THERMODYNAMIC MAPS OF MERGING GALAXY CLUSTERS

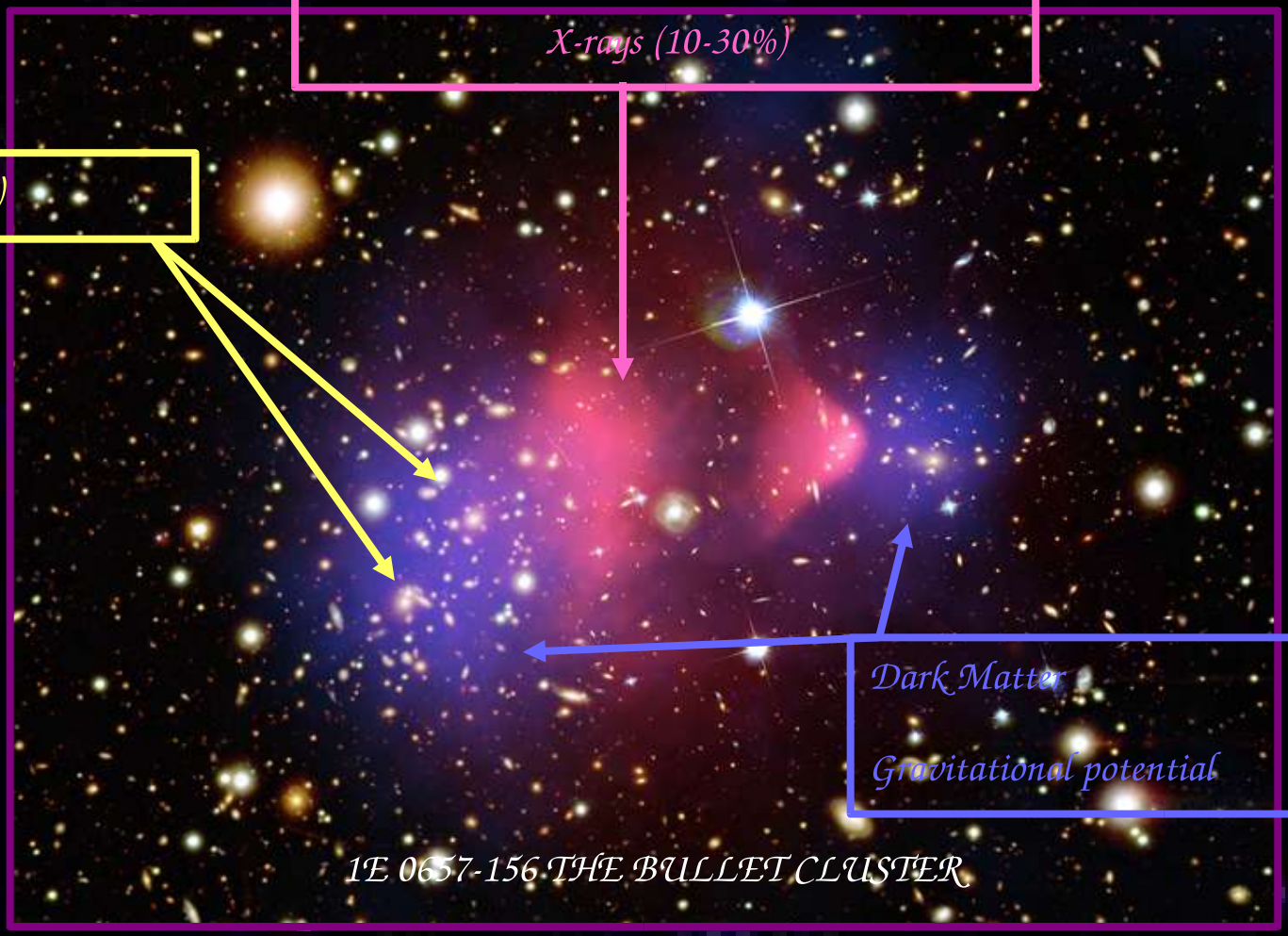
MARIACHIARA ROSSETTI

(G-)ASTRO SIESTA

Dottorato in Fisica, Astrofisica e Fisica Applicata XIX Ciclo

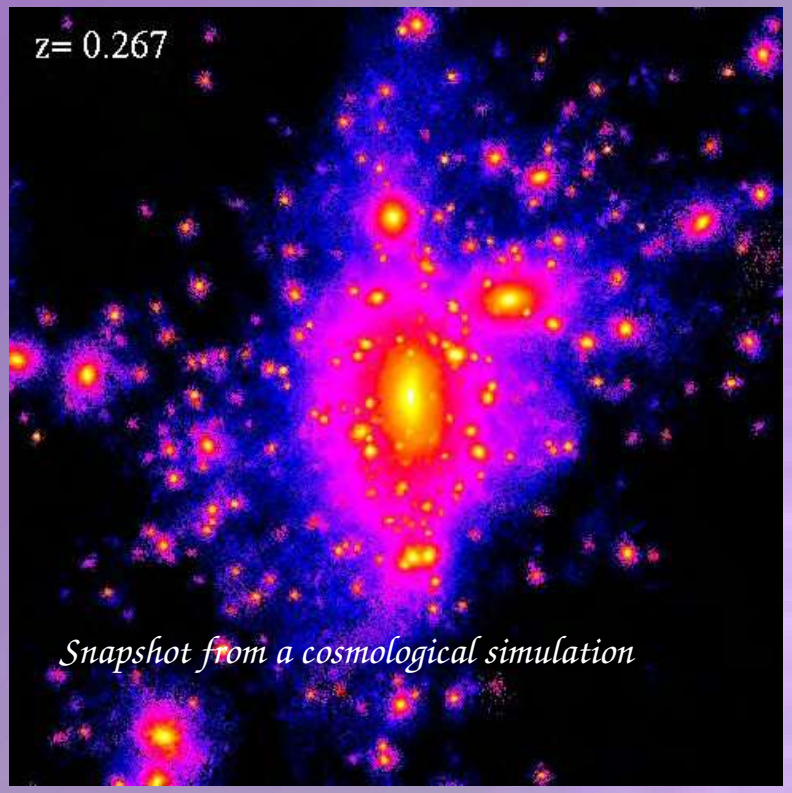
Università degli studi di Milano

AN INTRODUCTION TO MERGING GALAXY CLUSTERS



Galaxy clusters are the most massive ($M \sim 10^{14}$-10^{15} M_{SUN}) objects in the Universe

AN INTRODUCTION TO MERGING GALAXY CLUSTERS



Snapshot from a cosmological simulation

In the hierarchical scenario, they form the youngest population: the present is the epoch of cluster formation!

Cluster form through the accretion of smaller subunits and the interactions between nearly equal size objects:

CLUSTER MERGERS

Cluster mergers are the most energetic events in the Universe since the Big Bang and they can release up to 10^{64} ergs

WHY MERGING GALAXY CLUSTERS?

Galaxy clusters are often used as cosmological probes (barion fraction, mass function and its evolution...)

