Morphology and Evolution of Galaxies in Nearby Clusters

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The origin and the evolution of the morphology of galaxies is still poorly understood.
Since Hubble & Humason (1931) it is well known that in the local Universe spiral galaxies are abundant in the field, while S0 and E galaxies dominate in denser regions. It seems therefore that the galaxy environment play an important role in determining the history of galaxy evolution. Clusters of galaxies, being dense peaks in the galaxy distribution, are appropriate sites to investigate changes in the properties of galaxies as a function of cosmic time. They can be used to trace the evolution of the systems themselves as well as that of galaxies in them. Such a systematic analysis needs a fair knowledge of the properties of local clusters of galaxies and their content (the end point of the evolution), in-depth enough to cope not only with the average properties but also with their physical variance.
In the redshift range $0.4 < z < 0.5$, by exploiting the high spatial resolution achieved with the Hubble Space Telescope (HST), Dressler et al. (1997) and Smail et al. (1997) found that spirals are a factor of 2-3 more abundant and S0 galaxies are proportionally less abundant than in nearby clusters, while the fraction of ellipticals is already as large or larger. This implies significant morphological transformations occurring rather recently. On the other hand, on the basis of excellent-seeing, ground based imaging with the NOT telescope (La Palma), Fasano et al. (2000) have completed the picture in the range $0.1 < z < 0.25$, showing that the S0 population smoothly grows from $z \sim 0.5$ to $z \sim 0$, at the expense of the population of spiral galaxies. They have also highlighted the role that cluster type plays in determining the relative occurrence of S0 and E galaxies at a given redshift: clusters at $z \sim 0.1$-0.2 have a low (high) S0/E ratio if they display (lack) a strong concentration of E galaxies towards the cluster center. This dichotomy seems to support Oemler's (1974) suggestion that E-rich and S0-rich clusters are not two evolutionary stages in cluster evolution, but intrinsically different types of clusters in which the abundance of ellipticals was established at redshifts much greater than 0.5. That trend is supported by the morphological studies at $z < 0.5$, that find an even lower fraction of early-type galaxies, thus evidencing that this fraction would keep on decreasing up to $z \sim 1$ (van Dokkum et al. 2000; Lubin et al. 2002; Simard et al. 2005). The most recent works, based on the Advanced Camera for Surveys, demonstrate that it is the decreasing proportion of S0 galaxies that drives this decline also at $z \sim 0.8$-1.0. This change of the morphology mix in clusters has a correspondence in the evolution of the morphology-density relation with z.
The work on intermediate-redshift clusters observed by HST has been complemented with ground-based spectroscopic surveys that led to a detailed comparison of the spectral and morphological properties (Dressler et al. 1999, Poggianti et al. 1999, Couch et al. 1994, 1998, 2001, Fisher et al. 1998, Lubin et al. 1998, Balogh et al. 1997, 2000). These studies have shown that the spiral population includes most of the star-forming galaxies, a large number of post-starburst galaxies and a sizeable fraction of the red, passive galaxies; in contrast, the stellar populations of (the few) S0 galaxies appear to be as old and passively evolving as those in the ellipticals. These observations are consistent with the post-starburst and star-forming galaxies being recently infallen field spirals whose star formation is truncated upon entering the cluster and that will evolve into S0's at a later time.
At variance with intermediate redshift clusters, for which recent high-quality photometric data are available, the morphological reference for local clusters is still the historical database by Dressler (1980), based on photographic plates, giving the positions, the estimated magnitudes (down to $V \sim 16$) and the visual morphological classification for galaxies in 55 clusters in the range $0.011 < z < 0.066$. This situation can be easily understood since only with the new large format (wide-field) CCD mosaic cameras a significant number of low redshift clusters has been now reasonably well mapped. Trying to contribute to fill in the existing gap of information, <u>we started in 1999 an international collaboration, the **project WINGS**, aimed to secure a large database for a local sample of clusters, to study the cosmic variance of the cluster properties and their populations in a systematic way</u>. The results of this enormous observational efforts will appear soon on the literature, and will be a reference Zero-Point for any comparison with galaxies at higher z and for evolutionary studies. The WINGS survey collected wide-field photometric and spectroscopic data for an X-ray selected sample of 77 clusters at low redshift, spanning a wide range in X-ray and optical properties. The observational requirements have been set to ensure an adequate data quality, both for imaging and spectroscopy, in order to obtain detailed and reliable morphological classifications and estimates of stellar population ages, metallicities and star formation histories.
The project WINGS involves several researchers from different Institutes around the world. Different groups will follow different research aspects based on the large number of outputs that are going to be released by the survey. Here, we describe only two projects directly connected to such results, that have been pursued in the last 5 years by the members of the Padova Astronomy Department, within the WINGS collaboration.

