Shedding light on low-mass subhalo survival with numerical simulations

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in collaboration with

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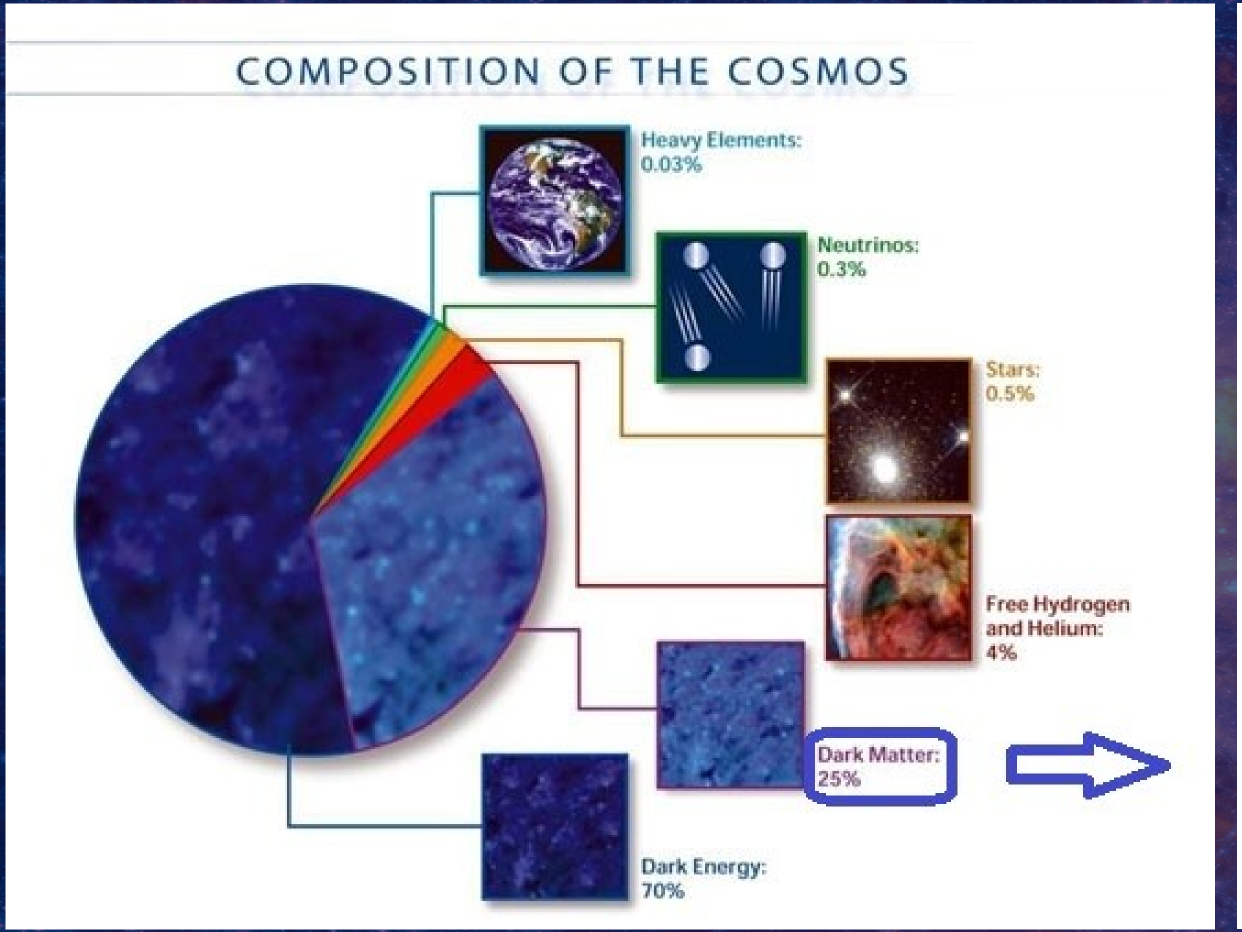
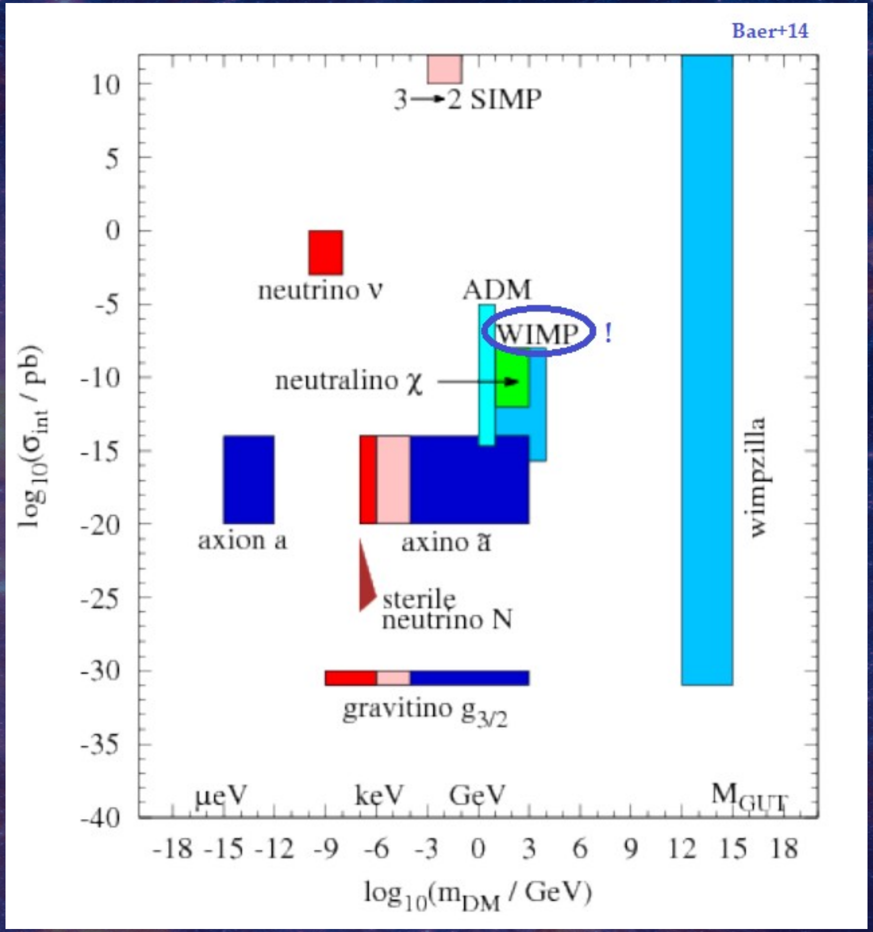
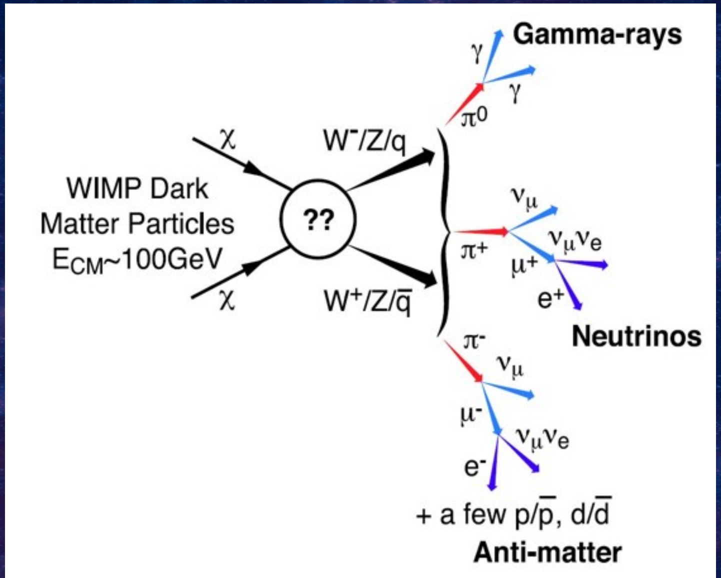
Introduction





