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Spins of Interacting Galaxies and a "Tri-Axial" Angular Momentum Hypothesis

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Abstract

The projected directions of the rotation axes of interacting galaxies tend to align orthogonal to each other. This can be explained in the case that paired galaxies with parallel spins have merged into single galaxies, while those with orthogonal spins survived unmerged. We suggest a "tri-axial" hypothesis for the spin and orbital angular momenta of interacting systems regarding their survival from merging.

Key words: Galaxy formation — Galaxy spins — Mergers — Rotation — Tidal interaction

1. Introduction

The spin angular momenta of galaxies contain information concerning the vorticity of primeval turbulence prior to the epoch of galaxy formation during the early universe (Gorbachev 1970; Karachentsev and Karachentseva 1974; Turner 1976; Noerdlinger 1979; Iye and Sugai 1991). If galaxies are in the process of clustering, their rotation characteristics would vary during their evolution due to an exchange of angular momentum through gravitational interaction. In particular, the angular momenta in paired and multiple galaxy systems vary significantly through close interactions (e.g., Barnes 1989). The angular momenta in close interacting systems would no longer represent the early history of primeval eddies, though they could contain information concerning dynamical evolution within the systems. The process of angular momentum exchange during an interaction has not been thoroughly understood. However, we could conjecture that parallel-spinned galaxies would have more easily merged to become a single galaxy due to stronger interaction and dynamical friction, and, thus, couldn't survive as a binary. We could therefore expect that paired galaxies, which have survived without merging, might exhibit spins that are more orthogonal to each other than parallel.

Several authors have examined the spin orientations in interacting systems (Gorbachev 1970; Karachentsev and Karachentseva 1974; Turner 1976; Noerdlinger 1979). However, since they were more interested in the parallel alignment of spins than orthogonal configurations, they always looked for and discussed a parallel tendency. In this *Letter* we examine a correlation between the angular momenta of interacting galaxies sampled from independent catalogs of those used in the previous works.

2. Projected Angles between Spin Axes

In order to avoid uncertainty in determining the and near sides of a disk galaxy, for which we need locity information, we use the projected orientation the major axis of a galaxy. Obviously, the major of the galaxy is perpendicular to the projected spin a We here examine the angles between the major axes ($0 \leq \theta \leq 90°$), of galaxy pairs.

For an analysis we used the *Atlas of Peculiar Gala* (Arp 1966) and *A Catalogue of Southern Peculiar Ga ies and Associations, Vol. II* (Arp and Madore 19 which contain a number of high-quality photographs interacting galaxies. First, we omitted any strongly turbed galaxies, whose major axes are difficult to def we also omitted single peculiars. In many cases there third and fourth smaller galaxies in the same field, ten making triplets or multiplets. In such cases we u the biggest two major galaxies in the system. Howe we did not use groups comprising galaxies of compara size. In this way we chose galaxy pairs, both of wh keep their grand disk design. Finally we omitted samples which contain at least one face-on galaxy. this way we chose galaxy pairs for which the major a can be defined and their mutual angles can be measu with an accuracy better than $\pm 10°$.

For samples from the Arp catalog we chose 134 pa from which 22 pairs containing face-on galaxies w omitted; we thus used 112 pairs. For samples from Arp-Madore catalog we chose 308 interacting pairs fr categories 1 (galaxies with interacting companions) (interacting doubles), 3 (interacting triplets), and 9 (M type). We did not use any galaxies of other categor such as categories 4 and 5 (quartets and quintets), 6 (w apparent companions), 7 to 16 and 20 to 22 (singles) to 19 (chains, groups, clusters), and 23 and 24 (possi

