Title: Missing Thermal Energy of the Universe

Date: Nov 10, 2006 11:00 AM

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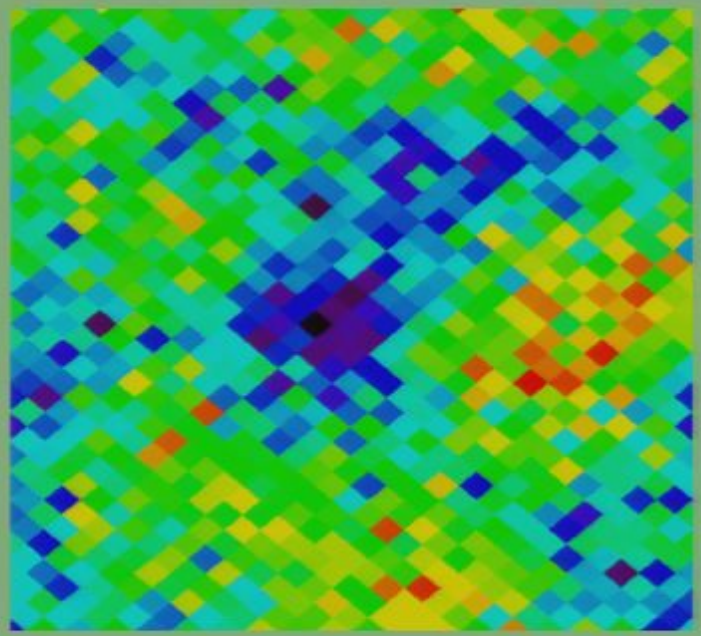
Abstract:

Missing Thermal Energy of the Universe

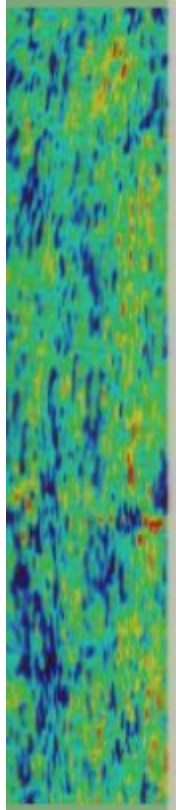


Niayesh Afshordi

Institute for Theory and Computation

Harvard College Observatory

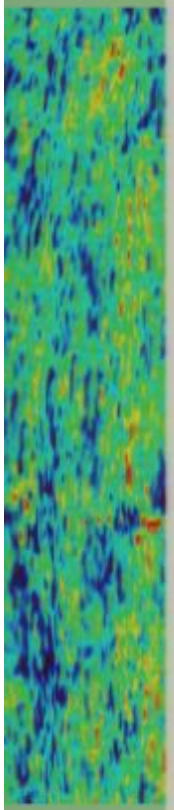
My Collaborators



Yen-Ting Lin
Princeton/ Catolica
Daisuke Nagai
CalTech
Alastair Sanderson
University of Birmingham

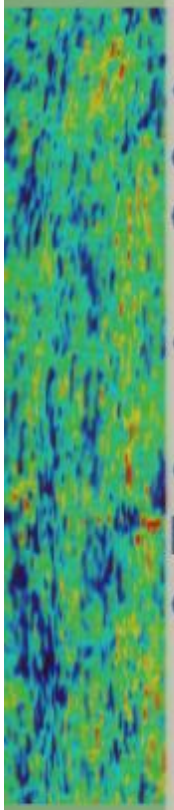
Afshordi, Lin, & Sanderson 2005 (1st yr)
Afshordi, Lin, Nagai, & Sanderson 2006 (3 yrs) submitted

Outline



- What is SZ effect?
- Cosmology with SZ effect
- CBI excess
- SZ effect in cross-correlation
- Reconstructing the pressure profile from WMAP
- Missing cluster baryons
- Conclusions

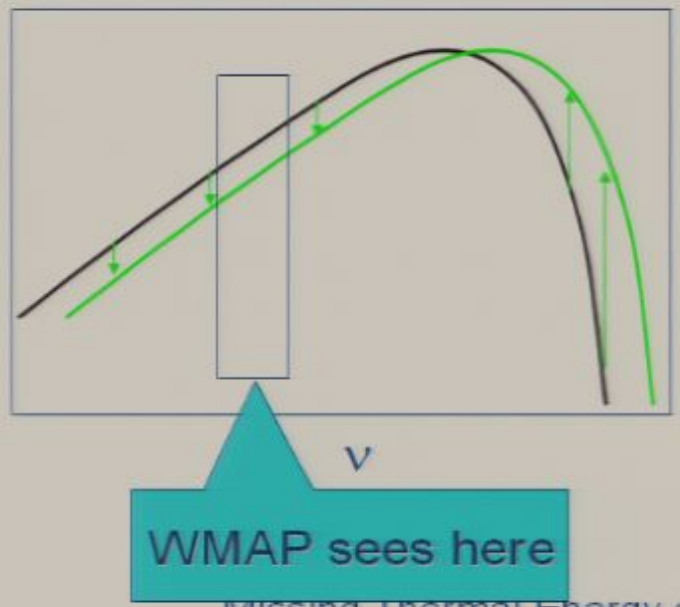
Thermal *Sunyaev-Zel'dovich* (SZ) Effect and *Intra-Cluster Medium* (ICM)



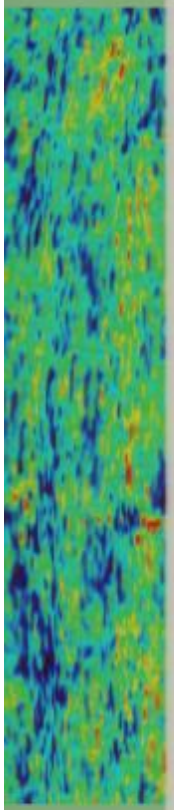
- Probes the thermal energy distribution of electrons in the Intra-Cluster Medium
- Dominates CMB at angles < 0.1°
- Generates an anti-correlation between WMAP and galaxy/cluster distribution

$$\frac{\delta T(\nu)}{T(\nu)} = -\frac{\sigma_T}{m_e c^2} F\left(\frac{h\nu}{kT_{\rm CMB}}\right) \int p_e dr$$

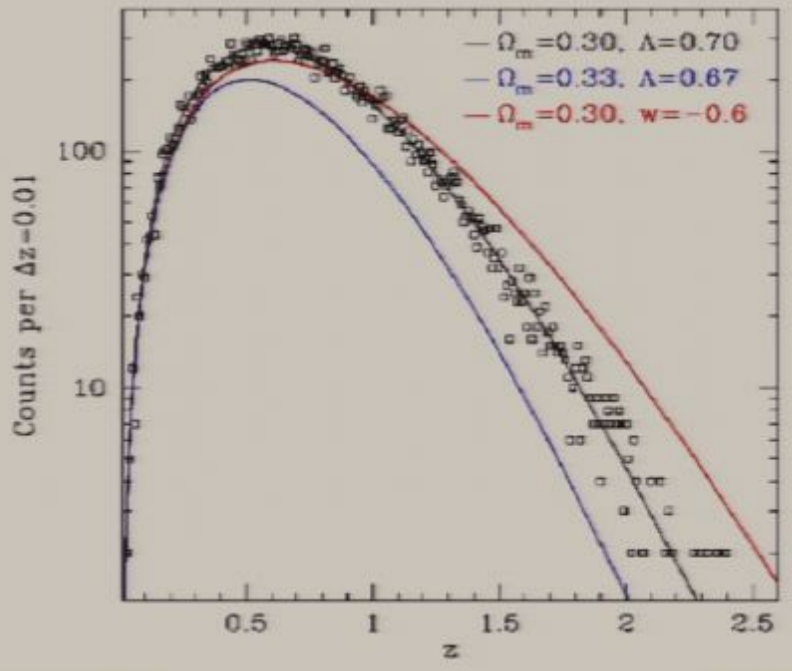
$$F(x) = 4 - x\coth(x/2)$$



Can SZ surveys sustain the CMB dominance?



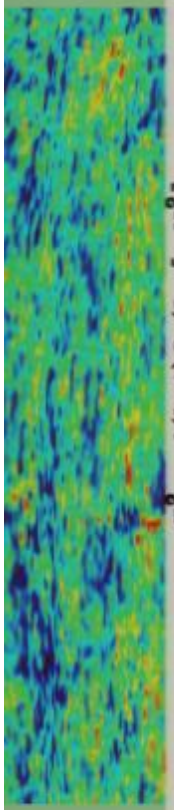
- SZ clusters can be Detected up to high redshifts
- Their number counts probe Dark Energy/Cosmology
- Many SZ surveys are underway: APEX, SZA, ACT, SPT, Planck, …
- Can they deliver? Calibration of SZ-Mass relation, Gastrophysics, …

