



Spin Parity of Spiral Galaxies. I. Corroborative Evidence for Trailing Spirals

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Abstract

Whether the spiral structure of galaxies is trailing or leading has been a subject of debate. We present a new spin parity catalog of 146 spiral galaxies that lists the following three pieces of information: whether the spiral structure observed on the sky is *S*-wise or *Z*-wise; which side of the minor axis of the galaxy is darker and redder, based on examination of Pan-STARRS and/or ESO/DSS2 red image archives; and which side of the major axis of the galaxy is approaching us based on the published literature. This paper confirms that all of the spiral galaxies in the catalog show a consistent relationship among these three parameters, without any confirmed counterexamples, which supports the generally accepted interpretation that all the spiral galaxies are trailing and that the darker/redder side of the galactic disk is closer to us. Although the results of this paper may not be surprising, they provide a rationale for analyzing the *S/Z* winding distribution of spiral galaxies, using the large and uniform image databases available now and in the near future, to study the spin vorticity distribution of galaxies in order to constrain the formation scenarios of galaxies and the large-scale structure of the universe.

Key words: catalogs – cosmology: large-scale structure of universe – galaxies: formation – surveys

1. Introduction

1.1. Observational Studies

The sense of winding of spiral arms in disk galaxies with respect to their rotation was a classic subject of debate in observational and theoretical studies of spiral galaxies until the 1960s.

Slipher (1917) and Curtis (1918) noted the asymmetric distribution of dark lanes in many of spiral galaxies and argued that the more obscured, redder side of the minor axis is likely nearer to us. Slipher (1917) even remarked that all spiral nebulae rotate in the same direction with reference to the spiral arms, as a spring turns in winding up. This type of spiral is called a trailing spiral. As the inner part of a galaxy revolves at a larger angular speed than the outer part, the trailing pattern will wind up in the course of time if the spiral arms are material arms. Hubble (1943) studied 15 spiral galaxies and concluded that all of them are trailing spirals, assuming that the darker side of galaxies is closer to us.

In contrast to the interpretation of trailing spirals, Lindblad (1940a, 1940b) developed a dynamical theory of the spiral structure of stellar systems. He argued that the direction of rotation of the system agrees with the direction in which the spiral arms wind around the center when followed outward from the central mass, suggesting that the spirals are unwinding. This type of spiral is called a “leading” spiral. Lindblad & Brahde (1946) further noted that the bright side of the tilted disk of spirals is the near side. They argued that the obscuring dust has a larger vertical extension than that of the luminous matter, and hence produces a “limb-darkening” effect on the far side of the tilted disk, because of the longer path length for obscuration. This interpretation implies that the

spirals are “opening up.” As the thickness of the distribution of the obscuring dust is now known to be much smaller than that of the luminous stellar system (Hacke et al. 1982), this historic argument is no longer valid.

Even if admitting the vertically thin distribution of obscuring matter, two different interpretations were still possible. Figure 1, reproduced from a review article by de Vaucouleurs (1959), illustrates the two interpretations. The upper panel shows usual interpretation that the dust layer is more or less uniformly spread in the equatorial plane of the disk and the obscured side is the near side. The lower panel shows Lindblad’s interpretation that the dust lanes localized in the inner edge of the bright arms and the obscured side is the far side.

Nevertheless, it is now generally accepted that the dust-lane-dominant side of the minor axis is the near side. Here dark lanes are more conspicuous on the side nearer to us because the interstellar dust lanes are silhouetted against the background light of the stellar bulge, as de Vaucouleurs (1959) suggested. In the absence of direct distance measurement of the near and far sides of tilted galactic disks, however, this interpretation remains incompletely verified by other independent methods, e.g., confirming the differential interstellar reddening of globular clusters and/or the detection of differences between forward and backward scattering of light from the stellar bulge by the interstellar dust using observations in polarized light and/or observations of spectral differences.

To identify whether a spiral arm of a galaxy is trailing or leading in a galaxy, one needs to know the projected spiral winding sense (*S*-wise or *Z*-wise) on the sky, the near side of the tilted galactic disk, and the approaching side of the major axis of the galactic disk.

Determining whether a spiral pattern exhibits *S* or *Z* winding is difficult for highly inclined galaxies, whereas for nearly face-on galaxies, it is hard to identify the near side of the disk from the asymmetric extinction. It must be emphasized that to date



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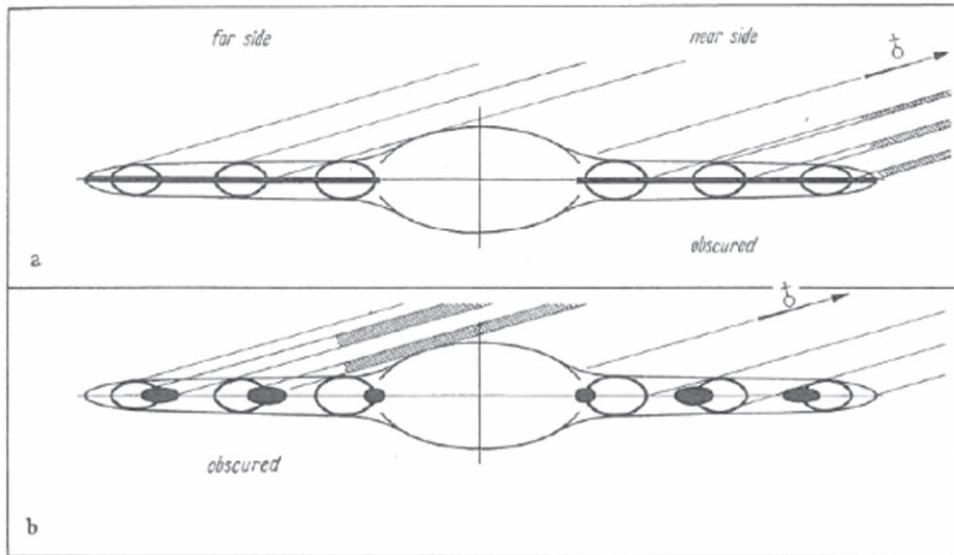


Figure 1. Two geometrical configurations for the distribution of obscuring dust layer in a tilted disk of a spiral galaxy. (a) Usual interpretation; the dust-lane-dominant side is the near side. (b) Lindblad's interpretation; dust-lane-dominant side is the far side (reproduced from de Vaucouleurs 1959).

there is no spiral galaxy for which all three pieces of relevant information are indisputably available.

1.2. Theoretical Studies

Hunter (1963, 1965), Iye (1978), and Kalnajs (1972) showed analytically that no spiral modes arise in uniformly rotating gaseous or stellar disks. This is called the “anti-spiral” theorem. Differential rotation is the key to spiral modes. One can formulate the dynamical stability of a self-gravitating disk as an eigenvalue problem of the dynamical response matrix of a disk galaxy. The eigenvalues of such a matrix with real components appear only in real values or in complex conjugate pairs. Consequently, if there is a growing trailing spiral mode, there is a corresponding decaying leading spiral mode. The actual spiral patterns observed in real galaxies can be regarded as a manifestation of superposition of these various modes of oscillation, at least in the linear regime.

Lin & Shu (1964) developed the density wave theory to explain the sustained existence of spiral structure as a manifestation of density waves rather than a material structure to avoid the so-called “winding dilemma.” They formulated the governing equations of local linear perturbations from the circularly rotating equilibrium state of a disk galaxy and derived the dispersion relation for waves. Toomre (1969) studied the propagation of such density waves across the galactic disk and found that leading arms are unwinding and turn into trailing arms that are wound up more tightly. He called this excitation mechanism of spiral “swing amplification.”

Hunter (1969) studied short-wavelength oscillation of cold, thin, gaseous disk models of galaxies using a Wentzel-Kramers-Brillouin approximation and concluded that leading spirals are gravitationally unstable and growing. Actual galaxies are not completely cold, and the dispersion equation of linear perturbation shows that short waves are easily stabilized by introducing a modest pressure or velocity dispersion of stars.

Hunter (1965), Bardeen (1975), Iye (1978), and Aoki et al. (1979) formulated the global dynamical stability of self-gravitating disk galaxies as an eigenvalue problem by expanding the linear perturbation in terms of a bi-orthogonal set of solutions of the

Poisson equation on simple disk models. The global modal approach to studying the gravitational stability of cool or warm gaseous disks shows that trailing spiral modes, in addition to bar-like modes, are generally growing.

Kalnajs (1977) developed a rigorous formulation to study the modal stability of stellar disk systems. Evans & Read (1998) extended the method to study the global spiral modes of power-law disks. Jalali & Hunter (2005) made an extensive study of the global spiral modes of the Kuzmin disk (Kuzmin 1956), Miyamoto disk (Miyamoto 1971), and isochrone disk. They demonstrated that trailing spiral modes are growing and that they transfer angular momentum from the interior outward.

In addition to these analytical studies, *N*-body numerical simulations on the dynamics of disk galaxies have shown from an early stage the development of trailing spirals (e.g., Hohl 1970). Sellwood & Athanassoula (1986) and many other works over decades of computer simulation studies have reached the commonly accepted view that the spiral structure in galaxies is trailing. In summary, there is a widely adopted theoretical expectation that the spiral structure observed in galaxies is trailing.

The following sections present a new view of this issue using a spin parity catalog of spiral galaxies by examining the current databases of images with consistent orientations and accumulated published results of kinematic observations.

