Abstract We present the analysis of the spin vector orientation of 5987 SDSS galaxies having negative redshift from $-87.6$ to $-0.3$ km s$^{-1}$. Two dimensional observed parameters are used to compute three dimensional galaxy rotation axes by applying ‘position angle–inclination’ method. We aim to examine the non-random effects in the spatial orientation of blue-shifted galaxies. We generate $5 \times 10^6$ virtual galaxies to find expected isotropic distributions by performing numerical simulations. We have written MATLAB program to facilitate the simulation process and eliminate the manual errors in the process. Chi-square, auto-correlation, and the Fourier tests are used to examine non-random effects in the polar and azimuthal angle distributions of the galaxy rotation axes. In general, blue-shifted galaxies show no preferred alignments of galaxy rotation axes. Our results support Hierarchy model, which suggests a random orientation of angular momentum vectors of galaxies. However, local effects are noted suggesting gravitational tidal interaction between neighboring galaxies.

Keywords galaxies: evolution – galaxies: formation – galaxies: statistics – galaxies: blue shift

1 Introduction

It is commonly believed that the blue-shifted galaxies are relatively nearby ones whose peculiar motion overcomes the Hubble flow. All of the most distant galaxies (and indeed the overwhelming majority of all galaxies) are red-shifted. According to the conventional definition, the redshift of galaxies is the sum of two terms: the isotropic cosmic expansion velocity and the peculiar velocity owning to gravitational attraction by the surrounding matter. In practice, determining the peculiar velocity of a galaxy requires knowledge of both its observable radial velocity relative to some reference system and the distance to the galaxy determined independently of the radial velocity. According to the linear theory of gravitational instability, the peculiar velocities of galaxies are related to fluctuations in the mass (Peebles 1980).

Burbidge & Demoulin (1969) first observed IC 3258 with a blueshift of $-490$ km s$^{-1}$. They give three possible interpretations of their observations. First, IC 3258 is a member of the Virgo cluster and has a very high velocity relative to the average for the cluster. Second, IC 3258 is a field galaxy closer to the Virgo cluster and its large velocity is just a random motion. Third, IC 3258 has velocity because it has been ejected in an outburst involving one of the radio galaxies in the Virgo cluster. Several other blue-shifted galaxies appear in the direction of the Virgo cluster.

By measuring the distance $d$ of a galaxy, one can obtain the peculiar velocity of a galaxy $V_{pec} = V_{obs} - H_0 d$, where $H_0 d$ is Hubble expansion velocity, $V_{obs}$ is observed velocity of the galaxy. Since the Hubble expansion velocity is small for nearby galaxies, the peculiar velocity could be negative. Negative peculiar velocities are seen all over the region around the Virgo cluster and this have long been seen as a reflex of the pull of the cluster on us (Aaronson et al. 1982). We live in the Local Supercluster, which is overdense part of the Universe. So there is possibly the a local retardation of the cosmic expansion or a net infall within this region. In another example, an observer living on the outskirts of a large concentration when the radiation propagates inside the collapsing body it is blue-shifted. If this blueshift is greater than the redshift caused by the propagation of the radiation through expanding universe, distant observer can detect the gravitational blueshift from the collapsing object.
Also the AGNs have blue-shifted spectrum. Bian et al. (2005) studied the radial velocity difference between the narrow emission-line components and of [O III] $\lambda$ and H$\beta$ in a sample of 150 SDSS narrow-line Seyfert 1 galaxies. They found seven ‘blue outliers’ with [O III] blueshifted by more than 250 km s$^{-1}$. They interpreted the blueshift as possible result of the outflowing gas from the nucleus and the obscuration of the receding part of the flow by an optically thick accretion disk and on the viewing angle.

Spatial orientation of angular momentum of blue-shifted galaxies (SDSS) has not been studied, so we are interested to carry out the spatial orientation of blue-shifted galaxies. An idea of the origin of angular momentum of galaxies is very important to understand the evolution of large scale structures of the universe. This paper is organized as follows: in Sect. 2 we describe the sample used and the method of data reduction. In Sect. 3 we describe the methods, statistical tools and the selection effects. Finally, a discussion of the statistical results and the conclusions are presented in Sects. 4 and 5.

