Astrophysical Phenomenology of a Dissipative Dark Sector

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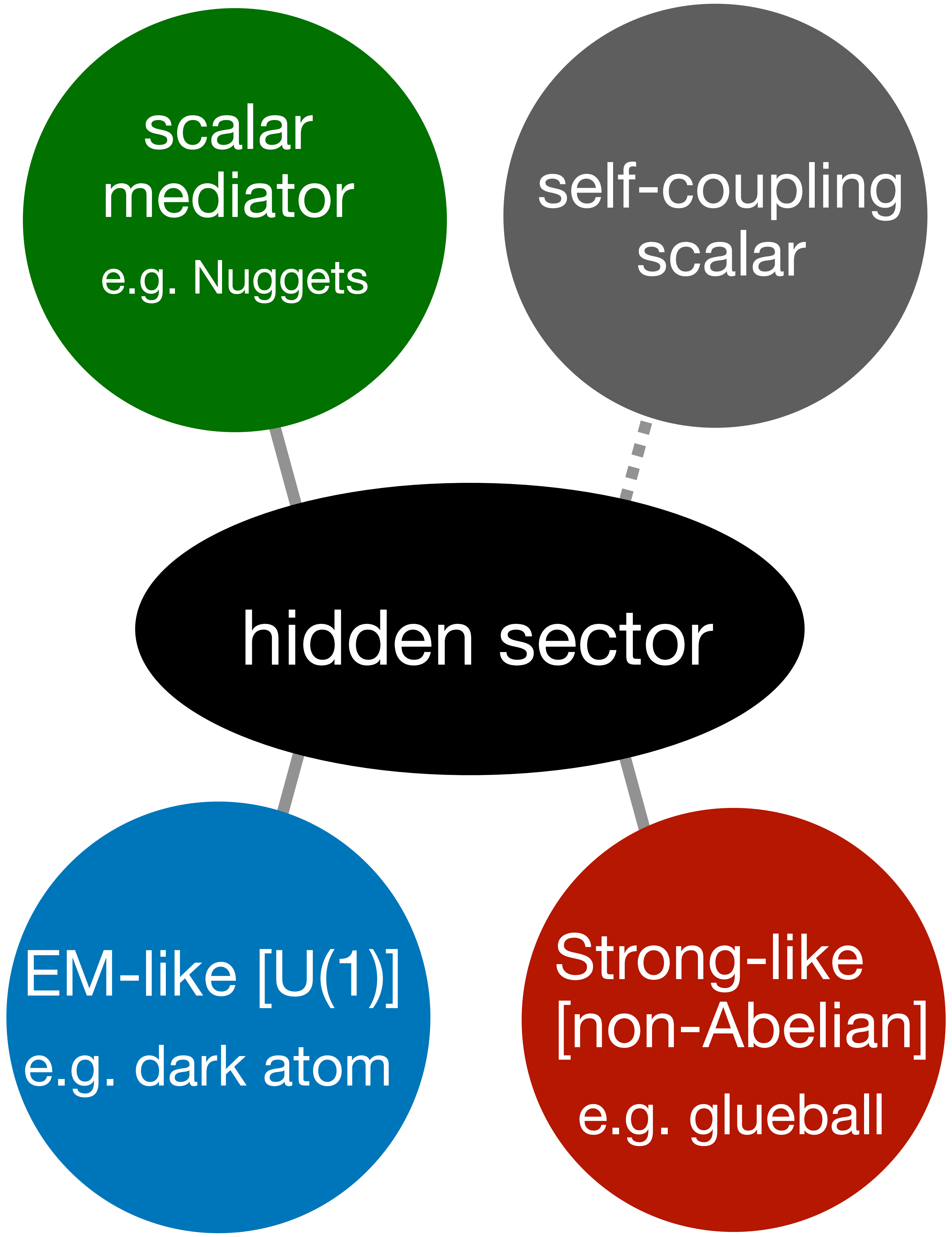
Valencia SIDM workshop
06/09/2025

Dissipative SIDM (dSIDM)

A realistic hidden sector

(e.g. Wise & Zhang 2014,
Gresham et al. 2017,2018)



(e.g. Ackerman 2009; Arkani-Hamed 2009 ;
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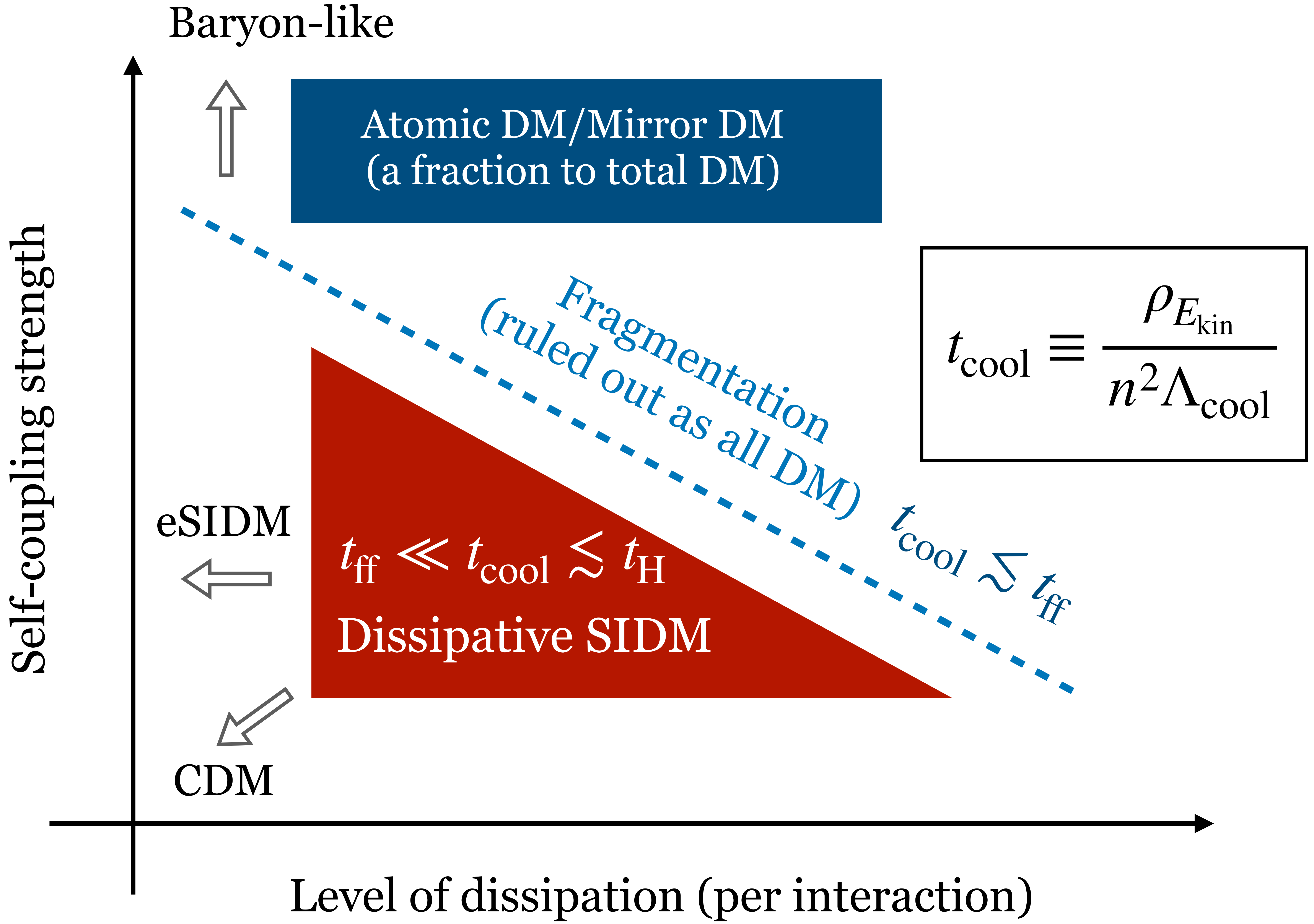

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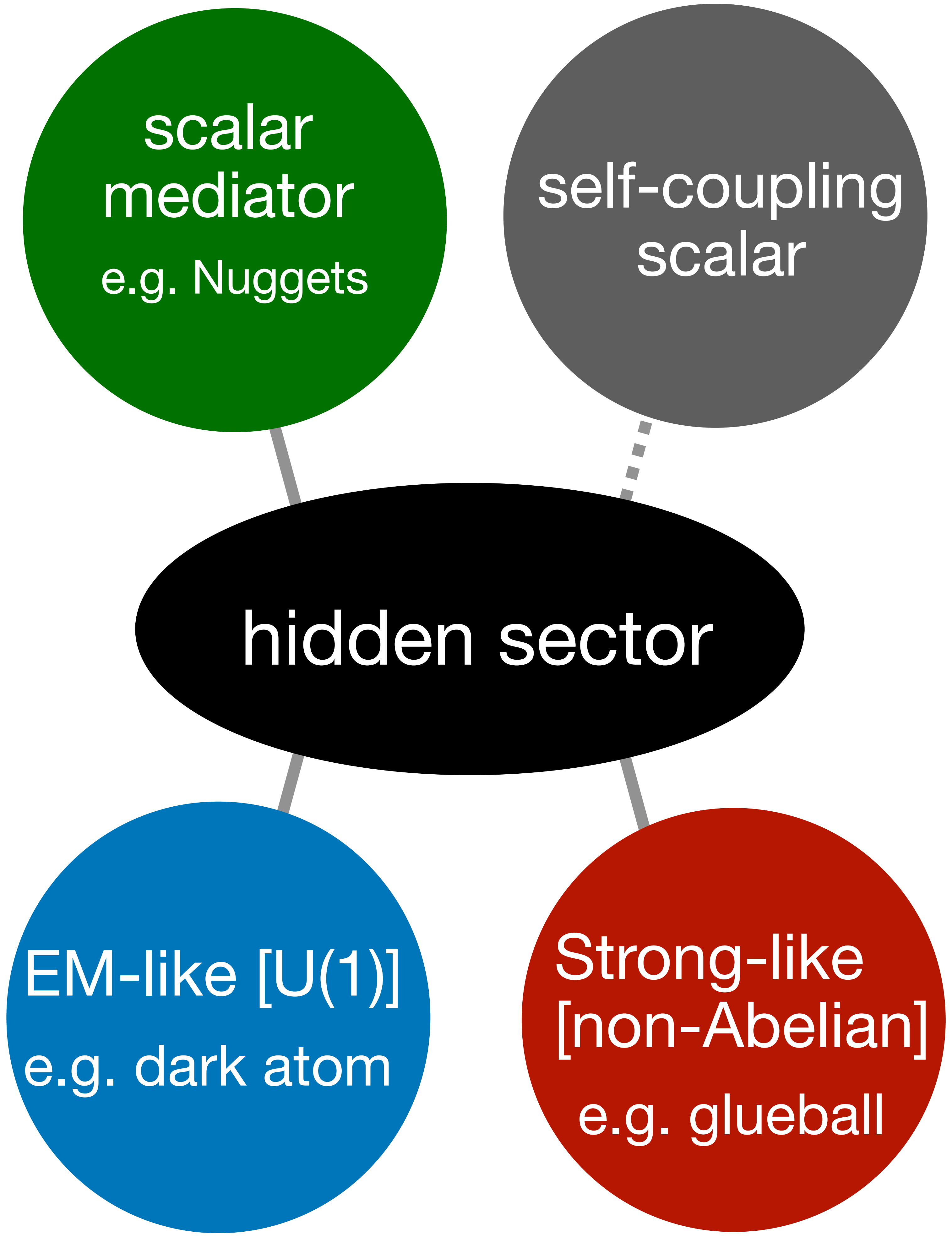

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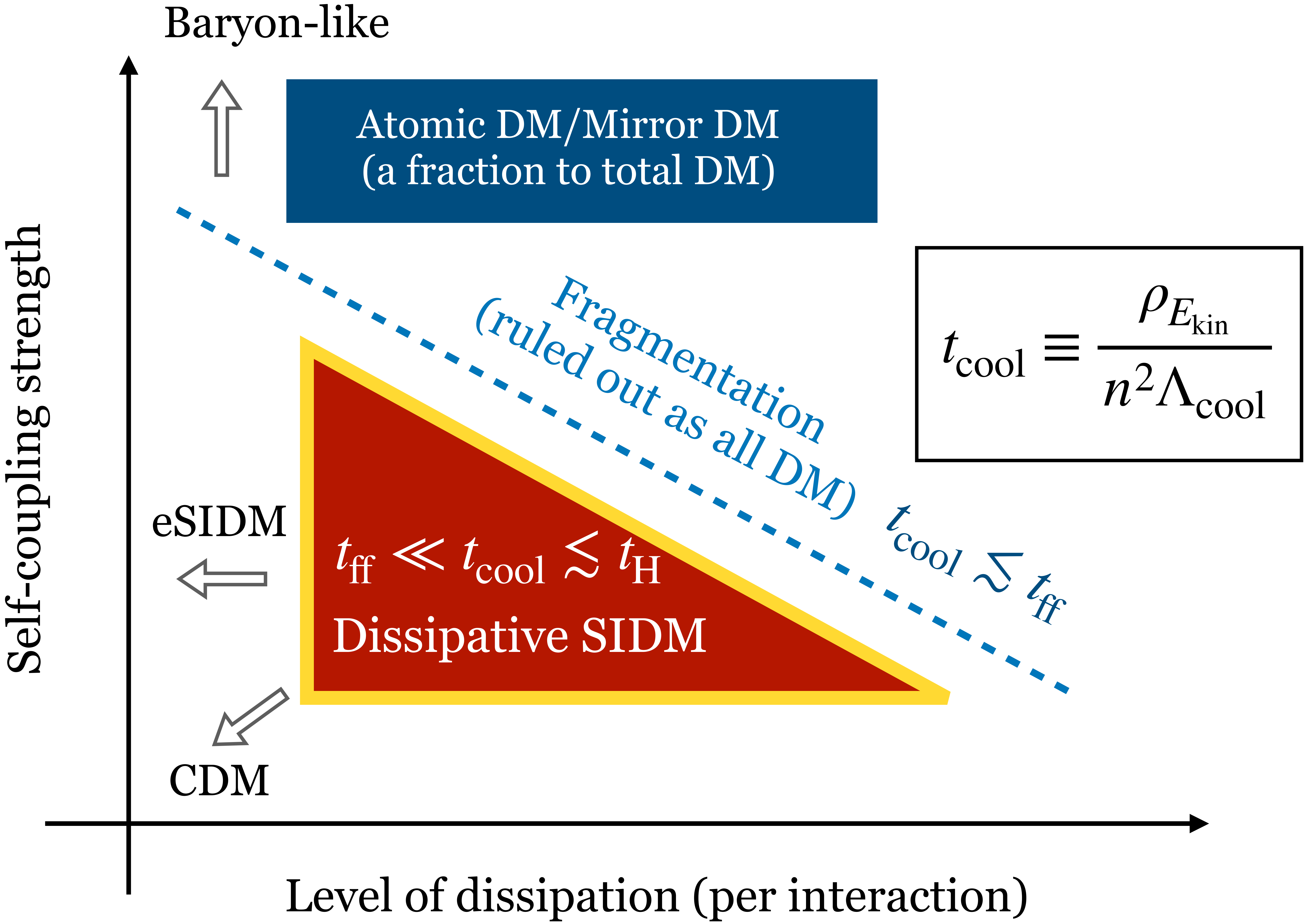


