Alignment of Spiral and Elliptical Galaxies with cosmic filaments

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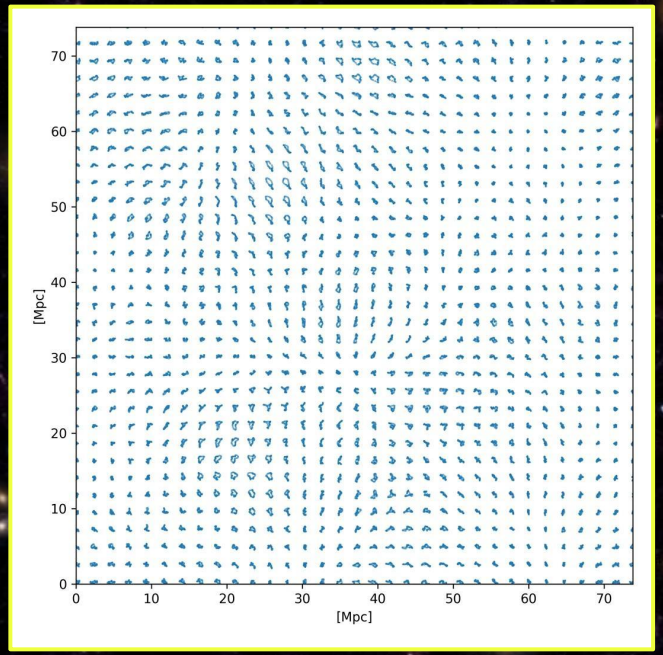
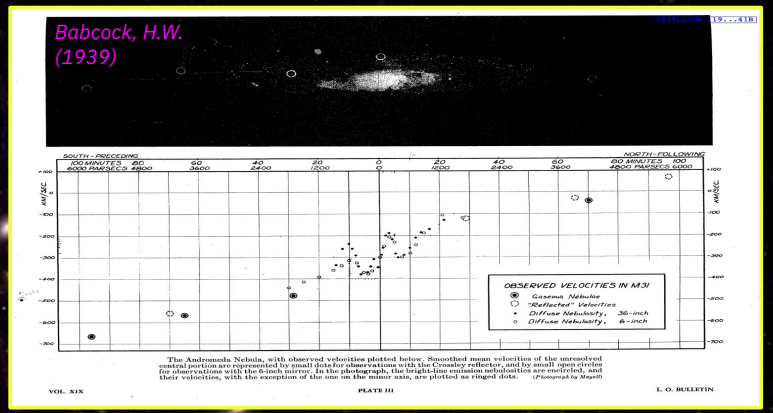
1700 - 2025 325 Jahre

The Young Astronomers Meeting 2026, 19th March, 2026

Origin of *Angular Momentum* from linear initial conditions



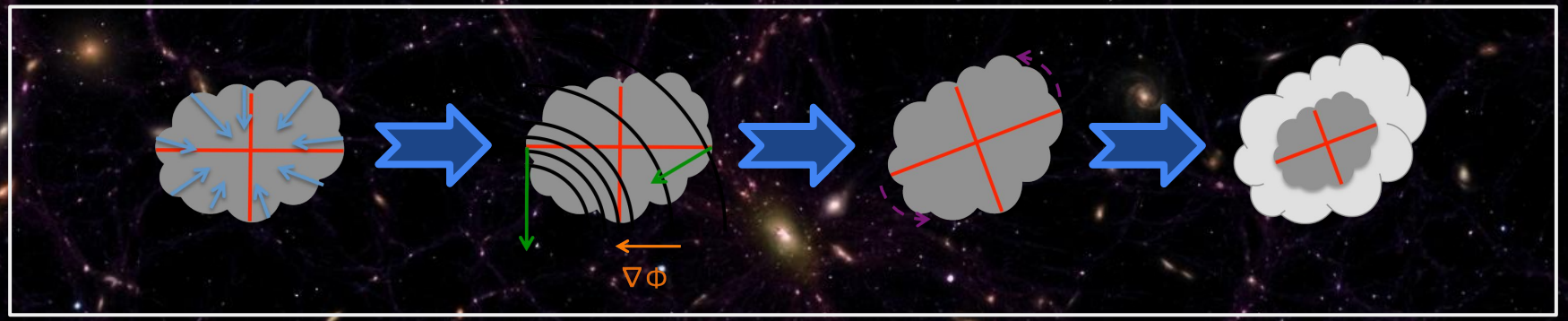
Gaussian ICs with curl-free velocities; non-linear structure formation to z=0
(Self - produced)



But still Galaxies ***rotate***

Angular momentum is not primordial but acquired during the structure formation

Tidal Torque Theory

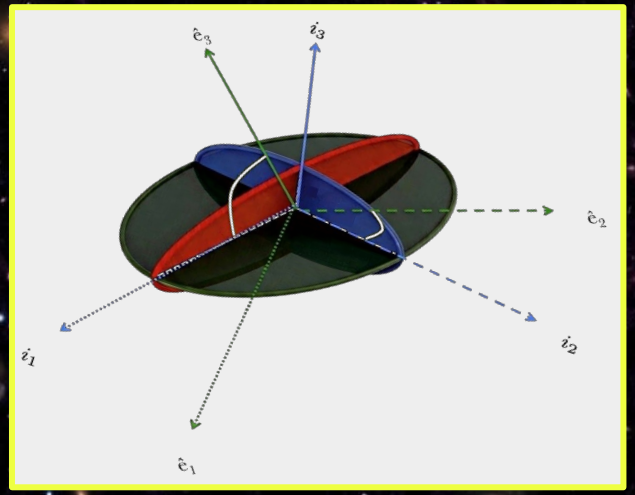


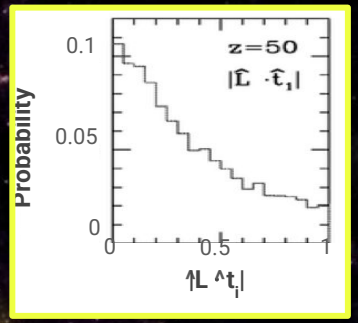
PJ Peebles 1969

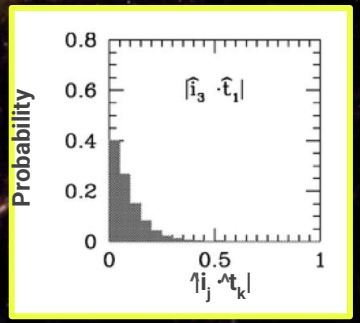
Torque induced by the misalignment of the inertia tensor with respect to the external tidal shear field results in the proto-halo gaining angular momentum, till the system turns non-linear

Tidal Torque Theory: Key Takeaways (from N body simulations)

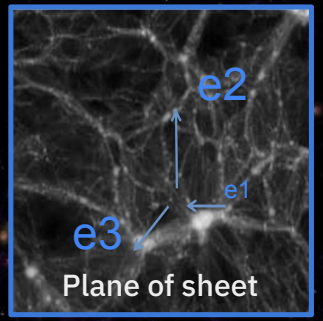
1) Avoidance of fastest-collapse axis (e_1)

