The Astronomical Journal, 138:1709–1713, 2009 December
doi:10.1088/0004-6256/138/6/1709

ORIENTATION OF BRIGHTER GALAXIES IN NEARBY GALAXY CLUSTERS

E. Panko[1], T. Juszczyk[2], and P. Flin[3]
[1] Astronomical Department, Odessa National University, Odessa, Ukraine; tajgeta@sp.mk.ua
[2] Czacki High School, Krakow, Poland
[3] Institute of Physics, Jan Kochanowski University, ul. Swietokrzyska 15, Kielce 25-406, Poland; sfflin@cyf-kr.edu.pl

Received 2009 March 25; accepted 2009 September 26; published 2009 November 2

ABSTRACT

A sample of 6188 nearby galaxy structures, complete to $r_F = 18\overset{\mathrm{m}}{.}3$ and containing at least 10 members each, was the observational basis for an investigation of the alignment of bright galaxies with the major axes for the parent clusters. The distribution of position angles for galaxies within the clusters, specifically the brightest, the second brightest, the third, and the tenth brightest galaxies was tested for isotropy. Galaxy position angles appear to be distributed isotropically, as are the distributions of underlying cluster structure position angles. The characterization of galaxy structures according to richness class also appears to be isotropic. Characterization according to BM types, which are known for 1056 clusters, is more interesting. Only in the case of clusters of BM type I is there an alignment of the brightest cluster member with the major axis of the parent cluster. The effect is observed at the 2 significance level. In other investigated cases the distributions are isotropic. The results confirm the special role of cD galaxies in the origin/evolution of large-scale structures.

Key words: galaxies: clusters: general – galaxies: evolution – galaxies: formation

1. INTRODUCTION

The origin of angular momenta in galaxies and cosmic structures is one of the most difficult problems in modern cosmology. The manner in which galaxies gain angular momentum differs in the three classic scenarios of galaxy origin. In hierarchical clustering (Peebles 1980) where isothermal perturbations are considered, the angular momenta of galaxies result from tidal torques (Peebles 1969; Thuan & Gott 1977). In the adiabatic perturbation (pancake) picture (Zeldovich 1970), shock waves generated during anisotropic collapse of the protostructure produces angular momentum in individual galaxies, while in the turbulence scenario it is the result of primordial vortices (Ozernoy 1978). Predictions for the spin distribution in each scenario differ. In hierarchical clustering of galaxy structures, they are distributed randomly, while in the case of the adiabatic and turbulence scenarios they are parallel and perpendicular, respectively, relative to the main plane of the pre-existing protostructure (Shandarin 1974; Iye & Sugai 1991). The mapping of the 3D distribution of galaxies, characterized by the existence of voids, bubbles, and filaments, led to a partial merging of the hierarchical and pancake pictures. It was shown that both filaments and pancakes occurred during an early stage of evolution (Sathyaprakash et al. 1996).

Cold dark matter (CDM) models are presently popular in the literature. In such models, structures are formed from hierarchical clustering of CDM (e.g., Bond et al. 1996; Springel et al. 2005; van de Weygaert & Bond 2008a, 2008b). The angular momentum of galaxies in clusters results from gravitational tidal torques.

Another potential alignment relates to galaxies and the parent structures. In the 1970s the existence of an alignment of the brightest cluster galaxy with asymmetry in the parent cluster was regarded as support for the pancake scenario (hot dark matter models). Additional studies showed that it also exists in the CDM model (e.g., Plionis 1994). The situation is not clear from the theoretical point of view, and it is difficult to conclude that such alignments support a particular scenario. Nevertheless, studies of the effect can constrain possible models of galaxy origin.

Spin rates are known for only a small number of galaxies. It is therefore necessary to study a parameter other than the distribution of galaxy spins in order to examine potential alignments in galaxy groups. One such parameter is the galaxy position angle, which can serve as a surrogate for angular momentum distribution. The present study was performed using only this parameter.

