THE ORIENTATIONS OF GALAXY GROUPS AND FORMATION OF THE LOCAL SUPERCLUSTER

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ABSTRACT

We analyzed the orientation of galaxy groups in the Local Supercluster (LSC). It is strongly correlated with the distribution of neighboring groups in the scale up to about 20 Mpc. The group major axis is in alignment with both the line joining the two brightest galaxies and the direction toward the center of the LSC, i.e., Virgo cluster. These correlations suggest that two brightest galaxies were formed in filaments of matter directed toward the protosupercluster center. Afterward, the hierarchical clustering leads to aggregation of galaxies around these two galaxies. The groups are formed on the same or similarly oriented filaments. This picture is in agreement with the predictions of numerical simulations.

Key words: galaxies: clusters: general

1. INTRODUCTION

Binggeli (1982) was the first who found that major axes of galaxy clusters tend to point toward their neighbors. Later the existence of this effect was discussed by several authors, and usually the significant alignment was reported. The distance between clusters for which the effect was detected changed from $10\ h^{-1}\text{Mpc}$ to $150\ h^{-1}\text{Mpc}$ (where $h = H_0/100\ \text{km s}^{-1}\text{Mpc}^{-1}$). The strength of the effect decreases with the distance (Struble & Peebles 1985; Flin 1987; Rhee & Katgert 1987; Ulmer et al. 1989; Plionis 1994; West 1989; Chambers et al. 2000; Hashimoto et al. 2008). These investigations involved both optical and X-ray data and clusters belonging (or not) to superclusters. Nowadays, it is accepted that the effect is not due to selection effects but is real and its distance scale is between $10\ h^{-1}\text{Mpc}$ and $60\ h^{-1}\text{Mpc}$. The alignment of the galaxy group was studied by West (1995). He used the CfA group catalog (Geller & Huhra 1983) and a catalog based on the Southern Sky Redshift Survey (SSRS; Maia et al. 1989). Each group should have at least four objects and less than 100. Decontamination of the groups by foreground and background objects was performed by removing objects with the redshift difference from the group mean over $1000\ \text{km s}^{-1}$. There were 59 groups, and the Binggeli effect was observed among galaxy groups until 15–30 $h^{-1}\text{Mpc}$. One should note that the investigation of galaxy group orientation is more difficult than in the case of galaxy clusters. The position angle of a group consisting of a few objects is determined with a much greater error than for rich clusters. Moreover, statistics with a small number are less reliable. The other investigations of galaxy groups were performed by Palumbo et al. (1993). During study, the orientation of 92 out of 100 compact groups listed in the Catalog of the Compact Groups (Hickson 1982); they do not find alignment, but the location of groups along long chains is noted.

The interpretation of the effect has changed with development of theories, but the main idea that this should reflect conditions during the structure formation is still very popular. Numerical simulations gave a better understanding of physical processes leading to structure formation. These simulations were performed in the framework of the cold dark matter (CDM) model presently regarded as the correct description of the large-scale structure formation. Using different approaches and codes, these investigations led to the conclusion that the preferred orientation of galaxy clusters in the CDM model is a natural consequence of processes leading to structure formation due to gravitational interaction. Onuora & Thomas (2000) using large-scale simulation found that in $\Lambda$CDM cosmological model effect reaches the distance up to 30 Mpc, while in $\tau$CDM model the range of effects is twice smaller. Also in SCDM and OCDM models, where smaller scale simulations were performed, some alignment effect could be noted. $N$-body simulation for standard $\Lambda$CDM model (Faltenbacher et al. 2002) for 3000 clusters showed the alignment of neighboring clusters in the distance range from 10 to 15 Mpc, while the Binggeli effect till about 100 Mpc is observed. The strong alignment, decreasing with the increasing distance between clusters, observed till about 100 Mpc was reported (Hopkins et al. 2005). The preferred orientation of clusters belonging to superclusters existed also in SHM + $N$-body simulations (Basilakos et al. 2006). Moreover, from some of the numerical simulations, it follows that the structure formation occurred along filamentary structures rather than the walls (Faltenbacher et al. 2005; Springel et al. 2005; Binggeli 1982; Hahn et al. 2007a, 2007b; Aragon-Calvo 2007; van de Weygaert & Bond 2008a, 2008b). In order to confirm, or deny, this scheme of structure origin, we carry out an analysis of the Local Supercluster (LSC) galaxy groups alignment, as well as the distribution of the acute angle between the position angle of the structure and the direction to all remaining clusters. Groups were taken from Nearby Galaxies (NBG) Catalog (Tully 1988). We also investigated the alignment of the brightest group galaxy and the parent group. We determined the position of the line joining the two brightest galaxies and checked the orientation of this line in respect to the parent group and direction toward the Virgo cluster. The distributions of these angles, as well as differences between some of these angles were tested for isotropy.

