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On the coherent orientation of spins of spiral galaxies

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Abstract. The method of convergence of planes developed by Battaner et al. (1991, hereafter BGSF) has been used for investigating coherent alignments of rotation axes of spiral galaxies in the Milky Way neighbourhood. Results are contrasted with previous analyses carried out by other means, taking into account that they were not conclusive either to confirm or to reject coherent alignments. Some improvements of the method are described. No evidence for coherent alignments has been found here, with the exception of some zones, in particular that around the Coma supercluster in which the angular momentum vectors tend to be perpendicular to the axis of the Coma supercluster.

Key words: galaxies: spiral – galaxies: clustering – galaxies: formation – methods: statistical

1. Introduction

Noticeable attention has been paid in the past as to whether galaxies are randomly oriented or not. The question is of considerable interest in itself as well as a test of some hypotheses on the origin and evolution of galaxies. Several theories have been proposed to explain alignments of galactic spin axes. Reinhardt (1971) has discussed alignments due to a uniform integalactic magnetic field. Öpik (1956) considered the possible effect of the motion of a group of galaxies through an intergalactic medium. Oort (1958) and Ozernoy (1974) pointed out that if a cluster of galaxies were a fossil eddy, the rotation axes of galaxies might be expected to line up along the eddy axis. Dekel (1985) has argued that the angular momentum acquired by a galaxy that was formed in a dissipative pancake may account for the spin observed in a typical spiral galaxy, being parallel to the pancake plane. In the hierarchical clustering model of galaxies however (Shandarin 1974), the distribution of momenta is predicted to be random.

Most searches for statistically significant alignments in the Local Supercluster did not yield any clear evidence (Helou & Salpeter 1982; Djorgovski 1983; Flin & Godlowski 1984), except for small-scale antialignments of galaxies in binaries (Helou 1984). Flin & Godlowski (1986) however, claimed to have found such an alignment for a sample of face-on galaxies. The brightest galaxies in rich clusters are often aligned with their parent clusters (Binggeli 1982), but this may be an exception as a result of cluster evolution. Perhaps the best evidence was reported for the Perseus supercluster (Gregory et al. 1981).

Three different statistical tests, which were introduced by Hawley & Peebles (1975), were adopted by many authors (Jaaniste & Saar 1977; Flin & Godlowski 1986, 1989, 1990; Flin 1988; Lambas et al. 1988) in order to study not only the distribution of galaxy position angles but also the galaxy's inclination.

The aim of this paper is a further investigation of the distribution of rotation axes of spiral galaxies in the Milky Way 50 Mpc neighbourhood. As many galaxies located in very different directions in the sky, as seen from the Sun, have been included in the sample, our correlation analysis was carried out for the angular momentum coordinates themselves, in a common three-dimensional reference frame. The unitary vector along the rotation axis of each galaxy was moved to have its origin at the Sun. The values of α and δ of the direction of the individual spin, constitute our statistical variables. An adapted χ^2-test was developed and applied to the data.

Therefore, two main differences of this work and previous analyses should be noted: i) the use of the "Convergence of planes" method, which may be considered as a fast and powerful tool, and ii) the use of the spin direction coordinates in a common frame as statistical variables. The importance of the topic and the ambiguity of previous results, demonstrate the need for the development of new procedures to study this basic input in the subject of the formation of large-scale structures.

2. The sample

Our sample consisted of all northern-hemisphere NGC spiral galaxies, with known radial velocities (corrected for solar motion) (Palumbo et al. 1983, Huchra 1981), belonging to two different types: i) edge-on, with $\log R_{25} \geq 0.45$, from de Vaucouleurs et al. (1976), i.e.; and ii) face-on, with

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$\log R_{25} \leq 0.055$, according to the same authors. [R_{25} is defined as log (major axis ÷minor axis) at $\mu = 25$ mag arcsec^{-2}.] These limiting values of $\log R_{25}$ were chosen such that the numbers balance each other for the total sample (166 face-on and 169 edge-on galaxies).

