The Intra-Cluster Medium

Recent results
&
future prospects

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Galaxy Clusters

Largest gravitationally bound structures in the local universe.

Subject of intense research

c)as cosmological tools

d)interesting structures

a) and b) are of course connected as some understanding of the structures is required to use clusters as cosmological tools.

Intra-Cluster Medium

Approach

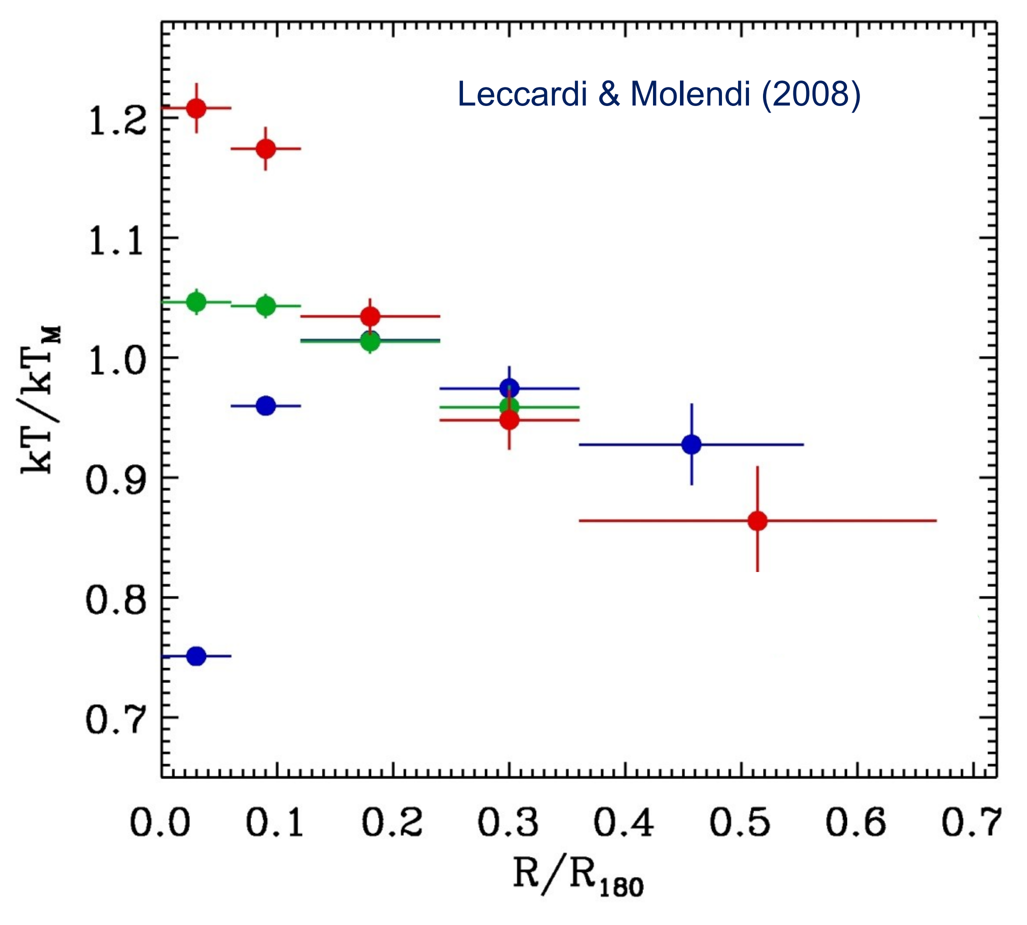
Organize objects in medium size sample (20-60) objects
We measure SB, T and metal abundances
Global measures, profiles and maps

It is not necessary that the samples be complete
It is important that they be to some extent representative of the cluster population as a whole

Temperature profiles

Measured by many authors using different experiments

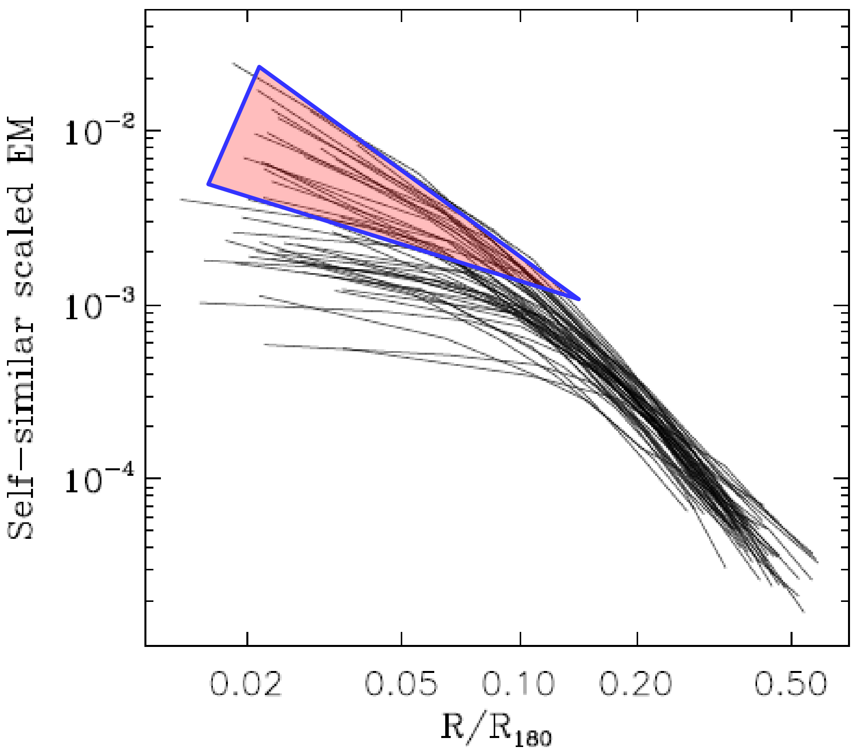
- At large radii profiles show similarity
- In cores we have different behaviours
- Clusters with rapid T drops known as cool cores (CC) clusters



