Photometric study of the IC 65 group of galaxies^{★,★★}

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ABSTRACT

Context. A large fraction of stellar mass is found to be located in groups the size of the Local Group. The evolutionary status of poor groups is not yet clear and many groups could still be at an early dynamical stage or even still forming, especially the groups only containing spiral and irregular galaxies.

Aims. We carried out a photometric study of a poor group of late-type galaxies around IC 65 (a) to search for new dwarf members and to measure their photometric characteristics, (b) to search for possible effects of mutual interactions on the morphology and star-formation characteristics of luminous and faint group members, and (c) to evaluate the evolutionary status of this particular group.

Methods. We made use of our *BRI* CCD observations, DPOSS blue and red frames, and the 2MASS *JHK* frames. In addition, we used the H I imaging data, the far-infrared, and radio data from the literature. A search for dwarf galaxies was made using the SExtractor software. Detailed surface photometry was performed with the MIDAS package.

Results. Four LSB galaxies were classified as probable dwarf members of the group and the *BRI* physical and model parameters were derived for the first time for all true and probable group members. Newly-found dIrr galaxies around the IC 65 contain a number of H II regions, which show a range of ages and propagating star-formation. Mildly disturbed gaseous and/or stellar morphology is found in several group members.

Conclusions. Various structural, dynamical, and star-forming characteristics lead us to conclude that the IC 65 group is a typical poor assembly of late-type galaxies at an early stage of its dynamical evolution with some evidence of intragroup (tidal) interactions.

Key words. galaxies: clusters: individual: LGG 16 – galaxies: photometry – galaxies: structure – galaxies: interactions

1. Introduction

Most galaxies reside in groups the size of the Local Group, which consists of a few bright members and dozens of dwarf galaxies (Tully 1987). While rich clusters of galaxies reveal the sites of the highest concentration of luminous and dark matter, less massive aggregates of galaxies are distributed in less dense regions of the Universe and/or trace the cosmic filaments (Grebel 2007). The physical nature of many compact, as well as of loose groups, has been confirmed through the detection of the X-ray emission of their hot inter-galactic matter (Mulchaey 2000). Zabludoff & Mulchaey (1998) discuss the evidence that a large fraction of the loose groups are still in at an early dynamical stage or even still forming, especially those containing only spiral and irregular galaxies. Plionis et al. (2004) note that groups are considerably more elongated than clusters, and they suggest that the poorest groups and/or subclumps in filaments may still be in the process of getting assembled through galaxy infall along a filament.

The group environment can play an important role in the evolution of its members. A variety of gravitational (tidal) and hydrodynamical mechanisms are at work in groups and clusters that can severely alter the properties of galaxies by modifying their original morphology, triggering star formation and/or

nuclear activities (Mamon 2007). According to the hierarchical scenario for the structure formation, rich clusters today could be assembled from groups of galaxies. Therefore, groups of galaxies may represent sites for a “preprocessing” stage of cluster galaxies through some varieties of tidal interactions (e.g. merging of galaxies in slow collisions) that are otherwise ineffective in high velocity dispersion environments (Boselli & Gavazzi 2006). Galaxies of both low mass and low density are expected to reflect the environmental influence on their evolution most prominently (Lake & Moore 1999).

In rich clusters of galaxies, the impact of the environment on the galaxy properties has already been well-studied, while the link between the environment and the galaxy evolution in poor groups is still not fully understood, and we have insufficient observational data about this connection. Several recent studies have focused on the photometry of dwarf galaxies in nearby groups (Bremnes et al. 1998, 1999, 2000; Trentham et al. 2001) and on the photometry of local field dwarfs (Barazza et al. 2001; Parodi et al. 2002). These authors have shown that the dwarf irregular galaxies that reside in a low-density environment (e.g. in loose groups or in the field) have a statistically lower scale length and, consequently, higher central surface brightness at a given luminosity than those galaxies residing in high-density environments. They argue that the difference in photometric characteristics could be an effect of different star-forming histories, as the higher SB dwarfs in low density environments are also found to be bluer. Alternatively, the photometric difference between the field/group and cluster dwarfs could primarily be a

[★] Based on observations obtained at the Calar Alto observatory, Almeria, Spain.

^{★★} Figures 5, 7, 9, Tables 2, 6, 7 and appendices are only available in electronic form at <http://www.aanda.org>

structural difference and the larger scale length of cluster dwarfs could plausibly be an effect of frequent tidal encounters in dense environments (Parodi et al. 2002).

This paper is the first in a series addressing the investigation of the galaxy properties in a sample of about ten poor/loose groups of galaxies located in low-density environments. The groups will be studied in available sky surveys (DPOSS, SDSS) and by means of our own CCD imaging in at least three optical bands. The studied groups are selected in a redshift range of $1000 \lesssim cz \lesssim 4000 \text{ km s}^{-1}$ in order to map them optically with a reasonable number of pointings. The study also aims to contribute to the detection and photometric characterisation of the faint galaxy population within the group area whose membership will be determined by follow-up redshift surveys (e.g. Hopp et al. 2008). Some preliminary results of this ongoing project are presented in Vennik & Tago (2007) and in Vennik & Hopp (2007).

Here, in the first paper of the series we present a search for new members and also a detailed study of the members and new candidates in the area of the IC 65 group of galaxies. This poor grouping of late type galaxies around the luminous spiral IC 65 is located in a cosmic void between the Local supercluster and the Perseus-Pisces supercluster (Haynes & Giovanelli 1984), and it is unfavourably close to the zone of strong Galactic extinction. Consequently, it has received little attention in previous studies, and very limited optical information exists only for the bright galaxies of this group. However, the HI aperture synthesis studies of van Moorsel (1983) provide detailed HI distribution maps, which reveal many irregularities in the HI distribution of the bright members. The maps also give hints for additional dwarf galaxies undetected so far. This motivated us to carry out our own dedicated optical observations, which we supplement by an analysis of the available near- and far-infrared and radio data, as well as of the published HI imaging and kinematics.

The main purposes of the paper are (1) to search for new (dwarf) galaxies in the area of this particular group and to discuss their membership probabilities; (2) to obtain a homogeneous photometric database and to derive structural characteristics of the bright (certain) and faint (possible) group members; (3) to search for possible effects of mutual interactions on the optical and HI morphology and star formation characteristics of luminous and faint group members; (4) to use the new photometry and available kinematical data to analyse the dynamics and the evolutionary state of the group.

The selection and classification of new group members are described in Sect. 2, CCD observations and data reduction are presented in Sect. 3, data analysis galaxy-by-galaxy is given in Sect. 4, and the dynamical and structural characteristics of the group are discussed in Sect. 5. The results are summarised in Sect. 6. Throughout this paper a Hubble parameter $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$ is assumed. All magnitudes are given in the Vega-magnitude system.

2. The IC 65 group of galaxies

Probably the first study of this group dates back to van Moorsel (1983, hereafter vM83), who carried out 21 cm neutral hydrogen observations of a sample of selected double galaxies. He included the pair of IC 65 with UGC 622 in his sample. In that field two additional systems containing HI were detected, namely UGC 608 and an unclassified “edge-on” galaxy. The latter is partly hidden by the bright 7th *B*-magnitude blue (spectral type B8) Galactic star HD 5764 (BD+47 272). This late type “edge-on” galaxy was later catalogued as PGC/LEDA 138291.

Fig. 1. DPOSS blue image of the IC 65 (LGG 16) group of galaxies: four bright group members are labelled with their catalogue numbers; four new probable dwarf galaxies are identified with their coordinates. The HI contours (white) have been obtained from vM83 and correspond to the $2.5\text{--}3\sigma$ noise level ($2.3\text{--}8.6 \times 10^{20} \text{ atoms cm}^{-2}$). The size of the image is $60' \times 60'$. The north is at the top and the east to the left.

This dense association of four galaxies has not been included in earlier catalogues of nearby groups of galaxies because of its location near to the zone of avoidance ($b \simeq -15^\circ$) and because most of its members are relatively faint ($B > 14.5 \text{ mag}$) except the luminous principal galaxy IC 65. Garcia (1993) assigned IC 65, UGC 608, and UGC 622 to his Lyon Group of Galaxies (LGG) 16. Later on he showed that this particular group of three galaxies fulfils the selection criteria for Hickson compact groups (Garcia 1995). The HI observations of vM83 show that the principal galaxy IC 65 has at least one HI-rich LSB anonymous dwarf companion, which is barely visible on POSS plates. This encourages us to look for more dwarf companion candidates in the area of the group.

Search for additional members

We carried out a systematic search for new dwarf members of the IC 65 group using the Digitised Second Palomar Observatory Sky Survey¹ (DPOSS). The blue (type IIIaJ) and red (IIIaF) emulsions of POSS II films have a small grain size with a resolving power of about 250 lines/mm (Reid et al. 1991), which leads to a highly uniform sky background. Consequently, the long-exposure Schmidt plates that reach a stellar limiting magnitude of $B_{J,\text{lim}} \sim 23 \text{ mag}$, are especially suited for detecting low-surface-brightness (LSB) features (Binggeli et al. 1985). We extracted a $60 \times 60 \text{ arcmin}^2$ field centred on the position of LGG 16 with $\text{RA}(2000) = 01^{\text{h}}00^{\text{m}}30^{\text{s}}.1$ and $\text{Dec}(2000) = +47^\circ 48' 38''$. Because of its low Galactic latitude, this field suffers heavy ($A_B \simeq 0.66 \text{ mag}$, $A_R \simeq 0.4 \text{ mag}$, Schlegel et al. 1998) and non-uniform Galactic extinction. Also, the area is crowded by a large number of Galactic stars. Both factors make detection of the LSB features more difficult.

The detection of galaxies depends on their apparent surface brightness (*SB*) and on their apparent diameters. Galaxies with

¹ <http://astro.ncsa.uiuc.edu/catalogs/dposs/>

extremely low SB disappear into the night sky background, while small galaxies can be hardly distinguished from the stars. A preliminary visual inspection of the selected area revealed four new large LSB dwarf galaxy candidates, which are distributed within $13'$ (~ 146 kpc at the group distance) around of the barycentre of the LGG 16. Based on their irregular morphology (LSB irregular contours, no pronounced central light concentration but allowing for luminous knots distributed in periphery), apparently blue colour, and relatively large diameters, we classified these LSB galaxies for probable new dwarf member candidates of the IC 65 group of galaxies. Eventually we registered a number of smaller LSB objects visible both in blue and red frames. The poor scale of the POSS II ($67''/\text{mm}$) does not permit classifying them confidently as dwarf galaxies, but we registered them as candidates for further investigation with higher resolution.

To quantify the selection criteria for new possible group members, we attempted to linearise and calibrate the used DPOSS frames. For the density-to-intensity transformation, we applied the average characteristic curves of representative IIIaJ and IIIaF plates as given in Reid et al. (1991). The photometric zero points were determined by comparing the SB profiles of the galaxies UGC 608 and UGC 622 from the linearised DPOSS images with those determined in exactly the same way from the CCD images (see Sect. 3). We mark the calibrated DPOSS blue and red magnitudes as B^* and R^* , respectively. Detailed photometric calibration of the DPOSS has been published recently by Gal et al. (2004); however, the IC 65 group area has not been covered with their CCD calibration pointings, as evident in their Fig. 3.

The detection of objects has been performed on the linearised and calibrated blue DPOSS image with the SExtractor software (Bertin & Arnouts 1996). We conducted experiments to minimise the impact of spurious detections on the resulting catalogue of candidate galaxies. Finally, all objects with a fixed SB threshold $25.5 B^* \text{ mag arcsec}^{-2}$ (~ 1.4 rms above the sky background level) and with the minimum consecutive area of 15 pixels were detected. The catalogue still contains some spurious detections, among them satellite trails and emulsion flaws. Most of those can be identified easily and removed from the catalogue by comparing the blue and red images. Therefore, we aligned and rescaled the red image to the blue one. SExtractor was then used in its double-image mode, taking the detection from the blue frame and the photometry from the red one. This procedure allows removal of image artefacts and also yields pixel-to-pixel colour maps for securely detected objects. In total, 12 275 objects were selected within a 3600 arcmin^2 area. The photometric data from linearised DPOSS frames are accurate enough to put the final object selection and classification on a more quantitative basis.

