LOW MASS SPIN BIAS

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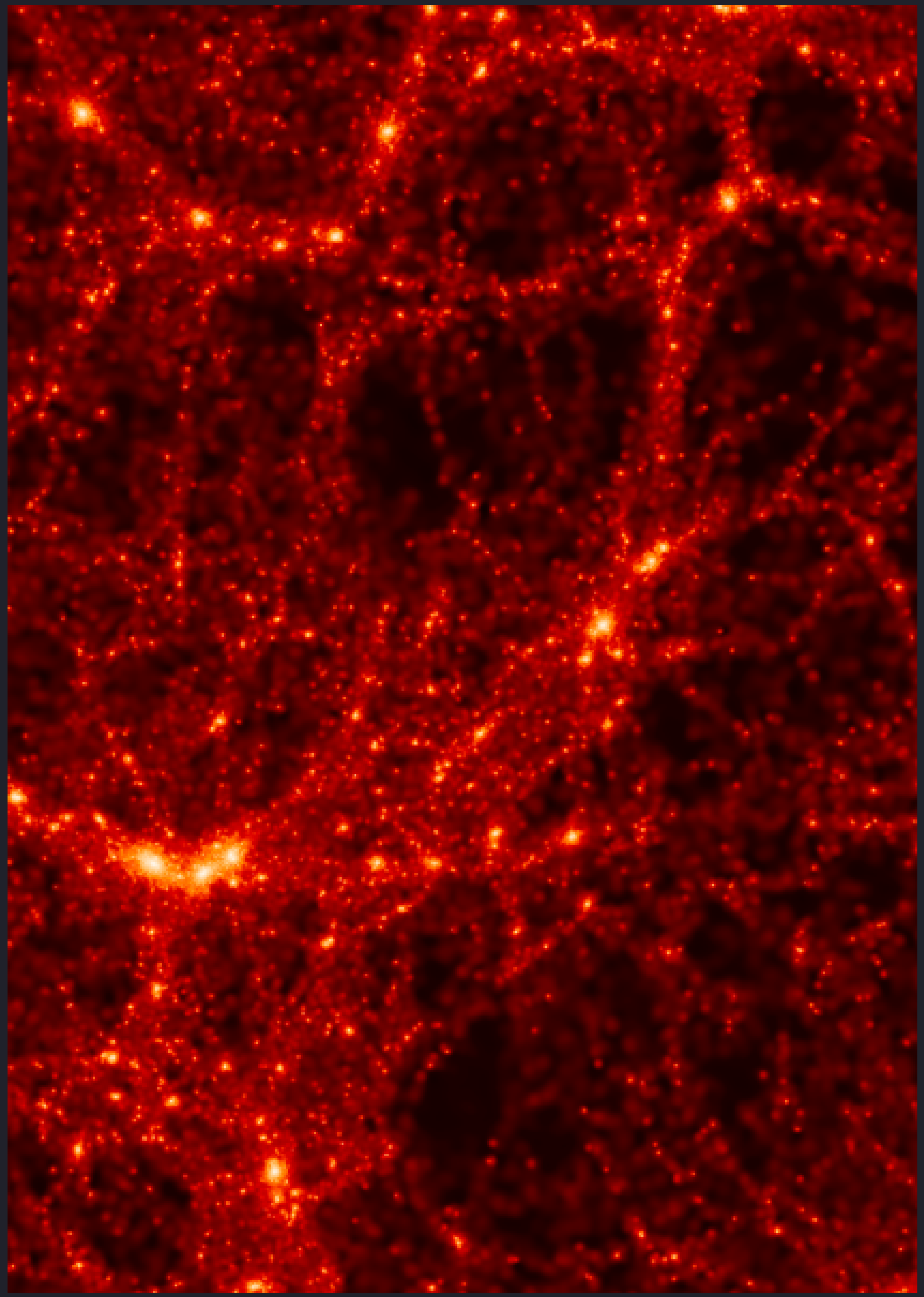
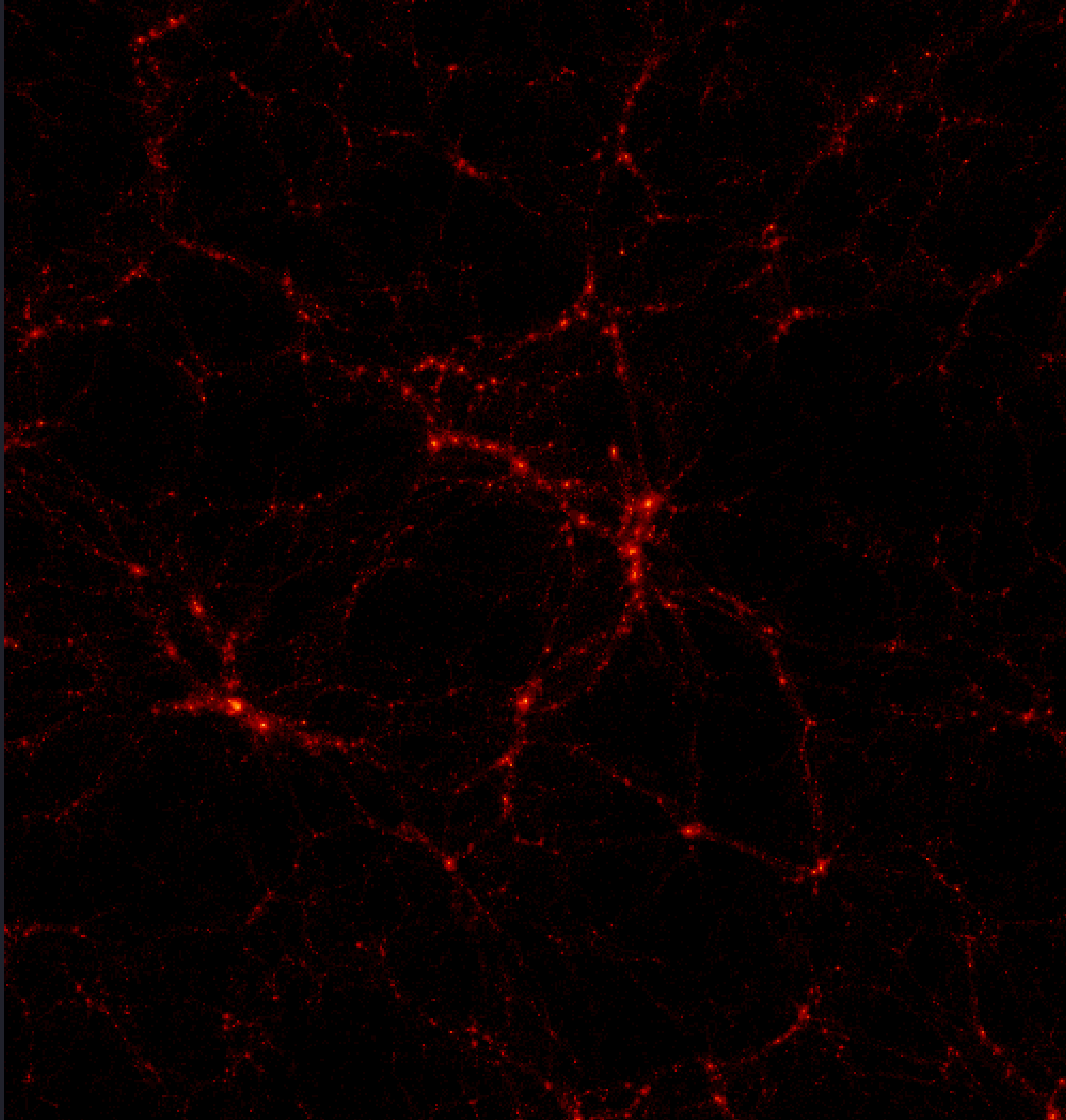


Outline

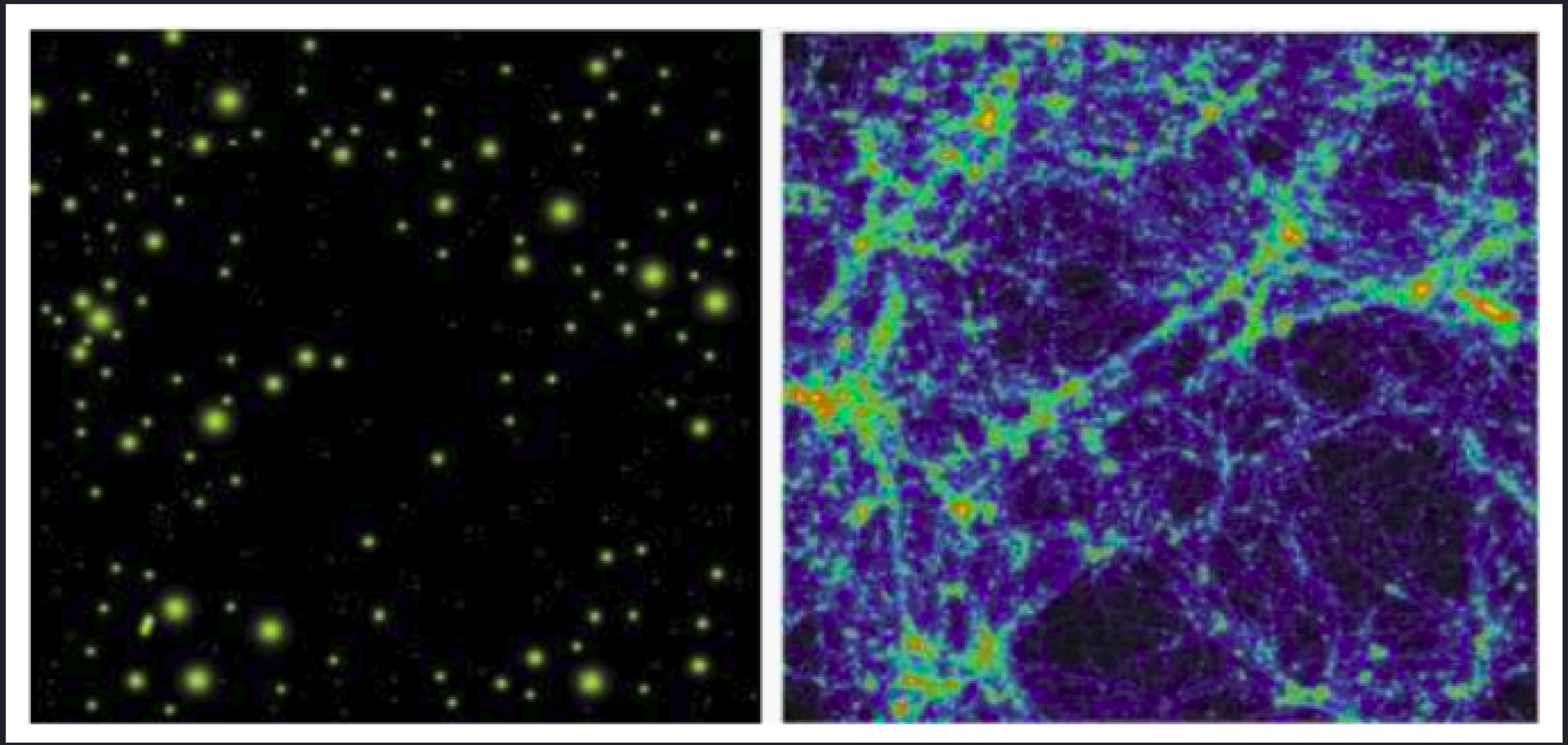
Points of Discussion

Assembly Bias
Methodology
Splashback Halos
Physical Mechanism
Summary & Next Steps



