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DISTRIBUTION OF ANGULAR MOMENTUM VECTORS OF GALAXIES IN THE CLUSTER GROUP SDSS CGG 3498

Janak Ratna Malla[1*], Daya Nidhi Chhatkuli[2], Walter Saurer[2], and Binil Aryal[3]

Amrit Campus, Tribhuvan University, Kathmandu, Nepal[1],Tri Chandra Campus, Kathmandu, Nepal[2], Institute of Astro-particle Physics, Innsbruck university, Austria[3], Central Department of Physics, Tribhuvan University, Kirtipur, Nepal[4],
[*]Corresponding author:janakratnamalla@gmail.com

Abstract
A study of the distribution of angular momentum vectors of 1,172 galaxies compiled from SDSS DR7 (Sloan Digital Sky Survey data release 7) as clusters of galaxies SDSS CGG 3498, has been carried out. The redshift-density map method technique is used to identify substructures in the group of clusters. We identified two substructures in the SDSS CGG 3498 on the basis of their compactness. Using inclination angle, positions and position angle of each galaxy, a conversion has been made to find polar angle and azimuthal angle of each galaxy with respect to the reference coordinate system. We made a hypothesis in such a way that any deviation from isotropic distribution is considered as a preference in the alignments. Three statistical tests: Chi-square, Auto-correlation and the Fourier are used to distinguish isotropy from anisotropy. Our aim is to identify preferred alignments in the frame work of three different galaxy evolution models: Hierarchy, Primordial vorticity and Pancake. It is found that the preferred alignments of galaxies are random with respect to the equatorial co-ordinate system in SDSS CGG 3498 as well as two of its substructures, supporting the Hierarchy model of galaxy formation.

Key words: Galaxies, Cluster, Supercluster, Substructure formation, Equatorial Coordinate, SDSS.

Introduction
The Universe is one of the biggest laboratories in which we aim to understand the evolution of galaxies in the groups, clusters and Supercluster. Galaxies have evolved with time to give us the galactic dynamics seen today. Galaxies are less understood than stars and stellar

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systems. There are so many complications leading less understanding of their formation and evolution. An additional factor making difficulties in understanding is the environmental effects through tidal and shearing effects. Galaxies can interact and even merge due to these effects. The clustering phenomenon does not stop with galaxies. Galaxy clusters and groups are the largest known gravitationally bound object in the cosmic structure formation. They are aggregation of galaxies with typical sizes of 20-100 h^{-1}Mpc (Einasto et al 2018). The directions of rotational axes of galaxies within these aggregations (clusters or group of clusters) may give us insight into the formation process of galaxies early in the history of the Universe. This aggregation of galaxies is believed to be formed through density perturbation, which is said to be dominated by the dark matter (Kravtsov and Borgani 2012). These perturbations evolve very slowly.

Gamow (1952) and Weizsckar (1951) first realized and later emphasized that observed rotation of galaxies are important for cosmology. According to them, these rotations should provide two information: formation history with kinematics and their dynamics. There are contradictory models in orientation of galaxies. Flin and Godlowski 1986, Kasikawa and Okamura 1992, Godlowski 1993, Hu et.al. 1998, Aryal et al 2004 have shown non random orientation of galaxies. Whereas Kizbichler and Saurer 2003, Godlowski 2011, Yadav et al 2017, Malla et. al. 2019 noticed no preferred alignment of galaxies.

In this work, we studied database of 1,172 galaxies in SDSS CGG 3498 having red shift range 0.107 to 0.123. Our aim is to identify substructure (density fluctuations) within the SDSS CGG 3498and analyze the angular momentum vectors of galaxies in the substructure of SDSS CGG 3498.

Data Compilation

The database that we have used in this work is compiled from Sloan Digital Sky Survey data release 7(SDSS DR7). There are 1,173 galaxies in the region of interest. But, we have rejected the data having low value of intrinsic flatness $q*$ (<0.10).

