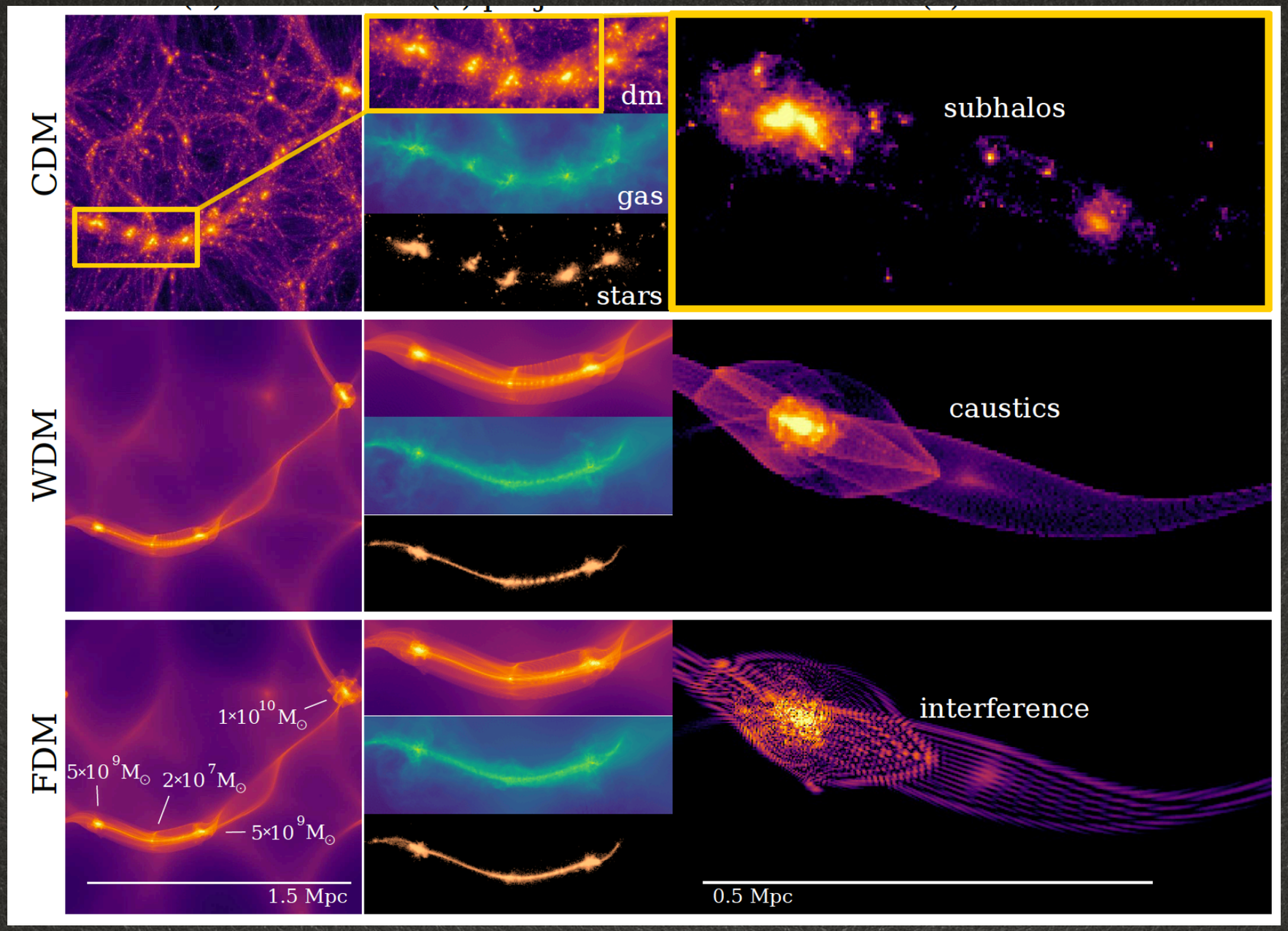
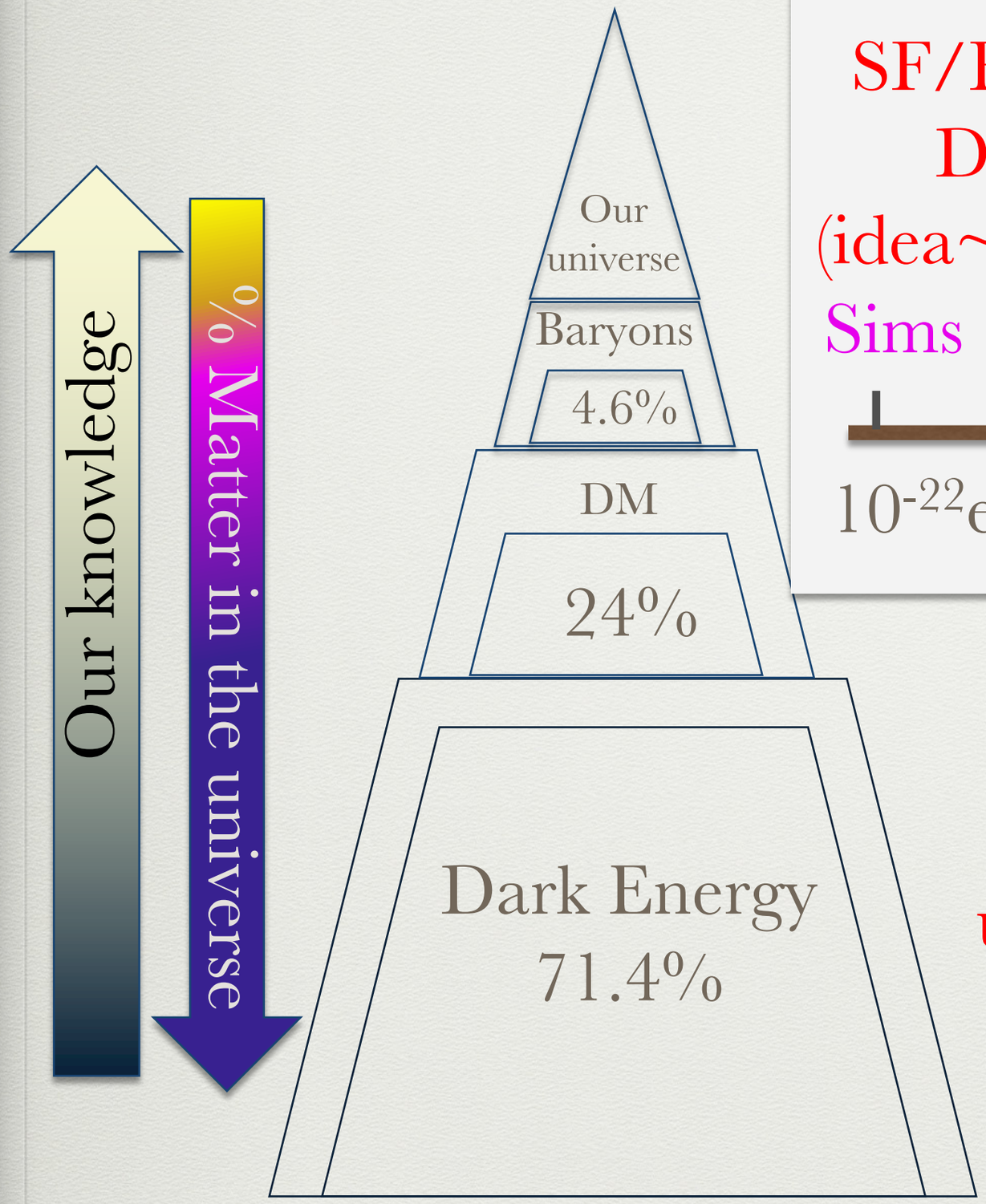
Using simulations to constrain the nature of DM

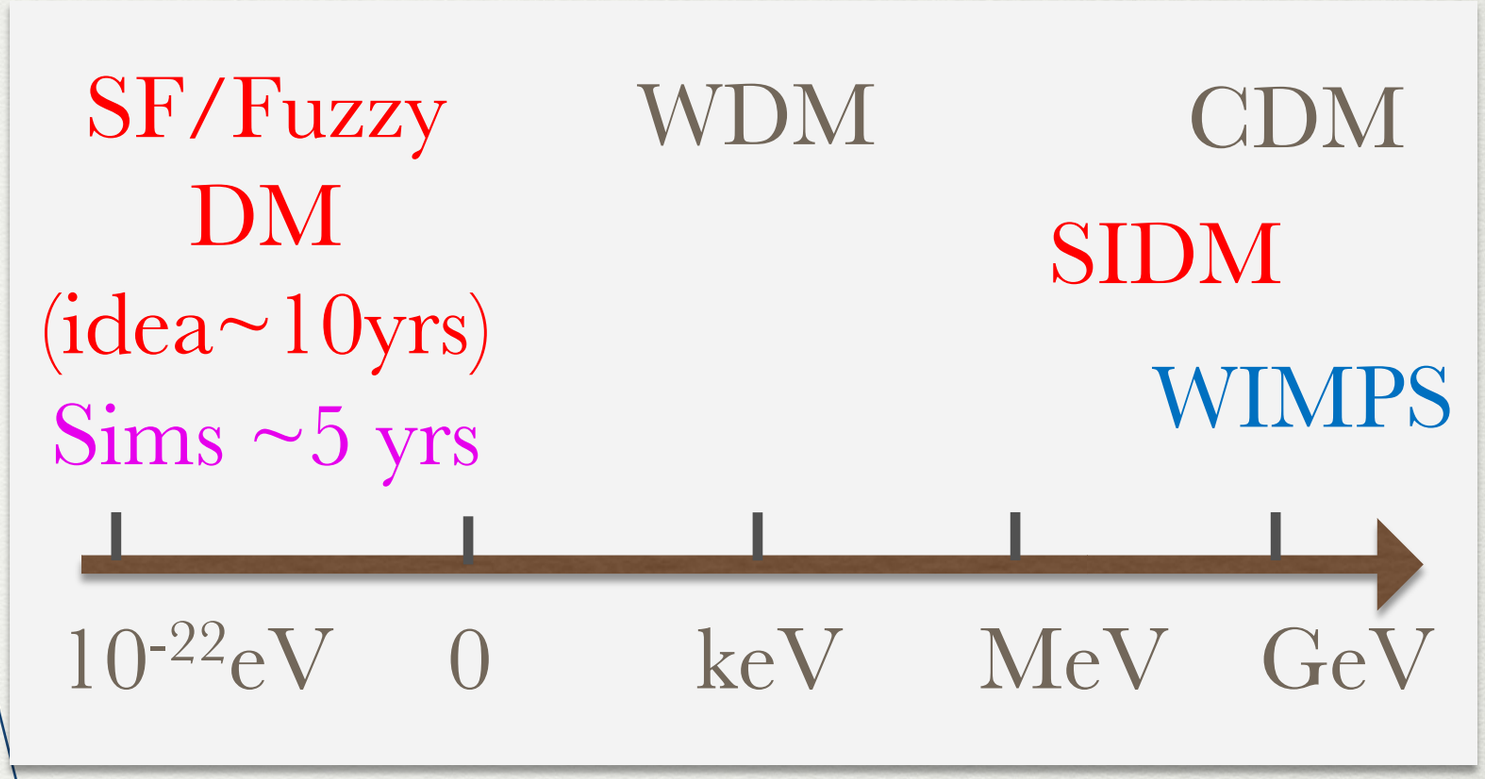


Victor H. Robles
UC Irvine,
LSST@KICP, Chicago, August 6, 2019

In collaboration with:
James Bullock (UCI), Philip Hopkins (Caltech),
Philip Mocz (Princeton), +FIRE project members

Pyramid of knowledge

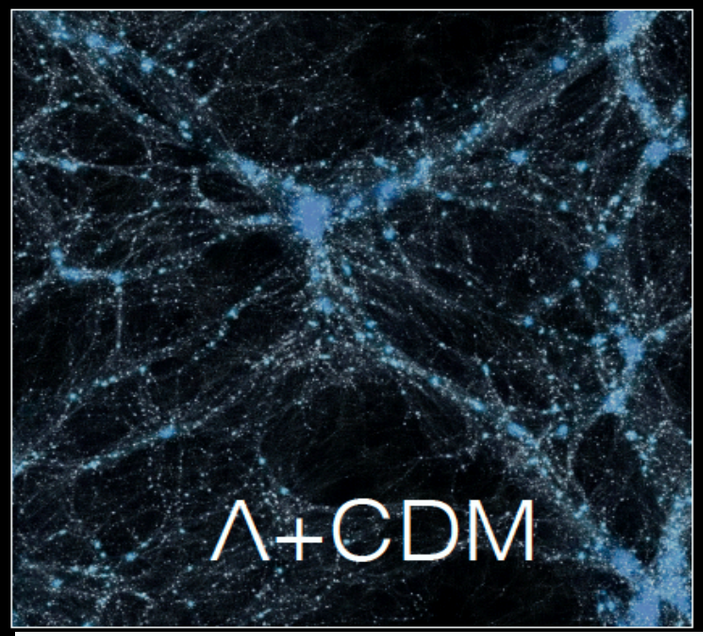


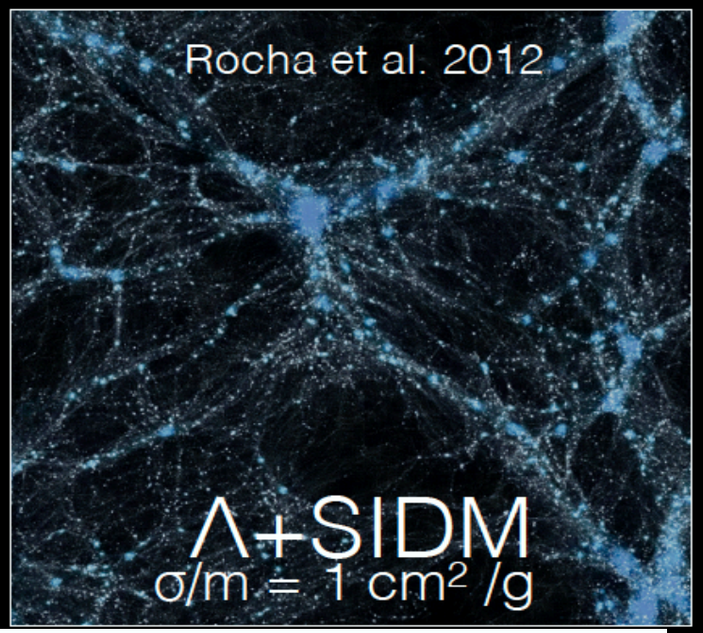


Simulations aim to
narrow the range
using obs. @ different scales!

