(No) Correlation between the Spins of Galaxies and Host Halos

— Do galaxy sizes care about halo spin at all?

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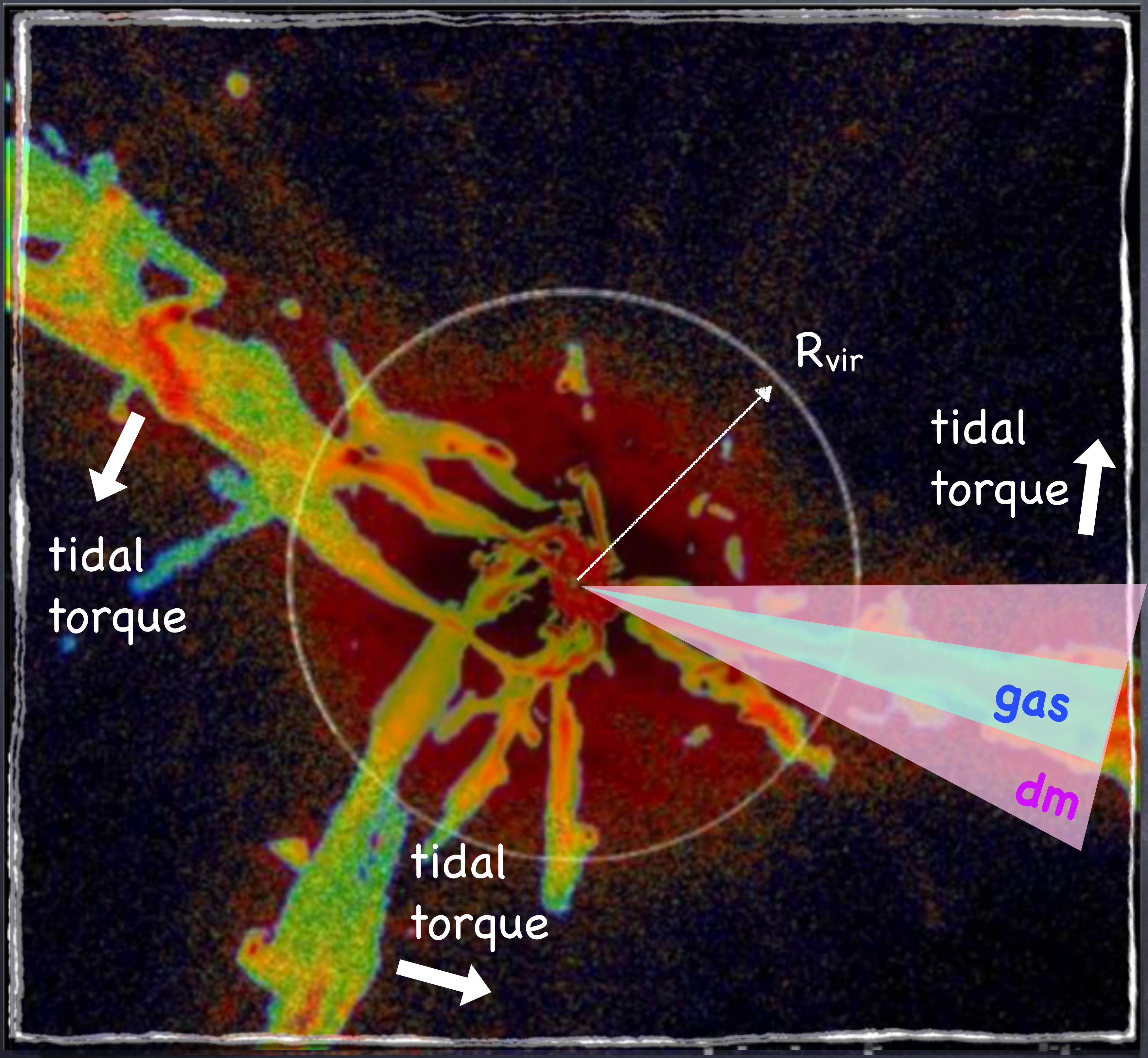
see also **Andreas' talk**

Avishai Dekel, Omer Kneller, Daniel Ceverino, Joel R. Primack, Andrea Maccio, Aaron Dutton, Rachel Somerville, Shy Genel, Sharon Lapiner, Tomer Nussbaum, Omry Ginzburg

UCSC, Aug.,2017



Danovich+15 cold gas and DM maps co-added

$$j_{\rm gas} \simeq j_{\rm dm}$$

- background:
  - long-standing assumption (Fall & Efstathiou80) in SAMs: $j_{\rm gal} \simeq j_{\rm halo}$
  - useful in predicting (disk) galaxy sizes R_g

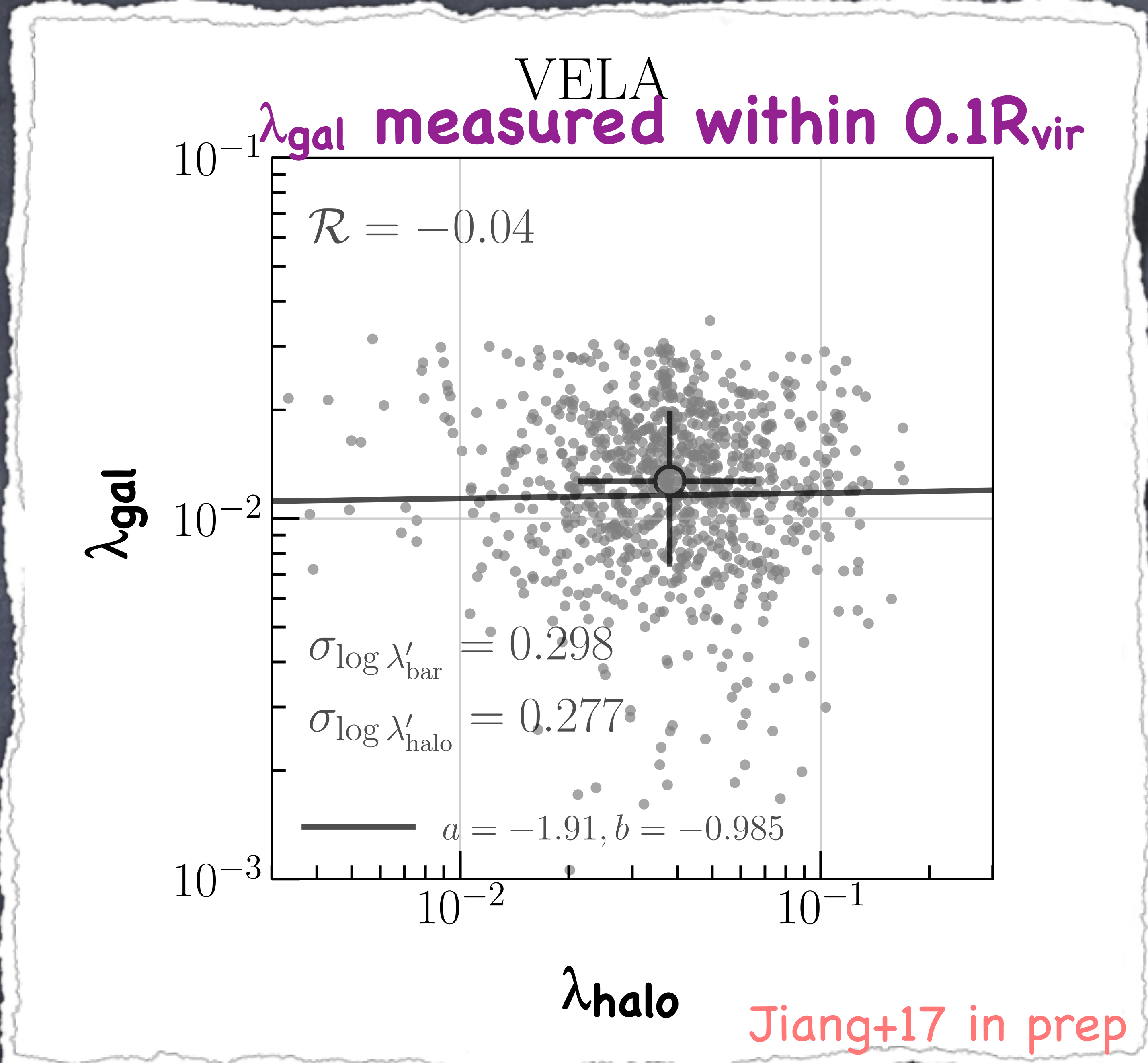
$$j_{\rm g} \simeq R_{\rm g} V_{\rm rot} \implies R_{\rm g} \simeq \frac{j_{\rm g}}{j_{\rm h}} \frac{j_{\rm h}}{R_{\rm vir} V_{\rm vir}} \frac{V_{\rm vir}}{V_{\rm rot}} R_{\rm vir} \simeq \lambda_{\rm h} R_{\rm vir}$$

$$V_{\rm rot} \simeq V_{\rm circ} \simeq V_{\rm vir}$$

  - evidence: 1) λ_g and λ_h ($\lambda_{\rm x} \equiv j_{\rm x}/\sqrt{2} R_{\rm vir} V_{\rm vir}$ (Bullock+01)) follow similar log-normal distributions (Burkert+16); 2) $P(0.5\lambda_h R_{vir} | M_{star})$ agrees with observed R_e distribution (Somerville+17)

- 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), $\epsilon_{cell} \approx 25$pc
  - 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 than VELA

λ_{gal} - λ_{halo} correlation



see also Teklu+15

regression line: $\log \lambda_{\rm g} = a + (1+b) \log \lambda_{\rm h}$

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

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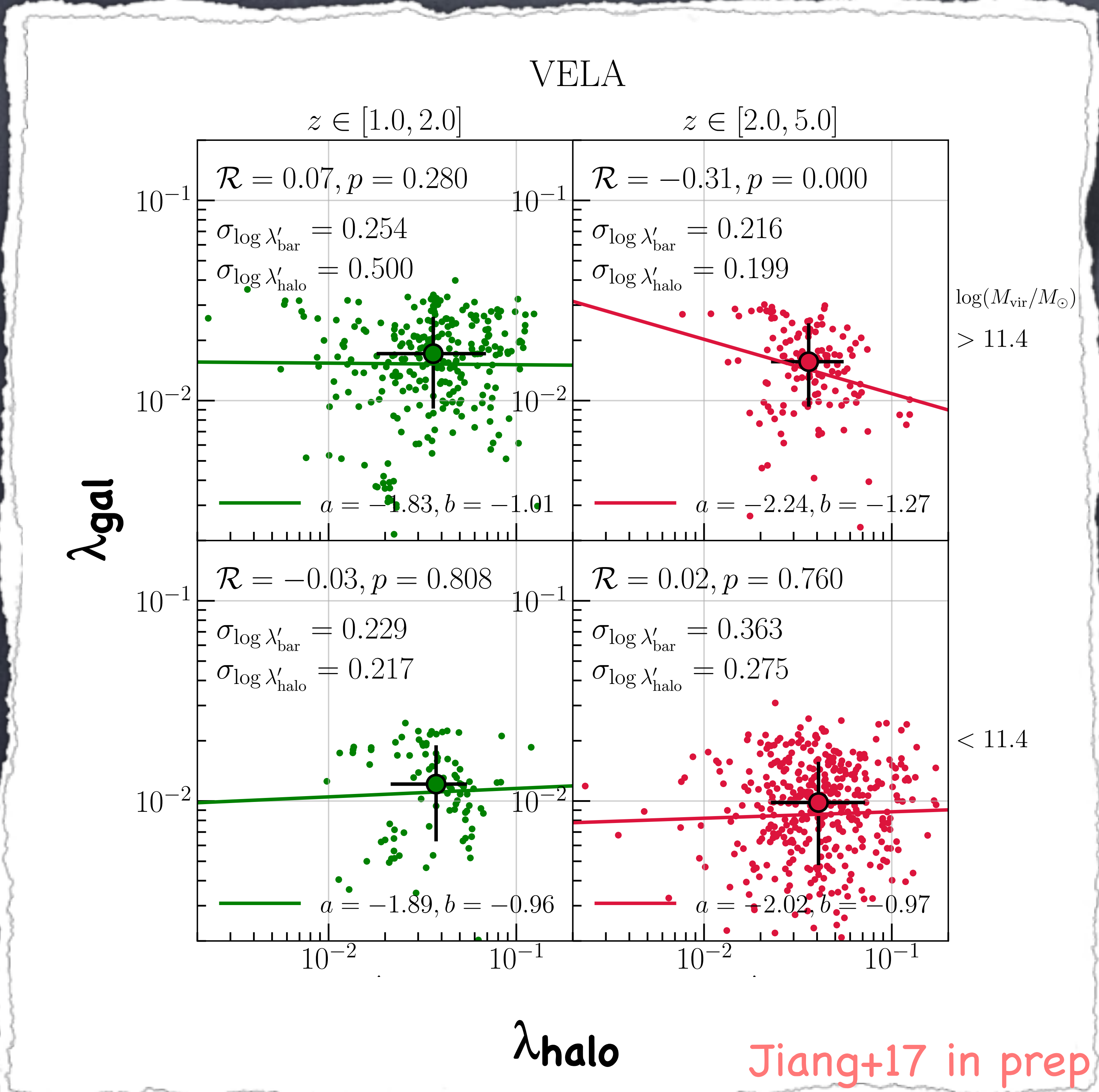
λ_{gal} - λ_{halo} correlation



