DYNAMICS AND CONFIGURATIONS OF GALAXY TRIPLETS

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ABSTRACT. Two methods are proposed for describing the distributions of the triplet configuration parameters characterizing a tendency to alignment and hierarchy: (1) obtaining a representative sample of configurations and determining its statistical parameters (moments and percentages); and (2) dividing the region of possible configurations of triple systems (Agekian and Anosova, 1967) into a set of segments and finding the probabilities for the configurations to find themselves in each of them.

Both these methods allow representation of the data by numerical simulations as well as observations. The effect of projection has been studied. It rather overestimates the alignment and hierarchy of the triple systems. Among the parameters of interest there are found some parameters that are least sensitive to projection effects.

The samples consist of simulated galaxy triplets (with hidden mass) as well as of 46 probably physical triple galaxies (Karachentseva et al., 1979). The observed triplets as well as numerical models show a tendency to alignment. The triple galaxies do not show any tendency to hierarchy (formation of the temporary binaries), but this tendency may be present for simulated triplets without significant dark matter. The significant hidden mass (of order ten times the total mass of a triplet) decreases the probability of forming a binary and so weakens the hierarchy.

Small galaxy groups consisting of 3-7 members are probably the most prevalent types of galaxy aggregate (Gorbatsky, 1987). Galaxy triplets are the simplest groups, but dynamically non-trivial ones.

Gravitationally connected triplets with negative total energy may be in the following dynamical states (see, e.g., Anosova, 1985): (1) close triple approach; (2) simple interplay; (3) ejection with return; (4) escape; and (5) stable revolution. Every dynamical state correspondeds to its most probable type of the configuration, i.e., some correlation exists between the type of dynamics and the configurations of triplets. The presence of large hidden mass influences the dynamics strongly, and therefore the configurations of galaxy triplets.

A purpose of this work is to infer the probable dynamical states of galaxy triplets by the observed data on their configurations.

The first attempt at a systematic selection of galaxy triplets was undertaken by Karachentseva et al. (1979). This list includes 84 isolated triple galaxies of the northern sky, the components having apparent magnitudes $m_p < 15.7$. Some detailed information on the triplets is included in a recent paper by Karachentseva et al. (1988).

In particular, the list includes the projected angular separations r_{ij} between the components.

Two methods of statistical study of the configurations of triplets are proposed:

1. a method of configuration parameters;
2. a method of configuration zones.

In the first method (Kiseleva and Orlov 1989), some chosen quantities are considered in order to characterize a degree of flatness or alignment as well as the hierarchy of the triplets.

The following parameters may characterize the alignment:

1. a sum of squares of the sines of angles in the configuration triangle

$$C = \sin^2 \alpha + \sin^2 \beta + \sin^2 \gamma \; ; \qquad (1)$$

2. a ratio

$$z = h/r_{max}, \qquad (2)$$

where r_{max} is the length of the maximum side in a triangle, h is the distance from the third component to this side;

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3. a ratio of area of a triangle to the area of the equilateral triangle with the same perimeter

$$Ke = S_{\Delta}/S^{*} ; \qquad (3)$$

4. a difference

$$\beta = \pi - \phi_{max} \text{ (in radians)}, \qquad (4)$$

where ϕ_{max} is the maximum angle in a triangle.

The following characteristics of the hierarchy of triplets are considered:

1. a variation of the squares of the mutual distances between components in a triplet

$$B = [(a^2 - A)^2 \pm (b^2 - A)^2 + (c^2 - A)^2]/(3A^2) \qquad (5)$$

where a, b, and c are the lengths of the sides of a triangle, $A = (a^2 + b^2 + c^2)/3$;

2. a ratio

$$\rho = r_{min}/rd, \qquad (6)$$

where r_{min} is the minimum mutual distance, r_d is the distance from the most distant component to the geometric center of a close pair;

3. a ratio

$$q = r_{min}/r_{max}; \tag{7}$$

4. a ratio

$$\lambda = qr_{min}/(r_{max} + r_{int}), \tag{8}$$

where r_{int} is the intermediate mutual distance between the components.

