



# Galaxy formation in dissipative dark matter

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# Motivations

## Theoretical

- Too many degrees-of-freedom
- candidate mass: 80 orders of magnitude

## Empirical/Observational/Experimental

- Subject to interpretation
- Evolving as we have better understanding of the baryonic physics

Since 1970s

SUSY/Universal Extra-Dimension/Little Higgs

$$m_\chi \sim 100 \text{ GeV}$$

Existence of particle DM

The “WIMP” miracle

~ 2000 - now

WDM (keV)

e.g. sterile neutrino

SIDM (kpc cores, elastic,  $\sigma_m \sim 1 \text{ cm}^2/\text{g}$ )

e.g. a hidden sector

Fuzzy DM ( $\lambda_{dB} \sim \text{kpc}$ )

e.g. axion-like particles

$$\mathcal{O}(1) \text{ kpc}$$

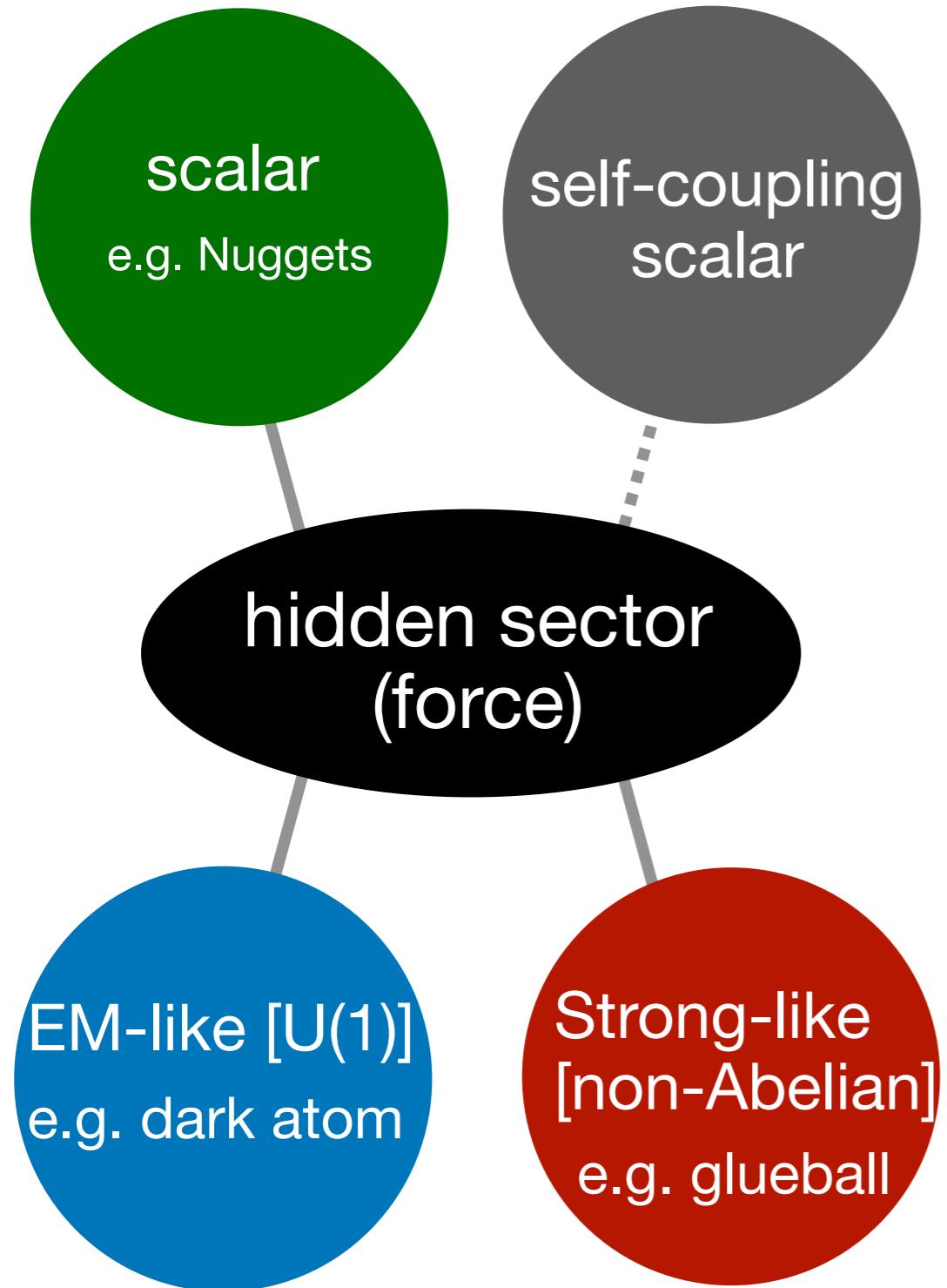
Local puzzles:

- Missing Satellites
- Core-cusp
- Too-big-to-fail
- Diversity
- ...

