UNIVERSITY OF OXFORD

The alignment of galaxies and AGN jets in the cosmic web

Speaker: Lyla Jung

In collaboration with

Imogen Whittam; Matt Jarvis; Catherine Hale; Madalina Tudorache; Tariq Yasin

Galaxy evolution in cosmological context

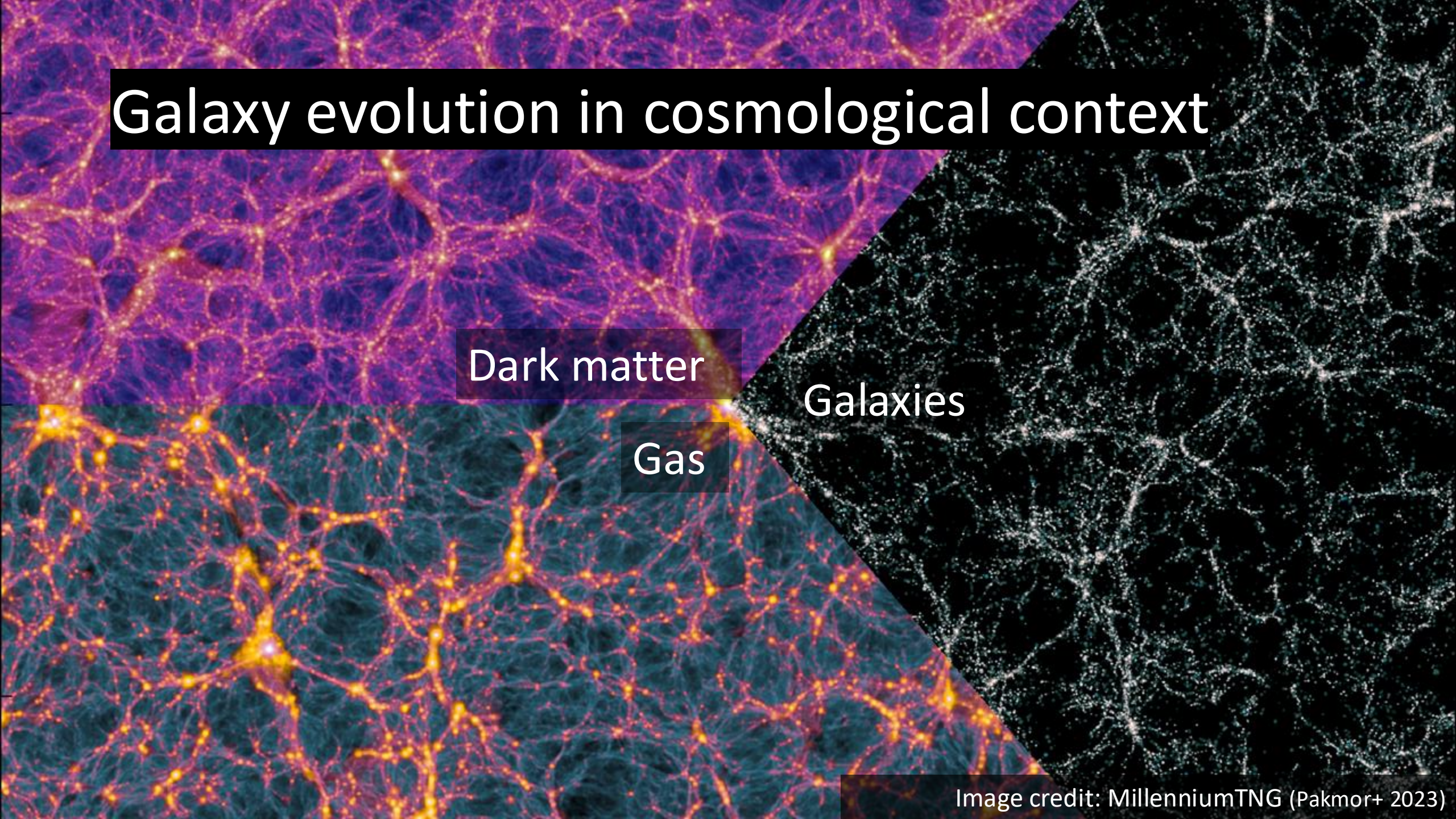
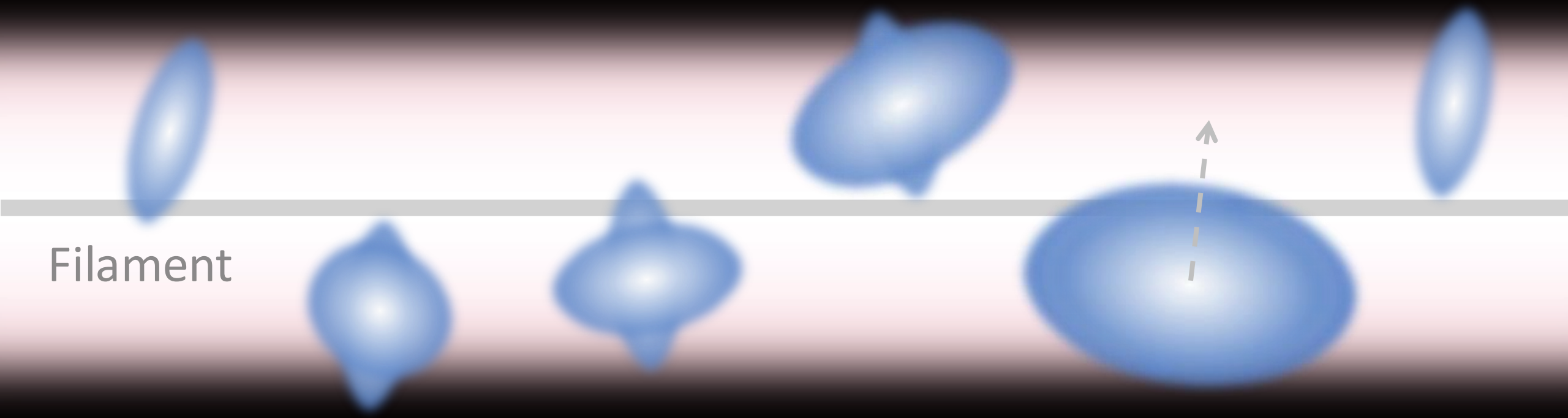


Image credit: MillenniumTNG (Pakmor+ 2023)

Galaxies in filaments grow by mergers/accretions along the direction of filaments

→ Major axis of massive galaxies tend to be <u>parallel</u> to the filament orientation



See also: Lee et al. 2008; Zhang et al. 2009; Libeskind et al. 2014; Kang & Wang 2015; Morinaga & Ishiyama 2020

AGN feedback in massive galaxies

Throughout their evolution the SMBH at the core injects energy into the surrounding medium

