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The WINGS Survey: a progress report

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Abstract. A two-band (B and V) wide–field imaging survey of a complete, all–sky X–ray selected sample of 78 clusters in the redshift range $z = 0.04 - 0.07$ is presented. The aim of this survey is to provide the astronomical community with a complete set of homogeneous, CCD–based surface photometry and morphological data of nearby cluster galaxies located within 1.5 Mpc from the cluster center. The data collection has been completed in seven observing runs at the INT and ESO 2.2-m telescopes. For each cluster, photometric data of about 2500 galaxies (down to $V \sim 23$) and detailed morphological information of about 600 galaxies (down to $V \sim 21$) are obtained by using specially designed automatic tools. As a natural follow up of the photometric survey, we also illustrate a long term spectroscopic program we are carrying out with the WHT-WYFFOS and AAT-2dF multifiber spectrographs. Star formation rates and histories, as well as metallicity estimates will be derived for about 350 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- to low-density environments, and across a wide range in cluster X-ray luminosities and optical properties.

Key words. galaxies: clusters: general – galaxies: evolution – galaxies: structure

1. Introduction

Clusters of Galaxies are the largest, yet well defined, known entities in the Universe. The identification of their properties and content could led to use them as tracers of cosmic evolution since they can be detected at large distances.

Over the past five years, the cluster environment has been discovered to be the site of morphological transformations at a relatively recent cosmological epoch. Thanks to the high spatial resolution achieved with the Hubble Space Telescope (HST), it has been ascertained that the morphological properties of galax-

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ies in the cores of rich distant clusters largely differ from those in nearby clusters: at $z = 0.4 - 0.5$, spirals are a factor of 2-3 more abundant and S0 galaxies are proportionally less abundant, while the fraction of ellipticals is already as large or larger (Dressler et al. 1997; Smail et al. 1997).

On the basis of excellent seeing images taken at the NOT and La Silla-Danish telescopes (Fasano et al. 2002), we have filled in the existing gap of information between local ($z \leq 0.1$) and distant ($z \sim 0.4 - 0.5$) clusters, confirming that, as the redshift decreases, the S0 population tends to grow at the expense of the spiral population (Fasano et al. 2000). This work has also highlighted the role played by the cluster type in determining the relative occurrence of S0 and elliptical galaxies at a given redshift: clusters at $z \sim 0.1 - 0.25$ have a low/(high) S0/E ratio if they display/(lack) a strong concentration of elliptical galaxies towards the cluster centre.

Concerning the evolution of the stellar populations in cluster galaxies, ground-based spectroscopic surveys of the intermediate-redshift clusters observed by HST have offered a detailed comparison of the spectral and morphological properties, elucidating the link between the evolution of the stellar populations and the changes in galaxy structure (Dressler et al. 1999; Poggianti et al. 1999; Couch et al. 1994, 1998; Fisher et al. 1998; Lubin et al. 1998). 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 ellipticals and of (the few) bright S0 galaxies appear to be old and passively evolving. 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.

A crucial ingredient for all these evolutionary studies should be the comprehensive knowledge of the physical properties of galaxies in nearby clusters, in order to control their local variance, prior to draw any conclusion on cosmic evolution. When confronted with such kind of requirement one realizes that, while a large amount of high quality data for distant clusters is continuously gathering from HST imaging and ground based spectroscopy, our present knowledge of the systematic properties of galaxies in nearby clusters remains surprisingly poor. Actually, the only reference sample available in the nearby universe for photometry and morphology is the 'historical' one of Dressler (1980a,b), who lists positions, visual magnitudes and morphological classifications of galaxies, relying on photographic plates taken at Las Campanas 2.5-m, Kitt Peak 4-m and Palomar 1.5-m telescopes. Instead, no reference sample is available for spectroscopy. It is obvious that an adequate photometric and spectroscopic information on nearby clusters is missing and is crucial for studying the morphology and the stellar populations of galaxies in a systematic way, as well as for setting the zero-point for evolutionary studies.

2. The WINGS photometric survey

The above mentioned lack of systematic information from CCD material on nearby galaxy clusters is mainly due to their huge angular size, which prevented astronomers from gathering large datasets until wide field CCD cameras (WFC) became available. In the last years excellent WFCs became operative in imaging mode (WFI), such as those at the INT 2.5-m and ESO 2.2-m telescopes, as well as wide-field multifiber spectrographs, e.g. at the WHT 4.2-m and AAT 3.9-m telescopes. We exploited the new opportunity starting with a program named Wide–field Imaging Nearby Galaxy–cluster Survey (WINGS). WFI proposals were presented for both the northern and the southern hemispheres, resulting in seven observing runs, for a total of 18 nights (9 at the INT 2.5-m telescope and 9 at the ESO 2.2-m telescope).

