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Joint Satellite Distributions in the Milky Way and Andromeda

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ABSTRACT
We focus on the spatial distribution of bright ($M_V < -8$) satellites and pairs of galaxies with similar masses, isolation and kinematic configurations as the Local Group.

Key words: Galaxies: halos — Galaxies: high-redshift — Galaxies: statistics — Dark Matter — Methods: numerical

1 INTRODUCTION

2 OBSERVATIONAL CHARACTERISTS OF ANDROMEDA AND THE MILKY WAY

3 LOCAL GROUP ANALOGUES IN THE ILLUSTRIS SIMULATION

We use publicly available data from the Illustris Project (**?**). This suite of cosmological simulations, performed using the quasi-Lagrangian code AREPO (**?**), follow the coupled evolution of dark matter and gas and includes parametrizations to account for the effects of gas cooling, photoionization, star formation, stellar feedback, black hole and super massive black hole feedback.

The simulation volume is a cubic box of 75 $\mathrm{Mpc}\,h^{-1}$ on a side. The cosmological parameters correspond to a ΛCDM cosmology consistent with WMAP-9 measurements (**?**).

We extract halo and galaxy information from the Illustris-1 simulation which has the highest resolution in the current release of the Illustris Project. Illustris-1 has 1820^3 dark matter particles and 1820^3 initial gas volumen elements. This corresponds to a dark matter particle mass of $6.3 \times 10^6 \mathrm{M}_\odot$ and a minimum mass for the baryonic volume element of $8.0 \times 10^7 \mathrm{M}_\odot$. The corresponding spatial resolution is 1.4 kpc for the dark matter gravitational softening and 0.7 kpc for the typical size of the smallest gas cell size.

3.1 Sample Selection: Local Group Analogues

We build a sample of Local Group Analgues (LGA) by performing a selection on the stellar mass and isolation properties of the galaxies in the simulation. The conditions to select LGA galaxies are the following.

- LGA galaxy pairs are composed by galaxies with stellar mass in the range $1 \times 10^{10}\mathrm{M}_\odot < M_\star < 1.5 \times 10^{11}\mathrm{M}_\odot$.
- For each galaxy A we find its closest galaxy B, if galaxy A is also the closest to halo B, the two halos are considered as a pair. Another way to phrase this selection is that pairs do not have neighbors closer than the pair's separation.
- The distance between the galaxies' center of mass must be in the range 500 kpc $< d_{AB} <$ 1500 kpc.
- For each galaxy in the pair there cannot be a galaxy more massive than the lightest galaxy in the pair within a radius of 2 Mpc.
- Each galaxy in the pair must have at least 5 satellites brighter than $M_V < -9$.

We find 11 pairs with these conditions. Figure 1 shows the stellar masses, maximum circular velocities and the number of bright satellites for all the pairs in the sample.

4 SATELLITE SPATIAL DISTRIBUTION AND ALIGNMENT

We characterize the bright ($M_V < -9$) satellite spatial distribution with four different metrics.

(i) The inertia tensor.
(ii) Fitting planes.
(iii) Velocity Anisotropy.

I what follows we describe the details of implementation of each metric.

4.1 Inertia Tensor

First, by computing the inertia tensor defined as

$$\bar{\mathbf{I}} = \sum_{k\in V} [(\mathbf{r_i} - \mathbf{r_0})^{\mathbf{2}} \cdot \mathbf{1} - (\mathbf{r_i} - \mathbf{r_0}) \cdot (\mathbf{r_i} - \mathbf{r_0})^{\mathbf{T}}], \tag{1}$$