This study examines the properties of nearby structures ($z \leqslant 0.18$), for comparison with the data for medium- and high-redshift clusters. The resulting investigation is tied to a very large sample of data obtained in homogenous fashion that probes the isotropy distribution of galaxy position angles for the brightest cluster galaxy, the second brightest, the third, and the tenth brightest galaxy. A search is also made of potential isotropy in the position angles of such structures, as well as tests for possible alignment of brighter galaxies with their parent clusters. Alignment study between galaxy clusters (Binggeli effect) is the subject of our present paper.

The paper is organized in the standard manner. Section 2 presents the observational data, Section 3 the results and their analysis, and conclusions are given at the end.

2. OBSERVATIONAL DATA

The Muenster Red Sky Survey (MRSS; Ungruhe et al. 2003) contains a homogeneous sample of galaxies covering 5000 deg^2 of the southern sky. The survey is based upon 217 ESO Southern Sky Atlas R Schmidt plates covering galactic latitudes of $b < -45°$ that were digitized using the two PDS microdensitometers of the Astronomisches Institut at Muenster. The classification of objects into stars, galaxies, and perturbed objects was done by an automatic procedure with a posterior visual check of the automatic classification, which considerably diminished the number of objects erroneously classified as galaxies. External calibration of the photographic magnitudes was carried out by means of CCD sequences obtained with three telescopes in Chile and South Africa. The MRSS contains positions, red magnitudes, radii, ellipticities, and position angles for about 5.5 million galaxies, and is complete to $r_F = 18\overset{\mathrm{m}}{.}3$.

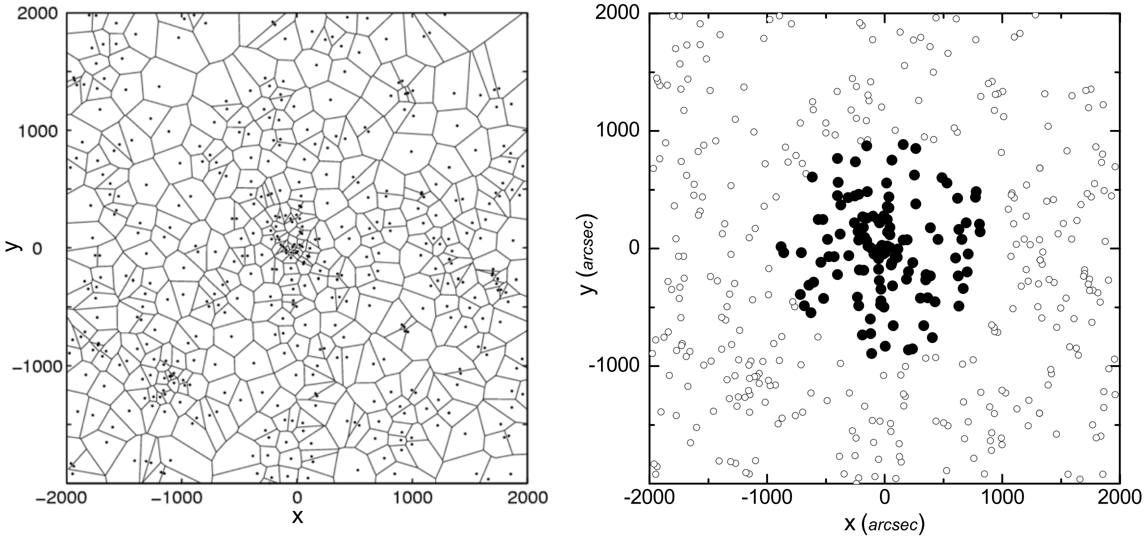

Figure 1. Voronoi cells for the region centered at R.A. = $22\overset{\mathrm{h}}{.}43$ and decl. = $-47\overset{\circ}{.}74$ (left panel) and the found cluster members as black dots with non-clustered galaxies as open symbols (right panel).

