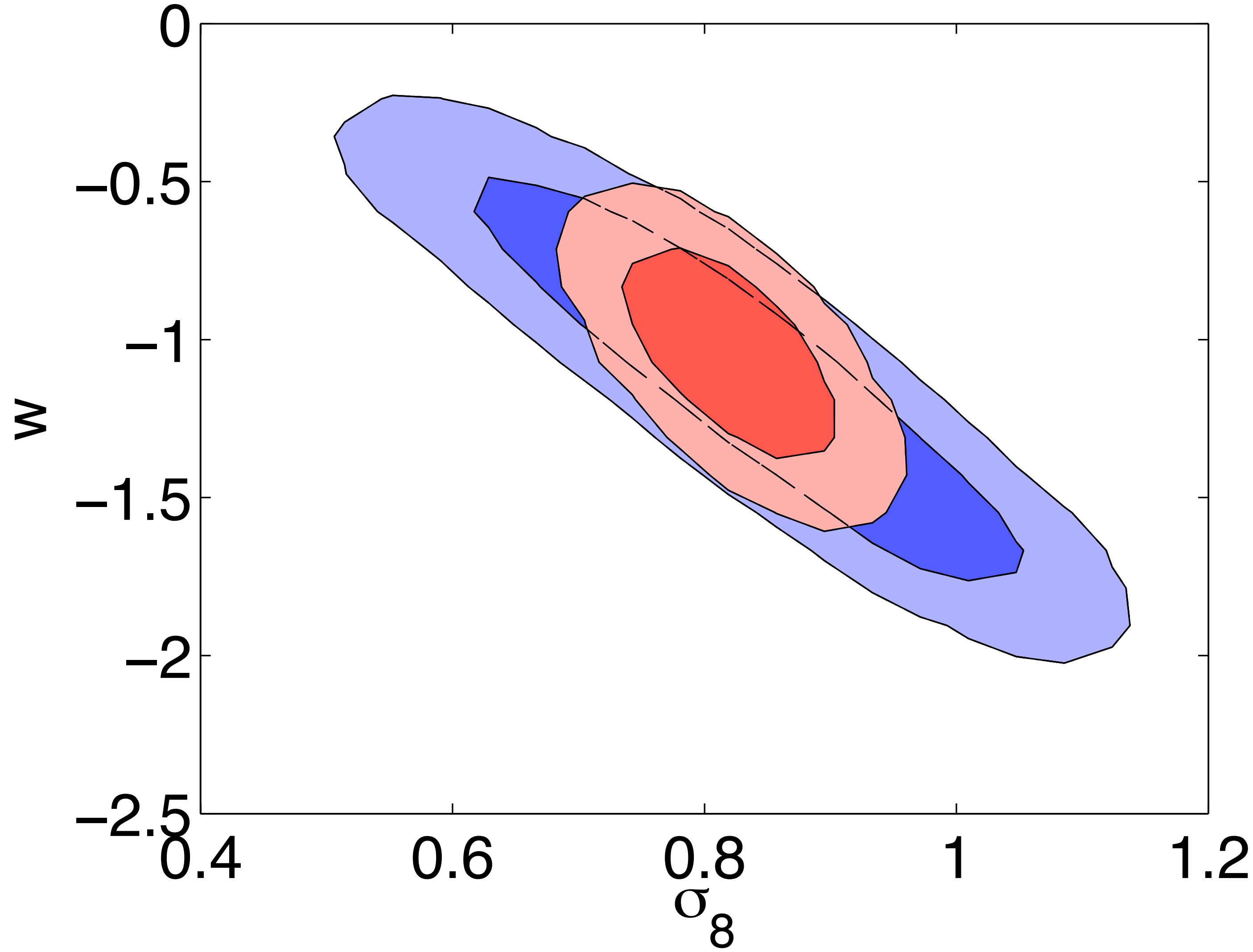
Cosmology Constraints Fixing the SZ Signal Mass Relation

WMAP7 alone

WMAP7 plus ACT Clusters



Y-M relation fixed to fiducial model

Spatially flat wCDM model

$$\sigma_8 = 0.821 \pm 0.044$$
$$w = -1.05 \pm 0.20$$

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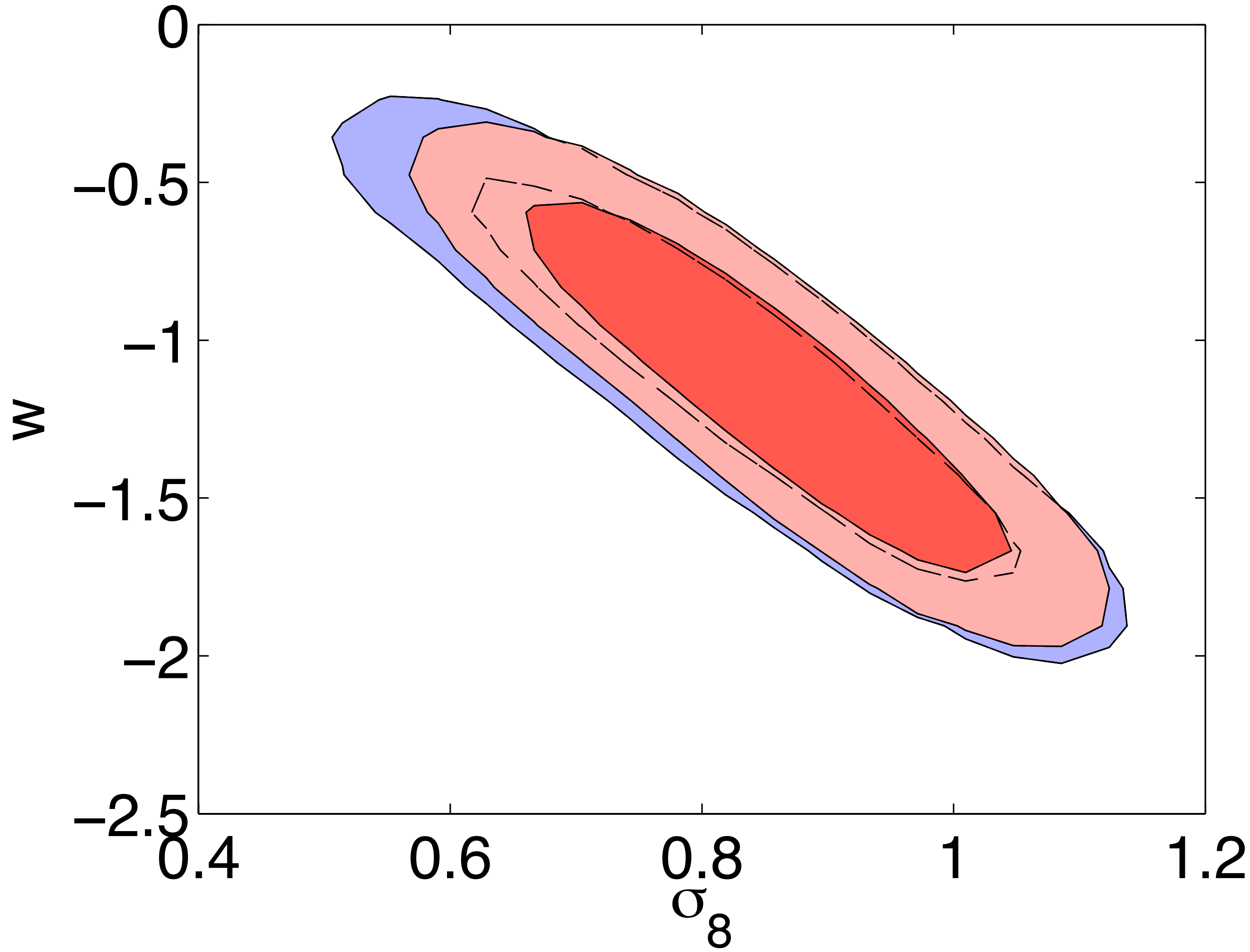
Cosmology Constraints Marginalizing over the SZ Signal Mass Relation

