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Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT

We investigate the 3D spin alignment of galaxies with respect to the large-scale filaments using the MaNGA survey. The cosmic web is reconstructed from the Sloan Digital Sky Survey using DisPerSE and the 3D spins of MaNGA galaxies are estimated using the thin disk approximation with integral field spectroscopy kinematics. Late-type spiral galaxies are found to have their spins parallel to the closest filament's axis. The alignment signal is found to be dominated by low-mass spirals. Spins of S0-type galaxies tend to be oriented preferentially in perpendicular direction with respect to the filament's axis. This orthogonal orientation is found to be dominated by S0s that show a notable misalignment between their kinematic components of stellar and ionised gas velocity fields and/or by low mass S0s with lower rotation support compared to their high mass counterparts. Qualitatively similar results are obtained when splitting galaxies based on the degree of ordered stellar rotation, such that galaxies with high spin magnitude have their spin aligned, and those with low spin magnitude in perpendicular direction to the filaments. In the context of conditional tidal torque theory, these findings suggest that galaxies' spins retain memory of their larger-scale environment. In agreement with measurements from hydrodynamical cosmological simulations, the measured signal at low redshift is weak, yet statistically significant. The dependence of the spin-filament orientation of galaxies on their stellar mass, morphology and kinematics highlights the importance of sample selection to detect the signal.

Key words: galaxies: kinematics and dynamics, evolution, formation – cosmology: large scale Structures of the universe

Откуда вообще галактики получают угловой момент?

Protogalaxies acquire their spin by tidal torquing coming from the surrounding matter distribution

Фактически – развитие идеи Codis etal,2015 (hydrodynamical simulation).

…gas is expelled from adjacent voids, towards sheets and filaments forming at their boundaries. Within these sheets/filaments, the gas shocks and radiatively loses its energy before streaming towards the nodal points of the cosmic network. In the process, it advects angular momentum, driving the morphology of galaxies (bulge or disc). The evolution of the Hubble sequence in such a scenario is therefore at least in part initially driven by the geometry of the cosmic web. As a consequence, the distribution of the properties of galaxies measured relative to their cosmic web environment should reflect such a process. In particular, the spin distribution of galaxies should display a preferred mass-dependent orientation relative to the cosmic web.

…

Результаты сравнения с наблюдениями противоречивы

- While some works confirmed the existence of a galaxy spin transition from parallel to perpendicular with respect to the filament’s direction, others found preferential perpendicular orientation with respect to filaments at all masses with no sign of a spin transition.
- Возможная причина - результат может зависеть от плотности филамента, от массы и угловогомомента гало галактик.
- A much better agreement seems to exist for elliptical/S0 galaxies, for which a preferential orthogonal orientation of their spin (or minor axis) with respect to their host filaments is found (Tempel et al. 2013; Pahwa et al. 2016), in agreement with with results of shape measurements.
- On the other hand, Krolewski et al. (2019) found no evidence for alignment in projection between galaxy spins, measured MaNGA kinematics and filaments from the SDSS Main Galaxy Sample.

- ЦЕЛЬ РАБОТЫ:

In this work, we measure the alignment between filaments identified in the SDSS Main Galaxy Sample and galaxy spins measured from MaNGA kinematics in 3D. (ВПЕРВЫЕ 3D).

- Исходные данные: обзор MANGA (3600-10300$^{\circ}A$, R =2000) for stellar kinematics, морфология – по GALAXY ZOO, филаменты from the publicly available code DisPerSE в приложении к SDSS galaxy catalogue, угол наклона – из фотометрического отношения b/a.
- we consider only galaxies that are not too faraway from the filaments (13 Mpc) and not too close to the nodes of the cosmic web (0.5 Mpc)

3D вектор спина

Проекция оси вращения на три направления

$$\hat{L}_r = \cos i,$$
$$\hat{L}_\theta = (1 - \cos^2 i)^{1/2} \sin \mathrm{PA},$$
$$\hat{L}_\phi = (1 - \cos^2 i)^{1/2} \cos \mathrm{PA},$$

