Tensions in the orbits of dwarf satellites

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Carlos Frenk and Shi Shao

Tensions in the LCDM paradigm
Mainz
15 May 2018

MC+ 2015a, 2015b
Shao, MC+ 2016, 2017
MC & Frenk, 2017
MC+ in prep

“Small scale problems”

- **The missing satellites problem**
- **The too-big-to-fail problem**
- **The core-cusp problem**
- **The plane of satellites problem**
- **The tangential motion excess**

“Small scale problems”

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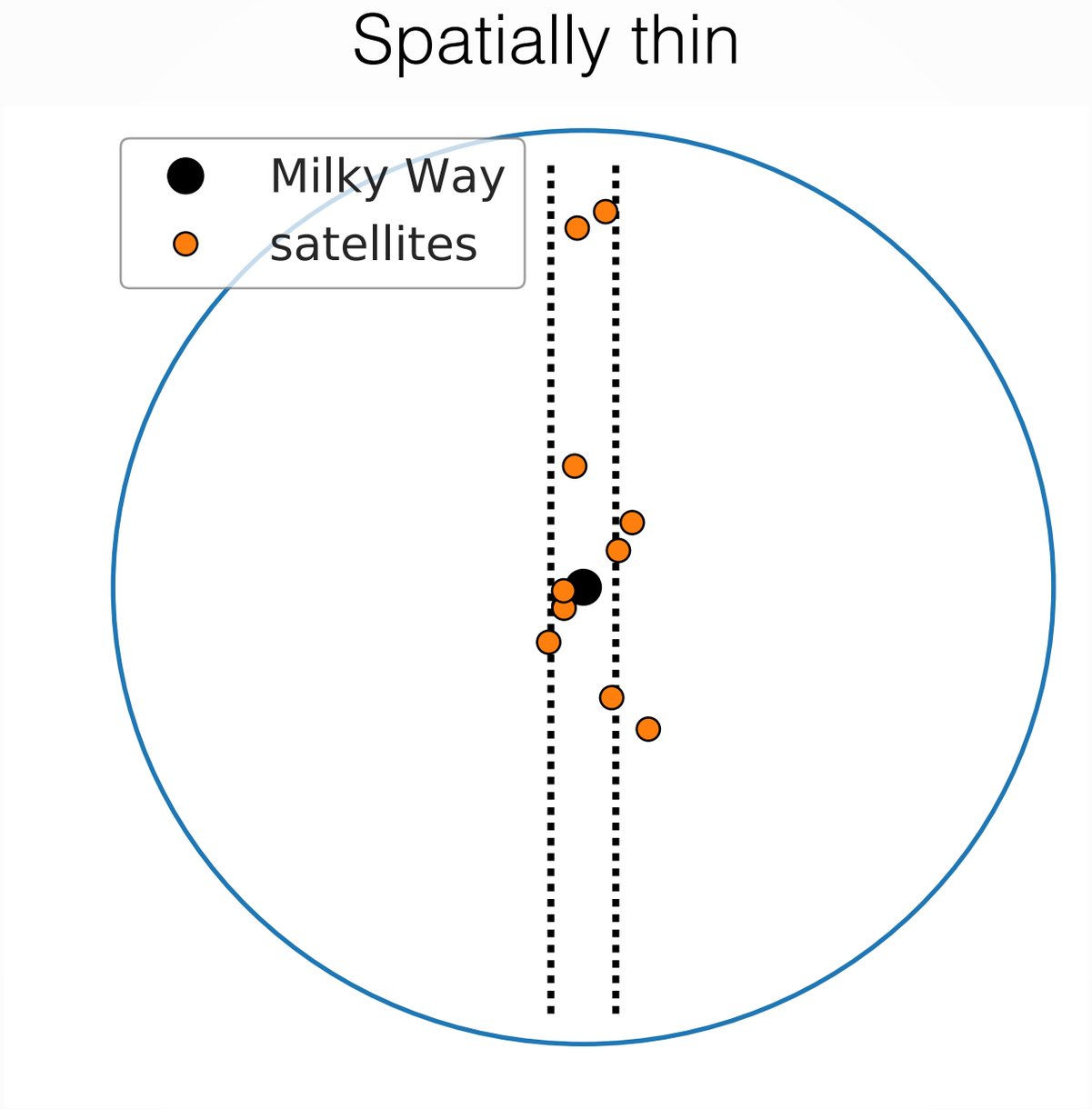
Potentially reflect our poor understanding of baryonic processes in dwarf galaxies (e.g. Sawala+ 2016).

Unlikely to be solved by baryonic processes.