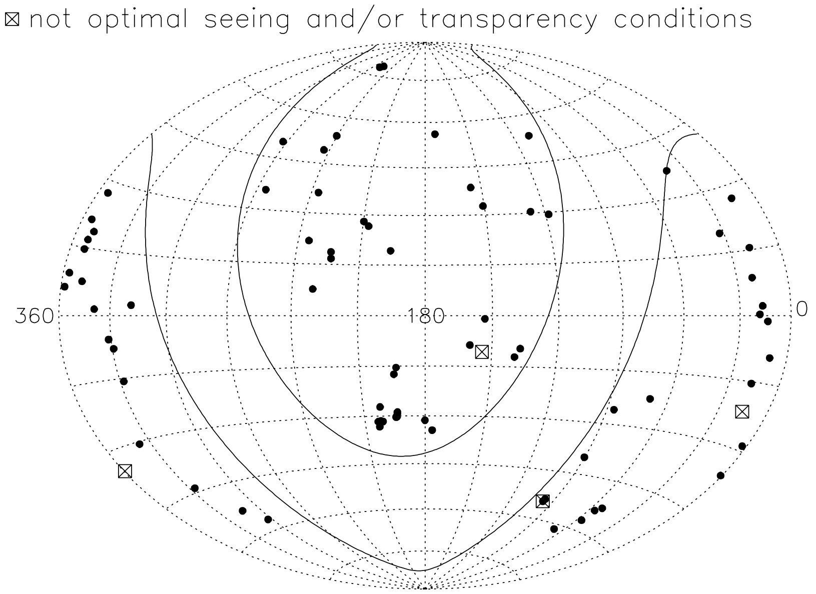

Fig. 1. All-sky aitoff map of the cluster sample (equatorial coordinates).

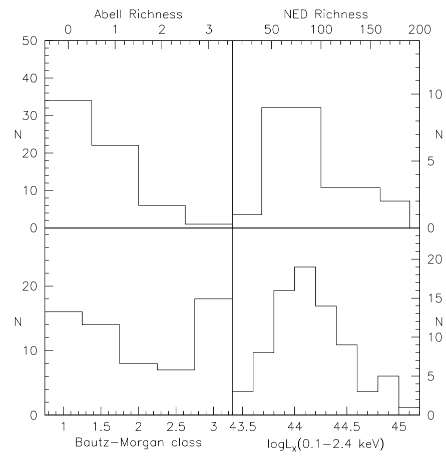

Fig. 2. Distribution of some cluster properties in our sample.

2.1. The sample of nearby clusters

The sample we observed has been selected from essentially complete X-ray (0.1-2.4 keV), flux-limited samples of clusters [XBACs: Abell clusters with $F_X \geq 5 \times 10^{-12}$ erg cm^{-2} s^{-1} (Ebeling et al. 1996); BCS+eBCS: northern clusters with $F_X \geq 2.8 \times 10^{-12}$ erg cm^{-2} s^{-1} (Ebeling et al. 1998, 2000)] compiled from ROSAT All-Sky Survey data. This sample is uncontaminated from AGNs and foreground stars and is not affected by the risk of projection effects as optically selected catalogs are.

Only clusters with galactic latitude $|b| > 20°$ in the redshift range $0.04 < z < 0.07$ have been included in the sample. The redshift upper limit ensures sufficient spatial resolution ($1'' = 1.3$ kpc at $z = 0.07$, $H_0 = 70$ km s^{-1} Mpc^{-1}), while the lower limit allows us to efficiently survey a sufficiently large area of the cluster (the central 1.5 Mpc^2 at $z = 0.04$), comparable to that observed at higher redshift with HST. Our aim is to cover a well defined area in physical terms, such as the r_{200} radius (the radius within which the average cluster density is 200 times the critical density) or the virial radius.

The final sample includes 78 clusters (42 in the southern hemisphere and 36 in the northern one, see Fig. 1), of which about a third are in common with the Dressler (1980) sample. This partial overlap will be useful for comparing the two data sets and cross-check the respective morphological classifications.

Fig. 2 presents the distribution of some 'popular' cluster properties in our sample, showing that it spans a broad range in both optical richness and X-Ray luminosity.

2.2. Observational strategy and data reduction

We decided to take images in the V and B bands. The former one allows us to compare our results with previous studies of nearby clusters, as well as with HST-WFPC2 (I_{814}) studies of clusters at $z \sim 0.5$. The second filter is valuable in order to get colors of galaxies and to compare with future HST(ACS)/NGST studies of clusters at $z \sim 1$.

