Cosmology 2018

Wobbling galaxy spin axes in dense environments

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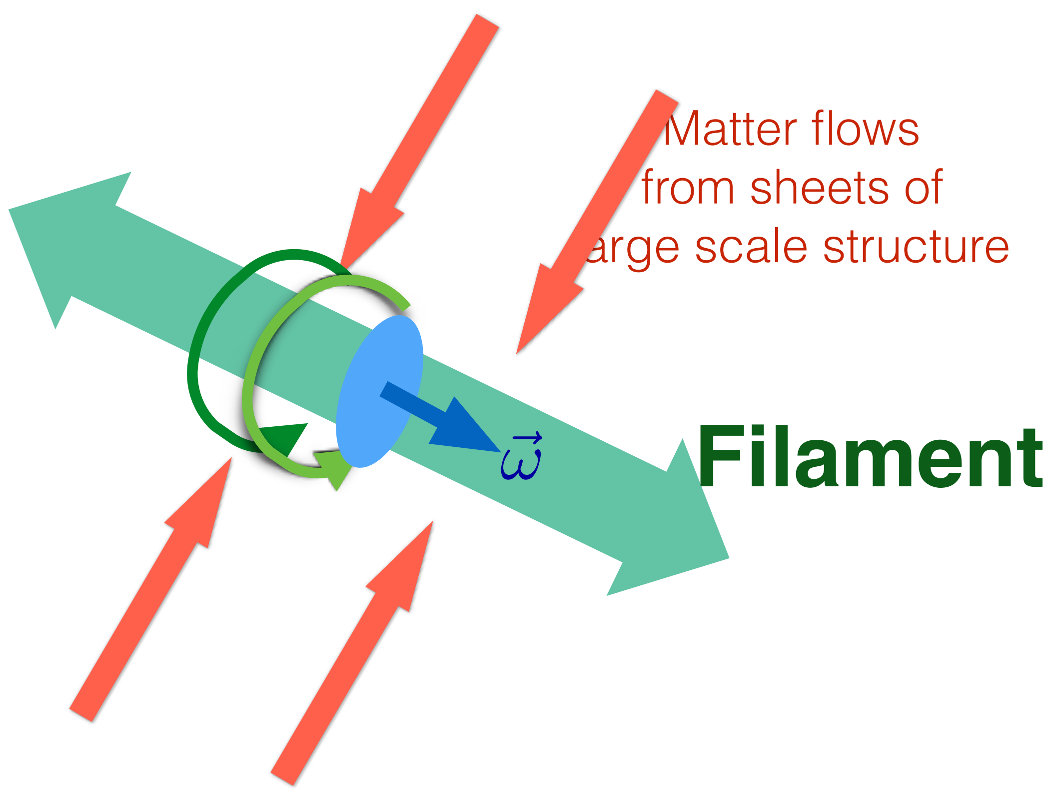
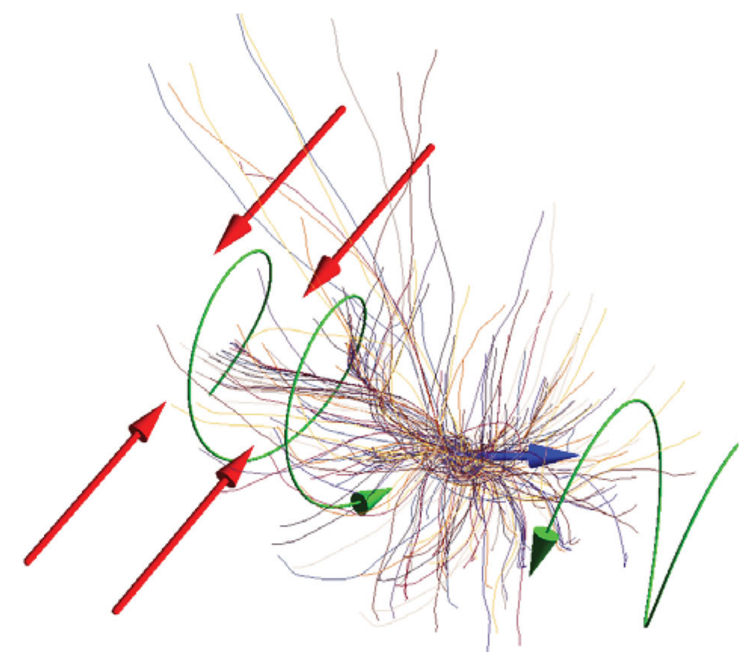
- Galaxies acquire their initial angular momenta via tidal torques
  - Tidal torque theory (Hoyle 1949, Peebles 1969)
  - In ideal circumstances, galaxies in filaments have spin axes aligned with nearby filaments

