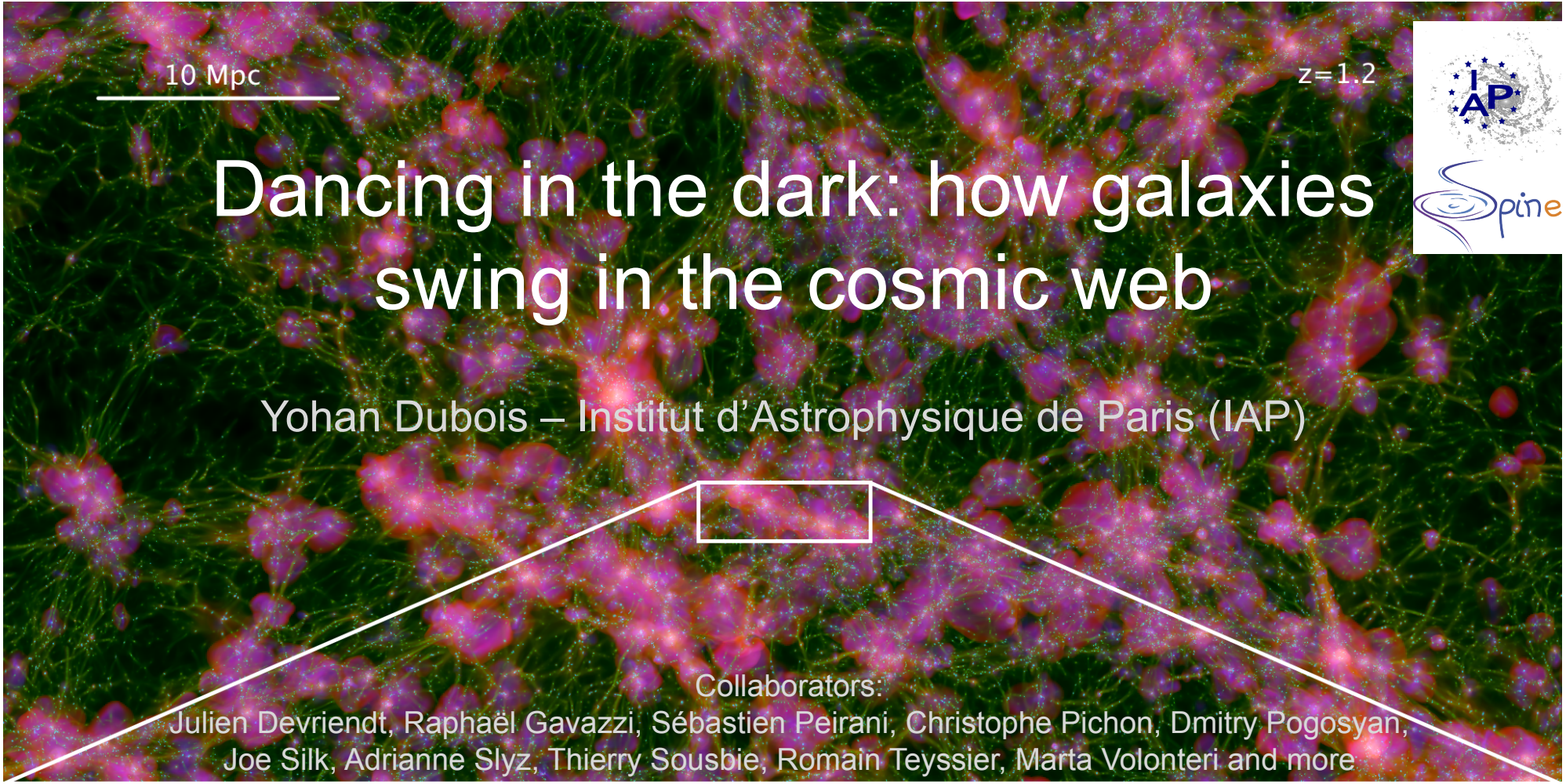


Dancing in the dark: how galaxies swing in the cosmic web

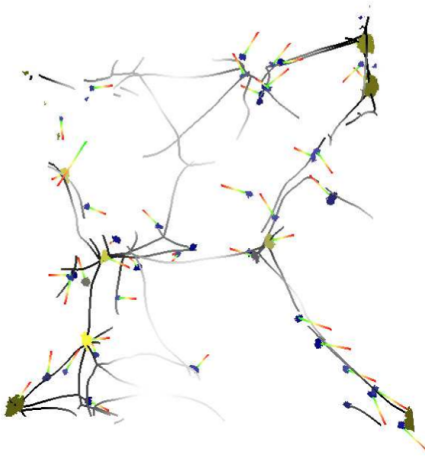
Yohan Dubois – Institut d'Astrophysique de Paris (IAP)

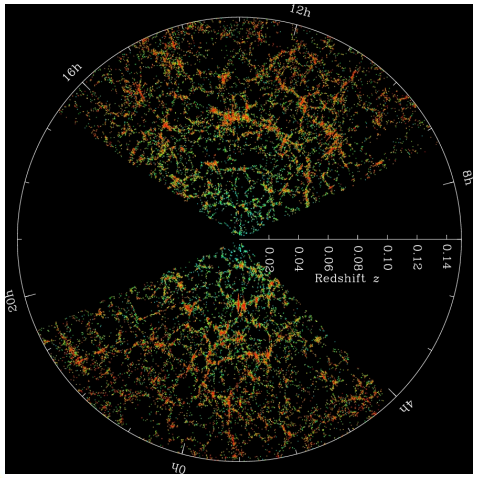
Collaborators:
Julien Devriendt, Raphaël Gavazzi, Sébastien Peirani, Christophe Pichon, Dmitry Pogosyan, Joe Silk, Adrianne Slyz, Thierry Sousbie, Romain Teyssier, Marta Volonteri and more

Sandrine Codis, Charlotte Welker, Clotilde Laigle

The Horizon-AGN simulation
http://www.horizon-simulation.org

Introduction





- Why should I care about the alignment of collapsed structures (dark halos, galaxies) with the cosmic web?

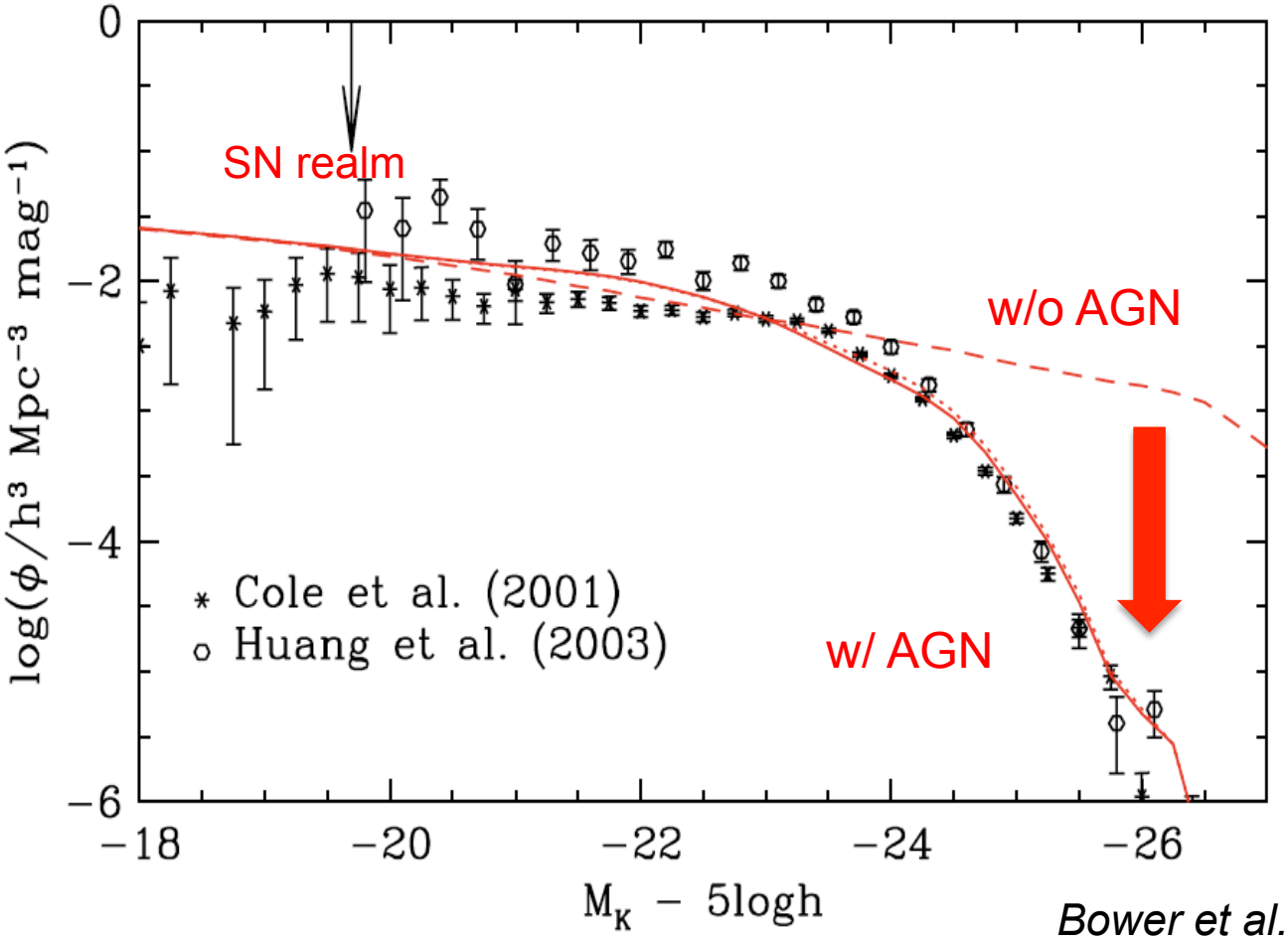
- Galaxies form at special locations of the cosmic web (sheets, filaments, nodes).
- Their angular momentum properties may be inherited from large-scale structures

1. Feedback changes the angular momentum content of galaxies
2. Evaluate the intrinsic alignment of structures
3. Feedback displaces the location of gas up to mega-parsec scales

- Euclid will constraint the nature of the dark energy with the amount of deformation of galaxies by gravitational lensing.
- The method works well if galaxies are randomly oriented.
- Intrinsic alignment of galaxies is a spurious bias that must be quantified for the success of the mission!
- Need for large-scale simulations and direct observations