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Methods

In the large scale structure, galaxies are supposed to be distributed isotopically and homogeneously but when we study the all-sky distribution of galaxies in the cluster group (figure1), we notice various substructures. Therefore a need of substructure analysis in the cluster group is important. For this, we used a circular bin of 0.5 square degrees in the all sky map of cluster group to count number of galaxies within the neighborhood of each galaxy in the region using an algorithm 'galaxy counting code'. We used MATLAB 7.0.1 for searching substructures within the SDSS CGG 3498is as follows:

Galaxy Counting Code

```
ra=importdata('ra.m');
dec=importdata('dec.m');
sc=[ra,dec];
n=numel(ra)
repeat='y';
while repeat=='y'
radius=input('Enter the radius of circle in degree: ')
fori=1 : n
count=0;
for j=1 : n
r=(ra(i) - ra(j))^2+ (dec(i) - dec(j))^2;
if r <= radius*radius
count=count+1;
end
end
neighgal(i)=count;
end
str=input('enter a _le name to store near galaxy numbers: ','s')
_d=fopen(str,'wt');
fprintf(_d,'fclose(_d);
repeat=input('enter c if you wish to continue for another size or e to exit:
','s' )
end
```

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Determination of Galaxy Rotation Axis

We have adopted "position angle inclination method" proposed by Flin and Godlowski (1986) to find direction of angular momentum of galaxies in the cluster group. The three dimensional (spatial) orientation of galaxies generally expressed by polar (θ)and azimuthal angle (ϕ).These angles are given by Flin and Godlowski [1986] equations in terms ofα,δ,i, p.

$$\sin\theta = -\cos i \sin\alpha \pm \sin i \sin p \cos\delta \tag{1}$$

$$\sin\varphi = (\cos\theta)^{-1}[-\cos i \cos\delta \sin\alpha + \sin i(\mp \sin p \sin\delta \sin\alpha \mp \cos p \cos\alpha)] \tag{2}$$

Here,α,δ,i, and p represent the right ascension (in J(2000)),declination (in J(2000)), inclination angle (in degree), and position angles (in degree) respectively.

The inclination angle (i) is the angle between the normal to the galaxy plane and the observers line-of-sight, can be calculated by using the Holmberg's formula (1946) as

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

Where, b/a is the axial ratio and q* is the intrinsic flatness of the galaxy.

It is essential to remove the systematic selection effects from the database. To remove these effects, we use numerical simulation method proposed by Aryal and Saurer (2000). For this, a true spatial distribution of the galaxy rotation axis is assumed to be isotropic. The investigation on alignments of the galaxies are made by applying statistical tests of the polar angle (θ) and azimuthal angle (ϕ) resulting from the Godlowski transformation. Galaxy clusters do not show an obvious alignment when looking at pictures, so statistical analysis is needed to check preferred alignments. In this work, we used the chi-square, First order Fourier and auto- correlation test. For statistical computations MICROSOFT OFFICE EXCEL 2009 and ORIGIN 5.0 was used for the

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all sky distribution of galaxies whereas for the redshift and magnitude distribution of galaxy ORIGIN 8.0 was used.

Results and Discussion

All sky distribution of the 1,172 galaxies in the Supercluster SDSS CGG 3498 and marker galaxy is shown in figure 1. We expect homogeneous distribution of galaxies according to cosmological principle. But the inhomogeneous distributions of the galaxies can be observed in the figure 1. As we observed the All-Sky plot of Supercluster in the figure 1, various galaxy-rich regions can be noticed (forming substructure region). We used counting algorithm (as described in galaxy counting code) to study galaxy concentration in various regions of all-sky plot of Supercluster and presented it as contour plot. In some region more galaxies are found to be concentrated forming substructure region.

