Entropy Profiles in Radio-Quiet Cluster Cores

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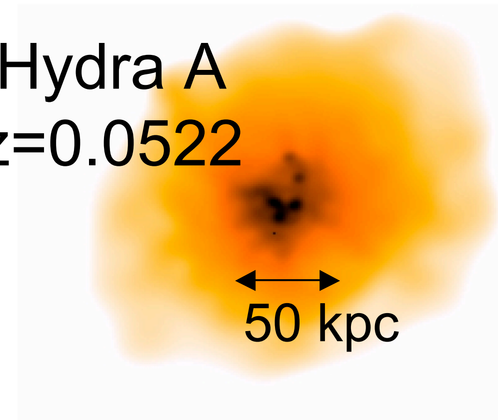
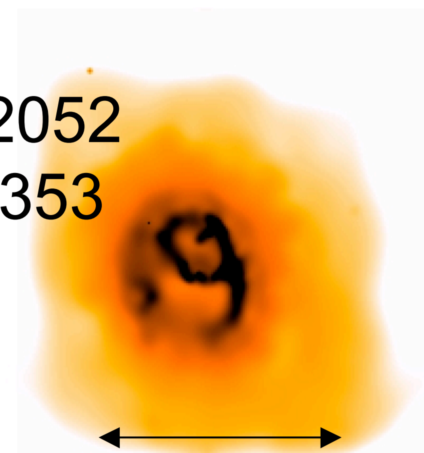
Radio Sources & Cluster Cores

- Can AGN balance radiative cooling in cluster cores?
- Bubbles in the ICM: (McNamara, Sarazin, Blanton)
- Heating occurs, but it's not clear how the AGN compensates for radiative losses.
- AGN may be the primary culprit in quenching the cooling in cluster cores: but how to tell?





Radio-quiet cluster cores

Peres et al. 1998:

- 23 clusters with cooling rates > 100 solar masses/year
- 13: emission line nebulae & strong central radio source
- 2: strong central radio source but no optical line emission (A2029, A3112)
- 3: emission lines but weak central radio source. (A478, A496, A2142)
- 5: no emission lines and little or no radio activity. (A644, A1650, A1651, A1689, A2244)

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Chandra Observations

- Chose 2 symmetric, relaxed clusters without radio sources, A1650 and A2244.
- ACIS-S observations sufficient to obtain >150,000 counts for radial deprojection of spectra and surface brightness.
- Temperature and metallicity gradients measured at lower resolution than density gradient.

A2244 & A1650

- Feedback free?
- Radio quiet -- upper limits or detections a factor of 30 or more below the others

