On a Weak Correlation between the Spins of Galaxies and Their Host Halos

— Do galaxy sizes care about halo spin at all?

Fangzhou Jiang (Arthur)

Hebrew University of Jerusalem

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see also:
- R. Somerville (Mon)
- M. Fall (Tue)
- A. Kravtsov (Tue)

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  - useful in predicting (disk) galaxy sizes R_g

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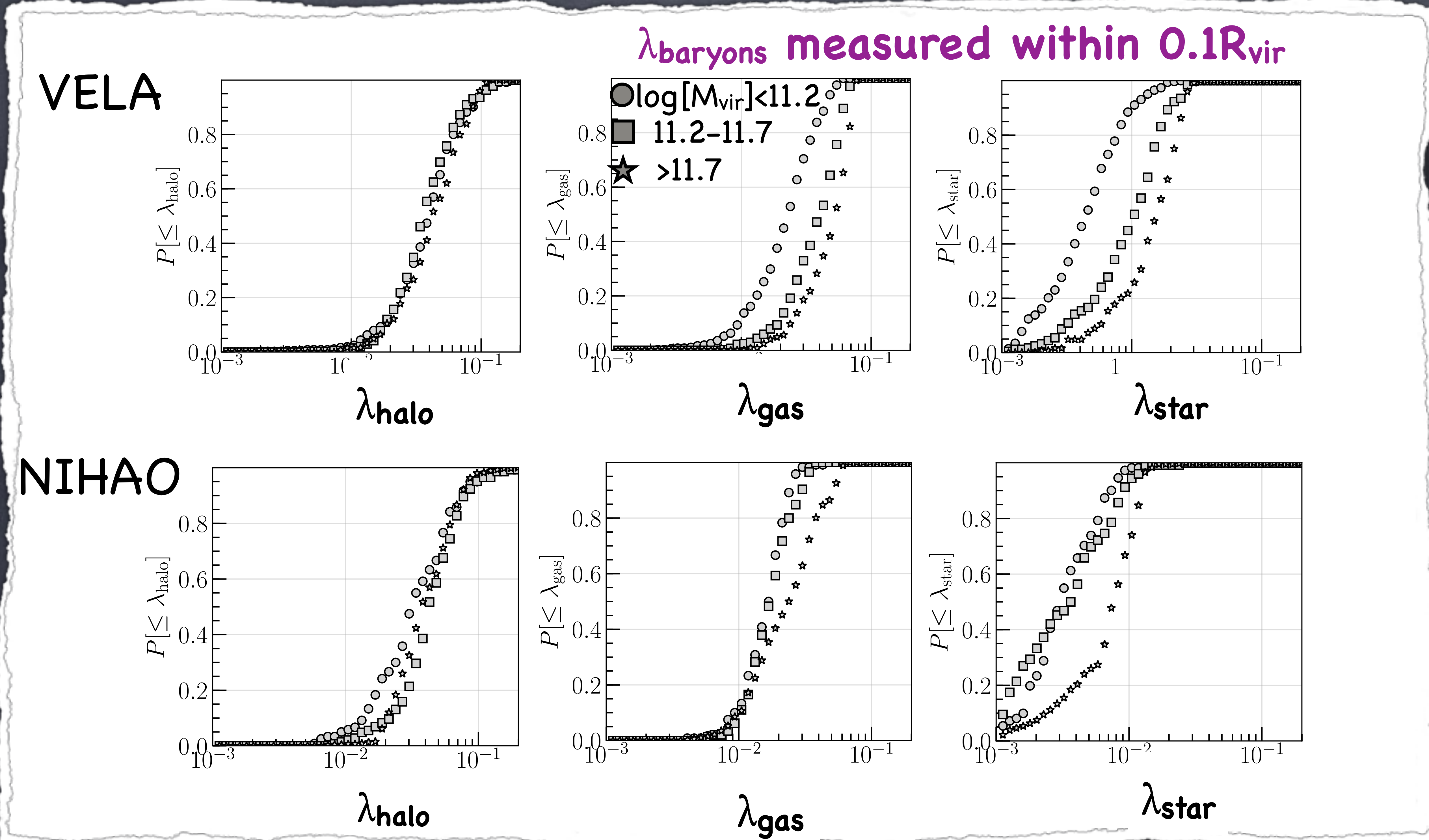
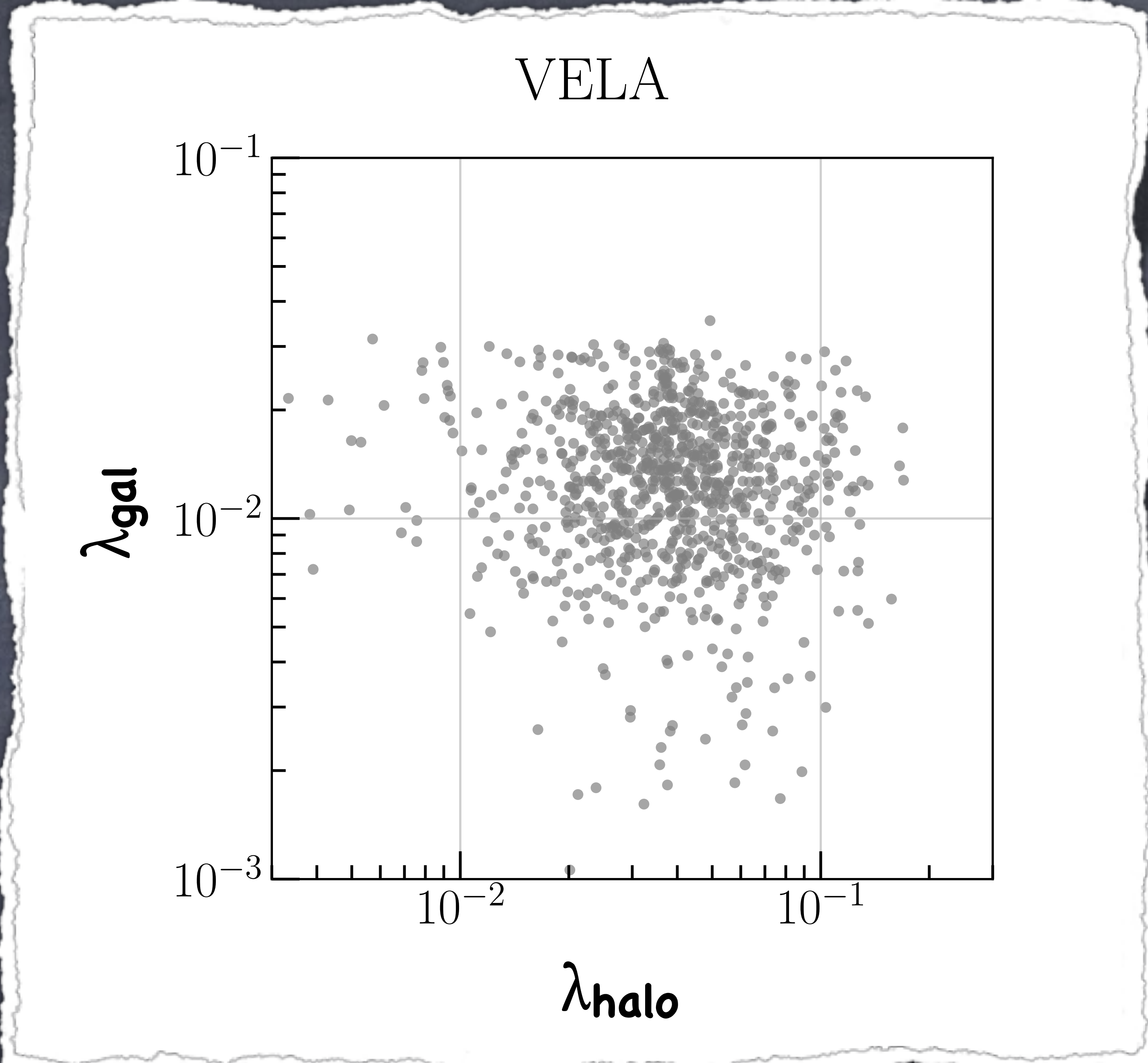
- test $\lambda_{\rm g} \overset{?}{\simeq} \lambda_{\rm h}$ using zoom-in hydro simulations
  - **VELA**: 34 gals, $z \geq 1$ (bracketing Milky Way if run to z=0), ART, $m_{cell} \approx 8.3 \times 10^4 M_{sun}$(dm), $10^3 M_{sun}$(gas), $\epsilon_{cell} \approx 17$-35pc
  - **NIHAO**: 13 Milky-Way-size gals, run to z=0, GASOLINE, $m_p \approx 1.7 \times 10^6 M_{sun}$ (dm), $3.2 \times 10^5 M_{sun}$ (gas), $\epsilon \approx 400$pc, much higher density threshold for SF and much stronger fdbk
  - (tentative) **Illustris(-TNG)** simulation

λ distributions



- $\langle\lambda_{halo}\rangle$ = 0.038, $\sigma_{\log\lambda}$ = 0.25; little M_{vir}-dependence
- $\langle\lambda_{gas}\rangle$ = 0.032, $\sigma_{\log\lambda}$ = 0.26; higher in higher M_{vir}
- $\langle\lambda_{star}\rangle$ = 0.007, $\sigma_{\log\lambda}$ = 0.37; stronger M_{vir}-dependence

λ_{gal} - λ_{halo} correlation



see also Teklu+15

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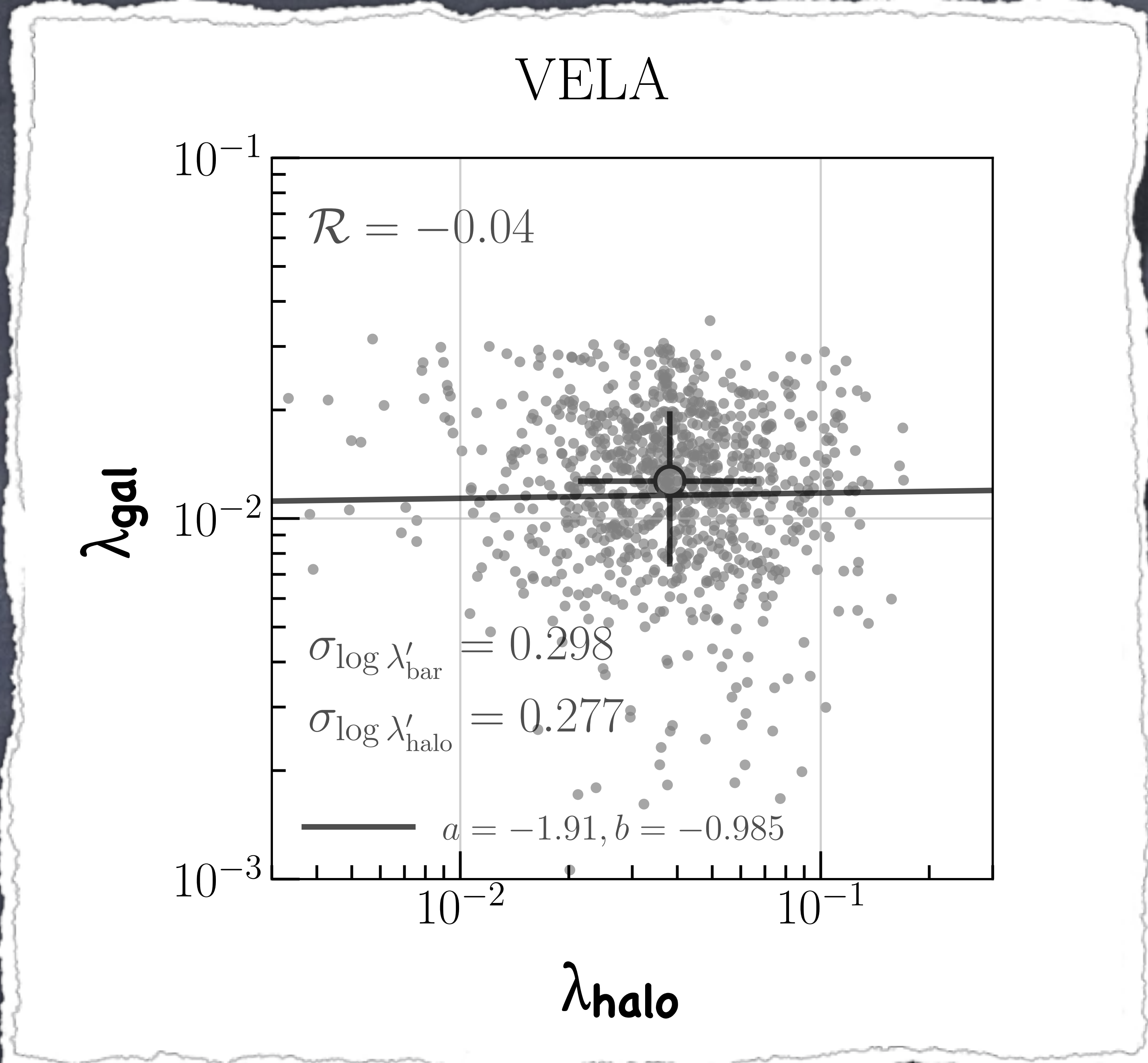

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regression line: $\log \lambda_g = a + (1+b) \log \lambda_h$

At $z \geq 1$, no correlation between λ_g and λ_h ($b \approx -1$)

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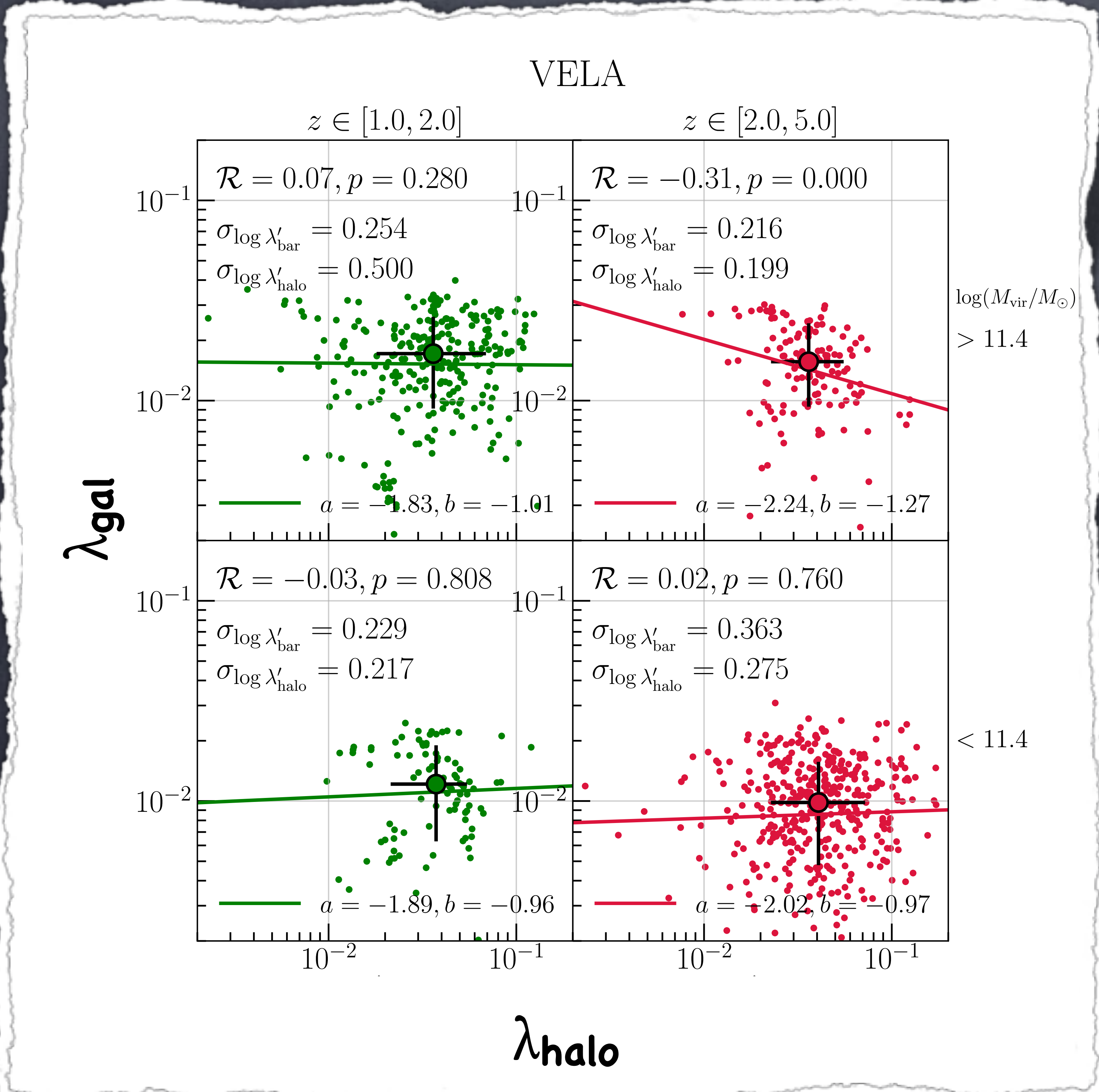

$M_{vir} \approx 10^{11.4} M_{sun}$: characteristic mass at which galaxies "compactify" to form "blue nuggets" (BN)