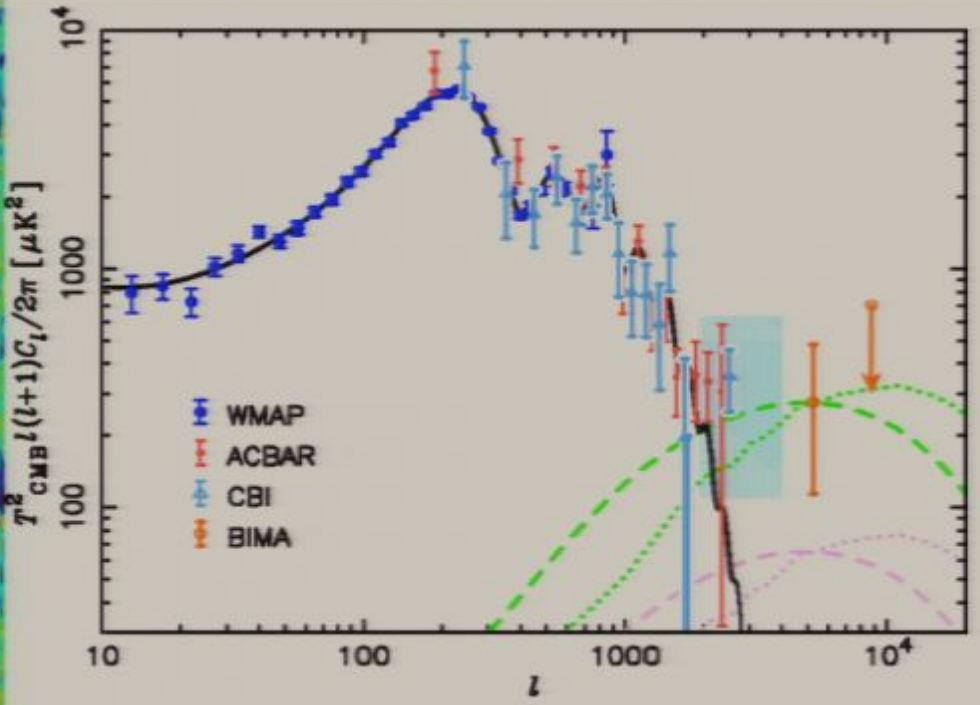


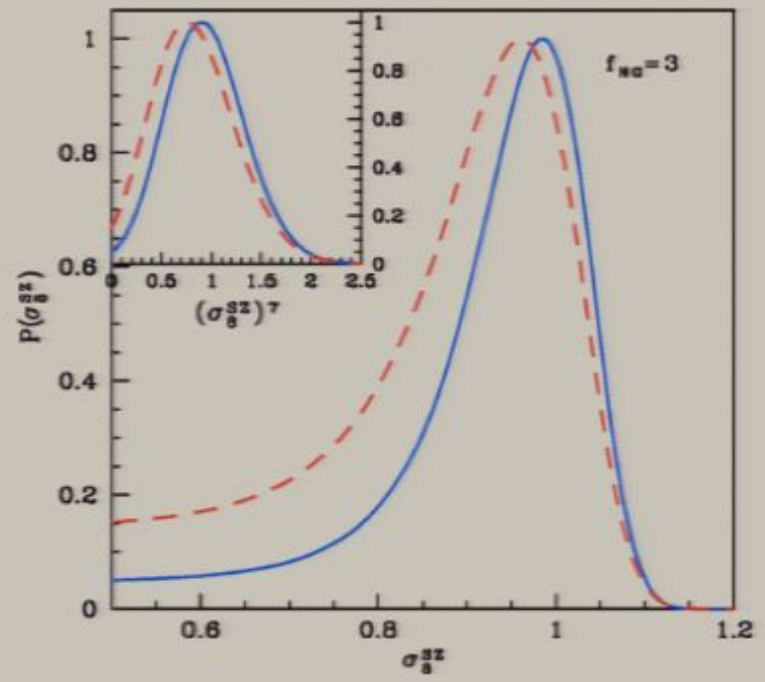
Courtesy of John Carlstrom

Missing Thermal Energy of the Universe

Thermal SZ Effect in the CMB: CBI excess







Readhead et al. 2004

Missing Thermal Energy of the Universe

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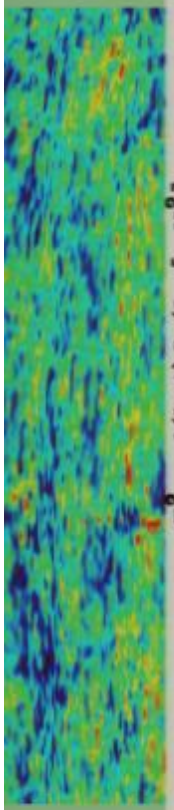
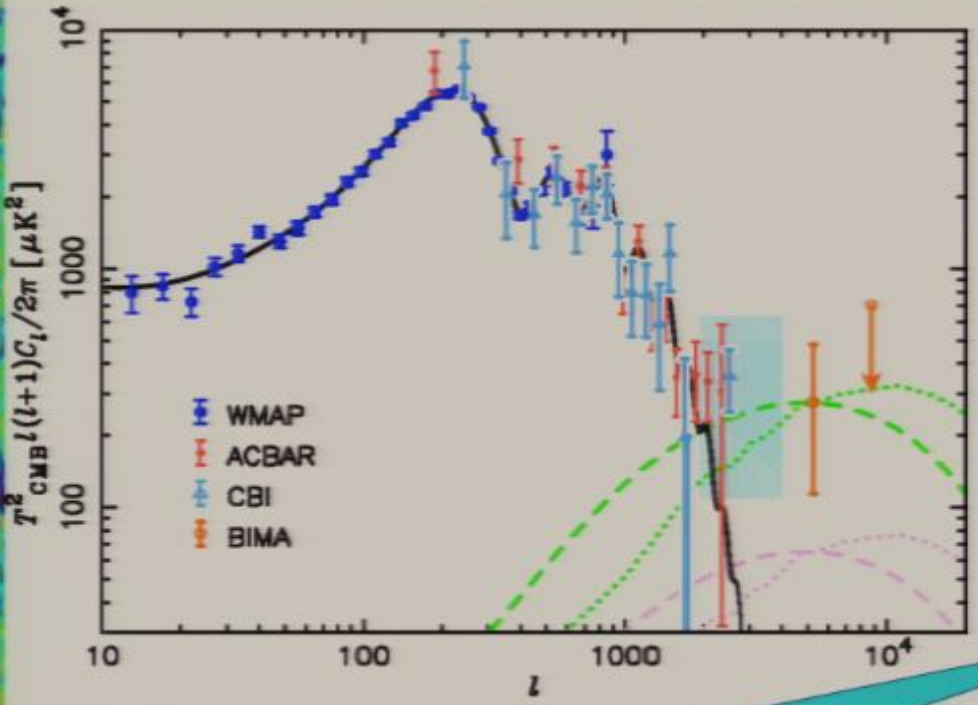
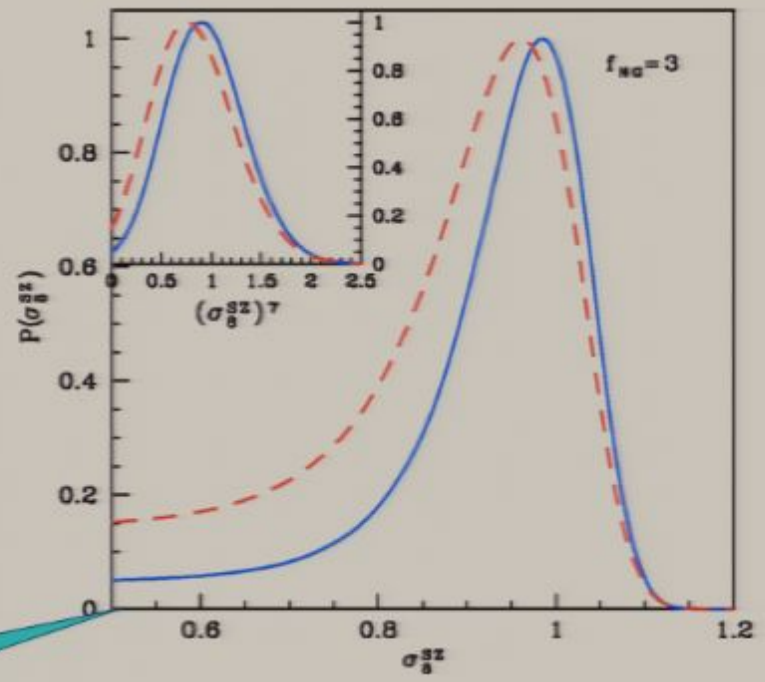




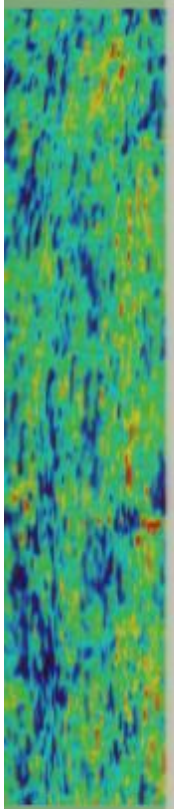


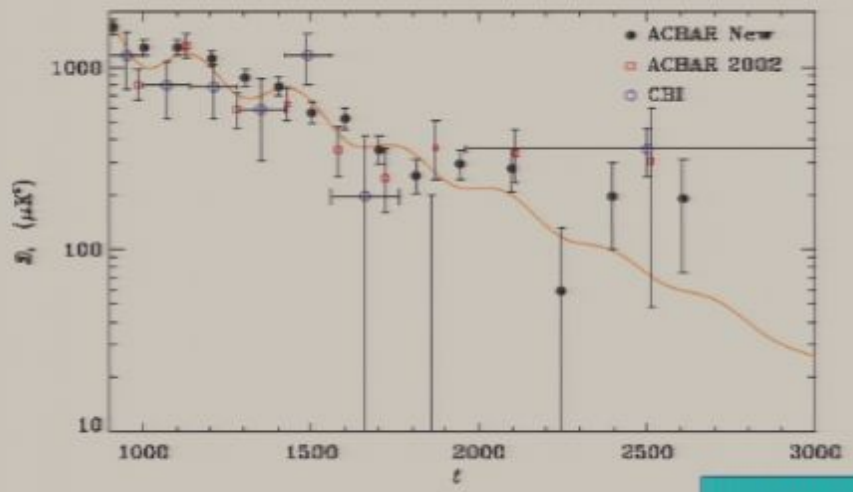
Tension with new low WMAP σ_8 ?!

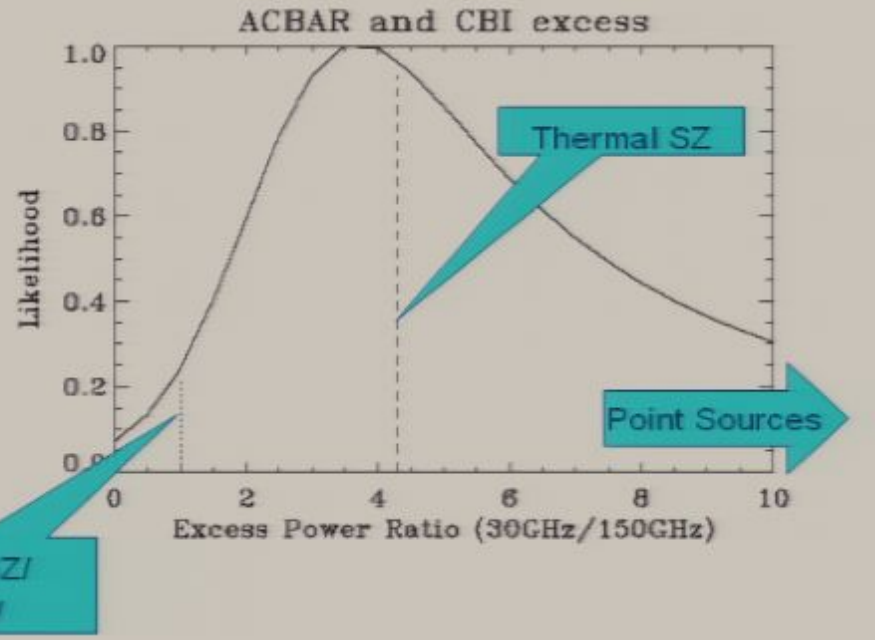
Readhead et al. 2004

Missing Thermal Energy of the Universe

ACBAR-CBI concordance
(Kuo, et al. 06)







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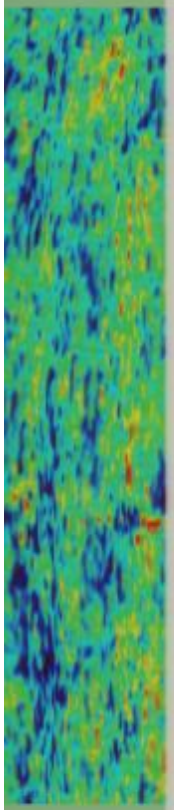
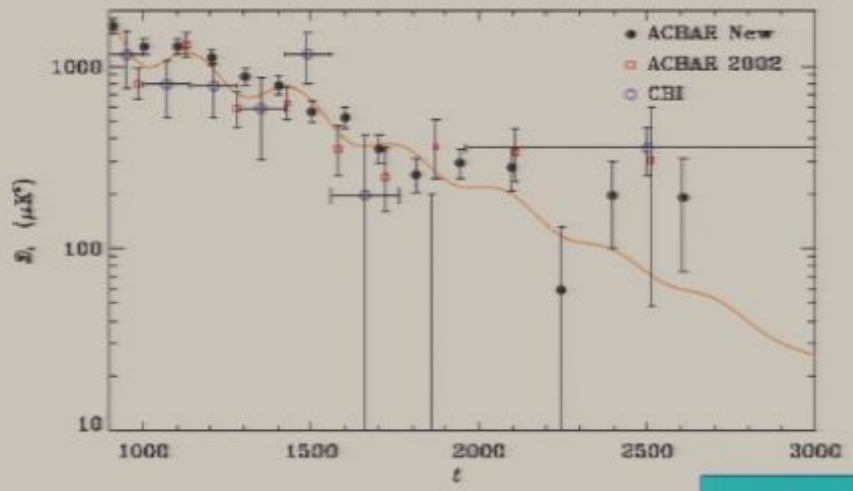
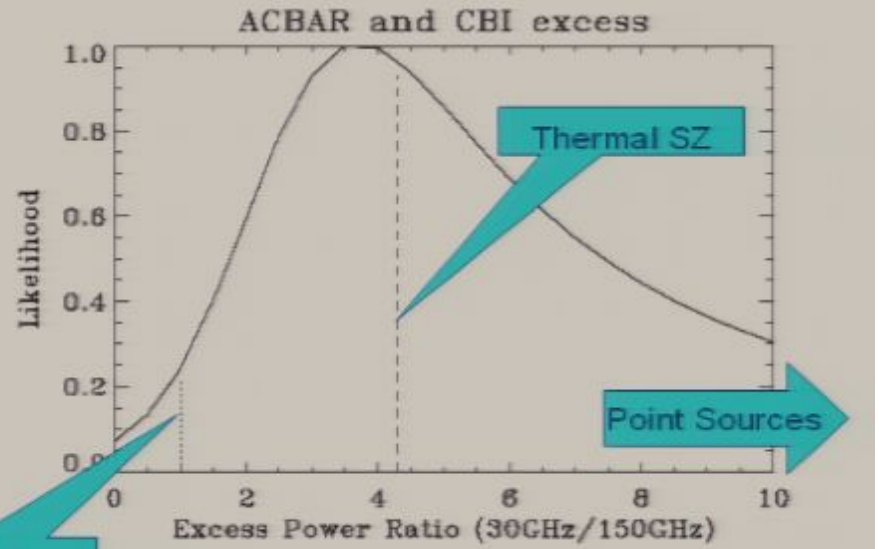
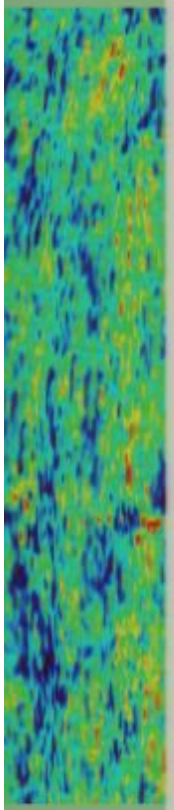




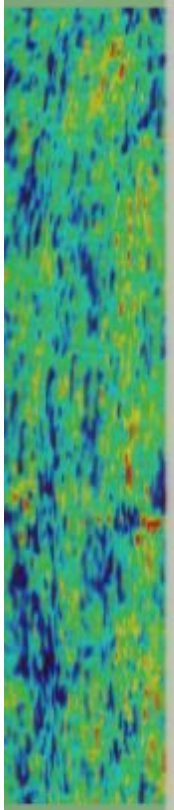


CBI excess has the frequency dependence of thermal SZ

SZ effect in WMAP



SZ detections in Cross-Correlation with Galaxy/Cluster Surveys

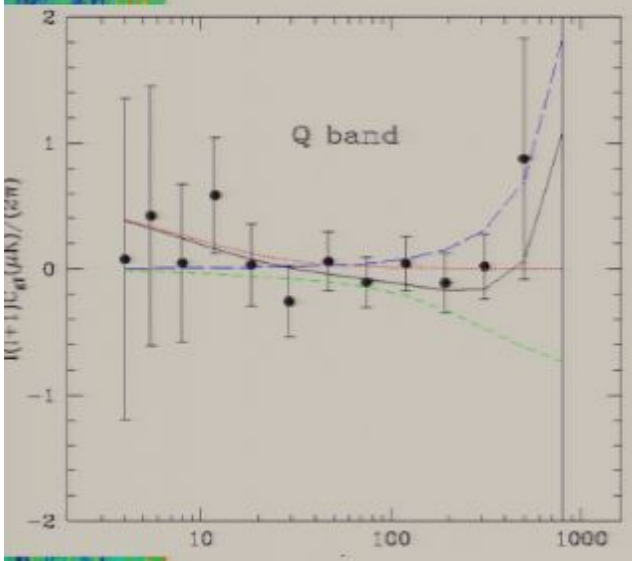


- Bennett et al. 2003 (XBAC's clusters; 2.5σ)
- Fosalba, Gaztanaga, & Castander 2003; Fosalba & Gaztanaga 2004 (SDSS, APM; 2.7σ)
- Myers et al. 2004 (APM+ACO; ~2σ)
- Afshordi, Loh, & Strauss 2004 (2MASS; 3.7σ)

tSZ in 2MASSxWMAP Correlation

Afshordi, Loh, & Strauss 2004 (2MASS Deepest magnitude bin):