Project 1: The local cosmic variance of galaxies in clusters

WINGS is one of the international surveys that have been dedicated in the last years to the studies of galaxies in clusters. On the spectroscopic side, the ESO Nearby Abell Cluster Survey (ENACS, Katgert et al. 1996; Biviano et al. 1997) collected redshifts for galaxies in 107 clusters, of which 67 with at least 20 spectroscopic members. This dataset yielded information on cluster velocity dispersions, kinematics and spatial distributions of different types of galaxies, that motivated detailed analysis of cluster properties (e.g. Katgert et al. 1998; Biviano et al. 1997, 1999; Mazure et al. 1996). Samples of low-redshift clusters have been also identified from the redshifts obtained by two recent large spectroscopic surveys, 2dF and Sloan (e.g. De Propris et al. 2003, see Nichol 2004 and Vogeley et al. 2004). Results based on these surveys have highlighted the strong correlation between star formation properties in galaxies and local galaxy density, and that such correlation exists both inside and outside of clusters (Lewis et al. 2002; G'omez et al. 2003; Kauffmann et al. 2004; Balogh et al. 2004).
The study of the cluster-to-cluster variations of morphological content, galaxy structure, luminosity, spatial and velocity distribution, is one of the main goals of the survey WINGS. The first results, that will present all the photometric analysis done on the 77 clusters, have been recently submitted to A&A.
WINGS is the deepest (MV ~ -14), best resolution (FWHM ~ 1 kpc) and more homogenous survey of galaxies in nearby clusters to date. For instance, even if the nominal resolution (FWHM in kpc) is only slightly better than that of the survey of Dressler (1980), its data quality (based on CCD device) is definitively better and its deepness is incomparably better (~ 6 mag) with respect to the Dressler's survey. More than $6*10^5$ galaxies have been already identified on the clusters fields by Sextractor, providing a sample of possible cluster members for more than 50000 galaxies, that have been studied (by means of the automatic tool GASPHOT, see Pignatelli 2003) in details determining their structural and photometric properties.
It is of fundamental importance to realize that a comprehensive knowledge of the properties of the local galaxies in clusters is an essential ingredient in order to control the variance of physical properties, prior to any conclusion about cosmic evolution.
To these result one should add that for 7 more nearby cluster already published (Fasano et al., 2002, A&A 387, 26; Moles et al., 2003, 2004). Apart from the luminosity function and surface brightness data for thousands of galaxies, this dataset will yield the relative occurrence of elliptical, S0 and spiral galaxies as a function of both the local density and the cluster properties (structure, luminosity and concentration of morphological types, as well as average color and central color gradients of the stellar population). This will represent the first CCD-based systematic investigation of morphologies, luminosities and colour for galaxies of several clusters in the nearby universe, and will become the local reference sample for any comparison made with galaxies at greater redshifts. Today a strong effort is devoted to the determination of redshifts from the spectroscopic follow-up survey, and when possible, of central velocity dispersions, in order to build the FP and the Kormendy relation for all the clusters at the different distances, taking into account the properties of the respective luminosity functions.

