Part 1: Setting the Scene

Introductory Reviews

The Stellar Content of Local Group Galaxies
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Stellar Content of Local Group Galaxies - An Introduction

Sidney van den Bergh

Dominion Astrophysical Observatory, Herzberg Institute of Astrophysics, National Research Council of Canada, 5071 West Saanich Road, Victoria, British Columbia, V8X 4M6, Canada
E-mail: vdb@dao.nrc.ca

1. Introduction

In *The Realm of the Nebulae*, Hubble (1936) first drew attention to the fact that the Milky Way system and the Andromeda galaxy belong to a small cluster that also contains M32, M33, the Magellanic Clouds, NGC 205, NGC 6822 and IC 1613. Hubble also listed IC 10 as a possible member of what he referred to as "the Local Group". Inspection of the prints of the Palomar Sky Survey shows (van den Bergh 1962) that a large fraction of all field galaxies are located in such small groups or clusters. Our Milky Way system therefore appears to be situated in a rather typical region of space. All of the well-established Local Group members that are listed above are at distances $D \leq 1.0$ Mpc. A conservative limit $D < 1.5$ Mpc may therefore be used to search for new Local Group members. An additional criterion for physical membership in the Local Group is that a candidate member with solar apex distance θ and radial velocity V_r should lie close to the V_r versus $\cos\theta$ relation for well-established Local Group members (Courteau & van den Bergh 1999). Finally candidates may be disqualified from membership if they appear projected on nearby groups of galaxies that are centered at distances greater than 1.5 Mpc. In particular the Local Group candidates NGC 1560, NGC 1569, UGC-A86 and Cassiopeia 1 were excluded because they appear projected on (or near) the IC 342/Maffei group. Furthermore NGC 55 and UKS 2323–326 were excluded because they appear projected on (or near) the Sculptor (= South Polar) group. Observational data on 35 probable Local Group members are given in Table 1.

Derived quantities for these objects are listed in Table 2. A detailed discussion of the entries in these tables is given in the monograph *The Galaxies of the Local Group* (van den Bergh 2000). Note that all of these objects except Aquarius ($D = 1.0$ Mpc) and SagDIG ($D = 1.3$: Mpc) have distances $D < 1.0$ Mpc. The galaxies NGC 3109, Antlia, Sextans A and Sextans B, which have distances in the range 1.3-1.5 Mpc, appear to form a compact physical grouping. The distance from NGC 3109 to the centroid of the Local Group is 1.7 Mpc. NGC 3109, Antlia, Sex A and Sex B are all slightly redshifted with respect to the V_r versus $\cos\theta$ relation for Local Group members. Relative to a Solar velocity of 306 km s^{-1} towards $l = 99°$, $b = -3°$ this group has a redshift of $+114 \pm 12$ km s^{-1}. This indicates that the Antlia/Sextans grouping is located slightly beyond the zero velocity surface of the Local Group. A plot of Local Group members in the V_r versus $\cos\theta$ plane is shown in Fig. 1. The dispersion of Local

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Table 1. Observational Data on Local Group Members