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



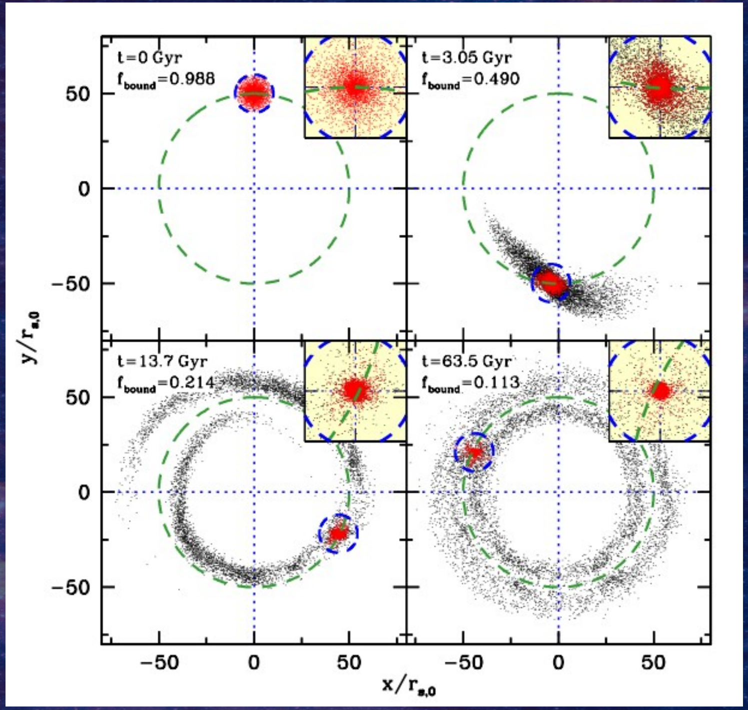

VL-II (Diemand+08)

This work

Main goal: shed light on subhalo survival via numerical simulations and study its impact for gamma ray searches

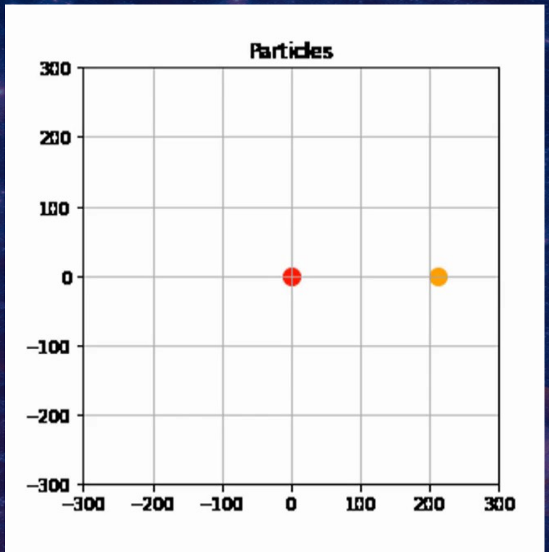
- We use a high-resolution numerical simulation to follow the evolution of the subhalo and choose several parameters:
  - Number of particles to simulate the subhalo
  - Softening length
  - Initial subhalo mass
  - Initial subhalo concentration $c = r_{vir} / r_s$
  - Accretion redshift
  - Orbital parameters: (Jiang+15)
    - Circularity $\eta = J / J_{circ}$ ($\eta = 0 \rightarrow$ radial, $\eta = 1 \rightarrow$ circular)
    - Orbital energy parameter $x_c = r_c(E) / r_{vir,h}(z_{acc})$
  - Inclusion (or not) of baryons in the host potential
- The subhalo will lose mass mainly in every