The Voronoi tessellation technique (hereafter VTT) was used here for cluster detection (Panko & Flin 2004). The suitability of the VTT for cluster searches has been discussed previously by Icke & van de Weygaert (1987), Ebeling & Wiedenmann (1993), Ramella et al. (1999, 2001), Marinoni et al. (2002), and Neyrinck et al. (2005). The more formally defined Delaunay–Voronoi tessellation technique is presented by Schaap & van de Weygaert (2000). The latter technique is completely non-parametric, and therefore sensitive to both symmetric and elongated clusters, permitting more acceptable studies of non-spherically symmetric structures. Moreover, it is the correct cluster-finding algorithm when the galaxy background is non-uniform (Kim et al. 2002).

For a distribution of seed galaxies, the VTT creates convex polygonal cells containing a single seed each and enclosing the whole area closest to the seed. That is the definition of a Voronoi cell in 2D. The natural partitioning of space by the VTT has been used to model the large-scale distribution of galaxies. Galaxy positions provide input as seeds for the 2D Voronoi tessellation, and the Voronoi cell around each galaxy is interpreted as the effective area occupied by each galaxy in the projection plane. The inverse values of the same areas yield local densities for each galaxy position. For each cell density contrast was defined as

$$\Delta = \frac{\overline{\rho} - \rho}{\overline{\rho}}, \tag{1}$$

where $\overline{\rho}$ is mean density.

The Voronoi cells for region centered at R.A. = $22\overset{\mathrm{h}}{.}43$ and decl.= $-47\overset{\circ}{.}74$ are shown in Figure 1, left panel. Overdensity in the center is clearly seen; it corresponds to the central part of the detected structure noted in the catalogue as PF 2243-4774. The positions of the cluster members and non-clustered galaxies are shown in the right panel of Figure 1 as black and open symbols, respectively.

The structure search was made using the procedure *kiang*, which is the key component of the Voronoi Galaxy Cluster Finder an automatic VTT package for the identification of galaxy clusters in two-dimensional galaxy catalogues (Ramella et al. 1999, 2001). The procedure determines the background density of objects by fitting the low-density end of the observed integral density distribution. The *kiang* compares the observed density distribution with the empirical density distribution expected for a Poisson-type distribution of points having the same density as derived from the fit to the low-density end of the observed integral density distribution.

The user establishes a density threshold above the Poisson-type distribution, i.e., a minimum confidence level for significant overdensities. Here, as in Ramella et al. 2001, we set the threshold at the 80% level (Panko & Flin 2006a). The algorithm then defines overdense regions as those composed of adjacent Voronoi cells with a density higher than the chosen threshold. By computing the probability that an overdensity corresponds to a background fluctuation, the *kiang* discards overdensities for fields that have probabilities greater than a given threshold. This threshold in our study was set at the 95% level.

The *kiang* regularizes the shape of the overdense regions. First, it assumes that all points inside the convex hull defined by the set of points belong to the overdensity itself. Next, it fits a circle to the overdense region and expands it until the mean density inside the circle is lower than the density of the original region. Note that the VTT does not assume density or luminosity profiles for clusters and does not smooth the data. Barrena et al. (2005) describe the procedure in detail.

Using the method makes it possible to extract structures with different numbers of galaxies and various shapes within the same statistical approach. A catalogue containing 6188 galaxy structures (Panko & Flin 2006b, hereafter PF Cat) is the observational basis for the present study. Each structure contains at least 10 galaxies located in the region considered to represent the structure, the resulting PF Cat being statistically complete to $r_F = 18\overset{\mathrm{m}}{.}3$.

The parameters of each structure were determined using the standard covariance ellipse method (Carter & Metcalfe 1980), taking into account galaxies within the magnitude limit m_3, $m_3 + 3^m$, where m_3 is the magnitude of the third brightest galaxy. As demonstrated by Monte Carlo simulations (Biernacka 2007), the covariance ellipse method is a good tool for establishing ellipticity.