Some generic beyond-standard-model theories

Astrophysical phenomenology

# SIDM by mediator type

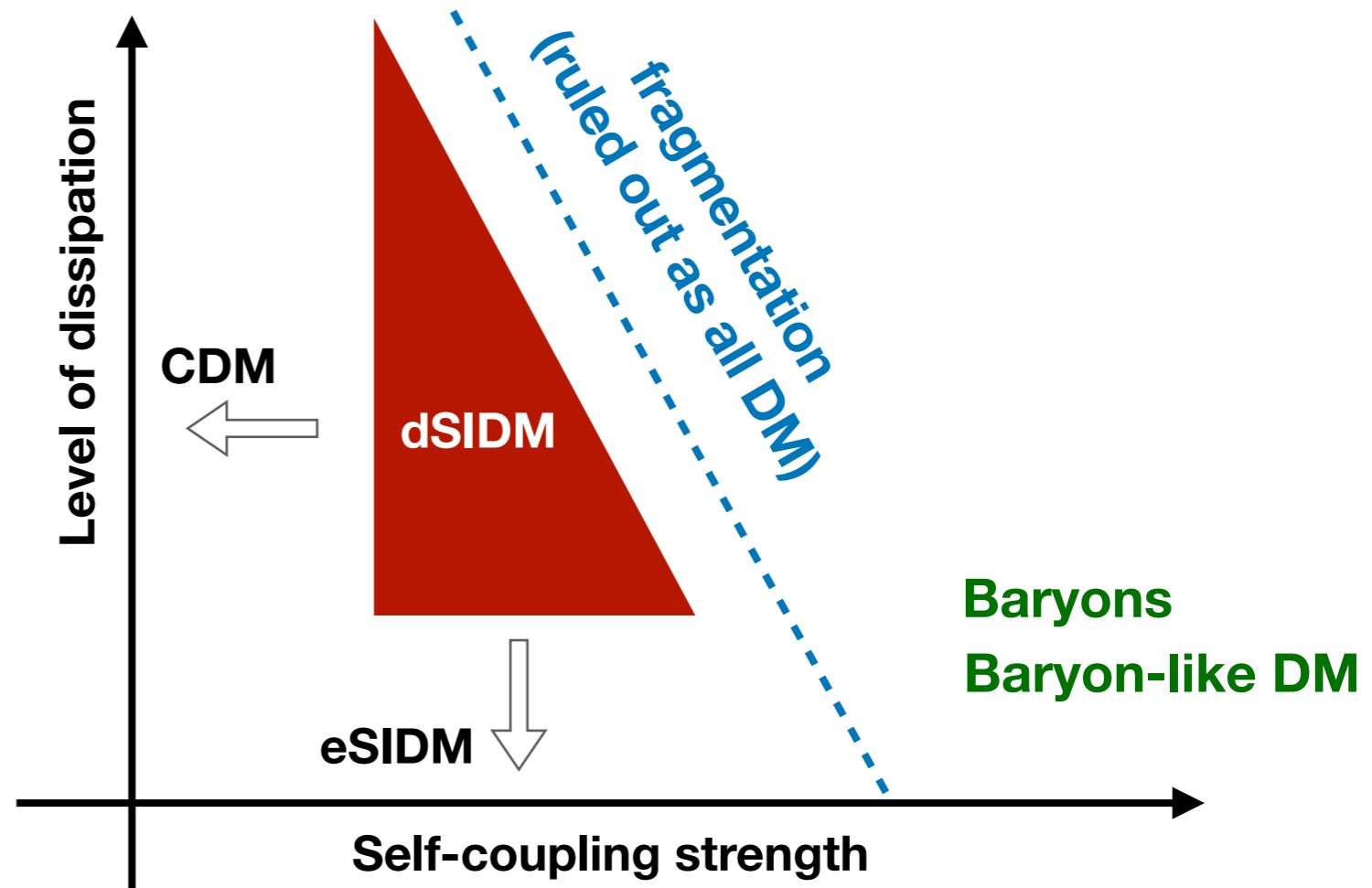


# FIRE-dSIDM suite

- FIRE-2 physics + dissipative DM self-interactions
- Low mass dwarfs ( $m_{10q,v,b}$ )  $\rightarrow$  bright dwarfs ( $m_{11a,b,q}$ )  $\rightarrow$  MW mass galaxies ( $m_{12i,f,m}$ )

Parameter space surveyed:

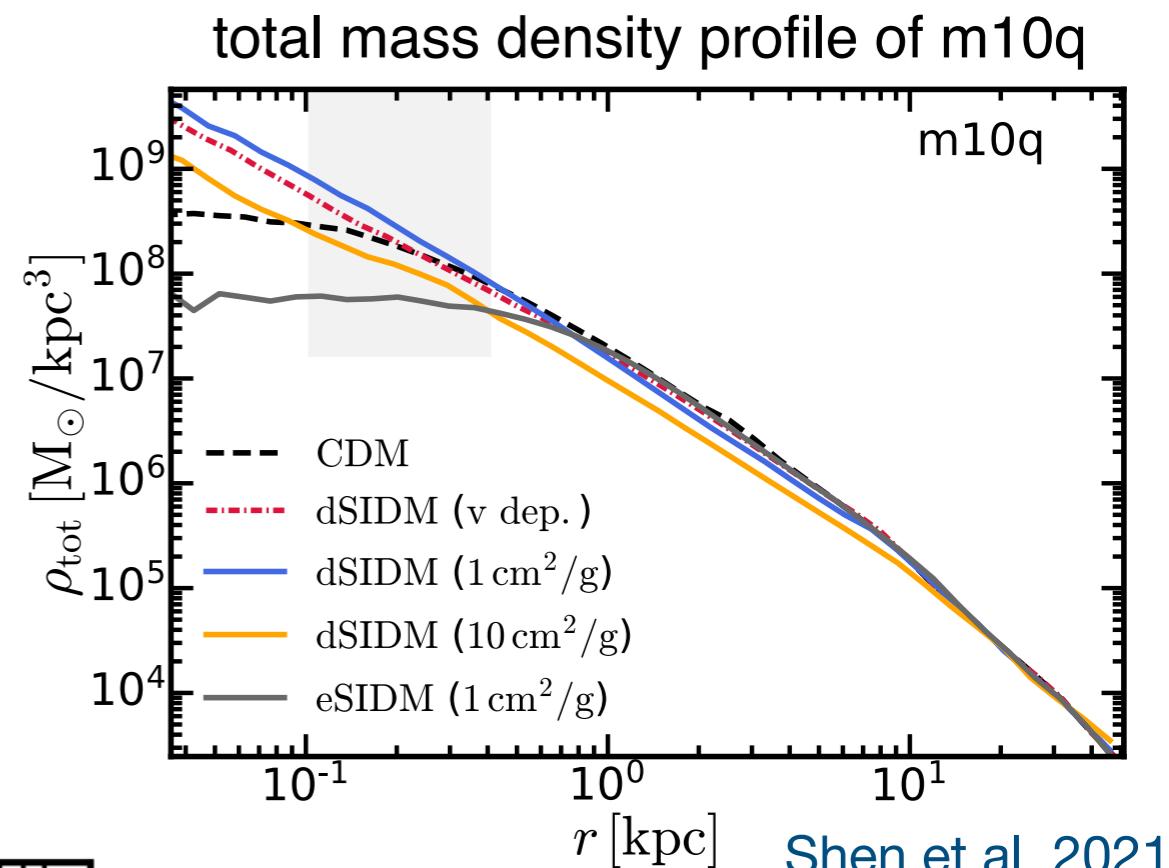
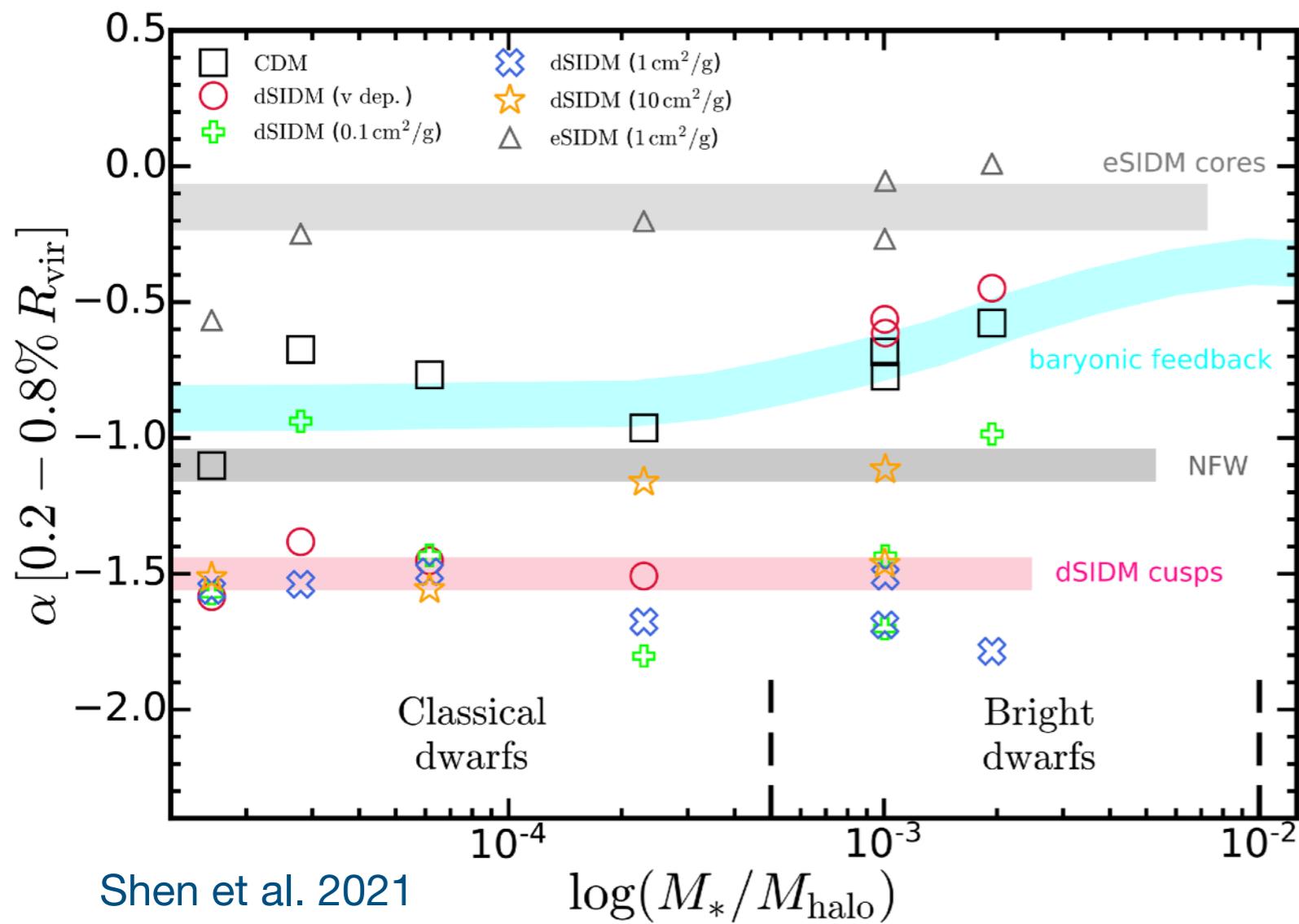
- $f_{\text{diss}}$ : a constant fractional energy dissipation during DM-DM collisions
- $\sigma/m \lesssim 10 \text{ cm}^2/\text{g}$ : weakly-collisional & weakly-dissipative