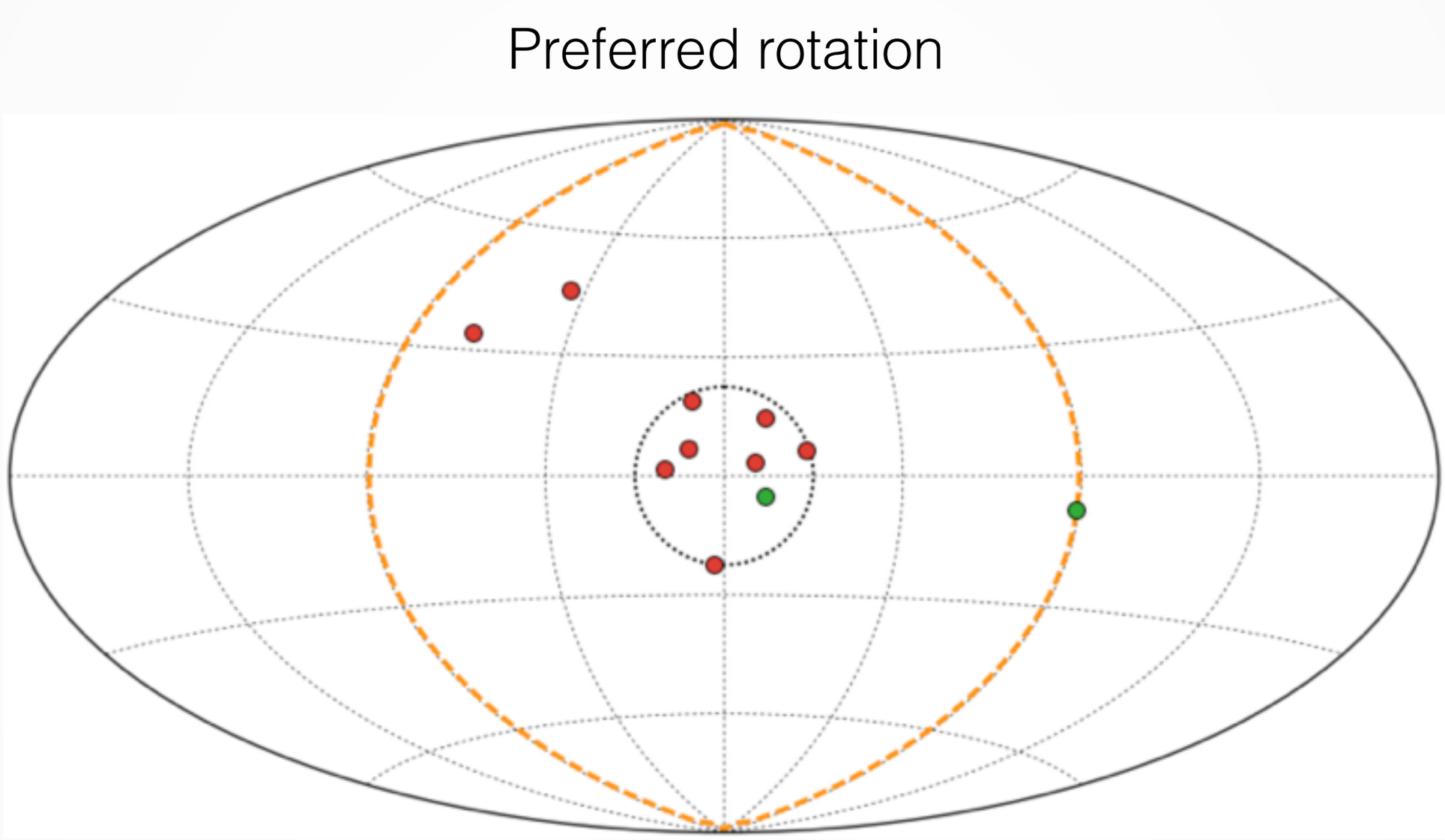
The plane of satellites problem

The Milky Way plane of satellites



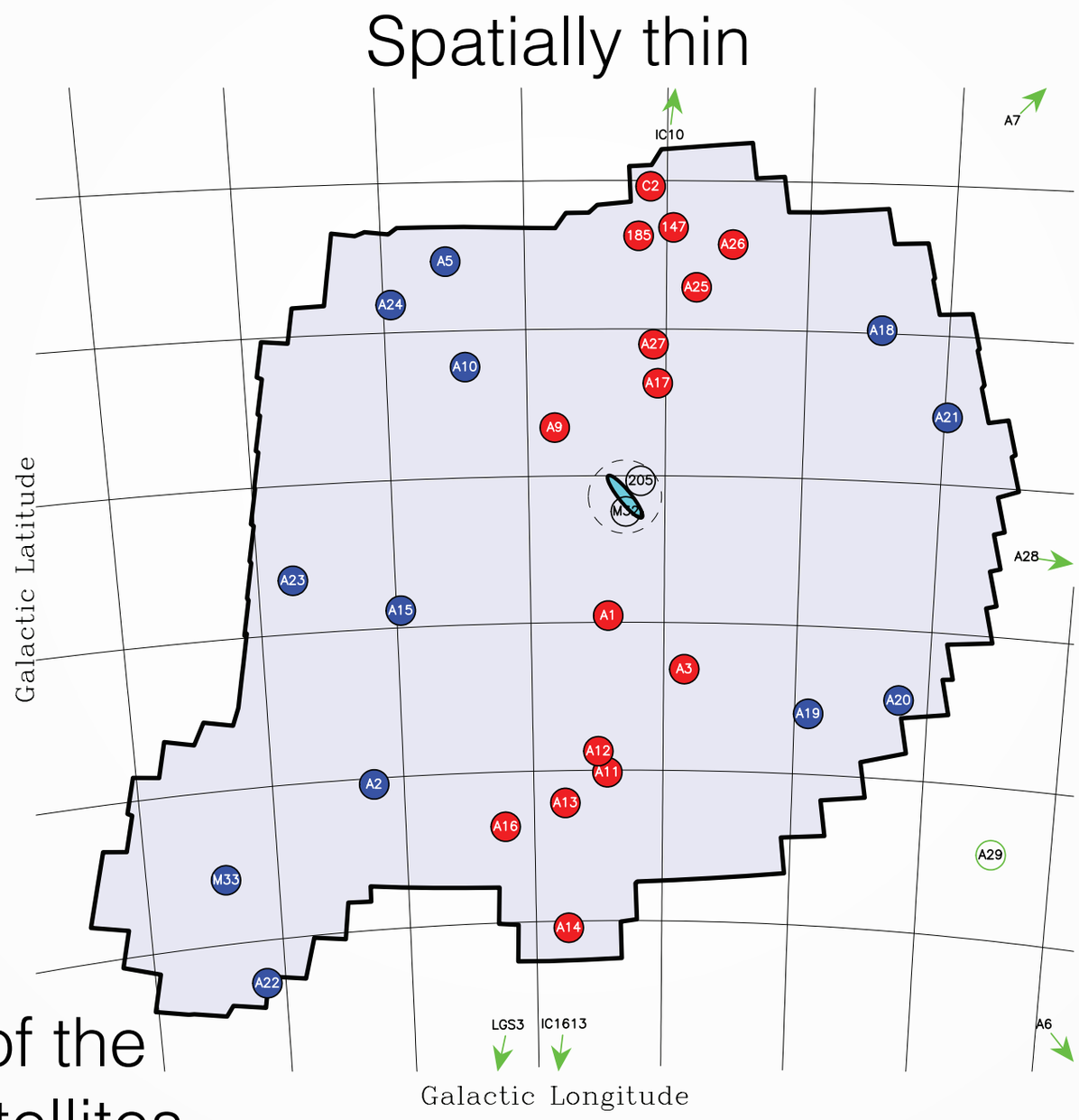
Kroupa 2005

The Milky Way plane of satellites



Pawlowski+ 2012

The Andromeda plane

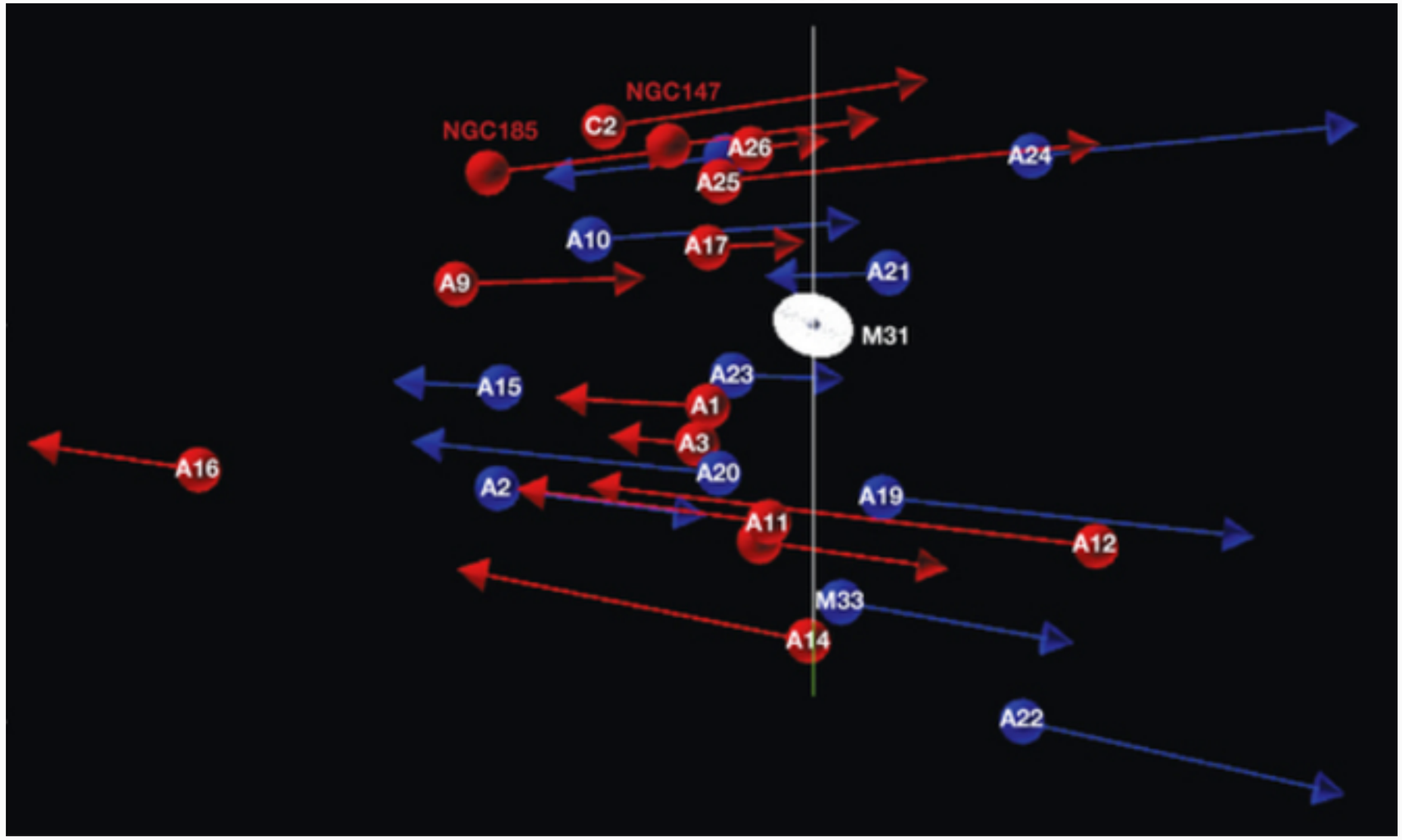


PAndAS view of the Andromeda's satellites.

Ibata+ 2013; Shaya & Tully 2013

The Andromeda plane

Preferred rotation

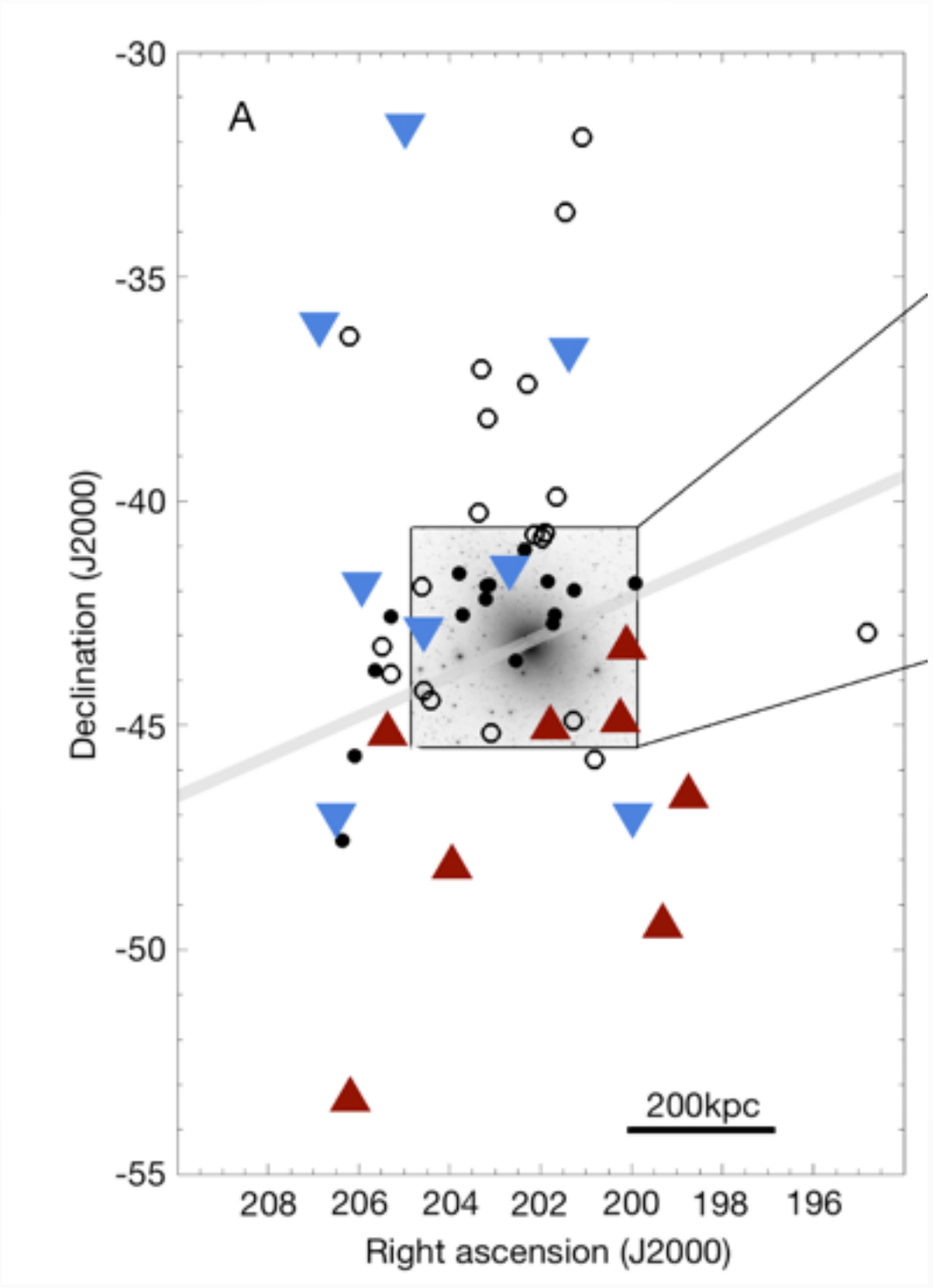


PAndAS view of the Andromeda's satellites.

Ibata+ 2013; Shaya & Tully 2013

The Centaurus-A plane

Spatially thin & preferred rotation



Mueller+ 2018

The incidence of MW and M31 satellite planes

	MW	M31
Satellites in the plane	**11** out of **11**	**15** out of **27**
Plane thickness	**19.6** kpc	**12.6** kpc
Same sense of rotation	**8** out of **11**	**13** out of **15**
Probability of the same exact system in LCDM	~**1** out of 10^3	~**1** out of 10^3

Is this a problem for LCDM ?

Ibata+ 2014; Pawlowski+ 2014

Testing against the LCDM paradigm

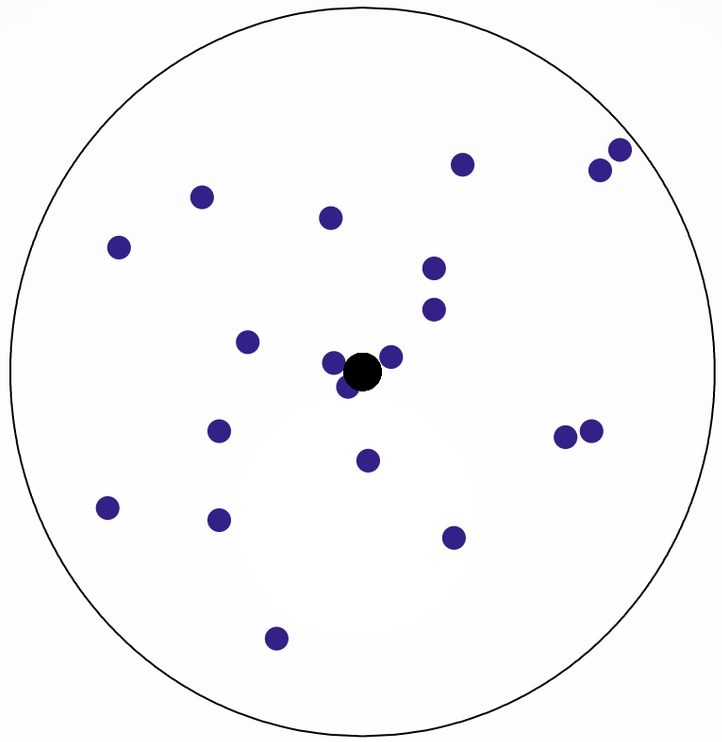
What is the probability within LCDM to obtain planes as extreme as those found in observations?

Testing against the LCDM paradigm

What is the probability within LCDM to obtain planes as extreme as those found in observations?

- Spatially thin
- High degree of coherent rotation

Identifying planes of satellites



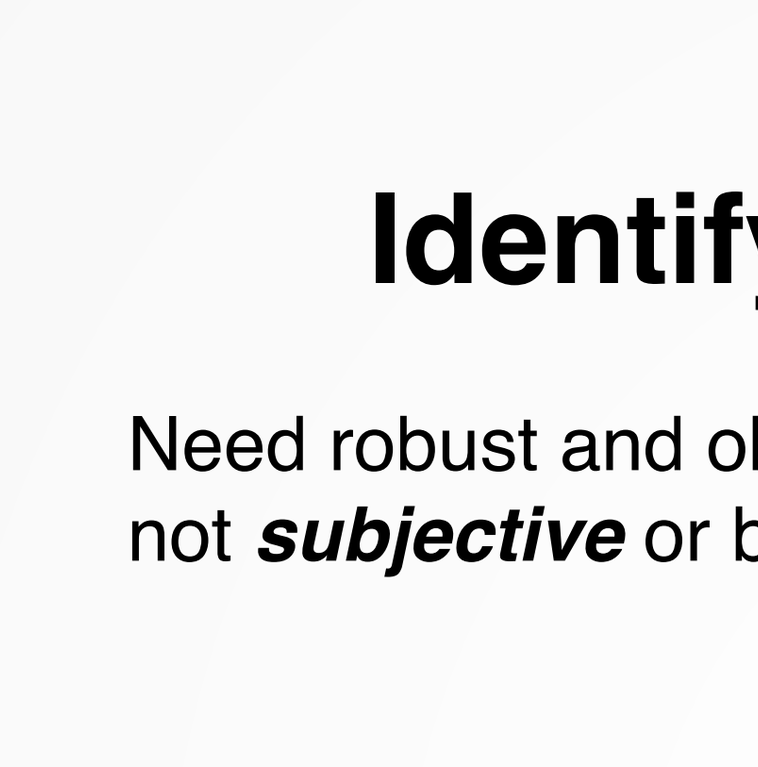
1. Does the system have a plane of satellites?

2. If so, which satellites are part of the plane?

Identifying prominent planes

Need robust and objective method for identifying planes that is not ***subjective*** or based on ***a posteriori*** information.

Which plane stands out the most?

