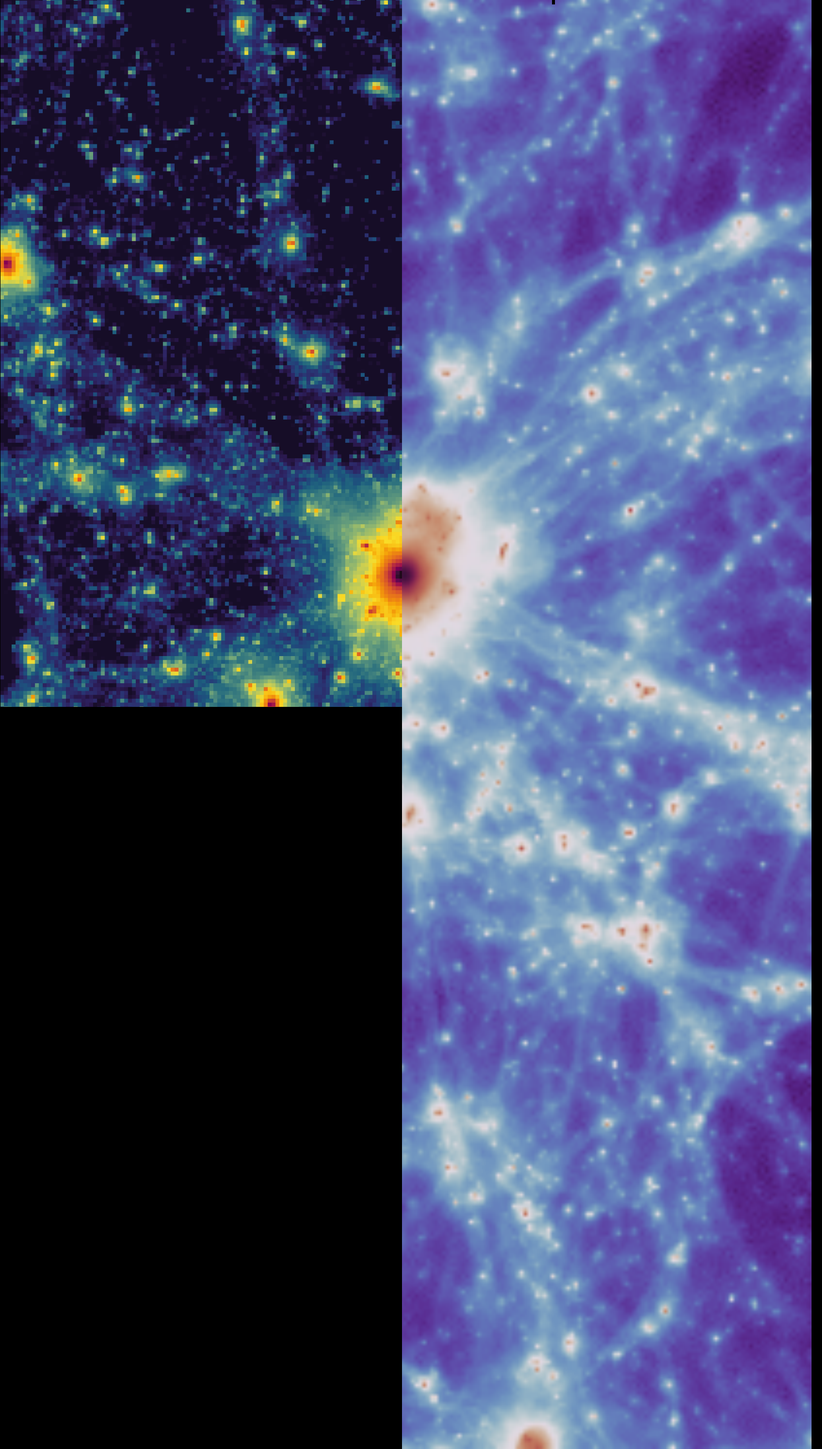

THE AIDA PROJECT:

NEW INSIGHTS ON ALTERNATIVE DARK MATTER MODELS IN SIMULATIONS OF GALAXY FORMATION

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MARK VOGELSBERGER
VOLKER SPRINGEL

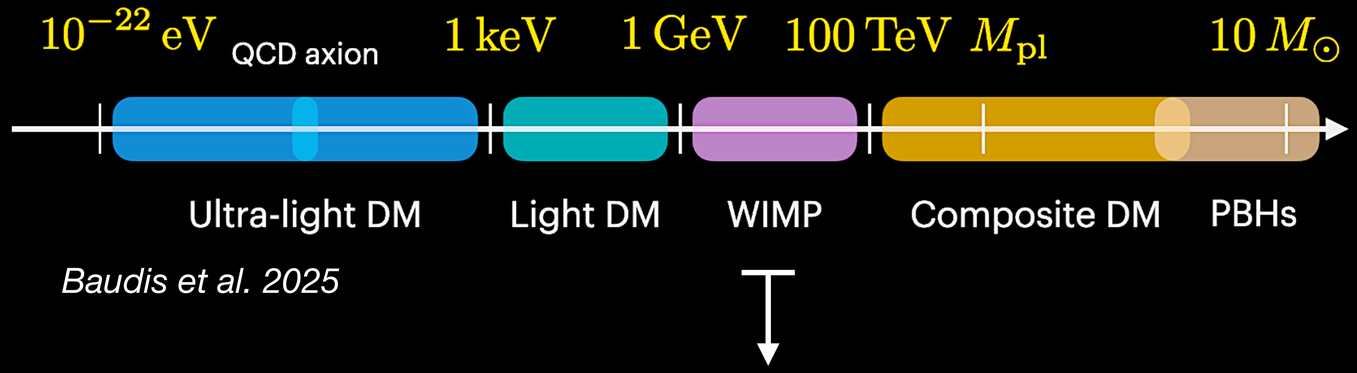
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

ICSC
Centro Nazionale di Ricerca in HPC,
Big Data and Quantum Computing

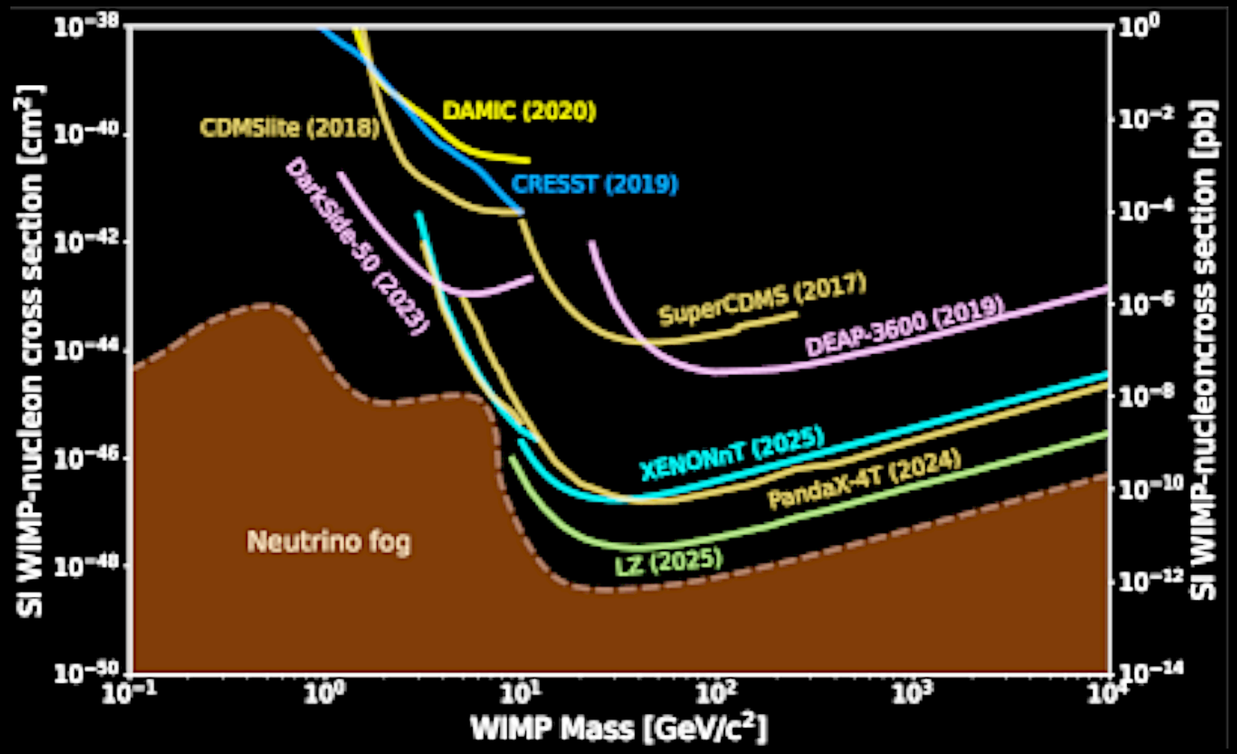
EuroHPC
Joint Undertaking

INTRODUCTION

we haven't detected dark matter particles!



Baudis et al. 2025



INTRODUCTION

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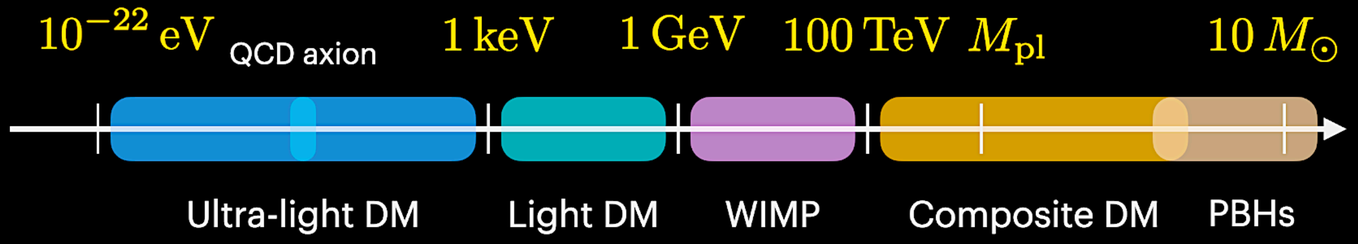
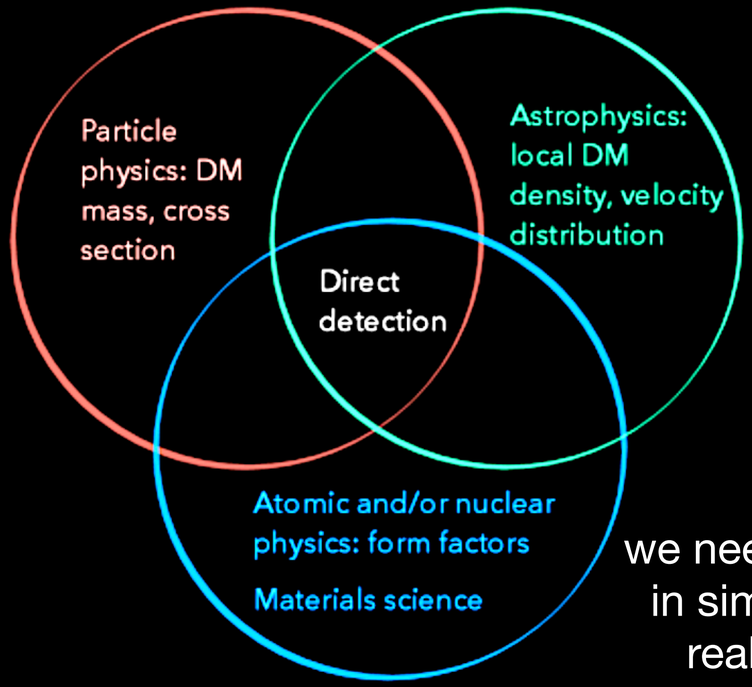
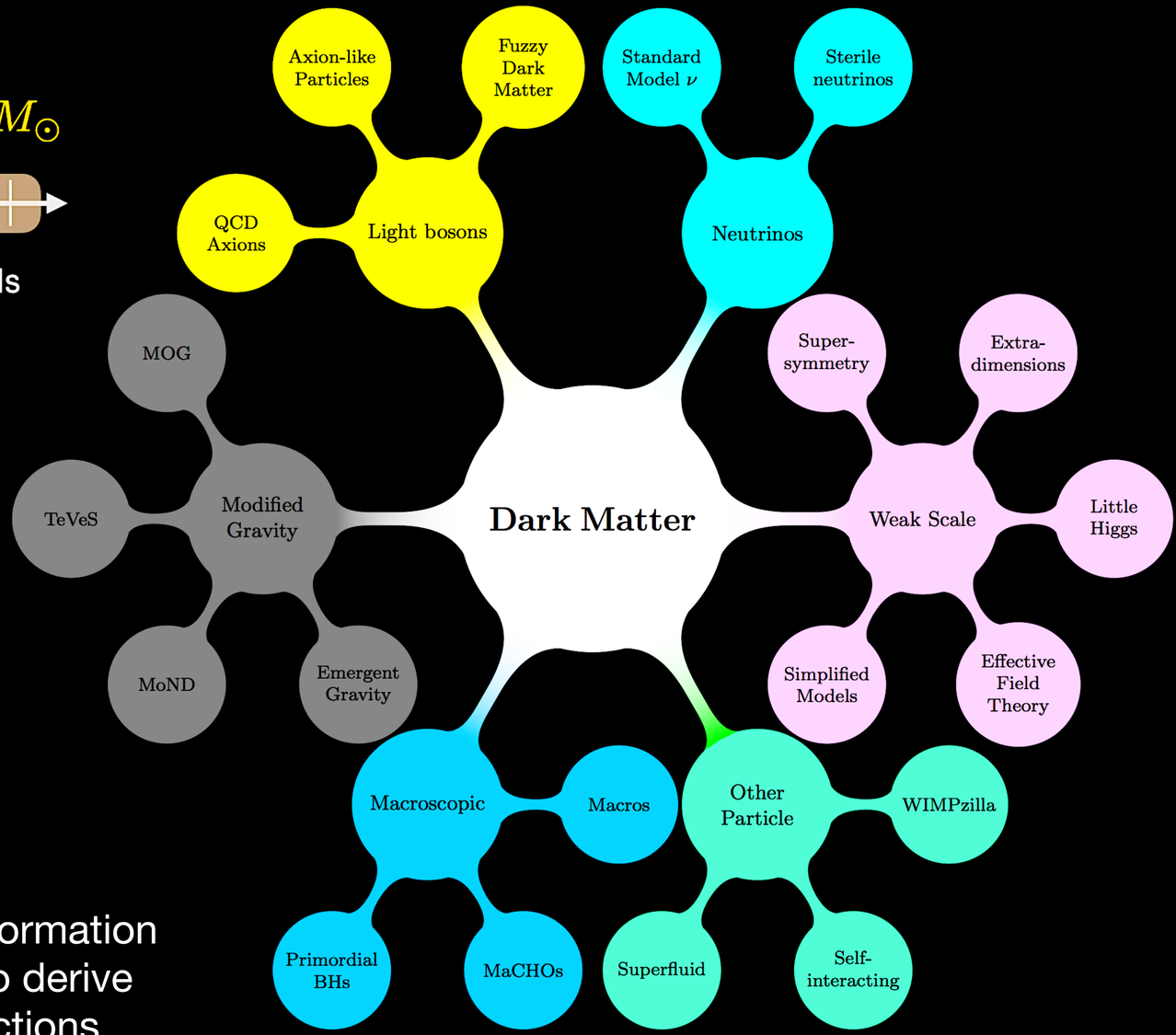


