

A wide-angle landscape photograph of a mountain valley. The foreground is a vast, vibrant green meadow. In the middle ground, there are rolling green hills and a dense forest of dark green trees. In the background, rugged mountains rise, some with patches of snow or light-colored rock. The sky is a pale, overcast white. The overall scene is peaceful and scenic.

**SIDM**

*Simon White*

*SHARP25, Cogne*

# Preliminaries

- Particle DM requires physics beyond the SM for the dark sector
- This physics *may* include new forces as well as new particles. These must couple very weakly to SM particles.

- For a Yukawa-like force, DM particles scatter with a cross-section

$$d\sigma(v, \theta)/d \cos(\theta) = 0.5\sigma_0(1 + (v \sin(\theta/2)/w)^2)^{-2}$$

where  $\sigma_0$  and  $w \equiv (m_{\text{med}}/m_{\text{dm}}) c$  are constants

- $v < w \rightarrow$  isotropic hard sphere scattering with constant  $\sigma = \sigma_0$
- $v > w \rightarrow$  velocity-dependent forward scattering;  $\sigma = 0.5 \sigma_0 w^4 v^{-4} \sin^{-4} \theta/2$
- The mean time between collisions is  $m_{\text{dm}}/(\rho_{\text{dm}} v \sigma)$  so the astrophysical relevant quantity is  $\sigma/m_{\text{dm}}$ , usually given in units of  $\text{cm}^2/\text{g}$

# Collisions in halos

For an NFW halo: for  $\sigma = \text{const}$ ,  $t_{\text{coll}} \propto 1/(\rho \langle v\sigma/m \rangle) \propto r^{3.5}$  at  $r \gg r_s$ ,  
 $\propto r^{0.5}$  at  $r \ll r_s$ .

for  $\sigma \propto v^{-4}$ ,  $t_{\text{coll}} \propto 1/(\rho \langle v\sigma/m \rangle) \propto r^{1.5}$  at  $r \gg r_s$ ,  
 $\propto r^{2.5}$  at  $r \ll r_s$ .

so collision rates always increase strongly inwards

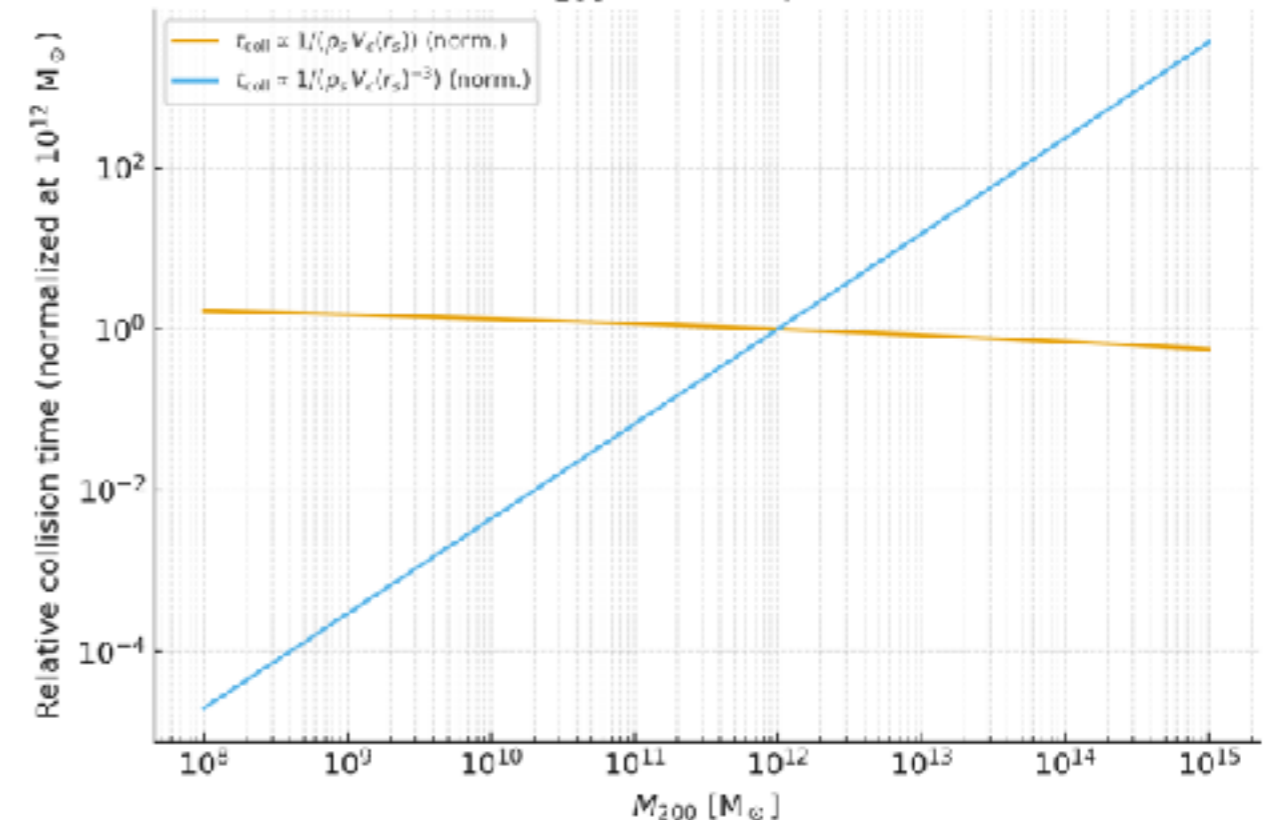
Comparing to the orbital times ( $t_{\text{dyn}} \propto r^{1.5}$  and  $\propto r^{0.5}$  in the two cases) the number of collisions per orbit  $t_{\text{dyn}}/t_{\text{coll}}$  also always increases inwards. Note,  $t_{\text{dyn}}/t_{\text{coll}} < (>) 1$  corresponds to the long(short) mean-free path regime

