# The alignment of galaxies and AGN jets in the cosmic web probed with LOFAR


Speaker: Lyla Jung

In collaboration with

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

# Large-scale structure of the Universe

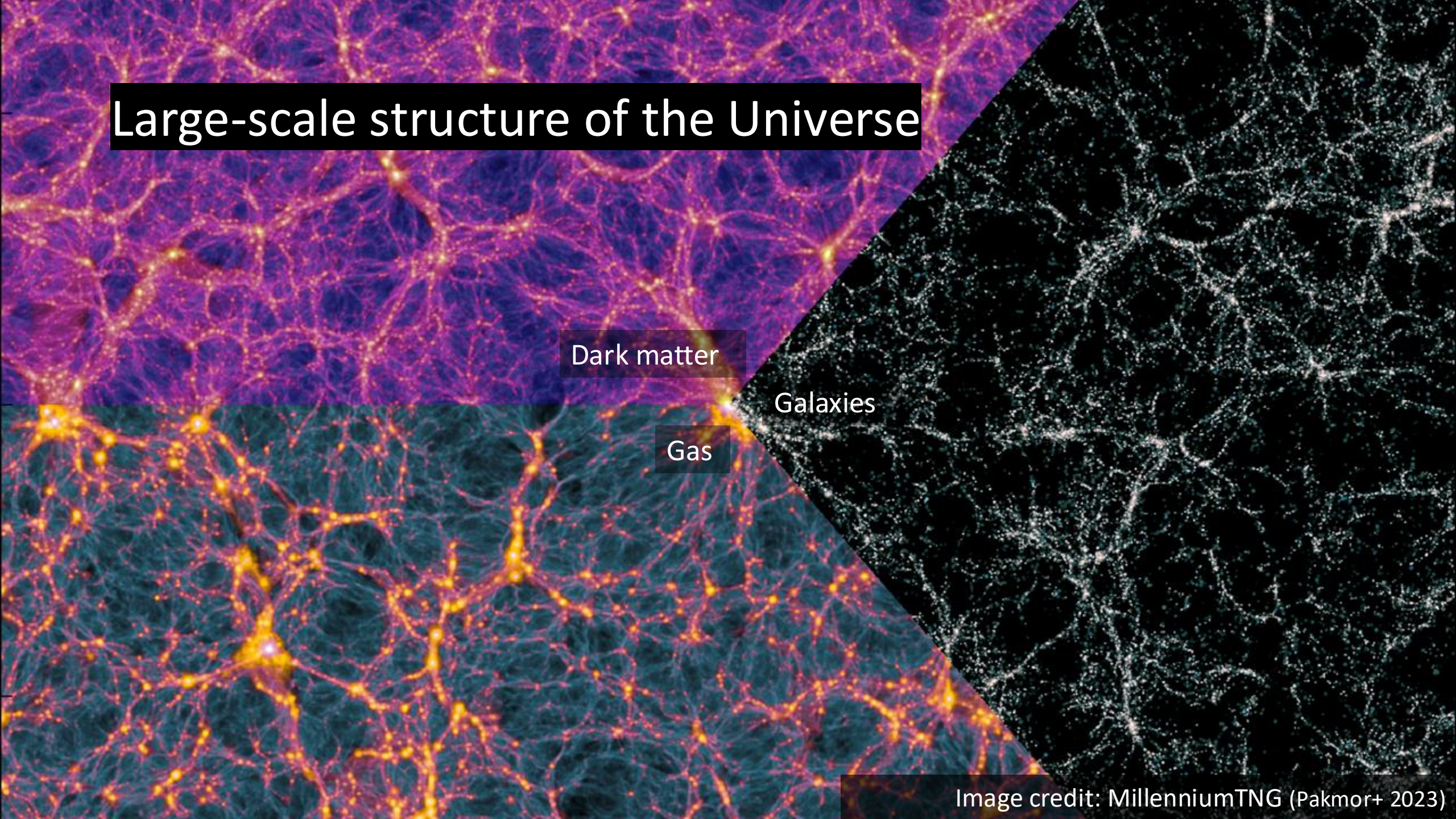
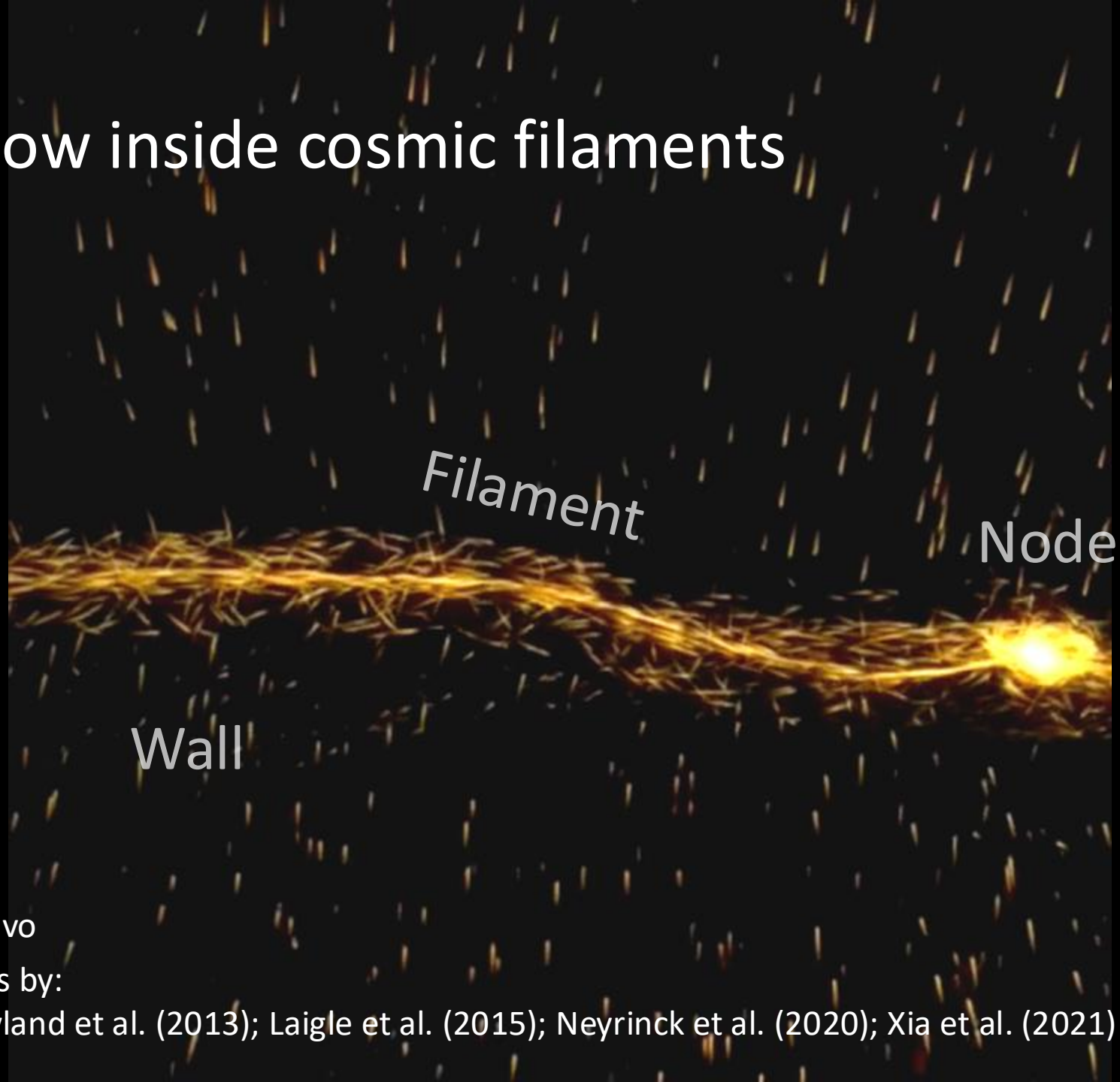