Baudis et al. 2025

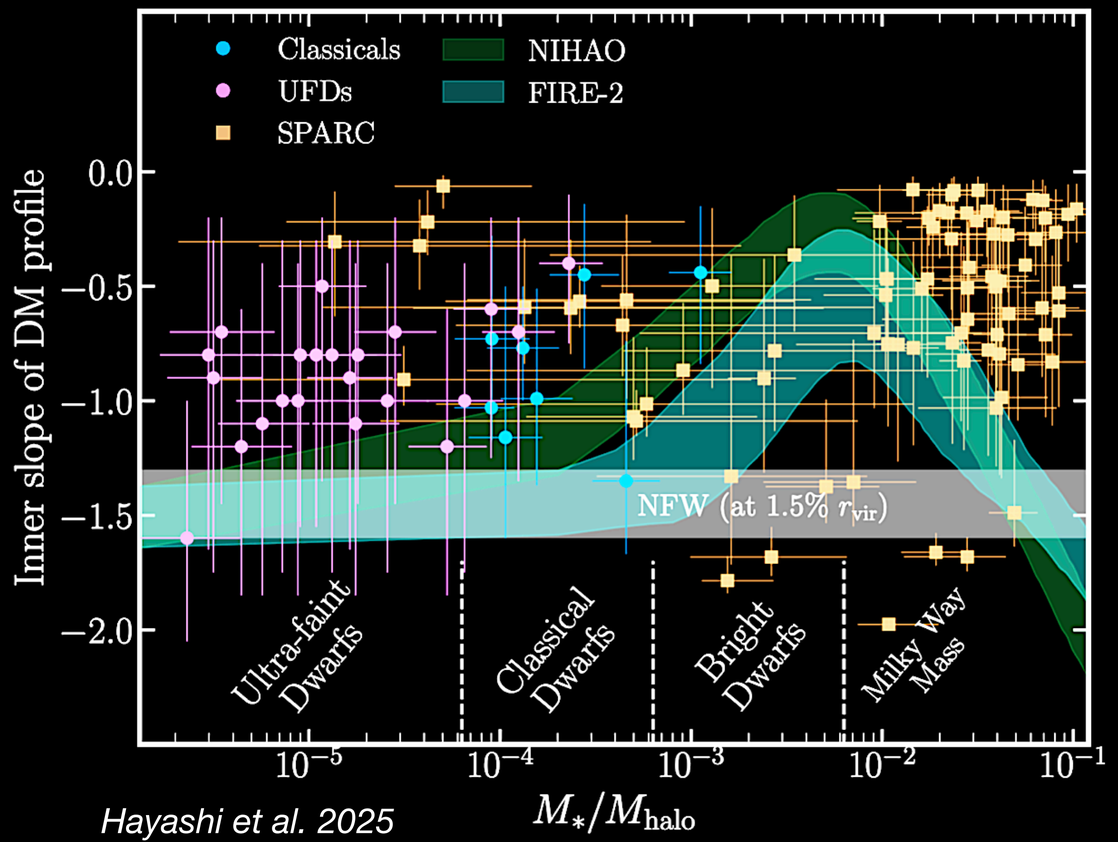


we need galaxy formation in simulations to derive realistic predictions



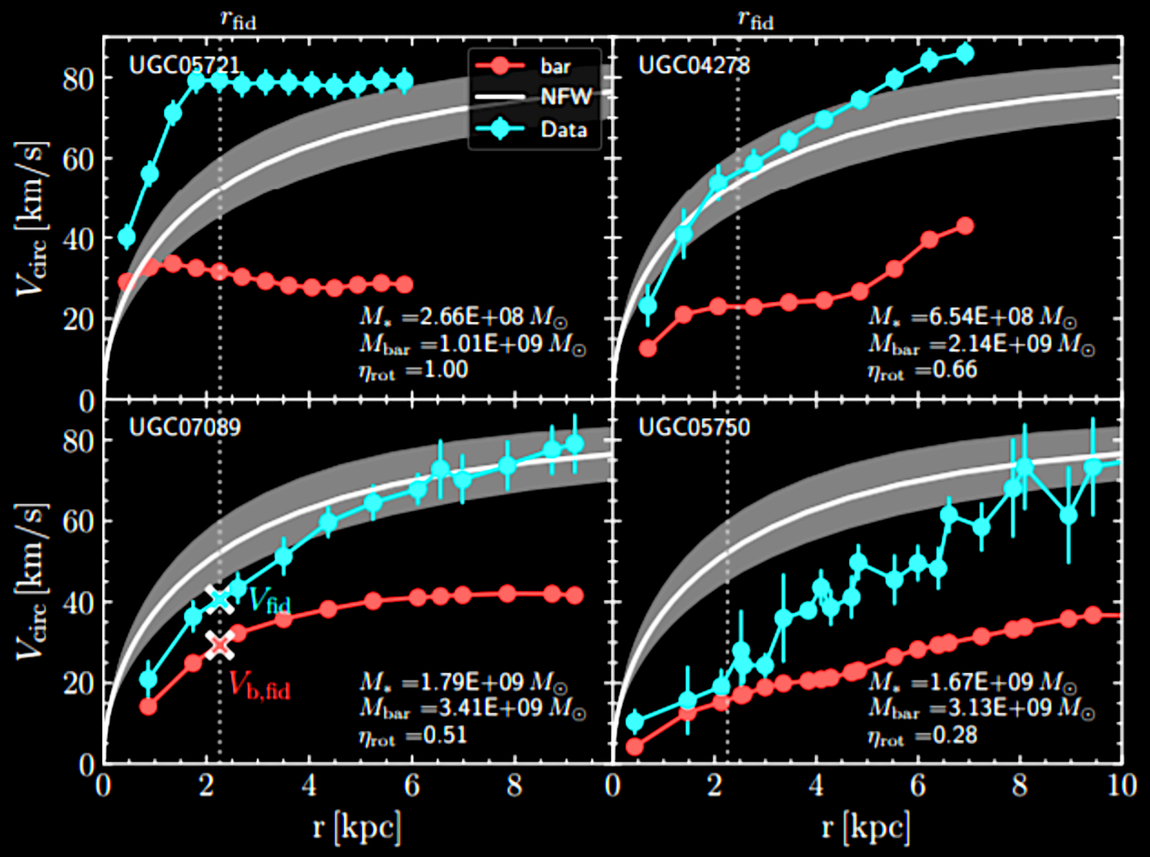
OPEN PROBLEMS IN CDM

inner slopes diversity



Hayashi et al. 2025

rotation curves of dwarf galaxies



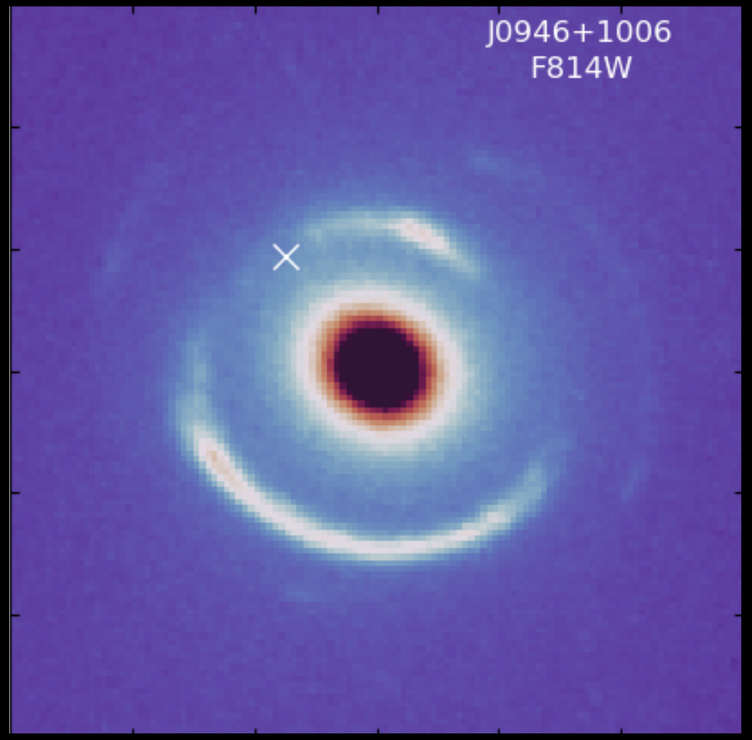
Santos-Santos et al. 2022

observations suggest a larger diversity of density distributions compared to CDM

gravitational lensing

OPEN PROBLEMS IN CDM

galaxy scales:
oberved subhaloes are too concentrated?



satellites of mass $10^{6\text{-}9} M_\odot$

cluster scales:
too many lensing events by satellite galaxies?

satellites of mass $10^{10\text{-}12} M_\odot$

observations suggest a larger diversity of density distributions compared to CDM

Rose et al. 2023

The EAGLE simulations

Evolution and Assembly of GaLaxies and their Environments

The FLAMINGO project

ILLUSTRIS

FIRE

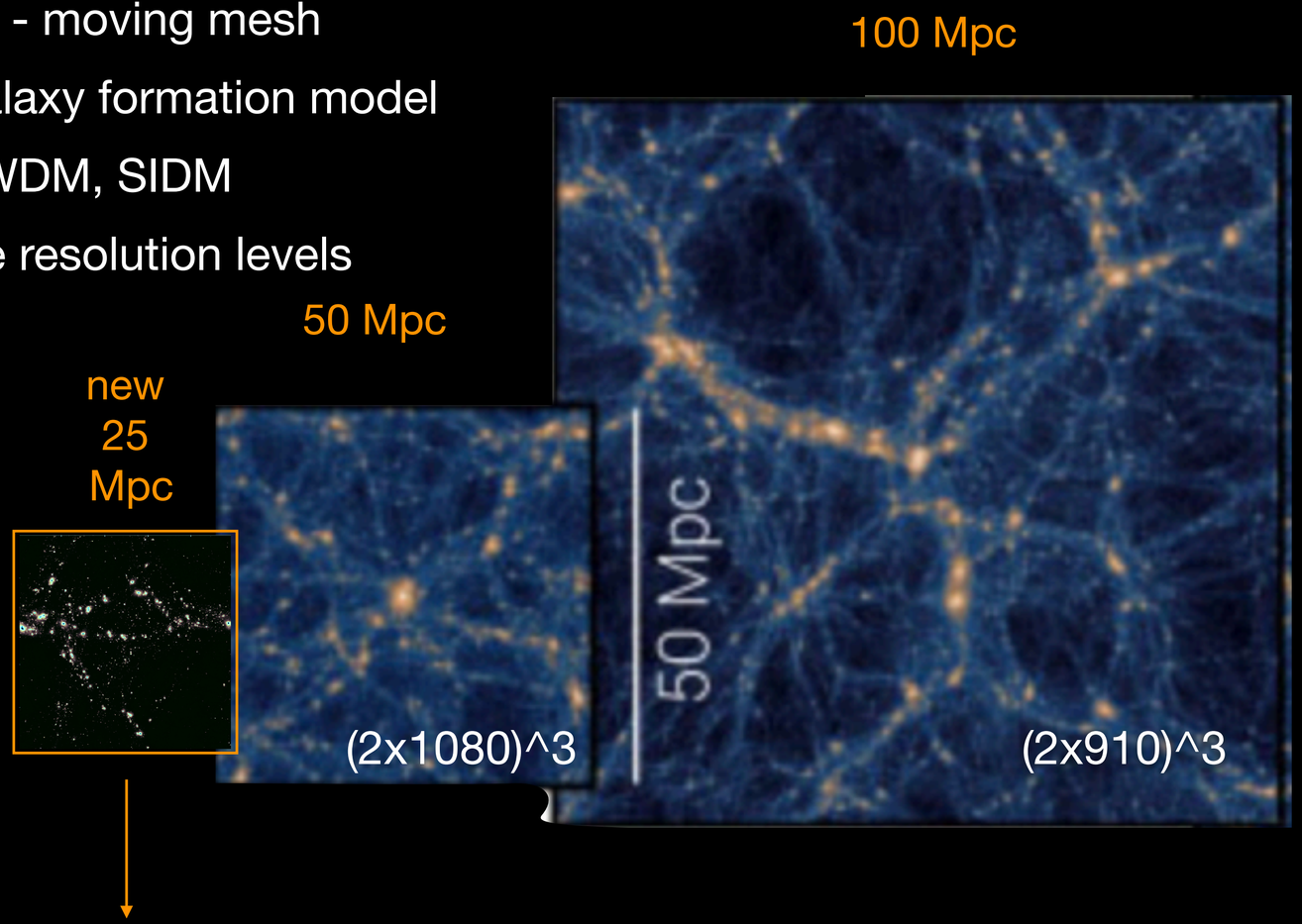
Feedback In Realistic Environments

MAGNETICUM

credit: Dylan Nelson, TNG

AIDA-TNG SIMULATIONS

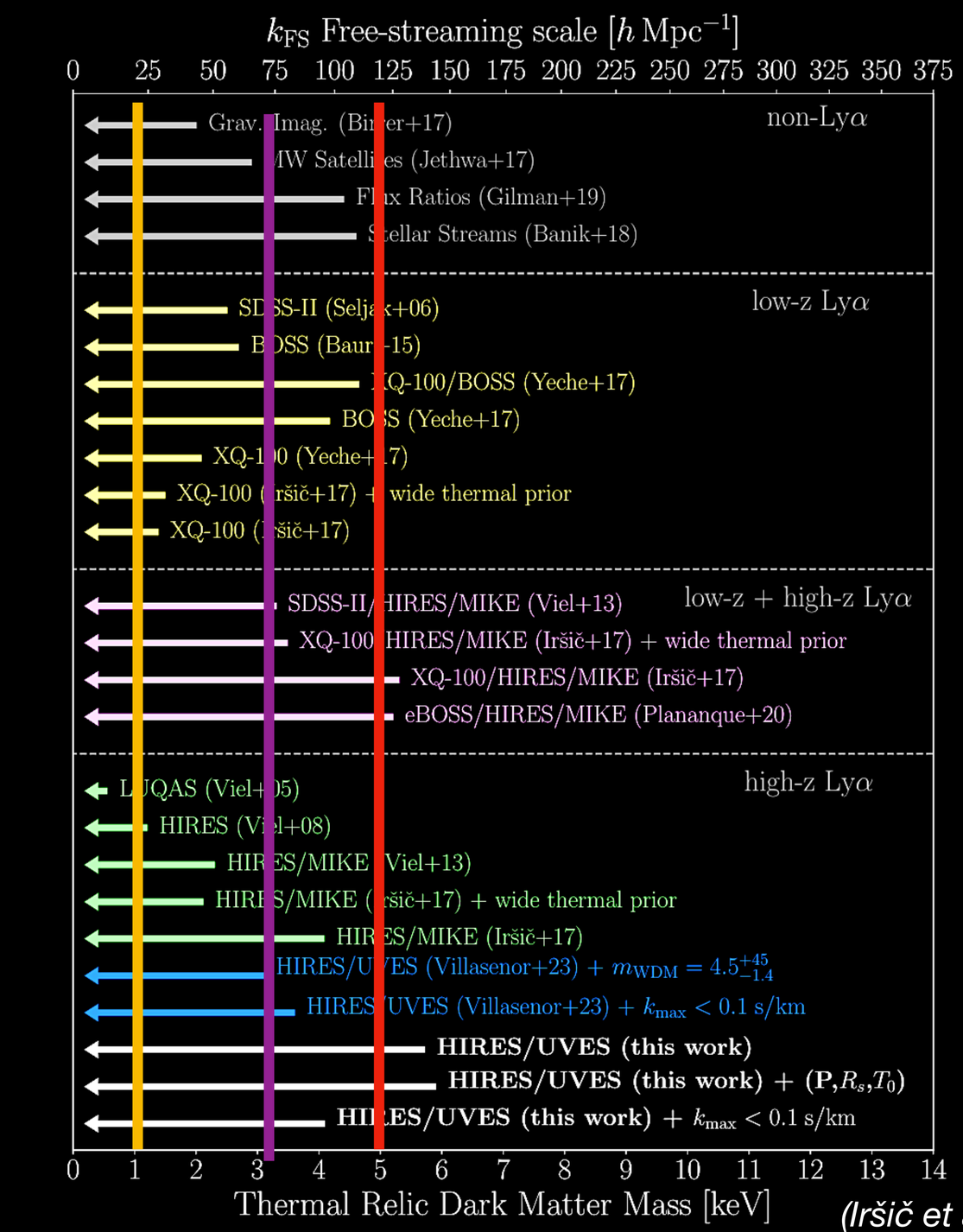
- ✓ three cosmological boxes
- ✓ AREPO - moving mesh
- ✓ TNG galaxy formation model
- ✓ CDM, WDM, SIDM
- ✓ multiple resolution levels



