On the Orientation of Double Galaxies

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Abstract

The double galaxies in the Local, the Perseus, and the Coma/A1367 superclusters were studied. It is shown that these objects reveal the same tendency of alignment as the other galaxies belonging to the supercluster. The galaxy planes tend to be perpendicular to the plane of the parent supercluster and perpendicular to the radius-vectors from the centre of the supercluster. The angle between the rotation axes of galaxies in pairs, denoted as β, was also determined. The ambiguity connected with the unknown sense of galaxy tilt and spin in the method presented was not removed, the range of the β-angle is $0° - 180°$. The distribution of the β-angle is highly non-random. There is a statistically significant excess of small absolute values of the β-angle and a deficit near perpendicular configurations.

1 Introduction

The search for alignments of galaxy rotation axes for the members of three superclusters with known spatial geometry has been performed (Flin and Godlowski 1986, Flin 1987) with positive results. The rotation axes of galaxies tend to align with the plane of the parent supercluster and the galaxy planes tend to be perpendicular to their radius vectors. It is interesting to check, whether similar alignments can be observed if we restrict ourselves to double galaxies. In the case of double galaxies it is worthwhile to consider the β-angle, determined by the difference between the rotation axes of the galaxies constituting the pair. Previous work on the orientation of galaxies in pairs was discussed in detail by Noerdlinger (1979) and Helou (1984). The issue was also taken up by Karachentsev (1981). The classic approach consists in studying the distribution of differences between the position angles of component galaxies, sometimes supplemented by additional information, *e.g.* the winding of spiral arms. This method was applied by most of the previous authors; the resulting acute angle gives usually an isotropic distribution. Helou (1984) had at his disposal data containing true galaxy spins, with the differences between spins ranging from 0° to 180° and he found anisotropy. Preferred is the anti-parallel alignment of spins.

Naturally, such spins are the most valuable ones, however, the number of galaxies with determined true spins is rather limited. Therefore, in the present paper a different approach to the question of relative orientation of paired galaxies is proposed. The investigated angle is that between the rotation axes of a pair, without solving the ambiguity connected with the sense of rotation and the sign of the galaxy tilt. This

gives the investigated range of β-angle $0° - 180°$ and permits to construct a large sample, which is important for any statistical investigation.

The paper is laid out in the following manner: observational data are presented in Sect. 2, the description of the method applied is given in Sect. 3, Sect. 4 is devoted to the alignment of galaxies in pairs in the three investigated superclusters, while Sect. 5 presents the result of the investigation of the β-angle. The conclusions constitute Sect. 6.

2 Observational data

In order to be included into the present study two galaxies had to be situated in the northern hemisphere and listed as a pair in Arigo *et al.*'s (1978) sample of double galaxies or in the notes to the UGC, as well as in the main part of the UGC (Nilson 1973). Moreover, the radial velocities, the major and minor axes, and the position angles of both components must be known. The galaxy coordinates came from the UGC. The radial velocities of galaxies were taken from the literature. The values of the major and minor axes and position angles were taken from the UGC or from Arigo *et al.* Sometimes they were determined on the Palomar Sky Survey prints by the present author who also calculated the position angles of each component from the relative values presented by Arigo *et al.* For performing the transformation, the position angle of the line connecting the centres of both components was taken from the UGC notes or from Tifft (1980) or determined by the author.

The Helou (1984) sample of 30 pairs (one non-UGC pair is excluded from the analysis) with differences between the radial velocities of the components $\Delta V \leq 250\ \mathrm{km\,s^{-1}}$ served to check the correctness of the applied method.

