

Local galaxy flows within 5 Mpc^{★,★★}

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Received 10 September 2002 / Accepted 22 October 2002

Abstract. We present Hubble Space Telescope/WFPC2 images of sixteen dwarf galaxies as part of our snapshot survey of nearby galaxy candidates. We derive their distances from the luminosity of the tip of the red giant branch stars with a typical accuracy of $\sim 12\%$. The resulting distances are 4.26 Mpc (KKH 5), 4.74 Mpc (KK 16), 4.72 Mpc (KK 17), 4.66 Mpc (ESO 115-021), 4.43 Mpc (KKH 18), 3.98 Mpc (KK 27), 4.61 Mpc (KKH 34), 4.99 Mpc (KK 54), 4.23 Mpc (ESO 490-017), 4.90 Mpc (FG 202), 5.22 Mpc (UGC 3755), 5.18 Mpc (UGC 3974), 4.51 Mpc (KK 65), 5.49 Mpc (UGC 4115), 3.78 Mpc (NGC 2915), and 5.27 Mpc (NGC 6503). Based on distances and radial velocities of 156 nearby galaxies, we plot the local velocity-distance relation, which has a slope of $H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and a radial velocity dispersion of 85 km s^{-1} . When members of the M81 and Cen A groups are removed, and distance errors are taken into account, the radial velocity dispersion drops to $\sigma_v = 41 \text{ km s}^{-1}$. The local Hubble flow within 5 Mpc exhibits a significant anisotropy, with two infall peculiar velocity regions directed towards the Supergalactic poles. However, two observed regions of outflow peculiar velocity, situated on the Supergalactic equator, are far away ($\sim 50^\circ$) from the Virgo/anti-Virgo direction, which disagrees with a spherically symmetric Virgo-centric flow. About 63% of galaxies within 5 Mpc belong to known compact and loose groups. Apart from them, we found six new probable groups, consisting entirely of dwarf galaxies.

Key words. galaxies: dwarf – galaxies: distances and redshifts – galaxies: kinematics and dynamics

1. Introduction

Until recently very little data have been available to describe the peculiar velocity field of galaxies around the Local Group (LG). This surprising situation was caused by the lack of reliable data on distances (not velocities) for many of the nearest galaxies. The local Hubble flow has been predicted by Lynden-Bell (1981) and Sandage (1986) to be non-linear because of the gravitational deceleration produced by the mass of

the LG, which could permit the calculation of the total mass of the LG independently from mass estimates based on virial motions inside the group. In a larger volume the deviations from pure Hubble expansion may be caused by the gravitational action of nearby groups as well as by the Virgo-centric flow.

Enormous progress has been made recently in accurate distance measurements for nearby galaxies beyond the LG based on the luminosity of the tip of the red giant branch (TRGB). This method has a precision comparable to the Cepheid method, but is much faster in terms of observing time. Over the last three years, “snapshot” surveys of nearby galaxies using WFPC2 aboard the HST have provided us with distances for about a hundred nearby galaxies obtained with an accuracy of about 10% based on the TRGB method. Further significant progress is expected in the near future due to observations with the Advanced Camera for Surveys (ACS) aboard the HST.

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* Based on observations made with the NASA/ESA Hubble Space Telescope. The Space Telescope Science Institute is operated by the Association of Universities for Research in Astronomy, Inc. under NASA contract NAS 5–26555.

** Table 2, and Figs. 1 and 2, are only available in electronic form at <http://www.edpsciences.org>

In this paper we present new precise distances to sixteen galaxies from the general “field” with radial velocities in a range of 160–400 km s⁻¹. Together the data on distances to nearby galaxies published before (Karachentsev et al. 2002a, 2002b, 2002c, 2003) as well as data from the literature, this gives us a basis to map the local field of peculiar velocities for galaxies situated within ~5 Mpc.

2. WFPC2 photometry and data reduction

Images of sixteen galaxies were obtained with the Wide Field and Planetary Camera (WFPC2) aboard the Hubble Space Telescope (HST) between October 22, 1999 and July 26, 2001 as part of our HST snapshot survey of nearby galaxy candidates (Seitzer et al. 1999; Grebel et al. 2000). The galaxies were observed with 600-second exposures taken in the *F606W* and *F814W* filters for each object. Digital Sky Survey (DSS) images of them are shown in Fig. 1 with the HST WFPC2 footprints superimposed. The field size of the red DSS-II images is 6′. Small galaxies were usually centered on the WF3 chip, but for some bright objects the WFPC2 position was shifted towards the galaxy periphery to decrease stellar crowding. The WF3 chip images of the galaxies are presented in upper panels of Fig. 2, where both filters are combined.

For photometric measurements we used the HSTphot stellar photometry package developed by Dolphin (2000a). The package has been optimized for the undersampled conditions present in the WFPC2 to work in crowded fields. After removing cosmic rays, simultaneous photometry was performed on the *F606W* and *F814W* frames using *multiphot*, with corrections to an aperture of radius 0′.5. Charge-transfer efficiency (CTE) corrections and calibrations were then applied, which are based on the Dolphin (2000b) formulae, producing *V*, *I* photometry for all stars detected in both images. Additionally, stars with a signal-to-noise ratio $S/N < 3$, $|\chi| > 2.0$, or $|\text{sharpness}| > 0.4$ in each exposure were eliminated from the final photometry list. The uncertainty of the photometric zero point is estimated to be within 0^m.05 (Dolphin 2000b).

3. Color-magnitude diagrams and distances to sixteen nearby galaxies

The tip of red giant branch (TRGB) method provides an efficient tool to measure galaxy distances. The TRGB distances agree with those given by the Cepheid period-luminosity relation to within 5%. As shown by Lee et al. (1993), the TRGB is relatively independent of age and metallicity. In the *I* band the TRGB for low-mass stars is found to be stable within ~0.1 mag (Salaris & Cassisi 1997; Udalski et al. 2001) for metallicities, [Fe/H], encompassing the entire range from -2.1 to -0.7 dex found in Galactic globular clusters. According to Da Costa & Armandroff (1990), for metal-poor systems the TRGB is located at $M_I = -4.05$ mag. Ferrarese et al. (2000) calibrated the zero point of the TRGB from galaxies with Cepheid distances and estimated $M_I = -4^m.06 \pm 0^m.07(\text{random}) \pm 0.13(\text{systematic})$. A new TRGB calibration, $M_I = -4^m.04 \pm 0^m.12$, was made by Bellazzini et al. (2001) based on photometry and on a distance

estimate from a detached eclipsing binary in the Galactic globular cluster ω Centauri. For this paper we use $M_I = -4^m.05$. The lower left panels of Fig. 2 show *I*, (*V* - *I*) color-magnitude diagrams (CMDs) for the sixteen observed galaxies as well as for their surrounding “field” regions.

We determined the TRGB using a Gaussian-smoothed *I*-band luminosity function (LF) for red stars with colors *V* - *I* within $\pm 0^m.5$ of the mean $\langle V - I \rangle$ for expected red giant branch stars. Following Sakai et al. (1996), we applied a Sobel edge-detection filter. The position of the TRGB was identified with the peak in the filter response function. The resulting LFs and the Sobel-filtered LFs are shown in the lower right corners of Fig. 2. The results are summarized in Table 1. There we list: (1) galaxy name; (2) equatorial coordinates of the galaxy center; (3, 4) apparent integrated magnitude and angular dimension from the NASA Extragalactic Database (NED); (5) radial velocity with respect to the LG centroid (Karachentsev & Makarov 1996); here we used new accurate velocities measured by Huchtmeier et al. (2003) for some galaxies; (6) morphological type in de Vaucouleurs’ notation; (7) position of the TRGB and its uncertainty as derived with the Sobel filter; (8) Galactic extinction in the *I*-band (Schlegel et al. 1998); (9) true distance modulus with its uncertainty, which takes into account the uncertainty in the TRGB, as well as uncertainties of the HST photometry zero point (~0^m.05), the aperture corrections (~0^m.05), and the crowding effects (~0^m.06) added quadratically; the uncertainties in the extinction and reddening are taken to be 10% of their values from Schlegel et al. (1998); (for more details on the total budget of internal and external systematic errors for the TRGB method see Mendez et al. 2002); and (10) linear distance in Mpc and its uncertainty. Below, some individual properties of the galaxies are briefly discussed.

