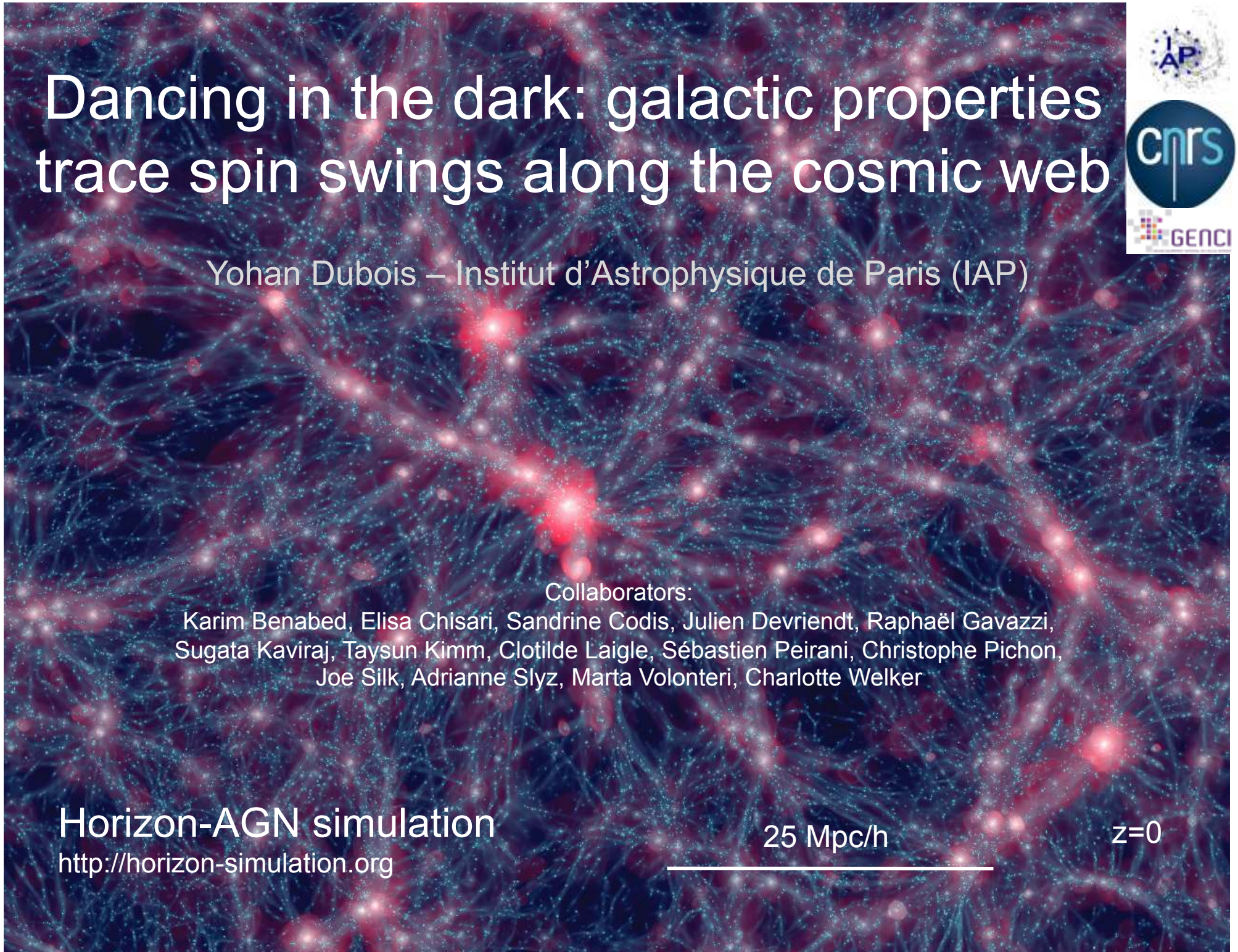
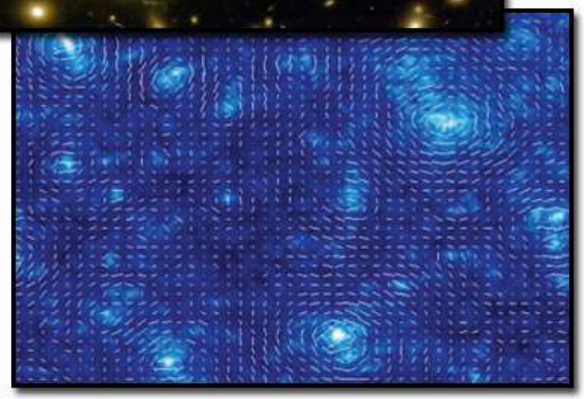
# Dancing in the dark: galactic properties trace spin swings along the cosmic web

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

Collaborators:
Karim Benabed, Elisa Chisari, Sandrine Codis, Julien Devriendt, Raphaël Gavazzi, Sugata Kaviraj, Taysun Kimm, Clotilde Laigle, Sébastien Peirani, Christophe Pichon, Joe Silk, Adrianne Slyz, Marta Volonteri, Charlotte Welker



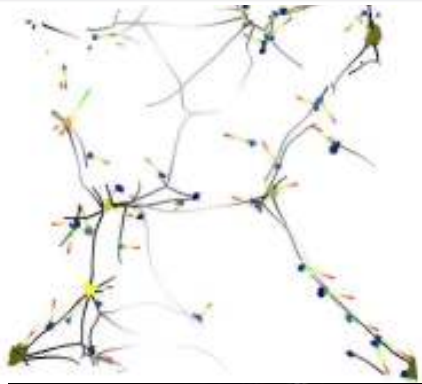
# Introduction



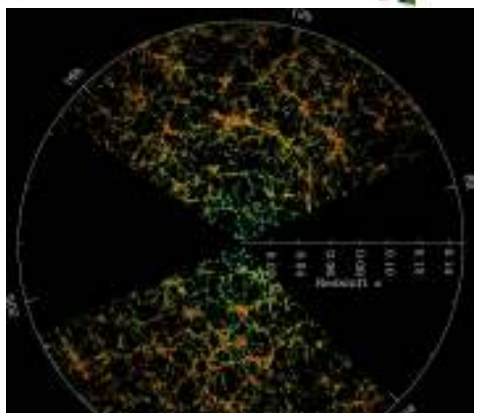
- Why should I care about the alignment of collapsed structures (dark halos, galaxies) with the cosmic web?

- 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

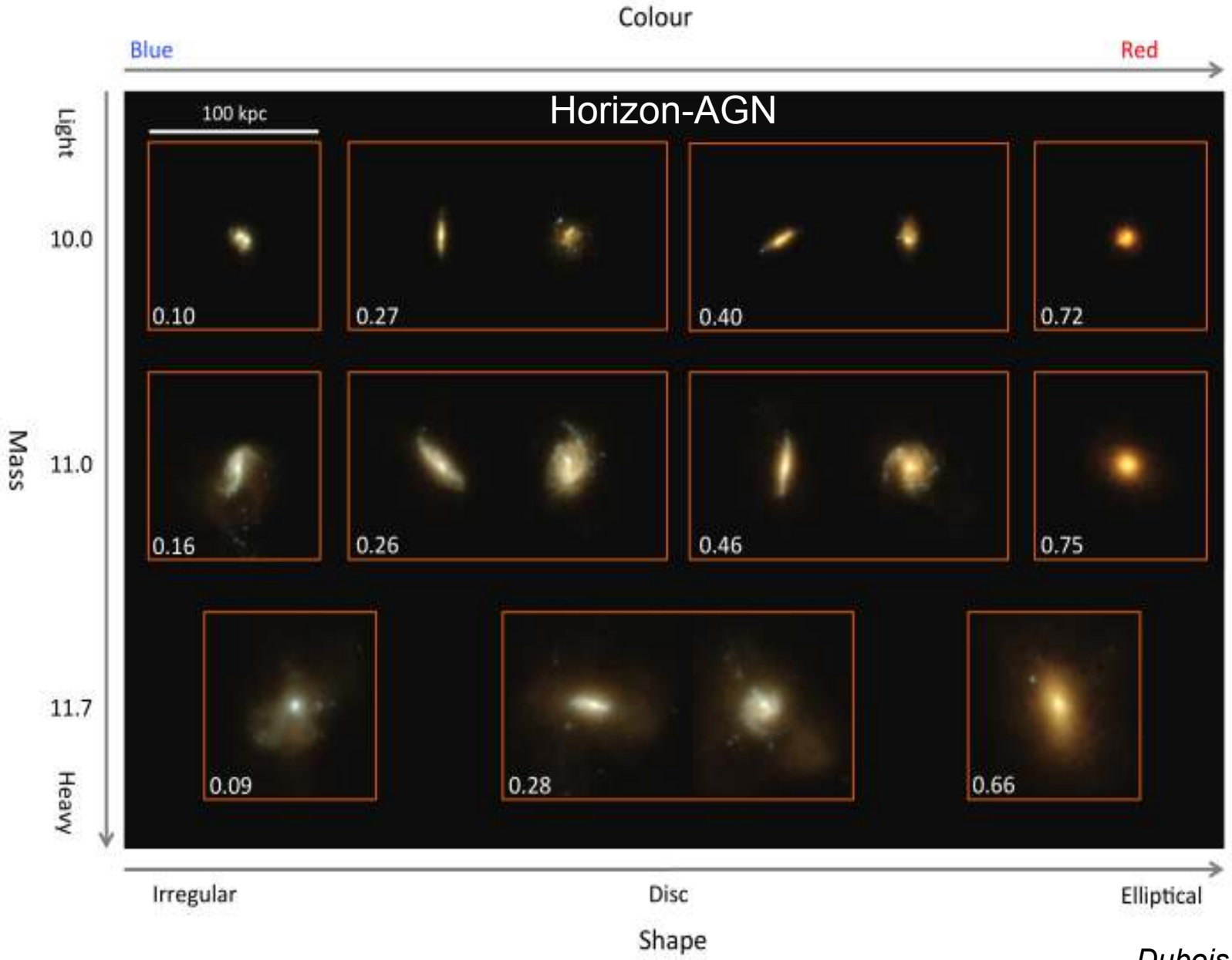


- Euclid will constraint the nature of the dark energy with the amount of deformation of galaxies by gravitational lensing
- The method works well if galaxies are randomly oriented
- Intrinsic alignment of galaxies is a spurious bias that must be quantified for the success of the mission!
- Need for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




Without AGN: massive blue spirals are everywhere!