schematic figure



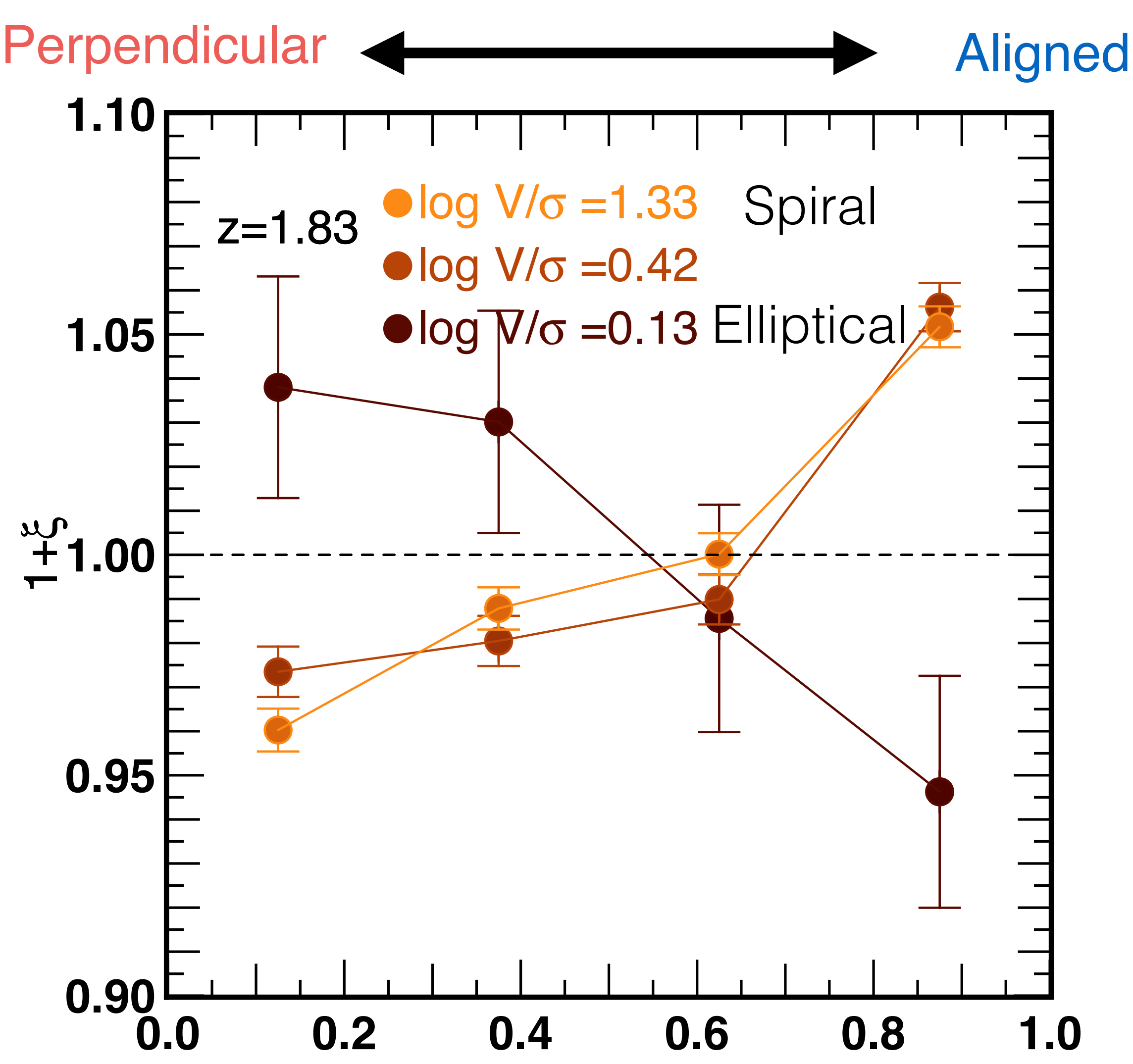
Numerical simulation



Codis+2012

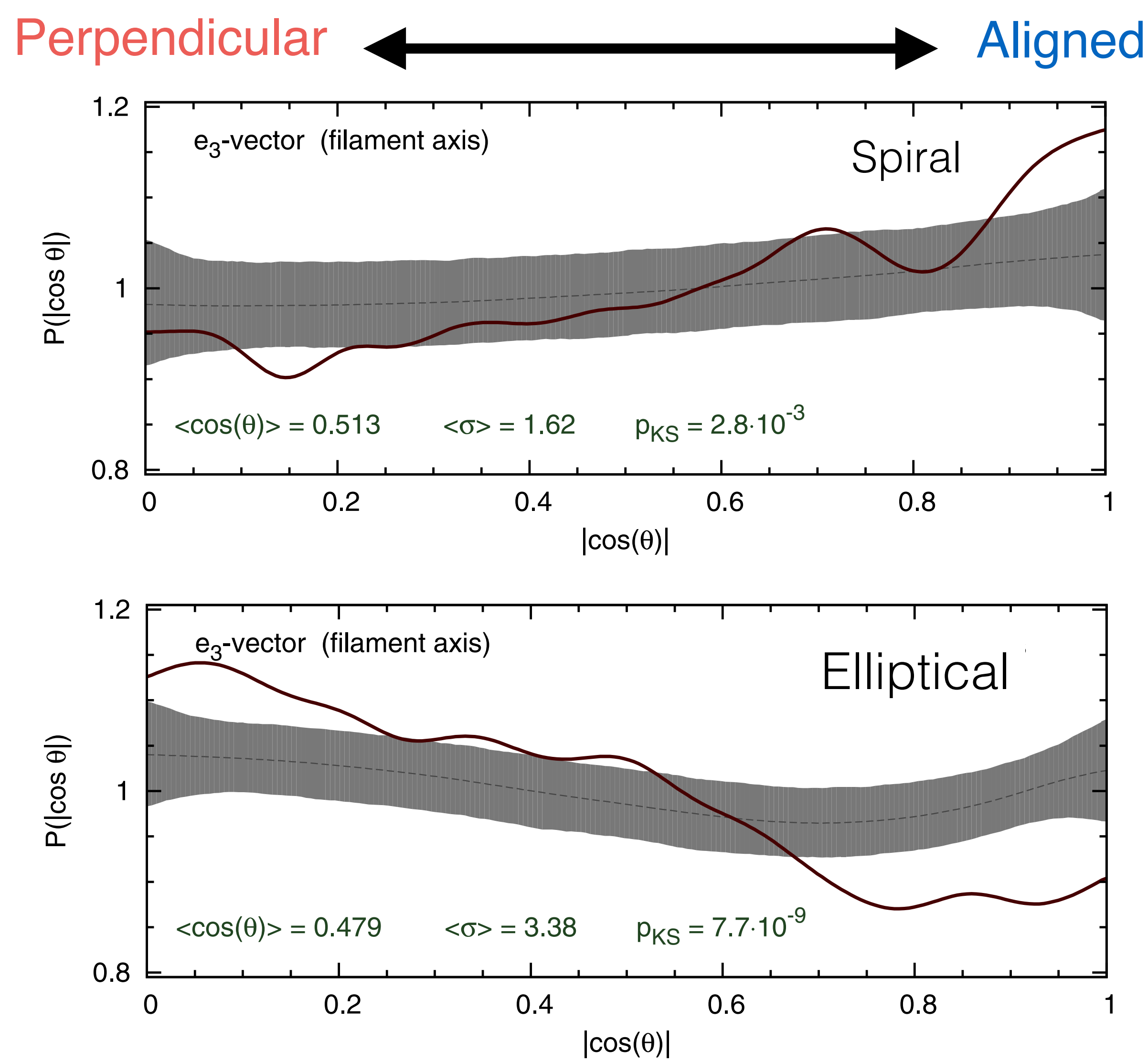
- Later type galaxies are aligned more with filaments in both simulations and observations

