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New distances to galaxies in the Centaurus A group⋆,⋆⋆

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Abstract. We present Hubble Space Telescope/WFPC2 images of seventeen dwarf galaxies in the Centaurus A group. Their distances derived from the magnitudes of the tip of the red giant branch are 5.2 Mpc (KK112), 3.2 Mpc (ESO 321-014), 3.5 Mpc (KK179), 3.4 Mpc (NGC 5102), 4.6 Mpc (KK200), 3.7 Mpc (ESO 324-024), 4.7 Mpc (KK208), 4.6 Mpc (ESO 444-084), 4.4 Mpc (IC 4316), 4.5 Mpc (NGC 5264), 3.6 Mpc (KK211), 3.6 Mpc (KK213), 3.4 Mpc (ESO 325-011), 3.8 Mpc (KK217), 4.0 Mpc (KK221), 4.8 Mpc (NGC 5408), and 3.6 Mpc (PGC 51659). The galaxies are concentrated in two spatially separated groups around NGC 5128 = Cen A and NGC 5236 = M 83. The Cen A group itself has a mean distance of 3.63 ± 0.07 Mpc, a velocity dispersion of 89 km s^{-1}, a mean projected radius of 263 kpc, an estimated orbital mass of $2.1 \times 10^{12} M_\odot$, and an orbital mass-to-blue luminosity ratio of 64 $M_\odot/L_\odot$. For the M 83 group we derived a mean distance of 4.57 ± 0.05 Mpc, a velocity dispersion of 62 km s^{-1}, a mean projected radius of 142 kpc, an estimated orbital mass of $0.8 \times 10^{12} M_\odot$, and $M_{\rm orb}/L_{\rm B} = 37\ M_\odot/L_\odot$. The M 83 group moves away from the Cen A group, which yields a radius of the zero-velocity surface of the Cen A group of $R_0 < 1.26$ Mpc. The total mass within R_0, $M_0 < 2.7 \times 10^{12} M_\odot$, agrees with the orbital mass estimate. The centroids of both the groups have very small peculiar velocities, $(+18 \pm 24)$ km s^{-1} (Cen A) and (-17 ± 27) km s^{-1} (M 83) with respect to the local Hubble flow with $H_0 = 70$ km s^{-1} Mpc^{-1}.

Key words. galaxies: dwarf – galaxies: distances and redshifts – galaxies: general

1. Introduction

The group of galaxies around the peculiar radio galaxy NGC 5128 = Centaurus A is the most prominent association of bright galaxies on the southern sky. It is situated at approximately the same distance from us (∼3.6 Mpc) as another nearby (northern) group of galaxies around M 81, but has been less extensively studied. Before the middle of the 90ies, only one galaxy of the group, NGC 5236, had a distance estimated via cepheids (Saha et al. 1995). For two other galaxies, NGC 5128 and NGC 5102, the distances were measured from the luminosity of planetary nebulae and the brightness of the red giant branch tip (Soria et al. 1996; Harris et al. 1999). The distance to NGC 5236 was determined by Schmidt et al. (1994) based on the expanding photosphere method for type II supernovae. Distances had been estimated only for the brightest galaxies in the group until Jerjen et al. (2000a) applied the method of surface brightness fluctuations to measure distances to five dwarf galaxies in the Centaurus A group. Population of dwarf galaxies around Cen A was also searched by Côté et al. (1997), Jerjen et al. (2000b), and the HIPASS group (Banks et al. 1999).

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⋆⋆ Figure 3 is only available in electronic form at `http://www.edpsciences.org`

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In this paper we present new distance measurements for an additional seventeen galaxies of the group. The distances were determined from the brightness of the tip of the red giant branch (=TRGB) based on V, I photometry obtained with the Wide Field Planetary Camera 2 (WFPC2) aboard the Hubble Space Telescope (HST) as part of the snapshot survey of probable nearby galaxies (Seitzer et al. 1999). Many of our targets in this program were taken from five lists by Karachentseva & Karachentsev, which contain results of an all-sky search for nearby dwarf galaxy candidates based on the POSS-II and ESO/SERC plates. Potential new members of the Centaurus A group are presented in two lists of southern objects (Karachentseva & Karachentsev 1998, 2000). These galaxies were surveyed in the HI line by Huchtmeier et al. (2000, 2001) to measure their radial velocities. As a result, about 20 new probable members of the Centaurus group are added to the ~30 known ones. It should be stressed that the dimension and population of the Centaurus A group remain still rather uncertain. For instance, de Vaucouleurs (1975), Tully (1987), and van den Bergh (2000a) recognized all the bright galaxies NGC 4945, 5128, 5236, and 5253 as members of a united group, but Karachentsev (1996) considered the giant galaxies NGC 5128 = Cen A and NGC 5236 = M 83 to be the centers of two separate groups. The measurements of accurate distances carried out by us for 17 galaxies allow us to make a choice between these assumptions.

The distribution of galaxies with radial velocities $V_{\rm LG} < 550$ km s^{-1} in and around the Centaurus A group is shown in Fig. 1 in the equatorial (B1950.0) coordinates. Here spiral (S) and irregular (Irr) galaxies are indicated by filled circles, and elliptical (E) and spheroidal (Sph) ones are marked with open circles. The two brightest galaxies, NGC 5128 and NGC 5236, are shown as boxes.

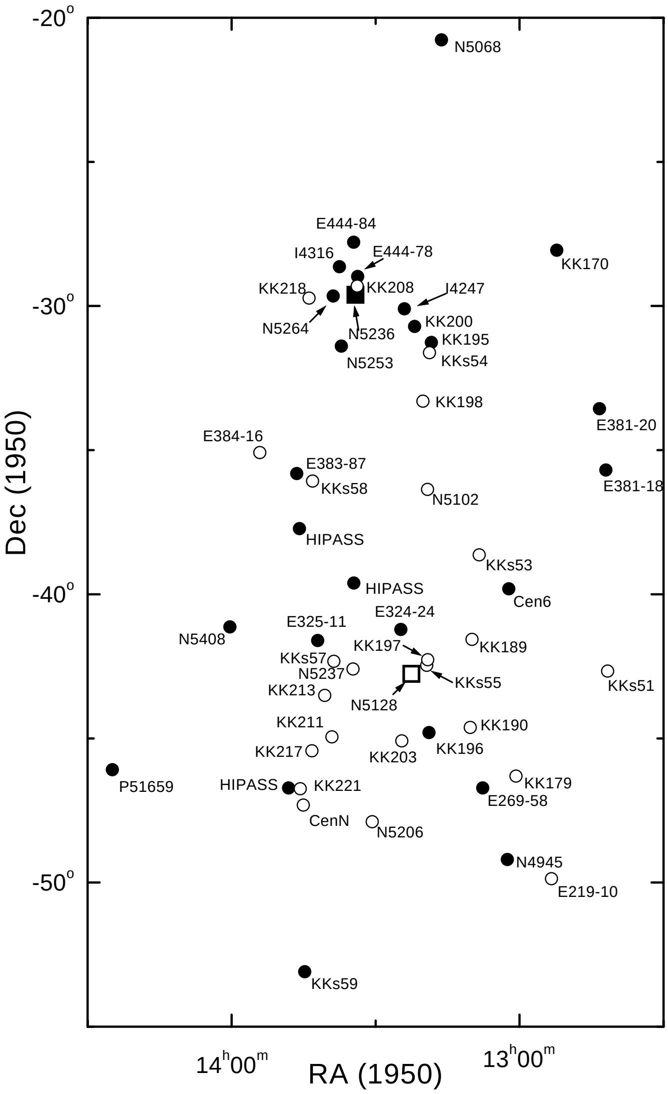

Fig. 1. The distribution of galaxies in the Centaurus A group region in equatorial coordinates. Spiral and irregular galaxies are indicated with filled circles, elliptical and dwarf spheroidal galaxies with open circles. The two brightest galaxies, NGC 5128 = Cen A and NGC 5236 = M 83, are shown by boxes.

