Shedding light on low-mass subhalo survival with numerical simulations

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in collaboration with

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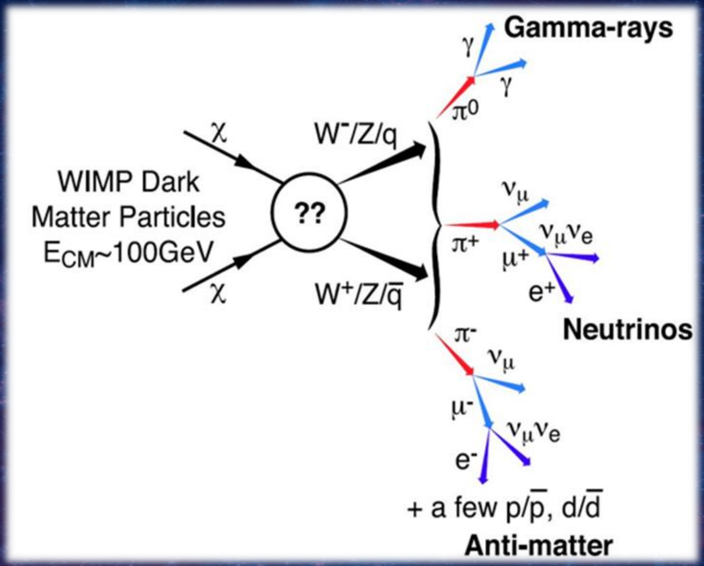
Introduction

- Standard ΛCDM cosmology: bottom-up structure formation scenario ⟶ dark matter (DM) subhalos inside DM halos (e.g., Zavala & Frenk 20)
- Well motivated DM candidate: WIMP ⟶ annihilation into gamma rays
- Galactic subhalos ⟶ large annihilation fluxes ⟶ excellent targets for DM searches (e.g., Coronado-Blázquez+19)
- Open debate: disruption or survival of small subhalos? (van den Bosch+18, van den Bosch & Ogiya 18)
  - Numerical resolution effects
  - Tidal forces within the host

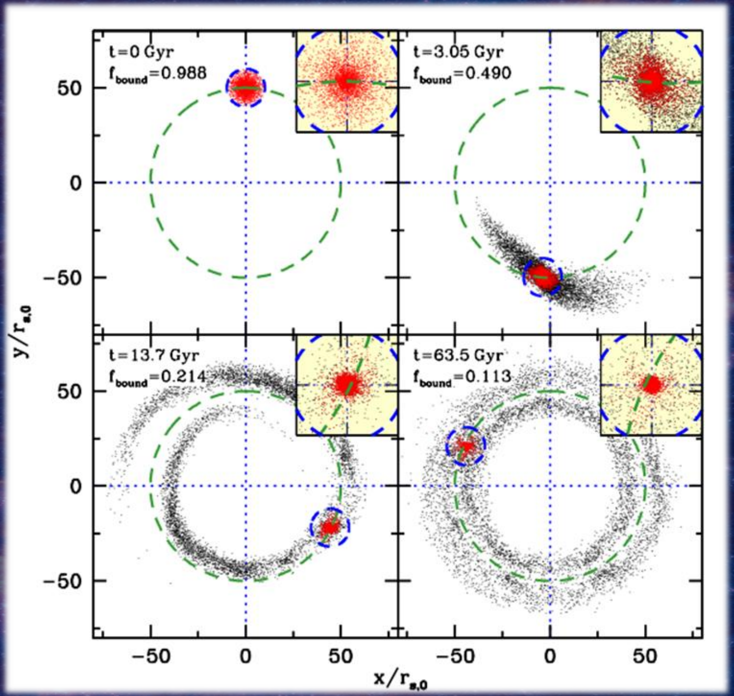



VL-II (Diemand+08)

This work

- We shed light on subhalo survival via numerical simulations and study its impact for gamma ray searches
- We use a high-resolution numerical simulation to follow the evolution of the subhalo
  - Large number of particles ($10^5 - 10^6$)
  - Host potential described analytically
  - Adopt a subhalo mass, concentration $c = r_{vir} / r_s$ and accretion redshift
  - We further add baryons to the analytical potential: stellar and gas disks, and a bulge
- We set the orbital parameters: (Jiang+15)
  - Circularity $\eta = J / J_{circ}$ ($\eta = 0$ → radial, $\eta = 1$ → circular)
  - Orbital energy parameter $x_c = r_c(E) / r_{vir,h}(z_{acc})$
- The subhalo will lose mass mainly in every pericentric passage

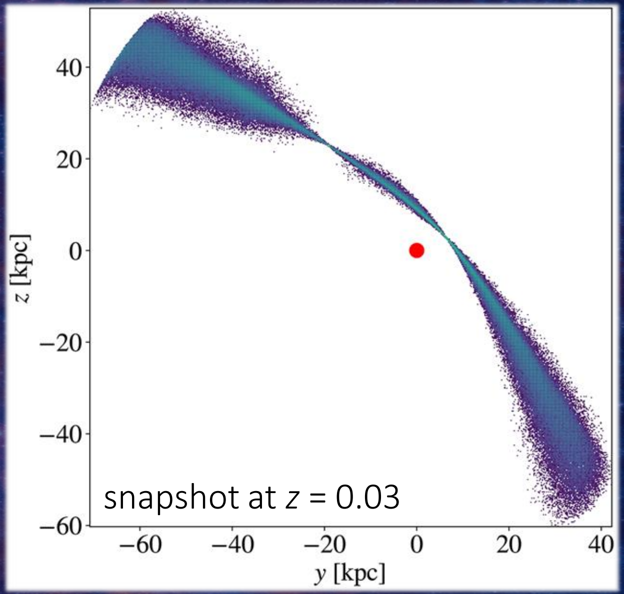
van den Bosch & Ogiya 18



Our code: DASH

- Developed by Go Ogiya (Ogiya+19) to follow the evolution of a subhalo in the host potential
- Tree-code optimised for GPU clusters
- Hierarchical tree algorithm; two working modes, `treecode` and `evolution`
- The subhalo is simulated using a very large number of particles, orbiting around its host halo since its accretion redshift z_{acc} until present (z=0)
- The host is described as an analytical potential
- Main further improvements for this work:
  - Inclusion of baryonic components: (Kelley+19)
    - Stellar: Miyamoto-Nagai disks
    - Gas: Miyamoto-Nagai disks
    - Bulge: Hernquist potential
  - Time evolution of host potentials

by J. Stücker



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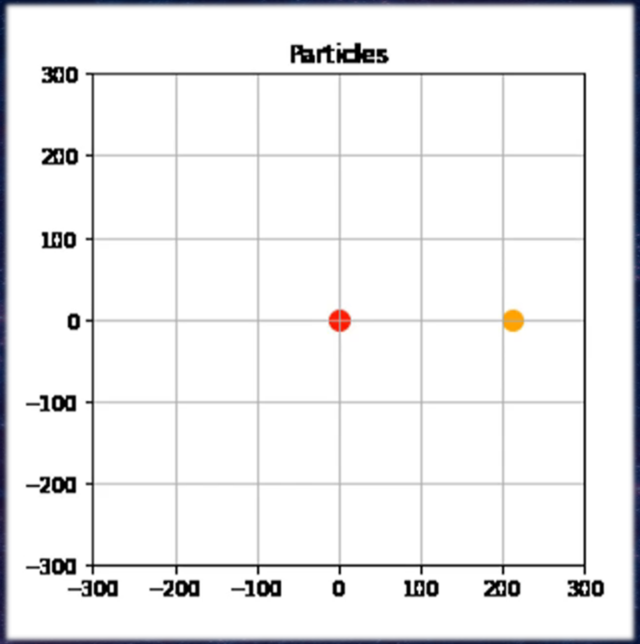