→ Regulate gas cooling and star formation

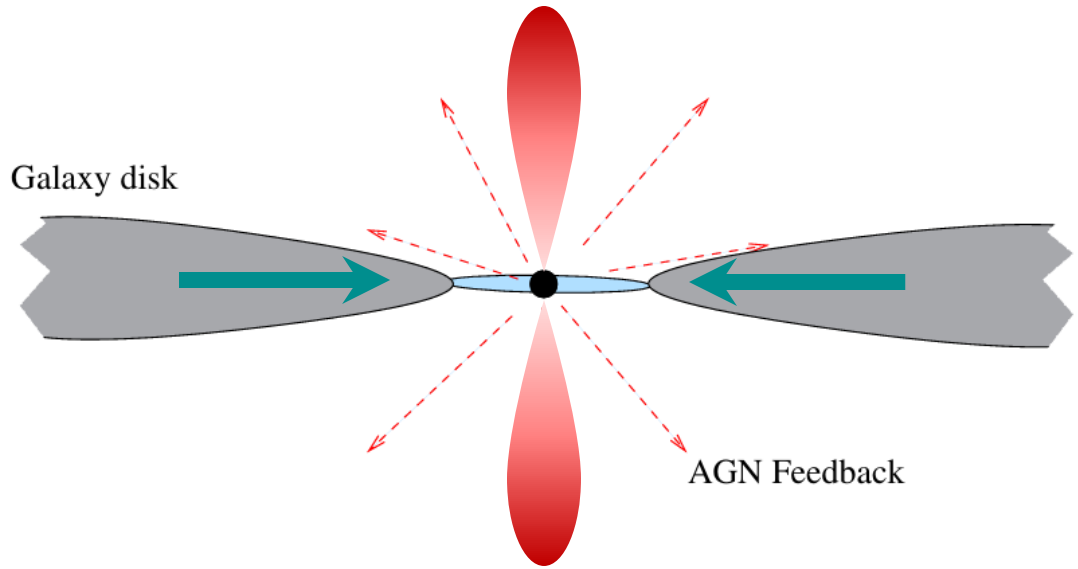
→ The direction of jets decides “where” the energy is injected

R. Perley and W. Cotton (NRAO/AUI/NSF)
NASA, ESA, S. Baum and C. O'Dea (RIT), and the Hubble Heritage Team (STScI/AURA)

Zooming into the small scale around the black hole

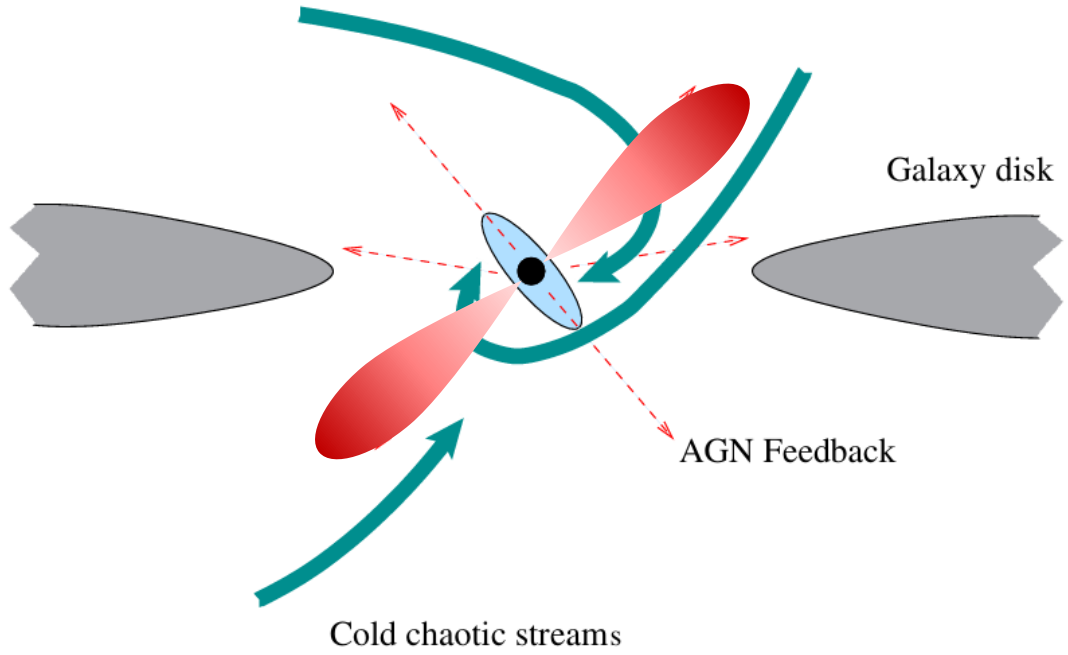
Secular accretion

: Angular momentum of the accreting medium is aligned with the galactic scale gas



Chaotic accretion

: Gas motion near the galactic nucleus is perturbed



Modified figure from Nayakshin+ 2012

(see also Battye & Browne 2009; Lagos+ 2011, Hobbs et al. 2011, Hopkins et al. 2012, Smethurst+ 2019; Zheng+ 2024 and others)

Cosmic filaments from SDSS
(Malavasi+ 2020)

Optical galaxies from DESI photometry (Dey+ 2019)

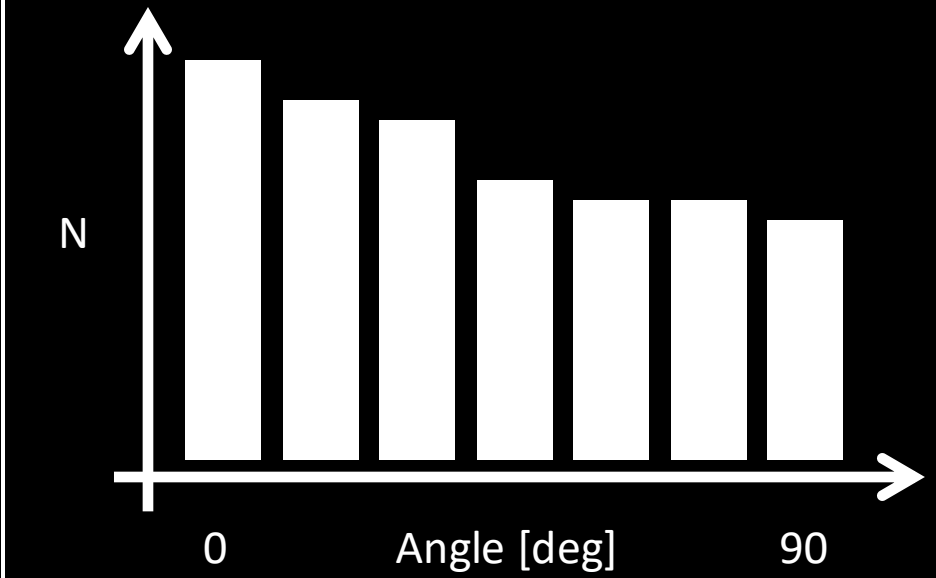
- N = 73077
- $\log M_*/\mathrm{M}_\odot > 11$
- z < 0.6

Radio jets from LoTSS
(Shimwell+ 2022; Hardcastle+ 2023)

- N = 6270
- $S/N > 10$
- $L_{144\,\mathrm{MHz}} > 10^{24}\ \mathrm{W\ Hz^{-1}}$
- Angular size > 20 arcsec

3D distance to the nearest filament (D_{fil})