2. WFPC2 photometry and data reduction

The observations of the seventeen galaxies in the Cen A group were obtained during 1999 July 17 to 2001 July 27 as part of our HST snapshot survey of nearby galaxy candidates (GO-8192, GO-8601, Seitzer et al. 1999). The target galaxies were centered usually on the WF3 chip, but for some bright objects the WFPC2 position was shifted towards the galaxy periphery to decrease the stellar crowding effect. 600 s exposures were taken in the F606W and F814W filters for each object. Digital Sky Survey images (DSS-II, red) of the seventeen galaxies are shown in Fig. 2 with the HST WFPC2 footprints superimposed. The field size of the DSS images is $8' \times 8'$.

The photometric reduction was carried out using the HSTphot stellar photometry package described by Dolphin (2000a). After removing cosmic rays with the HSTphot *cleansep* routine, simultaneous photometry was performed on the F606W and F814W frames using *multiphot*, with aperture corrections for an aperture of radius $0\farcs5$. Charge-transfer efficiency (CTE) corrections and calibrations were then applied, which are based on the Dolphin (2000b) formulae, producing VI photometry for all stars detected in both images. Because of the relatively small field of the Planetary Camera (PC) chip, very few bright stars are available for the computation of the aperture correction. Thus the PC photometry was omitted from further analysis. Additionally, stars with the signal-to-noise ratio $S/N < 5$, $\mid \chi \mid > 2.0$, or $\mid$ sharpness $\mid > 0.4$ in each exposure were eliminated from the final photometry list. We estimate the uncertainty of the photometric zeropoint to be within $0\fm05$ (Dolphin 2000b).

Mosaic images of the galaxies are shown in upper panels of Fig. 3, where both filters are combined. The compass in each field indicates the North and East directions.

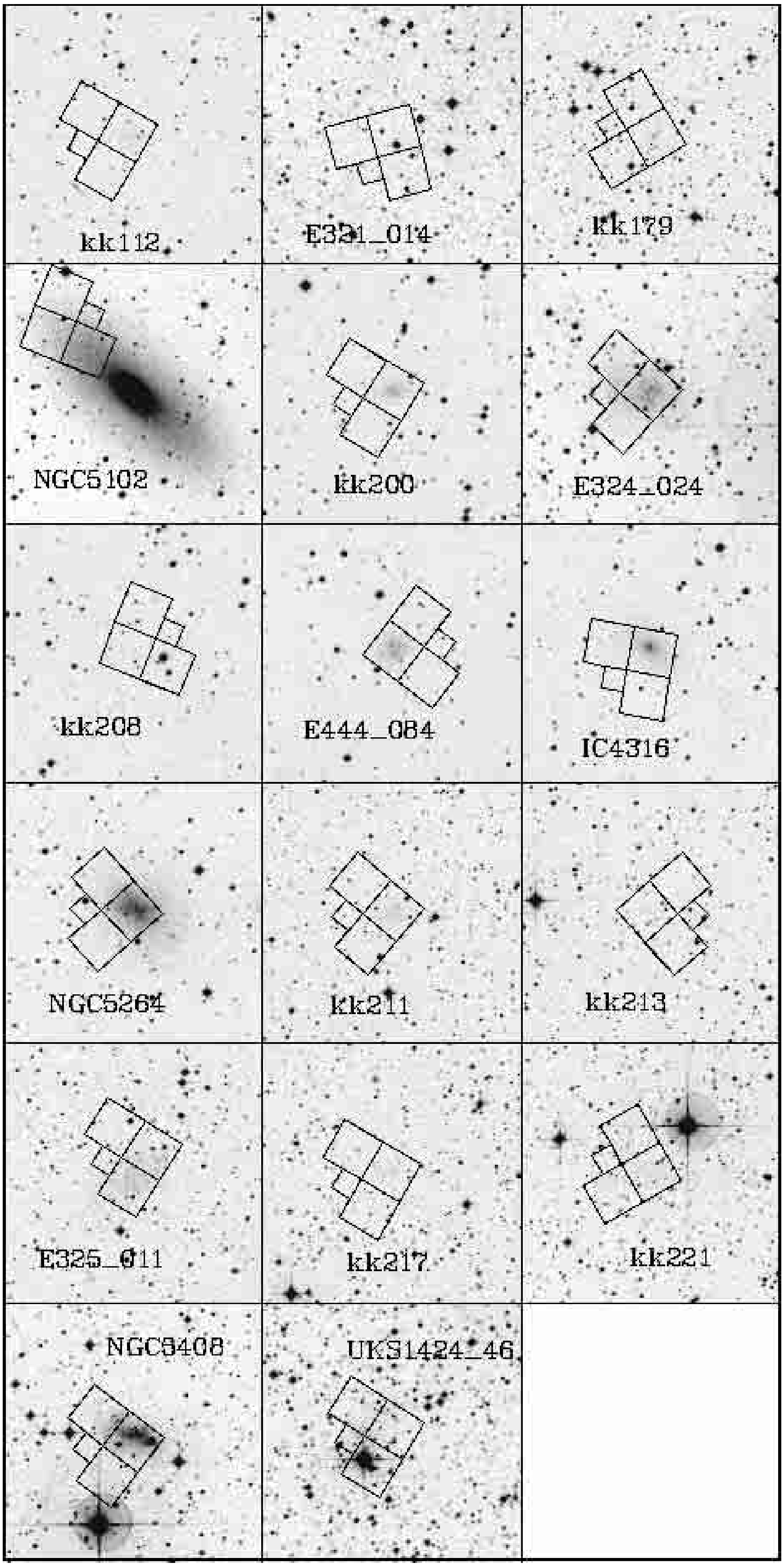

Fig. 2. The Digital Sky Survey images of 17 dwarf galaxies in the Centaurus group. The field size is 8′, North is up and East is left. The HST WFPC2 footprints are superimposed.