For each cluster, three slightly offseted frames per filter have been obtained in order to improve the cosmetics of the final mosaics. The exposures taken with insufficient transparency and/or seeing were repeated in different nights and/or runs, until matching the required conditions (FWHM$\leq$1.2 arcsec). A total exposure time of 1200 s (in each band) was usually enough to reach a S/N per pixel of $\sim$2.1(1.7) in the $V(B)$ band.

During each night several photometric standard fields were taken at different positions and zenith distances in order to secure a careful determination of the calibration coefficients as a function of airmass, color and chip number. Also a number of astrometric and empty fields have been observed. The latter ones will allow us to estimate the field contamination to galaxy counts for different bins of magnitude. The former ones have been used to determine, for each filter, the astrometric solutions relative to each observing run. This is well known to be an important ingredient in the reduction procedure of WFI data, even as far as the photometric accuracy is concerned.

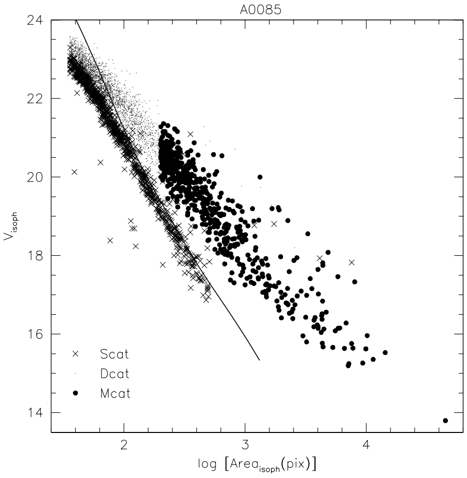

Fig. 4. Automatic S/G classification compared with the expected S/G partition line (see text) for the cluster Abell 85.

The standard IRAF-MSCRED package has been used for the basic reduction procedures (debiasing, flat-fielding), while the package WFPRED (Rizzi & Held 2003, in preparation) was used to perform astrometry, co-adding, mosaicing and alignment of images in different bands. A number of additional IRAF/shell scripts have been produced in order to make the whole reduction procedure fully automatic. As an example of the final result, Fig. 3 shows the INT-mosaic of the cluster Abell 2457 in the B band.

2.3. The catalogs

We used SExtractor (Bertin & Arnouts 1996) to produce a number of source catalogs for each cluster. Relying on extensive simulations of cluster fields, the S/N of our final V-band images turned out to be sufficient to make SExtractor able to provide a robust star/galaxy (S/G) sepa-