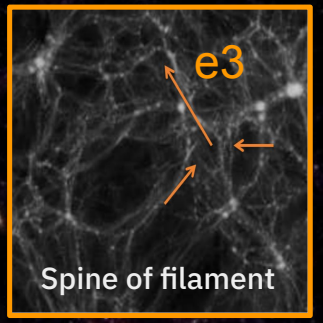






Porciani et al. 2002





Hahn et al. 2007

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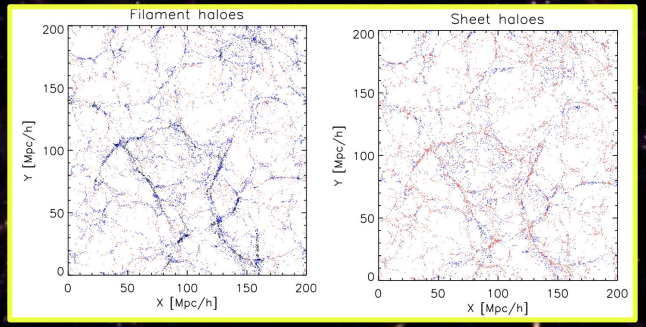
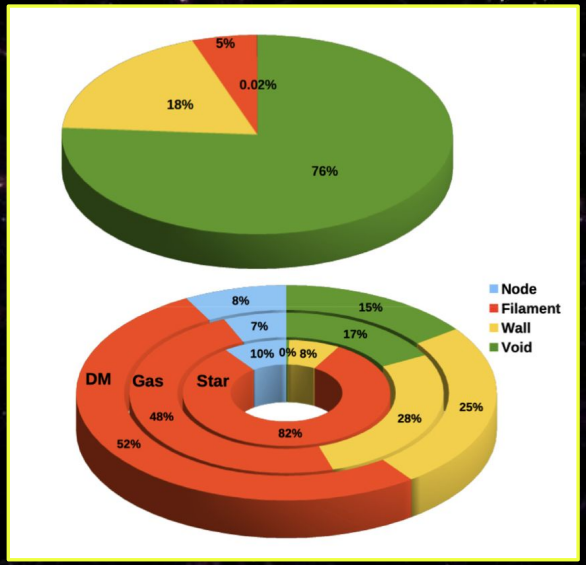
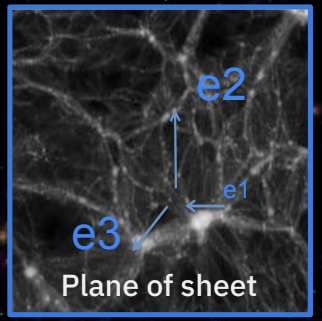


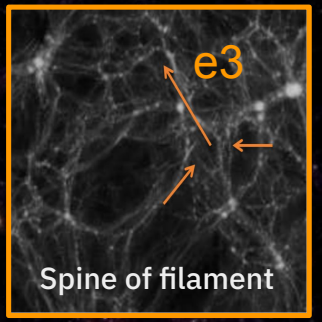
Libeskind et al. 2017

Filaments identified more robustly than sheets
(filaments show higher cross-method consistency than sheet structures)*



P Ganeshaiah et al. 2019



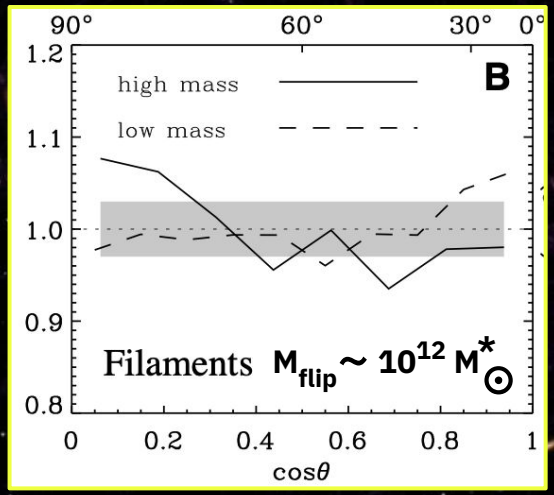


Hahn et al. 2007

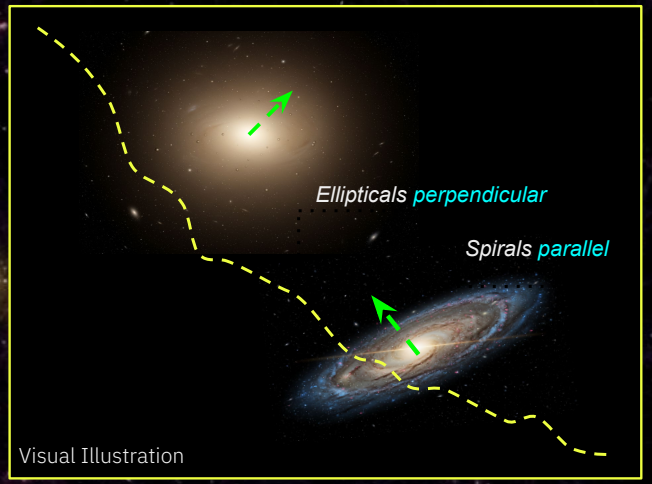
*higher the blue & black dots, more methods agree with the classification of the substructure type in that location

Tidal Torque Theory: Key Takeaways (from N body simulations)

2) Mass dependent alignment trend (The Spin Flip)