WMAP7 alone

WMAP7 plus ACT Clusters



Priors for Y-M relation given by range of nonthermal and adiabatic models

$$\sigma_8 = 0.851 \pm 0.115$$

$$w = -1.14 \pm 0.35$$

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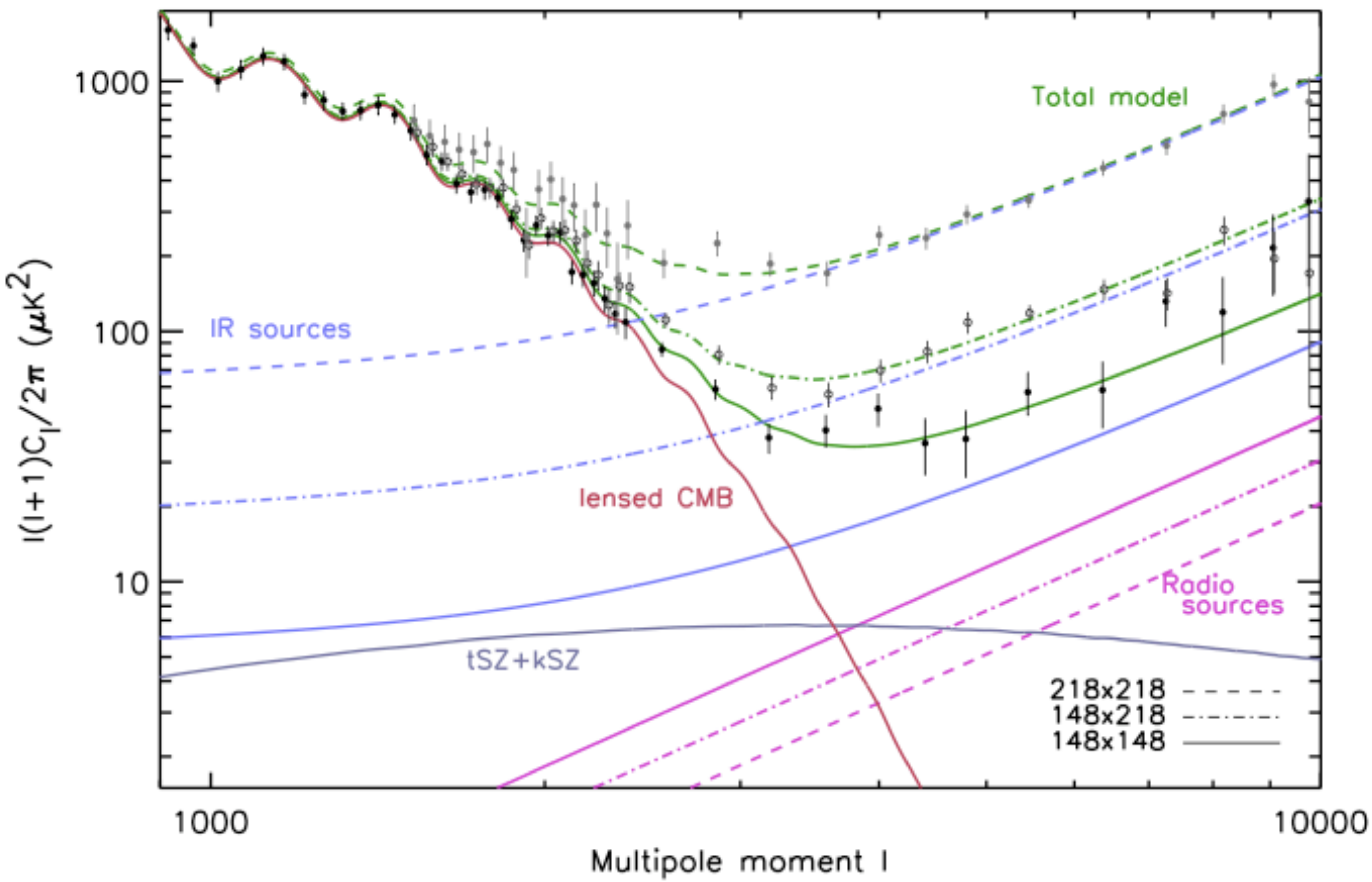
ACT Power Spectrum



Das et al. 2010, Dunkley et al. 2010

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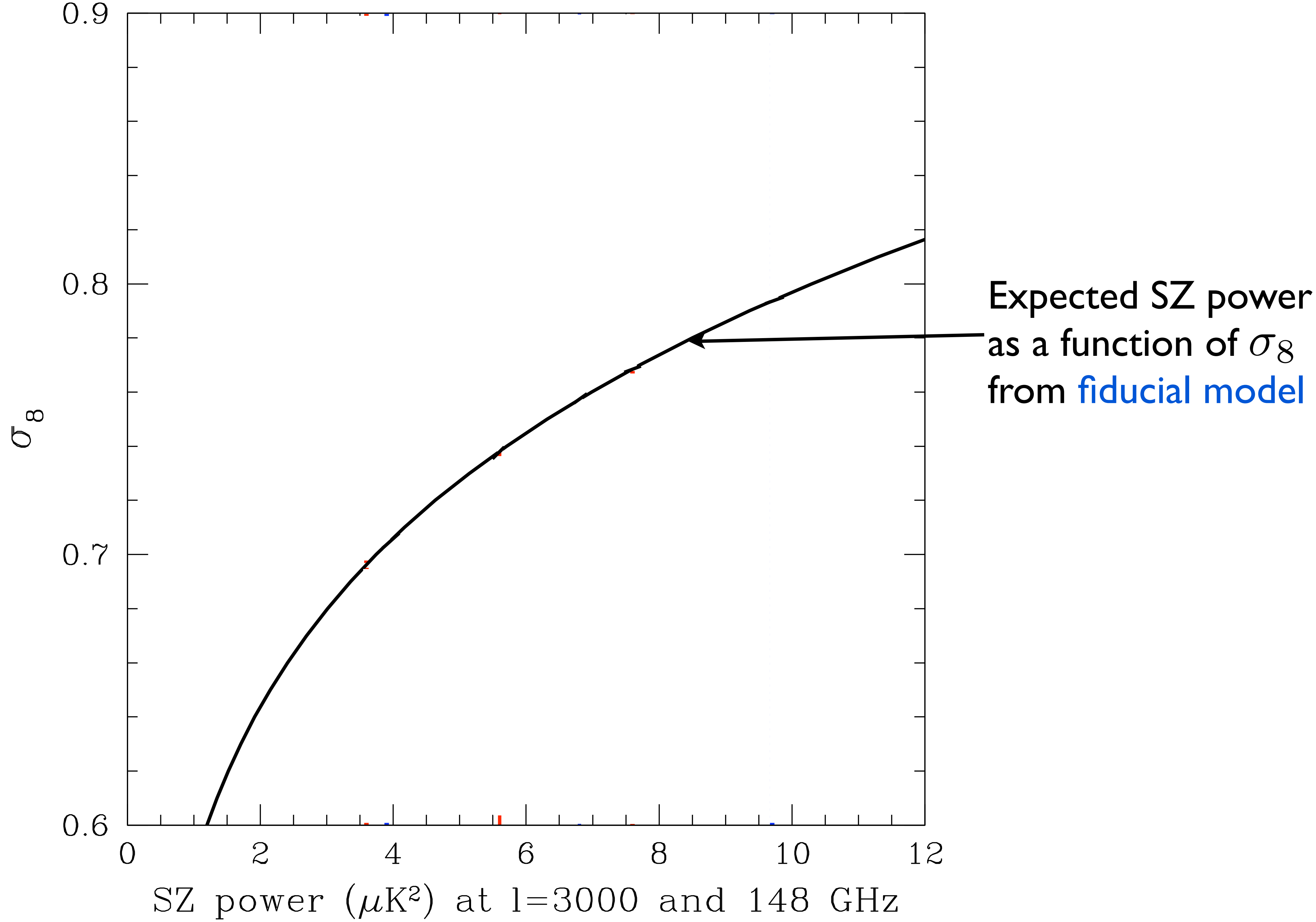
SZ Power Spectrum May Suggest Low σ_8