In Section 2, we describe the image data we used to evaluate the spiral winding sense and the dust-lane-dominant side of each spiral galaxy. We also describe the major surveys from which we retrieved the information to identify the approaching side. Section 3 describes the sample selection and Figure 8–11, which are the outcome of the present study. Figure 8 shows 146 spirals for which we were able to confirm the three pieces of relevant information. It clearly shows that all the spiral galaxies studied are trailing spirals, providing the main result of this paper. Figure 9–11 show additional catalogs for which only two of the three pieces of information were observationally confirmed. Our study makes it possible to infer the third piece of information by assuming that all the spiral galaxies in the universe are trailing spirals. Section 4 discusses some individual galaxies and our plan to use the present findings to



Figure 2. *S*-wise winding spiral NGC 157.

study the vorticity distribution of galaxies in the universe without recourse to spectroscopy.

2. Spin Parity of Spiral Galaxies

2.1. Projected Sense of Winding of Spiral Arms

For most spiral galaxies with morphological type classifications of Sb to Sd, the projected sense of winding of their spiral arms can be evaluated in a fairly straightforward manner. It must be noted, however, that some of the images shown on websites, in the literature, and in books are often inverted. For instance, the image of NGC 5055 in the classical “Atlas of Galaxies Useful for Measuring the Cosmological Distance Scale” by Sandage & Bedke (1988) is inverted, whereas the images of the same galaxy in Sandage & Bedke (1994) and Sandage (1961) show the galaxy correctly as seen in the sky. We evaluated whether the spiral winding direction on the sky is *S*-wise or *Z*-wise (reverse *S*-wise) from the consistently oriented images taken from PanSTARRS-1 data or ESO/DSS red data to avoid the potential confusion arising from such image inversion.

We adopted mainly the *y/i/g* color composite images from PanSTARRS-1 database. For some galaxies where the *y/i/g* color composite image has some defects, we adopted either *i*- or *g*-band images that show the dust-lane-dominant side and spiral features most clearly. When PanSTARRS-1 images were not available, we used ESO/DSS2 red images. We did not apply quantitative limits to their inclination angle of galactic disks to select and evaluate the spiral winding direction or dust-lane-dominant side. Figures 2 and 3 show typical examples of spirals with *S*-wise and *Z*-wise winding.

For NGC 224, NGC 1772, and NGC 4622, we employed images from other sources, as noted in Section 4, to evaluate the spiral winding direction. Spiral features with opposite winding directions reportedly coexist in a few galaxies, which are noted in Section 4.

2.2. Dust-lane-dominant Side on the Minor Axis

Interstellar dust lanes condensed mainly on the disk plane in front of the bulge are silhouetted against the background light of the stellar bulge, whereas the dust lanes behind the bulge are not clearly visible. Therefore, the dust-lane-dominant side of the tilted disk is generally considered to be nearer to us, as



Figure 3. *Z*-wise winding spiral NGC 877.

suggested by Slipher (1917). As the vertical thickness of the dust lanes is smaller than that of the stellar disks, this effect is still noticeable for some spiral galaxies with smaller bulges.

This notion is generally consistent with models that explain in detail the differential reddening and dust obscuration between the near and far sides of a galaxy, for example, Elmegreen & Block (1999) or Byun et al. (1994).

However, this interpretation has not been fully verified by independent observational methods. Measurement of differential interstellar reddening of globular cluster systems can be used to independently assess the correctness of this assumption. Globular clusters behind the galactic disk should be statistically redder than those in front of the galactic disk as a result of the reddening effect of interstellar dust in the galactic disk. To date, this has been clearly demonstrated only for M31 (Iye & Richter 1985), but no similar result has been reported for other galaxies. For M31, Iye & Richter (1985) showed that the northwest side, where the dust lanes are more conspicuous than on the southeast side of the disk, is actually the near side.

Differential reddening in different parts of the disk has also been observed in other local galaxies and used to deduce the geometry and near side of the disk, for example, in M33 (Cioni et al. 2008) and in the Large Magellanic Cloud (van der Marel & Cioni 2001).

In this paper, where possible, we visually identified the dust-lane-dominant side of the minor axis of the galactic disk. Figures 4 and 5 show two examples.

2.3. Approaching Side of the Major Axis

Published data from several useful systematic observational studies such as the Gassendi H-Alpha survey of Spirals (Epinat et al. 2010; Korsaga et al. 2018 and Moretti et al. 2018), PPak IFU survey (Martinsson et al. 2013), WIYN Telescope H- α IFU survey (Andersen & Bershadsky 2013), Westerbork Synthesis Radio Telescope HI survey (den Heijer et al. 2015), Calar Alto Legacy Integral Field Area, CALIFA survey (Garcia-Lorenzo et al. 2015; Holmes et al. 2015; Falcon-Barroso et al. 2017), and VLT/SINFONI integral field spectroscopy (Mazzalay et al. 2014) were compiled in the present study. Other published literature was searched using ADS with keywords of “rotation curve” or “velocity field” coupled with “spiral galaxies” or the explicit names of individual galaxies to confirm the approaching side on the major axis of the galactic disks.



Figure 4. The Circinus galaxy clearly shows more conspicuous dust lanes on its southeast (lower left) side.

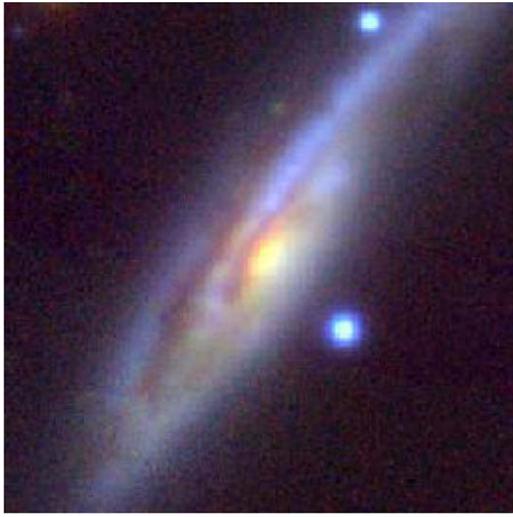


Figure 5. The northeast side of IC 2101 shows dust lanes more clearly than the northwest (upper right) side.

We made every effort to confirm that the maps used to establish the approaching and receding sides have the same orientation as the optical images. Only reports that explicitly describe the approaching side of the major axis were used. Note that some papers use folded rotation curves as a function of the distance from the center or rotation curves, showing approaching and receding velocities, but did not provide sufficient information on the direction of the approaching side. These papers were not used in the present study to determine the approaching side.

Figures 6 and 7 show examples of a velocity field map and a rotation curve, from which we identified the approaching side of the disk galaxy, respectively. The papers on galaxy kinematics used to infer the approaching side of the galaxies are listed in column (6) of Figure 8 and in column (5) of Figure 9.

3. Spin Catalog

We first compiled a master list of spiral galaxies, from the published literature, with available kinematical data to identify the approaching side. The literature survey was performed on

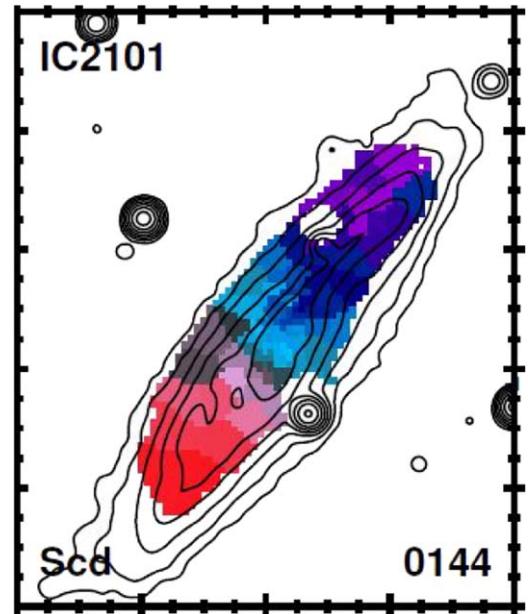


Figure 6. CALIFA isovelocity map of IC 2101 showing that the northwest (upper right) side is approaching (Falcon-Barroso et al. 2017).

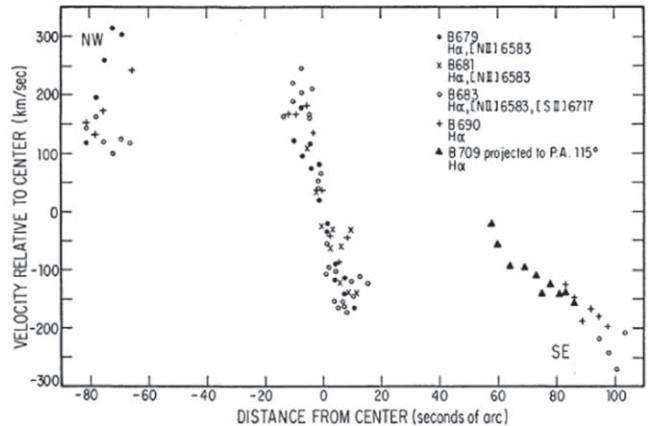


Figure 7. Kinematic study of NGC 613 showing that the southeast side is approaching (Burbidge et al. 1964).

ADS by searching for various relevant keywords. We then looked at images of these galaxies in the Pan-STARRS and/or ESO/DSS2 image archives to see if we can determine the spiral winding sense and dust-lane-dominant side. During this process we added spiral galaxies for which relevant information on spiral winding sense and/or dust-lane-dominant side can be retrieved from their images even though the kinematical data are absent. Image inspection processes were done independently by two of the authors, MI and HF. Only those galaxies for which both authors obtained the same spiral winding direction and dust-lane-dominant side were chosen for study.

