SIDM interpretations of Crater II and GD-1

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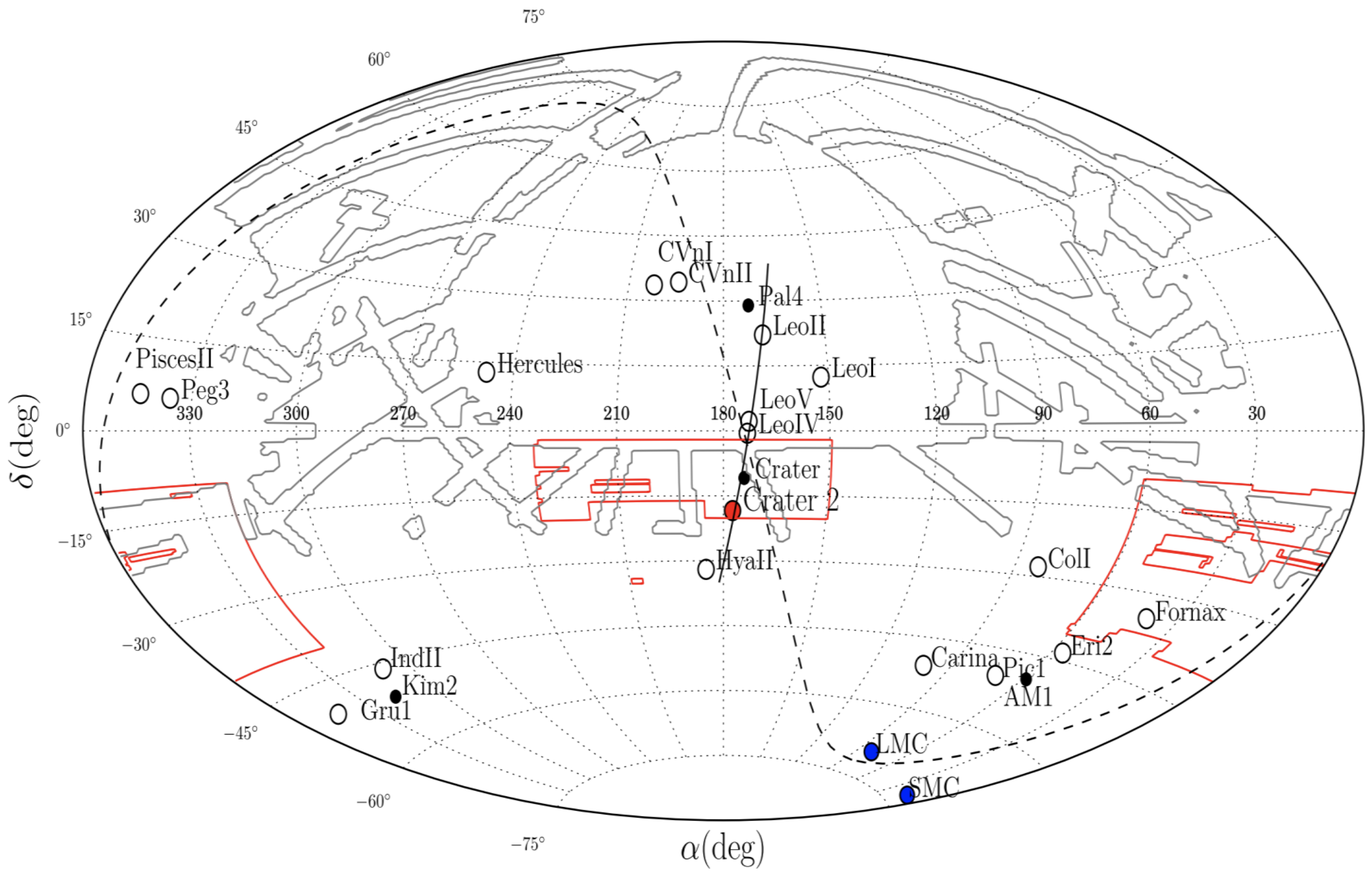
IFIC, Valencia, Spain

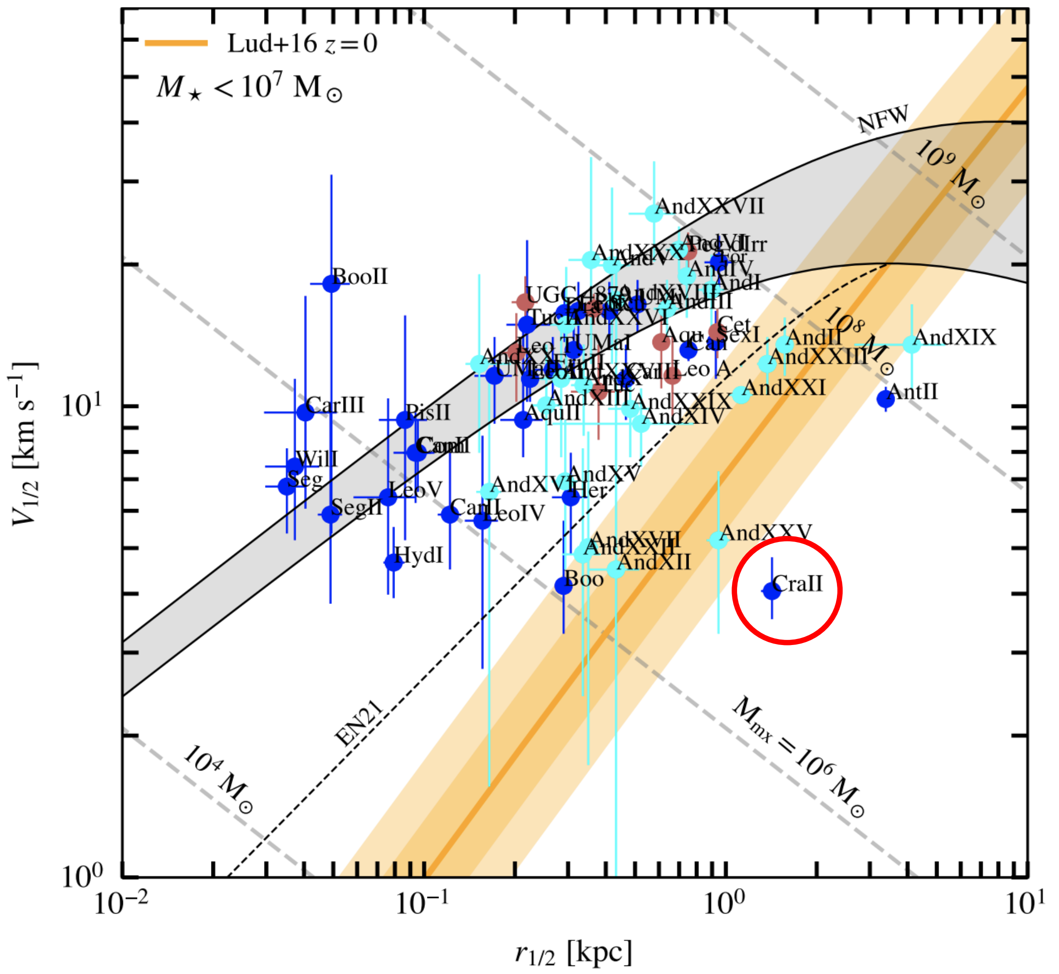
Xingyu Zhang, Hai-Bo Yu, Daneng Yang and Haipeng An, ApjL 968 L13 (2024) [2401.04985]
Xingyu Zhang, Hai-Bo Yu, Daneng Yang and Ethan Nadler, ApjL 978 L23 (2025) [2409.19493]



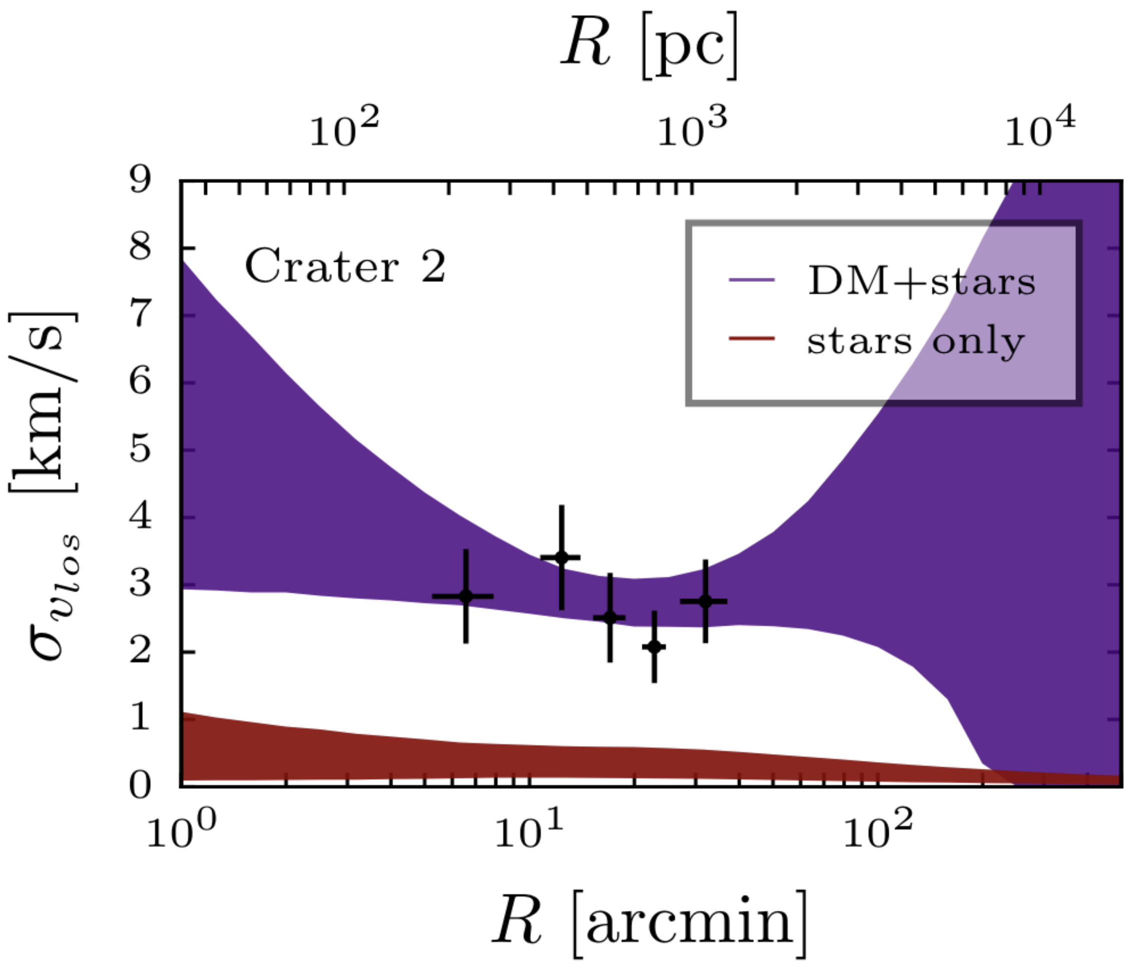
(Torrealba et al. 2016)

Crater II is one of Milky Way satellite galaxies discovered in 2016.

Ultra-diffuse satellite galaxy Crater II



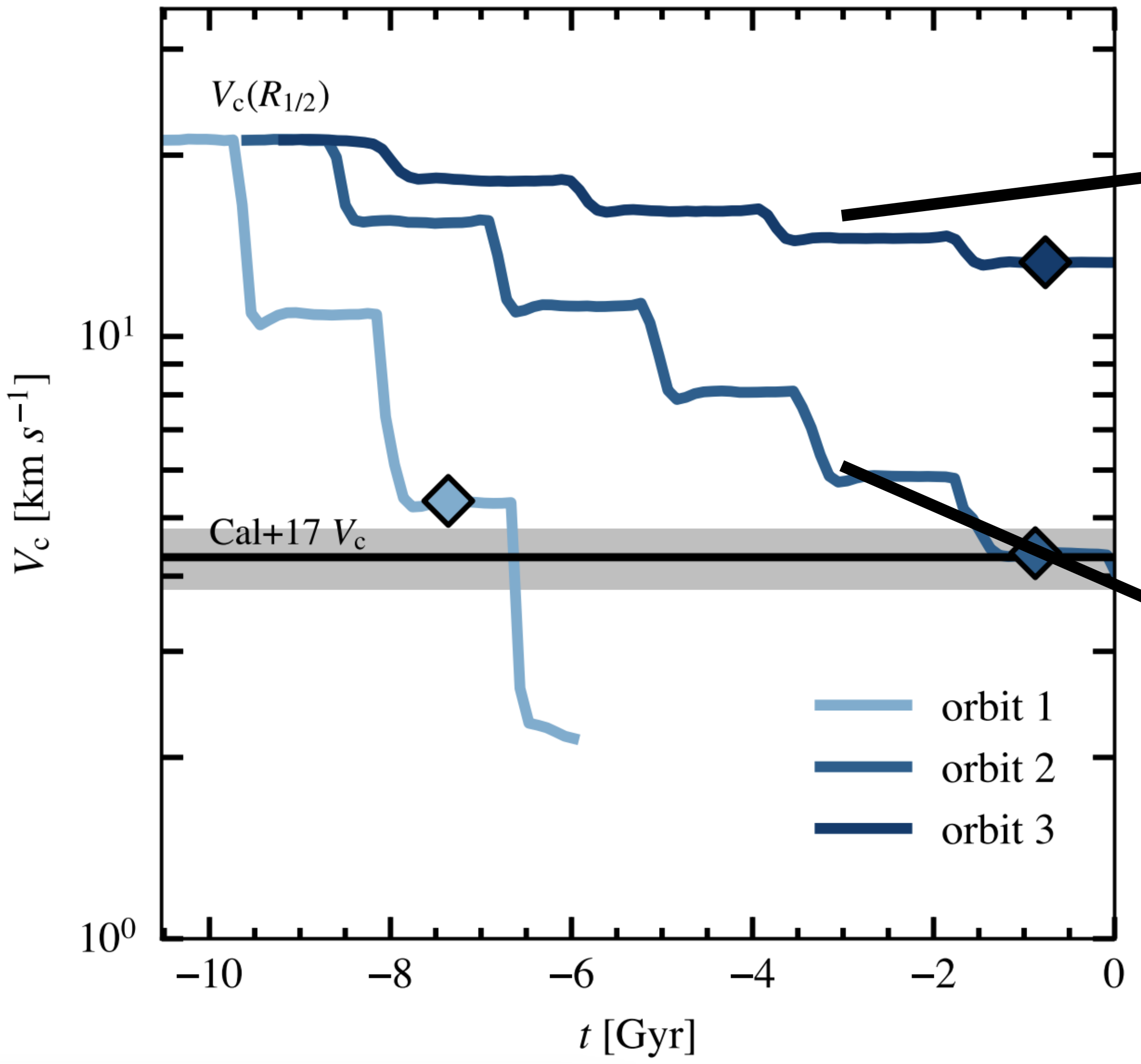
(Borukhovetskaya et al. 2022)



(Caldwell et al 2017)

Crater II is special because of its diffuse profile, $r_h = 1.06$ kpc, $\sigma_{los} \sim 2.3$ km/s, flat with respect to radius.

