Section C

Clusters in action

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Outskirts of Galaxy Clusters: Intense Life in the Suburbs
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Interacting clusters and their environment

S. Bardelli

INAF-Osservatorio Astronomico di Bologna, via Ranzani 1, 40127 Bologna, Italy
e-mail: sandro.bardelli@bo.astro.it

Abstract. Central regions of superclusters are the ideal places where to study cluster merging phenomena: in fact the accretion activity is enhanced, as predicted by the cosmological simulations. In this paper I review the case-study of the Shapley Concentration, aimed to understand the effect of major mergings on the intracluster medium and the galaxy population of the involved clusters.

1. Introduction

Cluster mergings are known to be among the most energetic phenomena in the Universe, but until now studies at all wavelengths have not been extensively carried on: therefore it is still unclear how the collision energy is dissipated and which is the effect of merging on the emission properties of the galaxies and on the physics of the intracluster medium.

In cosmological N-body simulations the cluster accretion happens along specific directions defined by the density caustics and richer clusters form preferentially where the environment density is higher. Superclusters can be considered as the observational counterparts of these caustics and it is expected that at their centers the cluster accretion is still strongly active. Therefore, superclusters are the ideal places where to study merging phenomena, because the cross-section for cluster collisions is enhanced.

The best place for these studies is the central region of the Shapley Concentration supercluster, a huge concentration of clusters at $z \sim 0.05$ (Raychaudhury 1989, Plionis & Valdarnini 1991, Raychaudhury et al. 1991, Zucca et al. 1993). This region is anomalously rich in clusters, considering that it has 25 members, while the Great Attractor (with a similar mass overdensity) contains only 6 clusters (see Table 3 of Zucca et al. 1993): for some reasons, in this region the cluster formation efficiency has been enhanced also with respect to similar regions. Moreover, as noted by Raychaudhury et al. (1991), the fraction of clusters with substructures in this supercluster is higher than elsewhere, meaning that the process of cluster formation is still strongly active, suggesting that this region could be considered a “nursery” of rich clusters.

2. Large-scale structure

Various redshift surveys have been conducted in order to study the large scale distribution of galaxies in the Shapley Concentration (Quintana et al. 2000, Bardelli et al. 2000, Drinkwater et al. 2004) and its relation with the distribution of clusters. Up to now, there are known a few thousands of galaxy redshifts in the supercluster, allowing not only to determine its geometry but also its overdensity and mass (see Figure 1). The distribution of inter-cluster galaxies is well described by a plane tilted with respect to the line of sight: the distribution of galaxies around this plane is a Gaussian with a dispersion of 3.8 h^{-1} Mpc (Bardelli et al. 2000). The huge overdensity in number of

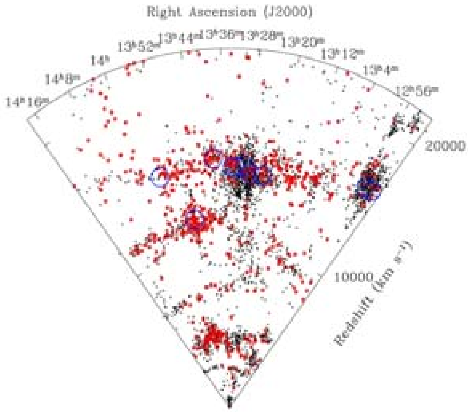

Figure 1. Central region of the Shapley Concentration supercluster (figure from Drinkwater et al. 2004; reproduced by permission of CSIRO Publishing, Melbourne, Australia; copyright Astronomical Society of Australia). Note the two structures (cluster complexes) at $\alpha = 13^h 30^m$ and $12^h 55^m$, connected by a bridge of galaxies resembling the Great Wall. Circles indicate the position of clusters.

galaxies (~ 11 on a scale of ~ 10 h^{-1} Mpc) found for this supercluster is consistent only with ΛCDM or open CDM cosmological scenarios (Bardelli et al. 2000; for a more recent determination on larger scales see Drinkwater et al. 2004). The determination of the mass of the supercluster is more difficult because, as indicated by the overdensity, the region is far from virialization. Various methods have been applied (Ettori et al. 1997, Bardelli et al. 2000, Reisenegger et al. 2000), leading to an estimate of $\sim 10^{16}$ $M_\odot$.

All these properties are extreme also for ΛCDM models and for this reason it is quite difficult to find a supercluster like the Shapley Concentration in numerical simulations.