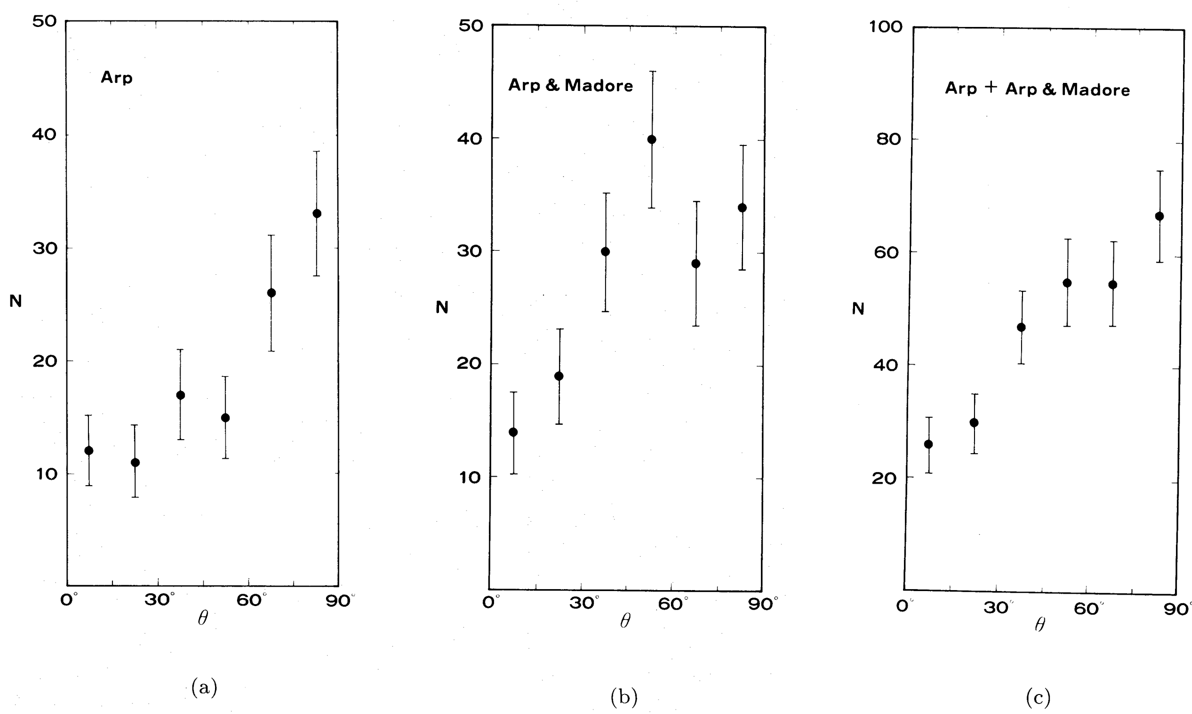

Fig. 1. (a) Distribution of the angles between the major axes of paired galaxies for samples chosen from the *Atlas of Peculiar Galaxies* (Arp 1966). Error bars indicate $\sqrt{N-1}$ with N being the number of galaxies falling in each 15°-bin. (b) The same as figure 1a, but for galaxies chosen from *A Catalogue of Southern Peculiar Galaxies and Associations Vol. II* (Arp and Madore 1987). (c) Summation of figures 1a and b.

apparent pairs and triplets). Among the 308 pairs, 30 contained at least one face-on galaxy, which were omitted; we thus used 278 pairs for which the major axes can be definitely determined. We mention that a large fraction of M51-type galaxies, about half (15 pairs) of the 31 pairs (after excluding strongly disturbed ones), was face-on pairs, because of the definition of classification type.

Figure 1a shows a distribution of angle θ measured for galaxies included in Arp (1966), where the number (N) of galaxies falling within each 15° is plotted. Figure 1b is the same, except for the southern interacting galaxies included in Arp and Madore (1987). Note that figures 1a and b are obtained from independent galaxy samples. Figure 1c is their addition. The errors are given by $\sqrt{N-1}$, with N being the number of galaxies in each bin of θ. The figures show the same trend, that the angles between the major axes tend to lie near $\theta = 90°$. Namely, the projected major axes, therefore the projected spin axes, of paired and interacting galaxies tend to be orthogonal. We mention here the effect of omitting the face-on pairs: the omitted face-on pairs, which share 10 to 15% of all chosen pairs, have no definite major axes; we could therefore evaluate the contribution of these samples as being even for any θ. This means that about 3.7 galaxies per bin should be equally added to N for any θ in figure 1a, 5 galaxies in figure 1b, and 8.7 galaxies in figure 1c. However, these contributions are small (~ 10%) compared to the total number, and we may ignore their contributions to the statistics.

We discuss the implication of the result obtained above. Let ϕ be a true angle between the rotation axes (AC and BC) of a pair of galaxies, or $\phi = \angle$ACB in figure 2. Suppose that there are many pairs and that their mutual spin angles (ϕ) are random. Namely points A and B are uniformly distributed over the sphere shown in figure 2. In this case the probability distribution of ϕ is proportional to sin ϕ: $P(\phi)d\phi = 1/2 \sin\phi \, d\phi$ ($0 \le \phi \le 180°$). Furthermore, if we project the angles on the sky, or on a plane perpendicular to the line of sight (CS), we obtain a probability distribution of θ which is uniform: $P(\theta)d\theta = (2/\pi)d\theta$. If the spin axes are parallel to each other, $P(\phi) = \delta(\phi)$, we obtain a probability function of θ confined near 0°, $P(\theta) = \delta(\theta)$. For the anti-parallel case of $P(\phi) = \delta(\phi - 180°)$, we obtain the same, $P(\theta) = \delta(\theta)$. However, if the spin axes are perfectly orthogonal in each pair, or $P(\phi) = \delta(\phi - 90°)$, we find that $P(\theta)$ is a monotonically increasing function of θ with a steep maximum at $\theta = 90°$ ($0 \le \theta \le 90°$), as shown in figure 3d. Figure 3 illustrates schematically the relation between the proba-