Ultra-diffuse satellite galaxy Crater II



(Borukhovetskaya et al. 2022)

Orbit 3: r_p = 38 kpc

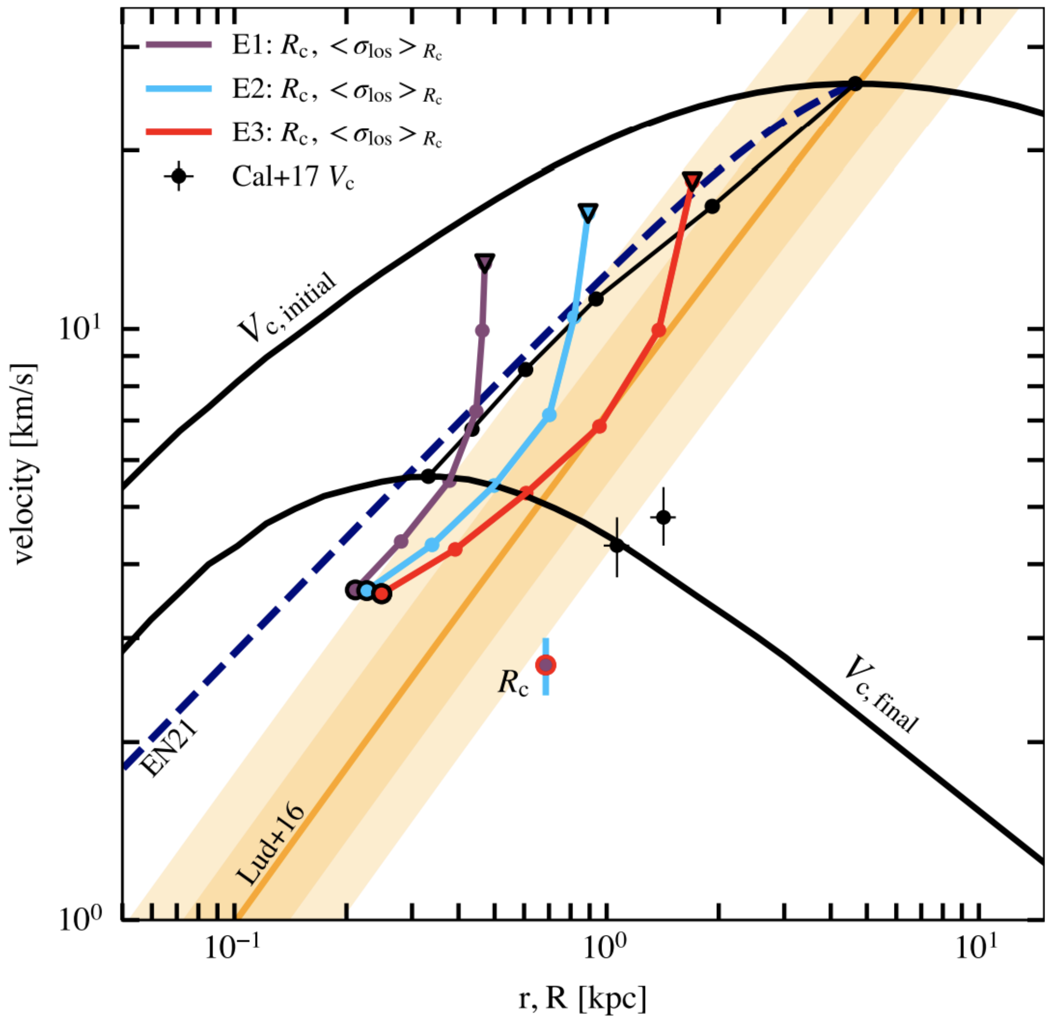
Measured by Gaia DR3

With the orbit, CDM fails

Orbit 2: r_p = 14 kpc

Required orbit to match V_c in CDM is much lower

Ultra-diffuse satellite galaxy Crater II



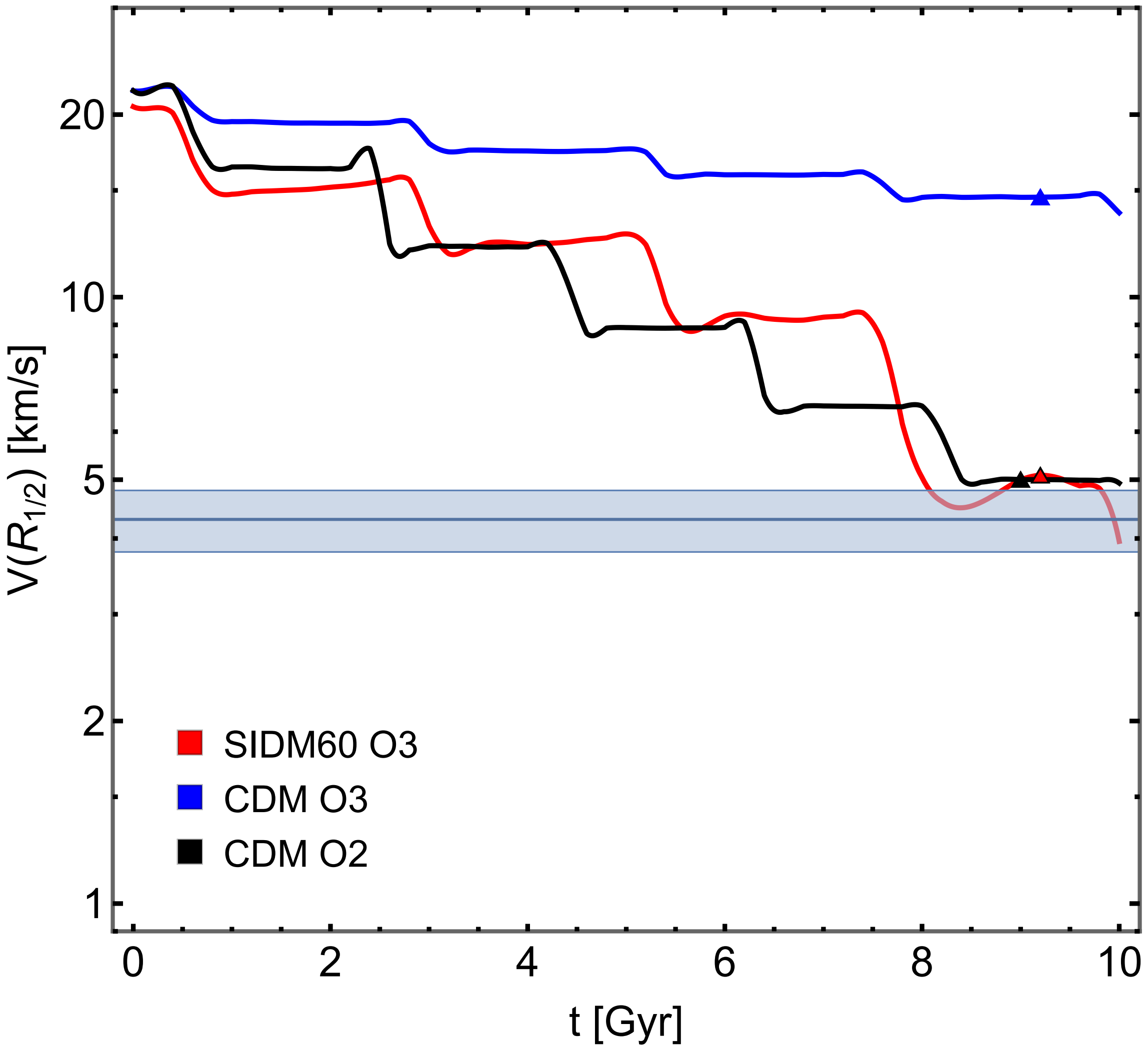
(Borukhovetskaya et al. 2022)

Orbit 2:

After tidal stripping, the halo mass could match the observation, but the half-light radius is too small.

Ultra-diffuse satellite galaxy Crater II

- SIDM solution: Mass



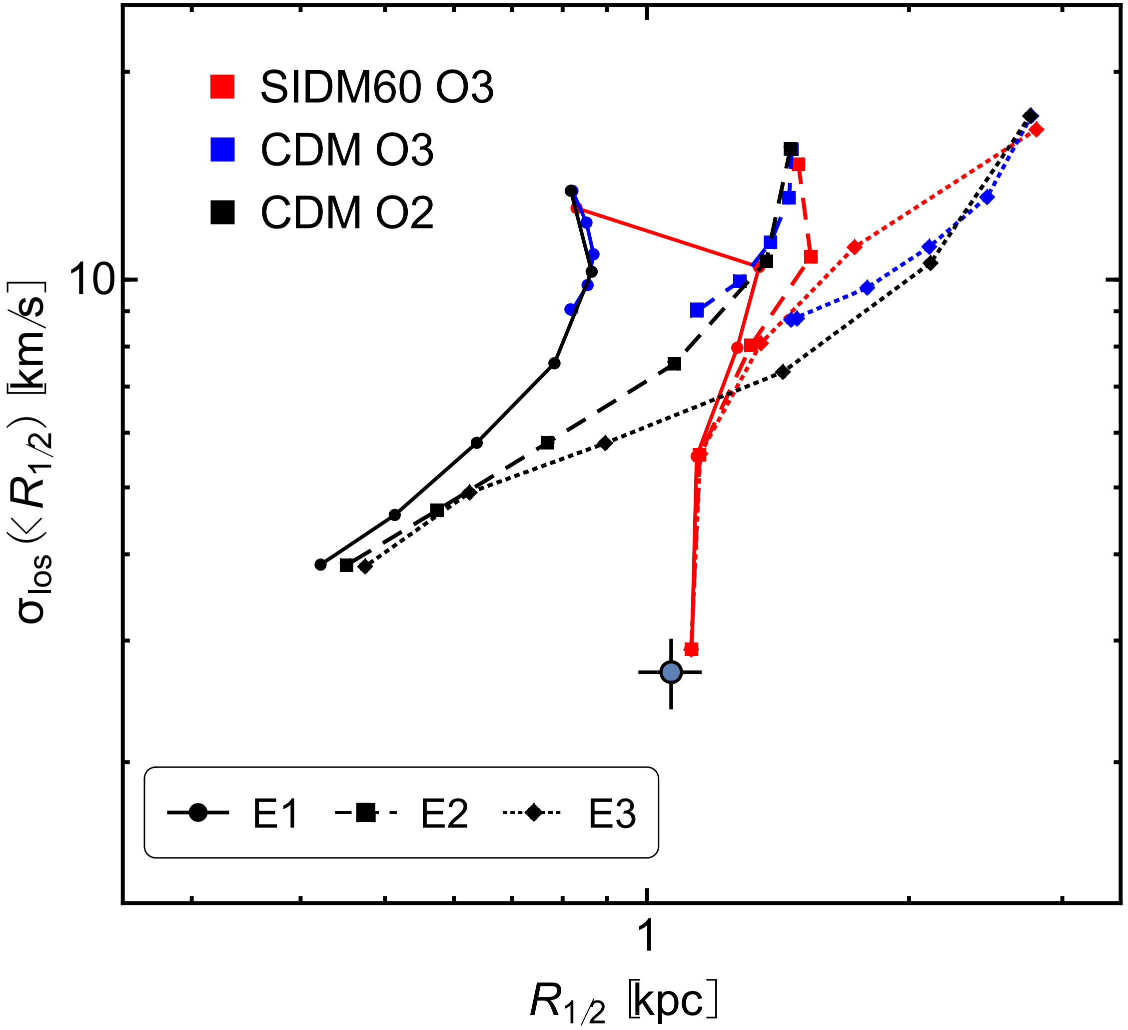
SIDM orbit 3, r_p = 38 kpc
σ/m = 60 cm^2/g