Bias

$$\delta_h = b\,\delta_m$$

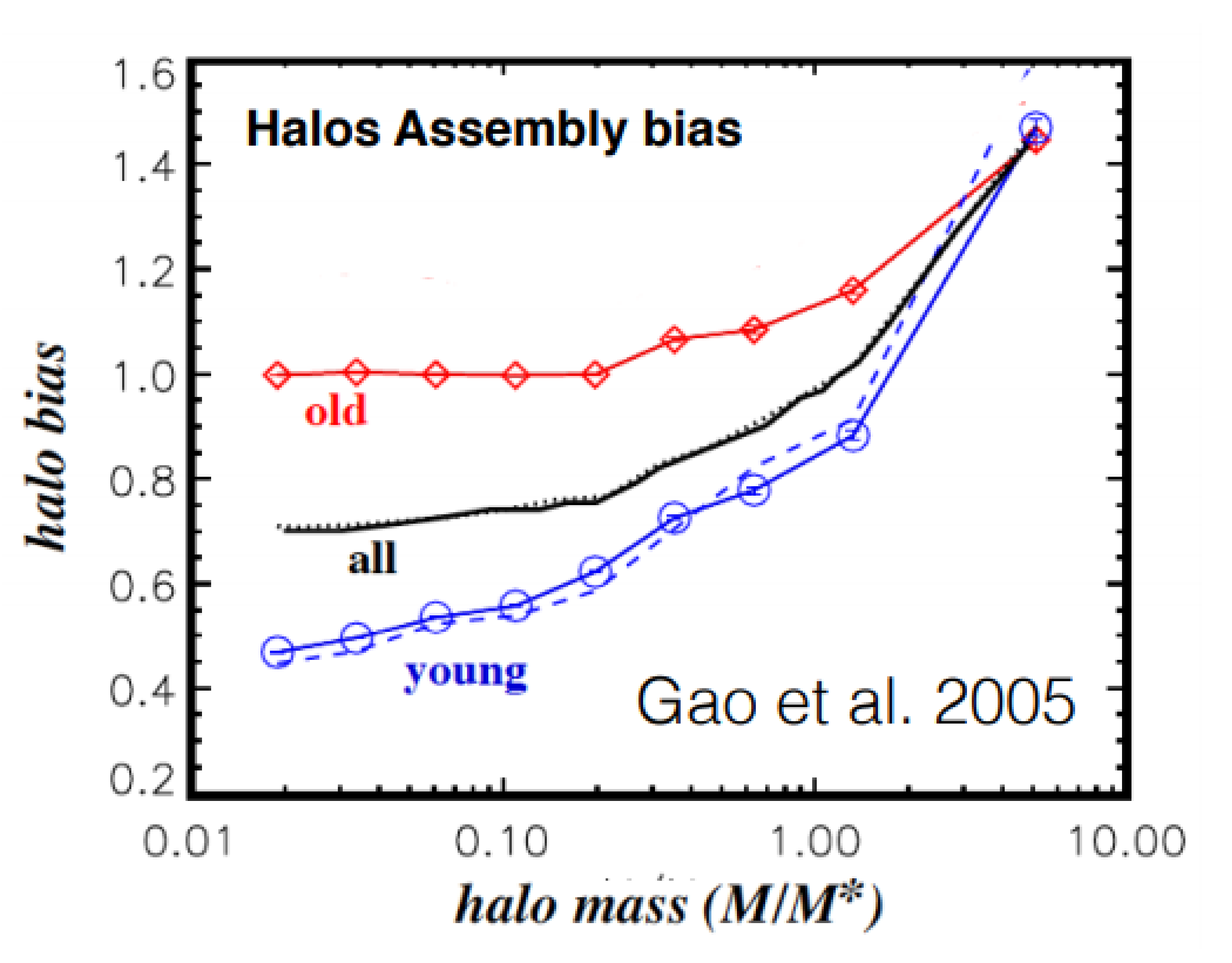


Cooray & Sheth (2002)

Assembly Bias

At fixed halo mass, halos that assemble earlier (older) are more tightly clustered than halos that assembly earlier (younger)

Sheth & Tormen (2002)

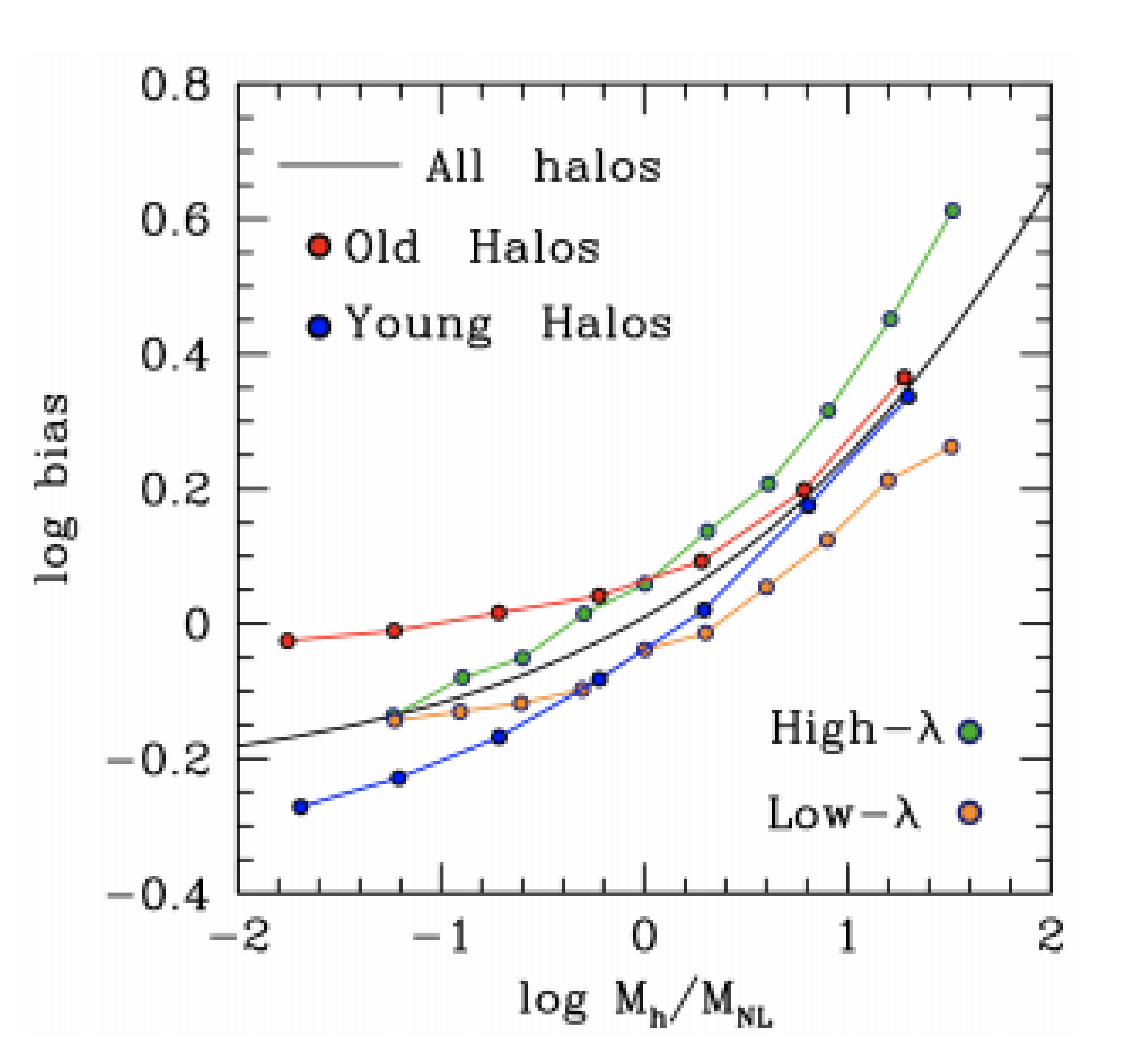


Secondary Bias

At fixed mass, halo clustering depends on several secondary halo properties

- age
- concentration
- spin
- shape

Wechsler et al. (2006)
Gao & White (2007)



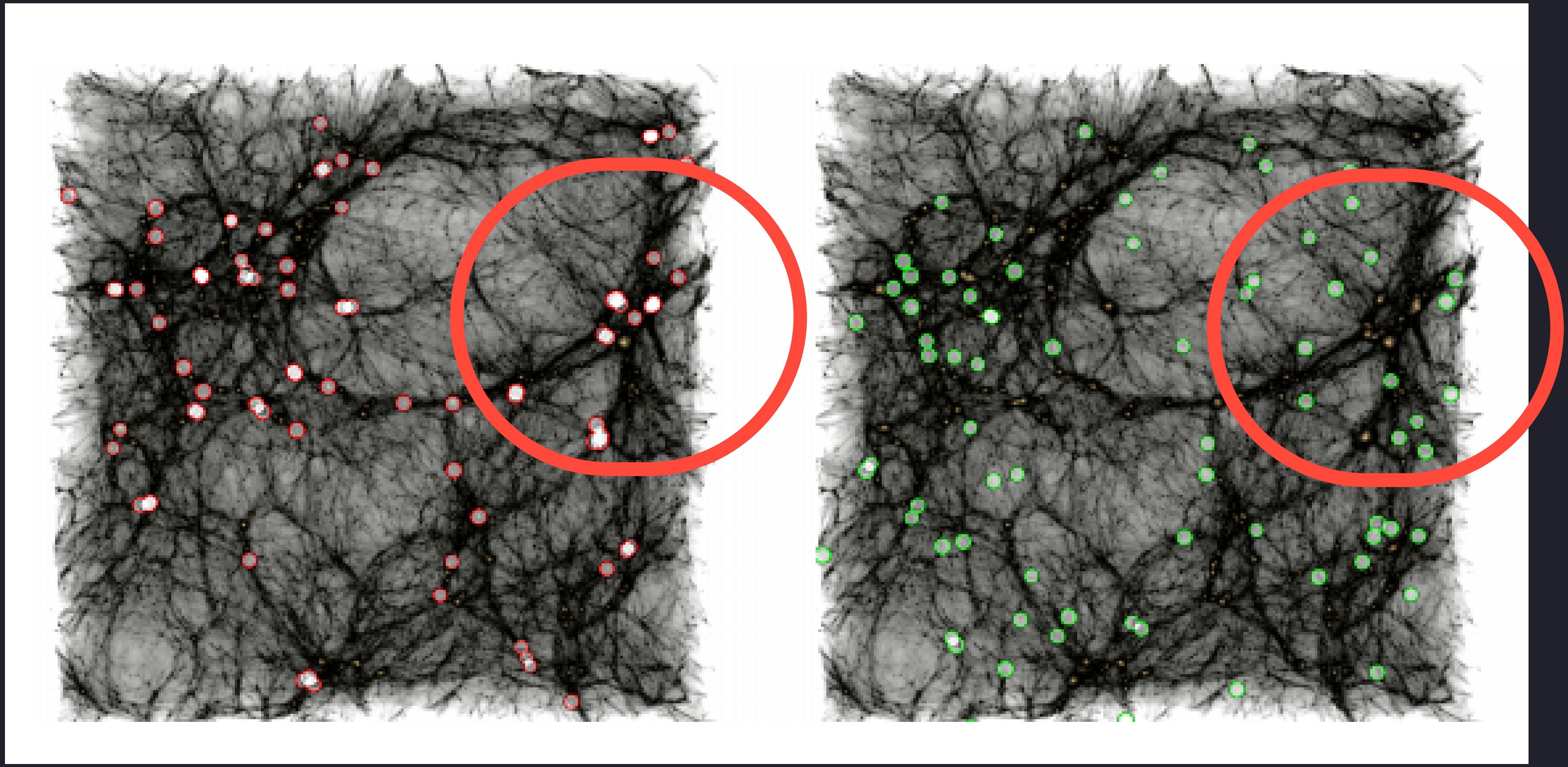
Bett et al. (2007)

Concentration Bias

90x90x30 Mpc slice of a cosmological simulation at z = 0

$$\log\left(M_{\rm vir}/M_{\odot}h^{-1}\right) = 10.8$$

Red halos are the 5% high concentrated



Li, Mo & Gao (2008)

Secondary Properties

- age

$$a_{1/2}$$

scale factor at which half of the halo peak mass was accreted

all properties are correlated!

