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A PANCHROMATIC STUDY OF TWO PAIRS OF GALAXY CLUSTERS

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Abstract.
We have analysed the properties of two pairs of intermediate redshift clusters Abell 222/223 and Abell 1758 North/South, based on XMM-Newton data, deep multi-wavelength optical imaging with CFHT/ Megacam, and, for the second pair, numerical simulations. Temperature and metallicity maps of the X-ray gas show striking features, particularly in one of the members of each pair, implying ongoing mergers at least in Abell 223 and in Abell 1758 North. The comparison of the metallicity map of the latter cluster with the results of numerical simulations suggests that in the metal rich regions, winds have been more efficient in transporting metal enriched gas to the outskirts than ram pressure stripping. Optical galaxy luminosity functions (GLFs) tend to show dips and wiggles, as well as an excess of bright galaxies over a Schechter function fit, confirming the merging structure of each of these four clusters.

Keywords: clusters of galaxies,optical,X-rays

1 Introduction

Environmental effects are known to have an influence on galaxy evolution, and can therefore modify galaxy luminosity functions (hereafter GLFs). This is particularly obvious in merging clusters, where GLFs may differ from those in non-merging (relaxed) clusters. The GLFs also allow us to trace the cluster-formation history, as shown for example for Coma (Adami et al. 2007).

This dynamical history can also be derived by analysing the temperature and metallicity distributions of the X-ray gas in clusters. These maps have revealed that in many cases clusters with emissivity maps that show a fairly relaxed appearance could have very disturbed temperature and metallicity distributions, implying they have undergone one or several mergers in the last few Gyr. The temperature distribution of the intra-cluster medium (ICM) provides insight into the process of galaxy cluster merging and on the dissipation of the merger energy in form of turbulent motion. Metallicity maps can be regarded as a record of the integral yield of all the stars that have released their metals through supernova explosions or winds during the cluster evolution. The comparison of these maps with the results of hydrodynamical numerical simulations allows us to characterize the last merging events that have taken or are taking place.

We briefly present here our results for two pairs of moderately distant clusters, where the effects of merging are expected to be even stronger: Abell 222/223 (redshift z=0.21) and Abell 1758 North/South (z=0.279). Our studies are based on archive XMM-Newton X-ray data and archive CFHT/Megacam optical images in the g and r bands. A full description of their properties can be found in Durret et al. (2010) and Durret et al. (2011).

2 X-ray temperature and metallicity maps

The X-ray temperature and metallicity maps of A222/223 are shown in Fig. 1. Abell 222 appears fairly isothermal when compared to Abell 223, but neither of these clusters presents a cool-core, precluding a fully

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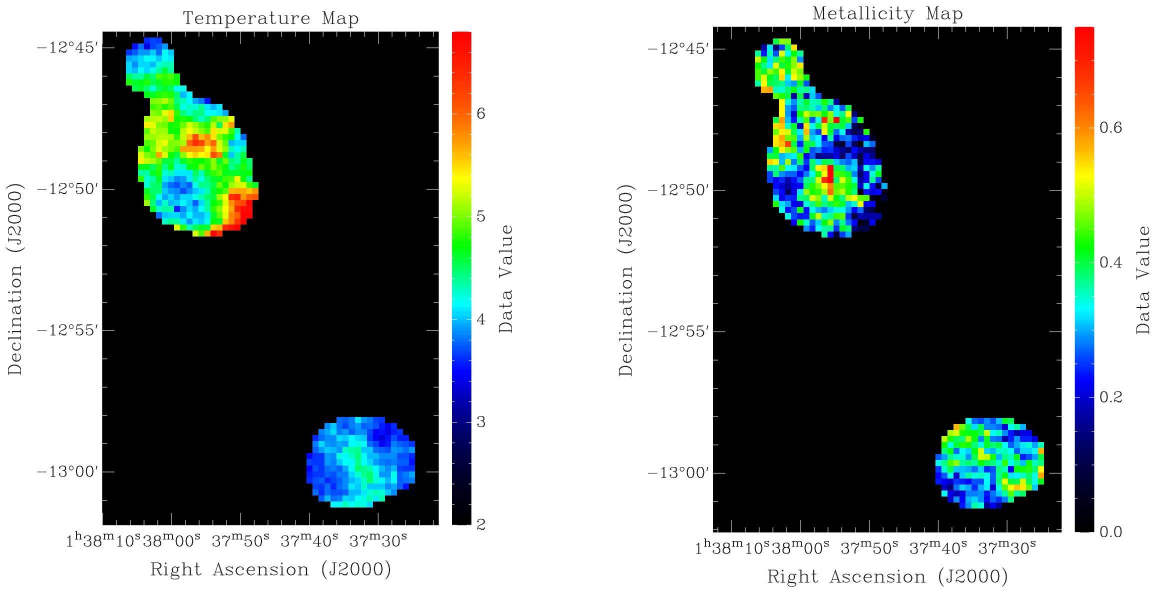

