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Research Article

STUDY OF SPATIAL ORIENTATION OF ANGULAR MOMENTUM OF Z-MAGNITUDE SDSS DR-13 GALAXIES WITH RED SHIFT 0.50 TO 0.53

Shiv Narayan Yadav[1*], **Santosh Kumar Sah**[1]

[1]*Department of Physics, Patan Multiple Campus, Tribhuvan University, Lalitpur, Nepal*
[*]*Corresponding author: ysibnarayan@yahoo.com*

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ABSTRACT

The spatial orientations of 142,929 SDSS DR-13, z- magnitude galaxies having red shift 0.50 to 0.53 have been analyzed. The main goal of this work is to examine the orientation of the angular momentum of galaxies within the given redshift limit in the framework of three different scenarios 'Hierarchy model', 'Pancake model', and the 'Primordial vorticity model'. By using Godlowskian transformation the two-dimensional data were converted into three-dimensional data (polar and azimuthal angles). The expected isotropy distribution curves were obtained by removing the selection effects and performing a random simulation to generate 10^7 virtual galaxies by using Matlab 2015a. Three statistical tests of Chi-square, autocorrelation, and Fourier were used to compare the expected isotropic data with observed. The data classified into nine subsamples having each of one magnitude size. In general, the results supported the Hierarchy model. The model advocates random orientations of angular. However, a local anisotropy observed in few subsamples suggested a gravitational tidal interaction between neighboring galaxies, an early-merging process in which the angular momentum vector distorts the initial alignment of nearby galaxies.

Keywords: Angular momentum, Clusters, Galaxies, Hierarchy, Orientations, Superclusters.

INTRODUCTION

The universe started with the Big Bang ~ 13.6 billion years ago. For the first tiny fraction of a second after the big bang, all four forces were fundamental symmetric, and hence event within 10^{-43}s is beyond physics. The main stages can be described as follows: from the time of the big bang to about 10^{-6} seconds particle physics dominates. After one second, subatomic particles were formed, and after 360,000 years, things have cooled down enough so that the normal elements like hydrogen could exist. The amount of hydrogen in the universe today is one of the important pieces of evidence for the big bang. According to Gamow (1952), exponential density fluctuations during inflation showed sudden density fluctuation. The theory of density fluctuations solves many problems of the standard big bang model.

The angular momentum and galaxies rotation might be the main scientific causes of the formation of these systems (von Weizscker, 1951). The study of spatial orientation of angular momentum gives an idea about the origin of the angular momentum of galaxies. The magnitude of the angular momentum of galaxies predicts a gravitational instability picture. The gravitational instability is the main clue of large scale structure formation (Peeble, 1969).

The work was related to find the direction of the angular momentum vector concerning the equatorial coordinate system. The different statistical tests were used to compare expected data obtained by Matlab simulations and observed data. The recent advancement in technology has provided us with a huge amount of data on various galaxies, clusters, and superclusters in the universe (Chattakuli *et al.*, 2020; Gautam & Aryal, 2019).

A proper analysis and interpretation of such data with proper computation of the available data can help us find the distribution of the angular momentum vector of galaxies in the cluster and supercluster which might be helpful to know the early stages of the formation of galaxies and clusters provided that the angular momentum of galaxies has not changed significantly. A comparative and analytical study of the preferred alignment of the angular momentum vectors of galaxies (SDSS) in the COMA cluster using the position angle inclination method (Flin & Godlowski, 1986) for equatorial coordinate system (ECS), Galactic coordinate system (GCS), and Super galactic coordinate system (SGCS) can reveal the evolution scenario of the COMA.

In the present work, SDSS data of z- magnitude was used. The SDSS z- filter corresponds to color not visible to the human eye i.e. infrared. The z- magnitude was observed through an 8931Å CCD Infrared filter attached to the SDSS telescope located in New Mexico, USA. These emission lines at this wavelength were expected to be emitted from the hot region (T < 5000 K), mostly from the interstellar medium of the galaxy, star-forming region, the extended HII region.