The paper is organized in the following manner. Section 2 describes observational data, Section 3 presents statistical method used in the paper, Section 4 presents results and discussions. In Section 5, we formulate conclusions.

2. OBSERVATIONAL DATA

In the present paper, we study the alignment of galaxy groups. Groups were taken from the NBG Catalog (Tully 1988). This catalog contains 2367 galaxies with radial velocities less
than 3000 km s\(^{-1}\). It is complete until the magnitude limit \(B_T = 12.0\); moreover, dimmer, low-surface brightness gas rich galaxies (late-type spirals) are also incorporated, which ensure that all more massive galaxies are taken into account. Due to our position in the LSC, it is complete for such objects till the Virgo Cluster center. An important point is that this catalog provides the uniform coverage of entire unobscured sky (Tully 1987), and only more massive galaxies are taken into account. Moreover, the galaxy distances are very well and in uniform manner determined. The galaxy distances are based on velocities, assuming the flat cosmological model \((q_0 = 1/2)\) with \(H_0 = 75\) km s\(^{-1}\) Mpc\(^{-1}\) and the model describing velocity perturbations in the vicinity of the Virgo Cluster (Tully & Shaya 1984). Galaxies’ position angles were taken from Nilson (1973, 1974), Lauberts (1982), and Lauberts & Valentijn (1989), and the seven missing measurements were made on PSS prints by the present authors.

The NBG Catalog also gives the affiliation of galaxies to groups. Groups were found using precise criteria. In our opinion, the groups extracted from the NBG Catalog (Tully 1988) are very good observational basis for study of their properties.

From the Tully’s Catalog, we extracted aggregation of galaxies having at least 40 members, which ensures that at least one substructure has 10 or more members. The substructures having at least 10 members were taken for the analysis, and we call them groups. We decided to select structures having at least 10 objects, because the determination of the structure’s major axis is reliable in this case (see also West 1989). There are 61 such groups. Moreover, we repeated the analysis for subsample containing 35 groups having at least 20 galaxies (Figure 1).

It was assumed that groups are two axial ellipsoids. The shape of each group has been determined considering only the projected position of galaxies on the celestial sphere in the supergalactic coordinate system \(L, B\), and applying the covariance ellipse method. This procedure gives the position angle of the major axis.

The position angle of each group \(PA_g\) is calculated counterclockwise from the great circle passing through the position of the group center on the celestial sphere and the northern pole of the LSC. It was assumed that the location of a group center corresponds to the mean of \(L\) and \(B\) coordinates of member galaxies and the mean of radial velocity, as given in the Catalog. Using standard formula from spherical trigonometry, we calculated the directions between the center of each group and the centers of the remaining groups. Each direction is a part of the great circle joining the centers of two groups. For each group, we calculated the acute angle \(\phi\) between the position angle of the major axis of a given group \(PA_g\) and direction toward other groups. In such a manner we have 3660 directions among groups. We also investigated the alignment of the brightest group galaxy \(PA_{bm}\) and the parent group \(PA_z\). Moreover, we determined the position of the line joining two brightest galaxies in the group \(PA_{mod}\) and checked the orientation of this line relative to the position angle of the parent group \(PA_z\), the position angle of the brightest galaxy \(PA_{bm}\) and the direction toward Virgo cluster \(PA_V\). The projected two-dimensional line between two groups is used to compute the acute angle \(\phi\).