Fig. 1. Left: Temperature map of A222 (bottom right cluster) and A223 (top left). **Right:** Corresponding metallicity map.

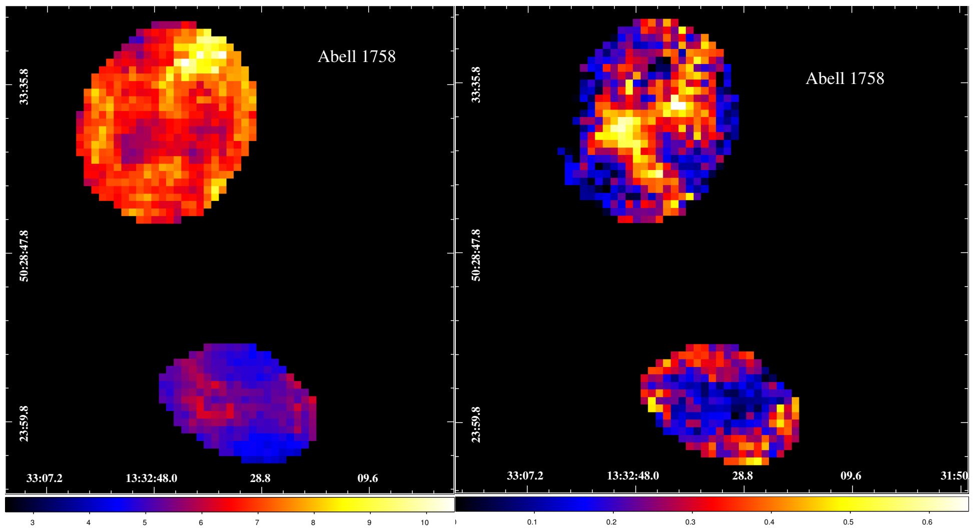

Fig. 2. Left: Temperature map of A1758 North (top cluster) and South (bottom). **Right:** Corresponding metallicity map.

relaxed state even in A222. The overall temperature map of Abell 223 is strongly inhomogeneous and shows a large number of sub-structures. The metallicity map, shows a metallicity enhancement in the central region of Abell 223.

The gas temperature maps of A1758N/S displayed in Fig. 2 do not present prominent inhomogeneities, except for a hotter blob in the northwest of Abell 1758 North. The North cluster is hotter (with temperatures in the range of 6-7 keV) and the South one cooler (kT= 4-5 keV). The hotter blob in the northwest of Abell 1758 North could be explained by heating of the gas in that region by the movement of the northwest system towards the north, as proposed by David & Kempner (2004). The most striking features are seen in the metallicity maps. The metallicity map of the South cluster is even more unusual, because it shows a deficit of metals in the central region. This deficit is probably the signature of an interaction with the central object that could have expelled metals towards the outskirts. We also detect two elongated regions of high metallicity in the North

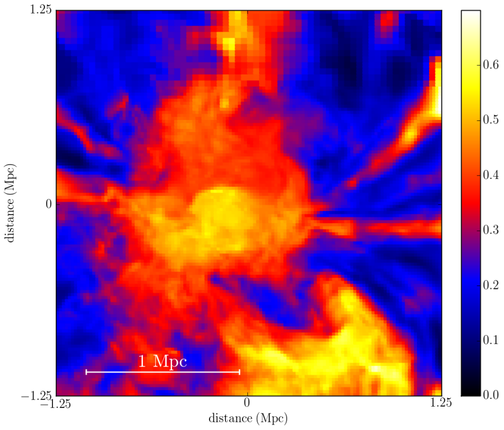

Fig. 3. Metal distribution predicted by numerical simulations for A1758 North

cluster, suggesting that it has been crossed by at least two smaller clusters.