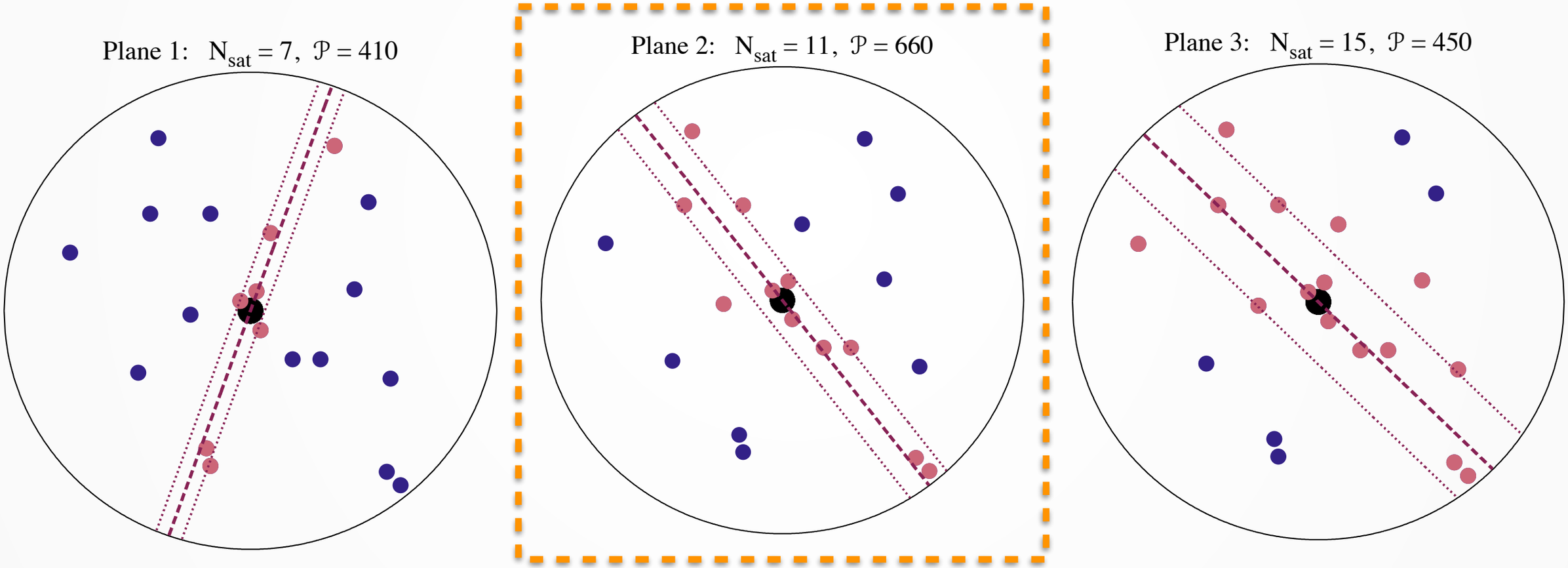


Define plane prominence:

$$\mathcal{P} = \frac{1}{\text{probability that it is due to a statistical fluctuation}}$$

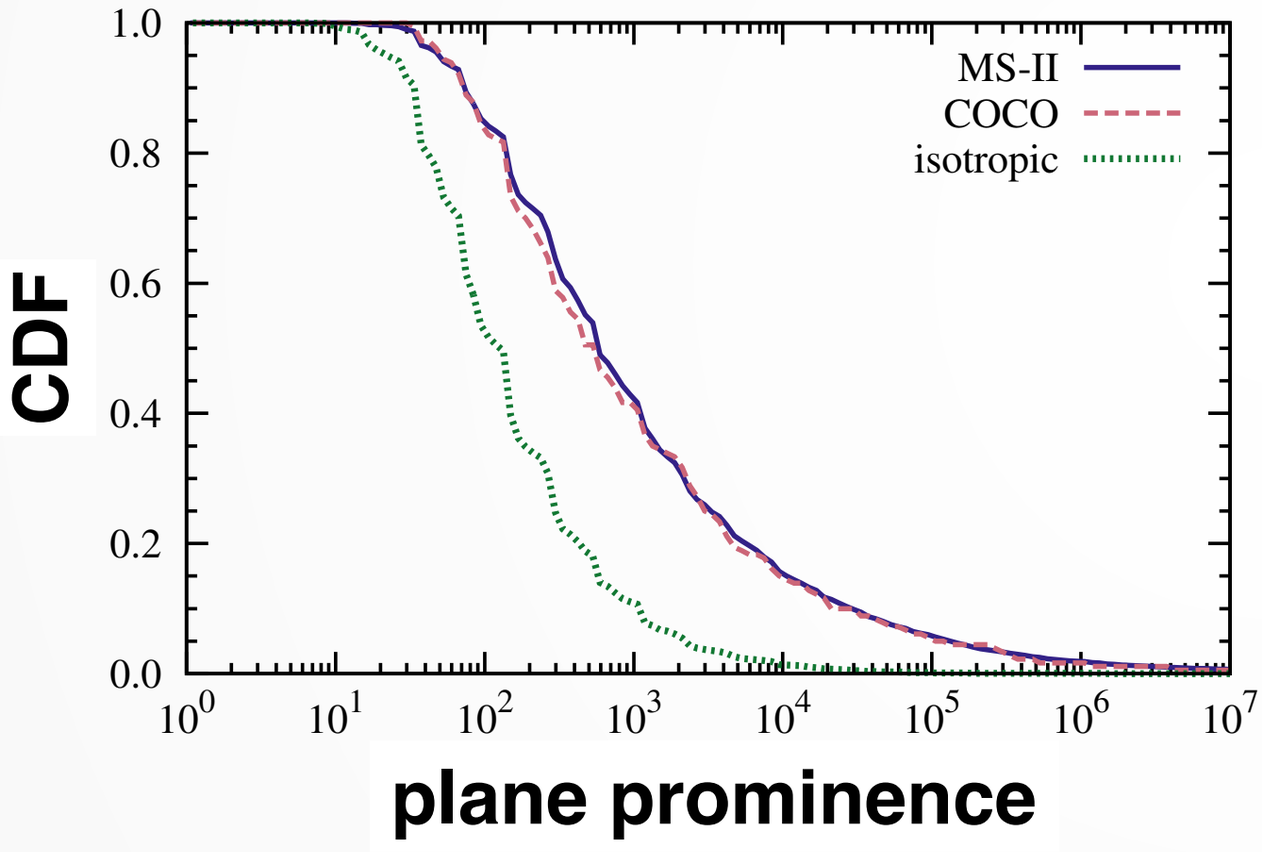
MC, Bose + 2015b

Identifying prominent planes



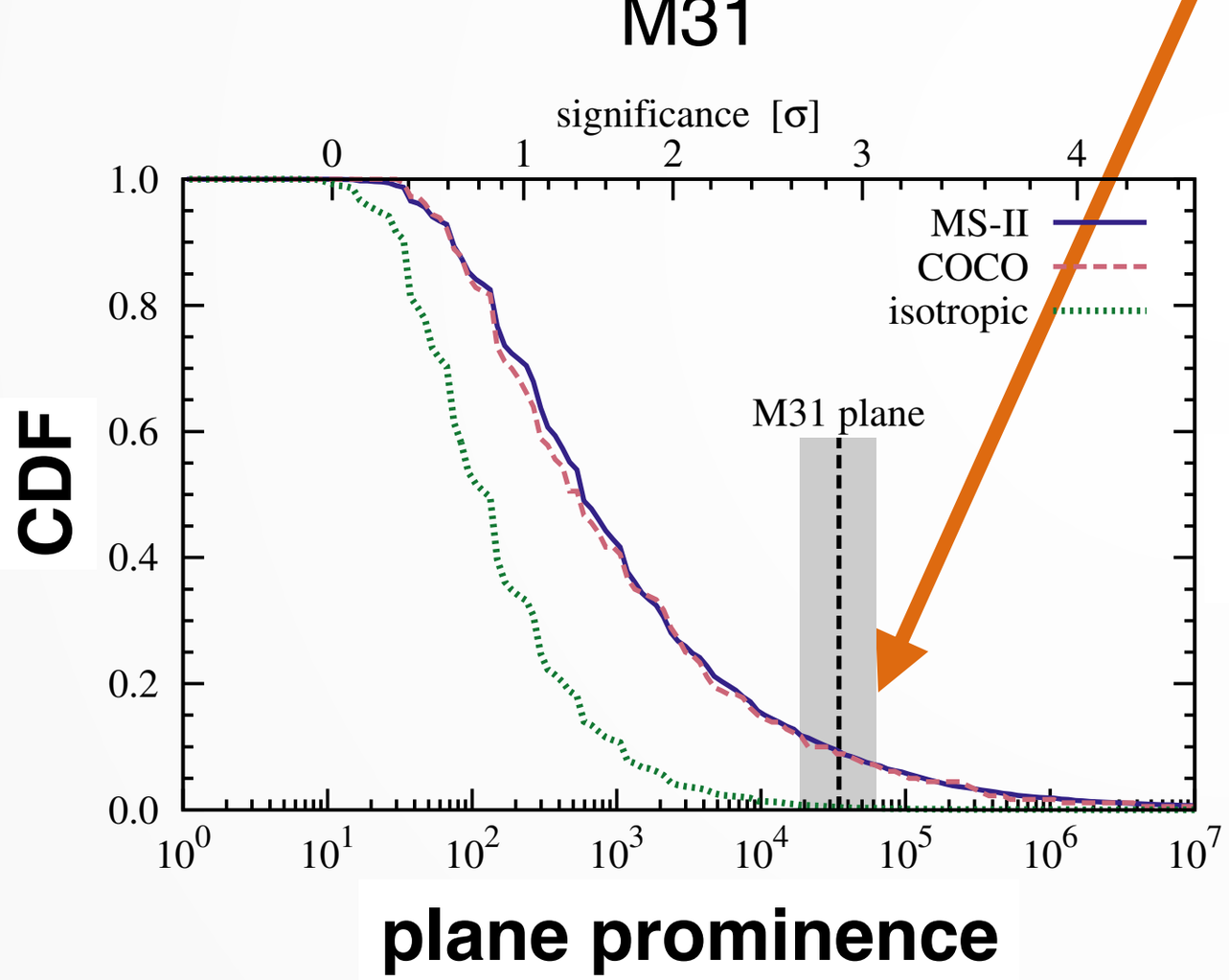
Each halo has a most prominent plane of satellites.
But, is this significant?