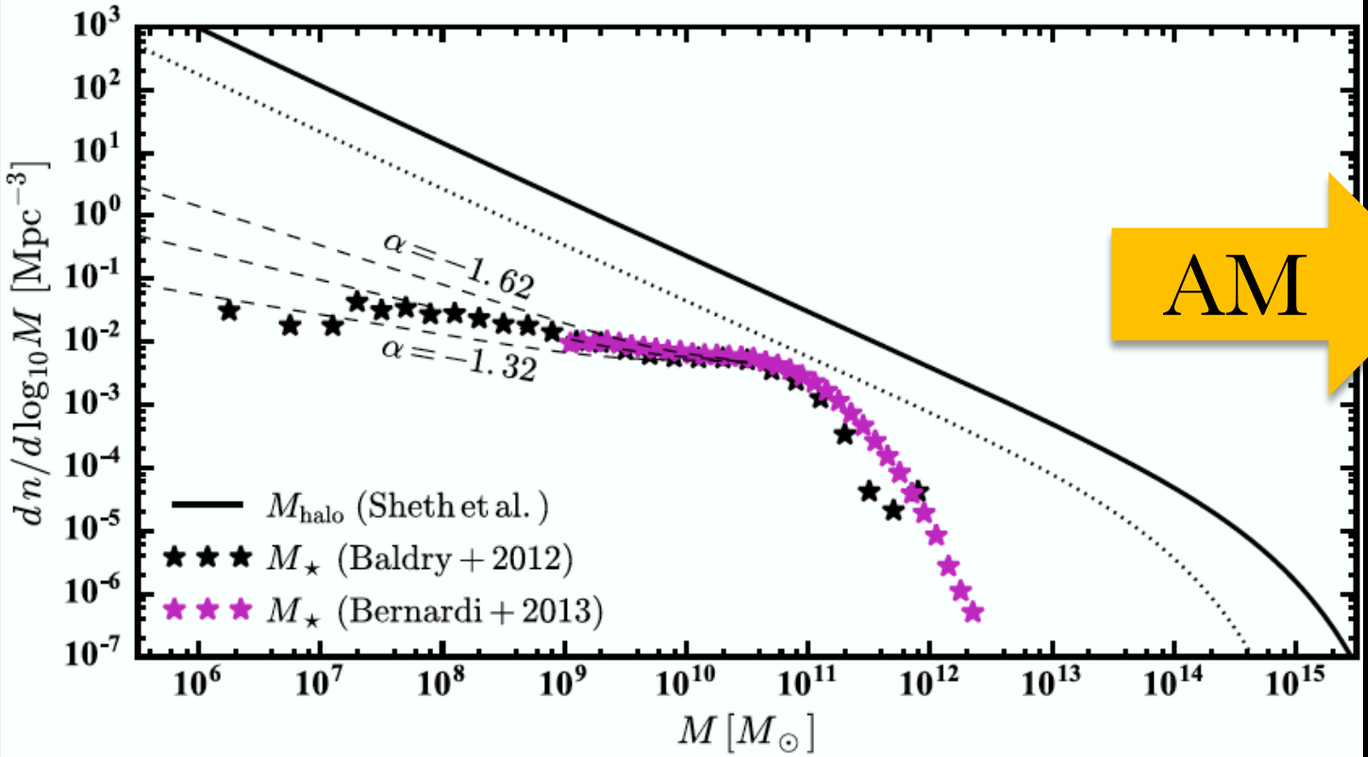
Cosmological Scales CDM vs SIDM

- same large scale structure
- same DM halo mass functions





Mass functions compared:
observed stars vs. **predicted dark matter**



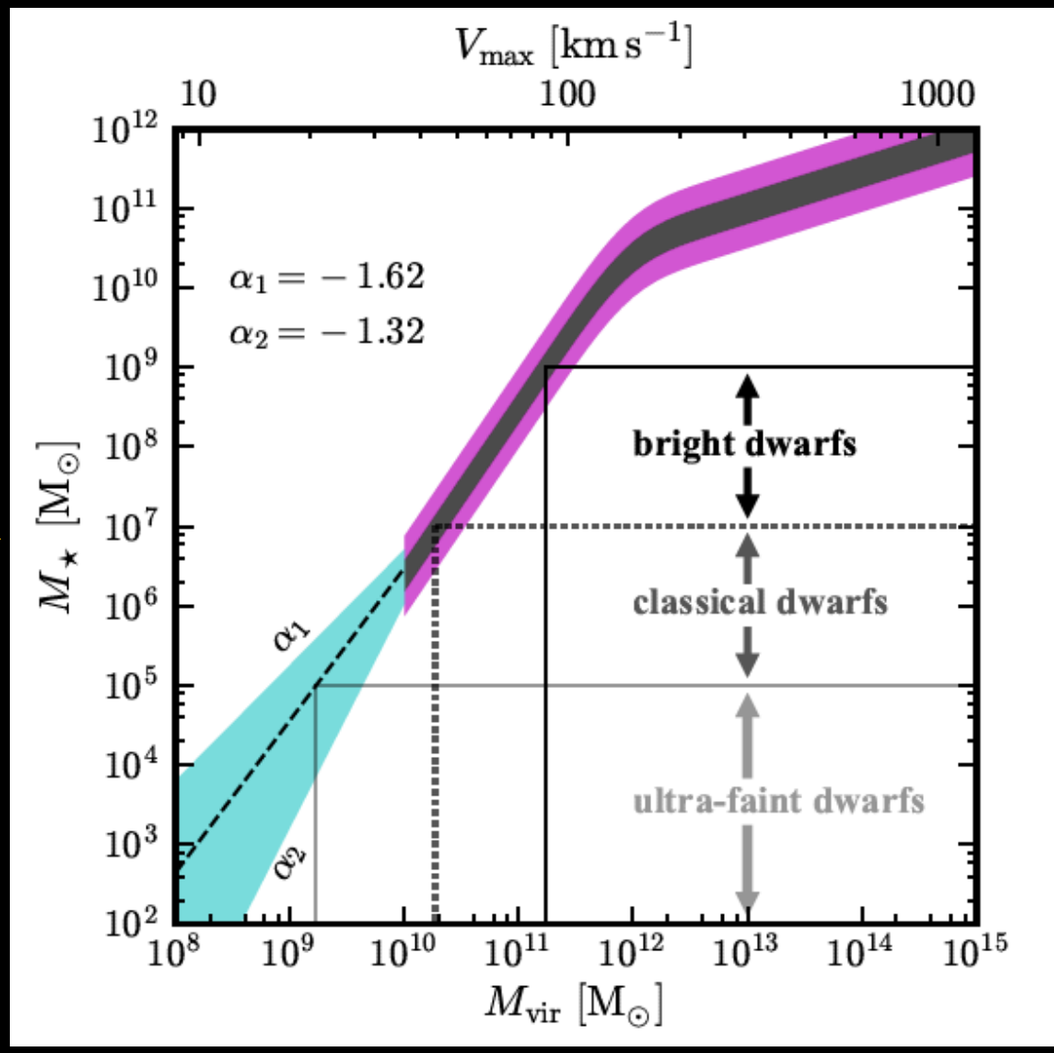
AM

SIDM model

$$\Gamma = \rho_{\rm dm} \left(\frac{\sigma}{m}\right) v_{\rm rms}$$

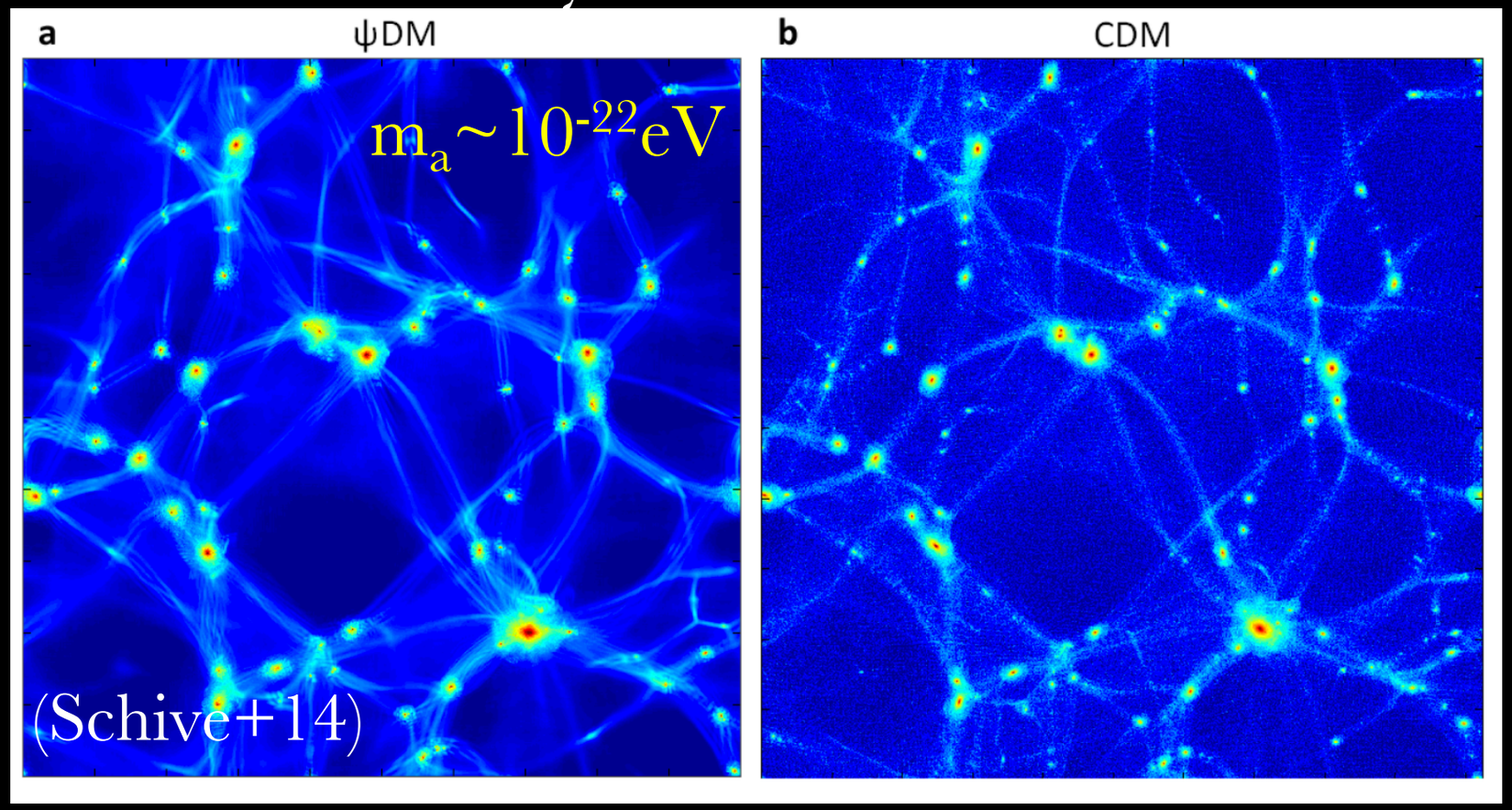
Scatt. rate >1/(10Gyrs)

