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THE LOW SURFACE BRIGHTNESS MEMBERS OF NEARBY GROUPS

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We are undertaking a large, wide-field survey 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 $M_R > -17$. Large areas (typically 0.3–0.5 degree^2 per system but up to 7 degree^2) of the groups Telescopium, Leo I, Dorado, N5575, HCG 42, HCG 44, HCG 68 and the poor clusters IC 4765 and Hydra have so far been surveyed in V and I. We present the preliminary results for the photometric study of the groups HCG 42, Telescopium (or NGC6868) and IC4765. Hundreds of new low surface brightness galaxies are catalogued. Their spatial distributions, colors, types and sizes will be studied as a function of the richness of their environments.

1 Introduction

Dwarf galaxies are the most common type of galaxies in the local universe. In addition, 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 [1]. 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, they are also the hardest galaxies to observe, due to their low-surface brightnesses and low luminosities. Only recently it has become possible to obtain deep, wide-field CCD *photometry* of significant numbers of these galaxies, mostly in clusters. *Spectroscopy* of such low luminosity systems is, however, still a challenge even with large-class telescopes unless emission lines are present.

Dwarf galaxies in nearby clusters and groups have been studied in detail with photographic material [2,3,4,5,6,7]. Only recently, with the advent of large-format CCDs, have these searches become possible in wide-field CCD images of nearby groups and clusters [8,9]. From these works we learned that the dwarf elliptical (dE/dS0) galaxies dominate the faint-end of the number counts in clusters while the dwarf-irregular population is the more numerous in poor groups and in the field. However, our own Local Group seems to be an exception, with a larger number of dwarf spheroidals than irregular galaxies.

The main goal of our project is to identify the population of low-surface-brightness (LSB) dwarf 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 [10], 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 preliminary results of the study of the dwarf galaxy population in three of the groups observed, HCG42, IC4765 and NGC6868.

2 The sample, data acquisition and photometry

- HCG42: This compact group is centered around the giant elliptical galaxy NGC3091 (radio source) and contains other four bright member galaxies.
- IC4765: This is a rich southern group fairly close to the galactic plane ($b \sim -23$). It is dominated by the central D galaxy IC4765 and by the barred galaxy IC4769 (Seyfert 2) that lies 12 arcmin away to the north. It was defined as an interacting pair: a spiral-poor group centered around IC4765 and a spiral-rich group centered on IC4769 [11].
- NGC6868: is a loose structure dominated by the giant elliptical galaxy NGC6868 (type E2). The group covers an area of 2×2 deg^2 on the sky with an elongated form in the NE-SW direction.

Table 1 shows some relevant observed properties of the groups.

The groups were observed in February and March 1998, with the 1.3m Warsaw telescope (Las Campanas Observatory, Chile). The standard Johnson V and Cousins I filters were used to obtain the images. All data were taken under photometric conditions except for one of the fields in NGC6868, with a seeing ranging from 1" to 1.3". The areas covered in each group are 1425, 388 and 394 arcmin^2 for HCG42, IC4765 and NGC6868 respectively. For each group, except for NGC6868, two or three images just outside the groups were taken as 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 [12].

The detection, photometry and classification of the objects were performed using the Source Extractor (SExtractor) software program [13]. 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 (25.7 mag/arcsec^2) and $\geq 1\sigma$ in I (~ 24.4 mag/arcsec^2) above the sky level and with a minimum area of 10 pix^2 (~ 1.8 arcsec^2) were found and extracted.

Photometry of all selected objects in both filters was done using elliptical apertures. Total magnitudes were computed using the Kron's "first moment" algorithm $r_1 = \sum rI(r)/\sum I(r)$. The catalogs in both filters were matched in order to obtain color information for all objects. Colors were determined by measuring magnitudes in a circular aperture of 3" of diameter, in both filters.

