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Dependence of the dark matter halo assembly bias on halo definition and orientation

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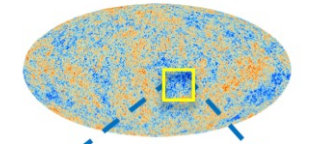
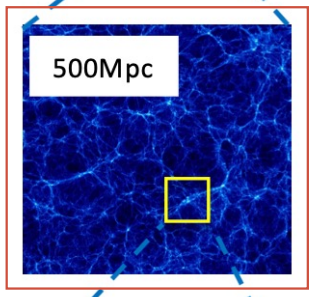
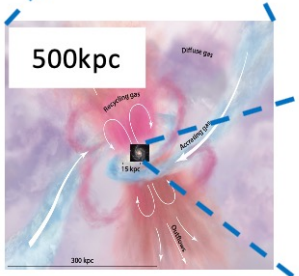
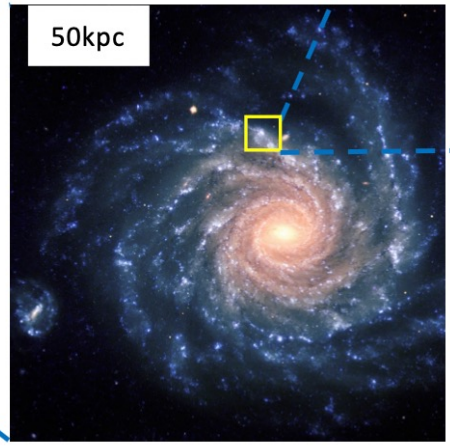
Galaxies form and evolve in dark matter haloes

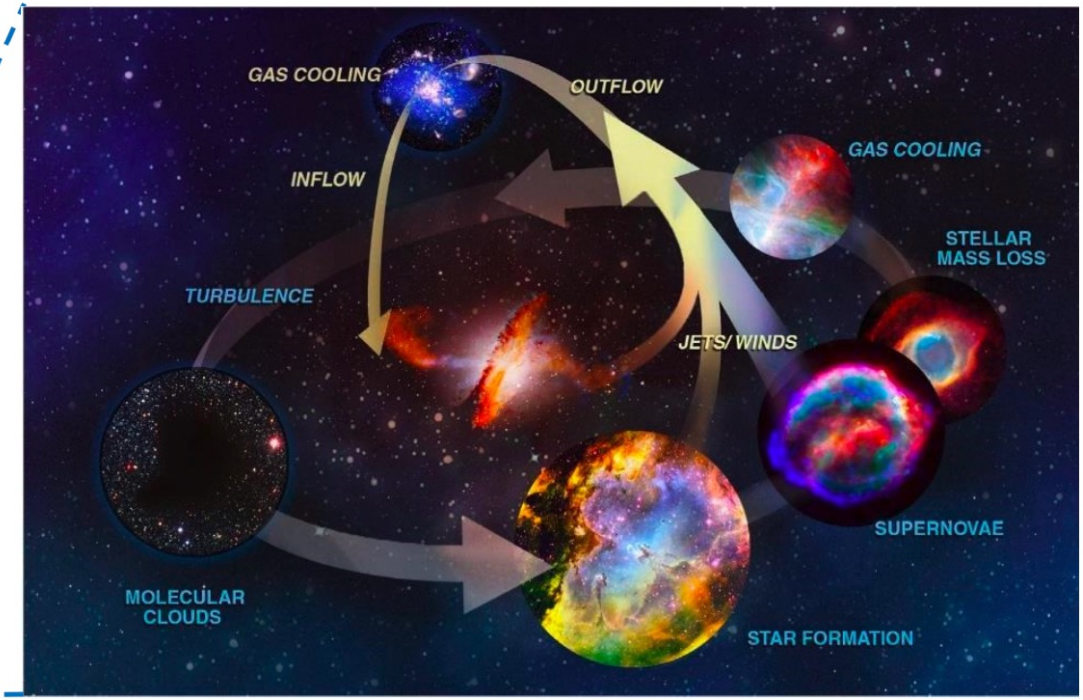








Dark matter halo is the vital bridge to connect cosmology and galaxy evolution!

