

THE ENVIRONMENTAL EFFECTS IN THE ORIGIN OF ANGULAR MOMENTA OF GALAXIES*

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(Received October 20, 2011)

We study the galaxy alignment in the sample of very rich Abell clusters located in and outside superclusters. The statistically significant difference among investigated samples exists. We found that in contrast to the full sample of clusters, where alignment increase with the cluster richness, the clusters belonging to superclusters do not show this effect. Moreover, the alignment decreases with the supercluster richness. One should note however that orientations of galaxies in analyzed clusters are not random, both in the case when we analyzed the full sample of clusters and only clusters belonging to superclusters. The observed trend, dependence of galaxy alignment on both cluster location and supercluster richness clearly supports the idea of influence of environmental effects to the origin of galaxy angular momenta.

DOI:10.5506/APhysPolB.42.2313

PACS numbers: 98.52.-b, 98.65.-r

1. Introduction

The problem of the origin of large scale structures is, till now, one of the most enigmatic ones. It is commonly accepted that presently observed structures originated from almost isotropic distribution in the early Universe.

* Presented at the XXXV International Conference of Theoretical Physics “Matter to the Deepest”, Ustroń, Poland, September 12–18, 2011.

The departure from isotropy, as estimated from CMBR is of the order of $\delta\rho/\rho \simeq 10^{-5}$. About a half century ago the main problems were connected with type of the perturbations, its amplitude and scale (mass or length). Different theories of galaxy origin called scenarios predicted various masses of newly originated structures and various manners in which galaxy gained angular momentum [1, 2, 3, 4, 5, 6, 7, 8]. In some scenarios, the distribution of galaxy angular momenta in structure were random ones, in others perpendicular or parallel to the structure main plane [2, 3, 4, 5, 9, 10, 11, 12, 13]. This way, the existence or not of the galaxy orientation can be used for testing scenarios of galaxy origin. Because the real location of rotation axes is known for very small number of objects, usually the study of orientation of galaxy planes is performed. In contemporary picture of large scale distribution known as “Cosmic Web” we practically have four components. These are long filaments, walls, voids and the rich, dense regions called galaxy clusters.

In our previous paper [14], we studied the orientation of galaxy groups in the Local Supercluster. We found the strong alignment of the major axis of groups with both direction toward the supercluster centre (Virgo cluster) as well as with line joining two brightest galaxies in the group. The interpretation of these observational facts was the following. The brightest (believed to be the most massive) galaxies of the group originate first. Due to gravitational forces other galaxies are attracted to these ones and a filament is forming. The other possibility is that at the pre-existing filament galaxies are forming. In this direction pointed the result of [15] who interpreted theirs founding that the spins of spiral galaxies located within cosmic web filaments tend to be aligned along the larger axis of the filament, as “fossil” evidence, indicating that the action of large scale tidal torques effected the alignments of galaxies located in cosmic filaments.

In our paper [14], analyzing the sample of 247 rich Abell Clusters, we found that the alignment of member galaxies in rich structures, having more than 100 members, is a function of the group mass. Richer groups exhibit stronger galaxy alignment. The change of alignment with the surrounding neighborhood was observed also in the alignment study in void vicinity [16], being a continuation of the earlier study of galaxy orientation in regions surrounding bubble-like voids [13]. They found that disk galaxies around large voids (greater than 15 Mpc/h) present a significant tendency to have their angular momenta aligned with the void’s radial direction. The strength of this alignment is dependent on the void’s radius and for voids with ≤ 15 Mpc/h the distribution of the orientation of galaxies is compatible with random distribution. Varela *et al.* [16] found that this trend observed in the alignment of galaxies is similar to that observed in numerical simulations of the distribution of dark matter *i.e.* in distribution of the minor axis of dark matter halos around cosmic voids, which suggests a possible link in the evolution of both components.

In view of these facts, it is interesting to look if the cluster belonging to the larger structures exhibit the same type of alignment as whole sample of the clusters. For this reason, we analyzed the alignment of member galaxies for the clusters belonging to superclusters. This problem was not investigated till now, although alignment of galaxies in superclusters was investigated many times. Presence of non-random galaxy spin orientation has been ascertained both in the Local Supercluster (for example [17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27] and in other superclusters, as the Hercules Supercluster, Coma/A 1367 and the Perseus Supercluster [28, 29, 30, 31, 32, 33, 34].