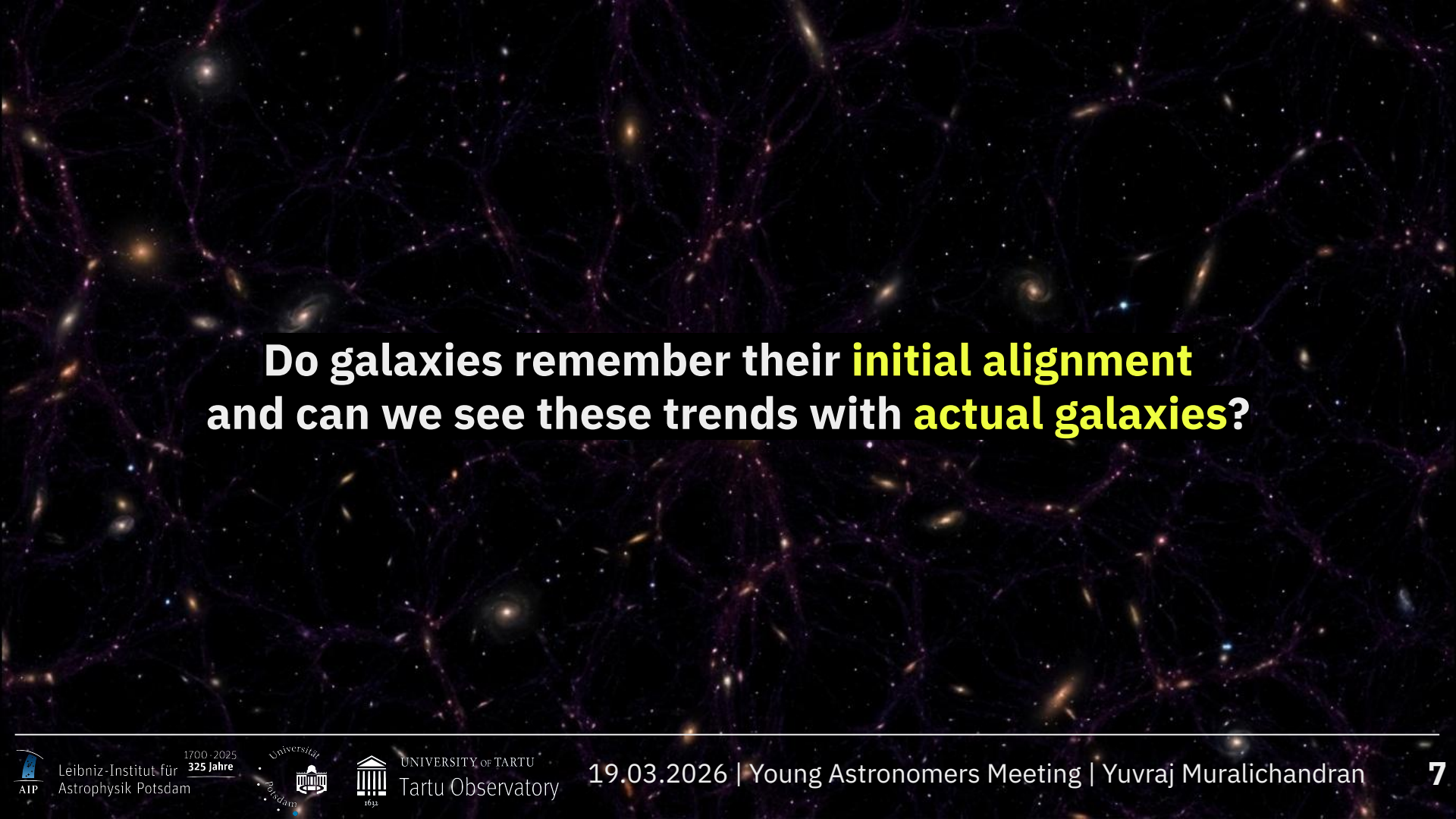
Aragón-Calvo et al. 2007



Low mass → parallel

High mass → perpendicular

(Simulation - dependent) *


Do galaxies remember their initial alignment
and can we see these trends with actual galaxies?

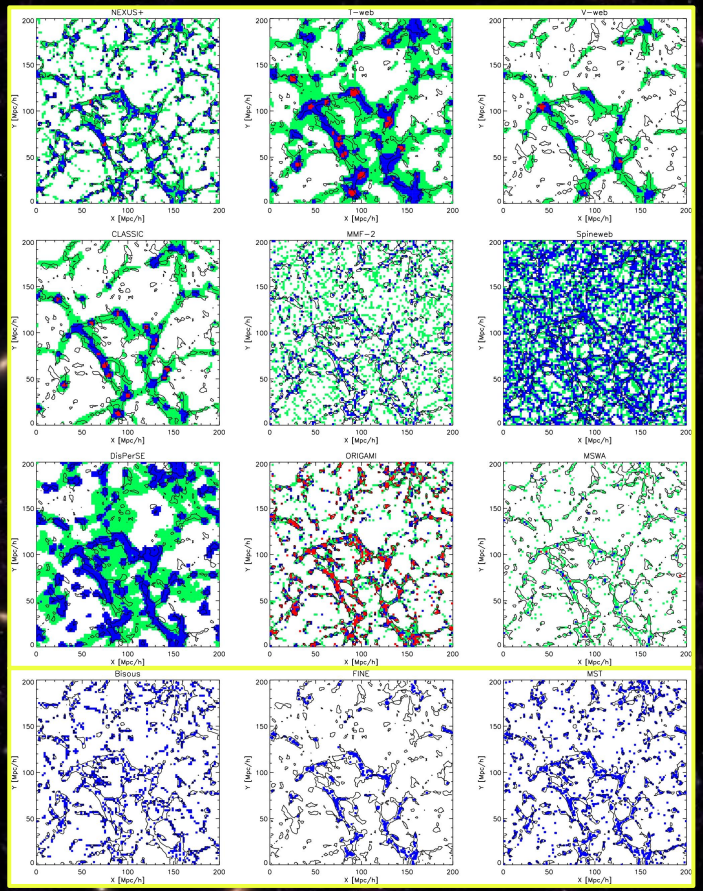
Obtaining Filaments

Monthly Notices
of the
ROYAL ASTRONOMICAL SOCIETY

MNRAS **473,** 1195–1217 (2018) doi:10.1093/mnras/stx1976
Advance Access publication 2017 August 3

Tracing the cosmic web

Noam I. Libeskind,[1]★ Rien van de Weygaert,[2] Marius Cautun,[3] Bridget Falck,[4] Elmo Tempel,[1,5] Tom Abel,[6,7] Mehmet Alpaslan,[8] Miguel A. Aragón-Calvo,[9] Jaime E. Forero-Romero,[10] Roberto Gonzalez,[11,12] Stefan Gottlöber,[1] Oliver Hahn,[13] Wojciech A. Hellwing,[14,15] Yehuda Hoffman,[16] Bernard J. T. Jones,[2] Francisco Kitaura,[17,18] Alexander Knebe,[19,20] Serena Manti,[21] Mark Neyrinck,[3] Sebastián E. Nuza,[1,22] Nelson Padilla,[11,12] Erwin Platen,[2] Nesar Ramachandra,[23] Aaron Robotham,[24] Enn Saar,[5] Sergei Shandarin,[23] Matthias Steinmetz,[1] Radu S. Stoica,[25,26] Thierry Sousbie[27] and Gustavo Yepes[18]