Horizon-AGN
Hydrodynamical cosmological simulation



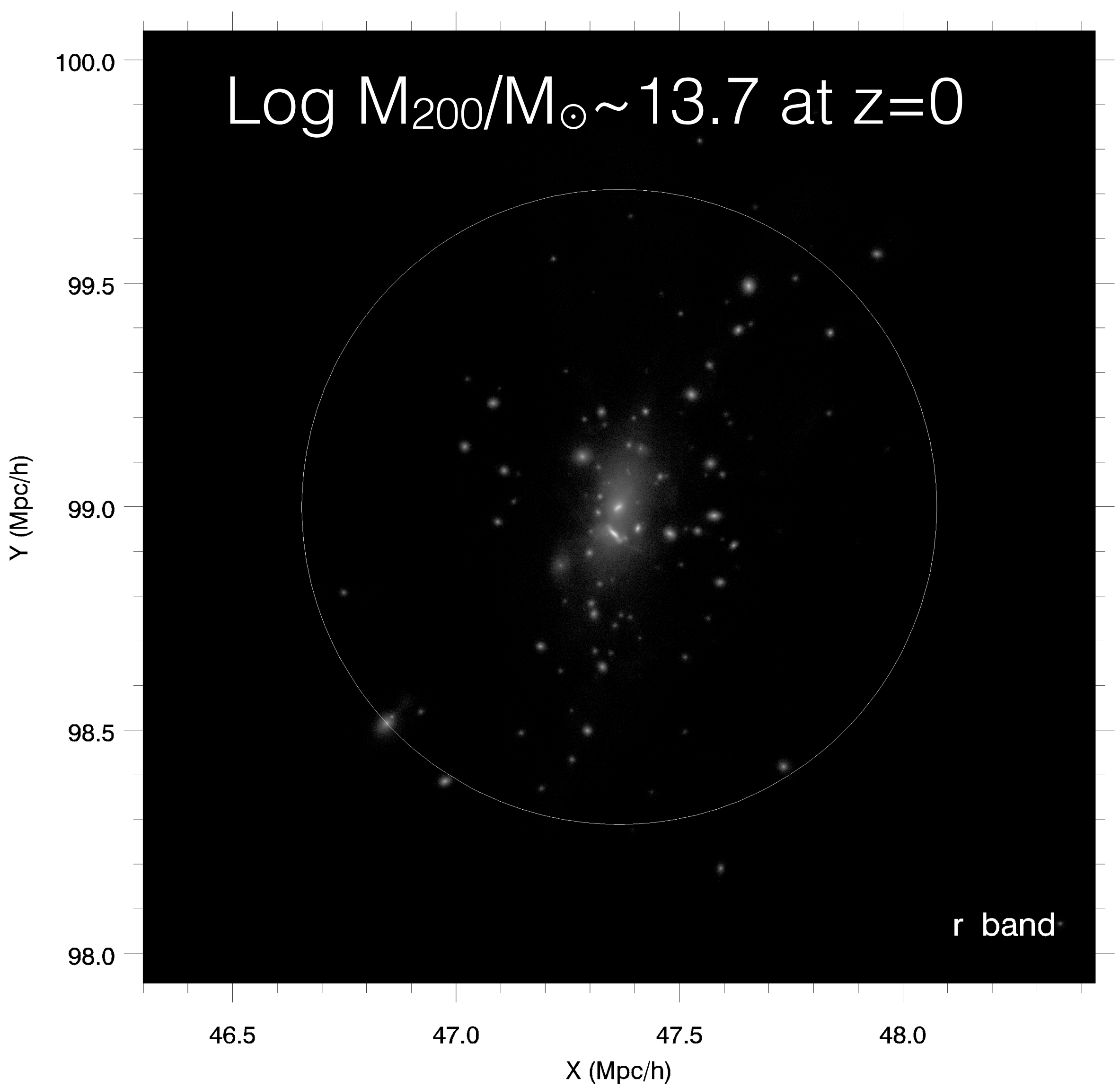
Dubois+2014

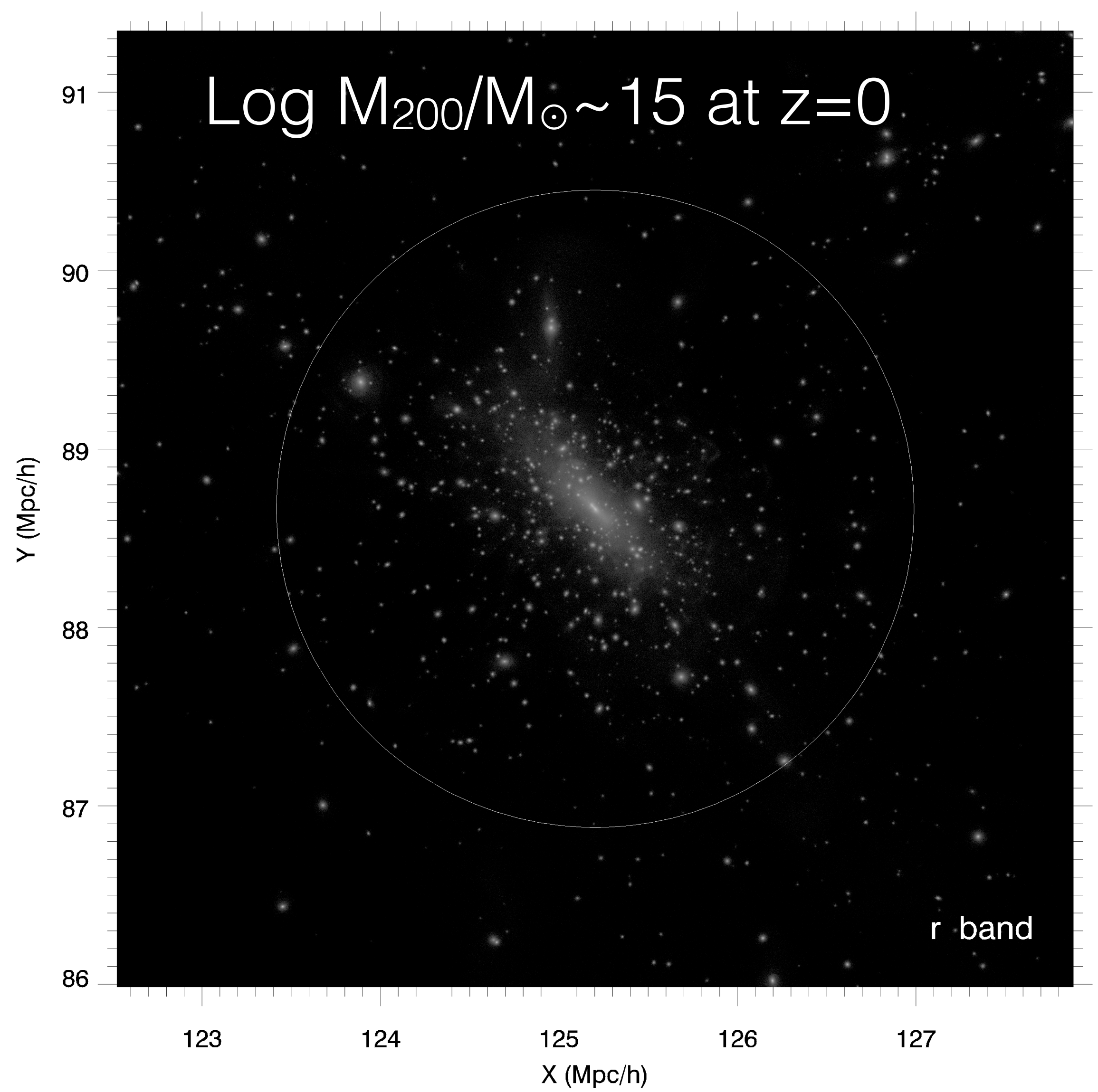
SDSS
DR8



Tempel+ 2013

- Simulation
  - Yonsei Zoom-in Cluster Simulations (Choi & Yi 2017)
  - 17 haloes in log $M_{200}/M_{\odot}$ ~13.5-15 at z=0
  - RAMSES with AGN feedback (Teyssier 2002; Dubois+2012)
  - Minimum cell size~0.78kpc/h, Minimum stellar particle mass~5×10^{5} $M_{\odot}$





- Parameterizing spin orientation changes
    - Galaxies with Log $M_*/M_\odot$ > 9.5 at z=0
    - Reference axes - galaxy spin vectors at infall epochs

$$\phi_{t_i}^{t_j} \equiv \frac{180}{\pi} \arccos \frac{\boldsymbol{L}(t_i) \cdot \boldsymbol{L}(t_j)}{|\boldsymbol{L}(t_i)||\boldsymbol{L}(t_j)|}$$