- data —— best fit model
- ····· ISW - - - SZ — — — Point Sources



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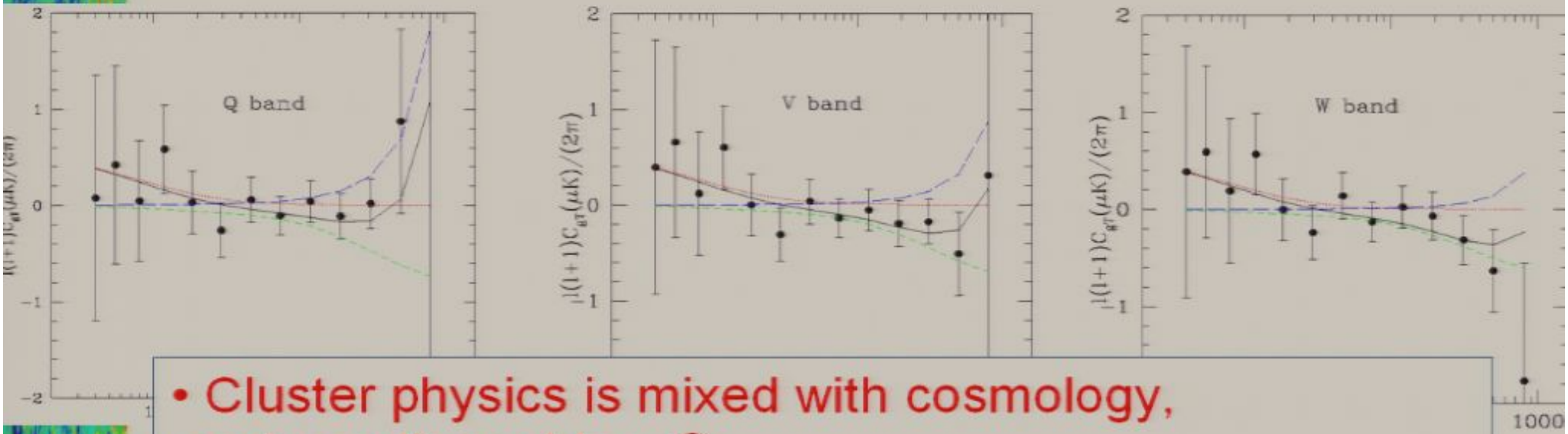

- Cluster physics is mixed with cosmology, and non-linear bias ☹
- Does not employ the non-Gaussianity of the signal ☹

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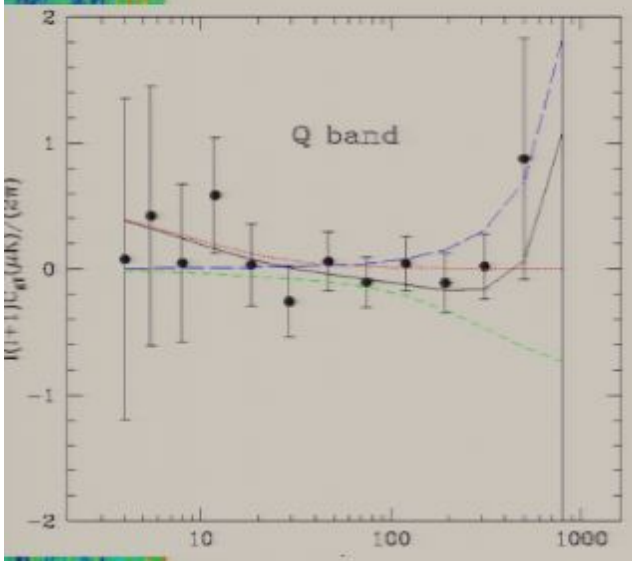

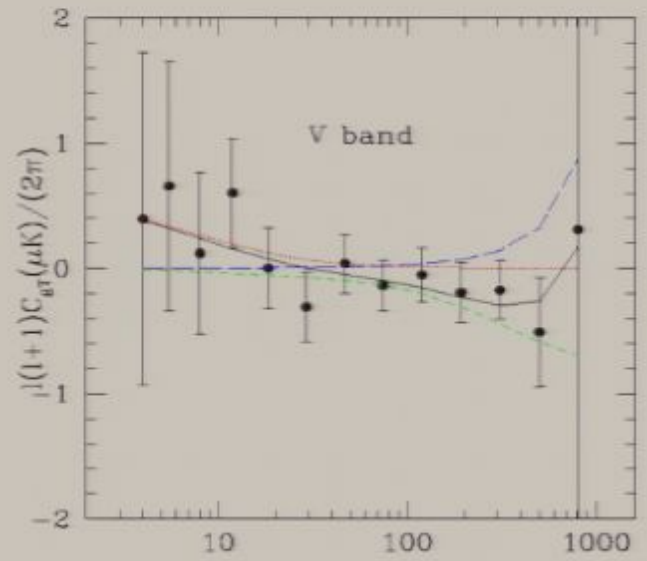

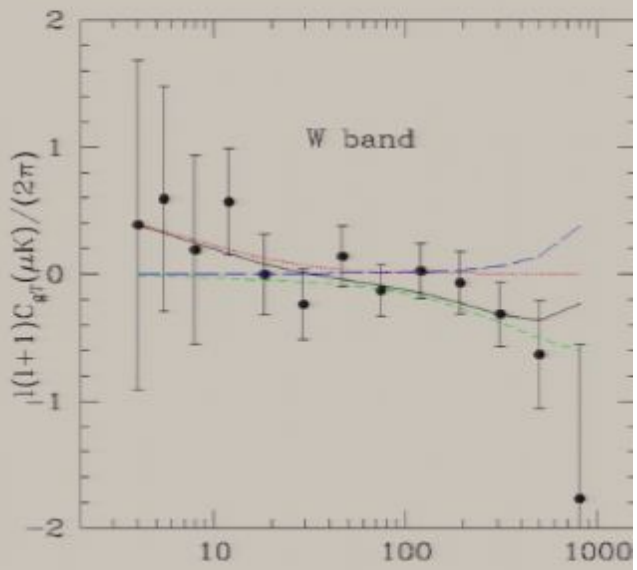

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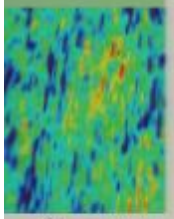

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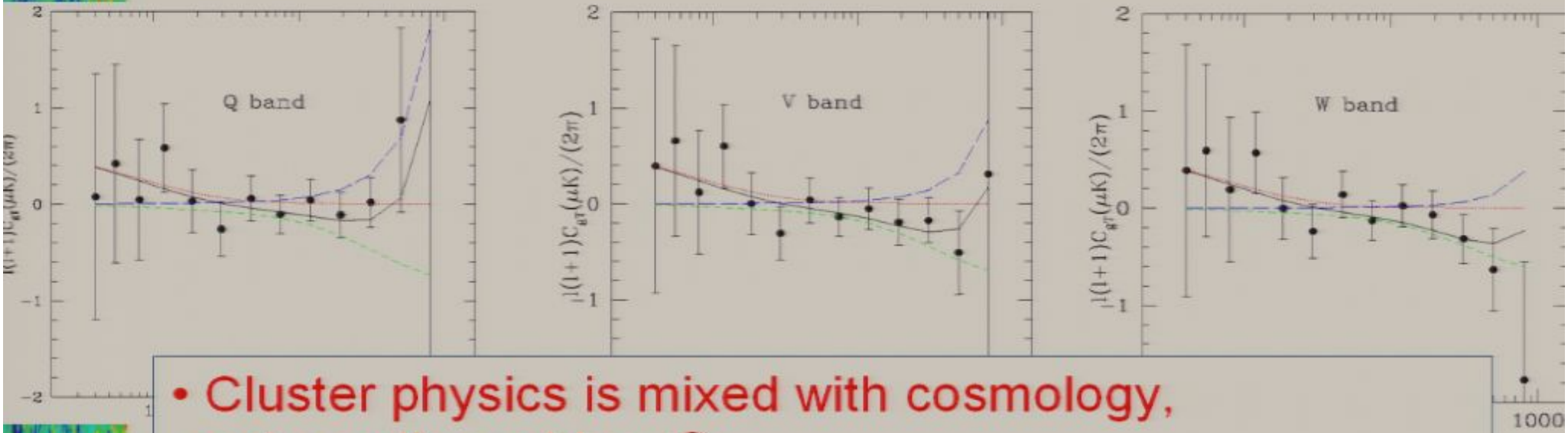

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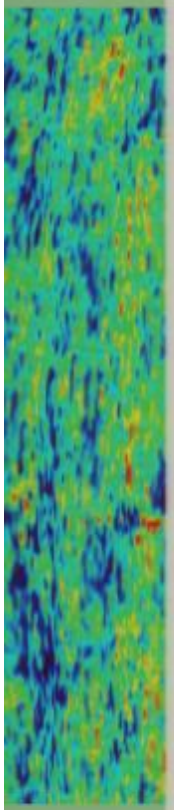
SZ detection based on SZ templates made out of Galaxy/Cluster Surveys



- Hernandez-Monteagudo & Rubino-Martin 2004 (BCS, NORAS, etc; 2-5σ)
- Hernandez-Monteagudo et al. 2004,2006 (2MASSxWMAP+Archeops; 5σ)

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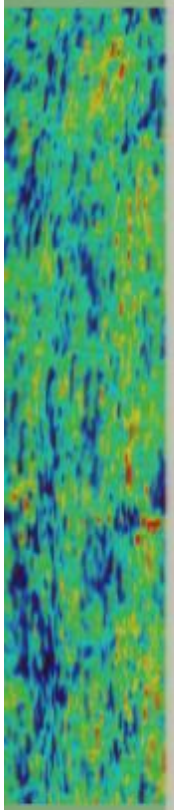

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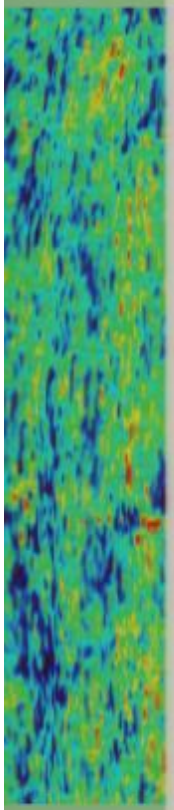
• Does employ the non-Gaussianity of the signal ☺
• Cluster physics is mixed with template making procedure in a non-trivial manner ☹

How to get the most physics out?



- Most Galaxies are NOT in clusters
- Most SZ signal comes from clusters

  thus…
- The SZ detection is more significant if we just look around clusters → Make an SZ template
- The S/N is maximized if the template matches the actual SZ profile → Constraint on the SZ profile

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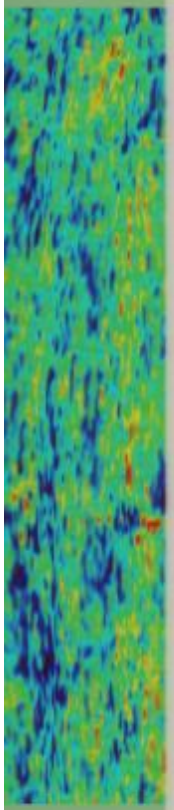

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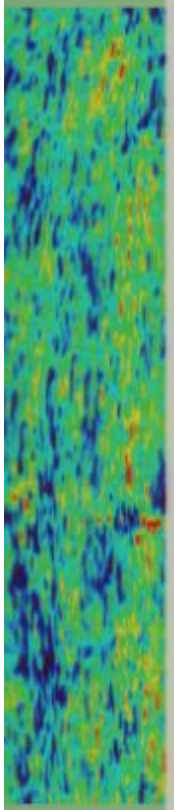

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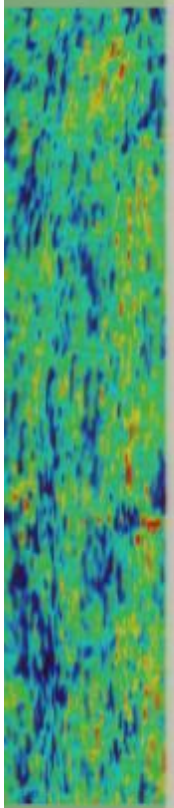

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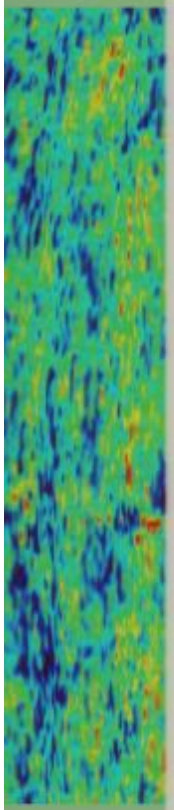

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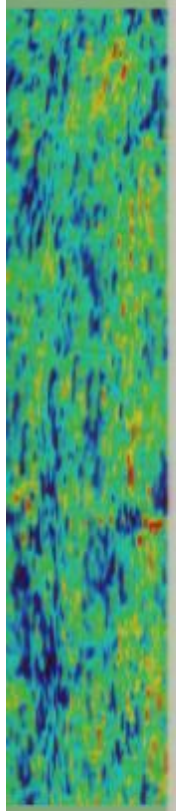
$$\chi^2 = \sum_{i,j;a,b} \left[T_{ia} - S_i(\nu_a)/\delta\Omega_{\rm pixel}\right] C^{-1}_{ia,jb} \left[T_{jb} - S_j(\nu_b)/\delta\Omega_{\rm pixel}\right],$$