Two position angles are parallel
→ Positively skewed



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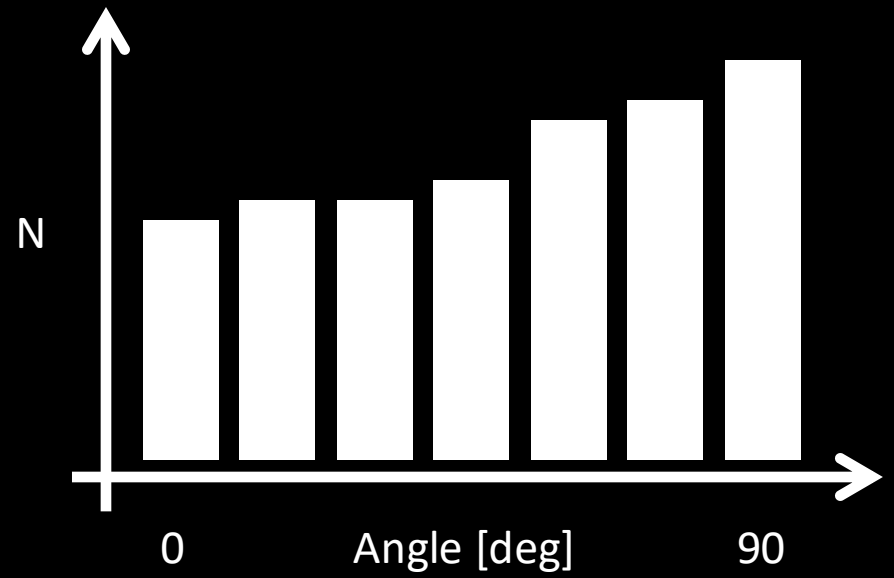
3D distance to the nearest filament (D_{fil})

Two position angles are perpendicular
→ Negatively skewed



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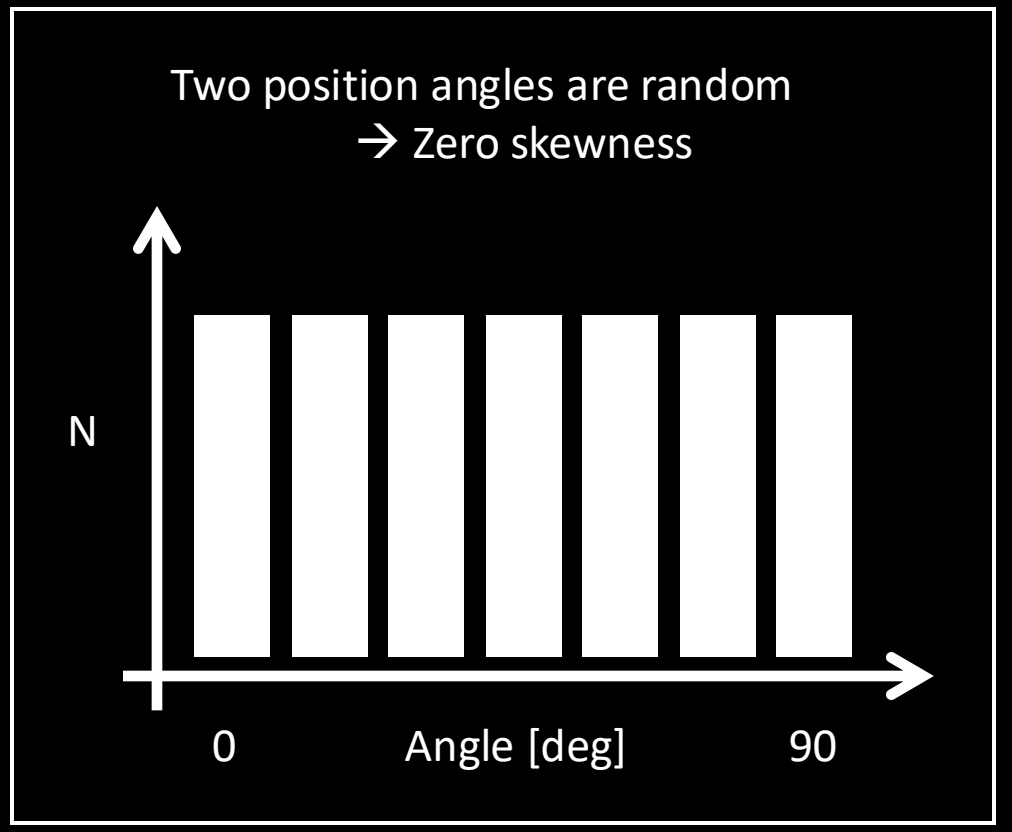
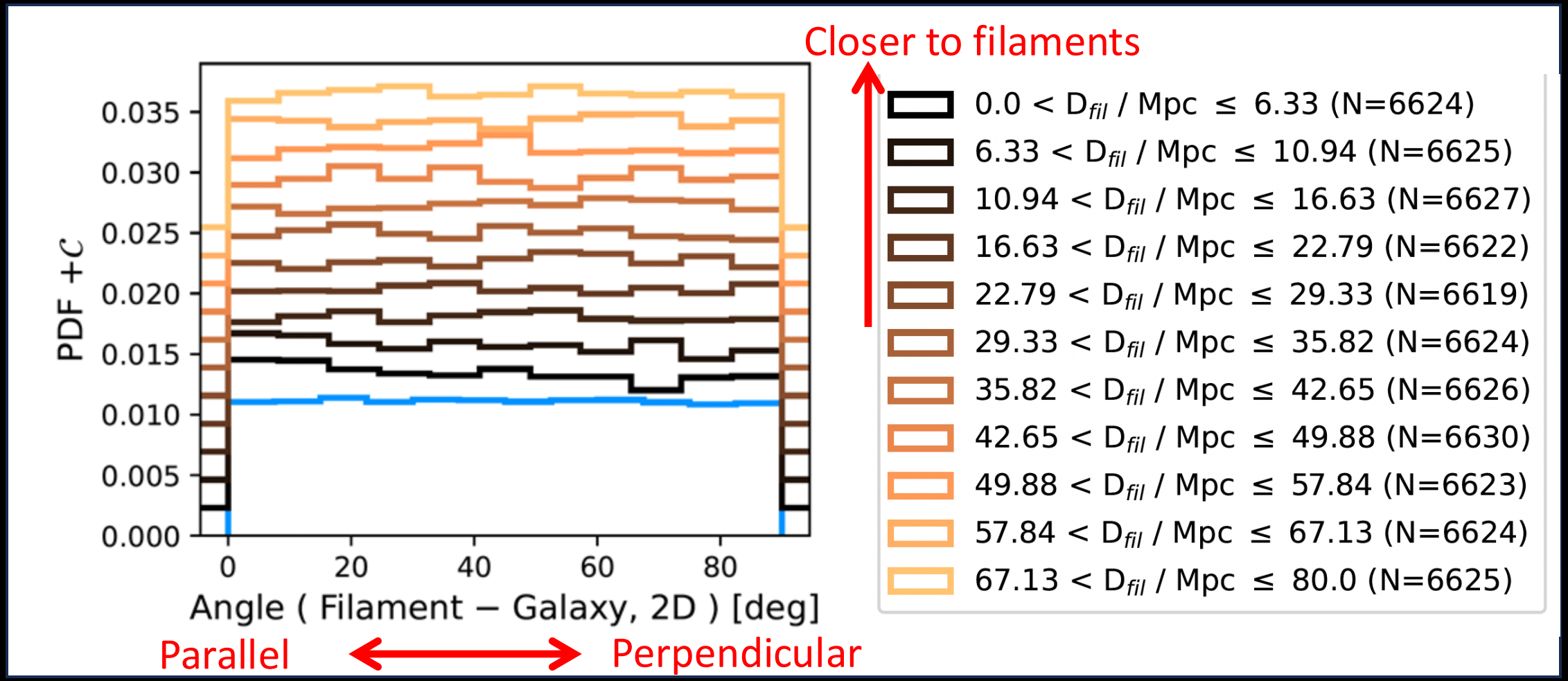
3D distance to the nearest filament (D_{fil})