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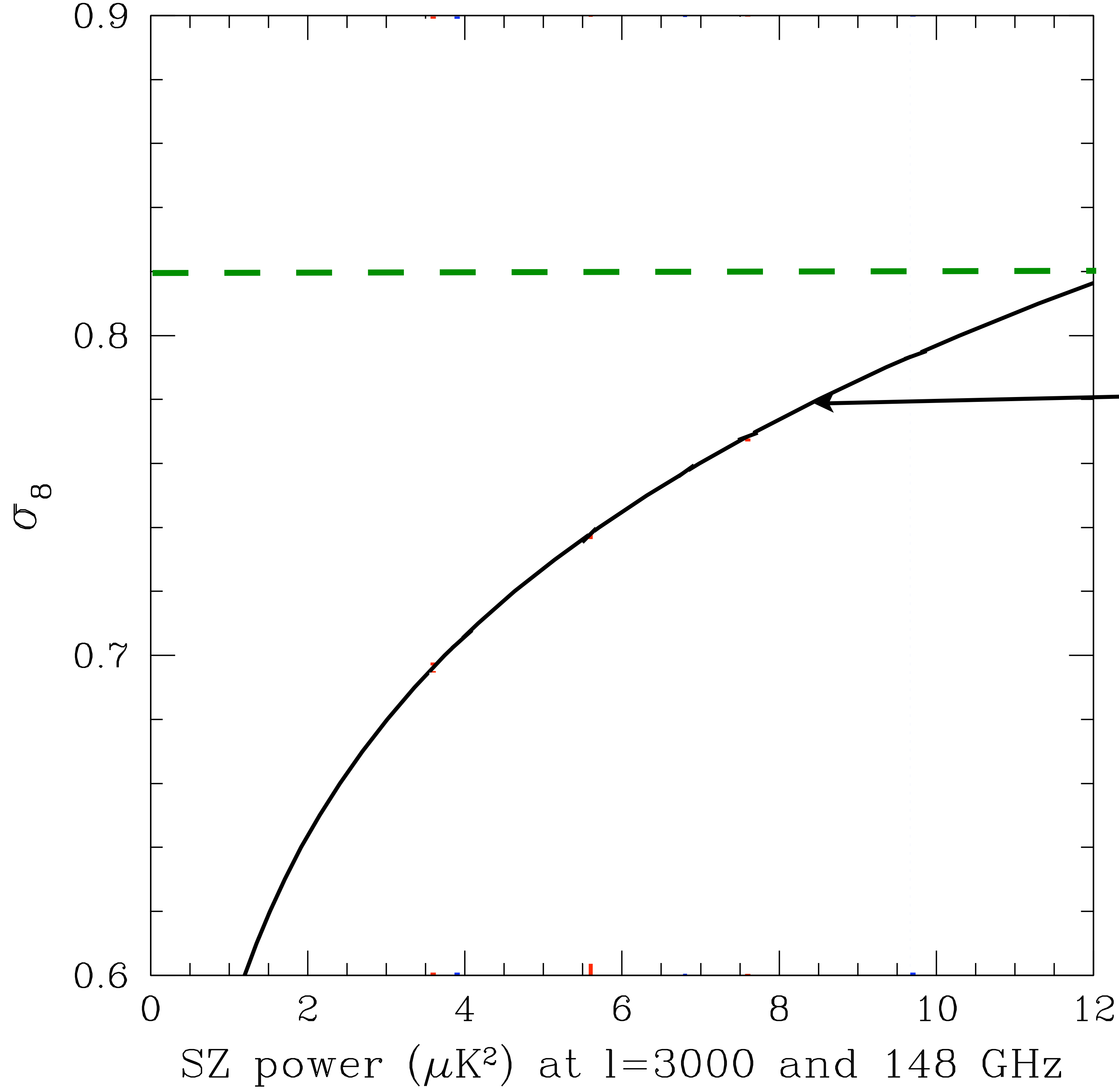

