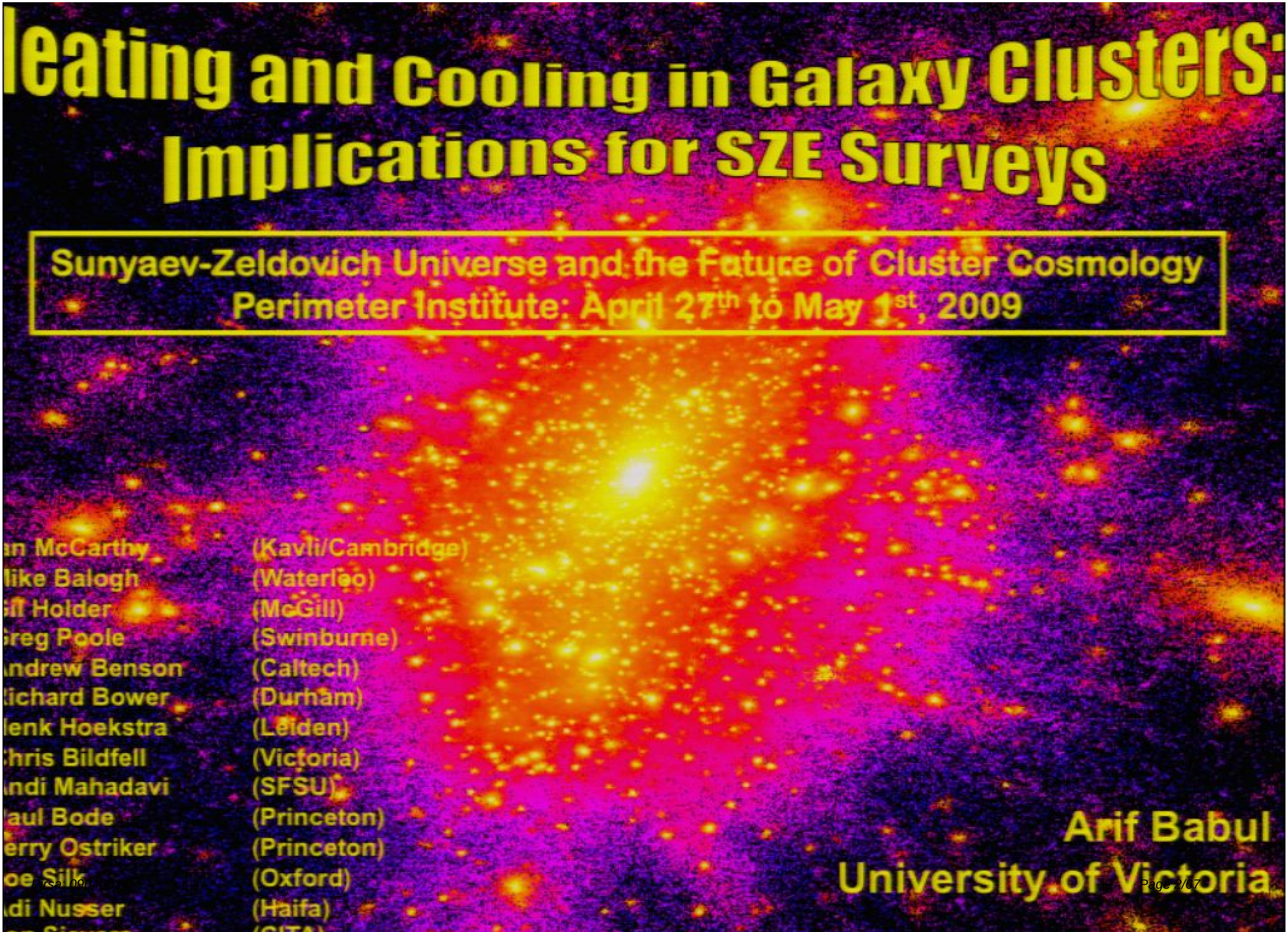
Title: Heating and Cooling of the Intracluster Medium

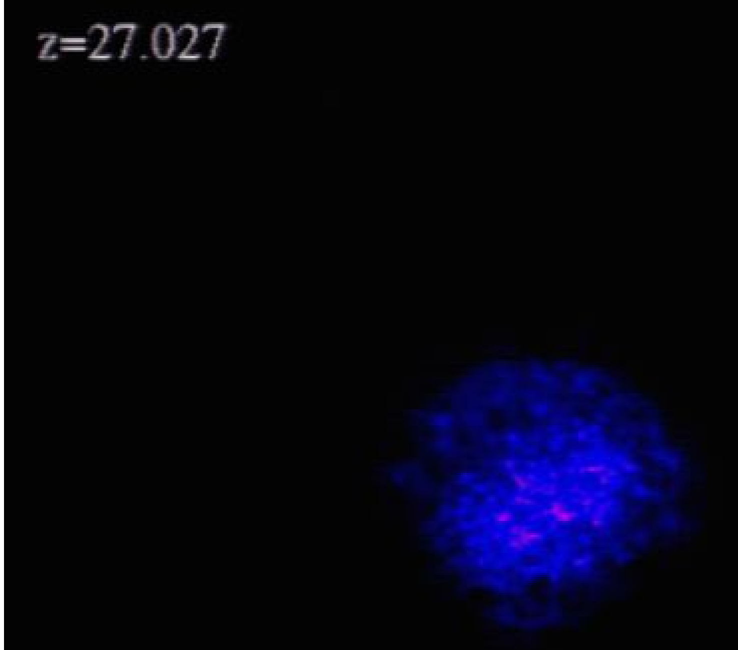
Date: Apr 27, 2009 11:30 AM

URL: http://pirsa.org/09040034

Abstract: The observed thermal properties of the ICM shows much greater dispersion than expected if the gas was subject only to shock-heating by mergers and during infall. This diversity can be best understood as a byproduct of AGN feedback occurring in galaxies destined to become cluster members, both before and after cluster formation. Theoretical considerations suggest that the level of preheating ought to vary from one proto-cluster region to another. The entropy profiles of roughly 50% of the clusters with long central cooling times require that the gas be "preheated" to high entropy. Gas density profiles in such systems form hot central cores. Clusters with gas that isn't preheated to sufficiently high values forms peaked density profiles. I will show how variable preheating explain the various observed X-ray/X-ray correlations and discuss some of its implications for SZ studies. I will also present optical results that shed new light on the fate of the cold gas in cooling-unstable clusters, and propose observations tests of the "AGN preheating" aspect of the picture.



leating and Cooling in Galaxy Clusters:
Implications for SZE Surveys
Sunyaev-Zeldovich Universe and the Future of Cluster Cosmology
Perimeter Institute: April 27th to May 1st, 2009
an McCarthy (Kavli/Cambridge)
like Balogh (Waterloo)
il Holder (McGill)
reg Poole (Swinburne)
ndrew Benson (Caltech)
ichard Bower (Durham)
lenk Hoekstra (Leiden)
hris Bildfell (Victoria)
ndi Mahadavi (SFSU)
aul Bode (Princeton)
erry Ostriker (Princeton)
oe Silk (Oxford)
di Nusser (Haifa)
Arif Babul
University of Victoria



Credit: Lewis, Babul, Katz et al. 2000
Movie courtesy of T.R. Quinn

From cluster to cluster, the DM distribution is nearly universal in shape:

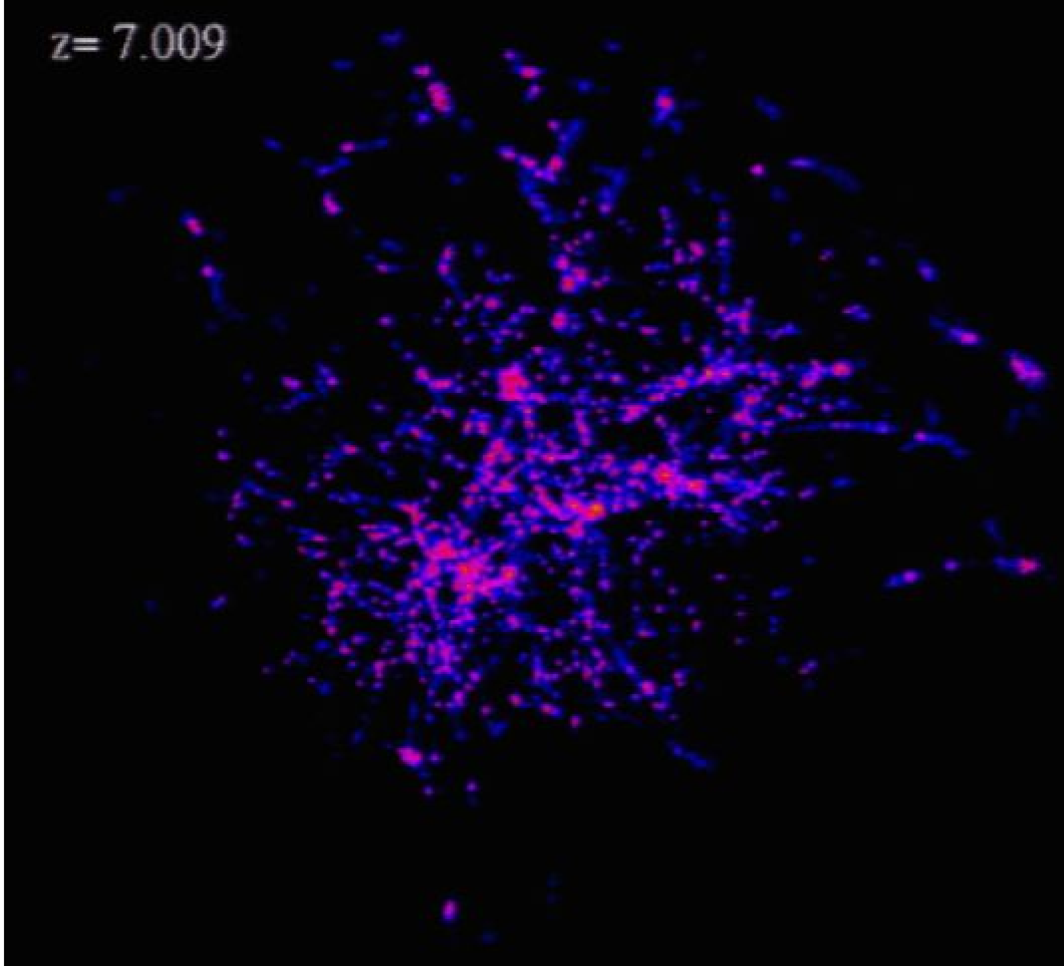
$$\rho \propto r^{-1}(1 + c_{200} r)^{-2}$$

with deviations being relatively mild and well understood.

The gas distribution is:

- shows much more variability,
- variations are not trivial,
- origin of variability is still an open question.

THIS IS IN ADDITION TO LONG-KNOWN SIGNS THAT GAS DOES NOT TRACE DM



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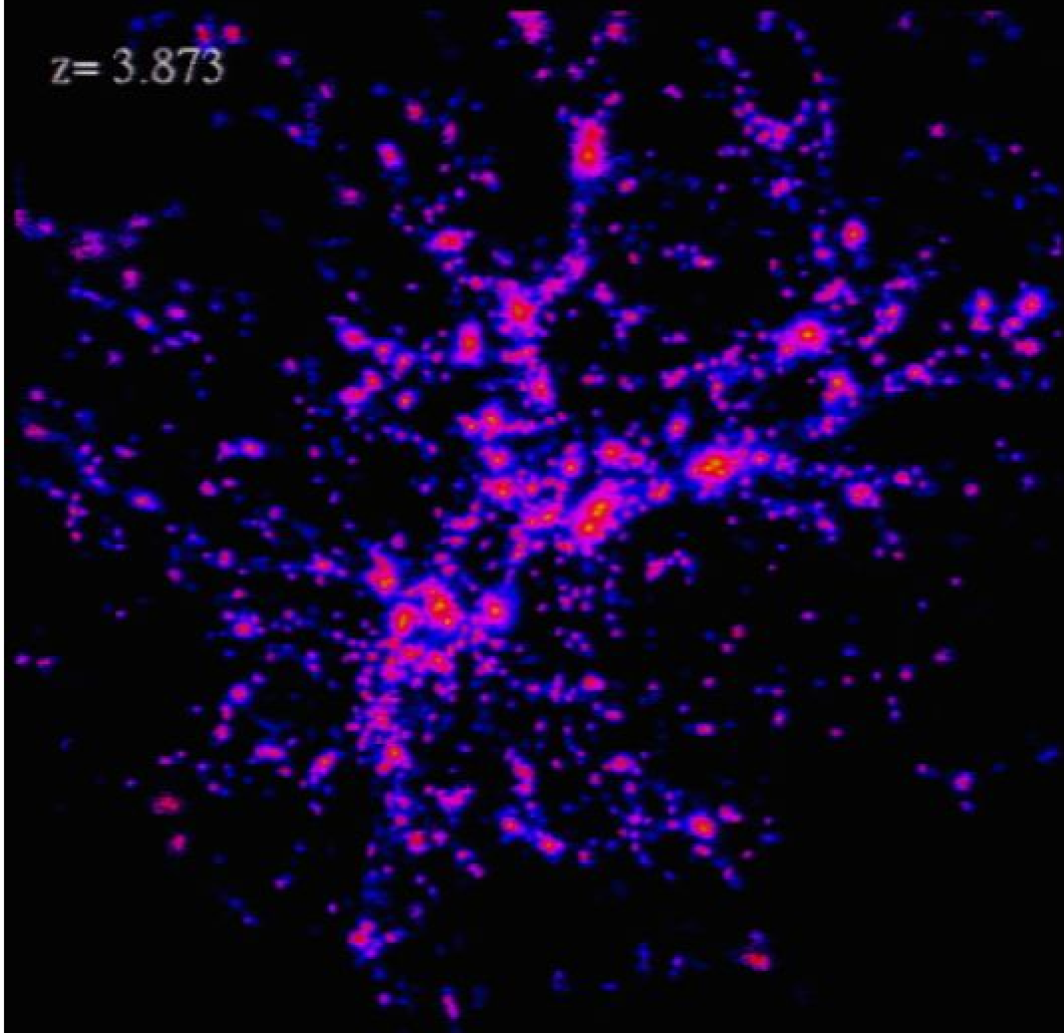

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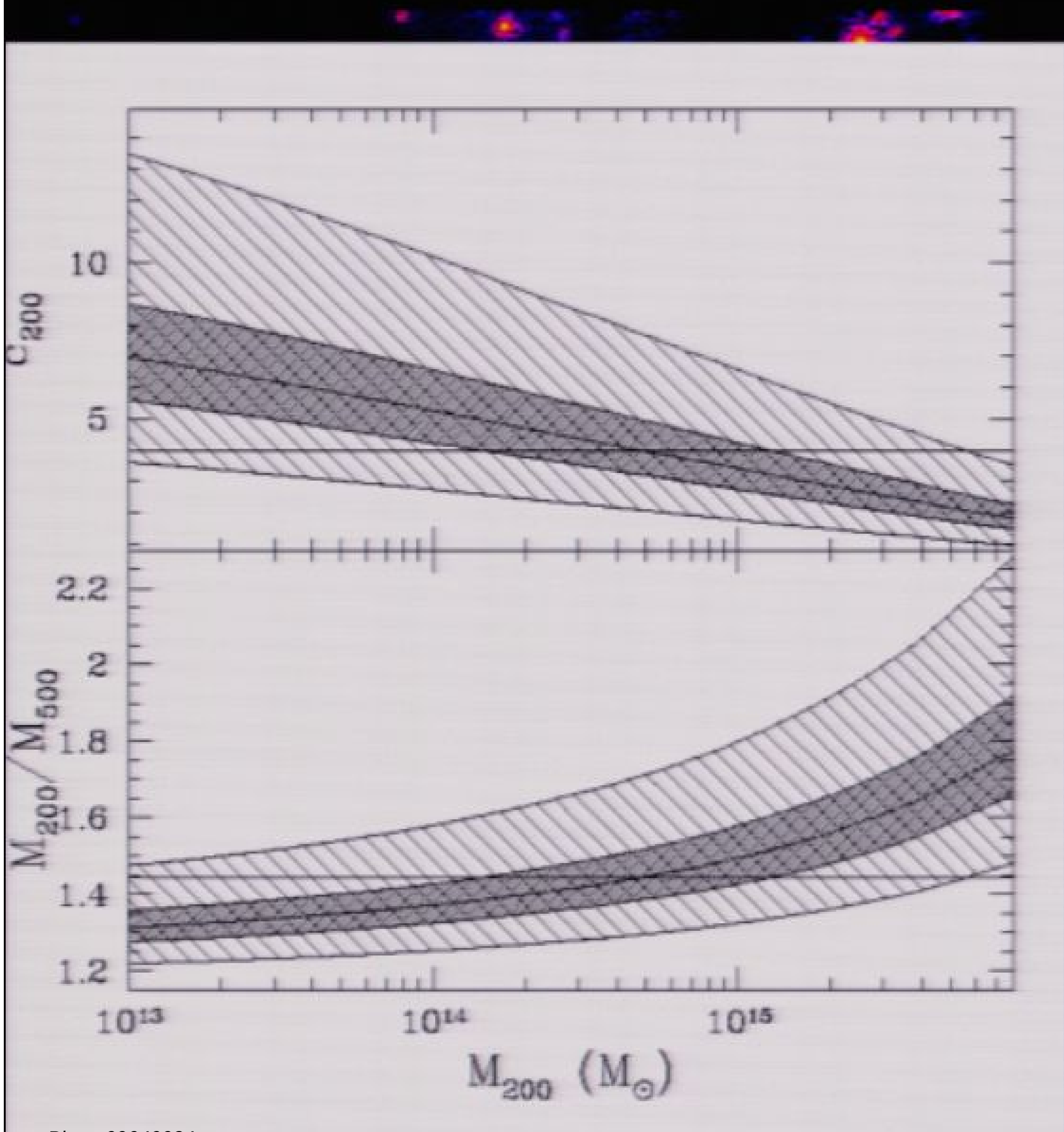

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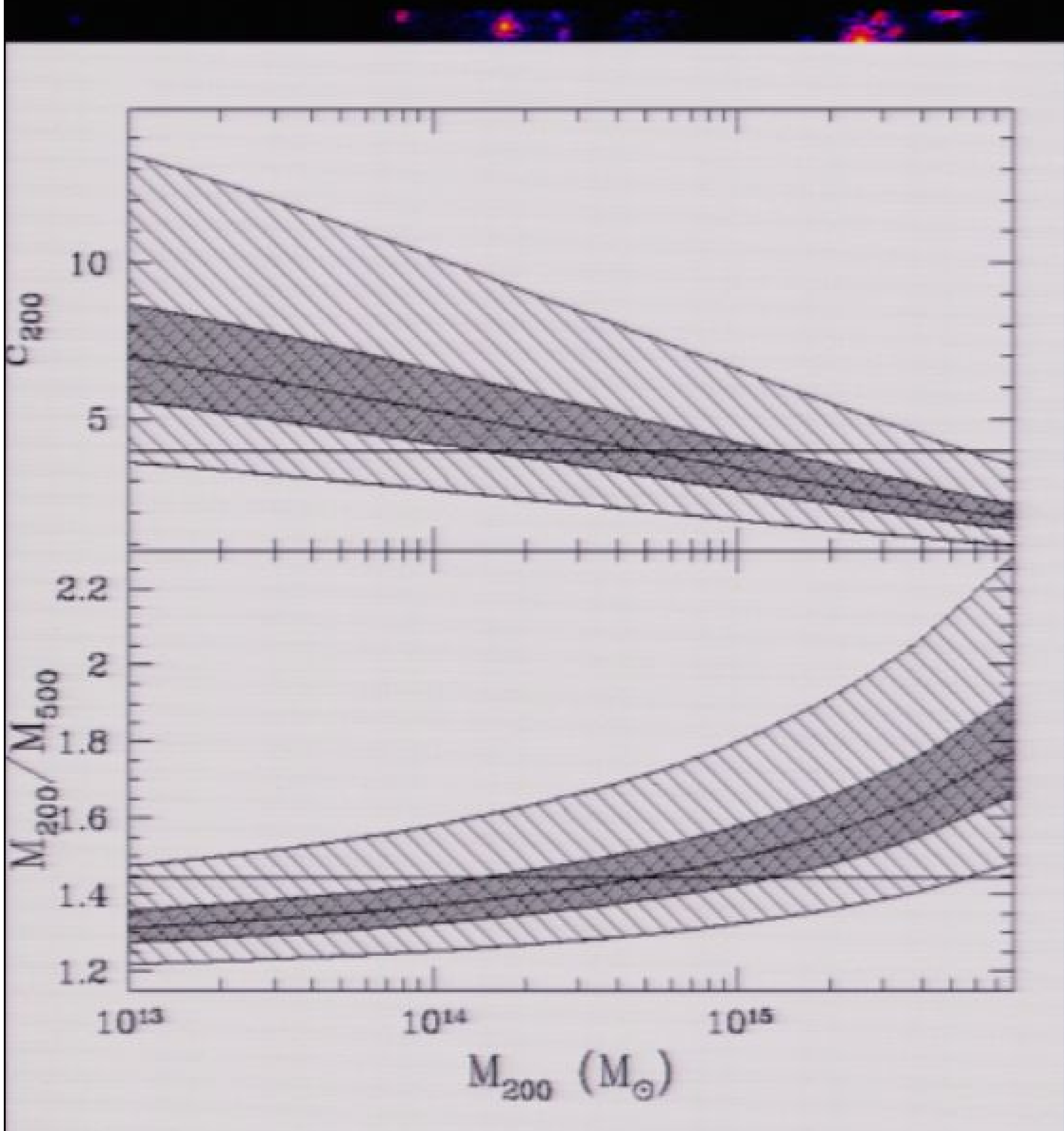

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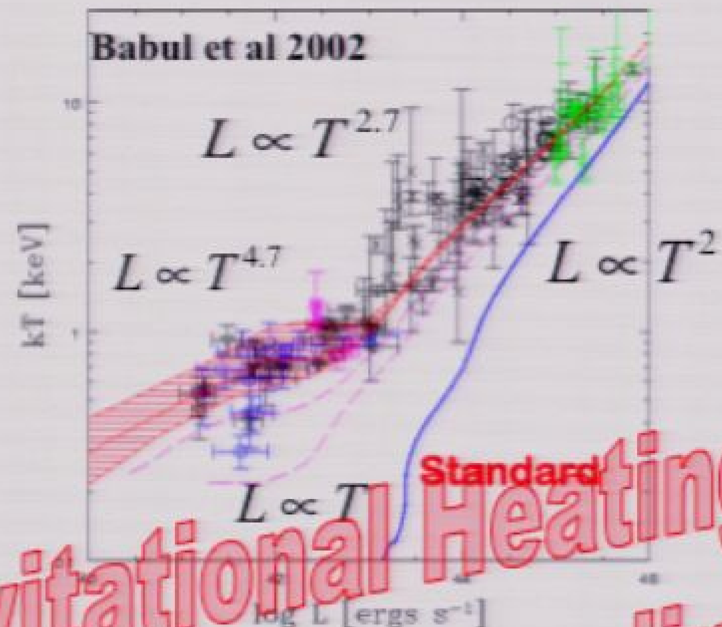
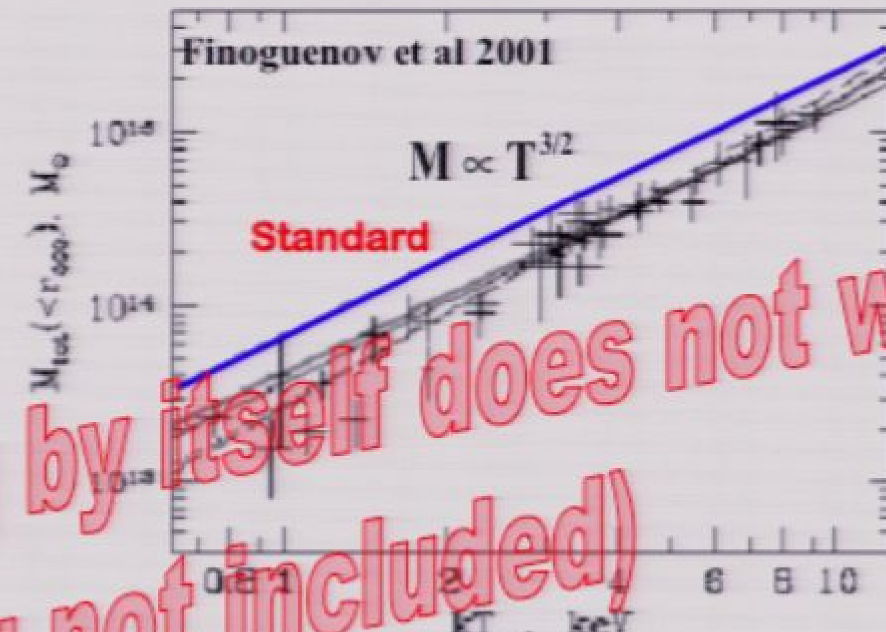
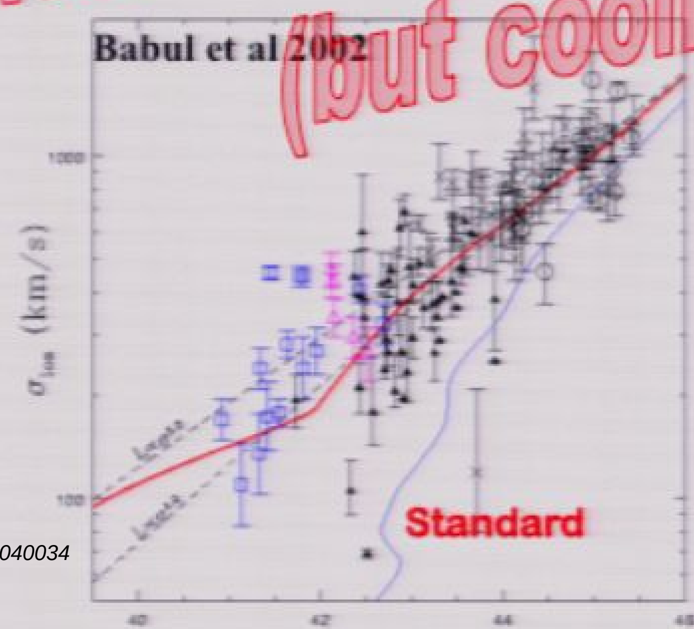
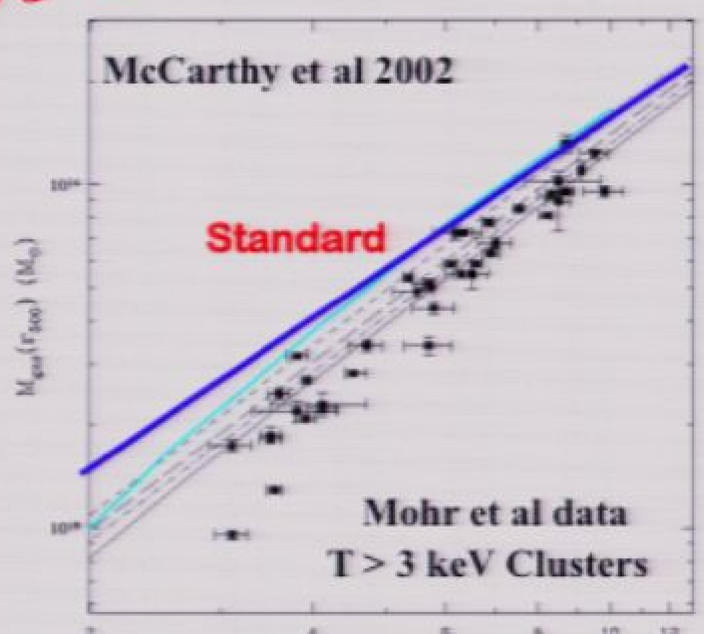
GLOBAL X-RAY/X-RAY & X-RAY/OPTICAL CORRELATIONS