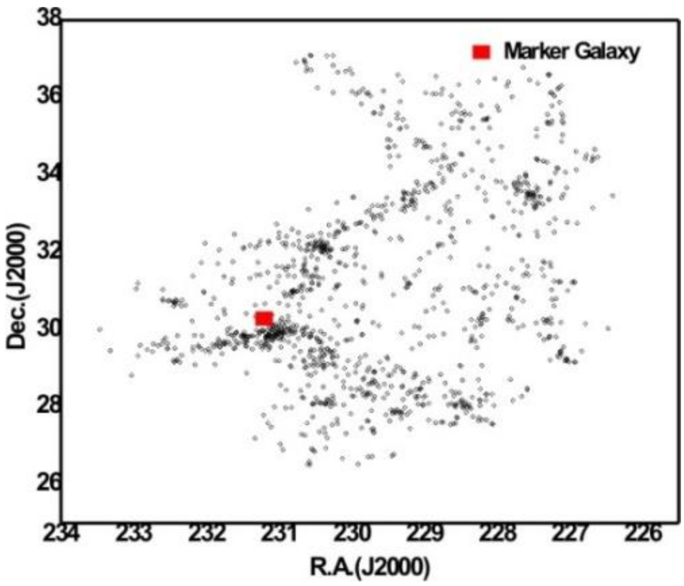

Figure 1: All Sky distribution of galaxies in the SDSS CGG 3498.

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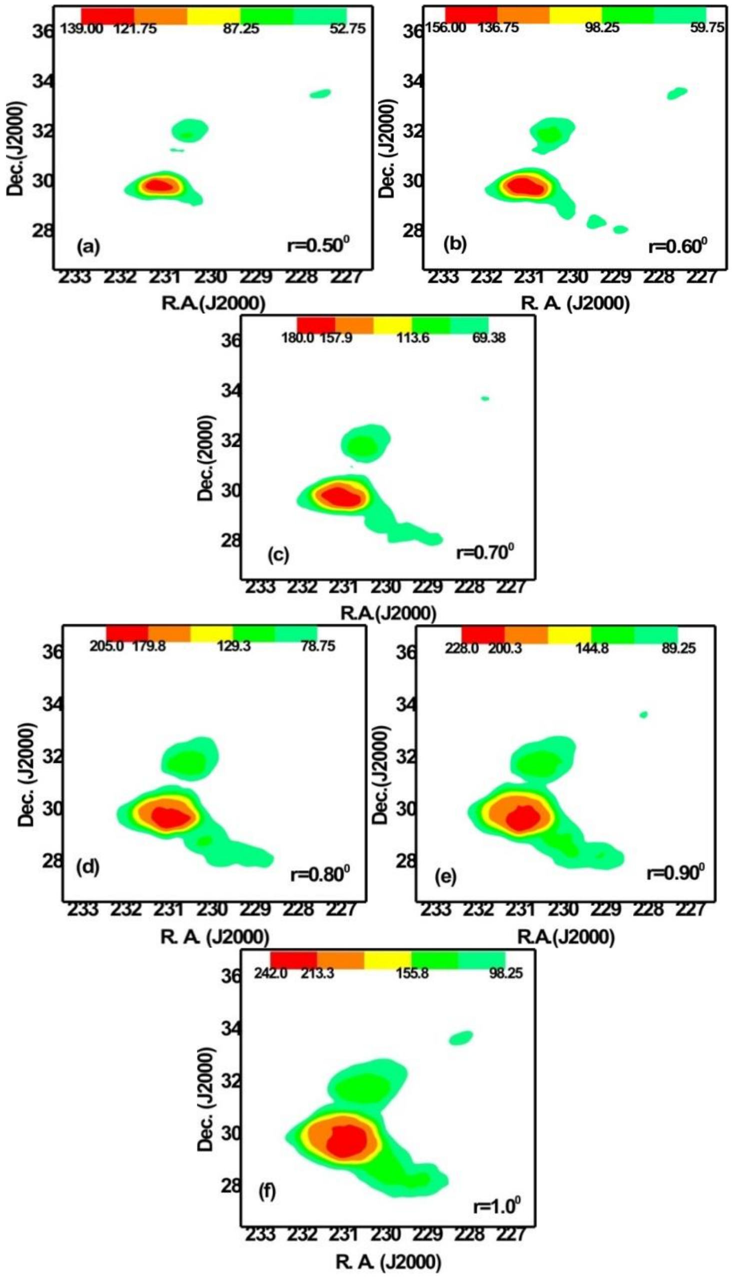

