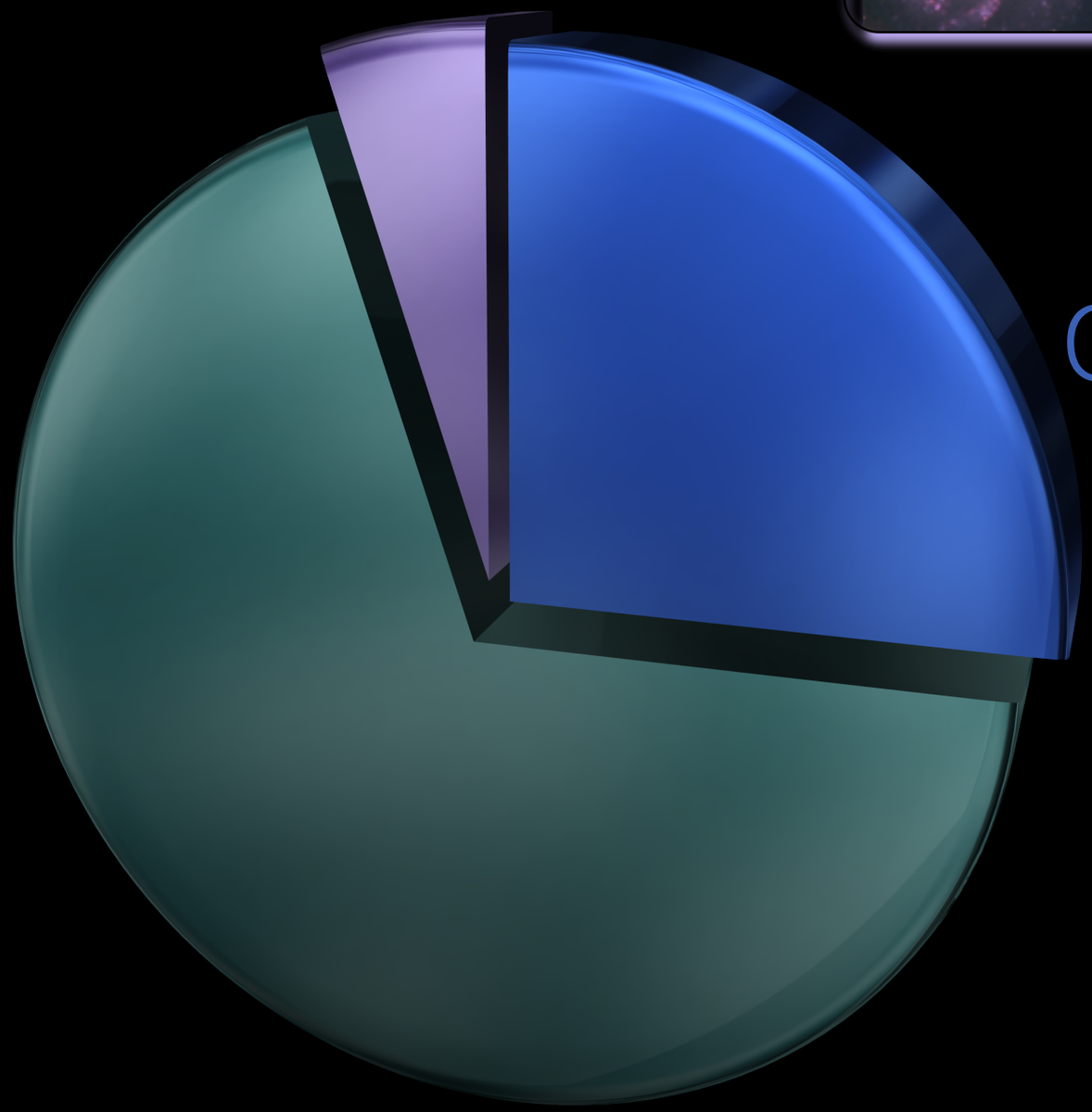
Self-interacting Dark Matter and Dwarfs

James Bullock (UC Irvine)

LCDM

Normal Matter
5%

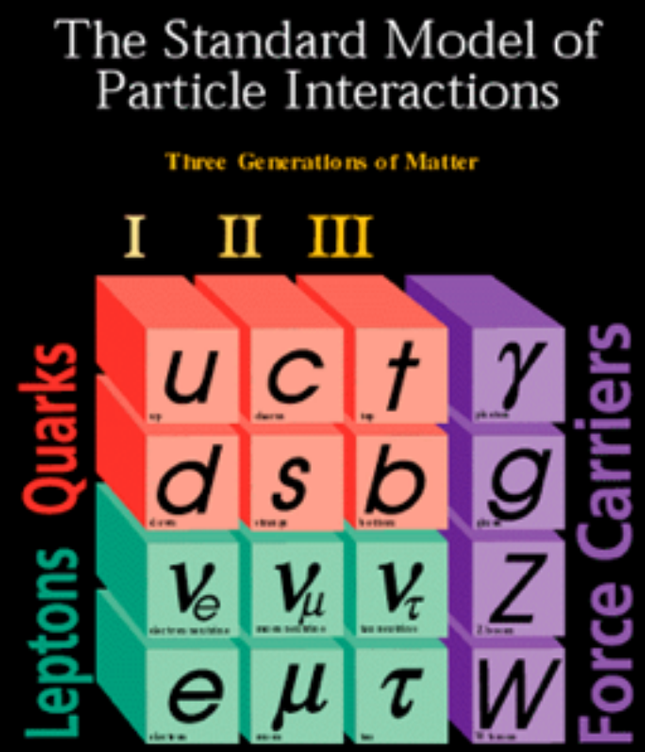


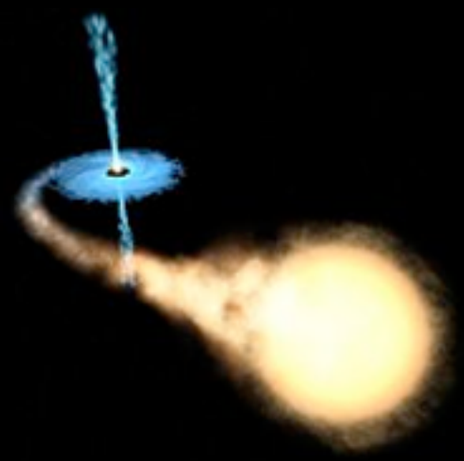
Cold Dark Matter
25%

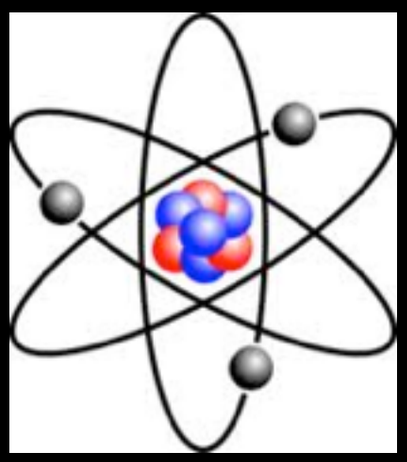
Cosmological constant
(Λ) 70%

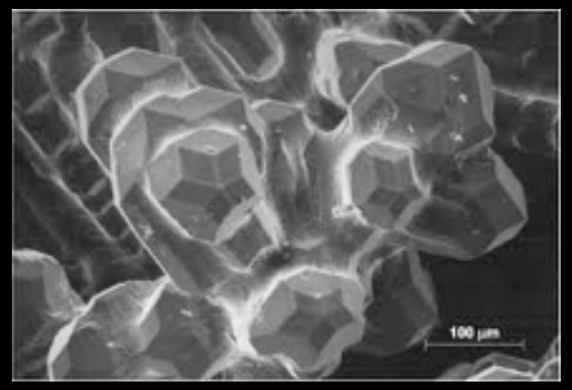
Normal Matter

5%

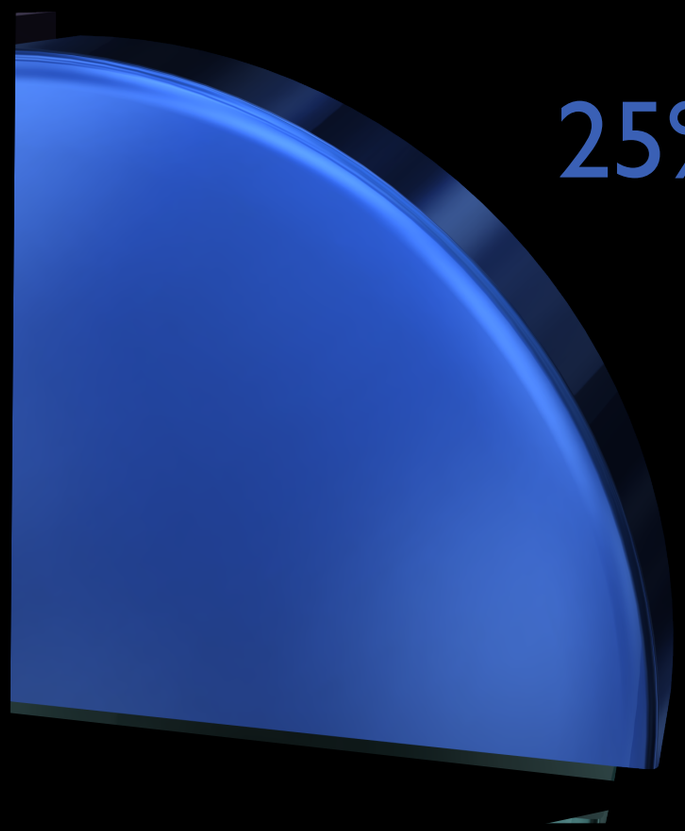


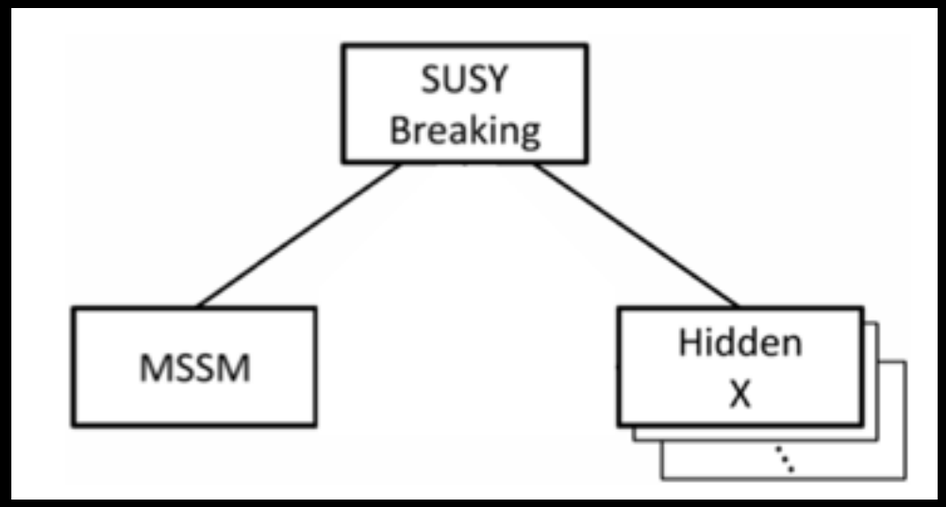






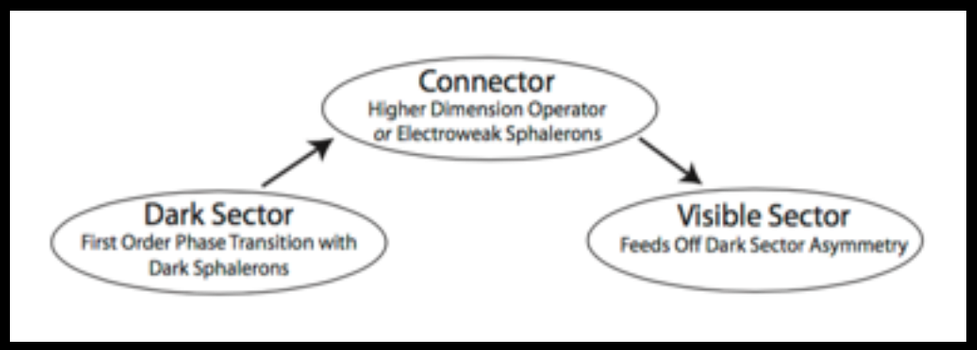
What if DM isn't so simple?





- A smorgasbord of particles and interactions?

- Dark photons (Ackerman et al. 08)
- Dark atoms (Kaplan et al. 09)
- Kaplinghat, Tulin, Yu (10,14ab,15ab)



Shelton & Zurek

- DM could be "hidden" w/no SM couplings (all evidence gravitational)

Dark Matter Phenomenology

Cold Dark Matter?
Warm Dark Matter?
Self-interacting Dark Matter?
Ultra-light Scalar Field Dark Matter?
Superfluid Dark Matter?
MOND?

Self Interacting Dark Matter

Spergel & Steinhardt (2000)

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

if rate is > 1 / T_{Hubble}
interesting things happen

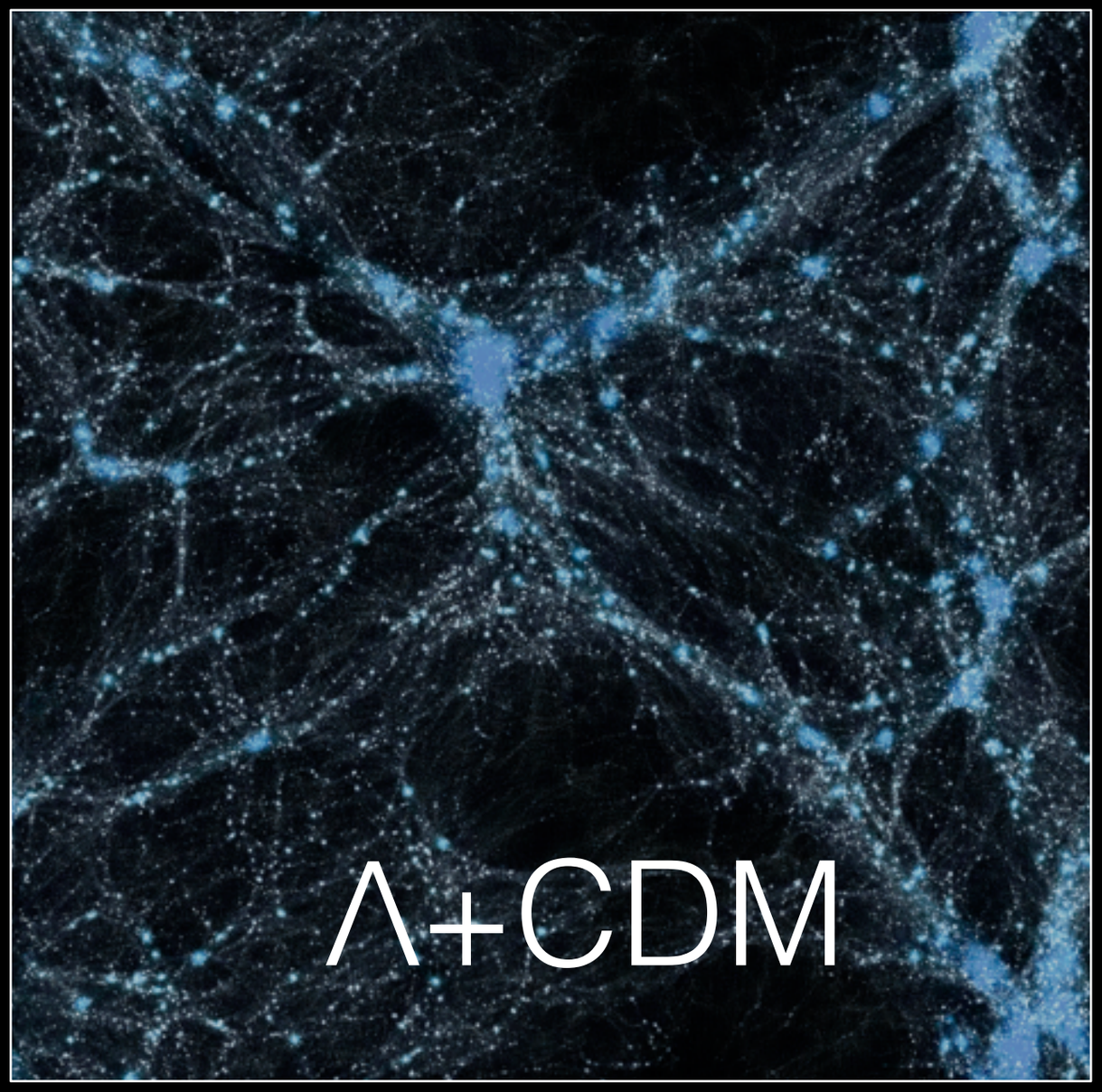
$$\frac{\sigma}{m} \sim 1\,{\rm cm}^2/g$$

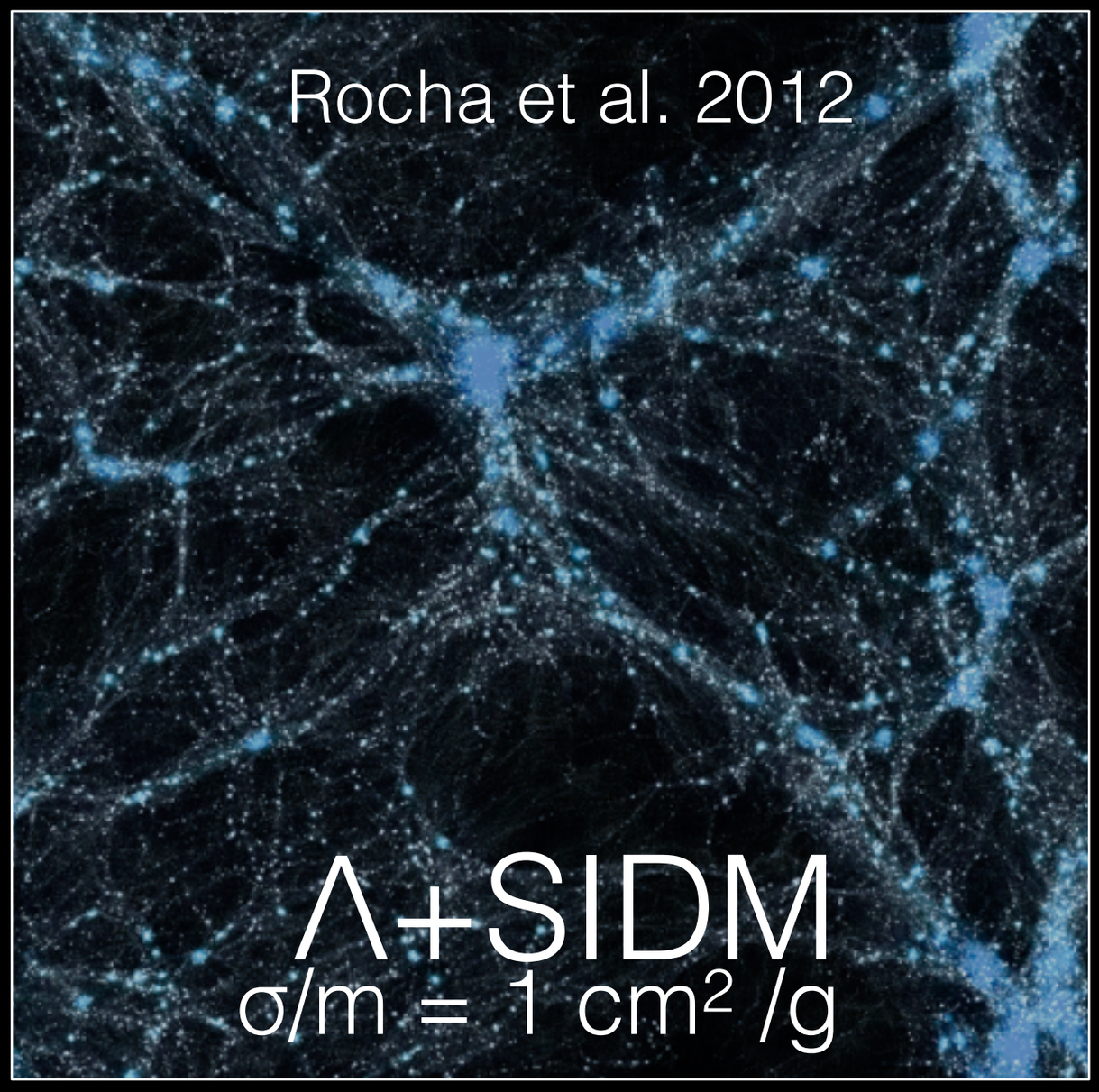
most models have velocity-dependent cross sections

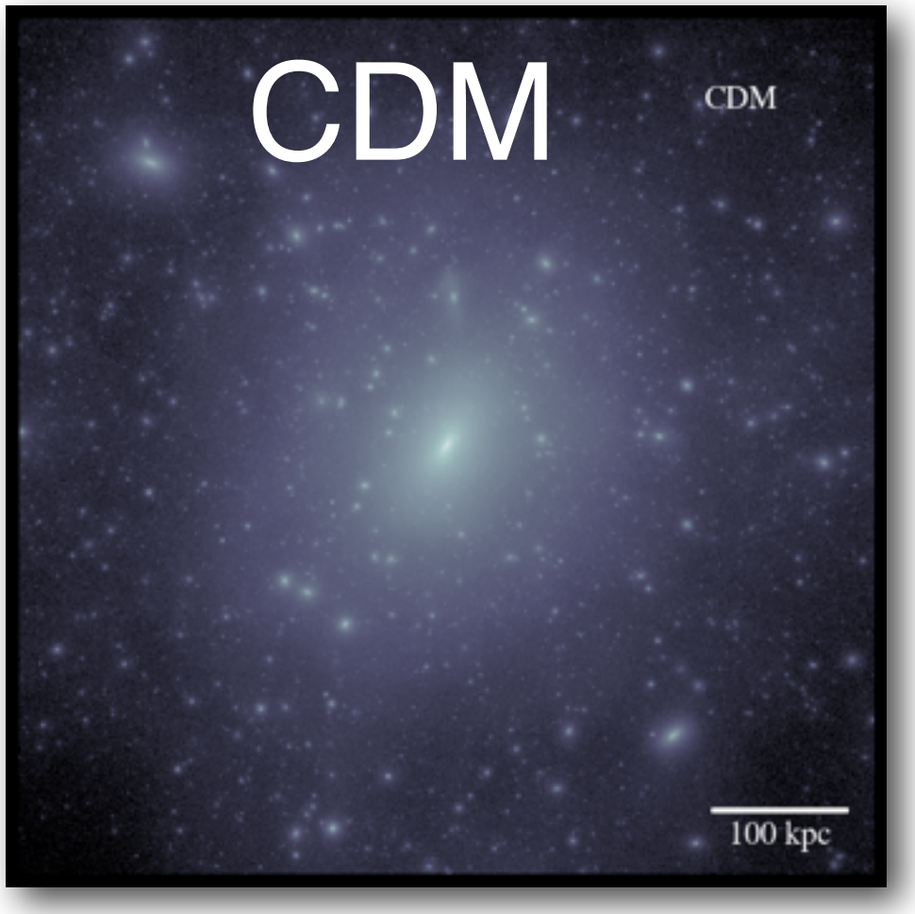
(Elbert+17,15; Rocha+13;Vogelsberger+12; Zavala+13; etc.).

