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The Low Surface Brightness Dwarf Members of Nearby Groups of Galaxies

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Abstract

We present the photometric and spectroscopic results of a survey done in a wide-field area of nearby groups and poor clusters. The main goals are identifying and characterizing the properties of low-surface-brightness dwarf galaxies and determining the galaxy luminosity function for $M_V > -13$. We surveyed areas (typically 0.1–1.0 degree^2) of the groups NGC 6868 (Telescopium), NGC 5846, HCG 42, Hydra I, Dorado and the poor clusters IC 4765 in V and I. In this work we present the results and the analysis of the photometry and spectroscopy done in four groups: HCG 42, NGC 6868, NGC 5846 and IC4765. In these groups, we detected hundreds of new low surface brightness dwarf galaxies. The analysis of their spatial distributions, colors, galaxy luminosity function and other propierties are presented.

1.1 Introduction

Many of the galaxies in the Universe are concentrated in low-density environments like groups. Except for the Local Group and other nearby structures (e.g. M81, Sculptor, Leo I), little has been done to characterize the galaxy population in these environments. Group of galaxies contain few bright galaxies with known redshifts and for magnitudes fainter than $M_V = -16$, the galaxy population is poorly know, basically because the spectroscopic redshift for low-luminosity (dwarf) galaxies are difficult to obtain. This had a direct impact in the determination of the luminosity function at fainter limits, where the dwarf galaxies dominate the galaxy counts.

Dwarf galaxies (dE, dSph, dIrr) are the most common type of galaxies in the Local Universe. They are thought to be the single systems with the largest dark-matter content, with M/L ratios as high as that of groups and poor clusters (Carignan & Freeman, 1988). Hence their spatial distribution and mass spectrum may give us important insight into the spatial scales over which mass is distributed in the Universe. However, because of their low luminosity and low surface brightness our understanding of these objects is rather limited. Dwarf galaxies in nearby clusters and groups have been studied in detail with photographic material (e.g. Impey et al. 1988, Ferguson & Sandge 1991). With the advent of large-format CCDs, the searches for low-surface brightness dwarf members have become possible in wide-field CCD images of nearby groups and clusters (e.g. Carrasco et al. 2001, Carrasco 2001, Trentham & Tully 2002).

The main goal of our project is to identify the population of low-surface-brightness dwarf

Table 1.1. *Main parameters of the observed groups*

Group	α(2000) [hh mm ss]	δ(2000) [dd mm ss]	N_{tot}	N_{grp}	V_{avg} [km/s]	σ_r [km/s]	D [h^{-1} Mpc]	R_{200} [h^{-1} Mpc]
HCG 42	10 00 11.4	–19 37 02	204	36	3828±51	211^{+30}_{-43}	54.5	0.67
NGC5846	15 06 28.5	+01 35 10	134	32	1950±75	416^{+43}_{-63}	24.1	1.18
IC 4765	18 47 32.9	–63 18 46	167	94	4488±65	620^{+40}_{-50}	60.9	1.66
NGC 6868	20 09 43.0	–48 17 08	57	19	2844±57	238^{+29}_{-49}	32.7	0.50

(LSBD) galaxies in nearby groups to M$_V = -10$ mag and determine the luminosity function in each of the groups. The selected sample is formed by groups with different environments, poor groups like Dorado and NGC 6868 and rich groups like Hydra I and IC 4765 with galaxy populations of different sizes and morphological mixtures. The program was started with the observation of the Dorado group (Carrasco et al. 2001a), at $cs \sim 1200$ km/s, and continued with the observation of other seven nearby groups with $1000 < cz < 4500$ km/s. The aim of this paper is to present the results of the study of the dwarf galaxy population in four of the groups: HCG 42, IC 4765, NGC 5846 and NGC 6868.

1.2 Data Acquisition and Reductions

The groups were observed in February and March 1998, with the 1.3m Warsaw telescope (Las Campanas Observatory, Chile), using the standard Johnson V and Cousins I filters. All data were taken under photometric conditions except for one of the fields in NGC6868, with a seeing ranging from 1” to 1.3”. For each group, except for NGC6868, two or three images just outside the groups were taken as a control fields. The targets were observed with a small overlapping region between the fields in order to check the photometry and estimate the photometric errors. The images were bias/overscan-subtracted, trimmed and flat fielded using standard procedures. The zero point calibrations were obtained using standard stars from Landolt (1992).

