Title: Understanding Fundamental Physics with Galaxy Clusters

Date: Feb 01, 2011 02:00 PM

URL: http://pirsa.org/11020078

Abstract: I will discuss a powerful way to examine the nature of dark energy using a measurement of the growth of galaxy clusters over cosmic time. A novel technique that uses the Cosmic Microwave Background as a backlight allows the detection of galaxy clusters out to the time of their first formation. Using this technique, I will present the first constraints on cosmological parameters obtained with the Atacama Cosmology Telescope, as well as exciting prospects for the future.

Understanding Fundamental Physics with Galaxy Clusters

Neelima Sehgal

Stanford/SLAC

Cosmology and Gravitation Seminar - Perimeter

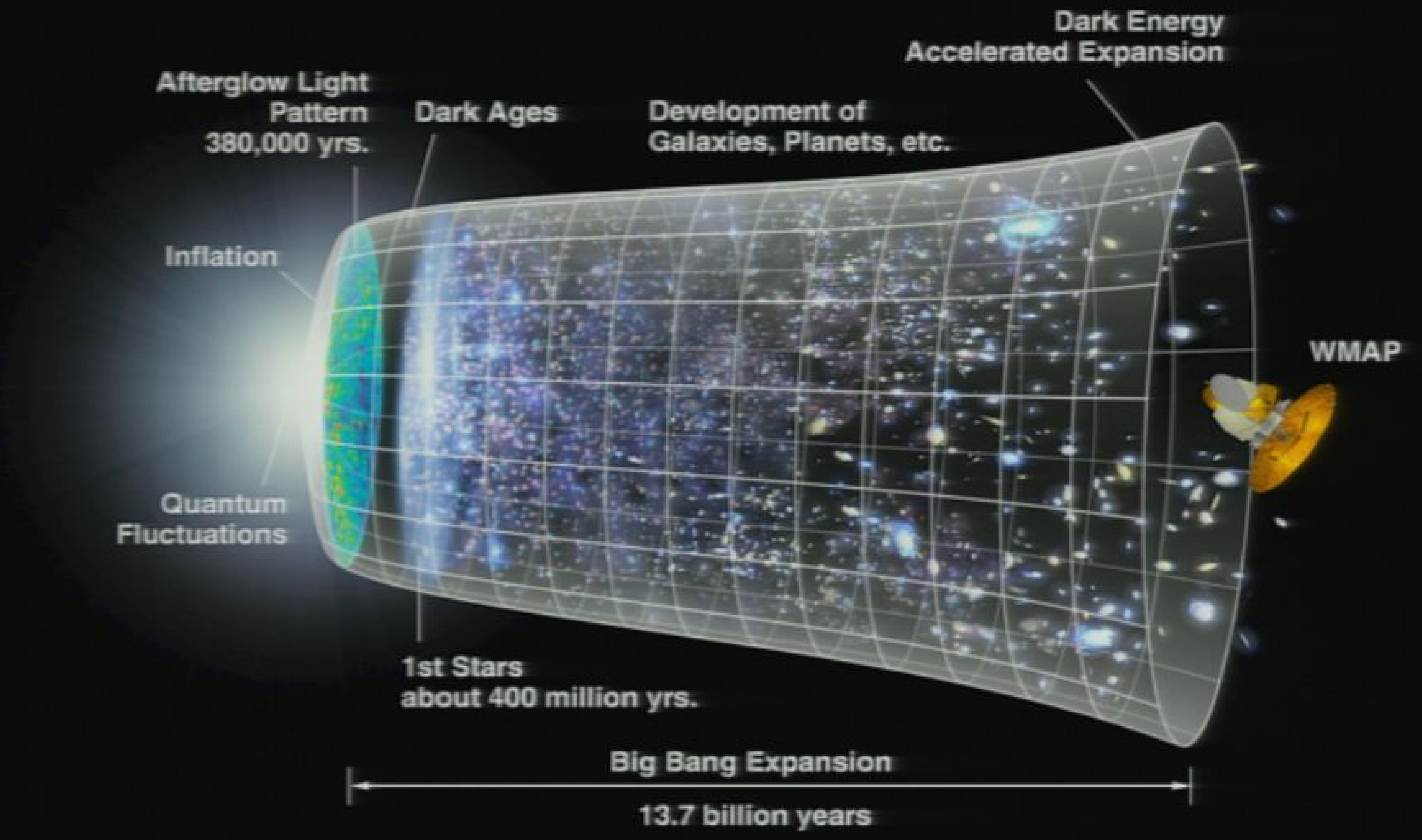
Overview

- Cluster Surveys as an Important Cosmological Probe

- First Cosmology Constraints from Atacama Cosmology Telescope Cluster Sample

- Cluster Power Spectrum as a Complementary Cosmological Probe and Future Prospects

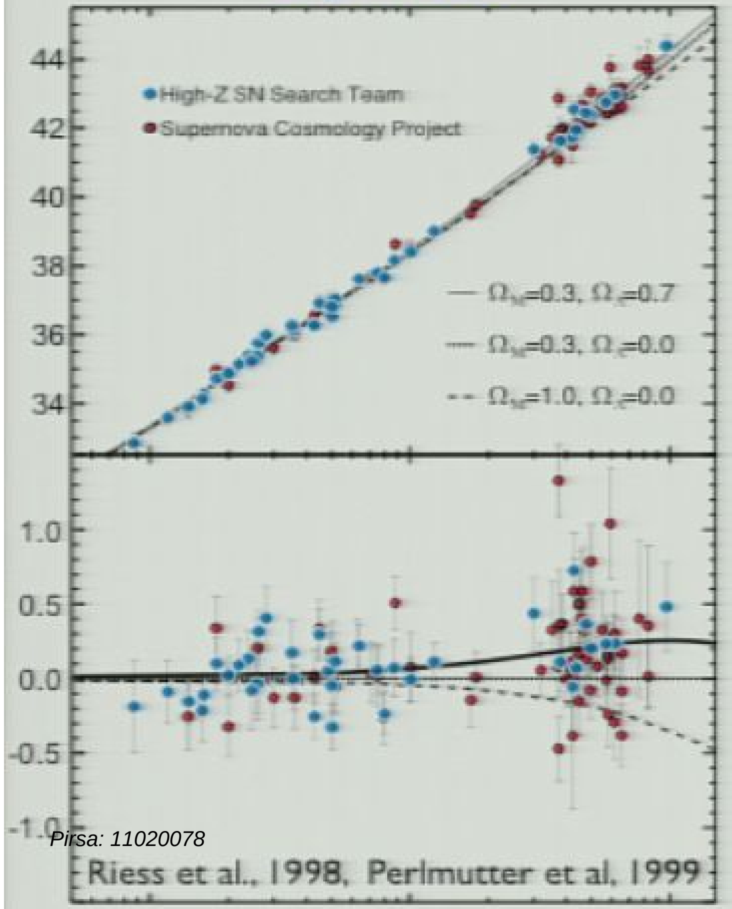
A STANDARD MODEL FOR COSMOLOGY



ow do we Measure our Universe?

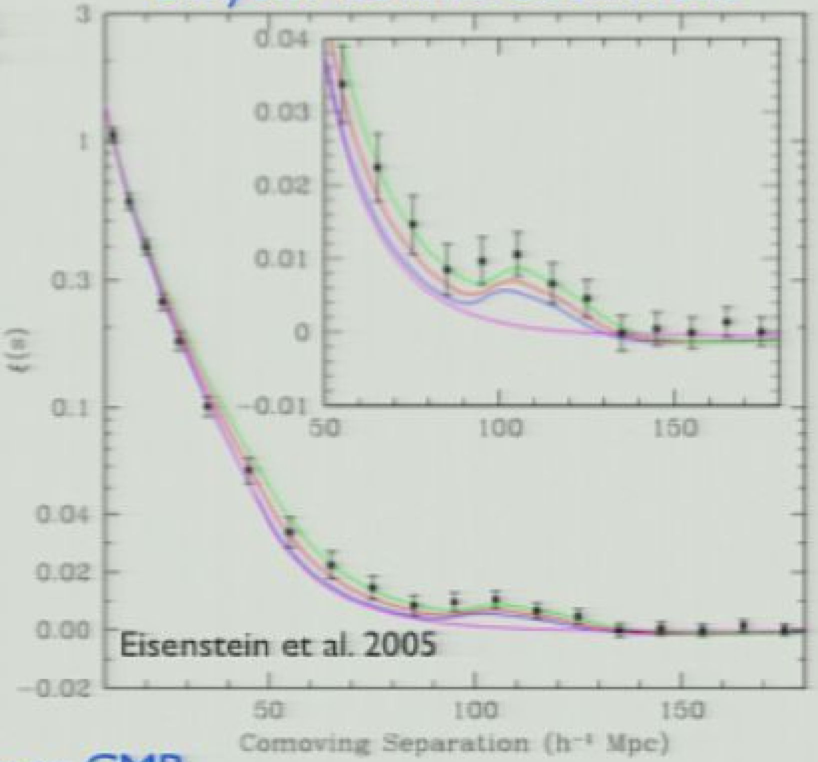
easures of the Expansion Rate

Supernovae



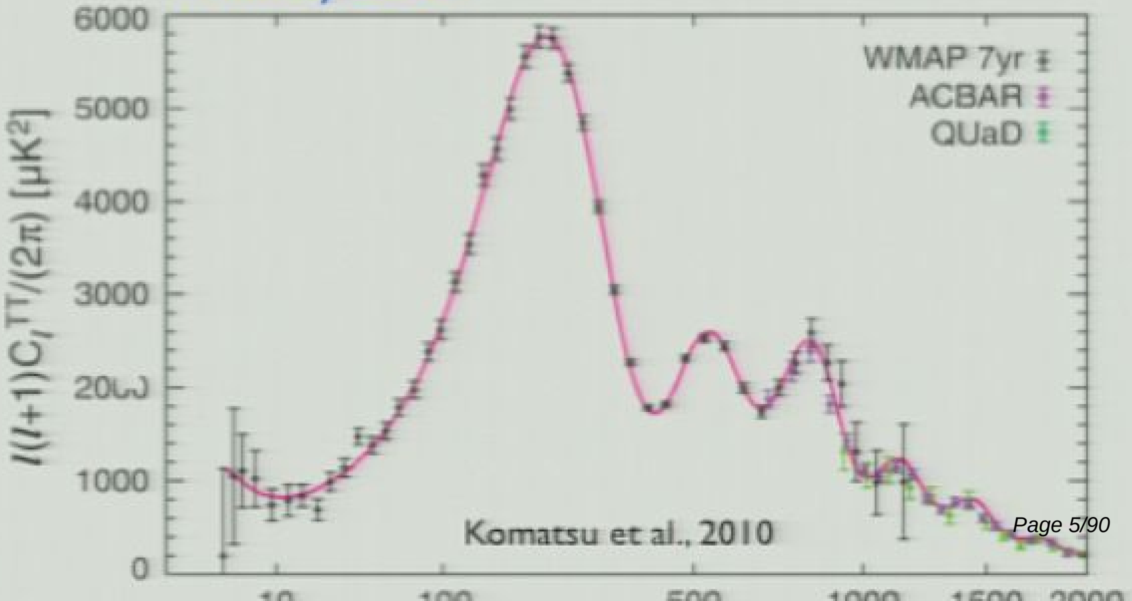
Riess et al., 1998, Perlmutter et al, 1999

Baryon Acoustic Oscillations



Eisenstein et al. 2005

Primary CMB

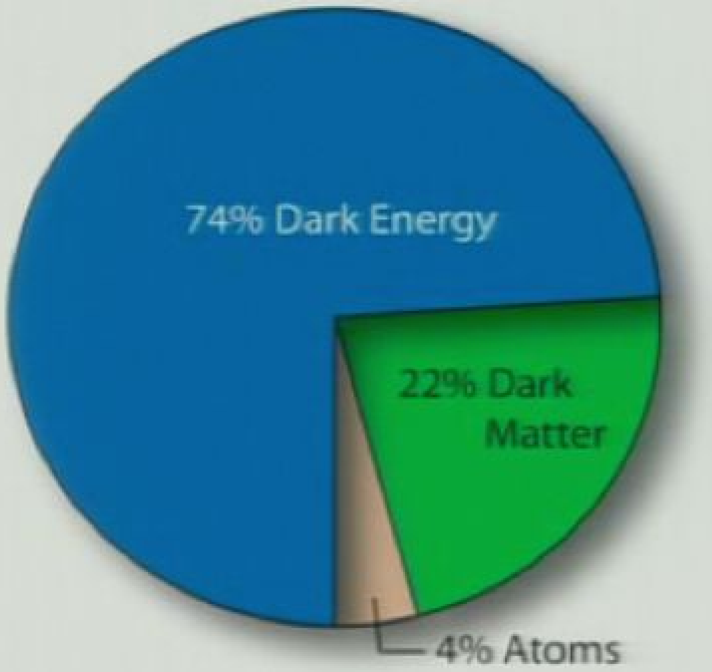


Komatsu et al., 2010

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



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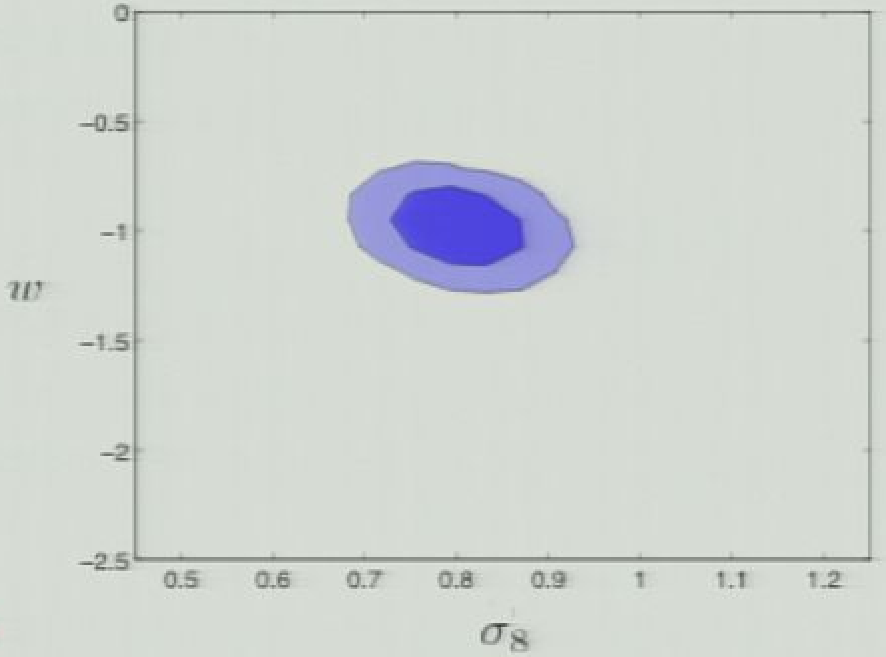

WMAP 7 + BAO + SN

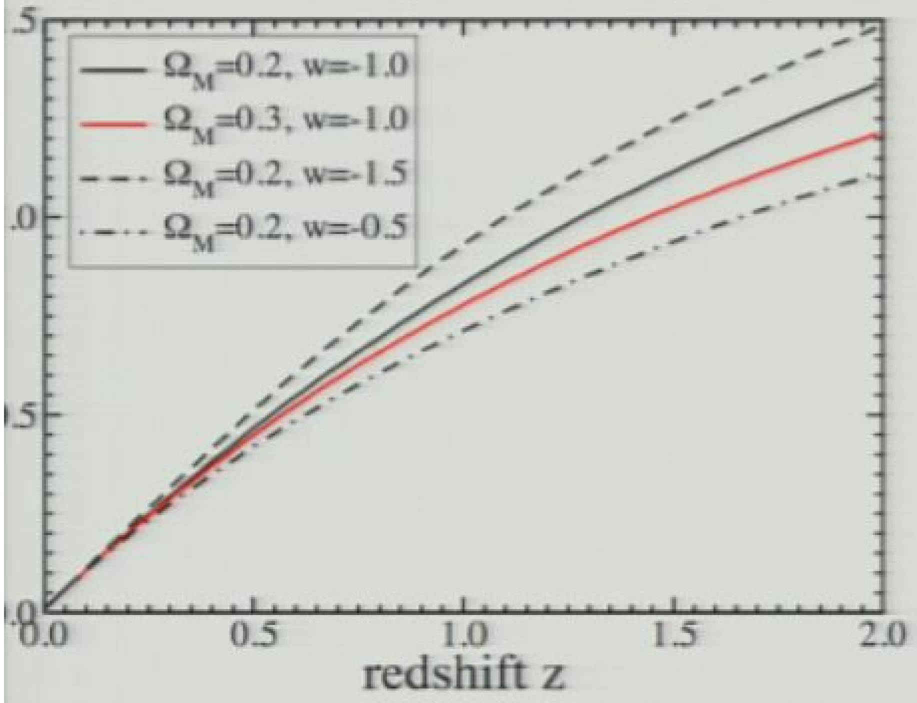
Two very interesting parameters are:

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

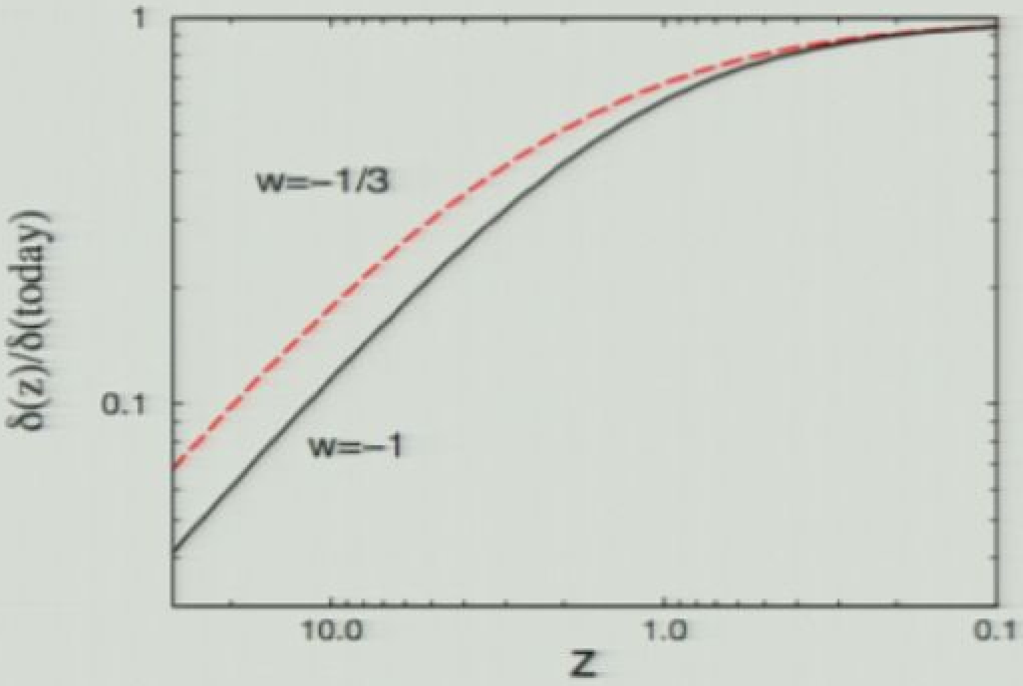
σ_8 = rms mass density fluctuations in 8 h^{-1} Mpc spheres today

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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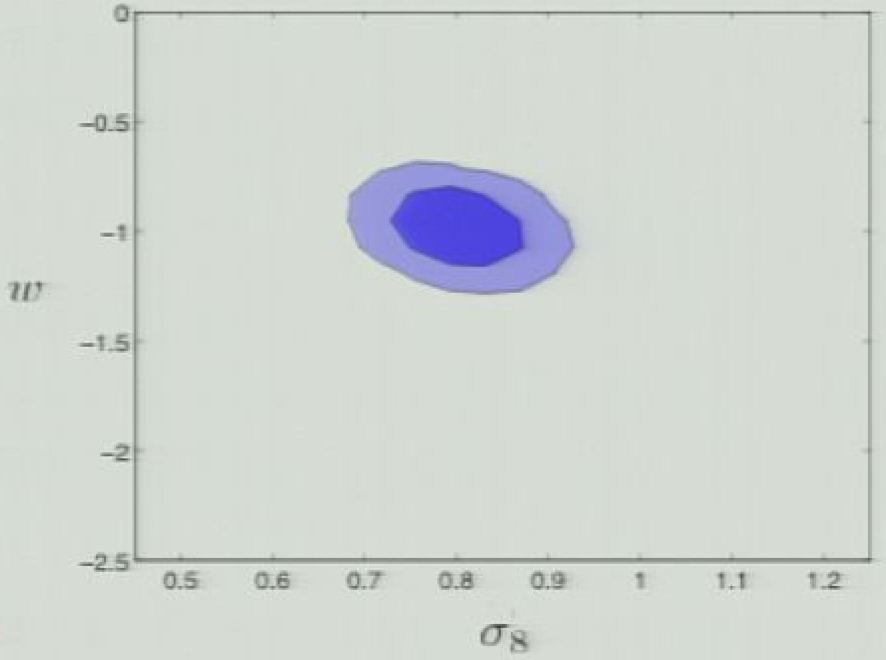
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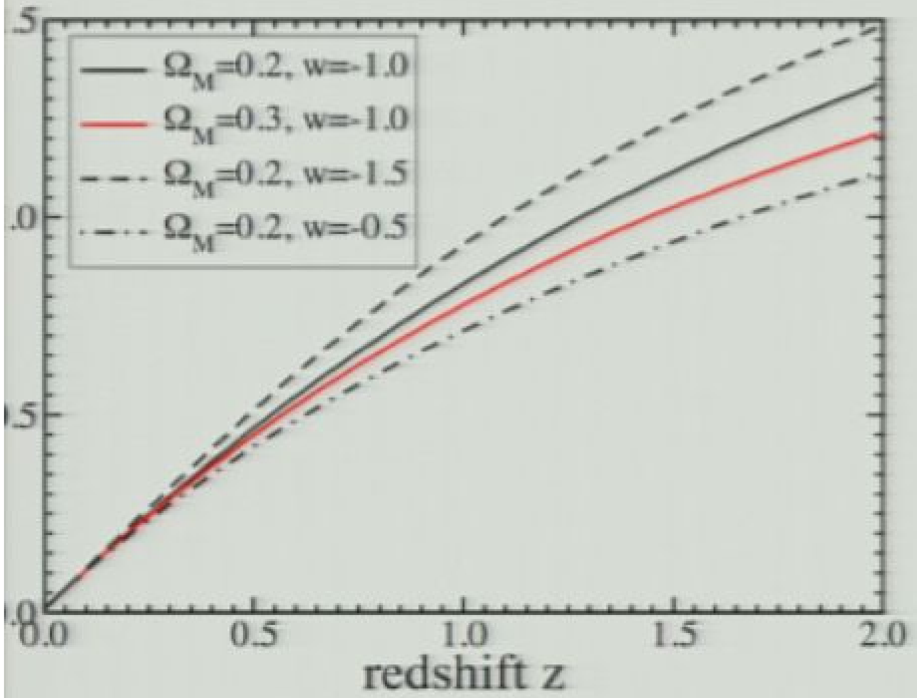

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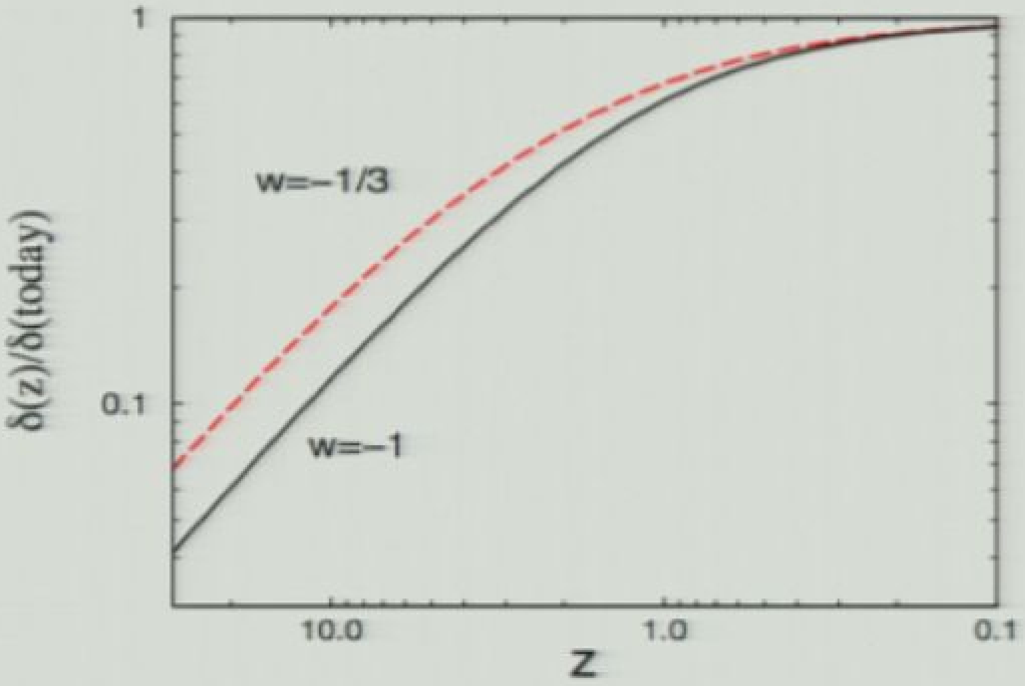

