Triplets of galaxies: Analysis of Configuration and Dynamics

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INTRODUCTION

The configuration of a triple system, defined as the shape of the triangle formed by their members, could be the result of the dynamical evolution of the group. Numerical simulations of three-body systems composed by particles with comparable masses show that during most of its lifetime the system presents a predominant type of configuration, called hierarchical, formed by a close binary and a remote third body (e.g., Valtonen & Mikkola 1991; Chernin et al. 1994). This scenario is significantly modified when the triplet is considered immersed in a dark matter halo that makes the dynamics of the whole system more stochastic, with no observed formation of close binaries within three crossing times (Kiseleva 2000). Nevertheless Aceves (2001) performed more consistent simulations of galaxy triplets by modelling the galaxies in the system as Plummer spheres and found that a large primordial common halo of dark matter is not required to avoid the existence of hierarchical triplets.

In previous works (O'Mill et al. 2012, Duplancic et al. 2013) we presented a method to identify triplets of galaxies in the Seventh Data Release of the Sloan Digital Sky Survey and analysed the properties of galaxies in a sample of isolated triplets of bright galaxies. Our results suggested that these systems could be considered as an analogous of compact groups with a lower number of members. Continuing with this series of papers, in the present work we focus on the characterization of the configurations and the dynamical properties of triplets of galaxies.

TRIPLE SYSTEM CONFIGURATION

The AA-map

Agekyan & Anosova (1968) proposed a particular map (AA-map), where the shape of any triangle, despite of its proper size, could be represented by the position of a single point. In order to represent on this map a triplet with components A, B and C, it is necessary to perform a series of transformations such that the plane coordinates (x_A,y_A) and (x_B,y_B) of the two particles at the extremes of the triangle largest side, will be (-1/2,0), (1/2,0), respectively. Then the triplet configuration is defined by the coordinates (x_C,y_C) of the third particle that should verify $x_C \geq 0$; $y_C \geq 0$; $(x_C+0.5)^2+y_C^2 \leq 1$. Through a geometrical analysis of configurations in this map, a triangle that has approximately equal sides will be represented by a point in the upper corner (Lagangian area, L), a triangle with a much smaller side than the other two will be located in the lower right corner (Hierarchical area, H) and linear configurations will be at the lower part of the map (Alignment area, A). Between the areas defined previously there is region of intermediate configurations (M).

Real-space versus projected configurations

The configuration of a triplet, defined through the AA-map, is based on the projected configuration and not on the study of the actual three-dimensional configuration of the system. In order to study the projection effects on the AA-map, we identify galaxy triplets in a SDSS-DR7 mock catalogue derived from the semi-analytic models of Croton et al. (2006) for the Millennium Simulation outputs (Springel et al. 2005). For these mock triplets we calculated the real three-dimensional configurations (3D) as well as the projected (2D) configurations on the AA-map. Figure 1 shows the real and projected AA-map for the triplets in the mock catalogue. We used different colors and symbols in order to discriminate 3D system configuration in the 2D AA-map. The purpose of this analysis is to estimate the percentage of triplets whose projected configurations match their real ones. In this figure the lack of systems in the right corner of the hierarchical area of the 3D AA-map is a consequence of the resolution limit of the simulation.

Table 1 present the number of systems in each area of the 3D AA-map and in the 2D AA-map, also the percentage of systems that retain they real configurations after projection (3D2D) and the percentage of triplets in each area that do not match their real 3D configurations (2Dno3D). The contamination by 2Dno3D triplets is significant in the H zone of the 2D AA-map, in agreement with Chernin et al. (1994), that found that the projection effect produces an excess of systems in the H area. Through the present analysis, we attribute most of this contamination (60%) to triplets with M-type real configuration. In general, approximately 64% of the mock triplets retain their real configurations after projection, so we can conclude that the AA-map is an appropriate tool for the analysis of triple systems configurations, as it represents consistently the real configuration of the triplets.

Table 1: Number of mock triplets in each area of the 3D and 2D AA-map and percentages of 3D2D and 2Dno3D systems.