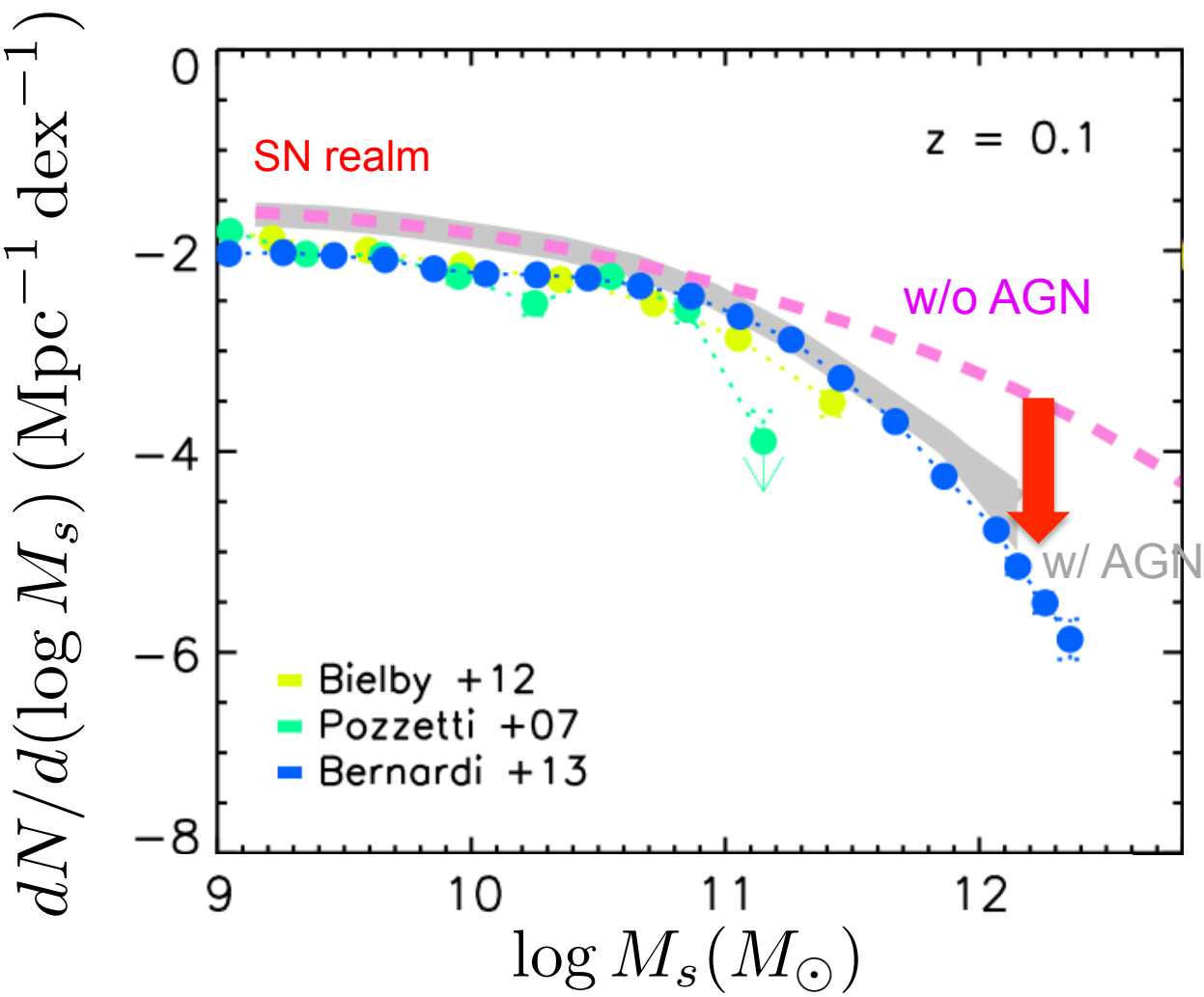
# Morphological variety




*Dubois et al, 2014*

# Motivation for AGN feedback

Galaxy mass functions in the Horizon-AGN project

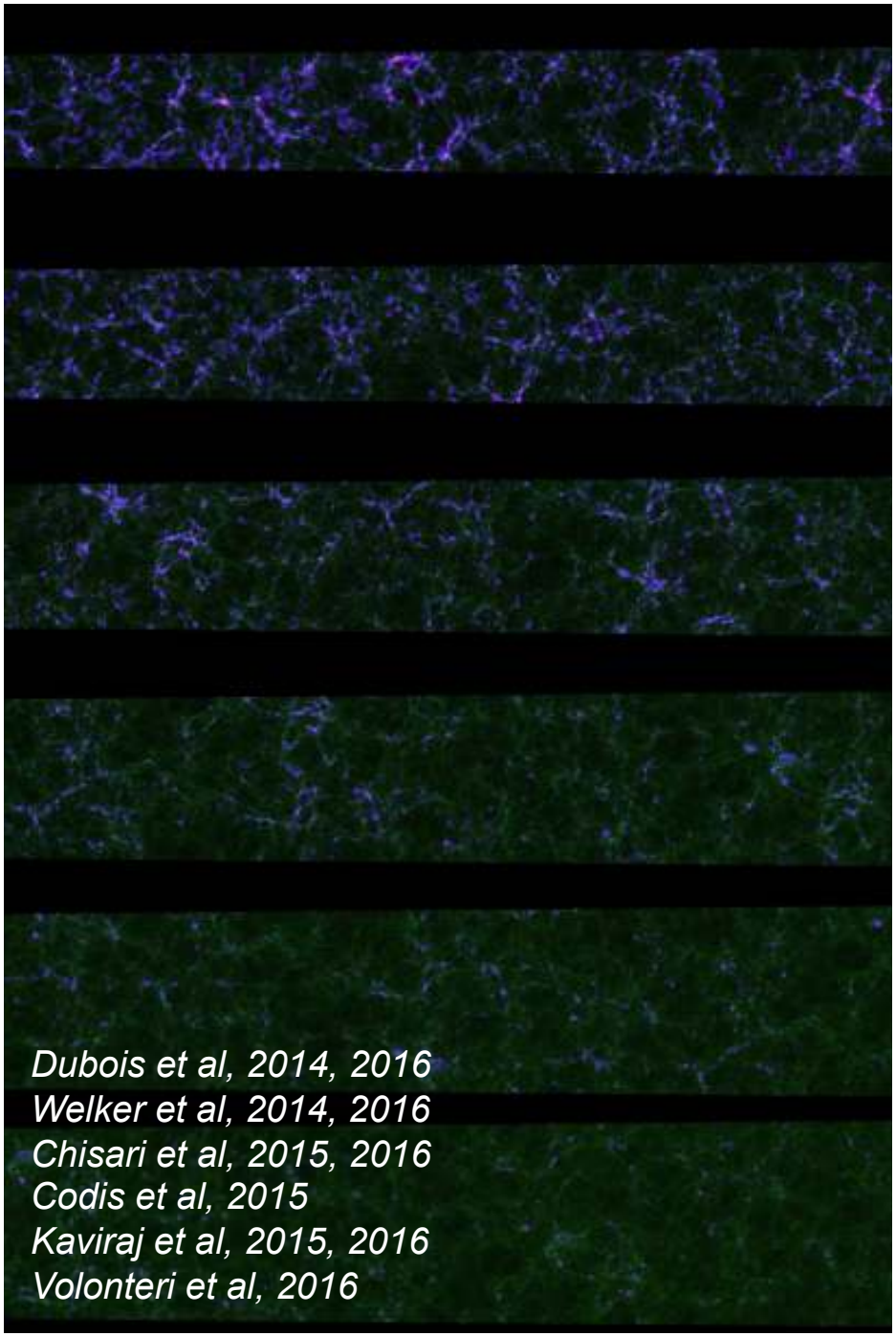



*Kaviraj, Laigle et al, arXiv:1605.09379*

# 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
  - Standard outputs ~200 Myrs
  - Star particles are backed up every 10-20 Myr
  - Lightcones (1°x1°) 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 using 10 Mhours on 4096 cores
- 150 000 galaxies per snapshot (> 50 part.)
- $7.10^9$ leaf cells (more than Illustris or Eagle)

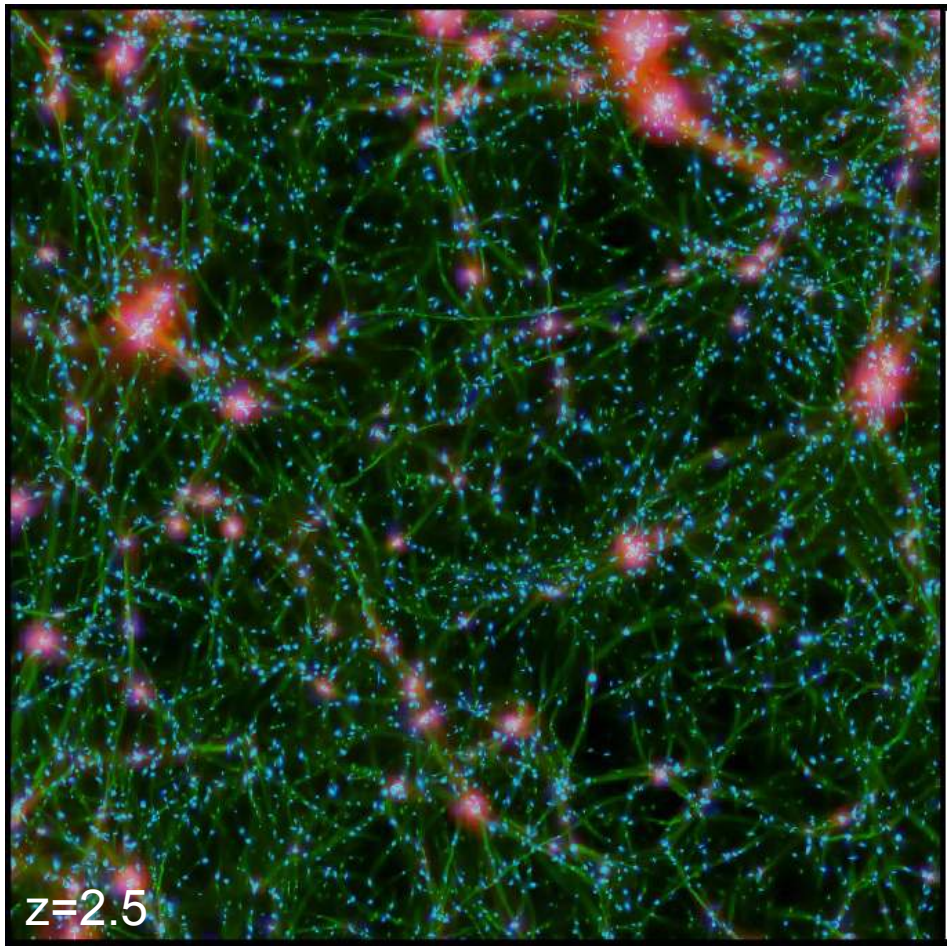
http://horizon-simulation.org/



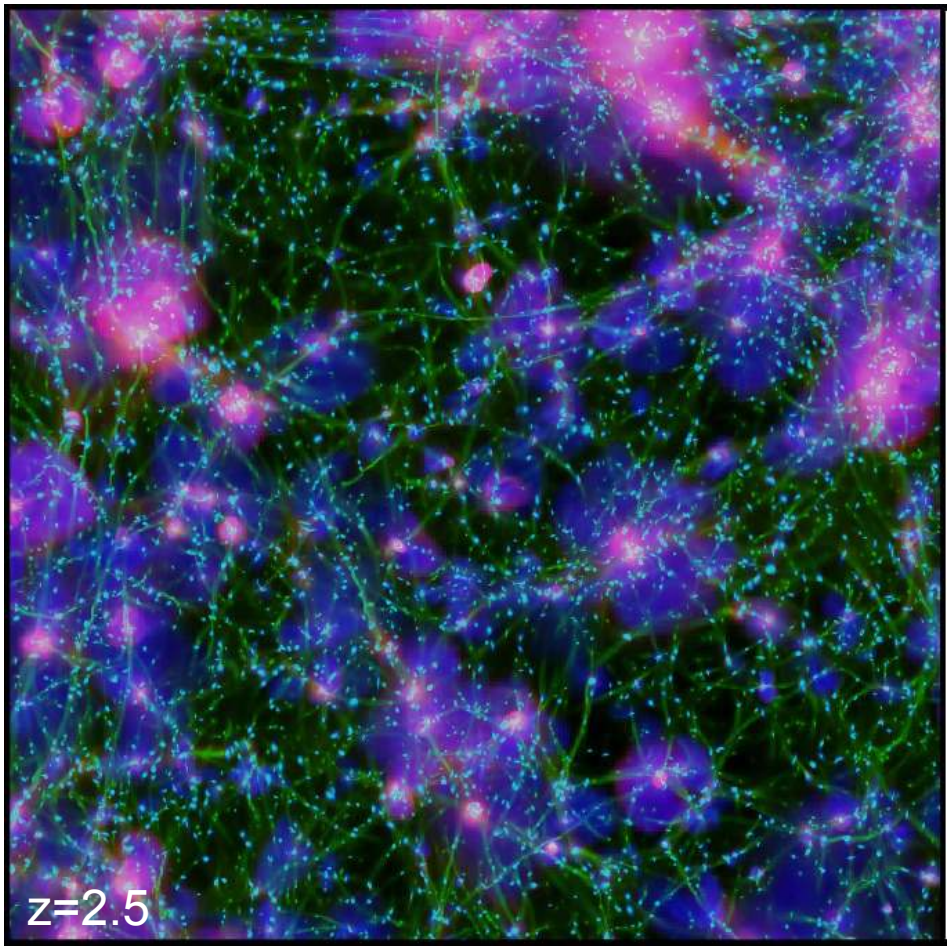
# A visual inspection of the impact of AGN feedback on large-scale structures