Because of projection effects, the distributions of the actual and apparent configuration parameters may be different. In this work we have selected the least sensitive of the above quantities to projection effects. The selection was carried out by some computer simulations: for 1000 random configurations within a circle of unit radius, we calculated the actual values of the parameters (1) - (8) as well as their apparent values obtained on a projection of the triangle plane to some "pictorial" plane. For every parameter X the following quantity S has been determined

$$S = \sum_{i=1}^{1000} (X_i - X_i')^2 \sqrt{\bar{X}^2}, \tag{9}$$

where X_i and X_i' are the actual and projection values of the parameter, $\bar{X}$ is an average actual quantity. The least sensitive parameter to the projection effect is that having the minimum S. The quantity S characterizes the average individual deviation of the projected quantities from the actual ones. The means and medians of the actual versus apparent parameters are also compared. The effect of projection is shown to overestimate the degree of the alignment of a system as well as its hierarchy. The parameters β and λ are the least sensitive ones to projection effects. By these parameters we have studied some trends in alignment and hierarchy for the galaxy triplets from the list by Karachentseva et al. (1979, 1988), that have been classified as probably physical systems in accordance with a criterion by Anosova (1987). The average projected quantities $\bar{\beta}'$ and $\bar{\lambda}'$ have been calculated for a sample of 46 probably physical triplets. The quantity $\bar{\beta}$ obtained has been compared with the mathematical expectation M_β for the uniform distribution of three points within a circle. We have estimated the probability P_β that a deviation $\bar{\beta}'$ from M'_β is chance.

A trend in the alignment of galaxies has been shown to be statistically insignificant - the quantities $\bar{\beta}' = 1.14$ and M'_β = 1.17. In order to estimate the hierarchy of a structure one has compared an average quantity $\bar{\lambda}'$ for the galaxy triplets, with the mathematical expectation M_λ, for uniform distribution of points within the ellipse with the flattening ε such that $\bar{\beta} = M_\beta$, for the uniform distribution within this ellipse. We have found $\varepsilon \simeq 1$ (this is a circle). In this case, $M'_\lambda = 0.51$, the observed $\lambda' = 0.49$.

Therefore no significant tendency to hierarchy has not been observed in the triplets by Karachentseva et al. (1979).

An analogous algorithm estimating a tendency to alignment and hierarchy has been used for the galaxy triplets simulated in the numerical experiemnts (see, e.g., Anosova et al. 1989). The dynamical evolution of triple galaxies with equal-mass components has been simulated; in a number of experiments we have included in a system hidden mass $M_o = 10$ M (M is the mass of a triplet), distributed according to the isothermal law within a sphere with radius R = 1d (d is the initial mean size of a triplet - Anosova et al., 1989). A tendency to alignment is observed in the numerical models as strongly with dark matter as without it. The hidden mass rather decreases the tendency to alignment. No significant tendency to the hierarchy is observed.

The second method of configuration zones consists of analysis of the distribution of points in the region D of all possible configurations (Figure 1 - see e.g., Agekian and Anosova, 1967). This region has been divided into four zones by degree of alignment and hierarchy of the structure. The bounds of these zones are circles with the radii 0.25, 0.50, and 0.75 with the centers at the point (0.5, 0.0). The procedure is complemented by determination of the density σ_i of the points in every zone: $\sigma_i = (n_i/S_i)/(\Sigma n_i/\Sigma S_i)$, where n_i is a number of hits in the zone i, S_i is the area of this zone.

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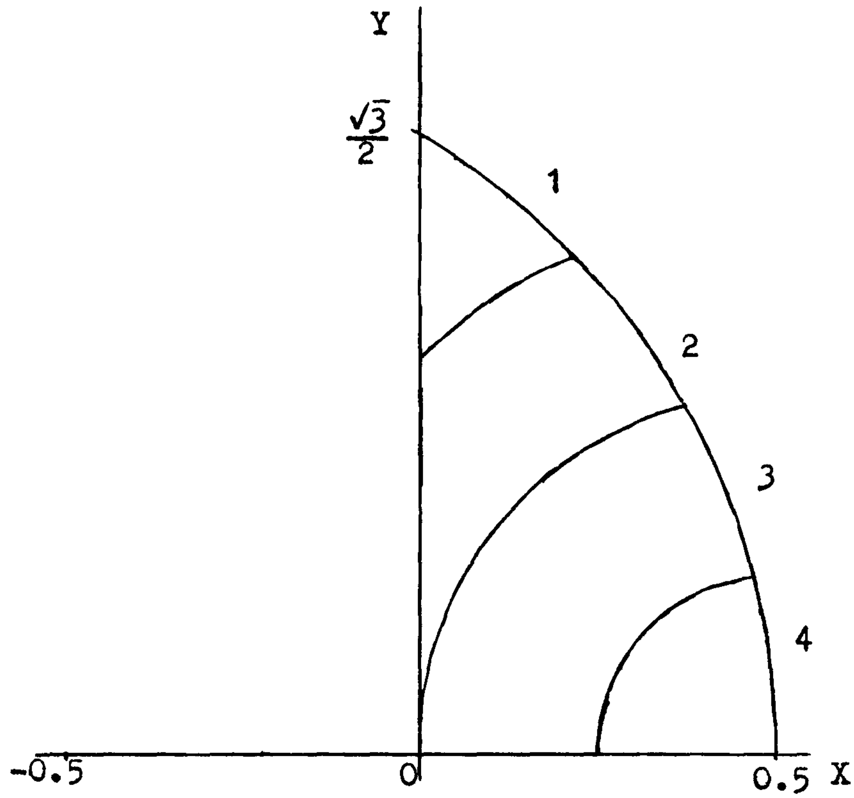

