Probing SIDM with Galactic halos

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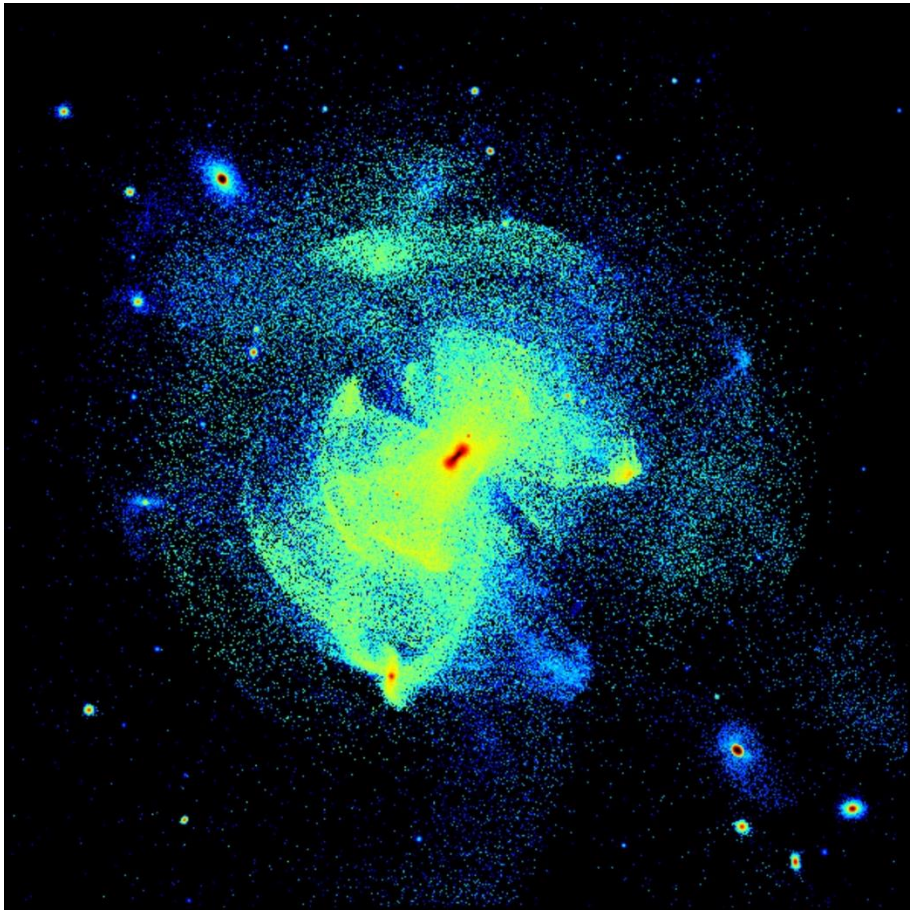
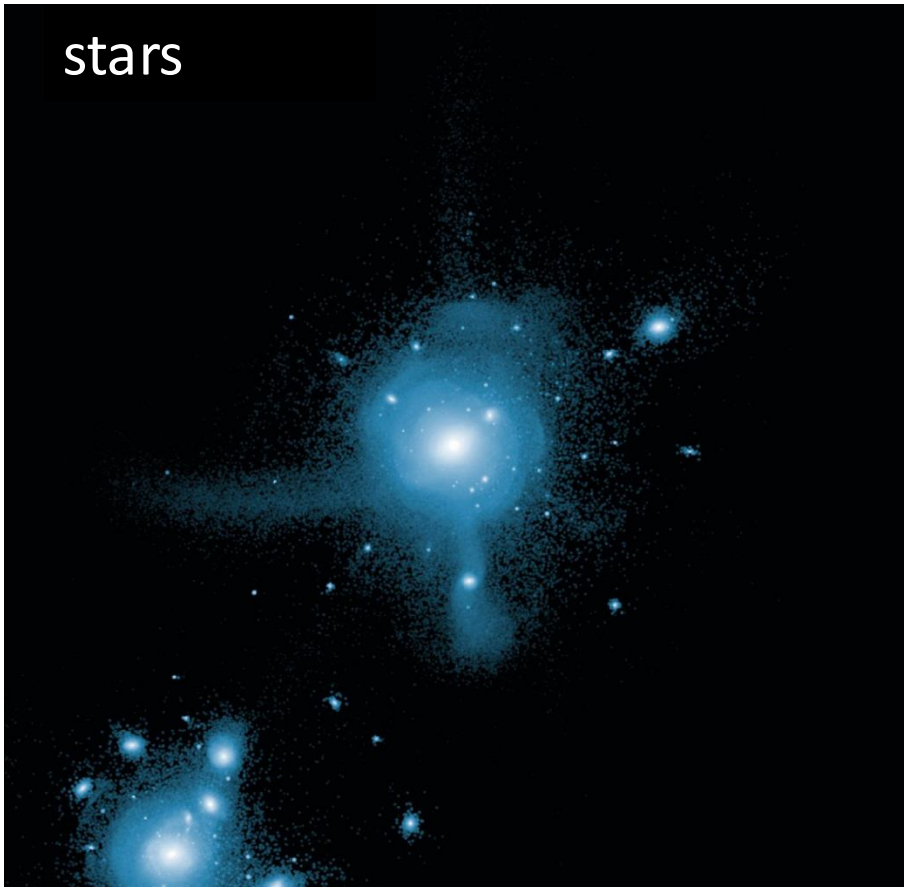
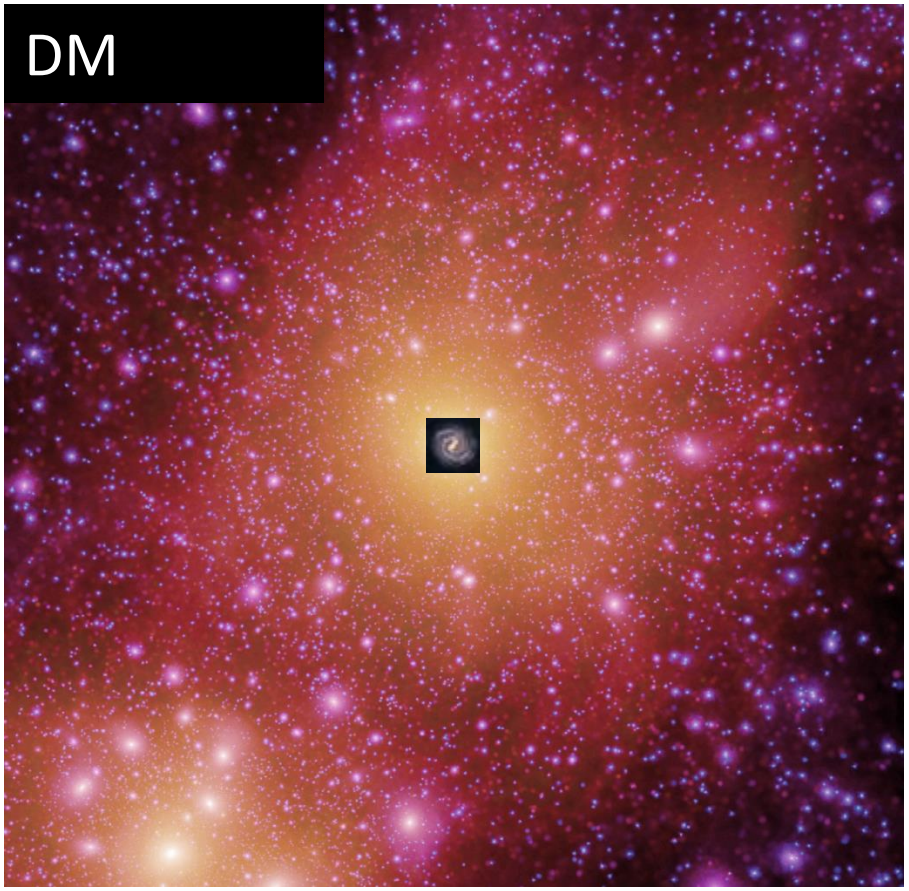
Small Scale Structure & SIDM
Valencia – June 2025