As can be seen in Figure 2, two main groups of clusters ("cluster complexes") dominate the central region of this supercluster. The A3558 complex (A3558 is the richest cluster in the region) is a structure elongated for ~ 7 h^{-1} Mpc in the East-West direction, comprising also A3562, A3556, SC1329-313 and SC1327-312. The A3528 complex extends for ~ 7 h^{-1} Mpc along the North-South direction and is formed by two pairs (actually A3528 is double) of interacting clusters, including also A3530 and A3532.

Dynamical studies of Bardelli et al. (2000) and Reisenegger et al. (2000) concluded that these structures (with mass of a few 10^{15} $M_\odot$ each) are in the collapse phase, while the entire central supercluster region already reached its turn-around radius and has started to collapse. In fact, the complexes represent a major merger at an advanced stage (the A3558 complex) and at an early stage (the A3528 complex). These two strucures are connected by a "bridge" of galaxies, resembling the Great Wall: within this wall the overdensity in number of galaxies is ~ 4, consistent with the overall overdensity of 3.3 obtained by Drinkwater et al. (2004) after having eliminated the cluster regions.

Formally, there is also another complex, dominated by A3571 (the cluster visible on the South-East in the lower panel of Figure 2) which is connected with A3572 and A3575 (two poor concentrations) in the optical image. However, in the X-ray this cluster appears well relaxed and this could indicate that the merging is "old", in the sense that the gas had

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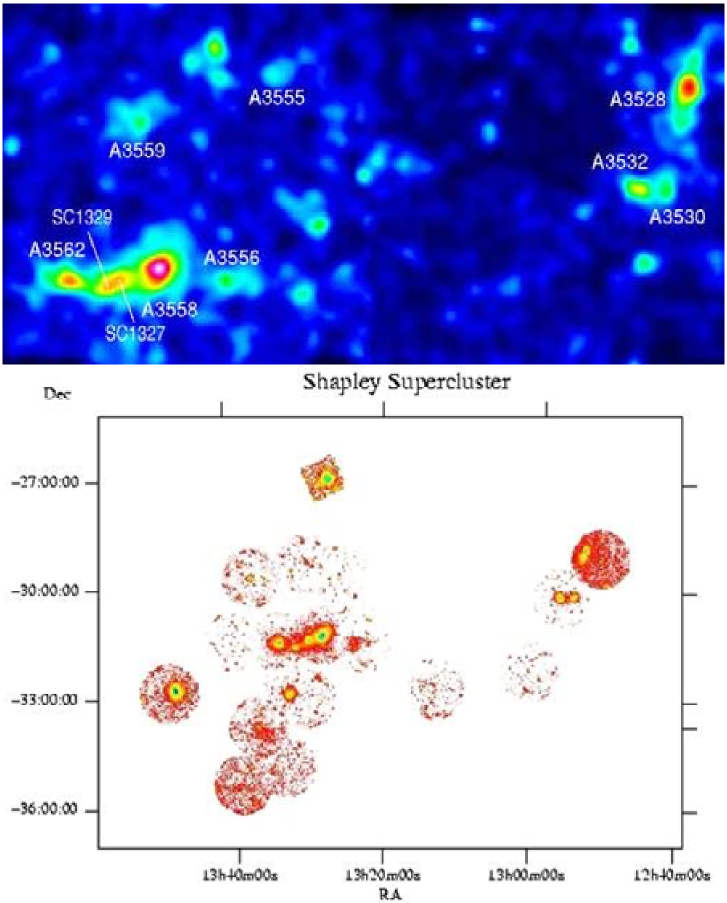

Figure 2. *Upper panel:* distribution of optical galaxies to b_J=19.5 in the central region of the Shapley Concentration. *Lower panel:* ROSAT-PSPC pointed observations mosaic of the same area. Note the presence of the two cluster complexes both in the optical and the X-ray bands.

time to reach dynamical equilibrium, while galaxies are still at the end of the relaxation process.

3. The A3558 complex

Clusters belonging to this structure are embedded in a continuous envelope of both hot gas (Kull & Böhringer 1999) and galaxies (Bardelli et al. 1998a) on a scale of $\sim 7 \ h^{-1}$ Mpc , i.e. surrounding the entire structure (see Figure 3). The hot gas has not had origin from the cosmological filament (or "wall") seen in the redshift survey, but probably it is intracluster gas expelled from the clusters by the merging (see the spatial analysis of A3562 in Ettori et al. 2000). Also the galaxy envelope has had the same origin, being formed by the less bounded cluster objects, shared by the whole structure after the merging.