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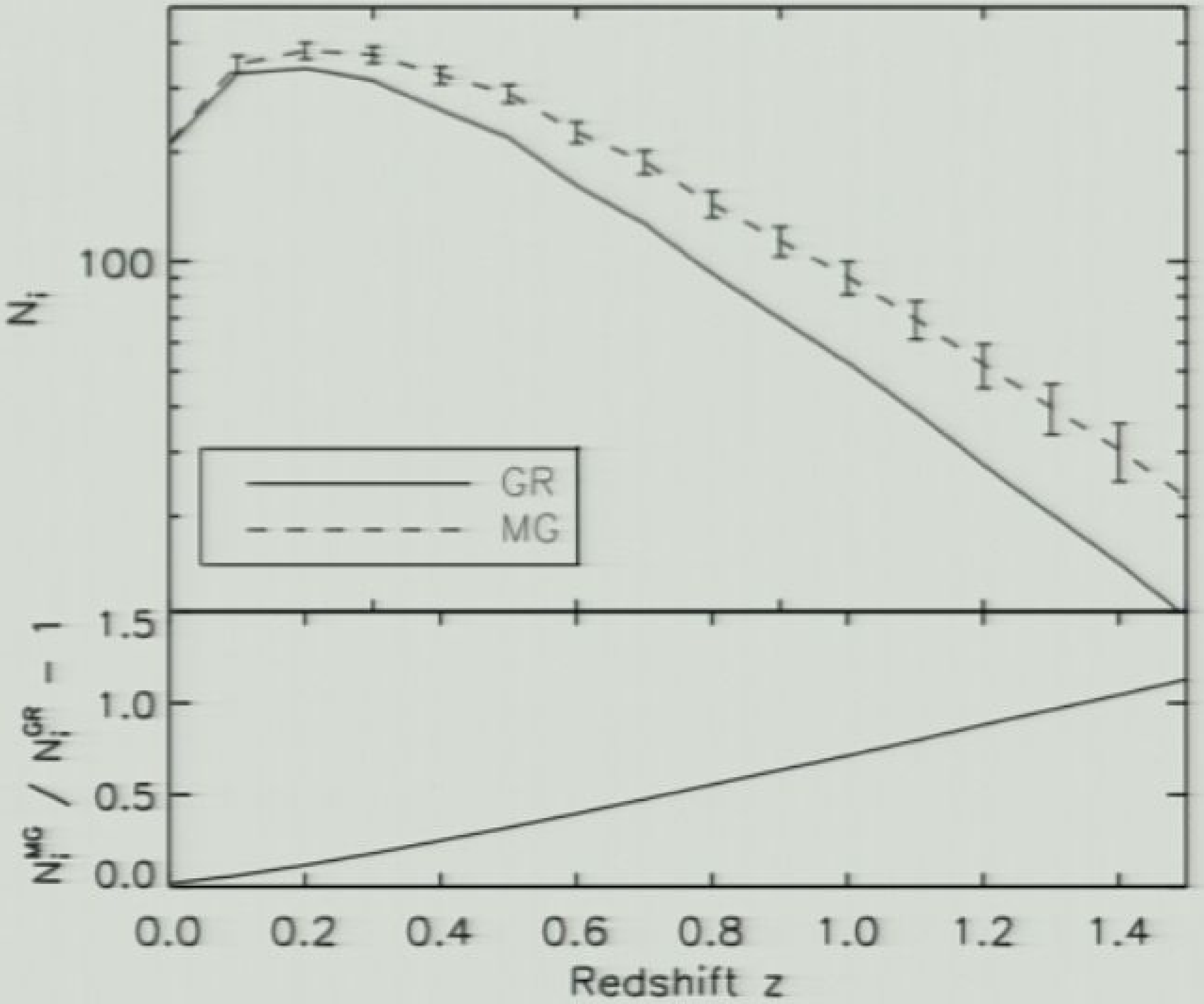
Learning about Dark Energy

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)

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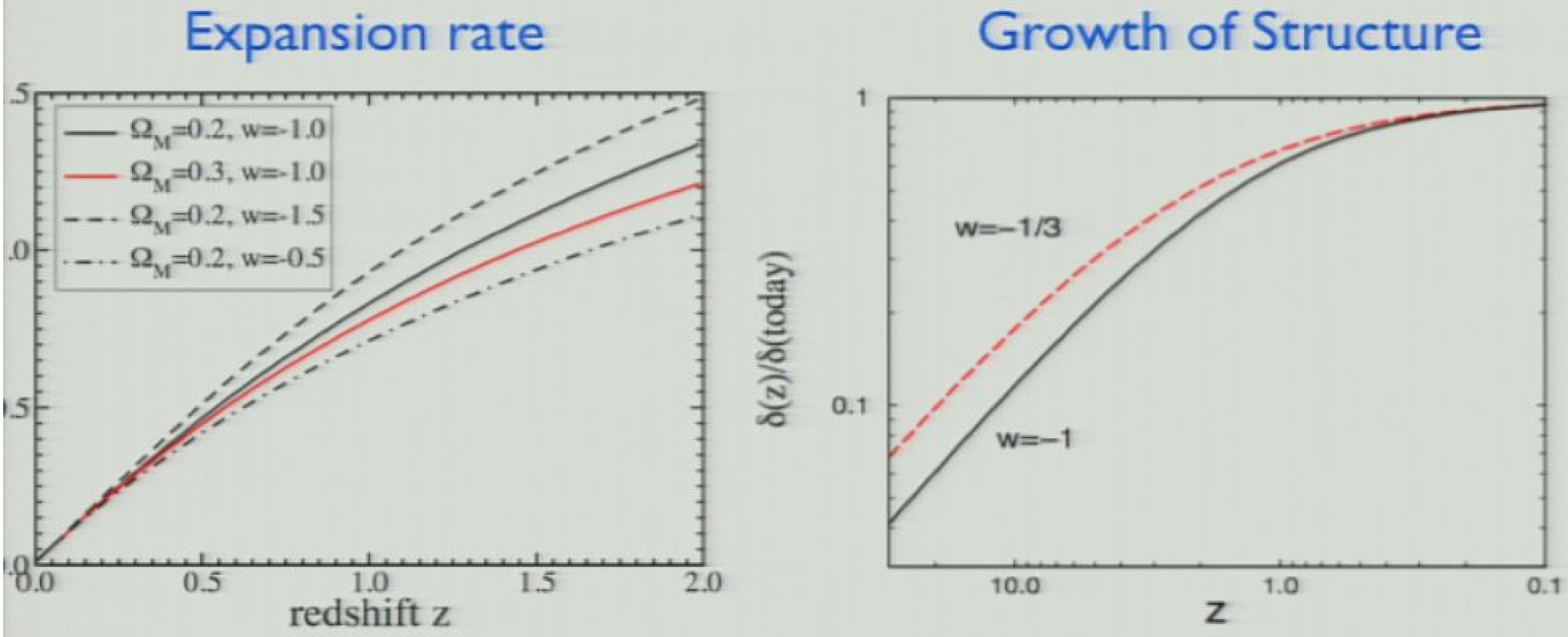

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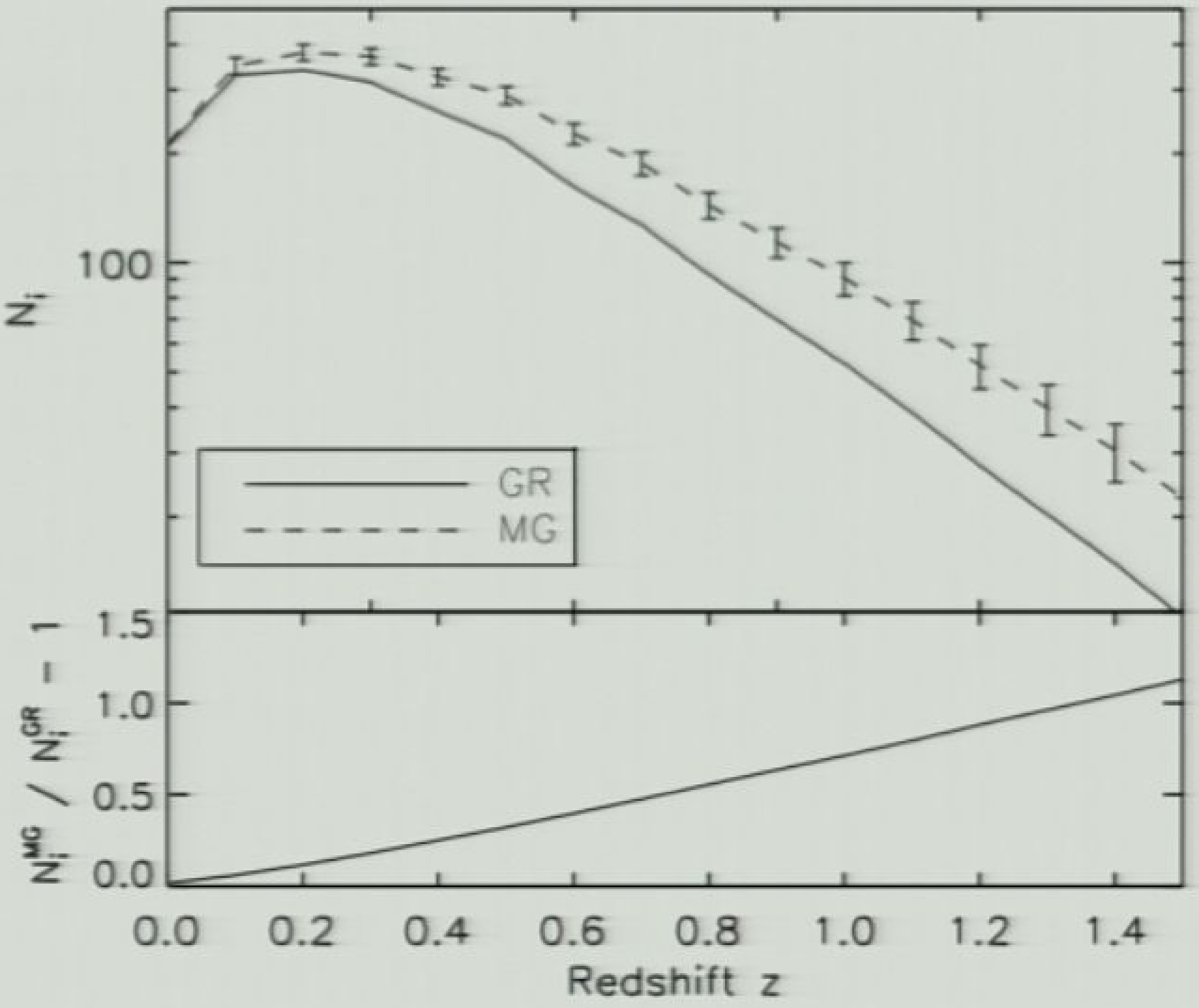

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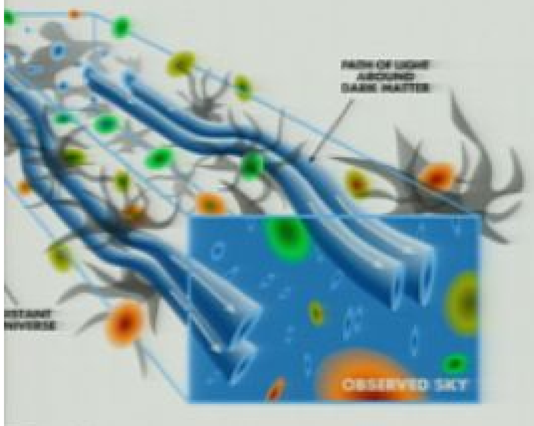
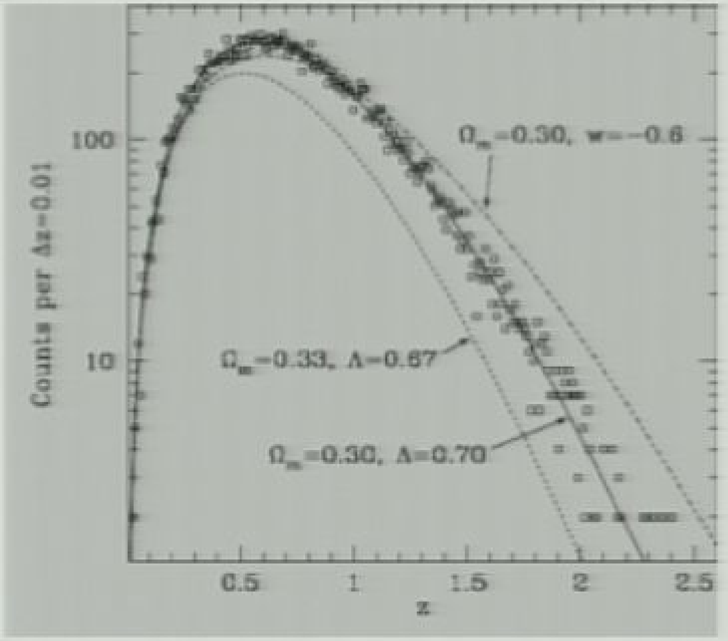
Measures of the Growth of Structure

Weak lensing



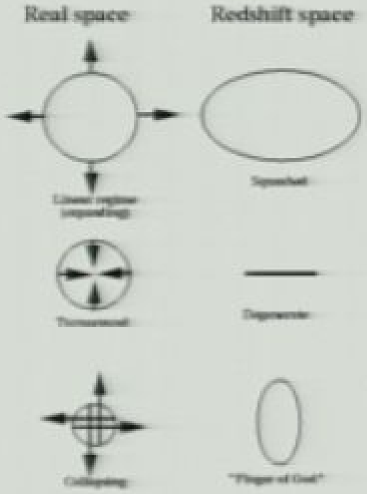
T website

Cluster Abundance



SPT website

Red-shift space distortions



W. Keel

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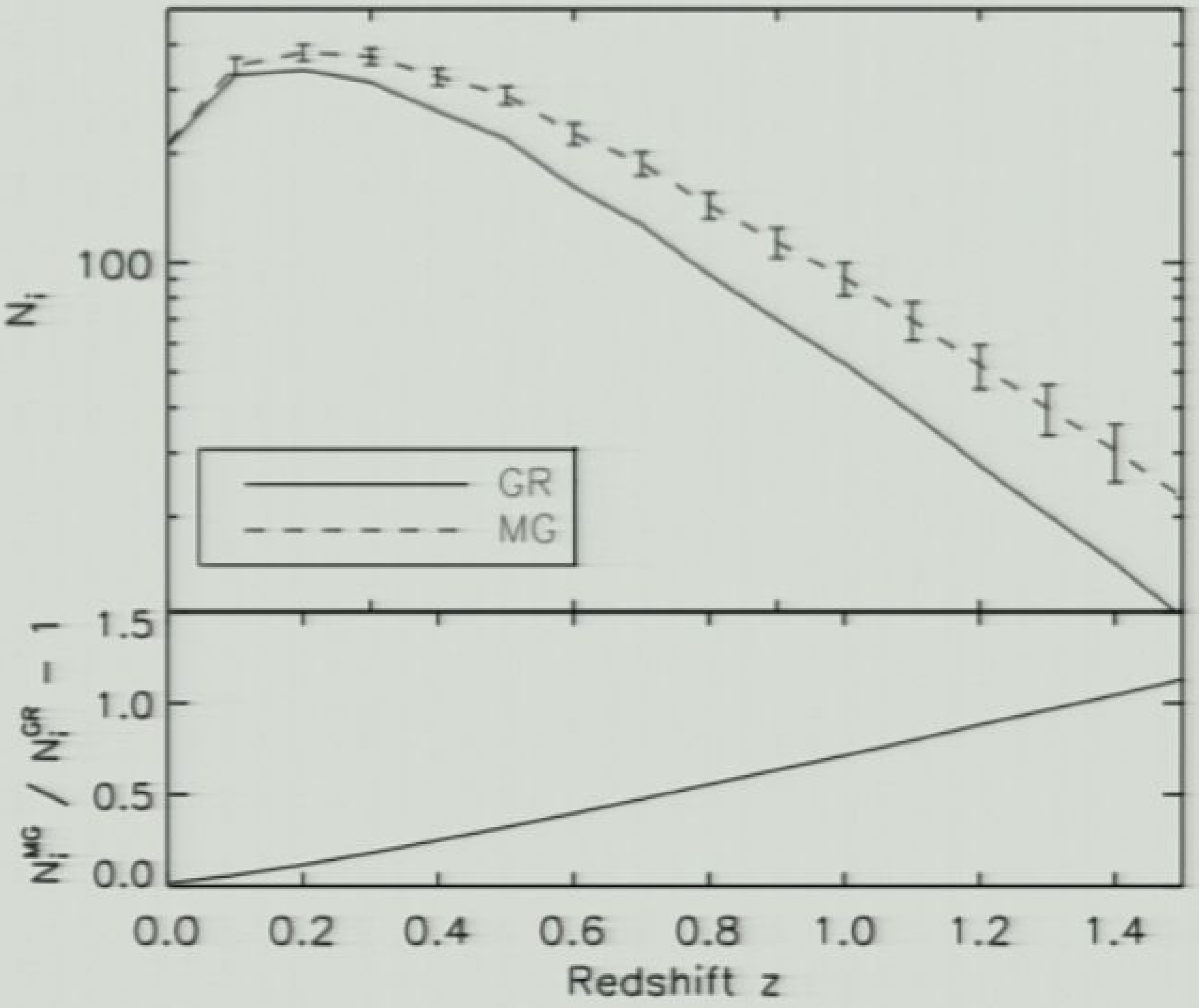

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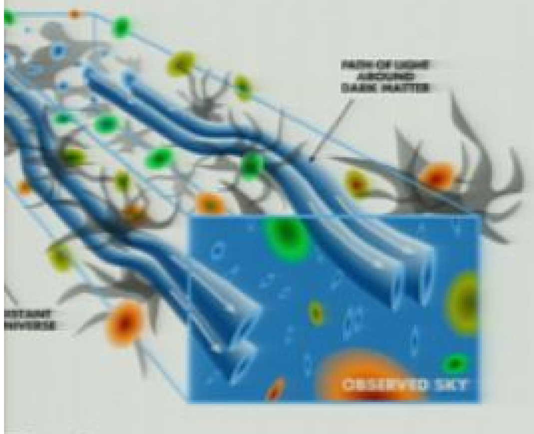

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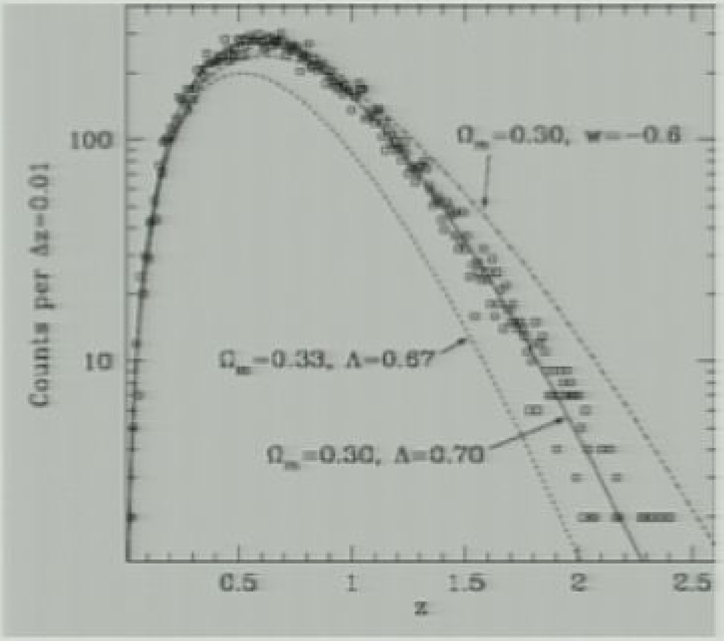

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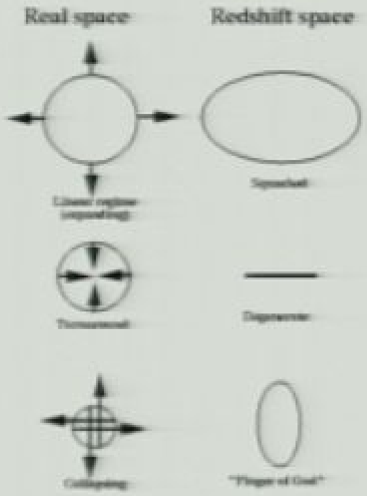

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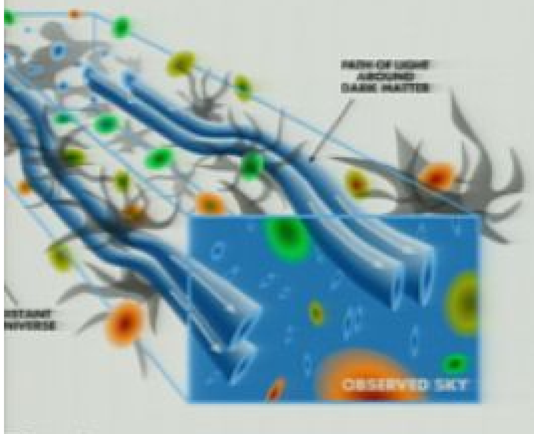

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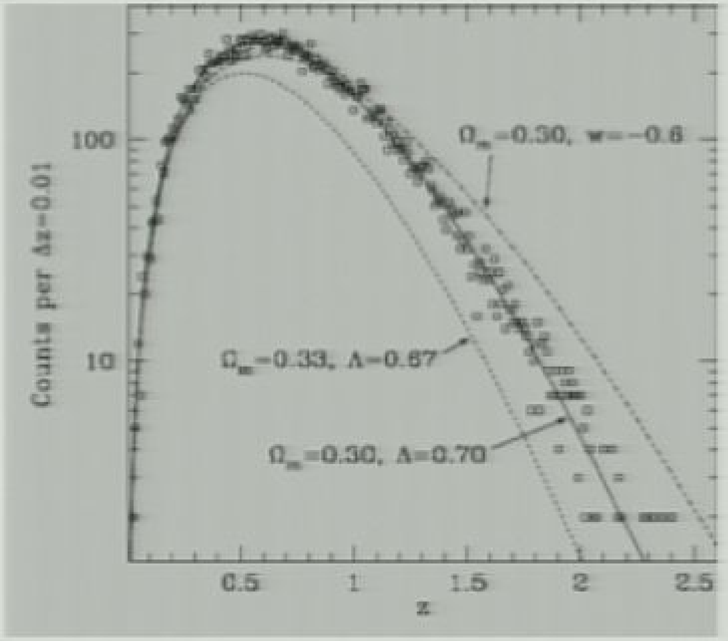
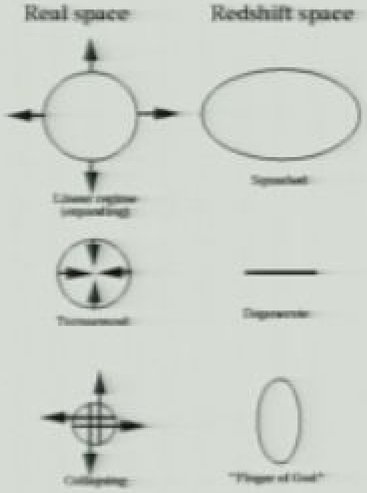


X-ray

Optical

CMB

Red-shift space distortions



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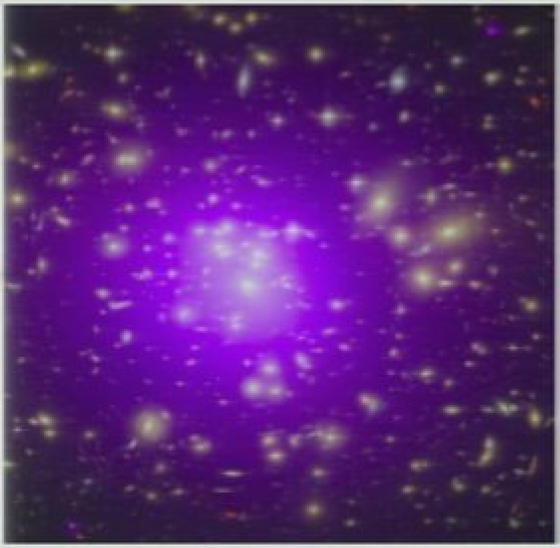
Measuring Cluster Abundance with the CMB

Radio & IR galaxies



Galaxy Cluster

1089
7 Gyr

z~2-5
10-12 Gyr

z~0.01-2
1-10 Gyr

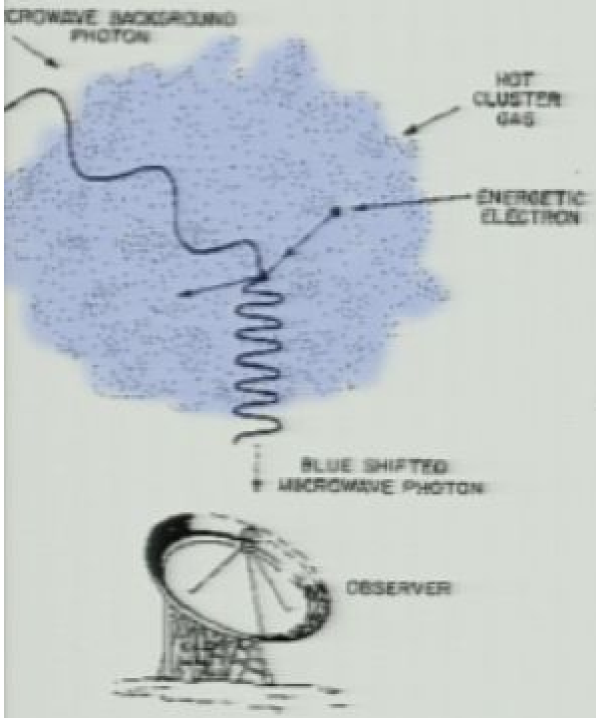
today

Using the CMB as a backlight, study structure as it was forming

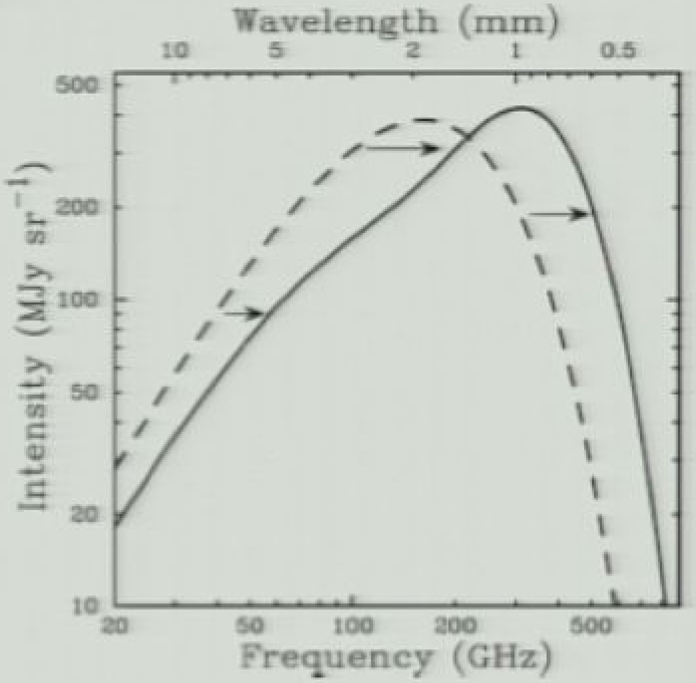
Structure formation tells us about Dark Energy