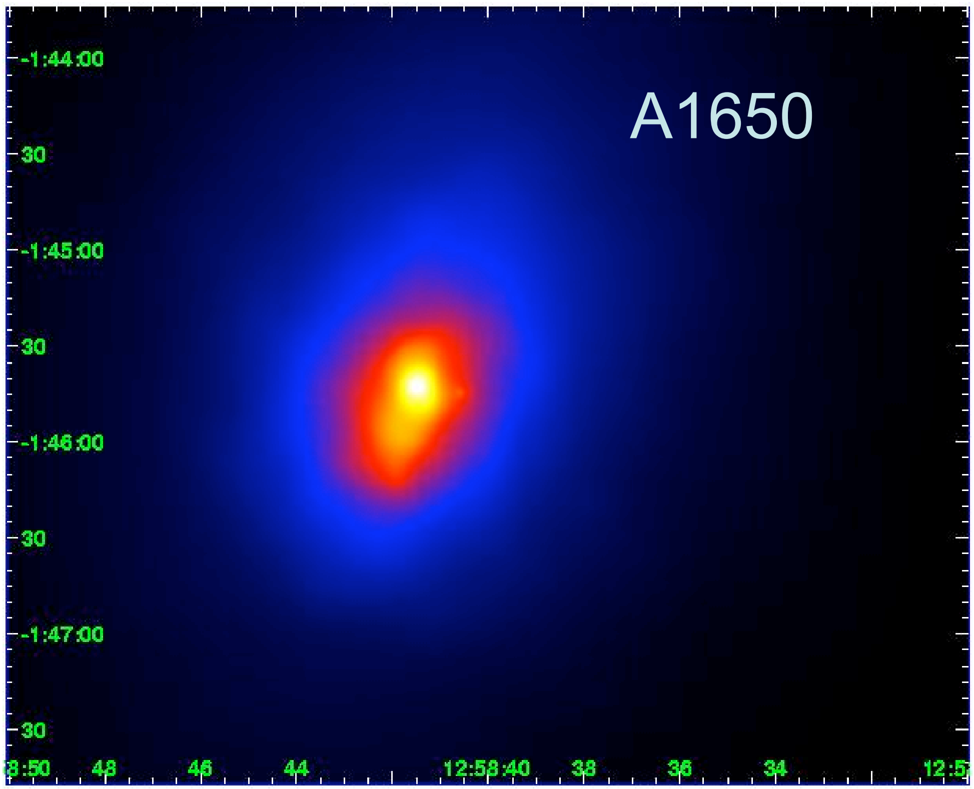
- Z = 0.095 and 0.085
- KT ~ 5-6 keV

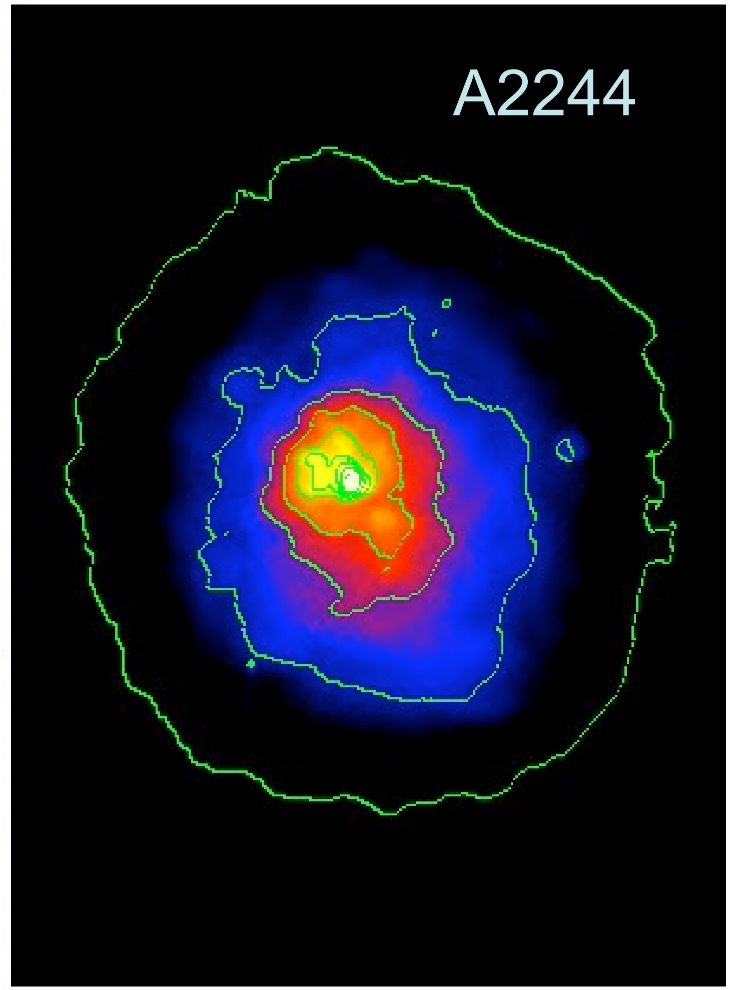
What might have been:

- Fossil radio lobes and/or X-ray cavities suggestive of earlier radio activity.
- Temperature gradients sufficient to quench cooling via conduction.
- Very low central entropy values, suggesting that these clusters are on the verge of a heating episode.