Two position angles are random
→ Zero skewness



Alignment between galaxy major axis and cosmic filament



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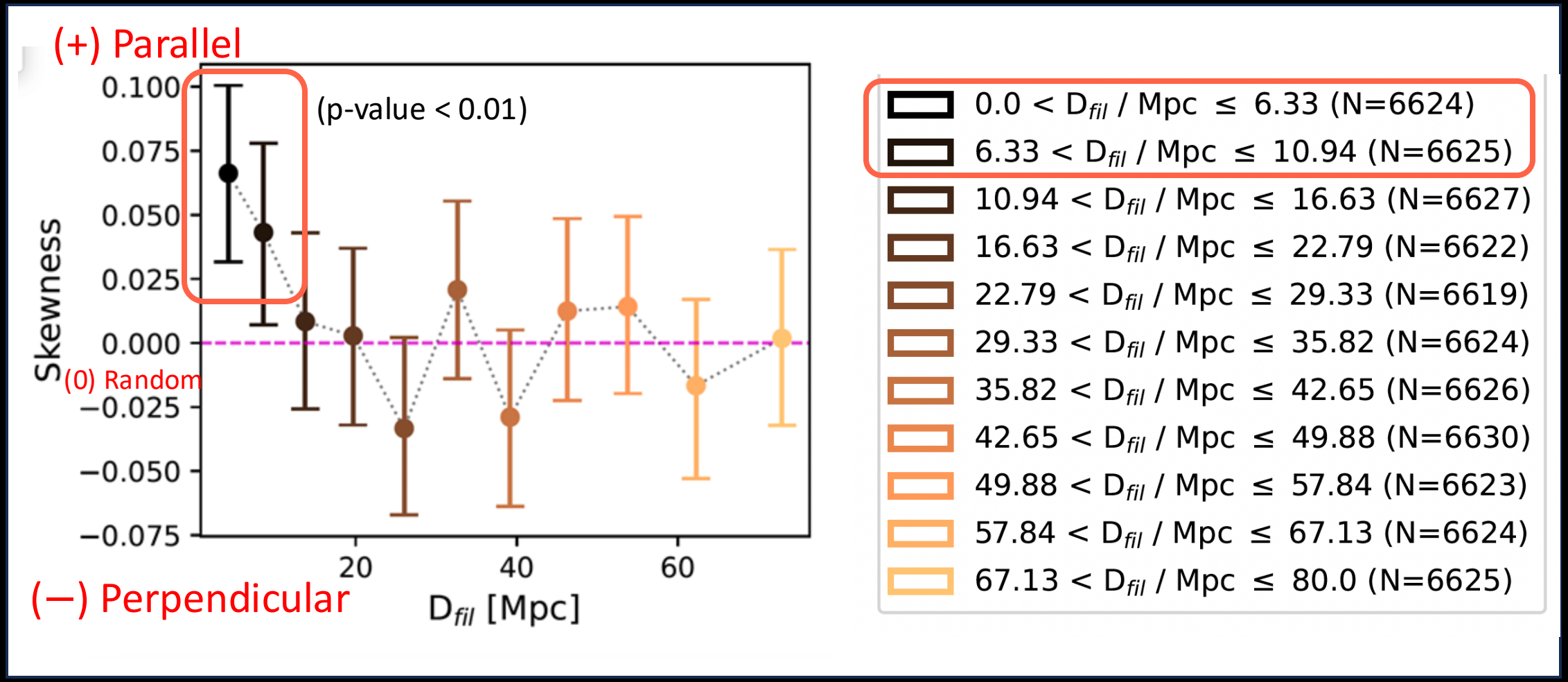