ROSAT, ASCA and Beppo-SAX (Bardelli et al. 2002, Hanami et al. 1999, Akimoto et al. 2004, Ettori et al. 2000) X-ray studies of this region did not detect shocks, although the gas distribution shows clear signs of disturbance. Only between A3562 and

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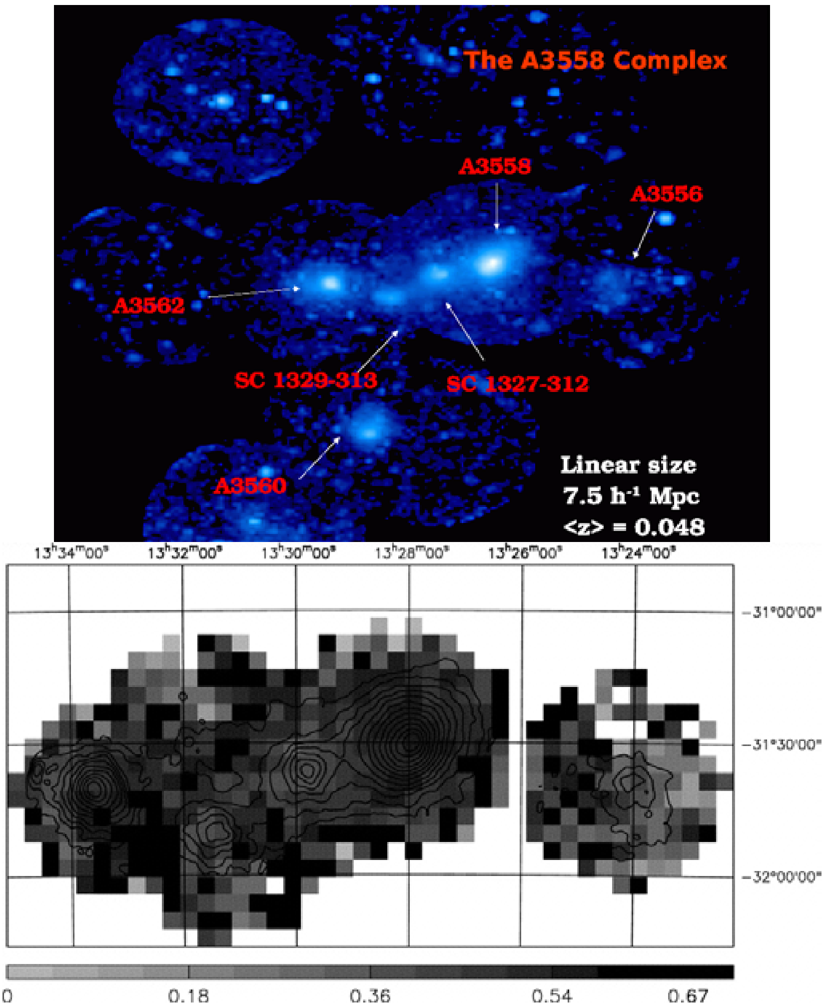

Figure 3. *Upper panel:* the A3558 cluster complex from the ROSAT-PSPC mosaic of Ettori et al. (1997). *Lower panel:* ASCA hardness ratio map of the A3558 complex from Akimoto et al. (2003). Note the "hot spot" between A3562 and SC1329-313 (reproduced with the permission of the American Astronomical Society).

SC1329-313, in the Eastern part of the structure, a hotter region is detected (see Figure 3). Furthermore, SC1329-313 has a gas distribution particularly disturbed with a comet-like shape (Bardelli et al. 2002): an ASCA analysis of its X-ray spectrum led Hanami et al. (1999) to claim the existence of significant turbulent motions or of a multiphase gas. This means that the merging is still at work and the clusters are far from equilibrium. As can be seen from Figure 4, most of the gas distribution features in the A3558 complex could be related with galaxy distribution substructures.

This spectacular major merging represents a unique opportunity to study the effect of merging at radio wavelengths (see also the contributions of Zucca and Giacintucci, this conference). In particular, a peculiar radio feature has been detected: it is formed by a radio halo and by a diffuse radiosource (see Figure 5); the only other known case is in the Coma cluster. The radio halo, detected at the center of A3562, is a head-tail radiogalaxy: we verified (Venturi et al. 2003) that this radiogalaxy furnished the electrons which, after