Image credit: MillenniumTNG (Pakmor+ 2023)

# Matter flow inside cosmic filaments

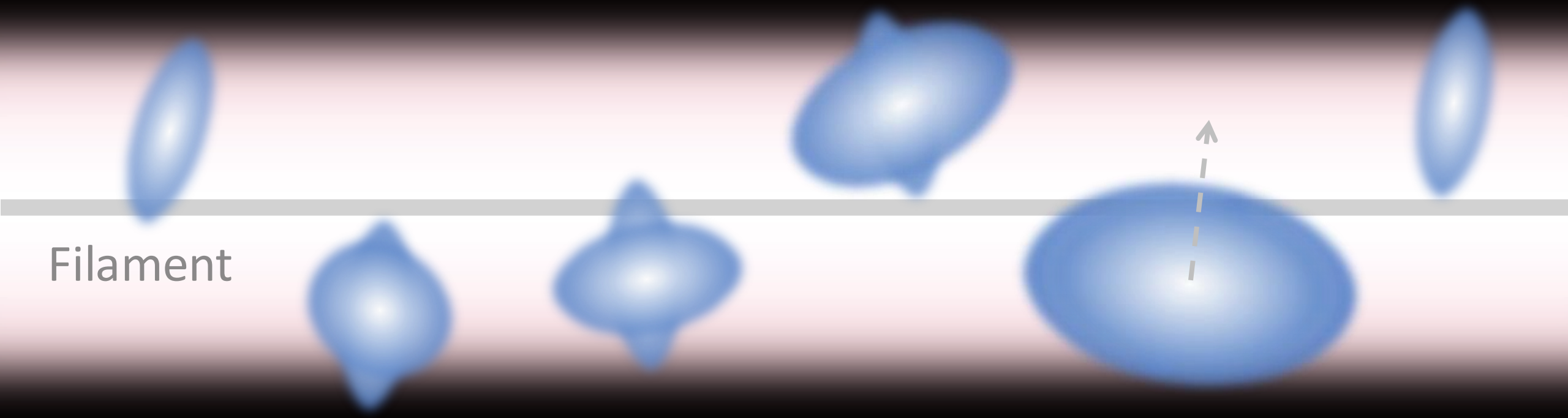



Video: Miguel Aragon-Calvo

See also theoretical works by:
Pichon et al. (2011); Trowland et al. (2013); Laigle et al. (2015); Neyrinck et al. (2020); Xia et al. (2021)