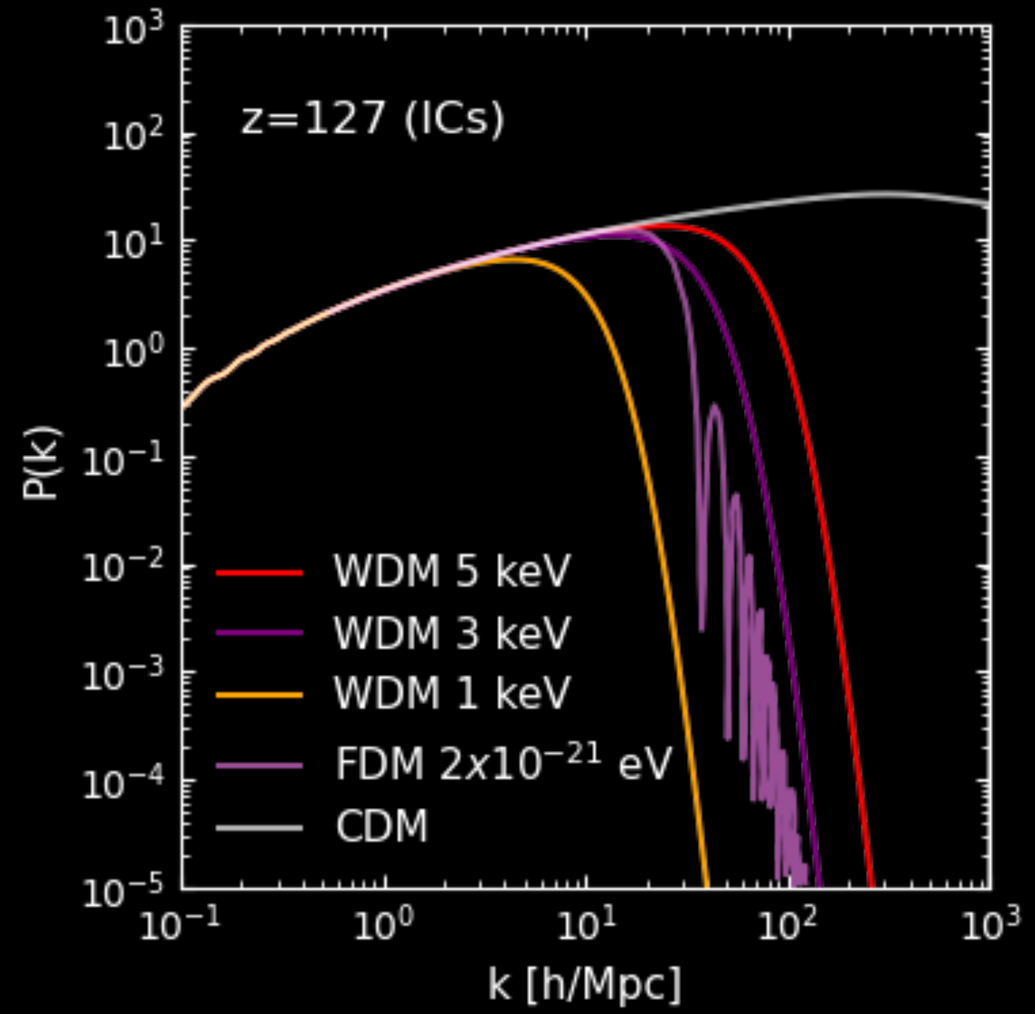
max resolutuion:
~280 pc

AIDA-TNG SIMULATIONS

Wark Dark Matter:
particles ~keV instead of GeV

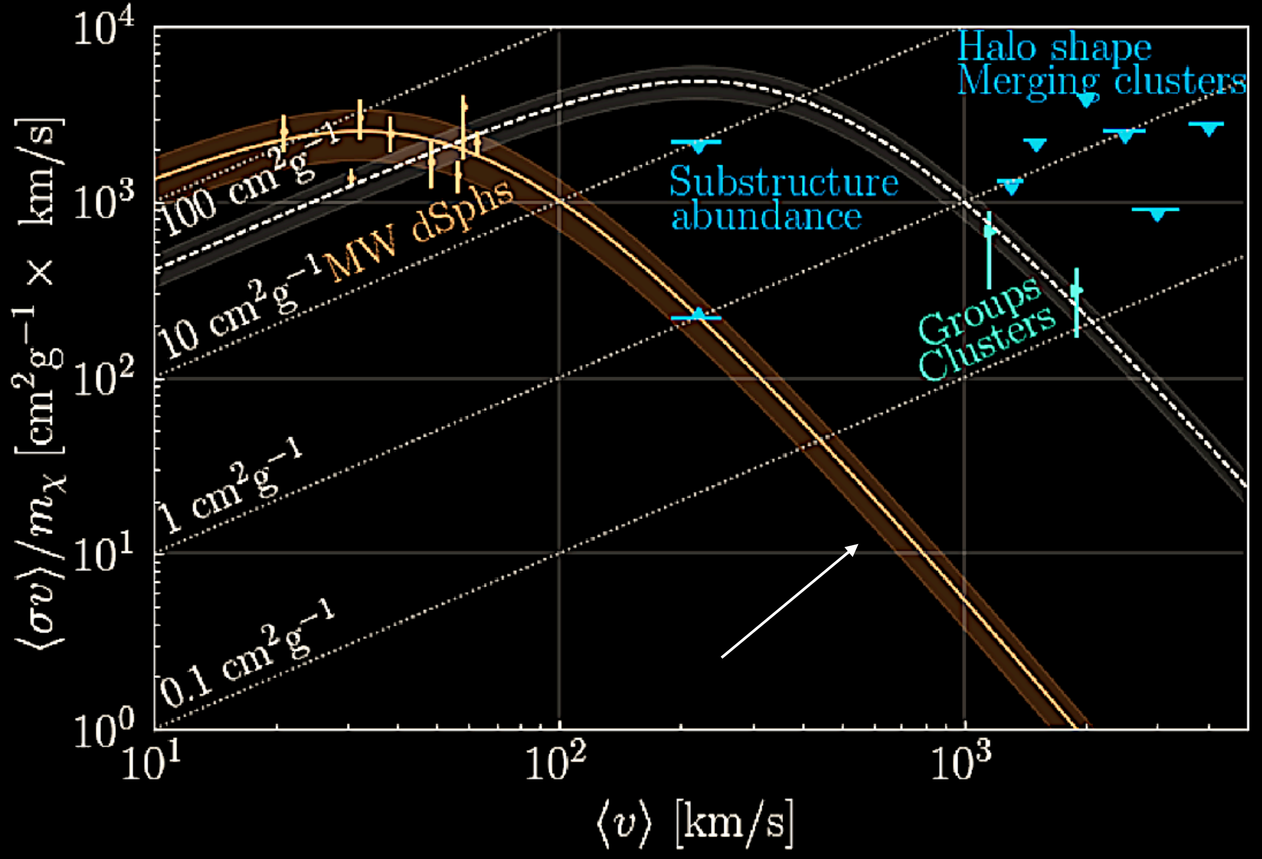


(Iršič et al. 2024)

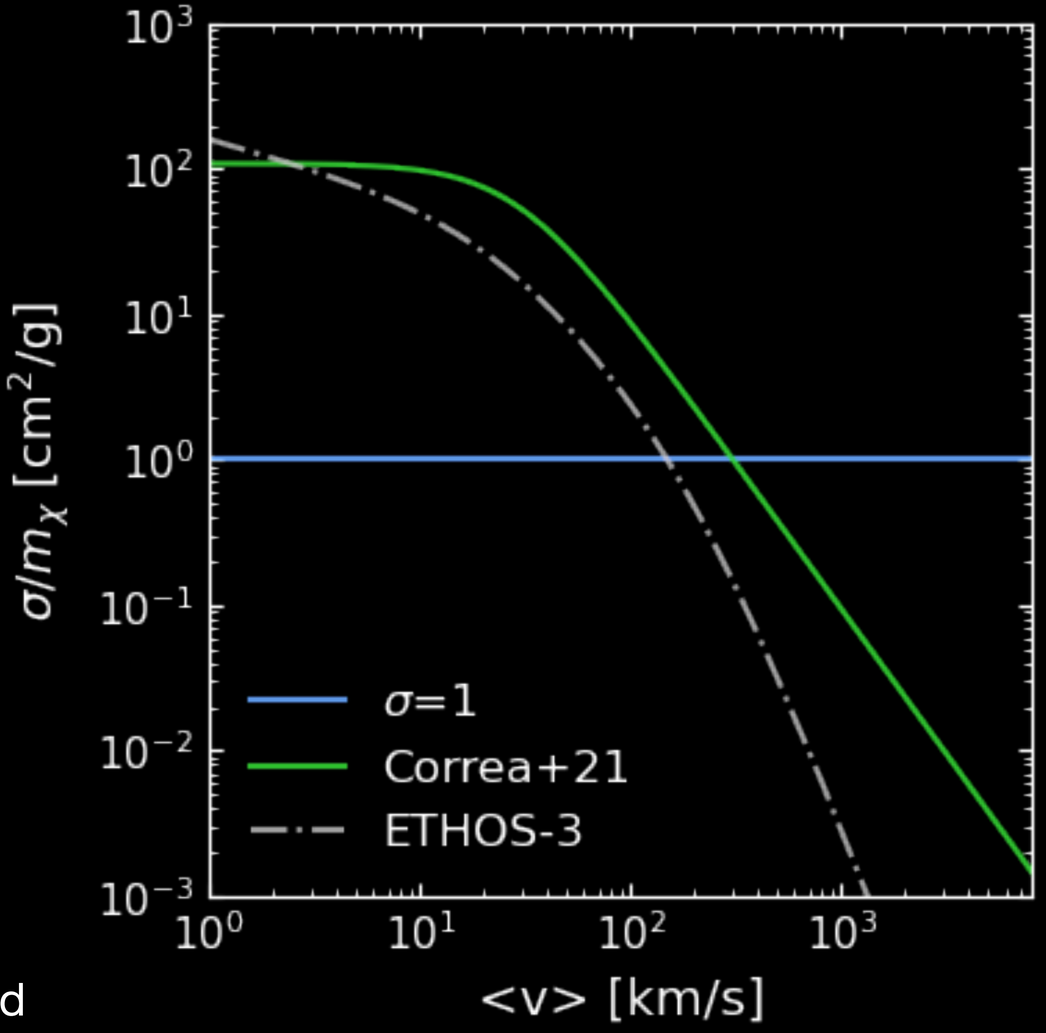


AIDA-TNG SIMULATIONS

Self-interacting Dark Matter:
particles interact with each other beyond gravity

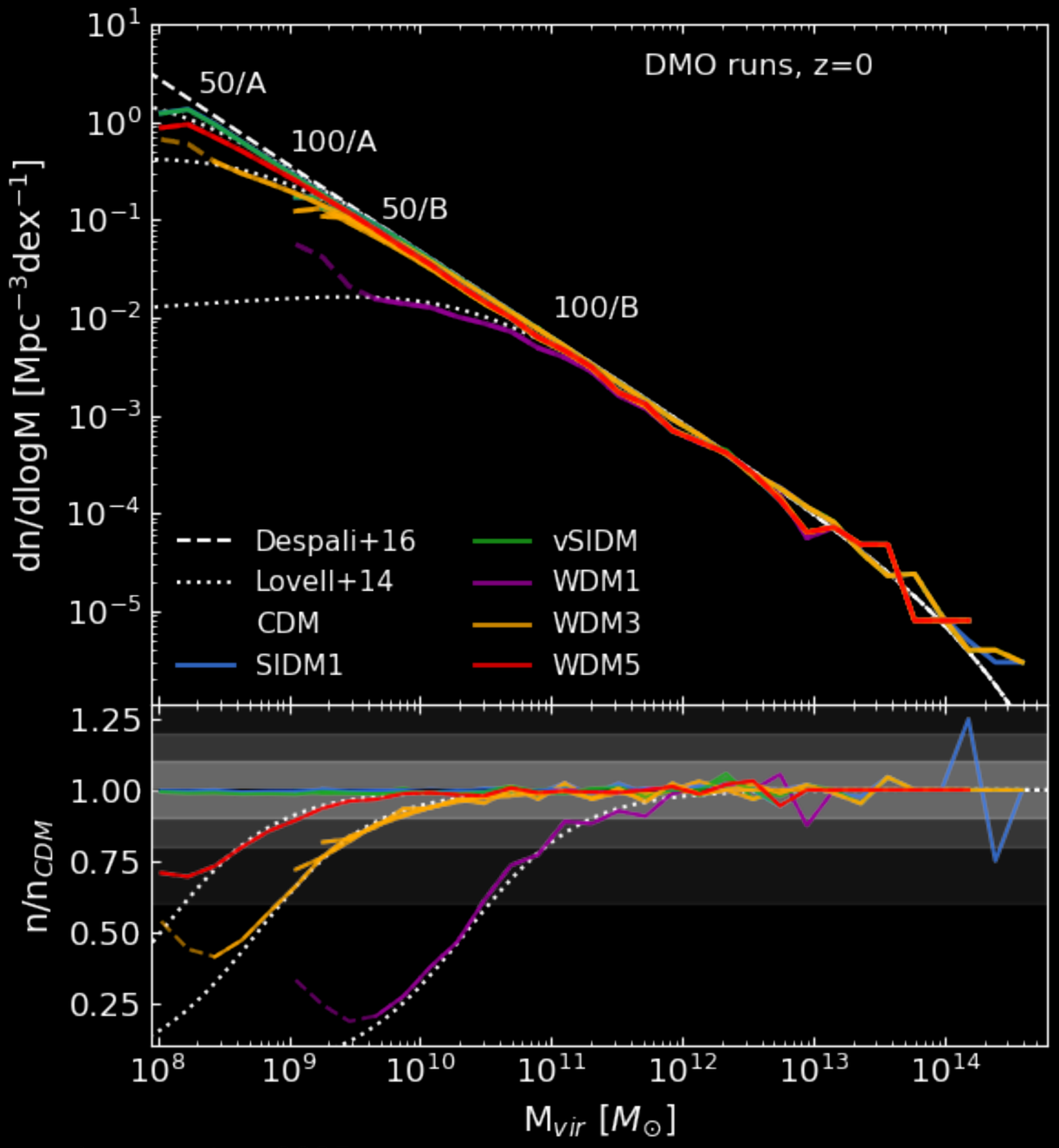


(Correa et al. 2021)



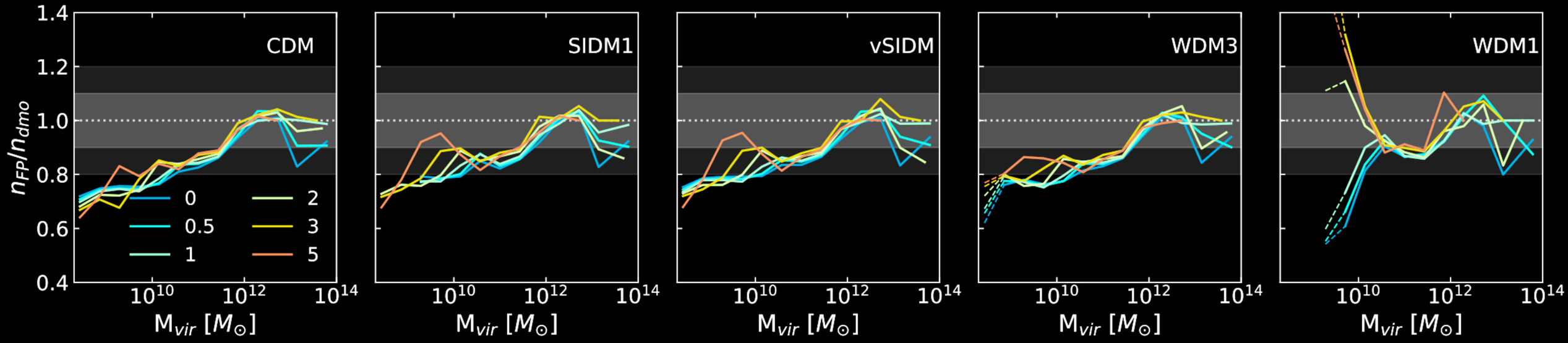
"natural" interactions often modeled
as a Yukawa potential