Name	Alias	Type	α J2000	δ J2000	V_r (km s^{-1})	V (mag)	E($B-V$) (mag)
WLM	DDO 221	Ir IV-V	00 01 57.8	−15 27 51	−120	10.42	0.02
IC 10	...	Ir IV:	00 20 24	+59 17 30	−344	10.4	0.8
NGC 147	...	Sph	00 33 11.6	+48 30 28	−193	9.52	0.17
And III	...	dSph	00 35 17	+36 30 30	...	14.21	0.05
NGC 185	...	Sph	00 38 58.0	+48 20 18	−202	9.13	0.19
NGC 205	...	Sph	00 40 22.5	+41 41 11	−244	8.06	0.04
M32	NGC 221	E2	00 42 41.9	+40 51 55	−205	8.06	0.06
M31	NGC 224	Sb I-II	00 42 44.2	+41 16 09	−301	3.38	0.06
And I	...	dSph	00 45 43	+38 00 24	...	12.75	0.04
SMC	...	IrIV/IV-V	00 52 36	−72 48 00	+148	1.97	0.06
Sculptor	...	dSph	01 00 04.3	−33 42 51	+110	8.8	0.00
Pisces	LGS 3	dIr/dSph	01 03 56.5	+21 53 41	−286	14.26	0.03
IC 1613	...	Ir V	01 04 47.3	+02 08 14	−232	9.09	0.03
And V	...	dSph	01 10 17.1	+47 37 41	...	15.5	0.16
And II	...	dSph	01 16 27	+33 25 42	...	12.71	0.08
M33	NGC 598	Sc III	01 33 50.9	+30 29 37	−181	5.85	0.07
Phoenix	...	dIr/dSph	01 51 03.3	−44 27 11	...	...	0.02
Fornax	...	dSph	02 39 53.1	−34 30 16	+53	7.3	0.03
LMC	...	Ir III-IV	05 19 36	−69 27 06	+275	0.4	0.13
Carina	...	dSph	06 41 36.7	−50 57 58	+223	10.6	0.05
Leo A	DDO 69	Ir V	09 59 23.0	+30 44 44	+24	12.69	0.02
Leo I	Regulus	dSph	10 08 26.7	+12 18 29	+287	10.2	0.02
Sextans	...	dSph	10 13 02.9	−01 36 52	+228	10.3	0.04
Leo II	DDO 93	dSph	11 13 27.4	+22 09 40	+76	11.62	0.03
Ursa Min.	DDO 199	dSph	15 08 49.2	+67 06 38	−247	10.6	0.03
Draco	DDO 208	dSph	17 20 18.6	+57 55 06	−293	11.0	0.03
Milky Way	...	S(B)bc I-II:	17 45 39.9	−29 00 28	+16	...	...
Sagittarius	...	dSph(t)	18 55 04.3	−30 28 42	+142	...	0.15
SagDIG*	...	Ir V	19 29 58.9	−17 40 41	−79	14.2	0.07
NGC 6822	...	Ir IV-V	19 44 56.0	−14 48 06	−56	8.52	0.25
Aquarius*	DDO 210	V	20 46 53	−12 50 58	−131	13.88	0.04
Tucana	...	dSph	22 41 48.9	−64 25 21	...	15.15	0.00
Cassiopeia	...	dSph	23 26 27.4	+50 41 31	...	15.2	...
Pegasus	DDO 216	Ir V	23 28 34	+14 44 48	−182	12.59	0.15
Pegasus II	And VI	dSph	23 51 44.4	+24 35 41	...	13.9	...

* Local Group membership needs to be confirmed

Table 2. Derived Properties of Probable Local Group Members

Name	Alias	DDO Type	$(m-M)_0$	M_V	l°	b°	D(kpc)	$\cos\theta$
M31	NGC 224	Sb I-II	24.4	−21.2	121.17	−21.57	760	0.880
Milky Way	Galaxy	S(B)bc I-II:	14.5	−20::	000.00	00.00	8	−0.150
M33	NGC 598	Sc II-III	24.5	−18.9	133.61	−31.33	795	0.729
LMC	...	Ir III-IV	18.5	−18.5	280.19	−33.29	50	−0.801
SMC	...	Ir IV/IV-V	18.85	−17.1	302.81	−44.33	59	−0.609
IC 10	...	Ir IV:	24.55	−16.7	118.97	−03.34	820	0.938
M32	NGC 221	E2	24.4	−16.5	121.15	−21.98	760	0.878
NGC 205	...	Sph	24.4	−16.4	120.72	−21.14	760	0.884
NGC 6822	...	Ir IV-V	23.5	−16.0	025.34	−18.39	500	0.292
NGC 185	...	Sph	24.1	−15.6	120.79	−14.48	660	0.910
IC 1613	...	Ir V	23.3	−15.3	129.73	−60.56	725	0.473
NGC 147	...	Sph	24.1	−15.1	119.82	−14.25	660	0.917
WLM	DDO 221	Ir IV-V	24.85	−14.4	075.85	−73.63	925	0.318
Sagittarius	...	dSph(t)	17.0	−13.8::	005.61	−14.09	24	−0.036
Fornax	...	dSph	20.7	−13.1	237.24	−65.66	138	−0.253
Pegasus	DDO 216	Ir V	24.4	−12.3	094.77	−43.55	760	0.764
Leo I	Regulus	dSph	22.0	−11.9	225.98	+49.11	250	−0.443
And I	...	dSph	24.55	−11.8	121.69	−24.85	810	0.859
And II		dSph	23.8	−11.8	128.91	−29.15	585	0.782
Leo A	DDO 69	Ir V	24.2	−11.5	196.90	+52.41	690	−0.136
Aquarius*	DDO 210	V	25.05	−11.3	034.04	−31.35	1025	0.398
SagDIG*	...	Ir V	25.7:	−10.7:	021.13	−16.23	1300:	0.224
And V	...	dSph	24.55	−10.5	126.22	−15.12	810	0.870
Pisces	LGS 3	dIr/dSph	24.55	−10.4	126.77	−40.88	810	0.705
And III	...	dSph	24.4	−10.2	119.31	−26.25	760	0.864
Leo II	...	dSph	21.6	−10.1	220.14	+67.23	210	−0.258
Phoenix	...	dIr/dSph	23.0	−9.8	272.19	−69.95	395	−0.299
Sculptor		dSph	19.7	−9.8	287.69	−83.16	87	−0.057
Tucana	...	dSph	24.7	−9.6	322.91	−47.37	870	−0.439
Sextans	...	dSph	19.7	−9.5	243.50	+42.27	86	−0.645
Carina	...	dSph	20.0	−9.4	260.11	−22.22	100	−0.853
Draco	...	dSph	19.5	−8.6	086.37	+34.71	79	0.767
Ursa Minor	...	dSph	19.0	−8.5	104.88	+44.90	63	0.660
Cassiopeia	...	dSph	24.45	...	109.46	−09.94	775	0.976
Pegasus II	And VI	dSph	24.25	...	106.04	−36.31	710	0.834

