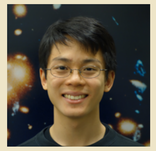

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Satellite Planes in the Caterpillar Simulations

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Introduction

Thin planes of co-rotating satellites have been observed around the Milky Way and M31 [1,2]. Such planes are not common in LCDM simulations, which has been proposed as a problem for the standard LCDM cosmological paradigm.

A large suite of cosmological zoom-in simulations with varied formation histories and environments can provide insight into whether and how satellite planes can form. We search the Caterpillar Simulations for planes of satellites at z=0. In 1/20 halos, we find a thin co-rotating plane matching the MW, although it appears to be transient. However, the general structure of subhalo angular momenta suggests that there may be long-lived planes in many galaxies.

The Caterpillar Simulations

High-resolution cosmological zoom-in simulations of ~10^{12} M_{sun} dark matter halos with varied merger history [4]. 20 halos are used here.

~10^4 M_{sun} particle mass, ~100 pc softening

Modified `rockstar` halo finding [5]
Correctly finds tidally-stripped satellites

`consistent-trees` merger trees [6]

Satellite Identification

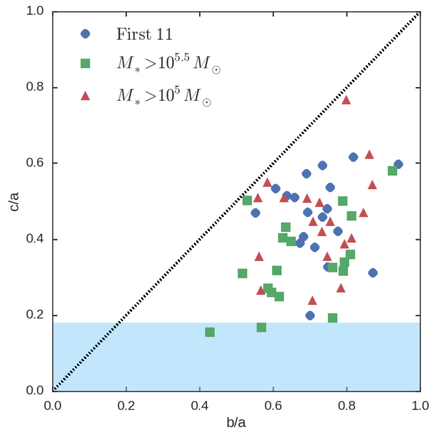
- First 11 satellites ranked by peak V_{max}
- Abundance matching mass above $10^{5.5}$ M_{sun}
- Abundance matching mass above 10^{5} M_{sun}

Abundance matching is done using M_{vir} at peak V_{max} with Moster et al. 2013 [7]

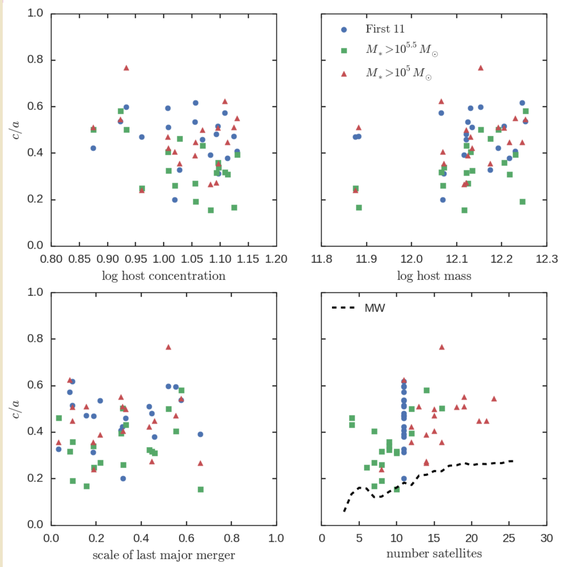
References

[1] Kroupa et al. 2005, A&A, 431, 517
[2] Ibata et al. 2013, Nature, 493, 62
[3] Griffen et al., in prep.
[4] Behroozi et al. 2013, ApJ, 762, 109
[5] Behroozi et al. 2013, ApJ, 763, 18
[6] Moster et al. 2013, MNRAS, 428, 312

Thin Satellite Planes



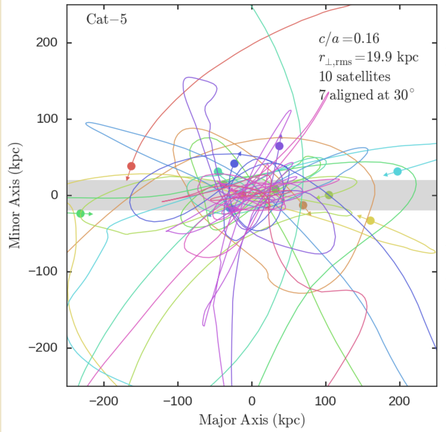
Ratio of eigenvalues of moment of inertia tensor for large satellites. The most luminous satellites of Cat-5, Cat-12, Cat-20 are about as thin as the MW. We do not include Cat-7 as it has a recent major merger.