2. Observational data

The PF Catalogue of galaxy structures [35] was used as observational basis of the present study. This Catalogue was constructed by finding structures in the Muenster Red Sky Survey (MRSS) [36]. We used the Voronoi tessellation technique for structure finding. MRSS is a large-sky galaxy catalogue covering an area of about 5000 square degrees on the southern hemisphere. It is the result of scanning of 217 ESO plates, giving positions, red magnitudes, radii, ellipticities and position angles of about 5.5 million galaxies and it is complete down to $r_F = 18.3^m$. As a result we have 6188 galaxy structures called clusters. Using standard covariance ellipse method we determined structure ellipticity and position angles. We chose the sample of 247 very rich clusters, having at least 100 members each, and being identified with one of the ACO clusters [37] — see [38] for details. The PF catalogue served also as a basis for supercluster detection. We found 54 superclusters having at least 4 clusters each. As expected, superclusters are rather flat structures (see Fig. 1). We found that 43 from total member of 247 clusters belong to the superclusters and they were chosen for detailed analysis.

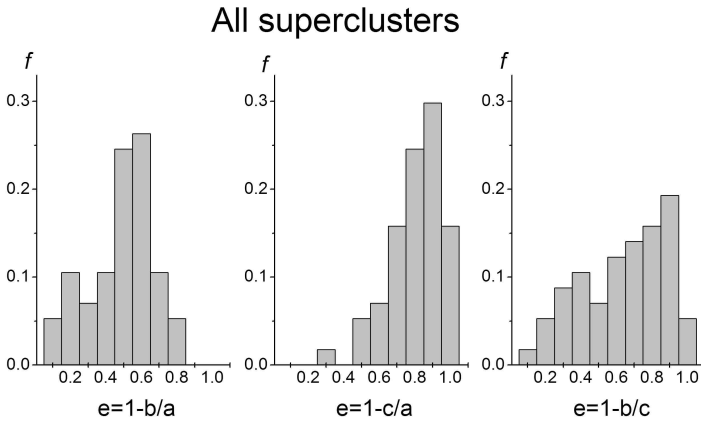


Fig. 1. Ellipticities of the analyzed superclusters.

3. Results and analysis

We studied the alignment of galaxies in very rich clusters belonging to superclusters. The study of alignment was done, as usual, by analyzing the angles connected with the orientation of galaxy plane. These are: the position angle of the great axis of the galaxy image and the angles describing the orientation of the normal to the galaxy planes: polar — δ_D and azimuthal η . At first we binned our samples into three bins according to the supercluster richness, These were: superclusters containing only 4 structures, subsample containing 5, 6 and 7 structures and finally subsample of superclusters each of them containing 8 and 10 clusters. One should note however that three clusters 0347–5571, 2217–5177 and 2234–5249 have double possible identification with supercluster and these clusters are counted for two bins.

At first, we studied the frequency of alignment of very rich clusters (having 100 and more members) belonging to supercluster (Table I). One can show that anisotropy decreased with supercluster richness. Moreover, we determined the frequency alignment in the full sample of 247 very rich Abell clusters. In the full sample of 247 clusters anisotropy on the distributions of the angle P was observed in 38% clusters, while galaxy plane anisotropy was noted in 85% and 77% clusters in the case of the angle δ_D and the angle η respectively. For the sample of galaxies belonging to the superclusters we observed anisotropy in 55% clusters in the case of position angles P and in 78% and 76% of the clusters in the case of the angle δ_D and the angle η , respectively.

TABLE I

The frequency of anisotropy of very rich clusters located in superclusters.

Richness	Angle P	Angle δ_D	Angle η
$N = 4$	0.84	0.74	0.84
$N = 5-7$	0.31	0.90	0.79
$N = 8-10$	0.43	0.57	0.43

The observed anisotropy is significantly greater when we analyzed the spatial orientation of galaxy plane (δ_a and η angles) than in the case of position angles p . In our opinion this is due to incorrectly assumed shapes of galaxies. This problem was analyzed in details by [39, 40, 41]. The work of Godłowski and Ostrowski [41] was based on the Tully’s NGC Catalog [42]. In this catalog during calculating galaxy inclination angles, Tully assumed that the “true” ratio of axes of galaxies is 0.2, which is a rather poor approximation, especially for non-spiral galaxies [43]. For our present analysis this effect is not so important because in the case of analysis of spatial orientation of galaxy planes our interest is how alignment is changing with belonging of clusters to the supercluster and with supercluster richness.