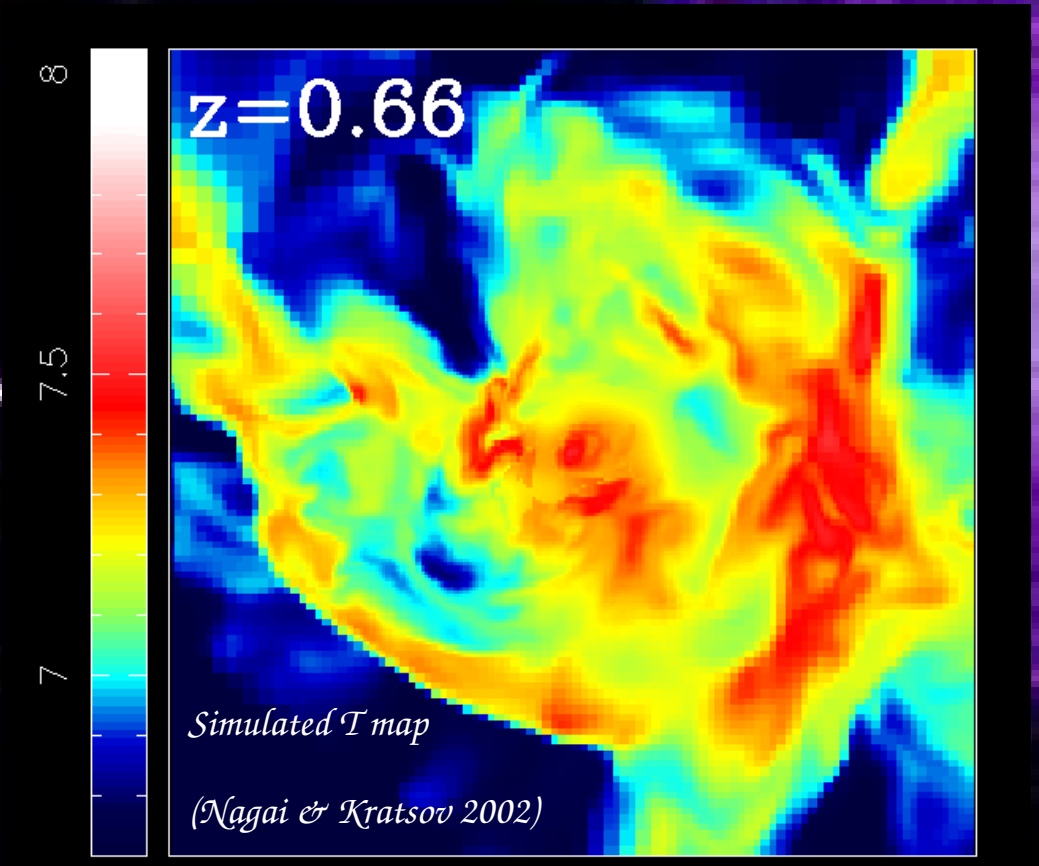
Results in present and future cluster surveys rely on our understanding of the cluster physics

The physical processes that happen during cluster mergers dominate the appearance of the most massive objects

1. *What are the physical processes that happen during cluster mergers?*
2. *What is the role of the merger in the physical processes of the ICM ("cooling flows", cold fronts, particle acceleration or re-acceleration,...)?*
3. *How the different kinds of mergers (minor, major, head-on, off-axis) or the different merger states affect the observational properties, especially those used for cosmology with clusters?*

WHY THERMODYNAMIC MAPS?

Merging processes compress and heat the ICM, driving SHOCK waves.
Two-dimensional maps of thermodynamic quantities can provide informations on the history of the cluster.



FROM X-RAY IMAGES TO THE THERMODYNAMICS OF THE ICM

From the distribution of the thermodynamic quantities of the ICM, we can derive informations on the dynamic state of the cluster

From the spectrum (bremsstrahlung), we derive temperature and density

$I \sim \langle n_e^2 \rangle$

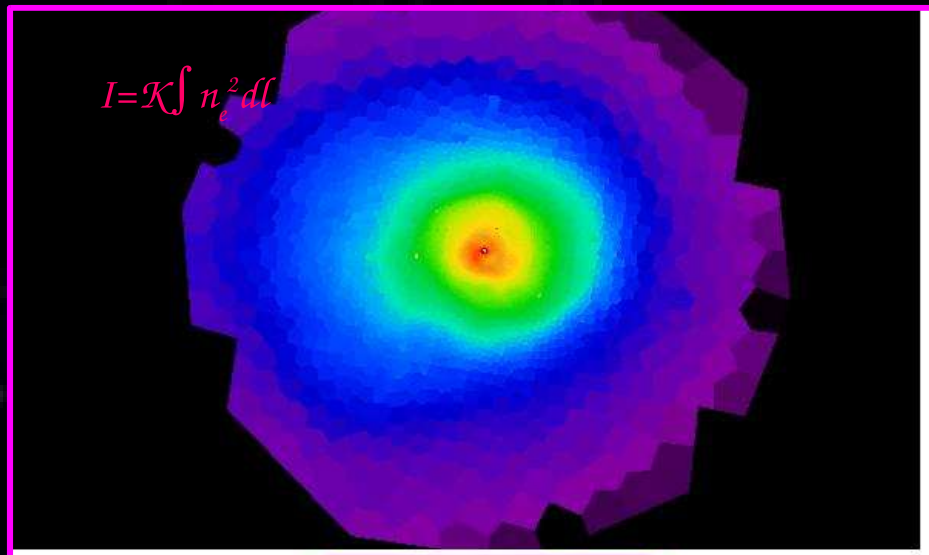
From temperature and surface brightness "pseudo-pressure" and "pseudo-entropy"