Fig. 1: The configuration diagram.

The points corresponding to the triplets from the list by Karachentseva et al. (1979, 1988) have been drawn within the region D. The distribution σ_i is shown in Figure 2a. The observed distribution by the Monte-Carlo method for random distribution of 46 points within the region D is shown in Fig. 2b.

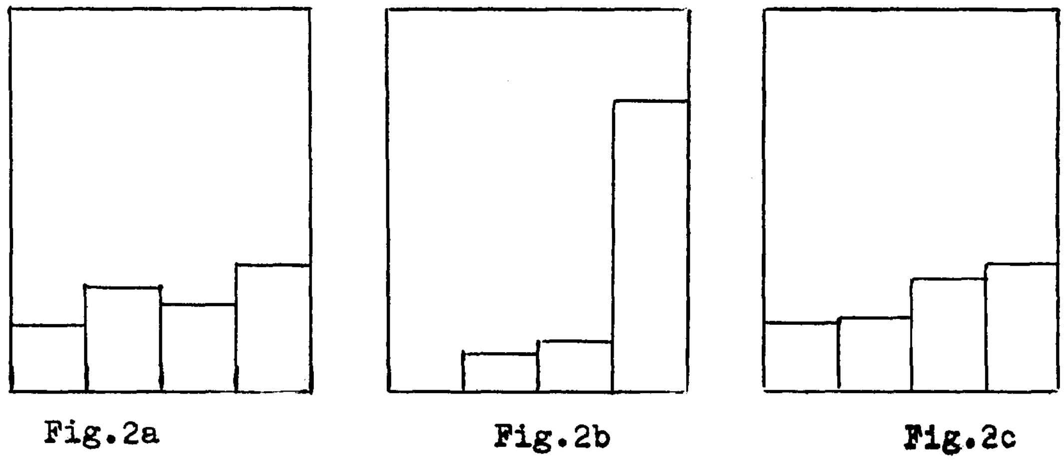

Fig. 2: Density of points in zones 1-4 for observed triplets (a), simulated triplets without dark matter (b), and with significant (M_O = 7M) hidden mass (c).

We have also studied the configurations of simulated equal-mass systems during evolution; in a number of the simulations some hidden mass M_O = 3, 7, 10 M has been included in the models. The dark matter was distributed in accordance with the isothermal law within sphere with R = 1 (in scale of Figure 1). We have considered 50 trajectories for the equipartition distribution of the initial configurations within the region D and zero initial velocities.

The results of computer simulations strongly favor models with large hidden mass (M_O = 10 M) versus the ones with its absence.

In the absence of the hidden mass in the ensemble of 50 triple systems during a rather short time (about 0.5 ± 1 τ, where τ is the mean crossing time - see Anosova et al.

(1988)), a distribution is established which is characterized by strong excess in zone 4 (Figure 2b), that corresponds to the trends in alignment and hierarchy. This settled distribution weakly fluctuates during the time in spite of a rather small number of trajectories.

In the presence of a large hidden mass distributed within the volume of a triplet (the motion take place within a sphere $R \simeq 0.8$), the apparent configurations have a significant diversity. Some excess of the configurations may take place within zone 1 as well as within zone 4 during the evolution. The most typical distribution is shown in Figure 2c.

Thus the statistics of configurations, forming during the dynamical evolution of the ensemble of the triple systems having some large dark mass, is in a better agreement with the statistics obtained by the analysis of galaxy triplets observed.

One can conclude that the two above methods of the study of distributions of configurations of the observed and simulated triplets of the galaxies have given similar results: no statistically significant tendency to alignment is observed.

No marked tendency to hierarchy is shown by the method of configuration parameters. The method of configuration zones does not allow division between the effects of alignment and hierarchy with certainty. The trend to alignment increases during evolution of the simulated triplets.

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