Galaxy Spin Directions Show Large-Scale Asymmetries and Redshift Dependence

Lior Shamir

Kansas State University

236th AAS Meeting, June 2020

Spiral Galaxies

A spiral galaxy is a unique astronomical object in the sense that its visual appearance depends on the perspective of the observer

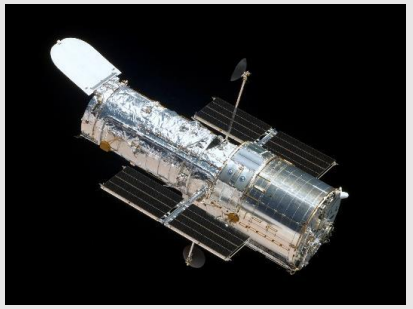
In a sufficiently large universe, the number of clockwise galaxies observed from Earth should be roughly equal to the number of counterclockwise galaxies

Data

Digital Sky Surveys

Sloan Digital Sky Survey

Pan-STARRS



HST (COSMOS)

Using multiple sources:

- More data
- Test agreement between instruments

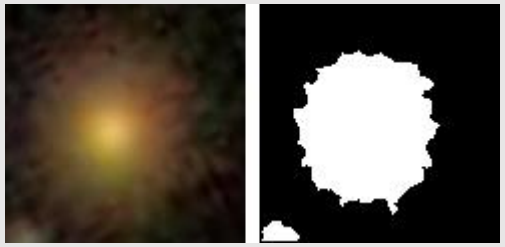
Manual annotation

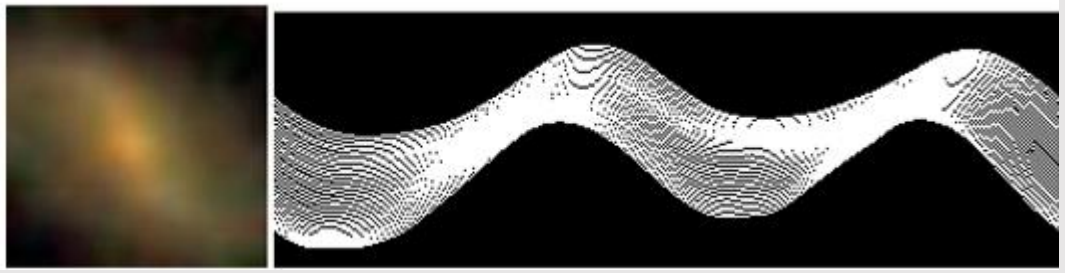
Study	Method	# galaxies
Iye & Sugai, 1991	Experts	~6.5K
Land et al., 2008	Crowdsourcing	~900K
Longo, 2011	Five undergraduate students	~14K

Limitations:

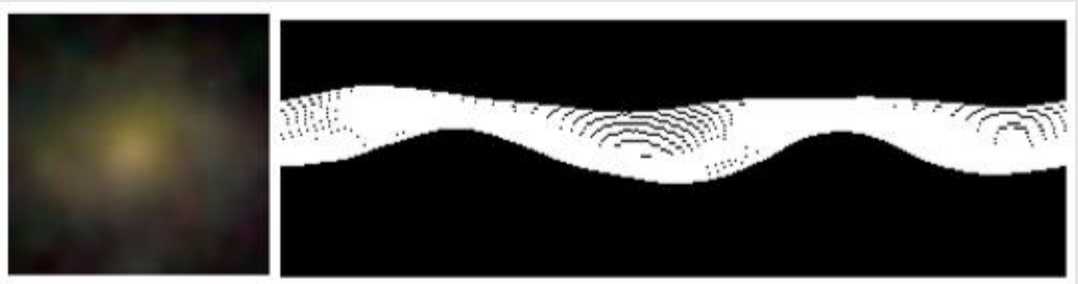
- Volume
- Bias

Computer vision





$I_{x,y}= (O_z+\sin(\theta)*r, O_y-\cos(\theta)*r)$



Radial Intensity Plot

Peak detection

Linear regression

~~Deep Learning~~
~~Machine Learning~~
~~"Black box"~~

- **Model-driven**
- **No training**
- **Defined rules**
- **Symmetric**

Shamir, L., Ganalyzer: A tool for automatic galaxy image analysis, *The Astrophysical Journal*, 736(2) 141, 2011.

