Submitted for publication in ApJ
Preprint typeset using LaTeX style emulateapj v. 01/23/15

SATELLITE ALIGNMENTS IN GALAXY PAIRS

Verónica Arias [1], Jaime E. Forero-Romero [2]
[1]Departamento de Física, Universidad de los Andes, Cra. 1 No. 18A-10, Edificio Ip, Bogotá, Colombia

Submitted for publication in ApJ

ABSTRACT

Alineaciones.

Subject headings: Galaxies: halos — Galaxies: high-redshift — Galaxies: statistics — Dark Matter — Methods: numerical

1. INTRODUCTION

Since the early works of (el que libeskind dice que habl de eso primero) and Lynden-Bell (1976), the observed anisotropic distribution of satellite galaxies in the Local Group has been a key point in the discussion of galaxy formation models within ΛCDM cosmology. These pioneer papers described that the then known satellite galaxies of the Milky May (MW) were distributed roughly following the plane that contained the Magelanic clouds and their stellar tails. This anisotropic distribution was further studied in the work of Pawlowski et. al. (2012), where they included all the known MW satellite galaxies (XXX more than in the original Lynden-Bell paper) as well as some MW globular clusters, and found that they are all contained in what they call a "Vast Plane Of Satellites" (VPOS). This structure is around 30kpc thick and is perpendicular to the stellar disc of the MW galaxy. This plane of satellites was considered a rarity until the PAndAS survey of the Andromeda (M31) galaxy and its halo (missing reference on the survey) provided a complete sample of the satellite galaxy population (above a XXXX magnitude) of our neighboring galaxy, allowing their consistent distance estimations (Conn et al 2012). In a groundbreaking work, Ibata et. al. (2013) found that 15 out of the 30 satellites are in a planar structure that is 15kpc thick and has an extension of 400kpc. Additionally, from line of sight velocity measurements, they found that the structure has an apparent coherent rotation, with the satellites south of M31 moving away from us and those north of M31 coming towards us. This apparent organized rotation of satellite galaxies was also statistically found to occur in diametrically opposed pairs of satellites from the SDSS (Ibata et al 2014), although this results were contested in a follow up paper by Cuatun et al (2014).

These discoveries of the planes in M31 and the MW were followed by the remark from Shaya et al (2013) that the other satellite galaxies in M31 could be part of a second plane, further reinforcing the idea that satellites in the local group are not isotropically distributed. Despite the challenges in estimating distances to the satellites galaxies, Tully et al. managed to go beyond the local group and found two planes of satellites galaxies in Centaurus A, making a clearer case for the planes of satellites¿in all the galaxies where distance measurements could be performed evidence of satellite planar structures have been found.

These observed planes present a challenge for current galaxy formation models (Pawlowski et. al 2014)

A comparison of the distribution of satellite galaxies around Andromeda and the results of ΛCDM simulations (Bahl and Baumgardt 2013) Encuentran planos en Millenium II.
A thousand shadows of Andromeda: rotating planes of satellites in the Millennium-II cosmological simulation (Ibata et al 2013) dicen que el paper de Bahl y Baumgardt está mal y que no hay planos en millenium II
Co-orbiting satellite galaxy structures are still in conflict with the distribution of primordial dwarf galaxies (Pawlowski et al 2014)
Co-orbiting planes of sub-halos are similarly unlikely around paired and isolated hosts (Pawlowski et al 2014)
Vast planes of satellites in a high resolution simulation of the Local Group: comparison to Andromeda (Gillet et al 2014). finds a plnes similar to that of M31 in Clues simulations.
Planes of satellite galaxies: when exceptions are the rule (Cautun et al 2015) encuentra que 10 por ciento de los halos tienen planos iguales o más prominentes que los del LG.

1.1. *Posibles orígenes de los planos:*

Preferential accretion (Libeskind et al 20??)
Alignments with the cosmic web (Tempel et al 20??)
The vast thin plane of M31 co-rotating dwarfs: an additional fossil signature of the M31 merger and of its considerable impact in the whole Local Group (Hammer et al 2013) Major merger in M31-MW system plane galaxies are tidal dwarfs (n-body simulations)
Kroupa tiene todo un carretazo de que las dwarfs son todas tidal dwarfs
MIRAR lo que está haciendo Pierre Alan Duc con tidal dwrafs porque en una conferencia este a;o habló de un posible escenario intermedio...
Evidence for Early Filamentary Accretion from the Andromeda Galaxy's Thin Plane of Satellites (Buck et al 2015)
Alignments between galaxies, satellite systems and haloes (Cautun et al 2016) NO LO HE LEIDO...

