

Spin parity distribution of spiral galaxies in the Spin Catalogs of PanSTARRS and HSC

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1. Background Motivation
2. S/Z as spin sign indicator
3. Spin Catalog of Galaxies
4. Local Universe (Shamir)
5. BAO shell (Tully)
6. HSC survey



Masanori Iye
家 正剛

1977: *Spiral modes (PhD)*
1984-2002: *Subaru Telescope project scientist*
2003-2012: *LGS Adaptive Opt*
2014-2019: *TMT Vice-Chair*
2020- : *Japan Academy*

1) Background of S/Z analyses

Basic Question: **Do galaxies spin randomly?**

- (1) Scalar Density Perturbation : CMB, Galaxy Distribution
Vector Field Perturbation: **Vortex**, velocity Distribution
- (2) Theoretical Scenarios of galaxy spin
 - (a) *Primordial Swirl*, (b) *Pan-cake Shock*, (c) *Tidal Torque*,
 - (d) Λ CDM fluctuation

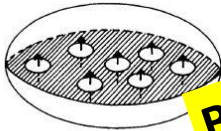
(1) Origin of cosmic vortex field

History : Galaxy Formation Schemes

(a) Primordial Whirl
Weizsaecker 1951
Gamow 1952
Ozernoi 1974

(b) Pan cake collapse
Zeldovich 1978
Doroshkevich 1973
Shandarin 1974

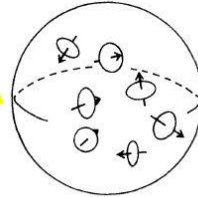
(c) Tidal torque
Peebles 1978
Barnes Efstathiou 1987



a)



b)



c)

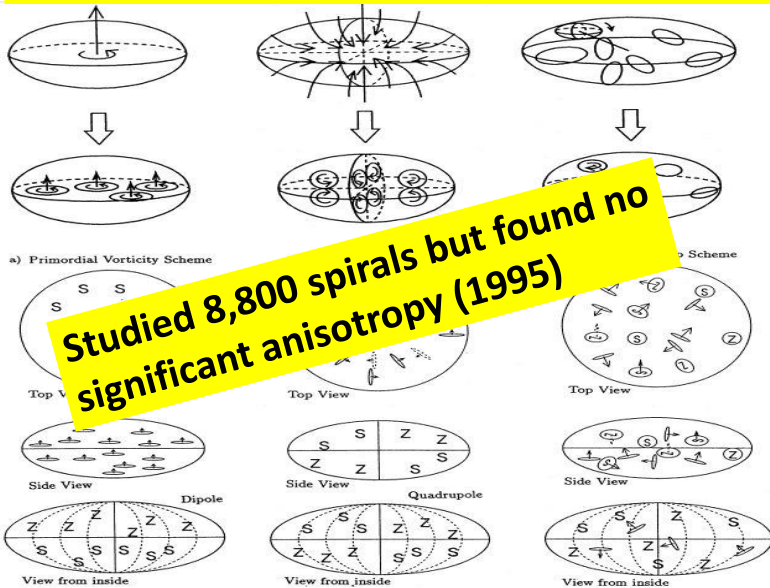
But who knows the reality?

Modern Standard
(d) Λ CDM Structure Formation
Random Gaussian,
Harrison-Zel'dovich spectrum

cluster-galaxy tidal force
galaxy-galaxy tidal force
Orbital mixing

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Inferred anisotropy Sugai & Iye 1995



Studied 8,800 spirals but found no significant anisotropy (1995)

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(4) S/Z Database

SDSS, Pan Starrs, DES, ESO DSS, HSC, => DL Classification of S/Z

(5) Formalism of dipole analysis and disproving Shamir's papers.

(Iye, Yagi & Fukumoto, 2021, ApJ 907,123)

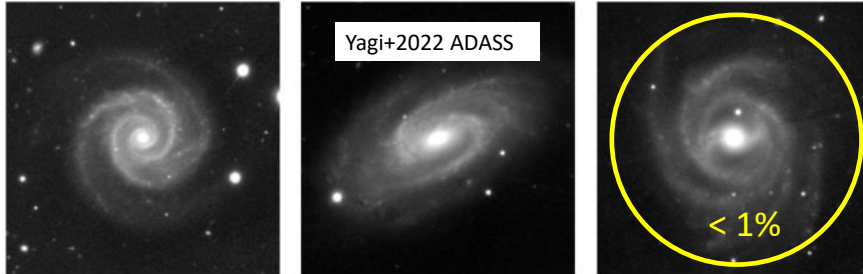


Figure 1. Examples of Z(left), S(center), and inside Z outside S(right)

Not relevant: Right/Left-hand spirals, Clockwise/Counter clockwise spirals.