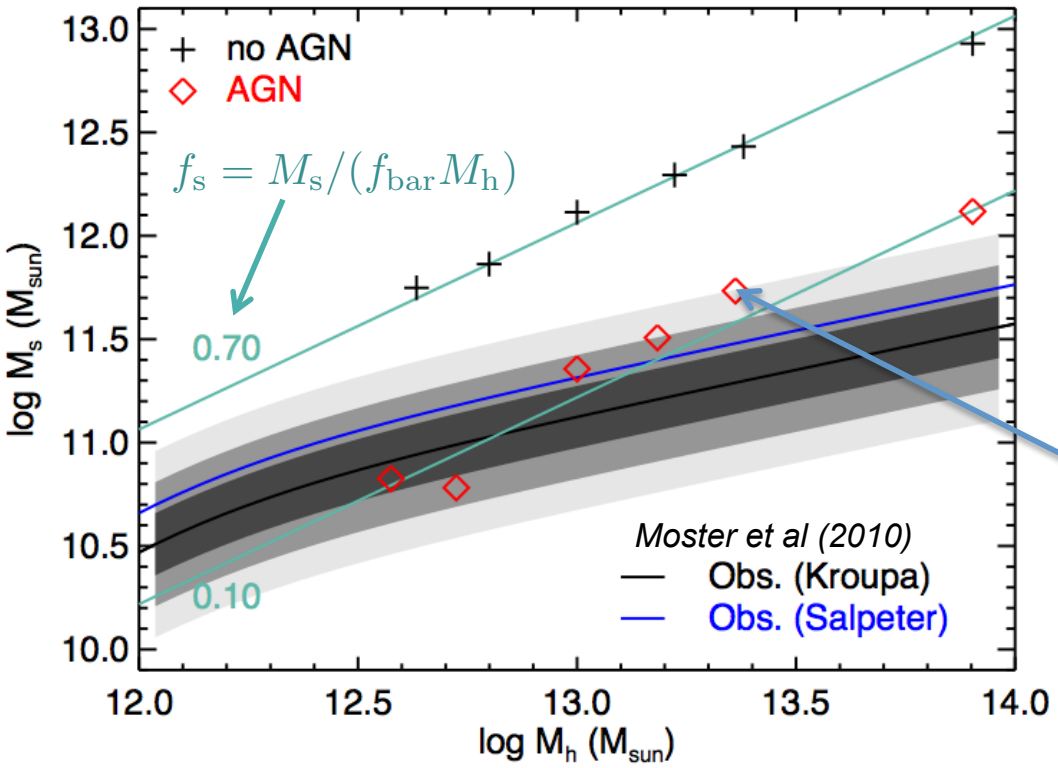
Motivation for AGN feedback

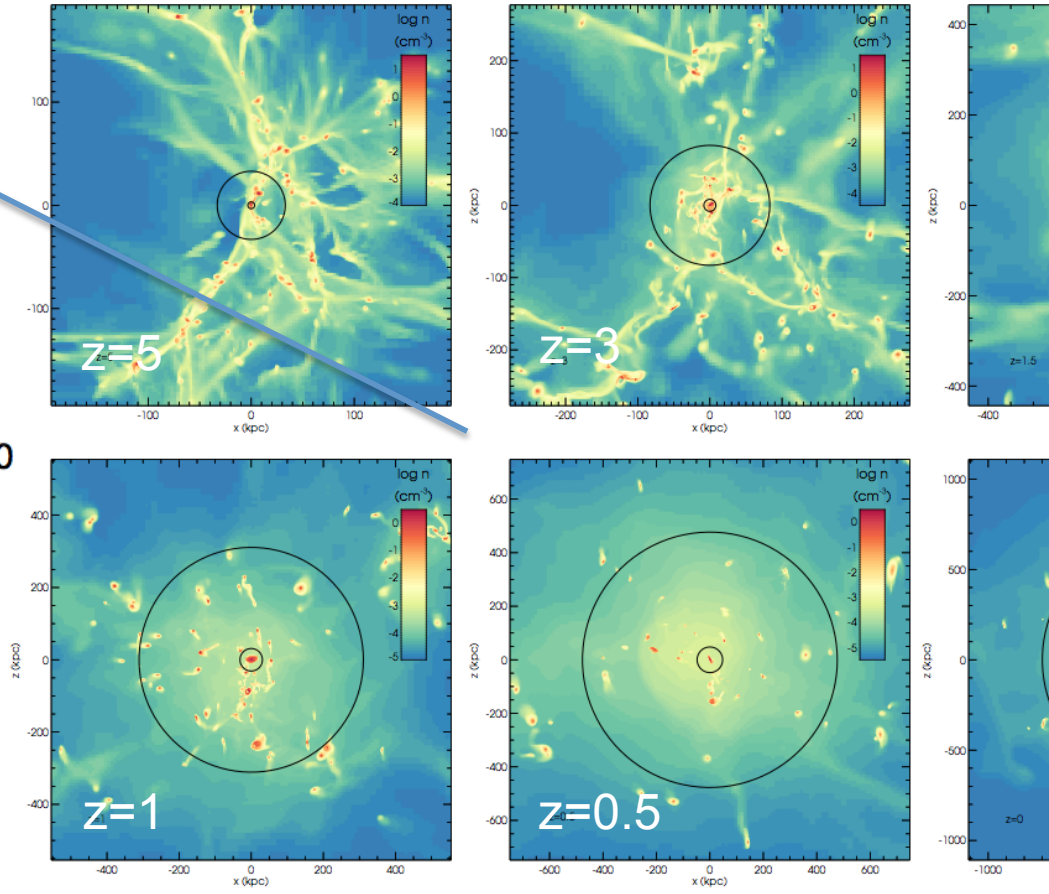
Galaxy luminosity (~mass) function
Semi-analytic models



Bower et al., 2006

Stellar mass in central massive galaxies

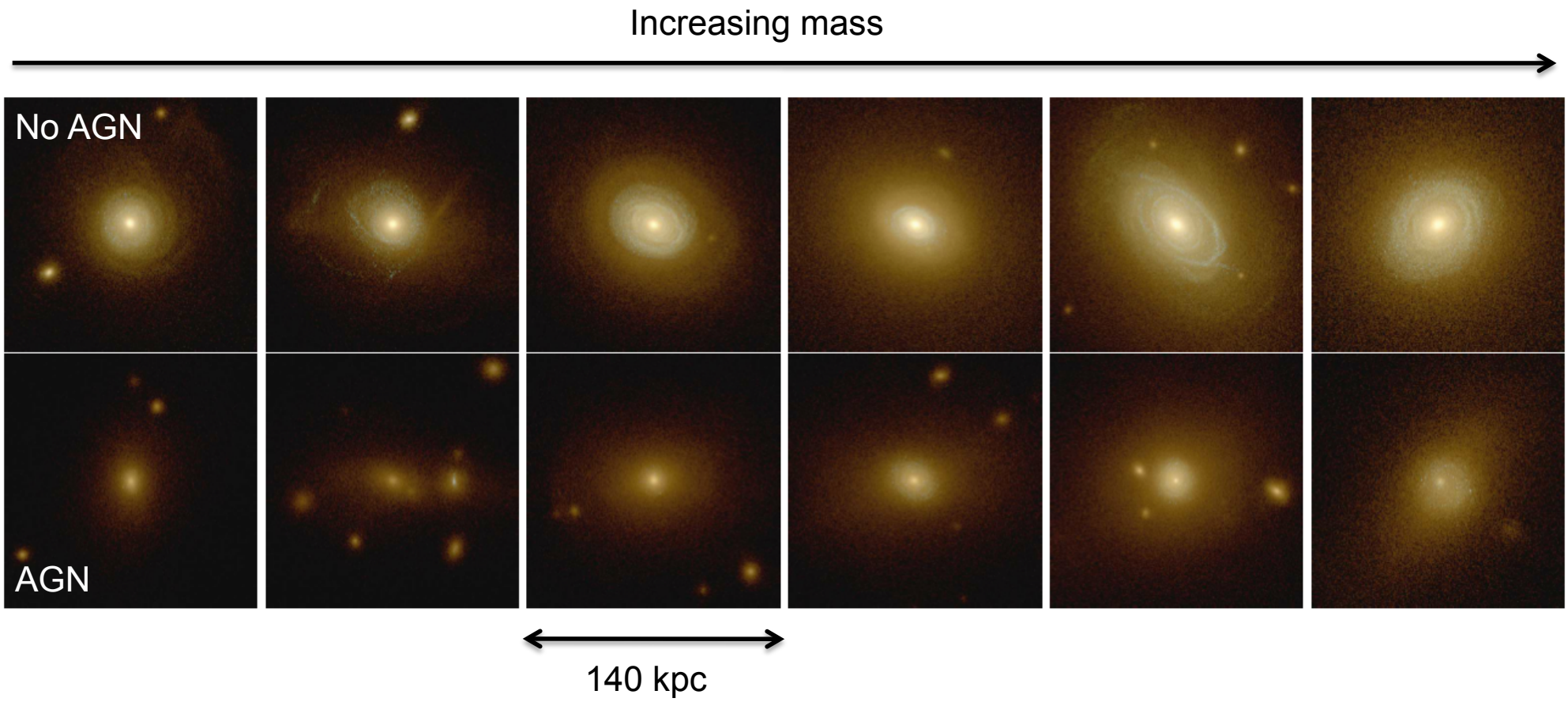




Radio-quasar (jet-heating) dual feedback model from Dubois et al (2012)

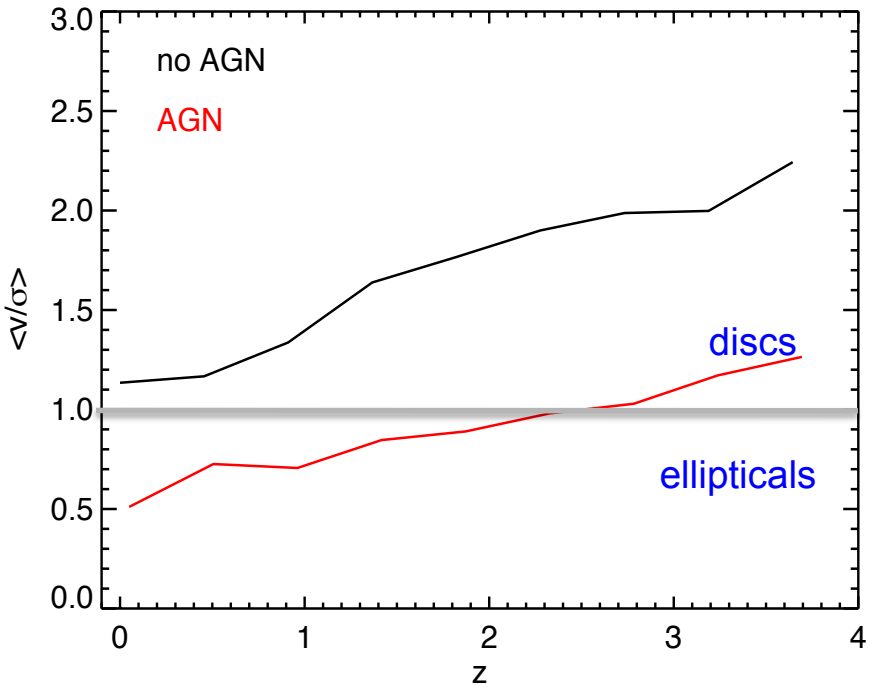
Dubois, Gavazzi, Peirani, Silk, 2013

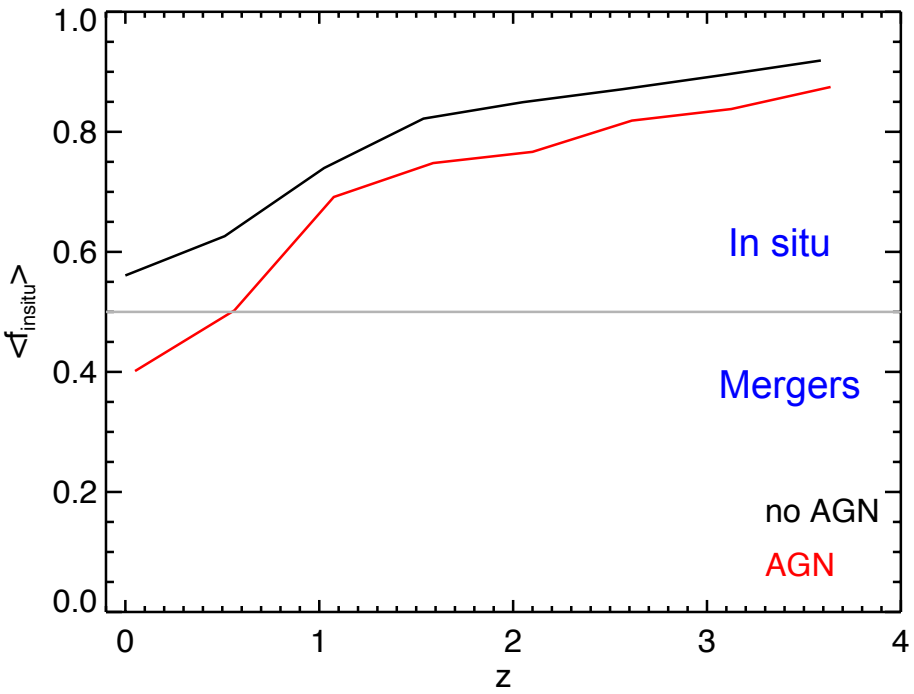
Can we get massive galaxies that look like ellipticals ?



Dubois, Gavazzi, Peirani, Silk, 2013

Rotation or dispersion-dominated galaxies?