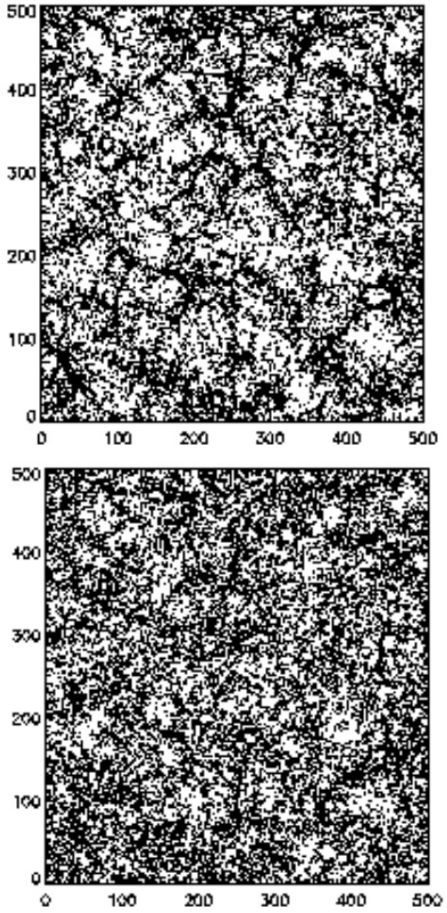


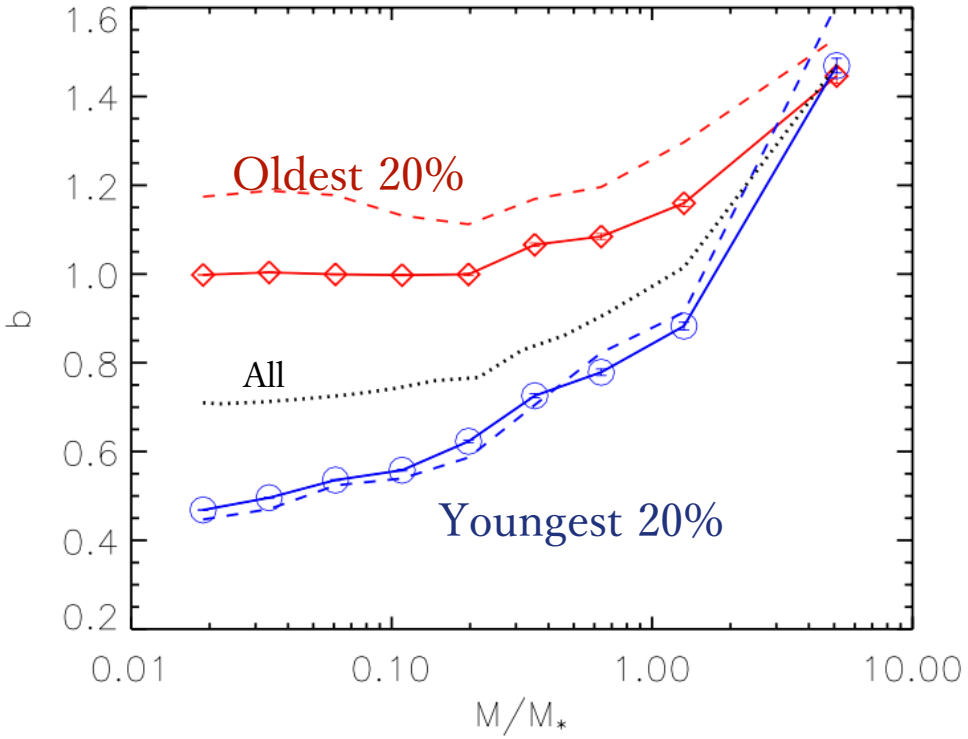
(see Astro2020)

Cite: slides by Cheng Li

The halo bias is not purely determined by the halo mass.

Halo assembly bias: Old haloes are strongly clustered than young haloes



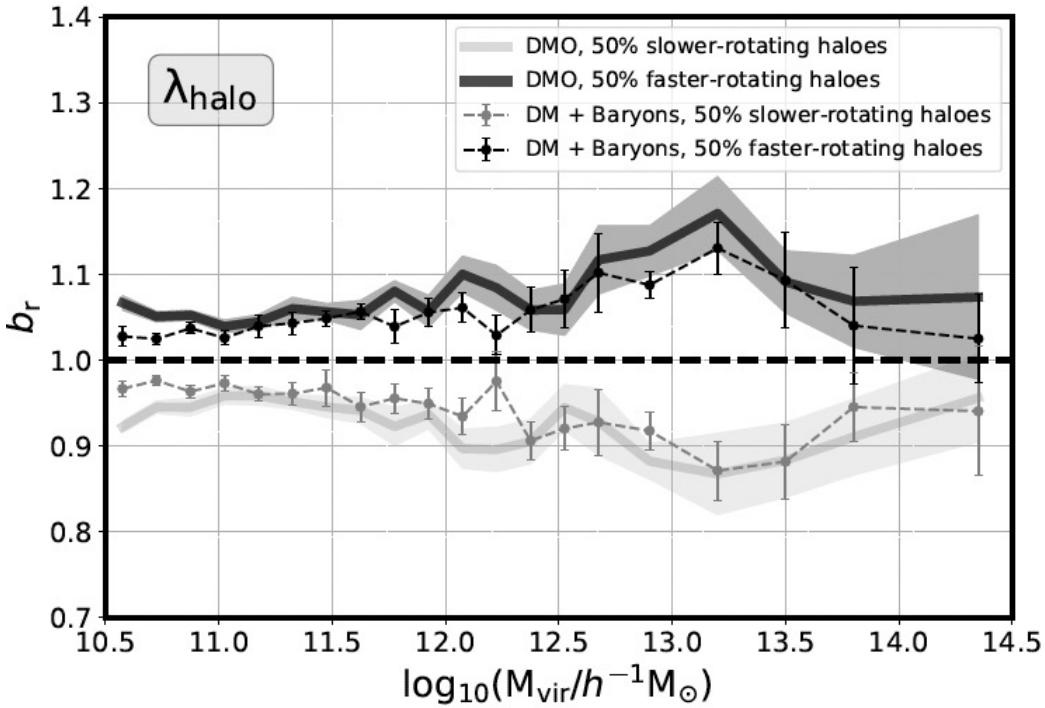


Gao et.al 2005

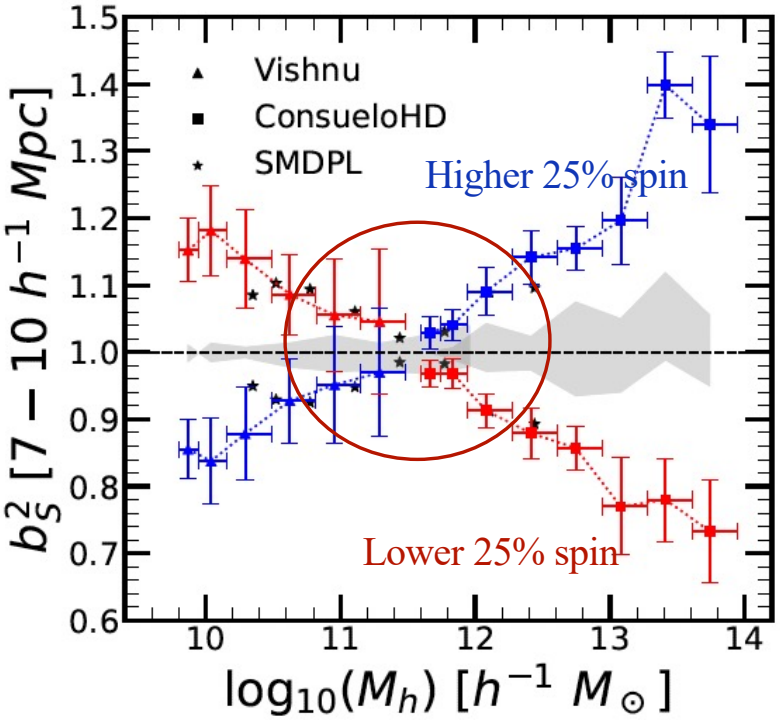
The halo assembly bias is related to halo properties, such as formation time, concentration, shape, spin …

A tension of the spin bias

$$b_\lambda^{rel}(r) = \sqrt{\frac{\xi_{hh}(r|M_h, S)}{\xi_{hh}(r|M_h)}}$$



Tension!