Sloan Digital Sky Survey

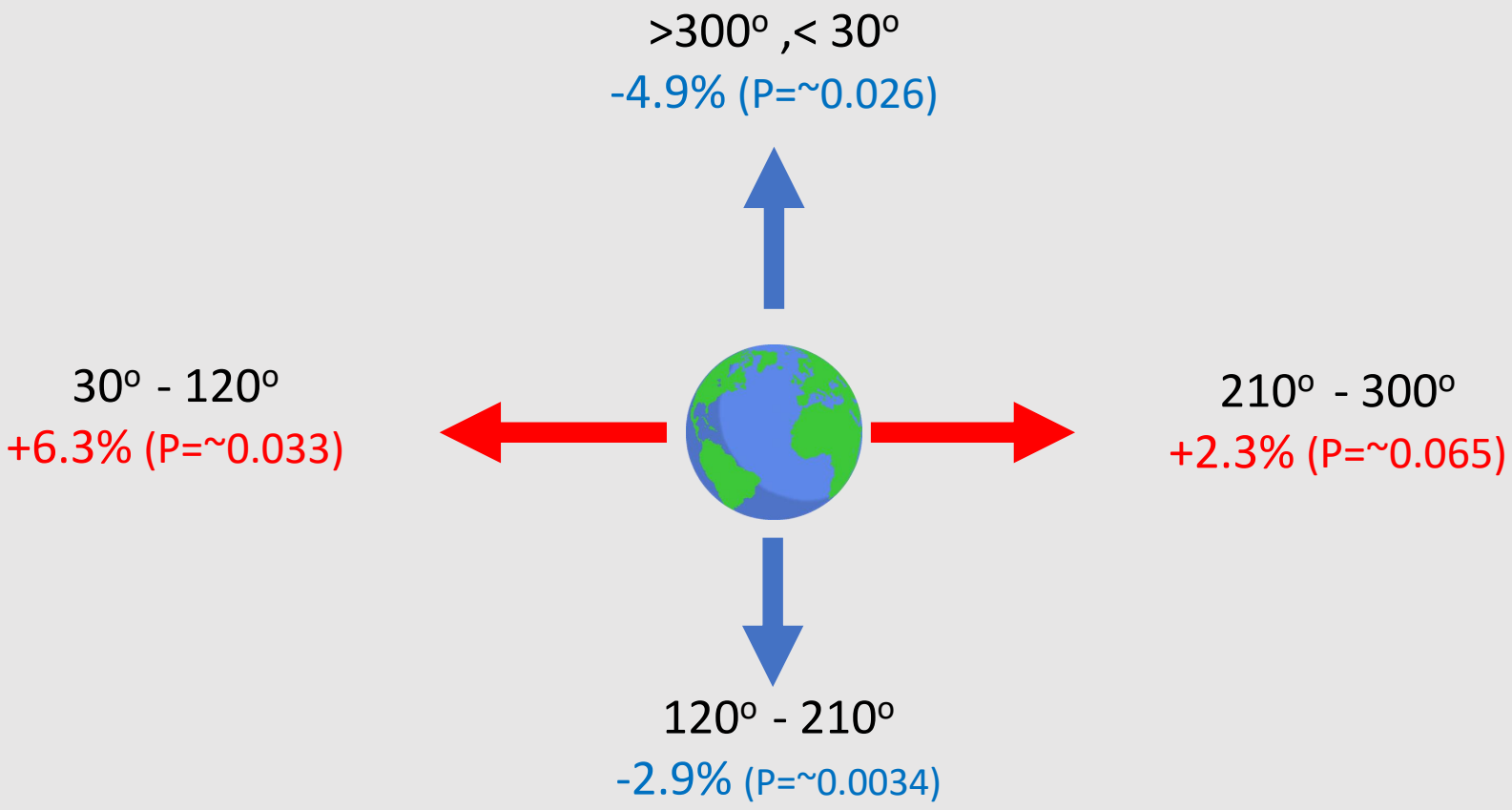
Clockwise: 88,273

Counterclockwise: 86,075

($P<10^{-7}$)

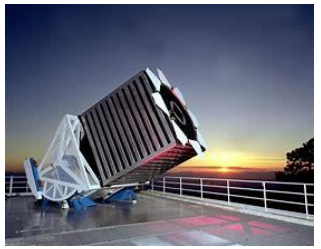
Question: Which spin direction is more frequent?

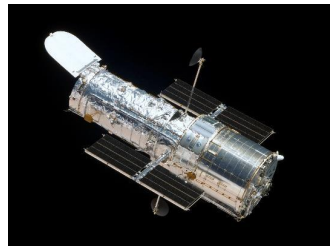
Answer: It depends on the direction of observation



