

Discs of satellites: the new dwarf spheroidals

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ABSTRACT

The spatial distributions of the most recently discovered ultra-faint dwarf satellites around the Milky Way and the Andromeda galaxy are compared to the previously reported discs-of-satellites (DoS) of their host galaxies. In our investigation, we pay special attention to the selection bias introduced due to the limited sky coverage of Sloan Digital Sky Survey (SDSS). We find that the new Milky Way satellite galaxies follow closely the DoS defined by the more luminous dwarfs, thereby further emphasizing the statistical significance of this feature in the Galactic halo. We also note a deficit of satellite galaxies with Galactocentric distances larger than 100 kpc that are away from the DoS of the Milky Way. In the case of Andromeda, we obtain similar results, naturally complementing our previous finding and strengthening the notion that the DoS are optical manifestations of a phase-space correlation of satellite galaxies.

Key words: galaxies: dwarf – Local Group.

1 INTRODUCTION

In recent years, a new class of ultra-faint companion galaxies with extremely low stellar densities were detected in the halo of the Milky Way (MW)¹ (Willman et al. 2005a,b; Sakamoto & Hasegawa 2006; Zucker et al. 2006a,b; Belokurov et al. 2006, 2007; Walsh, Jerjen & Willman 2007; Belokurov et al. 2008) by systematically scanning the Sloan Digital Sky Survey (SDSS)-DR6 photometric catalogue (York et al. 2000), more than doubling the number of known satellite galaxies within the virial radius of the MW. At the same time, new companions of the MW's sibling, the Andromeda galaxy (M31), were found via deep imaging (Martin et al. 2006; Zucker et al. 2007; Majewski et al. 2007; Ibata et al. 2007; Irwin et al. 2008; McConnachie et al. 2008).

The most luminous MW satellite galaxies have been known for more than three decades to exhibit an anisotropic spatial distribution (e.g. Lynden-Bell 1976, 1983; Majewski 1994; Hartwick 2000). The quantitative exploration of this phenomenon found that the dwarf galaxies lie close to a virtual plane, the disc-of-satellites (DoS), highly inclined with respect to the stellar disc of the MW (Kroupa, Theis & Boily 2005; Metz, Kroupa & Jerjen 2007, hereafter MKJ07; Li & Helmi 2008). Subsequent studies of kinematical data, radial velocities and proper motions (Lynden-Bell & Lynden-Bell 1995; Palma, Majewski & Johnston 2002) revealed that a correlation is apparent not only in their three-dimensional distribution, but also as a possible common motion, such that the DoS is likely a rotationally supported structure (Metz, Kroupa & Libeskind 2008).

The satellite system of Andromeda shows an asymmetric spatial pattern too (Grebel, Kolatt & Brandner 1999; Hartwick 2000;

Koch & Grebel 2006; Majewski et al. 2007). As for the MW, DoS is evident (MKJ07), and the entire satellite system is significantly shifted in the direction of the barycentre of the Local Group (McConnachie & Irwin 2006). It remains unclear whether this structure is also rotationally supported. Proper motion data are only available for two M31 companions, M33 and IC 10, from VLBI observations of water masers (Brunthaler et al. 2005, 2007), but van der Marel & Guhathakurta (2008) concluded that a possible intrinsic rotation of the satellite system is marginal from their statistical analysis. Also, no direct proper motion measurement is available for Andromeda itself, but various attempts have been made to constrain the possible transverse motion of M31 based on statistical properties of the motion of its satellite galaxies (e.g. Einasto & Lynden-Bell 1982; van der Marel & Guhathakurta 2008) or the persistence of the stellar disc of M33 under the assumption that it is on a bound orbit to Andromeda (Loeb et al. 2005).

This paper is to follow up the previous work by MKJ07, supplementing the data with more recent findings: the 11+11 newly discovered dSph satellite galaxies of the MW and Andromeda are added to the sample and compared to the proposed DoS in Section 2. For the MW, a statistic is derived to calculate the probability to find satellite galaxies away from a given reference plane, taking the sky coverage region of SDSS into account, and applied to the most recent discoveries. The results are discussed in Section 3.

2 SPATIAL DISTRIBUTION OF THE NEW SATELLITES

2.1 The Milky Way satellites

In MKJ07, we showed that the satellite galaxies of the MW are arranged in a pronounced disc-like distribution, the DoS. The

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¹ The discovery of the CVn II dSph was reported twice, by Sakamoto & Hasegawa (2006) as a Letter and by Belokurov et al. (2006).