Montero-Dorta et.al 2021

Johnson et.al 2019

The different trend of the spin bias is caused by different **halo definitions**

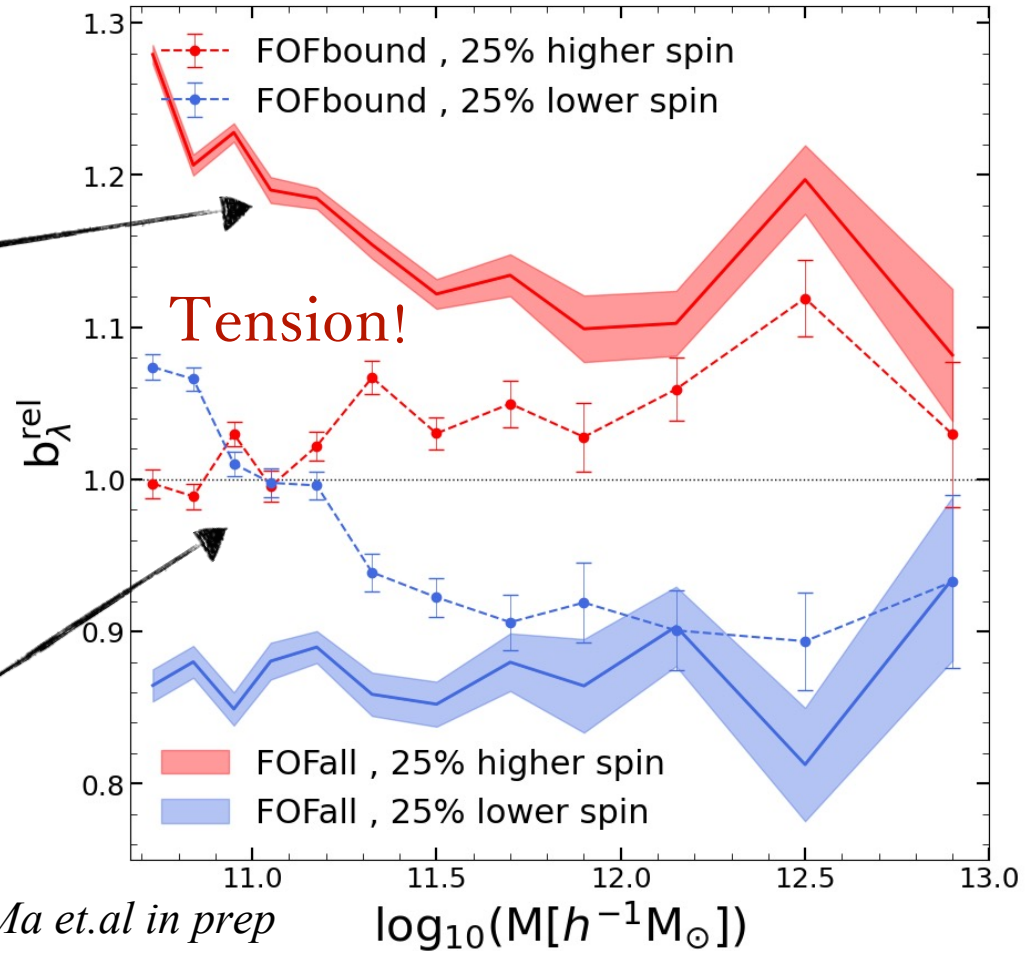
FOFall:

All particles within R_{vir} in the FOF-group.

FOFbound:

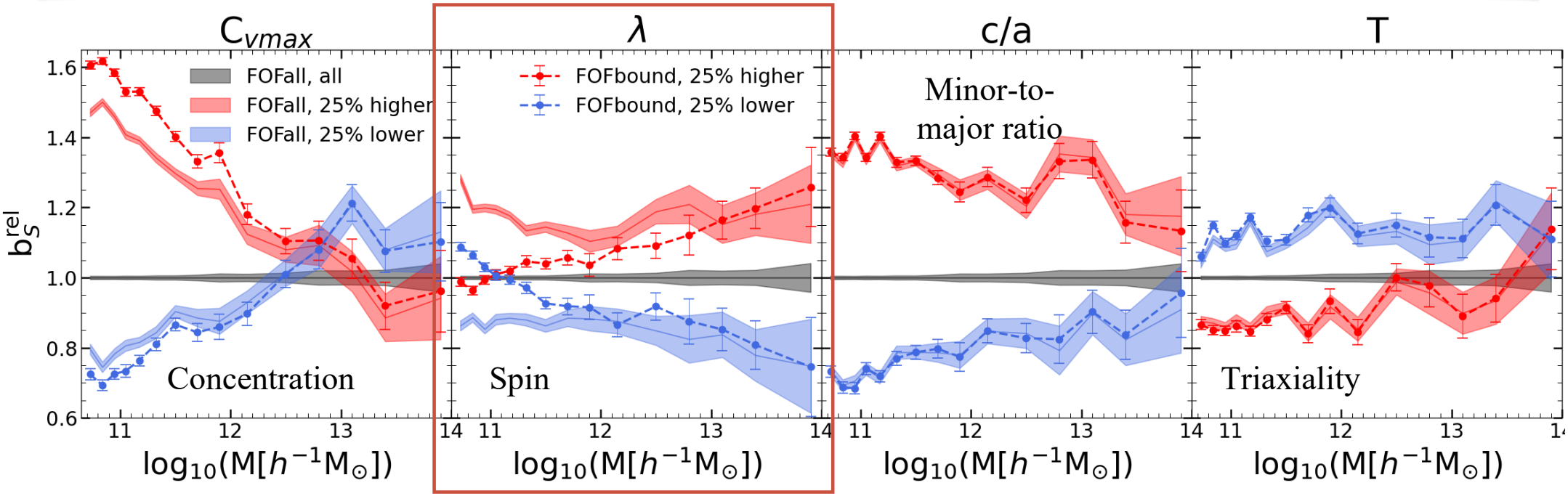
Gravitationally bound particles within R_{vir} in the FOF-group.

Bound: kinematic energy < potential energy



Ma et.al in prep

For different halo properties: spin bias is strongly dependent on the halo definition, while concentration bias shows a weak relation, and shape bias is not affected by the halo definition.



