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Galaxies Cluster formation: Numerical Simulations and XMM/EPIC Observations

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Abstract. In the hierarchical formation scenario, clusters of galaxies are formed by the merging of smaller units. Numerical simulations foresee differents signatures of such merger in the Temperature map following the initial conditions and age of the merging event. Thanks to their ability to perform spatially resolved spectroscopy, *XMM*-EPIC observations allow a direct comparison between numerical simulations and observations. Using AMR cosmological simulations convolved with the EPIC response and multiscale approach for the reconstruction of the temperature distribution, we are able to qualify what should be detectable in our *XMM* GT merging cluster program. In this paper, I present a confrontation of our 3 EPIC GT observations of merging clusters and their respective proposed status.

Key words. galaxies clusters – X-ray:galaxies clusters – X-rays:general

1. Introduction

From the numerical simulation and observations of galaxies clusters, we learn that clusters are forming now and in two paths : Through nearly continuous groups infall (when the subunit mass is small compared to the main unit) or via major merger event (when the merging event consists of two units of equivalent mass). It is known that 3 to 15 % of clusters have undergoing a major merger in the last Gyr at low redshift. Our main goal in observing these merging clusters in the GT program was to identify the formation of the compression wave in the early phase and then the shock wave in the later phase for the major merger events. In order to qualitatively compare our observations with the cosmological simulations, we have used 3 differents epoch of a RAMSES simulations that we have convolved with the EPIC response. For a complete description of the RAMSES numerical code, see Teyssier (2002). For a description of the convolutions and Temperature Map reconstruction see Bourdin et al. (2004).

2. *XMM* Observations of Major Mergers

Our four targets in the GT program (jointly with T. Ponman) were selected in order to observe various mass ratio and various stage of the merger event. All target have been selected to be has bright as possible while fittng the

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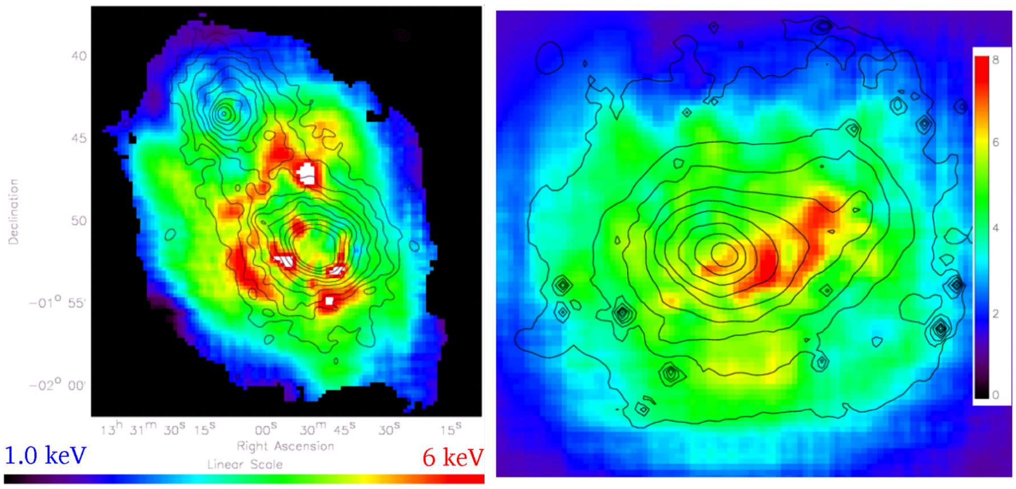

Fig. 1. Left panel: Low Energy Contours of A1750 EPIC observation onto the rwavelet reconstructed Temperature Map. Notice the already heavily perturbed temperature distribution and the hotter interaction region. Right panel: Same for A3921. Notice that the angle of the hot region is far from beeing perpendicular to the line defined by the two centers.

FOV of EPIC (meaning that the optimal redshift for such criteria is $z \simeq 0.1$. All exposure time were 30 ksec.