At  $z = 0$ , all halos have about the same  $t_{\text{coll}}$  at  $r_s$  for constant  $\sigma_0$ , but collisions are much more important at low mass in the  $v$ -dependent case

$\sigma \propto v^{-4}$  required since collisions aren't important in clusters,  $\langle \sigma/m \rangle < 1 \text{ cm}^2/\text{g}$

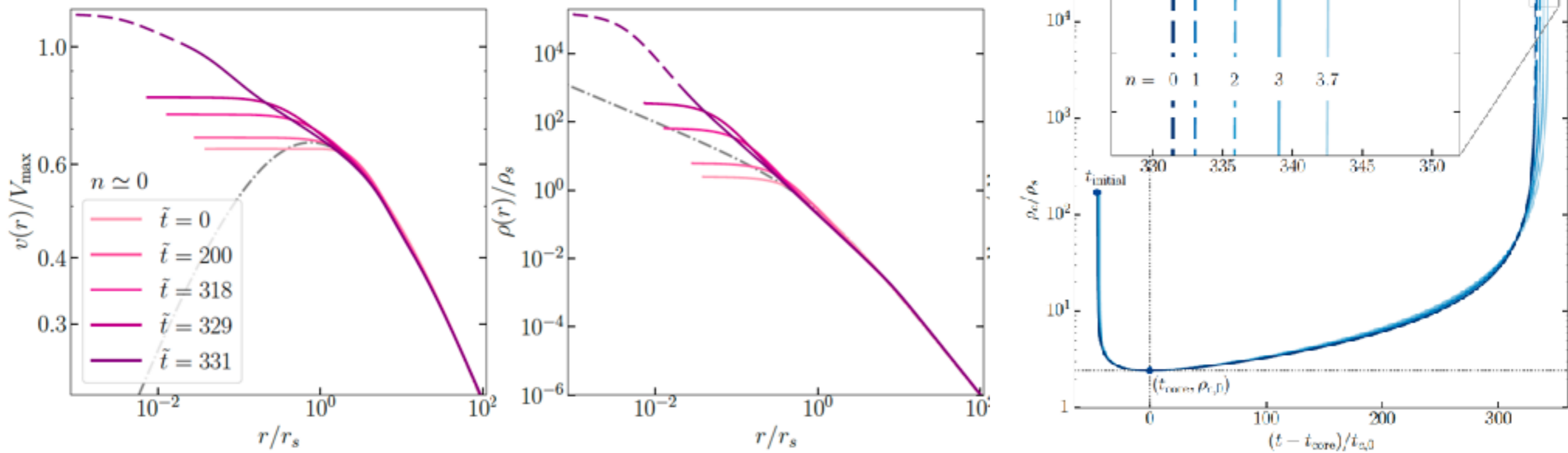
Then  $t_{\text{coll}} \propto c^{-1.5}(\ln c)^{-0.5}$  at given  $M_{\text{halo}}$   
 so evolution is faster in the high- $c$  tail

Relative collision time vs  $M_{200}$  at  $z = 0$  (NFW + Dutton & Macciò)



