

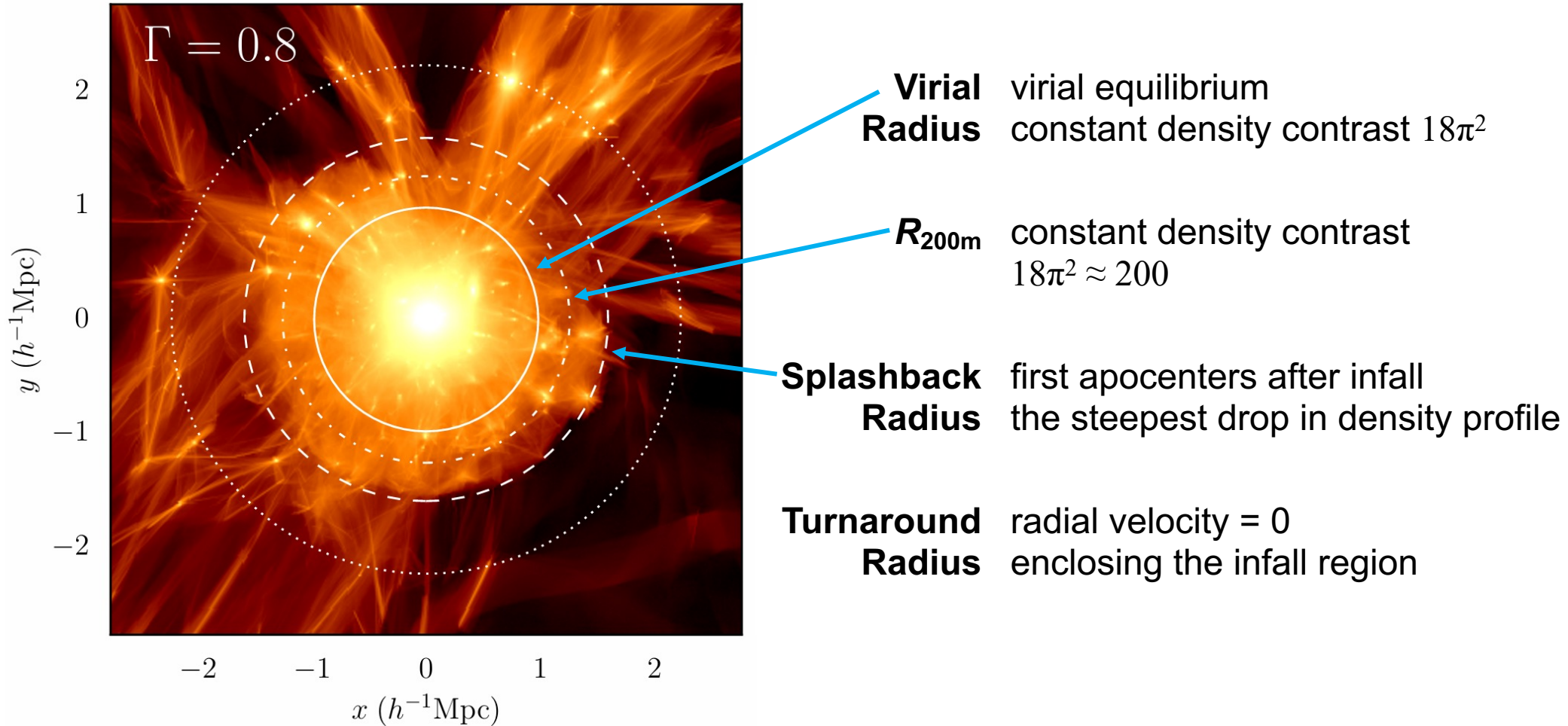
# The Dependence of the Depletion Radius on Mass Accretion Rate

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2025.9.19

# Boundaries of Dark Matter Halo



pseudo evolution  
incomplete

...

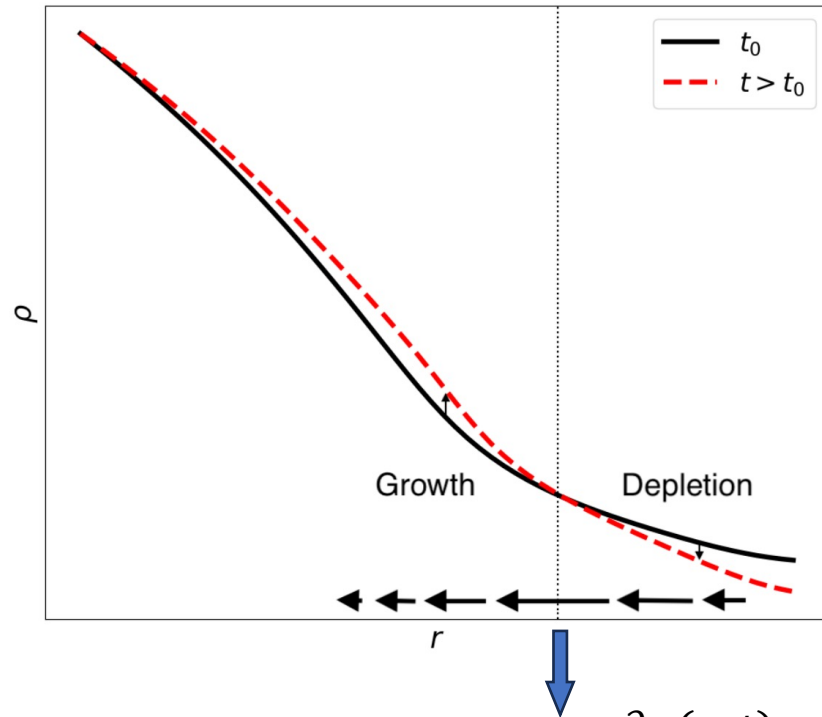
inaccurate

More, Diemer & Kravtsov. 2015

# Depletion Radius: Definition

Fong & Han. 2021

Growth of halo ↔ Depletion of environment



$R_{id}$ : inner depletion radius,  $\frac{\partial \rho(r, t)}{\partial t} = 0$

Continuity equation:

$$\frac{\partial \rho(r, t)}{\partial t} = -\frac{1}{4\pi r^2} \frac{\partial \text{MFR}(r, t)}{\partial r}$$

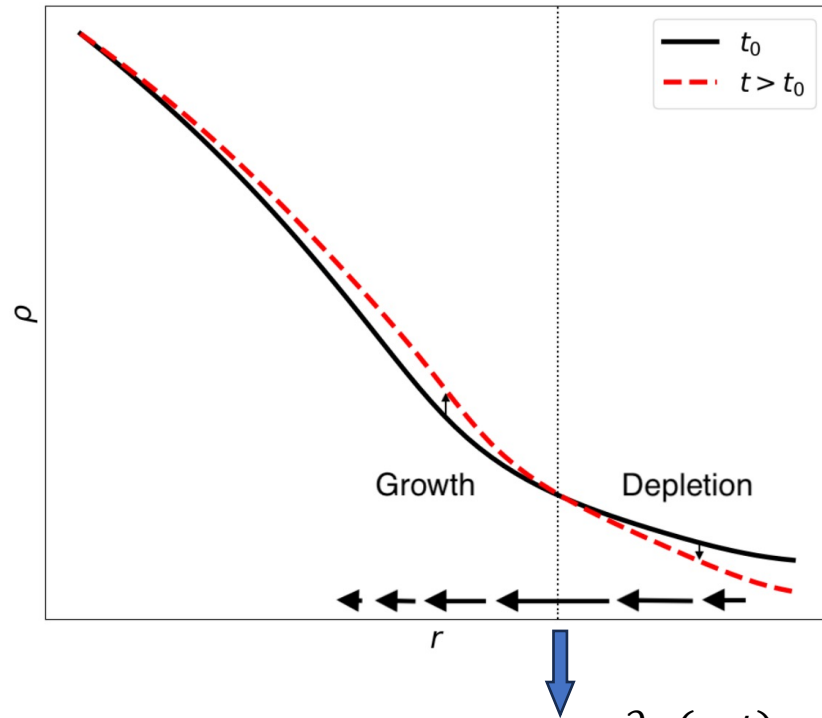
Mass Flow Rate:

$$\text{MFR}(r) \equiv \frac{dM(< r)}{dt} = 4\pi r^2 \rho(r) v_r(r)$$

# Depletion Radius: Definition

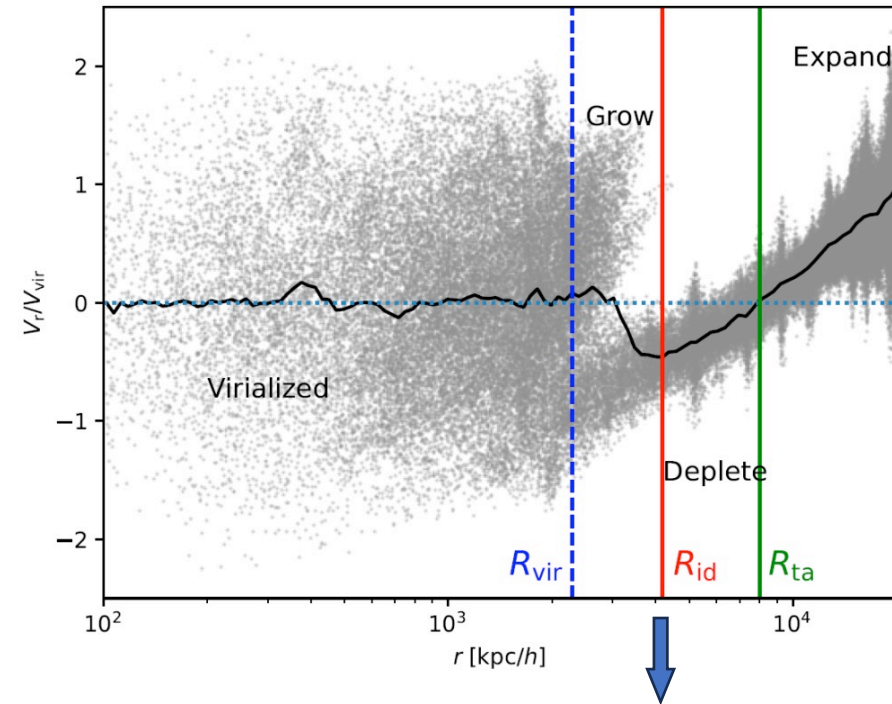
Fong & Han. 2021

Growth of halo  $\leftrightarrow$  Depletion of environment



$R_{id}$ : inner depletion radius,  $\frac{\partial \rho(r, t)}{\partial t} = 0$

$$\frac{\partial \text{MFR}(r, t)}{\partial r} = 0$$

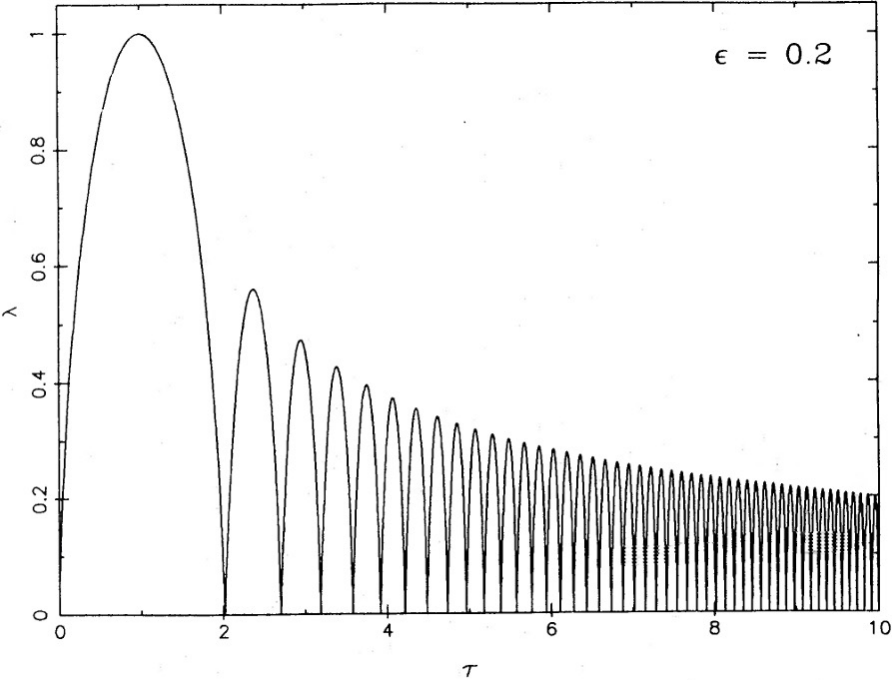


$R_{id} \sim$  the outmost splashback radius

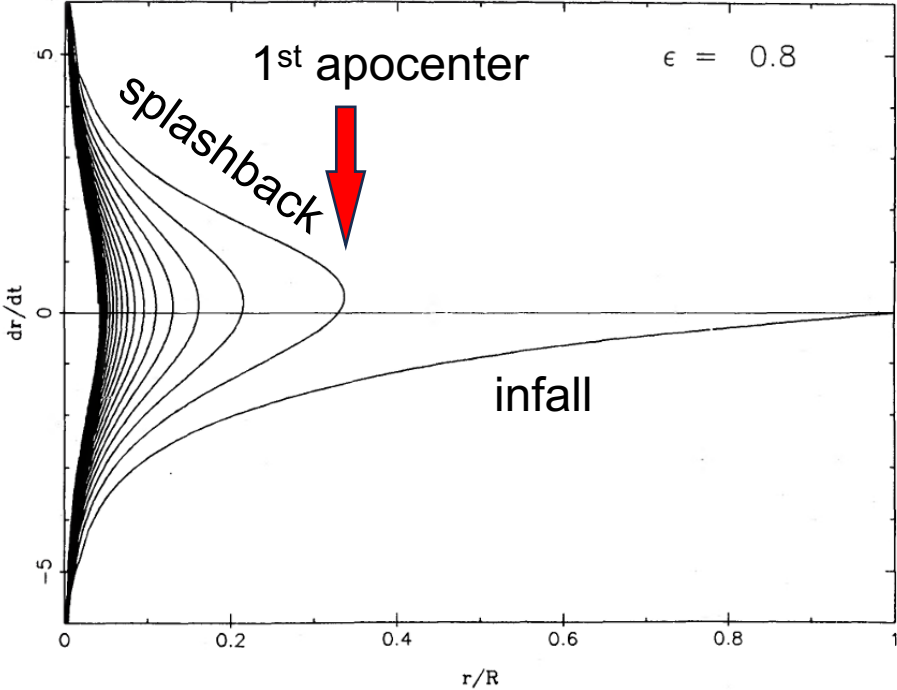
# Depletion Radius: Theoretical Expectations

Fillmore & Goldreich 1984  
 Self-similar spherical collapse model

$$\delta \equiv \frac{\delta M_i}{M_i} = \left( \frac{M_i}{M_0} \right)^{-\epsilon} \quad \frac{d^2 r}{dt^2} = -\frac{G}{r^2} M(r, t)$$