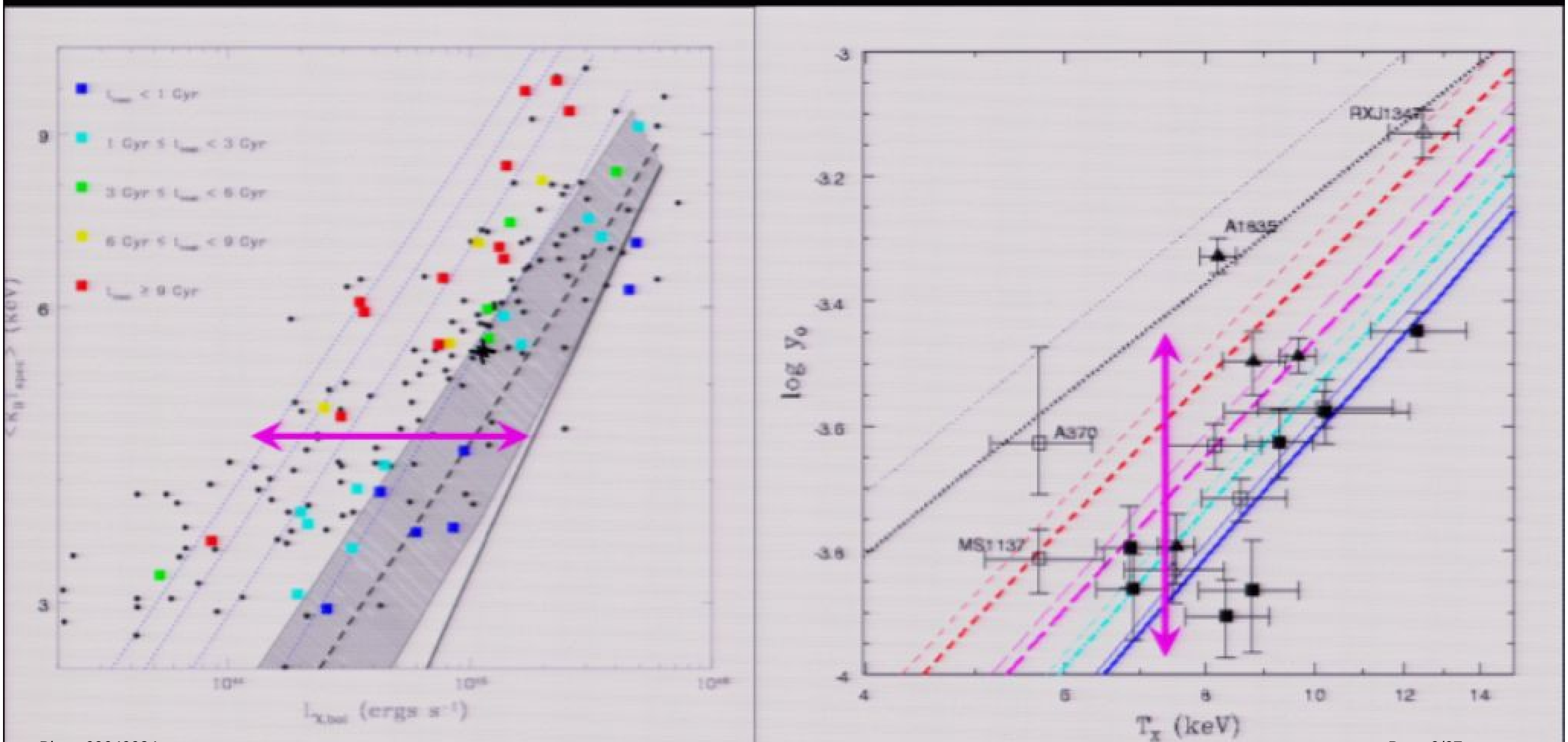


Gravitational Heating by itself does not work!
(but cooling not included)



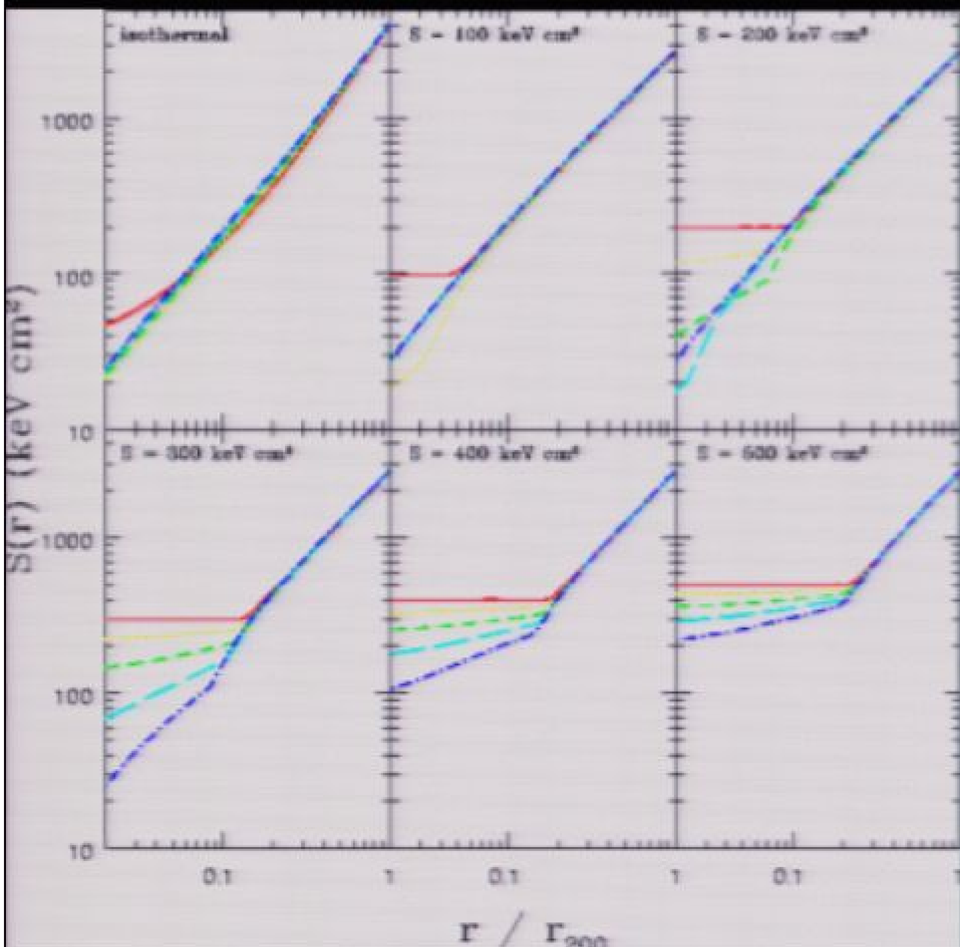


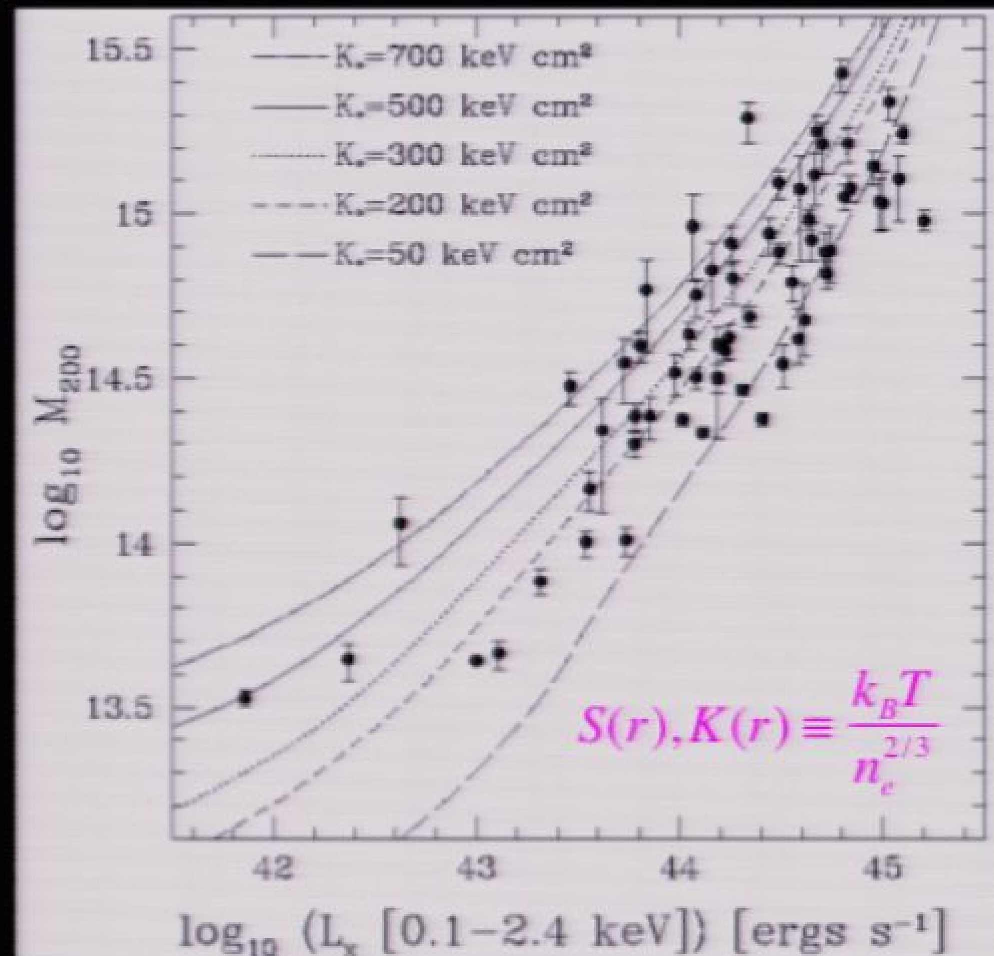
Indications of high variability in gas properties has been around for decades



McCarthy et al

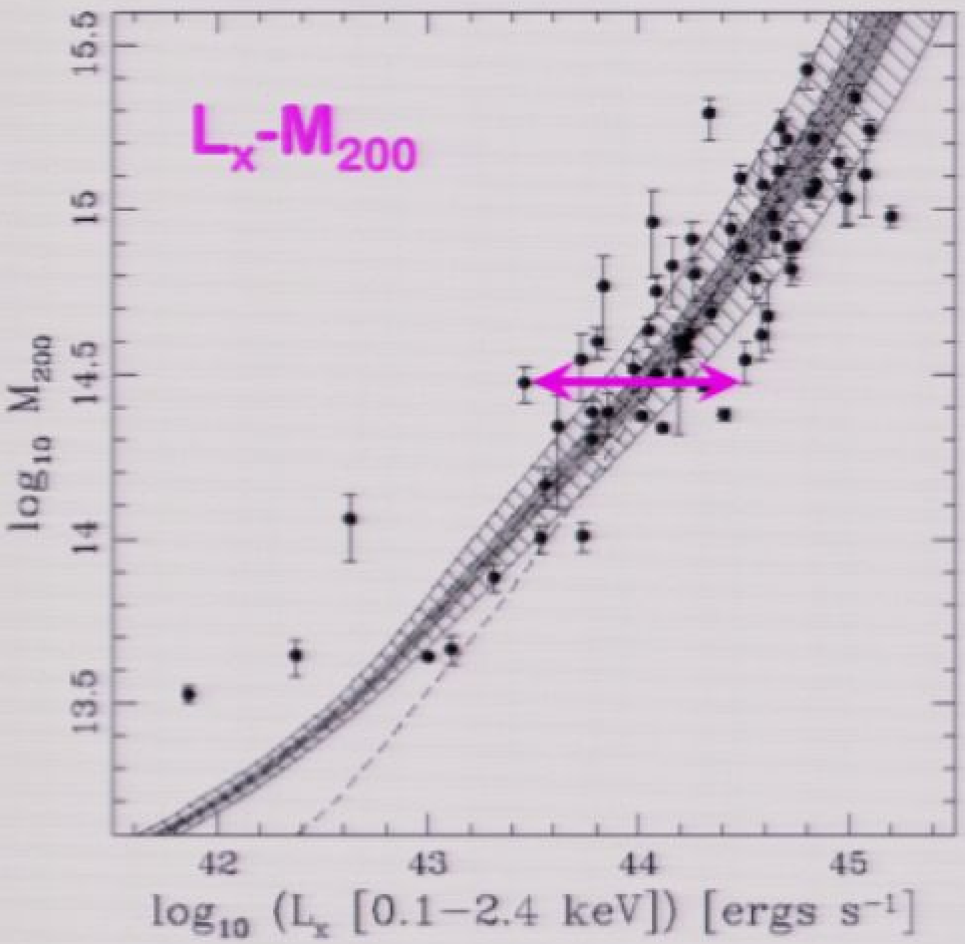
SCHEMATIC ENTROPY PROFILES:
Variations in Entropy Cores as Source of Scatter

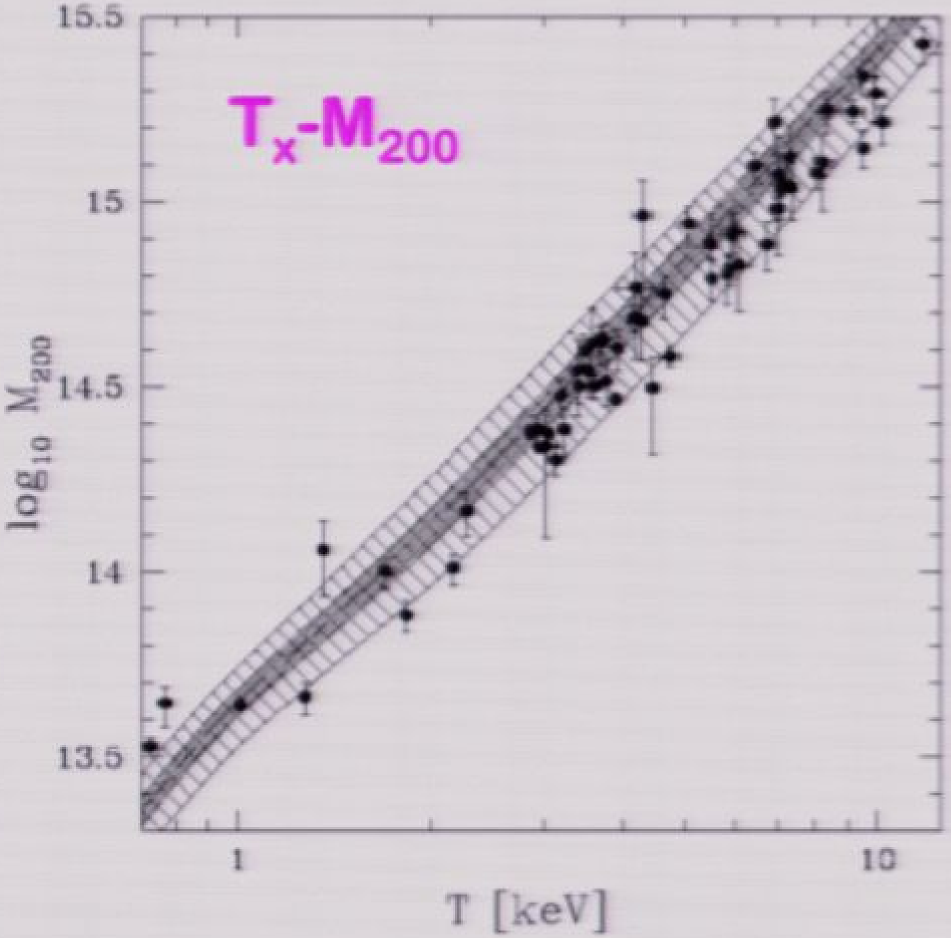




Balogh et al 1999; 2006; Babul et al 2002; McCarthy et al 2004; 2008

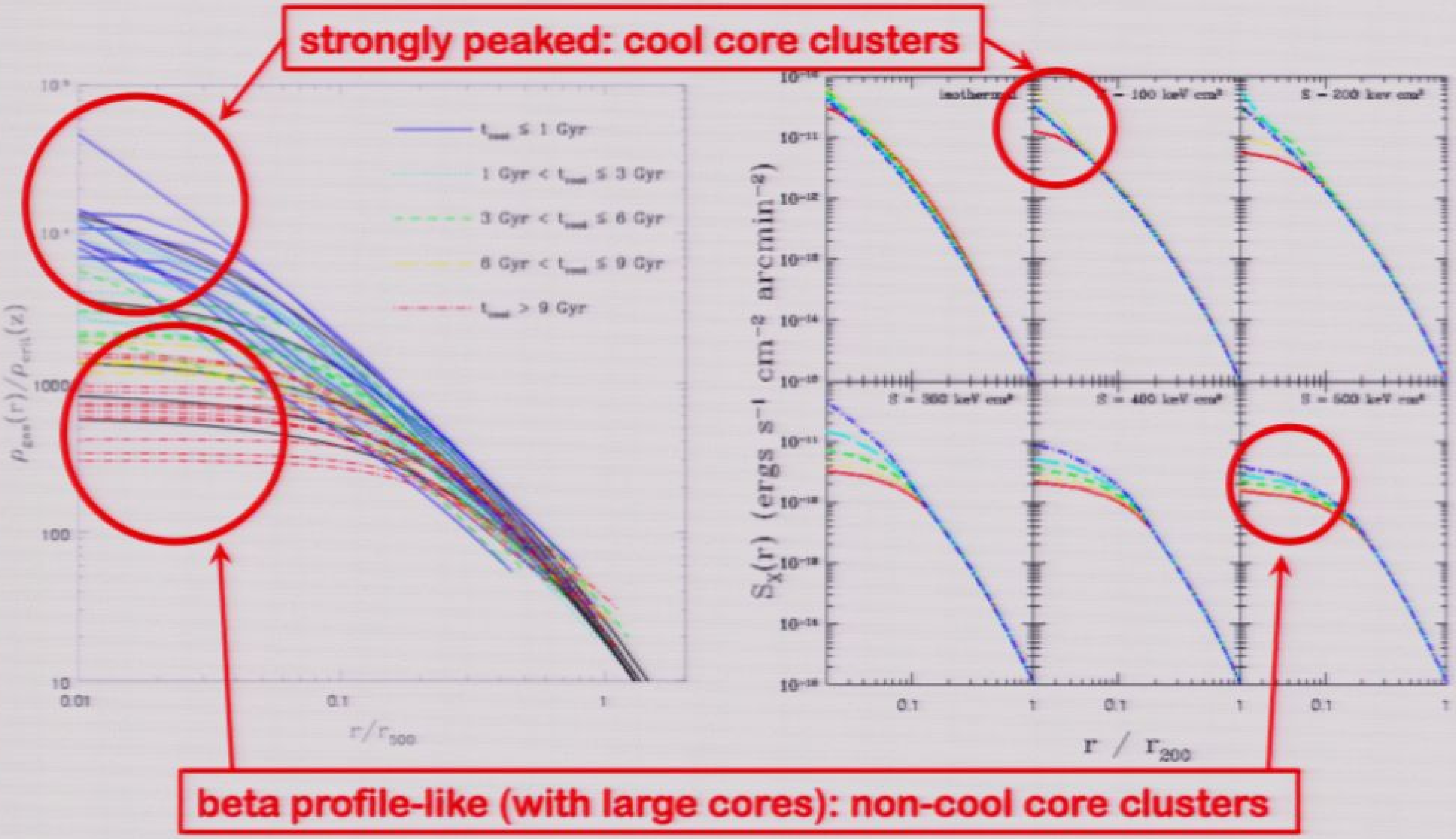
Variations In Halo Concentrations Cannot Account For Large Range In Lx



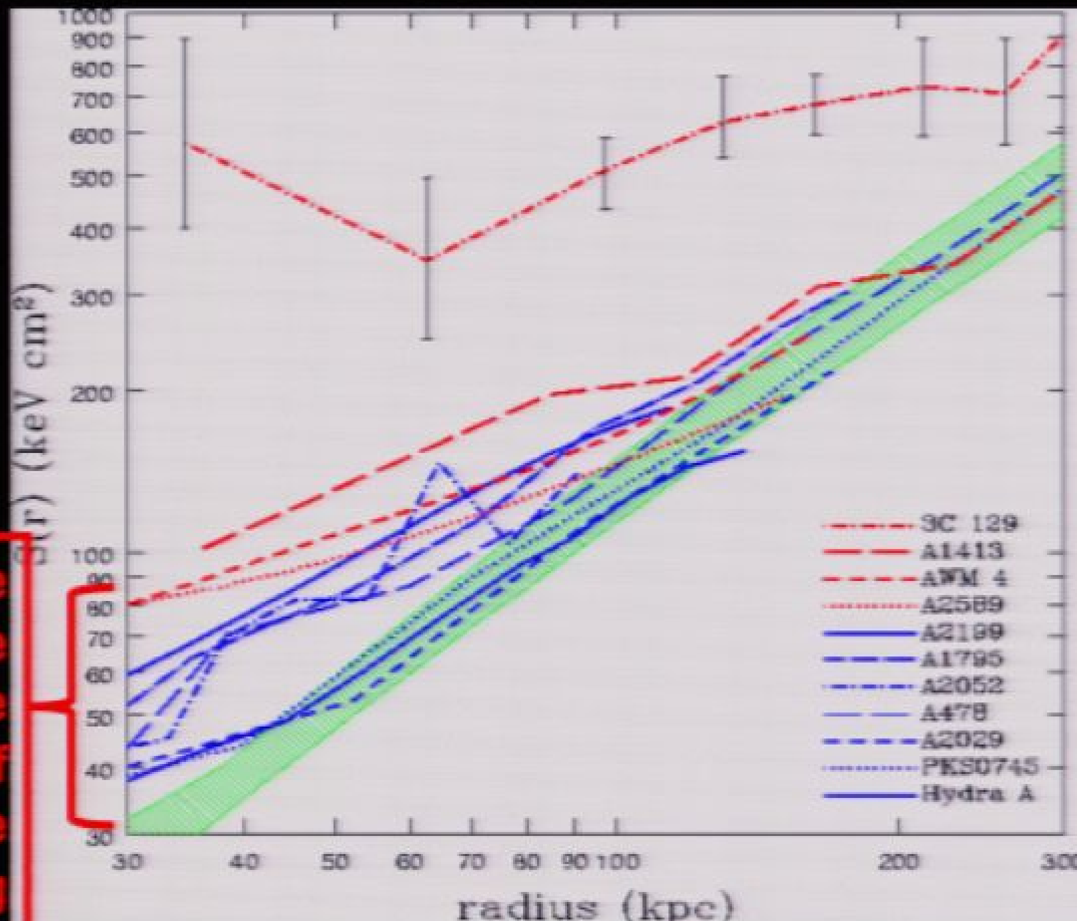


Balogh , Babul et al

Implications Of Varying Entropy Core Values: X-rays



OBSERVED CLUSTER ENTROPY PROFILES



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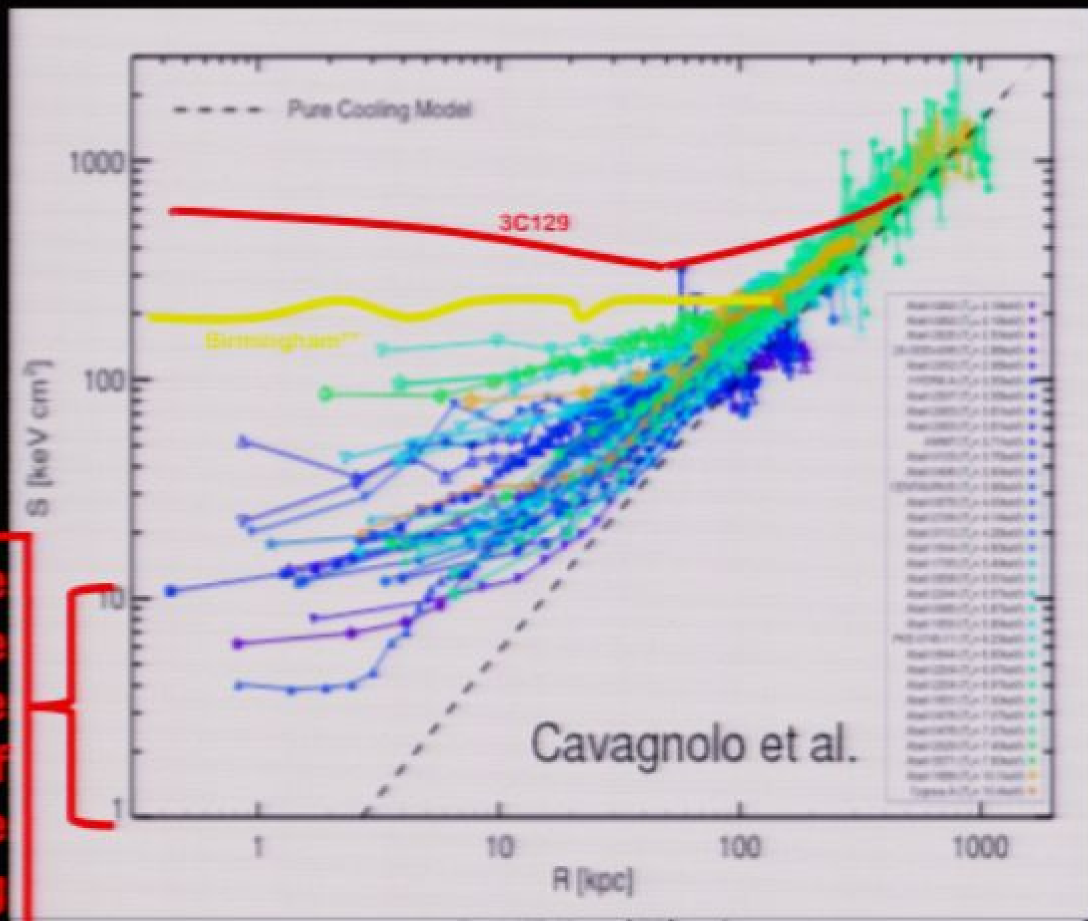