* Membership in Local Group not yet firmly established

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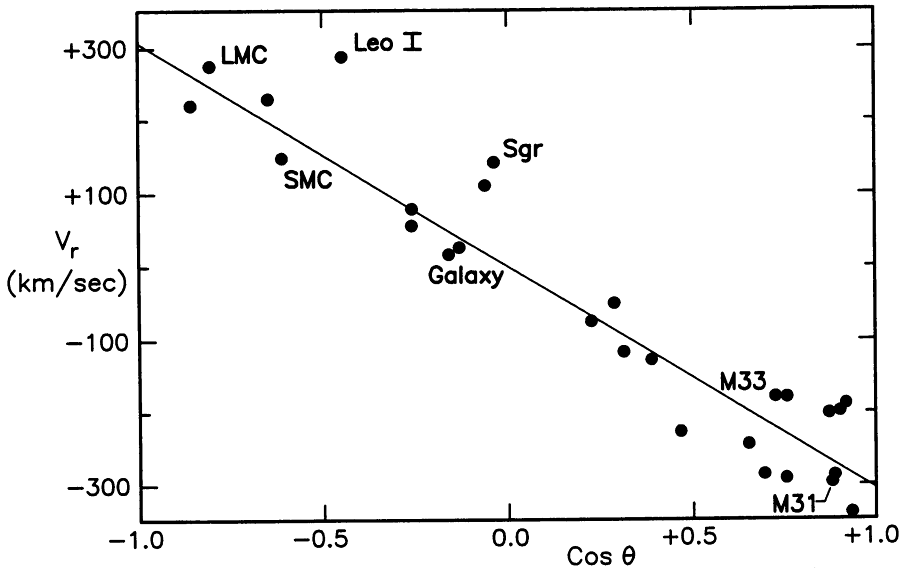

Figure 1. Radial velocity versus $\cos\theta$, where θ is the angular distance from the solar apex at $l = 99°$, $b = -3°$ (Courteau & van den Bergh 1999). The line in the figure has V_r = –306 km s^{-1} at $\cos\theta = 1.0$. The velocity dispersion of Local Group members about this regression line is 61 km s^{-1}. Note the M positions of Leo I and of the Sagittarius system (which has been perturbed by the Galaxy).

Group members about the relation shown in Fig. 1 is 61 km s^{-1}. In summary it appears that the Local Group has a radius R $\leq$ 1.0 Mpc.

Within this radius are located two major gravitationally bound (Kahn & Woltjer 1959) sub-groups centered on M31 and the Galaxy. Figure 2 shows a plot of the positions of all presently known members of the Andromeda sub-group of the Local Group. Note that M31/M32/ NGC 205 and NGC 147/NGC 185 form physical sub-clumpings within the Andromeda sub-group.

The Local Group is a sort of Noah's Ark that exhibits at least one example of most species of galaxies. It contains an early-type spiral (M31), a late-type spiral (M33), a dwarf elliptical (M32), a spheroidal galaxy (NGC 205) and a dwarf spheroidal (Sculptor). It is therefore possible to study these relatively nearby objects in great detail. Sadly the Local Group does not contain blue compact galaxies (formerly known as intergalactic H II regions), although IC 10 might qualify as a relatively inactive member of this class. Furthermore, the Local Group is not known to contain an example of the oversized dSph galaxies that are known in the Virgo and Fornax clusters and in the M81 group. However, such a low surface brightness object (which would have a disk scale-length of over a degree at the distance of the LMC) would be difficult to discover. Fortunately the Local Group does not contain a cD or giant E galaxy. Such an object might

