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Is the orientation of the galaxies in the Local Supercluster related to its Plane?

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Abstract. Modern cosmological models predict a close correlation between the angular momentum orientation of galaxies relative to the large-scale structure of the Universe. In the landmark 2004 paper, based on a sample of 30 galaxies, it was shown that the direction of the rotation axes of edge-on galaxies is predominantly in the plane of the Local Supercluster, supporting the theory of galaxy angular momentum formation by tidal forces. In the last two decades, the sample of known Local Supercluster galaxies has increased 7–8 times, giving us hope to estimate the correlation more accurately. We test the orientation of edge-on galaxies with respect to the Local Supercluster plane as a function of their redshift, position, luminosity, and color. We did not find a statistically significant correlation in any of the subsamples we examined. Most likely, the correlation found in the pioneering paper is due to the extremely small statistics.

Keywords: galaxies: evolution; cosmology: large-scale structure of universe

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1 Introduction

The tidal-torque theory, developed in the works of Peebles (1969), Doroshkevich (1970), White (1984), describes the acquisition of angular momentum (spin) by proto-galaxies in the early Universe under the influence of tidal torques. Proto-galaxies form within the gravitational potential wells of dark matter halos in the cosmic web of filaments, sheets, and voids. As these proto-galaxies collapse, they experience gravitational torques from nearby mass concentrations, such as neighboring proto-galaxies and large-scale structures. The torque exerted by the tidal field causes the proto-galaxy to spin. The direction of this angular momentum is influenced by the surrounding large-scale structures. The main prediction of tidal-torque theory is that galaxy spins should be nearly perpendicular to the minor axis of the shear tensor associated with the distribution of the surrounding matter. In other words, the spin of a galaxy must be perpendicular to the axis of greatest compression of the element of the large-scale structure to which it belongs.

In this contex, the Local Supercluster is an ideal laboratory to test this hypothesis. This nearby supercluster is one of the most studied structures in the Universe. Due to the location of our Galaxy within the Local Sheet, the Local Supercluster clearly stands out in the distribution of nearby galaxies on the sky as a narrow band with a noticeable concentration of galaxies around the center in the Virgo cluster. This fact makes easy to identify the plane of the Local Supercluster, which is determined by the great circle of the Supergalactic coordinate system. Edge-on disk galaxies allow us to reliably determine the spin direction. For arbitrarily oriented galaxies, the determination of the inclination angle is burdened with large errors and ambiguities. The use of the edge-on galaxies further simplifies the problem, reducing it to the measurement of the position angle (PA) of the galaxy's major axis in the Supergalactic coordinates. Using this approach, Navarro et al. (2004) found that the planes of nearby edge-on disk galaxies are predominantly oriented perpendicular to the plane of the Local Supercluster, which is consistent with numerical models of galaxy angular momentum formation within the Fig. 1, taken from the paper Navarro et al. (2004), shows the well-defined excess of objects with PA $< 20^\circ$ for nearby galaxies with velocities $cz < 1200$ km/s.

Thanks to massive deep photometric and redshift surveys, the sample of known Local Supercluster galaxies has increased by at least an order since work by Navarro et al. (2004), allowing us to significantly improve the statistics and study correlations more precisely. In addition, new catalogs of edge-on galaxies have recently been published. All this allows us to use the approach proposed by Navarro et al. (2004) and to test the alignment of galaxy spins with respect to the plane of the Local Supercluster at a new level.

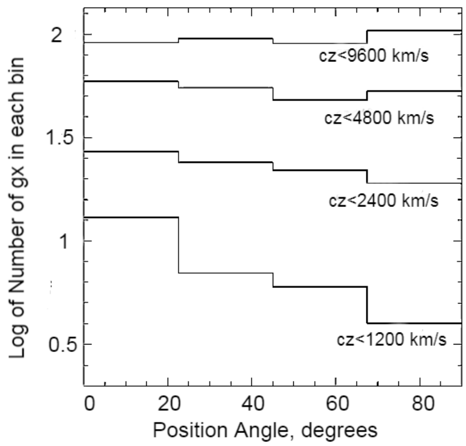

Fig. 1. Results from the article (Navarro et al. 2004).

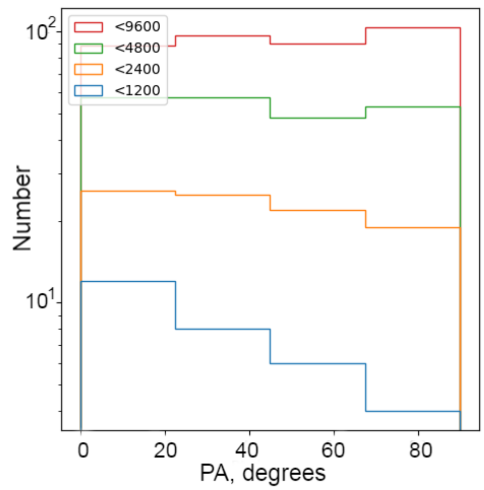

Fig. 2. Our reproduction of the results of (Navarro et al. 2004).