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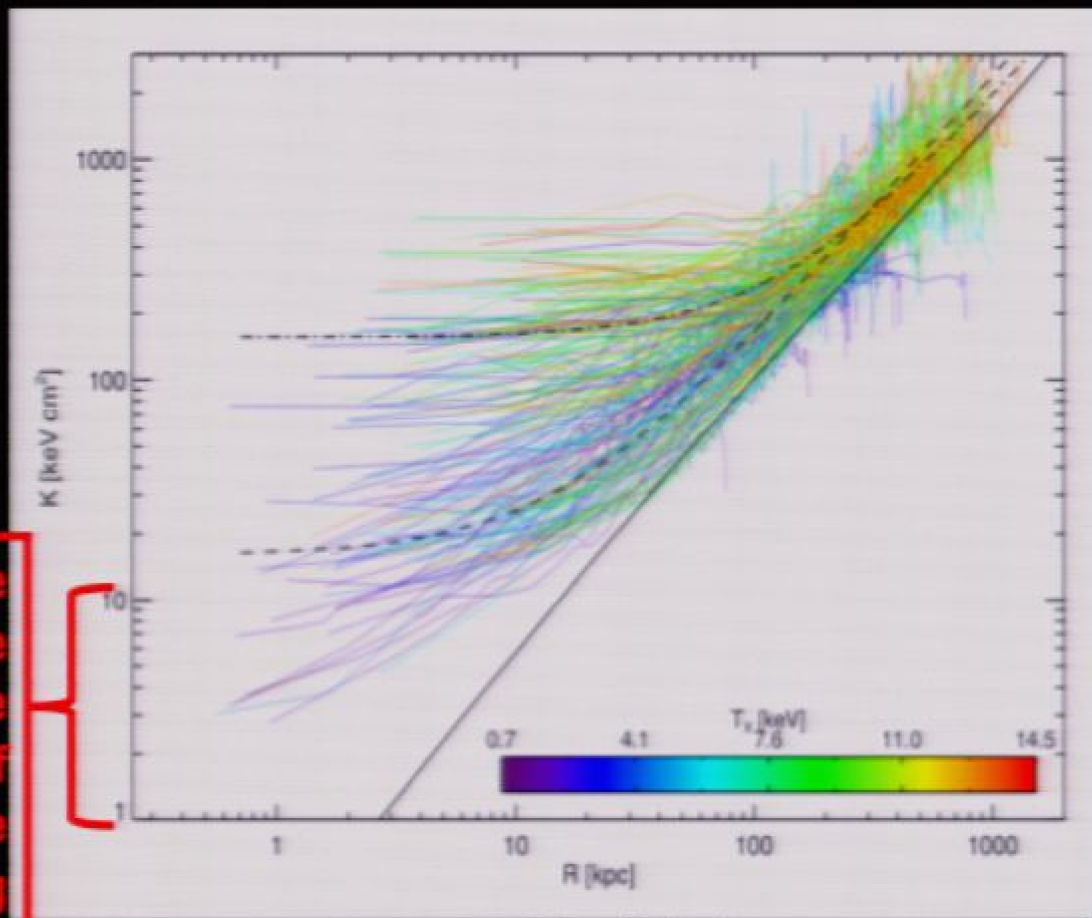

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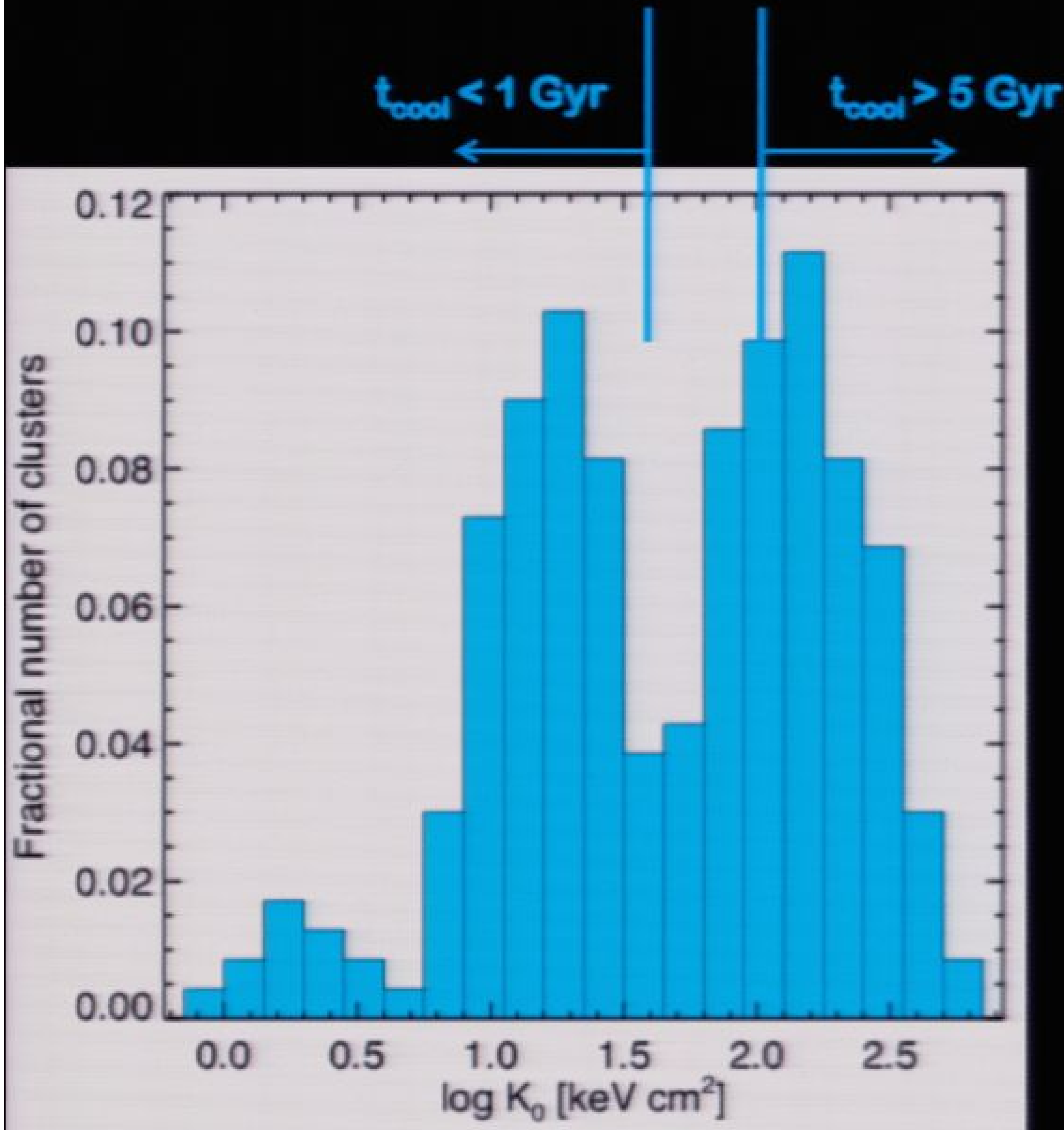


Cavagnolo et al 2009

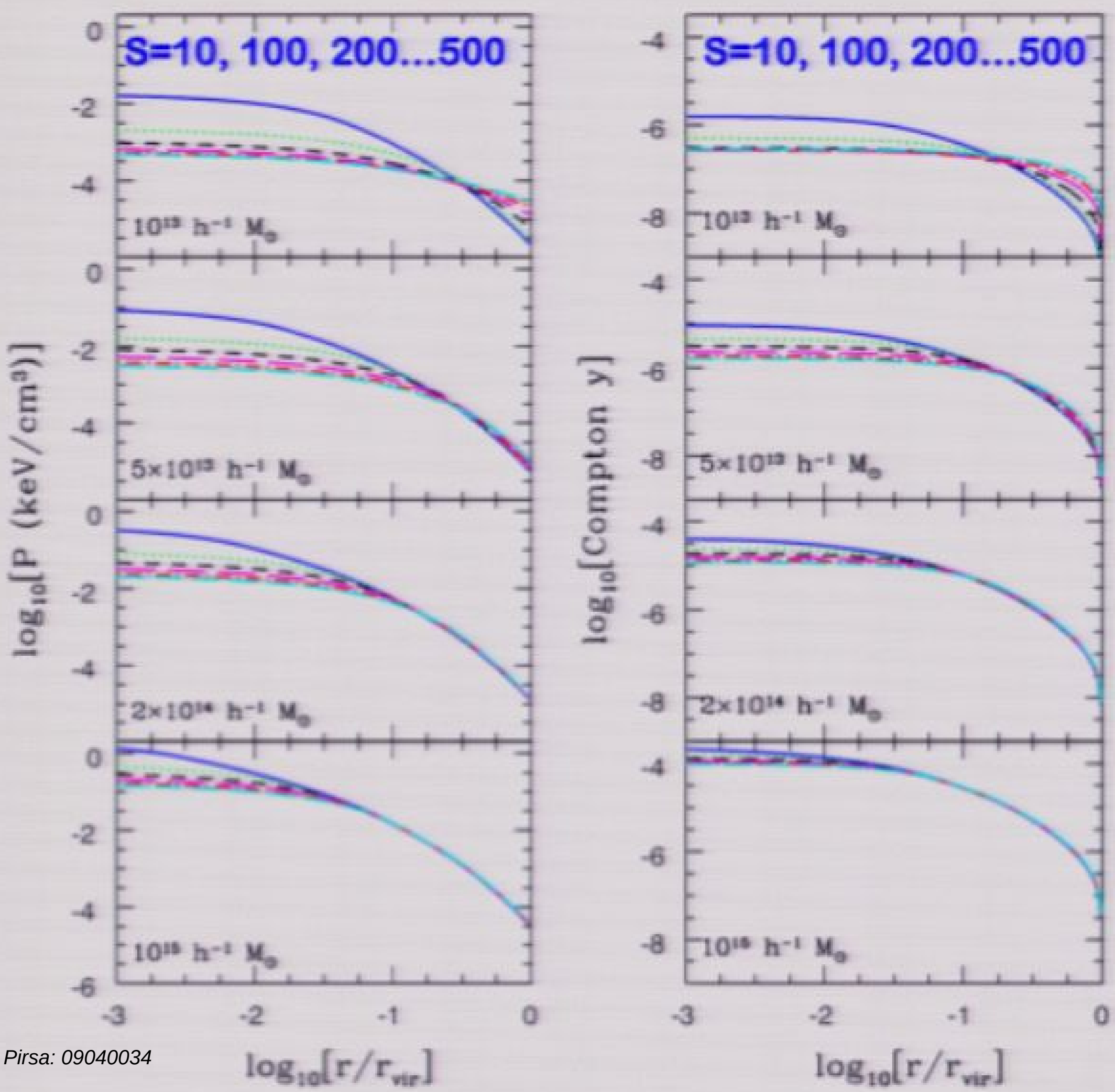
Fraction of clusters with t_{cool} < 1 Gyr: ~40-50%

Fraction of classical cool-core systems: ~15-20%

Fractions of clusters with t_{cool} > 5 Gyr: ~30-40%

Non-cool core systems have typical core entropy of 200-300, with tail extending to ~700

Implications Of Varying Entropy Core Values: SZE



At a given mass, larger S results in:

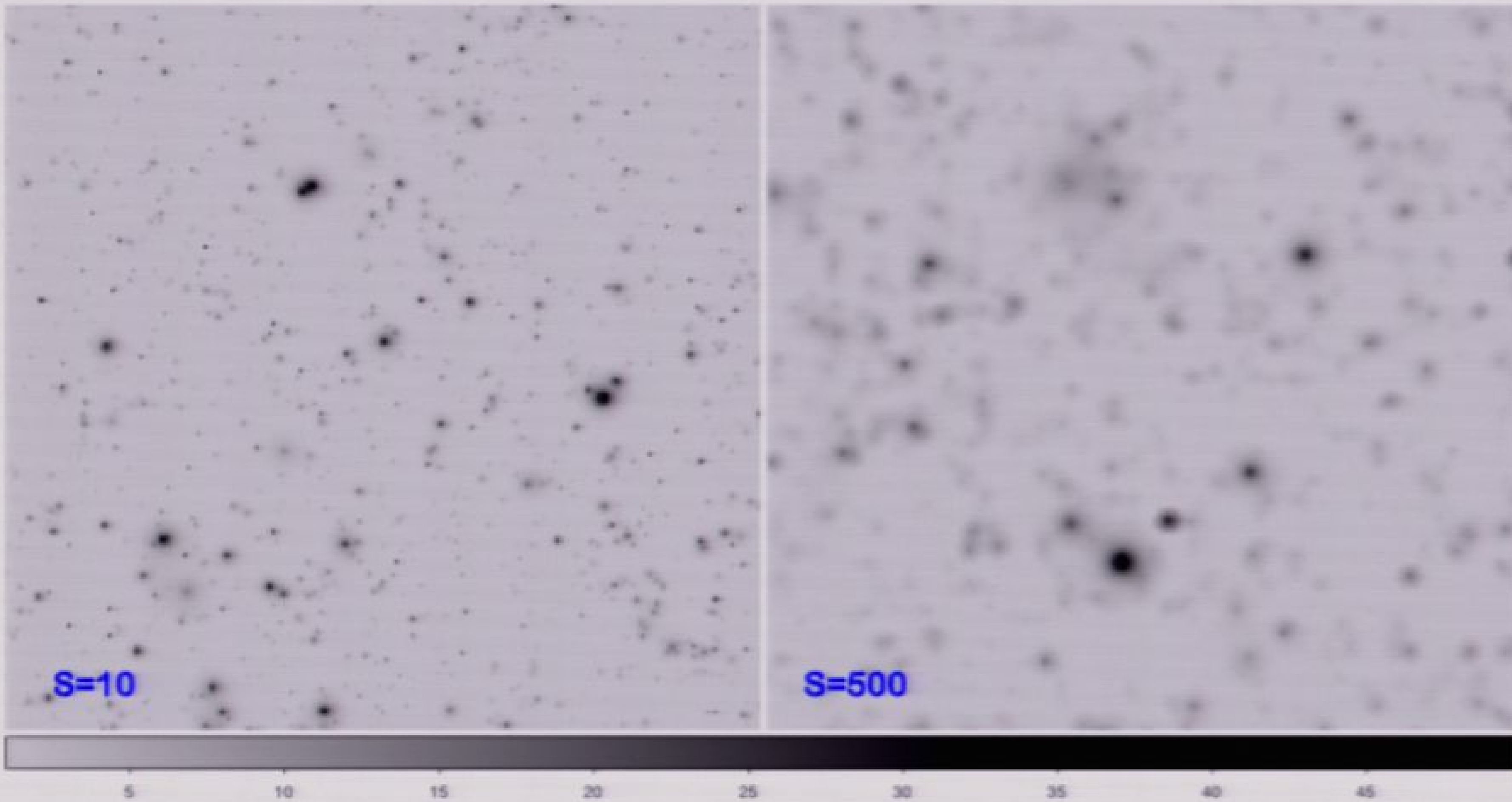
- **lower amplitude,**
- **flatter proj. y-profiles,**
- **higher signal outside the core**

With increasing mass, the fractional change is lower.

Changes are negligible for M > 10^{14} $M_\odot$

Holder, McCarthy, Babul

Implications Of Varying Entropy Core Values: y-maps



0°.85 Square Section Of 2°X2° SZ Sky Map

(σ_8=0.9; M > 10^{13} h^{-1} $M_\odot$; uniform core entropy; res=14" ; only thermal)

Holder, McCarthy, Babul

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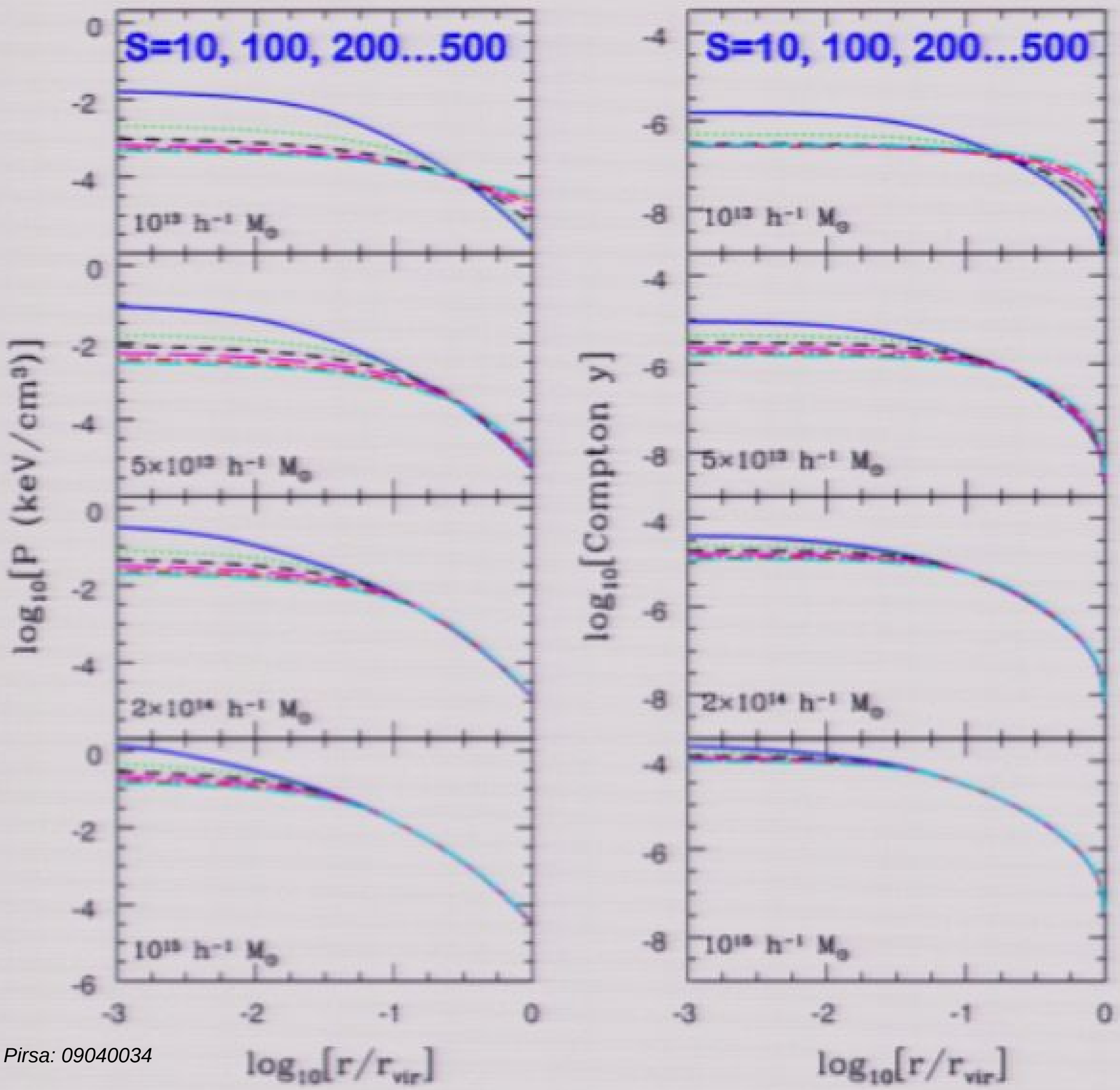

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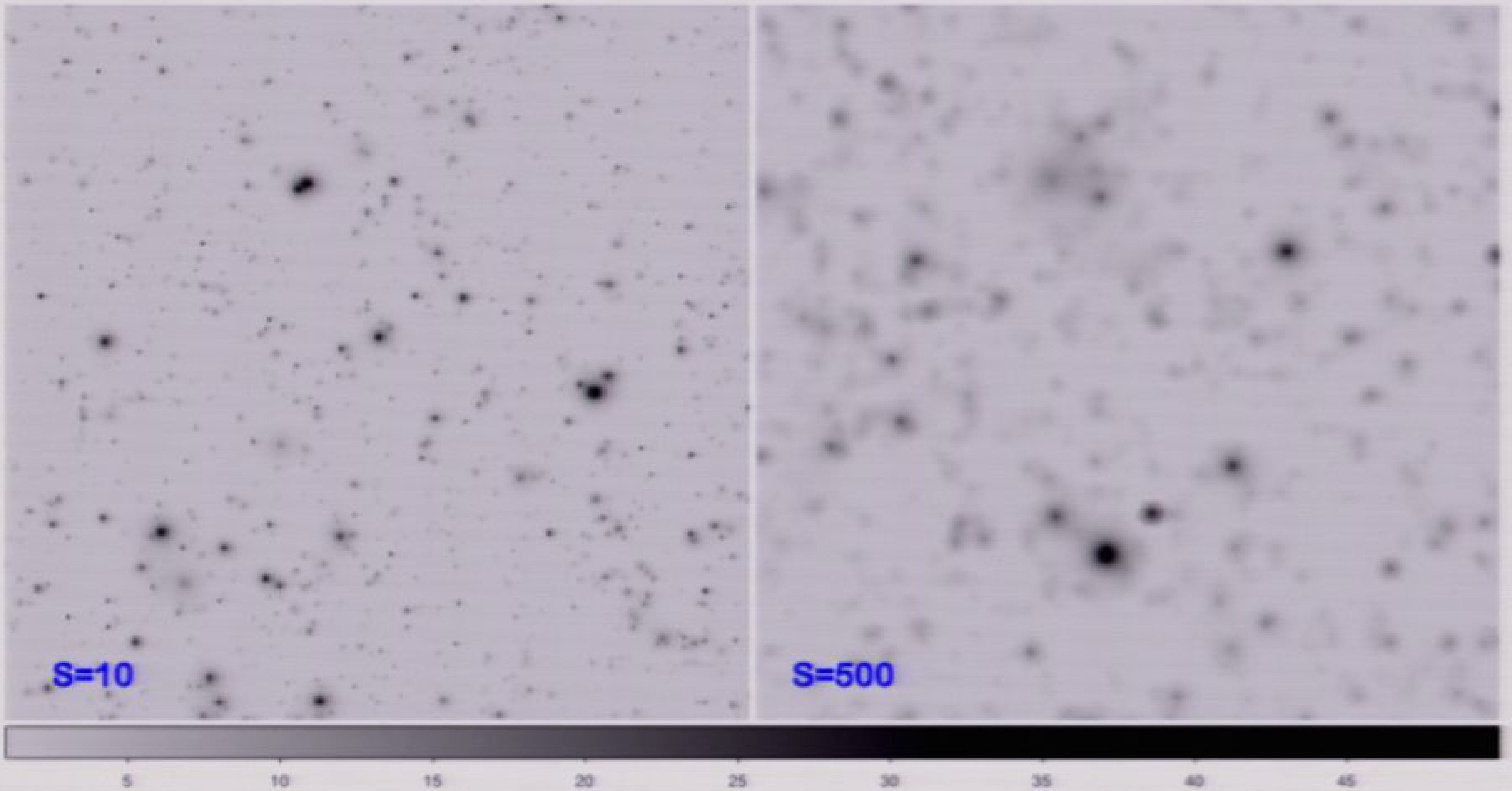