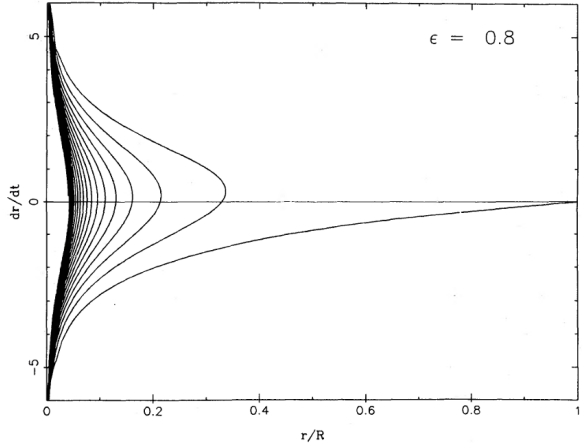
rescaled trajectory for one shell



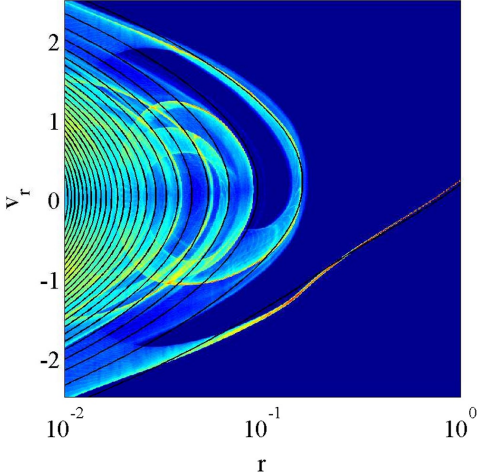
snapshot in phase space

# Depletion Radius: Theoretical Expectations

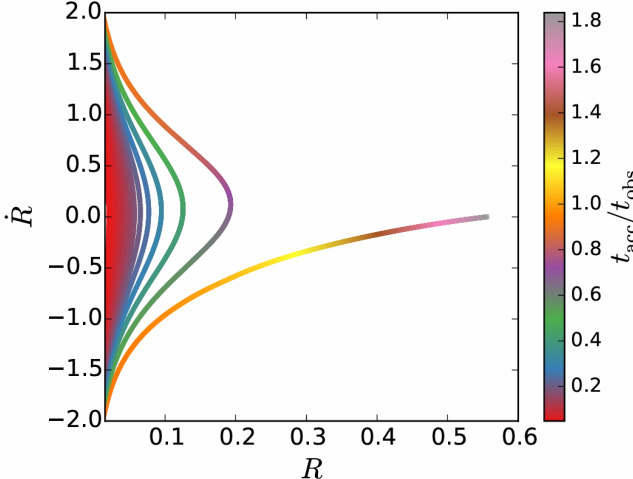
Fillmore & Goldreich 1984



Adhikari et al. 2014



Shi 2016

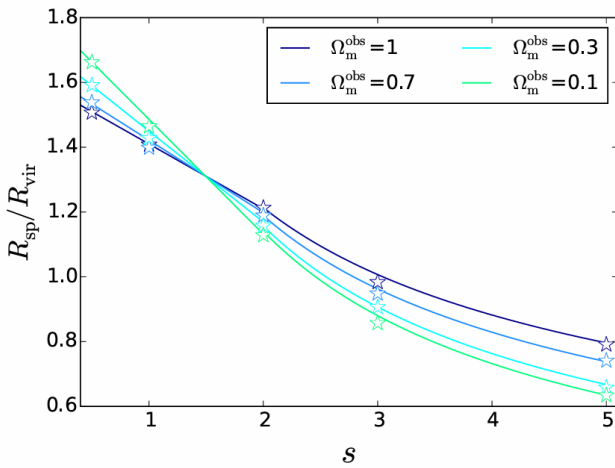
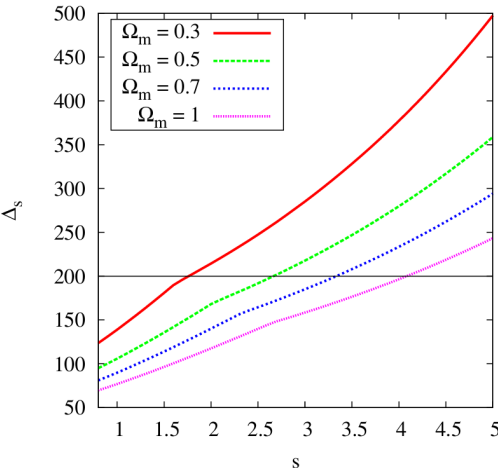


Self-similar spherical collapse model

$R_{\text{caustic}}/R_{\text{vir}}$  only depends on  $s$  and  $\Omega_m$

$s$  : initial profile  $\rightarrow$  mass accretion rate

$\Omega_m$  :  $\rightarrow$  redshift dependence



# Depletion Radius in Simulation

$z = 0, 13.15 \leq \log M_{\text{vir}} < 13.70$

Data:

Dark matter only simulation  
Cosmic Growth, Jing. 2019  
600Mpc/h,  $N=3072^3$

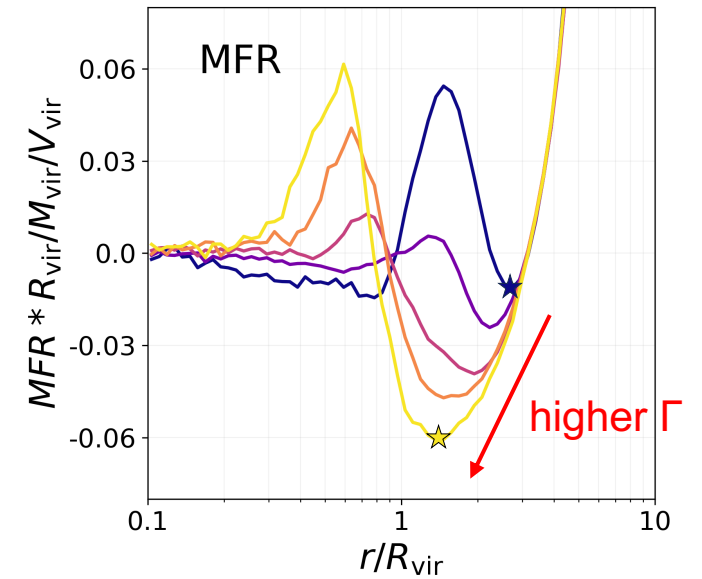
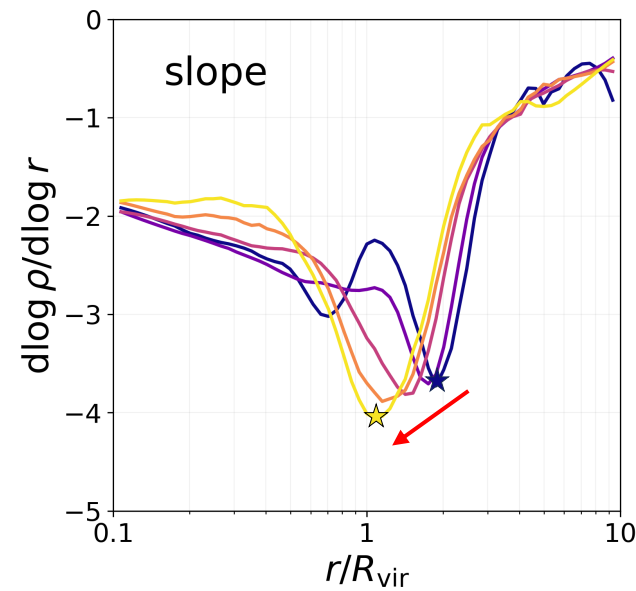
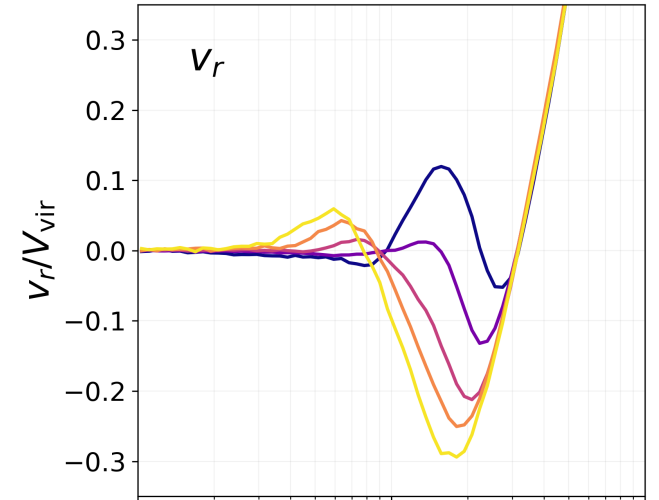
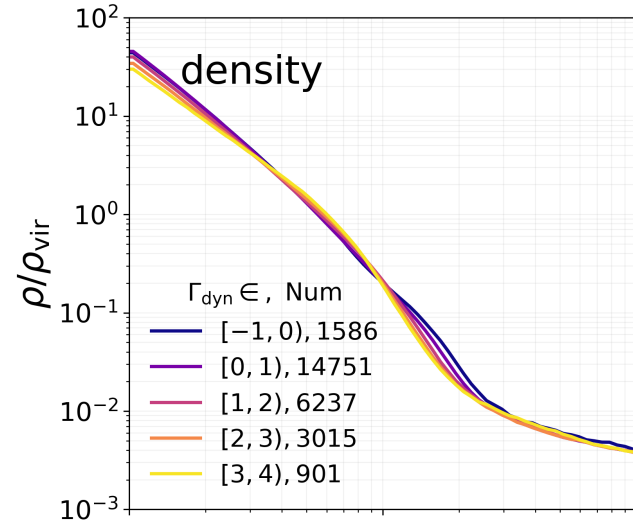
FoF halo, HBT+ subhalo & merger tree