3. Color-magnitude diagrams and distances

The middle panels of Fig. 3 present I versus $(V-I)$ color-magnitude diagrams (CMDs) for the seventeen observed galaxies. As demonstrated by Lee et al. (1993), the TRGB is a reliable distance indicator, which is relatively independent of age and metallicity. For metal-poor systems the TRGB may be assumed to be at $M_I = -4.05$ mag (Da Costa & Armandroff 1990). To determine the TRGB location we obtained the Gaussian-smoothed I-band luminosity function for red stars with colors $V-I$ within $\pm 0\overset{\text{m}}{.}5$ of the mean $< V-I >$ for expected red giant branch (RGB) stars. Following Sakai et al. (1996), we used a Sobel edge-detection filter. The position of the TRGB was identified with the peak in the filter response function. The resulting luminosity functions and the Sobel-filtered luminosity functions are shown in the bottom panels of Fig. 3. A summary of the derived distance moduli is given in Table 1. The data listed in the table columns are as follows: (1) galaxy name; (2) equatorial coordinates corresponding to the WF3 center; (3, 4) apparent integrated magnitude and angular dimension from NED or Karachentseva & Karachentsev (1998, 2000); (5) radial velocity in $\mathrm{km\,s^{-1}}$ in the Local Group rest; (6) morphological type in de Vaucouleurs (1975) notation; (7) position of the TRGB and its uncertainty derived with the Sobel filter; (8) Galactic extinction in the I-band from IRAS/DIRBE data (Schlegel et al. 1998); (9, 10) true distance modulus and linear distance in Mpc. Below we discuss some individual properties of the galaxies.

KK112 = FG315 = AM 1152-331. This irregular galaxy of low surface brightness was found by Feitzinger & Galinski (1985) and included in the catalog of southern peculiar galaxies by Arp & Madore (1987). Its radial velocity was measured by Matthews et al. (1995). The CMD of the galaxy shows the presence of RGB and asymptotic giant branch (AGB) stars, as well as bright blue stars on the upper main sequence. We determined the TRGB position as 1/2 of the peak width at 62% of its maximum. The TRGB position yields a true distance modulus $(m-M)_0 = 28.59$ mag. Judging from its distance, $D = 5.22$ Mpc, and the large separation from the group center, $(20\overset{\circ}{.}3)$, KK112 may be considered to be a background galaxy.

ESO 321-014 = PGC 39032. This is an irregular dwarf galaxy with well populated RGB, AGB and upper main sequence (MS) branches. The TRGB position yields a distance $D = 3.19 \pm 0.26$ Mpc, which is the closest among the galaxies considered. Its radial velocity, $V_{\mathrm{LG}} = 337\ \mathrm{km\,s^{-1}}$, seems to be typical of the Cen A group, but the angular distance from the group center exceeds 14°.

KK179 = ESO 269-037 = FG367. This dwarf spheroidal galaxy of low surface brightness is erroneously classified in NED as IABm probably because a group of foreground stars are projected onto the galaxy. In the HIPASS survey (Kilborn et al. 1999) KK179 does not show HI emission. Judging from its distance, 3.48 Mpc, derived via the TRGB, the galaxy belongs to the companions of Cen A.

NGC 5102. This lenticular galaxy with an angular size of $8\overset{'}{.}6 \times 2\overset{'}{.}7$ was excentered in the WFPC2 to decrease the effect of stellar crowding. Besides the strong branch of red giants, a small number of blue stars are present in the galaxy CMD. The detected HI emission indicates that NGC 5102 has a considerable amount of gas ($\sim 2\times 10^8\ M_\odot$) and hence a strong potential to form stars. The distance modulus, 27.66 ± 0.25, derived by us from the TRGB agrees with the modulus 27.47 ± 0.22 obtained by McMillan & Ciardullo (1994) via the luminosity of planetary nebulae.

KK200 = KDG15. The irregular galaxy of moderately low surface brightness was found by Karachentseva (1968). Its TRGB position yields the distance 4.63 Mpc. Judging from its coordinates and distance, KK200 is one of the companions of the giant spiral galaxy M 83.

ESO 324-024 = PGC 47171. Among the dwarf irregular galaxies of the group this object has the smallest angular distance from Cen A. The distance 3.73 Mpc derived from the TRGB confirms its membership in the Cen A group.

KK208. This is a peculiar elongated object of extremely low surface brightness with angular dimensions of $6\overset{'}{.}0 \times 2\overset{'}{.}5$. KK208 is practically invisible as a galaxy on the WFPC2 image, but nevertheless it is well resolved into faint, mainly red stars. Being situated 19′ North of the M 83 center, KK208 looks like its semi-disrupted tidal tail. However, it is more probable that KK208 is an individual dwarf spheroidal galaxy, similar to the Sagittarius dSph galaxy near the Milky Way (Ibata et al. 1994), whose shape is strongly disturbed by interaction with M 83. The TRGB distance to the object, 4.68 ± 0.42 Mpc agrees well with the distance 4.5 ± 0.7 Mpc derived for M 83 by Schmidt et al. (1994) from type II supernovae. We classify KK208 as dSph, basing on its population, but not on it's shape, which is rather irregular. In the direction of KK208 Huchtmeier et al. (2000) detected a strong HI emission with $V_{\mathrm{LG}} = +189\ \mathrm{km\,s^{-1}}$; however, this emission is apparently caused by the gaseous periphery of M 83.

ESO 444-084 = PGC 48111. This compact irregular galaxy contains numerous blue stars. Judging from its location and the distance $D = 4.61$ Mpc, derived by us from its TRGB, ESO444-084 belongs to the M 83 companions.

IC 4316 = PGC 48368. While the outer regions of this galaxy have a regular shape, its central part looks patchy because of the presence of some blue stellar complexes. The derived distance of IC 4316, 4.41 Mpc, and its location suggest the galaxy may be a companion of M 83.

NGC 5264. This bright dwarf galaxy of Magellanic type has numerous blue stellar complexes and dusty patches in its central part. The periphery of the galaxy is populated mainly with RGB stars, which are used by us to derive a distance estimate of $D = 4.53$ Mpc. Like the two previous objects, NGC 5264 belongs to the M 83 companions.

Table 1. Distance moduli for galaxies in the Centaurus A group.