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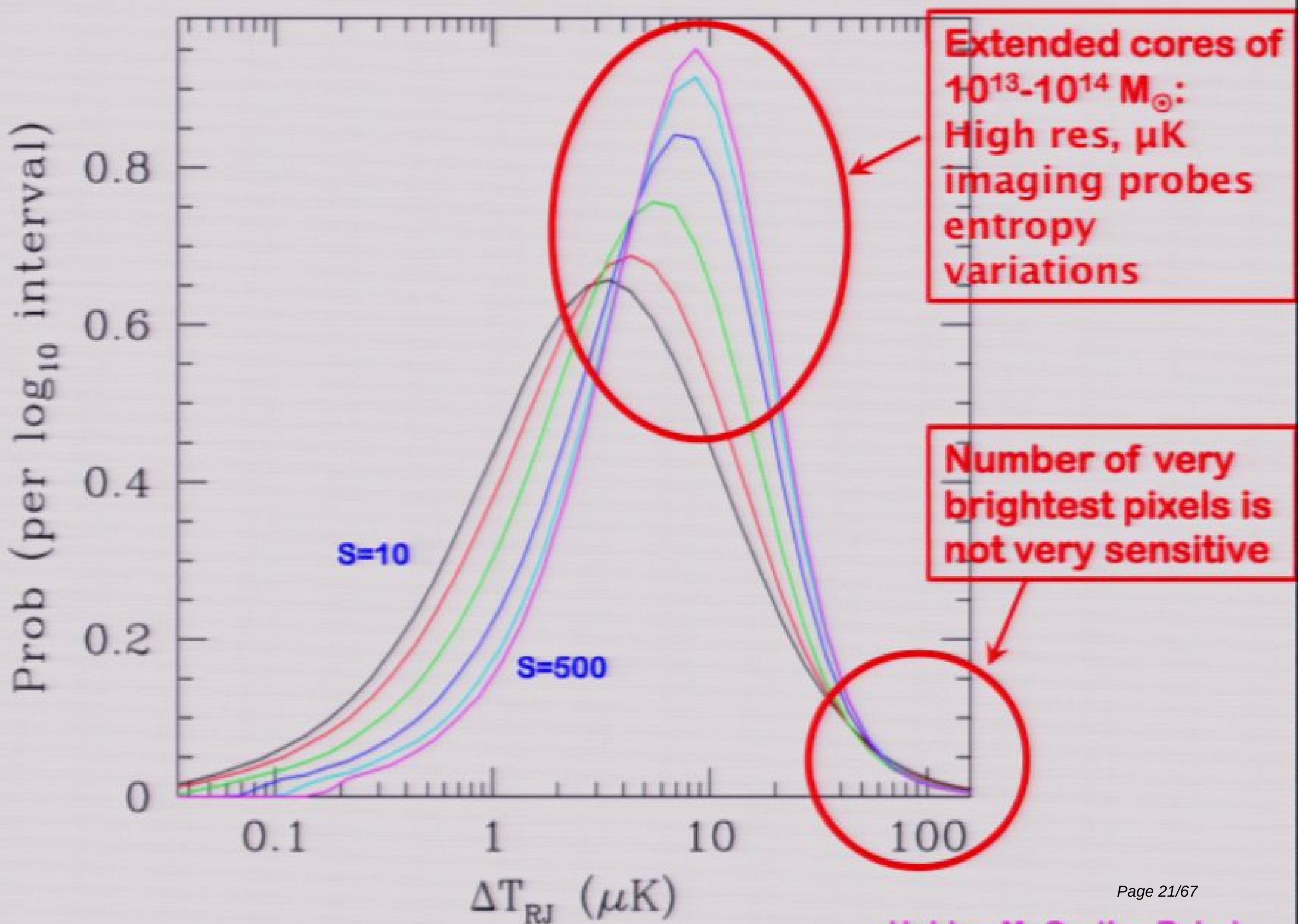
Distribution of Pixel Values – Unfiltered Sky Maps



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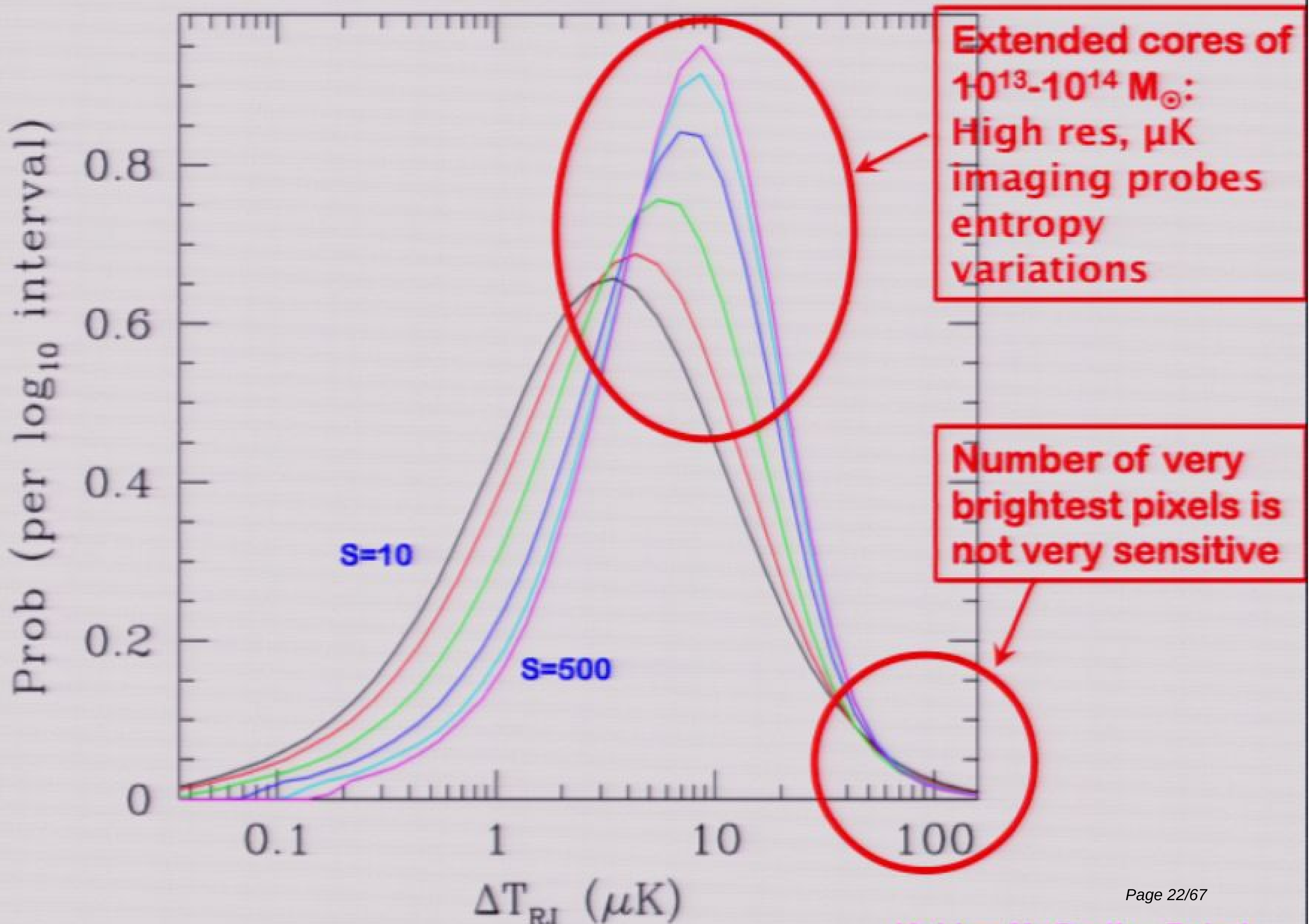
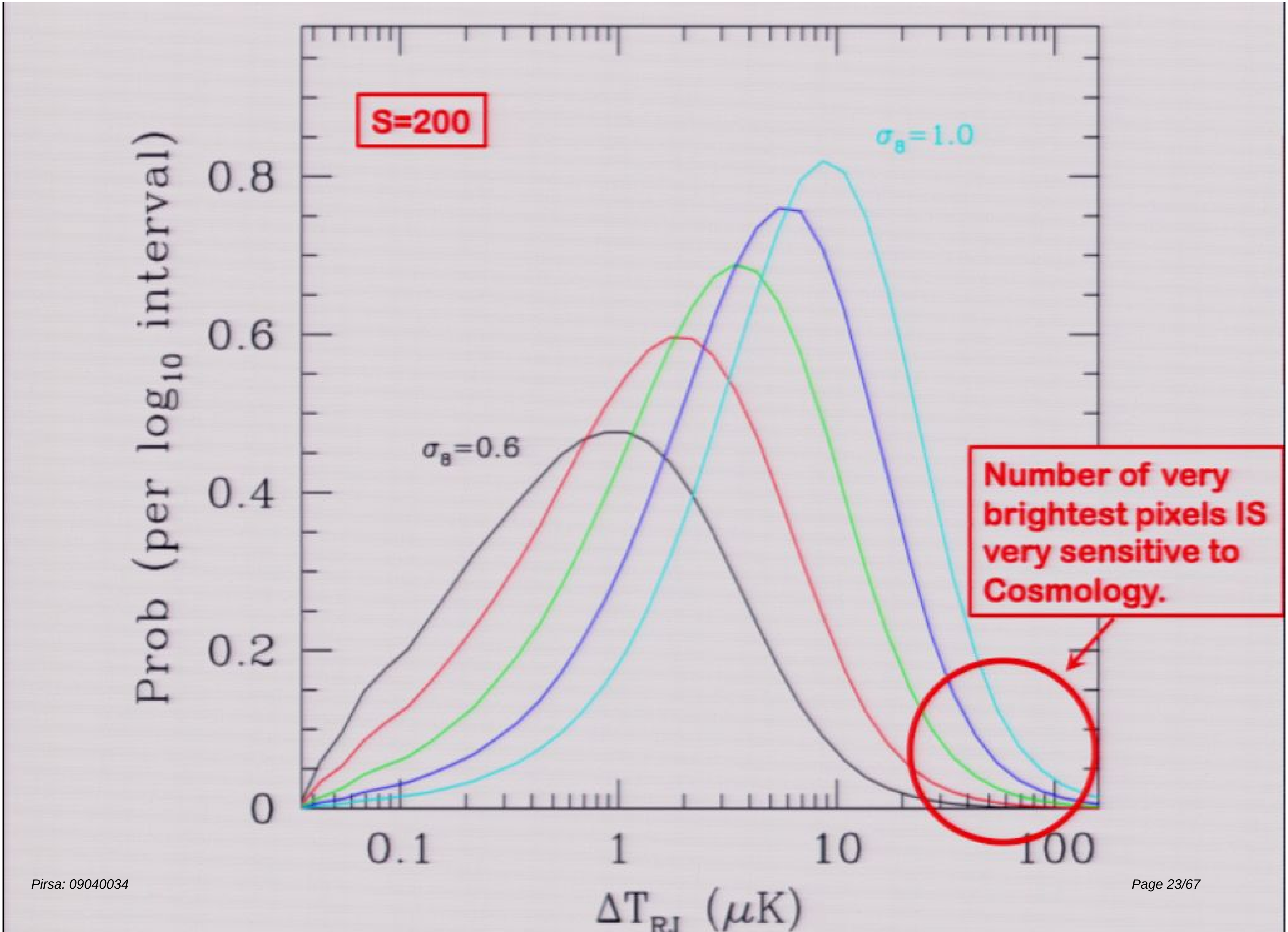
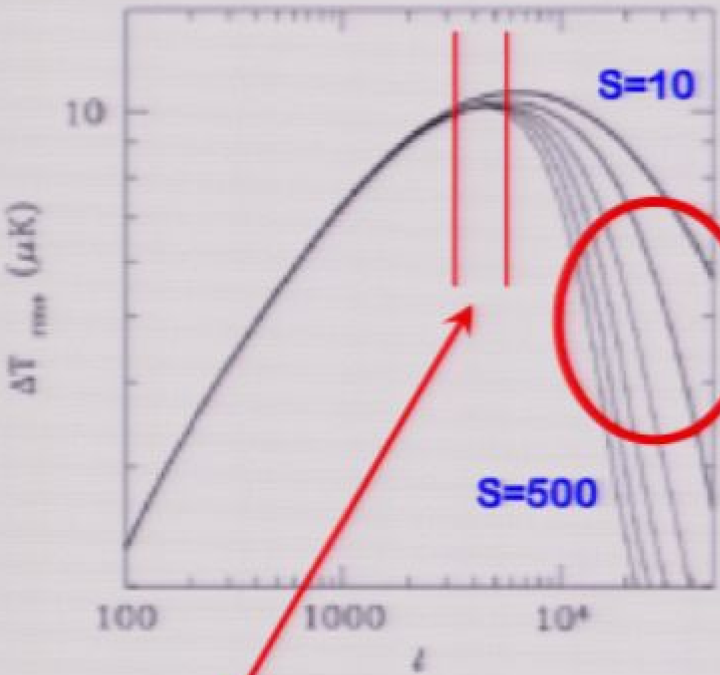


Holder, McCarthy, Babul


S=200
σ_8=1.0
σ_8=0.6
Number of very brightest pixels IS very sensitive to Cosmology.
Prob (per $\log_{10}$ interval)
0.8
0.6
0.4
0.2
0
0.1
1
10
100
ΔT_{RJ} (μK)

Distribution of Pixel Values – SZ Power Spectrum

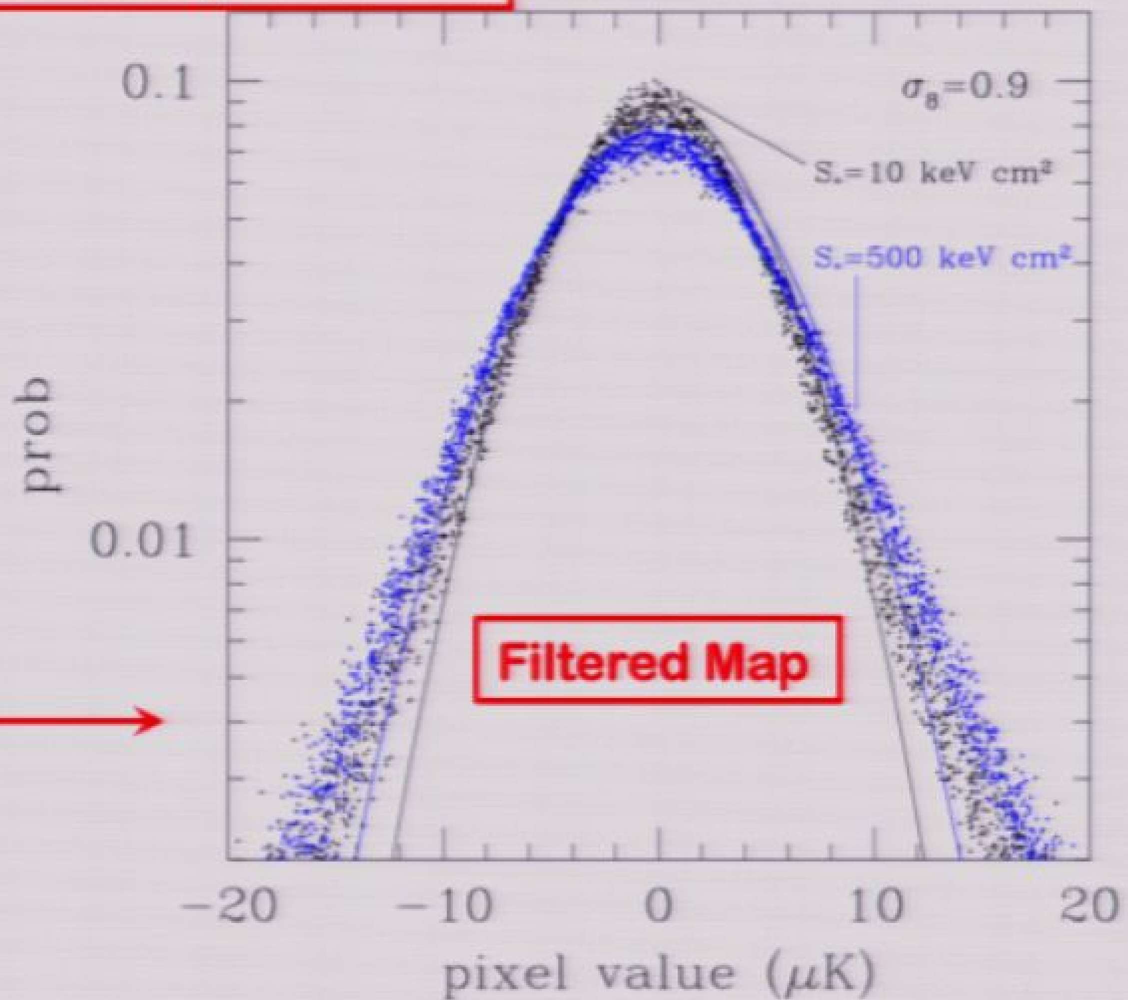
Damping of power on small scales: ~10s of kpcs



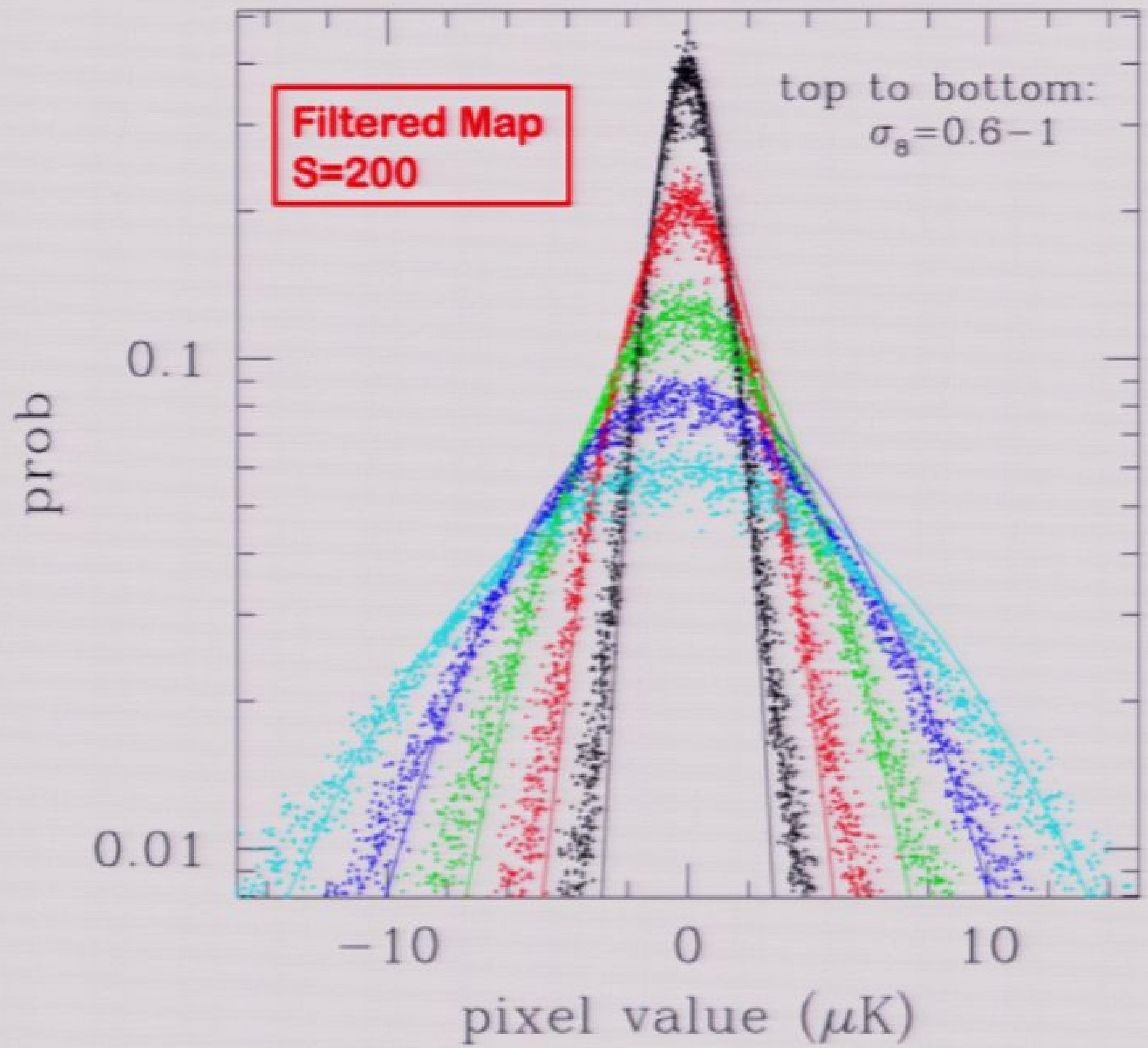
Intermediate scale weakly affected:

~100s of kpc

10^{14}-10^{15} $M_{\odot}$



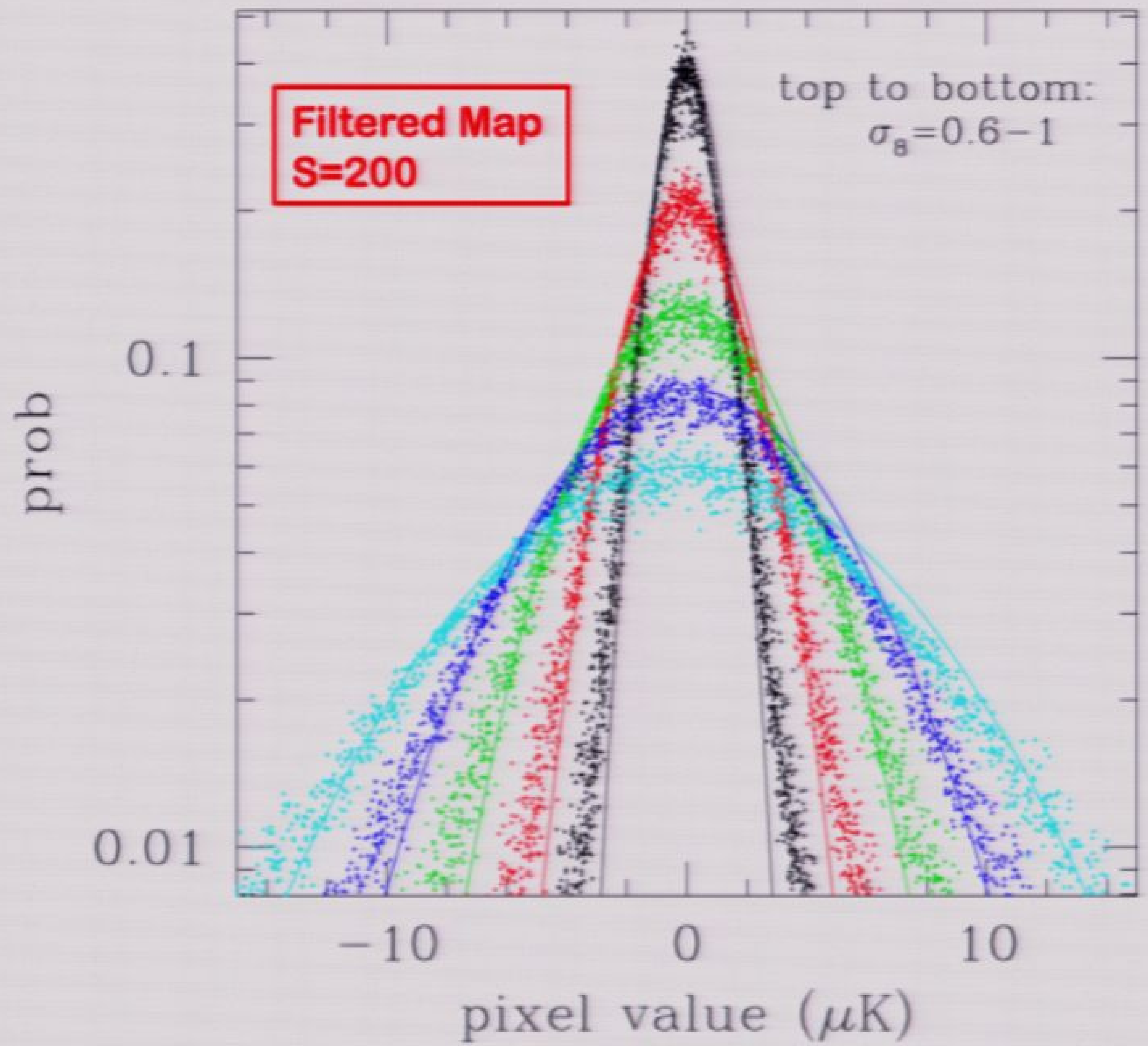
Holder, McCarthy, Babul


Filtered Map
S=200
top to bottom:
σ_8=0.6−1
0.1
0.01
prob
−10
0
10
pixel value (μK)

Mini-Recap

The effects of non-gravitational heating does not hamper the efficacy of SZ surveys to study cosmology as long as one is judicious in the choice of regime/bandpass or statistic.