3. STATISTICS

3.1. The General View

We checked for isotropy four discussed distributions of position angles \((PA_x, PA_y, PA_{bm}, PA_V)\) having range 0°–180°, as well as differences between position angles \((PA_x – PA_V, PA_y – PA_V, PA_{bm} – PA_x, PA_{bm} – PA_z)\) being the acute angles. Theoretically, the range of the angles \(PA_V\) and \(PA_z\) is between 0° and 360°, whereas the range of two remaining angles \(PA_x\) and \(PA_{bm}\) is restricted to the range 0°–180°. We are studying the difference between direction of angles. In such analysis, for \(PA_V\) and \(PA_z\) an angle \(\xi\) and \(\xi + 180°\) are identical.

The detailed statistical analysis was done using the Fourier test (Hawley & Peebles 1975; Flin & Godlowski 1986; Kindl 1987; Godlowski 1993, 1994), Kolmogorov–Smirnov test (K–S test), and the \(\chi^2\) test. Additionally, we carried out the analysis of these angles for subsample of 35 groups having at least 20 members. In all cases, the entire range of the analyzed angles (position angles and differences between position angles) was divided into \(n\) equal width bins. In the following analysis, we divided the range of analyzed angles into bins of 15° width, which gives 12 bins in the case of position angles and 6 in the
case of differences between position angles. Let us denote the total number of analyzed groups as \( N \), the number of groups with analyzed angles within \( k \)th angular bin as \( N_k \), and \( N_0 \) as the mean number of groups per bin.

### 3.2. \( \chi^2 \) Test

The dividing range of the analyzed angle into \( n \) equal width bins gives \( n - 1 \) degrees of freedom in the \( \chi^2 \) test. The value of the \( \chi^2 \) statistics is given by the formula

\[
\chi^2 = \sum_{k=1}^{n} \frac{(N_k - N_0)^2}{N_0}.
\]

(1)

The \( \chi^2 \) test yields at the significance level (\( \alpha = 0.05 \)) the critical value of 19.7 for 11 degrees of freedom at the significance level (\( \alpha = 0.05 \)) and 11.1 for 5 degrees of freedom.

### 3.3. The Fourier Test

If deviation from isotropy is a slowly varying function of the angle \( \theta \) one can use the Fourier test

\[
N_k = N_{0,k}(1 + \Delta_{11} \cos 2\theta_k + \Delta_{21} \sin 2\theta_k),
\]

(2)

where \( N_{0,k} \) are expected number of groups per bin (in our case all \( N_{0,k} \) are equal).

We obtain the following expression for the \( \Delta_{11} \) coefficients:

\[
\Delta_{11} = \frac{\sum_{k=1}^{n}(N_k - N_{0,k}) \cos 2\theta_k}{\sum_{k=1}^{n}N_{0,k} \cos^2 2\theta_k},
\]

(3)

\[
\Delta_{21} = \frac{\sum_{k=1}^{n}(N_k - N_{0,k}) \sin 2\theta_k}{\sum_{k=1}^{n}N_{0,k} \sin^2 2\theta_k},
\]

(4)

with the standard deviation given by expressions

\[
\sigma(\Delta_{11}) = \left( \frac{n}{\sum_{k=1}^{n}N_{0,k} \cos^2 2\theta_k} \right)^{-1/2} = \left( \frac{2}{nN_0} \right)^{1/2},
\]

(5)

\[
\sigma(\Delta_{21}) = \left( \frac{n}{\sum_{k=1}^{n}N_{0,k} \sin^2 2\theta_k} \right)^{-1/2} = \left( \frac{2}{nN_0} \right)^{1/2}.
\]

(6)

The probability that the amplitude

\[
\Delta_1 = (\Delta_{11}^2 + \Delta_{21}^2)^{1/2}
\]

(7)

is greater than a certain chosen value that is given by the formula

\[
P(\Delta_1) = \exp\left(\frac{-n}{4}N_0\Delta_1^2\right).
\]

(8)

with standard deviation of this amplitude

\[
\sigma(\Delta_1) = \left( \frac{2}{nN_0} \right)^{1/2}.
\]