The final galaxy selection in the SExtracted catalogue was made in several steps. First, we attempted to separate non-stellar objects by applying three selection criteria: the stellarity index <0.8 , the image major diameter $>4''$ (considering the stellar $FWHM \approx 3''$), and the mean surface brightnesses $\langle SB \rangle > 23 B^* \text{ mag arcsec}^{-2}$, within $25.5 B^* \text{ mag arcsec}^{-2}$ isophote. This reduced the original catalogue by almost two orders of magnitude as expected for the low Galactic latitude of the field. A total of 348 nonstellar objects remained. In a crowded sky such as the one of the IC 65 group and in the poor photographic material, the automatic selection is insufficient. We need to take the morphologies into account. Therefore, all 348 extended objects were carefully inspected by eye on both the blue and red DPOSS frames and finally classified according to their appearance in both frames. Actually, a final list of 105 galaxies with

Fig. 2. Classification of galaxies in the field of the IC 65 group. I. The mean surface brightness within $2''$ aperture $\langle SB_2 \rangle$ as a function of the total B^* -magnitude. The dashed line shows the predicted position of dwarf galaxies according to Ferguson & Bingeli (1994, Fig. 3), transformed to the distance of the IC 65 group, and corrected for the Galactic absorption. Coding: *filled squares* – certain group members; *open squares* – large LSB galaxies – probable new dwarf members of the group; *open circles* – other LSB galaxies in the field; *filled circles* – HSB galaxies in the field.

Fig. 3. Classification of the galaxies in the field of the IC 65 group. II. Light concentration parameter, as defined in the text, versus central $B^* - R^*$ colour index within an $2''$ aperture. Coded as in Fig. 2.

diameters larger than $4''$ was established. The remaining 243 objects were classified as plate flaws (42), satellite track or stellar spike fragments (97), or partly overlapping faint stellar images (104).

To distinguish the group dwarf members from the background field galaxies, we applied the following general considerations. First, we consider that, according to Bingeli (1994), both the dwarf ellipticals and dwarf irregulars follow the common absolute magnitude – central SB correlation (but see also Carrasco et al. 2006, on this issue). In Fig. 2 the central SB measured by SExtractor within a $2''$ aperture is plotted versus the apparent total B^* magnitude. Evidently, five LSB galaxies of our catalogue closely fit the empirical relation derived by Ferguson & Bingeli (1994).

A second consideration for separating group and field galaxies uses the lower light concentration in dwarf galaxies when compared to the HSB background galaxies. As suggested by Trentham et al. (2001), we can define the light concentration parameter (CP) as a difference between various aperture magnitudes measured with SExtractor software. After attempting this with different aperture combinations, we decided to use the

Table 1. Basic data of the observed galaxies.

Galaxy	RA[2000]	Dec[2000]	Type	$D \times d$	$V_{\odot}$	$V_{\text{rot}}^{\text{max}}$	B_T	K_T	$M_B^{b,i}$	$M_K^{b,i}$
(1)	(2)	(3)	(4)	(5)	[km s ⁻¹]	(7)	[mag]	[mag]	(10)	(11)
UGC 608	00 ^h 59 ^m 02. ^s 3	48°01′02″.3	SABdm	2′0 0′9	2755	104	15.42	12.2	-18.67	-20.8
PGC 138291	01 00 00.7	48 02 14	S(dm)	1.3: 0.3:	2598	62	17.2:		-17.5:	
A0100+4756	01 00 08.0	47 56 05	dIrr	0.6: 0.4:			19.1:		-14.5:	
A0100+4734	01 00 10.4	47 34 05	dIrr	0.8: 0.3:			17.55		-16.1:	
UGC 622	01 00 28.1	47 59 42	Scd:	1.1 0.7	2714	154	14.42	10.25	-19.50	-22.82
IC 65	01 00 55.5	47 40 54	SAB(s)bc	4.4 1.2	2614	168	13.33	9.51	-21.19	-23.60
A0101+4744	01 01 16.1	47 44 33	dIrr	0.7: 0.2:	2760	65:	18.20		-15.4	
A0101+4752	01 01 44.4	47 52 06	dIrr	0.4: 0.3:			18.7:		-14.9:	

concentration parameter as the difference of integrated B^* magnitudes within 16'' and 8'' apertures, respectively:

$$CP(16 - 8) = B^*(16'') - B^*(8''). \quad (1)$$

The CP is more negative for galaxies with larger scale length, i.e. with lower SB , for a given apparent magnitude, and the CP is close to zero for stars. At the distance of the IC 65 group of galaxies, the chosen CP characterises the light distribution on linear scales between about 0.75 kpc and 1.5 kpc. In Fig. 3, $CP(16 - 8)$ is plotted versus the $B^* - R^*$ colour index measured again within a 2'' aperture. The luminous group members (filled squares) show low concentrations of $-1.3 < CP < -0.8$, as expected. Four of the five LSB dwarf galaxy candidates selected in Fig. 2 classify into the category of low concentration galaxies. Furthermore, these four galaxies show the bluest central colours of the sample ($0.45 < B^* - R^* < 1.05$), indicative of star-forming dwarf irregular galaxies. For one of these four LSB galaxies, vM83 estimated a heliocentric radial velocity $V_{\odot} = 2760 \text{ km s}^{-1}$ in H I line, which is in accord with the mean velocity of the four bright group members $\langle V_{\odot} \rangle = 2670 \pm 76 \text{ km s}^{-1}$, obtained from the NED². These arguments strengthen our opinion that all of the first four LSB galaxies are indeed new dwarf companions of the IC 65 group. We rate them as confidence class 1. The fifth dwarf galaxy candidate, selected in Fig. 2 (and marked with a double circle in Figs. 2, 3) appears significantly redder ($B^* - R^* \simeq 1.5$). It is also farther from the group centre compared to other four candidates and therefore it was assigned a lower membership probability. Furthermore, there are 17 galaxies with LSB morphologies, but all of them with isophotal magnitudes fainter than 19.0 B^* -mag. At these fainter magnitudes and/or smaller diameters, we actually lose the ability to distinguish group members from background galaxies on SB grounds. Therefore, we classify these 17 LSB galaxies, with caution, as possible background galaxies (rated 2). The majority of the selected galaxies are HSB and/or red galaxies, so can be classified with confidence as probable field galaxies (rated 3), located in the background of the IC 65 group.

To summarise, now we have a list of five certain group members, confirmed by redshift, supplemented by three new LSB probable dwarf member candidates. Table 1 contains basic data for the group galaxies: (1) name of the galaxy, anonymous galaxies start with an ‘‘A’’; (2, 3) their 2000.0 epoch RA and DEC; (4) morphological type obtained either from the RC3³ or our classification; (5) major and minor diameters; (6) heliocentric radial velocity from the NED (for A0101+4744, the velocity is obtained from vM83); (7) maximal H I rotational

velocity, taken from vM83; (8, 9) total B and K_s magnitudes from our photometry; (10, 11) absolute B and K_s magnitudes calculated for the distance modulus $m - M = 32.93$ and corrected for the Galactic and internal (following Karachentsev et al. 2004) absorption.

3. Observations and data reduction

3.1. Optical data

Broadband B (Johnson) and R, I (Cousins) frames were obtained during two observing runs in 1995 and 1999 with the Calar Alto 1.23 m telescope. Its CCD camera is equipped with the 1024×1024 pixel chip that yields a field of view of 8.7'×8.7' and a spatial scale of 0.51''/pixel. The seeing varied between 1.5'' and 2.5'' ($FWHM$). More observational details are summarised in Table 2.

The observed frames were reduced by using the ESO MIDAS⁴ software package. The raw CCD frames were bias-subtracted and flat-fielded using twilight sky flats. An additional defringing procedure was applied to the I band images. Cosmic ray hits were removed using the FILTER/COSMIC task. Then, images of the same filter were registered and co-added.

Unfortunately, the observing session in 1995 occurred under non-photometric weather conditions. Two nights in January 1999 (the 18th and 19th) were of photometric quality, and the data obtained during these nights were calibrated by means of 138 measurements of standard stars in the star cluster NGC 7790 (Christian et al. 1985). Deep images obtained under non-photometric conditions were calibrated by means of comparing total fluxes of a sample of unsaturated stellar images in both photometric and non-photometric frames.

3.2. Near-infrared data

In addition to our optical observations in B, R , and I passbands, we extracted calibrated, full-resolution J, H , and K frames with a 1.0'' × 1.0'' sampling from the 2MASS⁵ archive (Jarret et al. 2000). As the NIR domain is largely dominated by stellar radiation and much less affected by extinction than the optical bands, they are sensitive to population changes and can uncover structural properties not visible in the optical bands either due to extinction or gaseous emission or both. Therefore, we included the archival NIR survey data in an attempt to further explore morphological components of galaxies and to enable a

² <http://nedwww.ipac.caltech.edu>

³ Third Reference Catalogue of Bright Galaxies (de Vaucouleurs et al. 1991).

⁴ MIDAS is developed and maintained by the European Southern Observatory.

⁵ <http://www.ipac.caltech.edu/2mass/>

Table 3. Model-free photometric parameters of the observed galaxies.

Galaxy	r_B^{eff} [arcsec]	$r_{25,B}$ [arcsec]	μ_B^0 [mag arcsec ⁻²]	μ_B^{eff} [mag arcsec ⁻²]	B_{25} [mag]	B_T [mag]	$B - R$ [mag]	$R - I$ [mag]	$B - J$ [mag]	$c31$	b/a	PA [°]	decen.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
UGC 608	11.1	26	20.8	23.11	15.08	14.75	0.74	0.33	1.60	3.50	0.42	128	0.8:
PGC 138291	7.7	13:	21.9	23.24	16.7:	16.5:	1.0:	0.2:		2.1	0.14	165	
A 0100+4756	6.3	4:	23.9:	25.0	20.3:	18.5	0.76:	0.2:		2.15	0.6:	40:	
A 0100+4734	9.1	8.4	21.7	24.4	17.65	16.85	0.74	0.25		2.56	0.4	108	
UGC 622	14.4	34.6	20.4	21.86	13.86	13.76	1.28	0.61	2.81	1.90	0.65	159	6.3
IC 65	23.5	54.4	19.7	22.10	12.80	12.69	1.07	0.56	2.47	2.81	0.27	153	8.2
A 0101+4744	6.8	7.8	22.15	24.15	18.07	17.55	0.80	0.1:		2.36	0.33	100	
A 0101+4752	5.4	6.0	23.05	24.15	18.63	18.00	0.65	0.2:		2.14	0.75	17:	
MCG+8-3-3	14.2	24.7	20.5:	23.32	14.89	14.60	1.51			3.52	0.65	49	
MCG+8-3-6	8.8	18.3	20.4:	22.55	15.27	15.13	0.97	0.52		2.60	0.66	72	

multi-wavelength comparison of their structural parameters over a wide wavelength range from almost 400 to 2200 nm.

The surface photometry performed on both the optical and NIR images, the relevant error analysis, and the profile fitting are all described in Appendix A and are only available in electronic form.

3.3. Main results of surface photometry

We discuss the optical morphology (and HI imaging data, if available) of each galaxy in Sect. 4. For each galaxy we present a grey-scale optical image. For IC 65 and UGC 622, useful composite NIR images are given, too. We go on to apply contours of the Laplacian filtered image (as described in Appendix A.1) to reveal specific morphological features in luminous parts of the galaxies. We also show grey-scale colour index images of the IC 65 and UGC 622 for which the S/N allowed construction of reliable colour maps. These maps are especially useful for visualising changes in stellar population and dust distribution. Finally, we show SB and colour profiles (see Appendix A.2) for each galaxy. For those bright galaxies with a regular appearance, we add (only in the electronic version) the radial profiles of the parameters of fitted ellipses (b/a , PA and decentring).