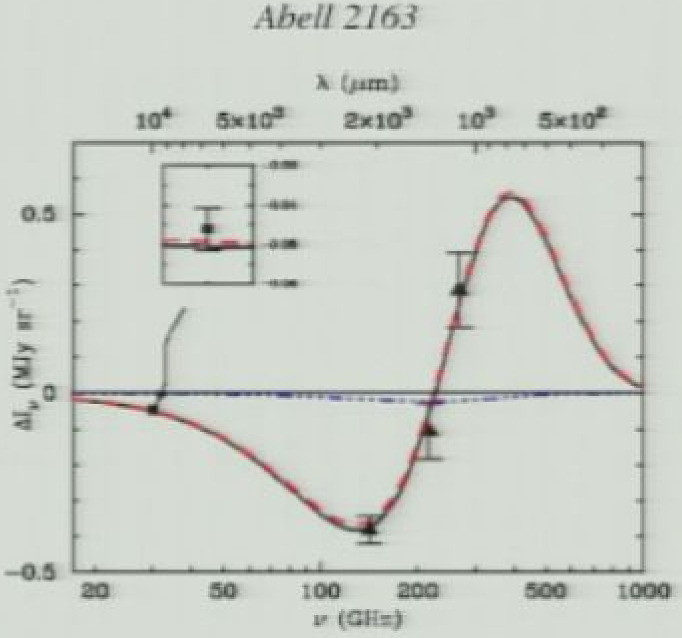
Sunyaev-Zel'dovich (SZ) Effect

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



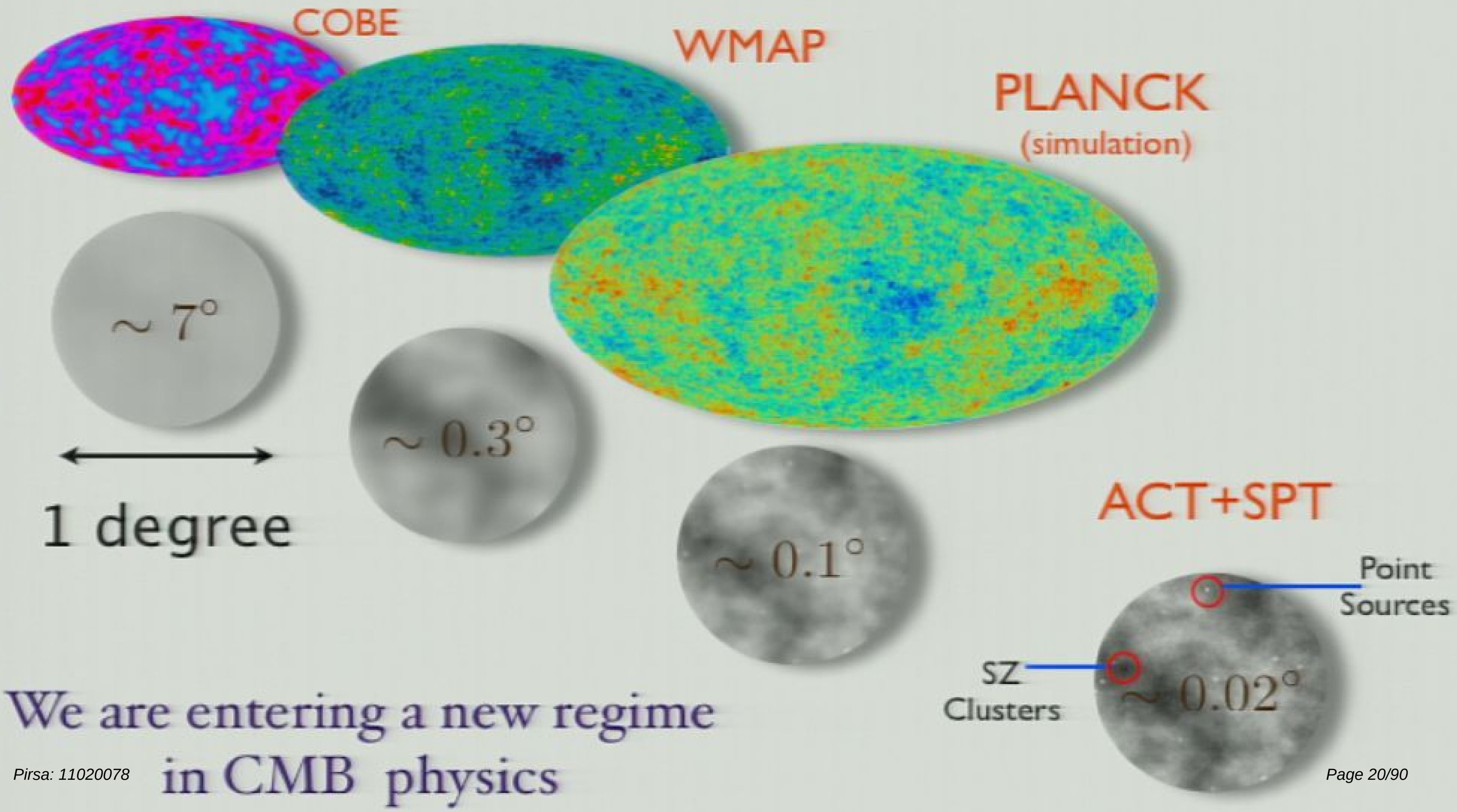


Redshift independent

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

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

New Generation of Microwave Observations



We are entering a new regime in CMB physics

ACT and SPT

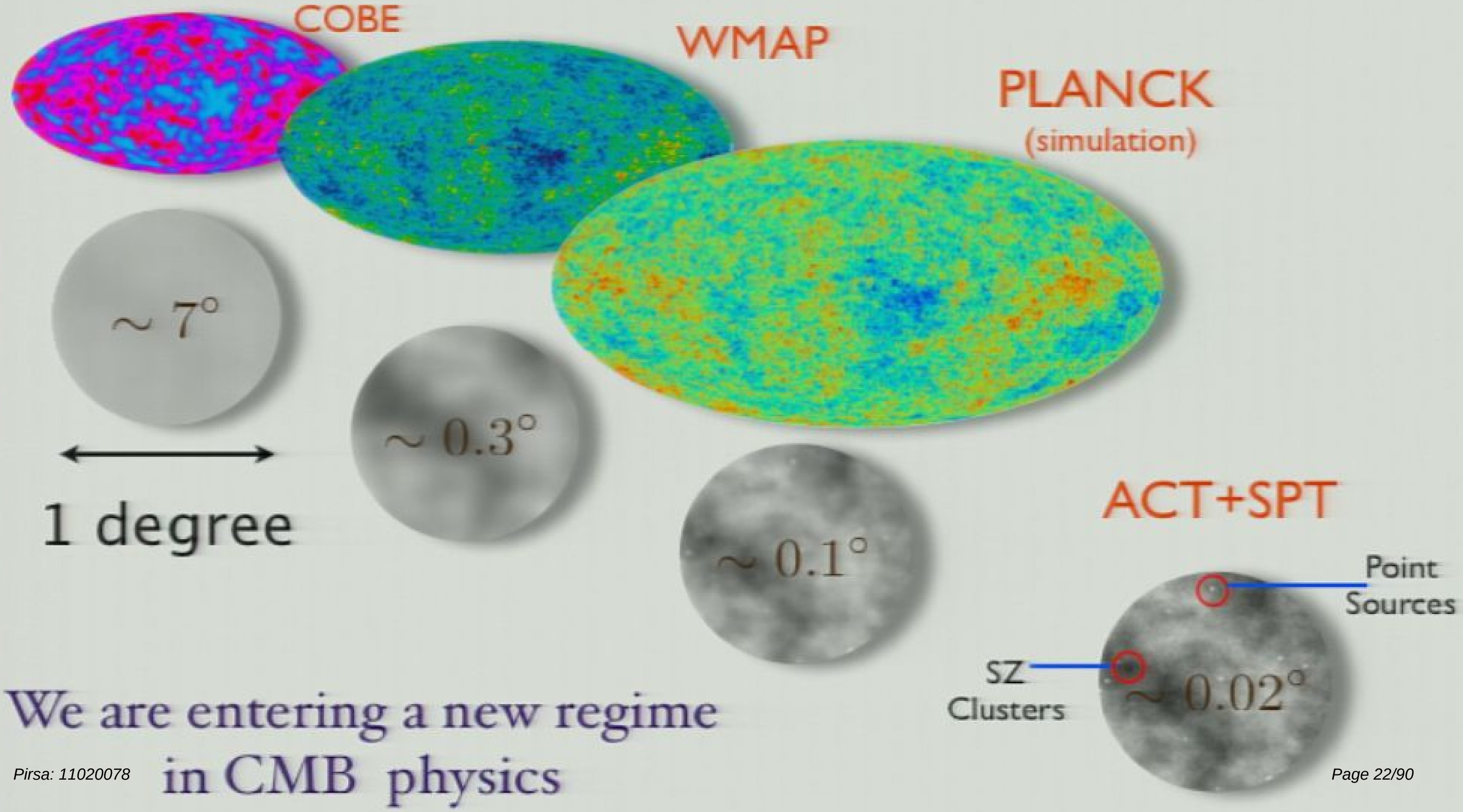
Atacama Cosmology Telescope (ACT)
in the Atacama desert in Chile.

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

South Pole Telescope (SPT)
at the South Pole.

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

New Generation of Microwave Observations



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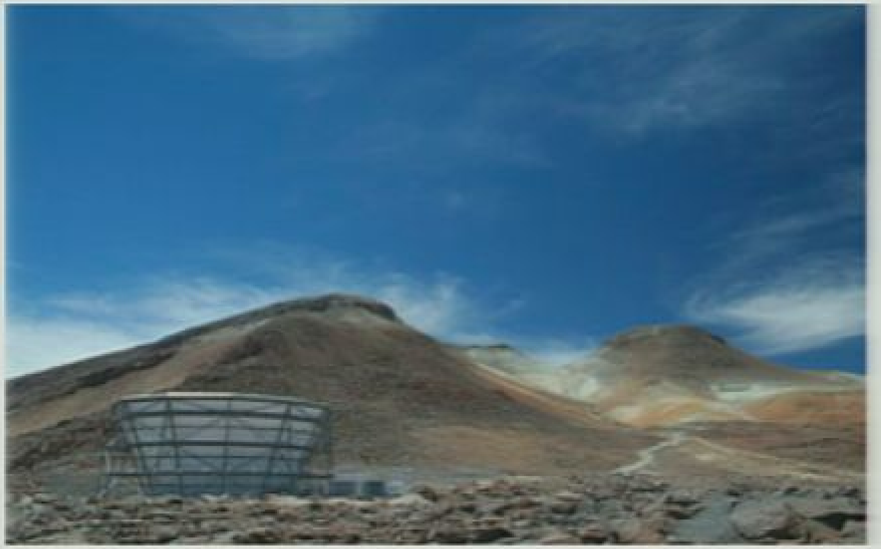
ACT and SPT



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

South Pole Telescope (SPT)
at the South Pole.

Main institutions:
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U. of Toronto, U. of British Columbia,
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Western, C.U. Boulder, Harvard-CfA,
Jet Propulsion Lab, U.C. Davis, McGill

Overview

- Cluster Surveys as an Important Cosmological Probe
- First Cosmology Constraints from Atacama Cosmology Telescope Cluster Sample
- Cluster Power Spectrum as a Complementary Cosmological Probe and Future Prospects

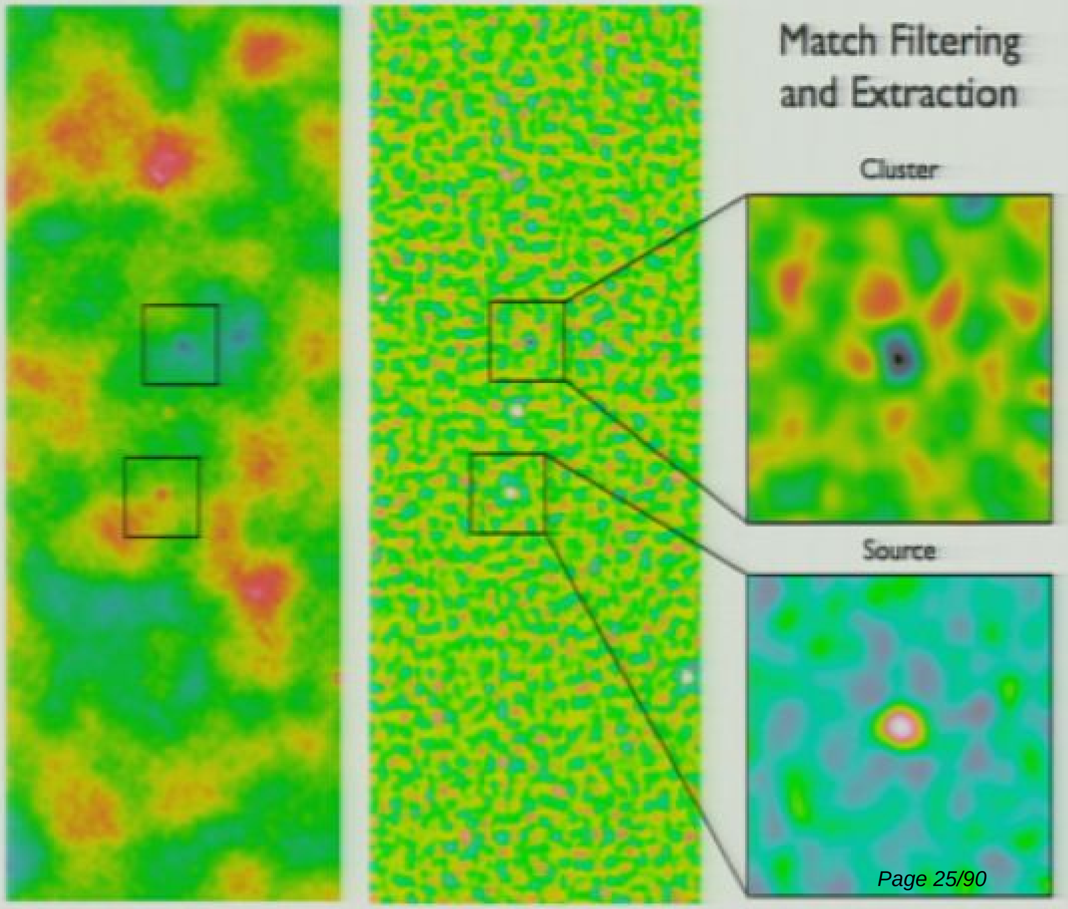
Atacama Cosmology Telescope

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

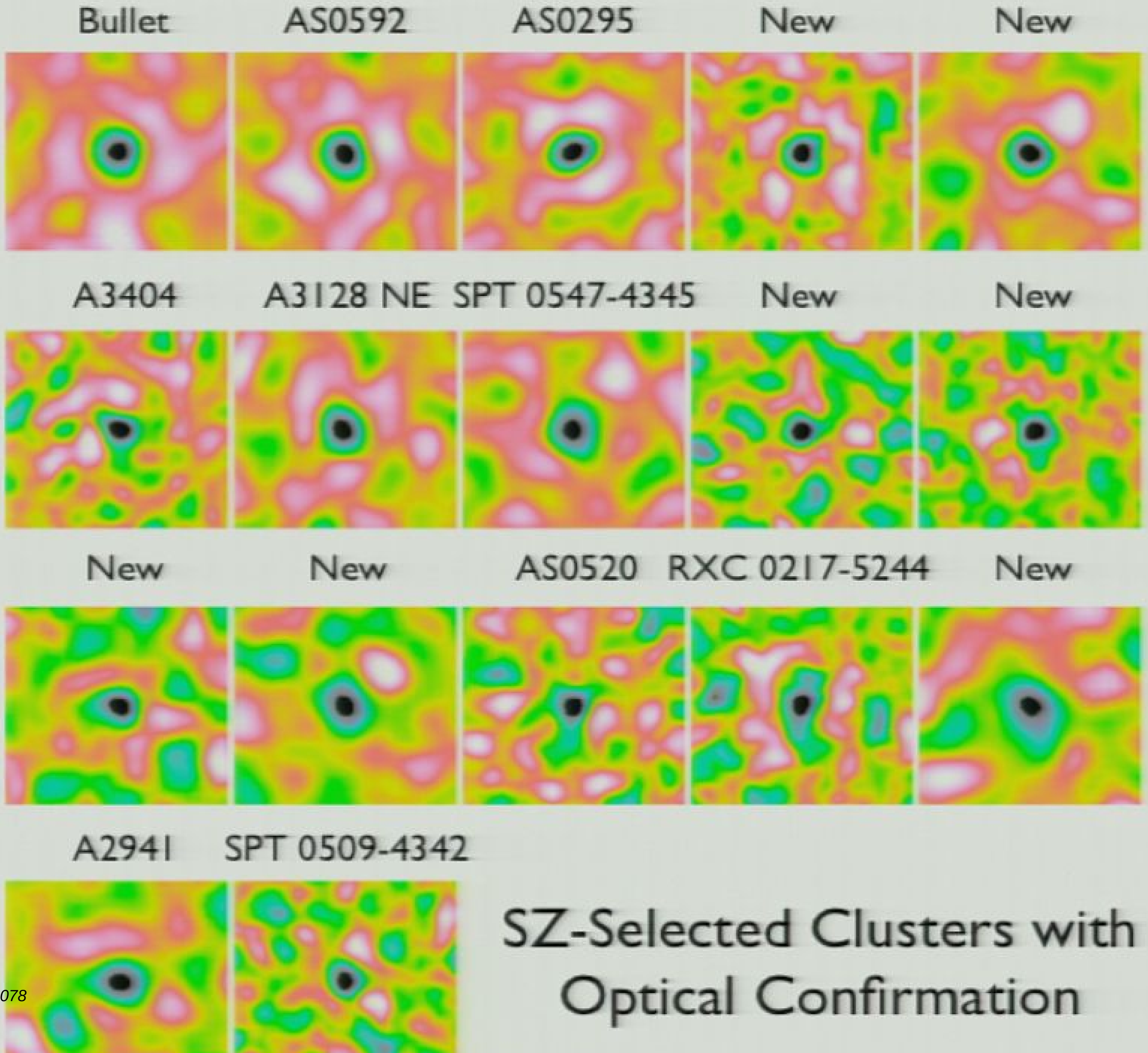
23 clusters detected
~50% are new

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

455 square degrees surveyed
in 2008 at 148 GHz



GHz
008
ata



New
Cluster
Fraction:
50 %

SZ-Selected Clusters with Optical Confirmation

ACT High-Significance Cluster Sample

9 clusters above 300 μK

measured within fixed aperture of 0.5 arcmin

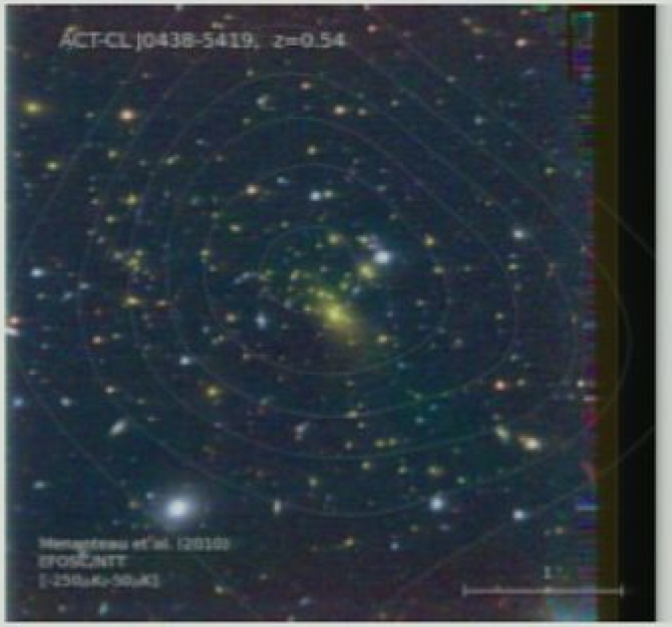
ACT CLUSTER CATALOG FOR HIGH-SIGNIFICANCE CLUSTERS FROM THE 2008 OBSERVING SEASON

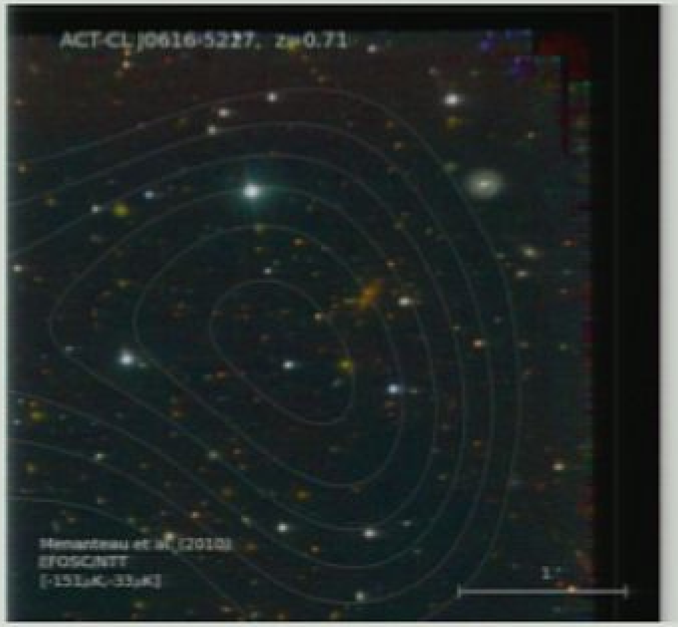
ACT Descriptor	R.A.	decl.	$yT_{\mathrm{CMB}}(\mu\mathrm{K})^{\dagger}$	Redshift	Other Name
ACT-CL J0645–5413	06:45:30	–54:13:39	340 ± 60	0.167[a]	Abell 3404
ACT-CL J0638–5358	06:38:46	–53:58:45	540 ± 60	0.222[a]	Abell S0592
ACT-CL J0658–5557	06:58:30	–55:57:04	560 ± 60	0.296[b]	1ES0657–558(Bullet)
ACT-CL 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

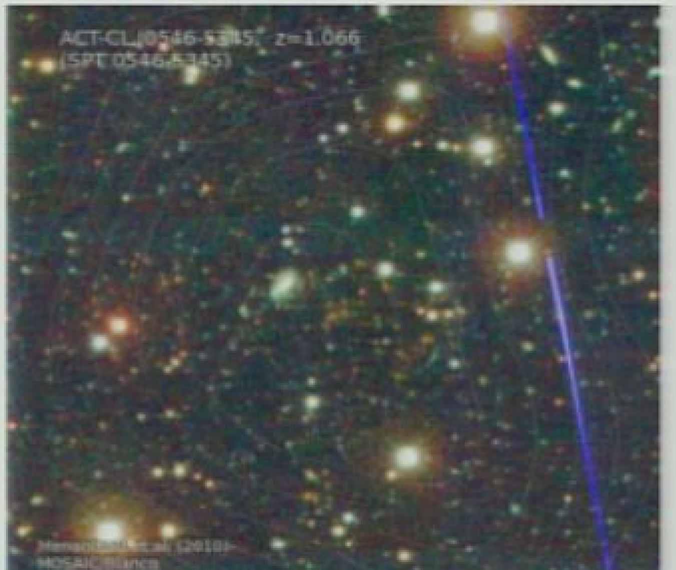
Clusters with $z > 0.5$ have been discovered with SZ

Sehgal et al., 2010, arXiv:1010.1025

High-z Clusters Discovered with SZ







Cosmology from Cluster Sample

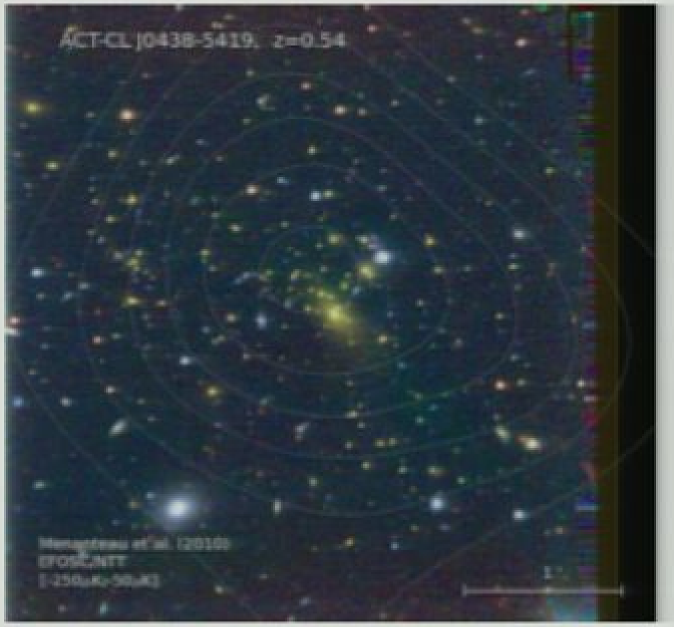
For cosmology we need:

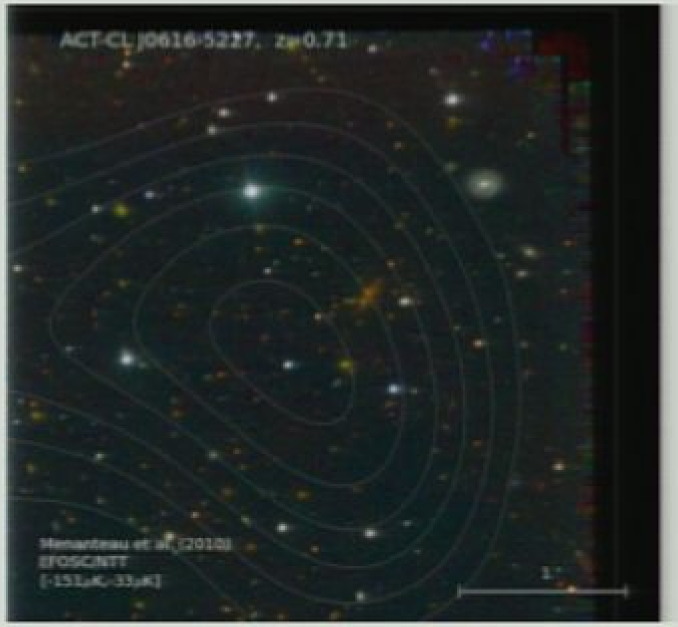
1.) Completeness of Sample - are we missing clusters?