What is

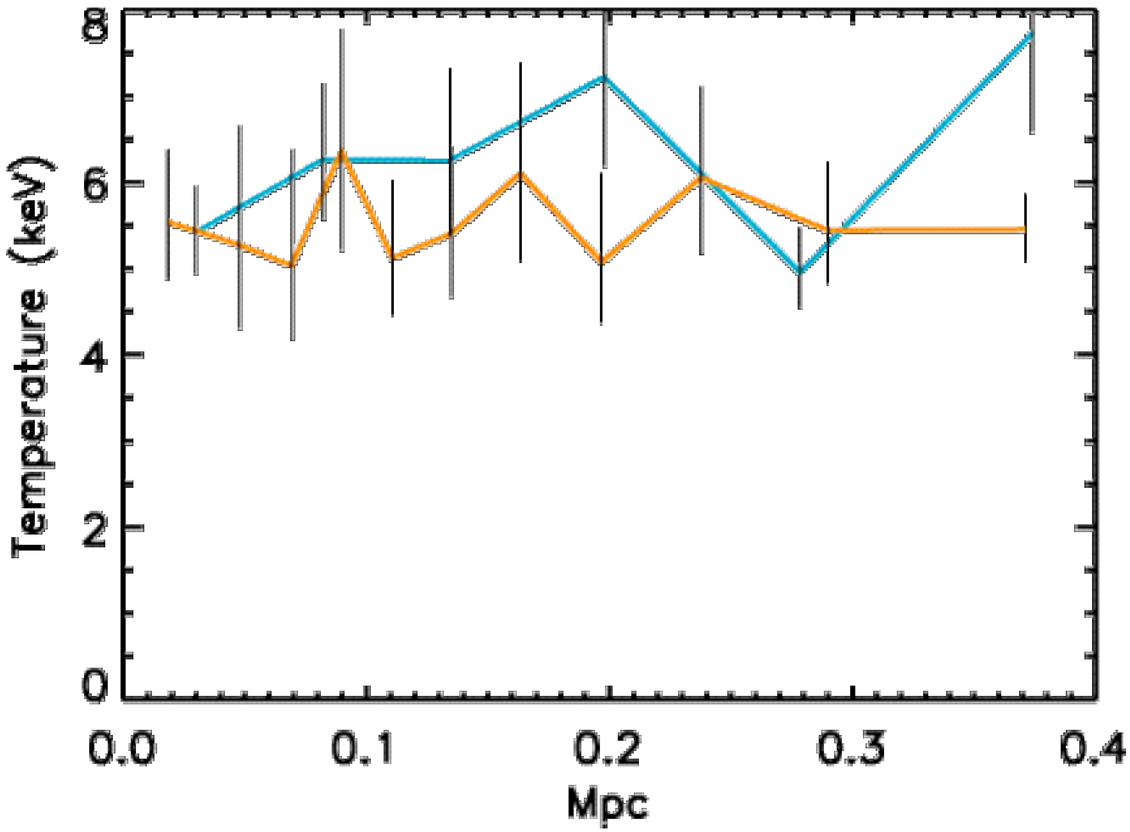
- No fossil lobes out to ~100 kpc





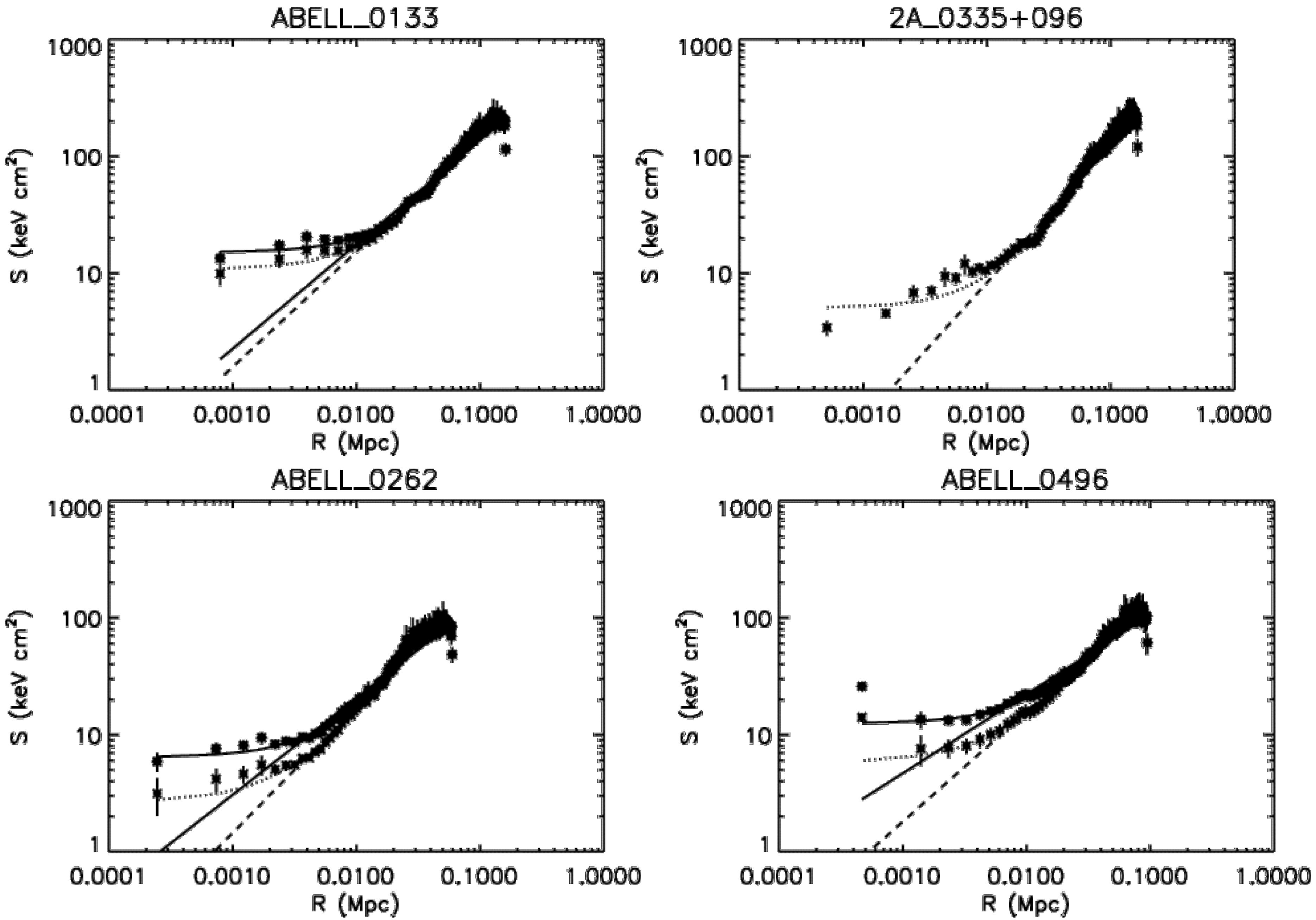
What is

- No temperature gradients: limited, if any, conduction.