- PA – кинематическая б.ось.
- i- через наблюдаемое отношение b/a (приближение диска с $(b/a)_0$ from 0.23 for S0 to 0.1 for Scd-Sdm types)
- PA – по анализу поля скоростей

Отдельно рассматриваются:

- Галактики поздних типов (S) и линзовидные (S0)
- Галактики массивные и маломассивные
- Галактики с рассогласованием динамических б.осей для эмиссионного газа и звезд, и без рассогласования (ΔPA < 10^0 для S- галактик и ΔPA <20^0 для S0).
- Галактики S0 разделялись по величине angular momentum estimator λ_R

Table 1. Number of galaxies, average $|\cos\gamma|$ and the KS probability $p_{\rm KS}$ that the sample is drawn from a random distribution for various sub-samples of LTGs, S0s, and galaxies with $\lambda_R > 0.73$ and $\lambda_R < 0.4$. For LTGs and S0s, we provide also the results for photometric data (shown in parenthesis).

	selection	$N_{\rm gal}$	$\langle\cos\gamma\rangle$	$p_{\rm KS}$
LTGs	all	611	0.53	6.2×10^{-3}
		(852)	(0.515)	(2.3×10^{-2})
	$M_\star \leq 10^{10}$ M$_\odot$	230	0.55	4.6×10^{-6}
		(377)	(0.521)	(1.9×10^{-2})
	$M_\star > 10^{10}$ M$_\odot$	381	0.517	6.4×10^{-1}
		(475)	(0.5)	(4.8×10^{-1})
	ΔPA $< 10°$	556	0.53	7.5×10^{-3}
S0s	all	269	0.465	6.5×10^{-3}
		(363)	(0.482)	(4.5×10^{-2})
	$M_\star \leq 10^{10}$ M$_\odot$	114	0.425	5.6×10^{-4}
		(170)	(0.447)	(2.9×10^{-3})
	$M_\star > 10^{10}$ M$_\odot$	155	0.496	5.9×10^{-1}
		(193)	(0.513)	(5.9×10^{-1})
	ΔPA $> 20°$	117	0.446	3.2×10^{-4}
$\lambda_{\rm R} > 0.73$	all	131	0.554	9.0×10^{-3}
	$M_\star \leq 10^{10}$ M$_\odot$	71	0.593	5.4×10^{-3}
	$M_\star > 10^{10}$ M$_\odot$	60	0.508	7.5×10^{-1}
	ΔPA $< 10°$	130	0.557	1.0×10^{-2}
$\lambda_{\rm R} < 0.4$	all	344	0.479	3.0×10^{-2}
	$M_\star \leq 10^{10}$ M$_\odot$	133	0.447	6.5×10^{-5}
	$M_\star > 10^{10}$ M$_\odot$	211	0.499	3.4×10^{-1}
	ΔPA $> 20°$	116	0.445	2.2×10^{-3}

Probability distribution function (PDF) cos γ для галактик S и S0 различных масс

cos γ=1 означает вытянутость вдоль филамента.

The solid grey line and shaded area represent the median and 95% confidence limits from 2000 random samples, respectively.