Stockholm University

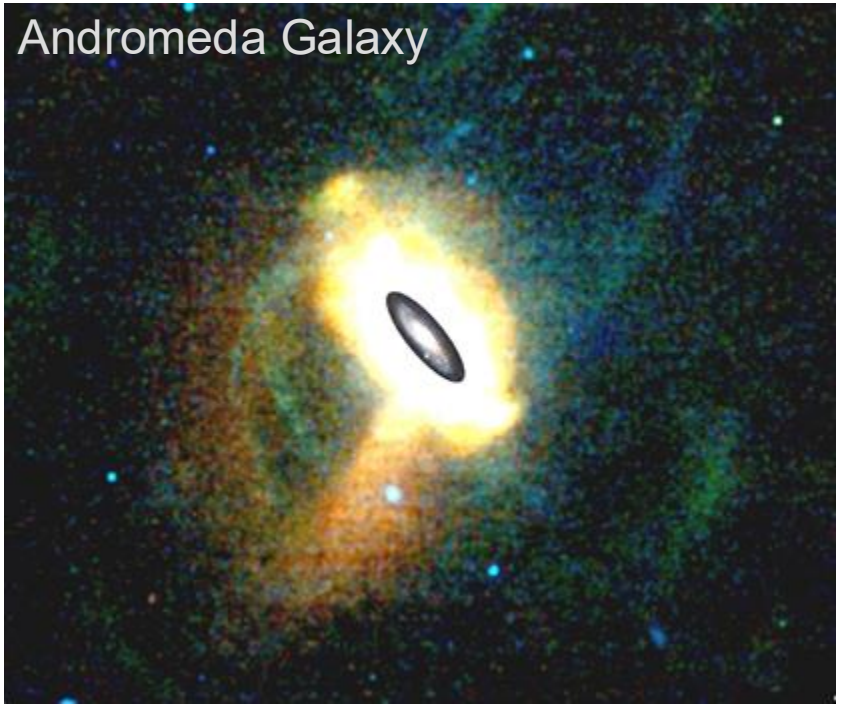
Disrupted (dwarf) galaxies and the formation of Galactic halos





APOSTLE Local Group simulations
(AF+2016, Sawala+2016)
Image: M. Lovell

Disrupted (dwarf) galaxies and the formation of stellar halos



PAndAS survey

Duc/Cuillandre/CFHT/Cole

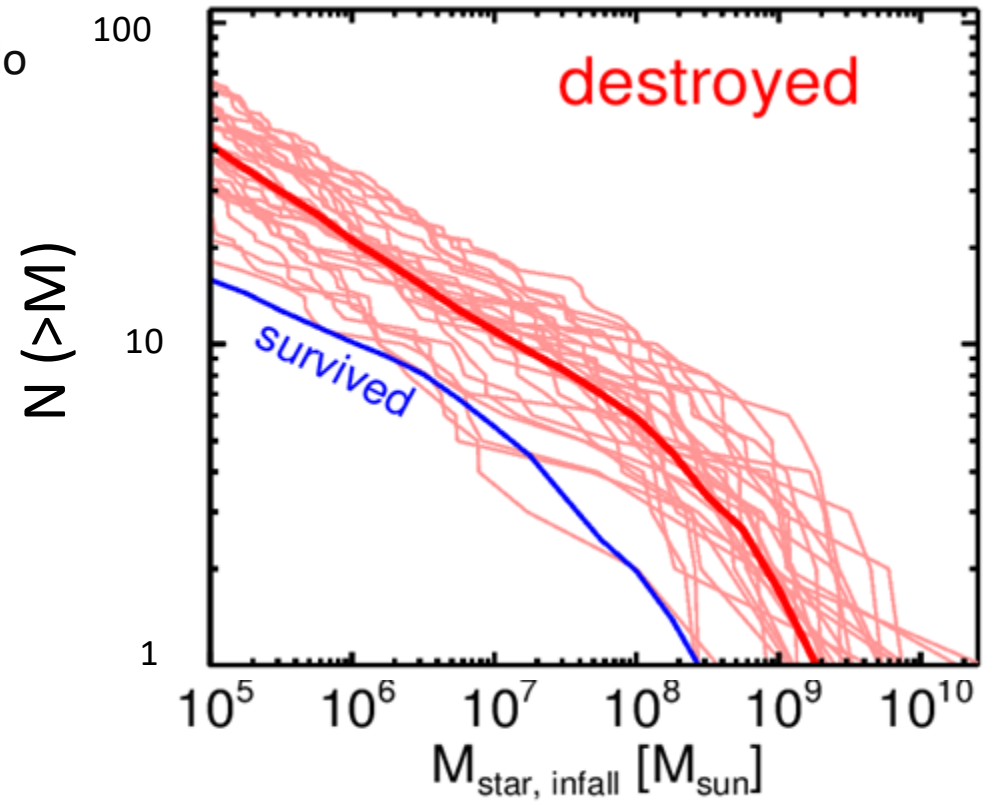
Disrupted (dwarf) galaxies and the formation of Galactic halos in CDM

Mass spectrum of destroyed dwarf galaxies (halo progenitors) in Milky Way-mass CDM haloes
based on 30 Auriga cosmological simulations

- A few tens of dwarf galaxies contribute towards the formation of Galactic halos
- The mass budget is dominated by the few more massive objects
- Dynamical friction drags these massive ones towards the centre, and radializes the orbits

(see, Deason+2016, Monachesi+2019, AF+2020, Amorisco+2017)

AF et al. 2020



How do things differ when looking into alternative dark matter models, such as self-interacting (SIDM), that affect low mass dark matter halos?

Victor Forouhar-Moreno - arXiv: 2407.05899
Fergus Henstridge + Alis Deason , Alex Riley,

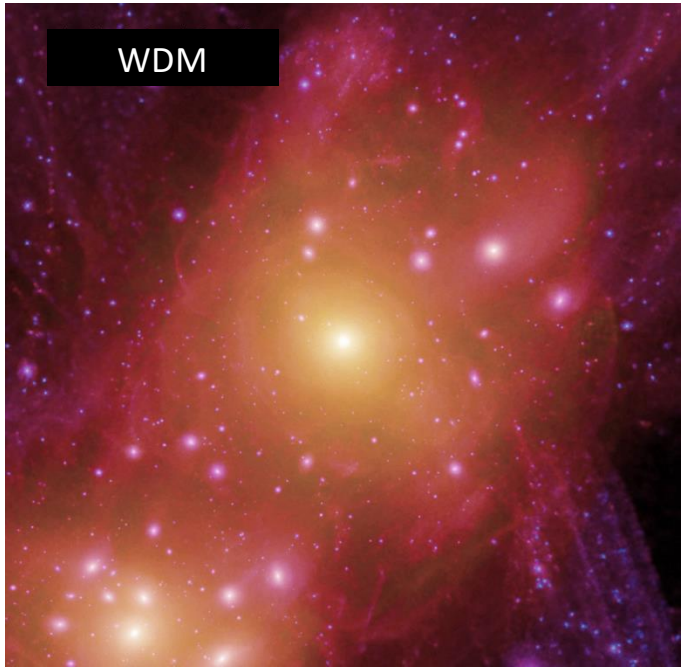
Alternative dark matter models: warm and self-interacting