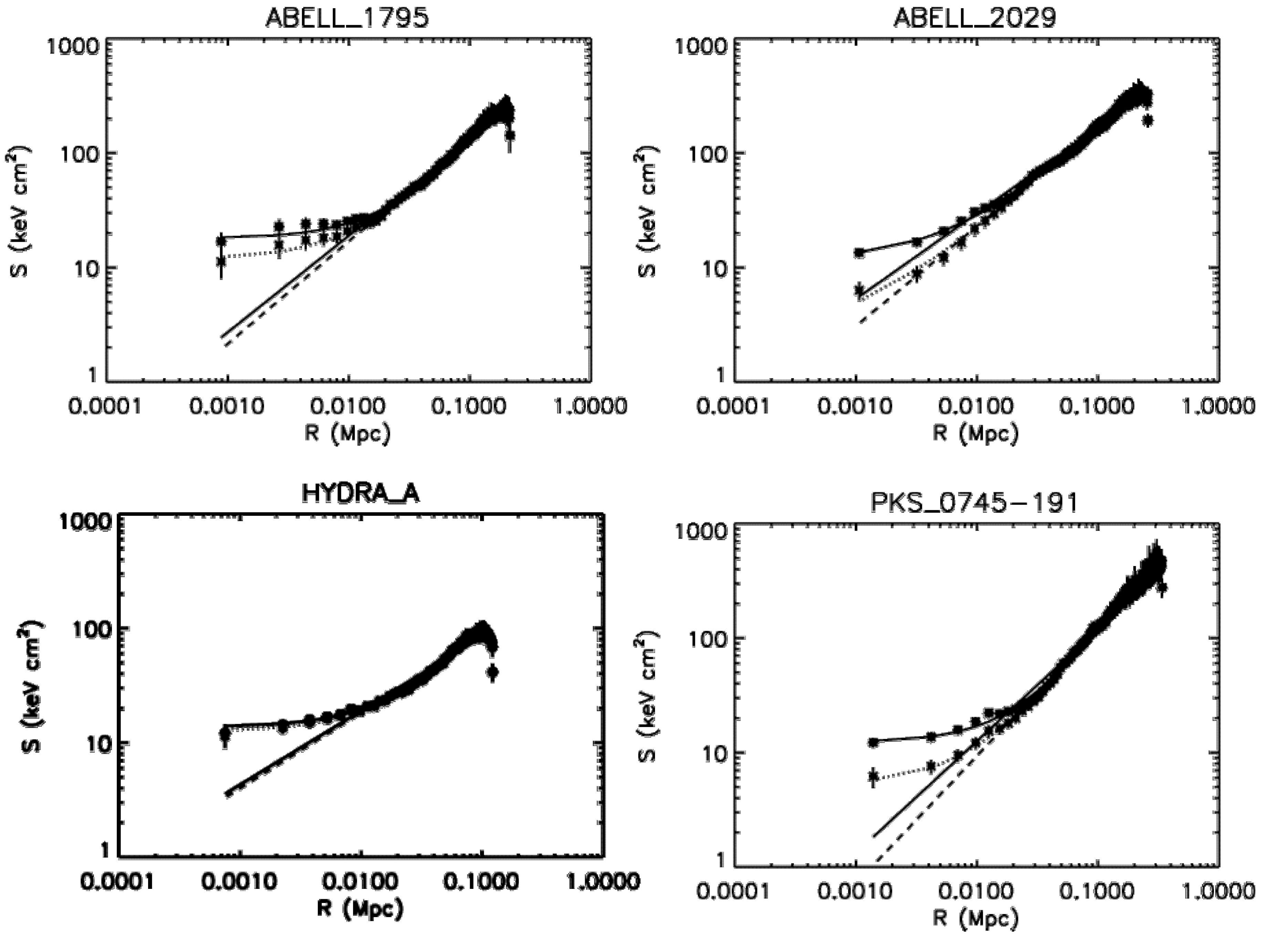


Entropy Gradients

- Cool cores ***with*** feedback evidence show a remarkable consistency in their entropy profiles:
- $S(r) = S_0 + (r/r_1)^{\alpha}$
  - $S_0 \sim 10$ keV cm^2
  - $\alpha \sim 0.9 - 1.3$
- α is about what one expects as a result of structure formation *outside* the core (but not necessarily *inside* the core).
- Almost all have non-zero S_0.



ABELL_0133
2A_0335+096
ABELL_0262
ABELL_0496
S (keV cm^2)
R (Mpc)
1000
100
10
1
0.0001
0.0010
0.0100
0.1000
1.0000


ABELL_1795
ABELL_2029
HYDRA_A
PKS_0745-191
S (keV cm^2)
R (Mpc)
1000
100
10
1
0.0001
0.0010
0.0100
0.1000
1.0000

Profile Consistency

- Quasi-steady configuration could be used to argue against episodic heating.
- No evidence for entropy inversions r > 10 kpc: suggests energy injection can’t just happen at the center.
- Entropy floors and small entropy inversions, bubbles show current energy injection.

