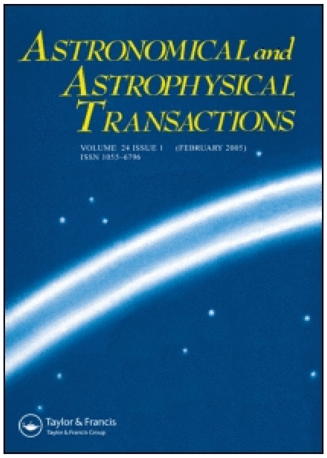

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TRIPLE GALAXIES: CONFIGURATION ANALYSIS

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Observed triplets of galaxies which are assumed to be isolated bound physical systems are scattered more or less randomly over the space of all possible geometrical configurations, while numerical simulations and dynamical considerations suggest that one should rather expect an excess of hierarchical structures. We show that this controversy may have important physical grounds and cannot be related to projection effects. Possible explanations may involve effective merging of galaxies at their close passing or the presence of smoothly distributed dark matter in the systems.

1 INTRODUCTION

Triple galaxies provide an important laboratory for the study of many properties of galaxies and their groups, from total mass estimates to galaxy interaction and merging. The mass estimates indicate that there may be large amounts of dark matter in these systems (Karachentsev *et al.*, 1989; Kiseleva and Chernin, 1988; Chernin and Mikkola, 1991; Anosova *et al.*, 1991, 1992). The evidence for dark matter is based on dynamical considerations first suggested in a classical work by Zwycky who pointed out that the Coma cluster could be in equilibrium at the large observed velocity dispersion only if a great mass of unseen matter were present.

The dynamical arguments of this kind and the dynamical estimations of the dark matter masses are applied most efficiently now to the two extreme classes of objects, rich clusters of galaxies and individual halos of galaxies. As far as binary galaxies, triplets and groups of galaxies are concerned, the situation remains less obvious and some degree of skepticism about the existence of dark matter in these intermediate-scale structures persists today (Sandage, 1986; Karachentsev, 1987). For instance, the dynamical estimations of masses in binaries are very sensitive to the assumed shape of the velocity ellipsoid and may also be biased by errors in the velocity measurements and contamination of the catalogue (Binney and Tremaine,

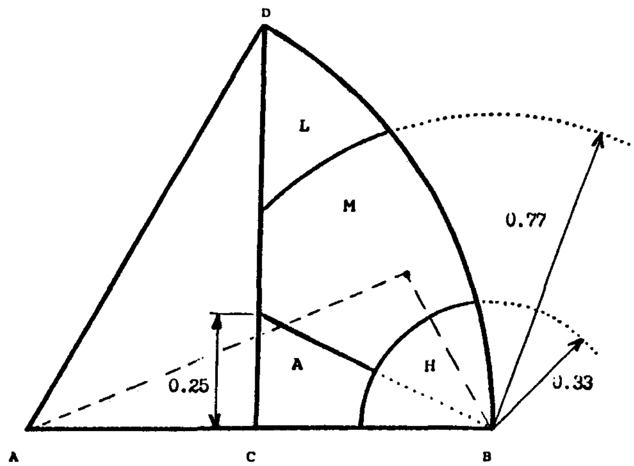


Figure 1 The configuration map, after Agekian and Anosova (1967) The characteristic areas: $\mathcal{L}$ – Lagrangian, $\mathcal{H}$ – hierarchical, $\mathcal{A}$ – alignment, $\mathcal{M}$ – middle.

1987). A considerable mass excess which reveals itself in a very high mass-to-light ratio is obtained for groups of galaxies (Huchra and Geller, 1982), but with a wide spread. Complications of similar kinds reveal themselves also in triple systems of galaxies.

In this paper we study configurational properties of triplets of galaxies and inquire if they may provide any other reasons to expect dark matter in groups of galaxies. We discuss the observational data on triplets of galaxies which are primarily due to Karachentsev's group at the 6-meter Telescope Observatory, SAO, of the Russian Academy of Sciences (Karachentseva *et al.*, 1979; 1988; Karachentseva and Karachentsev, 1982; Karachentsev *et al.*, 1989). We also use some data on triplets from the catalogue by Geller and Huchra (1983) and Maia *et al.* (1989), collected by Trofimov (1993). One may expect that our configurational analysis may contribute also to the studies of the evolution of groups of galaxies including possible galaxy merging in them (Chernin *et al.*, 1993; Zheng *et al.*, 1993).