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

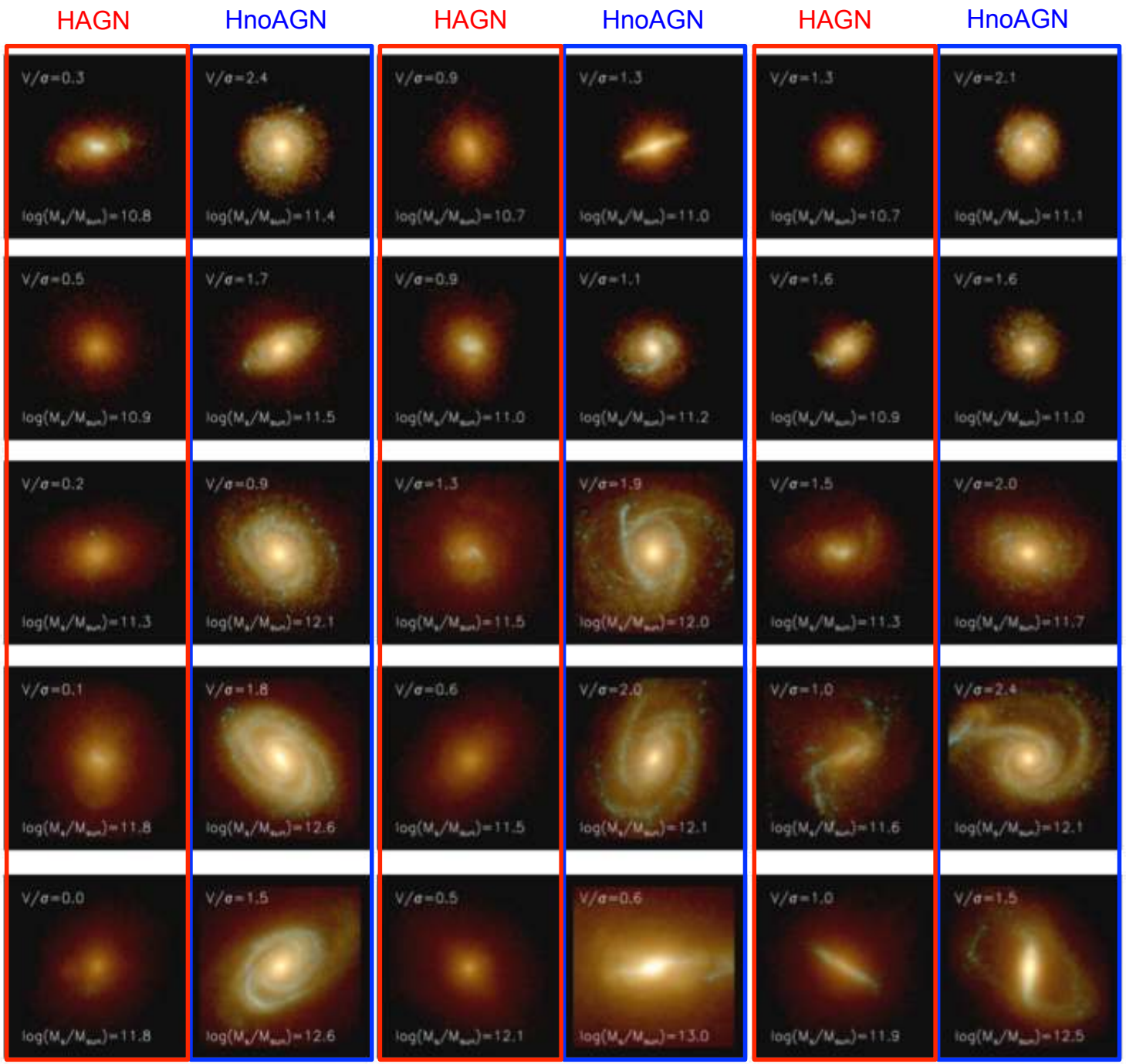
Horizon-noAGN




Horizon-AGN




+ one DM-only simulation


HAGN
HnoAGN
HAGN
HnoAGN
HAGN
HnoAGN
V/σ=0.3
log(M*/M⊙)=10.8
V/σ=2.4
log(M*/M⊙)=11.4
V/σ=0.9
log(M*/M⊙)=10.7
V/σ=1.3
log(M*/M⊙)=11.0
V/σ=1.3
log(M*/M⊙)=10.7
V/σ=2.1
log(M*/M⊙)=11.1
V/σ=0.5
log(M*/M⊙)=10.9
V/σ=1.7
log(M*/M⊙)=11.5
V/σ=0.9
log(M*/M⊙)=11.0
V/σ=1.1
log(M*/M⊙)=11.2
V/σ=1.6
log(M*/M⊙)=10.9
V/σ=1.6
log(M*/M⊙)=11.0
V/σ=0.2
log(M*/M⊙)=11.3
V/σ=0.9
log(M*/M⊙)=12.1
V/σ=1.3
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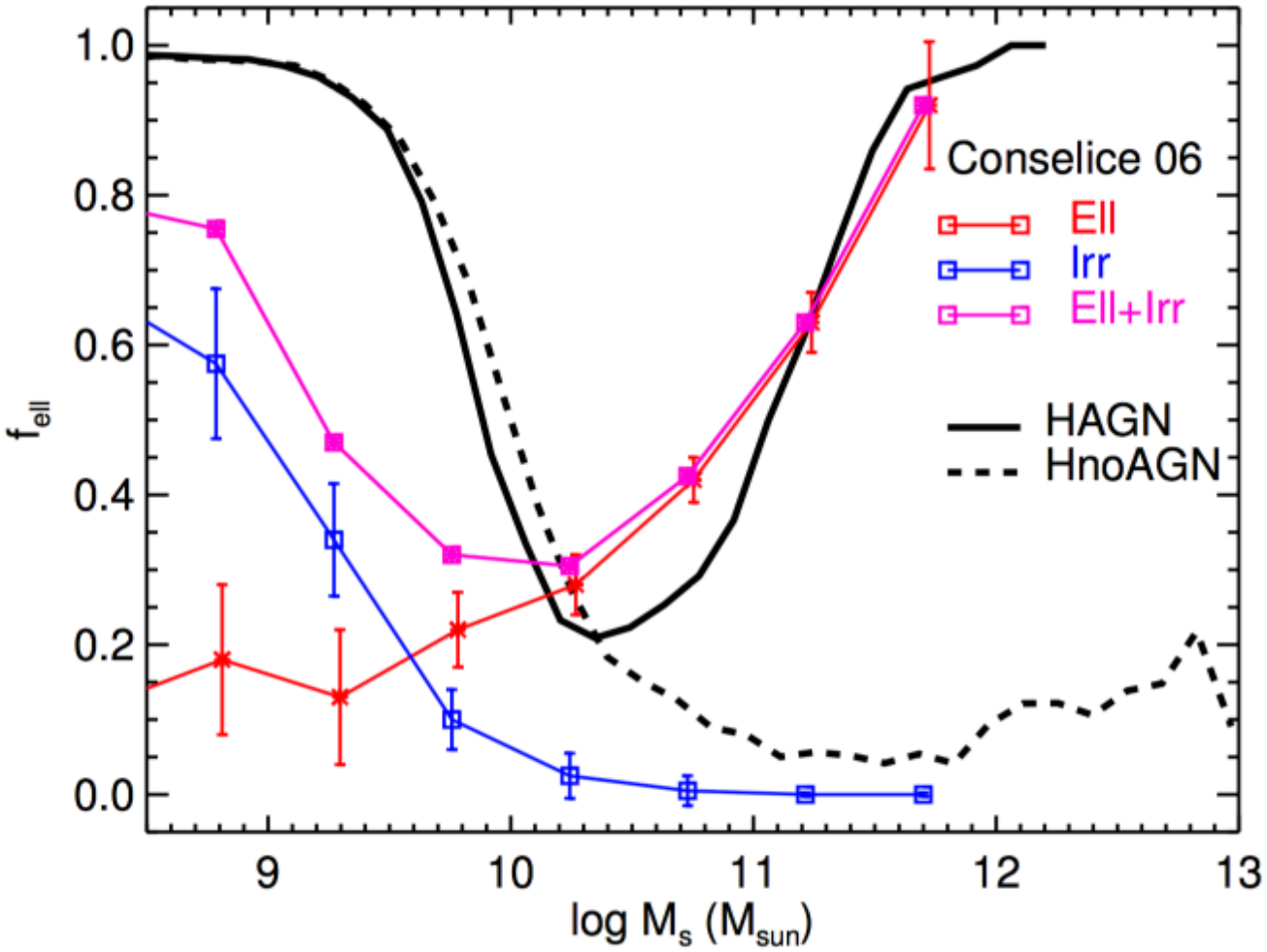
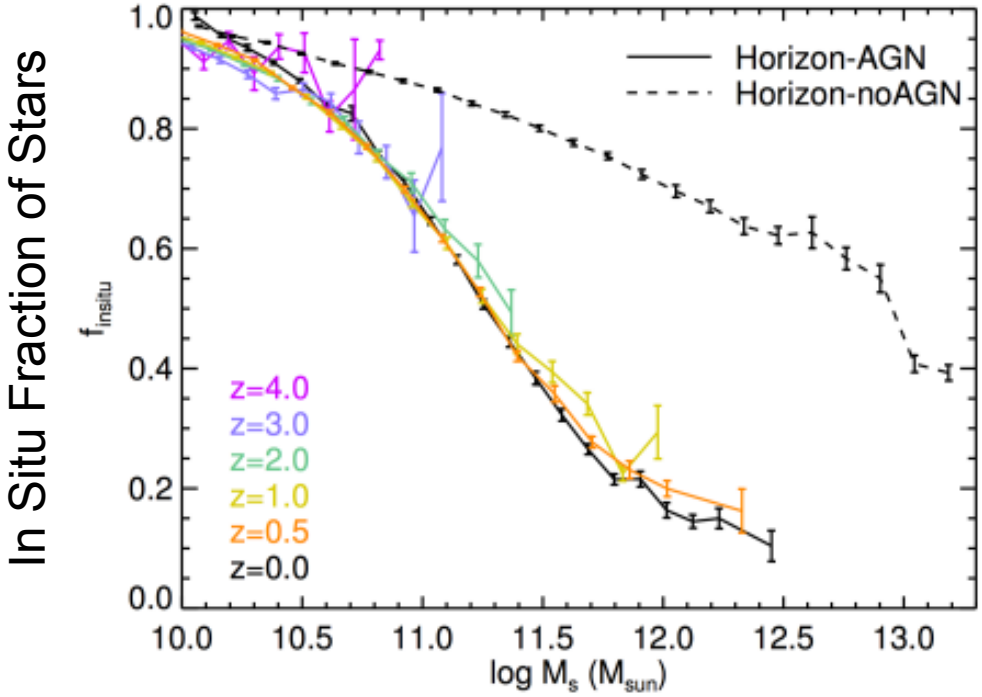
log(M*/M⊙)=13.0
V/σ=1.0
log(M*/M⊙)=11.9
V/σ=1.5
log(M*/M⊙)=12.5