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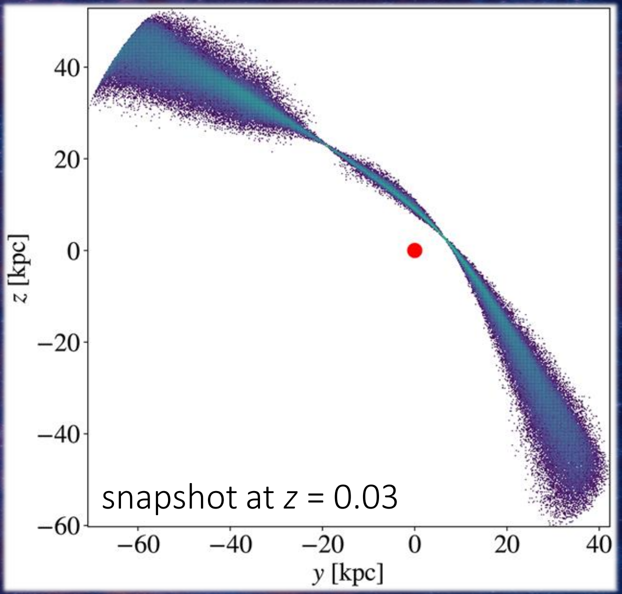
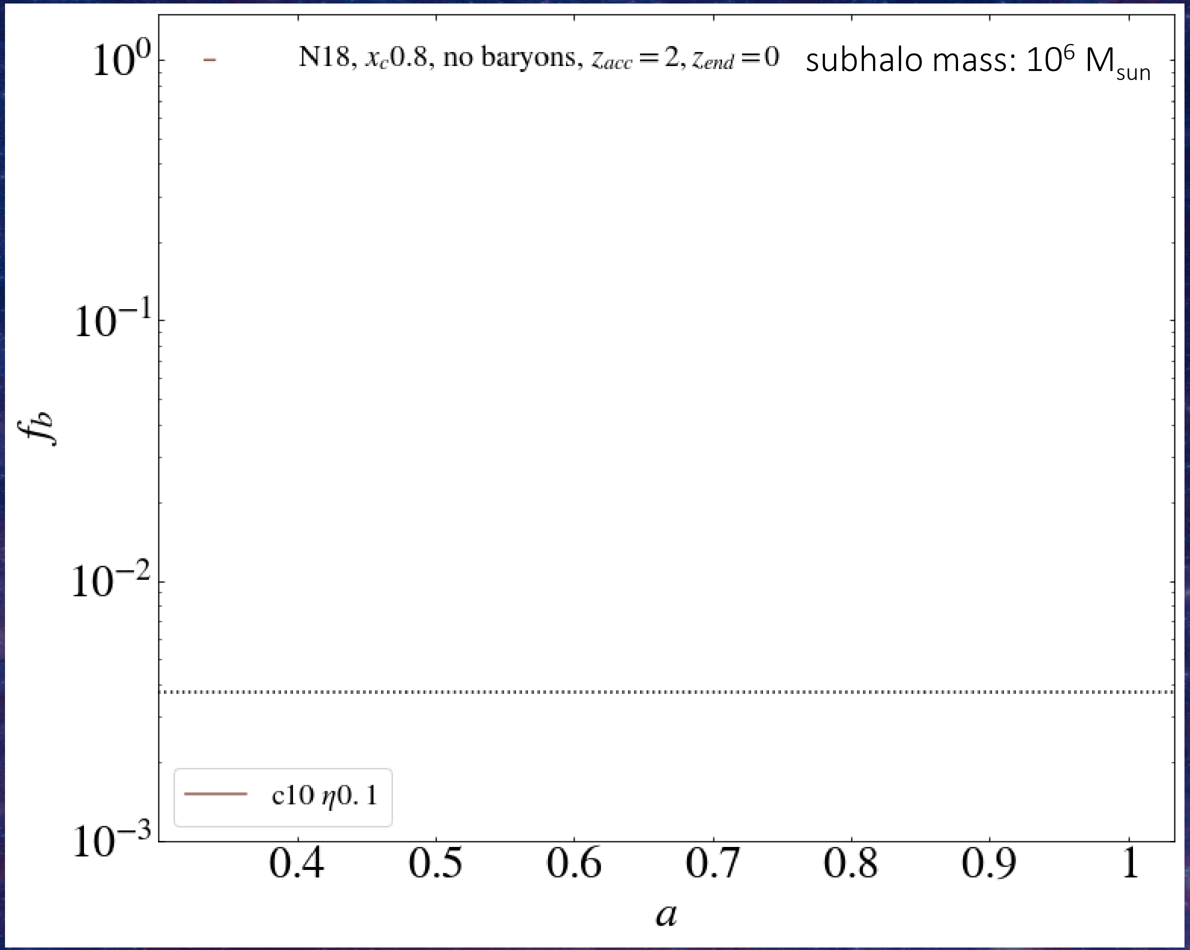


snapshot at z = 0.03

Simulation results

I. bound mass fraction (f_b)



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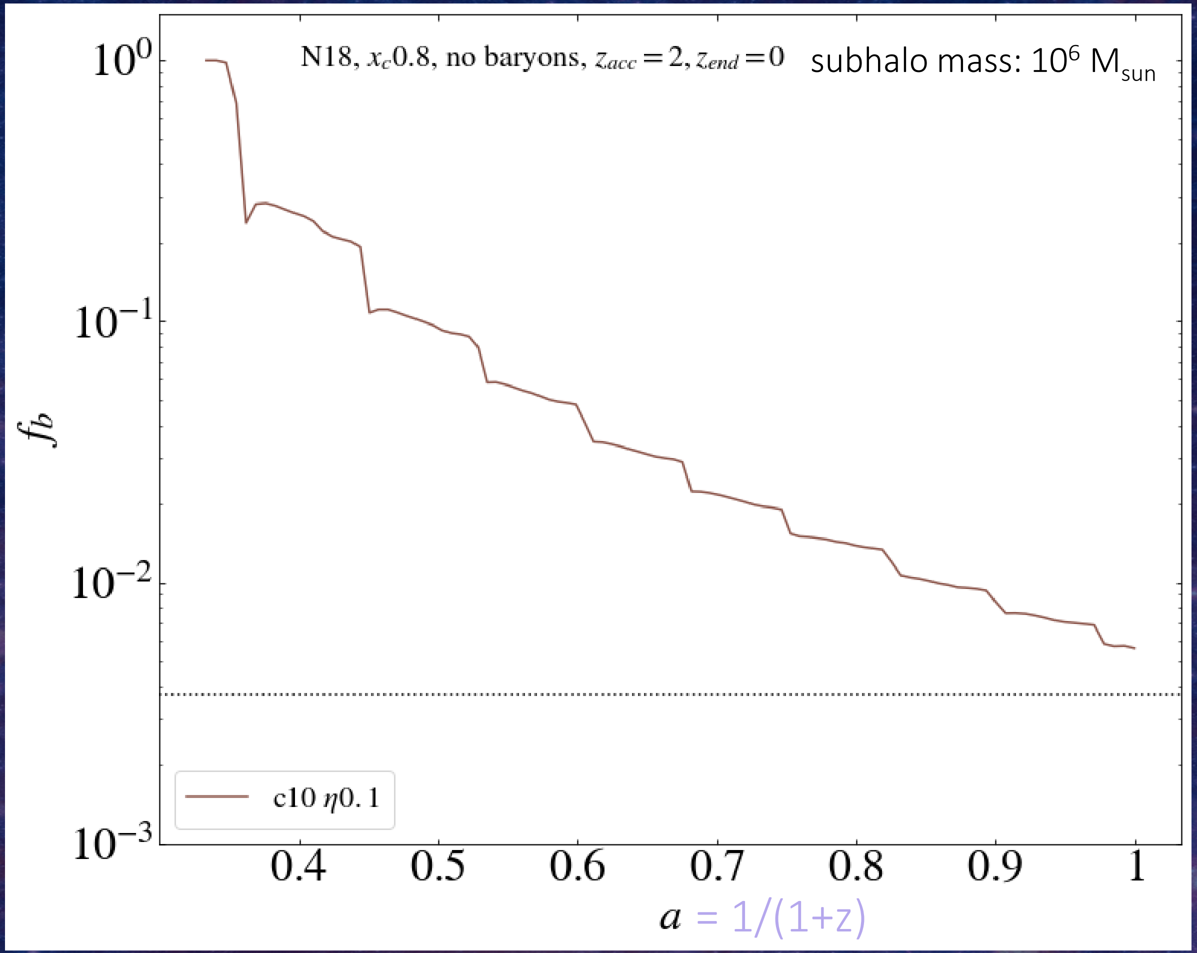

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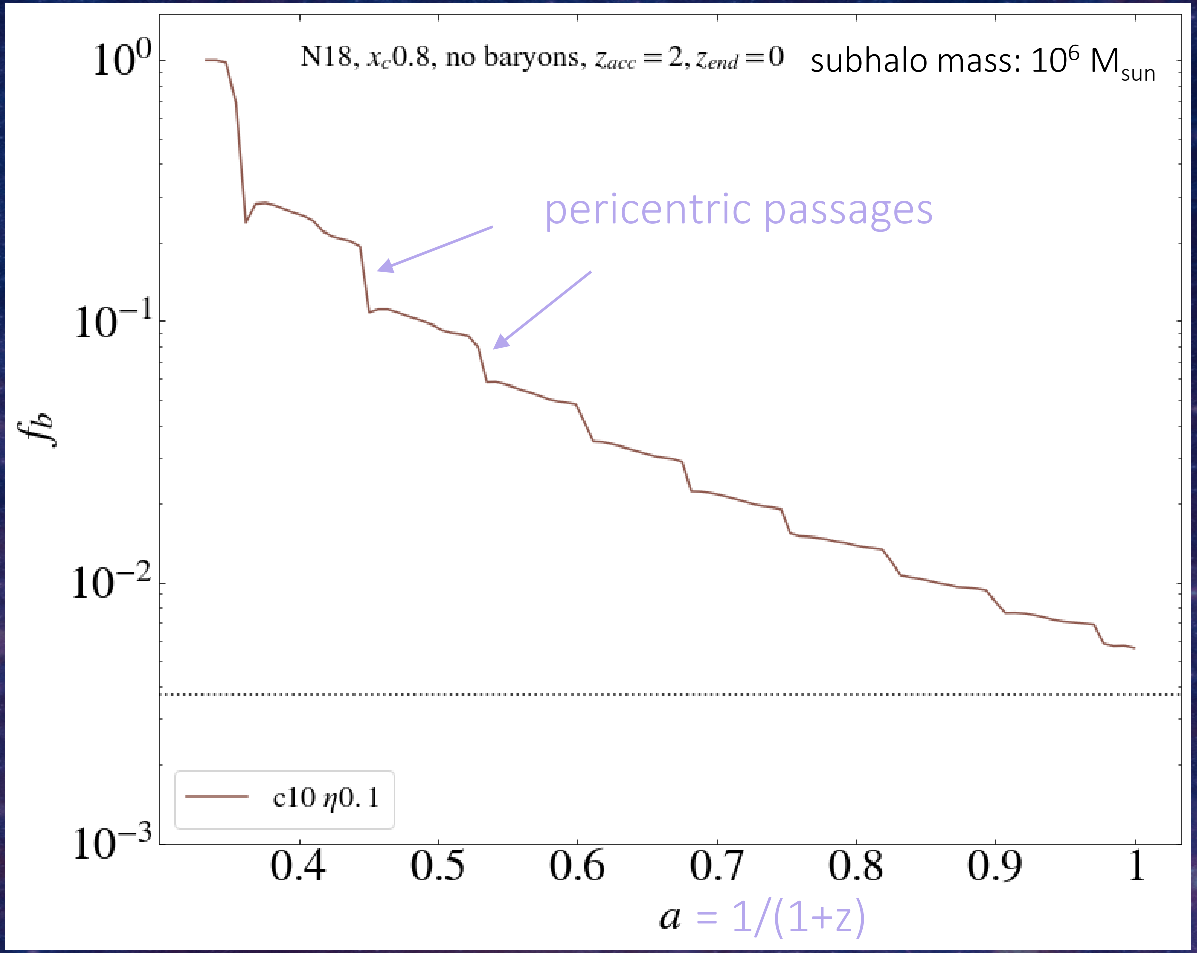