Our main aim here is to analyze the statistics of the visual configurations of the observed triplets and to demonstrate that this statistics reflects adequately basic properties of the three-dimentional geometry of these systems.

2 THE AGEKIAN-ANOSOVA CONFIGURATION MAP

In our analysis, we follow Agekian and Anosova (1967) who suggested an elegant way of the analysis of the geometrical properties of triple systems. They proposed a map in which any triangle is represented by a point located in accordance with its shape independently of its proper size. In this map (see Figure 1), AB is the largest side of the triangle, $AC = CB$, DB is a part of the circumference of radius AB with

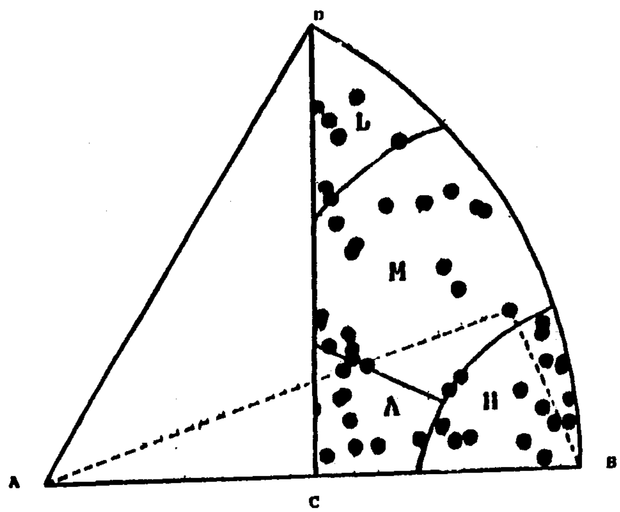


Figure 2 The configuration map for K-triplets.

the centre at A; CD is normal to AB. For any triangle with the largest side which is rescaled to AB, the top (opposite to the largest side) is located within the curve triangle CDB. So any triangle can be plotted as a point in the area CDB and the location of the point corresponds to the homologous structure of the triangle. It is easy to see that a triangle with more or less equal sides is presented by a point in the upper corner of the map; a triangle with one side which is much less than the two others finds a place in the right bottom corner of the map; a triangle with the three vertices lying almost along a straight line is presented by a point located near the bottom of the map.

In accordance with these considerations, we can define four characteristic areas in the map (Figure 1): the top corner of the map may be called the area of Lagrangian ($\mathcal{L}$) triangles – after the well-known dynamical case in the classical three-body problems; the right bottom corner of the map, where the triplets with close binaries within them are located, may be referred to as the area of hierarchical ($\mathcal{H}$) configurations; a strip near the bottom of the map may be defined as the area of aligned ($\mathcal{A}$) configurations; the rest is the area in the middle ($\mathcal{M}$) of the diagram.

Triplet Configurations

We used Karachentsev's data on the angular separations for the galaxies in 48 triplets (Anosova *et al.*, 1991) that are assumed to be isolated bound physical systems and reexamined them by direct measurements on the Palomar prints. The distribution of 48 Karachentsev's triplets (hereafter, K-triplets) on the configuration map obtained in this way is presented in Figure 2. As one can see, the triplets appear to be scattered more or less randomly over the map. Figure 3 shows the

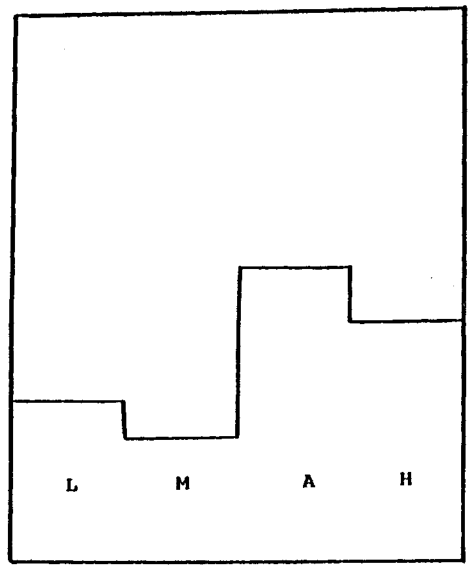


Figure 3 The number density of K-triplets in the configuration areas in the units of the average density $\rho_i / < \rho > = 0.71, 0.87, 1.67, 1.06$, respectively, $i = \mathcal{H}, \mathcal{M}, \mathcal{L}, \mathcal{A}$.

number density of the triplets (e.g., the average number per unit square in each area) in the characteristic areas. Though the statistics is not rich we may conclude that the triplets are shared by the four areas with an almost uniform density.