Galaxies lie in very different zones in space, so they were classified in groups defined in Table 1. Figures 1a and b are projections of the sky in the planes ($\alpha = 0^h$, $\alpha = 12^h$) and ($\alpha = 18^h$, $\alpha = 6^h$) around the Milky Way, taking the radial velocity as a radial coordinate.

3. Mathematical treatment

Once an edge-on spiral is observed the direction of its angular momentum must be determined as follows. Let us call $\boldsymbol{L}_i$ the individual angular momentum of the ith galaxy projected in the plane of the sky (perpendicular to the line of sight). An ambiguity remains, as $-\boldsymbol{L}_i$ is also possible. No attempt to determine the modulus of $\boldsymbol{L}_i$ has been made so that only the unitary vector $\boldsymbol{l}_i$ in the direction of $\boldsymbol{L}_i$ is here considered. A simple derivation provides the coordinates (α, δ) of $\boldsymbol{l}_i$ centred at the Sun as a function of the coordinates (α_0, δ_0) of the galaxy and the angle β (the position angle of $\boldsymbol{l}_i$):

$$\sin\delta = \cos\delta_0 \cos\beta \quad (1)$$

$$\sin(\alpha_0 - \alpha) = \frac{\sin\beta}{\cos\delta}. \quad (2)$$

Clearly the direction of the angular momentum of a face-on galaxy coincides with its position vector, i.e. the coordinates of $\boldsymbol{l}_i$ are the position coordinates (α_0, δ_0) of the galaxy.

Once $\boldsymbol{l}_i$ is known, the average direction for each group must be obtained. The problem is that we "a priori" do not know whether $\boldsymbol{l}_i$ of $-\boldsymbol{l}_i$ represents the actual direction of $\boldsymbol{l}$, i.e. the "polarity" of a galaxy is unknown. The numerical procedure for determining the mean direction of the angular momentum must provide a means of determining the polarity of each galaxy. It is clear that the mean direction will in turn have a polarity, which will remain unknown. Once it is arbitrarily chosen, individual polarities may be determined. The results obtained using the method of "convergence of planes" (BGSF) are shown in Table 2. Figures 2a and b are polar diagrams (α, δ) and (l, b) with $\boldsymbol{l}$ for each group.

Standard deviations for each group are also presented in Table 2. They are of the order of 50°. The value of 50° is very large indeed and means that a coherent orientation of rotation axes was not actually found in our sample. Suppose that all possible directions of $\boldsymbol{l}_i$ were equally probable; then a value of 61° would be obtained for the standard deviation (this is demonstrated in BGSF). Exceptions are groups 5, 8, 10 and 13, for which the standard deviation is noticeably small.

A further statistical test is required to study the randomness of the distribution. In order to adapt the χ^2-test to this specific problem the theoretical distribution for each group was considered to be given by the density distribution function:

$$f(x) = A \sin(x) \mathrm{e}^{-x^2/B} \quad (3)$$

where x is the angle between $\boldsymbol{l}_i$ and the mean direction of each group, and the constants A and B are obviously determined by the two following conditions:

$$1 = \int_0^{\pi/2} f(x)\,\mathrm{d}x, \quad (4)$$

$$\sigma^2 = \int_0^{\pi/2} f(x)\, x^2\,\mathrm{d}x. \quad (5)$$

Table 1. Geometrical definition of the groups

Group	Radial velocity (km s^{-1})	Right asc. (h)	Declination (deg)	Face-on galaxies	Edge-on galaxies
0	(0, 500)	All	All	9	20
1	>500	(3, 9)	(0, 45)	6	3
2	>500	(3, 9)	(45, 90)	4	5
3	(500, 2500)	(9, 15)	(0, 45)	43	51
4	(2500, 5000)	(9, 15)	(0, 45)	7	19
5	>5000	(9, 15)	(0, 45)	17	3
6	(500, 2500)	(9, 15)	(45, 90)	8	24
7	(2500, 5000)	(9, 15)	(45, 90)	6	7
8	>5000	(9, 15)	(45, 90)	7	2
9	>500	(15, 21)	(0, 45)	10	7
10	>500	(15, 21)	(45, 90)	9	9
11	(500, 2500)	(21, 3)	(0, 45)	9	8
12	(2500, 5000)	(21, 3)	(0, 45)	14	10
13	>5000	(21, 3)	(0, 45)	15	3
14	All	All	All	166	169