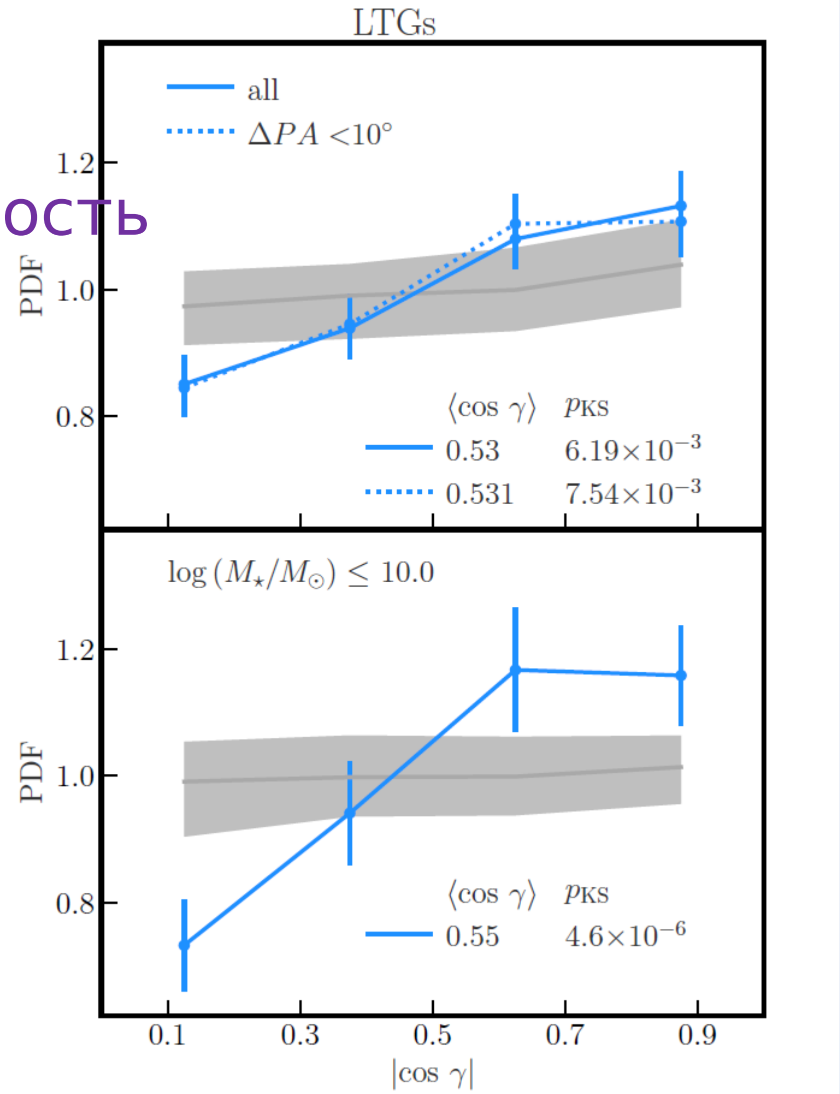

Figure 1. Alignment between the filaments and spin of all (*top*), and, low-mass (*bottom*) LTGs. The alignment signal for the kinematically aligned (i.e. ΔPA < 10°) galaxies only is shown by the dotted line. The error bars correspond to the bootstrap. The solid grey line and shaded area represent the median and 95 per cent confidence limits from 2000 random samples, respectively. The mean alignment angle together with the probability p_{KS} of the KS test are shown in each panel with corresponding symbols. LTGs in the probed mass range tend to have their spin parallel to their host filaments. The alignment signal seen for the entire population of LTGs is driven by the low mass sub-sample ($M_\star \le 10^{10}$ $M_\odot$).