# Some key findings

- Dark cusps formed when  $(\sigma/m)_{\text{eff}} \gtrsim 0.1 \text{ cm}^2/g$   
 $t_{\text{ff}} \ll t_{\text{cool}} \lesssim t_{\text{H}}$
- power-law-like central density profiles

- asymptotic slope  $\alpha$  versus  $M_*/M_{\text{halo}}$



→ eSIDM cores

→ baryonic feedback

→ NFW: collisionless CDM

→ dSIDM cusps

- steady-state “dark” cooling flow?

$$\rho(r) \sim r^{-1.5 \sim 1.6}$$

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

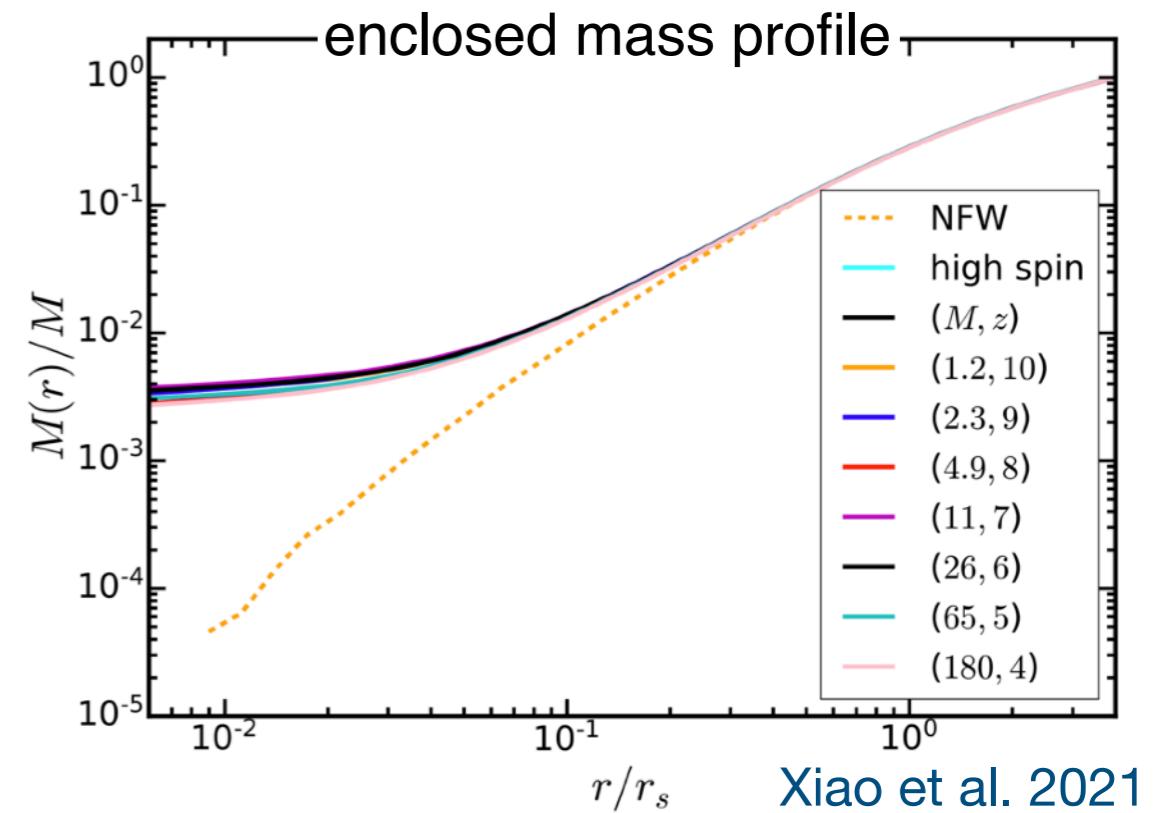
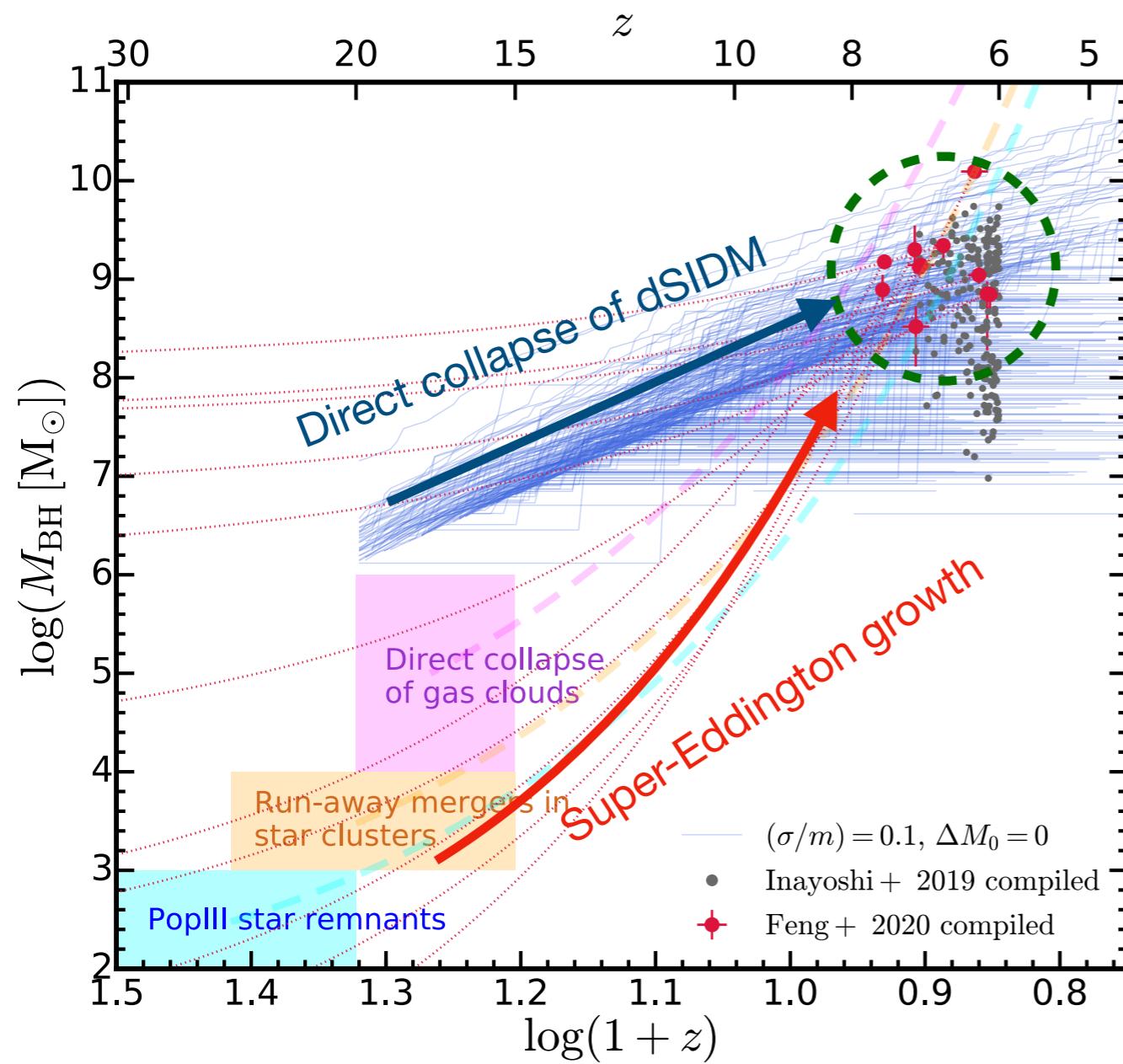
# More: Different epoch & mass scale

