THE CLUSTER-GALAXY CONNECTION: THE MORPHOLOGY OF CLUSTERS

I. Sakelliou
Max-Planck for Astronomy, D-69117 Heidelberg, Germany

ABSTRACT

It is now common wisdom, that structure in the Universe is formed hierarchically, by the merging of smaller units. Large clusters of galaxies are formed by the continual falling of galaxies into the clusters. The interactions of the cluster gas (ICM) with the moving galaxies modify the properties of the galaxies and the clusters by, for example, stripping the galaxies, and heating the ICM.

If we want to: i) understand the impact of galaxy-cluster interactions, ii) get a better insight into the factors that control the evolution of galaxies and clusters, iii) find when, how, and if, the transformations of galaxies and clusters occur, we need to study the clusters and their galaxies by combining X-ray and optical/IR data of merging/evolving clusters.

I am presenting a program, that is aiming at combining the properties of clusters obtained from X-ray observations, with those of their galaxies found from optical data. Preliminary results are shown, and future prospects are outlined.

1. INTRODUCTION

As structure forms via violent merging events, physical processes take place that have significant impact on the properties of the constituents of clusters [i.e. intracluster medium (ICM), and the galaxies].

•*Effects on the galaxies:* It has been known for long time that the galaxies' environment is responsible for their properties [e.g., (2)]. Although the physical processes that stimulate or regulate star formation, nuclear activity, and the transformation of galaxies are fairly well known, it is unclear which one dominates, and under which conditions. These processes are (i) galaxy-galaxy interactions and merging, and (ii) galaxy-ICM interactions, manifested as ram pressure stripping and accretion of ICM onto and around the galaxies. As theoretical work has shown, (i) galaxy-galaxy interactions and merging, and (ii)galaxy-ICM interactions, manifested as ram pressure stripping and accretion of ICM onto and around the galaxies, can strip the interstellar media (ISM), trigger nuclear activity, compress the ISM and induce star formation, igniting new starbursts [e.g., (1)]

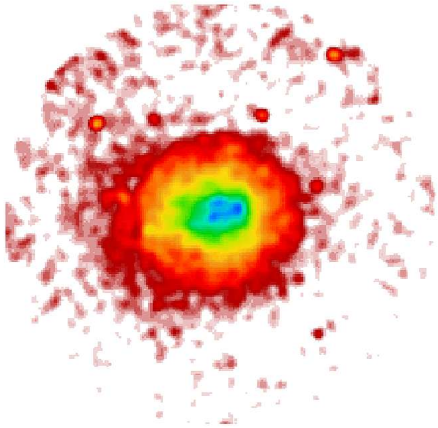
•*Effects on the clusters:* The clusters are also affected during the above interactions. The ICM, for example, is heated up by the outflows from the galaxies, which can be in the form of galactic winds from starburst galaxies, and/or radio jets from active galaxies. The galactic motion also contributes in the heating of the ICM. Evidence for the importance of galaxy/cluster interactions in the modification of the properties of the ICM is rapidly accumulating from the high quality data of the two major X-ray satellites (NASA's *Chandra* and ESA's *XMM-Newton*).

In forming/evolving clusters, the galaxies are falling towards the cluster centre, leaving galactic material behind forming a trailing galaxy wake. We have suspected for long time (based on theoretical and observational grounds) that ram pressure stripping would take place. If galaxies are stripped from their gas, the star formation rate can essentially stop or decline. On the other hand, during the galactic motion, the ISM might also get compressed by the ram pressure and the gravity force. Compression regions should be located in-front of the galactic core (immediately behind the leading bow shock, if the galactic motion is supersonic), and in the wake, due to the gravitational deflection and concentration of ICM behind the moving galaxy [Bondi-Hoyle accretion; e.g., (4)]. This extra compression may lead to a new burst of star formation.

2. DEFINING THE CLUSTER MORPHOLOGY

In order to understand the problems set in § 1 we need first to correlate the morphology of clusters in the optical/IR and X-ray lights. The feasibility of a method based on three 'simple' measures of the cluster morphologies (*centroid offset, ellipticity, and position angle*) is firstly explored. This method was first developed to investigate the structures of barred galaxies, and it was also applied to the X-ray images of clusters by (3).