The master list eventually contained 845 spiral galaxies, of which *S/Z* identification was made for 784 spirals, approaching side identification for 520 spirals, and dust-lane-dominant side identification for 245 spirals, respectively. Table 1 shows the statistics of the master list samples. The numbers of galaxies for which only one piece of information was available are also shown; 252 spirals with only *S/Z* identification, 8 spirals with only dark side identification, and 27 spirals with only

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
ID	S/Z	Dark Side	Appr. Side	T/L	References	Image 1	Image 2	Image 3	Image 4
Circinus Galaxy	S	SE	NE	T	Izumi et al. (2018)				
IC 1683	Z	W	N	T	Falcon-Barroso et al. (2017)				
IC 1755	S	SW	SE	T	Falcon-Barroso et al. (2017)				
IC 2101	S	NE	NW	T	Falcon-Barroso et al. (2017)				
IC 5376	Z	W	N	T	Falcon-Barroso et al. (2017)				
MCG-02-02-030	Z	SW	NW	T	Falcon-Barroso et al. (2017)				
MCG-02-51-004	Z	NE	SE	T	Falcon-Barroso et al. (2017)				
NGC 24	Z	NW	NE	T	Chemin et al. (2006)				
NGC 157	S	SE	NE	T	Fridman et al. (2001)				
NGC 169	Z	N	E	T	Falcon-Barroso et al. (2017)				
NGC 224	S	NW	SW	T	Babcock (1938)				
NGC 247	S	E	N	T	Hlavacek-Larrondo et al. (2011)				
NGC 253	Z	NW	NE	T	Lucero et al. (2015)				
NGC 598	Z	W	N	T	Kam et al. (2017)				
NGC 613	S	SW	SE	T	Burbidge et al. (1964)				
NGC 615	S	NE	NW	T	Sil'chenko et al. (2001)				
NGC 772	S	SW	SE?	T?	Rhee & van Albada (1996)				
NGC 801	S	SW	SE	T	Rubin et al. (1980)				
NGC 871	Z	W	N	T	Lee-Waddell et al. (2014)				
NGC 877	Z	SW	NW	T	Lee-Waddell et al. (2014)				
NGC 949	Z	SW	NW	T	Truong et al. (2017)				
NGC 972	S	SW	SE	T	Afanasev et al. (1991)				
NGC 1035	S	NE	NW	T	Rubin et al. (1980)				
NGC 1056	Z	SW	NW	T	Falcon-Barroso et al. (2017)				
NGC 1084	S	SE	NE	T	Moiseev (2000)				
NGC 1093	Z	N	E	T	Falcon-Barroso et al. (2017)				
NGC 1097	Z	SW	NW	T	Izumi et al. (2017)				
NGC 1386	S	NW	SW	T	Lena et al. (2015)				
NGC 1421	S	NW	SW	T	Rubin et al. (1980)				
NGC 1532	Z	SE	SW	T	Sandage & Fomalont (1993)				
NGC 1566	Z	NW	NE	T	Slater et al. (2019)				
NGC 1637	S	E	N	T	Roberts et al. (2001)				
NGC 1667	S	E	N	T	Schnorr-Mueller et al. (2017)				
NGC 1961	S	S	E	T	Rubin et al. (1979)				
NGC 2280	S	NE	NW	T	Mitchell et al. (2015)				
NGC 2347	Z	E	S	T	Levy et al. (2018)				
NGC 2403	Z	SW	NW	T	Fraternali et al. (2002)				
NGC 2410	S	NW	SW	T	Levy et al. (2018)				
NGC 2613	Z	SW	NW	T	Irwin & Chaves (2003)				
NGC 2639	S	NE	NW	T	Falcon-Barroso et al. (2017)				
NGC 2683	Z	NW	NE	T	Kuzio de Naray et al. (2009)				
NGC 2715	Z	NW	NE	T	Rubin et al. (1980)				
NGC 2742	S	SE	NE	T	Rubin et al. (1980)				
NGC 2775	Z	SW	NW	T	Hogg et al. (2001)				

Figure 8. Observationally confirmed spin parity of spiral galaxies. North is to the top and east is to the left in each image. The orientation is the same in the following tables.

approaching side identification. The catalogs for these spirals with insufficient information are not included in this paper.

Figure 8 lists the final sample of 146 spiral galaxies for which the winding direction (S/Z), dust-lane-dominant side, and approaching side are clearly confirmed. Column (1) lists the ID of each galaxy. Column (2) gives the spiral winding sense, S -wise (S) or anti- S -wise (Z), as projected on the sky. Column (3) is the sky cardinal direction of the dust-lane-dominant side along the minor axis. Column (4) shows the sky cardinal direction of the approaching side of the major axis. Column (5) shows whether the spiral structure is trailing (T) or leading (L) based on columns (2)–(4) where we assume that the dust-lane-dominant side is on the near side of the galactic disk. Column (6) is the reference we used to confirm the approaching

side. Columns (7)–(10) show postage-stamp images of four galaxies that cover the main spiral features of the galaxy; most of them came from the $y/i/g$ color composite images of PanSTARRS-1 Image Cutout Server (<https://ps1images.stsci.edu/cgi-bin/ps1cutouts>). If PanSTARRS-1 images of a galaxy were not available, we used the ESO/DSS-2 red images (<http://archive.eso.org/dss/dss>).

Two of the authors (MI and HF) visually inspected the images to classify the galaxies as S or Z and determined the direction of the dust-lane-dominant side. In visually judging S/Z , we relied more on the main outer features than on local features. Only when MI and HF confidently obtained the same results was a galaxy selected for study. The approaching side was identified using isovelocity contours or the velocity

NGC 2782	Z	N	E	T	Hunt et al. (2008)				
NGC 2841	S	NE	NW	T	Afanasiev & Sil'chenko (1999)				
NGC 2903	S	E	N	T	Muraoka et al. (2016)				
NGC 3031	S	SW	SE	T	Goad (1974)				
NGC 3160	Z	SW	NW	T	Garcia-Lorenzo et al. (2015)				
NGC 3175	S	SE	NE	T	Kondapally et al. (2018)				
NGC 3198	S	SE	NE	T	Begeman (1989)				
NGC 3227	Z	SW	NW	T	Mundell et al. (1995)				
NGC 3310	S	E	N	T	Mulder & van Driel (1996)				
NGC 3312	Z	E	S	T	McMahon et al. (1992)				
NGC 3368	Z	W	N	T	Sil'chenko et al. (2003)				
NGC 3521	S	W	S	T	Elson (2014)				
NGC 3623	S	NE	NW	T	Burbidge et al. (1961)				
NGC 3627	S	E	N	T	Zhang et al. (1993)				
NGC 3646	S	NW	SW	T	Afanasev et al. (1991)				
NGC 3672	Z	SE	SW	T	Rubin et al. (1980)				
NGC 3675	S	E	N	T	van der Kruit (1975)				
NGC 3718	Z	SW	NW	T	Schwarz (1985)				
NGC 3815	Z	NW	NE	T	Levy et al. (2018)				
NGC 3900	S	E	N	T	Haynes et al. (2000)				
NGC 3949	Z	NE	SE	T	Kalinova et al. (2017)				
NGC 4062	Z	SW	NW	T	Rubin et al. (1980)				
NGC 4088	S	SE	NE	T	Carozzi-Mayssonnier (1978)				
NGC 4258	S	W	S	T	Sawada-Satoh et al. (2009)				
NGC 4293	Z	SE	SW	T	Cortes et al. (2015)				
NGC 4310	S	SW	SE	T	Truong et al. (2017)				
NGC 4321	S	NE	NW	T	Rubin et al. (1980)				
NGC 4414	S	NE	NW	T	Pingel et al. (2018)				
NGC 4424	S	N	W	T	Cortes et al. (2006)				
NGC 4450	Z	E	S	T	Cortes et al. (2015)				
NGC 4451	Z	SW	NW	T	Truong et al. (2017)				
NGC 4501	S	NE	NW	T	Repetto et al. (2017)				
NGC 4527	S	NW	SW	T	Sofue et al. (1999)				
NGC 4569	S	W	S	T	Nakanishi et al. (2005)				
NGC 4580	Z	SW	NW	T	Cortes et al. (2015)				
NGC 4622	S	W?	S	T?	Buta et al. (2003)				
NGC 4625	S	SW	SE	T	Neumayer et al. (2011)				
NGC 4632	S	NW	SW	T	Truong et al. (2017)				
NGC 4651	S	SE	NE	T	Schneider & Corbelli (1993)				
NGC 4666	S	SE	NE	T	Voigtlander et al. (2013)				
NGC 4698	Z	SW	NW	T	Cortes et al. (2015)				
NGC 4826	Z	NE	SE	T	Israel (2009)				
NGC 5005	S	NW	SW	T	Sakamoto et al. (2000)				
NGC 5033	S	W	S	T	Mediavilla et al. (2005)				
NGC 5055	Z	S	W	T	Pismis et al. (1995)				
NGC 5236	Z	NW	NE	T	de Vaucouleurs et al. (1983)				
NGC 5248	Z	SW	NW	T	Yuan & Yang (2006)				
NGC 5303	S	S	E	T	Truong et al. (2017)				
NGC 5395	Z	W	N	T	Sharp & Keel (1985)				
NGC 5426	Z	W	N	T	Font et al. (2011)				
NGC 5448	Z	S	W	T	Fathi et al. (2005)				
NGC 5635	S	SE	NE	T	Saglia & Sancisi (1988)				

Figure 8. (Continued.)

curves in the references in column (6) of Figure 8 and column (5) of Figure 9. Ultimately we needed only the three relevant pieces of information, so we did not quantify the position angle.