Fig. 1a and b. Projections of the sky showing the different spatial regions of the different group of galaxies

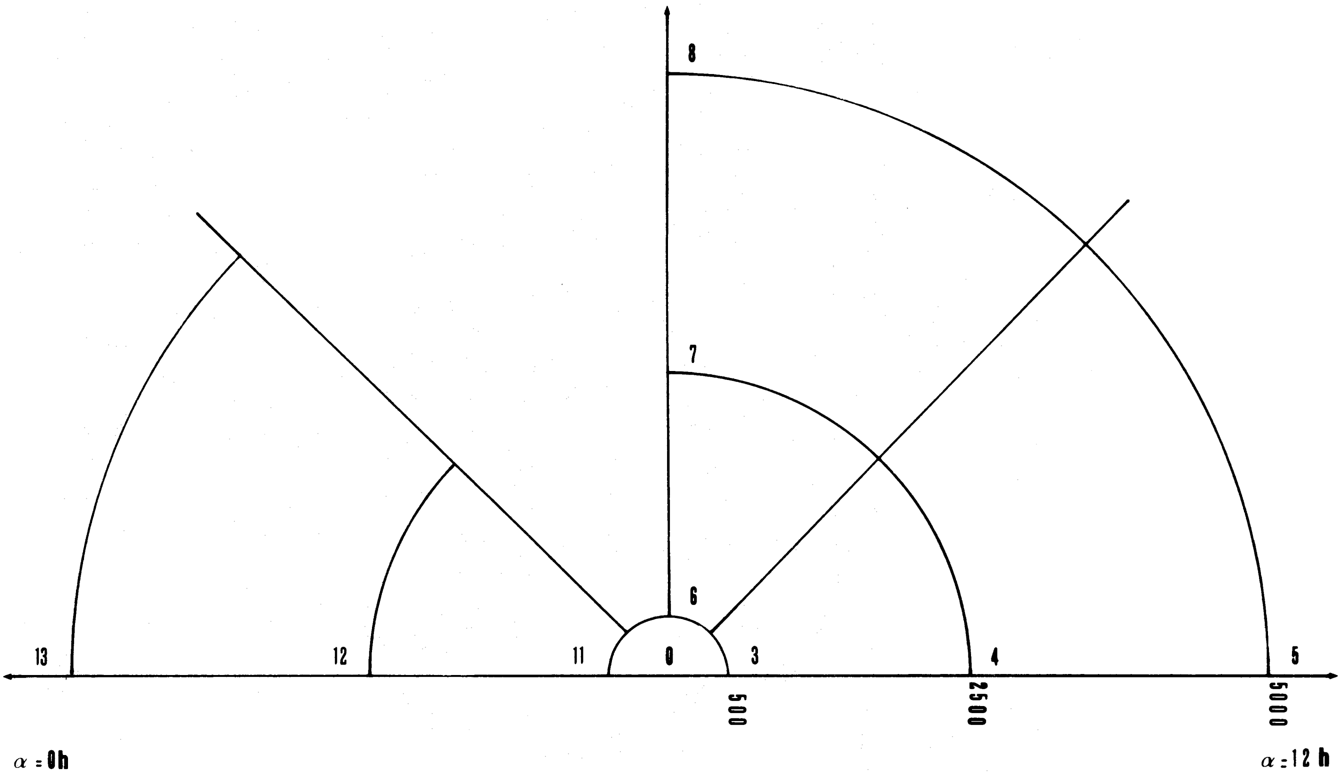

Fig. 1a. In the (α = 0ʰ, α = 12ʰ) plane