Name	RA (1950.0) h m s	Dec ° ′ ″	B_T m	$a \times b$ ′	V_{LG} km s^{-1}	T	I(TRGB) m	A_I m	$(m-M)_0$ m	D Mpc
KK 112	115210.5	−331647	16.60	1.1 × 0.8	363	10	24.68	0.14	28.59	5.22
FG 315							±.18			
ESO 321-014	121113.0	−375712	15.22	1.4 × 0.6	337	10	23.64	0.18	27.51	3.19
PGC 39032							±.17			
KK 179	130041.0	−461900	16.26	1.2 × 0.9	–	−3	23.92	0.26	27.71	3.48
ESO 269-037							±.19			
NGC 5102	131907.0	−362206	10.35	8.6 × 2.7	230	−3	23.72	0.11	27.66	3.40
							±.25			
KK 200	132148.1	−304243	16.67	1.3 × 0.8	262	9	24.33	0.13	28.33	4.63
KDG 15							±.19			
ESO 324-024	132442.0	−411318	12.90	3.2 × 2.3	270	10	24.02	0.21	27.86	3.73
PGC 47171							±.25			
KK 208	133346.5	−291900	14.3	6.0 × 2.5	–	−3	24.39	0.09	28.35	4.68
M 83 tail?							±.19			
ESO 444-084	133432.0	−274730	15.06	1.3 × 1.0	380	10	24.40	0.13	28.32	4.61
PGC 48111							±.19			
IC 4316	133729.0	−283830	14.56	1.6 × 1.0	382	10	24.29	0.12	28.22	4.41
PGC 48368							±.23			
NGC 5264	133847.0	−293942	12.60	2.5 × 1.5	269	9	24.33	0.10	28.28	4.53
							±.24			
KK 211	133903.4	−445711	16.32	1.2 × 1.1	–	−5	23.93	0.21	27.77	3.58
AM1339-445							+±22			
KK 213	134034.6	−433104	18.5	0.6 × 0.3	–	−3	23.94	0.19	27.80	3.63
							±.19			
ESO 325-011	134201.0	−413630	13.99	2.7 × 1.3	308	10	23.78	0.17	27.66	3.40
PGC 48738							±.25			
KK 217	134313.4	−452606	17.57	1.0 × 0.9	–	−3	24.11	0.24	27.92	3.84
AM1343-452							±.25			
KK 221	134540.5	−464454	18.	1.5 × 1.0	–	−3	24.22	0.27	28.00	3.98
							±.22			
NGC 5408	140018.0	−410811	12.21	1.9 × 1.2	288	9	24.49	0.13	28.41	4.81
							±.17			
UKS1424-46	142448.0	−460520	16.50	2.4 × 0.9	171	10	23.97	0.25	27.77	3.58
PGC 51659							±.20			

KK211 = AM 1339-445. This dwarf spheroidal galaxy, undetected in HI by Huchtmeier et al. (2001), contains mainly red stars. Its distance, 3.58 Mpc, derived from TRGB, allows one to rank KK211 among the Cen A companions.

KK213. This dwarf spheroidal galaxy of very low surface brightness is also undetected in HI (Huchtmeier et al. 2001). Its distance, 3.63 Mpc, derived from TRGB, confirms the membership of KK213 in the Cen A group. With an absolute magnitude of $-9\overset{\mathrm{m}}{.}7$, it is the faintest galaxy among the known members of the group.

ESO 325-011 = PGC 48738. A group of background spiral galaxies is projected onto the northern side of this irregular dwarf galaxy. As its CMD shows, the galaxy contains stellar populations of different types with a well populated RGB. The TRGB position yields a distance of 3.40 Mpc, which agrees with the galaxy's membership in the Cen A group.

KK217 = AM 1343-452. This dwarf spheroidal galaxy is not detected in HI (Huchtmeier et al. 2000). Its dominant population is made of RGB stars. The TRGB distance of 3.84 Mpc suggests that the galaxy is a companion of the Cen A. Based on the surface brightness fluctuations method, Jerjen et al. (2000a) estimated its distance to be 3.97 Mpc.

KK221. This dSph galaxy of extremely low surface brightness is undetected in HI by Huchtmeier et al. (2001). A bright star, situated North-West of the galaxy (see Fig. 2), produces diffraction spikes seen in the corners of WF3 and WF4. The galaxy is populated mainly with RGB stars, which yield a distance of 3.98 Mpc.

NGC 5408. This Magellanic type galaxy has prominent star-burst regions on its western side. The galaxy's CMD shows a lot of blue stars of the upper MS, which predominate over RGB stars. At the galaxy periphery, where stellar crowding effects are not so strong, we derive $I(\mathrm{TRGB}) = 24.49 \pm 0.17$, which yields a distance of 4.81 Mpc.

UKS 1424-46 = PGC 51659. This is an irregular dwarf galaxy of low surface brightness with many projected foreground stars. In its direction the HIPASS found HI line emission with a heliocentric velocity of $+386 \pm 4$ km s^{-1}. The TRGB position gives a distance of 3.55 Mpc for this galaxy, typical of the Cen A group. However, the large angular separation of UKS 1424-46 from Cen A makes its membership in the group questionable.

Apart from the seventeen galaxies discussed above, we also observed five other objects of low surface brightness in the Centaurus A region with WFPC2: KK201, KK202, KK210, KK222, and KK226 taken from the list of Karachentseva & Karachentsev (1998). All of them turn out to be background dwarf galaxies with distances $D > 6$ Mpc. For three of the galaxies the HIPASS survey finds HI emission with radial velocities of +1475 km s^{-1} (KK201), +1660 km s^{-1} (KK210), and +2537 km s^{-1} (KK226).

4. Membership and structure of the group

A list of properties of the galaxies in the surroundings of Cen A is presented in Table 2. It contains 62 galaxies with radial velocities in the Local Group rest frame $V_{\rm LG} < 550$ km s^{-1} and angular distances from Cen A of less than 30°. We also include in the table some dwarf spheroidal galaxies without radial velocities, which may be group members as well. The table columns contain: (1) galaxy name; (2) equatorial (epoch 1950.0) coordinates; (3) angular distance θ from Cen A in degrees; (4) morphological type; (5) apparent integrated magnitude $B_{\rm T}$ from NED or from Jerjen et al. (2000b); some faint diffuse objects, like KKs55, have only a rough estimate of $B_{\rm T}$ from a comparison with other objects of known magnitudes; (6) radial velocity in km s^{-1} in the Local Group (LG) rest frame; (7) Galactic extinction in the B-band from Schlegel et al. (1998); (8) linear distance to Cen A in Mpc; distances indicated with a colon correspond to the mean distance based on assumed galaxy membership in the group; (9) absolute magnitude; (10) the assumed membership of the galaxy in the Cen A or the M 83 groups. The galaxies are listed in order of increasing distance θ from Cen A. We included into the table a new galaxy, Cen 6, found in this area by Côté et al. (1997), three new dIrr galaxies revealed by the blind HIPASS survey (Banks et al. 1999), as well as a dwarf spheroidal galaxy of very low surface brightness, Cen N, recently found by I. Karachentsev. For some galaxies their radial velocities were refined from the HIPASS data available at Parkes Multibeam 21 cm Project site. The distance to the background galaxy NGC 3621 was determined by Rawson et al. (1997) from cepheids.

