Satellite Galaxy Phase-Space Correlations

- The positions and motions of satellite galaxies around a host are only mildly affected by baryonic processes.
- This makes their phase-space distribution a powerful testbed of cosmological models.
- Observed satellite systems in and beyond the Local Group show unexpected phase-space correlations – most prominently rotating planes of satellite galaxies.
- These constitute serious challenges for the ΛCDM model that are not easily addressed.

Planes of Satellite Galaxies: Observational Evidence

Comparison to Cosmological Simulations: The Planes of Satellite Galaxies Problem

Lopsided Satellite Systems

Contact and Further Information

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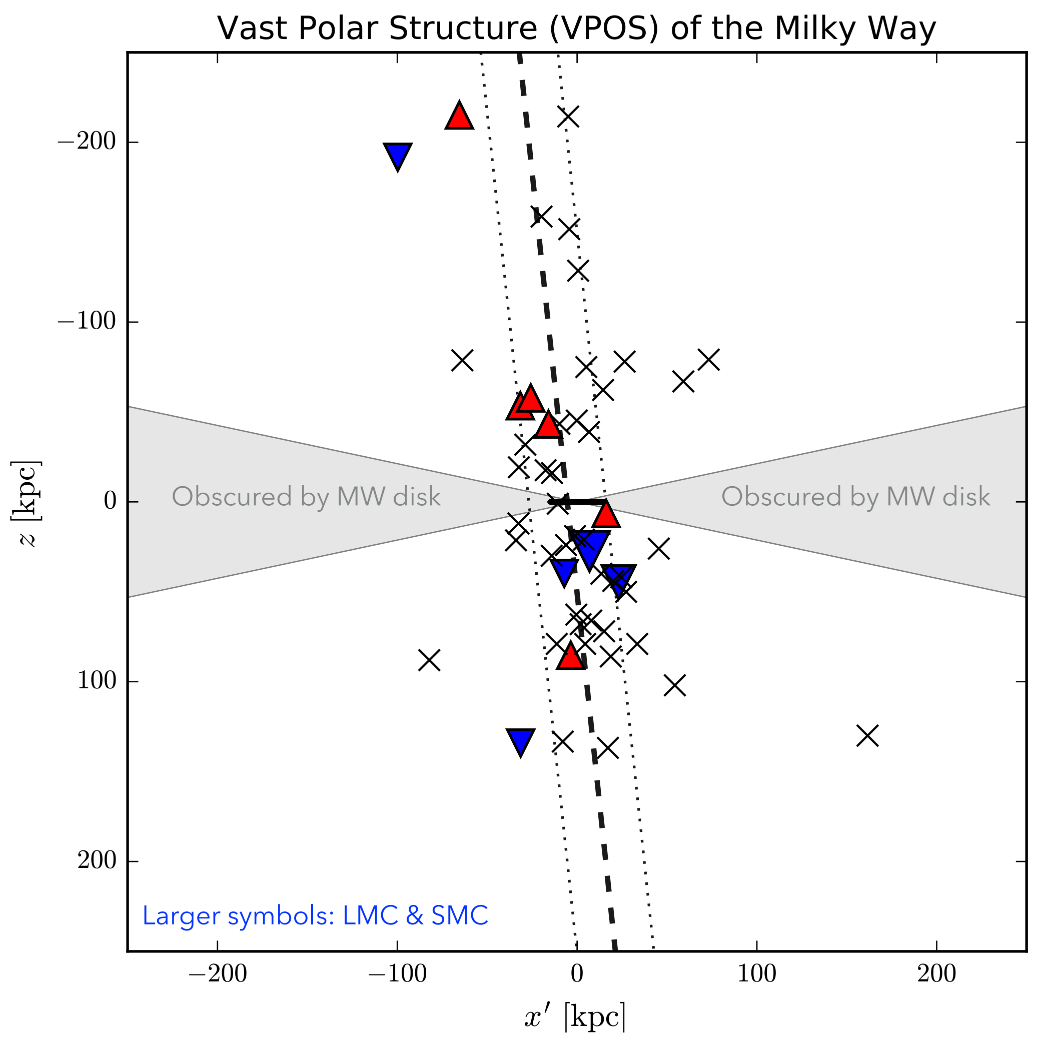
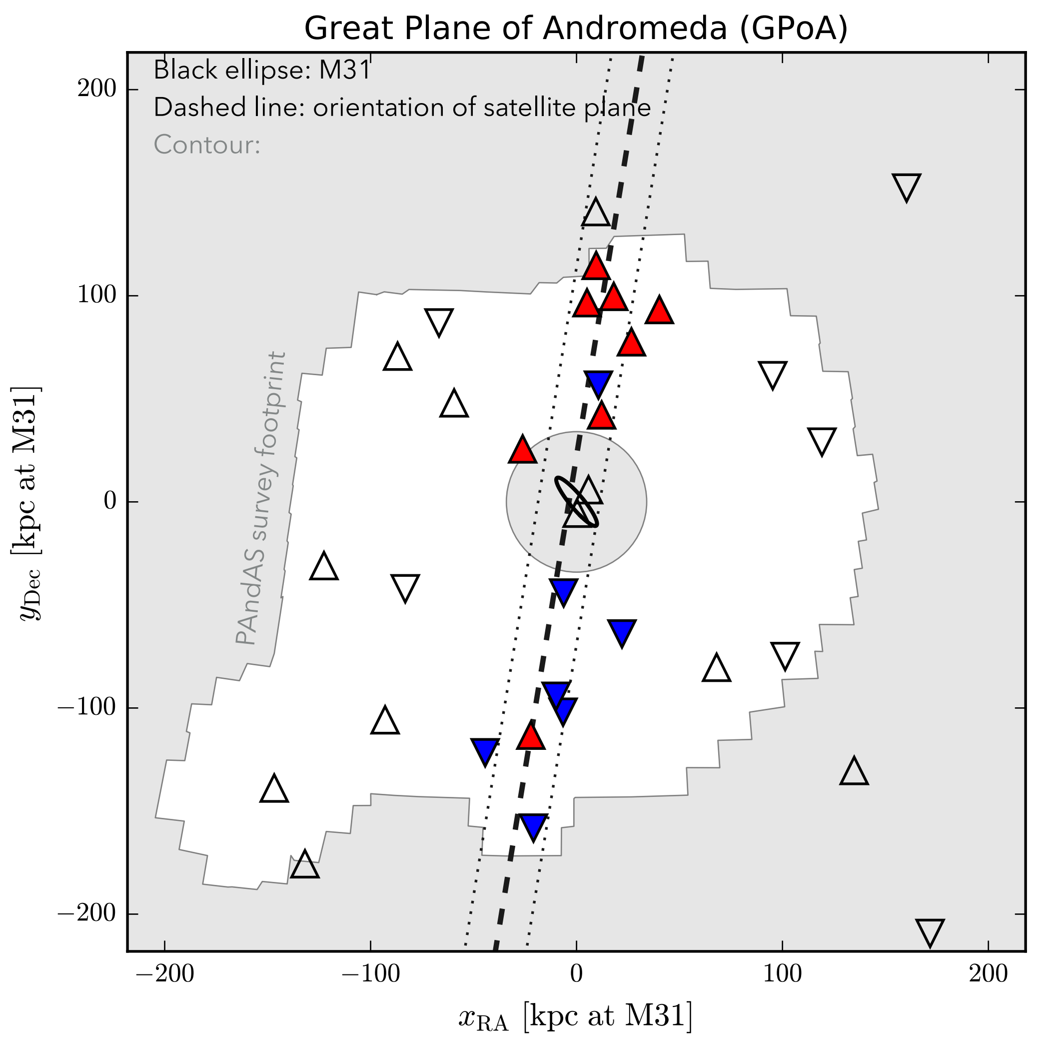
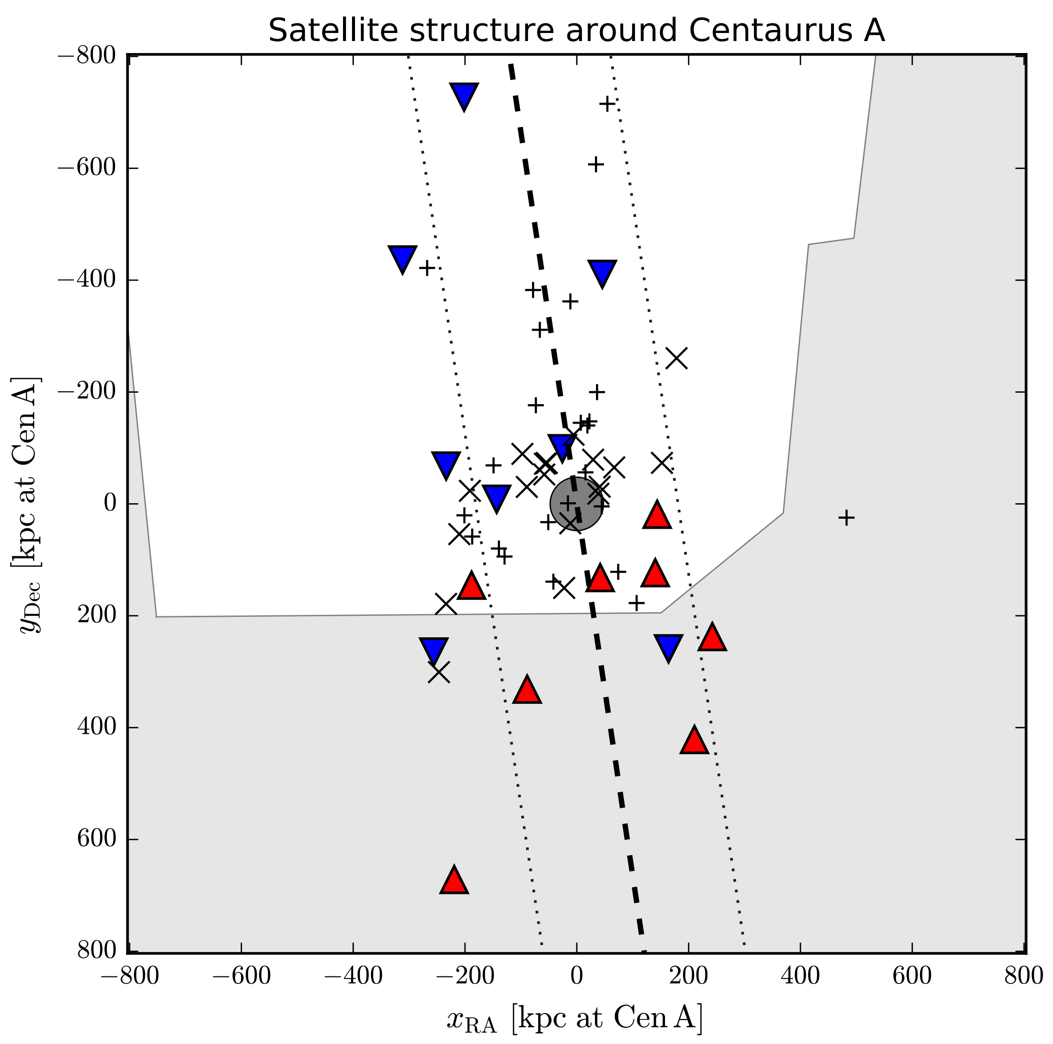
Planes of Satellite Galaxies: Observational Evidence