Galaxy evolution models

There are several theories based on different assumptions of the formations of a large-scale structure in which only three models (Pancake, Hierarchy, and Primordial vorticity) are based on the direction of the angular momentum vector as explained below. The Pancake model (Doroshkevich, 1973; Doroshkevich & Shandarin, 1978) predicts that the direction of the angular momentum of galaxies parallel to the reference plane (Fig. 1). According to this model, the formation of clusters took place first and was followed by their fragmentation into galaxies due to adiabatic fluctuations. According to the non-linear theory of gravitational instability, a growth of small inhomogeneity leads to the formation of thin, dense, and gaseous condensation that is called 'Pancakes'.

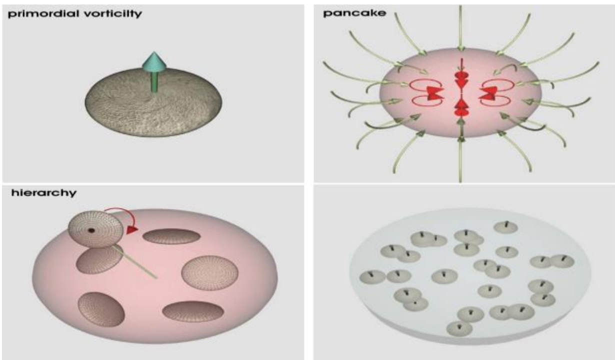

Fig. 1. An arrow represents the preferred direction of the angular momentum vector of a galaxy in each model (Kausch, 2004)

According to the Hierarchy model (Peebles, 1969), the direction of the angular momentum of galaxies vectors should be distributed randomly to the equatorial plane. In the Hierarchy model, galaxies were first formed and they obtained their angular momenta by the tidal force while they were gathering gravitationally to form a cluster. Those galaxies grow by subsequent merging of protogalactic condensation or even by merging of already-fully formed galaxies (Holmberg, 1946). This model predicts that the spatial orientation of angular momentum vectors of a system of rotationally supported large-scale structure (eg., spiral galaxies) should vanish. In order words, these vectors should align randomly. The spatial orientation of galaxies in 112 clusters was studied to date (Godlowski *et al.*, 1994; Flin *et al.*, 2001, Aryal *et al.*, 2013, 2010).

In most cases, no preferred alignment was noticed (Hierarchy model). However, few clusters strongly support the Pancake model. A systematic change in the galaxy alignments was noticed from early-type (BM I) to late-type (BM III) clusters (Aryal *et al.*, 2007). This result suggests that the spiral-rich (late-type) clusters (BM II-III and BM III) show a preferred alignment than that of elliptical-rich (early-type) clusters. Aryal *et al.* (2012) noticed very controversial result that angular momentum of galaxies depends upon reference co-ordinate system. Yadav *et al.* (2017) studied preferred alignments of angular momentum vectors of galaxies in six dynamically unstable Abell clusters and notice mixed results. The results suggest no preferred alignments of galaxies in general. However, local effects are noticed in the clusters that have substructures in 1D, 2D and 3D analysis. Malla *et al.* (2020) noticed the magnitude of galaxies are indepent upon angular momentum vector.

The primordial vorticity theory (Ozernoy, 1971; Stein, 1974) shows that the angular momentum vectors of galaxies are distributed primarily perpendicular to the reference plane. According to this model, at first rotating proto-cluster is formed due to cosmic vorticity in the early universe. Subsequent density and pressure fluctuation caused to form galaxies. Thus it is also called the top-down model of galaxies formation.

