Photometric differences between clockwise and counterclockwise spiral galaxies in COSMOS

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ABSTRACT

The spin pattern of a spiral galaxy is a matter of the perspective of the observer, and therefore galaxies with clockwise spin patterns are expected to be identical in their characteristics to galaxies with counterclockwise spin patterns. However, studies using a large number of galaxies show statistically significant differences between the photometry of spiral galaxies with clockwise spin patterns and spiral galaxies with counterclockwise spin patterns. These differences are oriented around an axis such that the photometric asymmetry in one hemisphere is inverse to the photometric asymmetry in the opposite hemisphere. Analyses using different sky surveys such as SDSS and PanSTARRS show similar magnitude and direction of the asymmetry. In this study the magnitude difference between clockwise and counterclockwise spiral galaxies imaged by the space-based COSMOS survey is compared to galaxies imaged by the Earth-based SDSS and PanSTARRS around the same field. The comparison shows that the same asymmetry was identified by all three telescopes. A possible explanation to the asymmetry is relativistic beaming.

Subject headings: Galaxies: general – galaxies: statistics – galaxies: spiral – galaxies: structure

1. Introduction

Recent Earth-based observations using large datasets of galaxy images have shown evidence of statistically significant difference between the photometry of spiral galaxies with clockwise spin patterns and spiral galaxies with counterclockwise spin patterns (Shamir 2013, 2016, 2017a,c,b). The photometric difference between clockwise and counterclockwise spiral galaxies was first observed by identifying minor color

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differences between clockwise and counterclockwise galaxies (Shamir 2013). A much stronger statistical signal of photometric differences was measured using machine learning (Shamir 2016). That is, a machine learning system was able to predict the spin pattern of a galaxy based on its SDSS photometric variables in accuracy much higher than the expected 50% mere chance. Similar results were observed with manually and automatically annotated sets of galaxies, with very strong statistical significance. The nearly perfect agreement between experiments done with manually annotated galaxies and experiments that used automatically classified galaxies (Shamir 2016) eliminated the possibility that the asymmetry is driven by a human bias or by a computer error. Although the dataset was too small to identify specific photometric variables that differentiate between galaxies with different spin patterns, it provided strong evidence of the existence of a link between the photometry of a spiral galaxy and its spin pattern (Shamir 2016).

More recent experiments with a much larger dataset of $\sim 1.62 \cdot 10^5$ galaxies showed clear statistically significant difference between the magnitude of galaxies with clockwise spin patterns and galaxies with counterclockwise spin patterns (Shamir 2017c). The experiments also showed that galaxies with clockwise spin patterns are brighter than galaxies with counterclockwise spin patterns in one hemisphere, while the inverse asymmetry is measured in the opposite hemisphere (Shamir 2017c). These observations are consistent across SDSS and PanSTARRS, both showing the same profile of the asymmetry (Shamir 2017b). Repeating the same experiment with manually classified galaxies also provided the same results, providing additional evidence that the asymmetry cannot be driven by a computer error (Shamir 2017b). The fact that two different telescopes and two different analysis methods provide the same profile of the asymmetry indicates that the asymmetry is not a feature of a specific instrument or photometric pipeline. The most likely axis around which the asymmetry is oriented is (α = 175^o,δ = 50^o), which is roughly aligned with the galactic pole at (α = 192^o,δ = 27^o). Data for all of these experiments are publicly available (Shamir 2016, 2017a,c,b).

While the previous experiments showed that the brightness differences between clockwise and counterclockwise galaxies exist in the entire sky as observed from Earth (Shamir 2017c,b), this paper focuses on a certain part of the sky, but imaged by three different telescopes. The results show that all three telescopes show the same asymmetry, and one of these telescopes is a space-based instrument.

2. Data

The data used in the experiment is galaxies imaged by the Cosmic Evolution Survey (COSMOS) survey. The COSMOS field (Scoville et al. 2007; Koekemoer et al. 2007; Capak et al. 2007) is the largest HST survey, covering a field of 2 square degrees, centered at (α = 150.119166^o, δ = 2.205833^o). It is a combination of 575 neighboring images taken in around 1000 hours of telescope time.