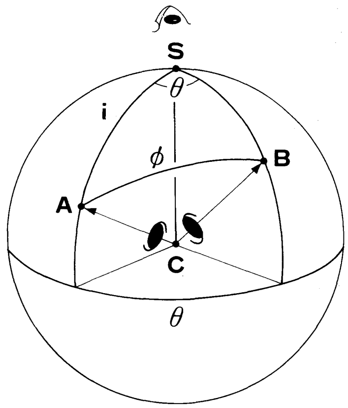

Fig. 2. The spin configuration of paired galaxies.

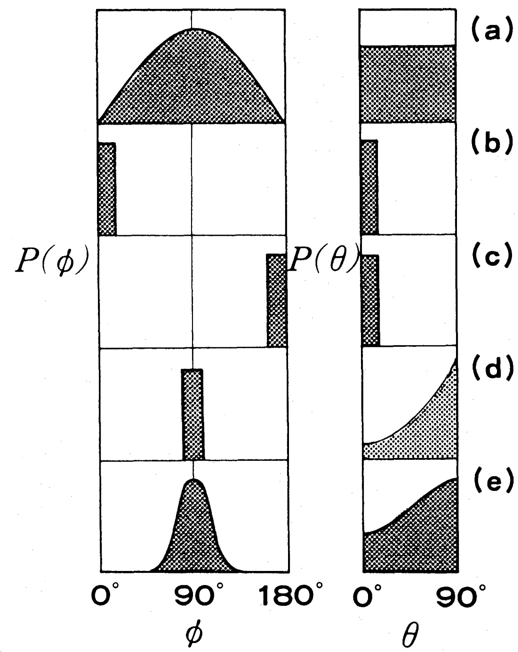

Fig. 3. A schematic representation of the probability function of angles between spins, $P(\phi)$, and the corresponding probability function for angles between projected spin axes, $P(\theta)$: (a) uniform spins; (b) parallel; (c) anti-parallel; (d) orthogonal; and (e) semi-orthogonal spins. The box-shaped functions represent the δ function.

bility functions of ϕ and θ. The probability functions, of course, satisfy $\int P(\phi)d\phi = 1$ and $\int P(\theta)d\theta = 1$.

Obviously, our data in figures 1a to 1c do not fit a uniform ϕ distribution. Also, they fit neither a parallel nor anti-parallel distribution. The observed distribution of θ, as shown in figure 1, can be fitted only by the one between the uniform ϕ and orthogonal ϕ cases. We may therefore conclude that our data indicate that spin angles (ϕ) in our samples tend to be orthogonal. Figure 3e illustrates such a case, where the true angle ϕ tends to be orthogonal in each pair. It is hard to deconvolve the data to obtain a ϕ distribution, not only because of the significant errors in data, but also due to the 180° ambiguity. Instead, we simulate the probability functions $P(\theta)$ from a given $P(\phi)$, where we assume that ϕ tends to lie around 90°, and the following function is assumed:

$$P(\phi) = C \exp[-(\phi - 90°)^2/\Delta\phi^2], \quad (1)$$

where C is constant and $\Delta\phi$ is taken as a parameter. In figure 4 we show the results for $\Delta\phi = 10°$, 30°, and 45°, and compare them with the cases of a uniform distribution and a perfect orthogonal alignment. The values given in figure 4 are normalized by the one at $\theta = 0°$. As can readily be seen from figure 4, the observed distribution (e.g., figure 1c) seems to be approximately reproduced by the probability function for $\Delta\phi$ = 15–20° around $\phi = 90°$.

3. Discussion

The present result seems to be unique among the related studies which analysed the configurations of paired galaxies: Gorbachev (1970) claimed a tendency of parallel alignment; Noerdlinger (1979) found no parallel tendency; our result suggests orthogonality. These different results may arise from the different sets of sample galaxies used by the authors: Since our analysis was based on a collection of strongly interacting peculiars, the chance for contamination of back- and foreground galaxies is small. Moreover, the used catalogs provide high-quality photographic data, which are needed in determining the major axis directions.

In the present analysis we did not distinguish between morphological types: The criterion to use a galaxy pair was if it contains galaxies with definite major-axes. On one hand, this procedure has an advantage in that it can avoid uncertainty arising from a very ambiguous task of galaxy classification in interacting and peculiar pairs. On the other hand, we might have missed characteristics which are dependent on the galaxy types, which may require a greater number of samples with a careful classification of individual galaxies.