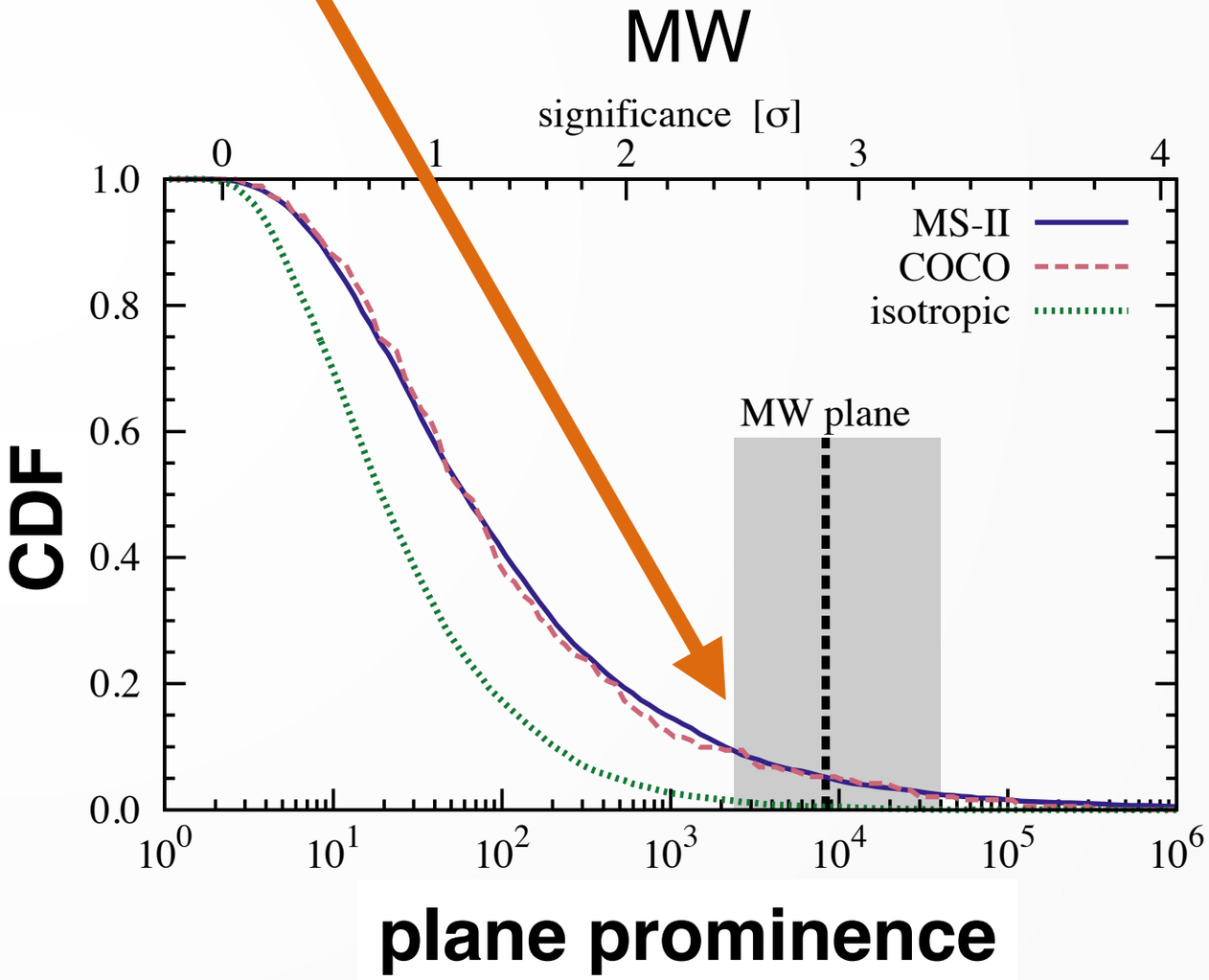
Planes of satellites



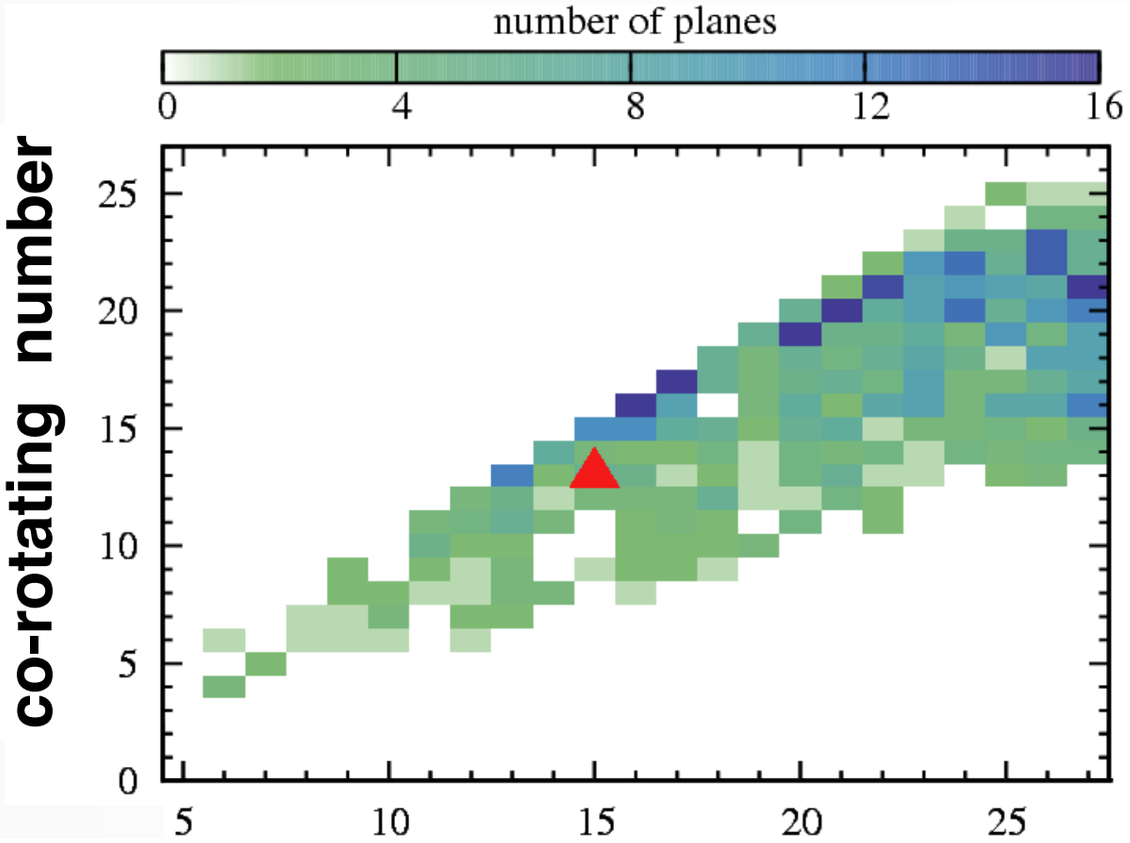
The Local Group planes

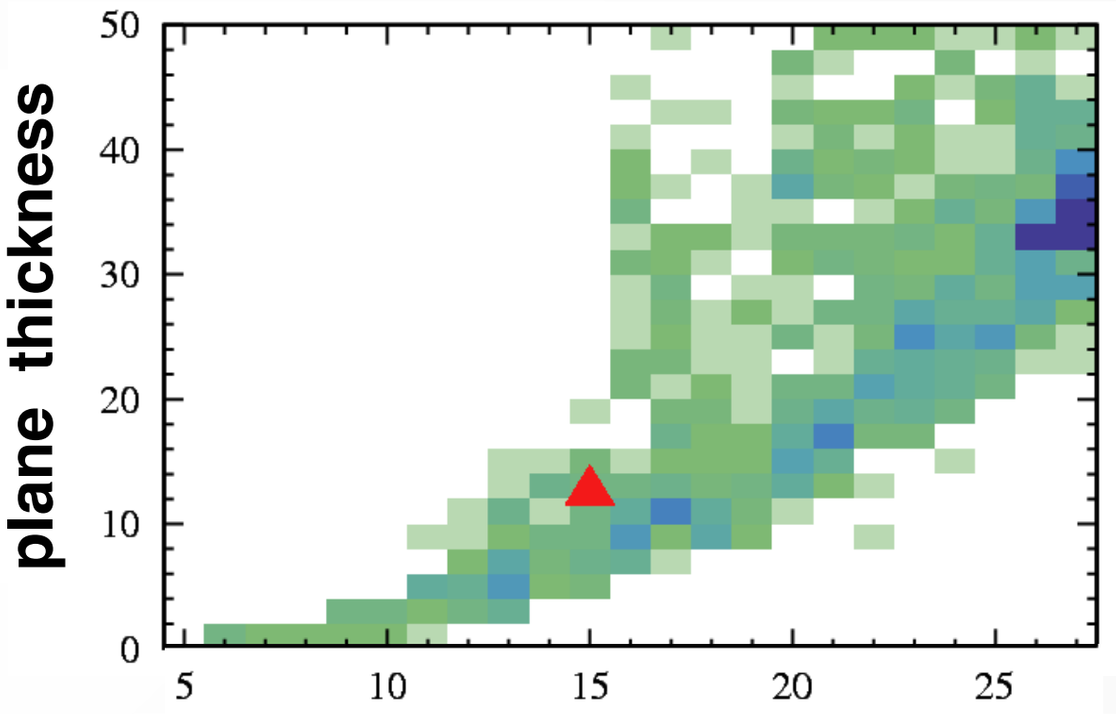
5-10% of LCDM systems
have more extreme planes





Properties of prominent planes





- Each plane is different, no two are the same.

In tension with LCDM?

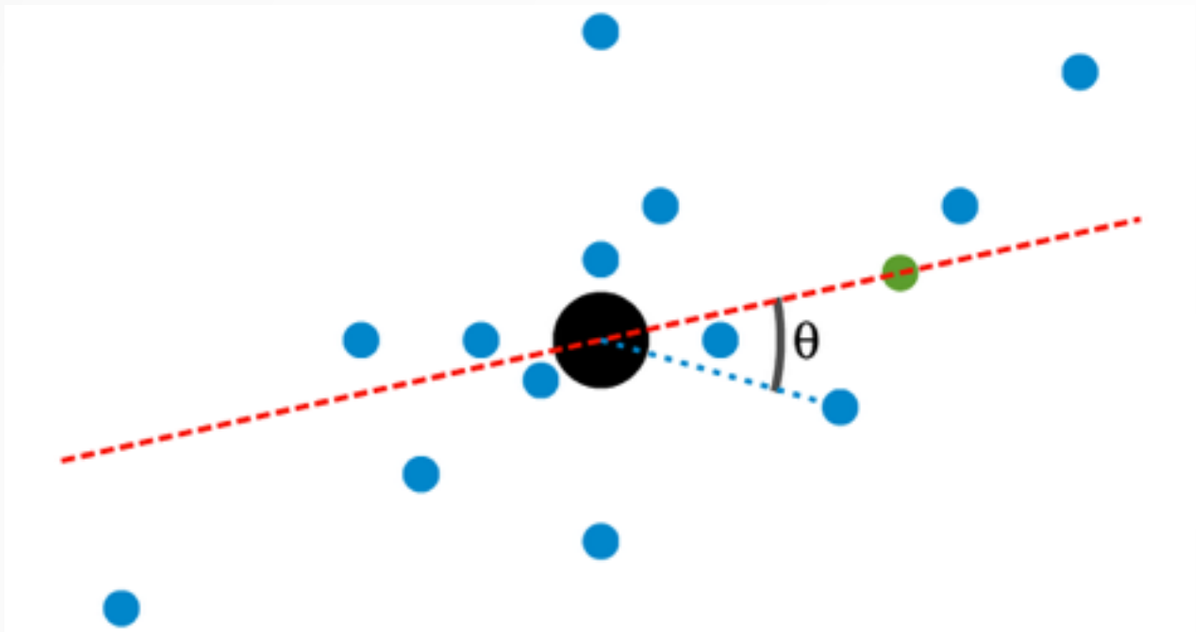
- **Milky Way:** **5%** **2.0 sigma**
- **Andromeda:** **10%** **1.6 sigma**
- **Centaurus-A:** **~10%** **~10%**

0.5 — 0.05 % (2.8–3.5 sigma)

What about tests for external SDSS galaxies?

MC, Wang, Frenk and Sawala 2015a

The spatial distribution



- Photometrically selected satellites
- Study anisotropies in the plane of the sky

MC, Wang, Frenk and Sawala 2015a

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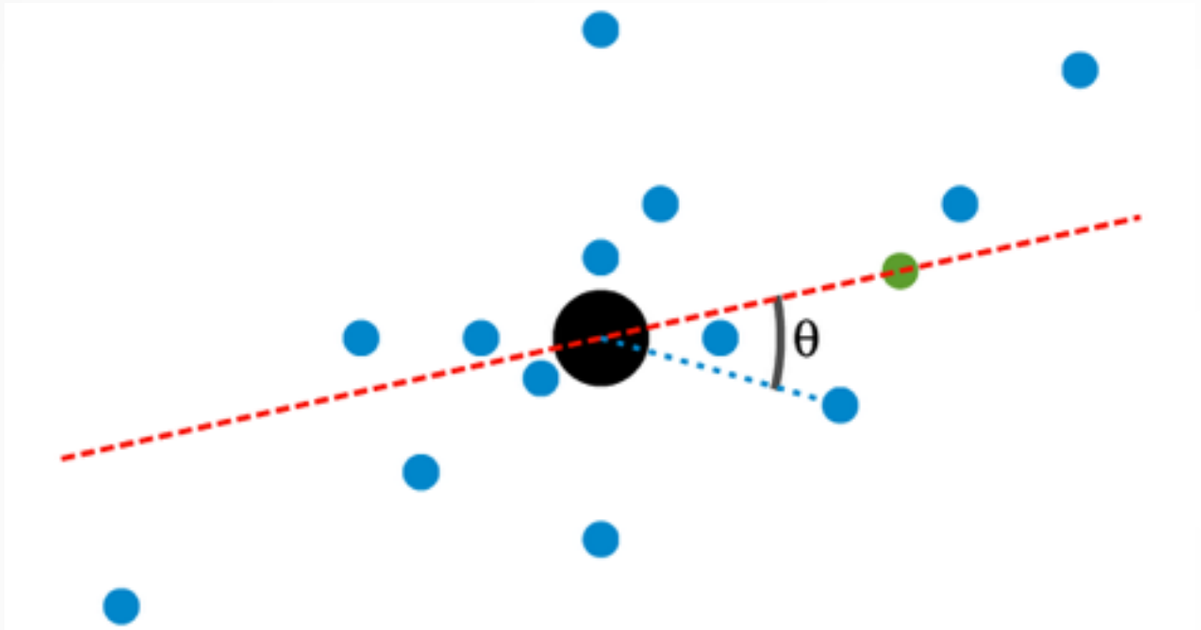