Expected SZ power as a function of σ_8 from fiducial model

With same fiducial model, SZ cluster counts give $\sigma_8 = 0.821 \pm 0.044$

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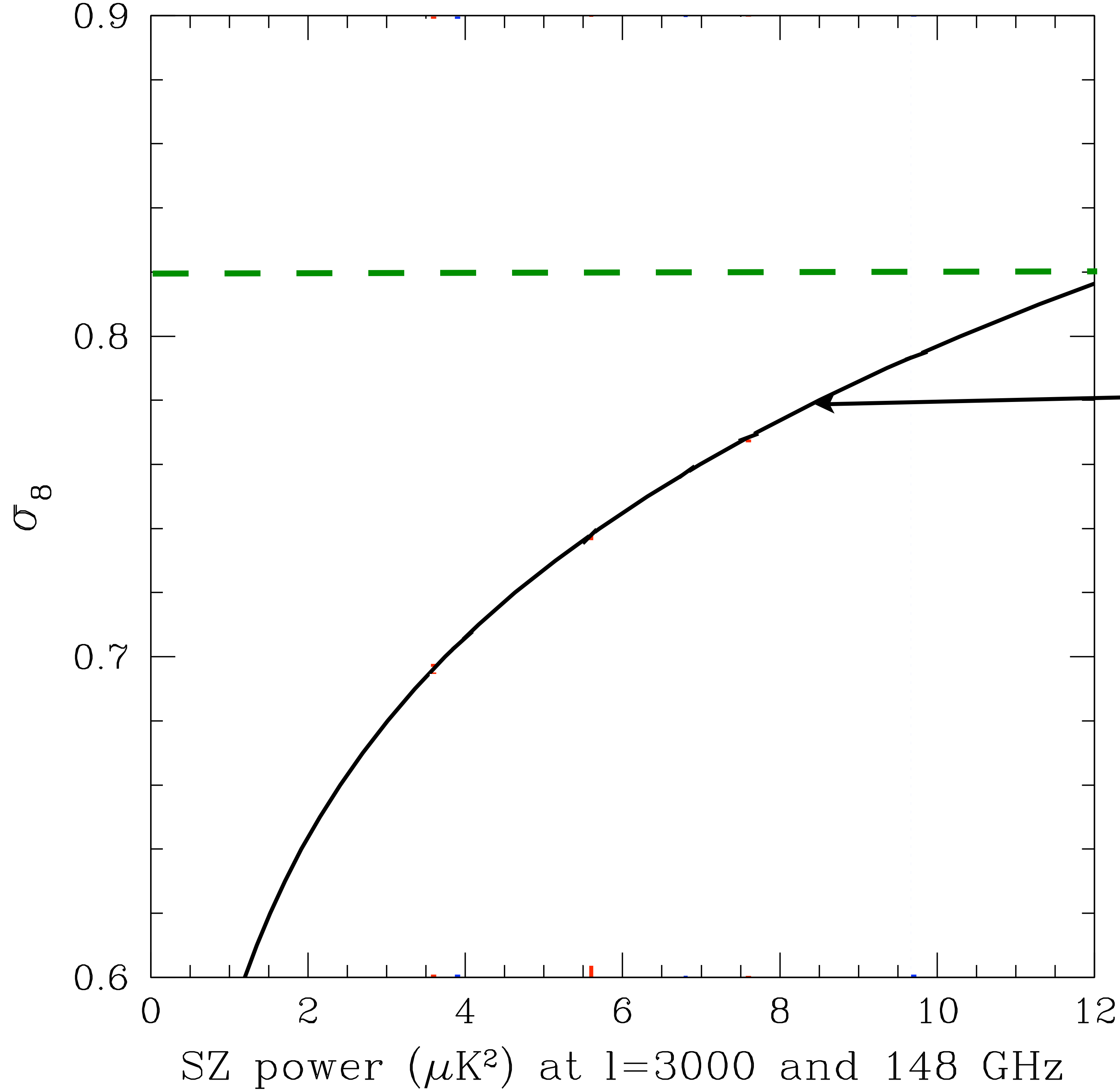
SZ Power Spectrum May Suggest Low σ_8

SZ cluster abundance consistent with expansion rate probes



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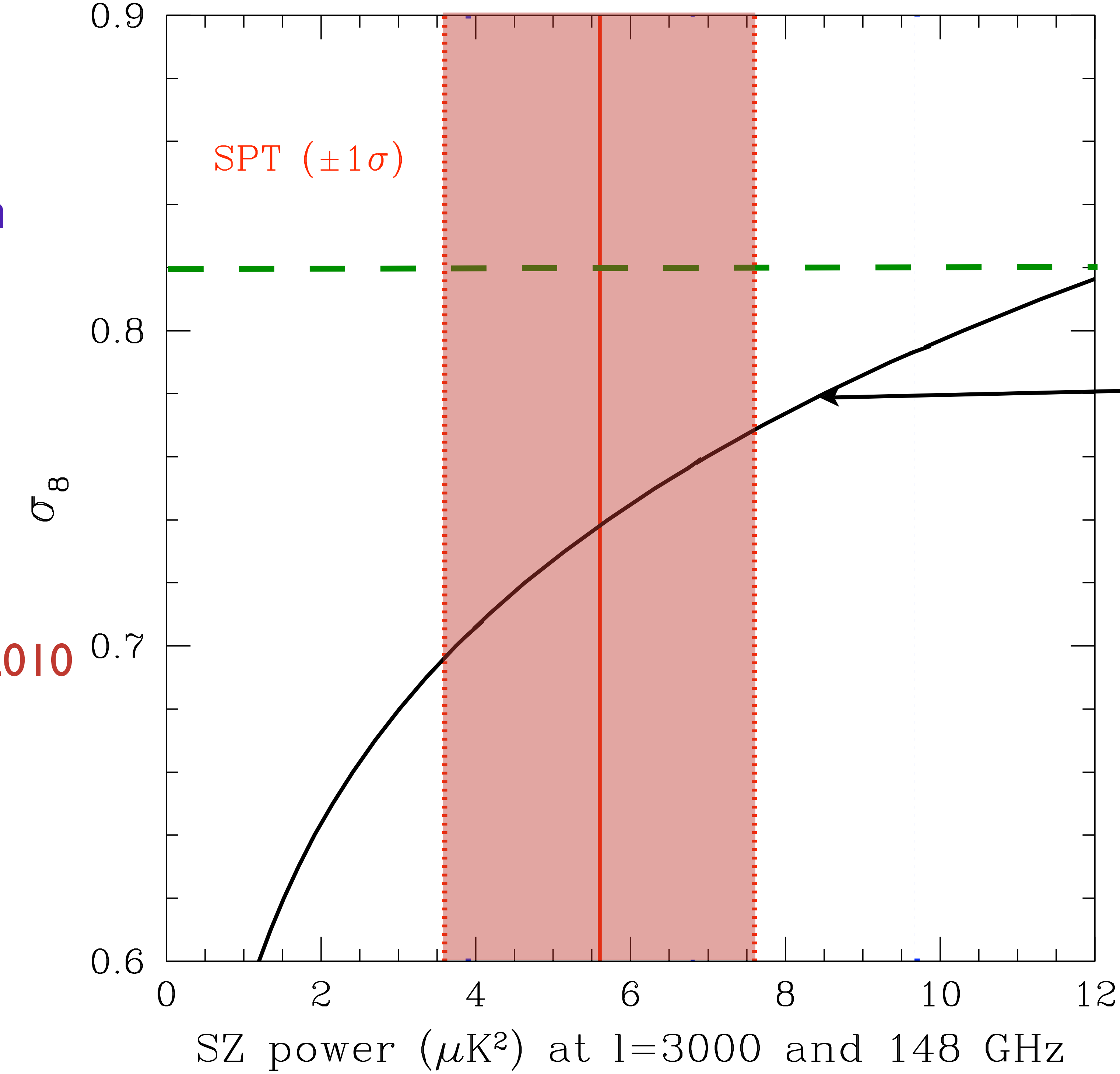
Neelima Sehgal, KIPAC

SZ Power Spectrum May Suggest Low σ_8

SZ cluster abundance consistent with expansion rate probes

SPT - Lueker et al. 2010



Expected SZ power as a function of σ_8 from fiducial model

With same fiducial model, SZ cluster counts give $\sigma_8 = 0.821 \pm 0.044$
SPT SZ power gives $\sigma_8 = 0.746 \pm 0.017$

