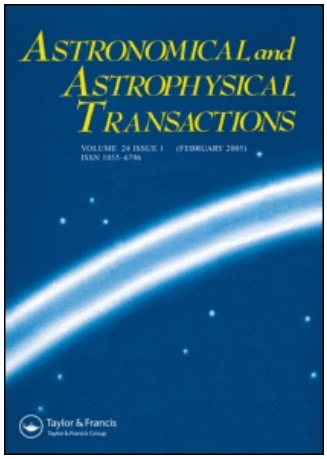

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

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Online Publication Date: 01 June 1996
To cite this Article: Flin, P. (1996) 'The alignment of galaxies in superclusters', Astronomical & Astrophysical Transactions, 10:2, 153 - 159
To link to this article: DOI: 10.1080/10556799608203023
URL: http://dx.doi.org/10.1080/10556799608203023

Astronomical and Astrophysical Transactions, 1996, Vol. 10, pp. 153–159
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THE ALIGNMENT OF GALAXIES IN SUPERCLUSTERS

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(Received November 25, 1994)

The orientation of galaxies in the Local Supercluster, Coma/A1367, Perseus and Hercules Superclusters was investigated. In each supercluster galaxy planes show a tendency to be perpendicular to the main plane of the parent supercluster.

1 INTRODUCTION

It is well known that some scenarios of galaxy origin predict the existence of galaxy rotation axes, while others not. Assuming that galaxy spins observed now are primeval, this reflects conditions during galaxy formation (Shandarin, 1974; Dekel, 1985; West *et al.*, 1990).

The number of galaxies with determined spins is rather small. Therefore, instead of studying the distribution of galaxy spins, it is convenient to perform an analysis of the orientation of galaxy rotation axes, which permits one to analyse a large number of galaxies. In our studies the approach of Opik (1969) and Jaaniste and Saar (1977) was applied. It consists in determination of the spatial orientation of a galaxy and not only in the analysis of a galaxy's position angle. In the latter paper some galaxies, i.e. galaxies seen "face-on", were rejected from the analysis. It is obvious that omission of such galaxies from the analysis leads to systematic errors. Galaxy rotation axis for a galaxy seen "face-on" is determined with the same accuracy as for an "edge-on" object.

2 METHOD OF ANALYSIS

The spatial orientation of galaxy is reckoned using values a and b of the major and minor axis of the galaxy's image, as well as the galaxy's position angle p. The tilt angle of a galaxy, denoted as i, i.e. the angle between the normal to the galaxy's plane and observer's line of sight, is calculated using a standard formula:

$$\cos^2 i = [(b/a)^2 - q_0^2]/(1 - q_0^2),$$

where q_0 denotes the true axial ratio of the galaxy, regarding galaxy as an oblate spheroid (the standard value is $q_0 = 0.2$, but it depends on the galaxy's morphological type).

The rotation axis of a galaxy is located along the normal. Due to projection, this formula gives two possible orientations of the galaxy's normals, i.e. two possible locations of the galaxy's rotation axis. In further calculations both positions are considered (Flin and Godlowski, 1986). The spatial orientation of each investigated supercluster is known, which allows us to determine the main plane of the supercluster. Because our purpose is to study the orientation of galaxies with respect to the parent supercluster, the galaxy's coordinates α, δ and its position angle p expressed in the equatorial coordinate system are transformed to the new coordinate system connected with the parent supercluster, and the suoercluster's main plane serves as the equator of the new coordinate system. The node and inclination are determined which determine the system connected with the supercluster. Two angles describe the spatial orientation of a galaxy's normal with respect to the parent supercluster. The polar angle δ_D is between the normal and the main plane of the supercluster and the azimuthal angle η is between the projection of the galaxy's normal and the zero semicircle of the supergalactic coordinate system. The angles are calculated using formulae (Flin and Godlowski, 1986):

$$\sin \delta_D = -\cos i \sin b \pm \sin i \sin P \cos b$$

$$\sin \eta = [-\cos i \cos b \sin l + \sin i(\pm \sin P \sin b \sin l \pm \cos P \cos l)](\cos \delta_D)^{-1},$$

where b and l are the latitude and the longitude in the coordinate system connected with the parent supercluster and P is the position angle in this system. (For galaxies seen face-on, $p = 0$).