# Fraction of Ellipticals




*Dubois et al, 2016*

# The origin of the stars

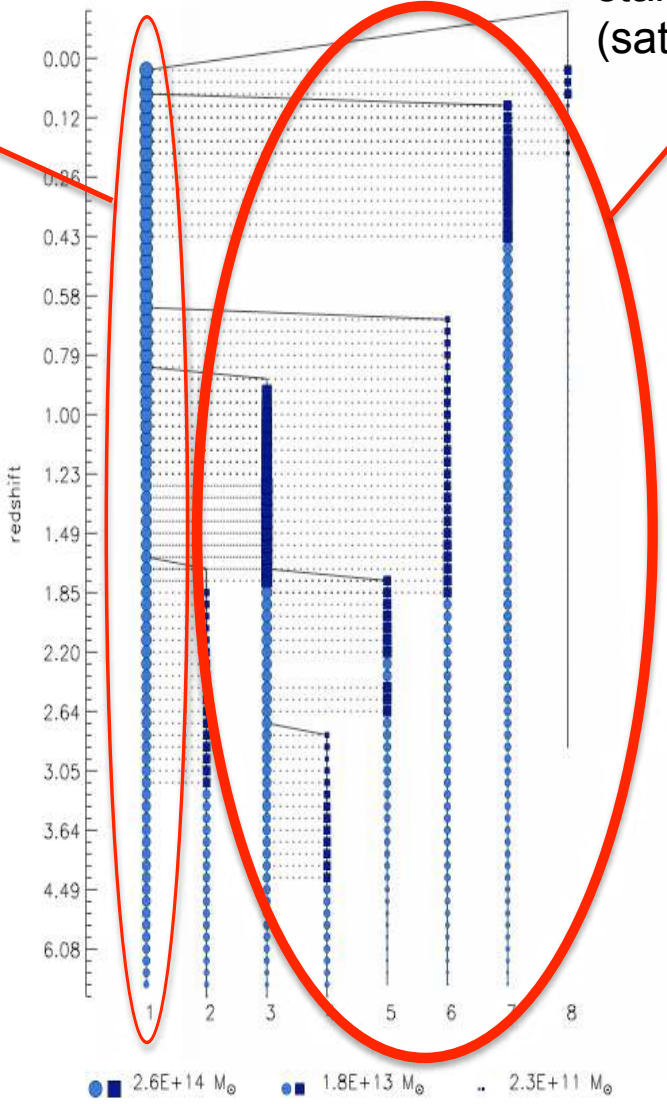



Log Stellar Mass

Merger Tree
*(Tweed et al. 2009)*

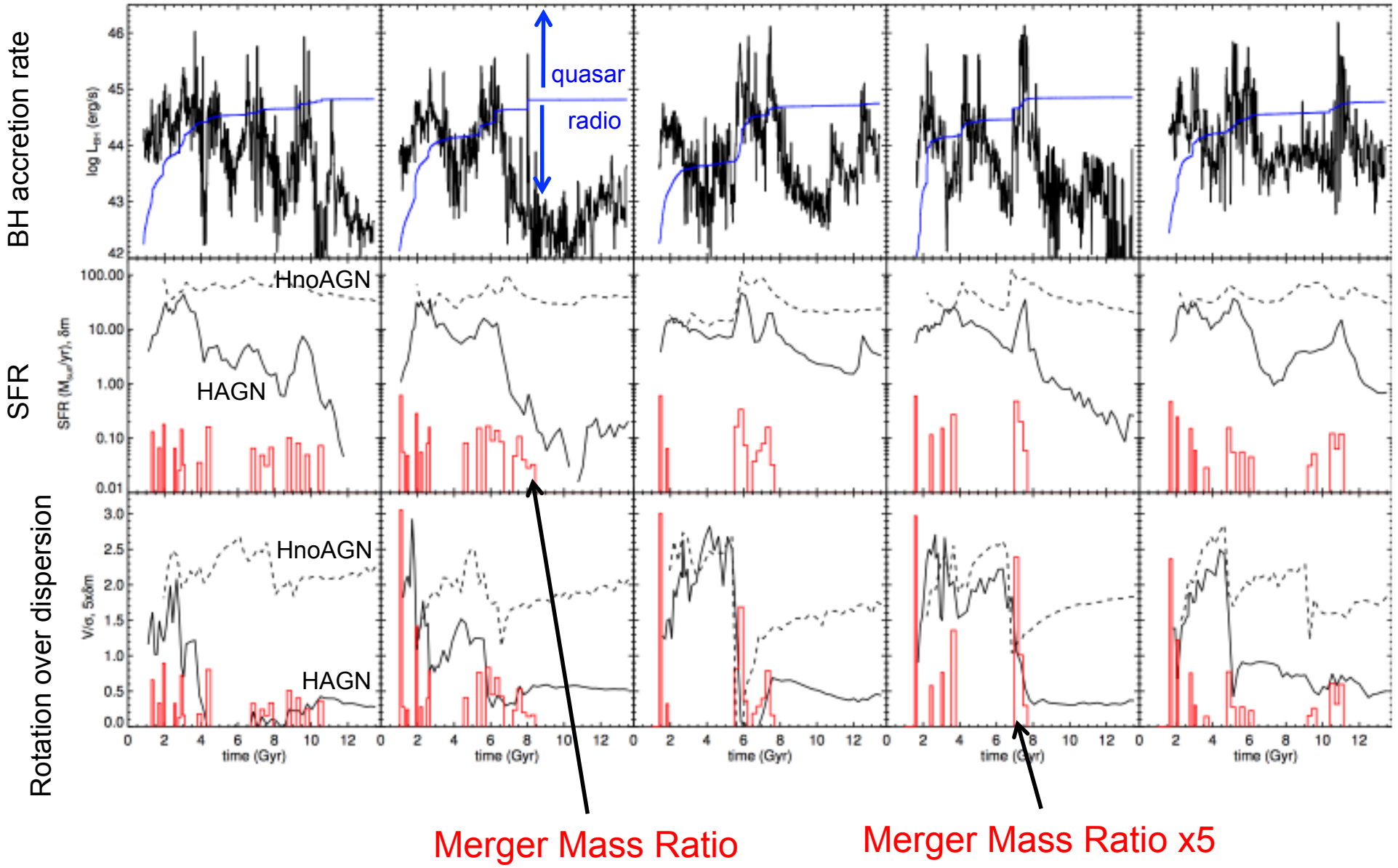
In situ

Accreted stars (satellites)




*Dubois et al, 2016*
*See also Dubois, Gavazzi, Peirani, Silk, 2013*
*Lee & Yi, 2013 (SAM)*

# A few exemples of $2x10^{11}$ $M_{sun}$ galaxies



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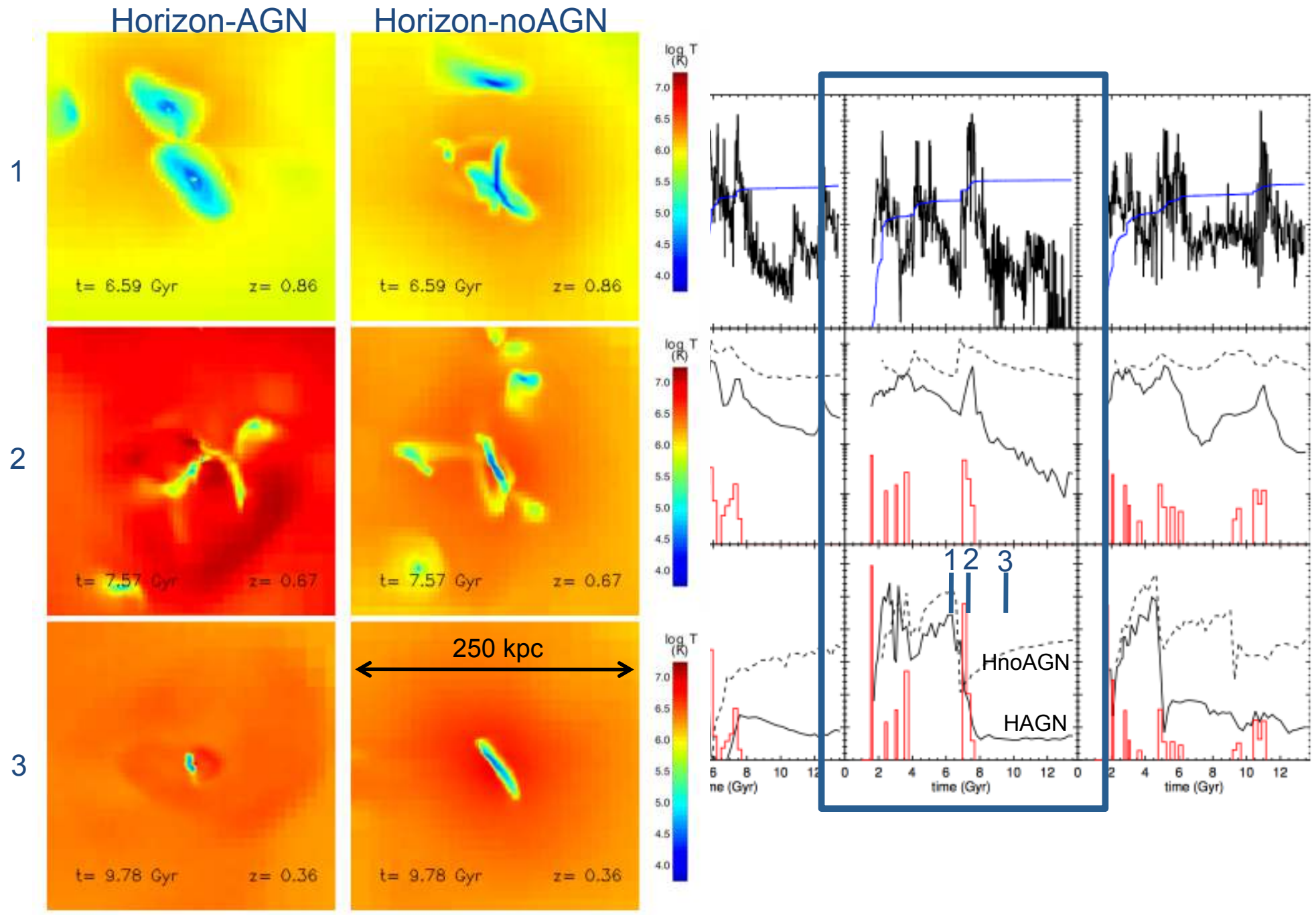
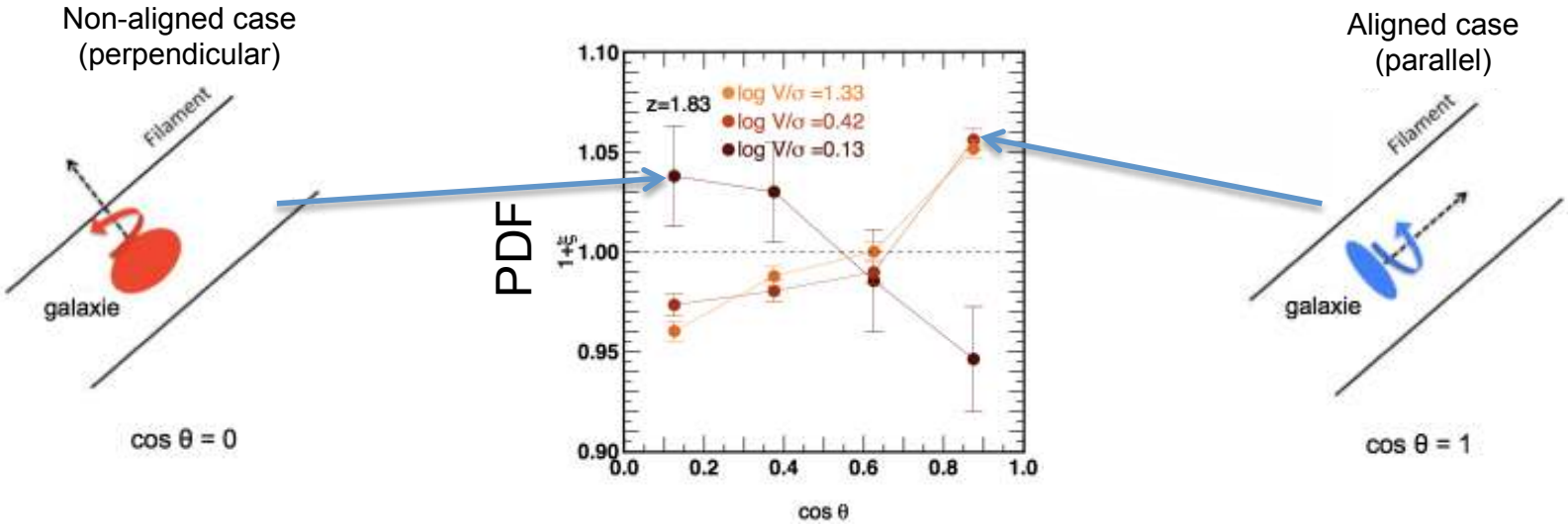