Configuration	3D	2D	3D2D	2Dno3D
A	59	59	73%	27%
H	19	39	74%	64%
M	71	53	56%	24%
L	10	8	50%	37%

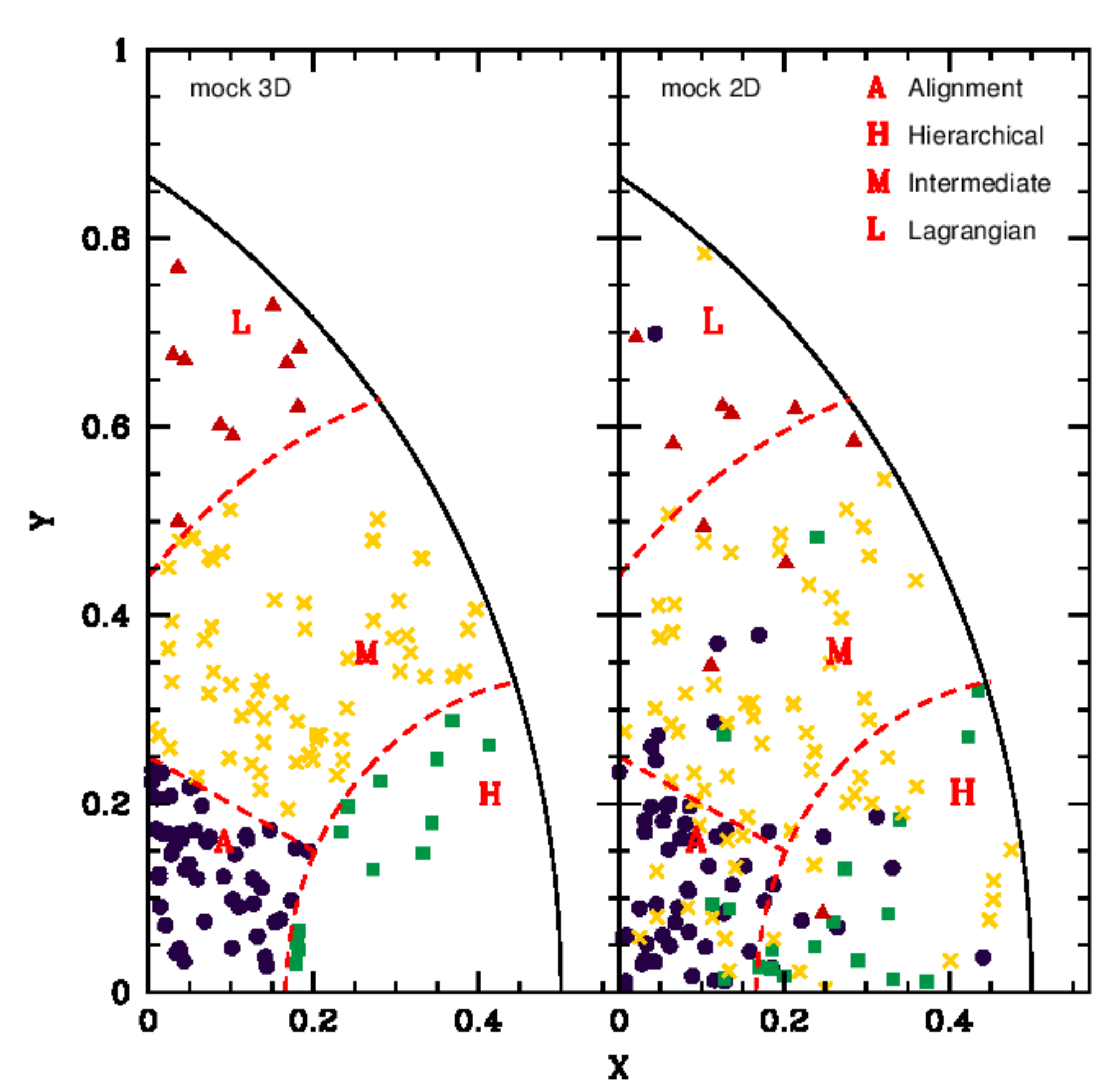
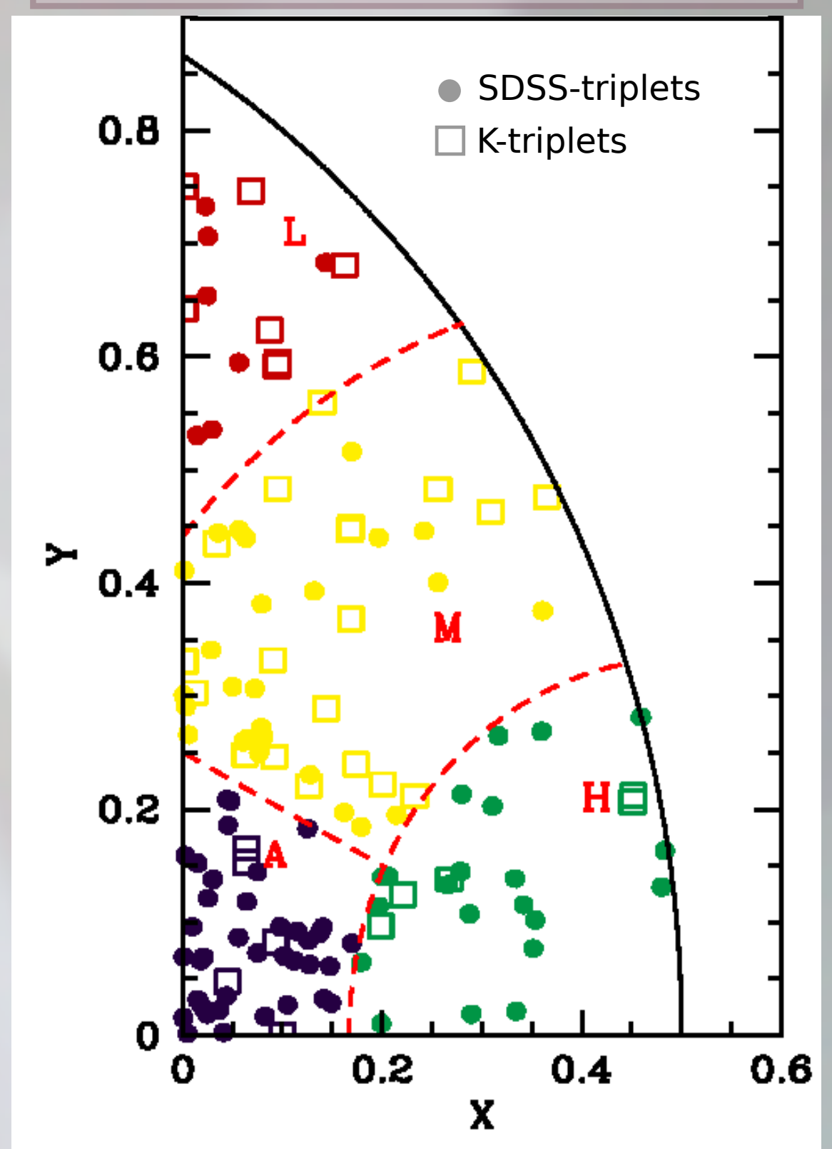