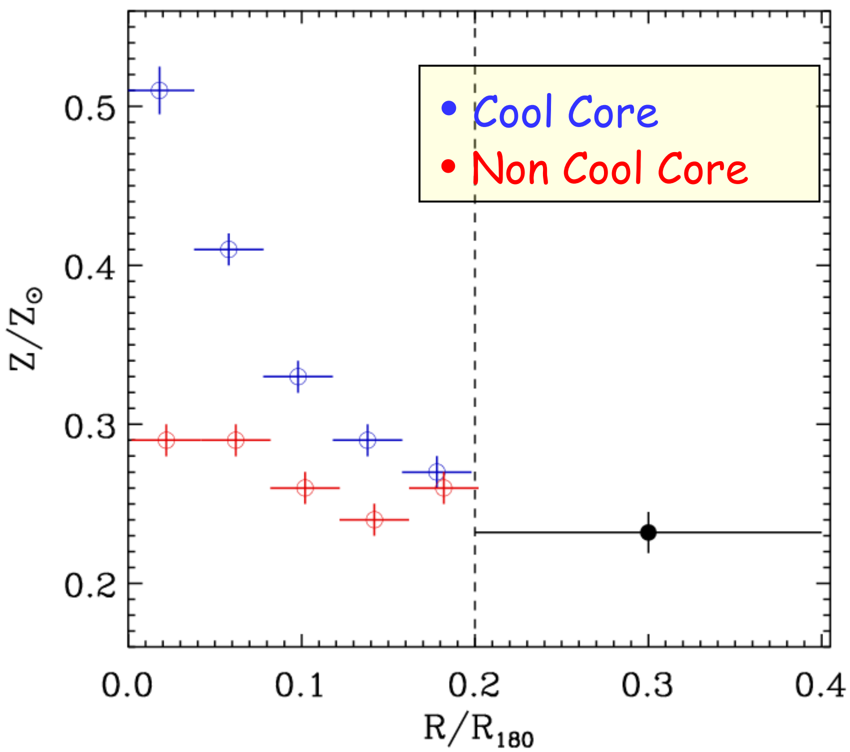
CC vs NCC

Surface Brightness

Metal Abundance



Leccardi, Rossettii & Molendi(2009)



Peaked SB profiles

Abundance excess

Entropy indicator

- More quantitative classification than CC and NCC
- Identified a thermodynamic quantity the entropy and constructed an entropy based indicator
- The entropy $s = T/n^{2/3}$
- We used pseudo-entropy $\hat{s} = T/EM^{1/3}$

Entropy Indicator

- Since we wish to compare core with cluster properties, we use a pseudo-entropy ratio

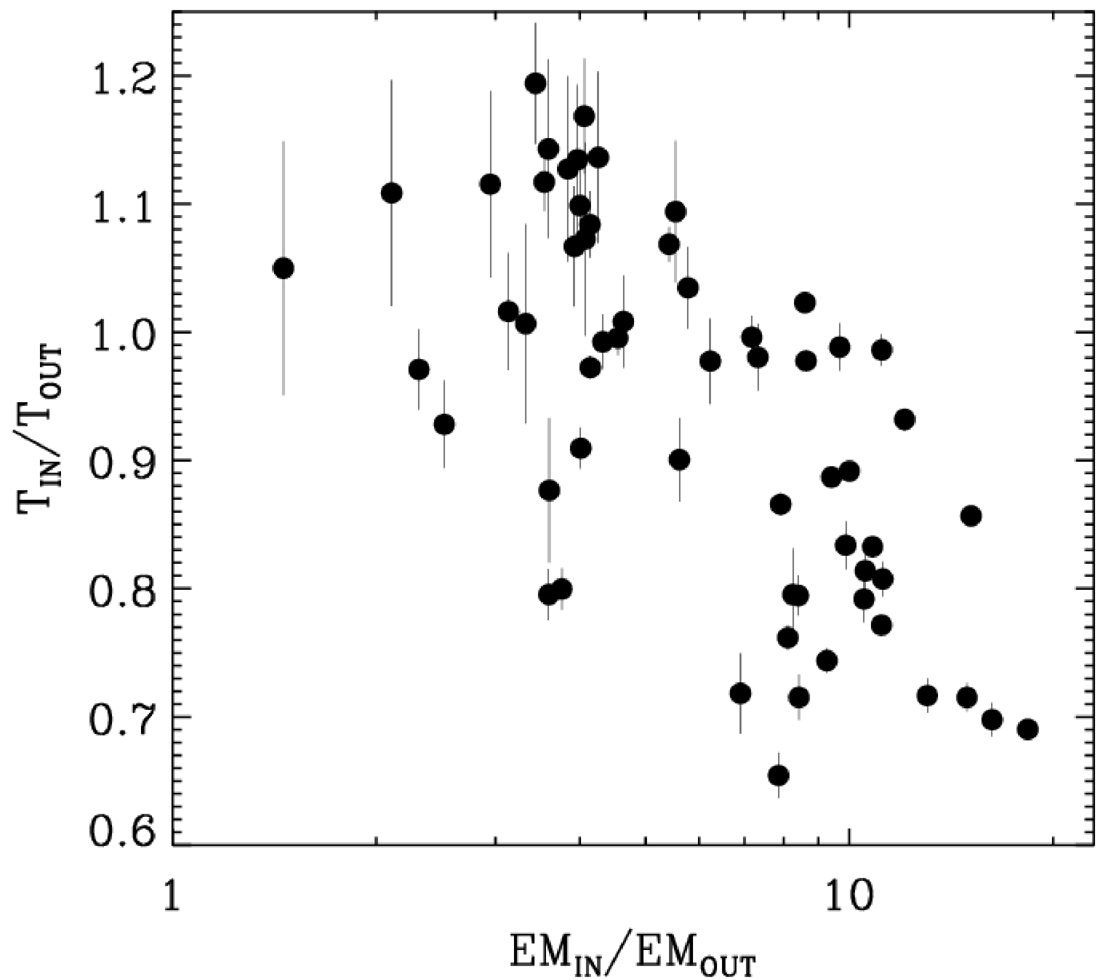
$$\sigma = \hat{s}_{in}/\hat{s}_{out} = T_{in}/T_{out} \cdot (EM_{in}/EM_{out})^{-1/3}$$

- In region circle $R < 0.05 \cdot R_{180}$
- Out region annulus $0.05 \cdot R_{180} < R < 0.2 \cdot R_{180}$