CDM orbit 3, r_p = 38 kpc

CDM orbit 2, r_p = 14 kpc

Ultra-diffuse satellite galaxy Crater II

- SIDM solution: Size (half-light radius)



CDM orbit 2

R_h = 0.45 kpc, too compact

CDM orbit 3

Insufficient mass loss

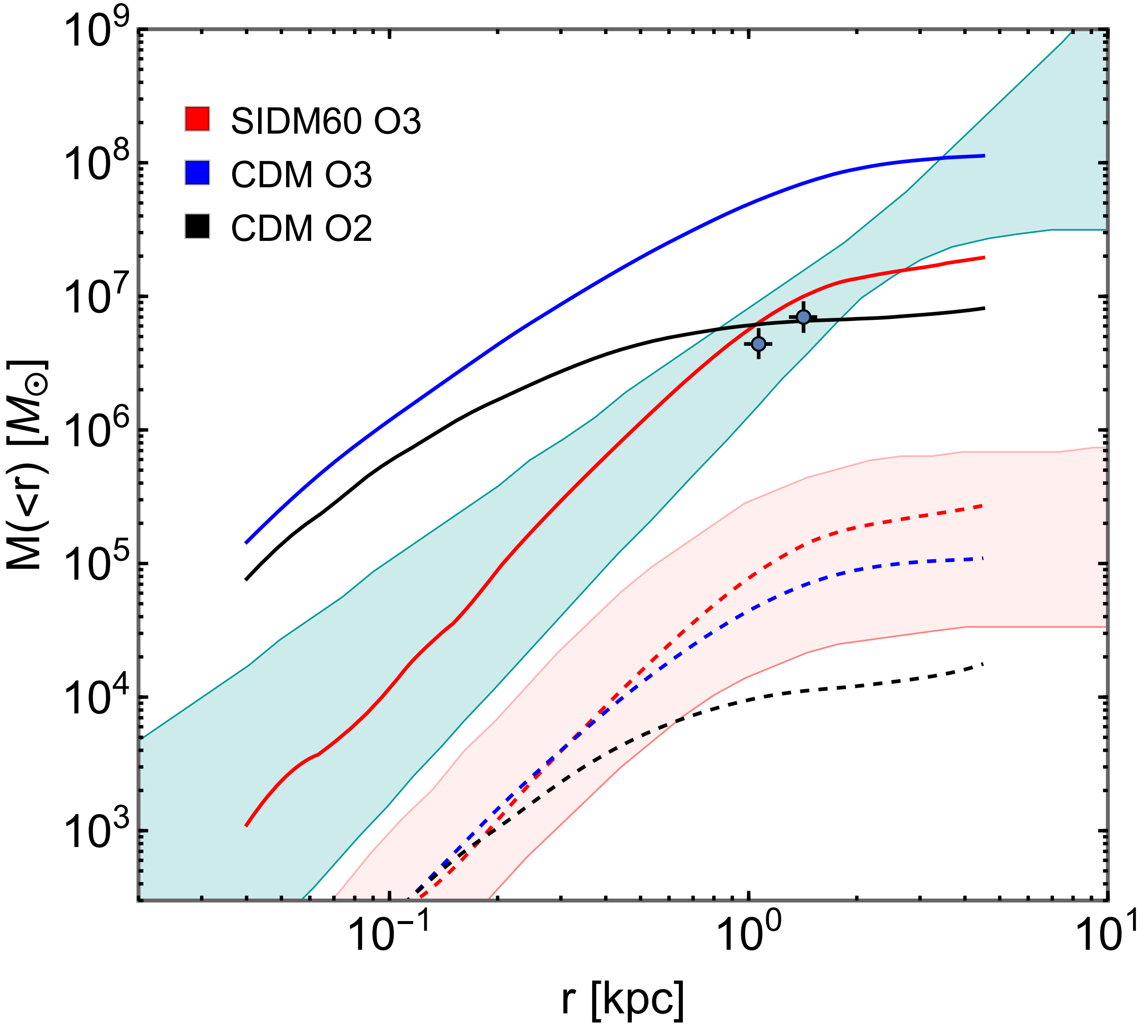
SIDM orbit 3

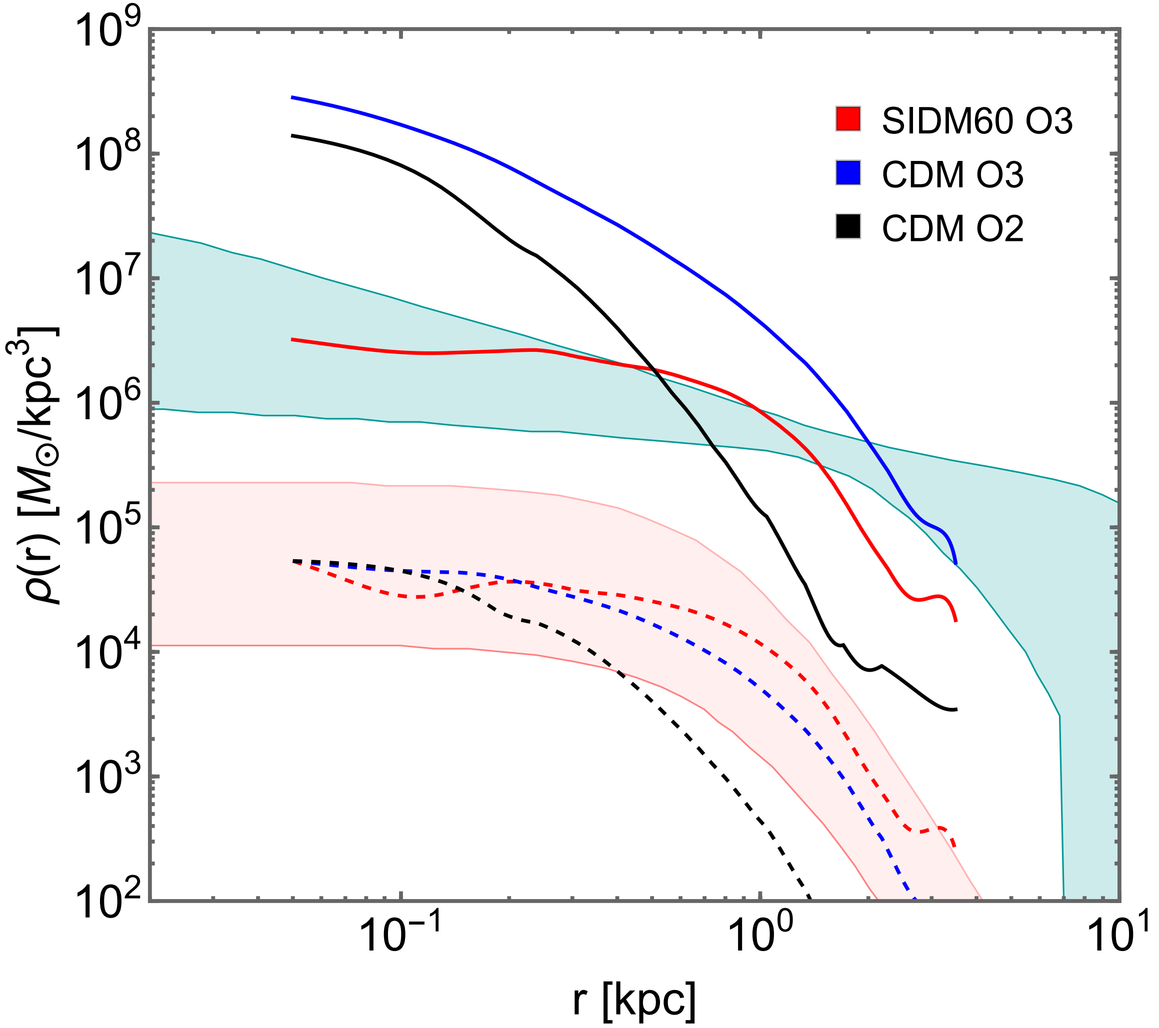
R_h = 1.1 kpc

Excellent agreement

Ultra-diffuse satellite galaxy Crater II

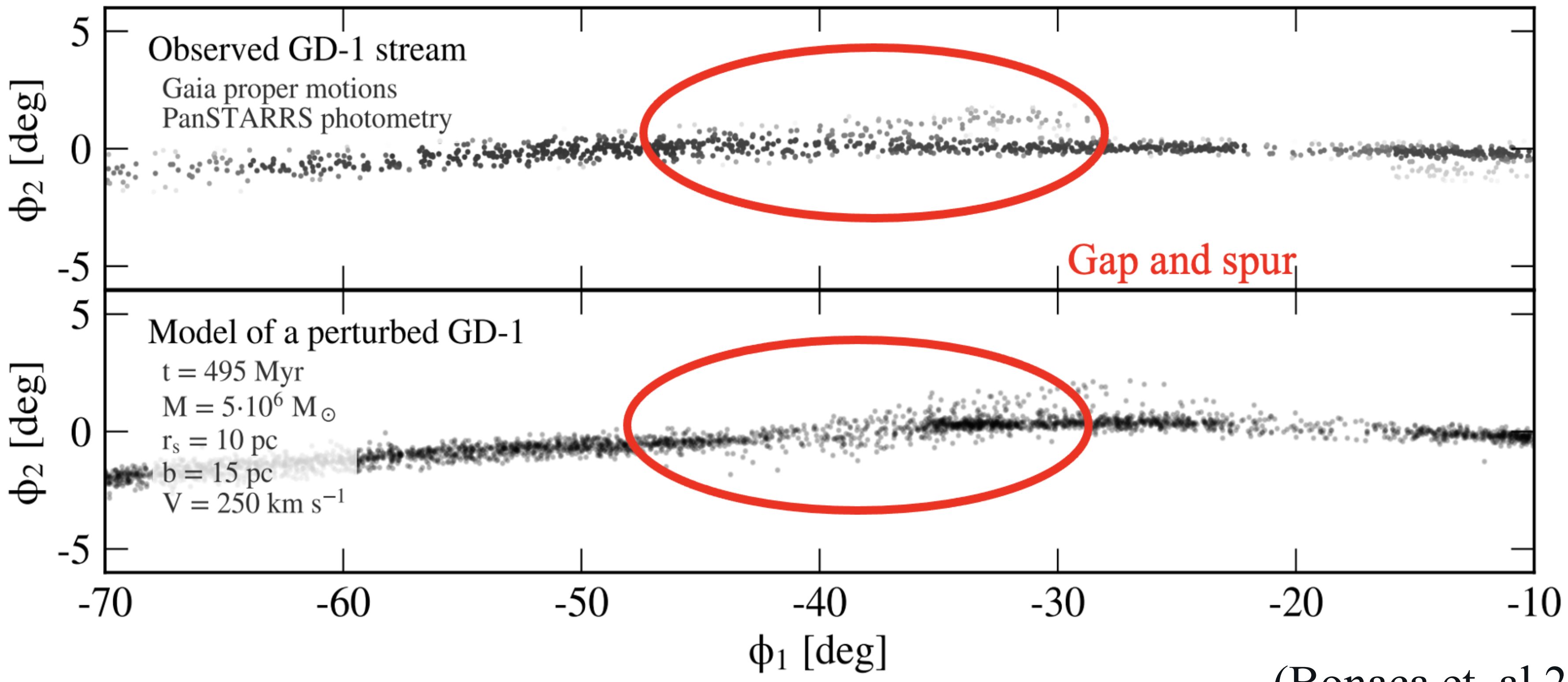
- SIDM solution: Density and mass profile