2 Sample

Our work is based on the catalog of 16551 Edge-on Galaxies In Pan-STARRS1 (EGIPS, Makarov et al. 2022), which is the largest list of edge-on galaxies to date. The Pan-STARRS1 survey (Pan-STARRS1, Chambers et al. 2019) covers three quarters of the sky above $\delta = -30°$. Due to the structure of the survey and the neural network used to search for galaxies, the EGIPS catalog may undercount the largest galaxies, as well as low surface brightness galaxies. To fill these gaps, we use the catalog of 5749 Edge-on Galaxies In SDSS (EGIS, Bizyaev et al. 2014). To update our sample, we manually checked all highly inclined $i > 85°$ near $cz_{\mathrm{LG}} < 4000$ km/s objects from the HyperLeda database (Makarov et al. 2014) to exclude false cases. Finally, our sample consists of 1986 edge-on galaxies, 230 of which are within $cz < 1200$ km/s, which is about 7.5 times larger than the 30 galaxies from the paper Navarro et al. (2004).

3 Analysis

We analyze the distribution of PA of the edge-on galaxies in the Supergalactic coordinates. We use the standard equations of spherical trigonometry to convert PA from the J2000.0 equatorial system to the Supergalactic one. We reduce PA to the

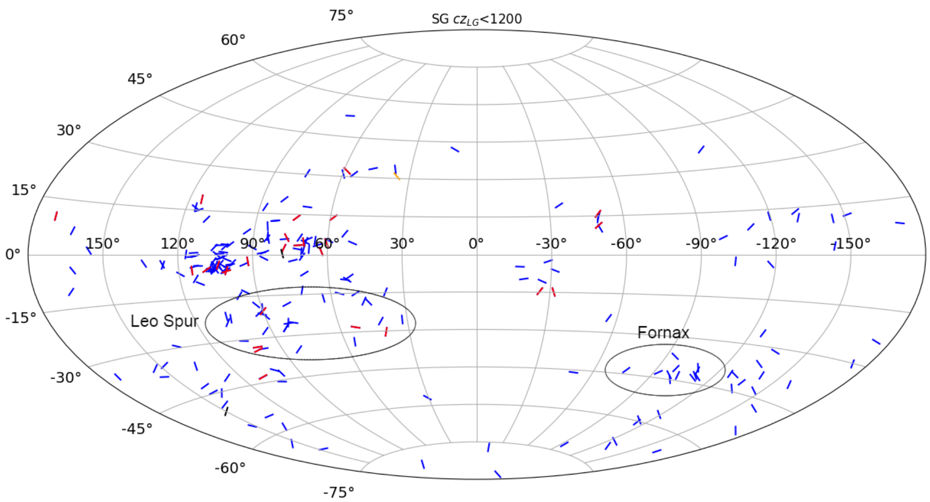

Fig. 3. Distribution of the close edge-on galaxies, $cz_{\rm LG} < 1200$ km/s in the Aitoff projection in the Supergalactic coordinates. The galaxy disk planes are indicated by dashes. The red, orange, and black dashes correspond to edge-on galaxies from the sample of Navarro et al. (2004). There are 27 reds in our sample, 1 orange falls in the range of $1200 < cz_{\rm LG} < 2500$ km/s, and 2 black are not in our samples.

range $[0°, 90°]$, since we are interested in the orientation with respect to the Local Supercluser plane, and in this sense the angles $\alpha > 90°$ and $(180° - \alpha)$ are equivalent.

First, to test our methodology, we replicated the sample from Navarro et al. (2004) as closely as possible, using the 1989 version of the Principal Galaxy Catalog (Paturel et al. 1989) and the prescription to identify spiral galaxies with an axis ratio $b/a < 0.175$ as edge-on oriented. As can be seen in Fig. 2, we can reproduce the original correlation well. The nearest galaxies, $cz < 1200$ km/s, show a well-defined tendency to be oriented perpendicular to the plane of the Local Supercluster.

The all sky distribution of the subsample of the closest, $cz_{\rm LG} < 1200$, edge-on galaxies indicating their orientations is plotted in Fig. 3. Most of the galaxies are concentrated within a 30° layer along the Local Supercluster plane. The concentration of edge-on galaxies in the Leo Spur and a near periphery of the Fornax Supercluster is also well defined. To our surprise, edge-on galaxies do not exhibit the expected prominent perpendicular orientation to the Local Supercluster plane.

The PA distribution for different subsamples of the edge-on galaxies is shown in Fig. 4. There is a clear peak at 90° in the EGIPS+EGIS subsample, but it disappears when HyperLeda galaxies are added. The main impression is that the distribution of galaxies across the PA is fairly uniform and show no statistically significant dominance in orientations.

