The segregation of baryons and dark matter during halo assembly

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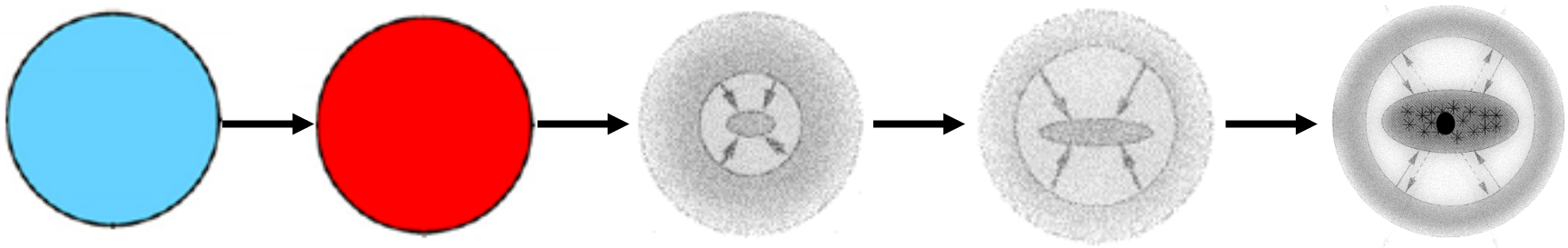
Galaxy formation--well-mixing assumption

- Baryons and dark matter are well mixed before they are segregated due to *radiative cooling*.



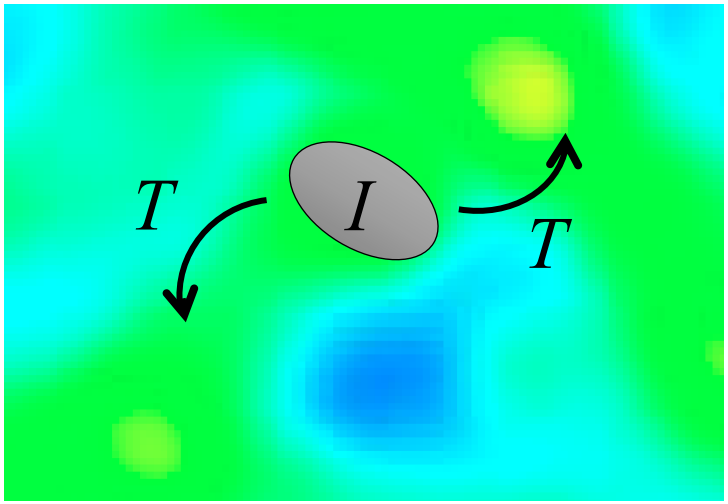
(Baugh 2006)

One important application: disk formation

The same spatial distribution (well-mixing) → the same tidal torques (Fall & Efstathiou 1980; Mo et al. 1998)

→ **identical specific angular momenta** ($\boldsymbol{j}=\boldsymbol{J}/\boldsymbol{M}$)

→ calculating disk radii



$j_{\downarrow gas} = j_{\downarrow dm}$

Tidal torque theory
(Peebles 1969; Doroshkevich 1970; White 1984)

How good is this assumption?

Dark matter

$\partial \boldsymbol{v}/\partial t + (\boldsymbol{v}\cdot\nabla)\boldsymbol{v} = -\nabla\phi$

- Collisionless
- Gravity only
- Violent relaxation
- …

Baryons (Gas)

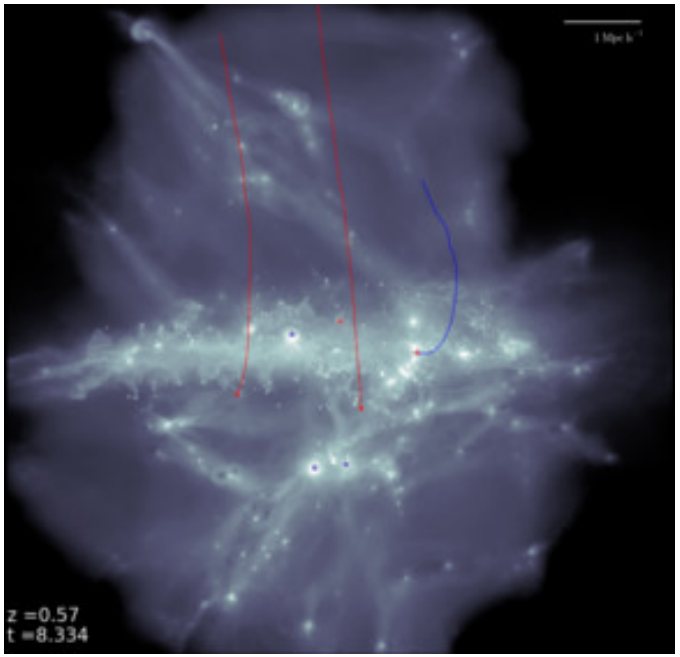
$\partial \boldsymbol{v}/\partial t + (\boldsymbol{v}\cdot\nabla)\boldsymbol{v} = -1/\rho \nabla P - \nabla\phi$

- Collisional
- Gravity + **pressure**
- Shocks
- …

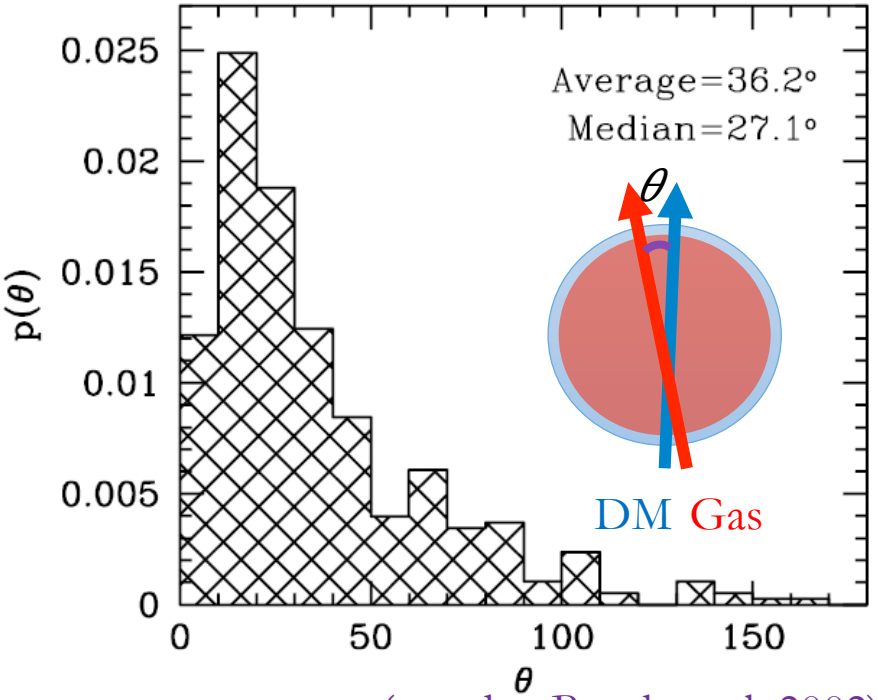
- It is not obvious that the well-mixing assumption should hold to high precision.