Ultra-compact subhalo perturber for GD-1

Spur and gaps of the GD-1 stellar stream

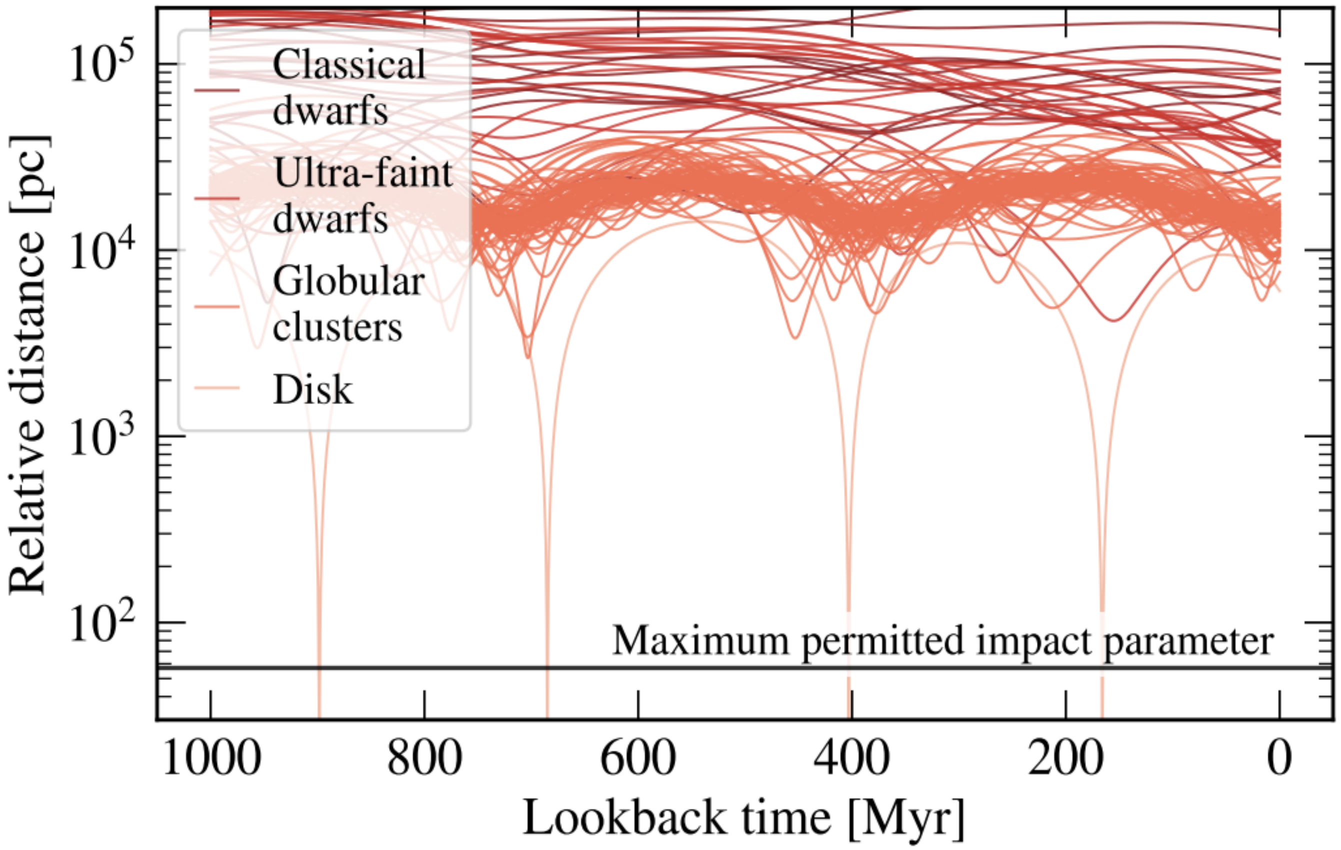


(Bonaca et. al 2018)

This gap-spur can be produced by a close encounter with an ultra-compact perturber

Ultra-compact subhalo perturber for GD-1

The missing compact perturber

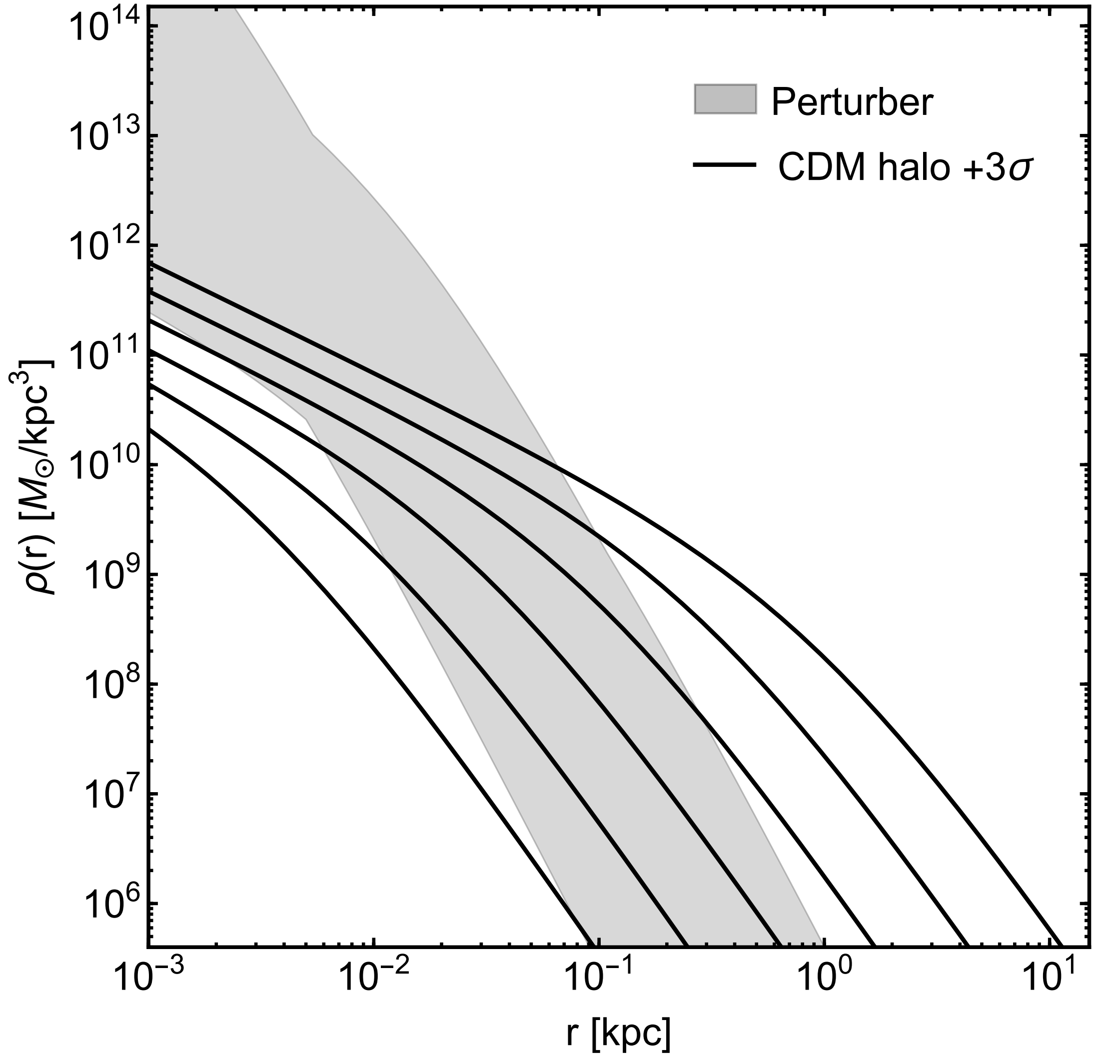


(Bonaca et. al 2018)

Through backward orbital integration, none of the observed objects matches the required orbit

The perturber is most likely a dark matter subhalo.

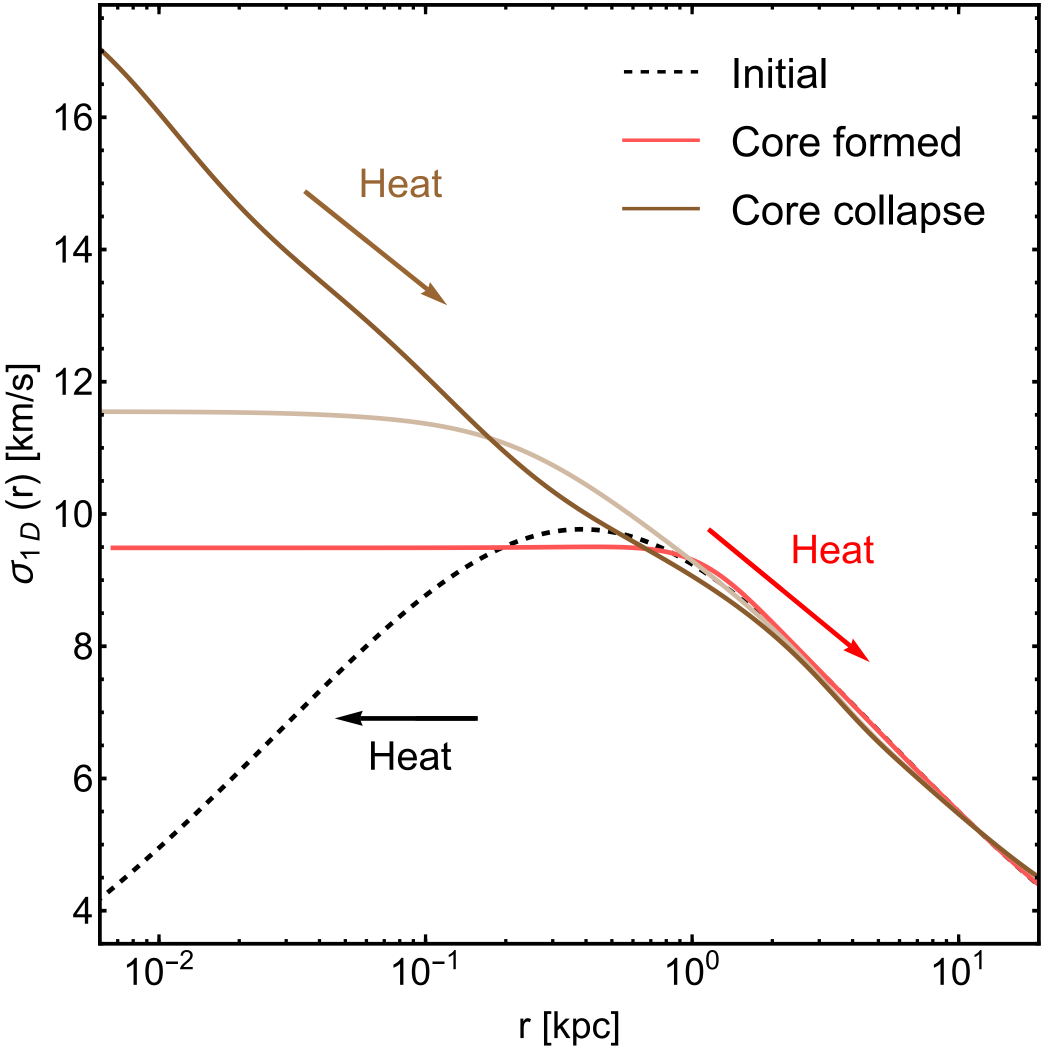
The missing compact perturber

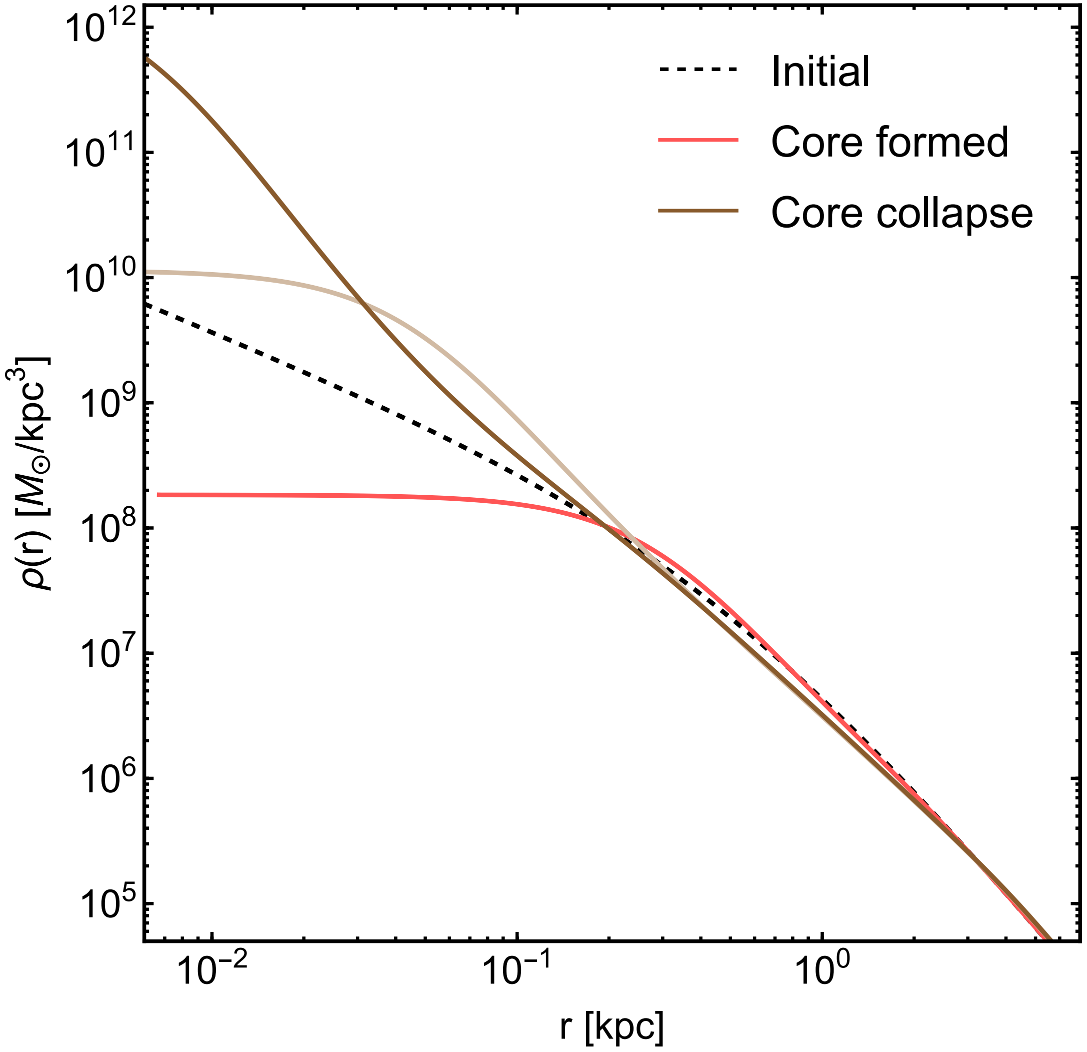


The reconstructed perturber density* is very compact, which is not likely to form in the CDM scenario