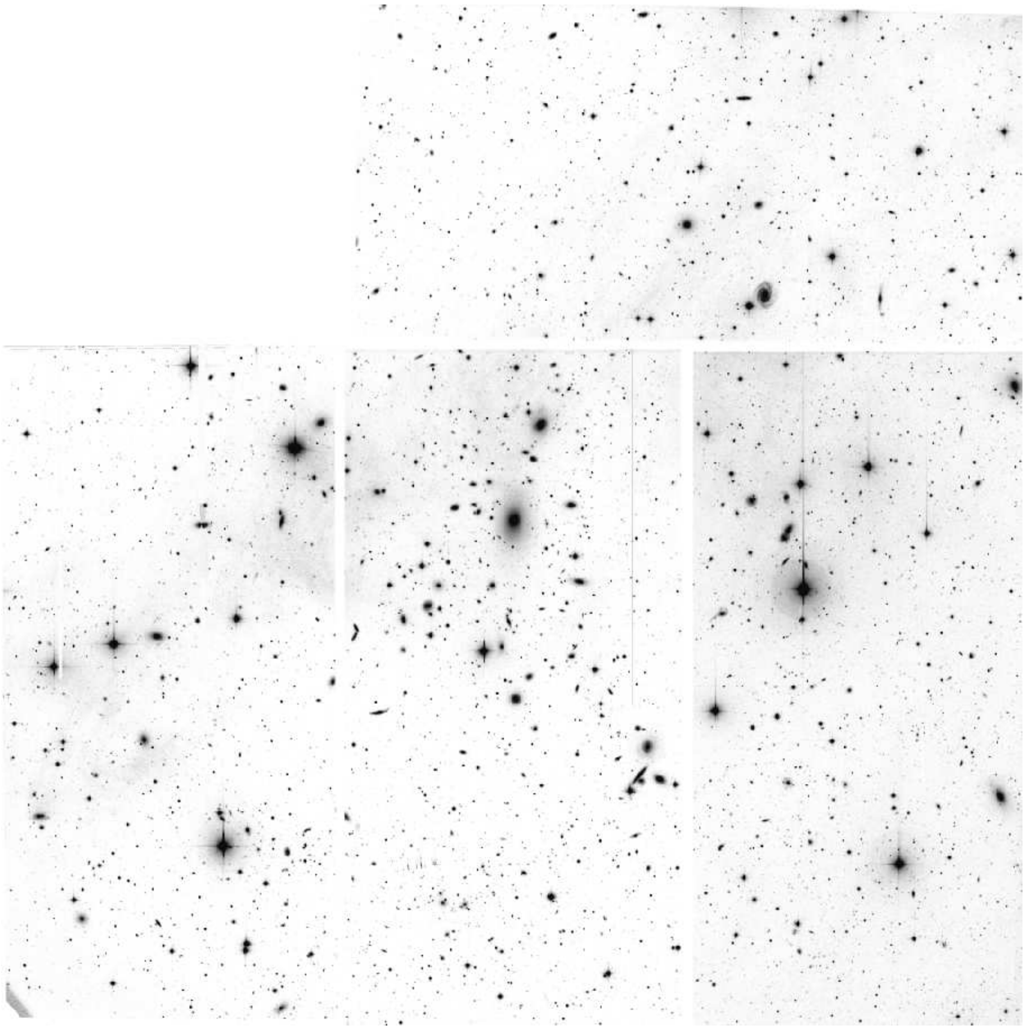

Fig. 3. INT mosaic of the cluster Abell 2457 in the B band.

ration down to a threshold ($1.5\times\sigma$) magnitude (area) of $\sim$23.5–24.3 (10–35 pixel), depending on both the sky surface brightness and seeing. Thus, for each cluster mosaic in the V band, the proper extraction limits of magnitude and area have been derived and four deep catalogs have been produced for: galaxies (Dcat; S/G$\leq$0.2), stars (Scat; S/G$\geq$0.8), other objects (Ocat; 0.2<S/G<0.8) and saturated sources (Satcat). Almost all objects with $V > 23$ turned out to belong to the Ocat catalog. An additional catalog for surface photometry and morphology of galaxies (Mcat; see next subsection) has been extracted from Dcat including only galaxies with threshold area A$\geq$200 pixel. Besides the different kinds of magnitudes (aperture, isophotal, total), all derived neglecting the color term, these catalogs contain some global information about size, ellipticity and position angle of objects. The V-

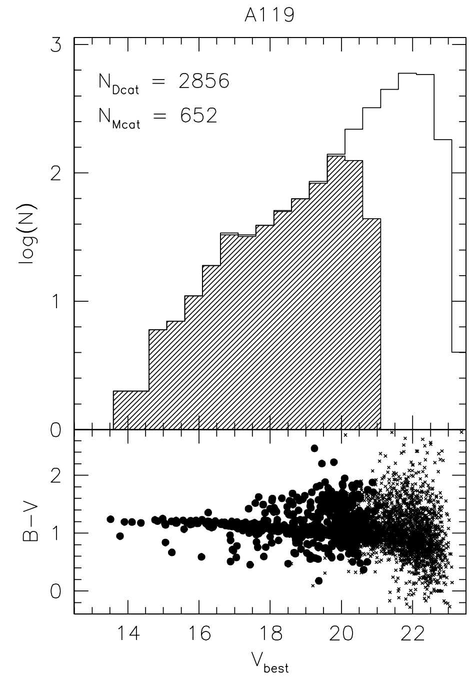

Fig. 5. Histogram of magnitudes (upper panel) and color–magnitude diagram (lower panel) of the cluster Abell 119.

band catalogs have been then used as reference lists to extract the corresponding catalogs in the B band, allowing us to measure the 5-kpc ($H_0 = 70$ km s^{-1} Mpc^{-1}) aperture colors and to evaluate the color corrected magnitudes in both the V and B bands.

The automatic S/G classifier can be sometime worsened by space–varying PSFs and blending. It has been improved interactively looking at the position in a plane like that of Fig. 4 (threshold area–V_{mag}), where the Star/Galaxy partition line, analytically derived from the proper PSF, is reported for the cluster Abell 85. This interactive cleaning task moves some automatically classified galaxies in the star catalog and viceversa.

In the upper panel of Fig. 5 we report the distributions of the total SExtractor magnitudes (V_{best}) from the galaxy catalogs Dcat and Mcat, relative to the cluster Abell 119. In the same panel also the number of galaxies in the two catalogs are indicated. The lower panel of the same figure illustrates the corresponding color–magnitude plot. Fig. 5 shows that the completeness of the bright and deep galaxy catalogs (Mcat and Dcat) is typically achieved down to $V \sim 20$ and $V \sim 22$, respectively, while the corresponding cutoff magnitudes turn out to be typically ∼1 mag fainter. Also typical are the sizes of the catalogs Mcat and Dcat indicated in the figure.