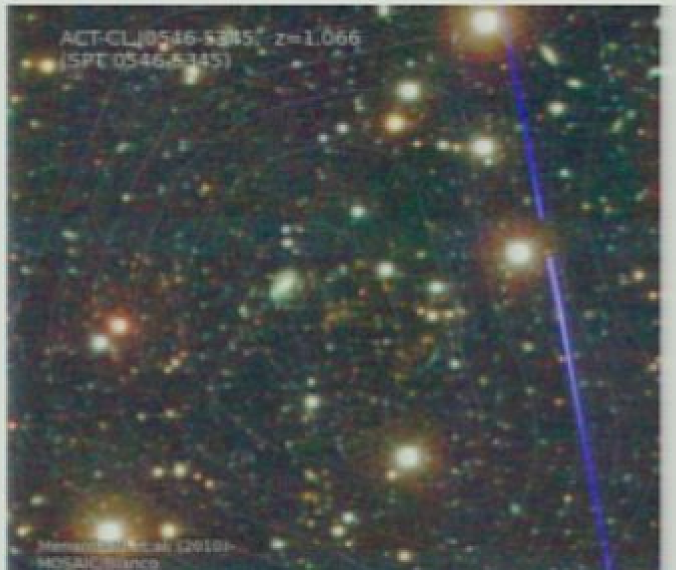
2.) Relation between SZ signal and mass

We answer these questions
with simulations

High-z Clusters Discovered with SZ







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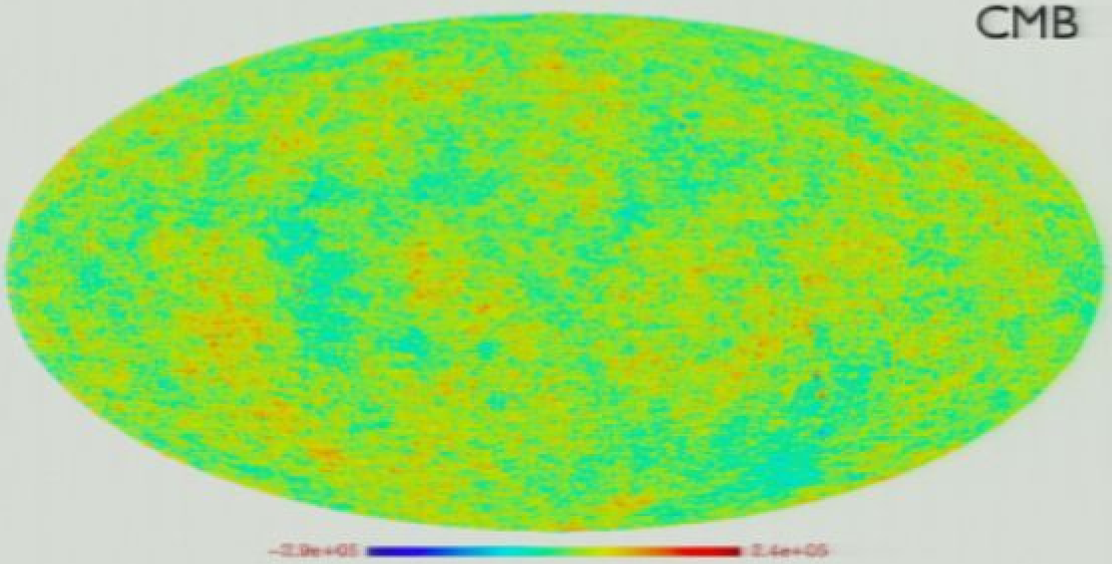
Simulations of the Microwave Sky

Lensed
CMB



Simulations are public at:
ttp://lambda.gsfc.nasa.gov/
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Units: Jy/ster

N. Sehgal, P. Bode, S. Das, C. Hernandez-Monteagudo, K. Huffenberger,
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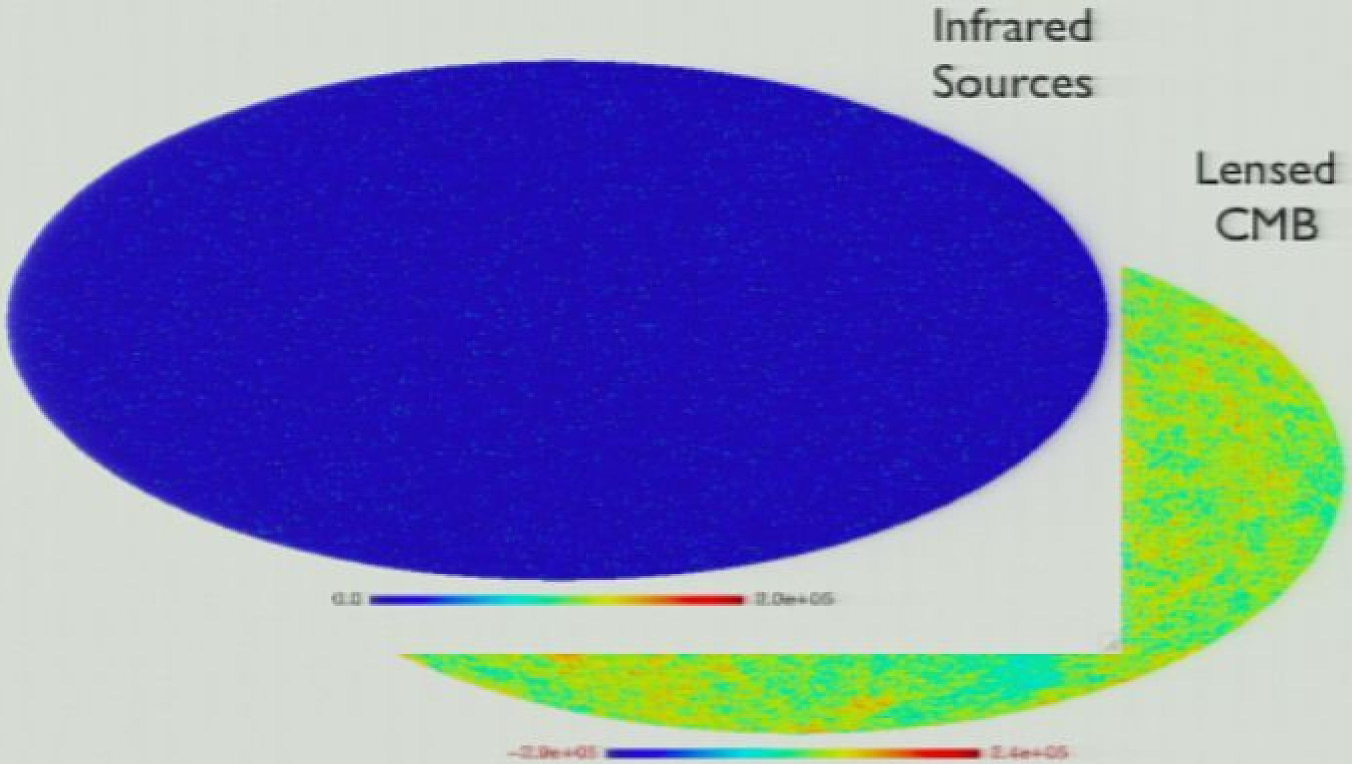

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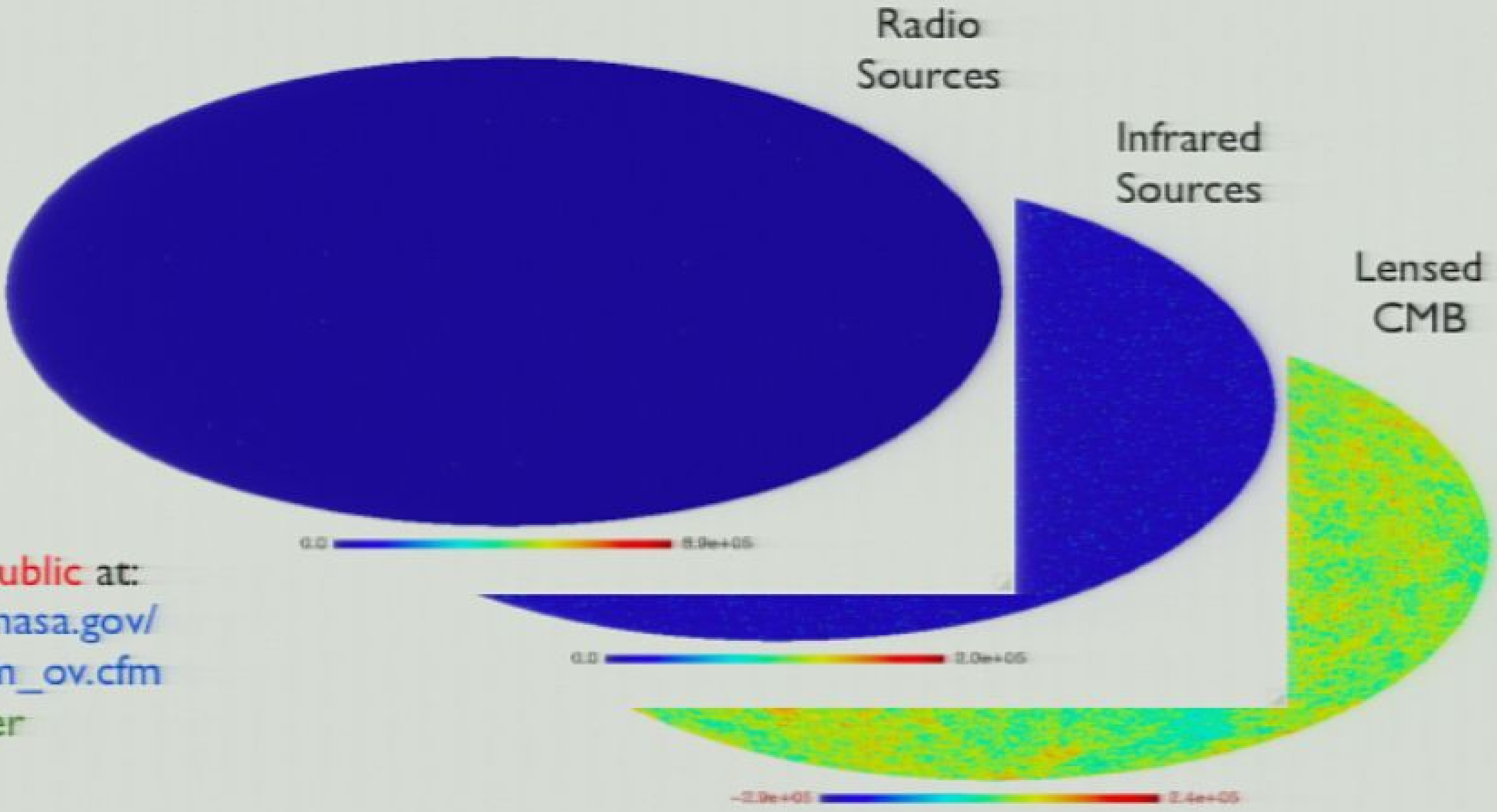

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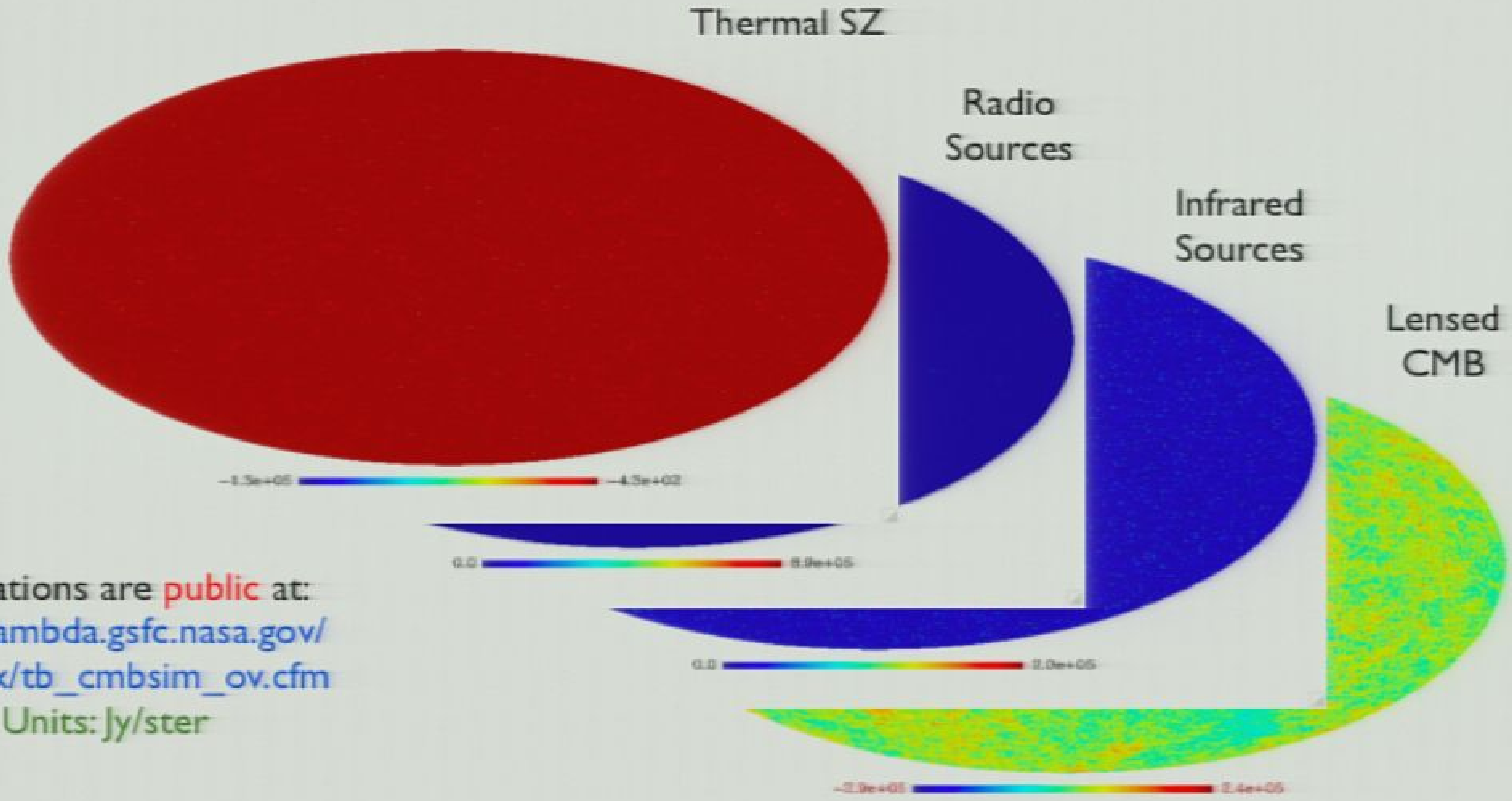

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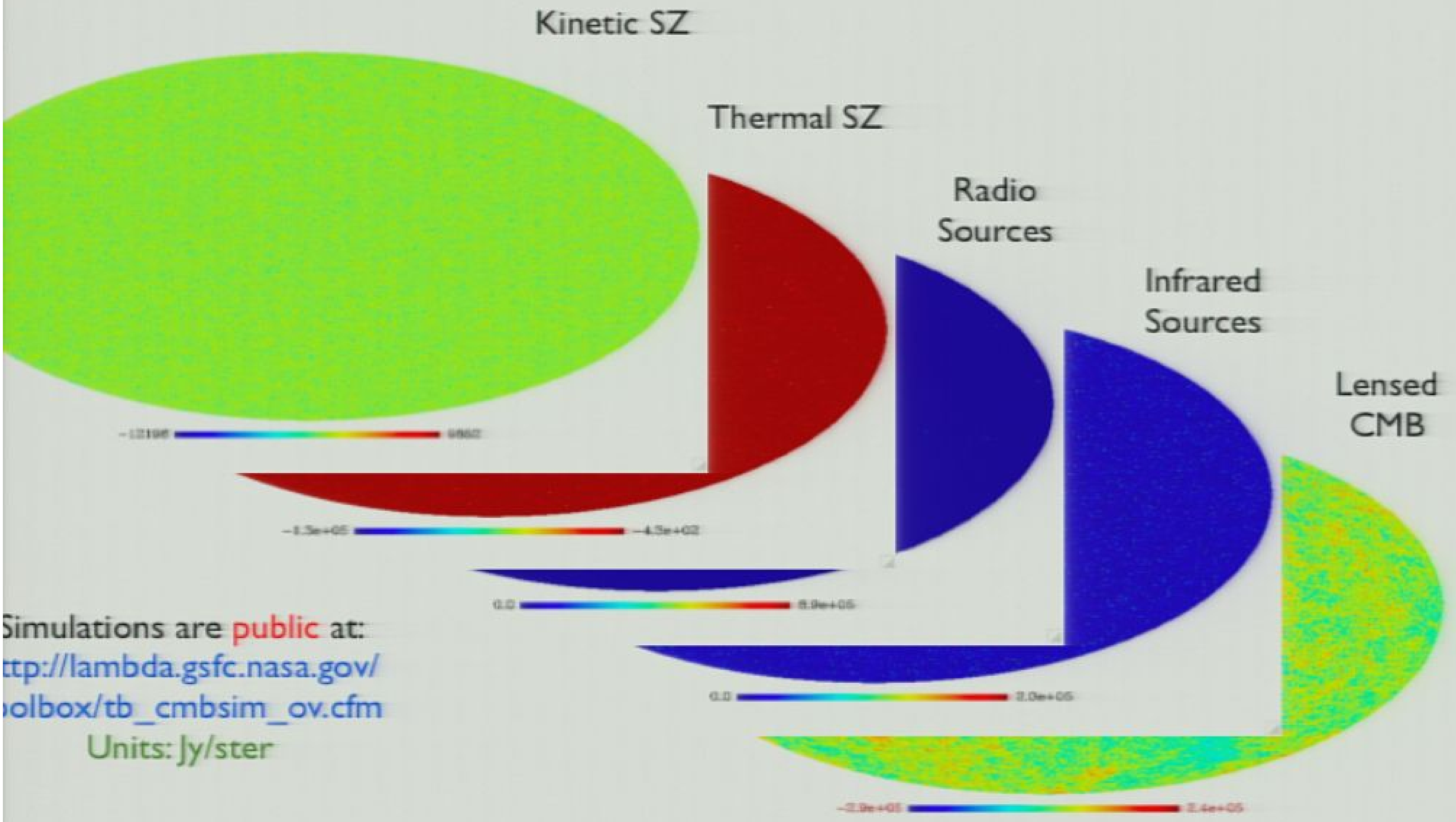

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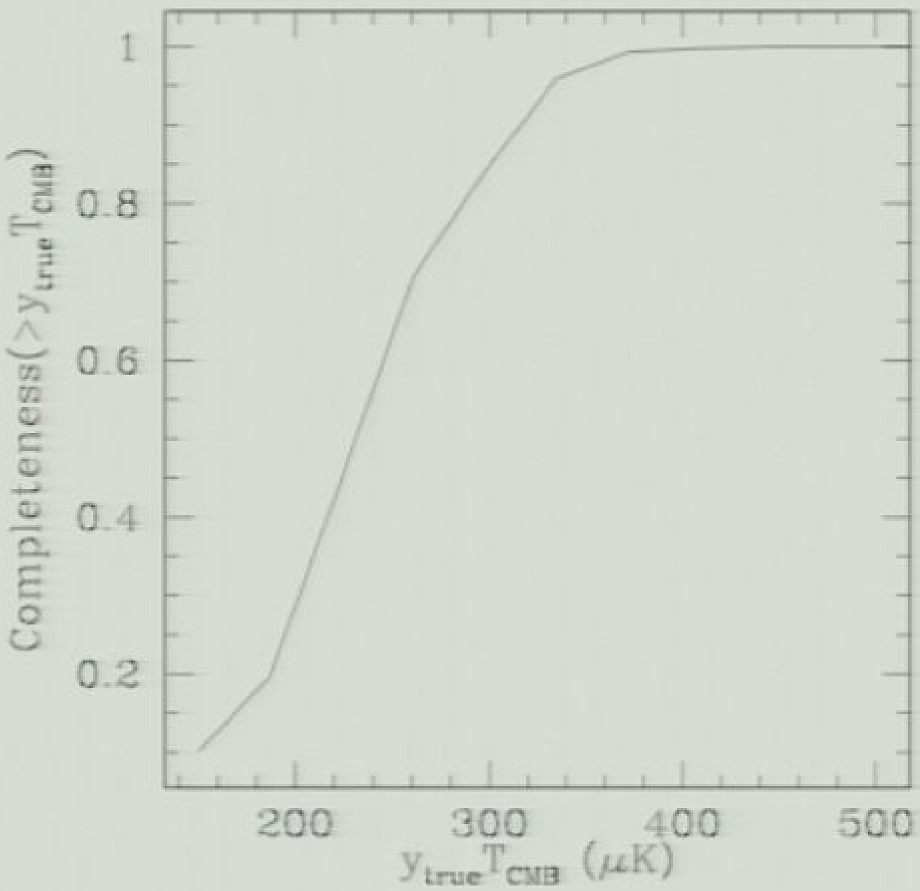
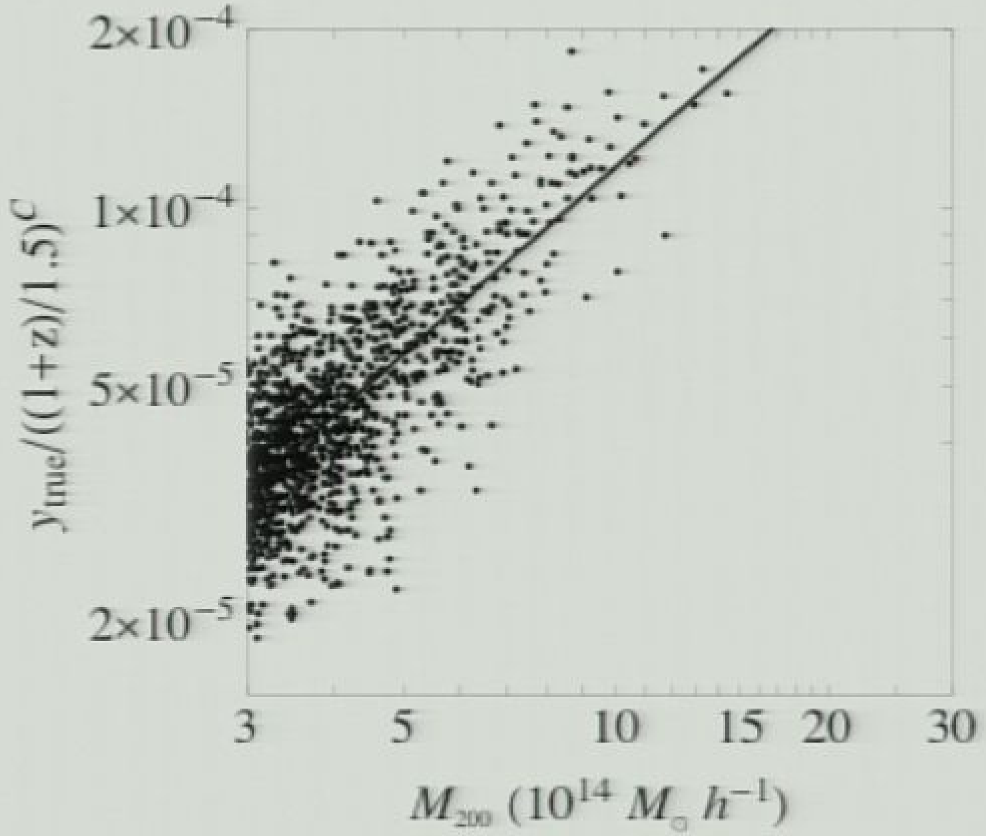
Completeness of Sample



Scaling Relation Between SZ Signal and Mass



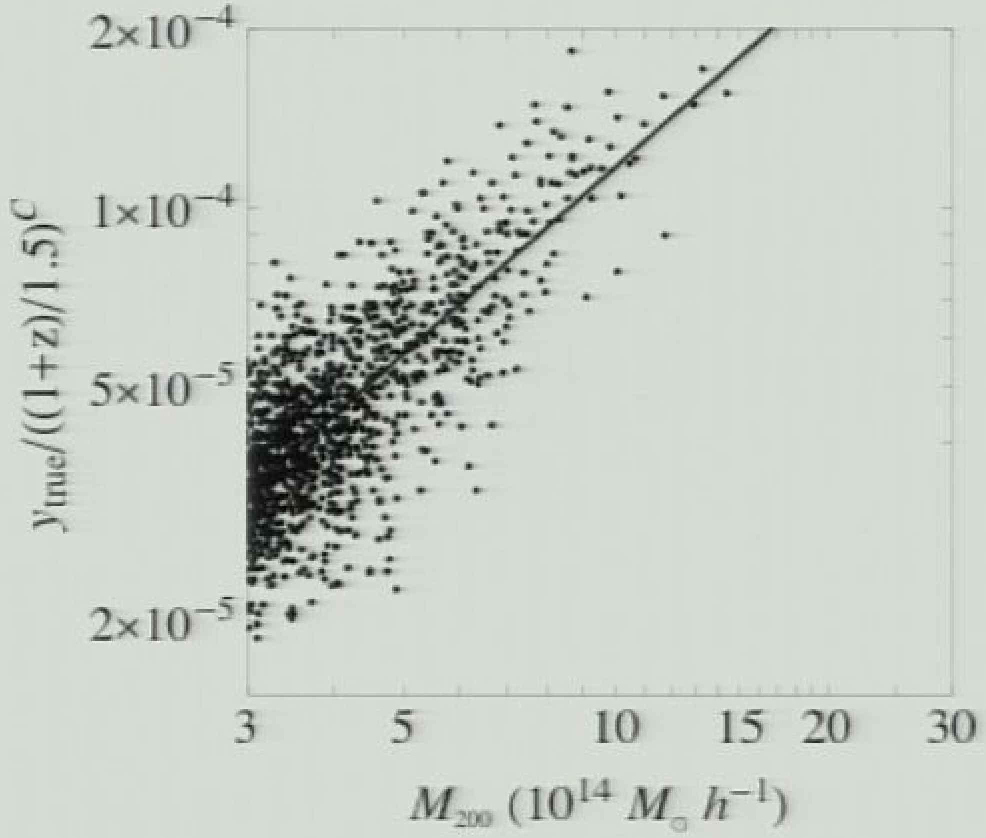
Gas model based on Bode, Ostriker, and Vikhlinin, ApJ 2009

This will be the fiducial relation

Y-M relation from simulations

Sims are from Sehgal et al. 2010

Scaling Relation Between SZ Signal and Mass



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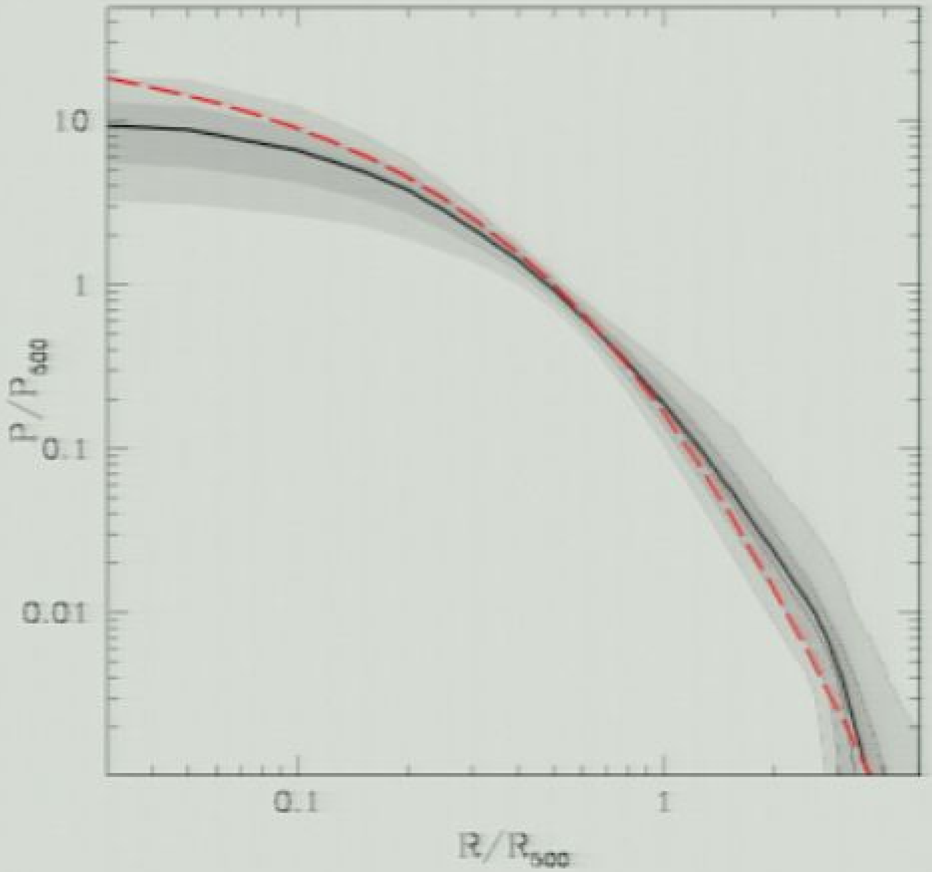
This will be the fiducial relation

Are these sims reliable?