van den Bosch & Ogiya 18

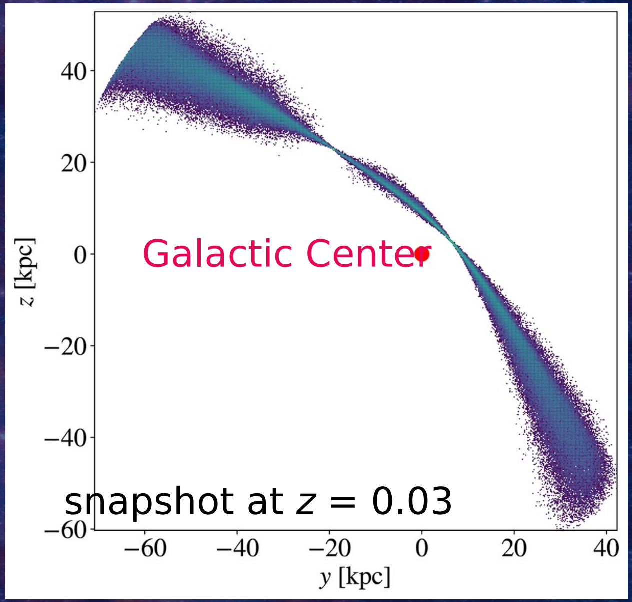


Our code: DASH

- 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

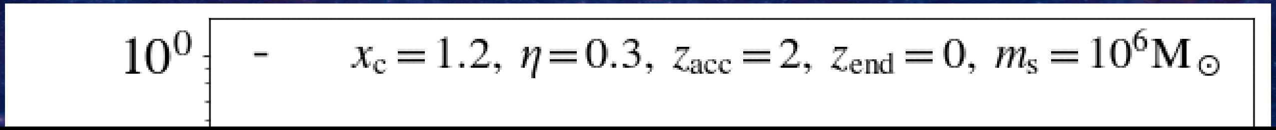


by J. Stücker



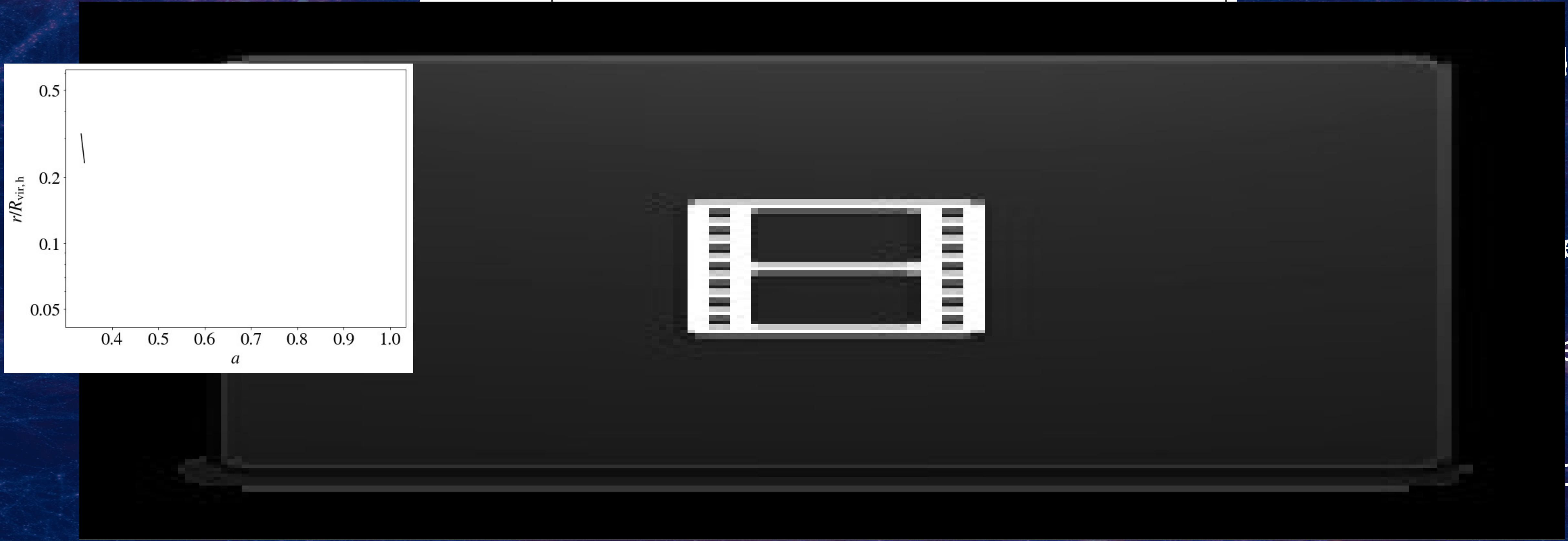
Simulation results

I. Bound mass fraction (f_b)



This subhalo loses

r



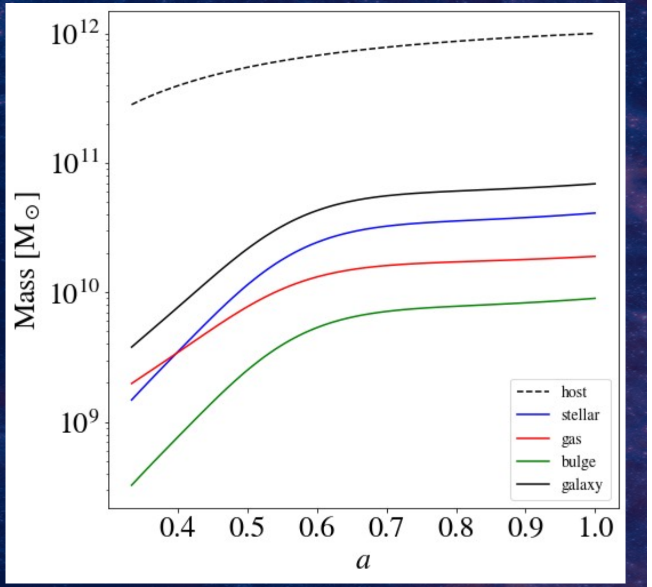
e

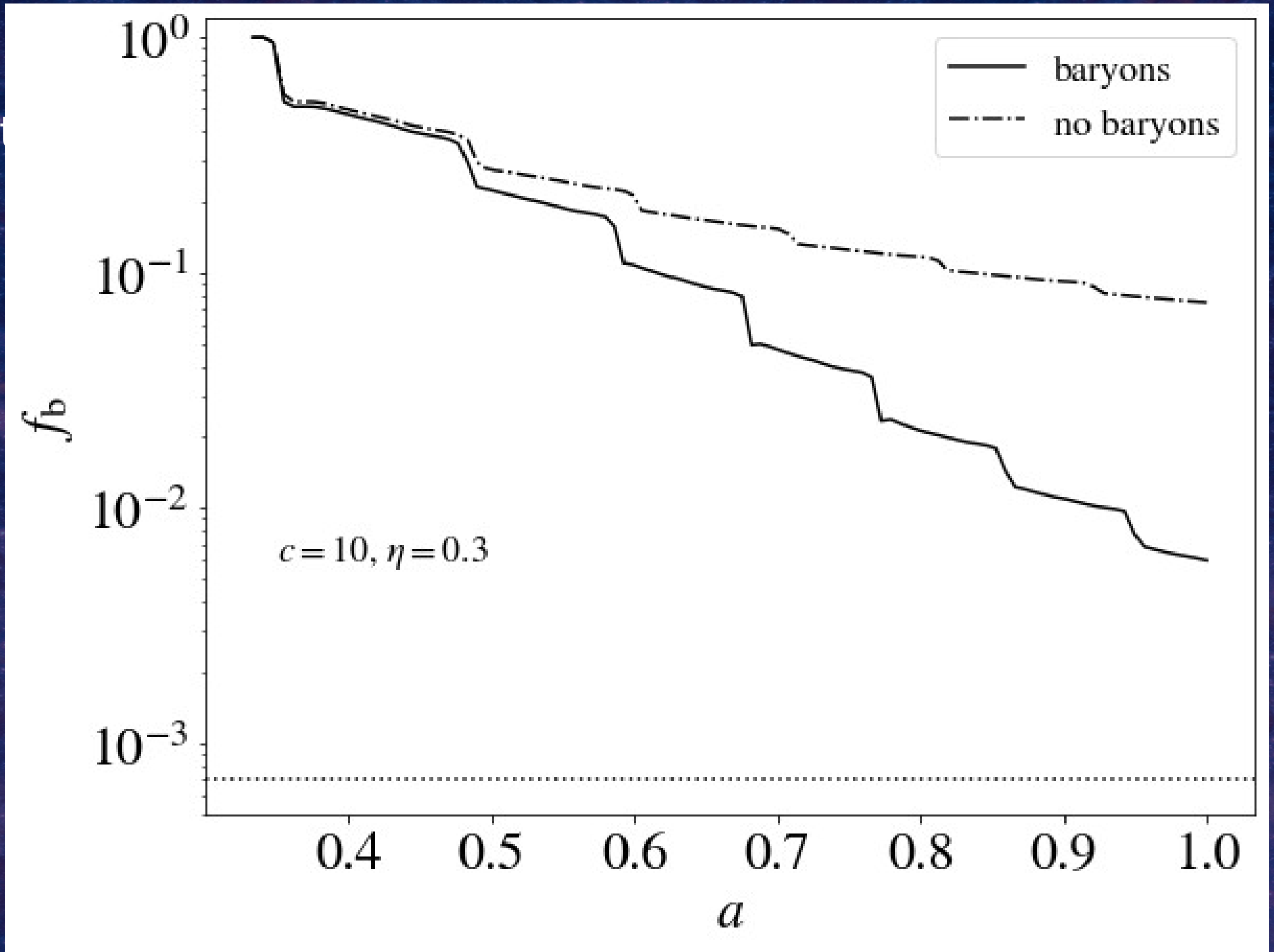
e

18)

I. Bound mass fraction (f_b)

Evolution of baryonic components (following Kelley+19)