=>effects@galactic scales



Cosmological Scales CDM vs Scalar Field DM

SF/BEC/Fuzzy DM CDM



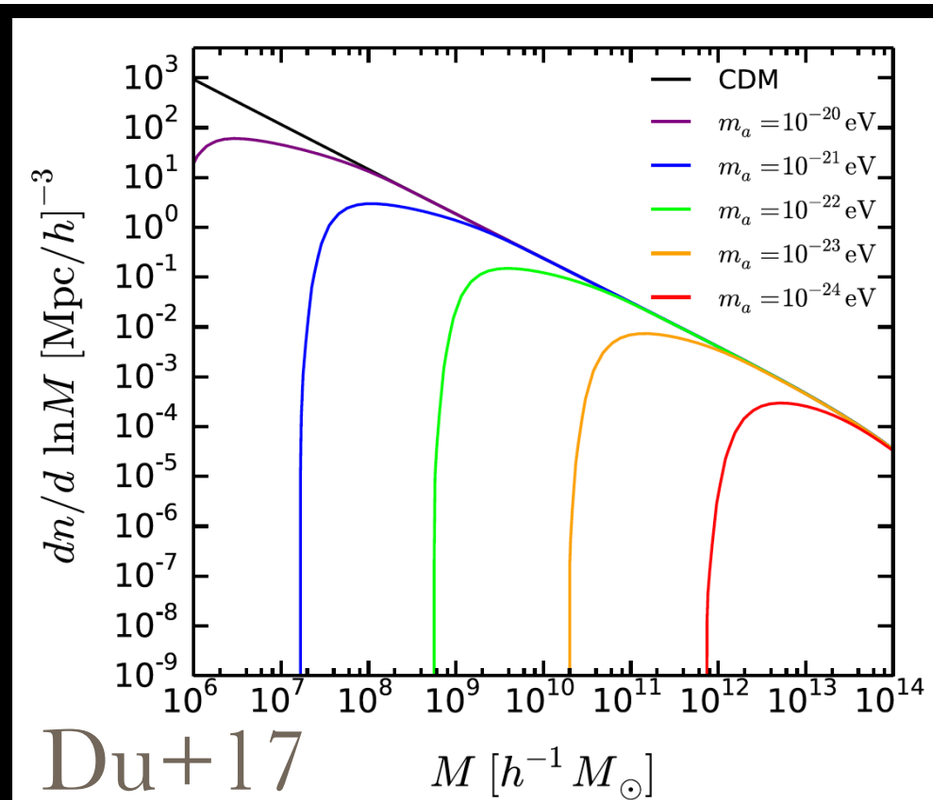
SFDM model

DM boson $m \sim 10^{-21\text{-}22}$eV/$c^2$
(Sin94,Matos+01,Guzman+00)

Quantum-like props at large scales $\lambda_{dB} \sim$kpc

Cores due to Henisenberg uncertainty principle

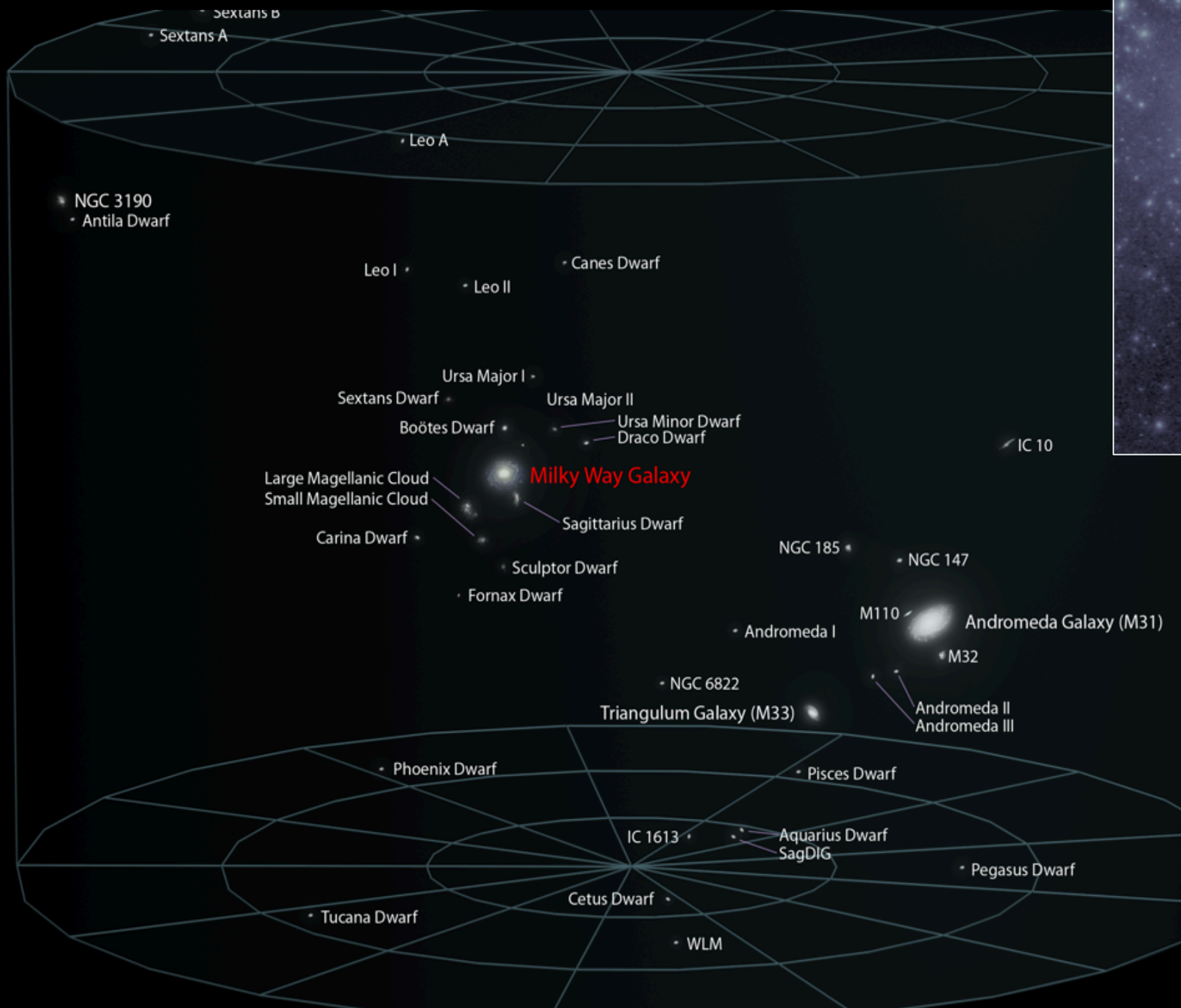
Cut-off in Power Spectrum



Lower Halo abundance

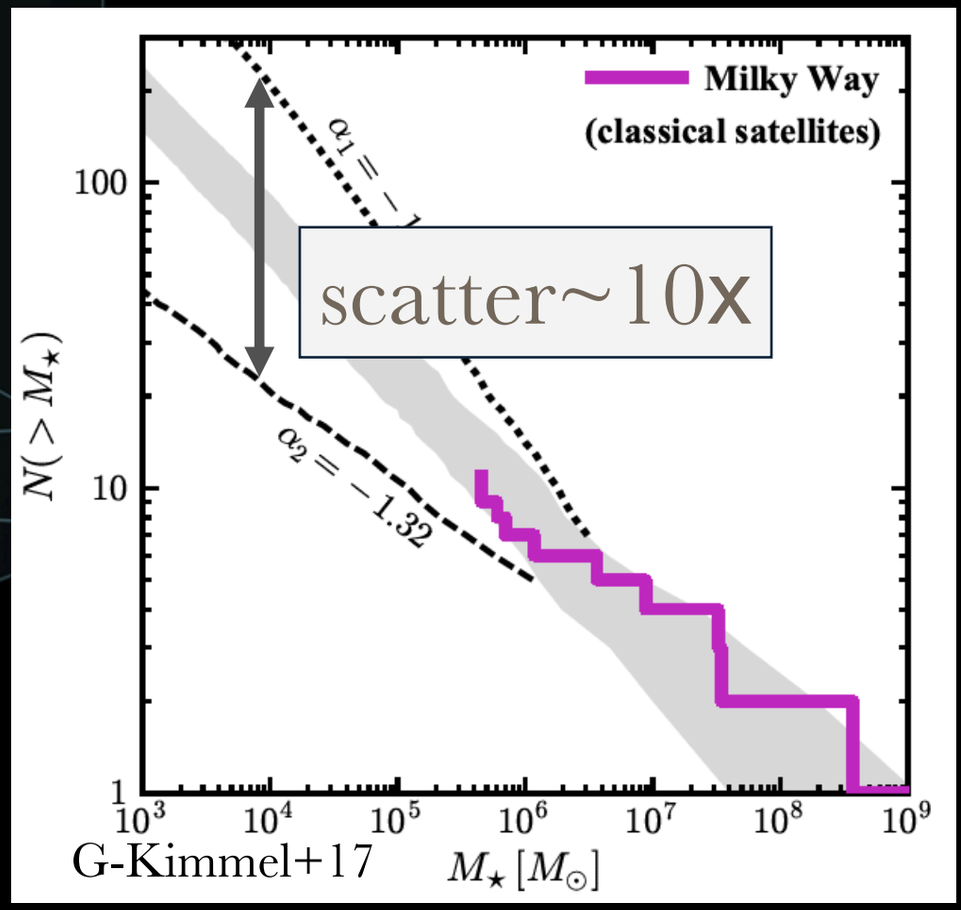
Cosmological constraint
LF => m_a>a few 10^{-24}eV

