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Anisotropies of the satellite systems around the Milky Way and Andromeda

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Abstract. We have studied the distribution of dwarf-galaxy satellite systems around our Milky Way (MW) and the Andromeda (M31) galaxy. The anisotropy is quantified and the form of their distribution is found to be incompatible with that expected if they were cold-dark-matter sub-structures. The origin of these satellites therefore can not be cosmological. Rather the Milky Way and Andromeda satellites probably stem from a local evolutionary mechanism.

Keywords. Galaxy: evolution, Galaxy: halo, galaxies: dwarf, galaxies: formation

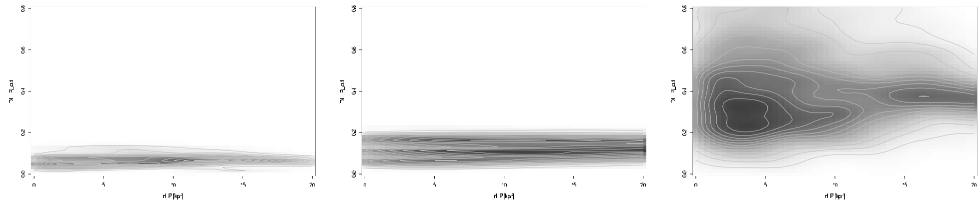
1. Introduction

CDM models predict about 500 dark matter dominated subhalos for Milky Way-type systems within a radius of 500 kpc. The distribution of these subhalos follows the density of the dark matter halo of their host galaxy. However, only 13 dwarf galaxies within 500 kpc have been found for the Milky Way and 15 for Andromeda respectivly. The *missing satellite problem* cannot be solved entirely by invoking baryonic processes (Kazantzidis *et al.* 2004). Furthermore, Kroupa *et al.* (2005) argue that the distribution of the MW satellites differs from what one would expect if these are CDM sub-structures. Instead the distribution of the MW satellites is highly unisotropic and can well be described by a planar-like distribution. Here we continue this work by performing a much more robust statistical analysis of both, the Milky Way and Andromeda satellite systems.

2. Algorithm

We have implemented a fitting routine which is an unweighted Algebraic Least-Squares Estimator (see Chojnacki *et al.* 2000)† similar to the method Hartwick (2000) used. Furthermore we now use some more advanced statistical methods: (1) a bootstrap method to investigate the stability of the fitted plane. If the origin of the distribution were NOT disc-like this would show up in a large scatter of the direction of the normal vectors of the fitted planes. (2) For analysis we use some quantities known from statistical analysis of spherical data (Fisher *et al.* 1987): (i) shape- and strength-parameter γ, ζ, (ii) an approximate confidence cone and (iii) a relative RMS-height Δ and Δ/R_{cut} as in Kroupa *et al.* (2005). We performed tests against random samples drawn from a spherical isotropic

† We used Python, Numeric and SciPy for the implementation. It is important to compare only results derived with identical fitting algorithms, because results may strongly depend on the algorithm used. All routines are available online: `http://www.astro.uni-bonn.de/~mmetz/`.



(a) MW (b) M31 (c) random sample

Figure 1. Density plot of $\Delta/R_{\rm cut}$ against $d_{\rm P}$ for for 5 000 bootstrap samples for 11 MW satellites (out to Leo I), 12 M31 satellites (out to LGS 3) and a random sample of 11 satellites

distribution with radial density profiles following a power-law $\propto r^{-p}$, (p =2,2.5) and a Burkert-profile (Burkert 1995).

3. Results and Conclusions

For the analysis we use data as given in Kroupa *et al.* (2005), McConnachie *et al.* (2005) and Grebel *et al.* (2003) and fitted planes to 5 000 bootstrap samples. The principal axes and opening angles of an approx 95% confidence cone are: $(l,b)_{\rm MW} = (158°, -12°)$, (0.3°,0.2°) and $(l,b)_{\rm M31} = (77°, -32°)$, (0.9°,0.3°). *It is remarkable that both satellite planes are highly inclined relative to the plane of the host galaxy.* We derive the following mean thickness ratios for the MW $\langle\Delta/R_{\rm cut}\rangle = 0.07$ and for M31 $\langle\Delta/R_{\rm cut}\rangle = 0.16$. In Fig. 1 $\Delta/R_{\rm cut}$ is plotted against distance $d_{\rm P}$ of the fitted plane from the center of their host. The large scatter in $\Delta/R_{\rm cut}$ is a clear indication for a not planar like origin of the random sample.† We have compared the shape parameters γ and ζ with random samples. We give the combined propability to find larger values for both parameters compared to 10 000 × 5 000 bootstrap samples drawn from random samples with radial density $\propto r^{-2}$. That is the propability for the normals to be more stable than the observed ones: $p_{\rm SP}^{\rm MW} = 0.6\%$ and $p_{\rm SP}^{\rm M31} = 17\%$. Tests performed with random samples with different radial densities ($\propto r^{-2.5}$, Burkert profile) show no significant difference.

With highly robust statistical methods we have shown that the propability of finding a distribution of 11 satellites like those of the MW drawn from a spherical isotropic distribution is less than 0.6%, for M31 less than 17%. The propabilities would be even lower if the MW/M31 dark matter halos are oblate and coplanar to the galactic disks. In addition, the observed distributions are remarkably thin for the MW and M31, confirming our interpretation of the MW and M31 satellite distributions in terms of disk-like systems.

References

Burkert, A. 1995, *ApJ* 447, L25

Chojnacki, W., Brooks, M., van den Hengel, A. & Gawley, D. 2000,*IEEE Transactions on pattern analysis and machine intelligence*, 22, 1294

Fisher, N., Lewis, T. & Embleton, B. 1987, Statistical analysis of spherical data (Cambridge University Press)

Grebel, E.K., Gallagher, J.S. & Harbeck, D. 2003, *Astronomische Nachrichten Suppl.* 324, 90

Hartwick, F.D.A. 2000, *AJ* 119, 2248

Kroupa, P., Theis, C. & Boily, C.M. 2005, *A&A* 431, 517

McConnachie, A.W., Irwin, M.J., Ferguson, A.M.N. *et al.* 2005, *MNRAS* 356, 979

† We note that tests showed that the ALS algorithm is not very sensitive for deriving the distances of planes which to some extend explains the spread in $d_{\rm P}$.

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