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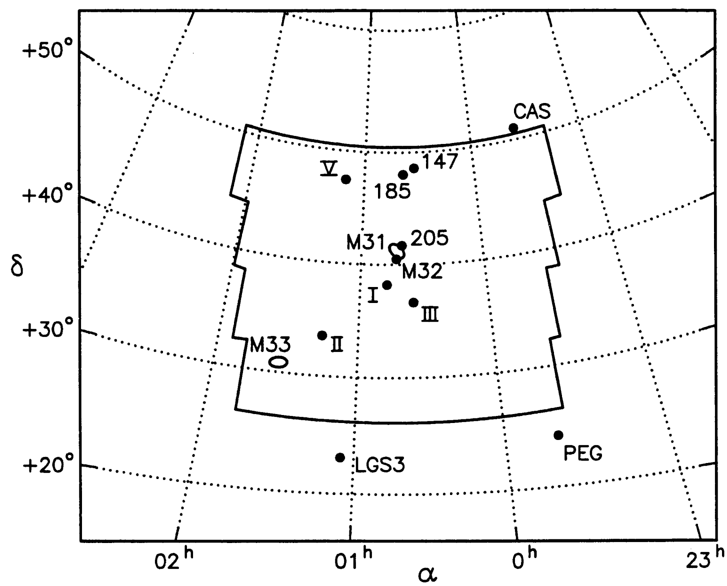

Figure 2. Andromeda sub-group of the Local Group. Note compact M31/M 32/NGC 205 and NGC 147/NGC 185 sub-groups. Heavy lines shows boundary of the area searched for dwarfs by van den Bergh (1972).

have destroyed the Milky Way - thus preventing us from meeting in beautiful Cape Town today!

2. The Andromeda Galaxy

Inspection of Table 1 shows that all three of the brightest members of the Local Group are spirals. The Andromeda galaxy (= M31 = NGC 224), which is a spiral of early Sb type, is the most luminous Group member. It has played a particularly important role in the recent history of astronomy because it was the first individual galaxy in which dark matter was discovered (Roberts & Whitehurst 1975). This demonstrated that the missing mass phenomenon, which had been discovered in the Coma cluster by Zwicky (1933), was not just restricted to rich clusters of galaxies. The rate of star and cluster formation in M31 seems to have declined much more rapidly than it has in the Galaxy. This difference manifests itself in the a high ratio of red clusters to blue clusters in the Andromeda galaxy, in the relatively large fraction of metal-rich globulars in M31 (van den Bergh 1969), and in the rather high average metallicity of stars in the halo of the Andromeda galaxy (Pritchet & van den Bergh 1994). These authors

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show that the bulge and halo of M31 may be represented by a single $r^{1/4}$ law. At this meeting Freeman made the interesting suggestion that the $r^{1/4}$ halo of M31 extends to very large radii because the Andromeda galaxy (in contrast to the Milky Way system) may have formed as the result of a violent merger. Another important discovery has been that the nucleus of the Andromeda galaxy is double (Lauer et al. 1993). It is not yet clear why the true nucleus of M31 has such blue colors. Is it because it swallowed a few globular clusters with blue horizontal branches, or have frequent collisions between individual stars prevented the growth of extended red giant envelopes?

3. The Milky Way System

Work by Lindblad and Oort in the 1920s showed that the Galaxy is a spiral galaxy that is in differential rotation around a point in Sagittarius. Spiral arms in the disk of the Galaxy were first identified by Morgan, Whitford & Code (1953). Later Morgan (1959) showed that the integrated spectrum of the nuclear bulge of the Galaxy (as seen through "Baade's window") was dominated by the light of metal-rich K giants. This came as a great surprise because Baade (1944a,b) had postulated that nuclear bulges consisted of metal-poor Population II stars. Finally Blitz & Spergel (1991) were able to show that a bar-like structure is embedded in the central region of the Galaxy.

The main differences between the Andromeda galaxy and the Milky Way system are:

(1) M31 is more luminous, and has a larger globular cluster population, than the Galaxy.

(2) The present rate of star formation in the Galaxy is higher than it is in M31. Furthermore, the rate of star and cluster formation has declined more rapidly in M31 than it has in the Galaxy.

(3) The Galaxy contains a nuclear disk that is actively forming stars, whereas the central region of the Andromeda galaxy is devoid of star formation.

(4) The halo of M31 contains a larger fraction of metal-rich globular clusters than does the Galactic halo.

(5) The brightness profile of the Galactic halo does not appear to form an $r^{1/4}$ extension of its nuclear bulge (Morrison 1993, Pritchet & van den Bergh 1994). This suggests that the outer halo of the Galaxy may have formed mainly by accretion.