KKH 5. This dwarf irregular galaxy of low surface brightness was discovered by Karachentsev et al. (2001a). It is situated in the Zone of Avoidance at the periphery of the Maffei/IC 342 group. The galaxy appears to be well resolved into stars. Its CMD (Fig. 2) reveals a sequence of blue stars with a Galactic foreground extinction of $E(V - I) = 0.39$ mag (Schlegel et al. 1998). The tip of the RGB stars is also seen. The stars above the RGB are likely to be asymptotic giant branch (AGB) stars. The CMD for a nearby field of the same area (the middle panel in the bottom row) shows that the CMD of the galaxy is not strongly contaminated by foreground stars in spite of its position at a low galactic latitude, $b = -11.3^\circ$. We determined the TRGB to be $24^m.65 \pm 0^m.15$, which corresponds to a distance modulus of $28^m.15 \pm 0^m.17$.

KK 16. We present the first deep CMD of this dIrr. Judging by its radial velocity, $V_{LG} = 400$ km s⁻¹, KK 16 is a dwarf companion of the other, brighter dwarf galaxy NGC 784 ($V_{LG} = 386$ km s⁻¹). The CMD (Fig. 2) shows a prominent RGB as well as some blue main-sequence stars and AGB stars. From the TRGB position of $24^m.46 \pm 0^m.22$ we obtain a distance modulus of $28^m.38 \pm 0^m.24$ yielding a linear distance of 4.74 ± 0.50 Mpc. This distance agrees well with the distance 5.0 ± 0.9 Mpc derived for NGC 784 from its brightest stars (Drozdovsky & Karachentsev 2000).

Table 1. New distances to nearby field galaxies.

Name	RA(1950) Dec hh mm ss °'""'''	B_t mag	$a \times b$ arcmin	V_{LG} km s ⁻¹	T	$I(\text{TRGB})$ mag	A_1 mag	$(m - M)_0$ mag	D Mpc
KKH 5	010435.0 511025	17.1	0.6×0.4	304	10	24.65 0.15	0.55	28.15 0.17	4.26 0.32
KK 16	015230.2 274234	16.3	0.8×0.3	400	10	24.46 0.22	0.13	28.38 0.24	4.74 0.50
KK 17	015718.1 283526	17.2	0.6×0.3	360	10	24.43 0.17	0.11	28.37 0.19	4.72 0.40
E115-021 P09962	023629.0-613324	13.34	7.2×0.8	337	8	24.33 0.20	0.05	28.34 0.22	4.66 0.48
KKH 18	030000.5 332956	16.7	0.7×0.4	375	10	24.57 0.22	0.39	28.23 0.24	4.43 0.47
KK 27	032029.5-663004	16.5	1.2×0.4	–	–3	24.10 0.18	0.15	28.00 0.20	3.98 0.36
Mai13 KKH 34	055323.0 732524	17.1	0.6×0.5	299	10	24.75 0.15	0.48	28.32 0.17	4.61 0.35
KK 54 E489-056	062416.7-261406	15.70	0.6×0.3	263	10	24.57 0.25	0.13	28.49 0.26	4.99 0.58
E490-017 P19337	063555.0-255718	14.01	1.7×1.3	268	10	24.23 0.21	0.15	28.13 0.23	4.23 0.42
FG 202 P20125	070430.0-582700	14.95	3.5×1.7	269	10	24.63 0.20	0.23	28.45 0.22	4.90 0.45
U3755	071106.2 103618	14.25	1.7×1.0	190	10	24.71 0.24	0.17	28.59 0.25	5.22 0.57
U3974 DDO 47	073902.9 165507	13.71	3.1×3.0	160	10	24.58 0.23	0.06	28.57 0.25	5.18 0.57
KK 65	073940.2 164047	15.6	0.6×0.3	168	10	24.28 0.16	0.06	28.27 0.18	4.51 0.36
U4115	075413.6 143117	15.23	1.8×1.0	210	10	24.71 0.21	0.06	28.70 0.23	5.49 0.56
N2915	092630.9-762430	13.19	1.9×1.0	184	10	24.37 0.24	0.53	27.89 0.26	3.78 0.43
N6503	174958.7 700926	10.74	7.1×2.4	301	6	24.62 0.21	0.06	28.61 0.23	5.27 0.53

KK 17. Like *KK 16*, this dwarf irregular galaxy of low surface brightness is a companion of NGC 784. Its CMD is dominated by red stars yielding a TRGB magnitude of $24^m43 \pm 0^m17$, the same as for *KK 16* within the errors. The group of three dwarf galaxies, NGC 784, *KK 16*, and *KK 17* has a radial velocity dispersion of 16 km s^{-1} , reminding of another group of four dwarfs: NGC 3109, Sex A, Sex B, and Antlia at the edge of the Local group. Tully et al. (2002) consider such loose systems as groups of “squelched” galaxies in a common dark halo.

E 115-021 = PGC 09962 = RFGC 566. Due to its size, $7'.2$ by $0'.8$, this edge-on irregular galaxy extends far beyond the WFPC2 field. The CMD shows a large number of AGB stars above the RGB. The TRGB is located at $24^m33 \pm 0^m20$. The “field” in Fig. 2 corresponds to the WF2 field away from the main galaxy body. It is populated mostly with RGB stars having about the same TRGB magnitude as the body of the galaxy.

KKH 18. This is a very isolated dIrr, box-like galaxy. The CMD shows a mixed population of red and blue stars. The TRGB at $24^m57 \pm 0^m22$, yields a distance modulus of $28^m23 \pm 0^m24$.

KK 27 = AM 0319-662. The object has a smooth regular shape typical of dwarf spheroidal galaxies. It is located $18'$

northeast of the prominent spiral galaxy NGC 1313, which has $V_{LG} = 270 \text{ km s}^{-1}$. In Fig. 3 of Ryder et al. (1995) *KK 27* is indicated by an arrow. It was observed in the HI line but not detected by Huchtmeier et al. (2000). The CMD appears to be populated mostly by RGB stars with $I(\text{TRGB}) = 24^m10 \pm 0^m18$, which yields $(m - M)_0 = 28^m00 \pm 0^m20$. This distance modulus agrees well with the distance modulus $28^m09 \pm 0^m06$ derived for NGC 1313 by Mendez et al. (2002), which confirms that *KK 27* is a dSph companion to NGC 1313.

KKH 34 = Mailyan 13. This dIrr galaxy of low surface brightness with a radial velocity $V_{LG} = 299 \text{ km s}^{-1}$ (Karachentsev et al. 2001a) is located at the outskirts of the Maffei/IC342 group. It is well resolved into stars, and its CMD (Fig. 2) shows a mixed population of blue and red stars. There is no strong discontinuity in the luminosity function but there is only a slight hint of a red giant branch. Two peaks are seen in the Sobel-filtered LF. The first peak appears to be caused by AGB stars, and the second one, at $I = 24^m75 \pm 0^m15$, which we interpret as the TRGB, yields a distance modulus of $28^m32 \pm 0^m17$.

KK 54 = ESO 489-056. This is an isolated dwarf irregular galaxy with a radial velocity $V_{LG} = 263 \text{ km s}^{-1}$, which is superimposed on a background spiral galaxy (see Fig. 2). *KK 54*

is situated at a high Supergalactic latitude, $\text{SGB} = -77.5^\circ$. The CMD reveals a mixed population of blue and red stars. The Sobel-filtered luminosity function shows a probable peak at $I = 24^m57$, which corresponds to a distance modulus of 28^m49 .