Godlowskian transformation

The polar angle (θ) and the azimuthal angle (Φ) are the parameters that determine the orientation of the angular momentum of galaxies. The detailed derivations of the expressions of the angles θ and Φ are given in Flin and Godłowski (1986). Using the equatorial coordinate system as reference, θ and Φ can be obtained from measurable quantities, as given in equations (1) and (2).

$$\sin\theta = -cosi\,sin\alpha \pm sini\,sinPcos\delta \qquad (1)$$

$$\sin\phi = (\cos\theta)^{-1}[-\cos i\cos\delta\sin\alpha + \sin i(\mp\sin P\sin\delta\sin\alpha\mp\cos P\cos\alpha)] \qquad (2)$$

Where, *i* is the inclination angle, the angle between the normal to the galaxy plane and the observer's line-of-sight. The inclination angle can be computed using the formula, as given in equation (3).

$$\cos^2 i = \frac{(q^2 - q*^2)}{(1 - q*^2)} \qquad (3)$$

The equation (3) is valid for oblate spheroids (Holmberg, 1946). Here, *q* and *q** represent the measured axial ratio (*b/a)* and the intrinsic flatness of the galaxy, respectively. The intrinsic flatness is the flatness factor of galaxies depending upon the eccentricity of ellipse formed by projection of galaxies on the celestial sphere and angle of inclination. Here, α is right ascension, δ is declination and P is the position angle of the galaxies.

MATERIALS AND METHODS

Selections in the database cause severe changes in the shapes of the expected distribution curves and hence to reduce the selection effect, virtual galaxies should generate, as described elsewhere (Aryal & Saurer, 2006, 2004, 2000). For these equations (1) and (2), θ and ϕ are taken from the Godwoskian transformations. The isotropic distribution curves are based on simulations including 10^7 virtual galaxies. By using given parameters α, δ, P, and i, 10^7 virtual galaxies were created. Matlab 2015a was used to make input files using given parameters.

Method of analysis

The present observation (real observed dataset) was compared with the isotropic distribution curves (obtained from simulation) in both θ and ϕ distributions using three different statistical tests, i.e., chi-square-, Fourier-, and auto correlation-tests.

Chi-square test

The χ^2 test is a measure of how well a theoretical probability distribution fits a set of data. Chi-square test is an objective way to examine whether the observational distribution deviates from the isotropic distribution (Godlowski *et al.*, 1994), as given by equations (4) and (5).

$$\chi^2_\nu = \frac{\chi^2}{\nu} \tag{4}$$

$$\chi^2 = \sum_{i=1}^{n} \frac{(N_{0i} - N_{ei})^2}{N_{ei}} \tag{5}$$

Here, n represents the number of bins, N_{0i} and N_{ei} represent the observed and expected isotropic distributions and ν is the degree of freedom (ν = n-1).

Fourier test

If the deviation from isotropy is only slowly varying with θ or ϕ, the Fourier test can apply. The expressions for the Fourier coefficients Δ_{11} and Δ_{21} are given in equation (6). The standard deviations $\sigma(\Delta_{11})$ and $\sigma(\Delta_{11})$ can obtain using the expressions (Godlowski *et al.*, 1994), as given in equation (7).

$$\Delta_{11} = \frac{\sum_{k=1}^{n}(N_k - N_{0k})\cos 2\theta_k}{\sum_{k=1}^{n} N_{0k}\cos^2 2\theta_k} \qquad \Delta_{21} = \frac{\sum_{k=1}^{n}(N_k - N_{0k})\sin 2\theta_k}{\sum_{k=1}^{n} N_{0k}\sin^2 2\theta_k} \tag{6}$$

$$\sigma(\Delta_{11}) = \left(\sum_{k=1}^{n} N_{0k}\cos^2 2\theta_k\right)^{-1/2} \qquad \sigma(\Delta_{21}) = \left(\sum_{k=1}^{n} N_{0k}\sin^2 2\theta_k\right)^{-1/2} \tag{7}$$

The amplitude of Fourier coefficient is given by, $\Delta_1 = \left(\Delta_{11}{}^2 + \Delta_{21}{}^2\right)^{1/2}$, and the first order Fourier probability that is given by the formula, $P(>\Delta_1) = \exp\left(-\frac{n}{4} N_0 \Delta_1{}^2\right)$ with standard deviation of $\sigma(\Delta_1) = \left(\frac{2}{nN_0}\right)^{1/2}$

The Fourier coefficient (Δ_{11}) is very important because it gives the direction of departure from isotropy. In the analysis of the polar angle (θ), an excess of galaxies with rotation axis parallel to the reference plane is present if $\Delta_{11}<0$, whereas the rotation axis tend to be perpendicular to that plane for $\Delta_{11}>0$.