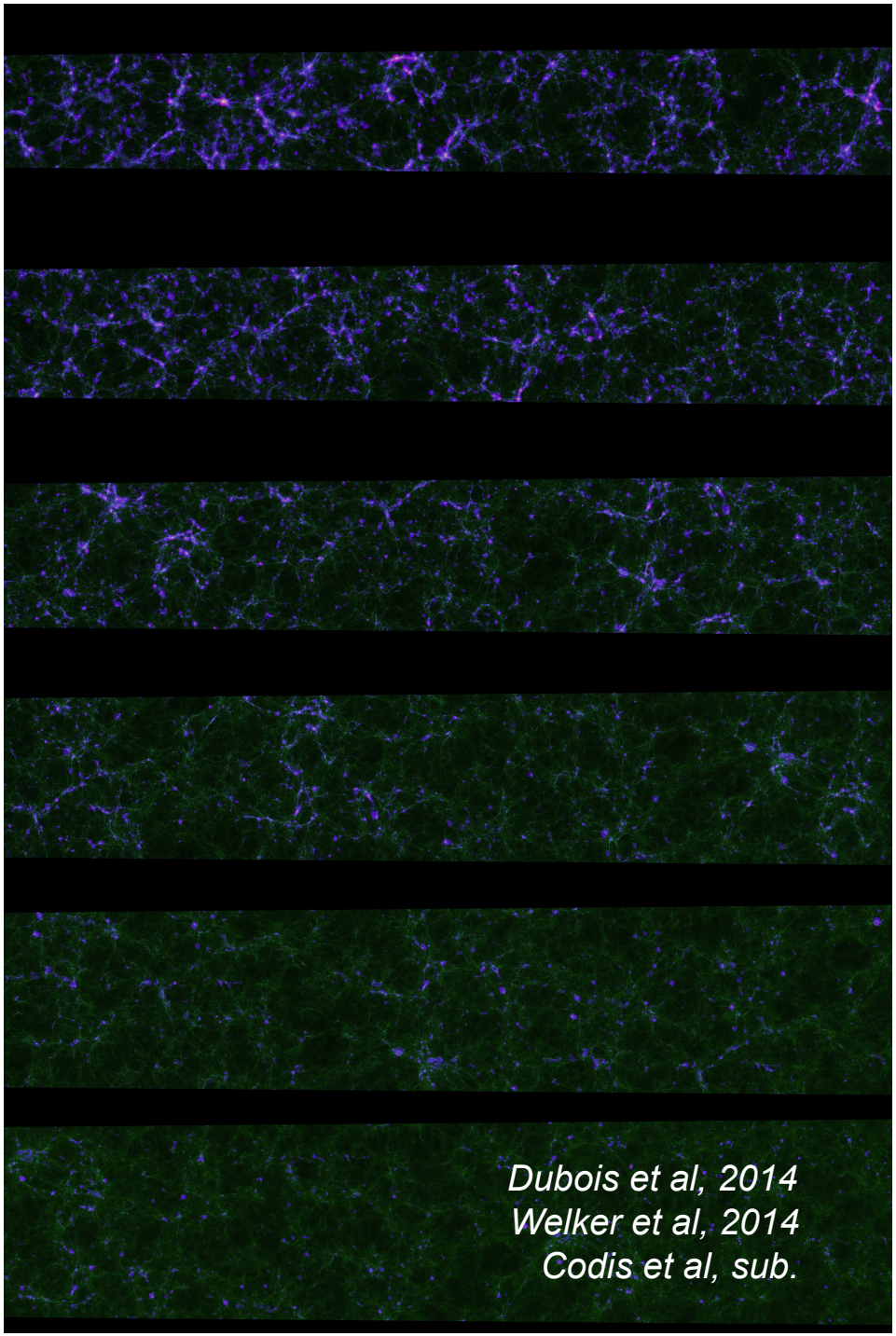


Dubois, Gavazzi, Peirani, Silk, 2013

The Horizon-AGN simulation

- Simulation content
  - Run with Ramses (AMR) *Teyssier (2002)*
  - L_{box}=100 Mpc/h
  - 1024^3 DM particles $M_{DM,res}=8x10^7\ M_{sun}$
  - Finest cell resolution dx=1 kpc
  - Gas cooling & UV background heating
  - Low efficiency star formation
  - Stellar winds + SNII + SNIa
  - O, Fe, C, N, Si, Mg, H
  - AGN feedback radio/quasar
- Outputs
  - Simulation outputs
  - Lightcones (0.5°x0.5°) performed on-the-fly
    - Dark Matter (position, velocity)
    - Gas (position, density, velocity, pressure, chemistry)
    - Stars (position, mass, velocity, age, chemistry)
    - Black holes (position, mass, velocity, accretion rate)
- z=0.6 using 6.7 Mhours on 4096 cores
- 150 000 galaxies per snapshot (> 50 part.)
- 7.10^9 leaf cells (more than Illustris or EAGLE)

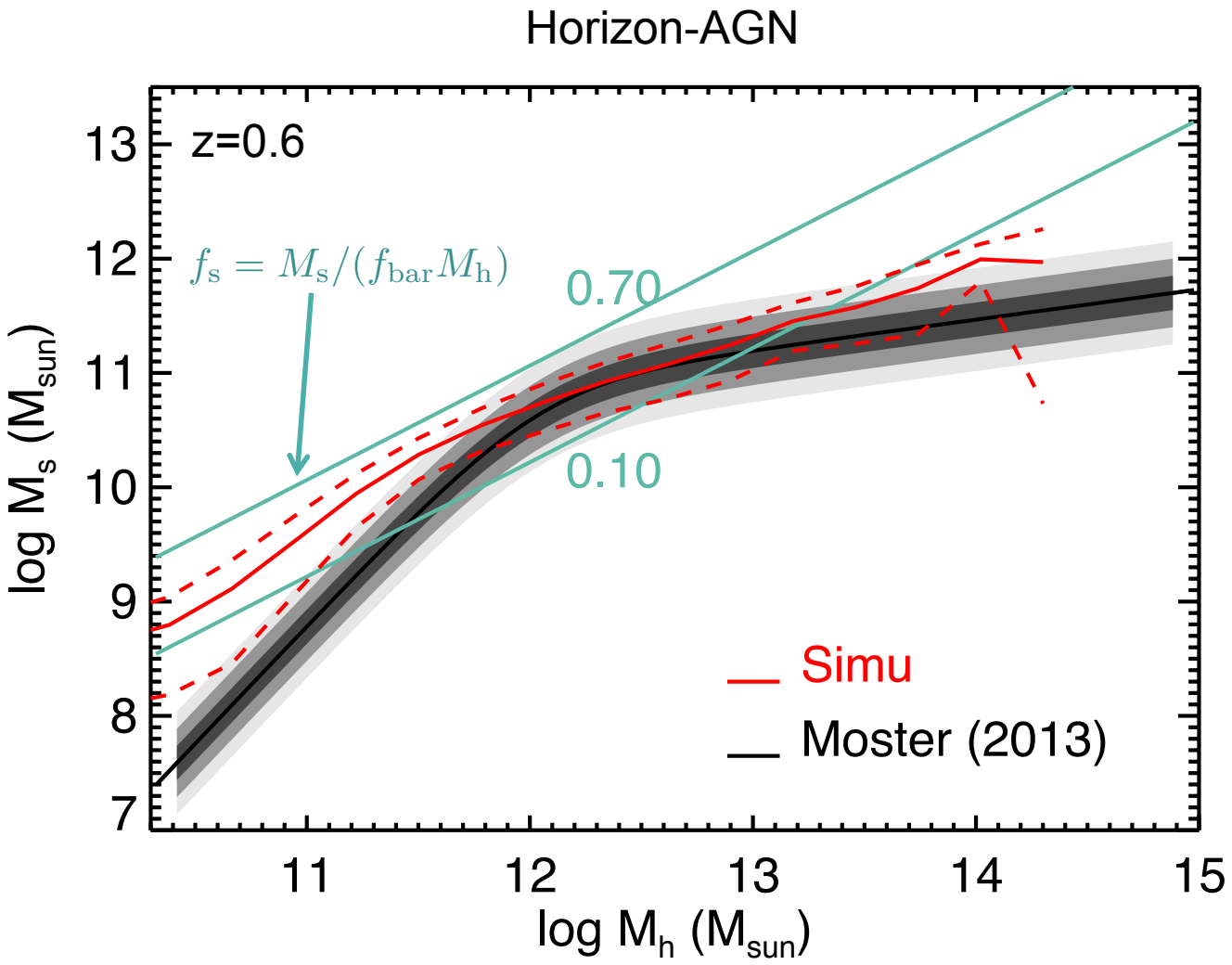
http://www.horizon-simulation.org/



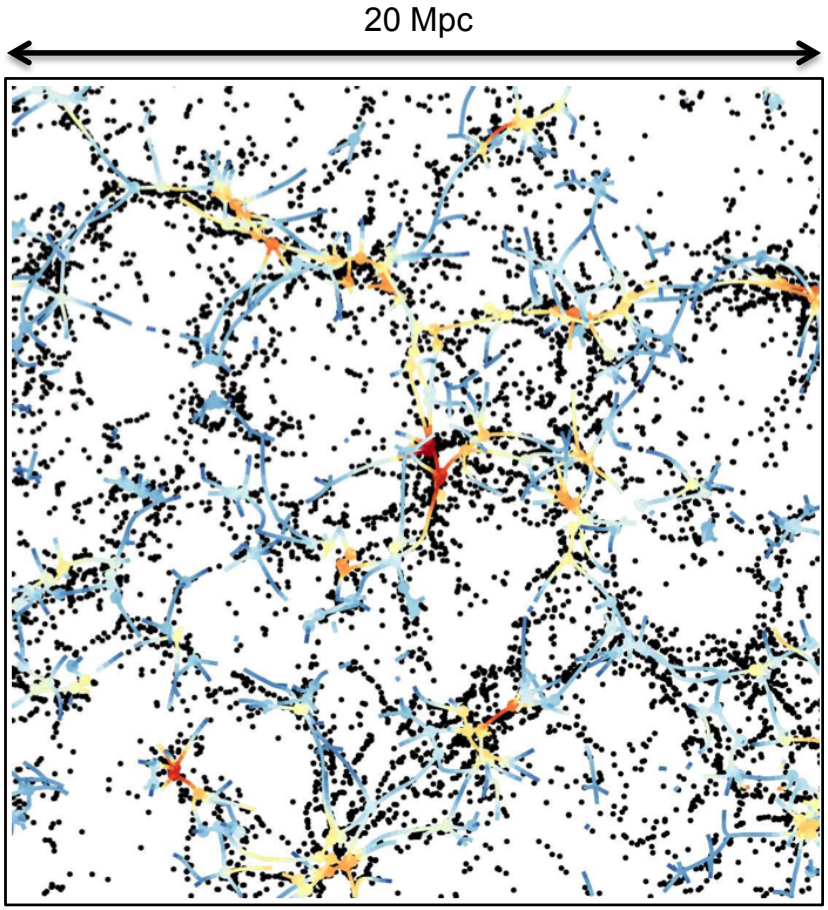
Green: gas density / Red: temperature / Blue: metallicity