Y-M relation from simulations

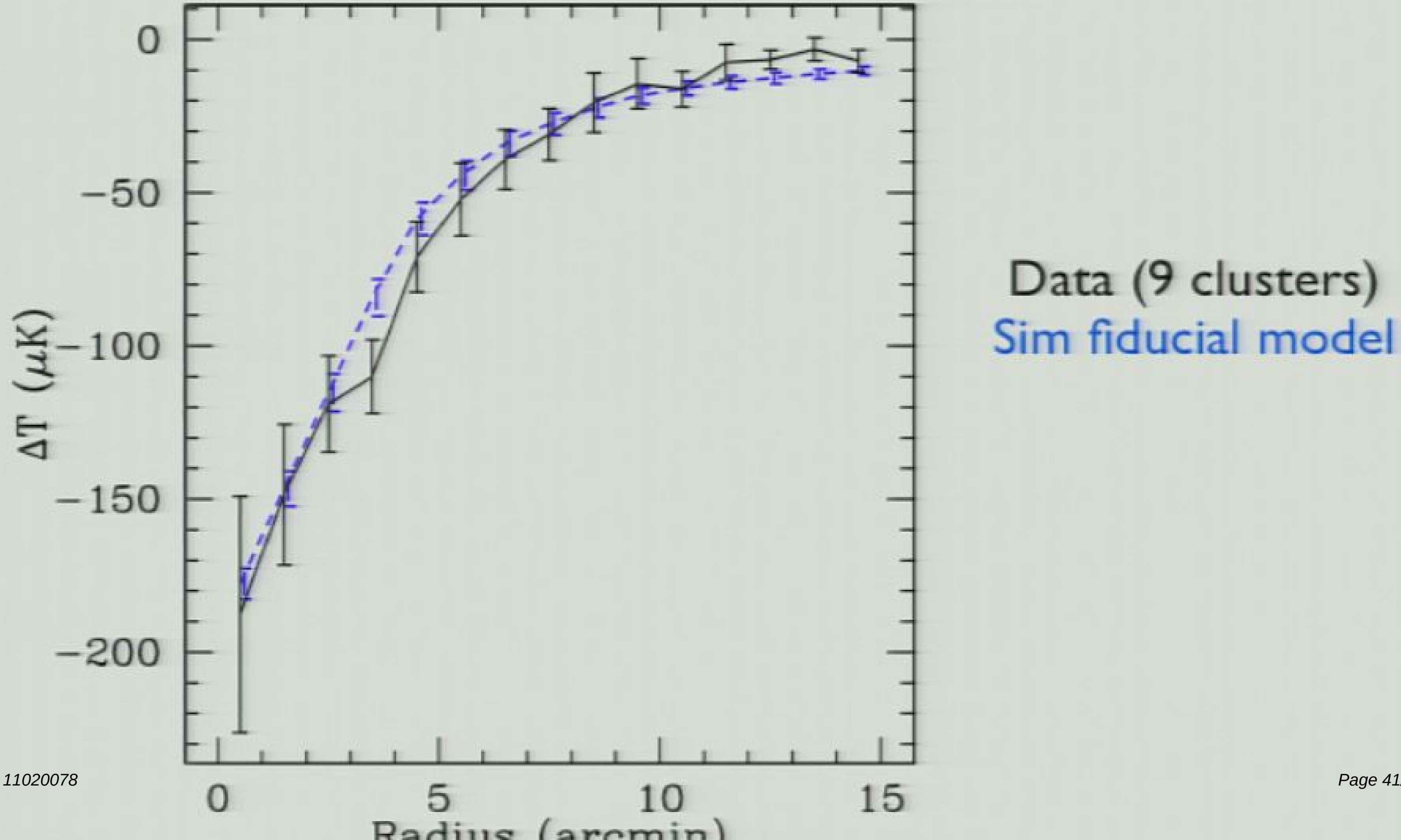
Sims are from Sehgal et al. 2010

Gas Model Matches X-ray Observations



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

Stacking the High-Significance SZ Clusters



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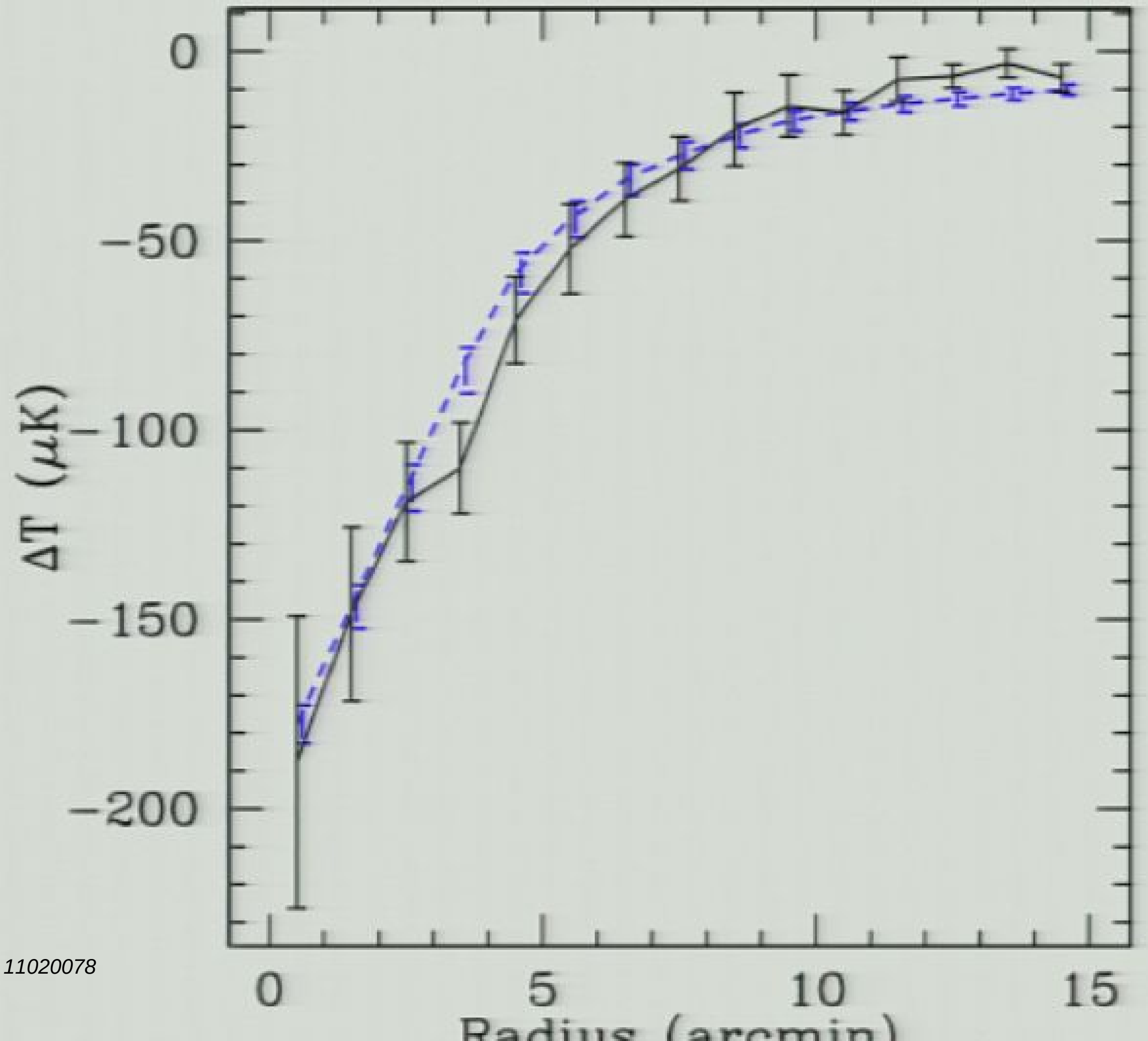

Data (9 clusters)

Sim fiducial model

$$M \propto P_{\rm grav} = P_{\rm thermal} + P_{\rm nonthermal}$$

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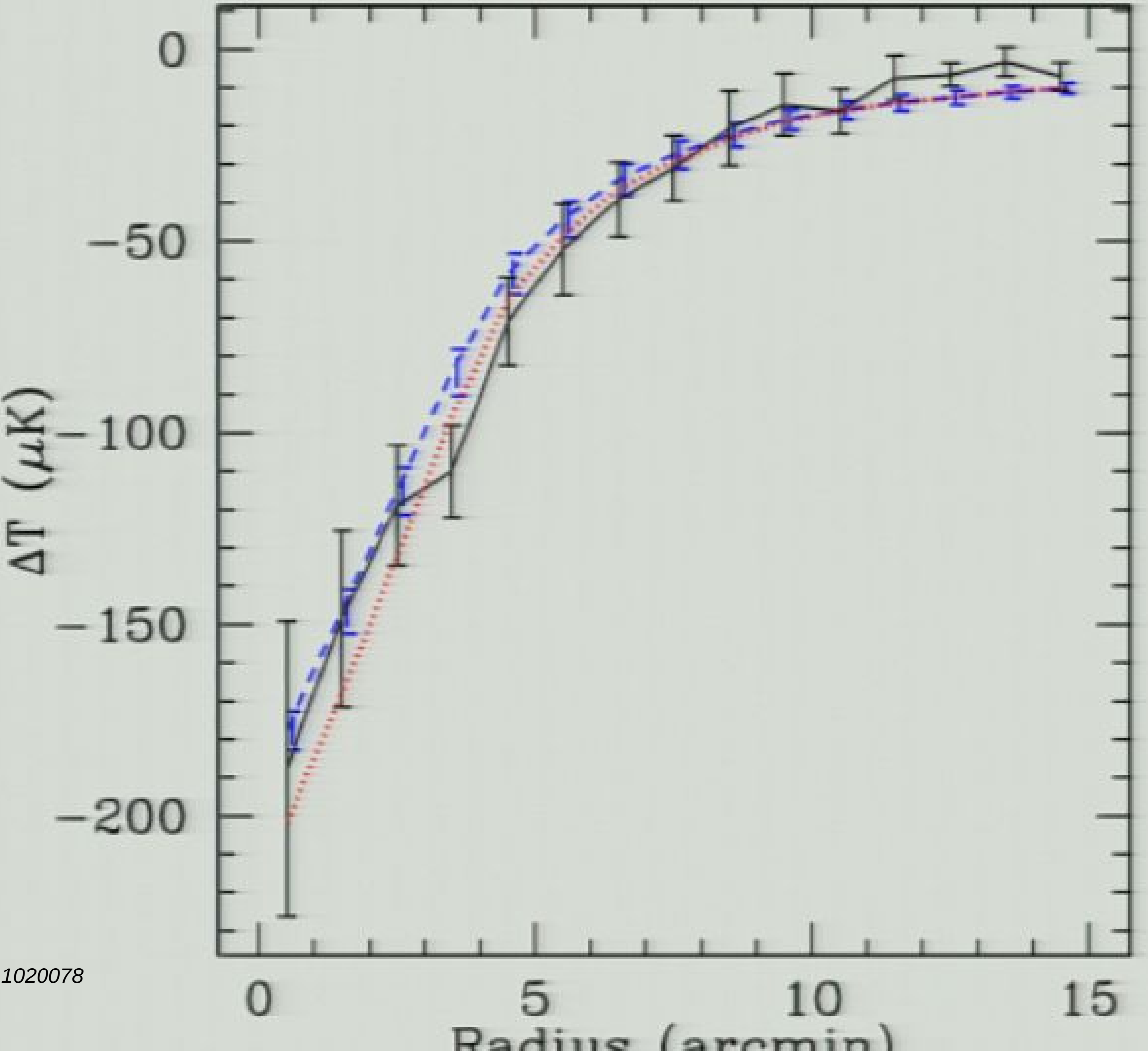

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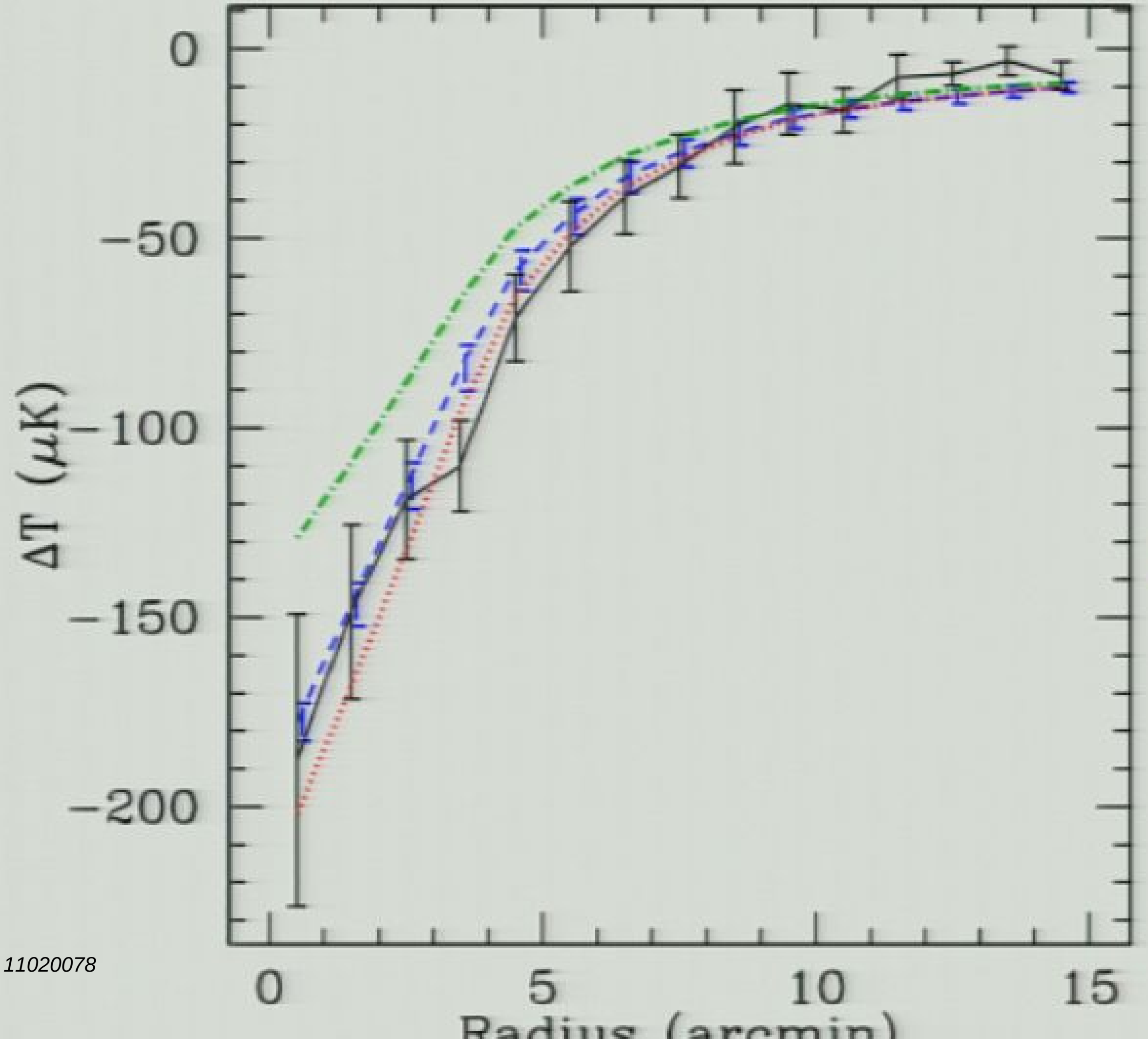

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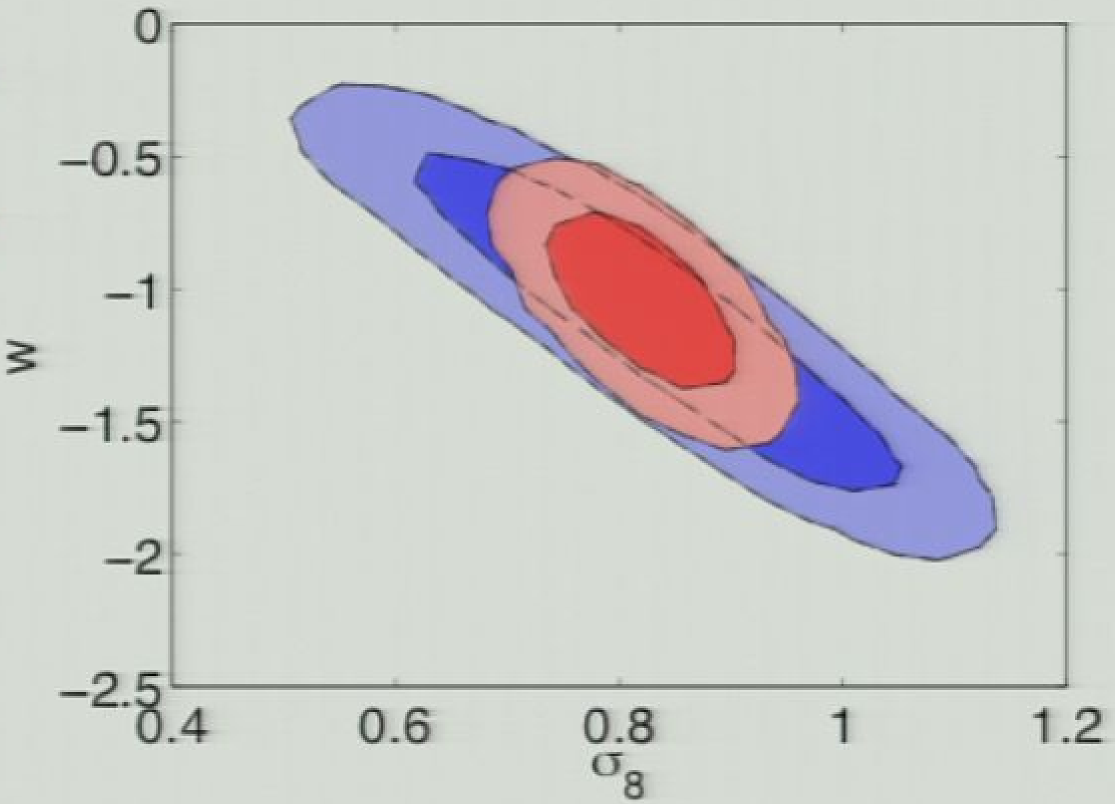
Cosmology Constraints Fixing the SZ Signal Mass Relation

VMAP7 alone

VMAP7+ ACT
Clusters



Y-M relation
fixed to
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Spatially flat
wCDM model

$$\sigma_8 = 0.821 \pm 0.044$$

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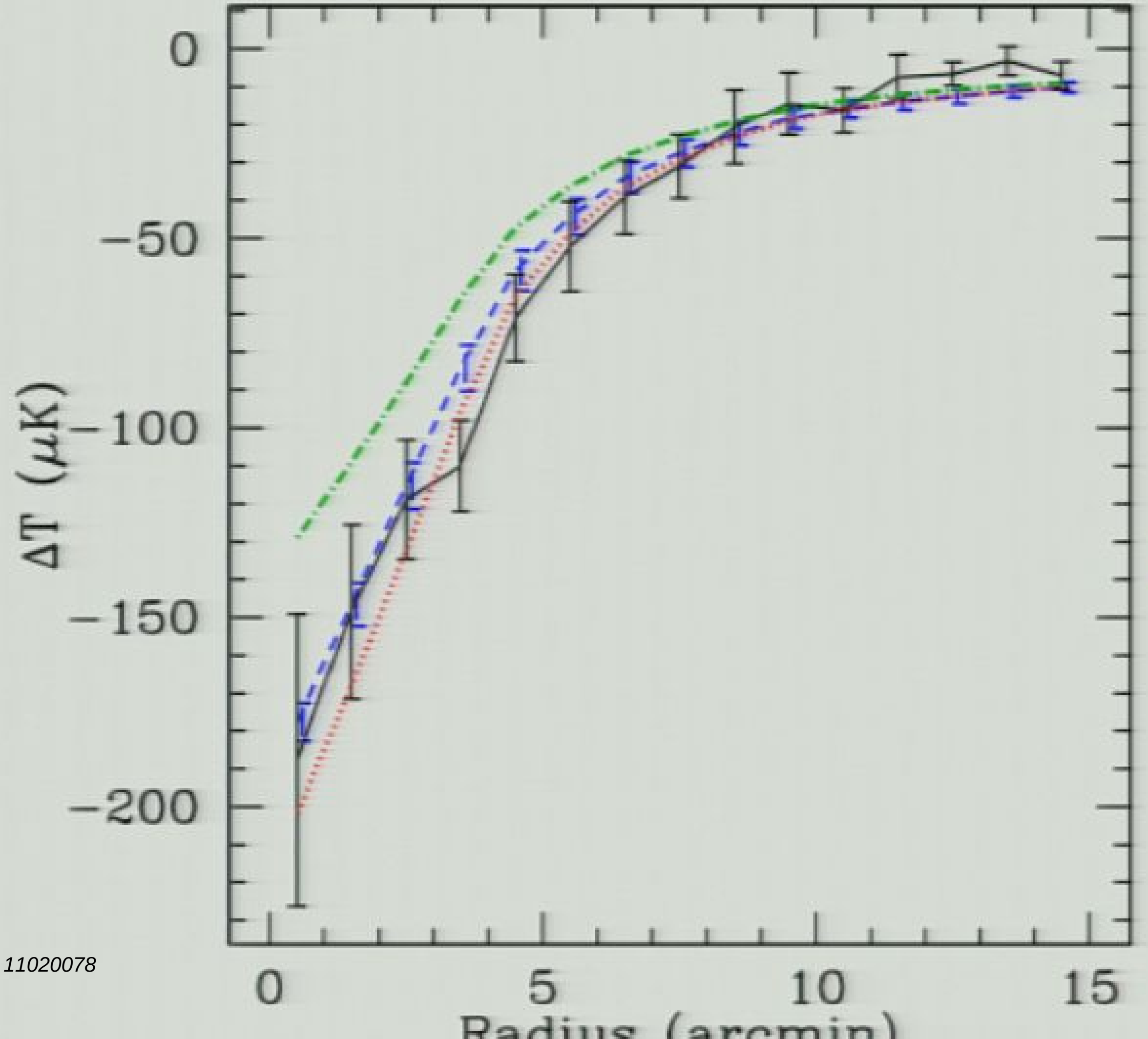