Now we decided to analyze the alignment in the cluster belonging to superclusters in more details. Hawley and Peebles [44] analyzed the distributions of position angles using χ^2 test, Fourier tests and autocorrelation test. Since [44] this method was accepted as a standard method for analysis of galactic alignment. One should note that there are several modifications and improvement of original Hawley and Peebles (1975) methods [20, 23, 24, 38, 45, 46]. Recently, Godłowski [47] performed a deeper improvement of the original Hawley and Peebles method and showed its usefulness for analysis of galactic orientations in clusters. In [47] the mean values of analyzed statistics was computed. The null hypothesis H_0 was that the mean value of the analyzed statistics was as expected in the cases of a random distribution of analyzed angles. The results were compared with theoretical predictions as well as with results obtained from numerical simulations.

Following this method, now we analyzed our sample of 43 clusters belonging to the superclusters in details. Because of small number of galaxies in some clusters we performed 1000 simulations of the distributions of the position angles in 43 fictitious clusters, each cluster with number of members galaxies the same as in the real cluster. In Table II we present average values of the analyzed statistics, their standard deviations, standard deviations in the sample and their standard deviations for distribution of P angles. The applied statistics in details were presented in our previous papers [38, 47]. We compared results obtained for real sample of our 43 clusters with that obtained from numerical simulations.

TABLE II

The random statistics.

Test	\bar{x}	$\sigma(x)$	$\sigma(\bar{x})$	$\sigma(\sigma(x))$
χ^2	34.9592	1.2843	0.0406	0.0287
$\Delta_1/\sigma(\Delta_1)$	1.2567	0.0983	0.0031	0.0022
$\Delta/\sigma(\Delta)$	1.8846	0.1027	0.0032	0.0023

For the sample of all 43 clusters located in superclusters the distributions of the position angles of members galaxies in the cluster are anisotropic and the departure from the isotropy is greater than 3σ (see Table II and Table III). For the angles which give the spatial orientation of galaxy planes (δ_d and η angles) the anisotropy is even greater but one should remember the above problem with approximation of the “true” ratio of axes of galaxies as 0.2.

TABLE III

The statistics of the observed distributions for real clusters.

Test	P		δ_D		η	
	\bar{x}	$\sigma(x)$	\bar{x}	$\sigma(x)$	\bar{x}	$\sigma(x)$
χ^2	38.772	1.574	57.079	6.190	84.656	7.391
$\Delta_1/\sigma(\Delta_1)$	1.797	0.148	3.594	0.385	5.324	0.586
$\Delta/\sigma(\Delta)$	2.339	0.148	4.906	0.407	6.475	0.522

The main point of our study is connected with trends appearing in the data. In the analyzed sample of 43 galaxies we do not observe the effects connected with cluster richness (Fig. 2, Table IV) which is significantly different from result obtained by [14] for whole sample of 247 rich Abell clusters. We suppose that such difference is probably due to environmental effects during superclusters forming.