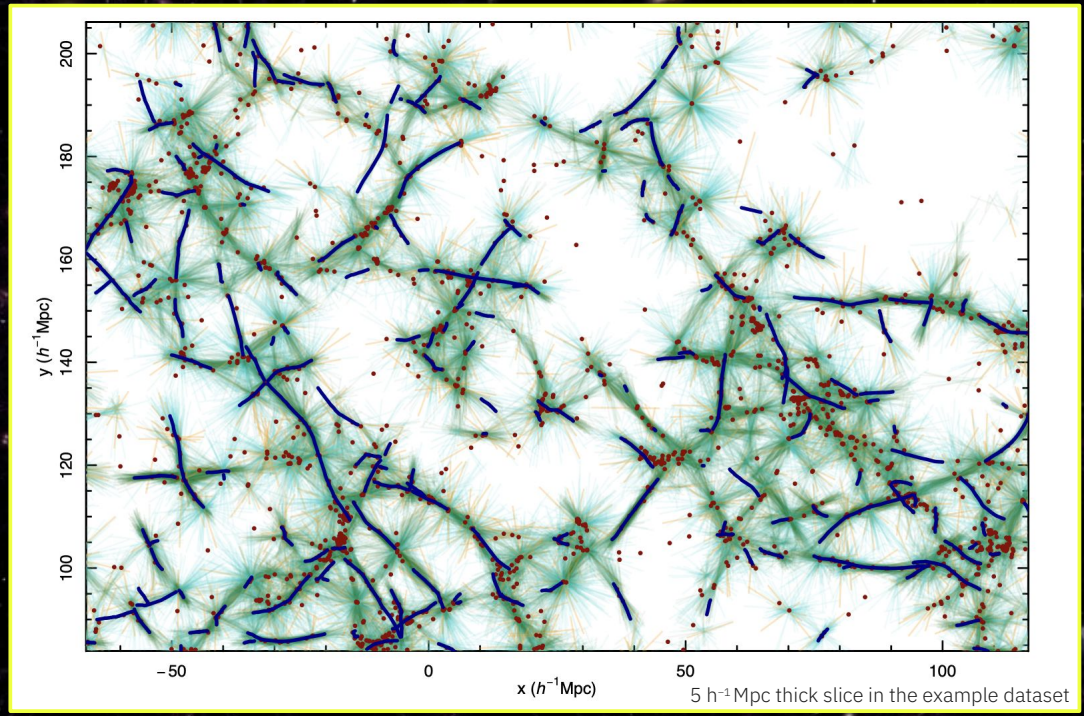
Libeskind et al. 2017

For observational studies, the filament finder must be compatible with real data:

→ operate directly on galaxy positions
→ provide a **local filament spine direction**
→ allow construction of a **cosmic-web reference frame**

Bisous Filaments

Stochastic, **marked**, **point process** using **interacting cylinders** guided by a **Gibbs distribution** with **data** and **interaction energies**, inferred via **MCMC** to extract **filament spines** from **SDSS - DR12**



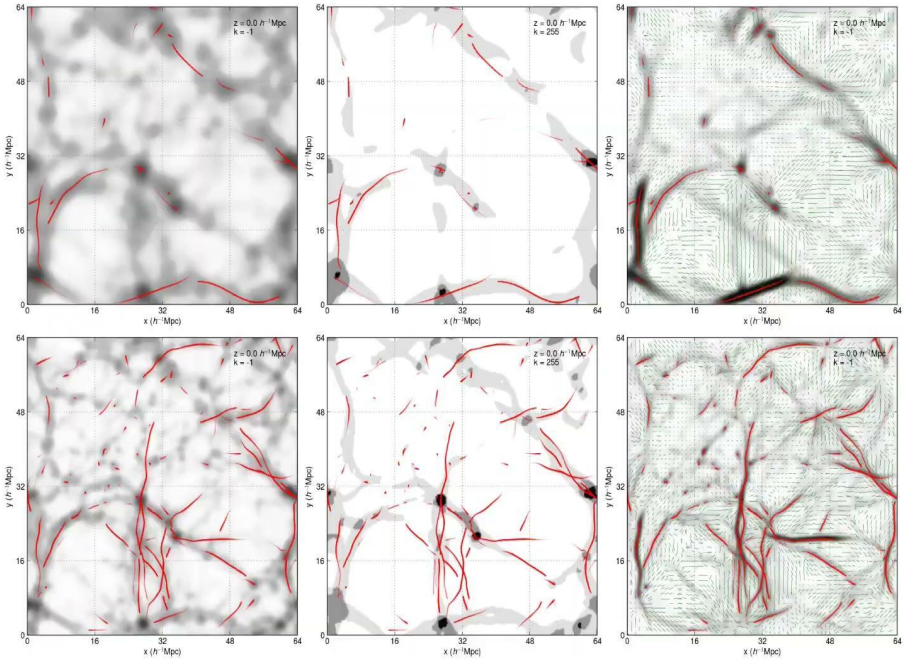
5 h^{-1} Mpc thick slice in the example dataset

Interested?
https://github.com/etempel/Bisous

Tempel et al. 2016

Bisous Filaments

Bisous filaments do trace the e3 component of tidal shear field, making them ideal to compare the alignment of spin normals of galaxies



Tempel et al. 2014

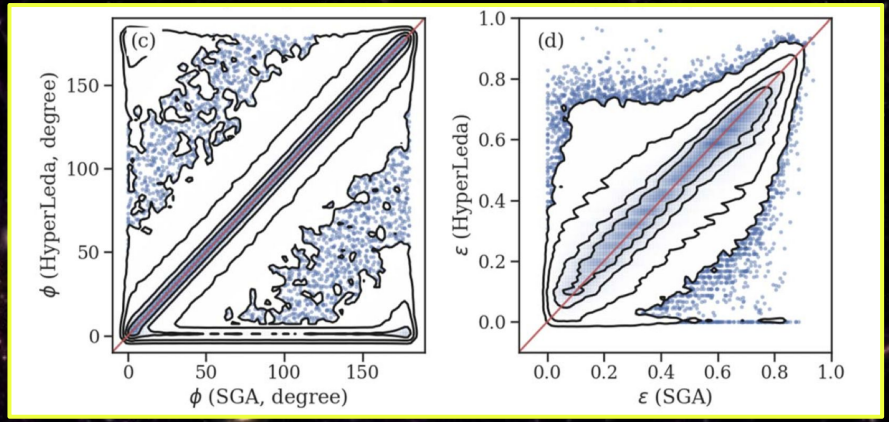
Siena Galaxy Atlas

Siena Galaxy Atlas (SGA) provides:

→ uniform re-measurement of galaxy geometry

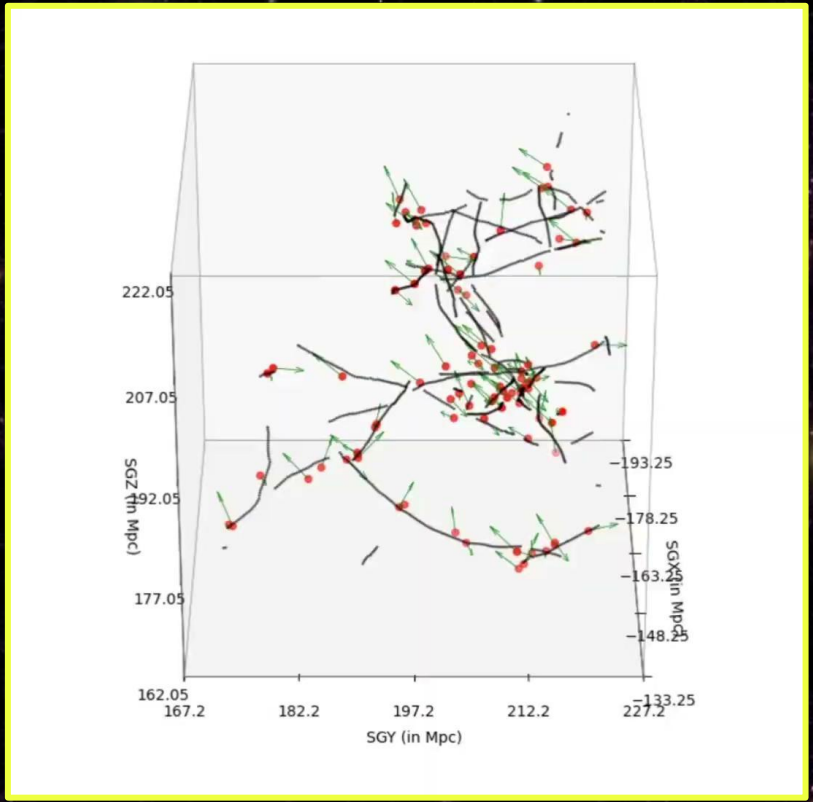
→ validated ellipticity and position angles