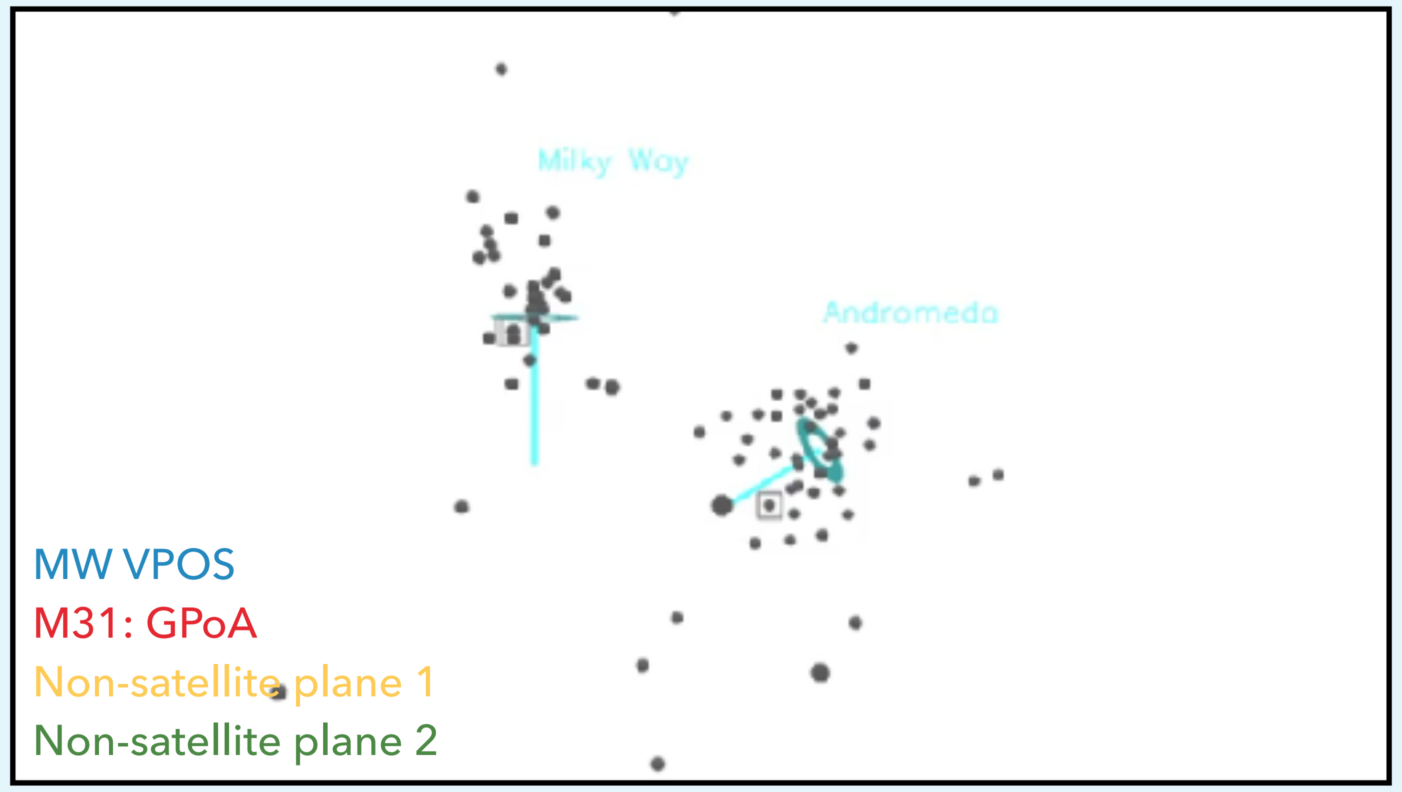
Caption: The three most prominent known planes of satellite galaxies in edge-on orientations, dotted lines denote their rms heights. The VPOS is seen from a position in which both the MW (black line) and the satellite plane are seen edge-on. The GPoA around M31 and the satellite structure around Centaurus A are shown as seen from the Sun, in almost edge-on orientations. Satellite galaxies with measured velocities (proper motions for the 11 classical MW satellites, line-of-sight velocities for the other systems) are color-coded according to whether they are approaching (blue, downward triangles) or receding (red, upward triangles) relative to their host's velocity in these views. This indicates coherent kinematics consistent with satellites co-orbiting in the planes.

Related References:

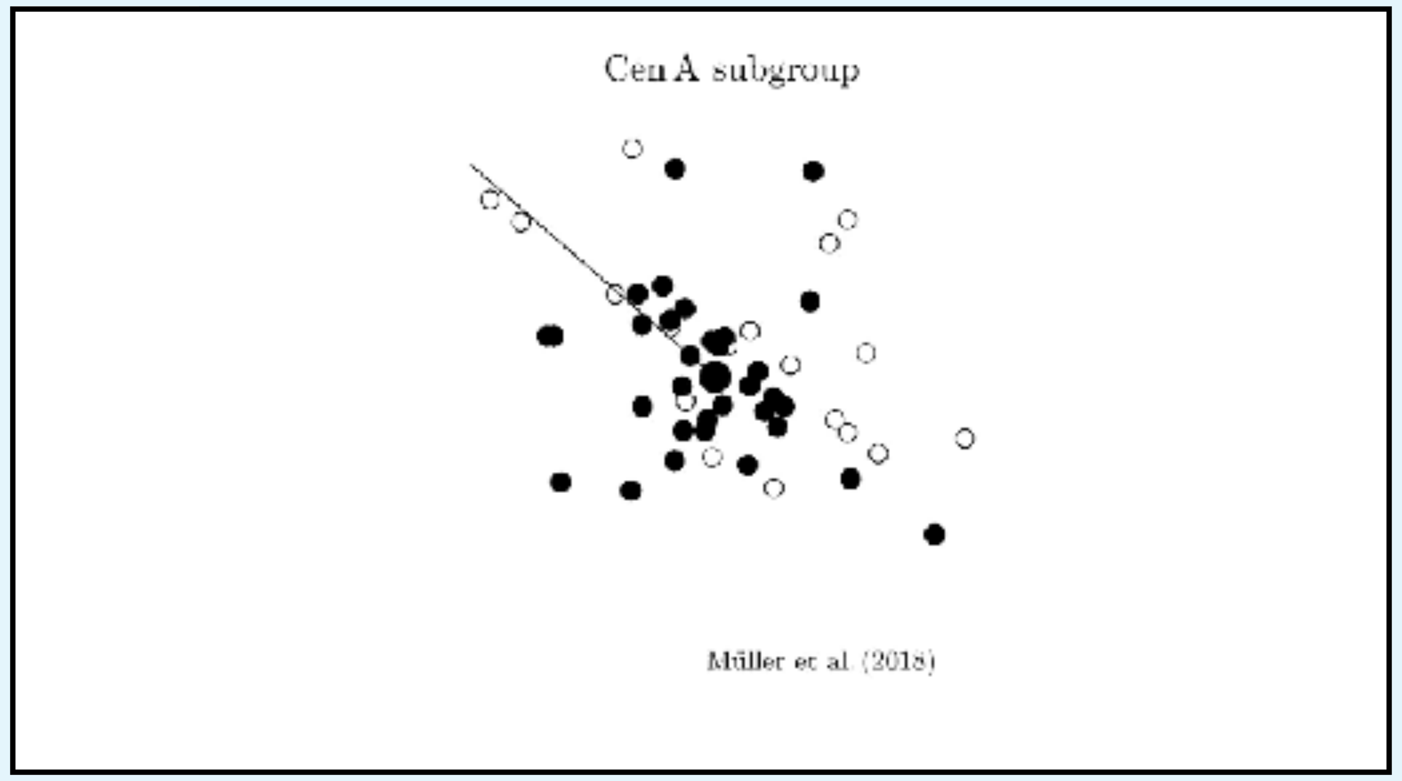
- Satellite Plane Review: Pawlowski (2018, *MPLA*, 33, 1830004)
- MW VPOS: Pawlowski et al. (2012, *MNRAS*, 423, 1109)
- M31 satellite plane: Ibata et al. (2013, *Nature*, 493, 62)
- Cen A Satellite Plane: Müller et al. (2018, *Science*, 359, 534)
- Local Group dwarf galaxy structures: Pawlowski et al. (2013, *MNRAS*, 435, 1928) Pawlowski & McGaugh (2014, *MNRAS*, 440, 908)

Movies (3D views of satellite planes)