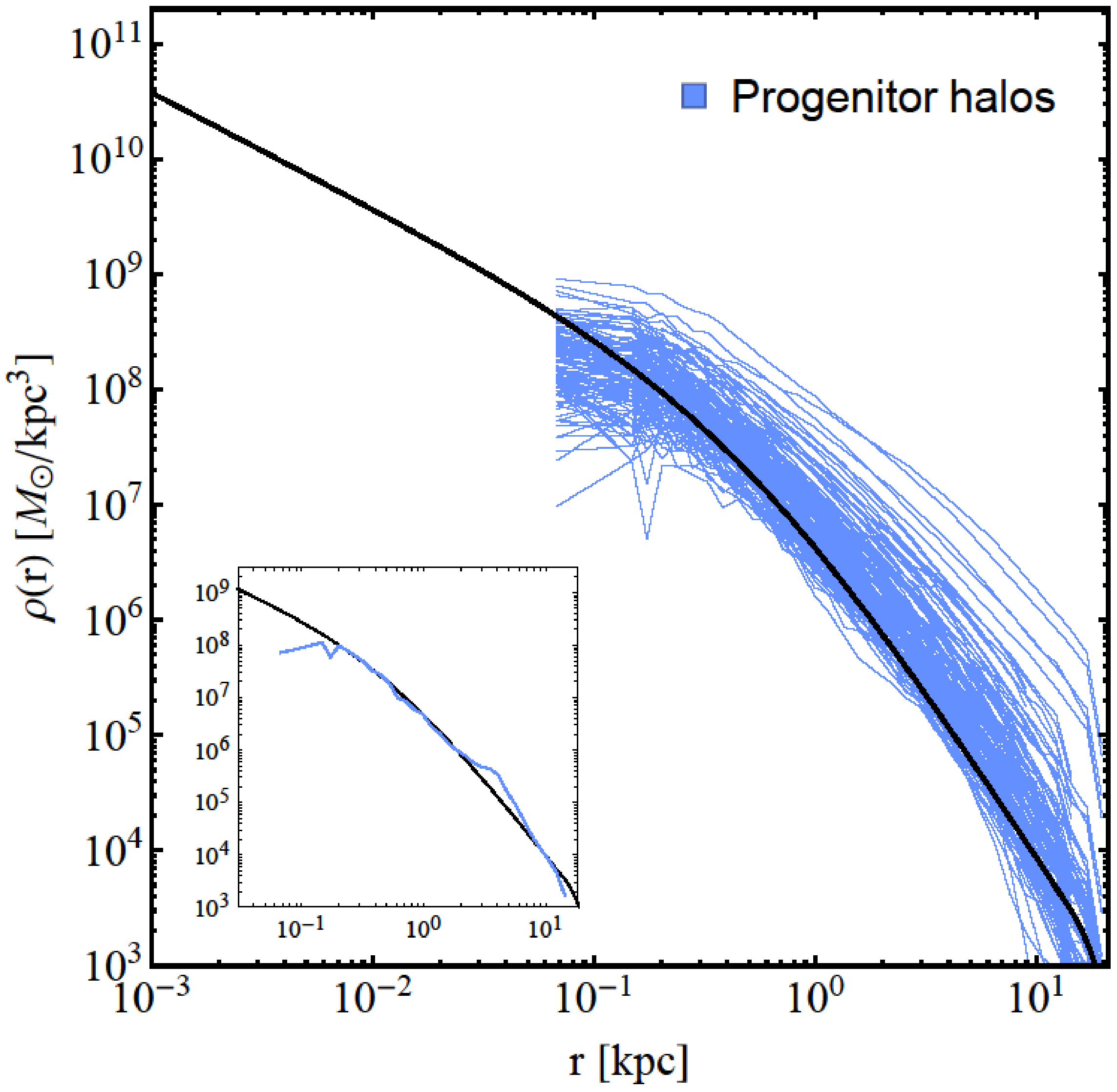
*(Bonaca et. al. 2018)

Two phase evolution of self-interacting dark matter halo





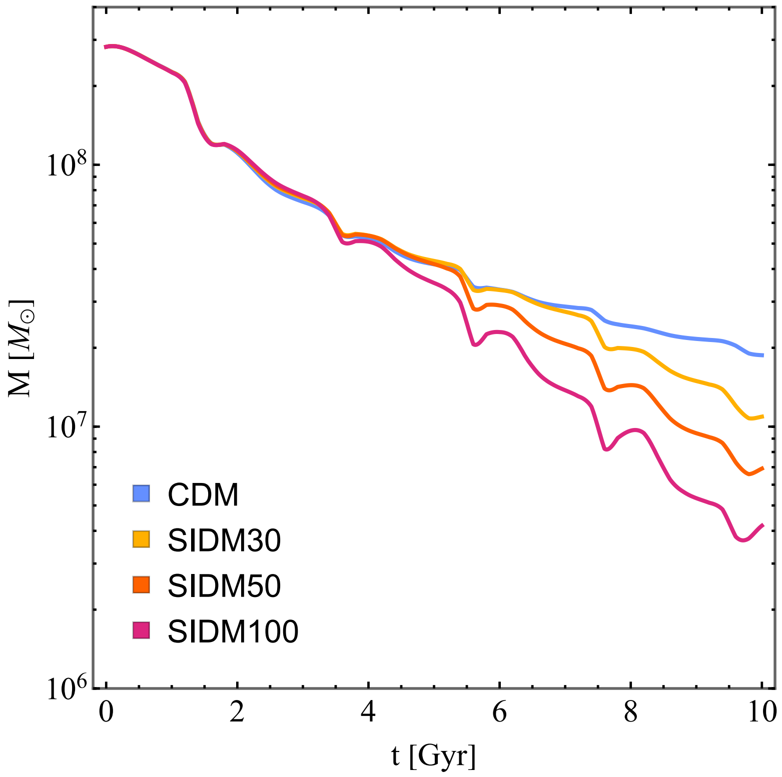
Ultra-compact subhalo perturber for GD-1



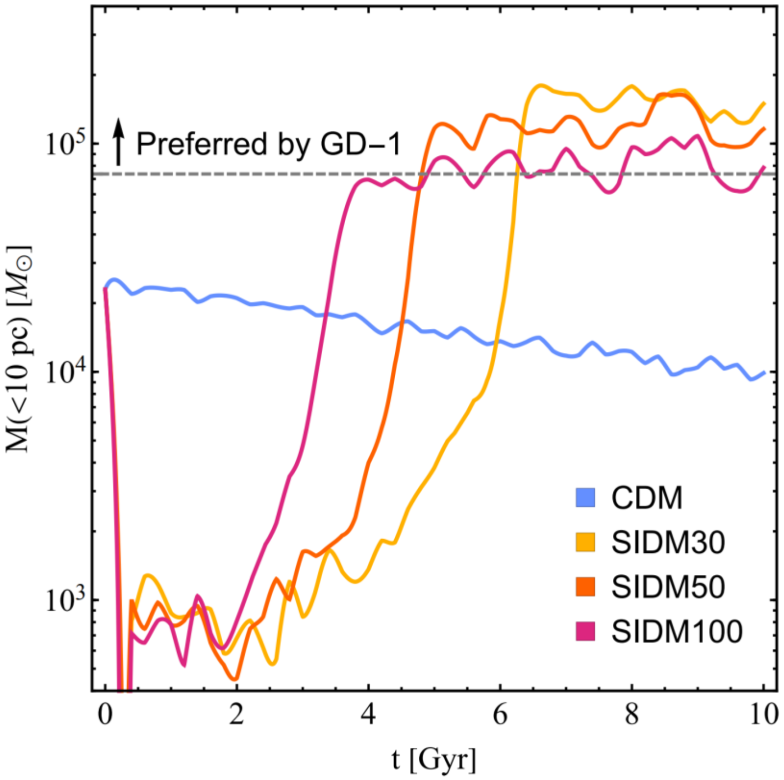
Milky Way subhalo progenitors from cosmological simulations

Select a small subhalo at infall as the initial condition

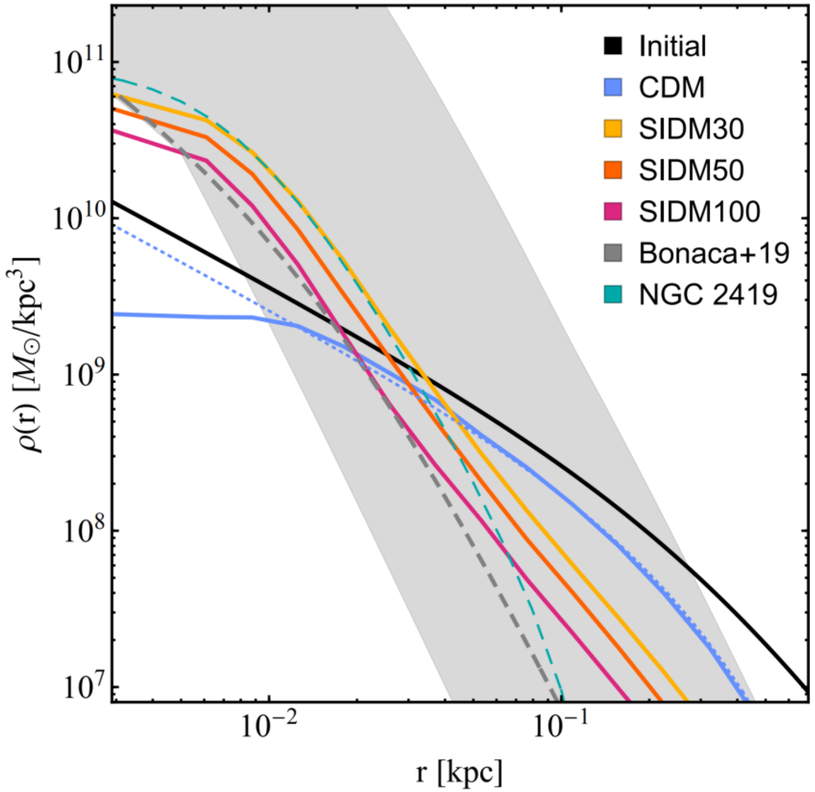
Ultra-compact subhalo perturber for GD-1