subhalo mass: 10^6 M_{sun}

pericentric passages

a = 1/(1+z)

The subhalo loses more than 99% of its initial mass after several orbits

Large mass loss after every pericentric passage

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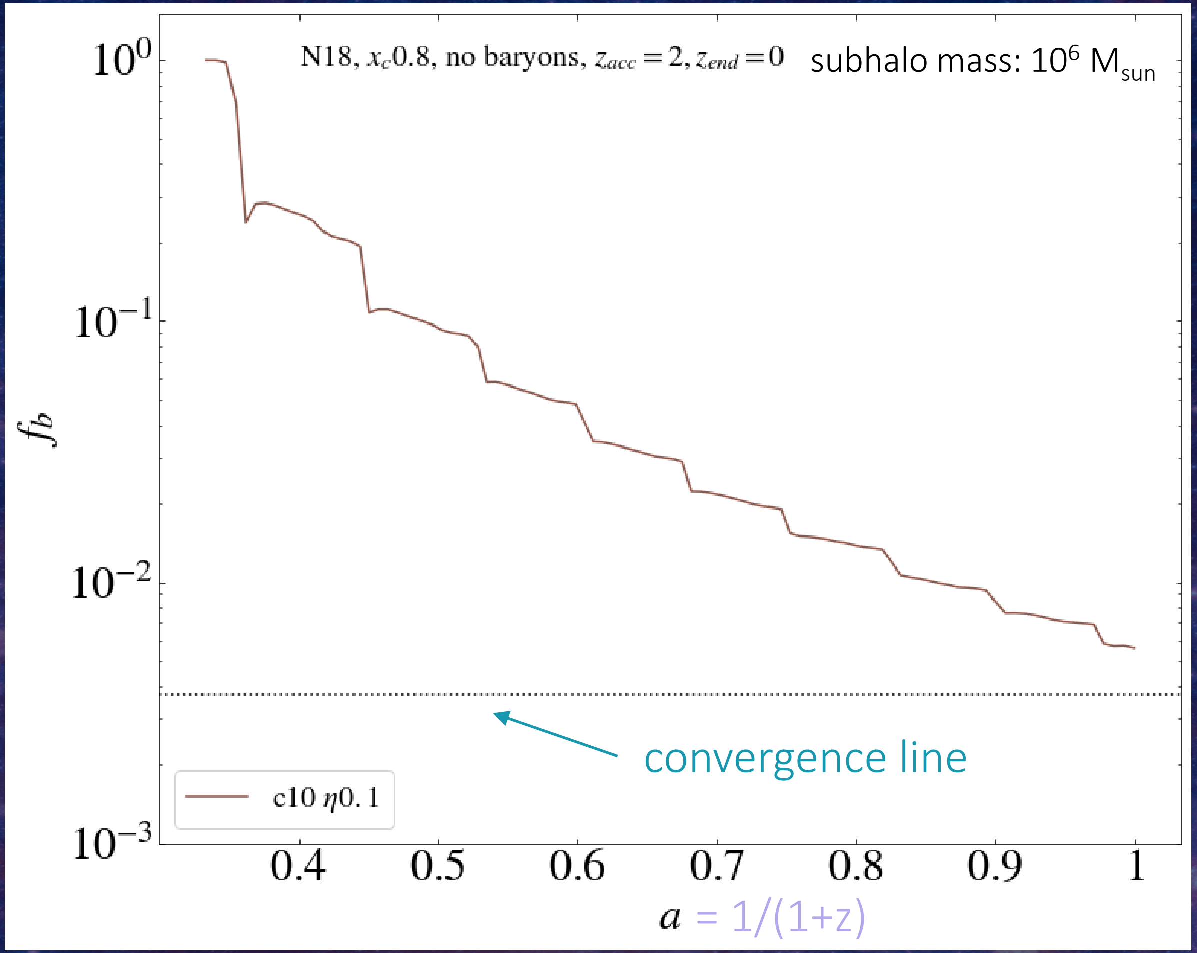

subhalo mass: 10^6 M_{sun}

convergence line

a = 1/(1+z)

The subhalo loses more than 99% of its initial mass after several orbits

Large mass loss after every pericentric passage

Convergence criteria:

$$f_{bound} > 1.12 \frac{c^{1.26}}{f^2(c)} \left(\frac{\varepsilon}{r_{s,0}} \right)^2$$

$$f_{bound} > 0.32 \left(\frac{N_{acc}}{1000} \right)^{-0.8}$$

(van den Bosch&Ogiya 18)