(9)

This test was originally introduced by Hawley & Peebles (1975) and substantially modified by Godłowski (1994) for the case of taking into account higher Fourier modes

\[
N_k = N_{0,k}(1 + \Delta_{11} \cos 2\theta_k + \Delta_{12} \sin 2\theta_k + \Delta_{12} \cos 4\theta_k + \Delta_{22} \sin 4\theta_k + \cdots).
\]

(10)

\footnote{However, please note that there is a printed error in Godłowski (1994). Equation (18) should have form \( P(\Delta) = (1 + J/2) \exp(-J/2) \).}

In our case (all \( N_{0,k} \) are equal), it leads to formulas for the \( \Delta_j \) coefficients

\[
\Delta_{1j} = \frac{\sum_{k=1}^{n}N_k \cos 2j\theta_k}{\sum_{k=1}^{n}N_0 \cos^2 2j\theta_k},
\]

(11)

and

\[
\Delta_{2j} = \frac{\sum_{k=1}^{n}N_k \sin 2j\theta_k}{\sum_{k=1}^{n}N_0 \sin^2 2j\theta_k},
\]

(12)

with the standard deviation

\[
\sigma(\Delta_{1j}) = \left( \frac{n}{\sum_{k=1}^{n}N_{0,k} \cos^2 2\theta_k} \right)^{-1/2} = \left( \frac{2}{nN_0} \right)^{1/2},
\]

(13)

and

\[
\sigma(\Delta_{2j}) = \left( \frac{n}{\sum_{k=1}^{n}N_{0,k} \sin^2 2\theta_k} \right)^{-1/2} = \left( \frac{2}{nN_0} \right)^{1/2}.
\]

(14)

If we analyzed Fourier modes separately, probability that the amplitude

\[
\Delta_j = (\Delta_{1j}^2 + \Delta_{2j}^2)^{1/2}
\]

(15)

is greater than a certain chosen value is given by the formula

\[
P(\Delta_j) = \exp\left(\frac{-n}{4}N_0\Delta_j^2\right).
\]

(16)

When we analyzed first and second Fourier modes together, we obtain

\[
\Delta = (\Delta_{11}^2 + \Delta_{21}^2 + \Delta_{12}^2 + \Delta_{22}^2)^{1/2},
\]

(17)

and

\[
P(\Delta) = \left(1 + \frac{n}{4}N_0\Delta_j^2\right) \exp\left(-\frac{n}{4}N_0\Delta_j^2\right).
\]

(18)

The value of coefficient \( \Delta_{11} \) gives us the direction of departure from isotropy. If \( \Delta_{11} < 0 \), then the excess of the group with position angles near 90° (parallel to LSC plane) is observed, while for \( \Delta_{11} > 0 \) the excess of the group with position angles perpendicular to LSC plane is observed.

### 3.4. K–S Test

The isotropy and the resultant distributions of the angles \( \phi \) were investigated using K–S test. We divided our sample according to distance \( D \) between group centers. We assumed that the theoretical, random distribution contains the same number of objects as the observed one. Our null hypothesis \( H_0 \) is that the distribution is the random one. In order to reject the \( H_0 \) hypothesis, the value of observed statistics \( \lambda \) should be greater than \( \lambda_{cr} \). At the significance level \( \alpha = 0.05 \) the value \( \lambda_{cr} = 1.358 \).

### 3.5. The Linear Regression

We study the linear regression \( y = a\phi + b \) between the number of the \( \phi \) angles falling into particular bin and the \( \phi \) angle itself for the difference of the PA_\( x \) or PA_\( l \) and the direction toward other groups.