Local Group



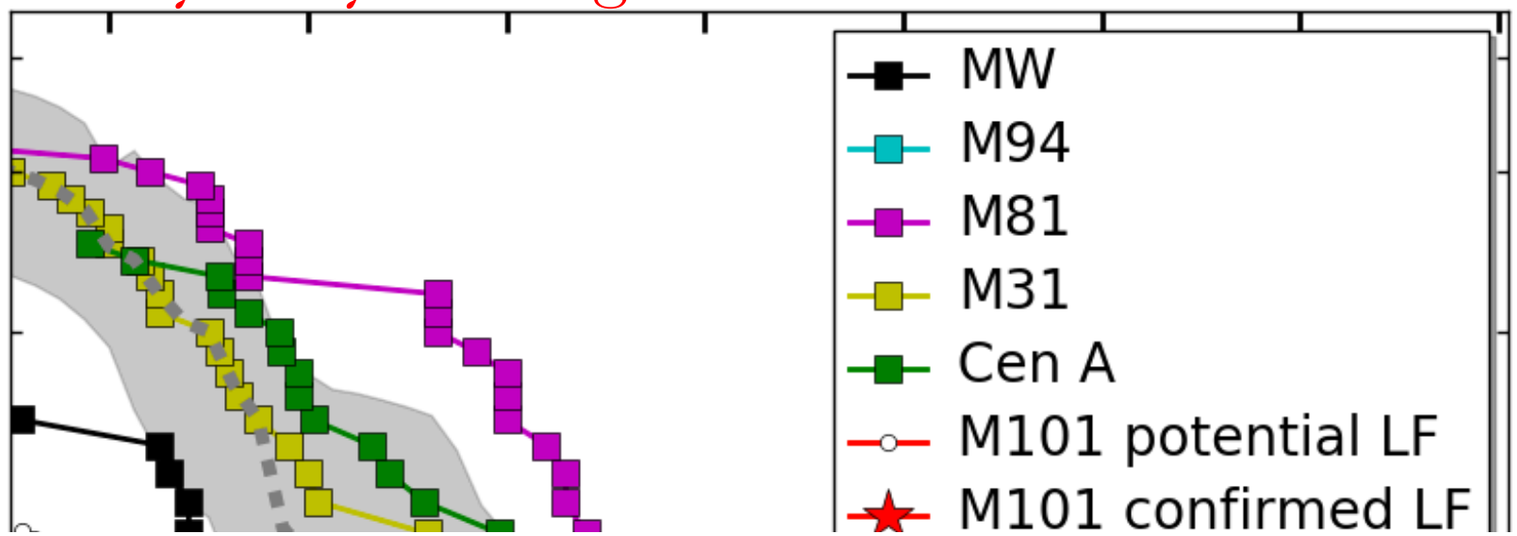
3 Mpc

CDM MW-M31 analogues



Satellite LF
Milky Way Analogues

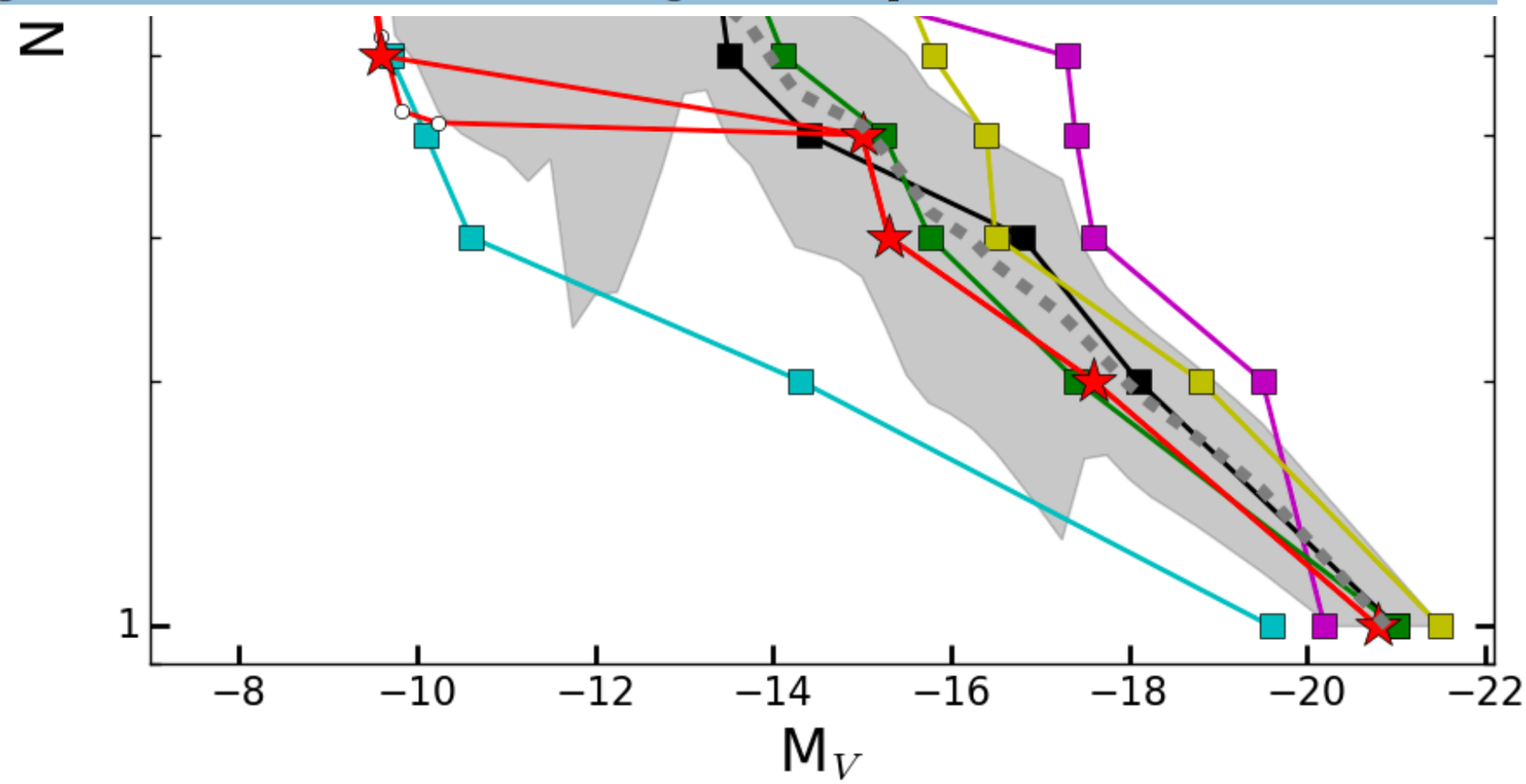
Bennet et al.2019



The M101 Satellite Luminosity Function and the Halo to Halo Scatter Among Milky Way Analogues

P. Bennet,[1] D. J. Sand,[2] D. Crnojević,[3,1] K. Spekkens,[4,5] A. Karunakaran,[5] D. Zaritsky,[2] and B. Mutlu-Pakdil[2]

which tend to have no ongoing star formation. Overall our results show a level of halo-to-halo scatter between galaxies of similar mass that is larger than is predicted in the ΛCDM model.



What is the subhalo abundance of MW-like halos beyond CDM?

Simulating more realistic MW-like galaxies beyond CDM and faster than hydro sims

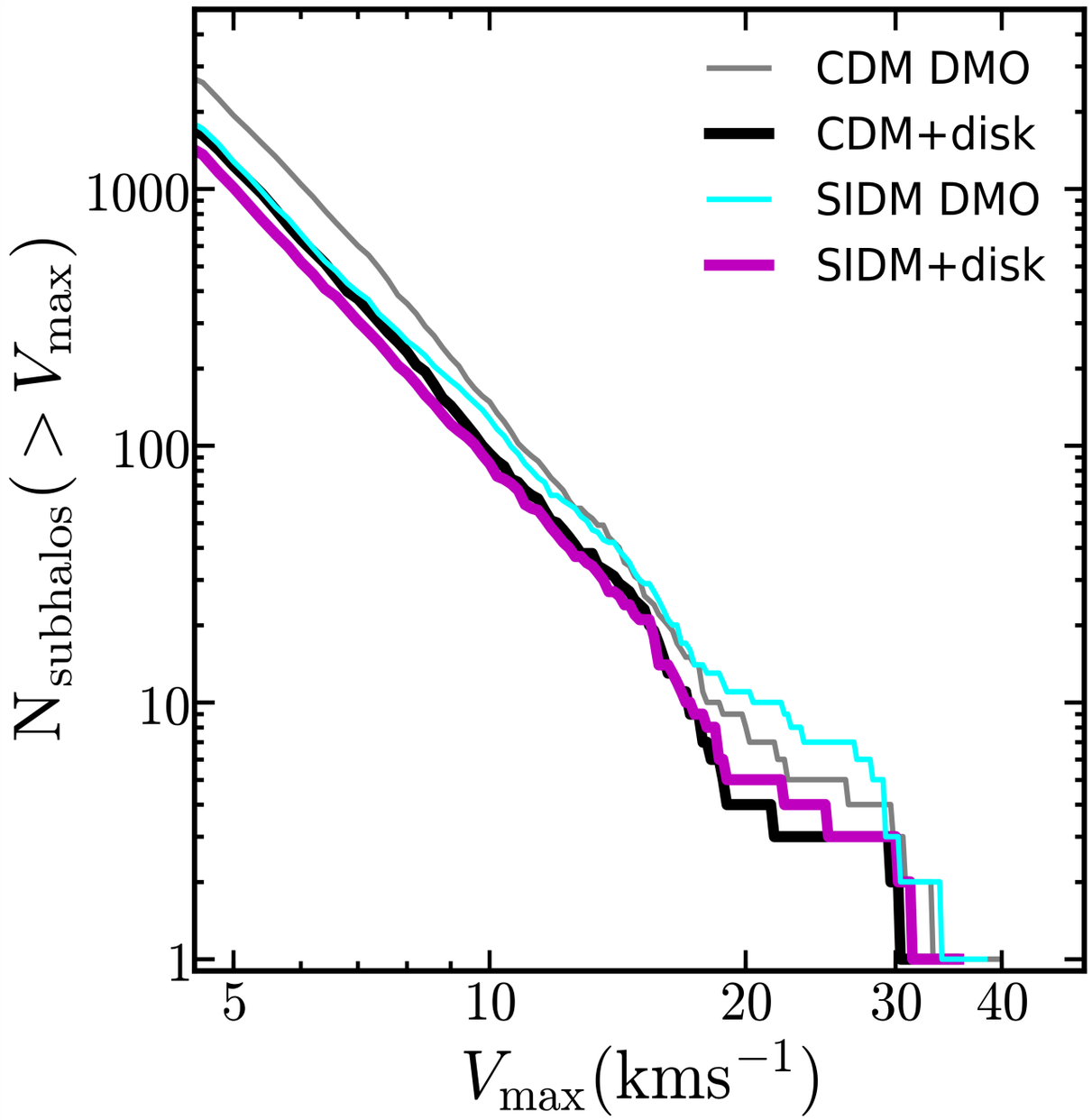
Dark Matter only (DMO)
$M_{vir}=10^{12}M_{\odot}$

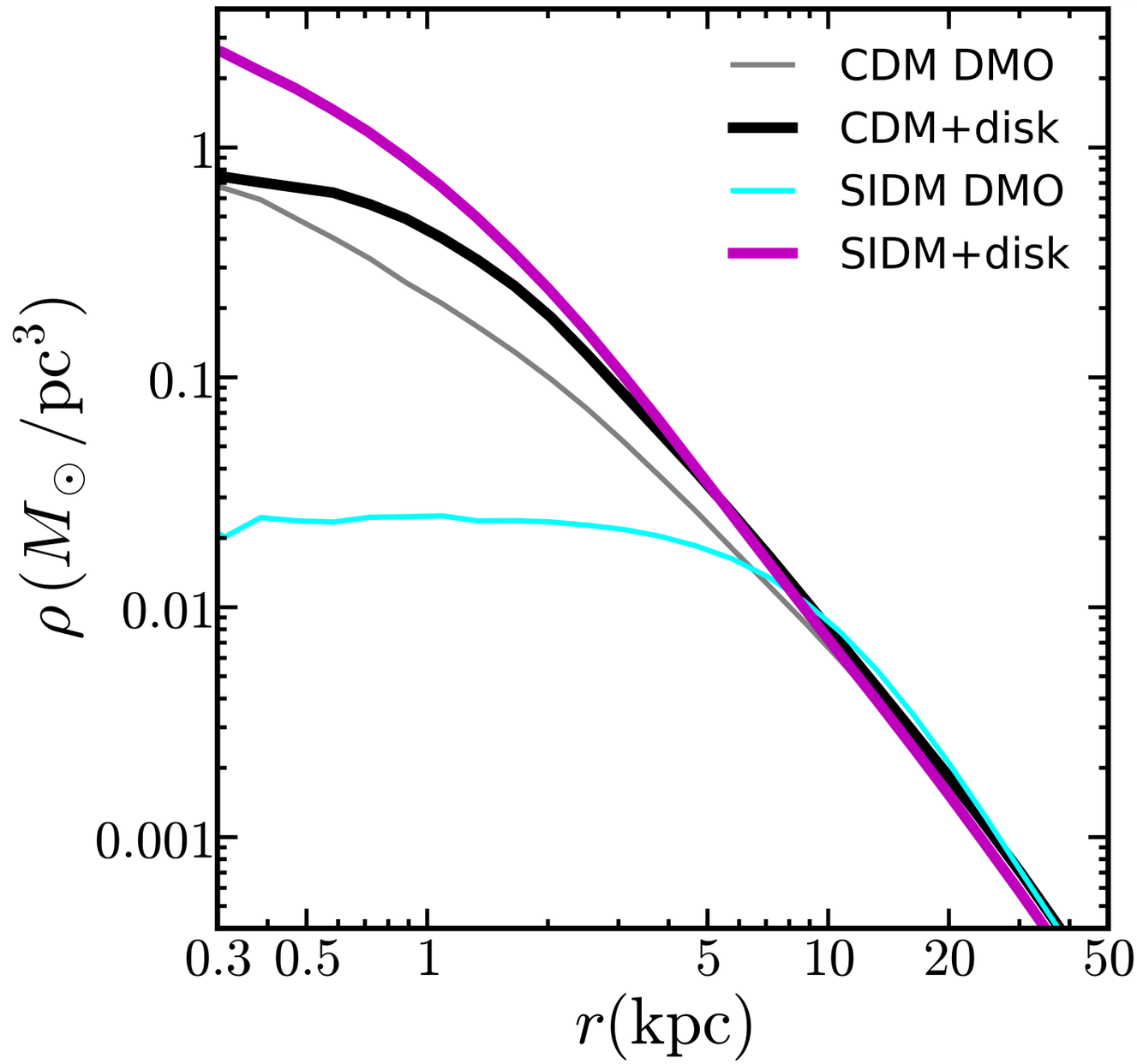
To MW+time-dependent baryonic embedded potential (Garrison-Kimmel+17, Kelley+19 phatELVIS, Robles+19)