Autocorrelation test

Autocorrelation test is a measure of a degree to which there is a linear relationship between two variables. In present case, it takes into account the correlation between the numbers of galaxies in adjoining angular bins. The correlation function is given by equation (8) with the standard deviation of $\sigma(C) = (n)^{1/2}$ (Godlowski *et al.*, 1994).

$$C = \sum_{1}^{n} \frac{(N_k - N_{0k})(N_{k+1} - N_{0k+1})}{(N_{0k} N_{0k+1})^{1/2}} \tag{8}$$

In an isotropic distribution, any correlation vanishes, so that $C \to 0$

RESULTS AND DISCUSSION

For anisotropic, the chi-square probability must be less than 0.050, autocorrelation coefficient greater than 1.0 and less than -1, first-order Fourier coefficient ($\Delta_{11}/\sigma(\Delta_{11})$) > 1.5 and less than -1.5 and first-order Fourier probability should be $P(>\Delta_1) < 0.150$. Local effect in the samples was explained in terms of humps and dips. Tables 1 and 2 are for θ and ϕ, respectively. The significant negative value of first order Fourier coefficient ($\Delta_{11}/\sigma(\Delta_{11})$) for θ, suggests that the angular momentum vectors of galaxies tend to be oriented perpendicular and the positive value suggests that the angular momentum vectors of galaxies tend to be oriented parallel concerning the equatorial coordinate system. Whereas, in the statistics of ϕ, a positive ($\Delta_{11}/\sigma(\Delta_{11})$ with significant value suggests that the angular momentum vector projections of galaxies tend toward the center of equatorial coordinate system and a significant negative value of ($\Delta_{11}/\sigma(\Delta_{11})$ implies that the angular momentum vector projection of galaxies tend to orient tangentially to the equatorial coordinate system.

In addition to the statistical tests, the `humps' and `dips' in the polar and azimuthal angle distributions were also studied. The solid circles with ±1σ error bars represent the observed distribution. A hump (or dip) in the smaller θ ($0^o < \theta < 45^o$) suggests that the angular momentum vectors of galaxies tend to orient parallel (or perpendicular) concerning the equatorial coordinate system. Similarly, a hump (or dip) in the larger θ indicates that the angular momentum vectors of galaxies tend to be oriented perpendicular with respect to the reference coordinate system.

In the histogram of the ϕ-distribution, the solid circles with ±1σ error bars represent the observed distribution. The humps and dips in the histograms of ϕ-distribution are not easy to interpret compared to θ-distributions (Godlowski 1993, 1994). It is because the range of ϕ was -90° to +90°. In the histogram of the ϕ-distribution, $\phi = 0^o$ means angular momentum vector projections tend to point radially towards the center of the equatorial coordinate system.

Table 1. The first column, second column, and third column correspond to sample or subsample, Chi-square probability and auto-correlation coefficient respectively while the fourth column and last column represent first-order Fourier coefficient and Fourier probability of polar angle distribution (θ)

Sample	*P* (>χ2)	*C/C* (σ)	Δ_{11}/σ (Δ_{11})	*P* (> Δ_1)
Total Sample (zT)	0.152	0.0	0.7	0.718
Subsample (z01)	0.043	-1.5	-0.4	0.900
Subsample (z02)	0.153	-0.8	0.5	0.791
Subsample (z03)	0.899	0.2	0.4	0.915
Subsample (z04)	0.738	-0.7	0.3	0.889
Subsample (z05)	0.051	-1.5	-1.4	0.330
Subsample (z06)	0.703	-0.7	0.6	0:817
Subsample (z07)	0.898	-0.2	-0.1	0.921
Subsample (z08)	0.906	-1.0	0.0	0.991
Subsample (z09)	0.297	0.0	1.1	0:515