The observed (model-free) photometric parameters, as measured from radial profiles, are given in Table 3, where the data are arranged as follows: (2, 3) equivalent radii in arcseconds of the effective and 25th B mag arcsec⁻² isophotes; (4, 5) central SB and SB at the effective radius (i.e. $\mu_B^{\text{eff}} = \mu(r_B^{\text{eff}})$); (6) total B magnitude within r_{25} ; (7) asymptotic B magnitude; (8–10) total $B - R$, $R - I$, and $B - J$ colour indices; (11) light concentration index $c31 = r(3/4L_T)/r(1/4L_T)$, defined by de Vaucouleurs (1977); (12, 13) galaxy mean minor-to-major axis ratio (b/a), and position angle (PA), determined as an average between the 24 and 25.5 B mag arcsec⁻² isophotes; (14) average *decentring degree* (*decen.*) in the optical passbands, calculated as the displacement of the centre of the external isophotes near the Holmberg radius (at 26.5 B mag arcsec⁻²) with respect to the centre of the innermost ellipse as defined in Marquez & Moles (1999). All magnitudes are corrected for the Galactic extinction obtained from the NED. Uncertain values are marked with a colon.

The results of the profile fitting are presented in Table 4: (2–4) exponential model central SB in B , R , and I bands, corrected for the Galactic absorption; (5–7) exponential model scale length in B , R , and I bands; (8–10) difference between the total light emitted by the model exponential disc and the measured asymptotic total light ($\Delta m = m^{\text{exp}} - m_T$) in B , R , and I bands. Tables 3 and 4 also list the photometric parameters

of two luminous early type galaxies, MCG+8-3-3 and MCG+8-3-6, in the area of the group but located in its background (Hopp et al. 2008).

4. Description of individual galaxies

4.1. IC 65

IC 65 is by far the brightest and most massive, i.e. the main galaxy in this group. Its optical and NIR images, as well as various light distribution characteristics, are shown in Figs. 4 and 5. The B band image depicts an oval central bulge and/or a short bar with the long symmetric double-armed spiral pattern starting at its ends. The spiral arms consist of a number of bright H II regions giving them a filamentary appearance. The short-exposure JHK composite image has a smoother intensity distribution compared to optical images. This reflects the dominance of an older stellar populations and the reduced effect of dust in the NIR images. The contours of the Laplacian filtered image (see Appendix A.1) delineate the possible bar in this NIR image. A small nucleus is located in the middle of the bar. The two round features beyond the ends of the bar may be either the starting points of the spiral arms or intersections of an inner tilted ring with the plane of the sky. The presence of a bar is shown further by the typical behaviour of fitted ellipses (Fig. 5): nearly constant PA $\approx 148^\circ$ and systematically decreasing axes ratio within $15''$ (equivalent radius of the bar). The total length of the bar is $\approx 32''$ (~ 6 kpc) and the axis ratio is $b/a \approx 0.25$.

The optical image of IC 65 appears slightly asymmetric with an extension to the SE. This asymmetry can be quantified by means of the decentring degree calculated from the drift of the centre of the fitted free ellipses (Marquez & Moles 1999). For the IC 65 the decentring amounts to $\sim 8.2\%$ in the radius range of $60''$ – $70''$. In contrast, the HI isophotes appear regular within the optical limits of the galaxy (vM83, Fig. 27), but show an extension to the NW at the lowest measured HI column density level of 2.3×10^{20} atoms cm⁻², well outside the optical image. The total extent of neutral hydrogen exceeds nearly twice the optical image of the IC 65.

The $B - R$ colour image shows blue spiral arms with typical colours in the range of 0.7–0.95 and a red ($B - R \approx 1.55$) central bulge/bar region. The area of red colours extends outside the bulge/bar region towards the SW, which probably indicates an enhanced amount of dust on the line of sight in that area.

The optical SB profiles allow the following structural components to be distinguished: a small bulge and/or nucleus within $\sim 10''$, a bar with round features beyond its end within $\sim 25''$, and an extended nearly exponential disc with

Table 4. Exponential model parameters of the observed galaxies.

Galaxy	$\mu_{0,B}^{\text{exp}}$	$\mu_{0,R}^{\text{exp}}$	$\mu_{0,I}^{\text{exp}}$	h_B	h_R	h_I	Δm_B	Δm_R	Δm_I
	[mag arcsec ⁻²]				[arcsec]			[mag]	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
UGC 608	21.93	20.98	20.90	10.0	9.20	11.0	0.19	0.03	-0.17
PGC 138291	22.04	21.19		6.50	6.90		-0.56	-0.49	
A 0100+4756	23.56	22.80	22.51	5.50	5.60	4.40	-0.60	-0.64	-0.31
A 0100+4734	22.81	22.17	21.89	6.50	7.10	7.30	-0.11	-0.22	-0.30
UGC 622	18.84	17.89	17.50	5.40	5.90	6.30	-0.58	-0.45	-0.36
IC 65	20.53	19.61	19.31	14.6	14.7	15.5	0.02	0.13	0.26
A 0101+4744	22.25	21.49	21.50	3.80	3.70	4.00	-0.19	-0.14	-0.22
A 0101+4752	22.65	22.20	22.41	3.80	4.20	6.40	-0.24	-0.41	-0.90
MCG+8-3-3	21.84	20.37		10.6	10.7		0.12	0.14	
MCG+8-3-6	21.45	20.10	19.21	6.90	5.70	5.10	0.13	0.17	0.04

Fig. 4. Light distribution in IC 65 I. 2D-frames. *Top left:* the B band CCD image; *top centre:* the H , J , and K composite image with K -band Laplacian-contours that delineate the nucleus, the bar, and a possible inner ring; *top right:* the $B-R$ colour index image in the range 0.7–1.8 mag. The dark shade is red, the light shade blue. The frames have a field size of about $4' \times 4'$; the north is at the top and the east is to the left. 1D radial profiles. *Bottom left:* surface brightness (SB) profiles in B , R , I , J , and K . The continuous lines represent the sum of the 2D-fits of the exponential disc and bulge components, as described in the text. *Bottom right:* colour index (CI) profiles, from bottom to top: $H-K$, $B-R$, $B-I$, and $B-J$. The observed SB and CI profiles are not corrected for Galactic absorption. The radii are equivalent radii (i.e. $\text{radius} = \sqrt{ab}$).

imprints of the spiral-arm-pattern superimposed on the underlying disc. The comparison of our data with the B profile, published by Blackman & Moorsel (1984), shows good accordance within $40''$, which is the extent of their photographic SB profile. Our new I -band photometry agrees with the results in Haynes et al. (1999). We performed the pilot modelling with only two major components, the bulge and the disc, neglecting the bar and the spiral-arm components. The resulting bulge+disc models in B and R are shown in Fig. 4 by continuous lines. The optical colour-index profiles show a strong negative colour

gradient within $r \leq 25''$, followed by a nearly flat disc region. The central red colours ($B-R$)₀ ≈ 1.5 , ($B-I$)₀ ≈ 2.2 , ($B-J$)₀ ≈ 3.3 , ($H-K$)₀ ≈ 0.3 nearly correspond to 5–8 Gyr old stellar populations with sub-solar abundances; however, large negative colour gradients, particularly in the NIR-optical colours, indicate some dust in that area. The mean disc colours of ($B-R$) ≈ 0.95 , ($B-I$) ≈ 1.4 , ($B-J$) ≈ 2.1 , and ($H-K$) ≈ 0.2 nearly correspond to stellar populations, which are several Gyrs younger than the nuclear ones. We compared the observed colours to those predicted by the evolutionary models of stellar populations

Fig. 6. Light distribution in UGC 622 I. 2D-frames. *Top left:* the R band CCD image with Laplacian contours delineating spiral arms, which consist of a number of star-forming H II regions; *top centre:* the composite J , H , and K band image; *top right:* the $R - I$ colour index image in the range 0.5–1.0 mag. The dark shade is red, the light shade blue. All frames have a field size of nearly $2' \times 2'$. The north is top and the east is to the left. 1D radial profiles. Coded as in Fig. 4.

of Bruzual & Charlot (2003) in order to obtain an estimate of the mean age of stellar populations by assuming (generally) sub-solar abundances of luminous galaxies. After allowing for typical errors of ± 0.15 mag of our colour estimates, the accuracy of the obtained ages is typically 1–2 Gyr.

4.2. UGC 622

The results of the surface photometry of the UGC 622 are summarised in Figs. 6 and 7. This late-type galaxy has an almost stellar nucleus and/or bulge and faint flocculent spiral arms. Numerous star-forming regions, distributed along the arms, are outlined with the help of the Laplacian contours. The NIR composite image shows a prominent nucleus and an almost featureless smooth disc. The red colour of the circumnuclear area ($B - R \approx 2.05$, $R - I \approx 0.75$) may be partly attributed to dust, and its asymmetry may be caused by inclination. Almost all knots and blobs distributed along the spiral arms are blue with colours in the range of $0.30 < R - I < 0.50$ and $1.10 < B - R < 1.22$. The mean colours of the underlying disc ($\langle B - R \rangle \approx 1.25$, $\langle R - I \rangle \approx 0.6$) refer to a relatively young (3–5 Gyr) stellar population with roughly 0.4 of solar abundances (Bruzual & Charlot 2003).

UGC 622 shows a classical type II light profile (Freeman 1970), where the central light cusp is followed by two exponential sections with different gradients. The inner exponential in the range of $3'' \leq r \leq 15''$ has a scale length of $h_B \approx 12.1''$ in B band. The outer ($r \geq 15''$) exponential has a steeper slope with scale lengths of $h_B \approx 5.4''$ in B band and $h_K \approx 6.6''$ in K band.

The optical and NIR light profiles show similar behaviour, but the difference between the inner and outer exponential disc gradients becomes less pronounced at longer wavelengths – an effect of dust extinction in optical passbands. The V -band SB profile, determined by Heraudeau et al. (1996), appears very similar to our optical SB profiles. The optical colour index profiles show a red (dusty) nuclear region, uniform colours within the inner disc, along with some evidence of the colour gradient in the outer disc. The conspicuous twisting and shifting of the fitted free ellipses (Fig. 7) could be explained as an effect of the patchy spiral arms.

VM83 noted asymmetries in the distribution of atomic hydrogen of the UGC 622. The H I map (his Fig. 28 and our Fig. 1) shows an extension towards SE (PA $\sim 145^\circ$), which differs from the orientation of the stellar disc (PA = 160°). Weak H I emission has been detected at the distance of 1.1' and 2' to the north and at 2.5' to the NE of UGC 622. The northernmost H I detection nearly coincides with an optical LSB feature, which has been registered by running SExtractor on the DPOSS blue frame. Other H I detections, classified as “barely significant” by VM83 were not confirmed later by the WSRT wide-field H I survey of van Braun (2003), nor could they have been identified in our optical search.

4.3. UGC 608

This is a late type SBdm spiral galaxy with a short luminous bar ($2a \approx 3.2$ kpc, $b/a = 0.25$, PA $\approx 120^\circ$) embedded in an LSB disc containing faint and knotty spiral arms (Fig. 8). The most

Fig. 8. Light distribution in UGC 608 I. The blue image ($2' \times 2'$) obtained from DPOSS with Laplacian contours superimposed and brightest knots labelled A through E (*left*); the *SB* profiles (*centre*), and the colour-index profiles (*right*).