Zoomed in

Stellar mass in central galaxies versus halo mass

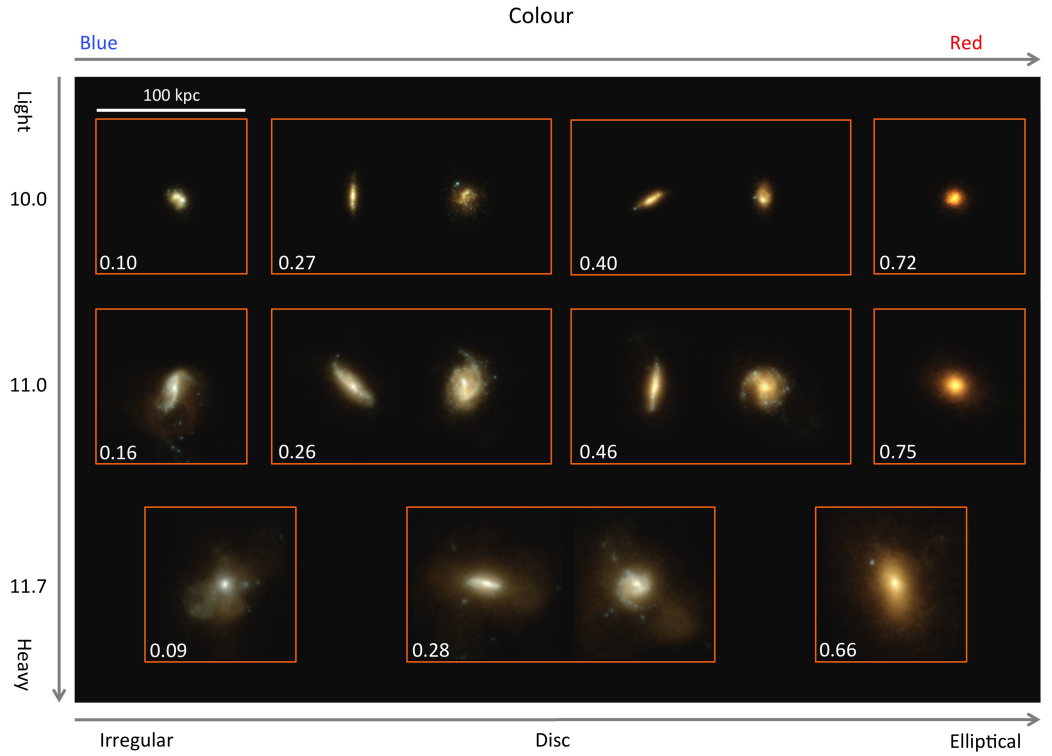


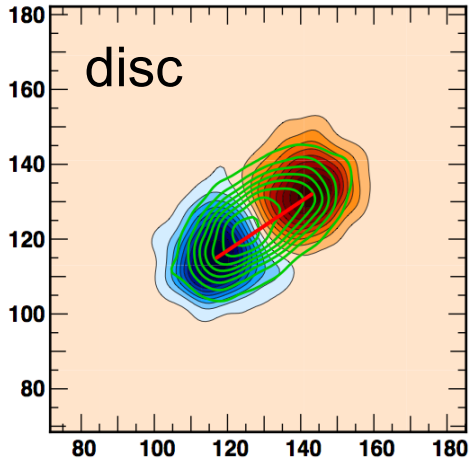
Galaxies and filaments

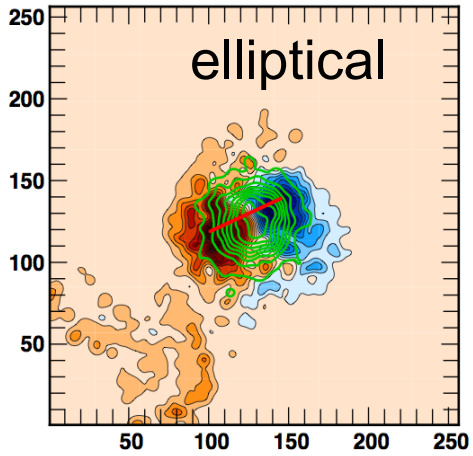


filament

galaxy

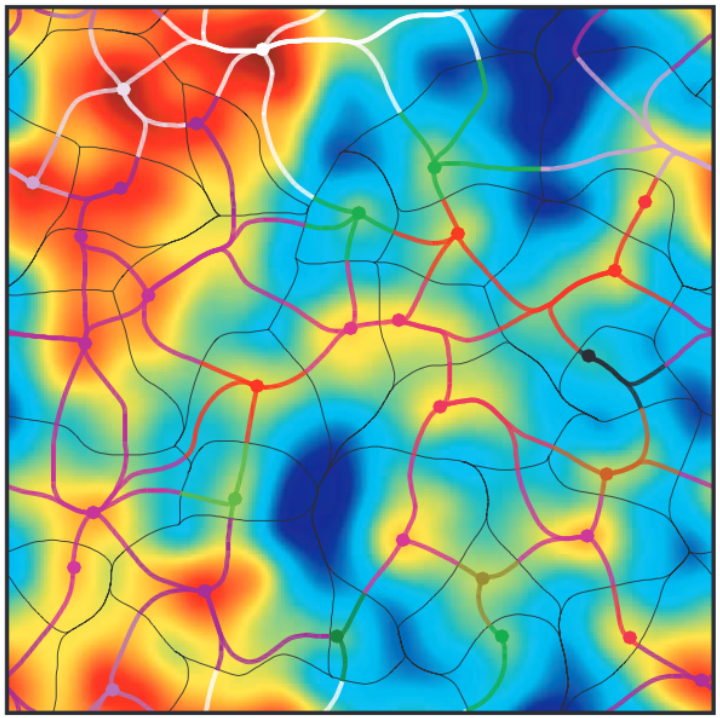


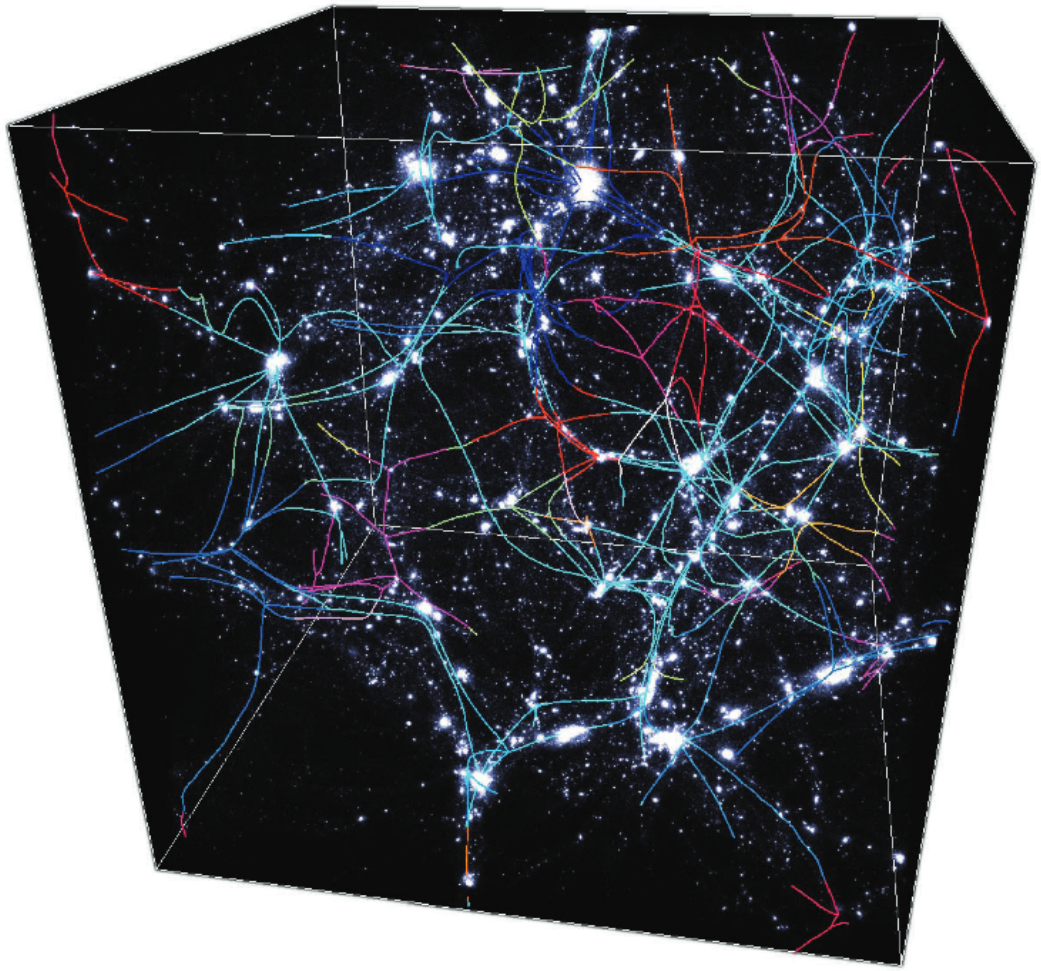




Extract the Skeleton of the cosmic web

Ridges of Marmot Basin

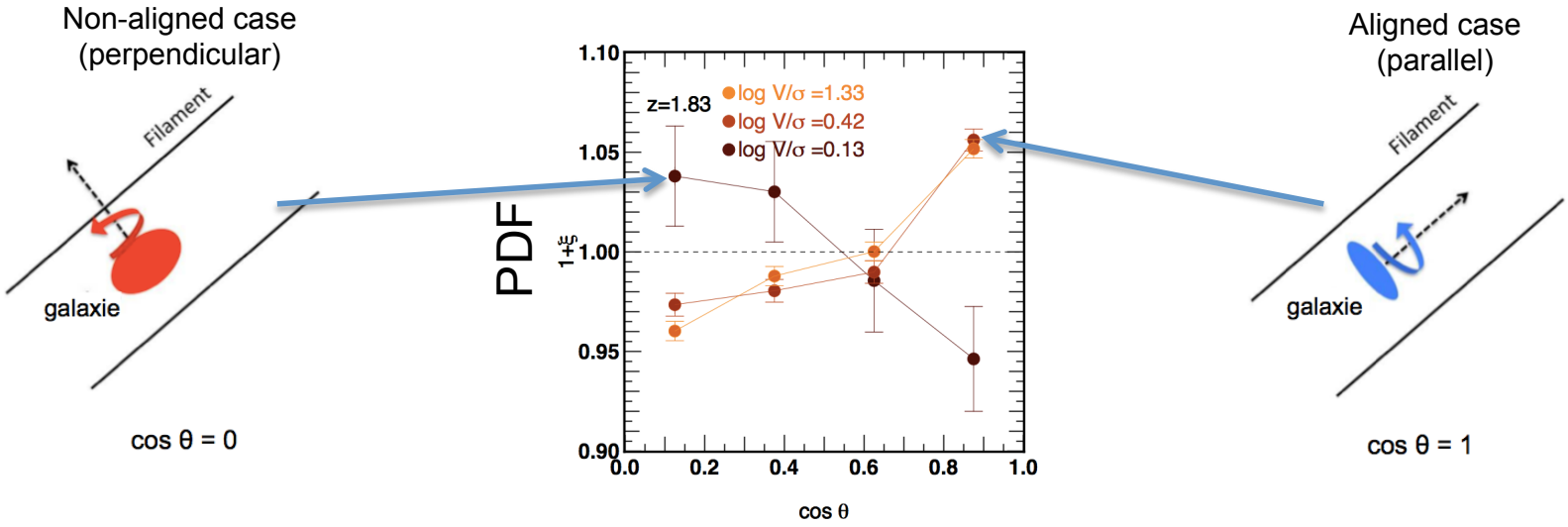




Skeleton of the LSS, *Sousbie et al (2009)*

Cosmic web and galaxies alignment

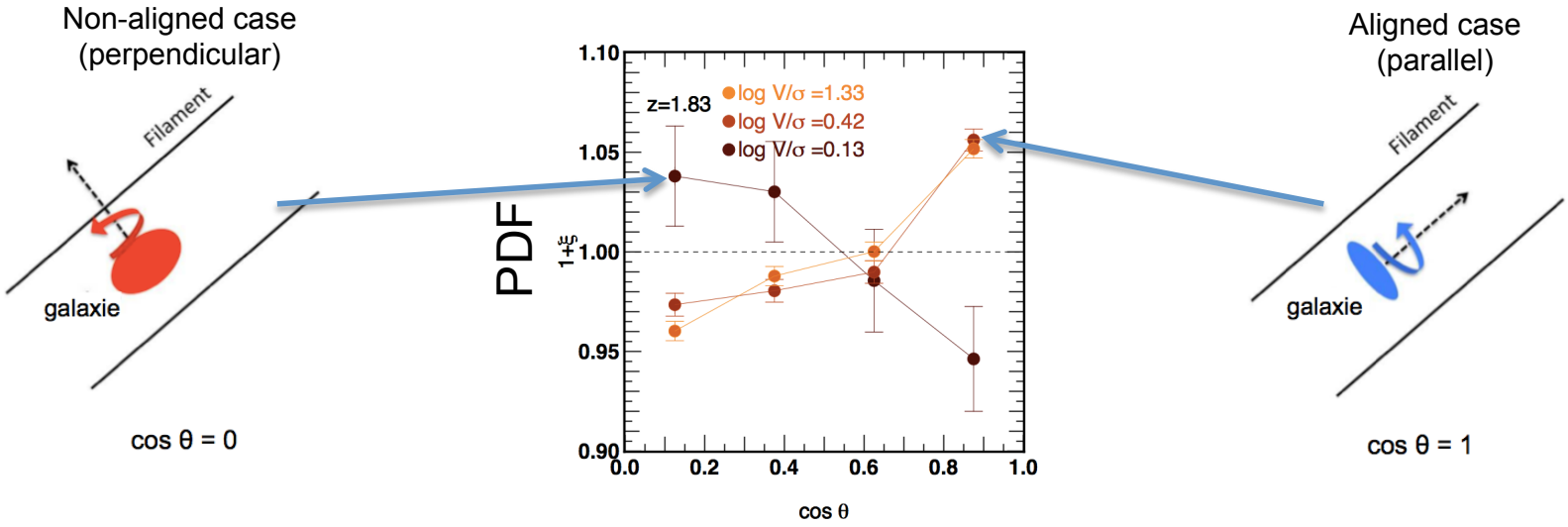
Discs : spin aligned with cosmic filaments
Ellipticals : spin perpendicular with cosmic filaments