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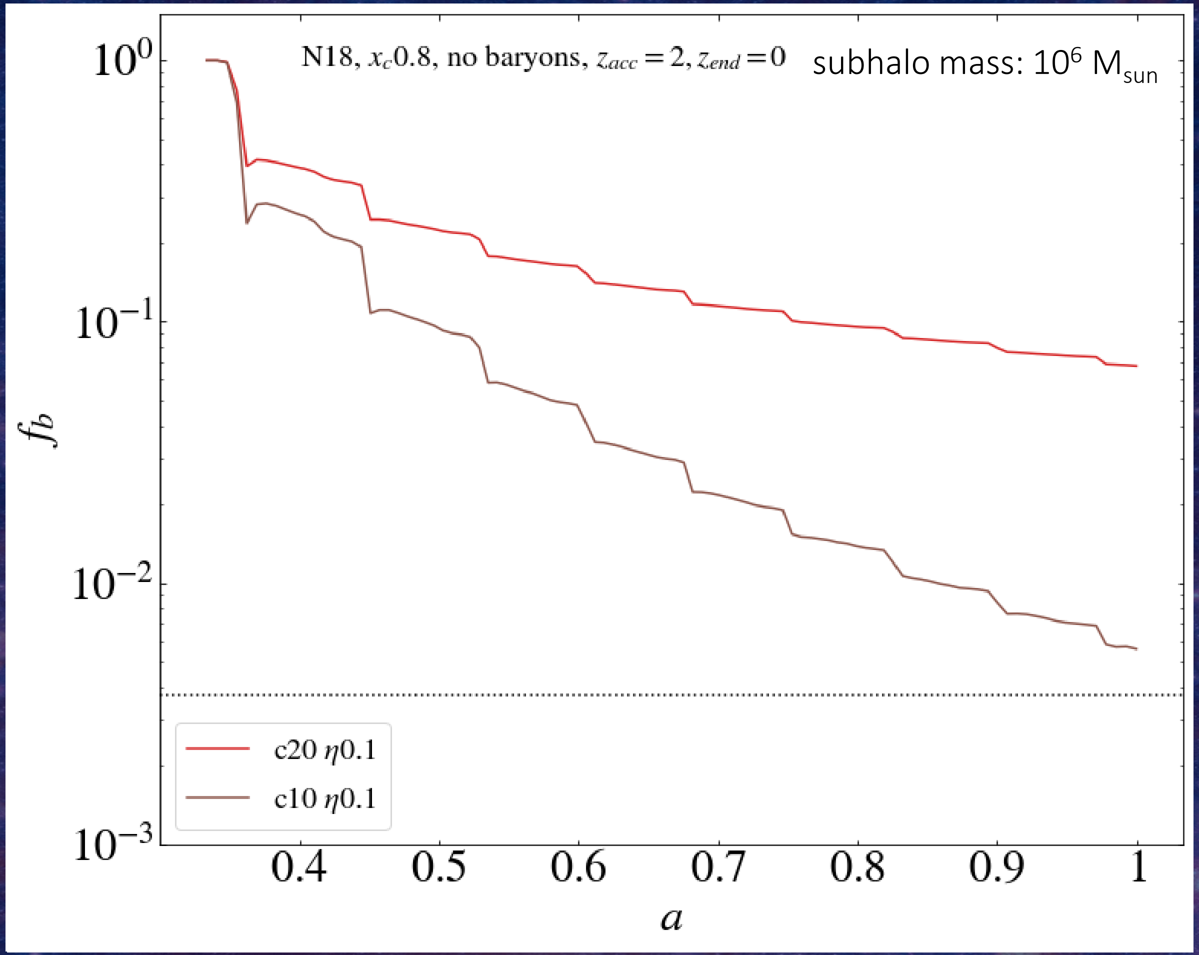
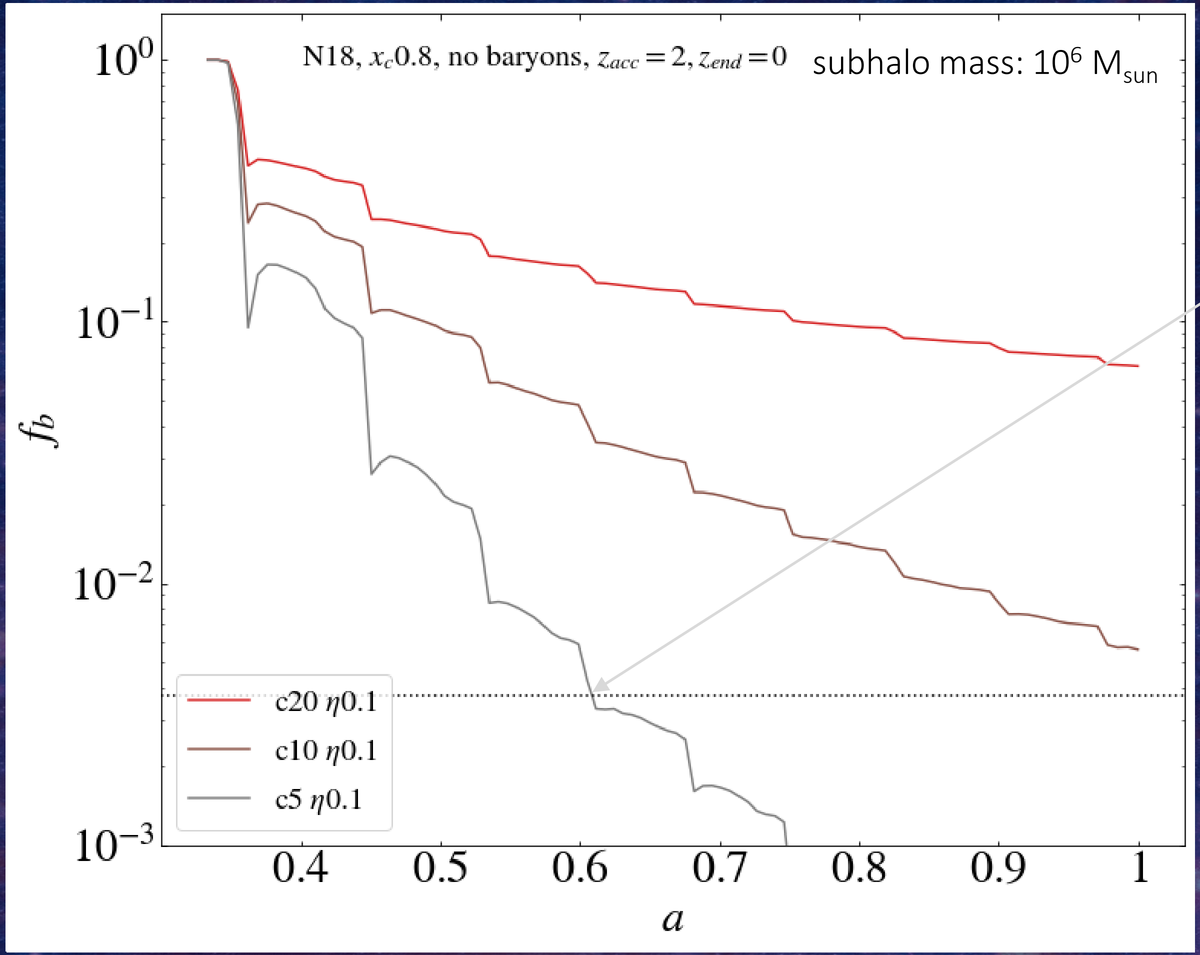


More concentrated subhalos lose less mass

I. bound mass fraction (f_b)



Insufficient numerical resolution

Disrupted subhalo?

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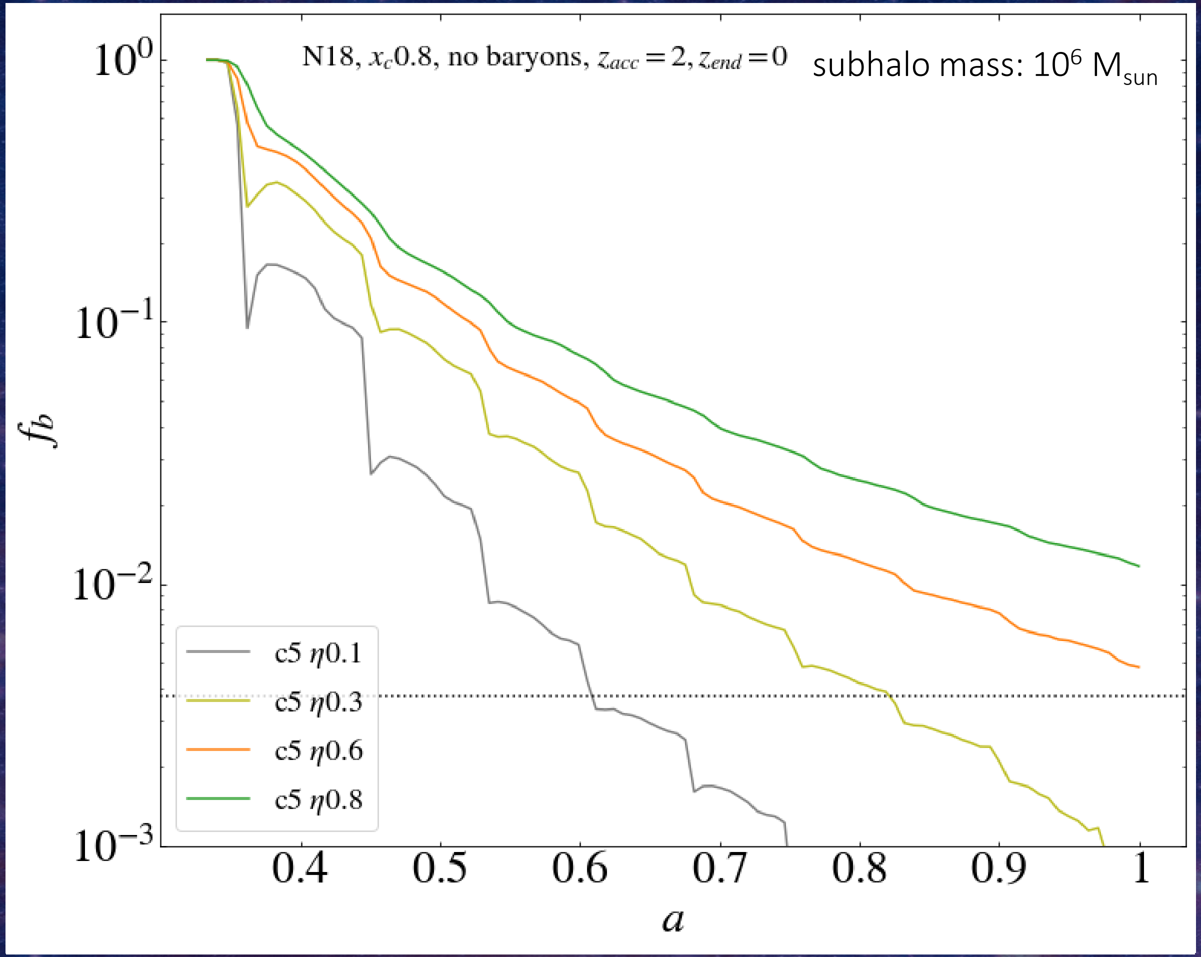

When x_c is fixed, subhalos with more eccentric orbits (smaller $\eta \Rightarrow$ smaller pericenter) lose more mass