Use nomenclature **S-wise/Z-wise spirals**: **S/Z** : Not the **Sunyaev-Zeldovich**

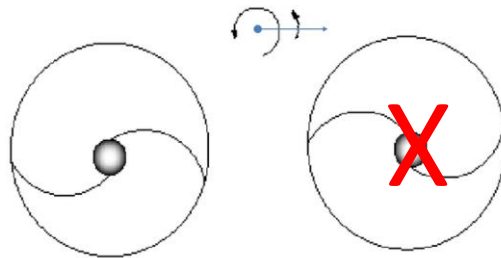
(3) Observational Test Methods

(a) shape distribution

ellipticity and position angle

(b) Spiral Parity distribution

differential rotation 差動回転



Trailing arms 巻込型

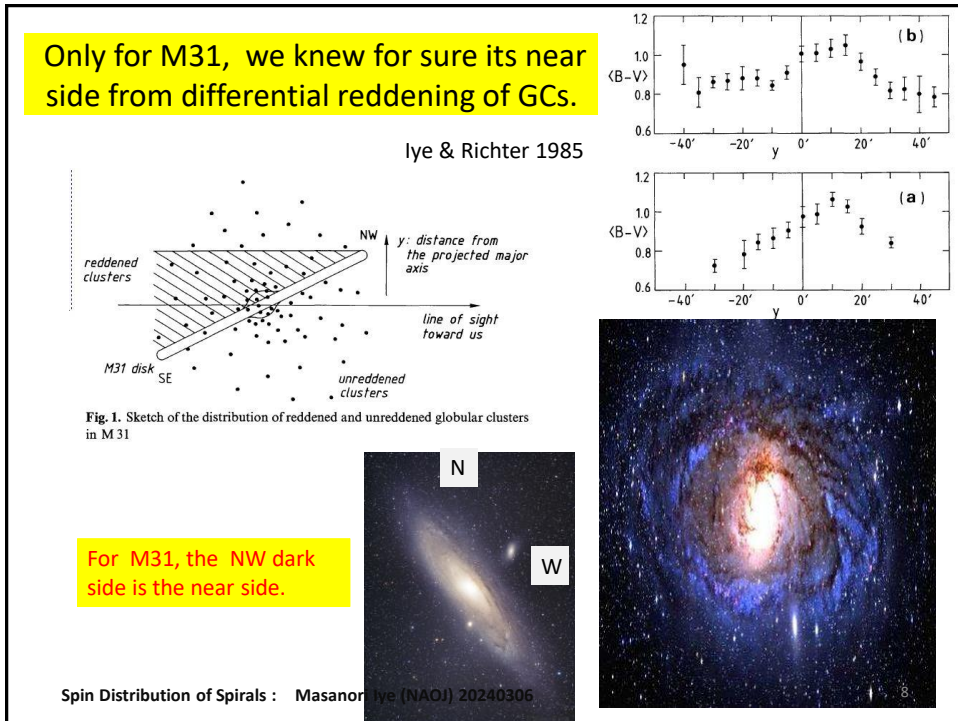
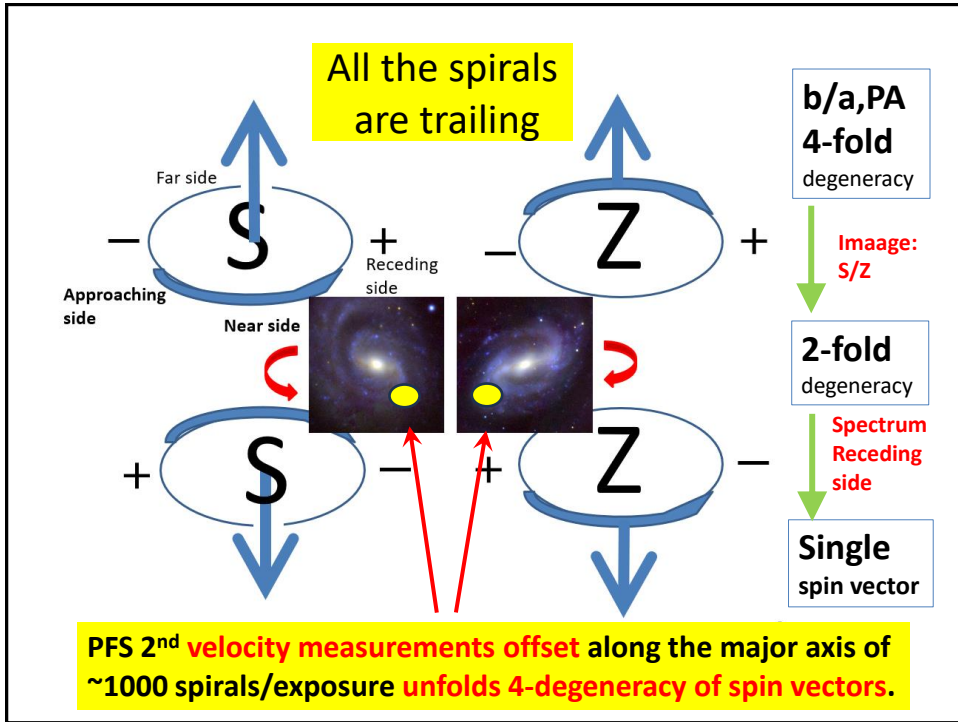
Leading arms ほどけ型