Net angular change of spin orientation between $z_{\rm infall}$ and z=0

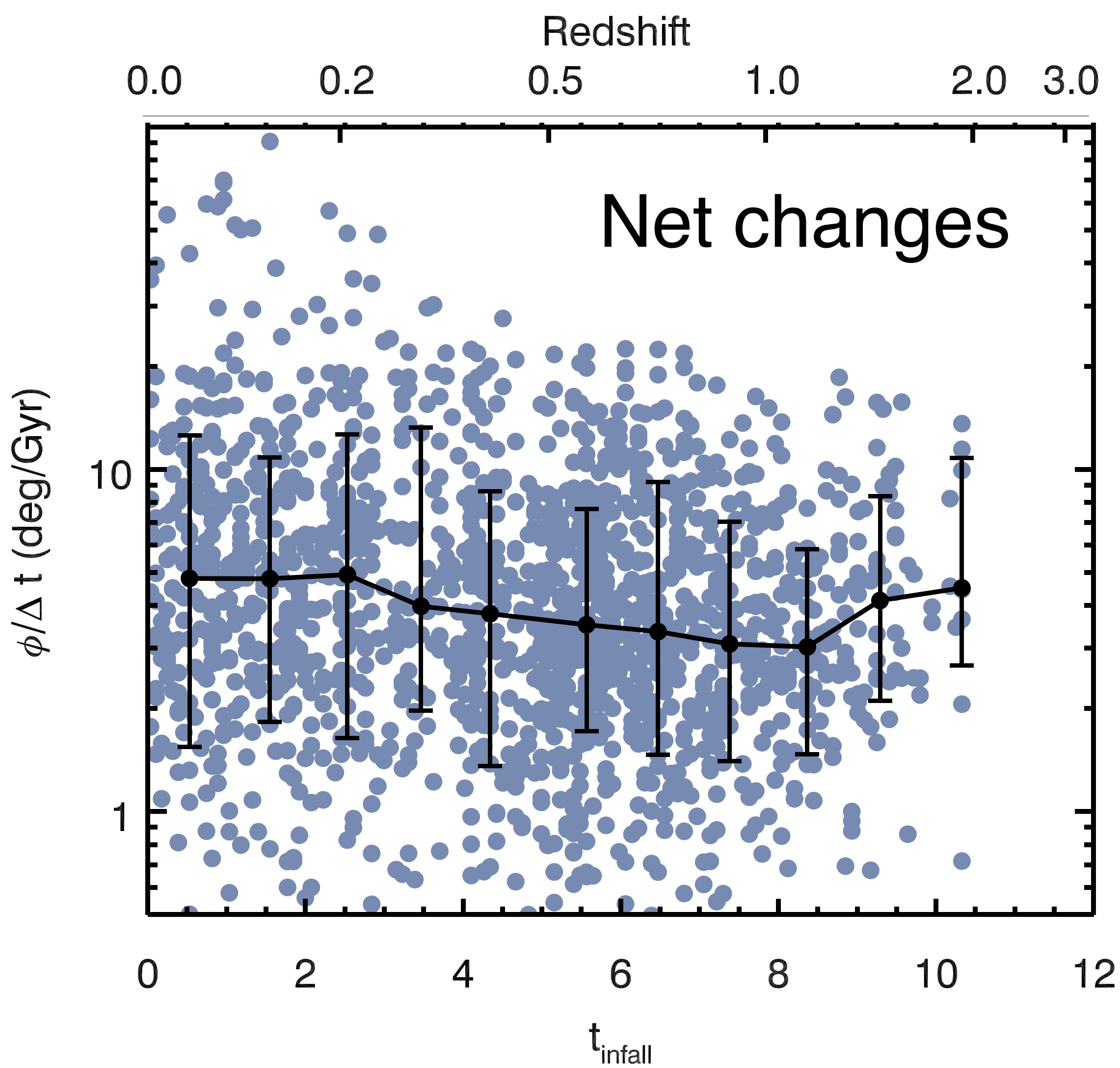
$$\phi_{z_{\rm infall}}^{z=0}$$

Cumulative angular change of spin orientation during z=$z_{\rm infall}$-0