Fig. 10. Light distribution in PGC 138291. *Left*: the DPOSS red image (the field size is $\sim 2' \times 2'$, the north is top and the east is to the left); *centre*: radial surface brightness profiles in *B*, *R*, and *I* with exponential disc models in *B* and *R* (continuous lines); *right*: the colour-index profiles.

prominent, generally blue knots and blobs are delineated with the help of Laplacian contours and labelled from A through E. The $B - R$ colour index image is noisy, and reliable individual colour estimates were obtained only for the brightest features. The luminous bar (C) is slightly redder ($0.85 \leq (B - R)_{\text{bar}} \leq 1.0$) than the surrounding LSB disc area, which is remarkably blue ($(B - R)_{\text{disc}} \approx 0.70$). The optical colours $B - R$ and $B - I$ show marginal blueing towards the periphery. Comparing the colours with the stellar population models of Bruzual & Charlot (2003), we can conclude that both the centre and the underlying stellar disc of the UGC 608 are populated with young (a few Gyrs) and metal-poor ($Z \approx 0.001$) stellar populations, which is quite typical of late type spirals. The fuzzy red ($B - R \approx 2.2$) non-stellar object A is probably a distant galaxy, seen through the disc of the UGC 608. The *B* and *R* band *SB* profiles show a dominating exponential disc component. Our *I* band image is rather noisy, and the corresponding *SB* profile is less reliable. Outside the bar region $r \geq 7''$, the free fitting ellipses trace the faint spiral pattern, and the centre of the successively fitted ellipses slightly oscillates around its starting value, mostly because of spiral arms and bright knots (Fig. 9). The H I map of UGC 608 (vM83, Fig. 30) shows a number of local maxima distributed in a generally regular gaseous disc. Several of these gaseous features coincide with optical star-forming knots (e.g. the triple knot E). The H I halo is $\sim 30'$ (32 kpc) at its largest extent, which is larger by a factor of about 2.4 than the isophotal major (optical) diameter of the galaxy as measured in the blue frame at the 25.0 *B* mag arcsec $^{-2}$ level.

4.4. PGC 138291

This galaxy was probably first discussed by vM83, who referred to it as an “edge-on” galaxy. Because of its poor visibility, only the position, velocity, and H I flux are reported in the literature. We derived its integral magnitudes and light distribution characteristics using our calibrated DPOSS frames. The severest problem was proper subtraction of the bright stellar halo. Fortunately,

the stellar halo appears nearly axisymmetric relative to the N-S stellar spike (but clearly non-symmetric relative to the E-W spike). Therefore, we flipped the image around the N-S spike, removed all other stellar images except the bright star itself, and finally subtracted the flipped and cleaned image from the original one. The derived *SB* profiles (Fig. 10) become noise-dominated at relatively high surface brightnesses. Nevertheless, we consider the central portion of the nearly exponential *SB* profiles within ≤ 25.0 mag arcsec $^{-2}$ and $r \leq 11''$ as reliable. The galaxy is very flat with an axis ratio of $b/a = 0.18$, and it generally has a smooth regular shape. Neither the *SB* profiles nor the optical images prove the presence of a bulge, while a tiny bulge may still remain hidden by a dominating disc component, seen edge-on. The mean colours ($B - R \approx 1.0$, $R - I \approx 0.2$) could have been explained by a dominating population of very young (a few Gyrs) and metal-poor ($\leq 1/5 Z_{\odot}$) stars and probably low ISM/dust content in the LSB disc of this galaxy (Bruzual & Charlot 2003). Approximate dimensions of the galaxy were measured on the DPOSS red frame, $D_{25} \times d_{25} \approx 1.1' \times 0.15'$, which yields a linear diameter of about 12.5 kpc. The H I contours in this “edge-on” galaxy as given by vM83 (his Fig. 29) appear regular.

4.5. A 0101+4744

This is a faint LSB anonymous galaxy located $\sim 5'$ (56 kpc in projection) to the NE of the IC 65. This galaxy was probably first discussed by vM83, who described it as “... a barely significant H I detection coinciding with faint optical feature ...”. This galaxy has an irregular head-tail shape with a major light concentration in a luminous and blue knot B (Fig. 11), which is located in the western part of the galaxy, and a faint diffuse curved tail on the opposite side. The very blue colours of the knot B ($B - R = 0.6 \pm 0.15$ and $R - I = 0.1 \pm 0.2$) may correspond to a recently formed (≤ 100 Myr) stellar supercluster (Vennik & Hopp 2007). Two more diffuse knots are distributed in the western (knot A) and eastern (knot C) periphery. Those knots are redder ($B - R \approx 1.0$ for the knot A, and $B - R \approx 1.2$

Fig. 11. Light distribution in an anonymous galaxy A 0101+4744. *From left to right:* 1) the *BRI* composite image. Unresolved stellar knots are labelled with 1, 2, and 3; resolved probable star-forming regions in the galaxy are labelled with A, B, and C. The field size is $2' \times 2'$; the north is top and the east is to the left. 2) radial surface brightness (*SB*) profiles in *B* and *R*. The lines represent the fits of the exponential disc model. 3) colour-index profiles *B* – *R* and *R* – *I*. Typical errors are shown by bars.

Fig. 12. Light distribution in an anonymous galaxy A 0100+4756. Coded as in Fig. 11.

for the knot C), when compared to the knot B. Three Galactic stars (labelled with 1, 2, and 3 in Fig. 11) could have been distinguished through their stellar PSF, and much redder colours ($B - R = 2.0 \pm 0.1$ and $R - I = 0.7 \pm 0.05$), when compared to the underlying LSB disc of the galaxy.

The light distribution in this LSB galaxy is nearly exponential. The $B - R$ colour index profile (starting from the knot B) shows a marginal radial colour (i.e. stellar population) gradient in the underlying disc and/or in bright knots. Because of the concordant H I radial velocity and the LSB morphology, this galaxy could be considered as a certain dIrr member of the group with an absolute blue magnitude of $M_B = -15.4$, a major axis length of about $D_{25} \approx 5$ kpc and the exponential scale length of $h_B \approx 0.7$ kpc.

4.6. A 0100+4756

This is a very faint LSB object located $\sim 5'$ (56 kpc in projection) to the SW of the UGC 622. The image (Fig. 12) has an amorphous light distribution with a maximal blue *SB* of 23.9 ± 0.3 mag arcsec $^{-2}$ and without any luminous knots. The derived *SB* profiles are nearly exponential and the $B - R$ and $R - I$ colour-index profiles are essentially flat, showing that nearly homogeneous stellar populations are distributed throughout the LSB disc. The de-reddened mean colours $B - R = 0.76 \pm 0.2$ and $R - I = 0.15 \pm 0.2$ are nearly consistent with a dominating population of metal-poor ($\sim 1/20 Z_\odot$) and young (≤ 1 Gyr) stars (Bruzual & Charlot 2003).

The distance of this object is unknown. Its LSB dwarfish morphology, nearly exponential *SB* profile, and particularly, its

blue colours very similar to those of the confirmed member A 0101+4744 and other two dwarf galaxies studied here, as well as its location close to UGC 622, all encourage us to consider it as a possible new dwarf member of the IC 65 group of galaxies. If it is true, then its absolute magnitude is $M_B = -14.4$ (but $M_B^{\text{exp}} \approx -15.0$), the diameter is $D \sim 3.6$ kpc, and the scale length $h \approx 1.0$ kpc.

4.7. A 0100+4734

This is an anonymous irregular galaxy located $\sim 10.3'$ (115 kpc in projection) to the SW of the main galaxy IC 65. It contains a number of bright resolved knots labelled A, B, C, and D (Fig. 13) with the brightest knot D located at the eastern periphery, giving the galaxy a head-tail appearance. The luminous blue knots, which are probably centres of active star formation, are embedded in the diffuse LSB underlying component of the size of $D \times d \approx 49'' \times 19''$. The radial *SB* profiles are approximated well by a simple exponential disc model. The brightest knot D is also the bluest one with colours of $B - R = 0.4 \pm 0.1$ and $R - I = -0.15 \pm 0.2$, probably indicating very young ages of the stars in the range of 10–100 Myr in it (Vennik & Hopp 2007). The individual knots show a range of colours with the fainter knots getting redder along the distance from the brightest/bluest knot D. These colour variations could probably be interpreted as an age effect, and they are generally used to support the self-propagating star formation mode hypothesis (e.g. Gerola et al. 1980). The colours of the underlying disc are similar to those of the A 0101+4744.

Fig. 13. Light distribution in an anonymous galaxy A 0100+4734. Coded as in Fig. 11.

Fig. 14. Light distribution in an anonymous galaxy A 0101+4752. Coded as in Fig. 11.

An attempt to measure the H I flux of this actively star-forming galaxy is described in Appendix B. Recent spectroscopic observations with the Hobby-Eberly Telescope have shown that this particular dIrr galaxy may be located in front of the IC 65 group (Hopp et al. 2008).

4.8. A 0101+4752

This is a faint irregular galaxy located 14' (157 kpc in projection) to the NE of IC 65, with a smooth LSB underlying light distribution and several faint resolved knots, labelled with A and B in Fig. 14, embedded in it. Faint arc-like features are evident on the northern and southern peripheries of this galaxy, both in our CCD frames and in deeper DPOSS images. The bright non-stellar knot B is extremely blue ($B - R \approx 0.24$) when compared to the colours of another, but a semi-stellar knot A ($B - R \approx 1.2$) or to the colours of two 22nd B -magnitude Galactic stars (labelled with 1 and 2) of $B - R \approx 2.0 \pm 0.15$. The blue colour of the knot B is typical of a very young and short-lived starburst, which is not unusual in a dIrr galaxy. The azimuthally averaged SB profiles (Fig. 14) are nearly exponential. The $B - R$ colour profile is very noisy and the reddening towards the periphery may appear unreliable. We checked our CCD photometry by using the calibrated DPOSS blue and red images. As a result, we obtained slightly more extended SB profiles, and the independently derived colour index profile confirms the reddening tendency towards the periphery.

The redshift of this LSB galaxy is not known yet, so we can only speculate about its relation to the IC 65 group of galaxies on morphological and colour grounds. Assuming that A 0101+4752 is located at the distance of the IC 65 group of galaxies, we derive the following global characteristics: $M_B = -14.9$, linear diameter of ~ 4.5 kpc, scale length ~ 0.8 kpc, and rather blue

Table 5. Gaseous and dynamical masses and mass-to-light ratios of H I detected galaxies in the group.

Galaxy	$L_B^{g,i}$ [$10^{10} L_\odot$]	$M(\text{H I})$ [$10^{10} M_\odot$]	$\frac{M(\text{H I})}{L_B}$	M_{dyn} [$10^{10} M_\odot$]	$\frac{M_{\text{dyn}}}{L_B}$
(1)	(2)	(3)	(4)	(5)	(6)
UGC 608	0.46	0.44	0.97	2.82	6.1
PGC 138291	0.16	0.14	0.91	1.00	6.2
UGC 622	0.98	0.315	0.32	4.44	4.5
IC 65	4.16	1.425	0.31	17.51	4.2
A0101+4744	0.023:			0.38:	16:

integral colours of $B - R \approx 0.65$, and $R - I \approx 0.20$, which are also similar to the colours of other new dwarf galaxy candidates of the group.

5. Discussion

5.1. Dynamical properties of the group

Combining the new photometry with the H I fluxes and rotational velocities given in vM83, we calculated the gaseous content and dynamical masses of bright group members and of the dwarf companion galaxy A 0101+4744. The results are listed in Table 5, where the data are arranged as follows: (1) name of the galaxy; (2) the B -band luminosity corrected for the Galactic and internal absorption; (3) total H I mass, calculated as $M(\text{H I})/M_\odot = G^{-1} D^2 \int S dV$, where $D = 38.5$ Mpc is the distance of the group and $\int S dV$ is the total H I emission in (Jy km s^{-1}); (4) the H I-mass-to-blue-luminosity ratio; (5) dynamical mass within the outermost rotational velocity measurement, calculated as $M_{\text{dyn}}(<R) = G^{-1} R V_{\text{rot}}^2(R)$; (6) the dynamical mass-to-blue-luminosity ratio.