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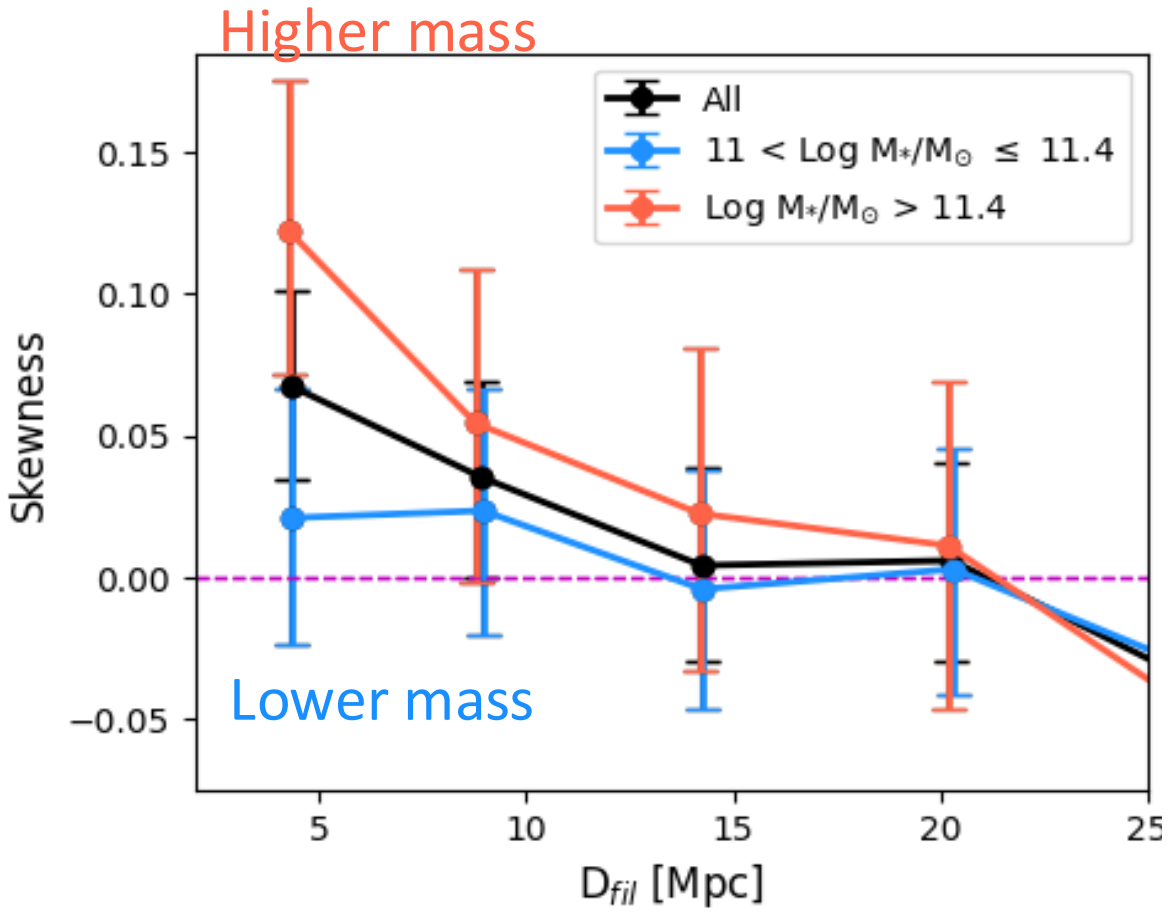
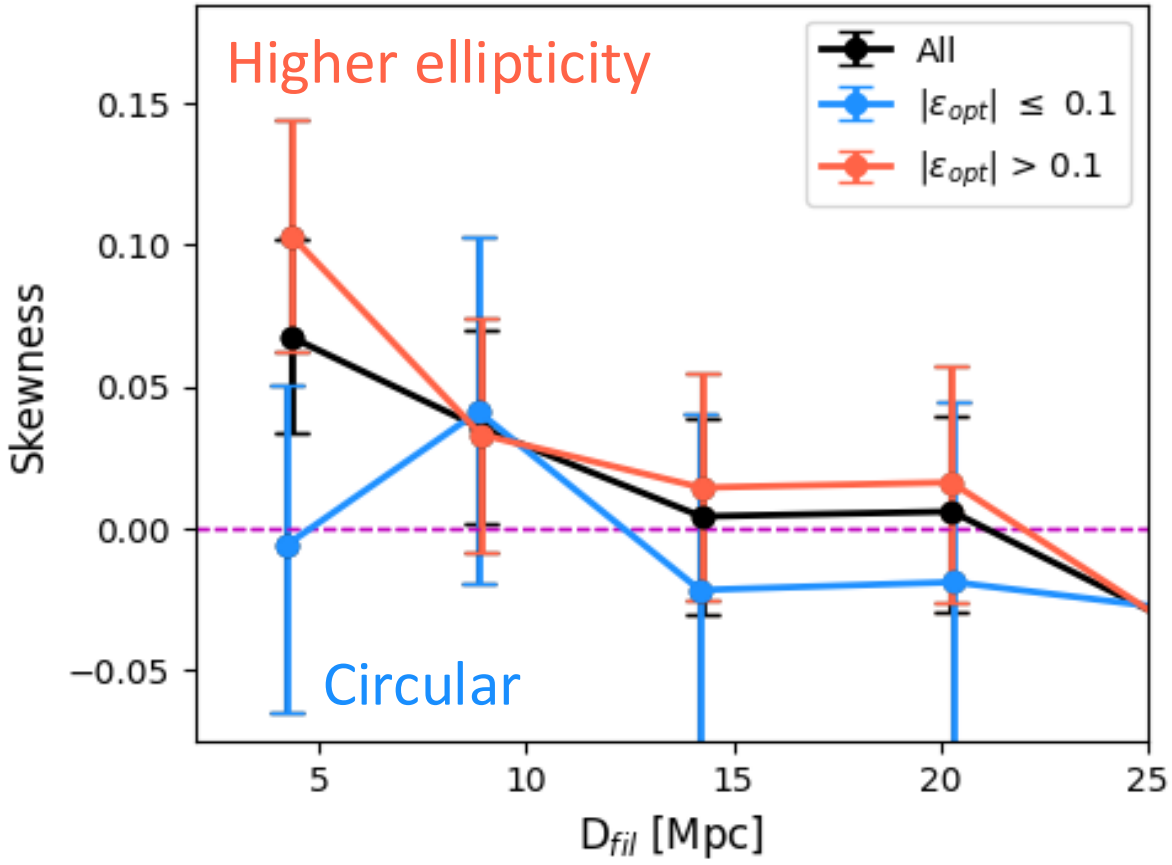
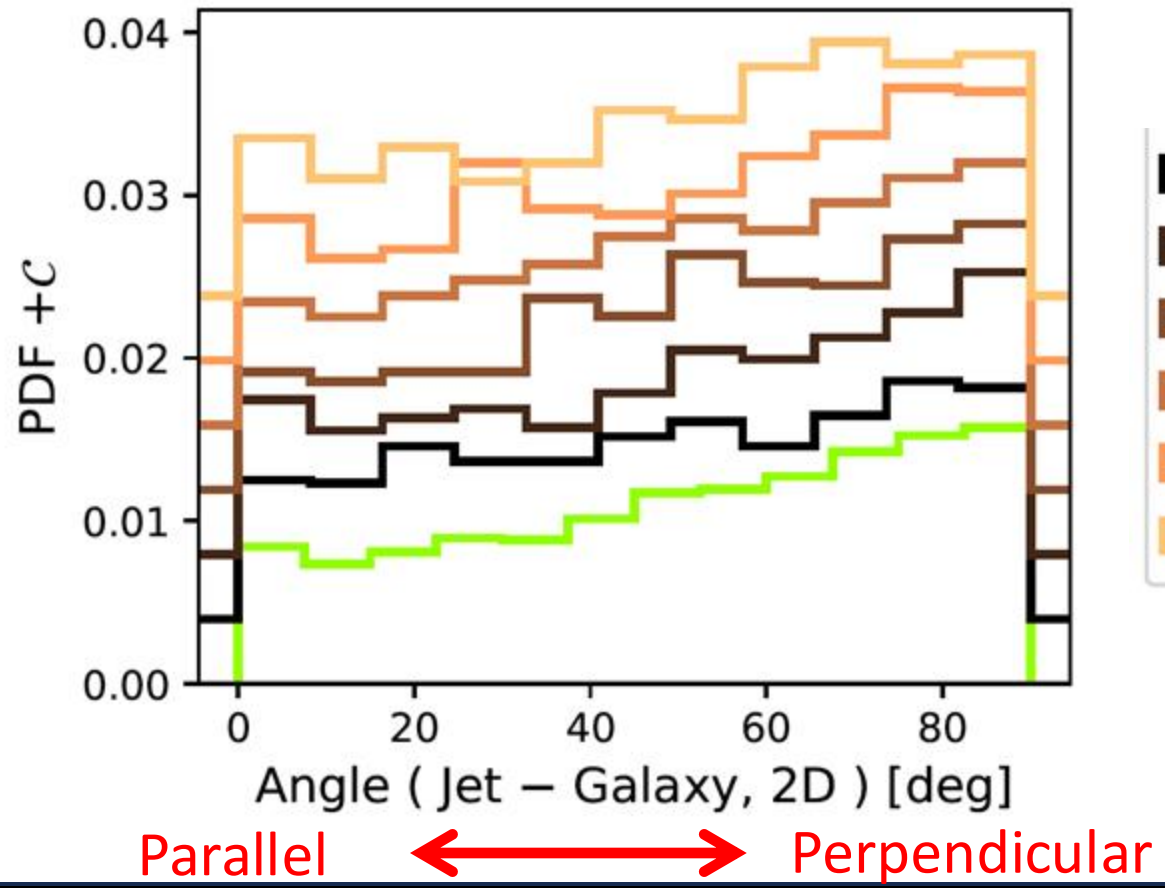
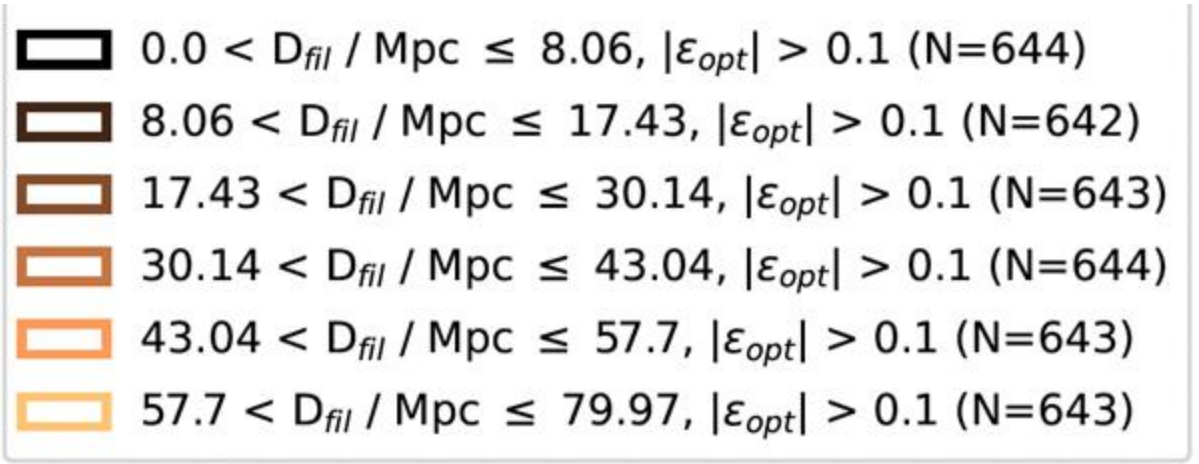




