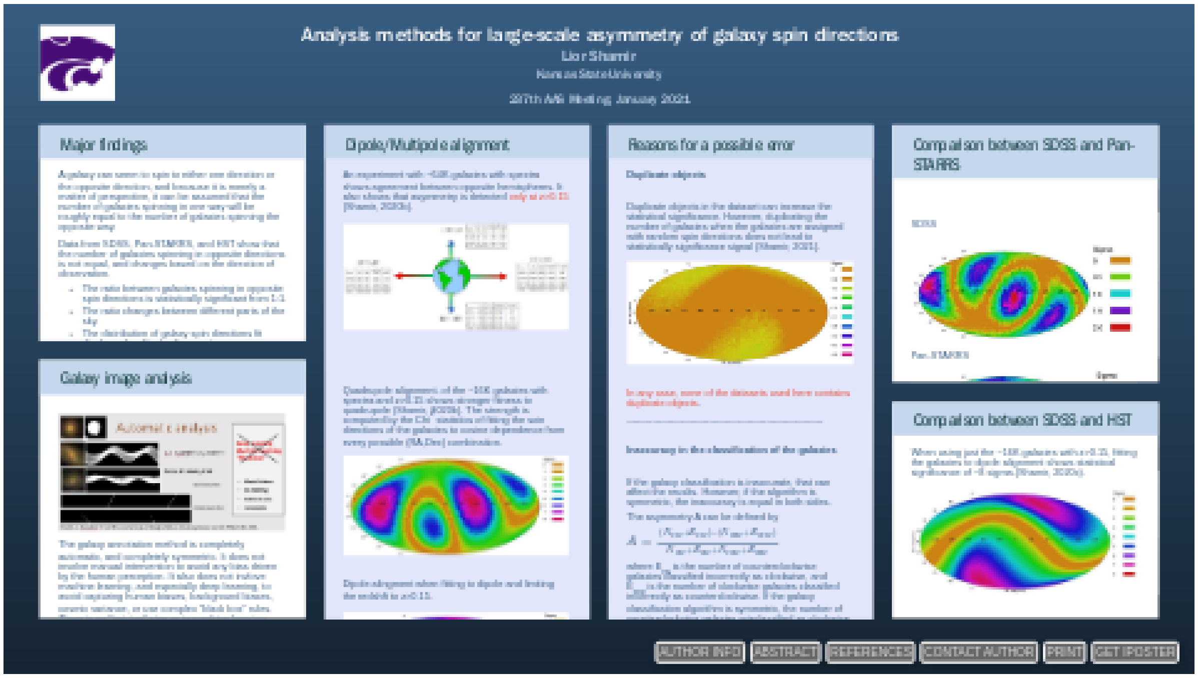
Analysis methods for large-scale asymmetry of galaxy spin directions



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VIRTUALLY ANYWHERE **11–15 JANUARY 2021**

MAJOR FINDINGS

A galaxy can seem to spin to either one direction or the opposite direction, and because it is merely a matter of perspective, it can be assumed that the number of galaxies spinning in one way will be roughly equal to the number of galaxies spinning the opposite way.