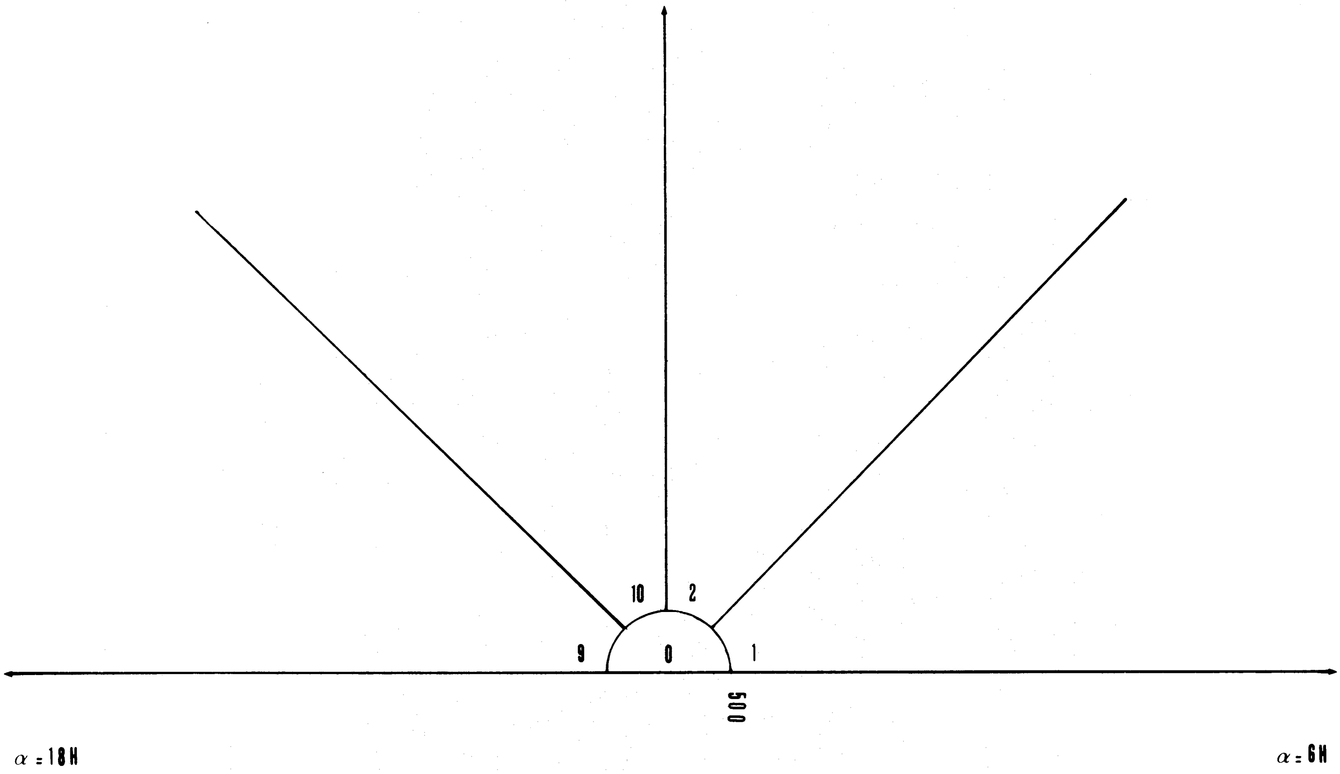

Fig. 1b. In the (α = 18ʰ, α = 6ʰ) plane

Fig. 2a and b. Plot of the angular momentum vectors for each group (with the method of convergence of planes)