In this experiment, extended sources with 5σ magnitude or brighter were used. The image of each galaxy was separated from the F814W band images using *Montage* (Berriman et al. 2004). That provided a dataset of 114,630 galaxy images. These galaxy images were then classified into clockwise and counterclockwise galaxies as was done in (Shamir 2016, 2017a,b,c). In summary, the classification was done by first applying the Ganalyzer method (Shamir 2011a). Ganalyzer works by converting each galaxy into its radial intensity plot, and then identifying the peaks of intensities at different radii from the center of the galaxy. These peaks correspond to the arms of the galaxy. The sign of the linear regression of these peaks at different distances from the center is sensitive to the shape of the arm, and therefore determines the spin pattern of the galaxy. Detailed information about Ganalyzer and its application to the identification of spin patterns of spiral galaxies can be found in (Shamir 2011a; Hoehn & Shamir 2014; Shamir 2016), and the source code is available through the Astrophysics Source Code Library (Shamir 2011b).

After the galaxies are classified automatically, a thorough manual process was applied to ensure that all galaxies are classified correctly (Shamir 2016). The process of manual classification was repeated twice, such that in the second pass the galaxies were mirrored to ensure that the dataset is not affected by a possible human bias. In the end of that long laborintensive process, a random set of 200 galaxies were selected from the dataset, and careful examination of the galaxies showed that all classifications were correct. Another set of 500 random galaxies were selected from the galaxies that were not assigned with a spin pattern, to ensure that no galaxies with an identifiable spin pattern were left out. Therefore, it is very reasonable to assume that the dataset is very clean, and that all galaxies in the dataset are classified correctly.

Since the dataset contained just spiral galaxies with clear spin patterns, the majority of the galaxies were rejected during the process of galaxy classification, as most of them were not spiral galaxies, or did not have identifiable spin patterns. When the process was completed, the dataset contained 5122 galaxies with identifiable spin patterns. These galaxies have mean g magnitude of ~23.1 (σ ' 0.97), V magnitude of ~22.58 (σ ' 1.03), and mean redshift of ~0.6 (σ ' 0.28). These galaxies are clearly brighter than the general COSMOS galaxy population (Hasinger et al. 2018), since only galaxies with clear morphology that allows the identification of the spin pattern are used. Fig. 1 shows the distribution of the V magnitude and photometric redshift taken from the COSMOS photometric redshift catalog (Mobasher et al. 2007) of all clockwise and counterclockwise galaxies in the dataset.

As the graph shows, some of the galaxies have photometric redshift that is greater than 1. While the photometric redshifts of these objects in the catalog (Mobasher et al. 2007) are clearly high, all of these objects are spiral galaxies with identifiable spin patterns. Examples of these objects are shown in Table 1. In any case, the photometric z is used here to provide basic information about the galaxy population, and is not used in the analysis.

3. Results

The mean magnitudes of the different filters were computed for the 2,607 COSMOS galaxies with clockwise spin patterns, and for the 2,515 galaxies with counterclockwise spin patterns. Table 2 shows the mean and standard error of the magnitude of clockwise and counterclockwise galaxies. The table also shows the one-tail P value of the t-test of the difference between the two means in each band. The magnitudes are the Subaru AB magnitudes B, V, g, r, i, and z taken from the COSMOS photometry catalog (Capak et al. 2007). A onetail P value is used here since Earth-based observations showed that counterclockwise galaxies have lower magnitude compared to clockwise galaxies in the part of the sky of the COSMOS field (Shamir 2017c,b).

The asymmetry detected in COSMOS galaxies was compared to the asymmetry of the galaxies around the same field in SDSS and PanSTARRS. Since SDSS and PanSTARRS are not as deep as COSMOS, the field was extended to the 20^o to each side from the center of the COSMOS field. Therefore, the field used in PanSTARRS and SDSS was (α = 130.119166^o, δ =

Table 1: COSMOS galaxies with high photometric redshift.