Such a random and uniform distribution of the triplets over the areas on the configuration map proves to be in obvious contrast with the results of the computer simulations of three-body dynamics. These simulations (Aarseth, 1963; Anosova, 1985; Saslaw *et al.* 1974; Kiseleva and Chernin, 1988; Valtonen and Mikkola, 1991) indicate definitely that there should be a strongly predominant type of three-body configurations, namely hierarchical configurations with a close binary and a remote third body. A configuration map for 1000 simulated triplets is shown in Figure 4. It demonstrates a major excess of hierarchical configurations (area $\mathcal{H}$).

This comparison of the observational data and the computer dynamical models for the triplet configurations poses first of all the following question: can this drastic difference be due to projection effects in the observed triplets?

3 THE PROJECTION EFFECT

We studied this effect with computer simulations which enable one to compile various ensembles of three-dimensional "true" triangles and then analyze how these ensembles may transform after random rotations (with isotropically distributed angles) and a subsequent projection on a two-dimensional picture plane. Figure 5 shows one instructive example of such computer experiments. It demonstrates that

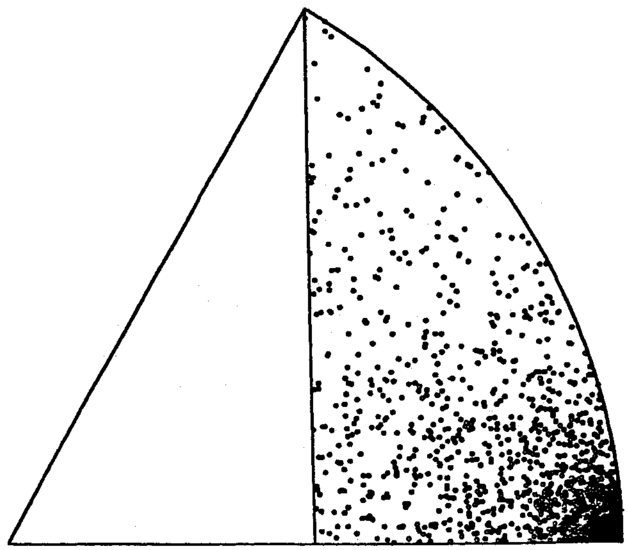
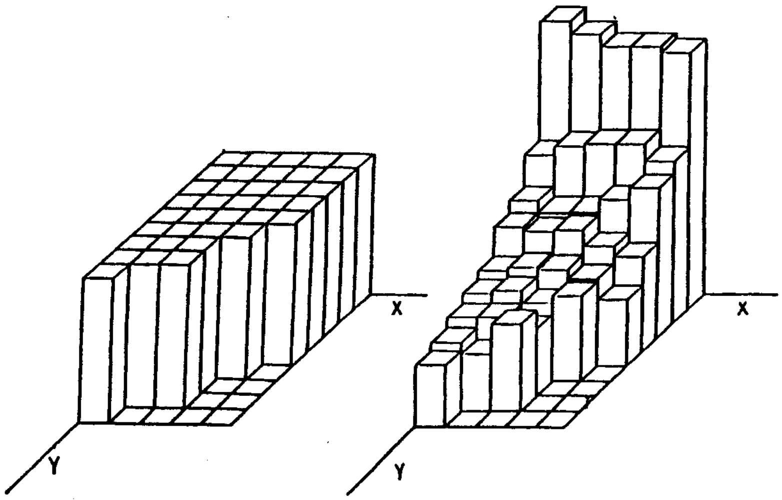


Figure 4 The configuration map for 1000 model triplets of the computer simulated three-body dynamics.

an ensemble of triplets with an exactly uniform density distribution on the "true" configuration map appears after projections on the "projection" configuration map to be strongly non-uniform. We see that the effect of projection does not diminish the number of visible triplets in the $\mathcal{H}$-area; on the contrary, it may only increase the number of the observed triplets there. So projections cannot be responsible for the lack of the excess of hierarchical configurations in the observed triplets of galaxies.