# Cosmic web and galaxies alignment

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




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

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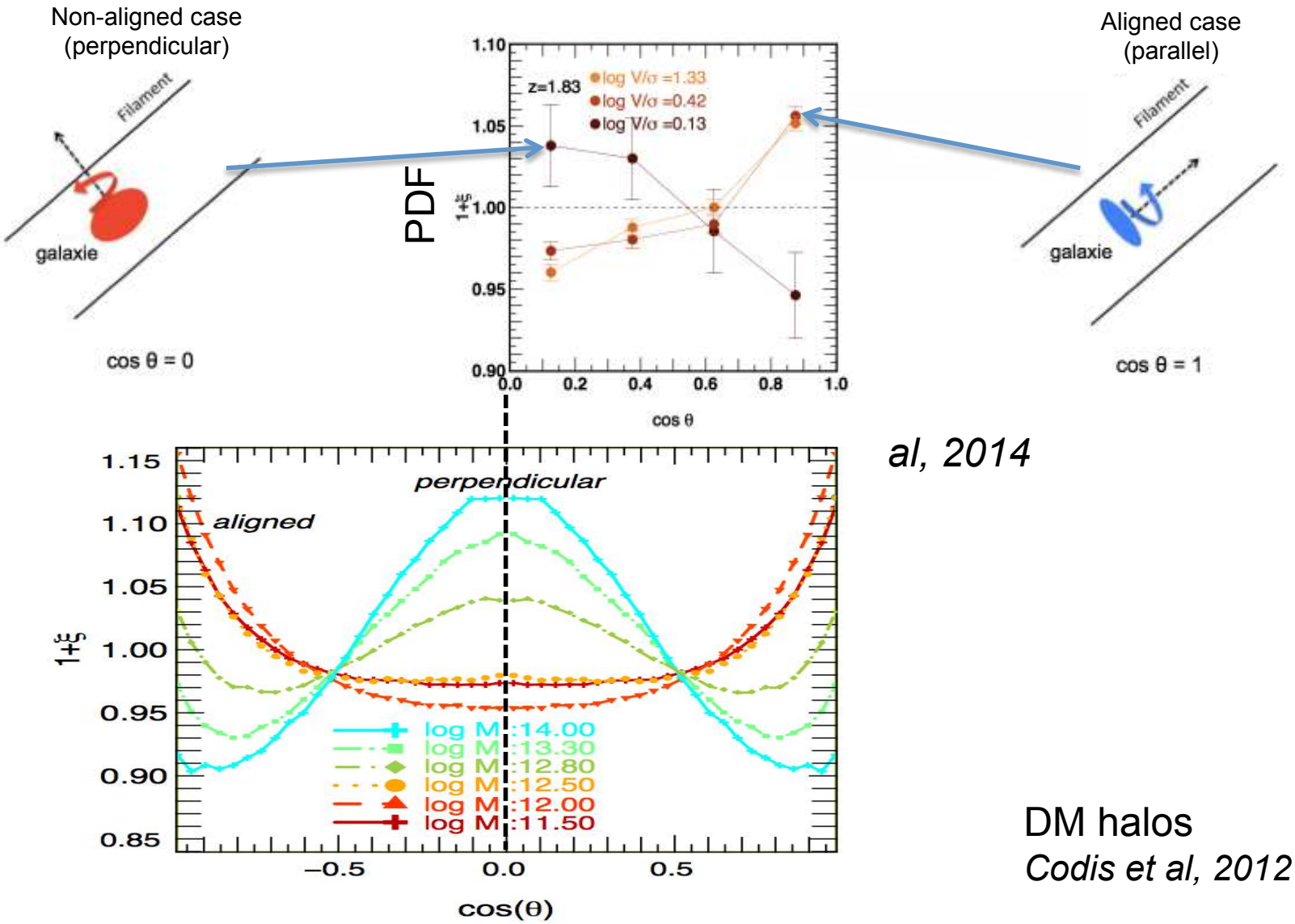


*al, 2014*

DM halos
*Codis et al, 2012*

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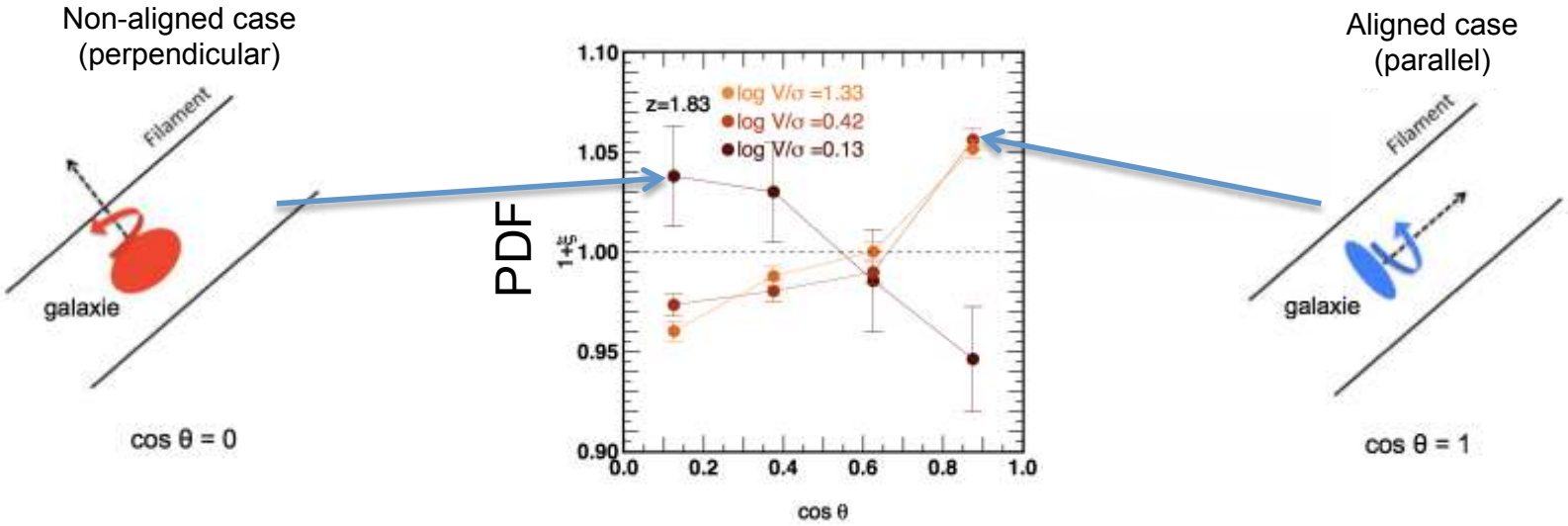