Brightness Asymmetry

Observation: The spin direction of the galaxy is linked to its brightness



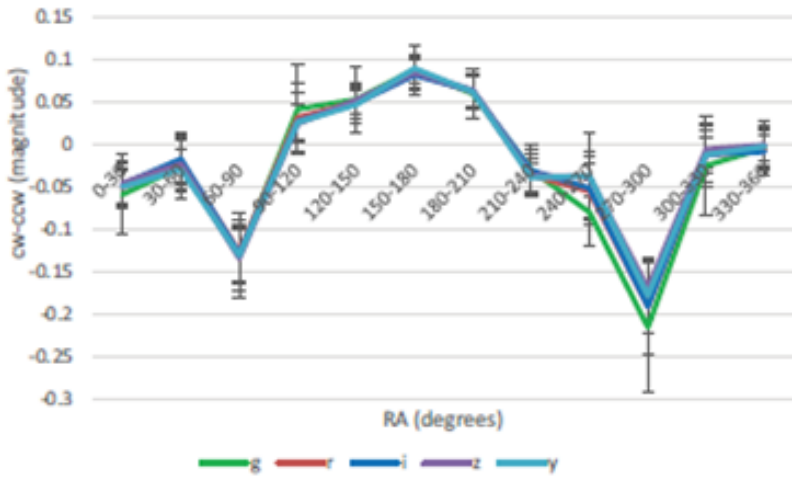


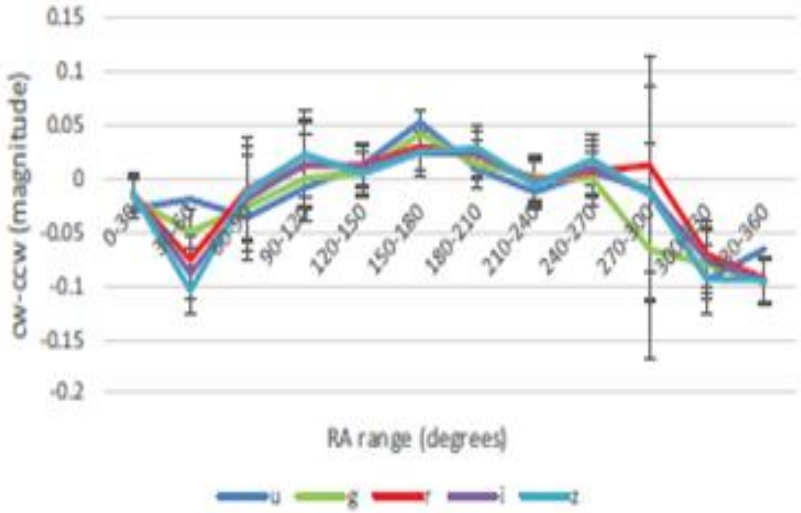
Pan STARRS (automatic)
29,013 galaxies

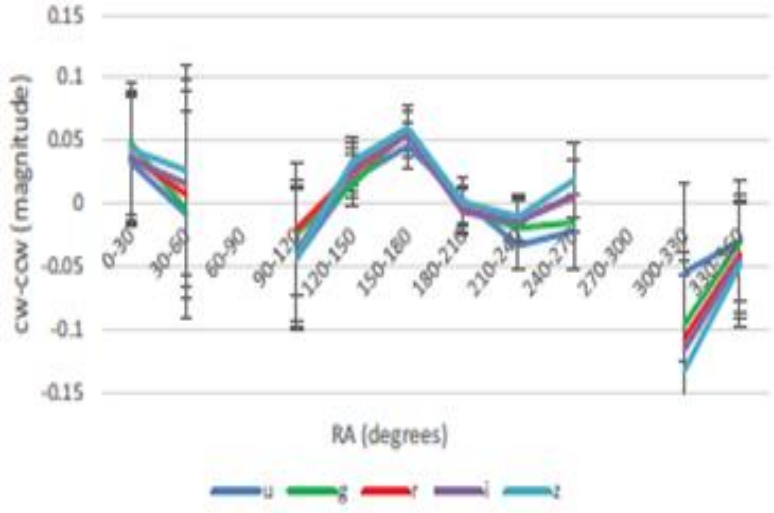
SDSS (automatic)
162,514 galaxies

SDSS (manual)
40,739 galaxies

HST
5,122 galaxies







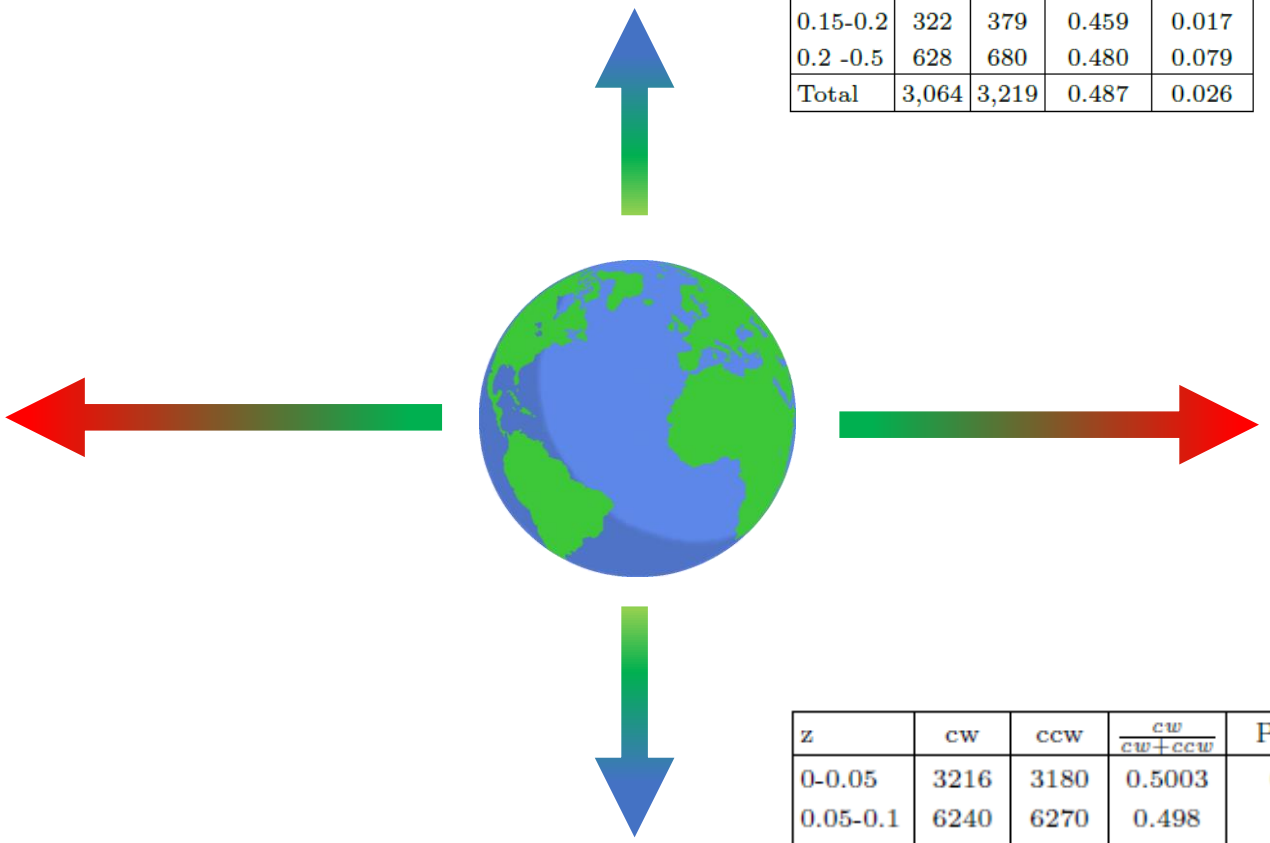
Redshift dependence

>300º ,< 30º

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

