Clusters and groups of galaxies: internal structure and dynamics

Strong constraints on cosmological theories and on the nature of dark matter can be obtained from the study of cluster masses, mass distribution, and internal structure. My main research lines in this field are:

1) the detection and characterization of subclusters, that are the remnants of galaxy groups, gravitationally accreted by clusters;
2) the determination of the relative distribution of dark and baryonic matter within galaxy clusters;
3) the comparison of different mass estimators (using observations in the optical and X-ray bands), also through the analysis of the results of numerical simulations;
4) the determination of the scaling relations of different cluster quantities (mass, luminosity, temperature, etc.).

These analyses are based in particular on data from the Wide Field Imaging Nearby Galaxy-clusters Survey (WINGS), from the ESO Nearby Abell Cluster Survey (ENACS), and from the SDSS.
Fig.1: Using the ENACS data-base, containing 3000 galaxies with velocities belonging to 59 clusters, complemented with ROSAT data, it has been possible to determine the relative mass fractions of the different mass components in galaxy clusters. In order to do so, the 59 clusters were stacked together to build a single 'ensemble' cluster. The Jeans analysis was applied to the projected phase-space distribution of cluster galaxies to determine the total mass. The baryonic components were evaluated separately for the galaxies and the IC gas. The split of the dark matter component into a diffuse component and a subhalo component is based on a model of dark matter halos around galaxies, coupled with a model of halo stripping due to the tidal effect of the cluster gravitational potential. Typical one-sigma uncertainties are displayed in the above figure. IC gas dominates the baryonic component at all radii except near the center where it is comparable to the baryonic contribution of the cD. Dark matter dominates at all radii, and diffuse dark matter dominates over subhalo dark matter, although the latter is a significant part of the total mass at large radii, where stripping of galaxy dark matter halos is ineffective -- see Biviano and Salucci 2006.
Fig. 2: Having determined the profile of the diffuse dark matter component in clusters (see caption to Fig. 1), it is possible to fit models to it. In the figure it is shown the circular velocity profile corresponding to the diffuse dark matter component, where \( V_c = \sqrt{GM/r} \), within 1-sigma uncertainties (black lines). A cuspy mass density profile (Navarro, Frenk and White 1996, NFW; blue line) and a cored mass density profile (Burkert 1995; red line) both provide acceptable fits. The concentration parameter for the NFW fit is as expected from cosmological numerical simulations. The core-radius of the Burkert model is of the order the size of the central cD galaxy, meaning we are hitting the intrinsic resolution allowed by our analysis. In other words, we cannot exclude that cluster mass density profiles have cores, but if they do, these cores must be very small (~50 kpc or smaller). This finding has relevant implications for the physics of cluster formation (e.g. the role of adiabatic contraction, dynamical friction) and for the characterization of the dark matter (self-interacting dark-matter particles with too large a cross-section are ruled out) – see Katgert, Biviano and Mazure 2004; Biviano and Salucci 2006.
Fig.3: Isaac Newton Telescope CCD mosaic image of the Abell 2589 cluster of galaxies, one of the 77 nearby clusters studied by the WINGS collaboration.
Fig.4: This figure illustrates the result of a substructure-detection algorithm applied on one of WINGS clusters, Abell 85. The algorithm is called DEDICA and is based on an adaptive-filtering technique. In this figure, isodensity contours (logarithmically spaced) of the galaxies in the Abell 85 field are shown. Galaxies belonging to the systems detected by DEDICA are shown as dots of different colors. Black, light green, blue, are for the main system and two substructures, respectively. Larger dots are for brighter galaxies in the denser parts of their structures. Open symbols mark the positions of the first- and second-ranked cluster galaxies. Running DEDICA on all the WINGS sample, it was found that almost 3/4 of all clusters have detectable substructures. The presence of substructures is found to be related to the luminosity contrast between the 2 brightest cluster members. The contrast increases in clusters without substructures. These findings have implications on the evolution of the clusters and their central galaxies. They suggest more recent growth of these structures than currently seen in cosmological numerical simulations -- see Ramella, Biviano et al. 2007.