Again we assumed that the theoretical, uniform, random distribution contains the same number of objects as the observed one. Our null hypothesis \( H_0 \) is that the distribution is a random one. In such a case, the statistics \( t = a/\sigma(a) \) has Student’s distribution with \( n - 2 \) degrees of freedom. We tested \( H_0 \) for the case (all \( N_{0,k} \) are equal), it leads to formulas for the \( \Delta_j \) coefficients
hypothesis that $t = 0$ against either $H_1$ hypothesis that $t \neq 0$ or, because we expected that decreasing of the effect with the distance, against $H_2$ hypothesis that $t < 0$. In order to reject the $H_1$ hypothesis, the value of observed statistics $t$ should be greater than $t_{cr}$. We divided the range of analyzed angles into nine equal bins. It gives, at the significance level $\alpha = 0.05$, the value $t_{cr} = 2.365$ in the case of $H_1$ hypothesis and $t_{cr} = 1.895$ in the case of $H_2$ hypothesis.

4. RESULTS AND DISCUSSIONS

First, we counted the number of analyzed position angles in bins with $20^\circ$ width and compared them with expected, theoretical distribution. The quoted 1σ error is equal to $\sqrt{N}$, where $N$ is the number of the groups falling into bin in random distribution. The strong excess of position angles $\text{PA}_g$ is observed in the bin $80^\circ–100^\circ$, which corresponds to the location of the supergalactic equator. In this bin, the excess of position angles of the structures is $5\sigma$, while the excess of the position line joining two brightest galaxies ($\text{PA}_l$) is $2.5\sigma$ (for 35 galaxy groups only), when compared to the number expected in a random distribution.

Distributions of the investigated angles for the groups with at least 10 members are presented in Figures 2 and 3. Statistics with $\text{PA}_{bm}$ were completed using 54 groups for which these angles were taken from the literature, as well as independently for sample of 61 groups.

The results of the statistical analysis for position angles ($\text{PA}_g$, $\text{PA}_l$, $\text{PA}_{bm}$, $\text{PA}_V$) are presented in the Table 1, where $df$ denotes the number of degrees of freedom. The distribution of position angles of the brightest galaxies ($\text{PA}_{bm}$) is isotropic, as is observed in galaxy structures not containing cD galaxy (Trense et al. 1992; Panko et al. 2009), which is the case of LSC. The distribution of group position angles ($\text{PA}_g$) is anisotropic at confidence level 99%. The distribution of the line joining two brightest galaxies ($\text{PA}_l$) is anisotropic at the confidence level 95% only when 35 richer groups are analyzed. The distribution of the direction toward Virgo center $\text{PA}_V$ is anisotropic at the confidence level 99%.

Now we discuss the differences between analyzed position angles. Due to symmetry, the range of differences between the position angles ($\text{PA}_g – \text{PA}_V$, $\text{PA}_l – \text{PA}_V$, $\text{PA}_l – \text{PA}_g$, $\text{PA}_{bm} – \text{PA}_l$, and $\text{PA}_{bm} – \text{PA}_V$) is restricted to the range between $0^\circ$ and $90^\circ$. The $\chi^2$ test shows that the difference between the group position angle ($\text{PA}_g$) and direction toward Virgo cluster ($\text{PA}_V$) is not random at the confidence level 99% (or 95% in the case of poorer groups) (Table 2). For 41 clusters, the differences $\text{PA}_g – \text{PA}_V$ are less than $45^\circ$, while only for 20 clusters they are greater than $45^\circ$. The distribution of the difference $\text{PA}_V – \text{PA}_l$ is anisotropic only for richer groups. The difference of angles

Table 1

| Angle  | df  | $\chi^2$ | $\Delta_{11}/\sigma(\Delta_1)$ | $\Delta_l/\sigma(\Delta_1)$ | $\Delta/\sigma(\Delta_1)$ | $P(>\Delta_1)$ | $P(>\Delta)$ |
|--------|-----|----------|-------------------------------|-------------------------------|--------------------------|----------------|-------------|
| $\text{PA}_g$ | 11  | 39.1     | -4.89 | 5.20 | 5.85 | <.001 | <.001 |
| $\text{PA}_l$ | 8.0 | -0.93    | 0.94  | 1.81 | .644 | .644 |
| $\text{PA}_{bm}$ | 9.6 | -1.58    | 1.57  | 1.72 | .290 | .290 |
| $\text{PA}_V$   | 33.2| -3.86    | 3.95  | 4.14 | <.001 | .002 |

Figure 2. Distribution (from top to bottom) of the position angle of the major axis of a given group $\text{PA}_g$, the position of the line joining two brightest galaxies in the group $\text{PA}_l$ and direction toward Virgo cluster $\text{PA}_V$. The dashed line presents the isotropic distribution. The error bar is equal to $\sqrt{N_0}$, where $N_0$ is average number structures per bin expected in random distribution.