Satellite and Dwarf Galaxy Planes in the Local Group

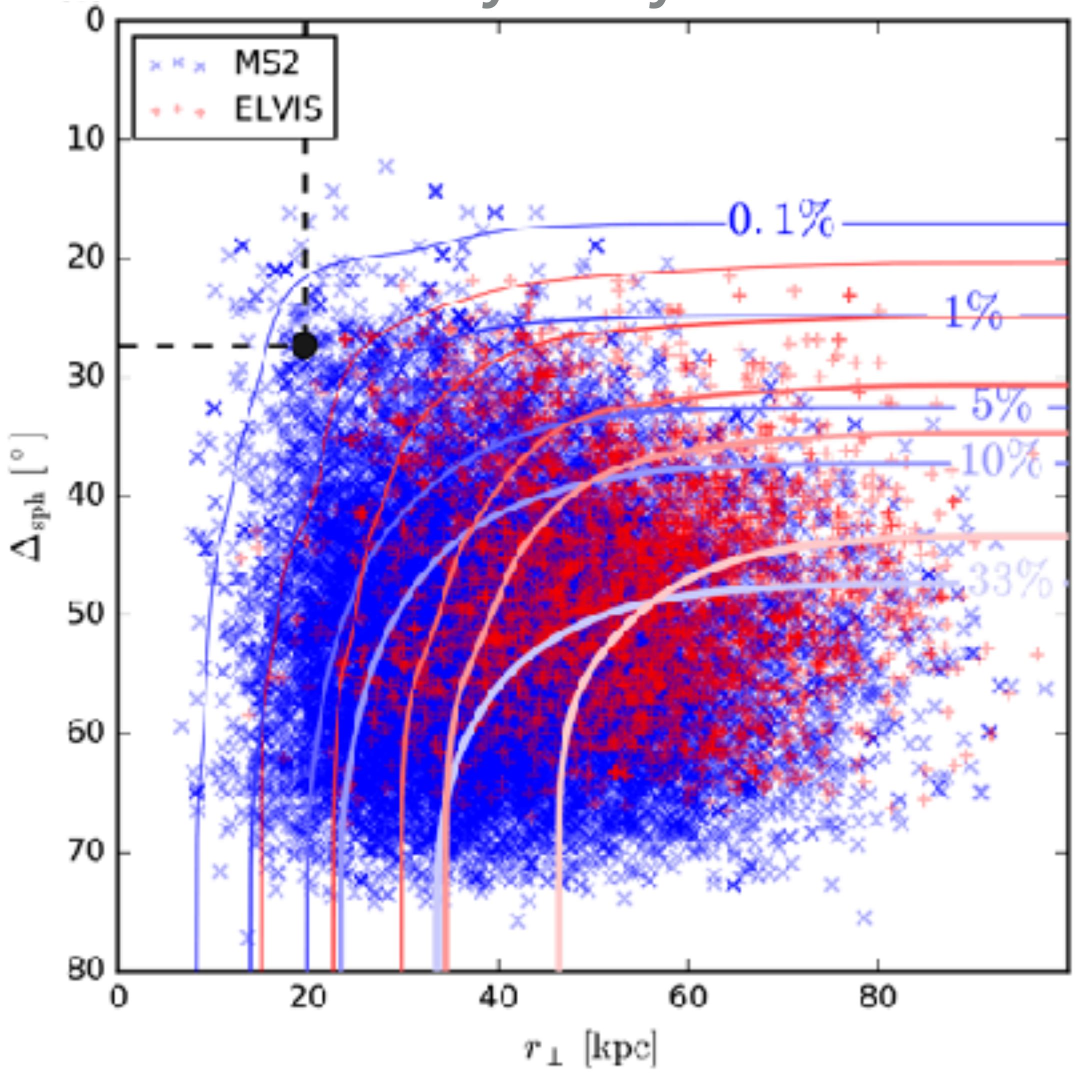


Cen A Satellite Galaxy Plane and Kinematic Correlation

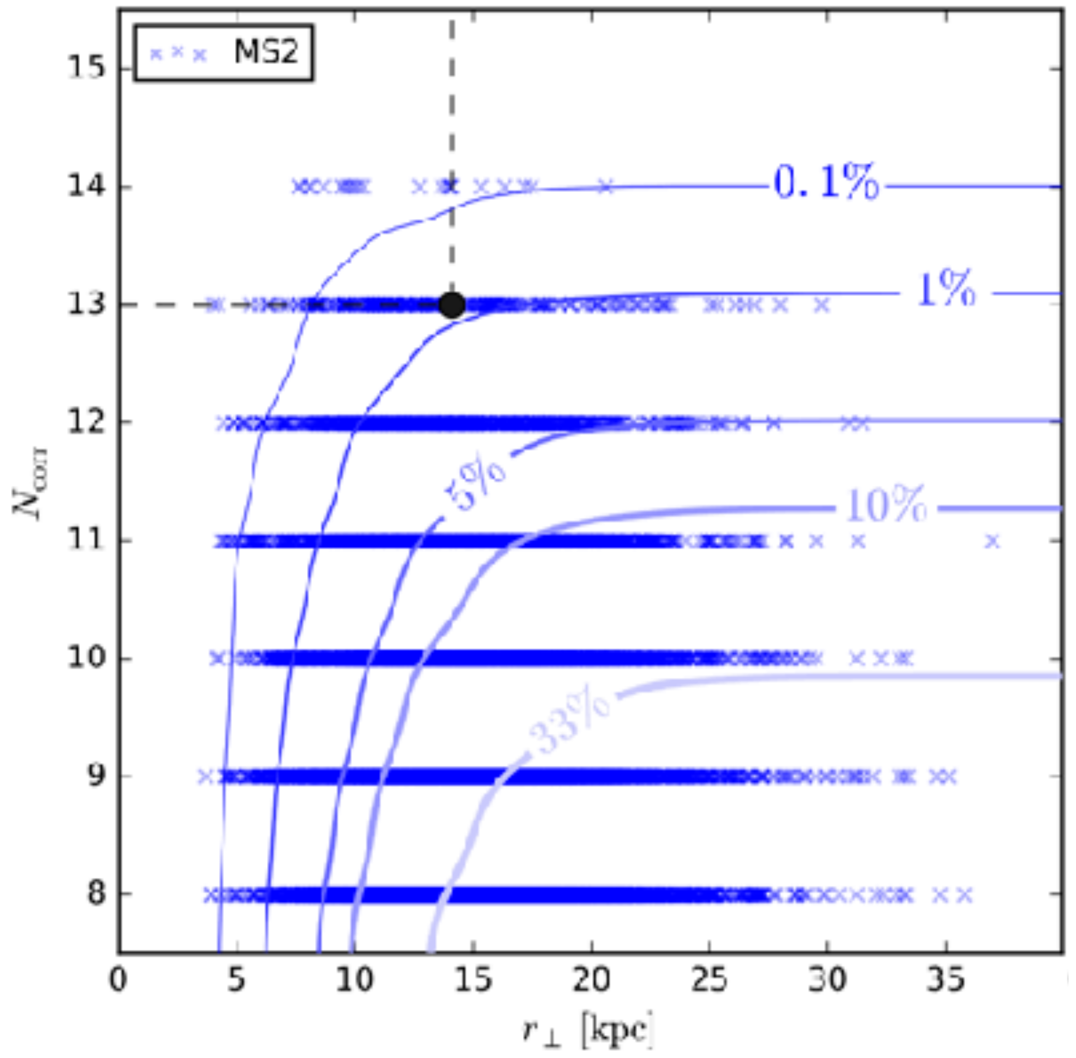


Planes of Satellite Galaxies: Comparison to cosmological simulations

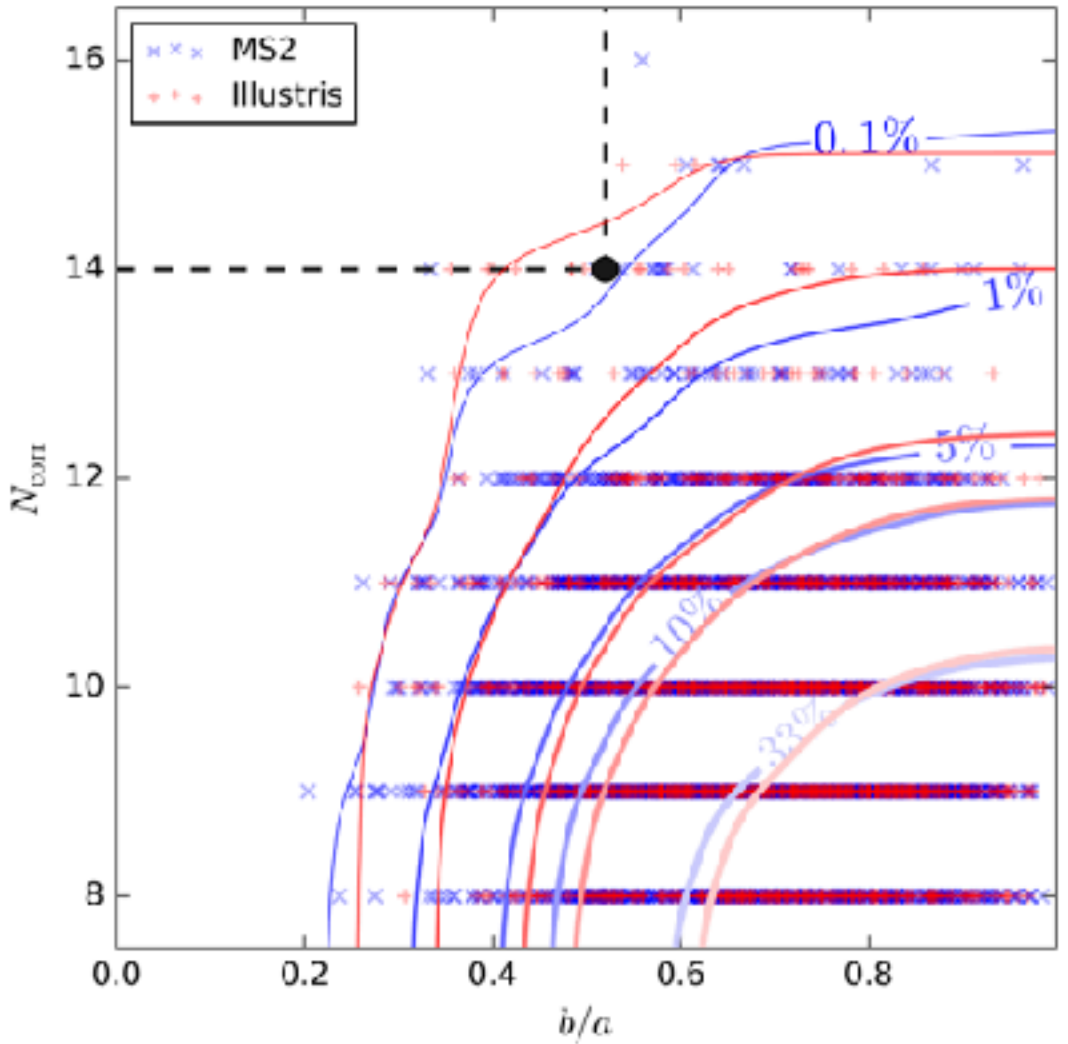
Milky Way VPOS



Andromeda Satellite Plane



Centaurus A Satellite Plane

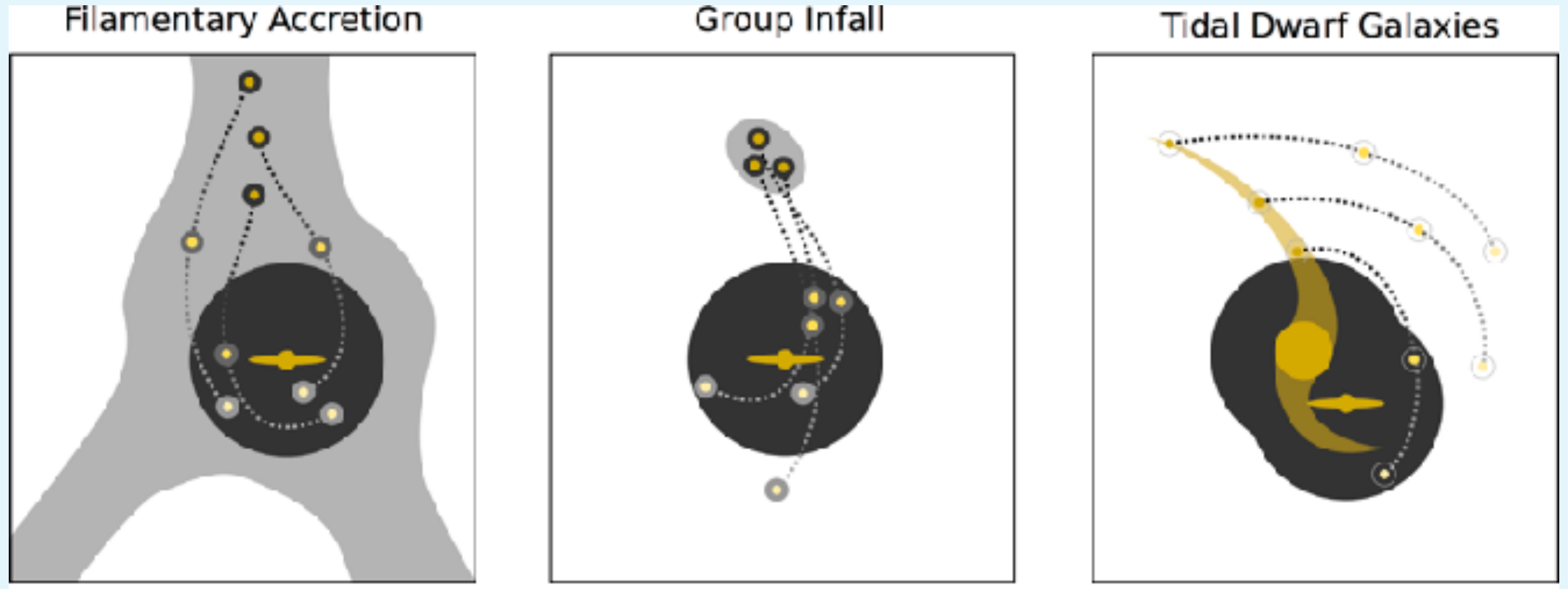


Caption: Analogs to the observed systems are rare in cosmological simulations. Red and blue points indicate satellite plane properties in ΛCDM simulations. The horizontal axes give a measure of flattening (rms height, or on-sky axis ratio for CenA). The vertical axes give a measure of kinematic coherence (rms scatter of angular momentum directions for VPOS, number of correlated line-of-sight velocities for M31 and CenA). Systems at least as extreme as the observed ones (black dots) are very rare (~0.1% frequency if only using these two properties alone). Including baryons in the simulations does not help (e.g. compare Millenium-2 and Illustris simulation results in CenA panel). *The observed planes of satellite galaxies thus constitute a serious challenge to ΛCDM.*

Figures from Pawlowski (2018)

What could solve the problem?

