An observed link between spin-filament alignment flips and bulge formation

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The study of the interplay between galaxy angular momentum and structures in the cosmic web is a powerful tool to constrain galaxy evolution scenarios. We study the alignments of galaxies' spin axes with respect to nearby cosmic web filaments as a function of various properties of the galaxies and their constituent bulges and discs [1]. We exploit the SAMI Galaxy Survey to identify 3D spin axes from spatially-resolved stellar kinematics and to decompose galaxies into their kinematic bulge and disc components. The GAMA redshift survey is used to reconstruct the surrounding cosmic filaments. The mass of the bulge is found to be the primary parameter of correlation with spin-filament alignments: galaxies with lower bulge masses tend to have their spins parallel to the closest filament, while galaxies with higher bulge masses are more perpendicularly aligned. Other galaxy properties, such as visual morphology, stellar age, star formation activity, kinematic parameters and local environment, show secondary correlations. The observational link between bulge growth and flipping of spin-filament alignments from parallel to perpendicular can be explained by mergers, which can drive both alignment flips and bulge formation. The separate study of bulge and disc spin-filament alignments reveals additional clues about the formation pathways of these galaxy components: bulges tend to have more perpendicular alignments, suggesting they are merger products, while discs show different tendencies according to the mass of the associated bulge, pointing to multiple formation scenarios. To our knowledge, this is the first time that such a study has been conducted using observations rather than simulations.

The puzzle of galaxy formation

Understanding how galaxies acquire their angular momentum in the cosmic web is crucial to complete the puzzle of galaxy formation. Large-scale cosmological hydrodynamical simulations predict that the alignment of the galaxy spin axis with respect to the orientation of the filament within which it resides depends on the stellar mass [2, 3]: low-mass galaxies tend to have spins aligned parallel with the closest filament, while the spins of high-mass galaxies are more perpendicular to the filament. Only recently has this mass-dependent trend been detected in the observations [4]. Since mergers are found to be mainly responsible for the flipping of the spin–filament alignments [5], it is interesting to ask whether we can detect a correlation between bulge properties and the alignments in the observations.

Galaxy sample and measurements

To identify the orientation of the spin axis of a galaxy, we take advantage of spatially-resolved stellar kinematics from the SAMI Galaxy Survey, an integral field spectroscopic survey of more than 3000 galaxies with stellar mass range $8 < \log(M_\star/M_\odot) < 12$ and redshift range $0.004 < z \leq 0.115$ [6]. We measure the stellar kinematic position angles (PA) and follow the 3D thin-disc approximation method [7]. To disentangle the spin axes of bulges and discs, we take advantage of the 2D kinematic bulge/disc decomposition [8]. Figure 1 shows velocity maps for a SAMI galaxy and its constituent bulge and disc. Our final SAMI galaxy sample comprises 1121 galaxies with $9 < \log(M_\star/M_\odot) < 12$, with measurements for 468 bulges and 516 discs.

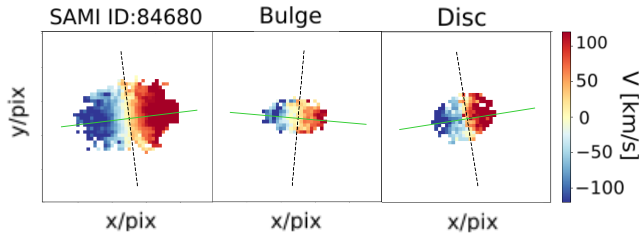

Figure 1: Stellar velocity maps for a SAMI galaxy and its constituent bulge and disc. The green line shows the kinematic PA and the black dashed line marks the projected axis of rotation.

Reconstruction of the cosmic web

We reconstruct the filaments of the cosmic web (shown in Figure 2) using the structure extractor DisPerSE [9] and the GAMA redshift survey [10] from which the SAMI Galaxy Survey has been selected.

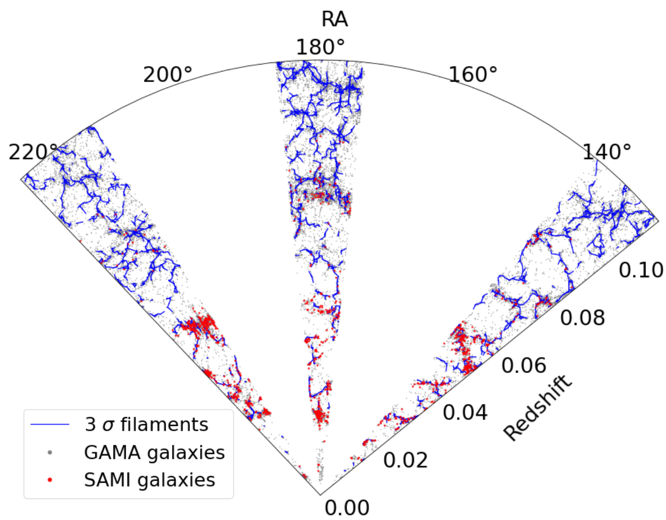

Figure 2: Projected network of cosmic filaments (blue lines) reconstructed from the GAMA galaxies (grey points). The red points represent the 1121 SAMI galaxies.