2 Blue-shifted SDSS Galaxies

We compiled a database of 5,987 blue-shifted galaxies from The Sloan Digital Sky Survey seventh Data Release (SDSS DR7). All sky distribution of blue-shifted galaxies is shown in Fig. 1a. The inhomogeneous distribution of galaxies is because of the nature of the survey. The distribution of blue-shifted galaxies is shown in Fig. 1b. We found a linear relationship between the blue-shift and logarithm of the number of galaxies $(-z \times \log(N))$. We have retained only those galaxies that have blue-shift $(z < -2)$ data at 95% level of significance. This removed 569 galaxies form the original data. Since blue-shift is found to be decreases lineally with number (Fig. 1b), the remaining 4,595 galaxies were classified into three bins by considering the bin size of 1\times10^{-4}. This resulted in three bins with number of galaxies roughly in the ratio of 3 : 2 : 1 in the largest, medium and the smallest bins respectively. In the binning process, galaxies that have very low and high blue-shift values were also removed.

Since our galaxies are blue-shifted, their apparent magnitude increases with time. In order to check the effect of blue-shift on preferred alignments, we have chosen two extreme filters: infrared ($i$) and ultraviolet ($u$). The wavelengths of SDSS $i$ and $u$ filters are 7,625 $\AA$ and 3,543 $\AA$, respectively. The true magnitudes of $i$ filter lies in the far-infrared and $u$ in the visual bands. The study of far-infrared and optical activity in the galaxy gives information regarding the early star formation activity and the HII region, respectively. Fig. 1c,d shows the magnitude distribution of near infrared and ultraviolet galaxies. For both, Gaussian distribution fits well with the observed distribution.

In order to find angular momentum vectors (or spin vectors, SV hereafter), the diameters, position angles and directions of the galaxy in the celestial plane should be known. We have compiled the database of diameters and position angle of galaxies using SDSS survey.

3 Method of analysis

We follow the method suggested by Flin & Godlowski (1986) to convert two dimensional parameters (positions, diameters, position angles) of the DR7 SDSS blue shifted galaxies into three dimensional parameters (galaxy rotation axes in spherical polar coordinates). The expected isotropic distribution for angular momentum vectors or SVs of galaxies are determined by using the method proposed by Aryal & Saurer (2000). The observed and expected distributions are compared with the help of three statistical tests namely chi-square, auto-correlation and the Fourier.

3.1 Observed distribution: SVs of galaxies

The two-dimensional SDSS parameters (positions, position angles and diameters) are converted into polar ($\theta$) and azimuthal ($\phi$) angles of galaxies using Flin & Godlowski (1986). Our blue-shifted galaxies have negative radial velocities probably due to their larger peculiar velocity. These galaxies are mostly nearby galaxies. Thus, it is convenient to use galactic coordinate system as a physical reference plane. The formulae to obtain $\theta$ and $\phi$ in are as follows (Flin & Godlowski, 1986):

$$\sin \theta = -\cos i \sin b \pm \sin i \sin p \cos b$$

(1)
\[
\sin \phi = (\cos \theta)^{-1}\left[ -\cos i \cos b \sin l \\
+ \sin i (\mp \sin p \sin b \sin l \mp \cos p \cos l) \right]
\]  

where \( l, b \) and \( p \) are the galactic longitude, latitude and position angle, respectively. The \( i \) represents the inclination angle, obtained using Holmberg’s (1946) formula:

\[
\cos^2 i = \left[ \frac{(b/a)^2 - q^2}{1 - q^2} \right]
\]

where \( b/a \) is the measured axial ratio and \( q \) is the intrinsic flatness of disk galaxies. The method of determination of intrinsic flatness of galaxies is the same as in Aryal et al. (2013).

The above formulae show that there are two possible solutions for a given galaxy. The normals \( N_1, N_2, N_3, N_4 \) shown in Fig. 2 can not be determined unambiguously, because we do not know the side of the galaxy which is nearer/far to us, and the direction of rotation. Thus, there are four solutions of the SV orientation for a galaxy. We count all four possibilities independently in our analysis.