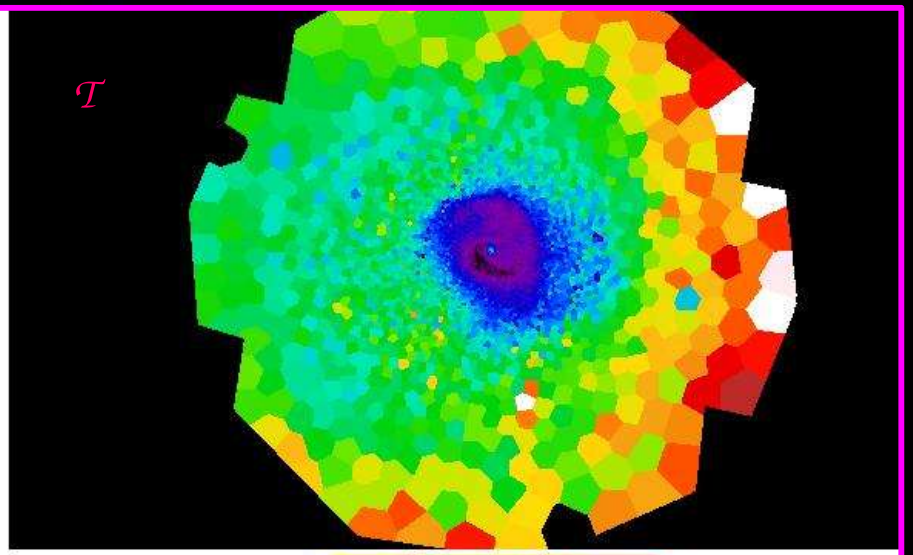
$P=(I)^{1/2}T$

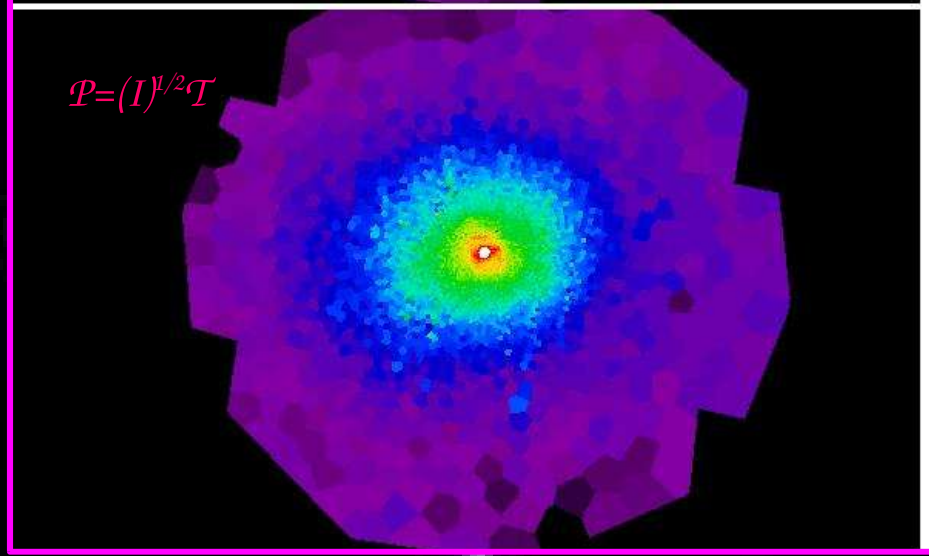
$s=T/(I)^{1/3}$

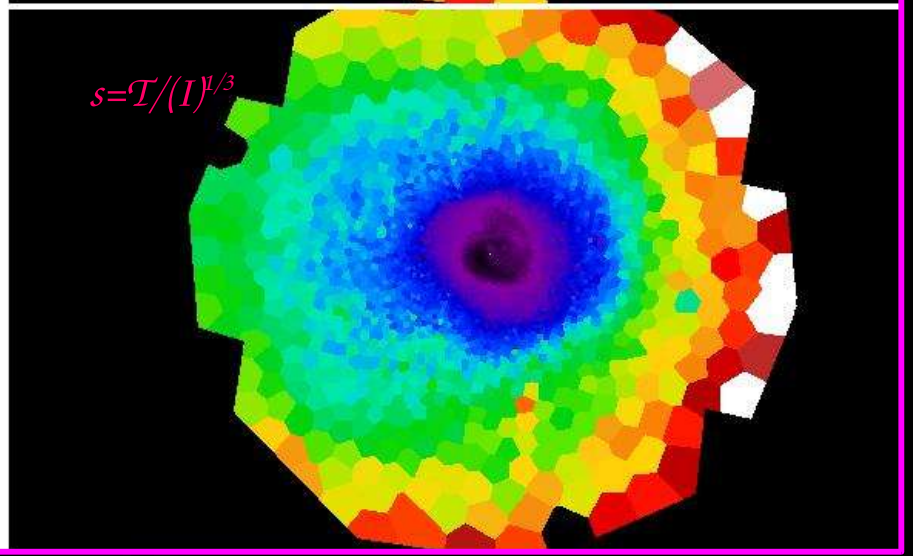
We developed a technique to produce quantitative bidimensional maps of the thermodynamic quantities, starting from X-ray images

FROM X-RAY IMAGES TO THE THERMODYNAMICS OF THE ICM









HOW TO STUDY MERGING CLUSTERS?

1. *Detailed analysis of single objects to study the dynamical state, multiwavelength approach.*

   "Simple scenarios cannot explain the complex details of the T map" (Markevitch et al. 2003)

   "A3266: a puzzling merger" (Finoguenov et al. 2005)

   "Simple mechanisms cannot explain the observed features" (Rossetti et al. 2007)

6. *It is now time to complement detailed analysis of single objects with large samples*

   Govoni et al, 2004: correlations with radio properties

   Finoguenov et al, 2005: deviations from the scaling relations

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OUR AMBITIOUS PROJECT IS TO BETTER UNDERSTAND THE PHYSICS OF CLUSTER MERGERS BY STUDYING THE THERMODYNAMIC MAPS OF A SAMPLE OF NEARBY CLUSTERS

A SAMPLE OF MERGING CLUSTERS

We selected a sample of 19 (22) bright clusters:

1. *nearby (z<0.1)*

   Need spatial resolution to produce significant temperature maps.

   15 arcsec ~ 27 kpc at z=0.1

4. *with indications of an ongoing merger (at all stages)*

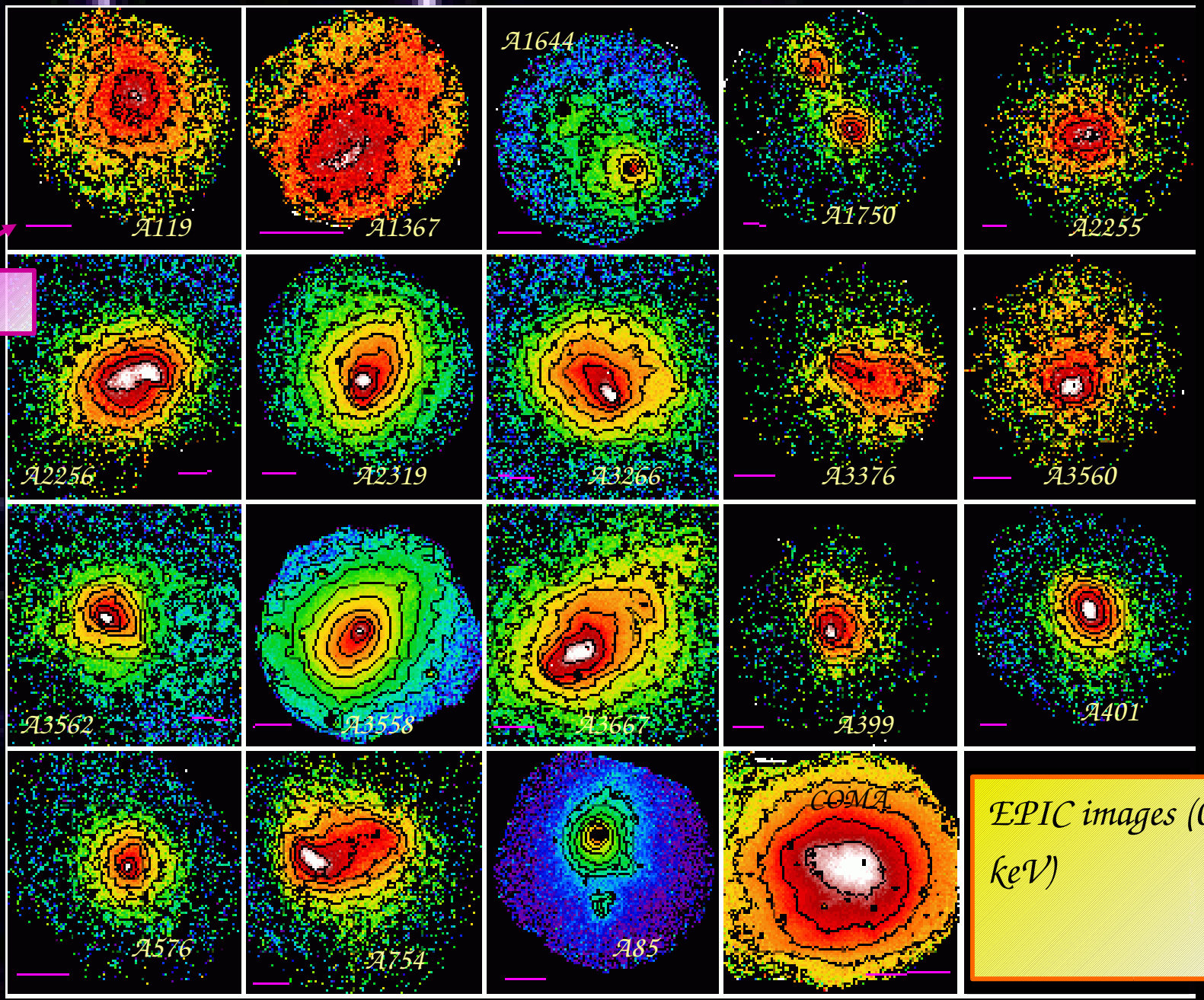
5. *Observed with XMM*

   "Large" FOV (better than Chandra): it allows to map a larger fraction of the cluster.