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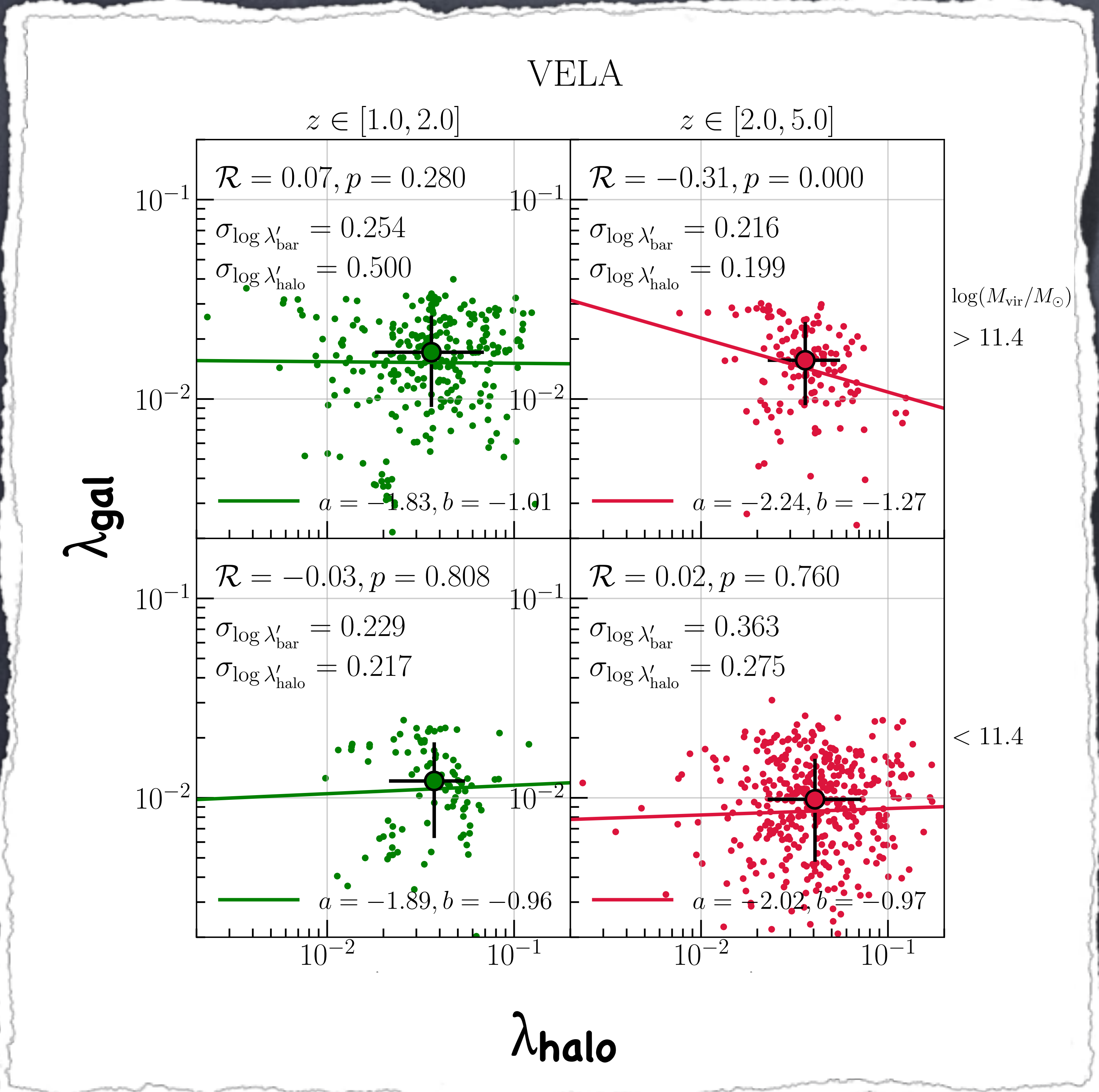

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- λ_{gal} is higher for higher-M_{vir} (post-compaction) systems

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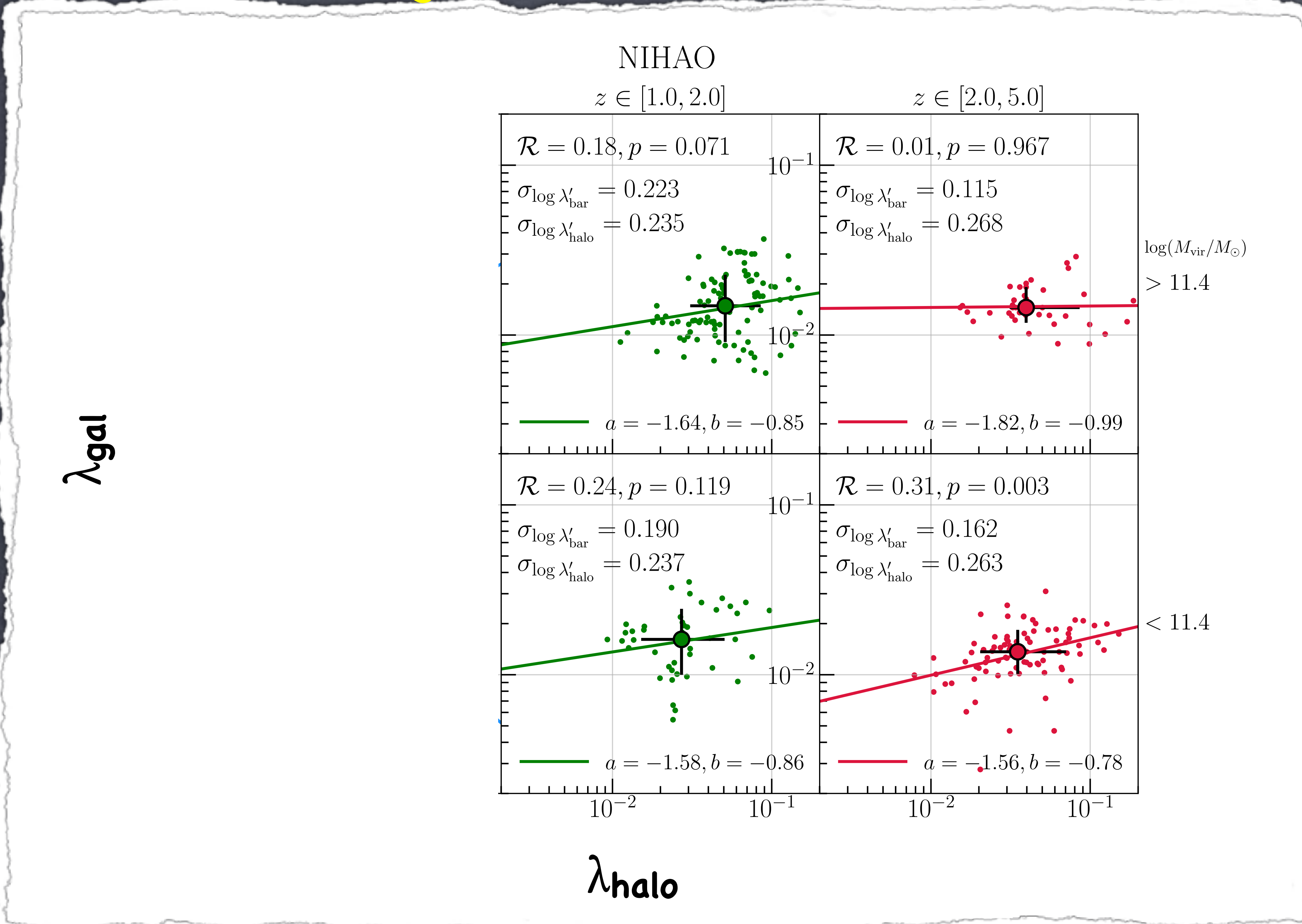

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- the same, lack of correlation at **z≥1**

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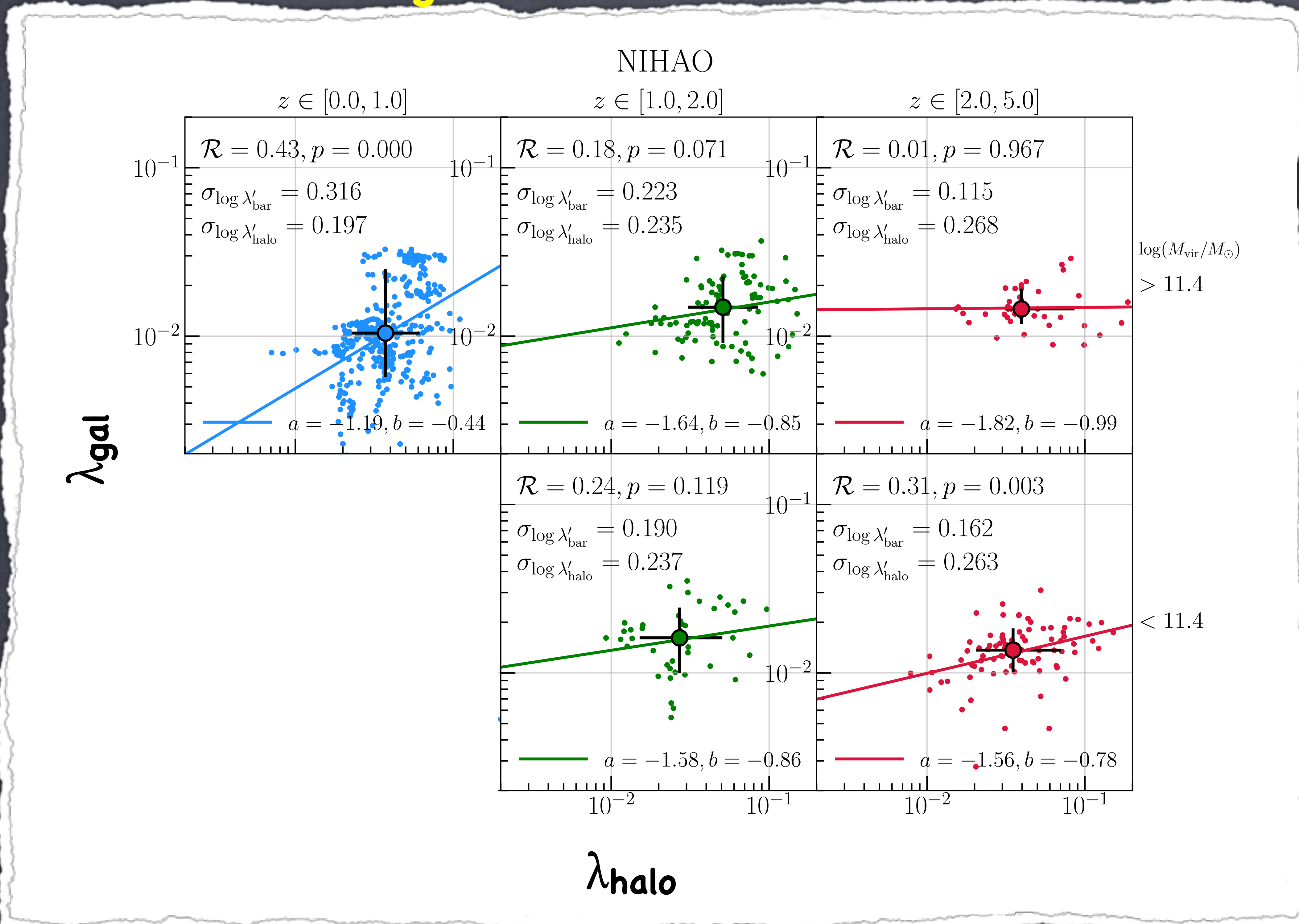

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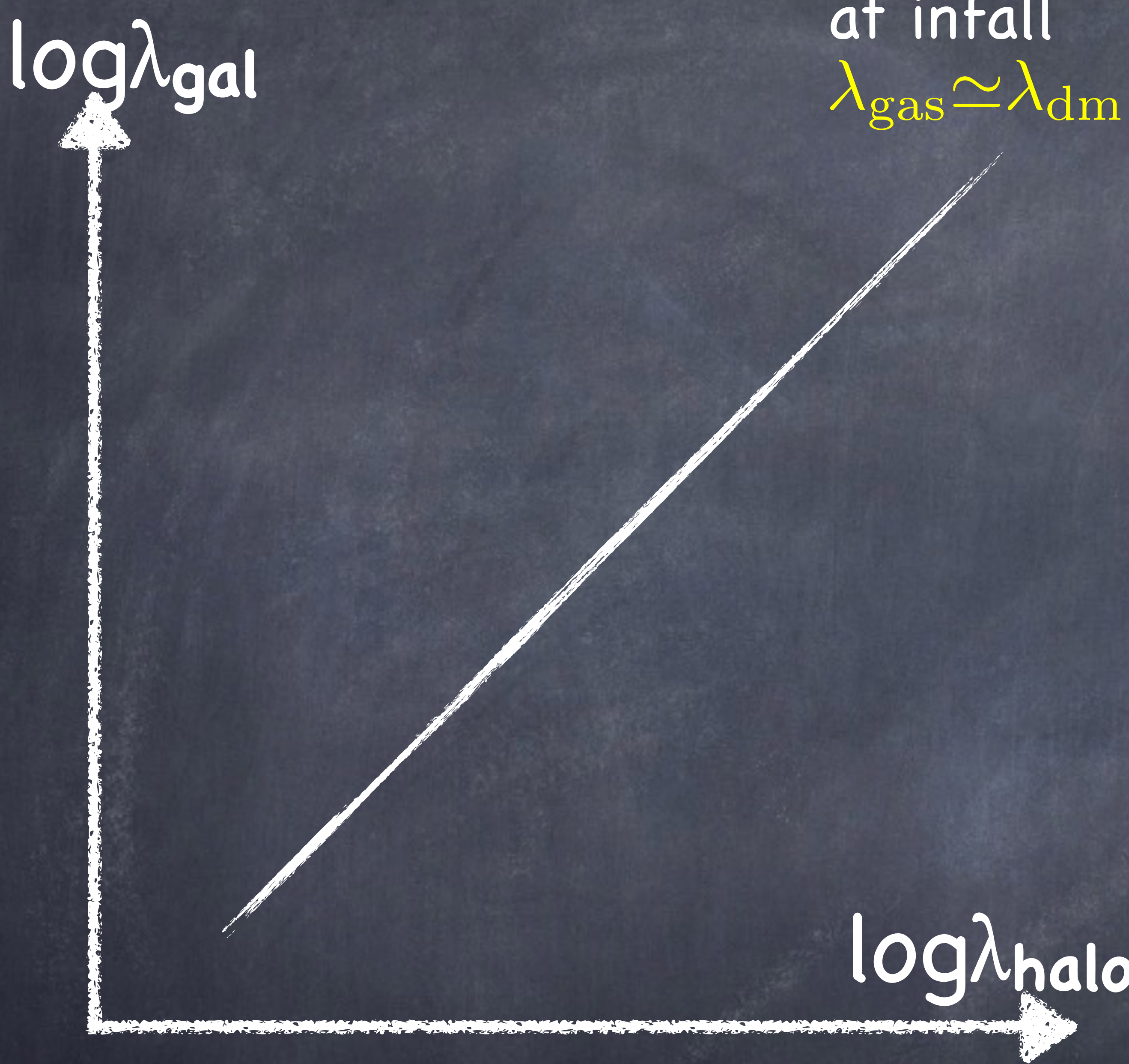
- the same, lack of correlation at $z \geq 1$
- a correlation develops towards lower z ($-1<b<0$)

λ_{gal} - λ_{halo} non-correlation



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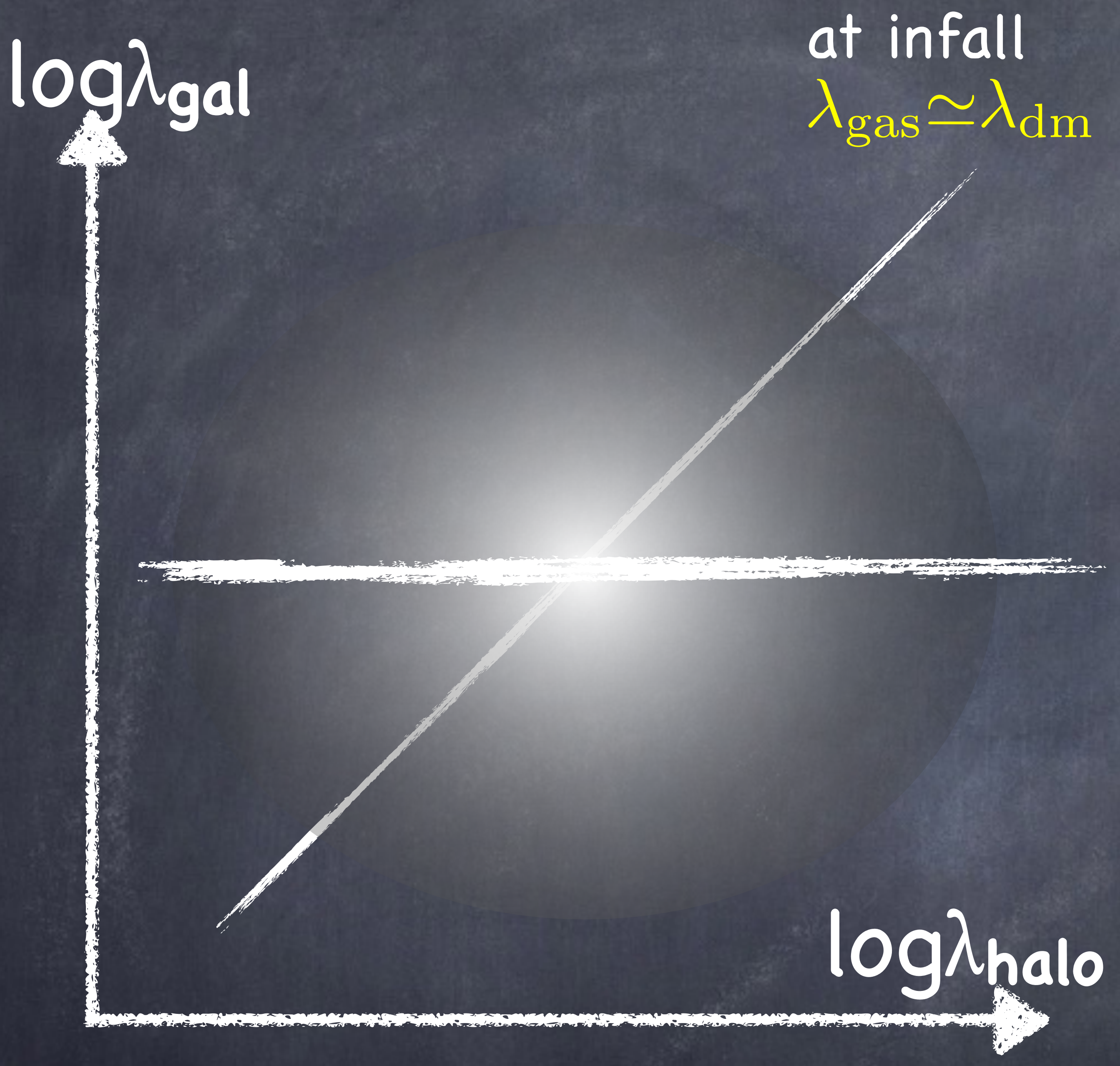