M_{bulge}, $M_{gas,disk}$
$M_{star,disk}$, M_{BH}

$\frac{\sigma}{m} \sim 1 cm^2/g$

Similar subhalo abundance in SIDM and CDM



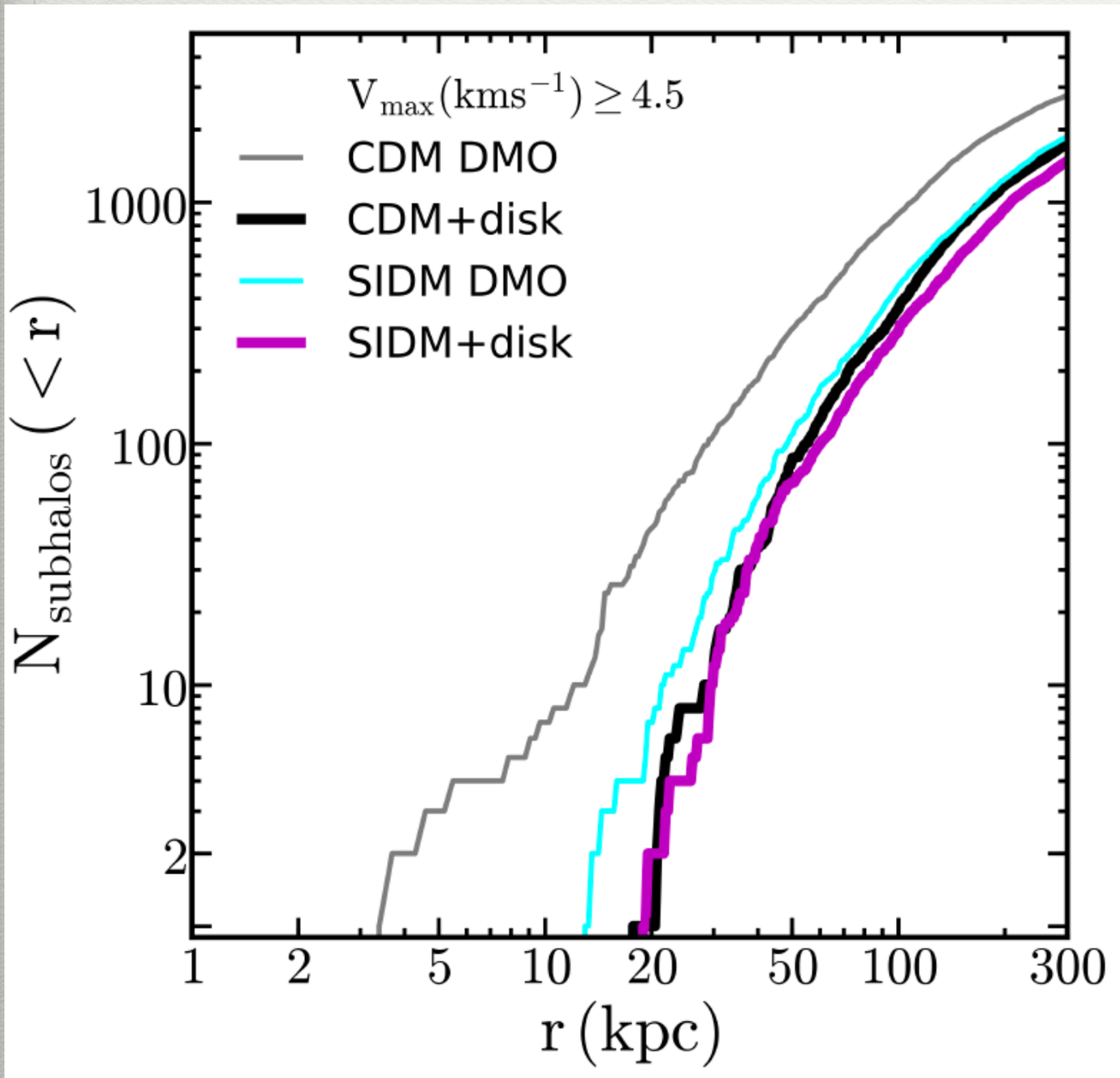


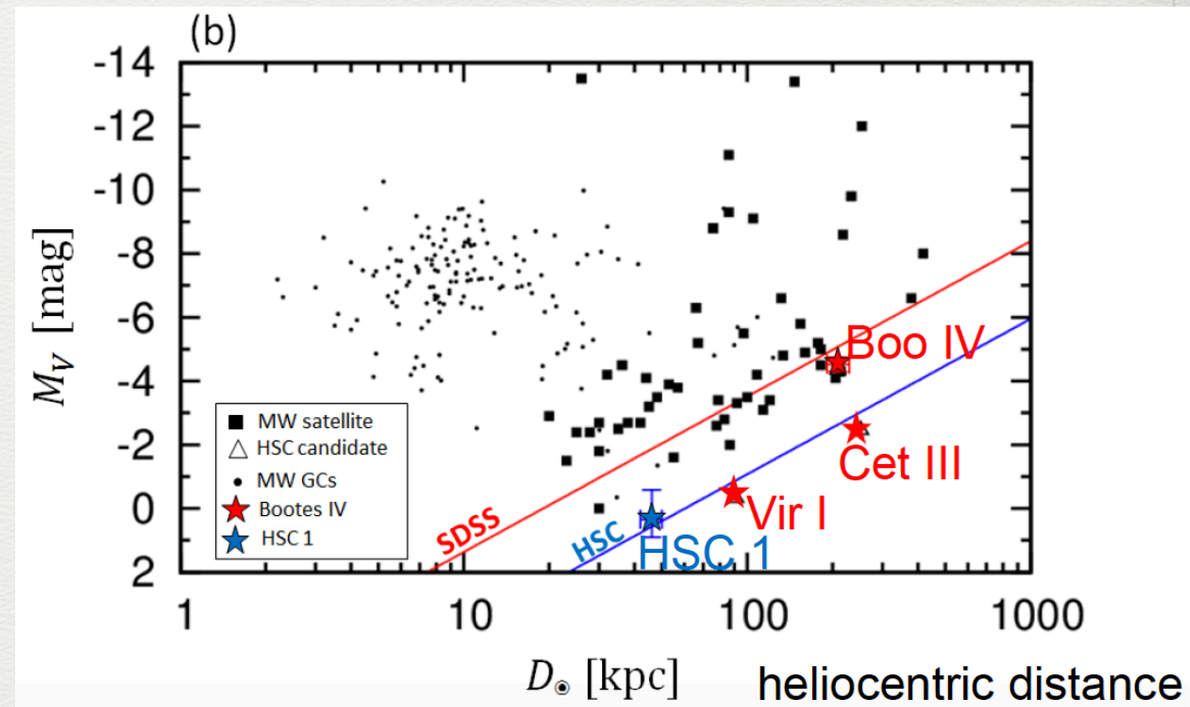
Stronger baryonic contraction in SIDM

One step further: Radial distribuions

Baryonic disk destroys subhalos r<20kpc

for SIDM($1 cm^2/g$) and CDM!



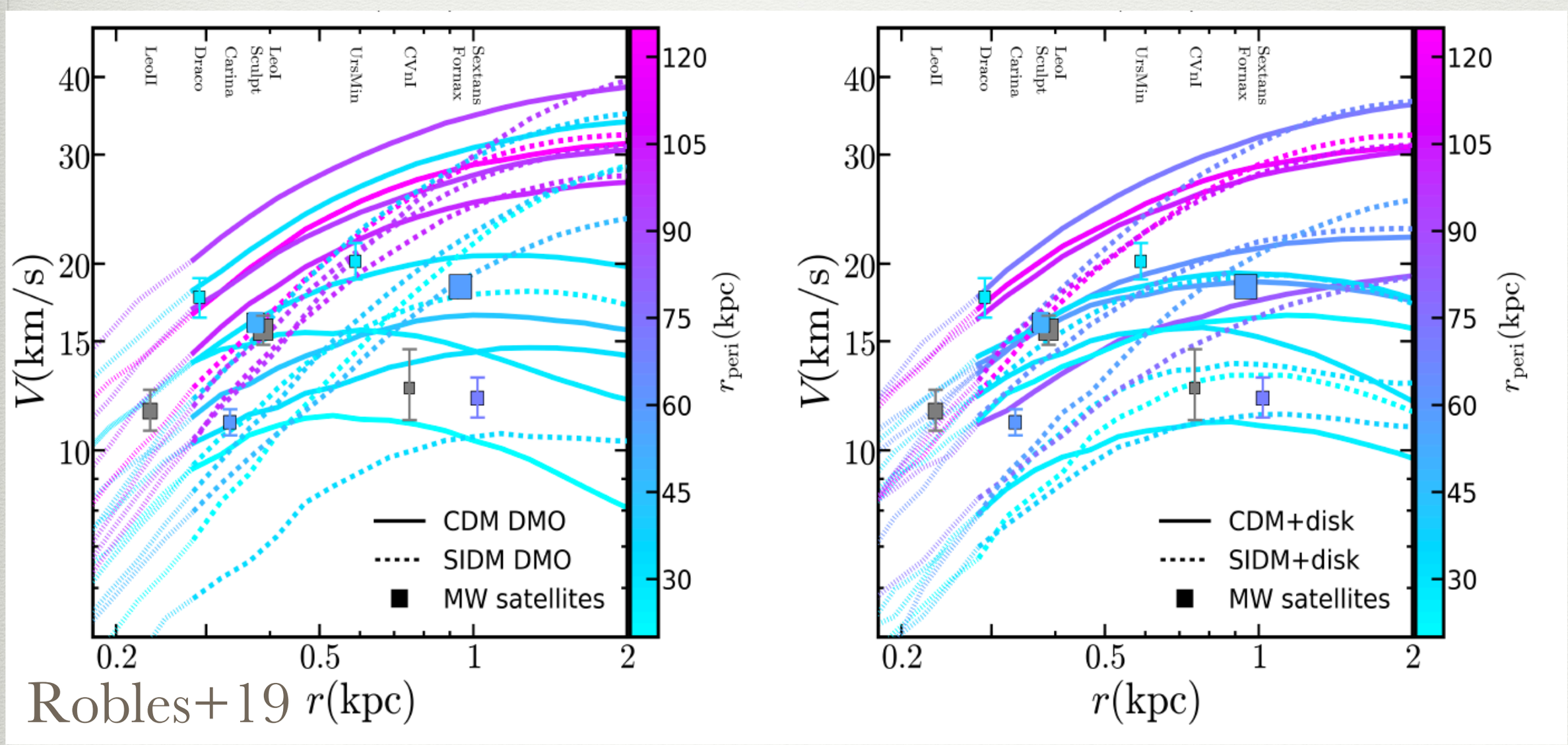


Deep surveys with HSC-Subaru and LSST will help constrain N(r) at large radii

Another step further : use Gaia proper motions

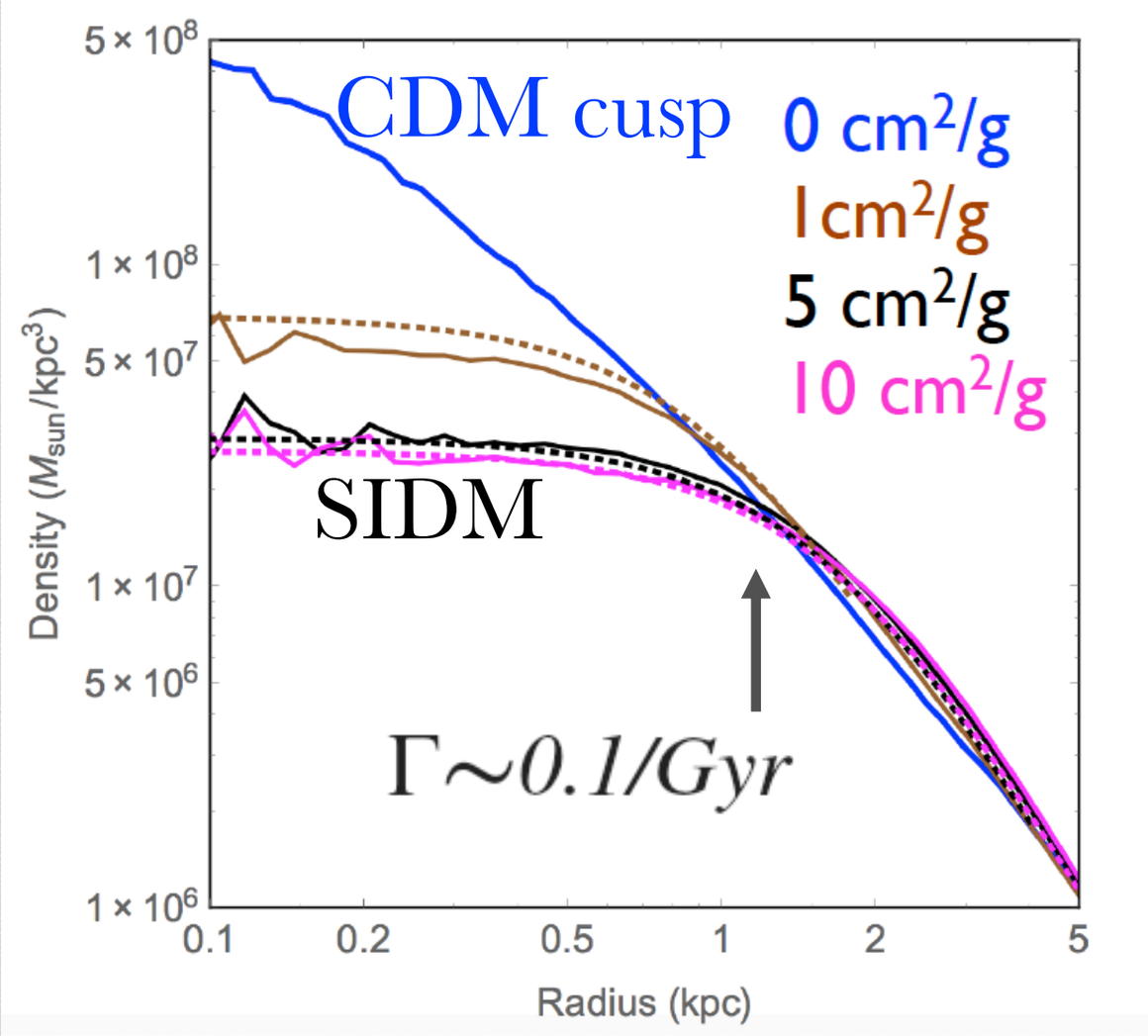
Sims: Most massive subhalos w closer pericenters are less dense