It is worth to note that, due to the extrapolation of the luminosity profiles (assumed Gaussian), the total galactic magnitudes given by SExtractor could be over–estimated up to 0.4-0.5 mag, the early–types being more biased than late–types (Fasano et al. 1998). This bias disappears if we consider the magnitudes from our surface photometry tool (see next subsection). However, the magnitudes of galaxies not belonging to the catalog Mcat need to be statistically corrected for the bias using concentration indices.

2.4. Surface photometry and morphology

The catalog Mcat contains those galaxies from the deep list (Dcat) that are large enough (A≥200 pixel) to be suitable for surface photometry and morphological analysis. This defines the reference list of galaxies to be processed by the automatic surface photometry tool GASPHOT.

The need for such a software has become more and more evident in the last years, as deep and/or wide imaging became more and more common. The usual 'one at a time' surface photometry tools (IRAF-ELLIPSE, Jedrzejewski 1987; AIAP, Fasano 1990) are clearly inadequate to process CCD frames containing several hundreds (or even thousands) of galaxies. For this reason we have developed a Galaxy Automatic Surface PHOtometry Tool (GASPHOT, Pignatelli & Fasano 1999) which is able to process 'all at once'

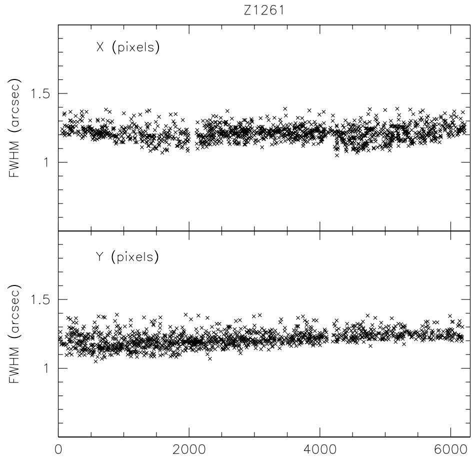

Fig. 6. FWHM along the X and Y axes for the cluster Z 1261.

a galaxy list like Mcat. It consists of four main tools:

- STARPROF produces a space–varying PSF profile. This is achieved by using an analytical (multi–Gaussian) representation of the PSF and turns out to be crucial in order to obtain reliable results in the morphological analysis (next steps), particularly when the variation of the FWHM along the axes is not negligible (see Fig. 6);
- SEXISOPH exploits SExtractor capabilities to produce luminosity, ellipticity and position angle profiles of the whole galaxy sample;
- GALPROF simultaneously fits the major and minor axis luminosity profiles of each galaxy by using a Sersic $r^{1/n}$ law and/or a two component ($r^{1/4}$ + exponential) profile, convolved in any case with the proper PSF. At variance with SExtractor, GALPROF produces unbiased estimates of the total magnitudes, independently on the morphological type. Fig. 7 and 8 illustrate the performances of GALPROF in recovering the Sersic's index of toy galaxies with $r^{1/4}$ and exponential luminosity profiles.

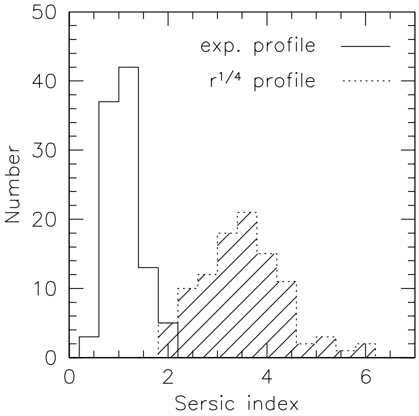

Fig. 8. Histograms of the Sersic index obtained by running GALPROF on a crowded artificial field containing 200 toy galaxies with different magnitudes and radii. Galaxies with exponential profiles (100 objects) are binned with the solid line histogram, whereas the dotted line histogram refers to galaxies with $r^{1/4}$ profiles.

- MORPHOT exploits some characteristic features of the luminosity and geometrical profiles, together with the Sersic index, to estimate the morphological type of individual galaxies.

For each cluster GASPHOT produces two more catalogs. The first one includes the whole set of luminosity and geometrical profiles obtained by SEXISOPH. The second one contains the photometric and morphological information extracted from the profiles by GALPROF and MORPHOT (effective radius and average surface brightness, total magnitude, Sersic index, B/D ratio, morphological type, etc.).

