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Spatial Orientation of Galaxies in the SDSS DR7 Supercluster

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Abstract

Spatial orientations of spin vectors 1423 galaxies in the SDSS DR7 Supercluster S[239+016+0037] was studied. The database of these galaxies is taken from the SDSS DR7 data release. Our main goal is to find out the angular momentum vectors of galaxies in the Supercluster S[239+016+0037]. Random simulation method is used to remove selection effects from the database. Finally, three statistics to compare the differences between theoretical and observed distributions: chi-square, auto-correlation, and the Fourier test. All these statistical tests suggest the random orientation of galaxies in the SDSS DR 7 Supercluster S[239+016+0037]. Furthermore, the evolution of the galaxies in the Supercluster supports the hierarchy model as suggested by Peebles (1969).

Keywords: Supercluster, Universe, SDSS, Galaxy, Isotropy

Introduction

The formation of the universe is a topic of great interest and speculation in the fields of cosmology and astrophysics. While our understanding of the early universe is continually evolving, the prevailing theory that describes its formation is known as the Big Bang theory. This theory suggests that the universe originated from a singular, extremely hot, and dense point around 13.8 billion years ago. It is important to note that our current understanding of the universe's formation is based on extensive observational evidence and theoretical models. Ongoing research, observations from powerful telescopes and space missions, and advancements in theoretical physics aim to further refine our understanding of the early universe and its formation.

Superclusters are massive cosmic structures made up of several galaxy clusters and groups. It refers to a large-scale structure in the universe, consisting of groups and clusters of galaxies bound together by gravity. Superclusters are thought to be inter connected by vast cosmic filaments, which are composed of dark matter and gas. It plays a crucial role in our understanding of the large-scale structure and evolution of the universe. Studying these massive cosmic structures helps astronomers investigate the distribution of matter, the formation of galaxies, and the nature of dark matter. Superclusters, which are vast structures consisting of numerous galaxies, offer a unique opportunity to explore the universe's large-scale structure. Studying Superclusters can contribute to a deeper understanding of how galaxies form, how they are distributed, and how they interact. By researching this field, we can contribute to expanding our knowledge of the cosmos and investigating some of the universe's mysteries.

Galaxies are a slightly difficult topic in astronomy at present. There remain many problems relating to their formation and evolution, and even with aspects of their structure. It is an area where that has been observed in large progress over few decades, however at the same time the number of challenges has increased day by day. To get deep insight into the evolution of these large-scale structures, it is necessary to understand how and when they were formed and how their structures and constituents have been changing with time. According to Gamow (1952) and Weizsacker (1951); the observed rotation of the galaxies is very important to understanding the origin of the angular momentum of galaxies regarding the origin of large-scale structures like galaxies and helps us to get the right insight into the initial condition that triggered the formation of these structures.

Materials and Methods

Database

We have obtained data of 1423 galaxies of Supercluster S[239+016+0037] after removing the galaxies having axial ratio (b/a)<0.2 from the Sloan Digital Sky Survey (SDSS) Data Release7 (DR7). The values of Right Ascension, Declination, Position angles, and Axial ratio (b/a) are known for all galaxies. The distribution of RA (α), DEC (δ), position angle (PA) and inclination angle (i) are shown below inTable1.