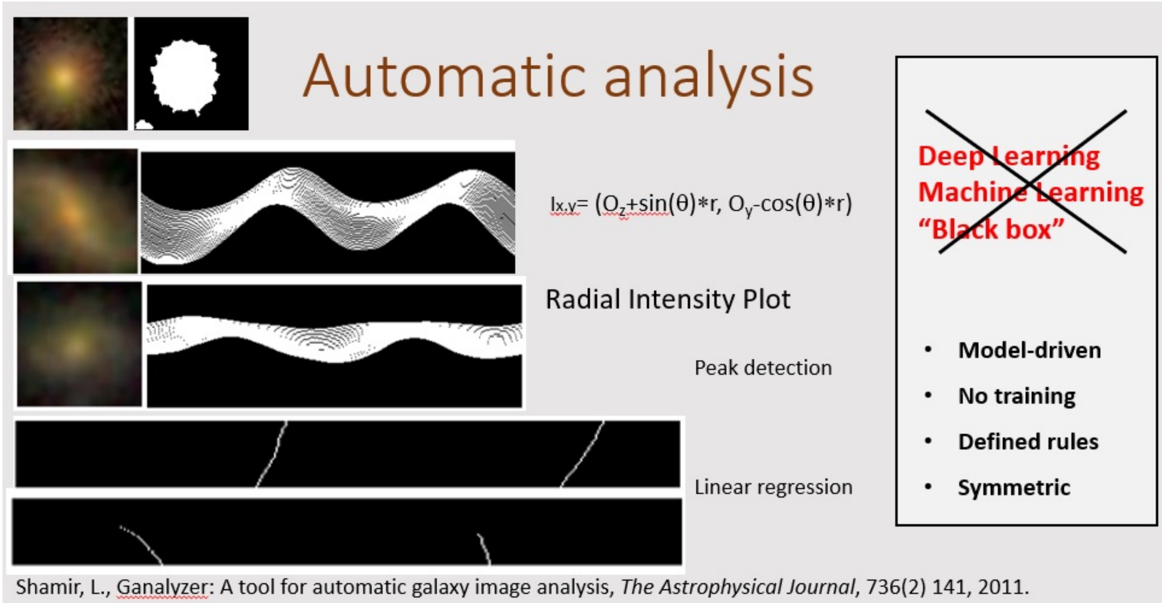
Data from SDSS, Pan-STARRS, and HST show that the number of galaxies spinning in opposite directions is not equal, and changes based on the direction of observation.

- The ratio between galaxies spinning in opposite spin directions is statistically significant from 1:1.
- The ratio changes between different parts of the sky.
- The distribution of galaxy spin directions fit dipole and multipole alignment.
- All three telescopes (SDSS, Pan-STARRS, HST) show similar profile of asymmetry.
- The asymmetry is detectable at $z>0.15$.
- Low redshifts ($z<0.15$) show no statistically significant asymmetry.

Conclusions

- Three telescopes show asymmetry in the distribution of galaxy spin directions.
- The asymmetry is consistent in all three telescopes.
- The galaxy classification is automatic and symmetric.
- The datasets contain no duplicate objects.
- Inaccurate classification or duplicate objects, even if existed, cannot lead to statistical signal (as long as the error is randomly distributed rather than consistently biased)..

GALAXY IMAGE ANALYSIS



The galaxy annotation method is completely automatic, and completely symmetric. It does not involve manual intervention to avoid any bias driven by the human perception. It also does not invlove machine learning, and especially deep learning, to avoid capturing human biases, background biases, cosmic variance, or use complex "black box" rules. There is no "training" step as in machine learning, and all rules are clear and defined with simple mathematics. The method is fully symmetric, and works according to clear and defined rules (Shamir, 2011a,b).

Ganalyzer first separates foreground pixels from backgroun pixels using the Otsu binary threshold, and then transforms the galaxy image into its radial intensity plot. Then, it applies peak detection to identify the peaks on the radial intensity plot in different distances from the galaxy center. The collection of neighboring peaks makes an arm. The sign of the linear regression of the x position of the peaks determines whether the galaxy is clockwise or counterclockwise (Shamir, 2011a).

DIPOLE/MULTIPOLE ALIGNMENT

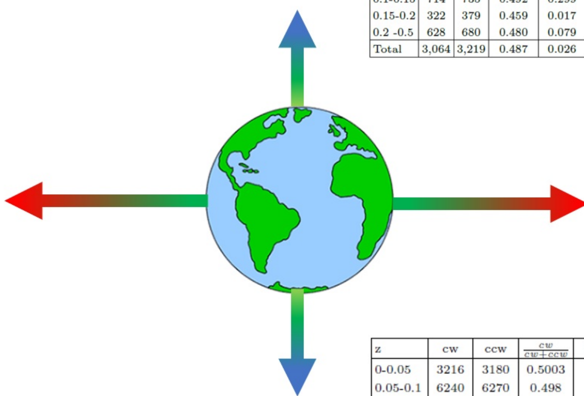
An experiment with ~64K galaxies with spectra shows agreement between opposite hemispheres. It also shows that asymmetry is detected only at z>0.15 (Shamir, 2020b).