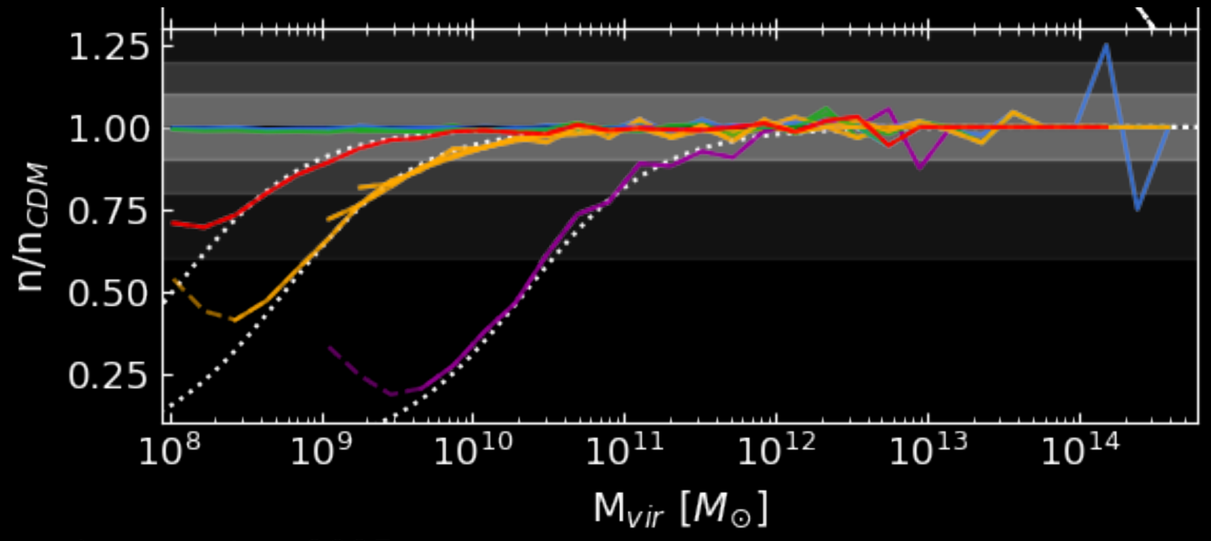
MASS FUNCTIONS



Despali et al. 2025

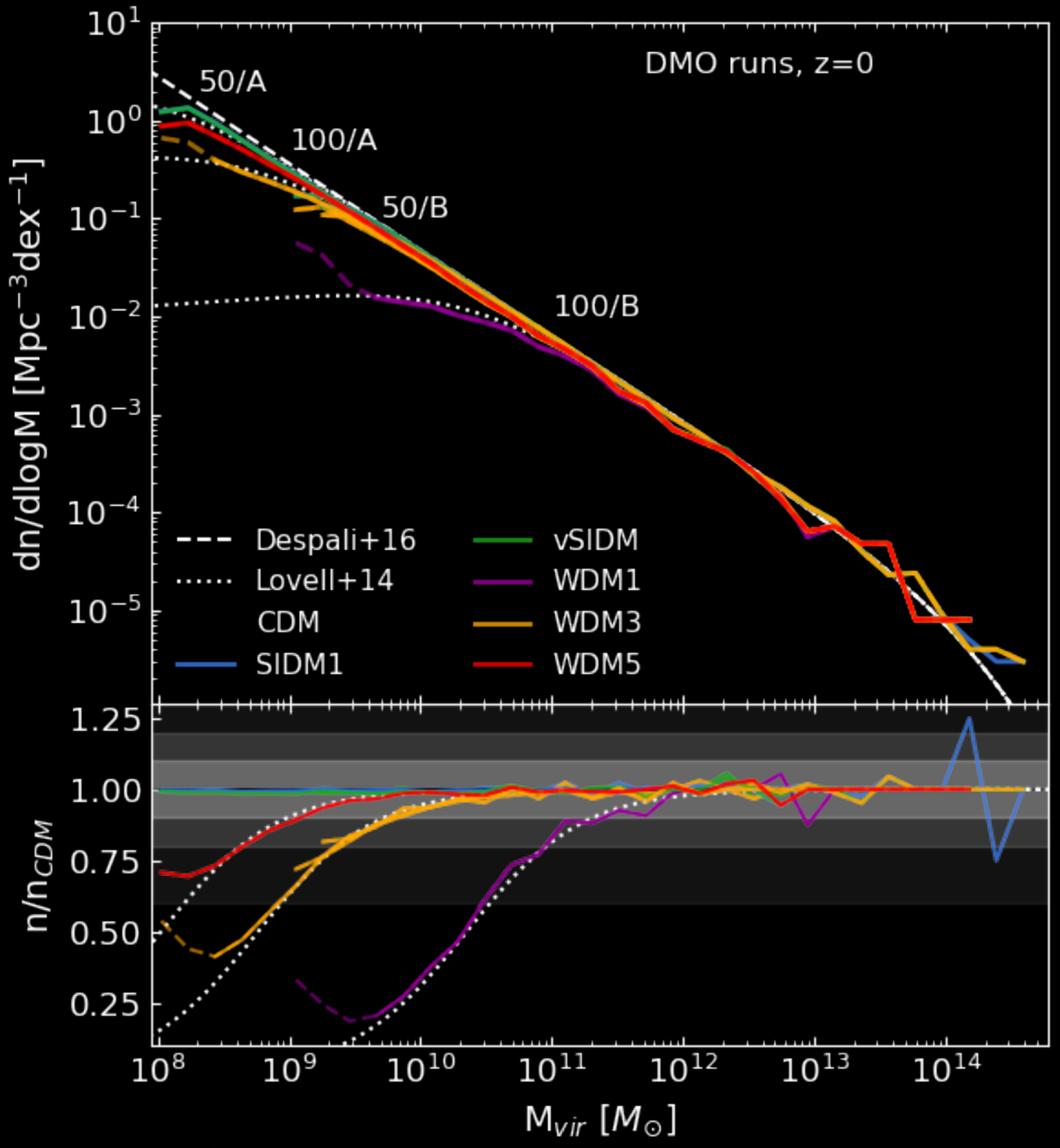
MASS FUNCTIONS





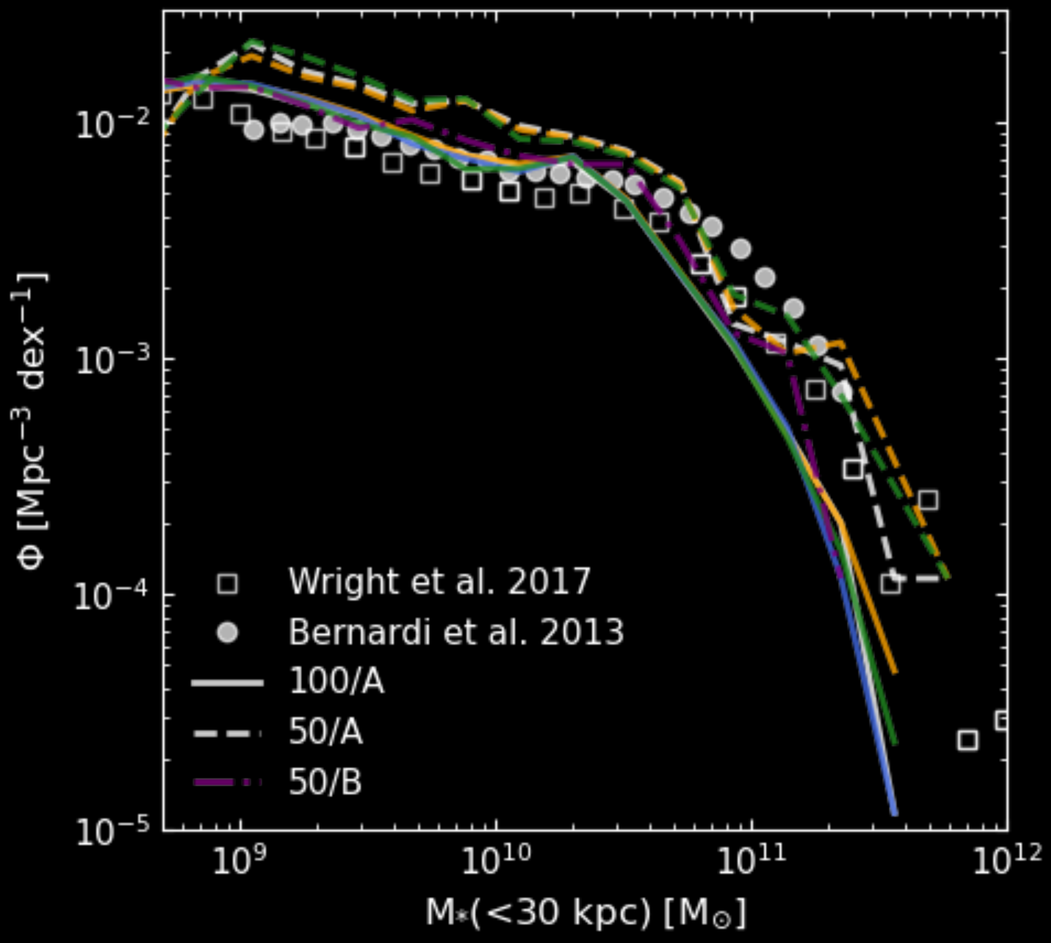
Despali et al. 2025

MASS FUNCTIONS

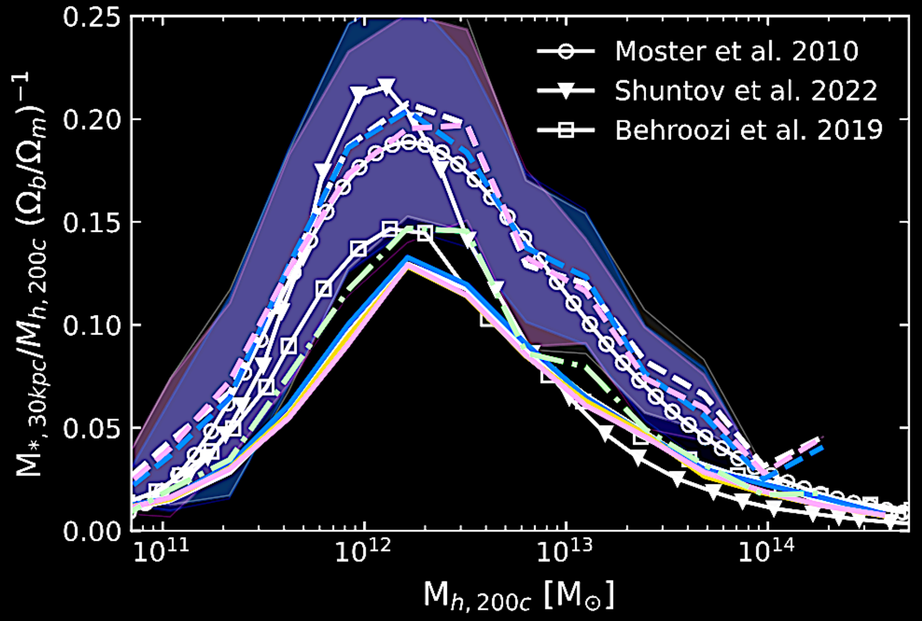


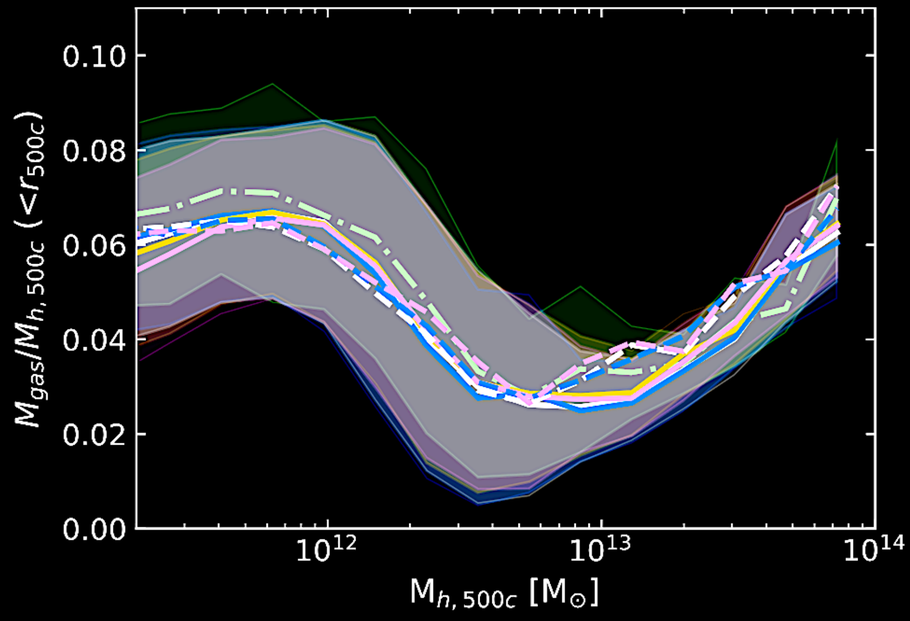
Despali et al. 2025

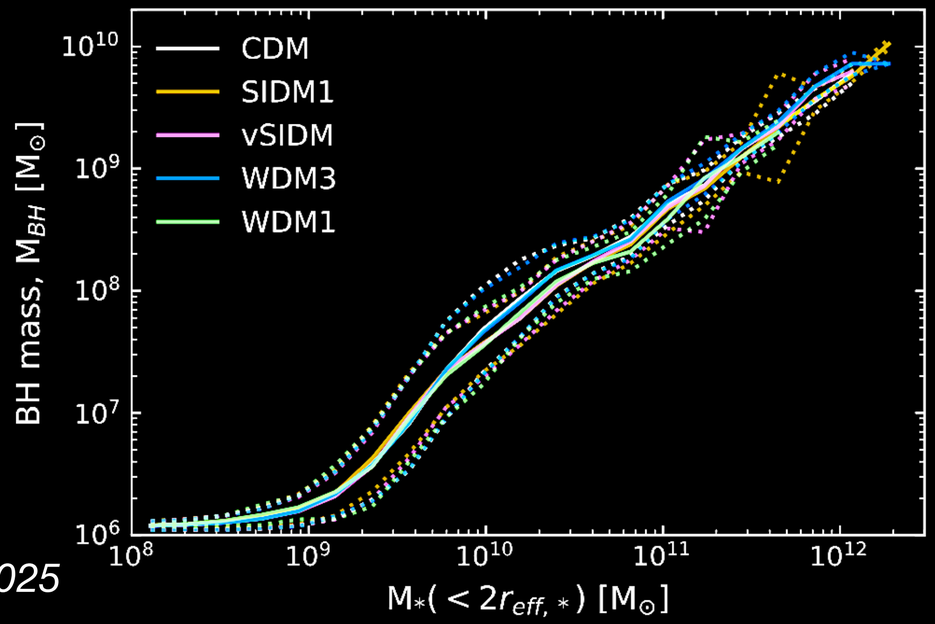
stellar mass function

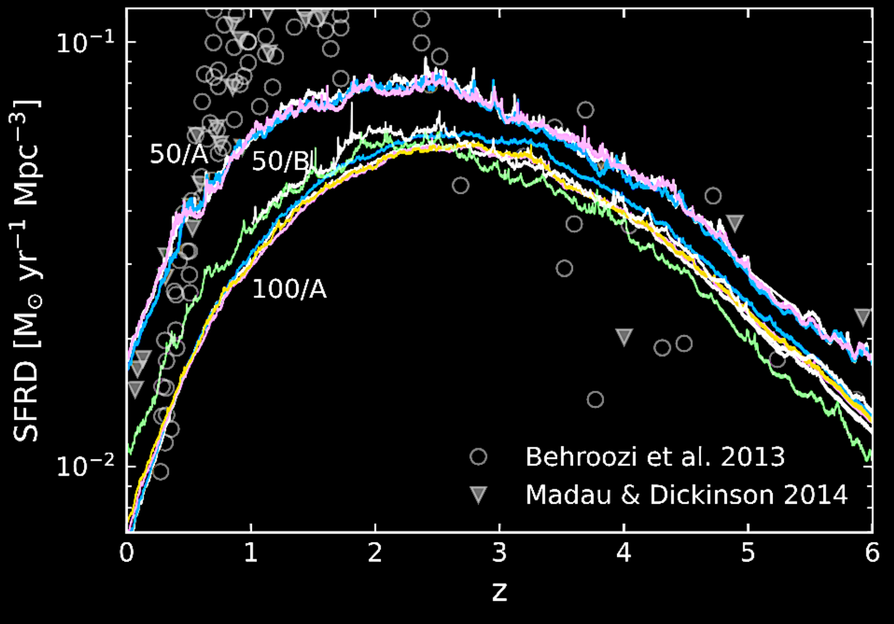


GALAXY PROPERTIES





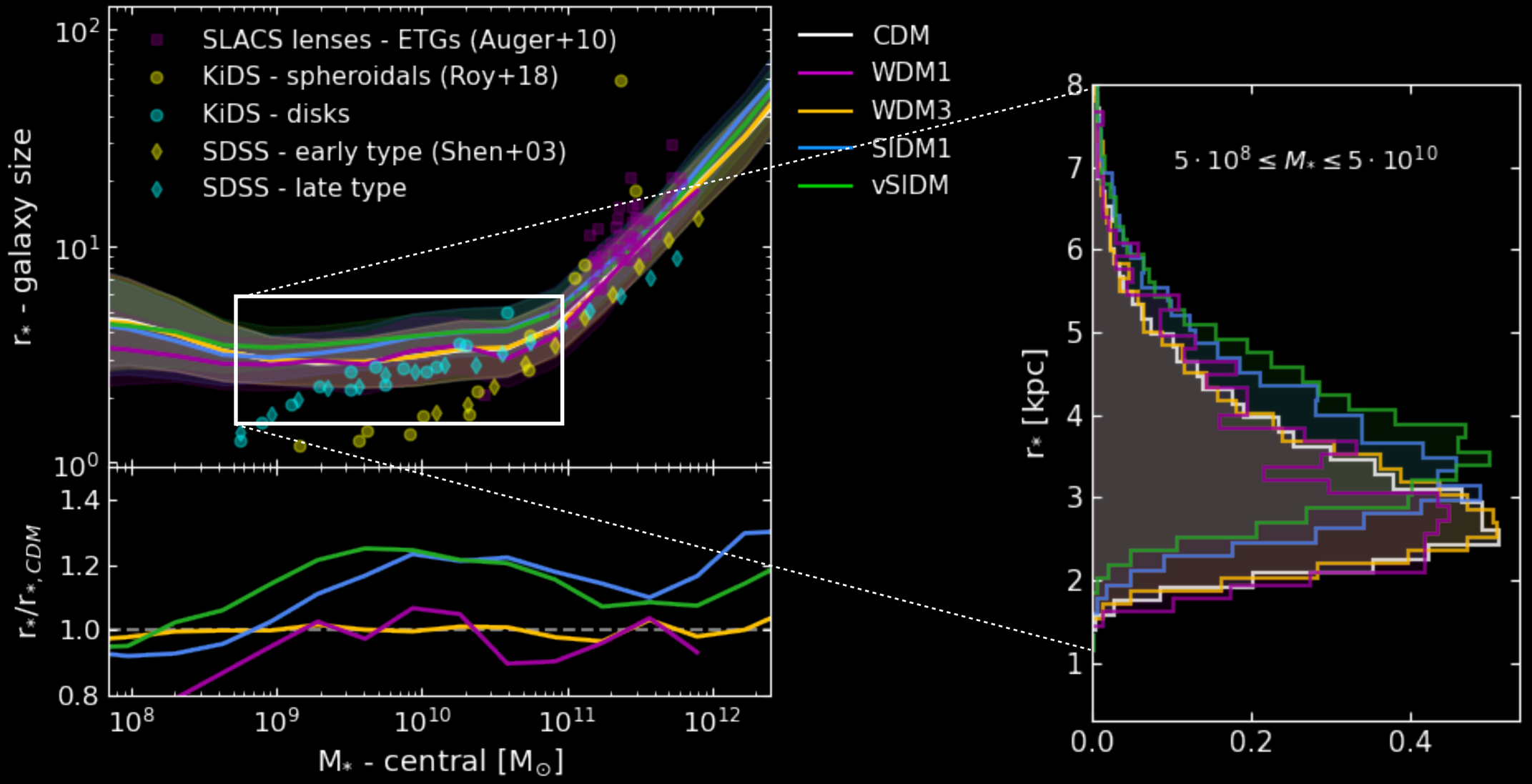