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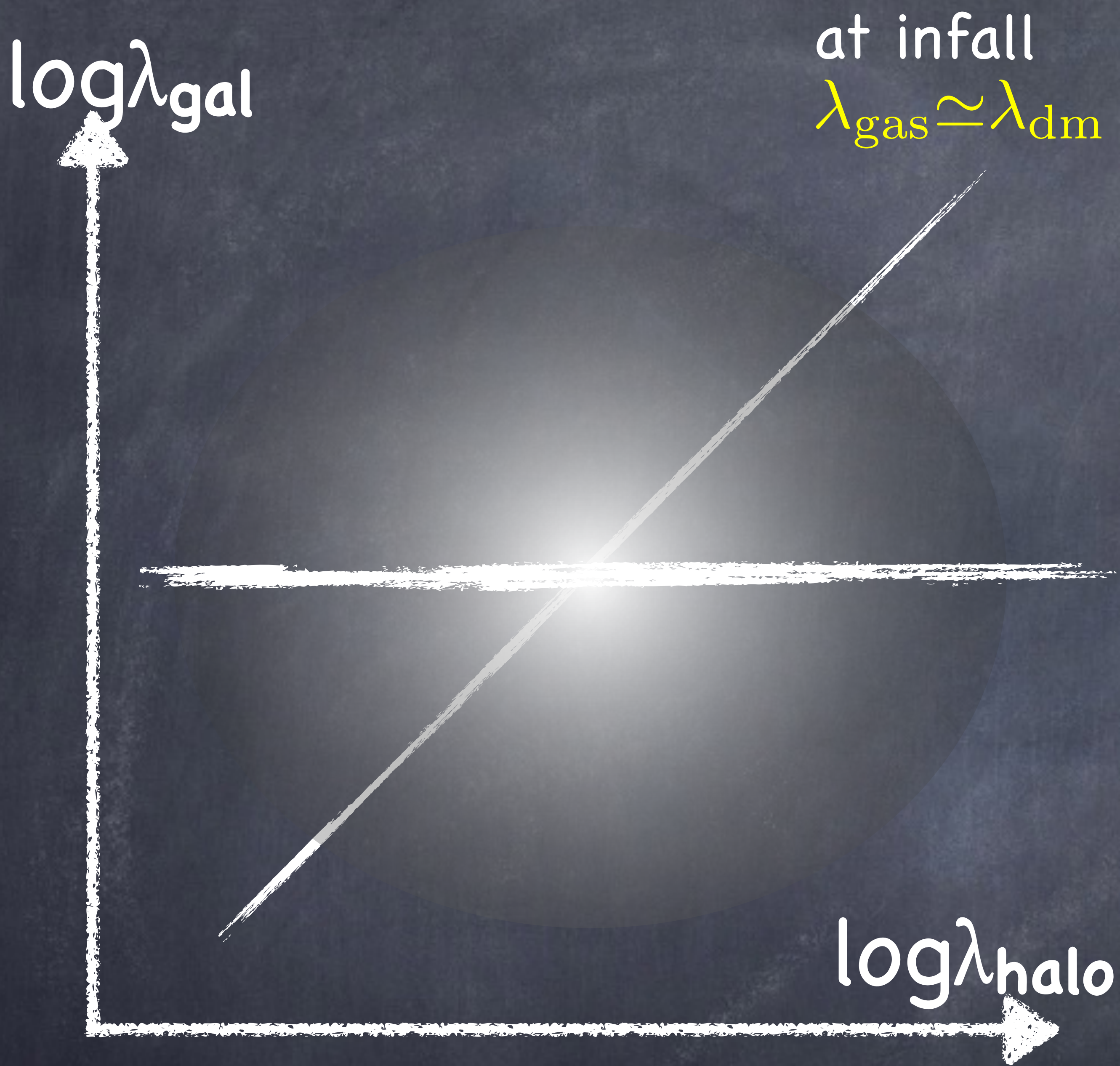

$$\lambda_g = \lambda_h \frac{\lambda_g}{\lambda_h}$$

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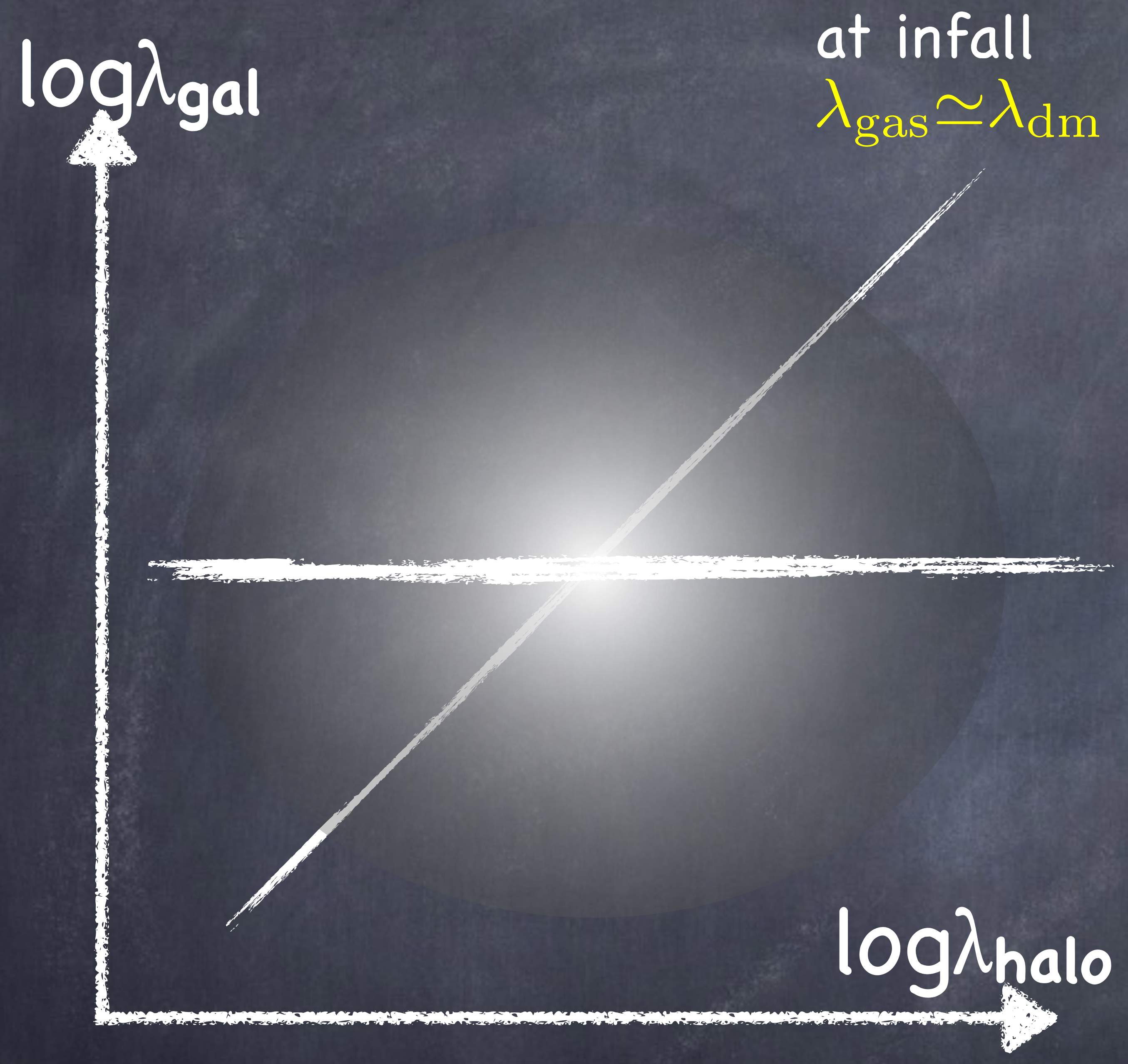

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- may depend systematically on λ_h
- suppose $\langle \frac{\lambda_g}{\lambda_h} \rangle \propto \lambda_h^b$

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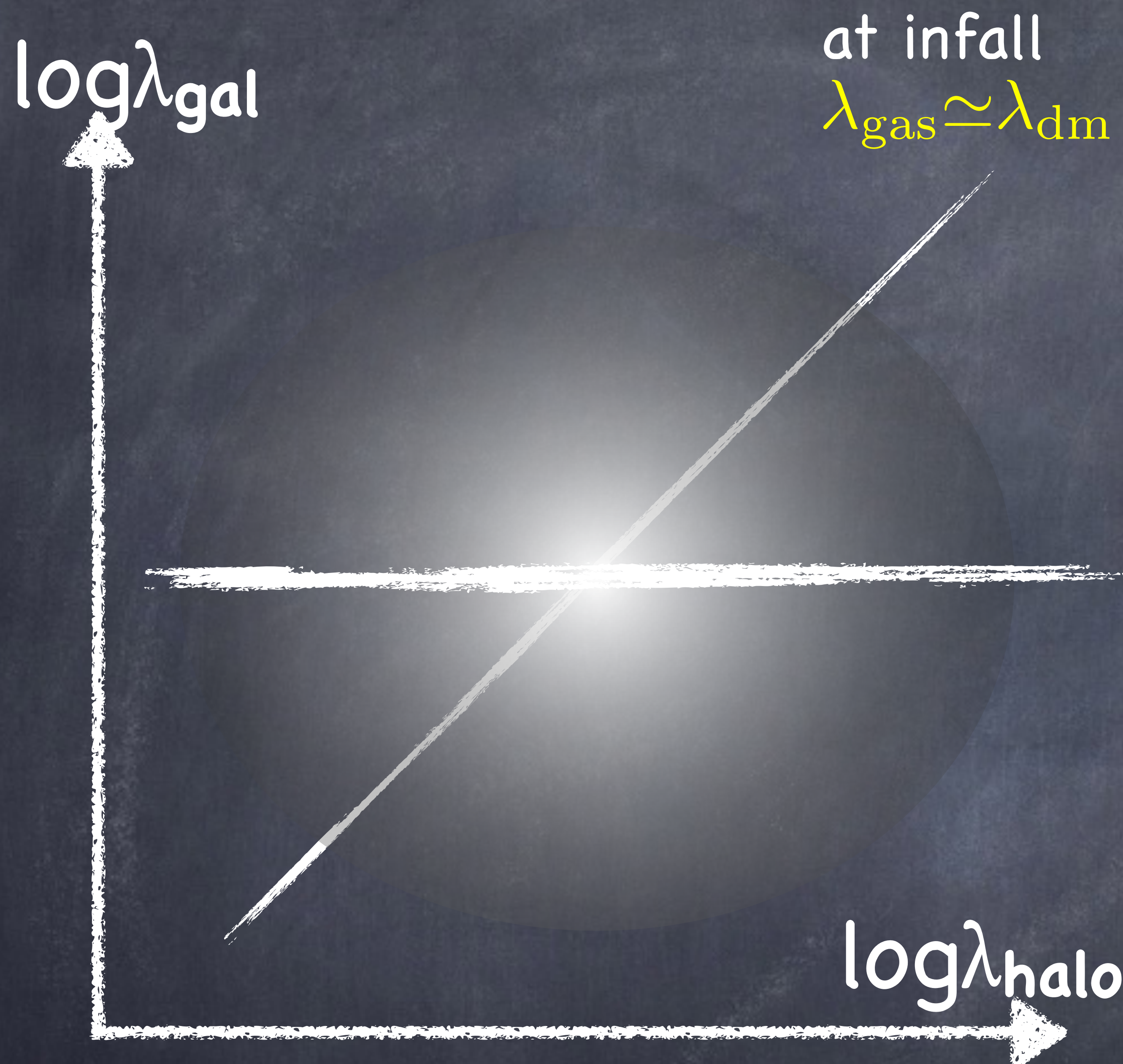

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$-1 < b < 0$ at low-z

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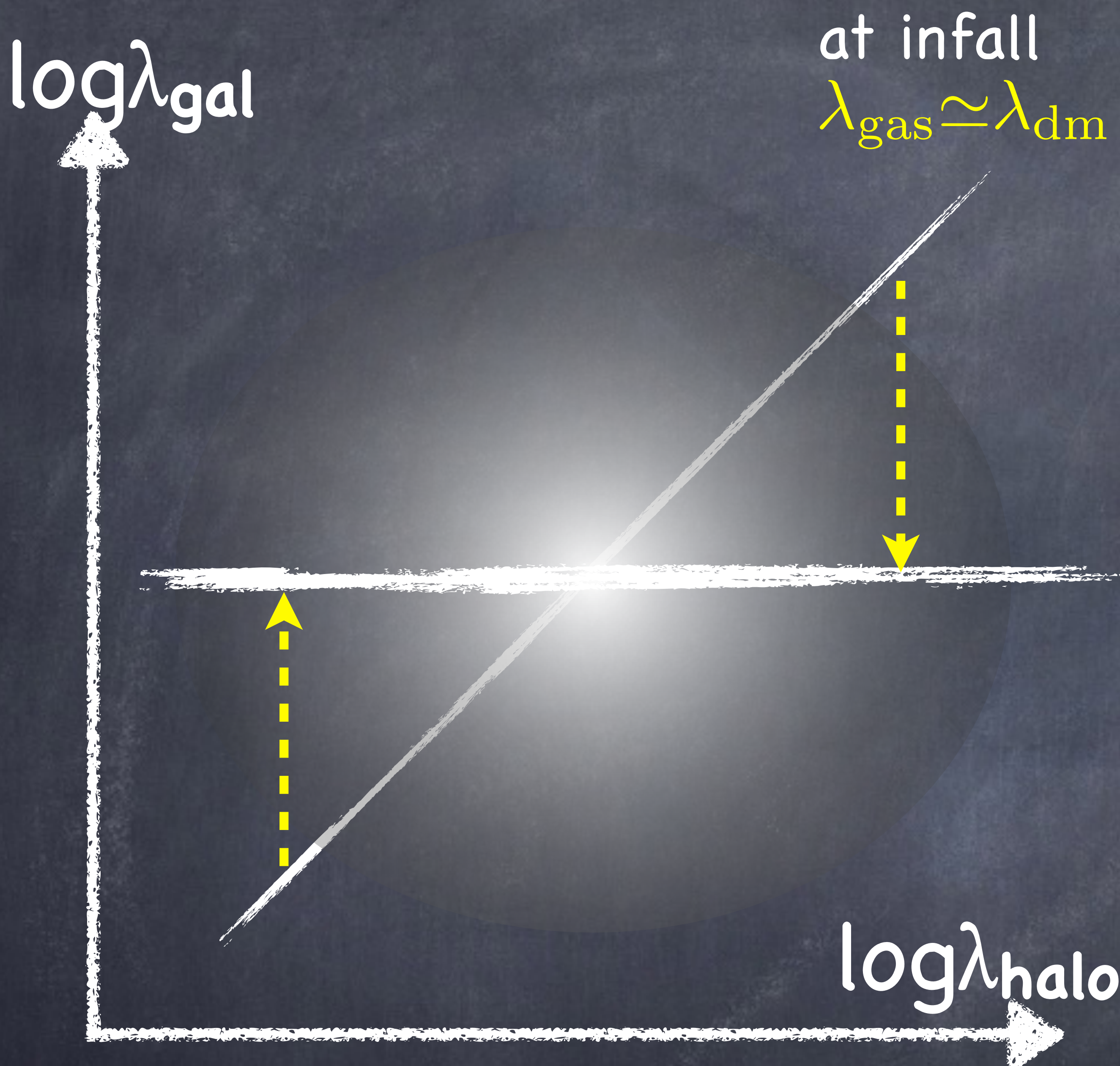

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To explain the non-correlation requires mechanisms for initially high-λ_h systems to lose sAM in baryons and low-λ_h system to gain sAM in baryons, i.e., **anti-correlation between λ_g/λ_h and λ_h**

possible reasons for a λ_g/λ_h - λ_h anti-correlation

- **galaxy compaction** (Dekel & Burkert 14)
  - a system starts with low λ_h and thus low λ_{gas}
  - low λ_{gas} -> high Σ_{1kpc} (**compaction**)
  - "Blue Nugget" (BN) forms -> high central SFR, gas depletion
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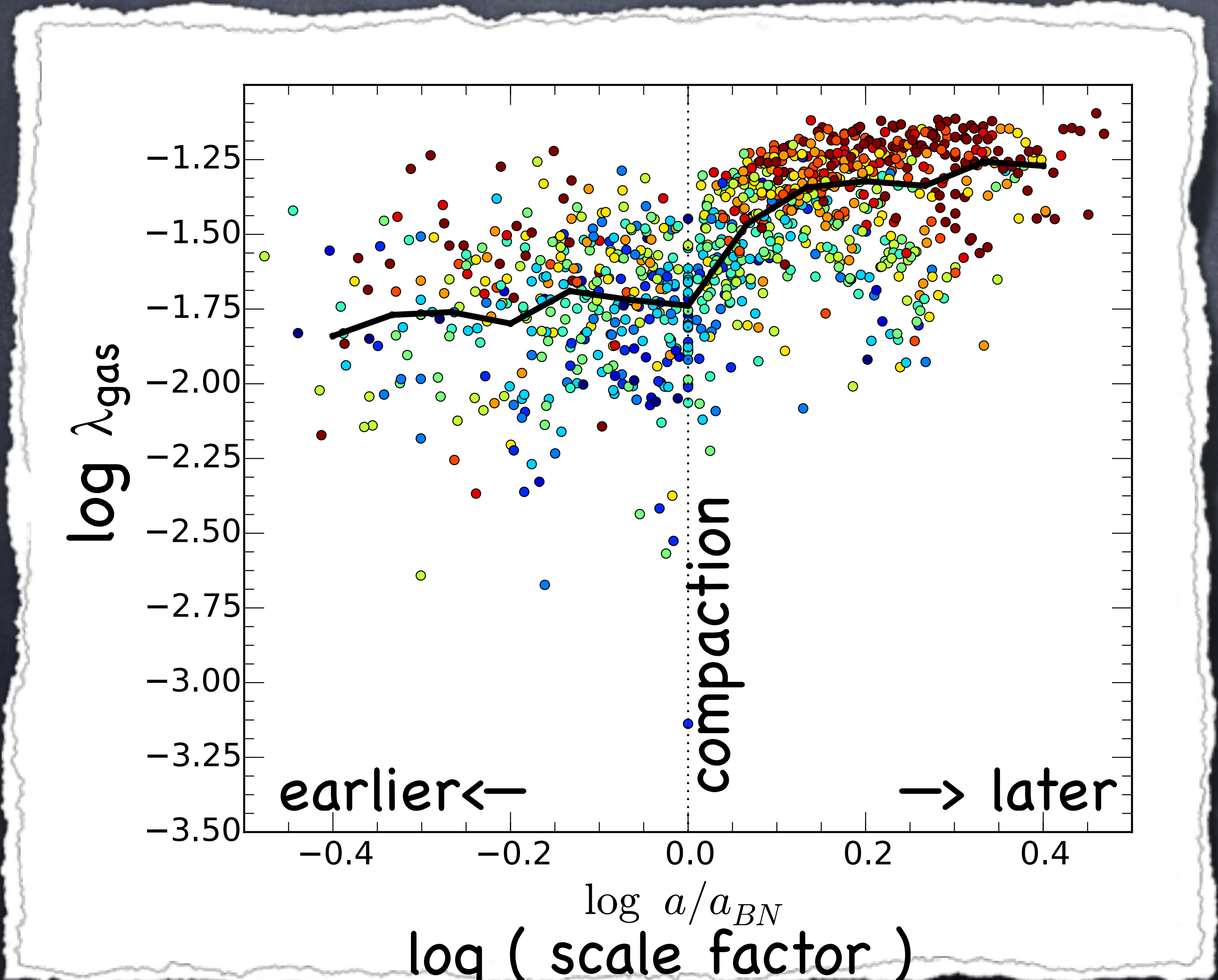


compaction happens at a characteristic mass scale

$M_{star} \approx 10^{9.5-10} M_{sun}$

$M_{vir} \approx 10^{11.4} M_{sun}$

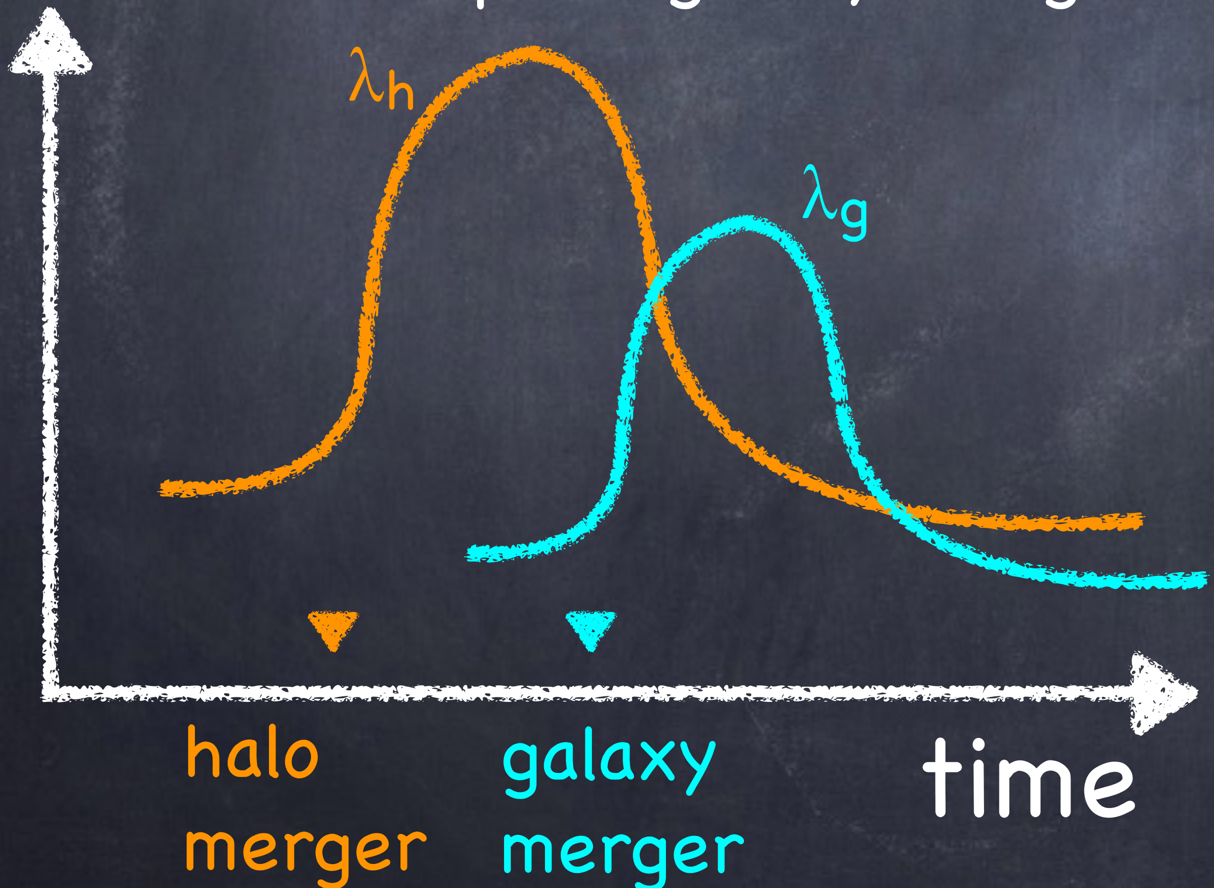
(caveat: depend on SF, fdbk etc)