>300° < 30°

z	cw	ccw	$\frac{cw}{cw+ccw}$	P value
0-0.05	360	402	0.472	0.068
0.05-0.1	1040	1023	0.504	0.362
0.1-0.15	714	735	0.492	0.299
0.15-0.2	322	379	0.459	0.017
0.2 -0.5	628	680	0.480	0.079
Total	3,064	3,219	0.487	0.026

30° < 120°

z	cw	ccw	$\frac{cw}{cw+ccw}$	P value
0-0.05	245	260	0.485	0.266
0.05-0.1	442	429	0.507	0.34
0.1-0.15	370	384	0.491	0.32
0.15-0.2	229	185	0.553	0.017
0.2 - 0.5	379	302	0.556	0.0018
Total	1,665	1,560	0.516	0.034



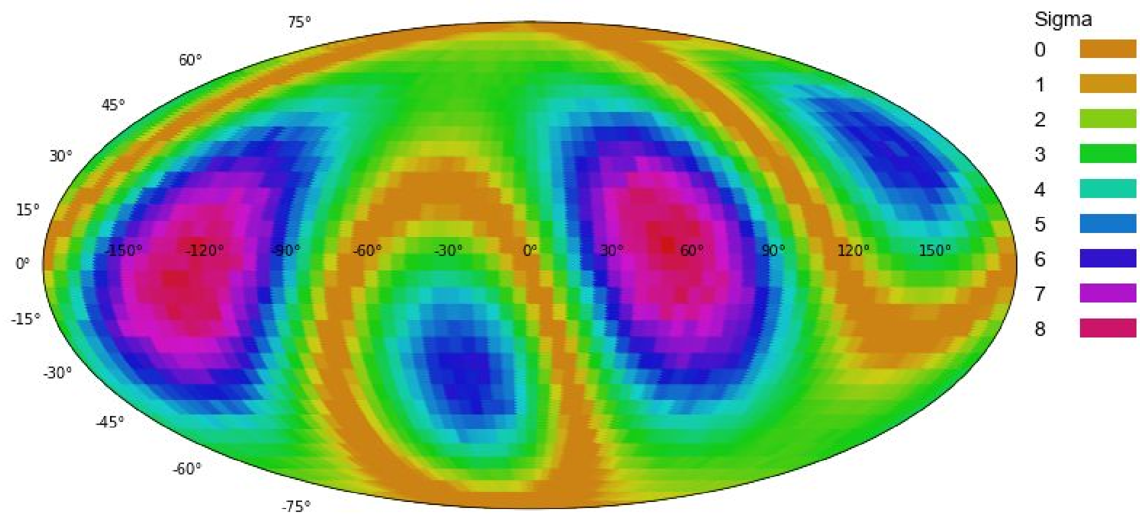
210° < 300°

z	cw	ccw	$\frac{cw}{cw+ccw}$	P value
0-0.05	1643	1635	0.501	0.451
0.05-0.1	3351	3162	0.514	0.01
0.1-0.15	2105	2115	0.499	0.445
0.15-0.2	797	782	0.500	0.362
0.2 - 0.5	1165	1163	0.500	0.492
Total	9,061	8,857	0.505	0.07