The main galaxy of the group, IC 65, considerably dominates other group members, emitting nearly 3/4 of the group's total blue light and containing $\sim 2/3$ of the dynamical mass of the secure members of the group. UGC 608 and PGC 138291 are rich in neutral hydrogen, which is typical of late type spirals. IC 65 and UGC 622 have a smaller gaseous fraction in agreement with the statistics of Sbc and Sc galaxies (Roberts & Haynes 1994). The individual mass-to-light ratios of the four bright group members fit into the range of typical ratios of the given morphological types (Roberts & Haynes 1994). For the dwarf irregular galaxy A 0101+4744 in the field of IC 65, vM83 measured the velocity width $\Delta V = 130 \text{ km s}^{-1}$. If we adopt a crude relation $V_{\text{rot}}^{\text{max}} \approx \Delta V/2 = 65 \text{ km s}^{-1}$ and the (optical) radius of $\sim 3.9 \text{ kpc}$, we obtain an estimate of its dynamical mass $M_{\text{dyn}} \approx 3.8 \times 10^9 M_{\odot}$ and $M_{\text{dyn}}/L_B \approx 16$ in solar units. Since a typical, isolated dIrr galaxy has a stellar and gaseous $M/L_B \approx 0.8\text{--}1$ in solar units (van Zee 2001; Roberts & Haynes 1994), then this particular star-forming dwarf galaxy appears to be severely dominated by dark matter.

Using the available exact HI radial velocity data, we attempted to estimate the total mass and the fraction of dark matter distributed in this group. The virial mass of the group can be calculated according to Karachentsev (1970) as

$$M_{\text{vir}} = 3\pi G^{-1} n(n-1)^{-1} R_H \sigma_V^2, \quad (2)$$

where n is the number of galaxies in the group, σ_V the dispersion of radial velocities, and the mean harmonic radius R_H is calculated as

$$R_H = D \sin \left[\frac{n(n-1)}{2 \sum_i \sum_{j>i} \theta_{ij}^{-1}} \right], \quad (3)$$

where D is the distance of the group and θ_{ij} the angular separation between the galaxies i and j . We obtain the following dynamical characteristics of the group: $\sigma_V = 77 \pm 13 \text{ km s}^{-1}$, $R_H = 135 \pm 24 \text{ kpc}$, the mean linear projected radius $\langle R_p \rangle = 192 \pm 34 \text{ kpc}$, and the virial mass $M_{\text{vir}} = (2.16 \pm 0.97) \times 10^{12} M_{\odot}$. Using the total blue luminosity of the group $L_T = 5.78 \times 10^{10} L_{\odot}$, as determined in this work, we obtain the dynamical mass-to-blue-light ratio $(M/L)_B \approx 37 \pm 17 (M/L)_{\odot}$. The rms errors are estimated using the jackknife method (e.g. Efron 1981). The determination of individual virial masses of small groups is uncertain because of the projection effects, temporary departures from overall equilibrium, and incomplete redshift data. Traditionally, spherical symmetry and isotropic velocities are assumed; however, the groups may actually be flat aggregates (e.g. Haud 1990) or prolate spheroids (Plionis 2004). Various numerical simulations of the dynamical evolution of poor galaxy systems (e.g. Aarseth & Saslaw 1972; Barnes 1985; Mamon 1993, 2007) have demonstrated that, as the net effect of the given uncertainties, the true mass is severely underestimated by application of the virial theorem.

Since the galaxy IC 65 essentially dominates the group dynamics, we can consider the other group members as the companions moving in arbitrarily oriented Keplerian orbits around the principal galaxy and apply an alternative mass estimator, the projected mass method, which is found to be generally more reliable than the virial theorem (Bahcall & Tremaine 1981). Assuming isotropic velocity distribution, which is appropriate when some relaxation has taken place in the past, we can compute the projected mass estimator as

$$M_{\text{proj}} = \frac{16}{\pi G n} \sum_{i=1}^n \Delta V_i^2 \times R_i = (2.89 \pm 1.6) \times 10^{12} M_{\odot}. \quad (4)$$

The standard deviation of the projected mass in Eq. (9) accounts for statistical uncertainties $1.263 n^{-1/2}$. An additional effect related to the uncertainties in the eccentricity distribution can be up to a factor of 1.5 (Bahcall & Tremaine 1981). We can indeed find a reasonably good agreement between these two dynamical mass estimates.

The dynamical state of the group is characterised by its crossing time. We used two different crossing-time definitions to check for possible variances, first the traditional virial crossing time, as defined by Huchra & Geller (1982):

$$t_c^{\text{vir}} = \frac{3}{5^{3/2} H_0} \times \frac{\pi R_H}{\sigma_V} = 1.4 \pm 0.4 \text{ Gyr}. \quad (5)$$

Another estimator, the linear crossing time t_c^{lin} (Gott & Turner 1977), which should be more stable in the presence of various irregularities as close pairs, central condensations, etc., is

$$t_c^{\text{lin}} = \frac{2}{\pi H_0} \times \frac{\langle V \rangle \langle \sin \theta_{ij} \rangle}{\langle V_i - V_j \rangle} = 1.3 \pm 0.4 \text{ Gyr}. \quad (6)$$

Both estimators yield concordant results, and the short crossing time shows that the group as a whole could have been dynamically relaxed. For comparison, the estimated crossing times in nearby poor groups range from 1.8 to 5.9 Gyr with a median around 2.3 Gyr (Grebel 2007). However, any occurrence of an amount of diffuse IGM would increase the predicted relaxation time computed for a point-mass configuration and, consequently, short t_c does not necessarily indicate a significant dynamical evolution of small bound groups. Therefore, interpretation of apparently relaxed small groups is not unique and even groups with short crossing times ($t_c \sim 0.1 H_0^{-1}$) may still be in a pre-virialized collapse phase (Barnes 1985; Nolthenius & White 1987). Mamon (1993, 2007) modelled the dynamical evolution of isolated galaxy systems and finds that the crossing time suffers from degeneracies between the expansion and initial collapse phases and also between the late collapse and rebound phases. He suggests that these degeneracies could have been partly solved by means of combining crossing time with the virial-to-true-mass ratio ($M_{\text{VT}}/M_{\text{true}}$), or virial-mass-to-optical-light ratio ($M_{\text{VT}}/L_{\text{opt}}$), when adopting a universal mass-to-light ratio. The location of a group in the plane defined by the dimensionless crossing time ($t_c H_0$) versus the virial mass-to-light ratio (M_{VT}/L_B) (e.g. Mamon 2007, Fig. 1) could help us judge the evolutionary status of a particular system. In this plot the IC 65 group is located well below the theoretical “fundamental track” of the group evolution (determined by assuming a universal $M_{\text{true}}/L_B = 440 h$, where $h = H_0/100 \text{ km s}^{-1} \text{ Mpc}^{-1}$) in the region of collapsing groups and within the area occupied by other low-multiplicity groups. In poor groups of galaxies, the statistical noise in the virial mass-to-light ratio and crossing time estimates increases, but the errors are obviously insufficient to explain the large number of groups well below the “fundamental track”. This tendency could be caused either by intrinsically lower mass-to-light ratios of the groups (e.g. because many group members are undergoing star-burst), by the bias near turnaround (Mamon 2007), or by mass segregation between galaxies and dark matter (Barnes 1985).

5.2. Substructure and galaxy interactions in subgroups

Numerical simulations of small galaxy systems (e.g. Barnes 1985) have demonstrated that, during their dynamical evolution, they tend to form subgroups that ultimately merge to a single final remnant (an E or cD galaxy). Observationally it has

been found (e.g. Karachentsev 1996, 2005) that nearby groups of galaxies tend to consist of two subgroups, which are respectively concentrated around two massive galaxies (e.g. MW+M31, CenA+M83, IC 342+Maffei). By analogy with nearby groups, it is tempting to also divide the LGG 16, despite very poor statistics, into two compact subgroups with a projected separation of ~ 220 kpc. (For comparison, only 5–7 brightest members of the Local Group could be detected at the distance of the LGG 16.) The southern subgroup consists of the principal galaxy IC 65 ($\langle V_{\odot} \rangle = 2614 \pm 8$ km s $^{-1}$) and at least one confirmed dIrr companion A 0101+4744 (the NE companion). The group membership of another nearby dIrr galaxy A 0100+4734 is not yet clear. The northern subgroup consists of three galaxies with comparable masses – UGC 622, UGC 608, and PGC 138291 ($\langle V_{\odot} \rangle_3 = 2689 \pm 66$ km s $^{-1}$) – and the probable dwarf galaxy A 0100+4756. Particularly, the northern dense triplet fulfils the isolation criterion of the Hickson compact groups (Hickson 1982) with respect to the principal galaxy IC 65. The fourth, newly-found, dwarf galaxy candidate A 0101+4752 is located between the two subgroups and could be considered as a “free-floating” dwarf member of the group.

Little is known about the depth of this group along the line of sight. We can speculate that the northern subgroup could possibly be located behind the principal galaxy IC 65, in agreement with the radial velocity difference of $\Delta V = 75$ km s $^{-1}$ and also in accord with the apparent magnitude difference, and that the triplet is currently approaching the IC 65. We can apply a simple test using the Tully-Fisher (hereafter TF) relation combining the published rotation velocities and newly determined optical and NIR magnitudes. We compared our data with the TF relation of 31 galaxies in the UMa cluster of galaxies (Verheijen 2001) and of 17 galaxies in the Eridanus group (Omar et al. 2006). Our data for three galaxies (IC 65, UGC 622, and UGC 608) with representatives from both subgroups nicely fit the relation defined by both comparison samples in the K band, with a very small dispersion of ~ 0.15 mag, which is less than the dispersion among comparison data. The TF relation for our five galaxies (the former three and PGC 138291, A 0101+4744) in the B band again has no systematic trend between the northern subgroup and the main galaxy, but shows a larger dispersion of ~ 0.78 mag comparable to the dispersion among the comparison data. A larger dispersion in optical bands is (partly) due to uncertainties in the Galactic and internal absorption in these bands.

Both dIrr galaxies around the IC 65 contain a chain of blue knots, bringing to mind the self-propagating star formation scenario. The eastern part of the LSB underlying stellar halo of the confirmed NE companion appears curved towards the primary IC 65. Both effects could be triggered by close encounters with the nearby principal galaxy; but see also e.g. Hunter & Elmegreen (2004) on this issue. In small groups, where galaxy encounters occur at low relative velocities; i.e., they may have sufficiently long duration, and when the galaxy radii are comparable to the average separation between galaxies, tidal interactions can be efficient in disturbing the morphology of the disc, and/or in enhancing the star-forming (SF) activity both in the circumnuclear region and throughout the disc. The tidal force (or asymmetric gravitational potential) per unit mass of the primary produced by a companion is proportional to $M_{\text{comp}} \times d^{-3}$, where M_{comp} is the mass of the companion and d its distance from the centre of the primary (Dahari 1984). The simulations of Byrd & Valtonen (1990) have shown that tidal interactions are efficient in enhancing the SF activity, when the perturbation parameter

$$P_{\text{gg}} = (M_{\text{comp}}/M_{\text{gal}}) \times (2d/D_{\text{gal}})^{-3} \quad (7)$$

is in the critical range $P_{\text{gg}} \geq 0.006\text{--}0.1$. The given range depends on the disc-to-halo mass ratio of the galaxy. We determined the main perturber of every single group member and the maximum values of the perturbation parameter are listed in Table 6 (only available in electronic form), where the data are arranged as follows: (1, 2) name of the galaxy, and number of the subgroup; (3, 4) gaseous and optical diameters (D_{gal}) of the galaxy; (5, 6) name of the main perturber, and its distance (d) from the galaxy; (7, 8) the perturbation parameter (P_{gg}), calculated both for the gaseous and optical discs.