ESO 490-017 = PGC 19337. This is a dIrr galaxy with a radial velocity of 268 km s^{-1} , which is also situated at a high Supergalactic latitude (-79.0°). The galaxy extends over all WFPC2 fields with the brightest part being centered on the WF3. The CMDs for the central (WF3) and the peripheric (WF4) regions of PGC 19337 are shown in Fig. 2. In both fields we find the TRGB to be at $24^m23 \pm 0^m21$, giving a distance modulus of $28^m13 \pm 0^m23$.

FG 202 = PGC 20125. This irregular galaxy of low surface brightness was found by Feitzinger & Galinski (1985). It extends far beyond the WFPC2 field. The CMD is populated by blue and red stars. The tip of the RGB is seen just above the detection limit at $I = 24^m63 \pm 0^m20$, which corresponds to a distance modulus of $28^m45 \pm 0^m22$.

UGC 3755. This is a very isolated irregular galaxy at a high supergalactic latitude (-63.4°) with a radial velocity $V_{\text{LG}} = 190 \text{ km s}^{-1}$. The galaxy was resolved into stars for the first time by Georgiev et al. (1997) who estimated its distance modulus to be $28^m08 \pm 0^m40$ from the luminosity of the brightest blue stars. Recently Mendez et al. (2002) have observed UGC 3755 with the WFPC2 and determined the TRGB distance modulus to be $28^m52 \pm 0^m07$. From the derived CMD (Fig. 2) we found the TRGB position to be $24^m71 \pm 0^m24$ and a corresponding distance modulus of $28^m59 \pm 0^m25$. Our exposures of UGC 3755 are likely not long enough to determine the true magnitude of the TRGB. The presence of many probable AGB stars makes it difficult to define reliably the tip of the RGB.

UGC 3974 = DDO 47. Like UGC 3755, this dIrr galaxy is located at a high supergalactic latitude (-55.5°). The galaxy has a low radial velocity, $V_{\text{LG}} = 160 \text{ km s}^{-1}$, and appears to be well resolved into stars. The CMD shows a mixed population of red and blue stars with a hint of the TRGB near the limiting magnitude at $I(\text{TRGB}) = 24^m58 \pm 0^m23$. Thus we derive a distance modulus of $28^m57 \pm 0^m25$, which is probably a lower limit on the galaxy distance. Using the magnitudes of the brightest stars, Georgiev et al. (1997) estimated the distance modulus to be $28^m15 \pm 0^m40$.

KK 65. KK 65 is situated $15'$ away from UGC 3974, having almost the same low radial velocity, $V_{\text{LG}} = 168 \text{ km s}^{-1}$. As Fig. 2 shows, this dwarf irregular galaxy has an arc-like shape resembling that of another nearby dIrr galaxy DDO 165. We estimated the TRGB magnitude to be $24^m28 \pm 0^m16$, corresponding to a distance modulus of $28^m27 \pm 0^m18$. The derived distances to KK 65 and UGC 3974 suggest marginally that they form a binary system.

UGC 4115. This dIrr galaxy with a low radial velocity, $V_{\text{LG}} = 210 \text{ km s}^{-1}$, belongs probably to the same loose group of dwarf galaxies as UGC 3755, UGC 3974, and KK 65 (Tully et al. 2002). The galaxy was resolved into stars by Georgiev et al. (1997), who estimated its distance modulus via the brightest stars to be $28^m61 \pm 0^m40$. The CMD in Fig. 2 shows the blue and red stellar populations with an indication of TRGB at $24^m71 \pm 0^m21$, which gives a distance modulus

$(m - M)_0 = 28^m70 \pm 0^m23$. Quite likely this is only a lower limit of the galaxy distance.

NGC 2915. This very isolated blue compact dwarf (BCD) galaxy with a low radial velocity, $V_{\text{LG}} = 184 \text{ km s}^{-1}$, contains two stellar subsystems: a high surface – brightness blue core and a red diffuse population. Based on the luminosity of the brightest stars, Meurer et al. (1994) estimated its distance as $D = 5.3 \pm 1.6 \text{ Mpc}$. According to Bureau et al. (1999) the HI disk of NGC 2915 extends to 22 optical scalelengths, providing a huge reservoir for star formation. The galaxy is well resolved into stars in Fig. 2. Its core, located in the WF3, contains a lot of blue and red stars, but the peripheric regions, indicated in Fig. 2 as “field”, are populated almost entirely with red stars. We determined the tip of the RGB to be $I(\text{TRGB}) = 24^m37 \pm 0^m24$, yielding a distance modulus of $27^m89 \pm 0^m26$. The derived new linear distance, $D = 3.78 \pm 0.43 \text{ Mpc}$, ranks NGC 2915 among the nearest BCD galaxies together with UGC 4483 (3.21 Mpc), NGC 6789 (3.60 Mpc), and UGC 6456 (4.34 Mpc).

NGC 6503. NGC 6503 is a Sc galaxy located at the edge of the Local Void. The galaxy was resolved into stars for the first time by Karachentsev & Sharina (1997), who derived its distance modulus to be $28^m57 \pm 0^m40$. Our HST observations were directed to the North-West edge of NGC 6503, which is less contaminated by blue stars. The left CMD in Fig. 2 corresponds to the entire WFPC2 field. The right one shows the stellar population in the halo region only (outer parts of WF2 and WF4). For the halo stars we determined the TRGB position at $I(\text{TRGB}) = 24^m62 \pm 0^m21$, which yields a distance modulus of $28^m61 \pm 0^m23$.

4. Status of the measured distances in the Local Volume

Apart from 35 members of the Local Group with distances $D < 1.0 \text{ Mpc}$, there are so far 191 galaxies with distance estimates $D < 5.5 \text{ Mpc}$. Among them 35 galaxies have no measured radial velocities. The present sample of data on radial velocities and distances of nearby galaxies is presented in Table 2. Its columns give: (1) galaxy name, (2) apparent integrated blue magnitude from the NED or some recent sources (Makarova 1999; Parodi et al. 2002), (4) Galactic extinction from Schlegel et al. (1998), (5) heliocentric radial velocity in km s^{-1} from the NED or recent measurements by Huchtmeier et al. (2003), (6) radial velocity in the frame of the Local Group, (7) galaxy distance with indication of the used method: “Cep” – Cepheids, “RGB” – tip of red giant branch stars, “SBF” – surface brightness fluctuations, “mem” – membership of known nearby groups, “BS” – luminosity of the brightest stars, and “TF” – Tully-Fisher relation. The last column gives the reference for the distance.

Figure 3 shows the distribution of the LV galaxies according to their distances determined using various distance indicators. The three lower panels correspond to the most reliable methods giving distances with an accuracy of $\sim 5\text{--}15\%$. The same error is probably similar for the members of some nearby groups (around M81, Cen A, and M83) with well determined average distances. A characteristic error on distances estimated via brightest stars or via TF- relation might be $\sim (20\text{--}30)\%$.

