The Vast Polar Structure of the Milky Way

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The Vast Polar Structure (VPOS)

(Pawlowski et al. 2012a)

The Milky Way (MW) is surrounded by numerous satellites: dwarf galaxies, globular clusters and streams of disrupted systems. The 'classical' (bright) satellite galaxies, the faint ones detected in the SDSS and globular clusters classified as young halo objects (YH GCs) are all unevenly distributed. Each sample can be described by essentially the same plane, highly inclined to the MW disc. Together, these objects form a vast polar structure (VPOS), spreading from Galactocentric distances as small as 10 kpc out to 250 kpc. The orbital poles (directions of angular momenta, Metz et al. 2008) of satellite galaxies and the orientations of streams (which trace the orbital planes) show that the objects preferentially orbit within the VPOS.

This observed, highly correlated phase-space distribution is at odds with cosmological expectations. Tidal dwarf galaxies formed in an ancient galaxy-collision are a very natural alternative formation scenario of the VPOS.

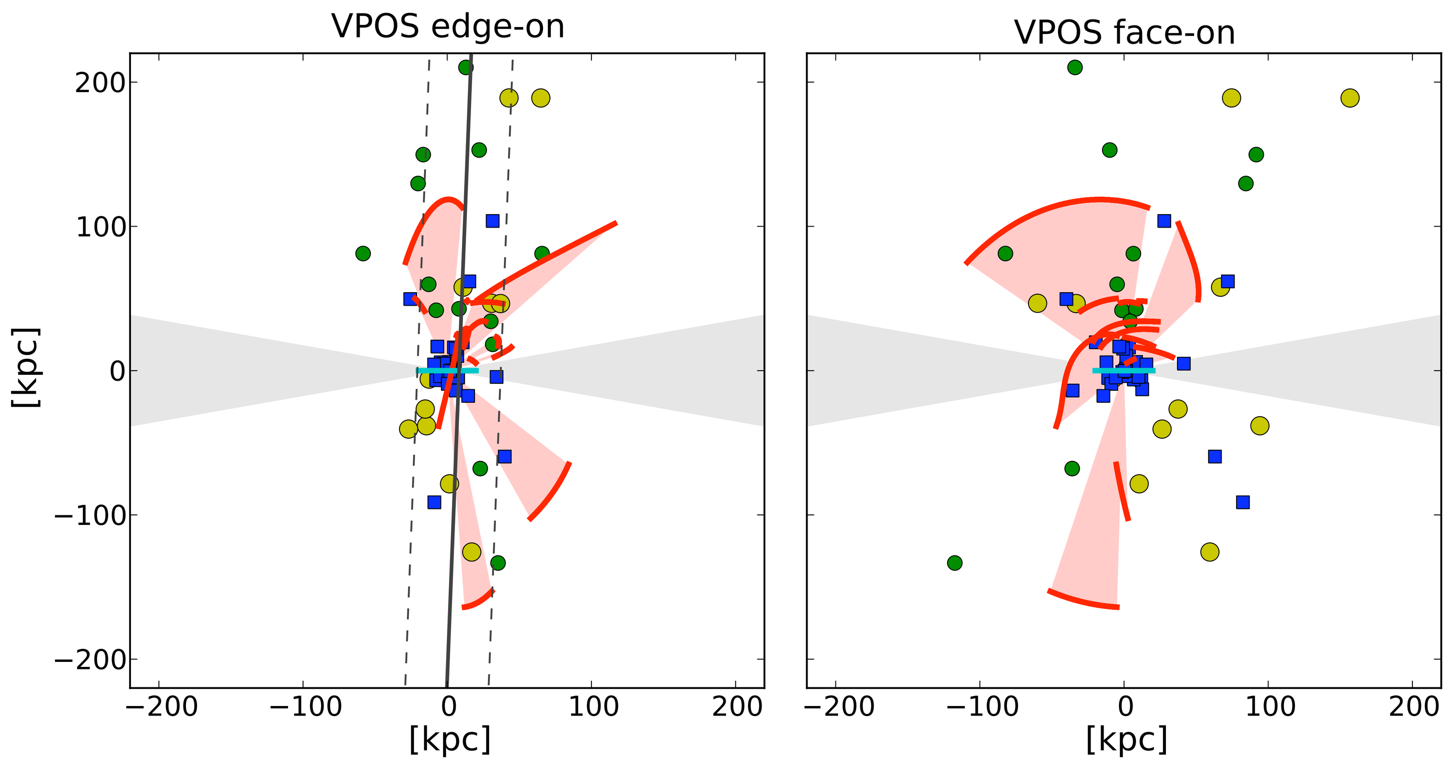


Fig. 1: The VPOS about the MW in Cartesian coordinates, consisting of the 11 classical satellites (yellow), the 13 faint satellites (green), 30 YH GCs (blue) and streams (red, 3x magnified). The MW disc is seen edge-on (cyan), its obscuration is given by the horizontal grey areas. *Upper panel*: edge-on view of the VPOS. The solid line shows the best fit to the satellite galaxies, the dashed lines illustrate the RMS-height (29 kpc). YH GCs and streams align in a similar direction. *Lower panel*: a view rotated by 90°, the VPOS is seen face-on. The satellite galaxies and YH GCs show a much wider distribution, the planes of most streams are also seen close to face-on.