Horizon-AGN simulation / *Dubois et al, 2014*

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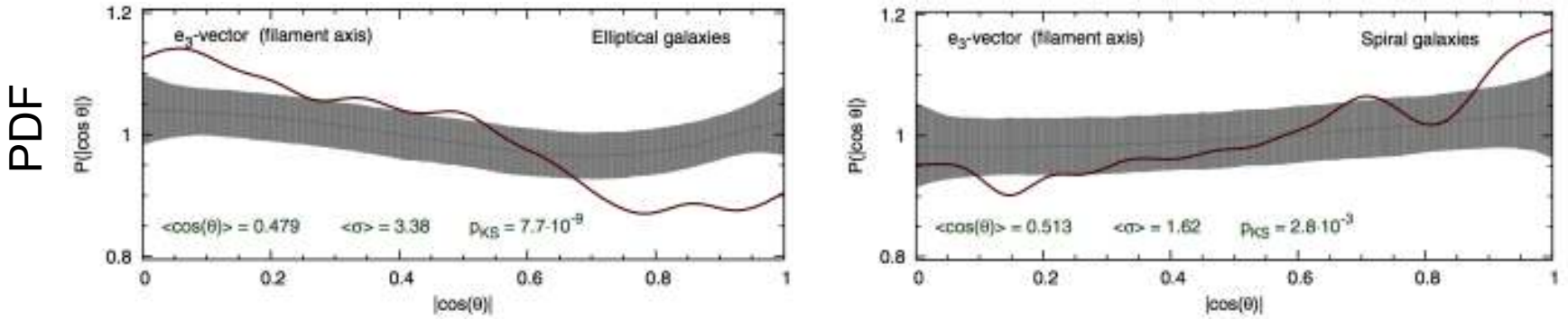
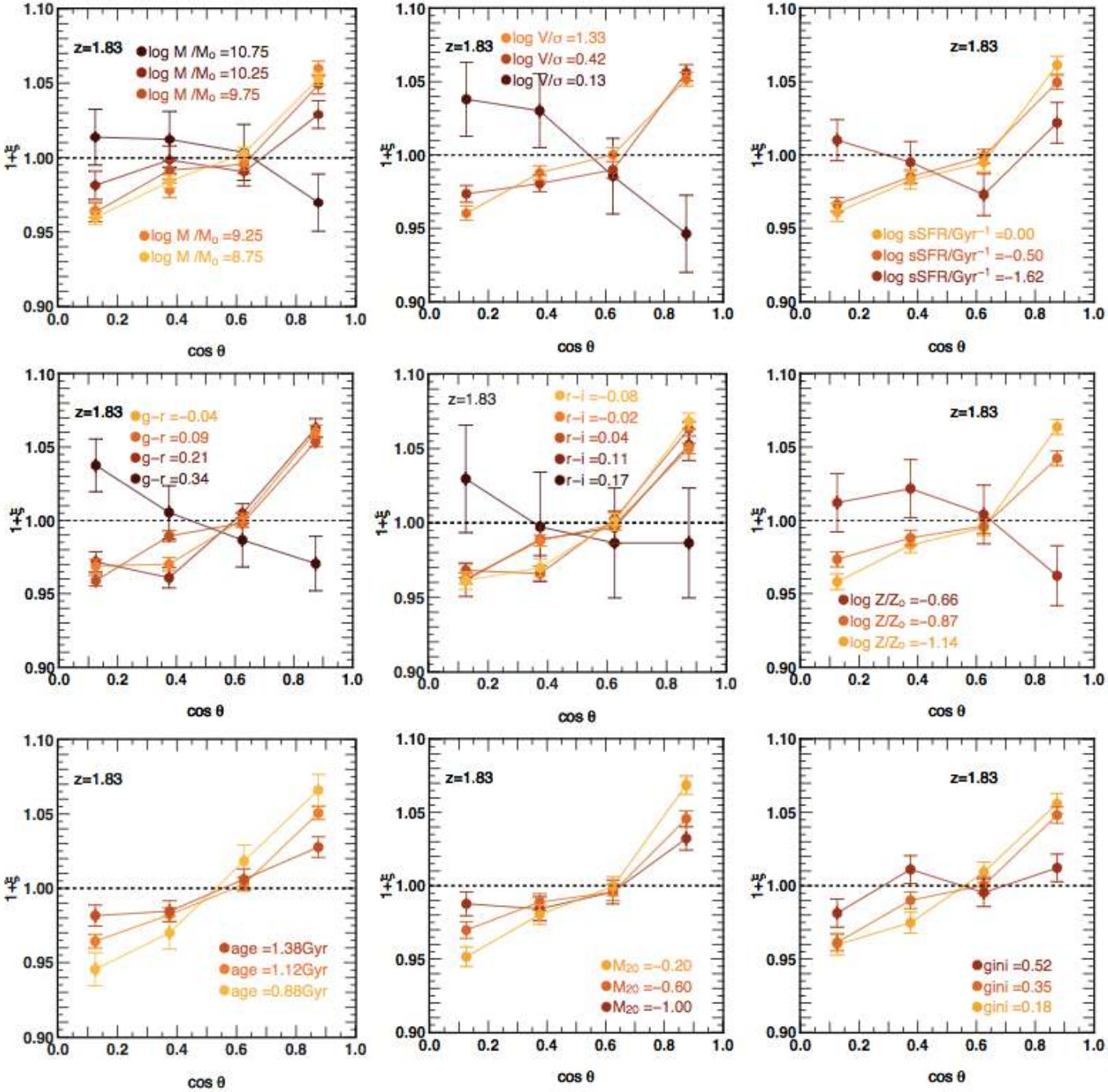
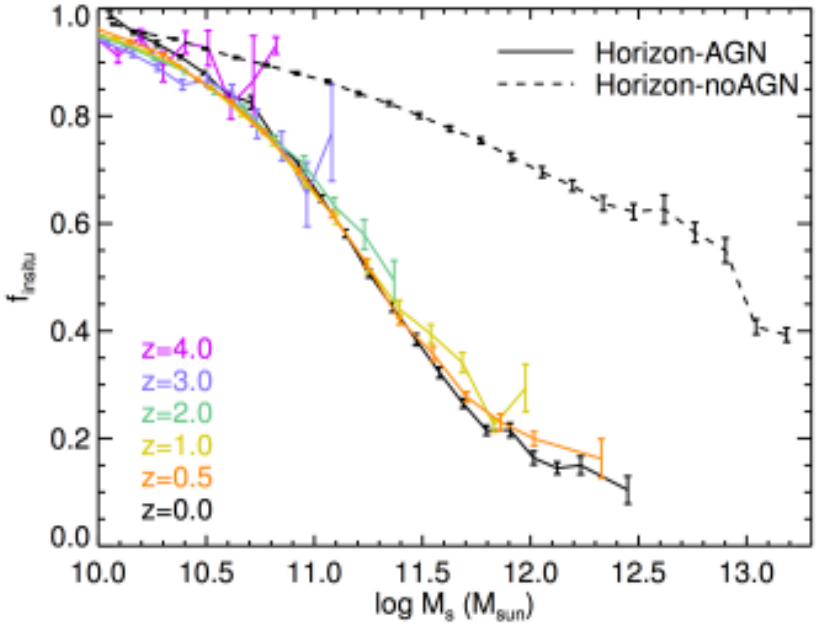
Observations (SDSS) / *Tempel & Libeskind, 2013*






*Dubois et al, 2014*

# How comes some galaxies are aligned and other misaligned?

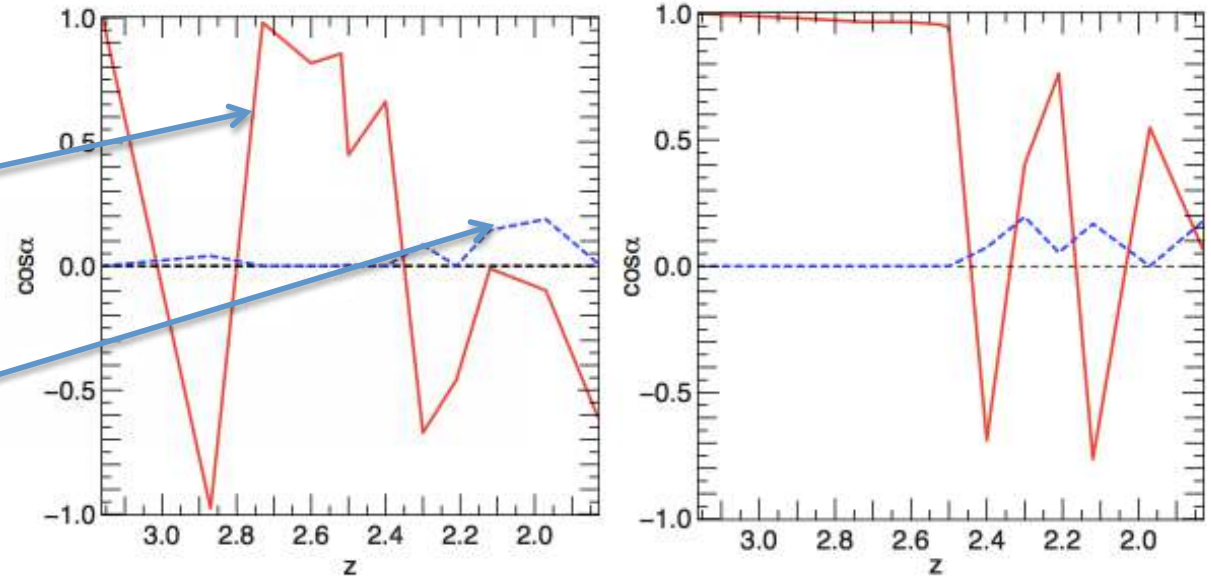



Mergers drive spin reorientation

Two exemples of galaxies with mergers

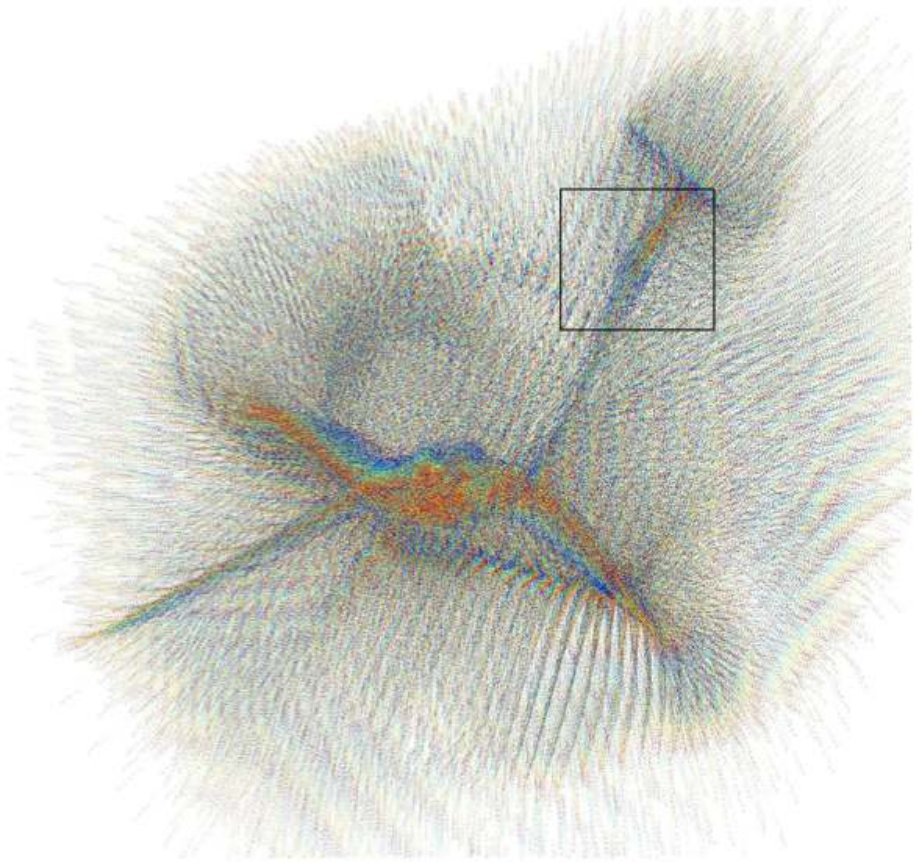
Angle between the galaxy spin and its initial orientation