Employed on fairly large (60 obj) & representative sample $0.02 < z < 0.25$

Entropy classification

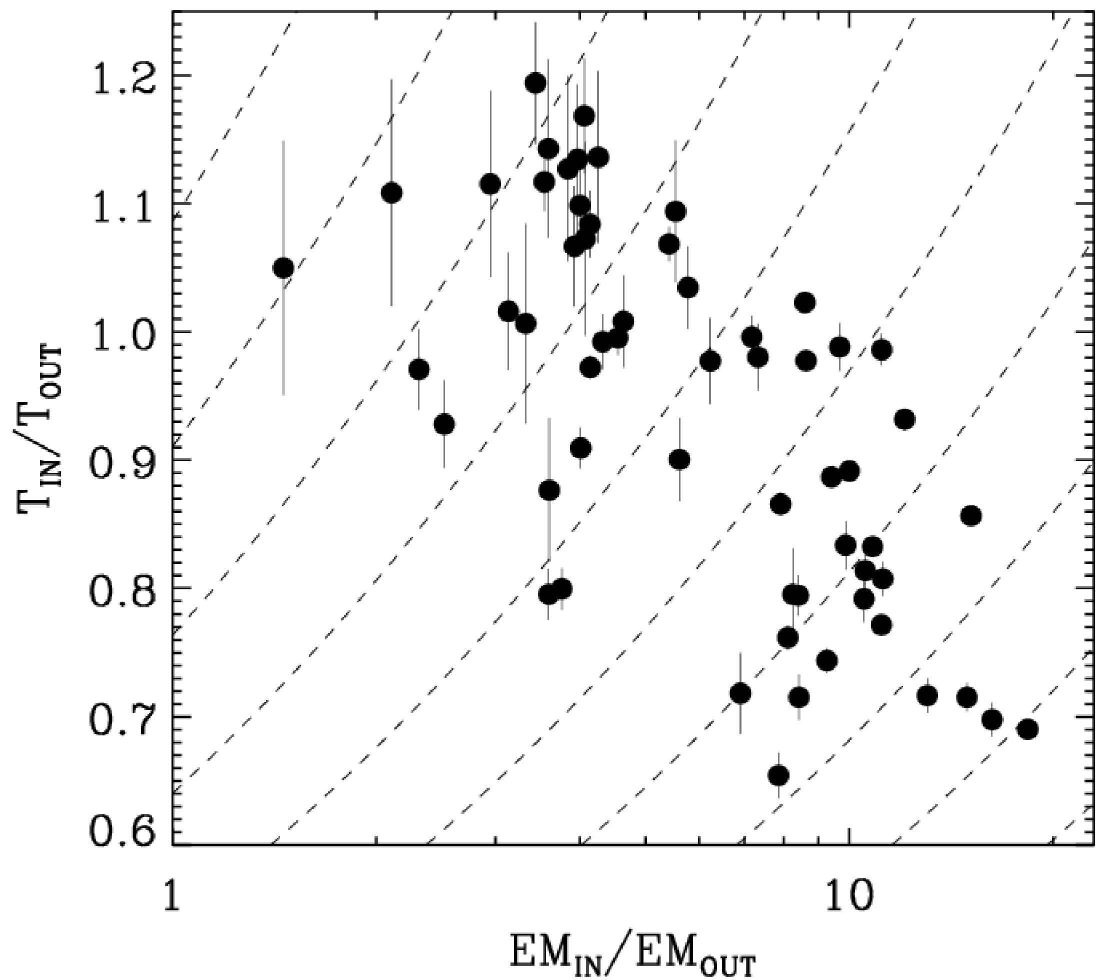
As expected T ratio anti-correlates with EM ratio.



Entropy classification

$\sigma = \hat{s}_{in}/\hat{s}_{out} = T_{in}/T_{out} \cdot (EM_{in}/EM_{out})^{-1/3}$

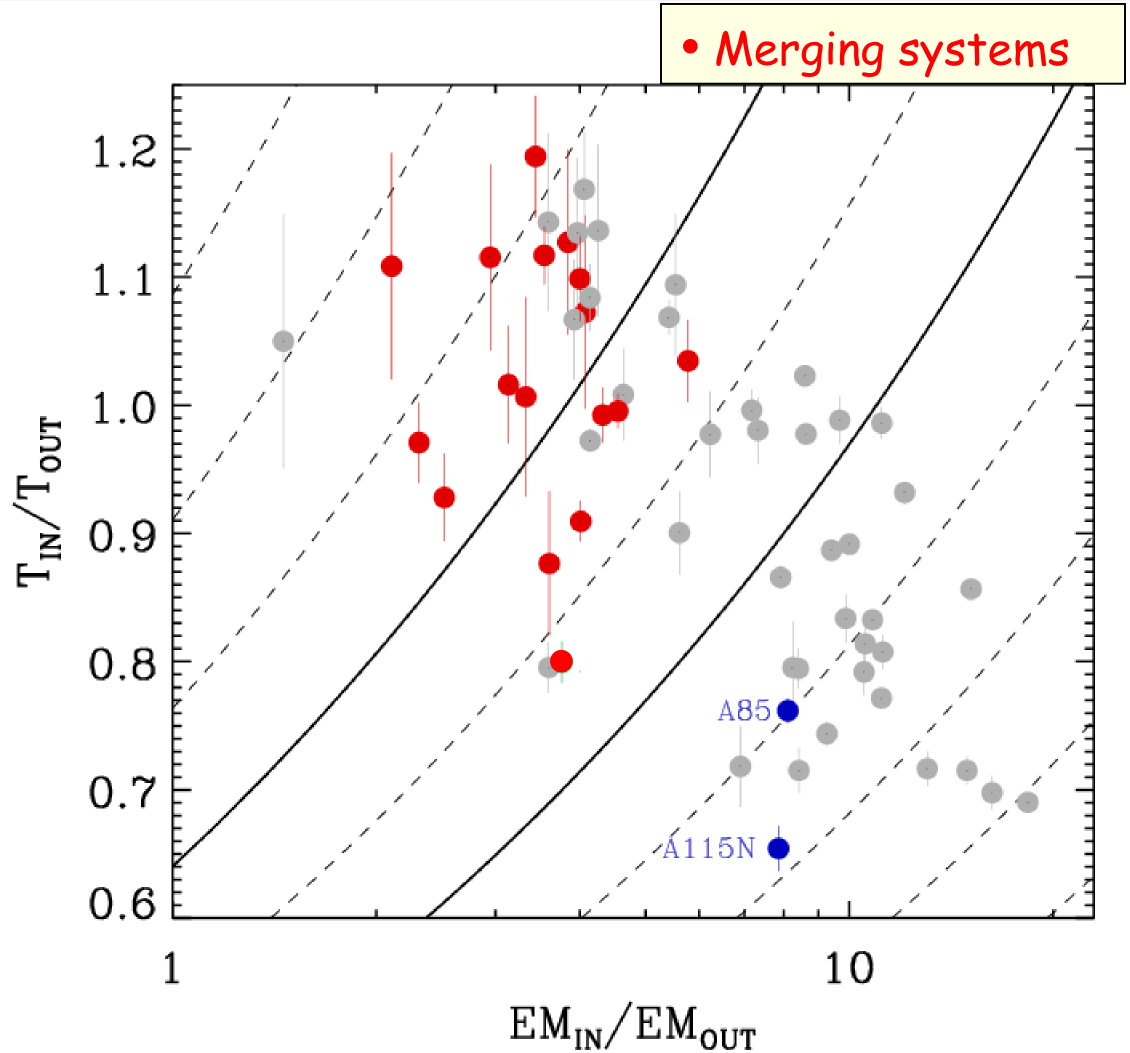
Plot regions of constant pseudo-entropy ratio



Entropy vs Merger classification

We classify objects as mergers on the basis of radio, optical and X-ray properties.

