The Structure and Dynamics of Rich Clusters of Galaxies

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Background

Rich clusters of galaxies are of great interest for several reasons. As the largest bound structures that can be fairly easily found and studied in detail, they represent a formidable constraint for theories of the formation of large-scale structure in the Universe. In addition, they provide an ideal laboratory for the study of the behaviour of galaxies in an environment of high galaxy-density; quite frequently in the presence of a hot, X-ray emitting, intracluster gas, that may have a mass comparable to the total visible mass in galaxies. As rich clusters can be detected out to fairly high red-shifts, they also allow one to study the evolution of the galaxy population in clusters over an appreciable fraction of the Hubble time. Even the evolution of their global structure on such time-scales is amenable to study (Gunn, 1989).

The significance of rich clusters as a boundary condition for theories of large-scale structure formation applies to a large range of scales.

First, the internal structure and dynamics of clusters contain information about their evolutionary "age", and probably also to some extent about the initial conditions from which structure on these scales has arisen. In their central regions, two-body relaxation and non-elastic collisions between galaxies (involving e.g. dynamical friction and merging) have a characteristic time-scale that is shorter than the Hubble time, so that memory of the initial conditions has quite likely been erased. However, the overall relaxation time is considerably larger than the Hubble time, even for a rich cluster with a moderate velocity dispersion.

From a detailed analysis of the kinematics of the galaxies in a cluster one can also get an idea about the distribution of the dark matter, in relation to that of the visible matter, if one assumes the cluster to be in a steady state (see e.g. Merritt, 1987, and Sharples et al., 1988). This is very important for an understanding of the role that dark matter has played in the formation history of clusters as a class.