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

regression line:

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

- No correlation b/w λ_{gal} and λ_{halo} at $z \geq 1$ in different M_{vir}, z bins
- λ_{gal} is higher in higher-M_{vir} (post-compaction) systems

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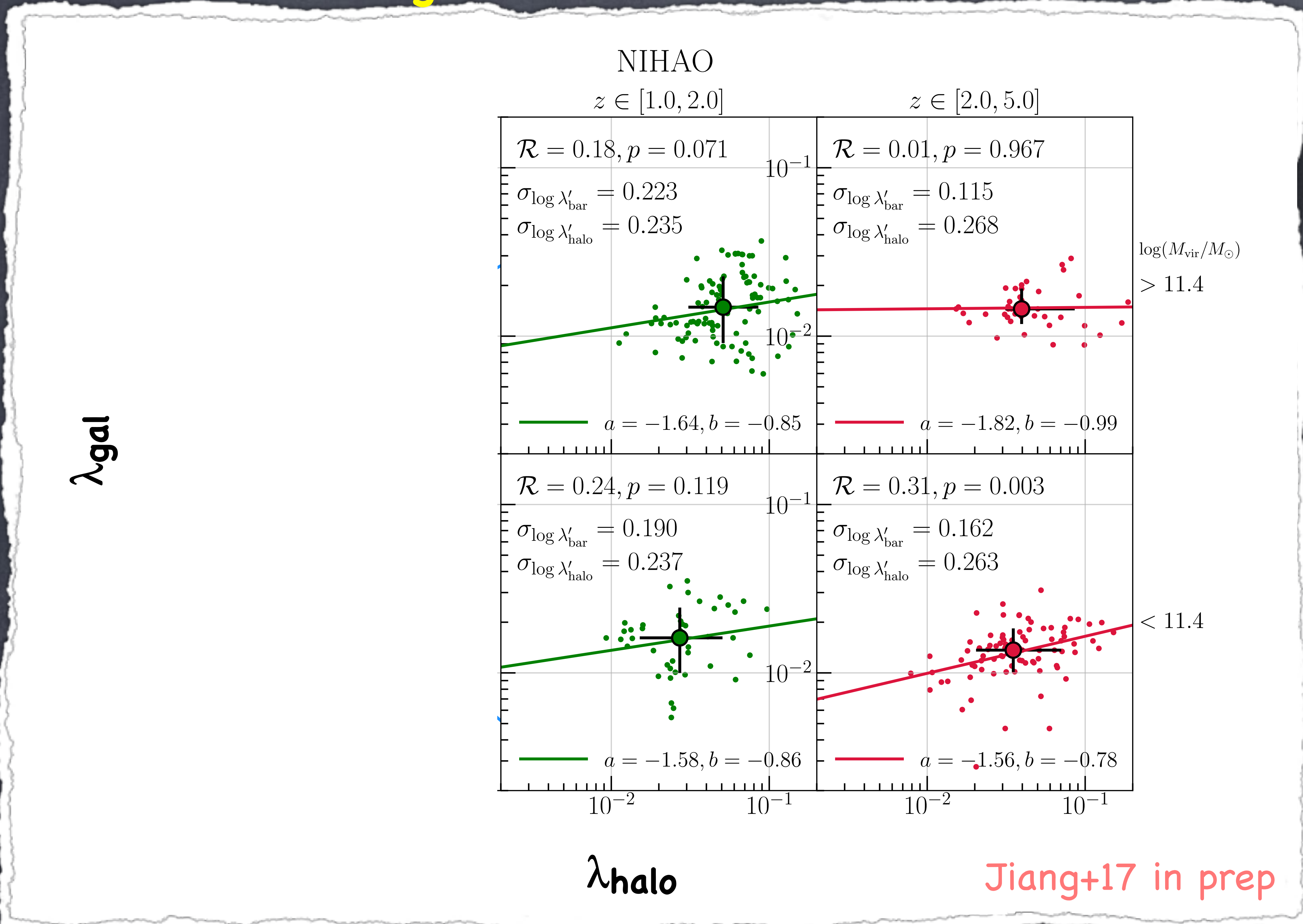
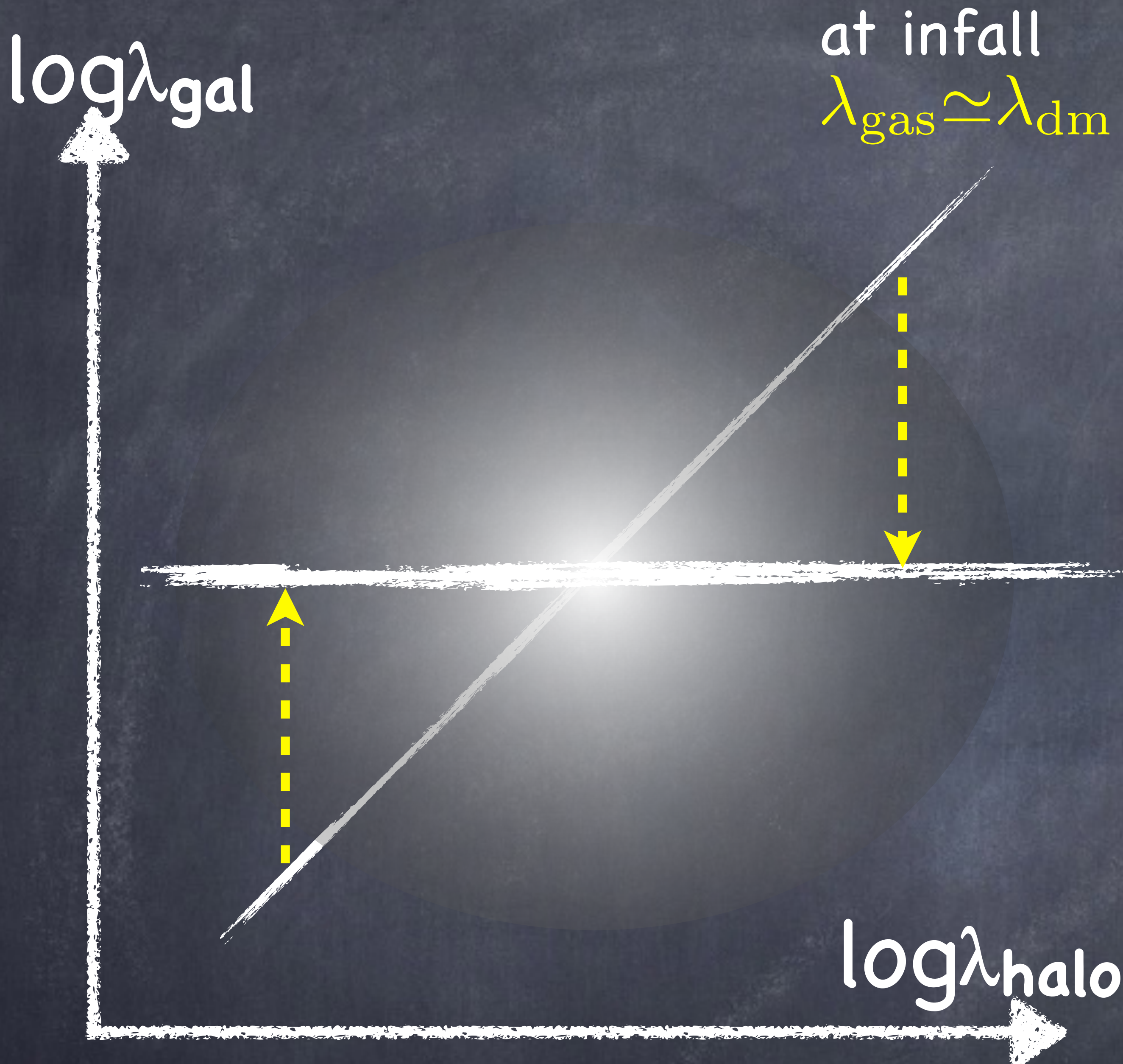
λ_{gal} - λ_{halo} correlation



regression line: $\log \lambda_{\rm g} = a + (1+b) \log \lambda_{\rm h}$

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

λ_{gal} - λ_{halo} non-correlation



$$\lambda_{\rm g} = \lambda_{\rm h} \frac{\lambda_{\rm g}}{\lambda_{\rm h}}$$

- change of baryon's spin wrt that at infall
- may depend systematically on λ_h
- assume $\langle \frac{\lambda_{\rm g}}{\lambda_{\rm h}} \rangle \propto \lambda_{\rm h}^b$

regression line:

$$\log \lambda_{\rm g} = a + (1+b) \log \lambda_{\rm h}$$

$b \approx -1$ at high-z

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

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

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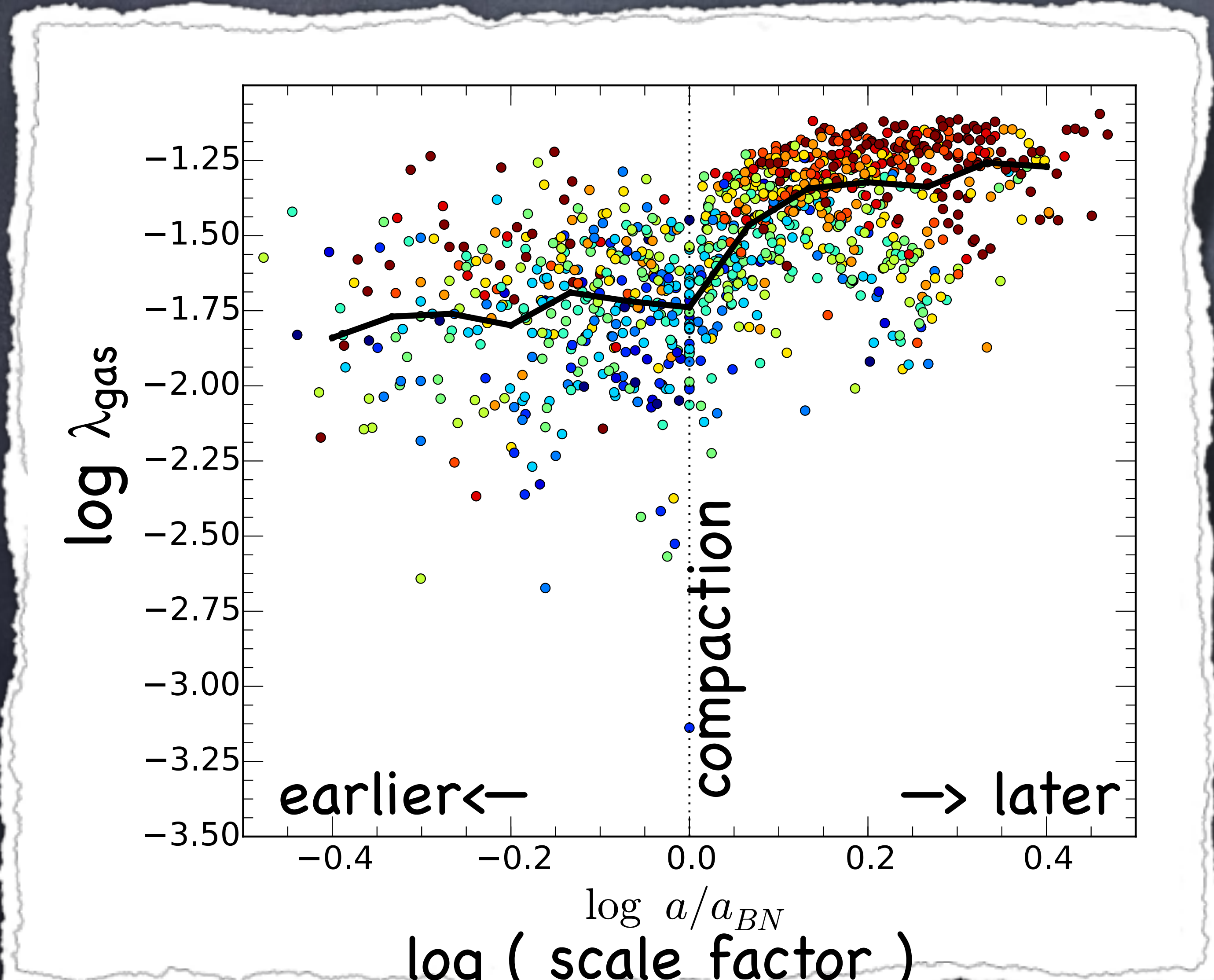
possible reasons for a λ_g/λ_h - λ_h anti-correlation

- **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
  - freshly accreted gas with high λ_{gas} forms a ring



compaction happens at a characteristic mass scale
$M_{star} \approx 10^{9.8} M_{sun}$
$M_{vir} \approx 10^{11.4} M_{sun}$
(which depends on SF, fdbk etc)

Dekel+17 in prep

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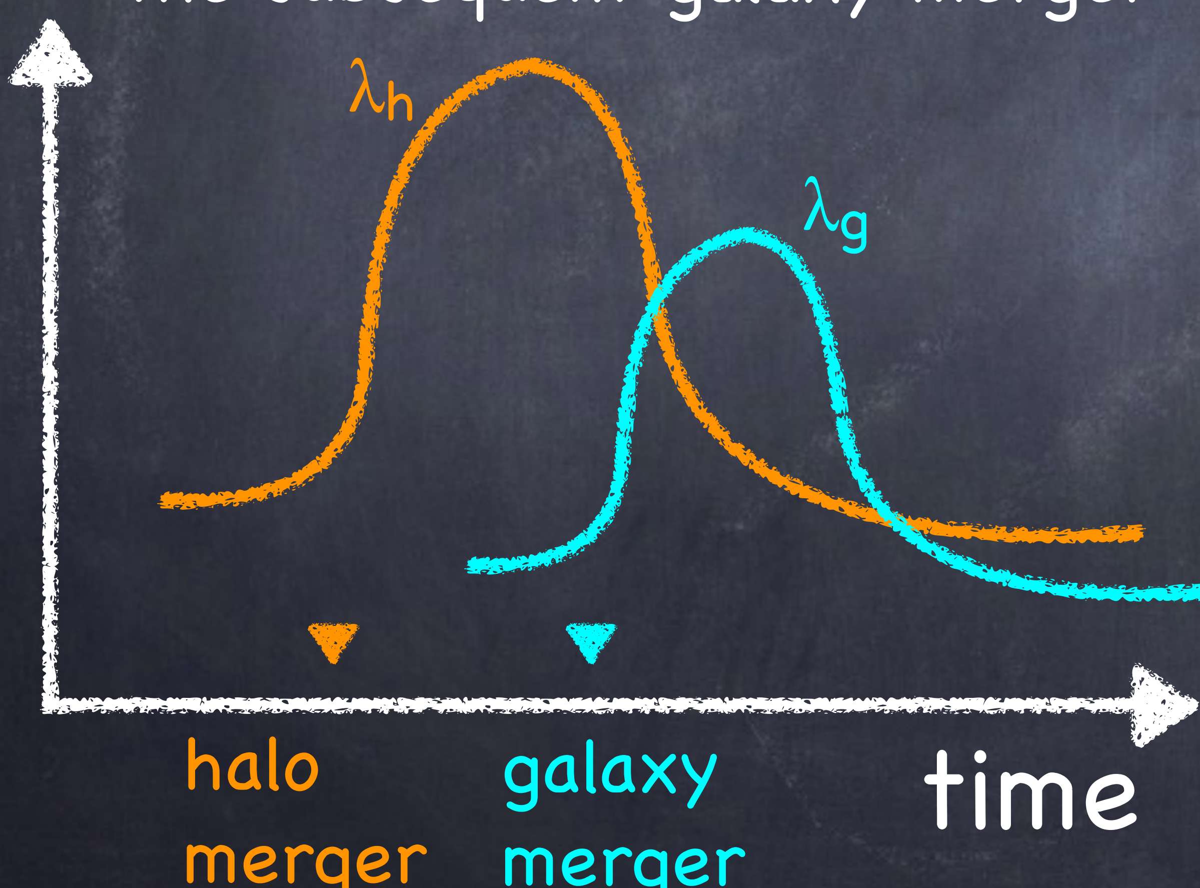
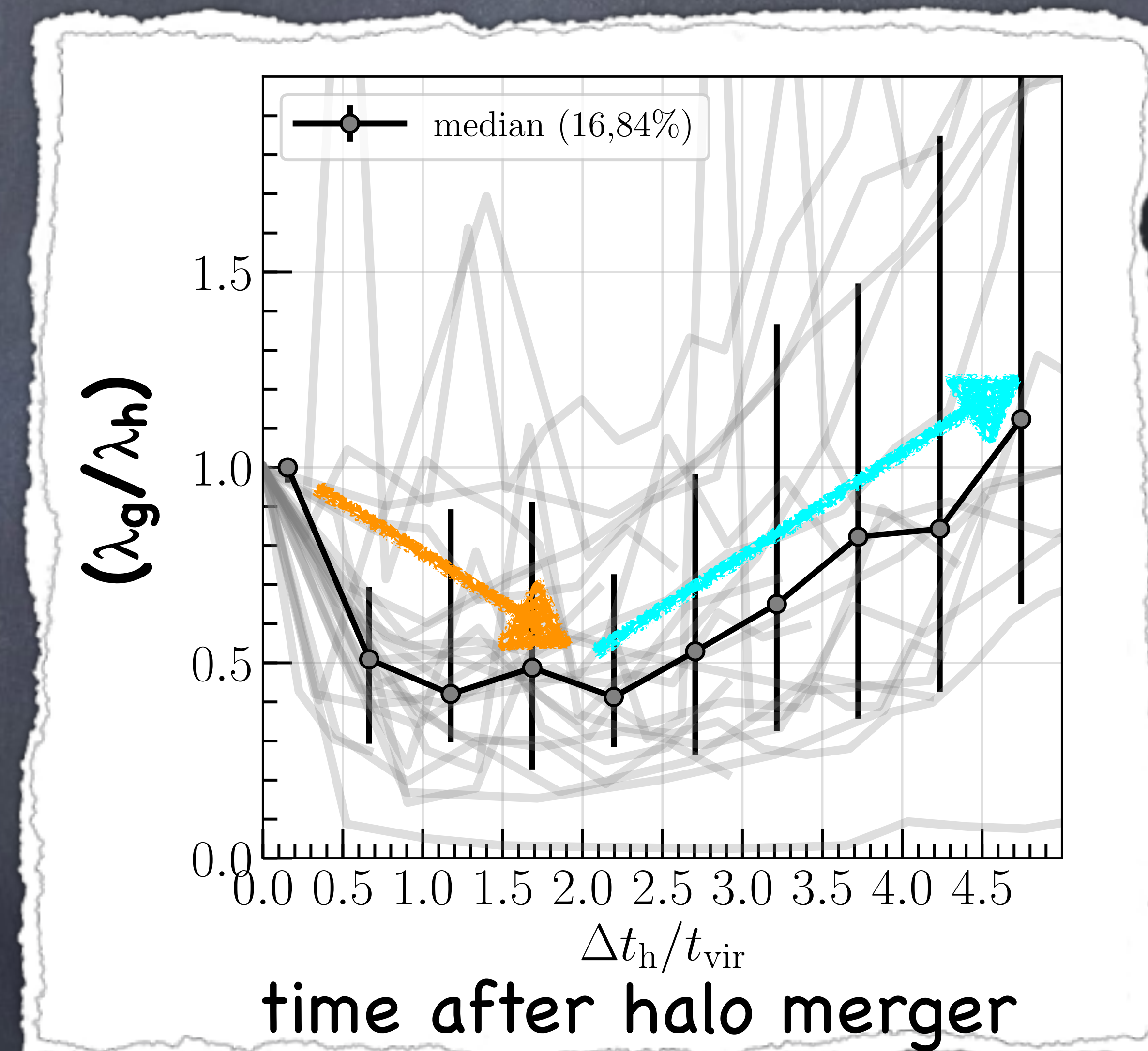
possible reasons for a λ_g/λ_h - λ_h anti-correlation

- **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



(see also Lee+17)