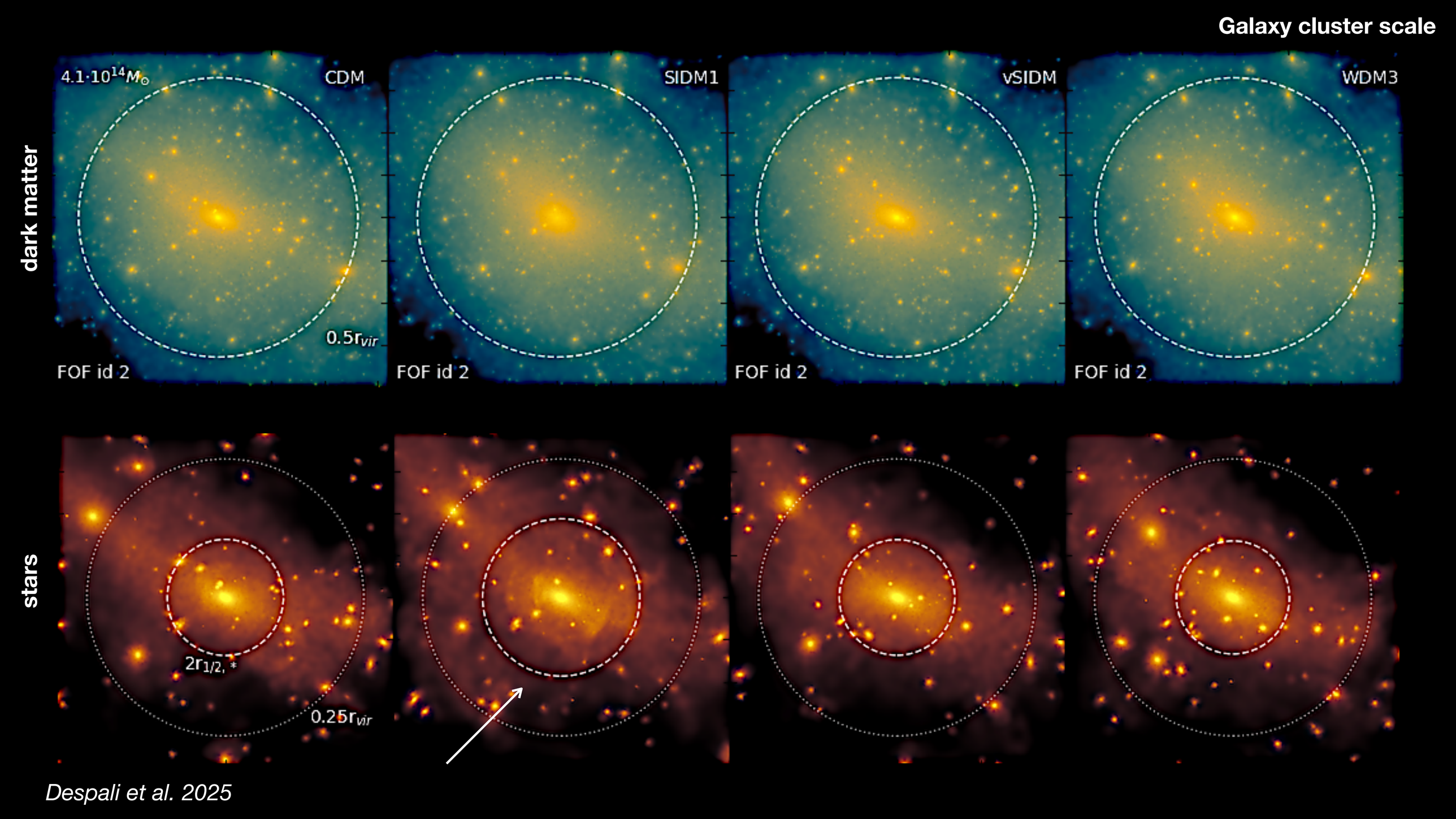
Despali et al. 2025

GALAXY PROPERTIES

galaxy sizes



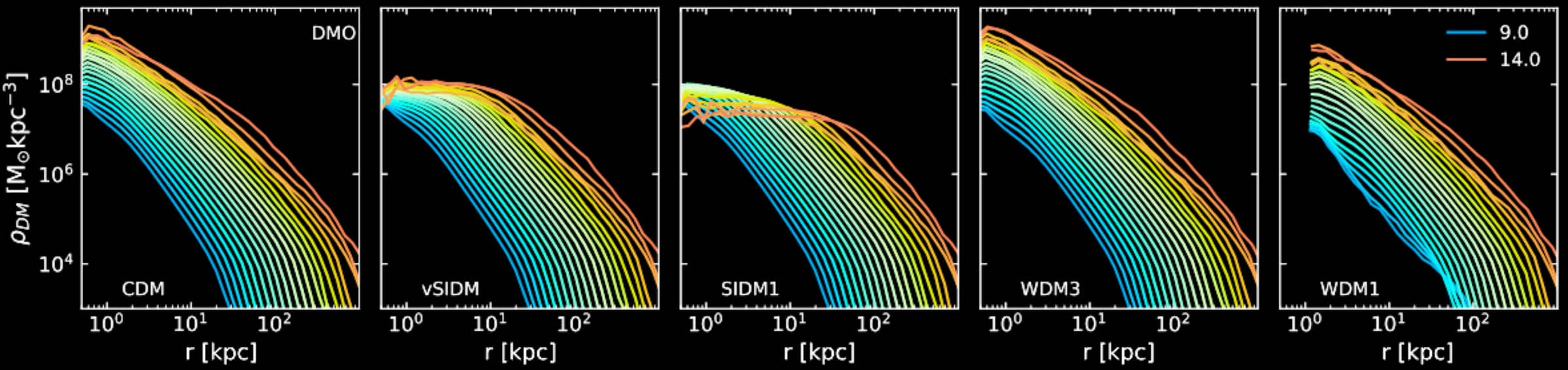
Despali et al. 2025



Despali et al. 2025

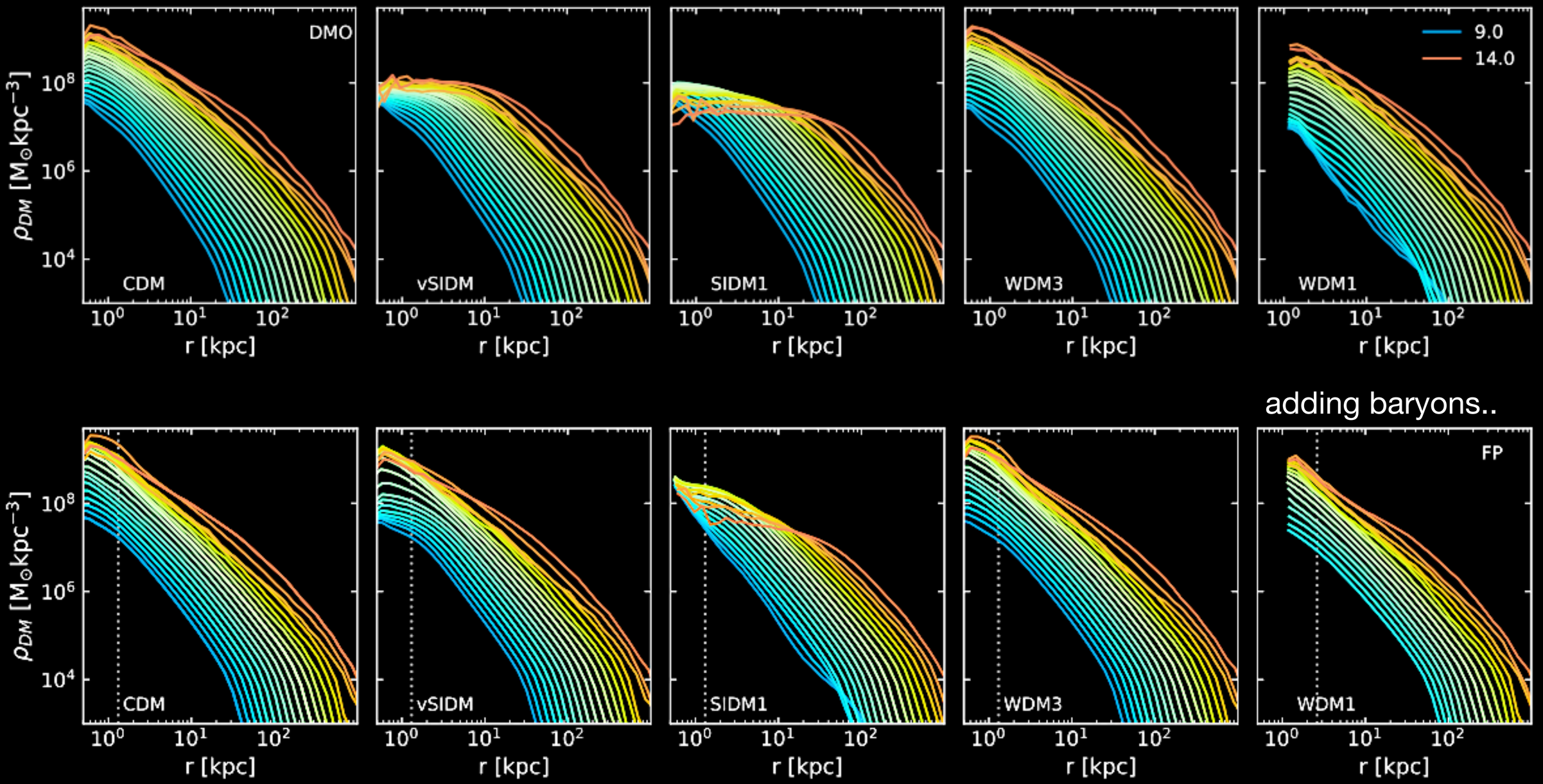
HALO PROFILES

CDM | Self-Interacting DM | Warm DM



HALO PROFILES

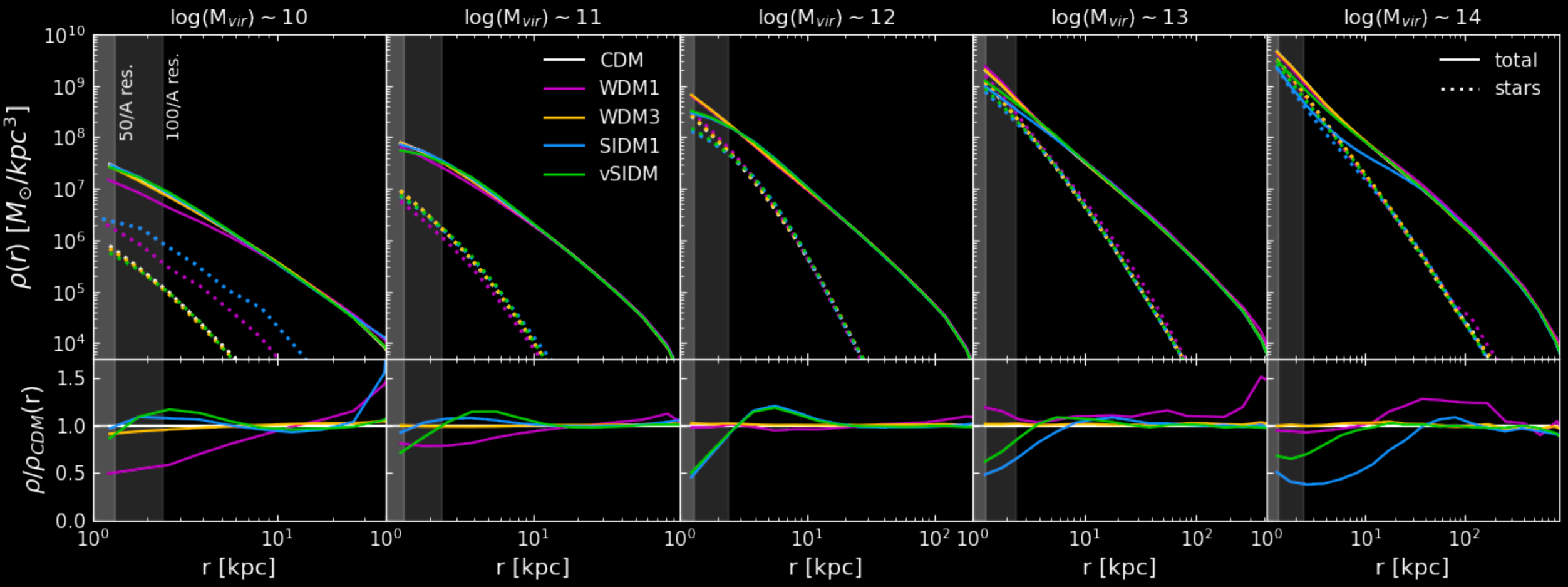
CDM | Self-Interacting DM | Warm DM



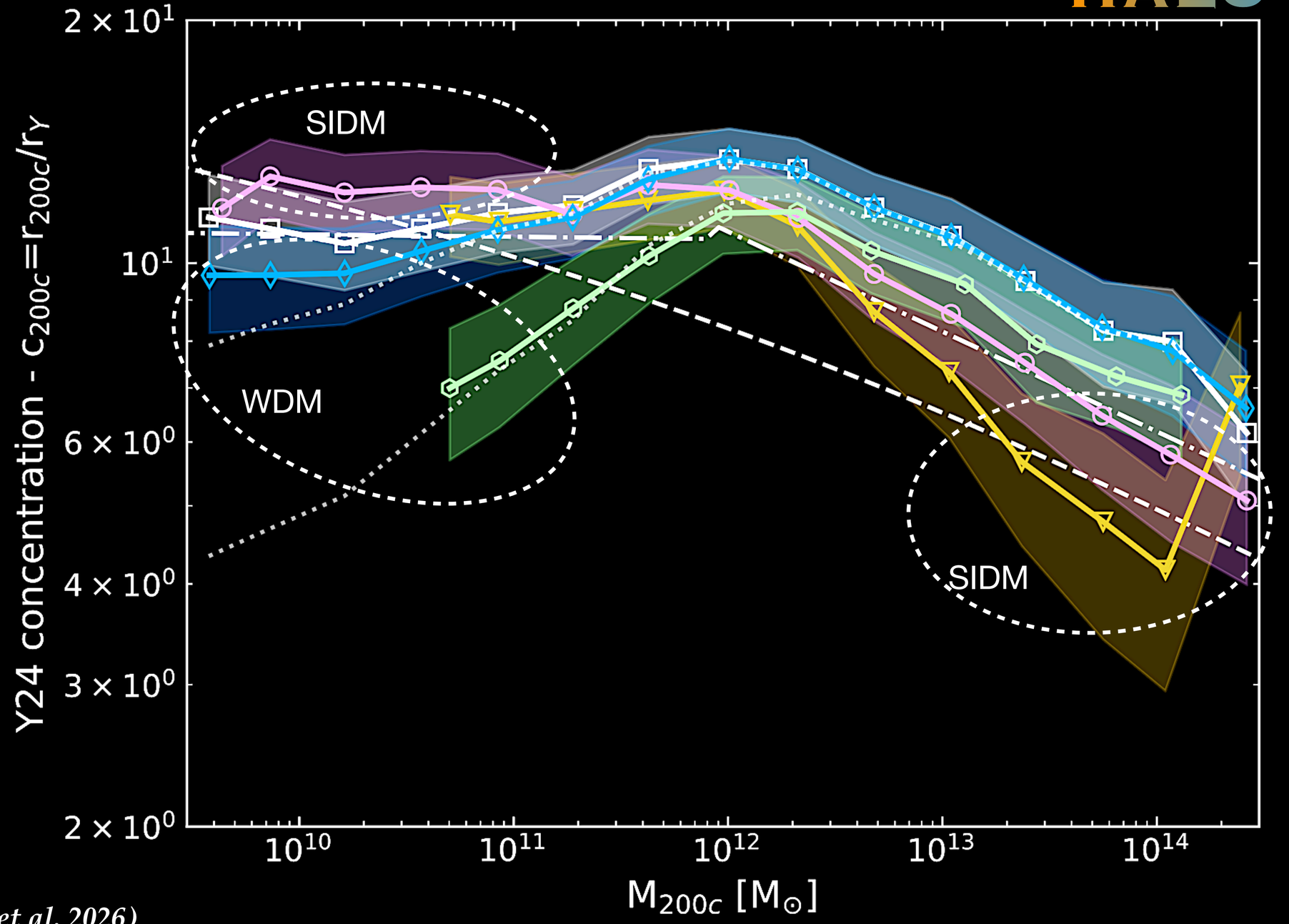
adding baryons..

HALO PROFILES

not only the DM profile is affected, but also the total density



HALO PROFILES



