Carnegie Observatories Astrophysics Series, Vol. 3:
Clusters of Galaxies: Probes of Cosmological Structure and Galaxy Evolution, 2004
ed. J. S. Mulchaey, A. Dressler, and A. Oemler (Pasadena; Carnegie Observatories:
http://www.ociw.edu/ociw/symposia/series/symposium3/proceedings.html)

MUSIC: Multiwavelength Sample of Interacting Clusters

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Abstract

In the framework of the hierarchical model of structure formation, galaxy clusters form through the accretion and merging of substructures of smaller mass. Our goal is to characterize the physics and dynamics of these processes through the study of merging clusters. For this purpose we have built a sample of 10 low–redshift clusters viewed at different stages of the merging process, and observed at optical, X–ray and radio wavelengths. In the following we will present the results obtained through the optical analysis on the first targets of our sample, i.e. A521 and A3921.

1.1 Introduction

The high frequency of dynamically and morphologically complex galaxy clusters observed even at low redshifts shows that clusters are still forming through the accretion and merging of smaller mass subunits. Besides the important cosmological constraints related to the analysis of dynamically young and complex systems (Richstone et al. 1992, Mohr et al. 1995, Schindler 2002), a detailed study of interacting clusters is crucial to characterize the physics of the merging event.

Multi-wavelength observations allow us to observe the different components of clusters, i.e. galaxies, intra-cluster gas, relativistic particles and magnetic fields. A complete modeling of interacting systems can be achieved only by comparing these observational results to numerical simulations of mergers. Using N–body and hydrodynamic codes it is possible to follow the evolution of a) the velocity and spatial distributions of cluster galaxies, and b) the density and the temperature of the intra–cluster gas, during the merging event (Schindler & Böhringher 1993, Takizawa 1999, Ricker & Sarazin 2001).

Let us briefly review here what are the main observational signatures that can be expected from our understanding of cluster formation. From the optical point of view, the main signatures are strong sub-clustering in projected positions and very high velocity dispersion of cluster galaxies, as, due to their mutual attraction, subclusters are accelerated and their velocity distributions diverge during their collision (Schindler & Böhringer 1993). Motions in cluster mergers are transonic, so the merger drives shocks and thus heating and compression into the intracluster gas. At early stages in the merger, the shocked region is located between the interacting sub-structures; then, the main merger shocks pass into the outer part of the merging system, and secondary shocks may appear in the inner regions. Finally the cluster returns to equilibrium (Ricker & Sarazin, 2001). At least a few percent of the shock energy is converted into the acceleration of relativistic electrons through a first order Fermi process. This originates diffuse extended radio emission, termed radio halo if it is centrally located, or radio relic if it lies away from the X-ray cluster center (Feretti 1999). It has also been observed an excess of low and high-power radio galaxies in merging clusters, probably due to enhanced star formation and AGN activity respectively (Owen et al. 1999). This excess may be due to environmental effects and dynamical processes in host clusters: both star formation and accretion onto massive black holes require reservoirs of cold gas, whose extent depends on the efficiency with which galaxies are stripped of their interstellar medium.

1.2 The Programme

We have begun a program of optical, X-ray and radio observations of a sample of 10 low-redshift clusters of galaxies at different stages of the merging process.

The selection of our targets is essentially based on the comparison between the X–ray and optical morphologies: the strong difference in the relaxation time scales of the gas and of the collisionless component in clusters (i.e. galaxies and dark matter) allows us to establish the status of the merging event by comparing their relative density distributions. Cluster morphologies are determined applying various indicators, such as ellipticity, power ratios and centroid shift (Kolokotronis et al. 2001), on available X–ray and optical data. We have thus defined a sequence of candidates from pre–merging (e.g. A1750, A2933), to intermediate (e.g. A3921, A2804) and post–merging stages (e.g. A1413), all in the redshift range $0.05 \div 0.15$, optimal for covering by wide field optical imaging and XMM.