Horizon-AGN simulation / *Dubois et al., 2014*

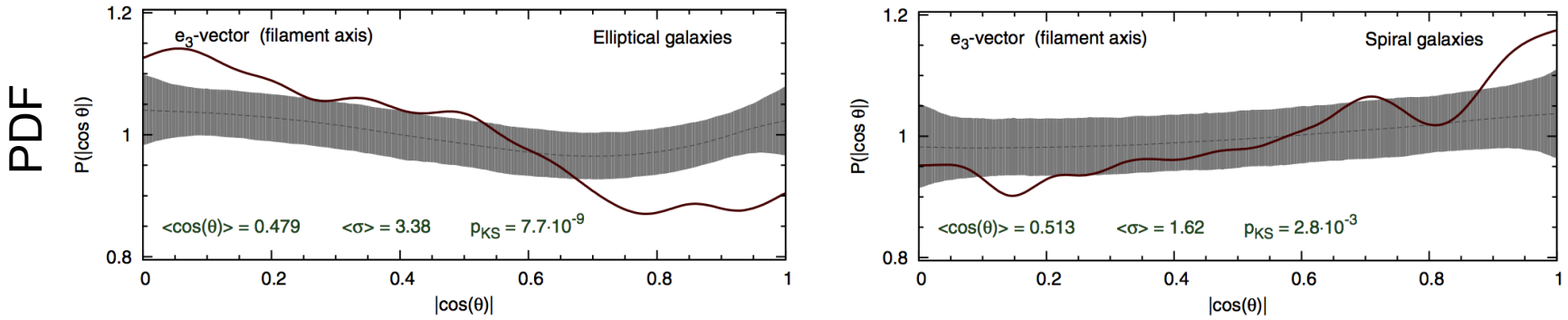
Cosmic web and galaxies alignment

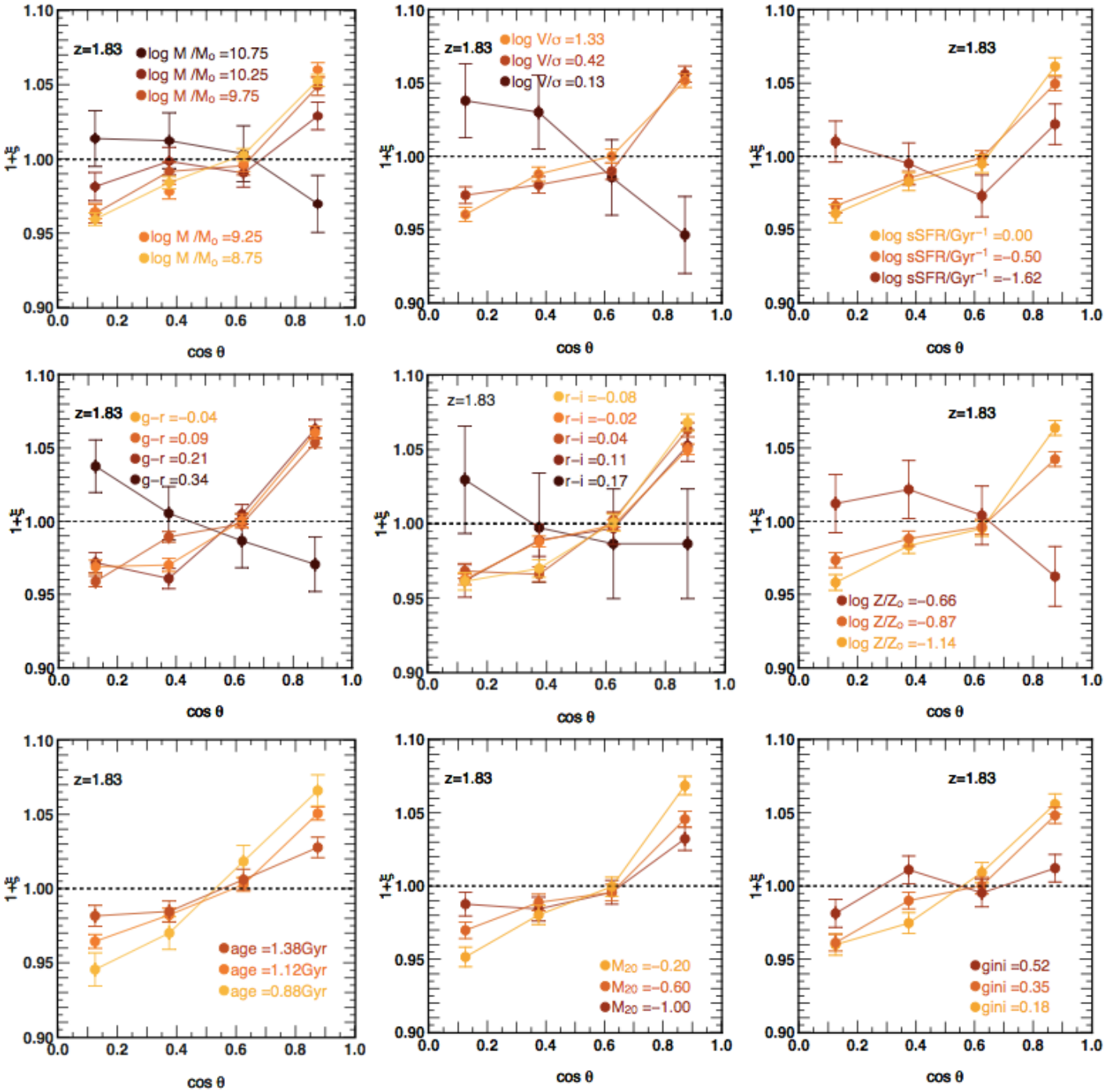
Discs : spin aligned with cosmic filaments
Ellipticals : spin perpendicular with cosmic filaments



Horizon-AGN simulation / *Dubois et al., 2014*

Observations (SDSS) / *Tempel & Libeskind, 2013*

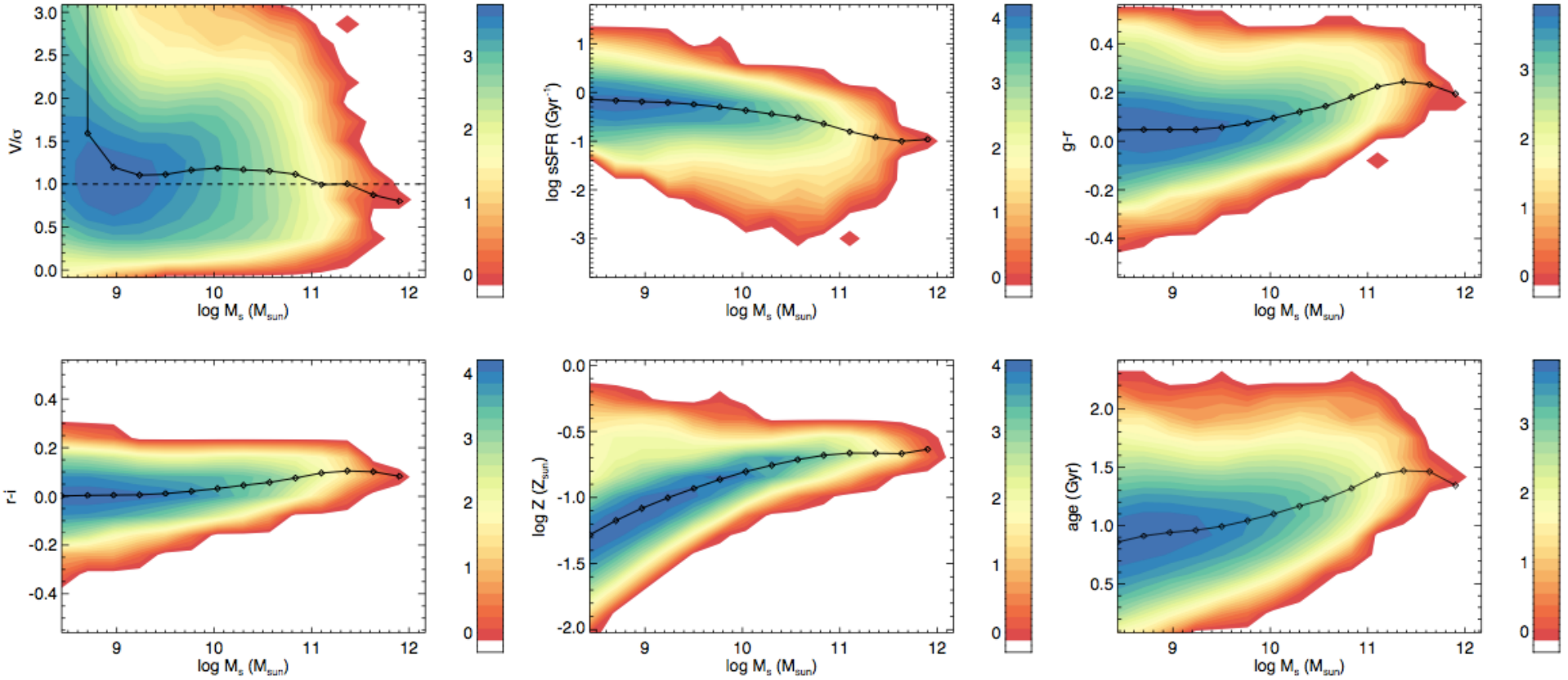




Dubois et al., arXiv:1402.1165

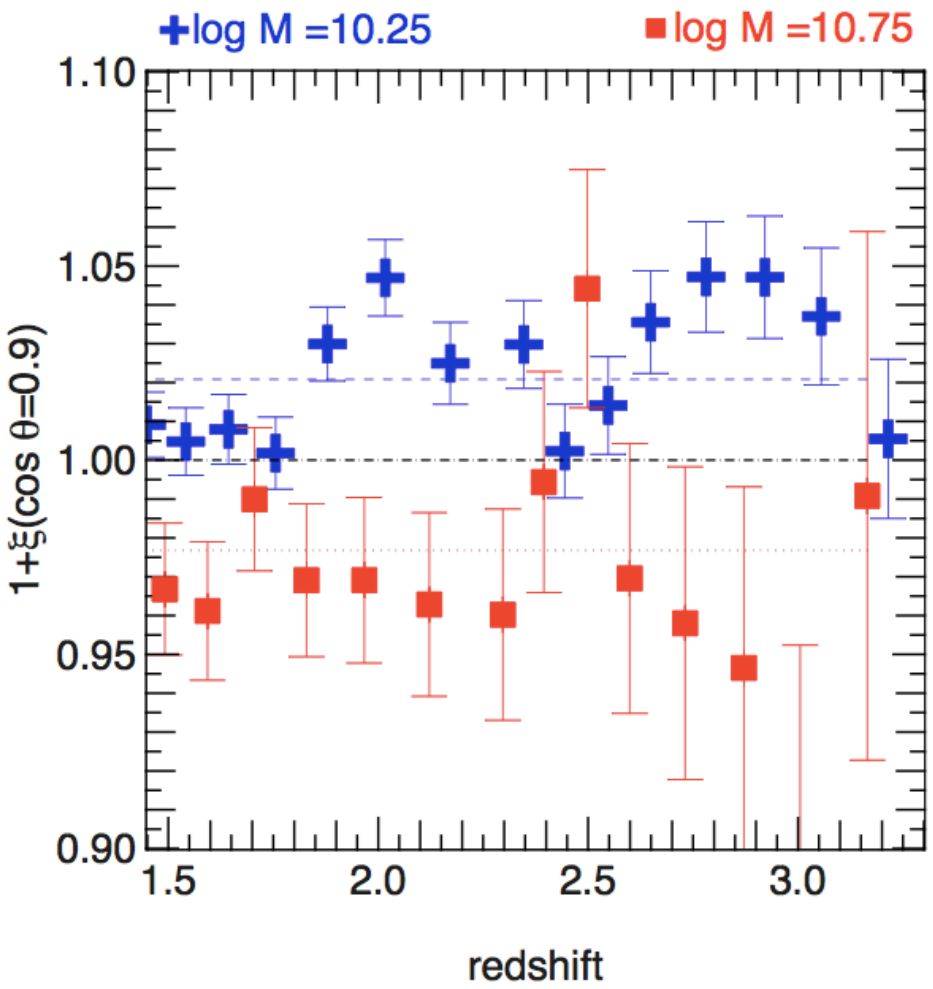
Galaxy properties correlate with their mass

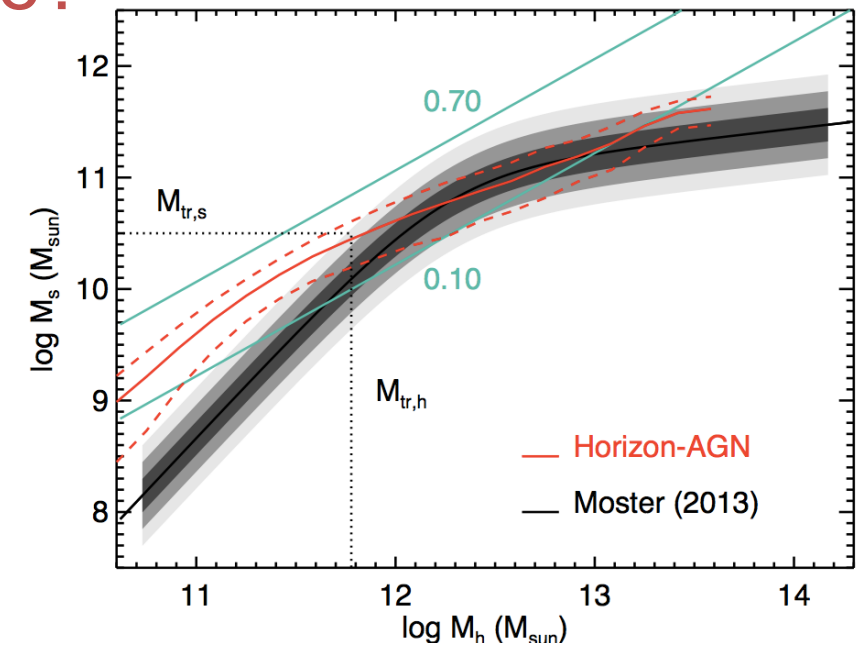
z=1.8

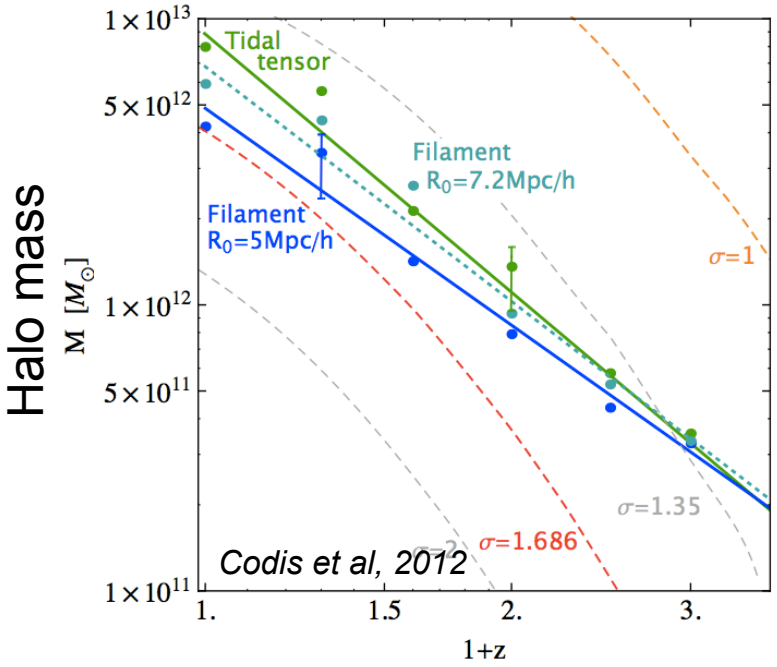


Dubois et al., arXiv:1402.1165

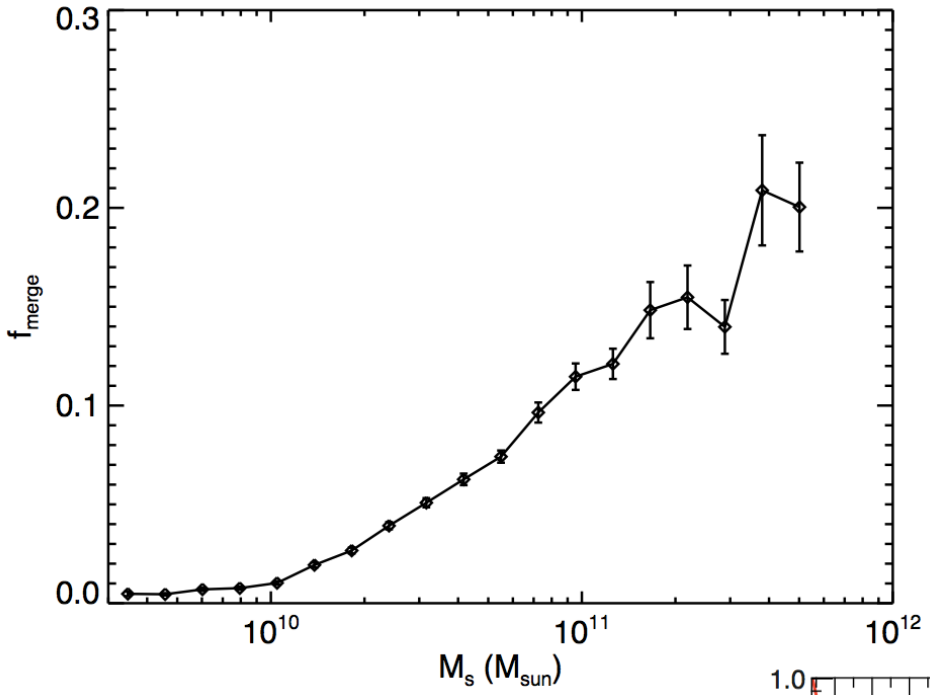
Is the transition from alignment to mis-alignment a robust feature?