Table 2. The first column, second column, and third column correspond to sample or subsample, Chi-square probability and auto-correlation coefficient respectively while the fourth column and last column represent first-order Fourier coefficient and Fourier probability of polar angle distribution (ϕ)

Sample	*P* (>χ2)	*C/C* (σ)	Δ11/σ (Δ11)	*P* (> Δ1)
Total Sample (zT)	0.000	66.6	17.6	0.000
Subsample (z01)	0.399	-0:2	1.1	0.540
Subsample (z02)	0.000	27.3	11.4	0.000
Subsample (z03)	0.000	36.2	12.4	0.000
Subsample (z04)	0.005	2.9	1.7	0.013
Subsample (z05)	0.042	1.7	2.1	0.118
Subsample (z06)	0.366	-1:8	0.2	0.971
Subsample (z07)	0.031	-24	-0:1	0.946
Subsample (z08)	0.106	-1:3	0.6	0.812
Subsample (z09)	0.926	-0:5	0.9	0:656

A hump in the middle (central eight bins) of the histogram suggests that the angular momentum vector projections of galaxies tend to point towards the center of the chosen coordinate system. Similarly, a hump at the first four and last four bins indicates that the angular momentum vectors projections of galaxies tend to be oriented tangentially with respect to the chosen reference coordinate system.

Table 1 shows the polar angle distribution of galaxies in samples for the equatorial coordinate system. The statistics for the polar angle distribution in the sample (*zT*) shows the value of chi-square probability (P(>χ2)) = 0.152, auto-correlation coefficient (C/C(σ)) = 0.0, the first-order Fourier coefficient ($\Delta_{11}/\sigma(\Delta_{11})$) = 0.7 and Fourier probability (P >(Δ_1)) = 0.71). All the statistics suggest isotropy. The polar angle distribution of galaxies in the sample *zT* is shown in Fig. 2. The number of observed and expected solutions for small-angle (<45°) were 217,352 and 217,049 respectively i.e. the observed distribution was 303 more than the expected. The difference was less than 5% of the total observed distribution. For the bimodal region (45°), the observed number and expected number of galaxies were 32,321 and 32,325 respectively such that the observed number of galaxies was less than by 4 than that of the expected number of galaxies.

Moreover, no humps and dips were seen at bimodal region. For large angles > 45°, the observed and expected number of galaxies were 68,506 and 68,809, respectively, which implies that the observed number of galaxies less than the expected solution by 303. There were no humps and dips seen. So the number of observed and expected distributions was balanced. All the statistical tests and graphical explanation shows that the distribution of galaxies to the equatorial coordinate system is isotropic.

Azimuthal angle distribution *(ϕ)* of galaxies in the total sample (zT) is shown in Table 2. The value of Chi-square probability (P(>χ2)) was found to be 0.000 (less than significant level 0.050), the value of Auto-correlation coefficient (C/C(σ)) was 66.6 (more than the limit 1), first-order Fourier coefficient ($\Delta_{11}/\sigma(\Delta_{11})$) was 17.6 (more than the limit 1.5) and first-order Fourier probability (P >(Δ_1)) was found to be 0.000 (less than the limit 0.150). In Fig. 3 (ZTb), the number of observed galaxies in central eight bins, the observed galaxies was more by 3,846 than that of the expected number of galaxies. In this region, there significant humps at angles -5°, 5°,-15°, 15°, 25°, and 35°. In the first four bins, the expected distribution was 2385 more than the observed and there were significant dips at an angle 65^0, 75°, 85°, 55° and in the last four bins. The expected distribution was 1461 more than the observed distribution dips observed at 65°, 75°, and 85°. All the statistical results and graphical results for azimuthal angles distribution suggested anisotropy. The controversial result is due to a large bin size as well as a coordinate system. Finally, we conclude that our result support Hierarchy model. Similarly, all statistics and graphical results for samples z01, z02, z03, z04, z05, z06, z07, z08, and z09 supports random orientation of galaxies with respect to equatorial coordinate system. Due to similarity, only 6 plots of azimuthal and six of polar are included here. The summary of results is given in Fig. 3 and Table 3.