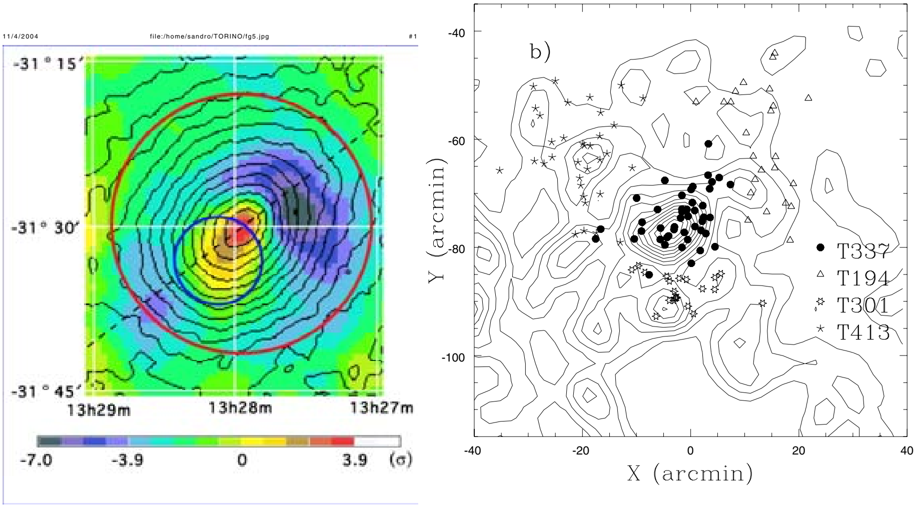

Figure 4. *Left panel:* ASCA surface brightness distribution of the cluster A3558, from Akimoto et al. (2003) (reproduced with the permission of the American Astronomical Society). Note the clumpy distribution. *Right panel:* optical isodensity contours; different symbols correspond to galaxies belonging to different substructures found in the α, δ and velocity space (see Bardelli et al. 1998b).

the reacceleration by a merging 0.4 Gyrs ago, are responsible for the halo emission. Also the radio spectrum of the halo is consistent with the last electron acceleration happened 0.4 Gyrs ago. Moreover, we found that there is a significant lack of radiosources in this structure (Venturi et al. 2000): this signal is coming mainly from the cluster A3558 and could indicate that merging could switch-off, at least for a period, the radiosource activity. Moreover, a relic radiosource has been found in the Westernmost part of the A3558 complex: a geometrical and dynamical reconstruction of this part of the structure lead to speculate that this relic had origin on the shock front (up to now undetected in the X-ray), caused by a small group in-falling onto the A3556 cluster (Venturi et al. 1998). A3556 itself presents peculiar characteristics, because of its very low X-ray surface brightness with respect to the optical richness: moreover, its optical luminosity function presents an unusual shape, with a pronouced excess of bright galaxies (Bardelli et al. 1998a).

4. The A3528 complex

A3528, the dominant cluster of the complex, is a double cluster formed by two twins subclumps separated by 0.9 h^{-1} Mpc and the other two clusters of the complex (A3530 and A3532) are a close pair, separated by ~ 1 h^{-1} Mpc .

Gastaldello et al. (2003) studied A3528 with XMM-Newton observations, obtaining surface brightness, temperature and abundance maps. Although a bridge of hot gas connecting the two clumps has been found, no shock is detected (see Figure 6): this fact is unexpected, given the estimated masses of the clumps ($\sim 8 \times 10^{13}$ $M_\odot$ each) and their relative distance. The most reasonable explanation is that the merging was not head-on but off-axis. After having subtracted a β model from the surface brightness of the two subclumps, we found emission excesses which can be used to determine the infalling direction (see right panel of Figure 6). The conclusion is that this system is in an off-axis post-merging phase, with the closest core encounter happened $\sim 1 - 2$ Gyrs ago.