Three major scenarios were suggested to explain the correlation of satellite galaxies in rotating planes around a central galaxy (yellow, edge-on disk). *Left*: the preferential accretion of dwarf galaxies along a small number of cosmic filaments onto the halo of a central host galaxy; *Middle*: the accretion of dwarf galaxies in a group; *Right*: the formation of second-generation Tidal Dwarf Galaxies out of material in the tidal tails of interacting galaxies. The dwarf galaxies in the first two scenarios are embedded in dark-matter (sub-)halos, whereas TDGs are expected to be dark matter free.



None of these satisfactorily address the issue within a ΛCDM framework.

The accretion of sub-halo satellites along filaments, or as part of groups, are already self-consistently included in cosmological simulations. While these two effects result in some anisotropy in the spatial distribution of satellites, as well as in a mild degree of kinematic coherence, these are not strong enough to account for the extreme properties of the observed satellite planes.

TDGs are known to form, but should be free of dark matter: they are formed out of stars and gas expelled as tidal tails in interacting disk galaxies, a process which requires the interplay of orbital and internal angular momentum of the galaxies, and to which the pressure-supported dark matter halo does not contribute. However, since the observed satellite galaxies making up the Planes of Satellites show high Mass-to-Light ratios, these objects should contain Dark Matter. Alternatively, one might switch to a modified gravity interpretation of the missing mass effect in galaxies, or question the assumption that the dwarf galaxies are in dynamical equilibrium.

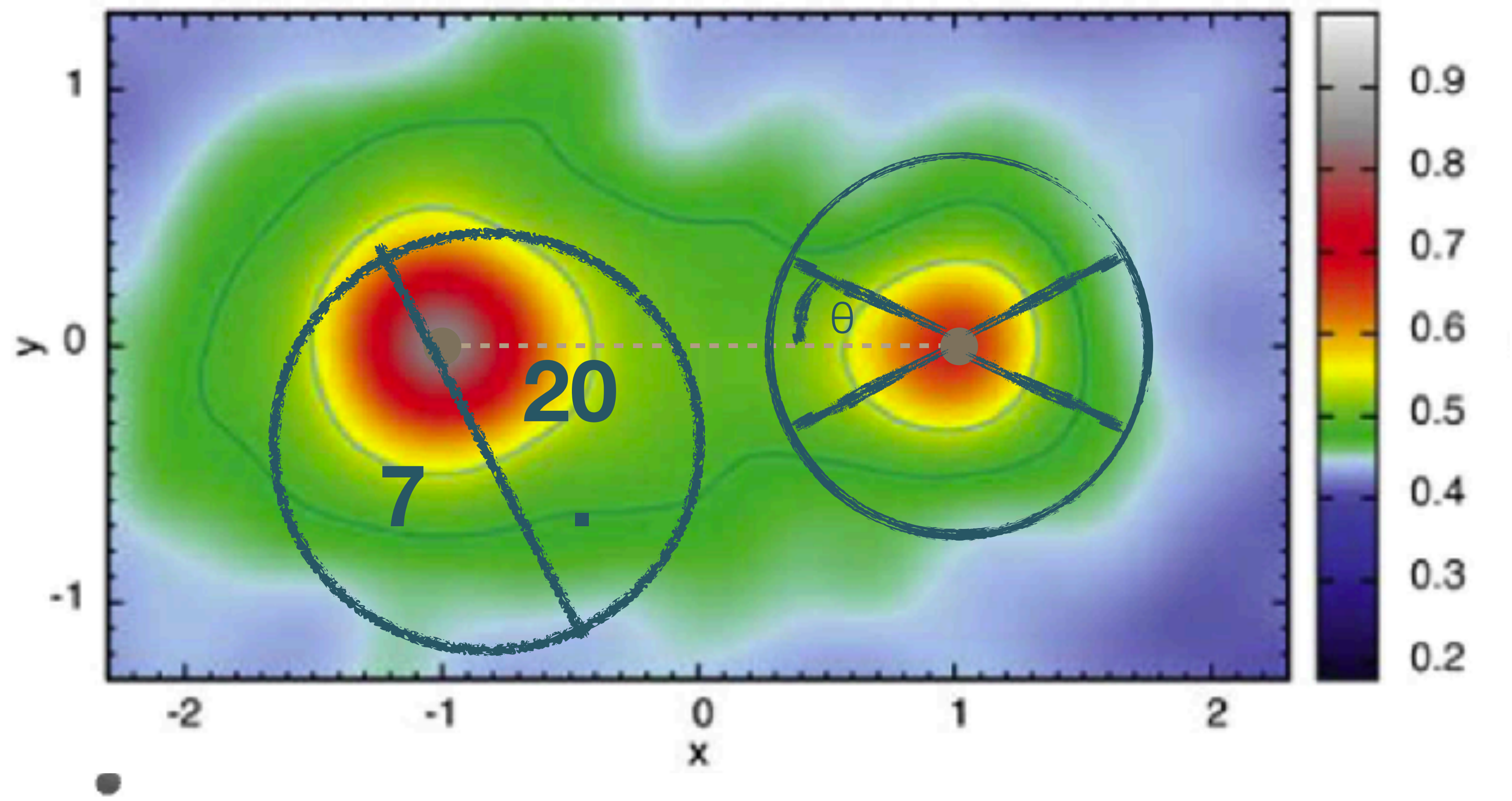
Related References:

- Satellite Plane Review: Pawlowski (2018, *MPLA*, 33, 1830004)
- Cen A Satellite Plane: Müller et al. (2018, *Science*, 359, 534)
- ΛCDM Comparisons: Pawlowski et al. (2014, *MNRAS*, 442, 2362) Pawlowski et al. (2015, *ApJ*, 815, 19)

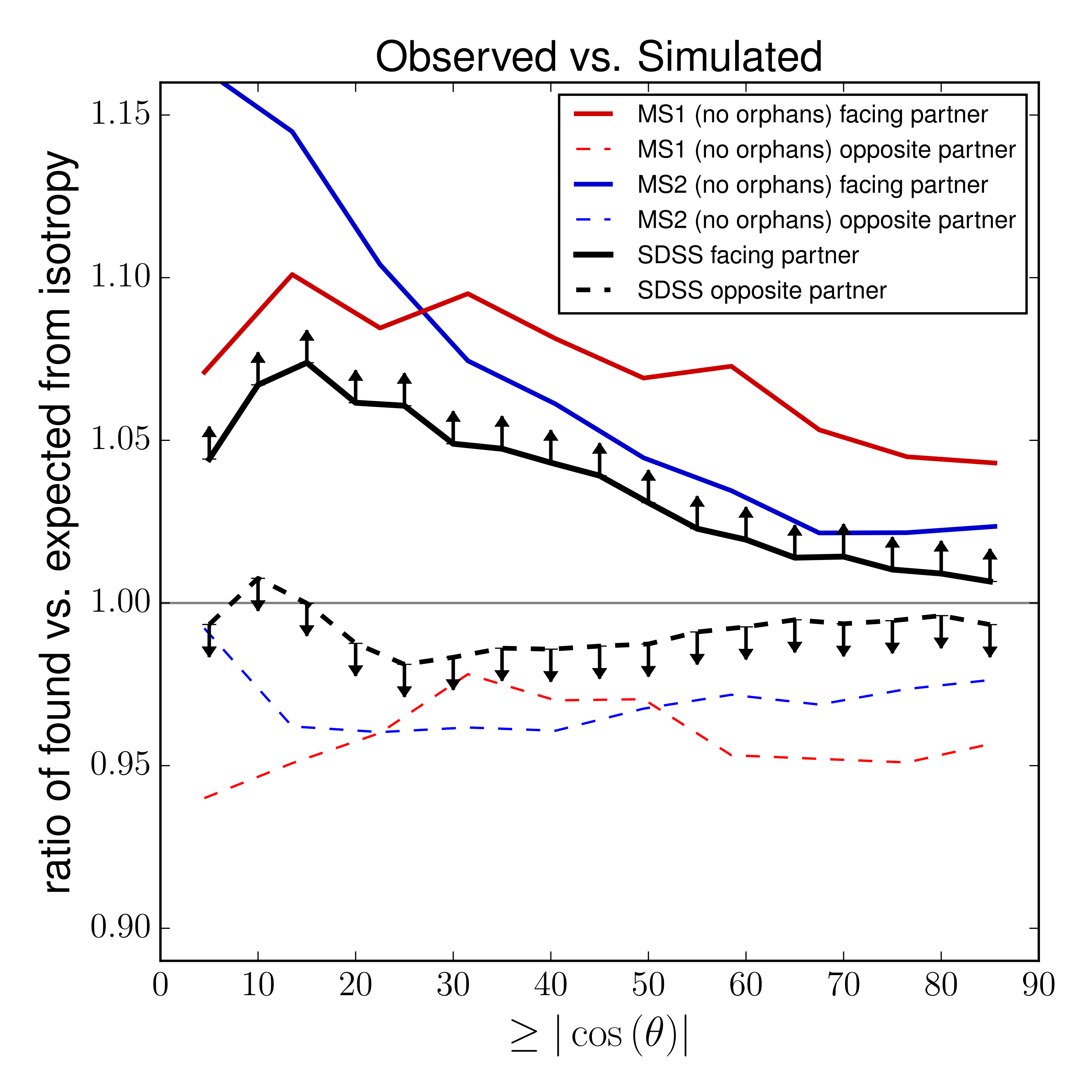
Lopsided Satellite Galaxy Systems

- The satellite system of M31 is lopsided; there are more satellites on the side facing the Milky Way than on the opposite one.
- This motivated a similar study using pairs of host galaxies in SDSS, which found a similar signal: a preference for satellites to be in the direction towards the host's partner (Libeskind et al., 2016).
- We asked, how does this observed signal compare to ΛCDM simulations? Is it another problem, or an expected behavior?

Libeskind et al. (2016): Lopsidedness in stacked host pairs in SDSS



We find a similar signal around paired hosts in ΛCDM simulations



Caption: Cumulative, relative overabundance of satellites along the angle θ measured from the respective host's partner satellite (solid: towards partner host, dashed: away from partner host). The observed lopsidedness signal (black line) is a lower limit (indicated by arrows) because fore- and background contamination is expected to be isotropic. The satellite distributions in simulations (here shown are Millennium 1 and 2) show a similar, somewhat stronger signal. From Pawlowski et al. (2017)

Related References:

- Lopsidedness in M31: Conn et al. (2013, ApJ, 766, 120)
- Lopsidedness in SDSS: Libeskind et al.(2016, ApJ, 830, 121)
- Lopsidedness in ΛCDM simulations: Pawlowski, Ibata & Bullock (2017, ApJ, 850, 132)

Contact Details and Link to More Information

Want to learn more?

Check out my talk at IAU Symposium 348 (Astrometry): Tuesday, August 28 at 15.45–16:00 in room E1.

Or find more information online, including this poster, links to publications, and movies:
marcelpawlowski.com/iau

… or scan this code:

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