3 Preliminary analysis and results

The galaxies were selected using the classification given by SExtractor, i.e. objects with stellarity index ≤ 0.35 (this index varies from 0: galaxies to 1: stars). This classification was

Table 1: Some relevant properties of the observed groups

Group	$\alpha(2000)$	$\delta(2000)$	$V_{\odot}$	σ	M_V	$N_{mem}^{(a)}$	A_V	Other names
HCG 42	10 00 13.0	-19 38 29	3828 [14]	211	0.42 [14]	22	0.13	
IC 4765	18 47 15.0	-63 21 59	4570 [15]	551	2.97 [17]	118	0.30	S805, DC184-630
NGC 6868	20 09 43.0	-48 17 08	2762 [16]	213		5	0.16	Telescopium

(a) number of bright galaxy members with known redshifts from the literature.

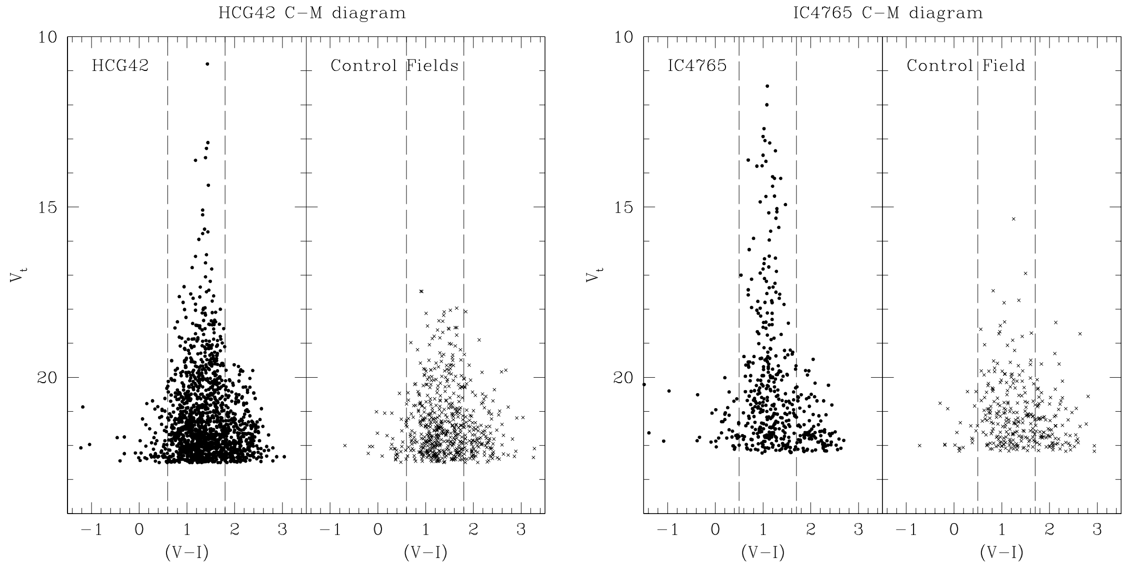

Figure 1: Color-magnitude diagrams for the HCG42 (left panel) and IC4765 (right panel) groups and for the control fields down to a limiting magnitude of $V = 22.5$. Colors and magnitudes are corrected for interstellar extinction. The dashed lines show the region within which the LSB are expected to lie ($0.5 \leq (V - I) \leq 1.7$).

checked by visual inspection of a subsample of galaxies and is adequate down to $V \sim 22.5$ for objects with stellarity index ≤ 0.35. For the brightest galaxies in each group, we calculated the total magnitudes and colors via surface photometry using the program ELLIPSE in the STSDAS package inside IRAF. In order to check the photometry and estimate the errors, we have compared the total magnitudes of all objects (galaxies and stars) in the overlapping regions of adjacent fields. The results for the three groups show an average difference of 0.016 ± 0.020 mag for $V \leq 20$ and $\Delta V < 0.3$ for objects close to the completeness limit ($V \leq 22.5$). Figure 1 shows the color-magnitude diagram for the galaxies in the groups HCG42 and IC4765 (left and right panels respectively) and for the galaxies in the control fields (plots on the right in both panels).