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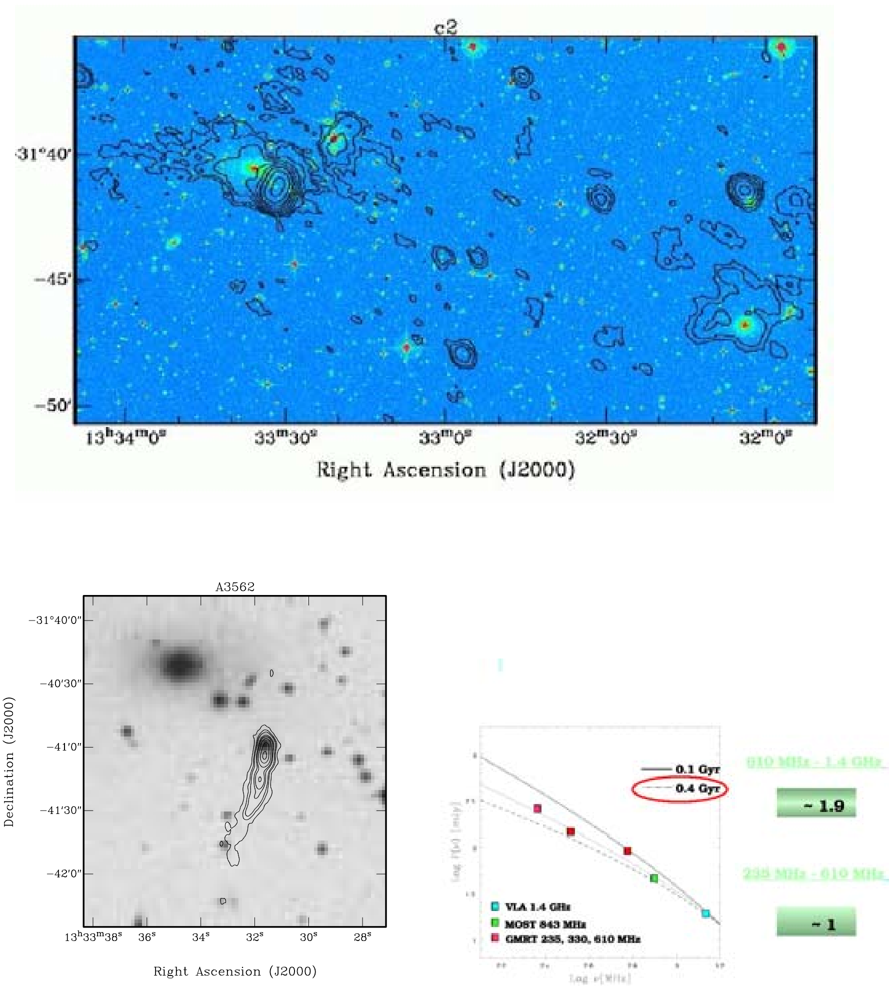

Figure 5. *Upper panel:* VLA 20cm isophotes overplotted to the Digital Sky Survey, in the A3562 region. On the left the system radio halo plus head-tail radiogalaxy (not resolved) is visible. Note the peculiar radiosource on the right. *Lower left panel:* the head-tail radiogalaxy seen at higher resolution. This object furnished the electrons to the halo. *Lower right panel:* radio spectrum of the halo. Solid lines are models with different reacceleration times.

The interesting point is that the optical blue luminosities of the two subclumps, which are twins for what regards the X-ray properties, differ by an order of magnitude. This could indicate that one of the two clumps suffered the galaxy "pealing" process more than the other, probably induced by a larger path through the large scale environment. XMM-Newton data on the couple A3530/A3532 are presently in the reduction phase.

Our general conclusion is that, although the two single pairs of clusters (the two clumps of A3528 and A3530/A3532) are mergings at an advanced state, the A3528 complex as a whole is at an earlier moment of collapse with respect to the A3558 complex, and the masses involved here are probably lower.

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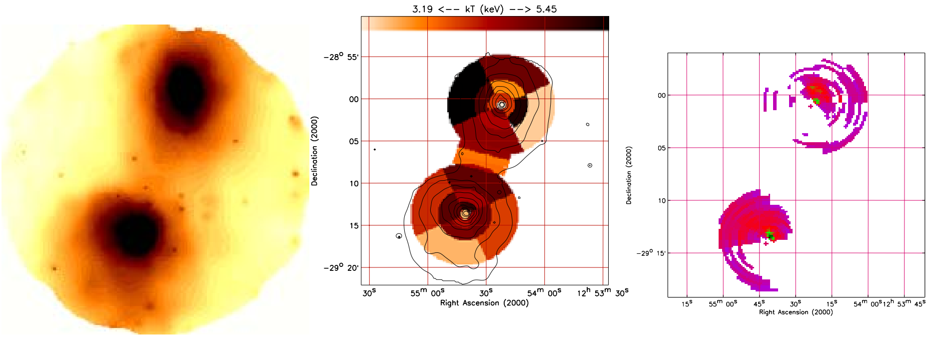

Figure 6. XMM-Newton observations of A3528. *Left panel:* X-ray surface brightness distribution; note the hot bridge connecting the two subclumps. *Middle panel:* temperature map. *Right panel:* surface brightness residuals, obtained after having subtracted a smoothed distribution.

5. Summary

Central regions of superclusters give the possibility to find cluster mergings at different phases and strengths and to study the consequences of cluster collisions on the intracluster medium and the galaxy population. The case study of the Shapley Concentration which I presented here shows that the multiwavelength approach is the best way to analyse merging clusters.

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