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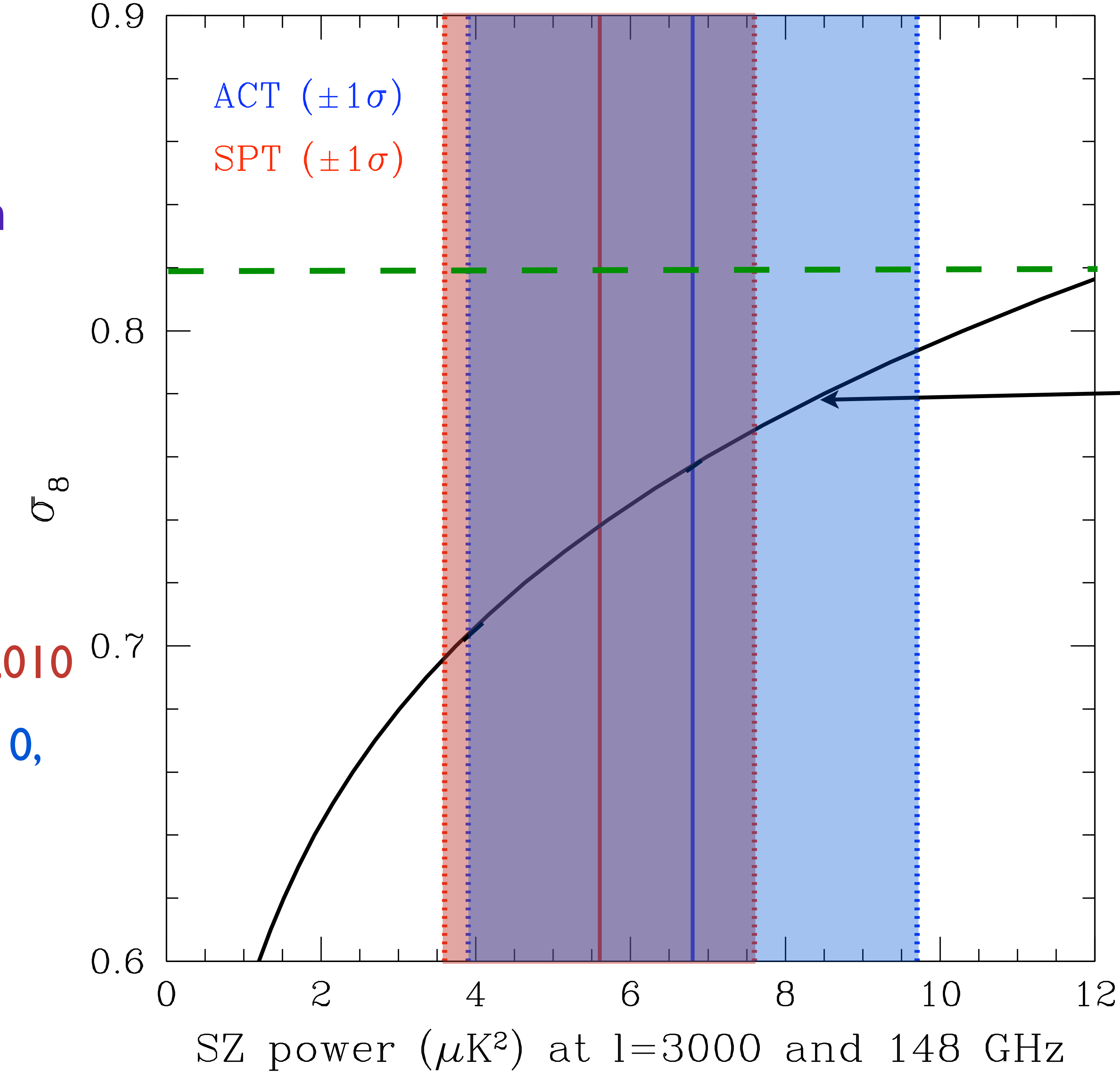
SZ Power Spectrum May Suggest Low σ_8

SZ cluster abundance consistent with expansion rate probes

SPT - Lueker et al. 2010

ACT - Das et al. 2010, Dunkley et al. 2010



Expected SZ power as a function of σ_8 from fiducial model

With same fiducial model, SZ cluster counts give $\sigma_8 = 0.821 \pm 0.044$

SPT SZ power gives $\sigma_8 = 0.746 \pm 0.017$

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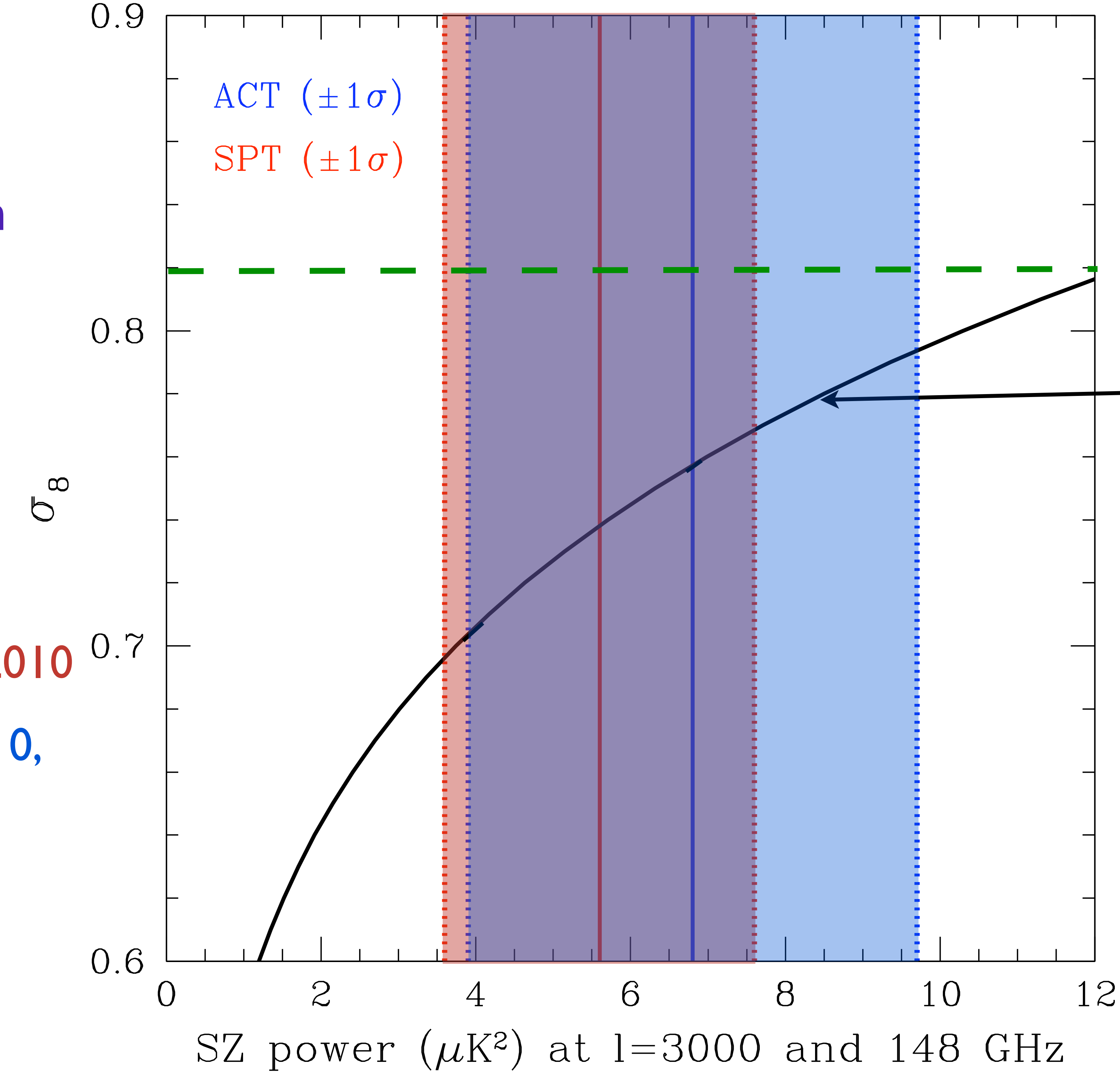
SZ Power Spectrum May Suggest Low σ_8