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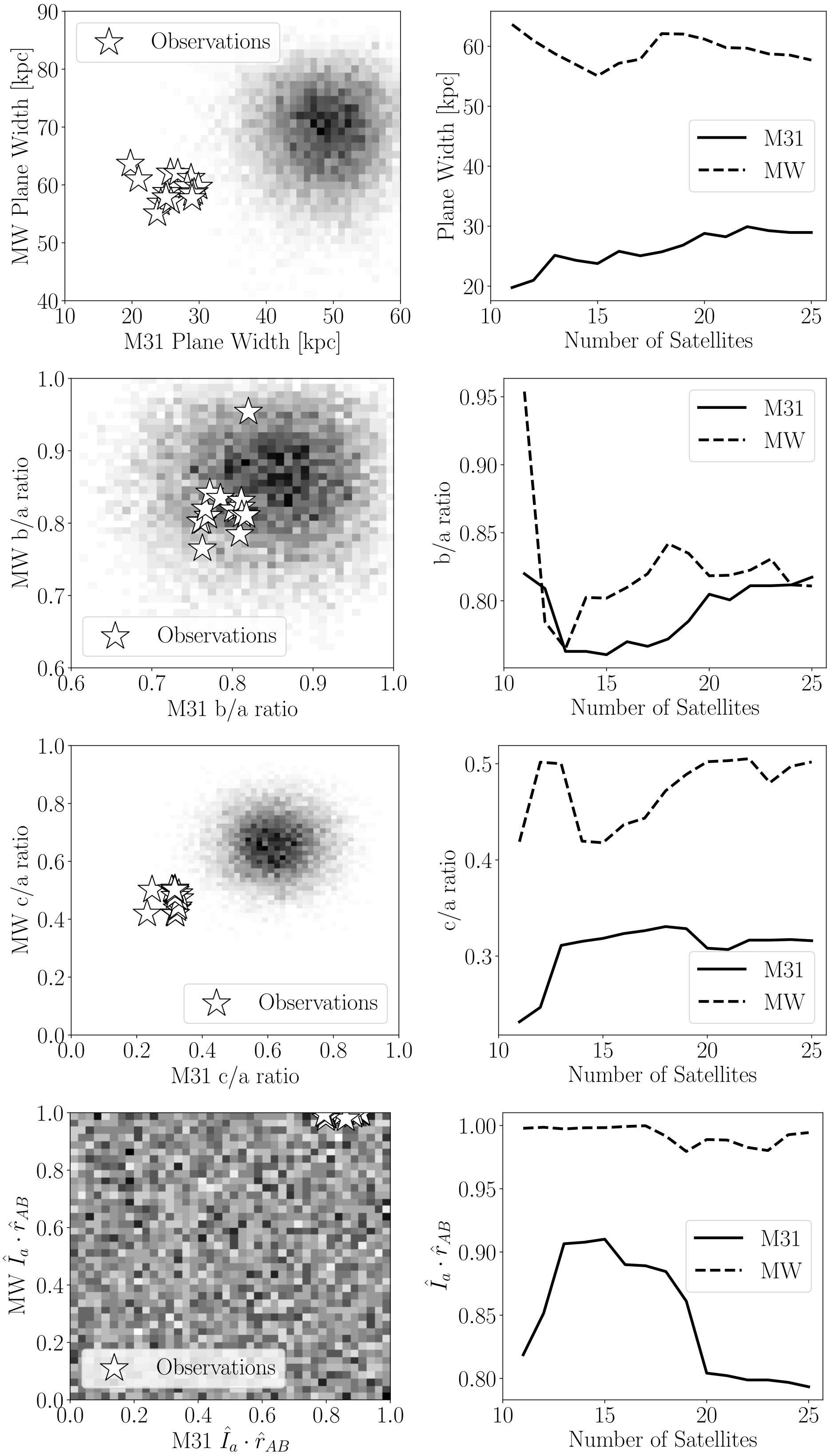

Figure 1. Basic characteristics for the MW and M31 satellite systems

where k indexes the set of satellites of interest $\mathbf{r_k}$ are the satellites' positions, $\mathbf{r_0}$ is the positions pof the host DM halo, $\mathbf{1}$ is the unit matrix, and $\mathbf{r}^T$ is the transposed vector $\mathbf{r}$. We finally compute the eigenvalues, $a > b > c$, and corresponding eigenvectors, $\hat{I}_a$, $\hat{I}_b$, $\hat{I}_c$, of this tensor. In the case of a sheet-like configuration the vector perpendicular to the sheet would be signaled by, $\hat{I}_a$, the eigenvector of the largest eigenvalue.

4.2 Plane fitting

We fit satellite planes around each galaxy in the pair by randomly generating 10000 unit vectors homogeneously distributed over the sphere. Each vector represents the direction perpendicular to a plane passing through the main galaxy's center of mass. We compute the dot product of this unit vector with the position vector for each satellite, this gives us the satellite distances to the plane. The best plane is determined by the vector that gives the lowest sample standard deviation in the satellite distances to the plane. In the set of unit vectors to be considered we also include the vector $\hat{I}_a$, which provides the exact solution in the case of 3 satallites. We take the sample standard deviation as a measure of the plane's width and denote by $\hat{p}$ the unit vector defining the direction perpendicular to the best plane. We also store the median of the satellite distances to the plane as a measure of the plane's location with respect to the central galaxy.

4.3 Velocity Anisotropy

The velocity anisotropy paramenter, β is defined as

$$\beta = 1 - \frac{\sum_i v^2_{\rm tan;i}}{2\sum_i v^2_{\rm rad;i}}, \tag{2}$$

where $v_{\rm tan/rad;i}$ correspond to the tangential/radial velocity of the i-th satellite with respect to the central galaxy.

5 RESULTS

Symbol	Units	Description
$M_\star$	$10^{10}\mathrm{M}_\odot$	Stellar mass of the central galaxy
N_s		Number of satellites with $M_V < -9$
$a > b > c$		Inertia tensor eigenvalues.
$\hat{I}_a$, $\hat{I}_b$, $\hat{I}_c$		Inertia tensor eigenvectors.
β		Satellite Velocity Anisotropy
σ_s	kpc	Plane width
$\hat{r}_{AB}$		Unit vector in the direction to the galaxy companion

Table 1. Overview of the parameters computed for each central galaxy and its satellite system.