Figure 1: AA-map for the triplets derived from the mock catalogue. Left: Real 3D configurations. Right: Projected 2D configurations.

Figure 2: AA-map of SDSS-triplets and K-triplets



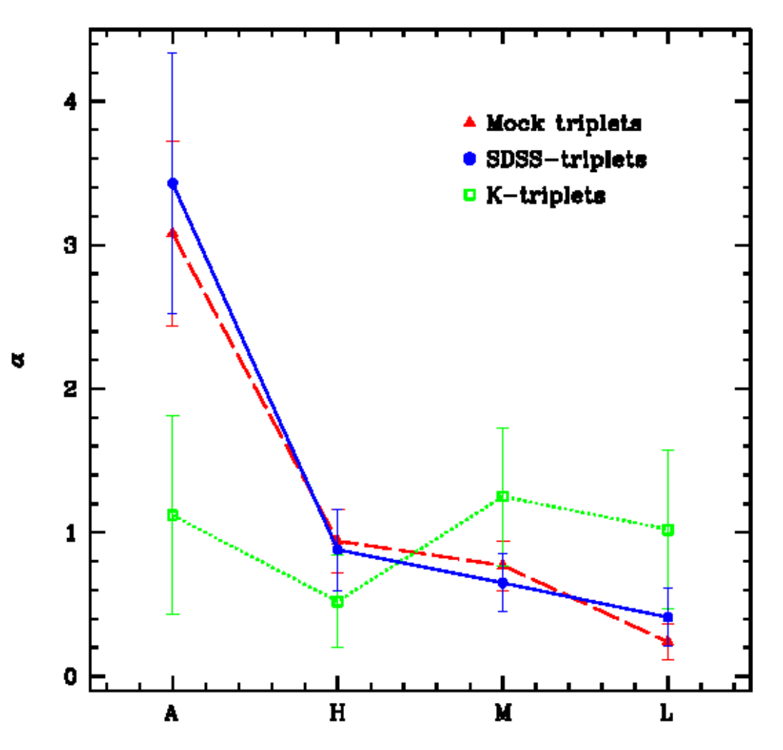


Figure 3: Relative density of triplets (α) for each AA-map configuration type, for the 2D mock triplets, the SDSS-triplets and the K-triplets. Error bars correspond to the standard error.

Configuration analysis

We analyse the configurations of the triplets of galaxies obtained fron the SDSS-SR7 (SDSS-triplets) and compare the results with a sample of physical isolated systems obtained from the catalogue "Isolated Triplets of Galaxies" of Karachentseva, Karachentsev & Lebedev (1988), considerng those triplets with isolation indicator equal to (+++) in the catalogue and that verify ΔV_{rms}<1000 km/s on the rms value of radial velocity difference of triplets member galaxies (K-triplets).

Figure 2 shows the configuration of the SDSS-triplets and K-triplets. From this figure it can be appreciated that there is no excess of hierarchical systems in both the SDSS-triplets and the K-triplets samples. In order to correctly quantify the number of objects in each area of the AA-map, we calculate the relative density of systems as $\alpha_i=\rho_i/\rho$ where ρi is the density of triplets in the area i (with i=A, H, M, L) and ρ is the density of systems in the entire AA-map. Figure 3 present the values of α for the SDSS-triplets and K-triplets. For comparison we also inlcude the values of α for the 2D AA-map for triplets in the mock catalogue. From the analysis of the relative density in each area of the AA-map we conclude that most of the SDSS-triplets, as well as the triplets from the mock catalogue, present type A configuration. In the case of K-triplets there is no strong preference of these systems to have a particular configuration in the AA-map, in agreement with the results found in others works (e.g., Zheng et al. 1993, Aceves 2001).

DYNAMICAL PROPERTIES OF TRIPLE SYSTEMS

Dark matter in galaxy triplets

There is a current controversy regardless the distribution of dark matter in galaxy triplets. Several authors performed simulations of triple systems and advocate the necessity of a primordial massive dark matter halo, in which galaxies are embedded, in order to describe the dynamics of these systems (e.g., Valtonen & Mikkola 1991, Kiseleva 2000). Nevertheless Aceves (2001) states that the presence of such dark matter halo would not be a strong requirement to describe the dynamical evolution of triplets. In this work we employed a sample of triplets obtained from a synthetic catalogue and it is worth to notice that all the triplets identified, considering real distances and isolation, have galaxy members that belong to the same dark matter halo. The typical halo mass is about 2×10^{13} $M_\odot$ that is comparable to the halo mass of compact groups, according to McConnachie et al. (2008). There is no significant difference in the average value of the masses of the halos according to the system configuration. However, for massive halos ($M_h>1.5\times10^{14}$ $M_\odot$) the A and H distributions present a fraction of triplets of 25% and 22%, respectively, compared to the M and L systems which fractions are 6% and 0%, for halos of these masses.