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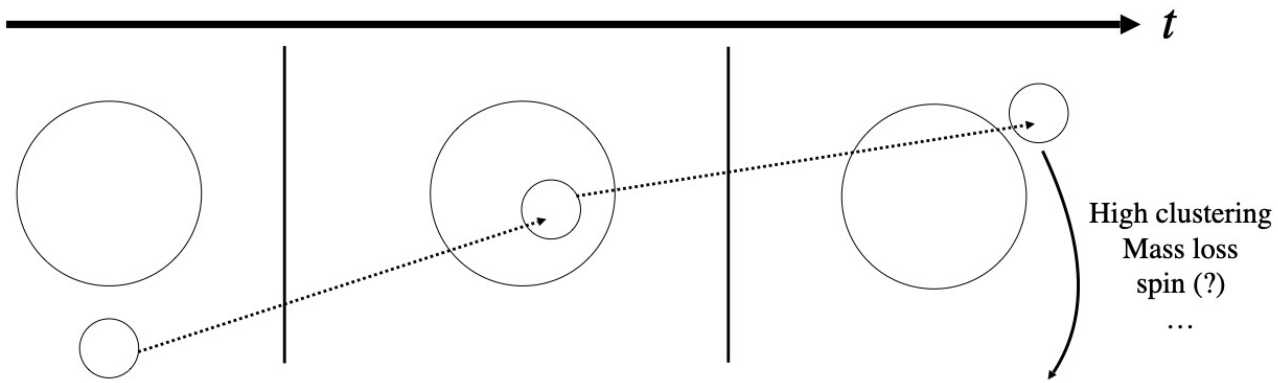
The physical origin of the low-mass spin bias:

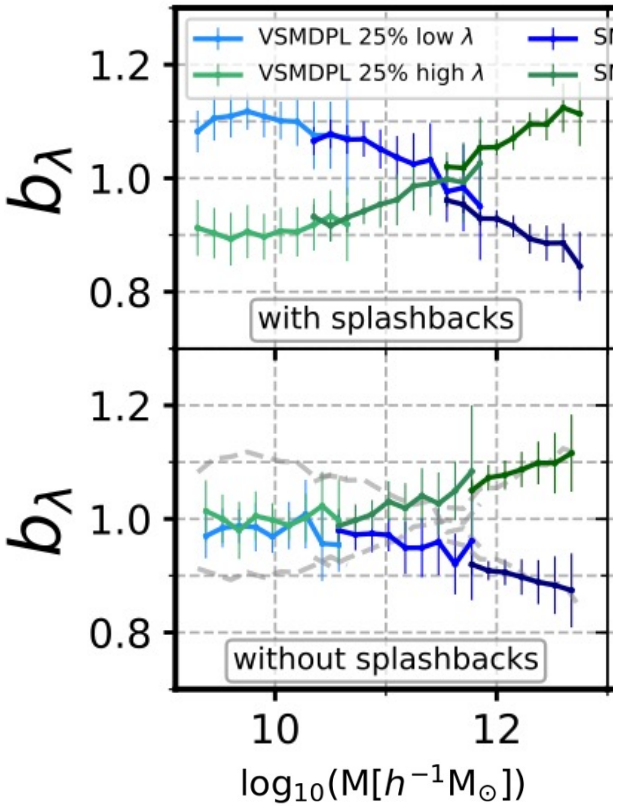
The splashback halo is thought to be the only reason for the low-mass spin bias

Calculate the spin by bound particles $z = 0.0$



Splashback halo (sb-halo):

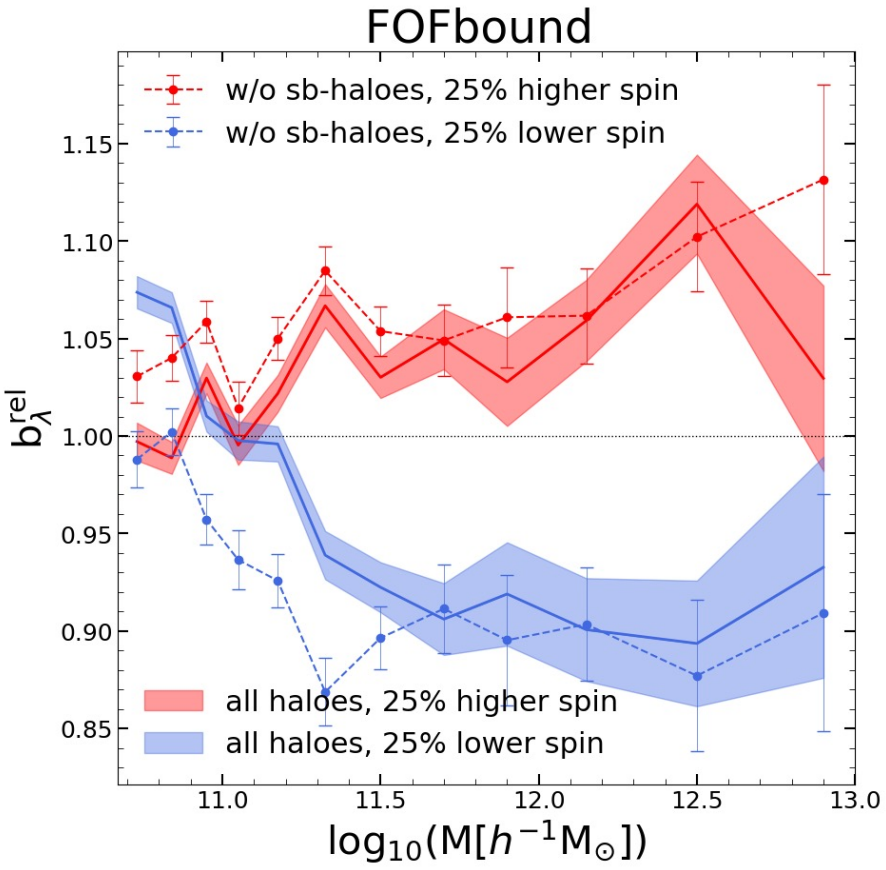
Distinct halo that was subhalo at some previous time, i.e., passed through the virial radius of a larger halo.