Evidences against the well mixing assumption

- "Cosmic web stripping" (Benitez-Llambay et al. 2013, 2016)
- Angular momentum misalignment (van den Bosch et al. 2002, 2003; Yoshida et al. 2003; Chen et al. 2003; Sharma & Steinmetz 2005; Croft et al. 2009; Bett et al. 2010; Zjupa & Springel 2016)



(Benitez-Llambay et al. 2013)



(van den Bosch et al. 2002)

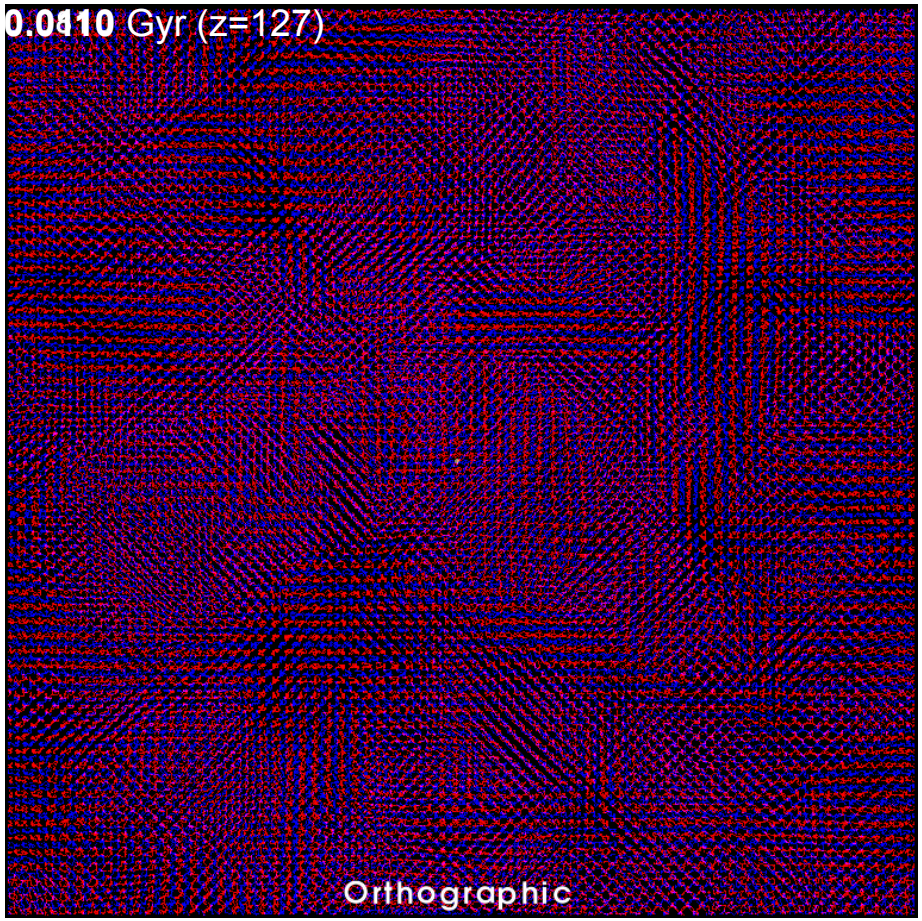
Questions

- Are DM and GAS component of a halo initially well-mixed or segregated?

- If segregated, any implications on current understanding of galaxy formation models? Any hints at the puzzling AMM between DM and gas?

Simulating halo assembly

Blue: dark matter
Red: gas



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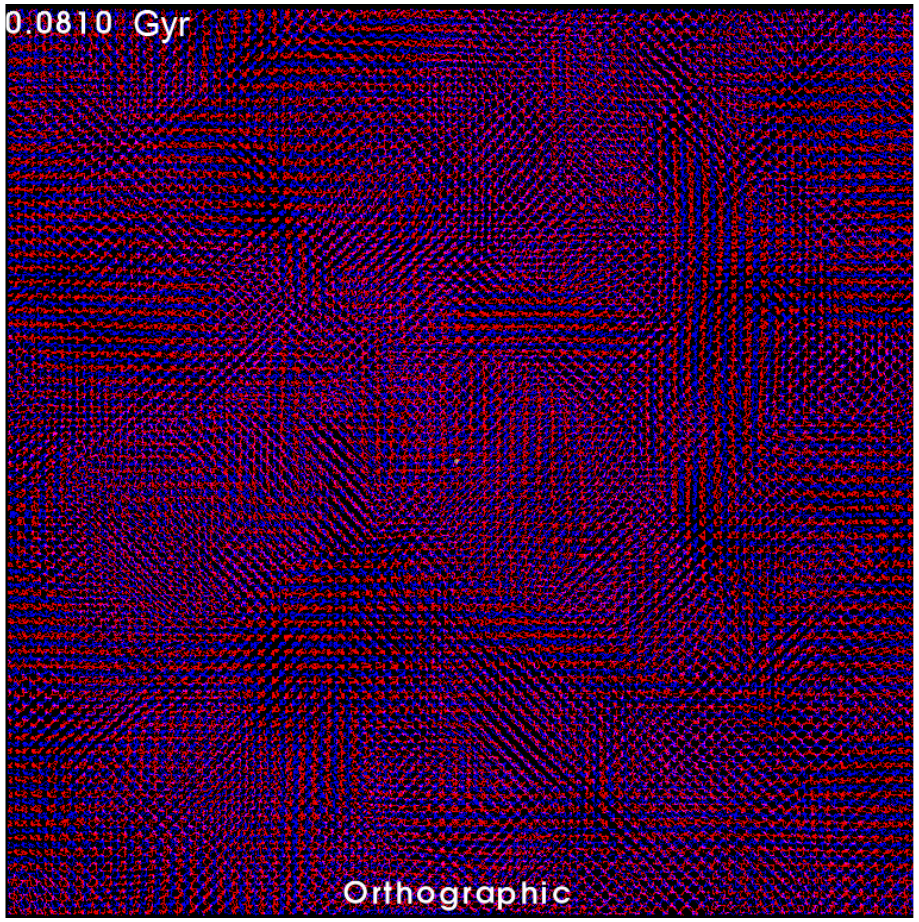