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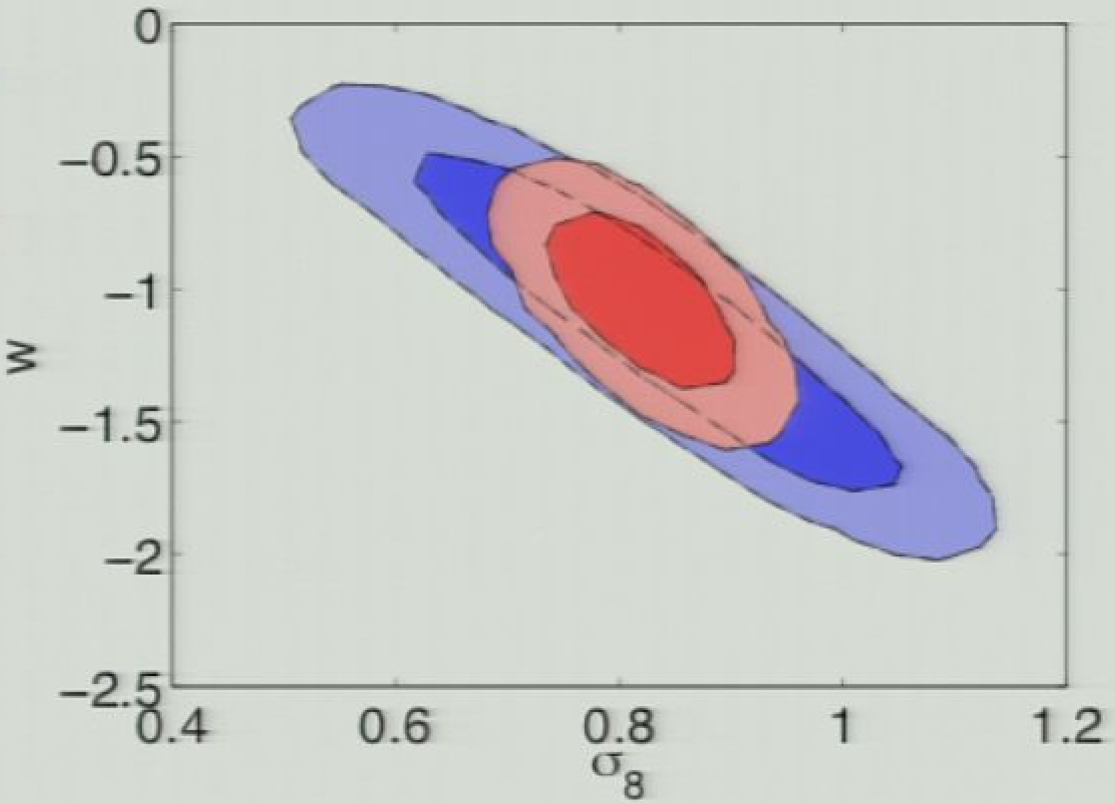

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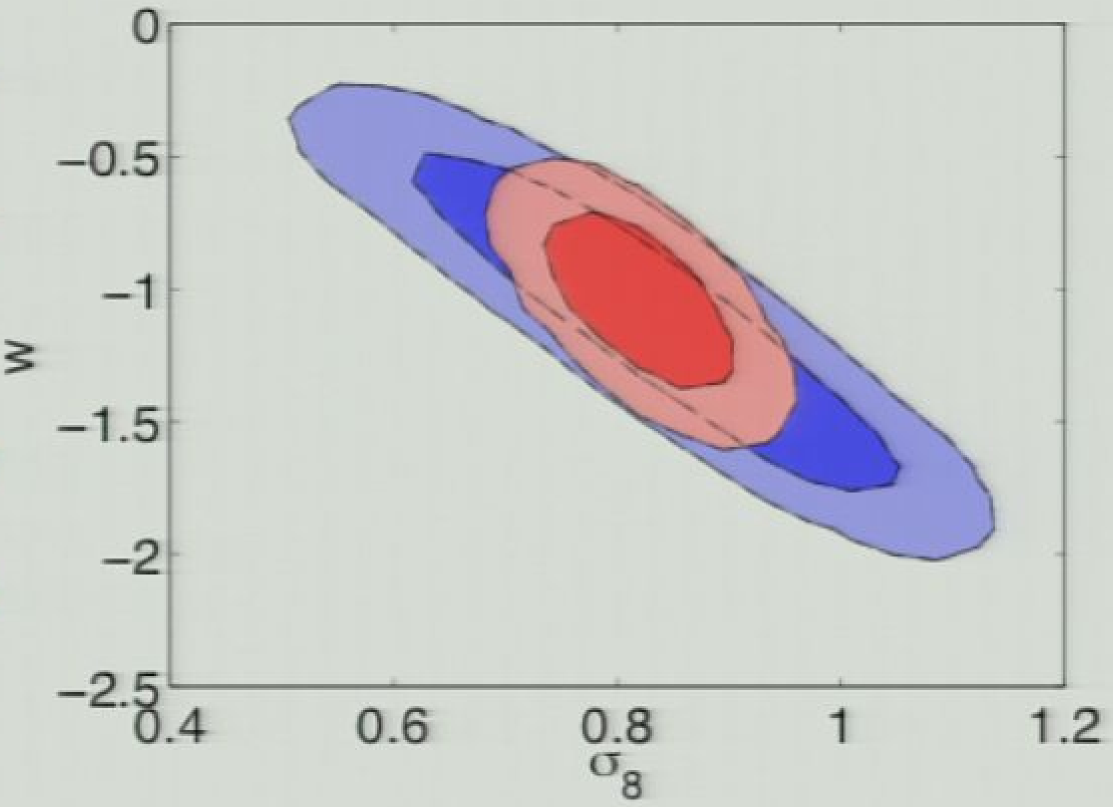

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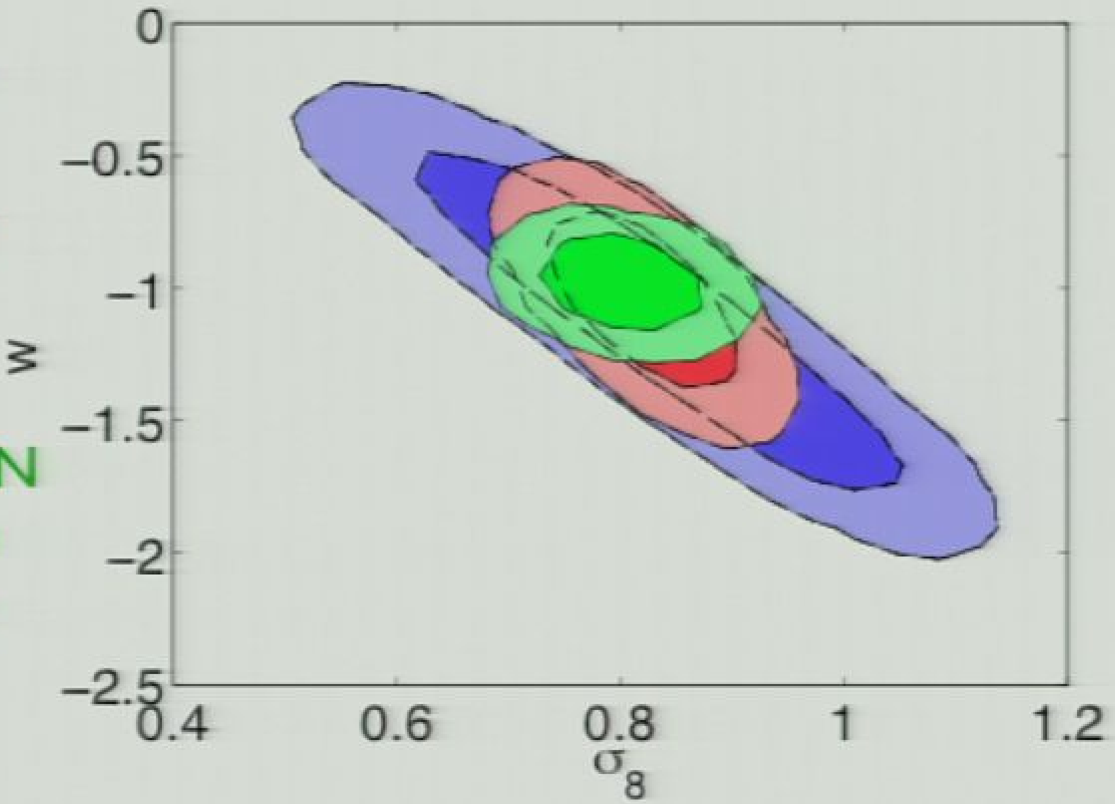

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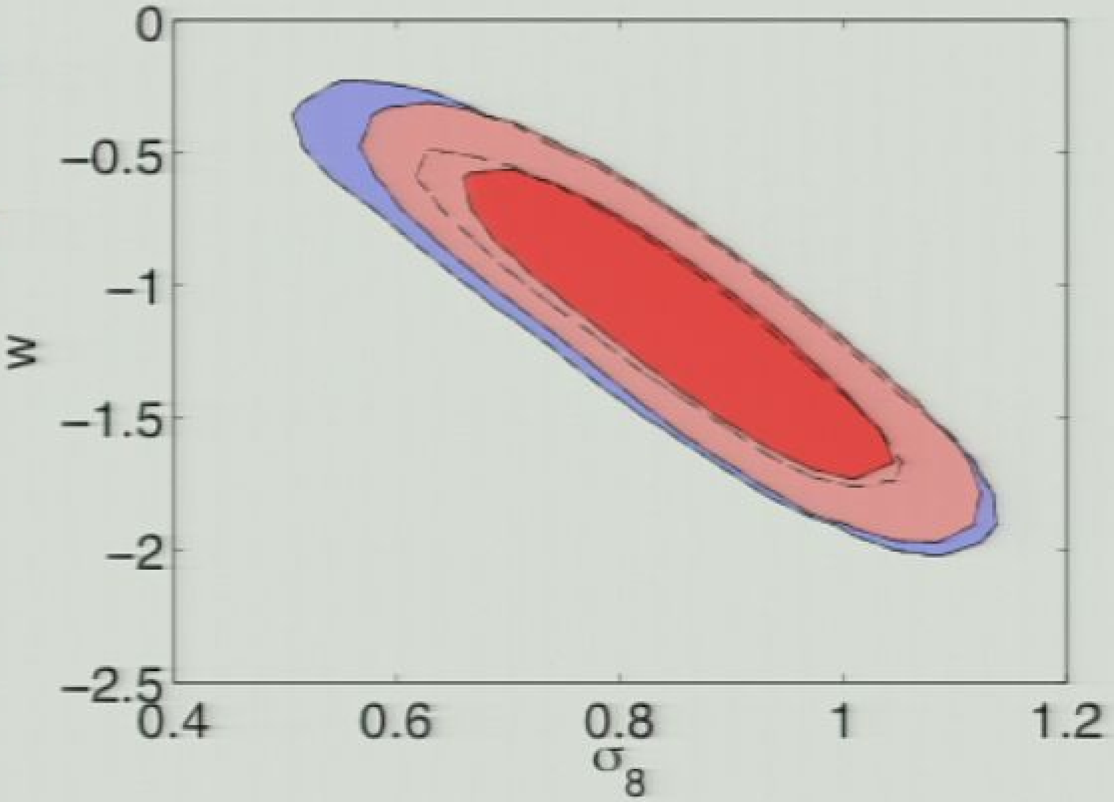
WMAP7+ ACT Clusters



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

$$\sigma_8 = 0.851 \pm 0.115$$

$$w = -1.14 \pm 0.35$$

Overview

- Cluster Surveys as an Important Cosmological Probe
- First Cosmology Constraints from Atacama Cosmology Telescope Cluster Sample
- Cluster Power Spectrum as a Complementary Cosmological Probe and Future Prospects

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For SZ cluster counts and SZ power spectrum to be robust probes of cosmology, need to understand cluster astrophysics

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

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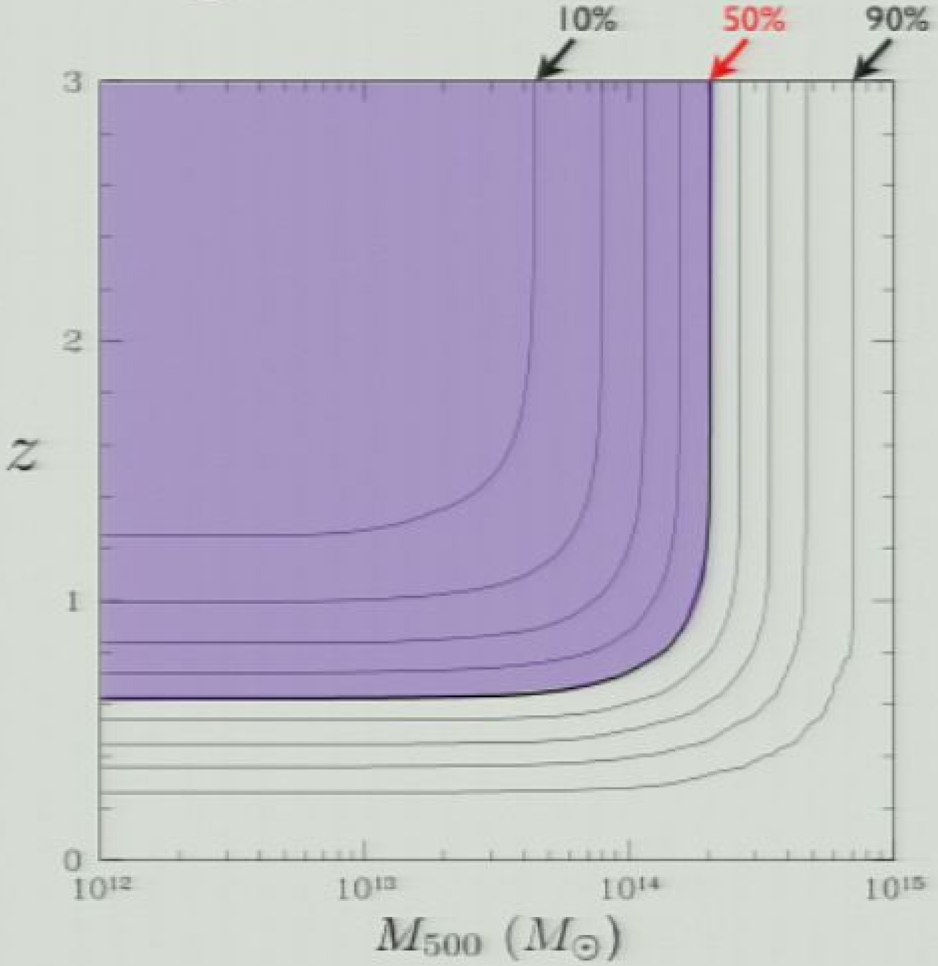

Contribution to SZ power: clusters with mass $< 2 \times 10^{14}$ and z > 0.6 give 50% of the power

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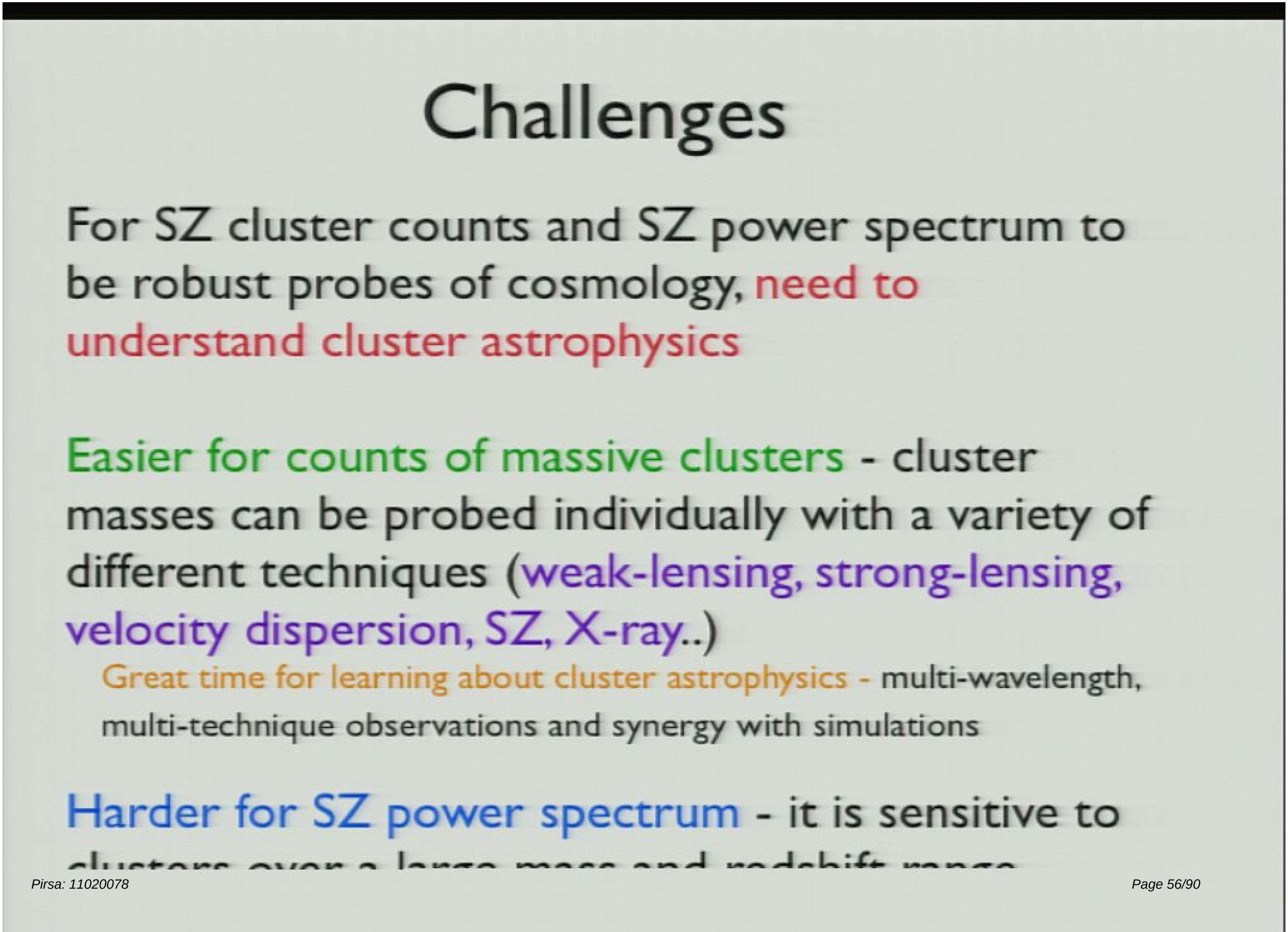

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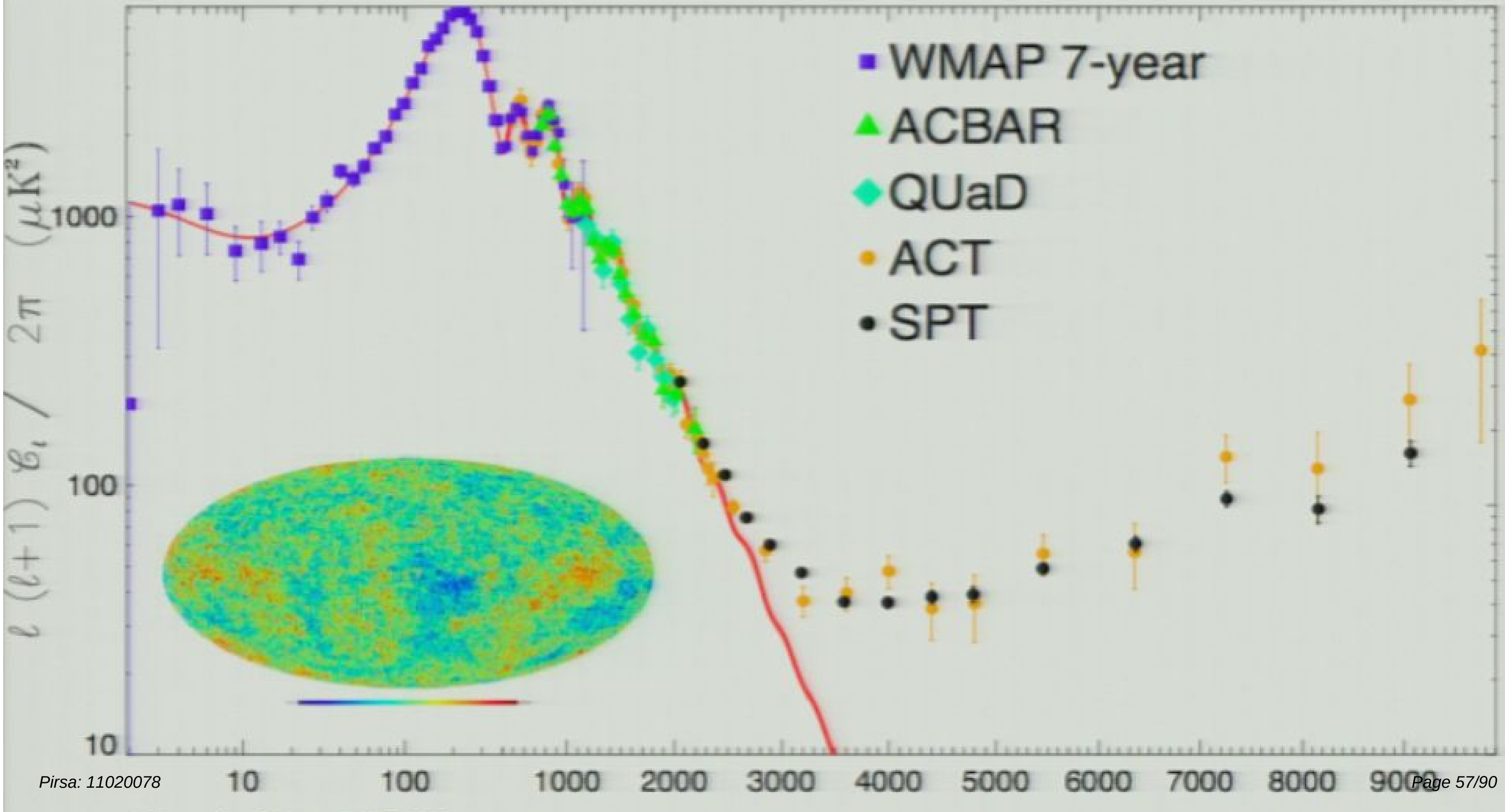

Shirokoff et al. 2010

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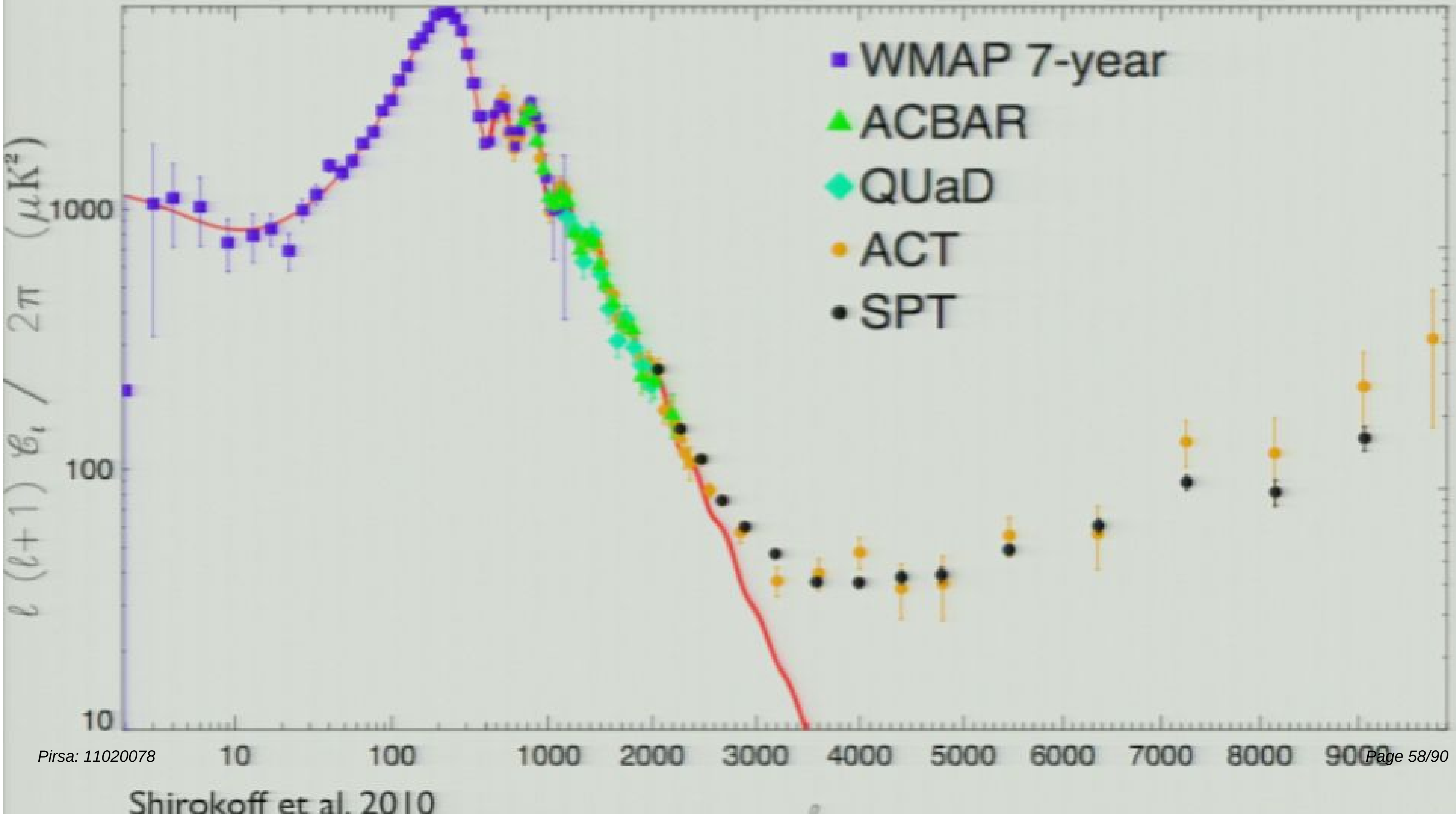