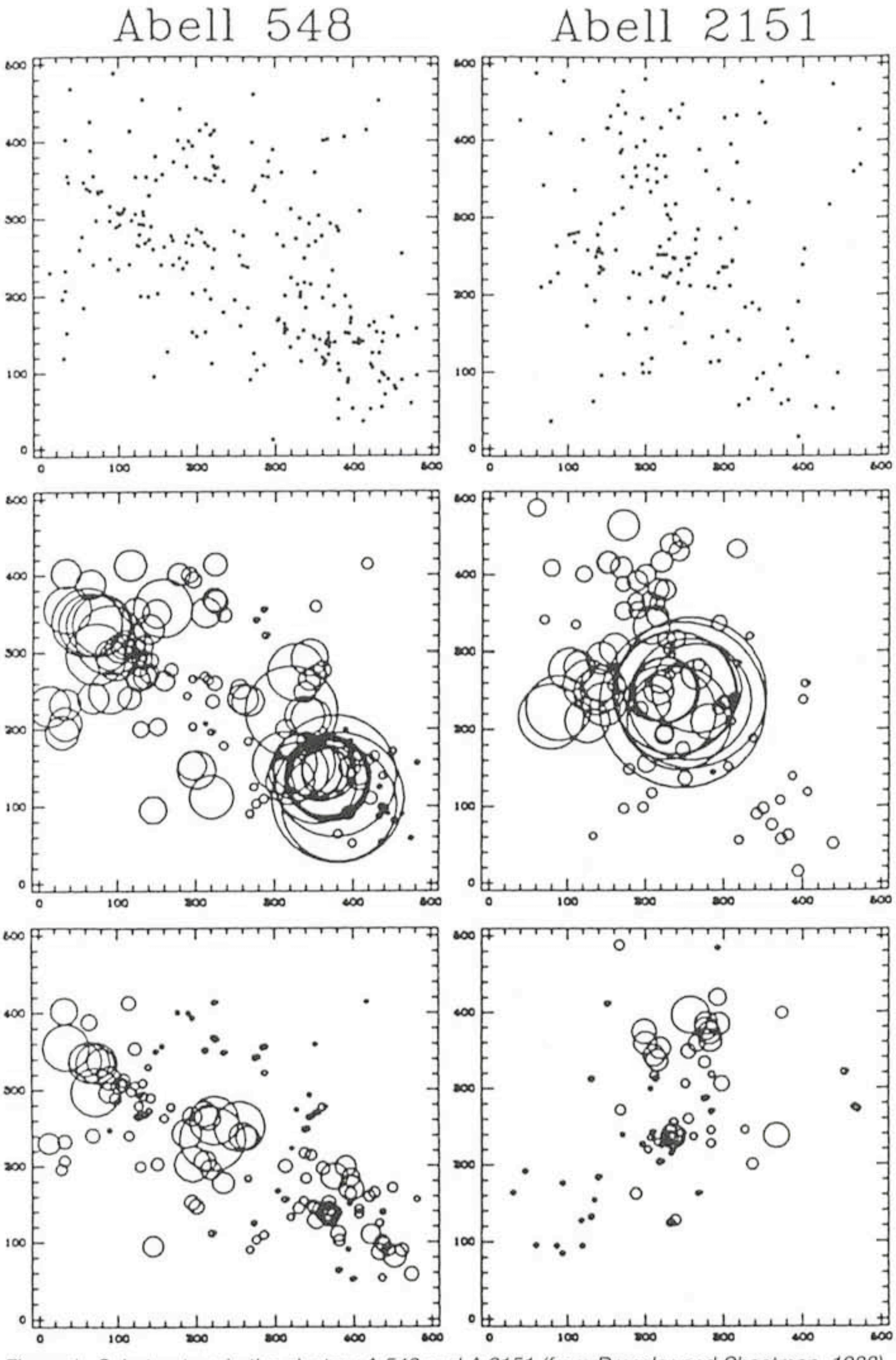

Figure 1: *Substructure in the clusters A 548 and A 2151 (from Dressler and Shectman, 1988). The upper panels show the distribution of the galaxies brighter than about 16 in V (from Dressler, 1980), in areas of about 8 h^{-2} Mpc^2. The middle panels show the deviation of the local kinematics (for each galaxy with a radial velocity, from its ten nearest neighbours with radial velocities) from the global kinematics. The diameter of the circle scales with the magnitude of the deviation. The lower panels show Monte Carlo models (derived from the observations by randomly reassigning the measured radial velocities). These models are selected because they show the largest amount of substructure among 11 such models made for each cluster.*

The second aspect that relates to theories of structure formation is the state of motion of the population of rich clusters as a whole, in relation to the general expansion of the Universe. The peculiar velocities that clusters may have with respect to the Hubble flow could, in principle, reveal the characteristics of the mass distribution on very large scales, of up to 50 Mpc or more. Such peculiar motions have been claimed to exist (Bahcall et al., 1986), but the evidence has been questioned by other authors.

Goals of the Programme

The purpose of our Key Programme is basically two-fold.

In the first place we will obtain detailed kinematical information for a carefully chosen sample of rich southern clusters. This will allow us to study the amount and nature of substructure. Secondly, we will get more global information on the dynamical state of a larger, complete sample of rich clusters. This will provide accurate mean velocities to be used in a study of the peculiar motions with respect to the Hubble flow. In addition, the latter data will yield global velocity dispersions, which we hope to correlate with other global properties of the clusters, such as e.g. the luminosity function, mix of different galaxy types, etc.

The question of substructure is an important one, both observationally and theoretically. Some time ago, Geller and Beers (1982) claimed that significant substructure exists in more than 40 per cent of the clusters in a sample defined by Dressler (1980). On the basis of the same data, West et al. (1988) reached the conclusion that there was very little evidence, if any, for significant substructure. Rhee et al. (1989) reached the same conclusion as did West et al., on the basis of a complete sample of more than 100 rich clusters. Note that all these results were based on projected 2-dimensional galaxy distributions.

The negative results seemed to be in agreement with theoretical predictions (by West et al., 1988) which showed that, independent of the formation scenario (Cold or Hot Dark Matter), substructure is not expected to survive in the central parts of clusters. These predictions did not take into account the effects of inelastic encounters.

