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Spin Transfer during Dark Matter Halo Formation

Jie Li, QUC fellow at KIAS
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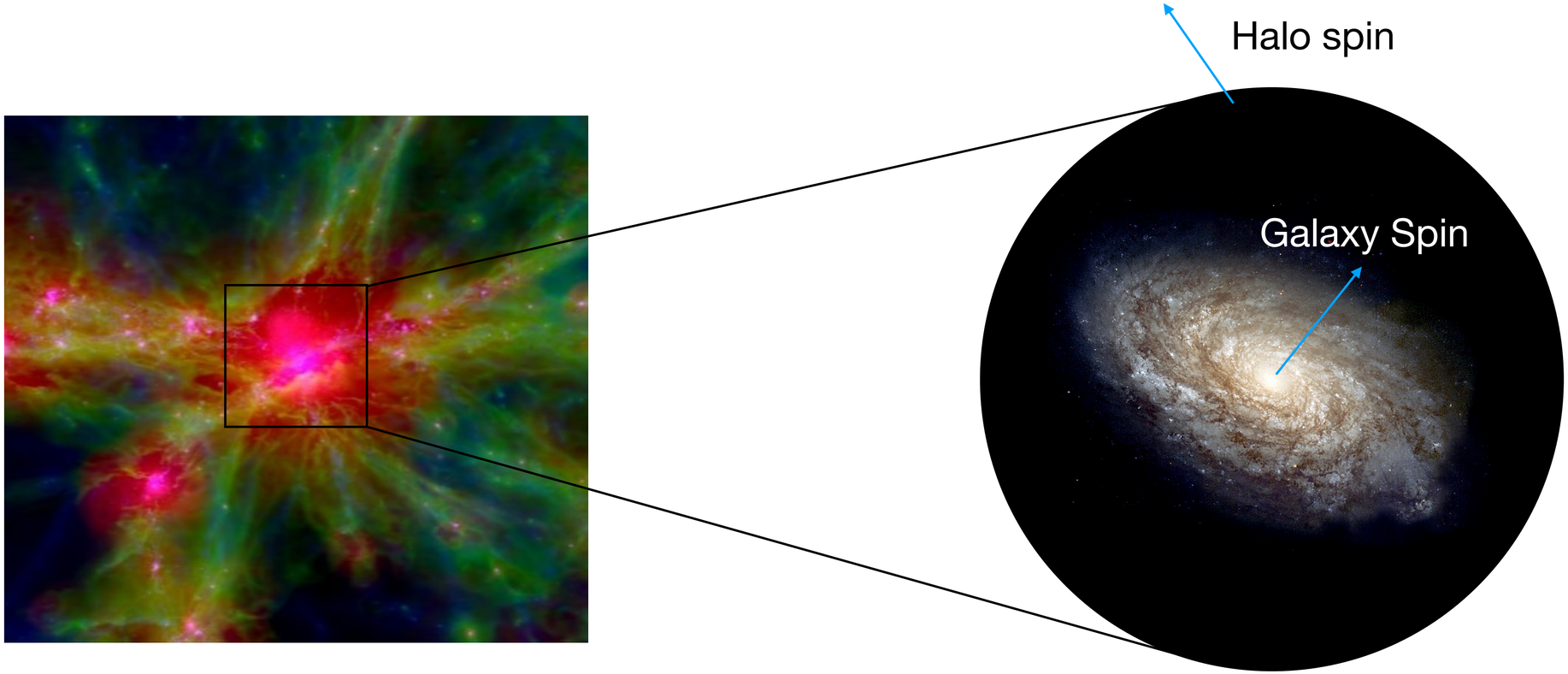
Supervisors: Prof. Changbom Park, Prof. Danail Obreschkow, A/Prof. Claudia Lagos, Prof. Chris Power

Large-scale origin of spin



Cosmic Web → (Tidal torques) → Halo spin → (Galaxy formation) → Galaxy spin → (Galactic Dynamics) → Galactic properties

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Parameters

$$\text{Angular momentum} : \vec{J} = \sum m\,\vec{r} \times \vec{v}$$

$$\text{Specific angular momentum} : j = \frac{\left| \sum m\,\vec{r} \times \vec{v} \right|}{\sum m}$$

$$\text{Spin parameter} : \lambda = \frac{J\,|E|^{1/2}}{GM^{5/2}}$$

$$j_{\rm gas}/j_{\rm DM} = \lambda_{\rm gas}/\lambda_{\rm DM}$$

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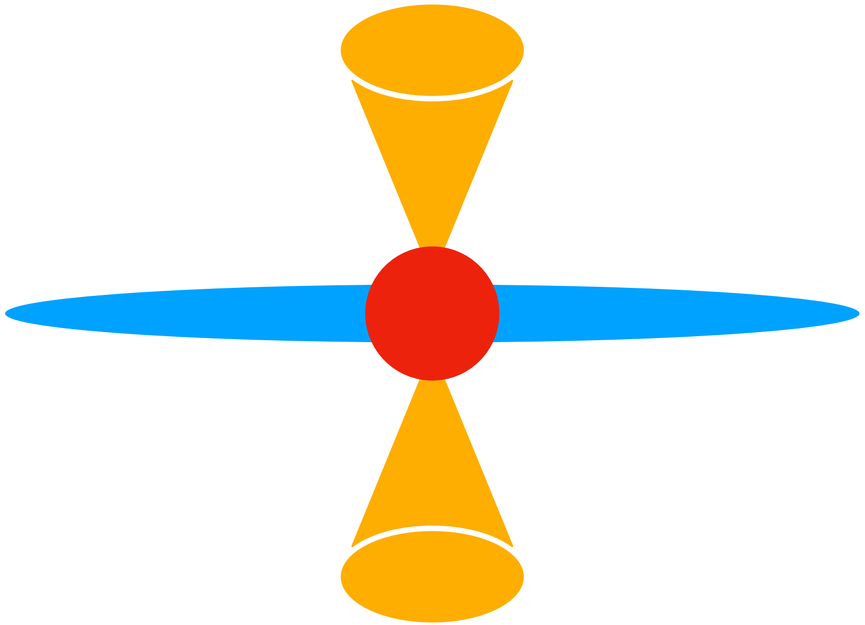
Assumption

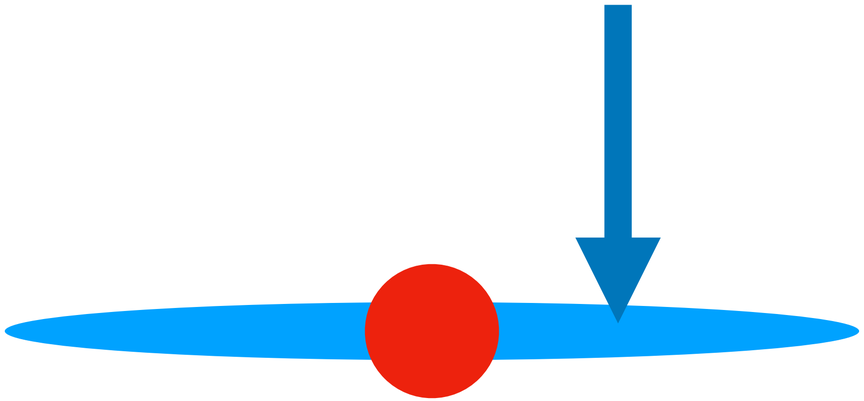
- Mo et al. 1998: Gas and dark matter share the same specific angular momentum within dark matter haloes
- Derived the scale length of disc galaxies in Mo et al. 1998
- Semi-analytical models; weak lensing
- However, the cosmological simulations have challenged this assumption!