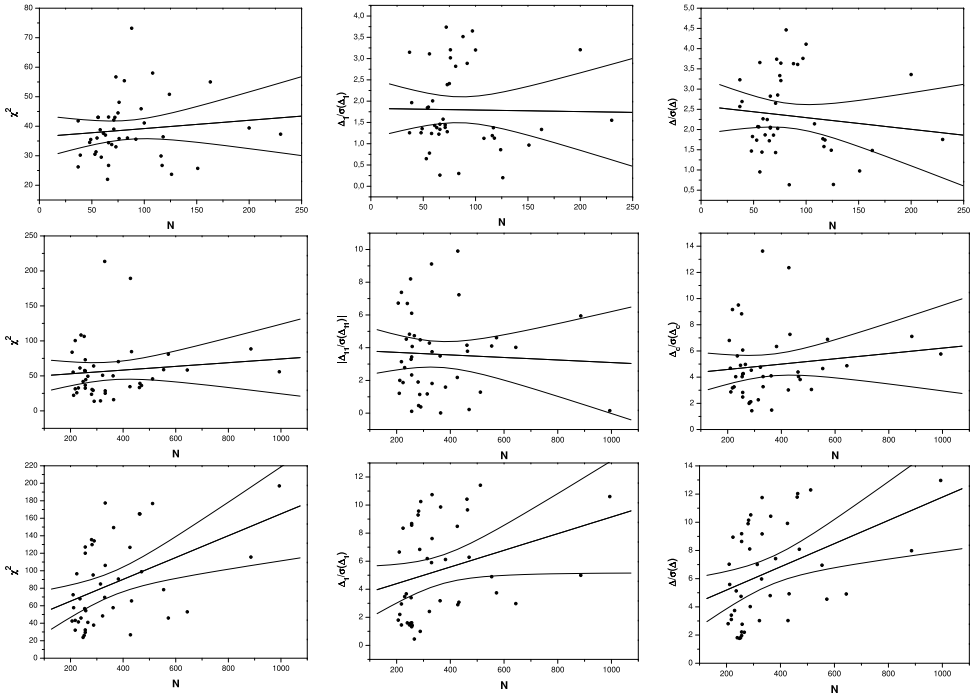


Fig. 2. The relation between the number of galaxies in the cluster N and the value of analyzed statistics (χ^2 — left panel, $\Delta_1/\sigma(\Delta_1)$ — middle panel, $\Delta/\sigma(\Delta)$ — right panel) for the position angles p (upper panel), δ_D angles (middle panel) and η angles (bottom panel) — equatorial coordinates. The bounds errors, at confidence level 95%, were presented as well.

TABLE IV

The results of the linear regression analysis — value of analyzed statistics as a function of the cluster richness for clusters belonging to the superclusters.

Angle	χ^2		$\Delta_1/\sigma(\Delta_1)$		$\Delta/\sigma(\Delta)$	
	$a \pm \sigma(a)$	$b \pm \sigma(b)$	$a \pm \sigma(a)$	$b \pm \sigma(b)$	$a \pm \sigma(a)$	$b \pm \sigma(b)$
P	0.028 ± 0.039	36.4 ± 3.7	-0.0004 ± 0.0037	1.83 ± 0.15	-0.0029 ± 0.0037	2.58 ± 0.34
δ	0.026 ± 0.037	47.7 ± 14.6	-0.0008 ± 0.0023	3.87 ± 0.91	0.0020 ± 0.0024	4.18 ± 0.96
η	0.125 ± 0.040	40.2 ± 15.7	0.0060 ± 0.0030	3.21 ± 1.17	0.0082 ± 0.0028	3.54 ± 1.13

In Table V we presented value of analyzed statistics for different superclusters richness. Generally, the anisotropies decreased with the superclusters richness. Anisotropy for the angles P and δ_d seems to increase again for very rich supercluster. One should note however, that subsample of supercluster richness 8–10 contain significantly less clusters (7) in comparison to the poorer superclusters and moreover two cluster belonging to this bin have possible double identifications. Result of linear regression between values of analyzed statistics and supercluster richness presented in Fig. 3 and in Table VI generally confirmed above conclusion, with exception for δ_d angle where influence of the 8–10 bin is significant. Because our binned analysis is based only on 3 bins it is difficult to decide about statistical significance of this results. For this reason we repeat our analysis for unbinned sample of 46 clusters (3 of them have possible double identifications). Analyzing the statistics $T = \frac{a}{\sigma(a)}$ which has Student’s distribution with $n - 2$ degrees

TABLE V

The statistical analysis: value of analyzed statistics for different superclusters richness.

Angle	Test	$N = 4$	$N = 5-7$	$N = 8-10$
P	χ^2	43.30 ± 2.42	34.99 ± 2.11	36.65 ± 1.55
	$\Delta_1/\sigma(\Delta_1)$	1.99 ± 0.25	1.50 ± 0.16	1.89 ± 0.32
	$\Delta/\sigma(\Delta)$	2.57 ± 0.23	2.08 ± 0.18	2.42 ± 0.36
δ_D	χ_c^2	54.52 ± 10.69	48.68 ± 4.57	89.07 ± 18.56
	$ \Delta_{11}/\sigma(\Delta_{11}) $	3.13 ± 0.63	2.76 ± 0.57	6.41 ± 0.84
	$\Delta_c/\sigma(\Delta_c)$	4.76 ± 0.72	4.40 ± 0.34	6.97 ± 1.09
η	χ^2	83.60 ± 12.09	95.57 ± 9.74	43.01 ± 5.44
	$\Delta_1/\sigma(\Delta_1)$	5.43 ± 0.86	5.83 ± 0.71	2.02 ± 0.29
	$\Delta/\sigma(\Delta)$	6.30 ± 0.88	7.31 ± 0.66	3.19 ± 0.38

of freedom, we conclude that only in the case of the η angle decreasing the anisotropy with the supercluster richness is statistically significant at the level of 0.05.