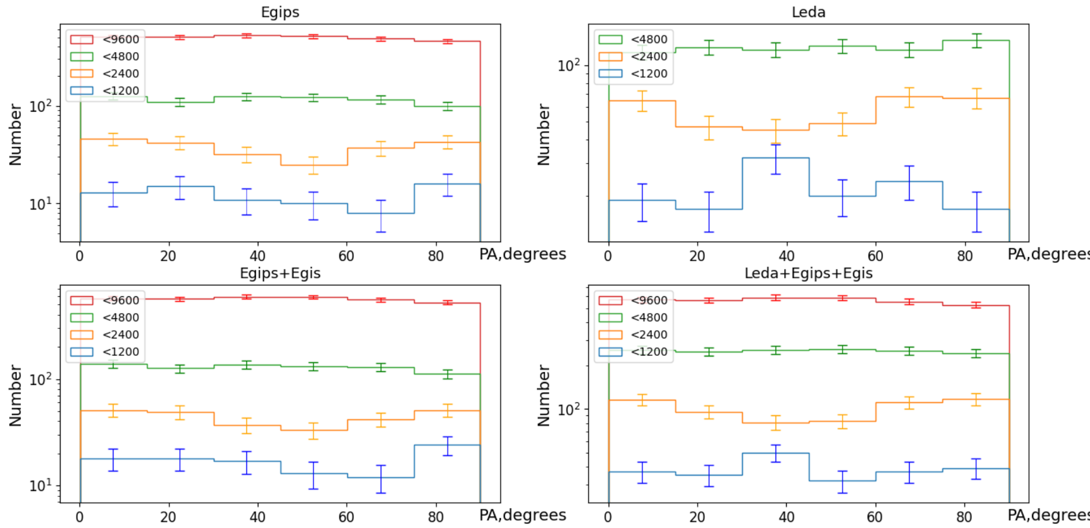

Fig. 4. PA distribution of edge-on galaxies in different subsamples at different scales.

Galaxies in the virial zone of a cluster should be randomized in their velocities, positions, and orientations. So we excluded the Virgo cluster galaxies within 6° of M 87 with velocities $cz_{\rm LG} < 3500$ km/s to cleanse the statistics from their influence. As in the previous case, the edge-on galaxies outside the virial zone show no obvious correlations or significant excess over the random distribution over PA.

We also tested different subsamples of edge-on galaxies for position, morphology, and luminosity. To identify galaxies taht belong exclusively to the Local Supercluster sheet, we considered four subsamples within $cz_{\rm LG} < 2500$ and $cz_{\rm LG} < 1200$ km/s, which lie within the ± 2 and ± 5 Mpc layers from the Local Supercluster plane. The virial zone of the Vigro cluster was excluded from consideration.

To account for galaxy morphology, we divide the sample into two equal parts of blue and red galaxies, and into faint and bright galaxies using the stellar mass. The $(g-i)_0$ color and the stellar mass, $\log M_*$, were taken from the 50 Mpc Galaxy Catalog (Ohlson et al. 2024).

We perform the one-sample Kolmogorov–Smirnov test under the null hypothesis that the PA are uniformly distributed. The test shows that the PA distributions of edge-on galaxies in all but one sample are not different from random at the $\alpha = 0.05$ significance level. The only exception is the case of small galaxies in the ± 2 Mpc layer of $cz_{\rm LG} < 2500$ km/s, where $p-$value $= 0.036$ is a slightly smaller limit. However, this is very weak evidence given the extremely small subsample size of 45 galaxies, where the one-sample Kolmogorov–Smirnov test should be treated with caution, and because the lack of the effect in the ±5 Mpc layer and for closer galaxies $cz_{\rm LG} < 1200$ km/s.

We checked if the small increase of perpendicular ($PA = 0°$) and parallel ($PA = 90°$) oriented galaxies in the case of the sample with $cz_{\rm LG} < 2400$ km/s (see Fig. 4) is related to galaxy morphology. However, blue and red galaxies have similar PA distributions and do not show the morphological separation.

4 Summary

We analyzed the distribution of the galaxy orientations relative to the Local Supercluster plane, following the idea proposed by Navarro et al. (2004). Our sample consists of 1986 edge-on galaxies within $cz_{\rm LG} < 4000$ km/s. The correlations were studied in different subsamples selected by redshift, the Local Supercluster sheet membership, morphological type, and stellar mass. In contrast to the work of Navarro et al. (2004), we did not find any statistically significant correlations. Testing the dependence of stellar populations on mass and color also revealed no correlations. The discovery of the correlation in the early work by Navarro et al. (2004) may be due to the extremely small sample size, only 30 galaxies. Our work represents a more complete compilation of current modern catalogs and gives the possibility to make more accurate estimates. The lack of the spin alignment predicted by theory may be due to the fact that galaxies located in the plane of the Local Supercluster are part of different filaments and are subject to complex tidal influences from the surrounding large-scale structure. Thus, although tidal force fields should lead to spin alignment, the intersections of filaments (knots) and the presence of sheets create complex time-varying gravitational fields that can lead to random orientation of spins. The interactions at these junctions can disrupt any initial alignment.

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