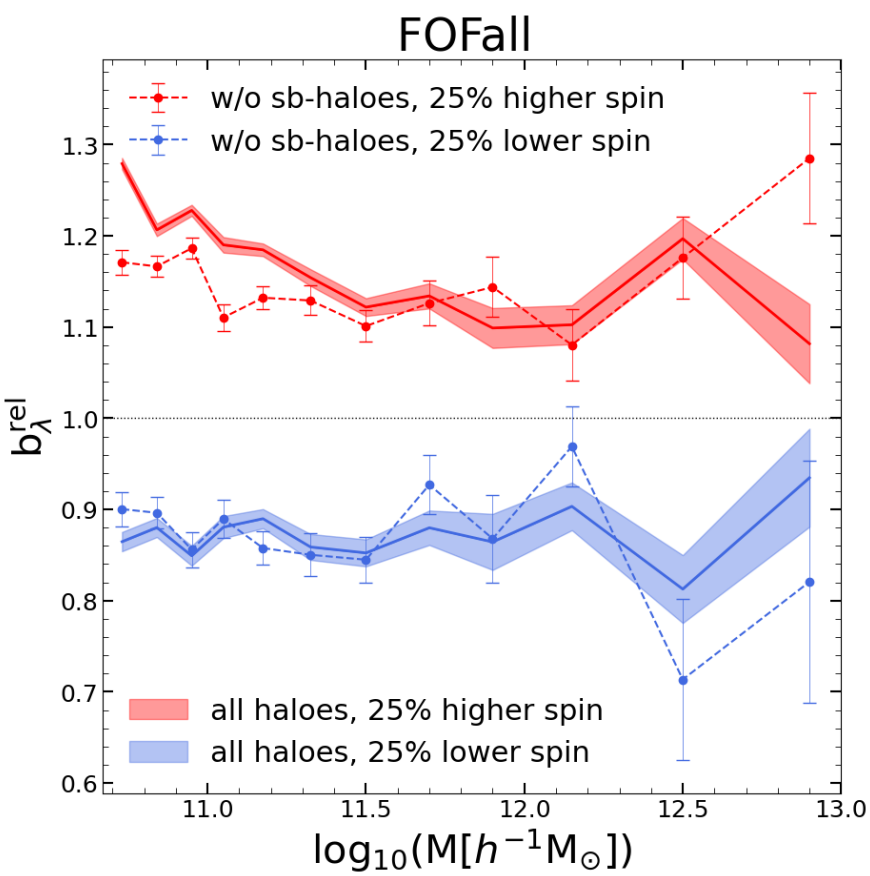


Montero-Dorta et.al 2020; Tucci et.al 2021

Spin bias is existed for FOFall at low mass for non-sb haloes:

The splashback halo is thought to be the only reason for the low-mass spin bias?





The physical origin of the spin bias:

Two mechanisms (dynamically unstable/stable halo) of spin bias

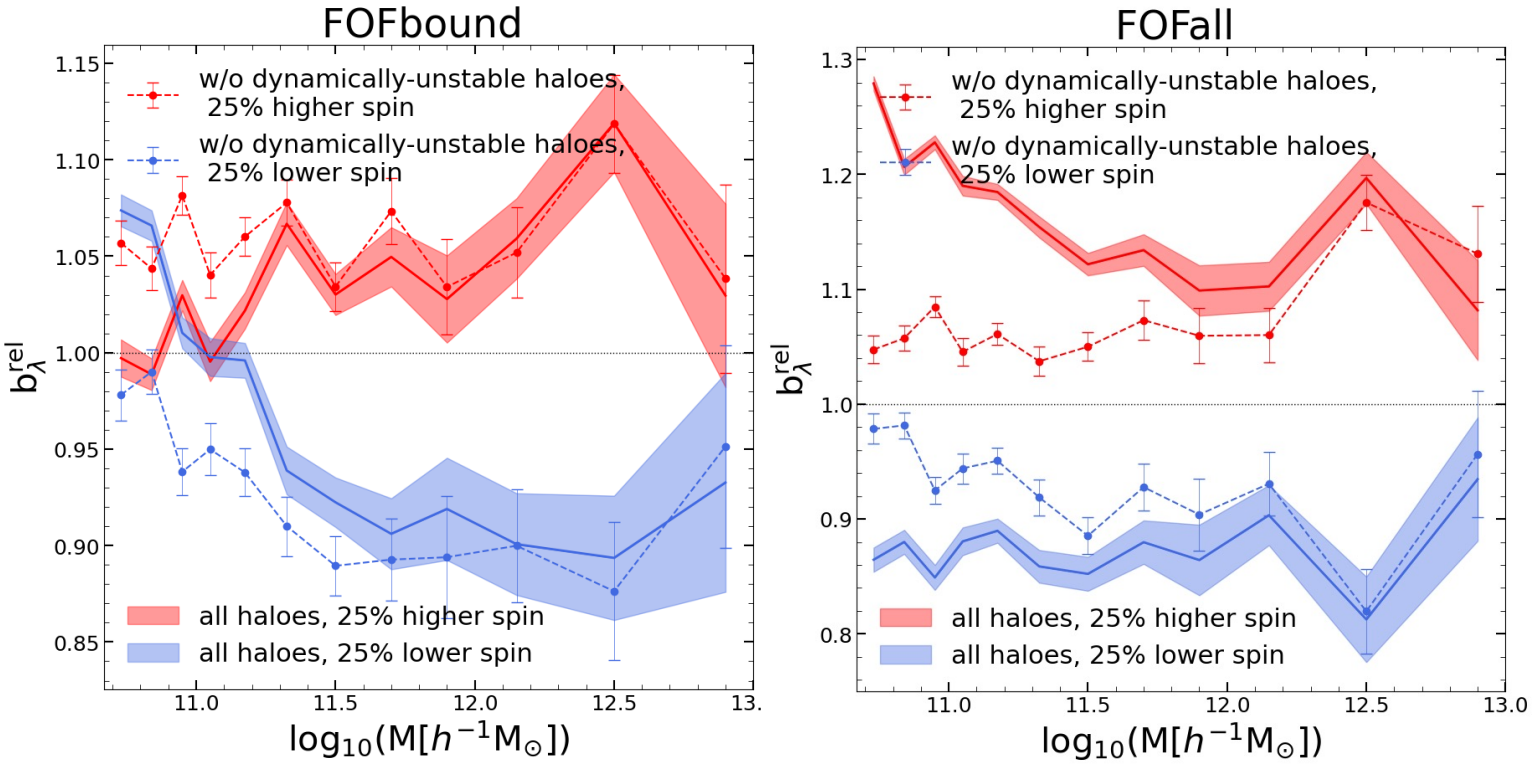
λ_{all}: all particles

λ_{bound}: grav-bound particles

$\lambda_{all} - \lambda_{bound} = \Delta\lambda$

$\Delta\lambda \geq 0.01$ **(unstable)**

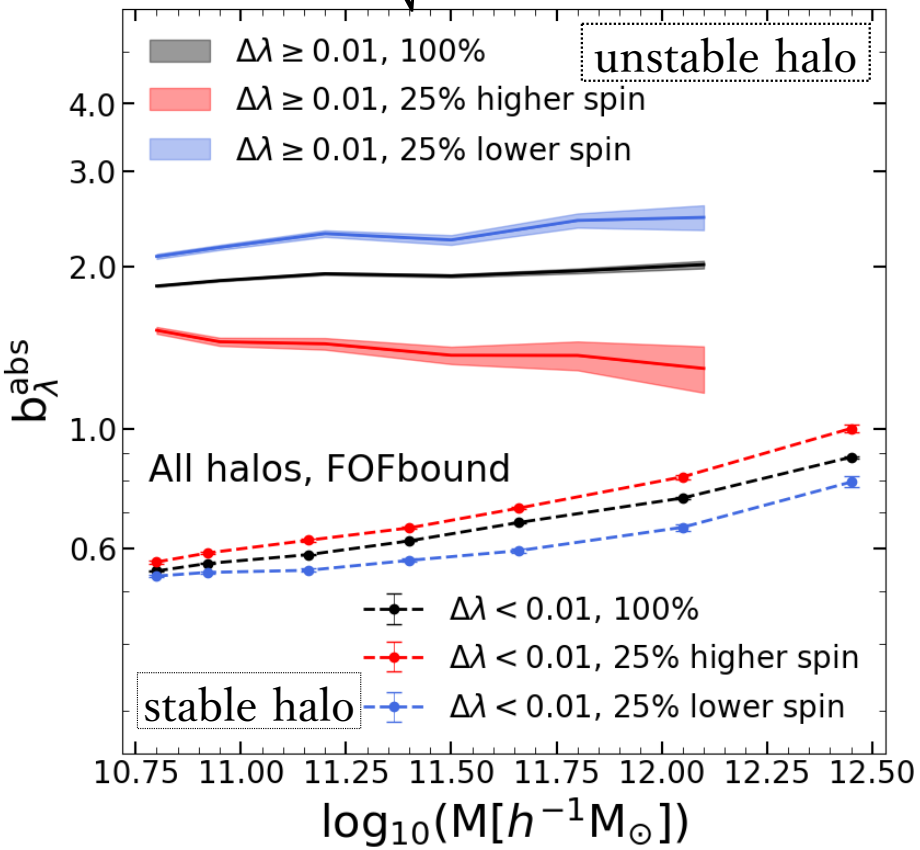
$\Delta\lambda < 0.01$ **(stable)**



If dynamically unstable halo is removed, the residual spin bias is same under any halo definition.

Two mechanisms of the spin bias

$$b^{abs}(r) = \sqrt{\frac{\xi_{hh}(r|M_h, S)}{\xi_{mm}(r)}}$$



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$\Delta\lambda < 0.01$ **(stable)**

Comparison between **unstable halo/stable halo:**

- The unstable halo has higher clustering than the stable halo

Unstable halo (5%):

- low-rotated halo has higher clustering. (Strong tidal field…)

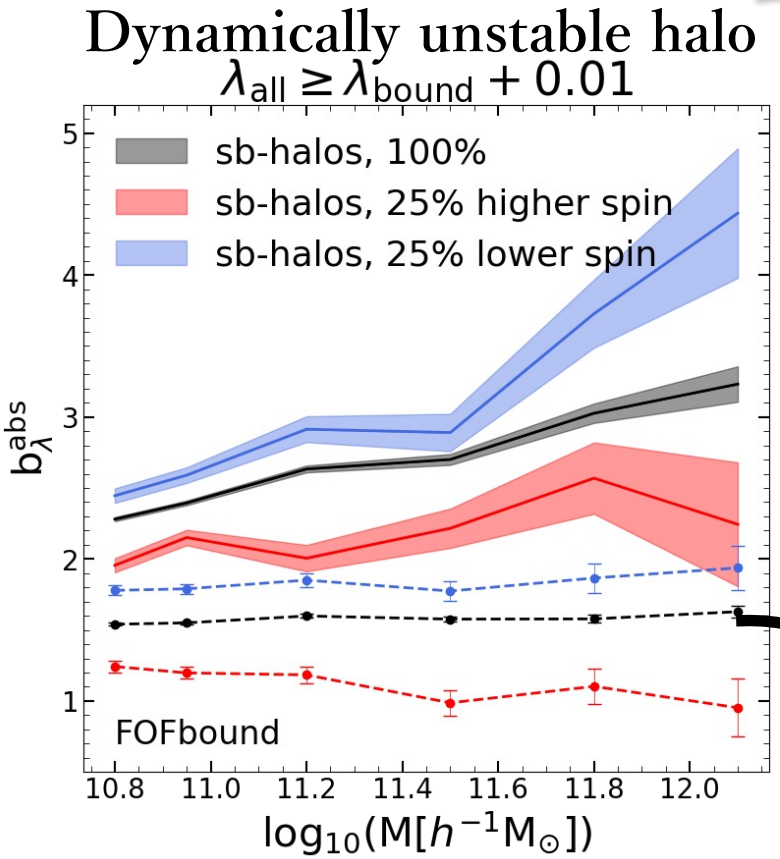
Stable halo:

- high-rotated halo has higher clustering. (Twin halo… Johnson et.al 2019)

Two mechanisms of the spin bias

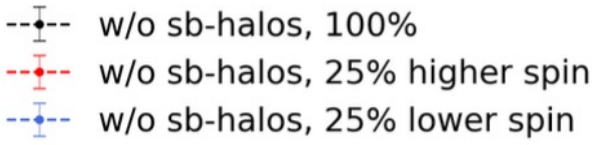
Dynamically unstable halo = splashback halo?

Only **40 %** of them are splashback haloes.



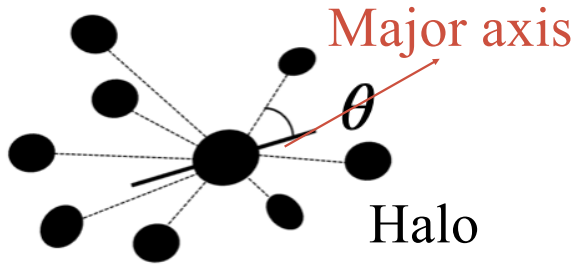
The splashback halo is one of the populations of the unstable halo.