3.2 Expected distribution: numerical simulation

Aryal & Saurer (2000) studied the effects of various types of selections in the database and concluded that such selections may cause severe changes in the shapes of the expected isotropic distribution curves in the galaxy orientation study. Their method has been applied by several authors in galaxy orientation studies (Hu et al. 2006, Aryal et al. 2013 and the references therein). Two kinds of selection effects are noticed in our database: (1) inhomogeneous distribution of positions of galaxies, and (3) less number of high inclination (edge-on) galaxies. These selection effects are removed and the expected isotropic distribution curves (\( \theta \) and \( \phi \)) are determined using the numerical simulation method as proposed by Aryal & Saurer (2000). For this, a true spatial distribution of S of galaxies is assumed to be isotropic. Then, due to the projection effects, \( i \) can be distributed \( \propto \sin i \), latitude can be distributed \( \propto \cos b \), the variables longitude \( (l) \) and PA can be distributed randomly, and formulae (1) and (2) can be used to simulate (numerically) the corresponding distribution of \( \theta \) and \( \phi \). The isotropic distribution curves are based on simulations including \( 10^7 \) virtual galaxies. The simulation procedure is described in Aryal & Saurer (2004). We perform numerical simulation with respect to galactic coordinate system systems. These expected isotropic distribution curves are compared with the observed distribution.

3.3 Statistical tests

Our observed \( \theta \) and \( \phi \)-distributions are compared with expected isotropic distribution curves. For this comparison we applied chi-square, autocorrelation and the Fourier (Godlowski 1993) tests. These tests are described in the appendix of Aryal et al. (2007). These statistical tests are a proper method in our case, because \( \theta \) and \( \phi \) are
independent data. The null hypothesis is established to be an equidistribution for the $\theta$ and $\phi$.

4 Results

We have classified our database into six subsamples on the basis of their redshift values and $u$ & $i$-magnitudes. Here we discuss the distribution of the polar ($\theta$) and azimuthal ($\phi$) angles of galaxy rotation axes in each subsamples. We study the spatial orientation of SVs of galaxies with respect to the galactic coordinate system. Any deviation from the expected isotropic distribution will be tested using four statistical parameters, namely the chi-square probability ($P(\chi_2^2)$), auto-correlation coefficient ($C/C(<\sigma'>$)), first order Fourier coefficient ($\Delta_{11}/\sigma(\Delta_{11})$), and first order Fourier probability ($P(\Delta_1)$). The conditions for anisotropy are the following: $P(\chi_2^2)$ < 0.050, $C/C(<\sigma'>$) > 1, and $P(\Delta_1)$ > 0.150. These statistical limits were proposed by Goddowski (1993, 1994). In the $\theta$-distribution, a positive (negative) $\Delta_{11}$ suggests that the SVs of galaxies tend to orient parallel (perpendicular) with respect to plane of the Milky Way. In the $\phi$-distribution, a positive (negative) $\Delta_{11}$ suggests that the SV projections of galaxies tend to point radially (tangentially) with respect to center of the Milky Way. Any ‘humps’ or ‘dips’ in the histogram will be discussed. Here ‘hump’ and ‘dip’ are defined as having more or less observed solutions than expected respectively.

4.1 Polar angle distribution

All three statistical tests suggest isotropy in the $\theta$ distribution of subsample $i01$ (Table 1). The galaxies in this subsample are nearby blue-shifted (RV < -28.5 km s$^{-1}$) having $i$-magnitude in the range 12.45 and 32.08. In the histogram, no significant humps or dips can be seen (Fig. 3a). Thus, a random orientation of angular momentum vectors of galaxies is found, suggesting hierarchy model of the structure formation as suggested by Peebles (1969).

Fig. 3 The polar ($\theta$) angle distributions of blue shifted SDSS galaxies in 6 subsamples. The solid circles with ± 1σ error bars represent the observed distribution. The solid line represents the expected isotropic distributions. The cosine distributions (dashed) are shown for the comparison.

The galaxies in the subsample $i02$ are moderately blue-shifted (RV: 28.5-58.5 km s$^{-1}$ and $m_i$: 10.46 - 36.10). The chi-square and the correlation tests show anisotropy (Table 1). However, the first order Fourier probability and the first order Fourier coefficient suggest isotropy. Since the observed distribution follow the expected, we regard the Fourier test as more reliable. There are small dips at 5°, ∼ 65°, and a hump at 15° (Fig.3b). These are possibly due to the binning effect.