Observationally verified

Iye+2019

N-body simulation results

grows in Linear theory for cold disks: (Kalnajs 1972)



(2c) New Developments

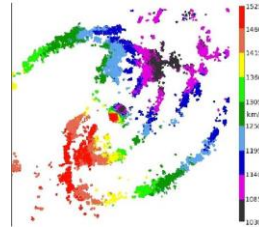
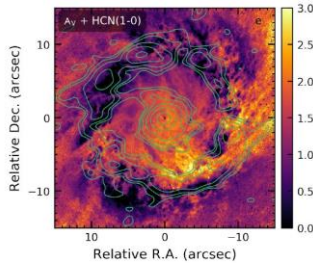
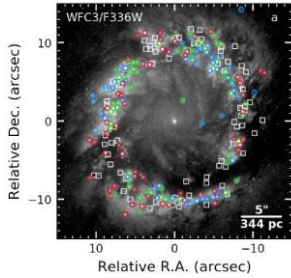
Another Evidence for Trailing Spiral: NGC1097

<https://arxiv.org/pdf/1902.09370v1.pdf>

Izumi 2018



Wikipedia image is reversed!



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“Corroborative Evidence for Trailing Spirals”

— 146 Spiral Galaxies —

Iye, Tadaki, Fukumoto 2019: ApJ

Table 1. Observationally confirmed spin parity of spiral galaxies

ID	S/Z Side	Dark Side	Appr.	T/L	Image1	Image2	Image3	Image4
Circinus Galaxy	S	SE	NE	T				
IC1683	Z	W	N	T				
IC1755	S	SW	SE	T				
IC2101	S	NE	NW	T				
IC5376	Z	W	N	T				
MCG-02-02-030	Z			T				
NGC 247	S	NW	SW	T				
NGC 247	S	E	N	T				
NGC 247	S	E	N	T				

All the spirals are Trailing! =>
 Enables identification of the sign of the line-of-sight component of the spin angular momentum vector just from S/Z spiral patterns

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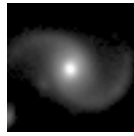
Galaxy Image Archives

	HSC	DES	PanStarrs	SDSS
Depth	r<26.5	R<24.4	r<23.2	r<20.8
redshift	<0.8	<0.1	<0.1	<0.05
Area(deg^2)	456	5,000 (South)	30,000	14,055

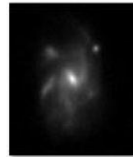


PS2

41135358515108699 (z=0.37)

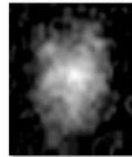


HSC



PGC001922_DES.

png



PGC001922_DSS.

png

(z=0.02)



PGC001922_PS1j

pg

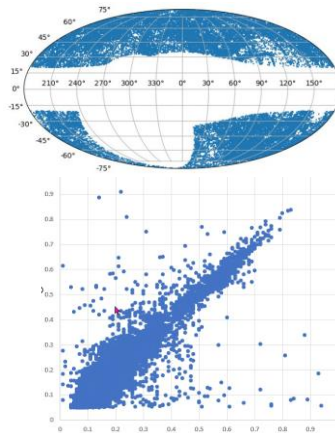
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3) Spin Catalog of galaxies

Available Spin Data

- All Sky PS1 ($\alpha, \delta, z, S/Z$)
44895 (z<0.05, without SGC)
- HSC PDR3(x,y,z,S/Z)
76635 with photz (of which 15,768 with **specz**)



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4) Anisotropy in the Local Universe

Number Asymmetry: $A = \{N(S) - N(Z)\} / \{N(S) + N(Z)\}$, $\sigma_A = \{N(S) - N(Z)\} / \sqrt{N(S) + N(Z)}$

Dipole vector:

$$\vec{d} = \left[\sum_N h_i f_i \vec{g}_i \right] / N$$

h_i : helicity

f_i : flip probability from viewer

\vec{g}_i : directional unit vector

$$\|\vec{d}\| = \frac{2 \sqrt{2(1 + \sin \theta_{\min} + \sin^2 \theta_{\min})}}{\sqrt{3\pi N}}$$

Paper III: Iye+ (2021)

Dipole formulation and with error evaluation and application to SDSS sample. ApJ, 907,123