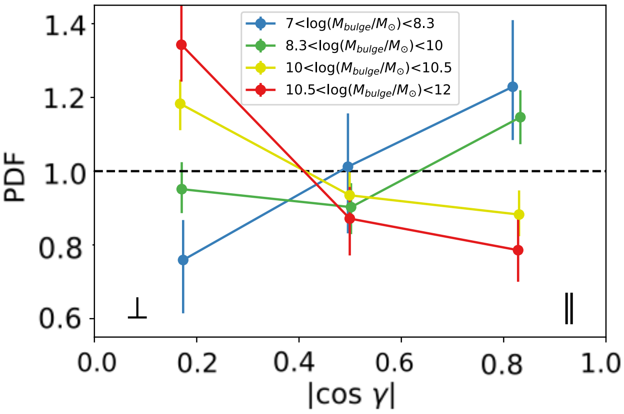

Figure 3: PDFs of the spin–filament alignments for 1121 SAMI galaxies in ranges of $M_{\rm bulge}$. High-$M_{\rm bulge}$ galaxies tend to have spins aligned perpendicular to the closest filament, whereas low-$M_{\rm bulge}$ galaxies tend to have parallel alignments.

Spin–filament alignment correlates best with $M_{\rm bulge}$

Our aim is to identify the galaxy properties that are most closely related to the flipping of the spin–filament alignments, to understand the physical processes involved. We focus on stellar mass, bulge-to-total flux ratio, and their geometric combination, the mass of the bulge: $M_{\rm bulge} = M_\star \times {\rm B/T}$. Each SAMI galaxy is assigned to the closest filament using the smallest 3D Euclidean distance. The spin–filament alignment is parametrised as $|\cos\gamma|$, the absolute value of the cosine of the angle between the galaxy spin axis and the closest filament: $|\cos\gamma|$=1 means that the galaxy spin axis is parallel to the filament while $|\cos\gamma|$=0 is perpendicular alignment.

Applying the Spearman test, we find significant correlations (coefficient; p-values<0.05) of the galaxy spin–filament alignments with $M_\star$ ($\rho = -0.07$; $p_{\rm S} = 0.014$), B/T ($\rho = -0.11$; $p_{\rm S} = 10^{-4}$) and $M_{\rm bulge}$ ($\rho = -0.13$; $p_{\rm S} = 10^{-5}$). The partial least squares regression technique shows that $M_{\rm bulge}$ is the single parameter with the largest contribution ($\sim$70%) to the $|\cos\gamma|$ variance. Other galaxy properties, such as visual morphology, stellar age, star formation activity, kinematic parameters and local environment, show secondary correlations.

We divide the 1121 SAMI galaxies into $M_{\rm bulge}$ ranges and explore the probability distribution function (PDF) of $|\cos\gamma|$ in Figure 3. Galaxies with higher values of $M_{\rm bulge}$ have spins aligned preferentially perpendicular to the closest filament, whereas galaxies with lower values of $M_{\rm bulge}$ preferentially have parallel alignments. The PDFs are significantly different from a uniform distribution according to the Kolmogorov-Smirnov test (p-values<0.05).

Thus $M_{\rm bulge}$ is the galaxy property that correlates best with spin–filament alignment. We conclude that bulge growth and spin-filament alignment flips from parallel to perpendicular are likely both caused by the same physical process, namely mergers.

Spin–filament alignments of bulges and discs

We investigate the separate spin–filament alignments of the bulge and disc components of galaxies in Figure 4. The alignment for bulges tends to be more perpendicular at all $M_{\rm bulge}$ values, suggesting they are merger products. Discs show a significant parallel tendency for low-$M_{\rm bulge}$ galaxies, but significant perpendicular alignment for high-$M_{\rm bulge}$ galaxies, implying multiple formation and evolution scenarios for discs.

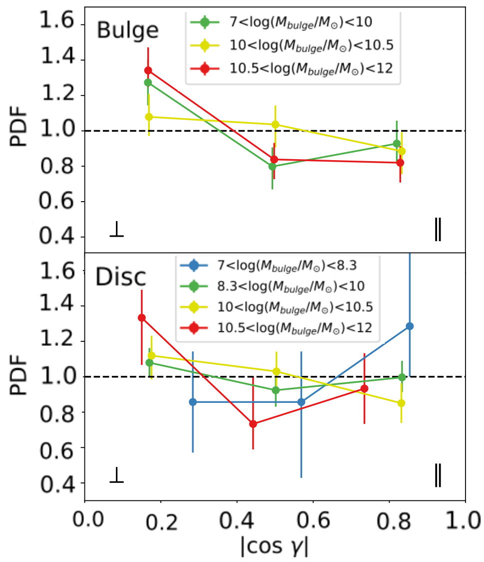

Figure 4: PDFs of spin–filament alignments for 468 bulges (top) and 516 discs (bottom) in ranges of $M_{\rm bulge}$. Bulges show more perpendicular alignments, while discs tend to be aligned parallel for low $M_{\rm bulge}$ and perpendicular for high $M_{\rm bulge}$.

Conclusions

Our findings highlight the importance of integral field spectroscopy surveys for elucidating how changes in the angular momentum of galaxies, bulges, and discs are related to their evolution within the cosmic web. The upcoming Hector galaxy survey will extend and deepen our understanding of spin–filament alignments.

References

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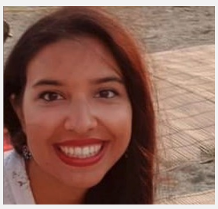

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