Cosmological Simulations of dwarf galaxies in dSIDM

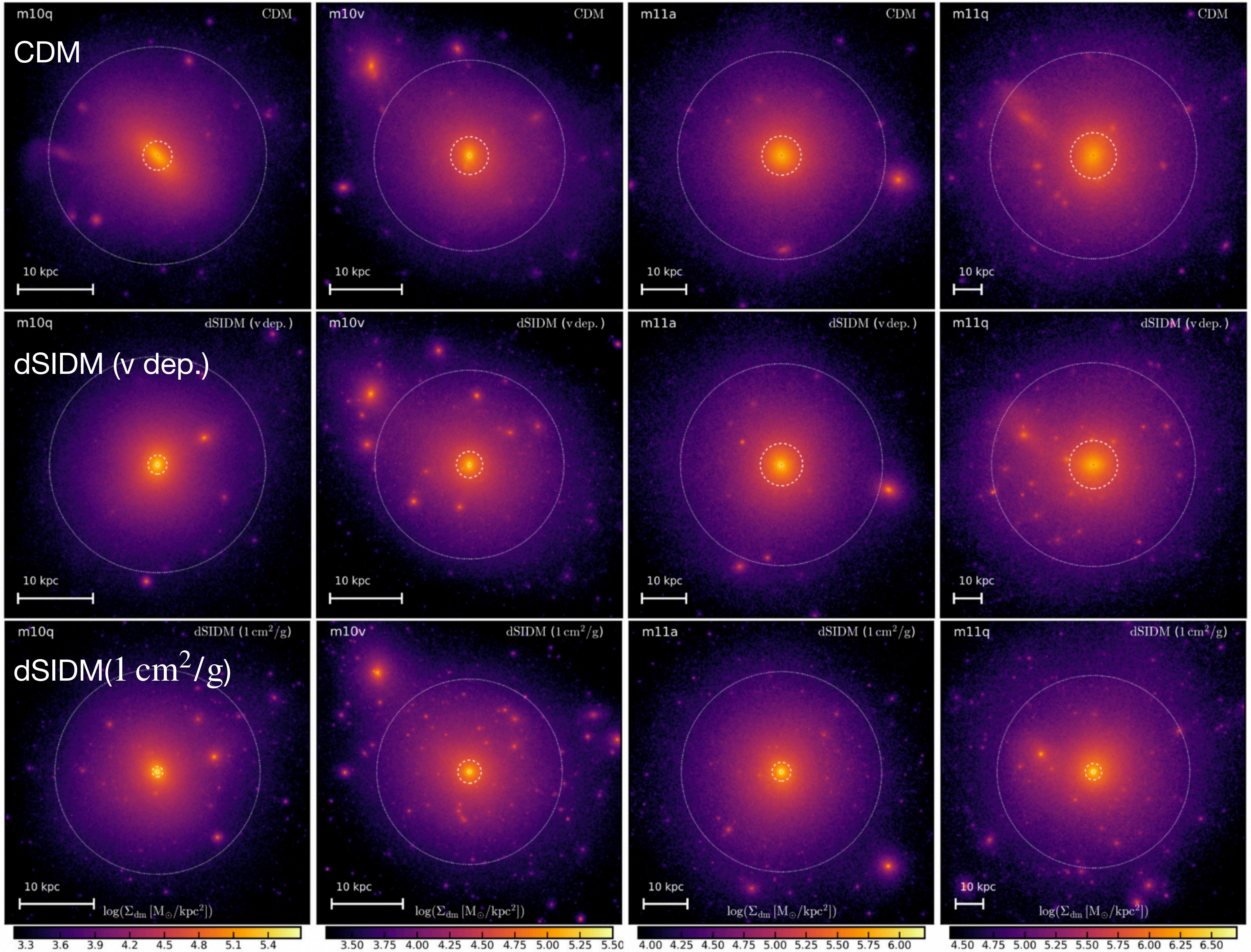
GIZMO (e.g. Hopkins+14)
SIDM: Monte-Carlo scattering

$M_{\rm halo} \sim 10^9 - 10^{12}\,{\rm M}_\odot$
from ultra-faint to MW-mass

constant dissipation factor
$f_{\rm diss} = 0.75$
$(\sigma/m) = 0.1 - 10\,{\rm cm}^2/g$
+ a velocity-dependent model

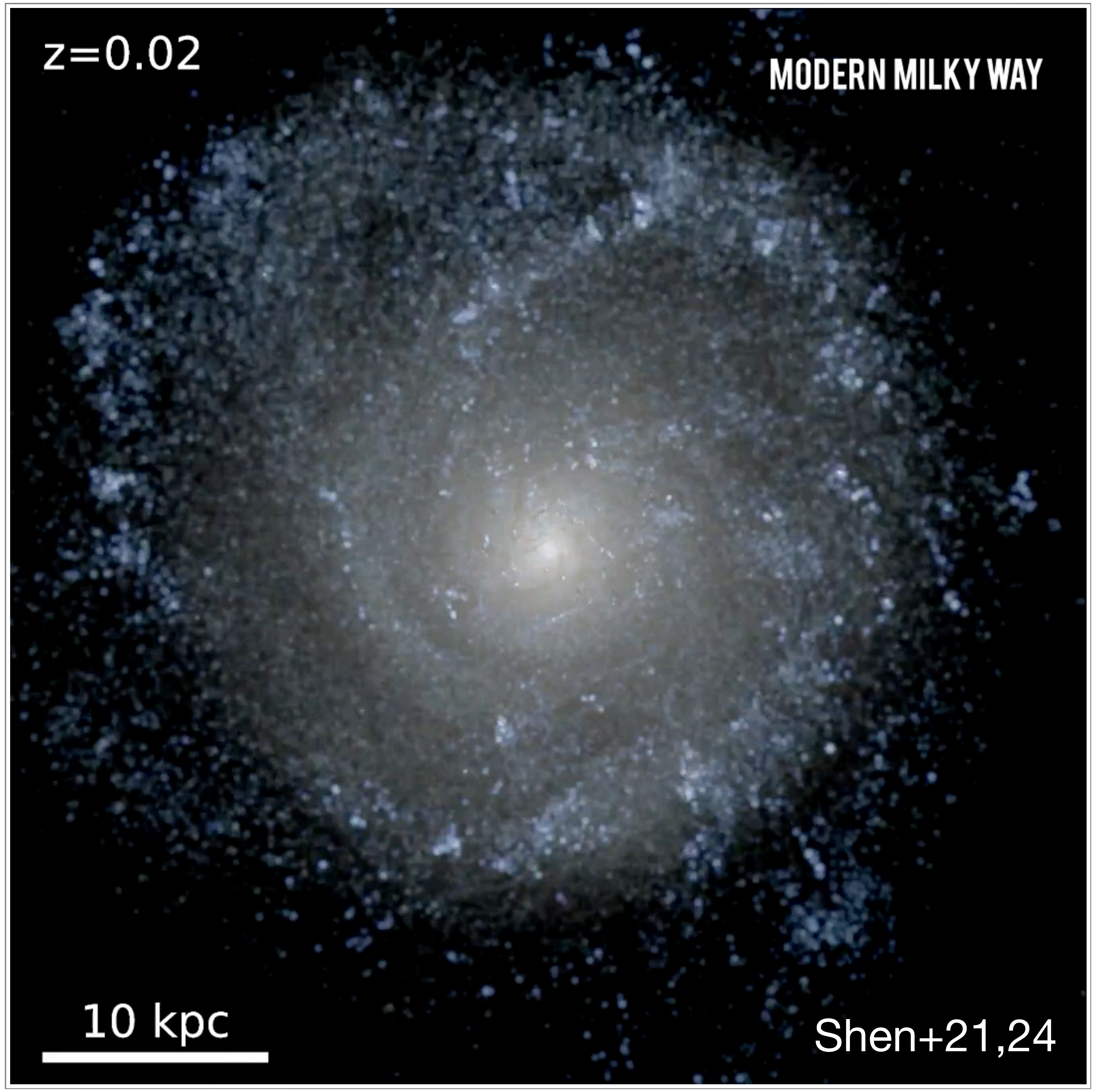
$$\frac{\sigma(v)}{m} = \frac{(\sigma/m)_0}{1+(v/v_0)^4} \qquad (\sigma/m)_0 = 10\,{\rm cm}^2\,{\rm g}^{-1} \qquad v_0 = 10\,{\rm km\,s}^{-1}$$

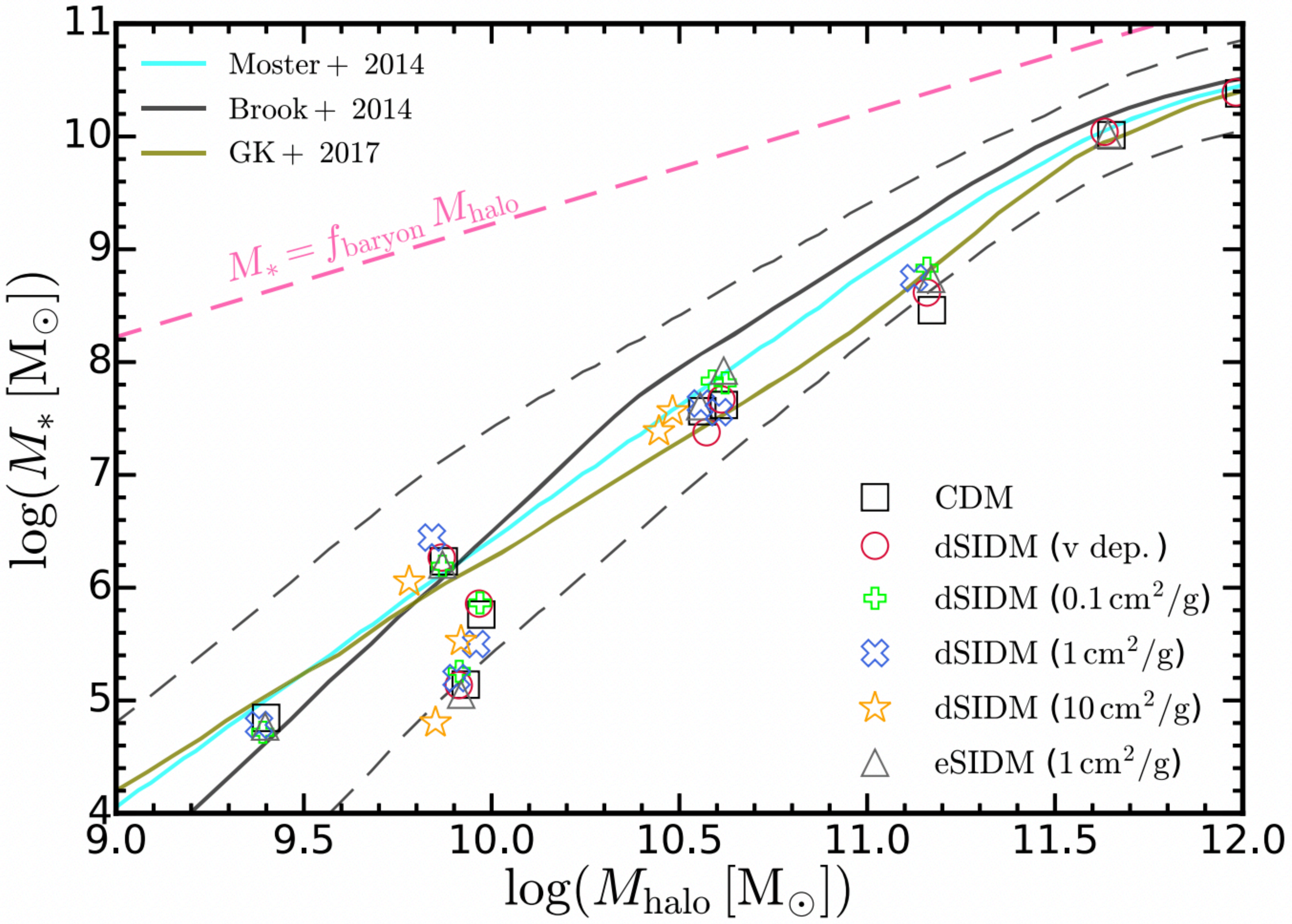
Shen+21,24



Cosmological Simulations of dwarf galaxies in dSIDM

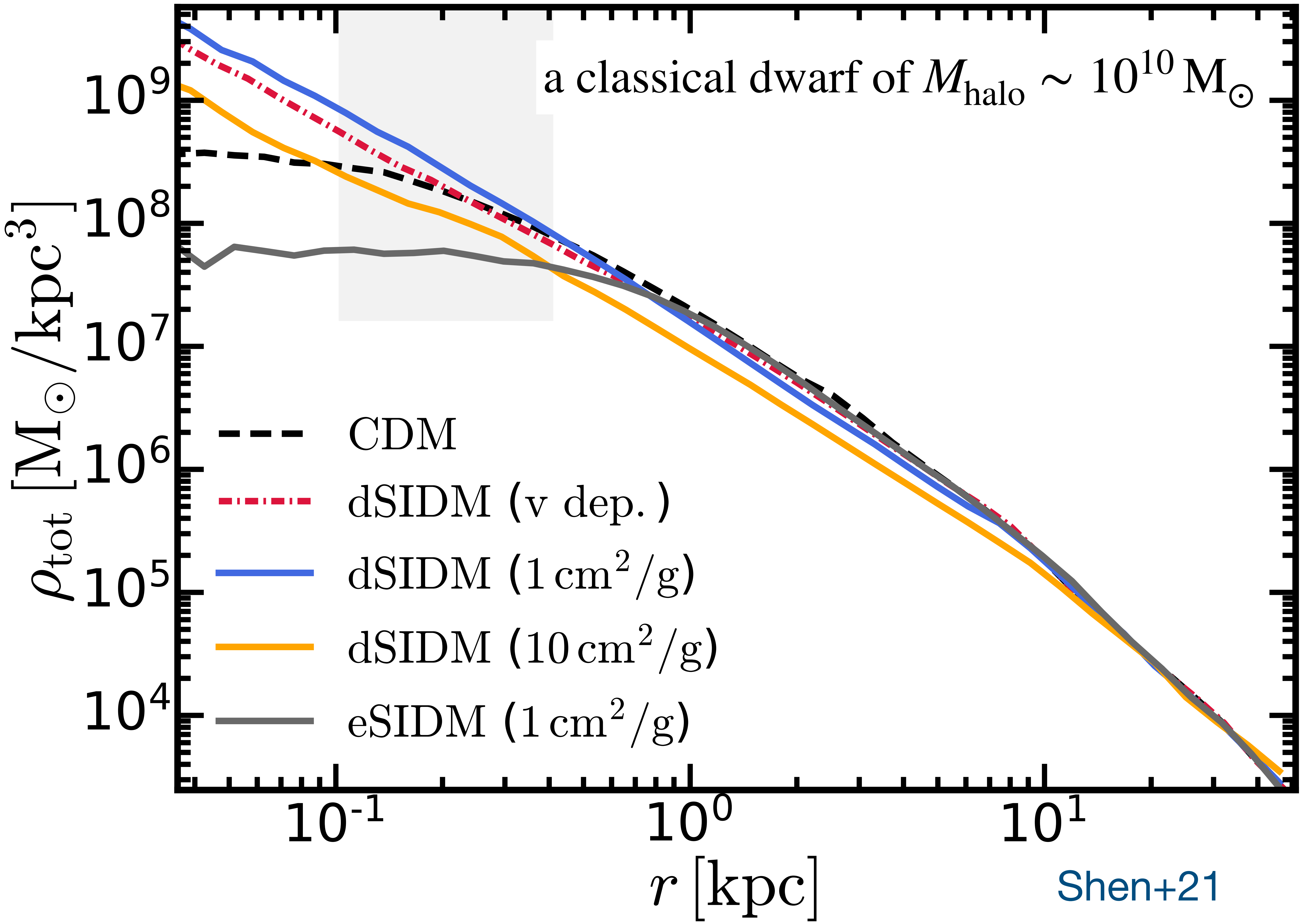
+ FIRE-2 galaxy formation model (e.g. Hopkins+18)