3 OBSERVATIONAL DATA

The membership of a galaxy in the parent supercluster is assigned on the basis of the galaxy's position on the celestial sphere and its radial velocity. The Local Supercluster galaxy should have $v_r < 2600$ km s^{-1} and arbitrary position on the celestial sphere. Spinal galaxies (from Zwicky Catalogue 1961–1968) located in the region: $22^h \leq \alpha \leq 4^h$, $21° \leq \delta \leq 45°$, with radial velocities 4000 km s$^{-1} \leq v_r \leq$ 8500 km s^{-1}, are regarded as belonging to the Perseus Supercluster. The Coma/A1367 supercluster galaxies (from Zwicky Catalogue) are located in the region: $11.5^h \leq \alpha \leq 13.5^h$, $18° \leq \delta \leq 32°$, with $v_r \in$ (6000 km s^{-1}, 8000 km s^{-1}). Spiral galaxies, extracted from the UGC and located in the region: $14^h \leq \alpha \leq 18^h$, $0° \leq \delta \leq 40°$ with radial velocities:

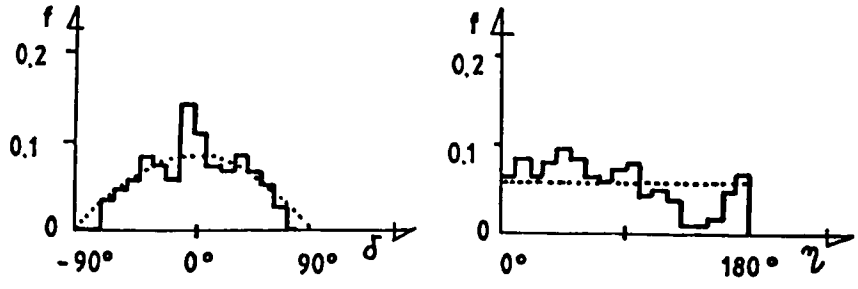

Figure 1 The frequency distribution of the δ_D and η angle for spiral galaxies in the Coma/A1367 supercluster (the dotted line denotes isotropic distribution).

8000 km s^{-1} < v_r < 15000 km s^{-1} (for $\delta \leq 25°$) and 7500 km s^{-1} < v_r < 15000 km s^{-1} (for $\delta > 25°$) are regarded as members of the Hercules Supercluster.

Data on radial velocities and morphological types of galaxies, as well as values of position angles and major and minor axes, were collected from the literature mainly from UGC (Nilson, 1973) and ESO catalog (Lauberts, 1982). When lacking, a, b and p have been determined by the author on PSS prints.

It should be stressed that the spatial orientations of these superclusters different. Galaxies are located inside the Local Supercluster, while the Perseus and the Coma/A1367 supercluster are seen practically "edge-on". Totally different is the spatial orientation of the Hercules Supercluster. It is seen almost "face-on".

4 STATISTICAL ANALYSIS

The obtained values of the angles δ_D and η were grouped into bins of 10° width. Three statistical tests were applied to these distributions, following Hawley and Peebles (1975). These are: the $\varkappa^2$ test, the auto correlation test C and the Fourier test checking the existence of anisotropy slowly varying with the investigated angle. This method of investigation was applied to galaxies in the Local, Coma/A1367, and Perseus Superclusters.

In the case of the Hercules Supercluster, the simple comparison of observed distribution with the theoretical, random one, has been performed, testing the isotropy of distribution of the angle γ between galaxy's plane and the main plane of the supercluster.

5 RESULTS AND DISCUSSION

The binned distributions of δ_D and η angles were tested for isotropy. Figure 1 presents the observed distributions of the angles for spirals in the Coma/A1367

Table 1. Statistical analysis of the δ_D and η angles

		angle δ_D				*angle* η			
	N	$P(\chi^2)$	$P(>\Delta)$	C	F	$P(>\chi^2)$	$P(>\Delta)$	C	F
LSC									
All	2227	0.00	0.00	37.0	−0.24	0.00	0.00	37.2	0.00
SO+S	1565	0.08	0.10	−4.9	−0.09	0.19	0.01	5.4	−0.06
Non SO+S	662	0.00	0.00	77.2	−0.62	0.00	0.00	38.3	−0.15
PER									
S	709	0.00	0.00	115.9	−0.21	0.00	0.00	63.8	−0.21
centre	265	0.00	0.00	77.0	−0.22	0.00	0.00	26.0	−0.41
$b > 3°$	444	0.01	0.00	50.9	−0.46	0.00	0.00	46.4	−0.29
COMA/A1367									
All	512	0.00	0.00	350.9	−0.63	0.00	0.00	287.0	−0.11
S	261	0.00	0.00	281.7		0.00	0.00	238.0	
S centre	178	0.00	0.00	81.9		0.00	0.00	48.2	
S $b > 3°$	73	0.00	0.00	34.1		0.00	0.00	31.0	

Supercluster (Flin, 1993). Table 1 contains the results of the statistical analysis, giving the probabilities that the distribution is random. For an isotropic distribution we expect $C = 0$ and $\alpha_C = 4.24$. The parameter F gives the direction of anisotropy. When $F < 0$, normals tend to be parallel to the supercluster main plane (for δ_D angle) and projections are grouped in the region 0°–90° (η angle). It can be seen that the distributions are anisotrpic. There is a tendency for δ_D to make small angles with the main plane of the parent supercluster. Moreover, the η angle shows that projection of rotation axes on the parent supercluster main plane tend to point toward the main structure.