Jiang+17 in prep

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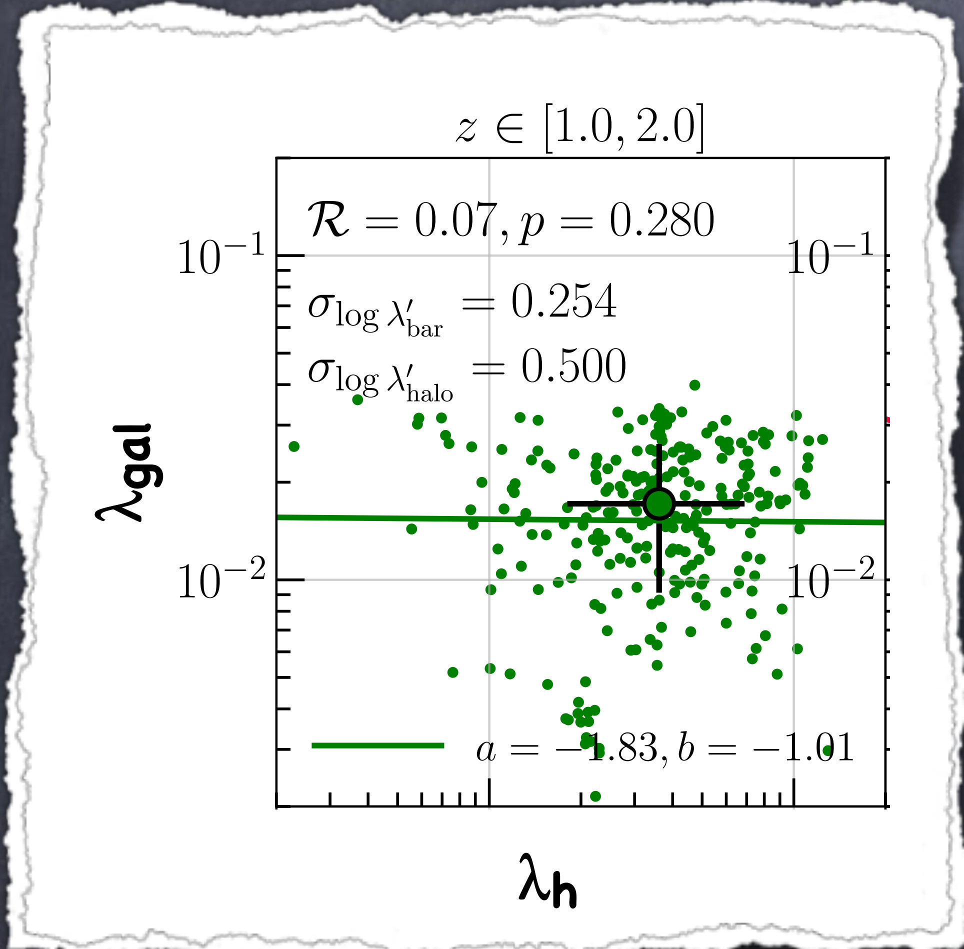
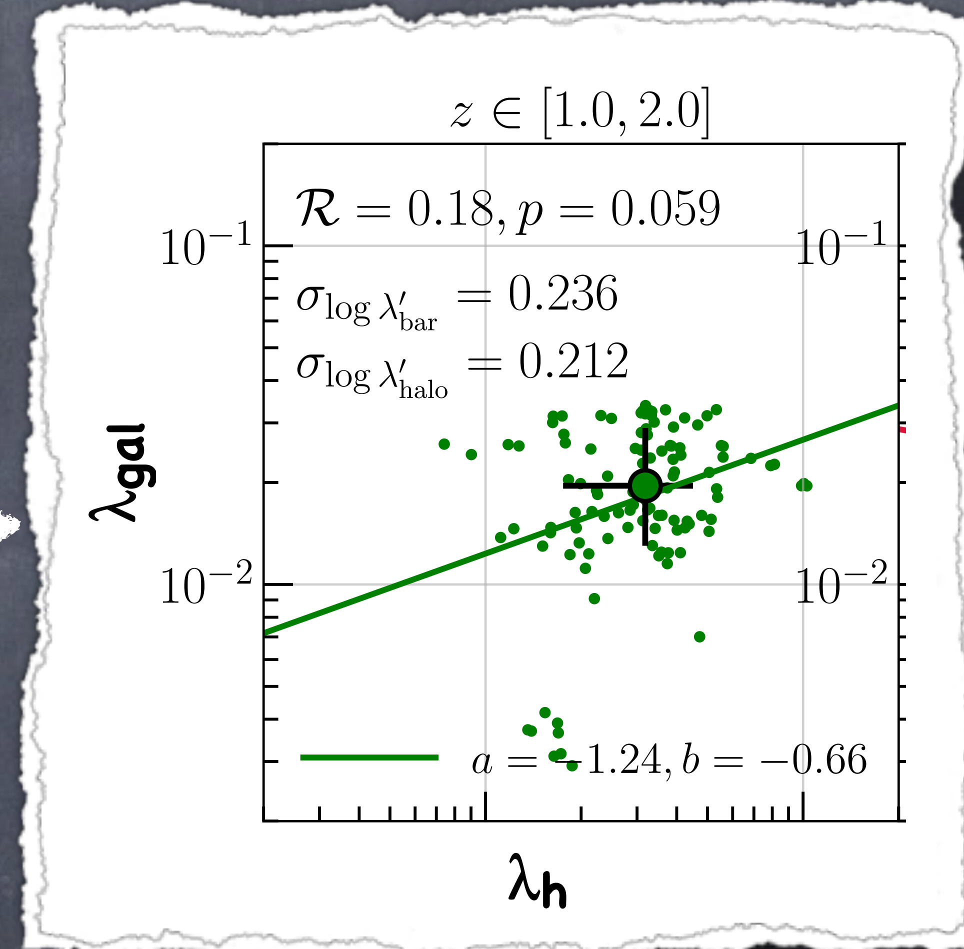