Cosmological simulations

Gas has more specific angular momentum than dark matter



Feedback



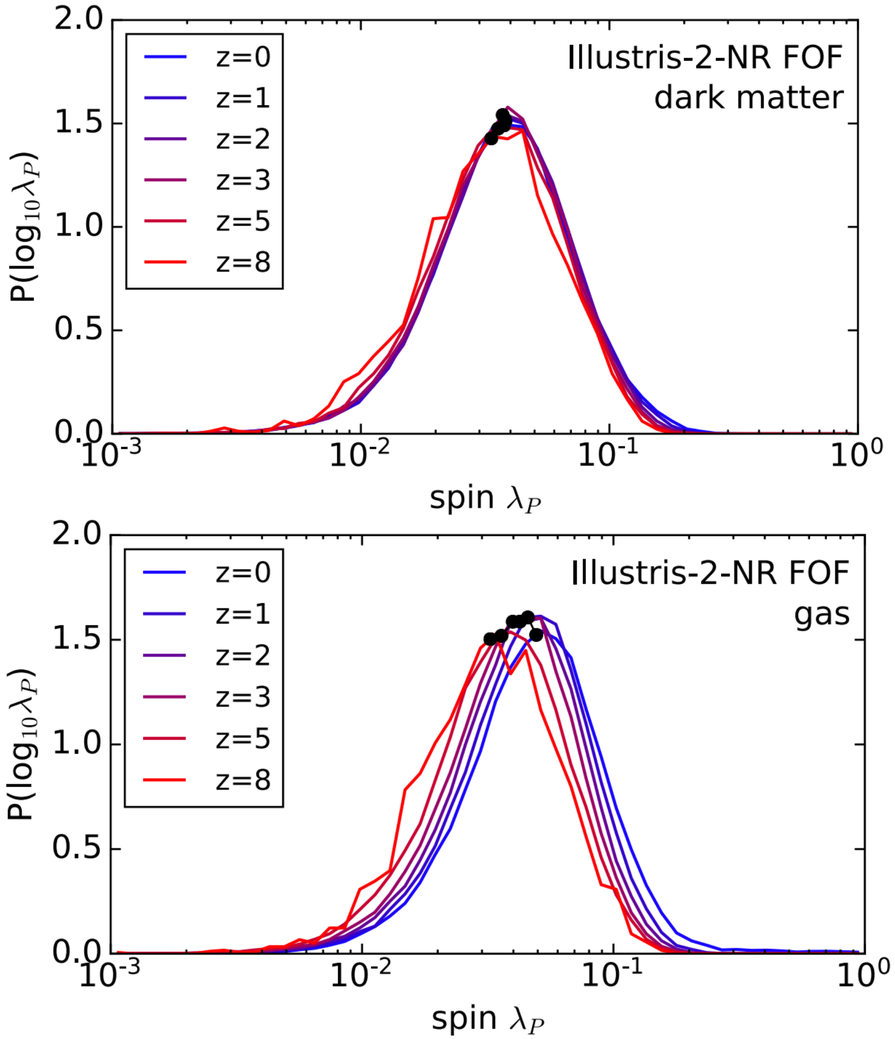
Cold gas stream accretion

Cosmological simulations

Even removing these sub-grid physics, the spin of gas is still higher than that of dark matter.

Non-radiative hydrodynamical simulations:

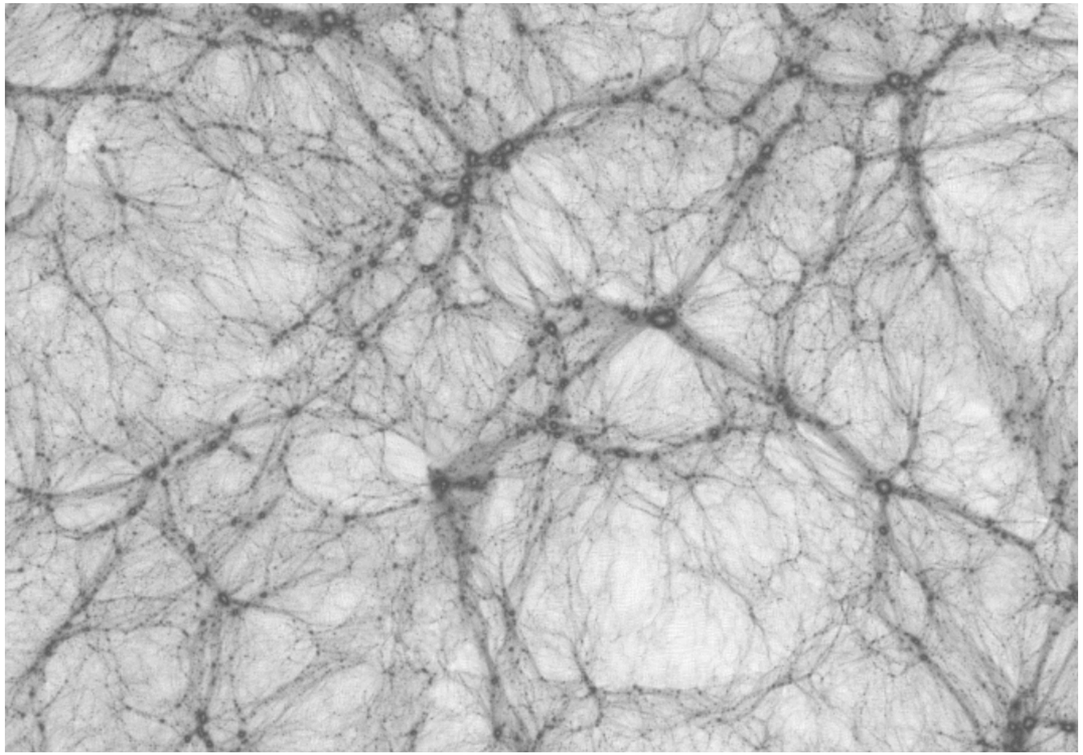
- z=0, λ_{gas} / λ_{DM} ~1.2 (Chen et al., 2003)
- z=0, λ_{gas} / λ_{DM} ~1.4 (Sharma & Steinmetz, 2005)
- z=0, λ_{gas} / λ_{DM} ~1.3 (Zjupa & Springel, 2017)