Seeding massive SMBHs with dissipative DM?

with Huangyu Xiao (UW) & Kathryn Zurek (Caltech)

in massive, rare, high-redshift halos.

$\gtrsim 10^{10} M_\odot$      $5\sigma$      $z \gtrsim 10$



A universal scale of collapse  $r_{\text{col}} \sim 0.07 r_s$  regardless of mass, redshift, spin.

$$M_{\text{col}}/M_{\text{halo}} \sim 0.3 \% \quad t_{\text{col}} \sim t_{\text{cool}}(r_{\text{col}})$$

- Naturally explains the existence of billion solar mass SMBHs at  $z \gtrsim 7$ , without super-Eddington accretion
- Match the observed QLF? Implies a bottom-heavy ERDF (a large population of “dark” SMBHs with a low level of accretion)

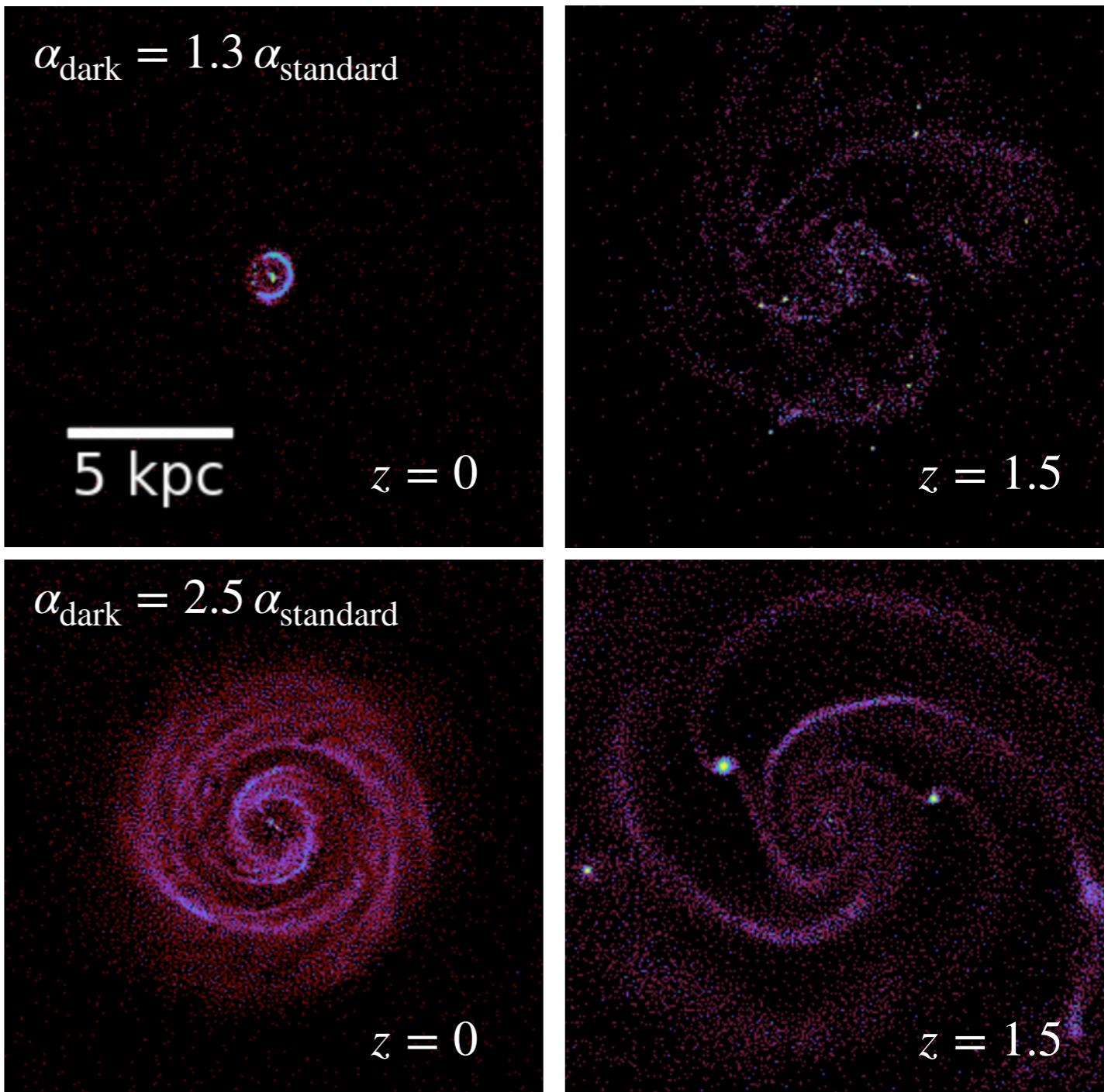
# More: Different types of models

- Highly-coupled atomic dark matter (fluid-like)
- Atomic cooling analogous to the baryons
- Sink particles form once becoming Jeans-unstable and self-gravitating
- No feedback/No UVB/No molecular cooling

- Very early onset of sink formation & very efficient
- Proto dark disks always formed, but were not necessarily sustained at  $z=0$
- ...

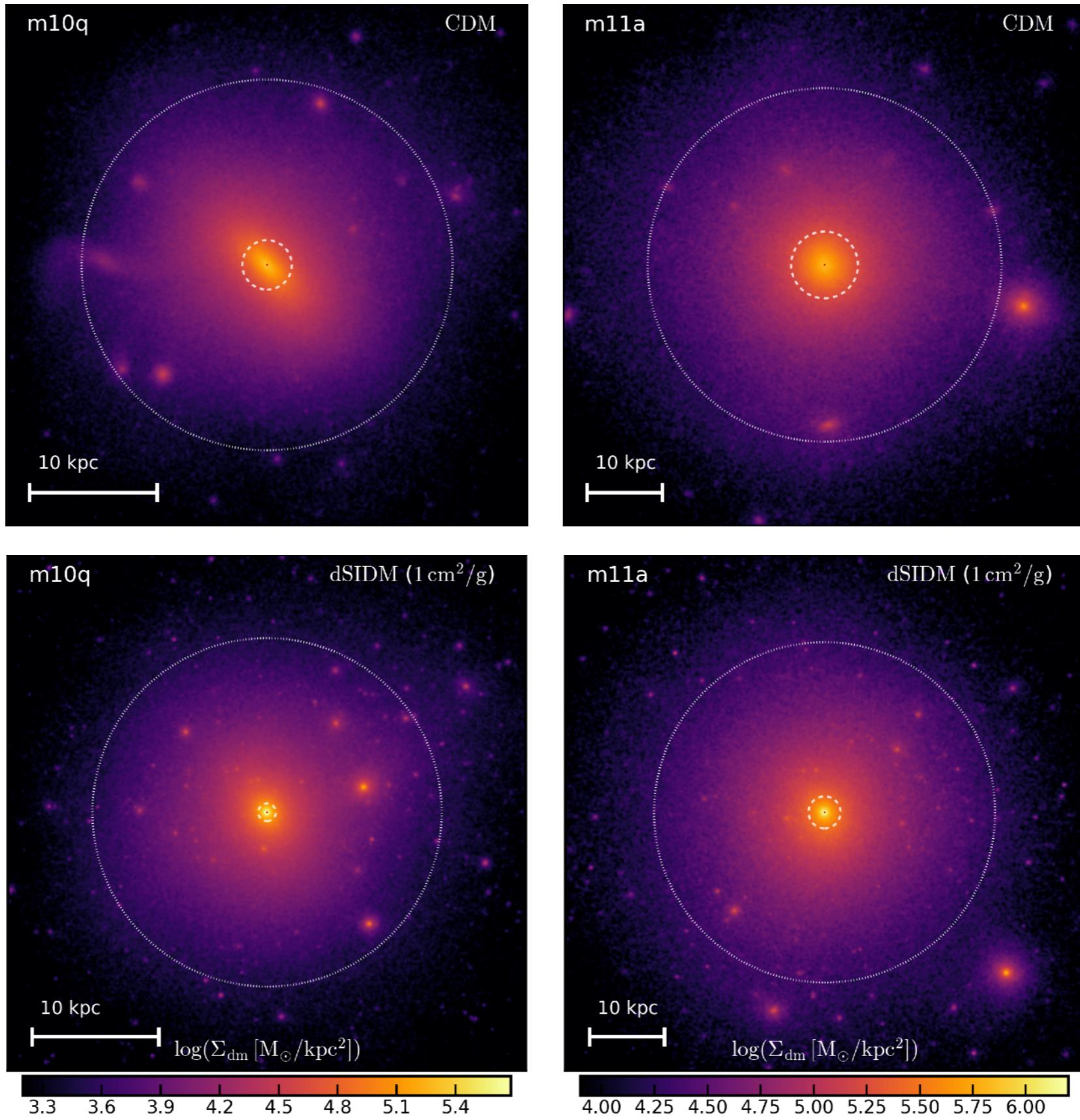
## Simulating Atomic dark matter on FIRE