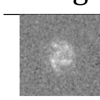
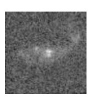
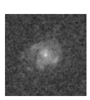
Image	RA (^{o})	DEC (^{o})	PhotoZ
	150.672643	1.616193	1.108
	149.593346	1.621579	1.284
	150.730916	1.656999	1.015
	150.628672	1.782231	1.188
	150.585146	1.663747	1.107

Table 2: Mean, standard error of the mean, and the one-tail statistical significance of the differences between the magnitude of clockwise galaxies and counterclockwise galaxies in COSMOS.

Band	mean clockwise	mean counterclockwise	P (t-test)
B	23.052±0.018	23±0.018	0.024
V	22.603±0.02	22.553±0.02	0.042
g	23.131±0.019	23.077±0.019	0.023
r	22.266±0.019	22.218±0.02	0.045
i	21.719±0.018	21.68±0.018	0.065
z	21.358±0.017	21.323±0.018	0.087

Table 3: Mean DeVaucouleurs magnitude of clockwise and counterclockwise SDSS galaxies in the field centered at the COSMOS field.

Band	mean clockwise	mean counterclockwise	P (t-test)
u	18.25758±0.014	18.22456±0.015	0.050
g	17.07524±0.012	17.03587±0.013	0.013
r	16.47325±0.012	16.44078±0.012	0.028
i	16.15131±0.012	16.120649±0.013	0.041
z	15.93929±0.013	15.9190±0.014	0.143

22.205833^{o}),(α = 170.119166^{o}, δ = −17.79417^{o}).

The SDSS data were taken from previous work (Shamir 2017c). The number of SDSS galaxies in that field is 5447 counterclockwise galaxies and 5774 clockwise galaxies. The means and standard errors of the DeVaucouleurs magnitude of the clockwise and counterclockwise galaxies in that field in the different bands are shown in Table 3.

The table shows statistically significant difference between the DeVaucouleurs magnitude of clockwise and counterclockwise galaxies, with the exception of the z band. The direction of the difference is aligned with the direction observed in the COSMOS field, in which galaxies with counterclockwise spin patterns were also brighter than galaxies with clockwise spin patterns.

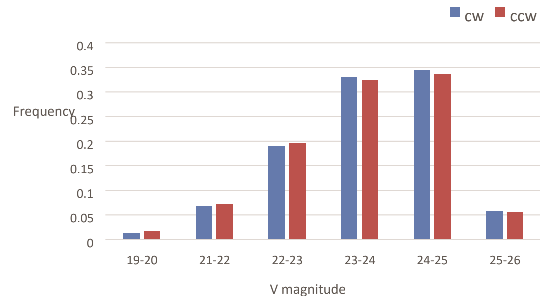
A similar experiment was done with PanSTARRS galaxies, using clockwise and counterclockwise galaxies that were used in a previous experiment (Shamir 2017b).

The number of PanSTARRS galaxies in the same field was 1444 clockwise galaxies and 1438 counterclockwise galaxies, and 21% of them are also present in the SDSS dataset of the same field. The average Kron magnitudes of the galaxies with clockwise spin patterns and counterclockwise spin patterns are shown in Table 4. Like COSMOS and SDSS, PanSTARRS also shows statistically significant differences between the brightness of galaxies with clockwise spin patterns and galaxies with counterclockwise spin patterns.

The observation that three different telescopes show similar asymmetry reduces the probability that the asymmetry is the result of an anomaly related to a certain telescope or photometric pipeline. Also, the statistical significance of the asymmetry when observed by three telescope is substantially stringer than the asymmetry observed in a single telescope. The mere chance probability that the g magnitude means are different in all three telescopes is $0.023 \cdot 0.013 \cdot 0.017 =\sim 5 \cdot 10^{-5}$. Similarly, the mere chance probabilities that the means are different in all three telescopes in the other bands are $2.6 \cdot 10^{-5}$, $4.7 \cdot 10^{-5}$, $1.5 \cdot 10^{-4}$, for the r, i, and z bands, respectively.