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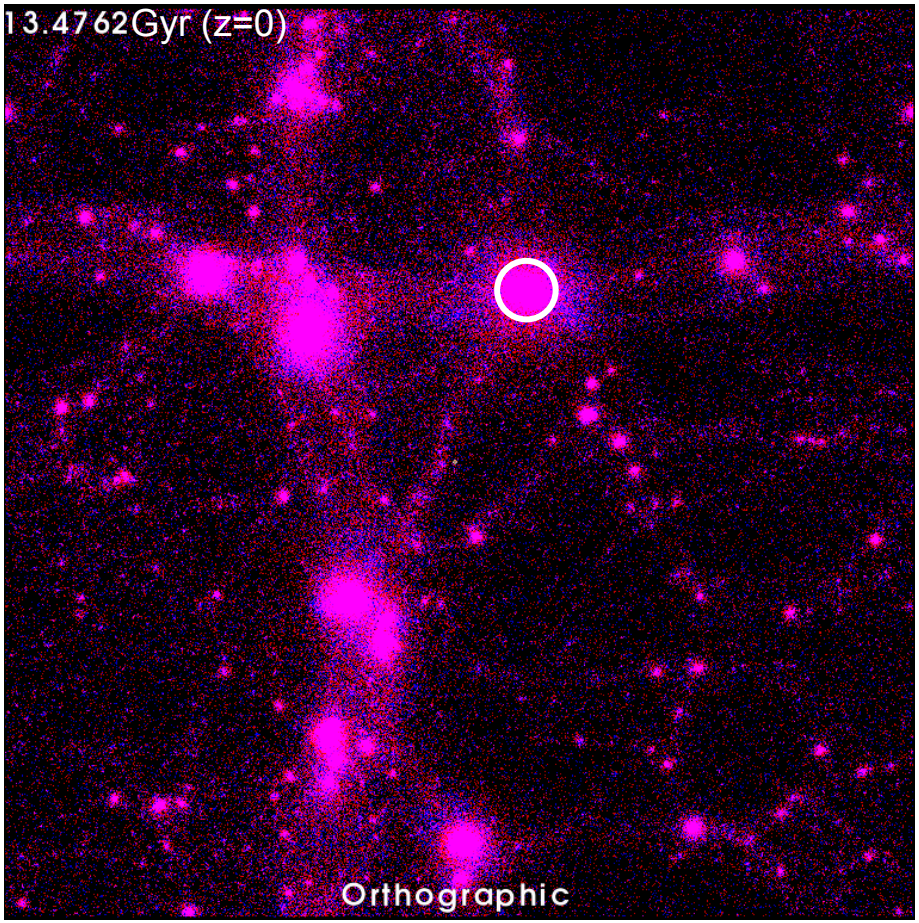

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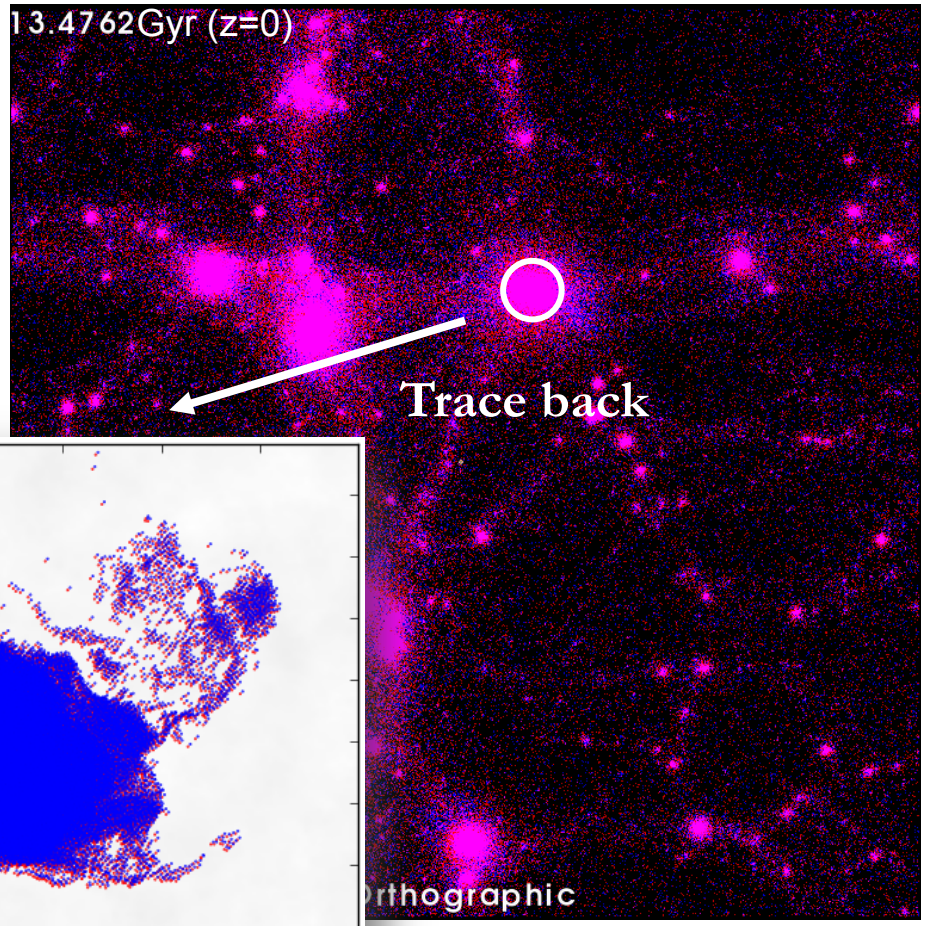