30º - 120º

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



210º - 300º

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

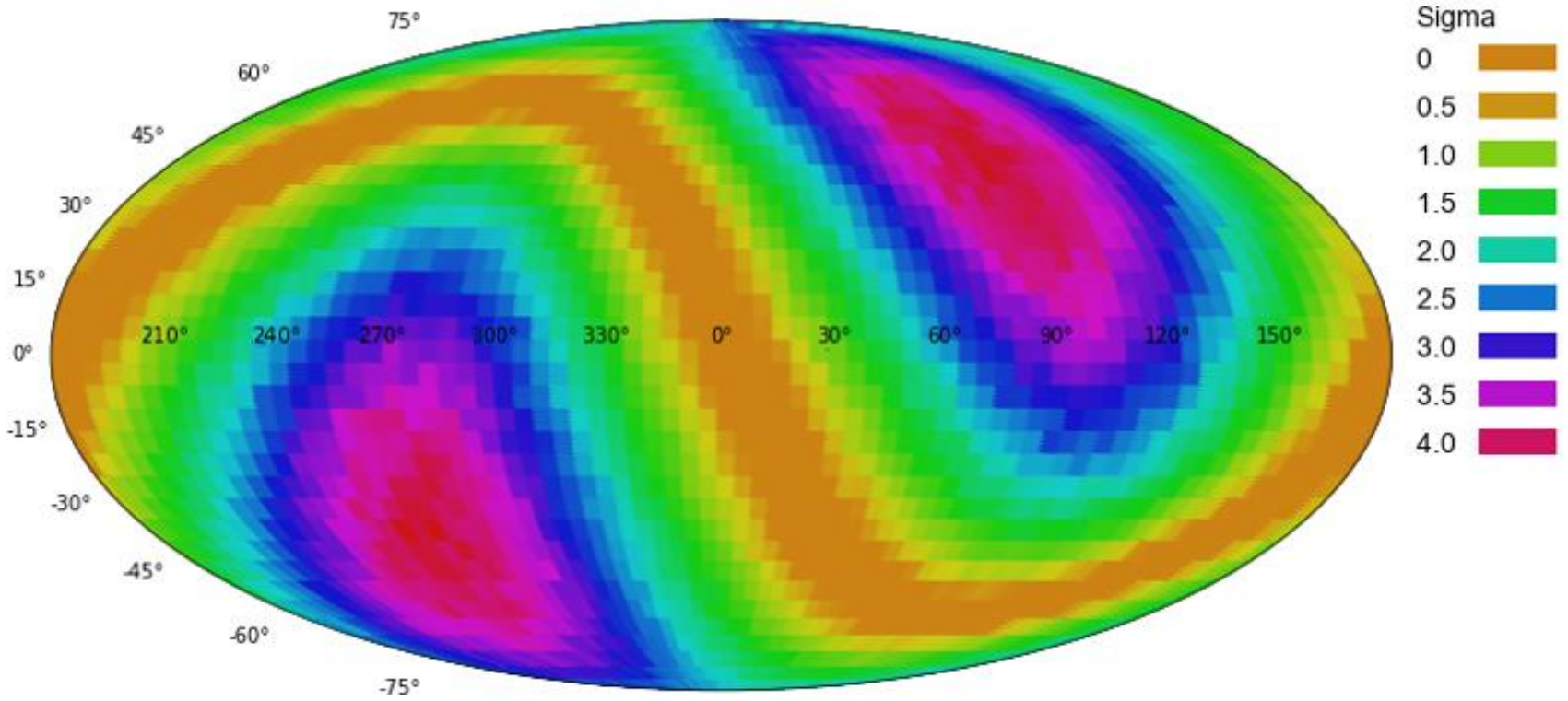
120º - 210º

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

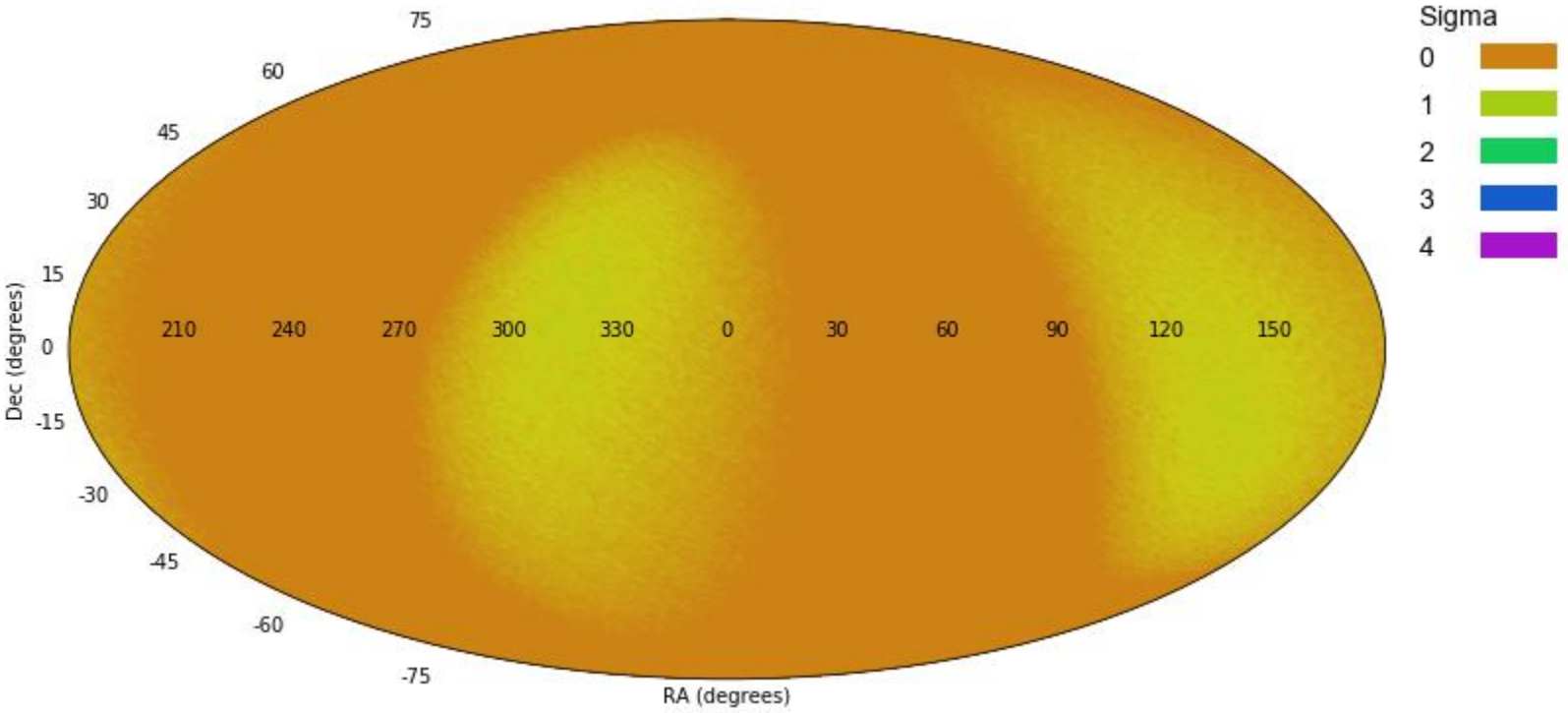
Dipole

Cosine dependence:
χ^2 (cos(ϕ) ,d · |cos(ϕ)|)
d ∈ {-1,1}

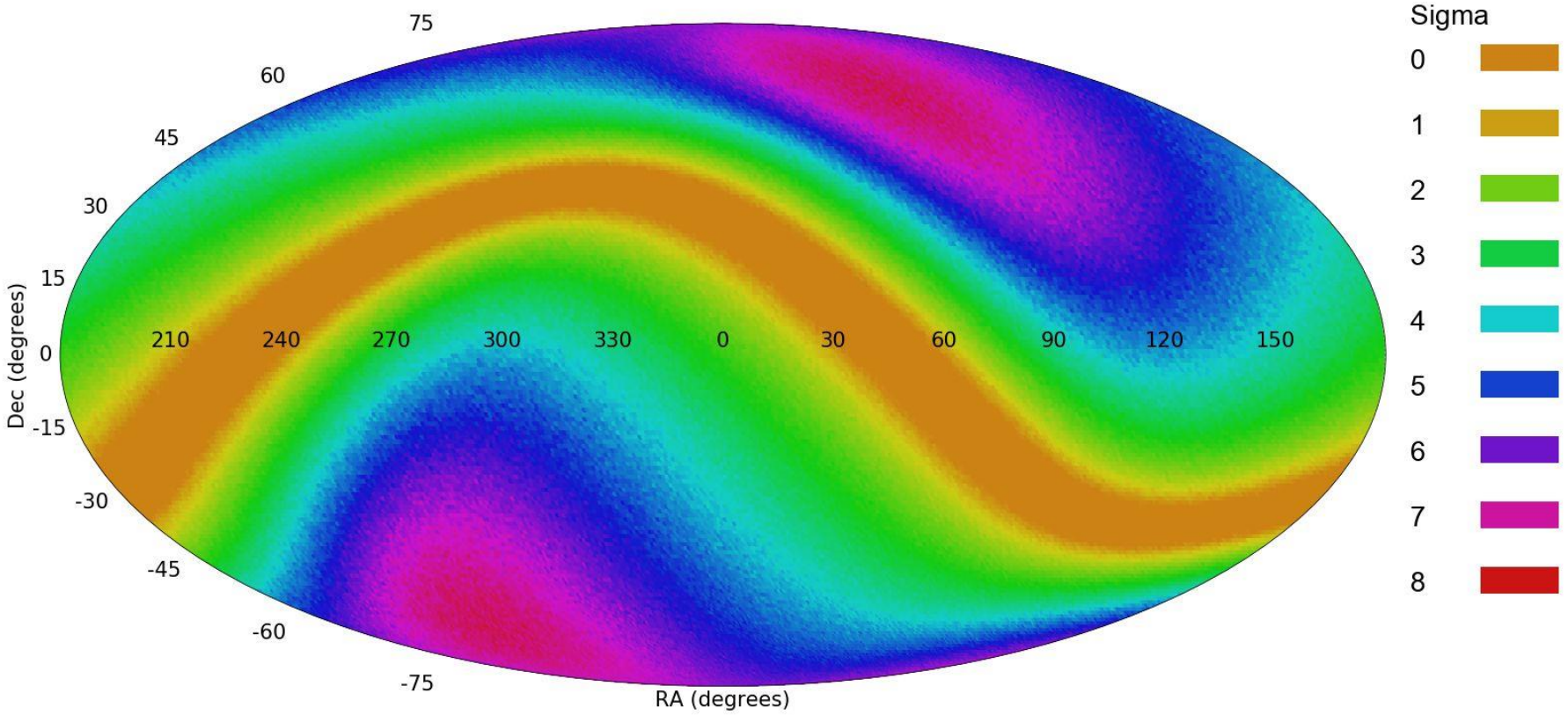
Most likely axis:
(α=88°, δ=36°)
Probability=4.34σ
(P<0.000014)