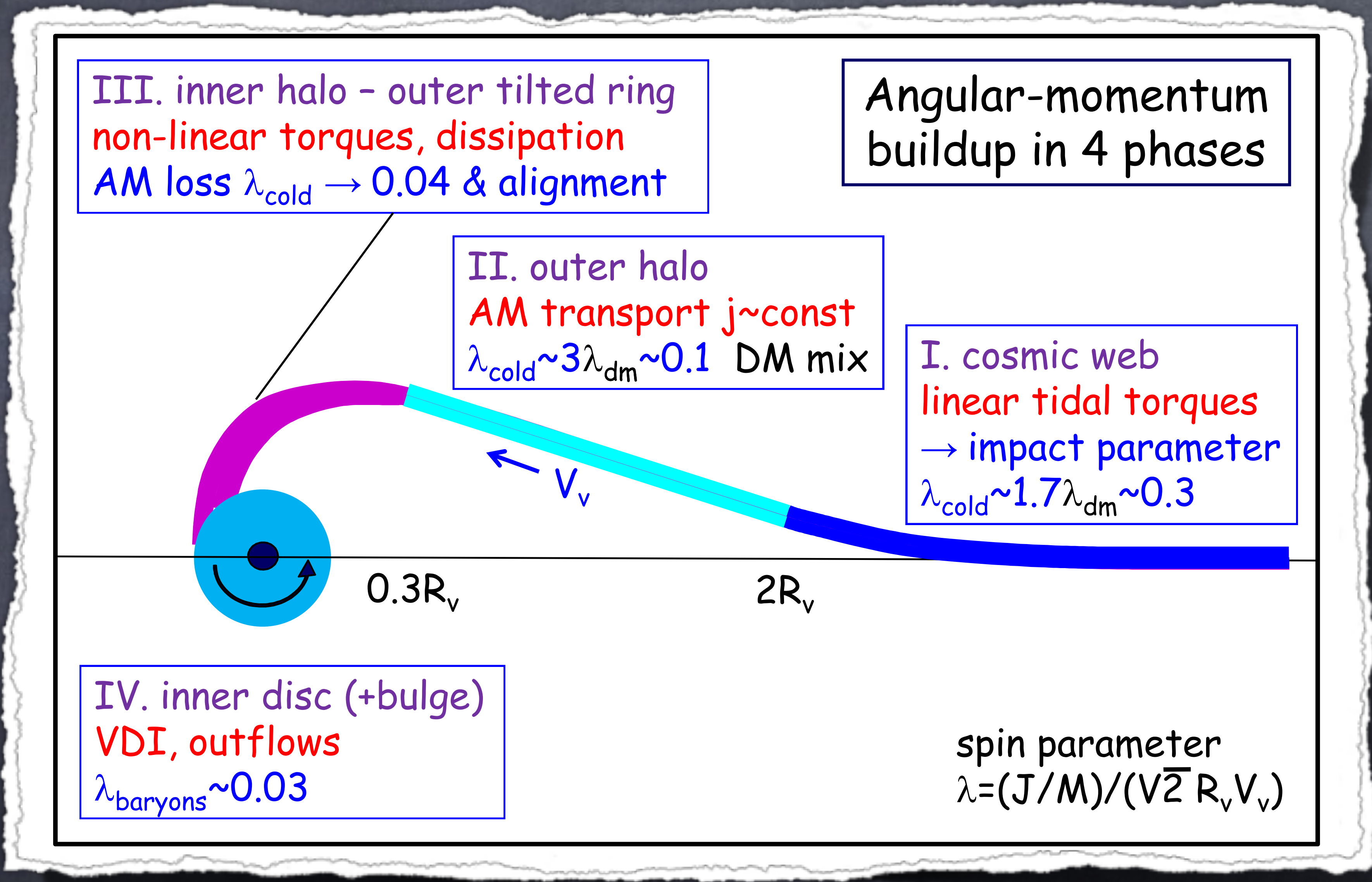
remove post-halo-merger snapshots



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

other possible reasons for smearing out λ_g - λ_h correlation

see Danovich+15



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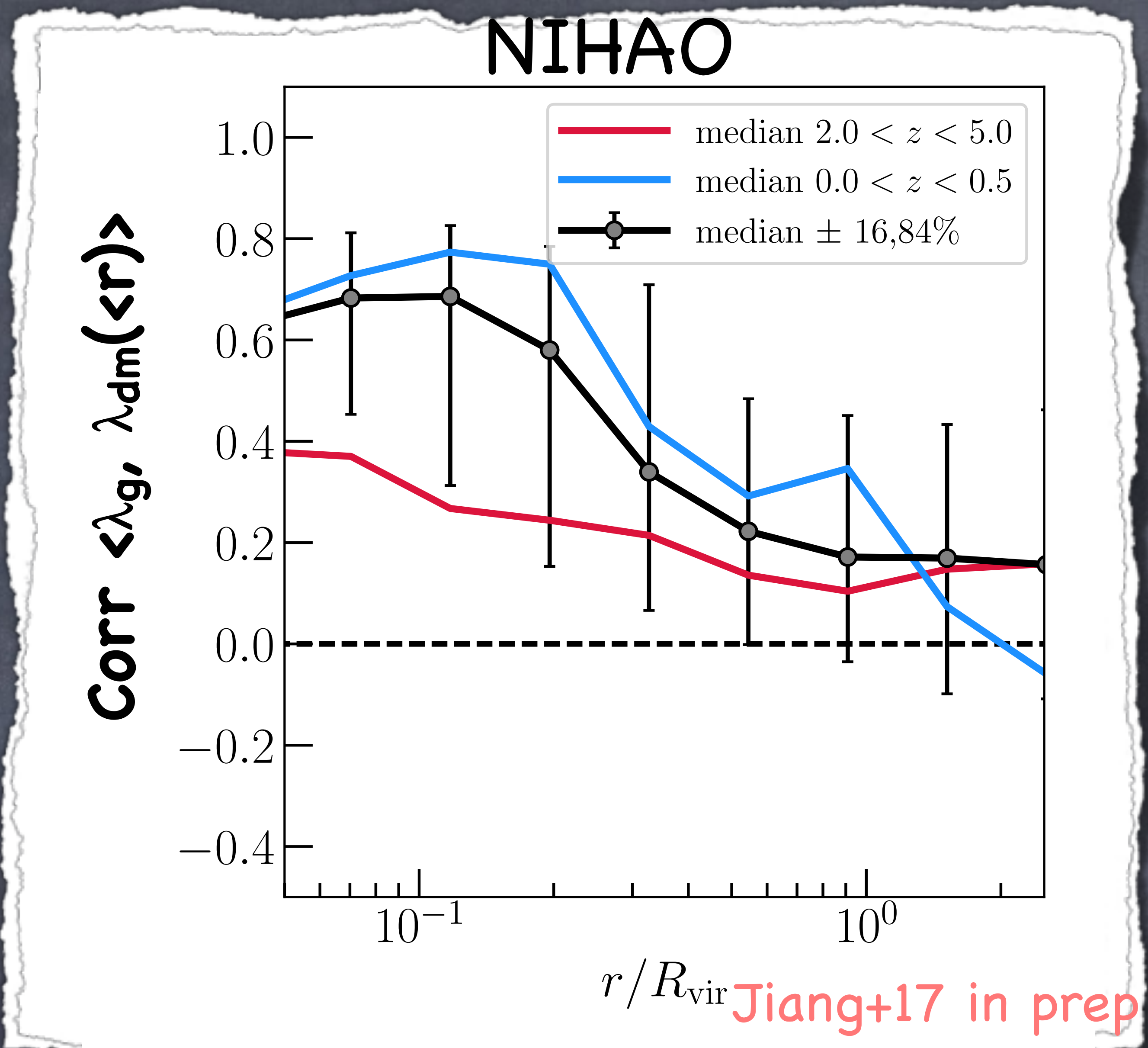
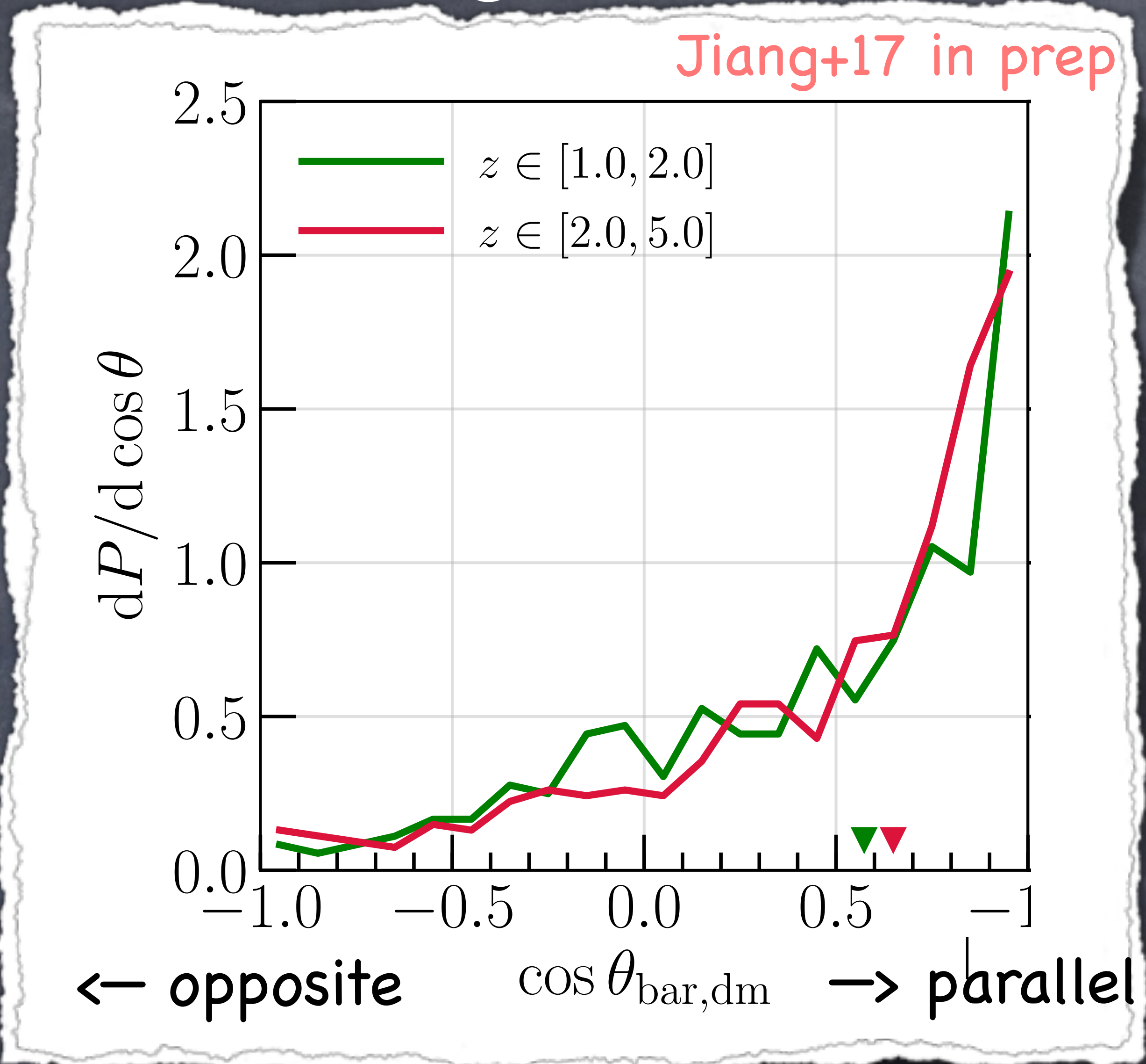
λ_{gal} and $\lambda_{inner\ halo}$?



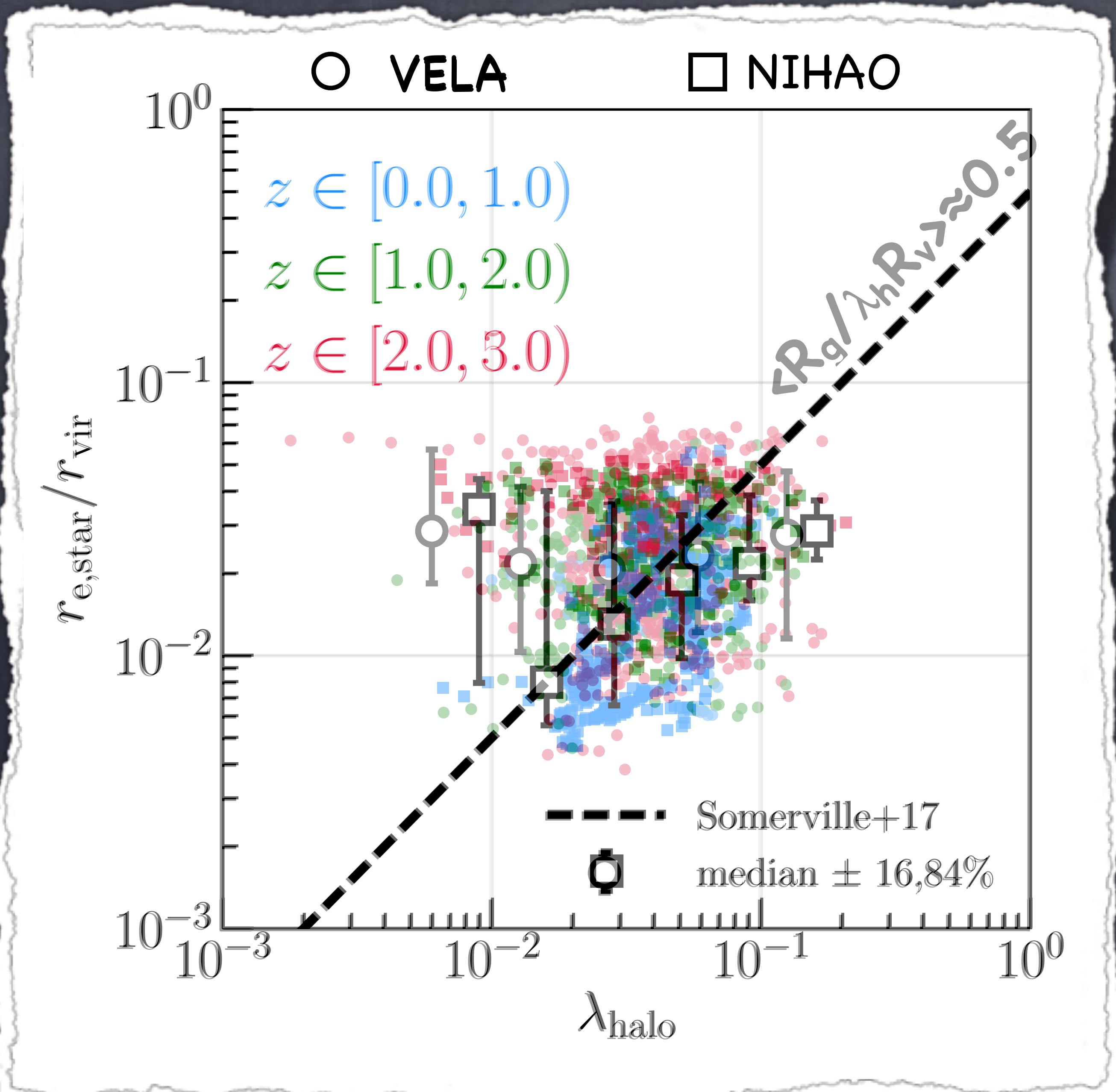
- strong correlation between λ_g and $\lambda_{dm}(<r)$ out to $0.2R_{vir}$, esp. low-z
- consistent with EAGLE (Zavala+16):
  tight correlation between the loss of sAM of the inner (0.1Rvir) DM and that of the baryons, by following Lagrangian volumes

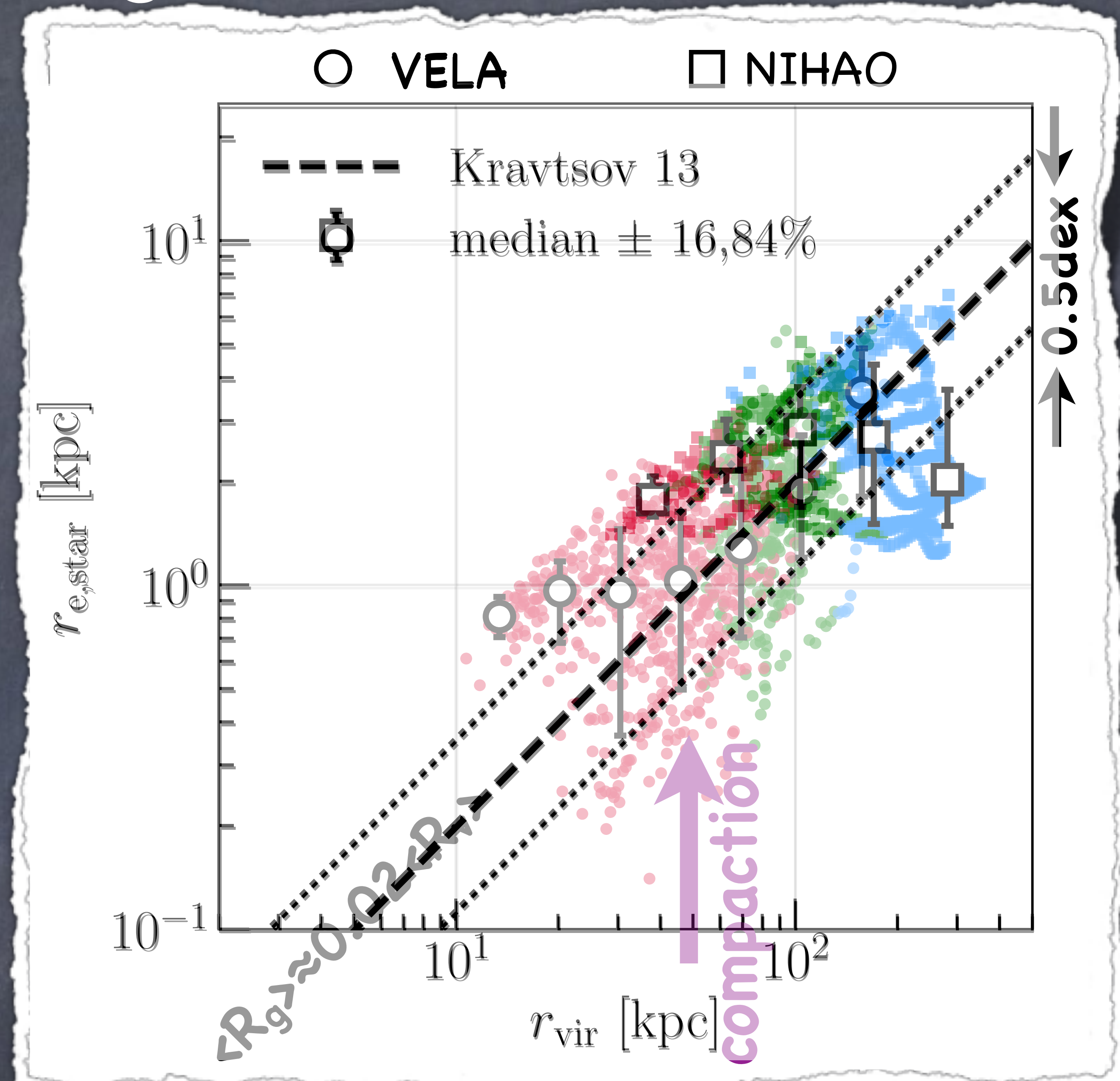
Alignment



- good alignment despite non-correlation in values: <cosθ> = 0.72 (gas-DM), 0.61 (stars-DM)
- mechanisms smearing out the $\lambda_g - \lambda_h$ correlation should NOT randomize the alignment too much
- alignment weakens slightly towards low-z, also seen in Illustris (Zjupa & Springel 2017)

Is λ_h relevant for galaxy size?