SZ cluster abundance consistent with expansion rate probes

SPT - Lueker et al. 2010

ACT - Das et al. 2010, Dunkley et al. 2010



Expected SZ power as a function of σ_8 from fiducial model

Fiducial model calibrated with high-mass/low-z clusters

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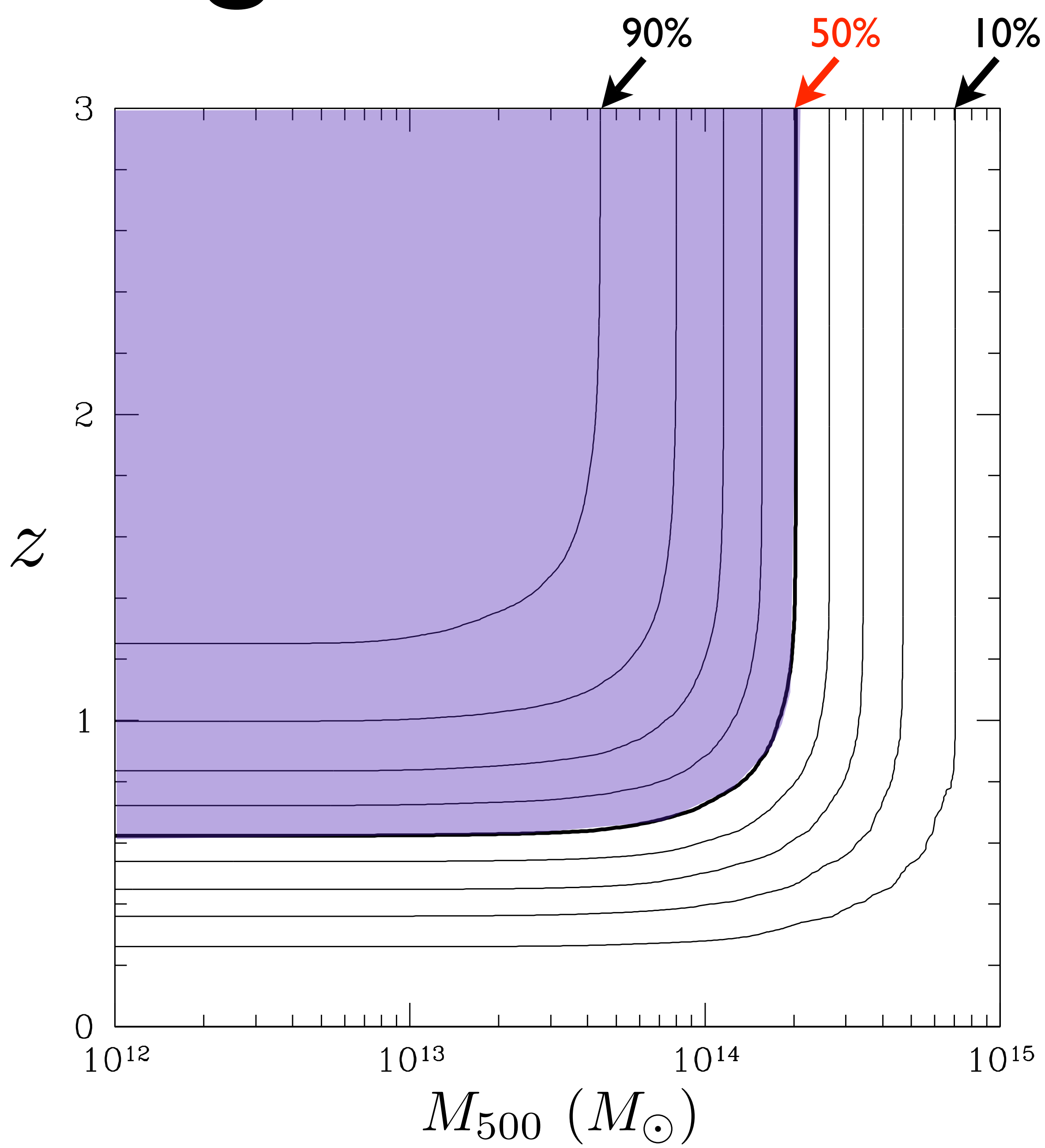
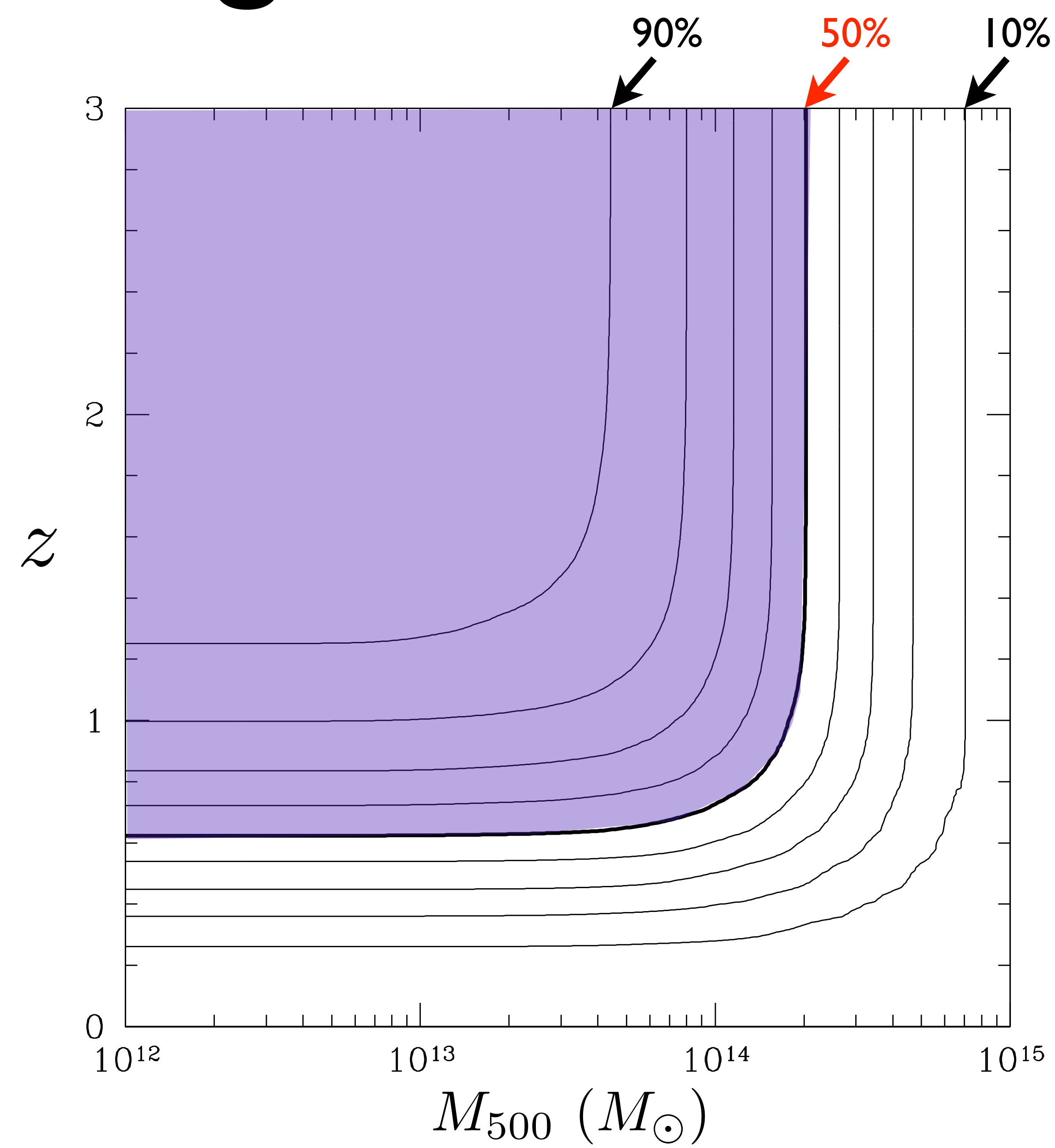
Half the SZ Power From Low-Mass/High-Redshift Clusters