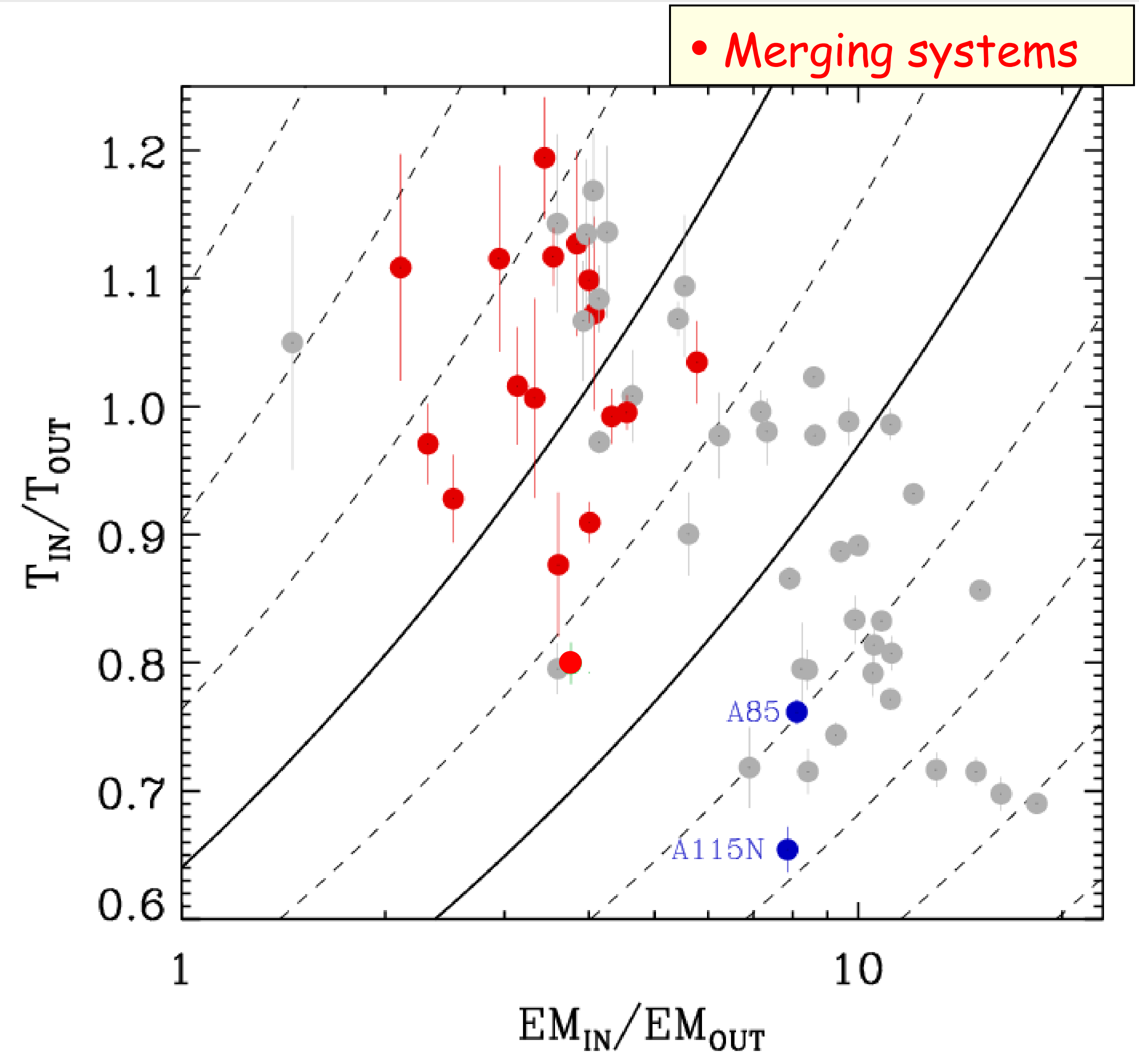
major mergers are fairly well segregated in entropy space