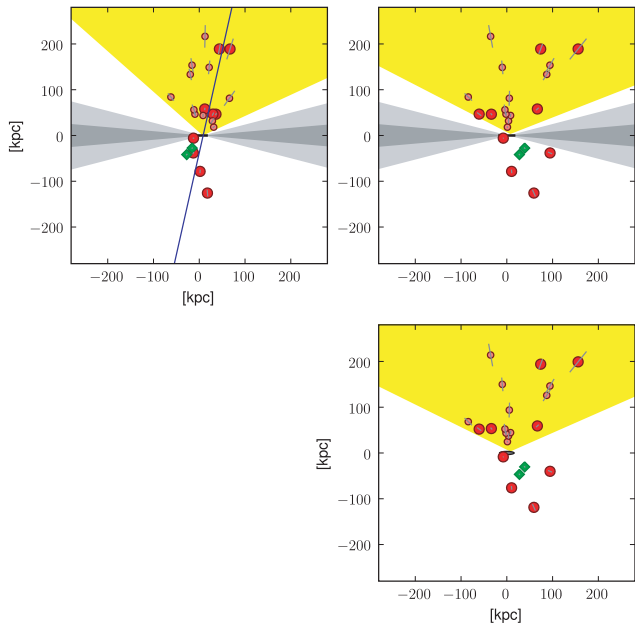


Figure 1. The 3D distribution of the MW satellite galaxies. In the top-left panel, an edge-on view on to the fitted DoS as given in MKJ07 is shown, derived using the large circles and diamonds. The MW disc, located in the centre of the plot, is seen edge-on. In the top-right panel, a view rotated by 90° about the polar axis of the MW is shown, and in the lower-right panel a face-on view on to the fitted disc is plotted. The Magellanic Clouds are marked by diamond symbols, the dwarf spheroidals by circles, whereby the smaller circles mark the newly discovered satellites (Table 1). Uncertainties are indicated by light grey sticks. In addition, the obscuration region, $|b| < 5^\circ$, of the MW is shown as the dark-shaded region (the light-shaded region being the 15° obscuration region). The *projected* northern sky coverage region of the SDSS is indicated by the yellow-coloured area.

direction of the normal vector of the disc is $l_{\text{MW}} = 157^\circ.3$, $b_{\text{MW}} = -12^\circ.7$, i.e. the DoS is almost perpendicular to the Galactic plane, and the closest distance from the Galactic centre is $D_p = 8.3$ kpc. The derived rms height of the disc is $\Delta = 18.5$ kpc, such that $\Delta/R_{\text{vir}} = 0.15$ is the relative thickness of the disc, where $R_{\text{vir}} = 250$ kpc is the approximate virial radius of the MW. The analysis was carried out for the ‘classical’ 11 brightest satellite galaxies. The different projections of the 3D distribution of the MW satellites are shown in Fig. 1 relative to the DoS. All objects recently discovered in SDSS (Table 1) were added to the plot as smaller circles. The projected northern sky coverage region of the SDSS is highlighted by the shaded (yellow) area.

All but one of the newly reported satellite galaxies of the MW are found close to the DoS (Table 1). The Hercules (Her) dwarf spheroidal, the left-most data-point marked by a small circle in the top-left panel of Fig. 1, is 87 ± 8 kpc away from the DoS at a Galactocentric distance of 134.2 kpc. Without Her, the improved fitting results are basically identical to the MKJ07 fit: $(l_{\text{MW}}, b_{\text{MW}}) = (159^\circ.7, -6^\circ.8) \pm 2^\circ.3$, $D_p = 6.7 \pm 1.3$ kpc and $\Delta = 24.9 \pm 1.1$ kpc, 1σ uncertainties were calculated using a Monte Carlo method. Including Her, the rms thickness increases to $\Delta = 28.5 \pm 1.2$ kpc and the direction of the normal of the fitted plane is $(l_{\text{MW}}, b_{\text{MW}}) = (149^\circ.6, -5^\circ.3) \pm 2^\circ.2$.

The bootstrap analysis described in detail in MKJ07 is repeated, now also incorporating the additional 11 new MW satellites. The resulting shape and strength parameter are $\gamma = 1.5$, $\zeta = 5.0$. These two parameters describe the distribution of normals fitted to the

Table 1. Galactocentric coordinates of the seven ultra-faint MW satellite galaxies reported in the last three years. Four extra objects are listed where the classification as dSph or globular cluster is still uncertain, i.e. UMa II, Willman I, CBe and Boo II. In the fourth column, the orthogonal distances from the DoS are tabulated (see table 1 in MKJ07 for a listing of all the other MW satellites).