→ high completeness at bright magnitudes



Moustakas et al. 2023

SGA is **directly compatible with observational spin-reconstruction methods** and is **well suited for cosmic-web studies**

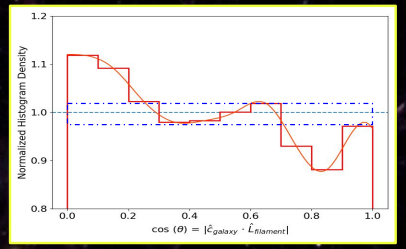


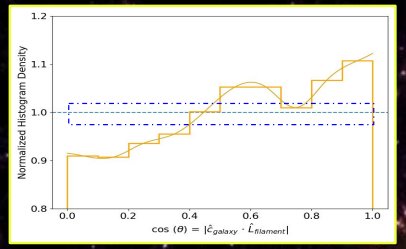
A subset of galaxies and filaments used in this study for visualization purpose

51,472 galaxies from Siena Galaxy Atlas, consisting of 32,517 spiral and 18,955 elliptical galaxies located within 2 Mpc of filament spine obtained from Bisous Method

Overall Alignment Trend

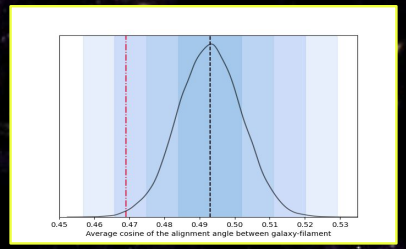
KDE-based significance ⟨σ⟩

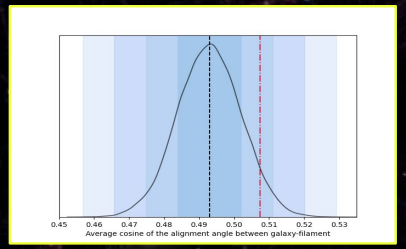




Case: Anti - Alignment

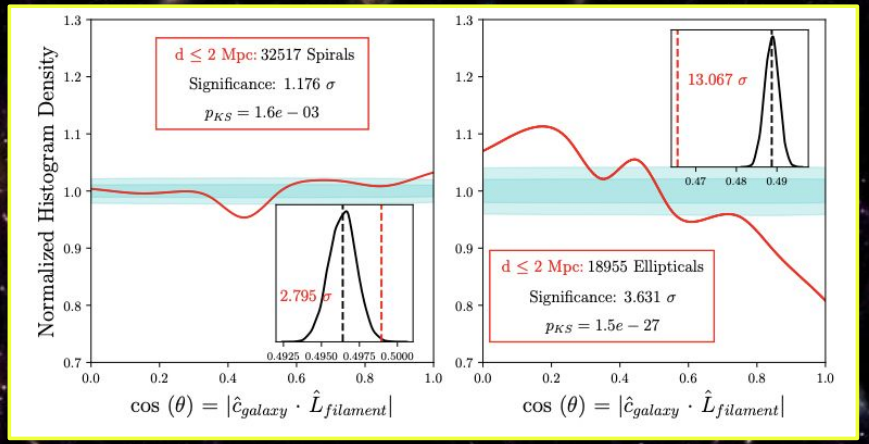
Case: Alignment





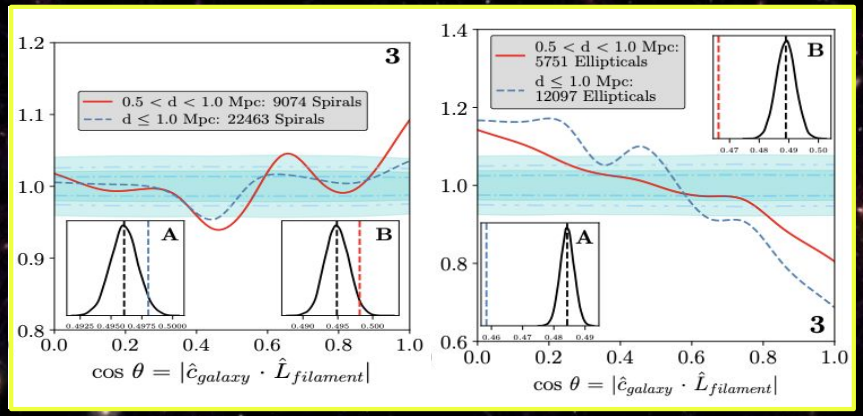
Mean-based significance $\sigma_{\langle\cos\theta\rangle}$

Null hypothesis constructed from 10,000 position-angle randomizations of galaxy subsets, generating 1 & 2 σ confidence corridor to quantify the strength of the alignment signal

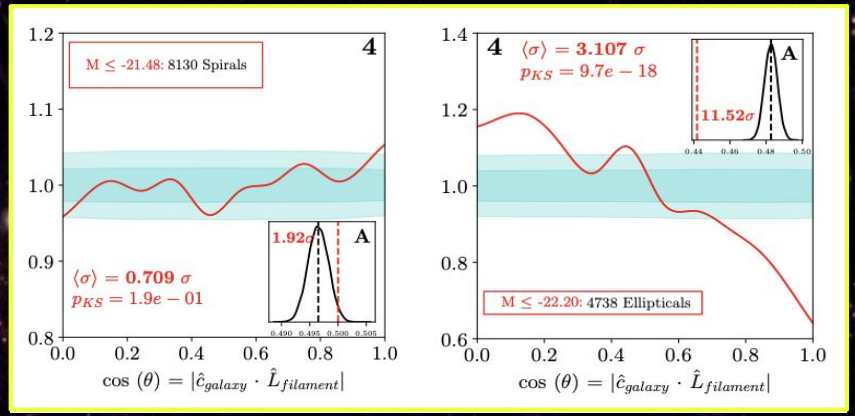


Muralichandran et al. 2025

Alignment trend as function of galaxy properties



Galaxies in the 0.5 - 1 Mpc proximity region



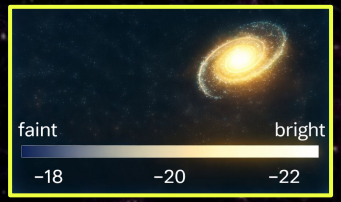
Brightest galaxies

Muralichandran et al. 2025

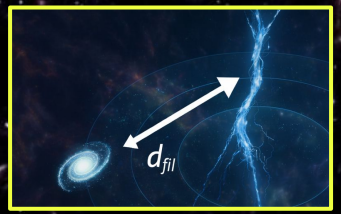
Finding the Subset with *maximum significance*

To see if there is a specific subset with maximum statistical significance, I implemented a Bayesian optimization involving the two factors we performed our study on:

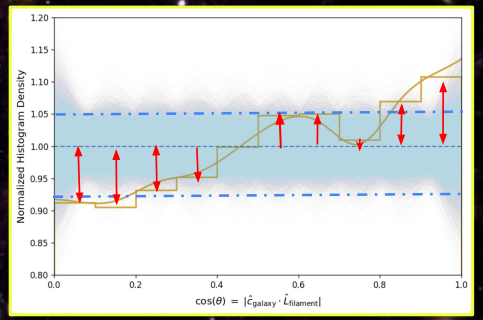
1) Absolute r-band magnitude

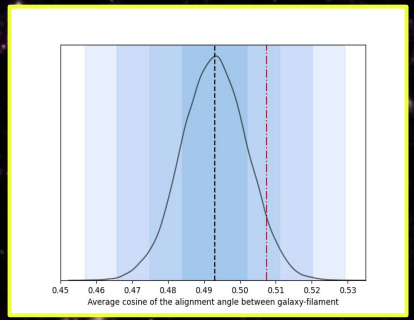


2) Projected filament distance



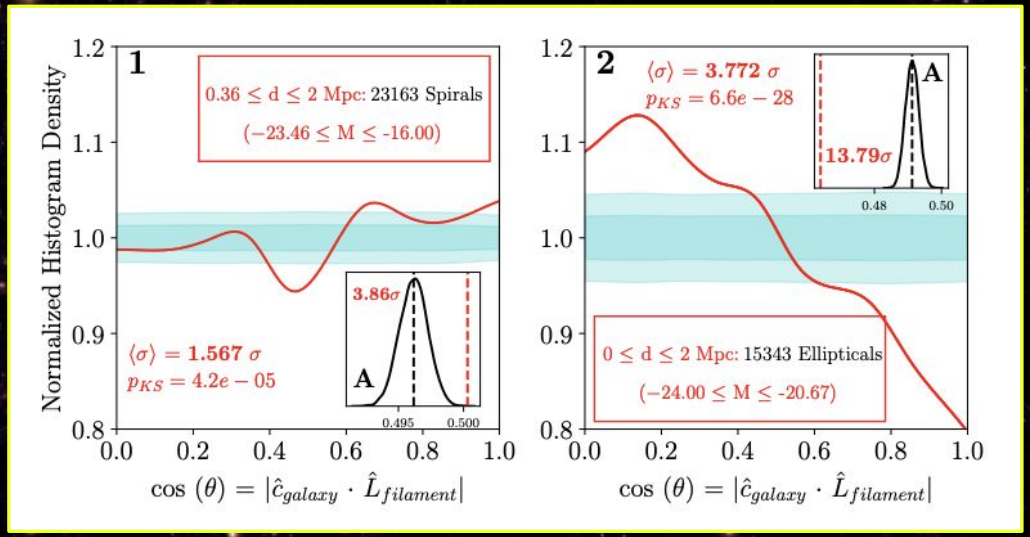
The combined alignment significance metric (comprising the KDE-based significance ⟨σ⟩ and the mean-based significance $\sigma_{\langle \cos\theta \rangle}$)





Subset with *maximum significance*

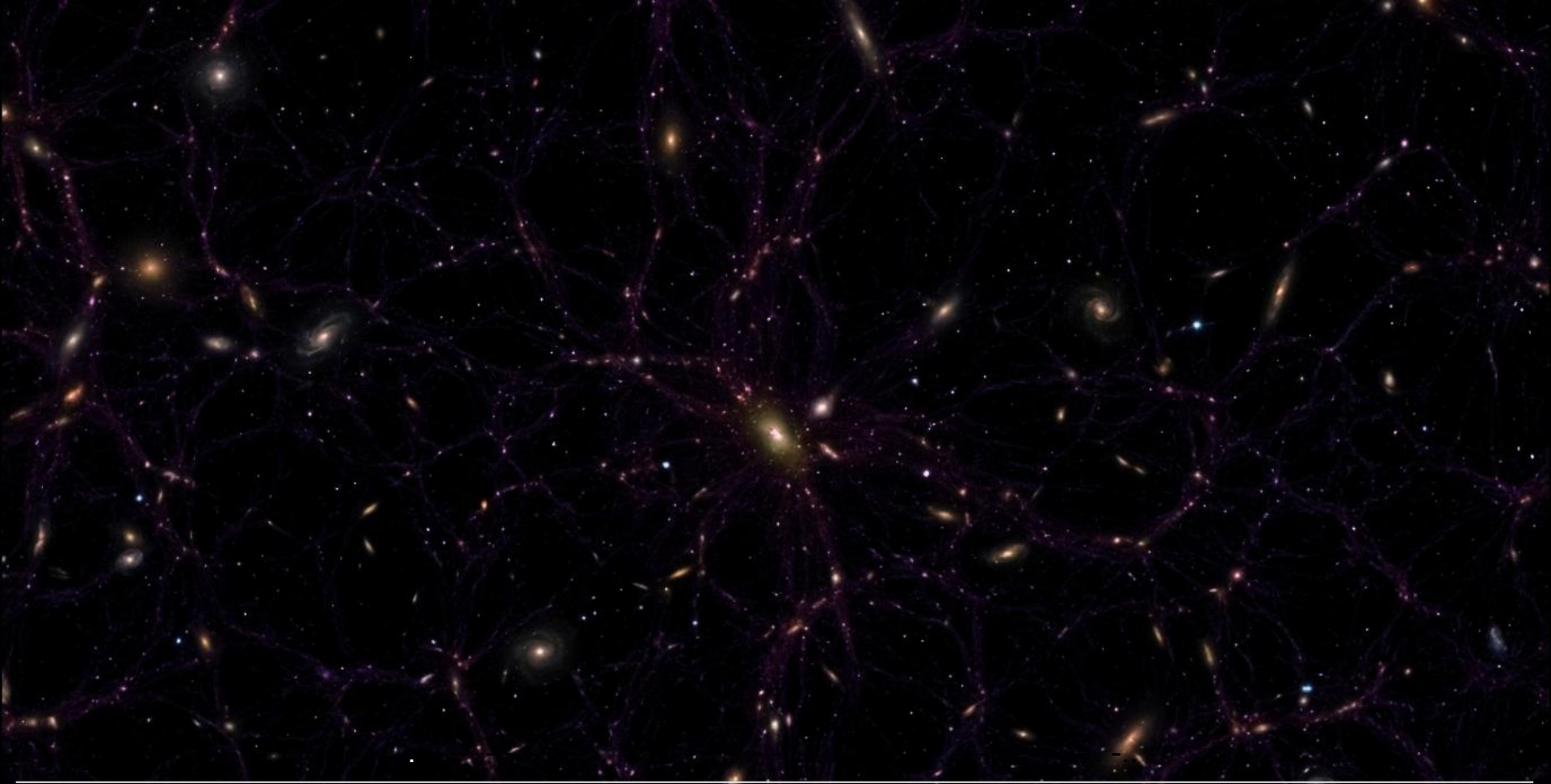
The brightest ellipticals and the spirals that are 0.36 - 2 Mpc away from the filaments (peripheral region) are the subsets with *maximum significance*



Muralichandran et al. 2025

Large-scale tidal fields leave a measurable imprint on galaxy spins but is selectively preserved depending on mass, morphology, and environment.