CDM

WDM 3 keV

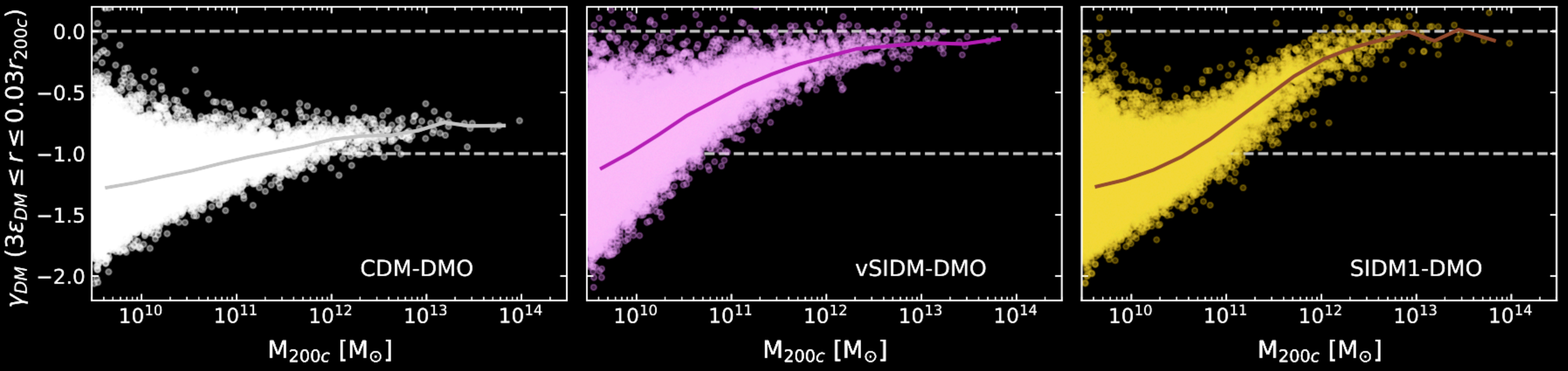
WDM 1 keV

SIDM cost =1

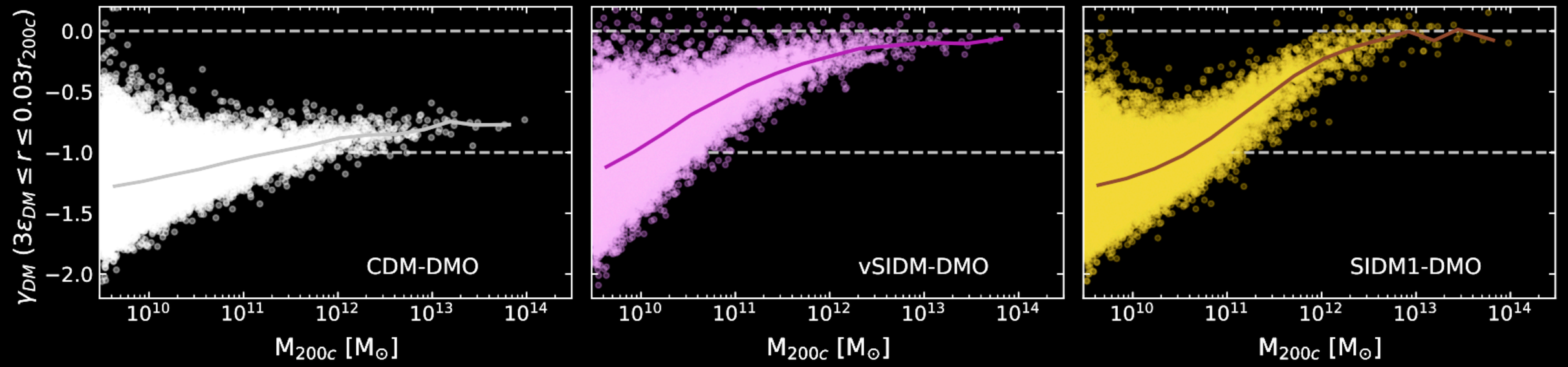
SIDM vel. dip.

(Despali et al. 2026)

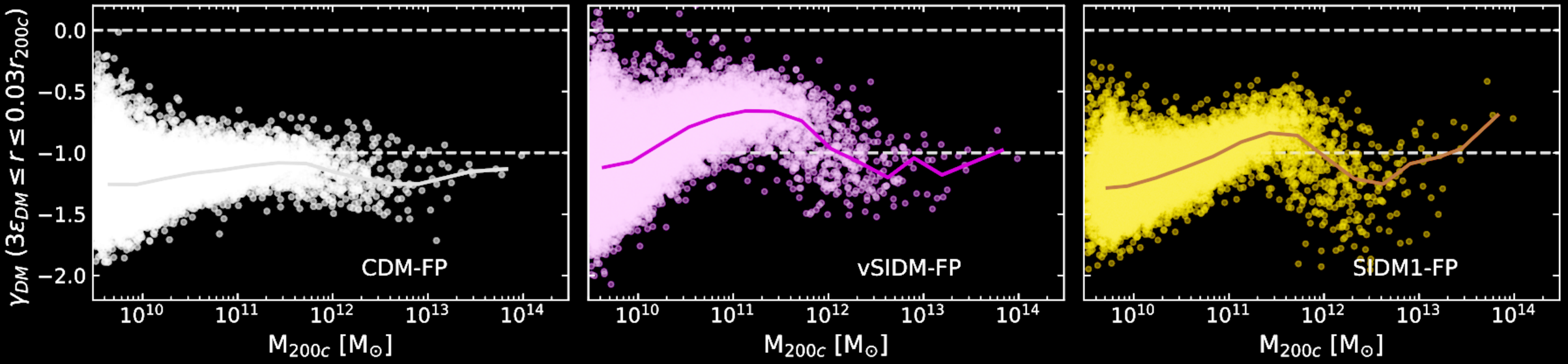
HALO PROFILES



HALO PROFILES



adding baryons..



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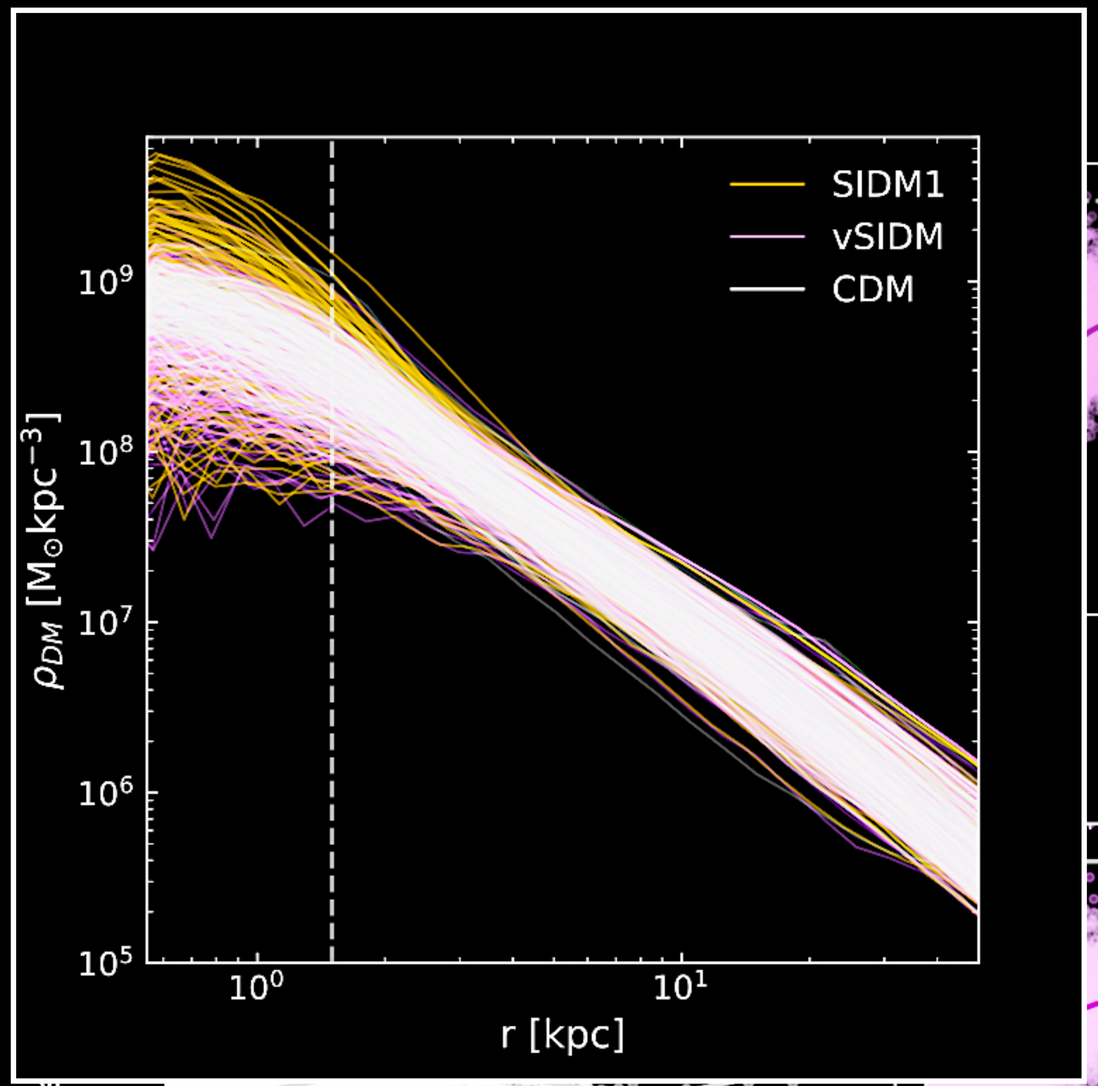
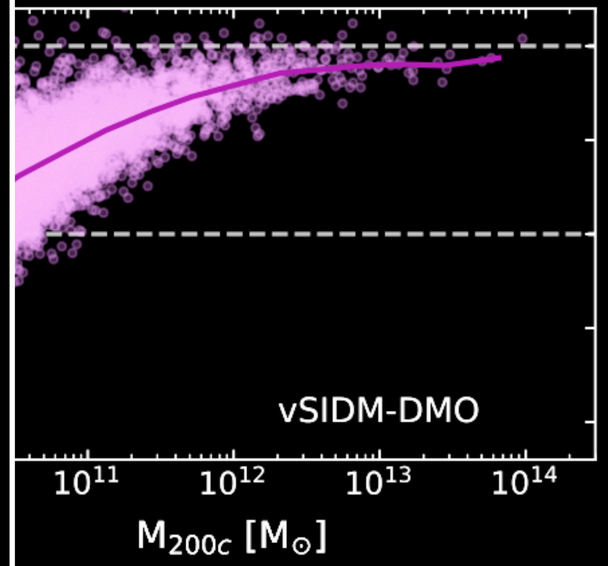
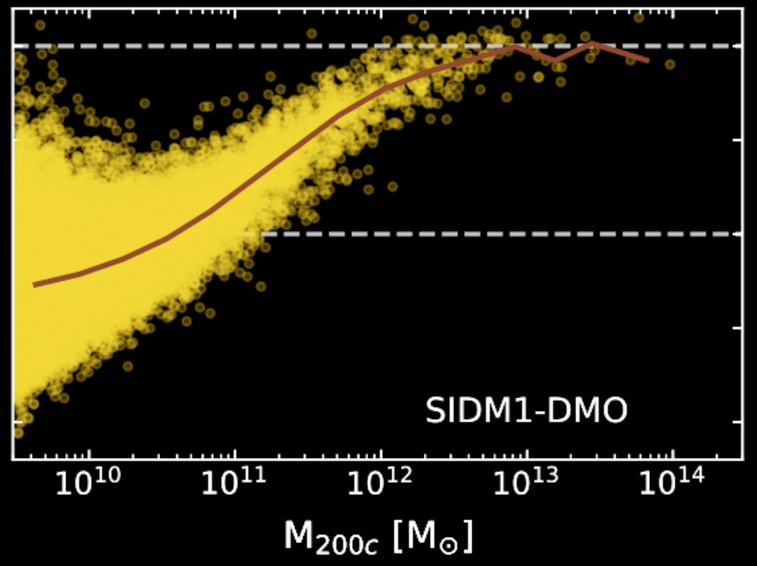
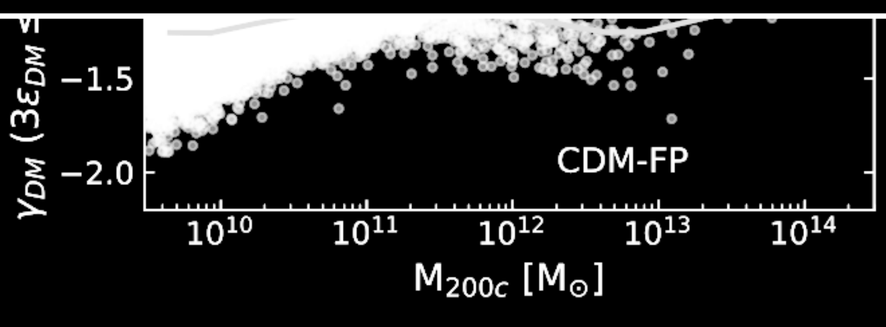
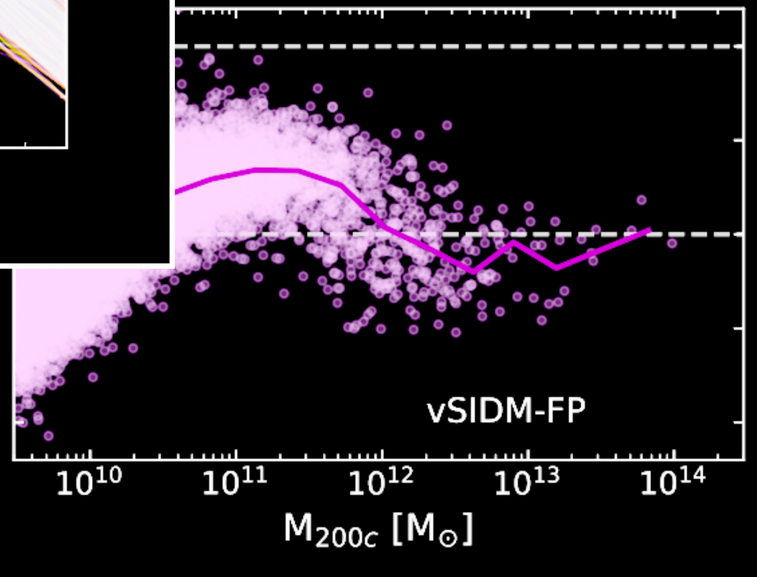