Table 2 shows that the Centaurus A group and its surroundings remain poorly understood. At present only 29% of the galaxies have individual distance estimates, and about 30% objects in the table still have no measured radial velocities. The incompleteness of observational data makes it difficult to distinguish between the group members and other galaxies. It should be stressed that the considered region is situated just in the Local Supercluster plane, where superpositions of background and foreground galaxies may be significant. NGC 5128, the principal galaxy of the group, has a luminosity that is very close to the luminosity of the Milky Way, M 31, and M 81. Systems of companions around each of these galaxies extend to a distance of ∼500 kpc. This limiting distance was chosen by us to select probable bound companions of Cen A. Twenty-four galaxies satisfying this condition are indicated in the last column of Table 2. Twelve of them have measured radial velocities. Their mean relative radial velocity is $< V - V_{\rm Cen\ A} > = -14 \pm 24$ km s^{-1}, and the velocity dispersion is $\sigma_{\rm v} = 89$ km s^{-1}. Eight companions to Cen A have known individual distances. Their average distance is $< D > = 3.63 \pm 0.07$ Mpc, which practically coincides with the average distance 3.66 ± 0.19 Mpc for NGC 5128 measured via the TRGB and planetary nebulae. Therefore, within the statistical uncertainties the Cen A group centroid lies at the same distance as the principal galaxy, whose peculiar velocity is negligibly small. Such a kinematic situation seems to be quite natural when one group member predominates by mass over the others.

A full view of the system of companions of Cen A is presented in Fig. 6, where the assumed bound companions are connected to with Cen A by straight lines. Some probable marginal companions are indicated by dashed lines. Galaxies of the types E, dSph and S, dIrr have the same symbols as in Fig. 1. The large numbers next to the circles indicate the radial velocity of the galaxies in km s^{-1}. The mean linear projected separation of the 24 companions of Cen A is $< R_{\rm p} > = 263$ kpc. The dispersion of radial distances of the companions, $\sigma(D) = 200$ kpc, is comparable to their mean linear projected separation. A similar situation is observed in the group around M 83 = NGC 5236, which is located in the upper part of Fig. 6. Out of nine companions of this galaxy, connected to it by straight lines, seven galaxies have measured radial velocities. Their mean radial velocity with respect to M 83 is $< V - V_{\rm M\,83} > = +8 \pm 27$ km s^{-1}, and their velocity dispersion is $\sigma_{\rm v} = 62$ km s^{-1}. For five companions with individual distance estimates the mean distance is $< D > = 4.57 \pm 0.05$ Mpc, which coincides with the distance of 4.5 ± 0.7 Mpc derived for M 83 from type II supernovae. Like the companions of Cen A, the system of companions of M 83 has a dispersion of radial distances, $\sigma(D) = 90$ kpc, comparable with their mean linear projected separation, $< R_{\rm p} > = 142$ kpc.

Thus, the majority of objects in the region considered are concentrated towards the two brightest galaxies, Cen A and M 83. Both of the separate groups have almost the same mean radial velocities, $+287 \pm 24$ km s^{-1} (Cen A group) and $+312 \pm 27$ km s^{-1} (M 83 group) but very different mean distances, 3.63 ± 0.07 Mpc and 4.57 ± 0.05 Mpc. It therefore seems that taking into account or neglecting the observed spatial separation of the groups can significantly affect their dynamical mass estimate.

Table 2. Galaxies around Cen A with $V_{\rm LG} < 550$ km s^{-1} and $\theta < 30°$.

Name	RA (1950.0) Dec	θ	T	$B_{\rm T}$	$V_{\rm LG}$	$A_{\rm B}$	Dist	$M_{\rm B}$	Memb
NGC 5128	132233.0 −424524	0.00	−2	7.84	301	0.50	3.66	−20.48	Cen
KKs 55	131917.8 −422800	0.66	−3	18.5	–	0.63	3.6:	− 9.95	Cen
KK 197	131906.8 −421620	0.79	−3	15.68	–	0.66	3.6:	−12.64	Cen
ESO 324-024	132442.0 −411318	1.59	10	12.90	270	0.47	3.73	−15.39	Cen
KK 196	131849.9 −444805	2.16	10	16.14	490	0.36	3.6:	−12.04	Cen
NGC 5237	133440.0 −423536	2.24	−3	13.23	131	0.41	3.6:	−15.00	Cen
KK 203	132429.6 −450536	2.37	−3	18.	–	0.44	3.6:	−10.26	Cen
KK 189	130953.5 −413401	2.63	−3	17.75	–	0.49	3.6:	−10.56	Cen
KK 190	131014.6 −443728	2.90	−5	14.59	528	0.40	4.0	−13.85	
KKs 57	133838.5 −421947	3.00	−3	18.1	–	0.39	3.6:	−10.11	Cen
KK 213	134034.6 −433104	3.38	−3	18.5	–	0.42	3.63	− 9.74	Cen
KK 211	133903.4 −445711	3.71	−5	16.32	–	0.48	3.58	−11.98	Cen
ESO 325-011	134201.0 −413630	3.79	10	13.99	308	0.38	3.40	−14.21	Cen
HIPASSa	133429.7 −393659	3.85	10	16.5	256	0.32	3.6:	−11.64	Cen
KK 217	134313.4 −452606	4.59	−3	17.57	–	0.52	3.84	−10.77	Cen
ESO 269-058	130738.0 −464330	4.78	10	13.29	142	0.46	3.6:	−14.99	Cen
KKs 53	130824.3 −383826	4.93	−3	17.3	–	0.38	3.6:	−10.90	Cen
KK 179	130041.0 −461900	5.28	−3	16.26	–	0.57	3.48	−12.13	Cen
NGC 5206	133041.0 −475342	5.36	−3	11.64	322	0.52	3.6:	−16.70	Cen
Cen 6	130212.8 −394854	5.49	10	16.33	366	0.44	3.6:	−11.93	Cen
KK 221	134540.5 −464454	5.74	−3	18.	–	0.60	3.98	−10.42	Cen
Cen N	134502.8 −471858	6.06	−3	17.5	–	0.61	3.6:	−10.93	Cen
HIPASSb	134805.4 −464323	6.08	10	17.5	292	0.62	3.6:	−10.94	Cen
NGC 5102	131907.0 −362206	6.44	−3	10.35	230	0.24	3.40	−17.71	Cen
HIPASSc	134549.8 −374334	6.69	10	16.9	347	0.33	3.6:	−11.25	Cen
NGC 5408	140018.0 −410811	7.20	9	12.21	288	0.30	4.81	−15.91	
NGC 4945	130230.9 −491212	7.35	6	9.27	296	0.76	3.6:	−19.31	Cen
KKs 51	124136.2 −423958	7.51	−3	16.7	–	0.38	3.6:	−11.50	Cen?
KKs 58	134305.7 −360441	7.76	−3	17.41	–	0.27	3.6:	−10.68	Cen?
ESO 383-087	134623.1 −354848	8.33	8	11.03	108	0.31	–	–	
ESO 219-010	125317.0 −495224	8.76	−3	16.42	–	0.96	4.7	−12.94	
KK 198	132007.0 −331823	9.48	−3	17.65	–	0.30	–	–	
ESO 384-016	135405.0 −350524	9.82	−3	15.11	350	0.32	4.2	−13.34	Cen?
KKs 59	134443.9 −530608	10.03	10	14.2	446	2.13	–	–	
ESO 381-018	124159.0 −354136	10.63	10	15.79	353	0.27	–	–	
KKs 54	131844.5 −313729	11.20	−3	17.6	–	0.29	4.6:	−10.98	M 83?
PGC 51659	142448.0 −460520	11.60	10	16.50	171	0.56	3.58	−11.81	
NGC 5253	133705.0 −312330	11.75	8	10.87	190	0.24	3.90	−17.33	
KK 195	131820.5 −311605	11.80	10	18.13	338	0.27	4.6:	−10.43	M 83
KK 200	132148.1 −304243	12.07	9	16.67	262	0.30	4.63	−11.92	M 83
ESO 381-020	124318.0 −333354	12.08	10	14.44	332	0.28	–	–	
IC 4247	132356.5 −300611	12.68	10	14.4	195	0.27	4.6:	−14.16	M 83
NGC 5236	133411.0 −293648	13.37	5	8.20	304	0.28	4.5	−20.37	M 83
NGC 5264	133847.0 −293942	13.51	9	12.60	269	0.22	4.53	−15.91	M 83
ESO 222-010	143141.0 −491212	13.60	10	16.33	415	1.11	–	–	
KK 208	133346.5 −291900	13.65	−3	14.3	–	0.19	4.68	−14.18	M 83
KK 218	134348.7 −294347	13.72	−3	17.60	–	0.26	4.6:	−10.95	M 83
ESO 444-078	133342.0 −285854	13.97	10	15.53	360	0.23	4.6:	−12.99	M 83
ESO 272-025	144009.0 −442936	14.12	8	14.77	422	0.69	–	–	
IC 4316	133729.0 −283830	14.44	10	14.56	382	0.24	4.41	−13.97	M 83
ESO 321-014	121113.0 −375712	14.46	10	15.22	337	0.40	3.19	−12.70	
ESO 444-084	133432.0 −274730	15.17	10	15.06	380	0.30	4.61	−13.53	M 83
KK 170	125211.5 −280412	16.02	9	17.06	406	0.28	–	–	
ESO 223-009	145742.0 −480542	17.47	10	13.82	387	1.12	–	–	
ESO 274-001	151047.0 −463727	17.63	6	11.71	335	1.11	–	-	
KK 112	115210.5 −331647	20.30	10	16.60	363	0.32	5.22	−12.31	
KKs 44	113525.2 −385637	20.62	10	15.85	362	0.62	–	–	
NGC 5068	131613.0 −204636	22.05	6	10.52	473	0.44	–	–	
Circinus	140917.1 −650618	23.42	3	12.1	192	6.22	–	–	
KKs 40	105516.8 −475440	26.16	10	16.03	286	0.95	–	–	
NGC 3621	111550.3 −323217	27.25	7	10.18	437	0.35	6.61	−19.27	
ESO 264-035	104042.0 −472112	28.65	7	14.02	459	0.80	–	–	