Dynamical analysis

In order to characterize the dynamics of a galaxy triplet we consider the radius of the group (R), as the minimum circle containing the centres of the members (Hearn & Vijay, 1982), the velocity dispersion (σ_v), the dimensionless crossing time (H_0t_c) and the virial mass (M_{vir}) of the system, following Hickson et al. (1992). We calculate these dynamical parameters for the SDSS-triplets and for K-triplets. In order to compare the dynamical properties of triples with those of similar systems we use a sample of Compact Groups derived from the Catalogue A of McConnachie et al. (2009), selecting systems that have all their galaxies with spectroscopic measurements and verify $\Delta v \leq 1000$ km/s, where Δv is the maximum line-of-sight velocity difference between group members, taking into account the SDSS-DR7 redshift information. We also estimate the dynamical parameters of the mock triplets in order to compare the dynamics of simulated and observed systems. Table 2 summarizes the results. From this comparative analysis we conclude that the SDSS-triplets, K-triplets and Compact Groups present similar dynamical parameters: they are compact systems with low crossing time values, present velocity dispersion and virial masses similar to loose groups. It can also be appreciated that the dynamical parameters obtained for the mock triplets are similar to those found for the SDSS-triplets, evidencing that simulated and observed systems present a concordant dynamical behaviour.

Table 2: Median of the dynamical parameter for the samples analysed in this work. Errors were calculated using bootstrap resampling techniques.

Sample	R $[h^{-1}$ kpc$]$	σ_v [km/s]	H_0t_c	log(M_{vir}) $[M_\odot]$
Mock triplets	42.7±1.3	126.9±13.2	0.019±0.002	11.8±0.1
SDSS-triplets	67.1±2.8	118.6±8.9	0.031±0.002	12.0±0.1
K-triplets	53.7±5.6	113.8±12.2	0.019±0.006	11.9±0.1
Compact Groups	81.3±5.5	199.3±16.6	0.021±0.003	12.5± 0.1

Relation between configuration and dynamics

It is also important to consider that different triplet configurations may be reflecting different dynamical stages of the system. Figure 4 shows the median of the dynamical parameters for the different AA-map configurations for the SDSS-triplets, the shade region corresponds to the median of the parameters for the entire sample. From this figure it can be appreciated that there is no strong trends of the dynamical parameters with respect to the different AA-map configurations. Nevertheless, despite the error bars, it can be appreciated that A configurations present higher values of R and σ_v which results in larger crossing time and greater values of M_{vir}. Furthermore, H triplets are those with greater deviation from the median of the sample.