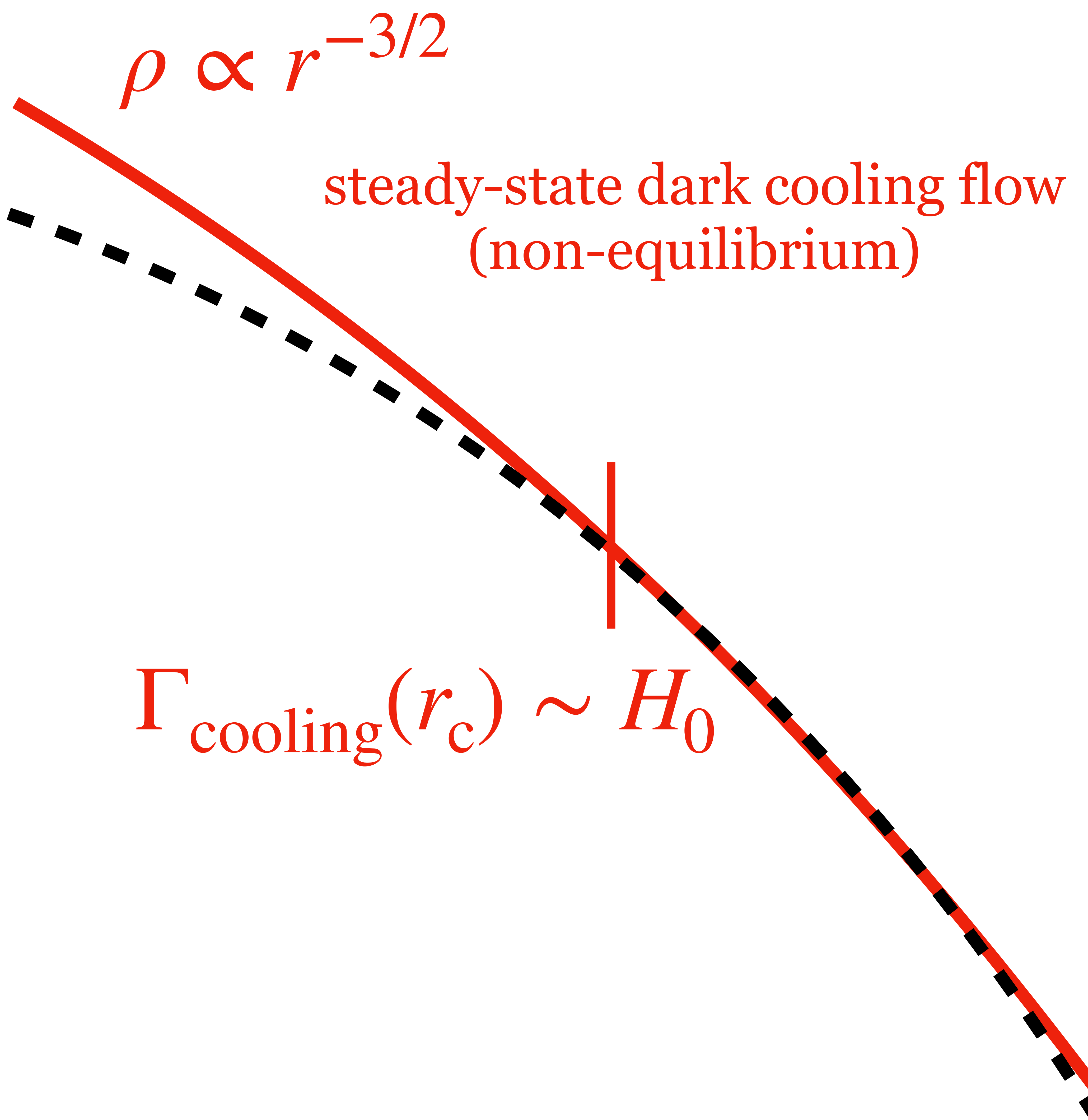




Cosmological Simulations of dwarf galaxies in dSIDM

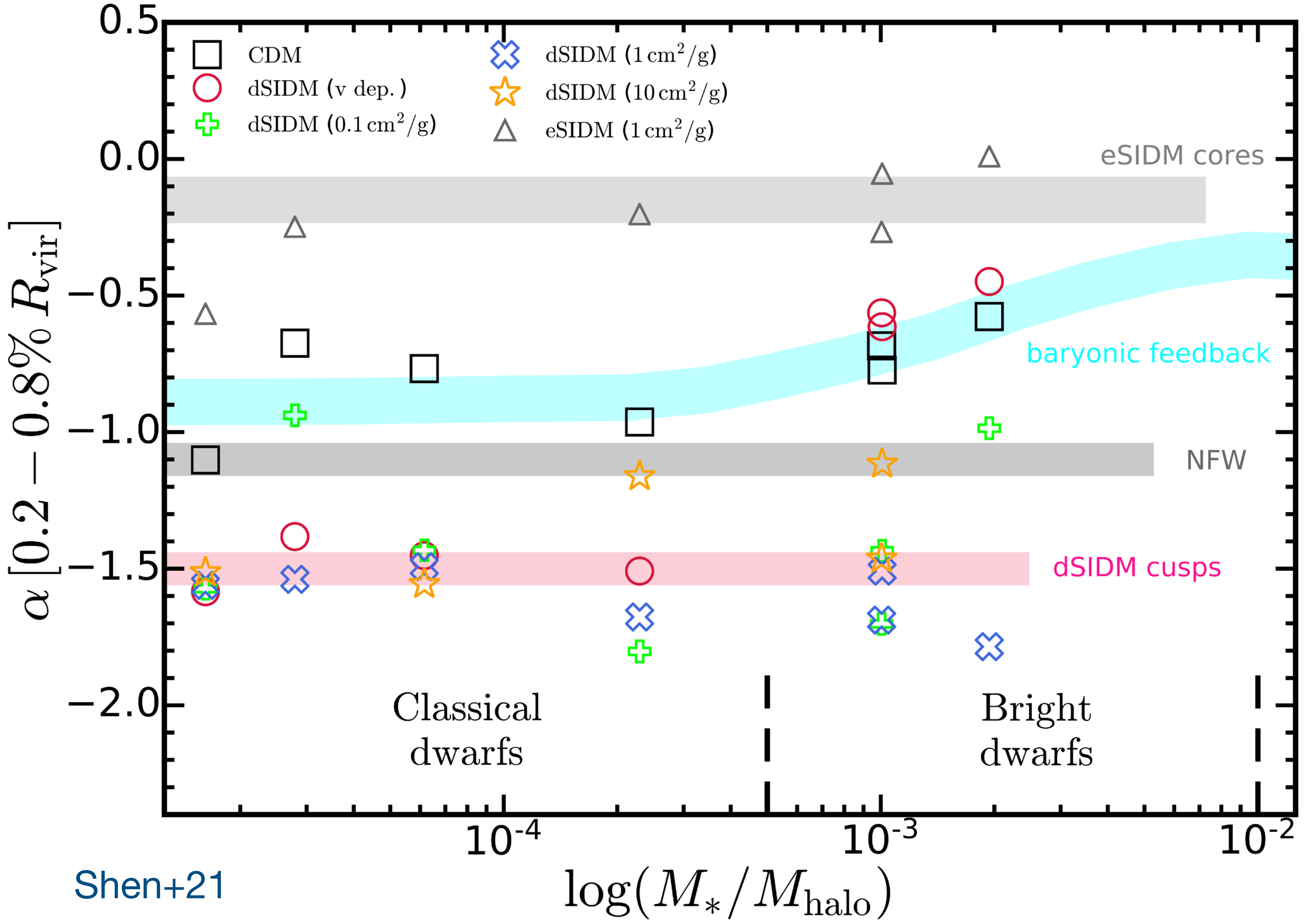
"cusps" in dSIDM $\quad f_{\rm diss} \sim \mathcal{O}(1) \quad t_{\rm cool} \sim t_{\rm coll} \lesssim t_{\rm H} \quad (\sigma/m)_{\rm eff} \gtrsim 0.1\,{\rm cm^2}/g$





Cosmological Simulations of dwarf galaxies in dSIDM

asymptotic slope α of density profile versus $M_*/M_{\rm halo}$



Shen+21

➡ **eSIDM cores**

➡ **baryonic feedback**

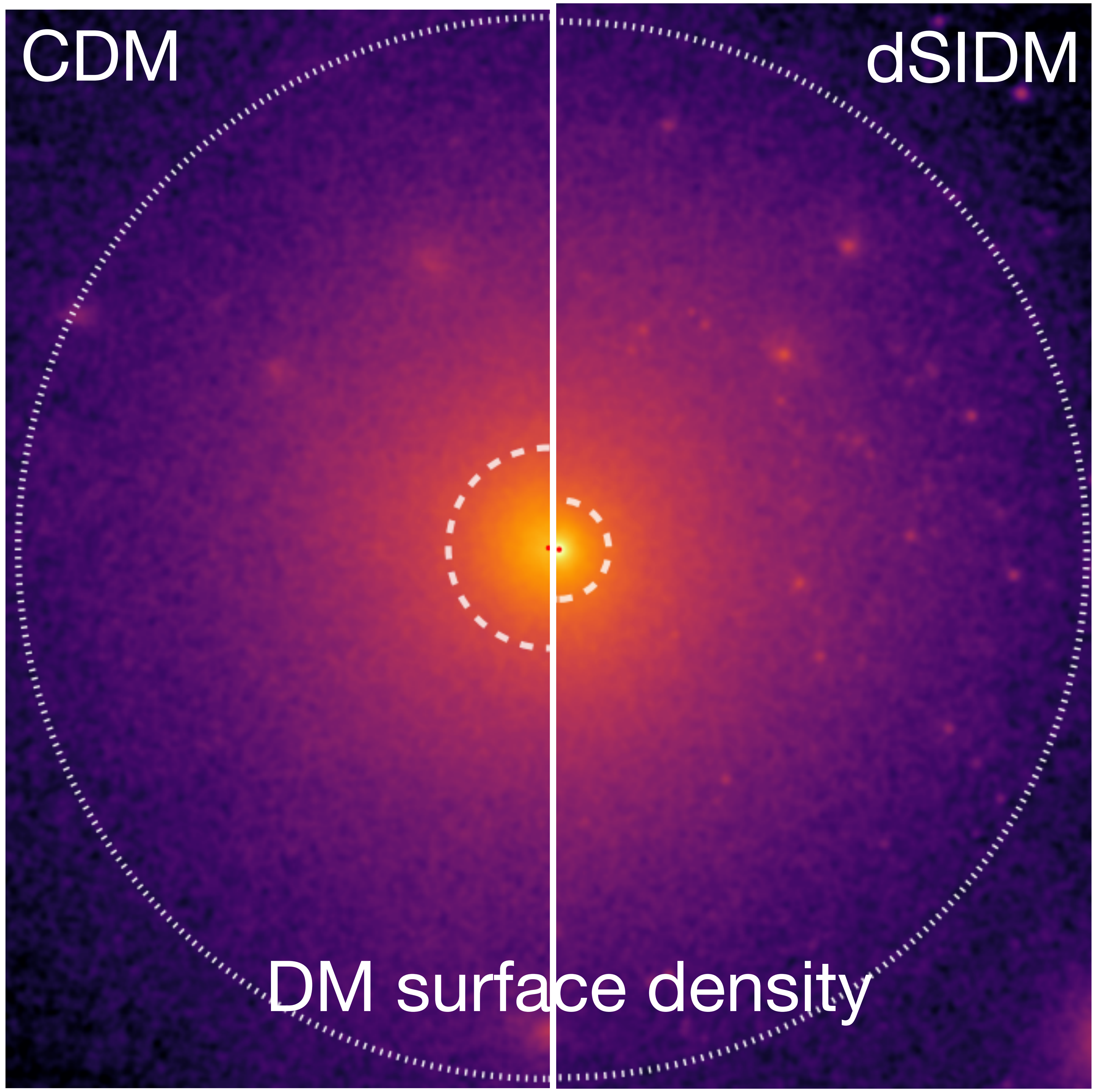
➡ **NFW: collisionless CDM**

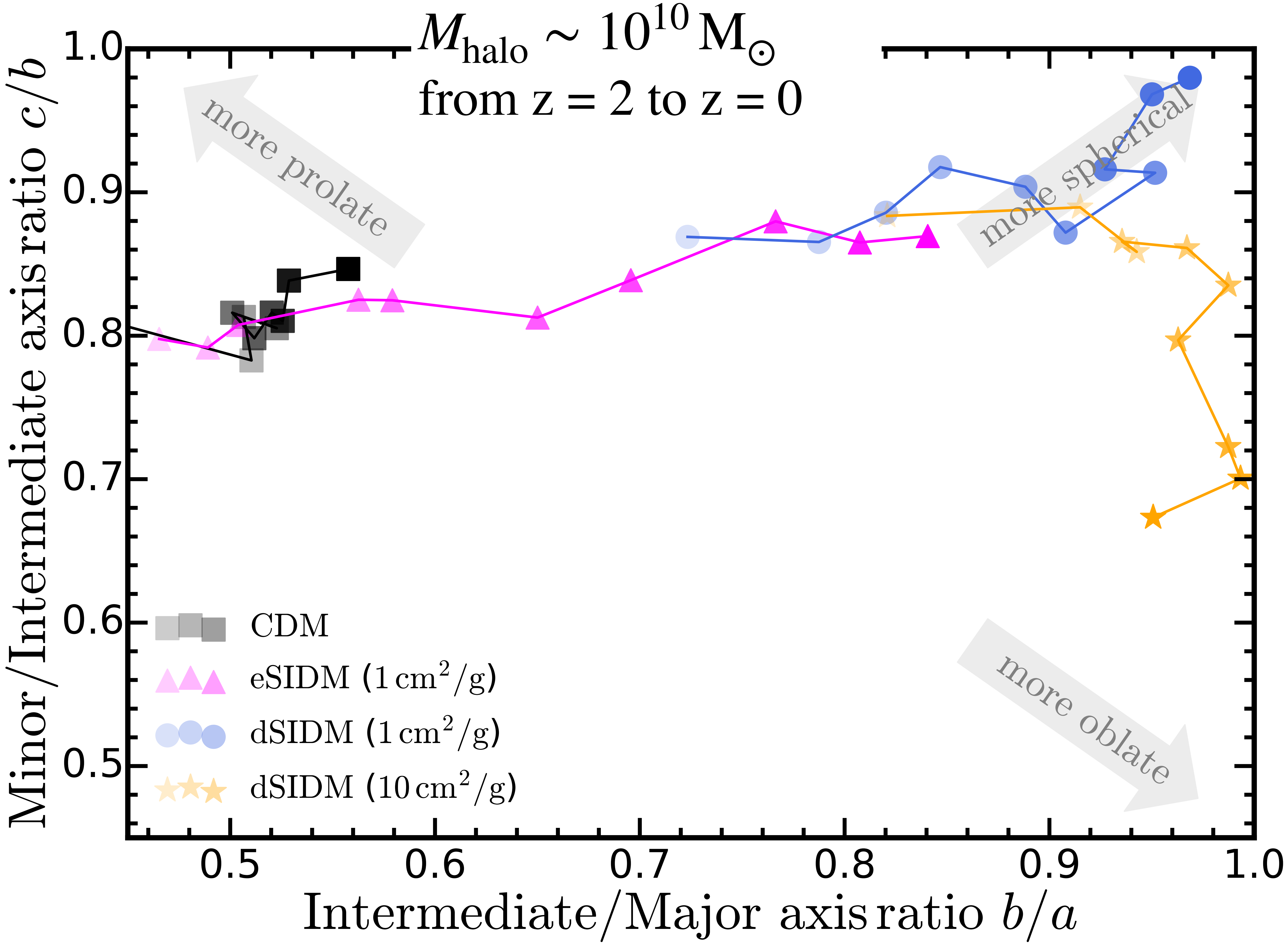
➡ **dSIDM cusps**

(dark cusps appear even in MW-mass galaxies, but are hidden behind baryons)