Observed Sky

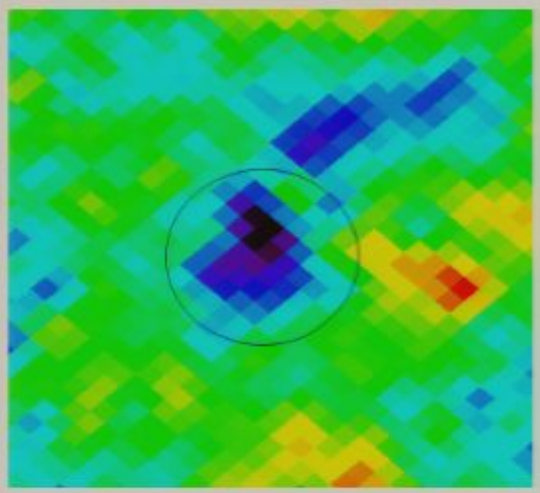
Template

WMAP SZ clusters …

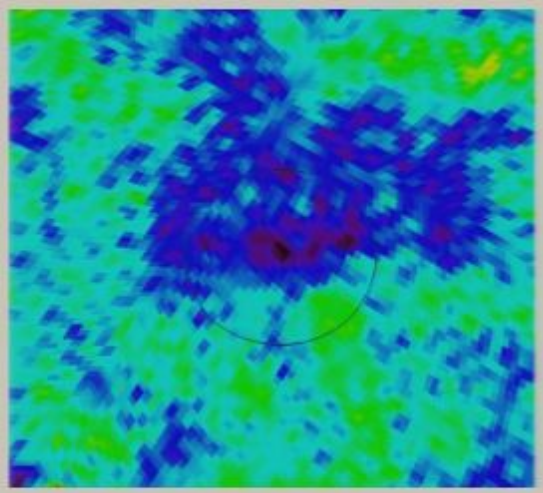
- Three close-by clusters in the 3yr cleaned map (Tegmark et al)



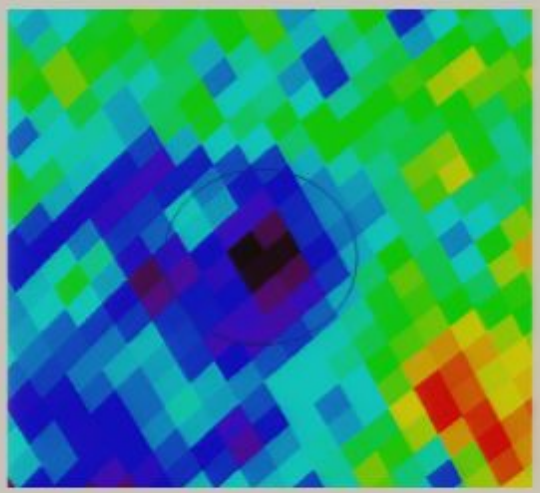
Abell 2319



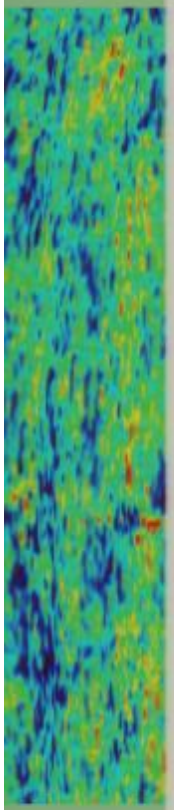
Abell 1656



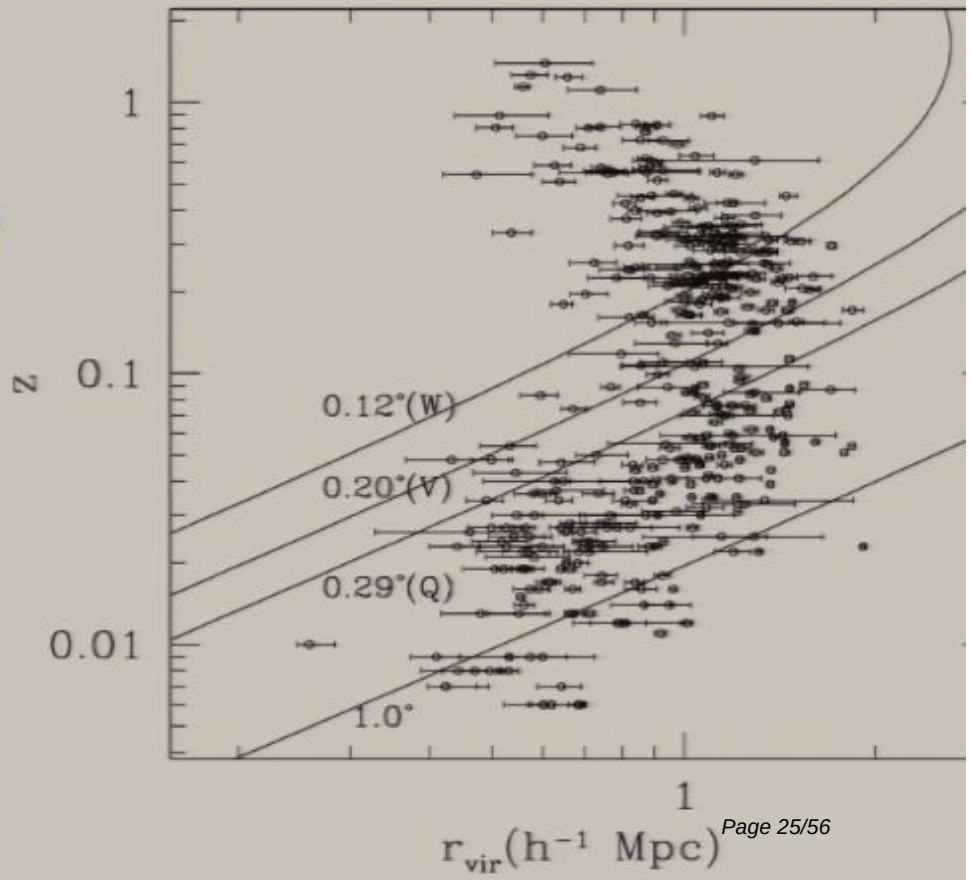
Abell 133



Filter-matched SZ detection in WMAP 3yr maps

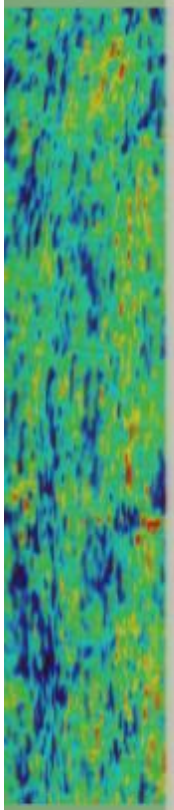


- WMAP 3 years
  - Temperature: Q,V,W
  - N_{res} = 9 (pixel size $\simeq$ 0.1 deg)
- 417 clusters
  - meaured X-ray temperature



Methodology

- Find R_{200} for each cluster using M_{200}-T_X relation



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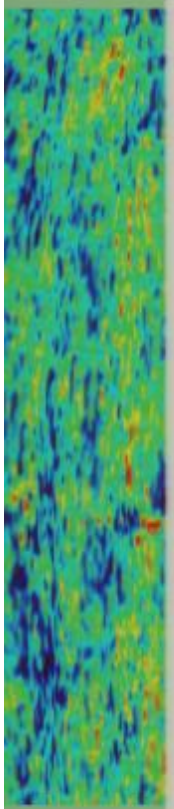
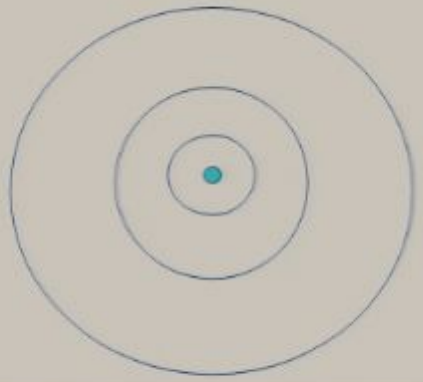
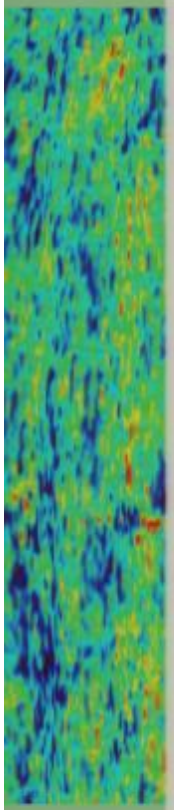


- Find R_{200} for each cluster using M_{200}-T_X relation
- Constrain pressure within spherical radial bins centered at: 0.25,0.5,1,2,4,8 x R_{200} + a central radio source :

Methodology





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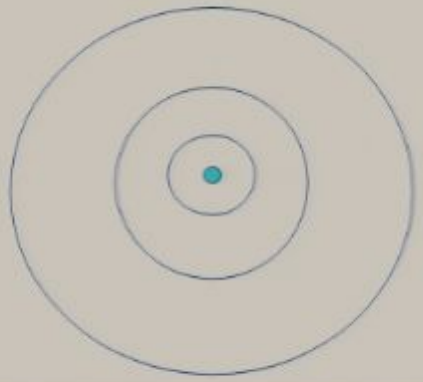
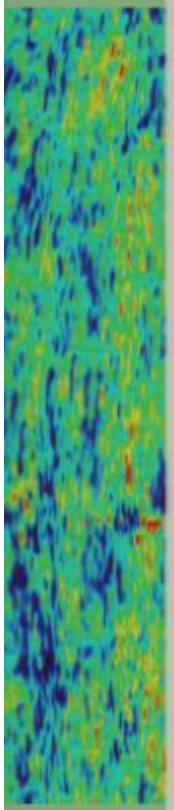
Methodology





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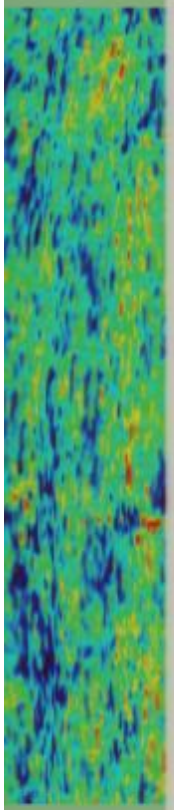
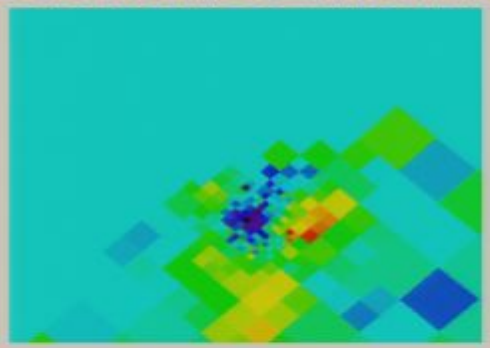
  → Makes covariance matrix tractable

Methodology

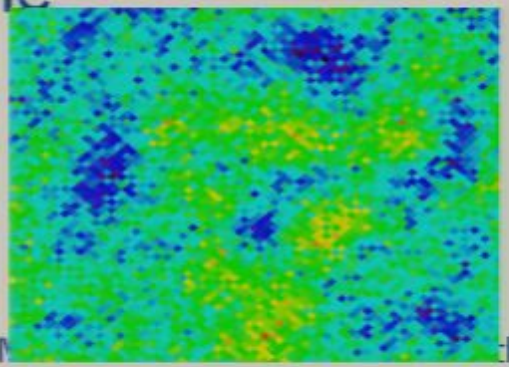


- Find R_{200} for each cluster using M_{200}-T_X relation
- Constrain pressure within spherical radial bins centered at: 0.25,0.5,1,2,4,8 x R_{200} + a central radio source :
- Only consider pixels close to each cluster, with resolution degrading with distance