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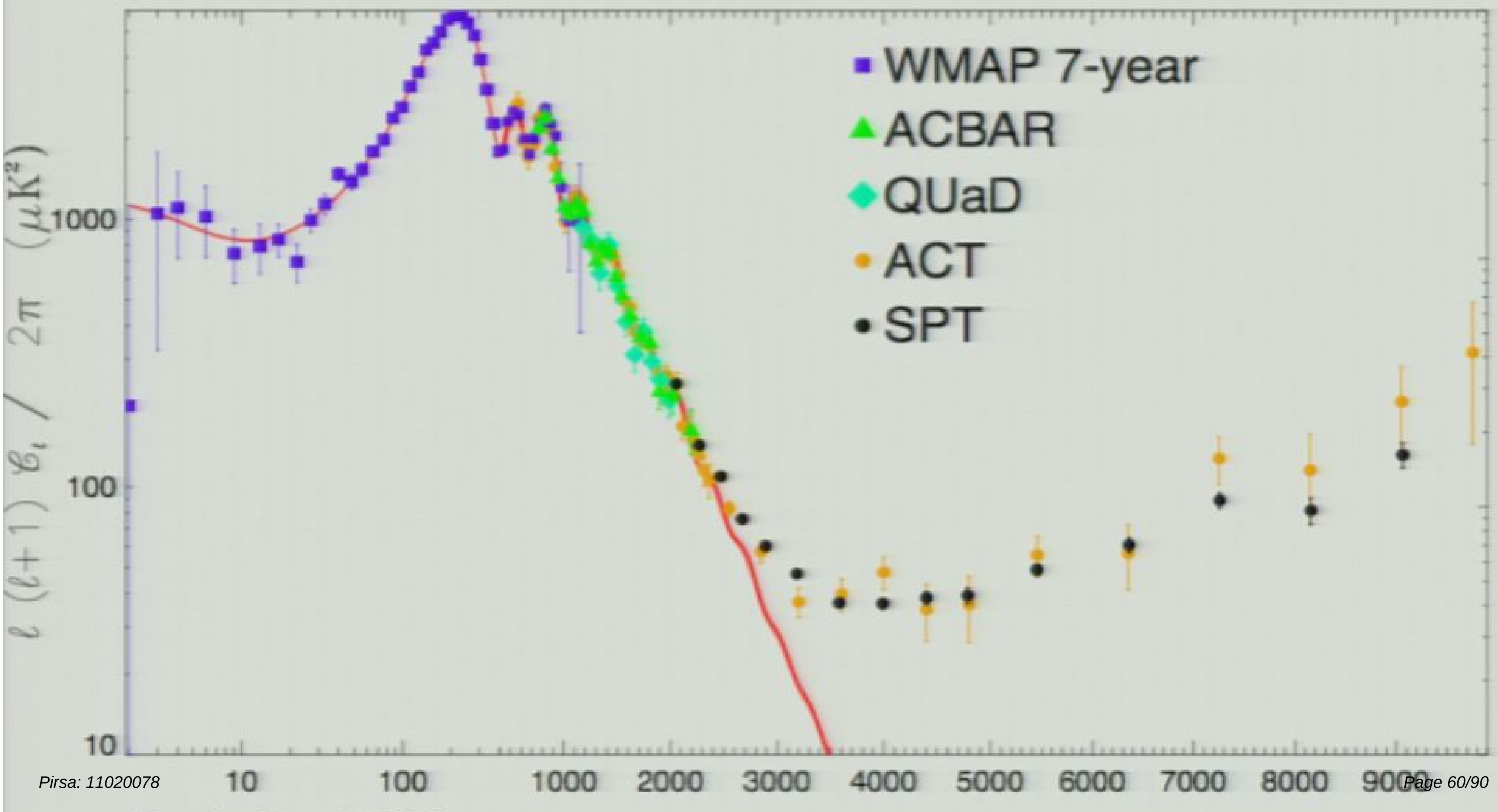

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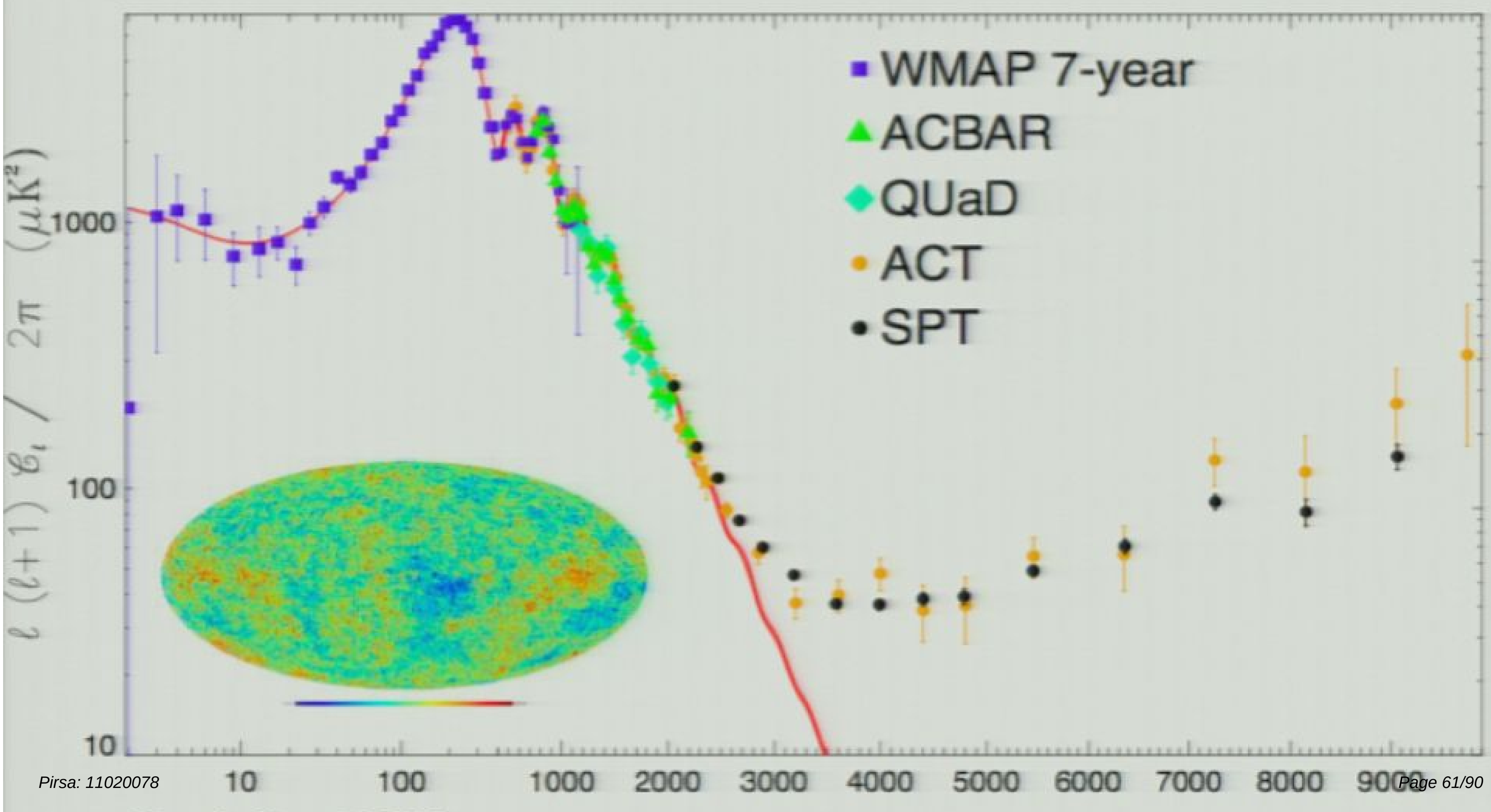

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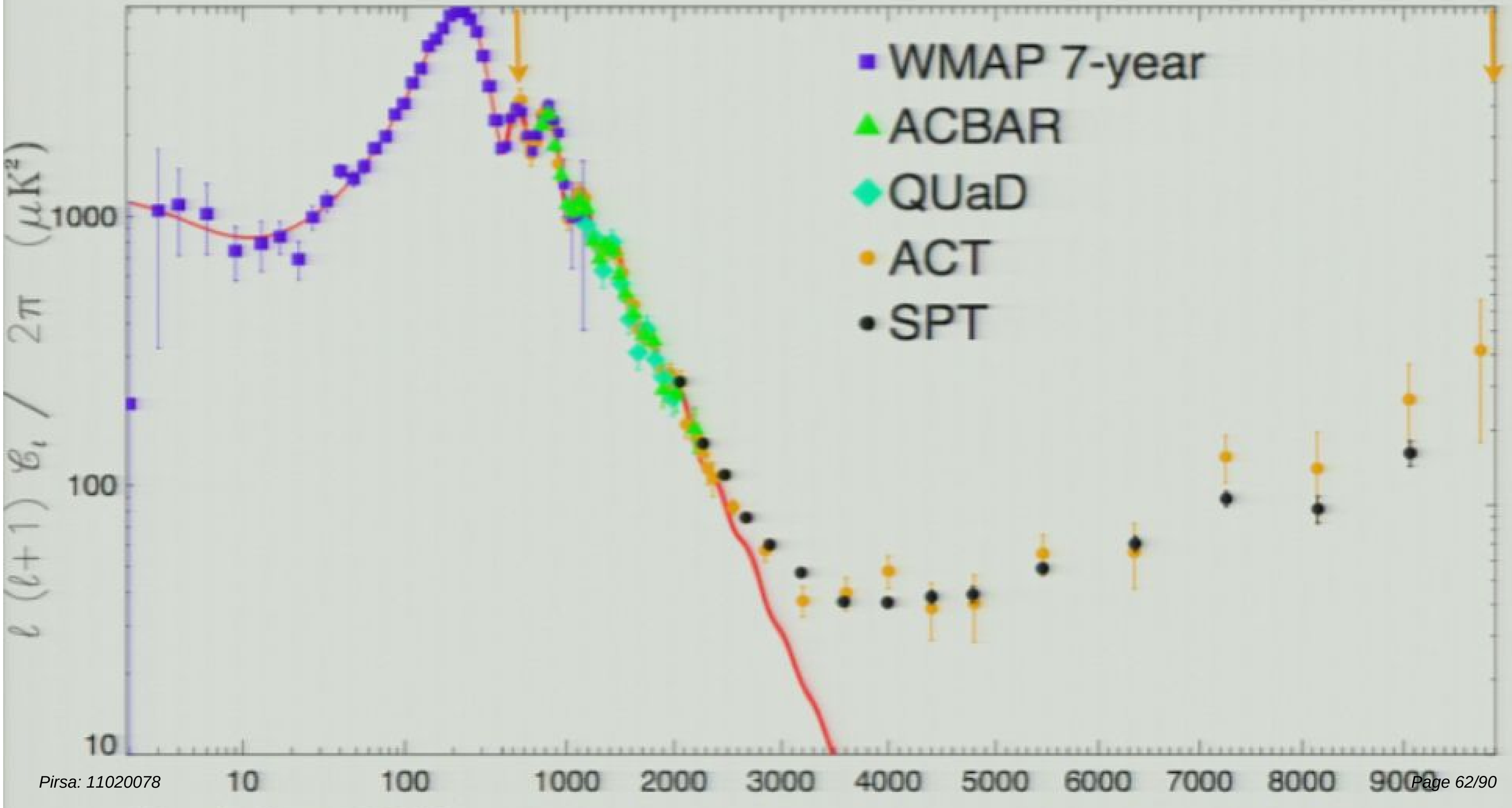
CMB Power Spectrum

ACT spectrum from ℓ =500 to 10,000!



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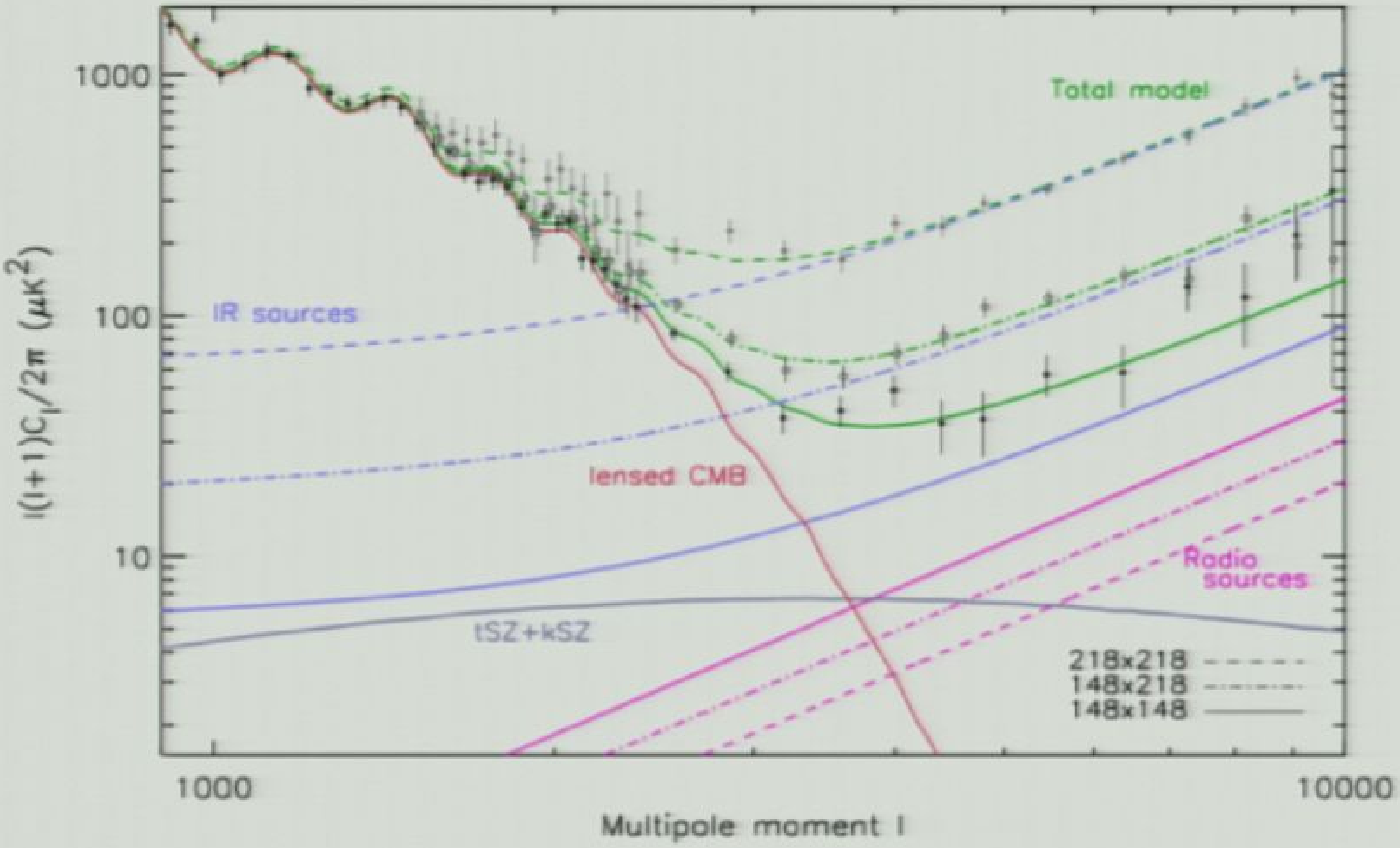

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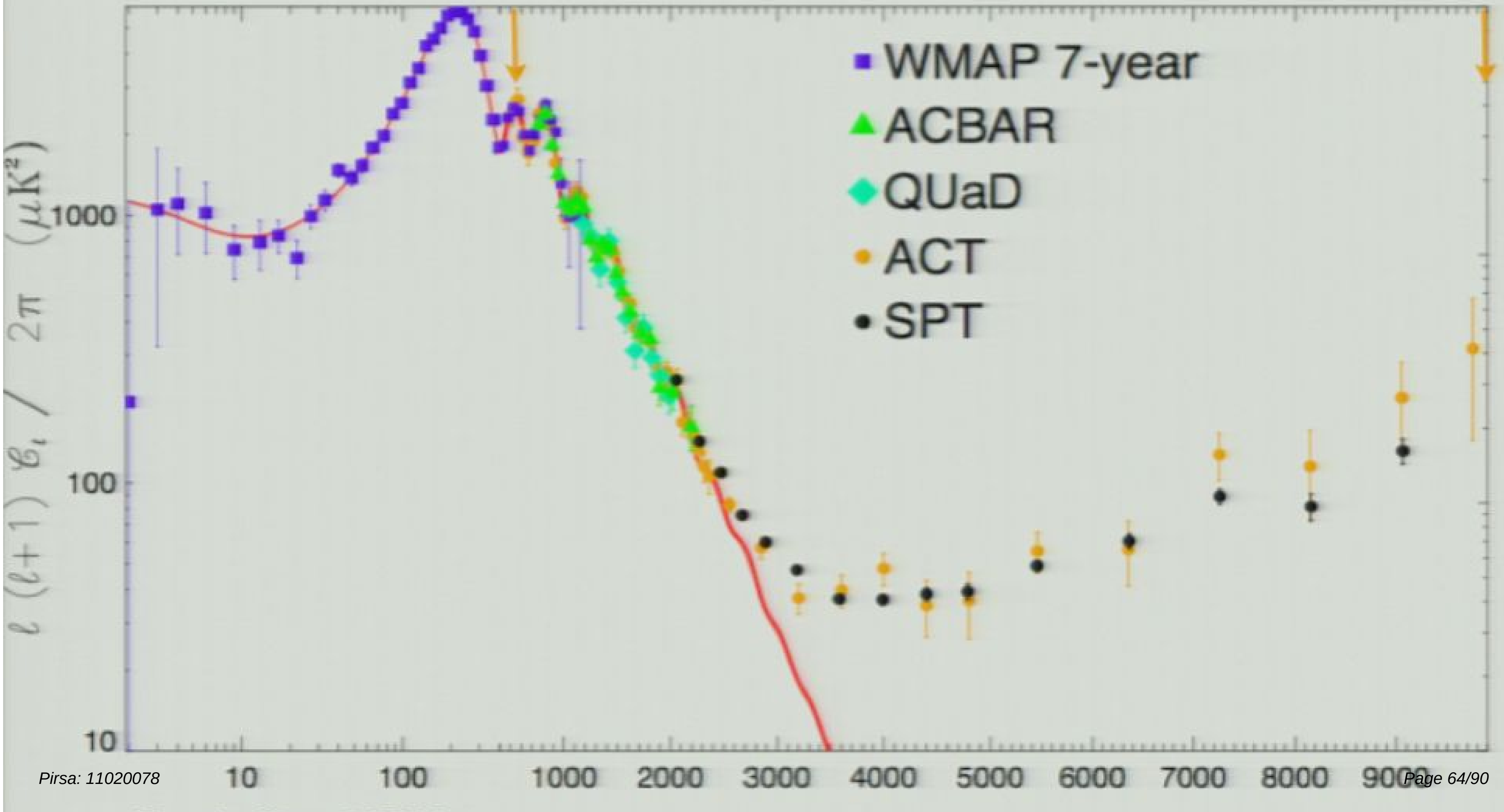

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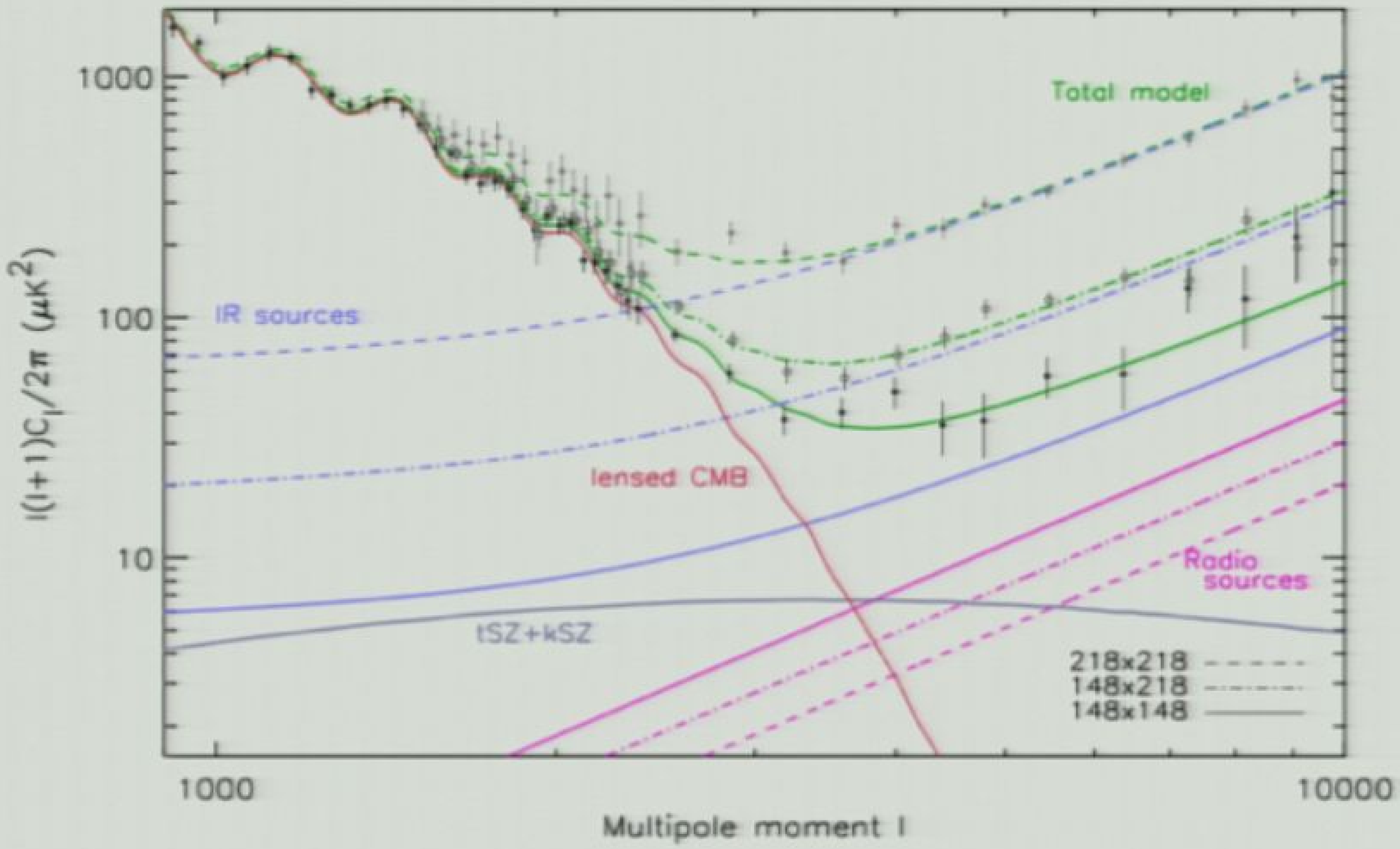

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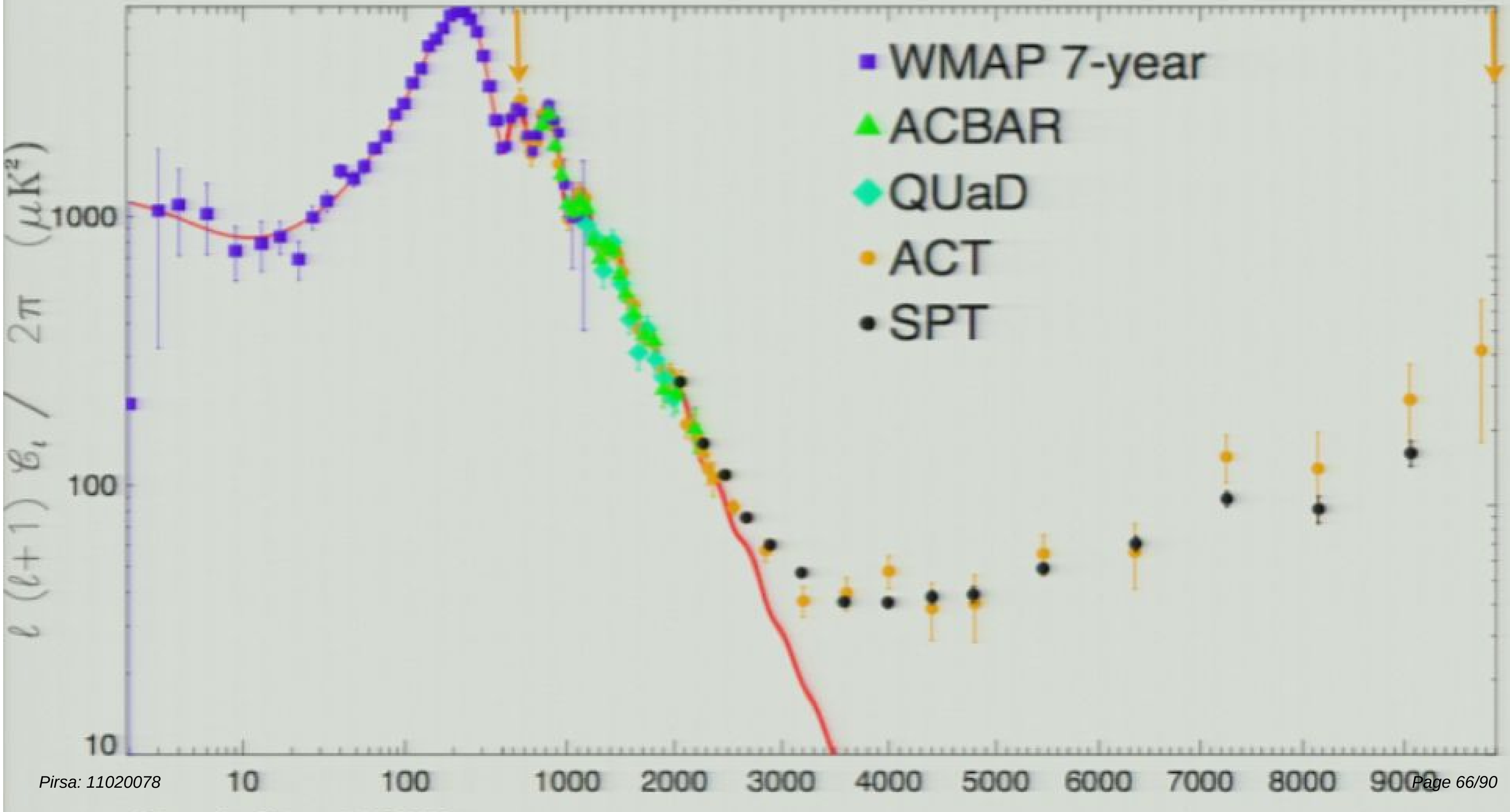