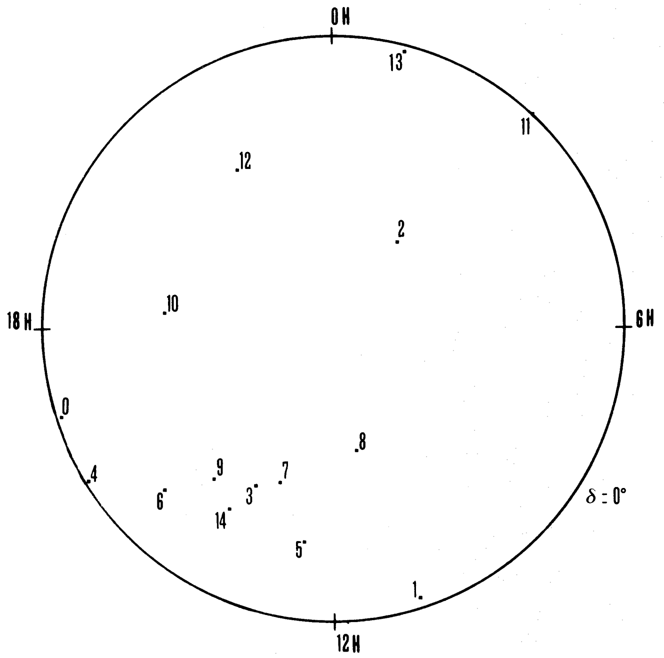

Fig. 2a. (α, δ) polar diagram

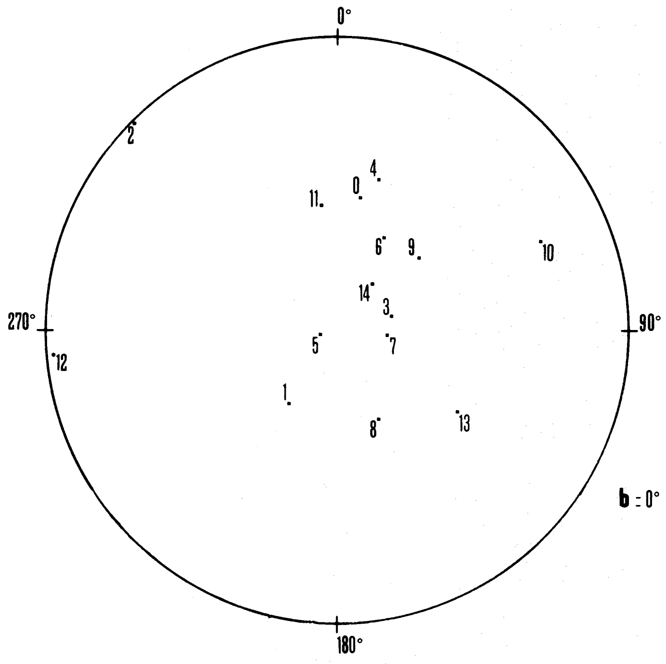

Fig. 2b. (l, b) polar diagram

In Eq. (3) the gaussian function has been multiplied by $\sin(x)$, as for larger values of x, areas with constant x are larger. Equations (4) and (5) are to be determined by numerical techniques. In Fig. 3 we show this theoretical distribution for group 5.

Table 2. Direction of the rotation axis and standard deviation, in each group

Group	Rotation axis RA (hh mm) / I (deg)	δ (dd mm) / b (deg)	Galaxies	Standard deviation (deg)
0	3 22.69	−6 51.6	29	54.7
	190.68	−48.03		
1	22 46.89	−24 06.6	9	49.1
	33.01	−62.60		
2	2 16.93	56 45.0	9	46.9
	135.00	−3.77		
3	1 44.28	−36 31.8	94	49.2
	254.00	−75.00		
4	3 50.85	−5 42.6	26	51.8
	195.00	−41.50		
5	0 34.25	−23 44.4	20	29.0
	82.00	−85.20		
6	3 07.61	−19 27.0	32	43.2
	206.00	−58.00		
7	1 26.26	−39 39.6	13	42.4
	272.50	−75.40		
8	23 12.97	−51 46.8	9	38.9
	332.70	−59.80		
9	3 18.49	−30 44.4	17	45.0
	228.00	−57.10		
10	18 18.86	37 06.00	18	35.2
	65.00	20.80		
11	2 47.02	0 00.6	17	49.6
	173.00	−51.10		
12	21 55.87	31 44.4	24	48.8
	84.70	−17.50		
13	0 51.42	16 36.0	18	32.1
	302.80	−46.50		
14	2 06.21	−26 18.0	335	52.0
	213.01	−72.55		