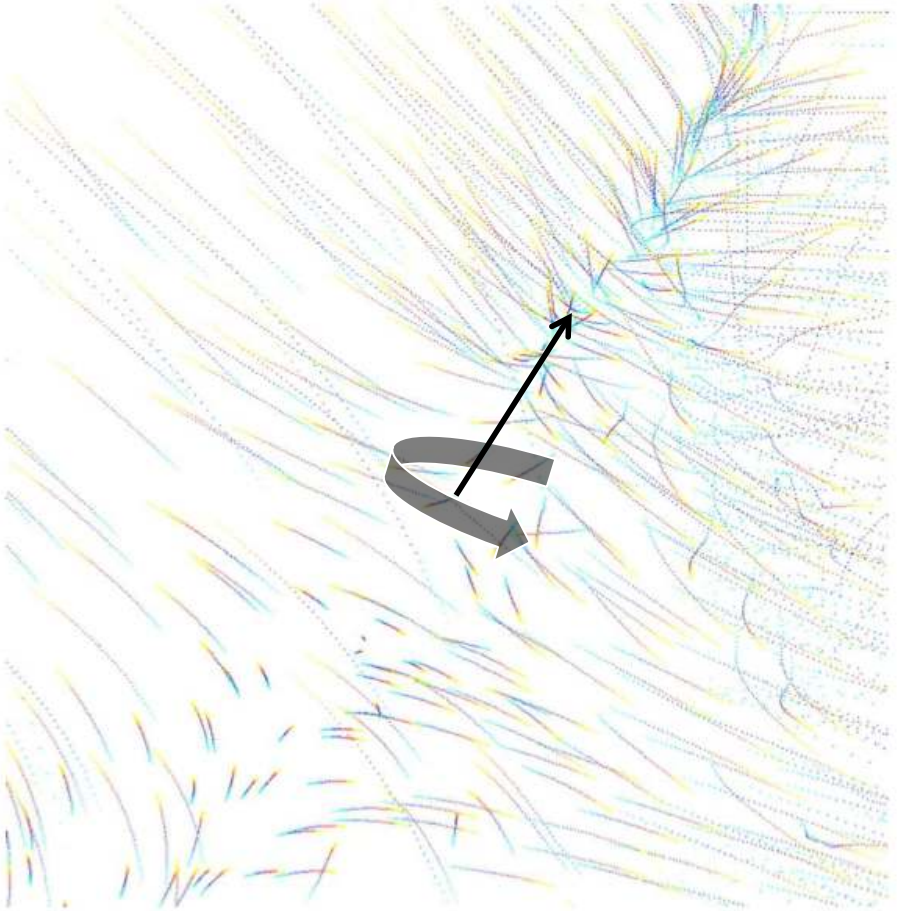
Merger mass ratio




*Dubois et al, 14*

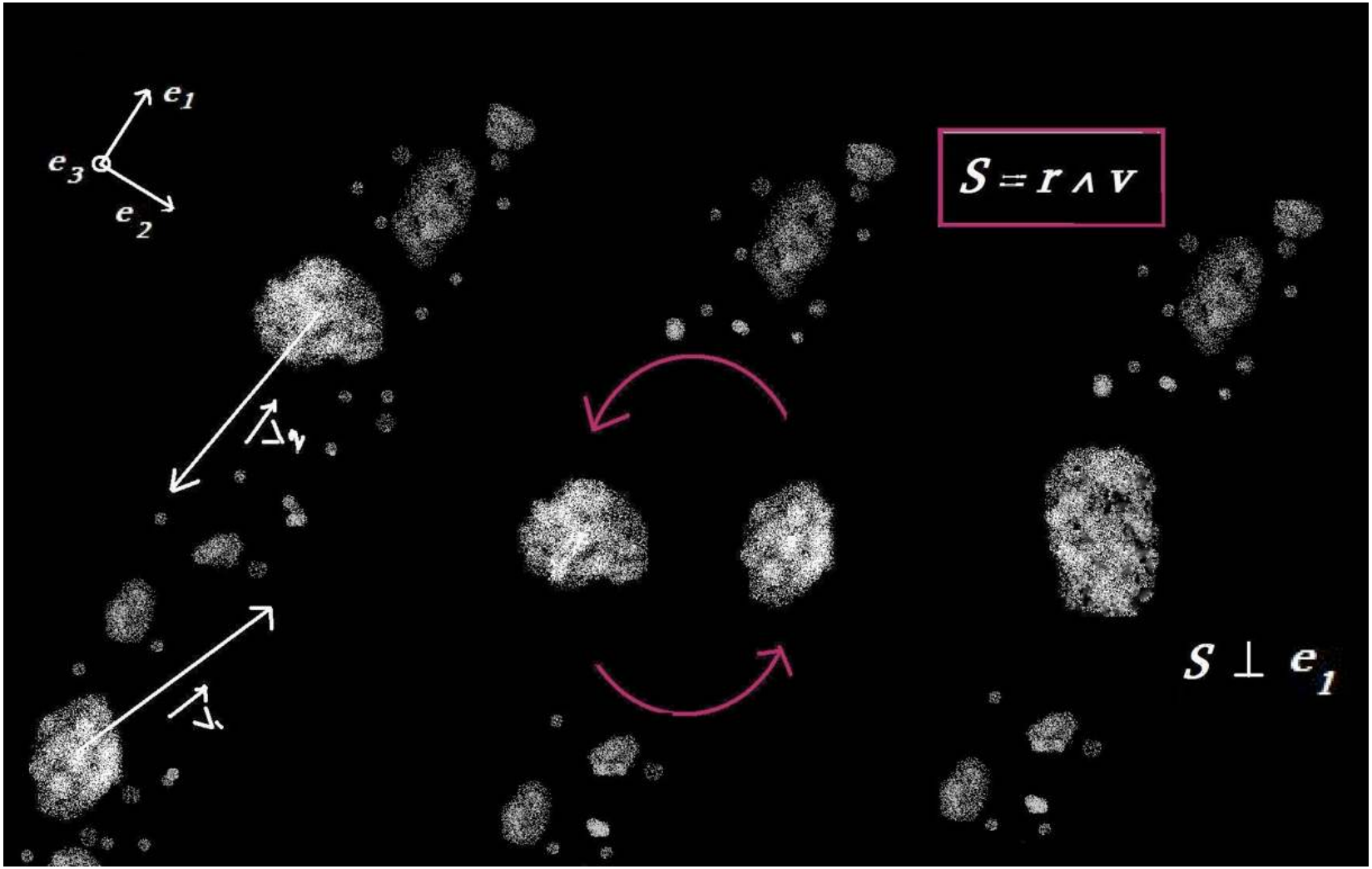
# Why do low-mass halos align with filaments?





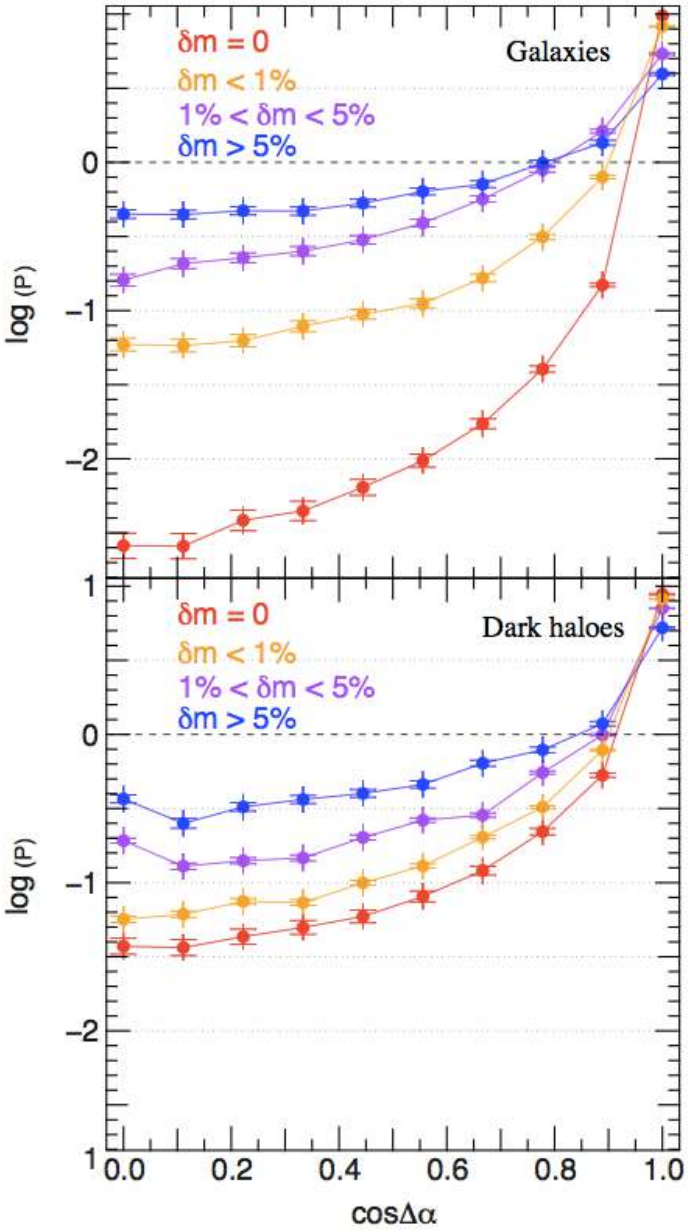
*Pichon et al (2011)*
*See also Pichon & Bernardeau (1999)*
*Laigle et al (2014)*
*Codis, Pichon, Pogosyan (2015)*

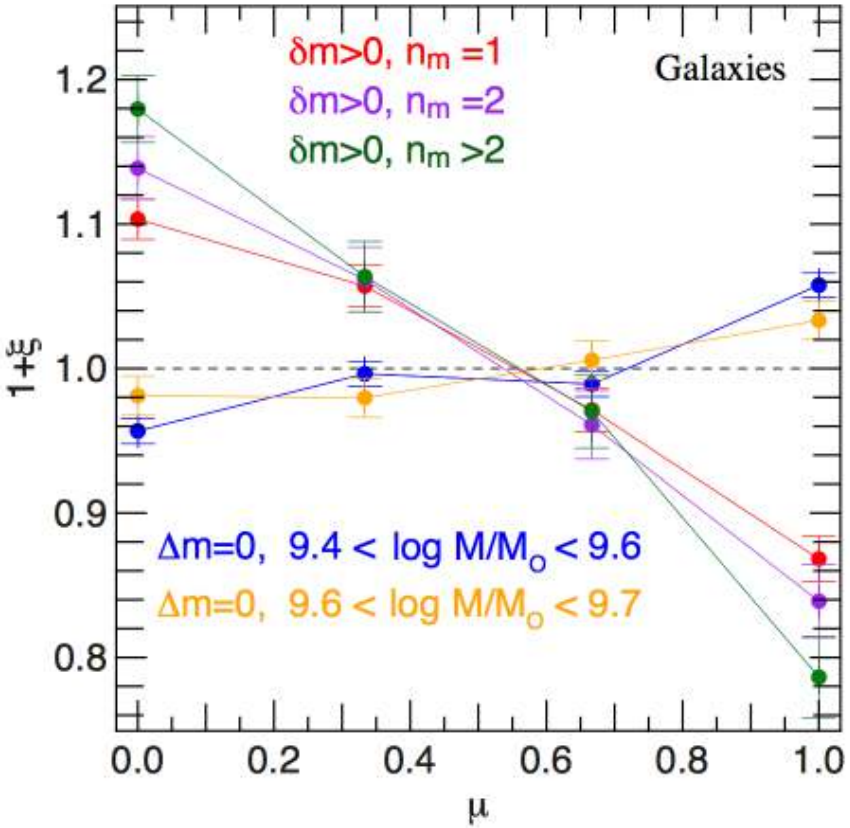
# Why do high-mass halos are perpendicular to filaments?