We calculated the tangential coordinates x, y in arcsec for each galaxy in structure using standard transformation, using R.A. and decl. of the center of structure as the point of origin.

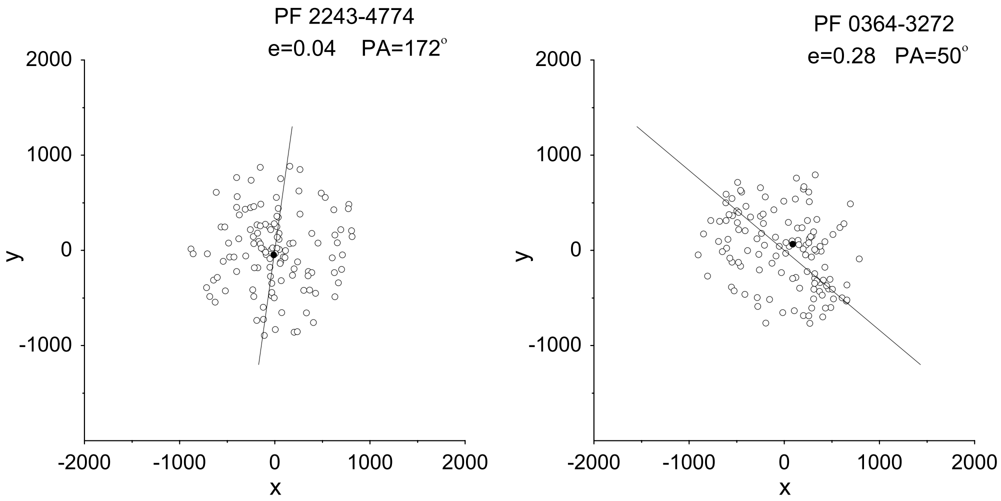

Figure 2. Structures PF 0364-3272 and PF 2243-4774 in tangential coordinates, north is up. Open dots represented the structure members, black symbols corresponded to brightest galaxy in cluster, and line notes the direction of fitted ellipse major axis. Ellipticity and major axis position angle are shown in the right corner for each structure.

The semiaxes a and b in arcsec for the best-fitting ellipse were calculated using $\overline{x^2}$, $\overline{y^2}$, and $\overline{xy}$ values. The ellipticity parameter was defined as

$$e = 1 - \frac{a}{b}, \qquad (2)$$

where a and b are the major and minor semiaxes of the fitted ellipse.

The positional angle P.A.$_s$ was found using $\overline{x^2}$, $\overline{y^2}$, and $\overline{xy}$ values from

$$tg\mathrm{P.A.}_s = 2\frac{\overline{xy}}{\overline{x^2} - \overline{y^2}}. \qquad (3)$$

A comparison of positions for structures identified in the PF Cat with ACO clusters (Abell et al. 1989) provides a selection of 1056 clusters in common to both studies. These 1056 clusters therefore have Bautz–Morgan morphological types.

As an example in Figure 2 we present the structures: PF 0364-3272 and PF 2243-4774 identifies with ACO 3148 and ACO 3876. Both are of BM type I. The position of the brightest galaxy in each structure is also shown.

3. RESULTS AND DISCUSSION

3.1. The distribution of galaxy position angles

An analysis was made to check the isotropy of position angles for cluster galaxies, in particular the brightest, the second brightest, the third, and the tenth brightest cluster galaxies, denoted as P.A.$_1$, P.A.$_2$, P.A.$_3$, and P.A.$_{10}$, respectively, relative to the position angles identified for the underlying cluster structures, denoted as P.A.$_s$. Such an analysis was performed on all program galaxies, as well as on the subsequent division of the samples according to structure richness. Samples were divided according to the number of galaxies n in each structure, with the following five groups being distinguished: from 10 to 29 galaxies, from 30 to 49, from 50 to 99, more than 100 galaxies, and the complete sample of galaxies.