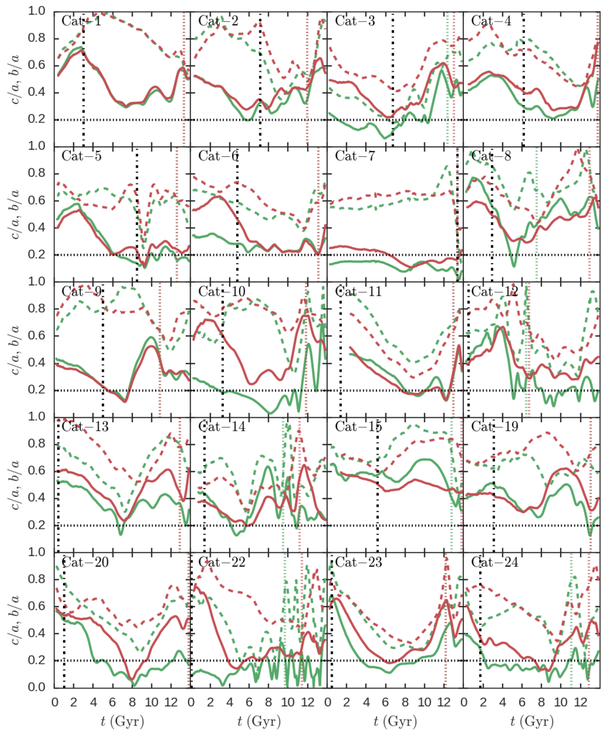
Plane thickness as a function of host halo properties. There is a mild anticorrelation with concentration, and a strong correlation with satellite number.

APJ thanks Peter Behroozi for his help on halo finding and merger trees, and Paul Torrey for useful conversations. This work has made extensive use of the python libraries `scipy`, `matplotlib`, `seaborn`, and `astropy`. More info at www.caterpillarproject.org

Satellite Plane Evolution

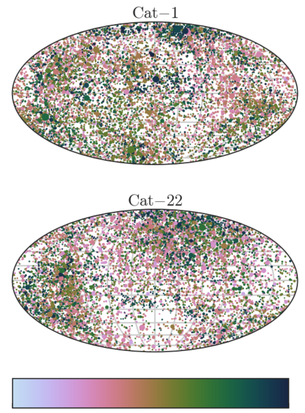


Cat-5, z=0 thin plane with tracks showing plane assembly. The satellites do not come from the same place, and the plane may not stay thin, although 7 angular momenta are aligned with the plane.



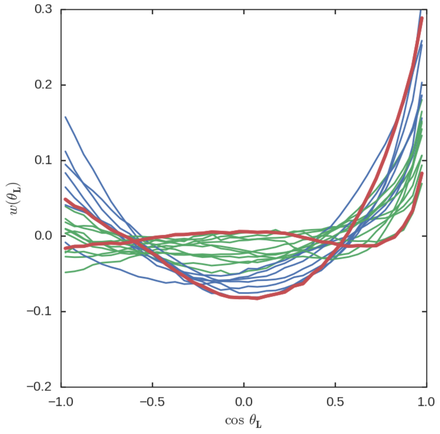
c/a (solid) and b/a (dashed) for the two abundance matching models (red and green) as a function of time. Vertical colored line indicates time when all satellites have entered the host virial radius. Vertical black line indicates last major merger.
Note Cat-22 has a long-lived thin plane (though with only 4 satellites) that dissipates by z=0.

Correlated Satellite Angular Momenta



Mollweide projection of direction of all satellite angular moment vectors (**L**) at z = 0 in two halos ($M_{peak} > 10^6\,M_{sun}$)
Clusters of **L** suggest but do not guarantee coherent planes.
Points are colored by the scale factor at infall.
Zenith is halo spin direction.

- Cat-1 has clusters of **L**, but the clusters are isotropically distributed on the sky.
- Cat-22 has two large **L** clusters opposite on the sky, suggesting a preferred orbital plane.



Cat-22 (poles)

Cat-1 (isotropic)

The angular correlation function $w(\theta_L)$ from the 20 halos. An isotropic distribution has w(θ) = 0.
Blue "u-shaped" lines indicate halos with a preferred direction. Green lines indicate isotropic **L** with minor clustering. Red indicates Cat-1, Cat-22.

Future Work

- Semi-analytic models for satellite identification
- Properties of clusters of angular momentum
- Shear tensor reference frame for accretion history
- Your ideas! E-mail Alex at alexji@mit.edu