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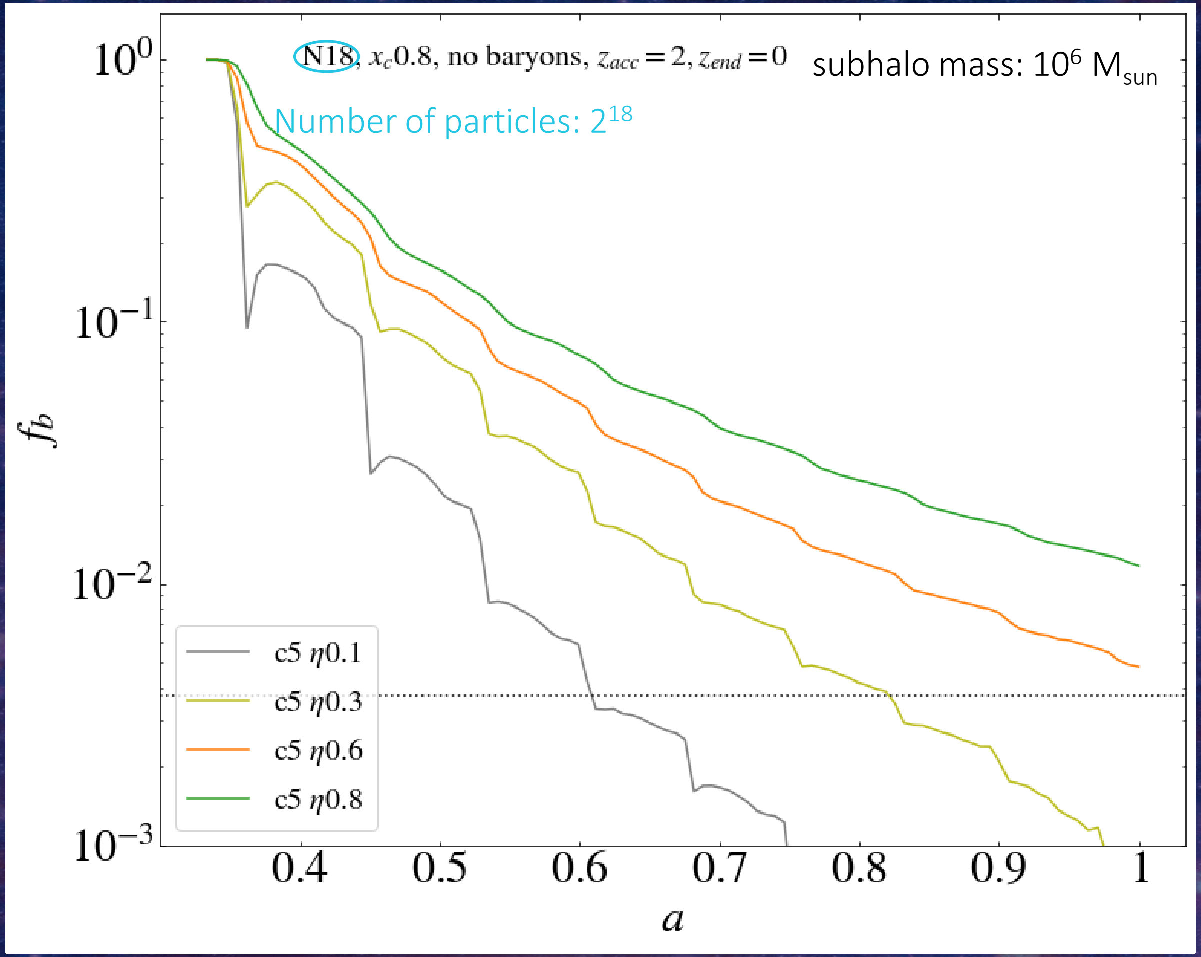

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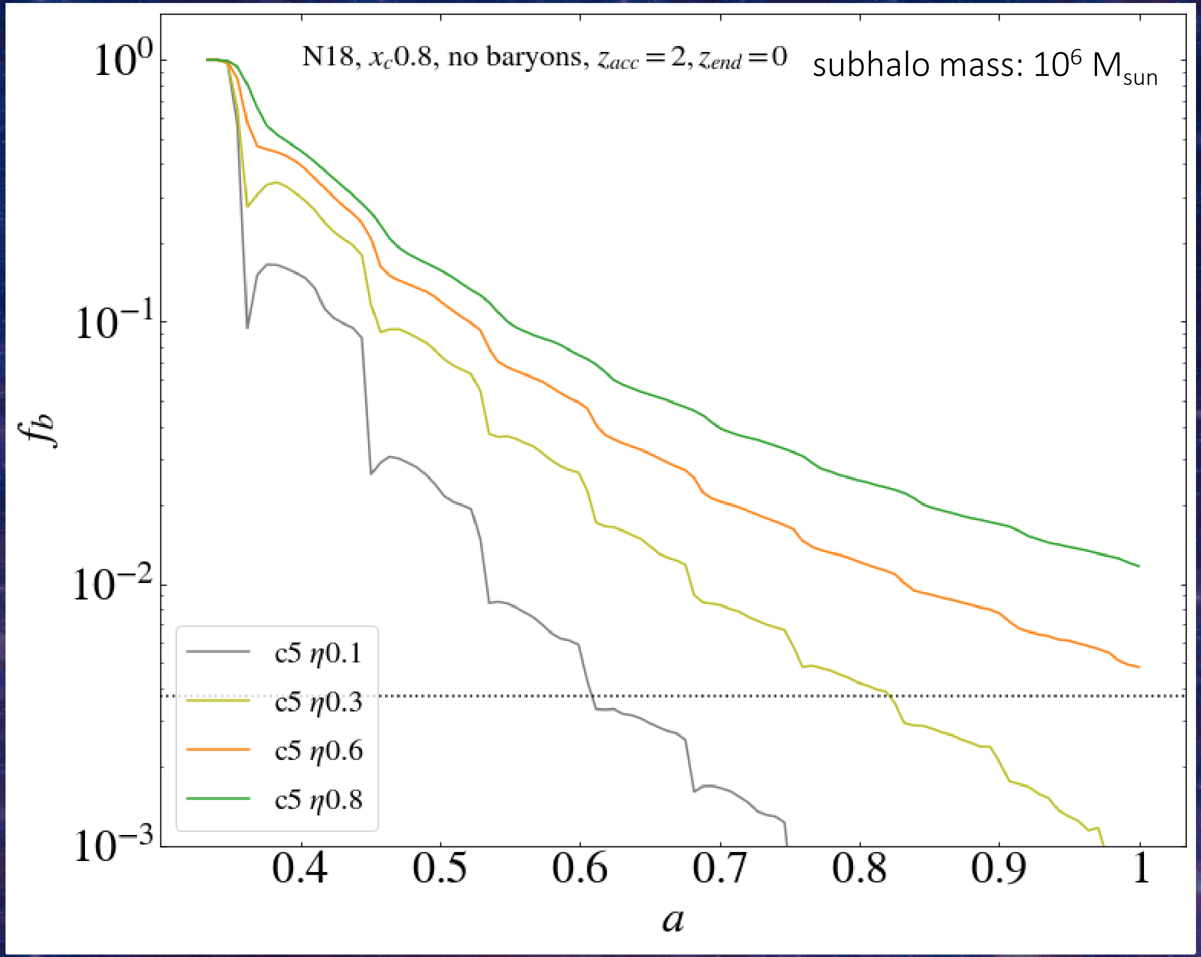

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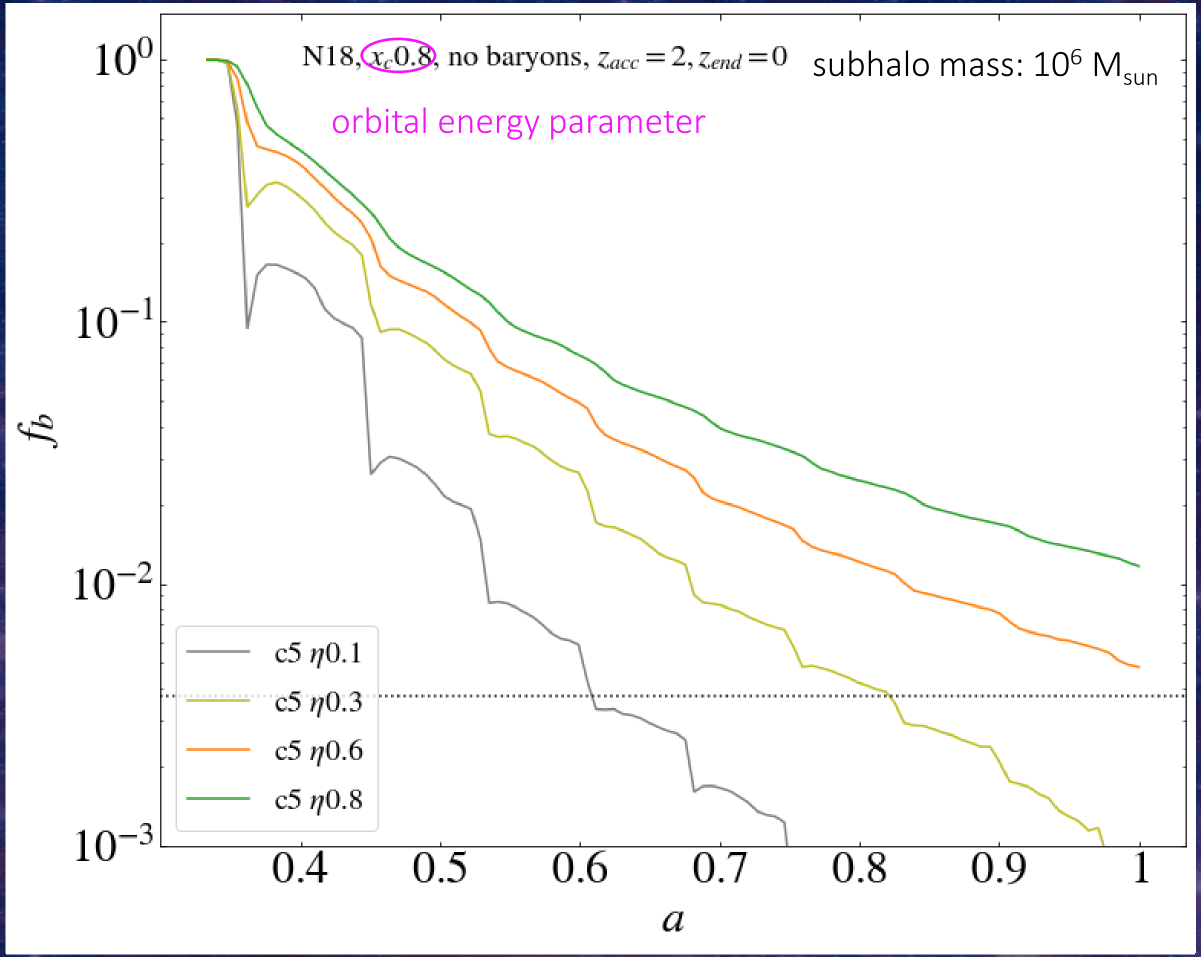

subhalo mass: 10^6 M_{sun}

orbital energy parameter

When x_c is fixed, subhalos with more eccentric orbits (smaller η ⇒ smaller pericenter) lose more mass