To better understand the nature of the most prominent features exhibited in the metallicity map of the North cluster, we performed five simulations with different initial conditions. Among these five simulations, we found one metal distribution that quite reasonably reproduces the elongated region of high abundance found observationally for the North cluster, although without a perfect spatial correlation (see Fig. 3). The results of our numerical simulations allow us to distinguish the role of metal transportation processes such as galactic winds and ram-pressure stripping. These phenomena act in different regions of the cluster, and it appears that in the metal-rich elongated regions of the North cluster winds are more efficient in transporting enhanced gas to the outskirts than ram-pressure stripping.

3 Galaxy luminosity functions

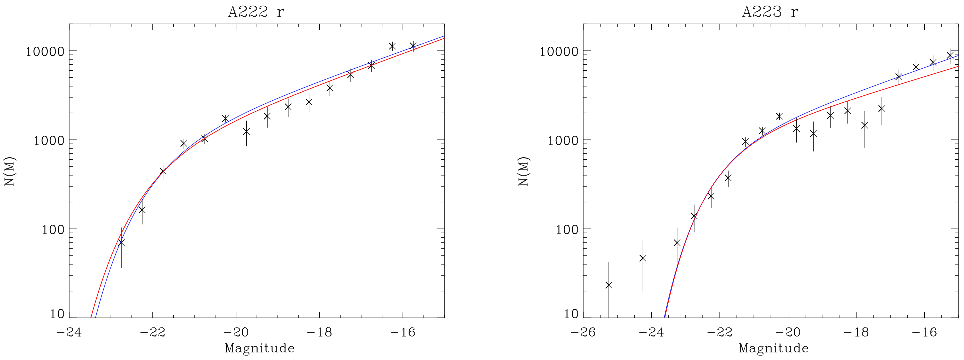

Fig. 4. Left: Galaxy luminosity function of A222 in the r band. **Right:** Galaxy luminosity function of A223 in the r band. The blue and red colours correspond to the best Schechter function fits obtained for two different background galaxy subtractions.

Abell 222 appears to be smaller and less massive than Abell 223. The galaxy luminosity functions (GLF) in the r band are shown in Fig. 4 for these two clusters. For Abell 222, the GLF is quite well fit by a Schechter function, while Abell 223 presents a "perturbed" GLF, with dips and wiggles, and an excess of bright galaxies over a single Schechter fit.

As seen in Fig. 5, the GLF of Abell 1758 North also shows an excess of galaxies over a Schechter function in the brightest magnitude bins, as well as a possible and unexplained excess of galaxies around $\mathrm{M}_{r'} \sim -17.5$. In contrast, for Abell 1758 South, which is metal-poorer than the North cluster, the GLF is not as well fit by