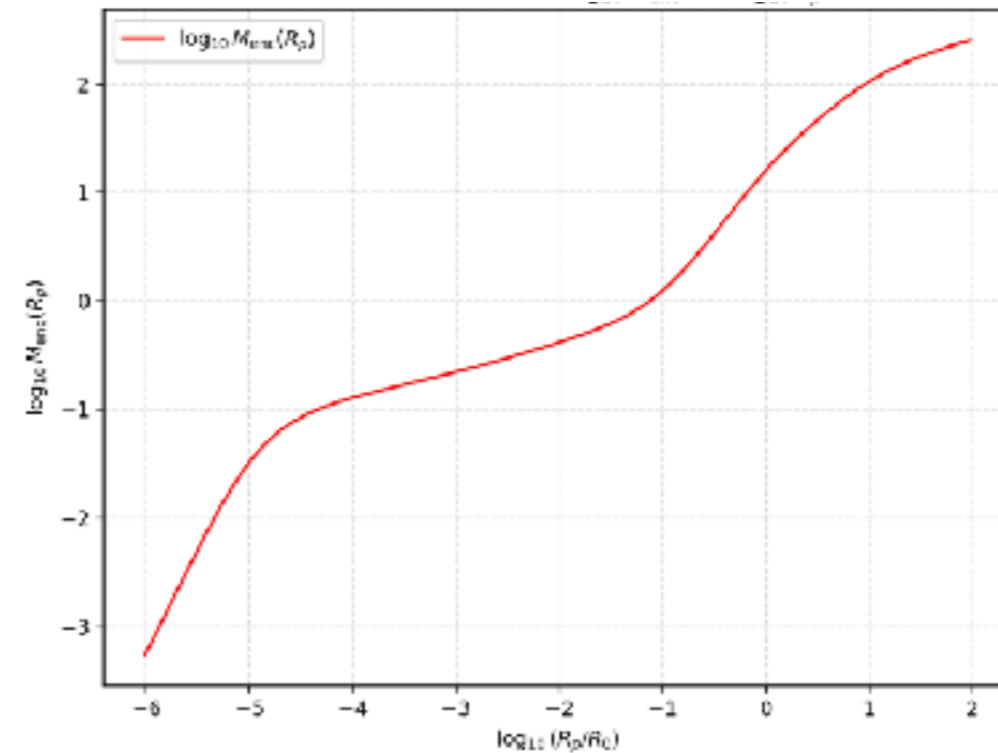
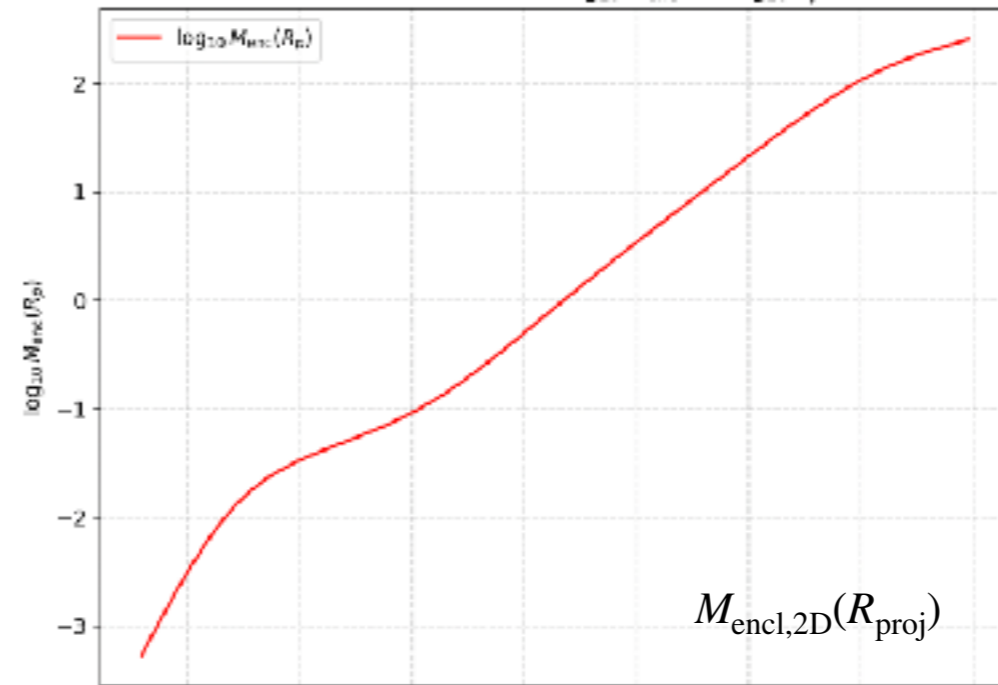