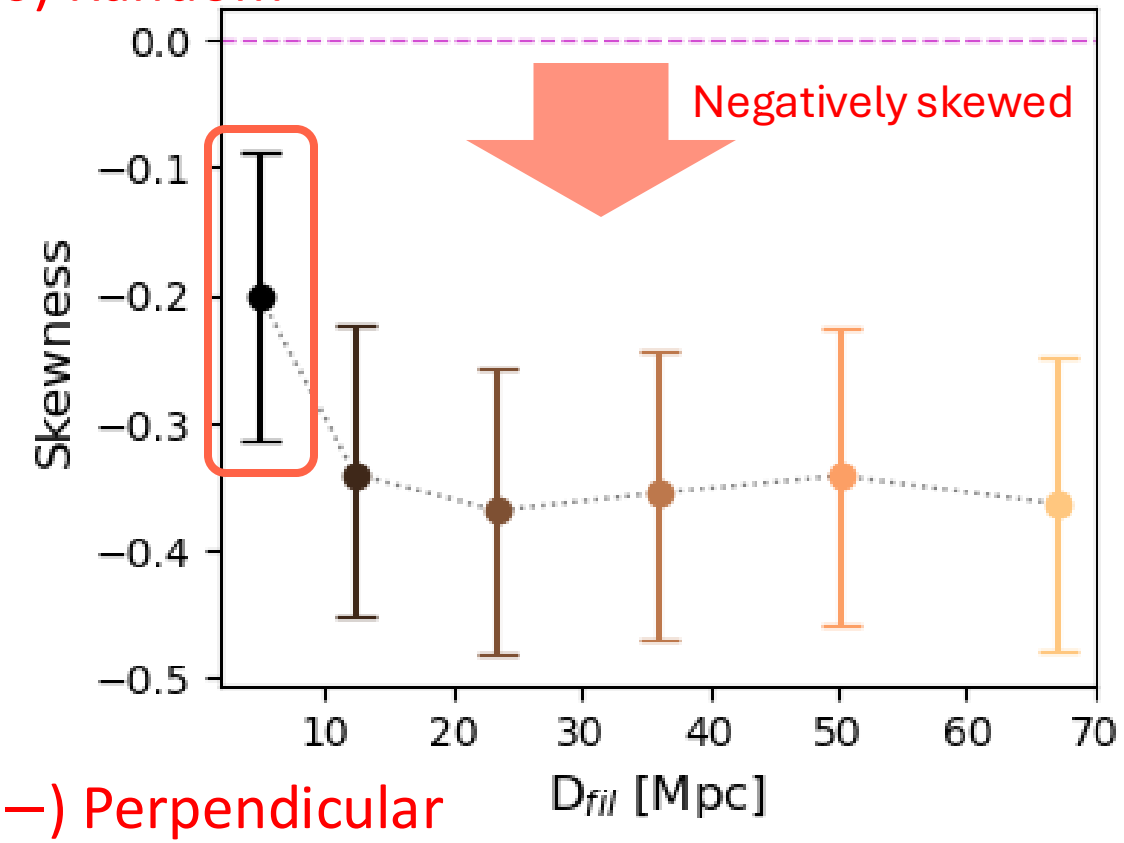
Alignment between galaxy major axis and radio jets





Alignment between galaxy major axis and radio jets

(0) Random

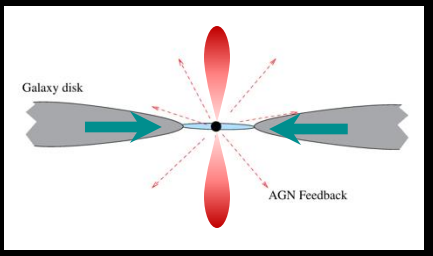


(−) Perpendicular

- 0.0 < D_{fil} / Mpc ≤ 8.06, $|\varepsilon_{opt}|$ > 0.1 (N=644)
- 8.06 < D_{fil} / Mpc ≤ 17.43, $|\varepsilon_{opt}|$ > 0.1 (N=642)
- 17.43 < D_{fil} / Mpc ≤ 30.14, $|\varepsilon_{opt}|$ > 0.1 (N=643)
- 30.14 < D_{fil} / Mpc ≤ 43.04, $|\varepsilon_{opt}|$ > 0.1 (N=644)
- 43.04 < D_{fil} / Mpc ≤ 57.7, $|\varepsilon_{opt}|$ > 0.1 (N=643)
- 57.7 < D_{fil} / Mpc ≤ 79.97, $|\varepsilon_{opt}|$ > 0.1 (N=643)

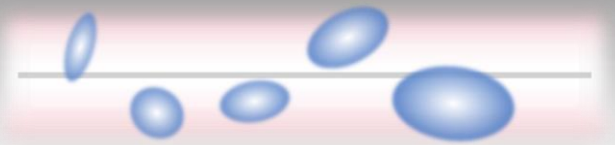
Outside cosmic filaments

Galaxy major axis – Filament : Random
Galaxy major axis – Radio jet : Perpendicular