# 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

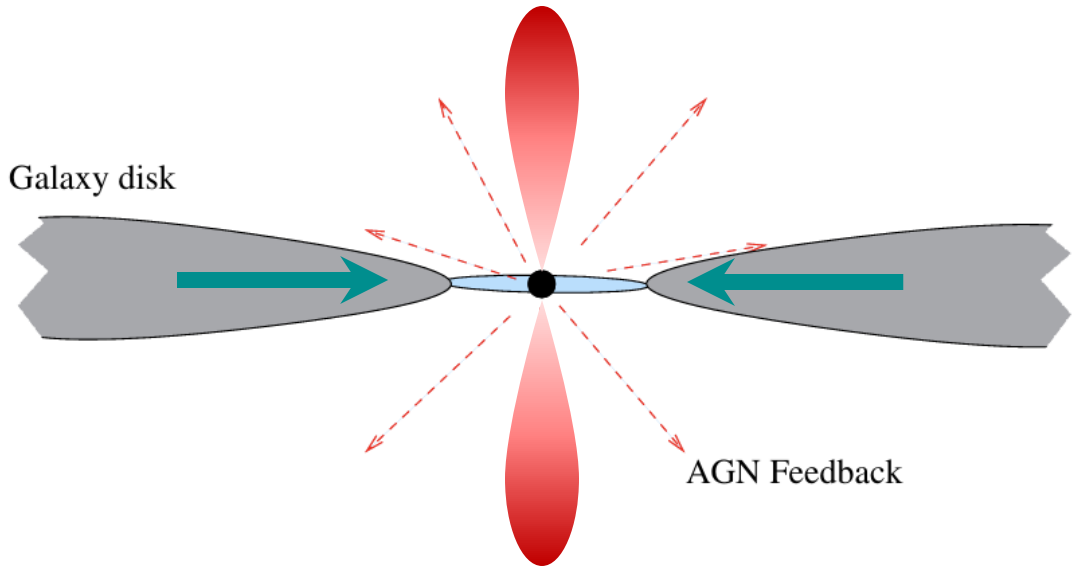
→ The direction of jets decides “where” the energy is injected

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

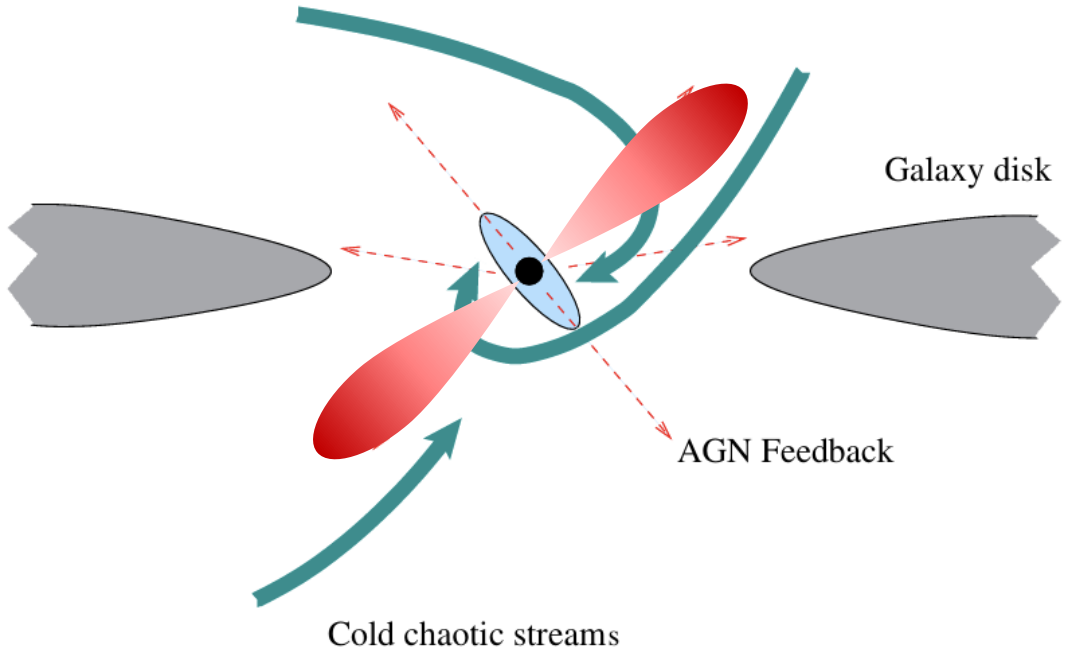
## Secular accretion

: 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)

## Cosmic filaments from SDSS
(Malavasi+ 2020)

## Optical galaxies from DESI photometry (Dey+ 2019)

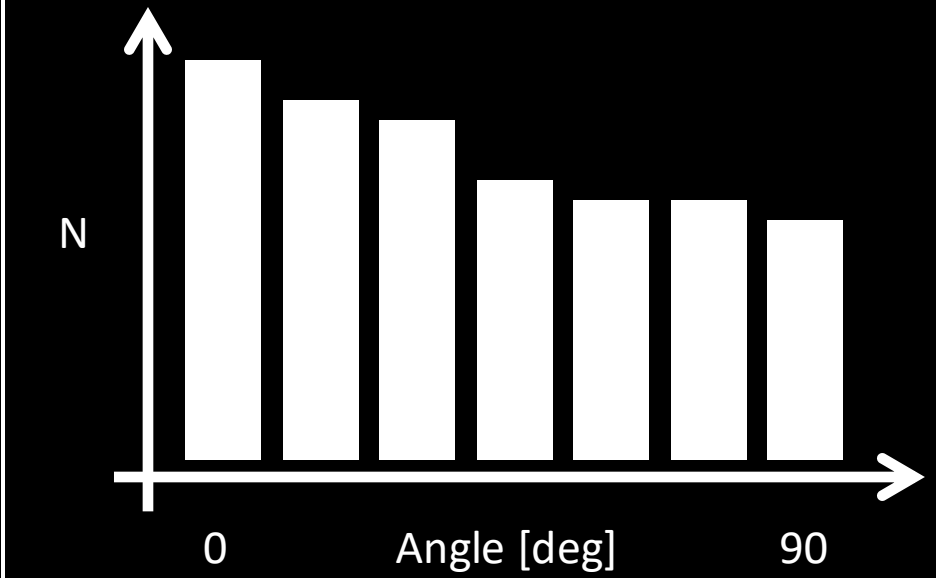
- N = 73077
- $\log M_*/\mathrm{M}_\odot > 11$
- z < 0.6