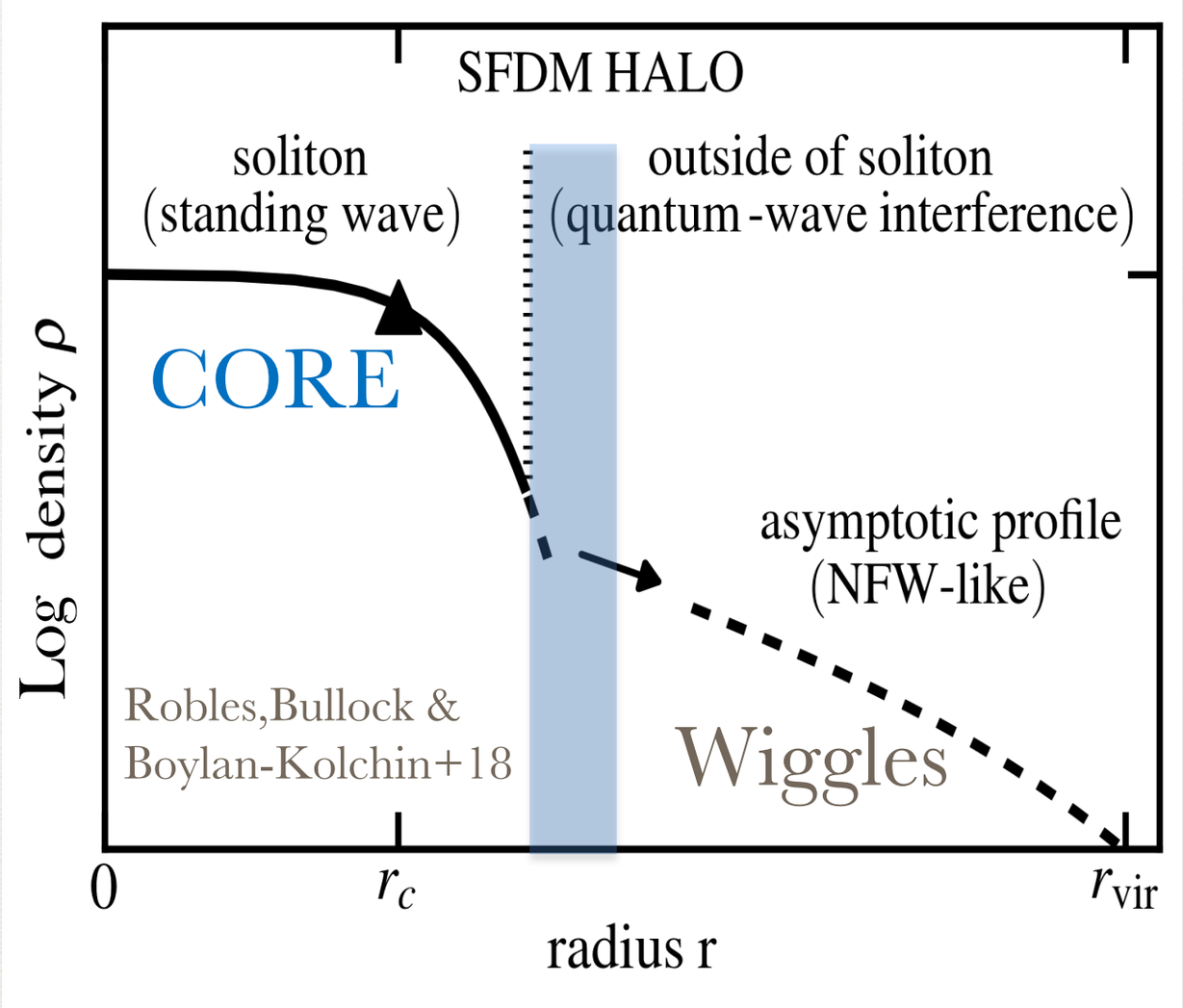
Data do not seem to follow the same trend



Robles+19

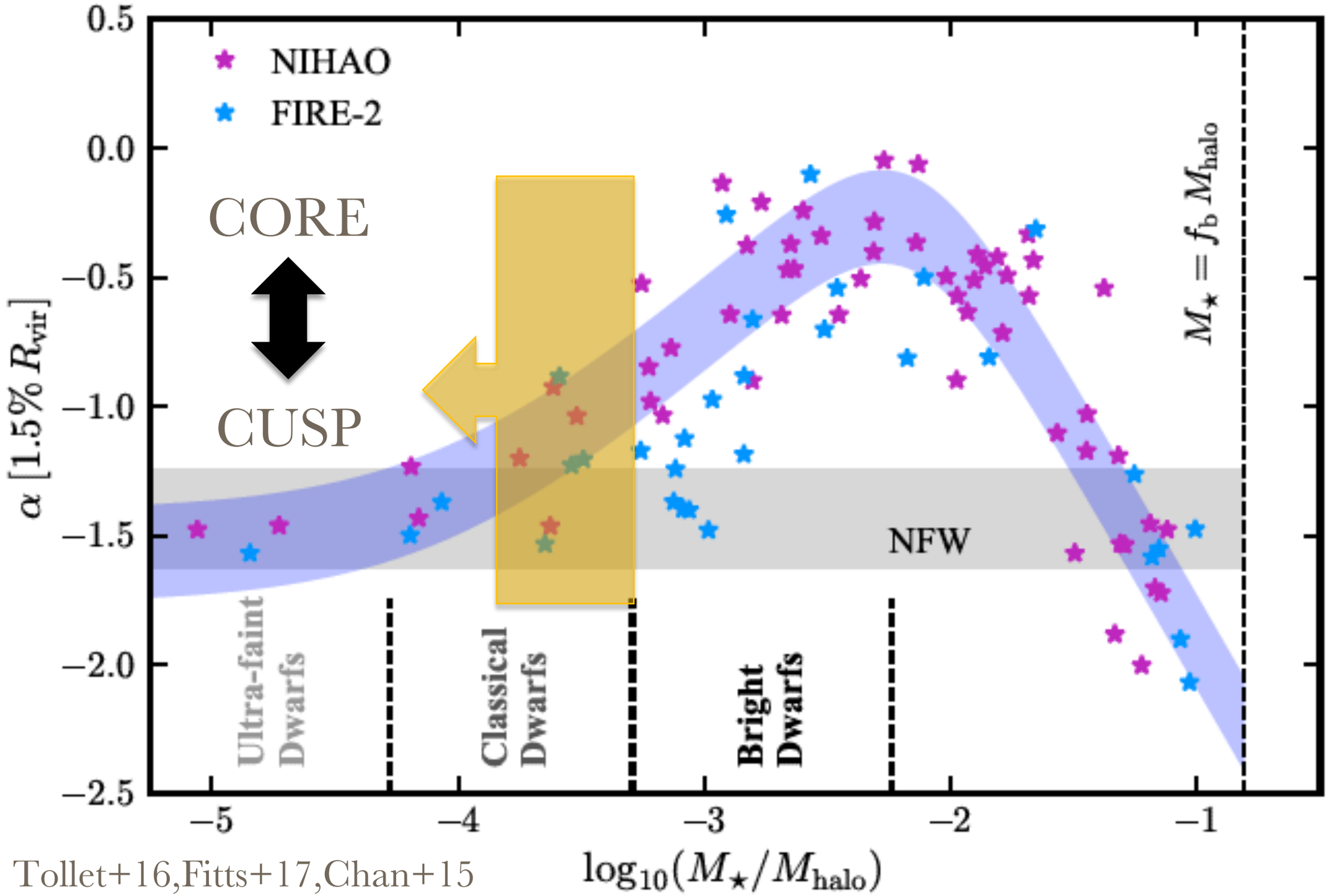
DM constraints from Core resilience to feedback and inner slopes in dwarf halos





How does baryonic feedback modify the cores?
Smoothness of the density profile

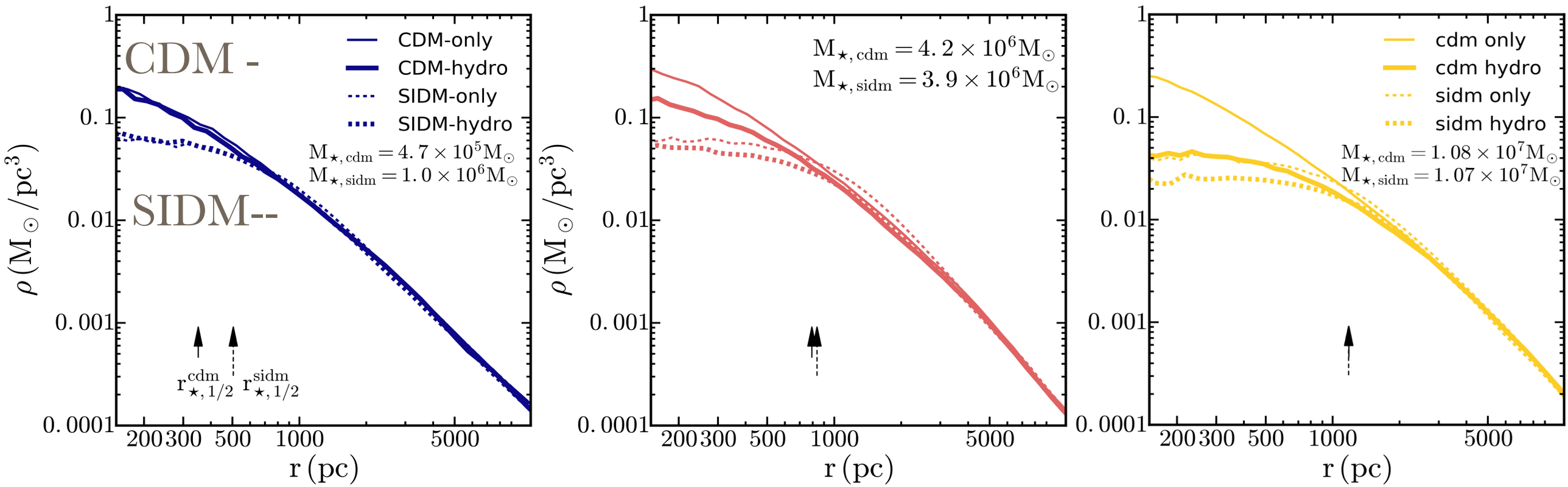
CDM +Hydro simulations:
Below $M_* \sim 3\times10^6\ M_\odot$ not enough energy from SNe to alter DM structure