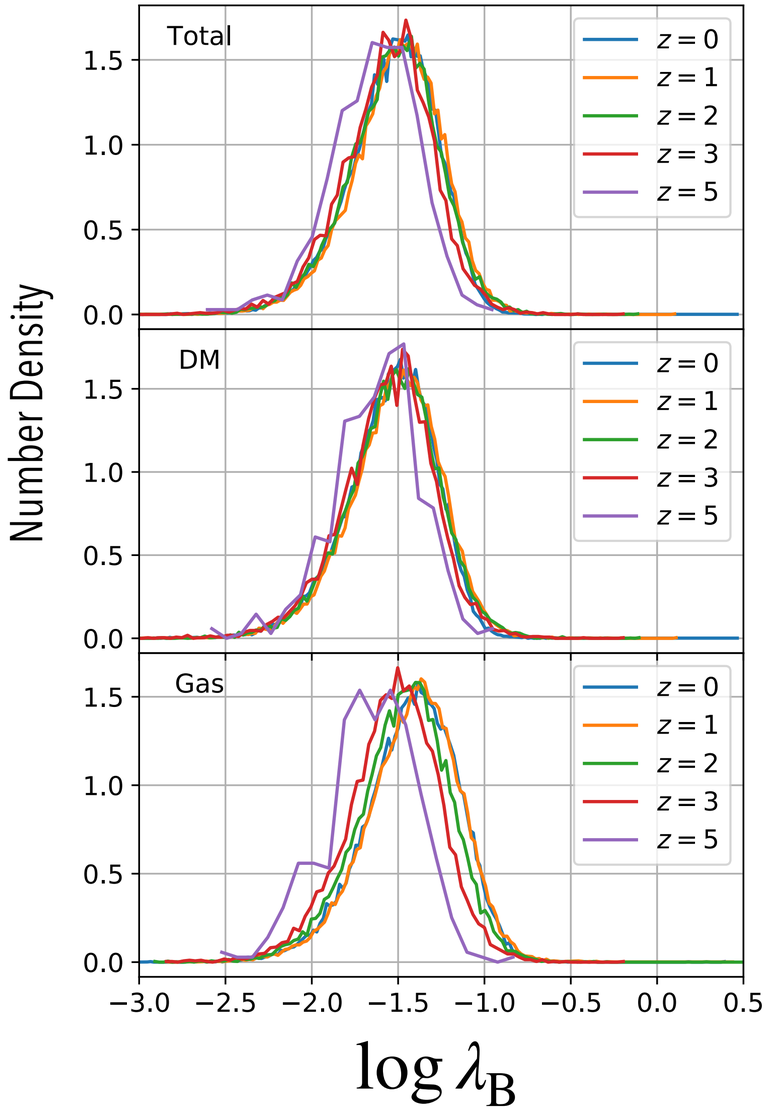
Zjupa et al. 2017

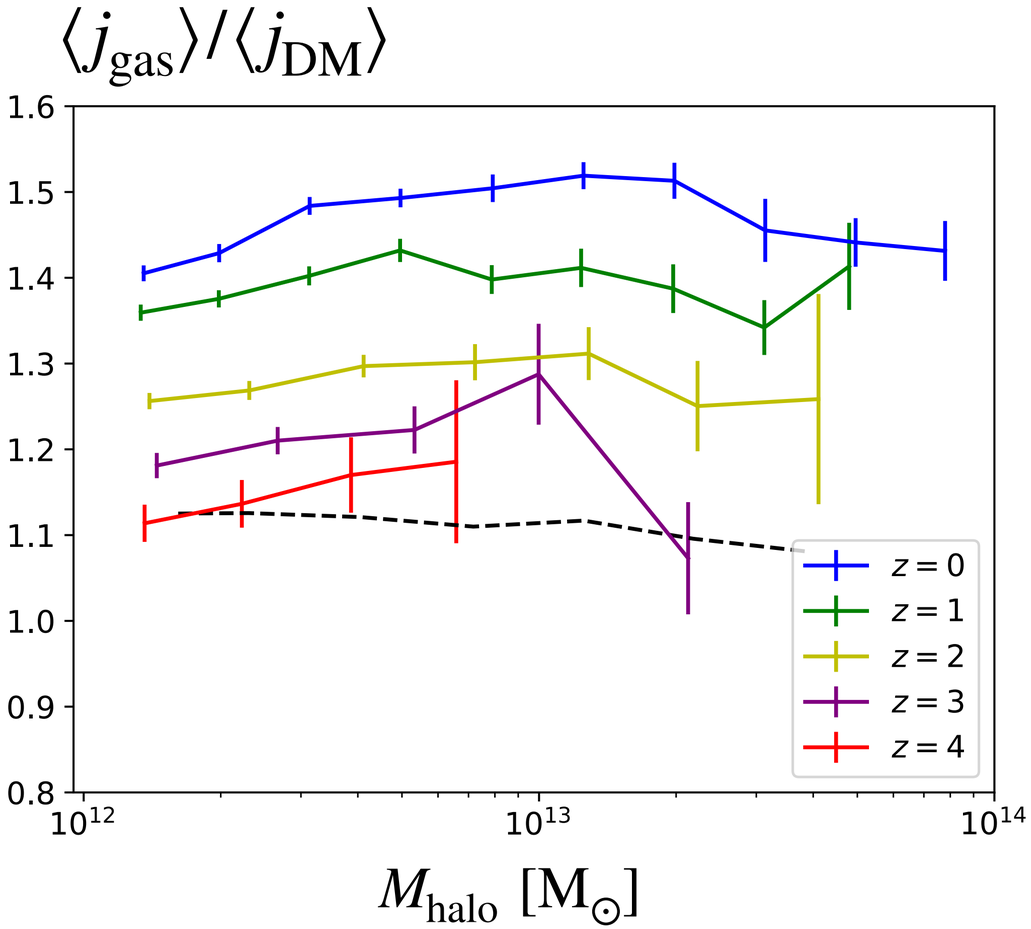
In-house cosmological simulation

- ☆Using the SUFR-hydro simulation (Elahi et al.2018) to investigate AM of gas and DM within haloes
- ☆Including DM & gas, gas without radiative cooling, no galaxy formation