The obtained perturbation estimates and the image analysis of the galaxies in the southern subgroup lead to the following conclusions: 1) the NE companion is expected to be perturbed by the primary since the perturbation parameter is in the critical range ($P_{\text{gg}} \approx 0.246/0.022$, for the H I/stellar components). The expected perturbation is confirmed both in its disturbed morphology (the LSB halo is curved towards IC 65) and in enhanced SFA (multiple H II knots); 2) the warped NW-part of the gaseous disc of the (otherwise regular) primary galaxy IC 65 could have been invoked during the possible close passage with the NE companion in the past, as indicated by the marginally significant perturbation parameter ($P_{\text{gg}} \approx 0.0065$) for the gaseous disc of the IC 65.

In the northern compact subgroup, the three luminous galaxies possess an almost undisturbed regular stellar morphology, which agrees with non-critical values of the perturbation parameter as given for their optical discs in Table 6. The situation is different for their more extended gaseous discs. VM83 noted that each of these three galaxies shows asymmetric features in their H I distribution, especially the UGC 622. This is in general agreement with perturbation estimates in Table 6. The outer H I isophotes of UGC 622 are clearly disturbed and its gaseous disc appears not to be aligned with the stellar disc, rather being aligned with the direction to the neighbouring “edge-on” galaxy. Poor resolution of the available H I data for the “edge-on” galaxy itself do not permit study of its gaseous morphology in more detail.

Huchtmeier & Richter (1982) noted the occurrence of a large proportion of interacting galaxies among those with large H I-extensions. Concerning the interaction time-scales Boselli & Gavazzi (2006) noted that the asymmetric H I distribution in a gaseous disc can last for a few disc revolution times ($t_{\text{rev}} = \pi D_{\text{gal}}/V_{\text{rot}}$), after which the differential rotation should re-distribute the gas uniformly over the disc. Since the $t_{\text{rev}} \approx 1 \times 10^9$ yr for the IC 65, and $\sim 2.5 \times 10^8$ yr for the UGC 622, thus observing an H I asymmetry, and the disturbed stellar disc in the SE part of the IC 65, too, possibly implies that the disturbing mechanism has been acting for a relatively short time. The time during which two galaxies stay close enough to get tidally perturbed – the tidal encounter time – can be estimated as $t_{\text{enc}} \approx \max(R_{1,\text{gal}}, R_{2,\text{gal}}, d)/\Delta V$, where d is their separation at closest approach (Binney & Tremaine 1987). In both subgroups, $t_{\text{enc}} = (5 \pm 1) \times 10^8$ yr. Furthermore, the frequency of encounters in subgroups could be estimated as an inverse of the relaxation time, $t_{\text{relax}} = 0.1 \times (R_{\text{vir}}/\sigma_V) \times (n_{\text{gal}}/\ln n_{\text{gal}})$. For both dense subgroups, the relaxation time is in the range $t_{\text{relax}} \approx (3\text{--}10) \times 10^8$ yr; i.e., close encounters should be frequent enough to significantly disturb the outer gaseous and possibly also the stellar morphology and, over a longer period, to strip the majority of the atomic gas. Rasmussen et al. (2006) argue that the atomic gas could have been stripped over the course of a few Gyr by the intra-group medium and that this should have a significant impact on the galaxy populations of compact groups. However, as found in the previous subsection, the gaseous content in regular galaxies

of both subgroups is nearly normal, and the group is populated only with late type spiral and irregular galaxies with weakly developed tidal tracers. *This strongly argues for the dynamical youth of the whole IC 65 group of galaxies. Probably, the group is still assembling and the galaxies in subgroups have had few encounters.*

There are many sophisticated numerical modelling experiments on the dynamical evolution of galaxy systems of different multiplicity performed during the past decades (see earlier reviews e.g. in Barnes & Hernquist 1992; Mamon 1993, 2007; Moore et al. 1998). Particularly, Moore et al. (1998) propose a new mechanism of galaxy harassment, in which the frequent high-speed encounters with massive galaxies cause impulsive gravitational shocks that severely remodel the fragile discs of late-type spiral and irregular galaxies. The cumulative effect of such encounters can ultimately change a disc galaxy into a spheroidal galaxy. Galaxy harassment is slightly more effective at removing mass than tides alone, and it will occur any time that galaxy encounters occur at speeds that are much greater than the galactic circular velocities (Lake & Moore 1999). Harassment should be effective in rich (virialised) clusters. The relative velocities can be too low in poor groups, leading to merging rather than harassment (Lake & Moore 1999). However, some dynamical models of poor groups like the Local Group with nearly 30 dwarf satellites have shown that the timescale for harassment of a dIrr galaxy like GR8 into something resembling present-day dwarf spheroidal satellites of the Milky Way (Dra and UMi) is roughly 3 Gyr (Moore et al. 1998), or a similar transformation could happen in ~ 7 Gyr when modelling 2–3 close (< 40 kpc) tidal encounters of an LSB satellite with its primary (Mayer et al. 2000). At the present stage, we are unable to identify the possible dwarf spheroidal “remnants” around the IC 65, owing to insufficient resolution of the available imaging data. The observed star-forming activity in dIrr satellite(s) around the IC 65 can possibly be triggered by tidal compression of gas at pericentre passage, and then the SF could possibly be truncated after the tidal stripping has removed the remaining gas (Mayer et al. 2000).

5.3. Star-forming properties of the brightest galaxies in subgroups

We attempted to estimate the current SF rates in the brightest galaxies of both subgroups, in the IC 65 and UGC 622, using the homogenised IRAS flux densities (S_{60} and S_{100}) and the 1.4 GHz radio flux density ($S_{1.4\text{ GHz}}$) as given in the NED. Both the far-infrared (FIR) and radio emission are expected to be enhanced in the instance of tidal interactions (Roberts & Haynes 1994) and, hence may serve as a clue to their interaction history. There are well-known complications with interpreting the FIR spectral data in terms of SF. The FIR spectra contain both a “warm” component associated with dust around young star-forming regions ($\lambda \sim 60\text{ }\mu\text{m}$) and a cooler IR cirrus component ($\lambda \geq 100\text{ }\mu\text{m}$) associated with more extended dust heated by the interstellar radiation field of older disc stars. In late type star-forming galaxies the FIR luminosity has been found to correlate with other tracers of SF (as UV-continuum or $\text{H}\alpha$ luminosity) and, consequently, dust heating from young stars is expected to dominate the 40–120 μm emission (Kennicutt 1998).

We estimated the FIR star-formation rate (SFR_{FIR}) and the radio star-formation rate ($\text{SFR}_{1.4\text{ GHz}}$) using the relations determined by Bell (2003), which account for old stellar populations and should be appropriate for late type spiral galaxies. The mean value ($\text{SFR}_{\text{current}} = 1/2(\text{SFR}_{\text{FIR}} + \text{SFR}_{1.4\text{ GHz}})$) and the deviations from the mean are listed in Table 7 (only available in electronic

form). Both luminous galaxies show relatively low current SFR s in the range of $1\text{--}2\text{ }M_{\odot}\text{ yr}^{-1}$, so there is no clear sign of SF enhancement by possible recent interactions. A useful parameter for characterising the SF history is the ratio of the current SFR to the past mean SFR the birthrate parameter (also known as the Scalo parameter) $b = \text{SFR}_{\text{current}}/\langle\text{SFR}\rangle_{\text{past}}$. To determine this parameter, we need to know the stellar mass of galaxies. Combining the B and K band luminosities and $B - R$ colours determined in the present work, with stellar population models of Bell & de Jong (2001), we calculated the maximum disc stellar mass-to-light ratios in B and K bands. Both the stellar mass (M^*) obtained as a mean from B and K band data and the past mean SFR over 12 Gyr ($\langle\text{SFR}\rangle_{\text{past}}$) are listed in Table 7. We conclude that the UGC 622 appears to have had a nearly constant SFR over its whole SF history (with $b \simeq 0.72$) and is now slowly running off its fuel with enough gaseous supplies to maintain the present SF level during the next $\tau_{\text{gas}} = M(\text{H I})/\text{SFR}_{\text{current}} \sim 2.6$ Gyr. The main galaxy IC 65 appears to have had a more active SF past ($b \simeq 0.54$). Either this may have included several short star-bursting activities, which possibly could have been triggered through accretion of its gas-rich dwarf satellites, or the given value of the birthrate parameter simply results from exponentially declining SFR , as is typical of unperturbed spirals. The available gas reserve of the IC 65 is large enough to maintain the current SFR during at least a half of another Hubble time ($\tau_{\text{gas}} \simeq 7.5$ Gyr). Both IC 65 and UGC 622 appear to be quiescently star-forming galaxies.

6. Summary

After selecting four LSB dwarf companion candidates of the IC 65 group of galaxies we performed the B , R , and I band surface photometry for the first time for all certain and probable members of the group. The bright group members were studied in the NIR J , H , and K bands, too. Their relevant physical and model characteristics were determined and the probable evolutionary status of the group was discussed.

An analysis of the available photometric and kinematic data of individual galaxies with emphasis on studying the possible mutual interactions between the group members leads to the following results:

- The available H I imaging data show that all bright members and at least one dwarf companion have a nearly normal gaseous fraction with H I-mass-to-blue-luminosity ratios in the range of 0.3–1.0, consistent with their morphological type. The outer H I isophotes of the IC 65, and especially of the UGC 622, appear disturbed, in agreement with perturbation estimates.
- The optical morphology of the bright galaxies generally appears to be regular, with barely significant disturbances in isophotes of the outer stellar disc of the IC 65 and UGC 622.
- All bright group members (except PGC 138291, which we could not study in such detail) consist of many blue star-forming knots and plumes, especially UGC 608. A comparison of the surface photometry with the stellar population models of Bruzual & Charlot (2003) indicates that these blue knots must have formed recently. The available data do not establish whether they formed simultaneously, e.g. in starbursts possibly triggered by interactions.
- Two dIrr galaxies around the IC 65 both contain a number of H II regions, that show a range of stellar ages and provide evidence of propagating SF. One of these galaxies –

A 0101+4744 is a confirmed member of the group; the second one – A 0100+4734 appears to be located in front of the group.

- The brightest galaxies in both subgroups can fuel their current star-forming rates of $\sim 1\text{--}2 M_{\odot} \text{ yr}^{-1}$ for about the next 3–7 Gyr.

The IC 65 group of galaxies obviously belongs to the class of less evolved groups. It is composed of late type spiral and irregular galaxies arranged in two subgroups. No massive early type galaxies are present. No hot gas has been detected in it by the ROSAT survey. Some morphological irregularities and signs of enhanced SF in its members could be indicative of recent/ongoing mutual interactions, and yet the individual group members have retained much of their initial gas component. A few available velocities point to a short crossing time of only $\sim 0.1 H_0^{-1}$; however, this hardly means that the group has already reached a stable (virialised) configuration. The evidence, discussed above, lets us conclude that the IC 65 group of galaxies is a dynamically young system at a still relatively early stage of its collapse.