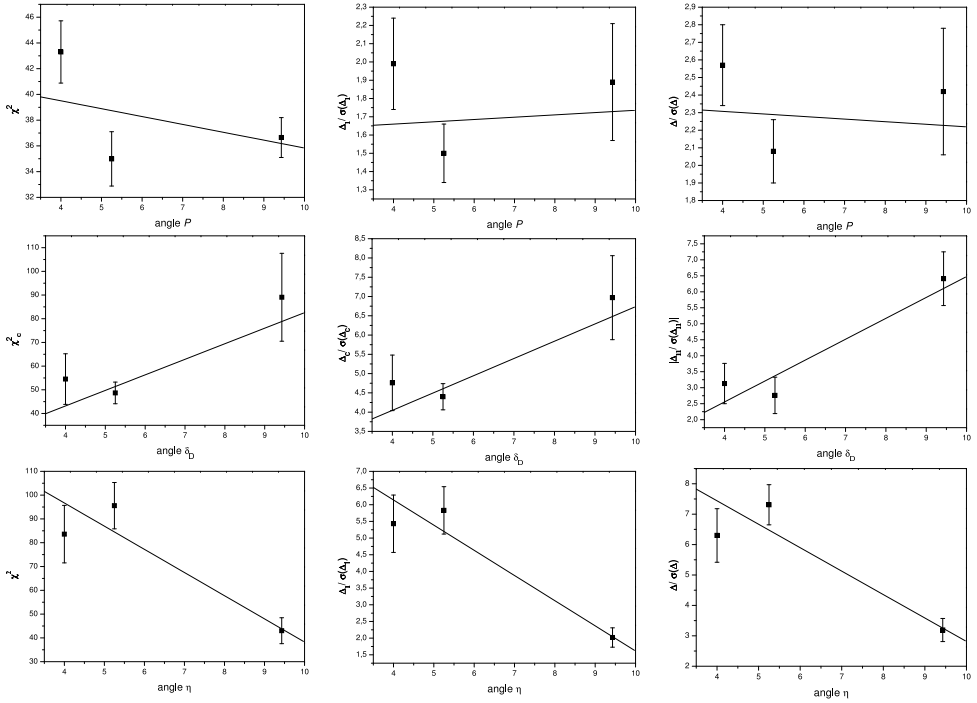


Fig. 3. The result of the regression analysis of the value of respective statistics (χ^2 — left panel, $\Delta_1/\sigma(\Delta_1)$ — middle panel, $\Delta/\sigma(\Delta)$ — right panel) and the number of clusters in superclusters for the position angles p (upper panel), δ_D angles (middle panel) and η angles (bottom panel) — equatorial coordinates.

TABLE VI

The results of the linear regression analysis — value of analyzed statistics as a function of supercluster richness.

Angle	χ^2		$\Delta_1/\sigma(\Delta_1)$		$\Delta/\sigma(\Delta)$	
	$a \pm \sigma(a)$	$b \pm \sigma(b)$	$a \pm \sigma(a)$	$b \pm \sigma(b)$	$a \pm \sigma(a)$	$b \pm \sigma(b)$
P	$-.61 \pm 0.46$	41.9 ± 3.5	0.014 ± 0.074	1.61 ± 0.43	$-.016 \pm 0.080$	2.39 ± 0.45
δ	6.57 ± 3.94	16.9 ± 21.2	0.656 ± 0.191	$-.08 \pm 1.14$	0.445 ± 0.240	2.27 ± 1.31
η	-9.74 ± 1.97	$135. \pm 16.$	$-.756 \pm 0.131$	9.14 ± 1.13	$-.770 \pm 0.139$	10.5 ± 1.1

4. Discussion and conclusions

We investigated a sample of 43 rich Abell galaxy cluster belonging to the supercluster and having at least 100 members in the considered area. As expected, the analyzed superclusters are rather flat structures. We found that orientation of galaxies in the analyzed cluster are not random. Godłowski *et al.* [38] found that for the rich Abell cluster alignment increases with the cluster richness. In contrast, the cluster belonging to the superclusters does not show such effect. The alignment in poor supercluster is greater than in the case of rich one. The obtained results, which show the dependence of galaxy alignment on both the cluster location inside or outside the supercluster and the supercluster richness clearly support the influence of environmental effects to the origin of galaxy angular momenta. In a very simple and naive picture, if the alignment of galaxies is primordial, the strongest effect should be observed in small structures. However, at the present moment we do not have such data. We considered only really very rich clusters and looked for trends. It could be accepted that gaining of angular momenta for galaxies in a structure is a rather complicated problem, in which several mechanism played roles. In some cases the angular momentum of galaxies is due to local anisotropic collapse of protostructures, in other ones due to tidal torque mechanism. Moreover, cluster merging introduces additional factors influencing the observed distribution of galaxy angular momenta. This suggests that the environment played crucial role in origin of galaxy angular momentum. Our result is preliminary because our investigations were based on sample of only very rich clusters and will be continued with analysis of the structures with various richness taken into account. Fortunately, PF catalogue will allow us to perform such analysis.

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