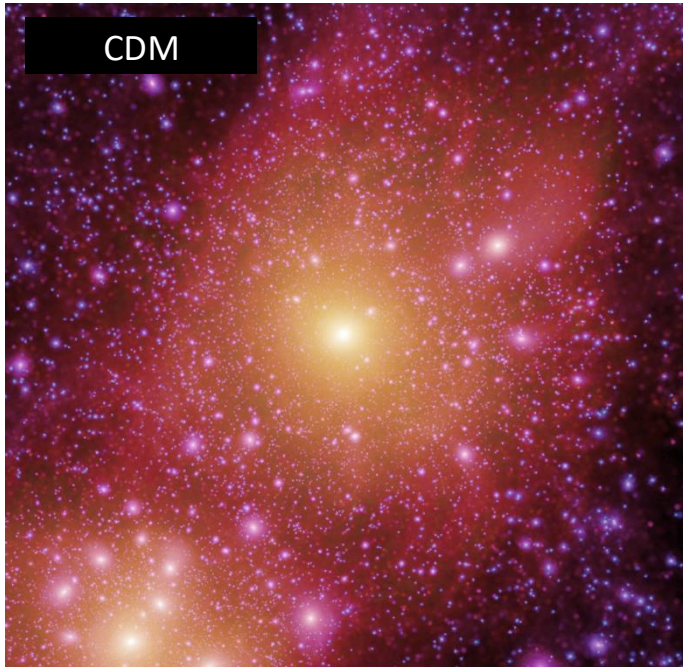
WDM

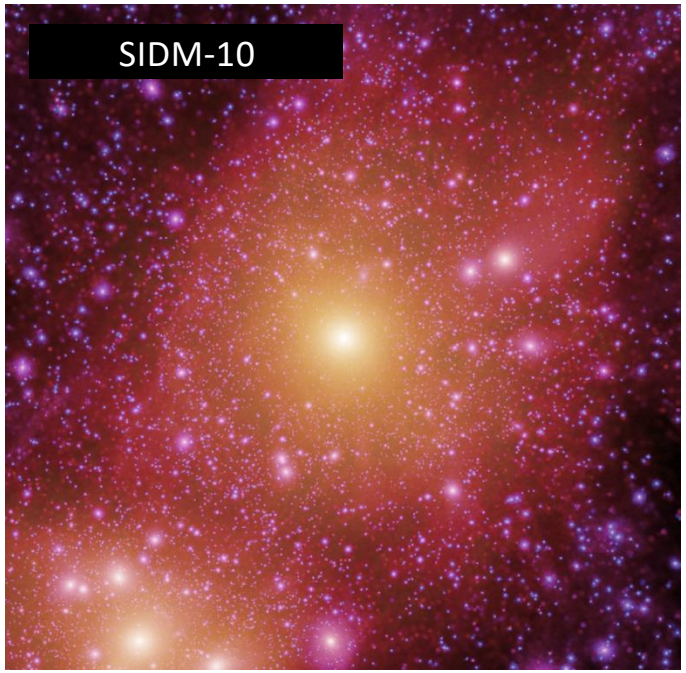
- Suppression of power at small scales -> lower abundance of low mass halos/subhalos
- Delay in formation time of the lower mass halos -> Lower concentration of DM halos

SIDM

- No change in the abundance of field low mass halos
- (self)interaction between DM particles thermalizes the inner regions of halos -> shallow DM density profiles in the centre





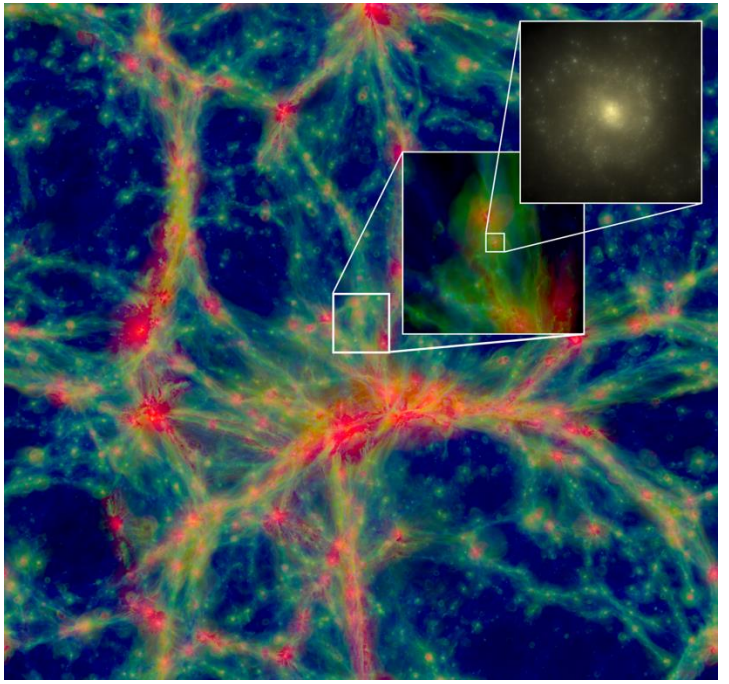


Simulations

Simulations presented in Forouhar-Moreno+2022

- periodic box with side length of 12Mpc
- Ran with P-Gadget3
- Galaxy formation model: EAGEL
- Resolution: $\sim 8 \times 10^4 M_\odot$ gas/stars
- 8 halos with halo mass $\sim 10^{12} M_\odot$

we looked into a higher resolution runs from the APOSTLE Local Group simulations and found similar results.



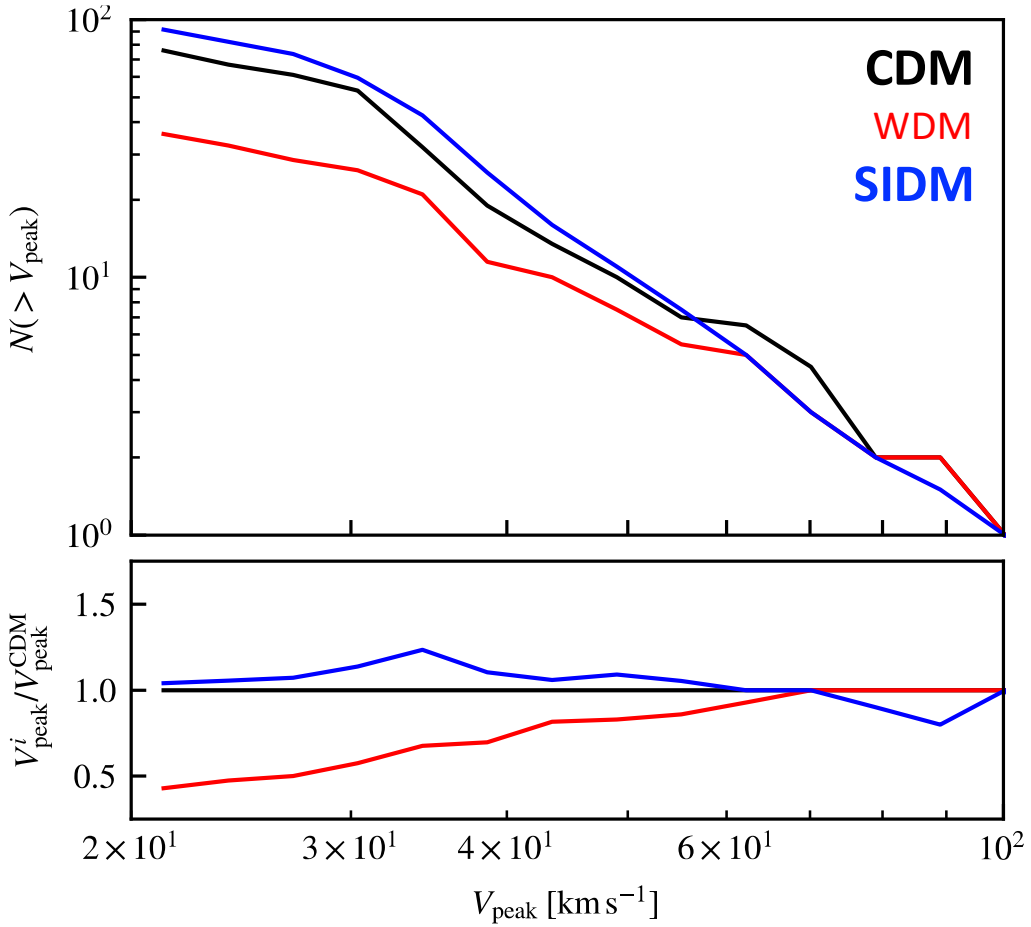
WDM flavour
Thermal mass: 2.5 keV
Half-mode mass: $\sim 10^9 M_\odot$