$h^i = +1(\text{Z-wise}), -1(\text{S-wise})$

$$D(l_P, b_P) = \sum_{i=1}^N h^i \Omega^i P / N = \sum_{i=1}^N h^i \cos \theta^i / N \quad (2)$$

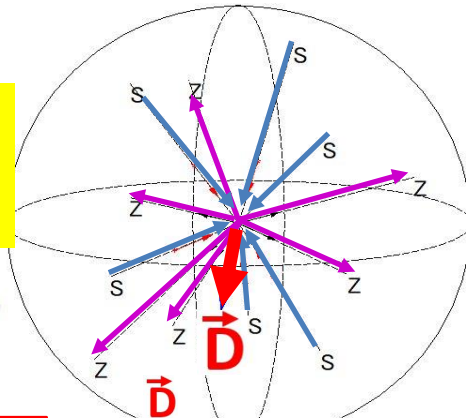
If random

3D random flight : \vec{D} is Gaussian distribution (Chandrasekhar 1943) and D^2 follows chi-squared distribution with 3 dof.

$$W(\mathbf{R}) = \frac{1}{(2\pi N \langle r^2 \rangle_{Av} / 3)^{3/2}} \exp(-3|\mathbf{R}|^2 / 2N \langle r^2 \rangle_{Av}) \quad (3)$$

$$\bar{D}_{max} = \frac{\sqrt{2}\Gamma(2)}{\sqrt{3N}\Gamma(3/2)} = \frac{2\sqrt{2}}{\sqrt{3\pi N}} \sim \frac{0.921}{\sqrt{N}} \quad (4)$$

$$\sigma_D \sim (D_{max} \sqrt{N} - 0.921) / 0.389 \quad (6)$$



N step 3D random flight

Dipole anisotropy in the Local Super Cluster (?) Shamir (2017), Iye+(2021)

Confirmed 4σ dipole for Shamir's data. But found data flaw. 160k =>75k sample. Cleaned data do not show dipole anisotropy.

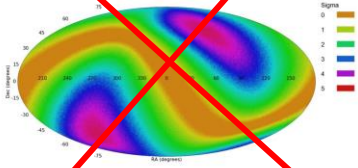
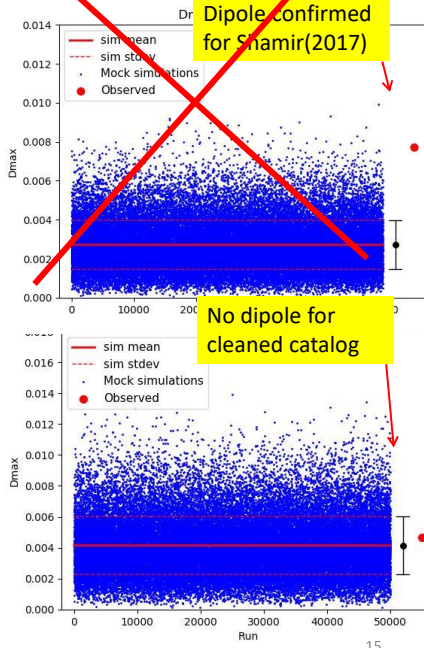


Fig. 5 The σ of the likelihood of a dipole axis of SDSS galaxies in different (α, β) combinations



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5. Analysis of Tully+23 BAO Shell

New spin catalog of 139,351 galaxies at $z < 0.05$ from PanSTARRS image data library.

The S/Z distribution of 10,581 spirals in the BAO shell (red sphere, Tully+2023) with its center at $z=0.068$ and radius of 155Mpc. Our sample (blue $z < 0.05$) covers only the near half of the volume. No striking parity violation for this structure with

$A = -0.0058$, $\sigma A = -0.593$, $D = 0.0069$, and $\sigma D = -0.532$.