- VELA and NIHAO gives different answer

$$j_{\rm g} \simeq R_{\rm g} V_{\rm rot} \Longrightarrow R_{\rm g} \simeq \frac{j_{\rm g}}{j_{\rm h}} \frac{j_{\rm h}}{R_{\rm vir} V_{\rm vir}} \frac{V_{\rm vir}}{V_{\rm rot}} R_{\rm vir} \simeq \lambda_{\rm h} R_{\rm vir} \; ?$$

random

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

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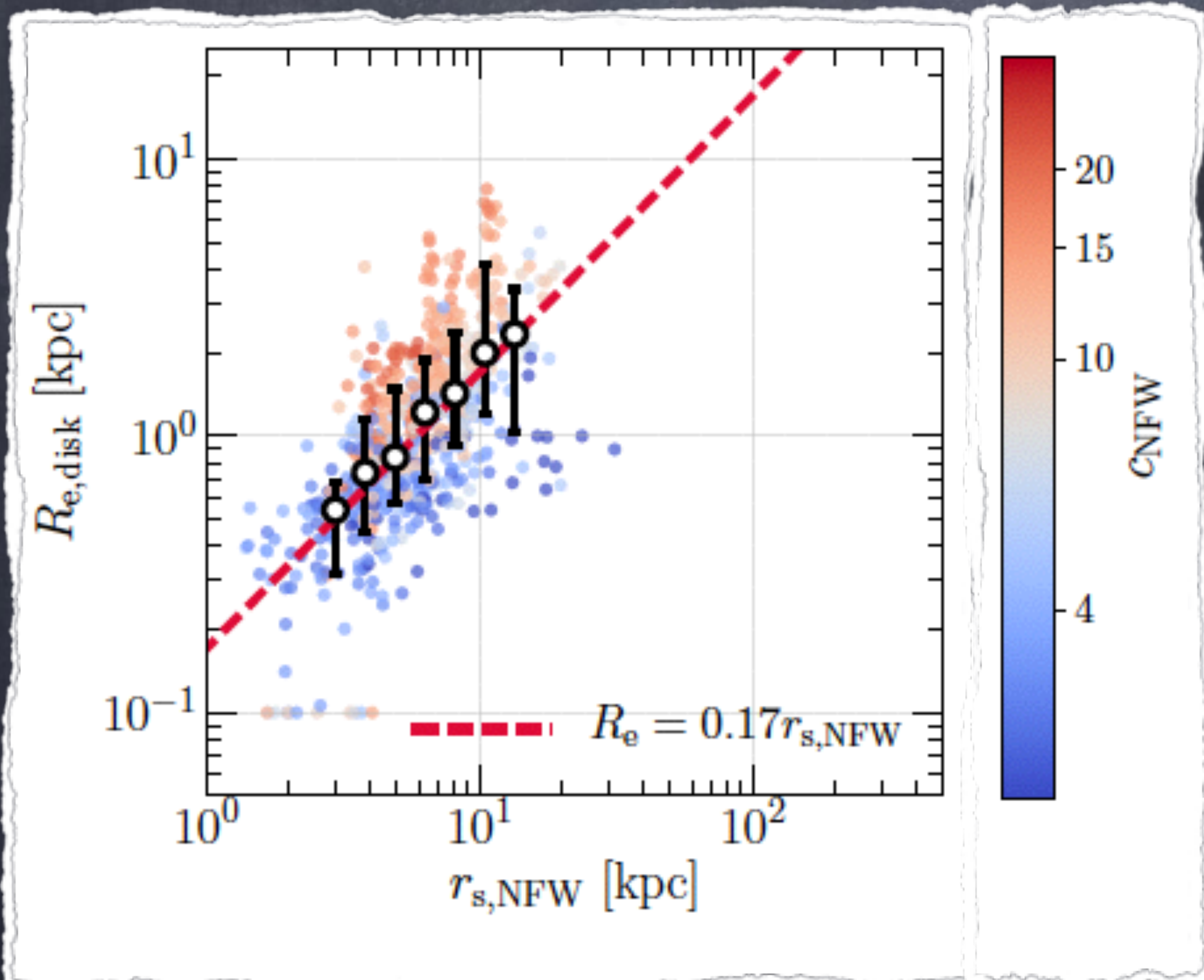
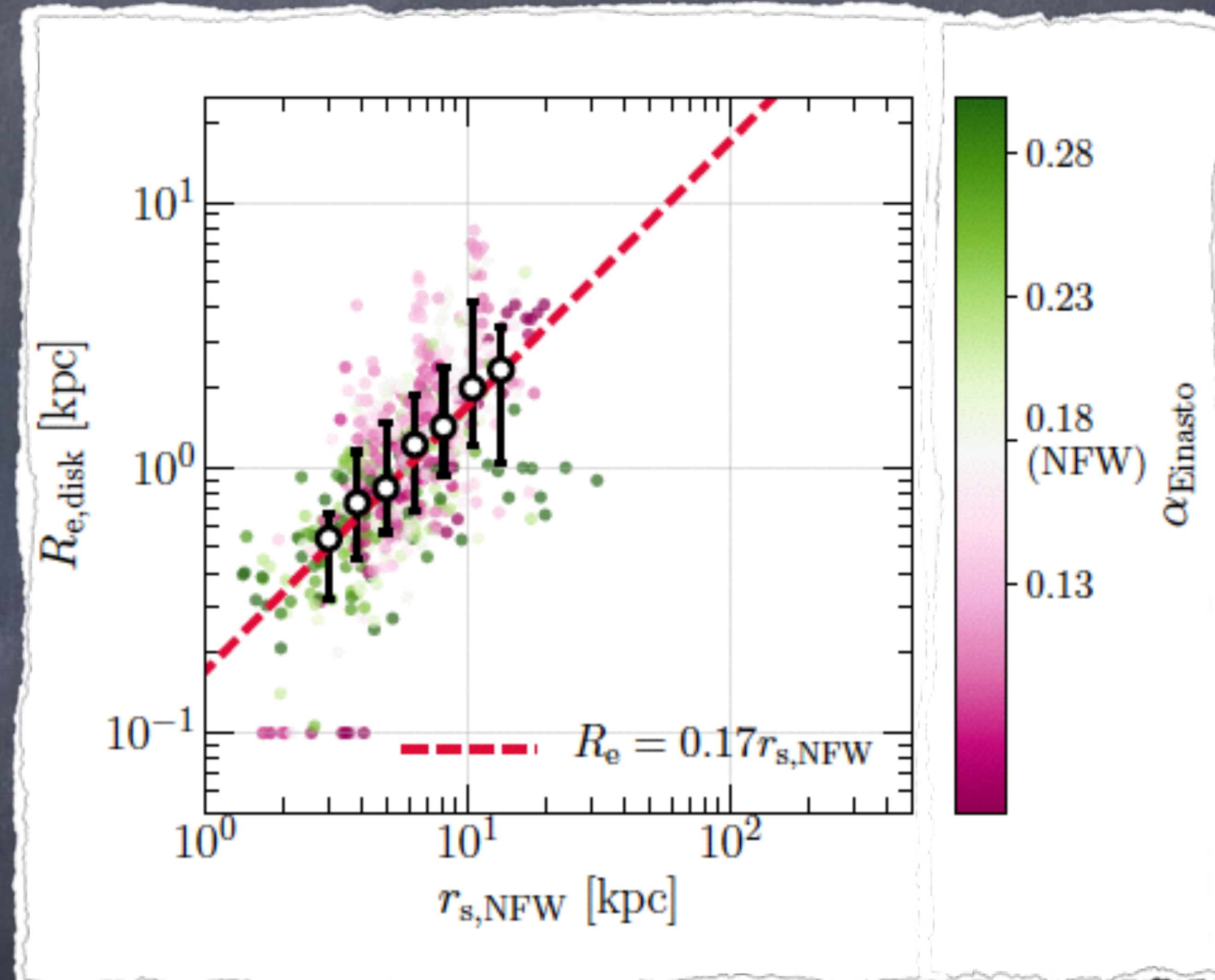
λ_{halo} irrelevant, but ...

$r_e \approx 0.17\ r_{s,NFW}$





secondary halo parameters may tighten r_e - r_x relation ?

halo concentration c_{NFW}?

halo density profile shape α_{Ein}?