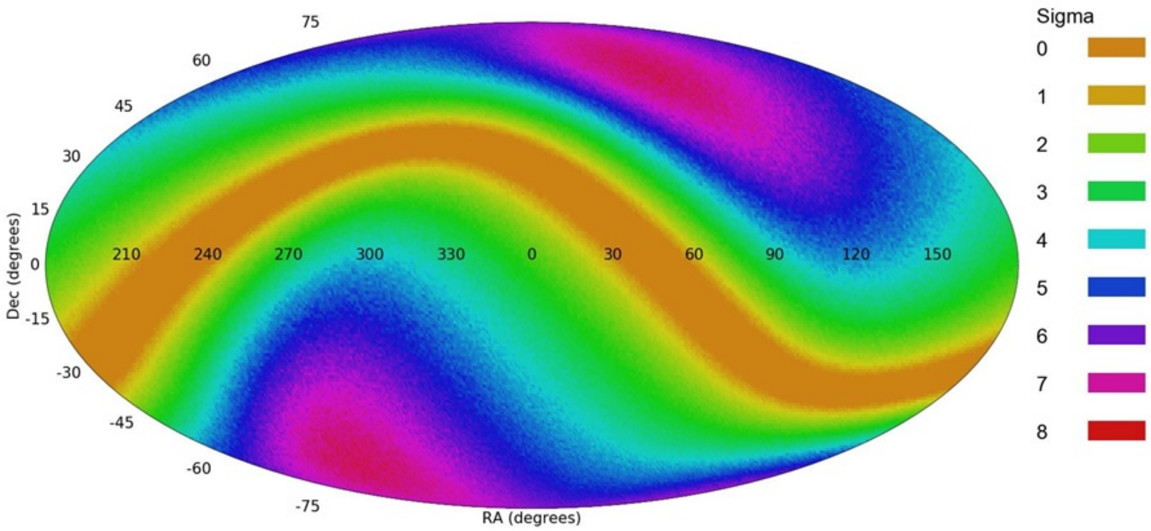
120° < 210°

z	cw	ccw	$\frac{cw}{cw+ccw}$	P value
0-0.05	3216	3180	0.5003	0.698
0.05-0.1	6240	6270	0.498	0.4
0.1-0.15	4236	4273	0.496	0.285
0.15-0.2	1586	1716	0.479	0.008
0.2 - 0.5	2598	2952	0.469	$1.07 \cdot 10^{-6}$
Total	17,876	18,391	0.493	0.0034

Quadrupole alignment. of the ~16K galaxies with spectra and z>0.15 shows stronger fitness to quadrupole (Shamir, 2020b). The strength is computed by the Chi^2 statistics of fitting the soin directions of the galaxies to cosine dependence from every possible (RA,Dec) combination.



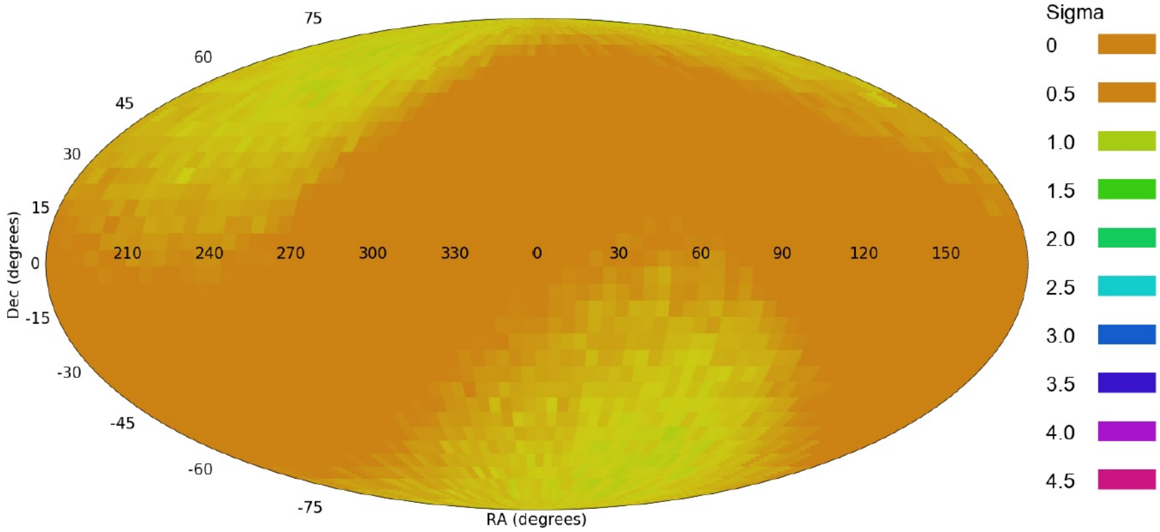
Dipole alingment when fitting to dipole and limiting the redshft to z>0.15.


Sigma
0
1
2
3
4
5
6
7
8
Dec (degrees)
RA (degrees)
210
240
270
300
330
0
30
60
90
120
150
75
60
45
30
15
0
-15
-30
-45
-60
-75

REASONS FOR A POSSIBLE ERROR

Duplicate objects

Duplicate objects in the dataset can increase the statistical significance. However, duplicating the number of galaxies when the galaxies are assigned with random spin directions does not lead to statistically significance signal (Shamir, 2021).



In any case, none of the datasets used here contains duplicate objects.

Inaccuracy in the classification of the galaxies

If the galaxy classification is inaccurate, that can affect the reuslts. However, if the algorithm is symmetric, the inaccuracy is equal in both sides.