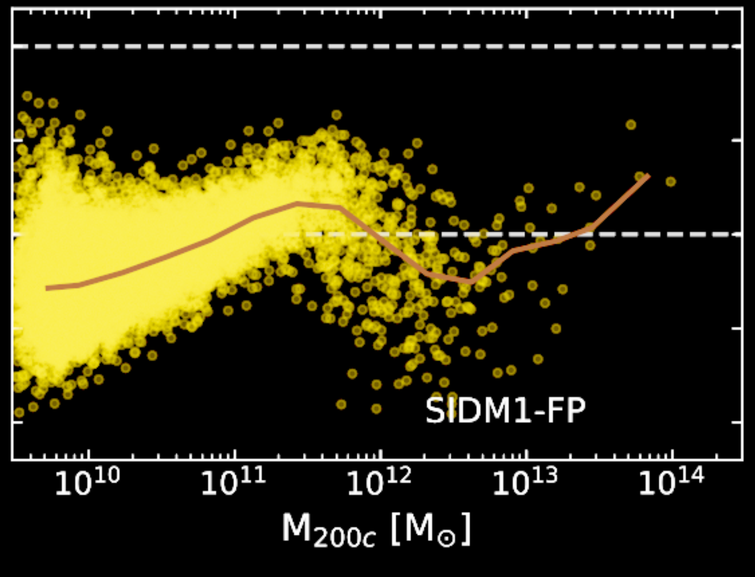




adding baryons..