Figure 4 represents the scatter plot of z- magnitude versus first-order Fourier coefficient for (a) polar angle and (b) azimuthal angle distributions for the total sample and subsamples. The shaded region represents the region of isotropy. In polar angle distributions, the linear line lies in the shaded region. We conclude that the spatial orientation of angular momentum vectors of galaxies is random with respect to the equatorial co-ordinate & is independent of the value of z-magnitudes, supporting the Hierarchy model of galaxy evolution. Similarly, the azimuthal angle distribution linear line lies outside the shaded region. This is due to results of a few samples like zT, z02, z03 and hence it suggests analyzing the results using a galactic or supergalactic coordinate system.

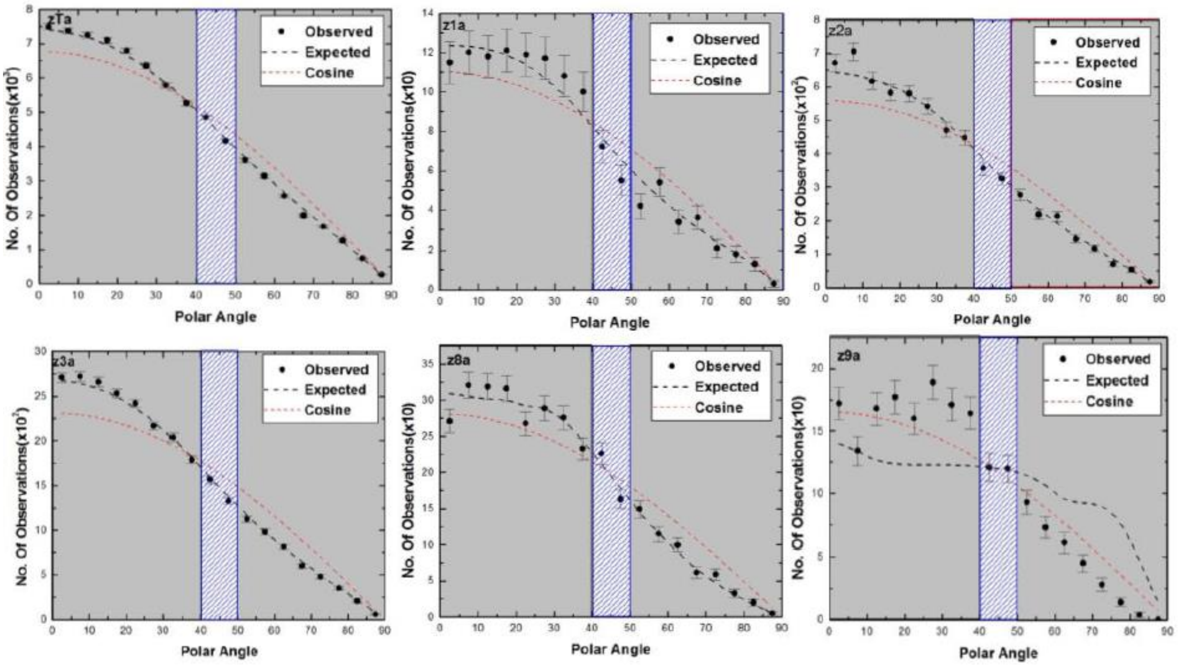

Fig. 2. The polar (θ) angle distributions of SDSS galaxies having z-magnitude. The solid line represents the expected isotropic distributions. The cosine and average distribution (dashed) are shown for the comparison. The statistical error (±1σ) bars are shown for the observed counts