Dekel+17 in prep

possible reasons for a λ_g/λ_h - λ_h anti-correlation

- **mergers**

  - halo mergers cause λ_h to rise (orbital AM dominating λ_h), while λ_g is untouched yet
  - halo re-virializes -> λ_h drops, while λ_g temporarily rises due to the subsequent galaxy merger



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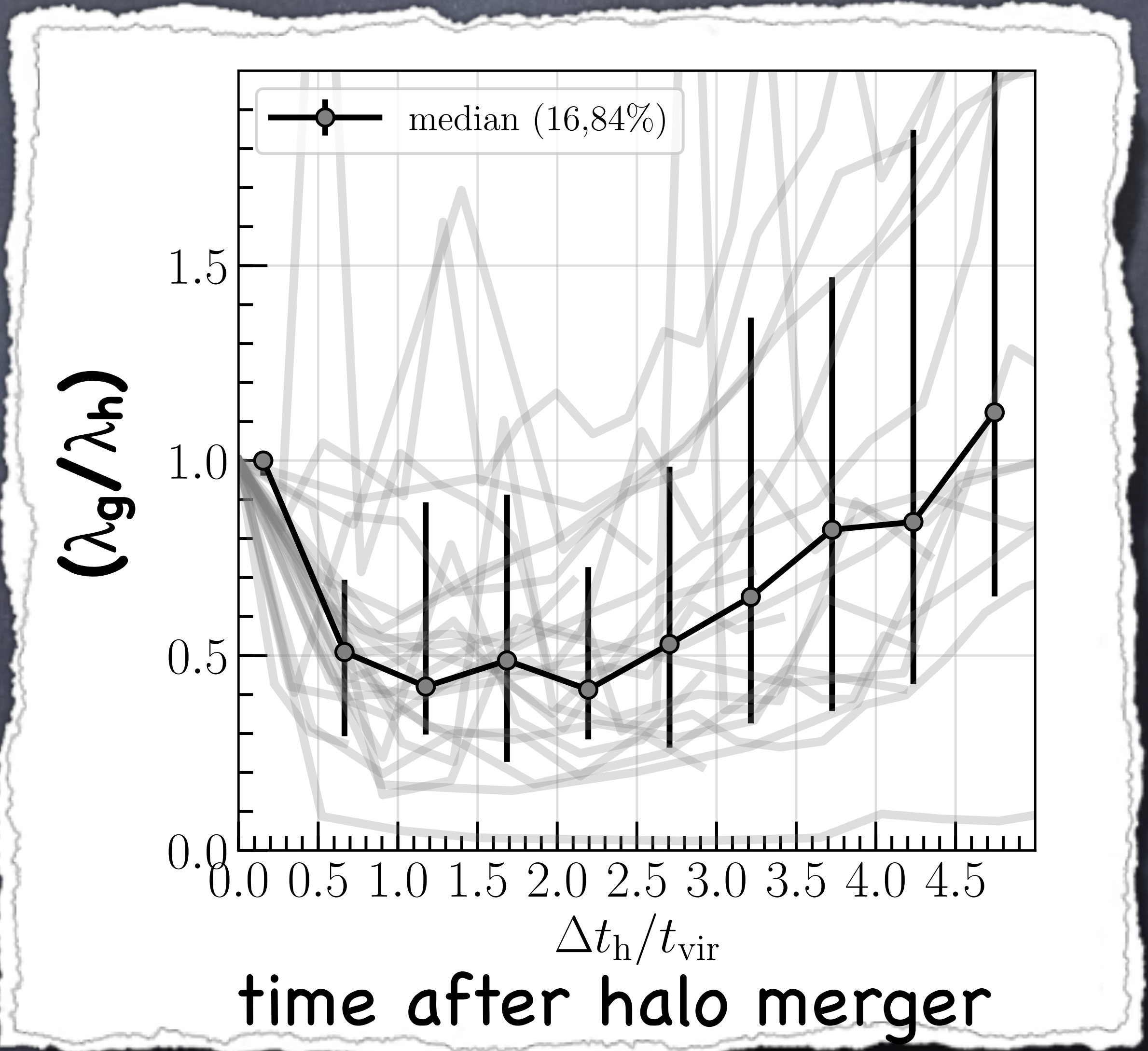

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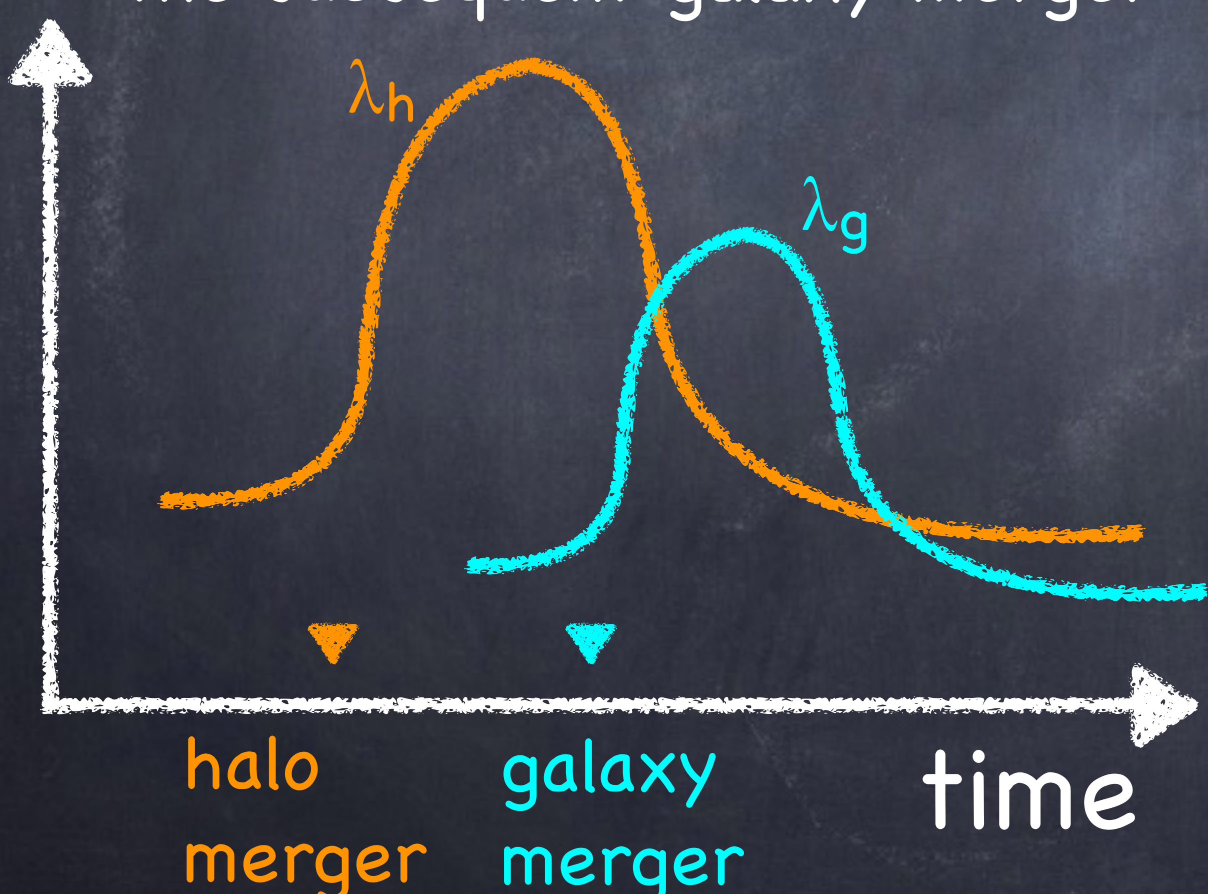

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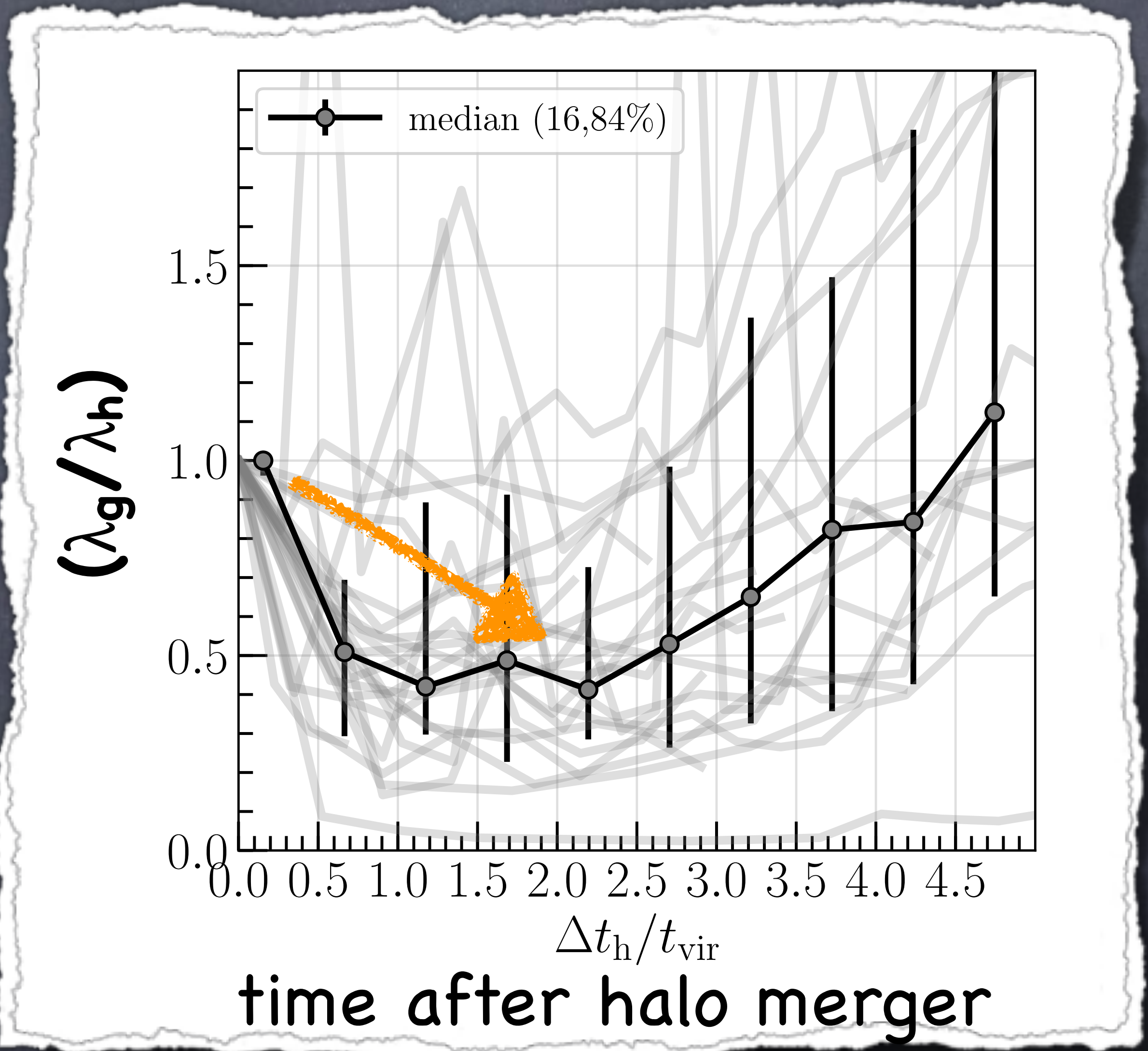

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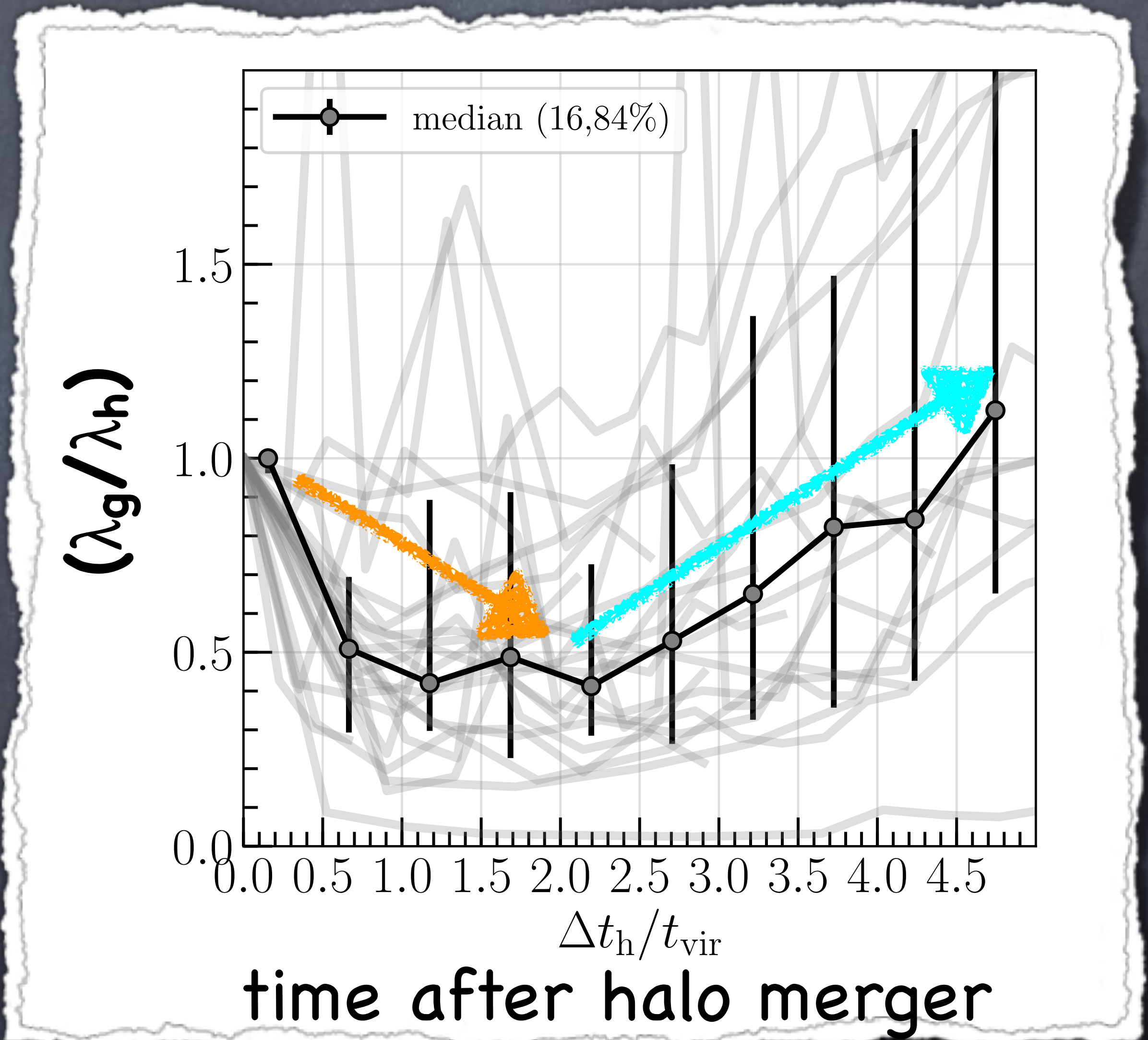