Suggested cosmological origins (Pawlowski et al. 2012b)

From numerical simulations of structure formation within the standard model of cold dark matter (DM) cosmology, we know that the MW should be surrounded by many DM sub-halos, commonly interpreted to host satellite galaxies. They are predicted to be relatively uniformly distributed, in contrast to the observed VPOS. This has been identified as a major problem for the standard cosmological theory. Several scenarios have been suggested within the DM paradigm, trying to explain the unexpected polar structure. None of these reproduce the large observed degree of anisotropy.

Chance alignment: Drawing from an uniform or prolate distribution of sub-halos (as predicted by simulations), a chance-alignment of the positions of the 11 classical satellites alone can be excluded at 99.5% confidence (Metz et al. 2007). Adding more objects makes this statement more stringent. The preference to orbit within the VPOS shows that it is stable.

Group infall: Li & Helmi (2008) and D'Onghia & Lake (2008) suggested that a number of satellite galaxies were accreted by the MW in a common group. But Metz et al. (2009) have shown that observed associations of dwarf galaxies are much wider (> 200 kpc) than the VPOS (50 kpc). A structure this thin can not be formed from a much larger one. The increased number of objects within the VPOS also speaks against this scenario, as in addition to the in-falling group, a more evenly distributed population of satellites must be around (see Figs. 1 and 2).

Filamentary accretion (see Fig. 2): Structure-formation simulations show a giant 'cosmic web' of material connecting galaxies. It was suggested that satellite galaxies are accreted preferentially along such filaments, and that this results in a preferred spacial distribution. This scenario has the same problem as group infall: filaments are too big (>500 kpc). While there are over-densities of infall-directions at large distances, no structure as well defined as the VPOS is produced. Nevertheless, the abstract of Lovell et al. (2011) claims that "Quasi-planar distributions of coherently rotating satellites, such as those inferred in the Milky Way [...], arise naturally in simulations of a ΛCDM universe". In Pawlowski et al. (2012b) it is shown that this statement is not supported by their own data. The likelihood that their models reproduce the orbital poles of the MW satellite galaxies is less than 0.5 per cent.