Spin in a single halo structure



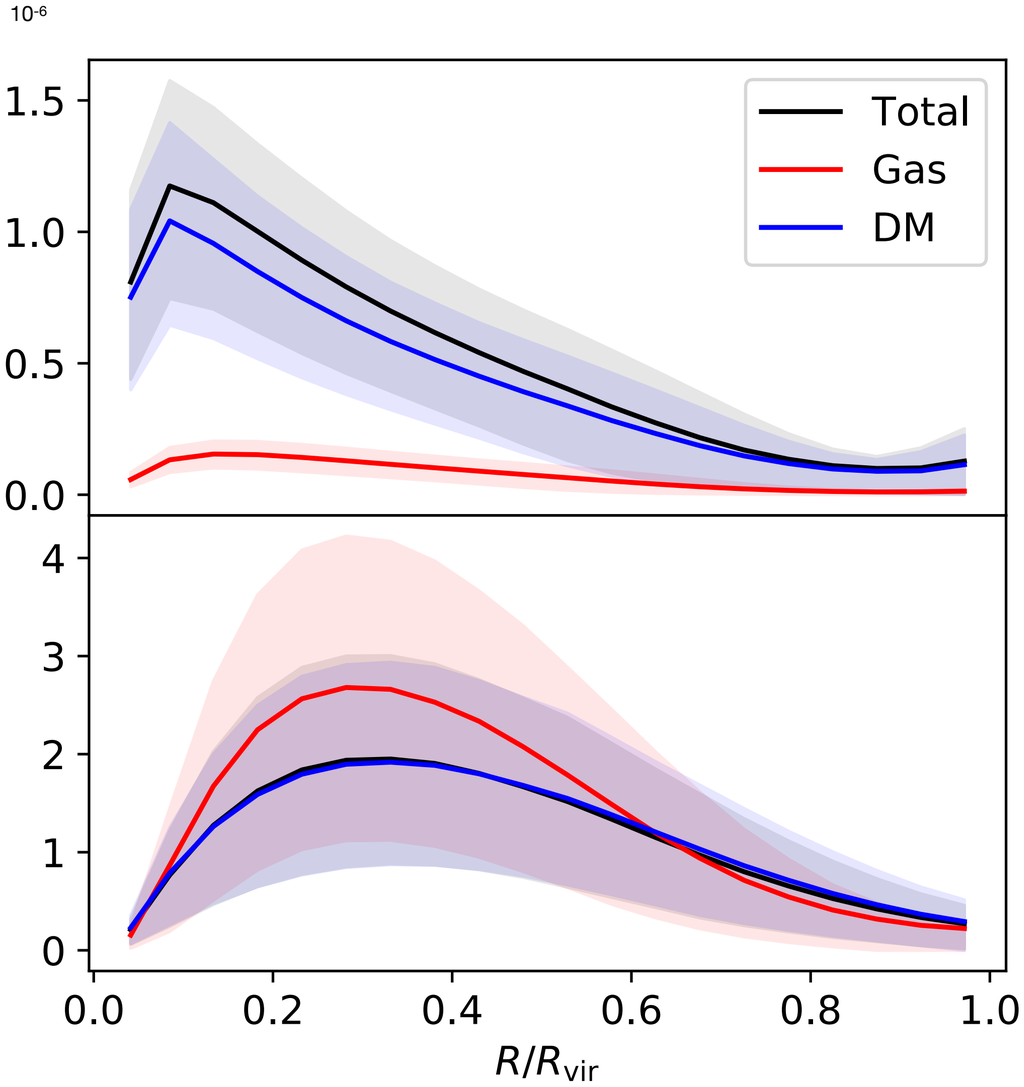


Li et al. 2022

Spin distribution within haloes

$$\frac{\mathrm{d}M}{\mathrm{d}V} \Big/ \left[\frac{4\pi R_{\rm vir}^3}{M_{\rm vir}}\right]$$

$$\frac{\mathrm{d}J}{\mathrm{d}R} \Big/ \left[\frac{f M_{\rm vir}^{5/3}}{R_{\rm vir}}\right]$$

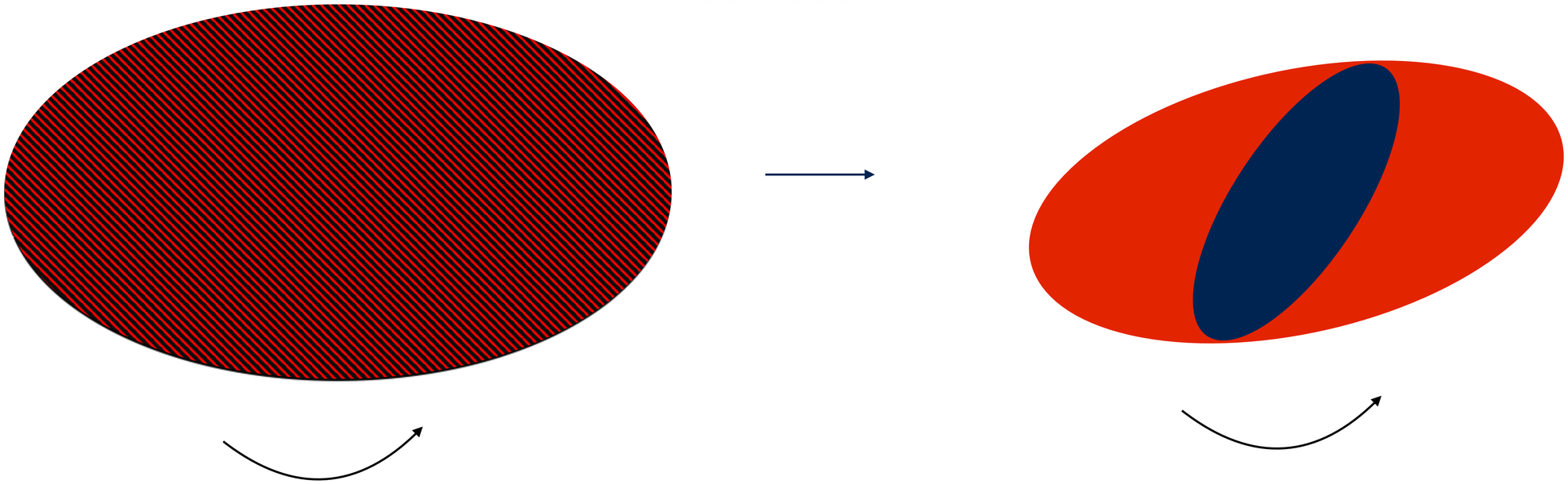


Li et al. 2022

Schematic idea

Black: dark matter

Red : Gas



Use controlled simulations to test!

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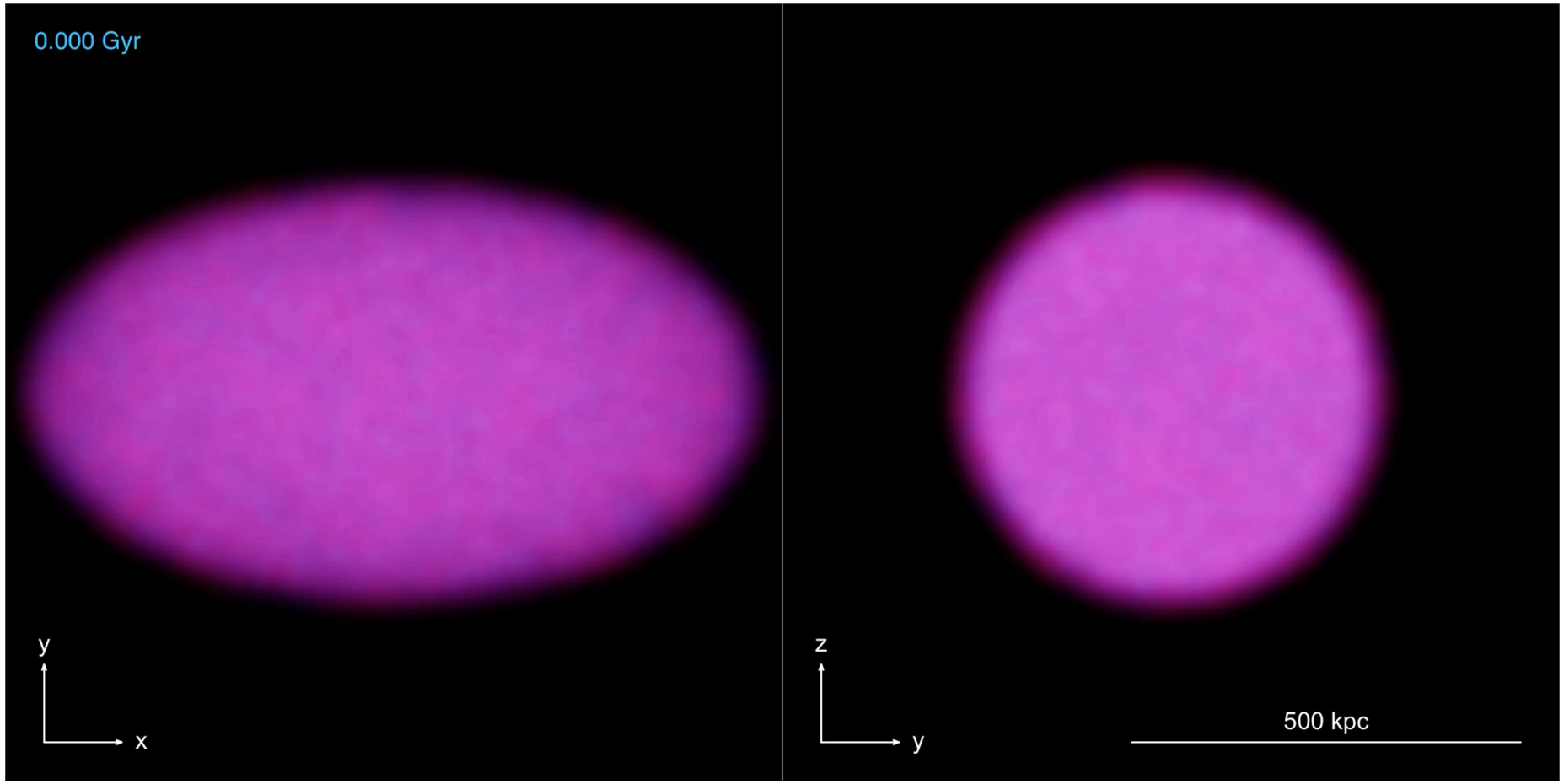
Controlled Simulation