Cosmological Simulations of dwarf galaxies in dSIDM

a classical dwarf of $M_{\rm halo} \sim 10^{10}\,{\rm M}_\odot$





Shen+21

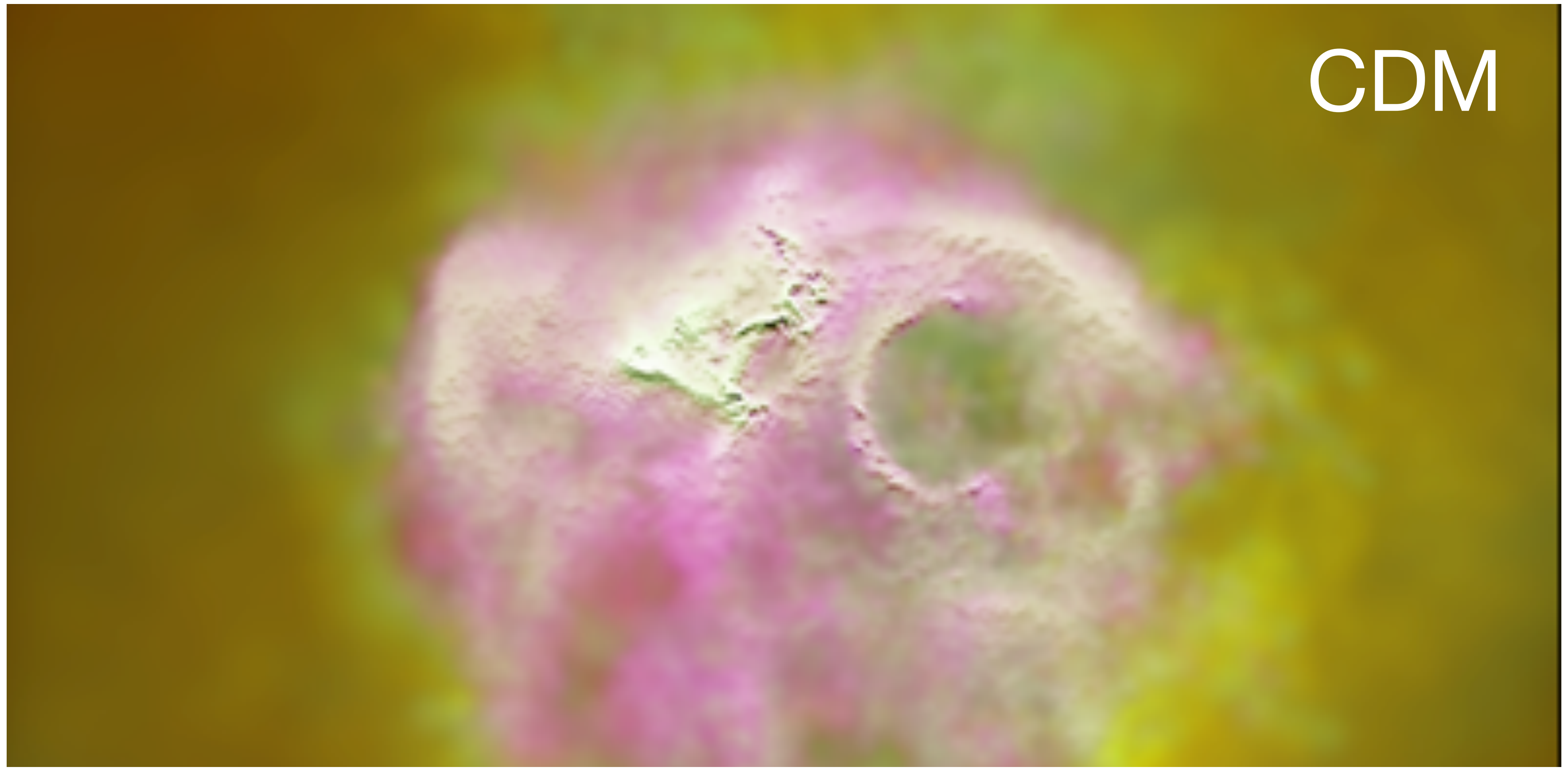
Cosmological Simulations of dwarf galaxies in dSIDM

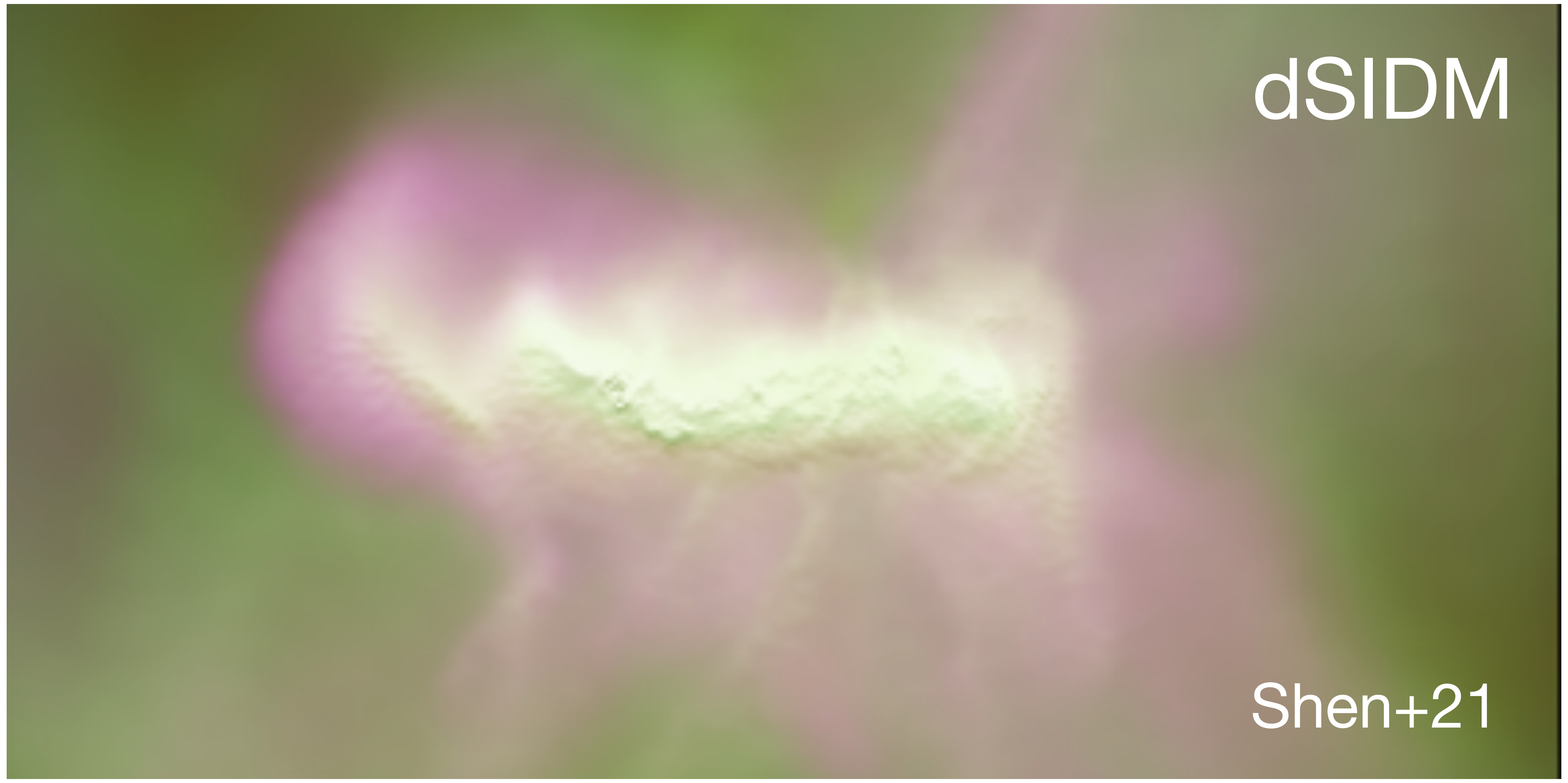
a dwarf of
$M_{\rm halo} \sim 10^{11}\,{\rm M}_\odot$

CDM: Strong, clustered Supernovae feedback disrupt gas disks

dSIDM: Concentrated mass distribution promotes disk formation in lower-mass halos and at earlier times

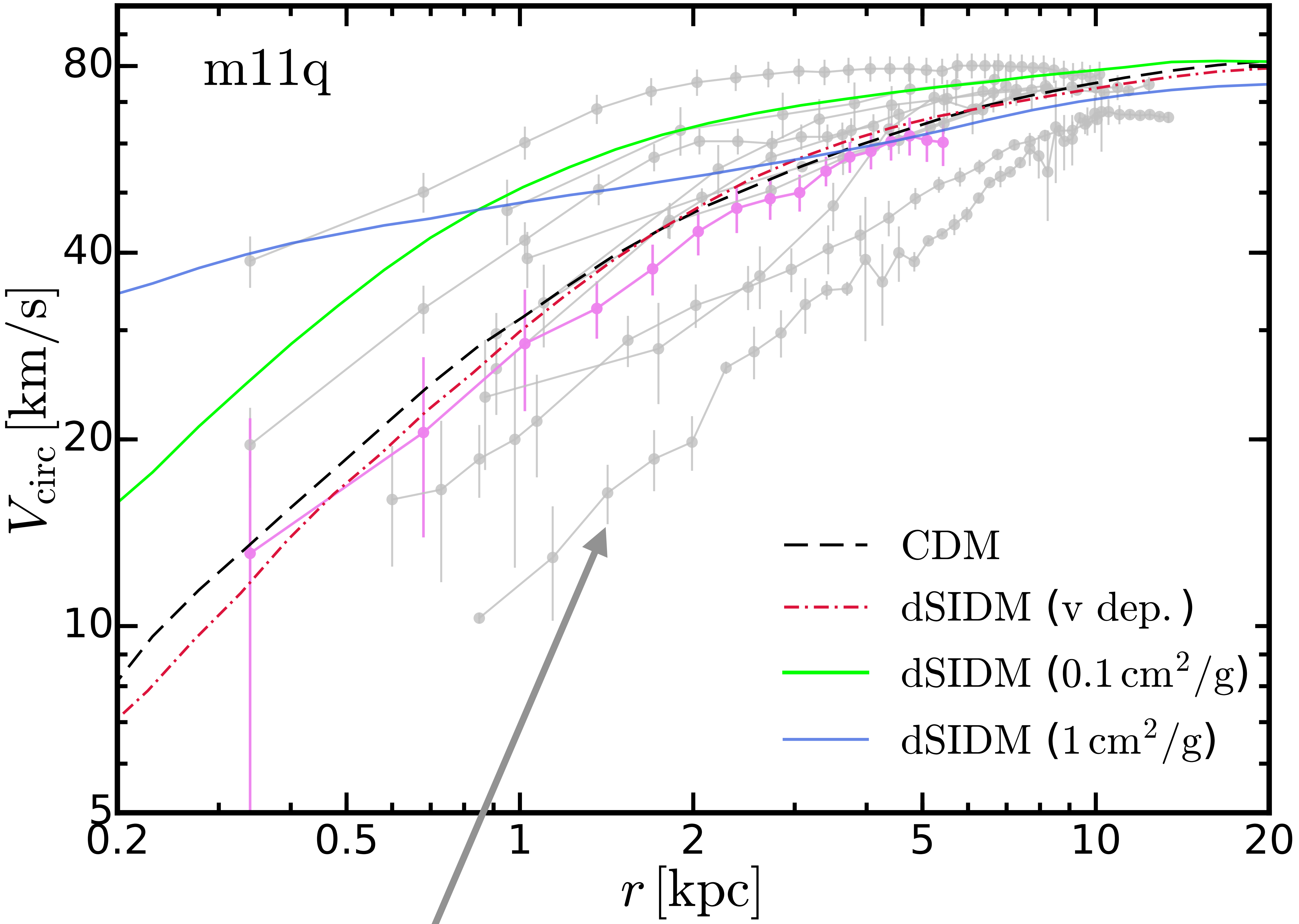
Shen+24 (See also Hopkins, Gurvich, Shen+23)