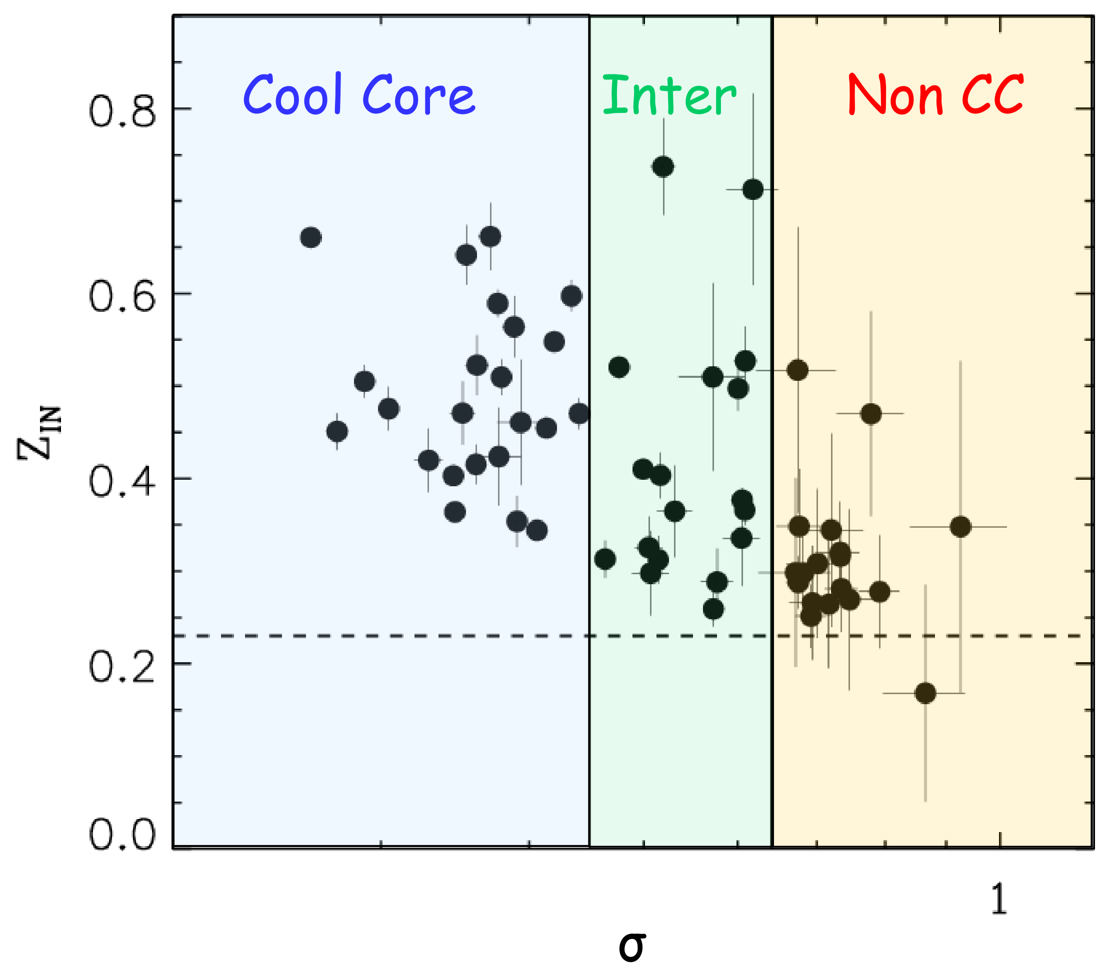
Entropy vs Merger classification

Lack of mergers observed in CC systems suggests that mergers can disrupt CC

major mergers are fairly well segregated in entropy space

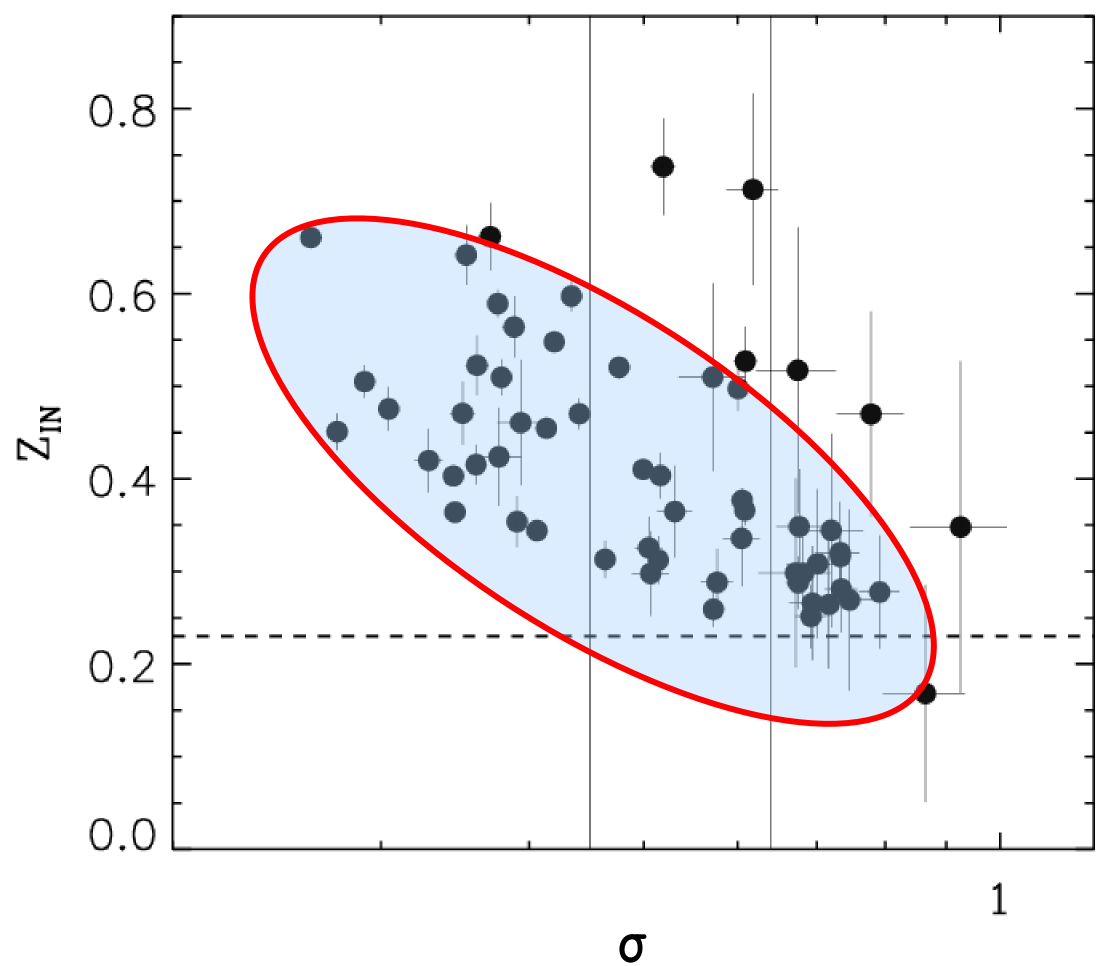


Z vs Pseudo Entropy Ratio



Z vs Pseudo Entropy Ratio

Objects with larger entropy gradients host more metallic cores

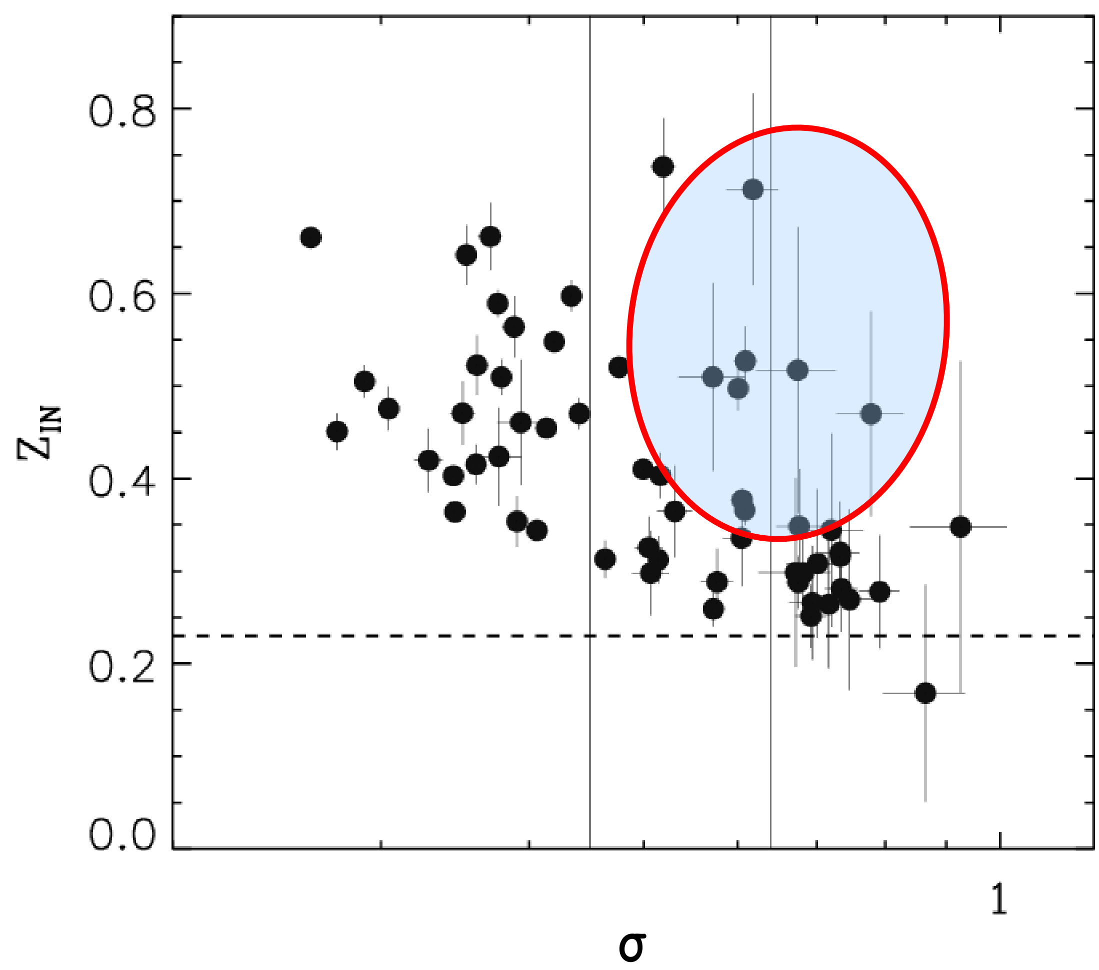


Z vs Pseudo Entropy Ratio

Quite a few outliers.