$$\Phi_{z_{\rm infall}}^{z=0} = \sum_{i=n_{\rm infall}}^{n_{\rm final}-1} \phi_i^{i+1}$$

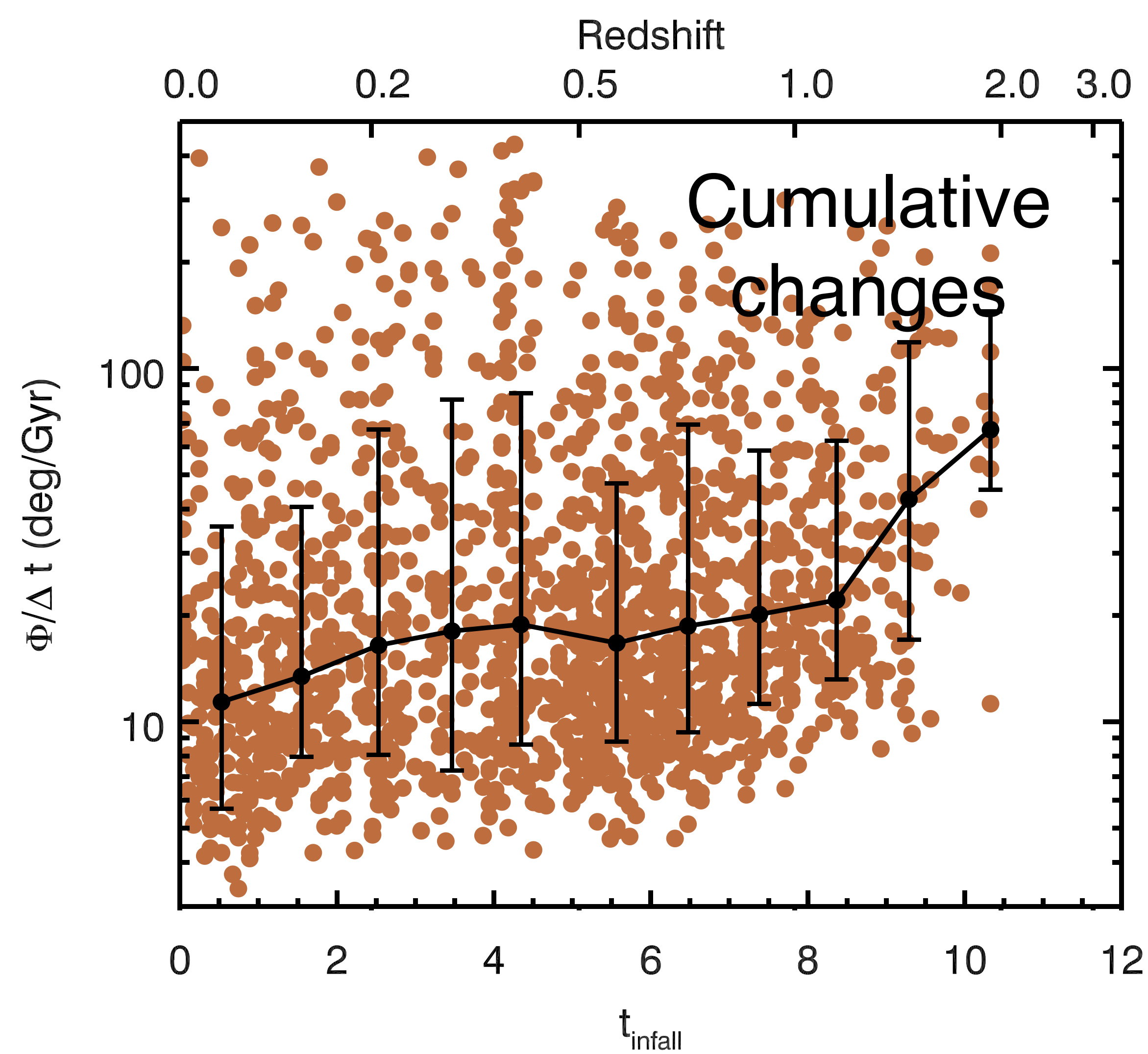
- Spin orientation change rates after infall