## 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 ($\mathrm{D_{fil}}$)

Two position angles are parallel
→ Positively skewed



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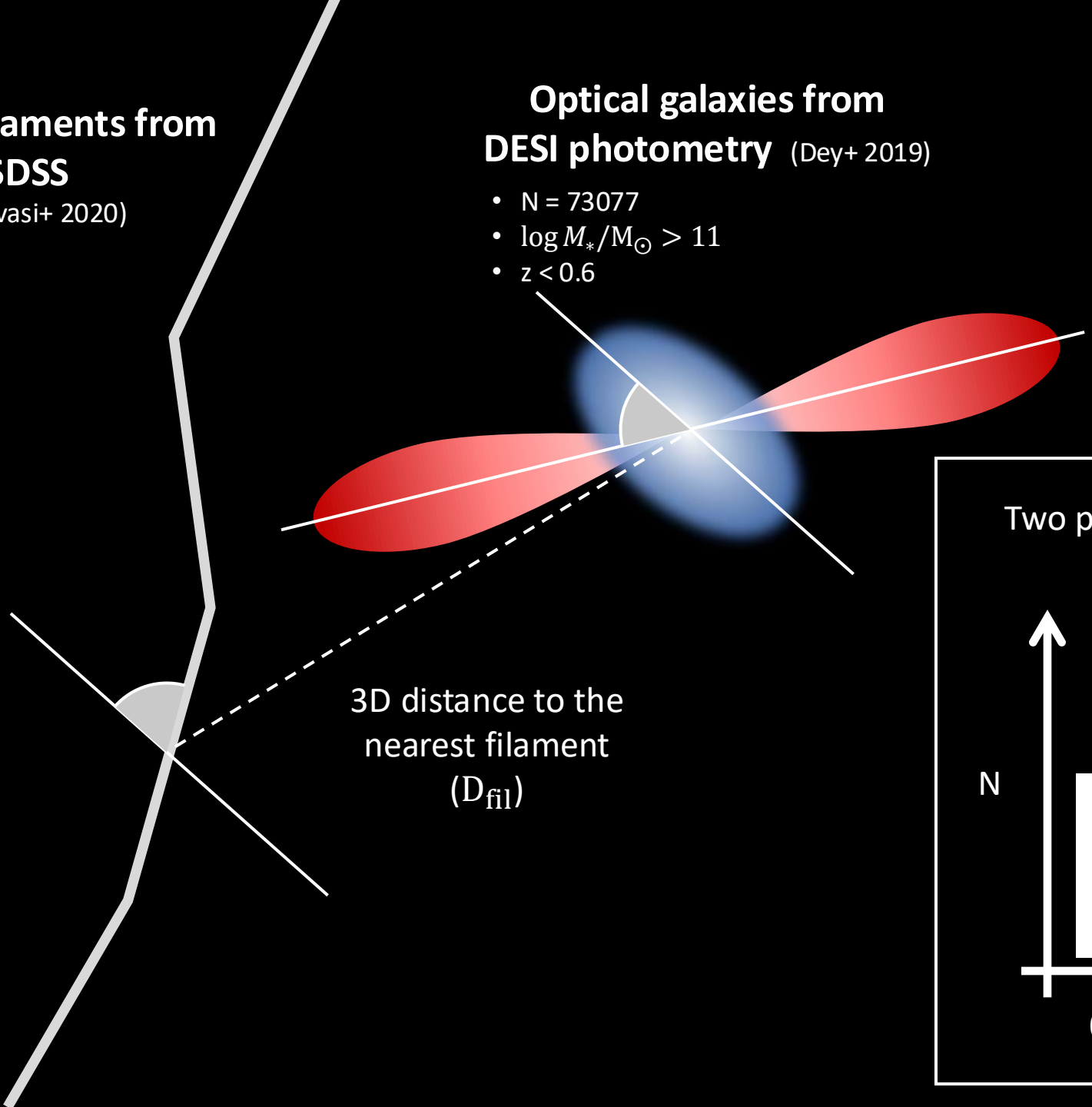
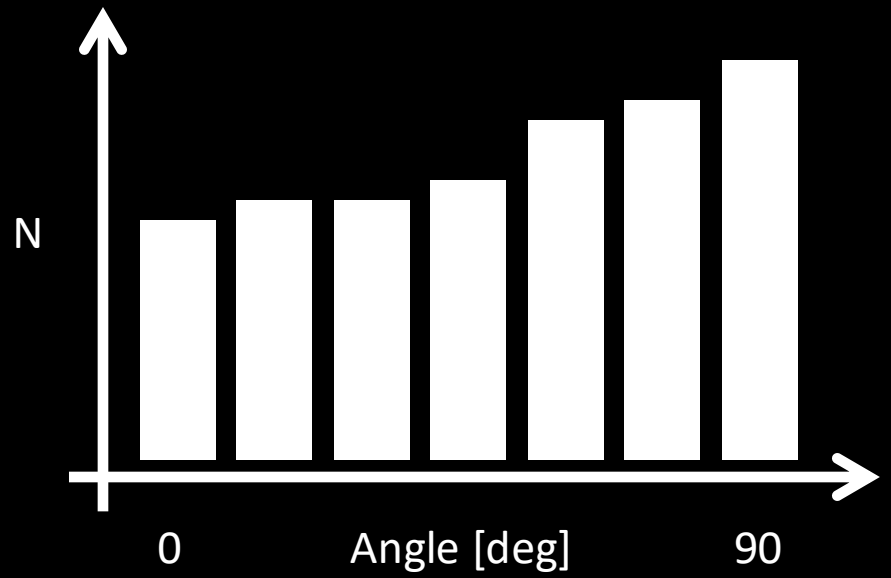


3D distance to the nearest filament ($\mathrm{D_{fil}}$)