1.2. *Problemas con esas explicaciones:*

The Vast Polar Structure of the Milky Way and Filamentary Accretion of Sub-Halos (Pawlowski et al

2012)
Paper de Collins (2013 y 2016) donde explica que no hay doferencias en las propiedades de los on-plane y los off-plane satellites
Problemas con la estabilidad a largo plazo de los planos: Bowden et al 2012, Gonzales et al 2015...
The Plane Truth: Andromeda analog thin Planes of Satellites are not kinematical coherent structures (Buck et al 2015)

2. ILLUSTRIS SIMULATION

3. SAMPLE SELECTION

We select all halos with maximum circular velocities in the range 150 km s^{-1} < $V_{\rm max}$ < 350 km s^{1}. We exclude sub-halos from this selection. From this set we construct a sample of pairs as follows. For each halo A we find its closest halo B, if halo 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 distance. We exclude the pairs that are closer thn There are 53 pairs with those conditions in the simulation.

We extract from the simulation spheres of 2 h^{-1}Mpcin radius around the pair's center of mass. We use this information to exclude all the pairs that have separations smaller than the sum of their virial radii, i.e. we exclude interacting pairs. This reduces to 49 the number of pairs in the sample.

We count the number of galaxies with $M_V < -9$ inside the virial radius of each halo, including the central galaxy. We only keep pairs where both halos have 5 bright galaxies at least. This reduces the sample to 24 pairs. We call this sample the Full Sample.

From the Full Sample we build a second sample based on the pairs' kinematics. Figure 1 shows the comoving separation and relative speed between the two halos in the pair. The stars in the Figure represent the pairs with a separation in the range $0.75h^{-1}$Mpc < R_{AB} < $1.50h^{-1}$Mpc and relative velocity in the range $V_{AB} > 100$ km s^{-1}, which are close to the Local Group Observed values. We call this sample the LG Sample.

The number of pairs in the Full Sample is consistent with previous calculations. Forero-Romero et al. (2013) performed a study of the LG kinematics using a cosmological N-body simulation as a benchmark. In their study, using criteria similar to ours to define the Full Sample, they found 1923 pairs in a volume of 250^3 h^{-3} Mpc^3. With the same number density we expect to find 52 pairs in the volume of the Illustris simulation, which is very close to the actual number of 49 pairs.

In the same study they found 158 pairs with broad kinematic caracteristics, similar to the definition of our LG sample. This represents a reduction of a factor of 12 from their General Sample. With those numbers in mind we would expect to keep at least 4 pairs in the Illustris volume. Given that our conditions are slightly more relaxed (we do not ask for isolation criteria from massive halos) we end up with a larger sample size, but still consistent with the fact that LG-like pairs are scarce.

4. RESULTS

5. METHOD

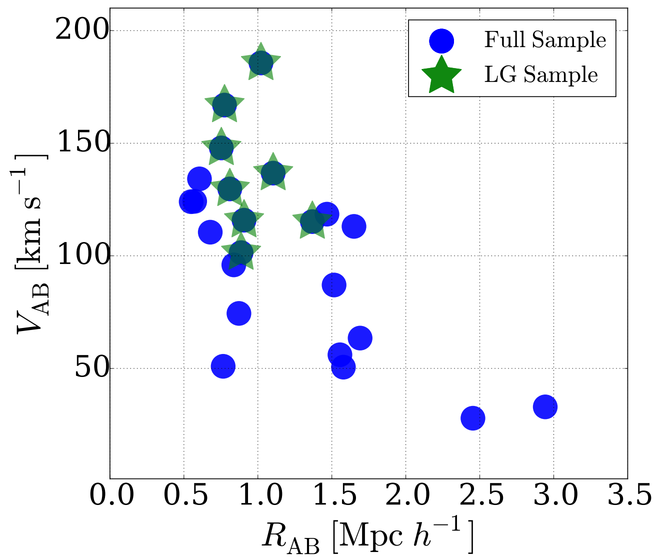

Fig. 1.— Halo pair samples used in this paper located in the plane of relative comoving velocity V_{AB} versus relative distance R_{AB} between the two halos in the pair. The R&V sample is the closest to the separation and kinematic conditions observed in the Local Group.