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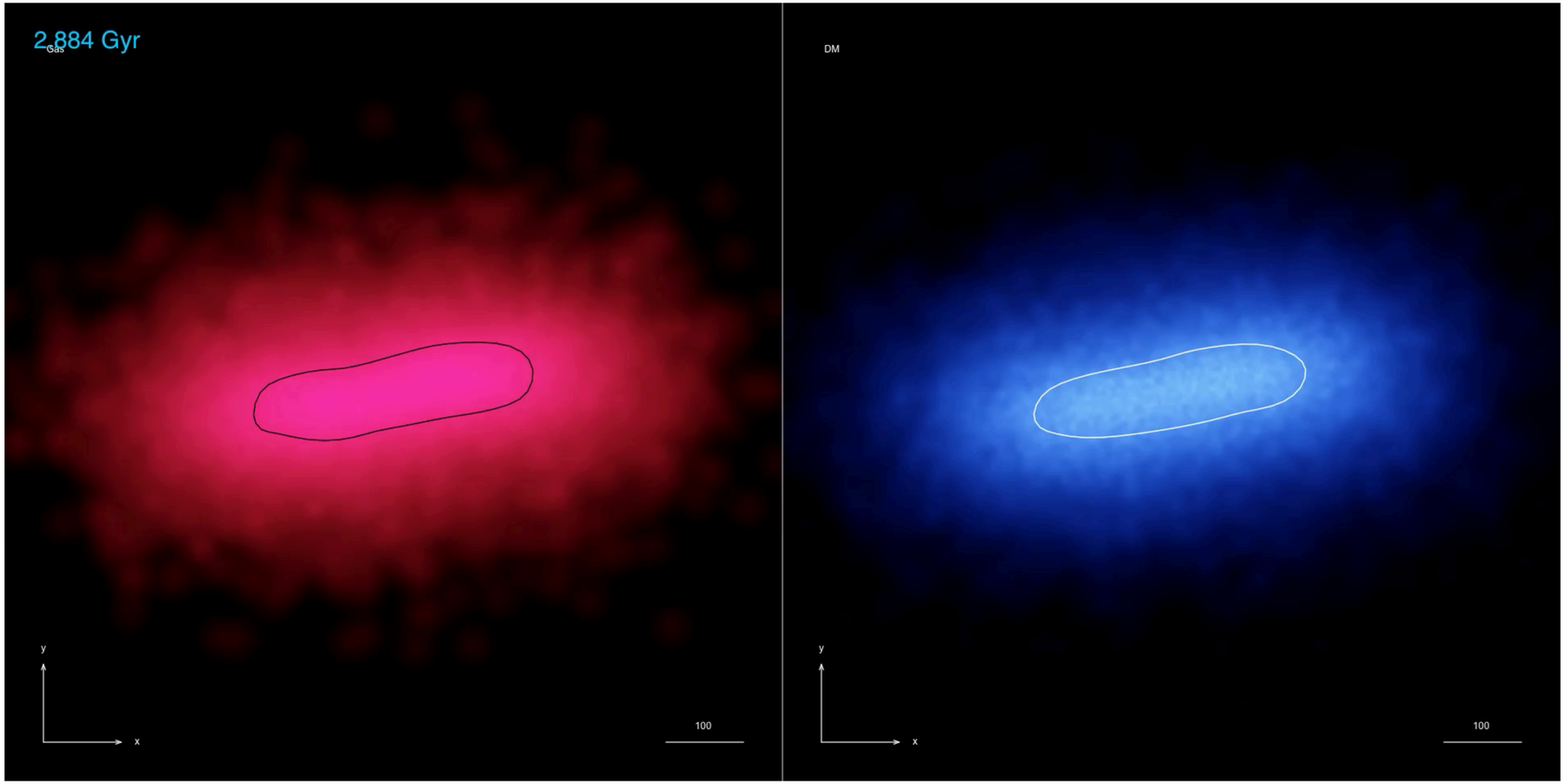
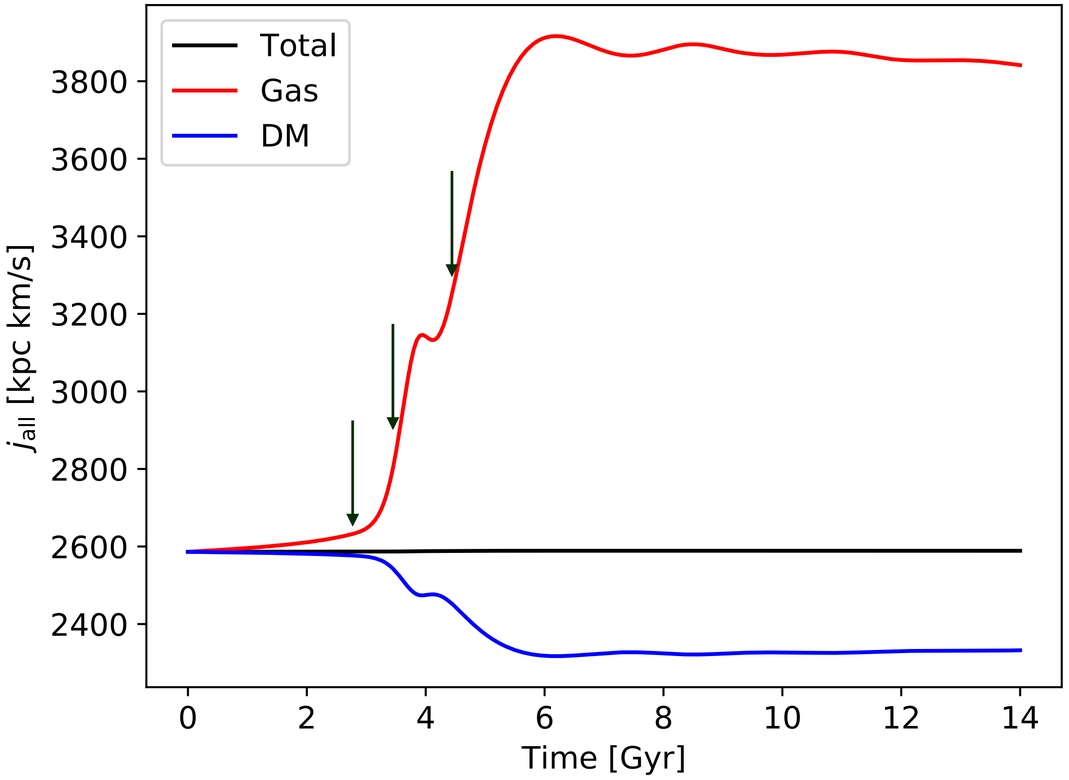
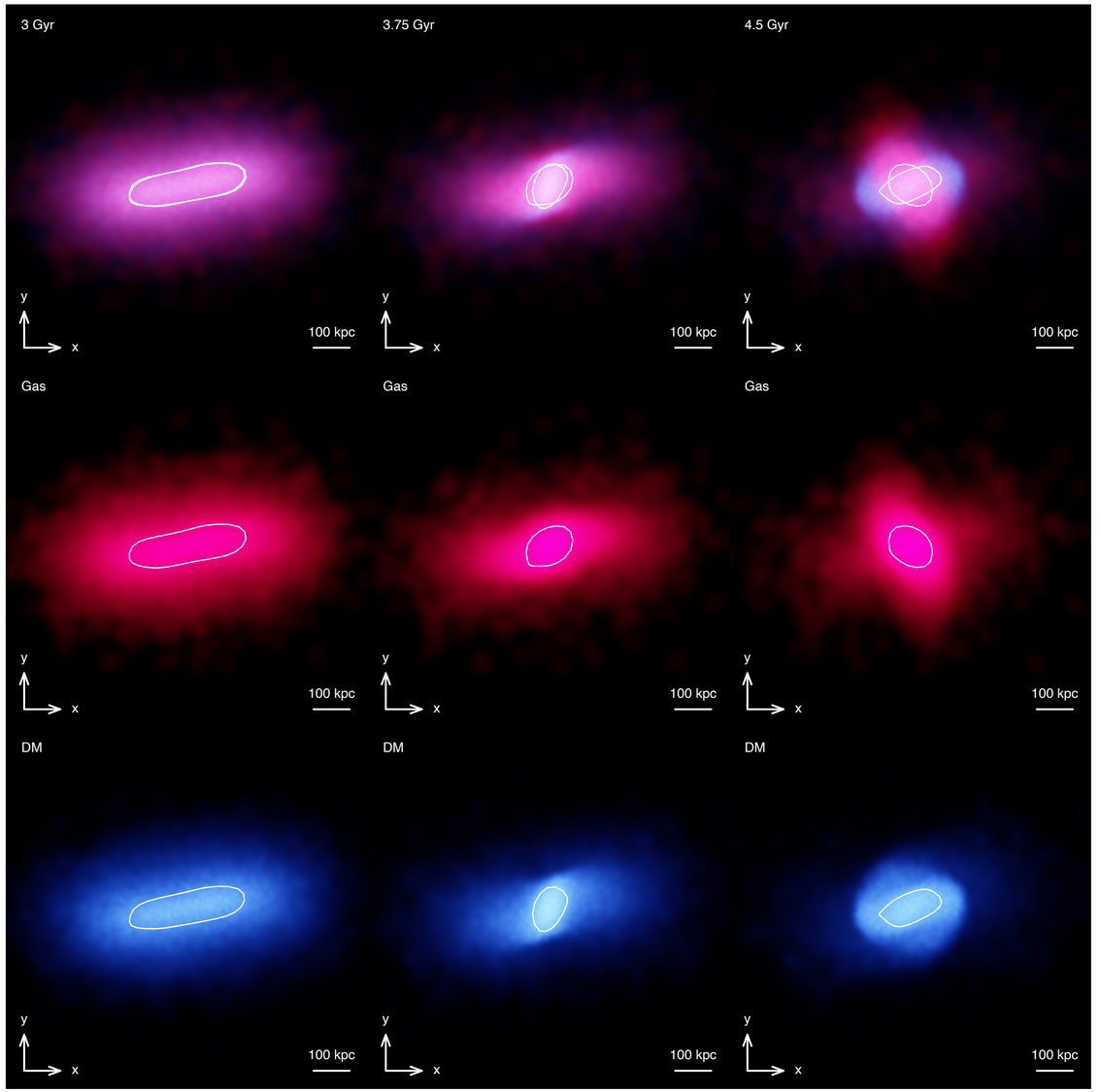
Controlled simulation