Mass accretion rate:

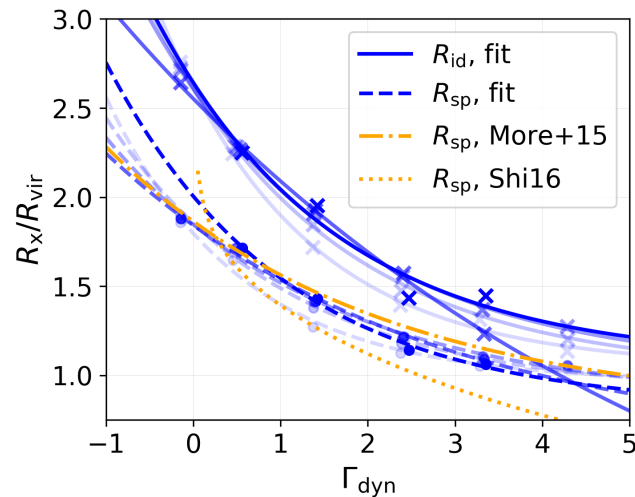
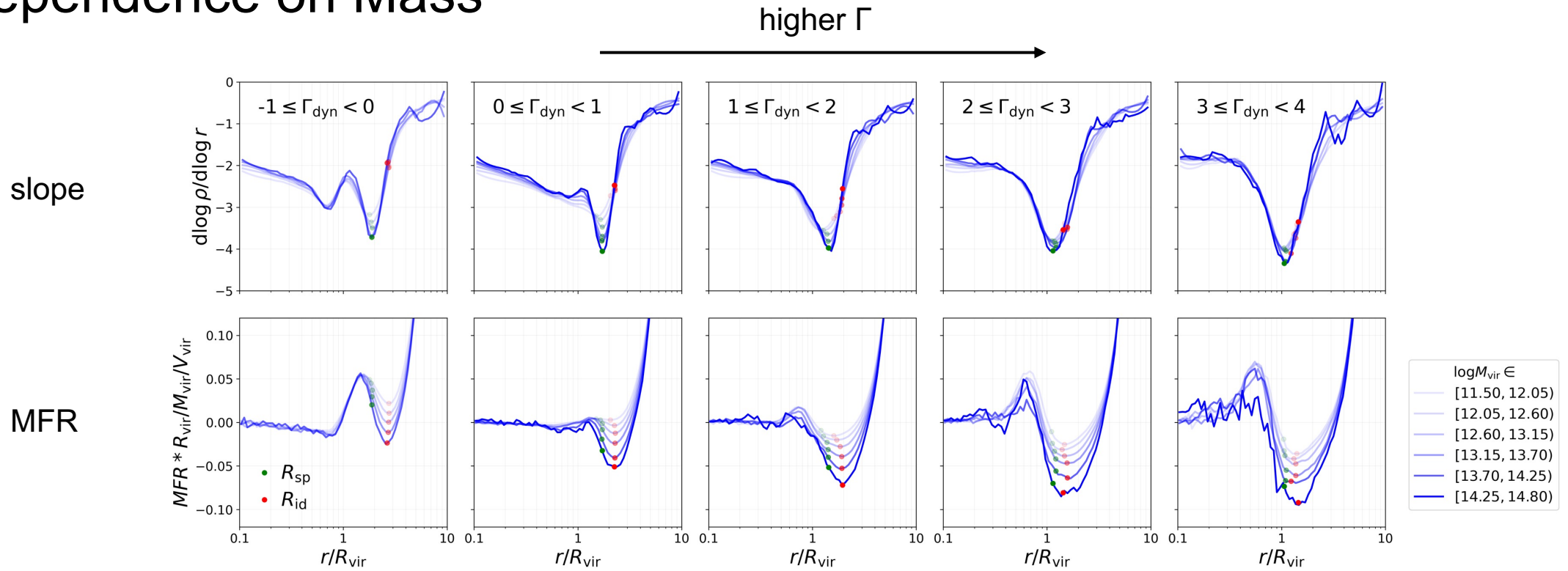
$$\Gamma = \frac{\Delta \log M_{\text{vir}}}{\Delta \log a} \quad (\text{Diemer \& Kravtsov. 2014})$$

in a dynamical time interval:

$$t_{\text{dyn}} = 2 \frac{R_{\text{vir}}}{V_{\text{vir}}} \propto \frac{1}{\sqrt{G \rho_{\text{vir}}}}$$



# Dependence on Mass



Fitting function:

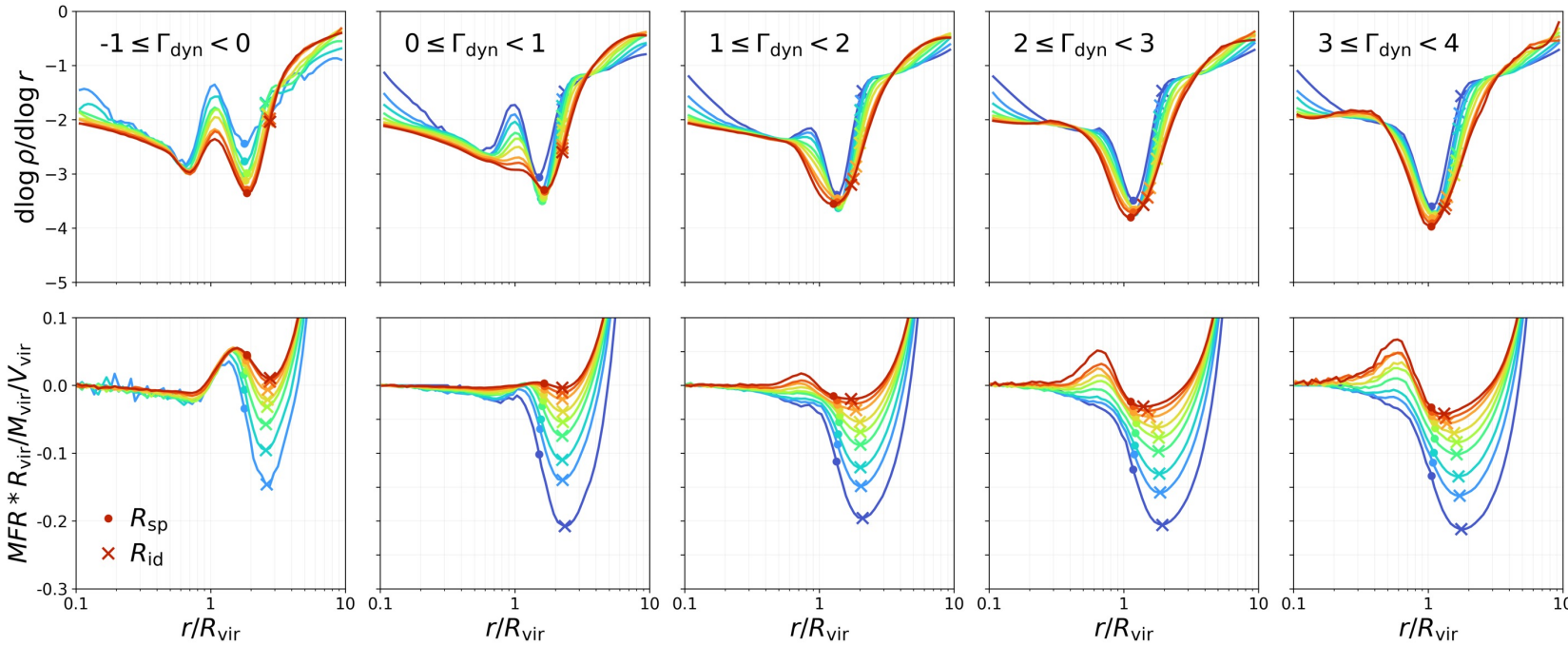
$$\frac{R}{R_{\text{vir}}} = A + B e^{-\Gamma/C} \quad (\text{More, Diemer \& Kravtsov. 2015})$$