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References

- Aarseth, S. J., & Saslaw, W. C. 1972, *ApJ*, 172, 17
- Andredakis, Y. C., Peletier, R. F., & Balcells, M. 1995, *MNRAS*, 275, 874
- Bahcall, J. N., & Tremaine, S. 1981, *ApJ*, 244, 805
- Barazza, F. D., Binggeli, B., & Prugniel, P. 2001, *A&A*, 373, 12
- Barnes, J. 1985, *MNRAS*, 215, 517
- Barnes, J. E., & Hernquist, L. 1992, *ARA&A*, 30, 705
- Bell, E. F. 2003, *ApJ*, 586, 794
- Bell, E. F., & de Jong, R. S. 2001, *ApJ*, 550, 212
- Bender, R., & Möllenhoff, C. 1987, *A&A*, 177, 71
- Bertin, E., & Arnouts, A. 1996, *A&A*, 117, 393
- Binggeli, B. 1994, in *Panchromatic View of Galaxies. Their Evolutionary Puzzle*, ed. G. Hensler, C. Theis, & J. S. Gallagher (Gif-sur-Yvette: Editions Frontières), 173
- Binggeli, B., Sandage, A., & Tammann, G. A. 1985, *AJ*, 90, 1681
- Binney, J., & Tremaine, S. 1987, *Galactic Dynamics* (Princeton Univ. Press)
- Boselli, A., & Gavazzi, G. 2006, *PASP*, 118, 517
- Blackman, C. P., & van Moorsel, G. A. 1984, *MNRAS*, 208, 91
- Braun, R., Thilker, D., & Walterbos, R. A. M. 2003, *A&A*, 406, 829
- Bremnes, T., Binggeli, B., & Prugniel, P. 1998, *A&AS*, 129, 313
- Bremnes, T., Binggeli, B., & Prugniel, P. 1999, *A&AS*, 137, 337
- Bremnes, T., Binggeli, B., & Prugniel, P. 2000, *A&AS*, 141, 211
- Bruzual, G., & Charlot, S. 2003, *MNRAS*, 344, 1000
- Byrd, G., & Valtonen, M. 1990, *ApJ*, 350, 89
- Carrasco, E. R., Mendes de Oliveira, C., & Infante, L. 2006, *AJ*, 132, 1796
- Christian, C. A., Adams, M., Barnes, J. V., et al. 1985, *PASP*, 97, 363
- Condon, J. J., Cotton, W. D., & Broderick, J. J. 2002, *AJ*, 124, 675
- Dahari, O. 1984, *AJ*, 89, 966
- Efron, B. 1981, *Biometrika*, 68, 589
- Ferguson, H., & Binggeli, B. 1994, *A&ARv*, 6, 67
- Freeman, K. C. 1970, *ApJ*, 160, 811
- Gal, R. R., Carvalho, R. R., Odewahn, S. C., et al. 2004, *AJ*, 128, 3082
- Garcia, A. M. 1995, *A&A*, 297, 56
- Garcia, A. M., Paturel, G., Bottinelli, L., & Gougouenheim, L. 1993, *A&AS*, 98, 7
- Gerola, H., Seiden, P. E., & Schulman, L. S. 1980, *ApJ*, 242, 517
- Gott, III, J. R., & Turner, E. L. 1977, *ApJ*, 213, 309
- Grebel, E. K. 2004, *Carneige Obs. Astrophys. Series*, 4, 237
[arXiv:astro-ph/0403222]
- Grebel, E. K. 2007, in *Proc. of the ESO workshop: Groups of Galaxies in the Nearby Universe*, ed. I. Saviane, V. Ivanov, & J. Borissova, *ESO Astrophysics Symposia*, 3 [arXiv:astro-ph/0605564]
- Haud, U. 1990, *A&A*, 229, 47
- Haynes, M. P., & Giovanelli, R. 1984, *ApJ*, 306, L55
- Haynes, M. P., Giovanelli, R., Salzer, J. J., et al. 1999, *AJ*, 117, 1668
- Heraudeau, Ph., & Simien, F. 1996, *A&AS*, 118, 111
- Hickson, P. 1982, *ApJ*, 255, 382
- Hopp, U., et al. 2008, in preparation
- Huchra, J. P., & Geller, M. J. 1982, *ApJ*, 257, 23
- Huchtmeier, W. K., & Richter, O.-G. 1982, *A&A*, 109, 331
- Hunter, D. A., & Elmegreen, B. G. 2004, *AJ*, 128, 2170
- Jarret, T. H., Chester, T., Cutri, R., et al. 2000, *AJ*, 119, 2498
- Karachentsev, I. D. 1970, *Probl. kosm. fiz.*, 5, 201
- Karachentsev, I. D. 1996, *A&A*, 305, 33
- Karachentsev, I. D. 2005, *AJ*, 129, 178
- Karachentsev, I. D., Karachentseva, V. E., Huchtmeier, W. K., & Makarov, D. I. 2004, *AJ*, 123, 2031
- Karachentseva, V. E., Prugniel, P., Vennik, J., et al. 1996, *A&AS*, 117, 343
- Kennicutt, R. C. 1998, *ARA&A*, 36, 189
- Lake, G., & Moore, B. 1999, in *Proc. of the IAU Symp. 186: Galaxy Interactions at Low and High Redshift*, ed. J. E. Barnes, & D. B. Sanders, 393
- Lorenz, H., Richter, G. M., Capaccioli, M., & Longo, G. 1993, *A&A*, 277, 321
- Mamon, G. A. 1993, in *Gravitational Dynamics and the N-body Problem*, ed. F. Combes, & E. Athanassoula, *Obs. de Paris*, 188
[arXiv:astro-ph/9308032]
- Mamon, G. A. 2007, in *Proc. of the ESO workshop: Groups of Galaxies in the Nearby Universe*, ed. I. Saviane, V. Ivanov, & J. Borissova, *ESO Astrophysics Symposia*, 203 [arXiv:astro-ph/0607482]
- Marquez, I., & Moles, M. 1999, *A&A*, 344, 421
- Mayer, L., Governato, F., & Colpi, M. 2000, *ASP Conf. Ser.*, 215, 42
- Moore, B., Lake, G., & Katz, N. 1998, *ApJ*, 495, 139
- van Moorsel, G. A. 1983, *A&AS*, 54, 1 (vM83)
- Mulchaey, J. S. 2000, *ARA&A*, 38, 289
- Nolthenius, R., & White, S. D. M. 1987, *MNRAS*, 225, 505
- Omar, A., & Dwarakanath, K. S. 2006, *JApA*, 27, 7
[arXiv:astro-ph/0602039]
- Parodi, B. R., Barazza, F. D., & Binggeli, B. 2002, *A&A*, 388, 29
- Paturel, G., Bottinelli, L., & Gougouenheim, L. 1995, *ApL&C*, 31, 13
- Persic, M., Salucci, P., & Stel, F. 1996, *MNRAS*, 281, 27
- Plionis, M., Basilakos, S., & Tovmassian, H. M. 2004, *MNRAS*, 352, 1323
- Rasmussen, J., Ponman, T. J., & Mulchaey, J. S. 2006, *MNRAS*, 370, 453
- Reid, I. N., Brewer, C., Brucato, R. J., et al. 1991, *PASP*, 103, 661
- Richter, G. M. 1978, *Astron. Nachr.*, 299, 282
- Roberts, M. S., & Haynes, M. P. 1994, *ARA&A*, 32, 115
- Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, *ApJ*, 500, 525
- Sersic, J.-L. 1968, *Atlas de galaxies australes*, Observatorio Astronomico, Cordoba
- Tanvua, L., Kelm, B., Focardi, P., Rampazzo, R., & Zeilinger, W. W. 2003, *AJ*, 126, 1245
- Trentham, N., Tully, R. B., & Verheijen, M. A. W. 2001, *MNRAS*, 325, 385
- Tully, R. B. 1987, *ApJ*, 323, 1
- Vader, J. P., & Chaboyer, B. 1994, *AJ*, 108, 1209
- de Vaucouleurs, G. 1977, in *Evolution of Galaxies and Stellar Populations*, ed. R. Larson, & B. Tinsley, *Yale Univ. Observatory*, New Haven, 43
- de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H. G., et al. 1991, *Third Reference Catalogue of Bright Galaxies* (New York: Springer-Verlag) (RC3)
- Vennik, J., & Hopp, U. 2007, in *Stellar Populations as Building Blocks of Galaxies*, ed. A. Vazdekis, & R. F. Peletier (Cambridge Univ. Press), *Proc. IAU Symp.*, 241, 525
- Vennik, J., & Tago, E. 2007, in *Proc. of the ESO workshop: Groups of Galaxies in the Nearby Universe*, ed. I. Saviane, V. Ivanov, & J. Borissova, *ESO Astrophysics Symposia*, 119
- Vennik, J., Richter, G. M., Thänert, W., & Bieriing, C. 1996, *AN*, 317, 289
- Verheijen, M. A. W. 2001, *ApJ*, 563, 694
- Zabludoff, A. I., & Mulchaey, J. S. 1998, *ApJ*, 498, L5

Fig. 5. Light distribution in IC 65 II. Parameters of the fitted free ellipses: the axes ratio (b/a , *top left*), position angle from the north through the east (PA, *bottom left*), displacement of the centre of fitted ellipses in x ($x - x_0$, *top right*) and in y ($y - y_0$, *bottom right*). The radii are equivalent radii (i.e. $\text{radius} = \sqrt{ab}$).

Fig. 7. Light distribution in UGC 622 II. Parameters of the fitted free ellipses. Coded as in Fig. 5.

Fig. 9. Light distribution in UGC 608 II. Parameters of the fitted free ellipses. Coded as in Fig. 5.**Table 2.** Log of the direct imaging with the Calar Alto (CA) 1.23 m telescope.

Date	Detector	Band	Exposure [s]	Sky [mag/□"]
01-02.09.95	Tek#6	<i>B</i>	1800	21.5
		<i>R</i>	1200	20.7
16-20.01.99	Tek#7c-12	<i>B</i>	300, 600	22.3
		<i>R</i>	100, 150, 600	21.5
		<i>I</i>	150, 600	19.7

Table 6. Interaction probabilities of galaxies in subgroups.

Galaxy	Subgr.	D_{gal}		Main perturber	d	P_{gg}	
		H I (3)	opt (4)			H I (7)	opt (8)
IC 65	1	6.9	4.4	A 0101+4744	5.2	0.0065	0.0017
A 0101+4744	1	1.8	0.8:	IC 65	5.2	0.246	0.0216
A 0100+4734	1		0.8:	IC 65	10.3		0.0027
UGC 622	2	3.2	1.4	PGC 138291	5.2	0.0066	0.0006
PGC 138291	2	2.1	1.3:	UGC 622	5.2	0.0365	0.0087
UGC 608	2	3.0	2.1	UGC 622	14.2	0.0019	0.0006
A 0100+4756	2		0.5:	UGC 622	5.0		0.0015
A 0101+4752	–		0.5:	IC 65	14.8		0.00005

Table 7. Star-forming properties of the brightest galaxies in subgroups.

Galaxy	S_{60} [Jy]	S_{100} [Jy]	$S_{1.4 \text{ GHz}}$ [mJy]	L_{FIR} [$10^{10} L_{\odot}$]	$L_{1.4 \text{ GHz}}$ [$10^{21} \text{ W Hz}^{-1}$]	SFR_{current} [$M_{\odot} \text{ yr}^{-1}$]	$\mathcal{M}^*$ [$10^{10} M_{\odot}$]	$\langle SFR \rangle_{\text{past}}$ [$M_{\odot} \text{ yr}^{-1}$]	b	τ_{gas} [Gyr]
IC 65	2.37	6.58	18.8	1.06 ± 0.10	3.35 ± 0.37	1.9 ± 0.3	4.2 ± 1.3	3.5 ± 1.1	0.54 ± 0.25	7.5
UGC 622	1.61	5.16	11.4	0.78 ± 0.11	2.03 ± 0.25	1.4 ± 0.2	2.0 ± 0.3	1.7 ± 0.3	0.72 ± 0.20	2.3

Appendix A: Surface photometry and error estimates

A.1. Image processing

Noise is a fundamental problem of image processing in astronomy because of the specific interest in faint signals. Smoothing stands for removal of the noise, and filtering is the usual tool. Stationary filtering with an impulse response (or point-spread function), which is invariant over the image, is unsuitable since the high-resolution objects in the image would be degraded and smeared. We need to apply a space-variable (adaptive) filter that recognises the local signal resolution and adapts its own impulse response to this resolution. As a result, the adaptive filter extensively smoothes the background, but does it less extensively for the galactic outskirts and not at all for the highest resolution features. We used the Potsdam adaptive filtering facility described in Lorenz et al. (1993) and implemented in the ESO MIDAS environment (task FILTER/ADAPTIV). The filter is based on the H-transform (Richter 1978). The local signal-to-noise (S/N) ratio as a function of decreasing resolution is evaluated by means of comparing the mean gradients and curvatures over different scale lengths (obtained from the H-coefficients of different order) to the corresponding expectation values of the noise. The order for which this S/N ratio exceeds a given parameter (threshold for significance) indicates the local resolution scale length of the signal and determines the size of the impulse response of the filter at this point. Before applying the adaptive filter, a mask frame was built, where bright stars and galaxies were masked out. The mask frame is essential for proper determination of the noise statistics. The noise statistics were created by the filter and used to distinguish between the local signal and noise at each scale length. We varied the maximum filter size between 7×7 pixels and 15×15 pixels depending on the quality of the frames. The filter strength, defined by the minimum S/N ratio for the detection of a local signal, was generally between $2.0 \div 2.5$ of the rms noise level of the sky background at each scale length. More details concerning the filtering procedures are given in Vennik et al. (1996). After filtering, the sky background was fitted by a tilted plane, created from a two-dimensional polynomial, using a least-square method FIT/FLAT_SKY. Then, the galaxy image was cleaned from disturbing objects, e.g. foreground stars, using the interactive polygon editor of the Potsdam Image Processing Software (PIPS) package, running within the MIDAS environment.