- spin

$$\lambda = \frac{|J|}{\sqrt{2}\, M_{\mathrm{vir}}\, V_{\mathrm{vir}}\, R_{\mathrm{vir}}}$$

- concentration

$$c_{200} = \frac{r_{200}}{r_s}$$

$$\overline{\rho}(r < r_{200}) = 200\, \rho_{cr}$$

Relative Bias

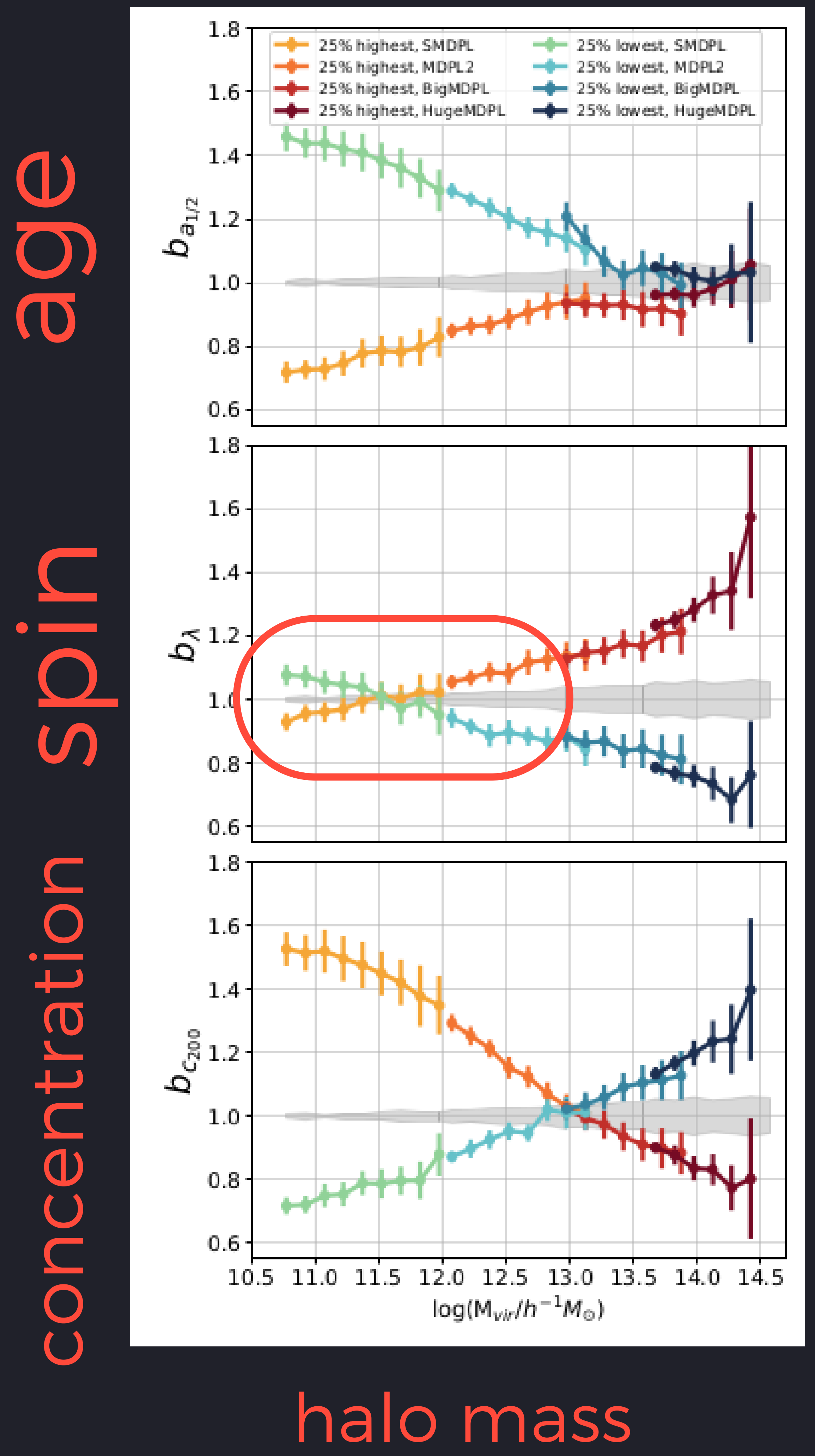
$$b^2(r, B, S) = \frac{\xi(r, B, S)}{\xi(r, B)}$$

- primary bias paramater B: $\mathrm{M_{vir}}$
- secondary parameter S: λ, $a_{1/2}$ or c_{200}

Low Mass Spin Bias

Sato-Polito et al. (2019)

- Measurement of Relative Bias with MultiDark simulations
- First to show low mass spin bias inversion
- Confirmed using 2 other simulations by Johnson et al. (2019)



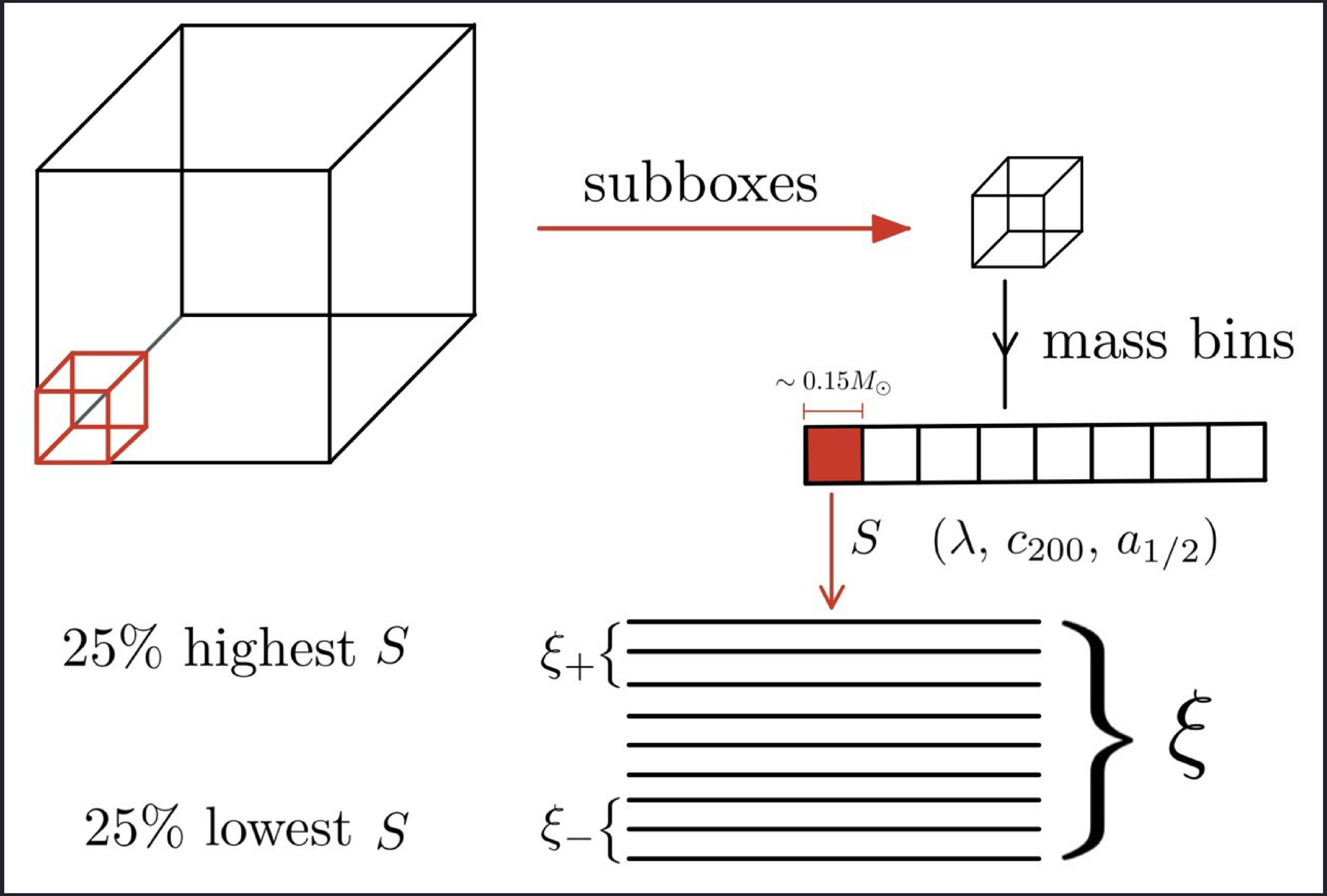
Methodology

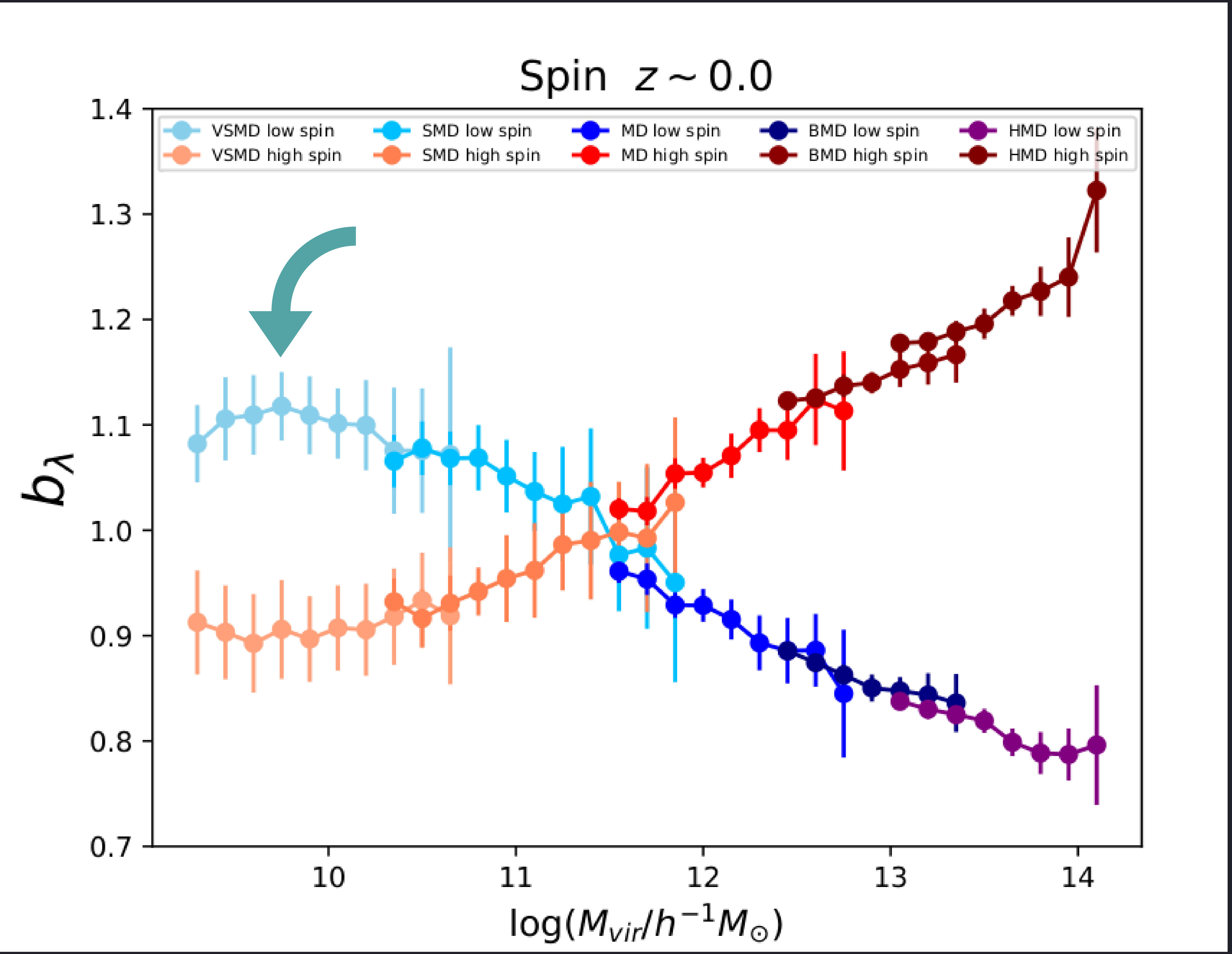
- Corrfunc python module
  M. Sinha (2007)