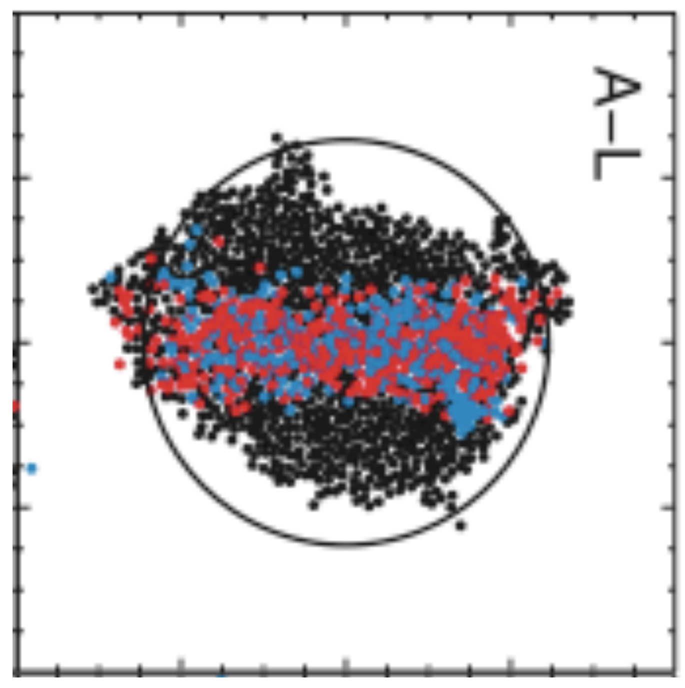
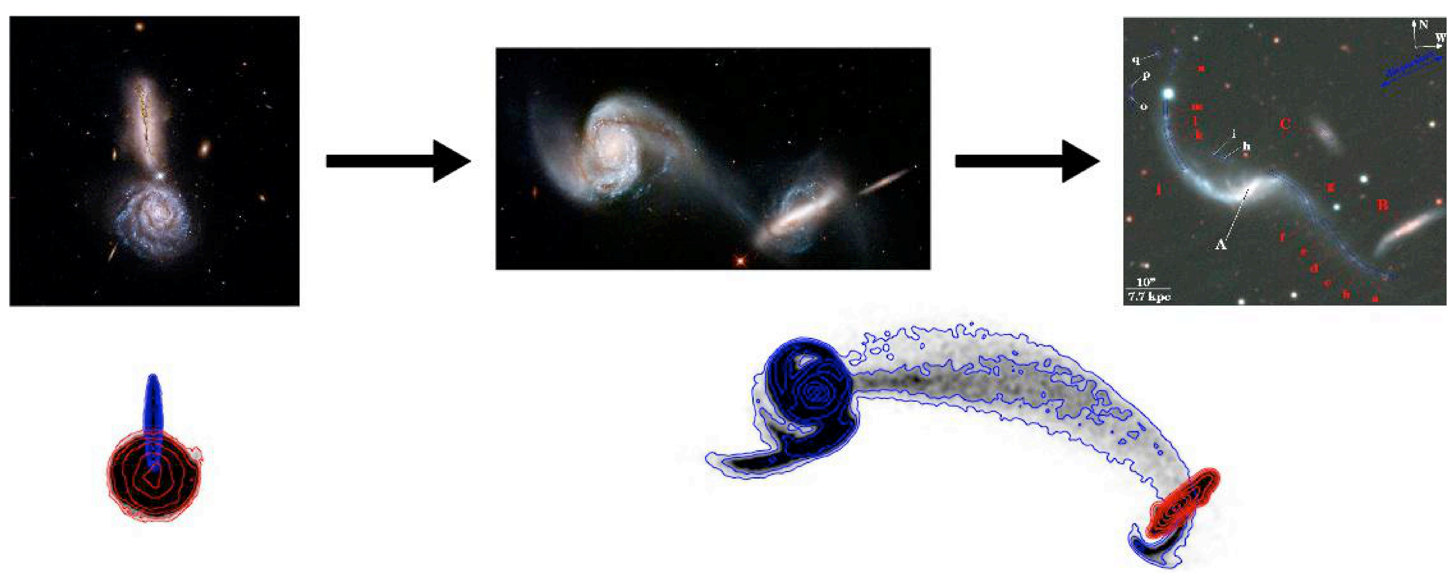


Fig. 2: Part of fig. 6 from Lovell et al (2011) showing simulated DM sub-halo positions. They predict an overabundance of sub-halo orbital poles aligning with the main halo spin. These sub-halos are colored in the plot, indicating a disc-like distribution. However, this consists of only 20% of all sub-halos. Making things worse, the marked 'disc' is perpendicular to the main halo spin, which most likely is the direction of spin of the central galaxy. Thus, a "disc" of subhalos *in the plane of the MW disc* is predicted, contrary to Fig. 1.

An alternative scenario

(Pawlowski et al. 2011)

The satellites orbiting the MW are highly correlated in phase-space, to a degree not natural for dark matter substructures. This shows that the majority of satellites, streams and YH GCs had to be formed as a correlated population. This is possible in tidal tails consisting of material expelled from interacting galaxies. We therefore suggest that 10-11 Gyr ago, the early MW experienced a polar collision with another galaxy (Fig. 3). From the tidally stripped material, new objects (dwarf galaxies and GCs) formed. These tidal debris naturally orbit within the orbital plane defined by the colliding galaxies. Their properties match with those of the MW satellites (e.g. Fig. 4).