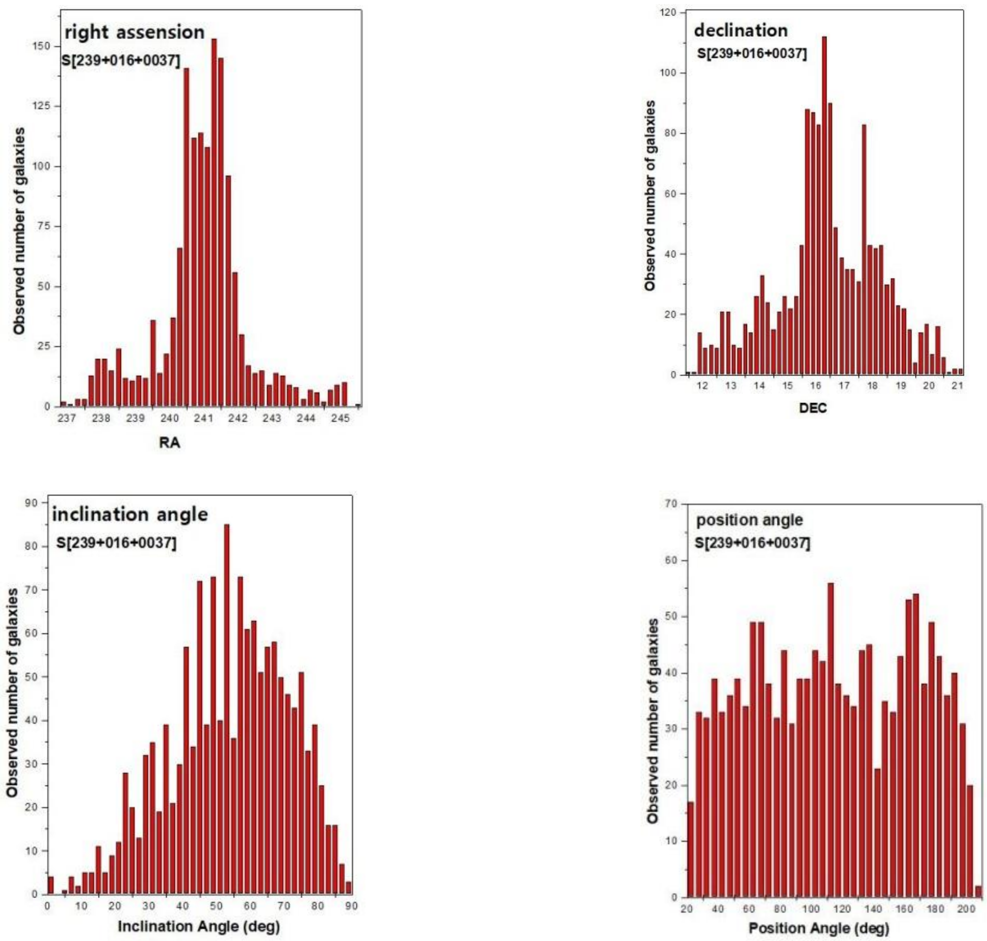
Table 1

Appropriate binning of RA, DEC, PA, and i with their observed number (O), and expected number (E). Here E is corresponding number of galaxies in 10^7 virtual galaxies created by the computer simulation in Supercluster S[239+016+0037].