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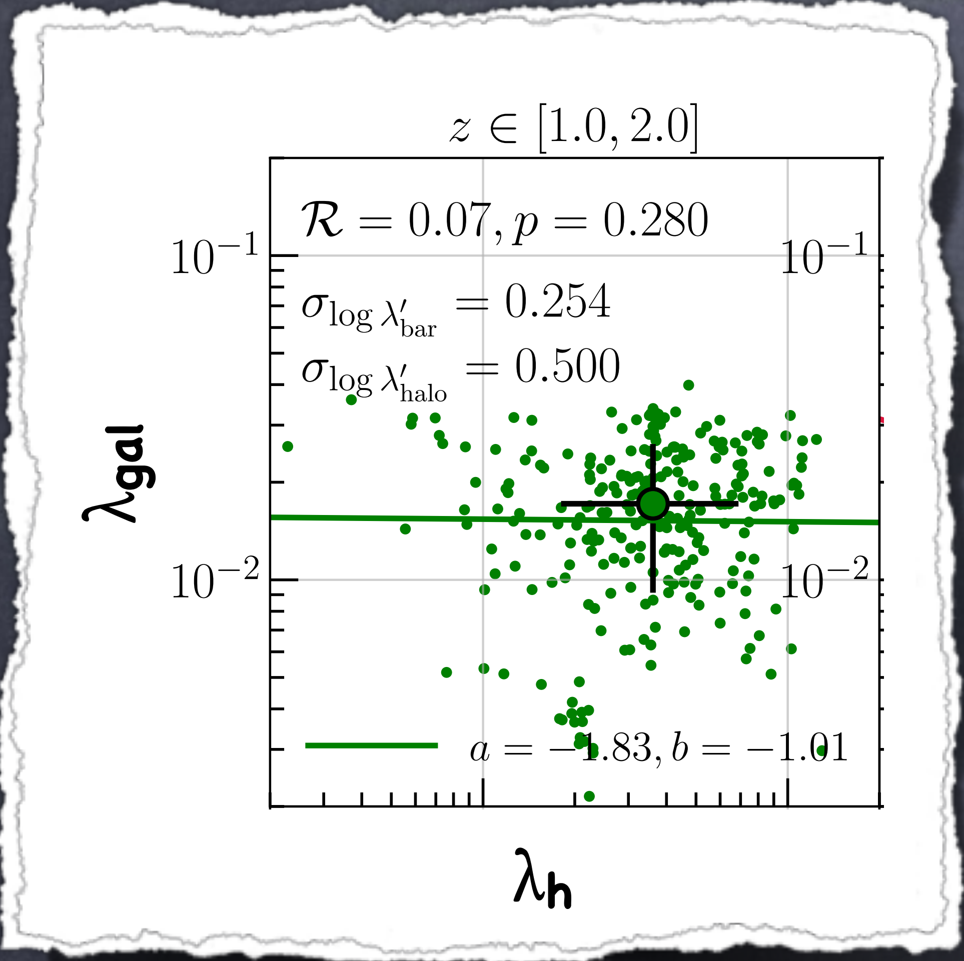
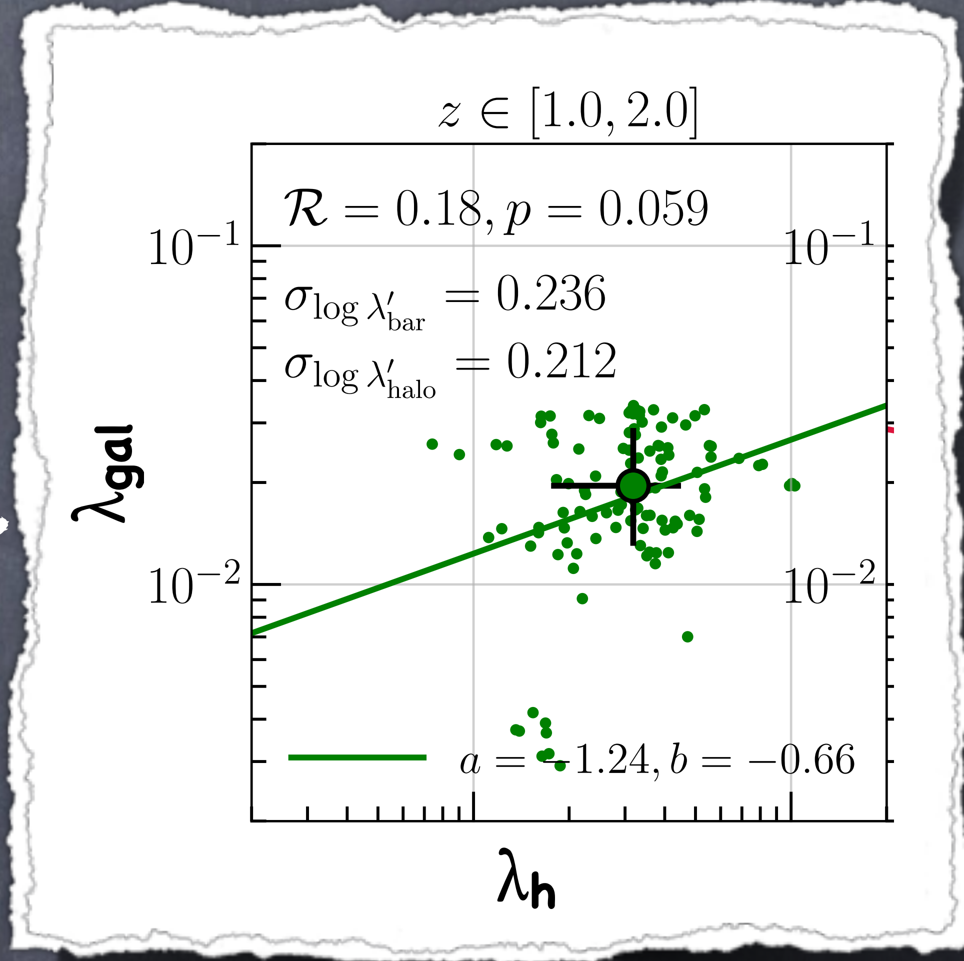
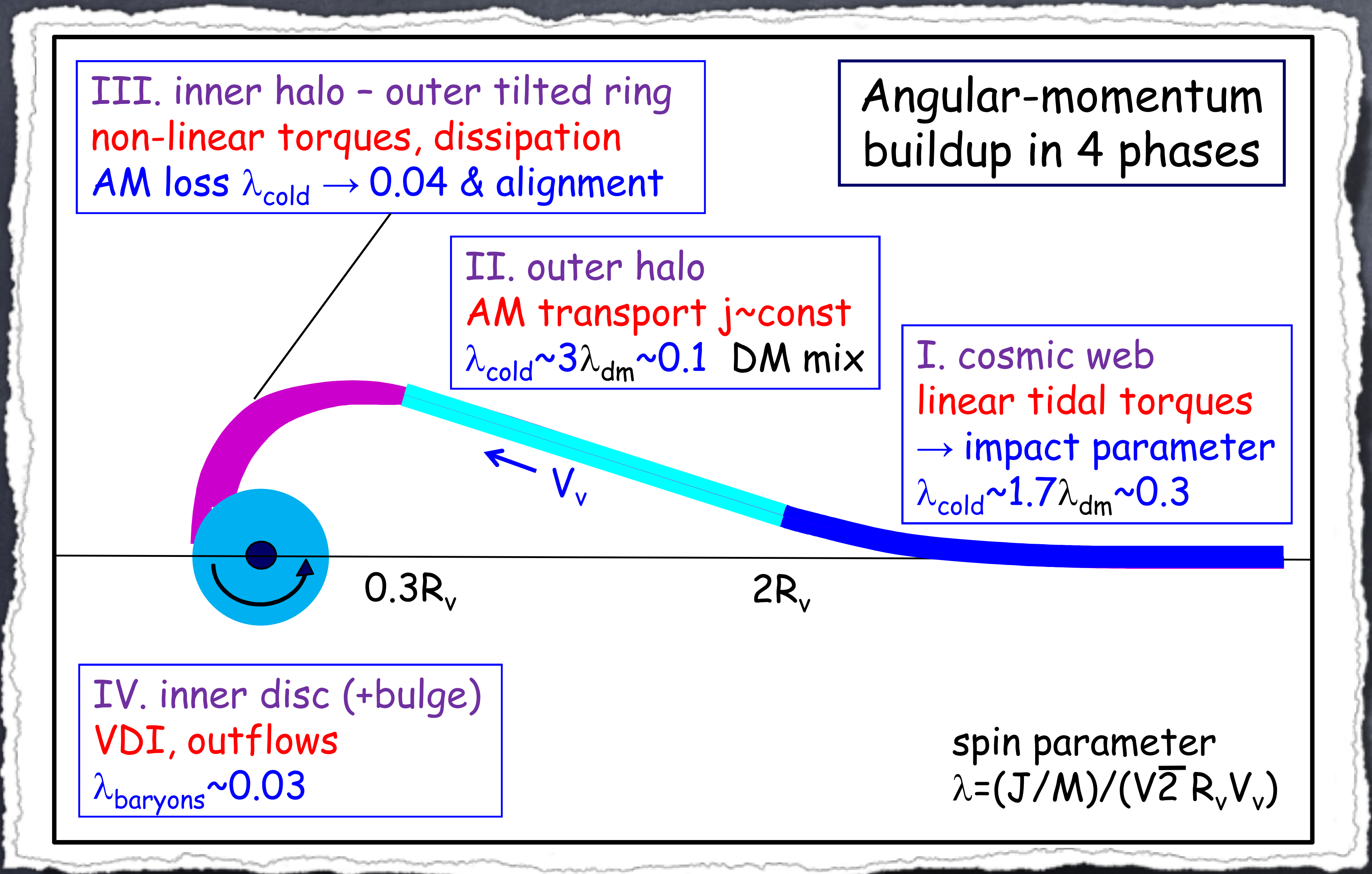


remove post-halo-merger snapshots



- removing post-halo-merger steps only gives a weak correlation,
- mergers alone cannot explain the non-correlation between λ_g and λ_h

- other possible reasons for smearing out the $\lambda_g - \lambda_h$ correlation



Danovich+15

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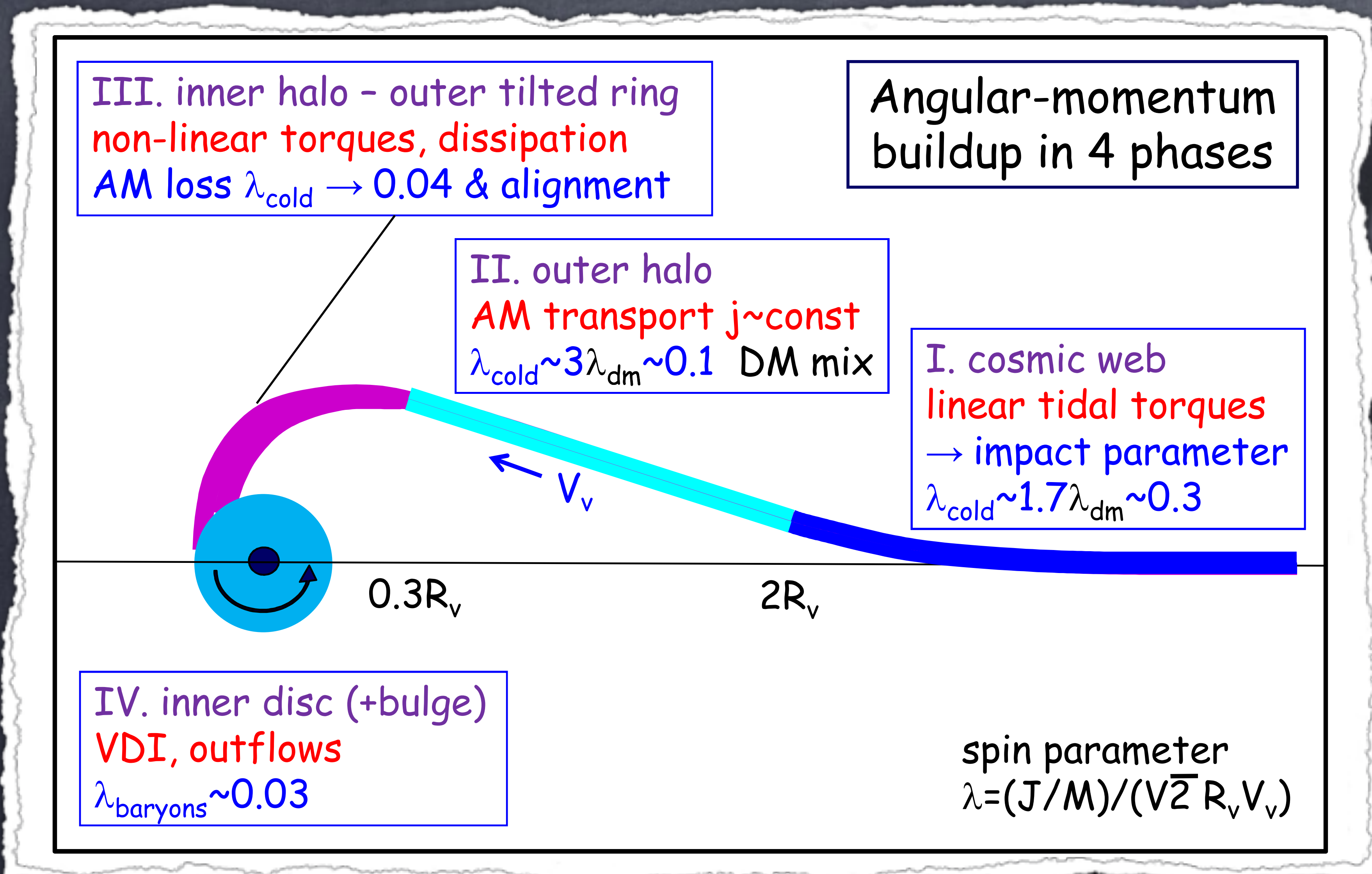

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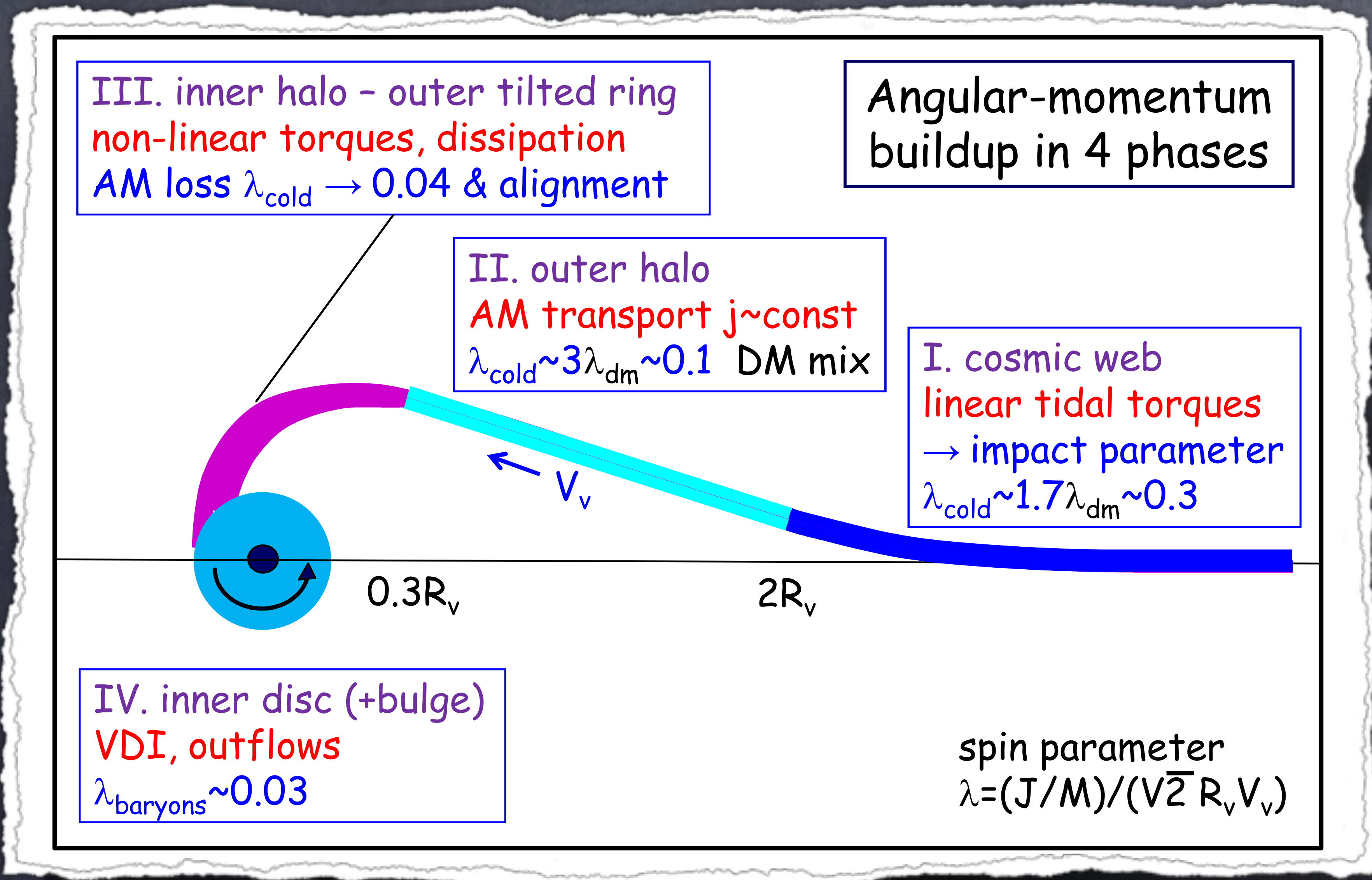
- <u>time domain effect</u>: λ_g more dominated by recently accreted gas; λ_h is integrated over accretion history — so variations in incoming streams from cosmic web affect gas more than the halo other possible reasons for smearing out the $\lambda_g - \lambda_h$ correlation



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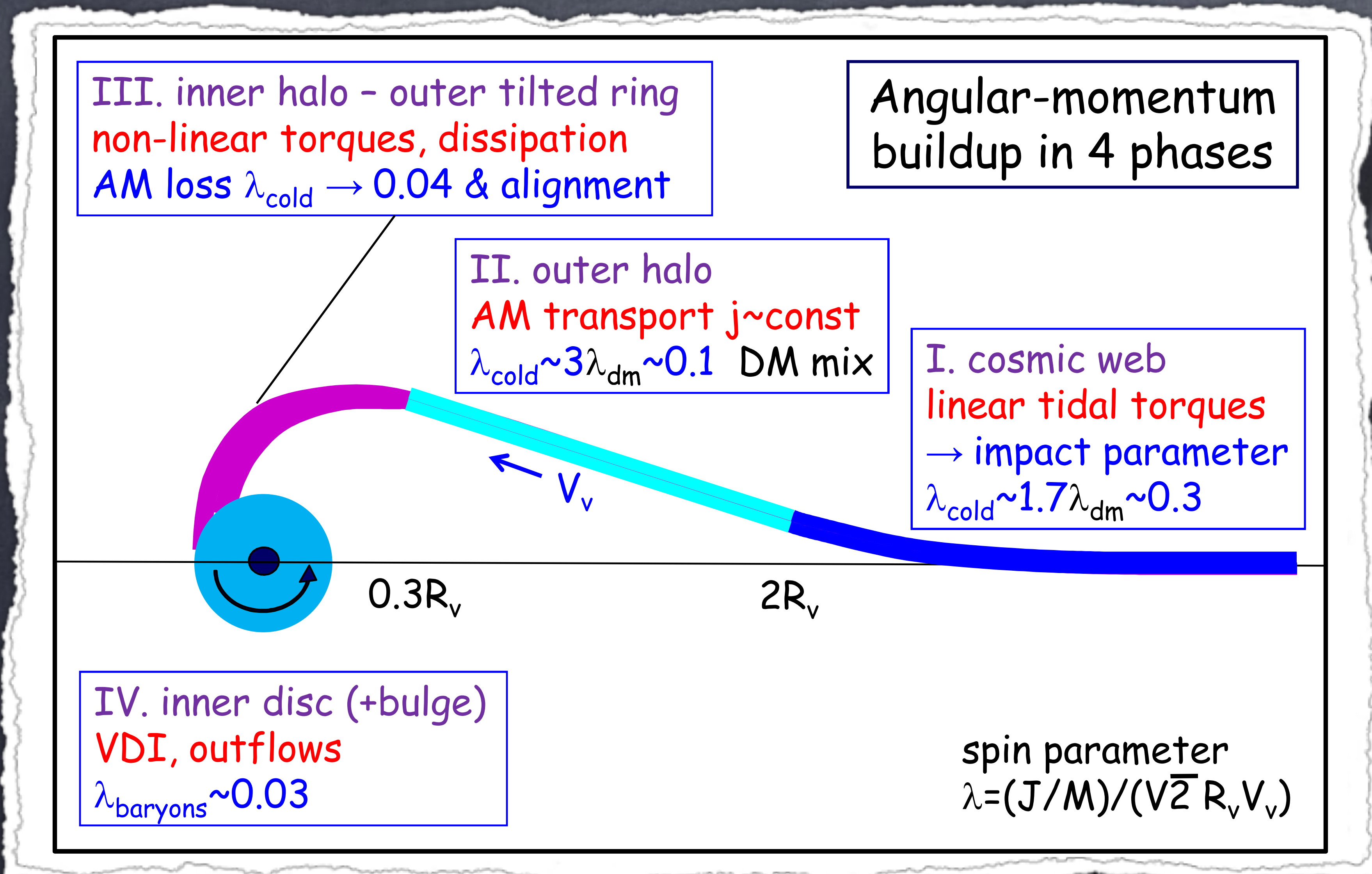