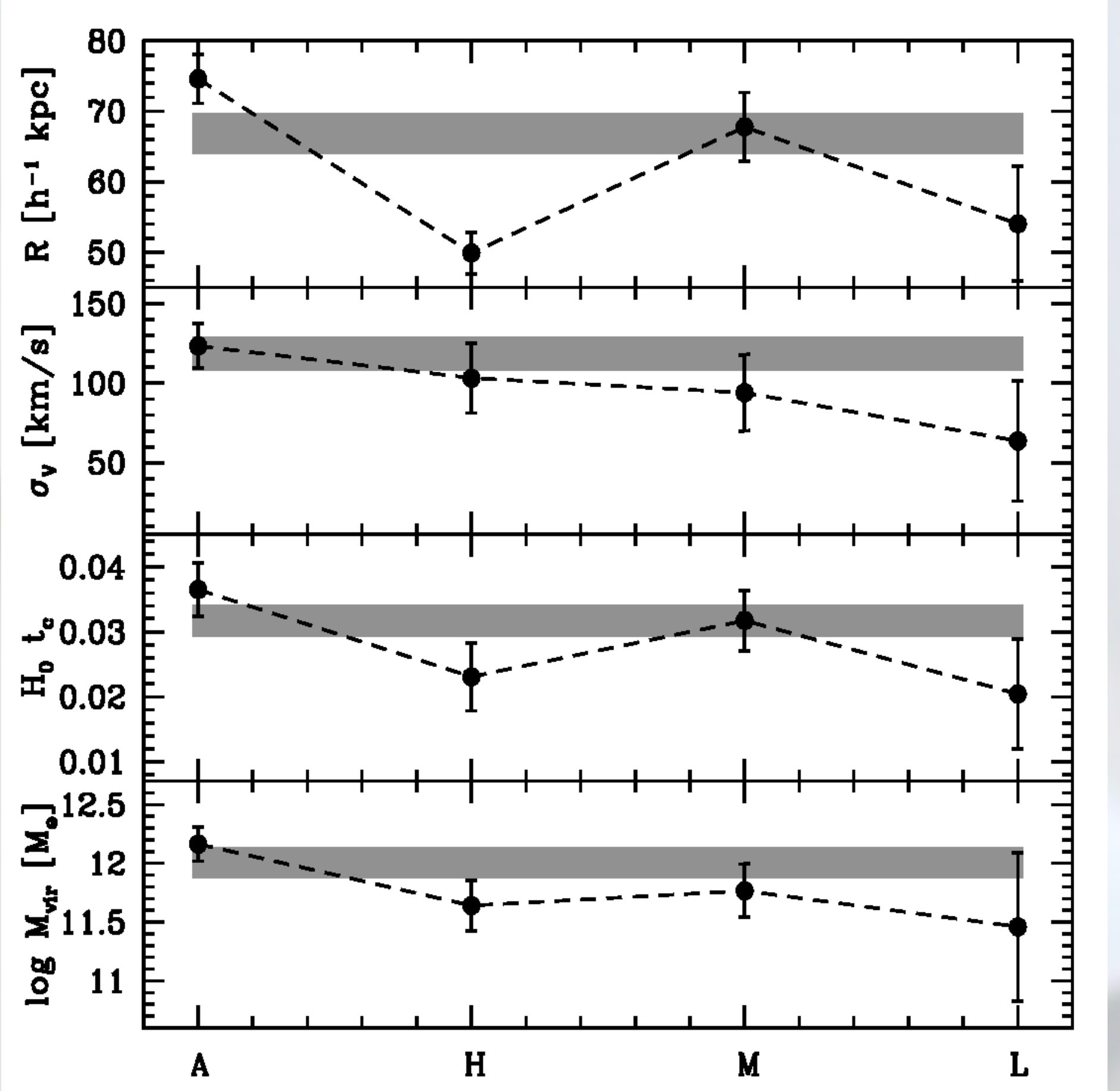


Figure 4: Median of the dynamical parameters for the SDSS-triplets for the different AA-map configurations. The shade region corresponds to the median for the entire sample. Errors were calculated using bootstrap resampling techniques.

CONCLUSIONS

Through an analysis of the real an projected configuration of triple systems we conclude that the AA-map represents consistently the real configuration of the triplets. Also we found that the projection effect increments the number of systems in the H area of the AA-map with a large contribution of this contamination (60%) by triplets with M-type real configuration. For the SDSS-triplets we found that most of these systems present type A configuration while K-triplets present an uniform distribution on the map.

We also performed and analysis of the dark matter content of galaxy triplets and found that the dark matter halos of these systems have masses similar to compact and loose galaxy groups. Moreover we found that member galaxies of mock triplets reside in a common dark matter halo.This result is a strong evidence of the dynamical co-evolution of the system. Furthermore, the presence of an underlying dark matter halo suggests that the system is dynamically evolved, giving time to the individual halos to merge.

We also found that triplets present low values of H_0t_c therefore it is expected that dynamical effects are most pronounced in these systems. Moreover, the compact configuration could be the result of the dynamical evolution of the system. This scenario may favour the formation of elliptical galaxies through mergers, in agreement with the results found in Duplancic et al. (2013) who show that SDSS-triplets present an important fraction of bulge-type, red galaxies, with low star formation activity indicators, similarly to galaxy members of compact groups.

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