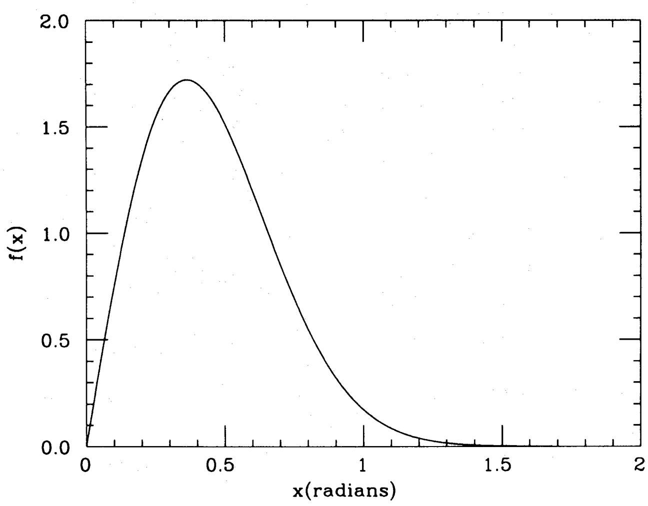

Fig. 3. Theoretical density distribution function for group 5: $A=2.9$ and $B=0.8\ \mathrm{rad}^{-2}$

Table 3. The distribution in the angle investigated

Sample	N	χ^2	$P(>\chi^2)$
0	29	12.60	0.00
1	9	2.34	0.02
2	9	2.25	0.06
3	94	9.32	0.00
4	26	6.30	0.00
5	20	23.10	0.70
6	32	12.00	0.00
7	13	14.10	0.01
8	9	4.82	0.15
9	17	14.90	0.40
10	18	2.48	0.00
11	17	3.36	0.01
12	24	8.26	0.00
13	18	12.40	0.20
14	335	12.70	0.00

The probability, $P(>\chi^2)$, for obtaining a value greater than the theoretical one, was determined from statistical tables (e.g. Beyer 1988). The results are presented in Table 3. Columns in Table 3 give: the description of the analysed subsample, the number of galaxies considered, the value of the χ^2-statistic and $P(>\chi^2)$. The results of the χ^2-test do not exhibit randomness. As pointed out in BGSF this result is independent of the alignment of warps found in this work.

4. Conclusions

Most investigations of the distribution of galaxy orientations concern the Local Supercluster (Djorgovski 1986). In this zone – our group 3 – we conclude that the spin axes are randomly oriented. The region containing the Virgo cluster – group O – also presented this property.

The overall conclusions is that for most of the groups considered, no coherent alignment exists, in agreement with the theory of hierarchical clustering of galaxies (Shandarin 1974). Only for some groups and in particular for group 5 the searched for alignment is appreciable. Group 5 includes the Coma supercluster, where galaxies may show a slight preference for alignment along the radius vector. This has already been pointed out by Hawley & Peebles (1975).

The presence of alignment clearly depends on the mixing ratio of face-on to edge-on galaxies. Clearly this mixing ratio must be a function of the standard deviation when individual groups are examined. The highest coherence degree is found for group 5, with a standard deviation of only 29°. Just for this group we have the most unbalanced mixing ratio (17 vs. 3). Even a linear relation of the type $\Psi = 0.21\,(-\sigma + 60)$ can be roughly obtained from de data. Here Ψ is the mixing ratio, defined either as the number of face-on galaxies over the number of edge-on ones, or as the inverse if this figure is less than unity. This relation would be not valid for the whole (4π stereoradians) sky, where a perfect alignment would produce the same number of face-on and edge-on galaxies. Also the group 13 ($\Psi = 5$) clearly shows it.

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