Total mass evolution



Enclosed mass within 10 pc



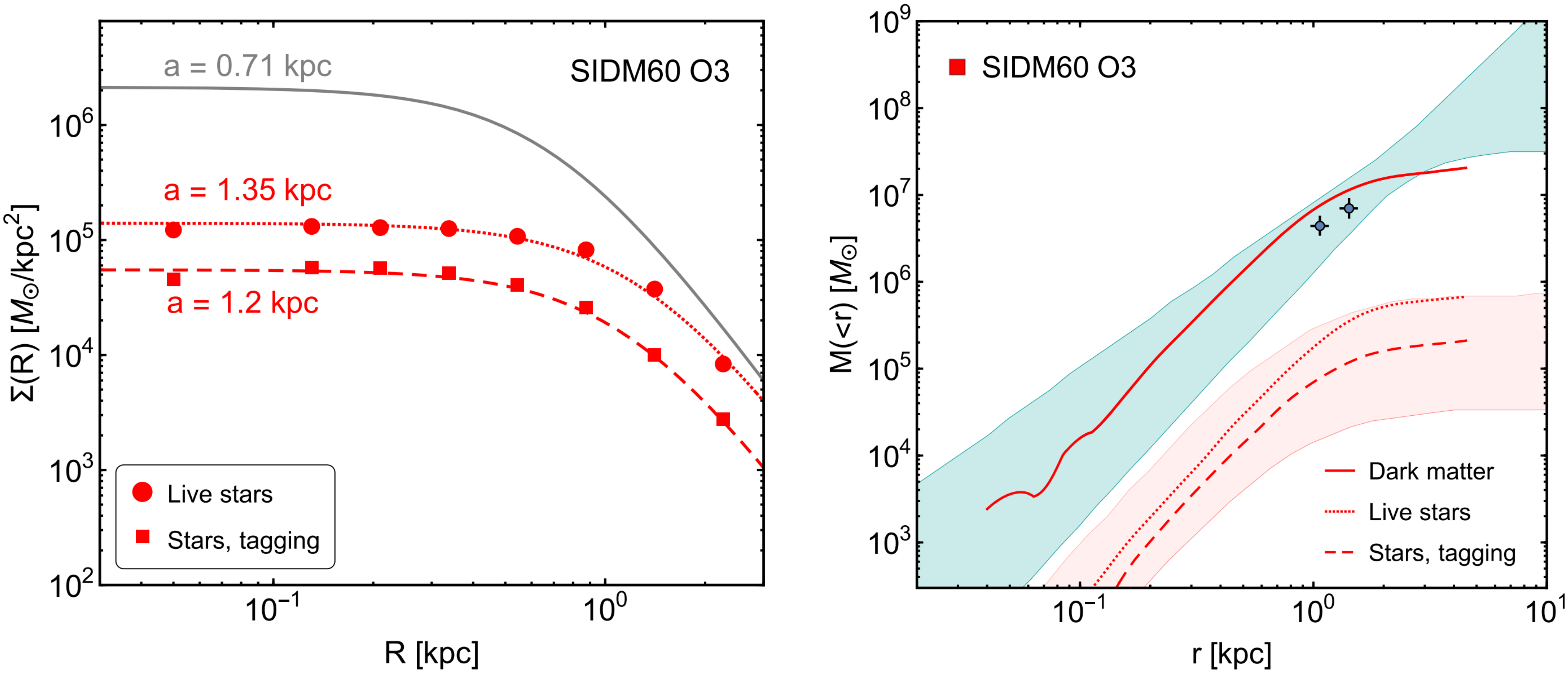
Final density profiles

The King model well fits the inner region of the core-collapsed subhalo

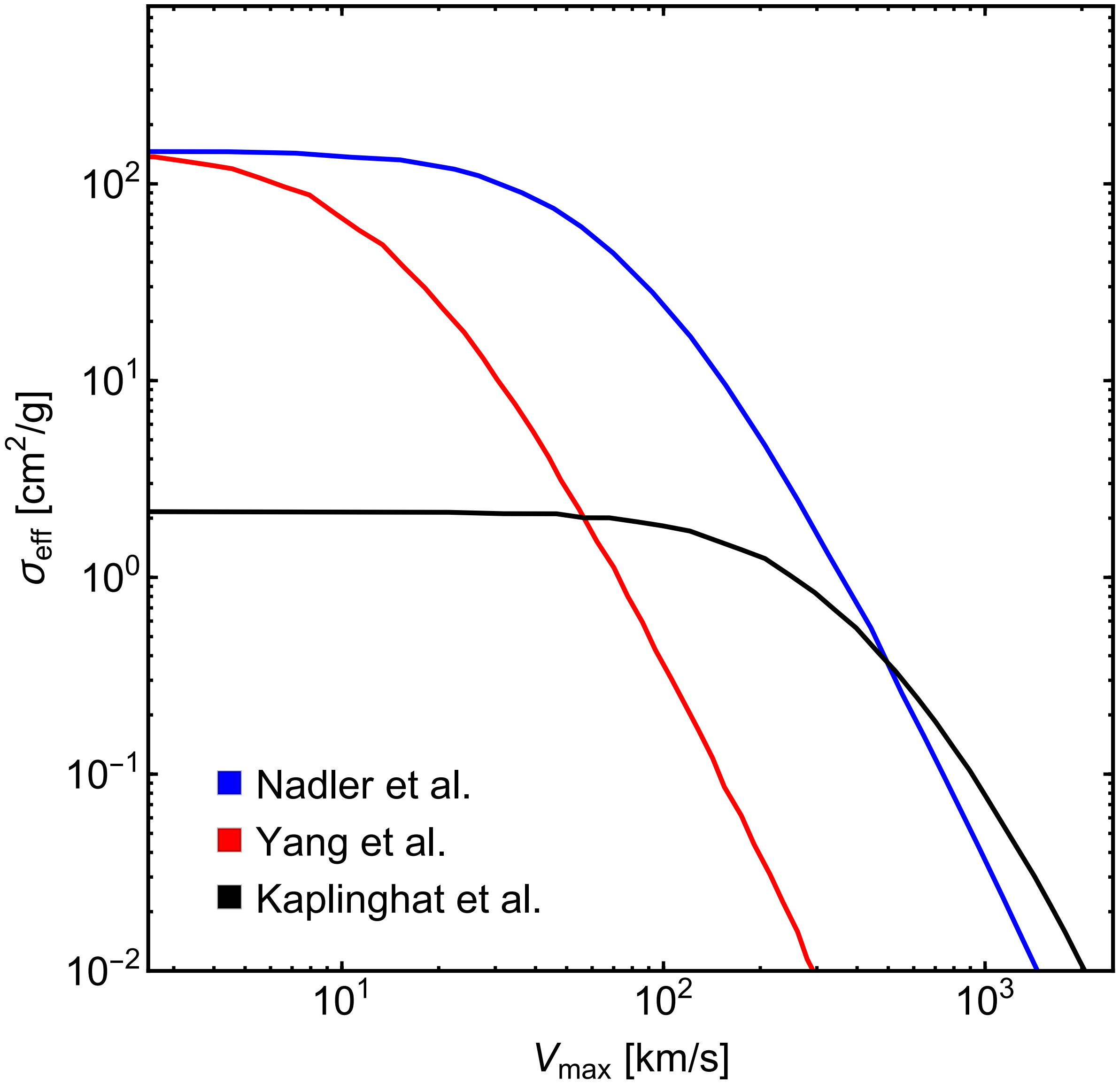

Thanks

Appendix

Ultra-diffuse satellite galaxy Crater II



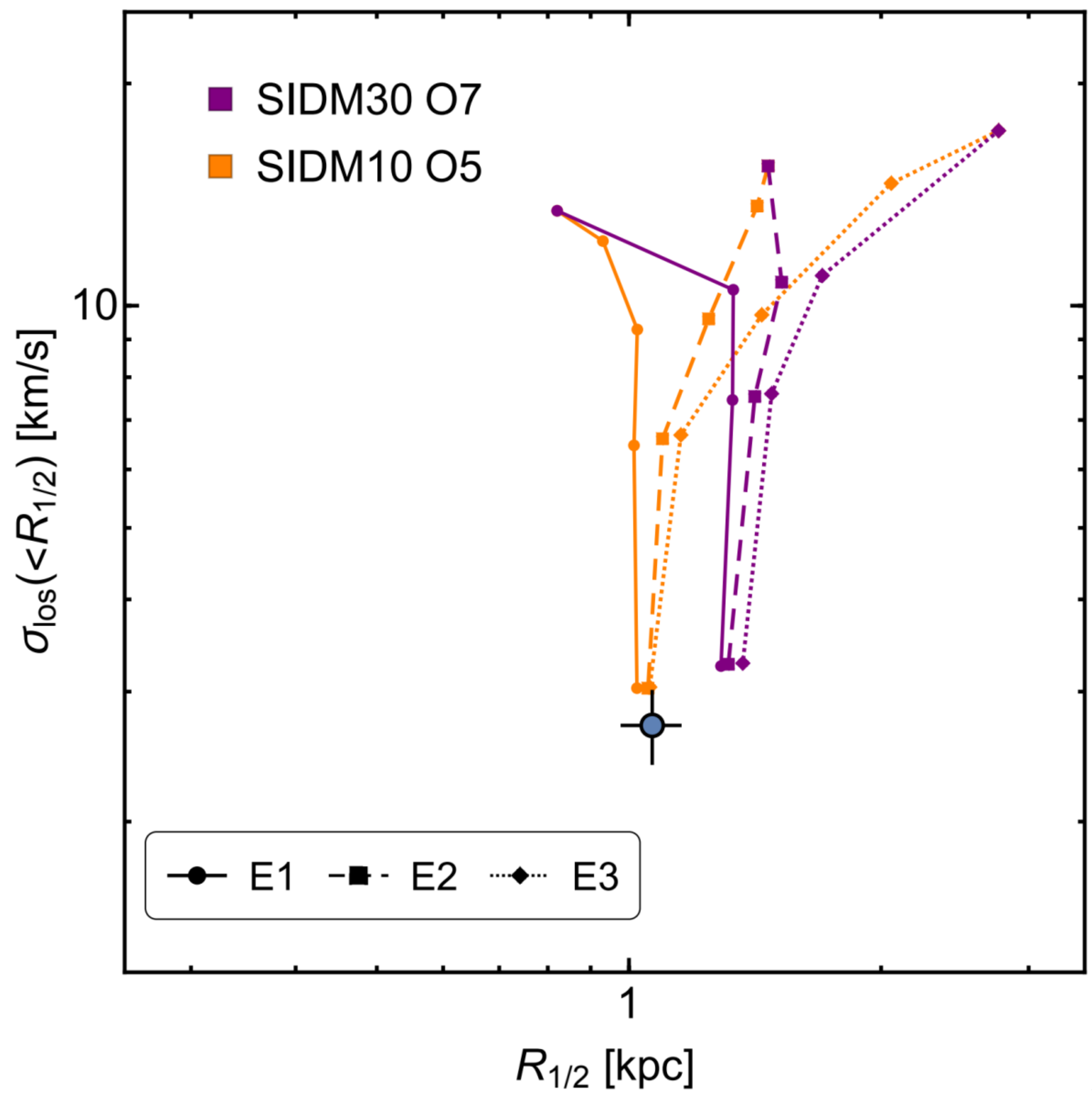
Appendix: velocity dependence



Self-interacting dark matter

Velocity-dependent cross section

Appendix: Crater II with different cross section



Other cross sections with different orbits

Appendix: equations of gravitational system

$$\frac{\partial M}{\partial r} = 4\pi r^2 \rho \,,$$

$$\frac{\partial(\rho v^2)}{\partial r} = -G\frac{M\rho}{r^2} \,,$$

$$\frac{L}{4\pi r^2} = -\kappa\frac{\partial T}{\partial r} \,,$$

$$\frac{\partial L}{\partial r} = -4\pi r^2 \rho\left[\left(\frac{\partial}{\partial t}\right)_M \frac{3v^2}{2} + p\left(\frac{\partial}{\partial t}\right)_M \frac{1}{\rho}\right]$$
$$= -4\pi r^2 \rho v^2 \left(\frac{\partial}{\partial t}\right)_M \log\left(\frac{v^3}{\rho}\right) .$$

$$\frac{\partial \tilde{M}}{\partial \tilde{r}} = \tilde{r}^2\tilde{\rho} \,,$$

$$\frac{\partial(\tilde{\rho}\tilde{v}^2)}{\partial \tilde{r}} = -\frac{\tilde{M}\tilde{\rho}}{\tilde{r}^2} \,,$$

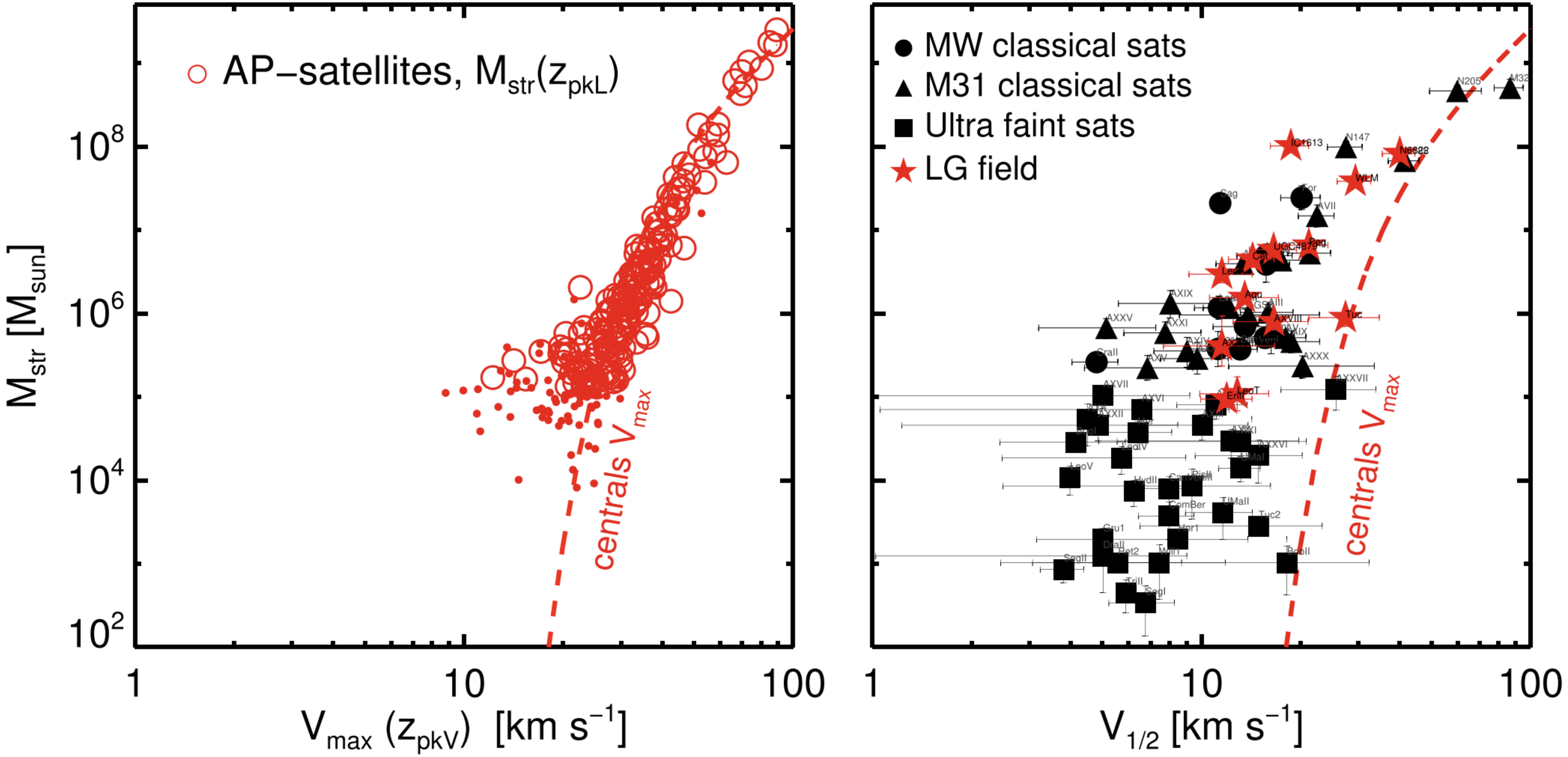
$$\frac{\partial(\tilde{v}^3/\tilde{\rho})}{\partial \tilde{t}} = \frac{3}{2}\frac{1}{\tilde{\rho}}\frac{\partial}{\partial \tilde{r}}\left(a\hat{\sigma}^2 + \frac{1}{\tilde{\rho}\tilde{v}^2}\right)^{-1}\frac{\partial \tilde{v}^2}{\partial \tilde{r}} .$$

$$\rho_0 = \frac{M_0}{4\pi R_0^3} \,, \quad v_0 = \left(\frac{GM_0}{R_0}\right)^{1/2} \,, \quad L_0 = \frac{GM_0^2}{R_0 t_0} .$$

$$\frac{L}{4\pi r^2} = -\frac{3}{2} b\rho v\left[\left(\frac{1}{\lambda}\right) + \left(\frac{v t_r}{H^2}\right)\right]^{-1}\frac{\partial v^2}{\partial r} .$$