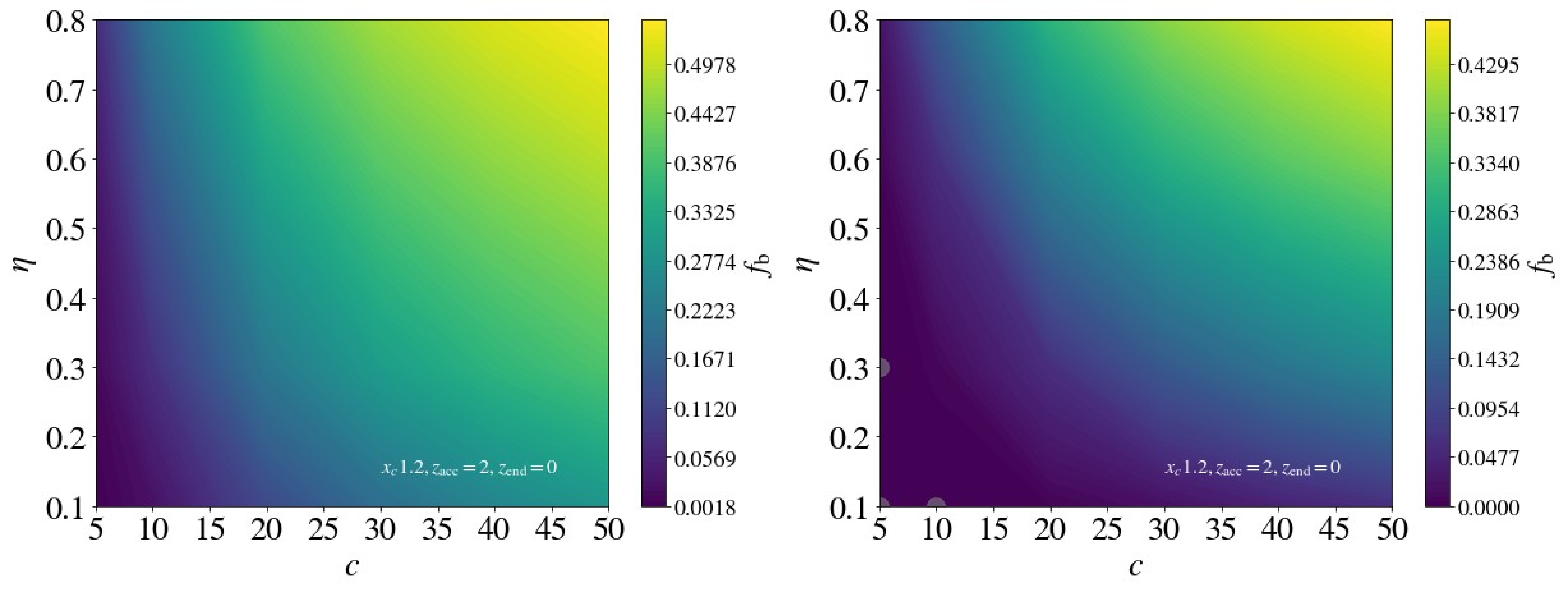


When baryons are included, the subhalo undergoes a larger mass loss, since the tidal stripping is enforced, specially near the pericenter due to baryons

When x_t is fixed, subhalos with more circular orbits (larger $\eta \rightarrow$ larger pericenter) experience a smaller tidal field due to baryons

And the other way around: Even though the concentration is larger, the mass loss is significantly increased due to baryons for subhalos in very eccentric orbits