Median $\boldsymbol{\phi}/\Delta$t ~ 4 deg/Gyr



$$\Delta t = t_{\rm infall} - t_{z=0}$$

Median $\boldsymbol{\Phi}/\Delta$t~17 deg/Gyr



~1/3 of $\boldsymbol{\Phi}/\Delta$t is non-physical

- Physical mechanisms reorienting spin vectors
    - Mergers - violently swinging spin vectors, but not frequent between satellites in clusters
    - Tidal perturbation

- Parameterizing tidal perturbation

$$p \equiv \frac{M_P}{M_g}\left(\frac{R}{d}\right)^3 \propto \frac{2GmM_P R/d^3}{GmM_g/R^2} = \frac{F_{\rm tidal}}{F_{\rm grav}}$$

Byrd & Howard 1992

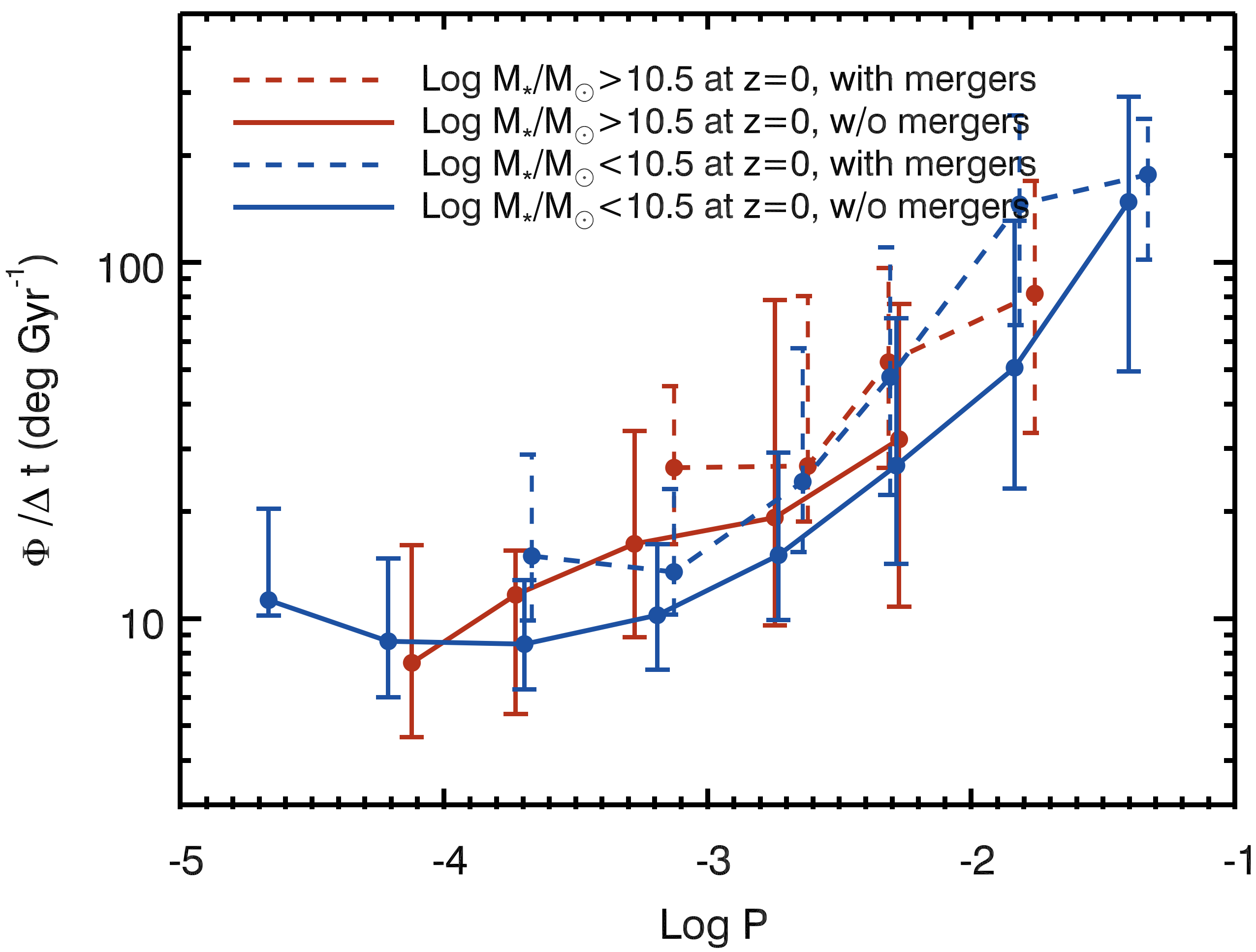
$$\log P_i(t_0,\, t_1) \equiv \log \frac{1}{\Delta t}\int_{t_0}^{t_1} p_i(t)\,dt$$

$$= \log \frac{1}{\Delta t}\int_{t_0}^{t_1} \frac{R_i^2(t)}{M_i(t)} \left| \sum_{j=1}^{j\neq i} \frac{M_j(t)R_i(t)}{d_{ij}^3(t)} \boldsymbol{u}_{ij}(t) \right| dt,$$