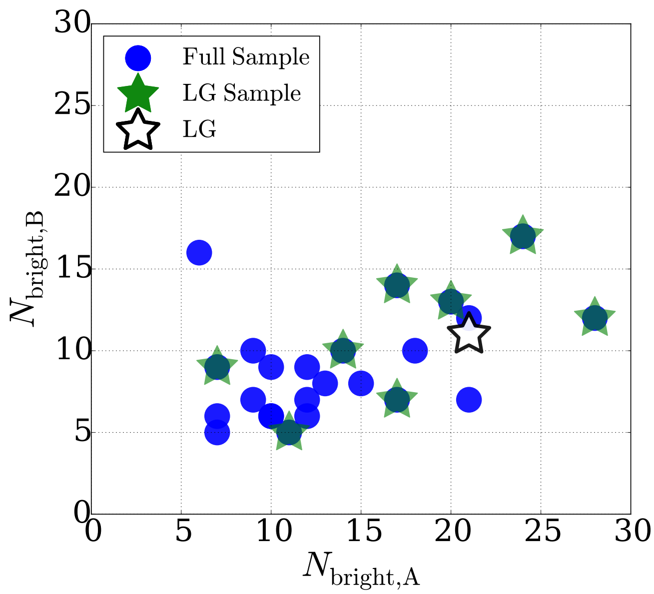

Fig. 2.— Number of bright substructures ($M_B < -9$) and dark matter substructures.

6. DISCUSSION

7. ACKNOWLEDGEMENTS

Gracias.

REFERENCES

Forero-Romero, J. E., Hoffman, Y., Bustamante, S., Gottlöber, S., & Yepes, G. 2013, ApJ, 767, L5

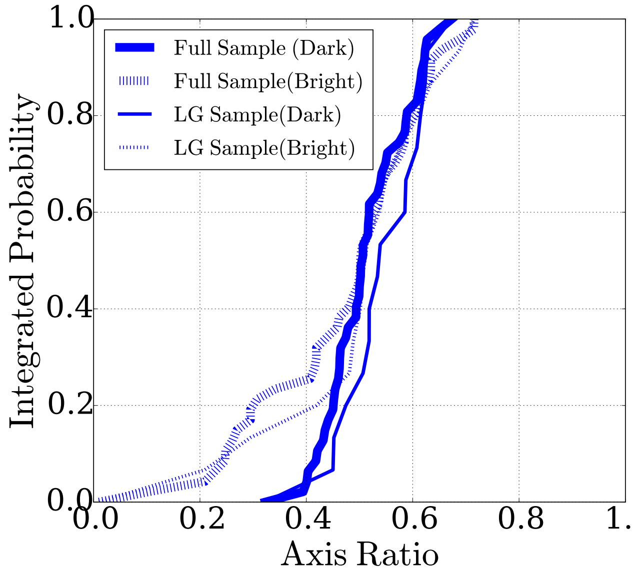

FIG. 3.— Axis ratio of luminous satellites versus the axis ratio for dark subhalos.

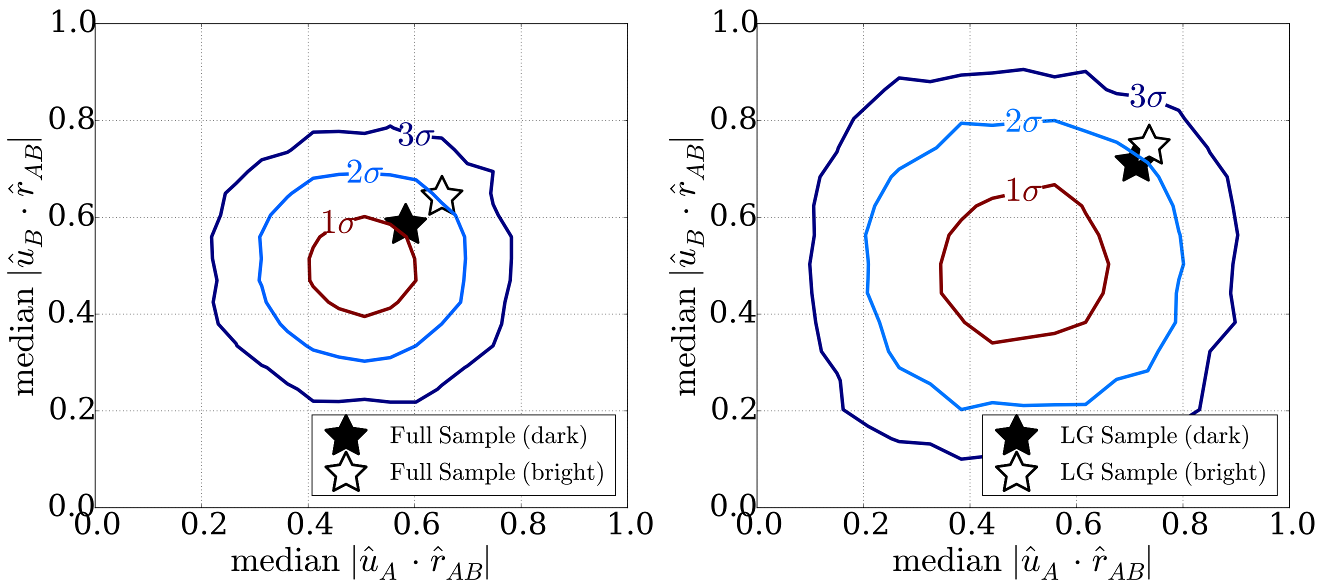

FIG. 4.— Significance of alignments.