Table 4: Magnitude of clockwise and counterclockwise PanSTARRS galaxies in the field centered at the COSMOS field.

Band	mean clockwise	mean counterclockwise	P (t-test)
g	16.97745±0.022	16.91335±0.021	0.017
r	16.37079±0.021	16.31182±0.020	0.021
i	16.03699±0.021	15.977536±0.019	0.018
z	15.87572±0.021	15.811690±0.019	0.012



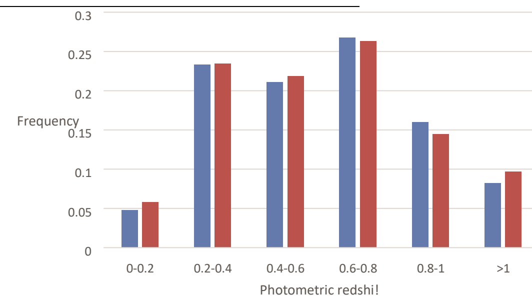


Fig. 1.— Histograms of the V magnitude and the photometric redshift of the clockwise and counterclockwise galaxy population.

4. Conclusion

The experiments described in this paper show that three different telescopes measure photometric differences between spiral galaxies with clockwise spin patterns and spiral galaxies with counterclockwise spin patterns. The spin patterns of the galaxies were classified automatically, therefore eliminating the possibility that the asymmetry is driven by human bias. Since the asymmetry changes with the direction of observation to create two hemispheres with inverse asymmetries, a flaw in the program that classifies the galaxies (Shamir 2011b) is not likely, as such error is expected to exhibit itself in a consistent manner, in the form of similar asymmetry in all parts of the sky. Another evidence that shows that the asymmetry is not the result of a software error is that in an additional experiment, ~41K galaxies that were classified manually showed results similar to the results of the automatic classification (Shamir 2017b). These results also agree with (Shamir 2016), where manually and automatically classified galaxies showed the same differences.

All three telescopes show the same asymmetry. Since both the clockwise and the counterclockwise galaxies were collected from the exact same field, the difference cannot be the result of cosmic variance (Driver & Robotham 2010). As shown in (Shamir 2017a,c,b), the photometric difference between clockwise and counterclockwise spiral galaxies can be observed in other parts of the sky, but the agreement between Earth-based and space-based observations shows that the asymmetry is not the result of atmospheric effects. The COSMOS field was also imaged in a relatively short time of ~1000 hours, as opposed to SDSS and PanSTARRS, in which data were acquired over a much longer period of time.

SDSS and PanSTARRS galaxies have a much lower redshift than the galaxies in the COMSOS field. The observation that data collected by all three telescopes show the same asymmetry despite the differences in redshift provides an indication that the source of the asymmetry is not related to the large-scale structure of the universe. A possible explanation to the asymmetry is relativistic beaming, proposed in the past in the context of exoplanets (Loeb & Gaudi 2003). In the majority of the cases, spin patterns indicate the actual direction in which the galaxy spins. That is, most galaxies with clockwise spin patterns indeed rotate clockwise. The motion of the Sun in the Milky Way is relative to the motion of stars in observed galaxies. Stars in observed face-on galaxies that rotate in the same direction of the Sun can be measured by an Earth-based system as brighter than identical stars in face-on galaxies that rotate in the opposite direction. The difference in the bolometric flux is by a fraction of 4 [redacted] (Loeb & Gaudi 2003). Assuming [redacted] of the Sun of ~0.001, it is expected that a maximum difference of ~ 0.8% can be observed between two identical stars in two face-on galaxies such that one rotates with the direction of the Sun, and the other rotates in the opposite direction. That assumption is also aligned with the proximity of the most likely axis of the asymmetry to the galactic pole (Shamir 2017b). Such observations are difficult to measure with a single object, but they can be measured to statistical significance when comparing a large number of galaxies.

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