➢ **Secular SMBH accretion**

Inside cosmic filaments

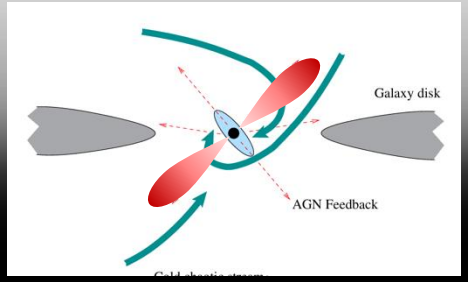


Galaxy major axis – Filament : Parallel

➢ **Mergers along cosmic filament**

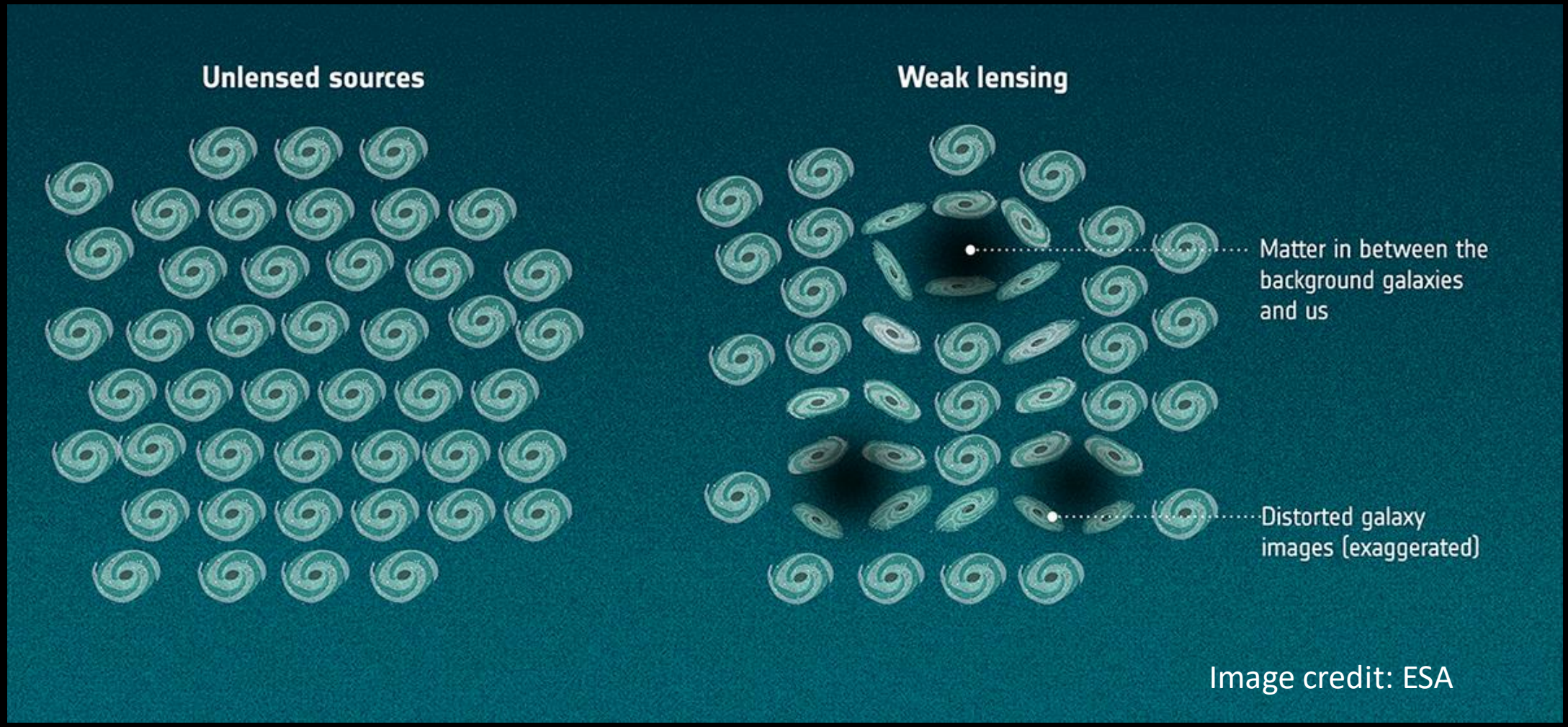
Galaxy major axis – Radio jet : (closer to) Random

➢ **Chaotic SMBH accretion**



Implications

Cosmic filaments can generate intrinsic alignment between galaxies



Cosmic filaments are less likely to generate alignment between radio jets

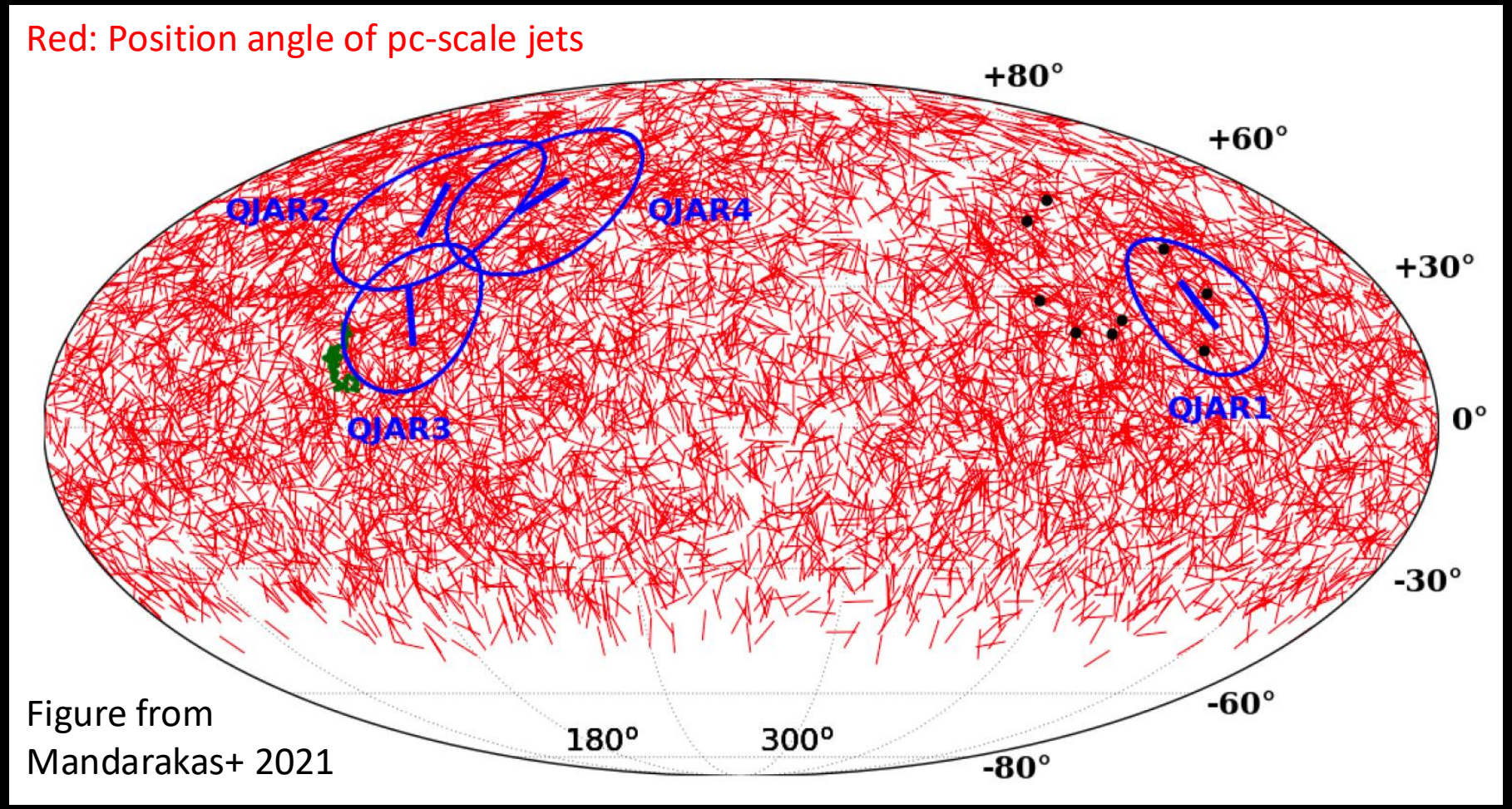


Figure from Mandarakas+ 2021

See also Taylor & Jagannathan 2016; Contigiani+ 2017; Osinga+ 2020; Panwar+ 2020; Simonte+ 2023