Contribution to SZ power: clusters with mass $< 2 \times 10^{14}$ and z > 0.6 give 50% of the power

Neelima Sehgal, KIPAC

Half the SZ Power From Low-Mass/High-Redshift Clusters



SZ power spectrum is complementary to SZ cluster abundance -- sensitive to different regimes of clusters

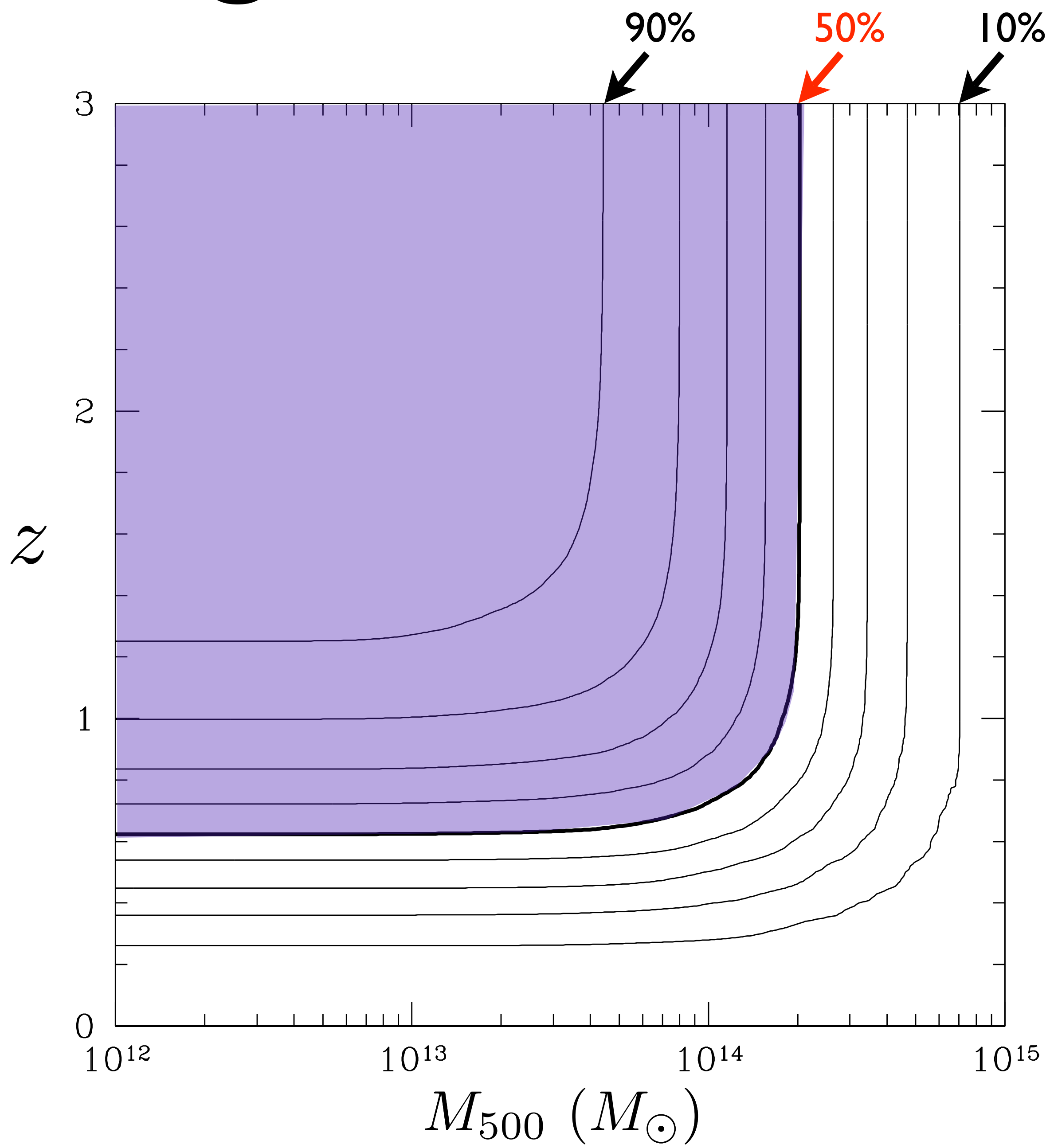
Contribution to SZ power: clusters with mass $< 2 \times 10^{14}$ and z > 0.6 give 50% of the power

Neelima Sehgal, KIPAC

Half the SZ Power From Low-Mass/High-Redshift Clusters

Less is known about low-mass/ high-z clusters

An extrapolation of fiducial model to low-mass/high-z clusters may not be correct



SZ power spectrum is complementary to SZ cluster abundance -- sensitive to different regimes of clusters

Contribution to SZ power: clusters with mass $< 2 \times 10^{14}$ and z > 0.6 give 50% of the power