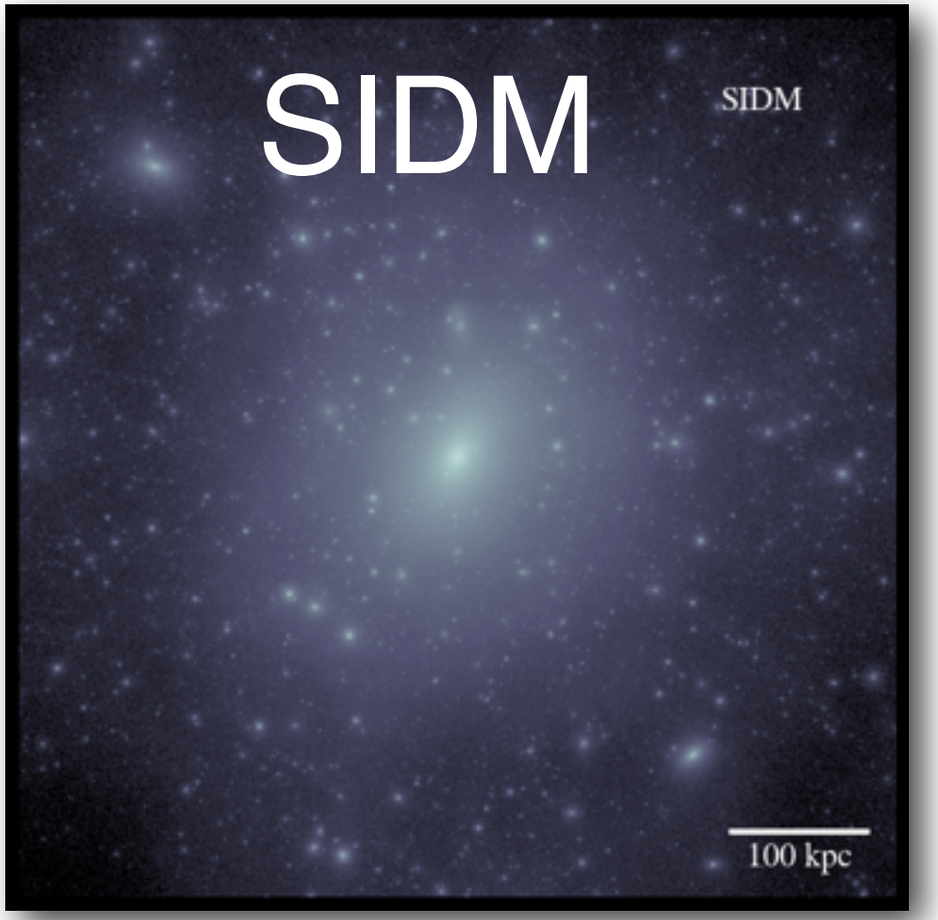
SIDM vs. CDM

- same large scale structure
- same DM halo mass functions





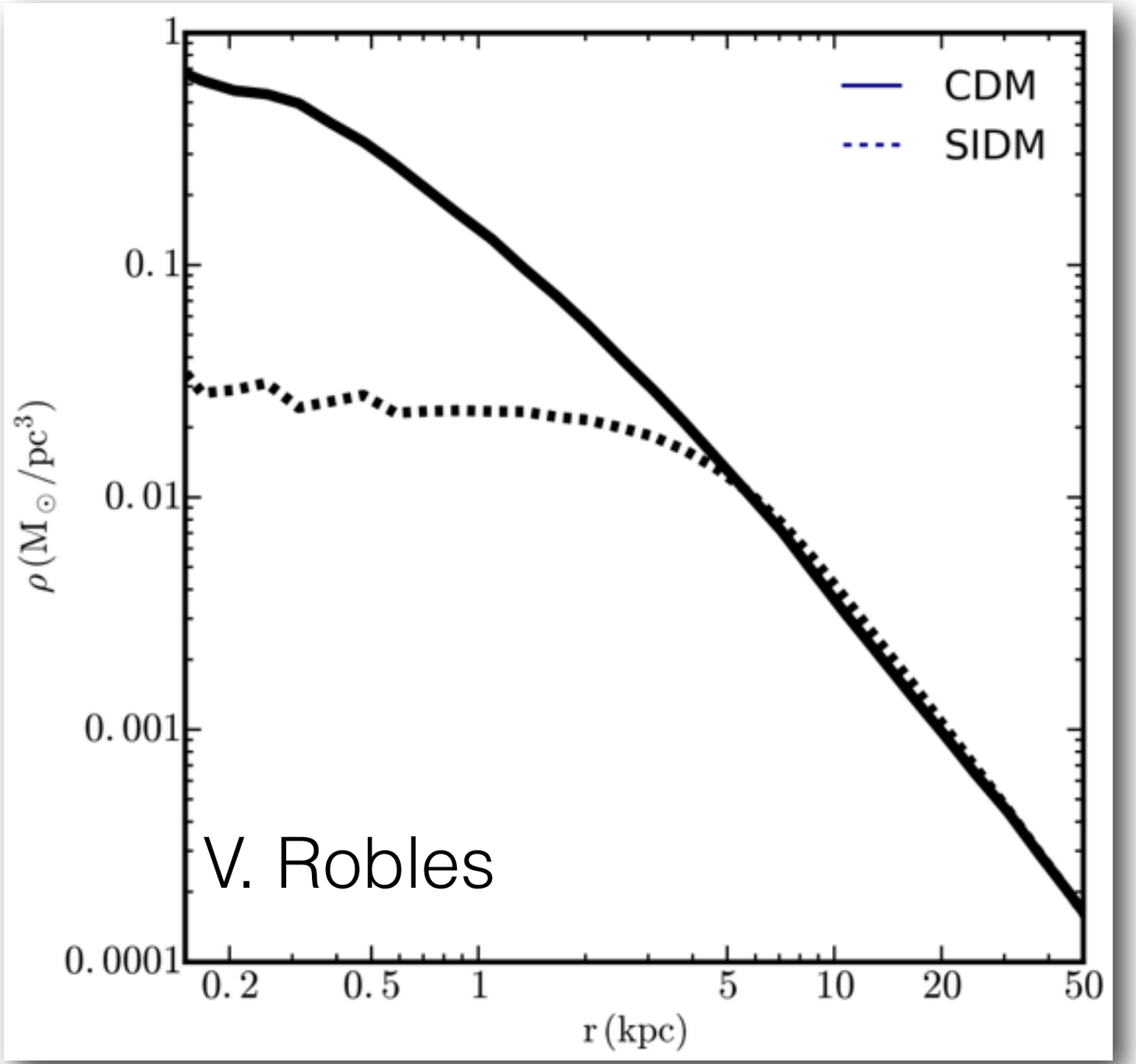




SIDM

similar substructure

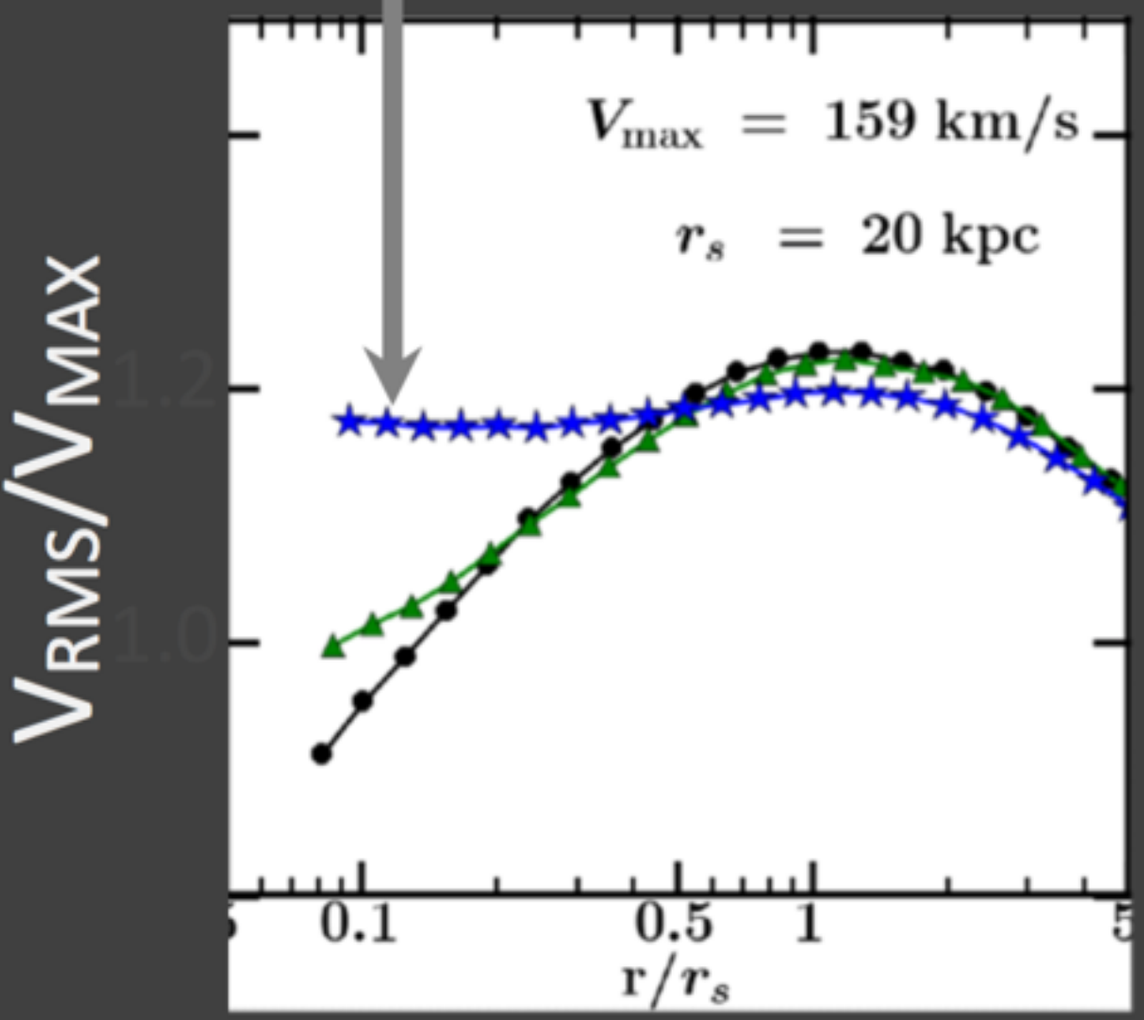
- cored density profiles

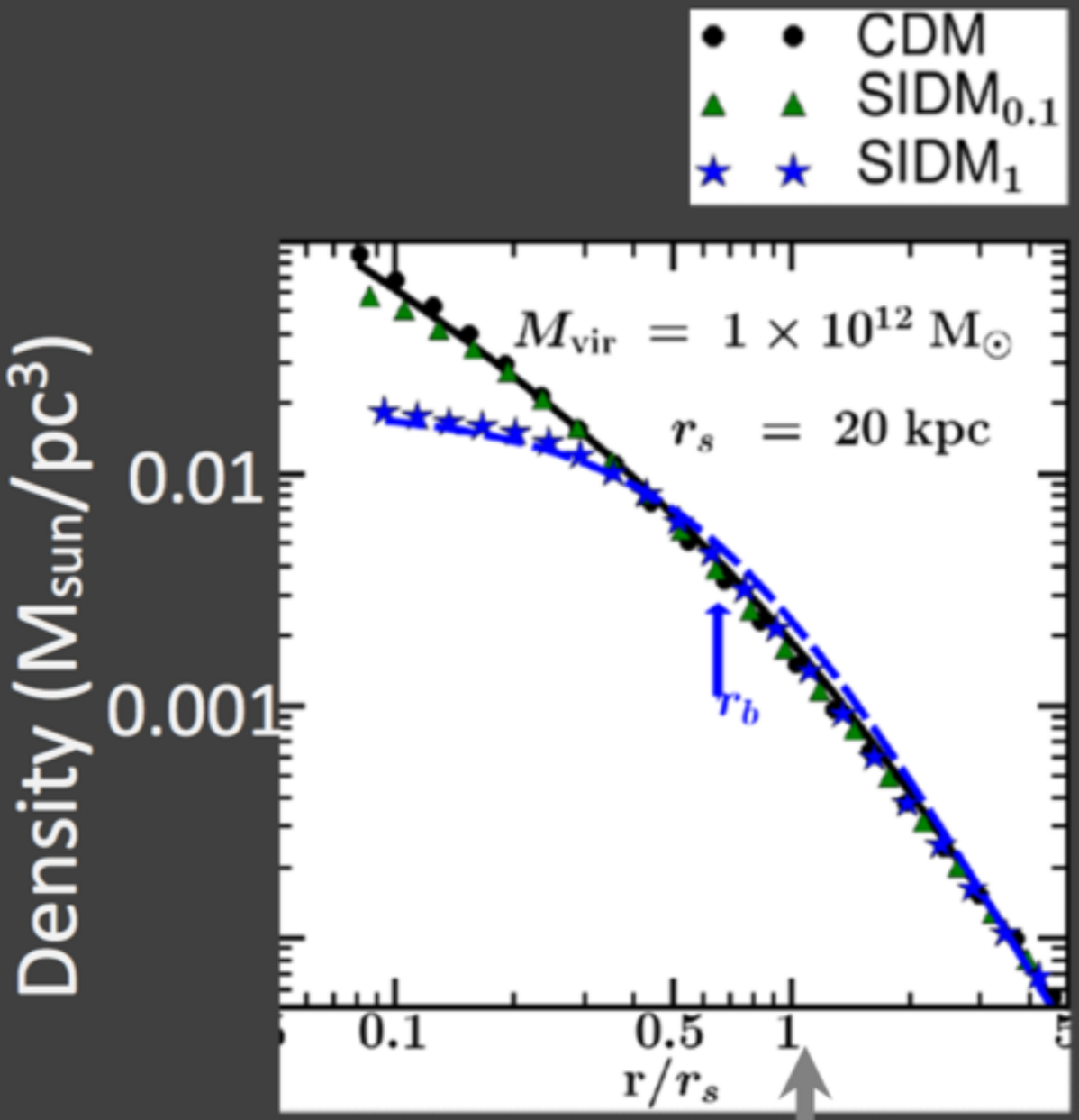


How does SIDM work?