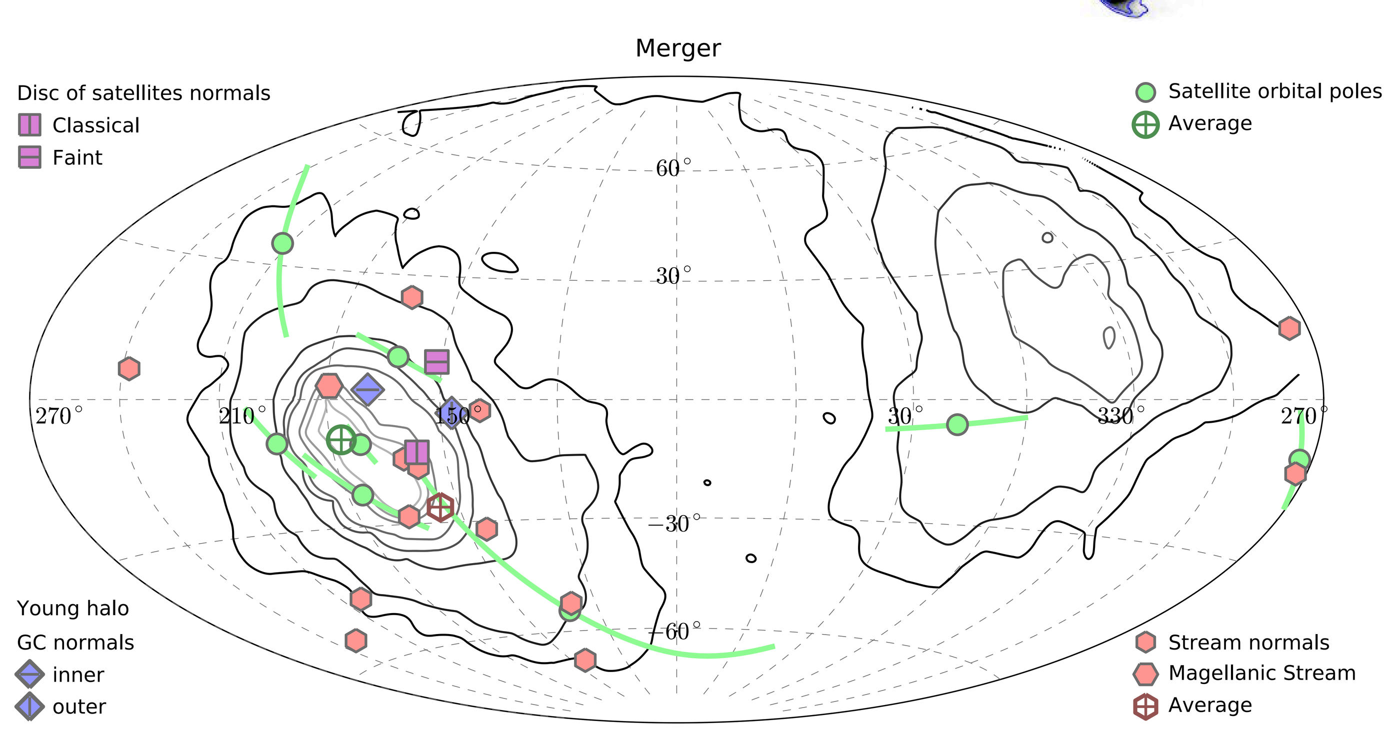


Fig. 3: Three examples of polar interactions observed at different stages. They illustrate qualitatively the possible interaction of the MW that resulted in the formation of its satellites. Two approximately perpendicular disc galaxies (left, Arp 302) collide. Material gets tidally stripped and is accreted in a polar structure around the other galaxy (central picture, Arp 87). New dwarf galaxies form in these tidal tails (right picture, the Dentist's Chair galaxy). They will orbit one of the two interacting galaxies in a plane defined by the interaction geometry. *The lower row* shows the particle densities of two snapshots from a model of two galaxies interacting in a similar geometry (Pawlowski et al. 2011). Before the interaction (left) the target galaxy (red contours) is seen face-on along the plane of the interaction. The second snapshot (right) shows a view projected onto the plane of the interaction, with the target galaxy seen edge-on.

Fig.4: The orbital poles (directions of angular momentum vectors) of the MW satellite galaxies (green) and the stream normal directions (red) compared to the distributions of orbital poles in tidal debris of a galaxy-interaction model, plotted as contours. The initial orbital pole of the in-falling galaxy in both models points to (l, b) = (180°, 0°). The contours show the densest regions. The agreement of the observed satellite orbital poles and stream normal directions with the contours of prograde material (left, centered on l = 180°) is striking, but also retrograde material close to the orbital pole of Sculptor is found. Even the diagonal elongation of the orbital poles and stream normals (from the upper left to the lower right) is reproduced.

References

Paper the poster is based on:

- "Making counter-orbiting tidal debris. The origin of the Milky Way disc of satellites?", M. S. Pawlowski, P. Kroupa, K. S. de Boer, 2011, A&A, 532, A118
- "The VPOS: a vast polar structure of satellite galaxies, globular clusters and streams around the Milky Way", M. S. Pawlowski, J. Pflamm-Altenburg, P. Kroupa, 2012a, MNRAS
- "Filamentary accretion cannot explain the orbital poles of the Milky Way satellites", M. S. Pawlowski, P. Kroupa, G. Angus, K. S. de Boer, B. Famaey, G. Hensler, 2012b, MNRAS

Other cited paper:

- E. D'Onghia & G. Lake, 2008, ApJ, 686, L61
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Online Material

Watch a movie rotating Fig. 1 around the MW, find links to the references and download the poster as a pdf file.

http://marcelpawlowski.com/poster2012/

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