The spectroscopic observations were done in July 1999 and March 2000, with the 2.5m Du Pont telescope at Las Campanas Observatory, using the the Wide Field CCD camera (WFCCD) in multi-object mode. The spectra were observed with a low resolution red grism (wavelength coverage $\lambda \sim 3800-7600$Å, dispersion $\sim$ 4Å/pix, resolution $\sim$ 8Å). All galaxies with $V \leq 21$ mag from the photometric catalogs, including the LSBD galaxies detected in the groups (see below), were selected for spectroscopic observations. Tipically, 30 to 40 spectra per mask were observed.

Table1.1 shows the main parameters of observed groups. The average velocity were calculated using the bi-weigthed estimators (Beers, Flynn & Gebhardt 1990) and using all galaxy members with known redshift from this work and from the literature. The two last column in the table are the distance (H_0 = 75 km/s/Mpc) and the radius where the density is 200 times the critical density (R_{200}).

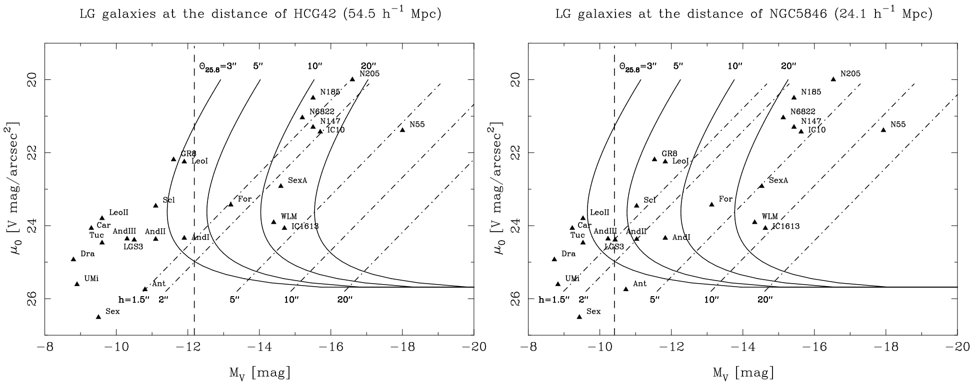

Fig. 1.1. $\mu_0 - M_V$ plane for the LSBD galaxies detected in HCG 42 (left) and NGC 5846 (right) groups.

1.3 Results

1.3.1 Photometry

The detection, photometry and classification of the objects were performed using the Source Extractor (SExtractor) software program (Bertin & Arnouts 1996). Before running SExtractor, we removed all bright galaxies, saturated stars and diffuse light from the fields. After sky subtraction, all objects with a threshold $\geq 1.1\sigma$ in V (25.8 mag/arcsec^2) and $\geq 1\sigma$ in I ($\sim$ 24.4 mag/arcsec^2) above the sky level and with a minimum area of 10 pix^2 ($\sim$ 1.8 arcsec^2) were found and extracted (the V images were used as a templates for the detection of the objects).

The selection of the LSBD galaxies was done using the the parameters given by the exponential profile fit (central surface brightness, the scale length and the limiting diameter). The fit to a pure exponential law was used to obtain the extrapolated central surface brightness and the scale length of the dwarf galaxy candidates in the sample. These two parameters are used as a primary cut of the data. LSBD dwarf galaxy candidates with $\mu_0 \geq 22$ V mag/arcsec^2 and scale length $h > 1.5$" were selected. The surface brightness cut is similar to that used by Impey et al. (1988) to search for LSBD galaxies in Virgo. The second cut was done selecting galaxies with a limiting angular diameter larger than 1.2 h^{-1} kpc at the given isophotal level. These limiting diameters are similar to those used to select the LSBD galaxies in the Dorado group. We used also an optimization method (smoothed filter, see the details in Carrasco et al. 2001) to search for galaxies with large profiles and very low surface brightness galaxies.

Ninety new LSBD galaxies were detected, for a cut in diameter of 1.2 h^{-1} kpc. Figure 1.1 shows the $\mu_0 - M_V$ plane for the LSBD galaxies detected in HCG 42 and NGC 5846. For comparison, we also plotted Local Group dwarf galaxies at the distance of these two groups (not shown here) where we can see that galaxies like Carina, Draco and Umi would not be detected in our survey but Fornax and SculptorŰ-like galaxies were detected.

Monte Carlo simulations were performed on the science frames in order to have the same characteristics as a real image. The computed completeness fraction of the sample for galaxies with magnitudes and sizes typical of LSBD found at the redshift of HCG42 and NGC5846 is $\sim$ 80% for galaxies with $22.5 < \mu_0 < 24.5$ V mag/arcsec^2 and $V < 20$ mag.