Rocha+2012

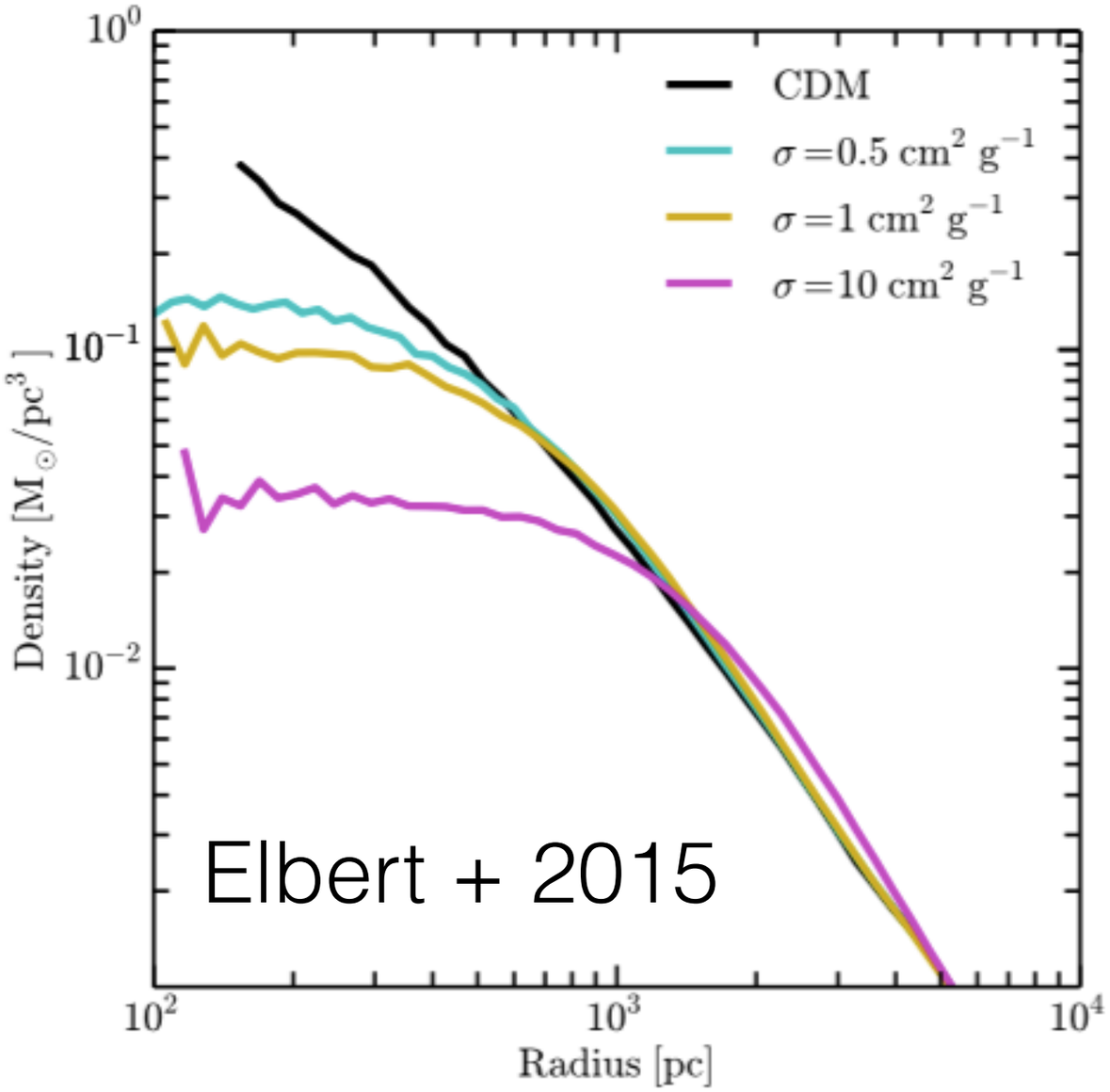
Isothermal

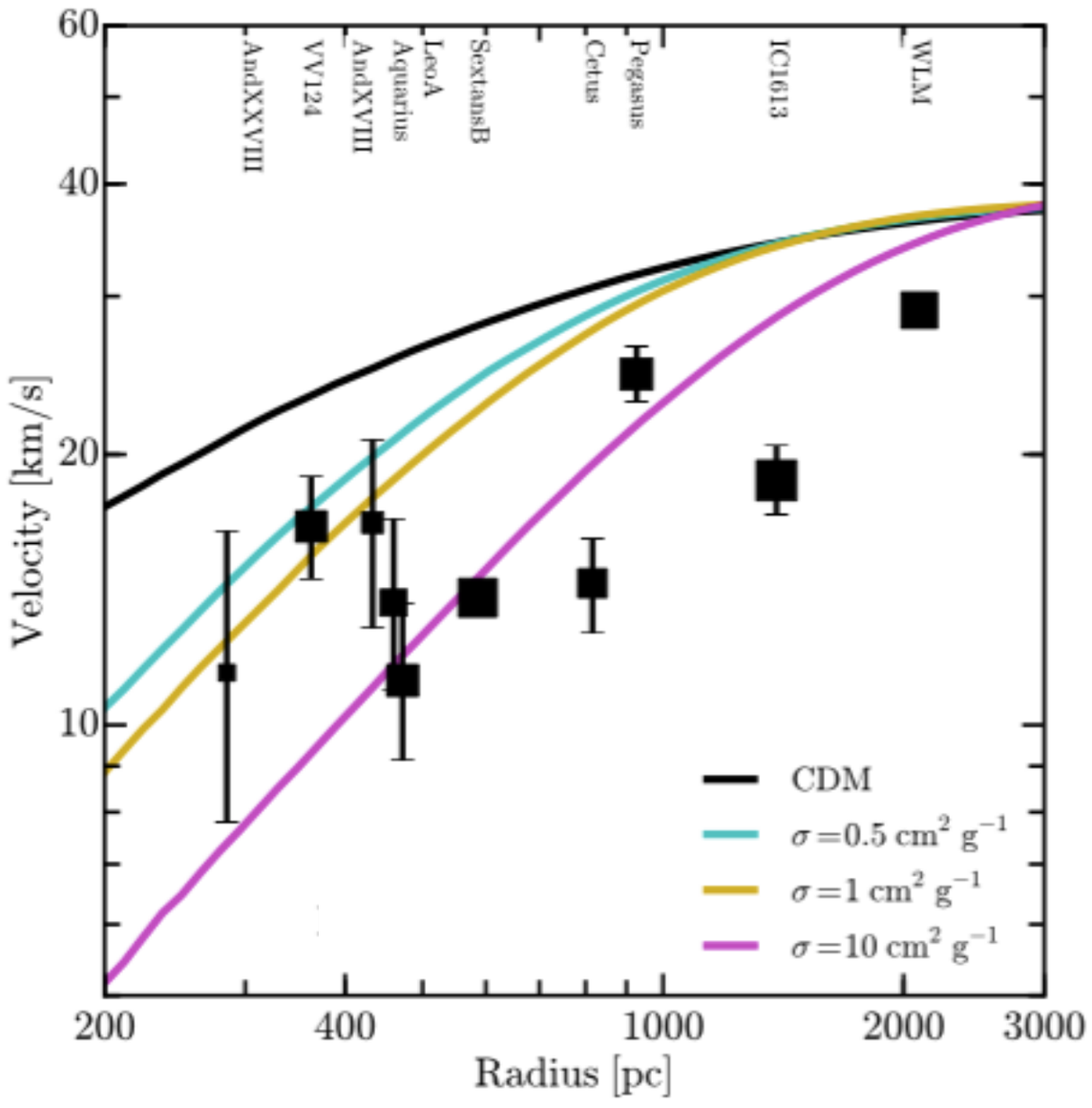




One interaction on average over halo age

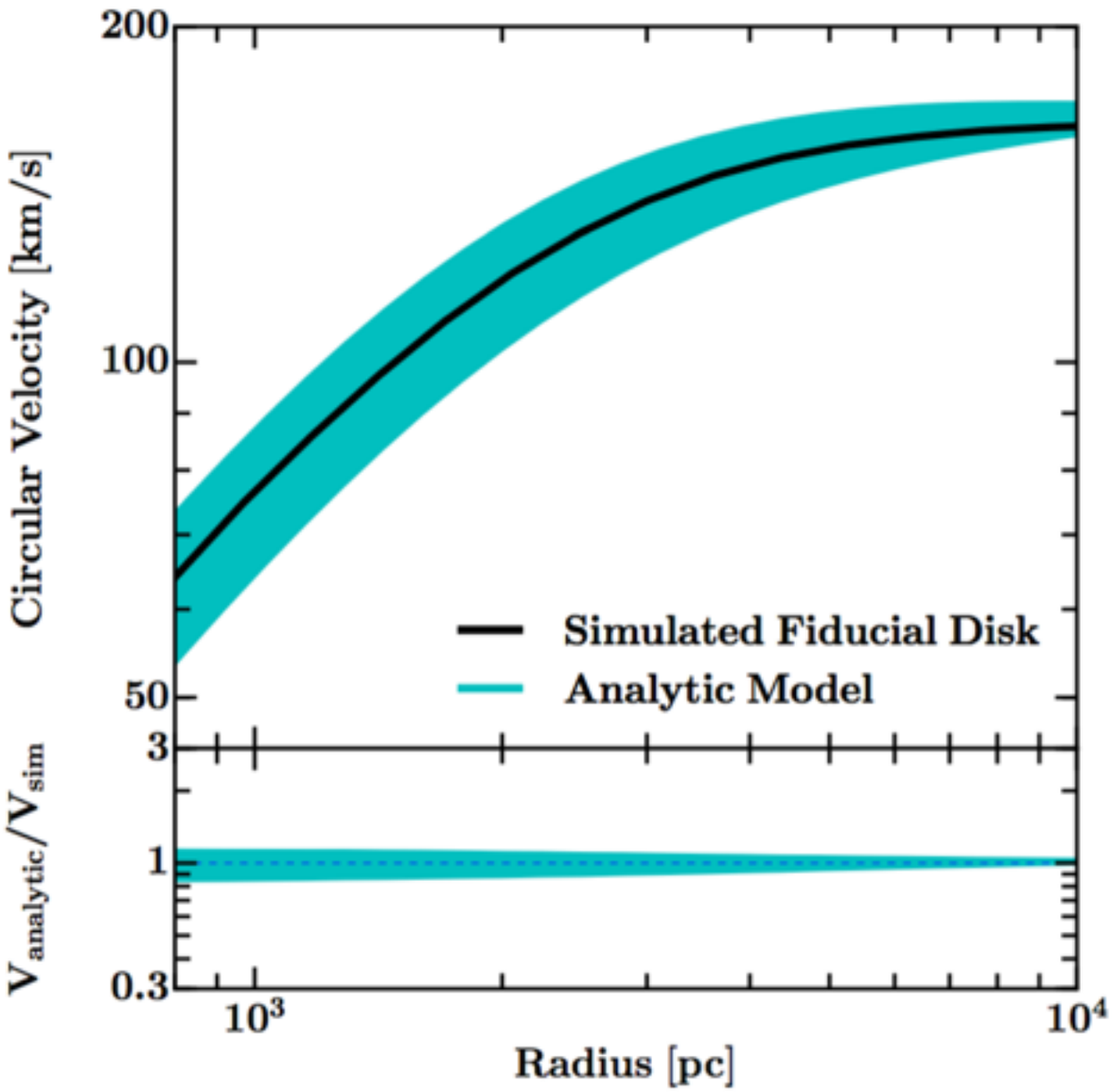
SIDM: Solves TBTF & Cusp/Core

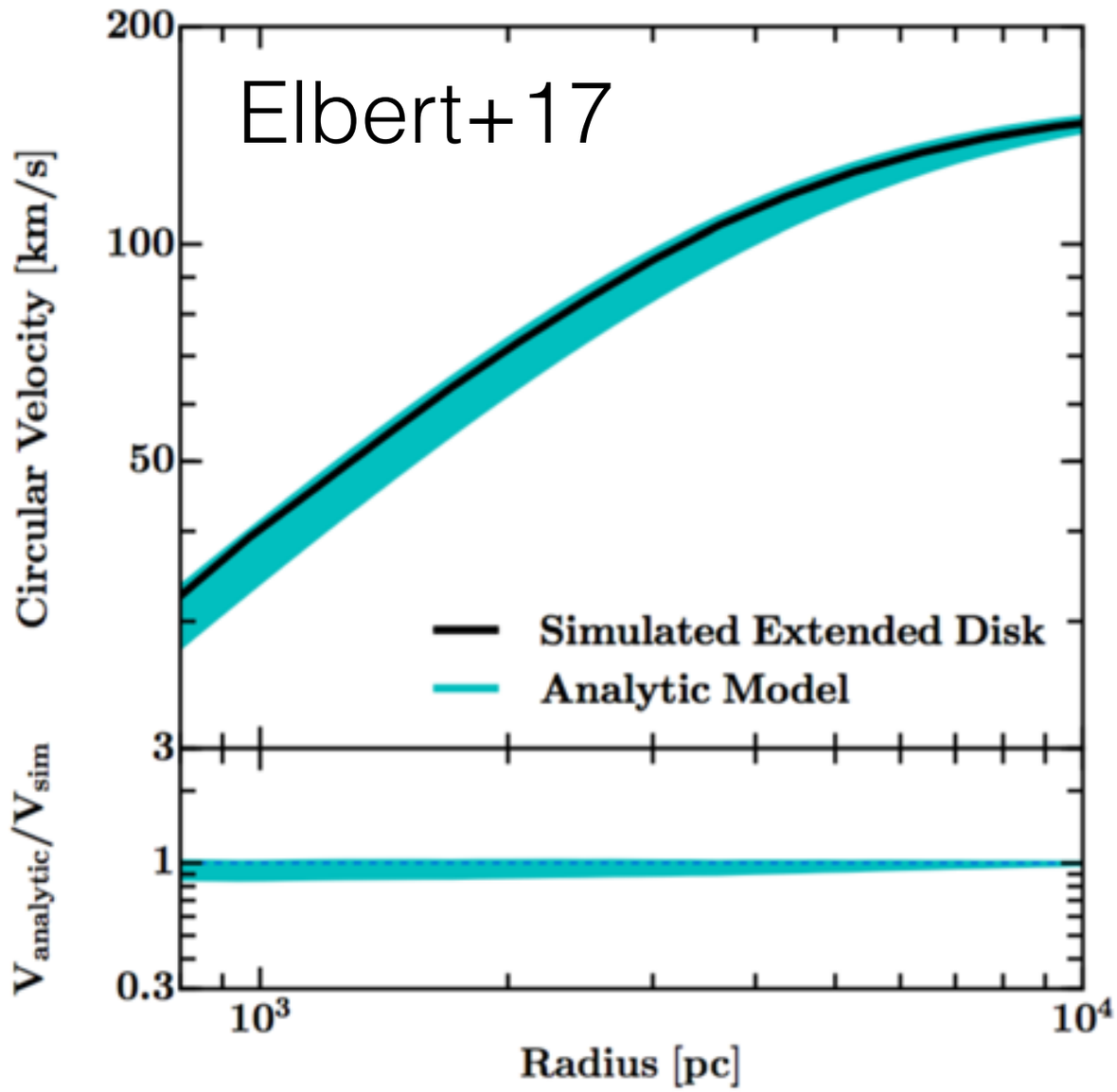




Spergel & Steinhardt (00); Vogelsberger+12; Rocha+13;Zavala+13

SIDM profiles can be predicted analytically (Kaplinghat+16)





SIDM/Baryonic cross-talk

$$\nabla^2 \ln \rho_{\rm DM}(r) = -\frac{4\pi}{\sigma_{v0}^2} {\rm G} \left[\rho_{\rm DM}(r) + \rho_{\rm baryon}(r)\right]$$

Garrison-Kimmel+2017

What About Feedback?

Star formation
Radiation pressure

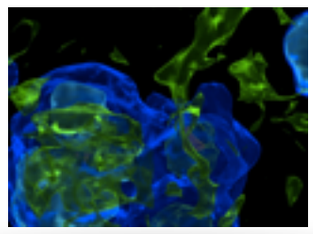
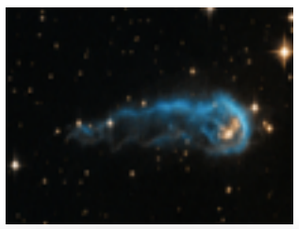
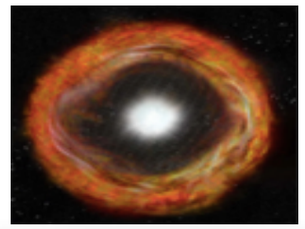


Photo-Ionization



Stellar winds

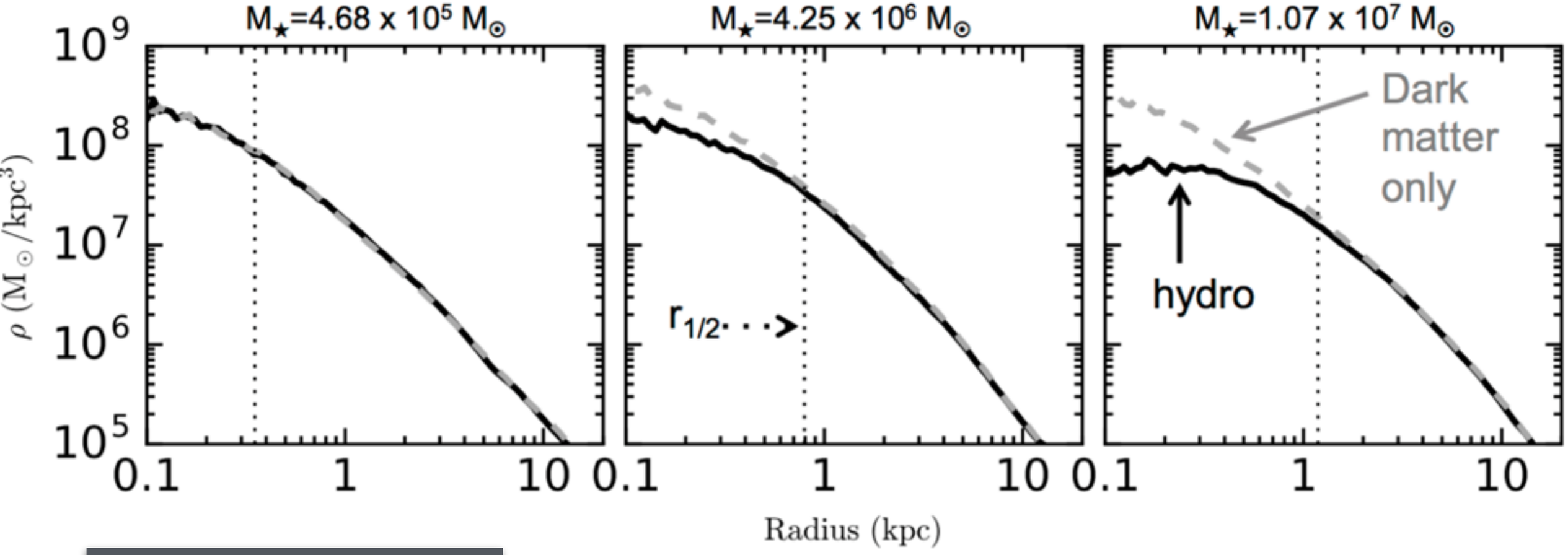


Supernovae

FIRE 2 physics

Hopkins+2017
Wetzel+2017
Fitts+2017

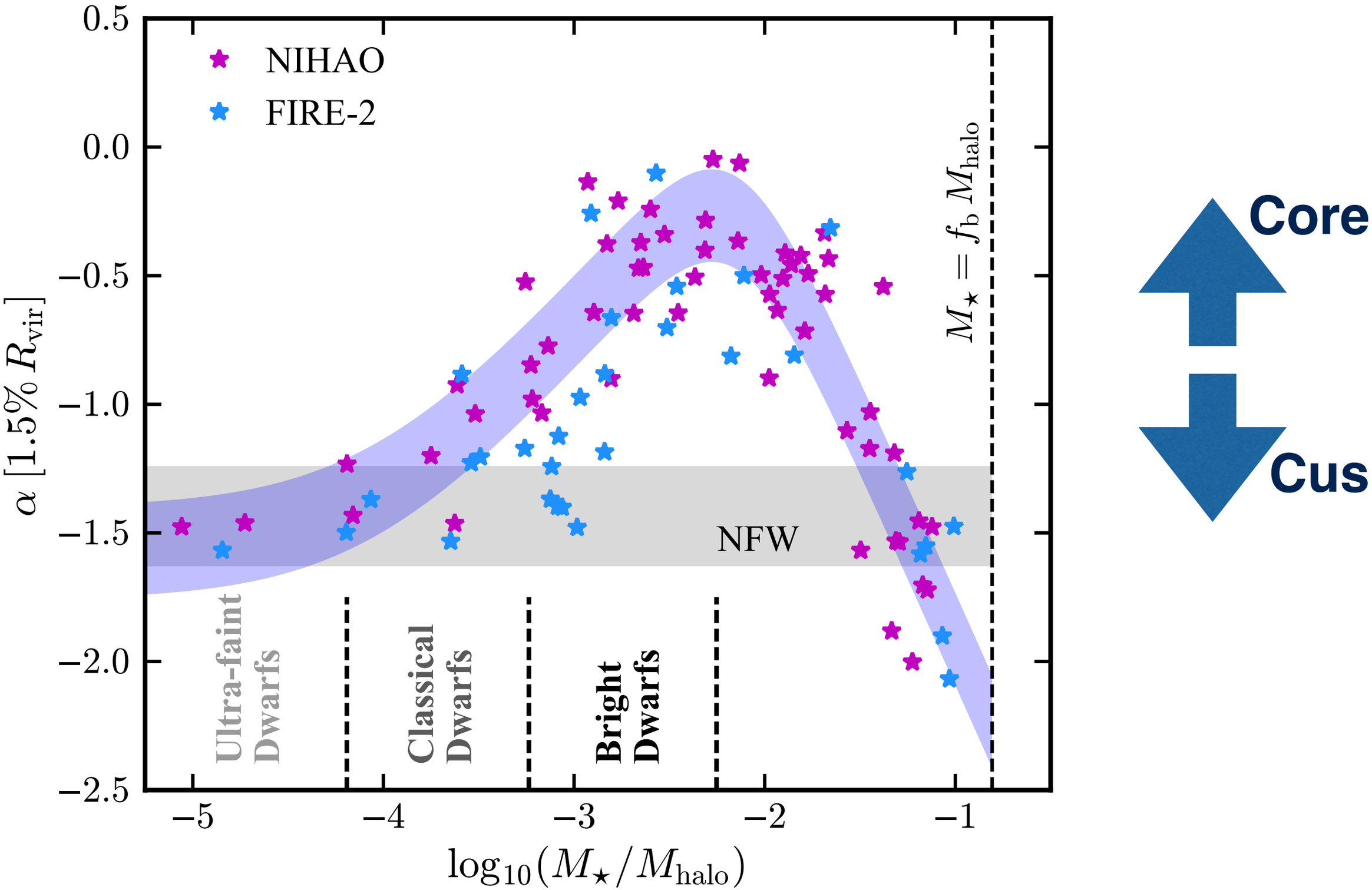
Need >3.e6M_{sun} stars to affect DM density profile in CDM



Fitts et al. 2017

Also: Governato+12; Penarrubia+12; Garrison-Kimmel+13, **Di Cintio+14**, Tollet+15

Agreement among frienemies



Core

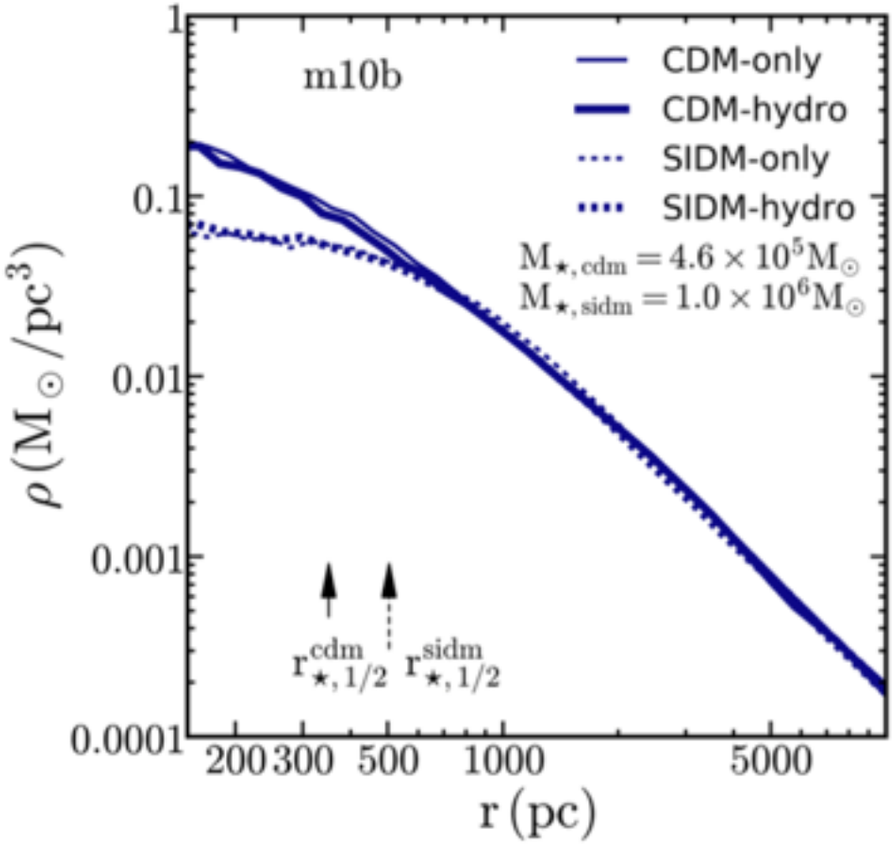
Cusp

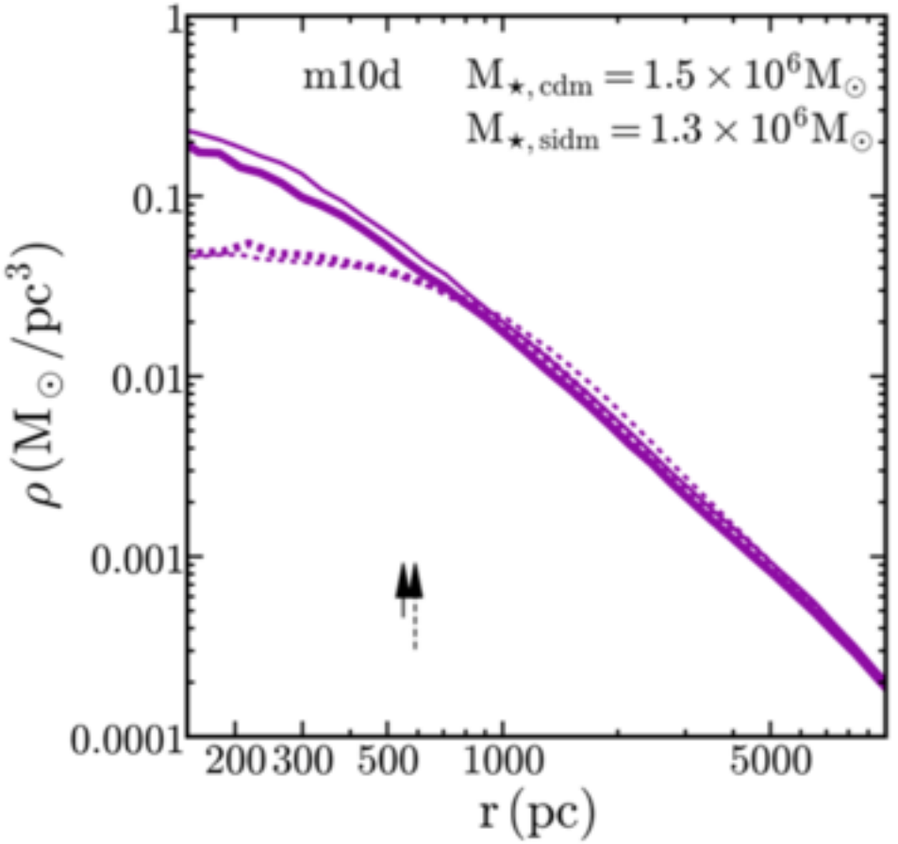
JSB & Boylan-Kolchin, ARAA, 2017

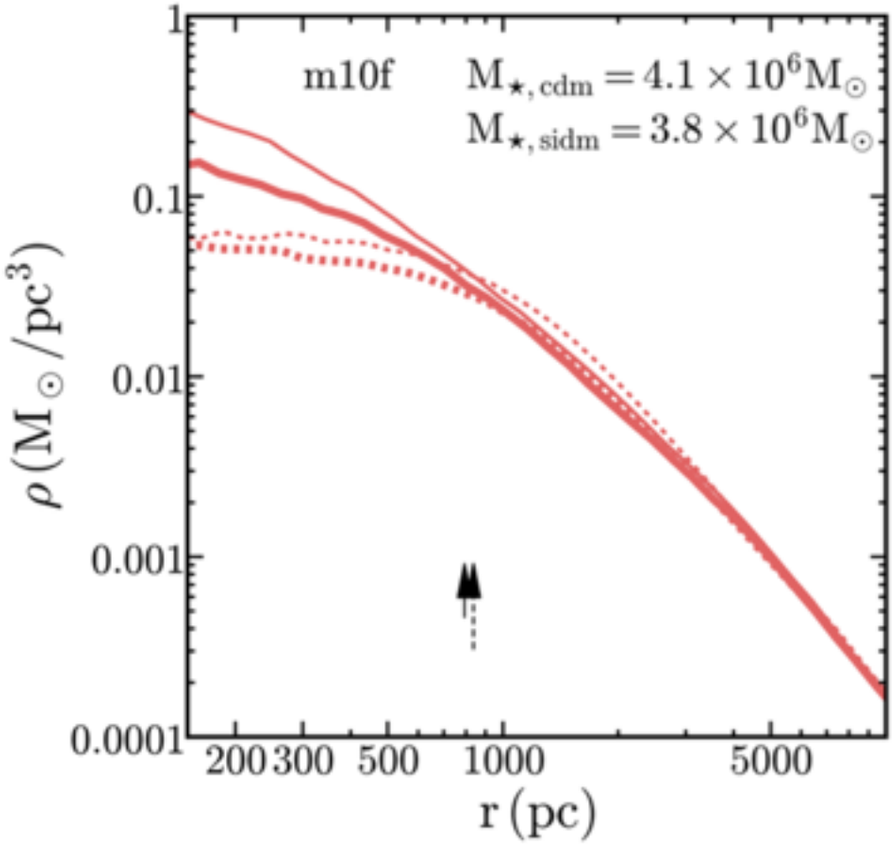
SIDM vs. CDM: Full FIRE physics

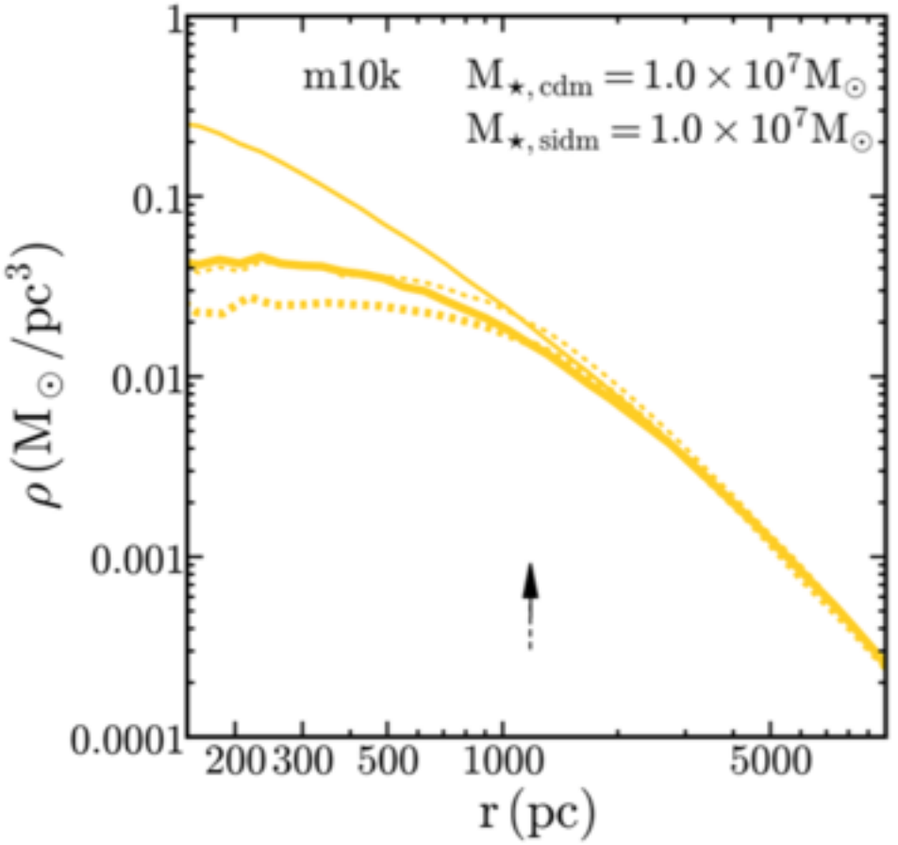
Robles+17

SIDM: "feedback proof"