RA	O	E	DEC	O	E	PA	O	E	i	O	E
236.9	2	1405.5	11.5	1	702.7	22.5	17	11946.6	1	4	2811
237.1	1	702.7	11.7	1	702.7	27.5	33	23190.4	3	0	0
237.3	3	2108.2	11.9	14	9838.4	32.5	32	22487.7	5	1	702.7
237.5	3	2108.2	12.1	9	6324.7	37.5	39	27406.9	7	4	2811
237.7	13	9135.6	12.3	10	7027.4	42.5	33	23190.4	9	2	1405.5
237.9	20	14054.8	12.5	9	6324.7	47.5	36	25298.7	11	5	3513.7
238.1	20	14054.8	12.7	21	14757.6	52.5	39	27406.9	13	5	3513.7
238.3	15	10541.1	12.9	21	14757.6	57.5	34	23893.2	15	11	7730.1
238.5	24	16865.8	13.1	10	7027.4	62.5	49	34434.3	17	5	3513.7
238.7	12	8432.9	13.3	9	6324.7	67.5	49	34434.3	19	9	6324.7
238.9	11	7730.1	13.5	17	11946.6	72.5	38	26704.1	21	12	8432.9
239.1	13	9135.6	13.7	14	9838.4	77.5	32	22487.7	23	28	19676.7
239.3	12	8432.9	13.9	26	18271.3	82.5	44	30920.6	25	20	14054.8
239.5	36	25298.7	14.1	33	23190.4	87.5	31	21785	27	13	9135.6
239.7	14	9838.4	14.3	24	16865.8	92.5	39	27406.9	29	32	22487.7
239.9	22	15460.3	14.5	15	10541.1	97.5	39	27406.9	31	35	24595.9
240.1	37	26001.4	14.7	21	14757.6	102.5	44	30920.6	33	19	13352.1
240.3	66	46380.9	14.9	26	18271.3	107.5	42	29515.1	35	39	27406.9
240.5	141	99086.4	15.1	22	15460.3	112.5	56	39353.5	37	21	14757.6
240.7	112	78707	15.3	26	18271.3	117.5	38	26704.1	39	30	21082.2
240.9	114	80112.4	15.5	43	30217.8	122.5	36	25298.7	41	57	40056.2
241.1	108	75896	15.7	88	61841.2	127.5	34	23893.2	43	34	23893.2
241.3	153	107519.3	15.9	87	61138.4	132.5	44	30920.6	45	72	50597.3
241.5	145	101897.4	16.1	83	58327.5	137.5	45	31623.3	47	39	27406.9
241.7	96	67463.1	16.3	112	78707	142.5	23	16163	49	73	51300.1
241.9	56	39353.5	16.5	90	63246.7	147.5	35	24595.9	51	40	28109.6
242.1	30	21082.2	16.7	49	34434.3	152.5	33	23190.4	53	85	59733
242.3	17	11946.6	16.9	39	27406.9	157.5	43	30217.8	55	36	25298.7
242.5	14	9838.4	17.1	35	24595.9	162.5	53	37245.3	57	73	51300.1
242.7	15	10541.1	17.3	35	24595.9	167.5	54	37948	59	61	42867.2
242.9	9	6324.7	17.5	31	21785	172.5	38	26704.1	61	63	44272.7
243.1	14	9838.4	17.7	83	58327.5	177.5	49	34434.3	63	51	35839.8
243.3	13	9135.6	17.9	43	30217.8	182.5	43	30217.8	65	57	40056.2
243.5	9	6324.7	18.1	42	29515.1	187.5	36	25298.7	67	58	40759
243.7	8	5621.9	18.3	43	30217.8	192.5	40	28109.6	69	50	35137
243.9	3	2108.2	18.5	30	21082.2	197.5	31	21785	71	46	32326.1

Figure 1

The distribution of RA (α), declination (δ), Position angle (P) and inclination angle (i) of the galaxies in the sample S[239+016+0037]. The Y-axes of histograms represent the number of observed galaxies.



Determination of Inclination Angle

We require knowledge of the inclination angle for studying the spin vector orientation of galaxies. The inclination angle refers to the angle between the line of sight of the observer and the normal to the galactic plane. The inclination angle of spiral nebulae to the celestial plane could be determined from the ratio of apparent major and minor axes (Holmberg, E., 1946). Holmberg equation is the relation between the axial ratio (b/a) and the inclination angle (i), which is given as:

$$cos^2 i = \frac{\left({}^{b}/_{a}\right)^2 - (q^*)^2}{1 - (q^*)^2} \tag{1}$$

This equation 1 is called the Holmberg formula. Here, q^* is the intrinsic flatness factor. Holmberg (1946) suggested a value of $q^*= 0.2$ for oblate spheroid and $q^*= 0.33$ for elliptical. This expression 1 is valid for oblate spheroids (Stein, R., 1974). For the galaxies with unknown morphology q*=0.20 is assumed (Holmberg, E., 1946).

Flin-Godlowski Transformation

The Flin-Godlowski transformation enables the potential of calculating the orientation of the angular momentum vector using the position angle and the inclination of the galaxy with respect to the plane of the cluster. The three-dimensional orientation of the angular momentum vectors of a galaxy is determined by two angles: the polar angle (θ), is the angle between the normal to the galaxy and equatorial plane and the azimuthal angle (ϕ), is the angle between the projection of this normal on the equatorial plane and reference axis directed towards the equatorial center. The following measurable quantities can be used to derive θ and ϕ when using the equatorial coordinate system as a reference:

$$\sin\vartheta = \cos i \sin\delta \pm \sin i \sin p \cos\delta \tag{2}$$

$$\sin\phi = \frac{-\cos i \cos\delta \sin\alpha \pm \sin i\,(\mp\sin p \sin\delta \sin\alpha \mp \cos p \cos\alpha)}{\cos\vartheta} \tag{3}$$

$$\sin\phi = \frac{-\cos i \cos\delta \cos\alpha \pm \sin i\,(\mp\sin p \sin\delta \sin\alpha \pm \cos p \sin\alpha)}{\cos\vartheta} \tag{4}$$

where, i is the inclination angle which is calculated using equation 1, δ is declination angle, α is right ascension angle and p is position angle. At first, we studied the right ascension (α), declination angle (δ), position angle (P) and inclination angle (i) distributions for the galaxies in the sample S[239+016+0037].