Dipole (random spin directions)

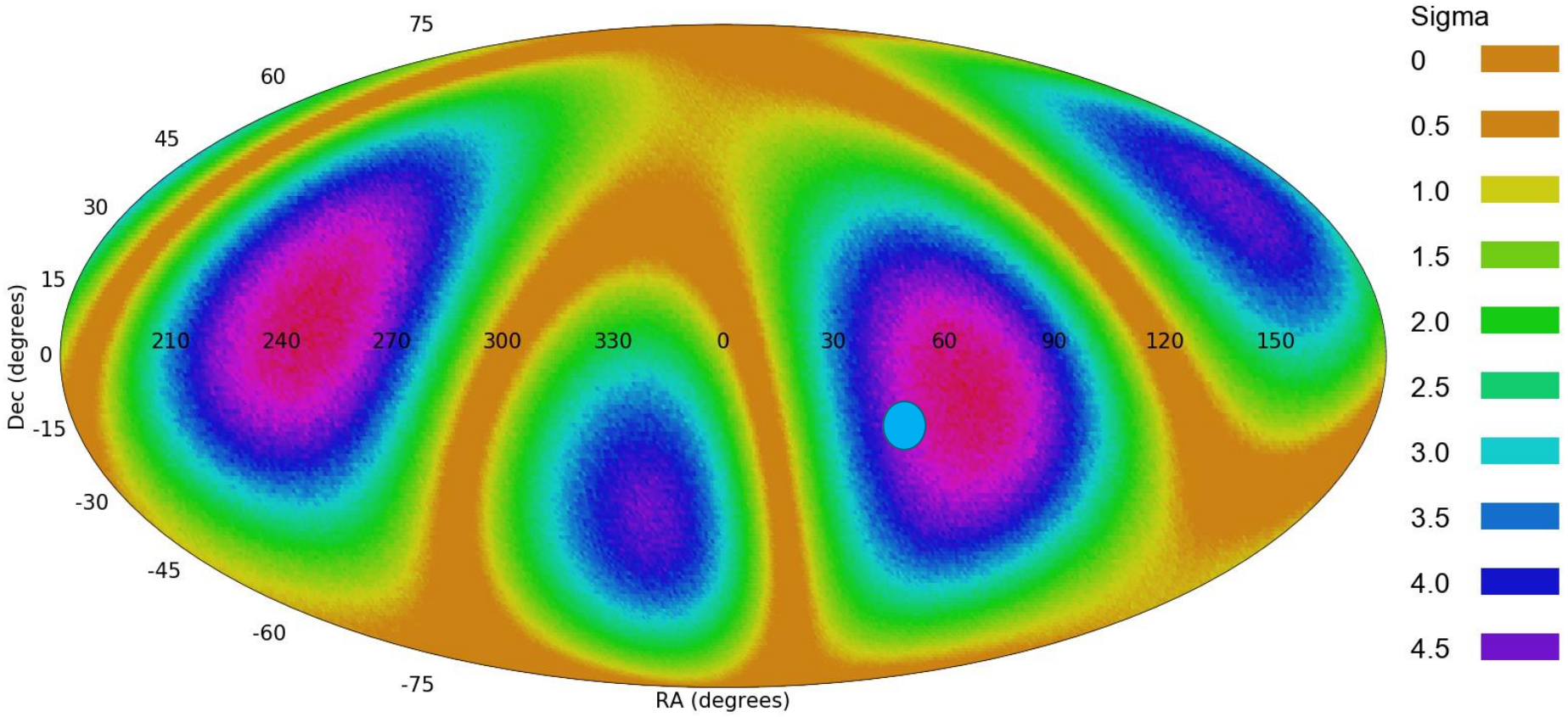


Dipole (z>0.15)