  → Makes covariance matrix tractable

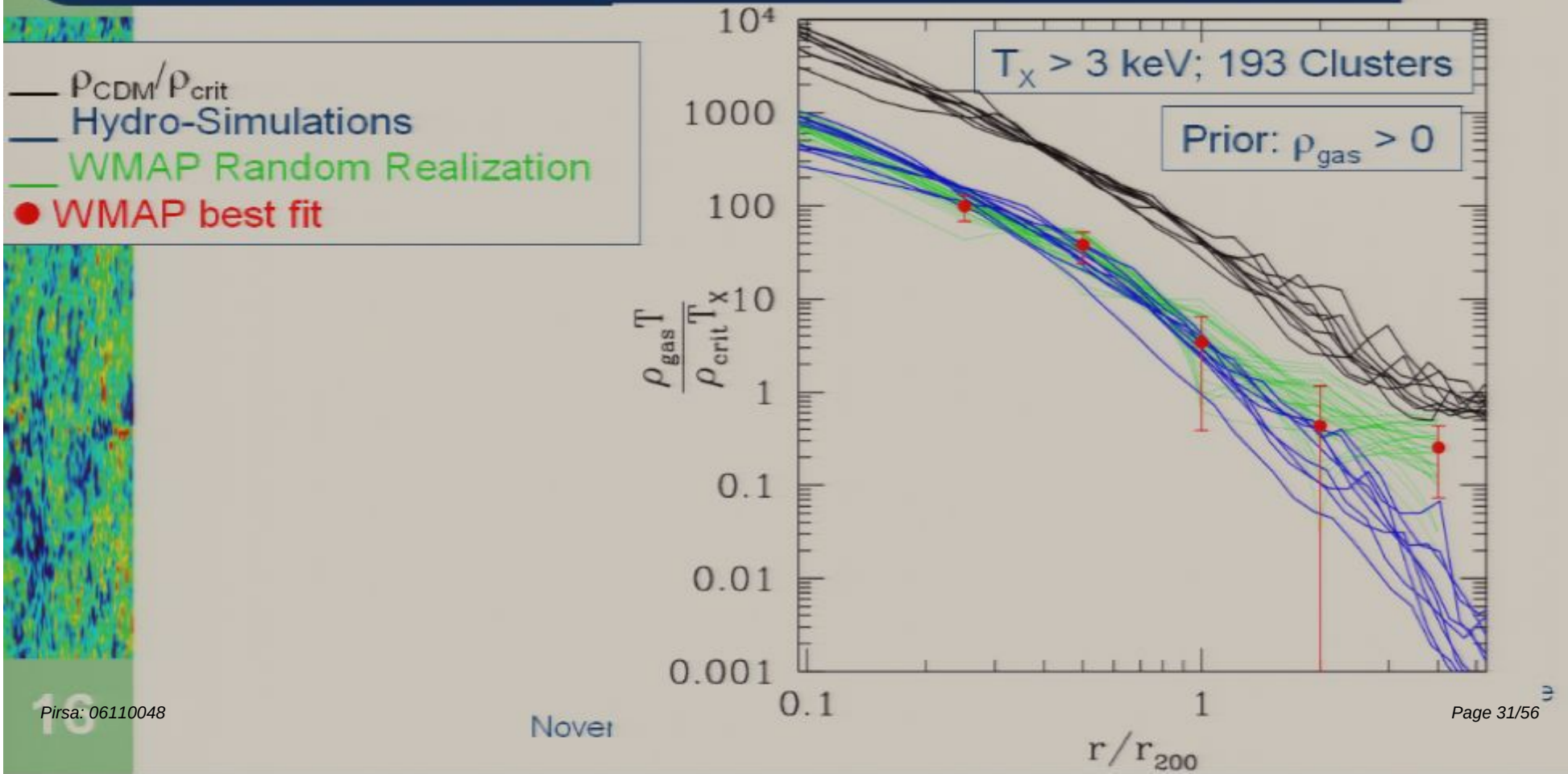


Degraded Abell 2319 in Q-band



Abell 2319 in Q-band

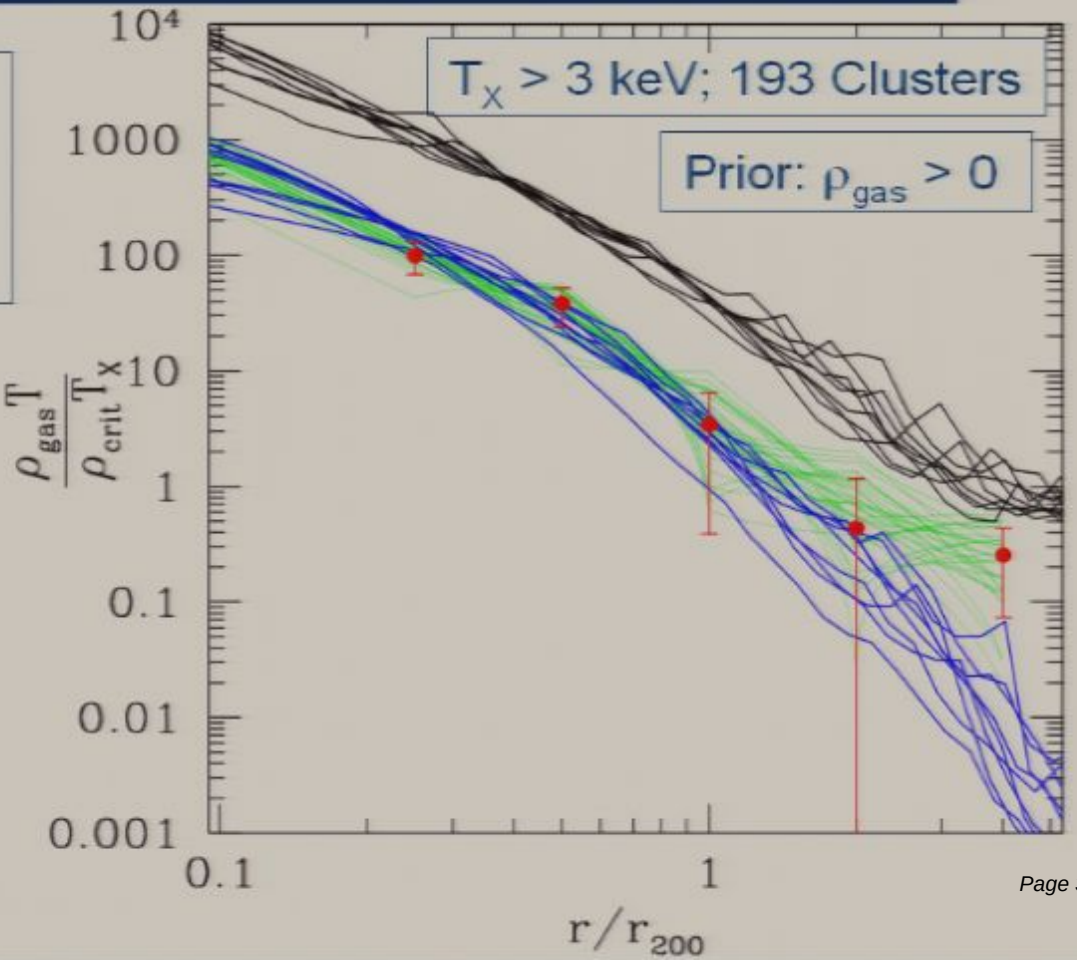
Universal Pressure Profile



Universal Pressure Profile

ρ_{CDM}/ρ_{crit}
Hydro-Simulations
WMAP Random Realization
WMAP best fit

First direct measurement of ICM pressure profile



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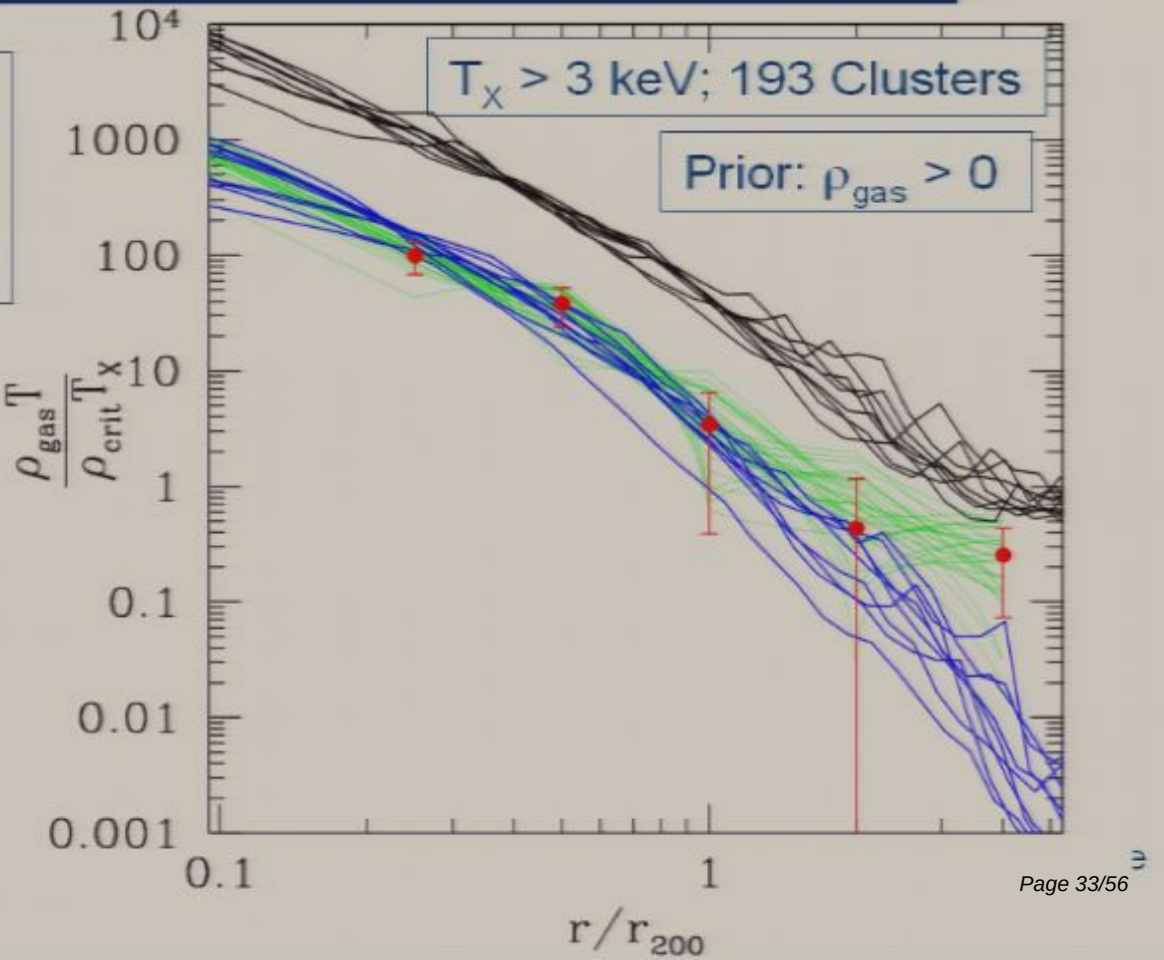
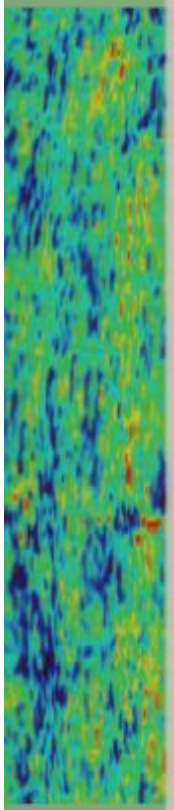
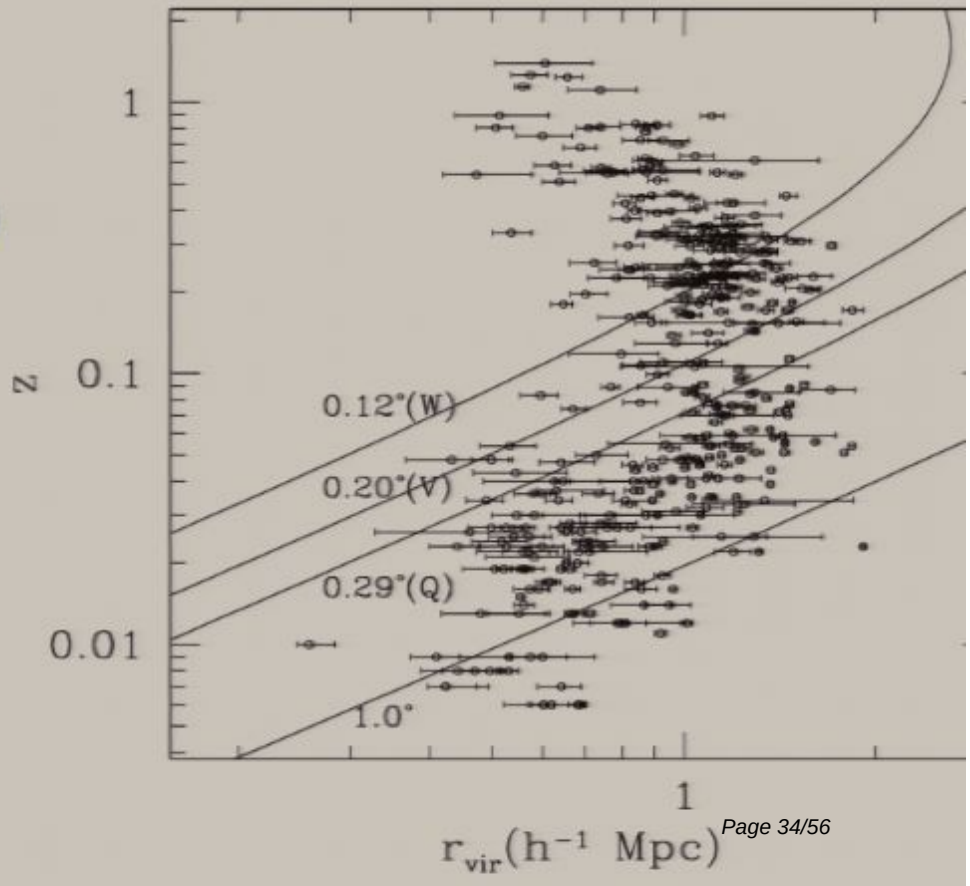
$\Delta\chi^2 \simeq 50$ for the simulated profiles
→ 7σ detection



Filter-matched SZ detection in WMAP 3yr maps



- WMAP 3 years
  - Temperature: Q,V,W
  - N_{res} = 9 (pixel size $\simeq$ 0.1 deg)
- 417 clusters
  - meaured X-ray temperature