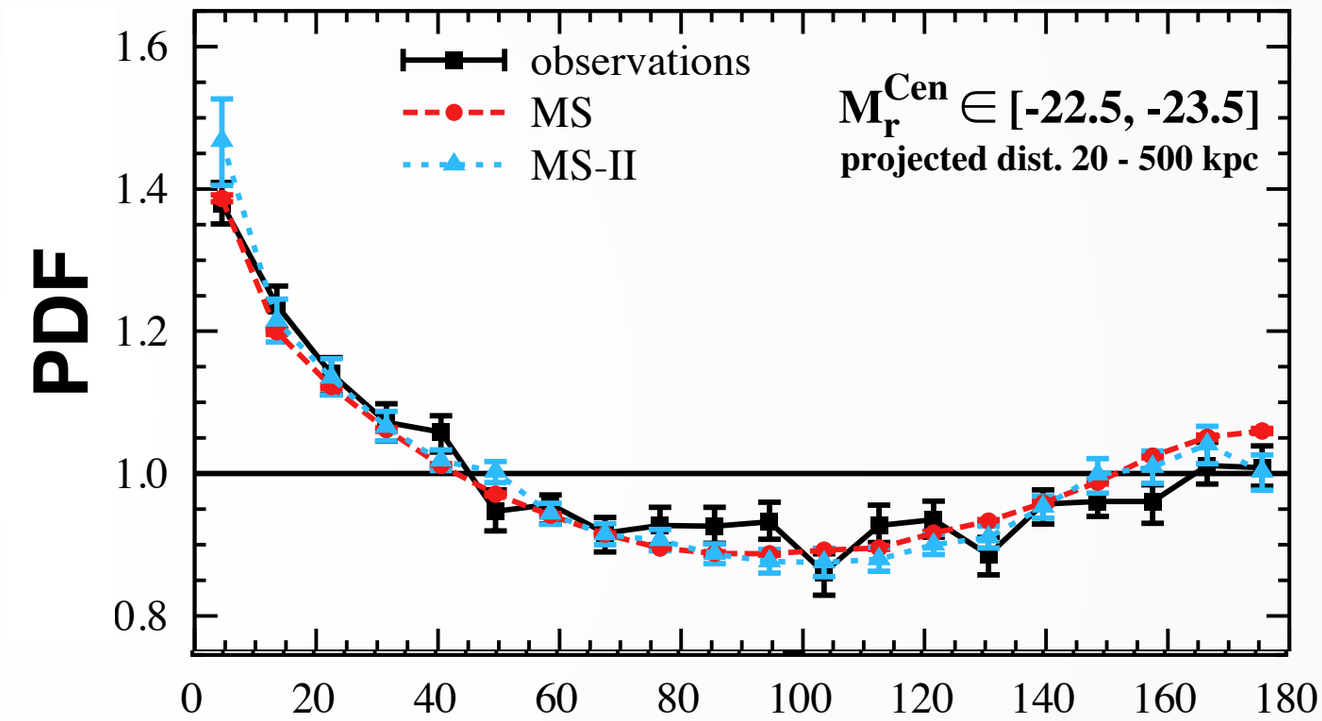

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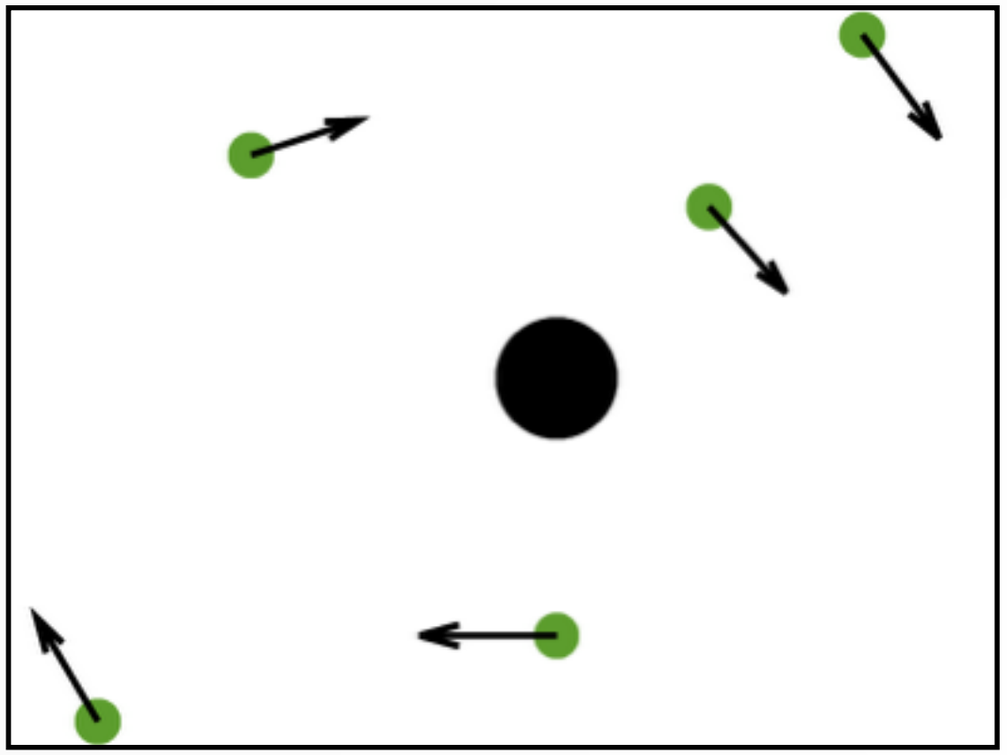
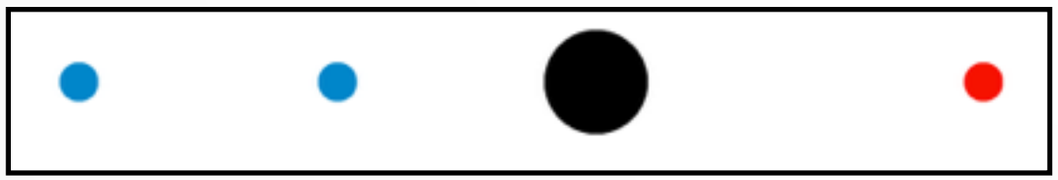
MC, Wang, Frenk and Sawala 2015a