Using radial velocity data, Dressler and Shectman (1988) showed that 3 out of the 5 clusters for which they had more than 100 radial velocities had distributions of position and radial velocity which were not consistent with smooth phase-space distributions. In other words: substructure would seem to be rather common, judged from a 3-dimensional projection of 6-dimensional phase-space.

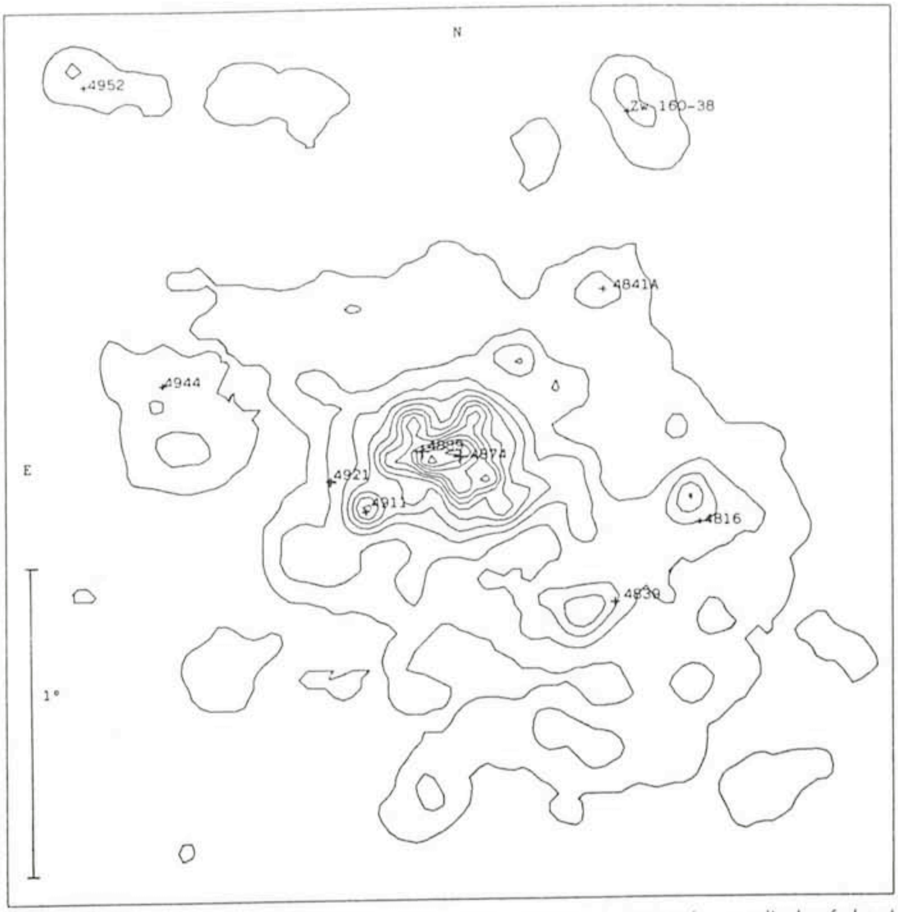

Figure 2: *Isopleth map of the distribution of the 1630 galaxies down to a b-magnitude of about 20, which are believed to be cluster members, in the central 3 × 3 degree area in the Coma cluster (from Mellier et al. 1988). From the available radial velocities, it is concluded that the high-density peaks around the brighter galaxies (indicated by numbers) represent "old", evolved substructure in a cluster which as a whole is probably less evolved (i.e. dynamically "younger").*

Yet, the subject is far from closed. Consider, for example, the various results on the Coma cluster. Fitchett and Webster (1987) and Mellier et al. (1988) report significant substructure in 2-dimensional maps. On the contrary, Dressler and Shectman (1988) find no evidence for substructure when they include radial velocities.