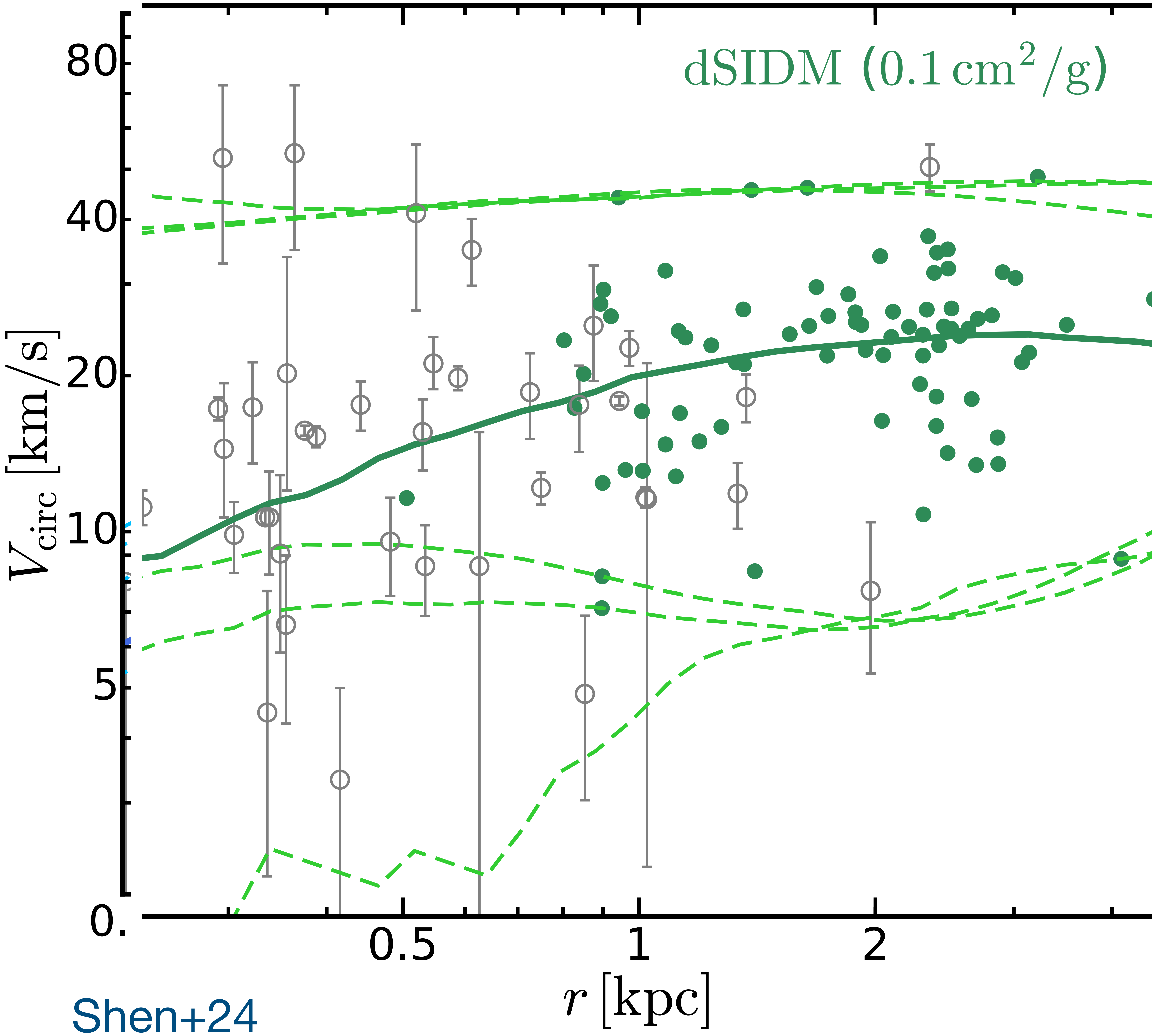
Cosmological Simulations of dwarf galaxies in dSIDM

Diversity of rotation curves of field dwarfs



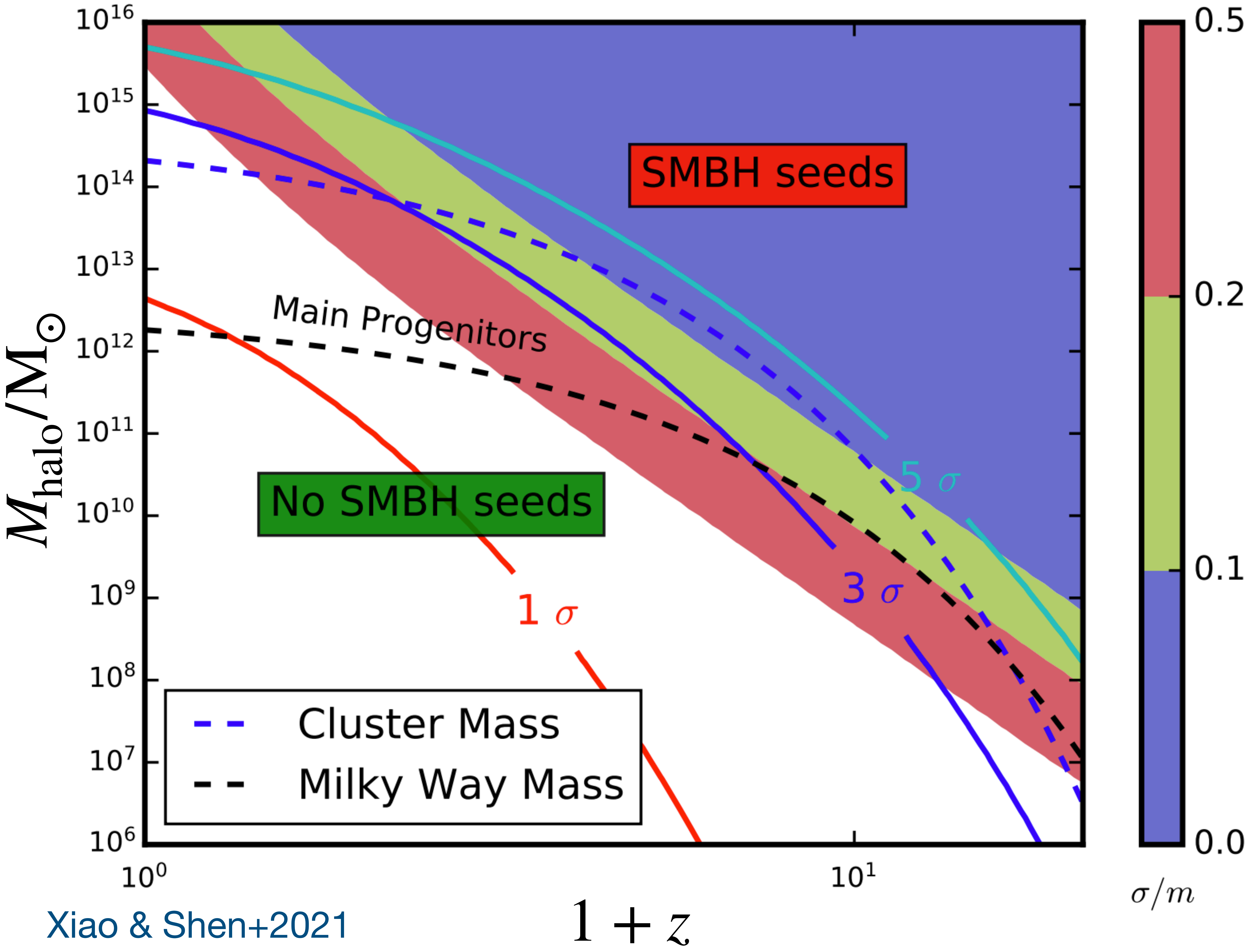
Observed rotation curves from the SPARC & LITTLE THINGS surveys

Diversity of “compactness” of MW/M31 satellites



Shen+24

Early Universe implications of dSIDM



Xiao & Shen+2021

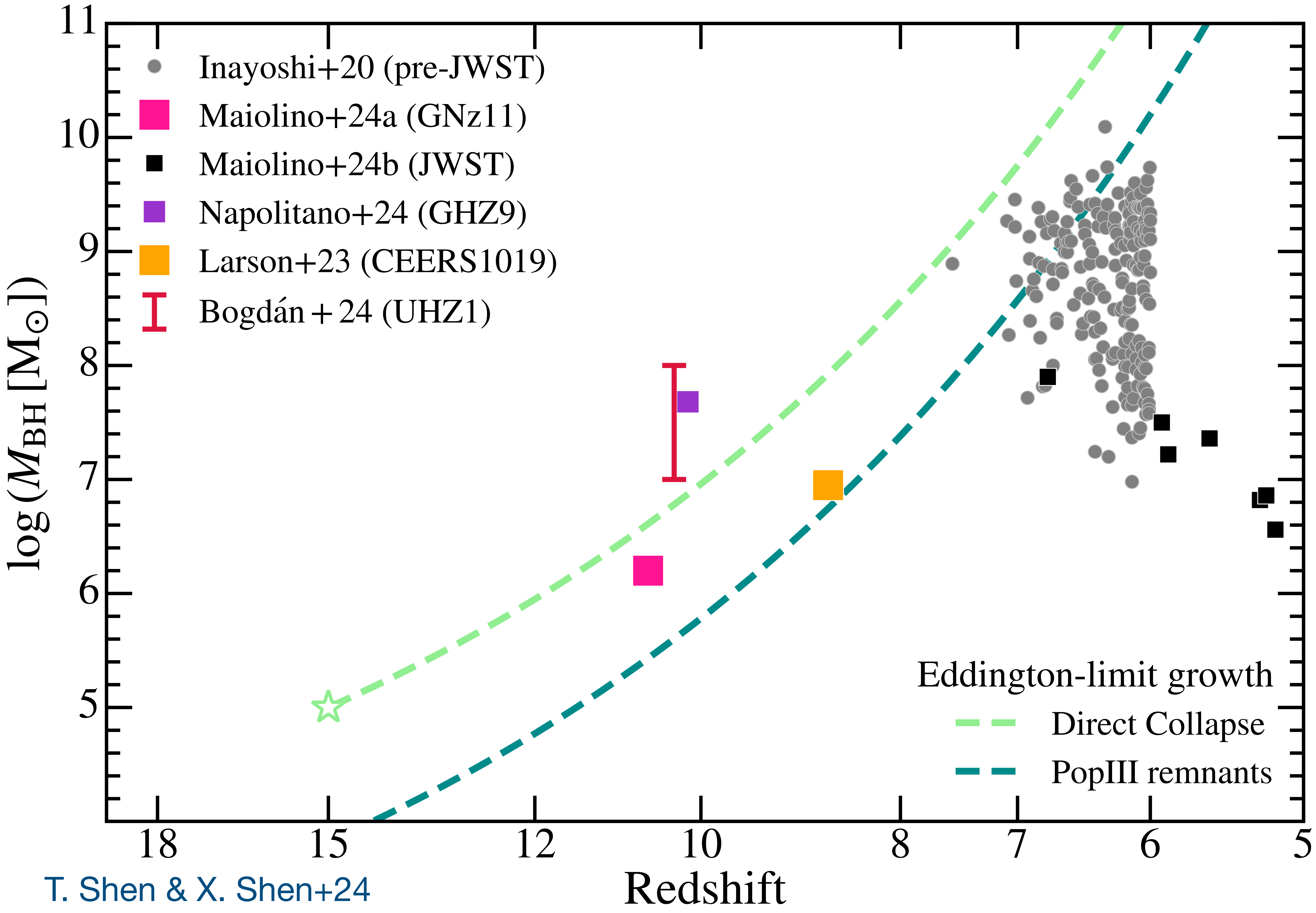
Huangyu Xiao
(Fermi Lab)

run-away collapse of central halo accelerated by dissipation within a "dark cooling" time

$M_{\rm BH} \sim 3 \times 10^{-3} M_{\rm halo}$

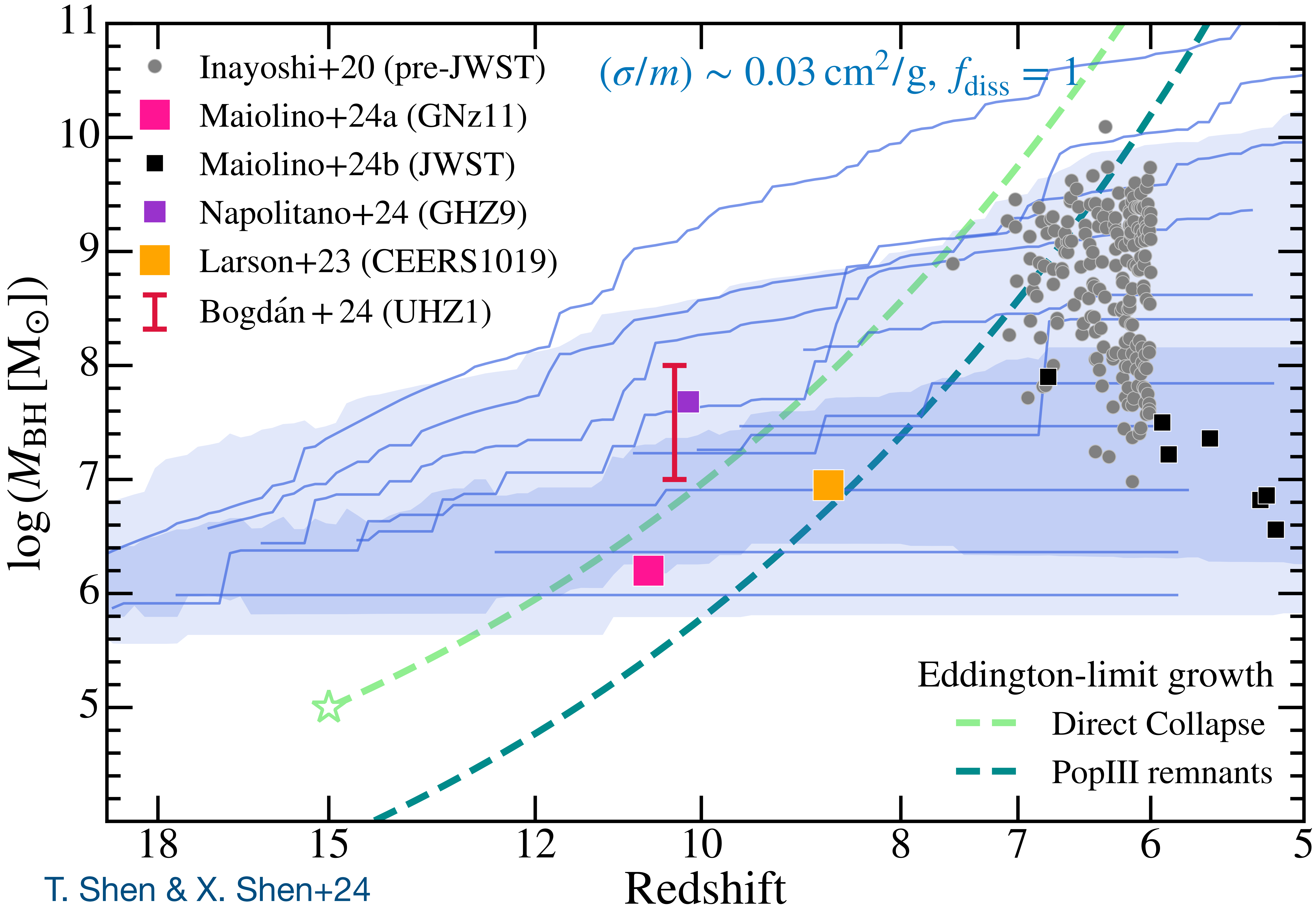
indep. of halo mass, z, spin ...