The selection of the LSB dwarf galaxies was done using the color information and the parameters given by the exponential profile fit (central surface brightness, the scalelength and the limiting diameter). Fig. 1 suggests that the dwarf galaxy population may be populating the region between $0.5 \leq (V - I) \leq 1.7$ mag (in general, the LSB dwarf galaxy population shows a median color of $V - I = 1.0$ with a dispersion of ± 0.6 mag [18,8]. As we can see, this galaxy population is absent in the control field. Using the area within the broken lines in Fig. 1 to restrict our sample, we used the structural parameters of the galaxies to select the LSB dwarf galaxy candidates in the groups.

The radial profiles of the dwarf galaxies fainter than $M_V \sim -17$ are in general well fit by an exponential profile of the form:

$$\mu(r) = \mu_0 + 1.086(r/h) \tag{1}$$

where μ_0 is the extrapolated central surface brightness and h is the scalelength obtained by the fit.

The fit to a pure exponential gave the scalelength of the dwarf galaxy candidates and was extrapolated to obtain the central surface brightness. These two parameters are used as a primary cut on the sample. LSB dwarf galaxy candidates with $\mu_0 \geq 22$ V mag/arcsec^2 and scalelength $h > 1.3$" were selected. The surface brightness cut is similar to that used in the selection of LSB galaxies in Virgo[4]. A second cut was done selecting galaxies with a limiting angular diameter larger than 4" (HCG42), 3" (IC4765) and 5" (NGC68678) at a given isophotal level. These limiting diameters are similar to those used to select the LSB dwarf galaxies in the Dorado group (0.83 h_{75}^{-1} kpc, where h_{75} is the ratio of the Hubble constant used to $H_0 = 75$ km/s/Mpc). The limiting diameter can be expressed as follows

$$\theta_{lim} = 0.735(\mu_{lim} - \mu_0)10^{0.2(\mu_0 - m_{tot})} \tag{2}$$

where μ_{lim} is the surface brightness at the limiting isophote and m_{tot} is the total magnitude of the object.

Figure 2 shows the $\mu_0 - V_{tot}$ plane for the LSB dwarf galaxies detected in the HCG42, IC4765 and NGC6868 groups after the cuts described above (small solid circles). For comparison, we plotted in both diagrams the Local Group dSph galaxies (solid squares) redshifted to the distance of the groups. From the figure we can see that only the brightest dSphs of the Local Group could be detected (like Fornax and Sculptor) at the distances of the groups (47.6, 59.2 and 36.3 h_{75}^{-1} Mpc for HCG42, IC4765 and NGC6868 respectively).

In order to check how many galaxies we lost using the selection criteria applied above, we performed a series of add-galaxy experiments. The observed frames were used for these experiments to insure the proper accounting of cosmetic defects, crowding, light gradients, noise and seeing. For each image we simulated galaxies with exponential profiles with scalelengths and central surface brightnesses typical of low-surface brightness galaxies at the redshift of the groups. Each artificial galaxy was convolved with a Gaussian point spread function constructed from bright stars in the frame. Then, for each bin of central surface brightness ($22 \leq \mu_0 \leq 25$) we generated 400 randomly distributed disk galaxies in groups of 20 (5 for the brightest bins) with magnitudes between 16.0 – 23.0 (in bins of 0.5 mag). Then we ran the SExtractor program with the same detection parameters previously used for the real-galaxy detection. After that, the output catalogues were matched with the input ones to detect the simulated galaxies with stellarity index ≤ 0.35. The extrapolated central surface brightnesses, the angular scalelengths and the limiting diameters were then calculated and compared with the input parameters.

The results of the simulations for the HCG42 group are shown in Figure 3. The left panel shows that the completeness fraction is, on average, $\sim 75\%$ for galaxies with central surface brightness between $22 - 24$ mag/arcsec^2 and brighter than $V = 20$ mag. The completeness fraction for galaxies with $22 \leq \mu_0 \leq 23$ decreases very quickly at fainter magnitudes. This could be an effect of a bad classification of the Sextractor program where the compact, high-surface brightness objects are easily confused with stars and missed from the catalogue (if these exist). However, the numbers of these objects may be small.