- $5h^{-1}\text{Mpc} < r < 15h^{-1}\text{Mpc}$

$$b_+ = \frac{\xi_+}{\xi}$$

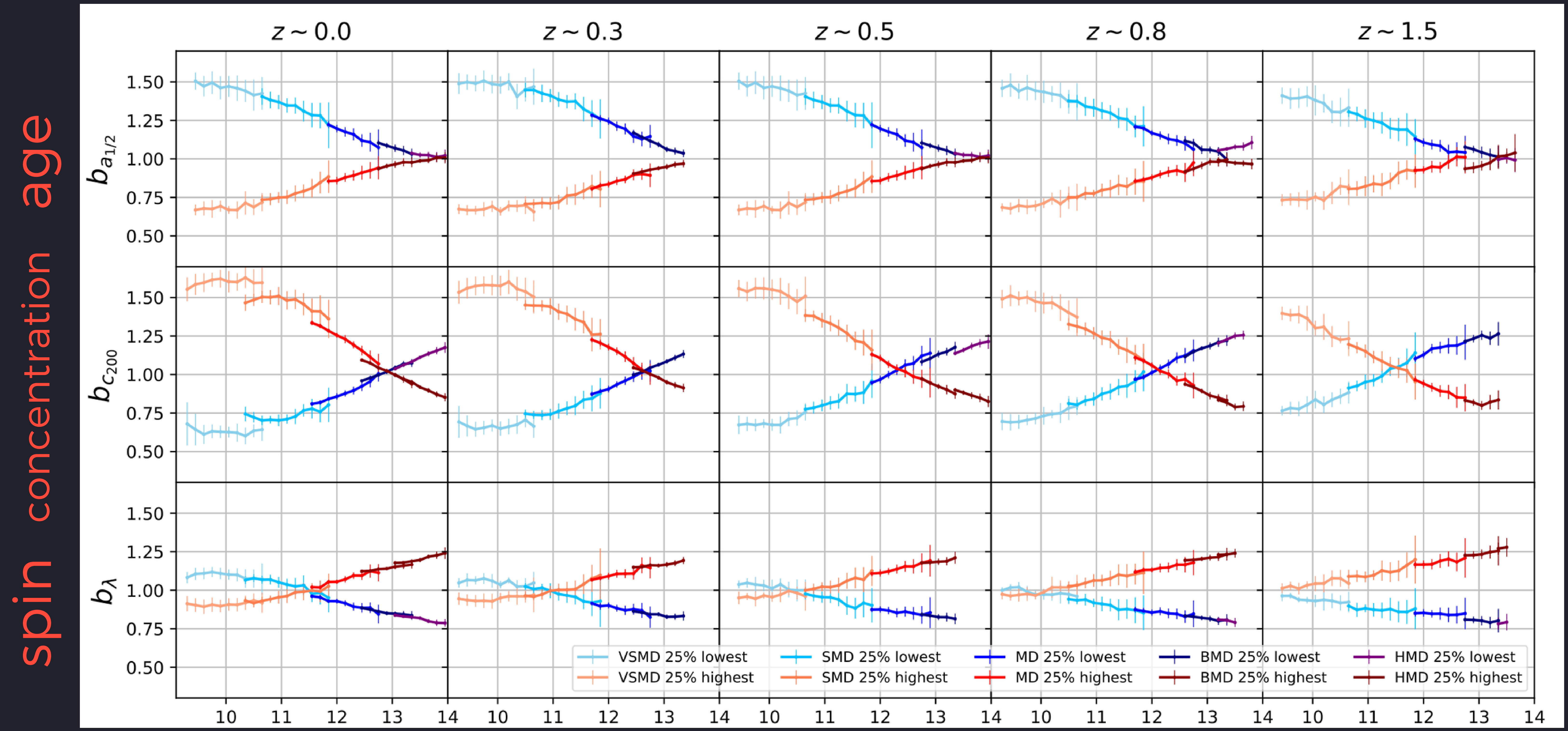
$$b_- = \frac{\xi_-}{\xi}$$




Spin $z \sim 0.0$
VSMD low spin
VSMD high spin
SMD low spin
SMD high spin
MD low spin
MD high spin
BMD low spin
BMD high spin
HMD low spin
HMD high spin
b_λ
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
10
11
12
13
14
$\log(M_{vir}/h^{-1}M_\odot)$

Spin Bias

Redshift Evolution



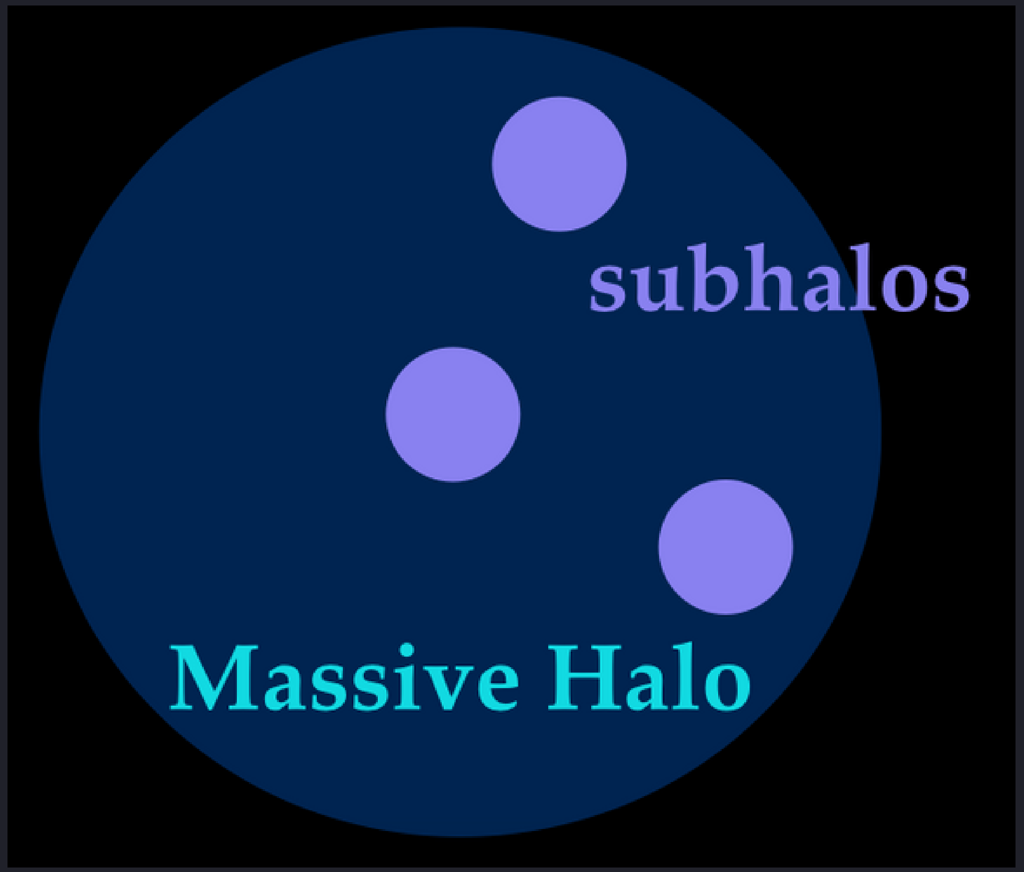
halo mass

WHAT CAUSES THE SPIN BIAS INVERSION?

Tucci et al. (in prep)

Splashback Halos

halo substructure



- aka "ejected subhalos": distinct halos at the analyzed redshift, but which have passed through the virial radius of a host halo previously

Causes of Assembly Bias

low mass

- supressed mass accretion
  (due to strong tides)
- splashbacks

Hahn (2009)
Sunayama (2016)
Vilarreal (2017)
Mansfield (2020)

high mass

- peak curvature

high bias <-> shallow peaks <->
low concentrated / old halos

Dalal (2008)

Cosmic Web Anisotropy

Paranjape (2018)
Ramakrishnan (2019)

internal halo properties
R_{vir} < ~ few 100 kpc h $^{-1}$

↔

tidal anisotropy
~ 4 x R_{vir}

↔

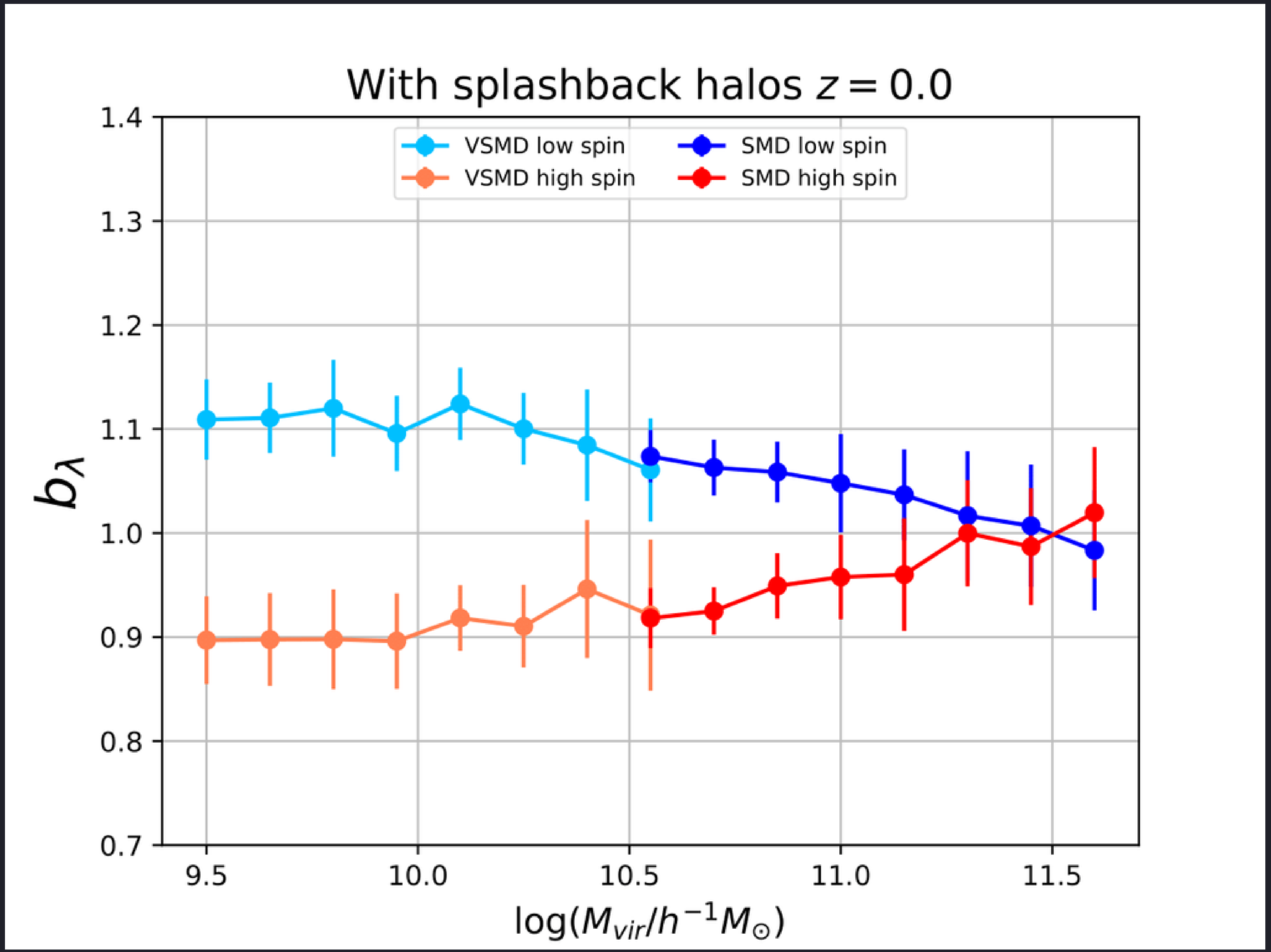
linear density field (bias)
> few 10 Mpc h $^{-1}$