5. Mass estimates of the groups

5.1. Virial mass estimate

According to Limber & Mathews (1960), the total mass of a group of N bodies in dynamical equilibrium can be expressed as

$$M_{\rm vir} = 3\pi N \cdot (N-1)^{-1} \cdot G^{-1} \cdot \sigma_{\rm v}^2 \cdot R_{\rm H}, \quad (1)$$

where $\sigma_{\rm v}^2$ is the dispersion of radial velocities with respect to the group centroid, $R_{\rm H}$ is the mean projected harmonic radius, and G is the gravitational constant. Applied to the Cen A group with $\sigma_{\rm v} = 89$ km s^{-1} and $R_{\rm H} = 177$ kpc, relation (1) yields the virial mass

$$M_{\rm vir}(\text{Cen A}) = 3.18 \times 10^{12}\, M_\odot.$$

The group of galaxies around M 83 has $\sigma_{\rm v} = 62$ km s^{-1} and $R_{\rm H} = 83$ kpc, which gives its mass estimate

$$M_{\rm vir}(M\ 83) = 0.78 \times 10^{12}\, M_\odot.$$

5.2. Orbital mass estimate

Because each of the groups contains one dominant massive galaxy the mass of the central galaxy may be estimated from the orbital motions of the companions. For arbitrarily oriented Keplerian orbits with eccentricity e a robust estimator of mass is

$$M_{\rm orb} = (32/3\pi) \cdot G^{-1} \cdot (1 - 2e^2/3)^{-1} < R_{\rm p} \cdot \Delta V_{\rm r}^2 > . \quad (2)$$

Adopting $e = 0.7$ as an average eccentricity, we derive for the companions of Cen A

$$M_{\rm orb}(\text{Cen A}) = 2.15 \times 10^{12}\, M_\odot.$$

The orbital mass estimate for M 83 yields

$$M_{\rm orb}(\text{M 83}) = 0.77 \times 10^{12}\, M_\odot,$$

in agreement with the virial masses. The characteristic crossing time determined as $T_{\rm crossing} = < R_{\rm p} > / \sigma_{\rm v}$ is 3.0 Gyr for the Cen A group and 2.3 Gyr for the M 83 group.

5.3. Total mass-to-luminosity ratio

From Table 2 we find that the total luminosity of the Cen A group members is $3.34 \times 10^{10} L_\odot$, where the contribution of NGC 5128 is 67%. Choosing $M_{\rm orb}$ as a more robust mass estimate, we obtain a total mass-to-total luminosity ratio

$$M_{\rm orb}/L_{\rm B}(\text{Cen A}) = 64\ M_\odot/L_\odot.$$

Our second group has a total luminosity of $2.09 \times 10^{10} L_\odot$, where the contribution of M 83 is 97%. Its total mass-to-total luminosity ratio is

$$M_{\rm orb}/L_{\rm B}(\text{M 83}) = 37\ M_\odot/L_\odot.$$

These $M_{\rm orb}/L_{\rm B}$ ratios for both the groups are close to the value of $M_{\rm vir}/L_{\rm B} = 50\ M_\odot/L_\odot$, derived by Tully (1987). However, our estimates of the total mass are 5–6 times lower than the total mass of the Centaurus group, $(14-18) \times 10^{12}\ M_\odot$, estimated by van den Bergh (2000a). A closer analysis of this strong disagreement leads us to the conclusion that the high excess of virial mass is mainly due to the neglect of the spatial separation of the groups around NGC 5128 and M 83. Moreover, calculating the Cen A group mass, van den Bergh (2000a) included in the group some galaxies (ESO 321-014, ESO 272-025, ESO 274-001), which are separated from Cen A by more than 14°, the background galaxy ESO 270-017 with $V_{\rm LG} =$ 575 km s^{-1}, and even a distant galaxy HIPASS1328-30, whose apparent velocity of $V_{\rm LG} = -28$ km s^{-1} is in fact due to confusion with the local Galactic HI. As a result, the radius of the Cen A group was increased by van den Bergh to 640 kpc, and the velocity dispersion was increased to 114 km s^{-1}.