Note that the distribution of eight cardinal directions assigned here is not uniform. Where possible, we assigned intercardinal directions (NW, NE, SE, and SW) rather than cardinal directions (N, E, S, and W). We did this to ensure self-consistency of the orthogonality of the directions of the dust-lane-dominant side and the approaching side, especially for spirals with their small inclination angles. Note also that the decision on whether the

spiral is the trailing or leading type (column (5)) was made only after all the information in columns (2)–(4) was determined so that the information in columns (2)–(4) was not affected by the information in column (5).

Remarkably, all 146 galaxies have trailing spiral arms if the dust-lane-dominant side is closer to us. The decisions for only two of the 146 spiral galaxies, NGC 722 and NGC 4622, are somewhat questionable, as will be discussed in Section 4. It has been widely assumed that all the spiral galaxies are trailing, but this paper provides an upto-date observational confirmation of this generally accepted idea.

NGC 5678	Z	W	N	T	Kalinova et al. (2017)				
NGC 5692	S	NW	SW	T	Truong et al. (2017)				
NGC 5949	Z	SW	NW	T	Truong et al. (2017)				
NGC 5980	Z	NW	NE	T	Levy et al. (2018)				
NGC 6015	Z	NW	NE	T	Verdes-Montenegro et al. (1997)				
NGC 6106	Z	SW	NW	T	Truong et al. (2017)				
NGC 6132	Z	NE	SE	T	Falcon-Barroso et al. (2017)				
NGC 6181	S	W	S	T	Burbridge et al. (1965b)				
NGC 6186	Z	NW	NE	T	Falcon-Barroso et al. (2017)				
NGC 6207	S	NW	SW	T	Carozzi (1976)				
NGC 6394	S	NW	SW	T	Falcon-Barroso et al. (2017)				
NGC 6503	S	SW	SE	T	de Vaucouleurs & Caulet (1982)				
NGC 6907	S	SE	NE	T	Scarano et al. (2008)				
NGC 6946	Z	NW	NE	T	Sanchez et al. (2009)				
NGC 6951	Z	SW	NW	T	Rozas et al. (2002)				
NGC 6978	Z	SW	NW	T	Falcon-Barroso et al. (2017)				
NGC 7311	S	SE	NE	T	Falcon-Barroso et al. (2017)				
NGC 7331	Z	W	N	T	Bottema (1999)				
NGC 7364	Z	SE	SW	T	Falcon-Barroso et al. (2017)				
NGC 7466	Z	SE	SW	T	Falcon-Barroso et al. (2017)				
NGC 7479	Z	NW	NE	T	Laine & Gottesman (1998)				
NGC 7536	Z	NW	NE	T	Garcia-Lorenzo et al. (2015)				
NGC 7541	Z	SW	NW	T	Rubin et al. (1980)				
NGC 7591	S	NE	NW	T	Falcon-Barroso et al. (2017)				
NGC 7608	Z	SE	SW	T	Falcon-Barroso et al. (2017)				
NGC 7625	S	SE	NE	T	Falcon-Barroso et al. (2017)				
NGC 7631	S	NW	SW	T	Falcon-Barroso et al. (2017)				
NGC 7738	S	NW	SW	T	Falcon-Barroso et al. (2017)				
NGC 7782	S	W	S	T	Pignatelli et al. (2001)				
NGC 7787	S	S	E	T	Falcon-Barroso et al. (2017)				
UGC 36	S	NW	SW	T	Garcia-Lorenzo et al. (2015)				
UGC 148	Z	SW	NW	T	Garcia-Lorenzo et al. (2015)				
UGC 1057	Z	SW	NW	T	Garcia-Lorenzo et al. (2015)				
UGC 1938	S	SW	SE	T	Garcia-Lorenzo et al. (2015)				
UGC 2405	S	NE	NW	T	Garcia-Lorenzo et al. (2015)				
UGC 3944	Z	SW	NW	T	Garcia-Lorenzo et al. (2015)				
UGC 3969	Z	NE	SE	T	Garcia-Lorenzo et al. (2015)				
UGC 4132	Z	SE	SW	T	Levy et al. (2018)				
UGC 5359	S	SW	SE	T	Garcia-Lorenzo et al. (2015)				
UGC 5396	S	NE	NW	T	Garcia-Lorenzo et al. (2015)				
UGC 5598	Z	SE	SW	T	Garcia-Lorenzo et al. (2015)				
UGC 7145	S	NE	NW	T	Garcia-Lorenzo et al. (2015)				
UGC 7901	S	SE	NE	T	Epinat et al. (2010)				
UGC 9873	Z	NE	SE	T	Garcia-Lorenzo et al. (2015)				
UGC 9892	S	SW	SE	T	Garcia-Lorenzo et al. (2015)				
UGC 10331	Z	NE	SE	T	Garcia-Lorenzo et al. (2015)				
UGC 10384	Z	S	W	T	Levy et al. (2018)				
UGC 10972	S	NW	SW	T	Garcia-Lorenzo et al. (2015)				
UGC 11792	Z	SW	NW	T	Garcia-Lorenzo et al. (2015)				
UGC 12519	S	NE	NW	T	Garcia-Lorenzo et al. (2015)				

Figure 8. (Continued.)

Figure 9 lists 321 spiral galaxies for which the spiral winding direction (column (2), uppercase letters) and the approaching side (column (4), uppercase letters) are taken from the literature (column (5)). Individual postage-stamp images are shown in columns (7)–(10), as in Table 1. Column (3) shows, in lowercase letters, the inferred near and dark sides of the minor axis of each galaxy, assuming that all the spirals are trailing. Figure 10 lists the spiral winding direction (column (2), uppercase letters) and dark side on the minor axis (column (3), uppercase letters) of 63 spiral galaxies. The inferred

approaching side of these spiral galaxies, assuming that all the spirals are trailing, is given in lowercase letters in column (4).

Figure 11 lists 25 galaxies for which the darker side (column (3), uppercase letters) and the approaching side (column (4), uppercase letters) are observationally confirmed. The inferred sense of spiral winding, assuming that all the spirals are trailing, is given in lowercase letters in column (2). Table 2 lists other names of some of the sample galaxies.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ID	S/Z	Dark Side	Appr. Side	Reference	Image 1	Image 2	Image 3	Image 4
IC 467	Z	se	SW	Rubin et al. (1980)				
IC 674	S	sw	SE	Falcon-Barroso et al. (2017)				
IC 776	S	sw	SE	Garcia-Lorenzo et al. (2015)				
IC 1151	S	nw	SW	Falcon-Barroso et al. (2017)				
IC 1199	S	ne	NW	Levy et al. (2018)				
IC 1256	Z	n	E	Falcon-Barroso et al. (2017)				
IC 1528	Z	se	SW	Falcon-Barroso et al. (2017)				
IC 2095	Z	se	SW	Garcia-Lorenzo et al. (2015)				
IC 2163	S	s	E	Rubin & Ford (1983)				
IC 2487	Z	ne	SE	Falcon-Barroso et al. (2017)				
IC 4566	S	sw	SE	Falcon-Barroso et al. (2017)				
IC 5309	S	se	NE	Falcon-Barroso et al. (2017)				
NGC 1	Z	nw	NE	Falcon-Barroso et al. (2017)				
NGC 23	S	se	NE	Falcon-Barroso et al. (2017)				
NGC 36	S	ne	NW	Falcon-Barroso et al. (2017)				
NGC 45	Z	sw	NW	Chemin et al. (2006)				
NGC 160	S	se	NE	Falcon-Barroso et al. (2017)				
NGC 171	S	n	W	Falcon-Barroso et al. (2017)				
NGC 177	Z	nw	NE	Falcon-Barroso et al. (2017)				
NGC 180	S	nw	SW	Falcon-Barroso et al. (2017)				
NGC 192	S	nw	SW	Falcon-Barroso et al. (2017)				
NGC 214	S	nw	SW	Falcon-Barroso et al. (2017)				
NGC 217	Z	ne	SE	Falcon-Barroso et al. (2017)				
NGC 234	S	nw	SW	Falcon-Barroso et al. (2017)				
NGC 237	S	e	N	Falcon-Barroso et al. (2017)				
NGC 257	Z	n	E	Falcon-Barroso et al. (2017)				
NGC 278	S	se	NE	Knapen et al. (2004)				
NGC 289	S	ne	NW	Walsh et al. (1997)				
NGC 300	S	s	E	Hlavacek-Larrondo et al. (2011)				
NGC 428	Z	sw	NW	Smoker et al. (1996)				
NGC 444	Z	ne	SE	Falcon-Barroso et al. (2017)				
NGC 450	Z	nw	NE	Rubin & Ford (1983)				
NGC 477	S	sw	SE	Falcon-Barroso et al. (2017)				
NGC 488	Z	e	S	Kalinova et al. (2017)				
NGC 496	Z	nw	NE	Falcon-Barroso et al. (2017)				
NGC 497	S	sw	SE	Afanasev et al. (1991)				

Figure 9. Dark side (3) inferred from the spin parity of spiral galaxies. Note that the uppercase letters in columns (2) and (4) are observational data, whereas the lowercase letters in column (3) are inferred results assuming that all the spiral galaxies are trailing. Asterisks indicate galaxies with an alternative name, which is listed in Figure 11.

4. Discussion

4.1. Notes on Individual Galaxies

4.1.1 IC 2101

IC 2101 is clearly redder on the northeast side and shows an S-type spiral structure.

4.1.2 NGC 224

NGC 224 (M31) is known to rotate with its southwest side approaching us (Peace 1918; Babcock 1938). A publicly available color image is adopted to fit in Figure 8. The northwest side of the disk, where the dust lanes are more conspicuous than on the southeast side, was confirmed to be the near side by a differential interstellar reddening study of its globular cluster system (Iye & Richter 1985). This galaxy remains the only galaxy for which there is firm independent proof of the generally adopted idea that the dust-lane-dominant dark side is the near side. Whether M31 has S-wise or Z-wise

spiral winding as projected on the sky has been somewhat controversial because of the rather high inclination of the galactic disk plane.