3.2. The alignment of brighter galaxies and parent structure

The 1056 PF structures identified with ACO clusters were divided into eight groups, according to BM type, as shown in Table 1. An additional division was made according to the richness of the galaxy cluster. A compilation was made for each cluster of acute angle between the position angle of the parent structure P.A.$_s$ and the position angle for the brighter galaxies P.A.$_i$ ($i = 1, 2, 3, 10$).

Table 1
Division of ACO Clusters Corresponding to PF Structures According to Structure Richness and BM Morphological Types

Type	All	100	50-99	30-49	10-29
I	105	34	38	22	11
I–II	223	50	82	63	28
I–II:	8	4	1	2	1
II	223	55	72	59	37
II:	34	5	13	7	9
II–III	229	50	59	65	55
III	220	48	62	76	34
III:	14	2	4	5	3
	1056	248	331	299	178

3.3. Statistical analysis and discussion

The isotropy of the distribution of galaxy position angles P.A.$_i$, as well as the P.A.$_s$ − P.A.$_i$ acute angle ($i = 1, 2, 3, 10$), was tested statistically using the χ^2-test and the Kolmogorov–Smirnov test. A separate test was made to establish whether the observed angle in a particular bin deviates from a chance alignment by more than a standard deviation $\sigma = \sqrt{N}$, where N is the number of objects expected in the bin for a random distribution. Tests were carried out for different binning in order to exclude potential artificial anisotropy created by the binning procedure itself. For the distribution of P.A.$_i$ ($i = 1, 2, 3, 10$) angles, the bin widths were 5°, 10°, 15°, 20°, and 30° when the investigated angle range was between 0° and 180°. Only three bin widths, 5°, 10°, and 30°, were used when the θ_i-angle lay between 0° and 90°.

It was found that all four distributions of position angles P.A.$_i$ ($i = 1, 2, 3, 10$) identified from the sample of all 6188 structures, each containing adequate numbers of galaxies, were isotropic. The distribution of position angles for all 6188 galaxy structures themselves was also isotropic. As described above, each separate position angle P.A.$_i$, as well as P.A.$_s$, was binned according to structure richness, which gave an additional 20 distributions. On occasion, small deviations from isotropy would appear for a particular binning, but for

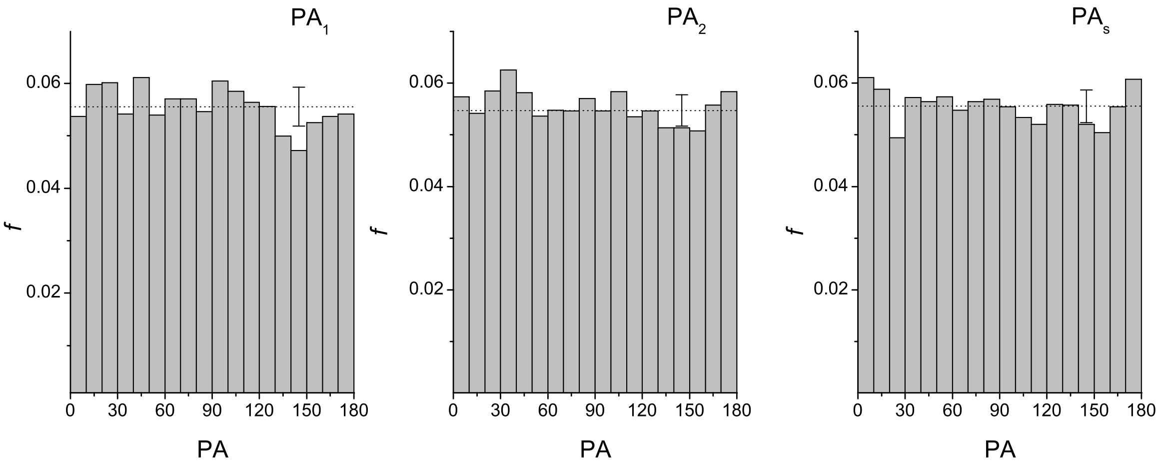

Figure 3. Frequency distribution of position angles for the two brightest galaxies P.A.$_1$ and P.A.$_2$ in the structure and structure position angle P.A.$_s$. Dotted lines refer to an isotropic distribution, and a 1σ error bar is also shown.