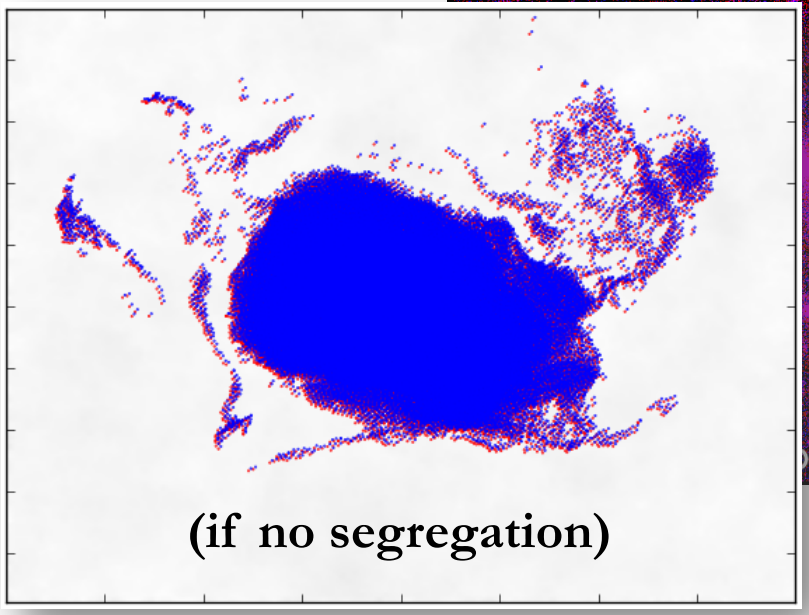

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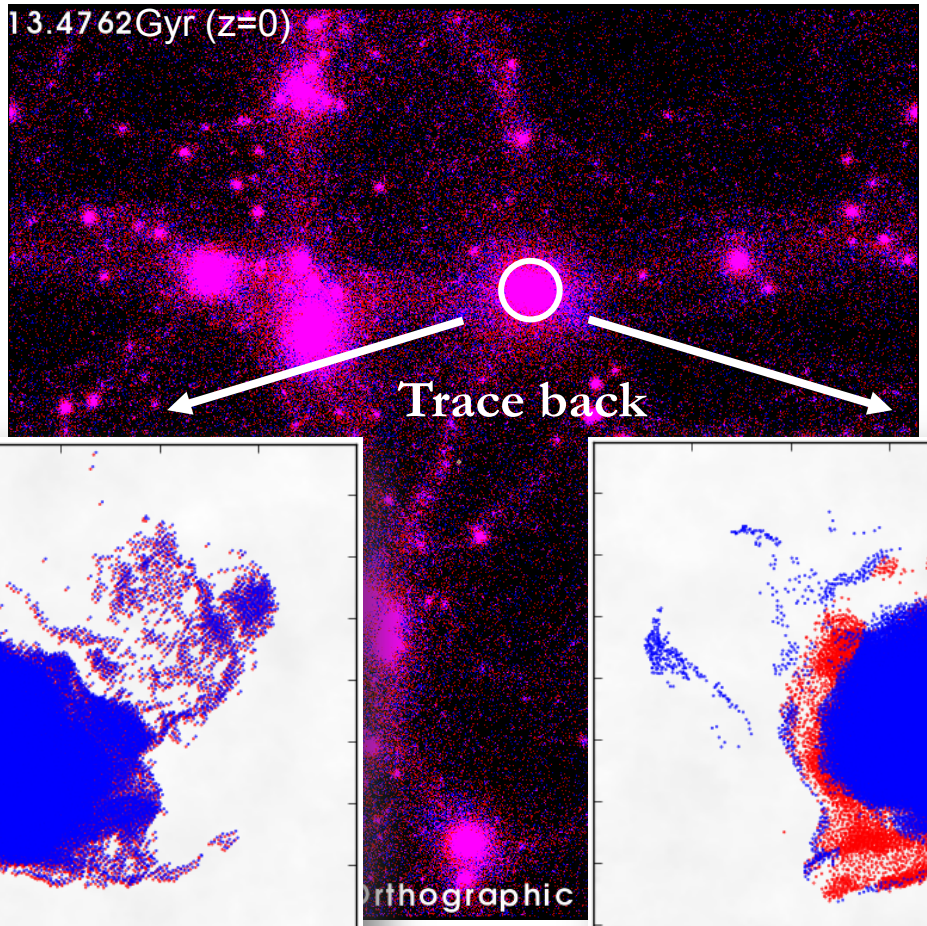
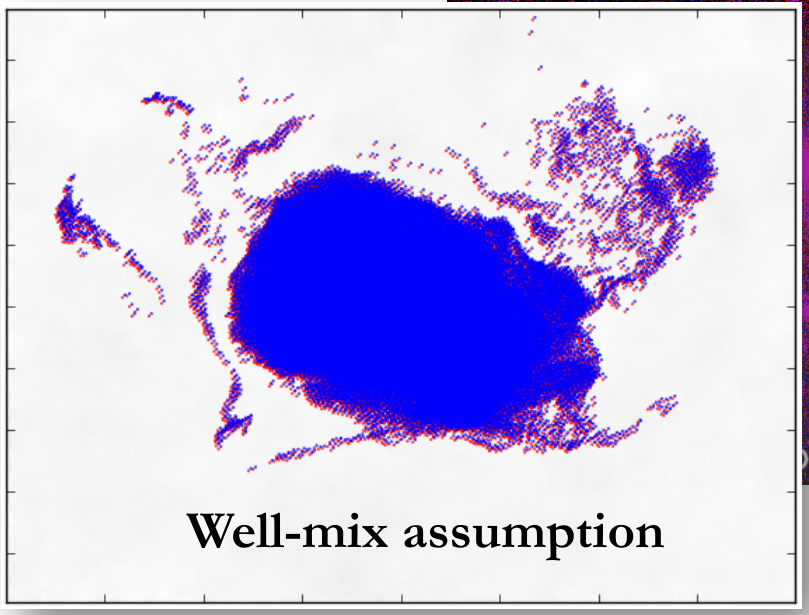
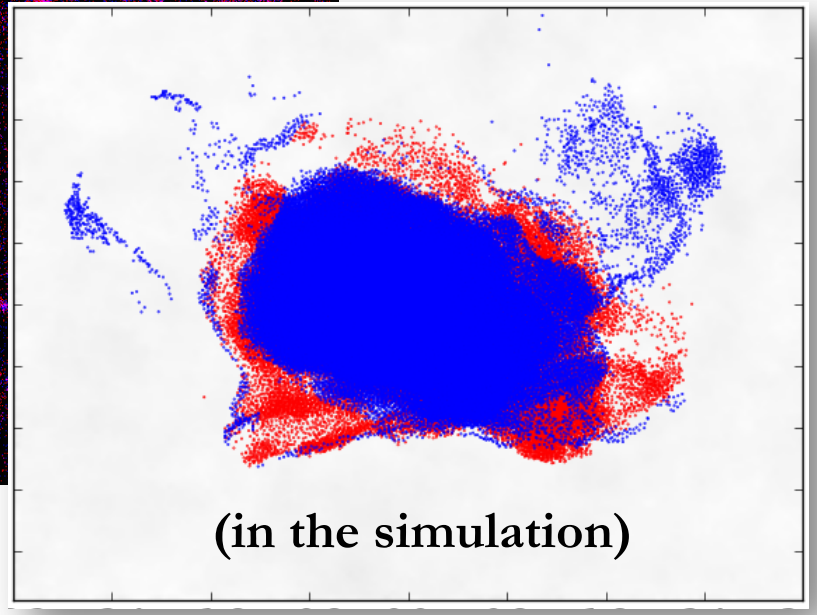
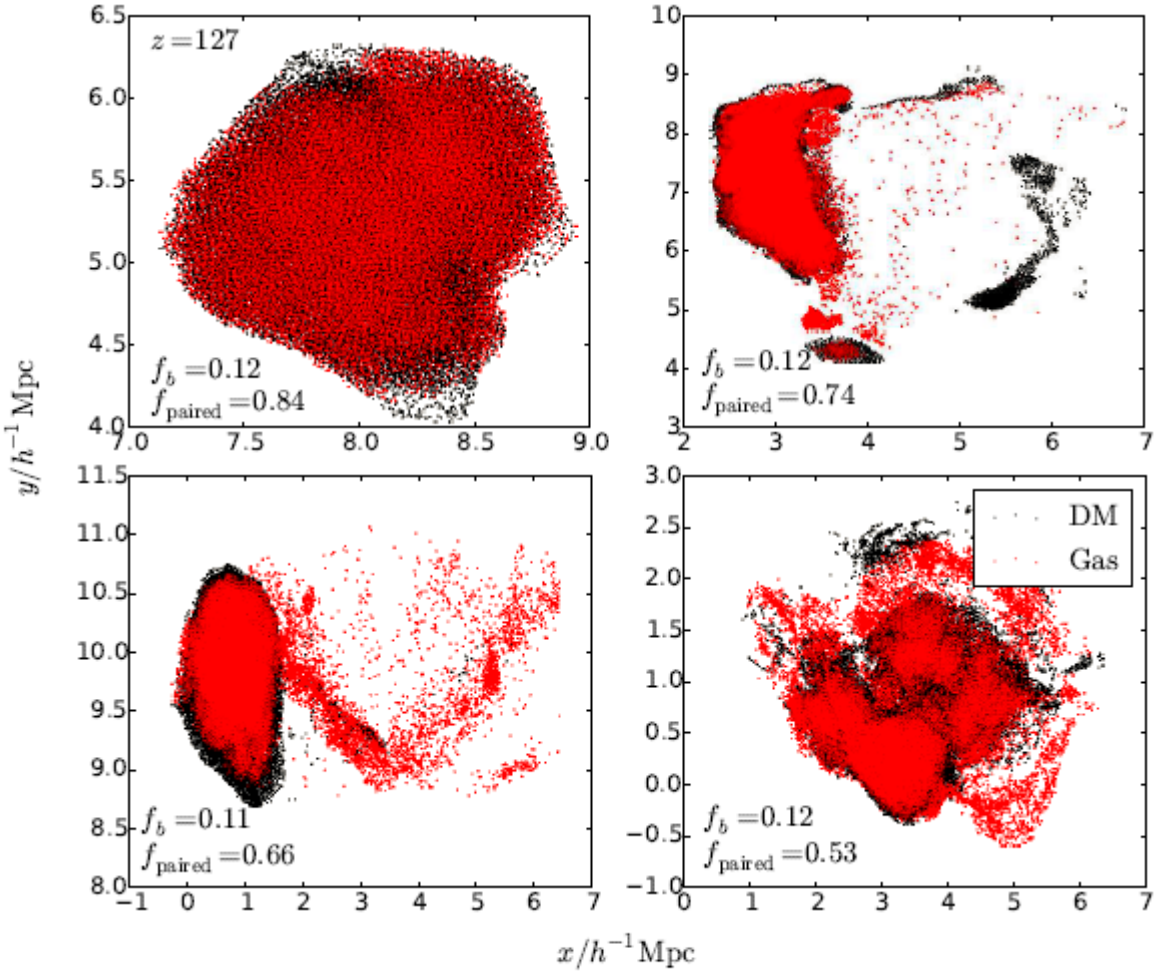