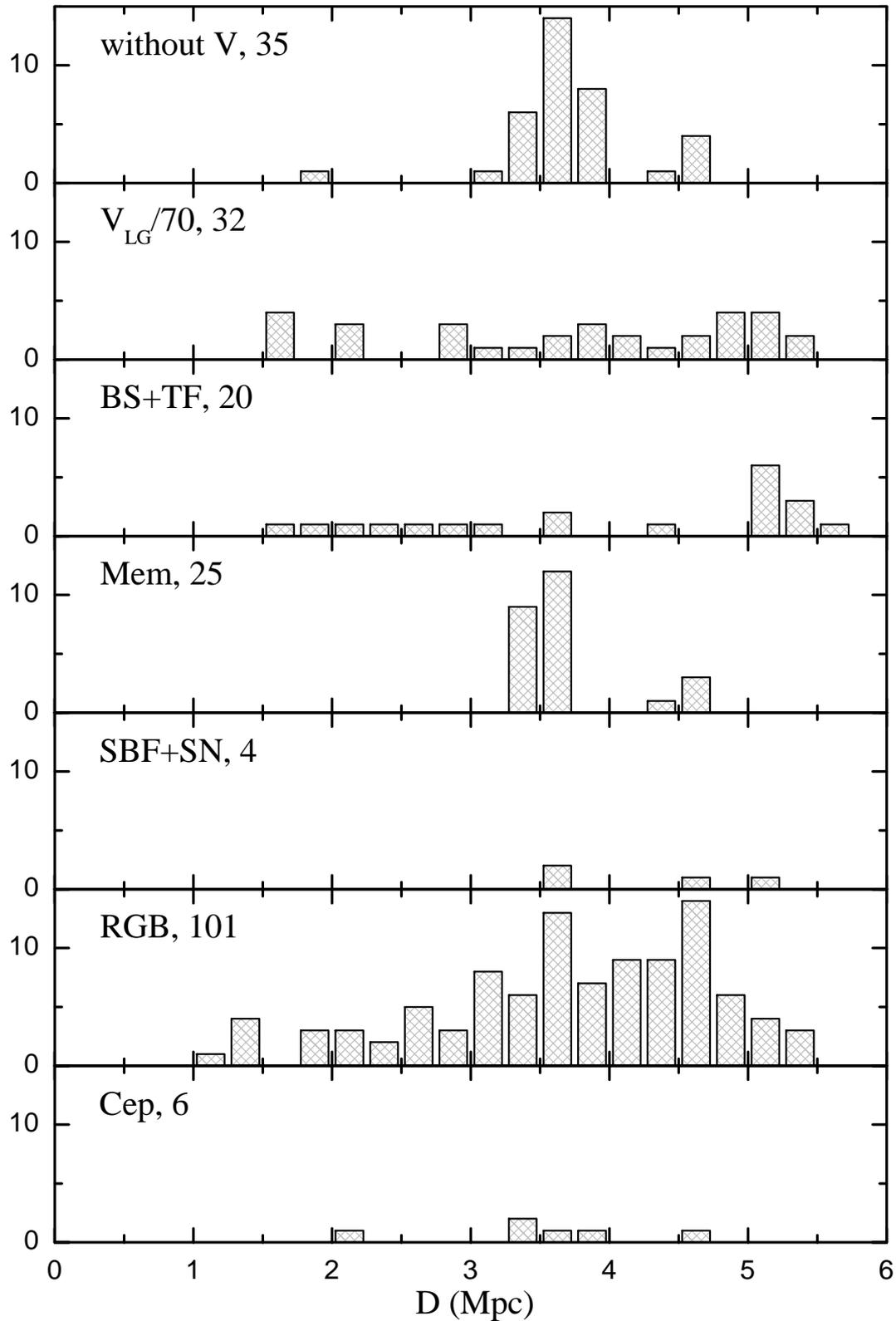


Fig. 3. Distribution of 223 Local Volume galaxies according to their distances derived by different methods: “Cep” – from cepheids, “RGB” – from the tip of red giant branch stars, “SBF” – from surface brightness fluctuations, “mem” – from the galaxy membership in the known nearby groups, “BS” – from the luminosity of the brightest stars, and “TF” – from the Tully-Fisher relation. Two upper panels present distance distributions for 35 galaxies without radial velocities, as well as for 30 galaxies with distance estimates from the Hubble relation $D = V_{LG}/H_0$, where $H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$ is adopted.

The two upper panels present distance distributions for 35 galaxies without radial velocities, and also for 32 galaxies with distance estimates from the Hubble relation $D = V_{LG}/H_0$, for which $H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$ is adopted. As seen from the histograms, the TRGB method is, in practice, the most efficient method to measure distances within ~ 5 Mpc. Besides, 99% of the TRGB distances have been obtained during the last three years taking advantage of the superior angular resolution of HST. It should be noted, however, that so far the relative number of the LV galaxies with radial velocities and accurate distance estimates is 111/223 or only 50%. The remaining 112 galaxies might be suitable targets for the next snapshot survey with the Advanced Camera at HST.

5. Local deviations from the Hubble flow

The Hubble relation (radial velocity – distance) for 156 nearby galaxies is shown in Fig. 4. Here galaxies with accurate distance estimates (“Cep”, “RGB”, “SBF”, and “mem”) are represented by filled circles, and galaxies with less reliable distance estimates (“BS” and “TF”) by crosses. In the considered volume there are two massive groups of galaxies around M 81 and Cen A, whose average distances of 3.73 ± 0.04 Mpc (Karachentsev et al. 2002a), and 3.63 ± 0.07 Mpc (Karachentsev et al. 2002b) are very similar. Members of these two groups are shown in Fig. 4 as open circles and open squares, respectively. The solid line corresponds to the Hubble relation with $H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$, curved at small distances because of the decelerating gravitational action of the Local Group (Sandage 1986) assuming a total mass of $1.3 \times 10^{12} M_\odot$ (Karachentsev et al. 2002c). The Hubble diagram for the LV galaxies reveals some important properties.

1. The largest deviations from the Hubble regression are seen in the range of distances between 3.5 and 3.8 Mpc. Their evident reason are the virial motions of galaxies inside the M 81 and Cen A groups. Other nearby groups, in particular those of M 83 and IC 342/Maffei, also contribute to the observed dispersion of radial velocities.
2. The galaxies situated at the near end of the M 81 and Cen groups, in the distance range 2.5–3.4 Mpc, have radial velocities that are on the average $\sim 60 \text{ km s}^{-1}$ larger than the expected Hubble velocities. In contrast, radial velocities of galaxies within the distance range of 4.0–4.6 Mpc tend to have velocities systematically below the Hubble regression line. Such a kind of “S”-shaped deviation of radial velocities is typical of the vicinity of a massive attractor (see, for example, Fig. 1 in Tonry et al. 2000), when galaxies at the front and at the back of the attractor fall towards its center. In particular, because of this the galaxies UGC 6456 and NGC 4236 behind the M 81 group lie in Fig. 4 much lower than the Hubble regression line.

As was shown by Karachentsev & Makarov (1996), the local Hubble flow on a scale of ~ 5 Mpc is significantly anisotropic. Based on rough estimates of distances to 145 galaxies obtained from the luminosity of their brightest stars, Karachentsev & Makarov (2001) derived that the local field of peculiar motions

can be described as a tensor of the local Hubble parameter, H_{ij} , which has the main values of $(81 \pm 3):(62 \pm 3):(48 \pm 5)$ in km s^{-1} . The minor axis of the corresponding ellipsoid is directed towards the polar axis of the Local Supercluster, and the major axis has an angle of $(29 \pm 5)^\circ$ with respect to the direction towards the center of the Virgo cluster. Broadly speaking, the observed anisotropy of velocities corresponds to a Virgo-centric flow, however, a spherically symmetric Virgo-centric flow does not fit well the observed peculiar velocity field.

Our new, more accurate data on galaxy distances given in Table 2 confirm the presence of an anisotropy of the Hubble flow in the Local Volume. In particular, Fig. 4 shows that isolated galaxies situated at high supergalactic latitudes (UGC 3755, UGC 3974, UGC 4115, and KK 65) have radial velocities that are about twice lower than expected with $H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

Figure 5 presents the all-sky distribution of 156 galaxies from Table 2 in Supergalactic coordinates. The galaxies with positive and negative peculiar velocities with regard to the isotropic Hubble flow ($H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$) are represented by open and filled circles, respectively. The position of the supergiant elliptical galaxy M 87 at the center of the Virgo cluster (SGL = 102.9° , SGB = -2.3°) is indicated with an asterisk. The observed peculiar velocities of galaxies were smoothed with a spatial 2D-Gaussian filter with dispersion $\sigma = 25^\circ$, and then were plotted in Fig. 5 as a contour map with intervals of 20 km s^{-1} . As can be seen, the local peculiar velocity field is quite symmetric about to the Local Supercluster equator. The most slowly expanding region of the local Hubble flow with an amplitude of -80 km s^{-1} occupies the southern Supergalactic polar cap (Monoceros constellation). Another negative peculiar velocity area with a lower amplitude, -20 km s^{-1} , corresponds to the northern Supergalactic cap, also pointing towards the Local Void (Draco constellation). Two regions of outflow peculiar velocity within the $+20 \text{ km s}^{-1}$ contours lie just on the Supergalactic equator in the Centaurus and Pisces constellations. However, they are located far from the Virgo/anti-Virgo directions, as would be expected in a spherical Virgo-centric flow.