For galaxies with a central surface brightness fainter than 24 V mag/arcsec^2, the completeness fraction is 60% and lower. The right panel in Fig. 3 shows the differences between the

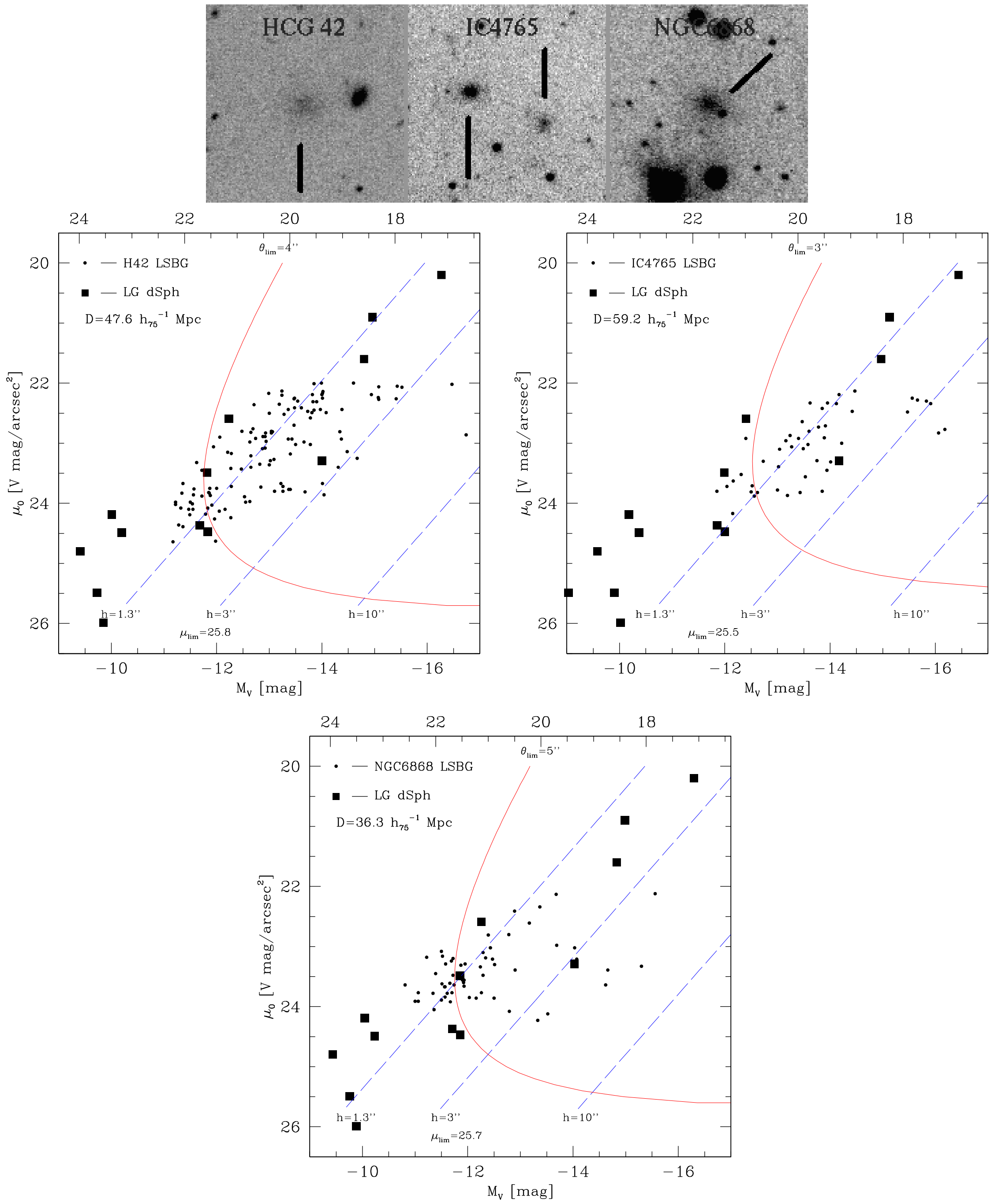

Figure 2: Upper panel: a mosaic of selected LSB dwarf galaxies detected in the groups (each box has a size of 1×1 arcmin^2); Lower panel: extrapolated central surface brightness versus total magnitude for LSB dwarf galaxies detected in the HCG42, IC4765 and NGC6868 groups respectively (small solid circles). For comparison, we show the Local Group dSphs galaxies (solid squares) redshifted to the distances of the groups (46.7, 59.2 a 36.3 h_{75}^{-1} Mpc for HCG42, IC4765 and NGC6868 respectively.)