   Mosaics

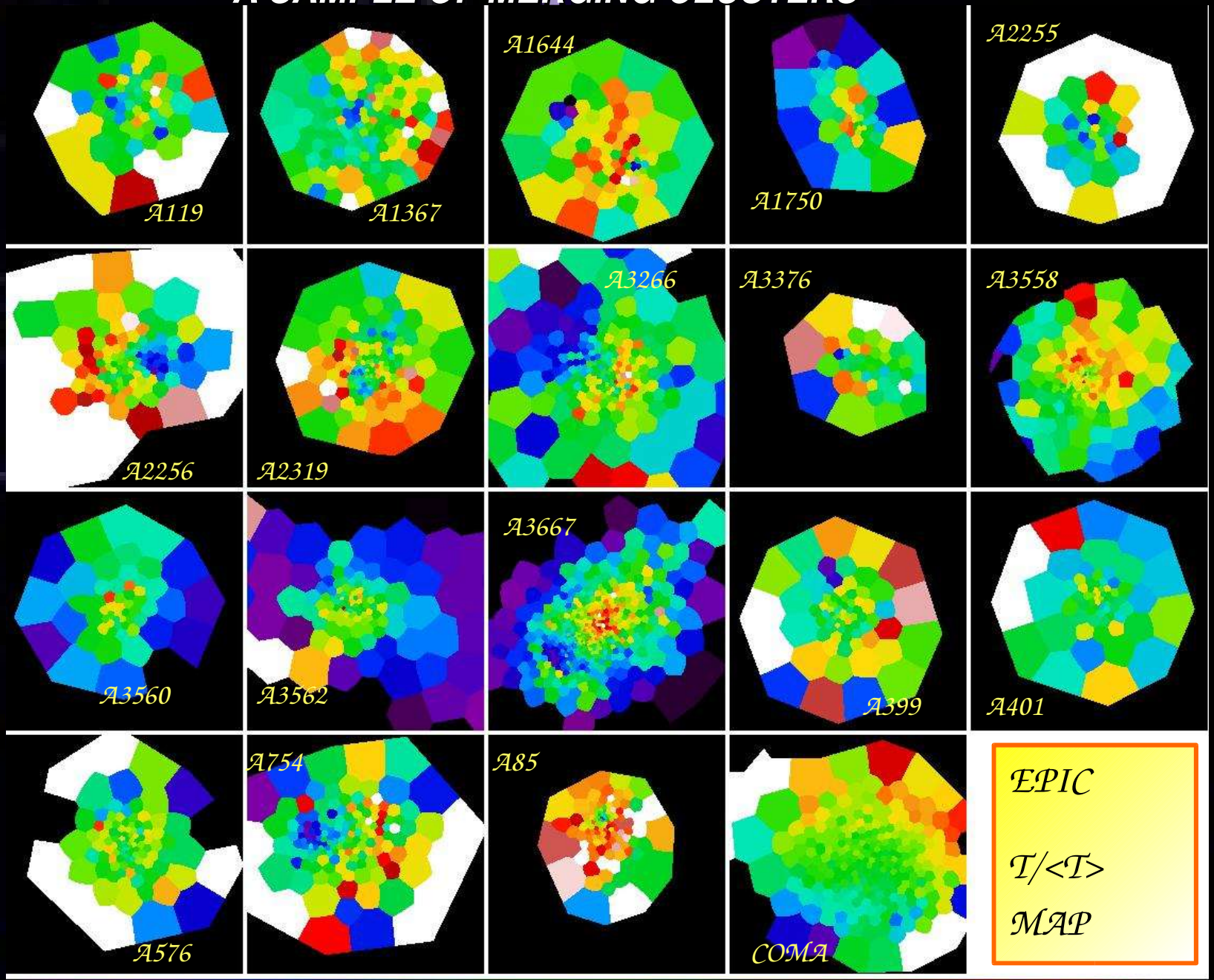
We analyzed 62 observations and prepared thermodynamical maps of all the clusters.

A SAMPLE OF MERGING CLUSTERS



EPIC images (0.4-2 keV)

A SAMPLE OF MERGING CLUSTERS



A SAMPLE OF MERGING CLUSTERS

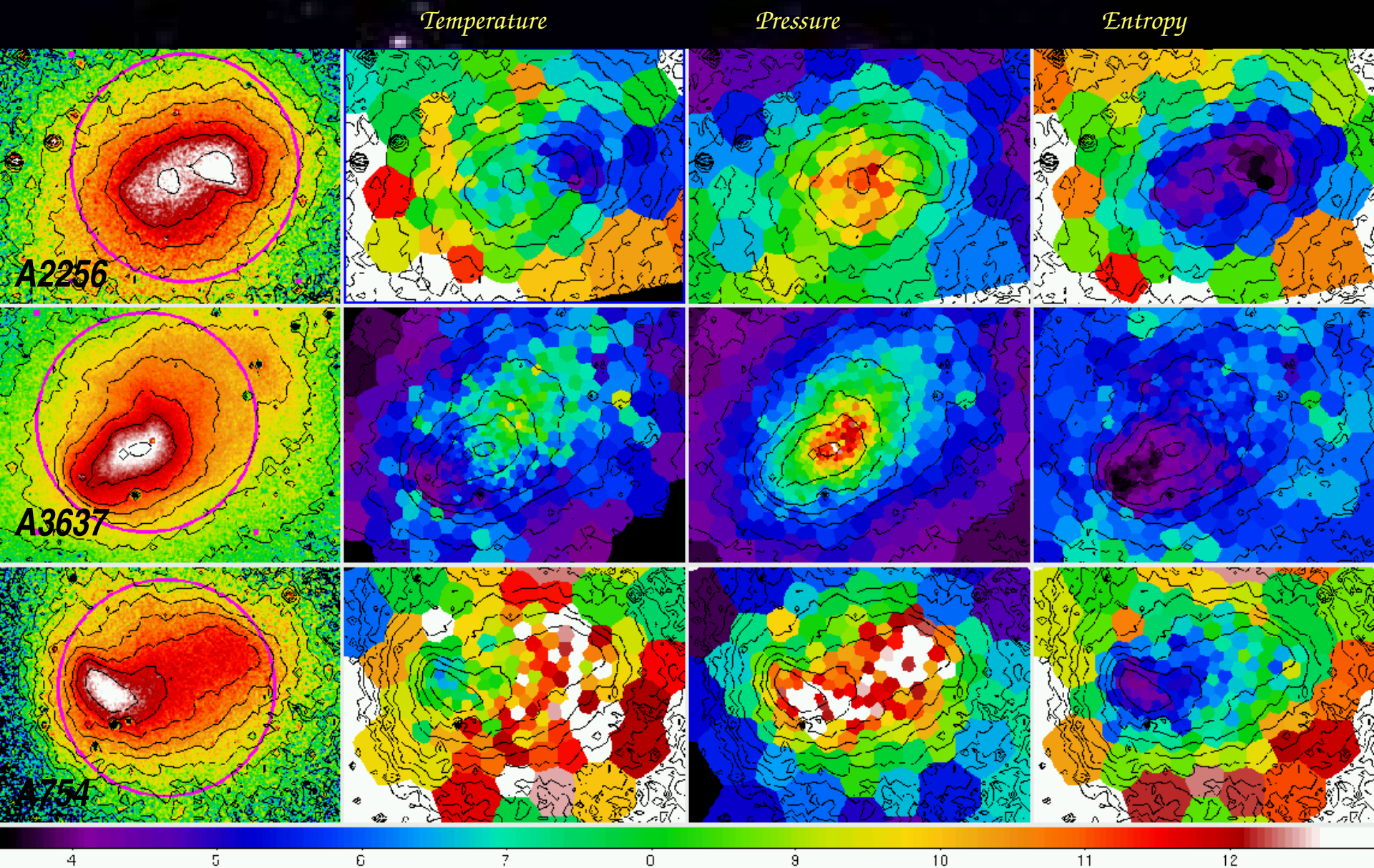
1. *Looking for common properties in the maps of clusters with a similar dynamical state*
2. *Looking for interesting features in the maps (shocks, cold fronts…)*