The same map of the local field of peculiar velocities is shown in Fig. 6 in galactic coordinates. Figure 6 is useful for comparison with the all-sky contour map of the predicted peculiar velocity field (see Fig. 1 in Mendez et al. 2002). That map derived from the IRAS galaxy distribution represents deviations from the pure Hubble flow on the shell corresponding to velocity $V_{LG} = 500 \text{ km s}^{-1}$. In general, the observed peculiar velocity map fits the predicted one, but has a 4–6 times lower amplitude and significantly different positions of the regions of outflow peculiar velocity.

6. Peculiar velocity dispersion

According to the results of N -body simulations (Governato et al. 1997; Klypin et al. 2002), the dispersion of the peculiar motions of field galaxies and group centers around the mean flow, σ_v , contains important information on galaxy formation and the local density of matter, Ω_m . Sandage et al. (1972) and Karachentsev (1971) found a radial velocity dispersion around

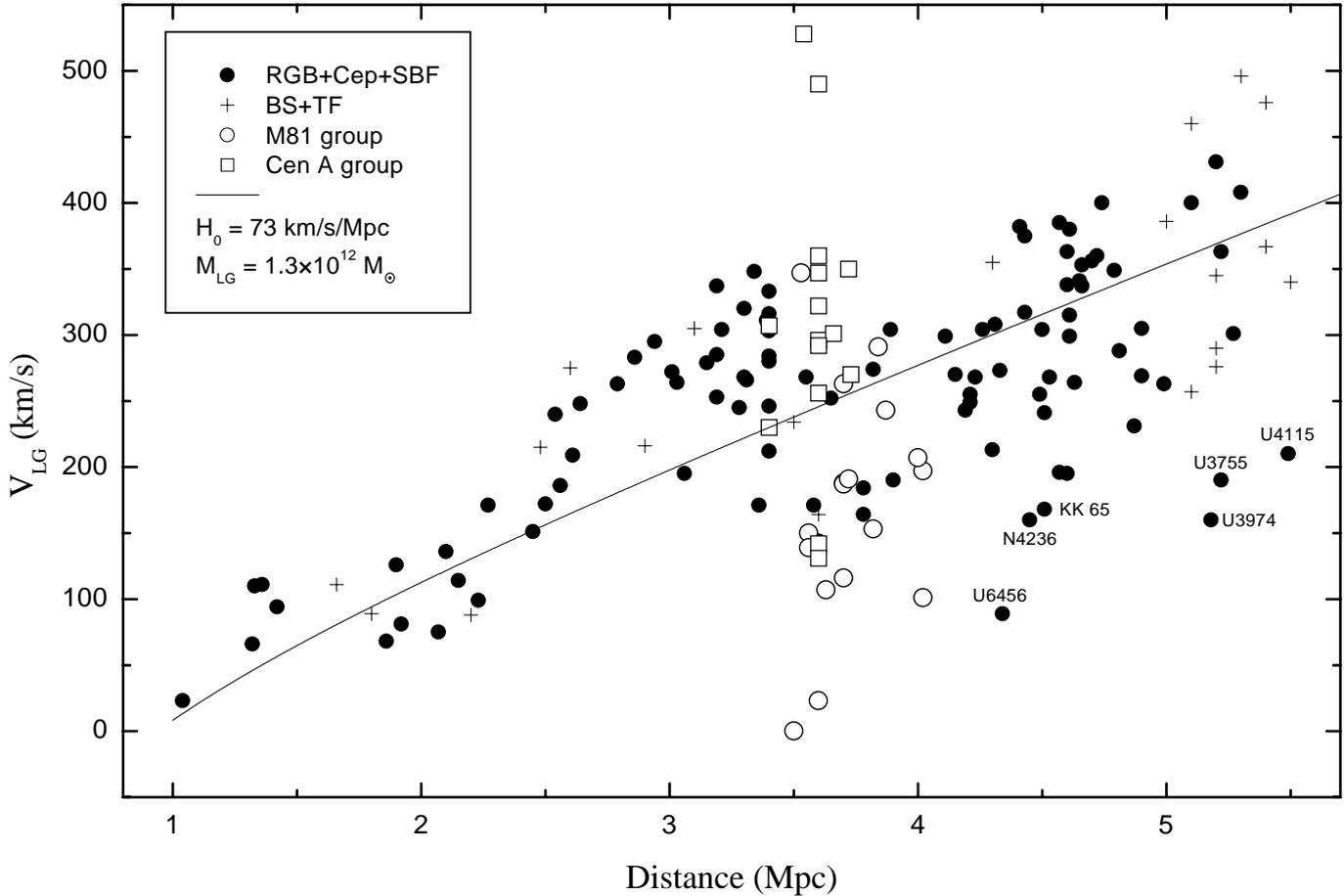


Fig. 4. Radial velocity – distance relation for 156 Local Volume galaxies. The galaxies with accurate distance estimates (“Cep”, “RGB”, “SBF”, and “mem”) are shown as filled circles, and galaxies with less reliable distance estimates (“BS” and “TF”) are indicated as crosses. The members of M 81 and Cen A groups with distances in the range of 3.4–4.0 Mpc are shown by open circles and open squares, respectively. The regression line corresponds to the Hubble relation with $H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$, curved at small distances assuming a decelerating gravitational action of the Local Group with a total mass of $1.3 \times 10^{12} M_\odot$.

the local Hubble flow of $\sim 70 \text{ km s}^{-1}$. Such “cold” random motions correspond to $\Omega_m \sim 0.1$. Recent observational data on galaxies situated within 3 Mpc around the LG yield a surprisingly lower dispersion, $\sigma_v \sim 25\text{--}30 \text{ km s}^{-1}$ (Karachentsev et al. 2002c). The peculiar velocities of the centroids of the nearest groups (Local Group, M 81 group, Cen A group, M 83 group, CVnI cloud) turn out to be $\sim 25 \text{ km s}^{-1}$ as well (Karachentsev et al. 2002a, 2002b, 2002c, 2003). The observed quiescence of the local Hubble flow can be considered (Chernin 2001; Baryshev et al. 2001) as a signature of a vacuum-dominated universe where the velocity perturbations are adiabatically decreasing.

There are several ways of considering σ_v . The dispersion of radial velocities in Fig. 4 around an isotropic Hubble flow yields $\sigma_v = 85 \text{ km s}^{-1}$, in good agreement with the initial estimate of Sandage et al. (1972). However, when members of the two groups around M 81 and Cen A with their high random motions are excluded, σ_v decreases to 73 km s^{-1} . If one considers the dispersion around the observed anisotropy of the local Hubble flow, σ_v drops to 59 km s^{-1} . Here we should remember that the distances of galaxies in Fig. 4 are determined with a typical relative error of $\sim 15\%$. With the mean galaxy

distance $\langle D \rangle = 3.8 \text{ Mpc}$ and $H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$, the mean distance error corresponds to an error on the radial velocity $H_0 \cdot \sigma_D = 42 \text{ km s}^{-1}$. Thus, after quadratic subtraction of this error the mean-square peculiar velocity of galaxies is reduced to $\sigma_v = 41 \text{ km s}^{-1}$. The true value of the random motions of isolated galaxies in the Local Volume may even be slightly lower because the random motions of galaxies within some other nearby groups (IC 342/Maffei, M 83, etc.) were ignored.

As shown by Karachentsev et al. (2002a, 2002b, 2002c), the total mass-to-blue luminosity ratios of the LG, M 81 group, Cen A group, and M 83 group lie within a range of $[30\text{--}65] M_\odot/L_\odot$. The low M_T/L_B ratio of the nearest groups and also the low velocity dispersion of their centers, $\sim 25 \text{ km s}^{-1}$, correspond to a low mean density of matter in the Local universe, $\Omega_m \sim 0.03\text{--}0.07$.