Name	$l_{\text{MW}} (^\circ)$	$b_{\text{MW}} (^\circ)$	R (kpc)	d_{DoS} (kpc)
UMa II ^(a)	159.6	+30.0	36.5	18.5
Wil I ^(b)	164.7	+47.7	43.0	12.7
CBe ^(c)	201.8	+75.1	45.2	9.8
Boo II ^(d)	348.1	+78.4	47.6	27.7
Boo ^(e)	356.6	+77.5	57.6	32.0
UMa ^(f)	162.0	+50.8	104.9	38.3
Her ^(c)	30.9	+38.8	134.2	87.2
CVn II ^(c,g)	132.7	+80.9	150.7	19.8
Leo IV ^(c)	260.0	+56.2	160.6	56.7
Leo V ^(h)	256.8	+58.1	180.8	57.3
CVn ⁽ⁱ⁾	86.9	+80.2	219.8	43.4

References: ^(a) Zucker et al. (2006a); ^(b) Willman et al. (2005a); ^(c) Belokurov et al. (2006); ^(d) Walsh et al. (2007); ^(e) Belokurov et al. (2006); ^(f) Willman et al. (2005b); ^(g) Sakamoto & Hasegawa (2006); ^(h) Belokurov et al. (2008) and ⁽ⁱ⁾ Zucker et al. (2006b).

bootstrapped samples on the sky: the higher the shape parameter γ , the more symmetric the distribution, and higher values of the strength parameter ζ indicate more concentrated distributions. If Her is excluded from the bootstrapping, we find $\gamma = 1.9$, $\zeta = 5.0$. Even though Her is well away from the DoS, the result of the bootstrapping analysis remains unaffected. The values are shown in Fig. 2 where the confidence contours are plotted for the null hypothesis that the satellite galaxies were drawn from an isotropic parent distribution. The random samples are set up to resemble the

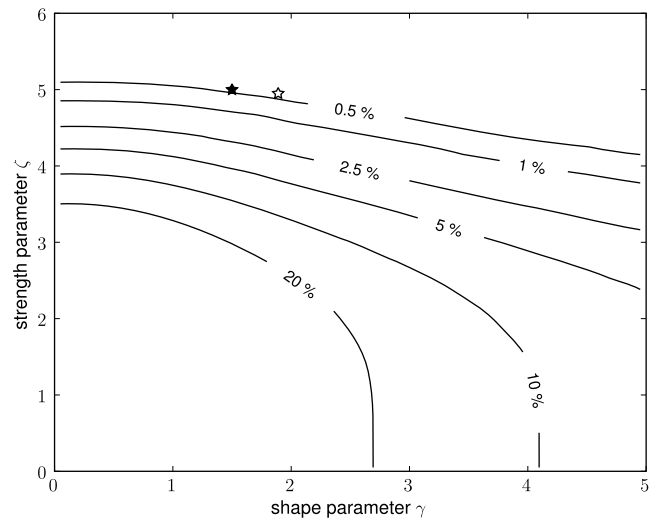


Figure 2. Samples of satellite galaxies were constructed from a spherical isotropic random distribution taking into account (i) the obscuration due to the MW disc and (ii) the influence of the SDSS sky coverage area. The strength parameter γ and shape parameter ζ were derived for 100 000 random samples each individually bootstrapped 10 000 times (see text for a definition of γ and ζ). The plot shows contour lines of enclosed values with significance levels α as labelled. The filled star marks the value for all MW satellites, the open star marks the Hercules dwarf galaxy. The null hypothesis that the MW satellites are drawn from a random sample is rejected at the $(1 - \alpha) = 99.5$ per cent confidence level.

observed satellite galaxies of the MW: what is new in our approach here is that we take into account two observational constraints: (i) the Zone of Avoidance is accounted for by not allowing any satellite to have Galactic latitude $|b| < 15^\circ$. The 11 classical satellite galaxies are set up with this bias only. (ii) The SDSS sky coverage is accounted for by allowing only satellites with $b > 30^\circ$ for the remaining ones. The null hypothesis is rejected at the $(1 - \alpha) = 99.5$ per cent confidence level. This clearly shows that, even though the updated DoS is somewhat ‘thicker’ than for the classical satellites alone, the currently known MW satellite galaxies are highly unlikely drawn from an isotropic distribution (cf. MKJ07).