SIDM flavour:
Constant cross section of 10 cm^2/gr
~ few kpc DM cores in dwarf scale; ~ 10kpc DM cores in Milky Way-size halos

Disrupted dwarf galaxies (halo progenitors) in various DM models

Mass spectrum of disrupted objects (halo progenitors)

- There are fewer disrupted objects in WDM
- There are more disrupted objects in SIDM



Peak mass before infalling to the MW-mass halos

Forouhar-Moreno, AF, Deason et al. 2024

Density profiles of halos in various DM models

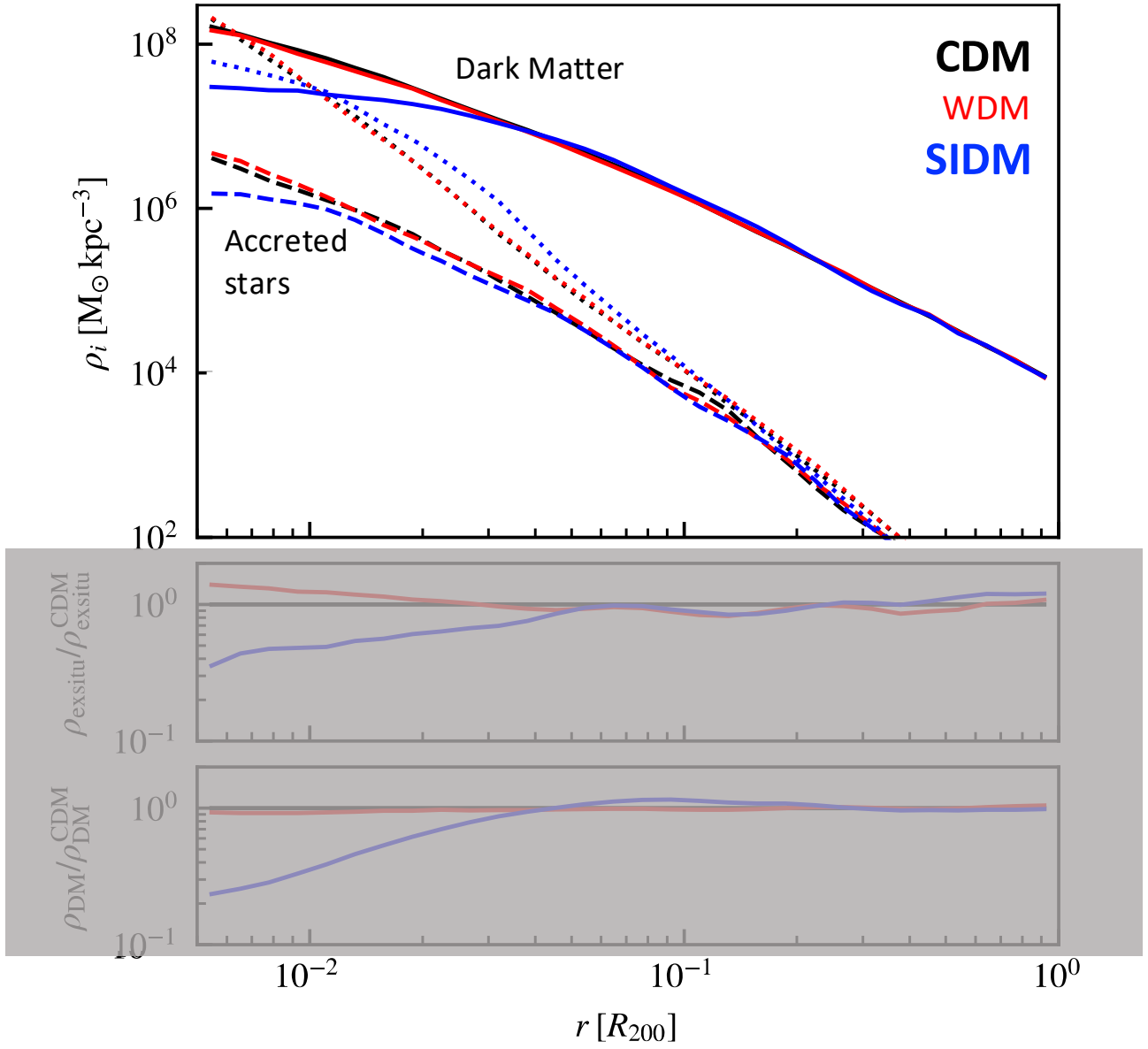
DM halos:

WDM and CDM are similar
SIDM is flatter in the centre

Stellar halos:

WDM is very similar to CDM

SIDM is shallower than CDM

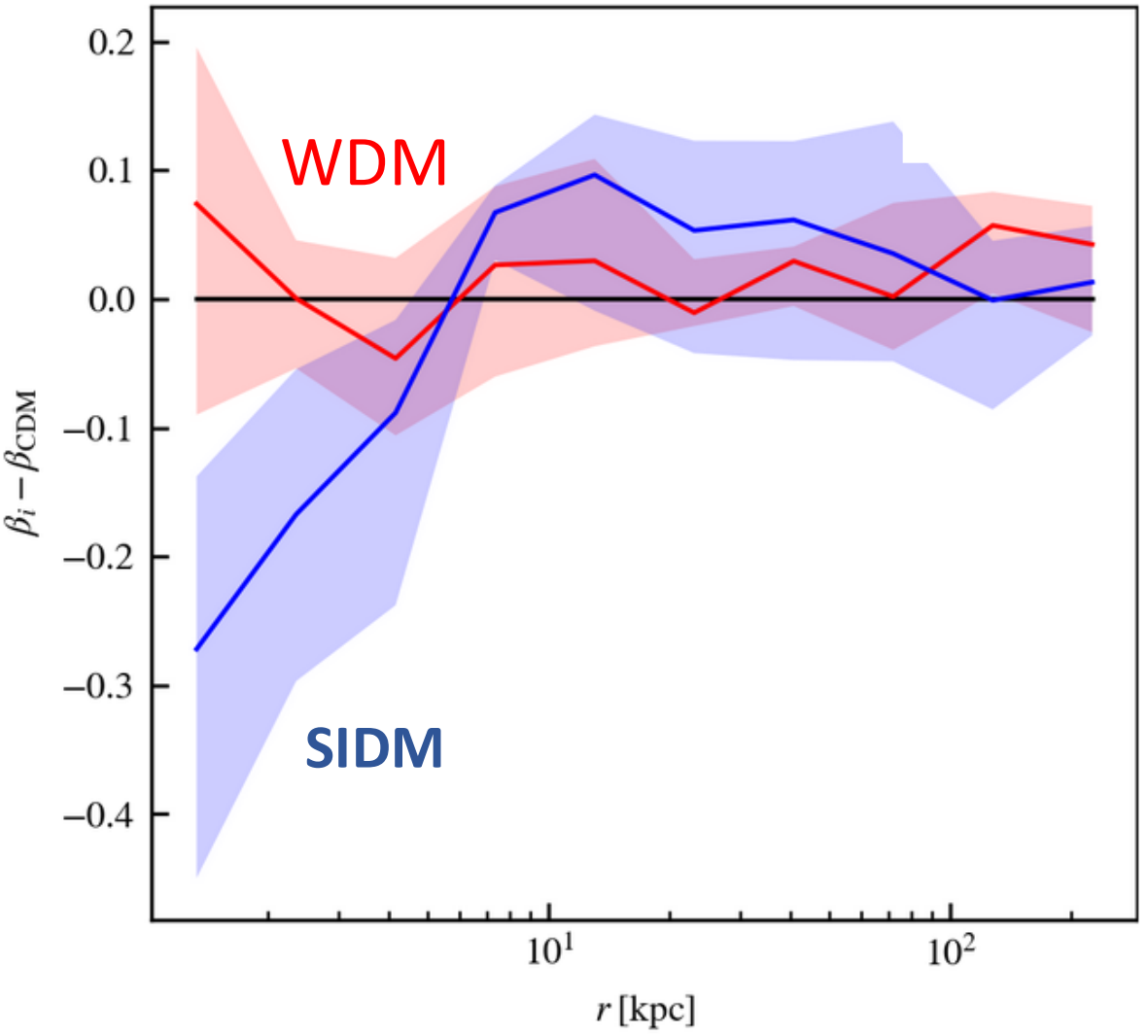


Kinematics of stellar halos in various DM models

Velocity anisotropy profile of stellar halos (relative to CDM)

$$\beta = 1 - \frac{\sigma_\theta^2 + \sigma_\phi^2}{2\sigma_r^2}$$

The inner regions of SIDM Galactic halos are less radial than CDM

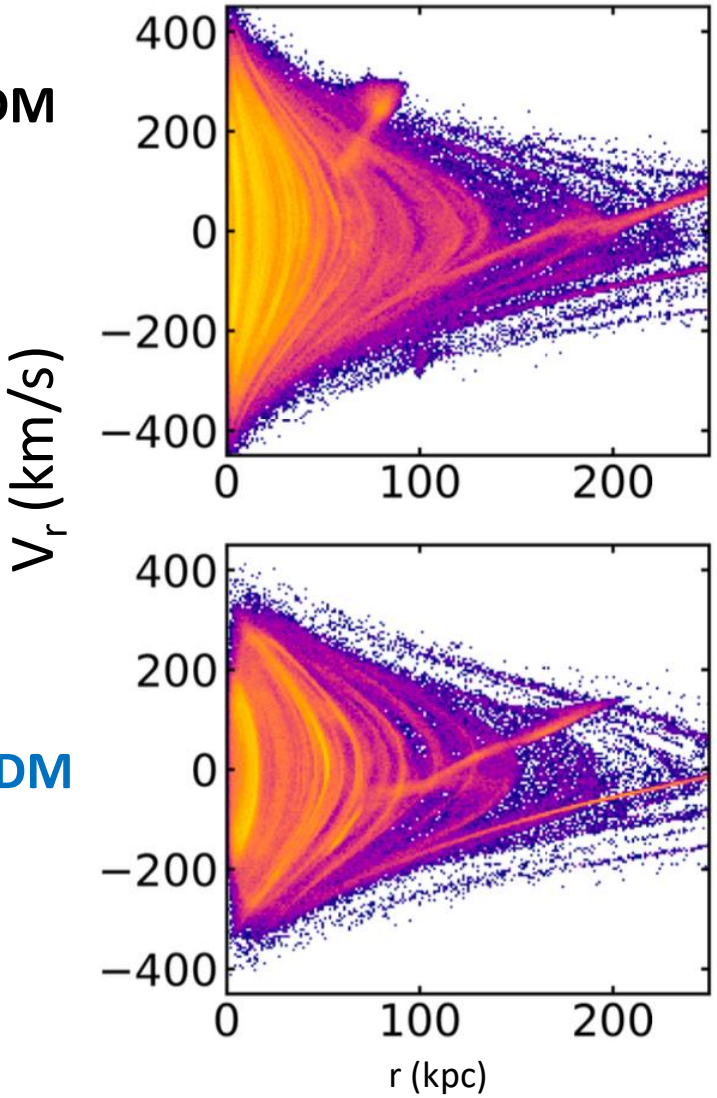


Kinematics of stellar halos in various DM models

Based on APOSTLE high res runs

CDM

SIDM



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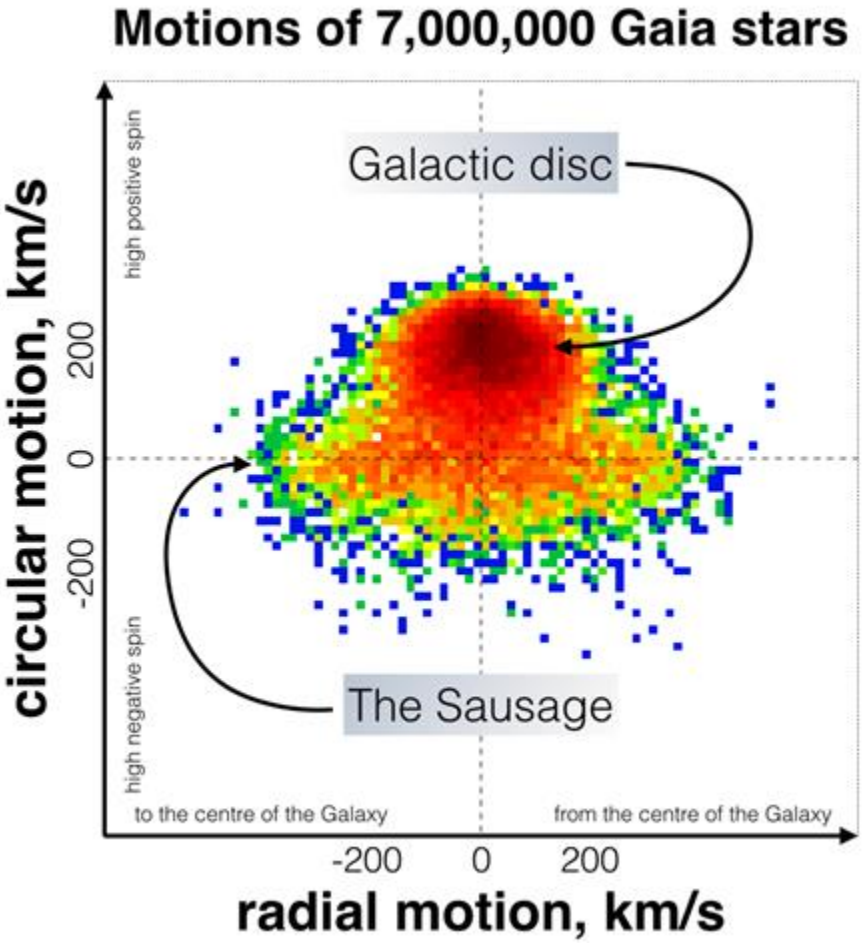
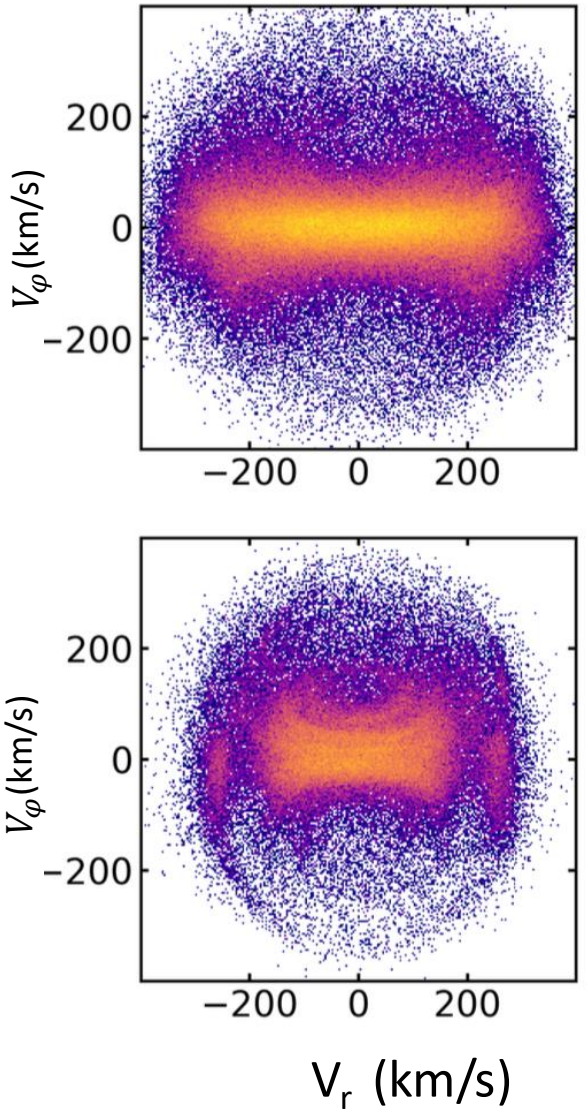