Simien et al. (1978) examined the distribution of 981 H II regions in M31 and concluded that a one-armed leading spiral fits the data better than a classical two-armed trailing spiral. However, we used the face-on image produced by Efremov (2009) to determine that M31 has S-type two-armed spiral structure rather than a Z-type spiral. This concludes that M31 is a trailing spiral.

4.1.3 NGC 772

The figures in both Pignatelli et al. (2001) and Rhee & van Albada (1996) show that the northwest side is approaching. This makes NGC 772 a unique galaxy with leading spiral arms. Heraudeau & Simien (1998), however, indicated that the southeast sides are approaching according to their convention of showing the rotation curve for PA = 130°, and this places NGC 772 in the category of trailing spirals. For NGC 772,

NGC 551	S	ne	NW	Falcon-Barroso et al. (2017)				
NGC 628	Z	e	S	Fathi et al. (2007)				
NGC 701	S	nw	SW	Rubin et al. (1980)				
NGC 753	Z	ne	SE	Rubin et al. (1980)				
NGC 768	Z	se	SW	Falcon-Barroso et al. (2017)				
NGC 776	Z	ne	SE	Falcon-Barroso et al. (2017)				
NGC 853	Z	se	SW	Truong et al. (2017)				
NGC 864	S	w	S	Erroz-Ferrer et al. (2012)				
NGC 895	Z	s	W	Afanasev et al. (1991)				
NGC 922	S	e	N	Elagali et al. (2018)				
NGC 925	Z	n	E	Pisano et al. (1998)				
NGC 1012	S	se	NE	Truong et al. (2017)				
NGC 1042	S	s	E	Luo et al. (2016)				
NGC 1058	S	nw	SW	Dickey et al. (1990)				
NGC 1068	S	w	S	Imanishi et al. (2018)				
NGC 1073	S	sw	SE	England et al. (1990)				
NGC 1087	S	nw	SW	Rubin et al. (1980)				
NGC 1169	S	nw	SW	van Driel & van Woerden (1994)				
NGC 1232	Z	n	E	van Zee & Bryant (1999)				
NGC 1300	Z	n	E	Lindblad et al. (1997)				
NGC 1358	S	ne	NW	Schnorr-Mueller et al. (2017)				
NGC 1512	Z	nw	NE	Buta (1988)				
NGC 1614	S	w	S	Garcia-Burillo et al. (2018)				
NGC 1645	S	s	E	Garcia-Lorenzo et al. (2015)				
NGC 1677	Z	sw	NW	Falcon-Barroso et al. (2017)				
NGC 1744	S	e	N	Pisano et al. (1998)				
NGC 1784	Z	n	E	Ratay & Gottesman (2001)				
NGC 1832	S	se	NE	Burbidge & Burbidge (1968)				
NGC 2139	S	ne	NW	Andersen et al. (2008)				
NGC 2207	Z	n	E	Rubin & Ford (1983)				
NGC 2276	S	s	E	Gruendl et al. (1993)				
NGC 2336	S	w	S	Wilke et al. (1999)				
NGC 2449	Z	sw	NW	Falcon-Barroso et al. (2017)				
NGC 2486	Z	n	E	Falcon-Barroso et al. (2017)				
NGC 2487	S	sw	SE	Falcon-Barroso et al. (2017)				
NGC 2500	Z	sw	NE	Sanchez-Gil et al. (2015)				
NGC 2525	Z	s	W	Blackman & Pence (1982)				
NGC 2540	S	ne	NW	Falcon-Barroso et al. (2017)				
NGC 2552	S	nw	SW	Neumayer et al. (2011)				
NGC 2553	Z	se	SW	Falcon-Barroso et al. (2017)				
NGC 2604	S	sw	SE	Falcon-Barroso et al. (2017)				
NGC 2608	S	se	NE	Rubin et al. (1980)				
NGC 2730	Z	se	SW	Falcon-Barroso et al. (2017)				
NGC 2776	S	sw	SE	Carozzi-Meyssonnier (1979)				
NGC 2805	S	sw	SE	Kalinova et al. (2017)				
NGC 2906	S	nw	SW	Falcon-Barroso et al. (2017)				
NGC 2915	Z	ne	SE	Masset & Bureau (2003)				
NGC 2916	S	nw	SW	Falcon-Barroso et al. (2017)				
NGC 2964	Z	n	E	Kalinova et al. (2017)				
NGC 2997	Z	se	SW	Peterson (1978)				
NGC 2998	Z	nw	NE	Rubin et al. (1980)				
NGC 3057	S	se	NE	Falcon-Barroso et al. (2017)				

Figure 9. (Continued.)

additional observational confirmation of which side of the major axis is approaching us is necessary to conclude whether the spiral is leading or trailing.

4.1.4 NGC 1097

Note that the identification of the near side based on the extinction A_v map obtained from the *Hubble Space Telescope (HST)* image ratio F814W/F438W of NGC 1097 (Prieto et al. 2019) is consistent with that from the dust

lanes. This confirms that the

NGC 3106	<i>S</i>	ne	NW	Falcon-Barroso et al. (2017)				
NGC 3145	Z	nw	NE	Kaufman et al. (2015)				
NGC 3166	Z	nw	NE	Lee-Waddell et al. (2012)				
NGC 3206	Z	w	N	Neumayer et al. (2011)				
NGC 3344	Z	sw	NW	Corbelli et al. (1989)				
NGC 3346	Z	ne	SE	Neumayer et al. (2011)				
NGC 3351	<i>S</i>	se	NE	Buta (1988)				
NGC 3359	<i>S</i>	w	S	Ball (1986)				
NGC 3367	<i>S</i>	nw	SW	Garcia-Barreto & Rosado (2001)				
NGC 3381	<i>S</i>	e	N	Falcon-Barroso et al. (2017)				
NGC 3395	Z	se	SW	Clemens et al. (1999)				
NGC 3423	<i>S</i>	nw	SW	Neumayer et al. (2011)				
NGC 3433	<i>S</i>	nw	SW	Beckman et al. (2018)				
NGC 3445	<i>S</i>	sw	SE	Neumayer et al. (2011)				
NGC 3614	<i>S</i>	ne	NW	Garcia-Lorenzo et al. (2015)				
NGC 3631	Z	ne	SE	Knapen (1997)				
NGC 3642	<i>S</i>	ne	NW	Verdes-Montenegro et al. (2002)				
NGC 3687	Z	sw	NW	Falcon-Barroso et al. (2017)				
NGC 3811	Z	w	N	Falcon-Barroso et al. (2017)				
NGC 3893	<i>S</i>	sw	SE	Gabbasov et al. (2014)				
NGC 3898	<i>S</i>	ne	NW	Pignatelli et al. (2001)				
NGC 3938	Z	nw	NE	Jimenez-Vicente et al. (1999)				
NGC 3955	<i>S</i>	w	S	Chromey (1974)				
NGC 3992	<i>S</i>	nw	SW	Wilke et al. (2000)				
NGC 3994	<i>S</i>	w	S	Falcon-Barroso et al. (2017)				
NGC 4027	Z	e	S	Sparke & Taylor (1989)				
NGC 4030	<i>S</i>	nw	SW	Kalinova et al. (2017)				
NGC 4047	Z	ne	SE	Levy et al. (2018)				
NGC 4051	<i>S</i>	sw	SE	Liszt & Dickey (1995)				
NGC 4064	<i>S</i>	s	E	Cortes et al. (2006)				
NGC 4102	Z	se	SW	Kalinova et al. (2017)				
NGC 4123	Z	ne	SE	Weiner et al. (2001)				
NGC 4136	Z	n	E	Allsopp (1979)				
NGC 4151	Z	se	SW	Asif et al. (2005)				
NGC 4185	<i>S</i>	ne	NW	Falcon-Barroso et al. (2017)				
NGC 4204	Z	nw	NE	Neumayer et al. (2011)				
NGC 4210	Z	sw	NW	Falcon-Barroso et al. (2017)				
NGC 4236	<i>S</i>	ne	NW	Shostak & Rogstad (1973)				
NGC 4254	Z	se	SW	Sofue et al. (2003)				
NGC 4299	Z	nw	NE	Neumayer et al. (2011)				
NGC 4303	Z	ne	SE	Koda & Sofue (2006)				
NGC 4351	<i>S</i>	nw	SW	Cortes et al. (2015)				
NGC 4457	Z	se	SW	Cortes et al. (2015)				
NGC 4470	<i>S</i>	ne	NW	Falcon-Barroso et al. (2017)				
NGC 4487	<i>S</i>	s	E	Kalinova et al. (2017)				
NGC 4490	Z	sw	NW	Elmegreen et al. (1998)				
NGC 4496A	Z	se	SW	Neumayer et al. (2011)				
NGC 4522	<i>S</i>	se	NE	Kenney et al. (2004)				

Figure 9. (Continued.)

4.1.6 NGC 2775

We determined the Z-wise winding sense of NGC 2775 from high-resolution *HST* images.

4.1.7 NGC 3124

This galaxy has well-defined *S*-wise main spiral arms. Treuhardt et al. (2014), however, pointed out that a Z-wise spiral feature is present at the end of the central bar.

4.1.8 NGC 3160

NGC 3160 is almost edge-on, but we can tell that the southwest side of the disk is nearer to us, as we can see that the

dust lane is located slightly southwest of the nucleus of this galaxy. The Z-wise spiral winding sense for this galaxy is inferred from the extended outer part of the disk.