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T_X > 3 keV; 193 Clusters

Prior: $\rho_{gas} > 0$

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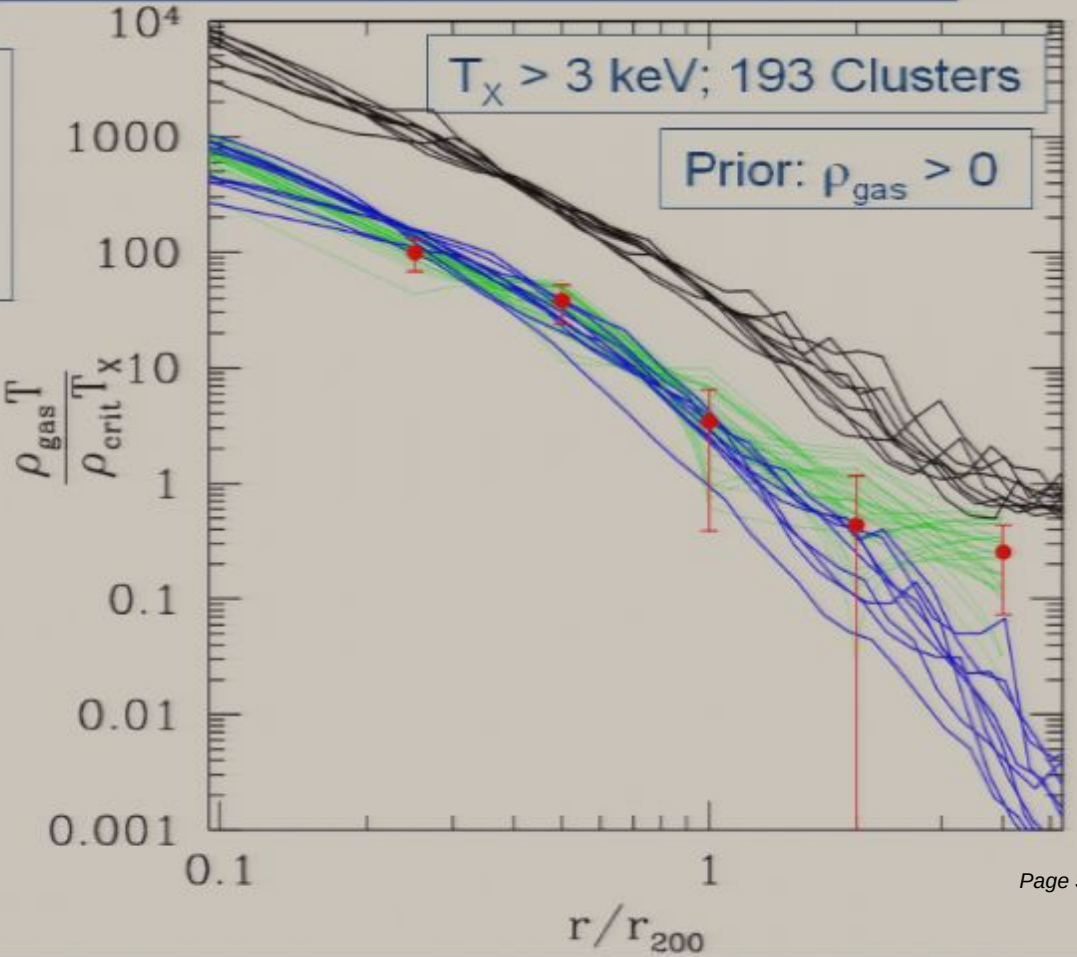
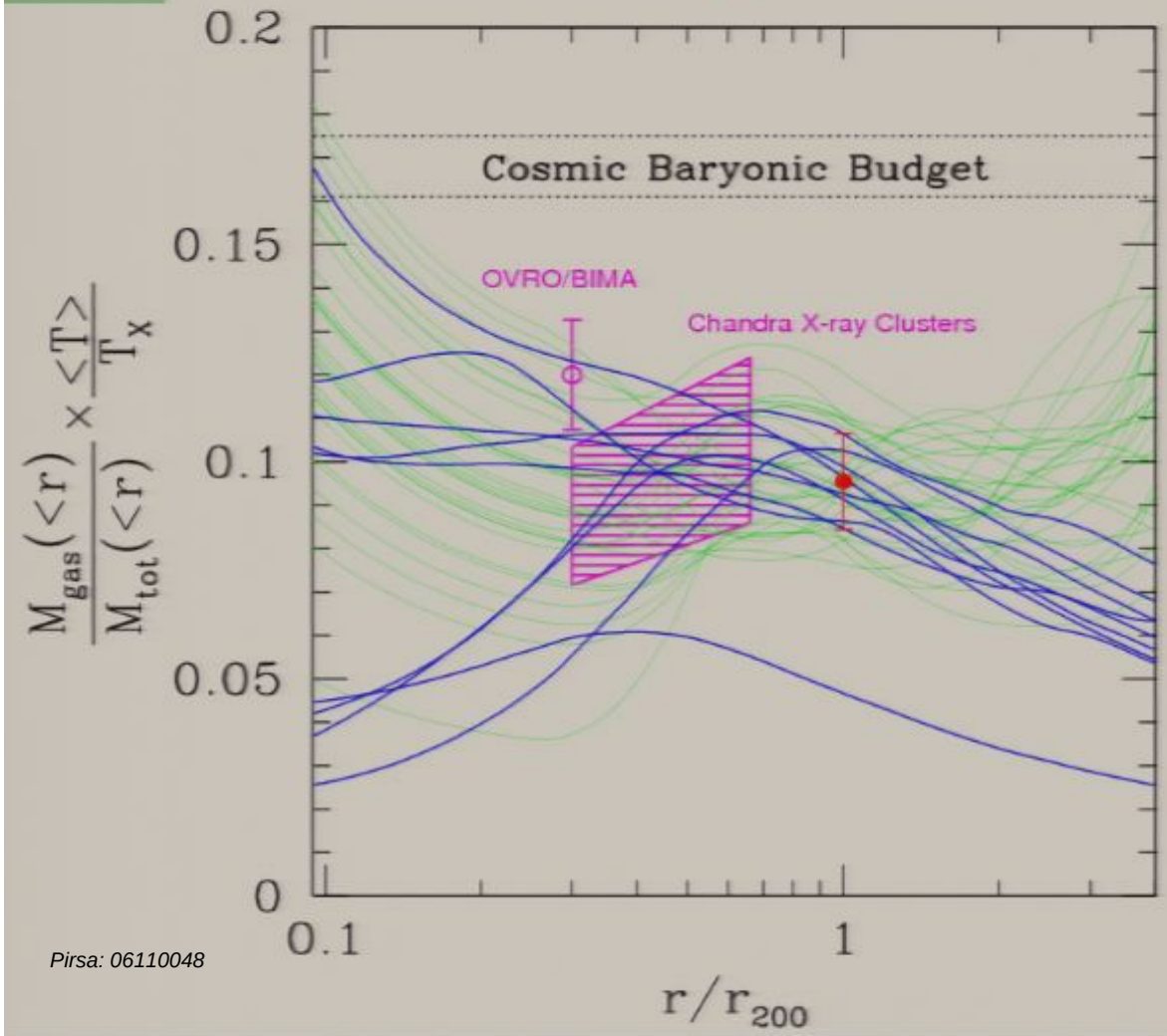


Total ICM gas fraction



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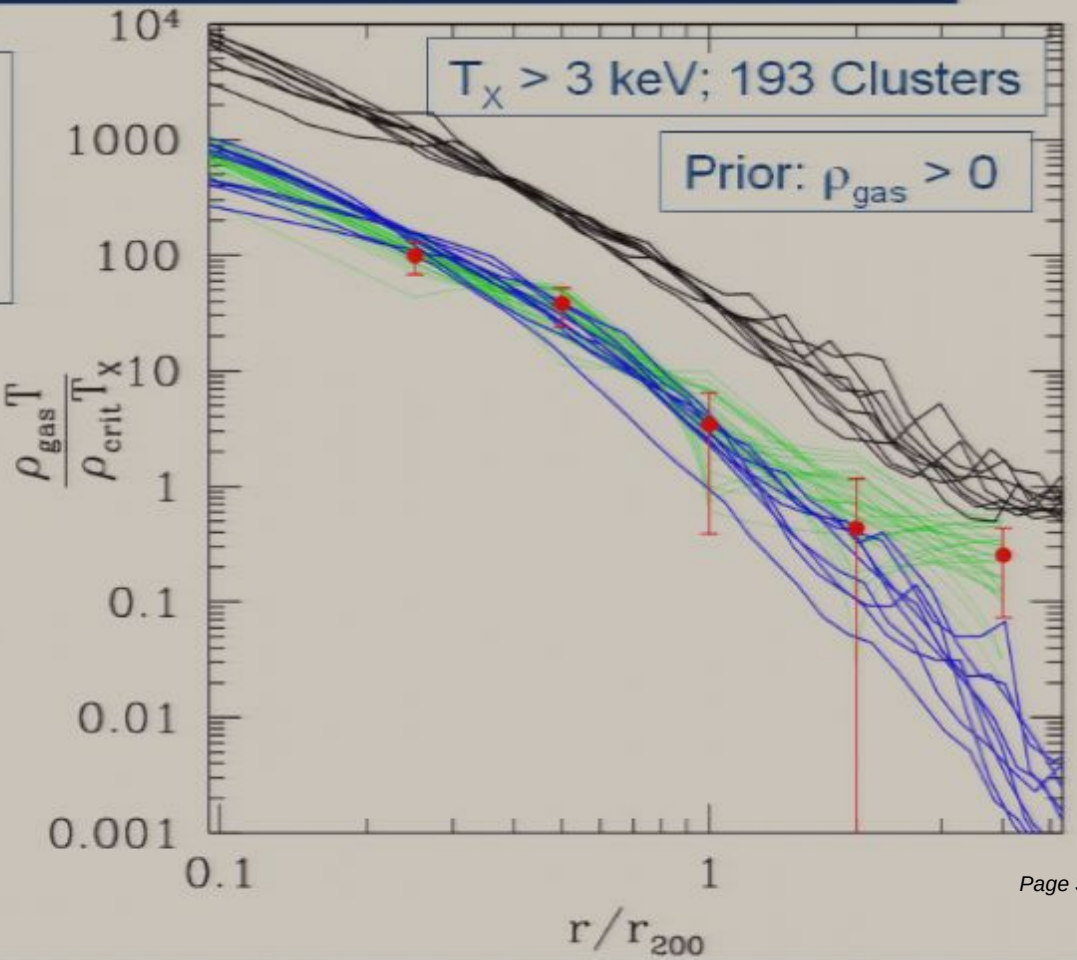

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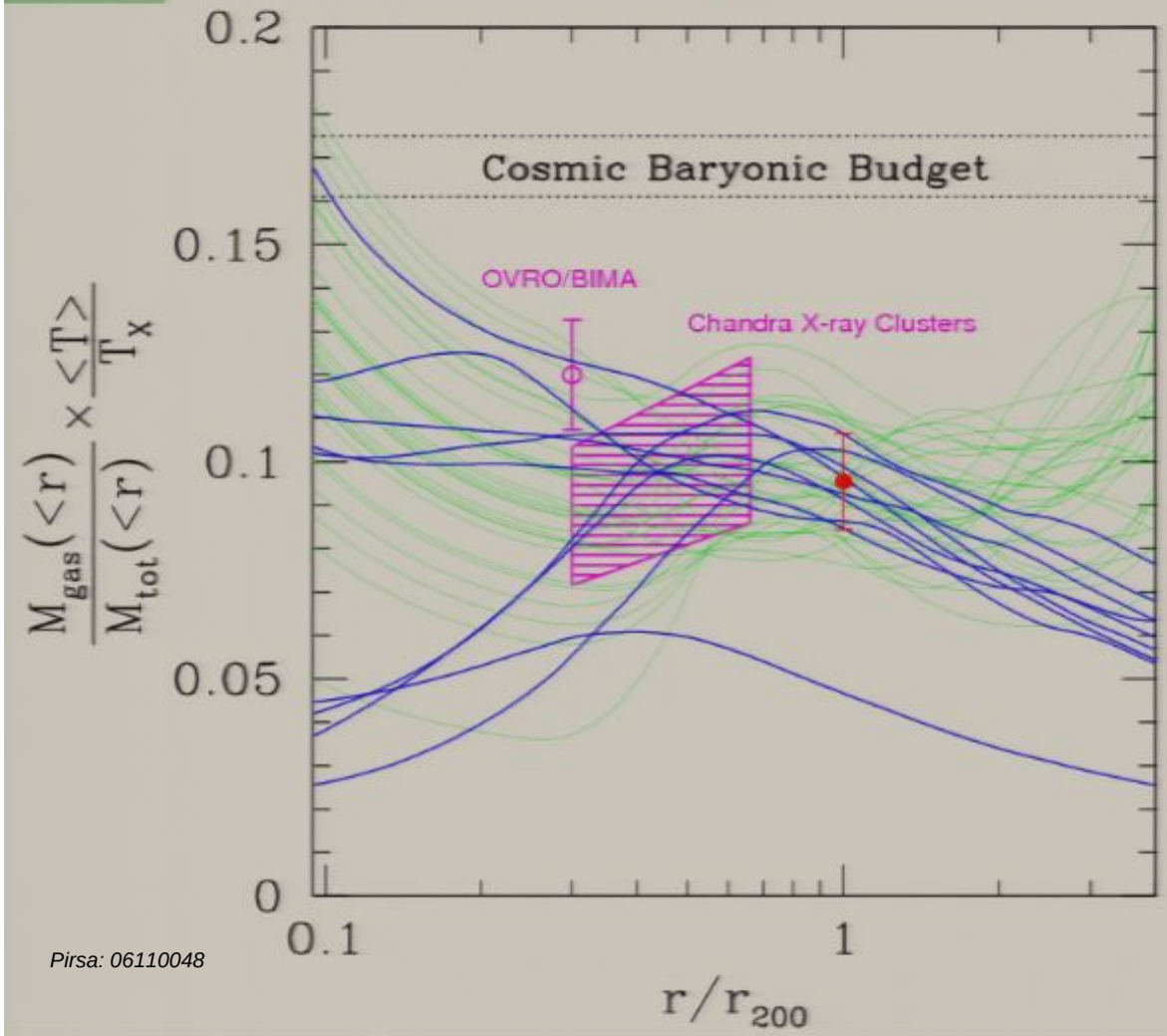