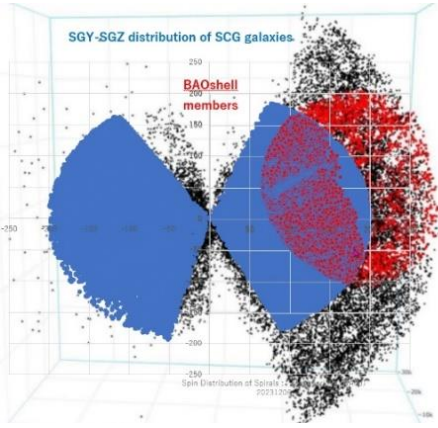
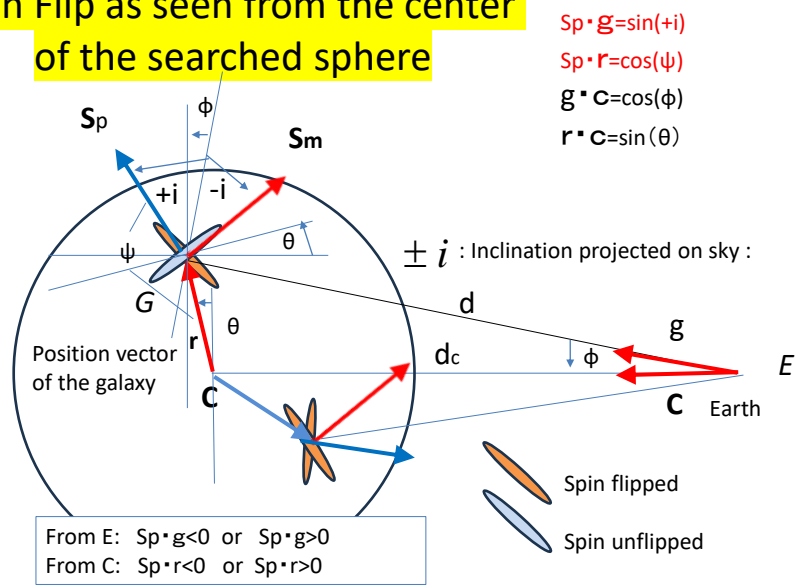


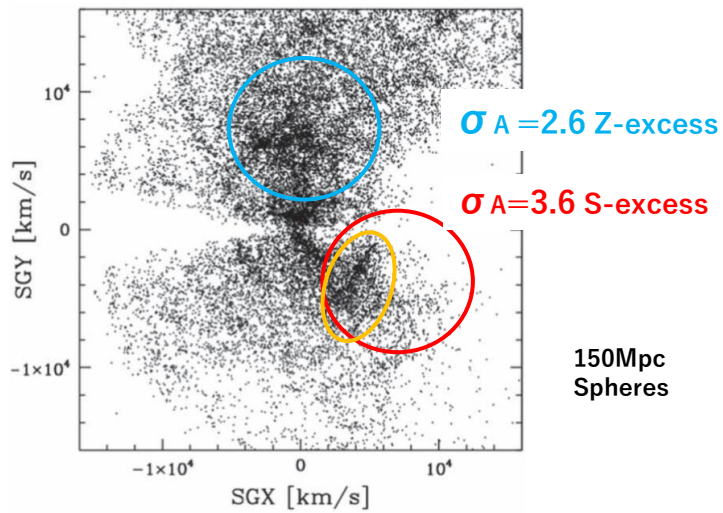
Fig. 5. Tentative analysis of BAO shell found by Tully+23 Did not show parity violation.