4.1.9 NGC 4622

NGC 4622 is well-known for its unique spiral structure winding in opposite directions. The two outer main spiral arms wind *S*-wise on the sky, but an additional Z-wise spiral arm is visible in the northeastern inner region. The south side of this galaxy is approaching (Buta et al. 2003). Thomasson et al. (1989) and Byrd et al. (1989) made an *N*-body simulation of a retrograde encounter by a companion galaxy to reproduce the formation of a leading arm as seen in NGC 4622. Buta et al. (1992) interpreted

NGC 4536	Z	w	N	Mazzalay et al. (2014)				
NGC 4540	S	w	S	Neumayer et al. (2011)				
NGC 4548	Z	sw	NW	Vollmer et al. (1999)				
NGC 4618	Z	sw	NW	Bush & Wilcots (2004)				
NGC 4644	Z	nw	NE	Levy et al. (2018)				
NGC 4647	S	n	W	Young et al. (2006)				
NGC 4654	S	ne	NW	Vollmer (2003)				
NGC 4682	S	se	NE	Rubin et al. (1980)				
NGC 4691	S	s	E	Wiklind et al. (1993)				
NGC 4701	S	se	NE	Truong et al. (2017)				
NGC 4711	S	nw	SW	Levy et al. (2018)				
NGC 4725	Z	se	SW	Buta (1988)				
NGC 4731	S	s	E	Gottesman et al. (1984)				
NGC 4736	Z	ne	SE	Buta (1988)				
NGC 4775	S	se	NE	Kalinova et al. (2017)				
NGC 4814	S	sw	SE	Zasov & Sil'chenko (1987)				
NGC 4904	Z	nw	NE	Neumayer et al. (2011)				
NGC 4961	Z	n	E	Falcon-Barroso et al. (2017)				
NGC 5000	S	se	NE	Falcon-Barroso et al. (2017)				
NGC 5016	S	se	NE	Levy et al. (2018)				
NGC 5056	S	w	S	Falcon-Barroso et al. (2017)				
NGC 5101	Z	sw	NW	van Driel et al. (1988)				
NGC 5135	S	w	S	Sabatini et al. (2018)				
NGC 5204	Z	w	N	Sicotte & Carignan (1997)				
NGC 5205	Z	ne	SE	Falcon-Barroso et al. (2017)				
NGC 5218	Z	se	SW	Falcon-Barroso et al. (2017)				
NGC 5371	S	w	S	Zasov & Sil'chenko (1987)				
NGC 5378	Z	s	W	Falcon-Barroso et al. (2017)				
NGC 5383	Z	sw	NW	Duval & Athanassoula (1983)				
NGC 5394	S	nw	SW	Roche et al. (2015)				
NGC 5406	S	sw	SE	Falcon-Barroso et al. (2017)				
NGC 5427	Z	se	SW	Font et al. (2011)				
NGC 5457	S	nw	SW	Comte et al. (1979)				
NGC 5474	Z	sw	NW	Rownd et al. (1994)				
NGC 5480	S	w	S	Levy et al. (2018)				
NGC 5520	S	nw	SW	Levy et al. (2018)				
NGC 5630	S	s	E	Falcon-Barroso et al. (2017)				
NGC 5633	Z	nw	NE	Levy et al. (2018)				
NGC 5657	S	ne	NW	Falcon-Barroso et al. (2017)				
NGC 5668	S	ne	NW	Schulman et al. (1996)				
NGC 5669	Z	se	SW	Neumayer et al. (2011)				
NGC 5682	Z	sw	NW	Falcon-Barroso et al. (2017)				
NGC 5720	Z	ne	SE	Falcon-Barroso et al. (2017)				
NGC 5732	S	se	NE	Falcon-Barroso et al. (2017)				
NGC 5789	Z	sw	NW	Neumayer et al. (2011)				
NGC 5850	S	sw	SE	Higdon et al. (1998)				
NGC 5888	Z	ne	SE	Falcon-Barroso et al. (2017)				
NGC 5905	Z	sw	NW	van Moorsel (1982)				
NGC 5930	S	sw	SE	Falcon-Barroso et al. (2017)				
NGC 5934	Z	w	N	Falcon-Barroso et al. (2017)				
NGC 5947	S	nw	SW	Falcon-Barroso et al. (2017)				
NGC 5964	S	ne	NW	Neumayer et al. (2011)				

Figure 9. (Continued.)

the inner arm of NGC 4622 as a leading arm produced by such an encounter. Buta et al. (2003) later argued, however, that the east side is the near side on the basis of dust features visible in *HST* images. This indicates that NGC 4622 is an exceptional galaxy with two main leading spiral arms. We think, however, the conclusion that the east side of NGC 4622 is the near side based on dust lanes is not obvious for this nearly face-on spiral. We note that dust features are also present on the west side, although they

are much fainter than those on the east side. We prefer, therefore, the interpretation that the west side of NGC 4622 is the near side, which allows a more reasonable understanding that the two main spirals are trailing.

4.1.10 NGC 5055

The image of NGC 5055 in the classical atlas of Sandage & Bedke (1988) is inverted, whereas the images of the same

NGC 5971	<i>S</i>	ne	NW	Falcon-Barroso et al. (2017)				
NGC 6004	<i>S</i>	n	W	Falcon-Barroso et al. (2017)				
NGC 6032	<i>Z</i>	se	SW	Falcon-Barroso et al. (2017)				
NGC 6060	<i>Z</i>	ne	SE	Falcon-Barroso et al. (2017)				
NGC 6063	<i>S</i>	ne	NW	Falcon-Barroso et al. (2017)				
NGC 6154	<i>S</i>	se	NE	Garcia-Lorenzo et al. (2015)				
NGC 6155	<i>S</i>	nw	SW	Yoachim et al. (2010)				
NGC 6301	<i>S</i>	ne	NW	Falcon-Barroso et al. (2017)				
NGC 6478	<i>Z</i>	nw	NE	Falcon-Barroso et al. (2017)				
NGC 6497	<i>Z</i>	sw	NW	Falcon-Barroso et al. (2017)				
NGC 6509	<i>Z</i>	n	E	Neumayer et al. (2011)				
NGC 6814	<i>S</i>	w	S	Liszt & Dickey (1995)				
NGC 6941	<i>S</i>	ne	NW	Falcon-Barroso et al. (2017)				
NGC 7047	<i>Z</i>	sw	NW	Falcon-Barroso et al. (2017)				
NGC 7217	<i>Z</i>	n	E	Buta et al. (1995)				
NGC 7321	<i>S</i>	nw	SW	Falcon-Barroso et al. (2017)				
NGC 7489	<i>Z</i>	sw	NW	Falcon-Barroso et al. (2017)				
NGC 7549	<i>S</i>	e	N	Falcon-Barroso et al. (2017)				
NGC 7653	<i>S</i>	ne	NW	Falcon-Barroso et al. (2017)				
NGC 7664	<i>Z</i>	s	W	Rubin et al. (1980)				
NGC 7691	<i>S</i>	sw	SE	Falcon-Barroso et al. (2017)				
NGC 7716	<i>S</i>	se	NE	Falcon-Barroso et al. (2017)				
NGC 7723	<i>Z</i>	se	SW	Chevalier & Furenlid (1978)				
NGC 7741	<i>S</i>	w	S	Blackman & Pence (1982)				
NGC 7743	<i>Z</i>	n	E	Katkov et al. (2011)				
NGC 7819	<i>Z</i>	s	W	Falcon-Barroso et al. (2017)				
NGC 7824	<i>S</i>	sw	SE	Falcon-Barroso et al. (2017)				
PGC02162	<i>Z</i>	ne	SE	Andersen & Bershady (2013)				
PGC03512	<i>Z</i>	ne	SE	Andersen & Bershady (2013)				
PGC05673	<i>S</i>	nw	SW	Andersen & Bershady (2013)				
PGC06855	<i>Z</i>	ne	SE	Andersen & Bershady (2013)				
PGC07826	<i>S</i>	se	NE	Andersen & Bershady (2013)				
PGC08941	<i>Z</i>	se	SW	Andersen & Bershady (2013)				
PGC14564	<i>S</i>	sw	SE	Andersen & Bershady (2013)				
PGC15531	<i>Z</i>	nw	NE	Andersen & Bershady (2013)				
PGC16274	<i>Z</i>	nw	NW	Andersen & Bershady (2013)				
PGC19767	<i>Z</i>	se	SW	Andersen & Bershady (2013)				
PGC20938	<i>Z</i>	se	SW	Andersen & Bershady (2013)				
PGC23333	<i>Z</i>	nw	NE	Andersen & Bershady (2013)				
PGC23598	<i>Z</i>	se	SW	Andersen & Bershady (2013)				
PGC23913	<i>S</i>	se	NE	Andersen & Bershady (2013)				
PGC24788	<i>Z</i>	ne	SE	Andersen & Bershady (2013)				
PGC26140	<i>S</i>	nw	SW	Andersen & Bershady (2013)				
PGC26517	<i>Z</i>	se	SW	Andersen & Bershady (2013)		</td		