A SAMPLE OF MERGING CLUSTERS

1. *Looking for common properties in the maps of clusters with a similar dynamical state*

In the literature, A754, A3667 and A2256 are all described as clusters which are currently undergoing a major head-on merger (Markevitch et al, 2003, Briel et al 2004, Vikhlinin et al 2002, Sun et al 2002)

A SAMPLE OF MERGING CLUSTERS



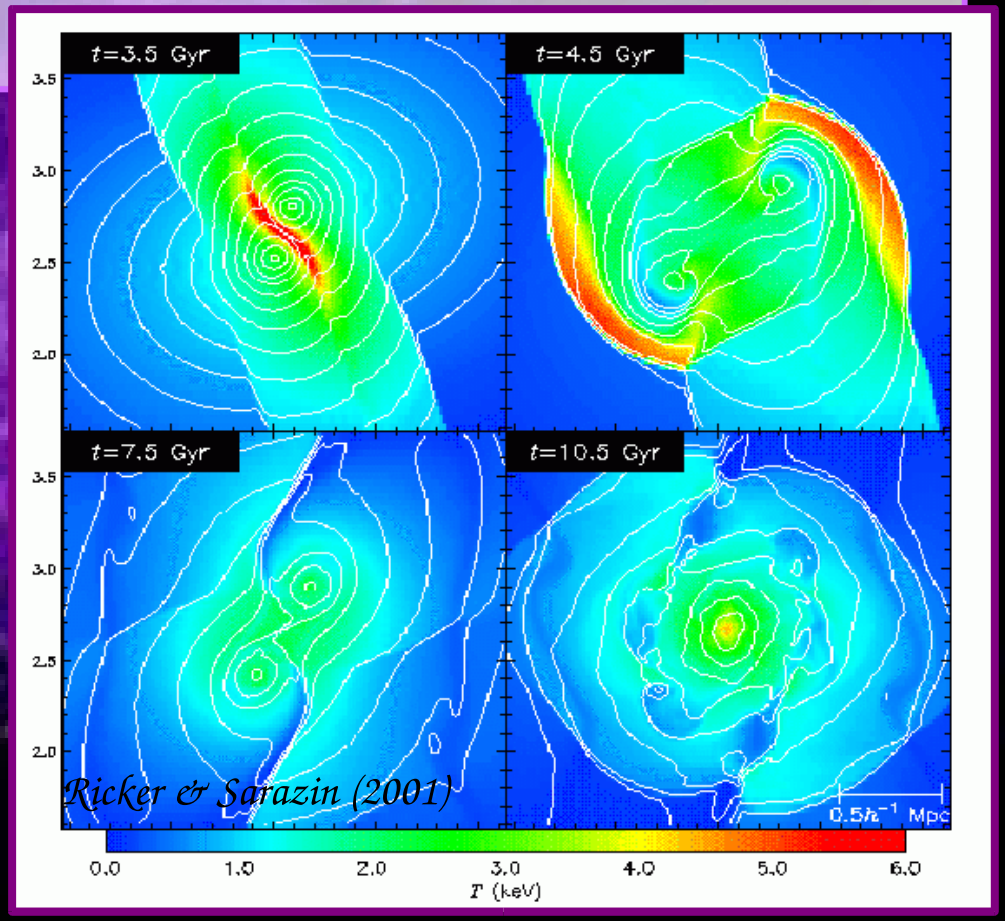
A SAMPLE OF MERGING CLUSTERS

1. *Looking for common properties in the maps of clusters with a similar dynamical state*

2. *Looking for interesting features in the map: shocks!*

Shocks are predicted in numerical simulations of cluster mergers.

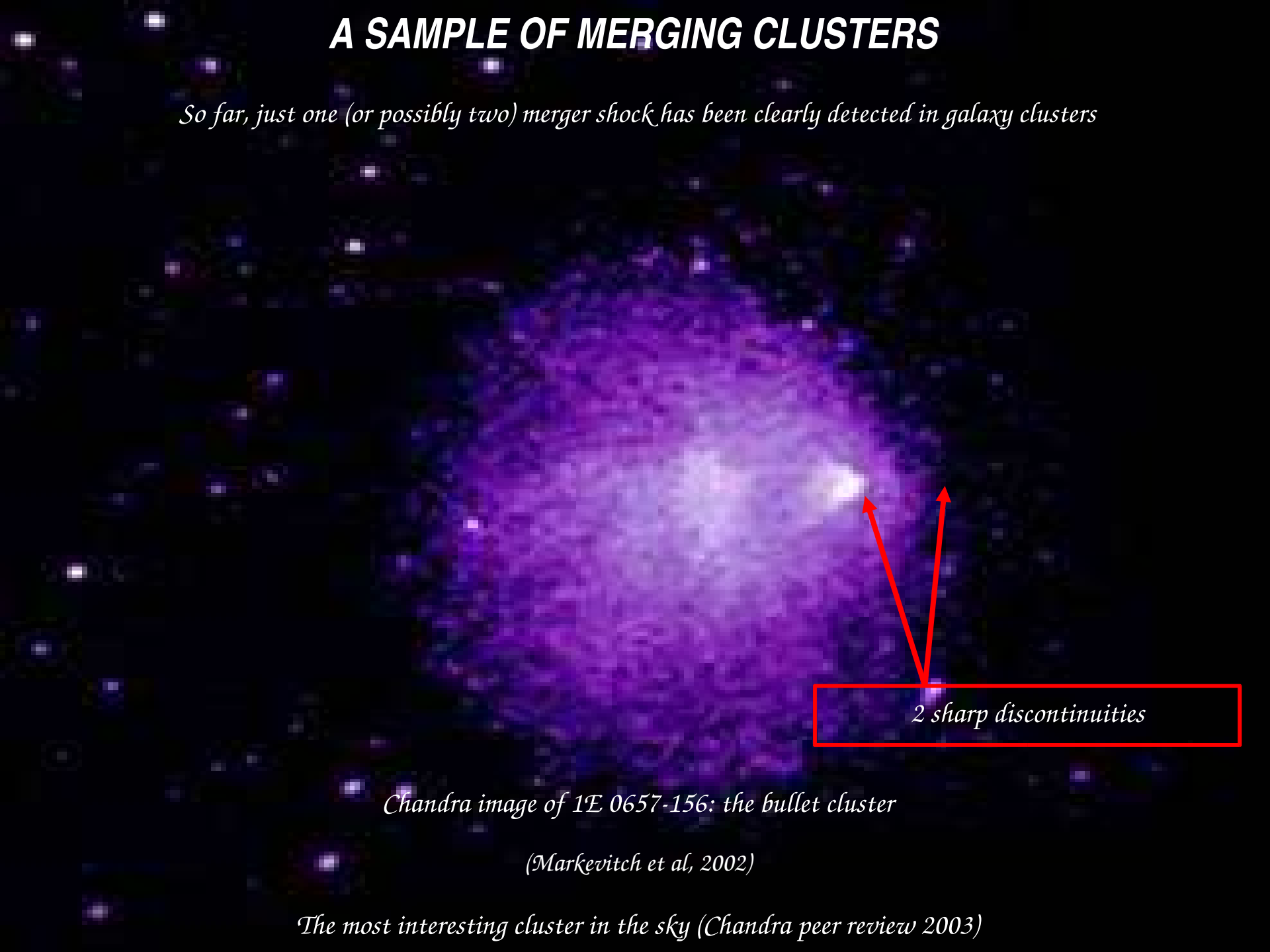
They heat and compress the ICM and could accelerate particles up to relativistic energies (radio emission)