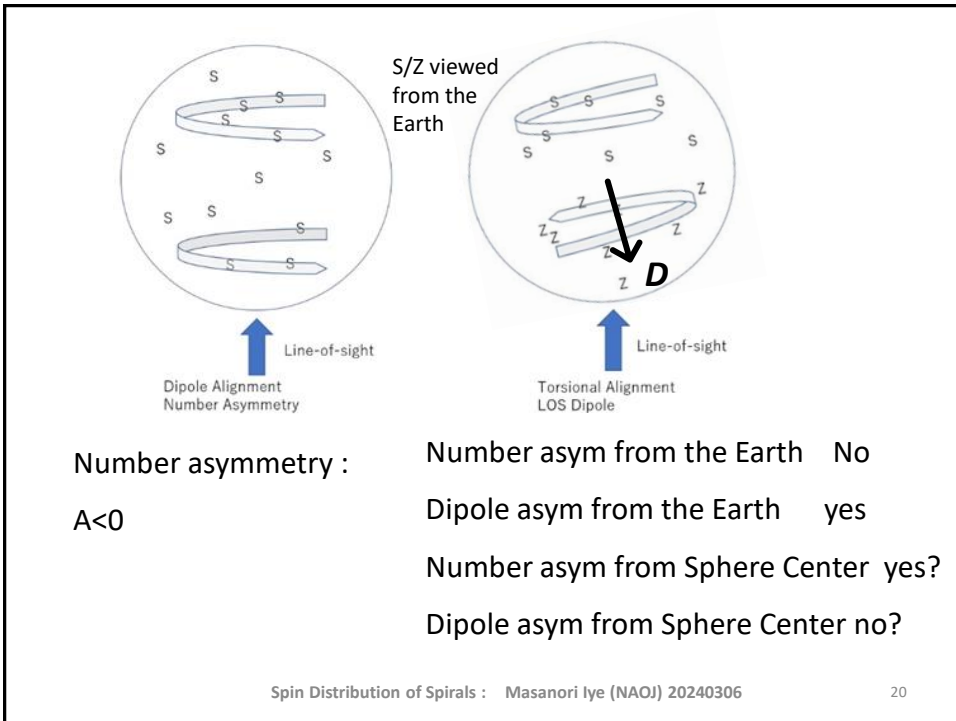
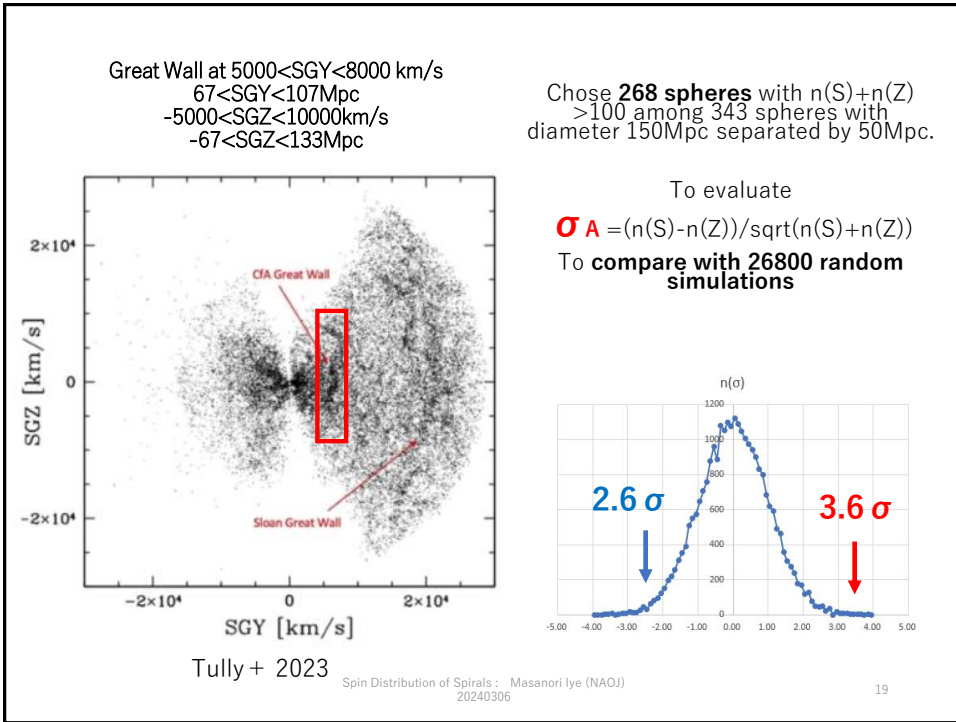
渦巻銀河のスピンドリフト: 全ての渦巻星は trailing 家立期(国立天文台), 20190913 Masanori Iye (NAOJ)