Luminosity profiles of faint and/or small galaxies are usually well enough represented by a simple Sersic law, even in case of multi–component objects (see Fig. 9). On the contrary, for bright and/or big galaxies two components are often necessary to model the luminosity profiles.

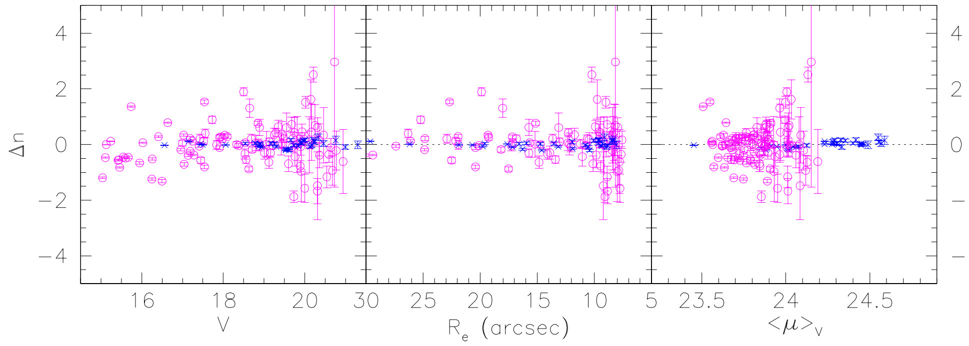

Fig. 7. Sersic index errors resulting from a GALPROF run on a grid of 200 toy galaxies with different magnitudes and radii. Exponential profiles (starred points) are much more precisely recovered with respect to the $r^{1/4}$ profiles (open circles).

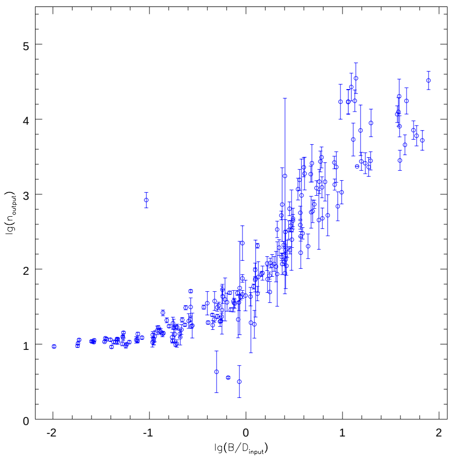

Fig. 9. Correlation between the Sersic index n resulting from GALPROF and the 'true' Bulge/Disk ratio for a sample of faint toy galaxies.

2.5. Status and perspectives

The data collection for the photometric survey has been completed in August 2002. The vast majority of the clusters in the sample (>90%) have been observed in good (sometime very good) weather conditions, making us confident that reliable photometric and morphological results will be obtained.

The INT–WFI frames have been fully reduced and most of the corresponding catalogs have been already extracted. They will be included in the first paper of the WINGS series (Fasano et al. 2003, in preparation). The morphological analysis of these clusters, which is presently being carried out with GASPHOT, will be the subject of a forthcoming paper. Concerning the ESO-WFI frames, the data reduction is currently in progress.

As stated in Sect. 1, The photometric WINGS survey has been conceived to fill in the lack of a systematic investigation of nearby clusters and their galaxy content. This is schematically illustrated in Fig. 10, where the limiting absolute magnitude and space resolution (in kpc) are reported as a function of redshift for most of the available and ongoing galaxy surveys. It can be seen that WINGS is the deepest ($M_V \sim -14$), best resolution (FWHM∼1 kpc) survey of a complete sample of galaxies in nearby clusters to date. For instance, even if the nominal resolution (FWHM in kpc) of WINGS is only slightly better than that of the survey of Dressler (1980), its data quality (CCD) is definitively better and its deep-