No significant dependence on halo mass

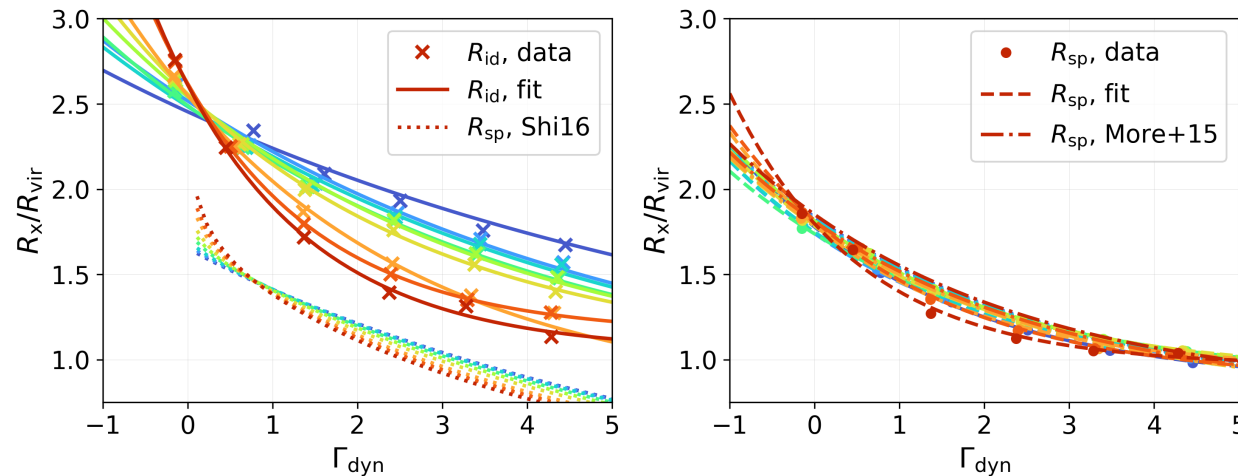
# Dependence on Redshift

higher  $\Gamma$   $\rightarrow$

slope



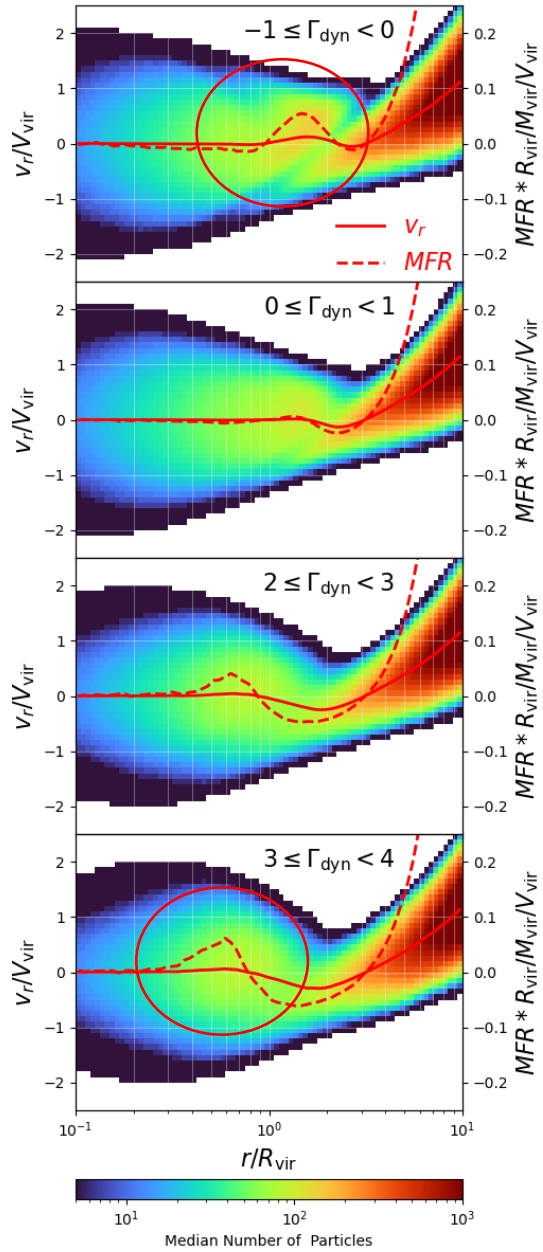
MFR



$R_{\text{id}}/R_{\text{vir}}$ : higher redshift  $\rightarrow$  weaker dependence on  $\Gamma$   
the trend is similar to the predictions of Shi 2016.

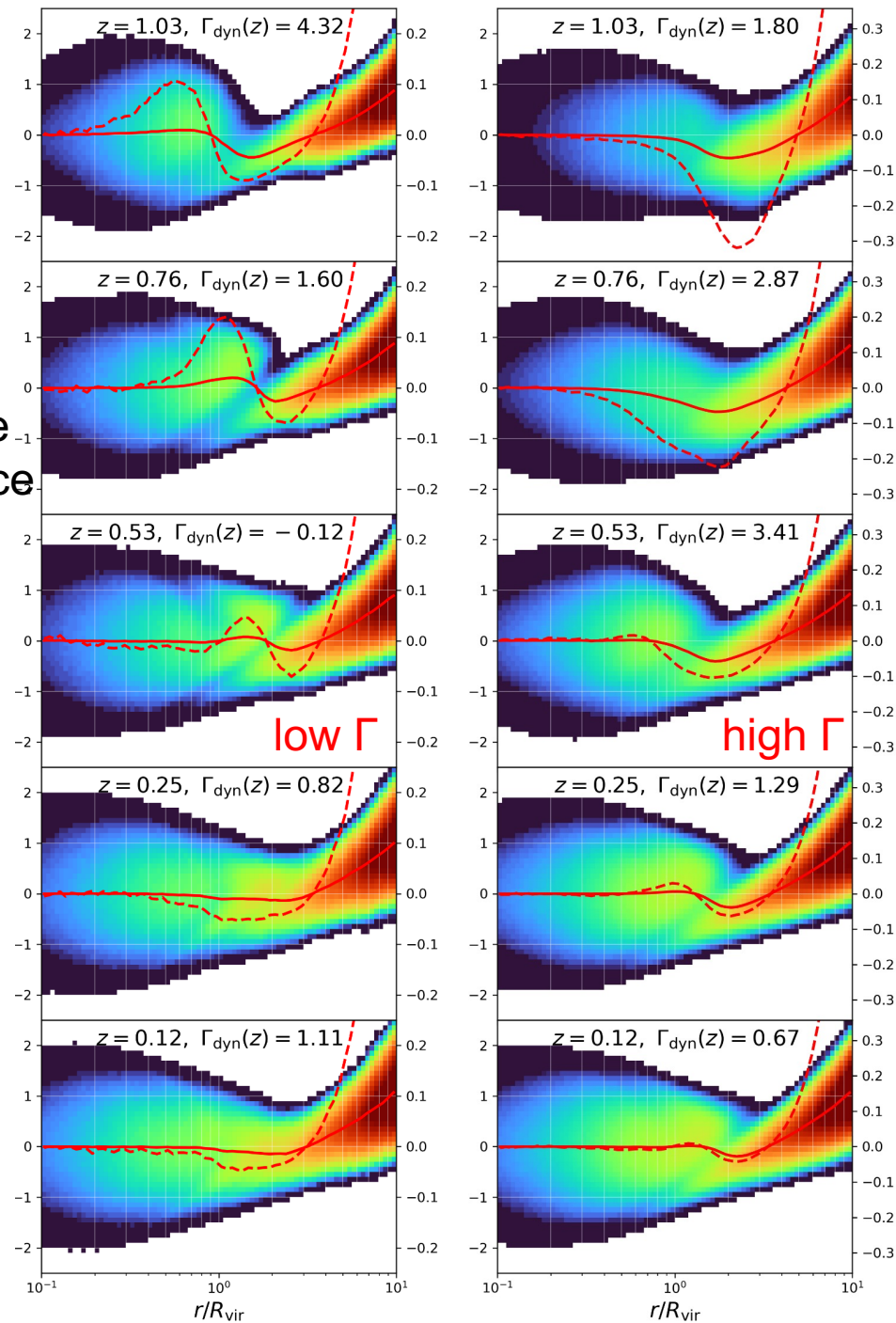
$R_{\text{sp}}/R_{\text{vir}}$ : largely independent of redshift