Figure 3. Distribution (from top to bottom) of the differences between position angles $\text{PA}_g – \text{PA}_V$, $\text{PA}_l – \text{PA}_V$, and $\text{PA}_l – \text{PA}_g$. The dashed line presents the isotropic distribution. The error bar is equal to $\sqrt{N_0}$, where $N_0$ is average number structures per bin expected in random distribution.
PA_g − PA_l is strongly anisotropic at the confidence level 99%. The observed excess is below 45°. We also performed Fourier test for differences between position angles. These angles have range only 90° instead of 180°, so only second (and third) Fourier modes can be taken into account. Therefore, this test can only confirm the existence of anisotropy.

Separately, we analyzed the differences between PA_g (or PA_l) and direction toward neighbors. These two parameters were chosen because they describe the possible orientation of structure within the LSC. The resultant distributions of the angles φ being the acute angles between the position angle of the major axis of a given group PA_g and direction toward other groups for the sample of group with at least 10 members are presented in Figure 4. We divided our sample according to distance D between group centers.

The results of the statistical analysis are given in Table 3. At first, we counted the number of φ angles in bins with 30° width and compared them to the expected, theoretical distribution. The theoretical numbers falling into bins and errors are rounded to the integer numbers. The first line of Table 3 presents the limits for subsamples division with respect to the distance D in Mpc between group centers. The next three rows present the numbers of the φ-angle in the observed distribution (denoted as obs) falling into three bins, and these numbers expected for the theoretical distribution (denoted as theo) together with their errors. The quoted 1σ errors are equal to √N, where N is the number of the angles falling into bin in random distribution. The greatest deviation from isotropy (on the 5σ level) is observed for subsample containing groups located closer than 10 Mpc. The excess of the φ angles is noted in the first bins. In the case of subsample containing all groups it is 2.9σ. Restricting our sample to groups located close each other, with distances between their centers smaller than 10 Mpc the excess is 4.8σ diminishing to 1.4σ in the next subsample (10 < D ≤ 20). It means that neighboring groups have tendency to be aligned. This tendency is vanishing with increasing distance among groups. The last row of Table 3, denoted as K–S, gives the value λ of K–S statistics for each distribution presented in Figure 4 (and for sample “all groups”). At the significance level α = 0.05 only two of five investigated subsamples are anisotropic. Again, the greatest anisotropy is observed in the subsample containing groups located closer than 10 Mpc.

The distribution of samples 10 < D ≤ 20 Mpc is close to anisotropy. When D > 20 Mpc distributions are isotropic. The distribution containing all 61 groups is anisotropic, which is due to the subsamples containing closer groups. The difference between the line joining two brightest galaxies (PA_g) and direction toward other groups does not show any clear evidence for anisotropy.

The further analysis based on linear regression was performed. We study the linear regression y = aφ + b between

| Angle Difference | df | χ² | Δ2/σ(Δ2) | Δ/σ(Δ) | P(>Δ2) | P(>Δ) |
|------------------|----|----|-----------|--------|--------|--------|
| PA_g − PA_l      | 5  | 16.0 | 2.20 | 2.71 | .088 | .119   |
| PA_g − PA_l      | 3.4 | 1.61 | 1.62 | .274 | .623   |
| PA_g − PA_l      | 2.7 | 1.17 | 1.47 | .504 | .709   |
| PA_g − PA_l      | 3.8 | 1.84 | 1.93 | .185 | .488   |
| PA_g − PA_l      | 9.9 | 1.84 | 2.34 | .185 | .241   |
| PA_g − PA_l      | 18.4 | 3.46 | 3.96 | .003 | .004   |

Figure 4. Distribution of the angle φ between the position angle of the major axis of a given group PA_g and direction toward other groups. From top to bottom the respective distributions for galaxies with D ≤ 10 Mpc, 10 < D ≤ 20 Mpc, 20 < D ≤ 30 Mpc, and D > 30 Mpc are presented. The dashed line presents the isotropic distribution. The error bar is equal to √N0, where N0 is average number structures per bin expected in random distribution.