The distribution of α, δ, P, and i for the galaxies in the sample S[239+016+0037] are shown in the figure above (Fig.1). The histograms represent the number of observed galaxies.

After simulation, we obtain the curves for polar angle (θ) and azimuthal angle (ϕ) distribution. Our observations (real observed data set) are compared with the isotropic distribution curves (obtained from simulation) in both θ and ϕ distributions. For this comparison we use different statistical tests.

Result and Discussion

Figure 2

All Sky Distribution of Supercluster S[239+016+0037]

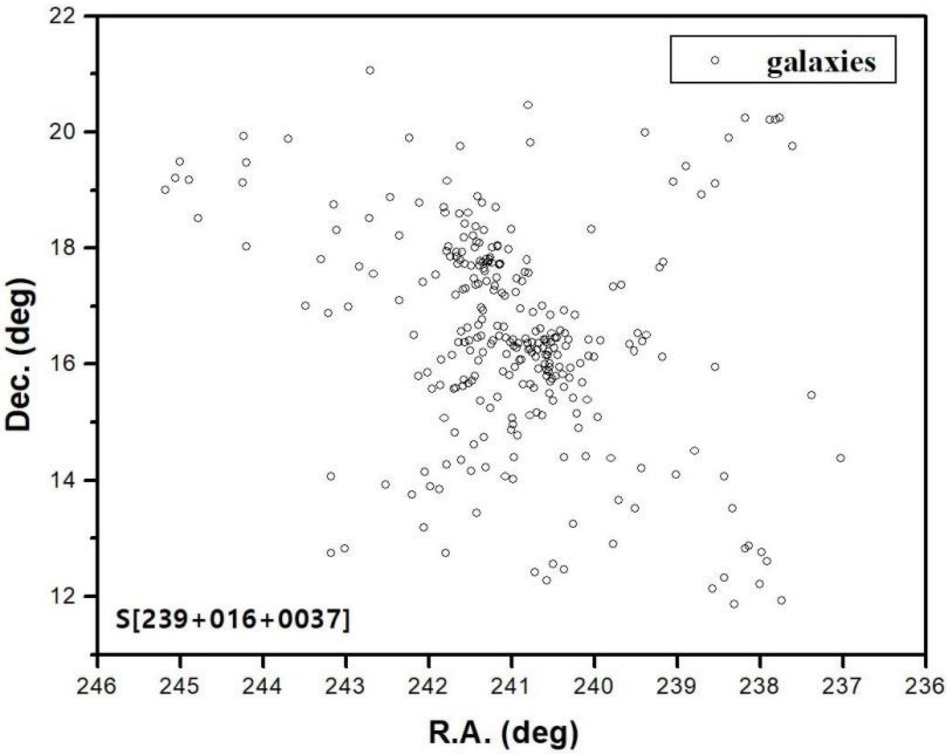
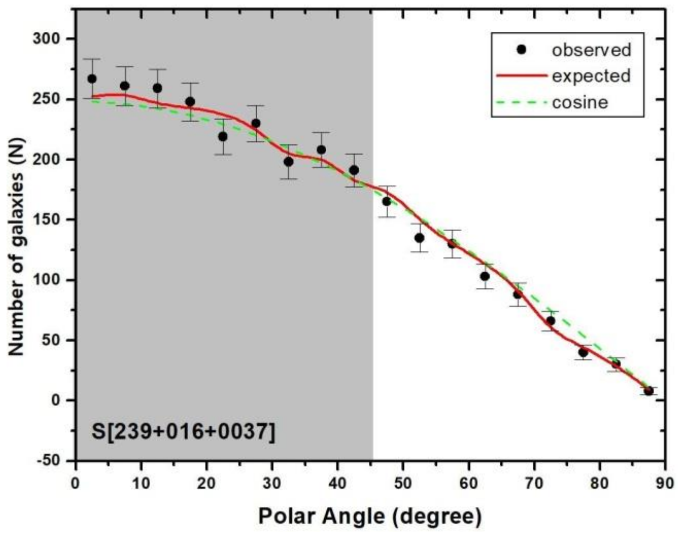