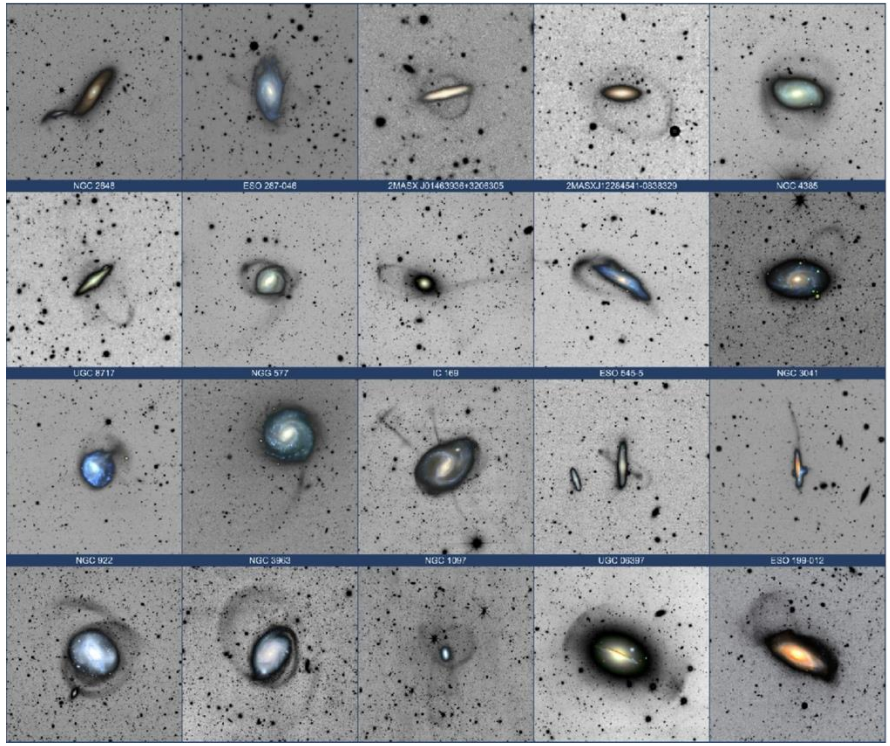


ARRAKIHS

ESA F2 MISSION (selected in Nov 2022, full adoption in 2026, launch around 2030)
Lead by Spain - PI: Rafael Guzmán

Science goal:

Observing the low-surface brightness (sub)structures around Milky Way-like halos for probing galaxy formation and dark matter physics on small scales.



Credit: Martinez-Delgado

Observing strategy:

Survey: > 80 MW-like galaxies

Total Observing time: 150 hrs/gal

SBlim ≤ 31 mag arcsec^{-2}

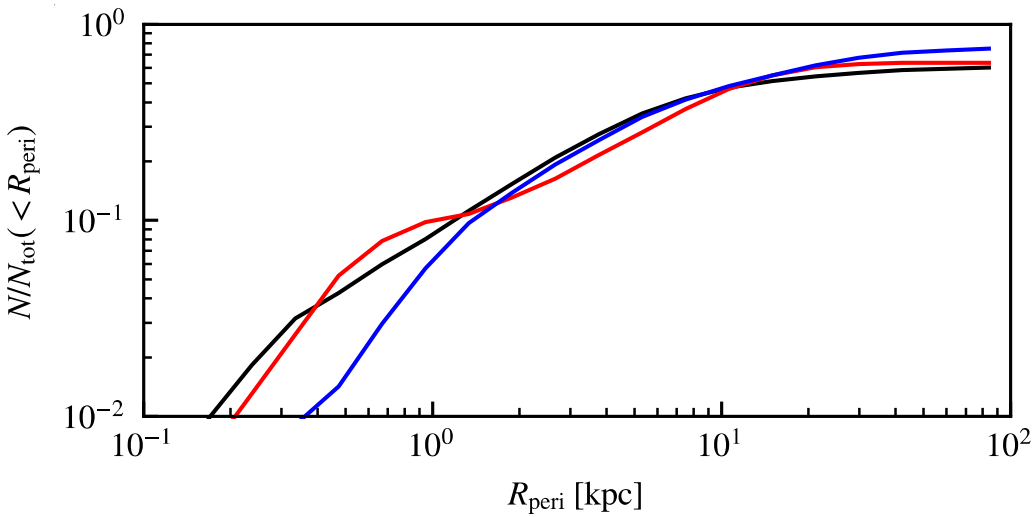
Key takeaway points on Galactic halos in CDM, (WDM) & SIDM

- Despite the change in the abundance of dwarf galaxies, stellar halos in WDM are very similar to CDM

- Stellar halos in SIDM (cross section: 10 cm^2/gr) have flatter density profiles in the centre, with significant differences in kinematics.
- Most noticeable: stars in the central regions of stellar halos in SIDM are in less radially biased orbits.

Disruption of dwarf galaxies in various DM models

V_{peak} < 50 km/s



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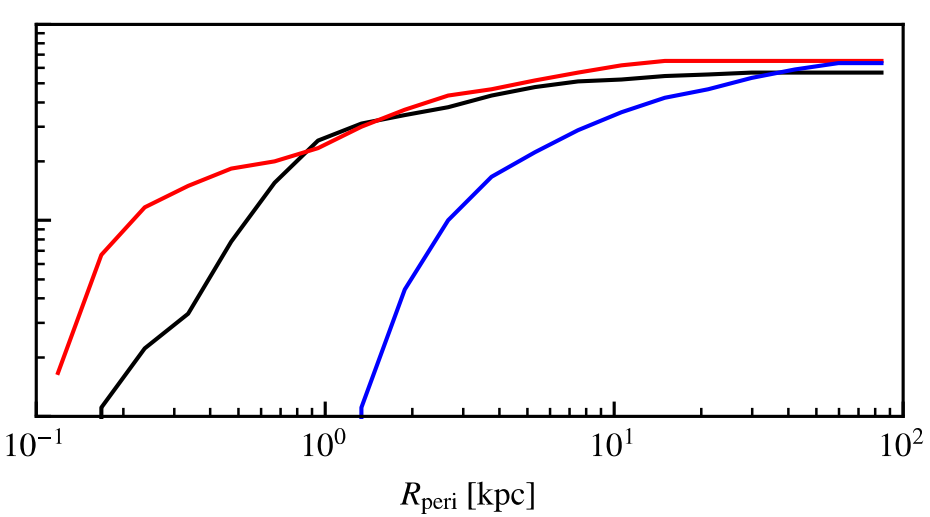