Project 2: The Kormendy relation and the Fundamental Plane

Since twenty years it is well known that the structural parameters of Early-Type (ET) galaxies, such as the effective radius Re (which encloses half the total luminosity of the galaxies), the effective surface brightness SBe, and the central velocity dispersion, are not mutally independent, but an important link among them does exist. The ET galaxies are infact approximately placed along a plane in the space of the structural parameters, named Fundamental Plane (FP), whose origin is mostly attributed to the virial theorem, but its tilt and scatter are difficult to understand in the current scenarios of galaxy formation and evolution. The FP and its 2D projection (such as the Kormendy relation), are commonly known as <u>scaling relations</u>. Since their discovery, these relations have been recognized to be very important for understanding the mechanisms driving the galaxy evolution, and to be useful tools to determine the distance scale of the Universe. Many efforts have been already spent, in particular from the theoretical point of view, for understanding whether the tilt and the scatter of the FP are compatible with the hierarchical merging scenario or with the monolithic scanario of the galaxy formation and evolution. Although the theoretical idea are quite well developed, today we are in the situation that the current available observational data do not permit any firm conclusions about the most correct models of galaxy evolution. Only few observational efforts have been done, in particular for studying the scaling relations at low and high redshifts, and the number of data is still very small for putting severe constraints on the origin of the tilt and the thickness of the FP.
We are currently facing these problems by exploiting the output of the survey WINGS. The clusters of galaxies are infact the ideal environment where to address such a study, for at least three reasons: 1) beacause many ET galaxies belong to clusters, in particular to their center, and it is possible to extract information on the role of the environment from the comparison between the properties of the scaling relations of the near and far away clusters; 2) because such comparison will give important constraints on

the evolution of the stellar population; 3) because it is possible to fix accurately the distance scale of the Universe.
Unfortunately, less good it is the situation for the spectroscopic data, although the new generation of spectrographs, such as VIMOS, will fill the gap with the photometric counterpart quite rapidly. The WINGS spectroscopic follow-up has been perfomed using WHT-WYFFOS (field ~ 1º×1º, ~100 galaxies in 1 exposure), and AAT-2dF (field ~ 2º×2º ~200 galaxies in 1 exposure). The spectral range is 3800÷8000Å with an intermediate resolution of 6÷9Å for measuring redshifts, equivalent widths and line indices of emission and absorption lines. Actually several clusters have been observed and the analysis is almost ready for ~5000 spectra. Many central velocity dispersions will be also soon available from the NOAO survey (Smith et al. 2004), which covers approximately the same sample of clusters.
The combination of these datasets will provide a fundamental database for addressing the problems connected to the scaling relations of ET galaxies in clusters. Star formation rates and histories, as well as metallicity estimates will be derived for hundreds of galaxies per cluster from the line indices and equivalent widths measurements, allowing us to explore the link between the spectral properties and the morphological evolution in high and low-density environments, across a wide range of cluster X-ray luminosities and optical properties.
At the end of this work we could manage the largest dataset of ET galaxies in clusters in the world. These data will be full of consequences for our understanding of galaxy formation and evolution in the cluster environment.

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Research Products:
Year 2000: 3 papers with referee
Year 2001: 8 papers with referee + 7 without
Year 2002: 2 papers with referee + 2 without
Year 2003: 5 papers with referee + 9 without
Year 2004: 1 paper with referee + 3 without

List of 5 most representative publications:
Rampazzo, R.; D'Onofrio, M.; Bonfanti, P.; Longhetti, M.; Reduzzi, L.
Comparative analysis of the properties of bright early-type galaxies in nearby clusters and in the field.
2000, ApL&C 40, 9

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2D modelling of the light distribution of early-type galaxies in a volume-limited sample - II. Results for real galaxies
2001, MNRAS 326, 1517

Fasano, G.; Bettoni, D.; D'Onofrio, M.; Kjærgaard, P.; Moles, M.
The scaling relations of early-type galaxies in clusters. I. Surface photometry in seven nearby clusters

2002, A&A 387, 26

Pignatelli, E.; Marmo, C.; Poggianti, B. M.; Bettoni, D.; Fasano, G.; Varela, J.; Moles, M.; Kjaergaard, P.; Couch, W.; Dressler, A.
WINGS: the first results
2003, Mem. SAIT Suppl. 3, 265

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2004, Mem. SAIT 75, 214