Ricker & Sarazin (2001)

A SAMPLE OF MERGING CLUSTERS

So far, just one (or possibly two) merger shock has been clearly detected in galaxy clusters

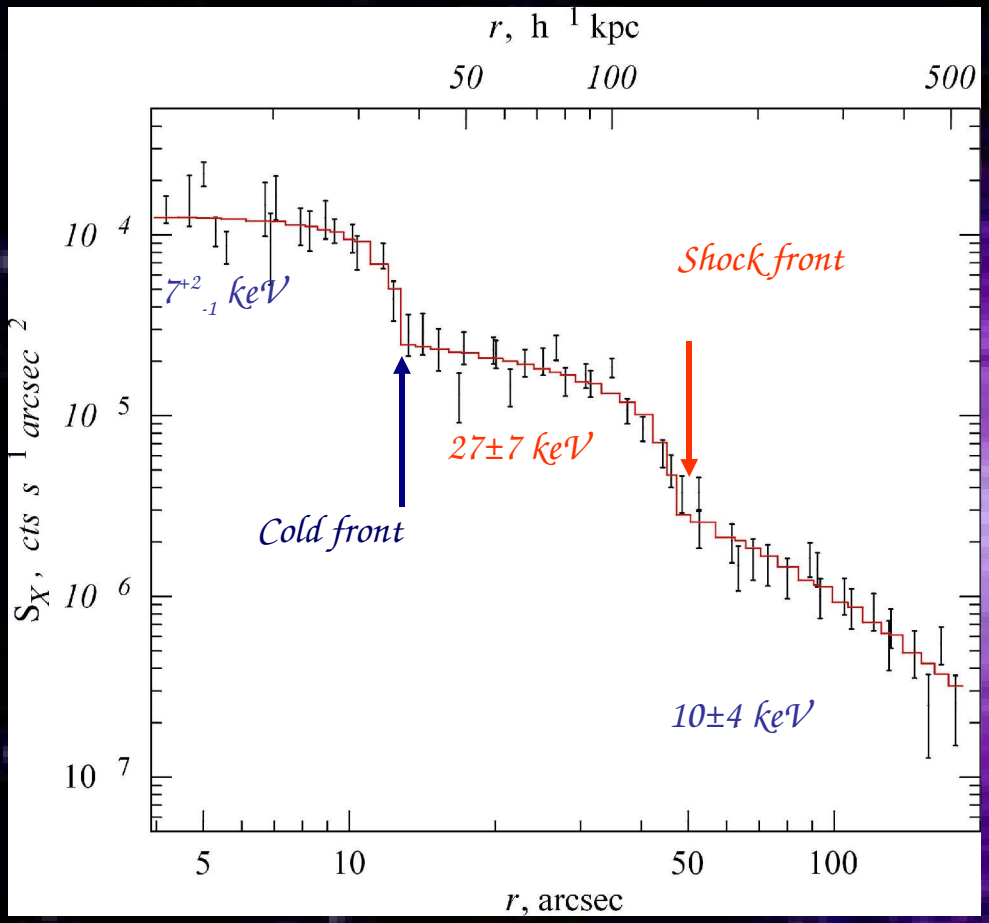


Chandra image of 1E 0657-156: the bullet cluster

(Markevitch et al, 2002)

The most interesting cluster in the sky (Chandra peer review 2003)

A SAMPLE OF MERGING CLUSTERS



2 sharp discontinuities

Shock front

Cold front

(the bullet)

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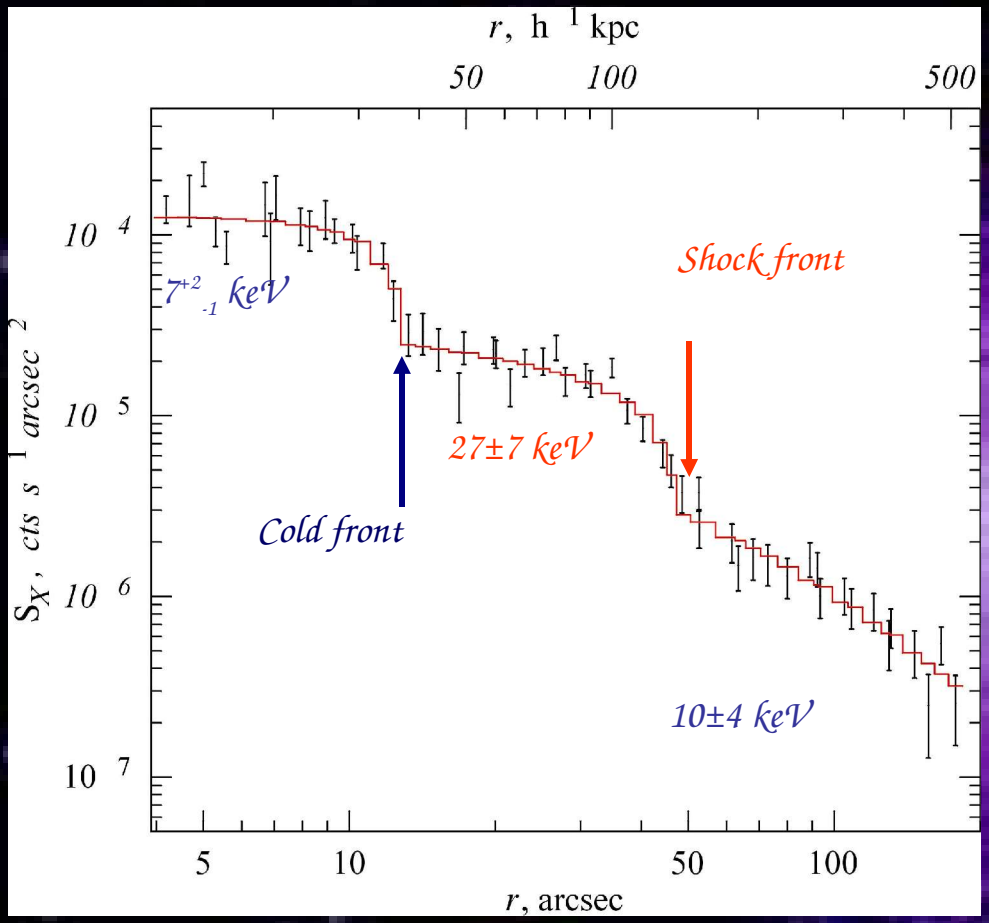


MACH NUMBER=2-3

v~3000-4000 km/s

(Markevitch et al, 02)

Large error bars: difficult to measure large temperature and bkg subtraction problem

IT IS DIFFICULT TO OBSERVE SHOCKS!