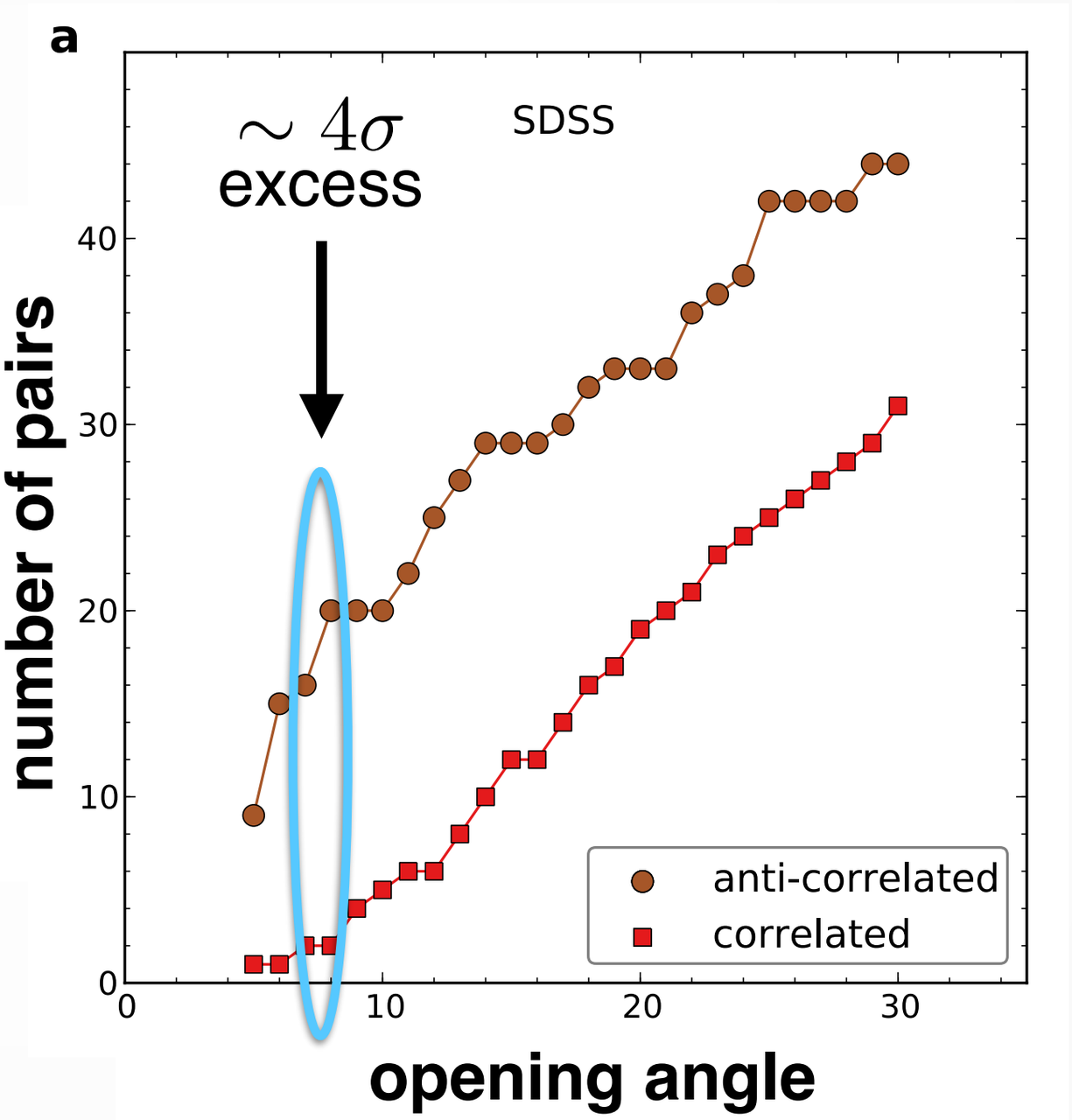
The kinematical distribution

face-on view



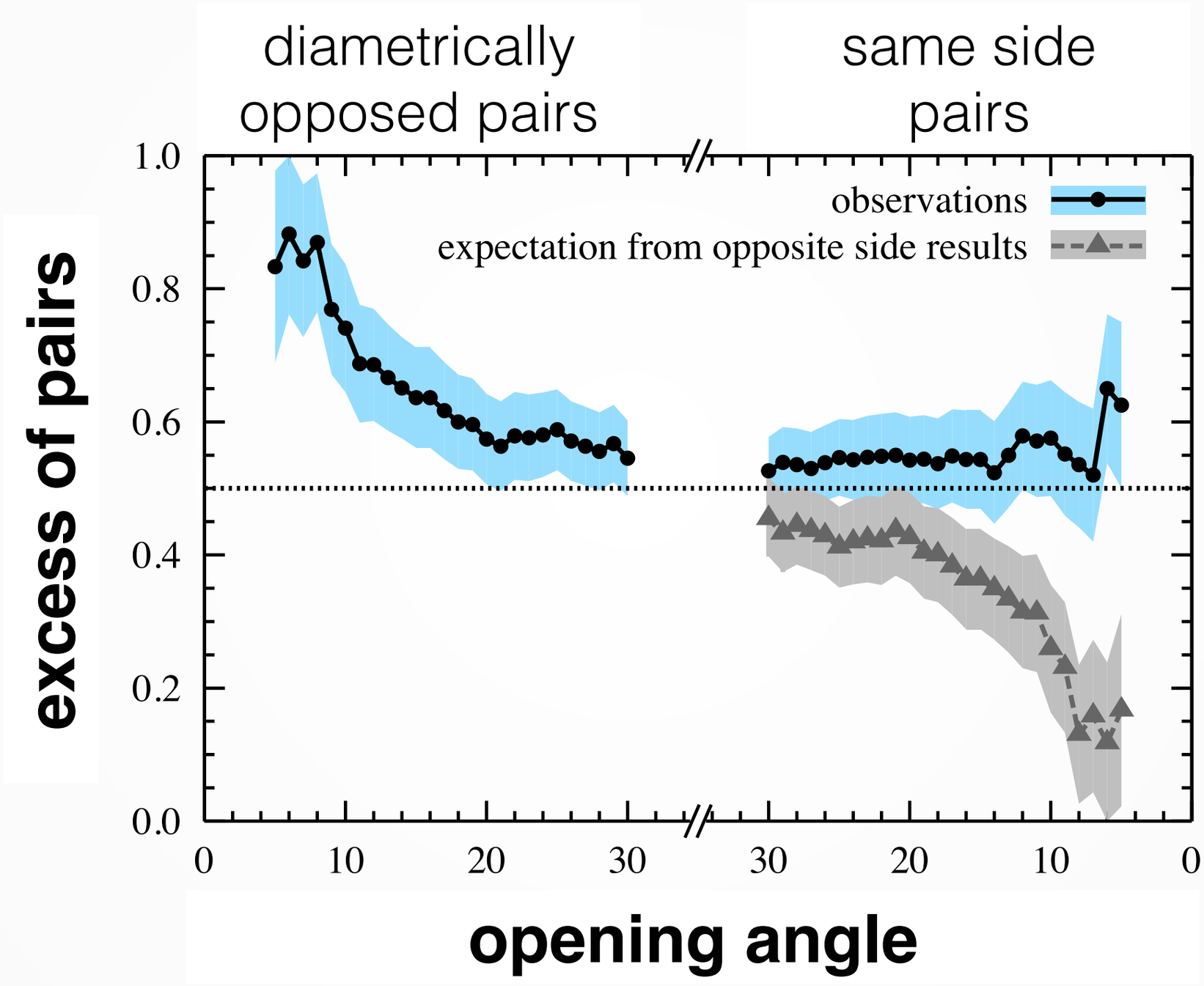
edge-on view





Ibata+ 2014a

The kinematical distribution



MC, Wang, Frenk and Sawala 2015a

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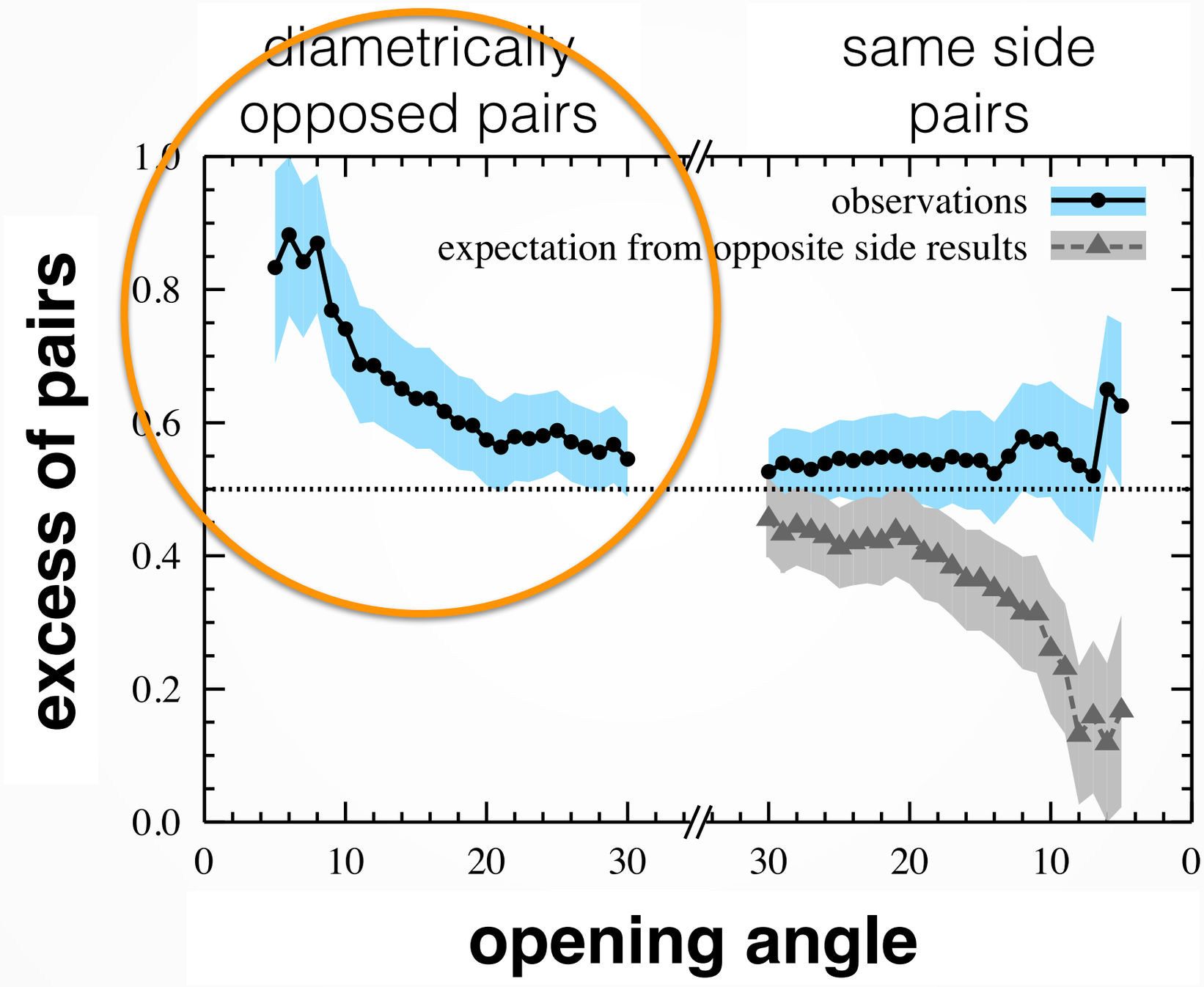

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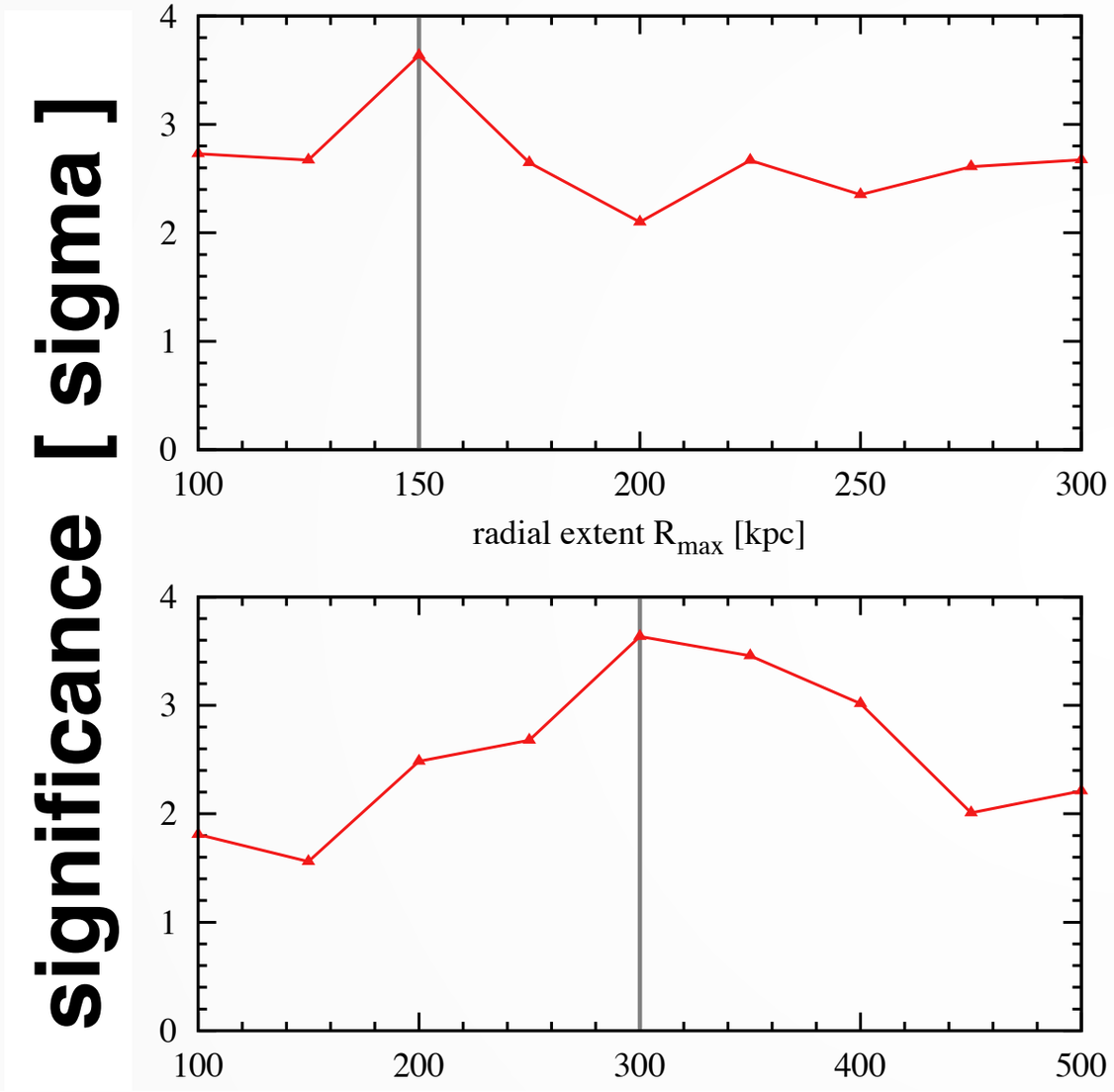


The significance of the original detection ($\sim 4\sigma$) decreases sharply when accounting for the **look-elsewhere effect**:

$\lesssim 2\sigma$

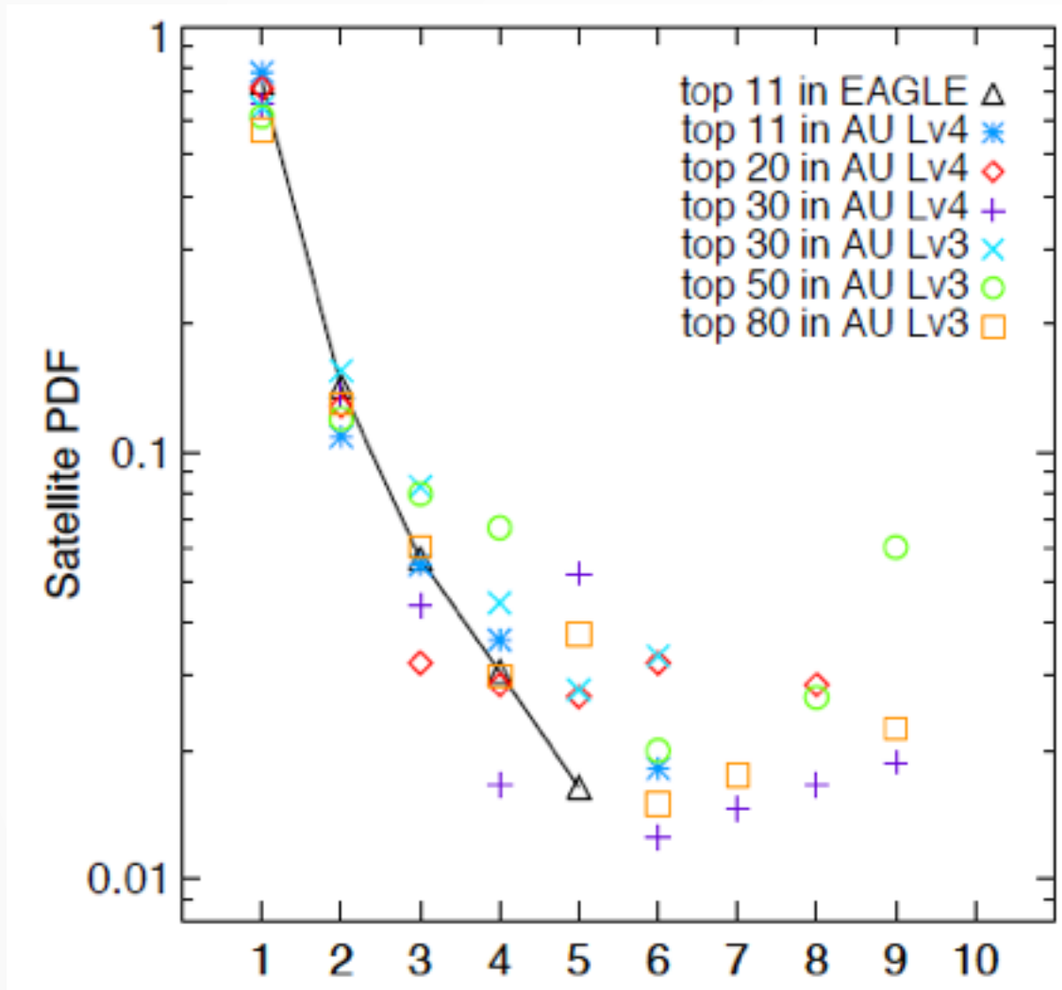
MC, Wang, Frenk and Sawala 2015a

How do planes of satellites form?