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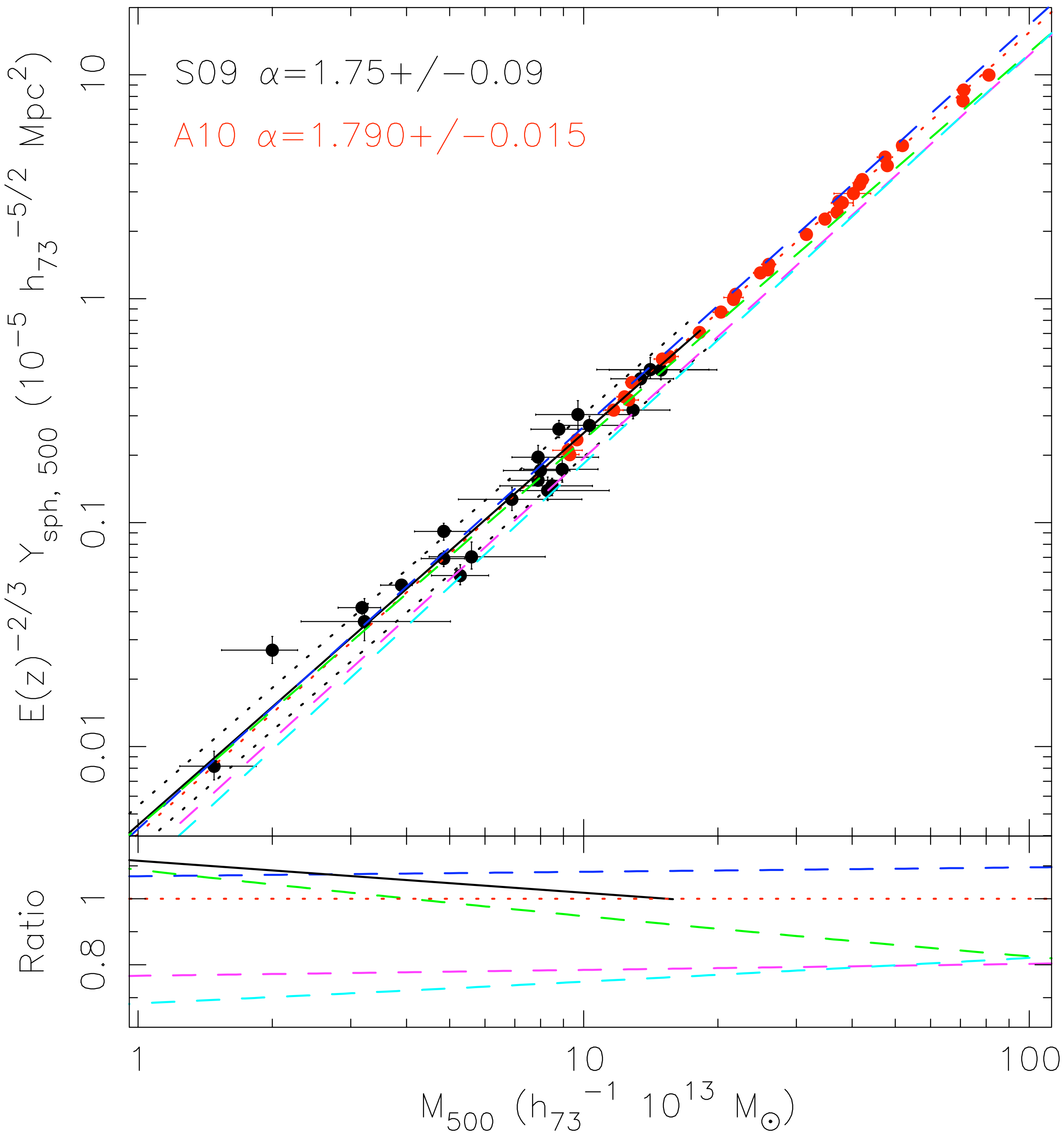
New Y-M Relation for Low-Mass Groups from X-ray Observations

Sample of X-ray selected, local groups

M. Sun, NS, et al., 2010 in prep



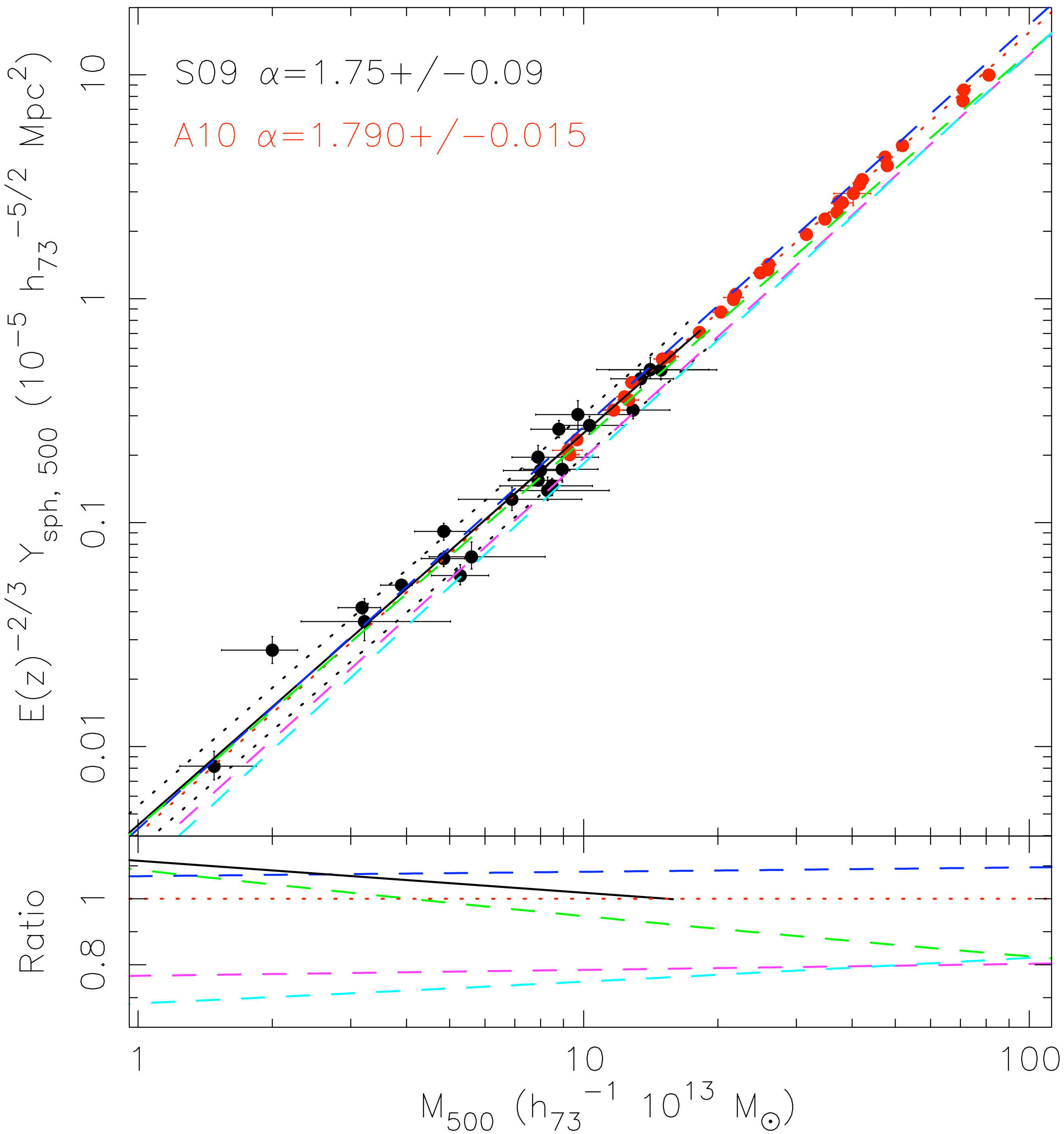
Data:
Arnaud et al. 2010
Sun et al. 2009

Neelima Sehgal, KIPAC

New Y-M Relation for Low-Mass Groups from X-ray Observations

Sample of X-ray selected, local groups

M. Sun, NS, et al., 2010 in prep



Data:
Arnaud et al. 2010
Sun et al. 2009

Models:
Sehgal et al. 2010
Shaw et al. 2010
Trac et al. 2010
Battaglia et al. 2010

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Nonthermal Pressure or Star-Forming Galaxies May Suppress SZ Power

Nonthermal gas pressure causes X-ray and SZ observations to underestimate cluster mass

Would need > 20% nonthermal pressure in low-mass clusters

Not clear if observations indicate this is true

See Battaglia et al 2010, Shaw et al 2010, Trac et al 2010

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Star-forming galaxies have microwave emission

Fills in cluster decrements

Fraction of star-forming galaxies increases for lower-mass and higher-redshift clusters and groups

Not clear from observations how significant this is

Conclusion

- Interesting constraints on cosmology with our first sample of clusters
- More knowledge about Y-M relation would make constraints very competitive with other methods
- Can use stacked clusters to get an additional handle on Y-M scaling
- SZ power spectrum may be telling us about astrophysics of low-mass/high-z clusters
- Will only get better in future (more data from ACT, SPT, Planck, ACTpol, and SPTpol)

Thank You