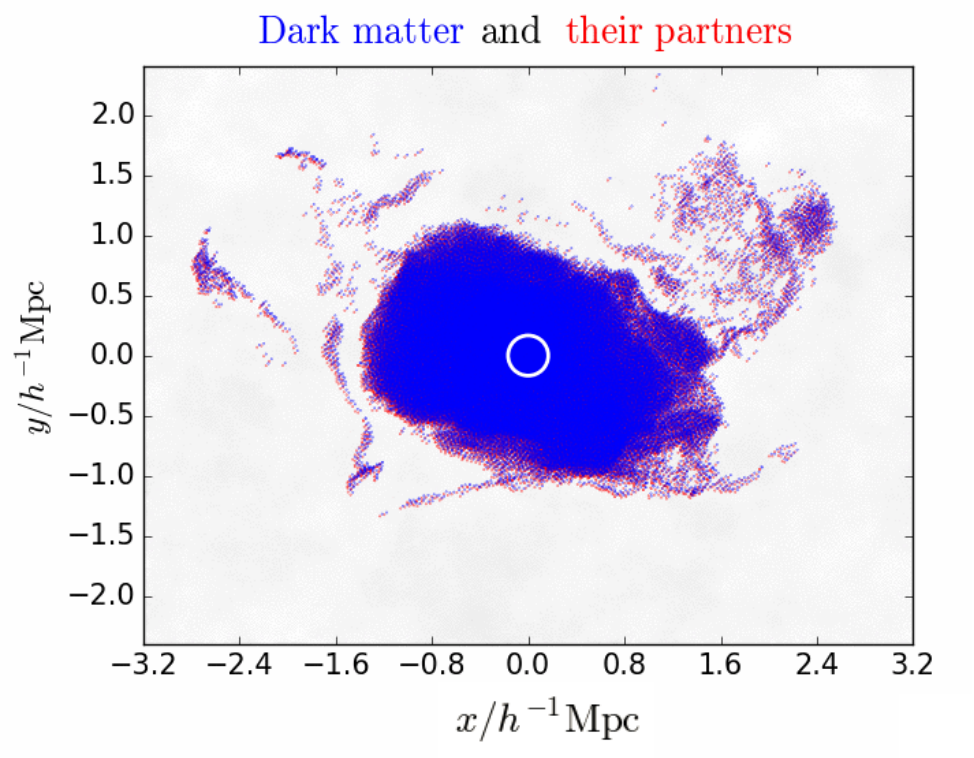
DM and gas of the present day haloes often do not come from the same regions in the initial conditions.



What causes DM-gas segregation?

- Merger
- Cosmic web striping
- Environmental effects
- …….

Example: halo merging can lead to segregation.