Azimuthal anisotropy in the circumgalactic medium around galaxies

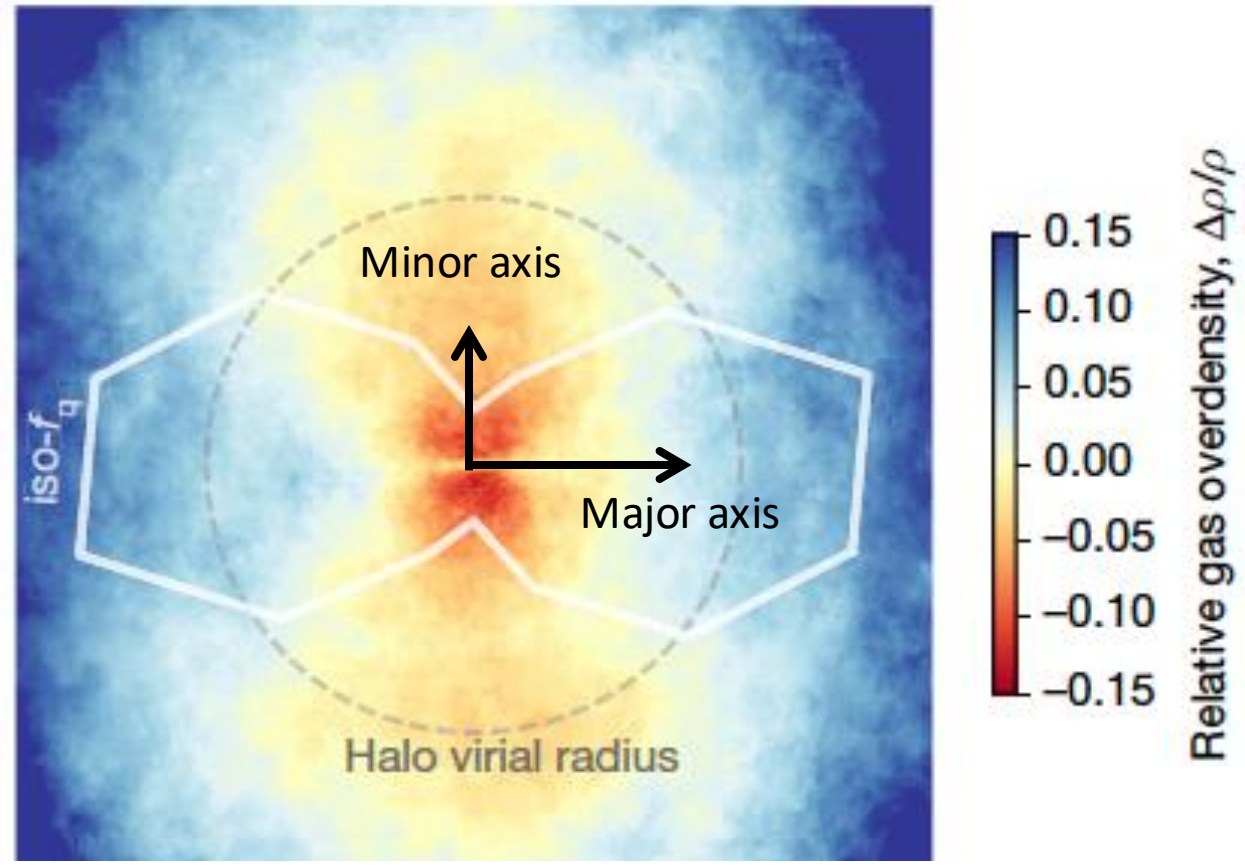


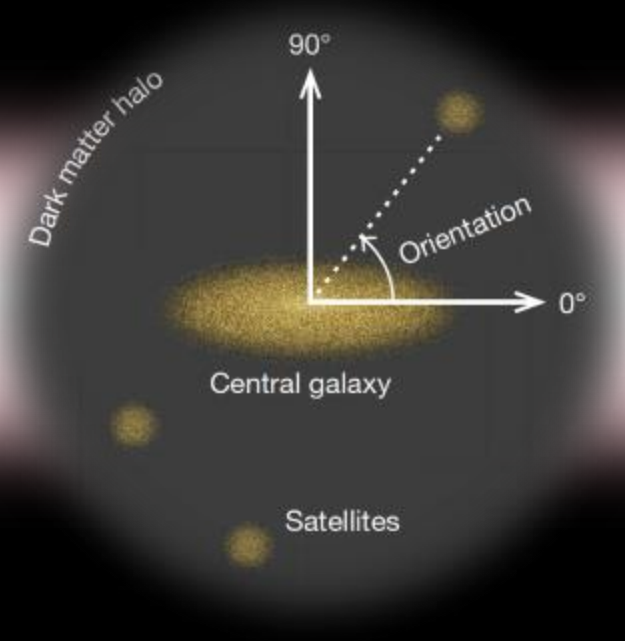
Image from Martin-Navarro+ 2021 (IllustrisTNG)

We show that AGN jets are in general parallel to the galaxy's minor axis

- This can heat the CGM predominantly along the minor axis direction

Azimuthal anisotropy in the quenched satellite distribution in groups/clusters

Accretion of pre-processed galaxies along filaments



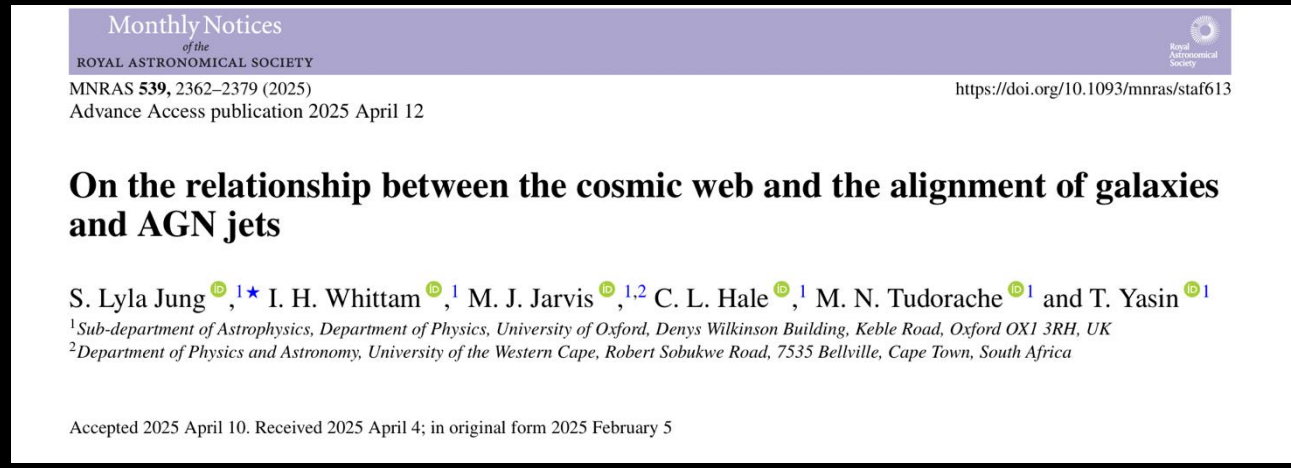
Quenched galaxies in filaments

We show that accretions in filament environments take place preferentially along the galaxy's major axis

- This could create anisotropy in the pre-processed satellite distribution

See Huang+ 2016; Stott 2022; Ando+ 2023; Karp+ 2023; Stephenson+ 2024

Take home messages



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On the relationship between the cosmic web and the alignment of galaxies and AGN jets

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- Massive galaxies in cosmic filaments grow by directional accretion & mergers
- Secular SMBH accretion mode is typical among massive radio galaxies with AGN jets
- Chaotic SMBH accretion mode is likely in galaxies in filament environments going through frequent mergers