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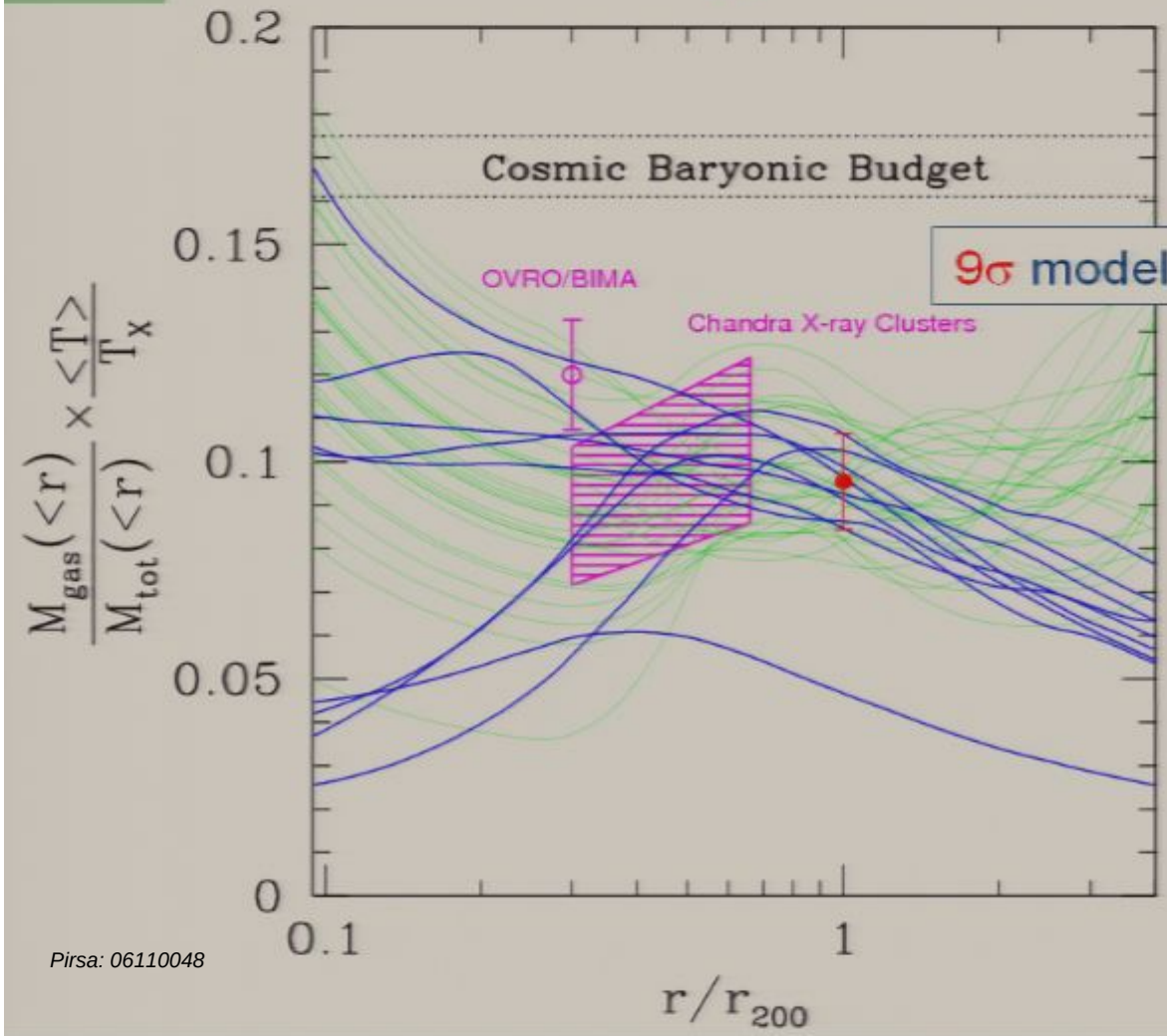
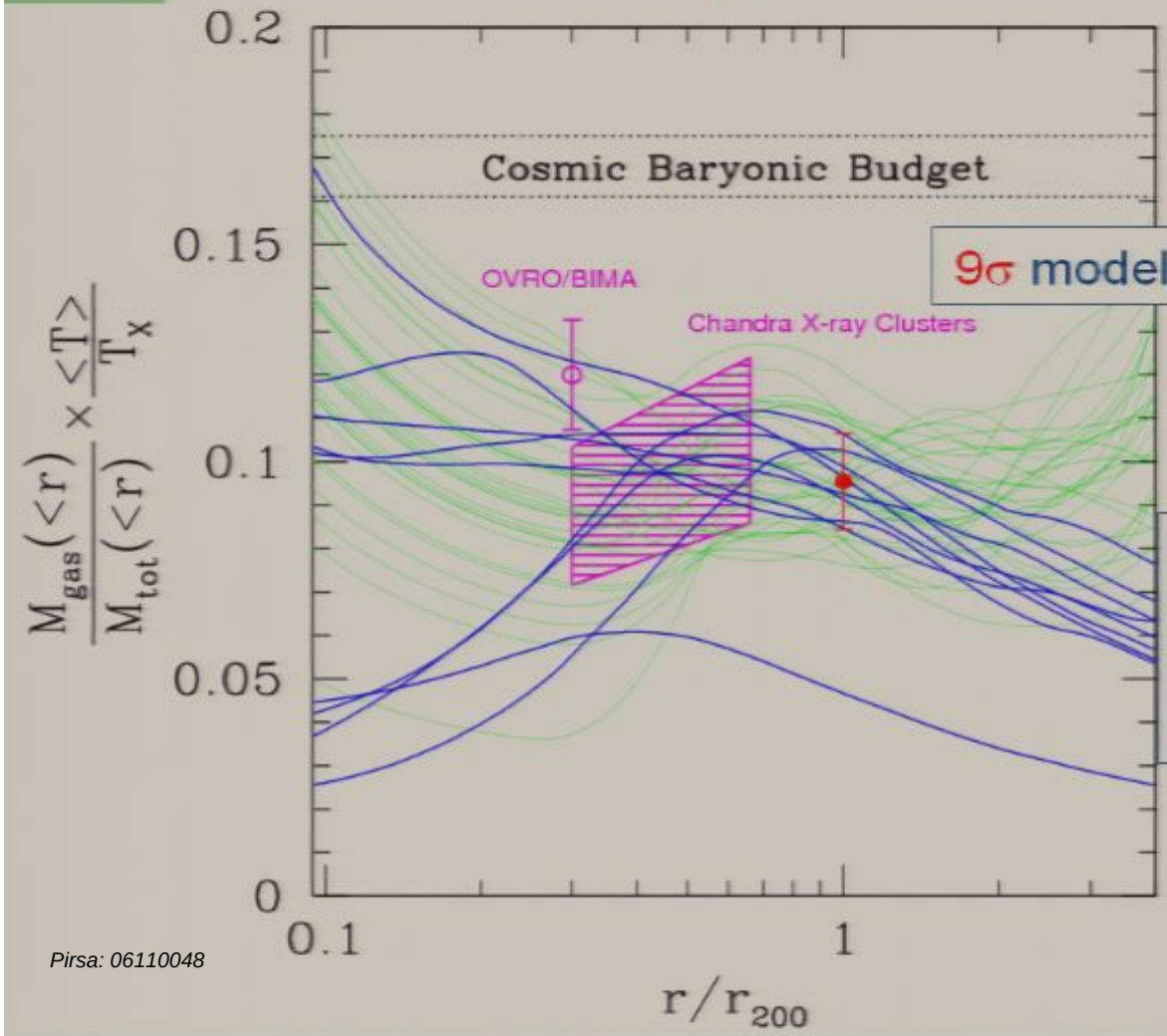


9σ model independent measurement of SZ

Missing Thermal Energy of the Universe

Total ICM gas fraction

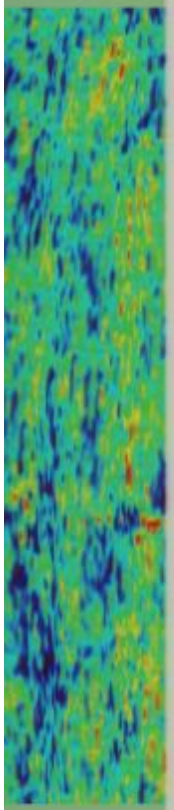


Hydro-Simulations
WMAP Random Realization
● WMAP best fit

9σ model independent measurement of SZ

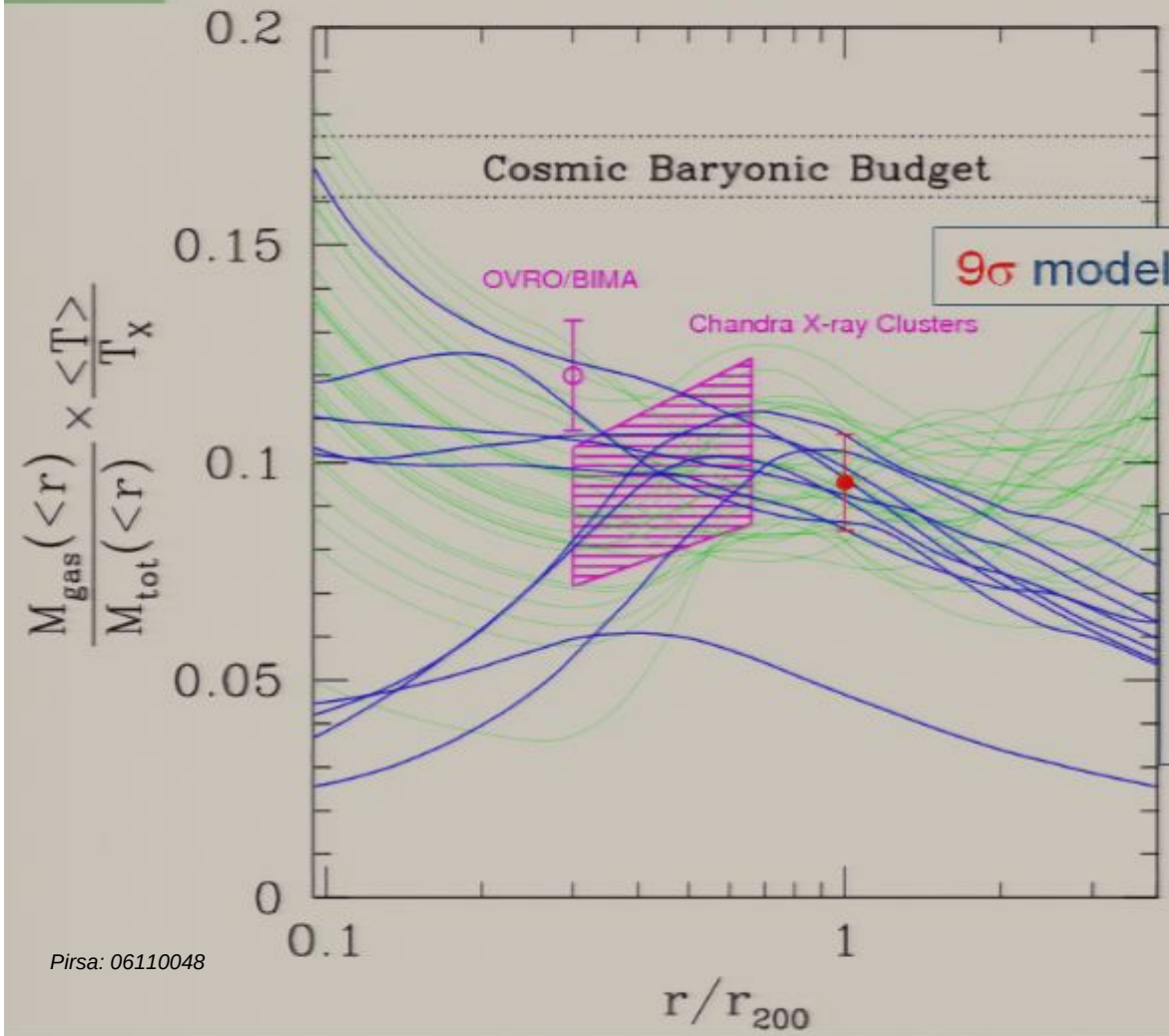
- X-ray and SZ observations are both missing ~30% of baryons
- Simulations are also missing the same fraction in cold gas

32 ± 10% of Baryons are missing from the ICM!



- Where are the rest of baryons?

Total ICM gas fraction



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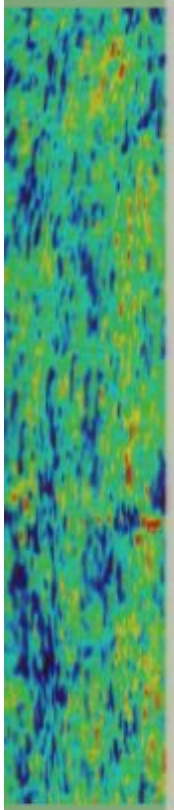

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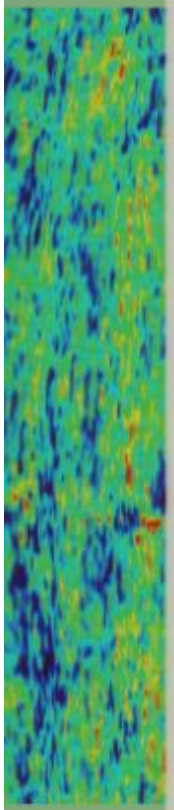

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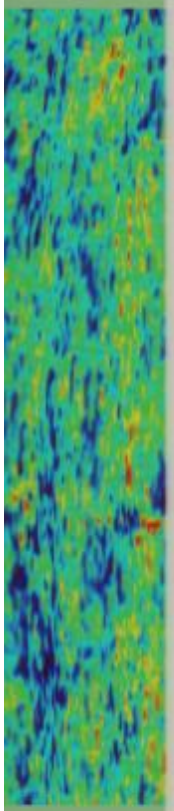

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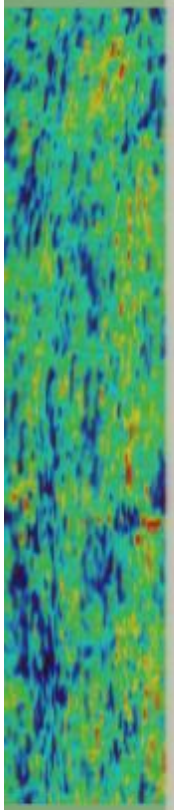

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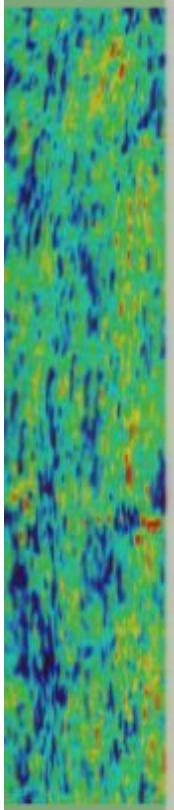

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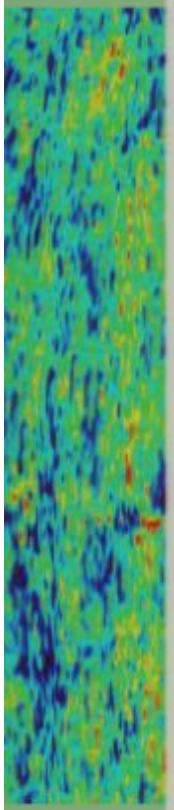