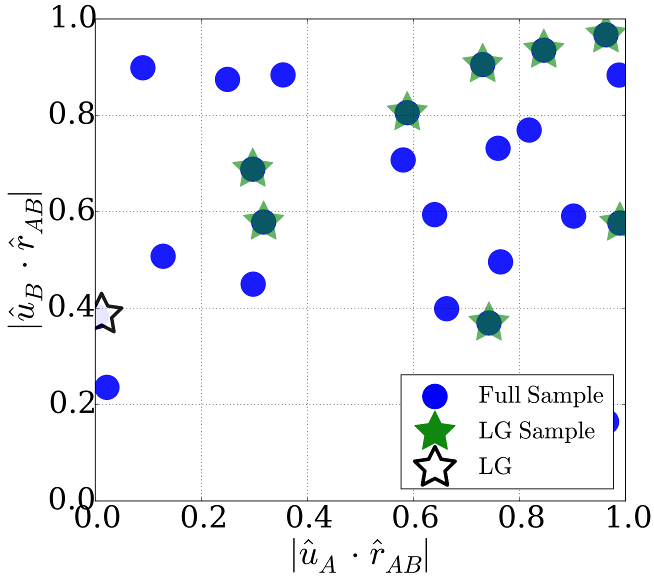

FIG. 5.— Alignment of the mayor axis with the vector connecting the two halos.

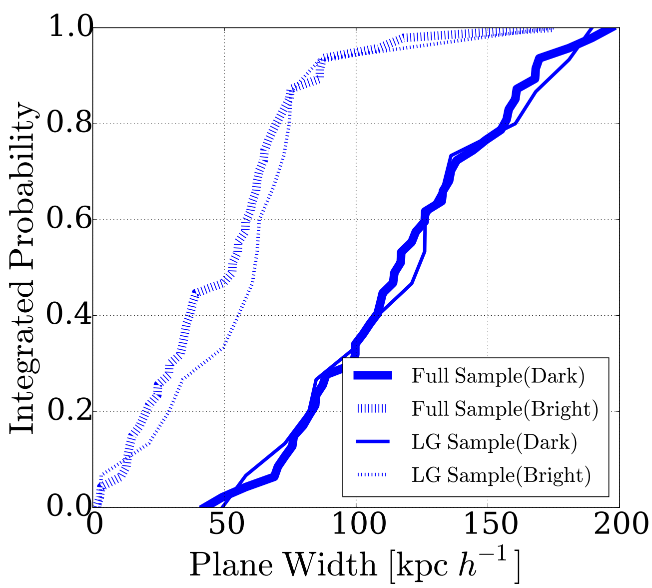

FIG. 6.— Plane width for the best planes in the luminious and dark cases.

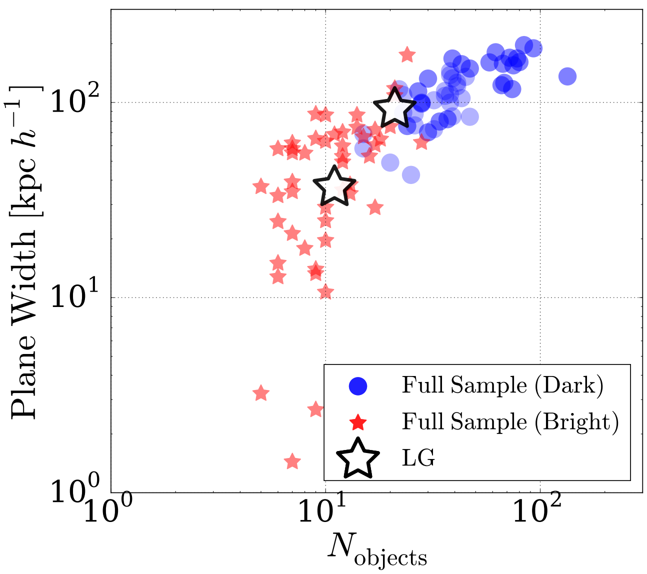

FIG. 7.— Plane width as a function of objects used to find the plane.