Figure 2: Contour plots of galaxy number for various radius of counting bin in SDSS CGG 3498. In above figure, a, b, c, d, e and f represent the contour map with radius values 0.50°,0.60°, 0.70°, 0.80°, 0.90°and 1.0° respectively. The contour levels are shown; X-axis and Y-axis represent right ascension and declination.

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In the figure 2a, we can see that the substructures cannot be visualized properly for counting bin of radius 0.50° due to presence of several smaller clumps. On changing the size of the circle, the pattern of the substructure seems somehow similar (Figure 2b and c). At radius 0.80°, two prominent substructures arise in figure 2d. At radius 0.90°and 1.0°, those substructures starts overlapping and become difficult to distinguish in figure 2e and f. So, we selected the appropriate radius of counting bin to be 0.80°. Now we have proceed the statistical tests on these two substructures by neglecting those galaxies does not include at least 70 galaxies and found galaxy number 224 and110 for S1 [231+030+0117] and S2[231+030+0117] respectively.

We studied a distribution of the polar (θ) and azimuthal (ϕ) angle of galaxy rotation in SDSS CGG 3498 and then its substructures and noticed random effect in the spatial orientation of spin vectors of galaxies with respect to equatorial coordinate system By using statistical tests like chi-square probability ($P > \chi^2$), autocorrelation coefficient (C/C (σ)), first order Fourier coefficient ($\Delta_{11}/ \sigma(\Delta_{11})$) and first order Fourier probability ($P > \Delta_1$) for statistically determining alignments of galaxies in our samples. The condition for anisotropy, the limit of chi-square probability $P (>\chi^2)$ is <0.050, auto correlation coefficient (C/C (σ)) is>1.0, first order Fourier coefficient ($\Delta_{11}/ \sigma (\Delta_{11})$) is>1.5and Fourier probability $P (>\Delta_1)$ is <0.150 respectively as used by Godlowski [1993, 1994].

Furthermore, the result is not only based on statistical tests, but also performs the preferences of` humps' (bins with more solutions than the expected) and `dips' (bins with less solutions than the expected)in the polar and azimuthal angle distributions of galaxies. The statistics of polar angle (θ) and azimuthal (ϕ) angle distribution of galaxies in this SDSS CGG 3498 are given in Table 1.

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Table 1: Statistics of the polar (Θ) and azimuthal (ϕ) angle distributions of galaxies in the SDSS CGG 3498.The first column lists the sample, the second column represents the chi-square probability P ($>\chi^2$),the third column represents first order Fourier coefficient (Δ_{11}/ σ (Δ_{11})) and the last two columns give first order Fourier probability P ($>\Delta_1$) and auto-correlation coefficient (C/C (σ))

Sample	**(P ($>\chi^2$)**	**(Δ_{11}/ σ (Δ_{11}))**	**P ($>\Delta_1$)**	**(C/C (σ)).**
Polar Angle				
SDSS CGG 3498	0.884	0.012	0.999	-0.601
S1[195 +028+0022]	0.227	0.100	0.994	-0.200
S2[176 +020+0023]	0.664	0.400	0.812	-0.300
Azimuthal angle				
SDSS CGG 3498	0.779	0.181	0.905	-0.077
S1[195 +028+0022]	0.873	-0.100	0.898	-0.500
S2[176 +020+0023]	0.504	-0.100	0.919	-0.900

In the polar angle (θ) distribution, Table 1 shows that chi-square probability (P ($>\chi^2$) to be 0.884(greater than the significant level 0.050). The first order Fourier coefficient ($\Delta_{11}/\sigma(\Delta_{11})$) is found to be 0.012 (negligibly smaller than the limit 1.5σ). The first order Fourier probability (P>(Δ_1)) is found to be 0.999 i.e. (greater than 0.15 limit).The auto-correlation coefficient (C/C (σ)) is found to be -0.601 (Smaller than 1σlimit). All these statistics shows strong isotropic distribution. Hence we can conclude that there is no preferential orientation of spin vectors of galaxies in the SDSS CGG 3498.