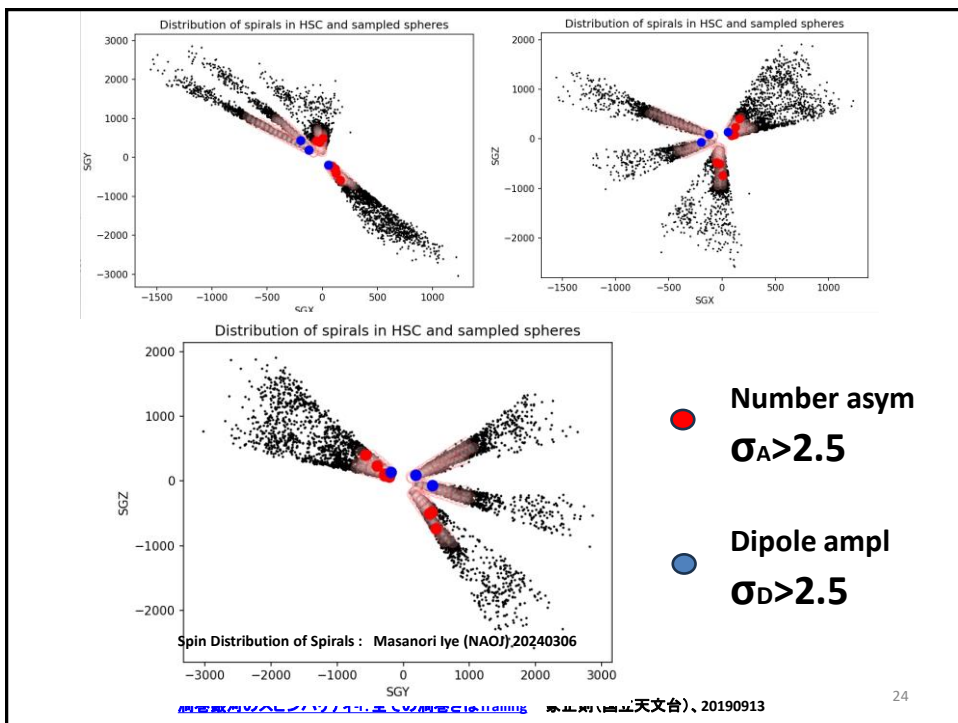
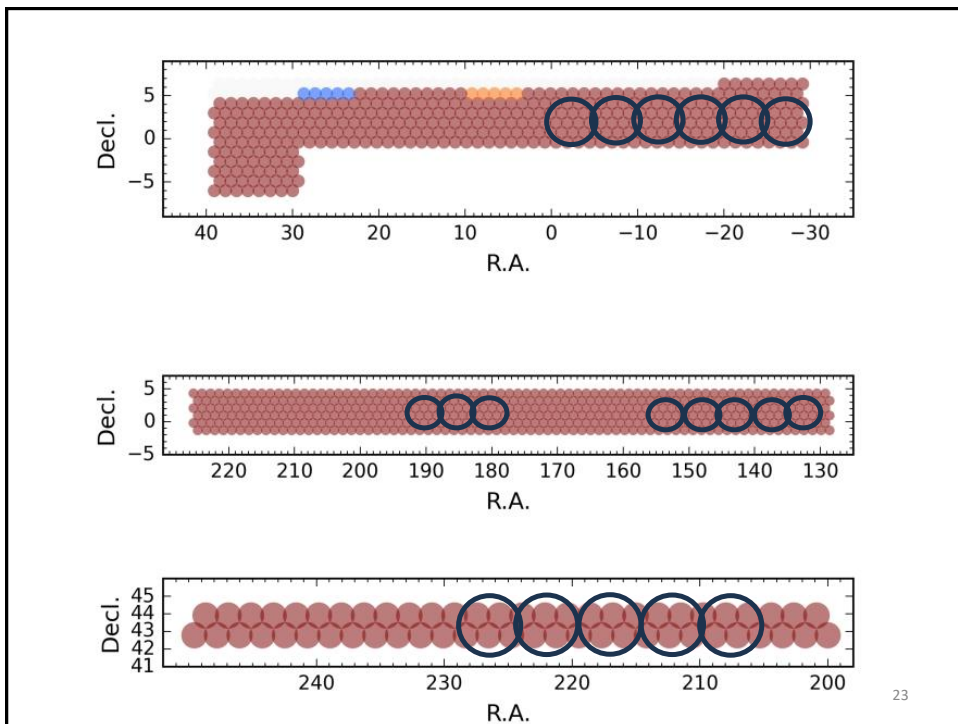
Spin Flip as seen from the center of the searched sphere

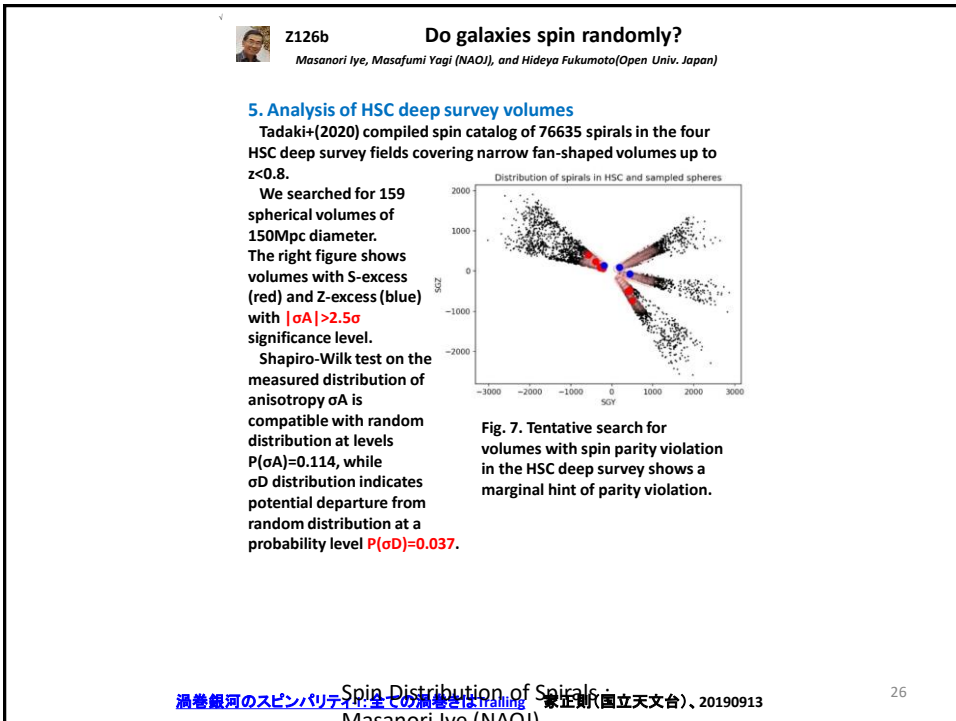
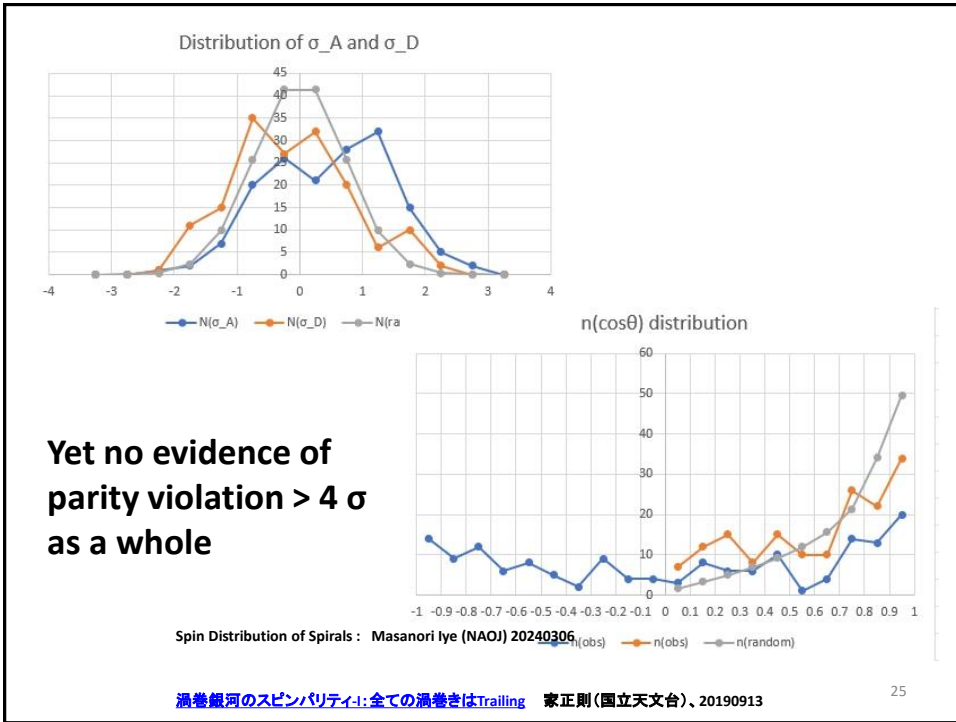