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  - Intracluster stars (how do they get there?)
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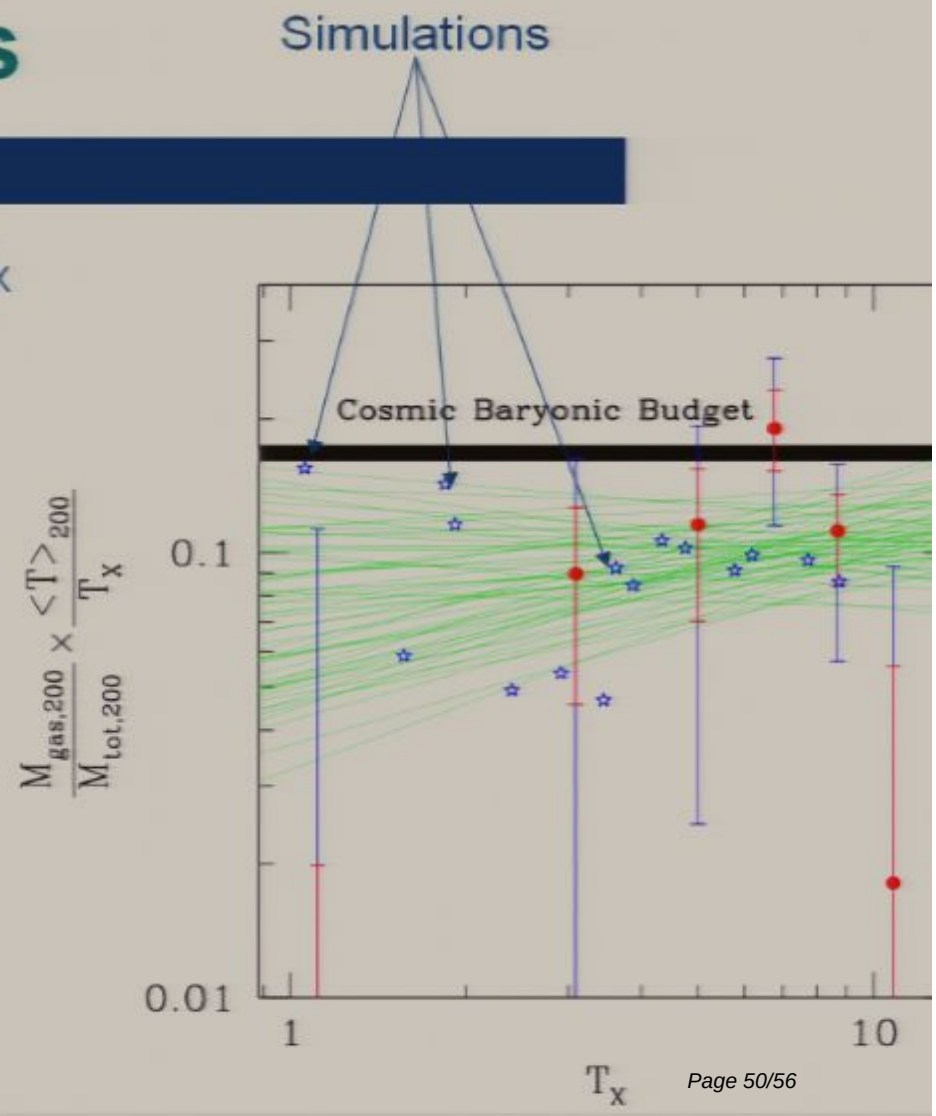
  - cold starless clouds
  - thermal evaporation from the cluster (Loeb 06)

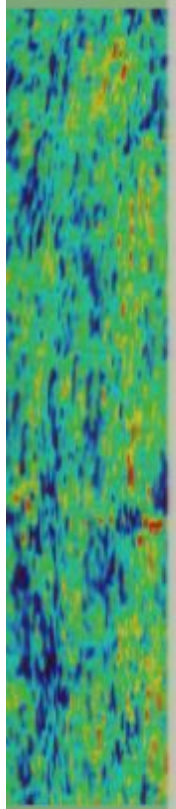
Systematic Trends

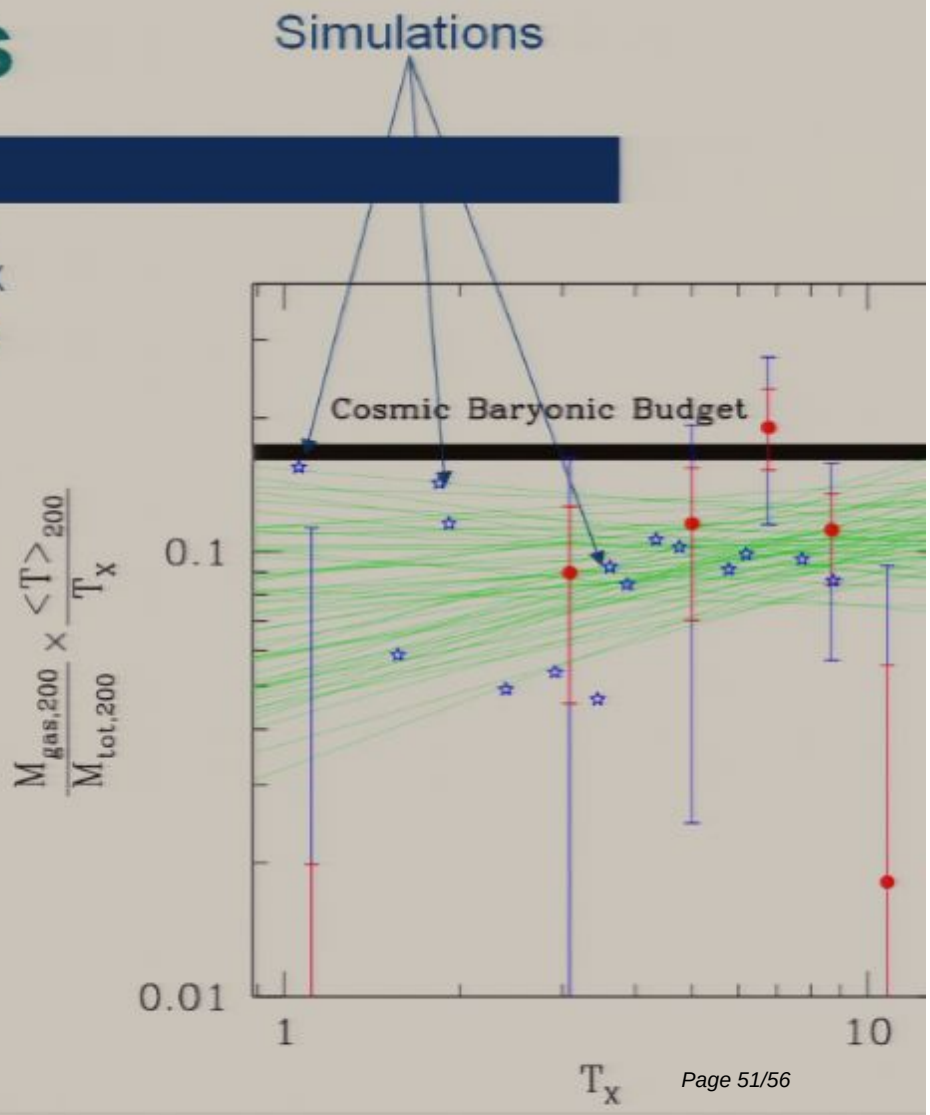
- No significant dependence on T_X



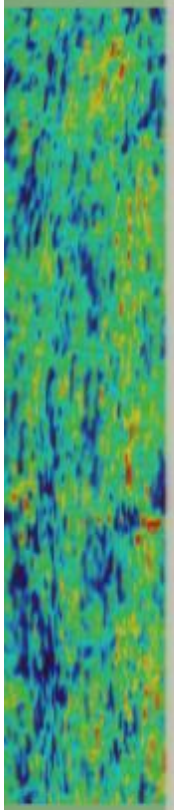
Systematic Trends

- No significant dependence on T_X
- Cool-core clusters seem to have
  - Larger gas fraction
  - Flatter inner pressure profile ????

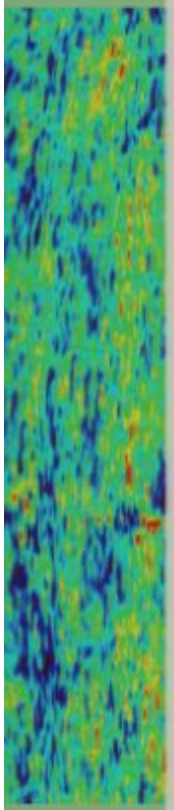




Conclusions



Conclusions



- A model-independent analysis of 3 year WMAP data with 193 massive clusters yields:

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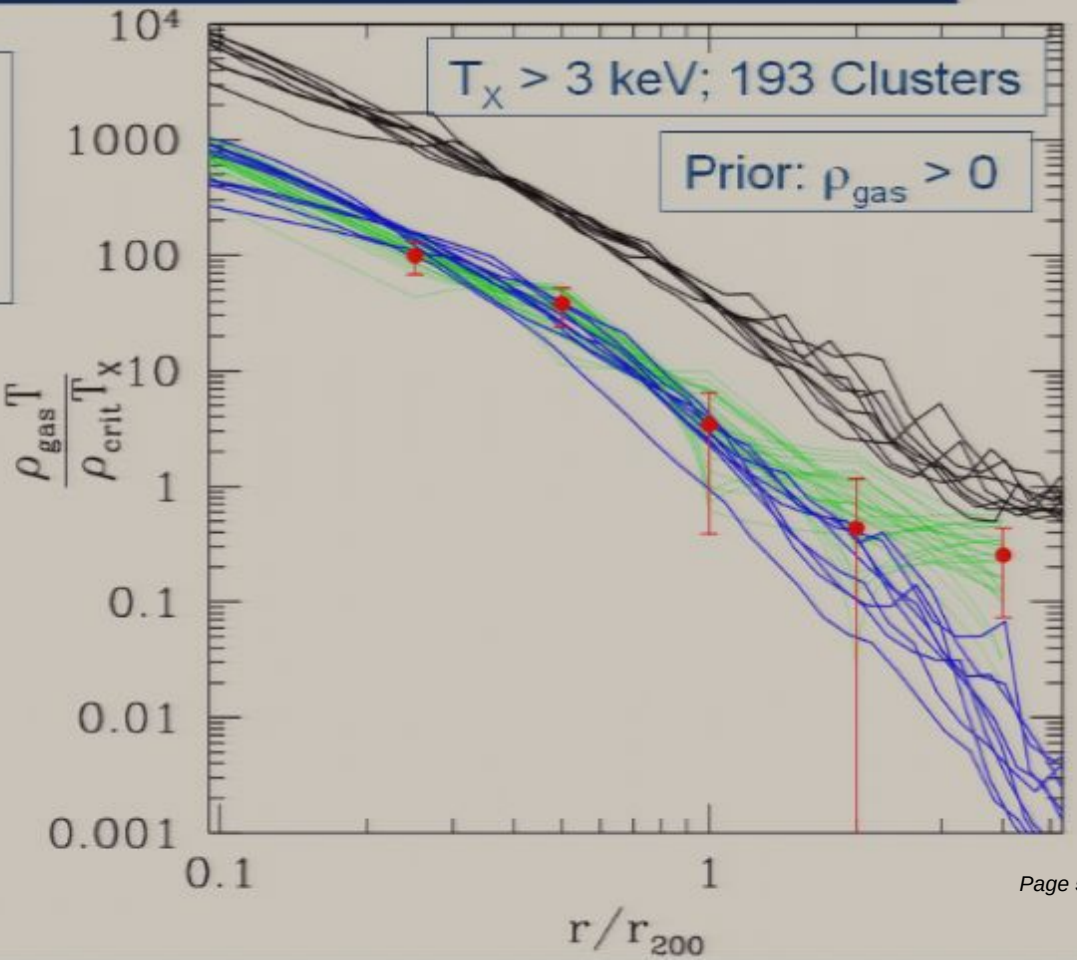
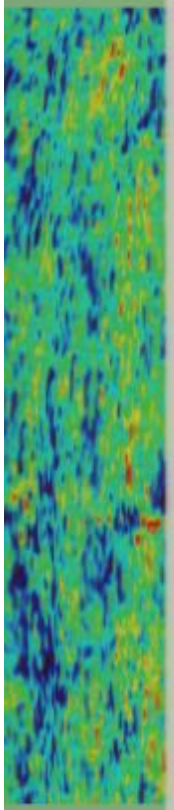
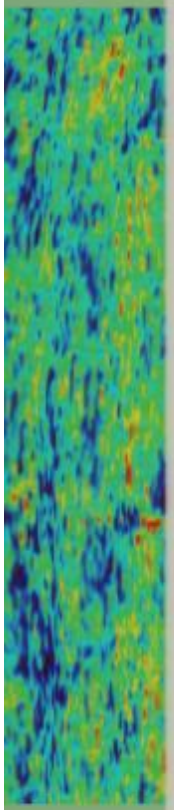


Conclusions



- A model-independent analysis of 3 year WMAP data with 193 massive clusters yields:
- The first model independent universal pressure profile, closely follows dark matter
- Prefers simulation results to null at $\sim 7\sigma$
- 30% of Intracluster medium is consistently missing in SZ and X-ray, as well as simulations, and is nowhere to be found!

The Moral



- In the run-up to high resolution SZ surveys, there is much more that can and should be learnt about ICM
- Higher Resolution CMB/SZ surveys (Planck, SZA, APEX, SPT, …) will be able to significantly lower their effective cluster detection mass threshold thru combination with wide-angle X-ray cluster surveys (e.g., DUO)
- X-ray and SZ surveys must be combined to provide reliable tests for models of Dark Energy or Cluster Physics