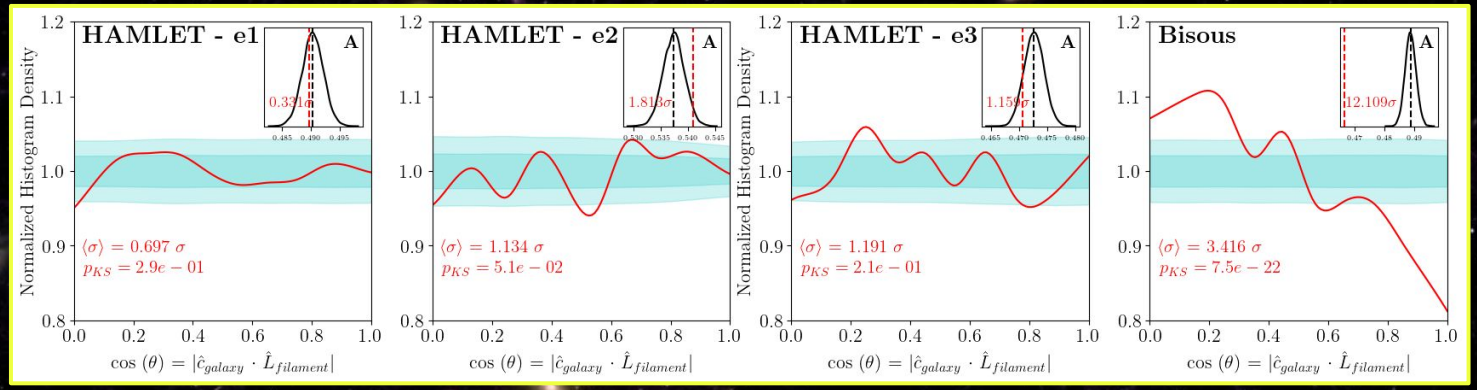

Thank you for listening and
for the opportunity!