•*Centroid offset:* The cluster images are analysed in circular annuli of constant width and increasing radius. The



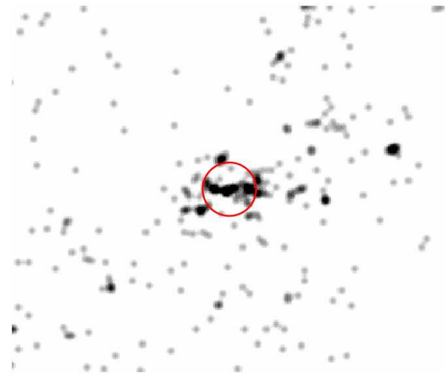


Figure 1. Left panel: The XMM-Newton mosaic of Abell 2255. Images from the MOS1 and MOS2 detectors in the (0.5-10.0) keV energy range have been co-added. Right panel: Distribution of all the galaxies with a redshift $0.06 < z < 0.1$ *taken from the SDSS. The red circle shows the position and extent of the XMM-Newton mosaic of the left panel.*

annuli are not concentric. The centroid offset for each annulus is defined as the difference between the geometrical and the intensity-weighted centre of each annulus.
•*Ellipticity:* Image counts (cnt) are accumulated in sectors with increasing angle (θ) along the above mentioned circular annuli. If the cluster is elliptical the distribution θ-cnt is double peaked, and its shape depends on the ellipticity and position angle of the cluster's shape.
•*Position angle:* It is calculated from the same θ-cnt distribution.

3. THE DATA

The 'simple' measures of cluster shapes described in § 2 has been applied to both, X-ray, and optical data of clusters. The need for 'simple measures' is dictated by the requirement that they have to be able to work efficiently for clusters at higher redshifts, for which the count rate in the X-ray images is expected to be low. To test this method, X-ray and optical data of nearby clusters are being used.

3.1. X-ray and optical data of Abell 2255

The first cluster that is being used is the nearby (z=0.08) cluster Abell 2255. The *XMM-Newton* data have been explored and presented in (5). Abell 2255 a rich cluster at a global temperature of ∼7 keV, and the *XMM-Newton* data showed that it is a merging cluster after the core crossing. The *XMM-Newton* mosaic is shown in Fig. 1(left panel).

Abell 2255 has been in the field of the SDSS survey. Galaxies that are within $6 \times 6\, deg^2$ around the cluster centre and in a redshift bin with $z\ 0.06 < z < 0.1$ have been selected. A smoothed image of the galaxy distribution is shown in Fig. 1(right panel).

4. RESULTS AND FUTURE PROSPECTS

The analysis outlined in § 2 has been applied succefully to the X-ray and optical data of Abell 2255. A visual inspection of Fig. 1 indicates that the ICM and galaxy distributions are both elongated along the x-axis. The analysis of the *XMM-Newton* and SDSS data with the techniques of § 2 finds that the centroid offset increases monotolically with radius in both the X-ray and the optical images. The position angles of the ICM and galaxy distributions are restricted both around $\theta = 0\, deg$.

Future plans include: 1) Application of the same or similar techniques to clusters at higher redshifts. The success of such a task is mainly challenged by the low count rates from distant clusters in the X-ray images. 2) Use of the same morphology measures of to analyze simulated X-ray images of clusters at different epochs of their evolution. Such a comparison will callibrate the morphology measures, and it will be possible to use them as indicators of the dynamical "age" of the ICM.

REFERENCES

[1] Barnes J.E., Hernquist L., 1992, ARA&A, 30, 705

[2] Kodama T., Bower R.G., 2001, MNRAS, 321, 18

[3] Mohr J.J., et al. 1995, ApJ, 447, 8

[4] Sakelliou I., 2000, MNRAS, 318, 1164

[5] Sakelliou I., Ponman T.J., 2005, MNRAS, submitted

ACKNOWLEDGMENTS

The author is greatful to T.J. Ponman, E. Bell, S. Falter, P. Motl, S. Borgani, and A. Dressler for interesting discussions, and help with the data. IS acknowledges the support of the European Community under a Marie Curie Intra-European Fellowship.