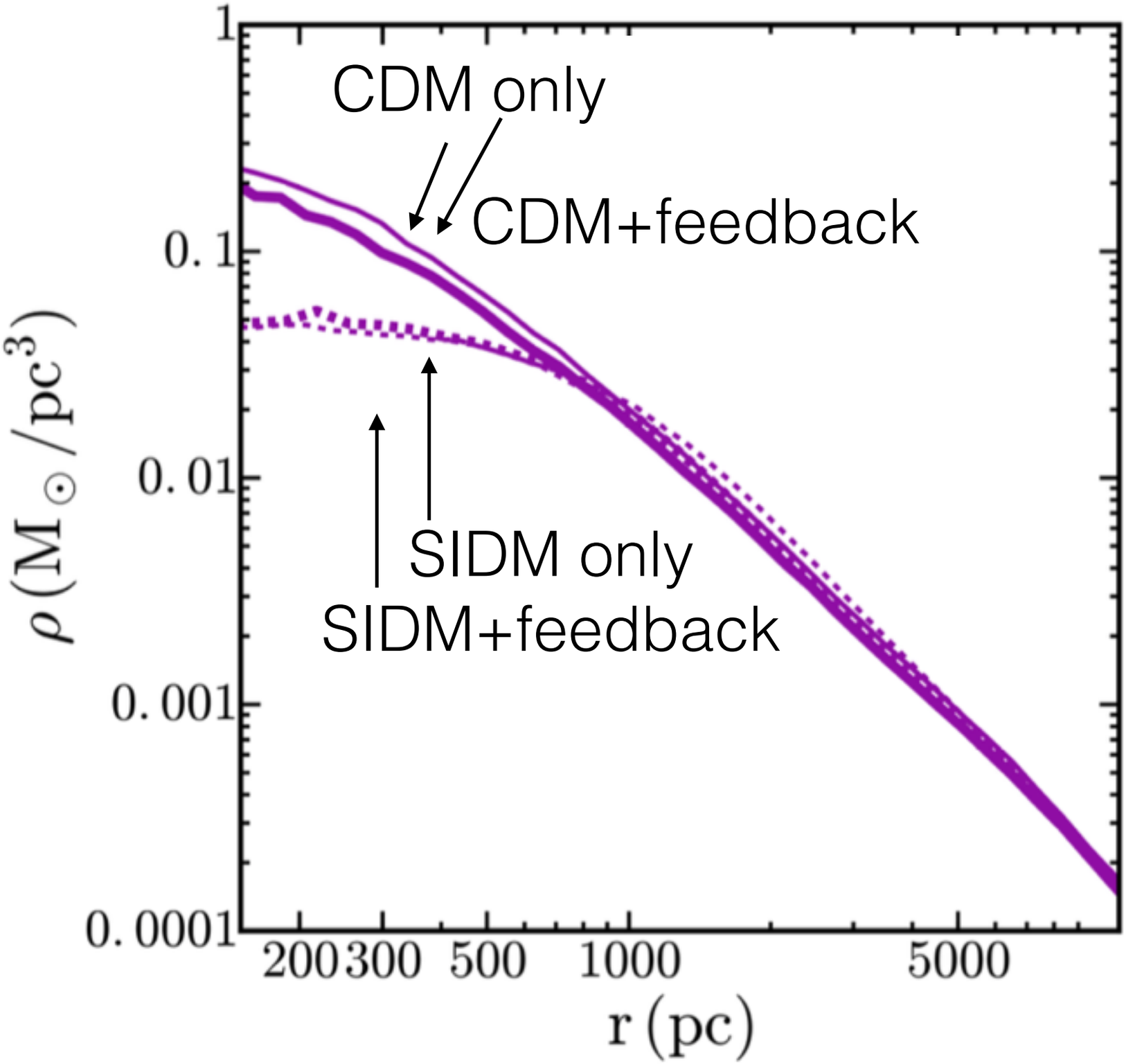








Falsifiable Prediction for SIDM

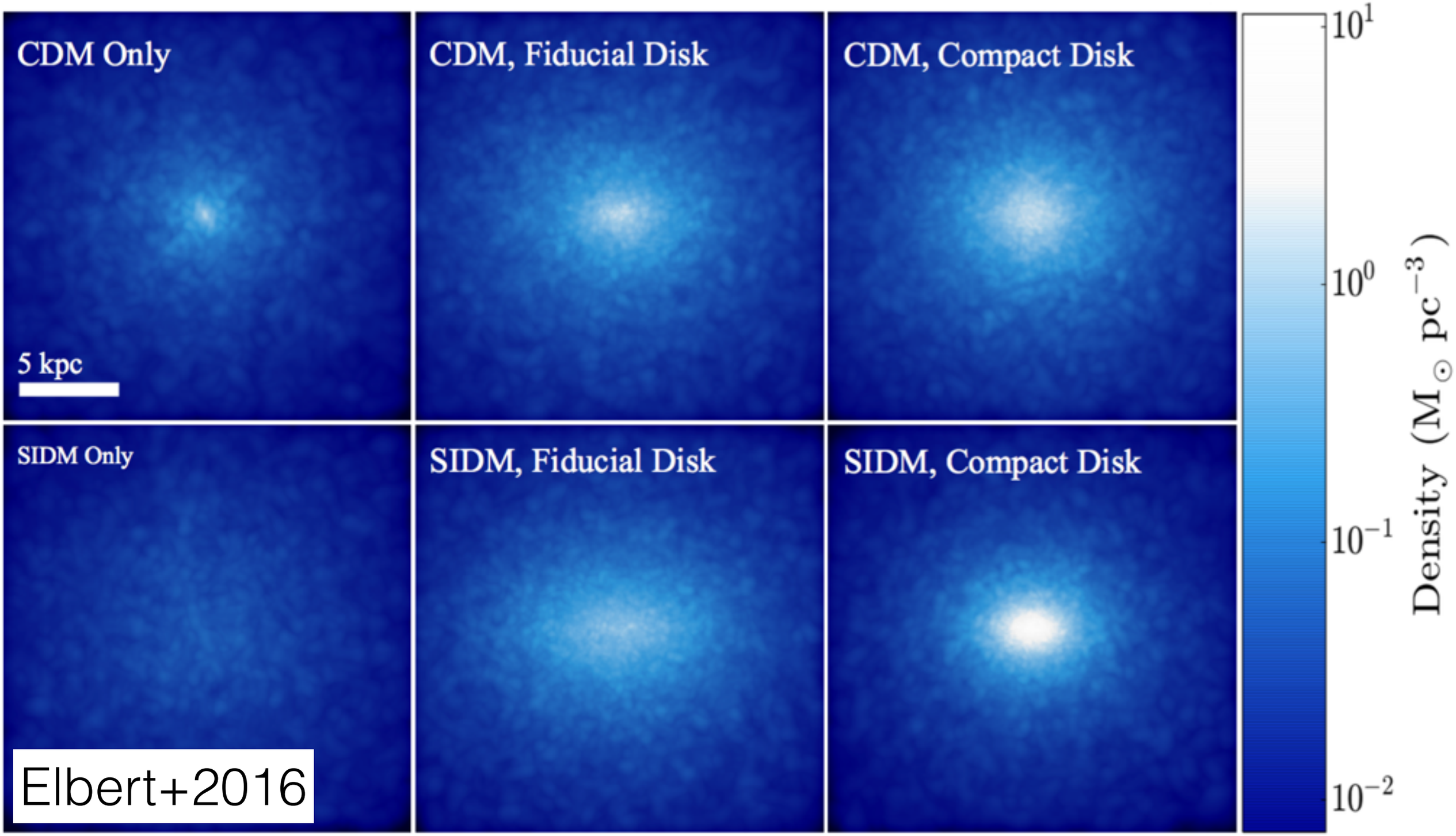


$M_* = 1.e6\ M_{sun}$

Smallest galaxies should have constant-density cores in SIDM.

Robles+17

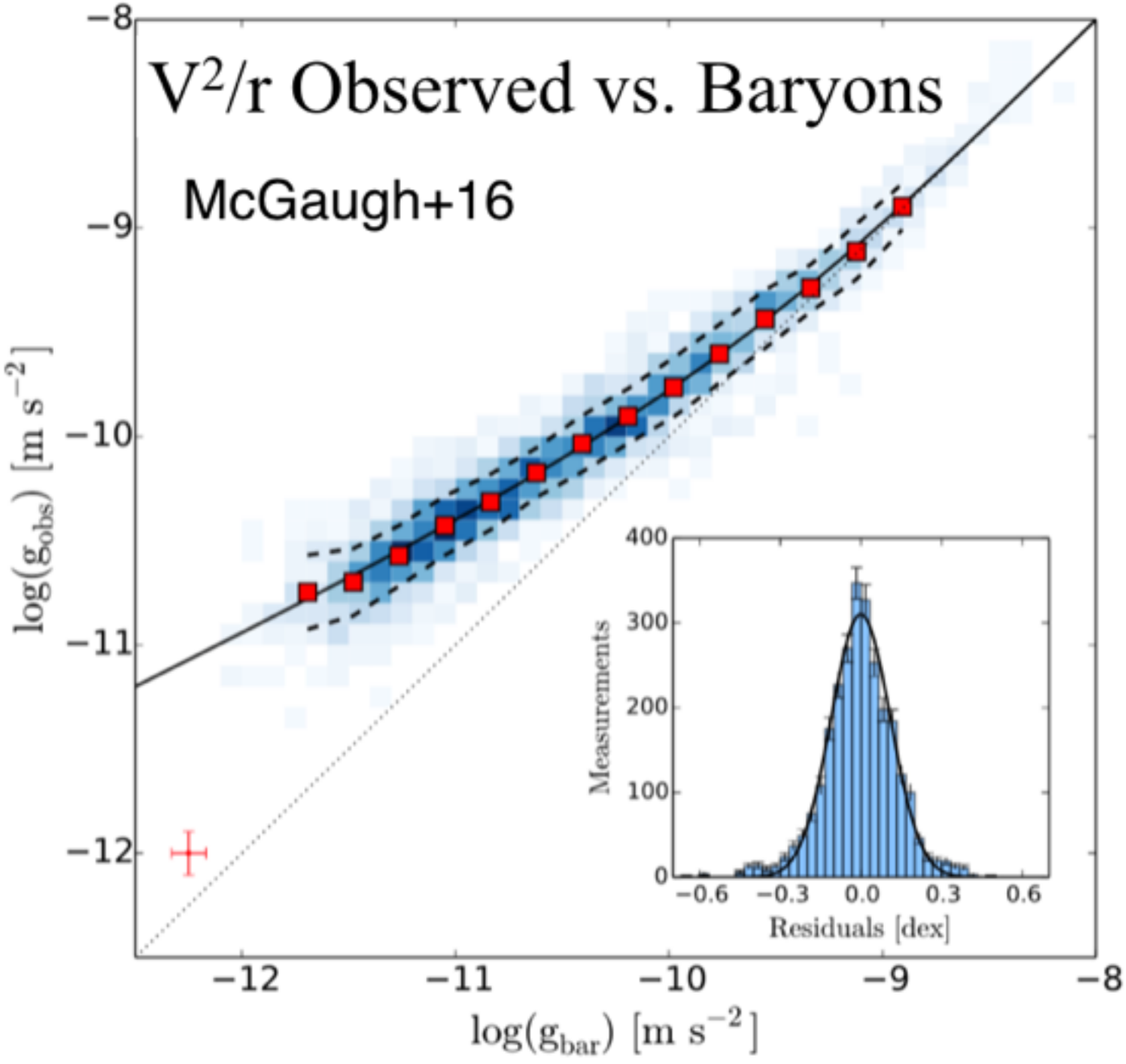
SIDM: baryon cross-talk



This is not feedback: it's about the potential

Radial Acceleration Relation

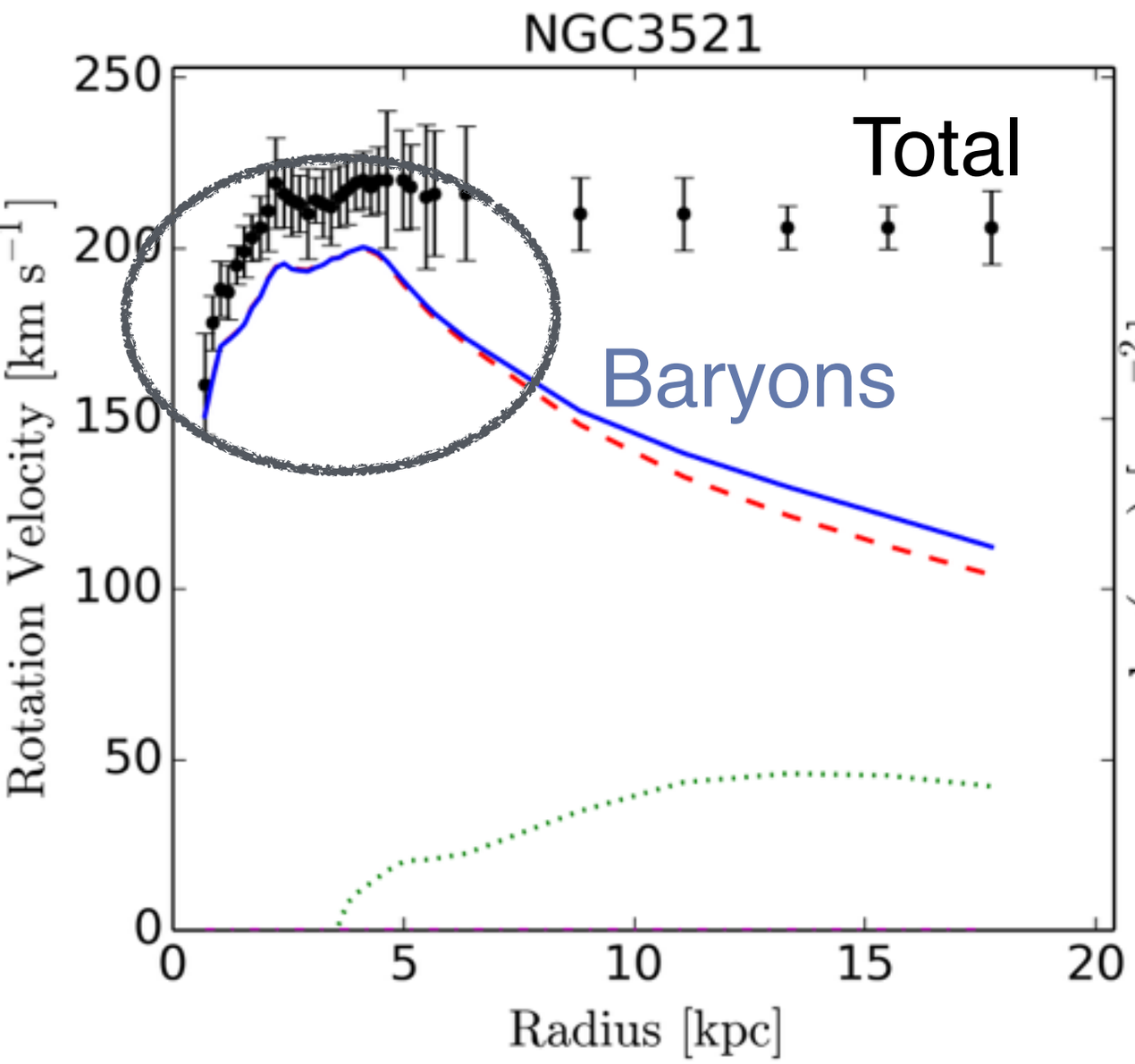
Observed acceleration

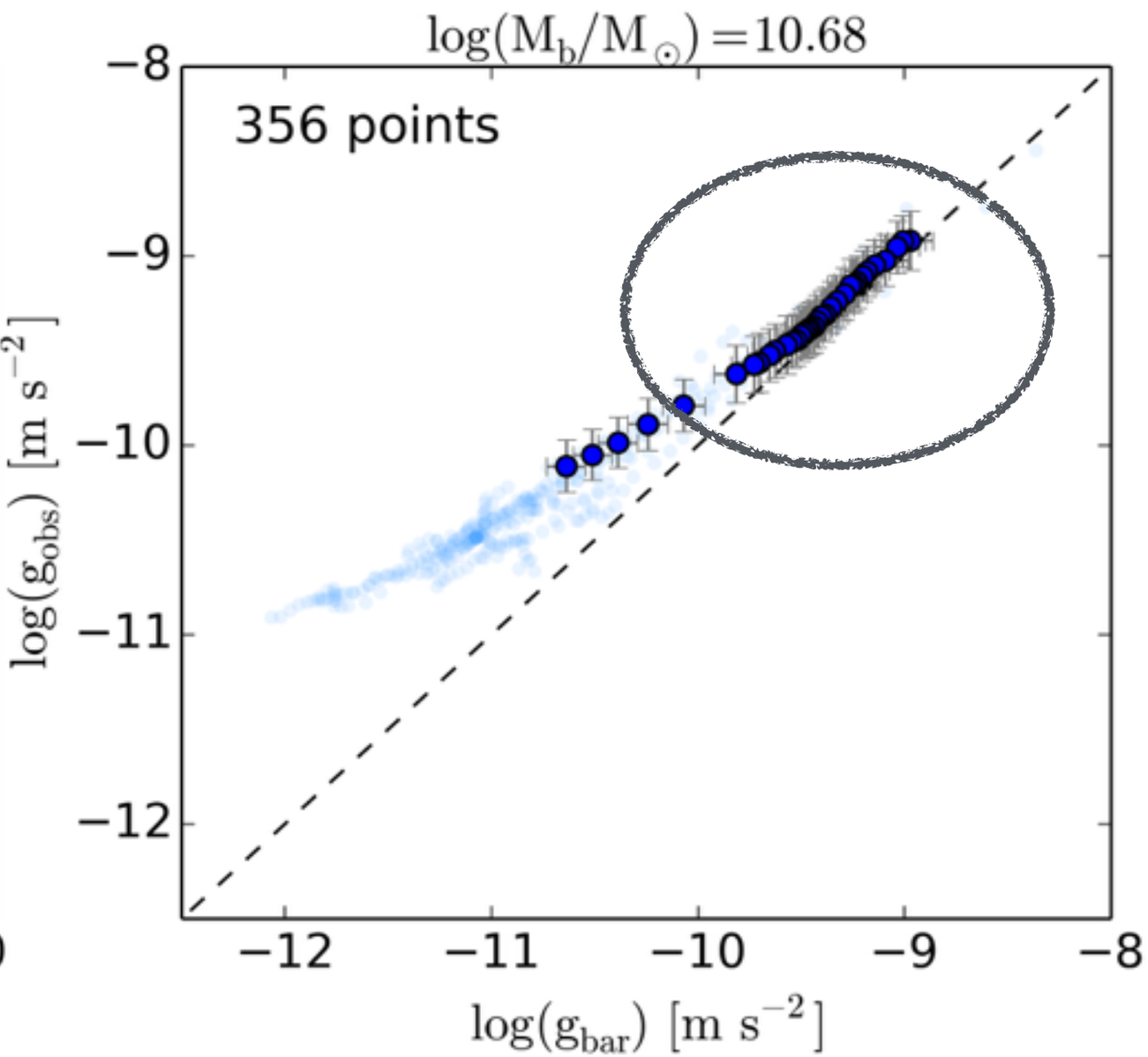


Baryonic acceleration

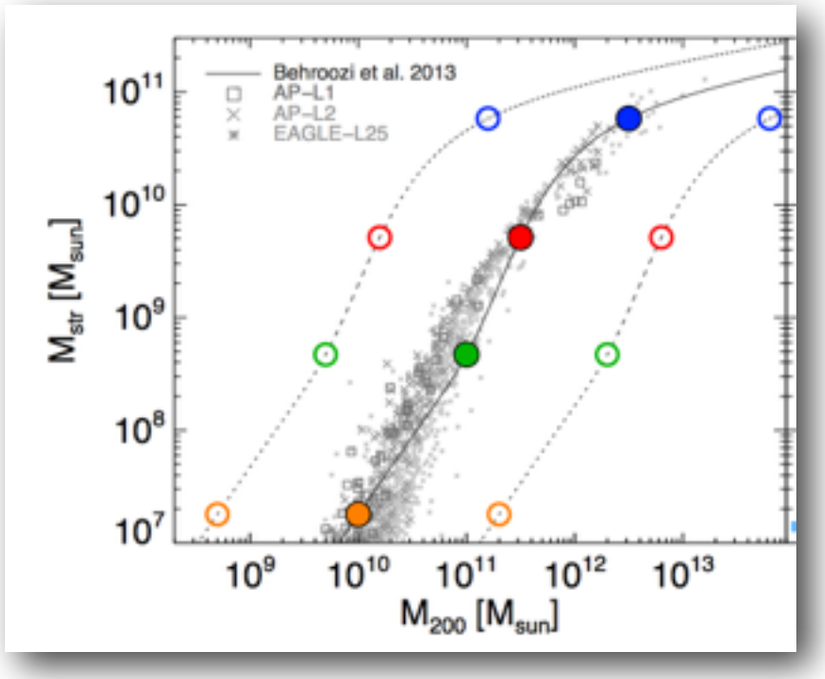
See Di Cintio & Lelli 2016; Keller & Wadsley 2016; Ludlow+16; Desmond 2017; Navarro+17 for CDM takes on RAR

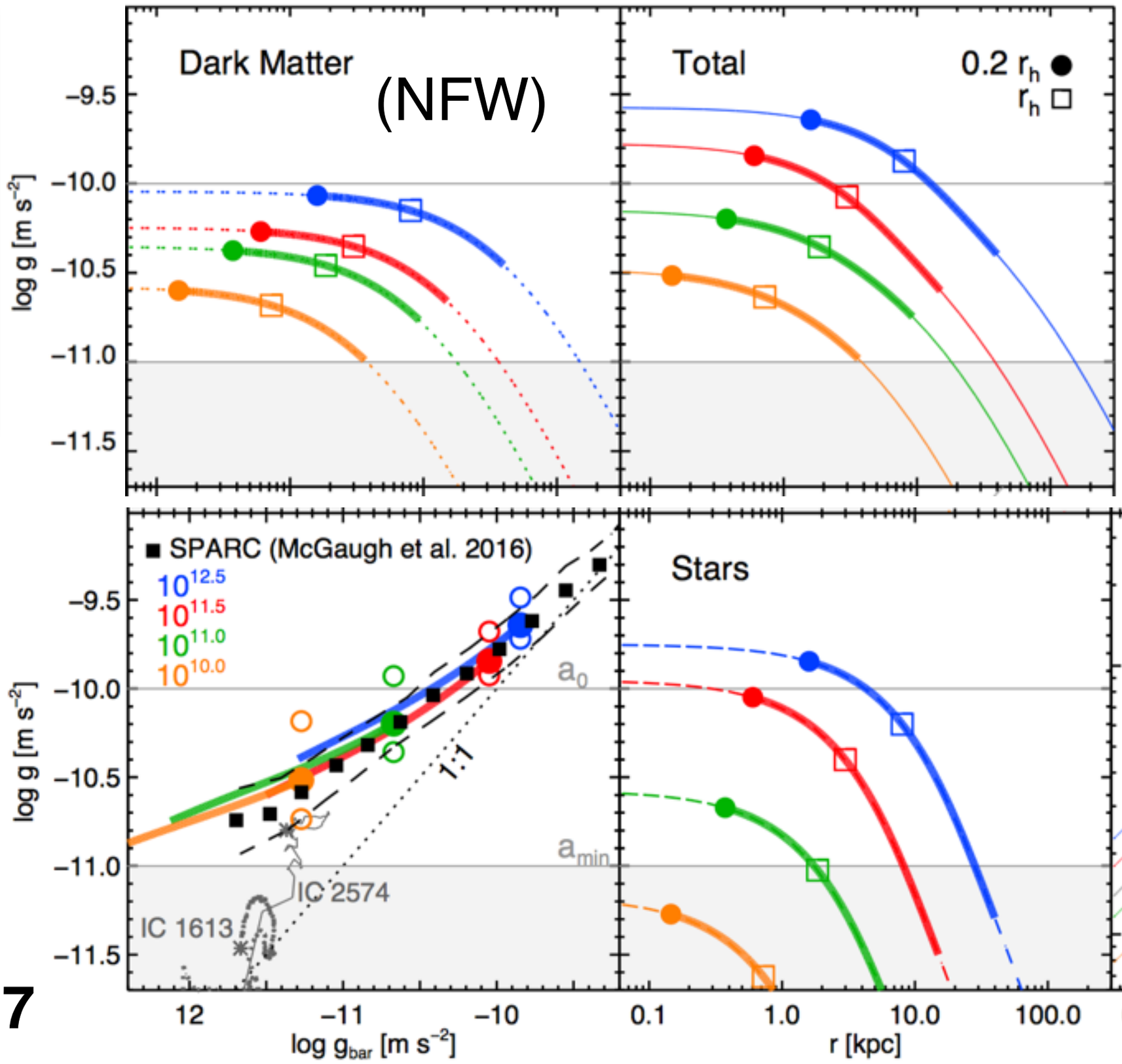
Massive galaxies - baryons dominate at small r