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

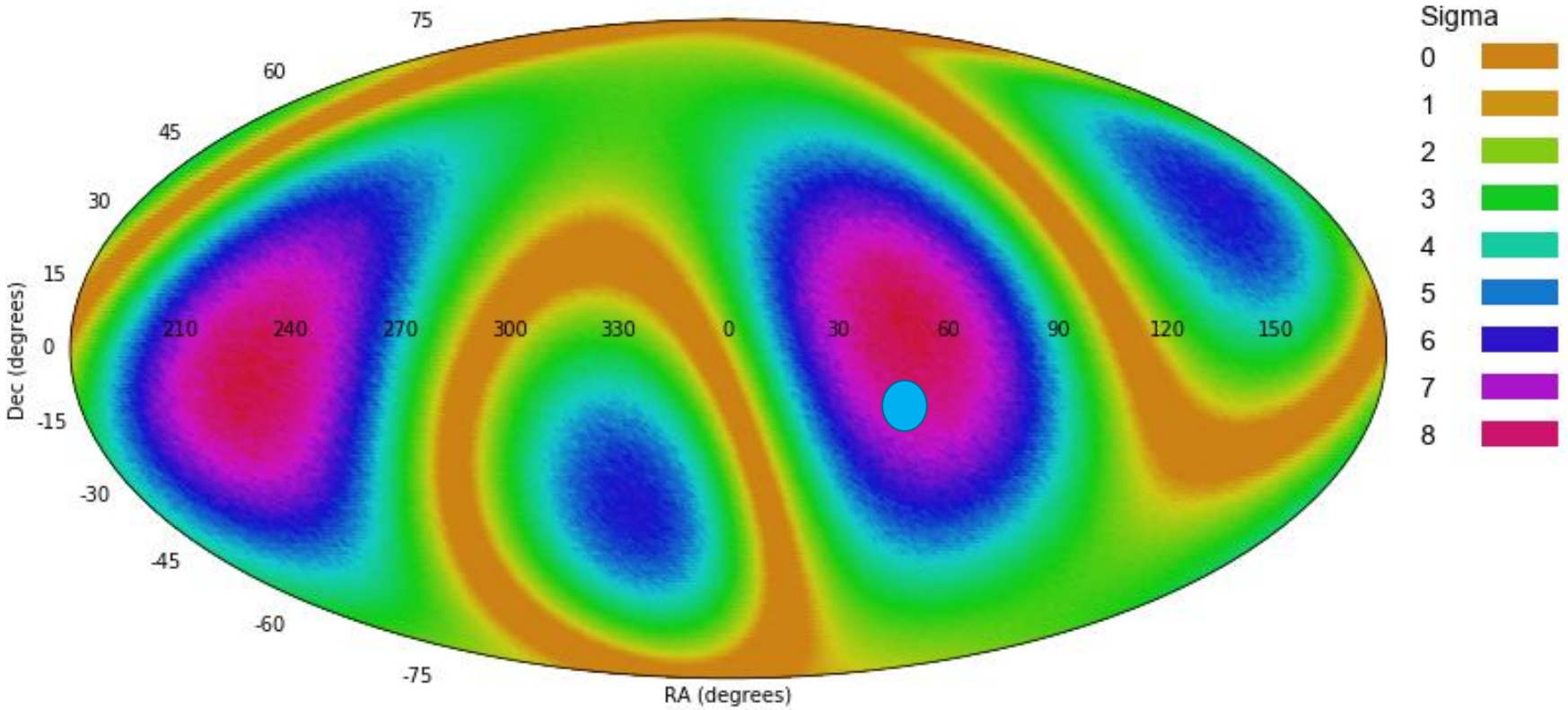
Quadrupole

Most likely axis:
(α=65^o, δ=-12^o)
Probability=4.94σ

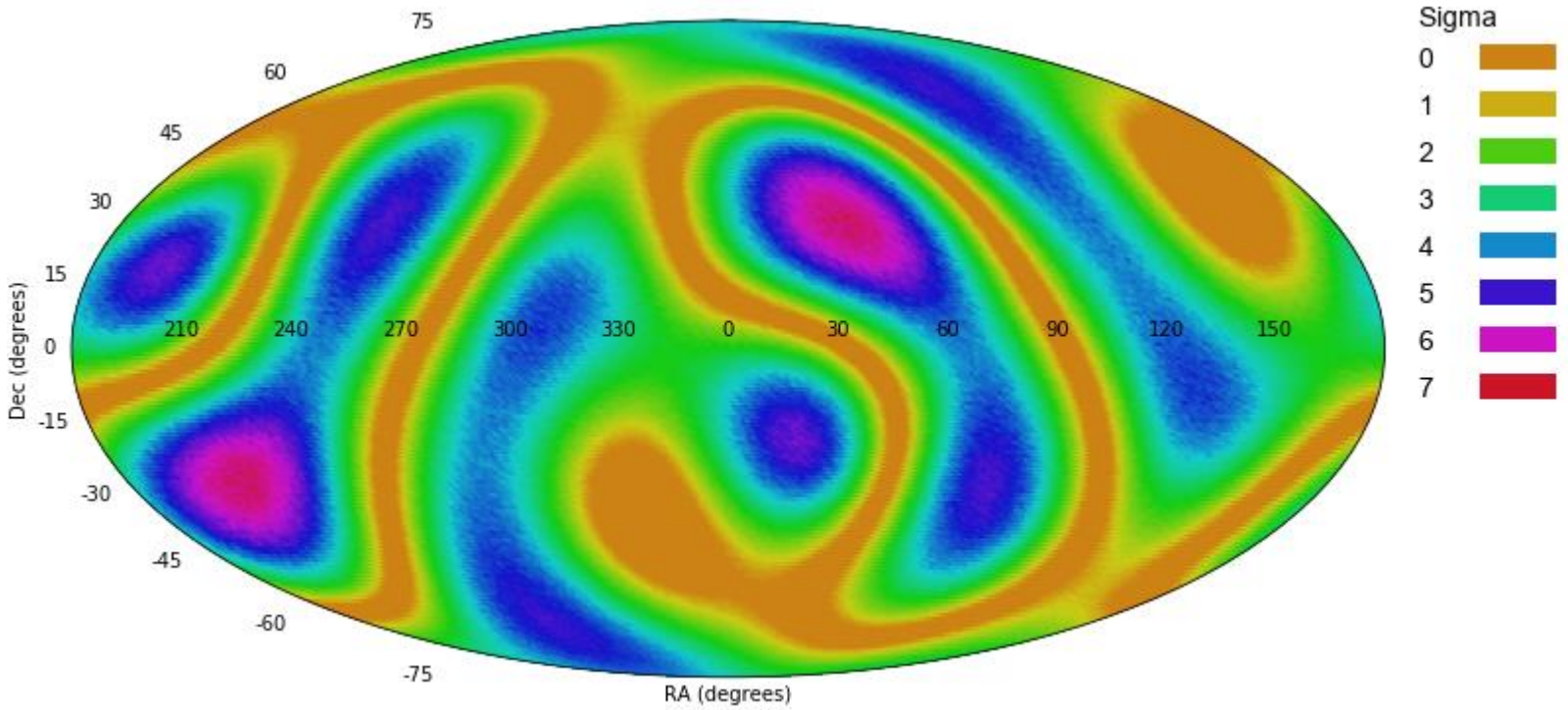


Dipole (z>0.15)

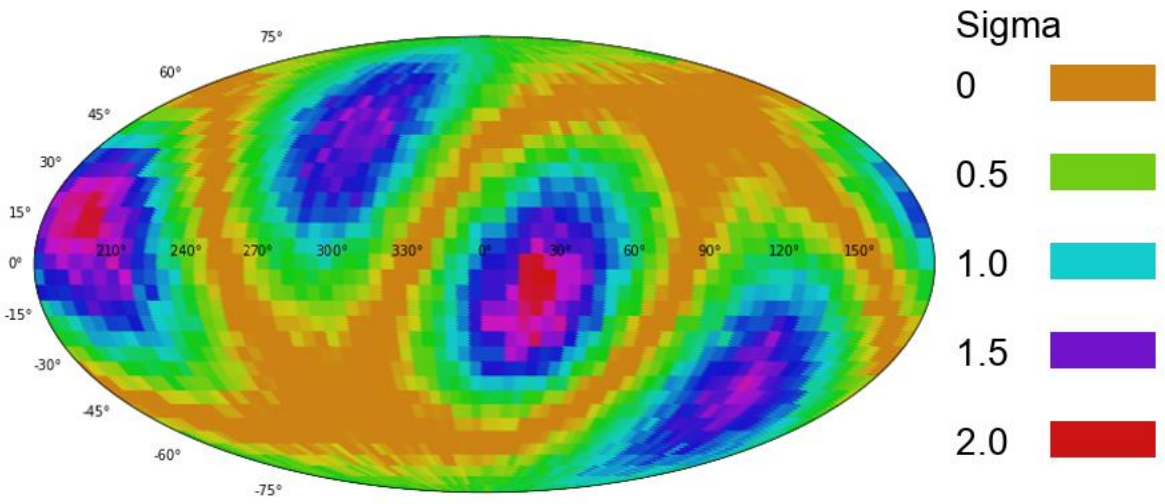
Most likely axis:
(α=52°, δ=-7°)
Probability=8.67σ