Early Universe implications of dSIDM



T. Shen & X. Shen+24

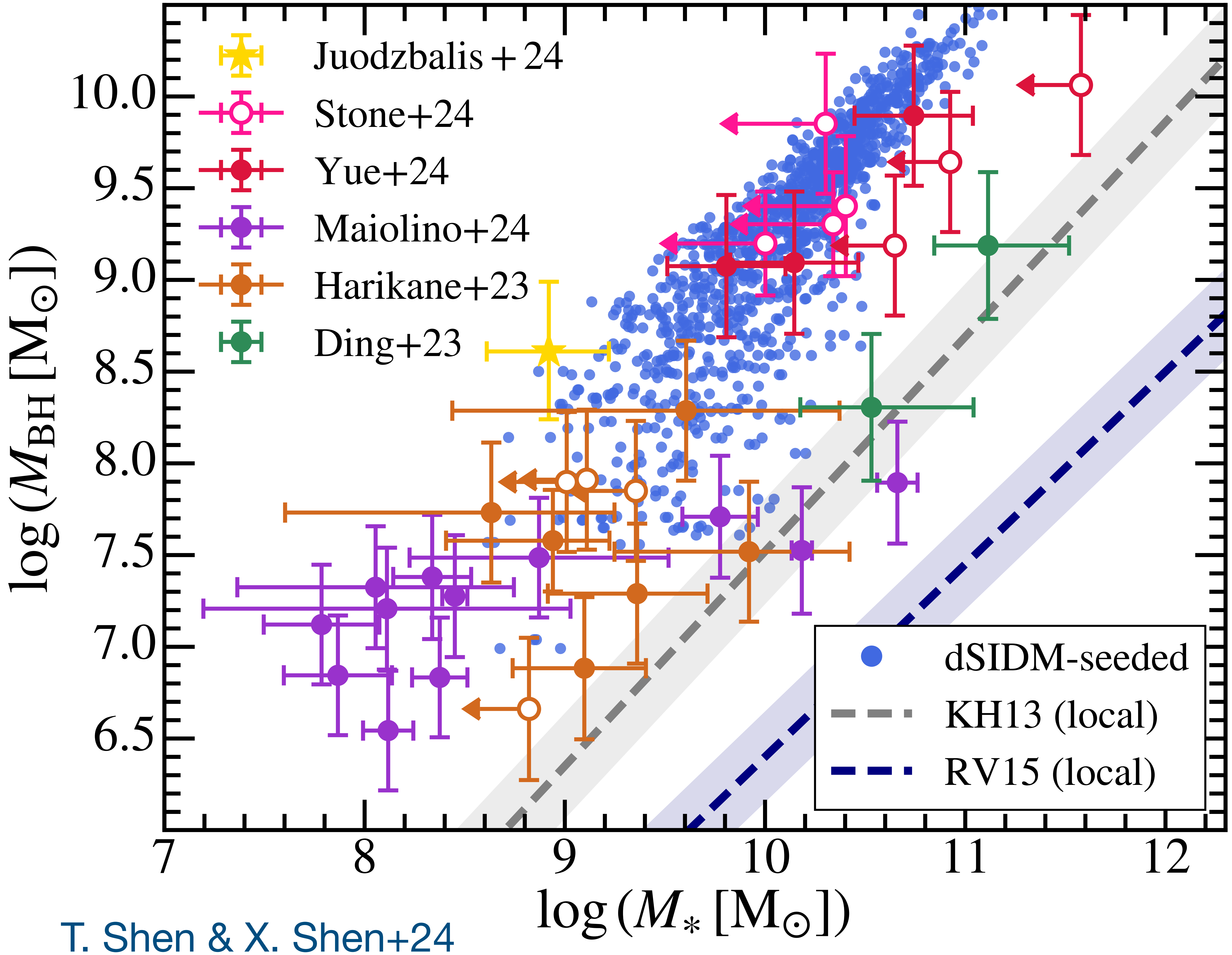
Early Universe implications of dSIDM



T. Shen & X. Shen+24

Charline Shen
(Harvard)

Early Universe implications of dSIDM



T. Shen & X. Shen+24

"Overlymassive" BHs compared to host galaxies
for quasars and Little Red Dots (a new class of faint obscured AGN found by JWST)

similar scenario in elastic SIDM as well but from pure gravothermal collapse (see Feng+2021, Jiang+2025)

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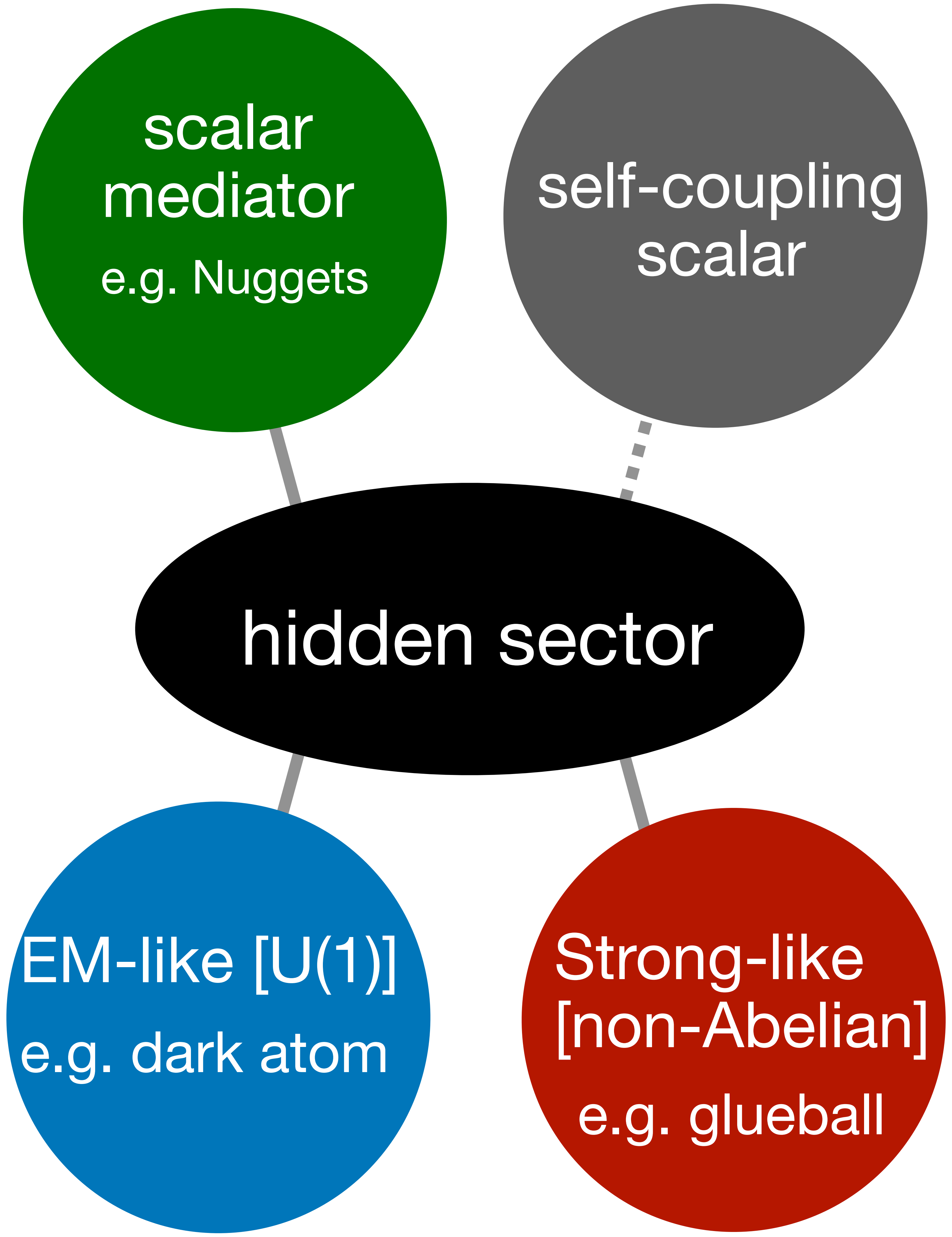

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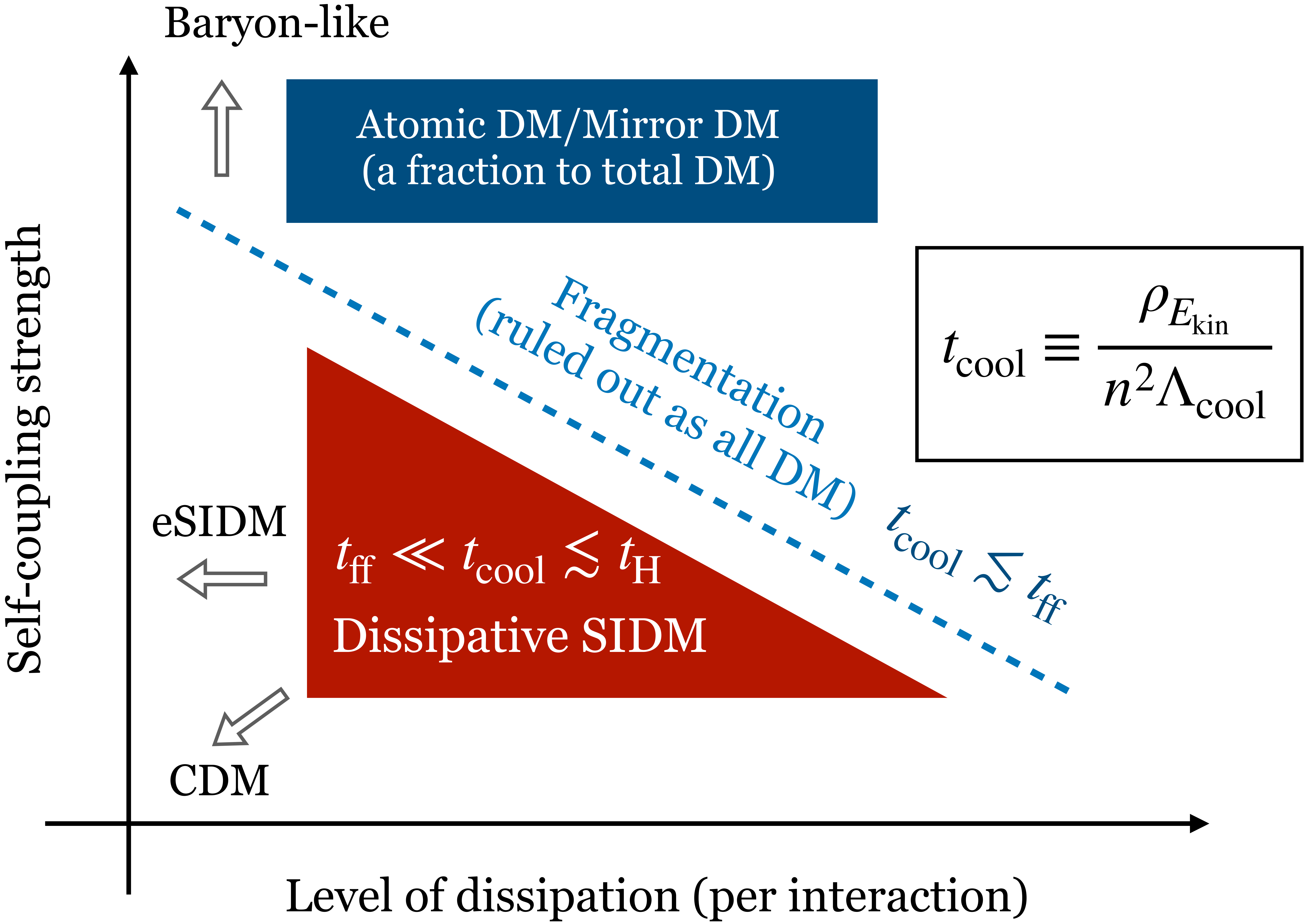