7. Concluding remarks

A general view of the Local Volume within a radius of 5.5 Mpc is presented in Fig. 7. Its upper panel shows the galaxy distribution projected onto the Supergalactic plane, and the lower

Supergalactic

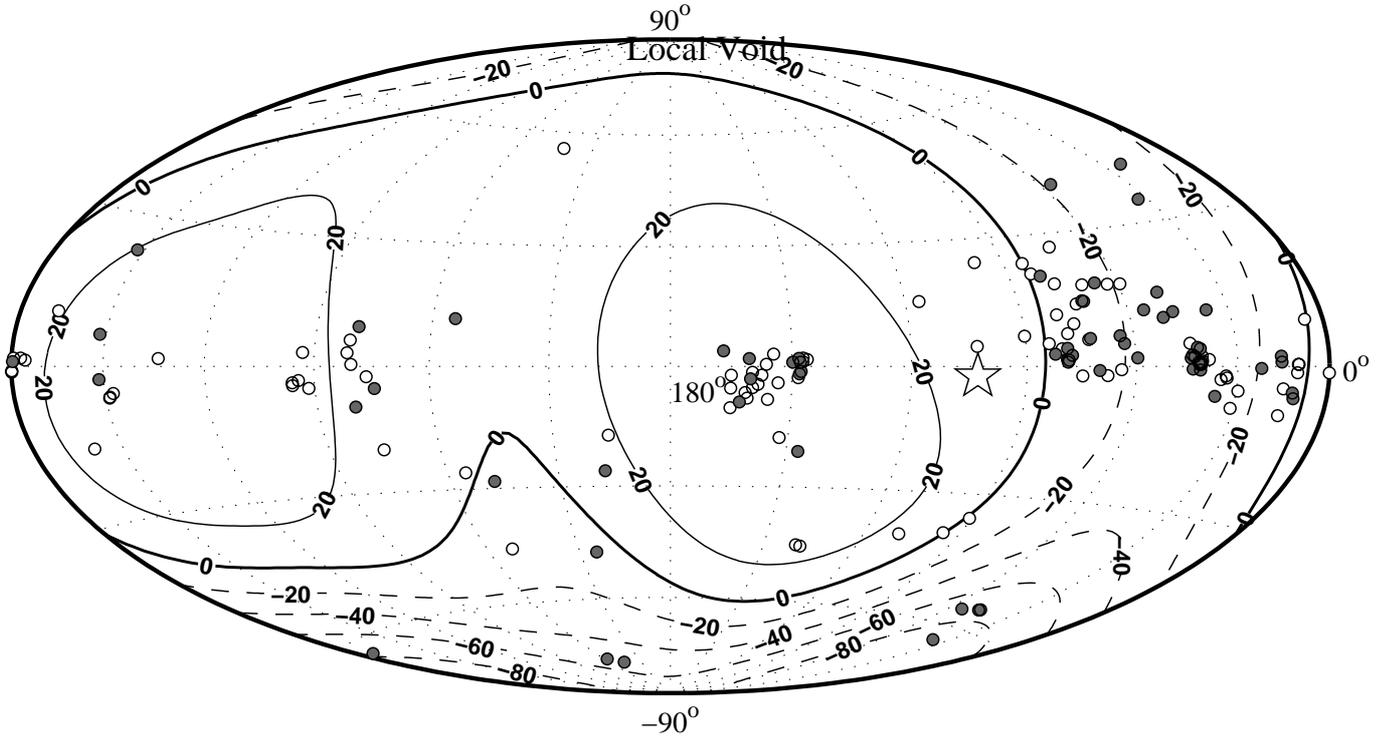


Fig. 5. Full-sky distribution of 156 galaxies from Table 2 in supergalactic coordinates. The galaxies with positive and with negative peculiar velocities with respect to the isotropic Hubble flow ($H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$) are shown as open and filled circles, respectively. The observed peculiar velocities of galaxies were smoothed with a 2D-Gaussian filter with a parameter $\sigma = 25^\circ$, and then were plotted as contour map with intervals of 20 km s^{-1} .

Galactic

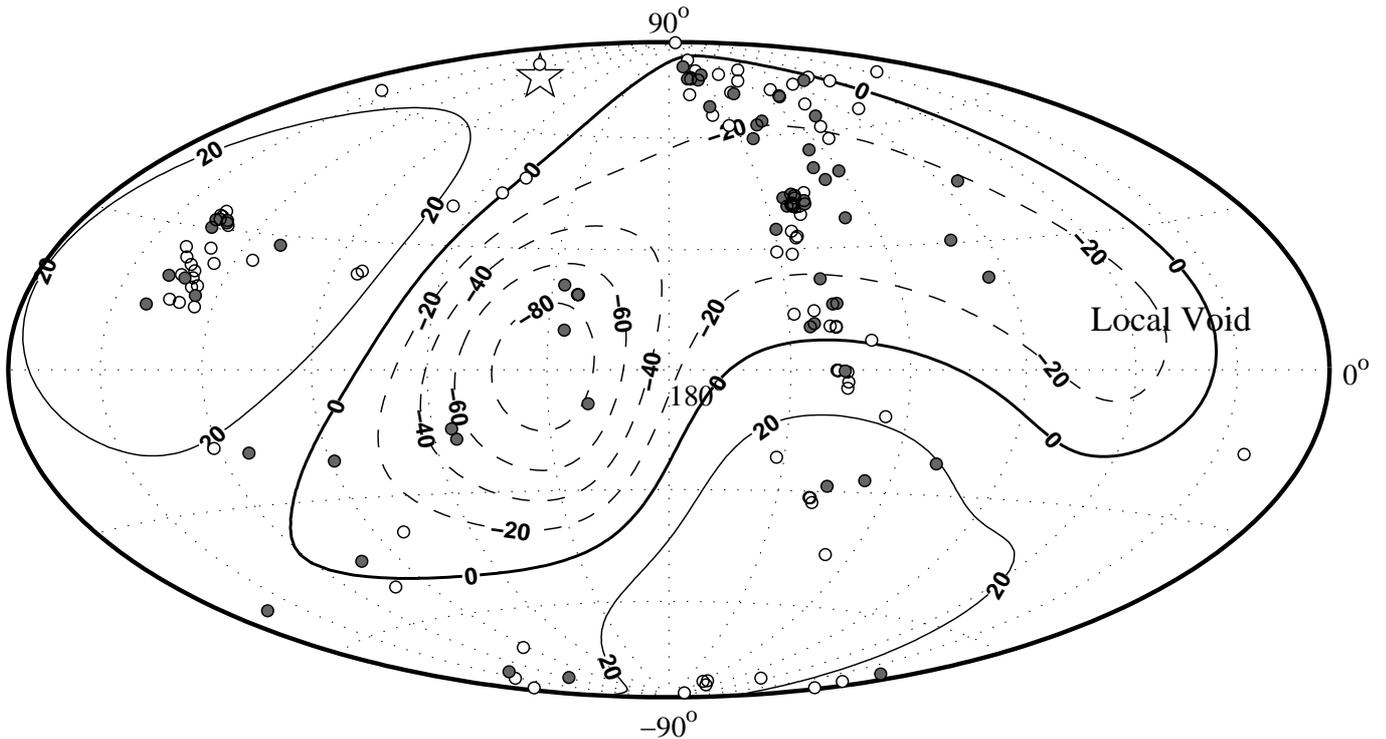


Fig. 6. The same map of the local field of peculiar velocities as shown in Fig. 5, but in galactic coordinates.