I. Bound mass fraction. Big picture

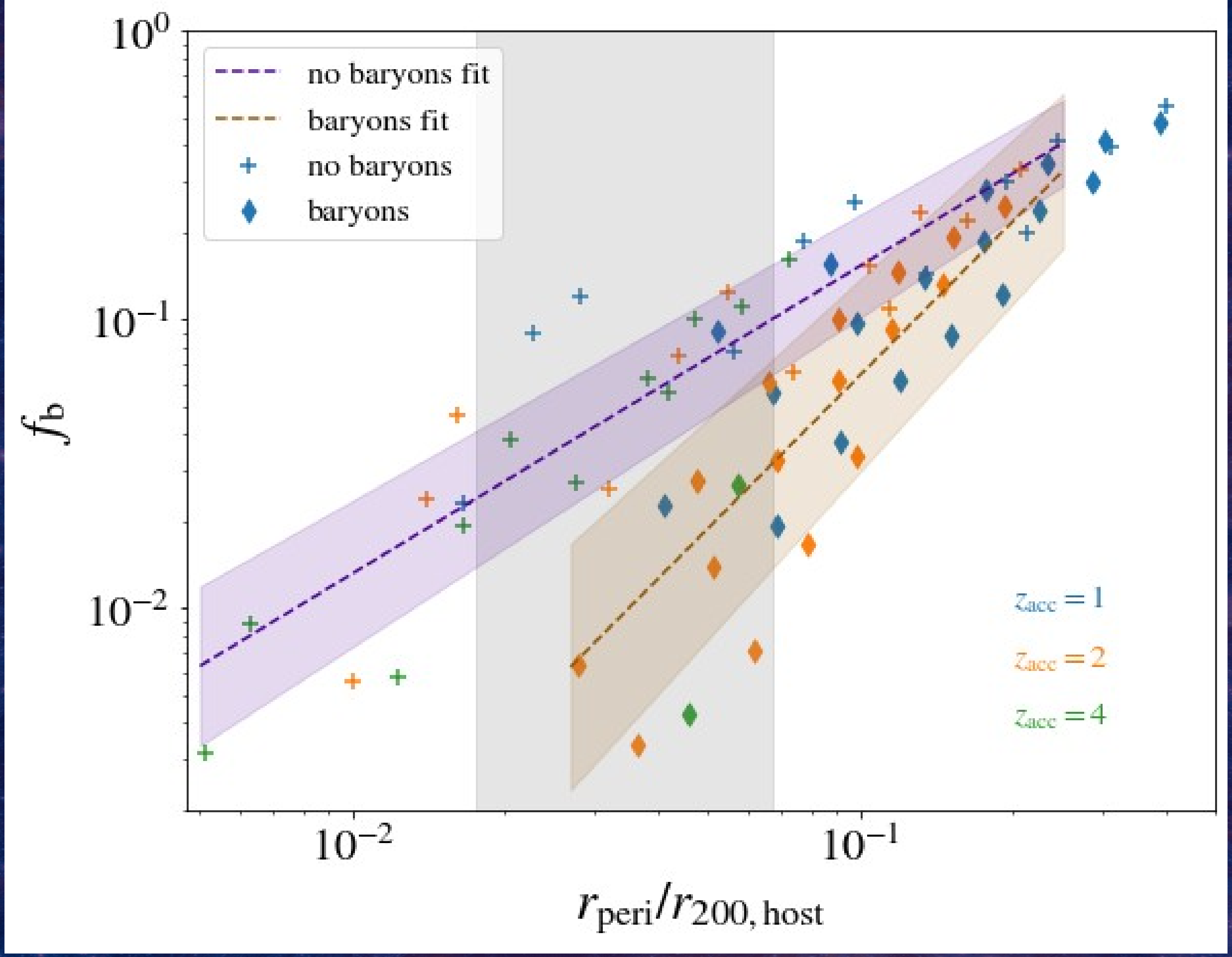


η values motivated by Jiang+15

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

gray points: no numerical convergence

f_b-pericenter relation



We find a power-law behaviour of f_b against the pericenter of the orbit (with some scatter)

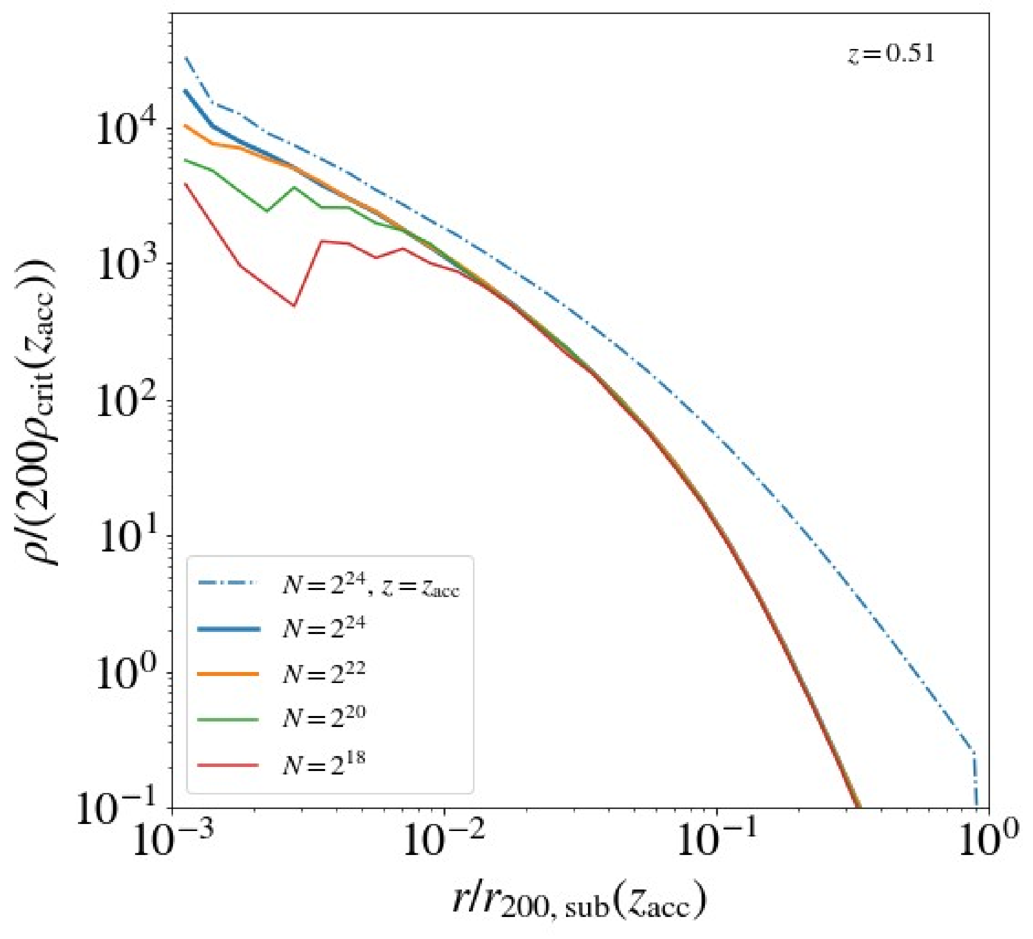
$f_b = c\, x^m$

	m	$\log_{10} c$
no-baryons	1.07 ± 0.08	0.25 ± 0.10
baryons	1.77 ± 0.16	0.58 ± 0.17

The pericenter distance is the driving parameter!