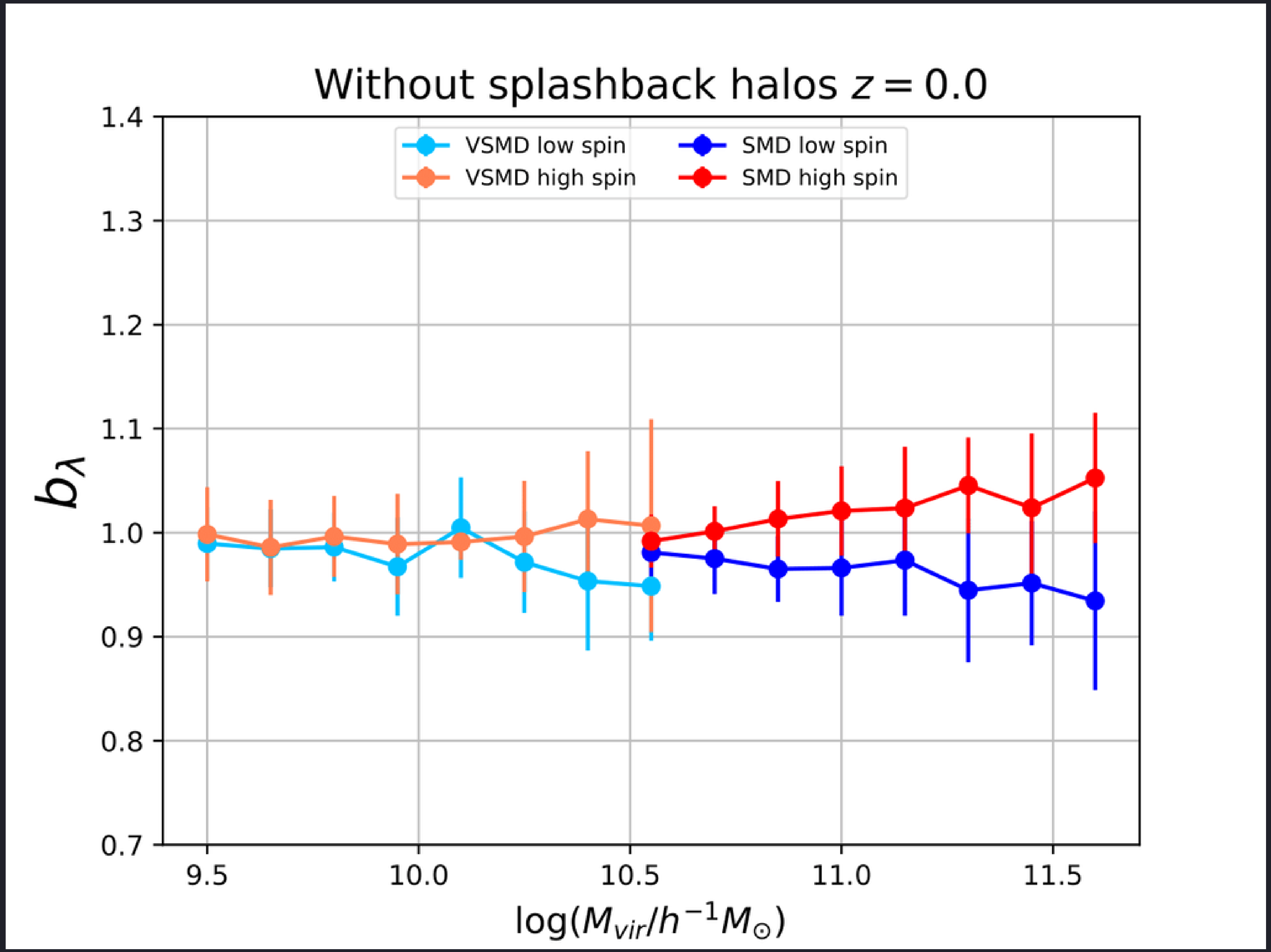
$$q^2 = \frac{1}{2}\left[(\lambda_2 - \lambda_1)^2 + (\lambda_3 - \lambda_1)^2 + (\lambda_3 - \lambda_2)^2\right]$$

$$\alpha = \sqrt{q^2} / (1 + \delta)$$

$$\delta = \lambda_1 + \lambda_2 + \lambda_3$$

The Effect of Splashback Halos





WHY SPLASHBACK HALOS?

High Bias
Tracers of their previous host halo

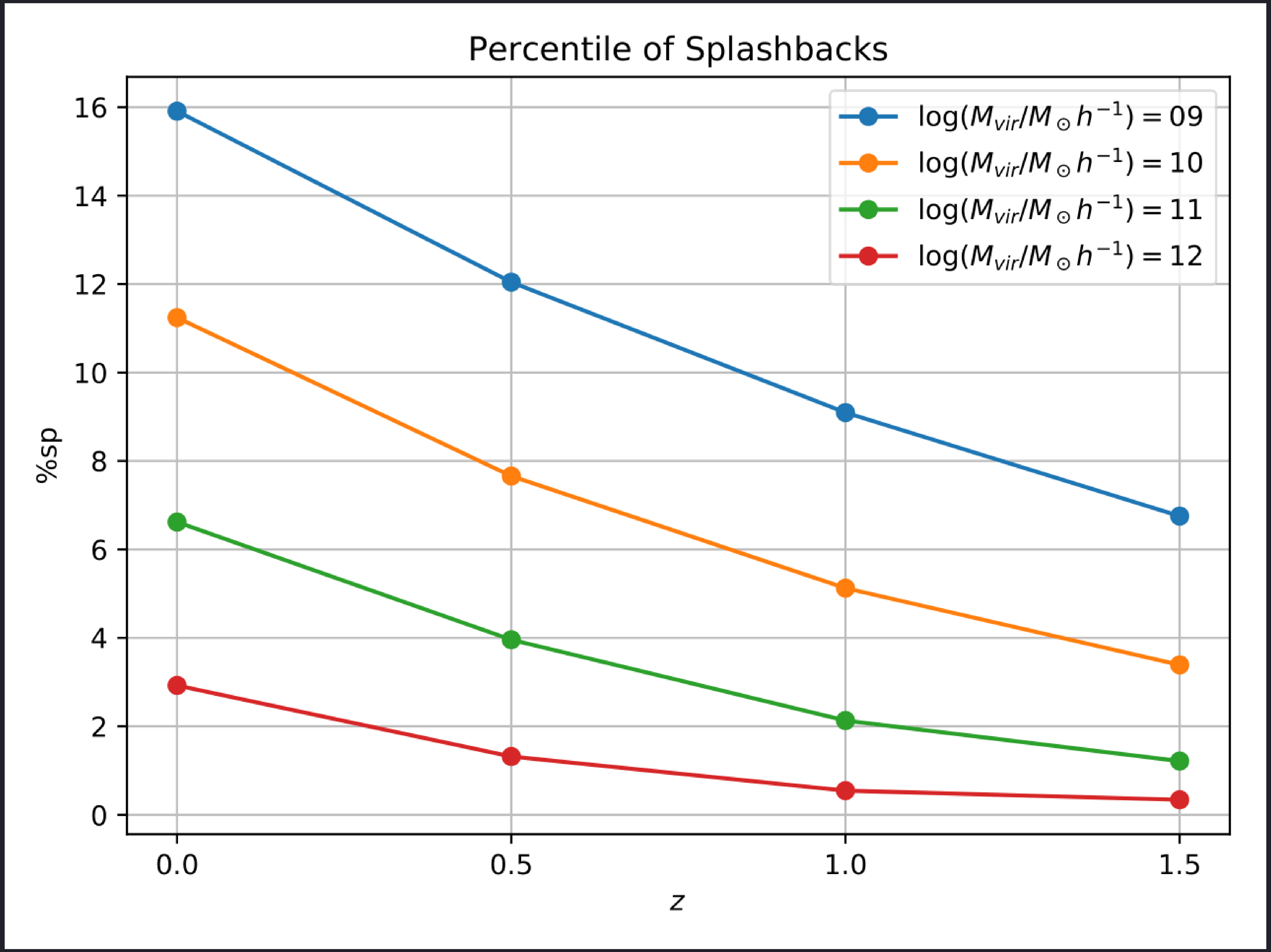
Low Spin
Lower spin than the average

Low Mass
Only significant at low masses

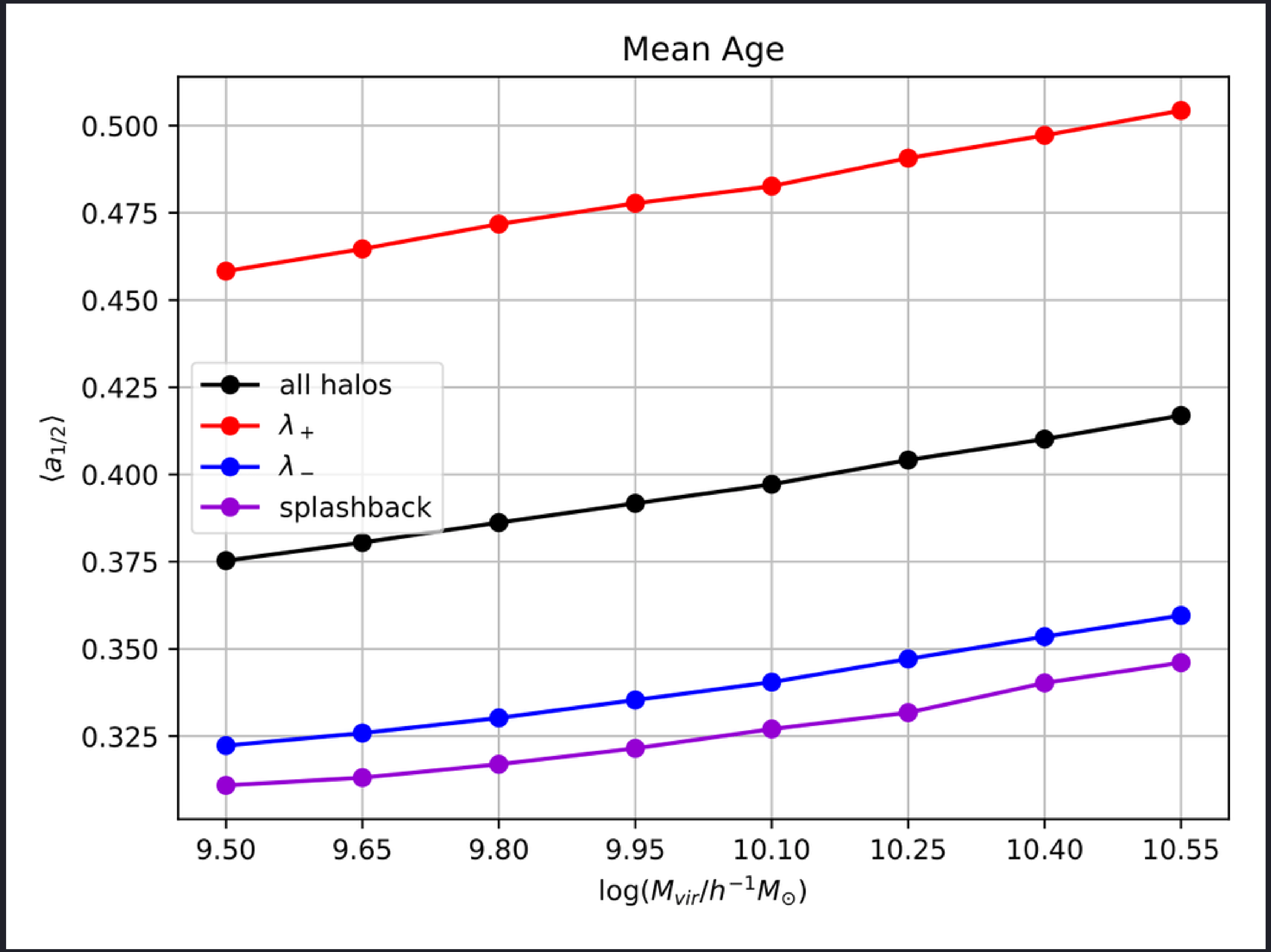
Recent Times
Only significant at recent times