### Table 3

| Angle Range | All D | D ≤ 10 | 10 < D ≤ 20 | 20 < D ≤ 30 | D > 30 |
|-------------|-------|--------|--------------|--------------|--------|
|             | obs   | theo   | obs theo     | obs theo     | obs theo |
| 0°–30°      | 1323  | 1220   | 146 98       | 286 263      | 419 398 |
| 30°–60°     | 1201  | ±35    | 100 ±10      | 261 ±16      | 383 ±20 |
| 60°–90°     | 1136  | ±10    | 48 241       | 392 ±16      | 455     |
| K–S test    | 2.276 | 3.130  | 1.274        | 0.849        | 0.514   |
The difference between the line joining two brightest galaxies served similar effect, but at 20 Mpc. We found that for closer neighbors ($D < 10$ Mpc) strong alignment is observed. It is at almost 5σ level. The BINGEL effect is diminishing with distance increase, vanishing at about 20 Mpc. We used the K–S test, which is usually applied for alignment investigation. Chambers et al. (2002) criticized it, because it does not point to the place where the departure of isotropy is observed. They preferred to use the Wilcox test on rank–sum, which, in their opinion, gave a higher confidence signal for alignment. However, Ono & Thomas (2000) applied both tests finding a little difference in the obtained statistics. Furthermore, we used the K–S test only to check the isotropy of the distribution and not to find the anisotropy location. Our results obtained with the help of K–S test are confirmed by linear regression analysis. The fact that detection of anisotropy is connected with the LSC coordinate system supports the point of view that formation of galaxies occurred within protostructures. The analysis of the differences between position angles shows that it is possible that there exists the alignment of the line joining two brightest galaxies with both position angle of the parent group and direction toward Virgo cluster center. The fact that detection of anisotropy is connected with the LSC coordinate system supports the point of view that formation of galaxies occurred within protostructures. From the presented analysis of the orientation of galaxy groups in the LSC, the following picture of the structure formation appears. The two brightest galaxies were formed first. They originated in the filamentary structure directed toward the center of the protocluster. This is the place where the Virgo cluster center is located now. Due to gravitational clustering, the groups are formed in such a manner that galaxies follow the line determined by the two brightest objects. Therefore, the alignment of the structure position angle and line joining two brightest galaxies is observed. The other groups are forming on the same or nearby filament. The flatness of the LSC additionally contributes to the observed alignment of galaxy groups. The majority of the groups lie close to us. Due to the completeness of the catalog, the lack of groups further than the Virgo Cluster center is observed, but nearby groups are very well selected and they contain only more massive galaxies. This picture is in agreement with predictions of several CDM models, in which structure formation is due to hierarchical clustering. Moreover, the formation is occurring on the filamentary structure. The further investigation considering groups clearly inside and outside superclusters on the greater data set will be very useful to support or reject this picture.

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### Table 4

| Angle | All $D$ | $D \leq 10$ | $10 < D \leq 20$ | $20 < D \leq 30$ | $D > 30$ |
|-------|---------|-------------|-----------------|-----------------|----------|
| $\phi(\text{PA}_g)$ | $a$ | $\sigma(a)$ | $a$ | $\sigma(a)$ | $a$ | $\sigma(a)$ | $a$ | $\sigma(a)$ |
| $\phi(\text{PA}_l)$ | $-1.12 \pm 0.26$ | $-0.52 \pm 0.07$ | $-0.31 \pm 0.12$ | $-0.21 \pm 0.14$ | $-0.08 \pm 0.16$ |
| $\phi(\text{PA}_g)$ | $-0.60 \pm 0.26$ | $-0.05 \pm 0.07$ | $-0.21 \pm 0.12$ | $-0.21 \pm 0.14$ | $-0.14 \pm 0.16$ |
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