The three-dimensional velocity dispersion of members of the Local Group is $\simeq 110$ km s^{-1}. The crossing time for the Galactic halo, which has a diameter of 200 kpc, is therefore ≤ 2 Gyr. Events that took place during the first two Gyr can therefore be considered as part of the formation of the Galaxy, whereas those that took place later might be interpreted as accretion. Nine "young" globular clusters, with ages that are > 3 Gyr smaller than those of the majority of Galactic globulars, are presently known. All of these young globulars are located in the halo at $R_{GC} > 15$ kpc (van den Bergh 1998a). Remarkably these young clusters have $< M_V > = -5.2$, which is significantly lower than the Galactic average of $< M_V > = -7.4$ (Harris 1991). In fact, every one of the "young" globulars is fainter than the Galactic globular cluster average. The fact that the old outer halo globular NGC 2419 has $M_V = -9.5$ suggests that the luminosities of clusters in the outer halo may have started out high, but then declined to values similar to those of open clusters after the first few Gyr. It is remarkable (and unexpected) that the first generation of globular clusters in the inner Galactic halo, in NGC 2419 at $R_{GC} = 90$ kpc, and in the Large Magellanic Cloud, all appear to have formed more or less simultaneously.

4. The Triangulum Galaxy

The Triangulum galaxy (= M33, = NGC 598) is a spiral of type Sc II-III. The integrated colors of its star clusters show that the number of young blue clusters greatly exceeds the number of old red ones. Unlike the Large Magellanic Cloud it does not appear to have undergone a recent burst of cluster formation. Schommer et al. (1991) showed that the M33 blue clusters with $B - V < 0.6$ exhibit disk kinematics, whereas the red clusters with $B - V > 0.6$ show halo kinematics with a radial velocity dispersion of ~ 70 km s^{-1}. Color-magnitude diagrams for the red M33 halo globulars have been obtained with the Hubble Space Telescope by Sarajedini et al. (1998). Their results show that these clusters are metal-poor. However, they find that eight out of 10 of these clusters possess exclusively red horizontal branch morphologies, which is generally thought to indicate that they are relatively young. This contrasts with the situation in the Large Cloud (Olsen et al. 1998) in which the globular clusters appear to be old and have blue horizontal branches. Furthermore Schommer et al. (1992) showed that these metal-poor old globulars in the Large Cloud appear to exhibit disk kinematics. It is presently a complete mystery why the LMC globulars constitute an old metal-poor disk, while M33 is embedded in a halo of relatively young globular clusters. M33 has little or no nuclear bulge (McLean & Liu 1996), even though it is surrounded by a significant halo. This demonstrates that its halo does not represent an extension of its bulge to large radii.

M33 is embedded in an extended hydrogen envelope. At a given surface density of gas the star formation rate is found to be highest in the inner region of the Triangulum galaxy (Madore, van den Bergh & Rogstad 1974). Since the rate of star formation probably depends on the volume density of gas, rather than on its surface density, this result suggests that the thickness of the M33 hydrogen layer increases towards larger radii. The outer part of the M33 hydrogen is strongly warped. The reason for this warp is not yet understood.

5. The Large Magellanic Cloud

5.1. Distance to the LMC

A review of distance determinations to the Large Cloud by Westerlund (1997) gives $< (m - M)_0 > = 18.48 \pm 0.04$. A compilation of 17 more recent distance determinations, which was shown at the present meeting, yields $< (m-M)_0 > =$ 18.50 ± 0.04. Strongly deviating results have, however, been published by Feast & Catchpole (1997) who obtain $(m - M)_0 = 18.70 \pm 0.10$ from the Hipparcos calibration of Galactic Cepheids, and by Udalski et al. (1998) who find $(m-M)_0$ $= 18.08 \pm 0.1$ from the Hipparcos calibration of Galactic red clump stars. For the

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time being it is probably best to continue to use the canonical value $(m-M)_0 = 18.5 \pm 0.1$, corresponding to a distance of 50 kpc. Such a value appears consistent with the geometrical distance determinations from the SN 1987A ring and from a detached eclipsing variable. It is, however, a source of concern that observations of RR Lyrae stars in the LMC (Walker 1992), in conjunction with statistical parallaxes determined from the Hipparcos proper motions of Galactic cluster-type variables, appear to favor a smaller Large Cloud distance.