Two position angles are perpendicular
→ Negatively skewed



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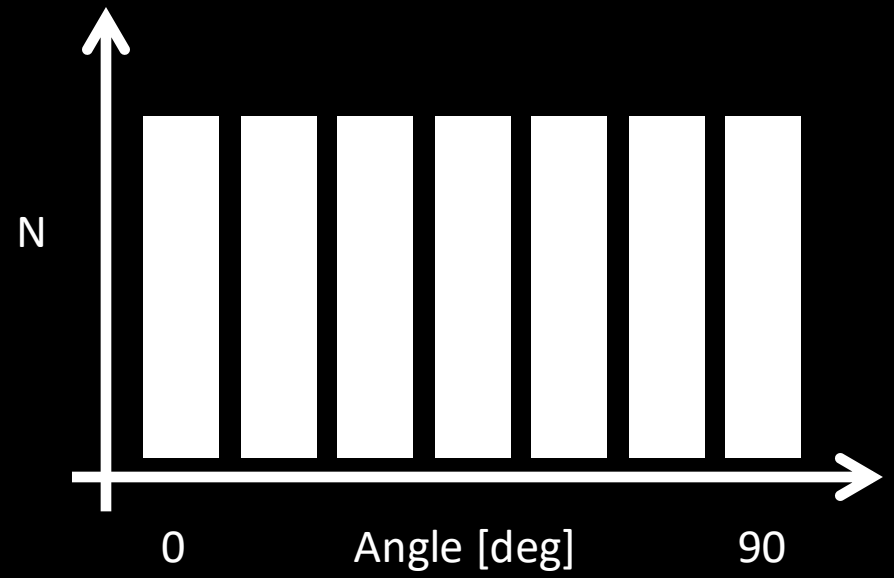
3D distance to the nearest filament ($\mathrm{D_{fil}}$)