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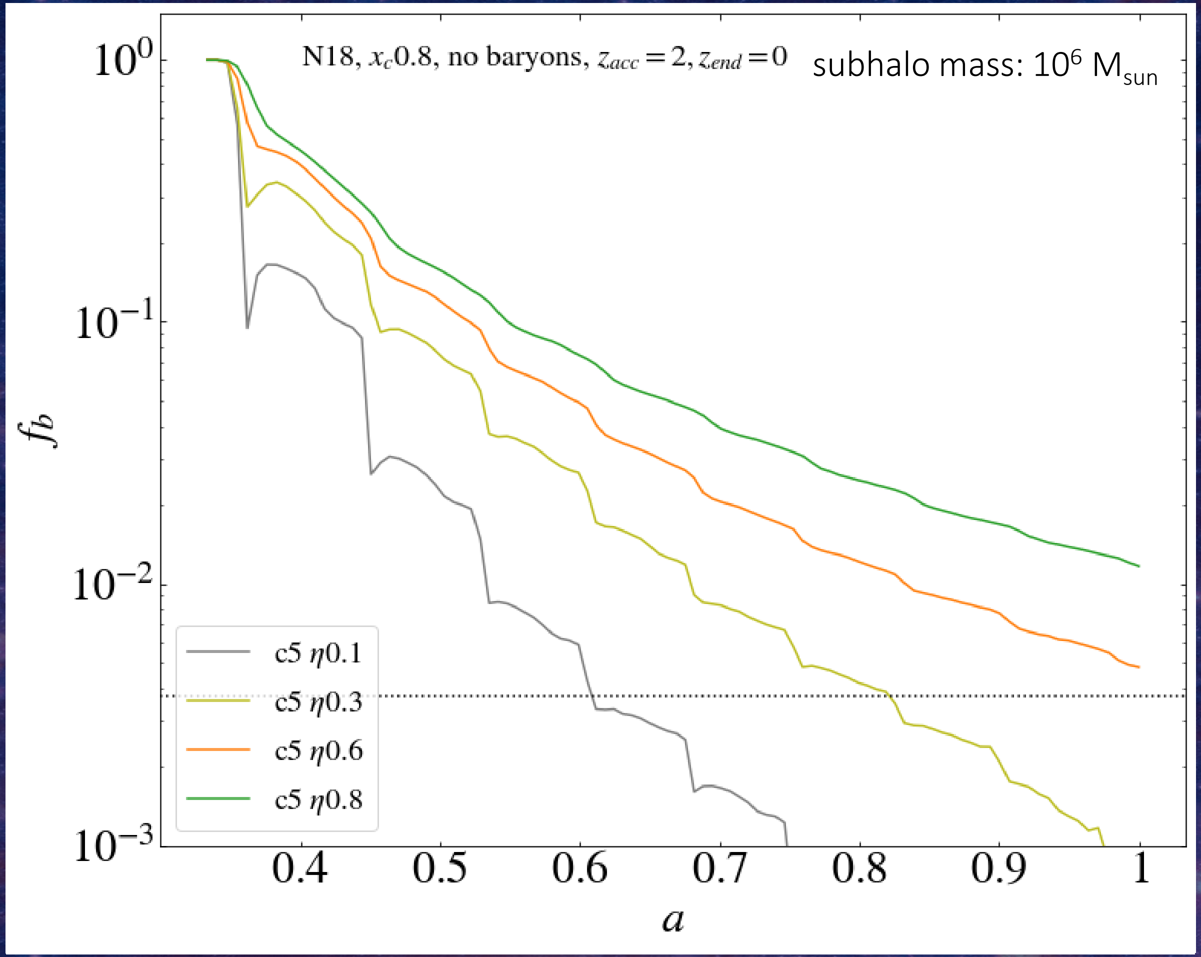

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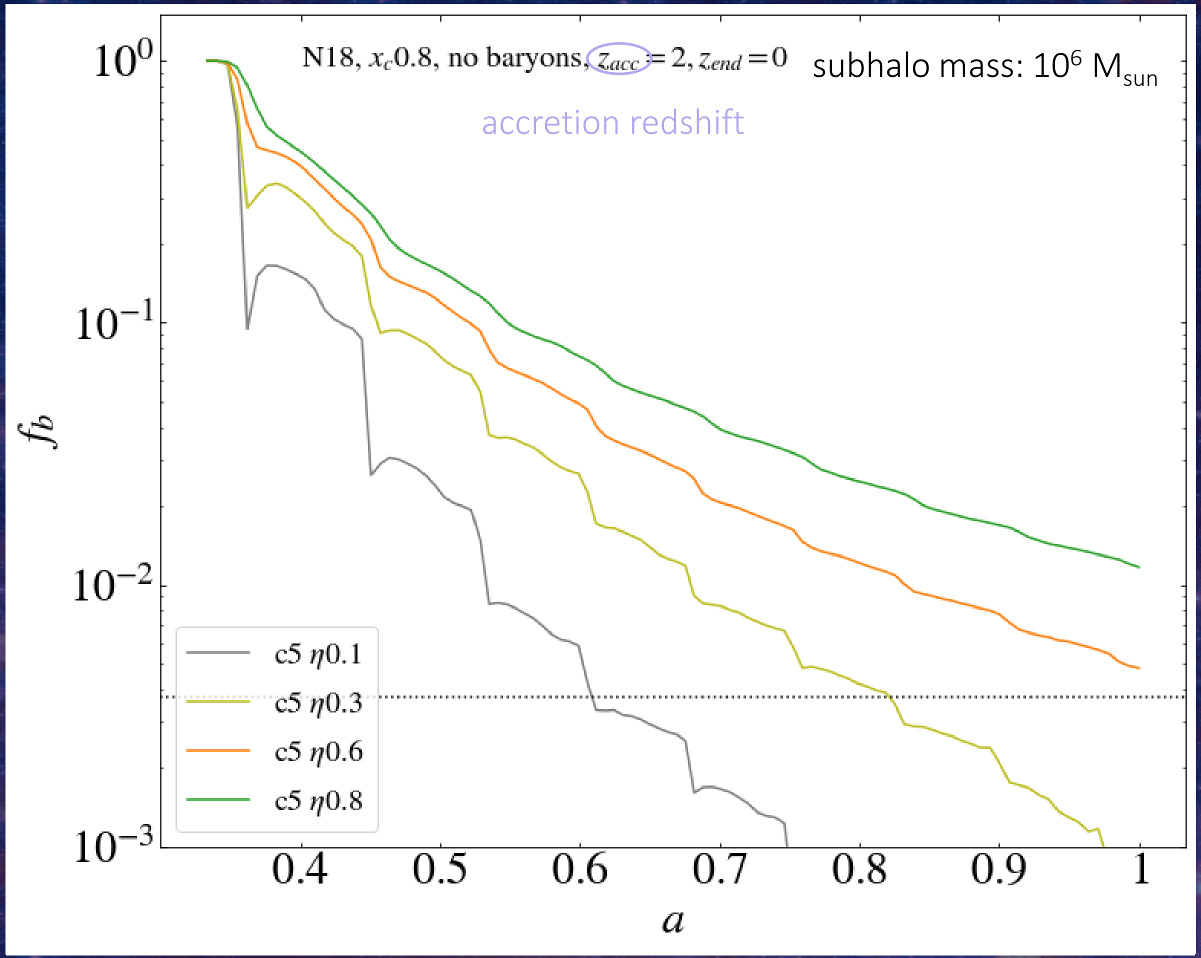