The statistics for the azimuthal angle (ϕ) distribution (Table 1) shows that the value of chi-square probability (P ($>\chi^2$)) to be 0.779, which is more than the significant level 0.050. The first order Fourier coefficient (Δ_{11}/σ (Δ_{11})) is 0.181 which is less than the limit 1.5σ, and the first order Fourier probability (P> (Δ_1)) is 0.905 (i.e., more than 0.150). The value of auto-correlation coefficient (C/C (σ)) is found to be -0.077 (smaller than 1σlimit). All these statistical tests support isotropy.

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In the small angle region $\Theta < 45^0$, there are two dips at an angle 22.5^0,$42.5^0$and two humps at an angle 28.5^0, 32.50with 1.5σ and 1σ error limit (Fig. 5a). For large angles region ($\Theta > 45^0$), one significant hump at an angle $52.5^0$with 1.5σ error limit. Thus, these results suggest that galaxy evolution in SDSS CGG 3498 supports random orientation of galaxies. This model predicts that galaxies were formed from clustering. In Fig 5(b), in the small angle region ($\phi < -45^0$) and for the range between($+45^0 < \phi > -45^0$) is found no significant 'hump' and 'dip'. The hump present at 85^0, which is due to the local effect. There is no significant humps or dips at smaller angle ($\phi < -45^0$). Thus, all these support isotropy.

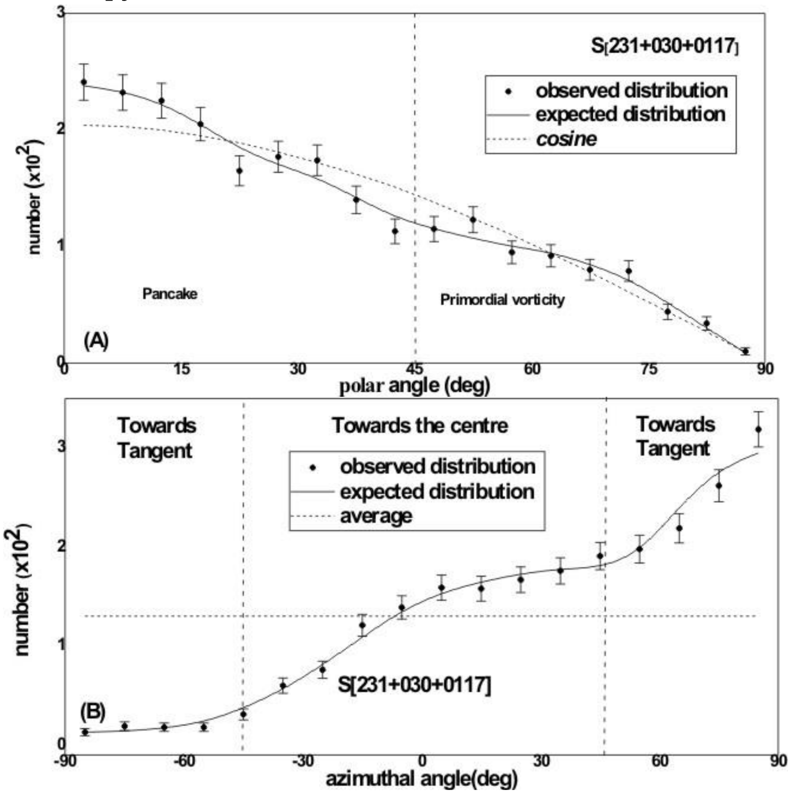

Figure 3: (a) The polar (θ) and (b) azimuthal (ϕ) angle distributions of galaxies in the Supercluster SDSS CGG 3498. The solid line represents the expected isotropic distributions. The dash lines represent the cosine and average distributions respectively. The solid circles with ±1σ error bars are represent the observed distribution.