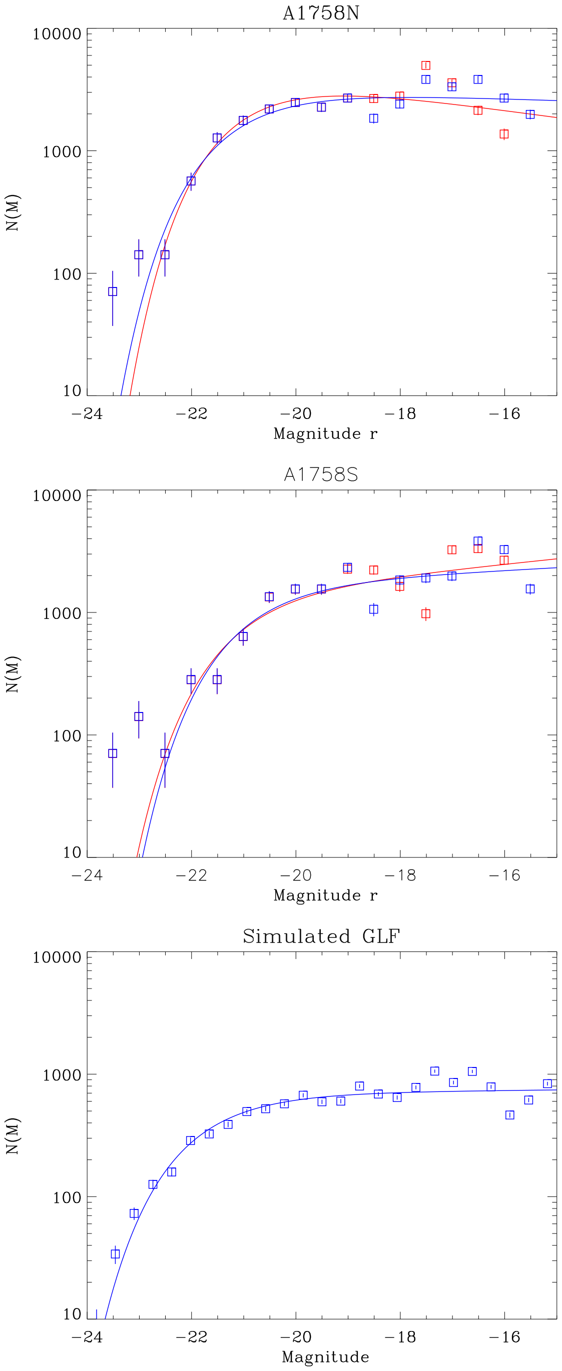

Fig. 5. Top: Galaxy luminosity function of A1758 North in the r band. **Middle:** Galaxy luminosity function of A1758 South in the r band. The blue and red symbols correspond to two different galaxy selections and the corresponding curves show the best Schechter function fits. **Bottom:** Simulated galaxy luminosity function for A1758 with best Schechter fit superimposed.

a Schechter function, and also shows an excess at bright magnitudes. The somewhat perturbed shapes of the GLFs of both clusters agree with the assumption that they are both undergoing merging processes.

The numerical simulations computed to account for the metallicity map of A1758 North also allowed us to simulate an optical GLF, and the result is consistent with the observed GLF, as seen when comparing the left and right panels of Fig. 5.

4 Discussion

The metallicity enhancement in the central region of A223 can be explained by the fact that this cluster has more very bright galaxies than A222. Assuming ram-pressure stripping with tidal disruption of the bright galaxies near the cluster center as a mechanism for metal injection, one would indeed expect this cluster to have a higher central metallicity than A222. The combined analysis of X-ray and optical data argues for a scenario in which the two clusters are beginning to collide. A223 presents signs of interaction in both wavelength ranges, and has probably been crossed by a small cluster heading north east, while A222 does not show strong evidence for interaction, except for the absence of a cool-core.

For A1758, signs of merger(s) are detected in the optical and the X-ray wavelength ranges in both subclusters, meaning that both galaxies and gas are still out of equilibrium. The presence of two elongated regions of high metallicity in the North cluster suggest that at least two smaller clusters have crossed the North cluster. Our temperature and metallicity maps agree with the scenarios proposed by David & Kempner (2004), who derived that the North cluster is in the later stages of a large impact parameter merger between two 7 keV clusters, while the South cluster is in the earlier stages of a nearly head–on merger between two 5 keV clusters.

The present study confirms that the analysis of temperature and metallicity maps of the X-ray gas, coupled with numerical simulations, can bring important knowledge on the formation history and evolution of individual clusters. In particular, these maps allow to show evidence for merging events even when emissivity maps show no clear evidence for substructures. A complementary approach to the study of merging clusters is the analysis of optical GLFs. It indeed appears that the GLFs of clusters revealing evidence for merging show dips and wiggles, together with an excess of galaxies over a Schechter function in the brightest magnitude bins. This could be used as a test for recent merging events in clusters where the evidence for mergers is not obvious.

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