In addition, SZ studies also has the potential for providing new insights into the "astrophysics" of the intracluster medium: When did this heating occur?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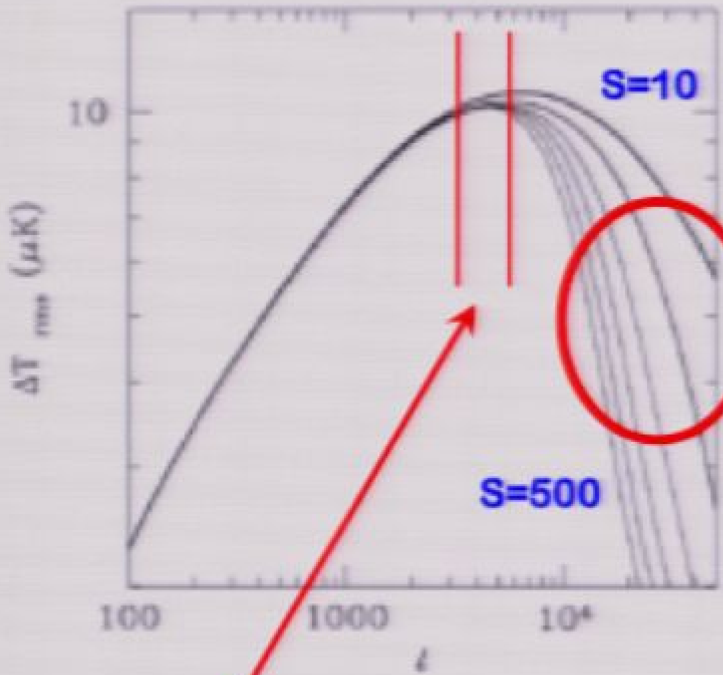

Damping of power on small scales: ~10s of kpcs

Intermediate scale weakly affected:

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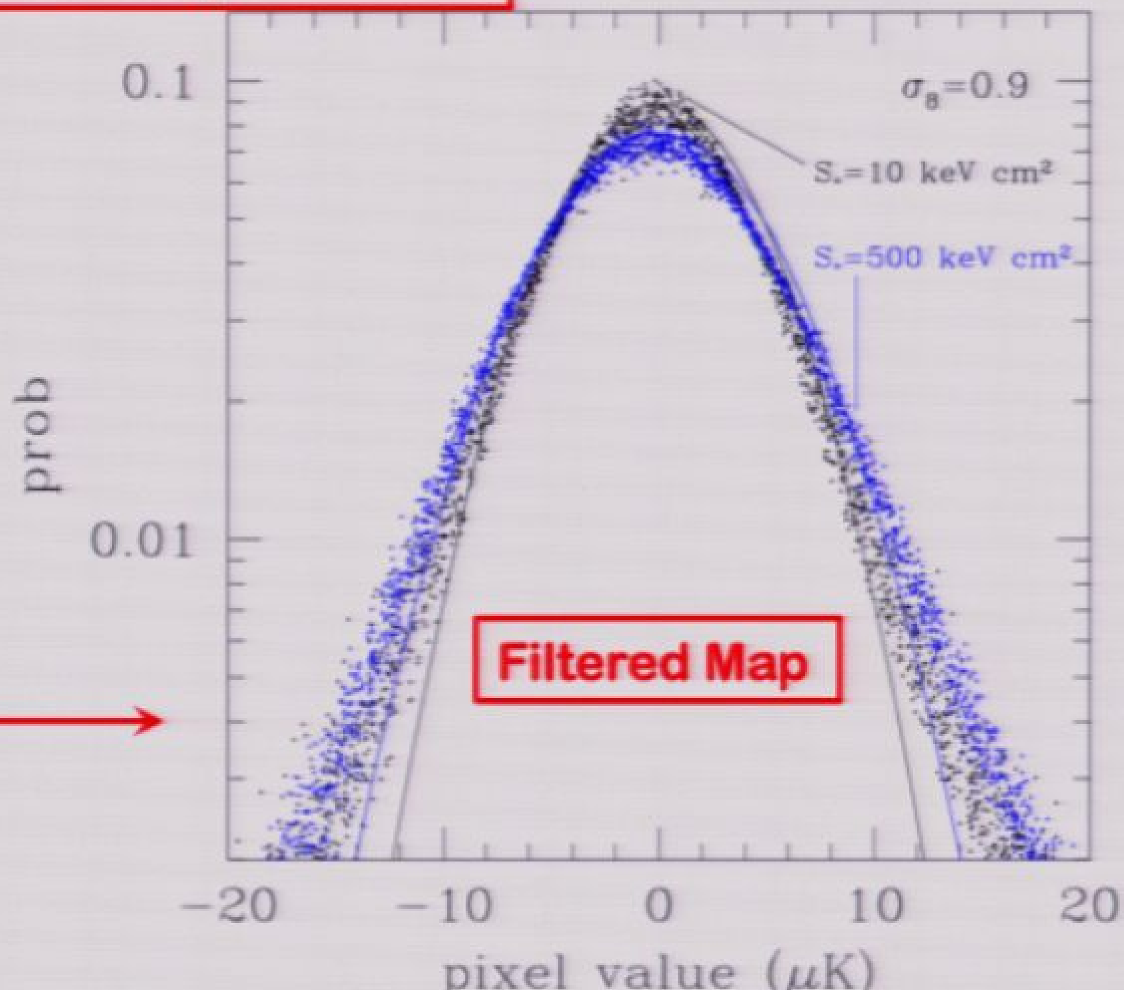
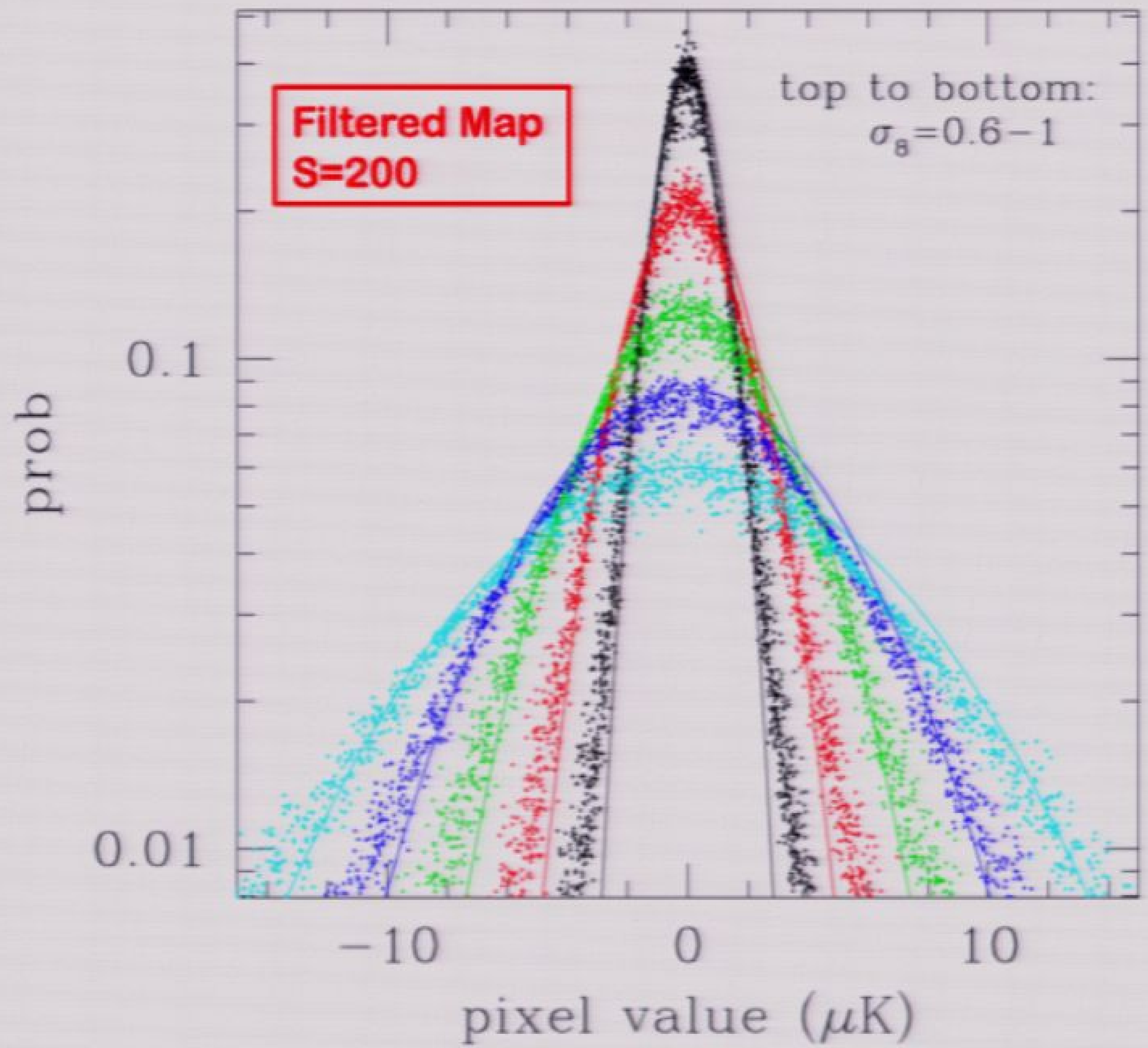
10^{14}-10^{15} $M_\odot$



Holder, McCarthy, Babul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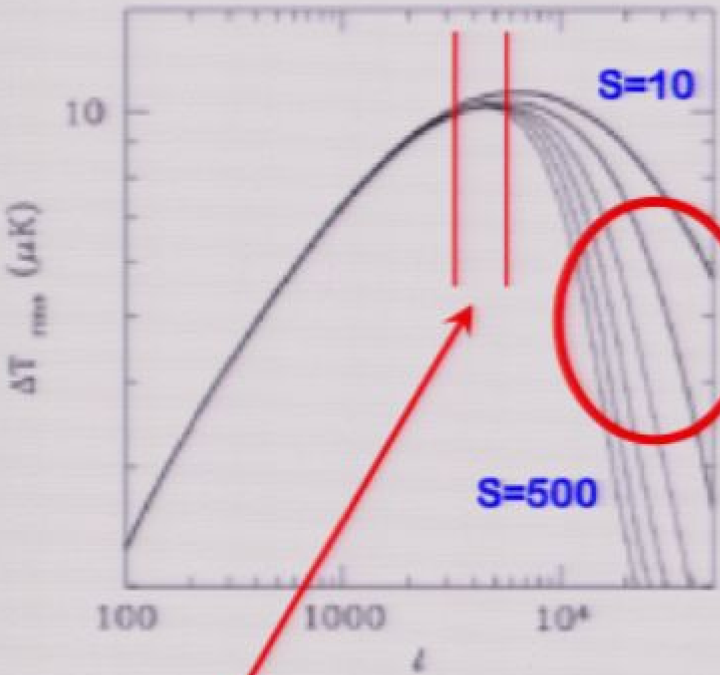

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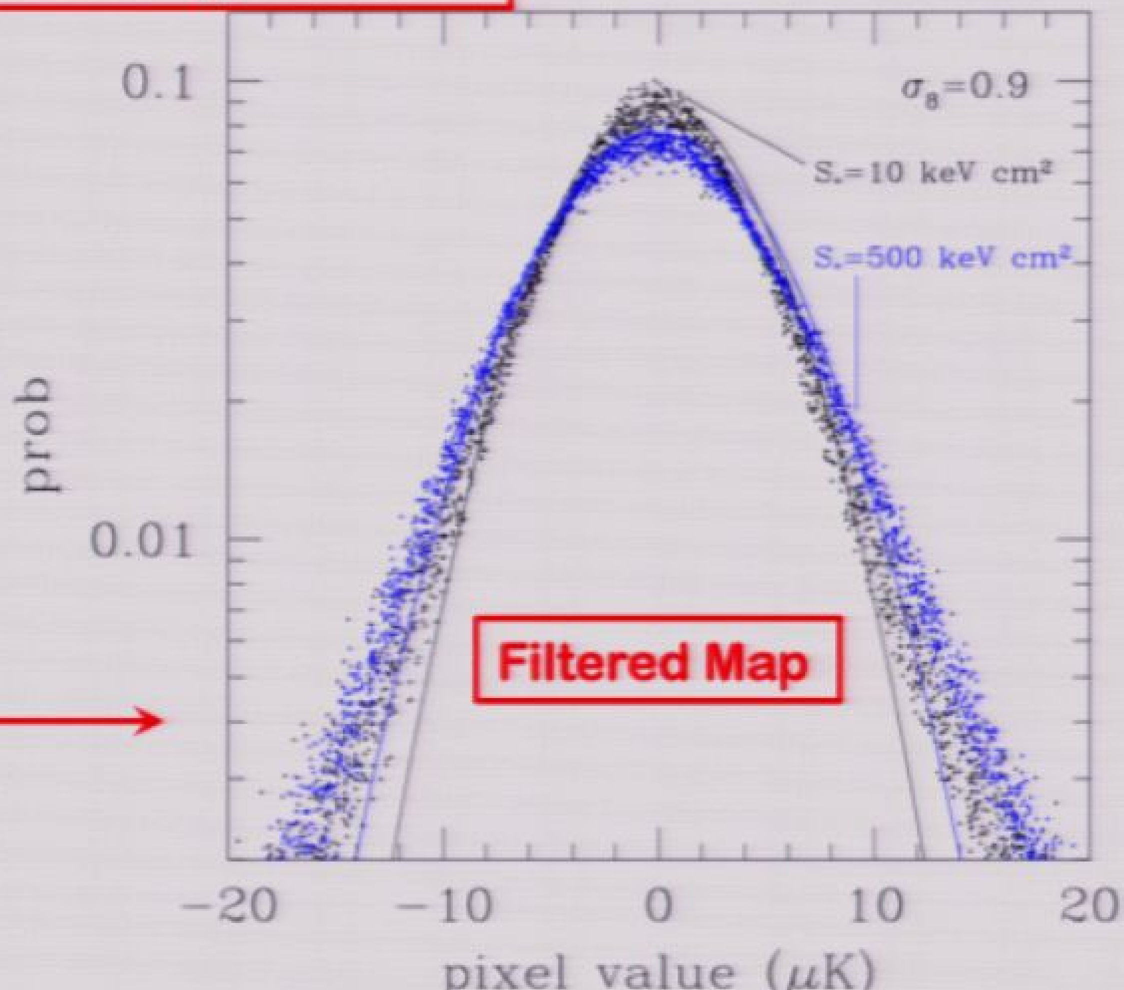

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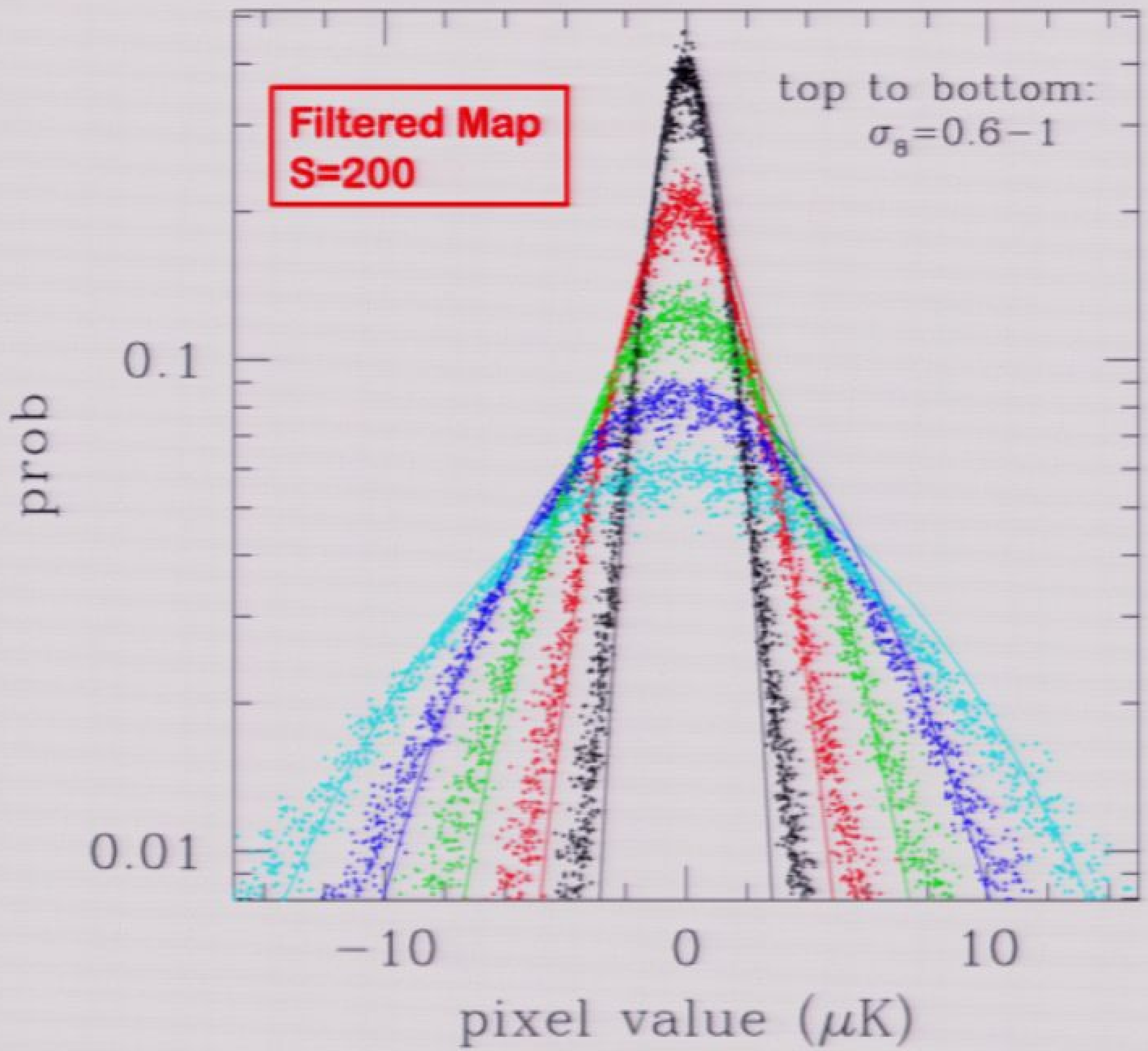
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And now a word about
... JACO by Mahdavi et al 2007

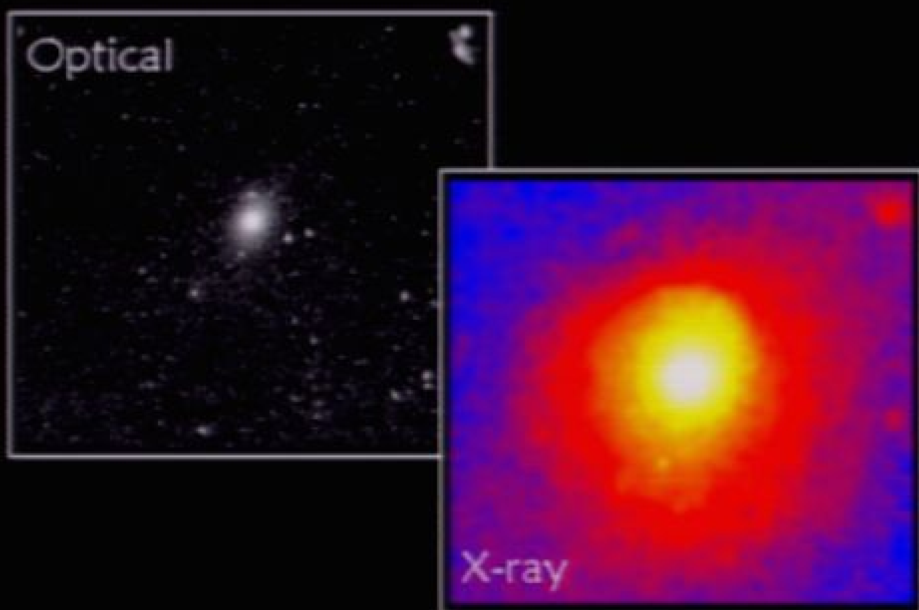
Joint Analysis of Cluster Observations

A sophisticated new framework for constraining the dark matter, stellar and gas distributions in clusters using X-ray (Chandra and XMM), SZ, weak lensing and and optical (photometry and spectroscopic) data.

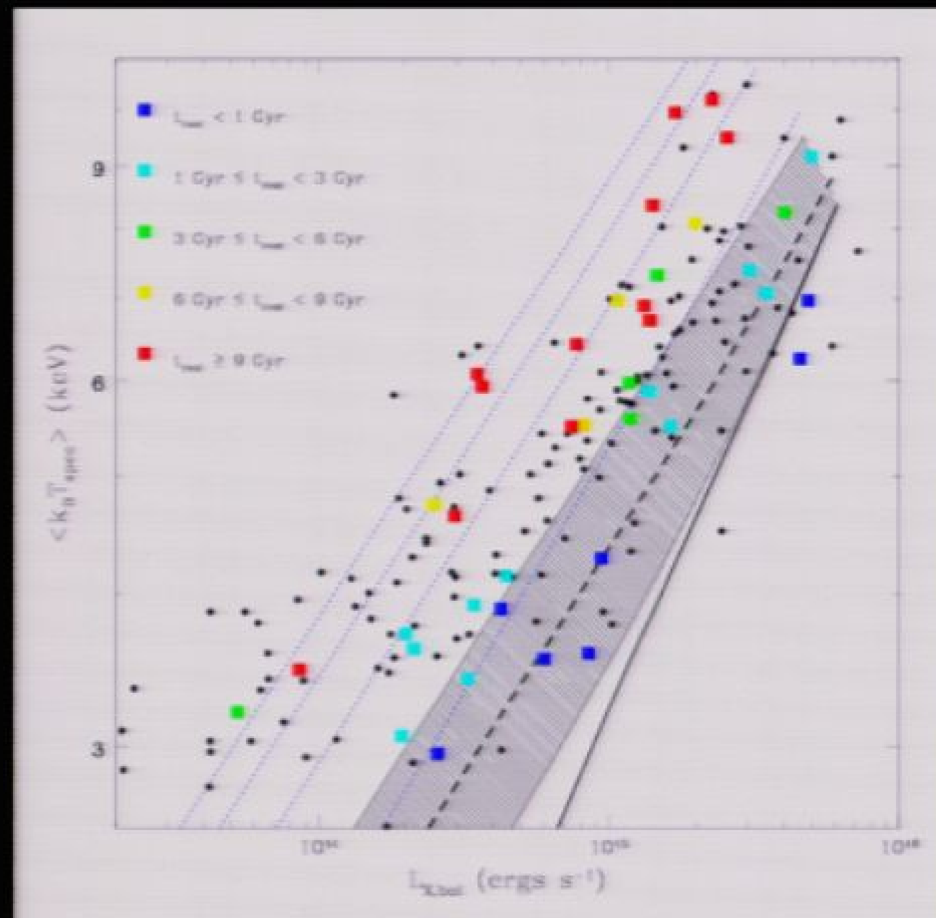
SZ DATA: If gas density profile is known (e.g. from X-ray data, the combination of weak lensing and SZ data provide orthogonal constrains on the total mass distribution.

UNDERSTANDING THE ORIGINS OF GAS ENTROPY CORES

For many years now, a common misperception has been:



The Virgo Cluster of Galaxies



Start with the assumption that "cool core" is the "natural" state of clusters...