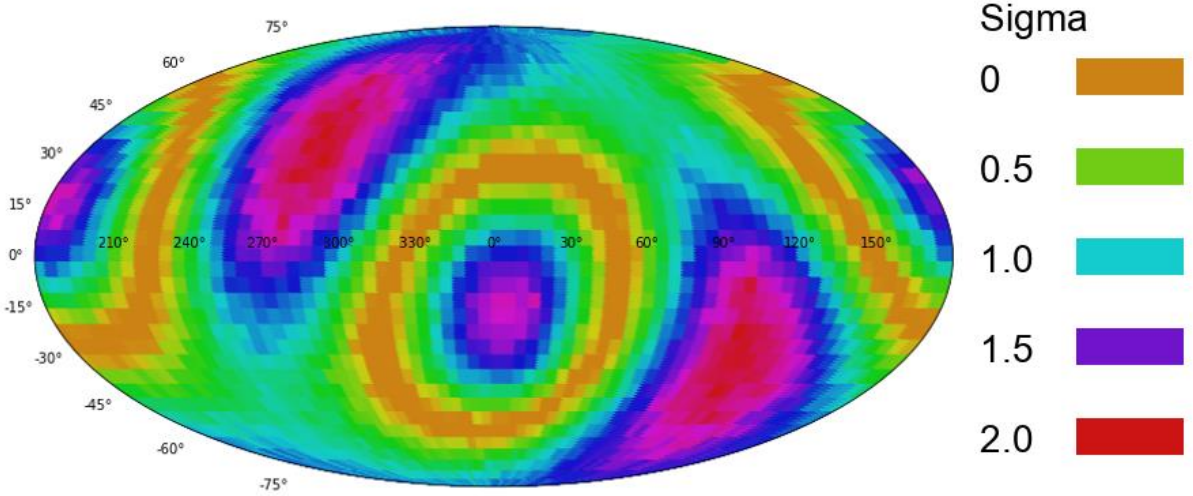


Octopole (z>0.15)