Tollet+16,Fitts+17,Chan+15

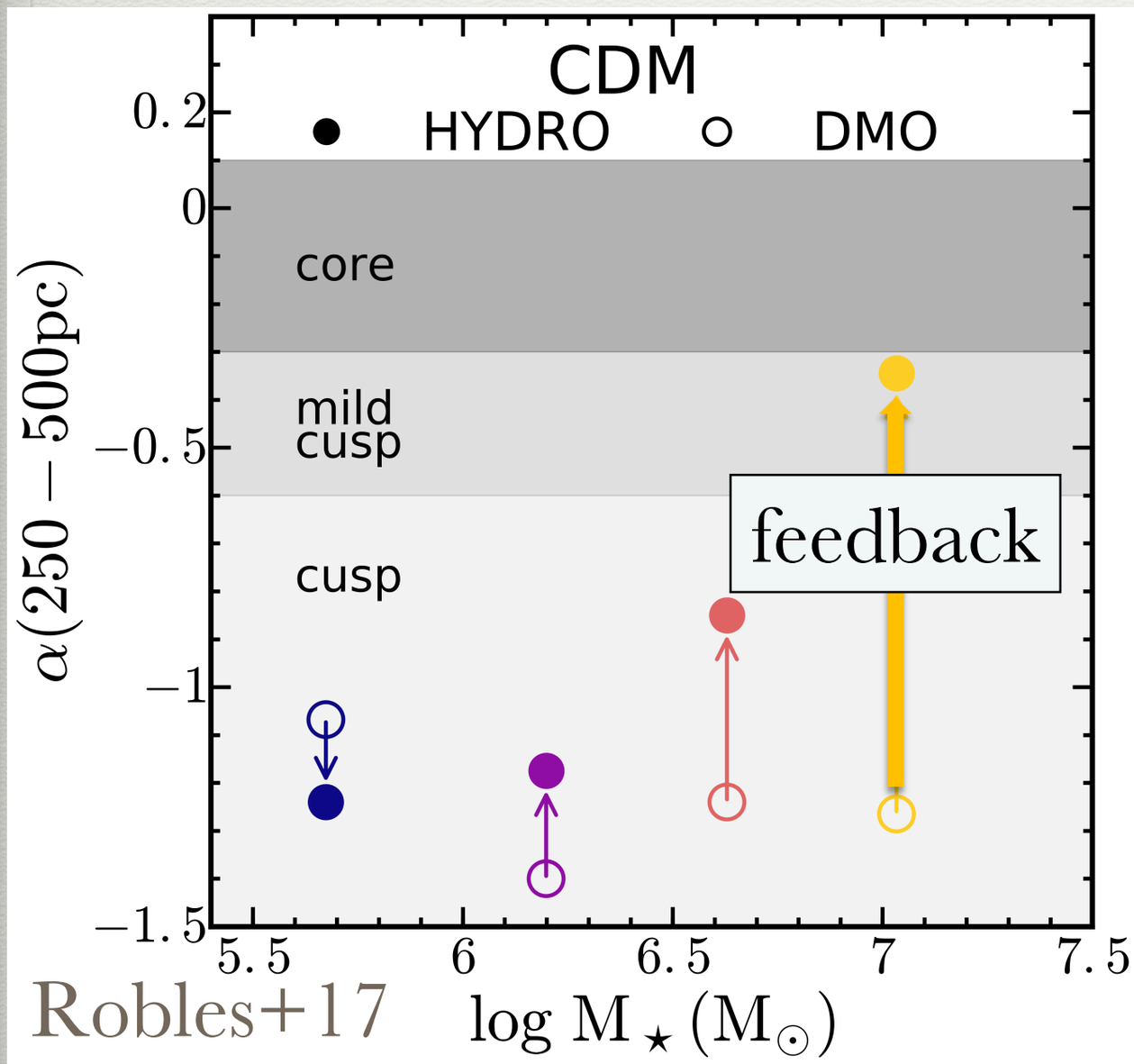
FIRE+SIDM $\sigma/m=1\,cm^2/g$ (Robles+17) $M_{vir}=10^{10}M_\odot$

SIDM $M_*\sim10^5\,M_\odot$ $\sim10^6\,M_\odot$ $\sim10^7\,M_\odot$

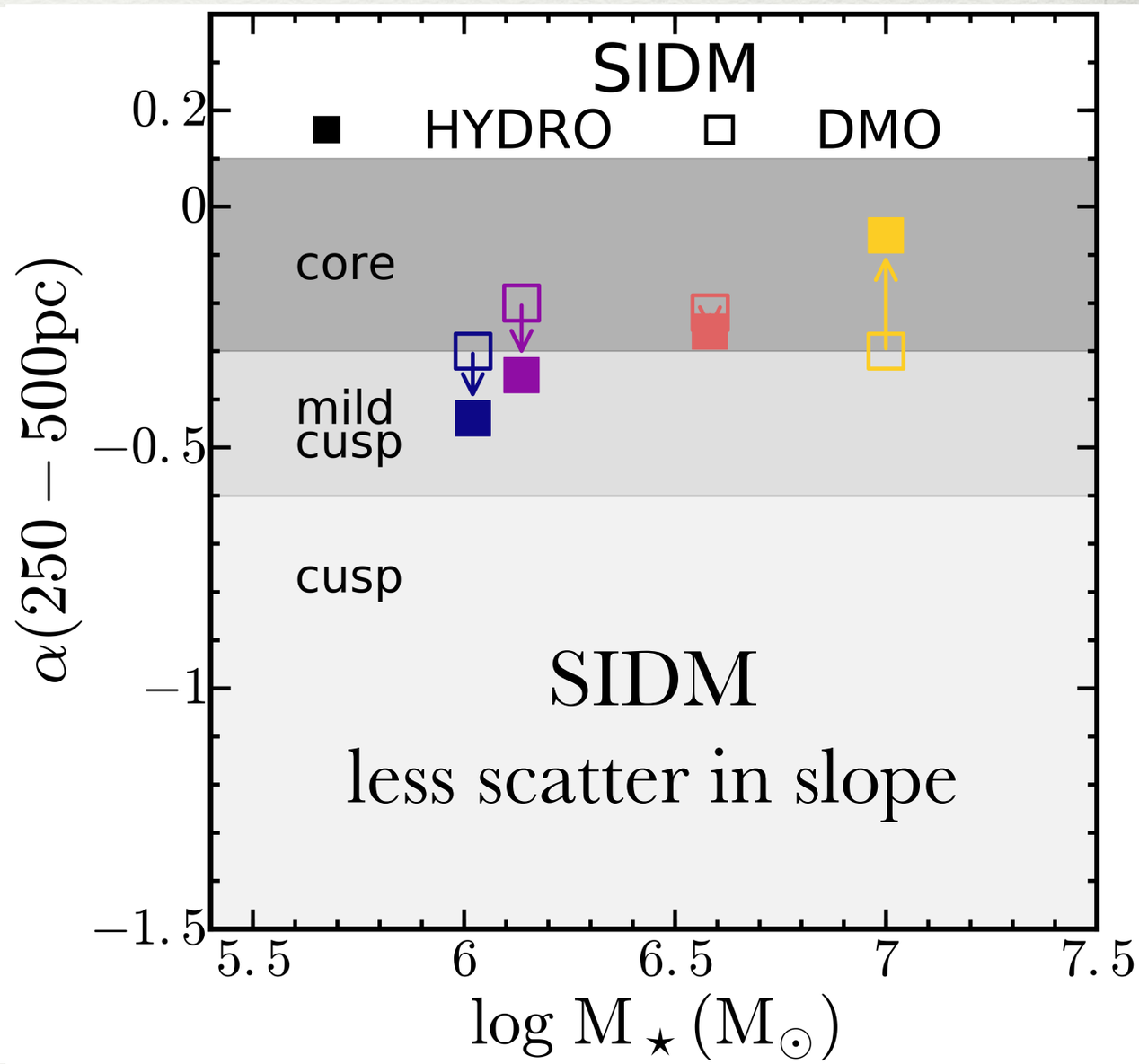


Dwarf galaxies in SIDM are much less sensitive to feedback

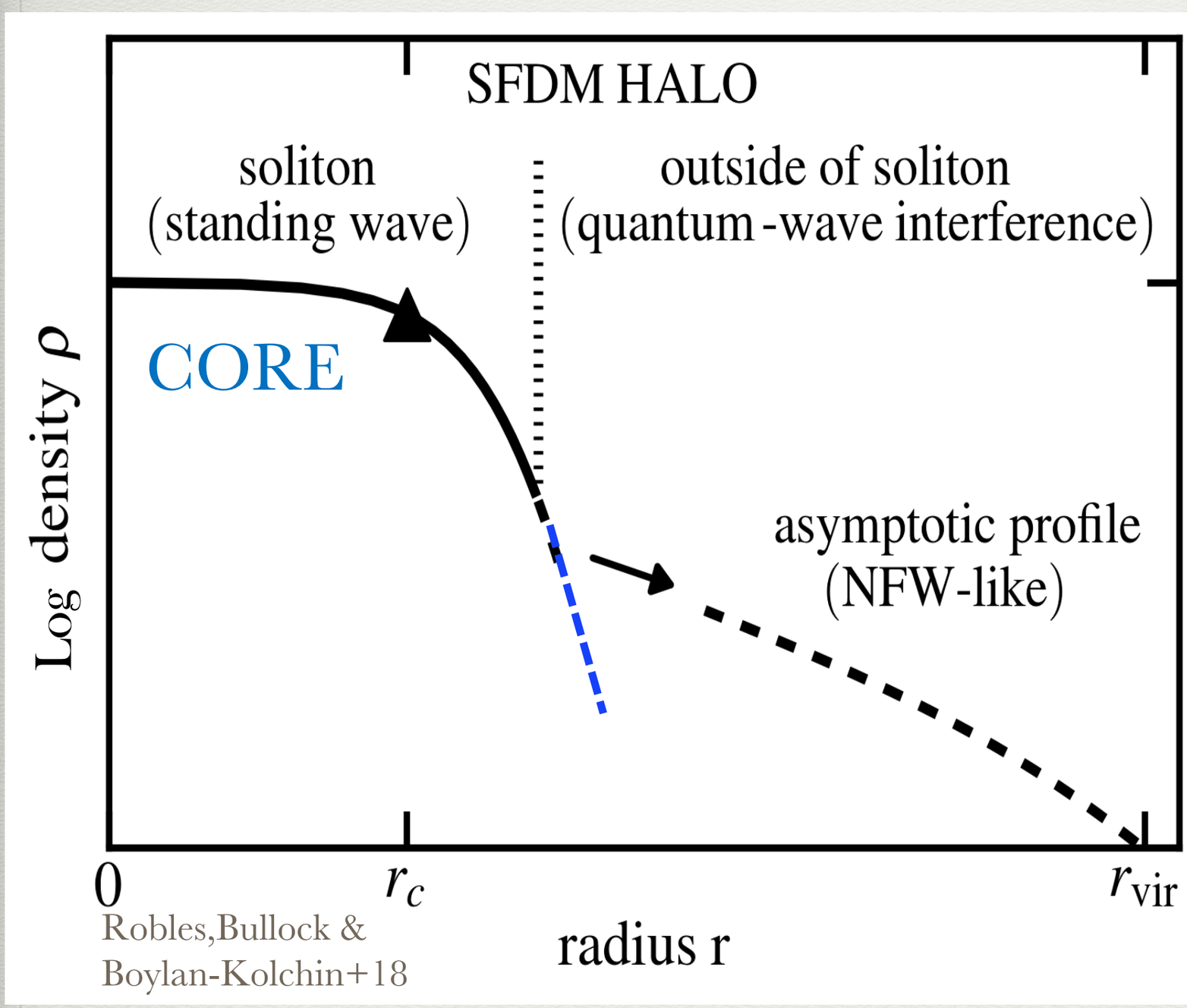
SIDM vs CDM: Inner Slopes



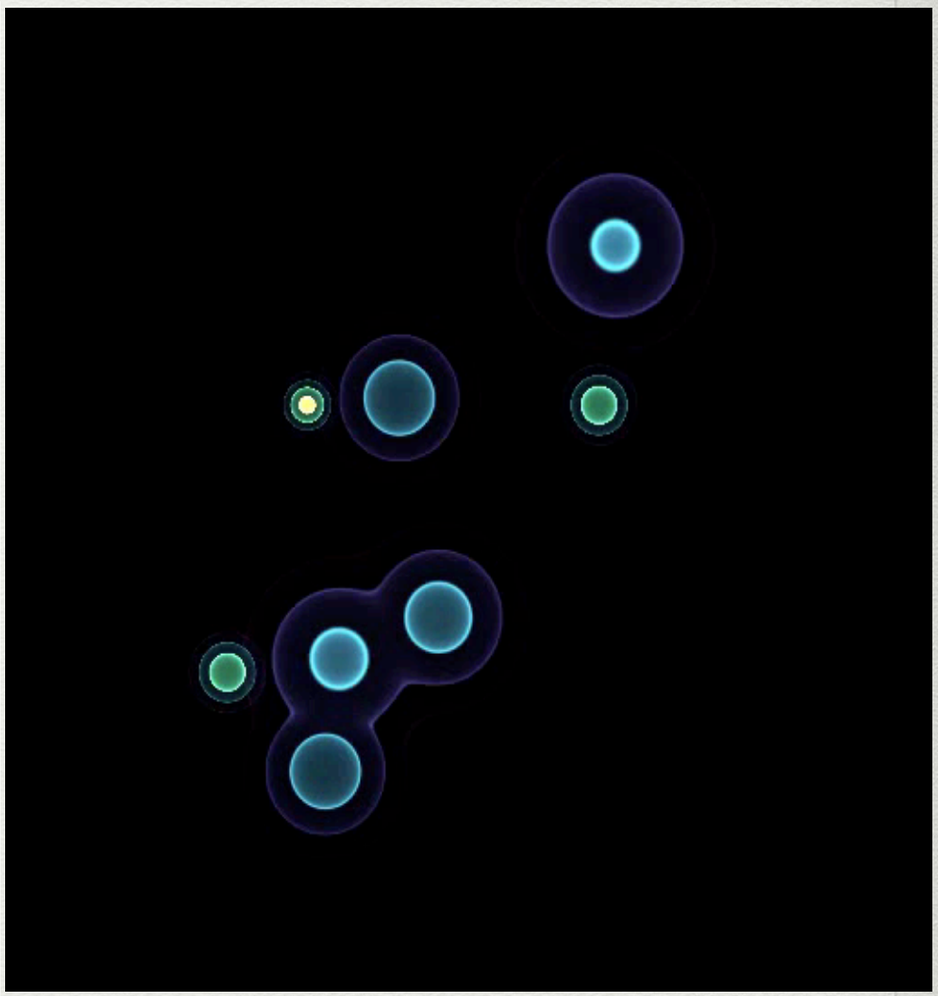
Robles+17



SFDM halos have inner cores (solitons)