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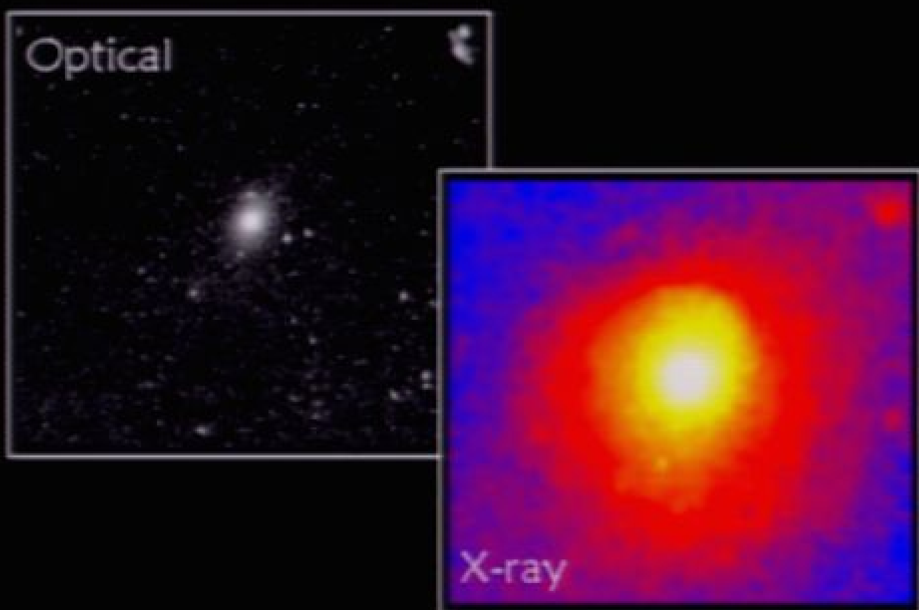

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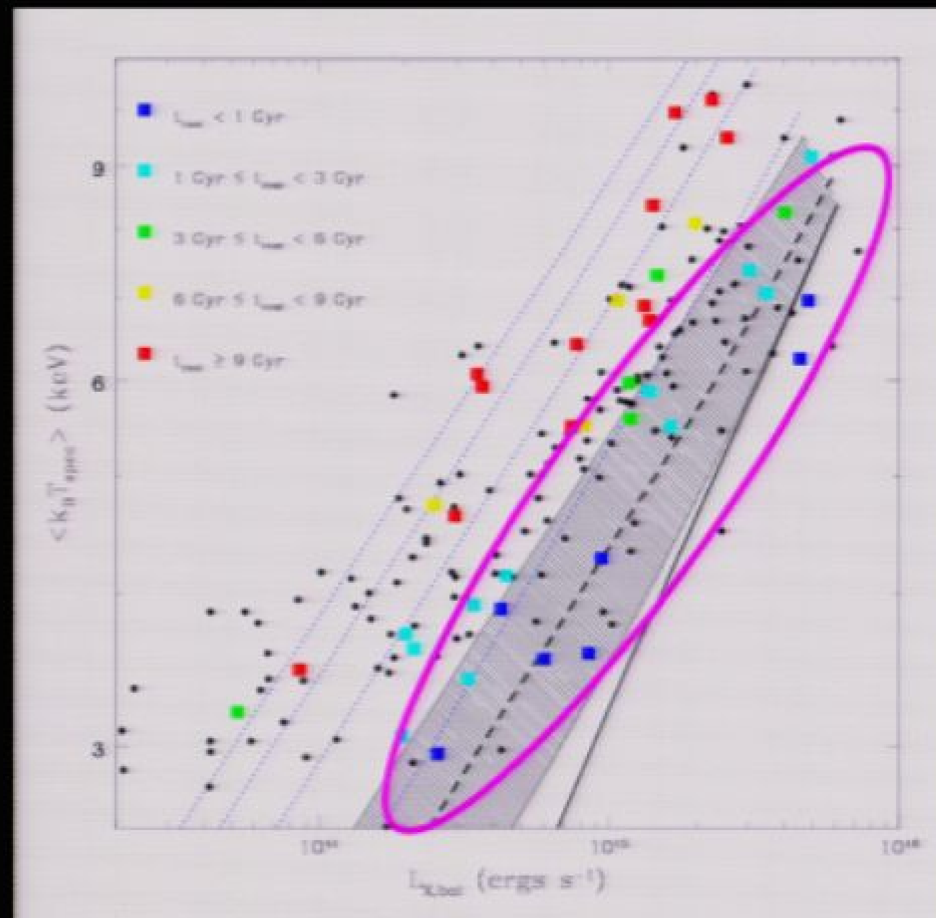

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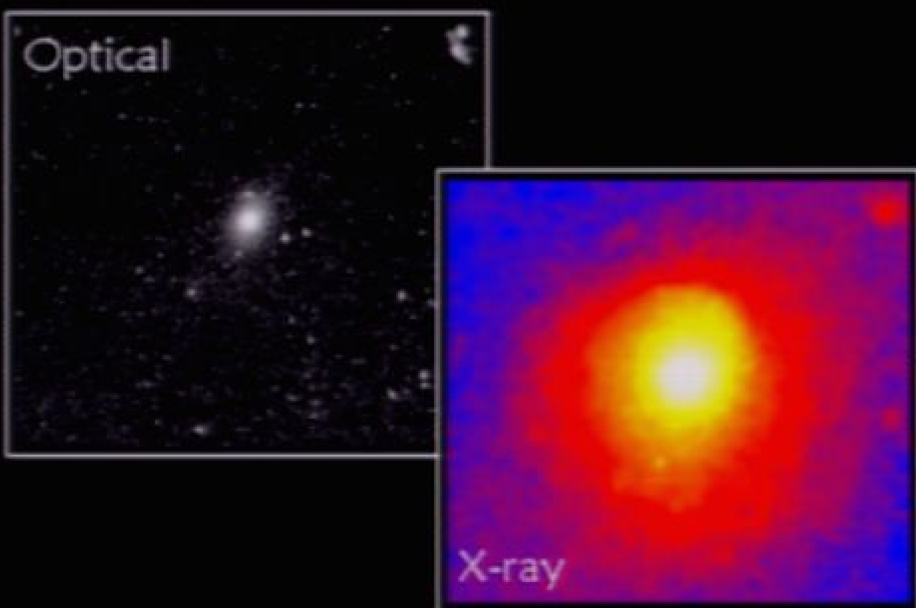

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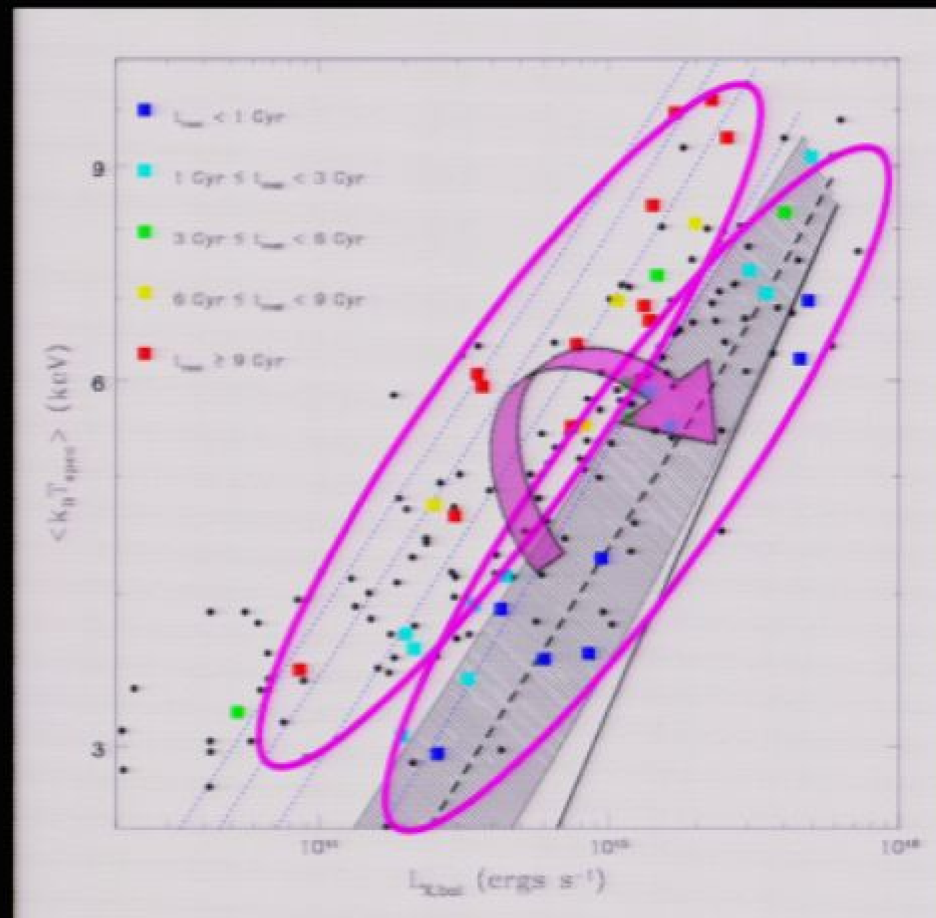

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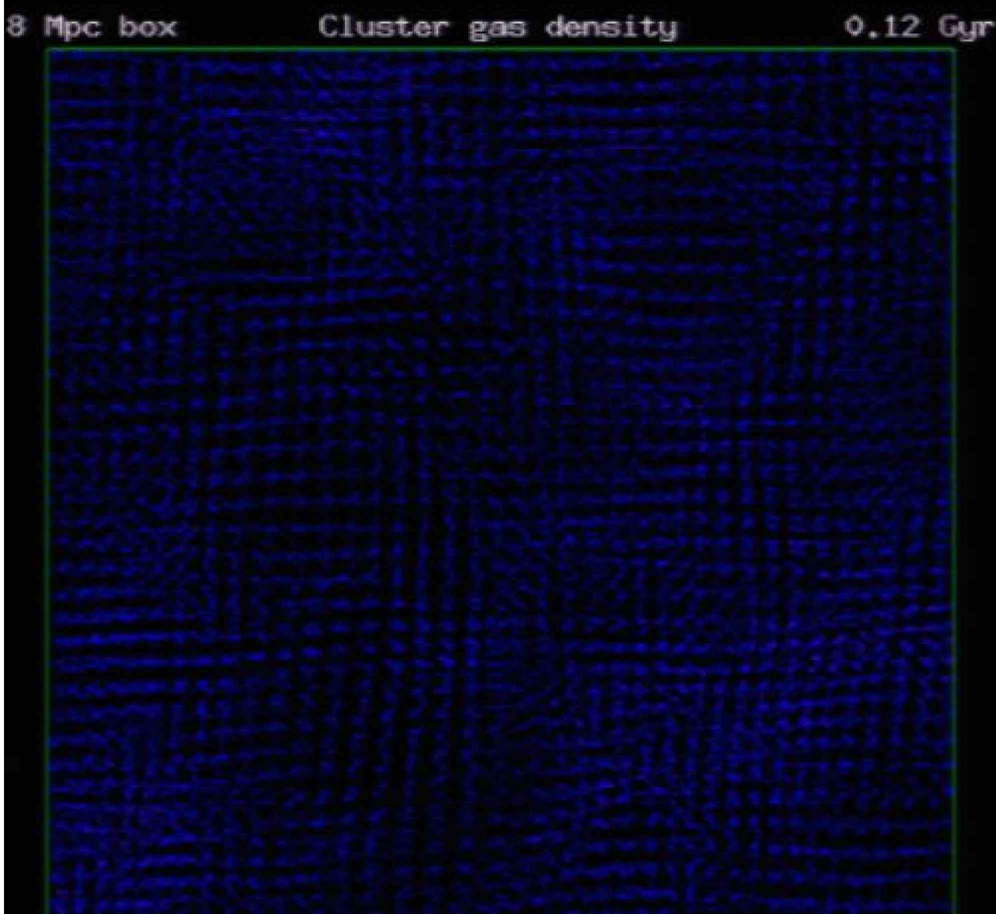
TRANFORMED BY MERGERS?



Lewis, Babul, Katz, Quinn, Hernquist, Weinberg 2000

- Mergers are part of the hierarchical picture.
- While some high entropy systems do look disturbed, a significant fraction look relaxed.
- And same is also true for low entropy systems!
- Large Cosmo Sims: there are too few major mergers in ΛCDM to explain the abundance of NCC systems.
- When mergers do occur…

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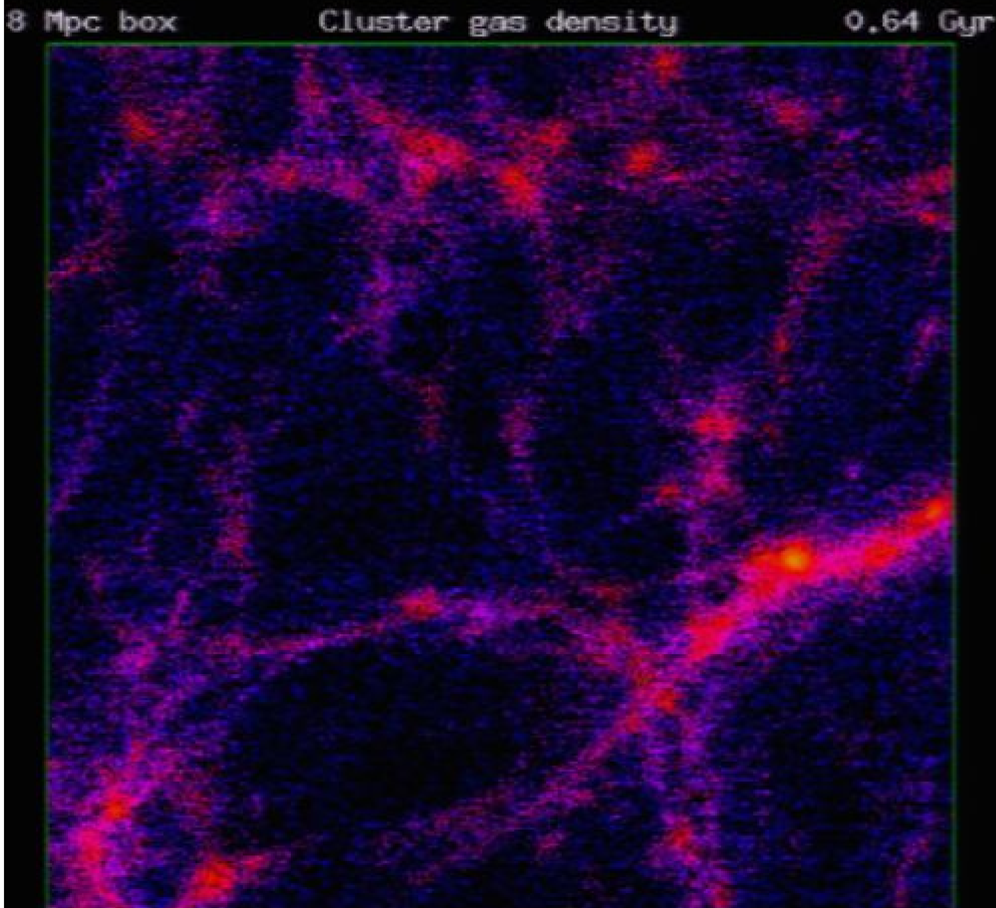

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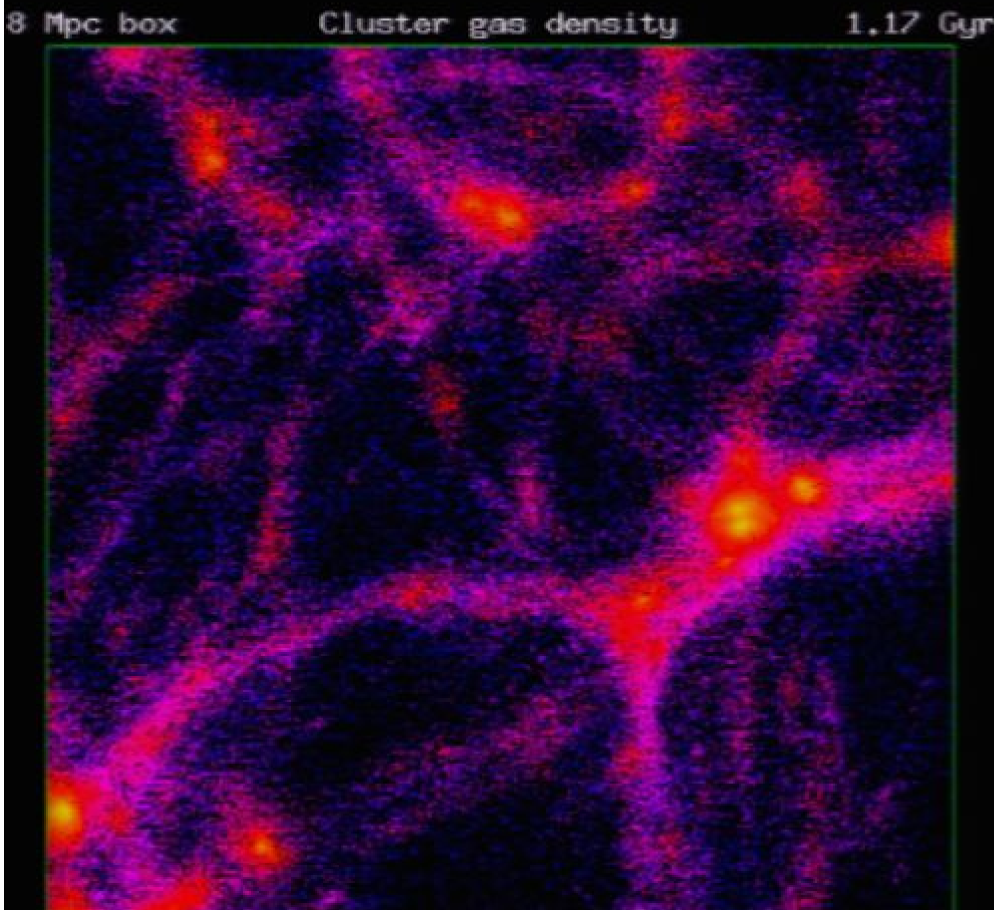

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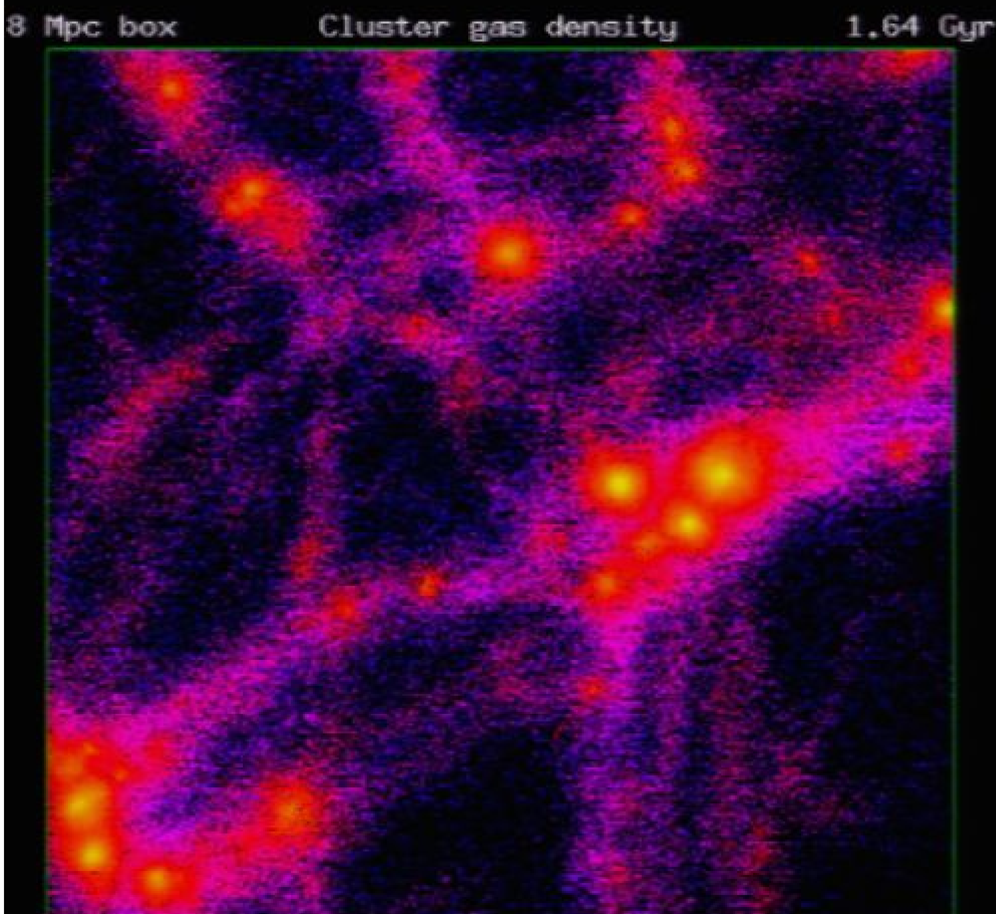
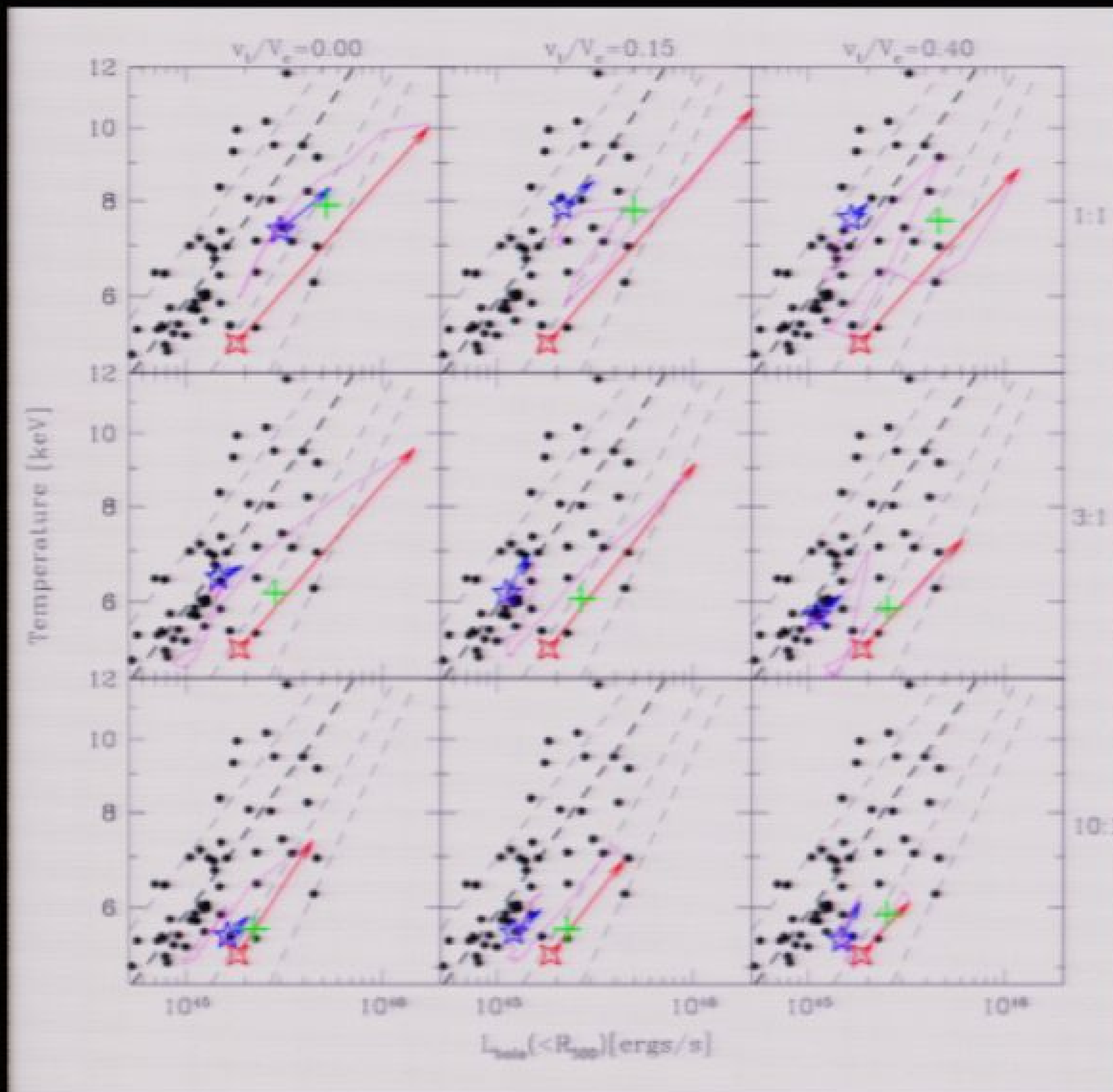


Lewis, Babul, Katz, Quinn, Hernquist, Weinberg 2000

- Mergers are part of the hierarchical picture.
- While some high entropy systems do look disturbed, a significant fraction look relaxed.
- And same is also true for low entropy systems!
- Large Cosmo Sims: there are too few major mergers in ΛCDM to explain the abundance of NCC systems.
- When mergers do occur…