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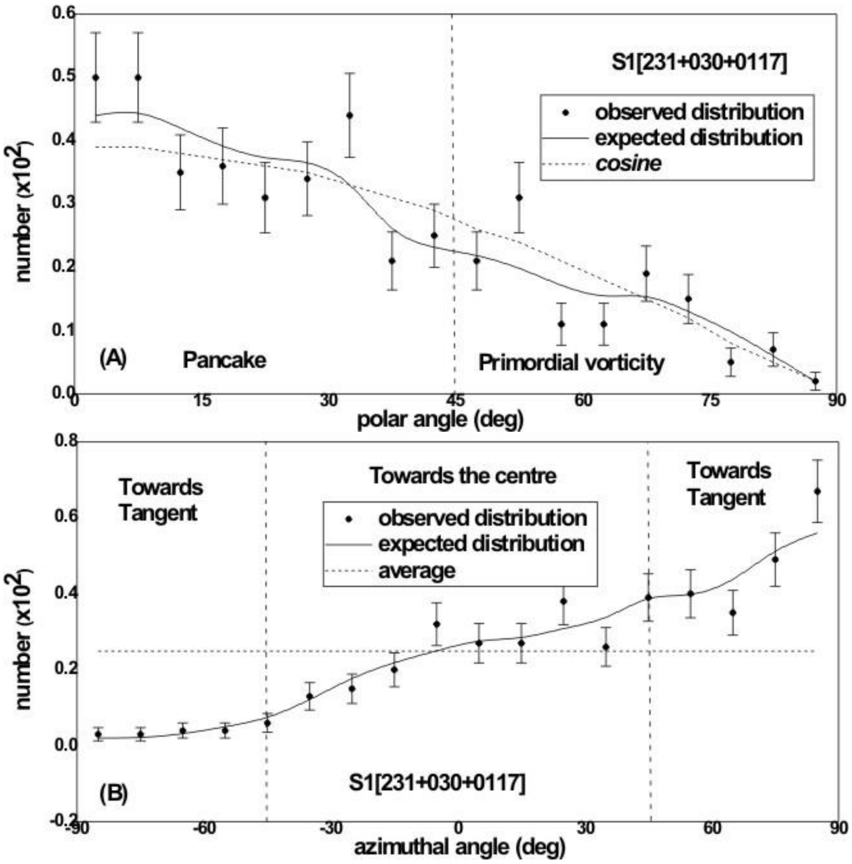
Thus, these 'humps' and 'dips' suggest the possibility of grouping or sub-clustering because of the tidal or gravitational shearing effects between the co-moving galaxies.