Two position angles are random
→ Zero skewness

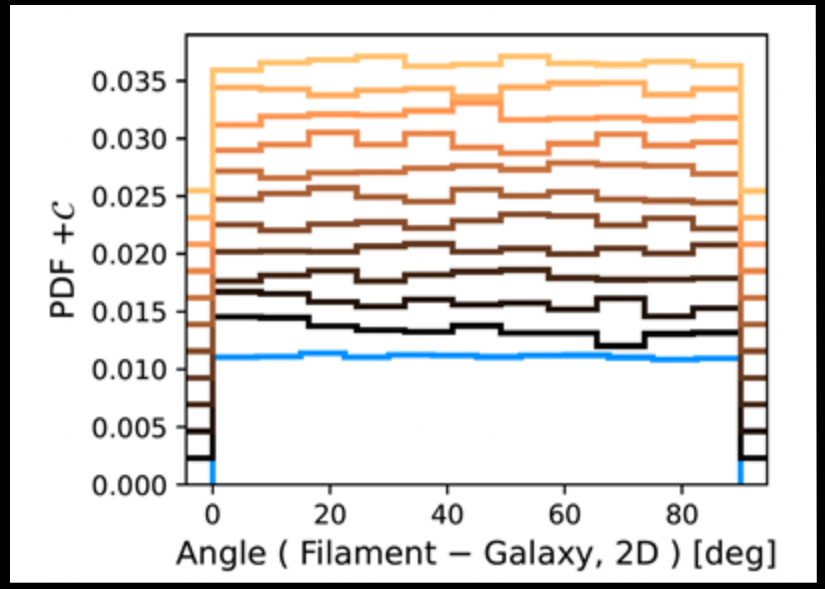


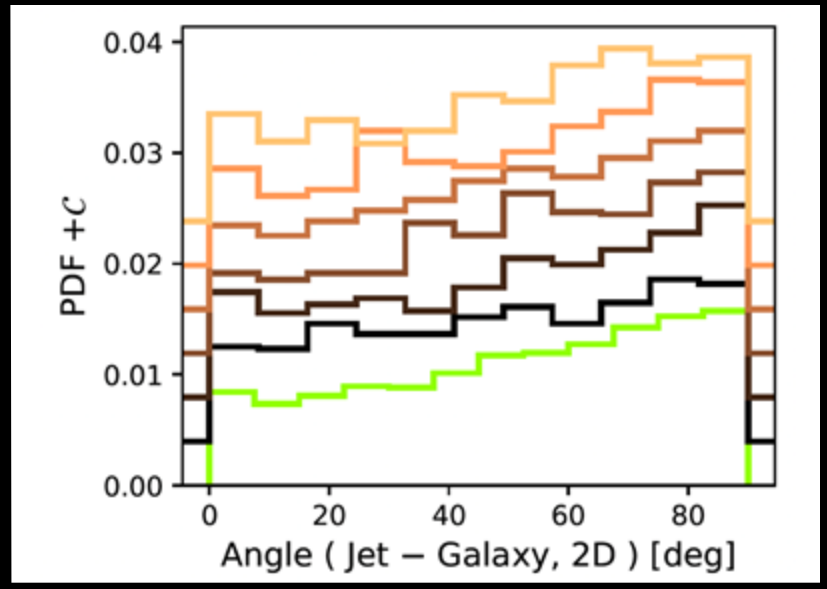
# Results

Galaxy major axis & Cosmic filament

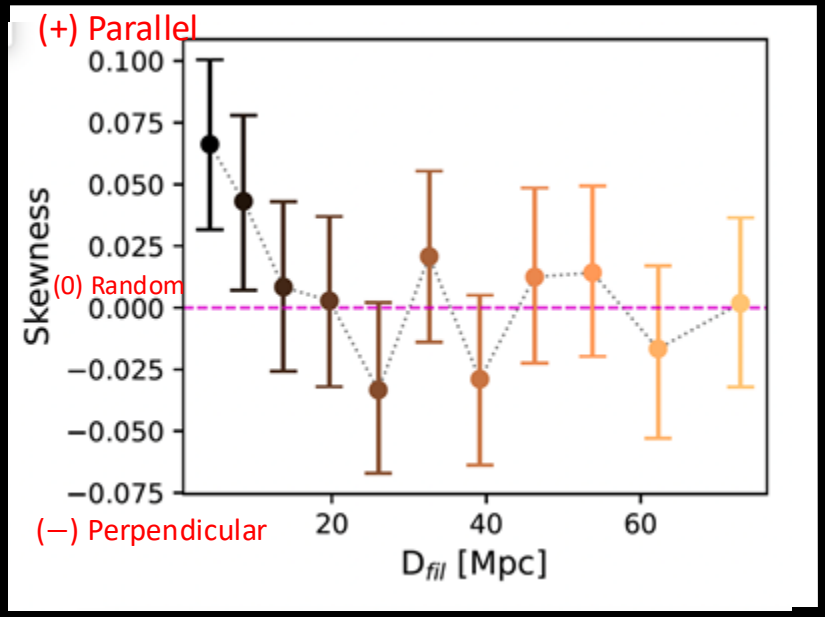
Galaxy major axis & Radio jet

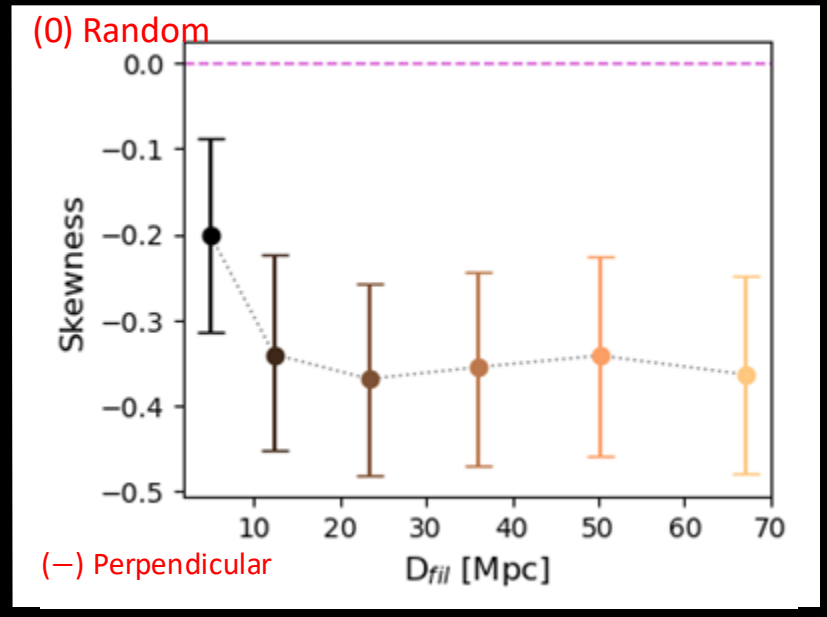
Histogram



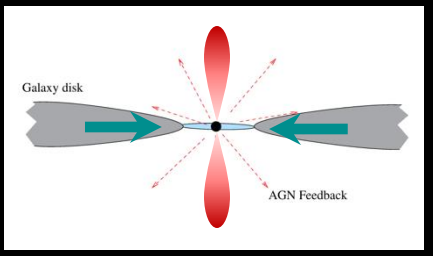

Skewness – $D_{fil}$



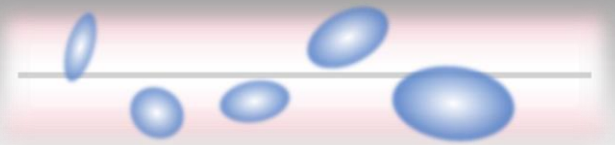
## Outside cosmic filaments

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




➢ **Secular SMBH accretion**

## Inside cosmic filaments

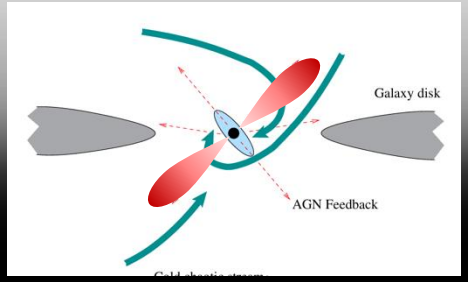