In addition to the adaptive smoothing, we performed an adaptive Laplacian filtering. The Laplacian filter computes the second derivative (i.e. curvature) of the SB distribution, which does not retain any photometric information. However, it is useful to disentangle the inner morphology as multiple nuclei, H II regions, spiral arms, and bridges, usually hidden by the large luminosity gradients of the central regions of galaxies.

A.2. Surface photometry and profile extraction

The structure of the galaxy is reflected to a large extent in the surface brightness (SB) distribution where the different structure components produce characteristic light distributions within the overall SB profile. Therefore, among the basic results of the present study are the SB profiles, as well as a set of isophotal and integral parameters derived from these profiles. A common approach to obtaining the SB profile of a regular galaxy is fitting a sequence of ellipses to the galaxy isophotes at pre-defined intensity levels and computing the mean SB between

successive ellipses. This simple technique is inadequate when dealing with objects having complex morphologies. For irregular galaxies, we applied an alternative strategy for calculating equivalent light profiles that does not depend on any a priori assumptions of the galaxy morphology. This approach is integrated into the PIPS package.

For this approach, we slice the smoothed image of a galaxy into k areas where each area n is enclosed by two isophotes I_n and I_{n+1} (n runs from 0 to k). The level of these isophotes is generally spaced by 0.1 mag. Total intensity of all pixels between successive isophotes I_n and I_{n+1} divided by the area enclosed between the two isophotes ($\Delta A = A_{n+1} - A_n$) yields the surface brightness for the equivalent light profile at the equivalent radius $r_{eq,n} = [(A_n + A_{n+1})/2\pi]^{1/2}$. A slight disadvantage of this approach results from the noise, especially at low galaxy light levels near the mean sky background. The routine integrates into the equivalent profile those random signal fluctuations that are a few sigmas above the mean sky level. As an effect, the derived equivalent radius will be artificially increased when approaching the sky level. Fortunately, this effect can be largely reduced by adaptive smoothing of the signal in the outskirts of the galaxy.

Finally, we determined the SB profiles twice for every galaxy. First, we calculated equivalent light profiles using the PIPS software. The resulting equivalent light profile yields the isophotal radii, and the mean SB . It further allows determination of the best-fitting parameters of the particular density distribution model. In addition, the light growth curve of the galaxy was calculated and the isophotal magnitudes, as well as the effective radius and effective SB , were determined on this basis. The total magnitude was estimated by asymptotic extrapolation of the radial growth curve.

Second, we applied the ellipse-fitting algorithm FIT/ELL3 within in the SURFPHOT package of MIDAS to obtain the shape and orientation of the isophotes of the regular galaxies. As a result, we generated a set of radial profiles in each particular passband: surface brightness (SB), minor-to-major axis ratio (b/a), position angle (PA), and displacement of the centre of fitted ellipses ($x - x_0, y - y_0$). Here, (x_0, y_0) are the coordinates of the centre of the innermost ellipse.

Finally, we obtained colour index profiles. Here, we forced the surface photometry in the second (or further) band(s) to follow the ellipticity fit of the first band, generally the R band as the deepest one.

A.3. The photometry errors

The magnitude errors consist of internal and external components. The internal errors of the instrumental (non-calibrated) magnitudes and those of the particular SB profile are dominated by the error in the adopted sky background value, and, in addition, includes, the random count error determined from the photon statistics in the aperture measurements. Following Vader & Chaboyer (1994), we calculated the internal errors in intensity as

$$\Delta I = \sqrt{N_{\text{tot}} + (\delta n_{\text{sky}} A)^2}, \quad (\text{A.1})$$

where N_{tot} is the total number of counts, as measured on the adaptive filtered frame within aperture A , which is defined as the area between successive isophotes (in pixels), and n_{sky} is the mean sky counts per pixel and δ the fractional error in the mean sky value. We measured the sky background fluctuations on the filtered CCD frames within small apertures in the vicinity of each galaxy. The variations in the sky background were typically about 0.45% (in B), 0.35% (in R), and 0.3% (in I).

Table A.1. Comparison of magnitudes from the present work with those taken from literature.

Cat./ Mag. (1)	<i>n</i> (2)	$\langle\sigma_{\text{cat}}\rangle$ (3)	$\langle\Delta m\rangle \pm \sigma$ (4)	σ_{our} (5)
RC3/ B_T	4	0.23	$+0.07 \pm 0.27$	0.135
RC3/ m_B	8	0.26	$+0.23 \pm 0.28$	0.11
LEDA/ B_T	8	0.35	-0.26 ± 0.40	0.21
LEDA/ I_T	4	0.08	-0.20 ± 0.26	0.25

Adopting the typical sky brightnesses of 22.0 (B), 21.2 (R), and 19.7 (I) mag arcsec⁻² (Table 2) the mean uncertainty introduced by the inaccuracy of the sky background determination is in the range of 0.10–0.06 mag. This uncertainty is primarily caused by the background variations across the frame due to some problems with flat-fielding, particularly on the B frames. The equivalent SB profiles have been measurable typically up to the level 27 to 28 mag arcsec⁻² in the B band, up to 26 mag arcsec⁻² in the R band, and up to ~ 25 mag arcsec⁻² in the I band. The photometric accuracy of the 2MASS images is estimated to be better than ~ 0.1 mag (Jarret et al. 2000). The azimuthally averaged SB sensitivities (3σ), obtained from the coadded NIR images, are ~ 21.0 , ~ 20.5 , and ~ 20.0 mag arcsec⁻² in the J , H , and K bands, respectively (Omar & Dwarakanath 2006). Typical internal uncertainties are shown with error bars on the SB and colour profiles in Sect. 4.

To estimate the true (external) magnitude calibration errors independently, we compared our total magnitude measurements with published data for the brighter galaxies, as quoted in the RC3 (de Vaucouleurs et al. 1991) and/or in the LEDA database (Paturel et al. 1995). The IC 65 group of galaxies contains only three bright galaxies (IC 65, UGC 608, and UGC 622) with reliable magnitudes in the above catalogues. To establish a comparison with a better statistical data base, we include here the galaxies NGC 2591, NGC 2655, NGC 2715, UGC 4701, and UGC 4714. They belong to the NGC 2655 group of galaxies and were observed during the same observing session. The data were handled exactly the same way as described for the IC 65 group members. All other results concerning this particular group will be presented in the forthcoming paper of this series. The results of comparisons are shown in Fig. A.1, and summarised in Table A.1, where columns contain the name of the catalogue and the magnitude system (1), number of common galaxies (2), their mean quoted magnitude error (3), the mean difference between our measurements and catalogued data ($\Delta m = m_{\text{our}} - m_{\text{cat}}$) with its 1σ standard deviation (4), and the mean uncertainty of our measurements calculated as $\sigma_{\text{our}}^2 = \sigma^2 - \sigma_{\text{cat}}^2$ (5).

The small number of available comparison sets, as well as the relatively large intrinsic errors of the literature data, complicate the estimate of our own systematic errors. We believe that the RC3 magnitudes are still the most reliable ones that give more weight to our conclusions. We find no significant indication of systematic magnitude zeropoint differences, and no trends appear with the apparent magnitude. Our error estimates in the B band range from ± 0.15 mag for bright galaxies to ± 0.20 mag for fainter ($B_T \geq 15$) galaxies. A similar error range should be proper to our R and I band magnitudes, too.

A.4. Profile fitting

The SB profiles depend on the morphological type and bear some information about the possible environmental influences on the dynamical evolution of galaxies. A preliminary inspection of the

Fig. A.1. Comparison of our measured total B magnitudes (B_{our}) with those taken from the RC3 (B_T – filled circles, m_B – filled triangles) and from the LEDA (open circles). The quoted errors of catalogued magnitudes are indicated with error bars.

SB profiles reveals that those of the LSB dwarf galaxies show only minor deviations from the pure exponential. These small deviations mostly appear in their inner parts of the galaxies and can be attributed to the occurrence of star-forming knots.

First, we fitted the equivalent light profiles of the dwarf galaxies with the Sersic (1968) power law

$$\mu(r) = \mu_0 + 1.086 \left(\frac{r}{h} \right)^{1/n}, \quad (\text{A.2})$$

and determined the best-fitting value of the parameter n . The radial range of the light profiles over which the best fit has been computed extends from the outside of the region dominated by seeing (typically 2–3 arcsec) out to where the uncertainties in the sky subtraction render the light profiles unreliable. We found the best-fitting values in the range $n = 0.7$ – 1.2 and concluded that the underlying stellar component (i.e. when excluding the luminous blue knots) of all four LSB dwarf galaxies could be reasonably well-fitted with a pure exponential model ($n = 1$). In the second attempt, we fitted the (outer) linear part of each profile with the exponential disc model and determined the best-fitting model parameters (μ_0, h) , which we aim to compare (for our full sample of groups) with the results of earlier studies of grouped and field LSB dwarf galaxies (e.g. Barazza et al. 2001; Parodi et al. 2002; Vennik et al. 1996). The total light emitted by the exponential disc can be computed as

$$m^{\text{exp}} = \mu_0^{\text{exp}} - 5 \log(h) - 1.995. \quad (\text{A.3})$$

The goodness of the pure exponential fit can then be expressed as the difference Δm between m^{exp} and the actual measured total magnitude m_T : $\Delta m = m^{\text{exp}} - m_T$.

Regular late-type spiral galaxies IC 65 and UGC 608 both show a reliable light excess above the exponential disc model. This extra light was modelled with the Sersic power law, which has been found correct when describing the light distribution of spiral bulges (e.g. Andredakis et al. 1995). The parameters (μ_0, h) of the best-fitting exponential model and the magnitude difference Δm for the individual galaxies are listed in Table 4. The results of fitting are discussed individually for each galaxy in Sect. 4.

Appendix B: Radio-observations of the A 0100+4734

We attempted to measure the HI flux of this actively star-forming late type galaxy. Pilot observations have been made

Fig. B.1. The H I spectrum of IC 65 (*top*) and of its dwarf companion A 0100+4734 (*bottom*). Flux densities along the y -axis are in relative units.

by W. Huchtmeier with the 100-m radio telescope at Effelsberg ($HPBW = 9'3$) in July 2002. The main galaxy IC 65 shows a broad ($\Delta V_{20} = 343 \text{ km s}^{-1}$) double-horned global H I profile (Fig. B.1), as typical of a classical rotation curve with an extended flat part in outer regions. The blueshifted horn shows a slightly higher amplitude, in accord with the result obtained earlier by vM83 (his Fig. 26). The dwarf galaxy A 0100+4734 was searched for emission in the same frequency band 6.25 MHz (1250 km s^{-1}) centred on the velocity of IC 65. The obtained spectra are compared to each other in Fig. B.1. A marginal signal registered by pointing the telescope in the direction of that dwarf is certainly corrupted by the signal from the parent galaxy, due to the close proximity of these two galaxies. New H I observations with better angular resolution and in broader redshift interval are needed to determine the H I properties of the A 0100+4734.