MERGER CANNOT EXPLAIN SCATTER IN THE L-T PLANE



Poole et al. 2006, 2007

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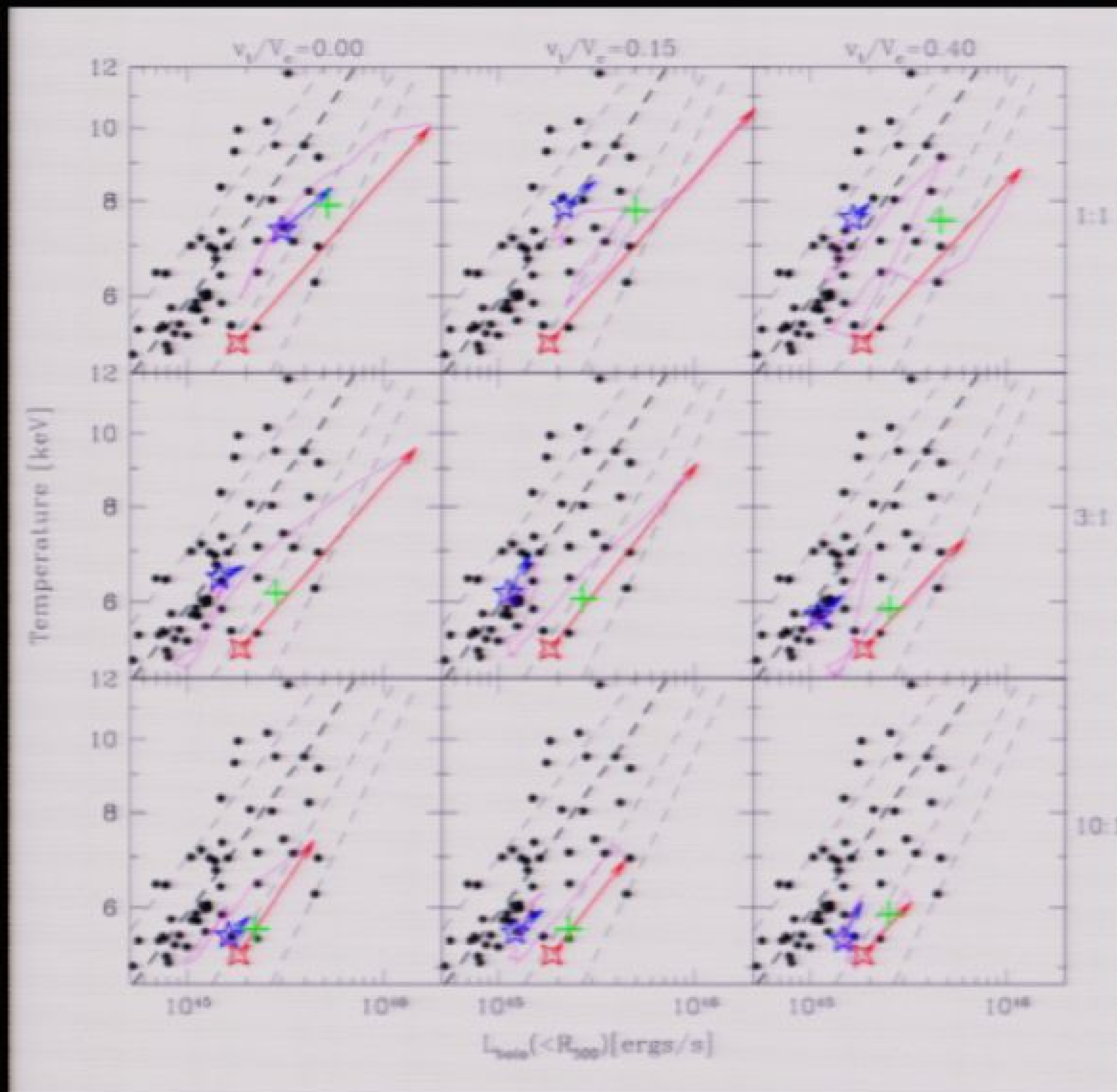
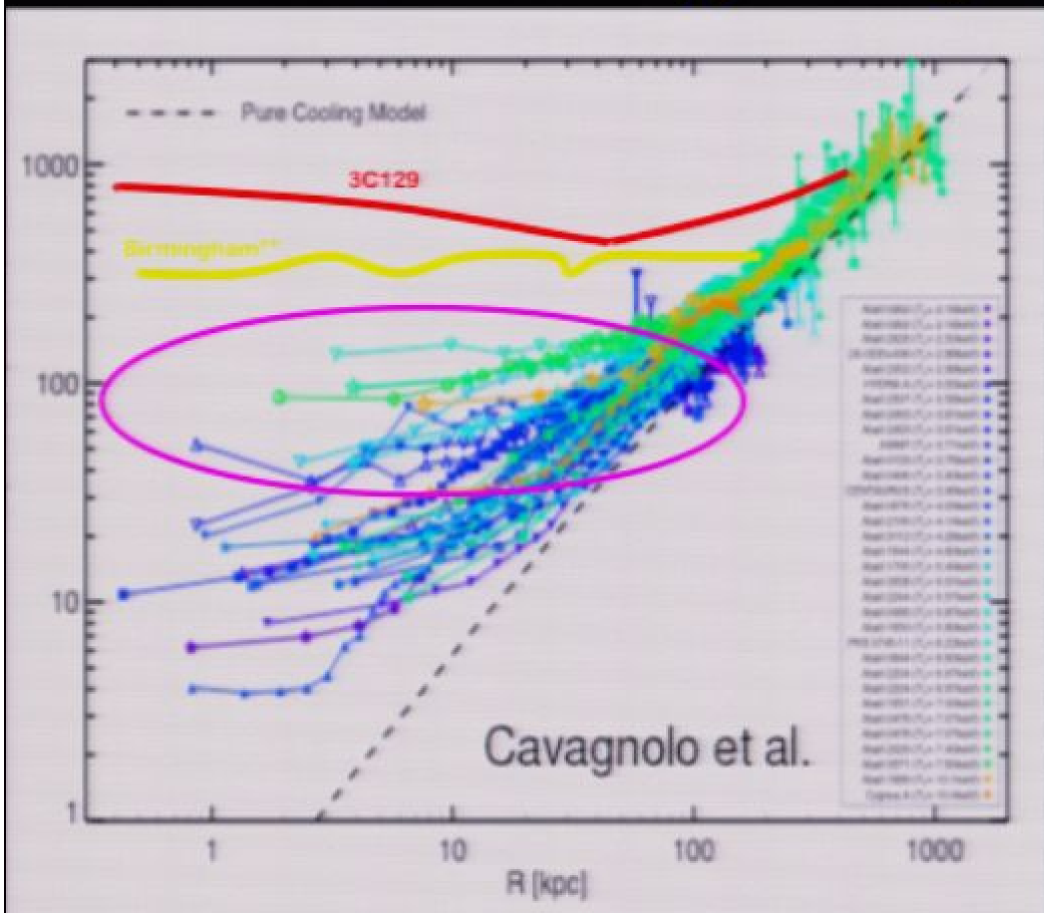
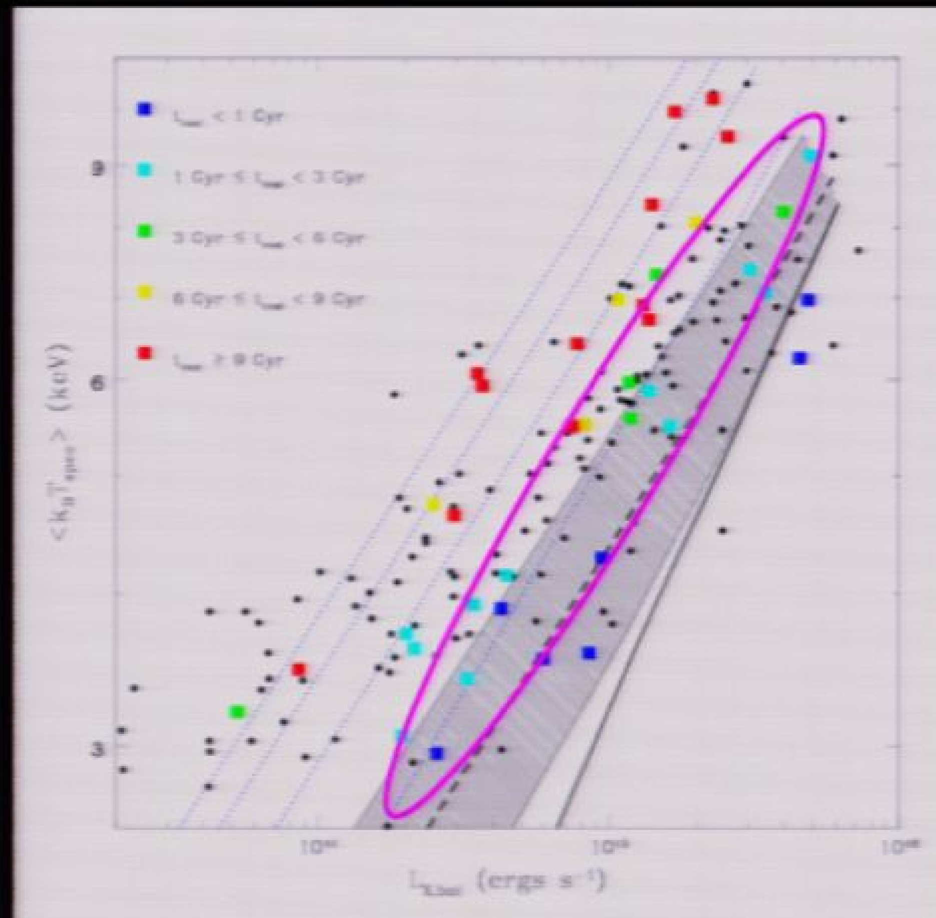


Poole et al. 2006, 2007

MERGERS CAN PRODUCE WARM CORE SYSTEMS

Chandra Core Entropy Survey

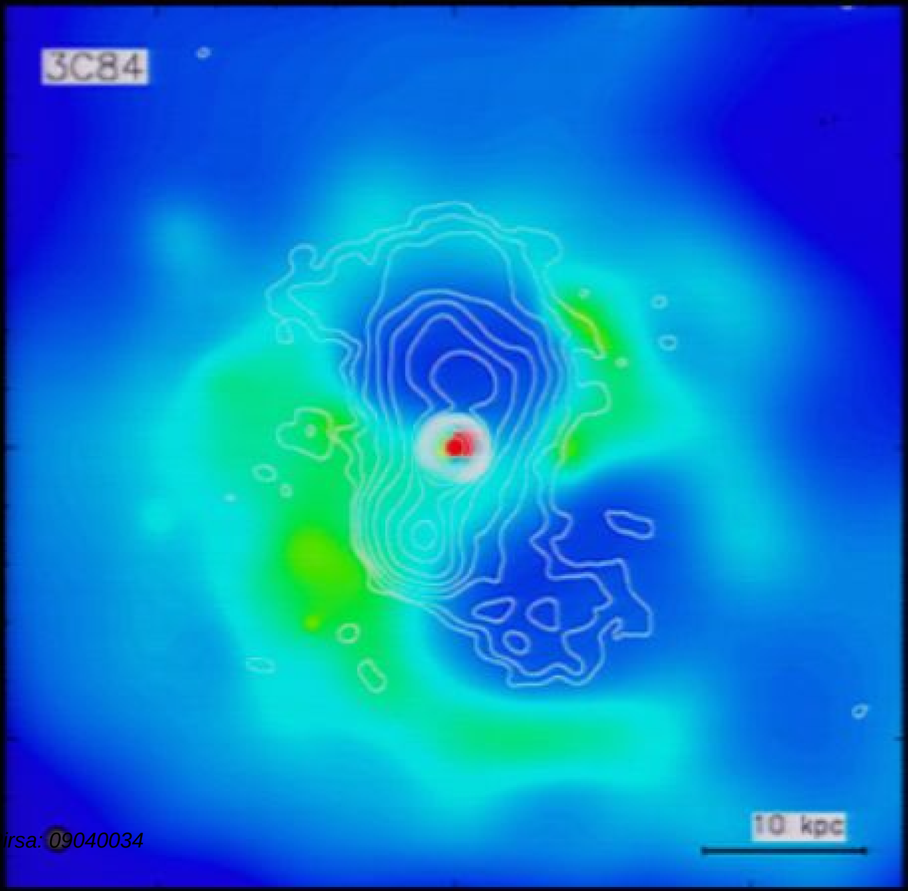


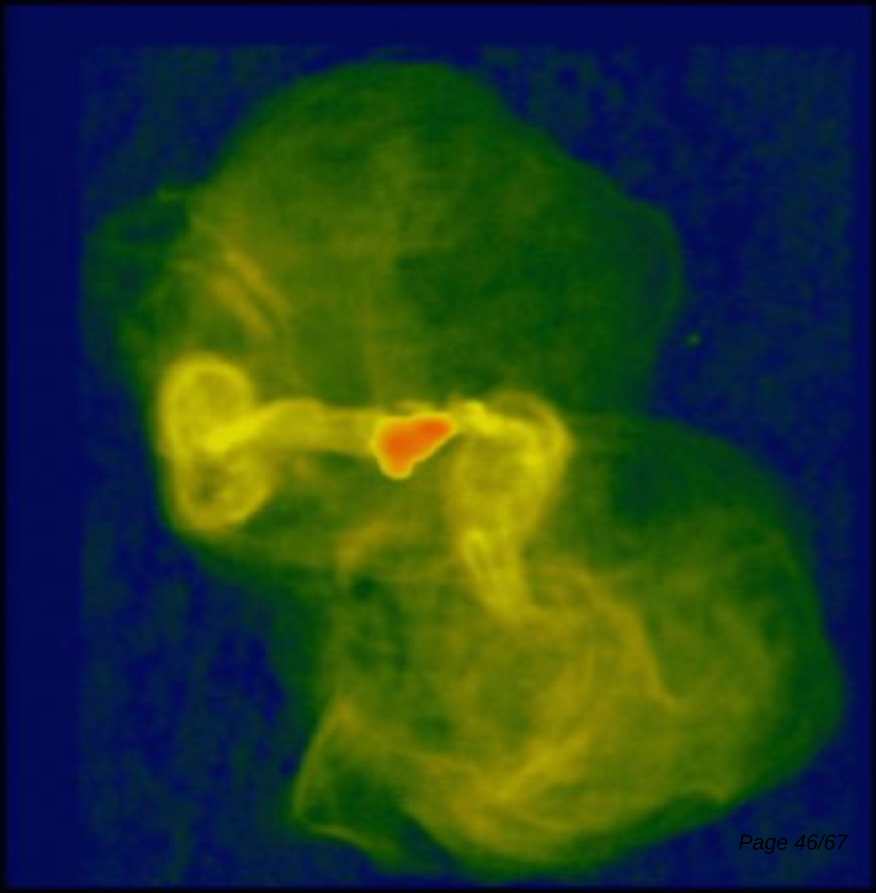


…SYSTEMS WITH S~30-50 keV cm^2 THAT ARE REMNANTS WITH ~2-5 Gyr LIFETIMES BUT NOT THOSE WITH S > 50 keV cm^2

AGNS IN LOW ENTROPY (COOL CORE CLUSTERS)

BCG at the centres of cool-core clusters host AGNs that are driving winds and jets, which heat the ICM and temper the cooling flow.





CAN MASSIVE CENTRAL AGN OUTBURT CONVERT LOW ENTROPY SYTEMS INTO HIGH ENTROPY?

Transforming cool core systems into NCCs with So > 100 Kev cm^2 requires > 10^{63} ergs

P > 10^{48} ergs/s

100X power of "bang" in MS0735 and this would need to occur in 30-50% of the clusters.

An aside: $\dot{M} \sim 50 - 200 \, M_\odot / yr$

This implies flow onto the BH of

$$(2.5 - 10) M_9^{-1} \dot{M}_{Edd}$$

For ADAF: $\dot{m} \leq 10^{-3} \rightarrow M_{BH} > 10^{12} M_\odot$

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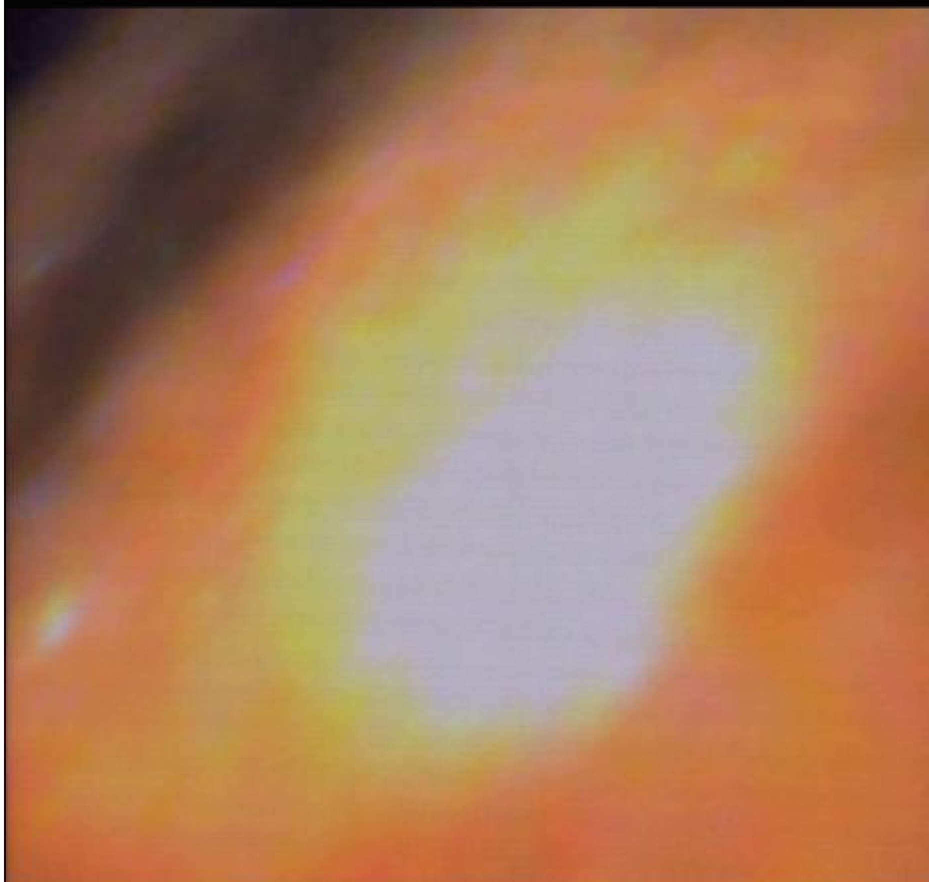

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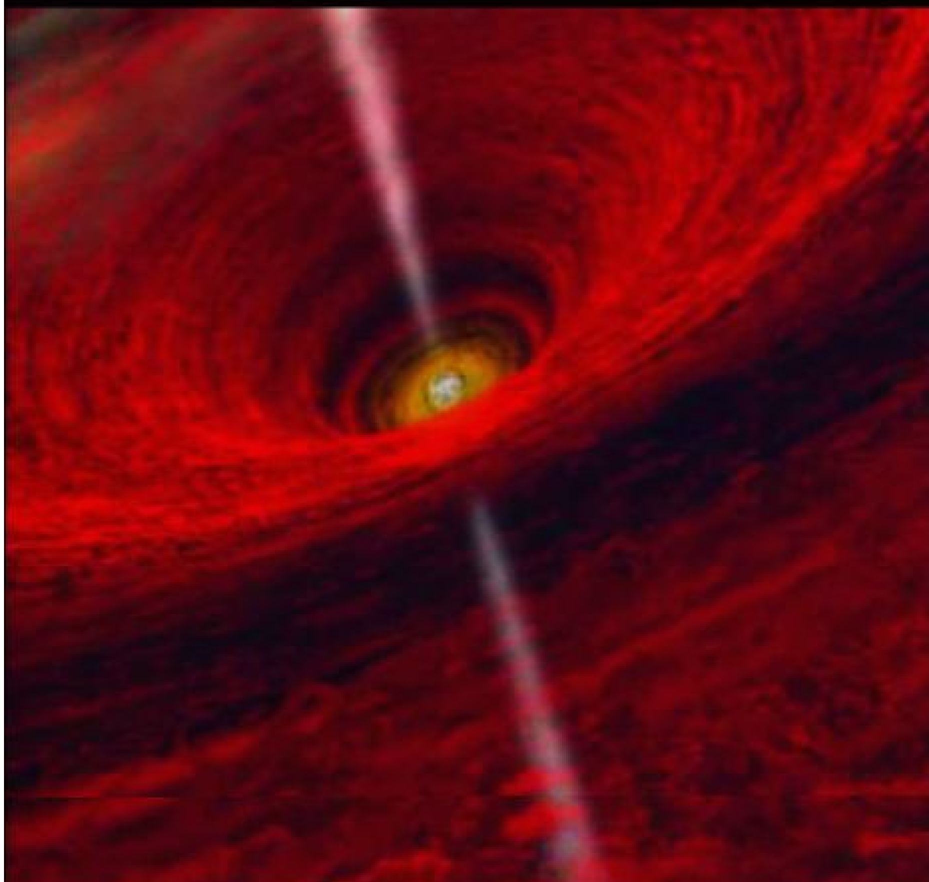

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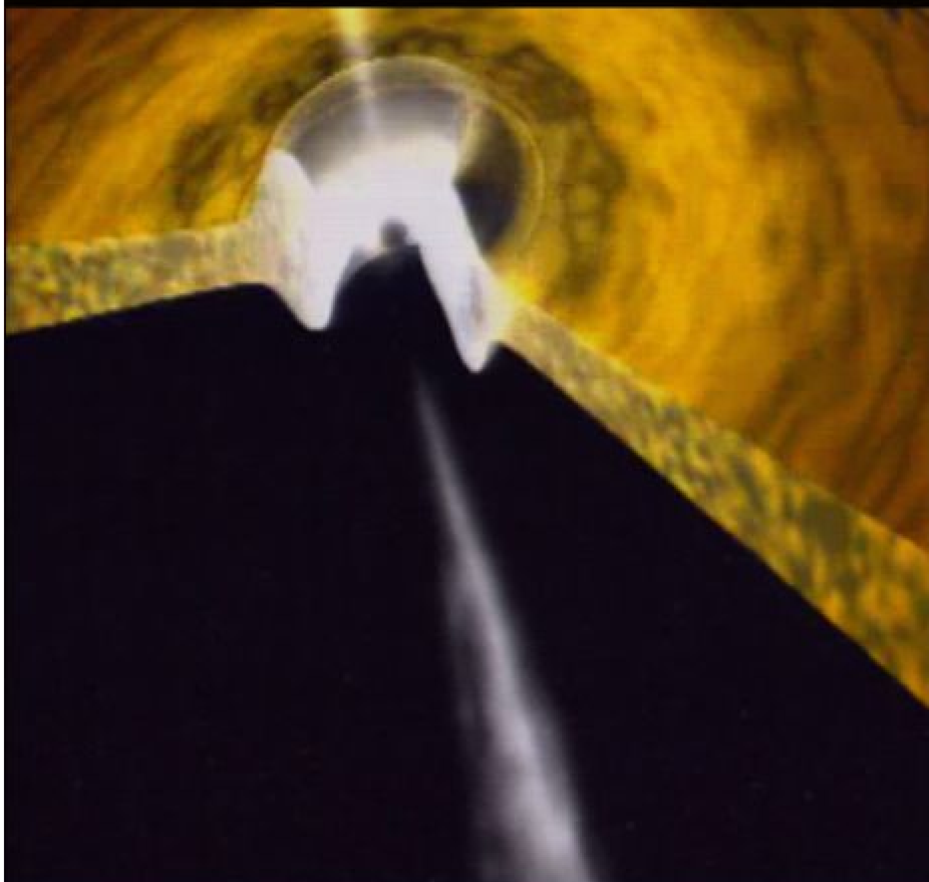

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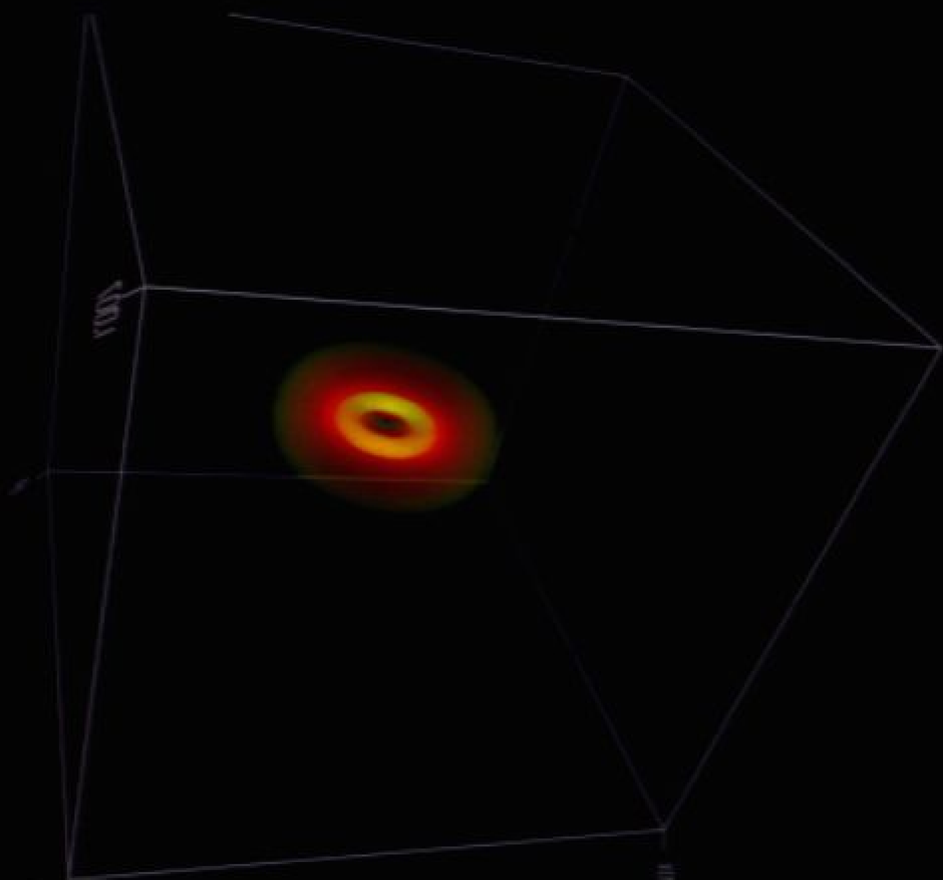
JETS AND WINDS FROM AGNs DURING EPOCH OF GALAXY FORMATION

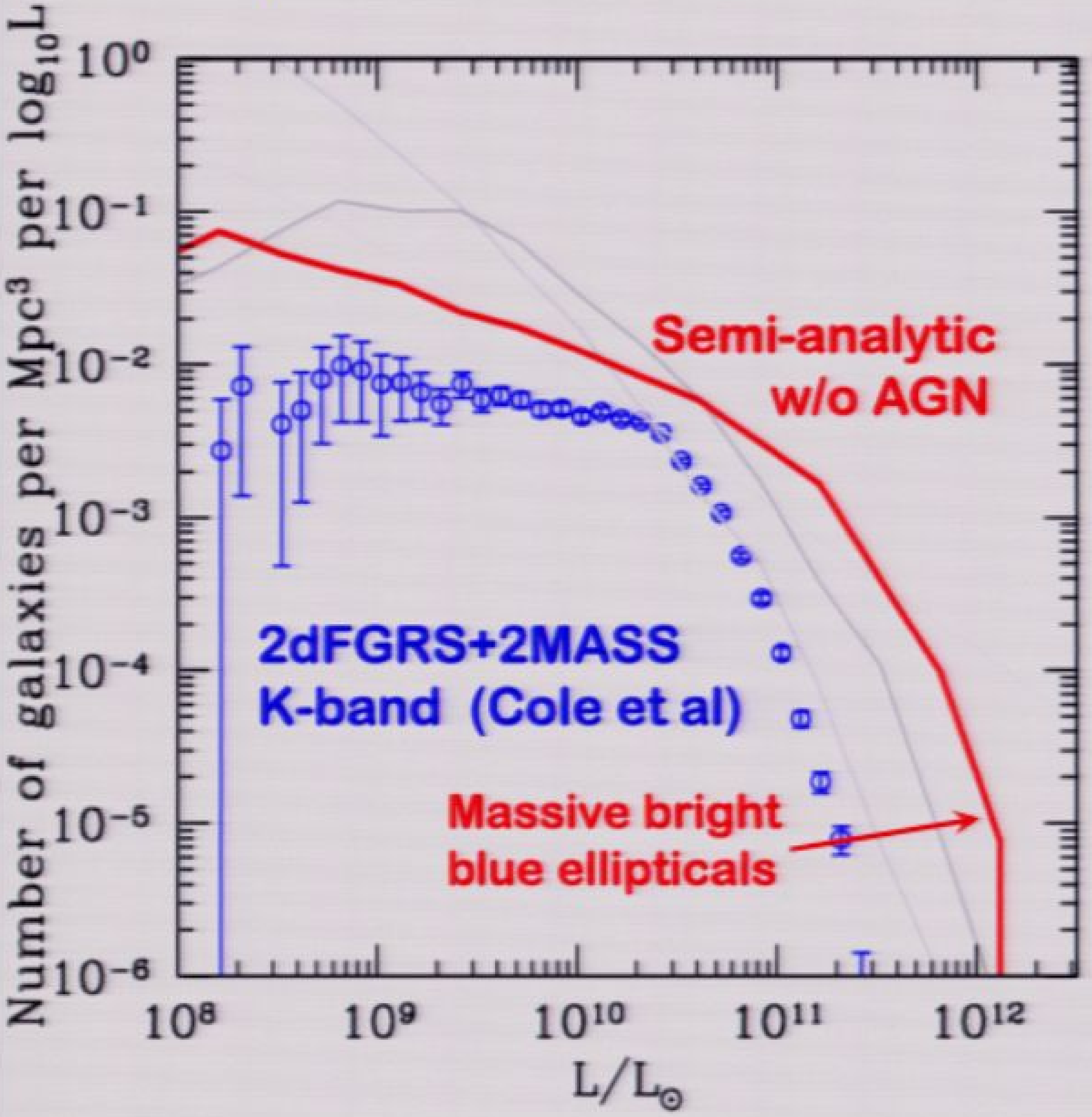


Credit: McKinney 2008

AGN feedback is a key element of theoretical models of galaxy form.