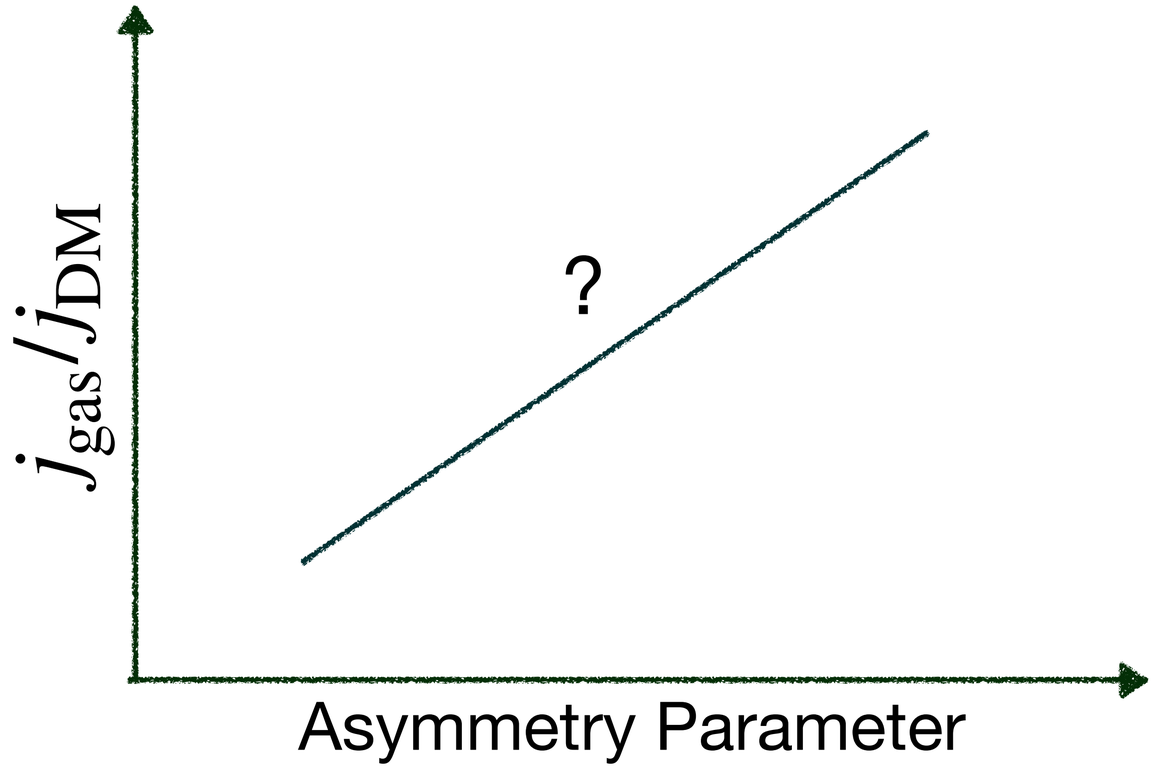


AM transfer in controlled simulation





Statistical results



Asymmetry parameter

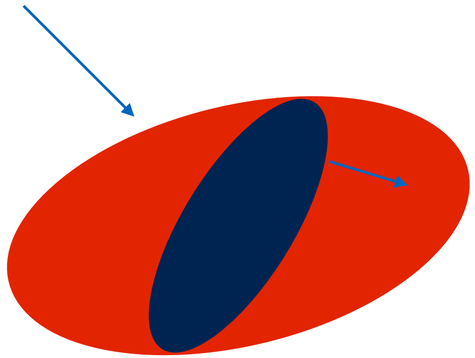
Geometric parameter

$$\alpha = \frac{\langle x^2 \rangle - \langle y^2 \rangle}{\langle z^2 \rangle} \ln(c)\,\lambda$$