**Analysys on Cosmic-Flow 4(Tully2023) sample
 $z < 0.05$**









Cluster/Filament Analyses *still not large enough samples ...*

Dipole analysis in
the Local universe

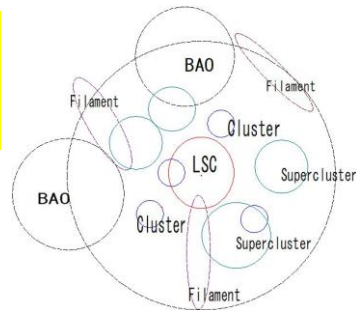


SDSS
PS2
DES
ESO DSS
($z < 0.1$)



Dipole analysis for
any sub-volume
around an
arbitrary center

HSC
($z < 0.8$)



Clusters	RA	DEC	z	Visibility
A1367	176.152083	19.758889	0.022	○
A2151	241.3125	17.748611	0.0366	○
A1689	197.8925	-1.3655555	0.1832	○
A520	73.515833	2.8925	0.199	△
A2163	243.891667	-6.123888	0.203	△
A1758	203.18	50.540472	2	0.279
J0916+2951	139.045417	29.81222	2	0.53

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5. Intrinsic Alignment of galaxies

- Whether galaxy shape aligns with LSS?
- Use the ellipticity and position angle of galaxies
- Merit: **Larger number of galaxies incl. Ellipticals**
Numerical simulations in Λ CDM.
- Demerit: **Difficult calibration**
- **Complementary: to Spiral Parity study**
- Caveats: following slides

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Spin Parity Paper Series

Question: ***Any asymmetry in the galaxy spin vector distribution?***

- Classic (Sugai+:1995) Concept of S/Z analysis and application to 9k spirals.
- SDSS (Shamir:2017) S/Z catalog of 160k spirals. “Found” a strong dipole.
- Paper I (Iye+:2019) Spirals are all “trailing”. Can use spiral parity S/Z to judge the galaxy spin vector to look for any anisotropy in their distribution.
- Paper II (Tadaki+:2020) DL Classified S/Z of 80k HSC spirals ($z < 0.8$)
- **Paper III (Iye+:2021)** Dipole analysis calibrated with Monte Carlo simulations and application to 70k SDSS spirals to **disprove Shamir’s claim.**
- **Paper IV (Fukumoto+:2024) Compilation of reliable spin catalog of 45k PanStarrs spirals at $z < 0.05$ in 3π str and its dipole analysis.**
- **Paper V (Iye+2024) Analysis on HSC cone regions $z < 0.4$**
- **Paper IV(Iye+2024): 2-point correlation analysis of S/Z distribution**