The same kind of anisotropy, however with different significance, is observed in all three superclusters. Moreover, galaxies located in the main part of the Perseus and Coma/A1367 superclusters (latitude $b \leq 3°$) and outside these regions similar alignment. In the latter structures investigations were performed with increasing number of galaxies, incorporating dimmer objects and enlarging area of the Perseus Supercluster. The results do not change (Flin, 1988a, b, 1993; Flin and Godlowski, 1989a). It can be pointed out that in the LSC, due to its complicated structure, galaxies located in various regions have different orientations (Flin and Godlowski, 1990).

Anisotropy is stronger for elliptical galaxies than for spiral ones, which was confirmed by independent investigations performed by Lambas *et al.* (1988) and Parnovsky *et al.* (1994).

Figure 2 presents the distribution of the γ angle, and statistical analysis is given in Table 2. The theoretical numbers in Table 2 correspond to random distribution of the γ angle, and their standard deviations were calculated as square roots of the number of values of the γ angle falling into the given range.

In this case also the perpendicularity of galaxy planes to the main plane of the parent supercluster is observed.

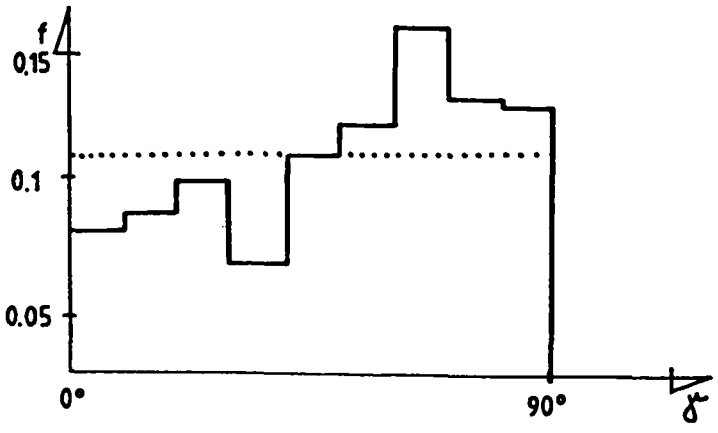

Figure 2 The frequency distribution of the angle γ for spiral galaxies in the Hercules supercluster (the dotted line denotes isotropic distribution).

The detected anisotropy can be caused by errors and uncertainties in values of the involved parameters. The detailed analysis of the factors influencing the result was performed (Flin, 1989; Flin and Godlowski, 1989b) and it was concluded that these are unable to produce a spurious anisotropy. It should be stressed that the reported anisotropy is not very strong. The applications of a coordinate system connected with parent supercluster is increasing signal-to-noise ratio (Kapranidis and Sullivan, 1983). It has been explicitly shown (Flin and Godlowski, 1986) that omission from the analysis of objects with axial ratio $b/a > 0.6$ produces a systematic effect leading to a spurious result. For the LSC, when the axial ratio b/a increases, the direction of anisotropy is changing from alignment of galaxies' planes with the main plane of the Local Supercluster (for galaxies seen "edge-on")through isotropy till perpendicularity of galaxies' planes (all investigations taking into account galaxies seen "face-on").

The northern part of the Hercules Supercluster was investigated using position angle analysis (Cerne and Peterson, 1990) with null result, i.e. isotropic distribution. As shown above, the analysis with larger number of objects and the search of anisotropy with respect to the supercluster main plane revealed the perpendicularity of galaxies' planes, as in the case of other structures.

Table 2. Results of the statistical analysis of the γ angle (Hercules Supercluster)

range of the γ angle	*number of γ angles*	
	observed	*theoretical*
0°–30°	174	207.3 ± 14.4
30°–60°	188	207.3 ± 14.4
60°–90°	260	207.3 ± 14.4

CONCLUSIONS

The performed investigations of four superclusters with well determined spatial orientation give the following result:

i. galaxies' planes tend to be perpendicular to the main plane of the parent supercluster,

ii. projections of rotation axes on the supercluster main plane point toward the main structure,

iii. the same type of anisotropy is observed in dense and sparse regions of a supercluster,

iv. points i. and ii. can be also interpreted as perpendicularity of the galaxy plane to the radius vector. The result support scenarios of galaxies' origin in which superclusters were formed prior to galaxies.

Acknowledgements

This work was supported by Polish Committee for Scientific Research/Cracow Pedagogical University grant.

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