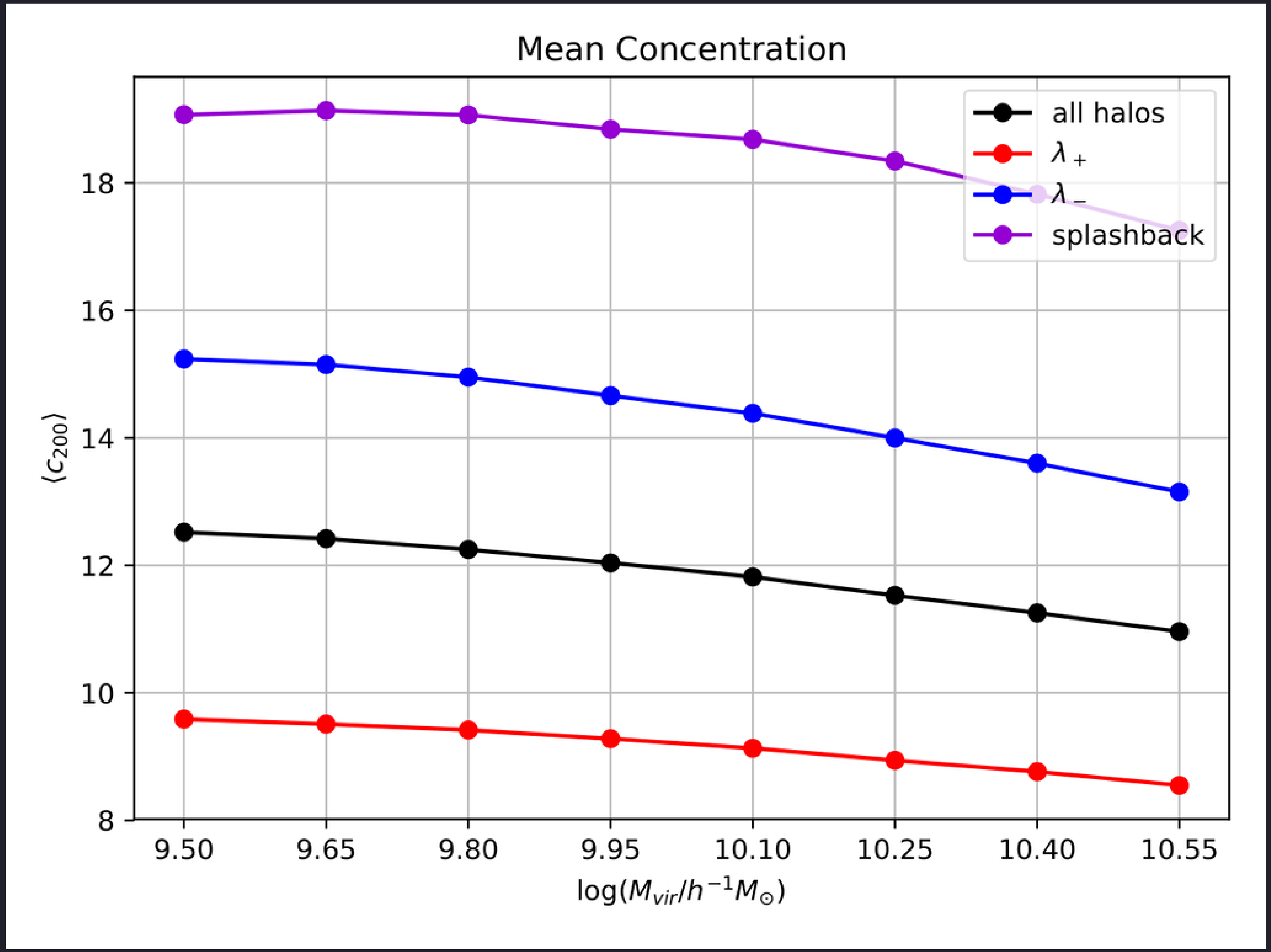
RECENT TIMES & LOW MASS

There are more splashback halos at low mass end and for low redshifts



OLDER & CONCENTRATED

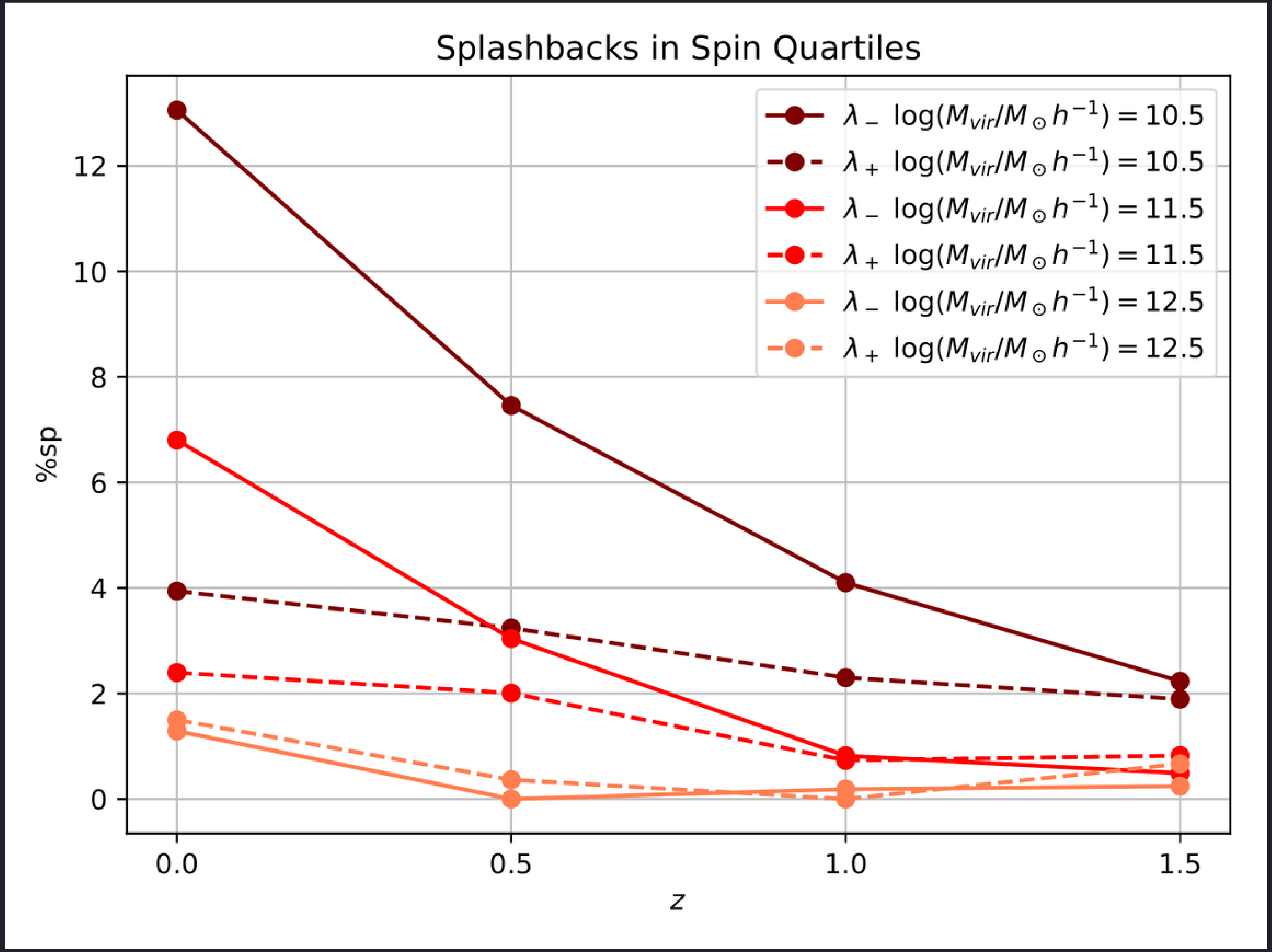




LOW SPIN

There are more splashback halos in the low spin quartile

WHY?