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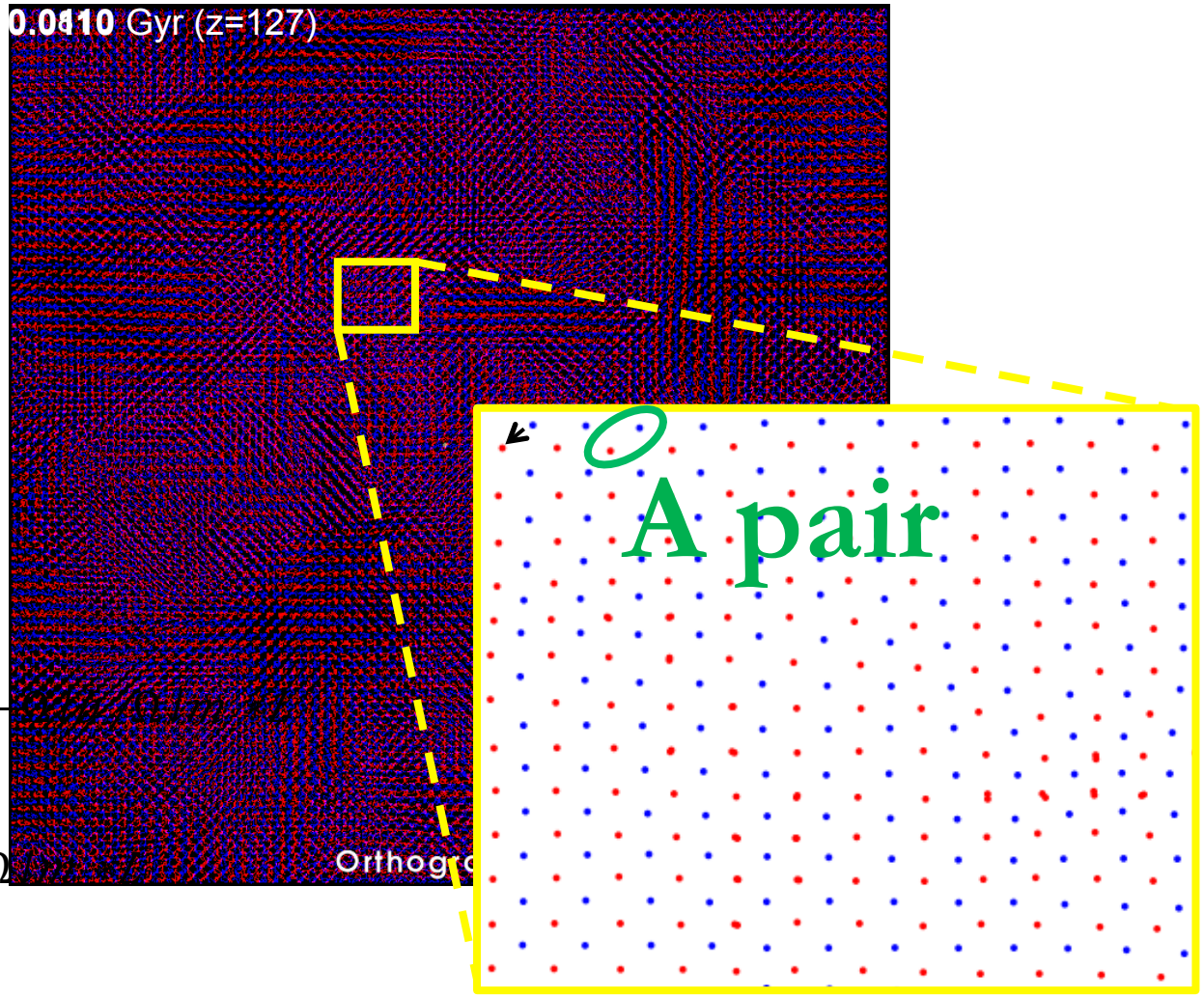
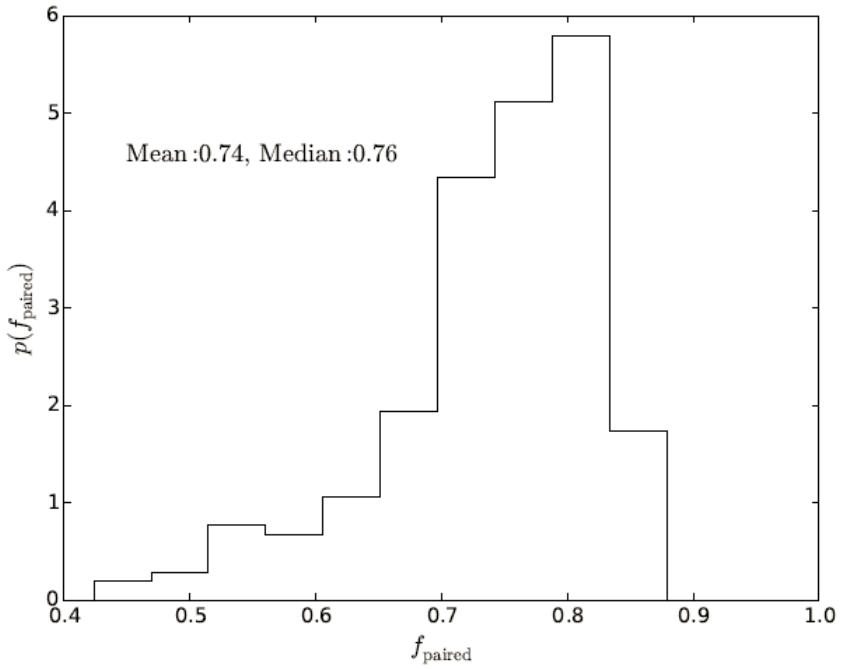


$x\downarrow gas \mathrel{+}= -0.5 * \Omega\downarrow m -$

$x\downarrow DM \mathrel{+}= 0.5 * \Omega\downarrow b \,/\Omega$

Quantifying the DM-gas segregation

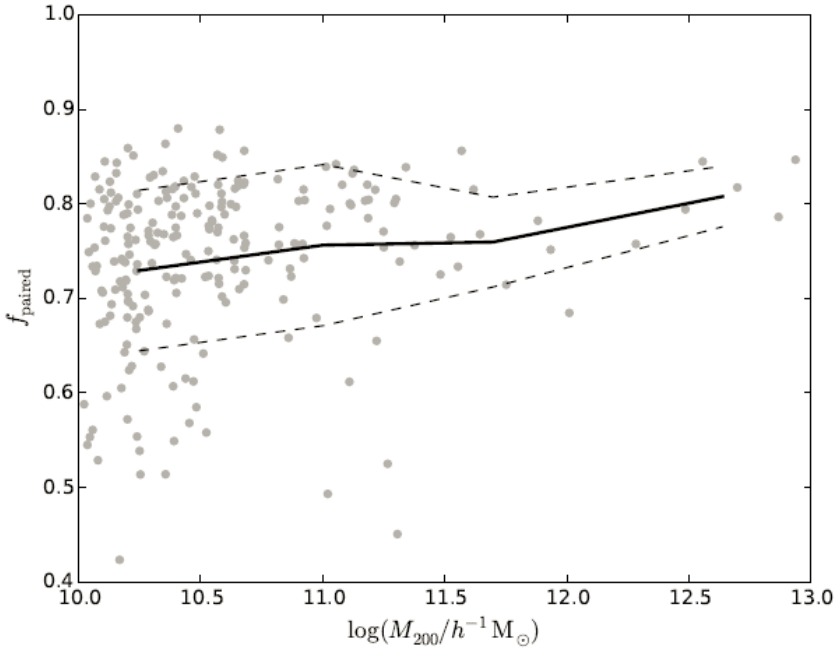
- Paired fraction $f_{\rm paired} \equiv \frac{2N_{\rm pairs}}{N_{\rm tot}}$



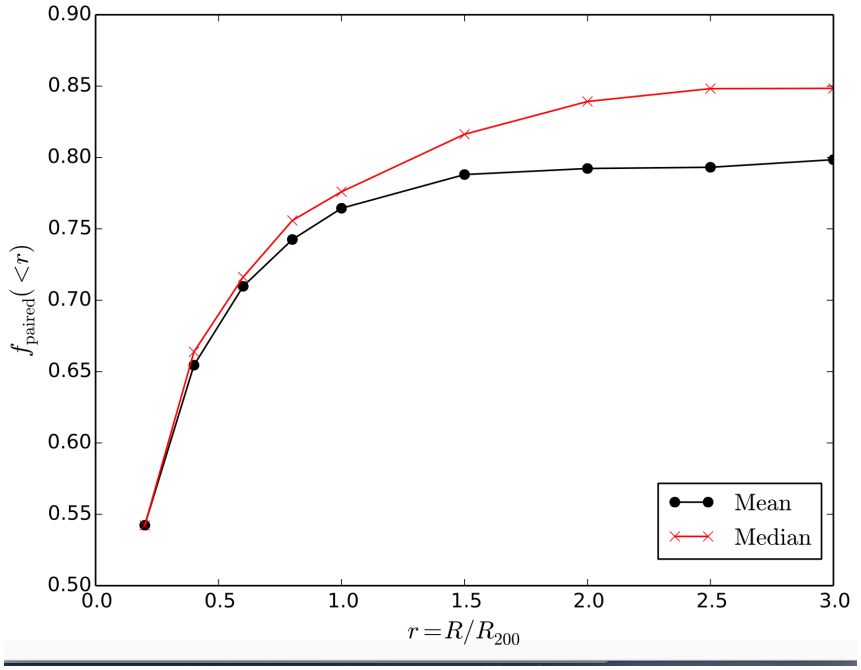
PDF of paired fraction

On average 26% of the particles in a halo are initially segregated, namely from different Lagrangian region