The first goal of our project is to analyze for each cluster the velocity field and mass ratio of the various components and determine the epoch and geometry of the collision between subunits. It is thus necessary to make a detailed dynamical and kinematical analysis of member galaxies through optical multi-object spectroscopy, combined with the study of density and temperature maps of the intra-cluster medium through spectro-imaging in X-ray. Our targets are therefore observed both with XMM in collaboration with the group of M. Arnaud and J.L. Sauvageot (CEA, Saclay, Paris) and with MOS instruments at ESO and CFHT. In order to fully characterize the history of merging process, we study the large–scale environment of interacting clusters through deep, multicolor, wide–field imaging at ESO with WFI@2.2m telescope and at CFHT with CFH12k. The next phase will be the comparison of our optical and X–ray results with detailed numerical simulations.

The effect of merging on galaxies in clusters is addressed by studying their stellar populations through optical spectroscopy (coll. P. Prugniel, Lyon Observatory), and by deriving their radio morphology and luminosity function (VLA observations, coll. L. Feretti and G. Giovannini, IRA, CNR, Bologna). Radio observations allow us to investigate the possible presence of halo and/or relic sources, and put constraints on the magnetic field and non-thermal processes within merging clusters.

1.3 Results

In the following, we present the main results obtained through the optical analysis of the first two clusters of our sample.

1.3.1 Abell 521

We have made a combined analysis of multi-object spectroscopy (EFOSC2, ESO3.6m telescope) and deep, wide–field imaging in B and I bands (CFH12k, CFHT) for the galaxy

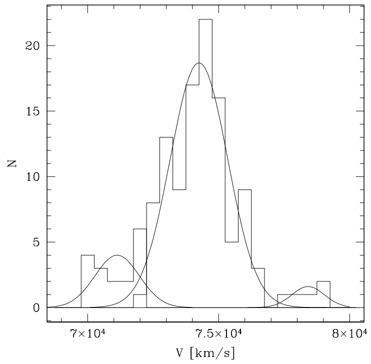

Fig. 1.1. Velocity histogram within Abell 521, obtained from the 125 members of the cluster. Three Gaussian functions corresponding to KMM partition, with velocity distributions derived with ROSTAT, are superimposed.

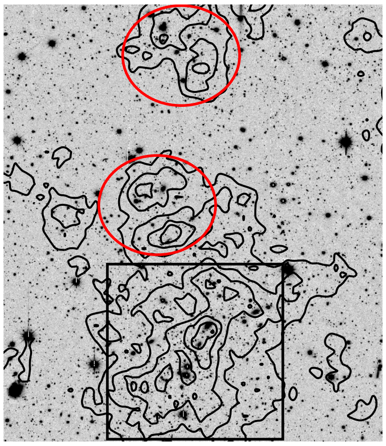

Fig. 1.2. Iso-density contours of the galaxies in the red sequence of the cluster (up to I=20) have been superimposed to the central 20'×30' field of A521 (deep I-band image, CFHT12k). The black square shows the field covered by spectroscopy at the ESO 3.6 m telescope. The red ellipses correspond to the Northern clumps of galaxies in the red-sequence of the cluster.

cluster Abell 521 (z=0.247). Our new results (Ferrari et al. 2003) show that it is a dynamically young and complex system, characterized by multiple merging events.

From the analysis of the 125 confirmed cluster members, we have found a complex velocity distribution, with a very high velocity dispersion (1325 km/s) and clear departure from a single Gaussian component. The KMM algorithm fits a three groups partition of the velocity distribution (Fig. 1.1)

The iso-density map of the cluster show a high degree of sub-clustering in galaxy projected positions: in the central 10'×10' field (black square in Fig. 1.2), the general structure of A521 follows a NW/SE main direction, crossed by a nearly perpendicular high density ridge of galaxies in the core region.

The Northern region of the cluster is characterized by a lower velocity dispersion (839 km/s) as compared to the whole cluster value; it hosts the BCG, which is not positioned on the X-ray center of the cluster, but in a dynamically bound complex of galaxies associated to a group detected in X-ray (Arnaud et al. 2000). We conclude that this group of galaxies around the BCG is in a pre-merger stage onto-the main cluster along NW/SE direction.

The central perpendicular high dense ridge of galaxies shows a lower mean velocity, a significantly higher velocity dispersion (1780 km/s), and a higher fraction of late type and emission line galaxies as compared to the rest of the cluster. This can be explained in a scenario in which a merging of subclusters has already occurred along the direction of the ridge with a significant component along the line of sight.