Lynden-Bell (1981) and Sandage (1986) showed that any group of galaxies with a total mass M_0 may be characterized by a spherical "zero-velocity surface", which separates the group from the Hubble flow. In the case of spherical symmetry, the radius R_0 of the sphere is given by a simple relation

$$M_0 = (\pi^2/8G) \cdot H_0^2 \cdot R_0^3, \quad (3)$$

where H_0 is the Hubble constant. For estimating R_0 we calculated for any galaxy with distance D, radial velocity V, and angular distance from Cen A θ, its spatial separation from Cen A

$$R^2 = D^2 + D_{\rm Cen\ A}^2 - 2D \cdot D_{\rm Cen\ A} \cdot \cos\theta$$

and its projected radial velocity with respect to Cen A

$$(V - V_{\rm Cen\ A})_{\rm p} = V \cdot \cos\lambda - V_{\rm Cen\ A} \cdot \cos(\theta + \lambda),$$

where ${\rm tg}\,\lambda = D_{\rm Cen\ A} \cdot \sin\theta/(D - D_{\rm Cen\ A} \cdot \cos\theta)$. Here we assumed that the peculiar velocities of the galaxies are small in comparison with velocities of the regular Hubble flow. Table 3 presents the estimated values of R and $(V - V_{\rm Cen\ A})_{\rm p}$ for 16 galaxies with known individual distances in the last two columns. The distribution of relative radial velocities and spatial separations is shown in Fig. 5. As one can see from these data, the group of galaxies around M 83, situated at the mean distance of 1.26 Mpc from Cen A, moves away from Cen A with a mean velocity of ∼50 km s^{-1}. The incompleteness of data on individual distances of galaxies in the vicinity of Cen A does not allow us to get a reliable estimate of R_0. For the moment we can only conclude that the radius of the zero-velocity surface for the Centaurus A group does not exceed 1.26 Mpc. According to relation (3), this corresponds to an upper limit for the total mass of the group $M_0 < 2.7 \times 10^{12}\, M_\odot$, which agrees with that derived from orbital motions of companions to Cen A. Measurements of accurate distances to the remaining 38 galaxies, listed in Table 2, will allow to derive the radius R_0 and, consequently, the total mass M_0 for the Centaurus A group with a better accuracy.

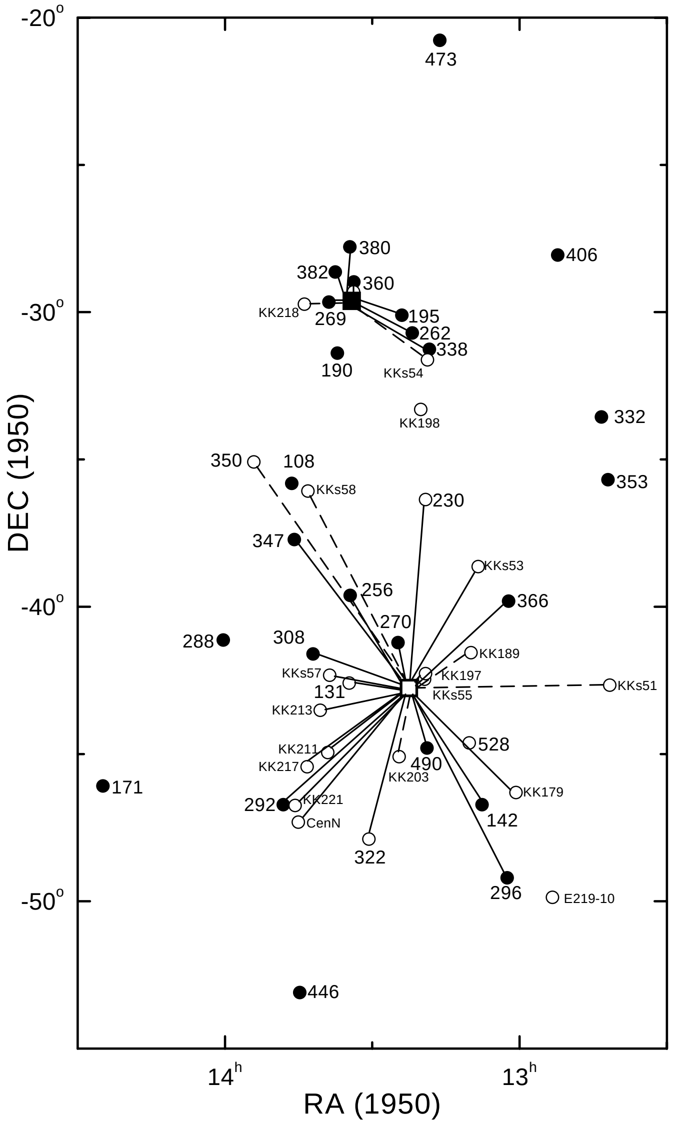

Fig. 4. The distribution of S, Irr galaxies (filled circles) and E, Sph galaxies (open circles) in the Centaurus complex. Companions of Cen A and M 83 are connected to the principal galaxies with straight lines. The large numbers next to the circles indicate the galaxy's radial velocity in $\mathrm{km\,s^{-1}}$ when known, transformed into the Local Group rest frame.

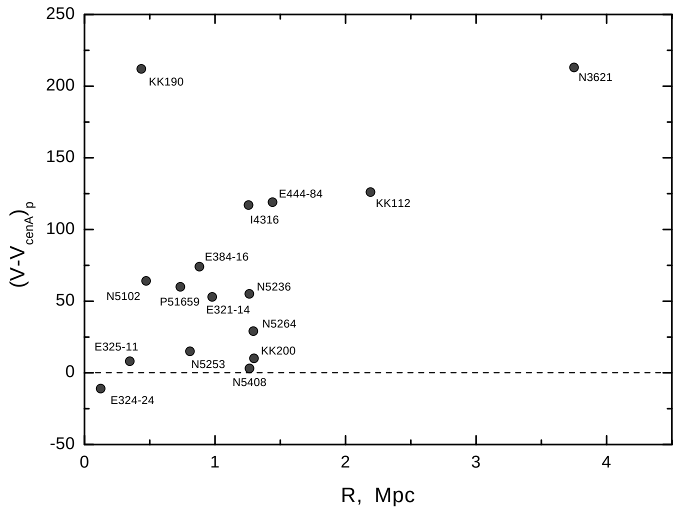

Fig. 5. The distribution of the radial velocity difference and of the distance of nearby galaxies with respect to Cen A. These data yield the radius of the zero-velocity surface of $R_0 < 1.26$ Mpc.

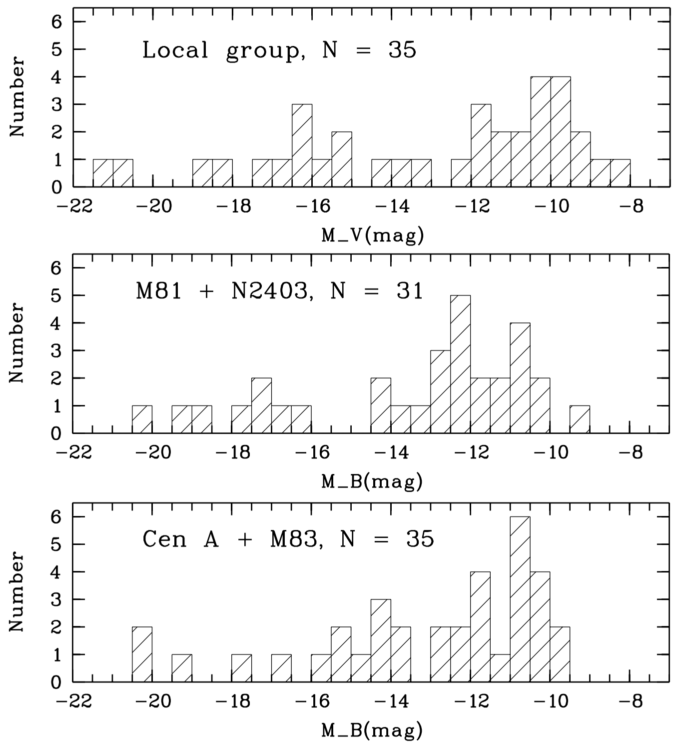

Fig. 6. The luminosity function of the Cen A/M 83 group in comparison with the Local Group and the M 81 group.