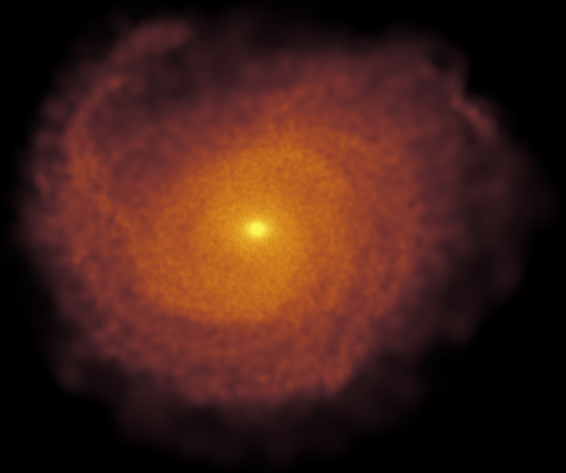


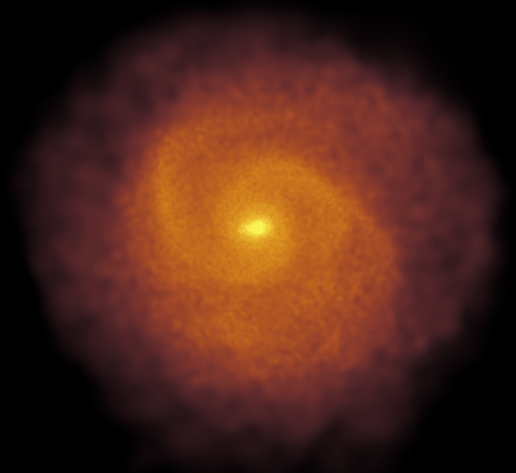
GALAXY MORPHOLOGY

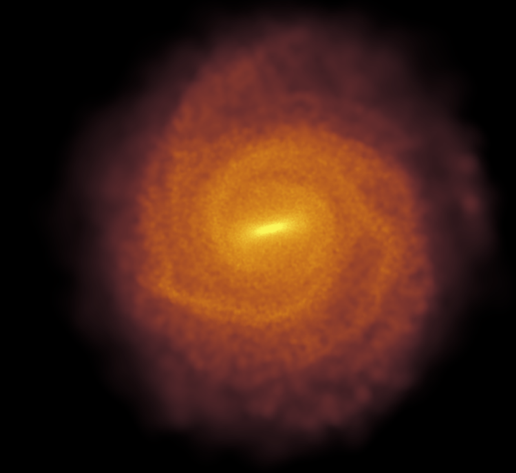
CDM

vSIDM ~0.2

SIDM 1





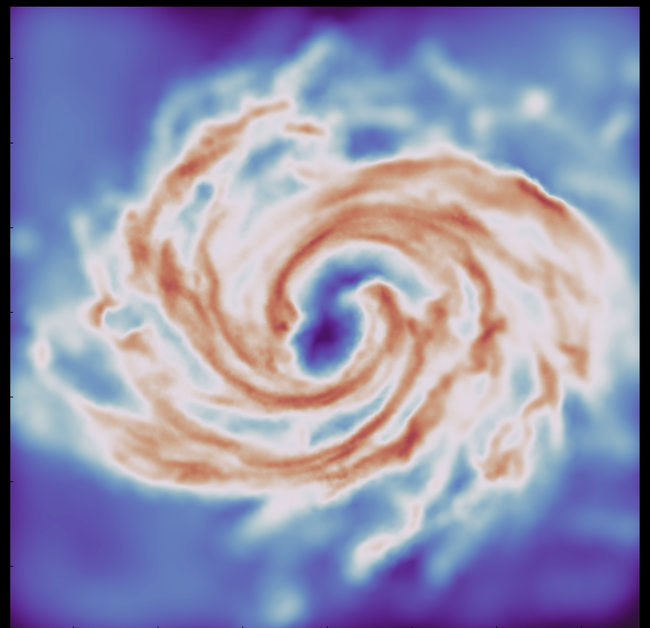


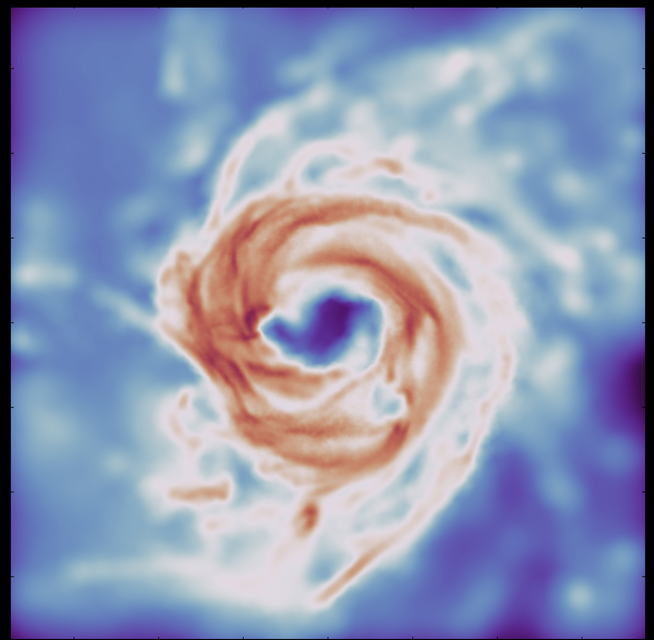
20 Kpc

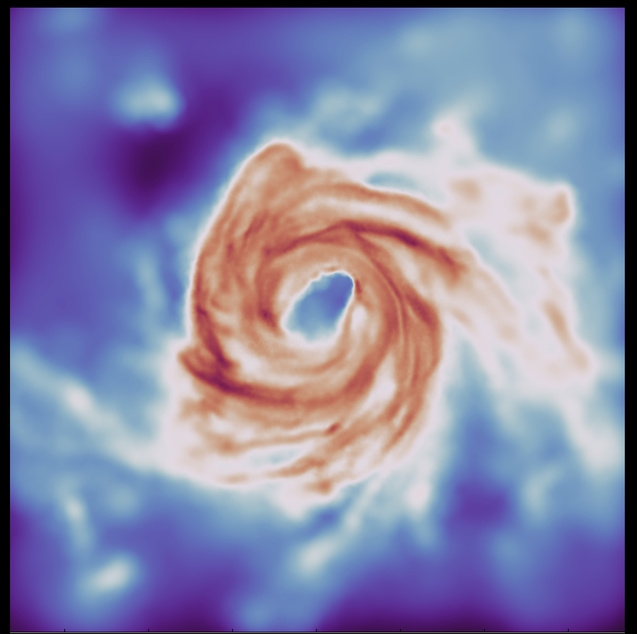
γ= -1.25

γ= -0.8

γ= -0.7







GALAXY MORPHOLOGY

CDM

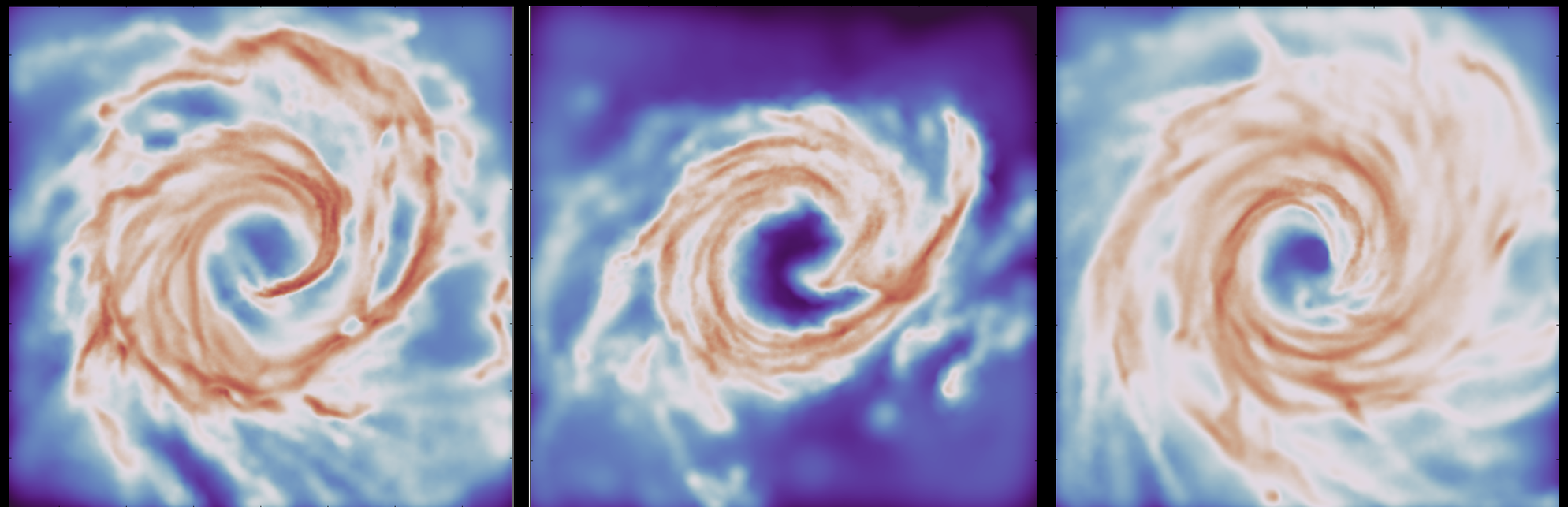
vSIDM ~0.2

SIDM 1

-1.2

-1.3

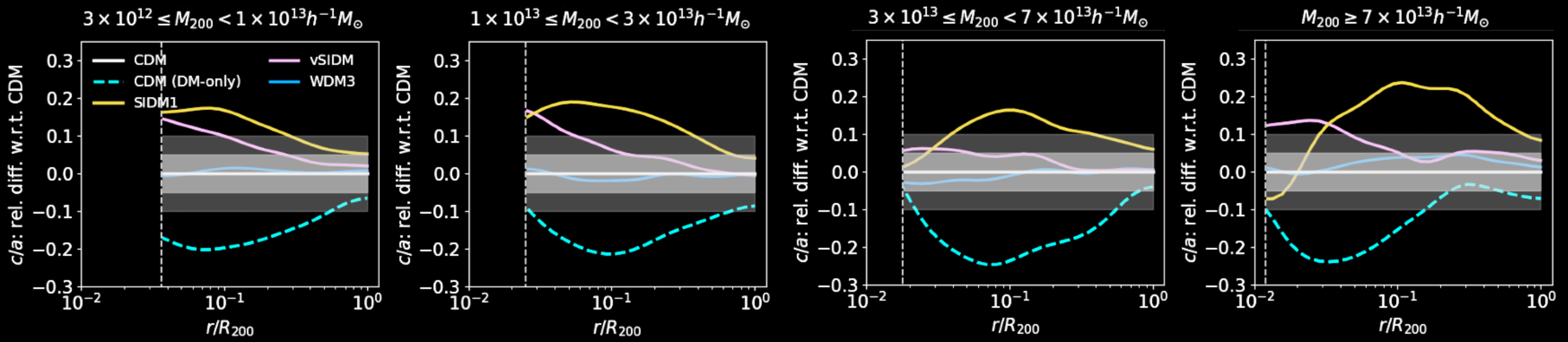
-1.8



haloes are less triaxial in SIDM

HALO SHAPES

Giocoli et al. 2026

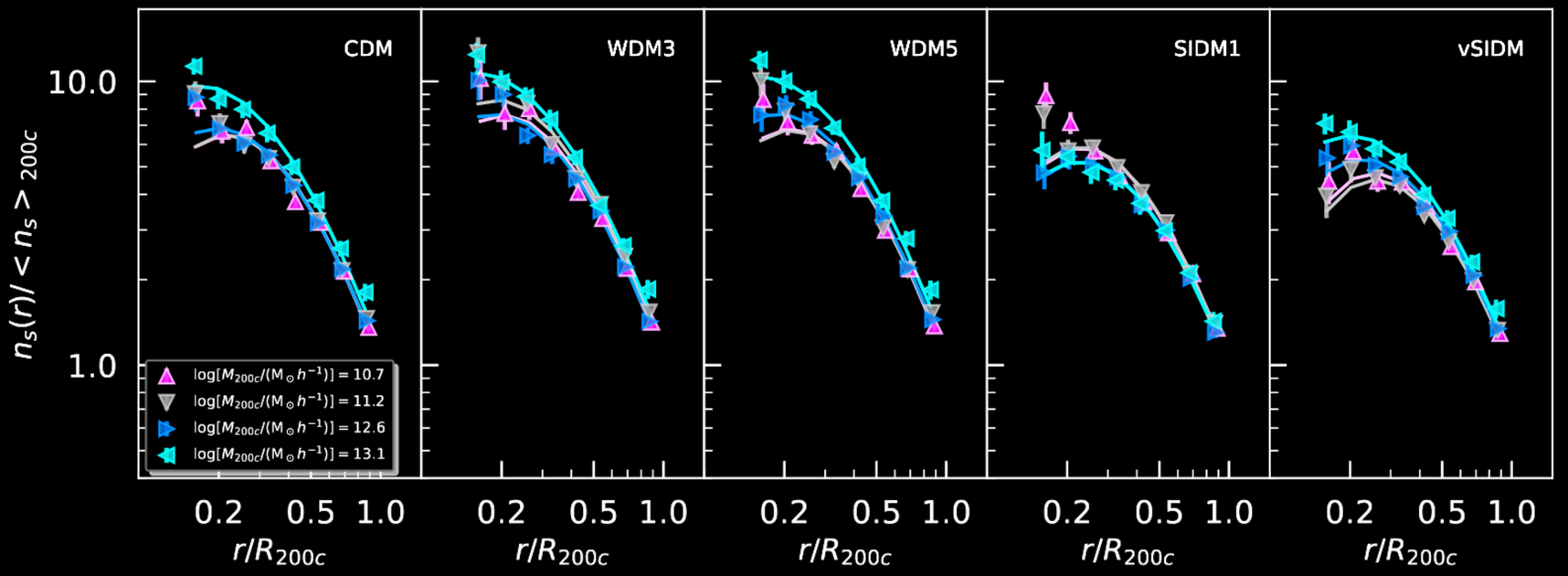


CDM dark → CDM + baryons → SIDM + baryons

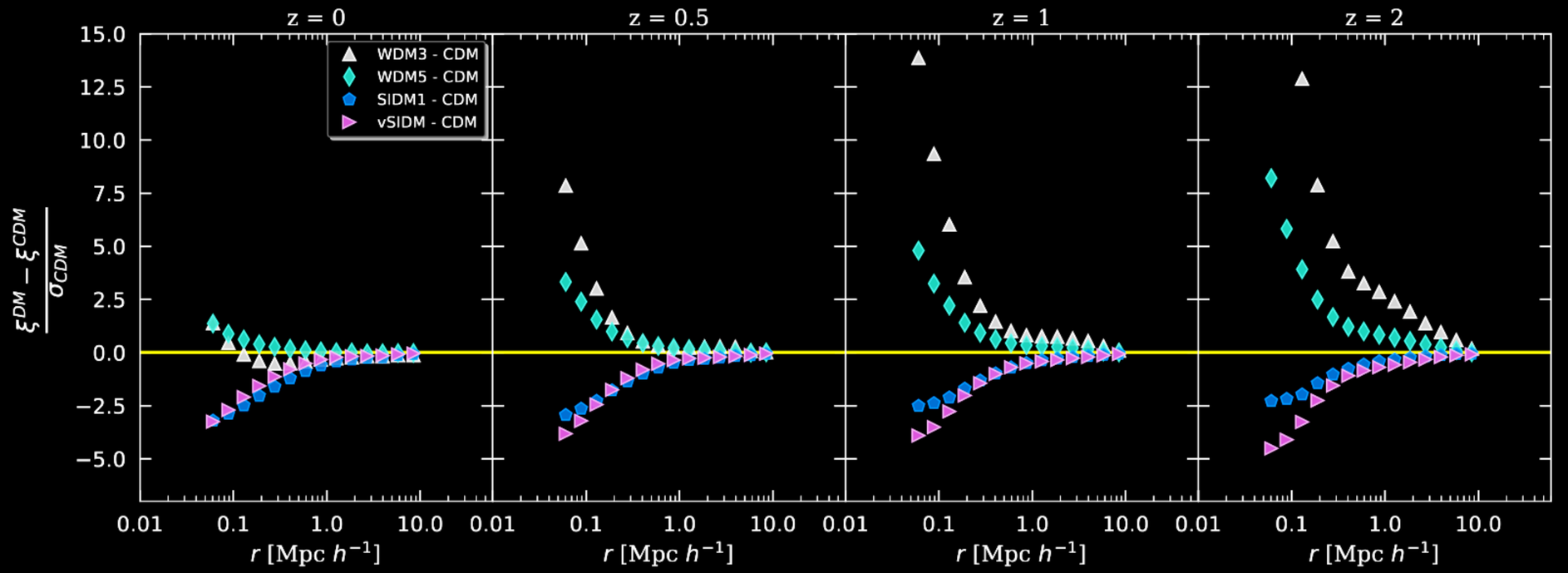
CLUSTERING

Romanello et al. 2026

radial distribution of subhalos

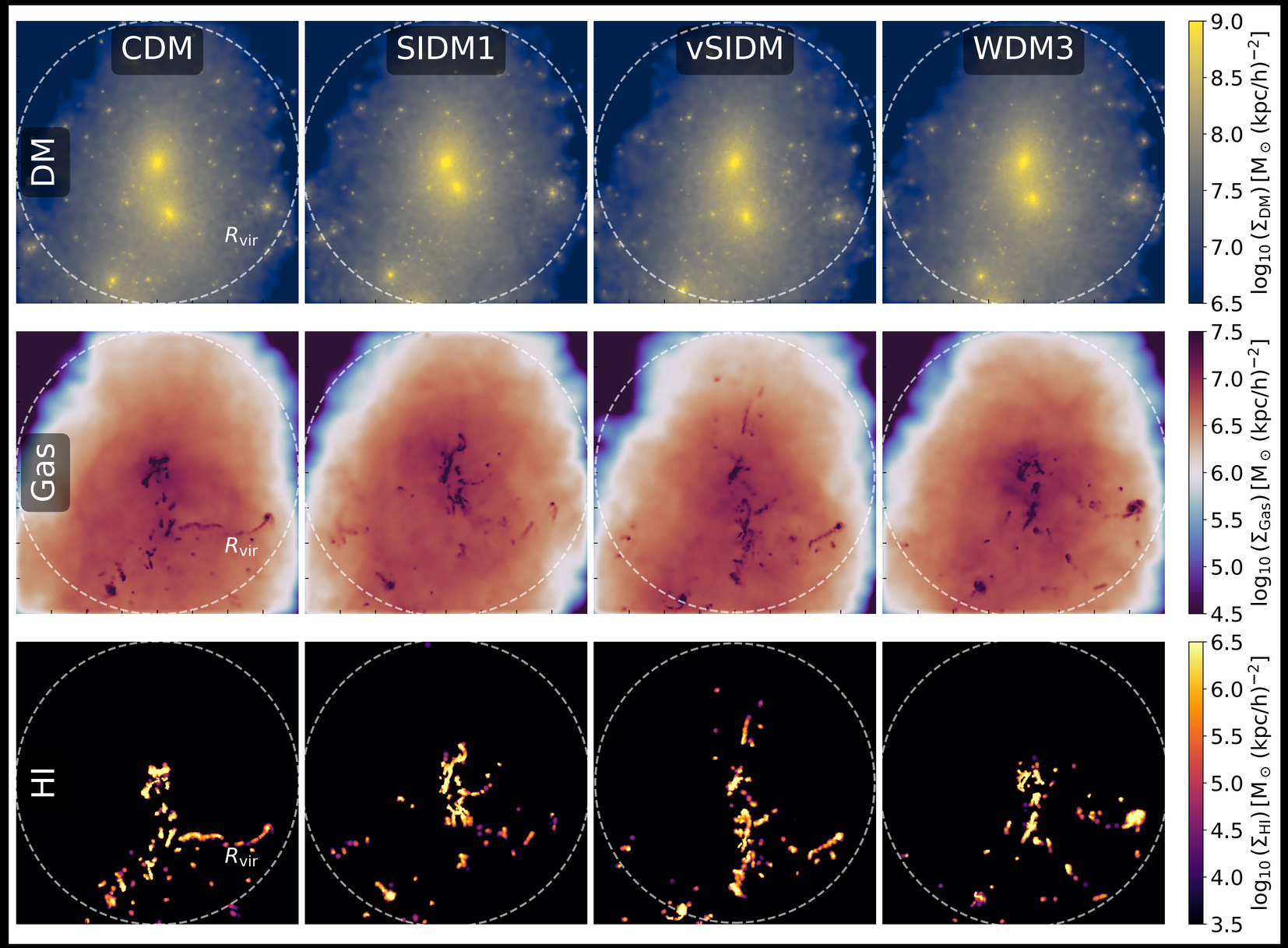


difference in the 2-point correlation function



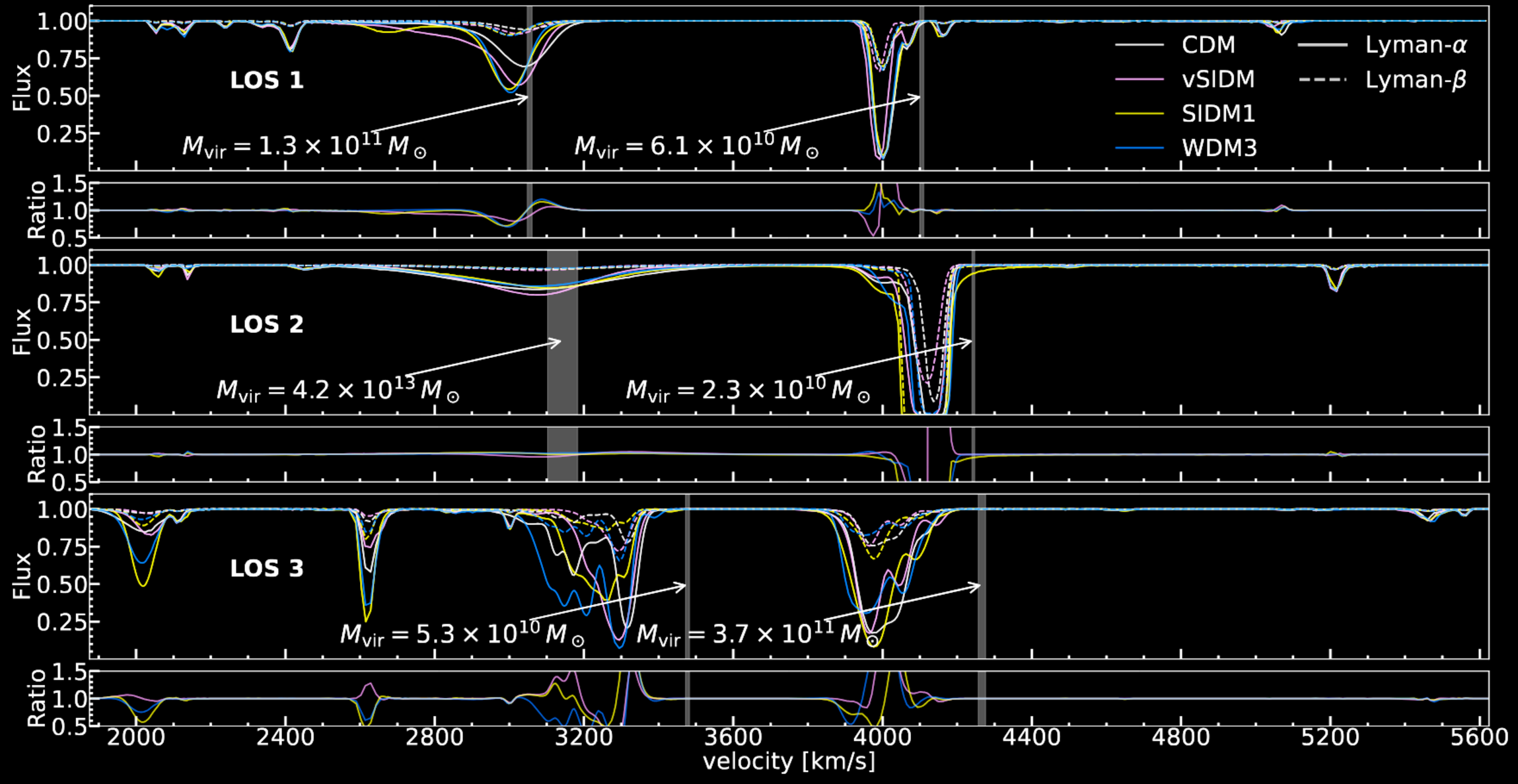
LYMAN-α

Zhang et al. 2026



LYMAN-α

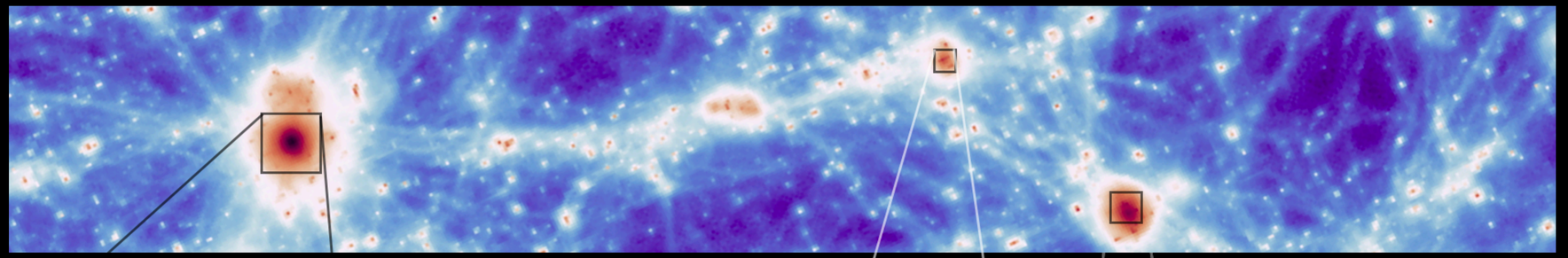
Zhang et al. 2026

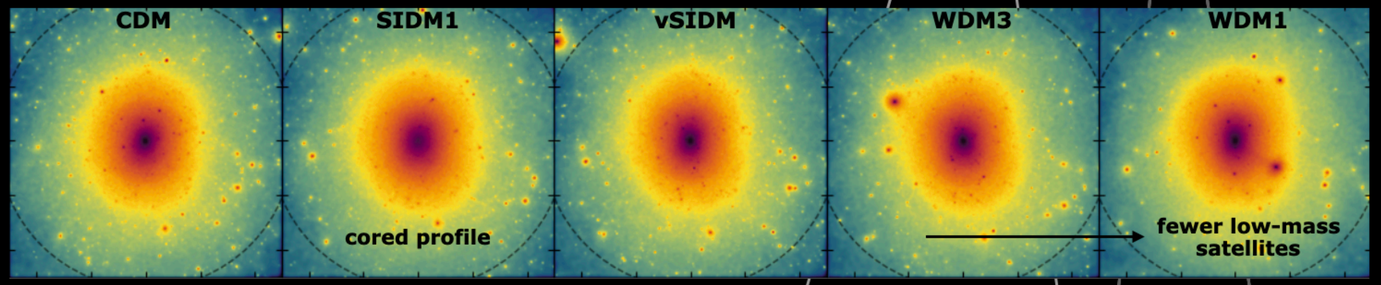


SUMMARY

new AIDA-TNG simulations

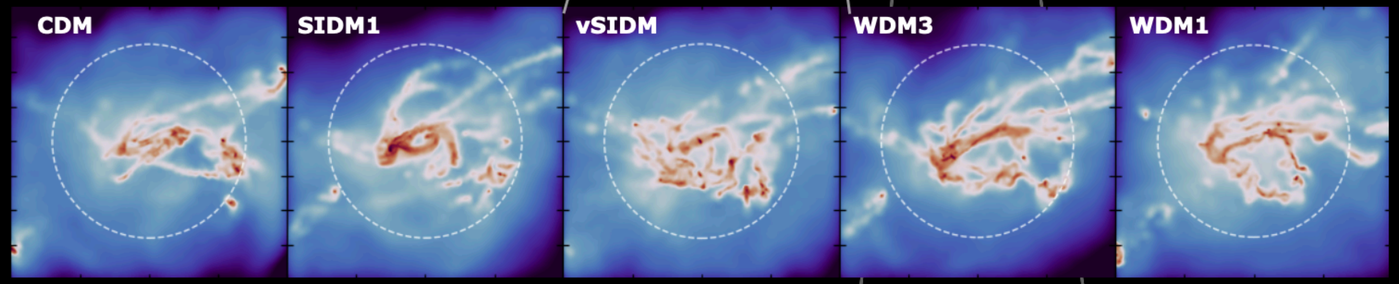
- ✓ three cosmological boxes
- ✓ AREPO - moving mesh
- ✓ TNG galaxy formation model
- ✓ CDM, WDM, SIDM
- ✓ multiple resolution levels
- ✓ large statistics of galaxies

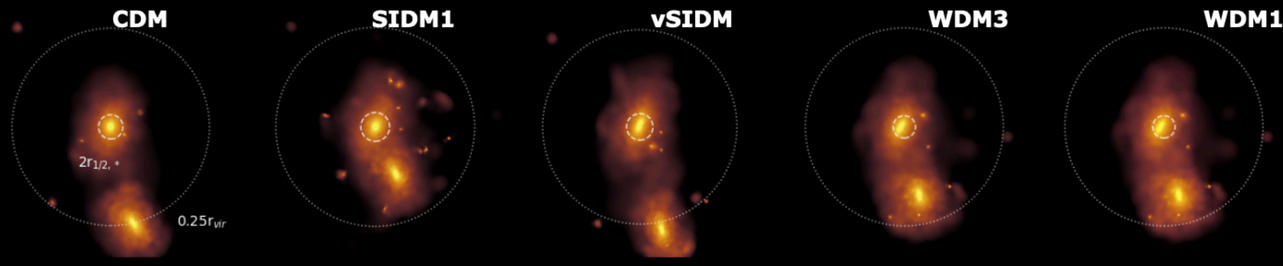




dark matter

gas





stars