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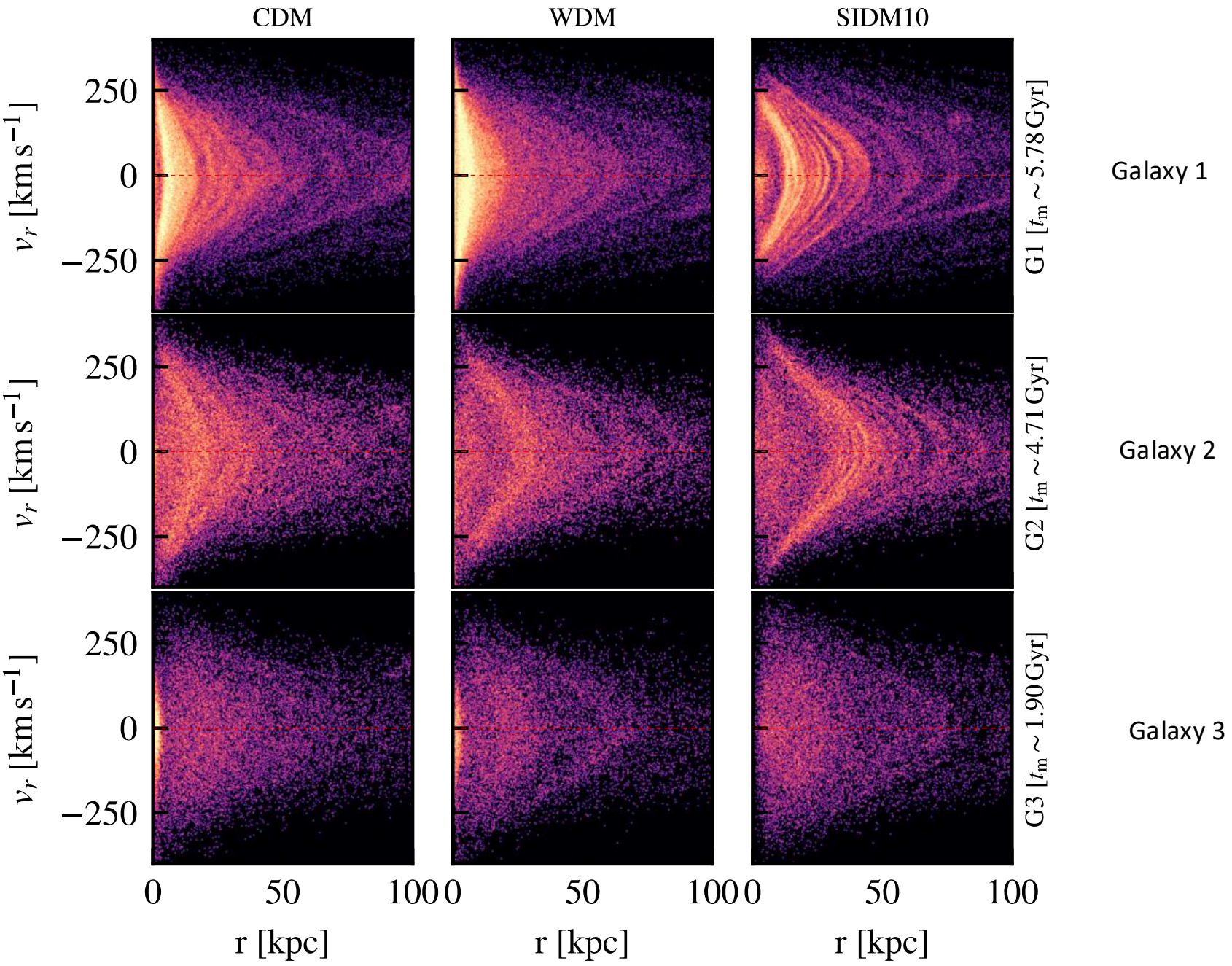
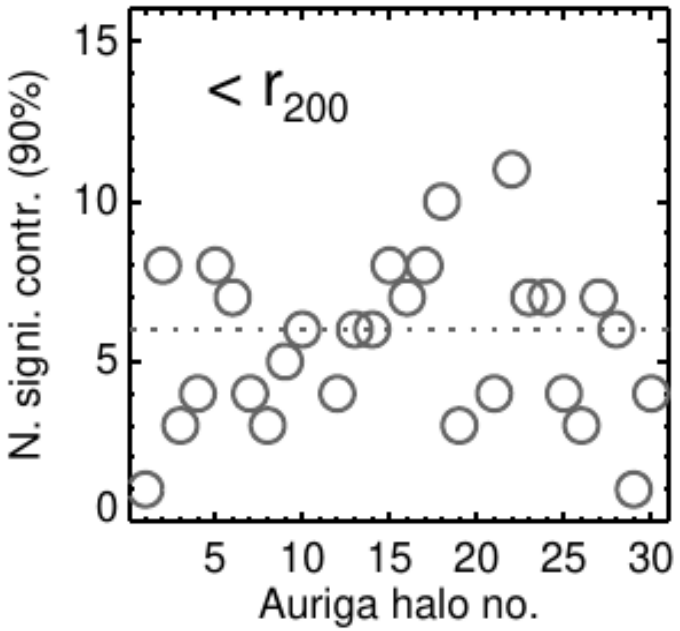


The formation of Galactic halos from disrupted dwarf galaxies

Number of “significant progenitors” (forming 90% of the stellar halo mass) at various radii:
the inner regions are formed by very few dwarf galaxies, thar are relatively bright
(see, also, Deason et al. 2015, Monachesi et al. 2019, …)

AF+2020



The formation of Galactic halos from disrupted dwarf galaxies

Tracing back accreted stars to their progenitors

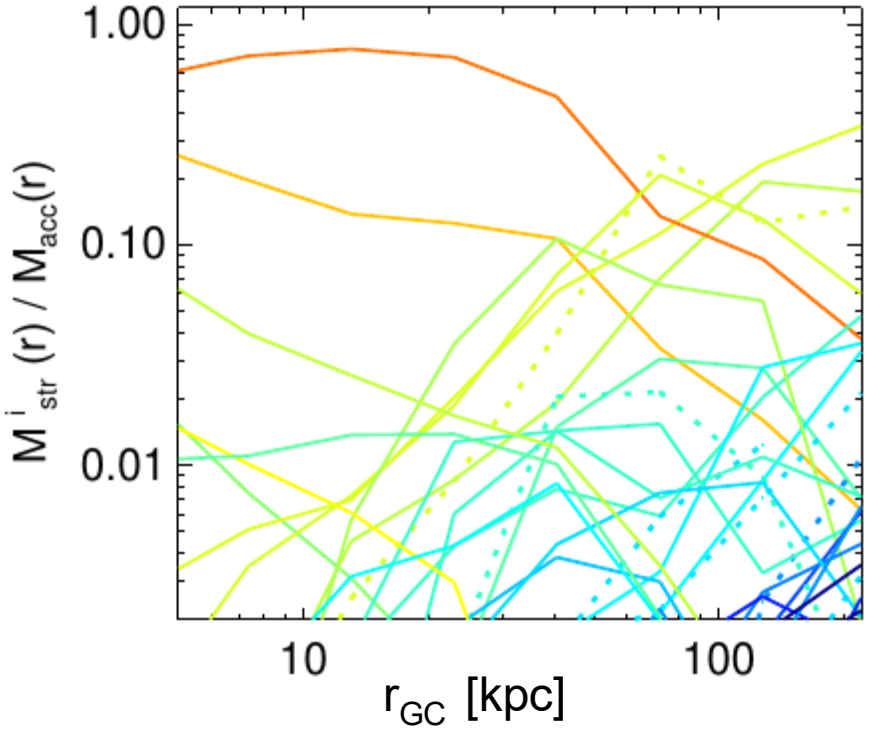
Low mass progenitors

High mass progenitors

One example:

AF+2020

Mass contributed from various progenitors spherical shells



Kinematics of the **inner** stellar halo: Gaia-Enceladus-Sausage

Belokurov et al. 2018:

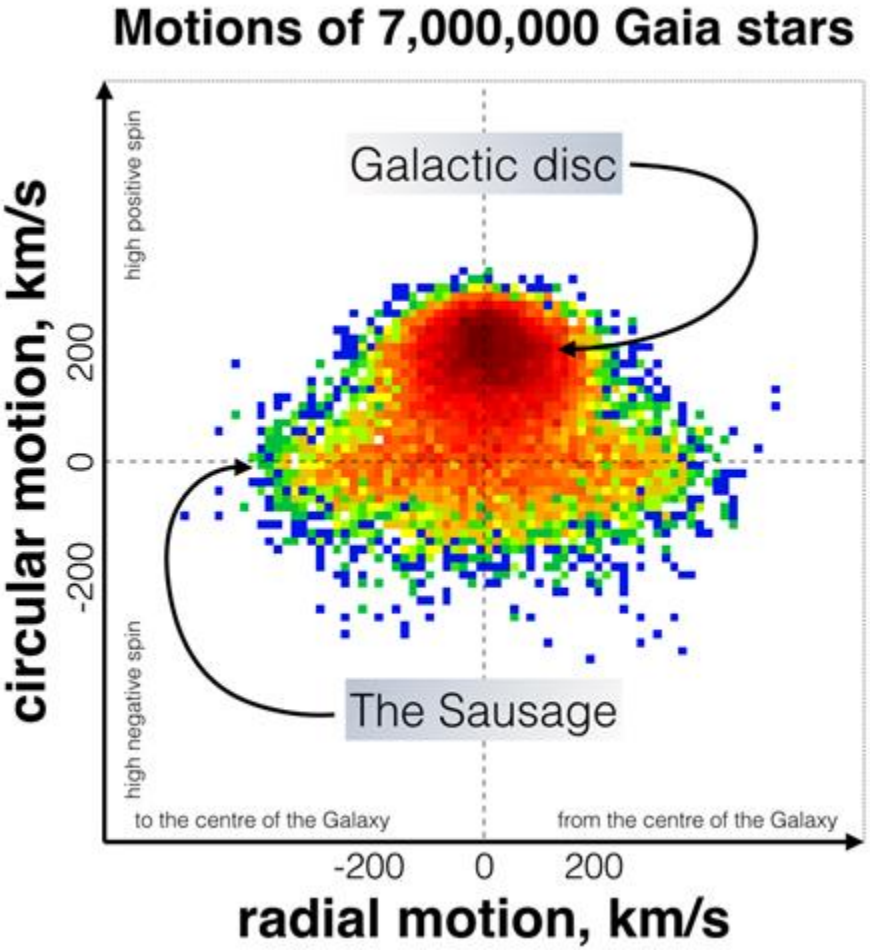
stars: [Fe/H] < -1 , b > 25 deg

Velocity space of stars shows two prominent features

I. Galactic disk rotating with ~ 200 km/s

II. halo component with highly orbital anisotropy, β ~ 0.85

$$\beta = 1 - \frac{\sigma_\theta^2 + \sigma_\phi^2}{2\sigma_r^2}$$



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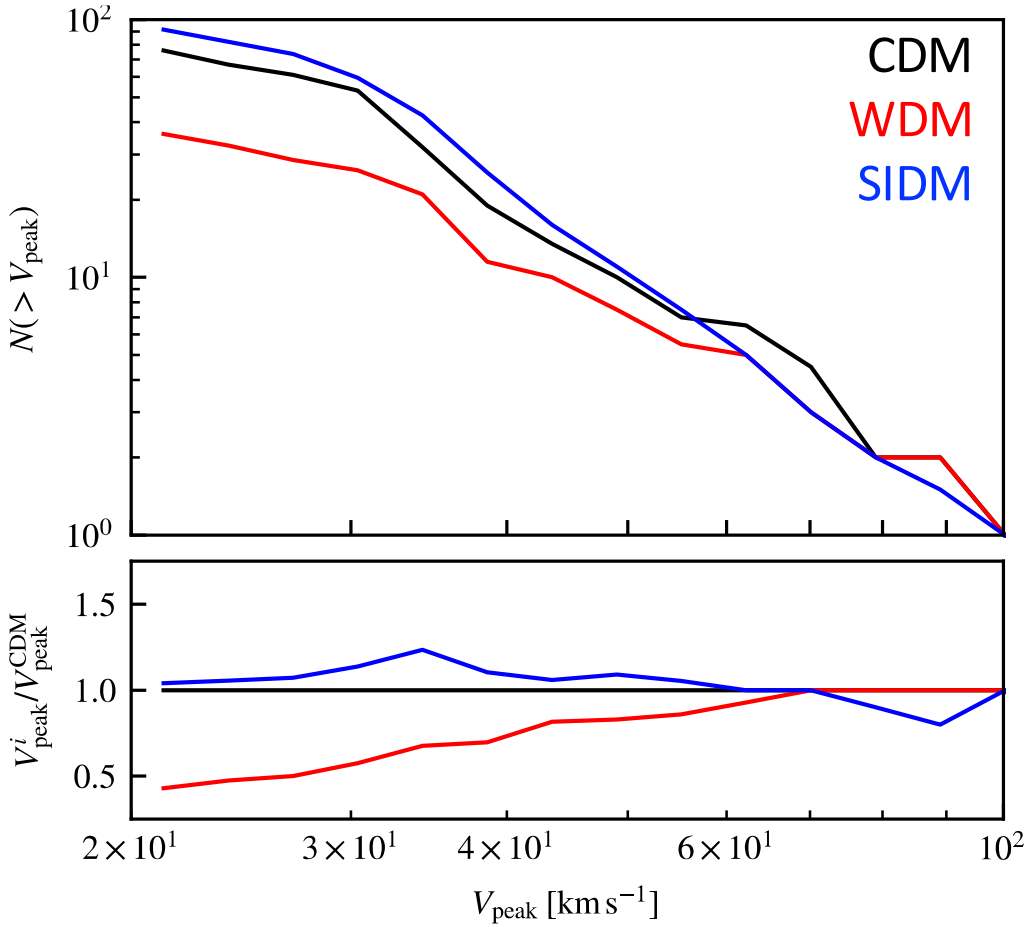
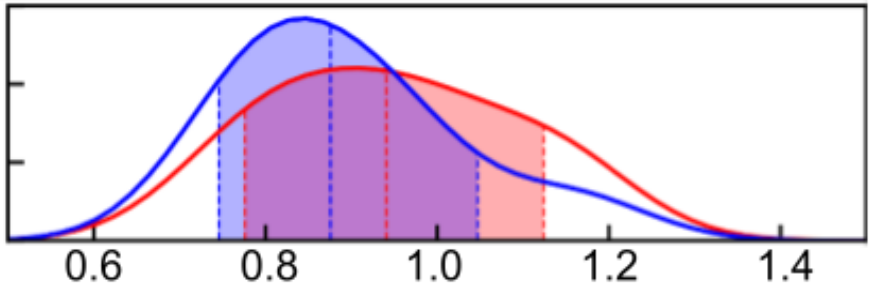


Peak mass before infalling to the MW-mass halos

Accreted stellar halo mass ($<R_{200}$) relative to CDM



$M_{acc,\,XDM} / M_{acc,\,CDM}$

Forouhar-Moreno, AF, et al. (2024)

Low mass halos in WDM and SIDM

Dark matter halo mass function