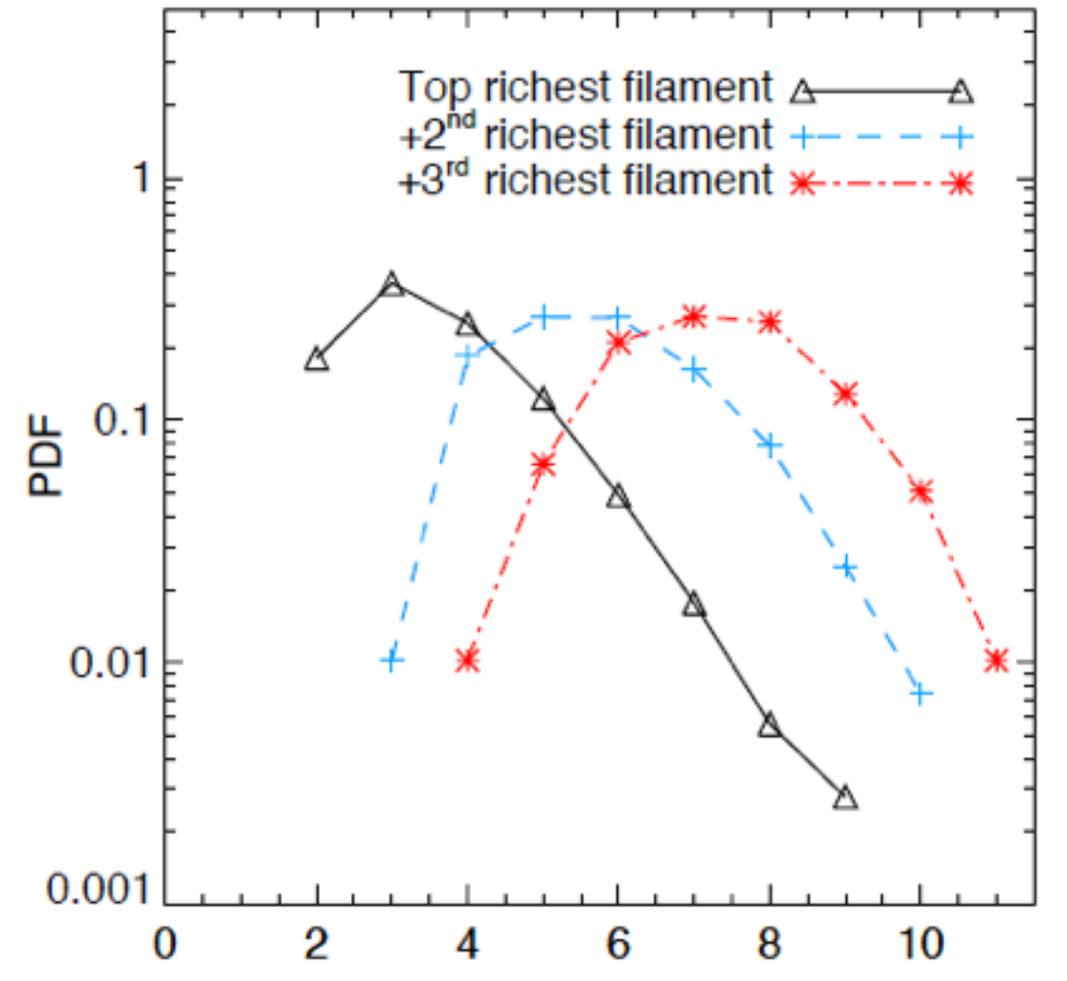
MC, Wang, Frenk and Sawala 2015a

Correlated infall

1. Accretion of dwarf galaxy groups



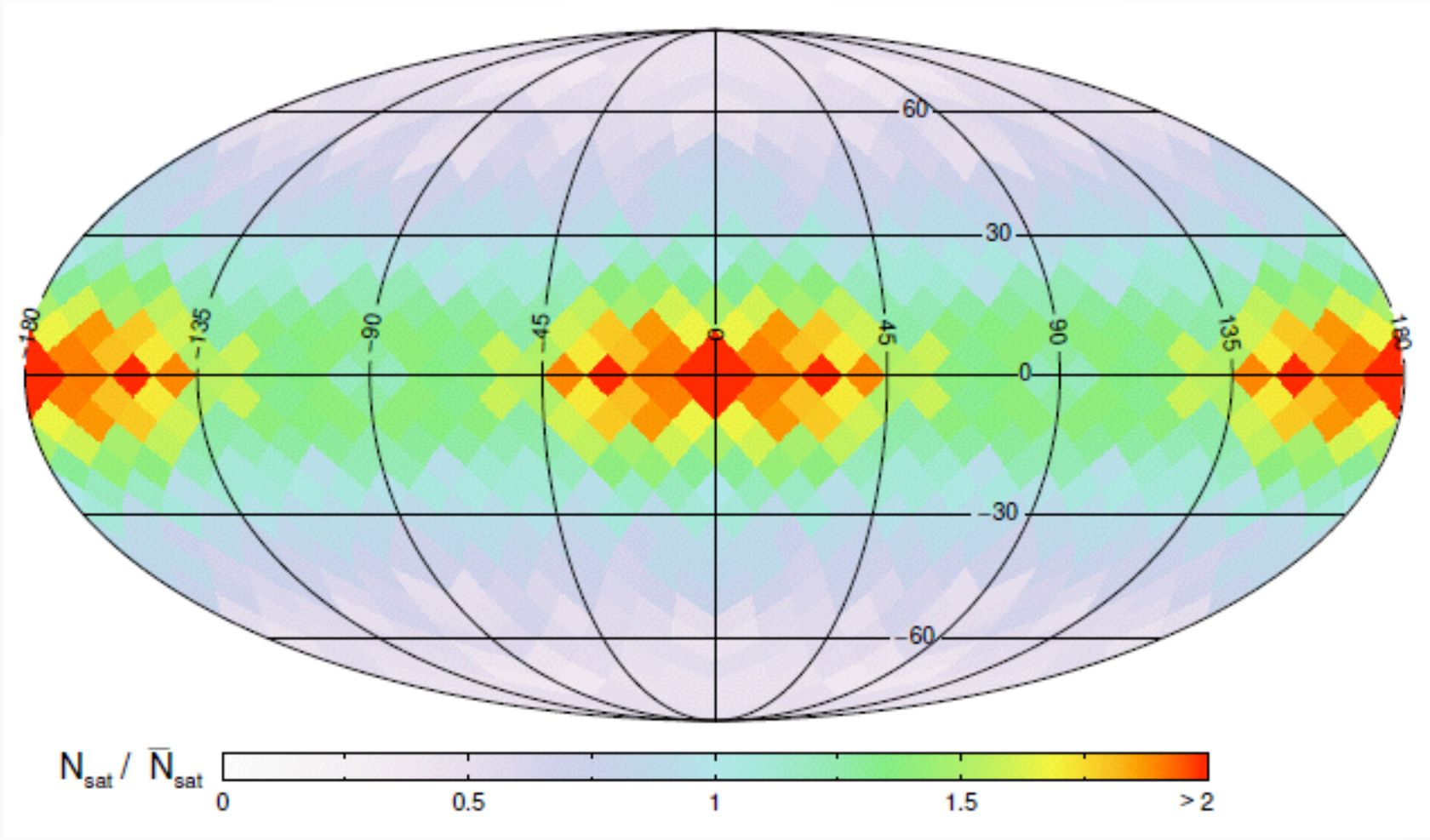
2. Accretion along the cosmic web filaments



Shao, MC+ (2017)

Correlated infall

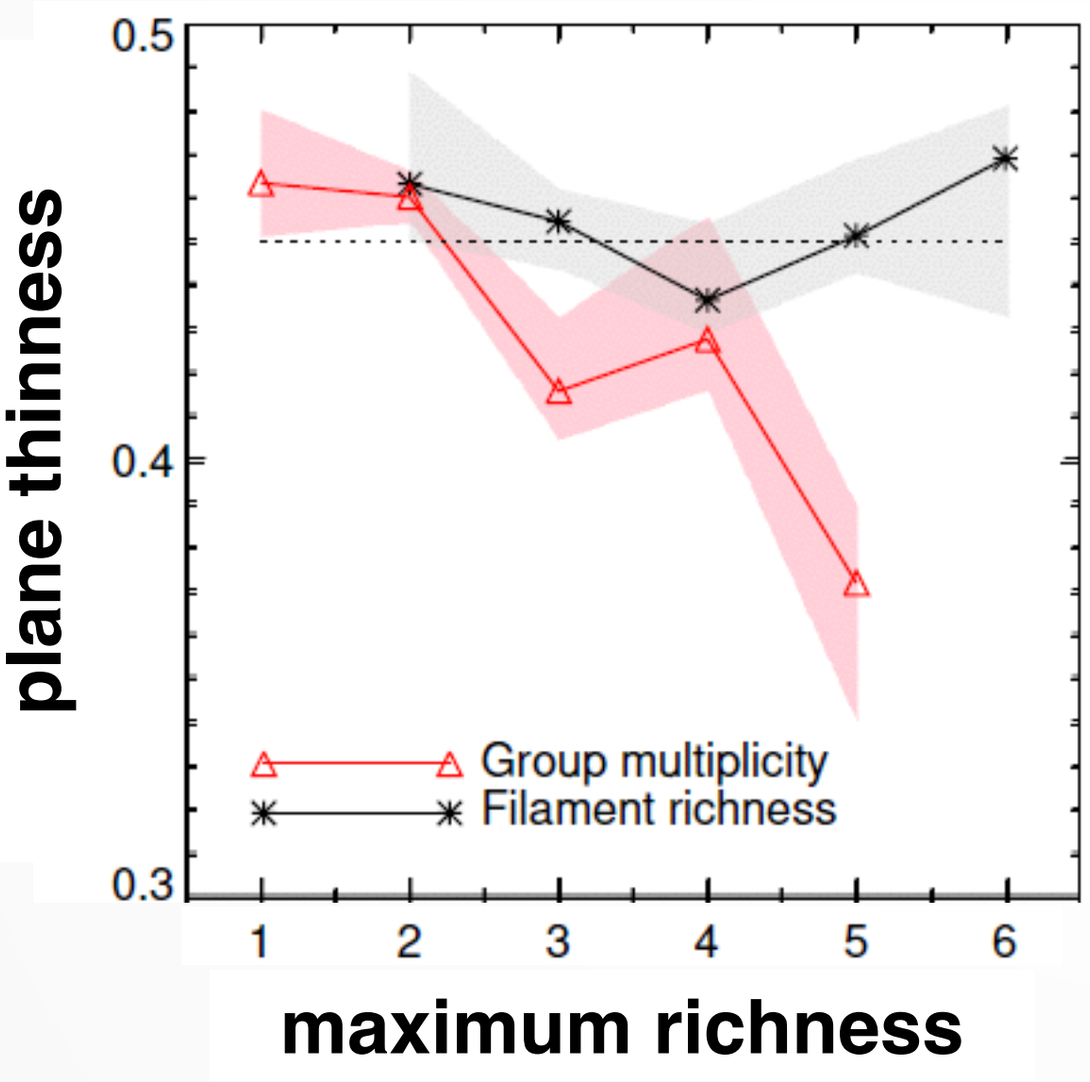
Accretion of satellite galaxies is highly anisotropic, with a preferential accretion direction along the halo major axis.

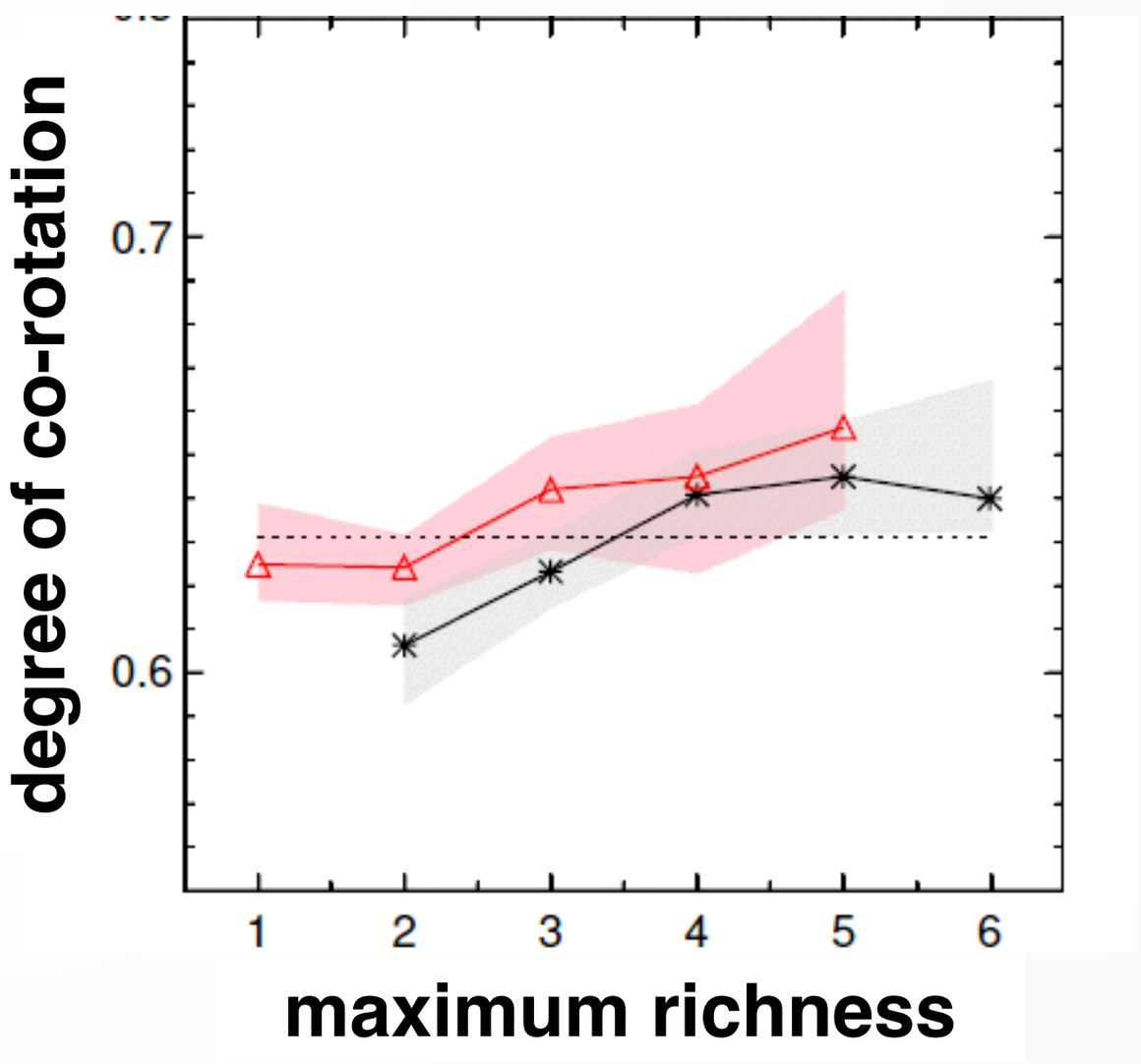


Shao, MC+ (2017)

Correlated infall

Can the plane of satellites be explained by the accretion of one rich group or many satellites along the same filament?