2.2 The effect of the SDSS sky coverage

The SDSS survey area covers about 20 per cent of the total sky, being merely a spherical cap at the Galactic North Pole with $b \gtrsim +30^\circ$, except for three narrow stripes in the southern Galactic sky. Certainly, this observational bias must have an influence on the derived spatial distribution of the satellite galaxies discovered in the SDSS data. Especially, since the DoS is almost perpendicular to the MW plane, the probability of finding satellite galaxies in the polar region close to the DoS is higher than at low Galactic latitudes.

One can now ask what the probability is to find a satellite galaxy at an orthogonal distance d from the DoS. For any given fixed plane at a distance $0 \leq D_p < R$ from the Galactic centre, the probability to find a satellite galaxy at a distance d perpendicular to this plane for a spherical isotropic parent distribution can be analytically expressed. The derived distribution function (DF), $F_R(d)$, is *independent* of the radial density DF of the satellite galaxies. For a cone-like region ($b > b'$) about an axis parallel to the reference plane, as in the case of SDSS, the DF $F_{R,b>b'}(d)$ can also be written down, but needs numerical integration. An important point to note is that the DF rises more steeply for the cone coverage area than for a full-sky (or full hemisphere) coverage area. This means that it is more likely to discover a satellite galaxy close to the DoS when only a polar cap is observed as is done for the SDSS. For example, at $R = 60$ kpc the probability to find an object at a distance $d = 25$ kpc from the DoS increases by 13 per cent from $F_{R=60}(25) = 0.42$ to $F_{R=60,b>+30}(25) = 0.55$.

The derived DF for a cone region is, strictly speaking, correct only for a plane parallel to the axis of symmetry. The fact that the DoS is tilted with respect to this axis by 12.7° introduces a correction factor of the order of 2 per cent, $\cos(12.7^\circ) \approx 0.98$, that will be neglected here. Also, the SDSS coverage region is not a perfect cone symmetric with respect to the Galactic North Pole (compare also fig. 1 in MKJ07), but only approximately so.

The probability that a satellite is found in the SDSS catalogue at its derived distance d or closer to the DoS is plotted in Fig. 3 for $D_p = 3.3$ kpc, which is the offset of the DoS from the Sun (as the Sun is at the vertex of the cone-like SDSS sky coverage region). For an isotropic distribution, these values are expected to be uniformly distributed. For objects with $R < 100$ kpc, the probabilities are consistent with a uniform distribution, but for the new dwarf spheroidals with $R > 100$ kpc only Hercules is found in the upper region. In contrast, five of the outer dSph have $F < 0.5$.

It is important to recall that $F_{R,b}(d)$ describes a property of the sky coverage area and does not tell anything about the true spatial distribution of the satellite galaxies. Consider, for example, a sky coverage region of only 10° about the North Pole. All satellite galaxies found in such a region must be very close to a polar DoS independent of whether they are highly an-isotropically distributed or not, and the DF may easily have values of the order of 1. Never-

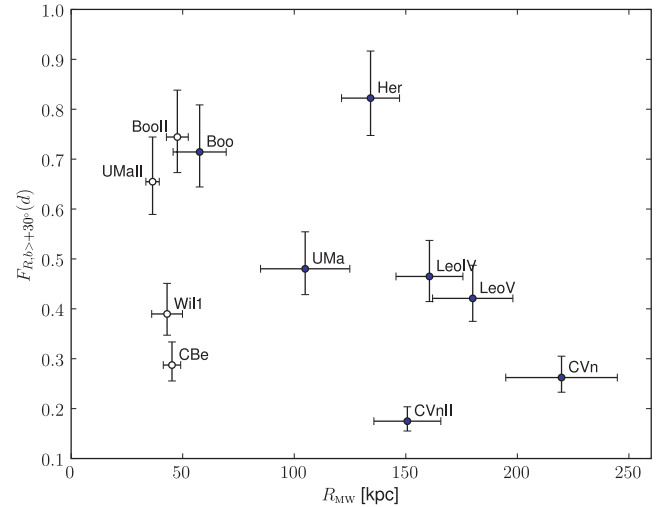


Figure 3. The probability that a satellite galaxy is found in the SDSS at its derived distance d or closer to the DoS versus their Galactocentric distance R . Galactocentric distance uncertainties were calculated from Heliocentric distance uncertainties as taken from the literature. Uncertainties in the $F_R(d)$ parameter were computed by considering sky coverage areas of $b > 20^\circ$ and $b > 40^\circ$, respectively. Open symbols mark objects where the classification as a dSph or disrupted globular cluster is uncertain.

theless, from Fig. 3 we can conclude that there is a deficit of satellite galaxies far off the DoS at galactocentric distances $R > 100$ kpc.