Given this undecided state of affairs, we want to study the rate of occurrence and the character of substructure on the basis of good radial velocity data for a well-defined sample of clusters.

Peculiar velocities of clusters with respect to the Hubble flow have the potential of deciding between competing scenarios for the formation of structure on very large scales. The Cold Dark Matter scenario (CDM), which seems fairly successful in many respects, does not predict large peculiar velocities (White et al., 1987). The local velocity field, as traced with ellipticals (e.g. Lynden-Bell et al., 1988) is already rather problematic for CDM; large peculiar velocities of clusters would be even more so.

Given the discriminatory power of the test involving peculiar motions of clusters, we want to complement the northern sample on which Bahcall et al. based their analysis, with a completely independent southern sample.

Observational Strategy of the Programme

We will observe about 100 rich southern clusters with Optopus on the 3.6-m telescope. In the present set-up Optopus yields simultaneous spectra for up to 30 galaxies per exposure, but in the near future this will be increased to 50.

For a sample of 30 clusters we will aim at about 150 radial velocities per cluster (from several Optopus exposures), or at least 100 velocities for cluster members (after the field galaxies are removed). The results by Dressler and Shectman (1988) indicate that this will allow a reliable study of substructure. The composition of the sample (30 clusters evenly distributed over Bautz-

Morgan type, at a redshift of about 0.05) should ensure that the results will have a general validity. This is also important for a study of the general distribution of dark matter in these clusters, to be based on the same data.

For a complete sample of 70 to 80 clusters with $z < 0.1$ we will get between 20 and 30 radial velocities per cluster, from a single Optopus exposure. These will yield unbiased estimates of the mean cluster velocity (for a study of peculiar velocities), and of overall velocity dispersions (to be correlated with other global cluster properties).

The candidate galaxies for spectroscopy are found from automatic scans of film copies of SERC IIIa-J survey plates, obtained with the Leiden Observatory automatic measuring machine Astroscan. This machine will also produce accurate photographic photometry, to be calibrated with CCD sequences for which time on the 1.54-m photometric telescope has been granted.

With an anticipated yield of over 5000 new radial velocities, possibly other useful information from the spectra, and new photometry, it is hard to imagine that this programme will not provide a better description and understanding of the class of rich galaxy clusters. We look forward not only to answers to the questions that we presently pose, but also to new questions raised by the new data.

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Surface Photometry Catalogue Presented

On June 14, 1989, Andris Lauberts and Edwin Valentijn presented their new "Surface Catalogue of the ESO-Uppsala Galaxies" during a Colloquium in the Auditorium at the ESO Headquarters. The appearance of this catalogue is the crowning event of many years of hard work by the authors. It is now available, both in printed form and on magnetic tape. The book may be obtained from the ESO Information Service and the computer readable version from Centre de Données in Strasbourg, cf. the announcement in *Messenger* 56, page 34. On the photo, Ed Valentijn (left) and Andris Lauberts (middle) present the first printed copy of their Catalogue to the ESO Director General, Professor Harry van der Laan, at the time of the Colloquium.

Operating Manuals Now Available

A number of Operating Manuals have recently become available. The following have already been distributed to institutes, etc. in the member states:

- **B & C Spectrograph**
- **CASPEC**
- **CAT/CES**
- **ECHELEC**
- **EFOSC**
- **IR Photometers**
- **PISCO**

The following three manuals will be ready for distribution later: **Dutch Telescope, CCD,** and **Optical Photometers.**

Copies of these manuals can be obtained from Visiting Astronomers' Service, ESO Headquarters, Karl-Schwarzschild-Strasse 2, D-8046 Garching bei München, F. R. Germany.

The Proceedings of the

1st ESO/ST-ECF Data Analysis Workshop

held on April 17–19 in Garching, will become available towards the end of September 1989.

The 230-page volume, edited by P.J. Grosbøl, F. Murtagh and R.H. Warmels, will be sold at a price of DM 30.–. This price includes packing and surface mail and has to be prepaid.

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