# What drives the dependence?



Halo structure  
in phase-space

higher  $\Gamma$



$t_0 - 1t_{\text{dyn}}$

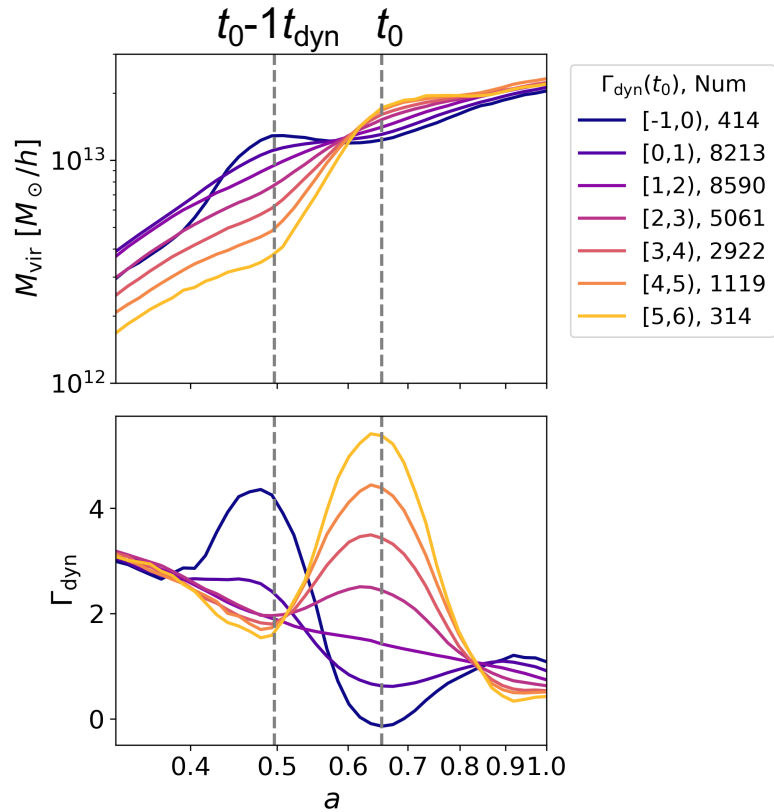
Evolution in  
phase-space

$t_0$

$t_0 + 1t_{\text{dyn}}$

# What drives the dependence?

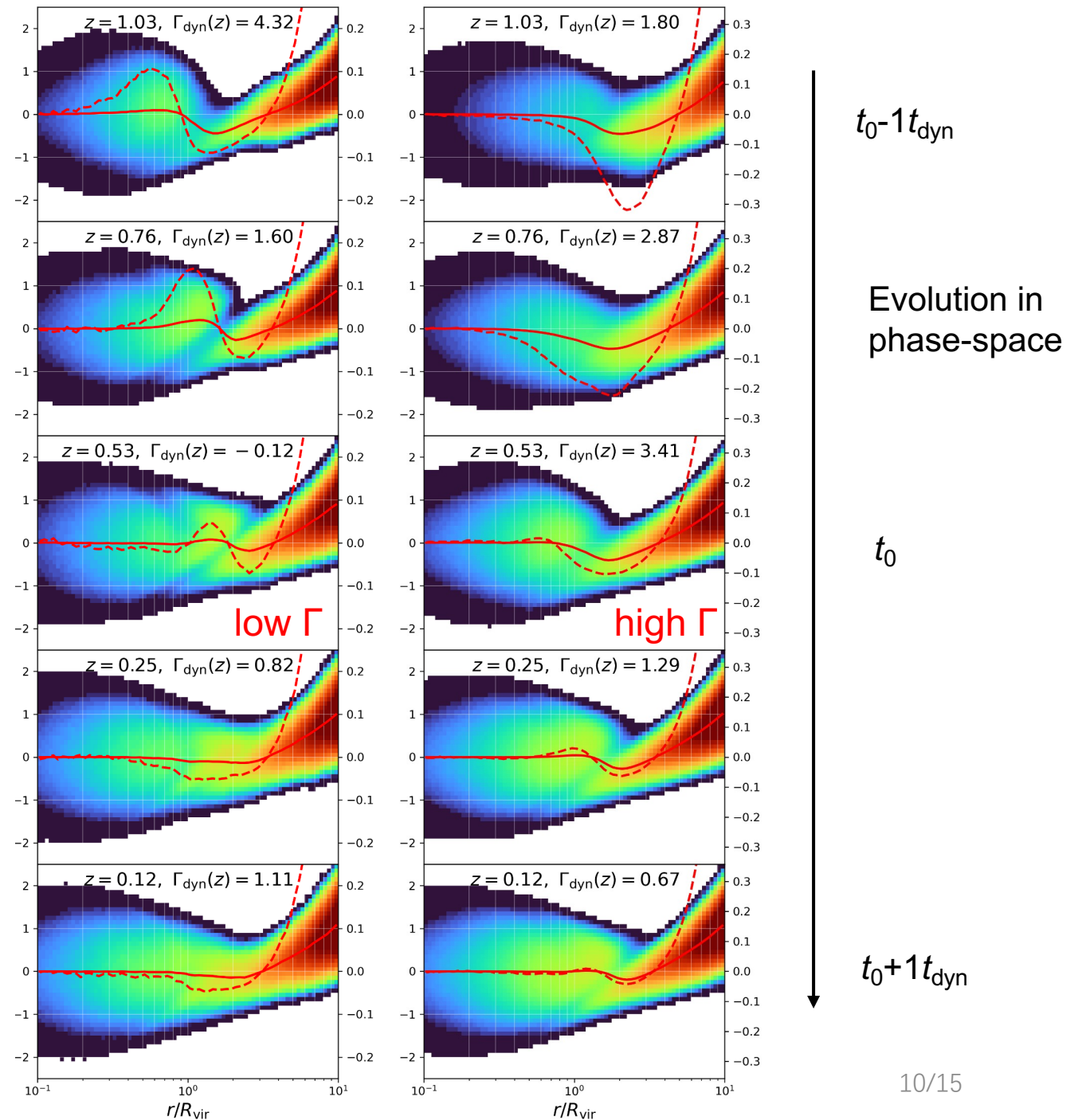
Mass evolution for different  $\Gamma$  bin