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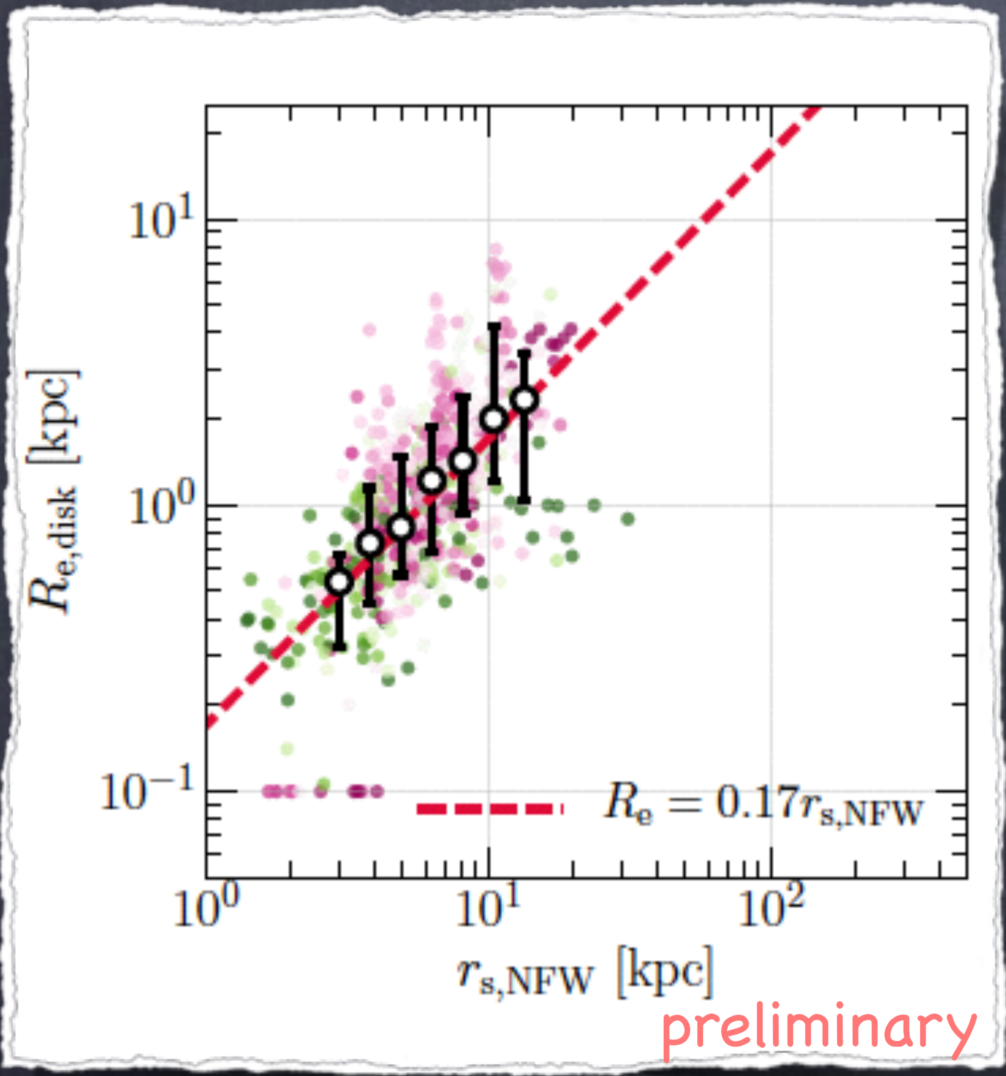
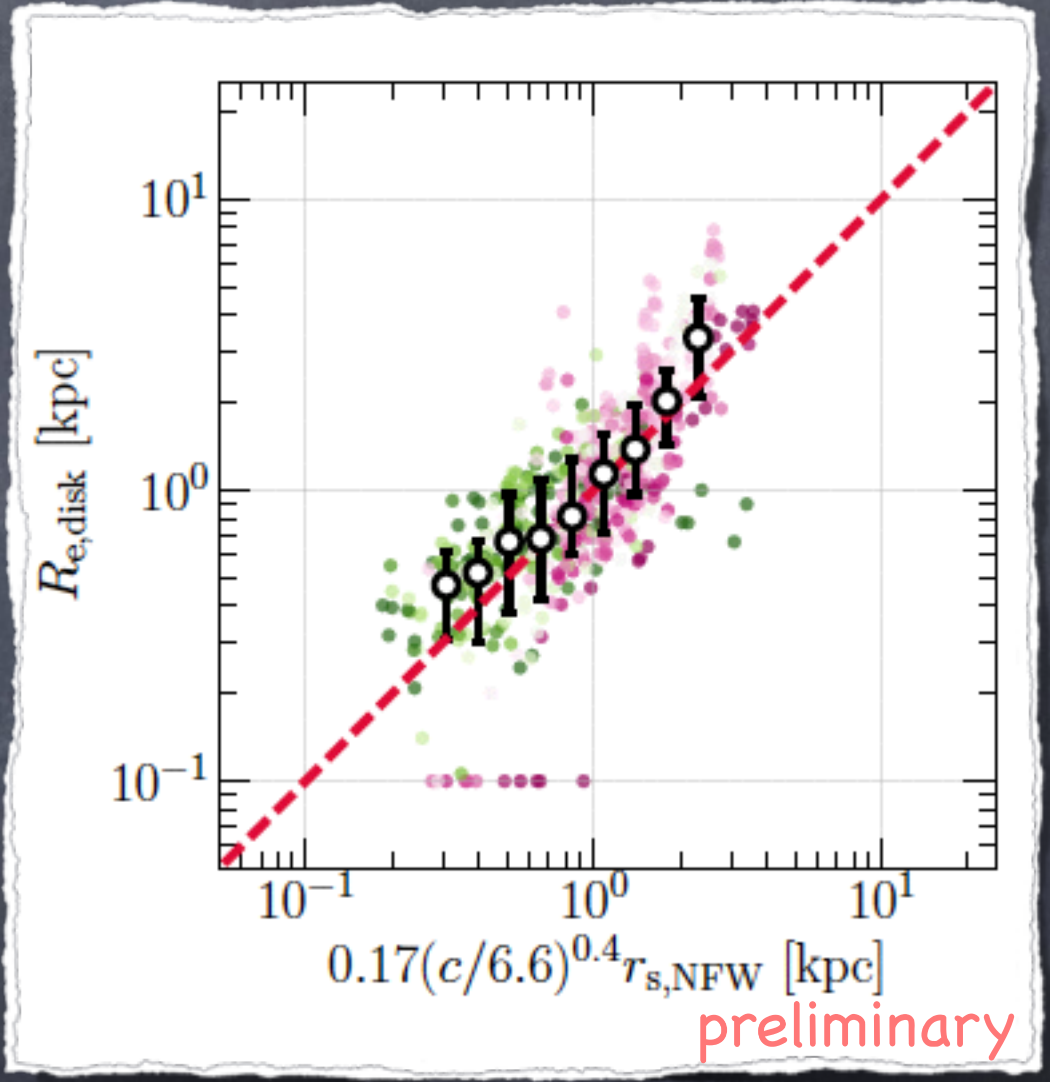
a simple galaxy size indicator

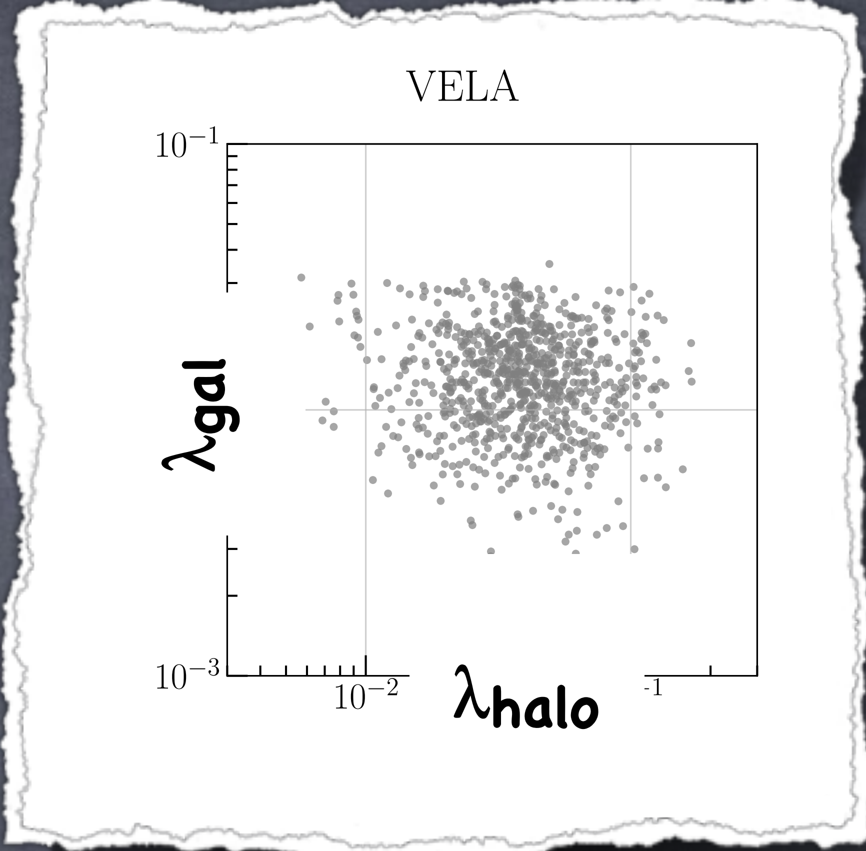




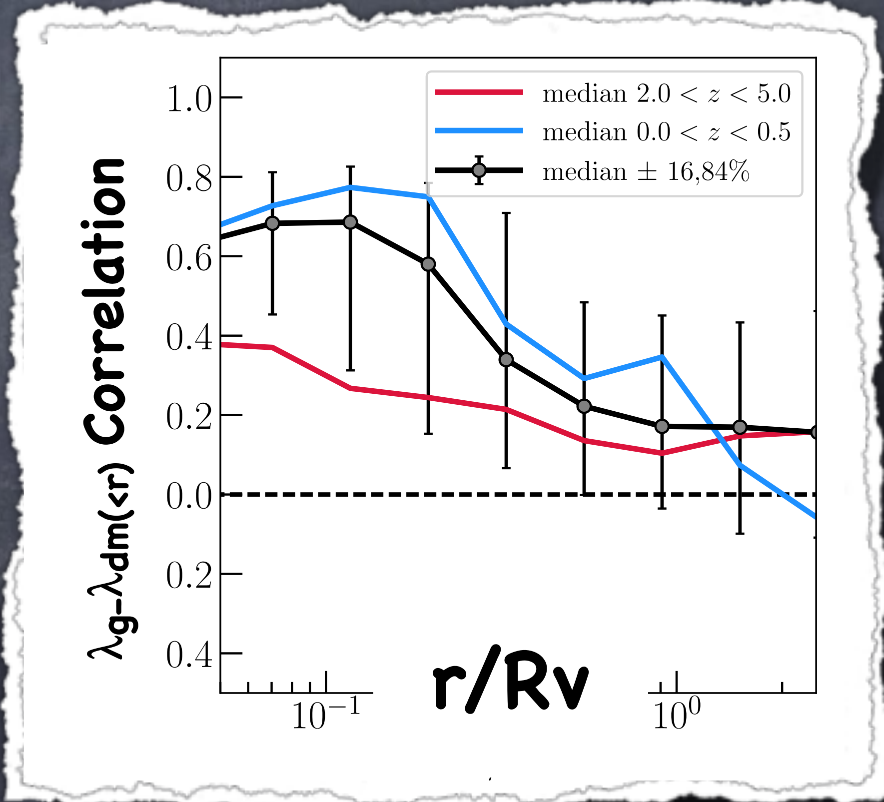
$$R_{\rm e} = 0.17 \times \left(\frac{c}{c_0}\right)^{0.4} r_{\rm s,NFW}$$

Summary

- no $\lambda_g - \lambda_h$ correlation at $z>1$
  - a weak correlation may develop at $z<1$
  - λ_g and $\lambda_{dm(<0.2Rv)}$ still correlated
  - λ_g–λ_h alignment always good
  - λ_g is higher in post-compaction halos



- mechanisms that smear out the $\lambda_g - \lambda_h$ correlation which must exist 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 irrelevant for galaxy size, while, at least in VELA, $R_e \approx 0.17\ r_s\ (c/7)^{0.4}$