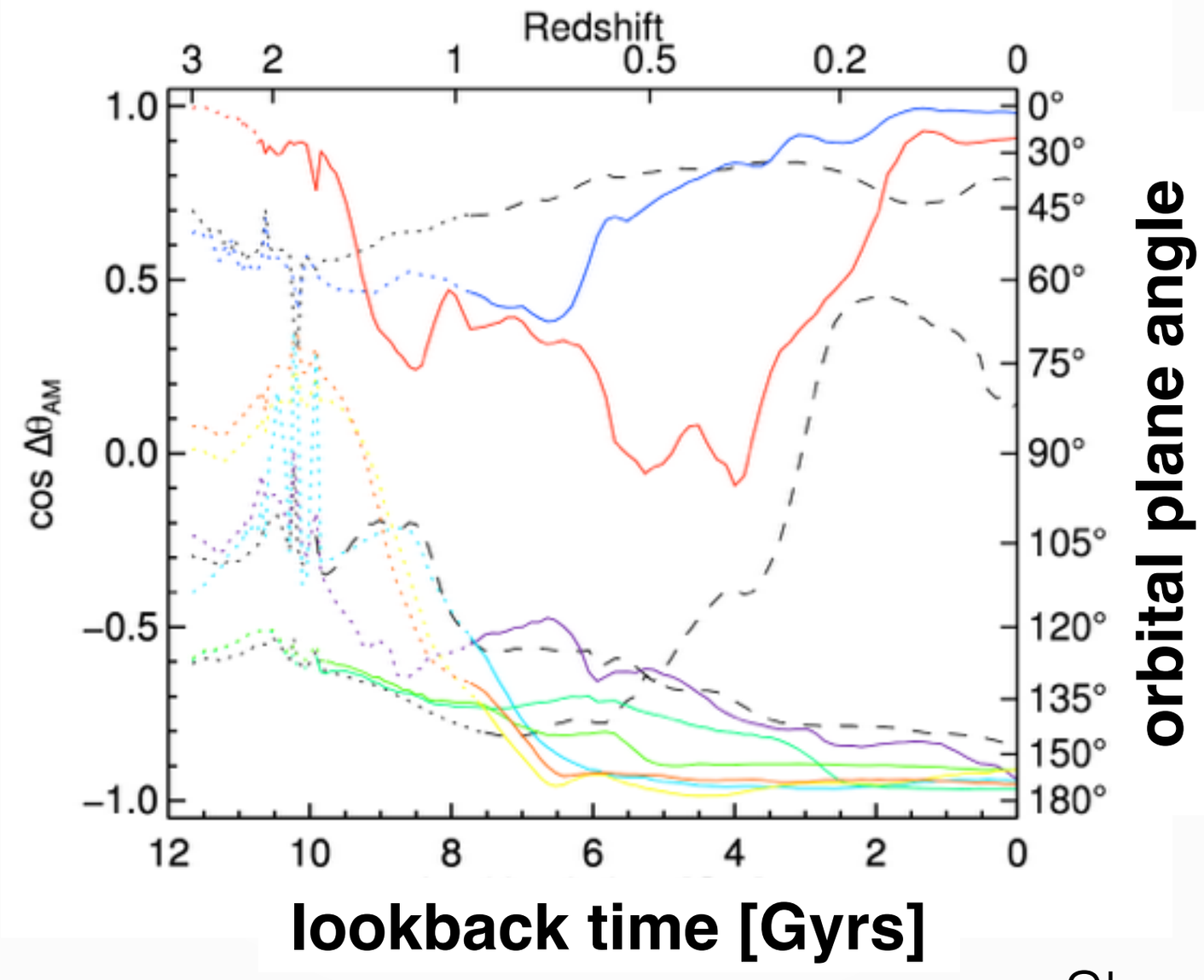




Shao, MC+ (2017)

Orbit evolution inside the host

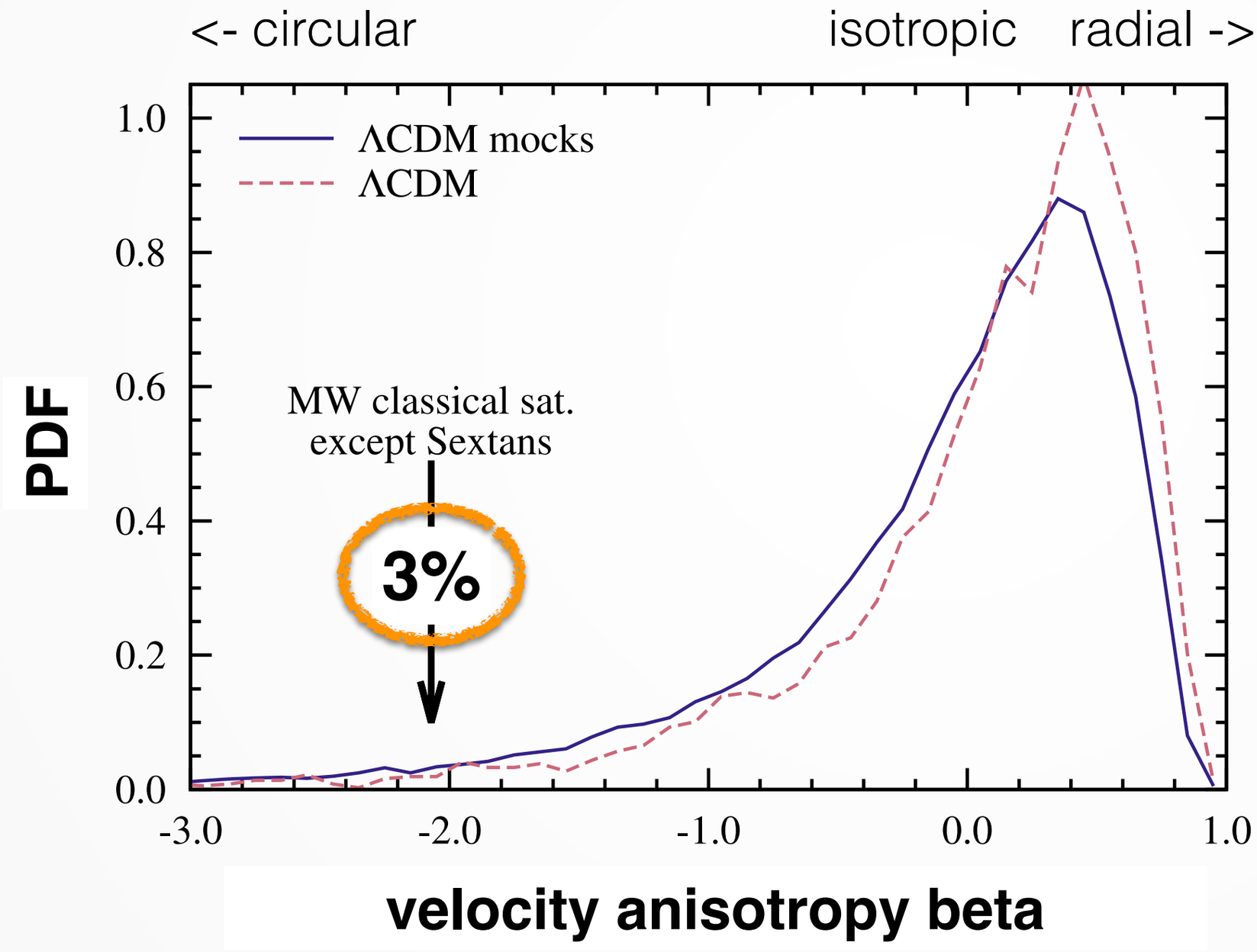
Can the plane of satellites be explained by the accretion of one rich group or many satellites along the same filament?



Shao, MC+ (in prep)

The tangential velocity excess

Satellites velocity anisotropy

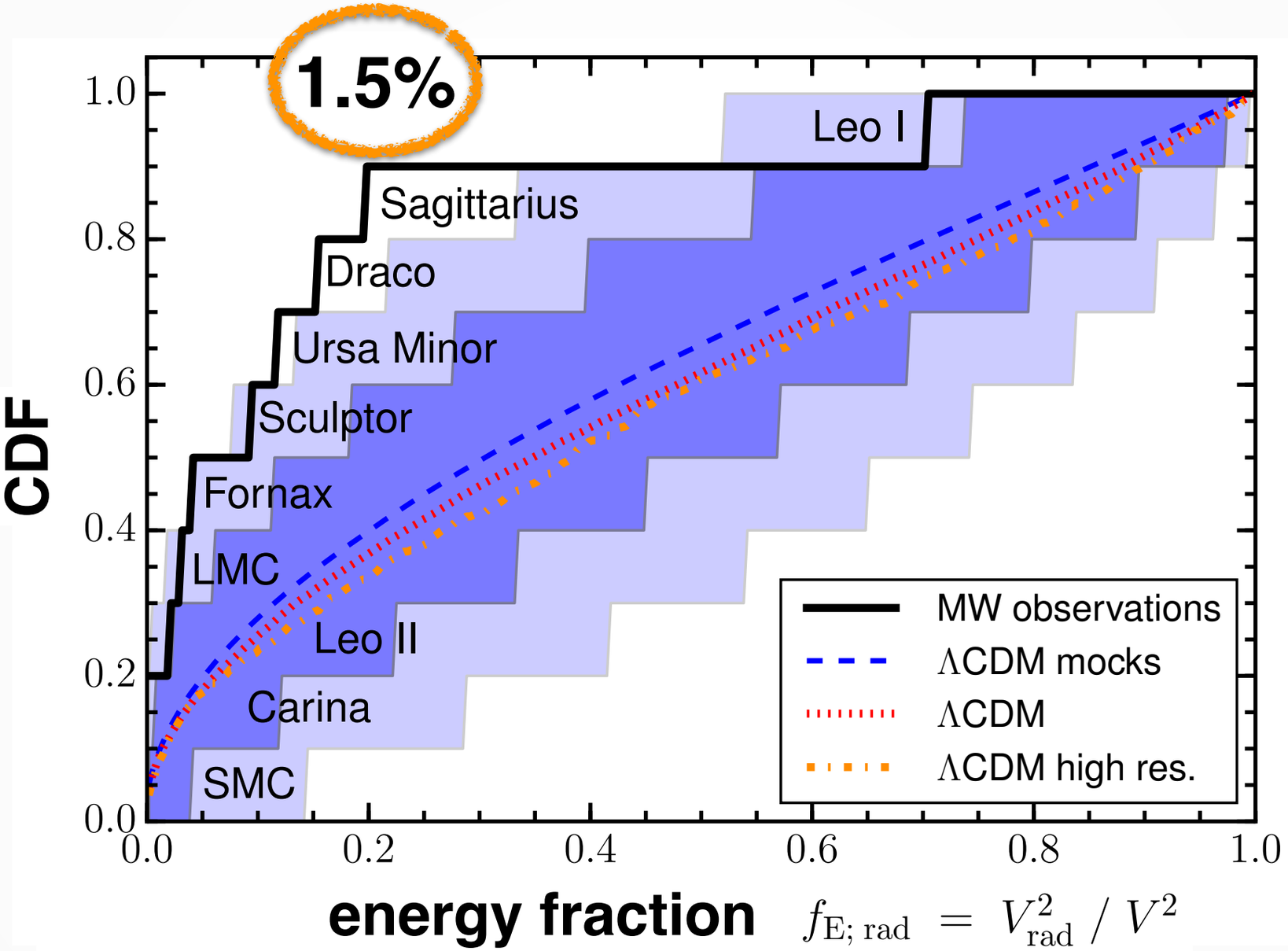


Velocity anisotropy:

$$\beta = 1 - \frac{\sum_i V^2_{\mathrm{tan;\,i}}}{2\sum_i V^2_{\mathrm{rad;\,i}}}$$

MC & Frenk 2017

Individual satellites



What could give rise to more circular orbits?

- Satellites with cored profiles since they are more easily disrupted by the Galactic tides.

- Self-interacting dark matter. This could potentially lead to a faster disruption of satellites on radial orbits.

- Unusually early accretion of the Galactic satellites. Dynamical friction can act for a longer time resulting in more circular orbits.

Summary

- Each of the observed “plane of satellites” for the three systems where observations are available are within the ~10% tail of the LCDM predictions.

- The Milky Way satellites have more circular orbits than expected, with only 1.5% of the LCDM systems being more extreme.

- So what do the two “problems” tell us about the Universe?
    A. The Local Group is very atypical. Which properties are unusual and how do they compare to the typical LCDM halo?
    B. Breakdown of the cosmological model on galactic scales.

Thank you!