halo mass dependence



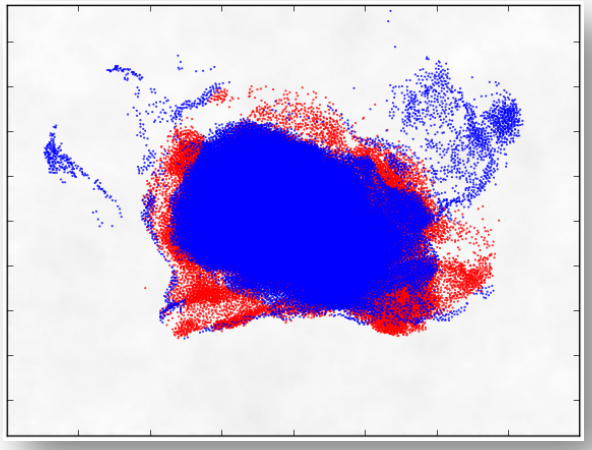
Radial dependence for
100 most massive halo



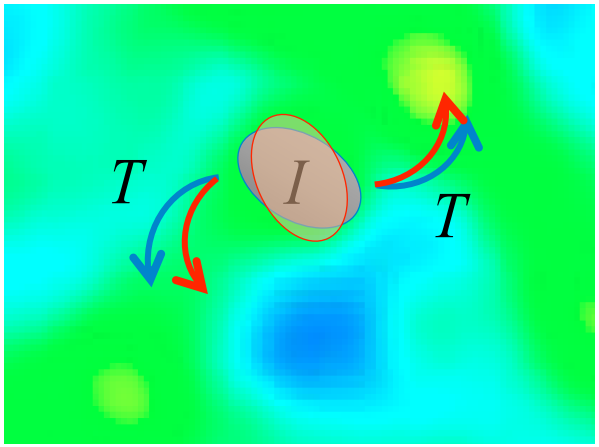
More massive halo less segregated

the inner particles of halo tend to be more segregated.

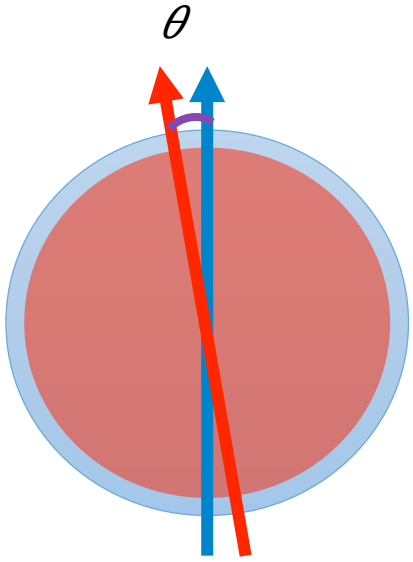
Implications on angular momentum misalignment between gas and DM



Segregation

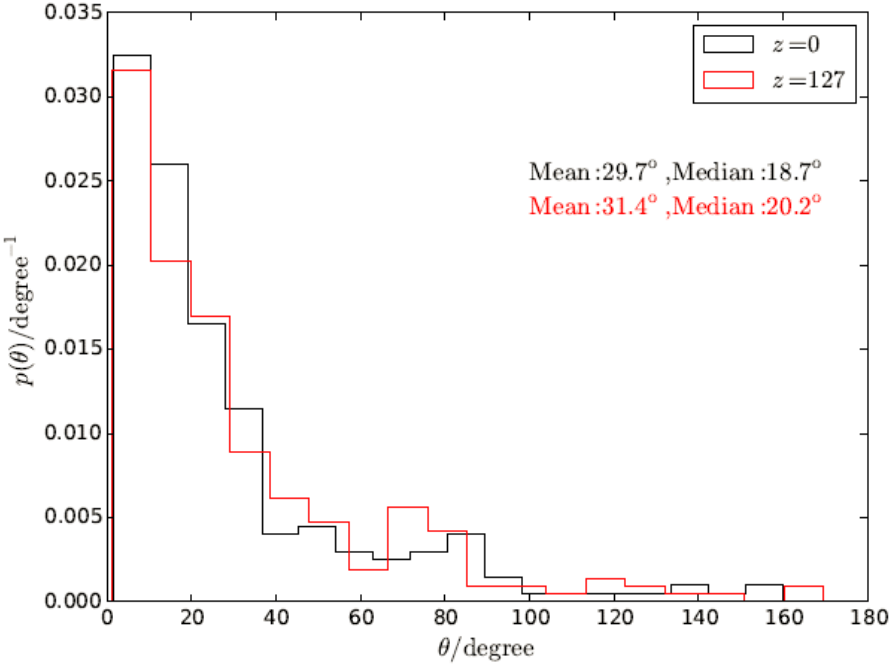


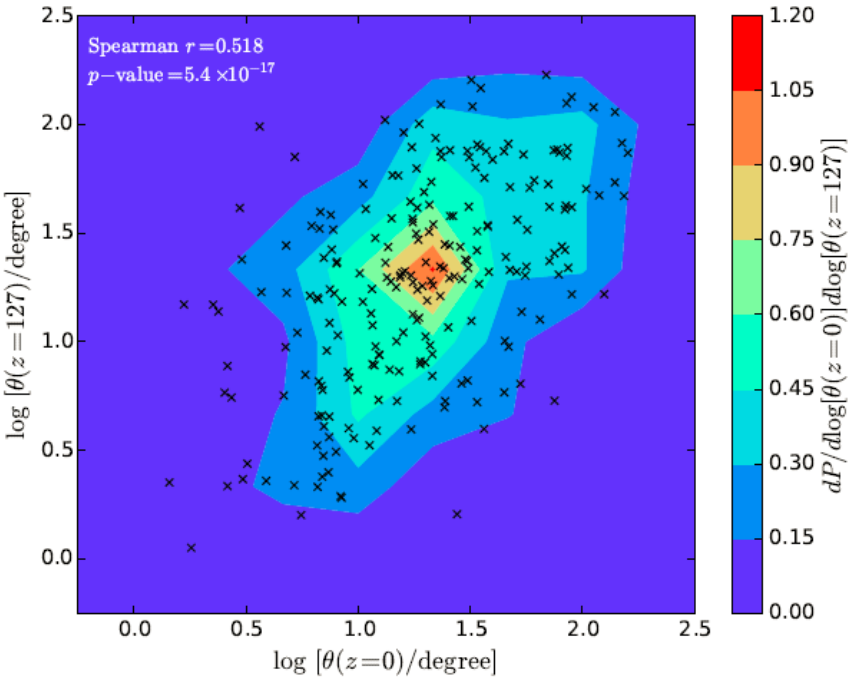
Different tidal forces



Different A.M.