PGC32091	<i>S</i>	e	N	Andersen & Bershady (2013)				
PGC32638	<i>Z</i>	nw	NE	Andersen & Bershady (2013)				
PGC33465	<i>S</i>	n	W	Andersen & Bershady (2013)				
PGC36925	<i>Z</i>	sw	NW	Andersen & Bershady (2013)				
PGC38268	<i>Z</i>	nw	NE	Andersen & Bershady (2013)				
PGC38908	<i>S</i>	sw	SE	Andersen & Bershady (2013)				
PGC39728	<i>Z</i>	s	W	Andersen & Bershady (2013)				
PGC46767	<i>S</i>	ne	NW	Andersen & Bershady (2013)				
PGC49906	<i>Z</i>	w	N	Andersen & Bershady (2013)				
PGC55750	<i>Z</i>	nw	NE	Andersen & Bershady (2013)				
PGC56010	<i>S</i>	ne	NW	Andersen & Bershady (2013)				
PGC57931	<i>S</i>	se	NE	Andersen & Bershady (2013)				
PGC58410	<i>Z</i>	nw	NE	Andersen & Bershady (2013)				
PGC71106	<i>Z</i>	e	S	Andersen & Bershady (2013)				
PGC72144	<i>S</i>	se	NE	Andersen & Bershady (2013)				
PGC72453	<i>Z</i>	se	SW	Andersen & Bershady (2013)				
UGC 5	<i>Z</i>	se	SW	Falcon-Barroso et al. (2017)				
UGC 312	<i>S</i>	nw	SW	Garcia-Lorenzo et al. (2015)				
UGC 448*	<i>Z</i>	sw	NW	Martinsson et al. (2013)				
UGC 463*	<i>S</i>	se	NE	Martinsson et al. (2013)				
UGC 807	<i>S</i>	se	NE	Rubin & Ford (1983)				
UGC 1081*	<i>S</i>	se	NE	Martinsson et al. (2013)				
UGC 1087	<i>S</i>	se	NE	Martinsson et al. (2013)				
UGC 1529*	<i>Z</i>	ne	SE	Martinsson et al. (2013)				
UGC 1635*	<i>S</i>	sw	SE	Martinsson et al. (2013)				
UGC 1862	<i>S</i>	se	NE	Martinsson et al. (2013)				
UGC 1908*	<i>S</i>	nw	SW	Martinsson et al. (2013)				
UGC 2885	<i>S</i>	se	NE	Rubin et al. (1980)				
UGC 3091	<i>Z</i>	se	SW	Martinsson et al. (2013)				
UGC 3140*	<i>Z</i>	sw	NW	Martinsson et al. (2013)				
UGC 3253	<i>S</i>	nw	SW	Garcia-Lorenzo et al. (2015)				
UGC 3574	<i>S</i>	n	W	Neumayer et al. (2011)				
UGC 3691	<i>Z</i>	nw	NE	Rubin et al. (1980)				
UGC 3701	<i>Z</i>	n	E	Martinsson et al. (2013)				
UGC 3740	<i>S</i>	se	NE	Epinat et al. (2008)				
UGC 3809	<i>S</i>	sw	SE	Garrido et al. (2004)				
UGC 3973	<i>Z</i>	ne	SE	Garcia-Lorenzo et al. (2015)				
UGC 3995	<i>Z</i>	nw	NE	Garcia-Lorenzo et al. (2015)				
UGC 3997	<i>Z</i>	nw	NE	Martinsson et al. (2013)				
UGC 4036*	<i>Z</i>	se	SW	Martinsson et al. (2013)				
UGC 4107	<i>Z</i>	sw	NW	Martinsson et al. (2013)				
UGC 4256*	<i>S</i>	ne	NW	Martinsson et al. (2013)				
UGC 4284	<i>Z</i>	w	N	Garrido et al. (2004)				
UGC 4368*	<i>S</i>	sw	SE	Martinsson et al. (2013)				
UGC 4380	<i>Z</i>	nw	NE	Martinsson et al. (2013)				
UGC 4458*	<i>Z</i>	sw	NW	Martinsson et al. (2013)				
UGC 4499	<i>Z</i>	sw	NW	Neumayer et al. (2011)				
UGC 4555*	<i>S</i>	s	E	Martinsson et al. (2013)				
UGC 4622	<i>Z</i>	ne	SE	Martinsson et al. (2013)				
UGC 4659	<i>Z</i>	sw	NW	Garcia-Lorenzo et al. (2015)				
UGC 4936	<i>S</i>	sw	SE	Garrido et al. (2004)				
UGC 5358	<i>S</i>	se	NE	Garcia-Lorenzo et al. (2015)				

Figure 9. (Continued.)

results have been reported. The near side of the nearly face-on spiral NGC 4622 is still open to debate.

The highly reasonable interpretation that the spiral structure seen in disk galaxies is essentially trailing provides us a basis to identify the sign of the line-of-sight component of the spin vector of a spiral galaxy just by identifying whether it is an *S*-wise spiral or a *Z*-wise spiral from images. We can see whether the spin vector of a spiral galaxy is pointing toward us or away from us without obtaining its spectroscopic observational data. Although it is unlikely, the opposite identification applies if all

the spirals are leading instead of trailing. We can still use *S/Z* identification of spiral galaxies to study if there is any anisotropy in the spin vector distribution of sample galaxies.

The distribution of the sign of the line-of-sight component of the spin vector of spiral galaxies provides a tool to investigate the origin of the vorticity distribution in aggregations of galaxies, including the Local Group, groups of galaxies, clusters of galaxies, and the Local Super Cluster of galaxies. Thompson (1973), Borchkhadze & Kogosvili (1976), Yamagata et al. (1981), and MacGillivray & Dodd (1985) made early attempts to

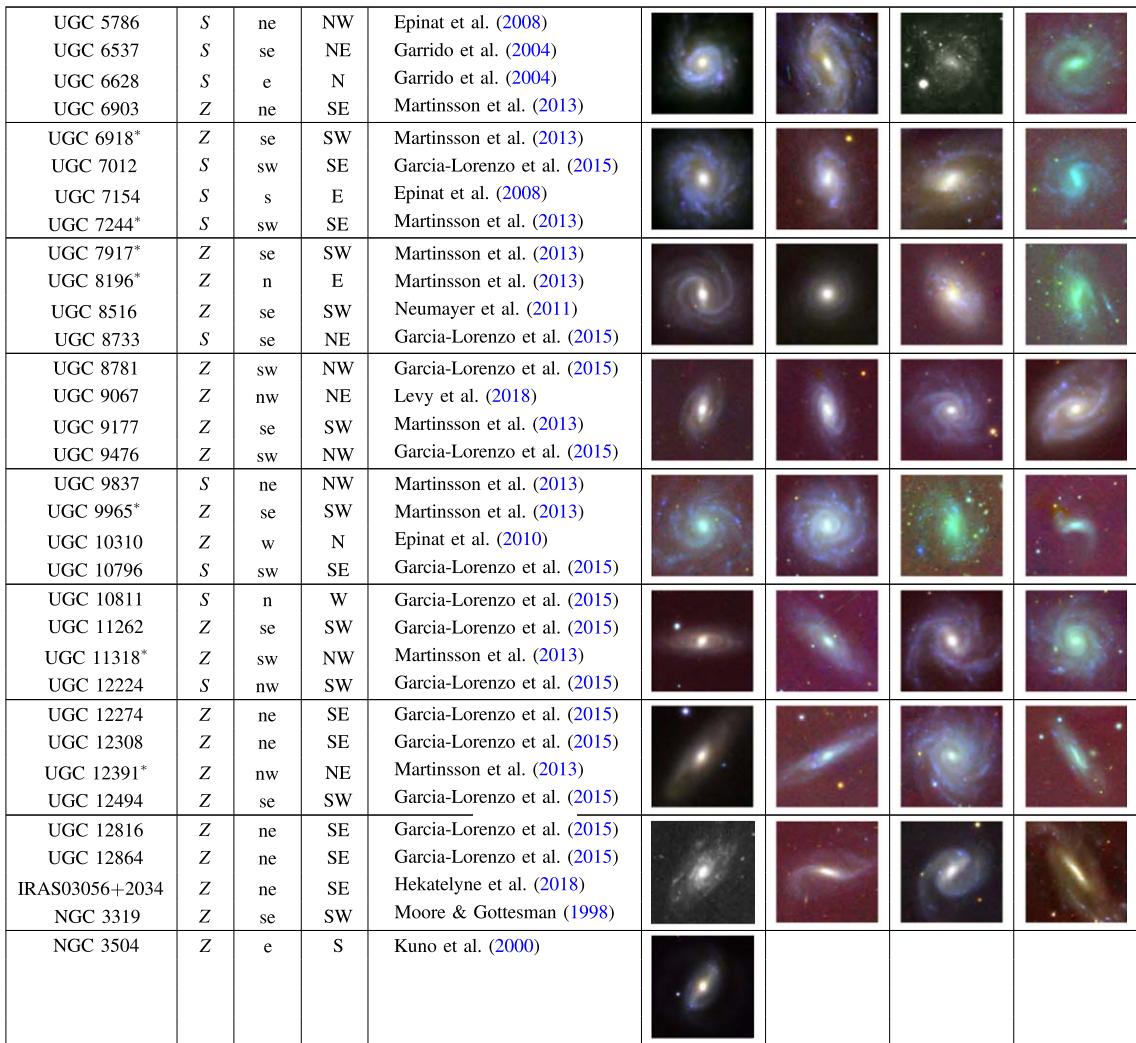


Figure 9. (Continued.)