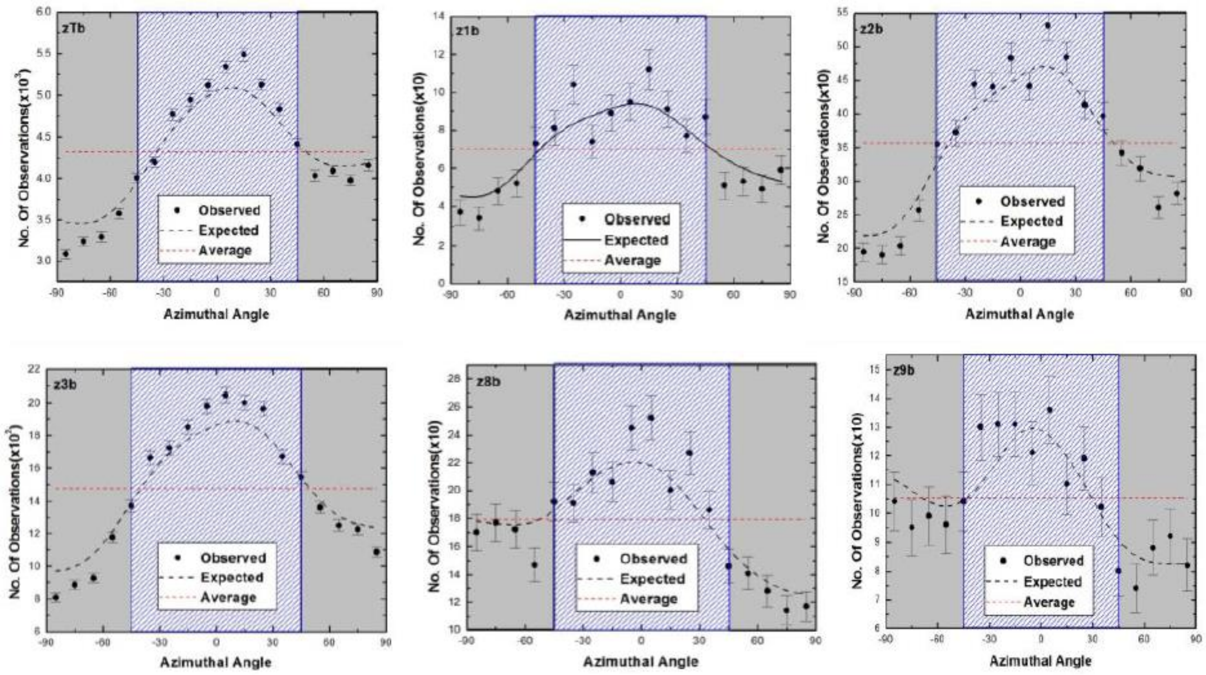

Fig. 3. The azimuthal (ϕ) angle distributions of SDSS galaxies having z-magnitude. The solid line represents the expected isotropic distributions. The cosine and average distribution (dashed) are shown for the comparison. The statistical error (±1σ) bars are shown for the observed counts

Table 3. The statistical and graphical results of the total sample and subsamples

Sample	Polar Statistics	Angle Orientation	Azimuthal Statistics	Angle Orientation
Total sample zT	Isotropy	Perpendicular	Anisotropy	Radially towards center
Subsample z01	Isotropy	Random	Isotropy	Radially towards center
Subsample z02	Isotropy	Random	Anisotropy	Radially towards center
Subsample z03	Isotropy	Random	Anisotropy	Radially towards center
Subsample z04	Isotropy	Random	Isotropy	Radially towards center
Subsample z05	Isotropy	Random	Anisotropy	Radially towards center
Subsample z06	Isotropy	Perpendicular	Isotropy	Radially towards center
Subsample z07	Isotropy	Random	Anisotropy	Tangentially towards center
Subsample z08	Isotropy	Random	Isotropy	Radially towards center
Subsample z09	Isotropy	Random	Isotropy	Radially towards center