Some mergers with high metal abundance

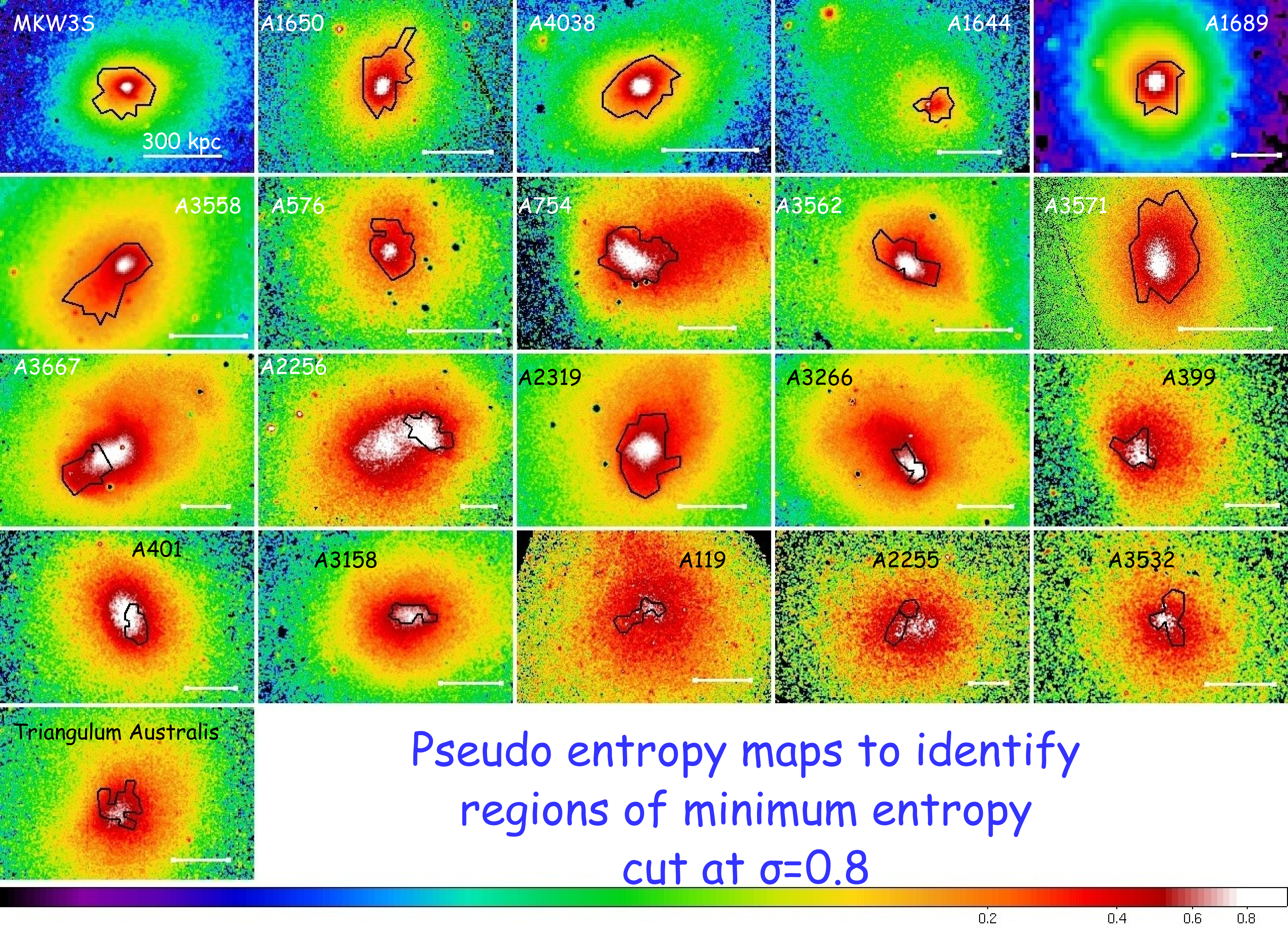
How do we explain them?



A more detailed study

Rossetti & SM see poster.

2. Low z representative sample ($0.02<z<0.1$) extracted from the B55 sample (Edge et al. 1991)
3. Considered the 21/35 objects that are not Cool Cores

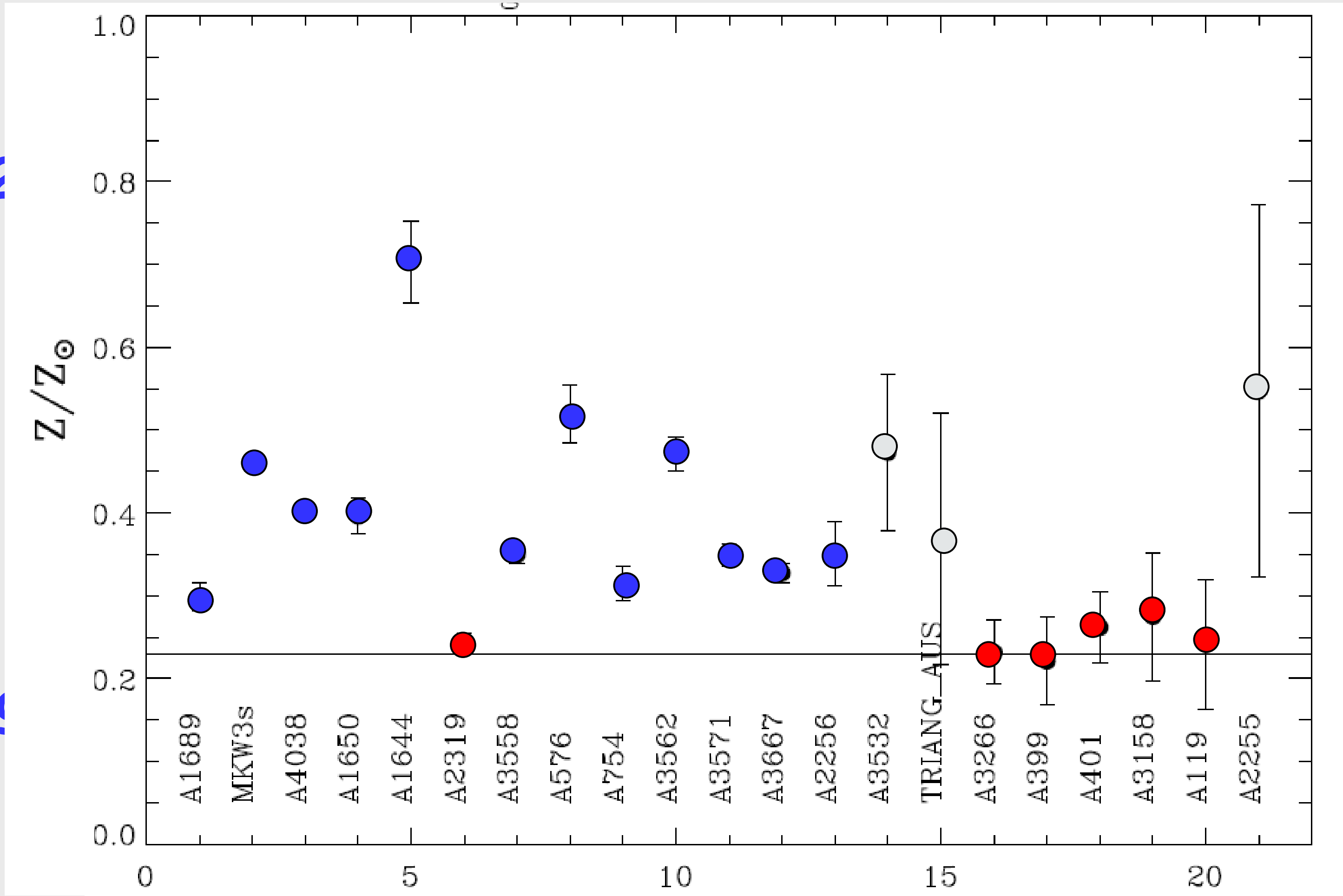


Pseudo entropy maps to identify regions of minimum entropy cut at σ=0.8

Abundance Excess

Extracted and analyzed spectra for low entropy regions

- For a large fraction 12/2
abundance excess
- For a few 6/21 no abundance excess
- For 3/21 errors to larg