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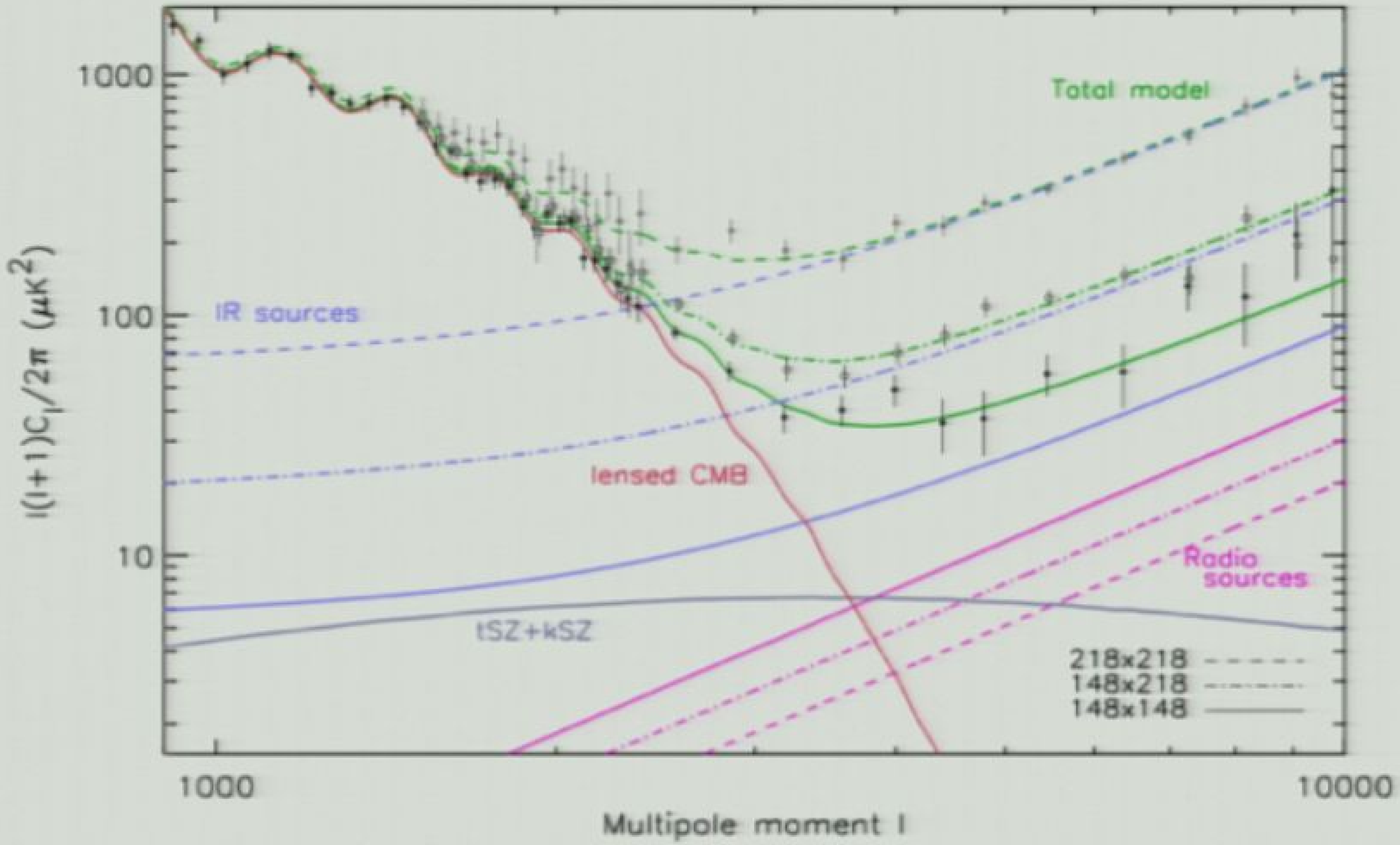

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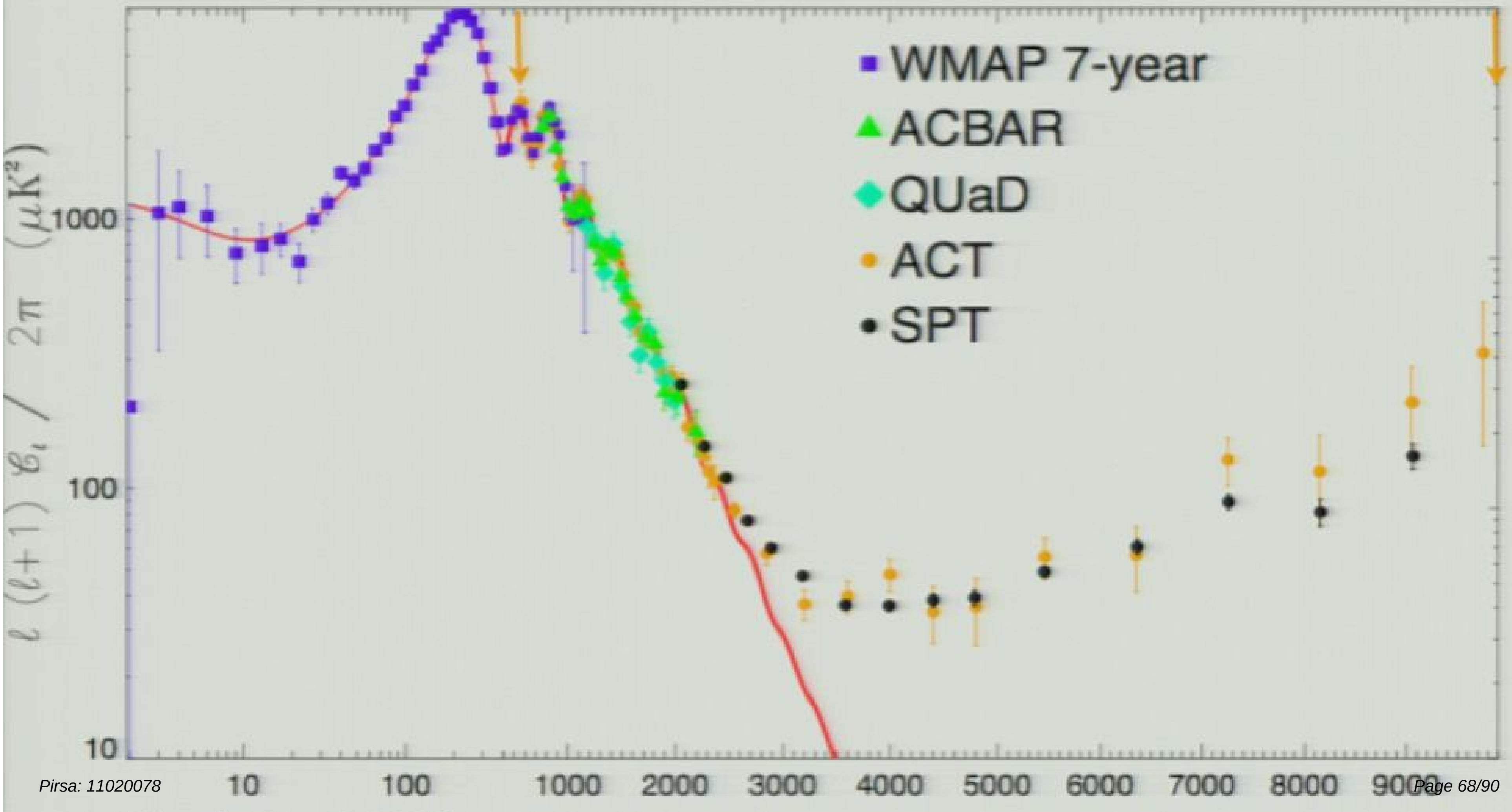

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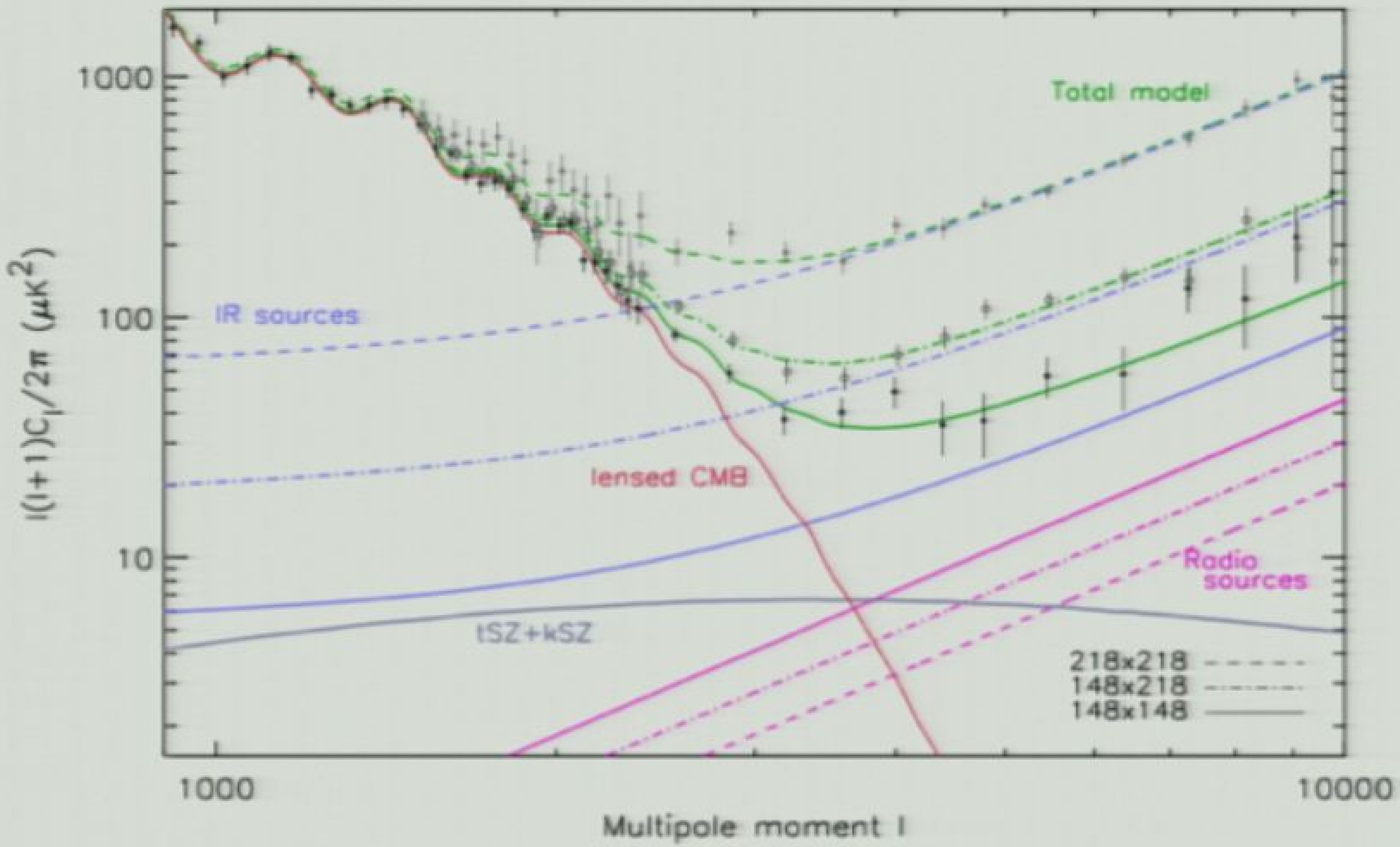

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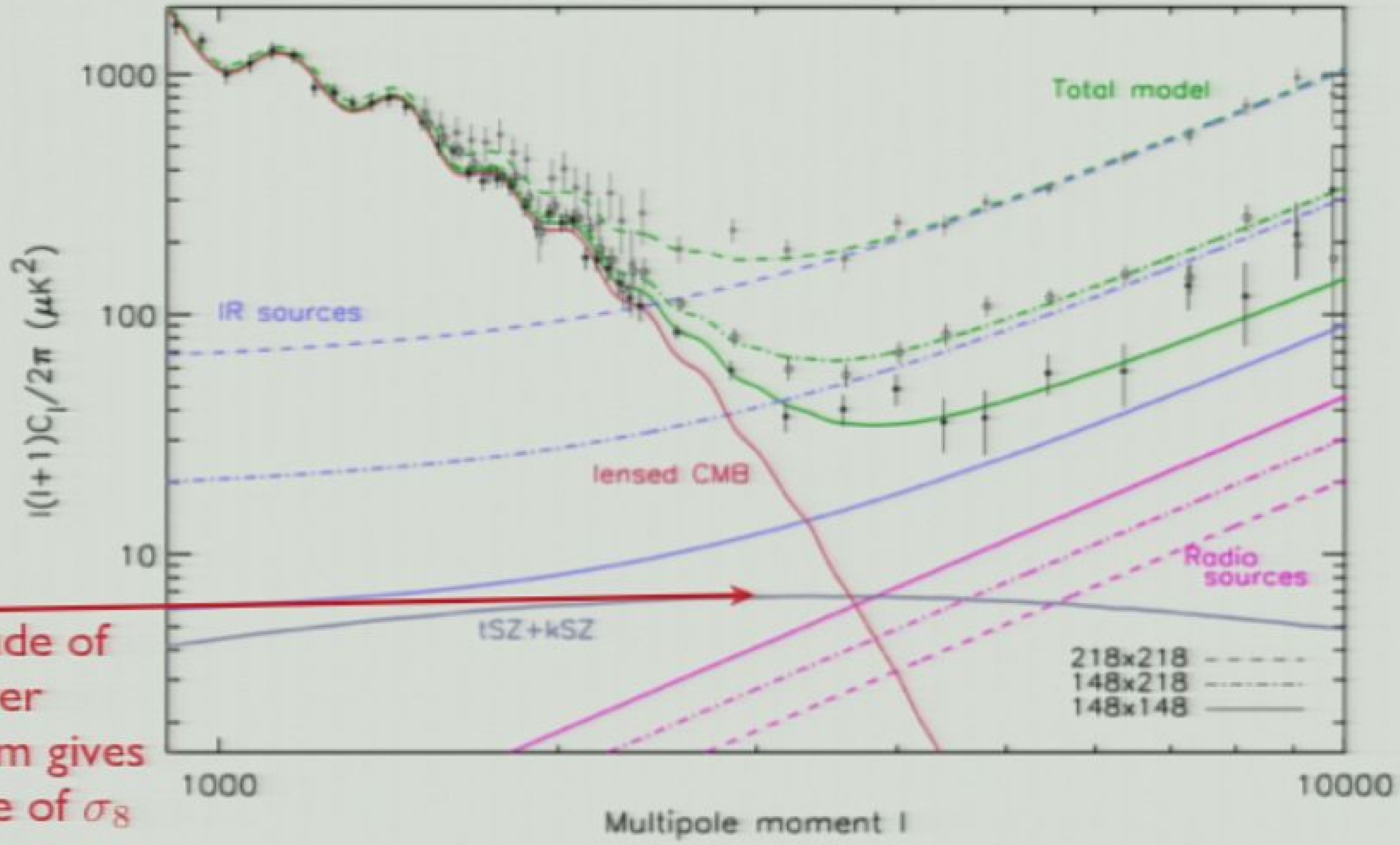

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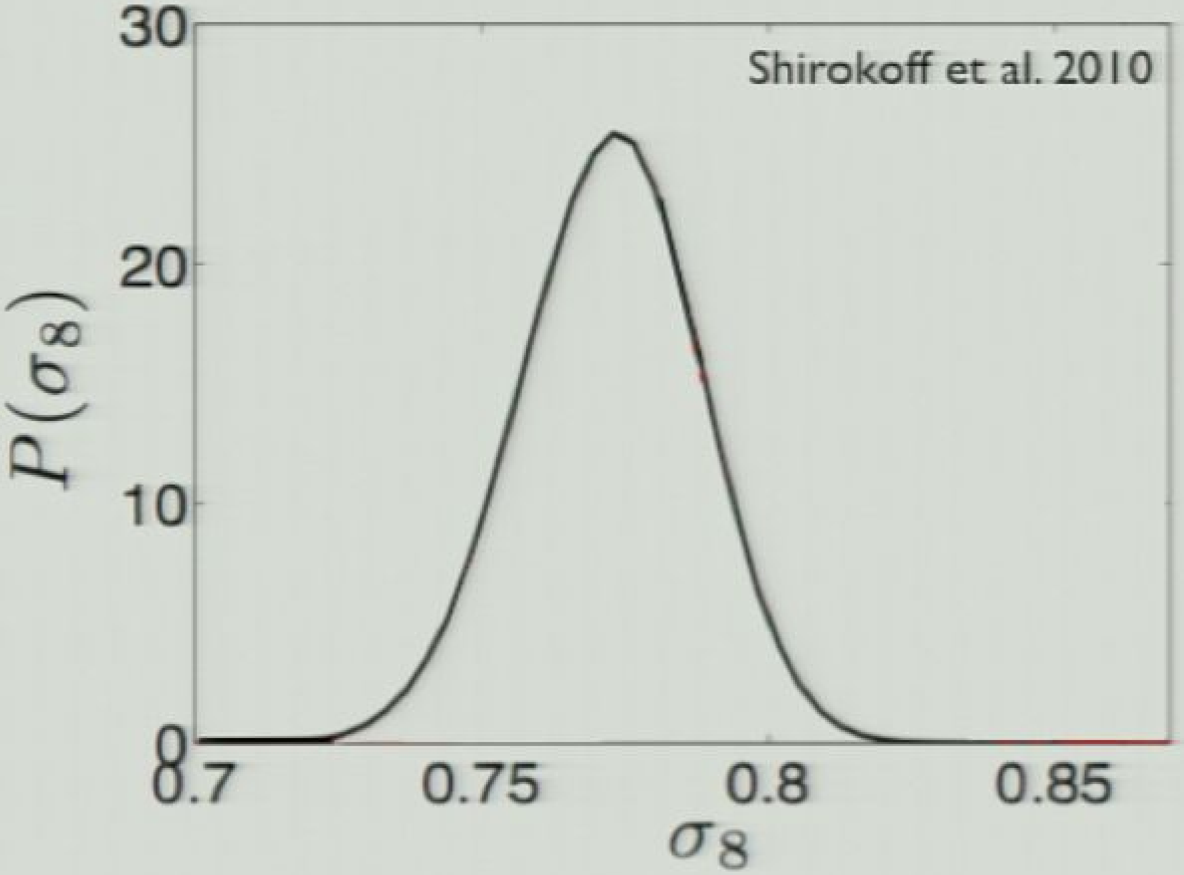

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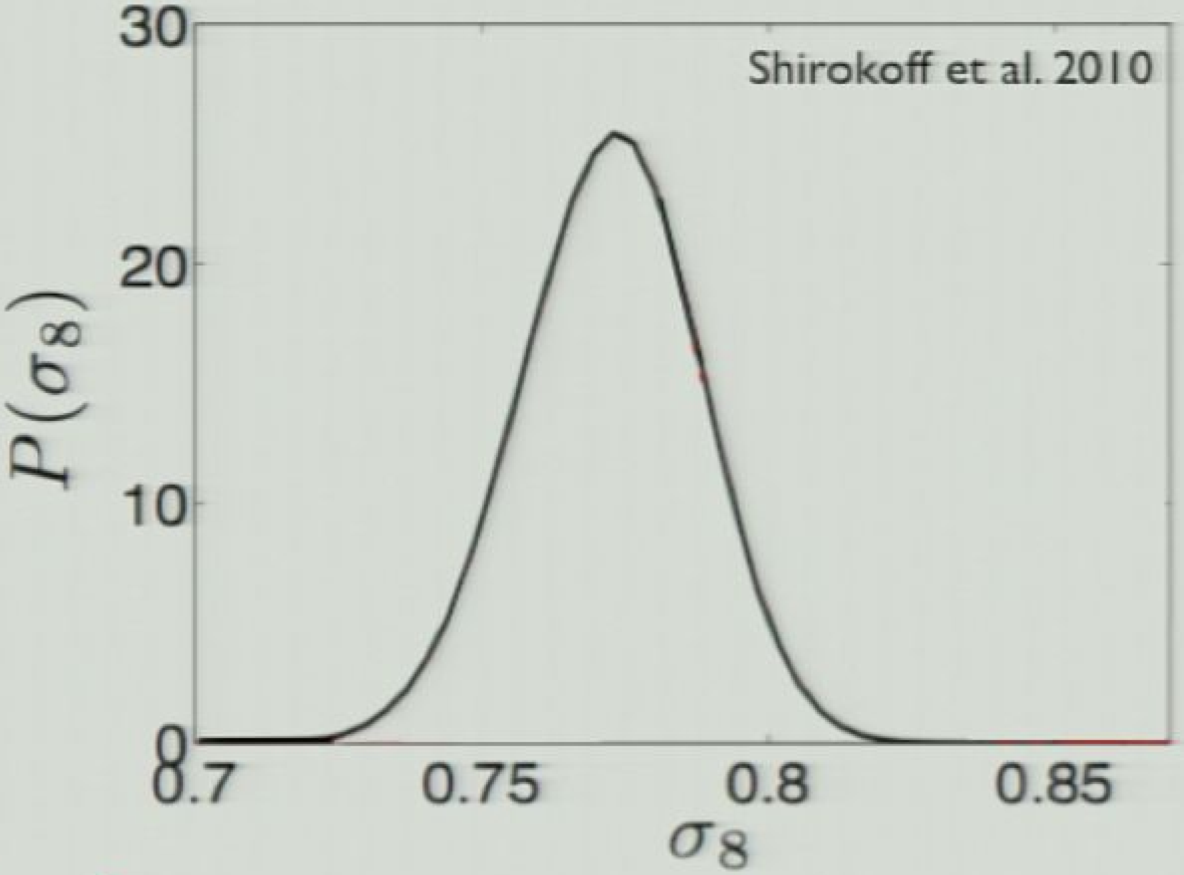

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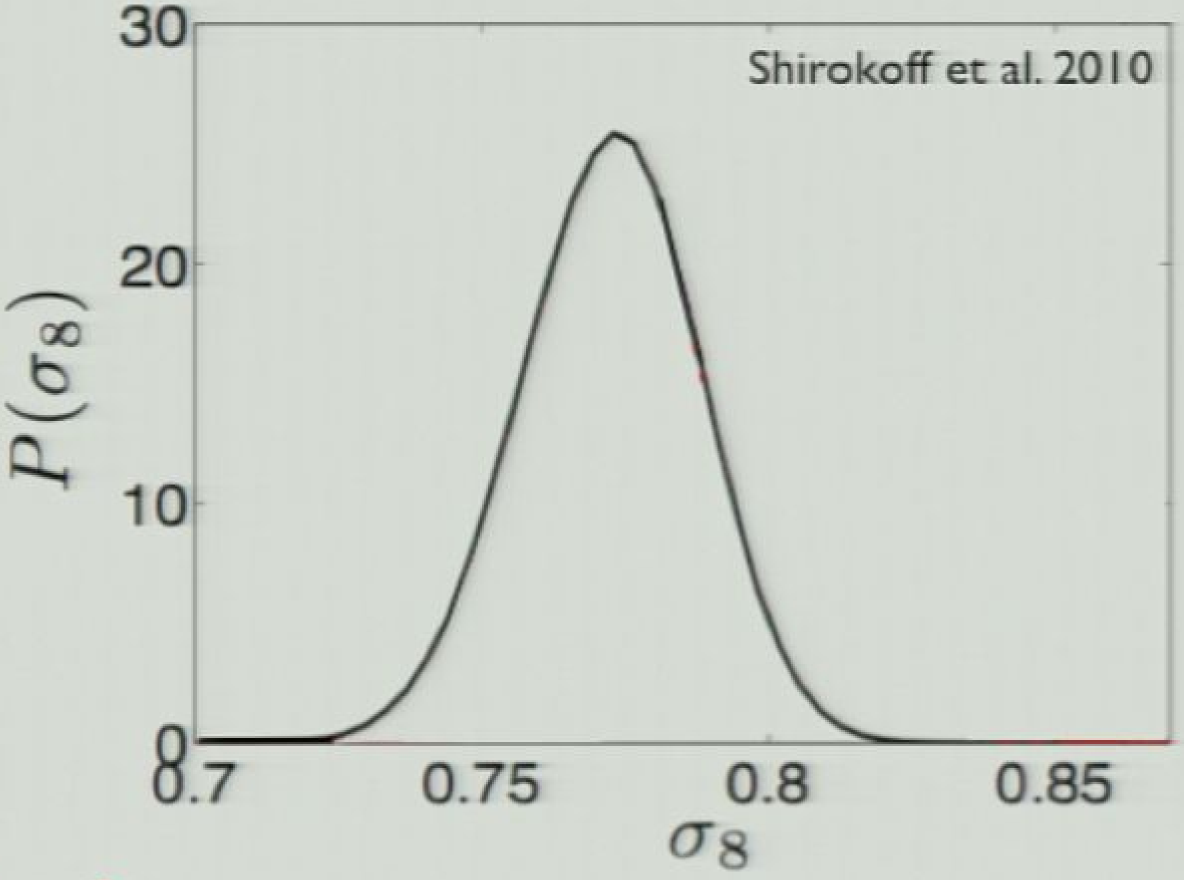

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Wavelength goal: 90 GHz to 1500 GHz

25-meter survey telescope

10 - 20 arcmin FOV

Coverage: 100s sq deg

Resolution: 0.5' at ~100 GHz

Sensitivity: ~1mJy
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Start of operations = 2020

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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 serves as complementary probe but harder to test relevant astrophysics
- Will only get better in future (more data from ACT, SPT, Planck, ACTpol, SPTpol, and CCAT)