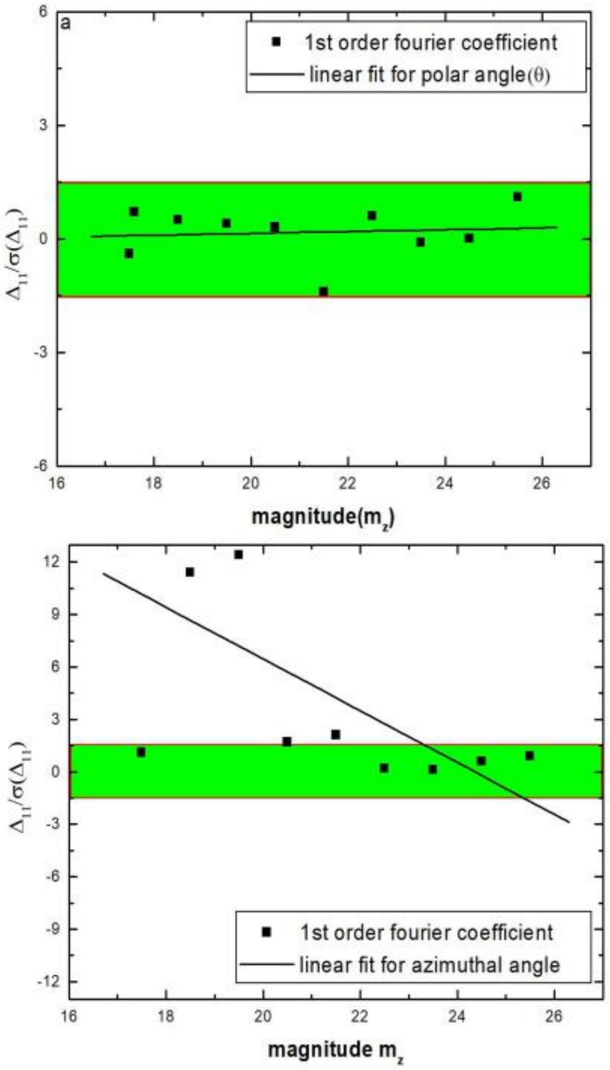

Fig. 4. The scatter plot of (a) polar angle and (b) azimuthal angle distributions for the total sample and subsamples

CONCLUSIONS

The spatial orientation of z- magnitude dependence of 142,929 SDSS Galaxies of redshift in the range 0.50 to 0.56 with respect to the equatorial coordinate system was studied. The z-magnitude is sensitive toward P- Fund series of hydrogen atom i.e. in the infrared region and hence there are possibilities of star formation. Thus we conclude that the distribution of angular momentum vector and projection of the angular momentum vector of z-magnitude SDSS galaxies are random except in the sample z0T and subsamples z02 and z03.

No preferred alignment to the equatorial coordinate system was noticed in the spatial orientation of angular momentum vectors of galaxies, suggesting the Hierarchy model of galaxies evolution in all sample and subsamples. In the case of the total sample, the polar angle distribution showed isotropic while the azimuthal angle distribution showed anisotropic. This controversial result is due to the huge number of galaxies (142,929) in the sample and also the problem in choosing the reference co-ordinate system.

In the subsamples z02 and z03 also the polar angle distribution showed isotropic while the azimuthal angle distribution showed anisotropic. This is due to a problem in our database because the number of galaxies was very less. The statistical and graphical results of samples z05 and z09 indicate departure from isotropy, which is due to gravitational lensing and tidal torquing effects, and possibilities of formation of cluster and supercluster. In several samples like z01, z07, z09 humps, and dips were observed suggesting that there are local effects like merging phenomena of galaxies.

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