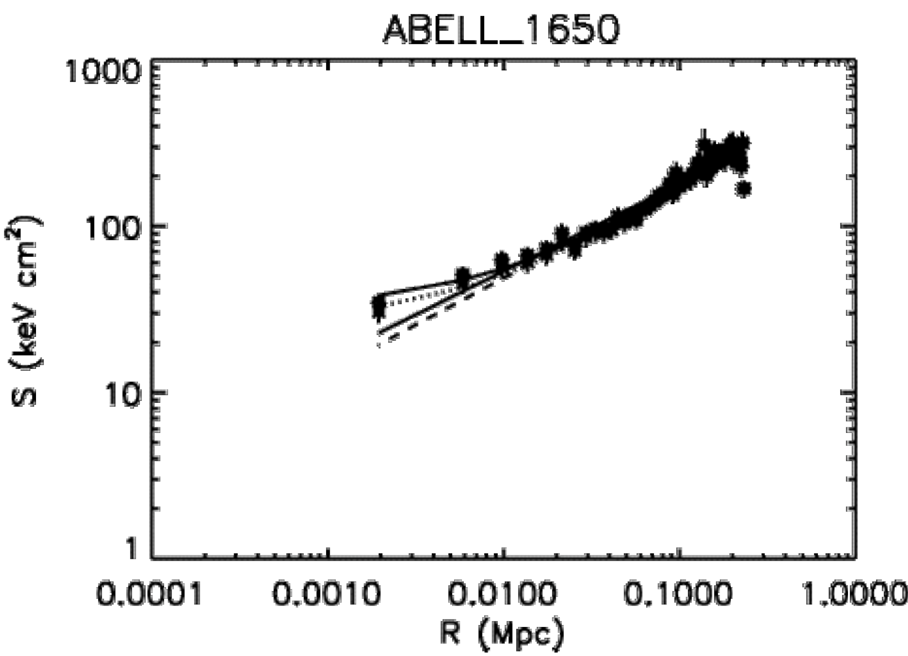
Iron Gradients

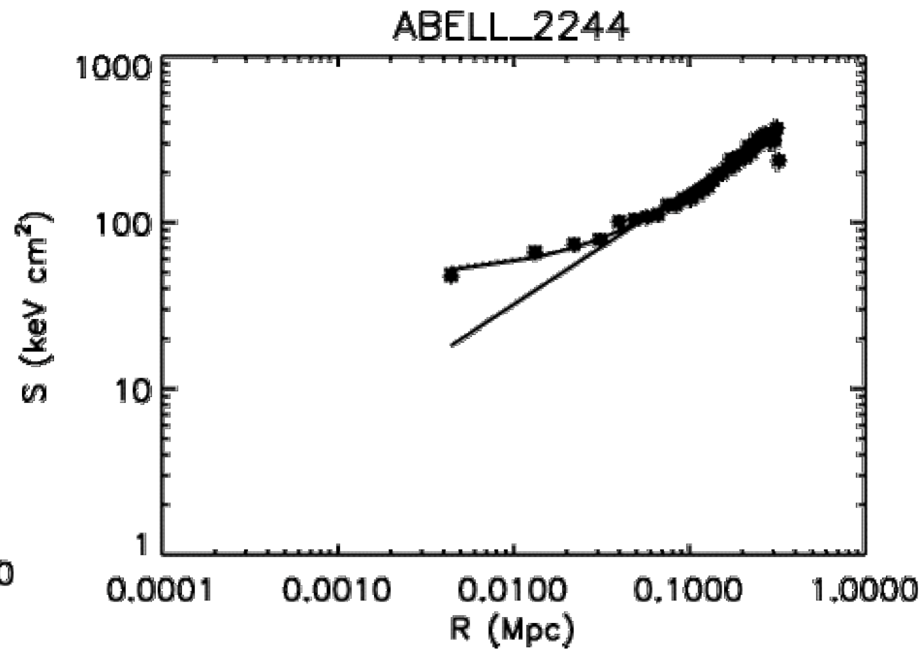
- Significant iron gradients, increasing toward the core measured in most of these systems.
- The presence of a gradient suggests