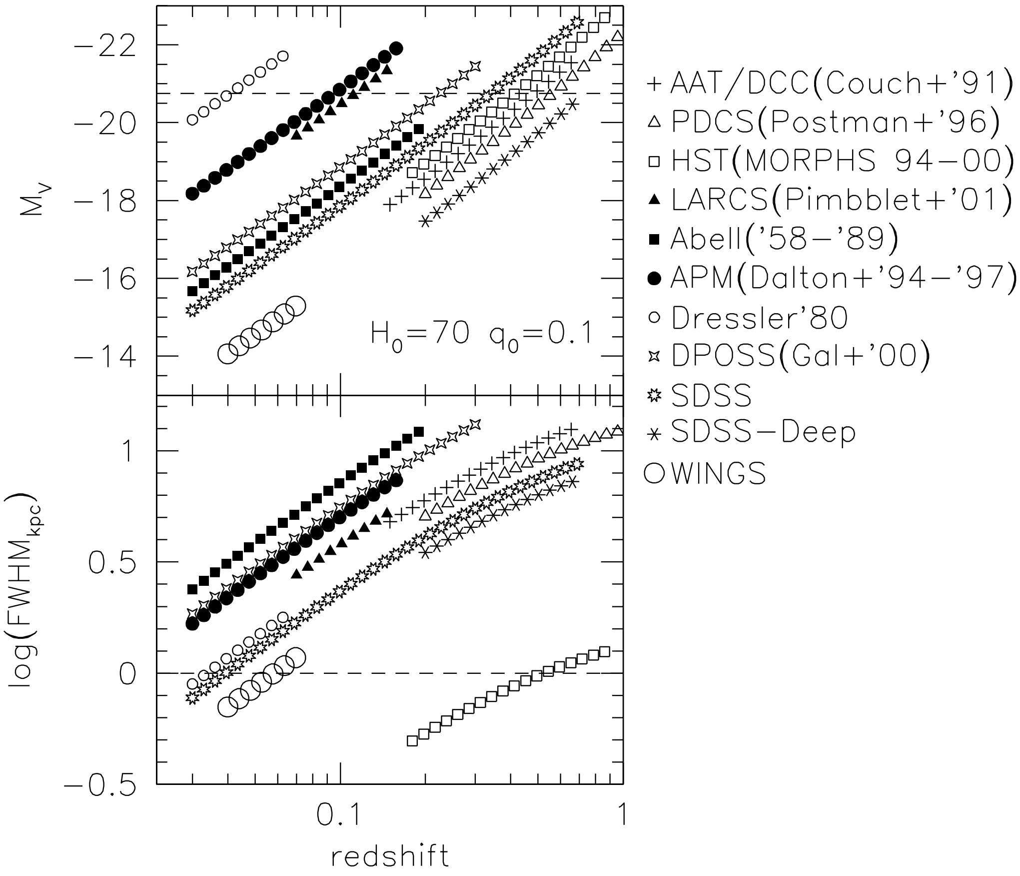

Fig. 10. Limiting absolute magnitude and space resolution (in kpc) as a function of redshift for most of the available and ongoing extragalactic surveys.

ness is incomparably better (~6 mag) with respect to the Dressler's survey.

This survey will produce detailed surface photometry and morphology for about $5{\times}10^4$ galaxies, while integrated photometry and rough structural parameters will be obtained for about $2{\times}10^5$ galaxies. This will represent the first CCD-based systematic investigation of the properties of cluster galaxies in the nearby universe and will provide a local reference sample for distant cluster studies.

What could we do with this huge dataset? The only limit we have is our imagination!

In the next few years deep imaging surveys of distant clusters will become an even stronger scientific drive for HST with the new Advanced Camera and will be parallelled by extensive spectroscopic surveys with 8-m class telescopes. While the high-z studies occupy the headlines, the knowledge of the local universe is crucial to allow a full exploitation of the high-z data.

Given the large cluster-to-cluster variations in properties and morphological content, a large and well-defined sample is needed to investigate in a systematic way what cluster property/ies are driving the variations in galactic properties.

We can do that! In fact, apart from a robust analysis of the global cluster properties (characteristic radius, total luminosity, ellipticity and shape, subclustering, etc.), this dataset will allow us to study with high statistical significance the global properties of cluster galaxies: luminosity function of different morphological types, morphological fractions E:S0:Sp:Irr, integrated colors, colour-magnitude diagrams, scaling relations ($< \mu_e > -r_e$–Sersic index). Besides, we will be able to look at all the above mentioned galactic properties as a function of the cluster properties (structure and concentration, X-ray and total optical luminosity), local density and clustercentric distance.

We plan to release the WINGS catalogs to the astronomical community in a couple of years.

3. The WINGS spectroscopic survey

The spectroscopic follow-up of WINGS (WINGS-SPE) is obtaining optical spectra of 300 to 500 galaxies per cluster in a statistically significant subsample of the WINGS clusters. This subsample consists of about 55 clusters with a range of X-ray and optical properties sufficiently large to explore the dependence on cluster properties. Clusters are known to lie on a 'fundamental plane' in a three-dimensional parameter space identified by optical luminosity, half-light radius and X-ray luminosity (e.g. Miller et al. 1999; Fritsch & Buchert 1999), and the deviations from such a plane are strongly correlated with substructure in the cluster. The cluster selection for WINGS-SPE ensures a coverage of this fundamental-plane over a factor of 30 in X-ray luminosity.