II. WIMP annihilation luminosity (L)

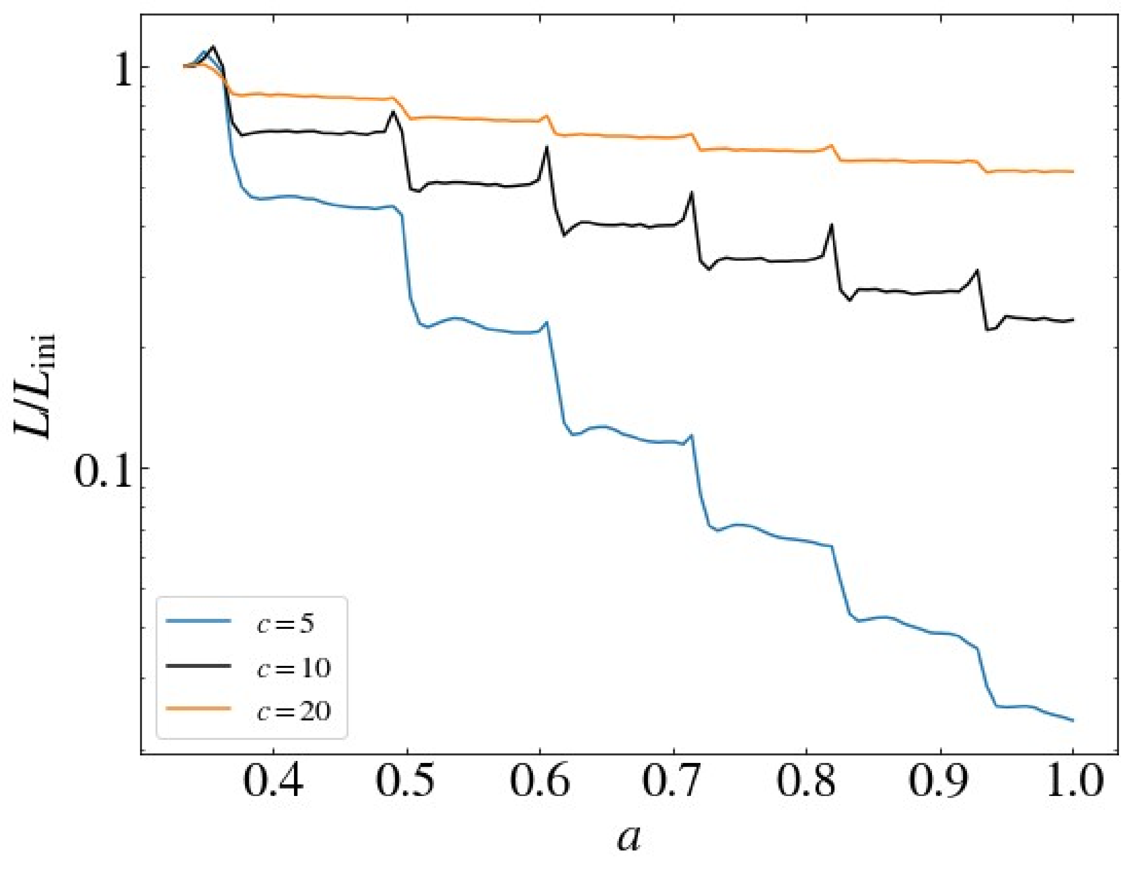
DM density profile

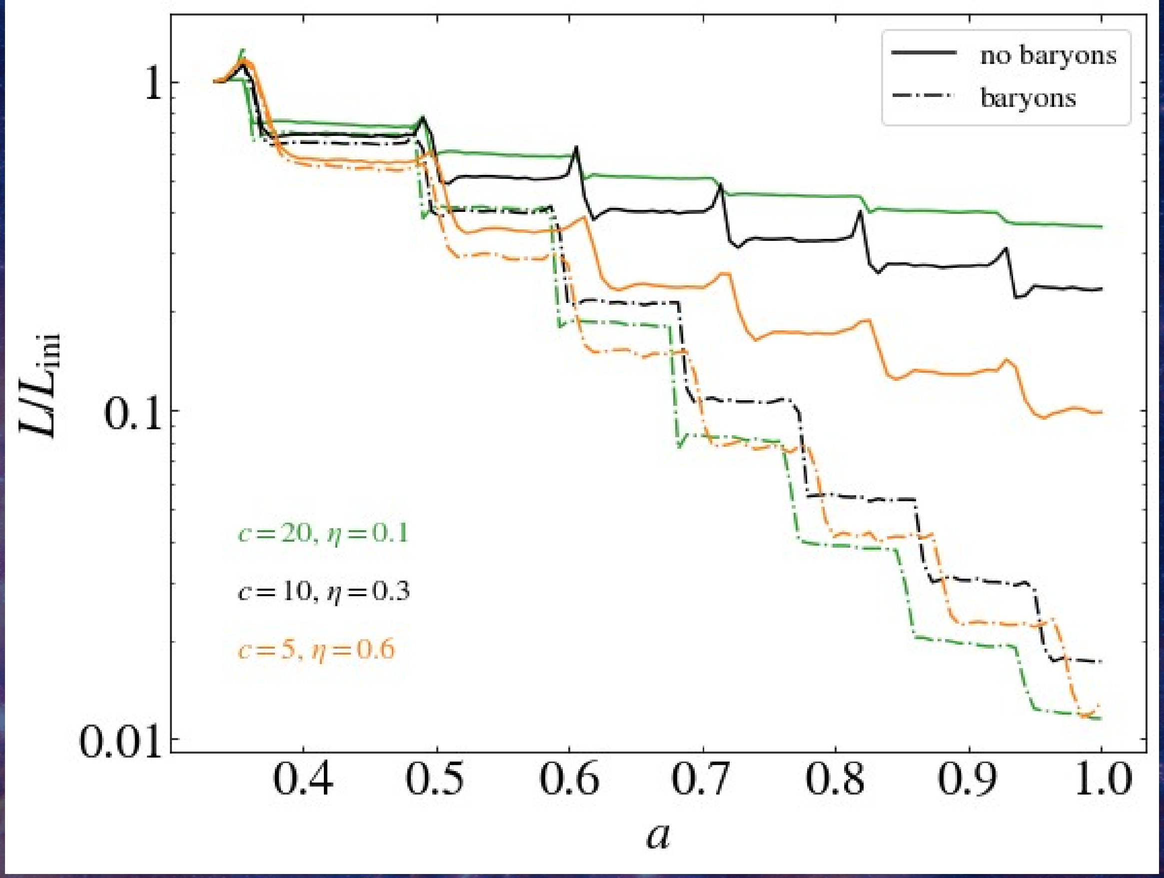


The subhalo DM density profile gets truncated as the mass loss takes place

The innermost part of the subhalo is not obtained accurately when the numerical resolution is insufficient