2.1. A1750 XMM Observation

This Bi-modal cluster is our earliest merger condidate with an estimated $\simeq 1 to 1$ mass ratio. The projected distance between units is $\simeq 1 Mpc$ and the velocitie difference between the 2 units is $\simeq$ 1000 km/s. Fig. 1 (left panel)shows the temperature map. A detailed description of these results can be found in Belsole et al. (2004). Our main conclusions are : the discovery of an enhancement in the interaction region and the importance of the history of merger of each unit. A1750 is an observational evidence that Time Interval between collision is (at least sometime) shorter than relaxation time. Moreover, comparing projected distance (1Mpc) and numerical simulations of major merger units at that distance, we can safely concluded that the real distance between units should be higher (strong Projection effect)

2.2. A3921

At the time of our selection, the ROSAT ovservation of A3921 leads us to think that this merger was a pre-merger event with a mass ratio of about 1:3 but more advanced than A1750 since it exhibits a highly elongated X-ray structure. What we have learned with EPIC is much more complex than this view. From X-rays Temperature map, we put in evidence a hotter interaction region NOT orthogonal to the line linking the centers of the sub-units but nearly parallel to it (Fig. 1 right panel). From the optical follow-up, we got spatial velocity information and galaxy density map (detailed in Ferrari et al. 2004). The proposed scheme of this merger is similar to the idealized simulations of Ricker & Sarazin of a group falling in the plan of the sky with a large impact parameter onto the main unit much after the minimum collapse . This could explain the velocity distribution and the angle of the enhancement of temperature un the interaction region. A detailed account of X-ray results can be found in (Belsole et al. 2004).

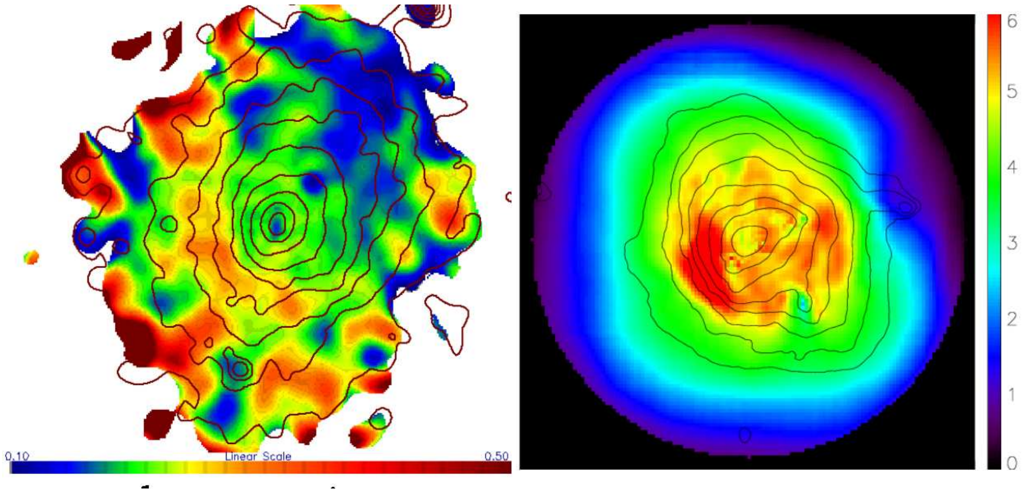

Fig. 2. Left panel:Hardness map of A2065 with low energy contour superimposed notice the arc like structure in the hardness ratio and the cool core in the inner region. Right panel: Last stage of our numerical simulation. Contour are the low energy and the image is the reconstructed temperatue map. One can see the develloping shock wave.

2.3. A2065

Unfortunately our observation of A2065 suffer of very high proton level during more than half of the observation. In order to be able to make some science with this set of data, we have developped a method to obtain a reliable way of building hardness ratio map taking into account the protons contamination. The main idea was to consider the proton spectum homogeneous over the field of view but its distribution vignetted. The proton distribution was obtain considering the highest part of the energy range (E> 10 keV). Obviously this analysis is limited by statistics and confidence but a shock wave could have been detected on A2065 while the inner center og A2065 seems to hold a surviving cooling flow (Fig. 2 left panel). Anyway A2065 will be re-observed during AO3.

3. Conclusion

The numerical simulations seem to agree qualitatively with X-ray observations of early mergers, BUT detailed quantitative comparisons still need to be done.

- A1750 seems to be an early merger bimodal system. But its 2 sub-units are already not relaxed due to their own history.
- A3921 may be an off-axis 3/1 Mass late merger. (detailed optical vs X-ray comparison to be done)
- A2065 really looks like a Compact Post Merger. Better quality data needed to confirm (*XMM*-AO3).

To understand the X-rays mergers observations, we definitely need the optical data and numerical simulations.

References

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