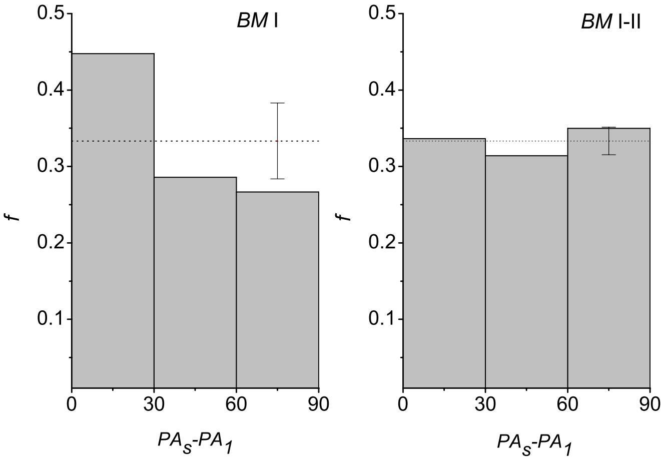

Figure 4. Frequency distribution of the acute angle between the parent cluster and brightest galaxy positional angles for sets of BM type I and I–II. Dotted lines show the isotropic distribution, together with a 1σ error bar.

another binning such departures from isotropy disappeared. The number of galaxies falling into a specific bin also differed from the expected number occasionally, but that result was not reproduced when the binning was changed.

It can be concluded that the distributions of positions angles P.A.$_1$, P.A.$_2$, P.A.$_3$, and P.A.$_{10}$, as well as the distribution of structure position angles P.A.$_s$ are isotropic at the $\alpha = 0.05$ significance level. Three typical distributions are presented in Figure 3. The isotropy of the distributions of the acute angles P.A.$_s$ − P.A.$_1$, P.A.$_s$ − P.A.$_2$, P.A.$_s$ − P.A.$_3$, and P.A.$_s$ − P.A.$_{10}$ was checked in the same manner described above.

The division of the complete sample of 1056 clusters into subsamples was made on the basis both of cluster richness and BM morphological type. A clear excess of small angles was found only for clusters defined as BM morphological type I, where there is a difference between the position angles of the structures and the brightest cluster member (see Figure 4). The first three bins display an excess relative to an isotropic distribution amounting to more than 2σ. A Kolmogorov–Smirnov test does not reject the hypothesis that the distribution is isotropic, although a χ^2-test shows that the distribution is anisotropic at the $\alpha = 0.05$ significance level. Given the ambiguity of the statistical tests, it can be concluded that the sample containing BM type I clusters displays some degree of alignment. The alignment is real, but weak.

4. CONCLUSIONS

The present study addresses the isotropy of the brighter galaxies in galaxy clusters. A statistically complete sample of 6188 low-redshift structures was used to test for isotropy in the distribution of position angles for the brightest galaxies, the second brightest, the third, and the tenth brightest galaxies in clusters. All four distributions investigated here appear to be isotropic. The distribution of position angles was also isotropic when the sample was further divided into groups connected with structure richness. The distribution of position angles among all 6188 structures also appears to be isotropic.

Position angle analysis is a useful tool for initial studies of possible alignments, but it is known that the method improves when the spatial orientation of galaxies is established using both inclination of the galaxy plane and position angle. In cases where the former reveals a weak alignment or a lack of non randomness, the latter, being more sensitive, can detect indications of a true alignment. It will therefore be interesting to perform similar analyses using the orientation of possible galaxy spins. A comparison with galaxy orientations in more distant structures will also be of interest. Such comparisons can shed considerable light on the problem of structure evolution from an observational perspective.