The Perseus sample contained 56 pairs situated within the supercluster, *i.e.* $22^{\mathrm{h}} \leq \alpha \leq 4^{\mathrm{h}}$, $21°.5 \leq \delta \leq 45°$, $4000 \leq V_r \leq 8500\mathrm{km\,s^{-1}}$ and with $\Delta V \leq 250\mathrm{km\,s^{-1}}$. The 33 pairs attributed to the Coma/A1367 supercluster are located within $11^{\mathrm{h}} \leq \alpha \leq 13.6^{\mathrm{h}}$, $16° \leq \delta \leq 37°$ and $4000 \leq V_r \leq 9000\ \mathrm{km\,s^{-1}}$, with $\Delta V \leq 250\ \mathrm{km\,s^{-1}}$. The fact that the region considered is more extended than the supercluster itself is due to the scarcity of data, but should not affect further considerations too much. From the Arigo *et al.* sample, 54 pairs with $V_r \leq 2600\ \mathrm{km\,s^{-1}}$ and $\Delta V \leq 250\ \mathrm{km\,s^{-1}}$ were extracted and considered as belonging to the Local Supercluster.

The samples of pairs are not complete from the statistical point of view, however, as the Helou (1984) sample, they are homogeneous with respect to the parameters considered.

The axial ratios q_o, as given in the UGC, were corrected to standard photometric diameters using the prescription of Fouqué and Paturel (1985), and they served for calculating the galaxy inclination:

$$i = \cos^{-1}\left(\frac{q_o^2 - q_t^2}{1 - q_t^2}\right)^{\frac{1}{2}} . \qquad (1)$$

It was assumed that q_t changes with morphological types from 0.25 to 0.15.

The question arises, how reliable the data given in the UGC are. There are a number of papers which deal with this problem. The Arigo *et al.* measurements are totally independent from the UGC. *Fig. 1* and *2* represent the comparison of position angles and axial ratio measurements in these two sources. From the inspection of the figures it follows that the position angles deviate slightly more for $b/a > 0.6$. Note that the Arigo *et al.* data were obtained using the value of the pair position angle, which certainly increases the errors. The angular deviation for the overall sample is 13°.4. The differences of axial ratios, as given in *Fig. 2*, are obtained from data which were both reduced to standard photometric diameters; the "standard", however, is different for each sample. The standard deviation is about 0.1. The mean value of the b/a

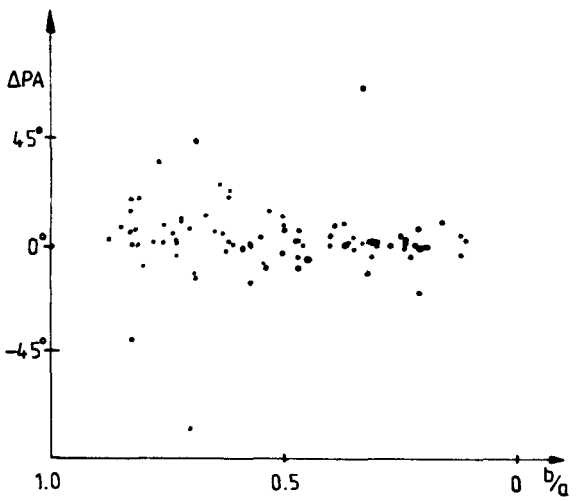

Fig. 1. The differences between position angles in Arigo *et al.* and the UGC relative to the axial ratios.

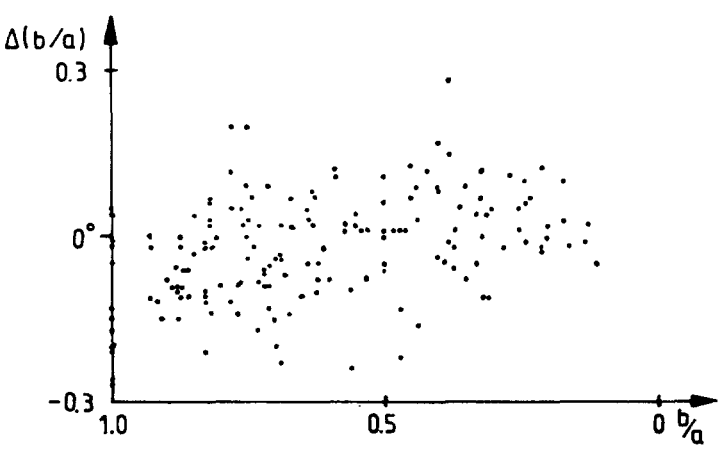

Fig. 2. The differences of the axial ratios in Arigo *et al.* and the UGC relative to the axial ratios.

differences for $b/a < 0.4$ is above the zero line, while for $b/a > 0.6$ it is below the zero line, which probably means that in at least one set of data the axial ratios were overcorrected.