Strong blue-shifted (RV: ≥58.5 km s$^{-1}$) SDSS galaxies ($m_i$: 10.82 - 42.23) are grouped in the subsample $i03$. In the histogram, a very good agreement between the observed and expected distributions can be seen. Similarly the subsample $i03$, chi-square probability and correlation coefficient show anisotropy, whereas first-order Fourier probability and the first-order Fourier coefficient suggests isotropy (Table 1). Several humps (0°, 45°, 60°) and dips (30°, 35°, 60°) suggests the local effect. Thus, the strong blue-shifted infrared galaxies are in the process of grouping or subclustering because of the tidal or gravitational shearing effect.

All three statistical tests support isotropy in $\theta$ distribution of $u$-magnitude low blue-shifted (RV < 58.5 km s$^{-1}$) galaxies. In Fig. 3d, no significant humps or dips are found. A small hump at 20° and a dip at 60° are because of the binning effects. These effects do not change the statistics of the subsample $u01$. Hence, no preferred alignments of SVs of galaxies in subsample $u01$ is noticed.
In subsample u02, all three statistics show isotropy in polar angle (θ) distribution. A small dip at 10° is because of the binning effect (Fig. 3c). A random orientation of SVs of galaxies is noticed in this subsample.

All statistics except correlation coefficient showed isotropy in the polar angle distribution of high blue-shifted (RV ≥ 58.5 km s⁻¹) u-magnitude galaxies (subsample u03). The correlation coefficient is found to be 1.8 (>1.5σ level). This is because of the humps at 10°, 45°, 55° and dips at 15°, 20°. These humps and dips suggest the possibility of grouping or subclustering because of the tidal or gravitational shearing effects between comoving galaxies.

To sum up, the spatial orientation of blue-shifted galaxies is found to be random, supporting hierarchy model (Peebles 1969) of structure formation. It is found that the rapidly moving blue-shifted galaxies are in the process of large structure (galaxy groups, subclusters, clusters, etc) formation. In addition, magnitude is found to be independent of the preferred alignments.

4.2 Azimuthal angle distribution

All three statistics support isotropy in the azimuthal angle distribution of low blue-shifted high magnitude infrared (subsample i01) galaxies (Table 2). There is a hump at +65° and dips at −5° and −55° (Fig. 4a). These are due to the binning effect and hence do not change the statistics. Thus, no preference is noticed for spin vector projections of low blue-shifted infrared galaxies.

All statistics except χ²-test suggest anisotropy in the φ distribution of the subsample i02. In the histograms for the φ-distribution of the subsample i02 (Fig. 4b), humps at −60°, +30° and +90°, and dips at −50° to +20° can be seen. These humps and dips lead this subsample to show anisotropy. The spin vector projection of i02 galaxies is found to be directed tangentially outwards with respect to the center of the Milky Way. Fig. 4c shows the distribution of the spin vector projections of high blue-shifted galaxies (subsample i03). Similar to the subsample i02, all statistical parameters except P(> χ²) show anisotropy. There is a significant hump at +90° and dips at −10° and 0°. The SV projections of high blue-shifted galaxies is found to be oriented tangentially with respect to the center of the Milky Way.

All statistics except C/C(σ) show anisotropy in the φ-distribution for subsample u01. In the histogram, several humps and dips can be seen: humps at −90° and +80°, and dips in the region from −50° to +50° (Fig. 4d). This subsample showed isotropy in the polar and anisotropy in the azimuthal angle distribution. This inconsistency is because of the inappropriate reference coordinate system. A physical reference system should be identified in the future.

Fourier test suggests isotropy in the subsample u02. There are dips at −40°, +20° and a hump at +90° (Fig. 4e). We observe weak anisotropy in the spin vector projection of u02 galaxies with respect to galactic coordinate system.

Interestingly, all statistics show isotropy in the distribution of SV projections of high blue-shifted galaxies (u03). There are small dips at 70° and 40°, not significant to alter the statistics of the subsample. There is a very good agreement between the observed and expected distributions (Fig. 4f). Thus, a random orientation of spin vector projections is found.