A SAMPLE OF MERGING CLUSTERS

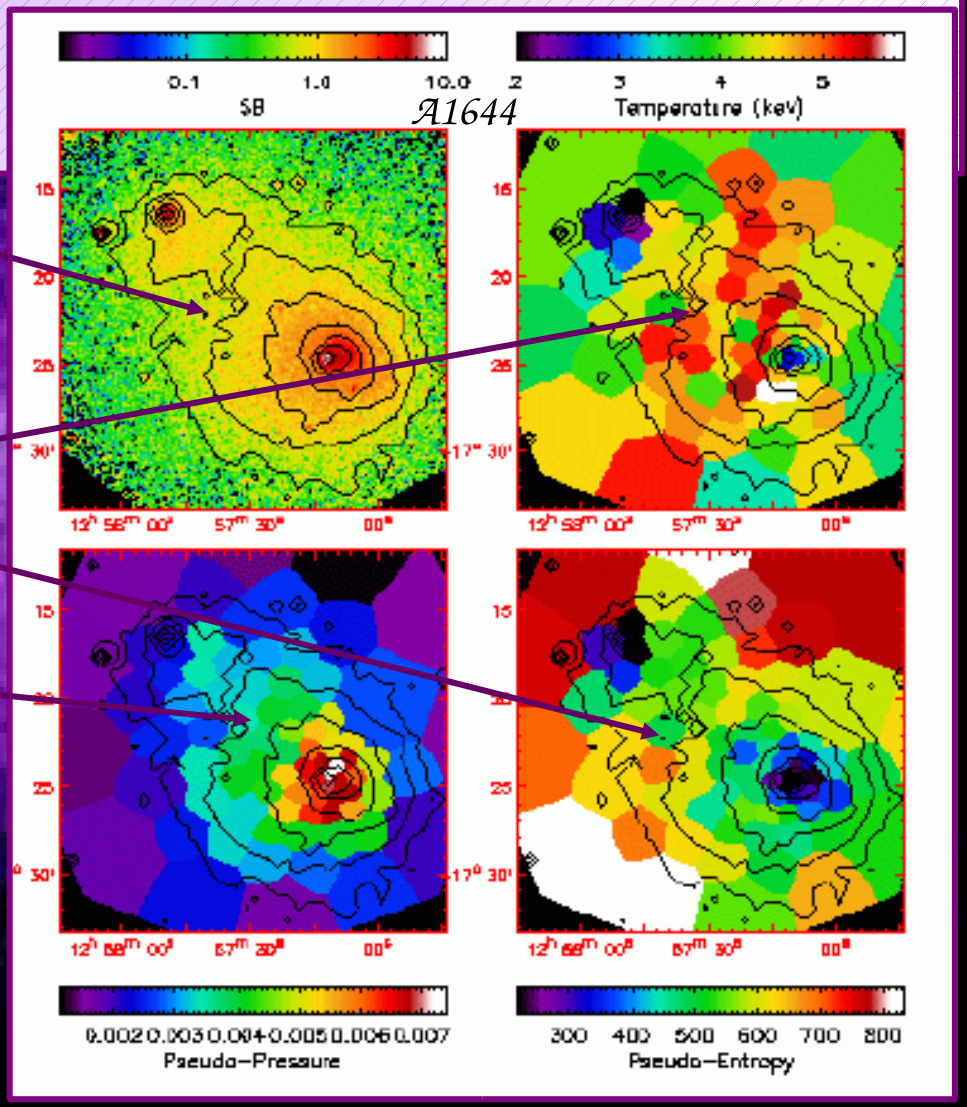
Many clusters in the sample show some indications of heating where shock fronts are expected: A1644, A1750, A2319, A3667, A85, A3562.

However these indications are often contrasting.

NO brightness discontinuity

BUT temperature increase

NO significant variations in pseudo-P and -S



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Many clusters in the sample show some indications of heating where shock fronts are expected: A1644, A1750, A2319, A3667, A85, A3562.

However these indications are often contrasting.

How do projection effects influence the discontinuity in thermodynamic quantities?

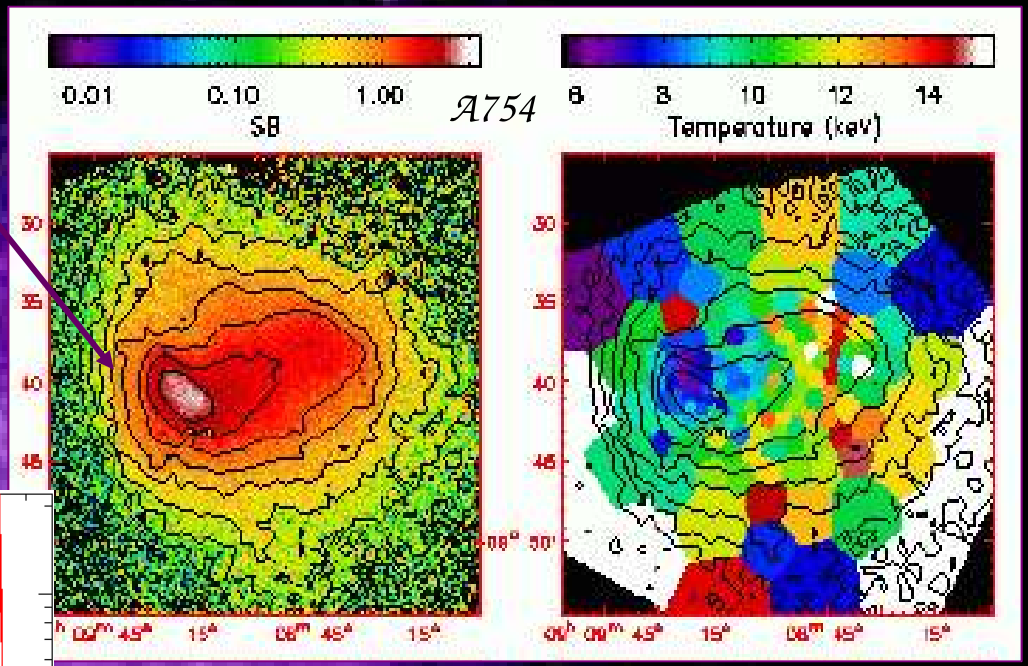
We plan to study this effect, as for cold fronts (Ghizzardi et al., 2006)

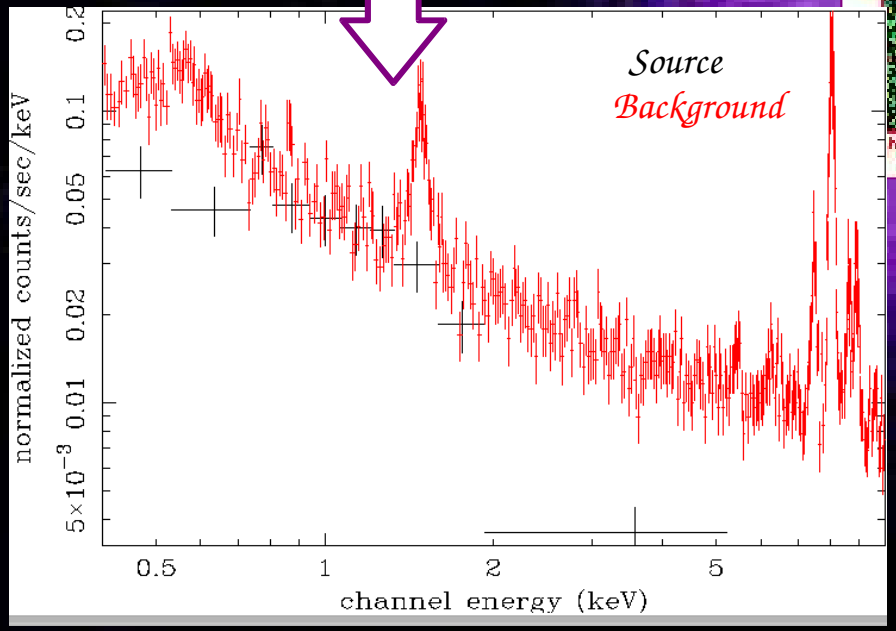
A SAMPLE OF MERGING CLUSTERS

Others show sharp brightness discontinuity which are expected to be SHOCK FRONTS (A754, A3376)