3 Method of analysis

The analysis is performed exactly in the manner presented in detail in the previous paper (Flin and Godlowski 1986). It is assumed that the galaxy rotation axis is perpendicular to the galaxy plane, which due to the ambiguity in the galaxy tilt gives two possible solutions for each galaxy. Both solutions are taken into account in the calculations. The coordinates of each galaxy are transformed from the equatorial coordinate system into a coordinate system connected with each parent supercluster. The value of the galaxy position angle is also expressed in the new coordinate system.

Two angular distributions are analysed: the polar angle δ_D between the rotation axis of the galaxy and the plane of the supercluster and the azimuthal angle η between the projection of the rotation axis on the supercluster plane and the x-axis, pointing towards supergalactic $l = 0, b = 0$. This analysis permits to study the alignment of galaxies with the plane of the parent supercluster.

The β-angle between the rotation axes of the components was calculated using the well-known formula of spherical trigonometry:

$$\cos\beta = \sin b_1 \sin b_2 + \cos b_1 \cos b_2 \cos(l_1 - l_2)\,, \tag{2}$$

where b and l are the coordinates of the galaxy rotation axes. For each pair eight possible solutions were obtained and included, as equally probable, into further calculations. In comparison to previous work, where only the analysis of position angles was performed, the allowed range of the β-angle is twice as large, but there is a symmetry of the angles β and $180° - \beta$. Galaxies seen "face-on" are, however, included into the analysis. The present analysis permits only to test the isotropy of the distribution, and in the case of anisotropy to check whether the rotation axes of paired galaxies are more nearly parallel or perpendicular. It does not allow to separate parallelism and anti-parallelism, as it was done in the work of Helou (1984).

4 Orientation of double galaxies in superclusters

It was shown (Flin and Godlowski 1986, Flin 1987) that galaxies in the three investigated superclusters tend to have their rotation axes aligned with the supercluster plane, that is the δ_D-angle tends to be small. Moreover, the distribution of the η-angle is also a non-random one. The projections of rotation axes are rather directed toward the main structure of the supercluster, which means that the galaxy planes tend to be perpendicular to the radius vector. The performed analysis does not permit to determine which effect is the principal one. It would be interesting to check whether similar alignments can be observed for paired galaxies. If this is so, it means that the dominant effect is due to membership in a supercluster and not to duplicity.

In order to test the distribution of rotation axes in pairs with respect to the main plane of the parent supercluster, the two angles, δ_D and η, were determined. The

Table 1. The result of the χ^2-test

Supercluster		no. of solutions	δ_D-angle degrees of freedom	δ_D-angle χ^2-value	η-angle degrees of freedom	η-angle χ^2-value
LSC	all	2550	13	13.1	15	17.5
	double	108				
Coma	all	140	10	12.7	13	30.4
	double	132				
Per	all	642	13	7.8	16	28.0
	double	224				

distributions of both angles were compared with the distributions of the respective angles for the general sample of galaxies belonging to each supercluster. The statistical hypothesis was that both samples do not differ significantly from each other, *i.e.*, they come from the same population. The check was performed using the χ^2-test for angular data (Batschelet 1981). The contingency tables are given in Table 1. From Table 1 it follows that the distribution of the δ_D-angle is always the same for double galaxies as for the general sample. In the case of the η-angle, the similarities between the distributions, though not as large as for the δ_D-angle, are statistically significant