4 THE INVERSE PROBLEM

Our studies of the projection effects suggest some possible methods of "inverse" transformation from the observed distribution of the triplets on the configuration map to the "true" distribution of the same triplets. This inverse problem may be solved, of course, only statistically, for the whole ensemble of the triplets (Trofimov, 1991, Chernin *et al.*, 1993). It is obvious also that possible uncertainties in such a solution decrease with the increase of the number of objects in the ensemble. For the real ensemble of 48 K-triplets, the uncertainties are fairly large. Nevertheless, the solution of the inverse problem may show what kind of a "true" configuration map for the triplets might be behind its projective appearance. Figure 6 demonstrates two solutions for K-triplets obtained with the method of chance coincidences (Chernin *et al.*, 1993) and the method of inverse matrix (Trofimov, 1991; Chernin *et al.*, 1993).



a) b)

Figure 5 Computer simulations for the effect of projection for the triplets: a) the initial "true" uniform distribution (the configuration map is put on the XY plane); b) the appearance of the same triplets on the projective map. The result is a superposition of the distributions of 150 ensembles of triplets with 48 objects in each of them.

The first of the methods is based on a computer-generated set of many "true" ensembles of triplets and their transformation to the "projective" ensembles. A similarity between the observational configuration map and the maps for these projective model ensembles enables one to select a sub-set of "true" ensembles from the whole initial set of them. This sub-set is considered as an ensemble of possible ensembles that represent the statistical solution of the inverse problem. Then, with this ensemble of ensembles, one can calculate the mean (or median) values for the number densities of the objects in the characteristic configuration areas and the standard deviations of them by the usual manner. The result is presented in Figure 6 (solid line). As we see, the number density of the "true" triplets in the $\mathcal{H}$-area cannot be excessive anyway.

The other method in this inverse problem is based on a computer analysis of the re-distribution of the objects from a given area of the "true" map over all the four areas of the projection map after a randomly isotropic projection. Applied to the K-triplets, this method leads to the result presented in Figure 6 (dashed line). The two solutions of the inverse problem for the triplets are not quantitatively the same mainly because the available statistics of the objects is rather poor. The difference between the solutions does not exceed, however, the error bars shown in Figure 6. Both of them give no indications for any excess of the hierarchical configurations in the "true" distributions of the triplets.

The method of an inverse matrix was applied also to the sample of 37 triplets compiled by Trofimov (1993). These T-triplets taken together are characterized by

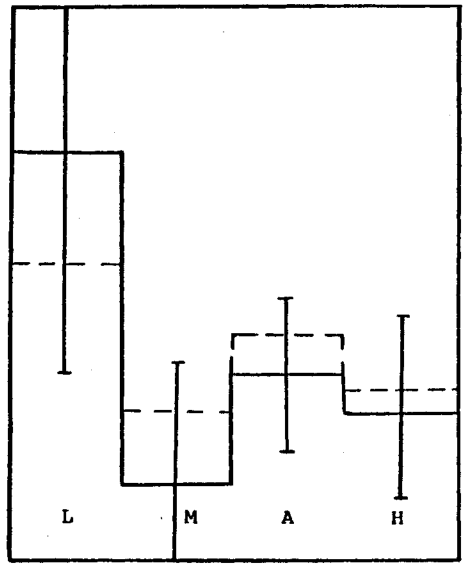


Figure 6 Reconstructions of the "true" configuration distribution for K-triplets: solid line, for the method of coincidences; dashed line, for the method of inverse matrix.

the median values of the virial mass $\sim 10^{12} M_\odot$ (which is close to the K-triplets), the mean harmonic separation of 416 kpc (which is about ten times larger than that for the K-triplets). The configuration map for these looser triplets shows a very weak excess of the number density in the $\mathcal{H}$-area, which, however, do not survive after the solution of the inverse problem for these triplets too (Figure 7).

5 CONCLUSION AND DISCUSSION

We can conclude that the observed triplets of galaxies do not reveal any excess of hierarchical configurations, and this cannot be due to the effect of projection.

The absence of the excess of hierarchical structures in the real distributions of the observed triplets may suggest that such configurations are not persistent because of galactic merging in these systems. If this process is efficient enough, many close binaries that would form in the triplets could be converted soon into single galaxies, and so the configurations with close binaries should not be as numerous as it follows from the three-body simulations mentioned above (see Section 2 and Figure 4). In this sense, the $\mathcal{H}$-area in the configuration map may be considered as a loss area: when the evolution of a triplet brings it into this area, the triplet leaves the map in one or two orbital periods of the close binary.