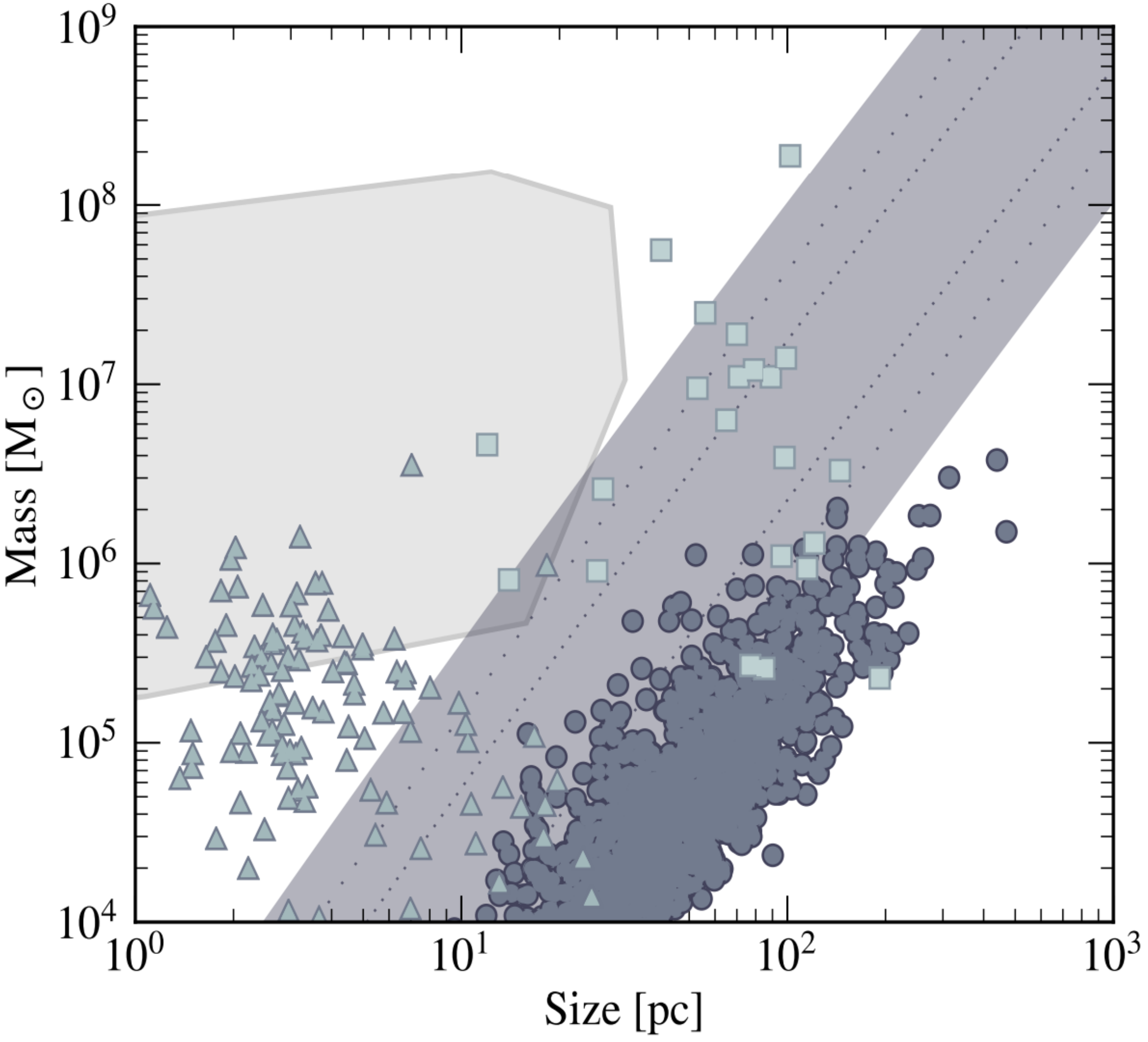
(Balberg et al 2002)

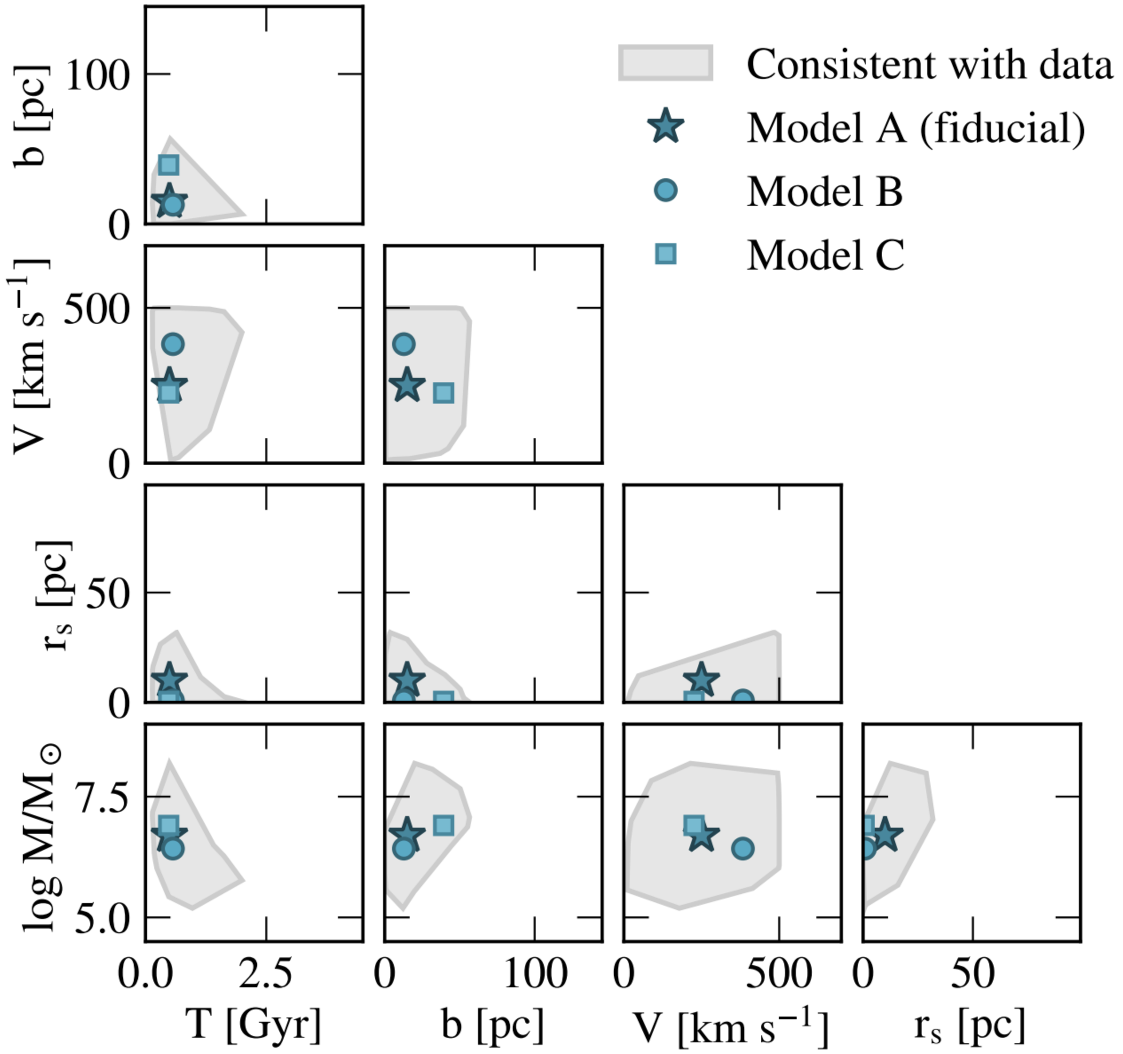
Appendix: observed satellites



(Fattahi et. al 2018)