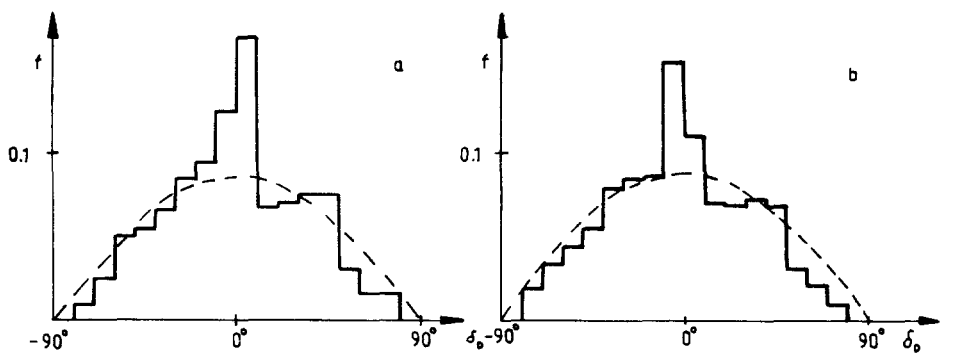

Fig. 3. The distribution f of the δ_D-angle for (a) double galaxies and (b) all bright ($m \leq 14.5$) galaxies in the Perseus supercluster (broken lines denote isotropic distributions).

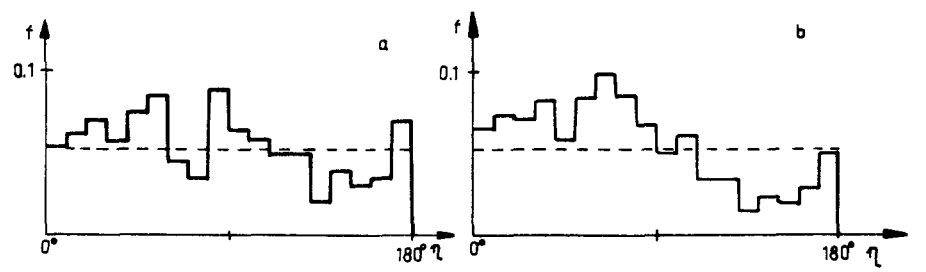

Fig. 4. The same as *Fig. 3*, but for the η-angle.

(at the significance level $\alpha = 0.01$). The distributions of the δ_D- and η-angles for single bright galaxies and for double galaxies in *Figs. 3* and *4* show that the two populations show noticeable similarities.

The performed analysis permits to state that the rotation axes of galaxies in pairs tend to be aligned with the plane of the parent supercluster, and that the projections of the rotation axes onto the supercluster plane tend to point towards the superclusters.

5 Analysis of the β-angle

The resulting distributions are shown in *Fig. 5*, separately for each investigated sample, and for the total sample of pairs belonging to superclusters. The isotropy of the distributions was checked by application of the Rayleigh test for angular data (Batschelet 1981); for each sample the probability of isotropy P was less than 0.001. Moreover, the number of solutions falling into bins with 15° width was compared with the number predicted from the random distribution, and the comparison is shown in Table 2. An excess of solutions is observed in the bins $0° - 15°$ and $165° - 180°$, while there is a manifest lack of solutions in the bins $75° - 105°$. In the sample containing the pairs in all superclusters the differences are about 2σ. It should be stressed that the observed anisotropy is not due to the ambiguity in the determination of the β-angles. Such an ambiguity could only blur the existing anisotropy, due to the symmetrisation of the β- and $(180° - \beta)$-angles, but it is not able to produce it.