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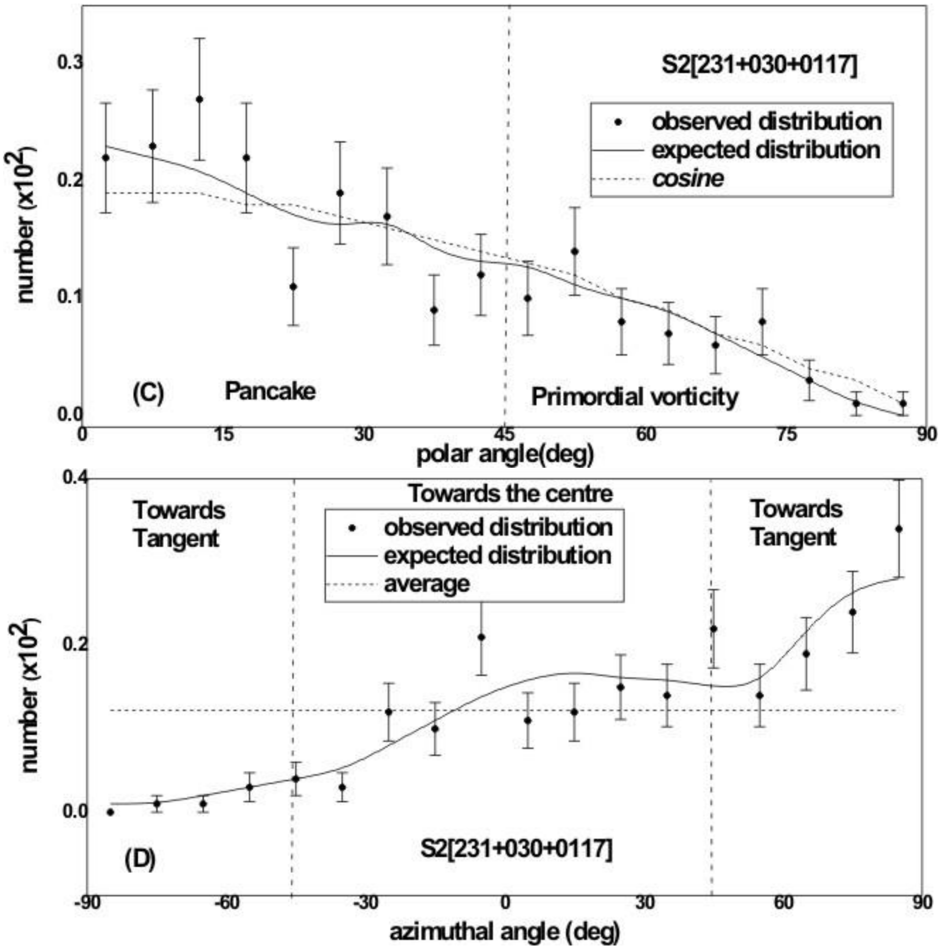

Figure 4: Polar (a, c) and azimuthal angle (b, d) distributions of galaxies in the substructures of Supercluster SDSS CGG 3498. Solid circles with statistical error bars (±1σ) represent observed distributions. The expected distributions are represented by solid curves

The substructure S1 [231+030+0117] has 224 galaxies. The statistical values for the polar (θ) distribution is shown in Table 1.the value of chi-square probability (P $(>\chi^2)$) is found to be 0.227 and the first order Fourier coefficient (Δ_{11}/σ (Δ_{11})) is found to be 0.100. In addition, the first order Fourier probability (P> (Δ_1)) is 0.994 more than significant level 0.150and the value of auto-correlation coefficient (C/C (σ)) is-0.200less than **1**σ level. Thus, all these statistics suggest isotropy.

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The statistics for azimuthal angle (ϕ) distribution are shown in Table 1, the value of chi-square probability (P ($>\chi^2$)) is 0.873, more than the significant level 0.050,the first order Fourier coefficient (Δ_{11}/σ (Δ_{11})) is -0.100 less than the error limit 1.5σ,the first order Fourier probability (P> (Δ_1)) is found to be 0.898 more than significant level 0.150 and the value of auto-correlation coefficient (C/C (σ)) -0.500 less than 1σ level. Thus, all these statistical tests suggest isotropy.

In the small angle region ($\theta < 45^0$),there is one hump at 32.5° with error limit1.5σ and two dips at 12.5° and 22.5° with 1σ and 1.5σ error limits are seen (Fig. 6a). At large angles ($\theta > 45^0$), there is one significant hump observed at an angle of 52.5° with an error limit of 2σ. Also, there are three effective dips at angles 57.5°, 62.5° and72.5° with 2σ, 1.5σ and 2σ error limits, respectively. These humps and dips observed in the polar angle distribution are due to the local effect. In Fig. 6b, there are no significant humps and dips are observed in the small-angle region ($\phi < 45^0$), for the range between ($+45^0 < \phi > -45^0$), there are two humps at an angles-5° and 25° within error limit 1σ and one dip at an angle 35° within error limit 1.5σare seen. For large angles region ($\phi > 45^0$), one hump at an angle 85° and one dip at an angle 65° within 1.5σ, error limit are observed due to some local effects. Overall, there is no preferred alignment of the spin vectors of galaxies is noticed in azimuthal angle distribution.