Clear brightness discontinuity

...BUT it is difficult to measure the temperature in the outer region





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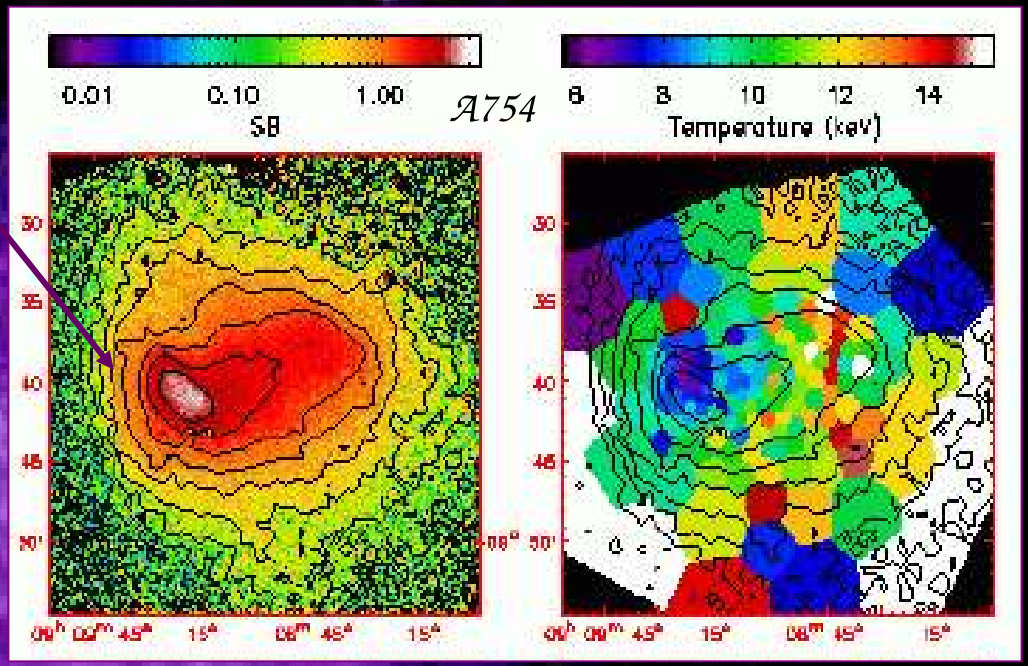
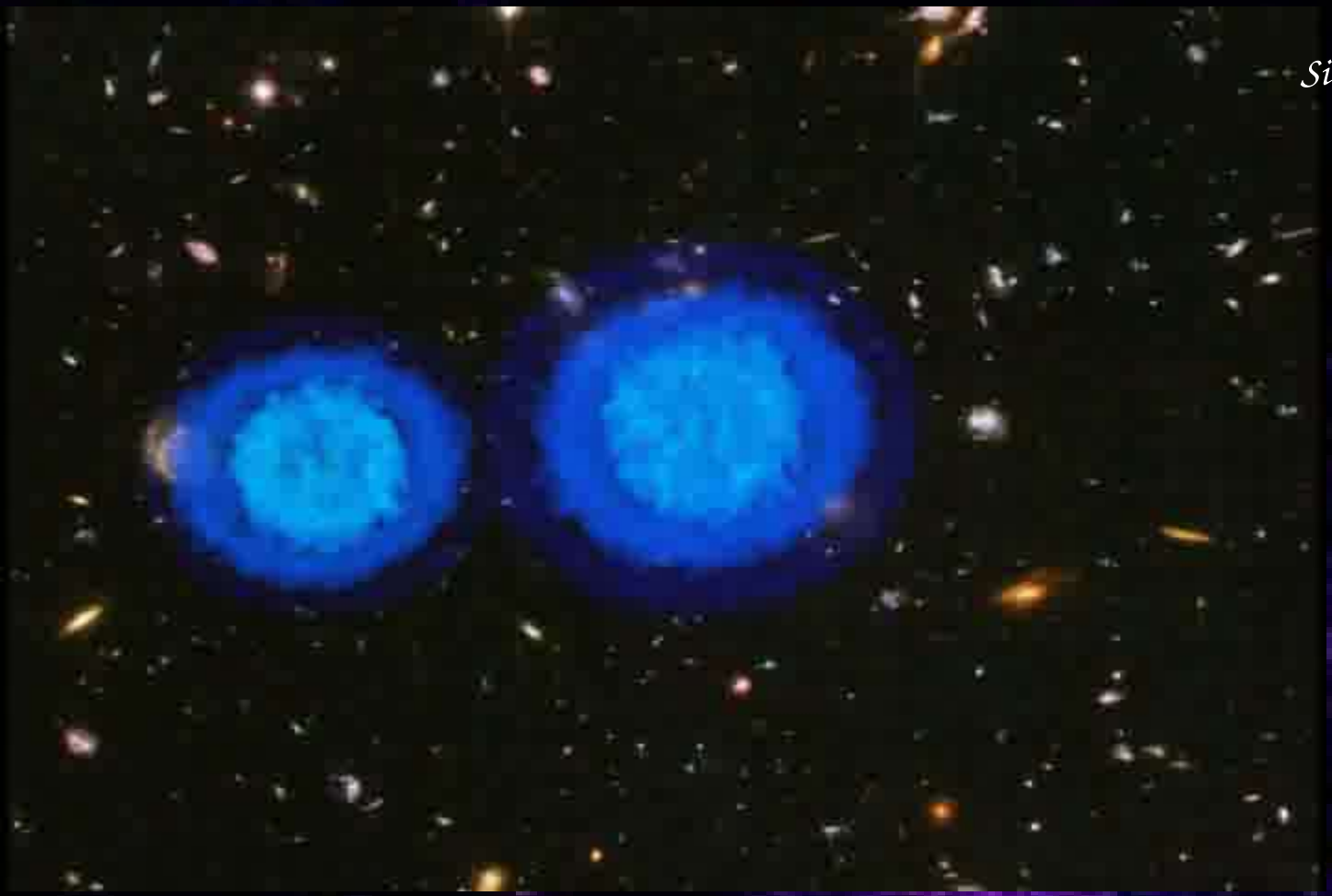


If the systematics due to bkg subtraction can be kept under control (Leccardi & Molendi, in prep.), deep XMM obs could allow to study shocks in detail. Looking for good candidates in our sample

A SAMPLE OF MERGING CLUSTERS



Simulation of the formation of the bullet cluster

Importance of projection effects!!!

Chandra image of 1E 0657-156: the bullet cluster

(Markevitch et al, 2002)

The most interesting cluster in the sky (Chandra peer review 2003)

A SAMPLE OF MERGING CLUSTERS

CONCLUSIONS AND FUTURE PROSPECTS

Future prospects:

2. *Common properties of clusters with similar dynamical state?*
3. *Projection effects and thermodynamic quantities*
4. *Detailed analysis of candidate shock regions (what can deep observations tell us?)*
5. *Metal abundance maps*
6. *Correlations with radio properties*