The asymmetry A can be defined by

$$A = \frac{(N_{cw}+E_{cw})-(N_{ccw}+E_{ccw})}{N_{cw}+E_{cw}+N_{ccw}+E_{ccw}}$$

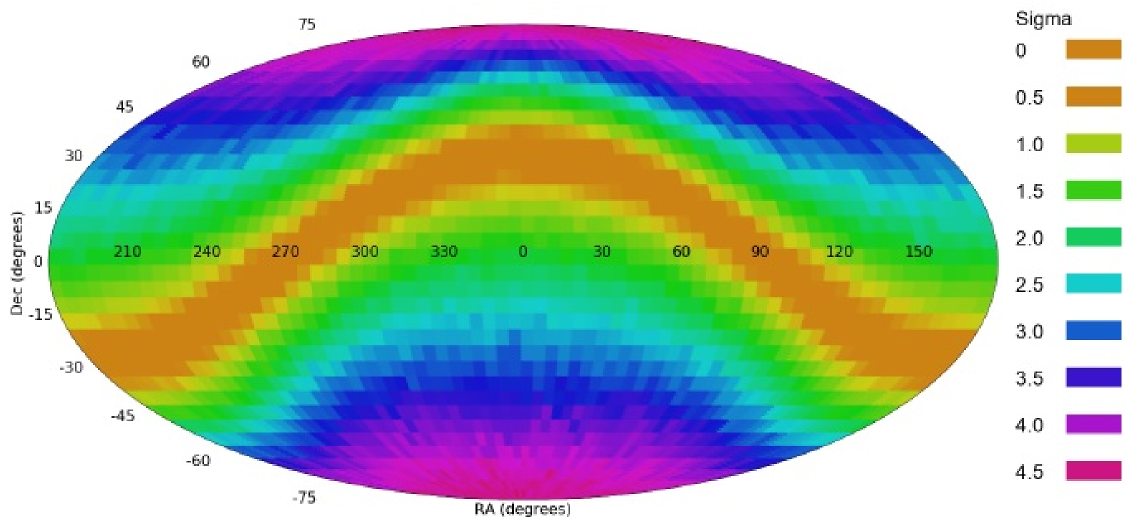
where E_{cw} is the number of counterclockwise galaxies classified incorrectly as clockwise, and E_{ccw} is the number of clockwise galaxies classified incorrectly as counterclockwise. If the galaxy classification algorithm is symmetric, the number of counterclockwise galaxies misclassified as clockwise is expected to be roughly the same as the number of clockwise galaxies missclassified as counterclockwise. Assuming $E_{cw}=E_{ccw}$, the asymmetry can be defined as

$$A = \frac{N_{cw}-N_{ccw}}{N_{cw}+E_{cw}+N_{ccw}+E_{ccw}}$$

Since E_{cw} and E_{ccw} cannot be negative, a higher rate of misclassified galaxies is expected to make the asymmetry A lower., but not higher. That is, misclassified galaxies can not lead to asymmetry (Shamir, 2021).

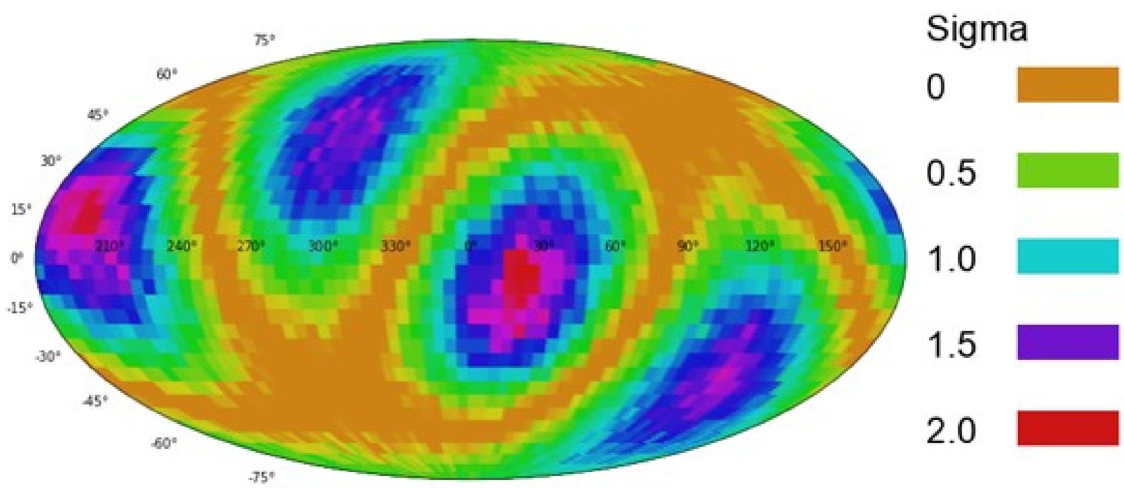
That is also supporetd by empirical experiments. For instance, when assigning 25% of the galaxies with random spin direction, the results do not change significantly.