Cool core remnants

How do we explain these high Z relatively low entropy regions?

Simply evolved to be the way they are?

Most systems are far from equilibrium

These are the regions in non-CC systems that are most similar to CC

Cool core remnants

Most likely interpretation: re-heated cool cores

In 3-4/12 systems the amount of heating required is within the reach of AGN heating. Example A1650 (Donahue et al. 2005)

For 8/12 the heating is beyond what AGN can provide
For 5/8 strong evidence of merging

Heating most likely provided by mergers

Abundance in Cool Core systems

De Grandi & SM 09, see also poster

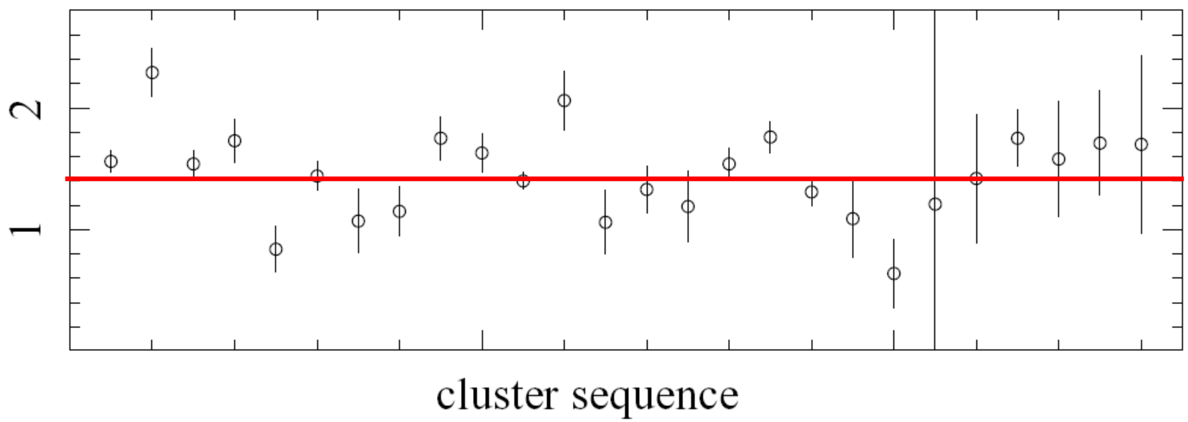
- 20 Brightest Cool Core clusters in the B55 (Edge et al. 1990) sample

- Analyzed spectrum from within ½ Rcool

- Measured Si, Fe, Ni (1.8-10. keV E band)

Abundance in Cool Core systems

Si/Fe



1.47 ± 0.05

$\sigma_{Si/Fe} \sim 20\%$

The Si, Fe, Ni abundances as well as Si/Fe and Ni/Fe abundance ratios distributions of the sample show only moderate spread (from 20% to 30%)

➔ this suggests similar ICM enrichment processes at work in all clusters cores.

Si/Fe comparison with other samples

- De Grandi+SM 2009
  - Cluster of galaxies sample
  - Si/Fe = 1.47 $\sigma_{Si/Fe}$ = 19%
- Rasmussen & Ponmann 2007
  - Groups of galaxies sample
  - Si/Fe = 1.35 $\sigma_{Si/Fe}$ = 32%
- Humphrey & Buote 2006
  - High L_X Elliptical galaxies sample
  - Si/Fe = 1.50 $\sigma_{Si/Fe}$ = 16%

The average Si/Fe ratio appears to be nearly constant from the galactic through the group and to the cluster scales

→ this suggests a common enrichment scenario in all these objects

Cold Fronts

Ghizzardi, Rossetti &SM see poster

- How does the occurrence of cold fronts relate to other cluster properties?
- CF are contact discontinuities discovered by Chandra
- Found in merging systems where they mark dense subcluster cores that have survived a merger
- Found in non merging systems were the origin is not as clear.

Cold Fronts

Ascasibar & Markevitch (2006) argue that cold fronts in relaxed CC are generated if 2 conditions are met:

1) a mechanism that decouples the coldest & densest gas from the bottom of the potential well defined by the DM peak (provided by minor mergers)

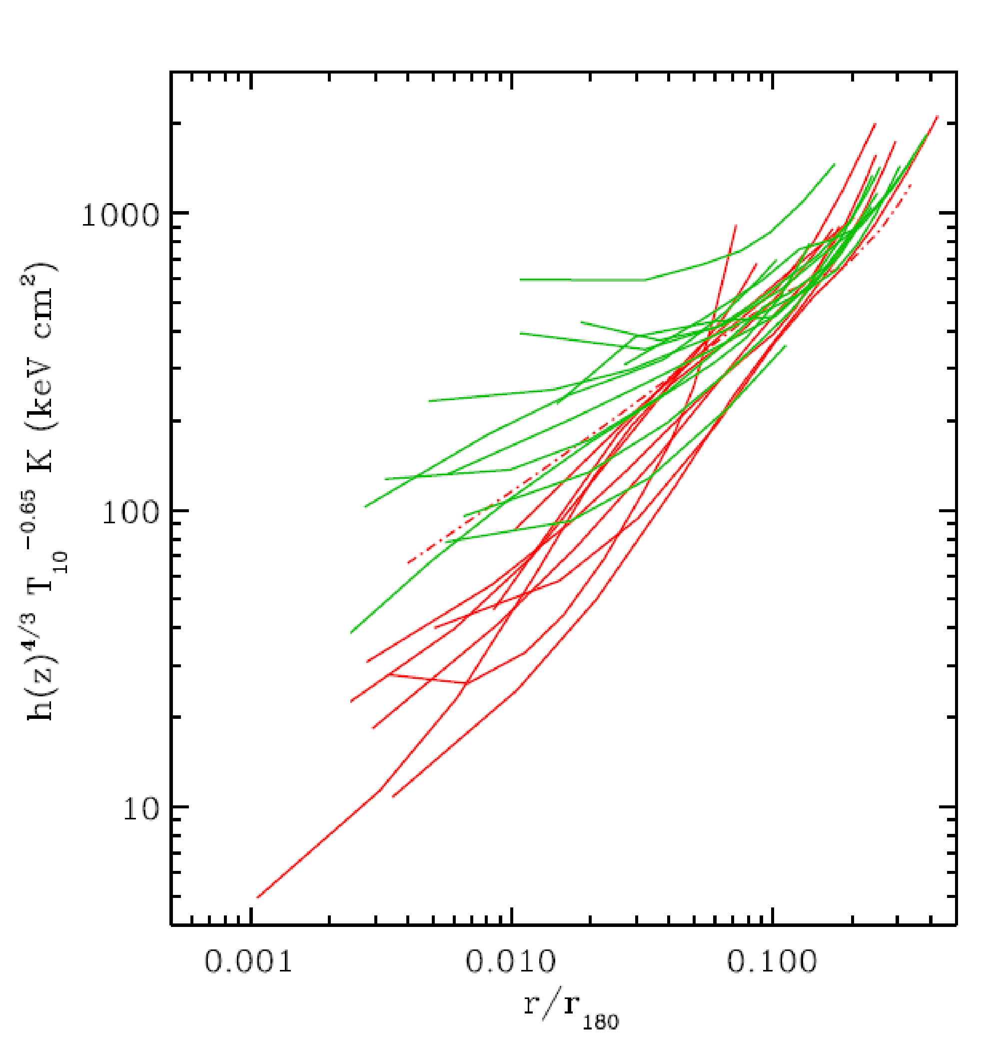
2) substantial entropy gradients within the ICM.