Misalignment at z=0 and in the initial conditions



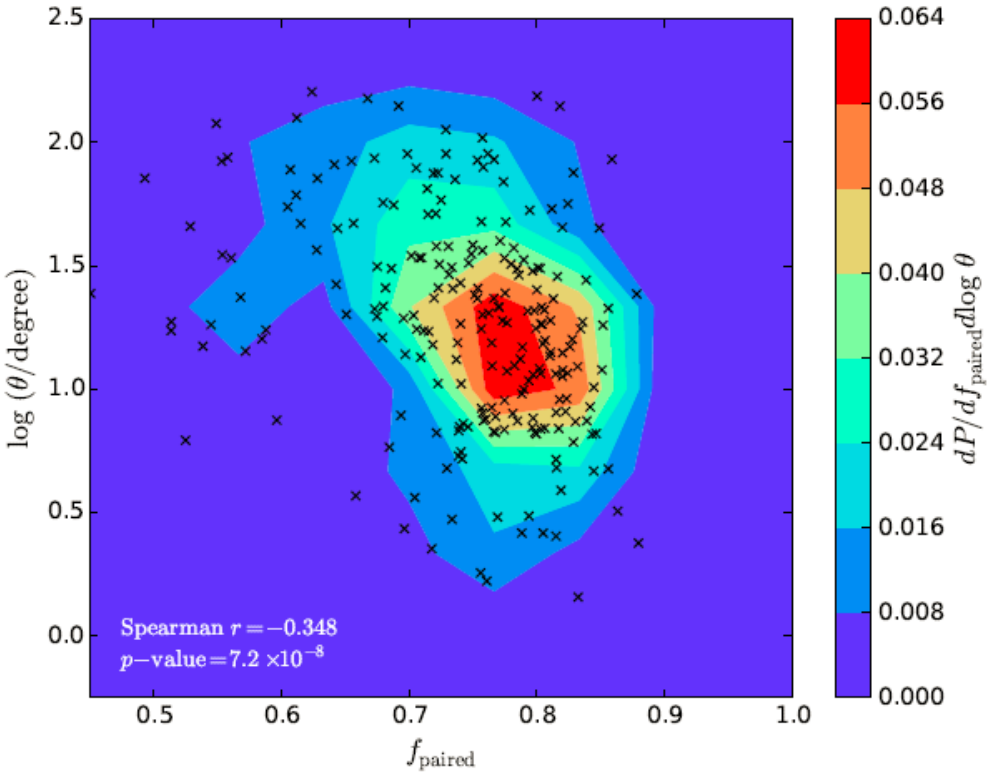


PDF misalignment angle is identical for the present day halos and their counterparts in the initial conditions

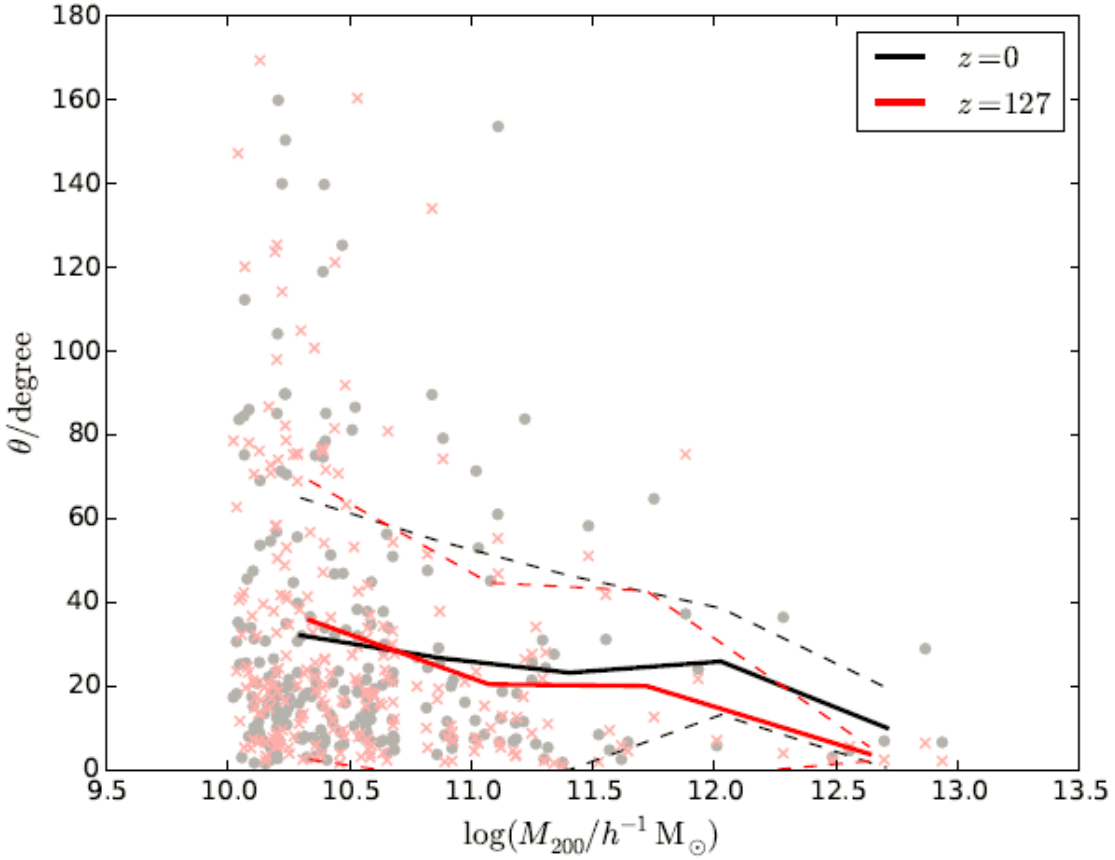
Strong correlation between Misalignment angle at z=10 and z=127 for individual halos

Correlation between the segregation strength and misalignment angle

- A halo that has a stronger segregation tends to have a larger misalignment angle



Halo mass dependence of misalignment angle naturally explained



Less massive halo, more segregated in the initial conditions

→ larger misalignment angle.

→Misalignment between gas and dark matter should be caused by gas-dark matter segregation effect in the initial conditions.

Summary

- Dark matter and gas components of halos are initially segregated with varying extend.
- On average ~ 25% of the matter (dark and baryonic) in a halo originates from different Lagrangian region.

- The gas-DM segregation effect is at odd with the standard assumptions in semi-analytical approaches.

- The gas-DM segregation effect naturally solve the AM misalignment puzzle.