5.2. History of Star Formation

It was first pointed out by Butcher (1977) that a great burst of star formation started in the LMC 3-5 Gyr ago. From observations of field stars it appears that the rate at which these field stars were made increased by a factor of only 2-4 during this burst. On the other hand observations of star clusters show that the frequency of cluster formation must have increased by at least an order of magnitude during the recent burst of star formation in the Large Cloud. These results suggest that the rate of cluster formation does not provide a reliable diagnostic for the rate of star creation. Observations of numerous populous blue clusters in colliding gas-rich spirals, such NGC 4038/39 ("the antennae"), suggest that strong shocks might favor the formation of massive clusters. The fact that the Small Magellanic Cloud exhibits no evidence for a recent burst of star and cluster formation shows that this event was not triggered by a close tidal encounter of the LMC and the SMC. Proof of the fact that some star, and hence supernova, formation did take place in the LMC between 5 Gyr and 12 Gyr ago (when few clusters formed) is provided by the observation that the metallicity of stars formed during this period increased with time. The history of star formation in the Large Cloud during the last ~100 Myr can be traced from the distribution of OB stars and Cepheids. These data show that star formation was strongly concentrated in the LMC Bar 50-70 Myr ago, but is now much more widely dispersed. It is not yet clear if any star formation took place in the Bar >1 Gyr ago, i.e. we do not know if the Bar is a relatively recent morphological feature of the Large Cloud.

6. The Small Magellanic Cloud

Tidal encounters between the LMC and the SMC produced the Bridge ~ 0.2 Gyr ago, and the Magellanic Stream ~ 1.5 Gyr ago. As a result of these encounters the SMC itself is greatly extended along the line-of-sight (Mathewson, Ford & Visvanathan 1986). Since many of the Cepheids are situated in the tidal plume behind the Small Cloud they may not give exactly the same mean distance as the SMC RR Lyrae variables, which are centered on the main body of the SMC. Much gas has been lost from the SMC during its two most recent tidal encounters with the LMC. This suggests that the Small Cloud might not have survived if the separation between the LMC and SMC had always been as small as it is now. Improved proper motion data might provide interesting insights into the orbital evolution of the Magellanic Clouds.

The presence of RR Lyrae variables suggests that Local Group dwarf irregular galaxies (with the possible exception of Leo A) started to form stars > 10 Gyr ago. In most of these objects past star formation was more dispersed than

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it is at the present time, i.e. they shrank as they evolved. Some, but not all, dIr galaxies are embedded in huge hydrogen envelopes. A fine example of such an extended envelope is seen surrounding NGC 6822 (Roberts 1972). Some Local Group dwarfs, such as Pisces (= LGS 3) and Phoenix, have morphological types that are intermediate between between dIr and dSph. It is not yet clear how such (presumably non-rotating) objects are related to rotating irregulars like the LMC.

7. The Spheroidal Galaxies NGC 147 and NGC 185

Luminous spheroidal galaxies, such as NGC 147, NGC 185 and NGC 205, belong to the same morphological family as the more numerous fainter *dwarf* spheroidals. The pair of spheroidal galaxies NGC 147/NGC 185 has played an important role in the development of our ideas on stellar populations (Baade 1944b). From their small velocity difference $\Delta V = 9$ km s^{-1} van den Bergh (1998b) shows that these objects must form a bound physical pair within the Andromeda sub-group of the Local Group. It is of interest to note that both of these galaxies are spheroidals. This, and the fact that the Magellanic Clouds are both irregulars, suggests that physical pairs of galaxies with comparable masses that formed in the same environment evolve into objects with similar morphological types. It is not clear (Sage, Welch & Mitchell 1998) why NGC 147 is essentially gas-free and contains no young stars, while NGC 185 contains both gas and dust, and a few young stars.

8. Dwarf Spheroidal Galaxies

Dwarf spheroidals, of which Sculptor is the type example, are probably the most common kind of galaxy in the Universe. About half of all known Local Group members are of this morphological type. Furthermore the majority of the recent (faint!) additions to the Local Group, such as Andromeda V, Cassiopeia and Pegasus II, are dwarf spheroidals. There is some evidence to suggest (Einasto, Saar & Kaasik 1974) that dSph galaxies are most common close to their parent giant galaxies, whereas the more distant faint companions of giant galaxies tend to be dwarf irregulars. Available data also hint at the possibility that the dSph galaxies that are situated closest to the Milky Way may, on average, have formed stars earlier than those dwarf spheroidals that are located at greater distances from the Galaxy. Most dwarf spheroidals appear to have had a complex evolutionary history. The Draco and Ursa Minor systems both experienced most of their star formation $\sim$ 15 Gyr ago. In Leo II the peak rate of star formation occurred $\sim$ 9 Gyr ago, and in Carina it took place $\sim$ 7.5 Gyr ago. Finally the peak rate of star formation in Leo I appears to have taken place only $\sim$4 Gyr ago. The Phoenix and Pisces dwarfs are examples of dwarf dIr/dSph galaxies in which some star formation is still taking place at the present time. It is not yet clear how some dwarf spheroidals were able to retain their gas over a Hubble time. The fact that the mean periods of the Bailey type ab RR Lyrae stars in Draco, Fornax, Sculptor etc. fall in the range $0.55 < \mathrm{P(days)} < 0.65$, while these variables in Galactic globular clusters have either $< P_{ab} > \approx 0.55$ or