The only criterion for spectroscopic target selection is the galaxy total magnitude limit $V < 20$, corresponding to $M_B \sim -17$ (on average) over our redshift range. In addition, galaxies lying above the color-magnitude sequence in the $B - V$ color magnitude diagram are sampled at a lower completeness rate than those on and below the sequence. This selection criteria provide an unbiased magnitude-limit sample of galaxies representative of the whole cluster populations, while enhancing the probability to reject non-cluster members.

The magnitude limit for spectroscopy reaches more than 5 magnitudes down the galaxy luminosity function, thus 1.5 magnitude deeper than large area spectroscopic surveys such as the Sloan or the 2dF Galaxy Redshift Survey. The depth of the spectroscopy is important for two reasons. First of all, because it allows an unprecedented view of both massive and intermediate-mass galaxies in clusters, allowing an investigation of the stellar content and morphology as a function of the galaxy luminosity. Second, a wide magnitude coverage is needed for a useful comparison with distant cluster studies. In fact, a large fraction of the luminous star-forming galaxies at high z are expected to fade significantly as a consequence of the decline in their star formation, thus populating the intermediate-to-faint luminosity regime in the nearby clusters.

WINGS-SPE is a long term spectroscopic campaign that has begun in semester 2002B and will stretch over (at least) two semesters. Fifteen nights of spectroscopy have been allocated so far. The spectra are obtained with a multifiber technique with the WYFFOS spectrograph at the William Herschel Telescope and the 2dF spectrographs at the Anglo-Australian Telescope. The use of both facilities is vital for the project, because the Northern and the Southern hemispheres contain the X-ray faintest and X-ray brightest subsets of the clusters, respectively.

Spectra cover the range 3600-8000 Å (with 2dF) and 3800-7000 Å (with WYFFOS), at a resolution of 9 and 6 Å, respectively. The wide magnitude range of the galaxies requires two different fibre configurations per cluster with different exposure times. From the spectra we are measuring redshifts, line indices and equivalent widths of the main absorption and emission features, which provide cluster membership, star formation rates and histories, and metallicity estimates.

Obviously, this dataset is suitable for addressing numerous scientific issues. Our primary goal is to study the issues described below.

3.1. The link between star formation and galaxy morphology in dense environments

The WINGS sample is unique in terms of the detailed, quantitative morphological information that is available for its galaxy populations. This virtue is particularly important when combined with similarly detailed information about the star formation activity and metal content of these galaxies.

Extensive work on galaxy clusters at high redshift has demonstrated that the combination of morphological and spectroscopic information is a powerful tool in the study of galaxy evolution (Dressler et al. 1999; Poggianti et al. 1999; Couch et al. 1998). High-z observations suggest that stellar populations in cluster ellipticals are old, while star formation in disk galaxies had a steeper evolution in clusters than in the field.

A similar study is missing in the nearby Universe. Studies of a few low-z clusters (Kuntschner & Davies 1998; Smail et al. 2001; Poggianti et al. 2001) have begun to uncover a difference in the age distributions of S0 and E galaxies, which is consistent with the hypothesis that star-forming spirals are transformed into passive S0s.

Based on WINGS spectra, we are currently exploring the stellar ages and metallicity of galaxies as a function of their Hubble type and luminosity. This will clarify whether the differences between S0s vs Es are a widespread phenomenon in clusters, will elucidate the spectroscopic properties of the cluster spirals and what is the incidence of passive, red spirals in high- to low-density regions.

3.2. The dependence of star formation on clustercentric position, local density and cluster properties

The effects that different physical mechanisms (ram pressure stripping, tidal encounters, loss of halo gas etc.) have on galaxy evolution are expected to vary with the local density and/or the global cluster properties and accretion history. Having a wide-area dataset of a large and variegate sample of clusters, we hope to isolate the different effects to understand what processes have a noticeable influence on galaxy evolution, and how they modify galaxies' star formation history. In fact, we are carrying out a simultaneous analysis of the galactic properties *and* their environment, with the aim of understanding how galaxy evolution is related with the cluster/group mass, with the amount of substructure and ongoing merging of groups and clusters, with the intracluster medium local density and metallicity.

3.3. The comparison with distant clusters

Finally, WINGS-SPE represents the first local spectroscopic database of its kind that can be used as a baseline for comparison with clusters at higher redshift. For this work, aperture effects need to be taken into account, since slit spectra at high z typically cover much larger galactic areas than the fibre spectra at low z. However, this problem is mitigated by the fact that aperture effects can be estimated from radial color gradients within each galaxy, based on the precision photometry of WINGS, using the fact that color and spectral type are largely correlated.

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