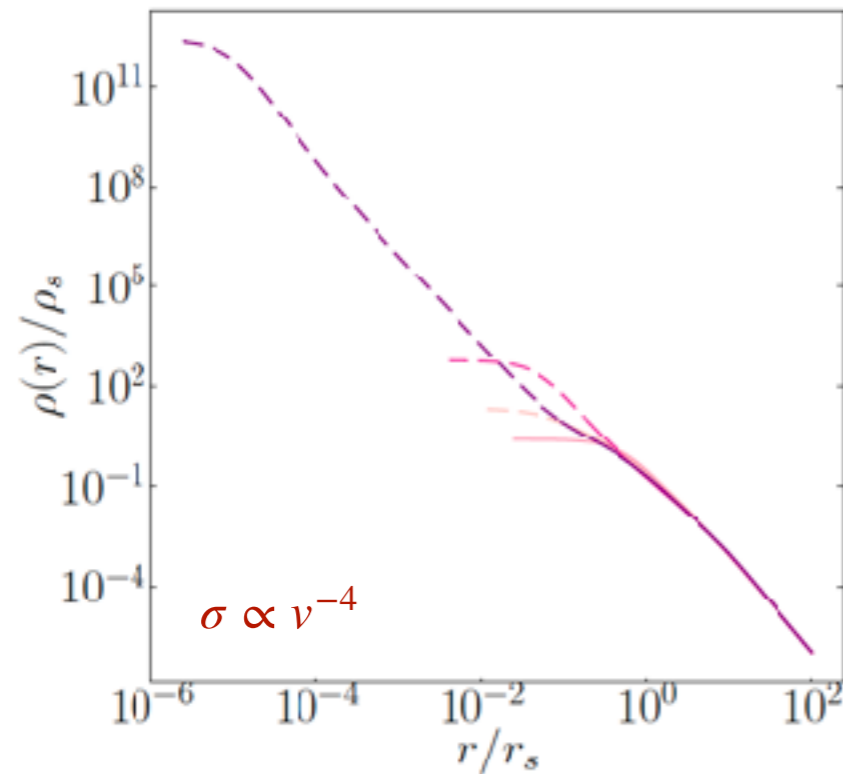
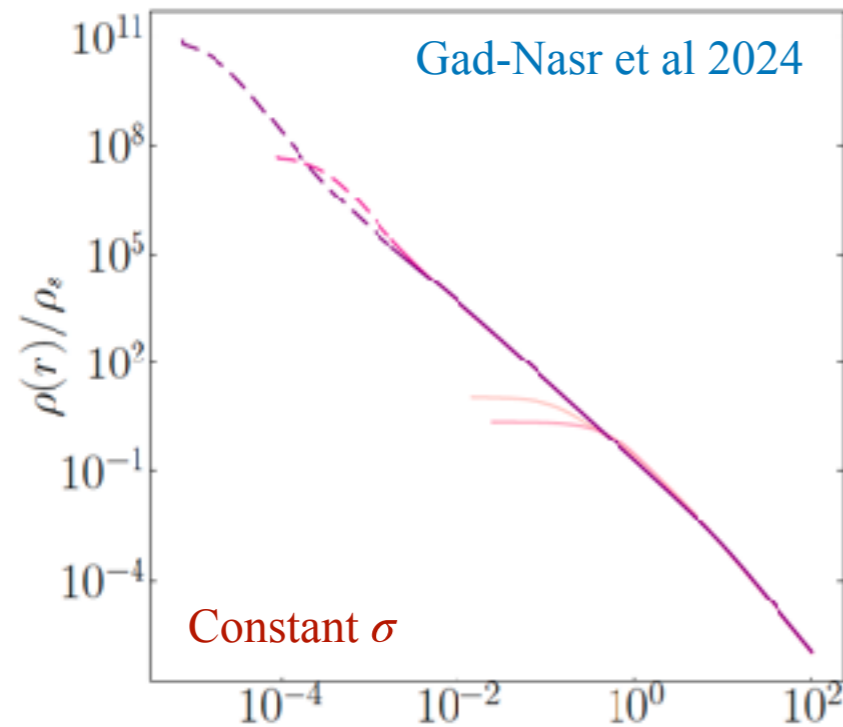
# Collisional evolution of NFW halos