Table 1
Number of Spiral Galaxies Examined

(1) <i>S/Z</i> Winding	(2) Dark Side	(3) Approaching Side	(4) Number of Spirals
✓	✓	✓	146
✓	...	✓	321
✓	✓	...	63
...	✓	✓	25
✓	252
...	✓	...	8
...	...	✓	27
782	242	519	842

Note. The check marks indicate that the judgment result is available for (1) *S/Z* spiral winding, (2) dust-lane-dominant side, denoted here dark side, and (3) the approaching side..

study the *S/Z* distribution of galaxies to find any bias in the spin parity distribution of galaxies in the northern sky. Iye & Sugai (1991) studied the *S/Z* distribution of 8287 spiral galaxies in the southern sky using the ESO/Uppsala Survey of the ESO(B) Atlas. Borchkhadze & Kogoshvili (1976) and Yamagata et al. (1981) identified more Sbc-Sc spirals in the northern hemisphere as S-spirals than as Z-spirals, whereas Iye & Sugai (1991)

reported that Z-spirals were slightly dominant over S-spirals in the southern hemisphere. Sugai & Iye (1995) searched for a spatial correlation in the spin angular momentum distribution of galaxies by analyzing the *S/Z* distribution of 9825 galaxies to constrain the galaxy formation scenarios but found no significant trend. All these studies were performed by visual inspection of image data.

We are exploiting such studies by compiling a much larger database for *S/Z* spin discrimination using a recent collection of high-resolution images of galaxies, such as the SDSS, PanSTARRS, and Subaru Hyper Suprime-Cam Public Data Release 2. To make robust catalogs, we are developing deep learning software that will allow unbiased, automatic *S/Z* classification, which will be reported in a forthcoming paper. The current paper forms the first basis of our series of studies using *S/Z* parity to study the distribution and origin of galaxy spin vector.

Several papers report on the distribution of the position angles of the major axes of disk galaxies and/or the axis ratio distribution of galaxies to check for departures from a random distribution (e.g., Flin & Godlowski 1990; Navarro et al. 2004; Trujillo et al. 2006; Bett et al. 2007; Lee & Erdogdu 2007). These approaches involve quantitative measurements of the

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ID	S/Z	Dark Side	Appr. Side	Image 1	Image 2	Image 3	Image 4
IC 750	Z	SE	sw				
IC 764	S	E	n				
NGC 150	S	NE	nw				
NGC 210	Z	E	s				
NGC 255	Z	NW	ne				
NGC 470	Z	SW	nw				
NGC 716	S	NW	sw				
NGC 779	Z	NE	se				
NGC 787	Z	SE	sw				
NGC 1309	Z	SW	nw				
NGC 1324	Z	SW	nw				
NGC 1337	Z	NE	se				
NGC 1353	S	SW	se				
NGC 1385	S	E	n				
NGC 1406	S	SW	se				
NGC 1415	Z	SW	nw				
NGC 1964	Z	NW	ne				
NGC 2268	S	S	e				
NGC 2713	Z	N	e				
NGC 2748	S	SE	ne				
NGC 2815	S	E	n				
NGC 3003	Z	N	e				
NGC 3185	S	SW	se				
NGC 3200	S	N	w				
NGC 3370	Z	NE	se				
NGC 3430	S	NW	sw				
NGC 3621	Z	NE	se				
NGC 3726	S	W	s				
NGC 3813	S	N	w				
NGC 3877	Z	SE	sw				
NGC 3887	Z	E	s				
NGC 3917	S	SE	ne				
NGC 4094	S	NW	sw				
NGC 4096	S	NW	sw				
NGC 4162	S	W	s				
NGC 4178	Z	SE	sw				
NGC 4192	S	NE	nw				
NGC 4220	S	NE	nw				
NGC 4274	Z	NE	se				
NGC 4579	S	NW	sw				
NGC 4586	S	NE	nw				
NGC 4593	Z	NW	ne				
NGC 4602	Z	S	w				
NGC 4771	Z	NE	se				
NGC 4800	S	W	s				
NGC 4845	Z	SE	sw				
NGC 4951	S	N	w				
NGC 5443	Z	SE	sw				
NGC 5522	S	SE	ne				
NGC 5533	Z	SE	sw				
NGC 5559	S	SE	ne				
NGC 5587	S	SW	se				

Figure 10. Approaching side (4) inferred from the spin parity of spiral galaxies. Note that the uppercase letters in columns (2) and (3) are observational data, and the lowercase letters in column (4) are inferred results assuming that all the spiral galaxies are trailing.

position angle and/or axis ratio, which are not free from measurement errors and could be subject to systematic error owing to the method employed.

The present method uses only three pieces of information (S or Z , which side of the minor axis is nearer to us, and which side of the major axis is approaching) and does not involve

NGC 5616	Z	NE	se				
NGC 5656	S	SE	ne				
NGC 5676	S	SE	ne				
NGC 5690	S	SW	se				
NGC 5750	Z	NW	ne				
NGC 6118	S	NW	sw				
NGC 7184	S	NW	sw				
NGC 7314	S	E	n				
NGC 7392	Z	NE	se				
NGC 7448	S	SW	se				
NGC 7721	Z	W	n				

Figure 10. (Continued.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ID	S/Z	Dark Side	Appr. Side	Reference	Image 1	Image 2	Image 3	Image 4
IC 540	z	SW	NW	Falcon-Barroso et al. (2017)				
IC 944	s	SW	SE	Falcon-Barroso et al. (2017)				
IC 2247	z	SW	NW	Garcia-Lorenzo et al. (2015)				
MCG-02-02-040	s	NW	SW	Falcon-Barroso et al. (2017)				
MCG-02-03-015	s	NW	SW	Falcon-Barroso et al. (2017)				
NGC 681	z	NW	NE	Burbidge et al. (1965a)				
NGC 1542	s	SW	SE	Falcon-Barroso et al. (2017)				
NGC 3067	s	NE	NW	Rubin et al. (1982)				
NGC 3079	z	SW	NW	Irwin & Seaquist (1991)				
NGC 3169	z	SE	SW	Lee-Waddell et al. (2014)				
NGC 3495	s	NW	SW	Rubin et al. (1980)				
NGC 3626	z	W	N	Haynes et al. (2000)				
NGC 4517	z	NW	NE	Neumayer et al. (2011)				
NGC 4605	z	NE	SE	Rubin et al. (1980)				
NGC 4772	s	NE	NW	Haynes et al. (2000)				
NGC 6314	z	W	N	Falcon-Barroso et al. (2017)				
UGC 3107	z	SE	SW	Garcia-Lorenzo et al. (2015)				
UGC 5111	s	SW	SE	Levy et al. (2018)				
UGC 5498	z	NW	NE	Garcia-Lorenzo et al. (2015)				
UGC 6036	z	NE	SE	Garcia-Lorenzo et al. (2015)				
UGC 8267	s	NW	SW	Garcia-Lorenzo et al. (2015)				
UGC 8778	z	NE	SE	Garcia-Lorenzo et al. (2015)				
UGC 9665	z	NE	SE	Garcia-Lorenzo et al. (2015)				
UGC 10205	s	SW	SE	Garcia-Lorenzo et al. (2015)				
UGC 10297	s	W	S	Garcia-Lorenzo et al. (2015)				

Figure 11. Spiral winding direction (2) inferred from the spin parity of spiral galaxies. Note that the uppercase letters in columns (3) and (4) are observational data, and the lowercase letters in column (2) are inferred results assuming that all the spiral galaxies are trailing.

quantitative errors in measurement. Therefore, we think that it provides a more robust comparison with theoretical models than using the position angle distribution or the axis ratio distribution. We emphasize that our approach using the spiral winding direction as described in this paper is independent of and complementary to approaches (e.g., Flin & Godlowski 1990; Navarro et al. 2004; Trujillo et al. 2006; Bett et al. 2007; Lee & Erdogdu 2007) using the position angle and/or axis ratio distributions to study the spin vorticity distribution of galaxies in the universe.

Shamir (2017a, 2017b) argued for the S/Z asymmetry observed in the samples of SDSS and PanSTARRS. On the other hand, Hayes et al. (2017) argued that the S/Z distribution in the Galaxy Zoo sample is consistent with a random distribution. Our second forthcoming paper will report on the technique and early results of S/Z classification by deep learning of about 80,000 Hyper Suprime Cam sample galaxies observed by the Subaru Telescope.

Observational mapping of the microwave background and studying the large-scale distribution of galaxies have been very

Table 2
Other Names for UGC Galaxies

UGC	Other Name	UGC	Other Name	UGC	Other Name	UGC	Other Name
UGC 448	IC 43	UGC 1908	NGC 927	UGC 4458	NGC 2599	UGC 81961	NGC 4977
UGC 463	NGC 234	UGC 3140	NGC 1642	UGC 4555	NGC 2649	UGC 99651	IC 1132
UGC 1081	NGC 575	UGC 4036	NGC 2441	UGC 6918	NGC 3982	UGC 113181	NGC 6691
UGC 1529	IC 193	UGC 4256	NGC 2532	UGC 7244	NGC 4195	UGC 123911	NGC 7495
UGC 1635	IC 208	UGC 4368	NGC 2575	UGC 7917	NGC 4662		

successful in constraining the expansion model of the universe. These two complementary approaches provided a glimpse of the evolution of the scalar density distribution of the universe. They were strong tools for understanding the formation of the structure of the universe. The present paper provides a new basis for examining the distribution of galaxy spins in the universe using only an imaging study without recourse to spectroscopy. Mapping the vector fields, velocity field, and vorticity vector field might provide new insights into the history of the universe.

5. Conclusion

We compiled a spin catalog of 146 spiral galaxies for which the sense of winding of the spiral structure (S/Z), the dust-lane-dominant side of the minor axis, and the approaching side of the major axis are observationally confirmed. The catalog shows a perfect correlation among these three pieces of information suggesting strongly that all the spirals are trailing provided that the dust-lane-dominant side of disk galaxies is closer to us which is generally assumed but has been demonstrated by means of differential reddening of globular cluster only for M31 (Iye & Richter 1985).

The present study provides a basis for using the S/Z winding direction of spiral galaxies to study the spin parity distribution of galaxies in order to constrain the formation scenarios of galaxies and the structure of the universe.

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