This substructure S2[231+030+0117] showed 110 galaxies. The statistics for polar angle (Θ) distribution is shown in Table 1. The value of chi-square probability (P ($>\chi^2$)) is found to be0.664 more than the significant level 0.050,the first order Fourier coefficient (Δ_{11}/σ (Δ_{11})) is 0.400 less than the error limit1.5σ, the first order Fourier probability (P> (Δ_1)) is 0.812 greater than significant level 0.150 and the value of auto-correlation coefficient (C/C (σ)) is -0.300 less than 1σ level. Thus, all these statistics advocate strong isotropy. The statistics for azimuthal angle (ϕ)distribution is shown in Table 1, the value of chi-square probability(P ($>\chi^2$)) is 0.504 greater than the significant level 0.050,the first order Fourier coefficient (Δ_{11}/σ (Δ_{11})) is -0.100 less than the error limit 1.5σ, the first order Fourier probability (P> (Δ_1)) is 0.919 more than significant level 0.150 and the value of auto-correlation coefficient (C/C (σ)) obtains -0.900 less than 1σlevel. Here, all these statistics suggest strong isotropy in the ϕ-distribution.

The region of small-angle ($\theta < 45^0$), there is one significant hump at an angle 12.5^0 with 1.5σ error limit and two dips at an angle 22.5^0 and 22.5^0 with 2σ error limit, are observed (see Fig. 6c). For the large angles region ($\Theta > 45^0$), no significant humps and dips, are observed. In this region, small humps, and dips, are seen due to the local effect. Thus, no preferred alignment of the spin vectors of galaxies is found in polar angle distribution. In Fig. 6d, no significant humps, and dips, are seen in the small-angle region ($\phi < 45^0$).For the range between ($+45^0 < \phi > -45^0$), two humps at an angle -25^0 with 1σ error limit and at -5^0 with 1.5σ error limit, are observed. Further, three dips at an angles -35^0,5^0 and 15^0 with 1σ, 1.5σ and 1.5σ, error limits, are observed in this region. In the bimodal region $\phi \sim 45^0$, one significant hump with an error limit of 1.5σ is seen. For the larger angle region ($\phi > 45^0$), no significant dips are observed but one significant hump is observed at 85^0. This is due to binning effects. Thus, no preferred alignment is noticed in the azimuthal angle distribution.

Conclusion

We converted two-dimensional given parameters (R.A., Dec., and equatorial PA) into three-dimensional (spin vectors or polar/azimuthal angles) parameters using axial ratios (b/a) and intrinsic flatness (q*) of galaxies. For this, we adopt the method described by Flin & Godlowski (1986) and calculated the polar (θ) and azimuthal (ϕ) angles of galaxies. The selection effects are removed and the expected isotropic distribution curves are determined using the numerical simulation by creating 10^7 virtual galaxies. With the help of density distribution contour, identified two distinct substructures. We study the spatial orientation of angular momentum of galaxies in cluster group SDSS CGG 3498and its two substructures S1 [231+030+0117] and S2 [231+030+0117]. We conclude our results as follows:

1. We found that the galaxy spin orientation is random and isotropic in SDSS CGG 3498 cluster groups.
2. Density fluctuation method showed two substructures in the region of galaxy cluster groups.
3. Both substructures showed no preference in the alignments of angular momentum of galaxies.

Our result suggests that the group of clusters of galaxies support hierarchy model (Peebles, 1969) of galaxy formation.

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