Outmezguine et al 2023



- In stage 0, the cusp evolves to an isothermal core and becomes less dense
- In stage 1, the core becomes small denser and hotter in the LMFP regime
- In stage 2, the central regions transition to the SMFP regime and contract faster
- At stage 3, an event horizon forms and grows rapidly through Bondi accretion
- $\rho_{\text{cen}} > \rho_{\text{cen},0}$  only for  $< 1\%$  of the total time until BH formation
- The evolution timescales depend almost exclusively on the initial  $t_{\text{coll}}$

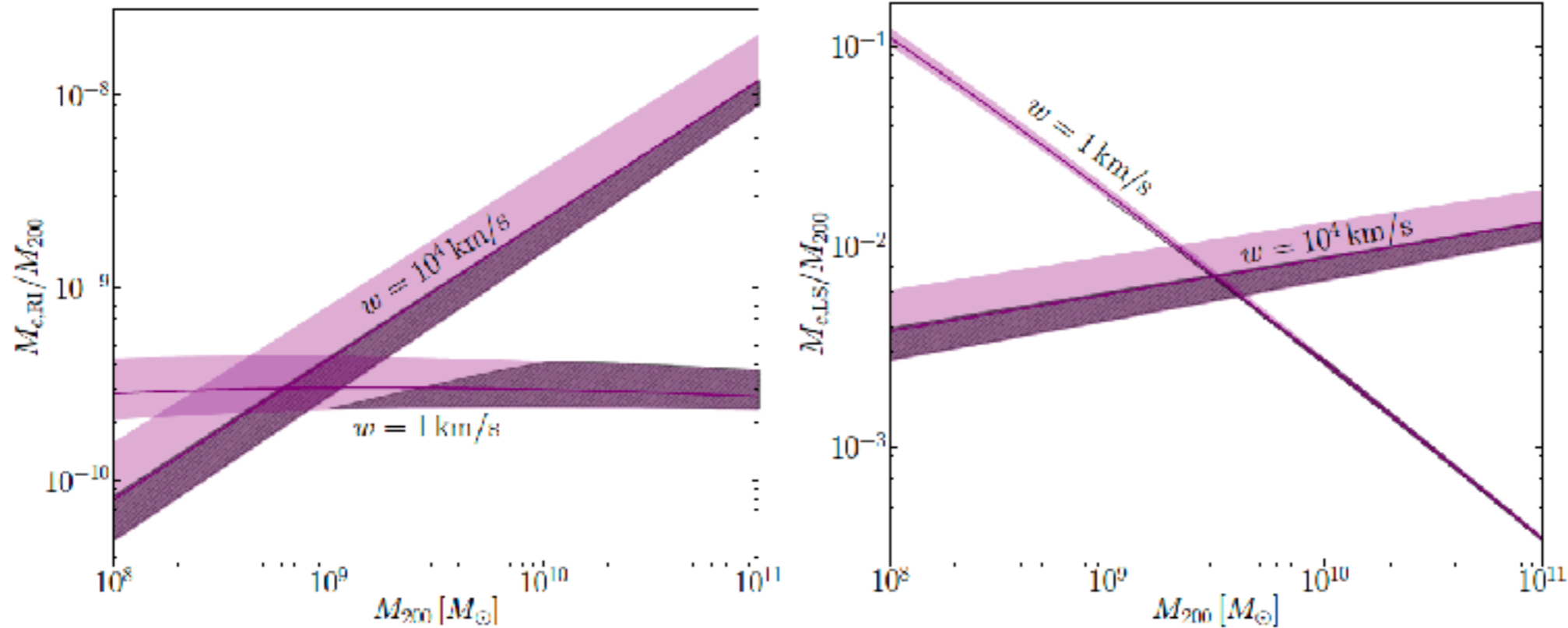
# Late stages of core collapse in NFW halos



- Varying  $\sigma_0$  and  $w$  alters the transition point LMFP  $\rightarrow$  SMFP and so  $M_{\text{smfp}}$

# Which halos should have core collapsed?

Gad-Nasr et al 2024



- The diversity of dwarf rotation curves → core collapse in some of their halos  
→  $w < 100 \text{ km/s}$ ,  $\langle \sigma/m \rangle > \sim 50 \text{ cm}^2/\text{g}$
- These should contain central black holes.
- If  $w < \text{a few km/s}$ , almost all low-mass halos (e.g.  $< 10^8 M_{\odot}$  or so) should have collapsed and so have central black holes
- These will plausibly have masses in the range  $0.01$  to  $>0.1 M_{200c}$
- There are currently no reliable calculations of  $M_{\text{bh}}$  and  $M(r)$  for such systems