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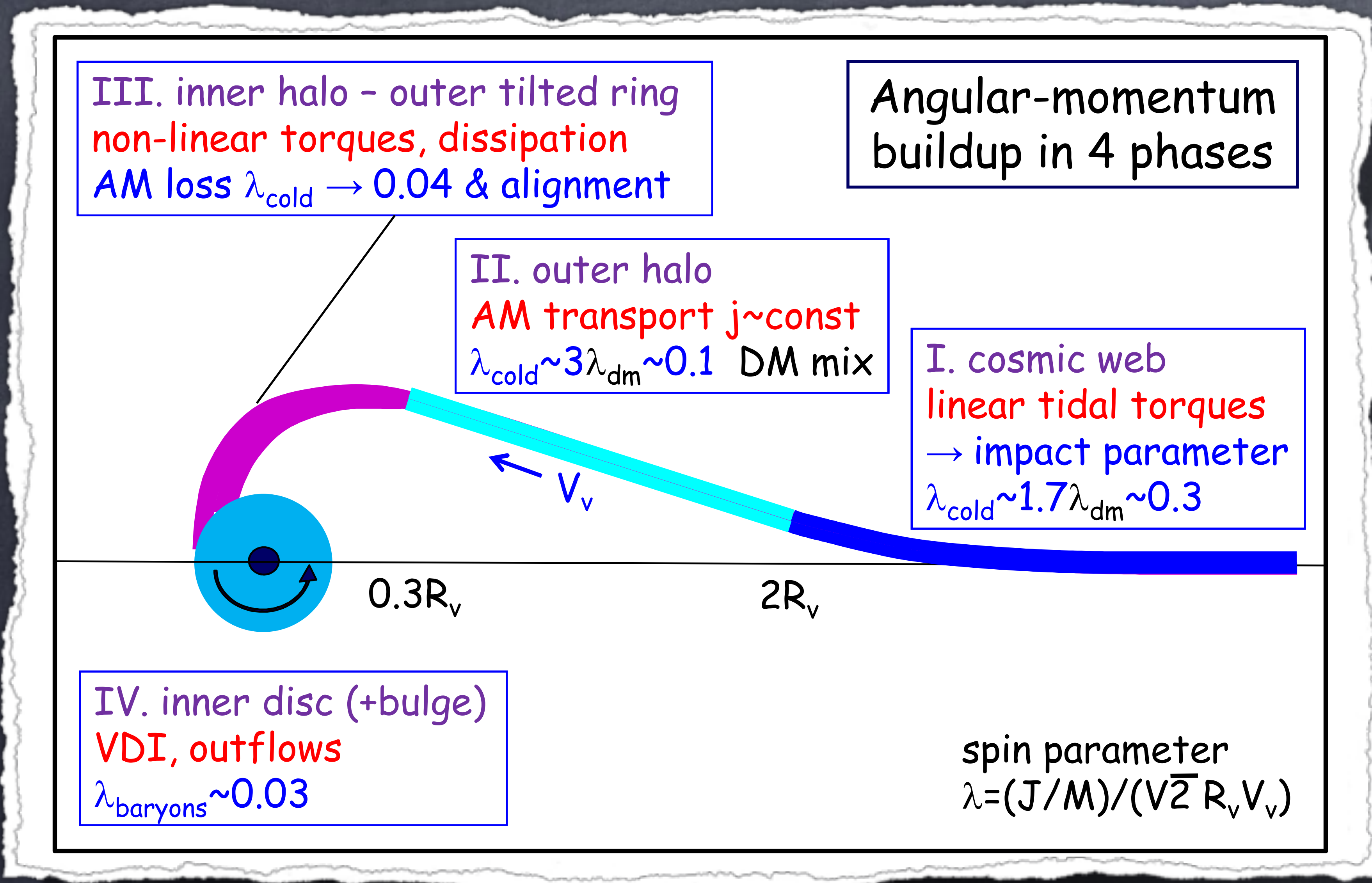

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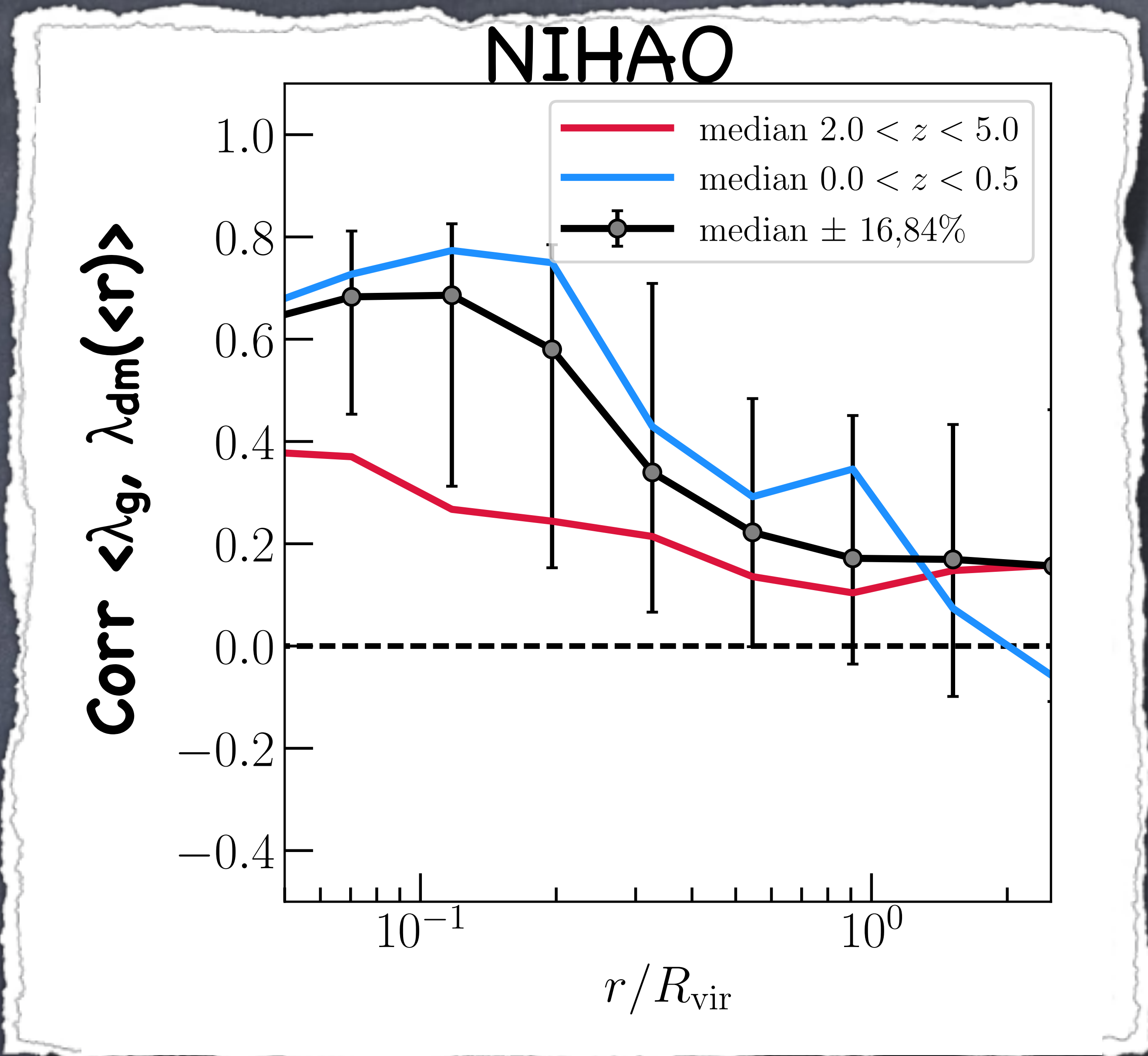
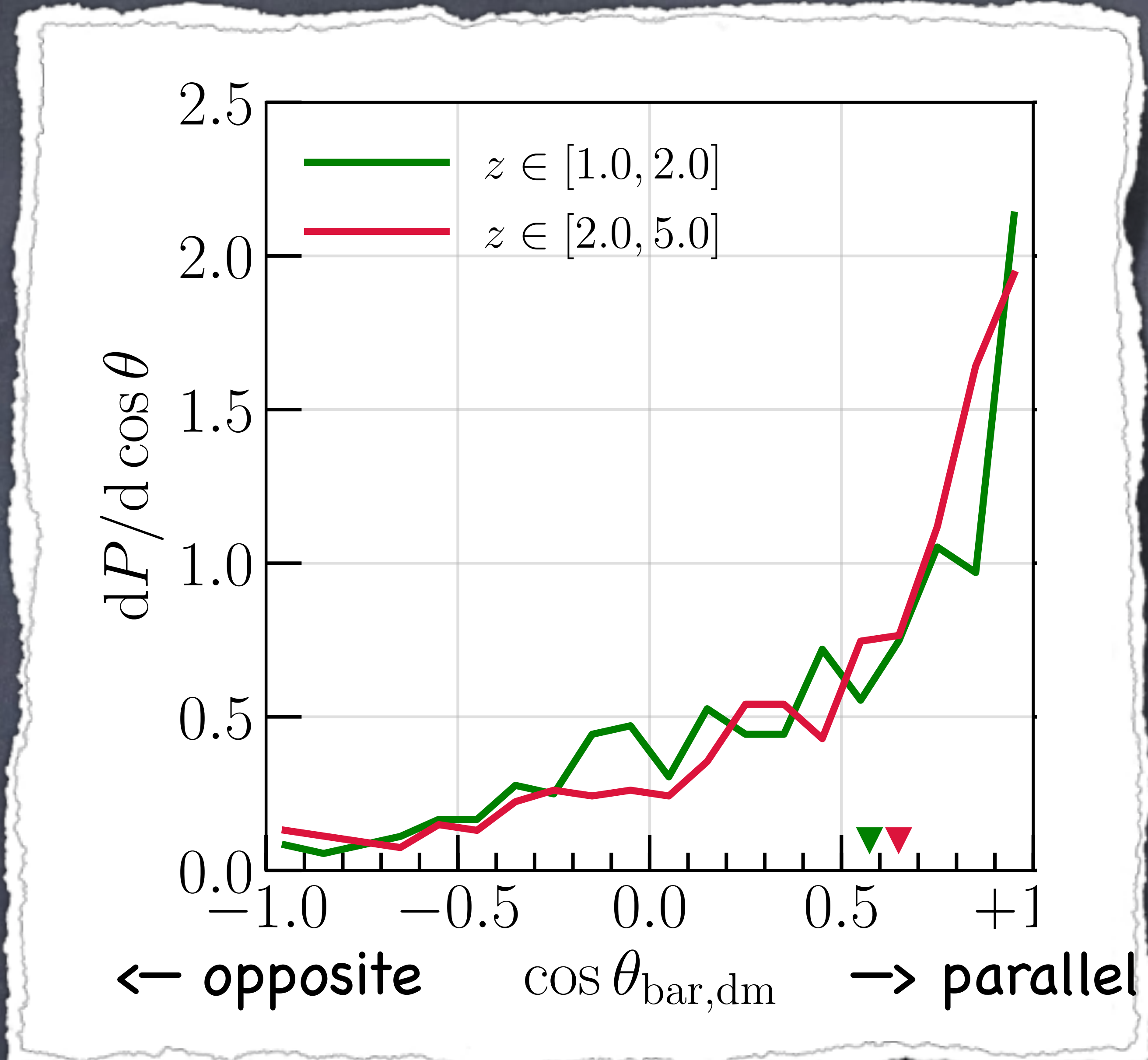
The settlement of λ_g is a very complicated process, no wonder not correlated with λ_h

λ_{gal} and $\lambda_{inner\ halo}$ still have a correlation



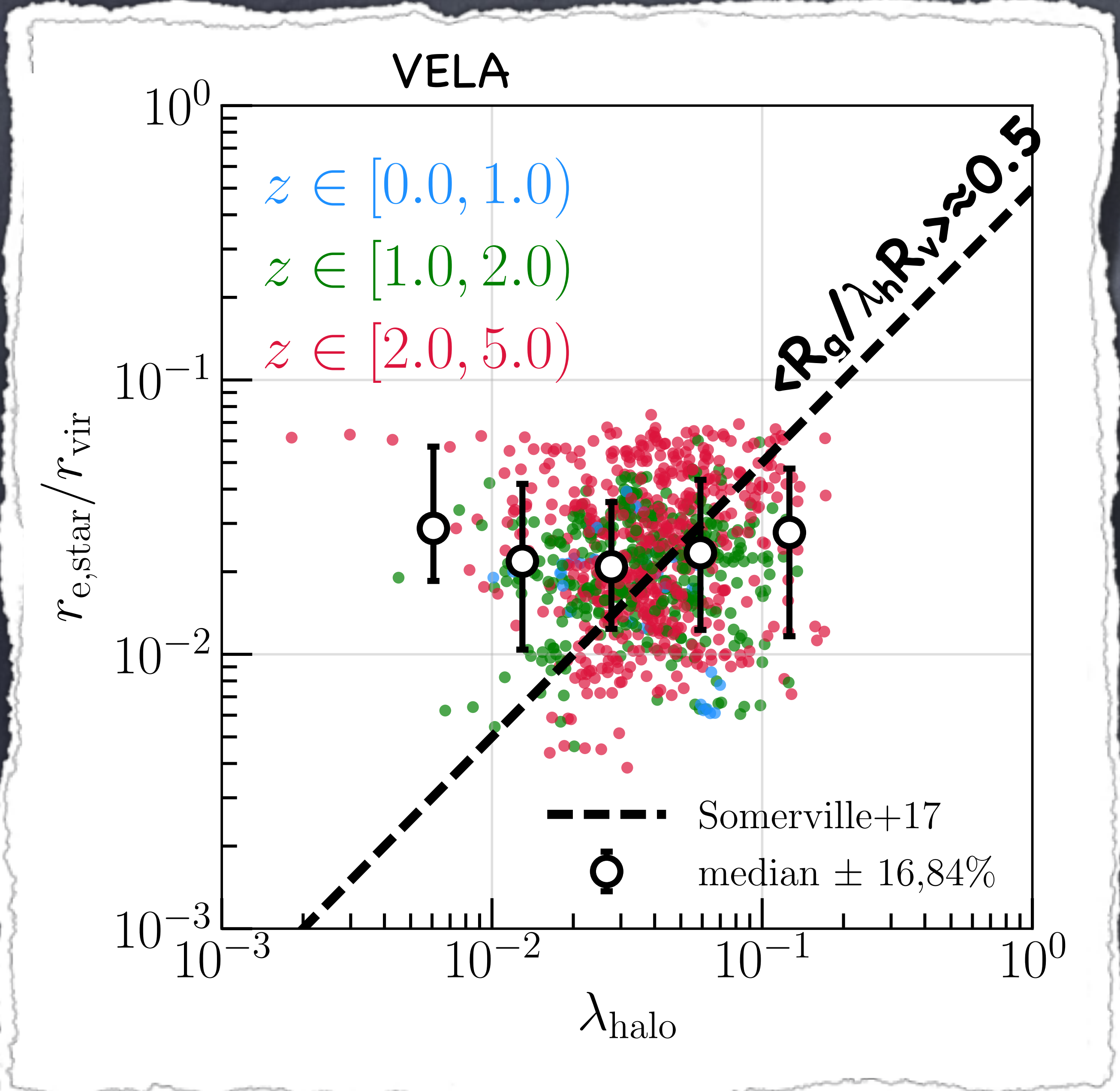
- fairly strong correlation between λ_g and $\lambda_{dm}(<r)$ out to $r=0.2R_{vir}$, but not at very high-z
- consistent with EAGLE (Zavala+16, see also J.Schaye's talk): tight correlation between the <u>loss of sAM</u> of the inner (0.1Rvir) DM and that of the baryons, by following Lagrangian volumes

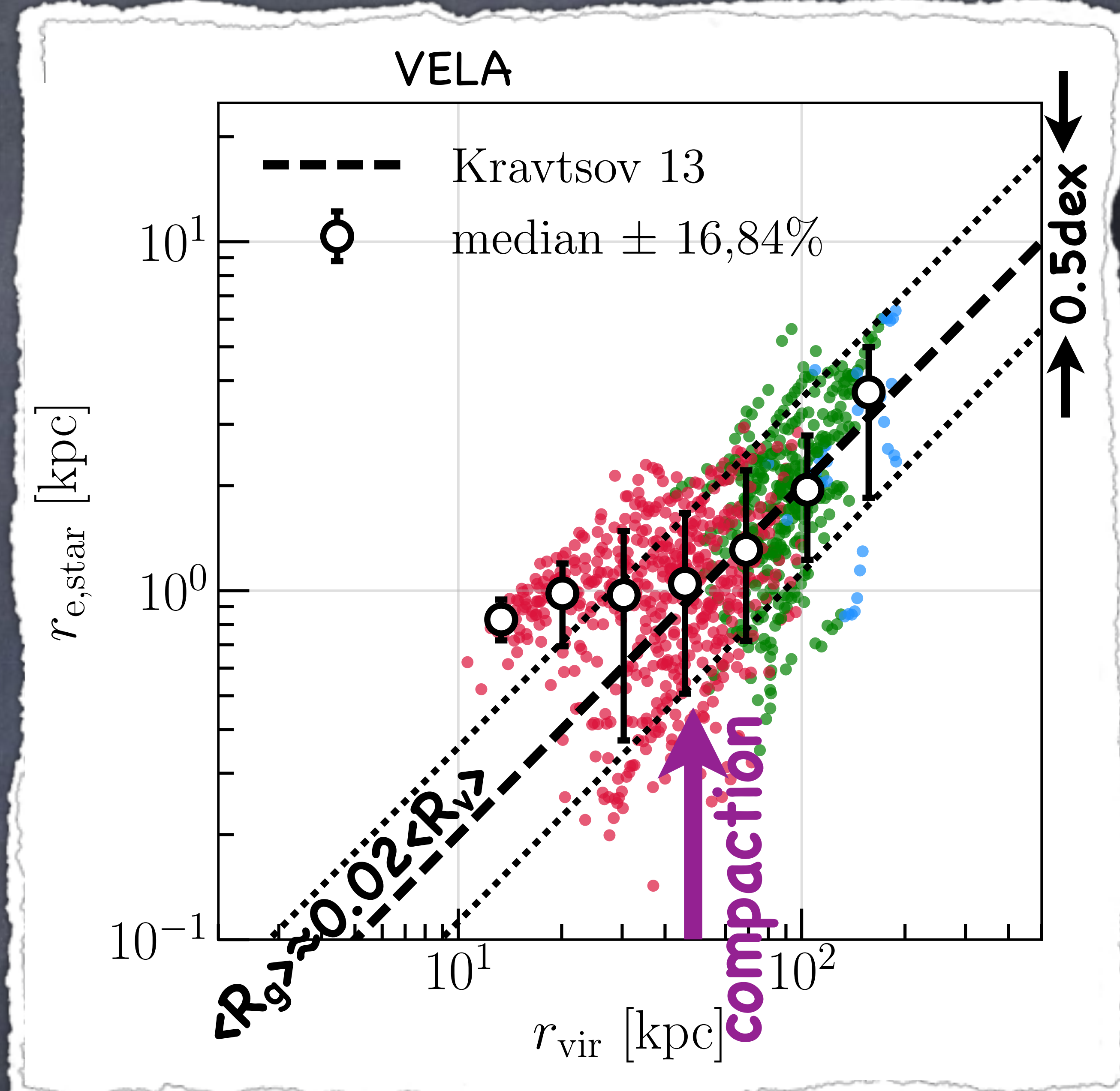
Alignment



- strong correlation of orientation: <cosθ> = 0.72 (gas-DM), 0.61 (stars-DM)
- the mechanisms smearing out the λ_g - λ_h magnitude correlation should not randomize the alignment too much
- alignment weakens slightly towards lower-z, also seen in Illustris (Zjupa & Springel 2017)

Is λ_h relevant for galaxy size?