Figure 2, shows all-sky distribution of galaxies in the Superclusters S[239+016+0037] several groups of galaxies can be seen. This distribution clearly reveals that the galaxies are not equally distributed as shown in the figure. The nature of galaxies is concentrated in the region of right ascension between 240° to 242° and declination angle between 15° to 18°. These groups of galaxies can form a substructure and, ultimately a cluster of galaxies.

The total number of galaxies in this work is 1423. For each galaxy, we have two solutions for polar angle (θ) and azimuthal angle (ϕ). Therefore, there is 2846 number of solutions altogether. We only used the absolute value of θ and plotted the distributions of polar and azimuthal angles separately. The following Figure 3 represents the polar angle (θ) and Figure 4 represents the azimuthal angle (ϕ) distribution of total galaxies in the Supercluster S [239+016+0037].

Figure 3

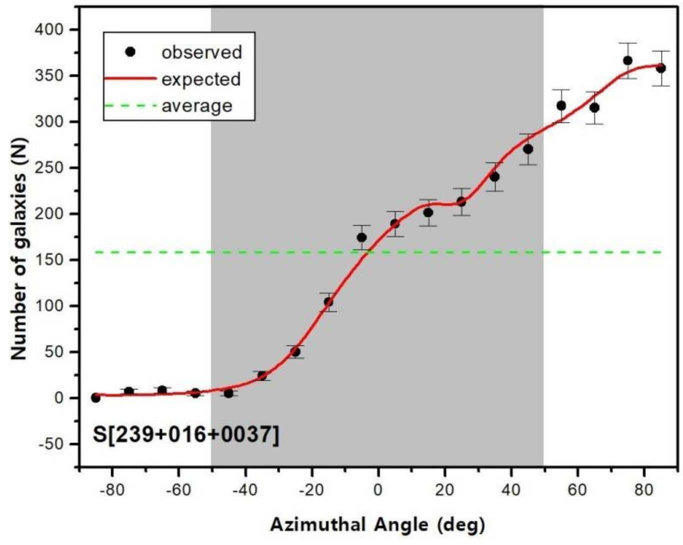
The polar angle (θ) distribution of galaxies in the Supercluster S [239+016+0037].



The expected isotropic distributions are symbolized by the solid line. The cosine distributions are symbolized by the dashed lines. The observed distribution is symbolized by solid circles with ±1σ error bars.

Figure 4

The azimuthal angle (ϕ) distribution of galaxies in the Supercluster S[239+016+0037]



The expected isotropic distributions are symbolized by the solid line. The average distributions are symbolized by the dashed lines. The observed distribution is symbolized by solid circles with ±1σ error bars.

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The solid curve in the histogram of the polar angle (θ) distribution indicates the expected isotropic distribution, whereas the dashed curve indicates the cosine distribution. The observed distribution is indicated by solid circles with ±1σ error bars. The shaded area indicates the 0°< θ < 45° range. A hump (or dip) in the smaller θ (θ < 45°) indicates that the spin vectors of galaxies are likely to orient parallel (or perpendicular) to the equatorial coordinate system. Likewise, a hump (or dip) in the larger θ (θ > 45°) indicates that spin vectors of galaxies are likely to orient perpendicular to the equatorial coordinate system. Figure 3 shows that one hump is seen at θ = 2.5 in the θ > 45° range. At this angle, the observed number of galaxies is 267 and the expected number of galaxies is 252, which is 15 more observed number than the expected number of galaxies. So, there arises a small hump. Likewise, one dip is seen at angle θ=22.5° in the θ > 45° range. At this angle, the observed value is 219 and the expected value is 237. So, there arises a small dip, which is due to 18 fewer observed values than expected values (number of galaxies).