On larger scales, the isodensity map of the red–sequence galaxies shows several clumps, aligned along North/South direction (red ellipses in Fig. 1.2). As even spectroscopical observations have confirmed the presence of galaxies at the cluster redshift in these clumps, we think that we are witnessing groups of galaxies infalling at large scale on the main body of the cluster along preferred direction, as predicted by the hierarchical model of structure formation.

1.3.2 Abell 3921

We have made a combined analysis of deep imaging and multi-object spectroscopy for the central field (∼20'×20') of Abell 3921 (z=0.093), observing this cluster with WFI and EFOSC2 at ESO 2.2m and 3.6m telescopes respectively.

Normality and shape tests show that the velocity distribution of the 108 member galaxies is a Gaussian with heavy populated tails (Fig. 1.3, left), characterized by a mean value $C_{BI} = 28038^{+79}_{-77}$ km/s and a dispersion $S_{BI} = 847^{+83}_{-92}$ km/s.

The iso-density map of the galaxies up to R=19 in the central field of the cluster shows a two components structure (Fig. 1.3, right), with a main component centered on the BCG (BG1 in Figs. 1.3), and a group in the North-West side of the cluster centered on another giant elliptical galaxy (BG2), with a very bright emission line galaxy located in its outskirts (BG3). We have analyzed separately the velocity distributions of these two spatially distinct components, and we have found that they are characterized by mean velocities very close to each other and to the whole cluster value (Fig. 1.3, left). Again, the greatest part of normality tests agrees with the hypothesis of Gaussian distributions for the two subclumps, and the shape parameters indicate that the two datasets have a symmetric distribution as well as rather populated tails. The main group is characterized by a higher velocity dispersion and a larger radius, so that, applying the virial theorem, we obtain a mass ratio for the two clumps of $M_{MAINcl.}/M_{NWgroup} \sim 3.6$.

In the case of merging between two groups of galaxies, N–body simulations (Schindler & Böhringer, 1993) show that, after the two components have crossed each other, they are decelerated by violent relaxation, resulting in an unimodal velocity distribution with heavy populated tails, as observed in A3921 velocity histogram.

All detected emission line galaxies lie in the region between the main cluster and the NW group (blue crosses in Fig. 1.3, right), indicating that star formation rate could have been accelerated by a recent merging event.

We interpret these results with a merging scenario in which the North-West group has just

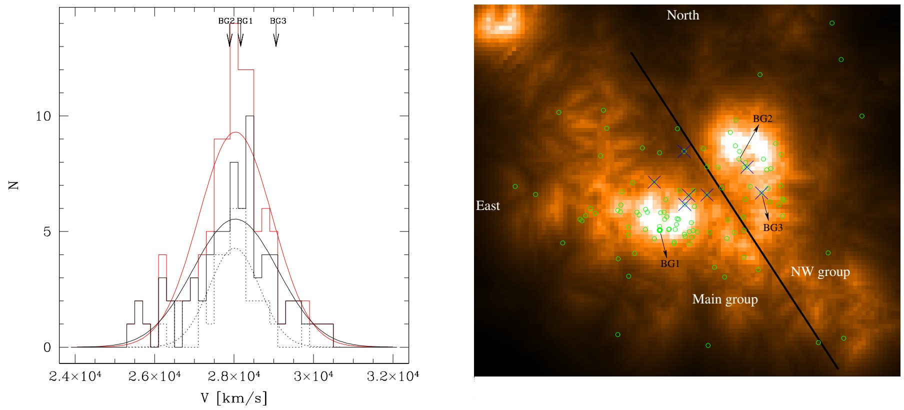

Fig. 1.3. **Left:** Velocity distribution of the whole cluster (red solid line), of the main cluster (black solid line) and of the NW group (dashed line). The three corresponding Gaussian functions with velocity distributions derived with ROSTAT are superimposed. The velocities of the three brightest cluster members are also shown. **Right:**Isodensity map of the galaxies with R<19 in the central 35'×32' of A3921. Green circles show the position of spectroscopically confirmed member galaxies, while blue crosses represent emission line objects. The position of the three brightest cluster galaxies is also shown.

passed through the center of the main cluster nearly on the plane of the sky, in agreement with the X-ray results by Belsole et al., 2002.

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