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

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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

09/15/2014  EGEE 2014
Motivation for AGN feedback

Galaxy luminosity (~mass) function
Semi-analytic models

SN realm

- Cole et al. (2001)
- Huang et al. (2003)

w/o AGN

w/ AGN

Bower et al., 2006
Stellar mass in central massive galaxies

\[ f_s = \frac{M_s}{f_{\text{bar}}M_h} \]

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

Increasing mass

No AGN

AGN

140 kpc
Rotation or dispersion-dominated galaxies?

![Graphs showing the evolution of galaxy properties over redshift](image)

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 $M_{DM,\text{res}}=8 \times 10^7 M_{\text{Sun}}$
  - 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 ($0.5^\circ \times 0.5^\circ$) 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/

Dubois et al, 2014
Welker et al, 2014
Codis et al, sub.
Green: gas density / Red: temperature / Blue: metallicity
Stellar mass in central galaxies versus halo mass

$\log M_s (M_{\text{sun}})$

$\log M_{h} (M_{\text{sun}})$

$z=0.6$

$f_s = M_s / (f_{\text{bar}} M_h)$

$0.10$

$0.70$

Simu

Moster (2013)
Galaxies and filaments

20 Mpc

- filament
  - galaxy

09/15/2014

EGEE 2014
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

PDF

Non-aligned case (perpendicular)

Aligned case (parallel)
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

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
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 alignment (II) signal

Codis et al, arXiv:1406.4668C
Spin-shear alignment (IG) signal (1-point)

Tidal shear tensor:

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

\( \phi \): gravitational potential

\[ \lambda_1 \leq \lambda_2 \leq \lambda_3 \]

\[ e_1 \]
\[ e_2 \]
\[ e_3 \]

\[ 8.3 < \log M < 9.5 \]
\[ 9.5 < \log M < 10.6 \]
\[ 10.6 < \log M < 11.8 \]

Mass decomposition

Codis et al, arXiv:1406.4668C
Spin-shear alignment (IG) signal (1-point)

Tidal shear tensor:

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

\( \phi \): gravitational potential

\( \lambda_1 \leq \lambda_2 \leq \lambda_3 \)

Color decomposition

Codis et al, arXiv:1406.4668C
Spin-shear alignment (IG) signal (2-point)

Codis et al, arXiv:1406.4668C
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.