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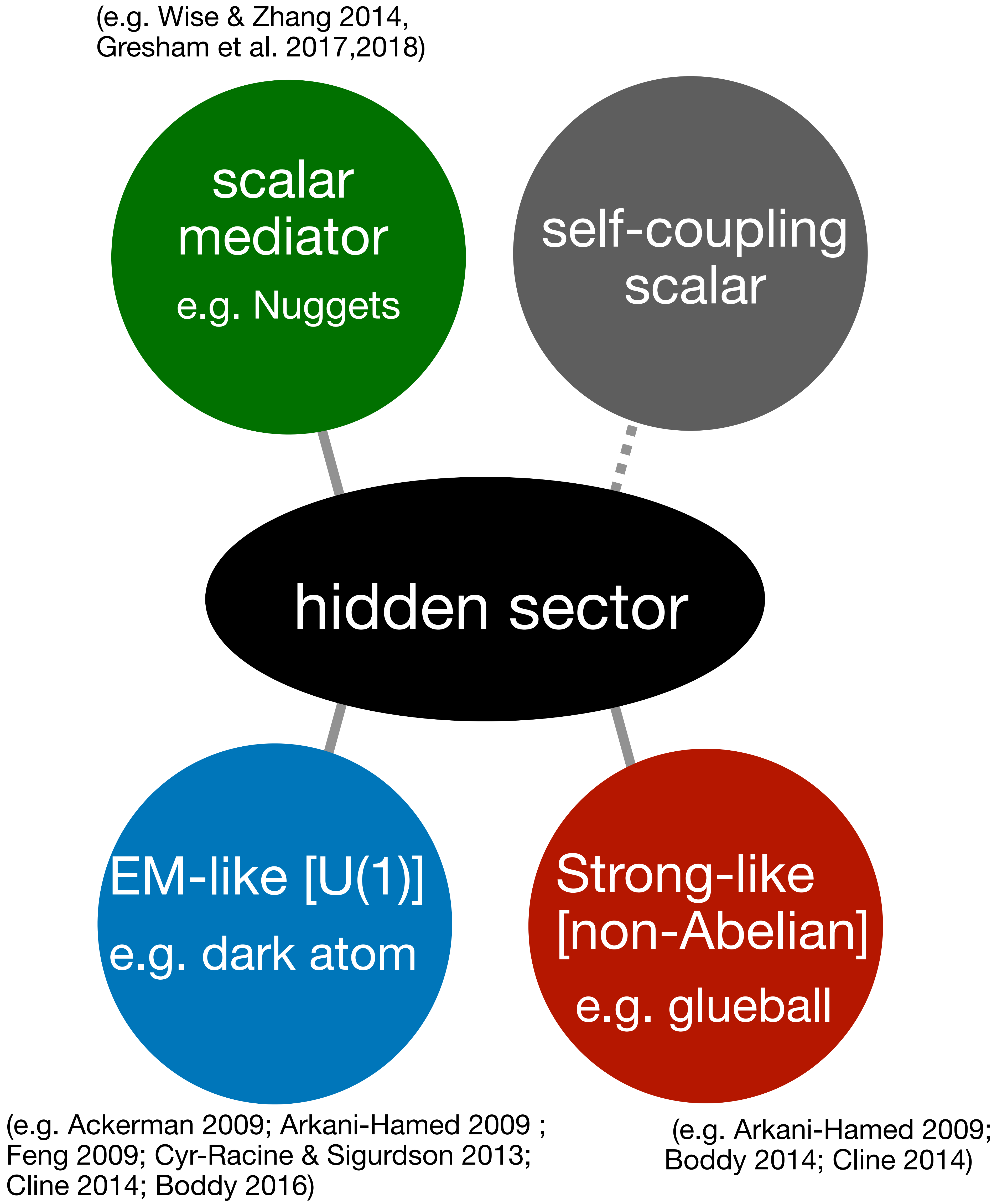
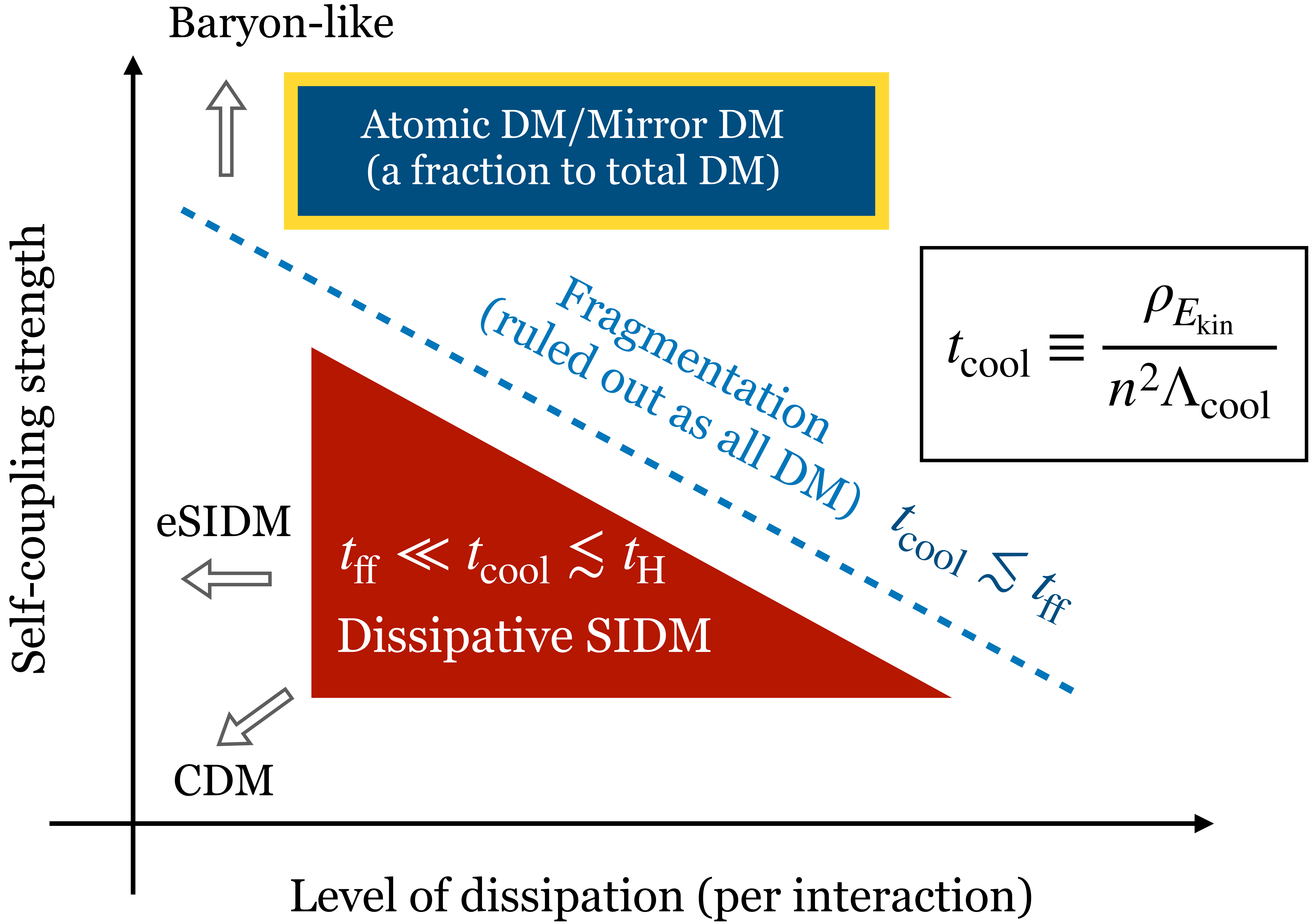
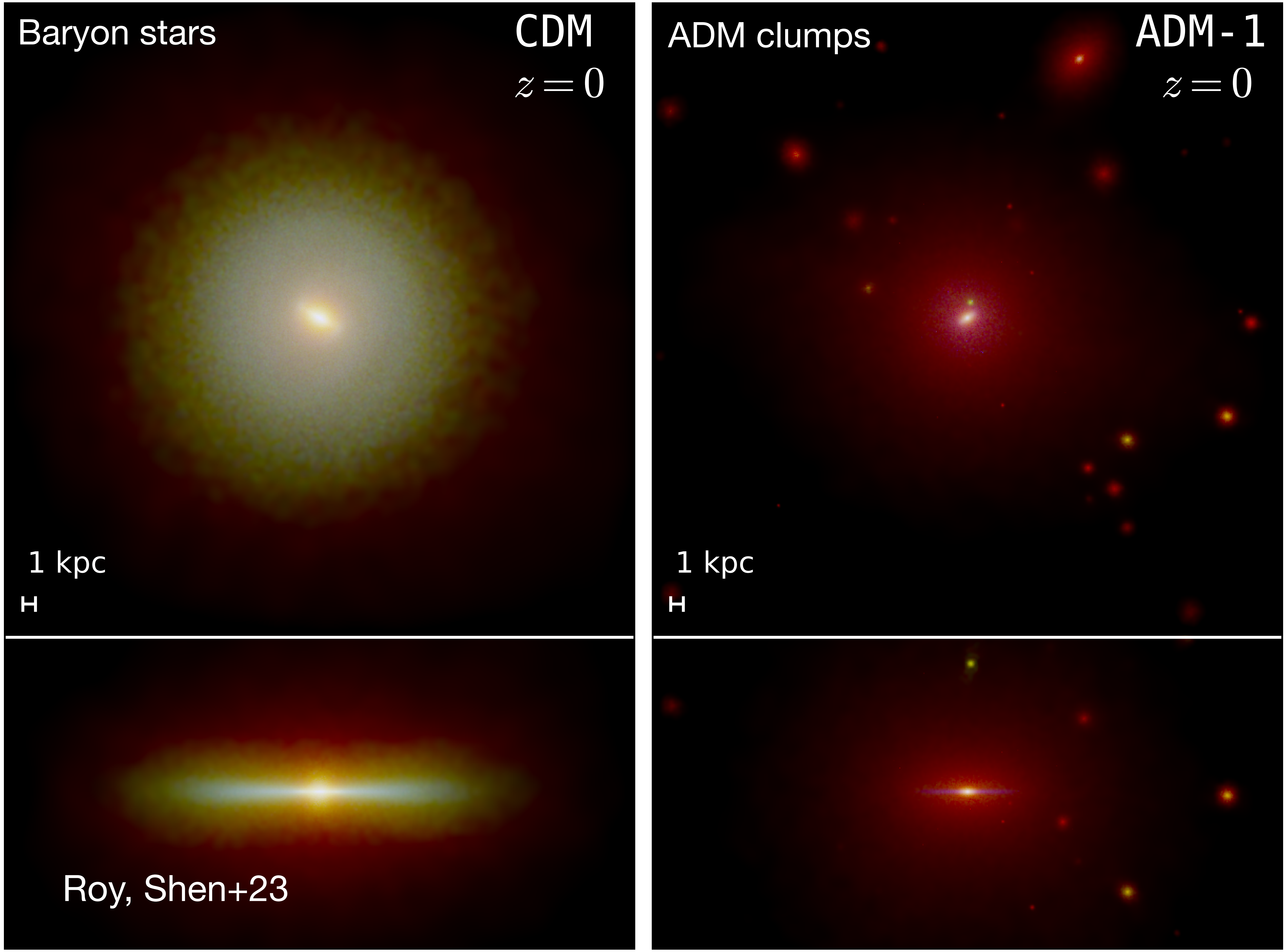




Cosmological Simulations of atomic dark matter (ADM)



~5% of DM behave as a "baryon copy"

$t_{\rm cool} \sim t_{\rm ff} \ll t_{\rm H}$

simulated as a parallel fluid in GIZMO

Sandip Roy (Princeton)

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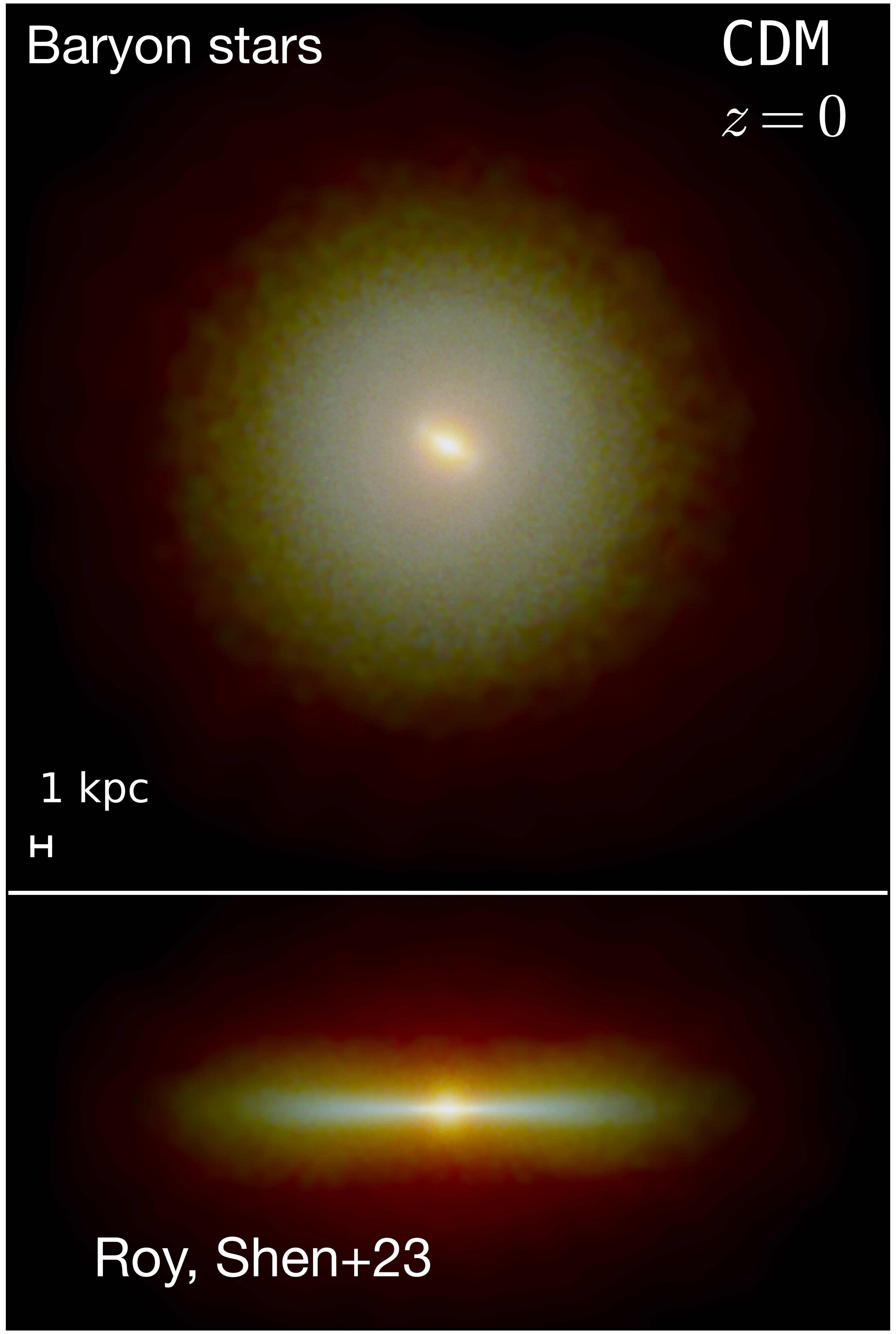
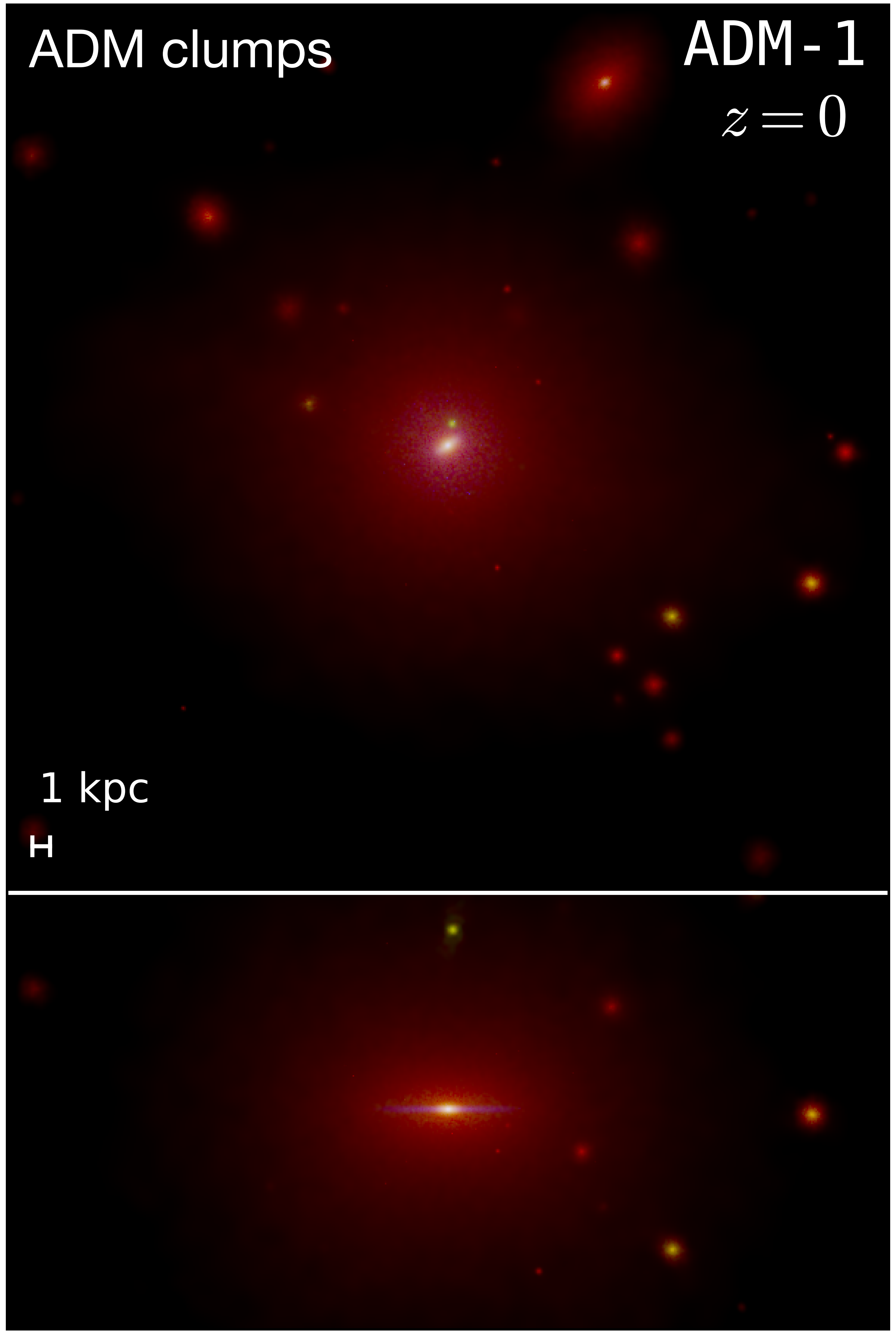
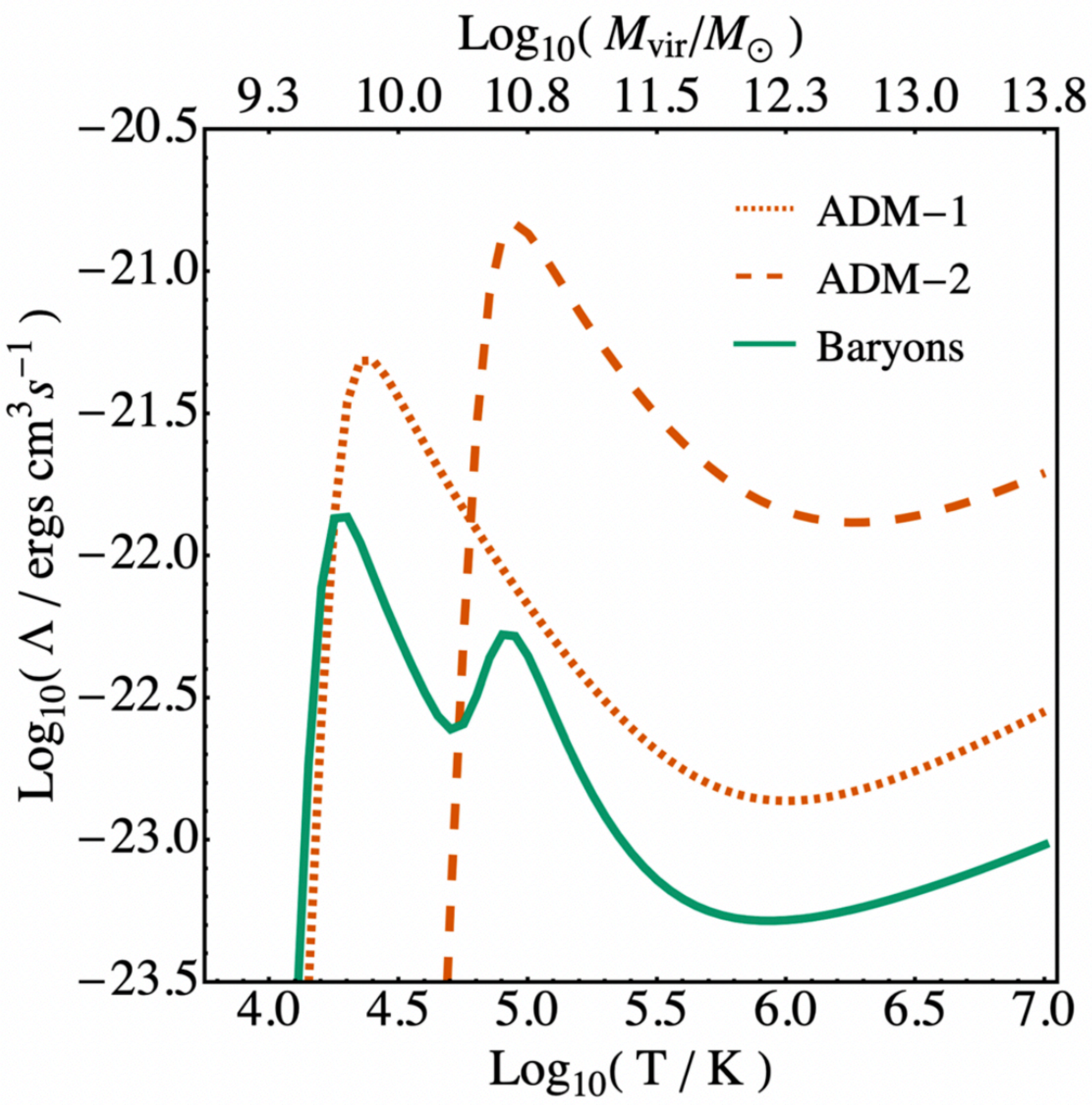
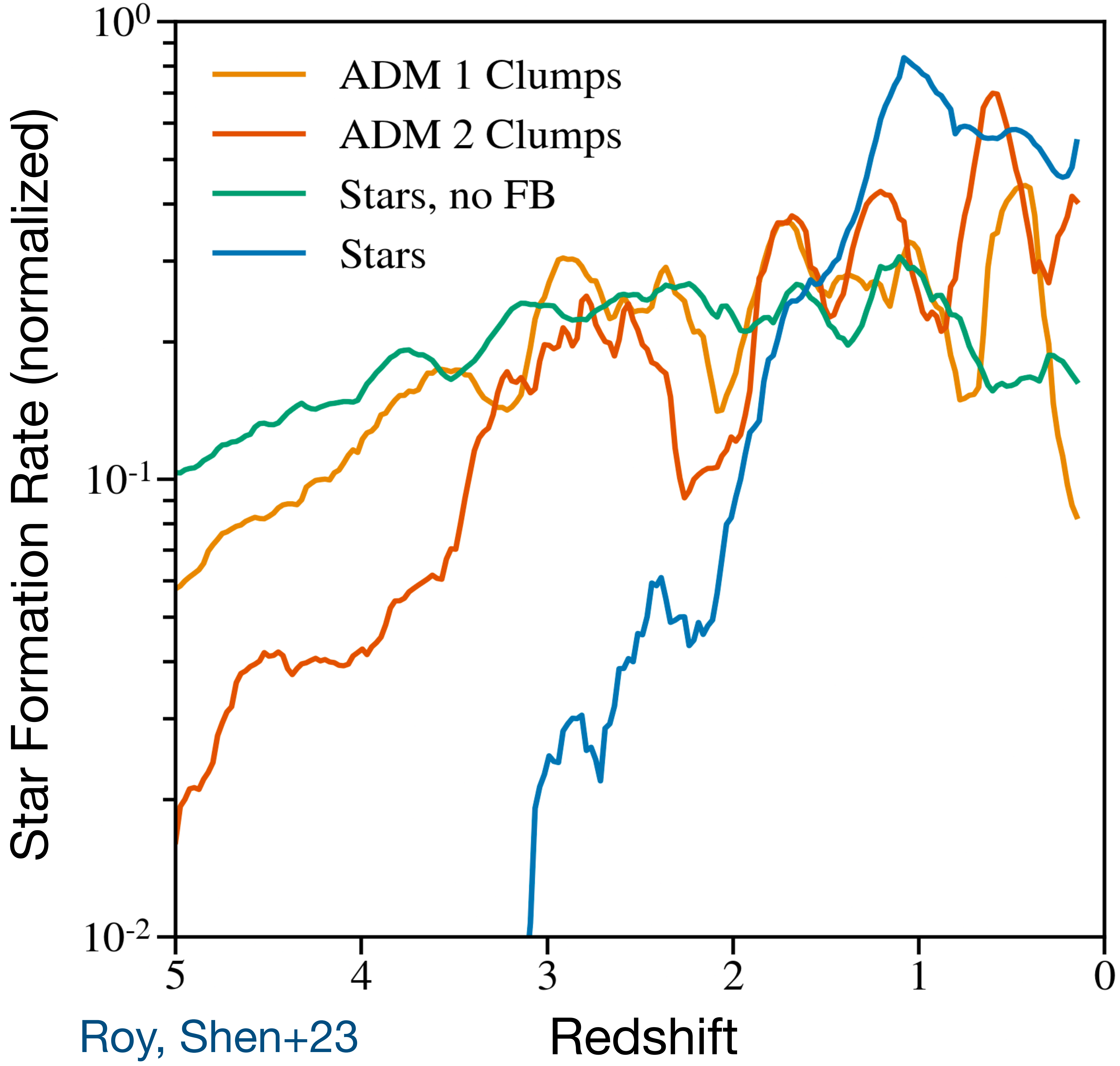