lack of disturbance (e.g. major mergers.)

    Quasi-stable core gas?

What do we see?

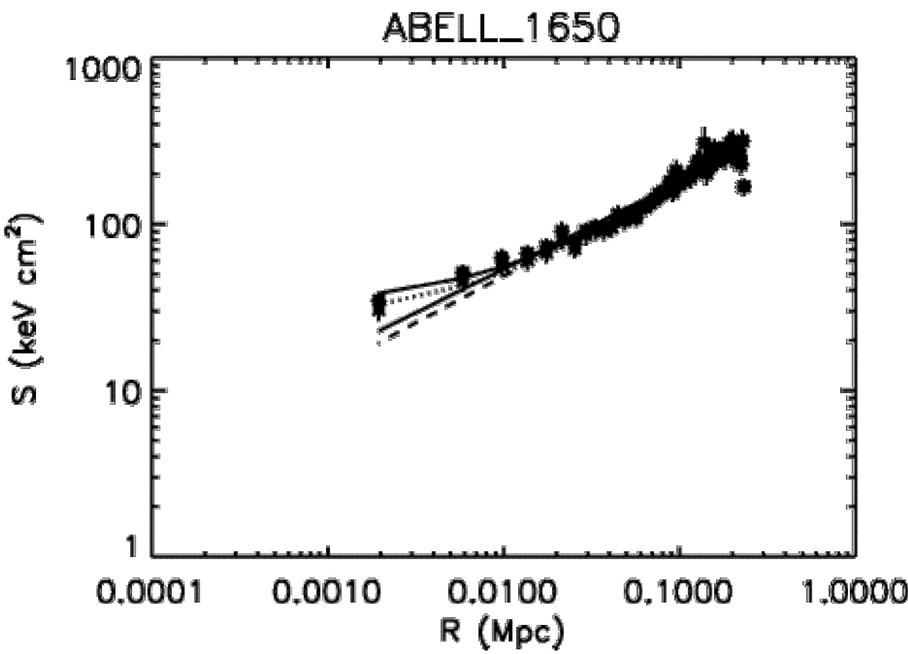
- High central entropy! 35-50 keV cm^2

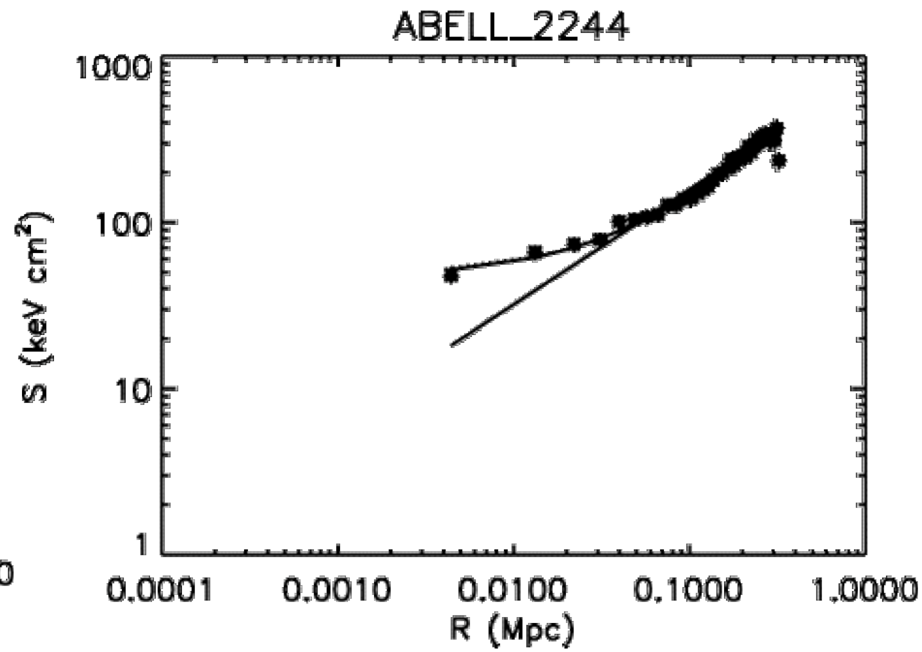




What do we see?