Similarly, a hump (or dip) in the larger ϕ implies that galaxies spin vectors tend to be perpendicular to the equatorial coordinate system. The solid curve in the ϕ-distribution histogram shows the expected isotropic distribution, although the dashed curve symbolizes average distribution. The observed distribution is indicated by solid circles with ±1σ error bars. The shaded area shows the range −45°< ϕ < +45°. The humps and dips in the histograms of ϕ-distributions are more difficult to interpret than those of θ-distributions. This is because the range of ϕ is −90° to +90°. In Figure 4, one hump is seen at angle ϕ = −5° in the −45°< ϕ < +45° range. At this angle, the observed value is 174 and the expected value is 151. So, there arises a small hump, which is due to 23 more observed values than the expected value (number of galaxies).

Table 2

Statistics of the polar (θ) and azimuthal (ϕ) angle distributions of galaxies in the Supercluster S[239+016+0037]

Statistics	**Polar angle(θ)**	**Azimuthal angle(ϕ)**
$P(>\chi^2)$	0.959	0.162
$C/C(\sigma)$	0.012	-0.252
$\Delta_{11}/\sigma(\Delta_{11})$	1.102	0.106
$P(>\Delta_1)$	0.461	0.899

The statistics of the polar (θ) and azimuthal (ϕ) angle distributions of galaxies in the Supercluster S[239+016+0037] are displayed in Table 2. In this sample, the statistics for the polar angle distribution show that the value of chi-square probability P ($>\chi^2$) is 0.959 which is higher than the significant level of 0.05, i.e., 5.0%. The auto-correlation coefficient C/C(σ) is obtained to be 0.012 which is smaller than 1σ limit. The first order Fourier coefficient Δ_{11}/σ (Δ_{11}) is obtained to be 1.102 which is smaller than 1.5σ limit. The first order Fourier probability P (> Δ_1) is obtained to be 0.461 which is greater than 0.15 i.e.,15%. Thus, all the statistical tests suggest strong isotropy. Isotropy in the first order Fourier coefficient test suggests that the direction of departure from isotropy. Similarly, in this sample, the statistics for the azimuthal angle distribution demonstrate that the value of chi-square probability, P ($>\chi^2$) is obtained to be 0.162 which is greater than the significant level 0.05 i.e., 5.0%.The auto-correlation coefficient C/C(σ) is obtained to be -0.252 which is smaller than 1σ limit. The first order Fourier coefficient Δ_{11}/σ (Δ_{11}) is obtained to be 0.106 which is smaller than 1.5σ limit. The first order Fourier probability P (> Δ_1) is obtained to be 0.899 which is greater than 0.15 i.e., 15%. Thus, all statistical tests suggest strong isotropy. Isotropy in the first order Fourier coefficient test suggests that the direction of departure from isotropy.

Moreover, the value of the first order Fourier coefficient in the statistics of θ is positive, indicating that spin vectors of galaxies are oriented parallel to the equatorial coordinate system. Also, the value of the first order Fourier coefficient in the statistics of ϕ is positive, indicating that spin vectors of galaxies tend to point radially with respect to the center of the equatorial coordinate system.

Conclusions

We have studied the spatial orientation of spin vectors of 1423 SDSS DR7 galaxies in Supercluster S [239+016+0037]. We applied the method proposed by Flin & Godlowski to convert two-dimensional data into three-dimensional galaxy rotation axes (polar and azimuthal angles). In order to find the theoretical distribution of galaxy rotation axes, we have carried out random simulation on 10^7 virtual galaxies using the method given by (Aryal & Saurer, 2004). We used three statistics to compare the differences between theoretical and observed distributions: chi-square, auto-correlation, and the Fourier test. All these statistical tests suggest strong isotropy in galaxy orientation in our samples. Moreover, the spatial orientation of SVs of galaxy in Supercluster S [239+016+0037] was discovered to be oriented randomly with respect to the equatorial plane. We can confirm that the evolution of the galaxy in the Supercluster supports the hierarchy model by studying the results of statistical tests. However, different samples show a local influence that creates humps and dips in the angular momentum distribution.

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