The alignment of brighter galaxies with their parent cluster structures was studied here for 1056 clusters with known BM types. The analysis was performed by testing the isotropy of the acute angles defined as the difference between the parent structure position angle P.A.$_s$ and the position angle of individual galaxies P.A.$_i$ ($i = 1, 2, 3, 10$) in the cluster. The statistical analysis for each investigated sample, except one, led to the conclusion that the distributions are indeed random. Only in the case of clusters of BM type I was there observed a weak alignment of the brightest cluster galaxy with the parent structure. It is a truly weak effect, displaying only a 2σ excess of small angles (0°–30°) relative to a random distribution. It indicates the special role played by cD galaxies during the origin and/or evolution of galaxies (Fuller et al. 1999).

Earlier studies of the orientations of galaxy position angle in clusters gave ambiguous results. The orientation of the 10–20 brightest galaxies in each cluster shows no preferred orientation

(Trevese et al. 1992). Only the brightest cluster members (BCM) exhibit alignments with the host cluster long axis. The effect was observed not only in the case of BM I clusters, but also in the study of intermediate type I–II clusters (Flin & Olowin 1991; Flin et al. 1997). Plionis et al. (2003) investigated the orientation of galaxies in 303 Abell clusters, based on POSS scans. They studied three samples: BCM, the sample containing 10 largest galaxies without BCM, and the total sample of galaxies. They found the correlation between the alignment of galaxies and dynamical status of clusters. Strong alignment was found for the BCM sample and also the largest galaxy sample, when these clusters were located in the high-density regions. A cluster-galaxy study in which the shape of the cluster was established from X-ray data revealed the same alignment of BCM galaxies with their host clusters (Hashimoto et al. 2008).

Our results are in agreement with previous studies based on the analysis of galaxy position angles. In general, the position angles of brighter galaxies in clusters are random. The influence of the environment on cluster galaxies is observed only in the case of BCM galaxies. Previous results were based upon a much smaller observational sample than ours. The lack of alignment of brighter galaxies in our sample, contrary to Plionis et al.'s (2003) finding, is probably due to the small fraction of clusters in superclusters in our data. The problem of whether the BCM—parent cluster alignment depends on cluster morphology should be investigated further, also using large X-ray data samples.

The absence of alignment for brighter cluster galaxies is consistent with the CDM scenario of galaxy formation. There are two different, but not exclusive, points of view about the physical processes in filaments. One stresses the importance of anisotropic merging (van Haarlem & van de Weygaert 1993; West 1994), the other tidal interaction (see, e.g., Lee & Evrard 2007). In the naïve prediction, one can expect that the anisotropic merging and infall of matter along filaments will result in galaxies oriented non-randomly, while the action of tidal torques will produce a random orientation of galaxies. Our result supports the idea that galaxies formed in long filamentary structures. The lack of alignment of brighter galaxies points toward a process in which galaxies acquire angular momentum from tides exerted by their neighbors in the early universe. On the other hand, the flow of matter along filaments causes the alignment of BCM galaxies with cluster long axes. The validity of this picture can be tested using much greater and multi-wavelength samples of galaxies in clusters.

We thank the anonymous referee for comments improving the paper. This research has made use of NASA's Astrophysics Data System. E.P. thanks Jan Kochanowski University for hospitality and financial support during her stays in Kielce. This research has been partially supported by Jan Kochanowski University grant $BS052/08$.