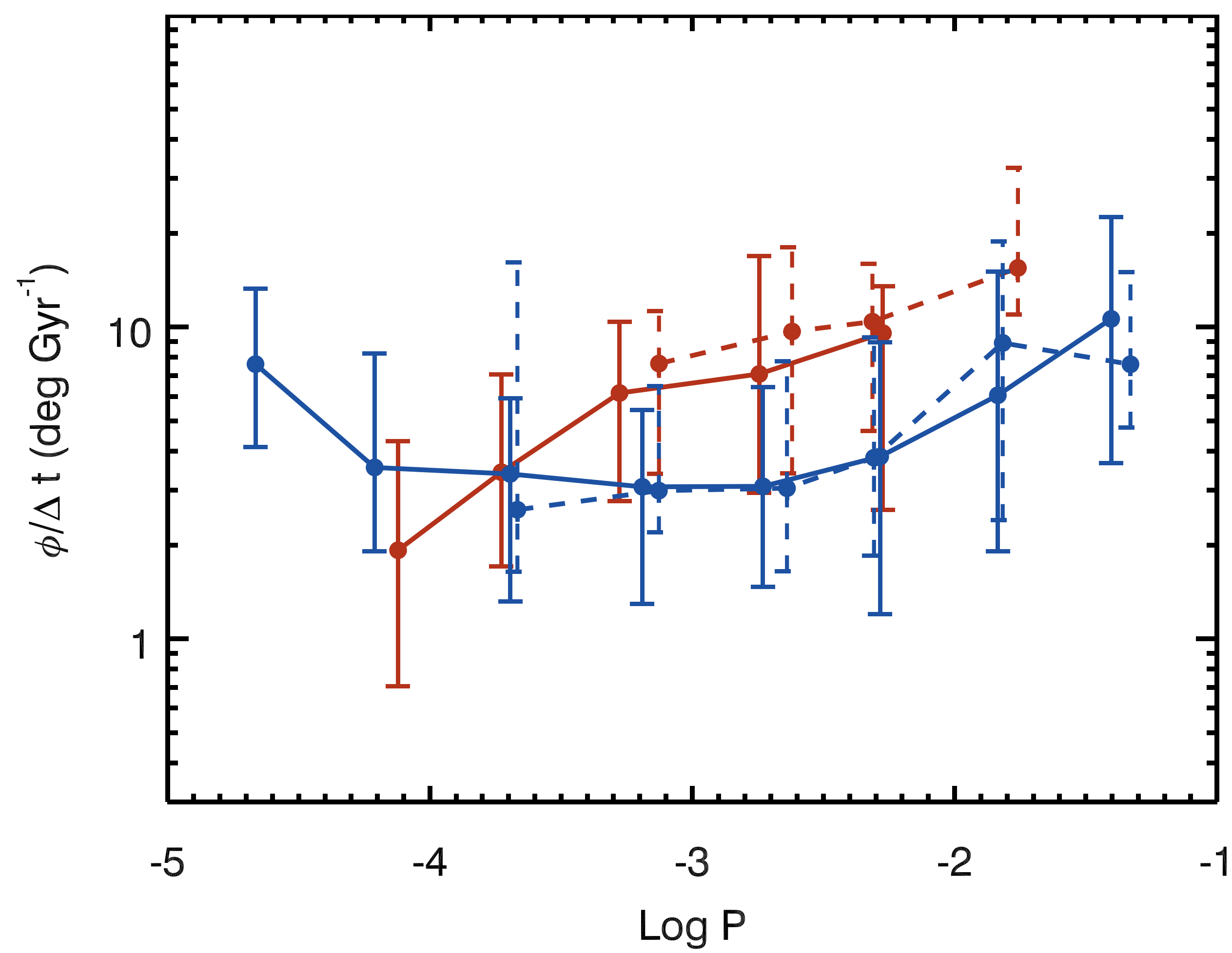
$$\Delta t = t_1 - t_0$$

- Tidal perturbation is strongly correlated with cumulative changes, but its net effect is easily canceled out.

Cumulative change rate



Net change rate



Perturbed More

Perturbed More

With-mergers
$M_2/M_1>0.1$

- Summary
  - Any signatures of spin alignment from the LSS can be preserved in cluster environments for gigayears
  - More rotating (higher V/σ) galaxies are more likely to maintain their initial spin orientation after infall into clusters
  - Tidal perturbation significantly swings spin vectors. However, its net effect is easily canceled out.