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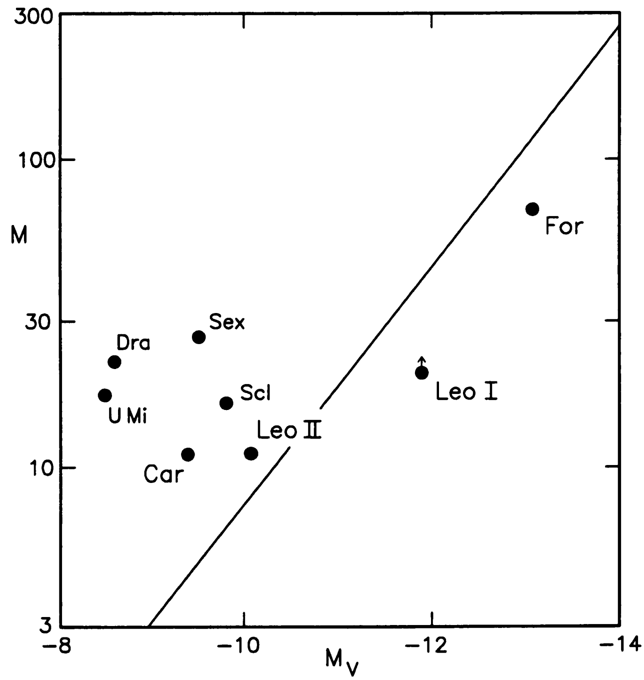

Figure 3. Visual absolute magnitude M_V versus virial mass (in units of 10^6 $M_\odot$) for dwarf spheroidal galaxies. Note that the least luminous dSph M galaxies have the highest mass-to-light ratios. Furthermore, known dSph galaxies exhibit a sharp lower mass cut-off at 1×10^7 $M_\odot$. The sloping line shows the locus of points with $M/L_V = 10$ in solar units.

$< P_{ab} > \approx 0.65$. This also shows that the oldest populations in the Galaxy and in dwarf spheroidals had different evolutionary histories.

Figure 3 shows a plot of virial masses of dwarf spheroidal galaxies as a function of their visual absolute magnitudes. This plot shows that (1) the least luminous dSph galaxies have the highest mass-to-light ratios, and (2) that there is a sharp cut-off in the masses of dSph galaxies at $M = 1 \times 10^7$ $M_\odot$. Both of these effects might be due to the fact that supernova shells and stellar winds will be able to expel gas from low-mass galaxies that do not have deep potential wells. Perhaps globs of dark matter with masses $< 1 \times 10^7$ $M_\odot$ exist, but were not able to retain (or capture) gas. Observational selection effects would prevent us from ever discovering such dark galaxies that never formed stars.

None of the known dSph galaxies fainter than $M_V = -12$ contains any globular clusters. By combining the observations of all of these objects one finds that one can exclude a specific globular cluster frequency S = 20 for these faint objects at the 98.5% confidence limit. Similarly a Kolmogorov-Smirnov test only excludes a mean value S = 5 at the 65% confidence level. These observations suggest that the Fornax system, which has the very high value S $\approx$ 29, must have had an unusual evolutionary history. The four globular clusters associated with the Sagittarius system have a bi-modal luminosity distribution, with one very luminous cluster (NGC 6715, with $M_V = -9.96$) and four faint globulars with $M_V > -6.0$. This bi-modal luminosity function is reminiscent of that of the outer Galactic halo beyond $R_{GC} = 70$ kpc. This raises the question whether the Sgr dwarf may be a Searle-Zinn (1978) fragment that has been captured into a relatively short-period orbit by the LMC + SMC.