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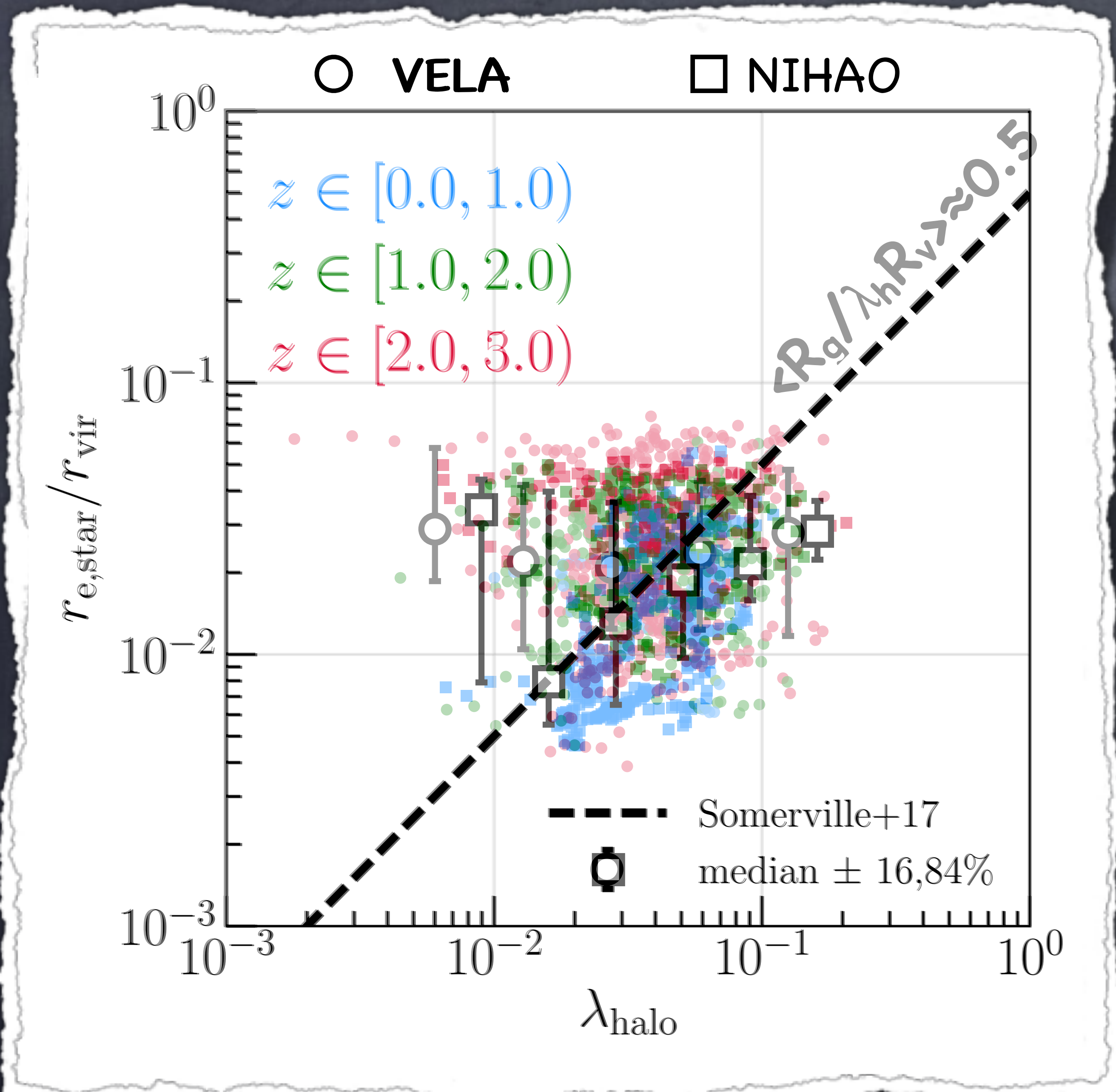

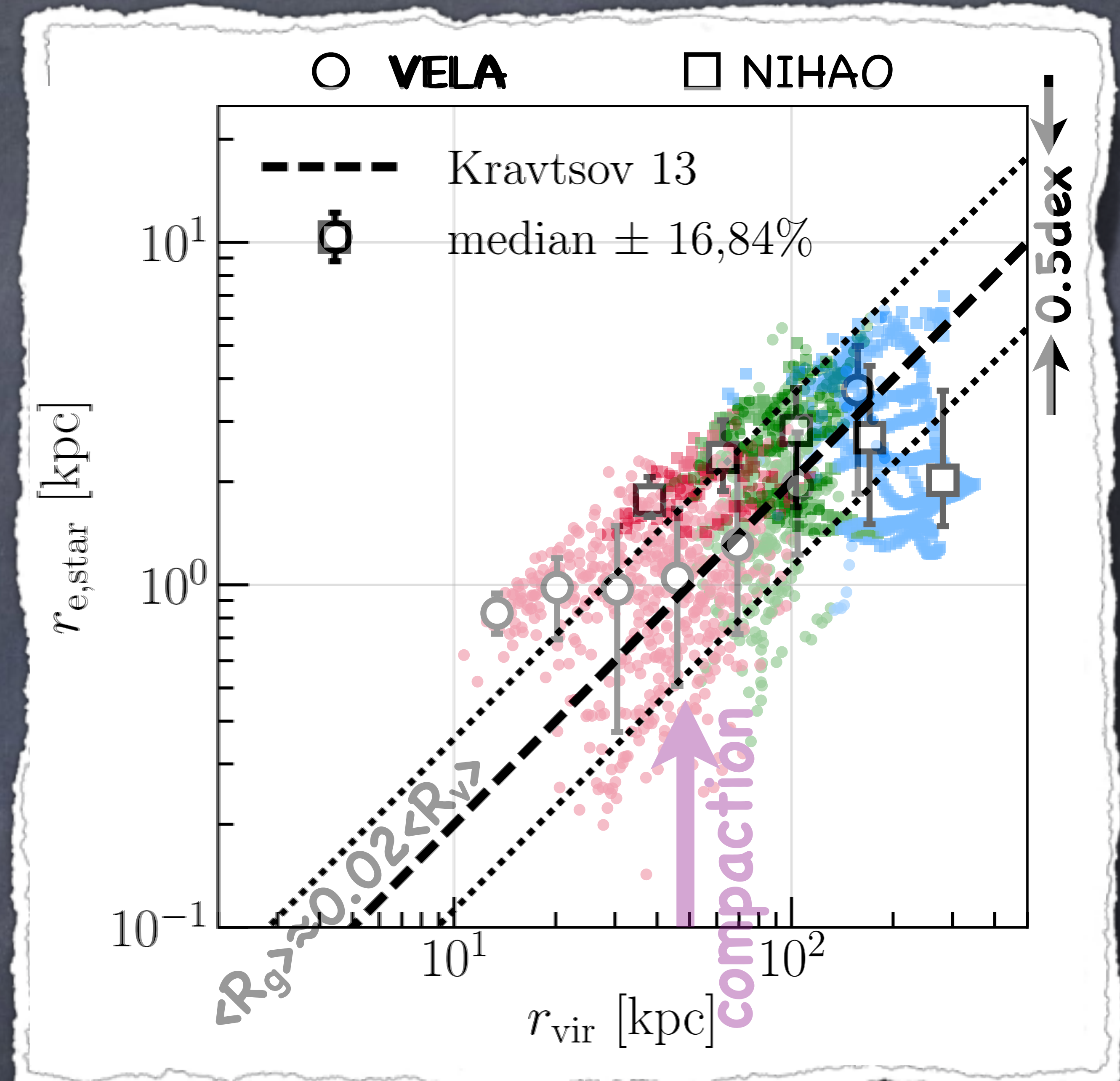

- VELA and NIHAO gives different answer

$$j_g \simeq R_g V_{rot} \Longrightarrow R_g \simeq \frac{j_g}{j_h} \frac{j_h}{R_{vir} V_{vir}} \frac{V_{vir}}{V_{rot}} R_{vir} \simeq \lambda_h R_{vir}$$

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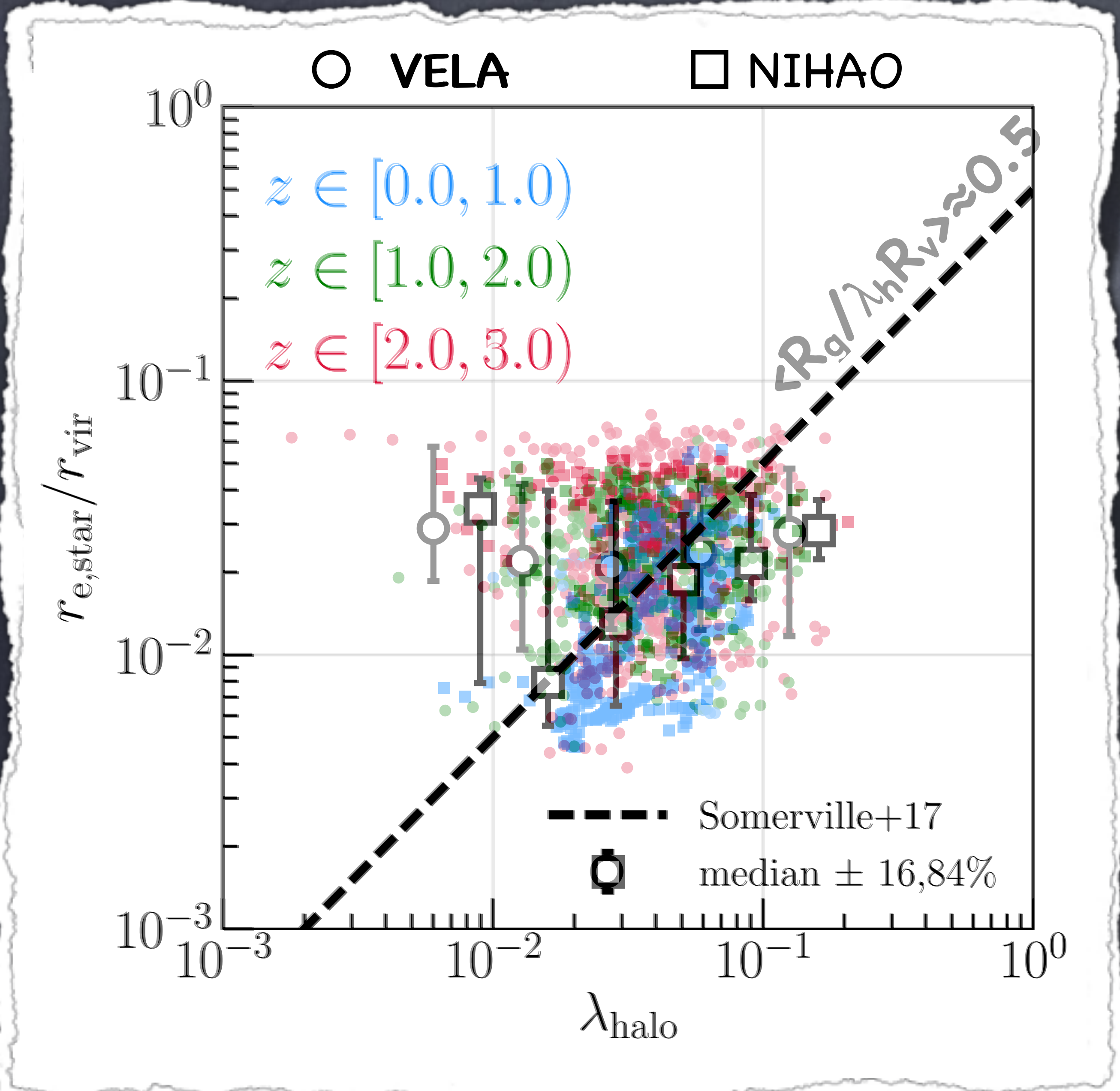

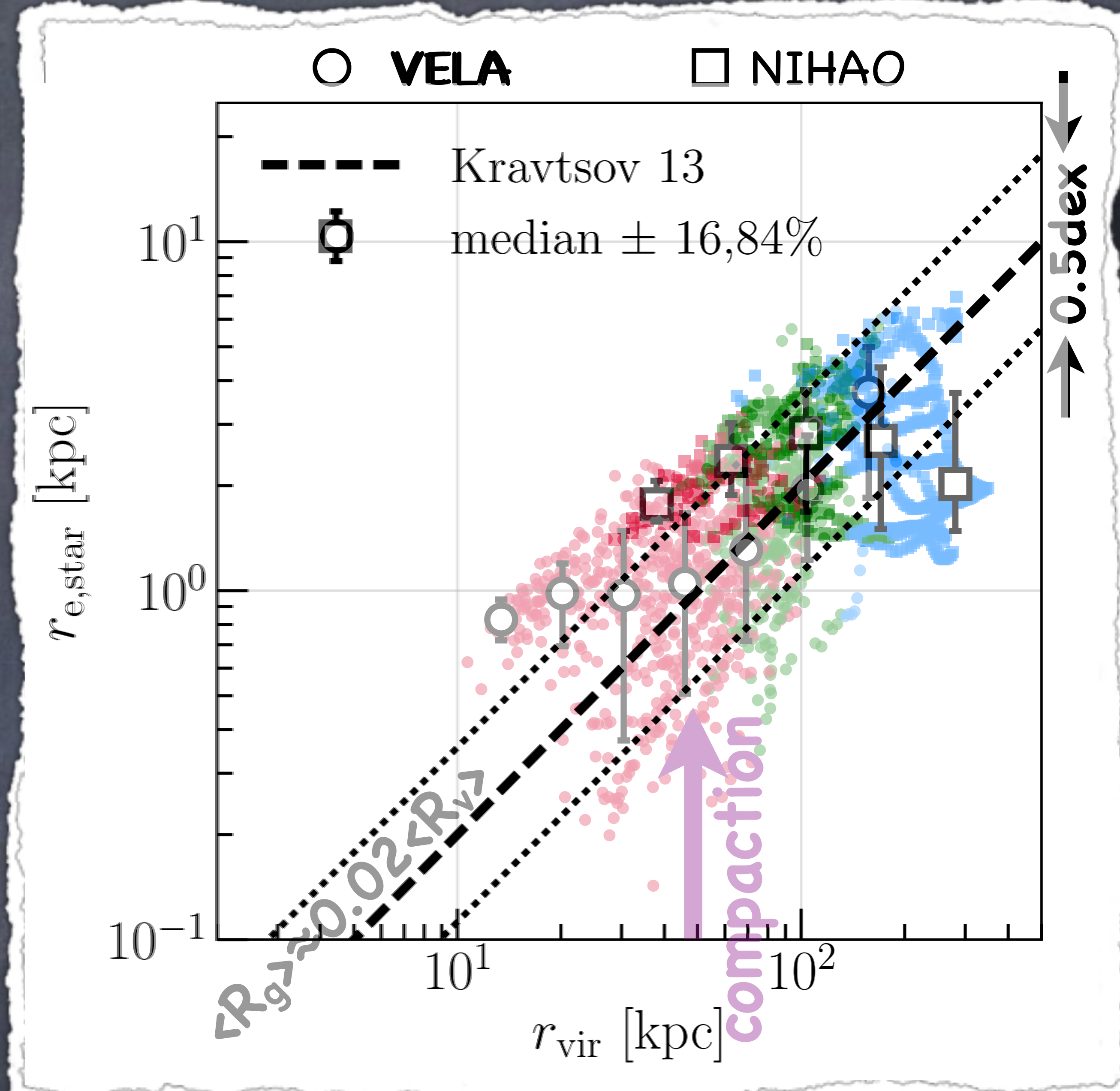

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random

$$V_{rot}^2 = V_{circ}^2 - \alpha\sigma^2$$

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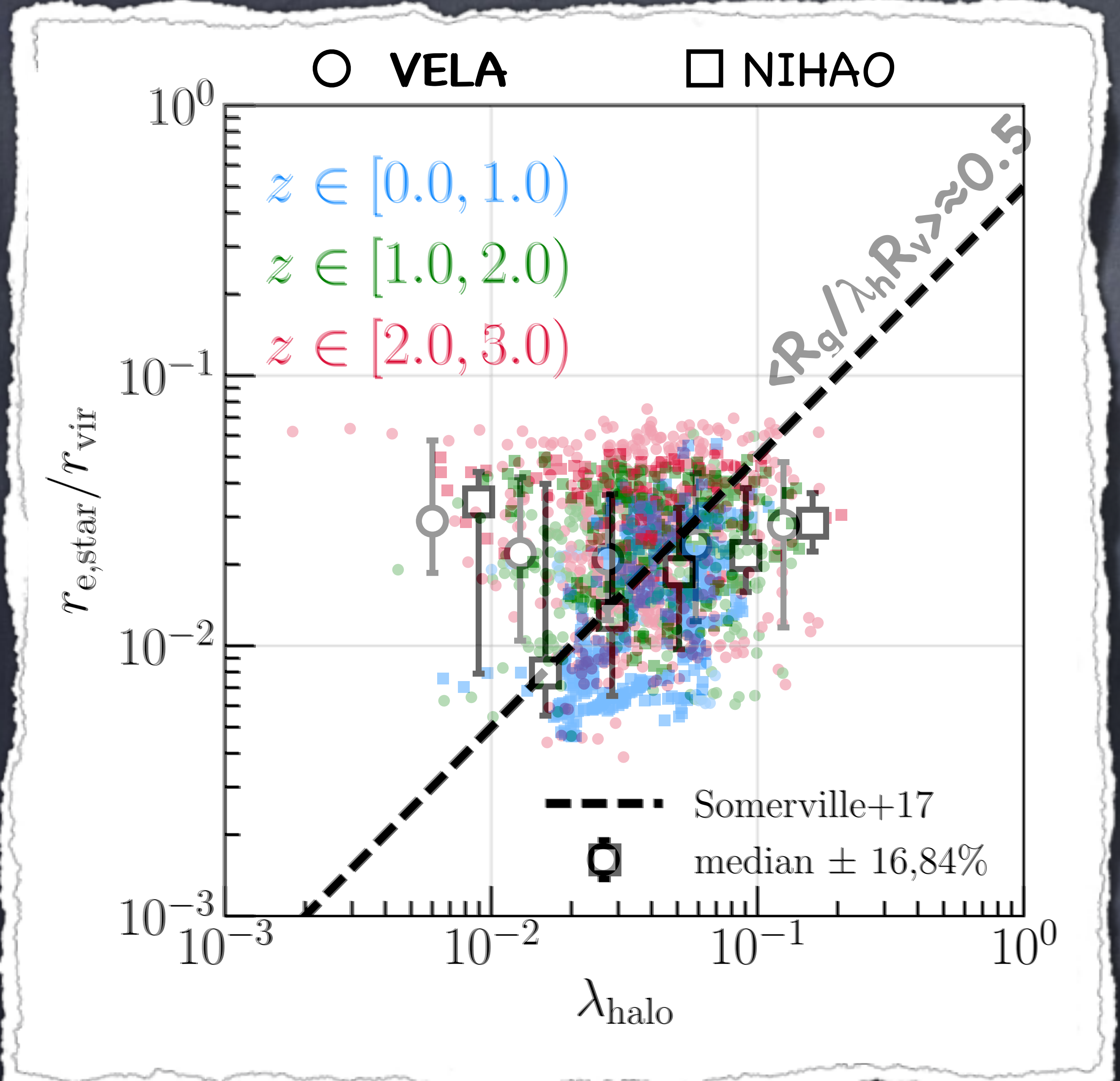