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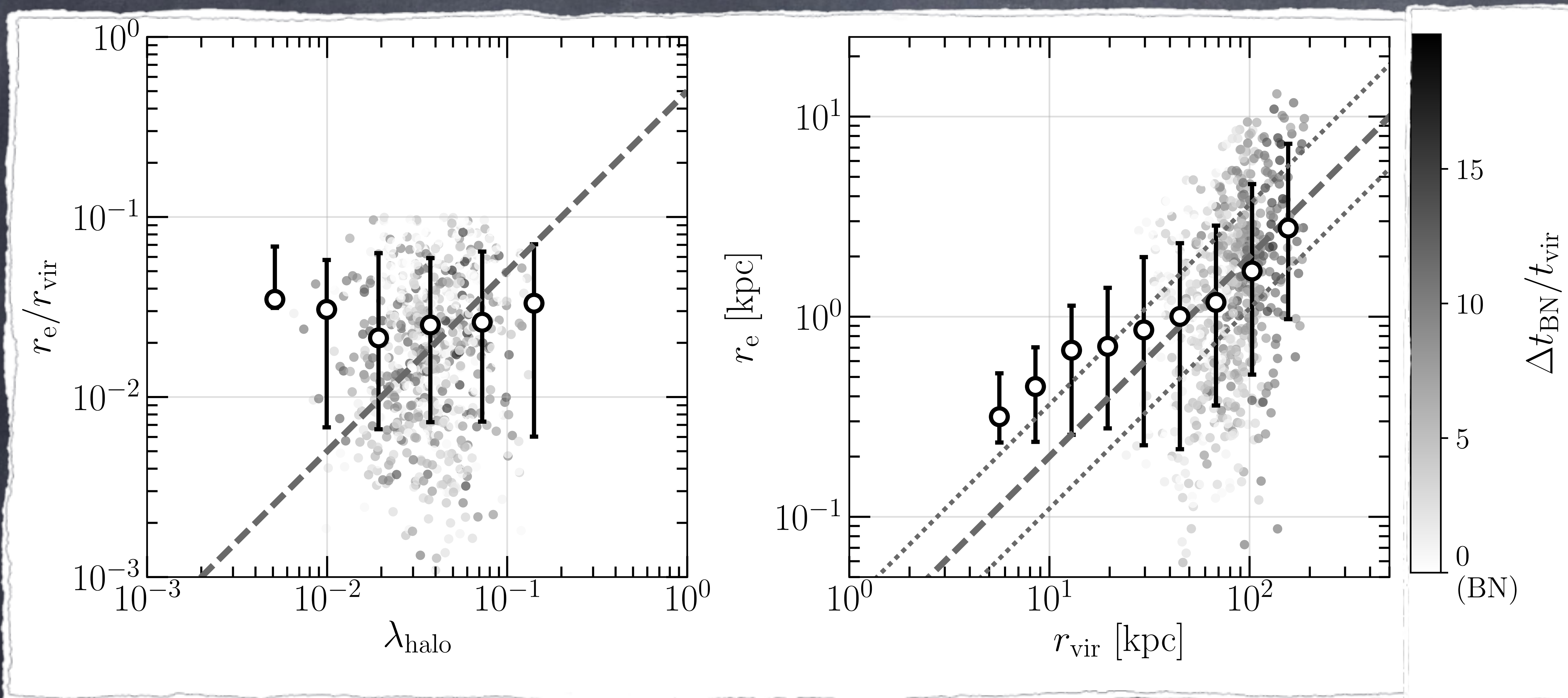
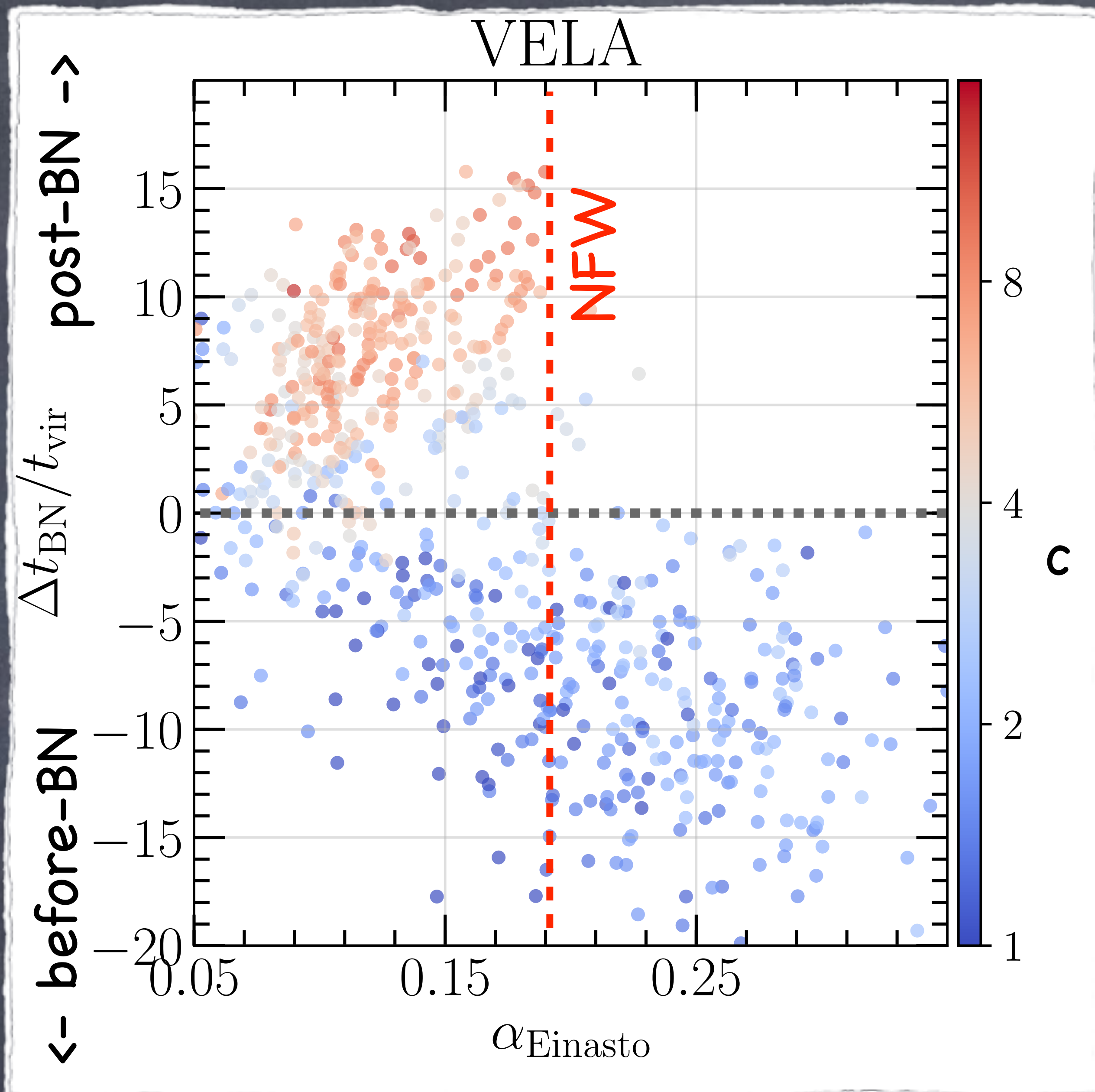
λ_{halo} irrelevant, but compaction matters ...



- post-compaction r_e-r_{vir} approaches the local empirical relation (Kravtsov13,17)
- which halo characteristic radius r_x gives a universal r_e-r_x relation?
- which halo parameters capture / manifest compaction?

compaction and halo structural parameters



- before compaction: uniform α
- after compaction: α<0.2, post-compaction time scales with α
- just halo response? or maybe c and α can predict compaction?

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

EPS merger trees

+

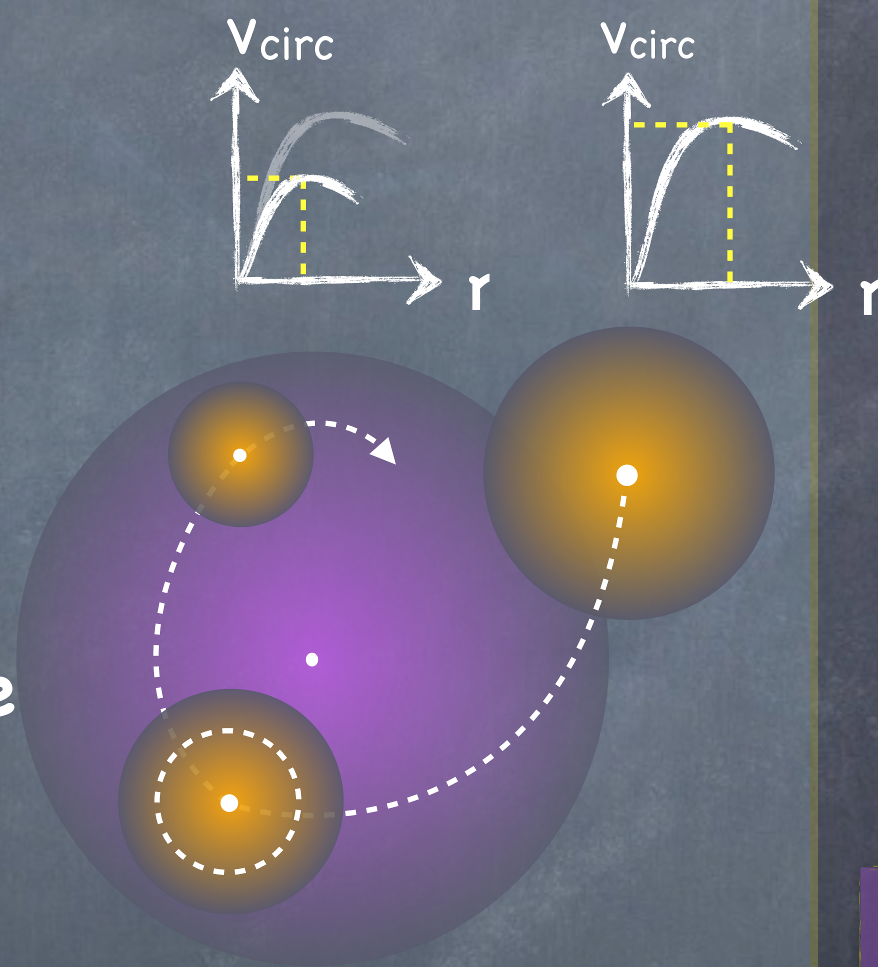
orbit integration

+

(sub)halo response

+

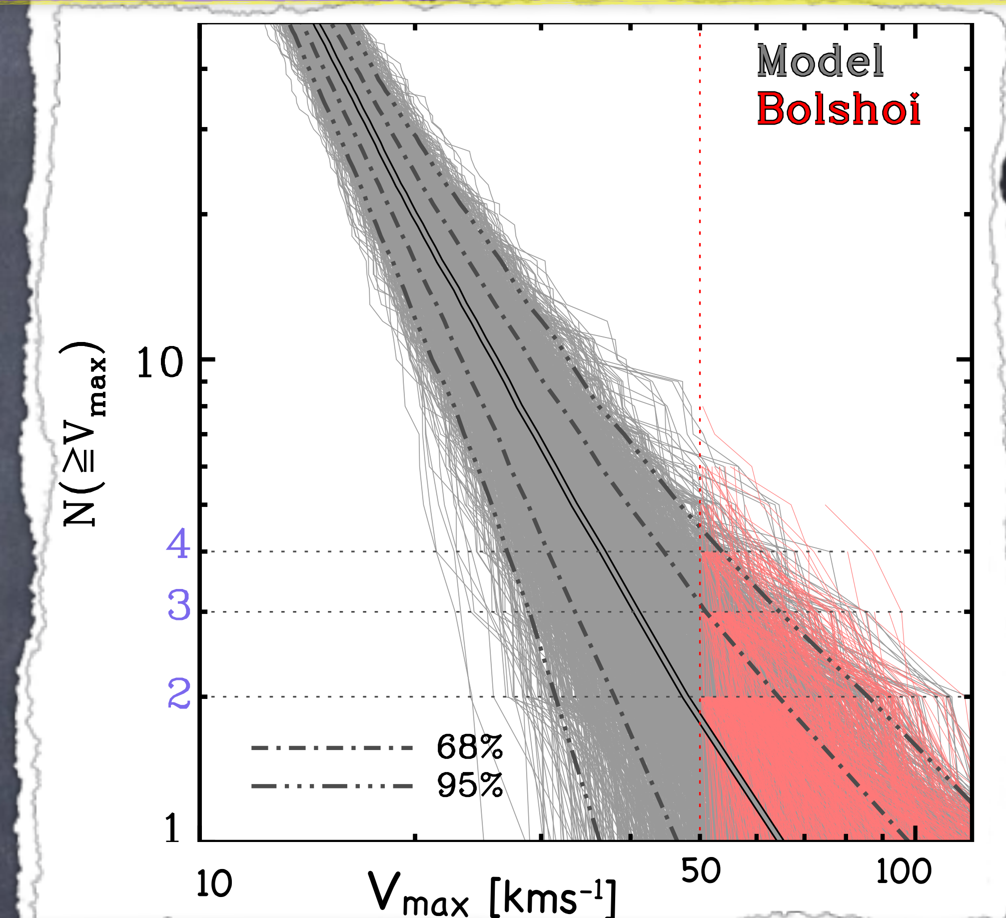
SHAM+



based on Jiang & van den Bosch 15,16

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

w/o the disk, we can simulate / outperform N-body simulations ...



Goal: to simulate hydro simulations (why feasible? see Garrison-Kimmel+17), we need a correct way to assign disks to halos !

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