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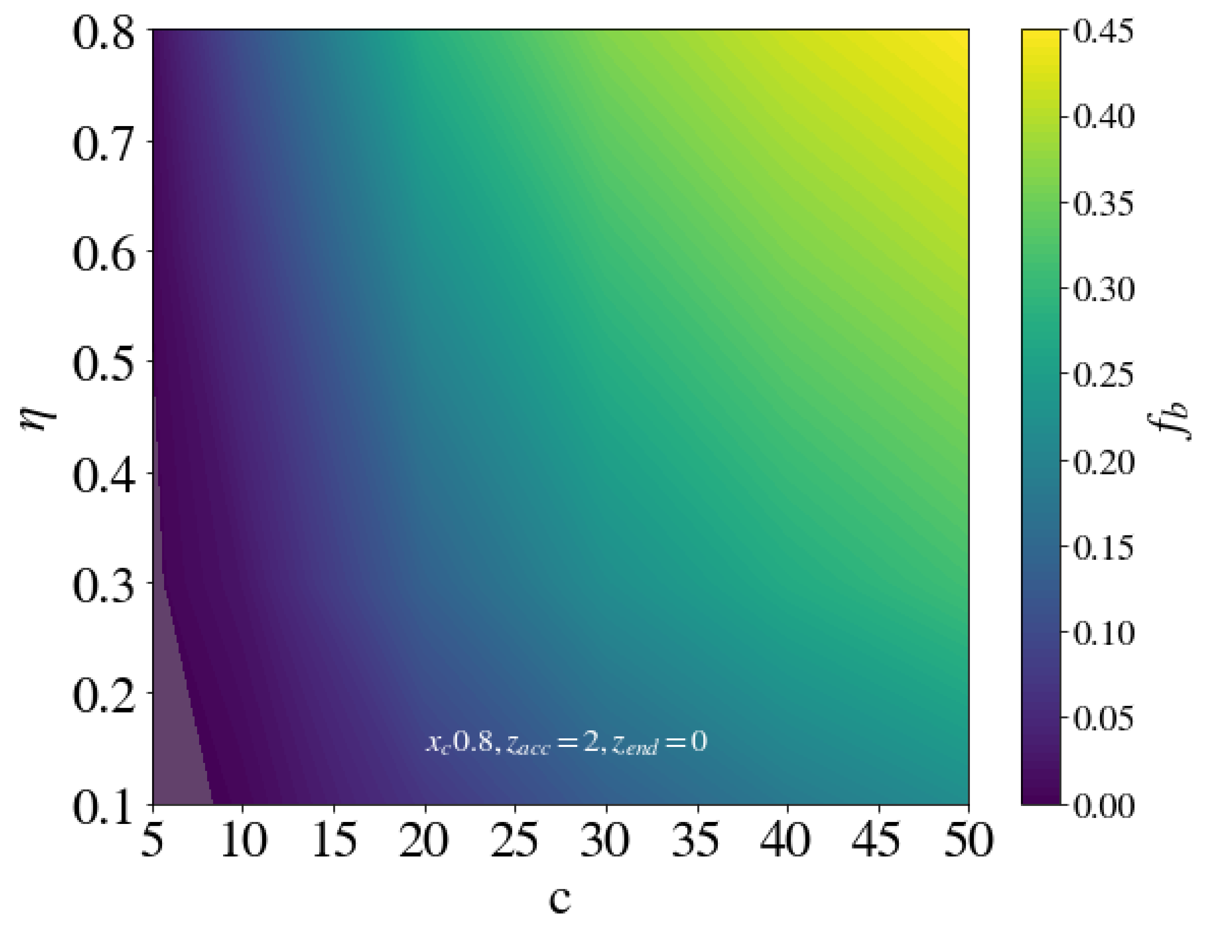
II. Bound mass fraction: big picture

DM-only host potential

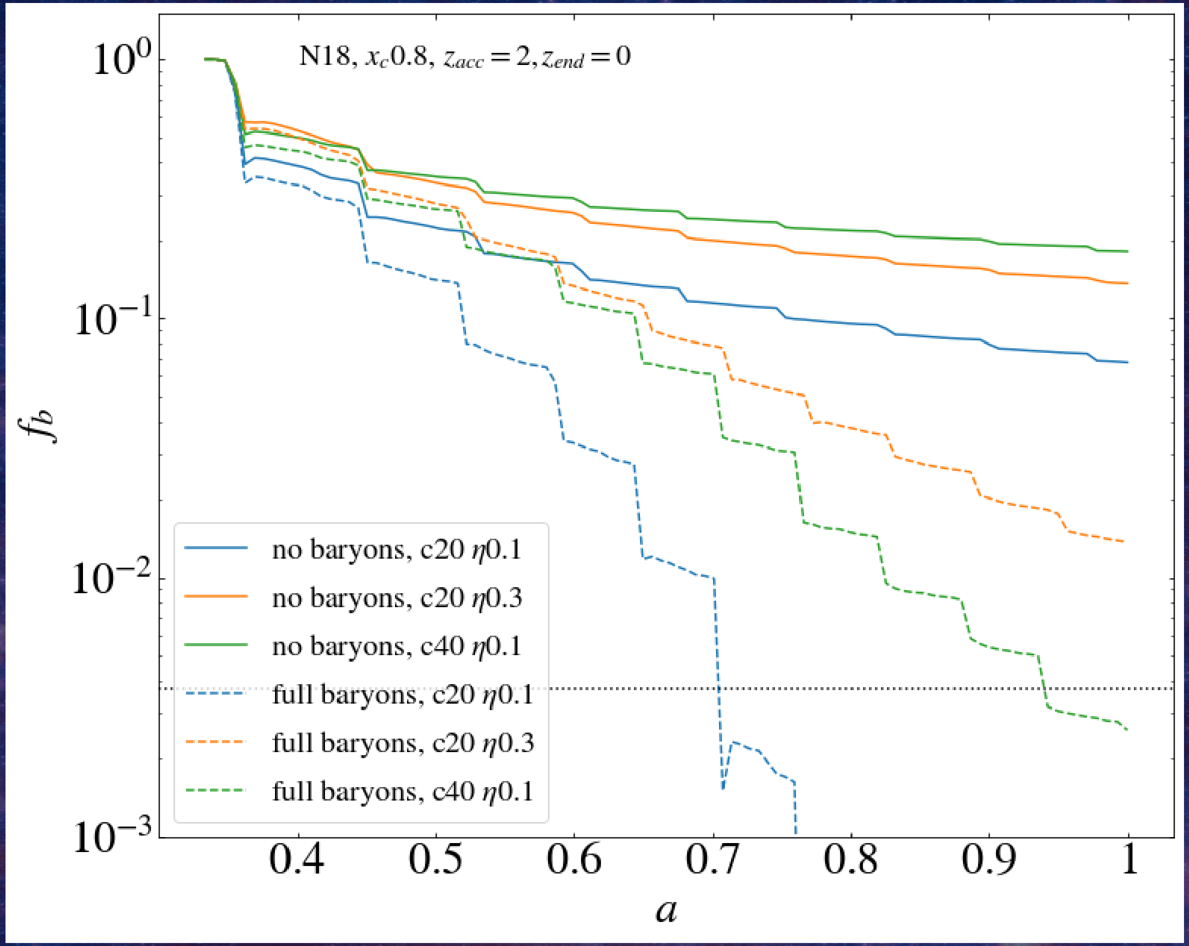


η values motivated by Jiang+15

c values as typical ones for low mass subhalos at z=2 (Ludlow+16)

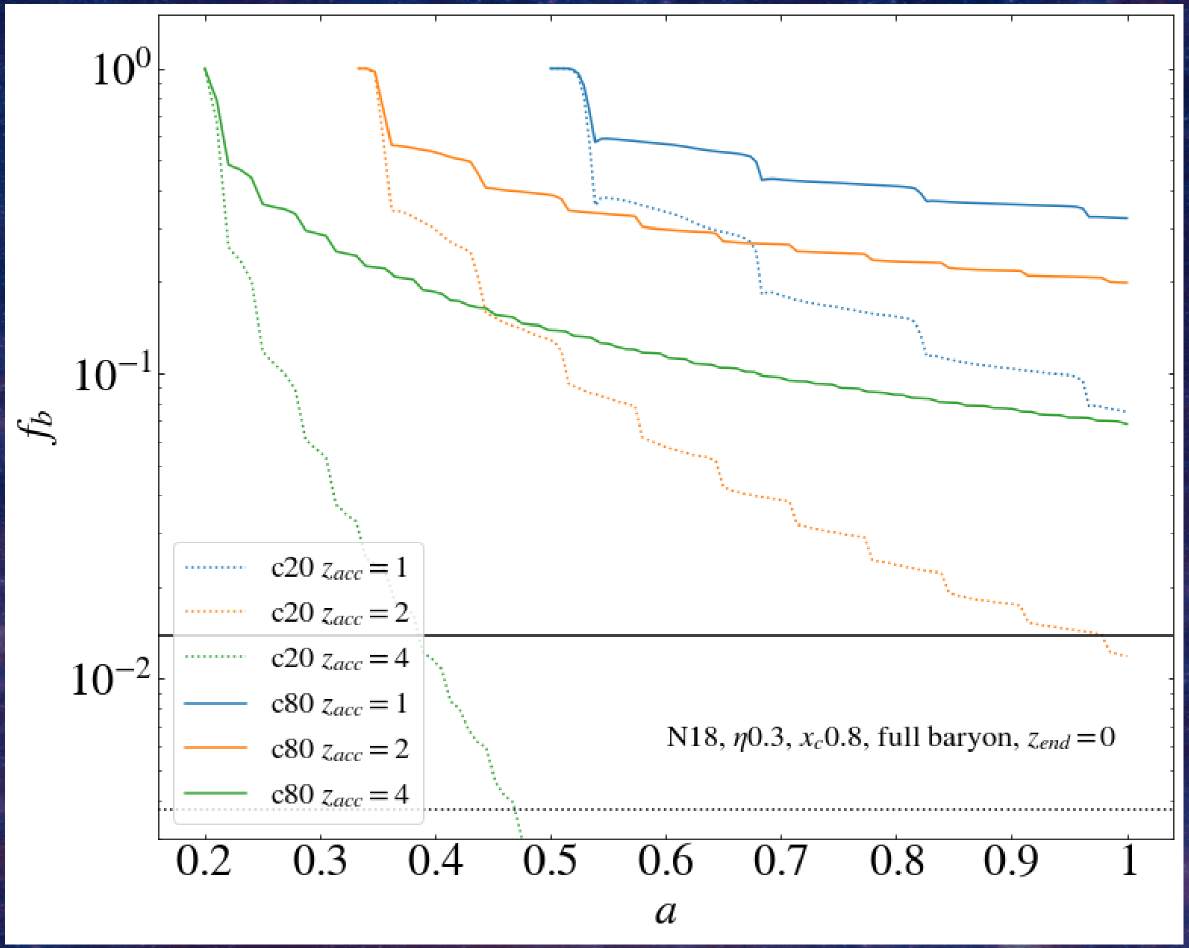
shadowed region:
no numerical convergence

III. Adding baryons to the host potential



Including baryons leads to much larger mass loss!