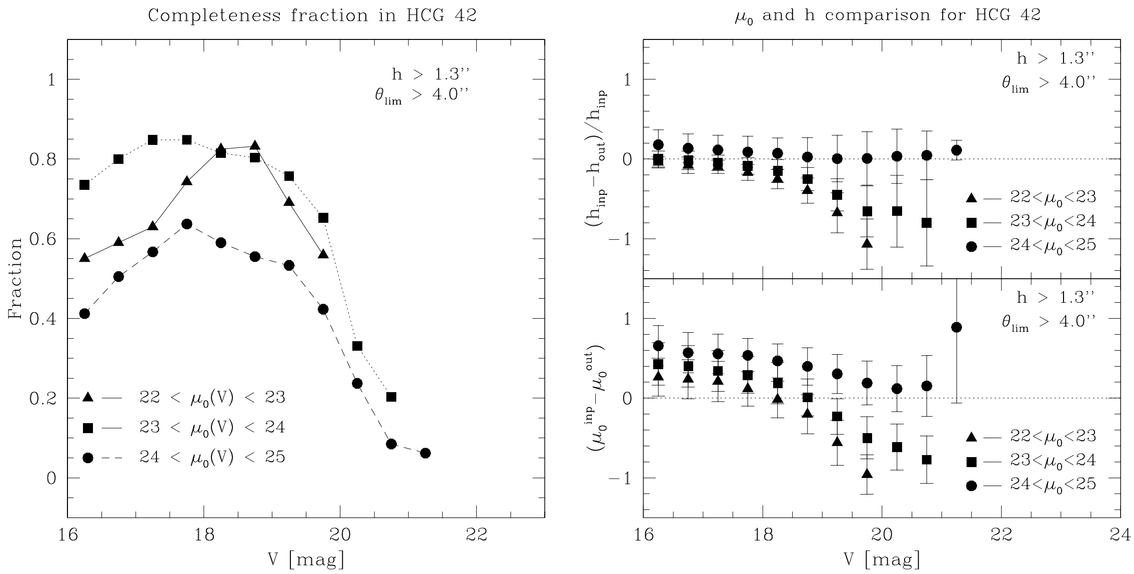

Figure 3: Completeness fraction as a function of the total magnitude. Right panel: Comparison between the input and output scalelengths (in percentage) and central surface brightnesses for simulated galaxies.

input and output central surface brightnesses (in magnitudes) and scale factors (in percentage) of the simulated galaxies. To $V \sim 19$, the mean difference is about 30% in the scale factor, and 0.5 in μ_0. These results are in agreement with those obtained for the Dorado group [10]

4 Summary

More than a hundred LSB dwarf galaxy candidates with $\mu_0 \geq 22$ V mag/arcsec^2, $h \geq 1.3$", $\theta_{lim} \geq 3$" and with $0.5 \leq (V - I) \leq 1.7$ were found in the groups HCG42, IC4765 and NGC6868. Our add-galaxy experiment showed that the completeness fraction was, on average, about $\sim 75\%$ for galaxies with $22 \leq \mu_0 \leq 24$, $V \leq 20$ and $\sim 50\%$ for lower surface brightness galaxies. After correction by completeness and background galaxies, we found an excess of LSB dwarf galaxies in the fields of the groups that must be group members. Further work will add the data of all groups together to determine the combined luminosity function. In addition, we plan to study the spatial distributions, colors, types and sizes of the dwarf galaxies as a function of the richness of their environments.

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