Dependence of  $R_{\text{id}}$  on  $\Gamma_{\text{vir}}$

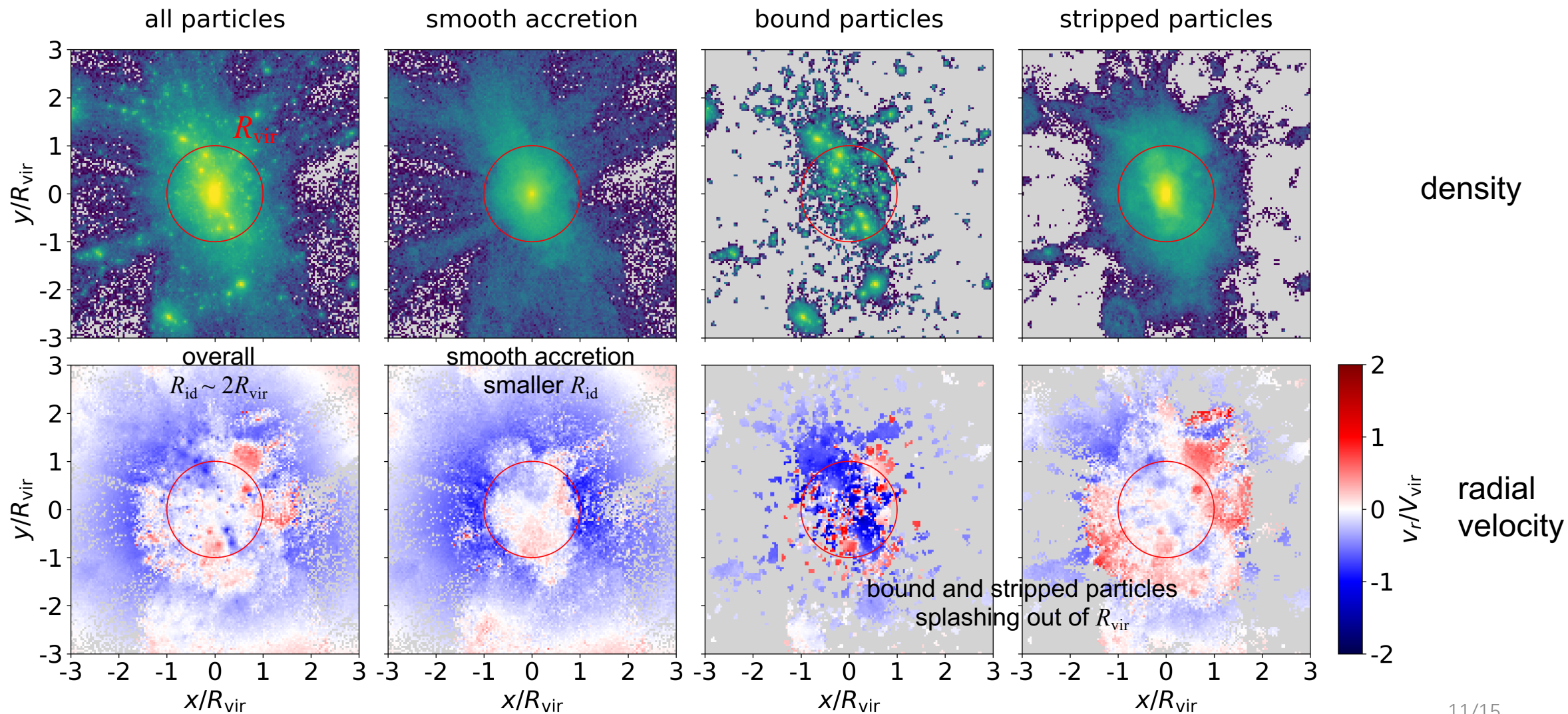
structure across  $R_{\text{vir}}$ , transient

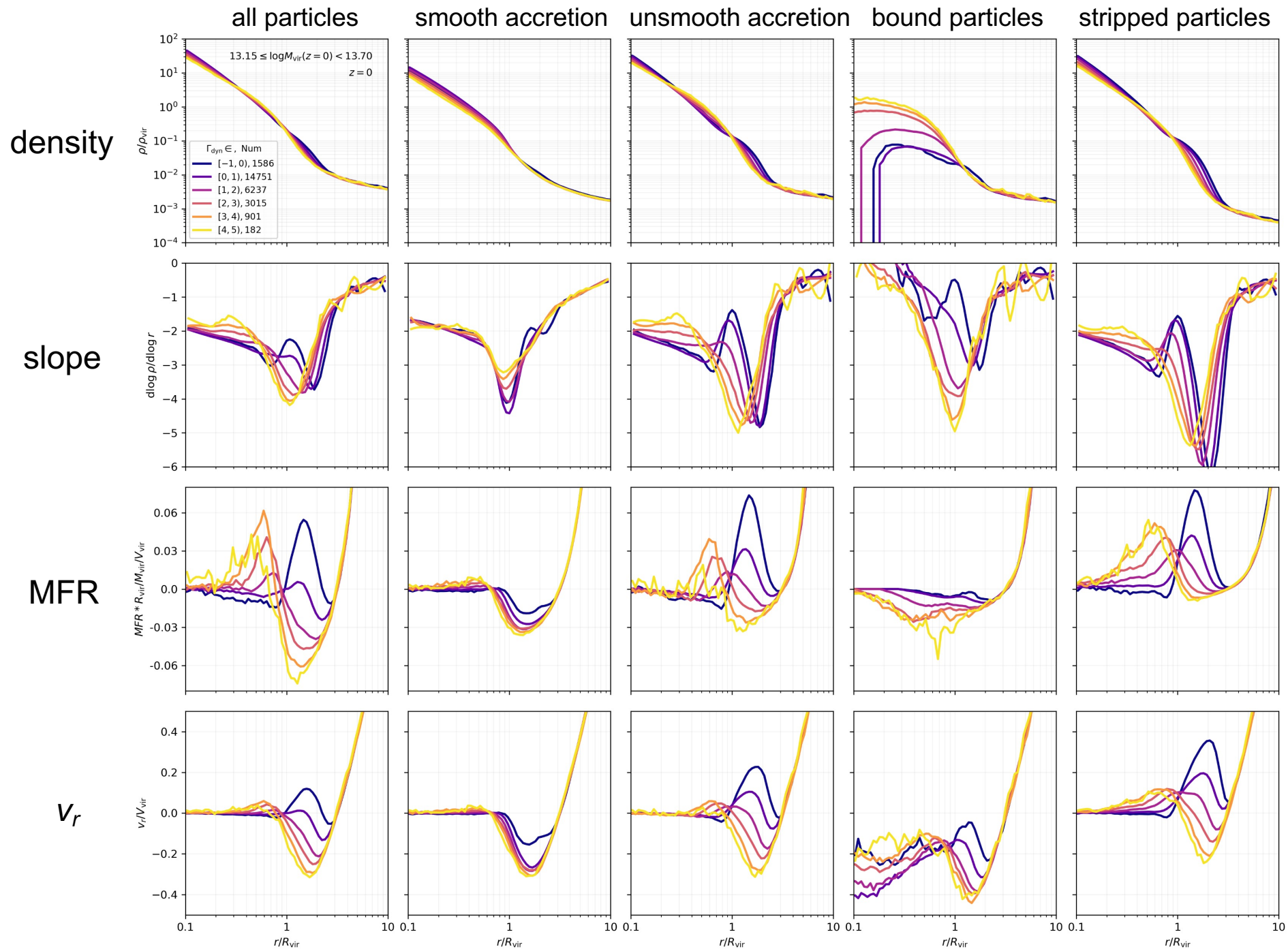
$M_{\text{vir}}$  is too small to evaluate accretion rate



# Contribution to the $R_{id}$ Feature

$$M_{\text{vir}} = 9.23 \times 10^{14} M_{\odot} / h, \quad \Gamma_{\text{dyn}} = 0.86$$