led by Sandip Roy (Princeton)

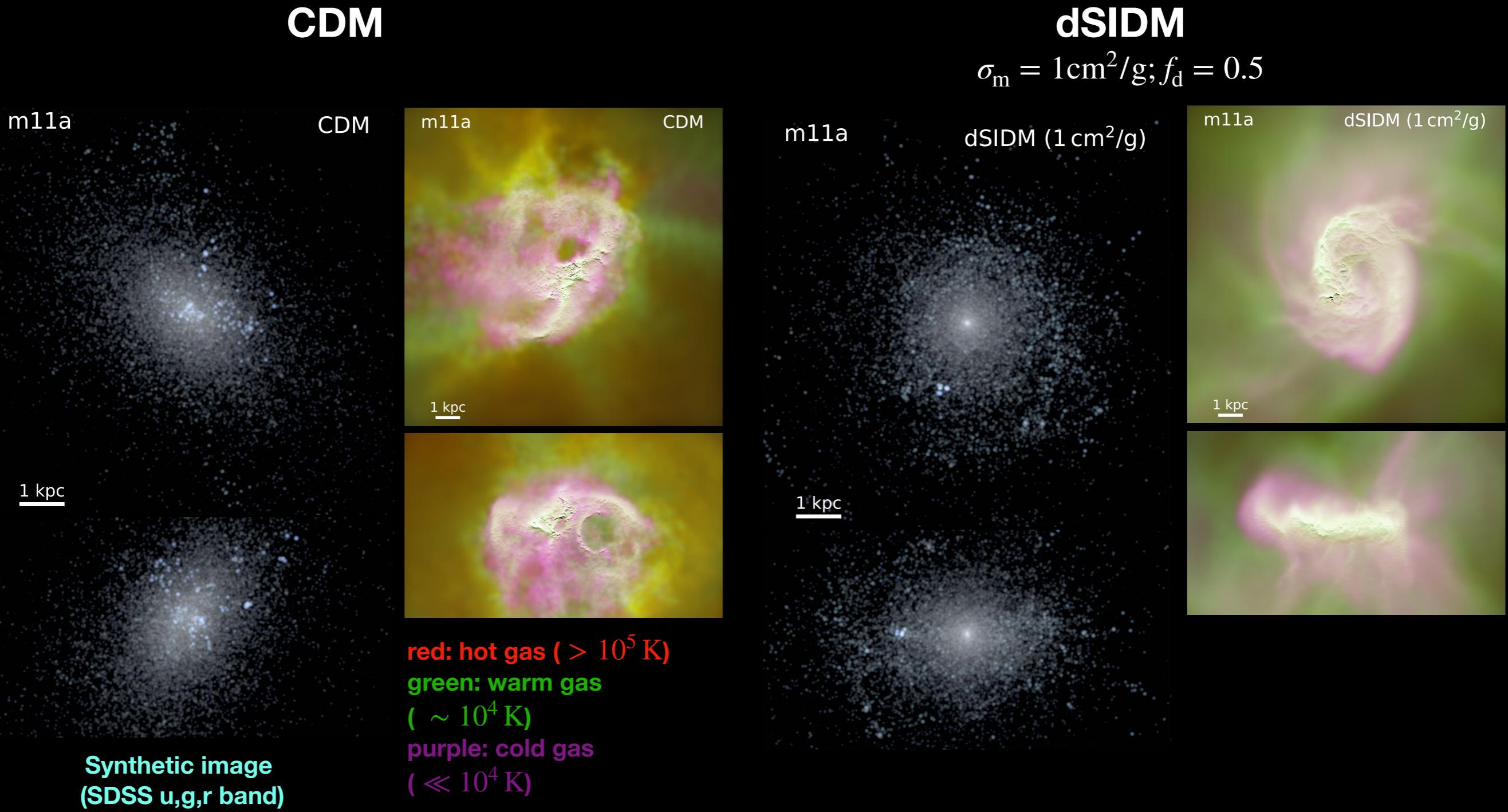


**Thanks!**

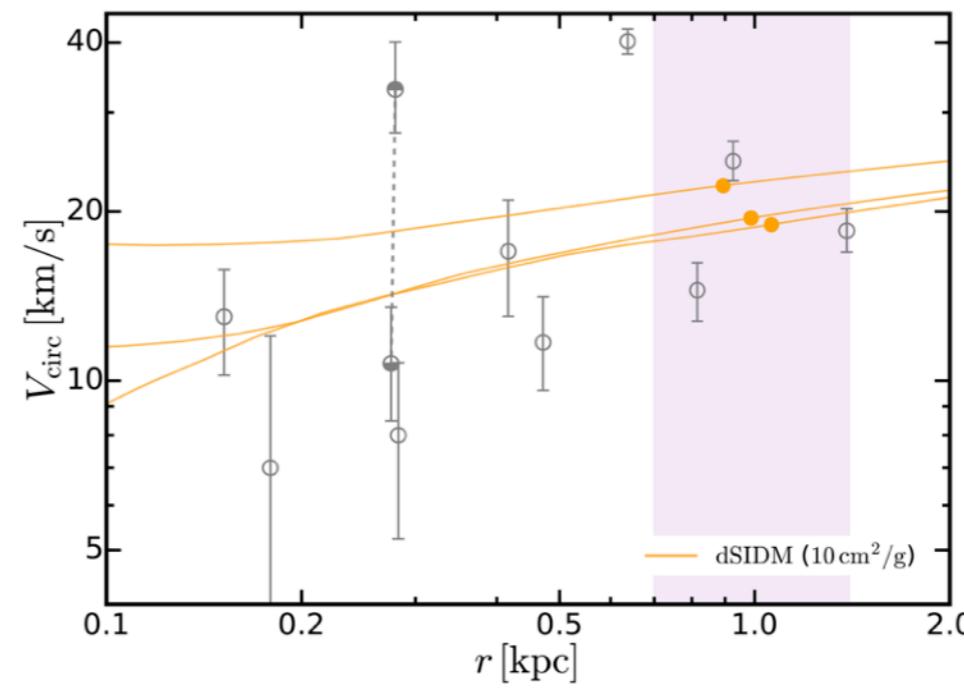