However, if the classification has a slight consistent bias, the results are skewed. For instance, even 2% bias leads to very strong asymmetry. In that case, the asymmetry peaks in the celestial pole (Shamir, 2021).

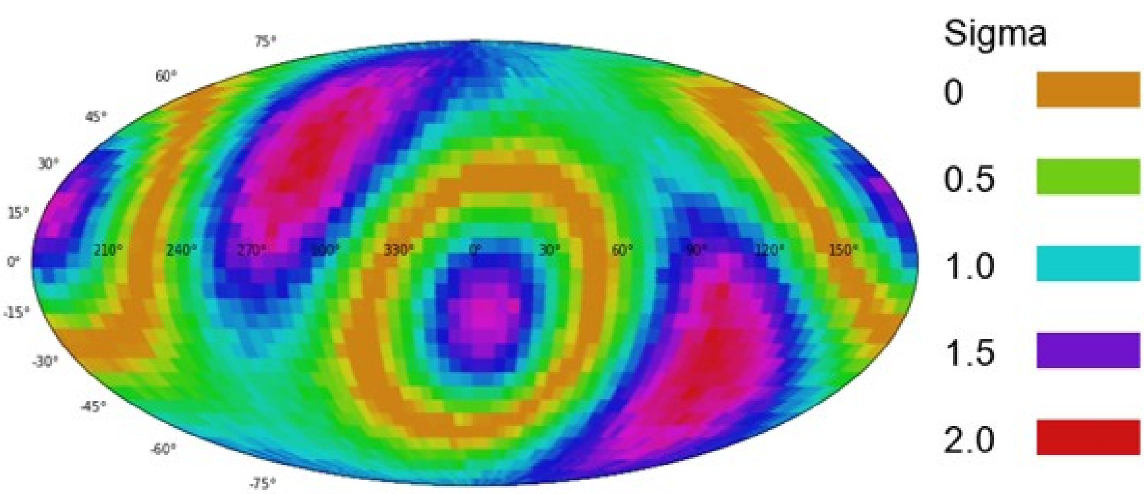


COMPARISON BETWEEN SDSS AND PAN-STARRS

SDSS



Pan-STARRS

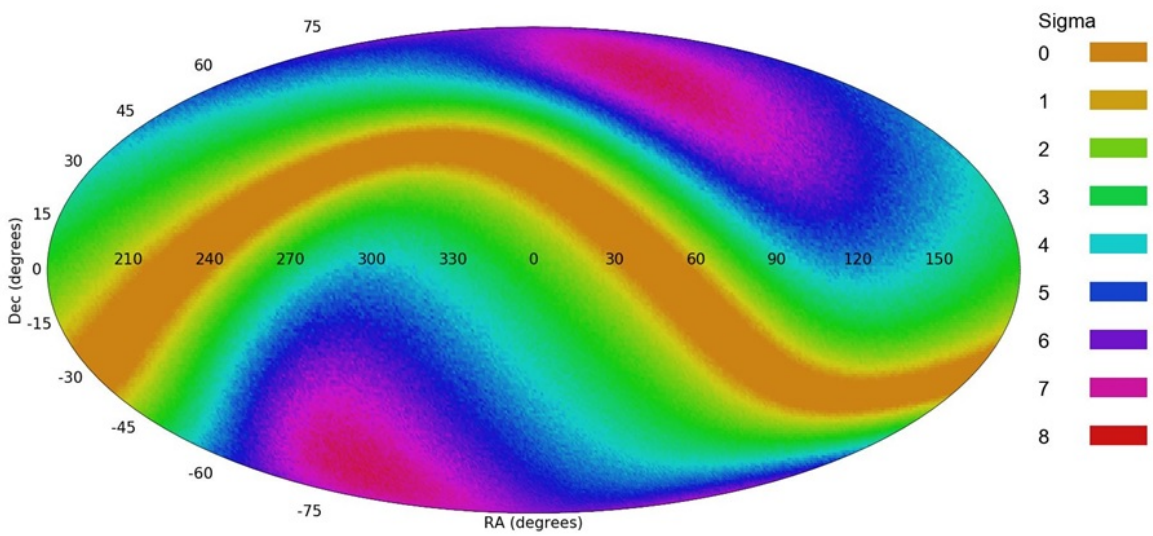


Most probable quadropole alignment in SDSS (top) and Pan-STARRS (bottom) such that the redshift distribution of the galaxies in both datasets is similar (Shamir, 2020b). Both telescopes show the same profile. The two datasets were normalized for the redshift, such that the redshift distirbution in both datasets is similar.