REFERENCES

Abell, G. O., Corwin, H. G., & Olowin, R. P. 1989, ApJS, 70, 1
Barrena, R., Ramella, M., Boschin, W., Nonino, M., Biviano, A., & Mediavilla, E. 2005, A&A, 444, 685
Biernacka, M. 2007, PhD thesis, Univ. of Lodz
Bond, J. R., Kofman, L., & Pogosyan, D. 1996, Nature, 380, 603
Carter, D., & Metcalfe, N. 1980, MNRAS, 191, 325
Ebeling, H., & Wiedenmann, G. 1993, Phys. Rev. E, 47, 704
Flin, P., & Olowin, R. P. 1991, in Physical Cosmology, ed. A. Blanchard et al. (Gif-sur-Yvette: Editions Frontieres), 512
Flin, P., Trevese, D., Krywult, J., & Cirimele, G. 1997, Astrophys. Lett. Commun., 36, 119
Fuller, T. M., West, M. J., & Bridges, T. J. 1999, ApJ, 519, 22
Hashimoto, Y., Henry, J. P., & Boehringer, H. 2008, MNRAS, 390, 1562
Icke, V., & van de Weygaert, R. 1987, A&A, 184, 16
Iye, M., & Sugai, H. 1991, ApJ, 374, 1121
Kim, R. S. J., et al. 2002, AJ, 123, 20
Lee, J., & Evrard, A. E. 2007, ApJ, 657, 30
Marinoni, C., Davis, M., Newman, J., & Coil, A. 2002, ApJ, 580, 122
Neyrinck, M. C., Gnedin, N. Y., & Hamilton, A. J. S. 2005, MNRAS, 356, 1222
Ozernoy, L. M. 1978, in The Large Scale Structure of the Universe, ed. M. S. Longair & J. Einasto (Dordrecht: Reidel), 427
Panko, E., & Flin, P. 2004, in IAU Colloq. 195, Outskirts of Galaxy Clusters: Intense Life in the Suburbs, ed. A. Diaferio (Cambridge: Cambridge Univ. Press), 245
Panko, E., & Flin, P. 2006a, in Astrophysics and Cosmology after Gamow: Theory and Observations, Proc. Gamow Memorial Int. Conf., ed. G. S. Bisnovaty-Kogan et al. (Cambridge: Cambridge Scientific Publishers Ltd), 293
Panko, E., & Flin, P. 2006b, J. Astron. Data, 12, 1
Peebles, P. J. E. 1969, ApJ, 155, 393
Peebles, P. J. E. 1980, Large Scale Structure of the Universe (Princeton, NJ: Princeton Univ. Press)
Plionis, M. 1994, ApJS, 95, 401
Plionis, M., Benoist, C., Maurogordato, S., Ferrari, C., & Basilakos, S. 2003, ApJ, 594, 144
Ramella, M., Boschin, W., Fadda, D., & Nonino, M. 2001, A&A, 368, 776
Ramella, M., Nonino, M., Boschin, W., & Fadda, D. 1999, in ASP Conf. Ser. 176, Observational Cosmology: The Development of Galaxy Systems, ed. G. Giuricin, M. Mezzetti, & P. Salucci (San Francisco, CA: ASP), 108
Sathyaprakash, B. S., Sahni, V., & Shandarin, S. F. 1996, ApJ, 465, L5
Schaap, W. E., & van de Weygaert, R. 2000, A&A, 363, L29
Shandarin, S. F. 1974, SvA, 18, 392
Springel, V., et al. 2005, Nature, 435, 629
Thuan, T. X., & Gott, J. R. 1977, ApJ, 216, 194
Trevese, D., Cirimele, G., & Flin, P. 1992, AJ, 104, 935
Ungruhe, R., Seitter, W. C., & Duerbeck, H. W. 2003, JAD, 9, 1
van Haarlem, M., & van de Weygaert, R. 1993, ApJ, 418, 544
van de Weygaert, R., & Bond, J. R. 2008a, in A Pan-Chromatic View of Clusters of Galaxies and the Large-Scale Structures, ed. M. Plionis, O. Lopez-Cruz, & D. Hughes (Dordrecht: Springer), 335
van de Weygaert, R., & Bond, J. R. 2008b, in A Pan-Chromatic View of Clusters of Galaxies and the Large - Scale Structures, ed. M. Plionis, O. Lopez-Cruz, & D. Hughes (Dordrecht: Springer), 409
West, M. J. 1994, MNRAS, 268, 79
Zeldovich, Ya. B. 1970, A&A, 5, 84