Initial spin parameter

Collapse factor

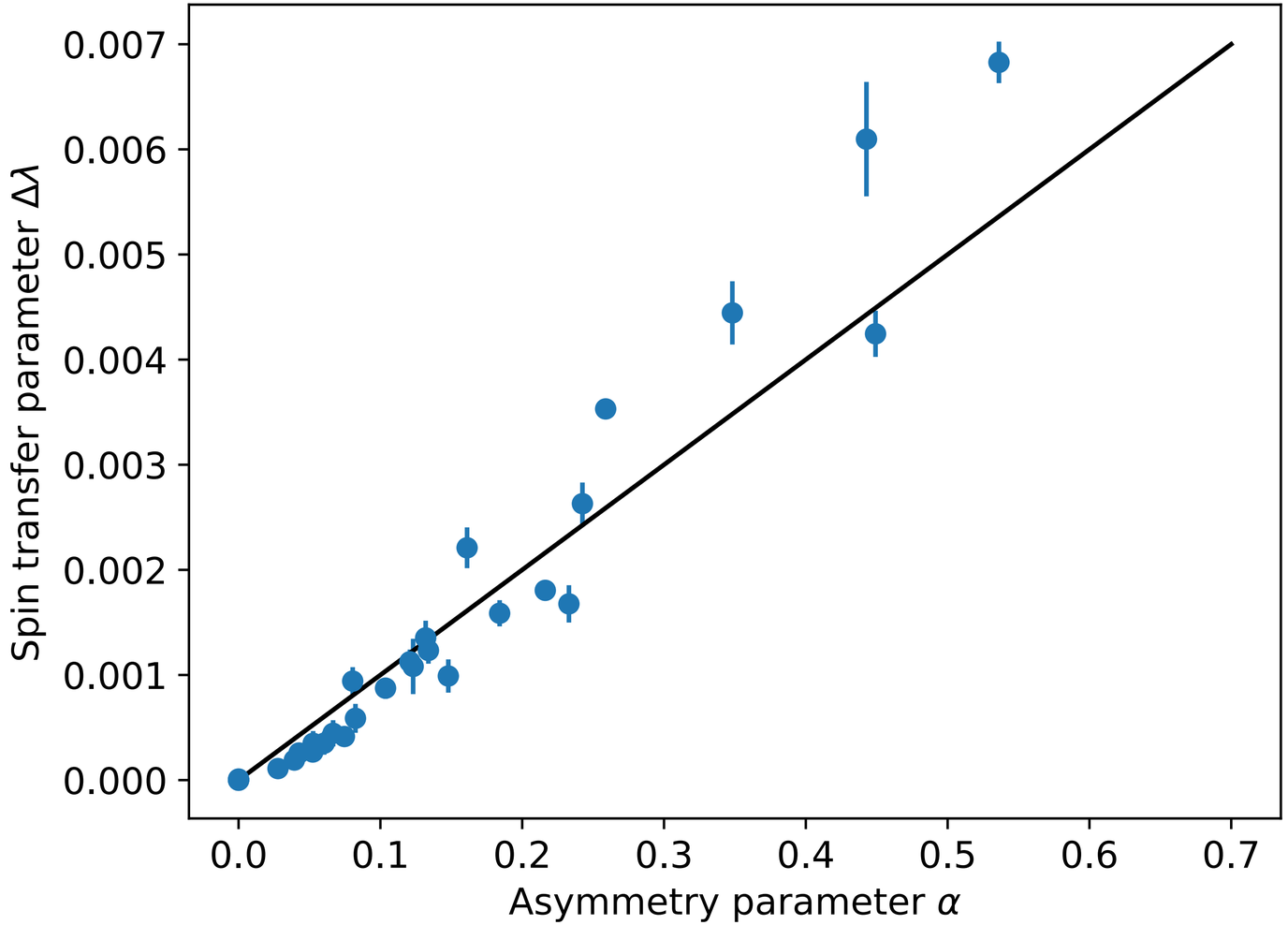
Spin transfer parameter



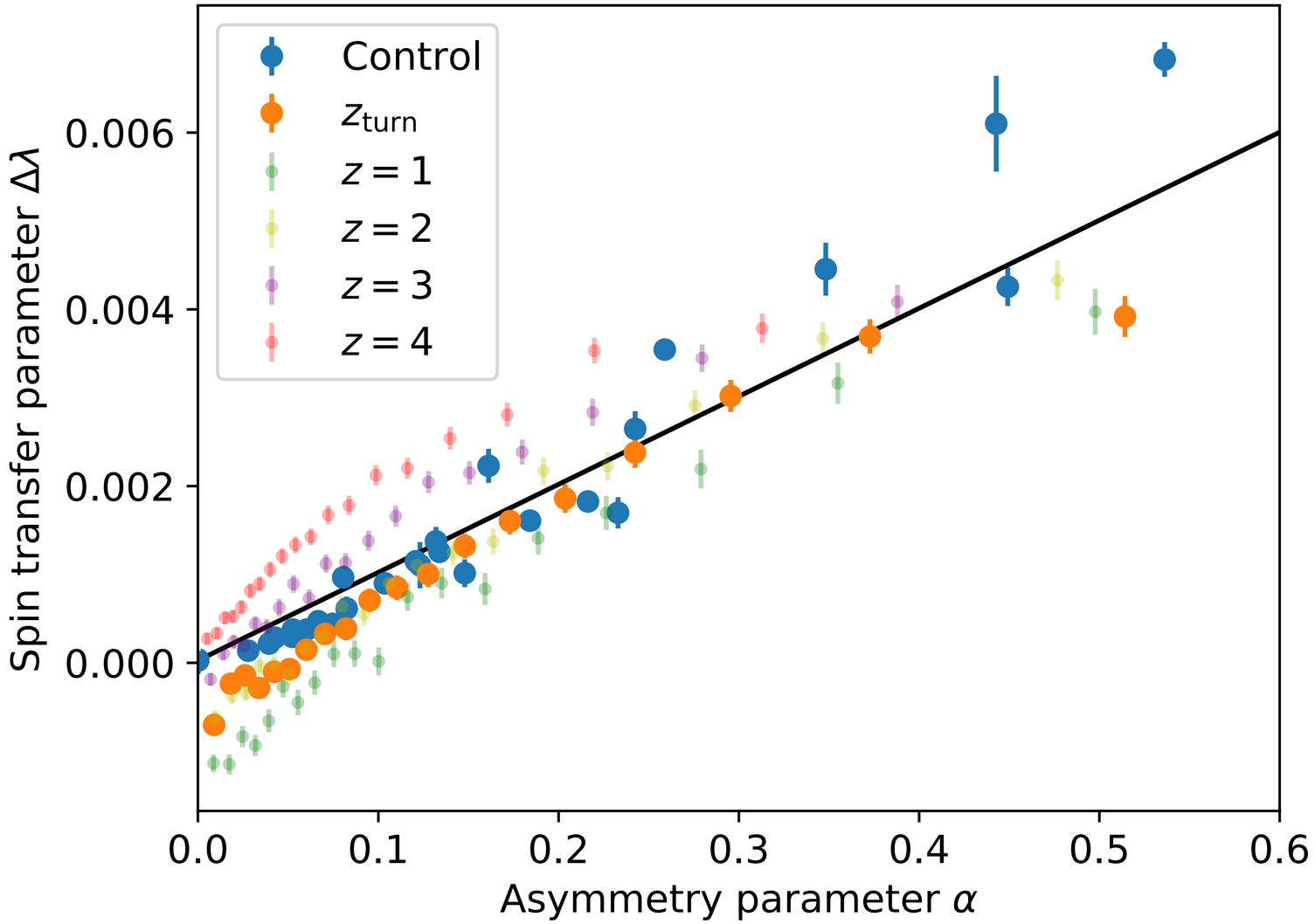
$$\rightarrow \Delta\lambda = \frac{\Delta j\,|E|^{1/2}}{GM^{3/2}}$$ (for controlled simulations)

$$\rightarrow \Delta\lambda = \frac{\Delta j}{(2GM)^{2/3}}$$ (for cosmological simulations)

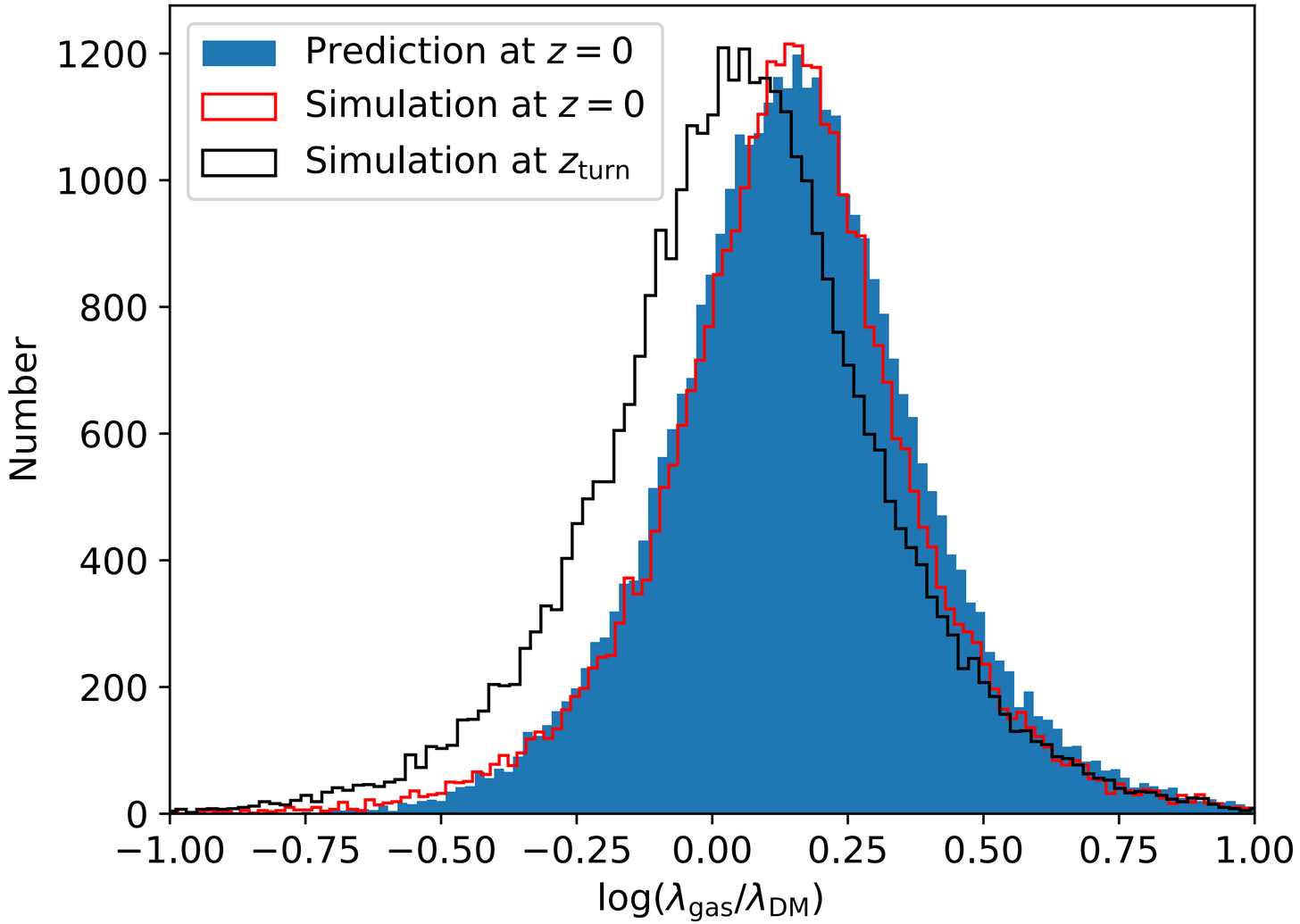
Asymmetry parameter



AM transfer in cosmological simulation



Prediction


Prediction at $z = 0$
Simulation at $z = 0$
Simulation at $z_{\rm turn}$
Number
0
200
400
600
800
1000
1200
−1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
$\log(\lambda_{\rm gas}/\lambda_{\rm DM})$

Conclusion & Future

- This project gives a solid explanation of the enhancement of mean $j_{\rm gas}$ to $j_{\rm DM}$ in non-radiative simulations.
- The enhancement mainly comes from the torques between gas and DM during asymmetrical collapse.
- The amount of angular momentum transfer based on the asymmetrical depends on the shape, collapse factor, and initial spin parameter of the proto-halo.

- Future
- What will happen if switch on more physical processes?