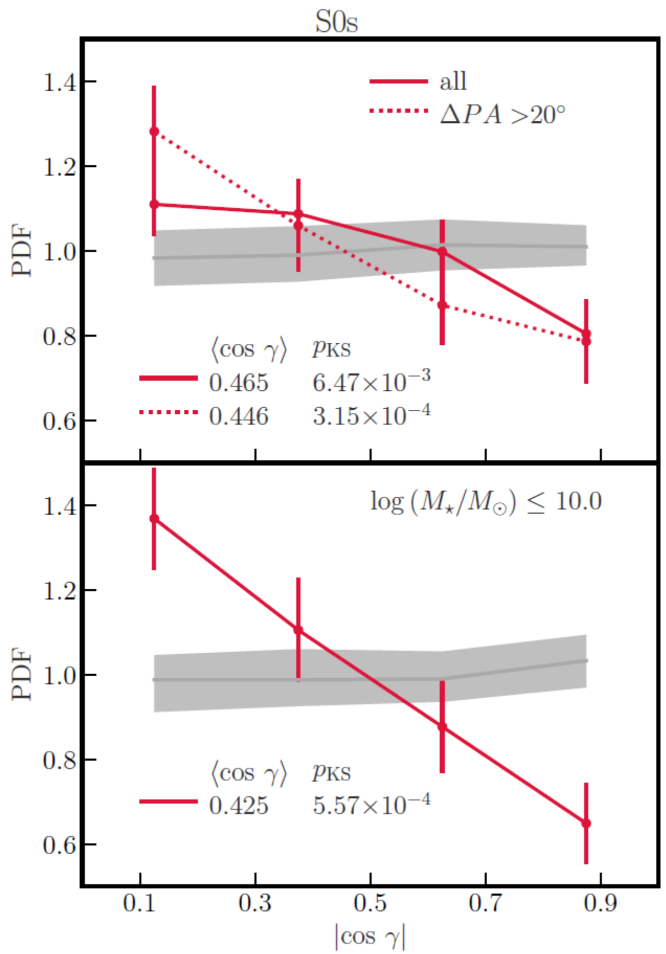

Figure 2. Alignment between the filaments and spin of all (*top*) and low-mass (*bottom*) S0s. The error bars correspond to the bootstrap. The solid grey line and shaded area represent the median and 95 per cent confidence limits from 2000 random samples, respectively. The mean alignment angle together with the probability p_{KS} of the KS test are shown in each panel with corresponding symbols. S0s in the probed mass range tend to have their spin perpendicular to their host filaments. The alignment signal seen for the entire population of S0s is driven by the kinematically misaligned ($\Delta PA > 20°$; red dotted line on the top panel) and low mass sub-sample ($M_\star \le 10^{10}$ $M_\odot$).

- Что является определяющим в ориентации спина относительно филамента – упорядоченность вращения диска (V/σ) или морфология?
- Сравнение angular momentum estimator (λ_R)

$$\lambda_R \equiv \frac{\langle R\,|V|\rangle}{\langle R\sqrt{V^2+\sigma^2}\rangle},$$

and measured via two-dimensional spectroscopy as

$$\lambda_R = \frac{\sum_{i=1}^{N_\mathrm{p}} F_i R_i |V_i|}{\sum_{i=1}^{N_\mathrm{p}} F_i R_i \sqrt{V_i^2+\sigma_i^2}},$$

where F_i is the flux inside the ith bin, R_i its distance to the centre, and V_i and σ_i the corresponding mean stellar velocity and velocity dispersion