It is worthwhile to consider that those objects marked with open symbols are likely strongly influenced by tides (Gilmore et al. 2008; van den Bergh 2008). If they came close to the Galactic disc, they are also likely prone to precession in the non-spherical potential induced by the Galactic disc or to scattering events (Zhao 1998; Peñarrubia, Kroupa & Boily 2002). Only for the Böotes dwarf at $R = 57.6$ kpc, there seems to be a general agreement that it has to be classified as a dSph; its total luminosity is about 10 times higher than for all the other objects with $R < 100$ kpc. If the other four objects, UMa II, Willman I, CBe and Boo II, are not dSphs, they may also have a completely different parent distribution. Interestingly, also the Her dSph has been strongly affected by tides (Coleman et al. 2007). If this is due to a recent close perigalactic passage, the orbit of Her might have been influenced by the MW disc, thus possibly causing a drift of the orbit out of the DoS if it were within before.

2.3 The Andromeda galaxy

For the Andromeda satellites, we performed the same steps as for the MW. The recently discovered companions listed in Table 2 were added to the sample and are plotted in Fig. 4 with respect to the Andromeda DoS as given in MKJ07. For this figure, the data set taken from McConnachie & Irwin (2006) is used and supplemented with data as given in Table 2. Again, most of the recently discovered satellite galaxies are found close to the previously fitted DoS. This is particularly remarkable as the Andromeda system is much less affected by foreground obscuration due to the disc of the MW (McConnachie & Irwin 2006), and it is also not as biased as is the MW system towards the Galactic North Pole region. Only the two Andromeda companions reported very recently (McConnachie et al. 2008) lie off the disc, whereas the third one, And XVIII at $R_{M31} = 589$ kpc and thus outside the virial radius of Andromeda, is again found close to the M31 DoS. As for the

Table 2. Positions of the recently discovered Andromeda dSph satellite galaxies in Andromeda-centric coordinates as defined in MKJ07 and their distances to the M31 DoS. Heliocentric coordinates and distances were taken from the respective discovery works, the assumed distance to Andromeda used for the transformation is 785 kpc (McConnachie & Irwin 2006). And XI–XIII were all assumed to be located at a common Heliocentric distance and thus appear to be clustered (see also Fig. 4), which may in reality not be valid. We also list And XVIII here for completeness, but with a distance of 589 kpc this galaxy is well outside the virial radius of M31.

Name	l_{M31} (°)	b_{M31} (°)	R_{M31} (kpc)	d_{DoS} (kpc)
And XVII ^(a)	90.6	56.5	45	4
And X ^(b)	139.8	−16.7	110	46
And XII ^(c)	314.2	−30.6	117	3
And XI ^(c)	310.8	−30.3	124	8
And XX ^(d)	269.5	13.8	129	116
And XIII ^(c)	312.3	−37.6	136	5
And XIV ^(e)	250.6	−48.2	162	20
And XV ^(f)	172.8	−36.9	176	33
And XIX ^(d)	316.9	9.5	188	79
And XVI ^(f)	189.7	−27.8	281	27
And XVIII ^(d)	356.9	31.7	589	61

References: ^(a) Irwin et al. (2008); ^(b) Zucker et al. (2007); ^(c) Martin et al. (2006); ^(e) Majewski et al. (2007); ^(f) Ibata et al. (2007) and ^(d) McConnachie et al. (2008).