How comes some galaxies are aligned and other misaligned?

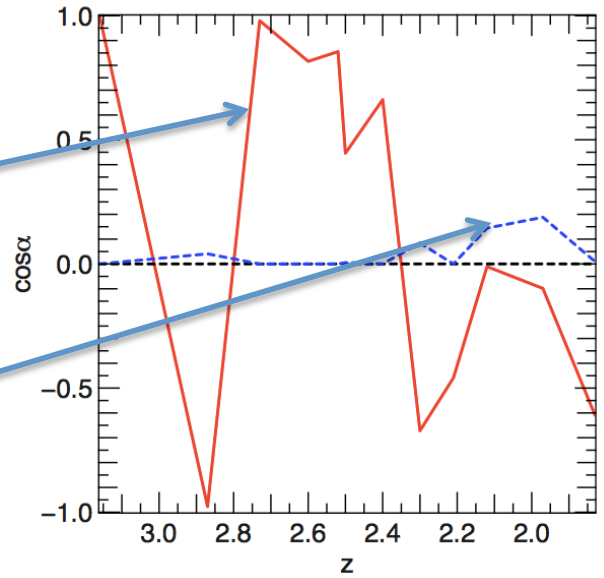


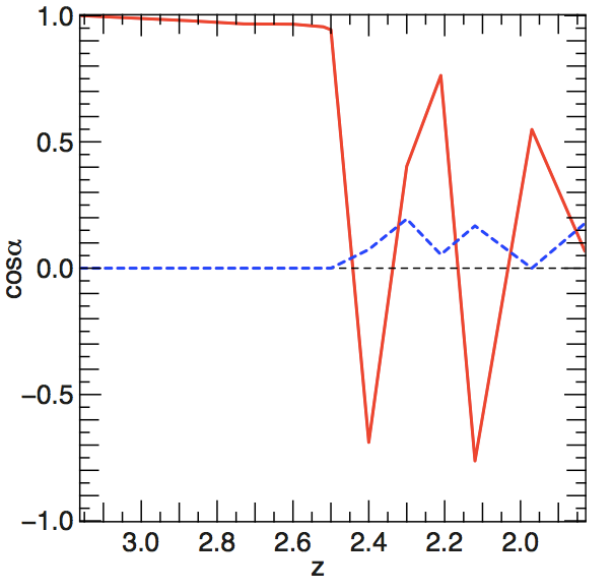
Mergers drive spin reorientation

Two exemples of galaxies with mergers

Angle between the galaxy spin and its initial orientation

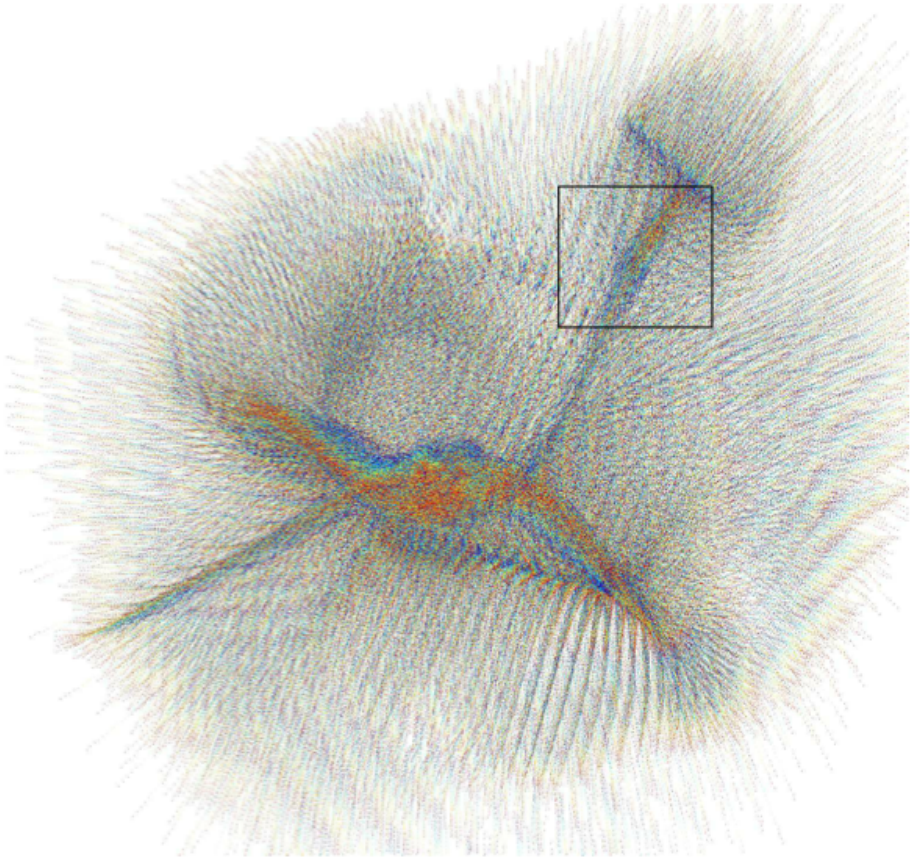
Merger mass ratio

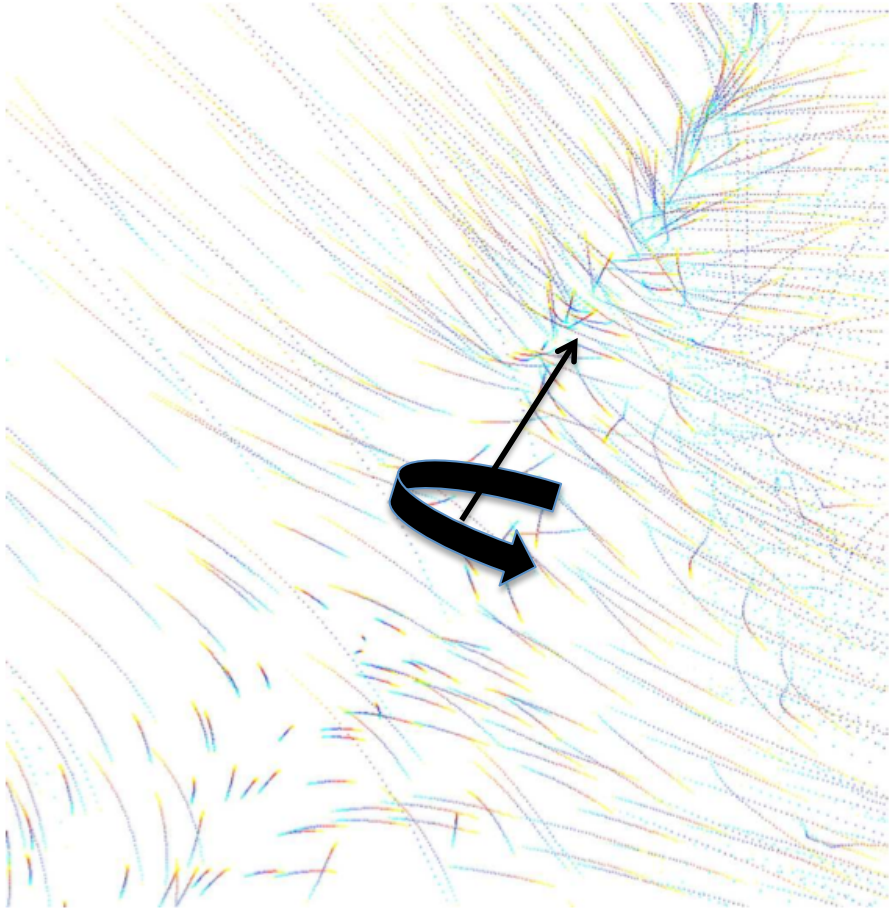




Dubois et al., arXiv:1402.1165

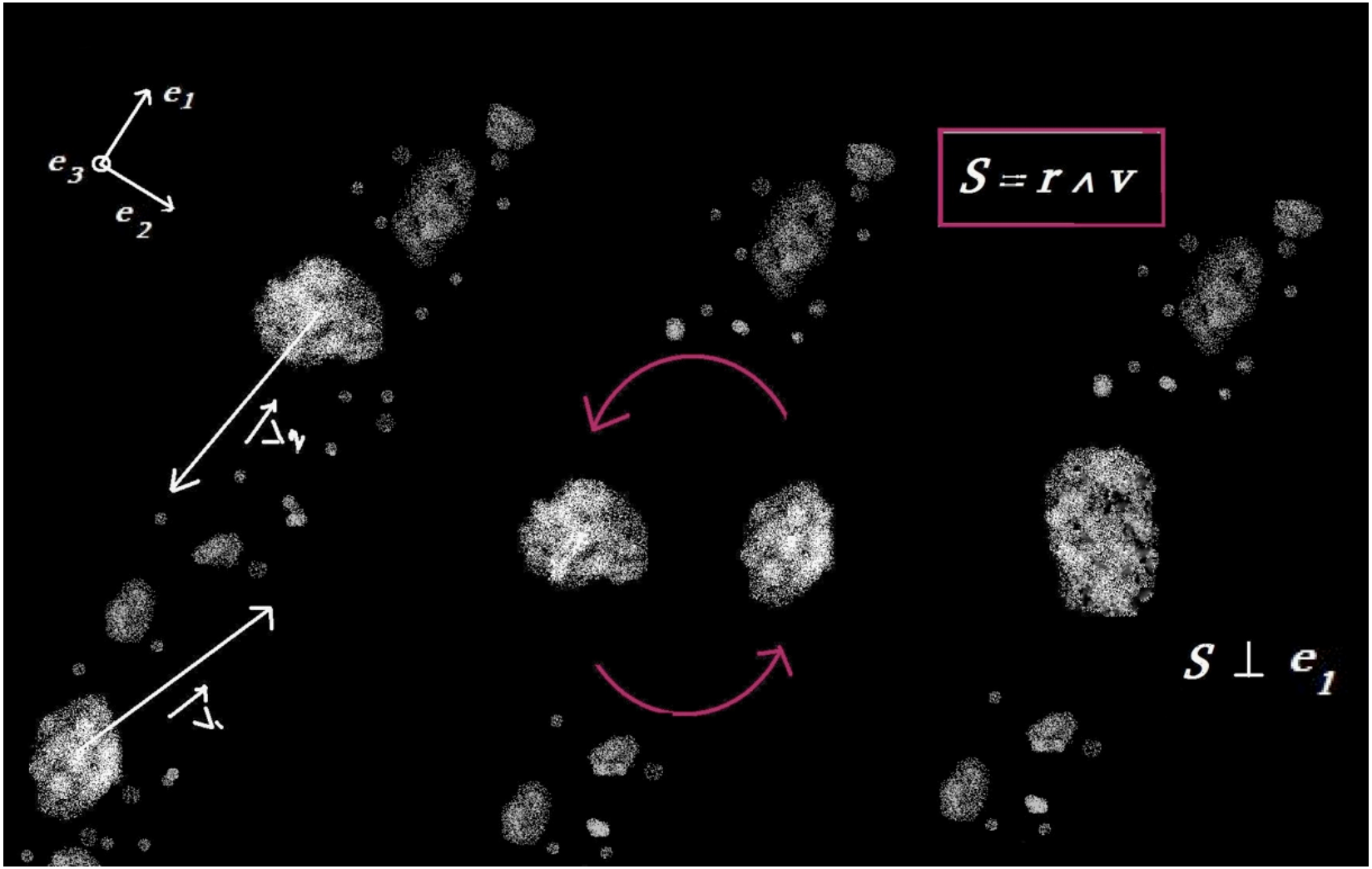
Why do low-mass halos align with filaments?