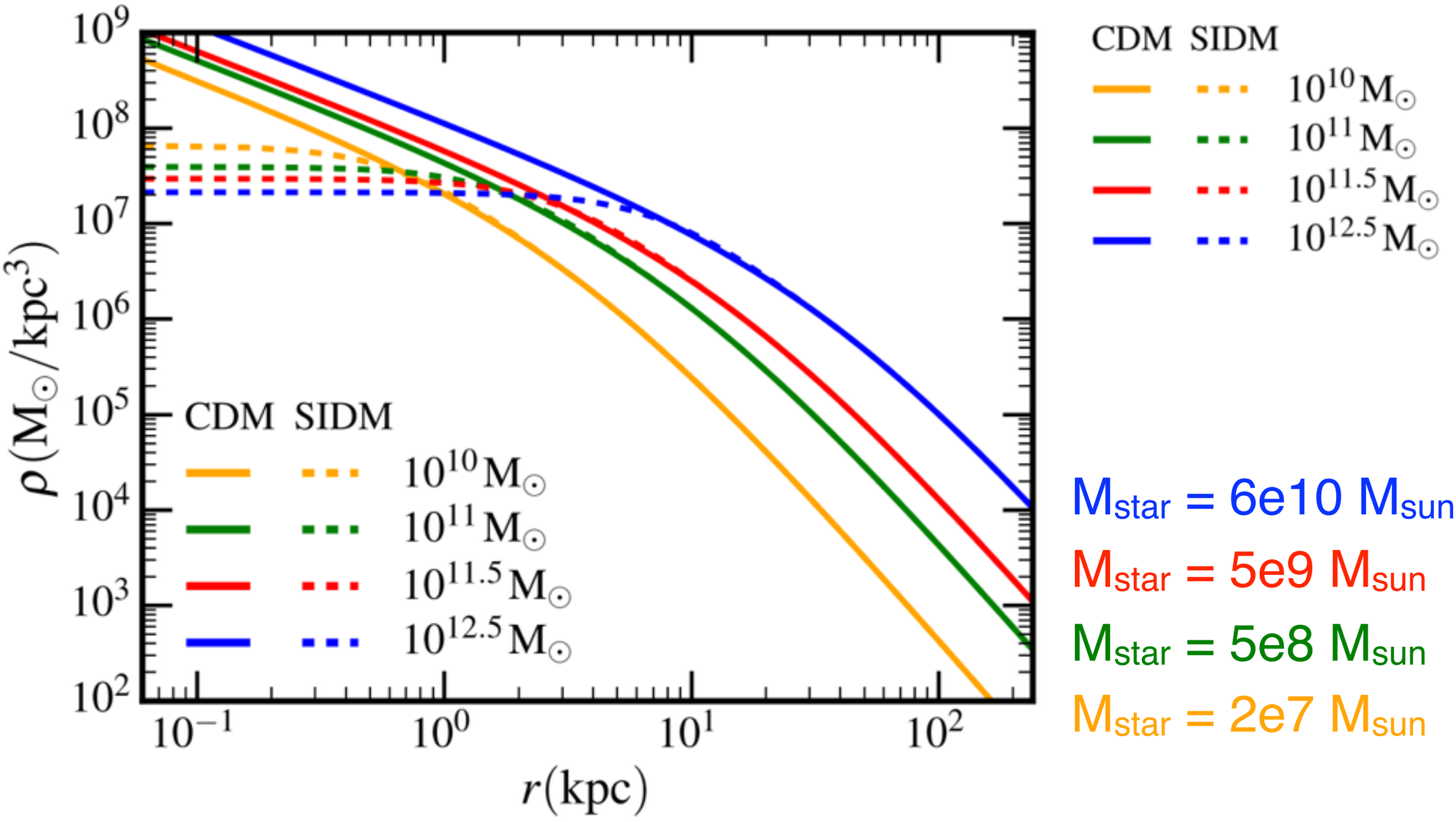
“The origin of the mass discrepancy-acceleration relation in ΛCDM”





Navarro et al. 2017

Predicted density profiles for dark matter



M_{star} = 6e10 M_{sun}

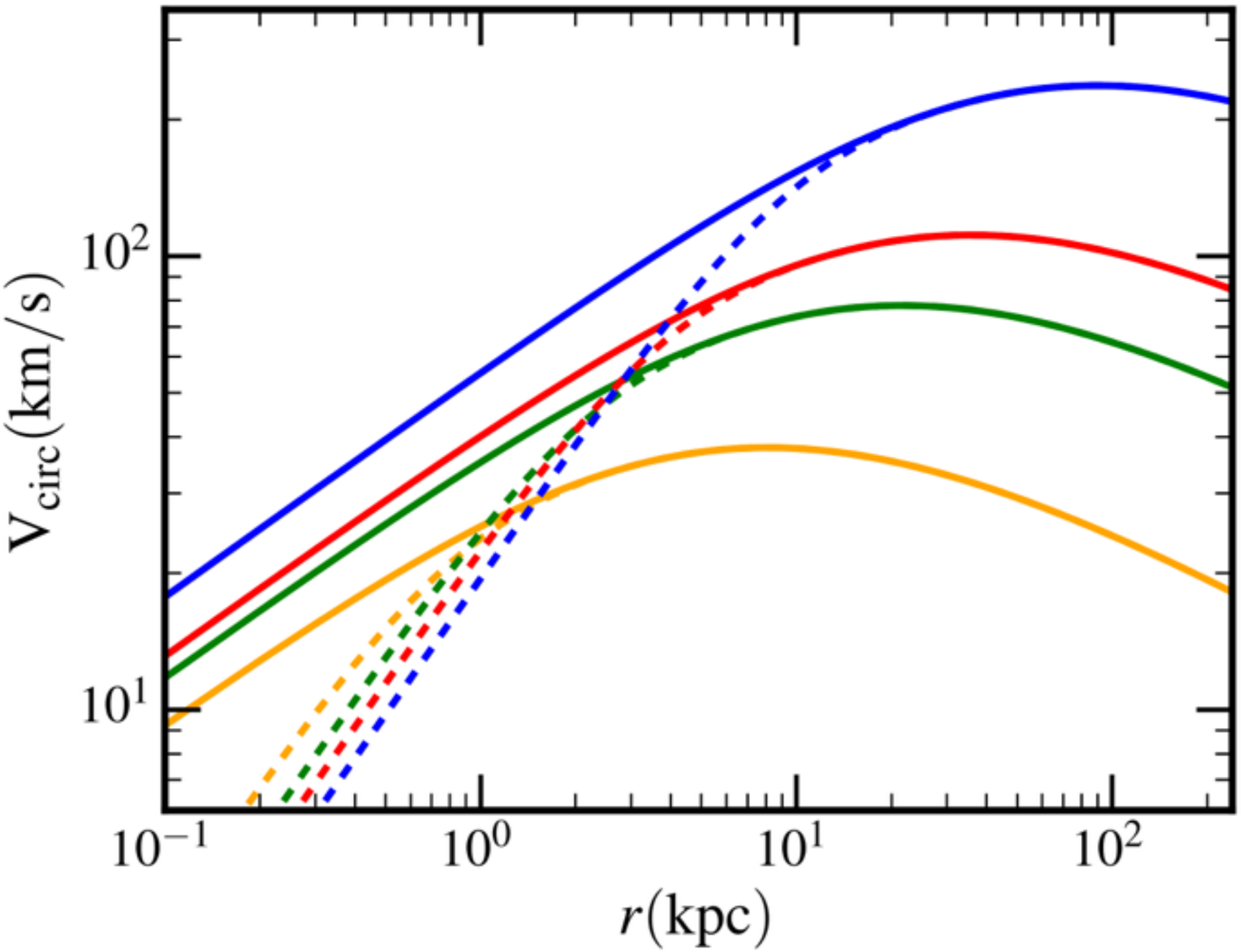
M_{star} = 5e9 M_{sun}

M_{star} = 5e8 M_{sun}

M_{star} = 2e7 M_{sun}

Robles, Pawlowski, JSB 2017

Predicted $V_c(r)$ for dark matter



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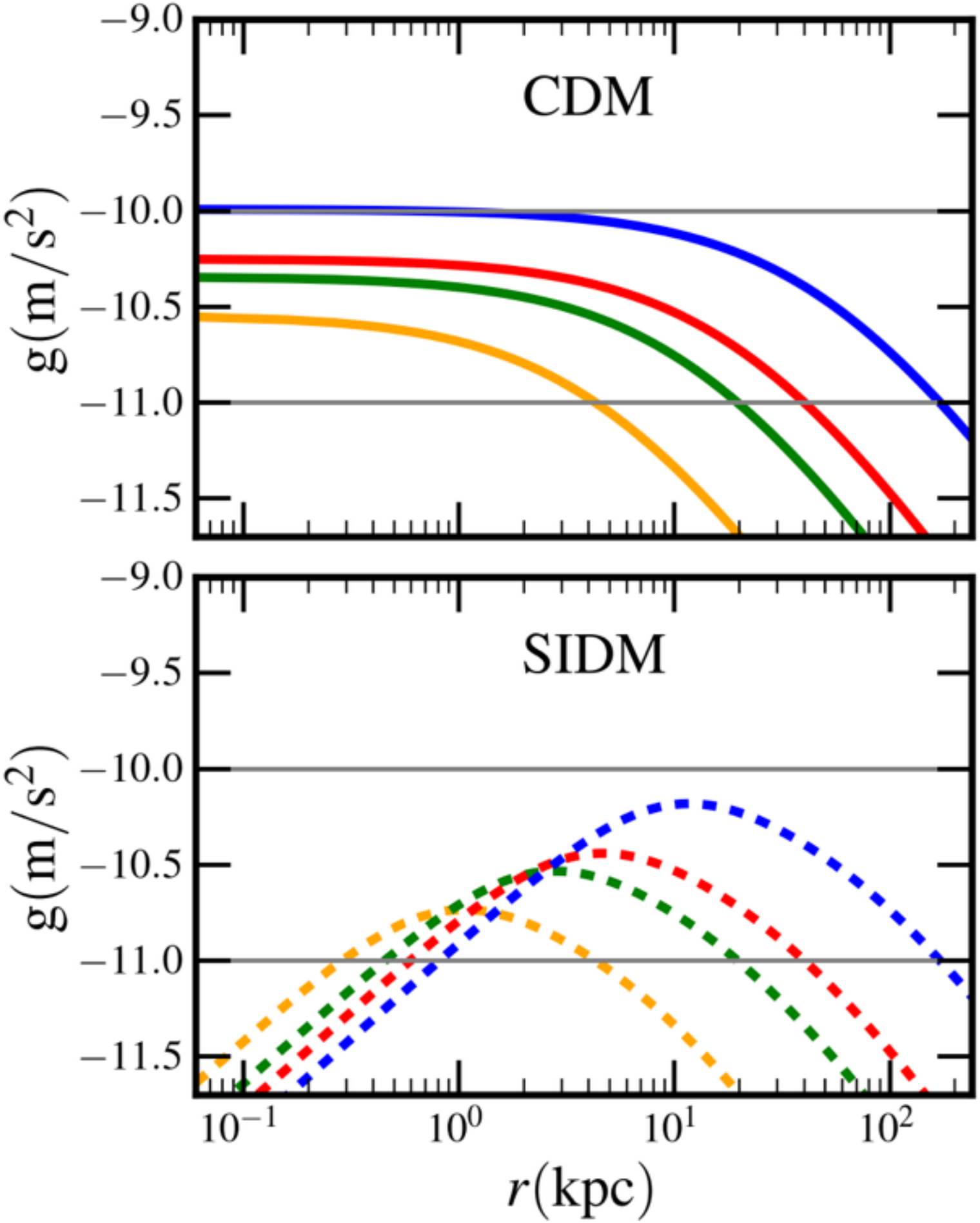
Robles, Pawlowski, JSB 2017



Predicted g(r) from dark matter

M_{star} = 6e10 M_{sun}

M_{star} = 5e9 M_{sun}

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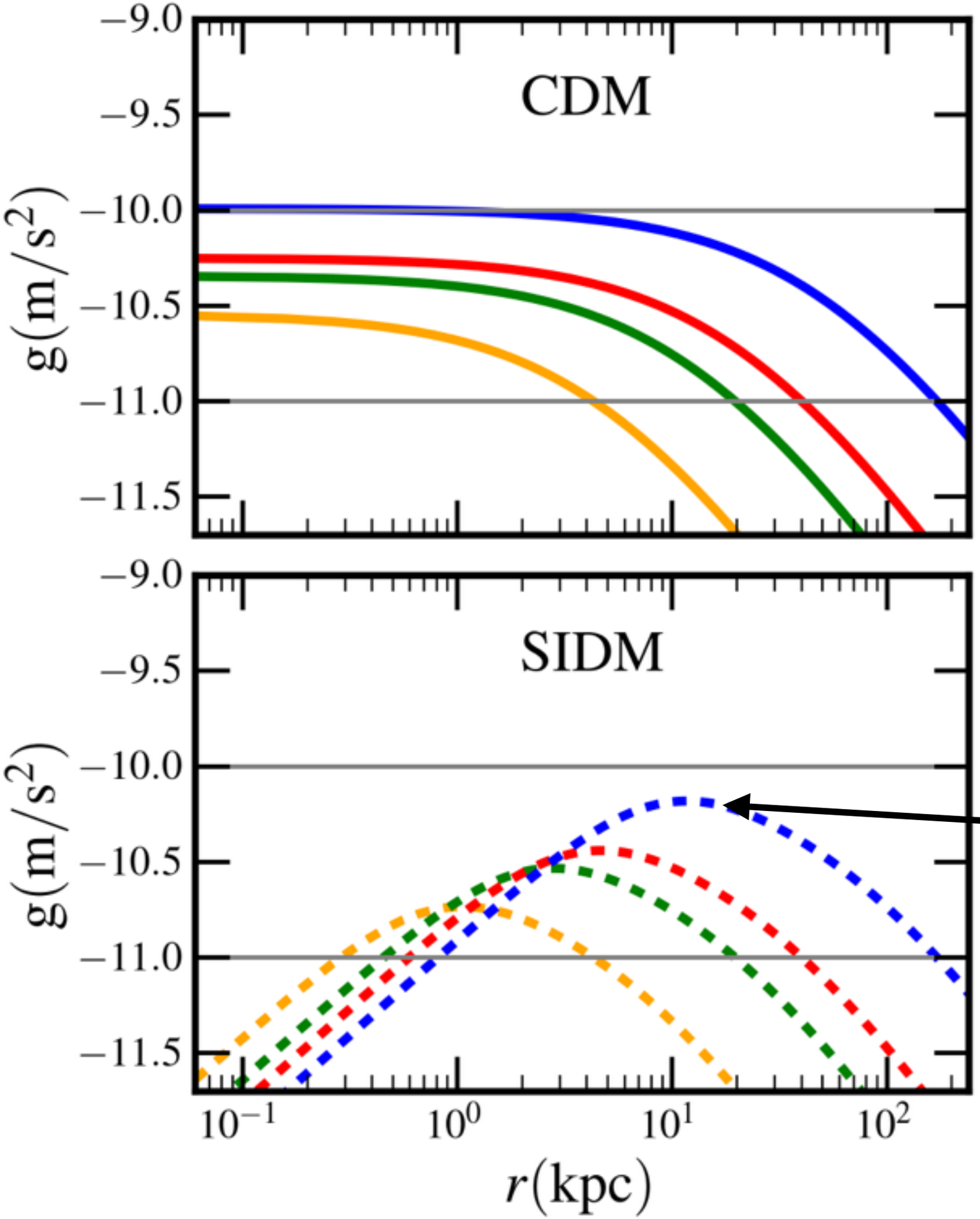
M_{star} = 2e7 M_{sun}