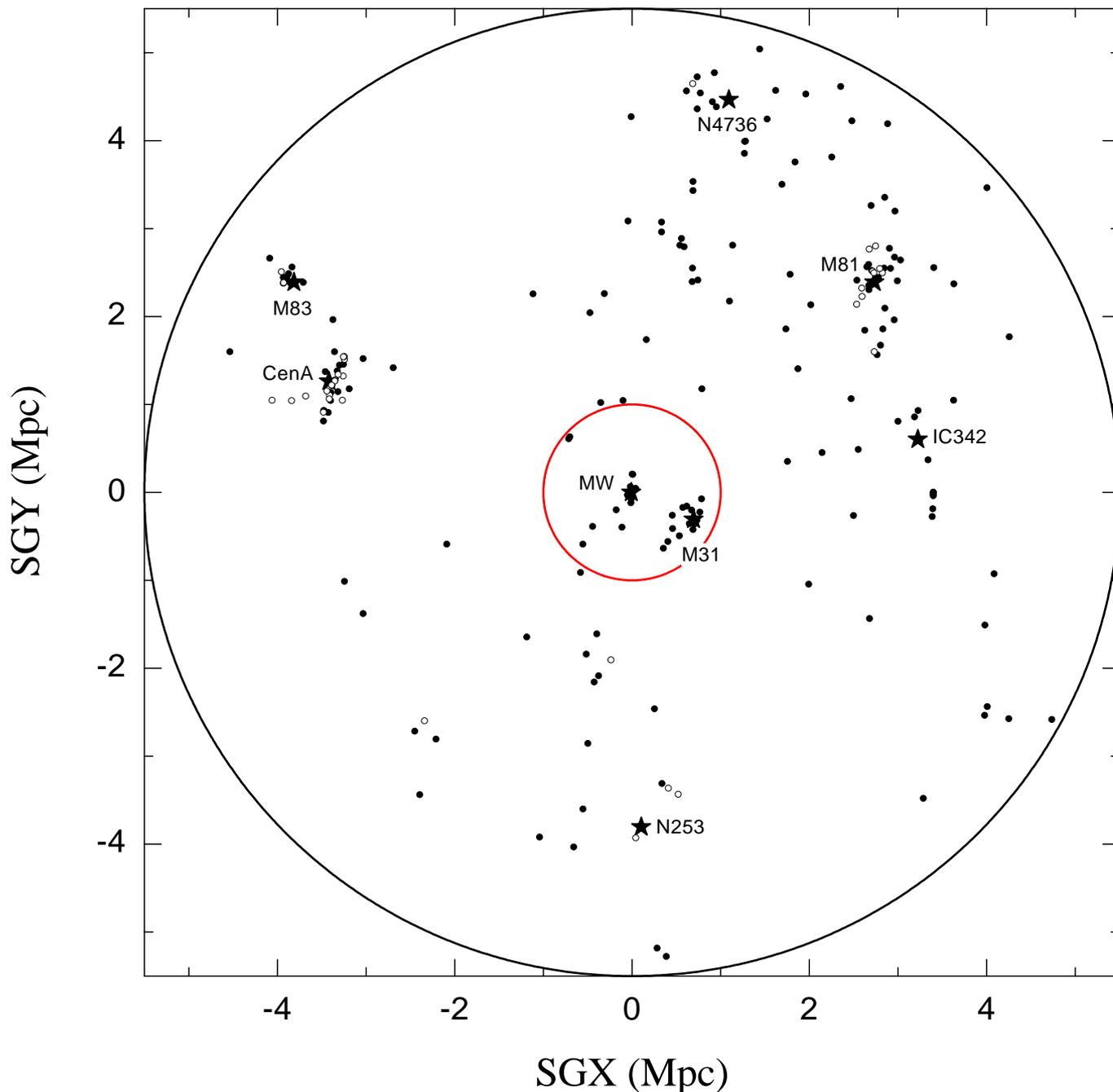


Fig. 7. Panorama of the Local Volume within a radius of 5.5 Mpc. The upper panel shows the galaxy distribution projected onto the Supergalactic plane, and the lower panel corresponds to the edge-on view. The galaxies with known radial velocities are shown as filled circles, the 35 galaxies of dSph, dE types without radial velocities are indicated as open circles. The brightest members of nearest groups are shown as asterisks.

panel corresponds to an edge-on view. Apart from 156 galaxies with radial velocities known so far (shown with filled circles), we also plot in Fig. 7 35 galaxies without radial velocity estimates (open circles). All of them are dwarf galaxies of the dSph and dwarf elliptical (dE) morphological types. In the considered volume there are six known groups, besides the LG, whose brightest members: M 81, NGC 5128 (=Cen A), M 83, IC 342, NGC 4736, and NGC 253 are shown with asterisks. Altogether, 121 galaxies, or 63% of their total number inside the shell of $1.0 < D < 5.5$ Mpc, belong to these compact or loose groups.

Apart from the well-known groups, where 1 or 2 giant galaxies dominate over other members, there are also some groups consisting entirely of dwarf galaxies. Tully et al. (2002) found four groups of this kind, the principal members of which are NGC 3109, UGC 8760, UGC 3974, and NGC 784, respectively. In the Local Volume we found six more such groups. Their complete list is given in Table 3. The table columns contain: (1) group member names, where the brightest galaxy ranks first, (2) number of galaxies in the group, (3) mean distance to the group, (4) mean projected linear radius of the group, (5) radial velocity dispersion, (6) absolute B magnitude

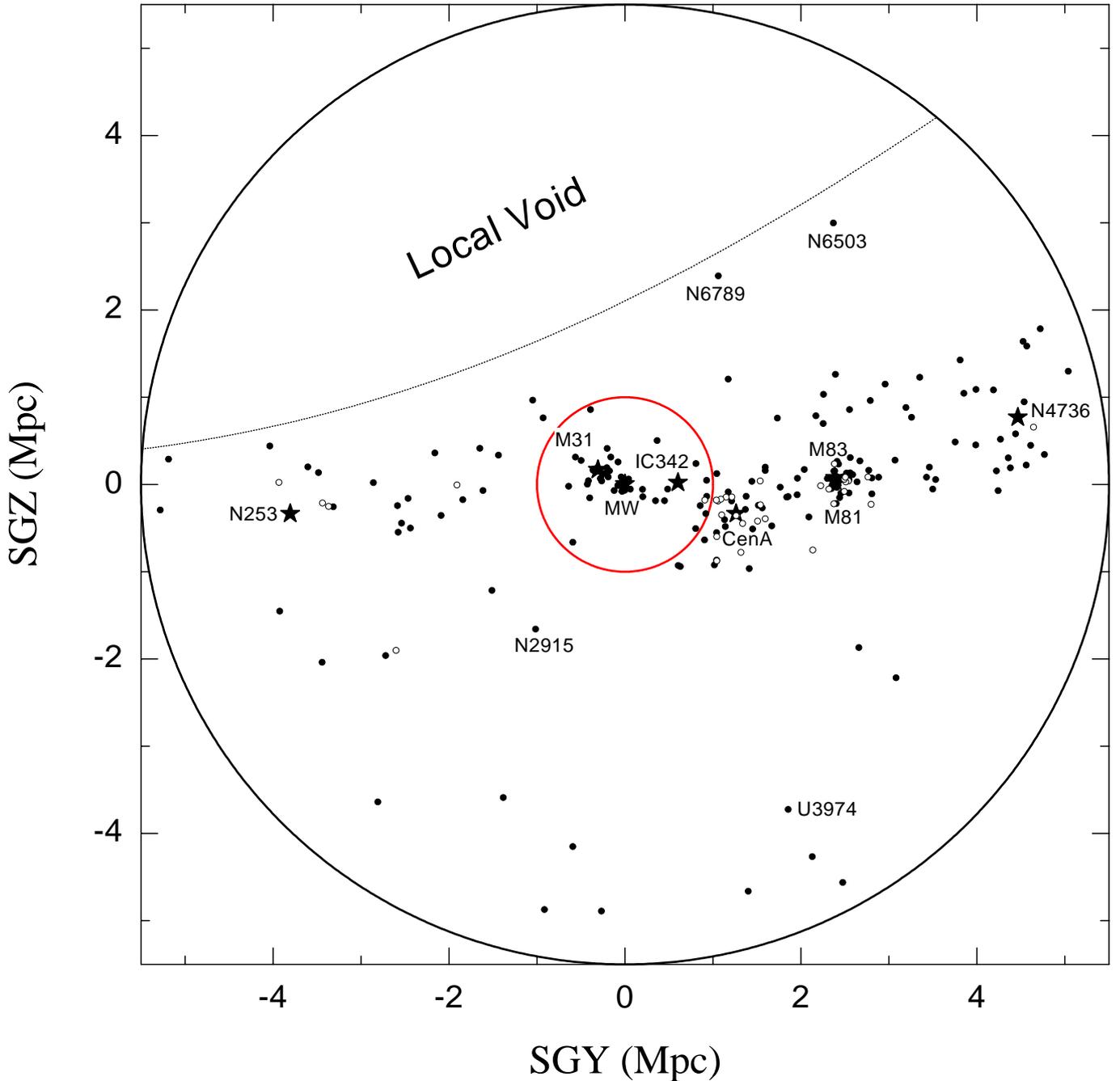


Fig. 7. Continued.

of the brightest member, (7) integrated luminosity of the group, (8,9) virial and orbital (Karachentsev et al. 2002a) mass estimate normalized to the luminosity unit, (10) crossing time.