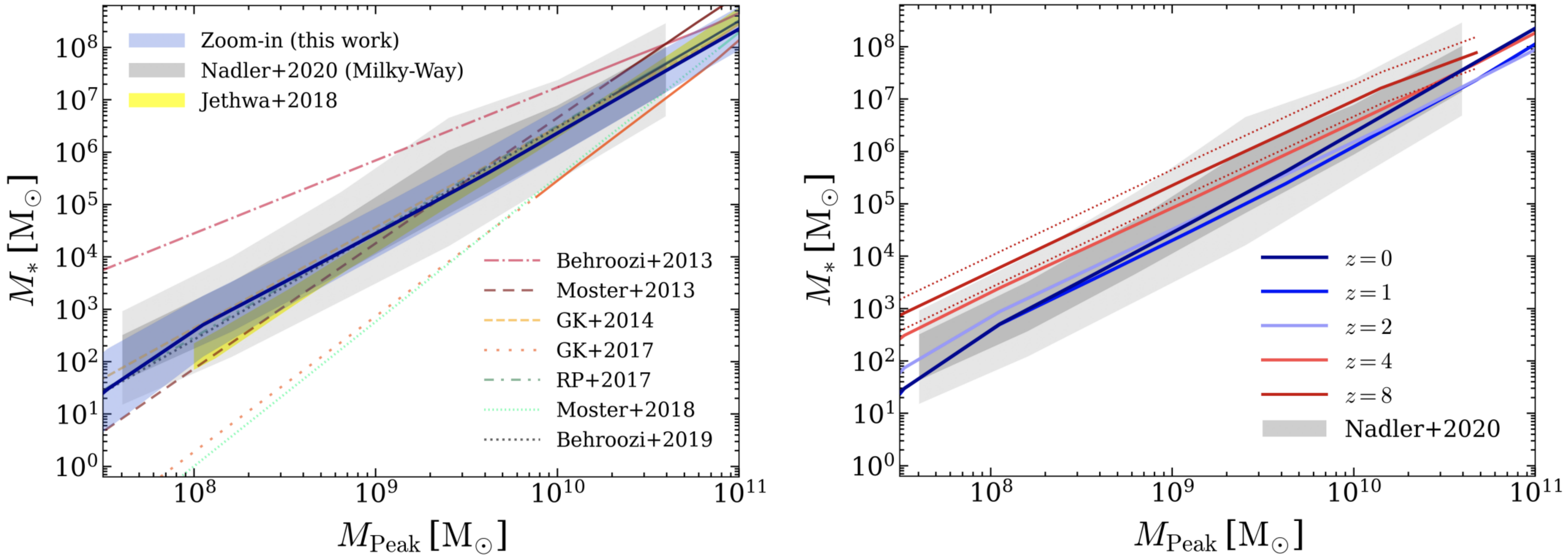
Appendix: parameter space





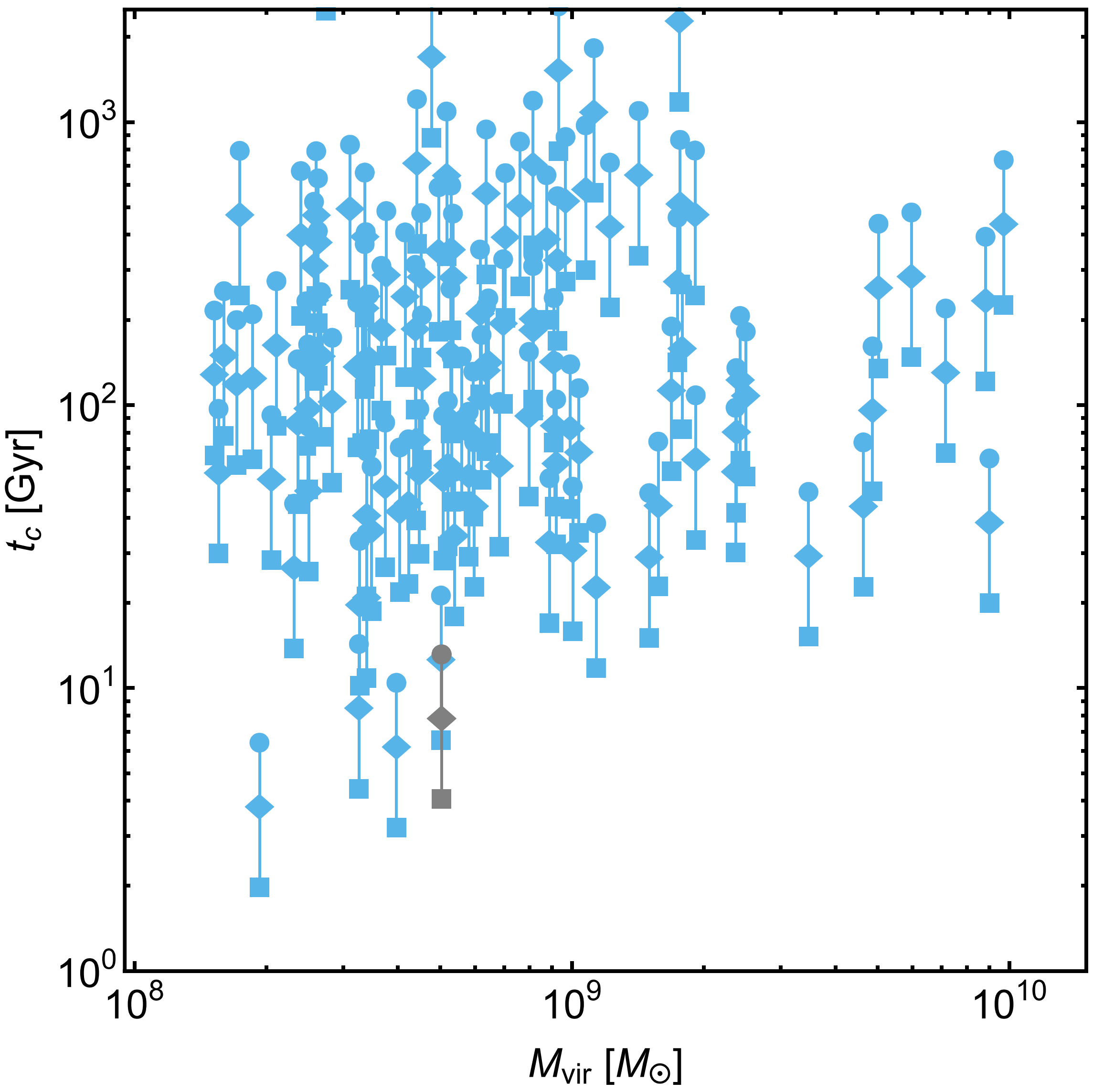
(Bonaca et al. 2018)

Appendix: stellar mass-halo mass relation



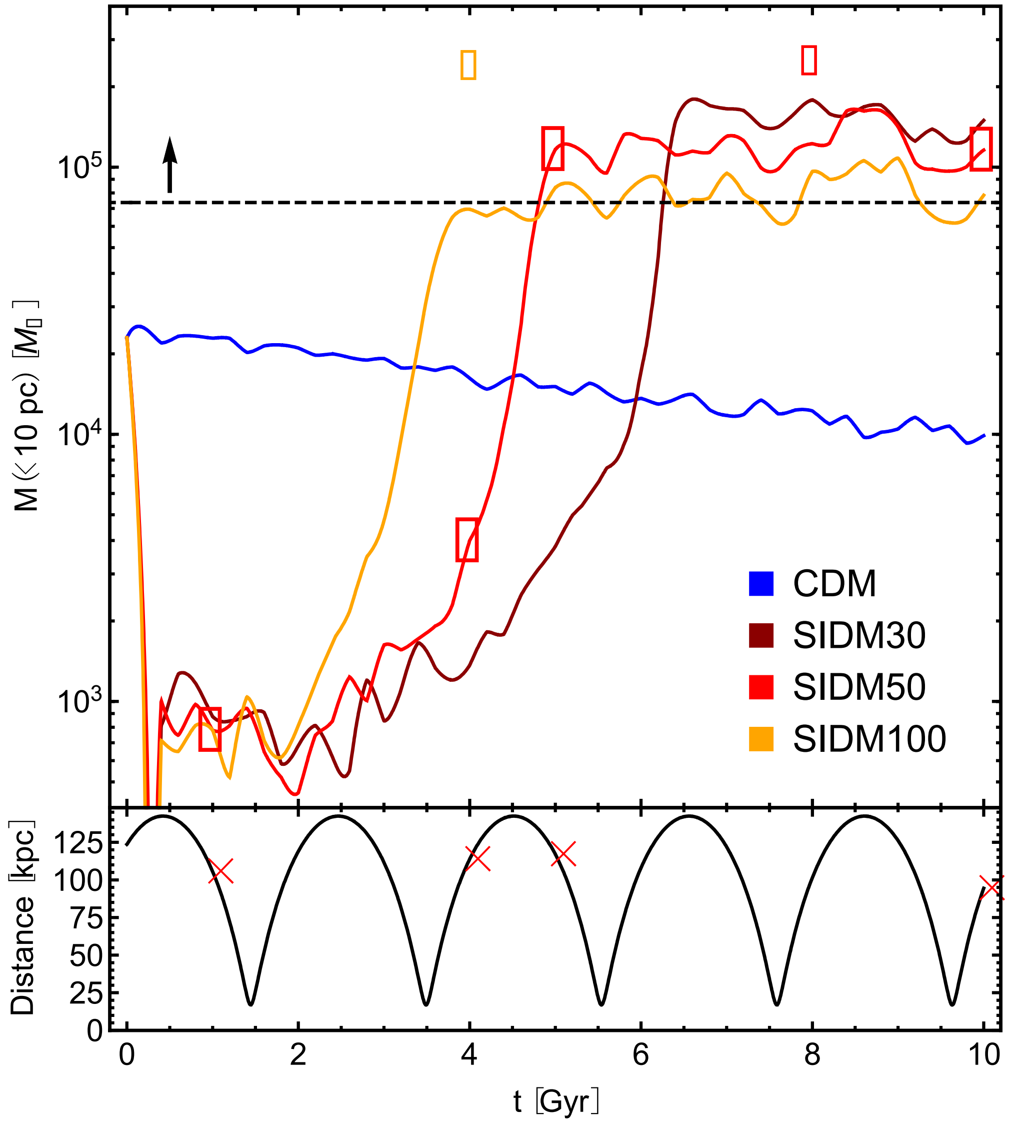
(Wang et. al 2021)

Appendix: initial condition selection

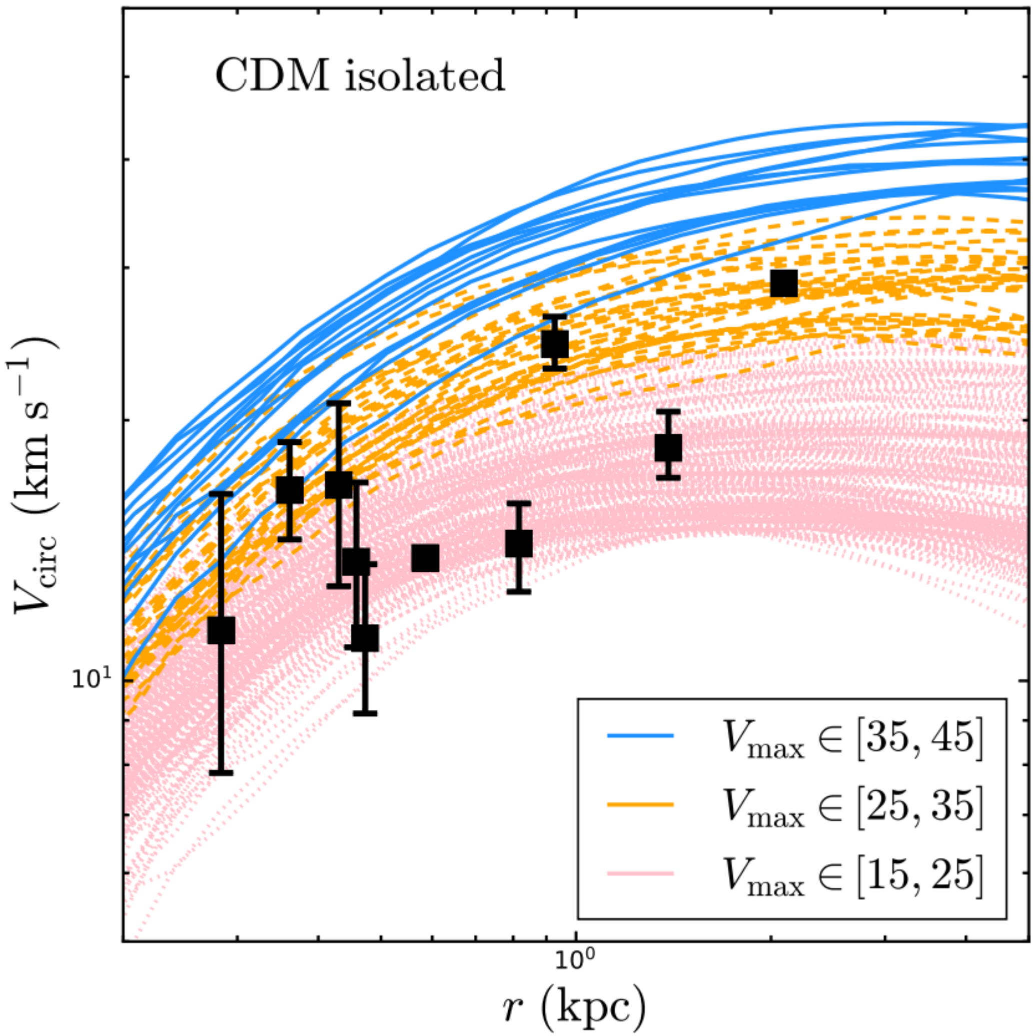


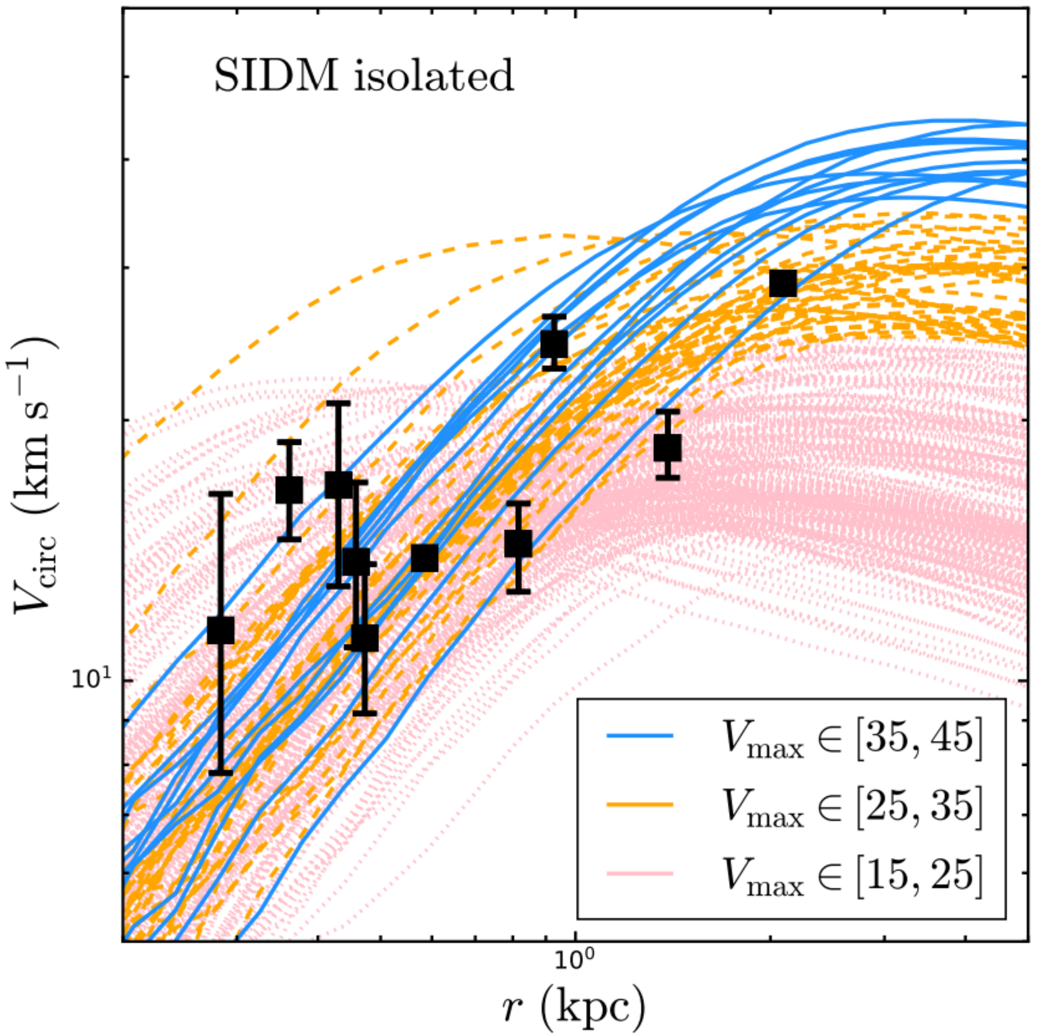
$$t_{\rm c,iso} \simeq \frac{200}{r_s \rho_s \left(\sigma_{\rm eff}/m\right)} \frac{1}{\sqrt{4\pi G \rho_s}}$$

Appendix: inner 10 pc mass of various cross sections



Appendix: diversity of SIDM halos





(Yang et al. 2023)

Appendix: energy inconservation of N-body simulation