Galaxy major axis – Filament : Parallel

➢ **Mergers along cosmic filament**

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

➢ **Chaotic SMBH accretion**



# Cosmic filaments are less likely to generate alignment between radio jets

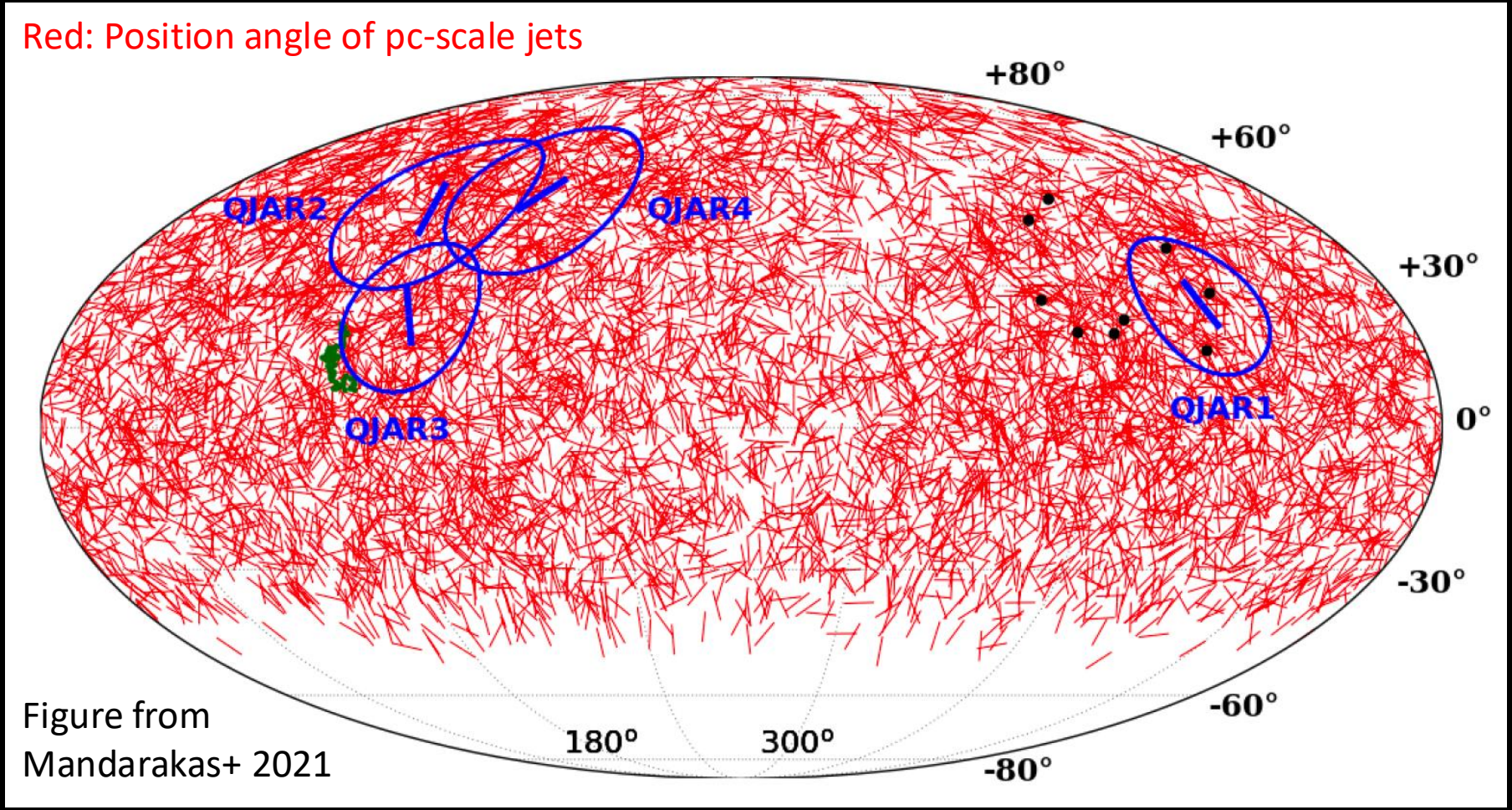



Figure from Mandarakas+ 2021

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

# Future with the SKA

- With better sensitivity …
  - Larger sample of AGNs spanning variety of host galaxy / AGN properties
    → Allow statistical population studies

- With better angular resolution …
  - Better definition of jet orientation & complex morphology