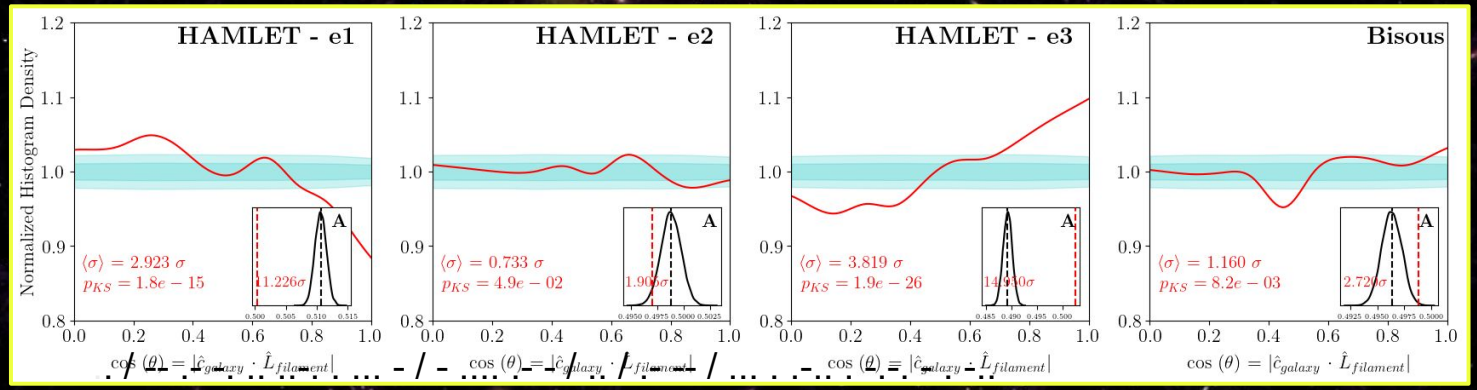
Extra Slides

Why filament finder method matters

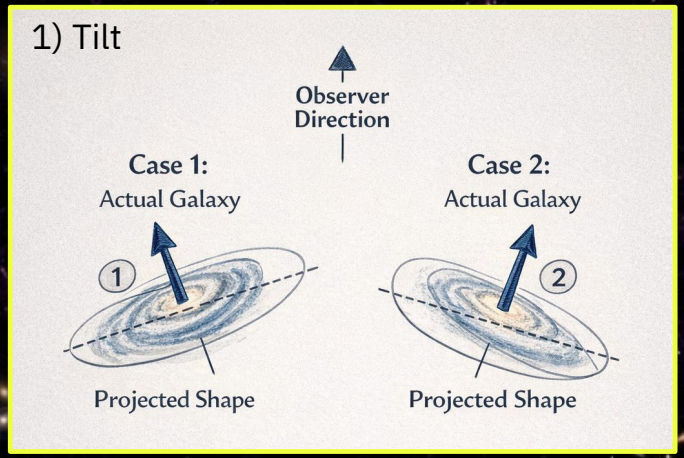
Ellipticals (SGA) - 18325 galaxies

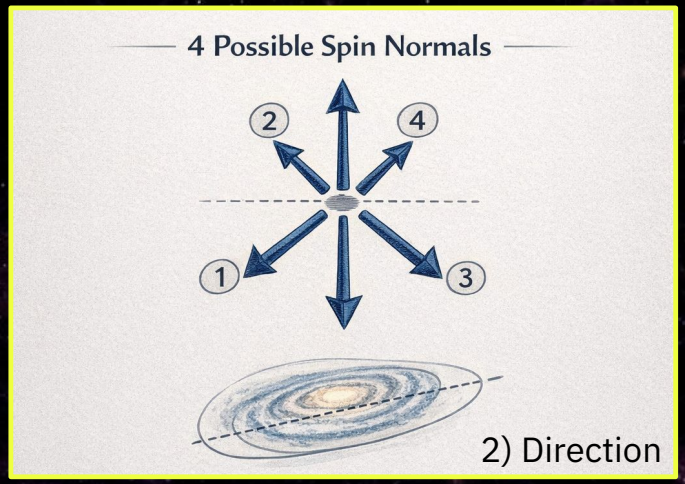


Spirals (SGA) - 32292 galaxies



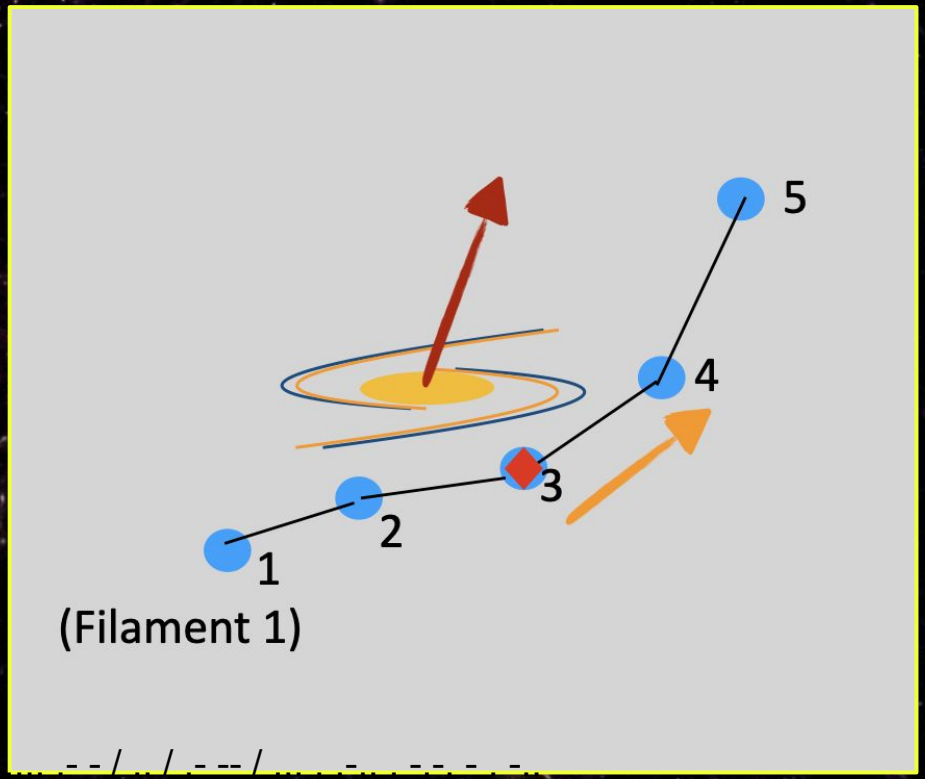
Ambiguity in spin normal - visualized





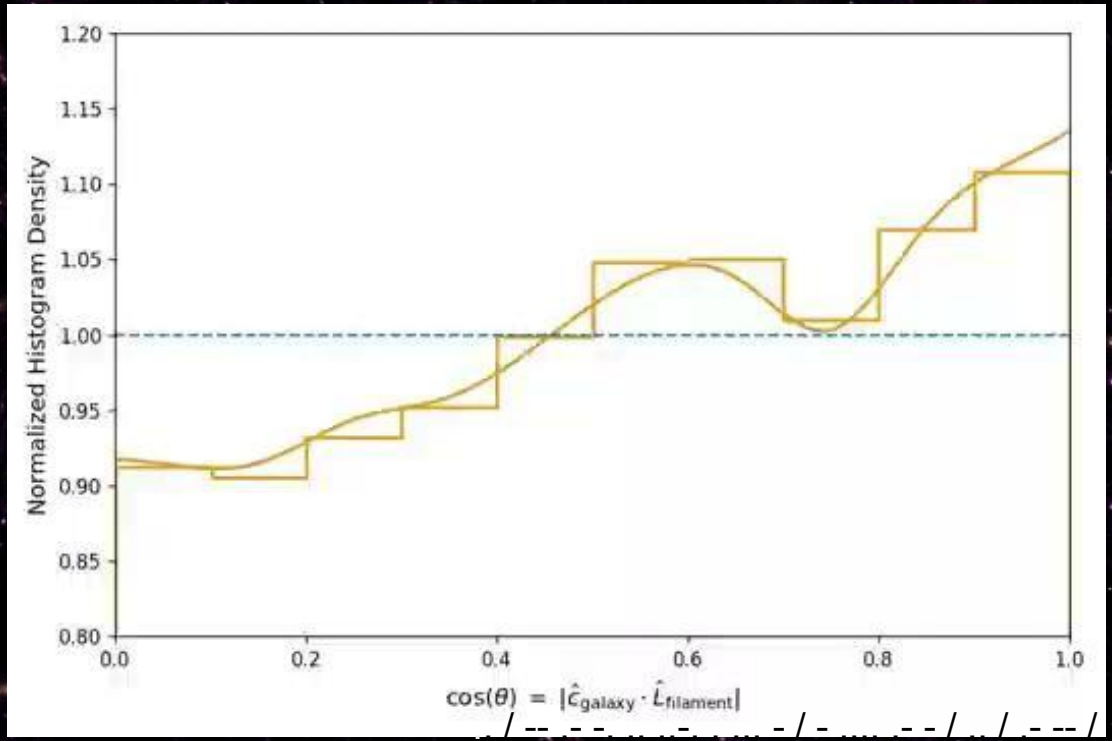
Obtaining the Dot Product - between spin normal and filament spine

The orientation of the filament point is obtained by obtaining the unit vector between successive points



Inferring statistical significance of the signal

1) KDE based significance:



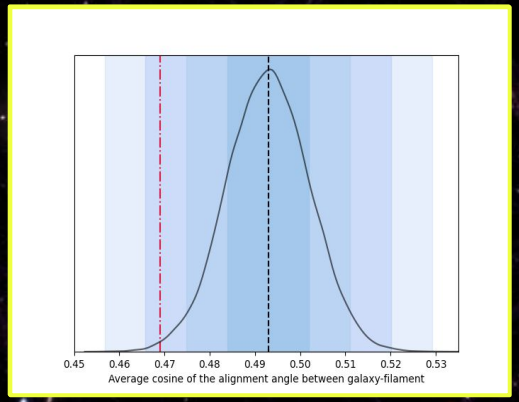
To test the null hypothesis, we create 10000 Mock samples, each mock sample is created by randomizing each galaxy's position angle

For each randomized sample a probability distribution of the cosine of the angle between the galaxy's (new, randomized) spin axis and the filament spine to which it is assigned is obtained.

These 10000 probability distributions are used to obtain the median and 1σ for the null hypothesis

Inferring statistical significance of the signal

2) Significance from Mean of the Alignment Signal ($\sigma_{\langle \cos\theta \rangle}$):



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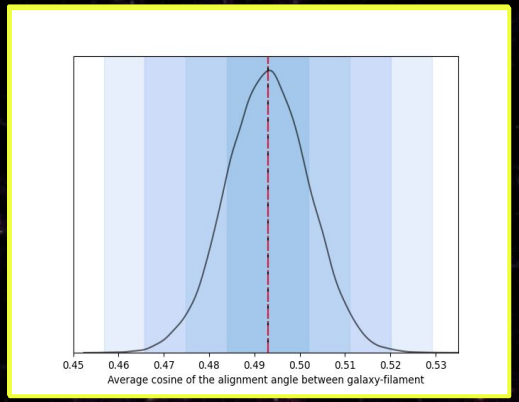
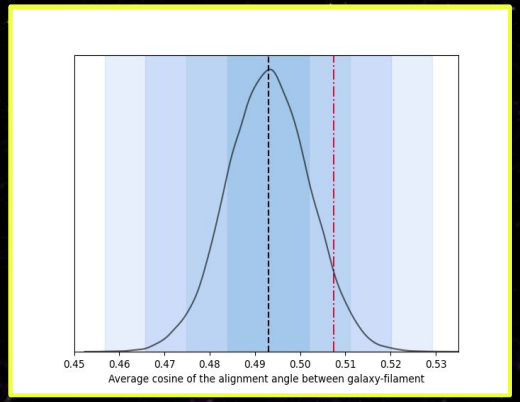


Case: Null hypothesis (Random Alignment)



Case: Alignment

3) Kolmogorov - Smirnov (KS) test:

compares two distributions by measuring the largest difference between their cumulative curves to see if they come from the same source.