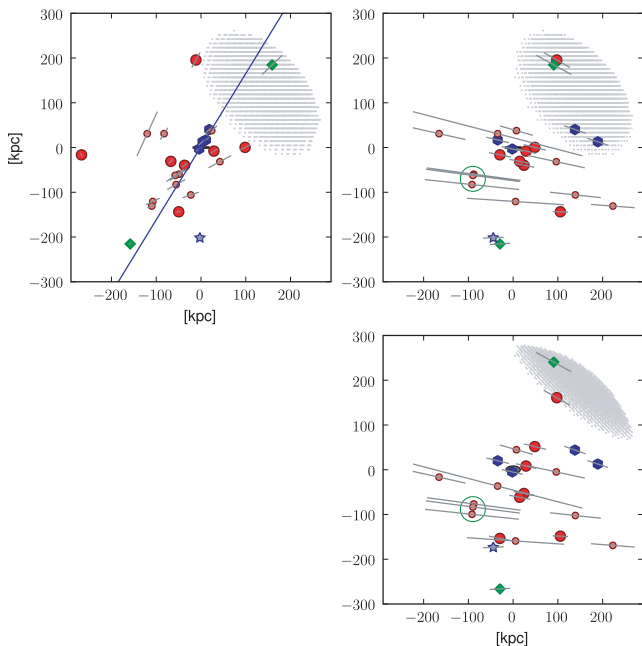


Figure 4. The 3D distribution of Andromeda satellite galaxies as in Fig. 1 for the MW. Galaxy types are indicated as follows: dIrr galaxies are marked by diamonds, dEs by hexagons and dSphs by circles, smaller circles marking the newly discovered dSphs. The location of M33 is marked by the star symbol. The light grey sticks are distance 1σ uncertainties of the satellites only. The grey-shaded area indicates the projected region where potentially some satellite detections may be hindered by foreground MW structure (see also McConnachie & Irwin 2006). A group of satellite galaxies, consisting of And XI, XII and XIII, is marked by a light circle. These dSph were assumed to all have the same heliocentric distance.

MW, incorporating the data of all the newly discovered dSphs to the fitting methodology of MKJ07 has only a marginal influence on the fitting parameters: $l_{M31} = 60^{\circ}.2$, $b_{M31} = -30^{\circ}.7$, $D_P = 15.6$ kpc and $\Delta = 45$ kpc, whereby the strongest effect is caused by those two outlying satellites, And XIX and XX. Without them, we find $l_{M31} = 70^{\circ}.2$, $b_{M31} = -32^{\circ}.9$, $D_P = 1.7$ kpc and $\Delta = 39.2$ kpc, compared to the results as previously derived in MKJ07: $l_{M31} = 73^{\circ}.4$, $b_{M31} = -31^{\circ}.5$, $D_P = 1.0$ kpc and $\Delta = 45.9$ kpc (l_{M31} and b_{M31} are the longitudes and latitudes of the pole of the fitted DoS in the Andromeda centric coordinate system as defined in MKJ07.).

The proximity of the dwarf spheroidals to the M31 DoS is in particular not strongly influenced by the still uncertain distances to them which are of the order of 10 per cent, as the DoS of M31 is seen nearly edge-on from the Sun. Thus, a large distance uncertainty only marginally influences their perpendicular distance to the DoS (see the indicated line-of-sight distance uncertainties in the top-left panel of Fig. 4). Thus, also the apparent grouping of And XI, XII and XIII, marked by the light circle, which is caused by their assumed common heliocentric distance (Martin et al. 2006), is not biasing the finding that these satellites are close to the M31 DoS.

3 CONCLUDING REMARKS

In Fig. 1, the biasing due to the sky-coverage area of the SDSS is obvious. Nevertheless, there are remarkably large portions of the sky that are way off the DoS – but no satellite galaxies are reported to be located there (top-left panel in Fig. 1). Especially at large Galactocentric distances, $R > 100$ kpc, there is a deficit of satellites far off the DoS (Fig. 3). The same is true for the Andromeda system, which is much less influenced by obscuration: only the two most recently reported Andromeda companions (McConnachie et al. 2008) are not found close to the disc, but eight are found very close to the DoS. Majewski et al. (2007) noted that along a radial vector from the centre of M31, connecting NGC 147 and And XIV, in total six satellite galaxies are located in projection, and Irwin et al. (2008) found that And XVII is also on that line. We demonstrated that the new dSphs lie on a straight line not only in projection, but taking their full three-dimensional data into account, we find that they belong to the same DoS as reported in our previous work (MKJ07). This holds true despite large distance uncertainties.