For example,

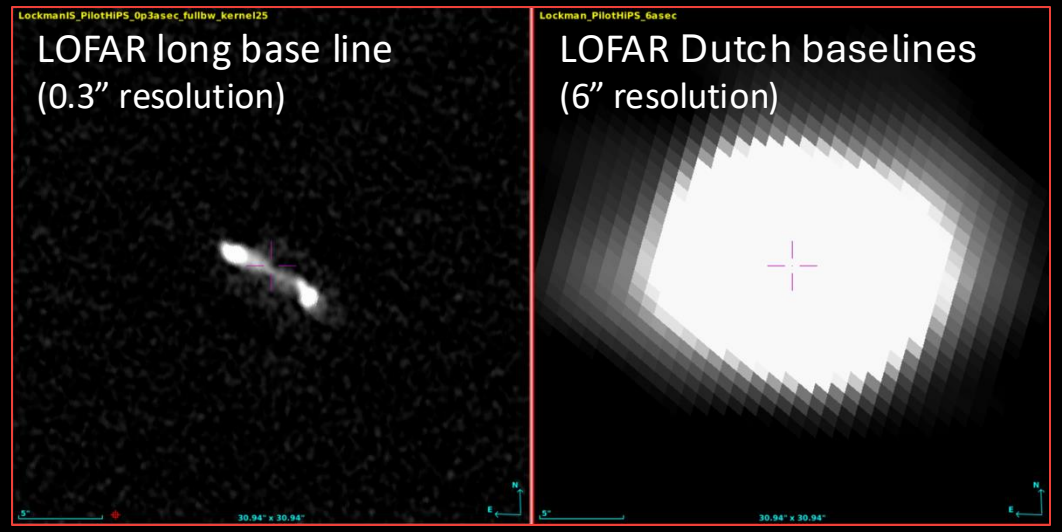
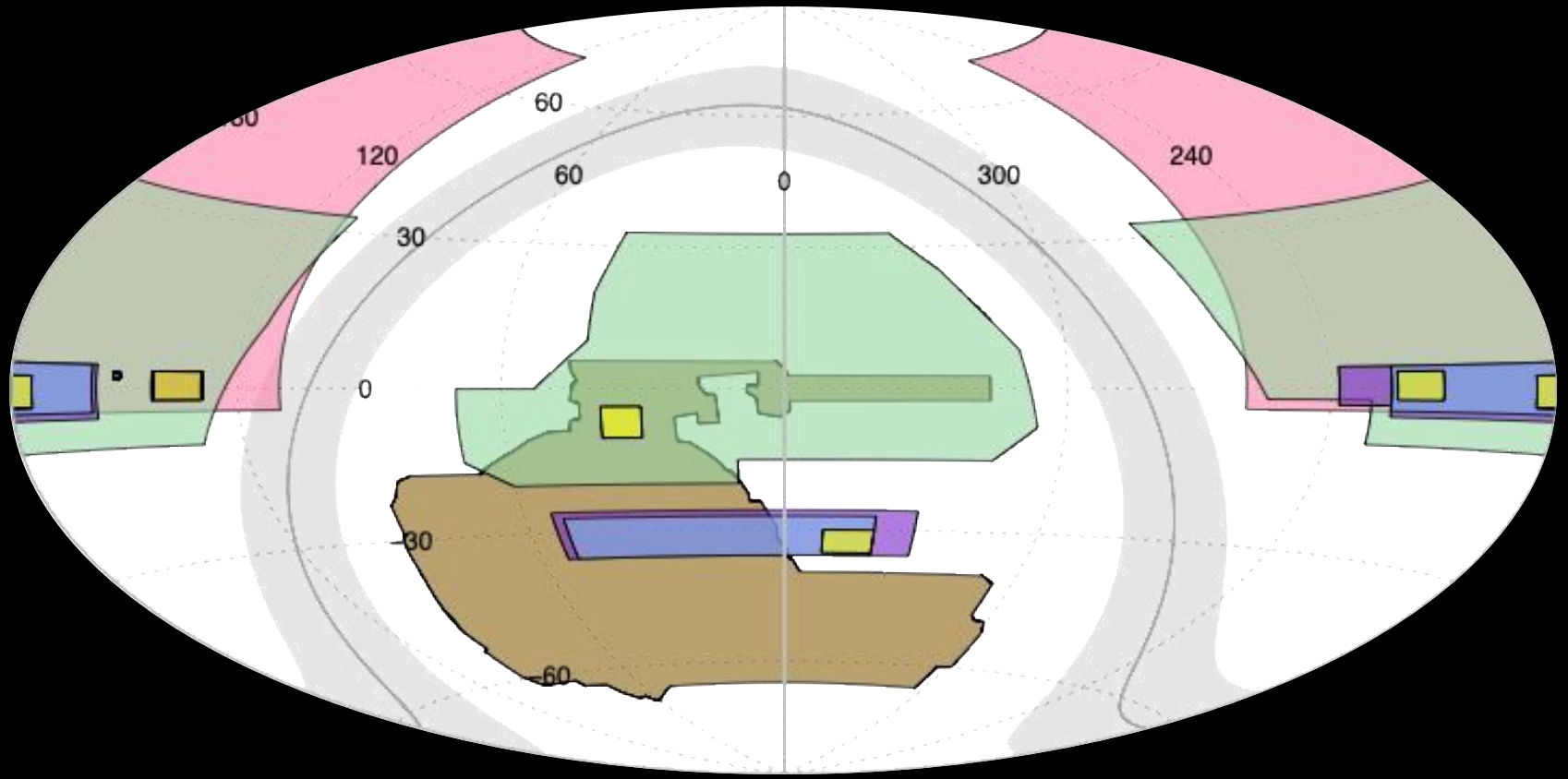



Image credit: lofar-surveys.org
Sweijen+ 2022

# Future with the SKA
# & multi-wavelength extragalactic surveys




Spectroscopic surveys

- DESI
- SDSS
- GAMA
- WAVES

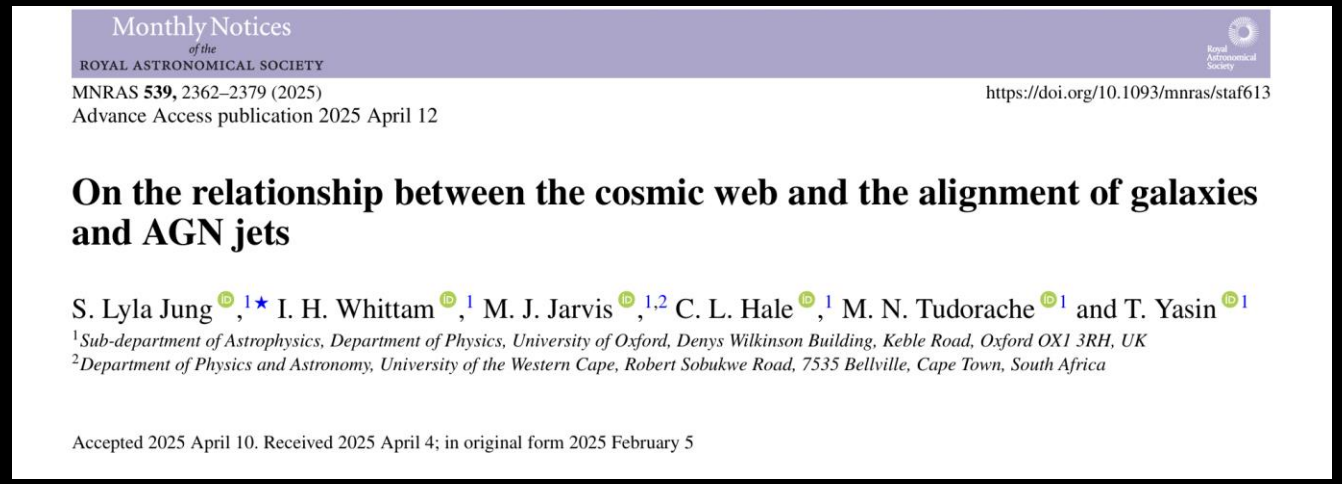
Imaging surveys

- KiDS
- DES

Image created with astromap.icrar.org (Celestial coordinate, Aitoff projection)

# Take home messages

- 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



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

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