- **Note the definition of the splashback halo could affect the result.**

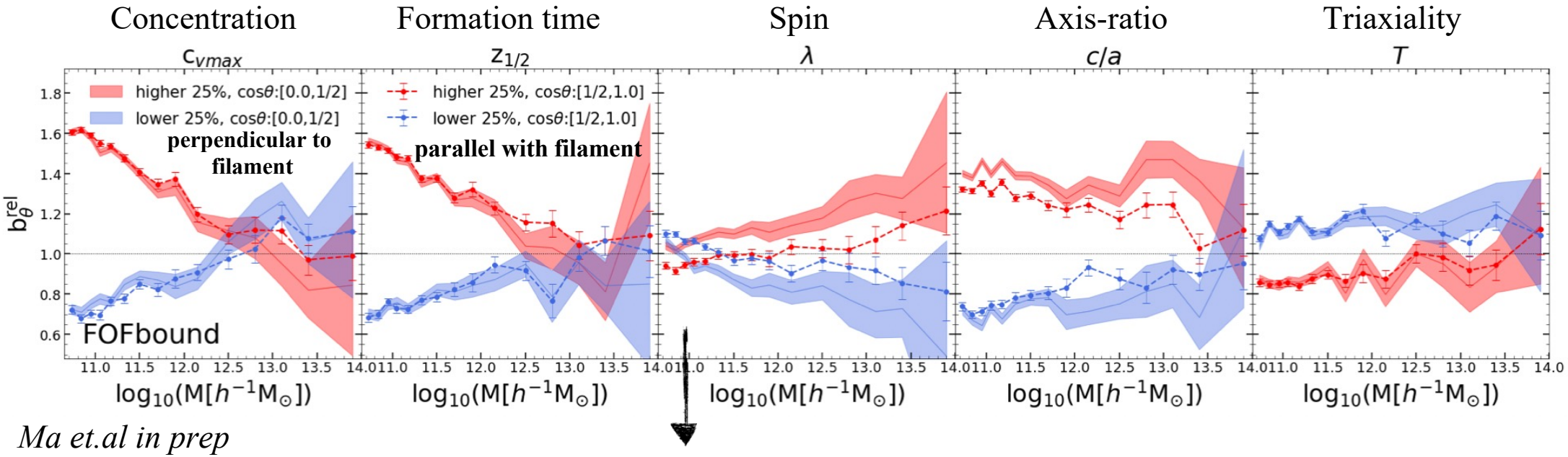


Anisotropic assembly bias:

Strong anisotropy of the assembly bias is shown for the halo spin or the axis-ratio of halos, which indicates that the slow-rotated and elongated halo is more aligned with the filament



$$b_\theta^{rel} = \sqrt{\frac{\xi_{hh}(r|M_{vir},S,\theta)}{\xi_{hh}(r|M_{vir},\theta)}}$$



Ma et.al in prep

The spin bias becomes weak along the major axis (filament)

Summary

- **Halo definition:**

(1) The tension of the spin bias is caused by the halo definition

(2) Halo definition largely affects the spin bias, weakly varies the concentration bias, but does not change the shape bias.

(3) The spin bias is from two kinds of mechanisms: the dynamically stable halo with an intrinsic feature and the dynamically unstable halo with an inverted feature.

- **Spatial anisotropy:**

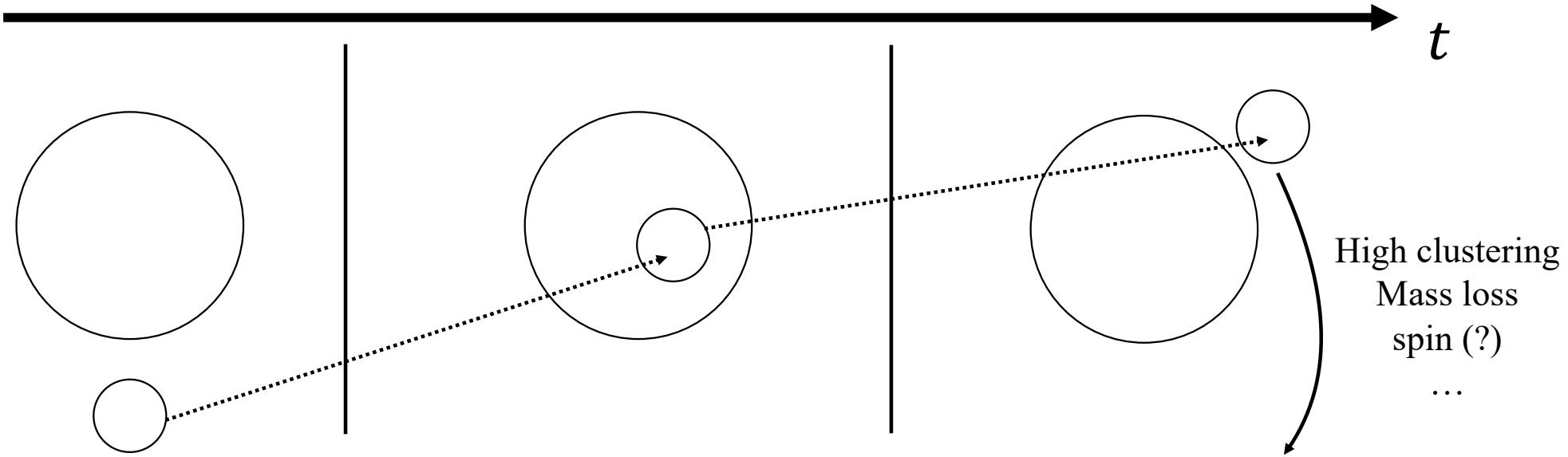
(1) Strong anisotropy of the assembly bias is shown for the halo spin or the axis ratio of halos, while there is no anisotropy for other properties