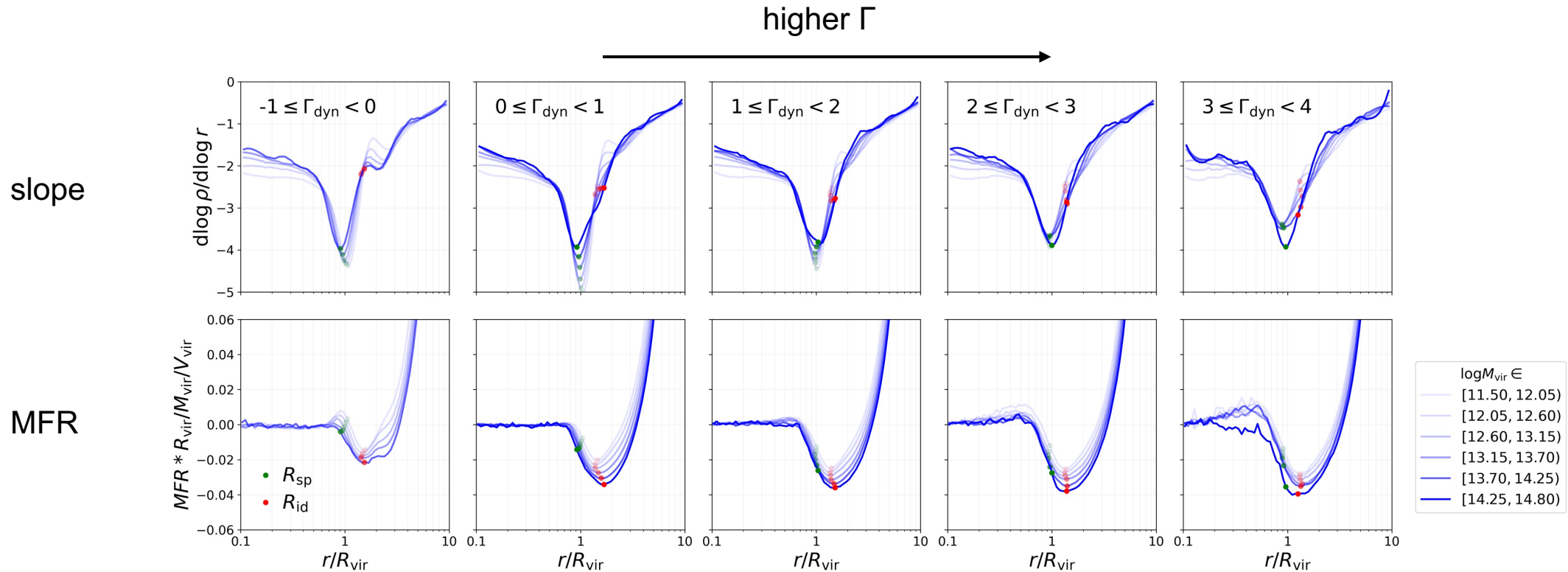




Depletion feature mostly comes from:

**unsmooth accretion**  
→ minor merger

# Dependence on Mass

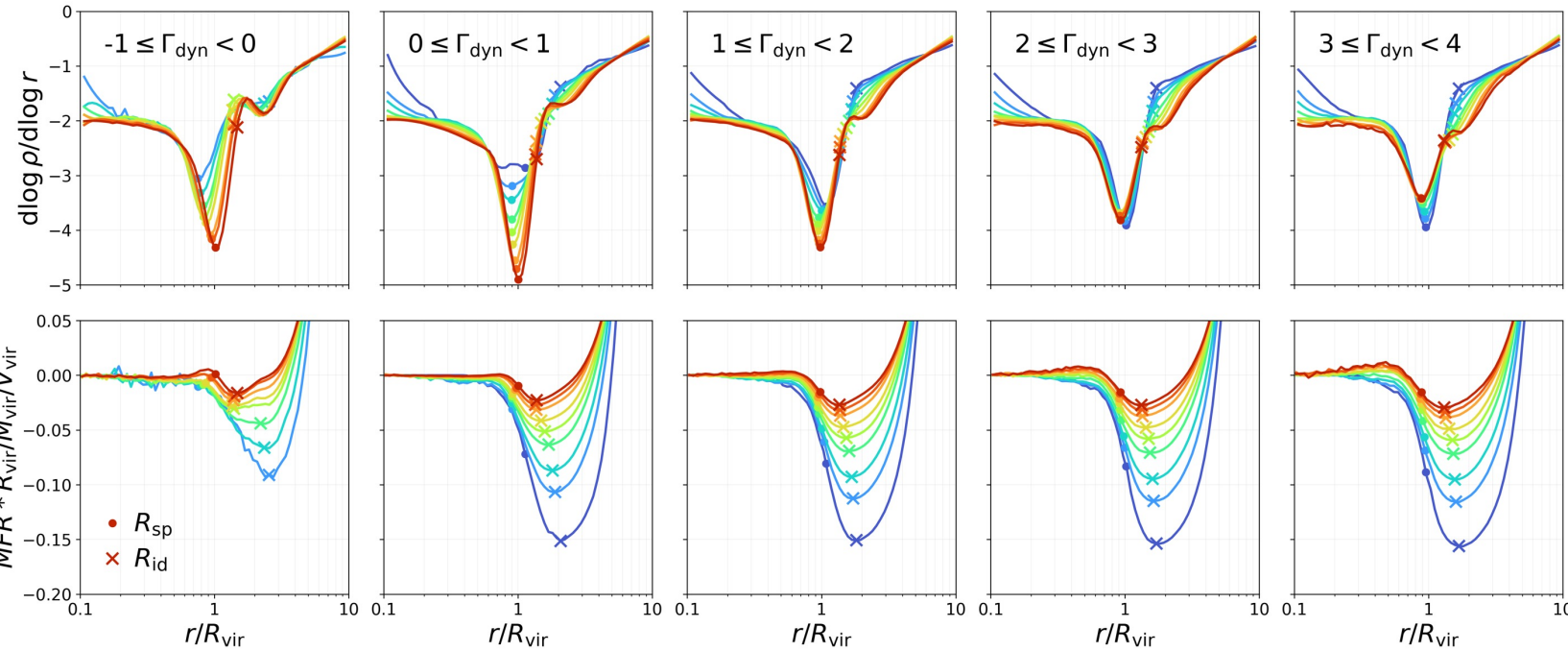


higher self-similarity  
low mass halo also has a distinct accretion process

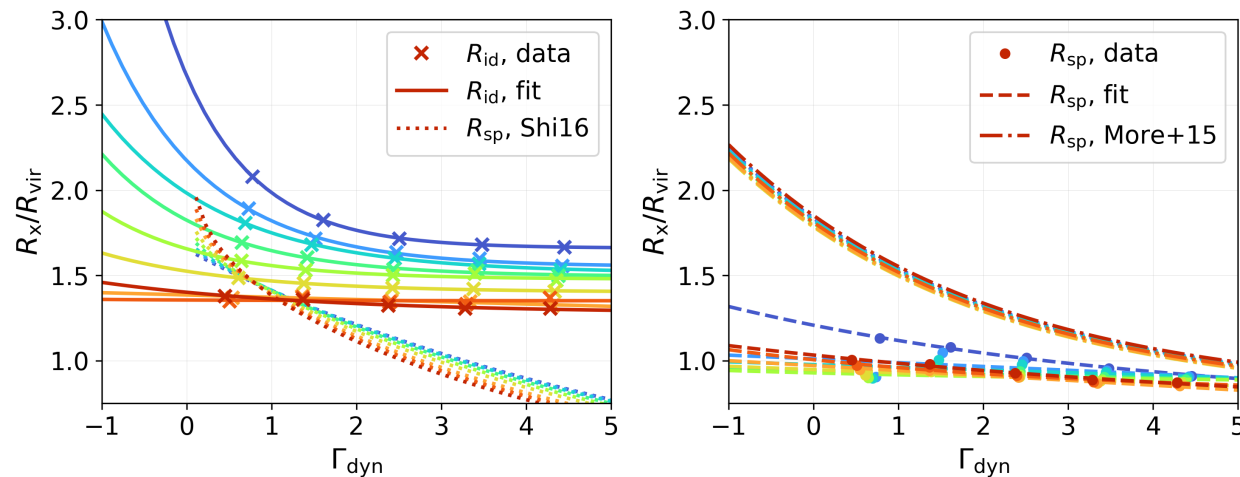
# Dependence on Redshift

higher  $\Gamma$

slope



MFR



$R_{\text{id}}/R_{\text{vir}}$ : higher redshift  $\rightarrow$  stronger dependence on  $\Gamma$   
can not be interpreted by previous model

$R_{\text{sp}}/R_{\text{vir}}$ : largely independent of redshift

# Summary

1. The depletion radius depends majorly on mass accretion rate  $\Gamma$ ,  
higher  $\Gamma \rightarrow$  smaller  $R_{\text{id}}/R_{\text{vir}}$ , similar to splashback radius;
2. The depletion radius also depends on redshift,  
higher  $z \rightarrow$  larger  $R_{\text{id}}/R_{\text{vir}}$ , weaker dependence on  $\Gamma$ ;
3. The dependence on  $\Gamma$  is actually on the transient accretion state of halo.  
 $M_{\text{vir}}$  is not a good proxy for evaluating accretion rate;
4. The depletion feature mostly comes from unsmooth accretion (minor merger).  
The smooth accretion component exhibits higher self-similarity and opposite evolution.

**Thanks!**