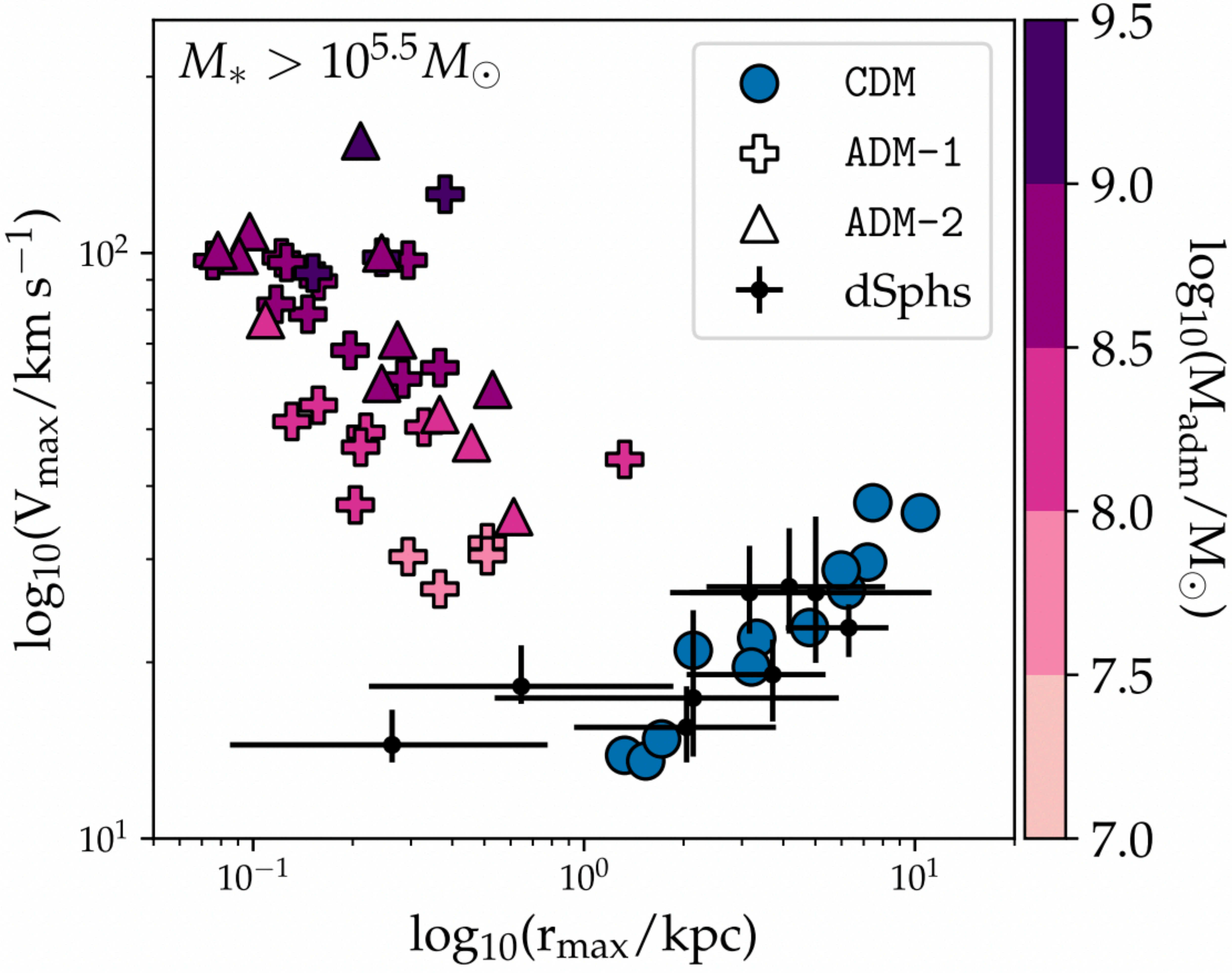
Cosmological Simulations of atomic dark matter (ADM)

ADM clumps formed in the early universe



Roy, Shen+23

overdense satellites in ADM



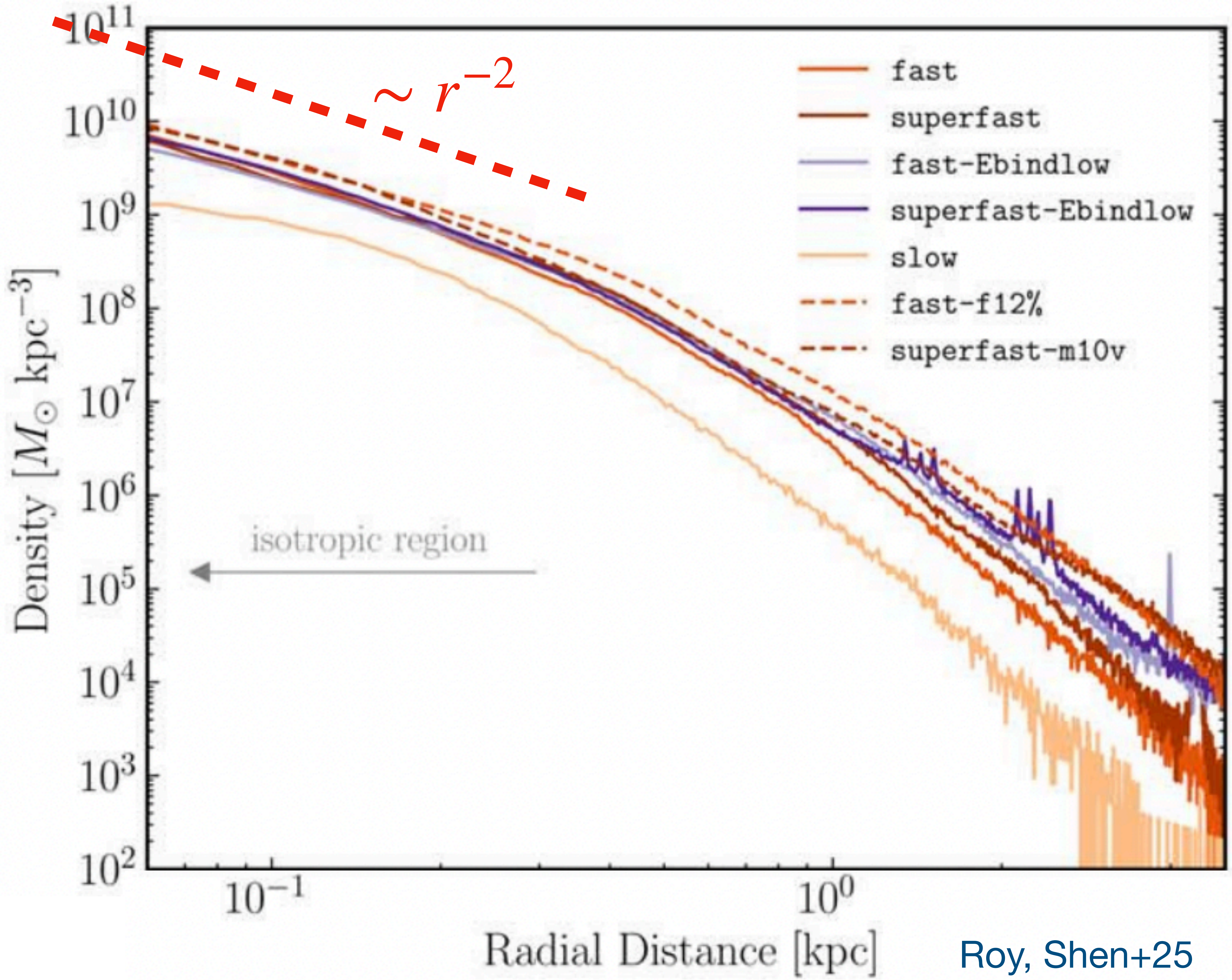
Gemmell, Roy, Shen+24

Cosmological Simulations of atomic dark matter (ADM)

nearly universal cuspy isothermal density profile (when $t_{\rm cool} \ll t_{\rm H}$)

similar to other flavors of models with a break in the effective cooling function

e.g. Essig+19, O'Neil+23



Roy, Shen+25

Take-aways

Dissipative dark matter (quasi collisionless limit)

- cuspy central density profile ($\sim r^{-1.5}$)
- more concentrated, spherical halos + promote baryonic disk formation
- diversity of dwarf structures from competition between dissipation and stellar feedback

Dissipative dark matter (fluid limit; e.g. atomic dark matter)

- cuspy density profile and close to isothermal ($\sim r^{-2}$)
- thick disk with large number of aDM clumps formed already in the epoch of reionization

Massive SMBH seeds from dissipative dark matter

- naturally explain massive bright quasars & the LRDs at $z \gtrsim 4$
- strong GW signatures detectable with LISA