*Courtesy of S. Codis*

# Spin flips driven by mergers

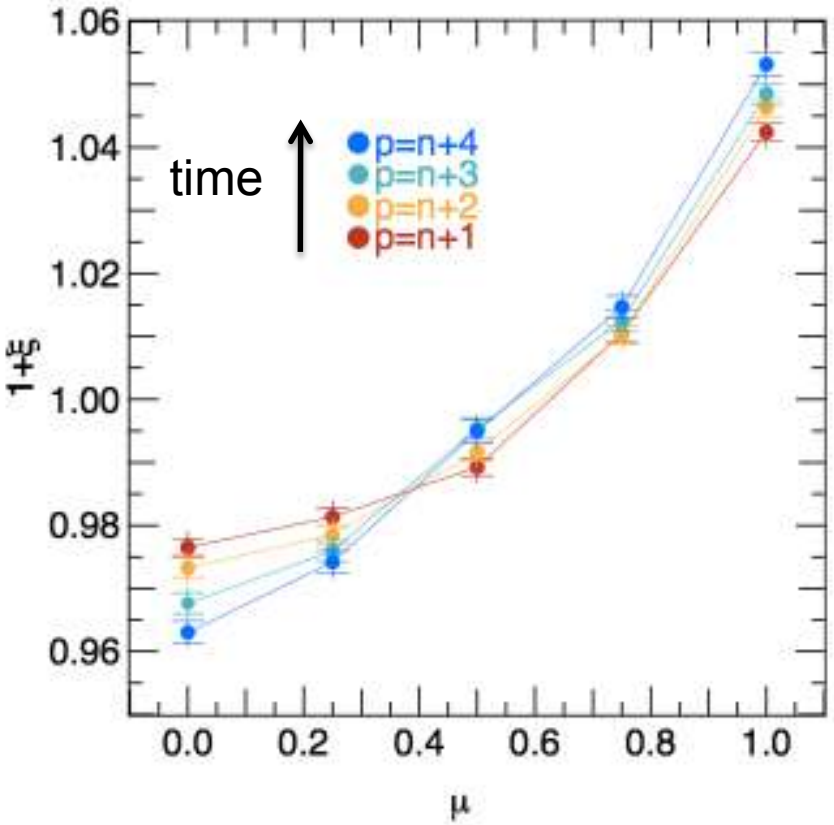



*Welker et al, 2014*

# Re-alignment of galaxies

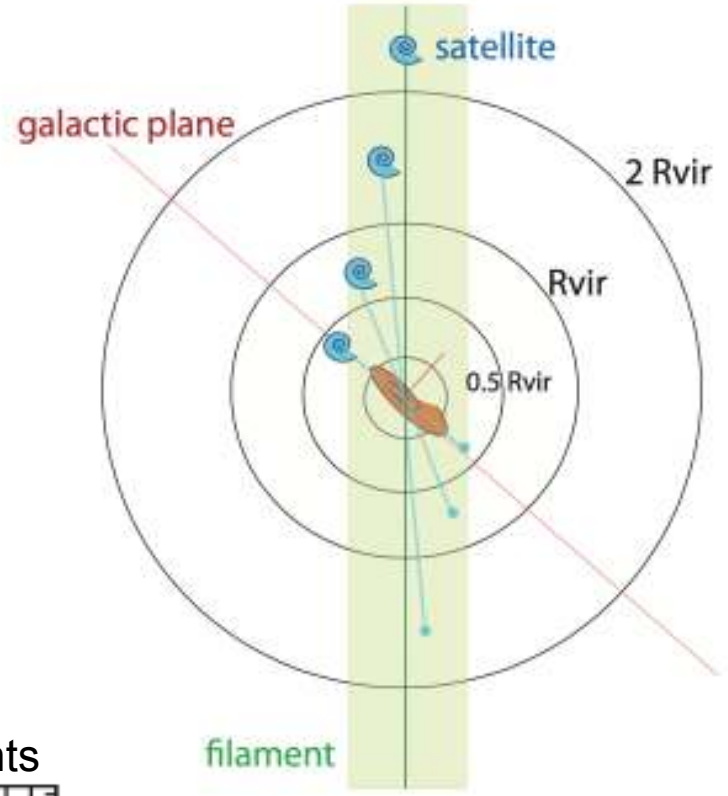
In absence of mergers, galaxies tend to realign with the cosmic web because of gas accretion



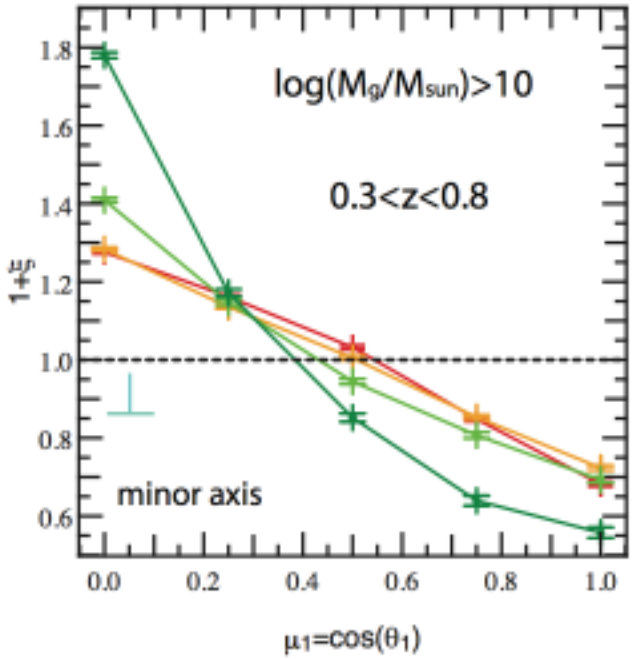

As AGN feedback prevents gas accretion in massive galaxies, it also prevents massive galaxies to realign with the cosmic filaments after a merger.
Therefore, AGN feedback is mandatory to get galaxies perpendicular with cosmic filaments.

*Welker et al, 2014*

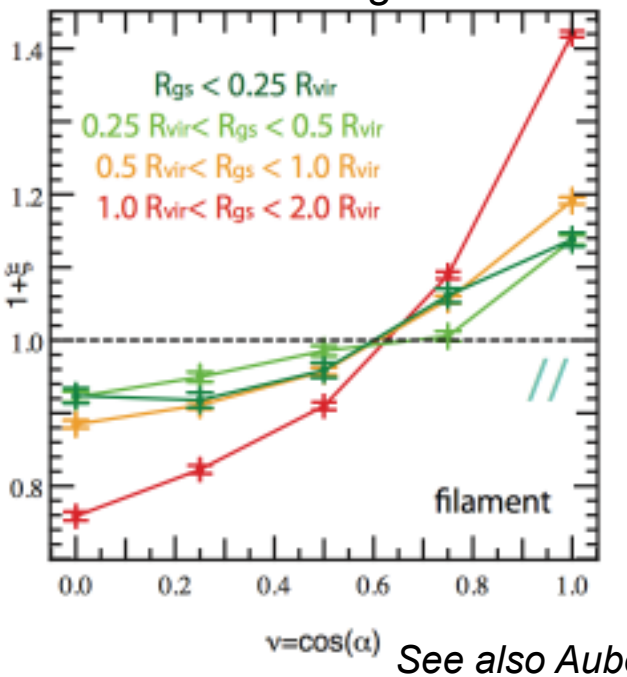
# Satellites rotate in the galactic plane of the central as they get closer




Satellites perp. to central minor axis




Satellites along filaments




Compatible with cold streams dynamics (Danovich et al, 2015)

*Welker, Dubois et al, sub.*

*See also Aubert, Pichon, Colombi, 2004 (DM only)*

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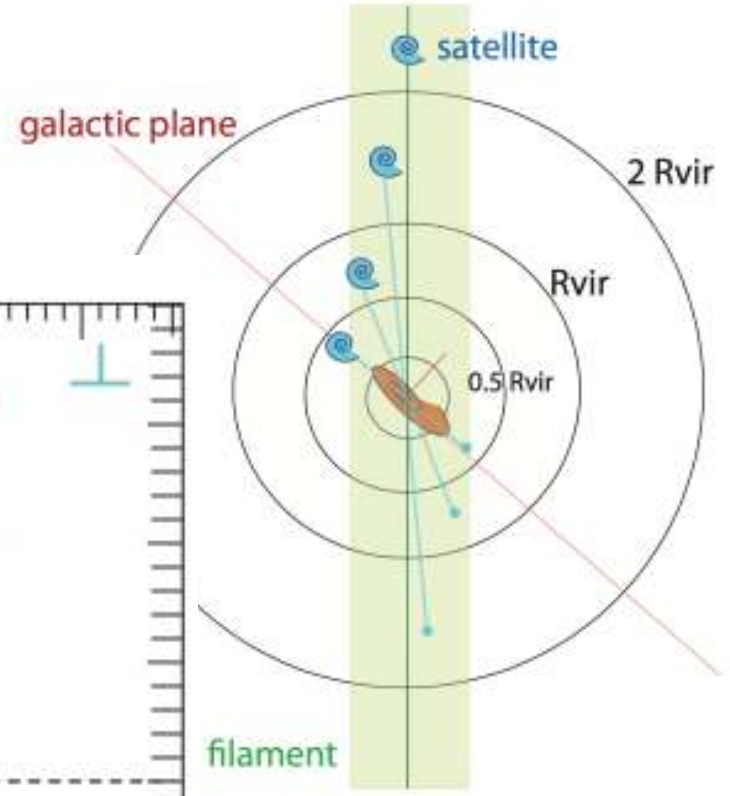


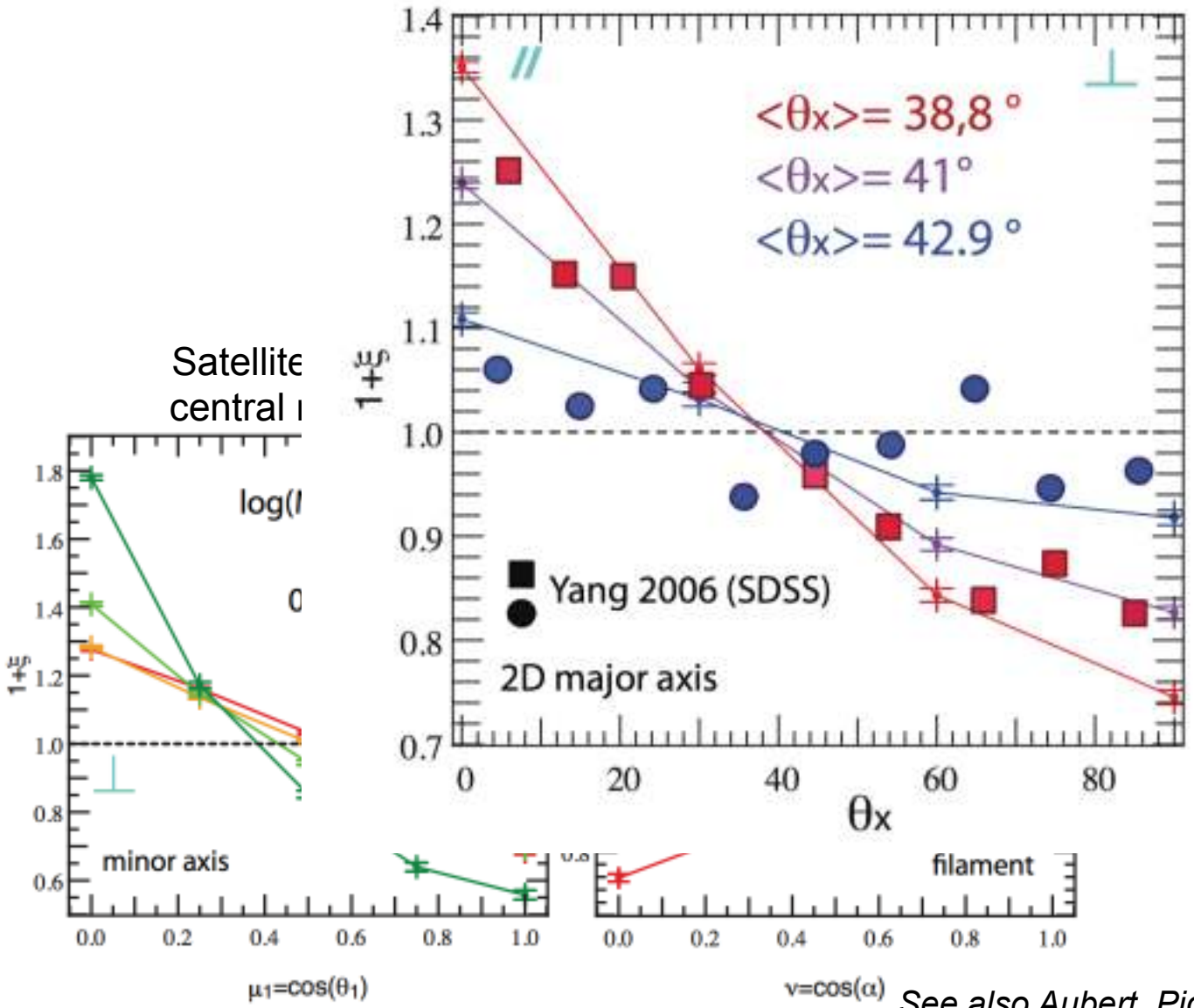


Compatible with cold streams dynamics (Danovich et al, 2015)

*Welker, Dubois et al, sub.*
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# Take home message

- AGN feedback is a key player in shaping massive galaxies mass, size 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