Robles,Bullock & Boylan-Kolchin+18



Mocz,Vogelsberger,VHR+17

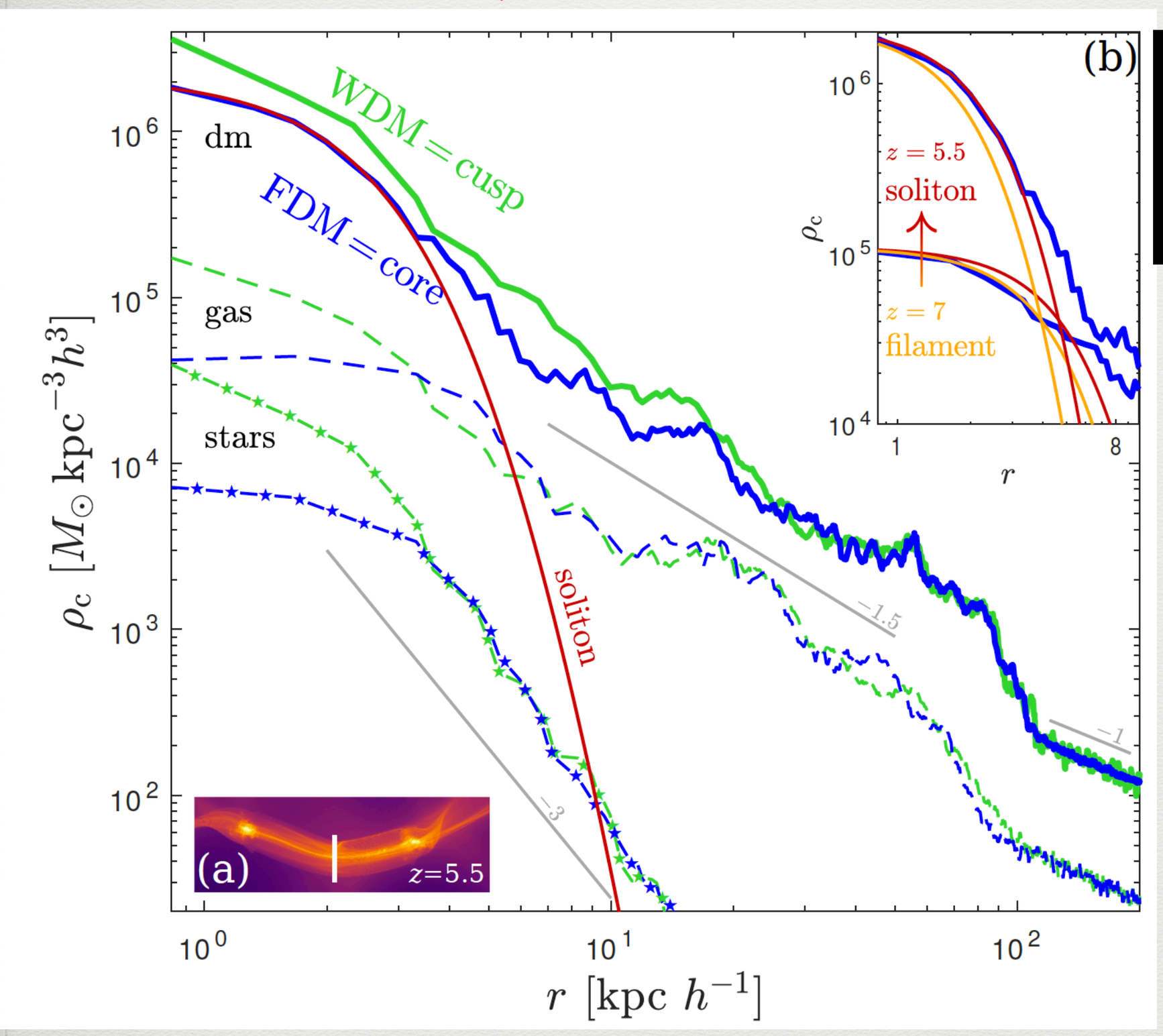
Central Solitons robust to mergers!

Non cosmological simulations

(Velmaat & Niemeyer 16, Schwabe+16, Schive+14)

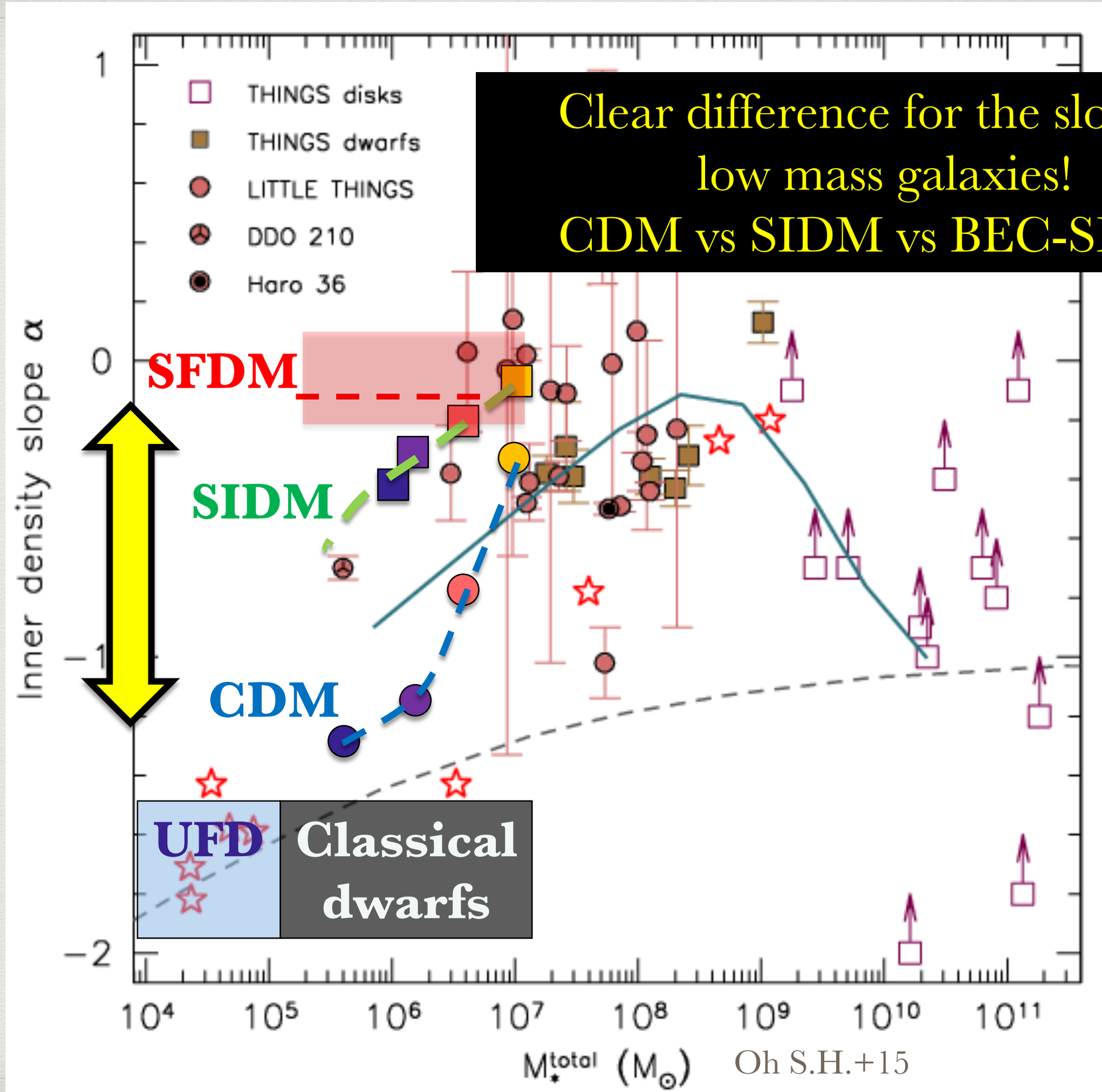
SFDM/BECDM +IllustrisTNG (z~5.5)

First Hydro SFDM sim (Mocz,VHR+19)



Stars/gas follow the DM soliton core

Smallest DM halo $M_{vir} \sim 10^7 M_\odot$ below expected $M_{Jeans} \sim 10^8 M_\odot$

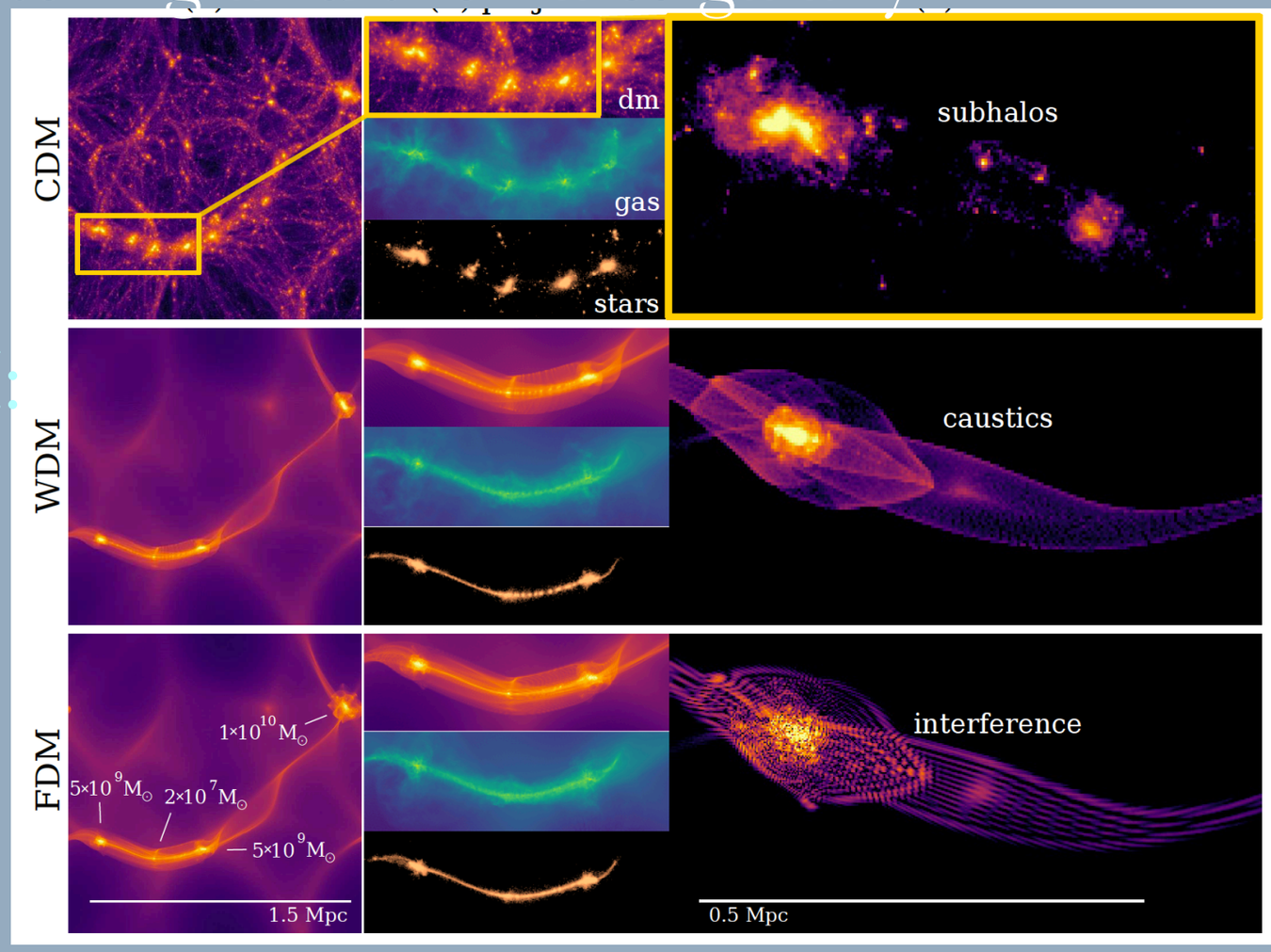

Clear difference for the slope in low mass galaxies!
CDM vs SIDM vs BEC-SFDM
THINGS disks
THINGS dwarfs
LITTLE THINGS
DDO 210
Haro 36
SFDM
SIDM
CDM
UFD
Classical dwarfs
Inner density slope α
1
0
−1
−2
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹
10¹⁰
10¹¹
M*total (M⊙)

Oh S.H.+15

CONCLUSIONS

Cosmological scales:

-DM nature DOES change clustering and the halo/galaxy assembly!



Local Group can constrain DM:

-Scatter in low mass end

-Radial distribution

-Proper motions

Dwarf galaxies w feedback:

-Scatter in cores :

-SIDM is more robust to FB than CDM

-SFDM galaxies display a core in GAS/Stars resembling the DM

-Inner slope in UFD as a test for CDM/SIDM/SIDM