6. Concluding remarks

Three nearest and best understood groups of galaxies: the Local Group, the M 81 group, and the Centaurus A group have similar structure and galaxy populations. The distribution of absolute magnitudes of their members magnitudes is presented in Fig. 6, where the data on M 81/NGC 2403 group are taken from Karachentsev et al. (2002) and the data on the Milky Way/M 31 (the Local Group), are from the book of van den Bergh (2000b).

Recent measurements of accurate distances to galaxies situated in and around the groups allow one to determine the radius of the zero-velocity sphere, which separates these groups from the homogeneous cosmological flow. The values of R_0 for all three groups turn out to be close to each other: 0.96 ± 0.05 Mpc (LG), 1.05 ± 0.07 (M 81 group), and <1.26 Mpc (Cen A group). As a result, the total masses of the groups are close to each other as well. The total mass-to-total luminosity ratios that we derived are in the range of $M_{\rm T}/L_{\rm B} = (25 - 65)\ M_\odot/L_\odot$, which is significantly lower than the typical values for the groups selected by Turner & Gott (1976), Huchra & Geller (1982), and Tully (1987). As one can see, the measurement of distances to nearby galaxies allow us to determine more accurately their membership in groups and has lead to

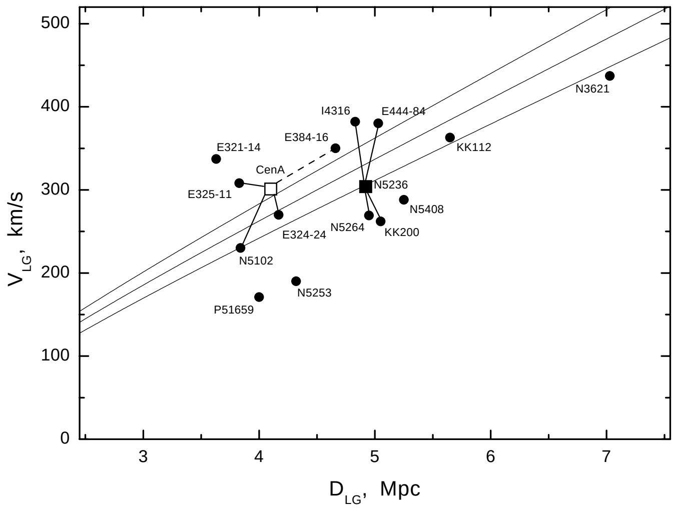

Fig. 7. The distribution of galaxies in the Centaurus complex with accurate distance estimates on the Hubble diagram. The three lines correspond to the Hubble relation with $H_0 = 65$, 70, and 75 km s^{-1} Mpc^{-1}, and a Local Group mass of $1.5 \times 10^{12} M_{\odot}$. The companions of Cen A and M 83 connected by straight lines to the central galaxies.

Table 3. Galaxies around Cen A with measured distances and velocities.

Name	$V_{\rm LG}$ km s^{-1}	$D_{\rm MW}$ Mpc	$D_{\rm LG}$ Mpc	R Mpc	$(V - V_{\rm Cen\ A})_{\rm p}$ km s^{-1}
NGC 5128	301	3.66	4.10	0.000	0
ESO 324-24	270	3.73	4.17	0.124	−11
KK 190	528	4.05	4.49	0.436	212
ESO 325-11	308	3.40	3.83	0.349	8
NGC 5102	230	3.40	3.84	0.474	64
NGC 5408	288	4.81	5.25	1.265	3
ESO 384-16	350	4.23	4.66	0.882	74
PGC 51659	171	3.58	4.00	0.736	60
NGC 5253	190	3.90	4.32	0.810	15
KK 200	262	4.63	5.05	1.300	10
NGC 5236	304	4.5	4.92	1.264	55
NGC 5264	269	4.53	4.95	1.294	29
IC 4316	382	4.41	4.83	1.258	117
ESO 321-14	337	3.19	3.63	0.980	53
ESO 444-84	380	4.61	5.03	1.442	119
KK 112	363	5.22	5.65	2.192	126
NGC 3621	437	6.61	7.03	3.751	213

a decrease in the relative amount of dark matter in the groups. Because about 40% of the galaxies belong to such loose groups like the LG the revision of the amount of dark matter affects the value of the average density of matter, $\Omega_{\rm m}$.

According to Governato et al. (1997) and Klypin et al. (2002), the dispersion of peculiar motions of the centers of groups and field galaxies contains important information about the scenario of galaxy formation and the value of $\Omega_{\rm m}$. In the vicinity of the LG on a scale of (1–3)R_0 the field galaxies have very low mean-square peculiar velocities, ∼25 km s^{-1} (Karachentsev & Makarov 2001). For galaxies in the Centaurus A region the Hubble diagram is presented in Fig. 7, where the distances are given with respect to the LG centroid (Col. 4 in Table 3). The three lines correspond to the Hubble relation with $H_0 = 65$, 70, and 75 km s^{-1}, when the effect of deceleration due to the LG with the total mass $M_{\rm LG} = 1.5 \times 10^{12}\ M_{\odot}$. Here companions to Cen A and NGC 5236 are connected to their principal galaxies by straight lines. As can be seen, six field galaxies, situated outside the Cen A and M 83 groups, have mean-square peculiar velocities of 76 km s^{-1} with respect to the $H_0 = 70$ km s^{-1} Mpc^{-1} curve and of 67 km s^{-1} with respect to $H_0 = 65$ km s^{-1} Mpc^{-1}. Incidentally, the typical error of ∼0.20 mag in distance moduli contributes by ∼30 km s^{-1} to the velocity dispersion. It is remarkable that the centroids of both groups have very small peculiar velocities of $+18 \pm 24$ km s^{-1} (Cen A) and -17 ± 27 km s^{-1} (M 83) with respect to the $H_0 = 70$ km s^{-1} Mpc^{-1} curve, i.e., the groups are almost at rest with respect to the Hubble flow.

We would like to emphasize that at present accurate distances and velocities have only been determined for less than 1/3 of the galaxies in the vicinity of Centaurus A. A complete map of the peculiar velocity field, will be of great importance for the cosmology of the Local Universe.

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