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1 Monte Carlo tests for statistical significance

To determine the best plane that fits the data it is necessary to take the distance uncertainties into account. This is accomplished as follows: first, we generate a set of 27 (three-dimensional) positions, by randomly drawing from the distance PDFs of each satellite. Subsequently, we find the plane that has the lowest root-mean-square (rms) distance to any sub-sample of $n_{sub} = 15$ satellites. By repeating 1000 times the procedure of drawing 27 satellites from their distance PDFs and calculating the lowest rms plane, we obtain a probability density function for the root mean square thickness of a possible planar sub-structure of $n_{sub} = 15$ satellites given the data. The distribution is approximately Gaussian with $\sigma = 0.6\,\mathrm{kpc}$, and mean $12.6\,\mathrm{kpc}$. The 15 satellites that are closest to the lowest rms plane are marked with red circles in Figures 1 and 2.

The next question we need to assess is: given the M31-centric distance distribution to the satellites, what is the chance that they could be arranged at random to form a planar structure with equal or lower rms? To answer this question we performed a careful Monte Carlo simulation using random realisations of satellite configurations that are isotropically-distributed in the Andromedan sky, but preserve the same distribution of radial (not projected) distances to the centre of M31 as the observed one. To achieve this, an artificial satellite is generated by selecting a satellite at random from the real set, giving it a random 3-dimensional orientation with respect to Andromeda, and assigning the same line of sight distance PDF as the real satellite has (although shifted to the new distance). If the resulting artificial satellite is located outside of the PAndAS area, or within a projected distance of $2.^{\circ}5$, it is discarded. In this way we draw a random sample of 27 artificial satellites (with replacement) which we process in an identical way as we processed the real sample:

creating a new set of 1000 rms values, from which we construct a probability density function for the rms for that particular sample of 27 artificial satellites. The whole procedure is repeated 10^5 times. The corresponding histogram of mean rms values in the artificial satellite samples is shown in Figure S1. We find that a mean rms scatter of $12.6\,\mathrm{kpc}$ or less occurs with probability 0.13%. Thus the sample of 15 satellites that is closely aligned on the great circle in Figure 2 (red circles) is indeed a highly surprising and statistically significant detection.

The above choice of $n_{sub} = 15$ members for the sub-sample size was made by examining the effect that this parameter has on the rms thickness and on the position of the best-fit plane. We find that for $5 \leq n_{sub} \leq 15$ the position of the pole to the lowest rms plane remains very stable, while the plane rms thickness increases only slowly with increasing n_{sub}. However, for values of $n_{sub} \geq 16$ the plane rms increases rapidly, and also there is no well-defined plane solution, unlike the tight solution for $n_{sub} = 15$ displayed as the background image in Figure 2. A slightly higher significance is derived by choosing an n_{sat} value of 13 or 14, as the smaller rms scatter about the plane more than compensates for the lower statistics in the sub-sample.

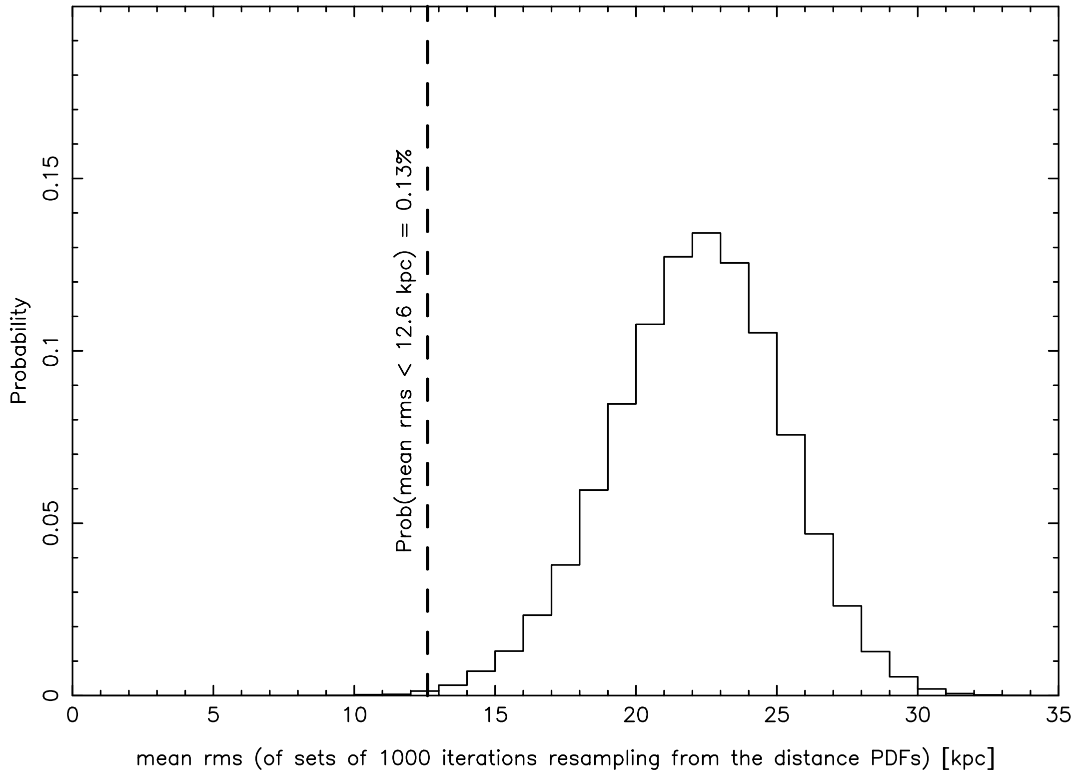

Figure S1: Statistical significance of the spatial alignment. The histogram presents the distribution in 10^5 random trials of the average root-mean-square distances from a best-fit plane of sub-samples of 15 satellites. The average rms value of $12.6\,\mathrm{kpc}$, derived from the real configuration, is extremely rare, occurring with probability 0.13% in random realisations. This demonstrates that the observed spatial alignment of dwarf galaxies is very unlikely to be a random coincidence. If we had chosen a smaller sub-sample size, the chance alignment becomes even more extreme: e.g. 0.06% for $n_{sub} = 13$.

2 The planar satellites

The co-rotating satellites are: And I, And III, And IX, And XI, And XII, And XIV, And XVI, And XVII, And XXV, And XXVI, Cas II, NGC 147 and NGC 185. The two satellites that do not partake in this motion are And XIII and And XXVII; it seems likely that these are interlopers from the normal non-planar population, although they may nevertheless be members of the planar subgroup if the population has significant velocity dispersion. Figure 1 shows that of the known M31 satellite galaxies, M32, NGC 205, LGS 3, IC 10 and IC 1613 (the latter three are situated up to 40 degrees from M31 in the directions indicated) also lie along the same axis as the red-coloured objects from our sample, and published distance estimates[28] are consistent with all five satellites being at the same distance as their host within the uncertainties. However, only LGS 3, IC 1613 and NGC 205 share the same sense of rotation as the 13 planar satellites listed above, and may plausibly be associated with the structure.

No obvious differences in the physical properties (metallicity, stellar populations or velocity dispersion) were found between the 13 kinematically-coherent coplanar satellites and the remainder of the sample.

References

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