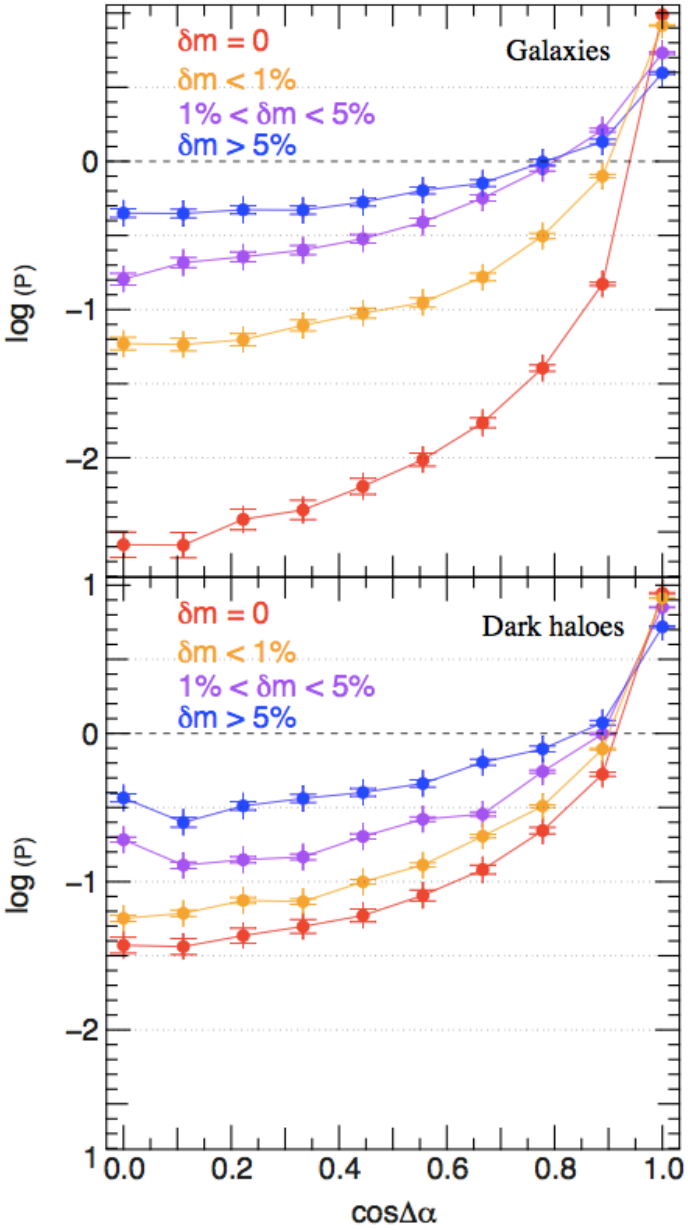
Pichon et al (2011)
See also Pichon & Bernardeau (1999)
Laigle et al (2014)

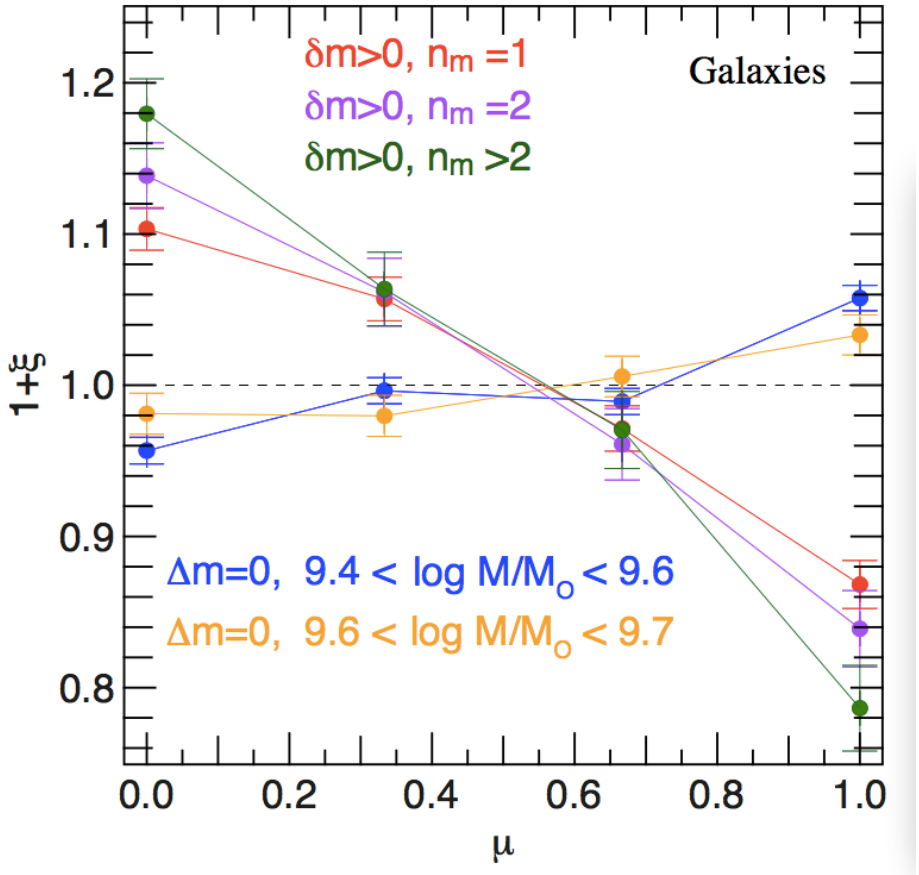
Why do high-mass halos are perpendicular to filaments?



Courtesy of S. Codis

Mergers are responsible for spin swings

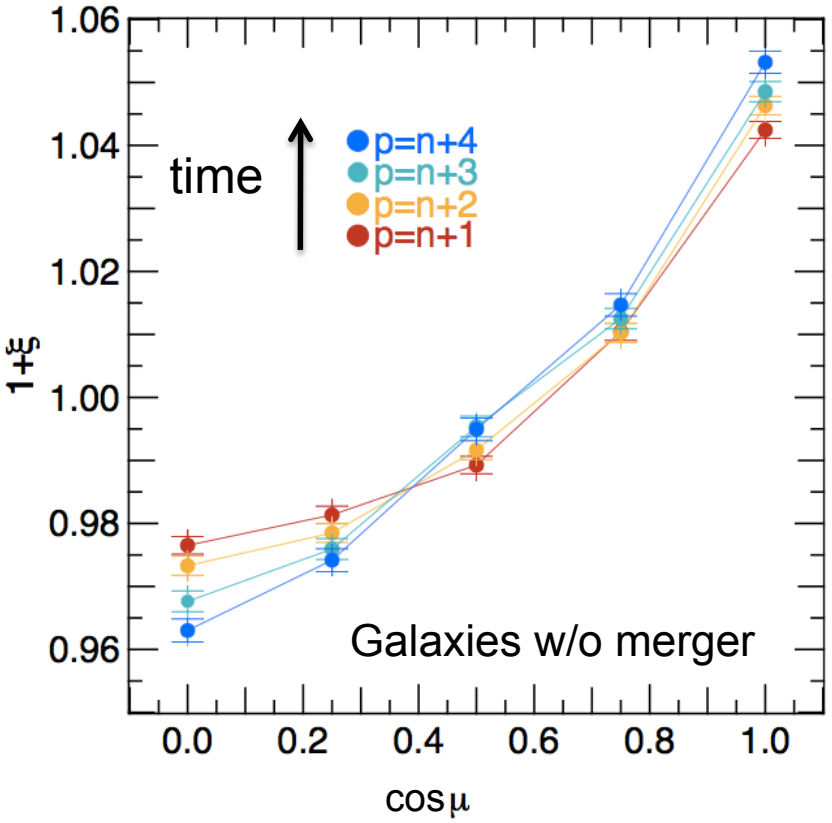




Welker et al, 2014

Re-alignment of galaxies

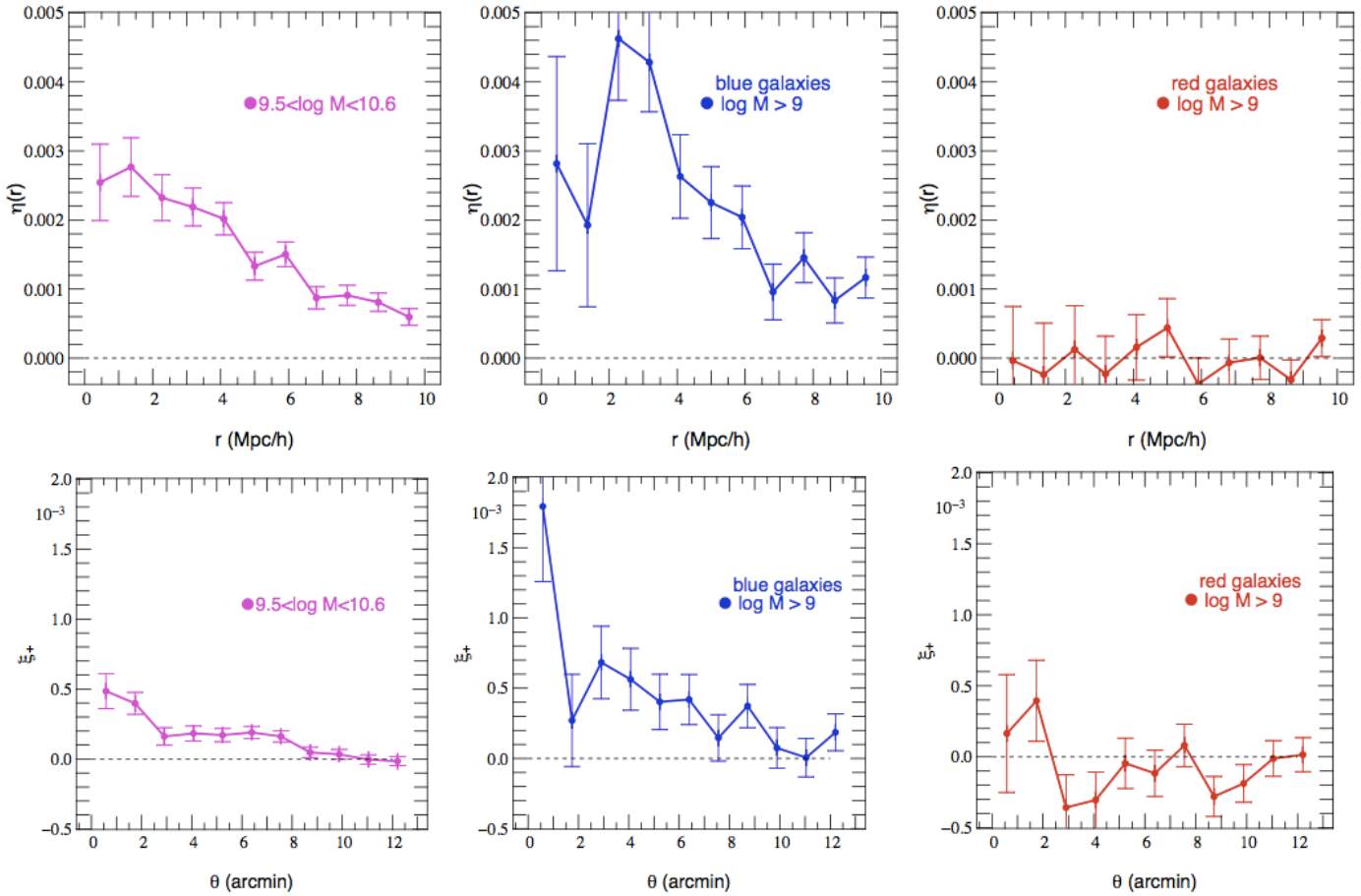
In absence of mergers, galaxies tend to realign with the cosmic web because of gas accretion



As AGN feedback prevents gas accretion in massive galaxies, it also prevents massive galaxies to realign with the cosmic filaments after a merger.
Therefore, AGN feedback is mandatory to get galaxies perpendicular with cosmic filaments.