Robles, Pawlowski, JSB 2017



Predicted g(r) from dark matter

M_{star} = 6e10 M_{sun}

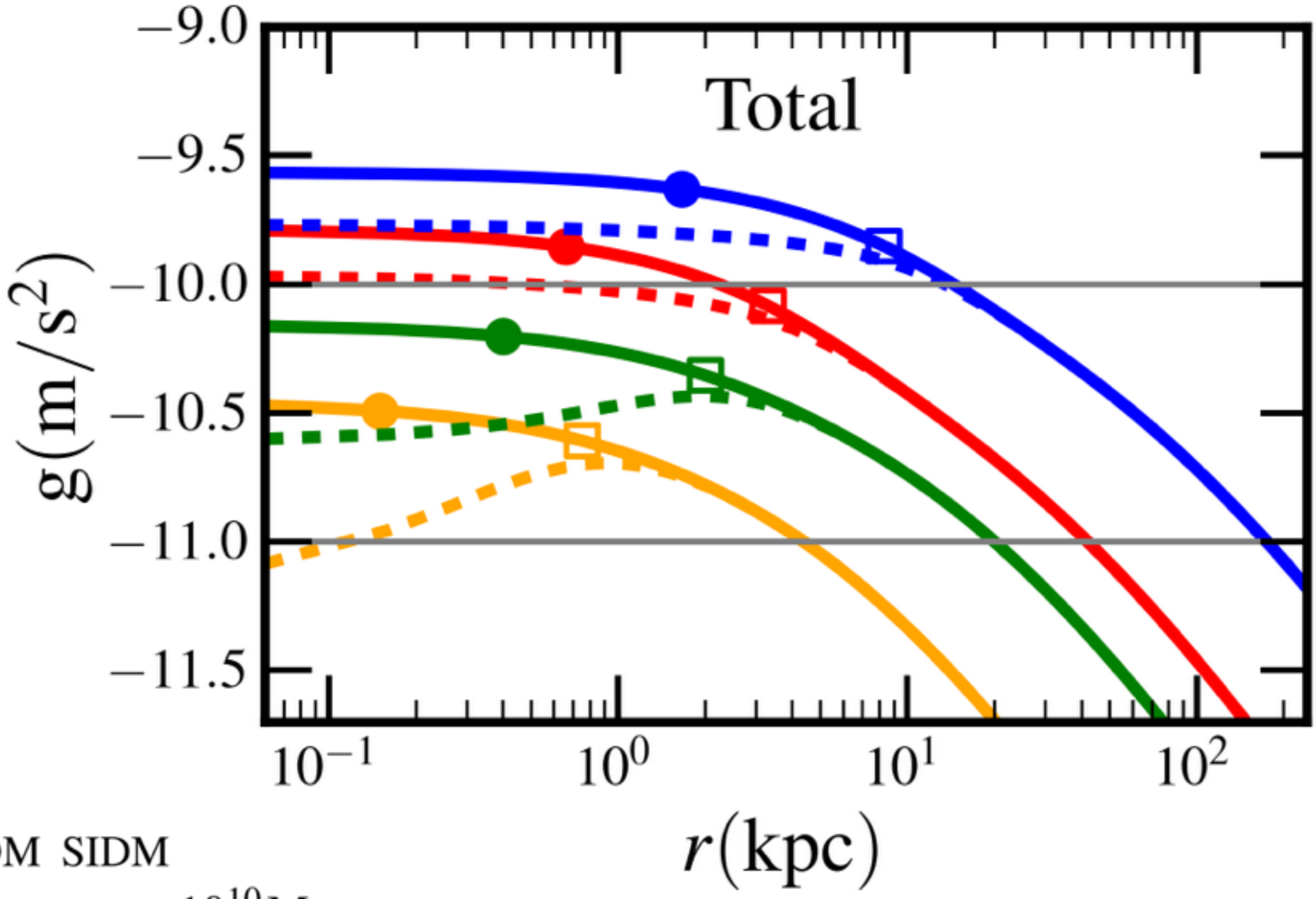
M_{star} = 5e9 M_{sun}

M_{star} = 5e8 M_{sun}

M_{star} = 2e7 M_{sun}

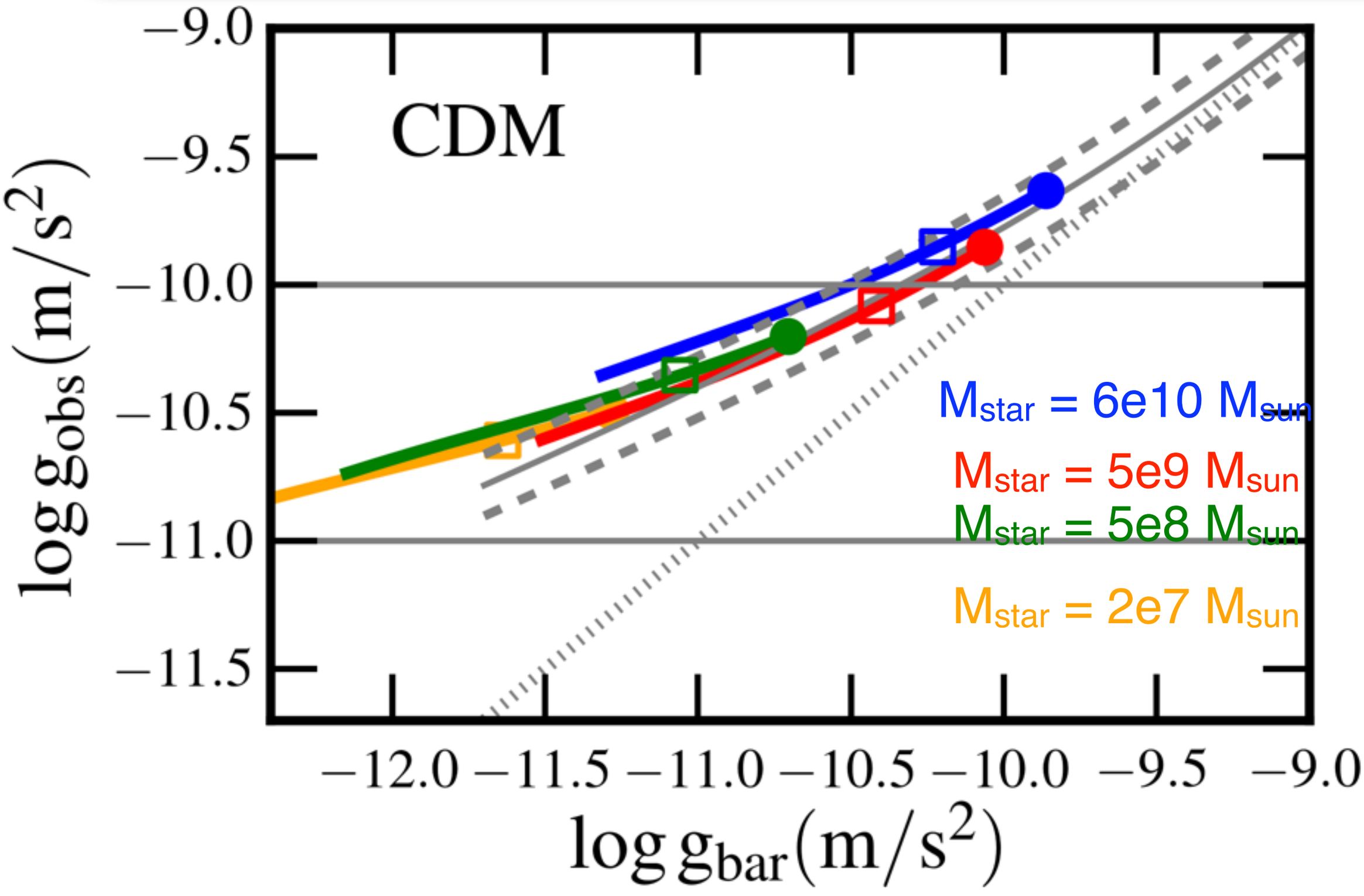
Peaks near -10

Robles, Pawlowski, JSB 2017



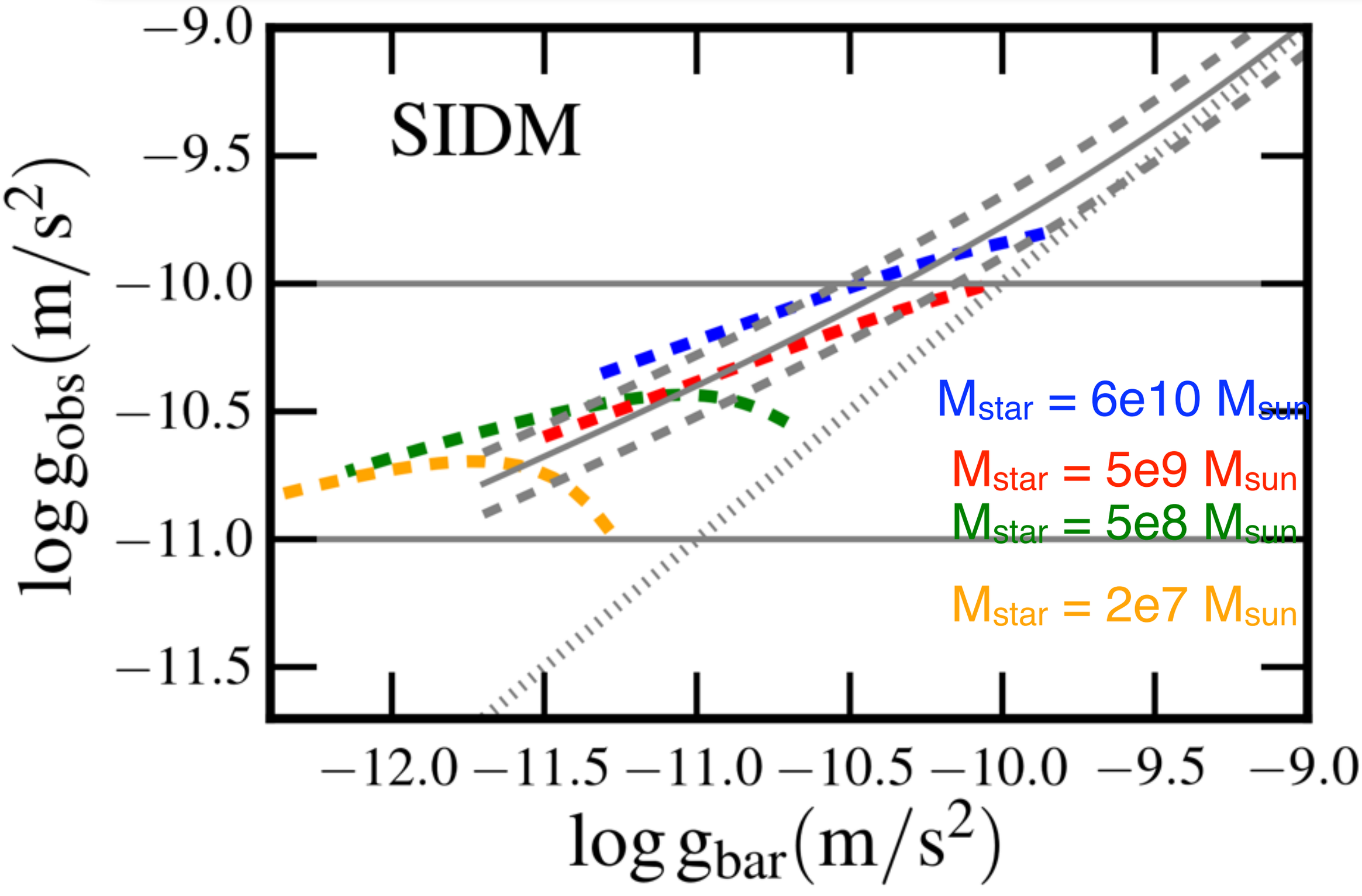
Robles, Pawlowski, JSB 2017

CDM

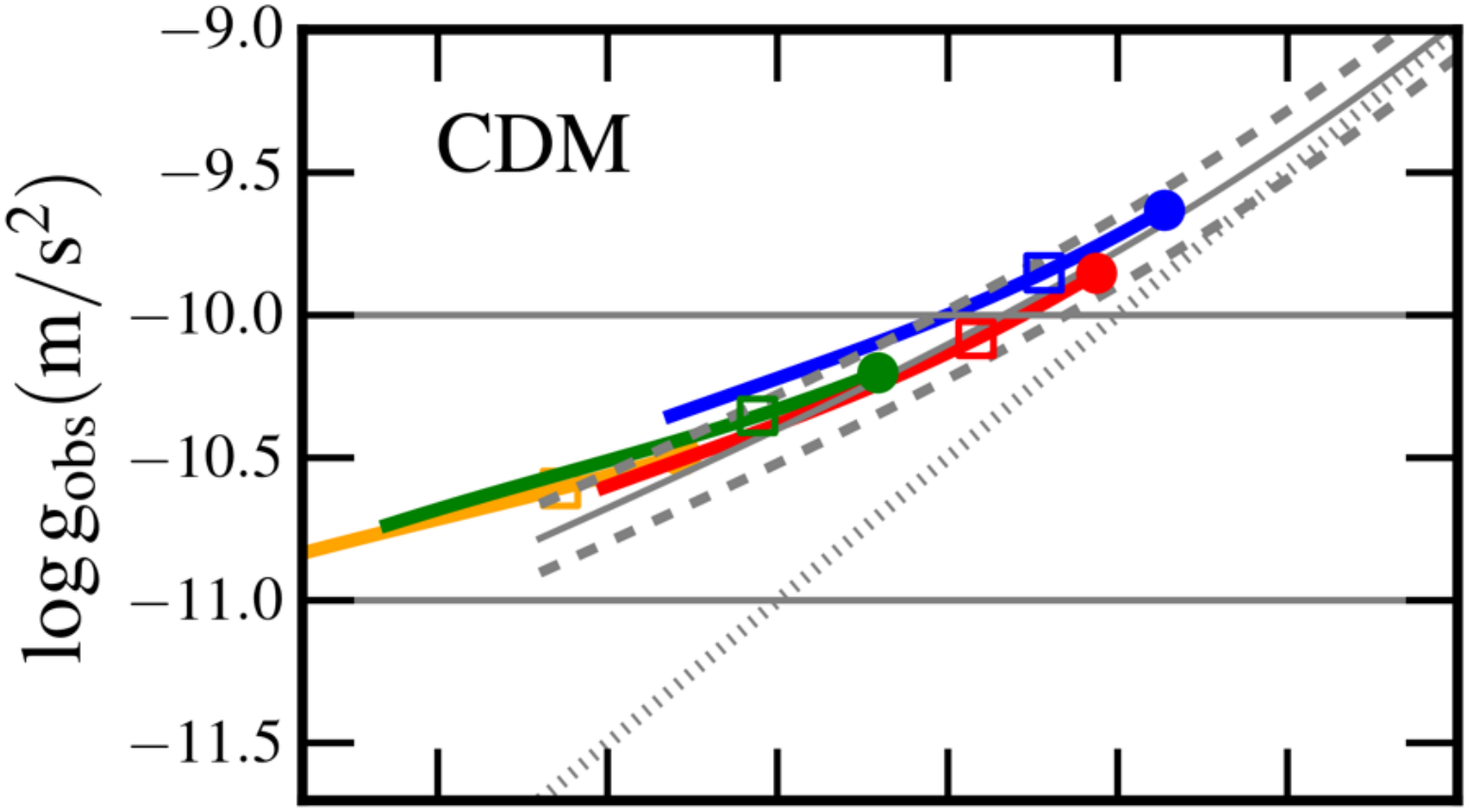


Robles, Pawlowski, JSB 2017

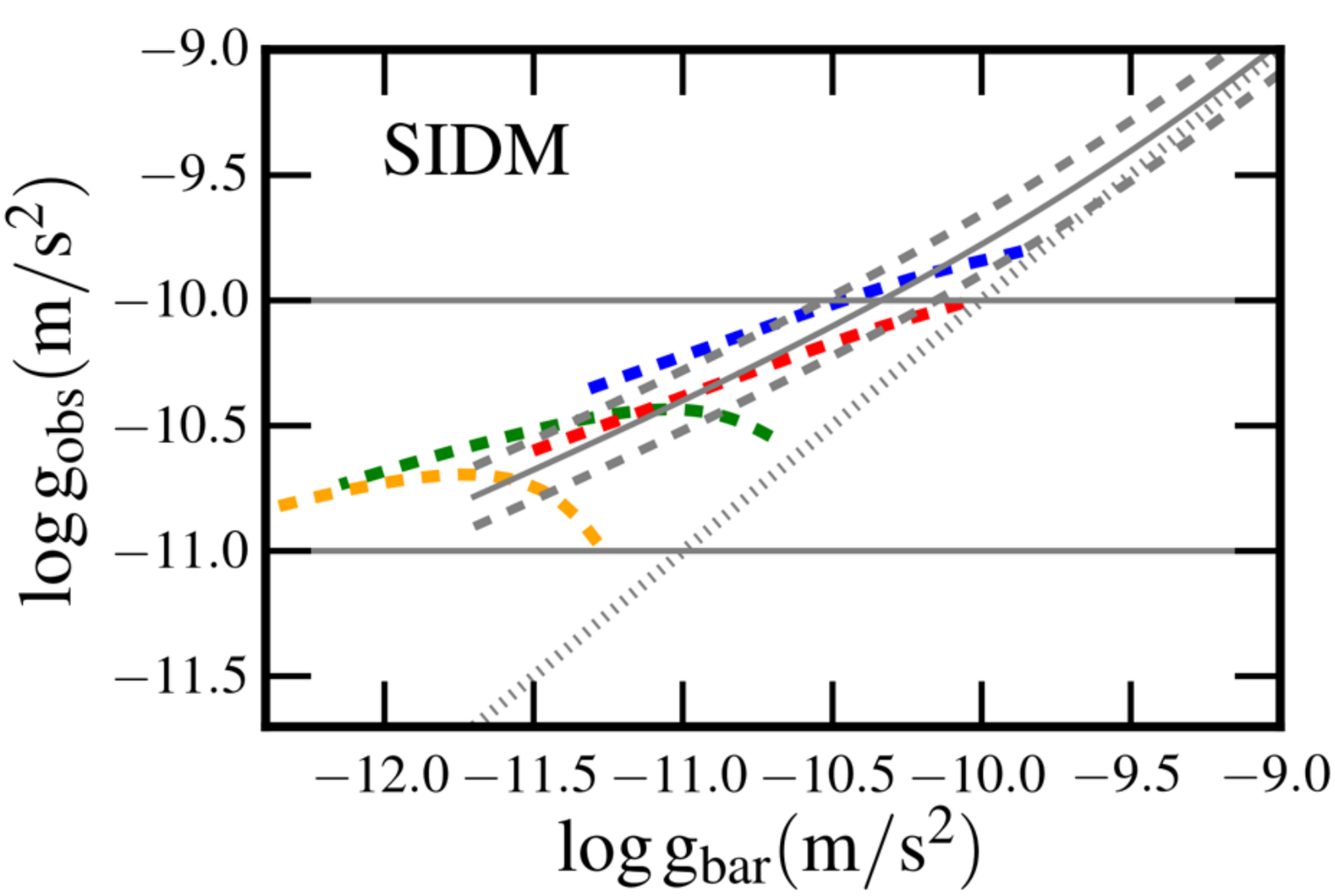
SIDM



Robles, Pawlowski, JSB 2017



CDM (NFW)
no “hooks”



SIDM “hooks”
in dwarfs

M_{star} = 6e10 M_{sun}

M_{star} = 5e9 M_{sun}

M_{star} = 5e8 M_{sun}

M_{star} = 2e7 M_{sun}

F

Emergent gravity: upward hooks!

Testing Verlinde's emergent gravity with the radial acceleration relation

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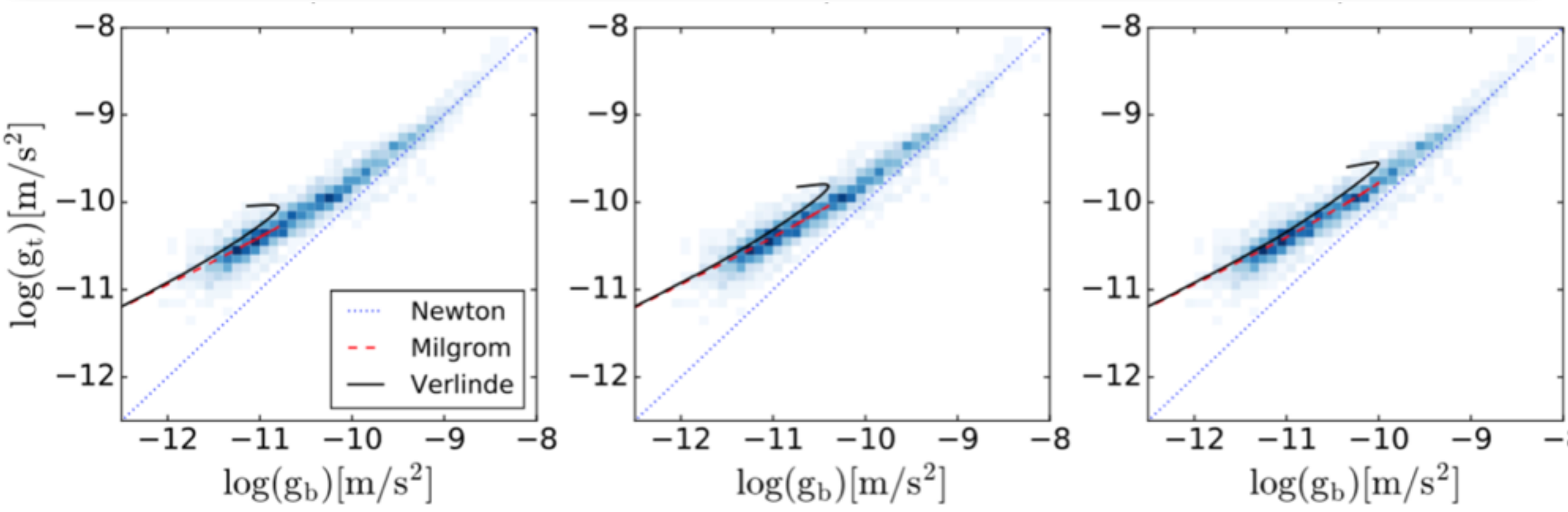
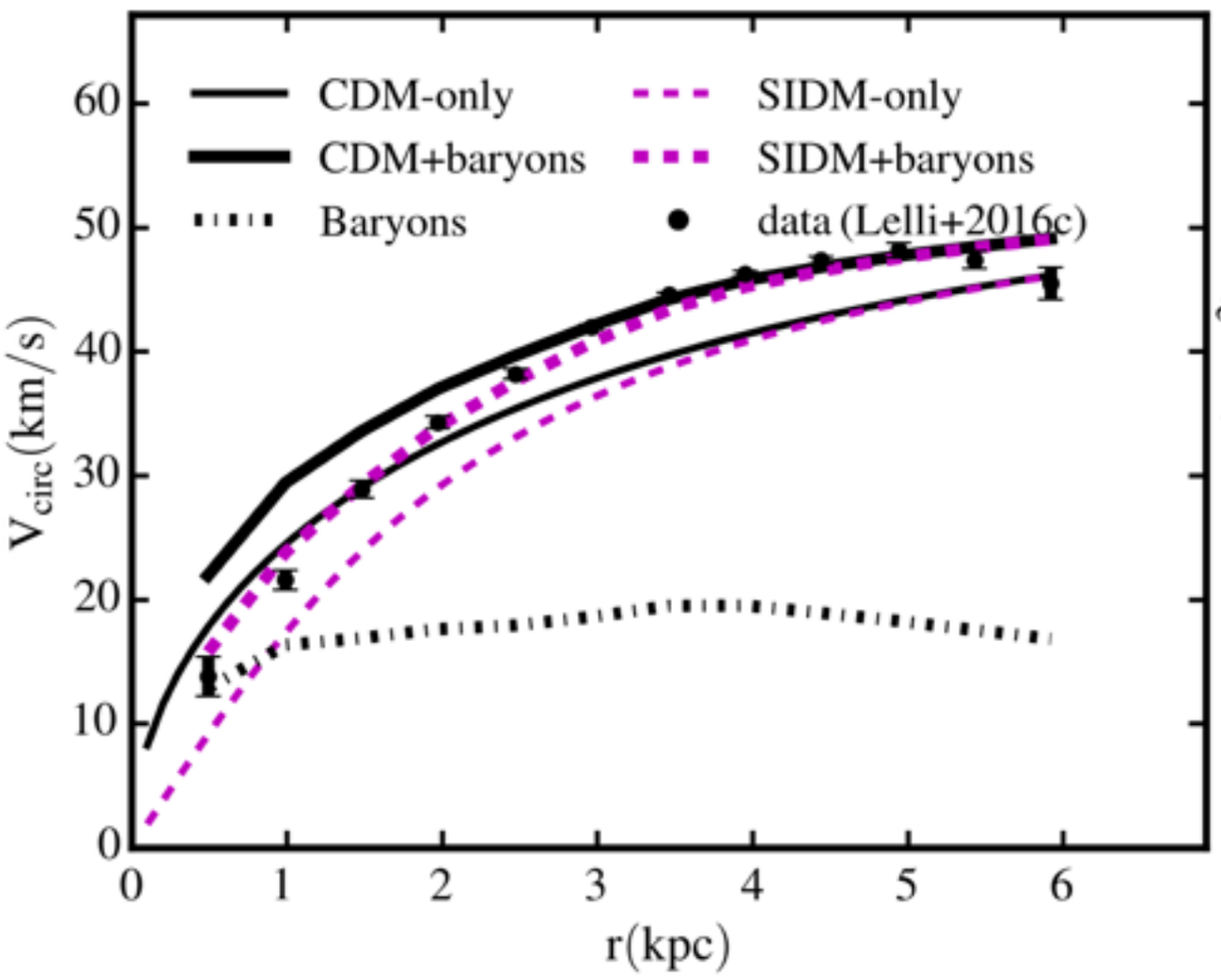
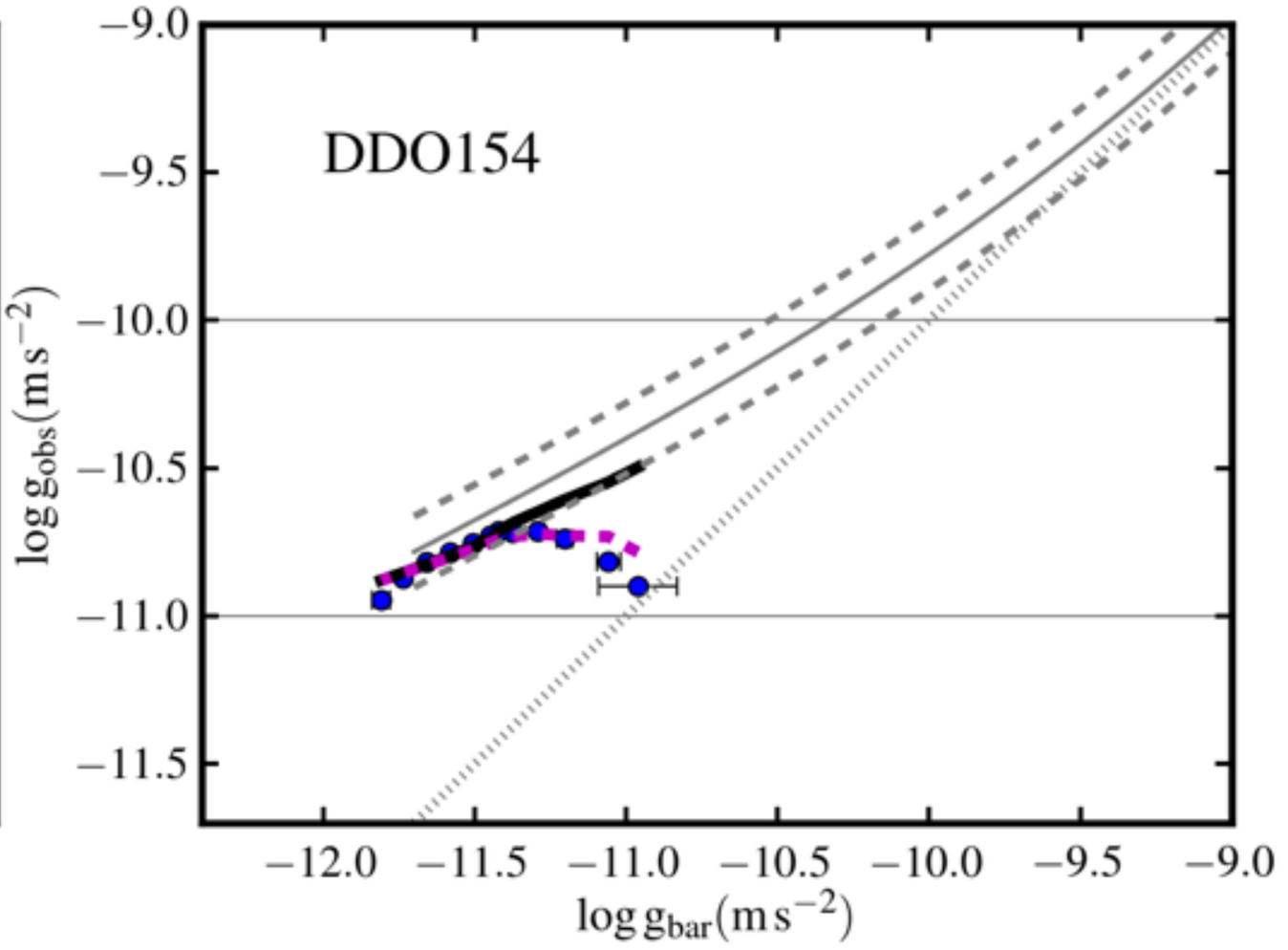
[2] *Department of Astronomy, Case Western Reserve University, 10900 Euclid Avenue, Cleveland, OH 44106, USA*
[3] *Department of Physics, University of Oregon, Eugene, OR 97403, USA*