In the absence of 2) the sloshing of gas within the DM potential well cannot be established.

Cold fronts in Cool Cores

- We studied a sample of 32 objects extracted from the B55 sample ($z<0.075$).
- Excluding clusters that are manifestly undergoing mergers we are left with 23 objects.
- Constructed entropy profiles

- Clear difference btwn systems hosting CF and others



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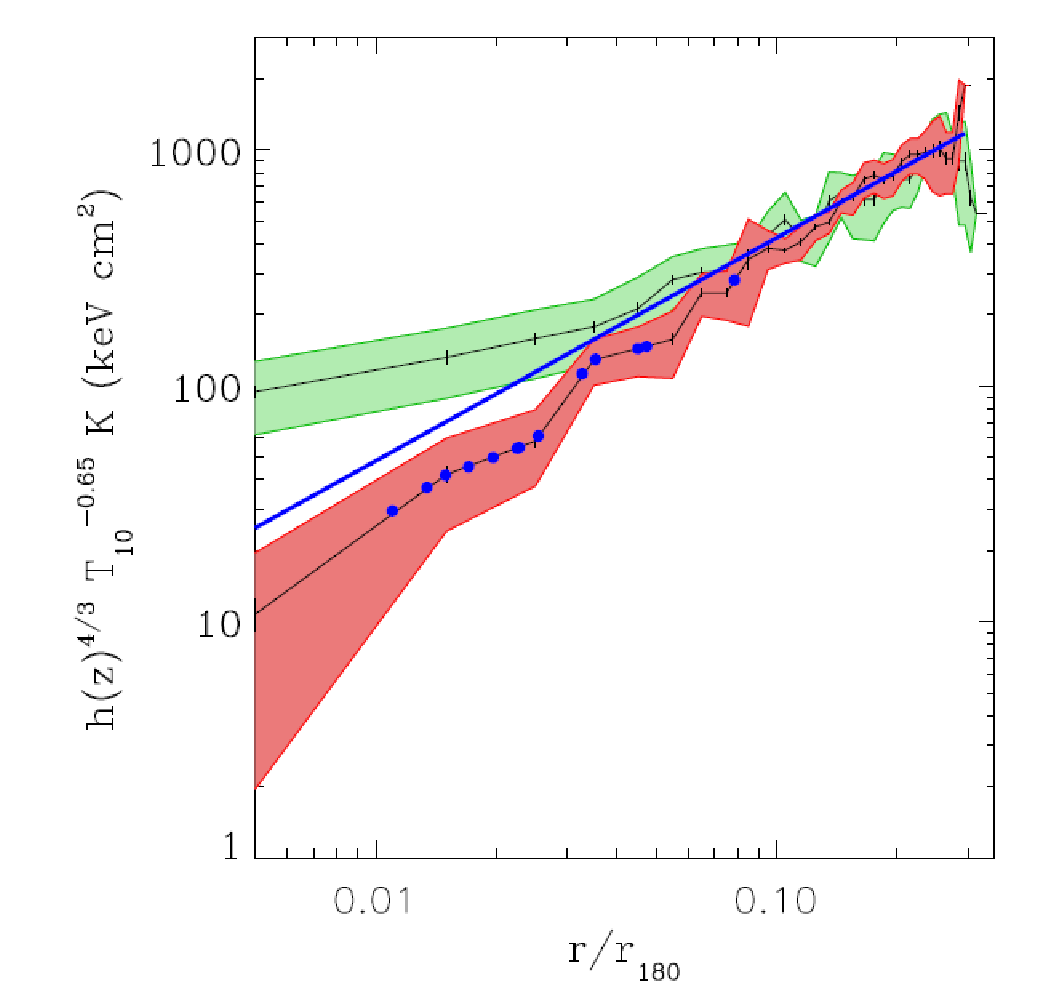

- Clear difference btwn systems hosting CF and others

Future Prospects for Clusters

- Within the framework of NASA's Beyond Einstein and ESA's Cosmic Vision programs Cluster science is highly rated
- In NASA's BE the accent is strongly on clusters as cosmological tools
- In ESAs CV study of structure formation is recognized an important topic worth pursuing in its own right.
- NASA's BE program is now being recast into "Physics of the Cosmos" hopefully the importance of studying clusters "per se" will be recognized.

- JAXA ASTRO-H mission (2013)
  Cluster Science as one of major goals

What we need

A) Micro-calorimeter

Few eV resolution moderate ang. resolution 30 arcsec

- velocity measures turbulence and viscosity cool core physics
- metal abundances from O to Fe measures

B) Wide Field X-ray Imager

5-10 arcsec res over Full FOV & Low Background

- extend SB,T and Z measures out to Rvir.
- detect and characterize clusters at formation epoch

What we need

C) Hard X-ray imager, Low bkg, 1 arcmin resol., XMM like FOV

- Non Thermal emission
- Shocks
- Hot systems

D) Few arcsec resol, several m^2 eff.area   imager/spectrometer

Detailed studies of:

- Clusters/group @ formation epoch
- Interesting regions (cores) in local systems

What we need

A) ASTRO-H XENIA

B) WFXT XENIA eROSITA

C) NuSTAR ASTRO-H SIMBOL-X

D) IXO

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Summary

- Mergers located in Non CC systems
- We find evidence of re-heated CC in most of our non CC systems "Cool Core Remnants"
- There appears to be a common enrichment process at work from the galactic through the group to the cluster scales
- In non merging systems, Cold Fronts are found in objects with steep entropy profiles

- A number of X-ray mission under development
- A number of proposed X-ray missions