Welker et al, 2014

Intrinsic alignement (II) signal



Codis et al, arXiv:1406.4668C

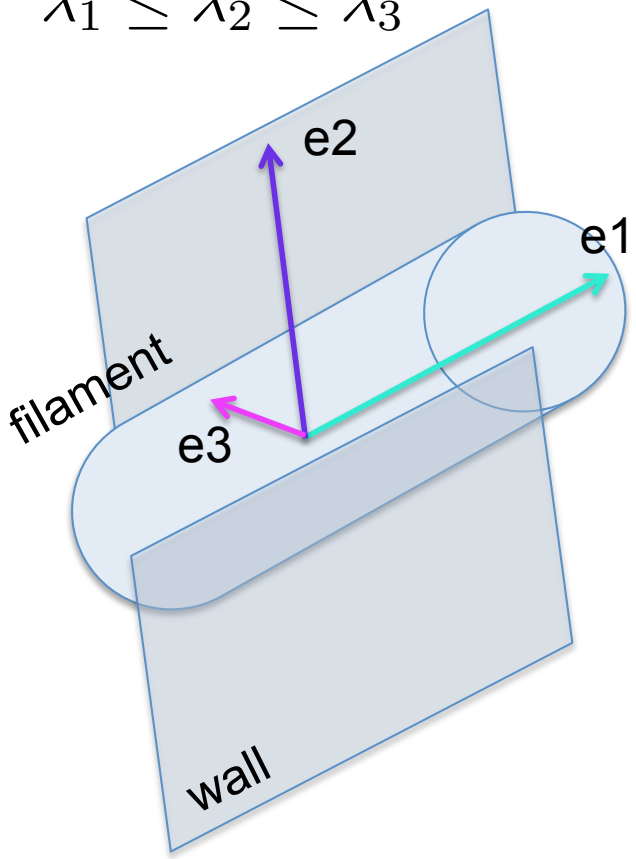
Spin-shear alignement (IG) signal (1-point)

Tidal shear tensor:

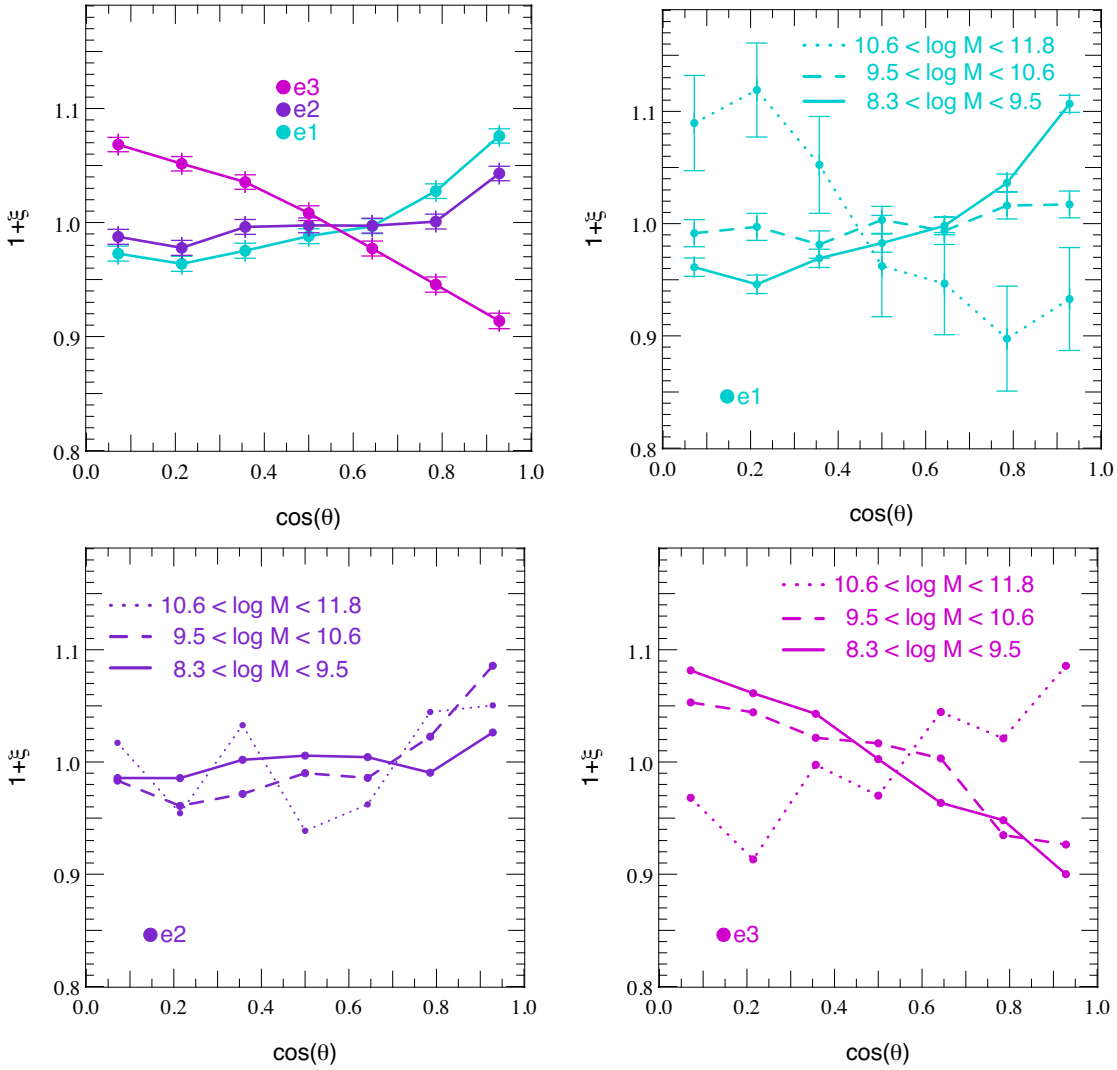
$$T_{ij} = \partial_{ij}\phi - \frac{1}{3}\Delta\phi\delta_{ij}$$

ϕ: gravitationnal potential

$$\lambda_1 \leq \lambda_2 \leq \lambda_3$$



Mass decomposition



Codis et al, arXiv:1406.4668C

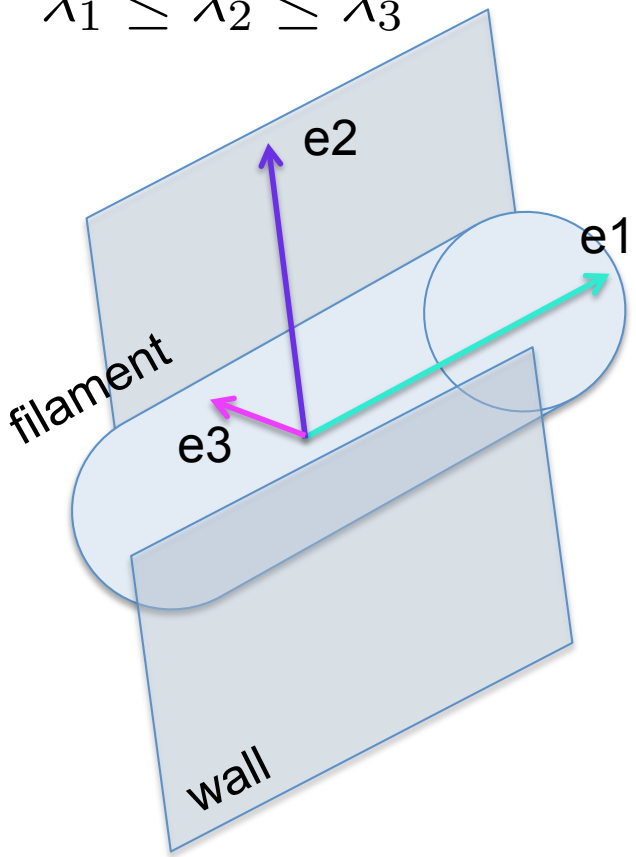
Spin-shear alignement (IG) signal (1-point)

Tidal shear tensor:

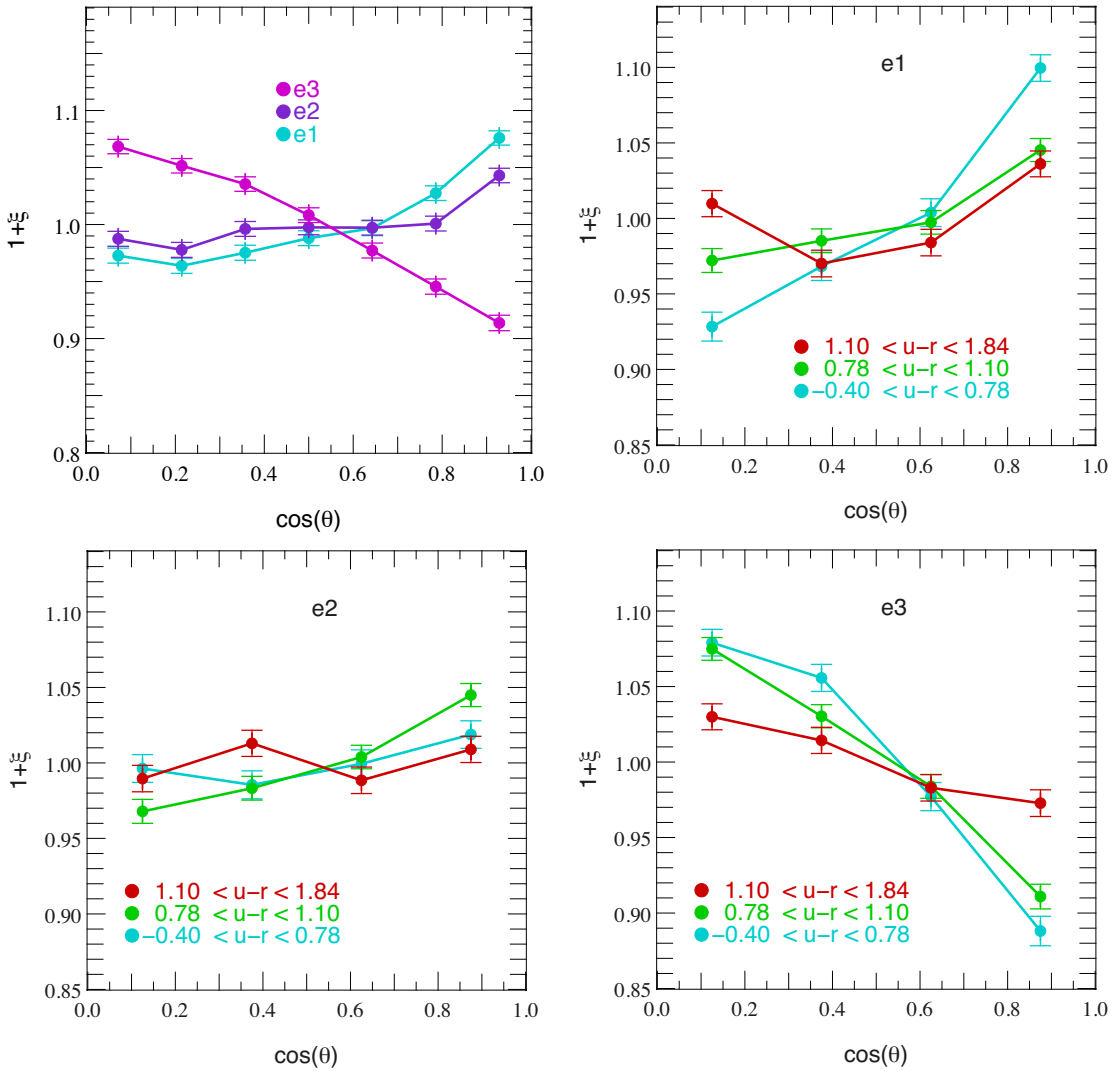
$$T_{ij} = \partial_{ij}\phi - \frac{1}{3}\Delta\phi\delta_{ij}$$

ϕ: gravitationnal potential

$$\lambda_1 \leq \lambda_2 \leq \lambda_3$$

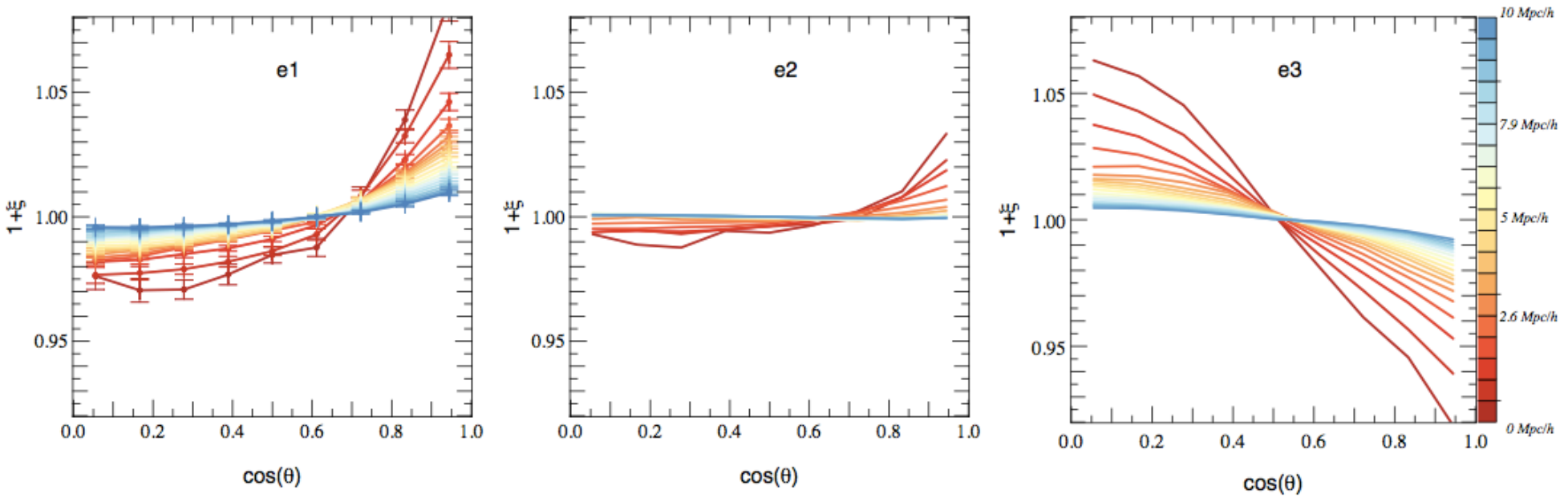


Color decomposition



Codis et al, arXiv:1406.4668C

Spin-shear alignement (IG) signal (2-point)



Codis et al, arXiv:1406.4668C

Take home message

- AGN feedback is a key player in shaping massive galaxies mass, color and morphology
- Low-mass galaxies align with filaments because of the coherence of cosmic gas accretion
- High mass galaxies are perpendicular to filaments because of mergers along filaments
- Excess of spin-spin (II) alignment at small distance (<2 Mpc)
- Excess of spin-tidal shear (IG) alignment