It follows from the presented data that a typical group of dwarf galaxies ($N = 4$ members) is characterized by a median projected radius of ~ 180 kpc, a median velocity dispersion of only 18 km s^{-1} , a median absolute magnitude of the brightest member of -15.5 mag, and a median virial/orbital mass-to-luminosity ratio of $(220\text{--}440) M_{\odot}/L_{\odot}$. Tully et al. (2002) suggest that these galaxy groups contain a large amount of dark

matter as low mass halos, as expected in a Λ CDM cosmology, which have never hosted significant star formation. The high virial mass-to-luminosity ratios favour this idea. However, the typical crossing time for these groups, 23 Gyr, exceeds largely the age of the Universe, which means that virial/orbital mass estimates are fictitious. Altogether, about 13% of the Local Volume galaxies belong to these loose associations of dwarf galaxies.

Together with the usual groups and groups of dwarf galaxies, the Local Volume contains small empty regions of different

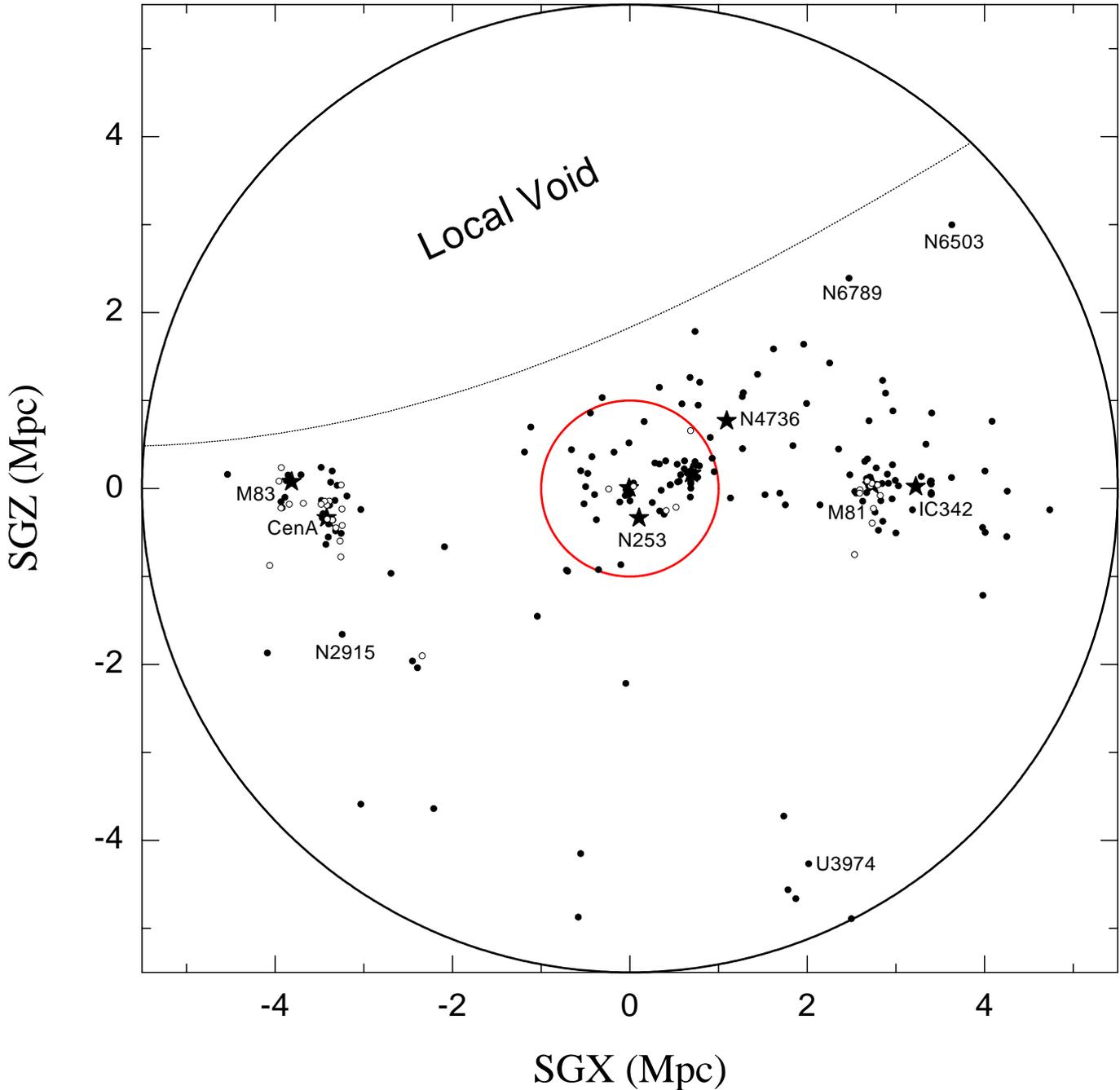


Fig. 7. Continued.

sizes, which are completely devoid of any galaxy. The biggest one is known as the Local Void (Tully 1988). In this respect, a study of the topology of the Local Volume would be of interest for cosmology (Gottlober et al. 2002).

Acknowledgements. We thank the referee, J. Lequeux, for his very useful comments. Support for this work was provided by NASA through grant GO-08601.01-A from the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555. This work was partially supported by RFBR grant 01-02-16001 and

DFG-RFBR grant 02-02-04012. D.G. gratefully acknowledges support from the Chile *Centro de Astrofísica* FONDAF No. 15010003.

The Digitized Sky Surveys were produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166. The images of these surveys are based on photographic data obtained using the Oschin Schmidt Telescope on the Palomar Mountain and the UK Schmidt Telescope. The plates were processed into the present compressed digital form with permission of these institutions.

This project made use of the NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, Caltech, under contract with the National Aeronautics and Space Administration.

Table 3. Properties of nearby groups of dwarf galaxies.

Group	N	$\langle D \rangle$	$\langle R_p \rangle$	σ_V	M_1	L_B	M_{vir}/L_B	M_{orb}/L_B	T_{cross}
		Mpc	kpc	km s ⁻¹	mag	10 ⁸ L _⊙	M _⊙ /L _⊙	M _⊙ /L _⊙	Gyr
N3109, SexB, Antlia, SexA	4	1.36	414	18	-15.57	3.58	214	201	23
U8760, U8651, U8833	3	3.20	162	7	-13.23	0.59	398	430	23
U8320, U8215, U8308, U8331	4	4.20	84	37	-15.46	2.58	869	948	2.3
N4395, N4244, U7559, U7605, IC 3687	5	4.43	320	54	-17.69	35.9	625	452	5.9
N784, U1281, KK 16, KK 17	4	4.96	184	16	-16.58	8.52	45	84	12
U3974, U3755, KK 65, U4115	4	5.10	412	19	-14.97	3.43	222	1945	22
Orion, KK 49, U3817	3	5.95	300	41	-16.33	6.94	2045	2999	7.3
U3966, U3860	2	6.25	142	1	-14.80	1.94	–	7	142
U5272, KK 78, KKH 54, U5186	4	7.10	114	14	-14.91	1.91	33	859	8.1
N2337, U3698, U3817	3	7.90	174	6	-16.77	9.09	7	3	27
Median	4	5.0	179	18	-15.52	3.5	218	441	23

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