II. WIMP annihilation luminosity (L)



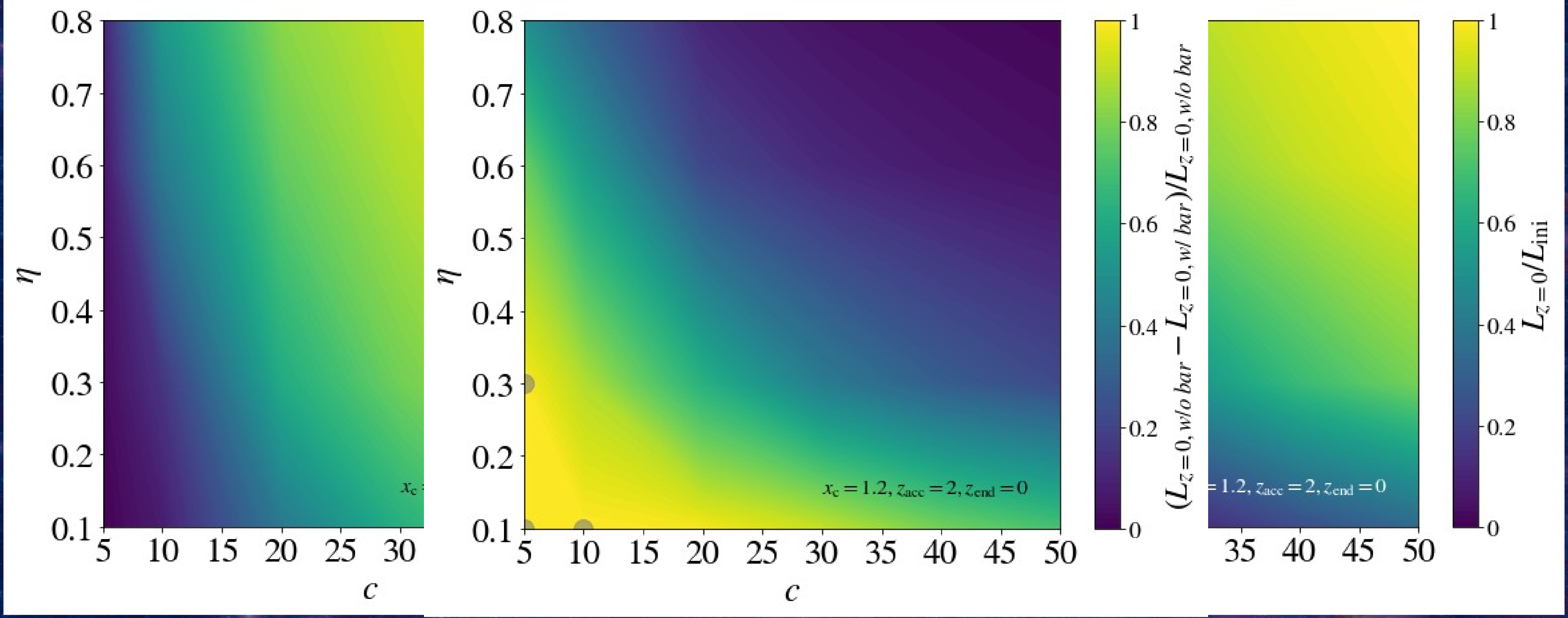


L is calculated as the integration of the density profile ρ squared

same behaviour as $f_{\rm b}$

we expect some subhalos to lose ~99% of their initial

II. WIMP annihilation luminosity (L)

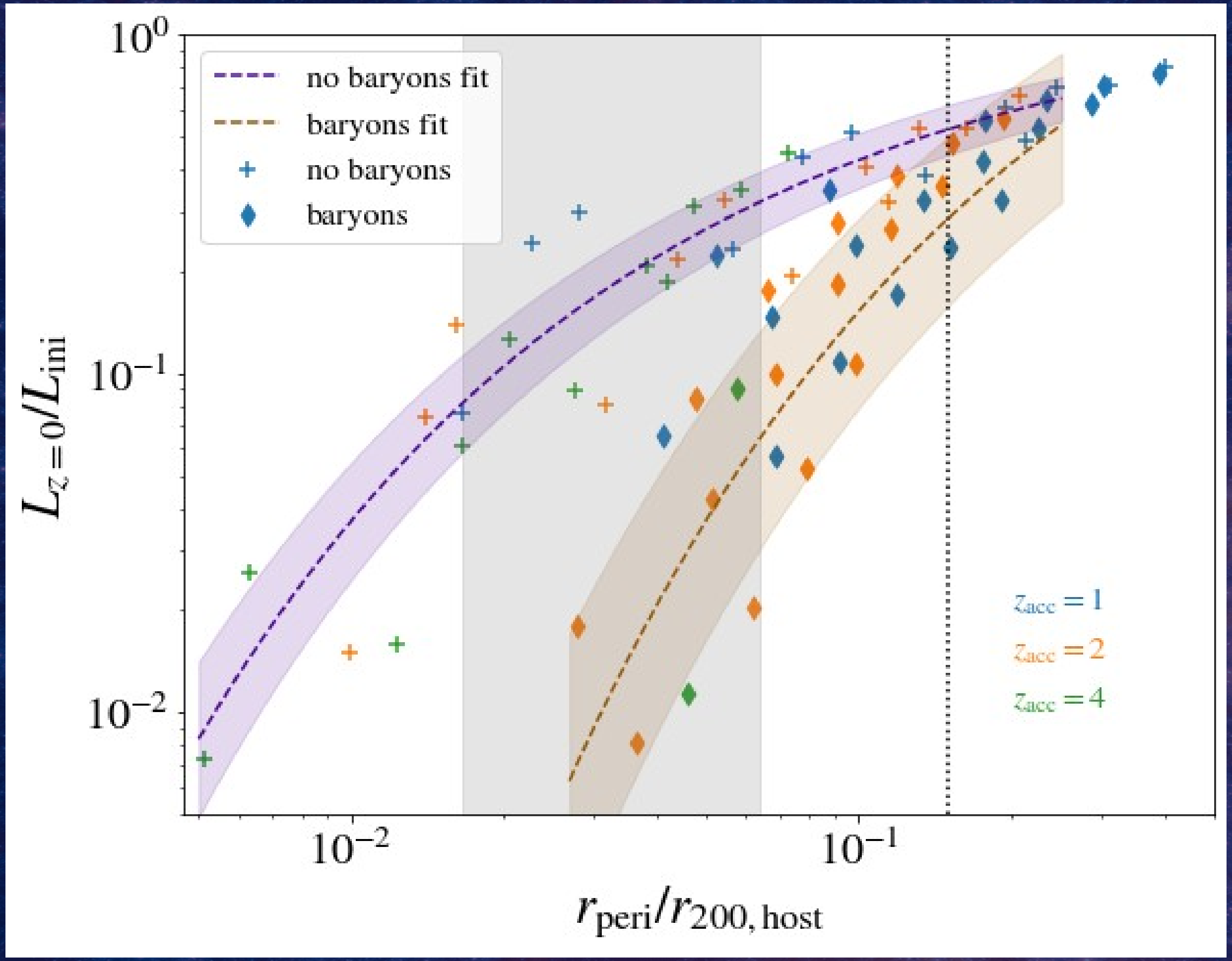


Concentration is the driving parameter when baryons are not included

Subhalos in eccentric orbits are affected by baryons even if their concentration is high

The relevance of the circularity increases when one adds baryons

L-pericenter relation



Subhalos in the solar neighbourhood would have lost 60~90% of their initial annihilation luminosities without baryons and 90~99% with baryons

$L_{z=0} /L_{ini} = c \cdot m^{-1/}$

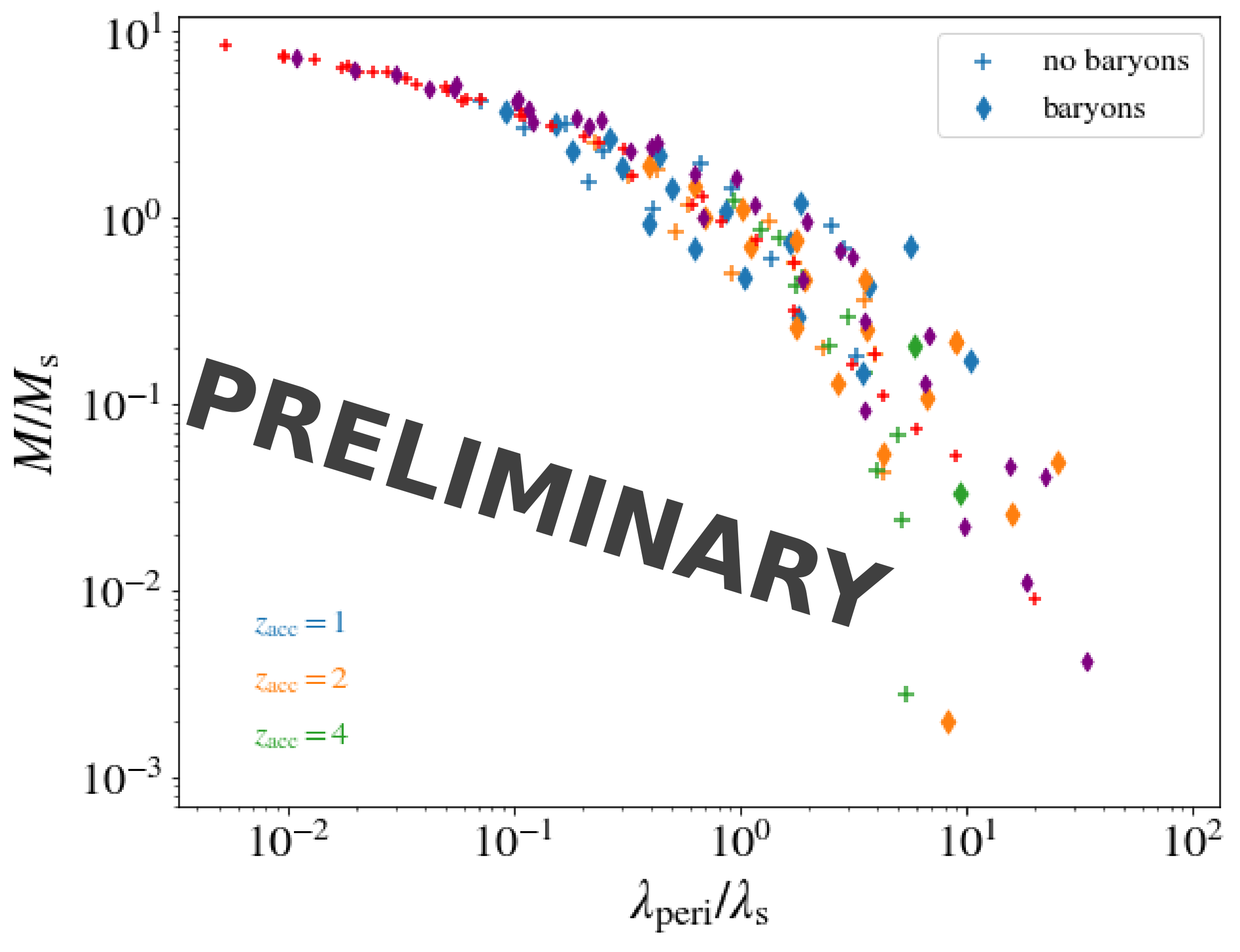
m

c

no-baryons 1.43 ± 0.04 1.3 ± 0.1

baryons 3.0 ± 0.4 5 ± 1

f_b-tidal field relation



λ: largest eigenvalue of a "tidal tensor"

Degeneracy in concentrations, orbital parameters, accretion redshifts and (non)-inclusion of baryons!

Conclusions

- Quantifying subhalo survival is crucial to understand the actual role of small subhalos in DM indirect searches
- We simulate subhalos with $10^{5\sim7}$ particles orbiting the host under different configurations: (no) baryons, concentrations, orbital parameters, accretion redshift…
- The host is described with an analytical potential
- Our results show:
  - Pericenter passages drive both mass and annihilation luminosity loses
  - Including baryonic material induces 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
  - The tidal field drives the mass loss
  - **Most subhalos don't disrupt even after losing more than 99% of their mass**
- Future work: study the evolution of concentrations, v_{max} and r_{max}

Thank you for listening!

Questions?

Back-up slides

I. Bound mass fraction (f_b)