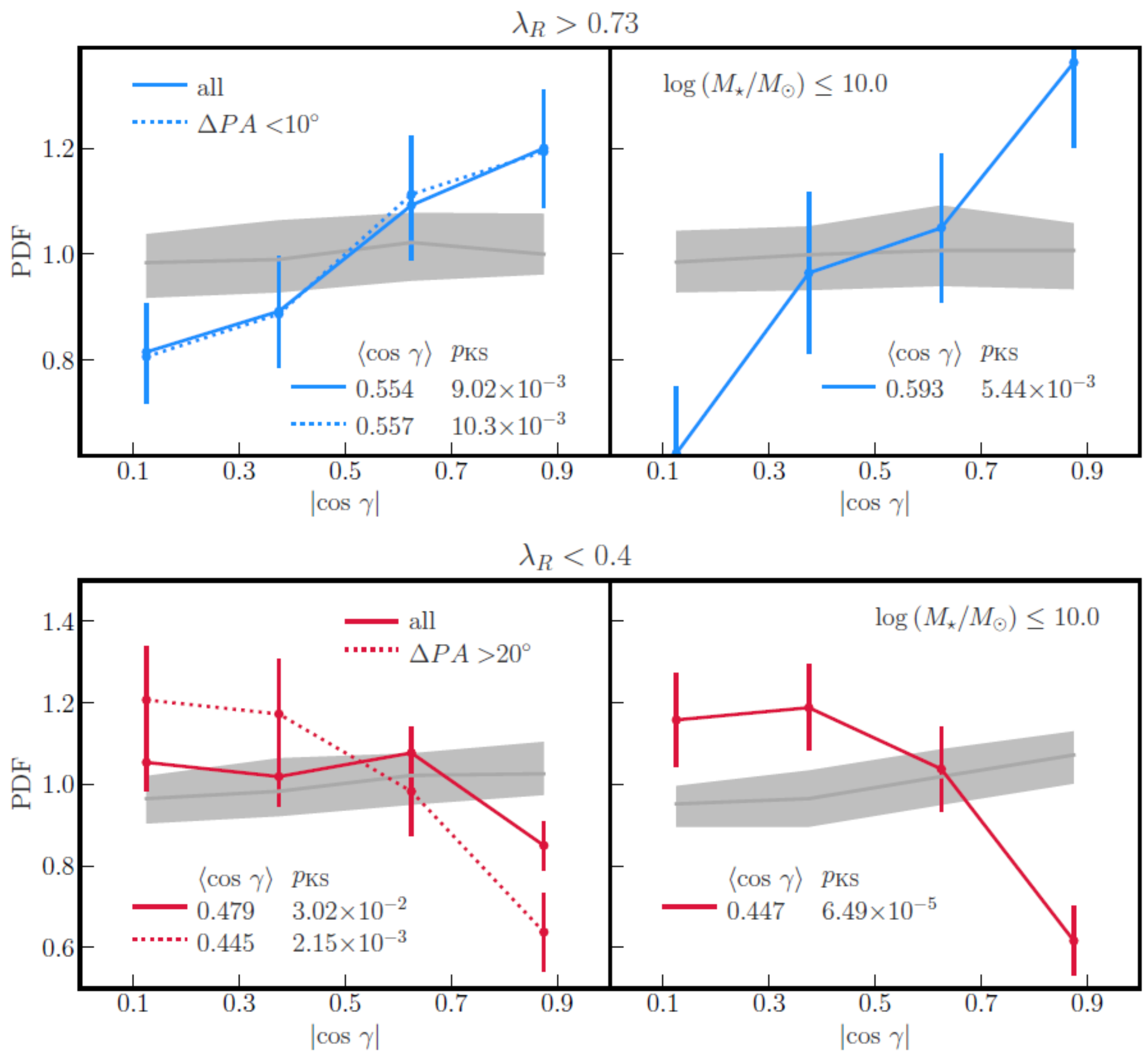

Figure 3. *Top*: Alignment between the filaments and spin of all (*left*) and low-mass (*right*) galaxies with high spin magnitude ($\lambda_R > 0.73$). *Bottom*: Alignment between the filaments and spin of all (*left*) and low-mass (*right*) galaxies with low spin magnitude ($\lambda_R < 0.4$). The error bars correspond to the bootstrap. The

The strongest alignment signal was obtained for galaxies with λ_R >0.73 and orthogonal signal for galaxies with λ_R<0.4. **Galaxies with λ_R >0.73 tend to be more aligned (higher <cos γ>) than the morphology-based sample of LTGs**

РЕЗУЛЬТАТЫ

- Для S-галактик характерно направление спина преимущественно вдоль ближайшего участка филамента, для S0 - перпендикулярно
- Для галактик меньшей массы эффект ориентации спина выражен сильнее
- Results agree with the trends seen in hydrodynamical simulations (Codis et al. 2018; Kraljic et al. 2020b) showing that at fixed stellar mass the alignment signal is dominated by galaxies with high v/σ (ratio of rotation to dispersion dominated velocities, used as a proxy for morphology), while the perpendicular orientation is mostly dominated by galaxies with low values of v/σ.
- Qualitatively similar results are obtained when splitting galaxies based on the degree of ordered stellar rotation, such that galaxies with high spin magnitude have their spin aligned, and those with low spin magnitude in perpendicular direction to the filaments.
- Для галактик, выделенных по большому моменту, эффект ориентации выражен сильнее, чем для галактик, выделенных по морфологии. However it is hard at this stage to disentangle kinematics from morphology.

ОБЩИЙ ВЫВОД

- In the context of conditional tidal torque theory, these findings suggest that galaxies’ spins retain memory of their larger-scale environment. In agreement with measurements from hydrodynamical cosmological simulations, the measured signal at low redshift is weak, yet statistically significant.