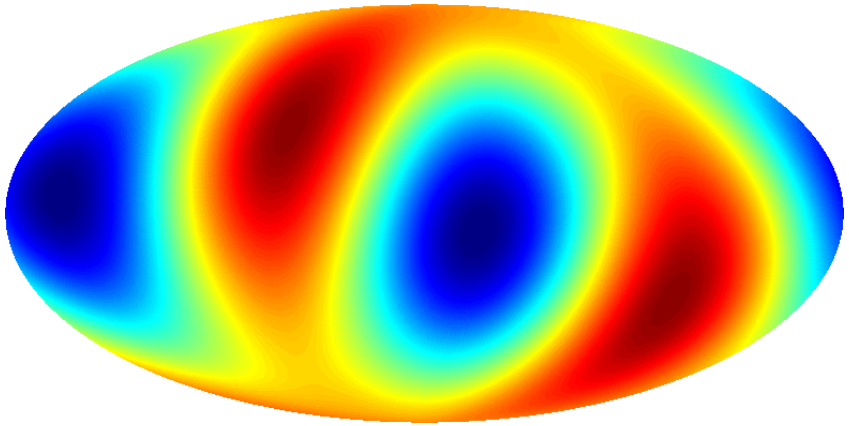


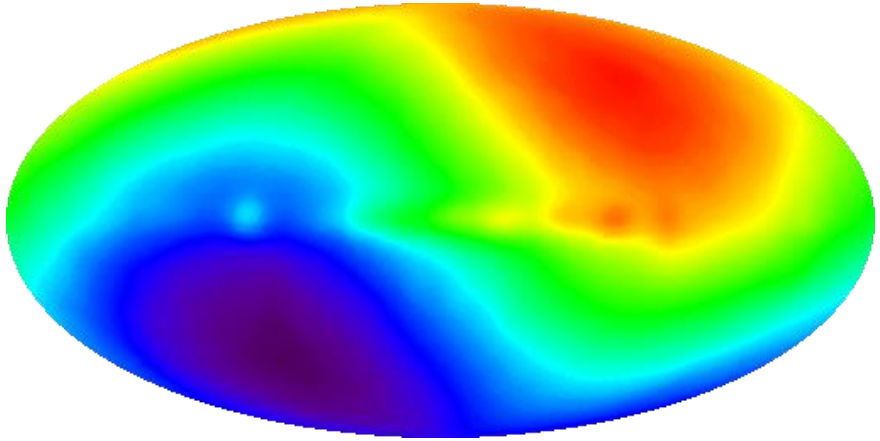
SDSS vs. Pan-STARRS

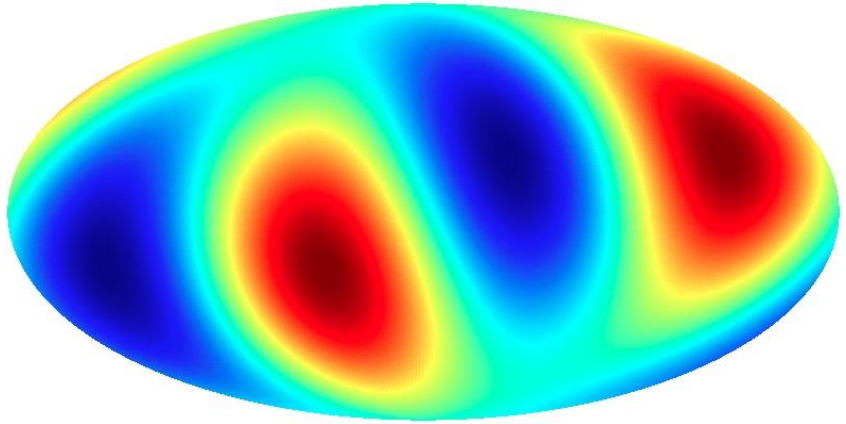


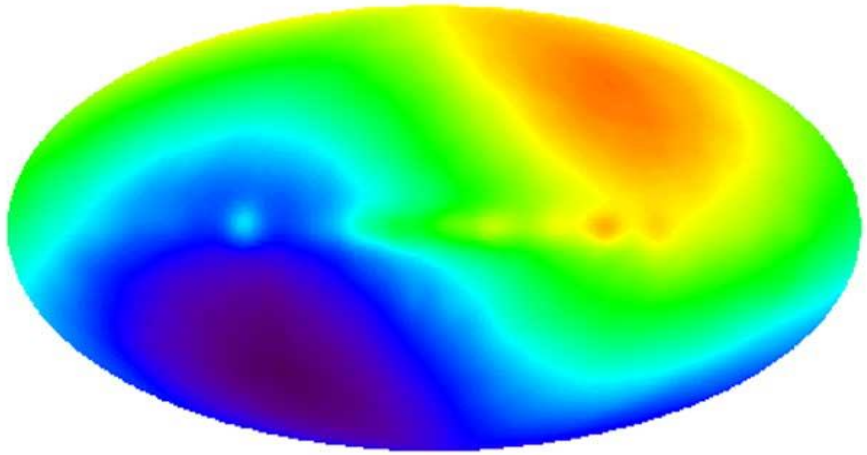


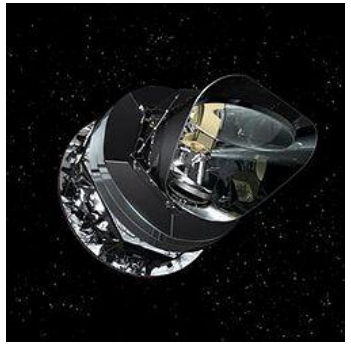
Cosmic Microwave Background



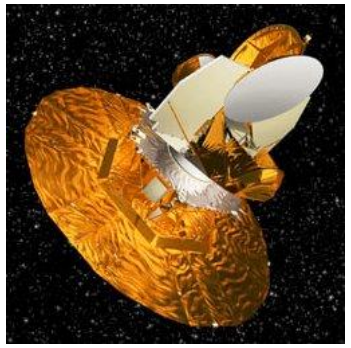




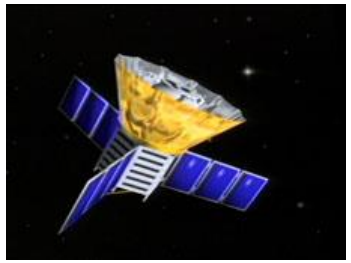




Planck



WMAP



COBE

Contact information

lshamir@ksu.edu

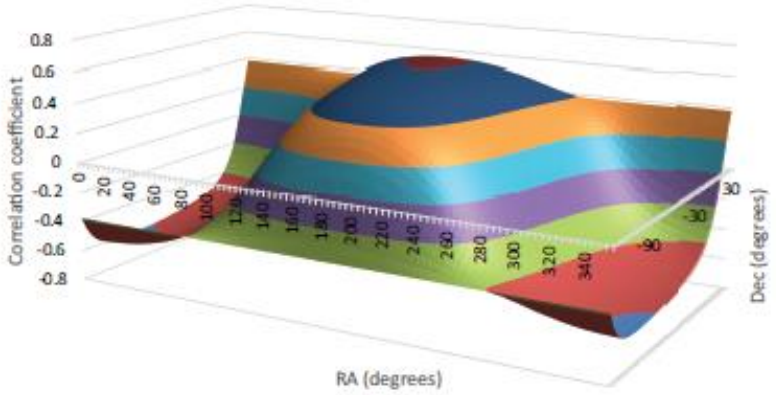
(Lior Shamir)

Relativistic beaming

$$F = F_0\left(1 + 4\frac{v_r}{c}\right)$$

$$F_\nu = F_{\nu 0}\left[1 + (3 - \alpha)\frac{v_r}{c}\right]$$

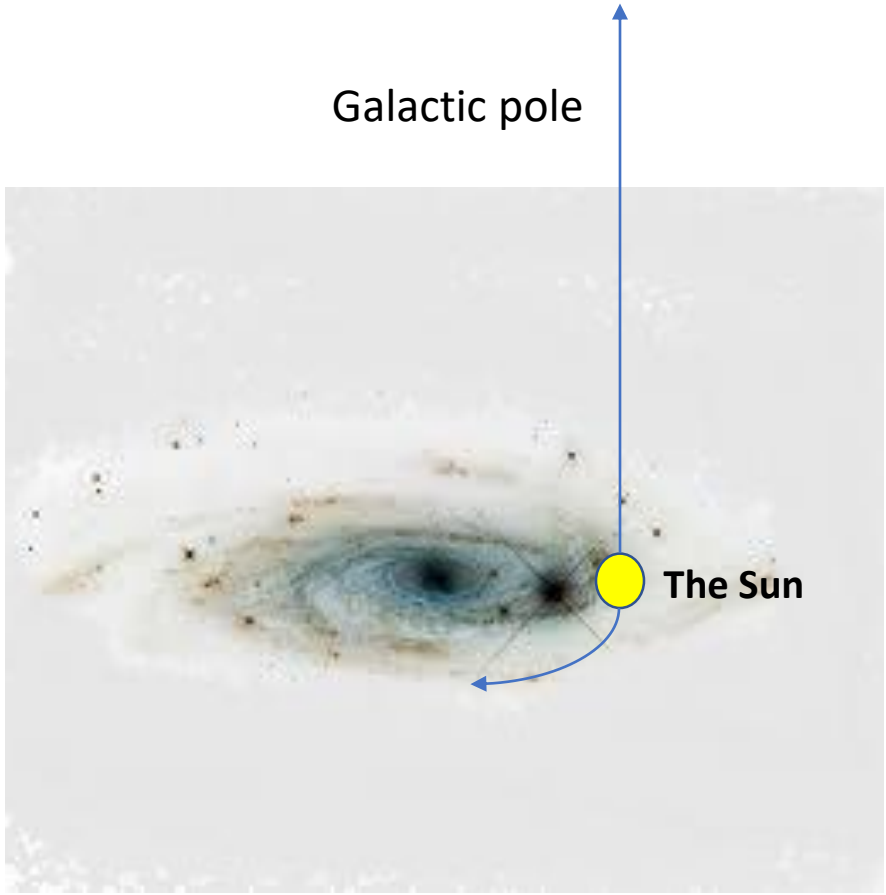
Loeb & Gaudi, 2003



Expected maximum difference: ~0.009 magnitude

Observed difference: ~0.05 magnitude

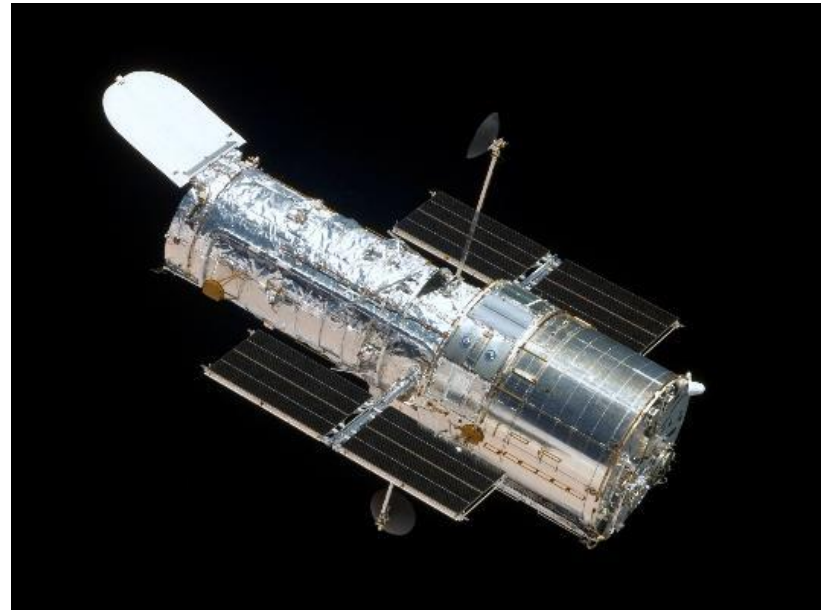
Relativistic beaming can explain the asymmetry only if galaxies rotated much faster (at least 10 times faster than the Milky Way).



Brightness Asymmetry peaks at (172°,50°)

Galactic pole (192°,27°)

COSMOS (Hubble Space Telescope)
(5,122 galaxies)



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

Direction of Observation (Right Ascension)

64K galaxies with spectra

RA	cw	ccw
120^o-210^o	17876	18391
$> 300^o < 30^o$	3064	3219
30^o-120^o	1665	1560
210^o-300^o	9061	8857

>300º ,< 30º
-4.9% (P=~0.026)

30º - 120º
+6.3% (P=~0.033)

210º - 300º
+2.3% (P=~0.065)

120º - 210º
-2.9% (P=~0.0034)