4.3 Discussion

In the numerous past literatures authors have studied the spatial orientation of red-shifted galaxies in the field, clusters and Superclusters and found mixed result: (1) noticed anisotropy supporting either ‘pancake model’ (Flin & Godlowski 1986; Godlowski 1993, 1994; Godlowski, Baier & MacGillivray 1998, Flin 2001) as suggested by
The azimuthal ($\phi$) angle distributions of blue shifted SDSS galaxies in 6 subsamples. The solid circles with $\pm 1\sigma$ error bars represent the observed distribution. The solid line represents the expected isotropic distributions. The average distributions (dashed) are shown for the comparison.

In addition to these scenarios a bimodal tendency (Kashikawa & Okamura 1992), local anisotropy (Flin 1995, Djorgovski 1983, Aryal & Saurer 2004, 2005b), global anisotropy (Parnovsky, Karachentsev & Karachentseva 1994) are noticed. Godlowski & Ostrowski (1999) noticed a strong systematic effect, generated by the process of deprojection of a galactic axis from its optical image. In isolated Abell clusters, only brightest galaxies are preferentially aligned (Trevese, Cirimele & Flin 1992). Panko et al. (2013), Godlowski (2012) and Godlowski et al. (2010) noticed a dependence of alignment with respect to cluster richness.

The anisotropy is found mostly for those samples which is taken from a limited region of the sky (e.g., clusters, sub-clusters, groups, etc). For the field galaxies and superclusters, i.e., the database taken from the large scale structure, authors notice a random orientation supporting hierarchy model. In both the cases (isotropy or anisotropy), a local effect is noticed. This effect might arises due to the tidal connections between the neighboring galaxies or because of the gravitational shearing effect. Interestingly, blue-shifted galaxies support hierarchy model. Thus, it can be concluded that the blue-shift is not different cosmological effect, it is because of the peculiar velocity as suggested by Aaronson et al. (1982).

5 Conclusion

We studied the spatial orientation of spin vectors of 5 987 blue-shifted galaxies ($-87.6$ to $-0.3$ km s$^{-1}$) observed through $i$- and $u$-filter. These database were taken by SDSS ($7^{th}$ data release). We classified our data into 6 subsamples based upon their blue-shift. We have used the ‘PA-inclination’ method proposed by Flin & Godlowski (1986) to convert two dimensional observed parameters to three dimensional galaxy rotation axes (polar and azimuthal angles) and carried out random simulation by creating $5\times10^6$ virtual galaxies in order to remove selection effects from the database (Aryal & Saurer 2000). To check for anisotropy or isotropy, we have carried out three statistical tests: chi-square, auto-correlation and the Fourier.

Since our observed distributions do not vary significantly from the expected distribution, we have regarded the Fourier test as more reliable. The local effects are examined by the correlation test. We have taken $\chi^2$ test in order to check the binning effect. In general, we found isotropic distribution of the spin vector of galaxies in all six subsamples with respect to the galactic coordinate system. There are humps and dips in the polar angle distributions, and these humps and dips alter the correlation test showing anisotropy in subsamples i02, i03, and u03. Hence, local effect was observed in these subsamples suggesting a local tidal connection between the rotation axes of neighboring galaxies or the gravitational shearing effect. However, in the rest of the subsamples

Doroshkevich (1973) or ‘primordial vorticity model’ (Baier, Godlowski & MacGillivray 2003) as proposed by Özer- noy (1978)(2) found isotropy suggesting a random orientation of spin vectors of galaxies supporting ‘hierarchy model’ (Bukhari & Cram 2003; Aryal & Saurer 2005a, Aryal et al. 2006, 2012, 2013) as recommended by Peebles (1969).
(i01, u01, and u02) small humps and dips do not alter the statistics of the total subsample, so we suppose these as binning effects. In general, we observe that there is no preferred alignment of spin vectors of galaxies. Our results of φ-distribution support the hierarchical clustering scenario (Peebles 1969), which predicts the random orientation of the directions of the spin vectors of galaxies.

On the other hand, we found interesting results for the θ-distribution. As mentioned above, we have regarded the Fourier test as more reliable. Out of six subsamples only two subsamples (i01 and u03) show isotropy in all tests. Rest of the subsamples (i02, i03, u01, and u02) show anisotropic distribution of the spin vector projections of galaxies. Also, all subsamples (except u03) have negative value of the first order Fourier coefficient Δ11. Therefore, in general the spin vector projection of the galaxies tend to be orientated perpendicular to the equatorial plane. However, this result needs to be examined by using other reference system such as Supergalactic coordinate system in the future.

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