How anisotropic bias reflects the alignment

$$b_\theta^{rel} = \sqrt{\frac{\xi_{hh}(r|M_h,S,\theta)}{\xi_{hh}(r|M_h,\theta)}} \qquad b_\theta^{rel,alignment} = \sqrt{\frac{\xi_{hh}(r|M_h,S,\theta)}{\xi_{hh}(r|M_h,S)}}$$

$$\frac{b(\theta_1,\lambda_2)}{b(\theta_2,\lambda_2)} = \sqrt{\frac{\xi(\theta_1,\lambda_2)/\xi(\theta_1)}{\xi(\theta_2,\lambda_2)/\xi(\theta_2)}} = \sqrt{\frac{\xi(\theta_1,\lambda_2)/\xi(\lambda_2)}{\xi(\theta_2,\lambda_2)/\xi(\lambda_2)}} * \sqrt{\frac{\xi(\theta_2)}{\xi(\theta_1)}} = \frac{b^{alignment}(\theta_1,\lambda_2)}{b^{alignment}(\theta_2,\lambda_2)} * \sqrt{\frac{\xi(\theta}{\xi(\theta}}$$

$$\frac{b^{alignment}(\theta_1,\lambda_2)}{b^{alignment}(\theta_2,\lambda_2)} = \frac{b(\theta_1,\lambda_2)}{b(\theta_2,\lambda_2)} * \sqrt{\frac{\xi(\theta_1)}{\xi(\theta_2)}}$$



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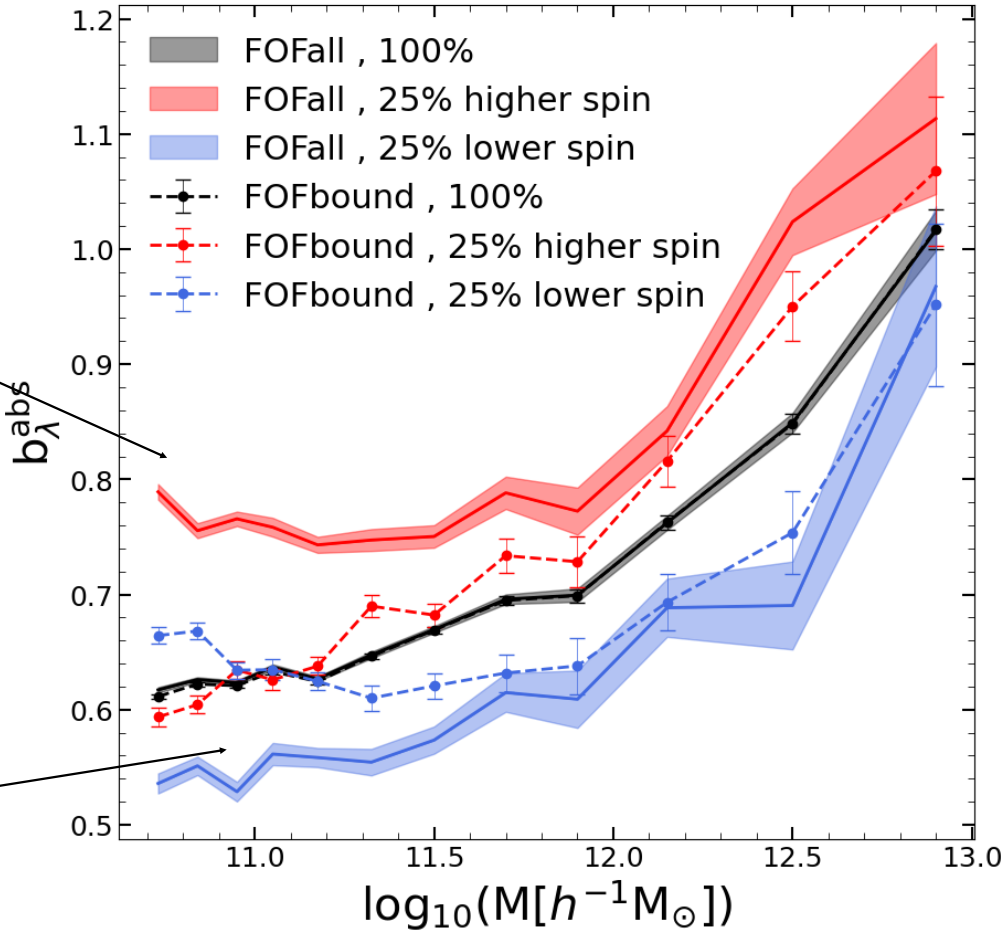

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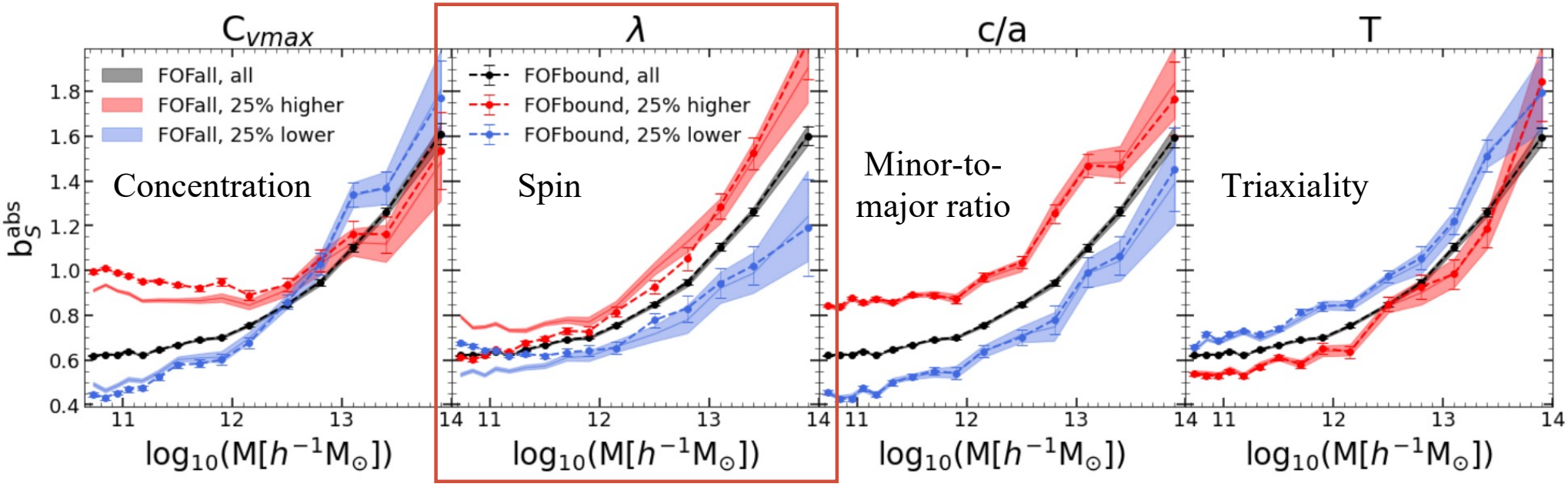

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Explanation of anisotropic spin bias