The assumption about effective merging can be tested on observational grounds. In fact, N-body simulations of galactic merging (White 1982, Binney and Tremaine, 1987) predict merger products to be elliptical-like galaxies. If so, one can expect

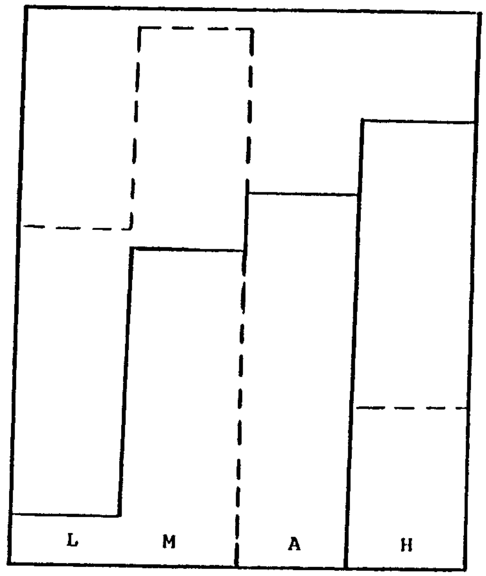


Figure 7 The configuration distribution for Trofimov's triplets: solid line, for observations; dashed line, for the "true" distribution (the method of inverse matrix).

that there should be many elliptical (and also lenticular) galaxies in the groups, triplets and binaries. An estimate of the elliptical fraction in these systems using the catalogeu of K-triplets and also data published by Dressler (1980), Karachentsev (1987), Geller (1984), Hickson *et al.* (1984) and Mezzetti *et al.* (1984) shows that elliptical do not dominate either in the triplets or in the binaries. Their fractions in the triplets and binaries are similar and almost the same as in the field or in loose groups and less than that in compact groups (Chernin *et al.*, 1993). This seems to imply that there is no morphological evidence for the possibility that a fraction of the members of the binaries can be a product of galactic merging. If so, the configuration map for the triplets may not be affected largely by the galactic merging.

However, the problem of the morphological content of binaries, triplets and groups of galaxies needs more studies. Actually, some merger remnants may have blue colour and structural features like tidal tails or/and bridges produced by their interactions with other galaxies in the systems. Such galaxies may be identified observationally as spirals, and this may introduce some confusion into the data on the morphology. Special observational programs could clarify this situation.

Another aspect of the problem is related to a possible role of galaxy merging in groups of galaxies which have more than three members and become triplets as a result of merging (Zheng *et al.*, 1993).

The lack of the excess of hierarchical structures seems to point also to some other important physical features of these systems, e.g., possible presence of dark matter in them. Dynamical estimates suggest (Kiseleva and Chernin, 1988; Chernin and Mikkola, 1991) that the dark mass may exceed the luminous matter of galaxies in the triplets by the factor of 3–5 or even more. While the estimates of the dark mass clearly suffers from uncertainties, they are supported by the fact that there are a number of much stronger indications for dark matter in the coronae (or halos) of individual galaxies and in rich clusters of galaxies.

The assumption about dark matter in triplets may provide an explanation to the structure of the configuration map for these systems. One can see that a high probability of the formation and existence of close binaries in triplets is mainly due to effective body-body interactions in close passings of the galaxies. It is the physical cause of the predominance of hierarchical configurations in three body systems demonstrated by numerical simulations (Figure 4). The probability of the binary formation can be significantly reduced if, in addition to the three bodies, there is a smoothly distributed matter in the volume of the system (Chernin *et al.*, 1989).

Indeed, if the dynamical influence of the distributed matter is dominant, its gravitation makes the body-body interactions much less efficient: the motions of the galaxies in the system are controlled mainly by the dark matter background rather than by the mutual gravity of the bodies. In extreme, the body may move simply as a test particle in a sea of dark matter. It is obvious that if physical conditions like this are realized in the observed triplets, the configuration map for them should not reveal any excess of hierarchical structures. If so, the observational configuration map presented in Figure 2 appears to be probably of this kind. In this sense, the observed statistics of triple galaxies may be considered as an independent additional indication for dark matter in these systems besides usual dynamical considerations. This line of reasoning deserves further discussion on somewhat more definite quantitative grounds.

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