9. Problems for the Future

The Local Group presents us with a number of important unanswered problems:

• If the Local Group is a typical region of the Universe then it must once have contained the "boojums" (Babul & Ferguson 1996) that are presently observed at $0.5 < z < 1$. Which Local Group galaxies could once have been such luminous blue galaxies?
• Armandroff and Karachentsev have recently discovered a number of nearby low-luminosity galaxies. This suggests that many more faint new Local Group members remain to be discovered. However, Irwin (1994) reports finding only a single new dwarf galaxy in a survey of 20 000 square degrees at high Galactic latitude. The question "does the faint end of the Local Group luminosity function continue to rise steeply towards very faint luminosities?" therefore remains to be answered.
• It would be interesting to know if the lower limit of $1 \times 10^7 M_\odot$ found for the masses of dwarf spheroidals is entirely due to observational selection effects, or if it represents a real lower limit to the masses of globs of dark matter.
•The Large Magellanic Cloud and M33 are both late-type galaxies that have comparable luminosities. It is therefore puzzling that all of the LMC globular clusters appear to be very old and located in a disk, whereas the M33 globulars are halo objects that appear to have formed at a somewhat later time.

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Discussion

Gallart: I would like to know your opinion about how we should name the new galaxies that are being found in the Local Group and that we suspect may be associated with the Andromeda galaxy? Should we follow the And # notation or rather use the name of the constellation?

Van den Bergh: I think that this is a question for the IAU Committee on nomenclature to settle. My inclination would be to name the close, probably physical, satellites And I, And II and And III, while the more distant ones that belong to the Andromeda sub-group might be named by the constellation in which they occur.

Armandroff: I was interested in your suggestion that NGC 147 and NGC 185 form a binary system. You gave the radial velocity difference and the separation on the sky. What do the distance determinations say about the association?

Van den Bergh: The error bars on their RR Lyrae distances overlap.

Lynden-Bell: I have been in astronomy so long that I don't really believe astronomical distances are much good. I am very doubtful that the SMC is a very long object pointed at us. Elongations of 2 to 1 or 3 to 1 seem not unlikely; 5 to 1 or more seem most unlikely.

Van den Bergh: Donald, I think that I'm older than you, but not quite as cynical about the Cepheid distances. Since their metallicities are similar and typical reddening values small, I would tend to believe the results by Mathewson et al. and more recent investigators.

Gurzadyan: Are there any peculiarities observed in the properties of the two subgroups of galaxies - of Milky Way and that of M31?

Van den Bergh: The samples are small, but there seem to be no systematic differences except that M31 has three spheroidal companions (NGC 147, NGC 185 and NGC 205). Also the Galactic Subgroup contains the LMC and SMC, which have no M31 Group counterparts.

Freeman: On the coevality of clusters all over the Milky Way: did I pick up a hint that you believe clusters formed near apogalacticon? If yes, are there arguments why this should be so?

Van den Bergh: The large diameters of true halo globulars shows that they cannot be objects that formed in the inner halo and were subsequently ejected.

Cannon: (1) Do any of the M31 dSph galaxies contain globular clusters like those in Fornax? (2) You mentioned the 2 pairs of very similar galaxies in the Local Group. Are there any such similar "binary" pairs in other nearby groups of galaxies?

Van den Bergh: (1) Taft Armandroff tells me that And V and And VI have no associated globulars. (2) Many years ago Erik Holmberg also found a similar trend for binary pairs to often have similar morphological types.

Whitelock: I am surprised you have a different explanation for the difference between the RR Lyraes and Cepheids in the SMC and in the LMC. Would you like to say more about this?

Van den Bergh: Bill Kunkel made the reasonable suggestion at IAU 190 that *some* of this difference in the SMC might be due to the fact that Cepheids occur in both the main body and in the tidal tail of this object, while the RR Lyrae stars are expected to be centered on the main body of the Small Cloud. *All* of the differences in the LMC must be intrinsic because there is no reason to assume that there is any systematic difference between the distances of LMC Cepheids and RR Lyrae stars.

Laney: It's not only true that the Cepheid magnitudes show greater dispersion in the SMC, but also that the *BVI* reddenings in the SMC show such small dispersion that the dispersion in metallicity in SMC Cepheids must be quite low. Hence it's hard to see how the dispersion in SMC Cepheid magnitudes can be interpreted except in terms of an SMC that is really extended in the line of sight.

Van den Bergh: I think that Bill Kunkel would say that there are Cepheids in both the main body of the SMC and in the tail behind it. However, the RR Lyrae stars might be centered only on the main body of the SMC.

Terndrup: In both the LMC and the SMC, you quoted the difference in distance modulus derived from the RR Lyr and the Cepheids. Is this difference in the same sense and of the same magnitude in both Magellanic Clouds?

Van den Bergh: Yes! If either the Cepheid or the RR Lyrae calibrations are wrong this could account for the difference in the moduli.