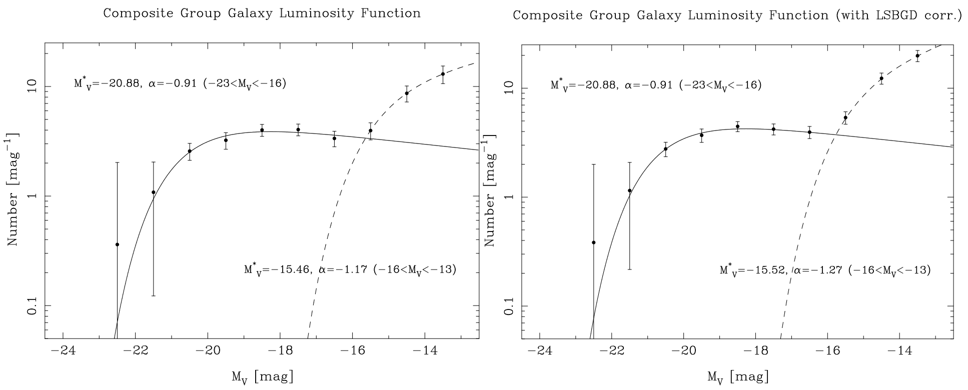

Fig. 1.2. Composite Group Luminosity Function (CGLF) for group sample. Left panel: CGLF without the correction for incompleteness in the detection of the low-surface brightness dwarf galaxies. Right panel: CGLF with the correction in the detection of the low-surface brightness dwarf galaxies.

Using the smoothed filter (optimization, see above), the completeness fraction increases from $\sim 60\%$ to $\sim 80\%$ for $V < 20$ mag. The differences in magnitude and in the cetral surface brightnesses are lower than 0.3 mag. However, the scale length output values are, on average, larger than the input ones by $\sim 20\%$.

1.3.2 Spectroscopy

Radial velocity measurements for $\sim$ 400 galaxies were obtained. Of these, only 78 are members of the groups. We also identified new structures behind the groups. In particular, HCG 42 shows two wellŰ defined background structures with $cz = 54541 \pm 202$ km/s, $\sigma_r = 853^{+103}_{-159}$ km/s (HCG42-Back1, $N_{mem} = 26$) and $cz = 72981 \pm 101$ km/s, $\sigma_r = 311^{+42}_{-43}$ km/s (HCG42-Back2, $N_{mem} = 16$). In addition, the distribution of the galaxies in HCG42 suggests the presence of two voids at $cz \sim 30000$ km/s and $cz \sim 44000$ km/s. The poor cluster IC 4765 also shows a well defined background with a $cz = 10975 \pm 125$ km/s, $\sigma_r = 461^{+66}_{-115}$ km/s (IC4765-Back1,$N_{mem} = 16$).

1.3.3 Galaxy Luminosity Function

We determined the using group galaxies with and without corrections for incompleteness in the detection of the low-surface brightness dwarf galaxies. Figure 1.2 shows the Composite Galaxy Luminosity Function (CGLF) for the groups without the completeness correction (left) and with the completeness correction (right plot) in the detection of LSDBs (the completeness corrections were calculated using Monte Carlo simulations, see above). The results show that a single Schecter function does not provide a good fit to the data, i.e. the luminosity function shows a bi-modal distribution, with a similar faint-end slope of $\alpha \sim -1.2$ The results are in agreement with the results found in the Local Group and other groups and clusters (e.g. Pritchet & van den Bergh 1999; Zabludoff & Mulchaey 2000; Trentham & Tully 2002).

1.4 Summary

Ninety new LSBD galaxies were detected in the group sample. Following Carrasco et. al (2001), extensive simulations were done to determine the completeness of our sample and characterize the success of detection. We find that galaxies like Sculptor and Fornax are easily detected at the distance of the groups. Spectroscopic redshifts of ~ 400 galaxies in the field of the HCG42, NGC5846, IC4765 and NGC6868 groups were obtained. The results show that only 78 galaxies are members of the groups. Galaxies up to 100000 km/s were identified in our spectroscopic survey. Several new structures were identified behind the groups. In particular, in the region of the HCG42 we found two new clusters and a filamentary distribution of the galaxies up to 75000 km/s. Two voids are clearly presented in the distribution. We find that the projected radial distribution for the dwarf red and blue galaxies is the same. However, the distribution in the velocity space shows differences, suggesting that the two population occupy different orbits (blue low surface brightness galaxies show a larger peculiar motion than the red population). Finally, The composite luminosity functions, determined using group galaxies with and without corrections for incompleteness in the detection of the low-surface brightness dwarf galaxies show that a single Schecter function does not provide a good fit to the data, given a bi-modal distribution, with a similar faint-end slope. This faint-end slope found in this and other works is difficult to reconcile with the slope predicted by the Cold Dark Matter theory ($\alpha \sim -1.2$).

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