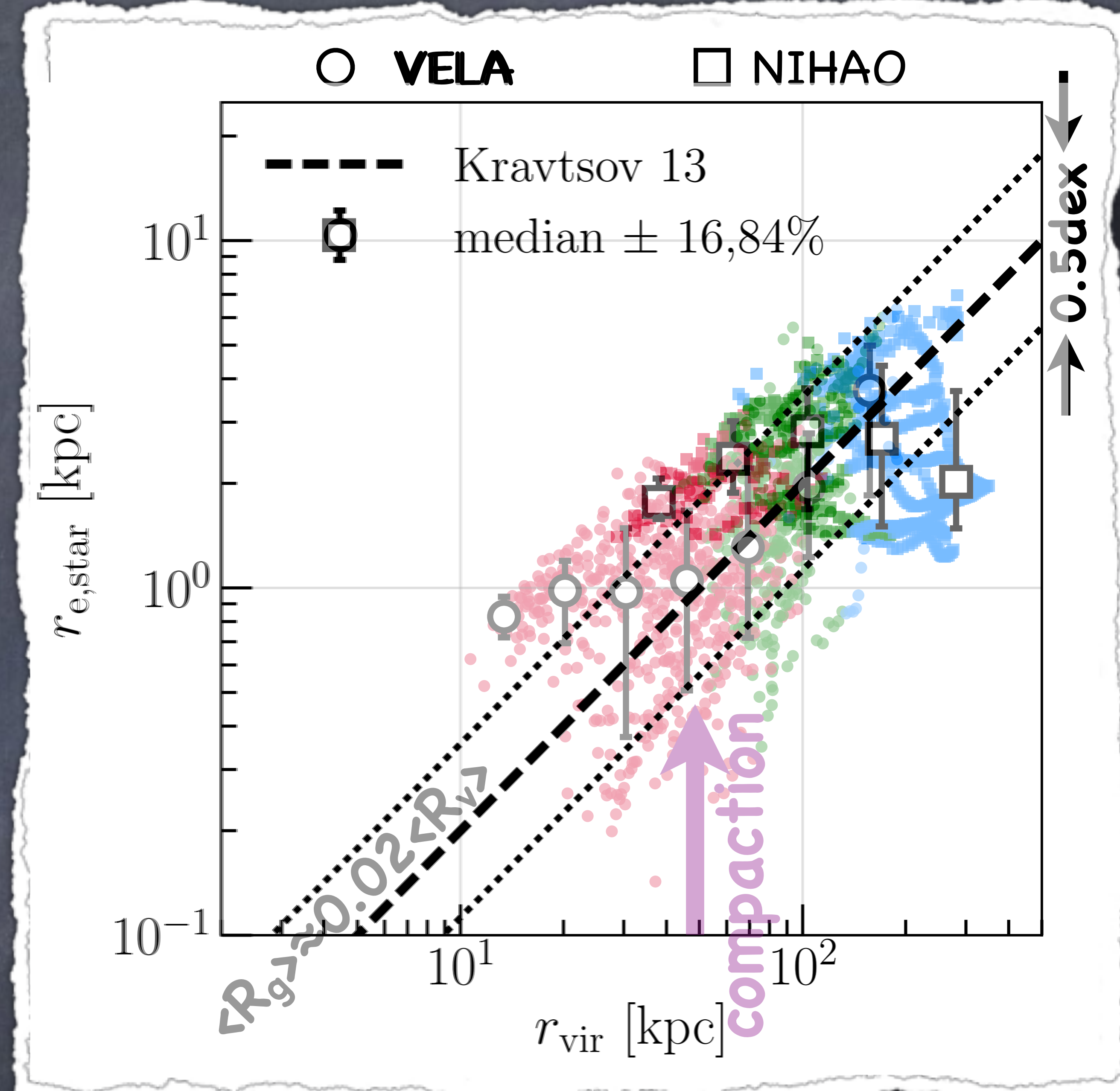

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$$j_g \simeq R_g V_{rot} ==> R_g \simeq \frac{j_g}{j_h} \frac{j_h}{R_{vir} V_{vir}} \frac{V_{vir}}{V_{rot}} R_{vir} \simeq ? \; \lambda_h R_{vir}$$

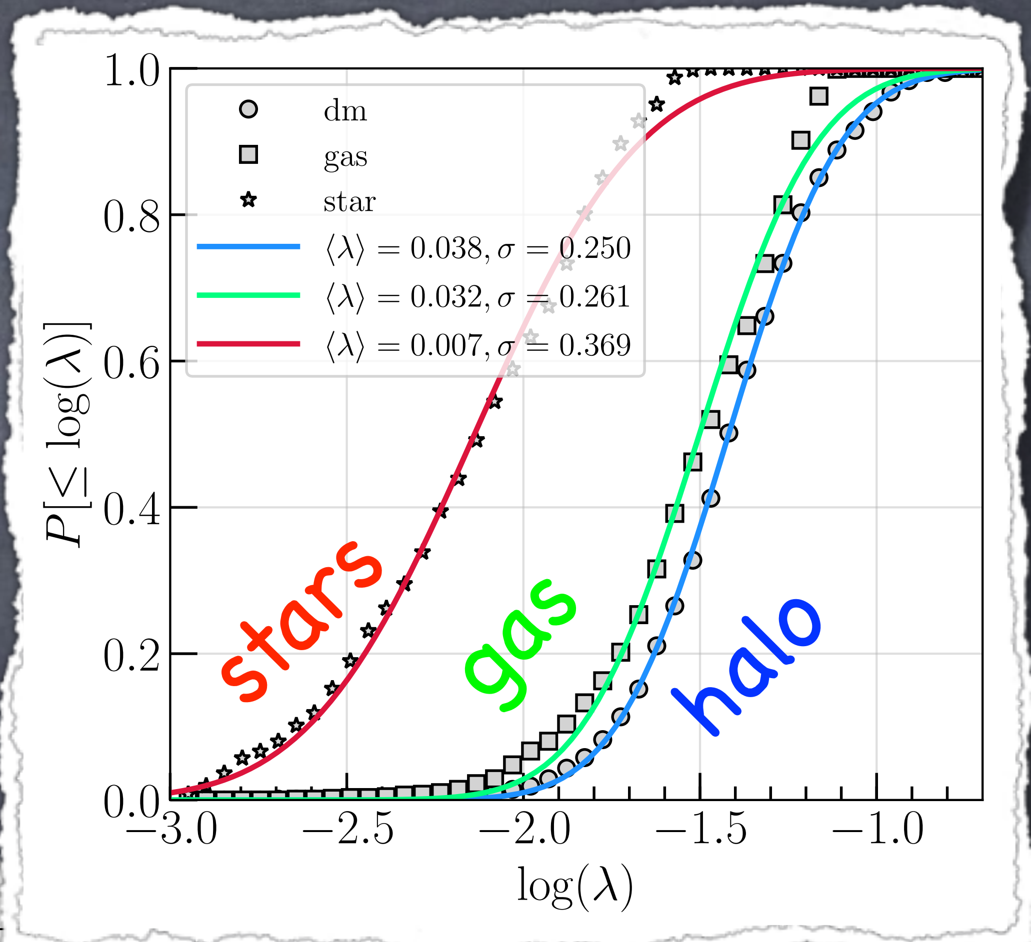
random

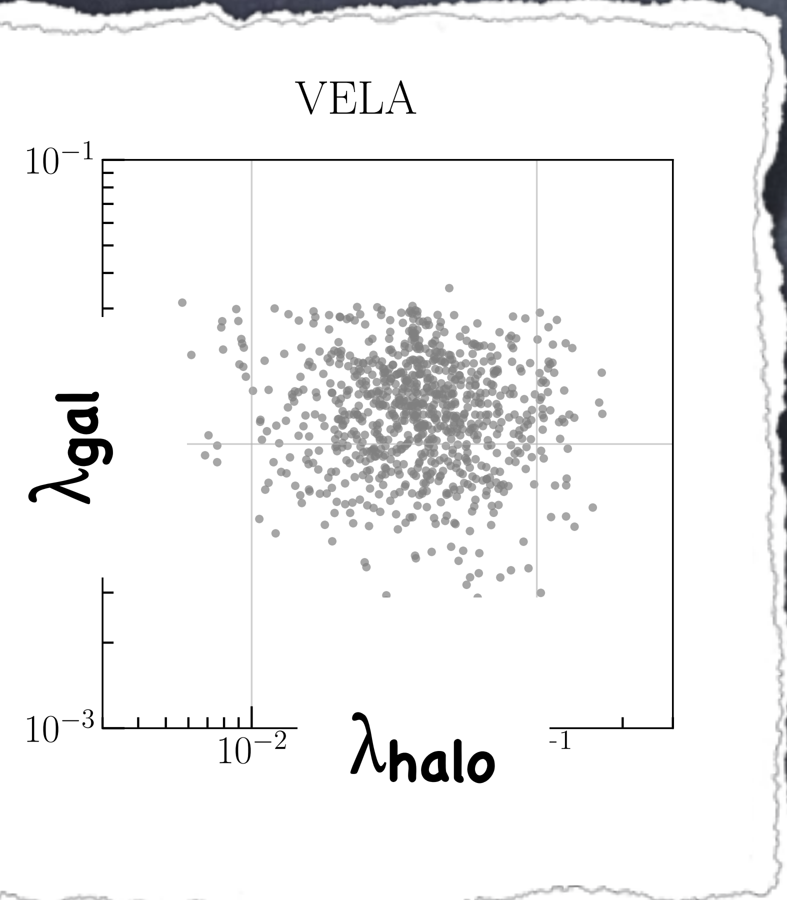
$$V_{rot}^2 = V_{circ}^2 - \alpha\sigma^2$$

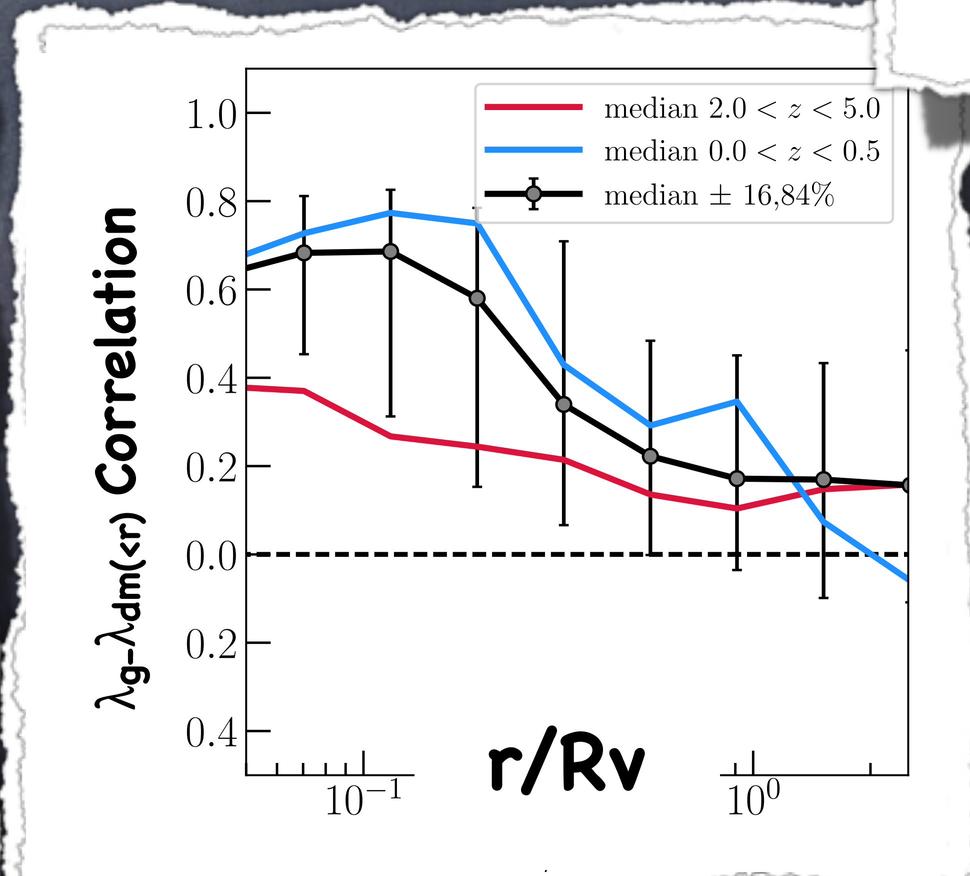
Fangzhou Jiang, May 17 KITP

Summary

- with baryonic physics, λ_{halo} similar to DMO; baryonic spin (λ_{gas}, λ_{star}) also log-normal, higher in more massive (post-compaction) halos
- no correlation between λ_{gal} and λ_{halo} at $z>1$; weak correlation at lower z; λ_{gal} and $\lambda_{dm(<0.2Rv)}$ still correlated; λ_{gal}-λ_{halo} alignment always good







- mechanisms that smear out the correlation at infall need to
  - cause an anti-correlation between λ_g/λ_h and λ_h
  - be less effective at low-z
  - not randomize the orientation

- λ_h is perhaps irrelevant for galaxy size (?)

Advertisement: **SatGen** — a poor(wise) man's satellite galaxy population factory

EPS merger trees

+

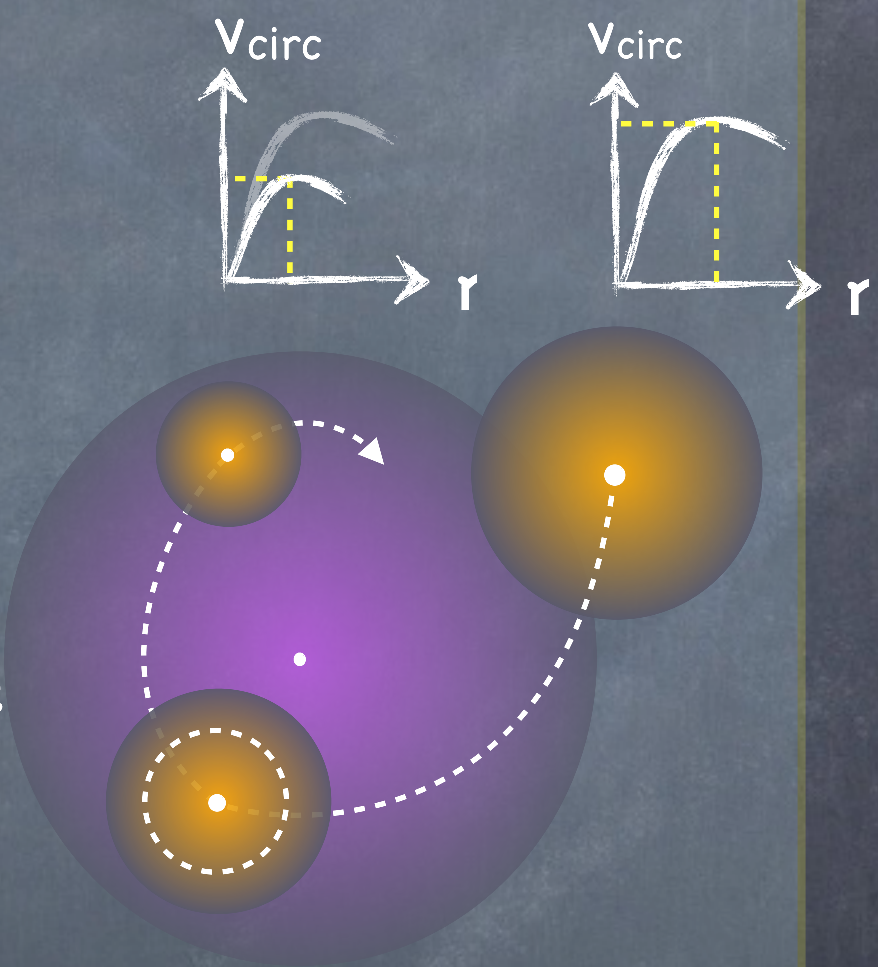
orbit integration

+

(sub)halo response

+

SHAM+



Jiang & van den Bosch 15,16

similar model: Zentner+05

$$\frac{\mathrm{d}^2\mathbf{r}}{\mathrm{d}t^2} = -\frac{\partial\Phi_{\mathrm{halo+disk}}(r)}{\partial r}\frac{\mathbf{r}}{r} + \mathbf{F}_{\mathrm{df}}$$

motivation: see S. Garrison-Kimmel's talk