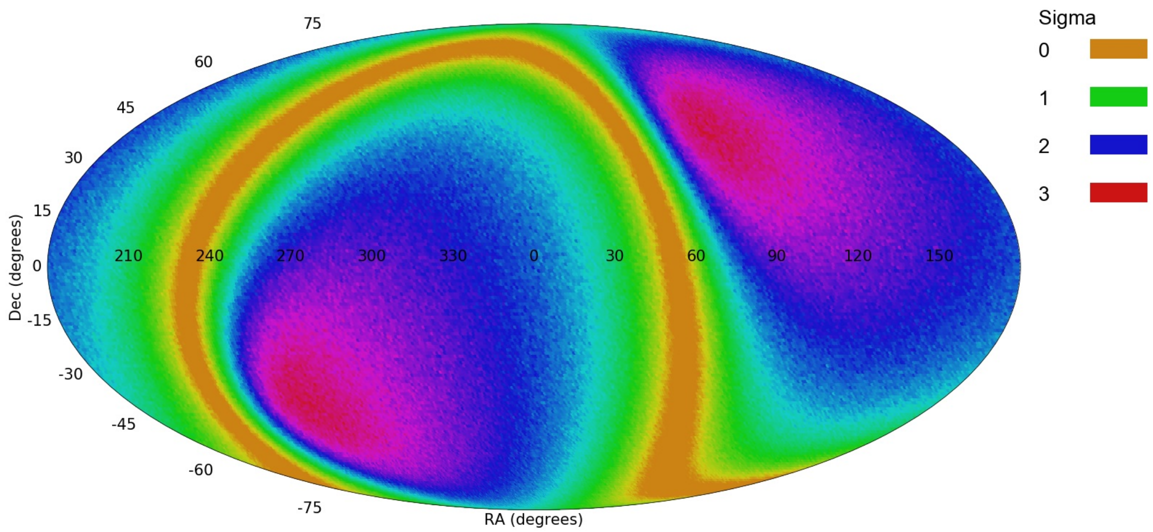
This comparison is added to the comparison between SDSS and HST to show that different telescopes show similar asymmetry.

COMPARISON BETWEEN SDSS AND HST

When using just the ~16K galaxies with z>0.15, fitting the galaxies to dipole alignment shows statistical significance of ~8 sigma.(Shamir, 2020c).



~9K galaxies from HST show a similar pattern (Shamir, 2020c).



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ABSTRACT

Previous studies using large datasets of spiral galaxies suggest that asymmetry between the number of galaxies that spin clockwise and the number of galaxies that spin counterclockwise exhibits possible patterns of cosmological scale. The asymmetry was observed by several different instruments, including SDSS, Pan-STARRS, and HST. The detected patterns change with the direction of observation and the redshift, and can also exhibit photometric asymmetry between galaxies with opposite spin directions. Different statistical and computational methods are needed to analyze these potential large-scale patterns. These methods include the identification of the existence of possible asymmetry, and profile the differences in different parts of the sky and different redshift ranges. Identification of a possible dipole alignment or multipole alignment of the asymmetry of the spin directions of the galaxies can be done by fitting the entire galaxy population into cosine dependence. Redshift dependence can be identified by correlating the asymmetry with the redshift of the galaxies in small but densely populated regions of the sky. Identification of the links between the redshift dependence and the direction of observation can be done by repeating the analysis with data separated into different redshift ranges. Analysis with real and simulated data shows that the presence of duplicate objects in the dataset or inaccuracy of the galaxy annotation cannot not practically lead to false identification of large-scale patterns. However, if the annotation error is consistently biased towards a certain type of galaxies, even a small bias can lead to statistically significant dipole alignment centered around the celestial pole. That reinforce the use of model-driven annotation algorithms with clear symmetric rules.

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