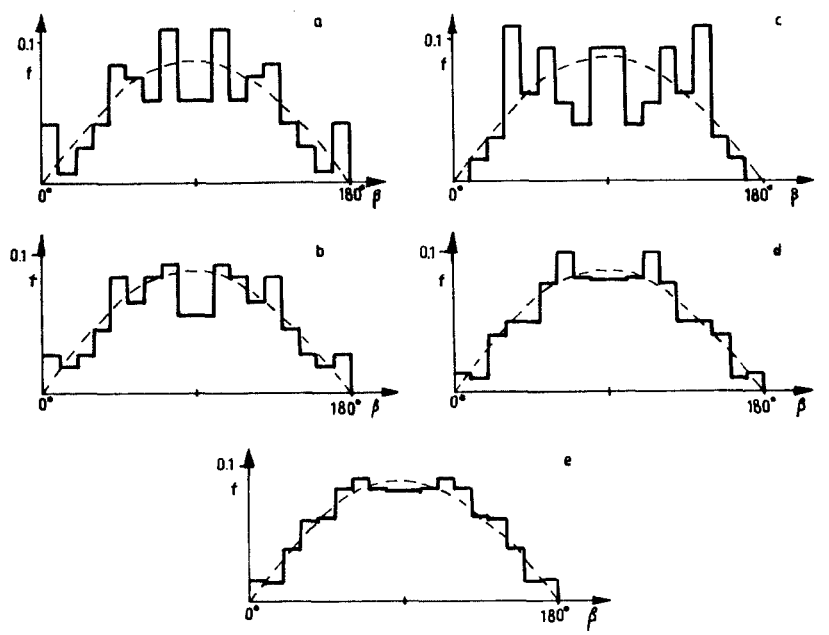

Fig. 5. The distribution of the β-angle in the double galaxies for (a) the Helou sample, (b) the LSC, (c) the Coma/A1367 SC, (d) the Perseus SC, and (e) composite plot for double galaxies in superclusters (the broken lines denote isotropic distributions).

Table 2. Check of isotropy of the β-angle

β-angle	Helou		LSC		Coma		Per		pairs in SC	
range	obs	exp	obs	exp	obs	exp	obs	exp	obs	exp
$0° - 15°$ and $165° - 180°$	24	8	16	7	4	4	16	15	36	27 ± 5.1
$15° - 30°$ and $150° - 165°$	12	24	16	22	8	13	40	45	64	79 ± 8.9
$30° - 45°$ and $135° - 150°$	52	38	36	34	44	20	68	71	148	126 ± 11.2
$45° - 60°$ and $120° - 135°$	44	50	48	45	24	26	90	93	162	164 ± 12.8
$60° - 75°$ and $105° - 120°$	48	58	60	52	20	31	128	108	208	191 ± 13.8
$75° - 90°$ and $90° - 105°$	60	62	40	56	28	33	106	116	174	205 ± 14.3

6 Conclusions

It is shown that the applied method is a useful tool for studying the mutual orientation of rotation axes of paired galaxies. It has the advantage that it includes objects for which the true spins are not known and thus permits to study large samples, so important in statistics. Moreover, in comparison to the position angle analysis it allows to include galaxies seen "face-on". Two galaxies forming a pair when seen "face-on" or nearly "face-on" have rotation axes close to each other, *i.e.* the β-angle is small. To drop these galaxies off the analysis is to introduce a systematic shift in the observed distribution. This is probably the reason that random distribution was so frequently obtained. The effect for the Helou sample is the same as in the present study, which validates the applied method; due to the limitation of the method, however, parallel and anti-parallel alignments cannot be separated.

The main results of the present study are:

i. the rotation axes of galaxies forming pairs tend to be aligned with the plane of the parent supercluster,

ii. the projections of rotation axes of paired galaxies onto the supercluster plane tend to point toward the centre of the structure, *i.e.* the galaxy planes tend to be perpendicular to the radius vector from the centre of the structure,

iii. the distribution of the β-angle is a non-random one, there is a strong tendency for rotation axes of paired galaxies to form a small $|\beta|$-angle and to avoid angles $90° \pm 15°$.

The observational results should be compared with predictions resulting from theoretical considerations of galaxy origin. From (i) and (ii) it follows that the alignments of paired galaxies and of single ones within superclusters are similar. This supports the hypothesis of a common origin of galaxies belonging to superclusters. The existence of an anisotropy and the direction of alignment (parallelism of the rotation axes with

the supercluster main plane) are in agreement with a dissipative scenario of galaxy origin.

The lack of isotropy in the distribution of the β-angle is an argument against both the capture mechanism and the tidal torque hypothesis as explanations of the origin of double galaxies. The anti-parallelism of spins detected by Helou (1984) is against the turbulence scenario, exactly as points (i) and (ii). Thus, all observational evidence strongly favours the non-turbulence "top-down" scenario of galaxy origin.

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