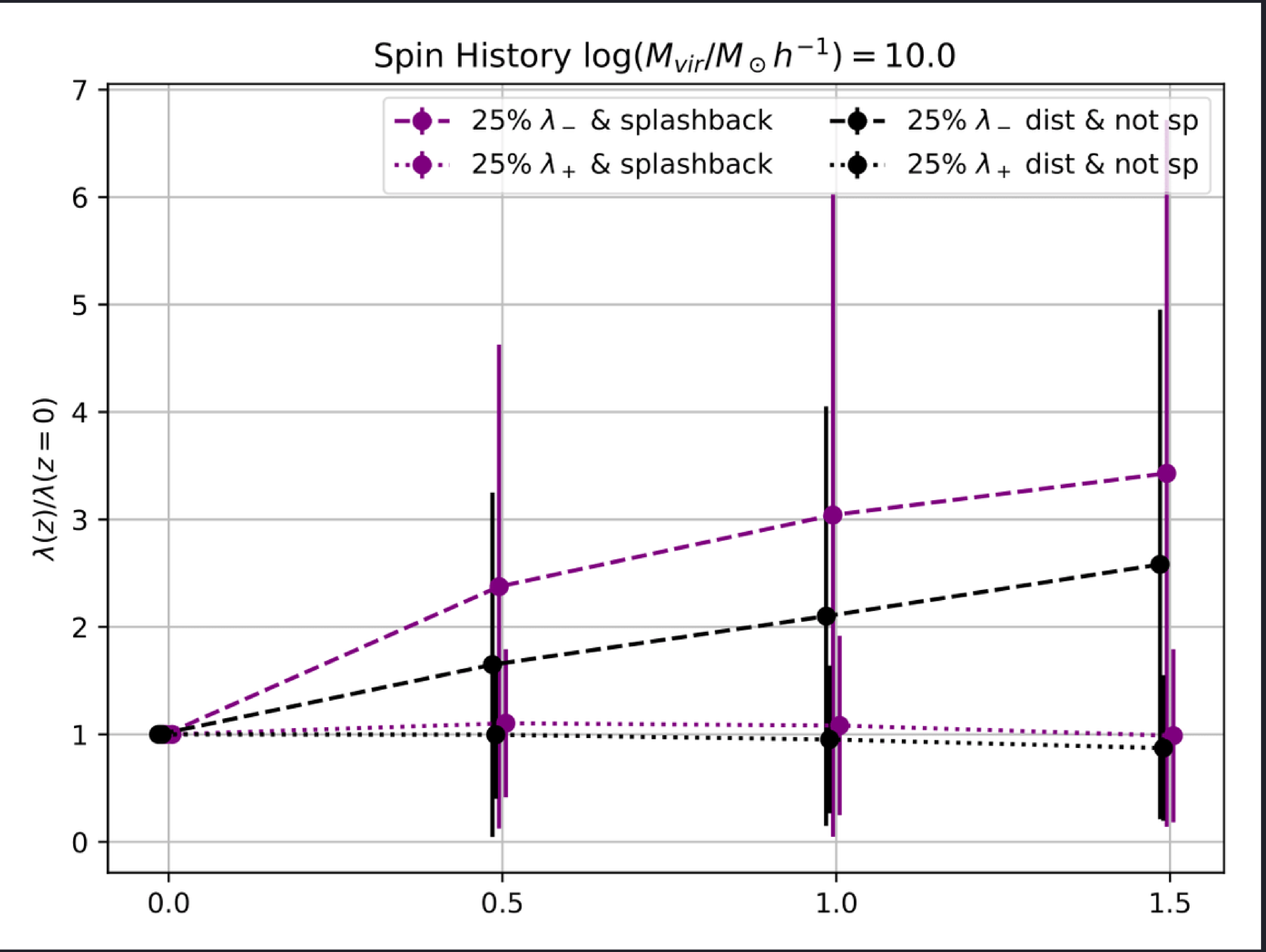


SPIN LOSS

Low spin halos lost spin with time

The extent of spin loss is higher for splashback halos

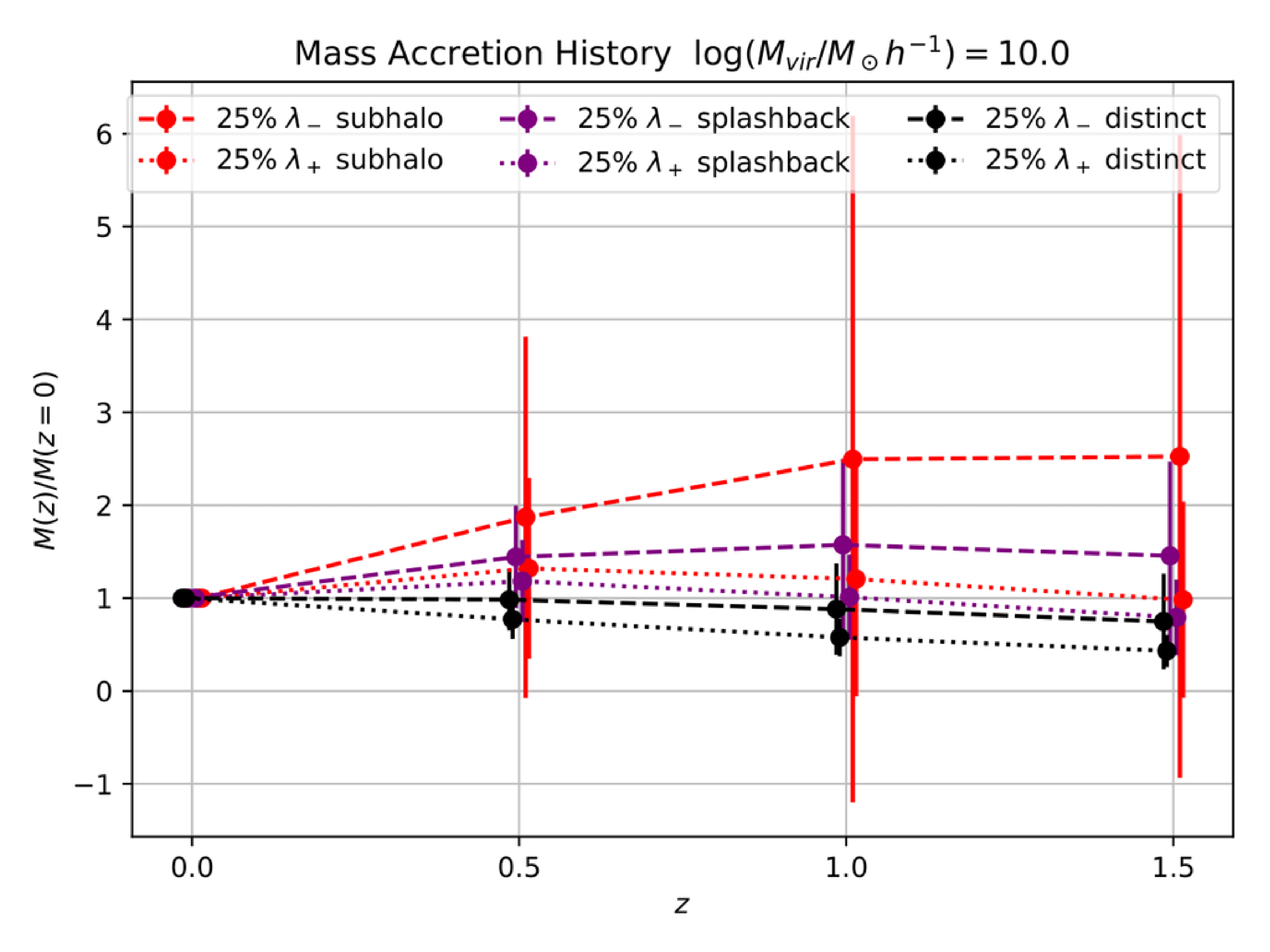
The spin of high spin halos remains constant with time

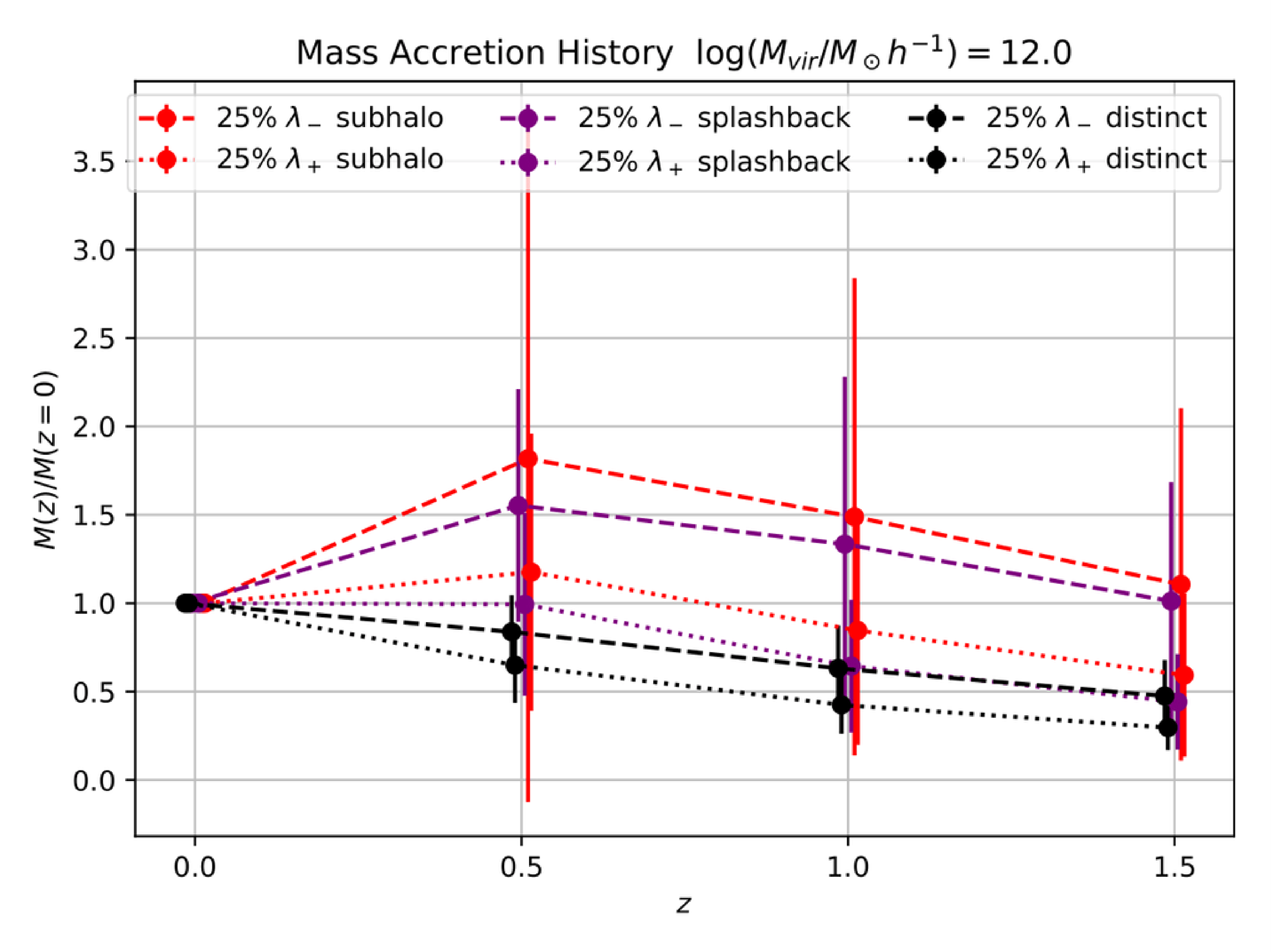


MASS LOSS

Splashback halos (and subhalos) lose mass with time;
the effect is more pronounced for low mass and low spin halos

The hierarchical structure formation scenario predicts halo mass growth with time





Causes of Mass Loss

distinct halos - Lee (2017)

tidal stripping

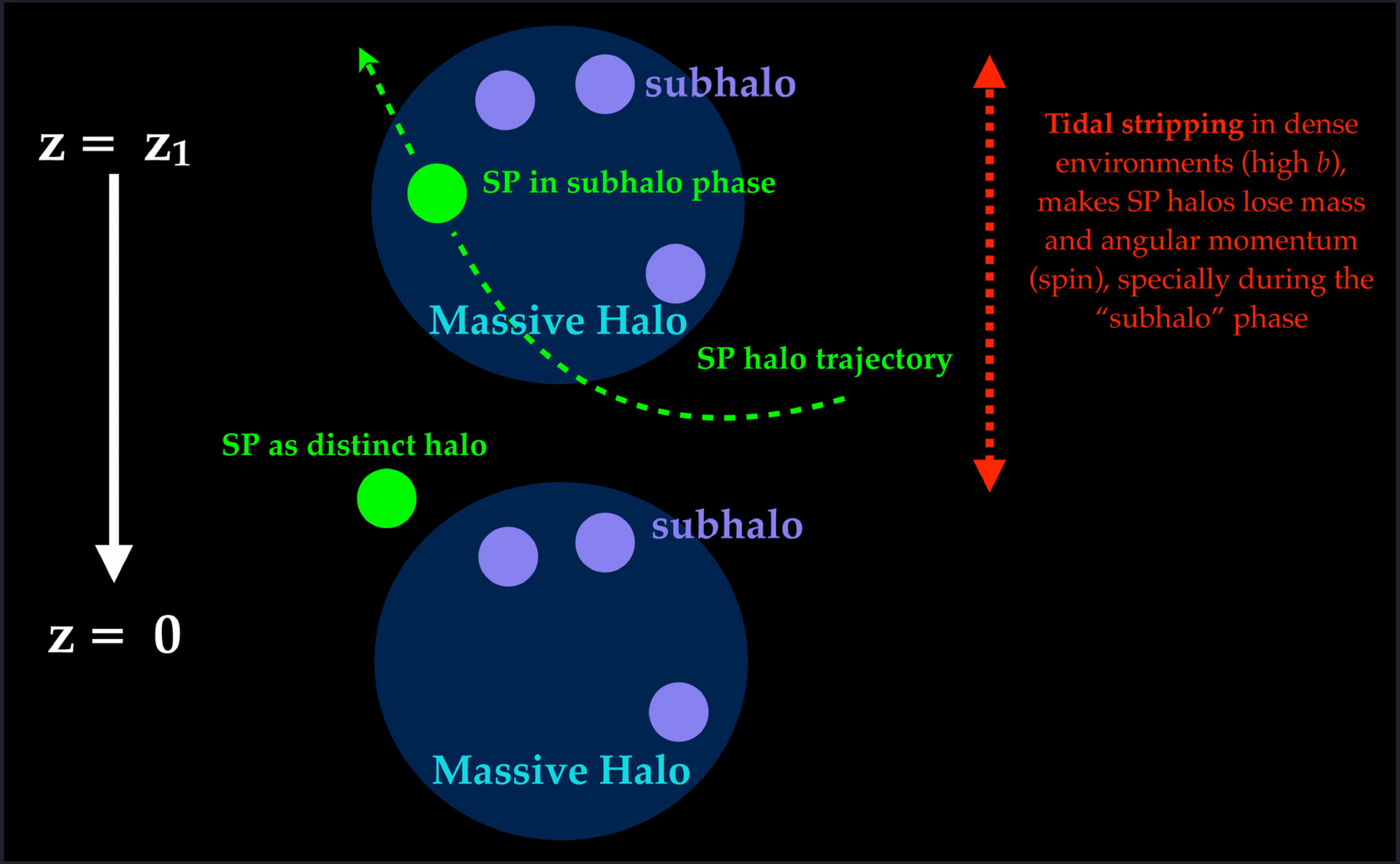
- decrease in spin
- only at low masses

major mergers

- increase in spin

Vitvitska et al. (2002)