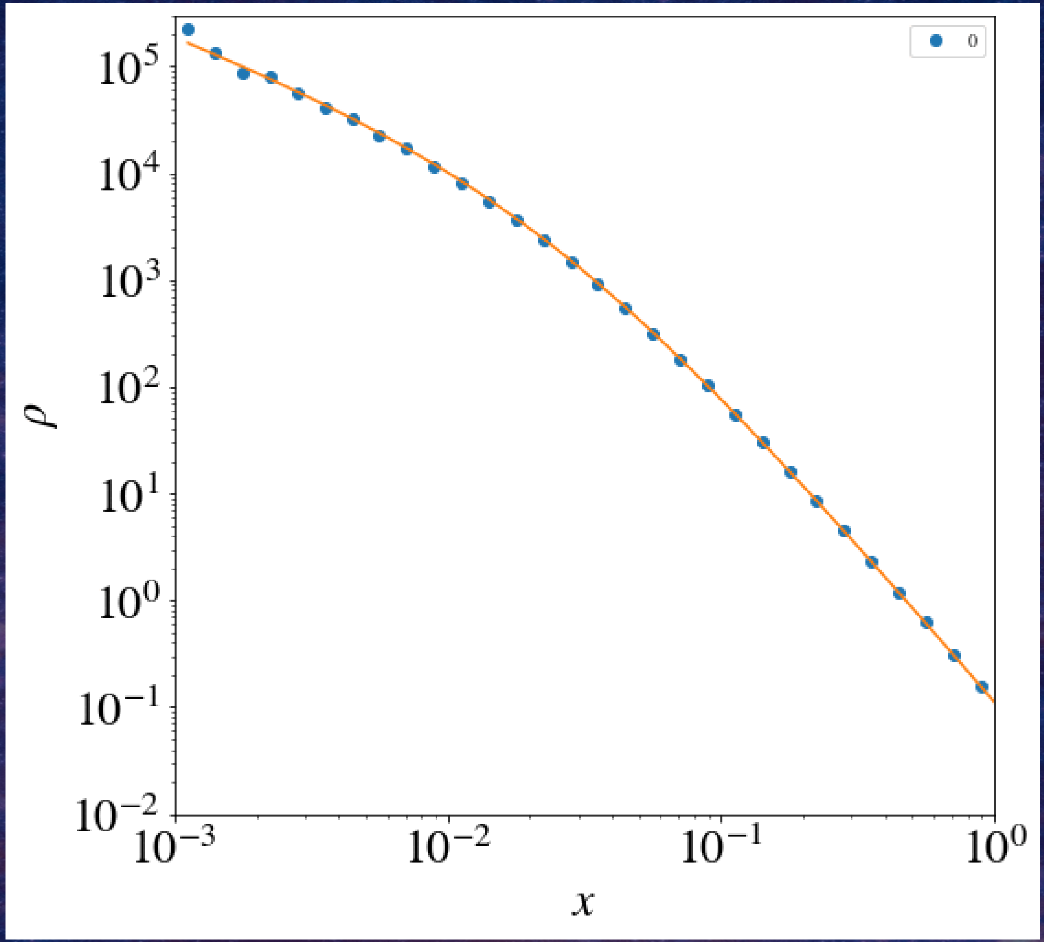
IV. Accretion redshift



An earlier accretion redshift means a higher number of orbits and larger mass loss

Later accretion redshifts induce a larger orbital radius and thus more distant orbits

V. Evolution of radial profiles



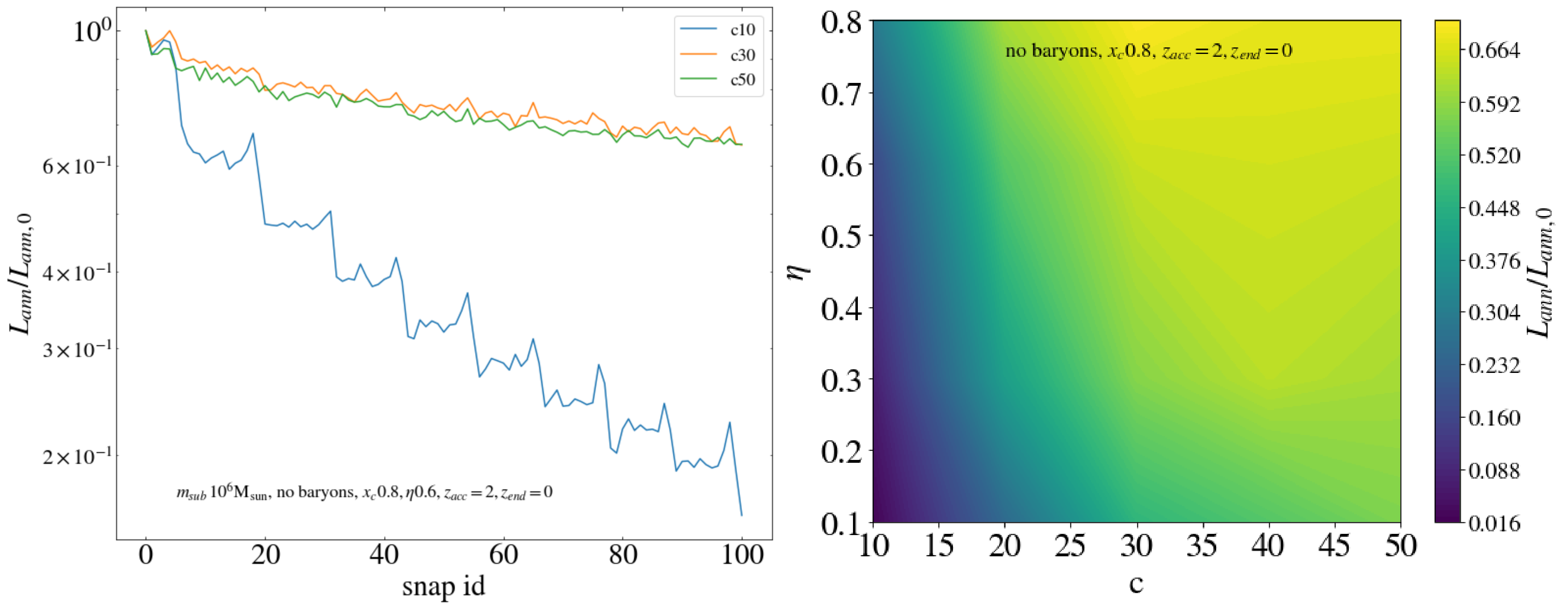
We model the subhalo internal structure as an NFW + exponential cutoff: (Kazantzidis+04)

$$\rho(r) = e^{-r/(r_s a)} \frac{\rho_s}{\frac{r}{r_s}\left(1+\frac{r}{r_s}\right)^2}$$

Subhalo profile gets truncated as mass loss takes place

$x = r/\, r_{vir,sub}\, (z_{acc})$

VI. WIMP annihilation luminosity



No baryon case

Annihilation luminosity is calculated as the integration of the density profile ρ squared

Concentration is the driving parameter here

Luminosity decreases by more than 30% even for the most concentrated subhalos, and can be only 1% of the initial one for the less concentrated ones

Conclusions

- Quantifying subhalo survival is crucial to understand the actual role of small subhalos in DM indirect searches
- We study subhalo survival with an improved versión of DASH (Ogiya+19)
- The host is described with an analytical potential
- We simulate subhalos with 2^{18} particles orbiting the host under different configurations: (no) baryons, concentrations, orbital parameters, accretion redshift…
- Our results show:
  - Elliptical orbits fixing x_c imply significantly larger mass loss
  - Subhalos initially more concentrated lose less mass
  - Including baryonic material induce larger mass loss
  - Luminosity can get significantly decreased as the subhalo loses mass
  - We checked different masses down to 1 M_{sun} finding similar results
- Future work: expand our parameter space (x_c) and study concentration evolution

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Thank you for listening!

Questions?