The implication of the result is not straightforward, and it would be difficult to obtain a unique model. Here, we simply propose the following possibility for the origin of the present orthogonal alignment: Suppose that double galaxies were born with their spins being parallel (figure 5a). In such a case it is natural to assume that their orbital plane would be parallel to their disk planes (e.g., Noerdlinger 1979). Namely, both galaxies (A and B) would be orbiting around each other in a direct (prograde) sense. It is known that tidal disturbance

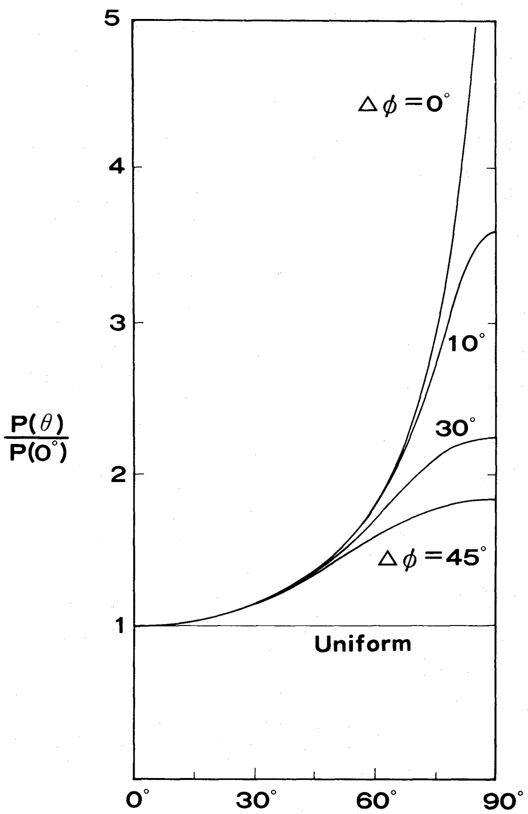

Fig. 4. The probability function $P(\theta)$ as normalized by $P(0)$ for a Gaussian form of the probability $P(\phi)$ around $\phi = 90°$ for cases of $\Delta\phi = 10°$, $30°$, $45°$, and for a uniform and perfectly orthogonal ($\Delta\phi = 0°$) case.

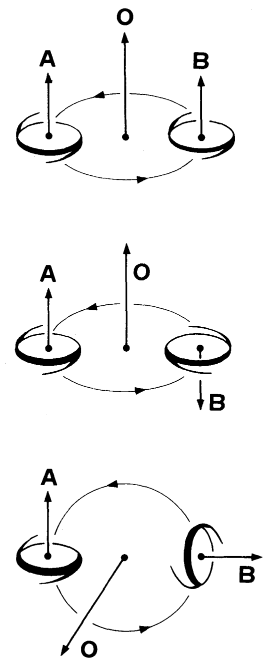

Fig. 5. Configurations among the spin angular momenta of galaxies, A and B, and the orbital angular momentum, O. If either A or B is parallel to O, the system will be easily merged into a single (a and b). The system will be most stable for "tri-axial" configuration as (c).

of a galaxy due to a companion is strongest when the companion is orbiting in a direct sense to the rotation of the galaxy. Hence, such doubles with parallel spins would suffer strong tidal disturbances from each other (e.g., Keel 1991). As a consequence, doubles with parallel spins would be more easily merged into a single galaxy, so that the chance for survival as a parallel-spinning pairs would be small.

We next suppose a case in which double galaxies have anti-spins (figure 5b). In this case their rotation planes are parallel to each other; it is thus natural to suppose that their planes are also within their mutual orbital plane. In such a case, one of the galaxies (B in figure 5b), always orbits around the other in a direct sense, although A is orbiting around B in retrograde. Then, the same argument as above applies for merging, and galaxy B would be merged by galaxy A. Thus, the chance for an anti-spin pair to survive from merging is also small.

Finally, let us suppose a case in which two galaxies with orthogonal spins are rotating around each other, and their orbital plane is orthogonal to both of the galaxy planes (figure 5c). Namely, the spin angular momenta of the two galaxies (A and B) and the orbital angular momentum (O) are "tri-axial." In such a case the tidal disturbance on either galaxy is smaller than in the above two cases, and the merging would be less effective.

Even though there would be various intermediate configurations among these three cases, the "tri-axial" configuration is considered to be most stable against merging and tidal disturbance. Hence, we may conclude that the orthogonal trend of major axes of interacting galaxies, as found in the above analysis, is a manifestation of the fact that galaxies born in other configurations were already merged into single systems, and were not able to survive as a stable pair.

The hypothesis of "tri-axial" angular momenta (TAAM) for interacting galaxies seems worthwhile to be investigated by numerical simulations. Namely it would be an interesting subject to simulate the merging processes starting from initially random configurations of the three angular momenta, A, B, and O, and to investigate the probability of survival as pairs for a Hubble time.

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