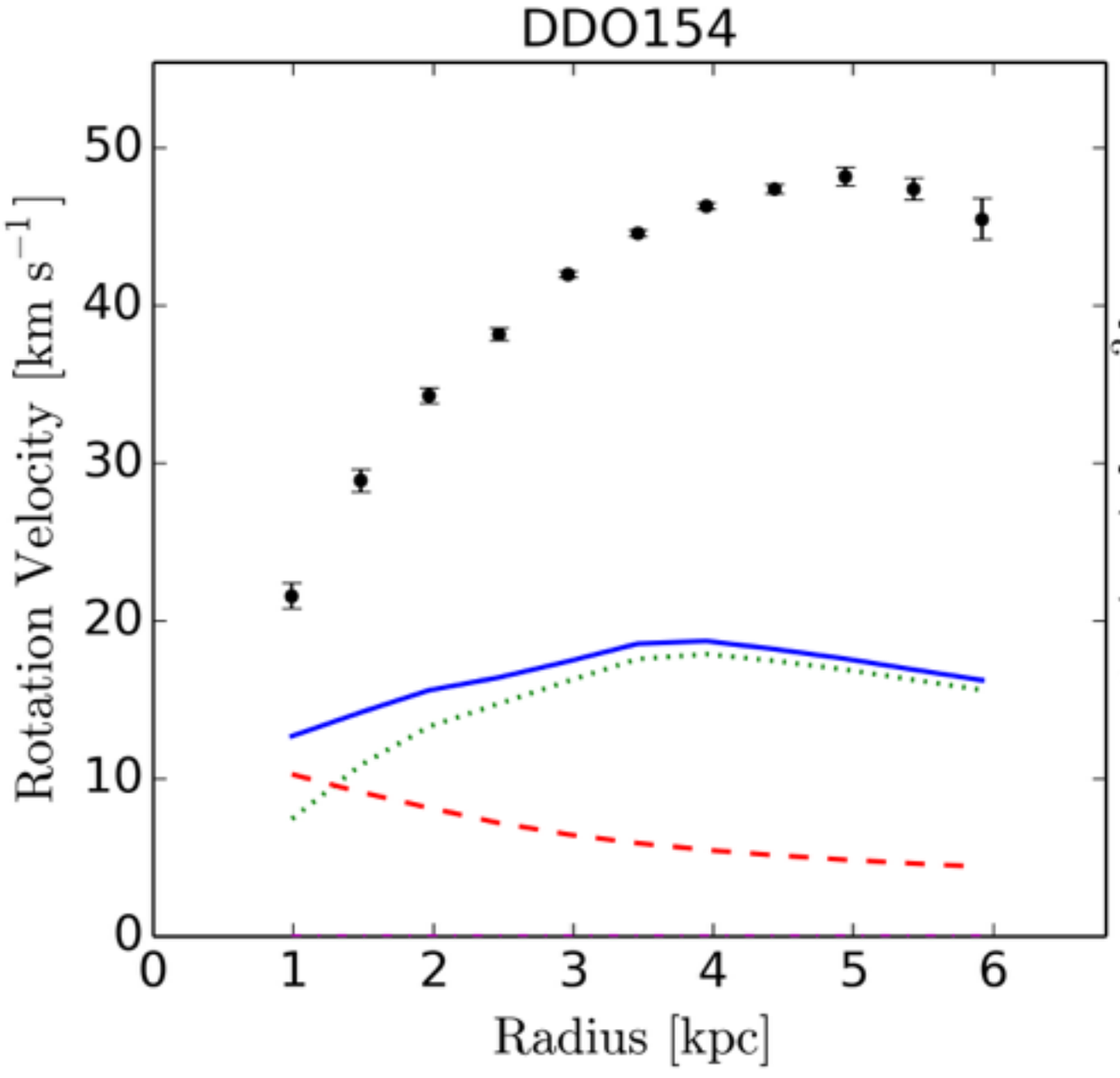
SIDM-type relation for DDO154

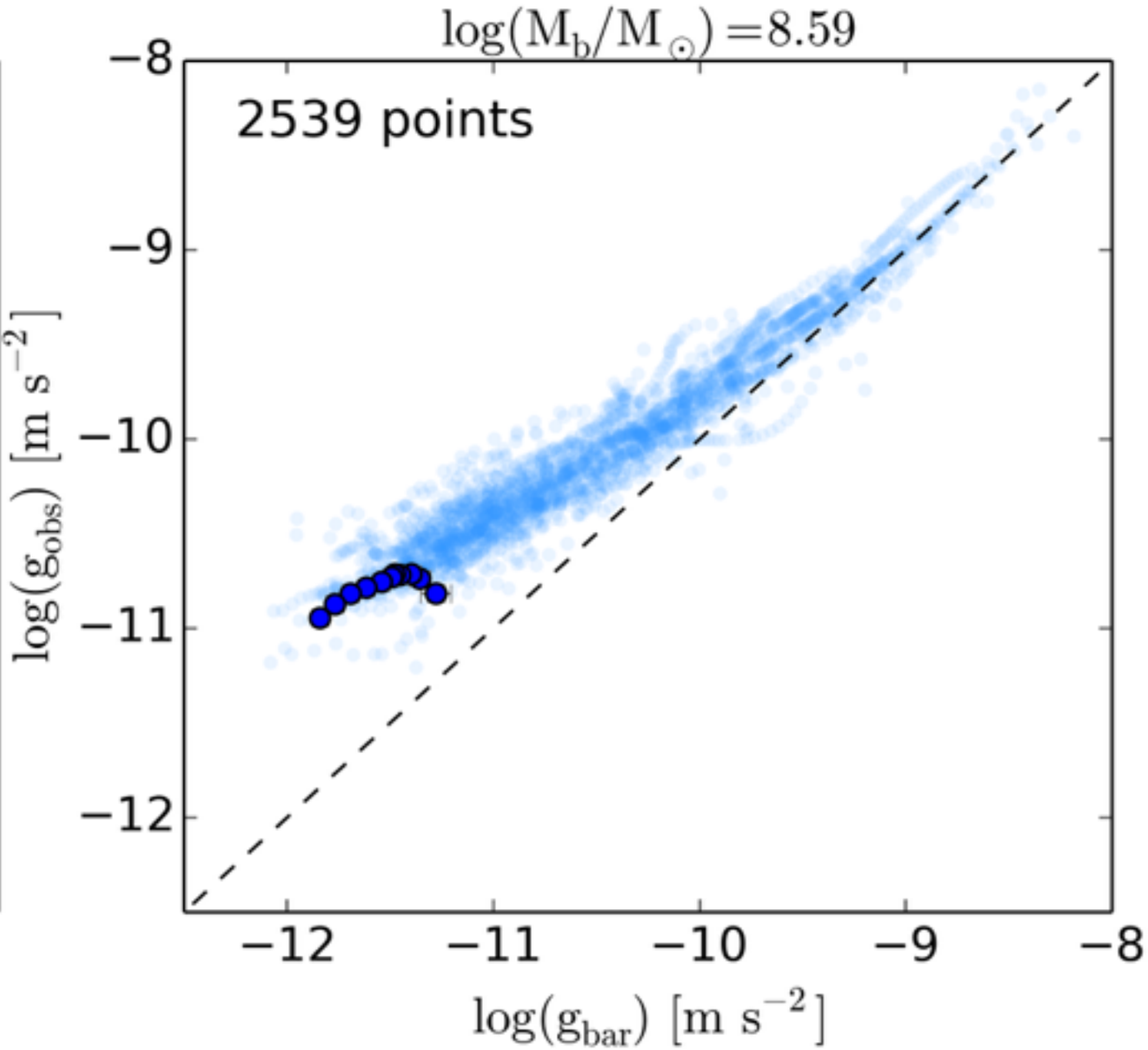




$M_b = 10^{8.6}\ M_{sun}$

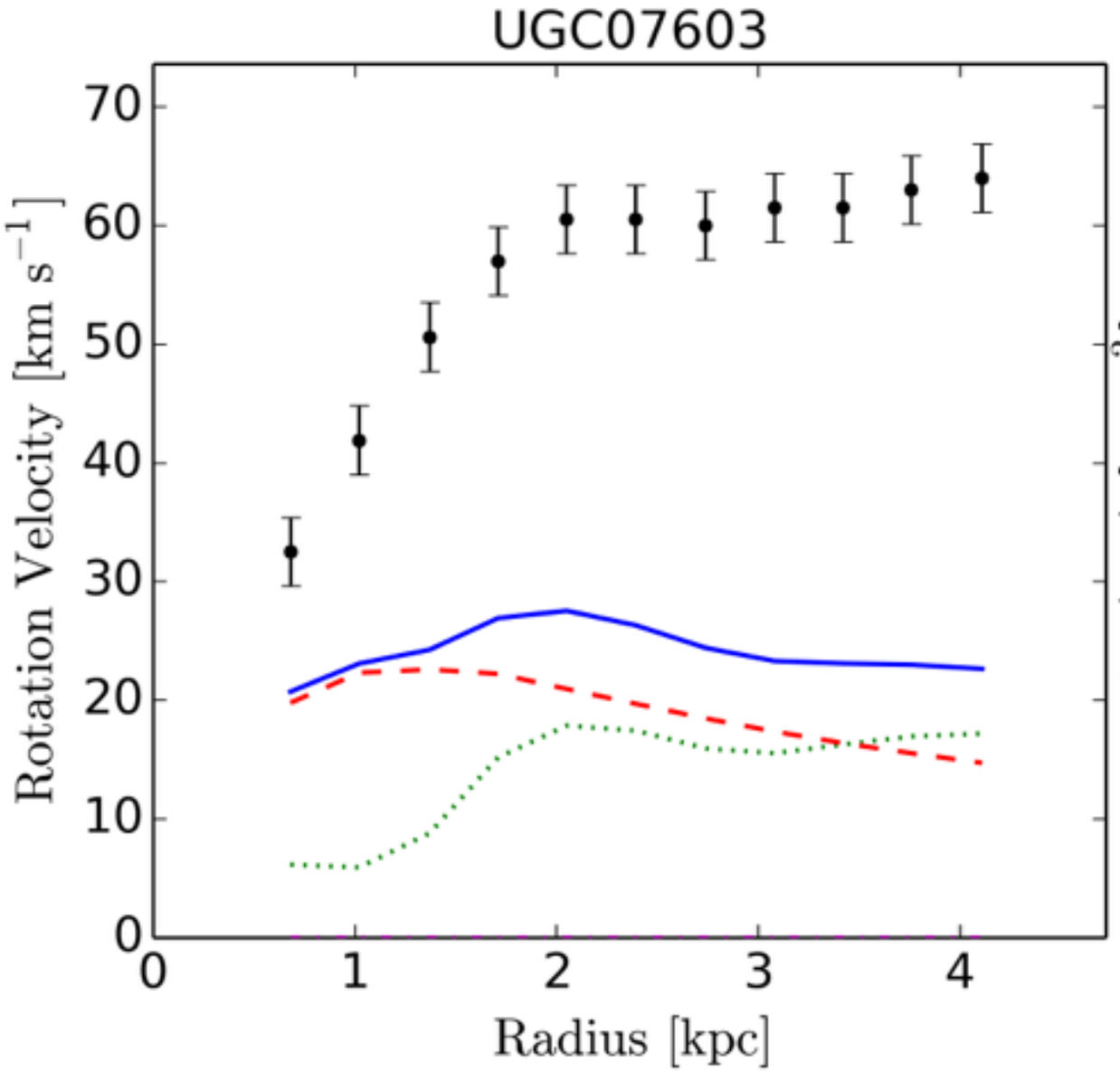
Do see hooks in the data (sometimes)

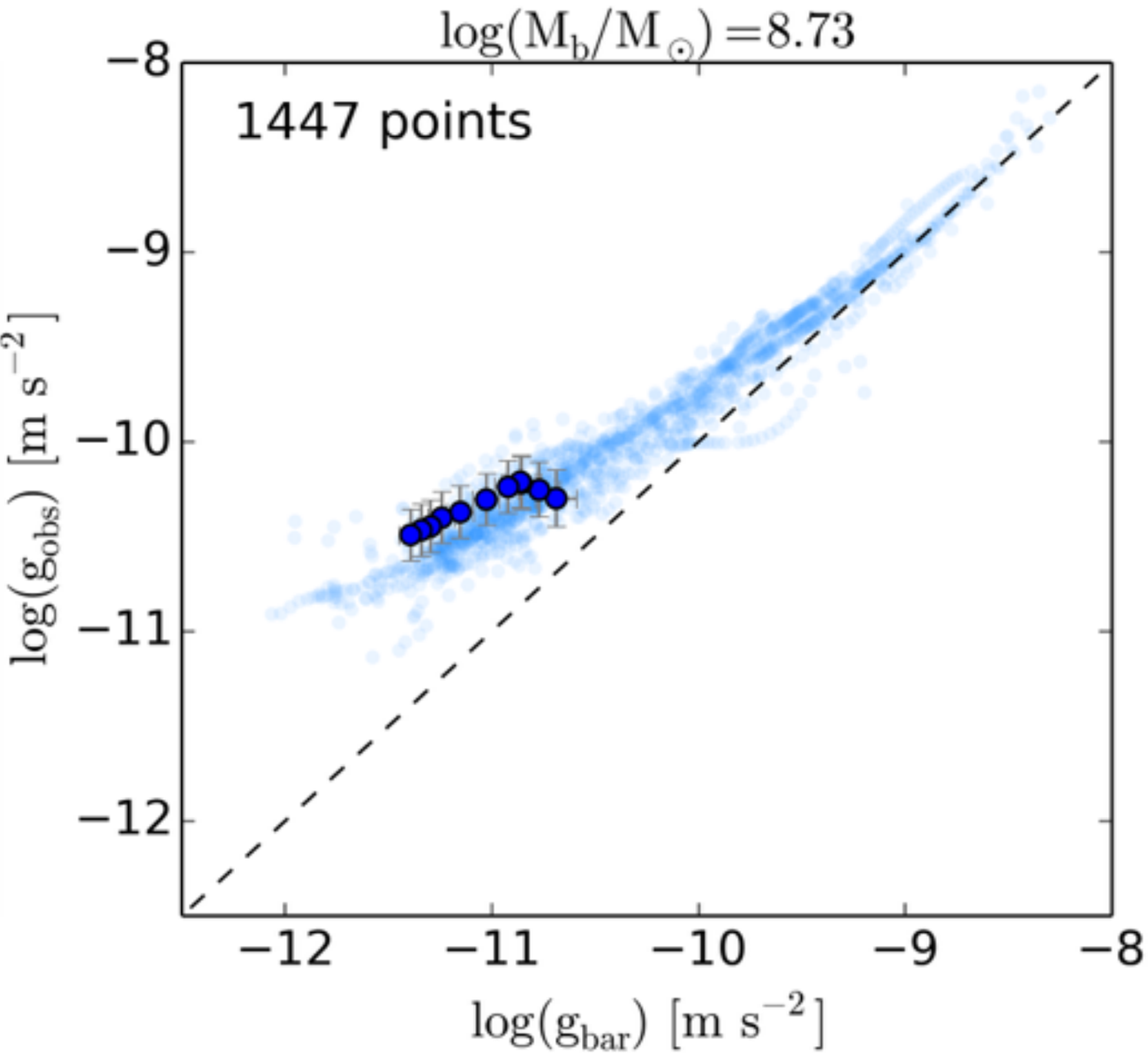




$M_b = 10^{8.6}\ M_{sun}$

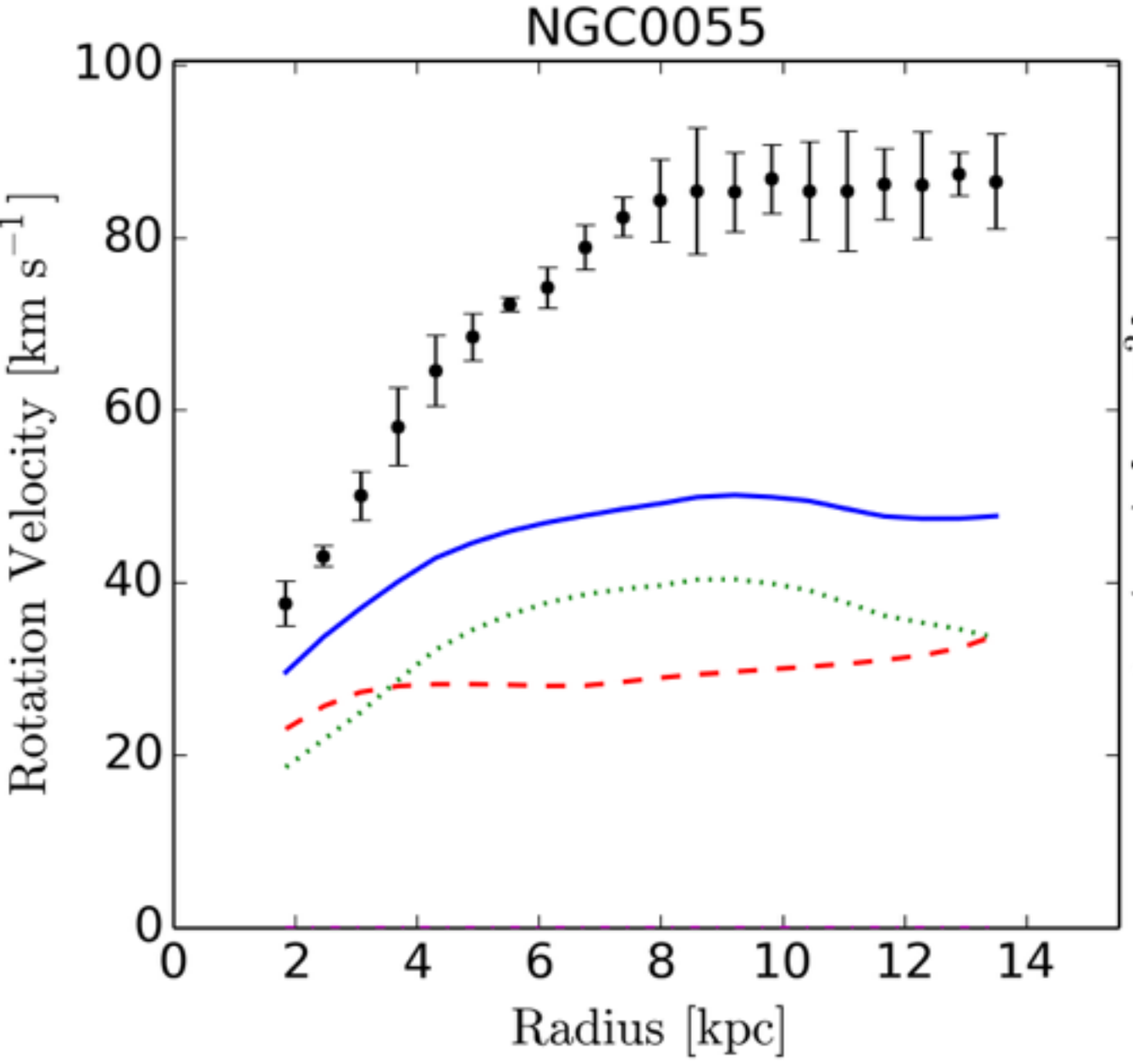
Looks like a hook

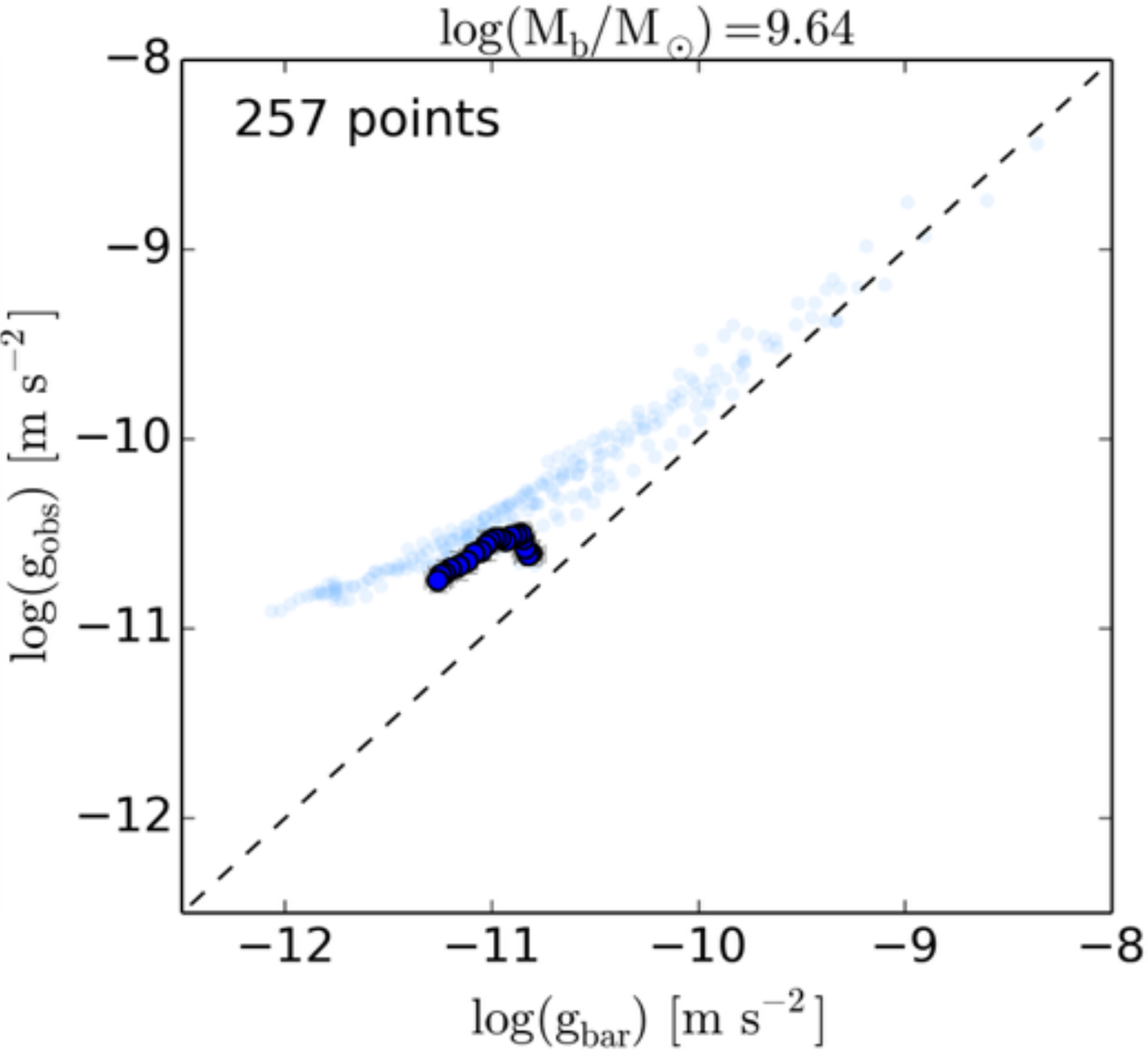




$M_b = 10^{8.7}\ M_{sun}$

Hook!