It appears highly unlikely that the DoS for the two dominant galaxies in the Local Group are the result of observational biases. The bootstrapping analysis shows, taking the biasing effects due to the SDSS sky coverage area into account, that it can be excluded at a very high significance level of 99.5 per cent that the MW satellites are drawn from an isotropic distribution, even then when we include the outlying satellite Hercules. At the same confidence level, it has been excluded that the classical 11 MW satellites are drawn from an isotropic distribution (MKJ07). The findings presented here strengthen the case that the DoS for both the MW and Andromeda are real and evidence of a spatial (and kinematical: Lynden-Bell & Lynden-Bell 1995; Palma et al. 2002; Metz et al. 2008) correlation of the satellite galaxies. We emphasize that it has been found that the orbital angular momenta of the innermost classical satellites point in a direction close to the pole of the DoS (Metz et al. 2008), which itself is mostly defined by the outer satellites, now including also the new discoveries. This suggests a strong phase–space correlation of the satellites.

Different solutions have been proposed to account for the satellite galaxies of the MW in the context of them being cold dark matter (CDM) substructures. A strong central clustering of subhaloes that mimics a ‘thin’ DoS distribution (Kang et al. 2005;

Zentner et al. 2005) is unlikely to be the explanation (MKJ07). The most massive subhaloes before accretion (Libeskind et al. 2005) do not account for the apparent rotational support of the MW DoS (Metz et al. 2008). Other solutions, not directly addressing the DoS problem, range from the most massive subhaloes (Stoehr et al. 2002) to the least massive subhaloes (Sales et al. 2007), or the earliest forming subhaloes (Strigari et al. 2007) as being the Local Group satellites. Recently, it has been proposed that infalling groups of subhaloes can account for the satellite galaxies (Li & Helmi 2008; D’Onghia & Lake 2008) or that the dwarfs form in chain structures tracing the dark matter filaments (Ricotti, Gnedin & Shull 2008). This would imply that most satellite galaxies belong to a single group that came in, or that multiple groups came in from the same direction along the intermediate-scale filamentary structure. But this direction must then have been different for the MW and Andromeda, and cannot have been the supergalactic plane. Not all of the proposed scenarios to explain the satellite galaxies as luminous dark matter dominated haloes mutually exclude each other, but it appears to be very controversial within the CDM community which are the main characteristics that make dark matter subhaloes to be luminous.

A possible alternative is that most of the satellite galaxies are of tidal origin (Zwicky 1956; Lynden-Bell 1983). If the interaction of a gas-rich galaxy with the proto-MW took place in the early Universe, a large number of tidal dwarfs would have likely been produced (Okazaki & Taniguchi 2000), that are naturally arranged in a disc-like structure: due to the conservation of angular momenta, their orbital poles are determined by the plane of the interaction. This process may also explain dwarf galaxies on similar orbits if they were formed in adjacent regions in the tails (Belokurov et al. 2008). Initially gas-rich, the TDGs may retain their gas for some time, having prolonged star formation epochs (Recchi et al. 2007), and may evolve into dSph-like galaxies we see today (Kroupa 1997; Metz & Kroupa 2007). But, it remains to be seen whether Newtonian dynamics can account for the detailed velocity DFs observed in the satellites (Łokas 2001; Gentile et al. 2007).

Recently, looking at distant host galaxies in the SDSS, Bailin et al. (2008) and Steffen & Valenzuela (2008) found for isolated blue galaxies that their satellites are, in projection, isotropically distributed (in contrast to what Holmberg 1969 originally found). The MW and M31 seem to be exceptions in this case as both have highly an-isotropic satellite distributions. It is, however, worthwhile to consider that per host typically only one single satellite is found in these studies. All of the dSphs, which build up the DoS, would not be considered in these analyses due to their faintness. That said, from a statistical point of view, the brightest satellites [Large Magellanic Cloud (LMC) or M33 type] can be isotropically distributed for a large sample of hosts. But each primary individually might well have a highly an-isotropically distributed satellite galaxy system of dSphs.

The next years will be exciting: new satellite galaxies are expected to be discovered by upcoming search campaigns such as the Stromlo Missing Satellites Survey (Jerjen 2008) – especially also at lower Galactic latitudes. If the expected ultra-faint galaxies turn out to be isotropically distributed, we are still left with the fact that the most luminous MW satellites are arranged in the DoS, whereas the low-luminous systems would be isotropically distributed. However, if they turn out to be located within the DoS, this will substantiate the suggested strong correlation of the satellite galaxies, and it will become more challenging to explain them as luminous, dark matter dominated substructures. It is quite clear that dSph satellite galaxies hold important clues not only to the physical processes

acting at early cosmological times, but also on the foundation of cosmological theory.

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