TIDAL STRIPPING



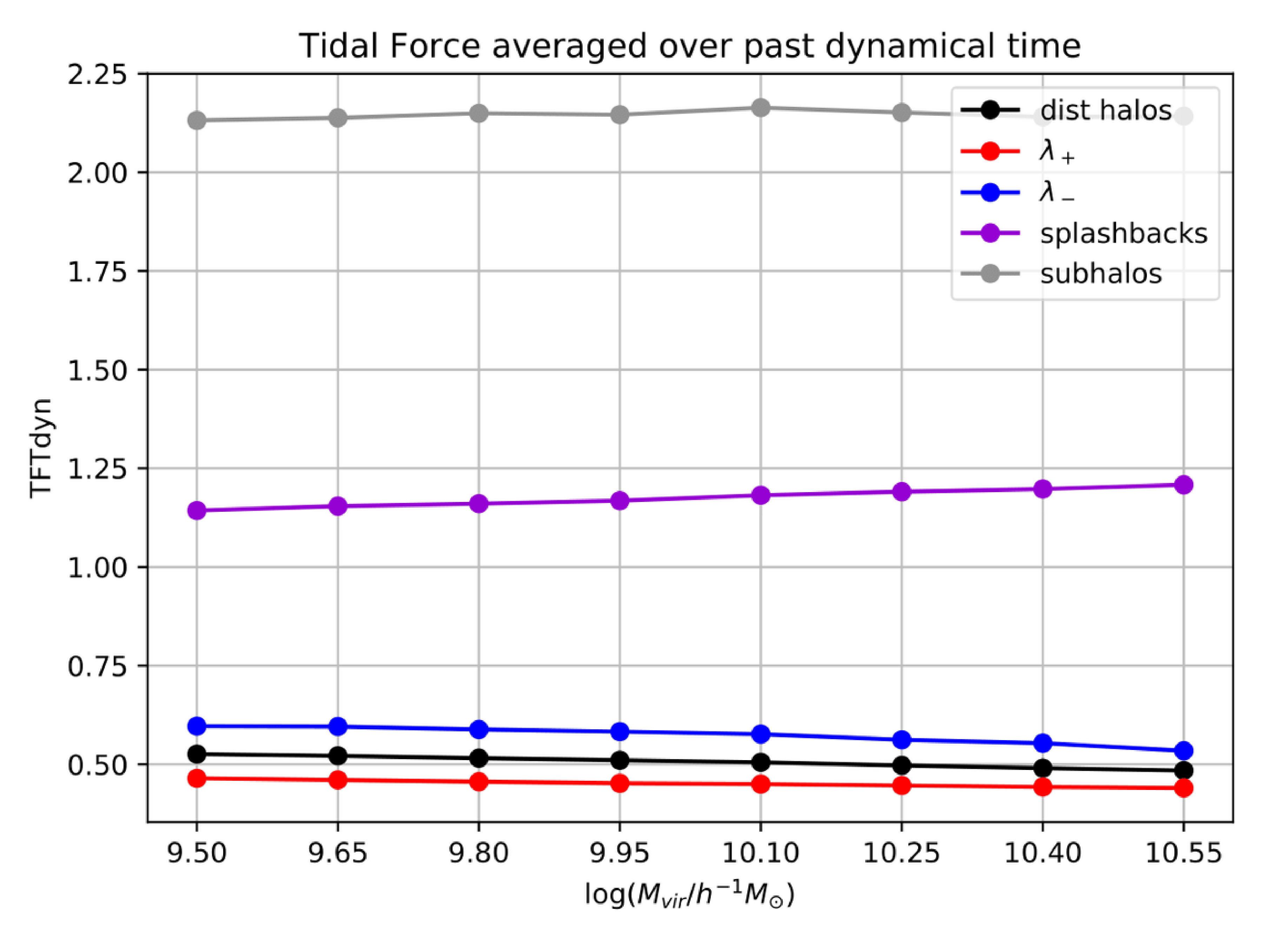
Lee (2017)

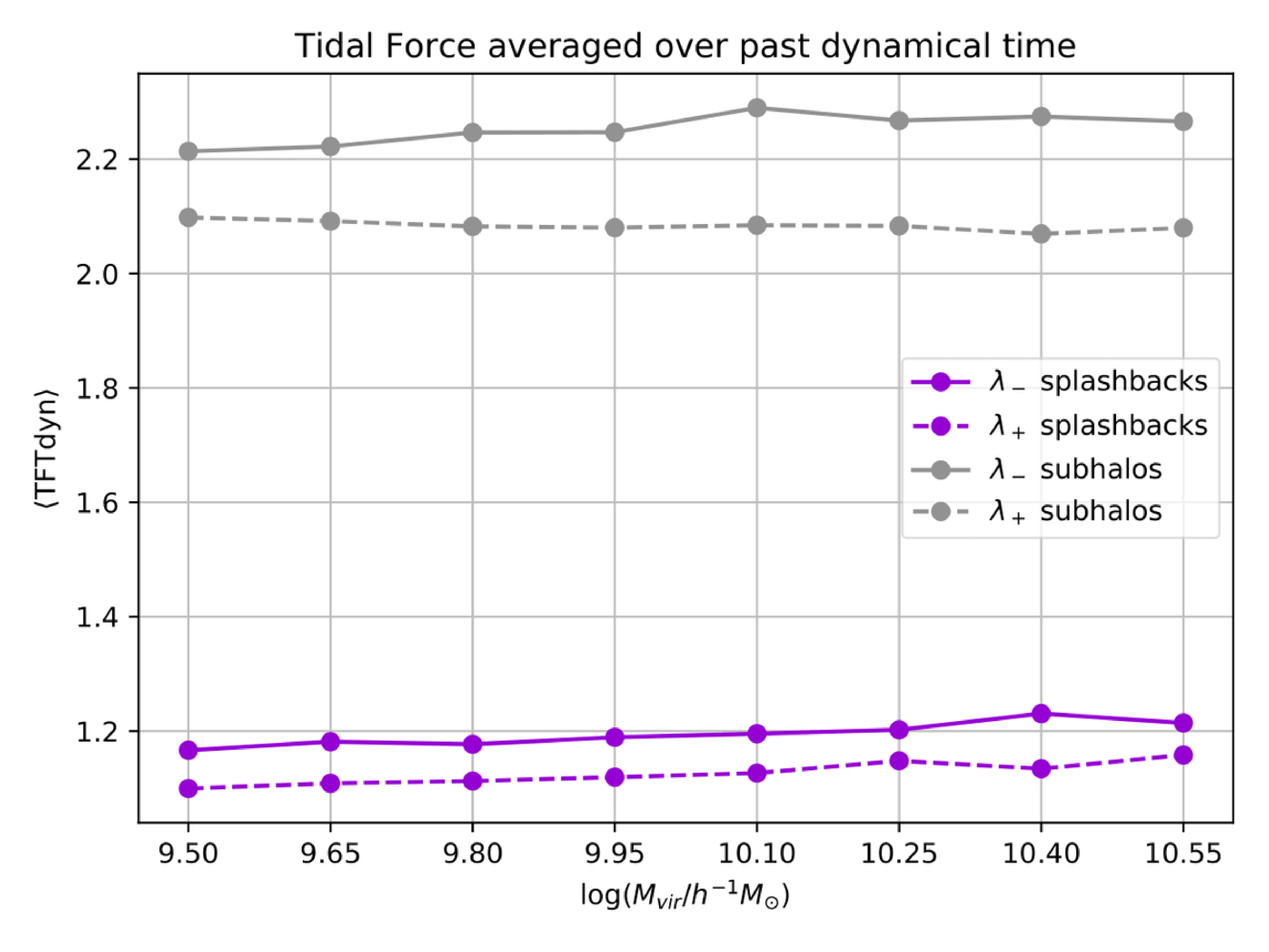
Borzyszkowski (2017)

TIDAL STRIPPING

TF (Rhill / Rvir)

Splashback halos (and subhalos) have suffered more tidal force





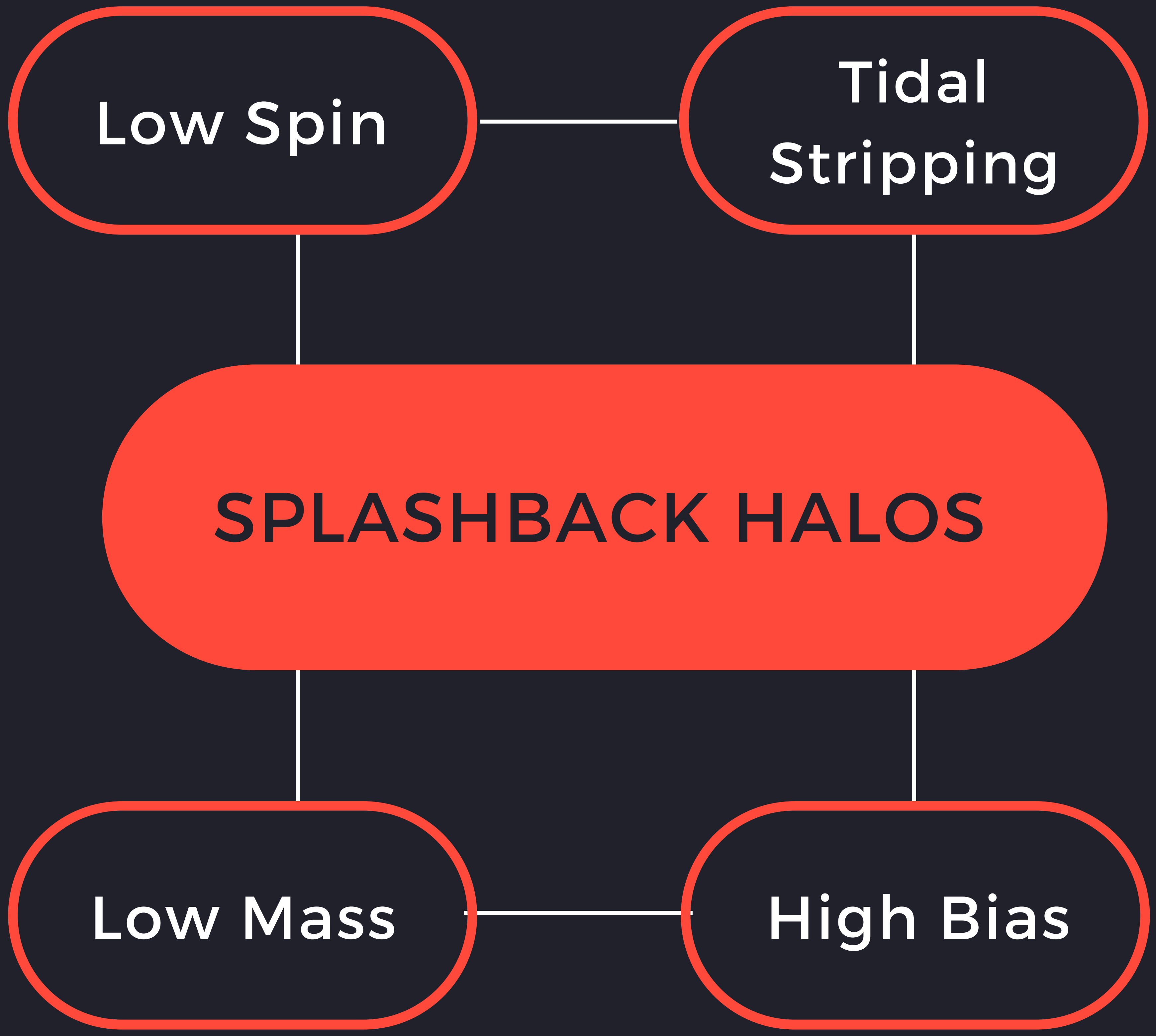
Substructure tidal anisotropy?

Ramakrishnan (2019)

"Objects that have always been in tidally mild, isotropic environments (small α) would then be distinguished from objects that have spent a considerable fraction of their existencein anisotropic sheets or filaments (large α)"

- splashbacks are extremes: have experienced very high tidal forces at some point in their past
- construct a local tidal indicator of large-scale assembly bias trends for them?
- α in the scale of the host halo

WRAPING UP


Low Spin
Tidal Stripping
SPLASHBACK HALOS
Low Mass
High Bias

Summary

- There is significant spin bias at the low mass end
- The population of splashback halos can explain this signal
- Splashbacks are tipically low mass and low spin halos important only at recent times
- They have higher bias and apparently lose angular momentum due to tidal stripping during the subhalo epoch

Next Steps

- How to prove tidal stripping? How to predict the amount of mass and angular momentum that is lost?
- Tidal anisotropy parameter for splashbacks?
- Secondary bias scale dependence?
- How can we probe splashback halos?

THANK YOU!

QUESTIONS?

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