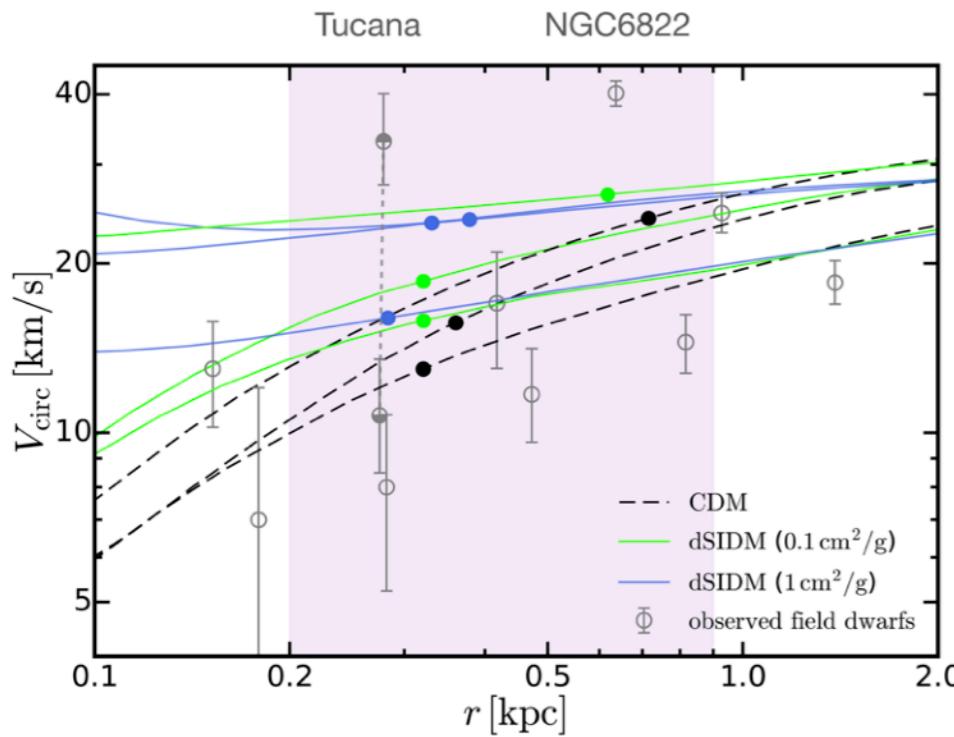
# Supplement Materials



- Promote disk settling?



## Local Field dwarfs



## HI-selected LSBs