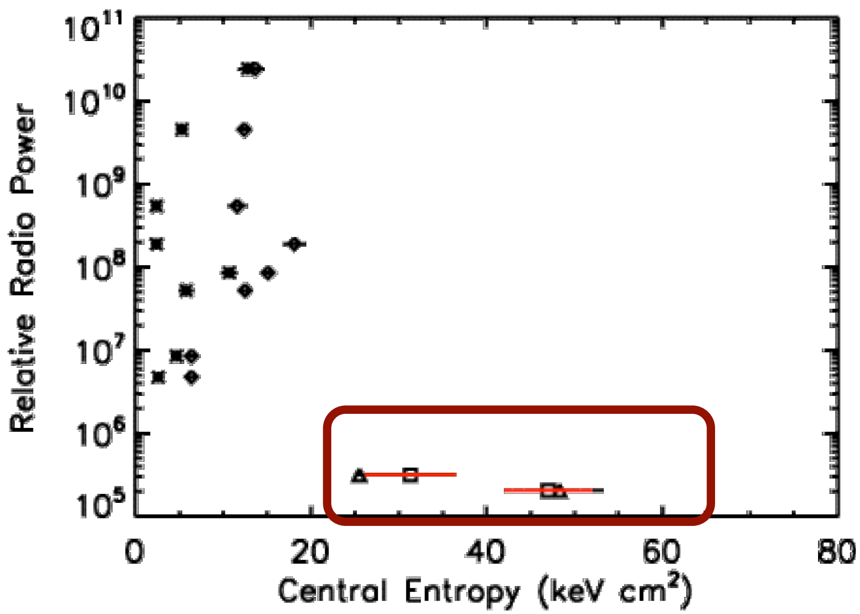
- T~5-6 keV => $t_{cool} > 10^9$ years



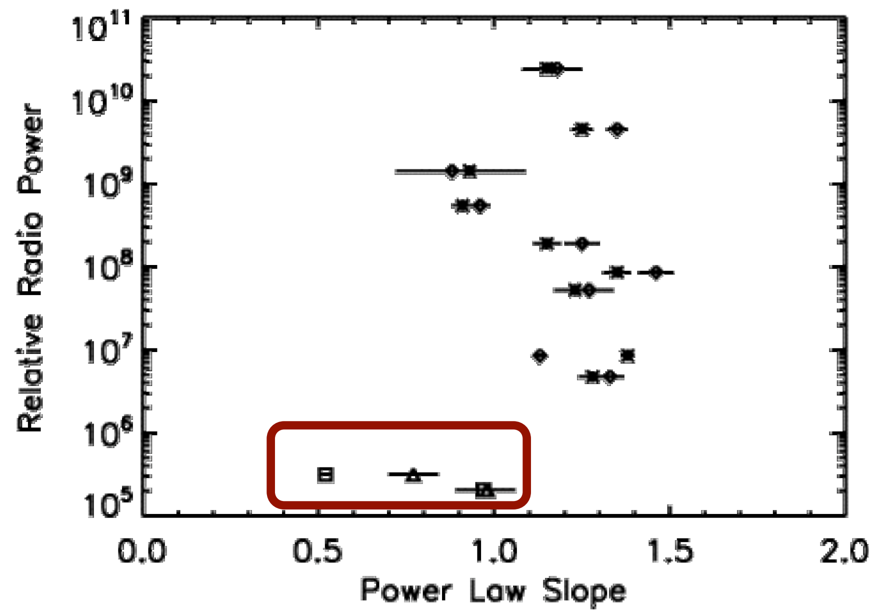


Comparison

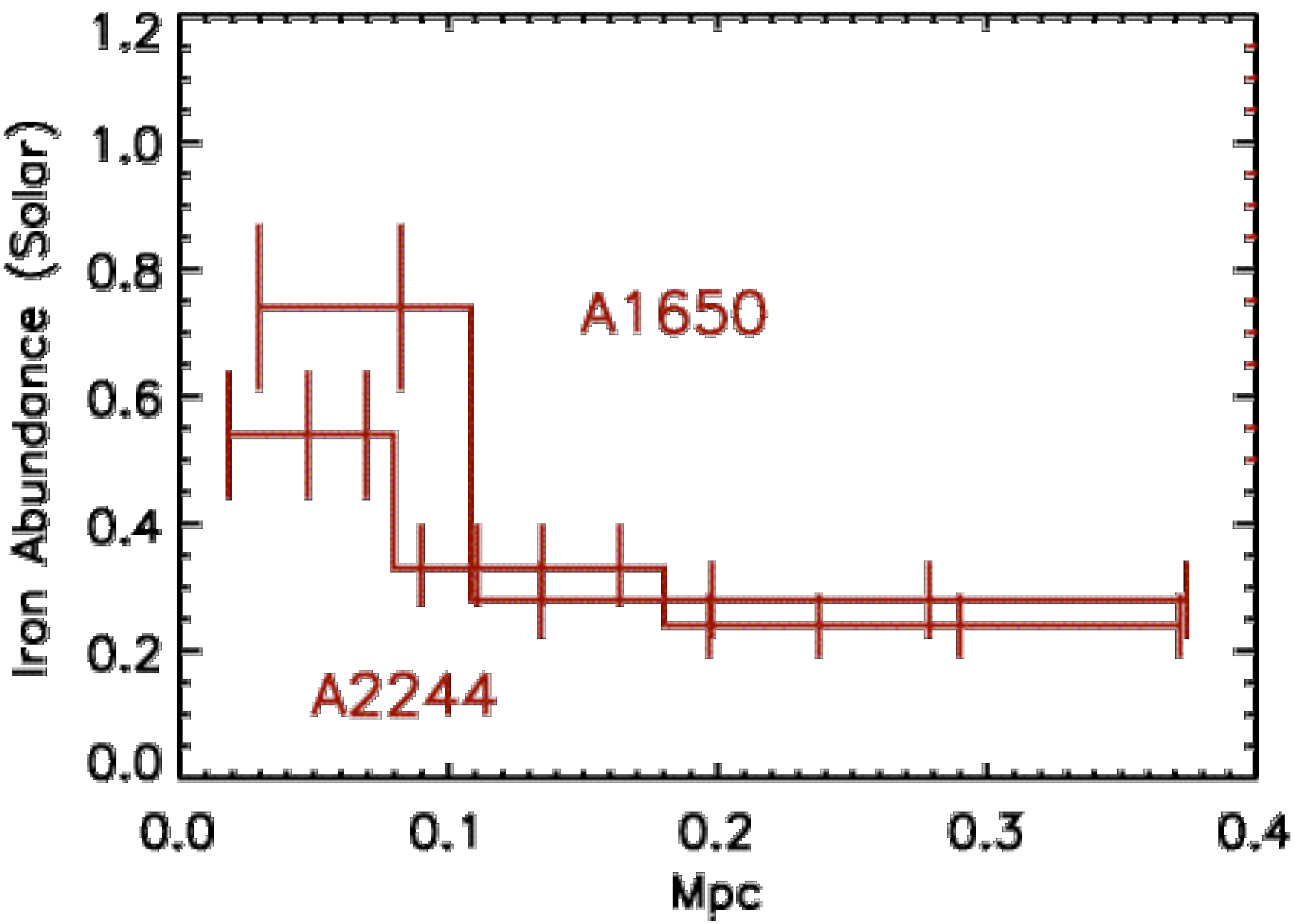
L_R vs. Central Entropy



L_R vs. Power-Law Slope



Significant Iron Gradients



What happened?

- These cluster cores have not yet cooled to low entropy, and will trigger an outburst in the future.

OR

- The AGN in these clusters have a very low duty cycle, requiring enormous energy injection by AGN in the past.

AGN heating?

- Yes!
- That these radio-quiet cooling cores do not require feedback strengthens the connection between radio sources and heat input.
- If the trend holds for the other radio quiet clusters with short central cooling times, then AGN are almost certainly the primary stabilizing mechanisms for cooling cores at z~0.

Next Work

- Complete entropy profile extraction on other radio quiet clusters (almost done).
- Test idea that cooling rates ~ star formation rates with RGS and Astro E-2 spectra (faint Fe XVII and O VII lines should be present.)
- Test deprojection assumptions with realistic hydro simulations.

Conclusions

- We observed that radio quiet clusters with short central cooling times have high central entropies and somewhat shallower entropy profiles than radio-loud clusters.
- We propose that these clusters will eventually look like the radio loud clusters.
- AGN are a significant source of feedback in gas surrounding galaxies and must be included in galaxy formation models: star formation in central galaxies may be regulated by the AGN.