AGN feedback is invoked to quench star formation in massive galaxies thru the removal of gas in the galaxy via heating and outflows.

Impact of Galaxies On Their Local Environment



AGN feedback is required to prevent massive ellipticals from turning out blue and over-luminous.

Processes such as AGN feedback do more than simply establish observed properties of these systems.

They can also impact the local environment in a profound way.

Credit: A. Benson

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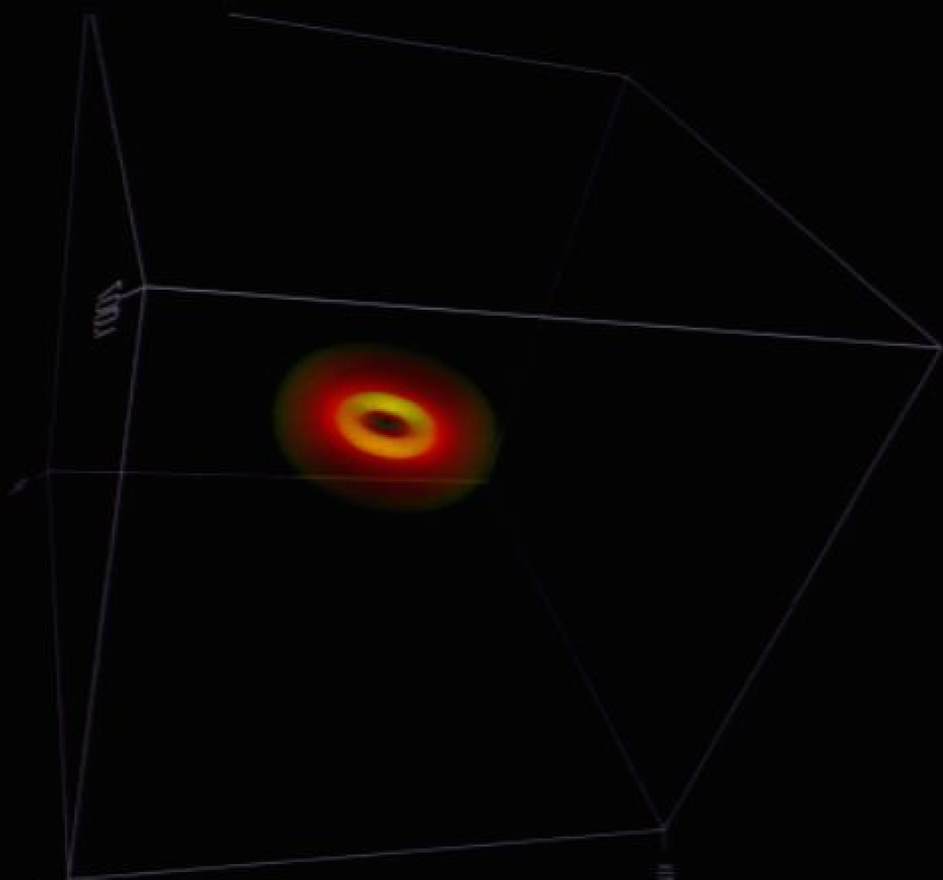

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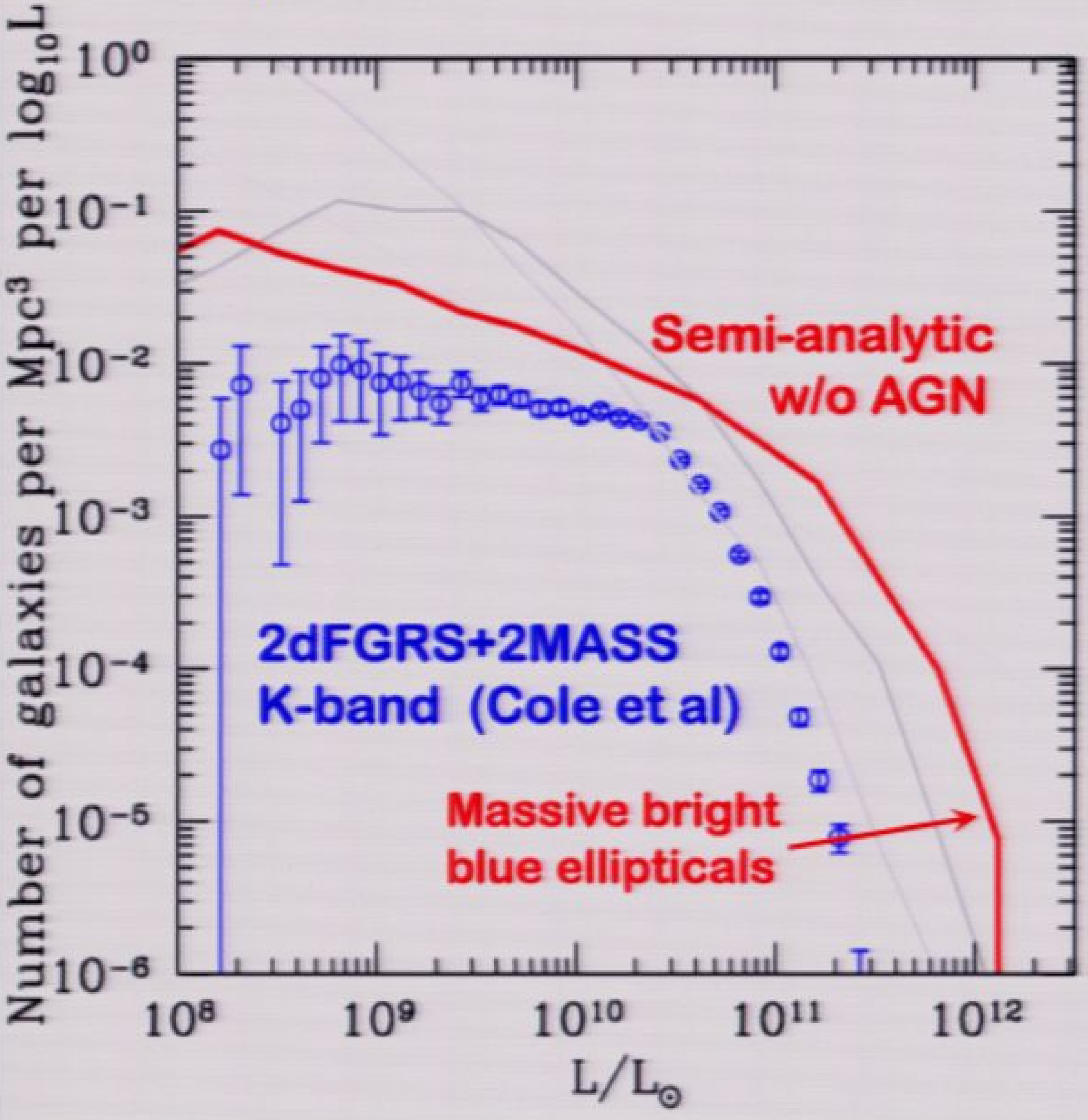

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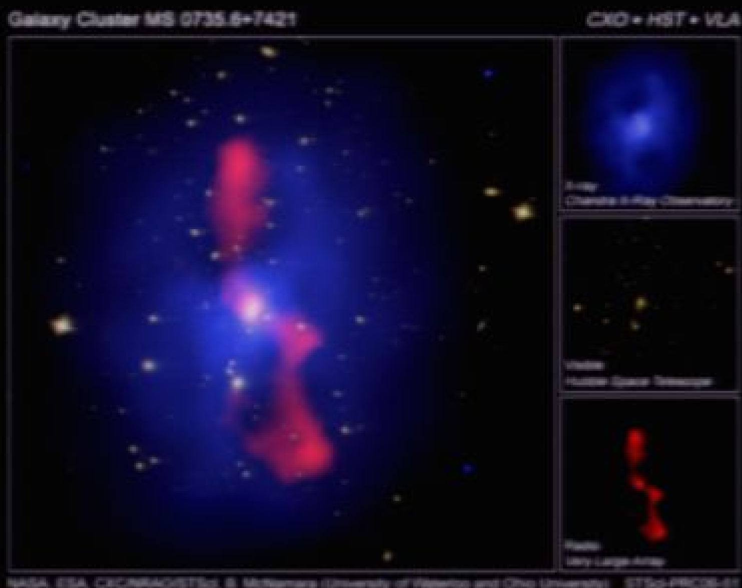
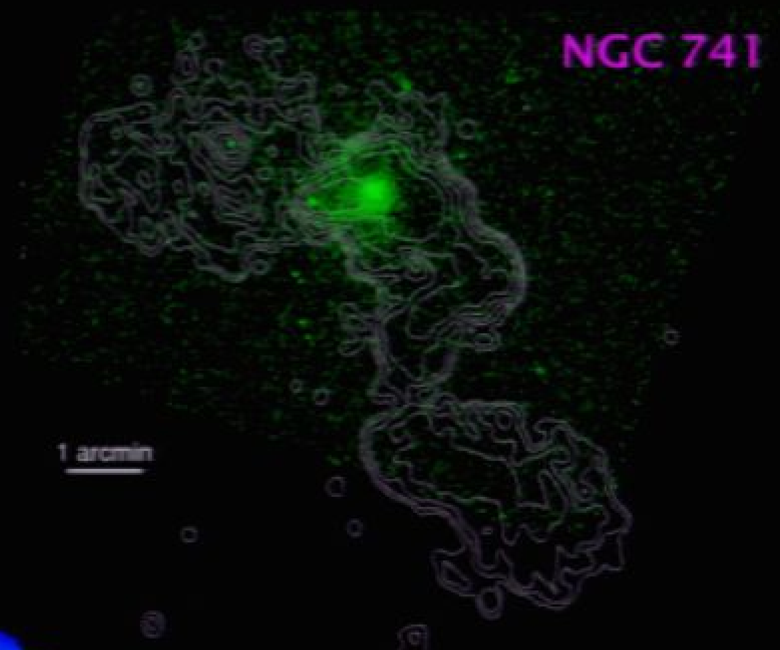
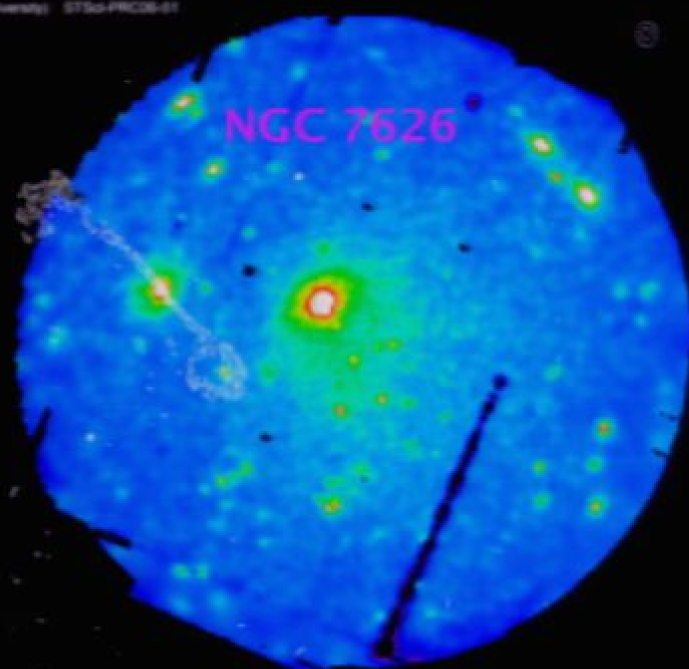
POWERFUL JETS CAN EXTEND WELL BEYOND HOST GALAXY



McNamara et al.

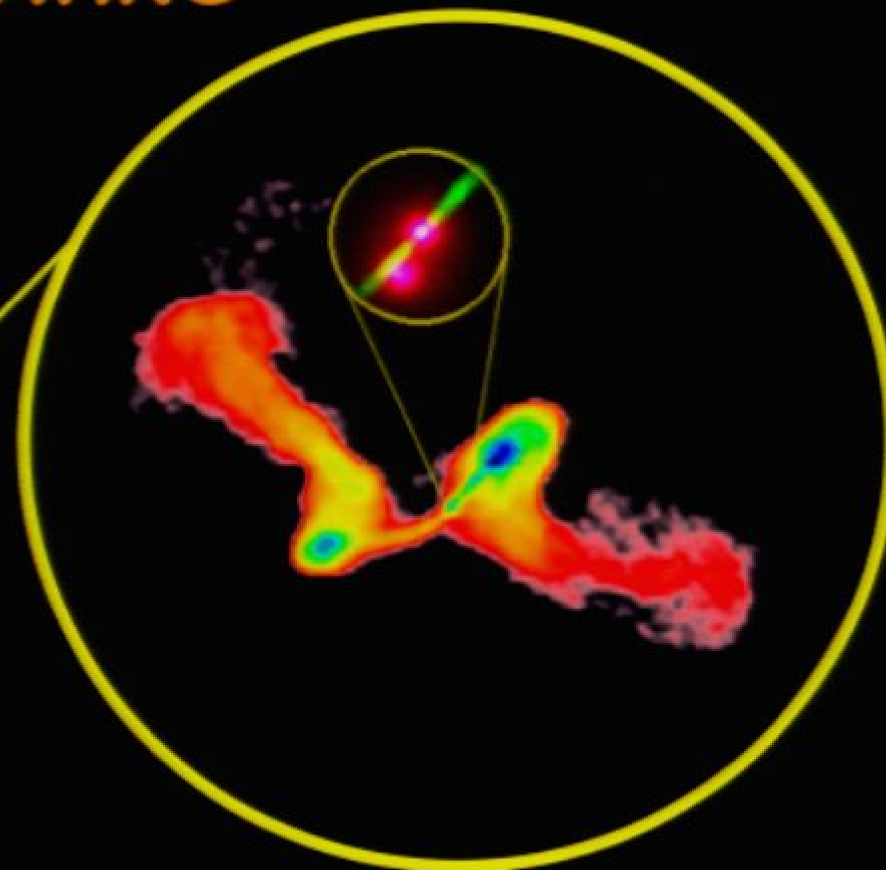


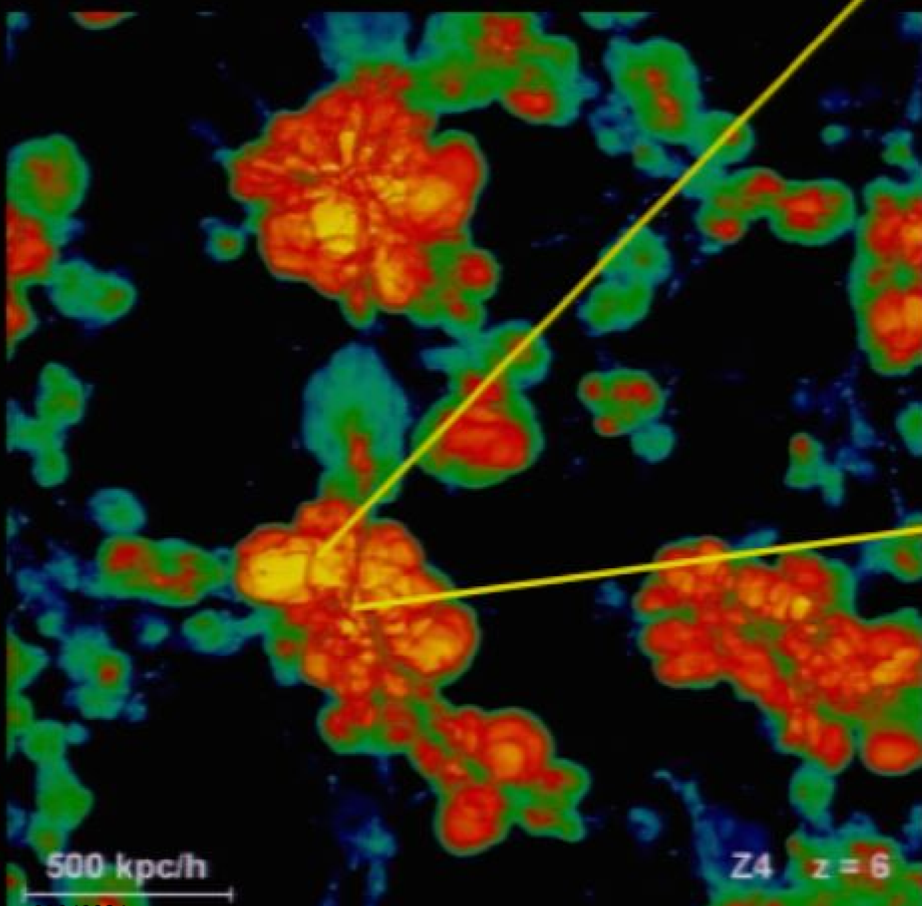
S. Raychaudhury



PREHEATING

OUTFLOWS GENERATED DURING EPOCH OF AGNS (Z~1-3) WILL HEAT THE GAS IN THEIR ENVIRONMENT





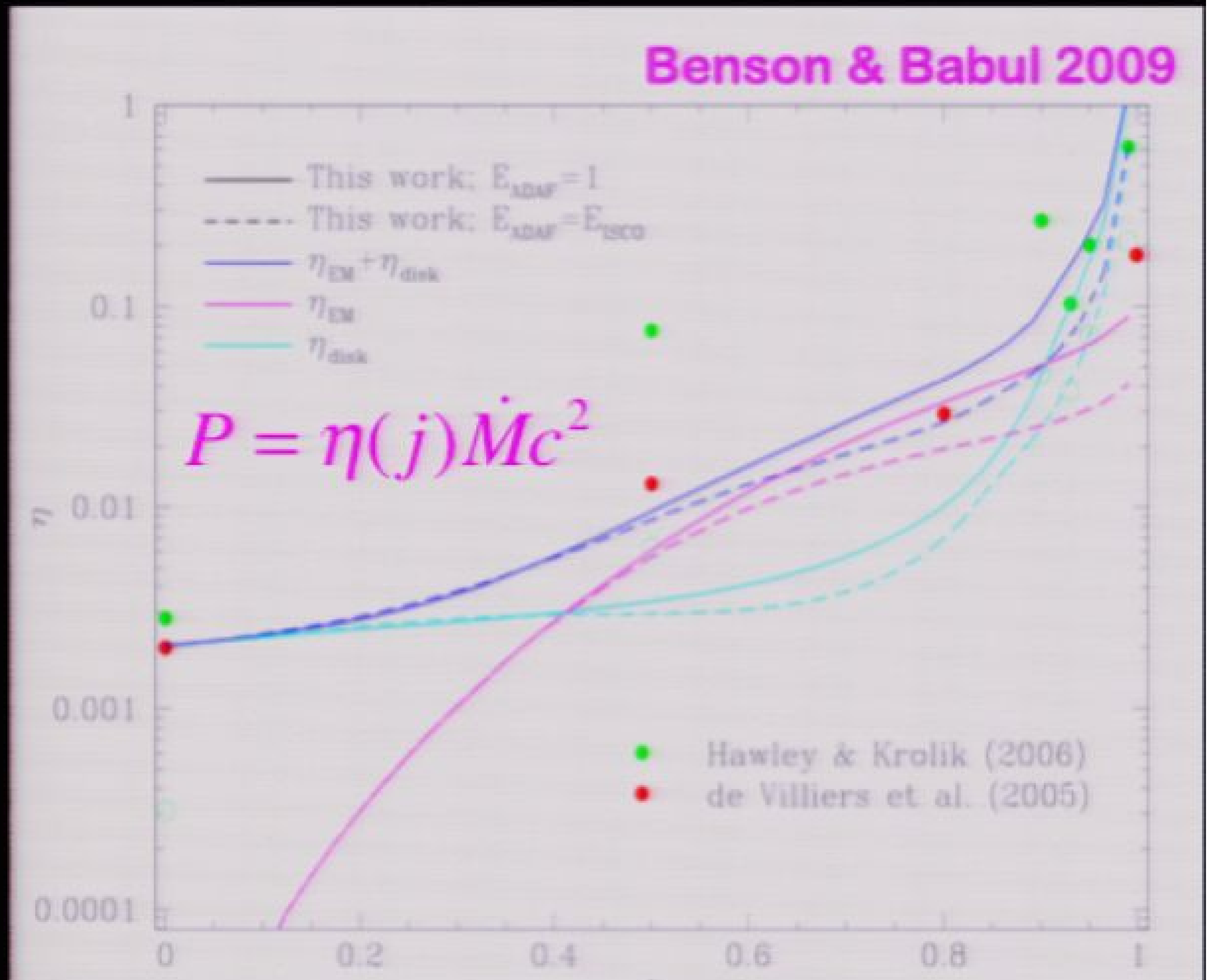
Credit: T. Theuns

HEATING WILL VARY WITH AGN OUTFLOW POWER.

AS HEATED GAS COLLECTS IN GROUPS AND CLUSTER HALOS, IT WILL GIVE RISE TO CENTRAL CORES

SITE-TO-SITE VARIATIONS IN AGN POWER NOT UNEXPECTED

- Variations in local environment about AGN
- Black Hole Spin
- Mergers vs. Smooth Mass Deposition
- Output Mode:
  - radiative
  - low-p vs. high-p jets
  - winds



THE VARIATIONS IN FEEDBACK AND CORRESPONDING HEATING OF GAS IS PREHEATING FOR SYSTEMS FURTHER UP THE HIERARCHY: GROUPS AND CLUSTERS

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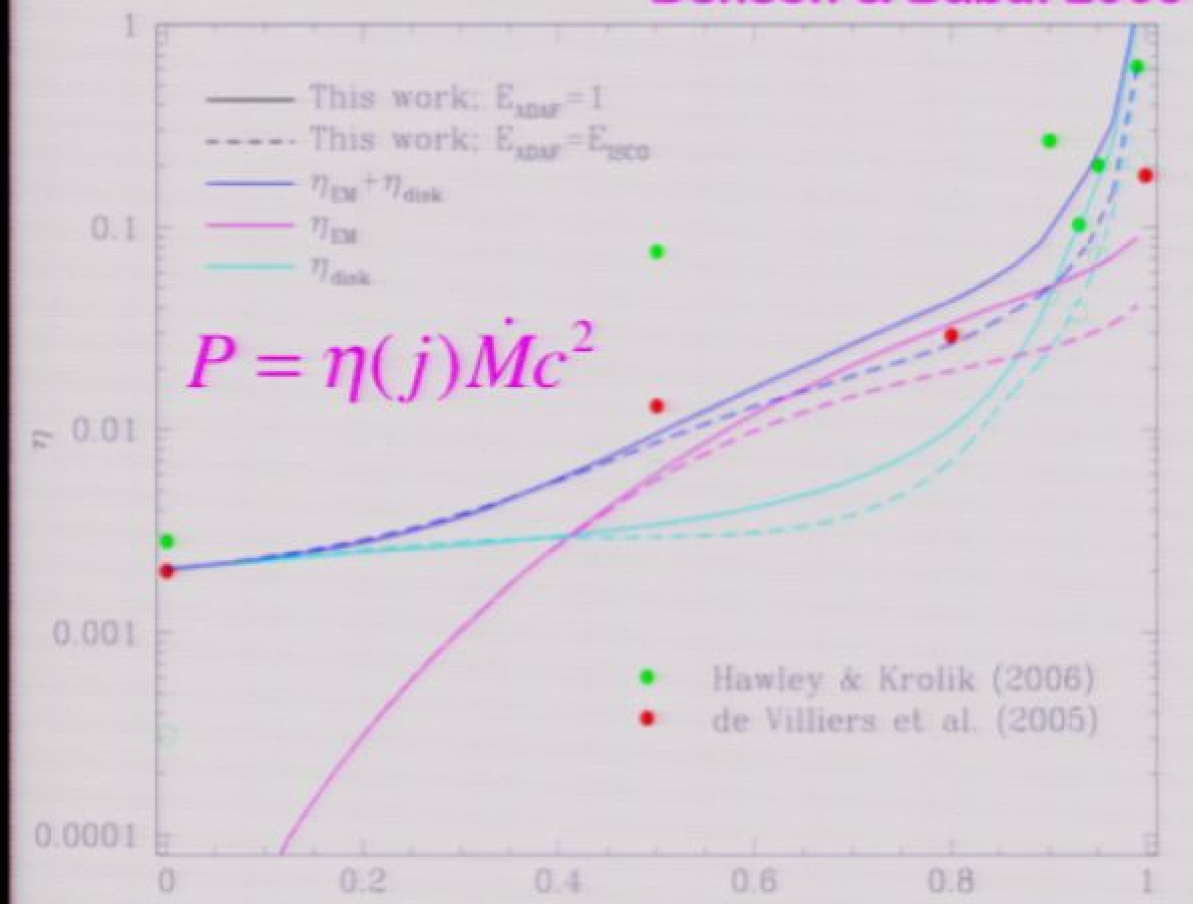
Benson & Babul 2009



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FINAL SUMMARY

WE PROPOSE THAT:

CLUSTER PROPERTIES AND THEIR THERMAL EVOLUTION IS INTRICATELY TIED TO PROCESSES OCCURING ON GROUPS AND GALACTIC SCALE

SPECIFICALLY: PREHEATING SHOULD BE VIEWED AS A BY-PRODUCT OF GALAXY FORMATION

PREHEATING+COOLING+POST FORMATION AGN FEEDBACK CAN ACCOUNT FOR THE FULL RANGE OF ENTROPY PROFILES AND ICM PROPERTIES OF HIGH TO LOW ENTROPY SYSTEMS.

THIS VARIATION SHOULD NOT AFFECT THE POTENTIAL TO DO COSMOLOGY WITH SZ SURVEYS…BUT SZ MAPS CAN ALSO PROVIDE NEW INFORMATION ABOUT PREHEATING – LIKE WHEN IS IT HAPPENING.

THE TRUE TEST OF THE MODEL WILL COME ON THE GROUP SCALE