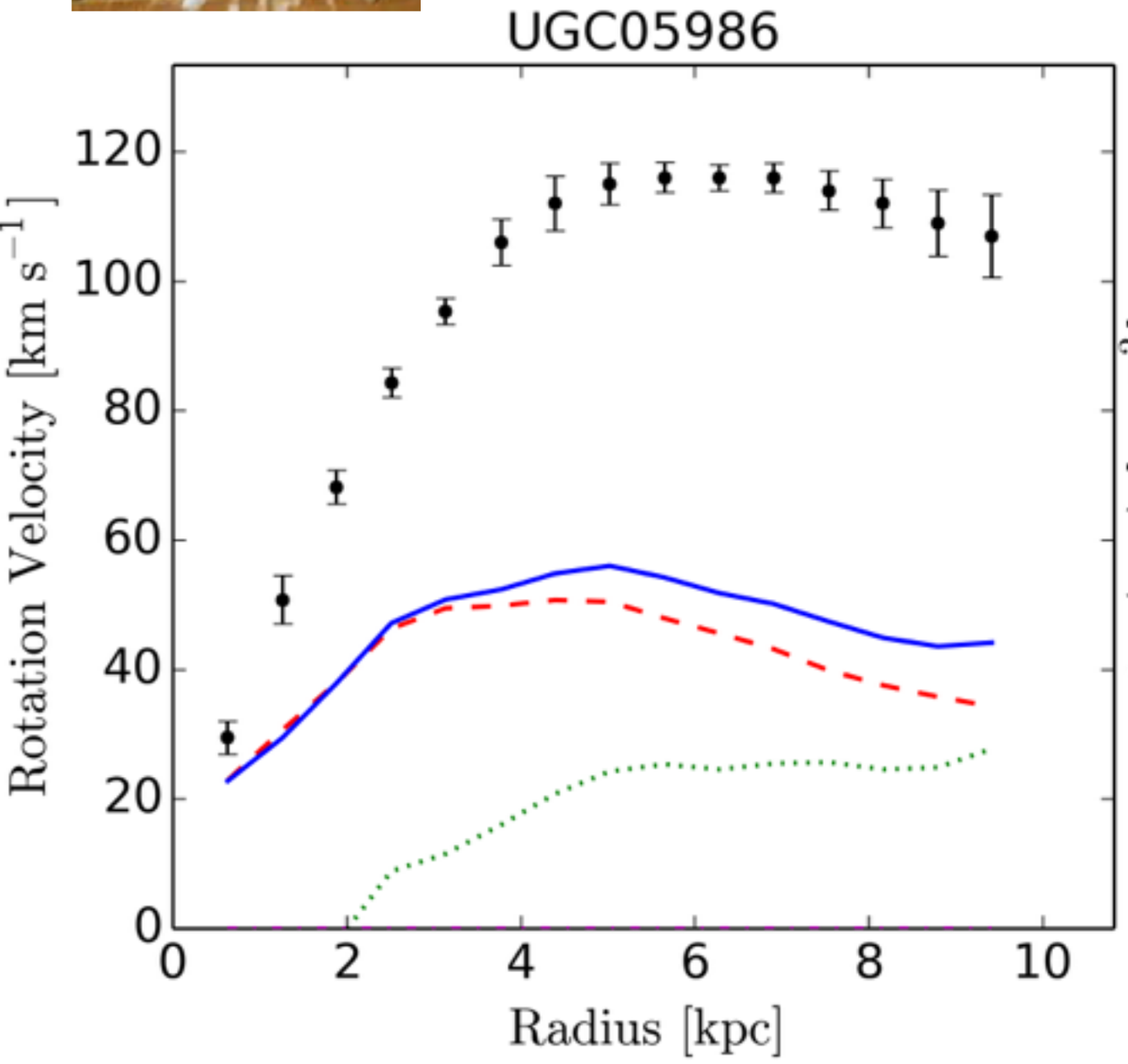


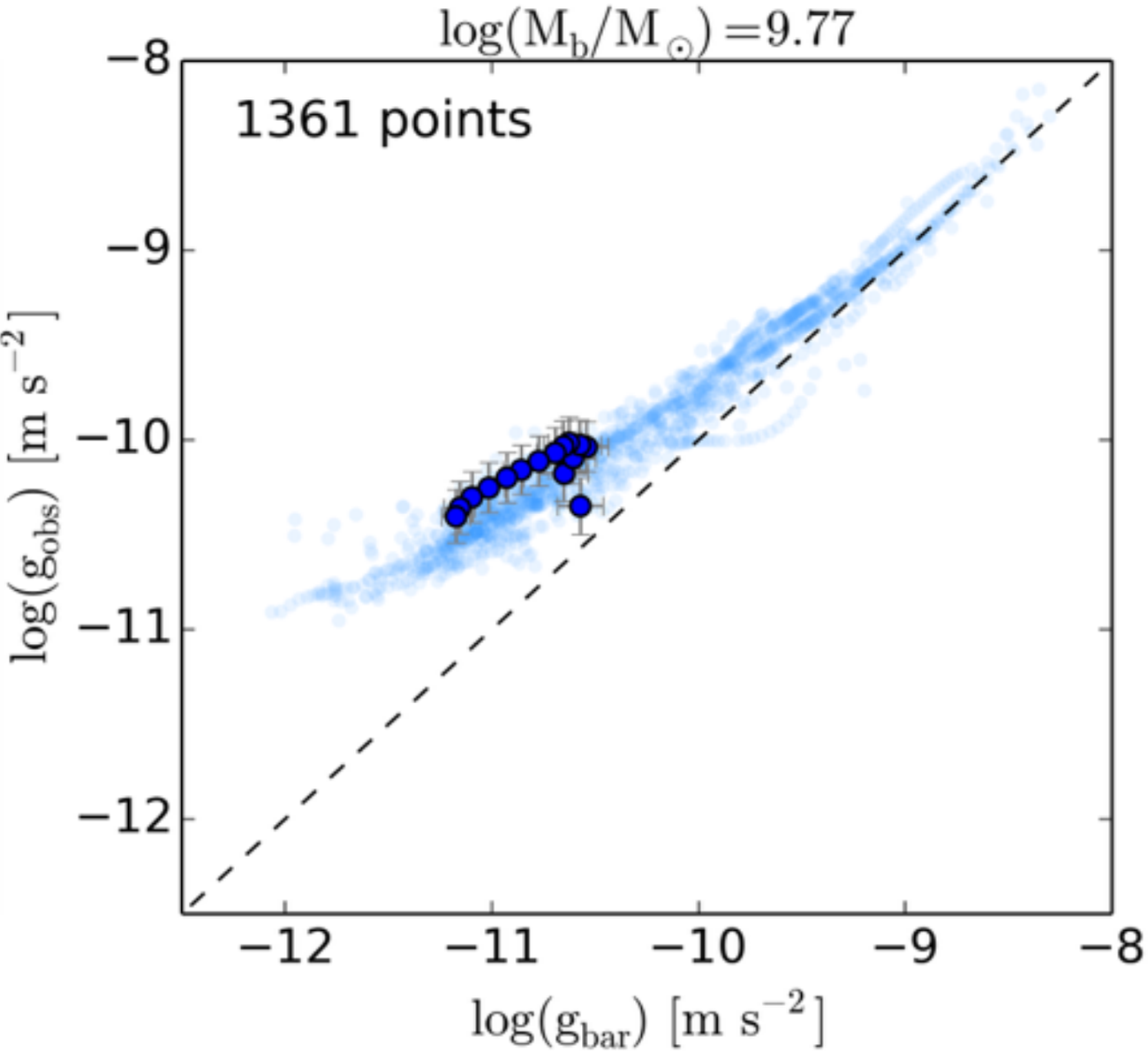


$M_b = 10^{9.7}\ M_{sun}$

Sky hook

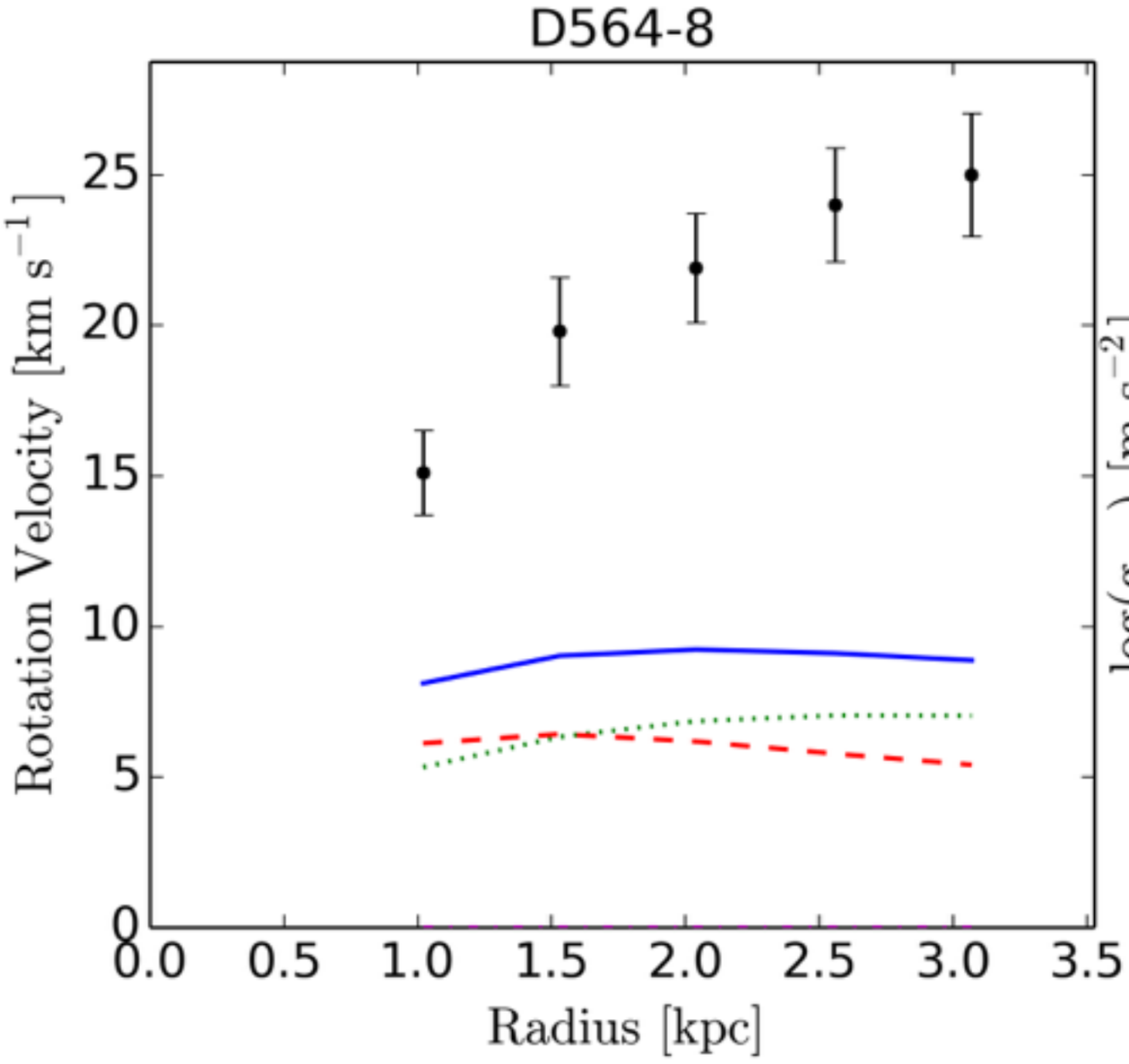
$M_b = 10^{9.8}\ M_{sun}$

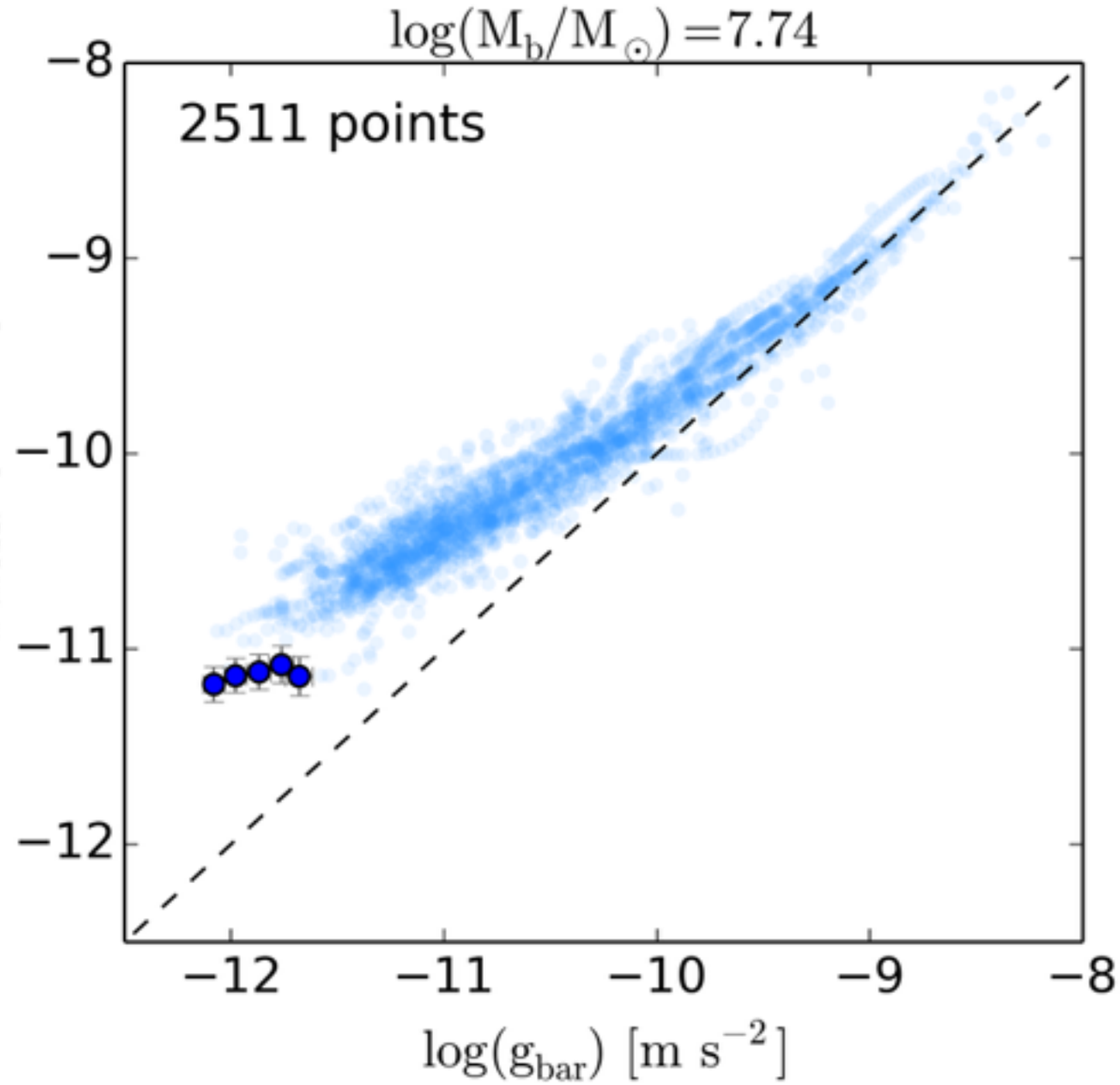




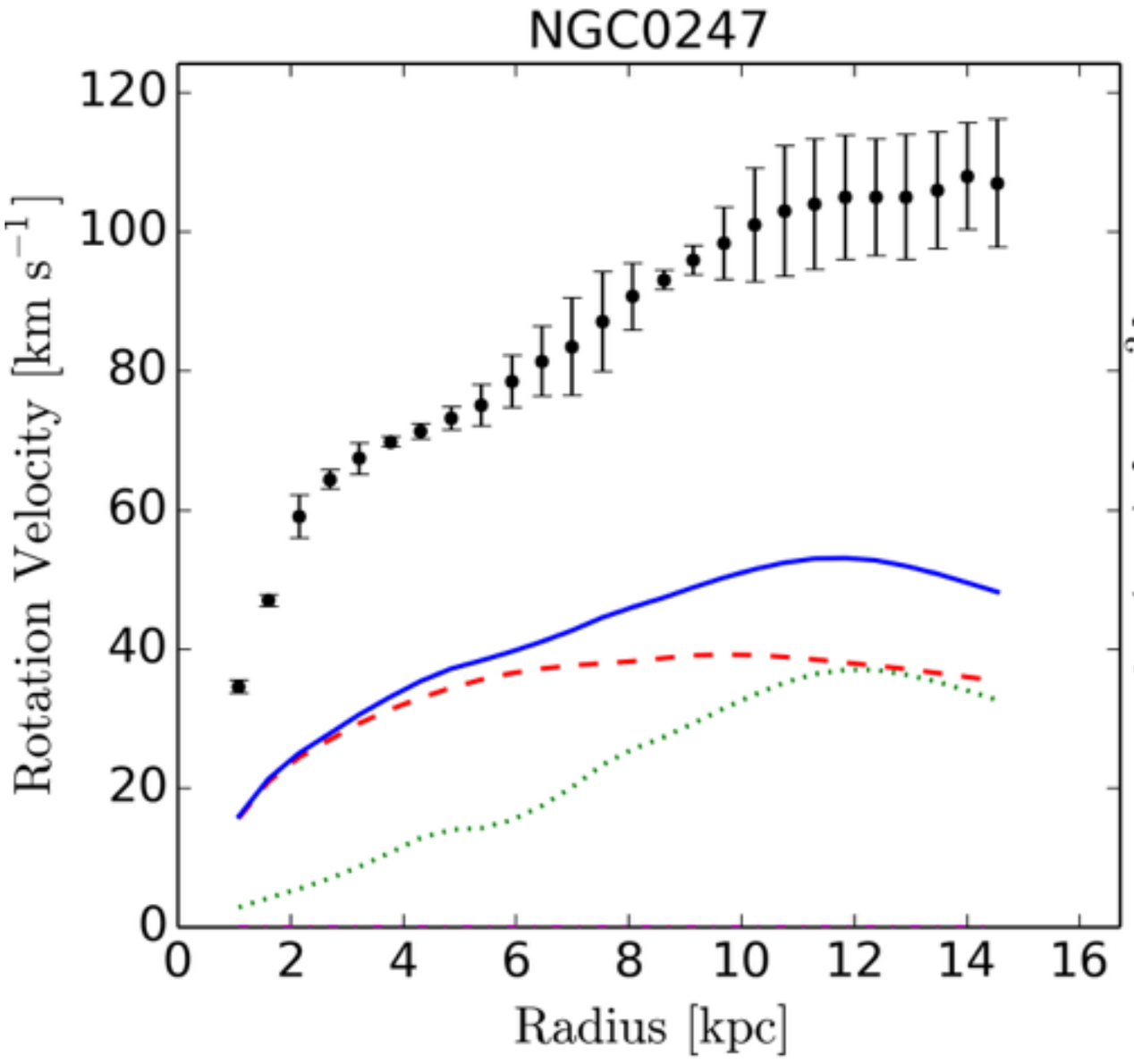
Baby hook

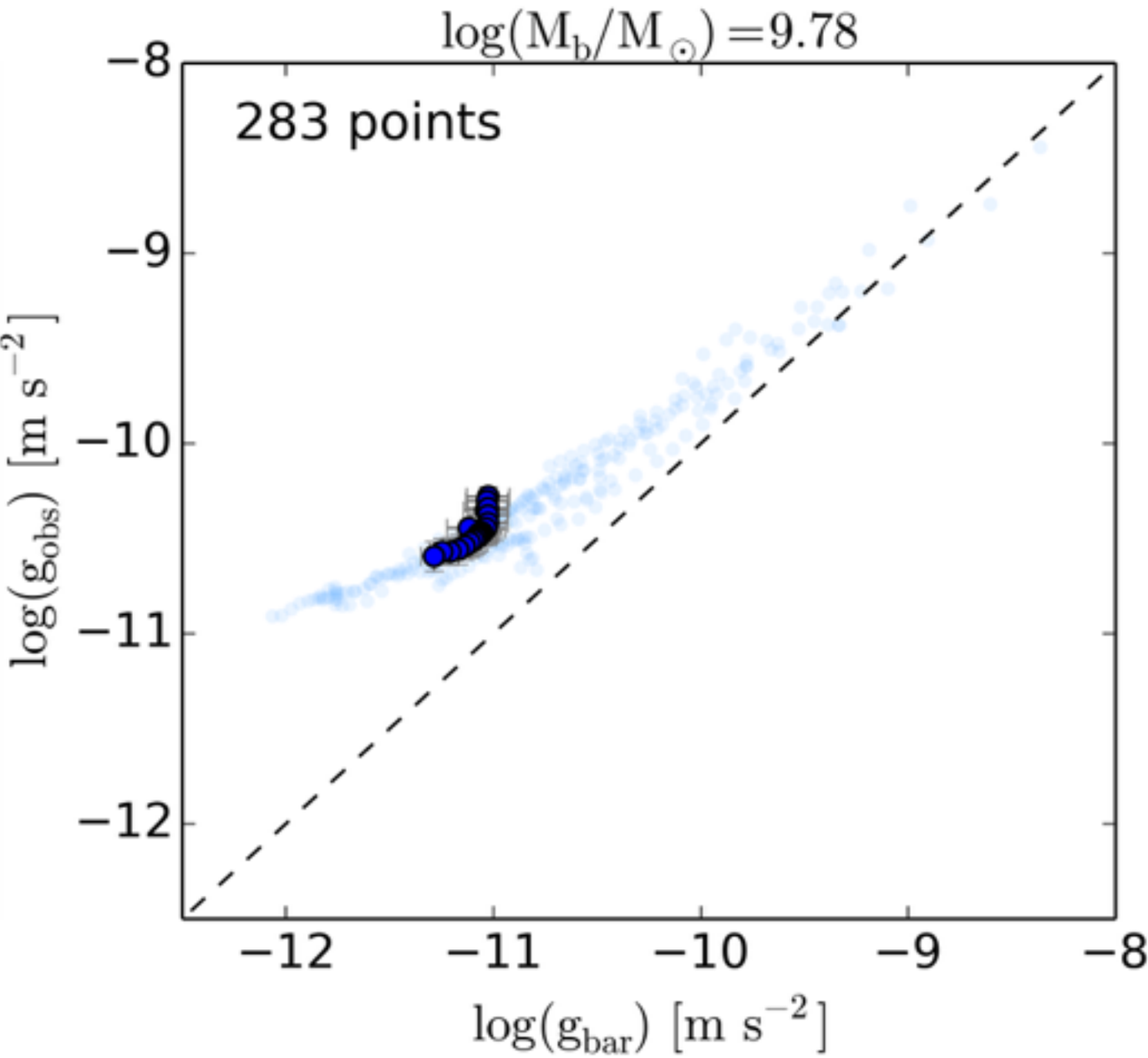
$M_b = 10^{7.7}\ M_{sun}$





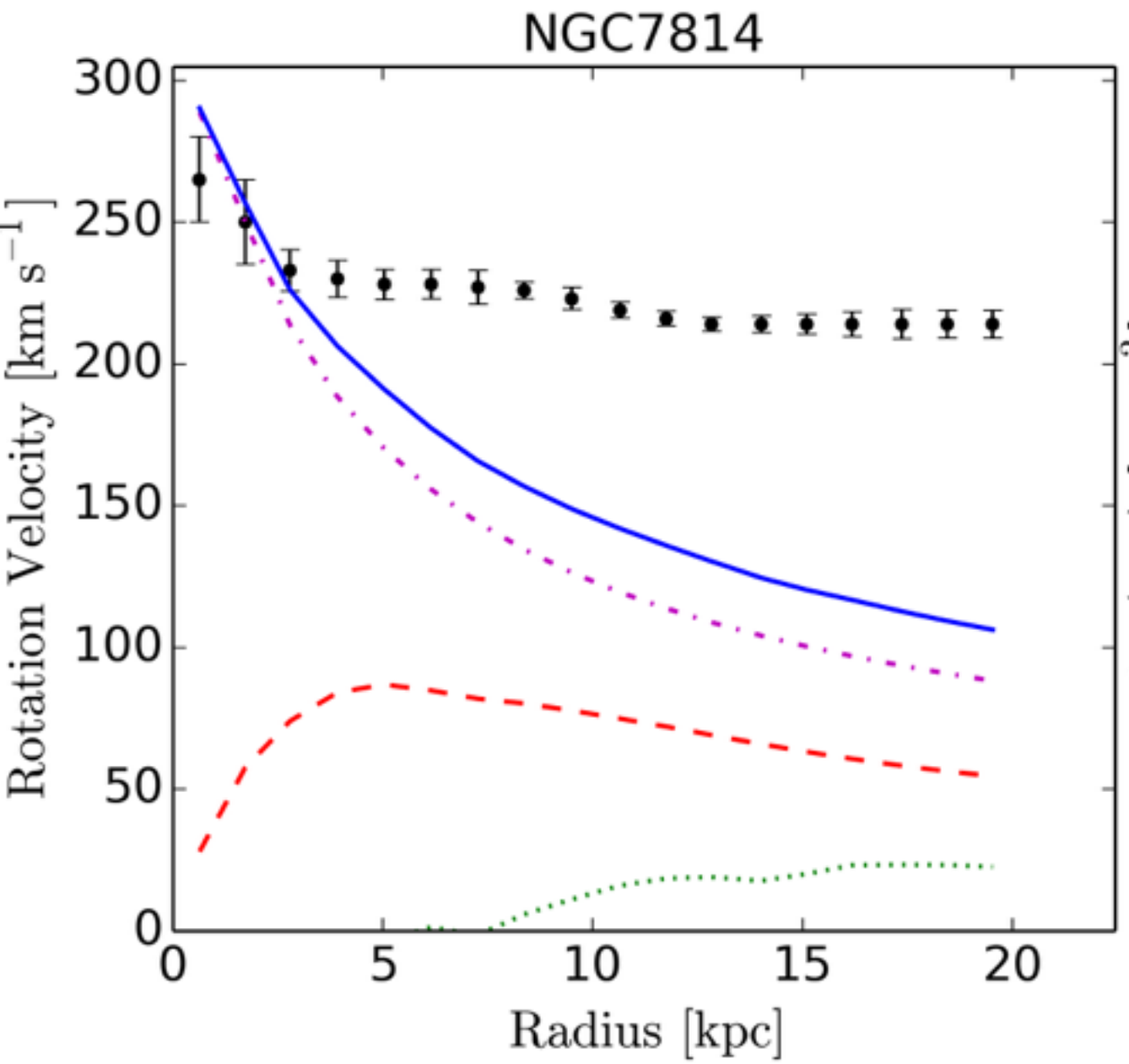
Upwards hook?

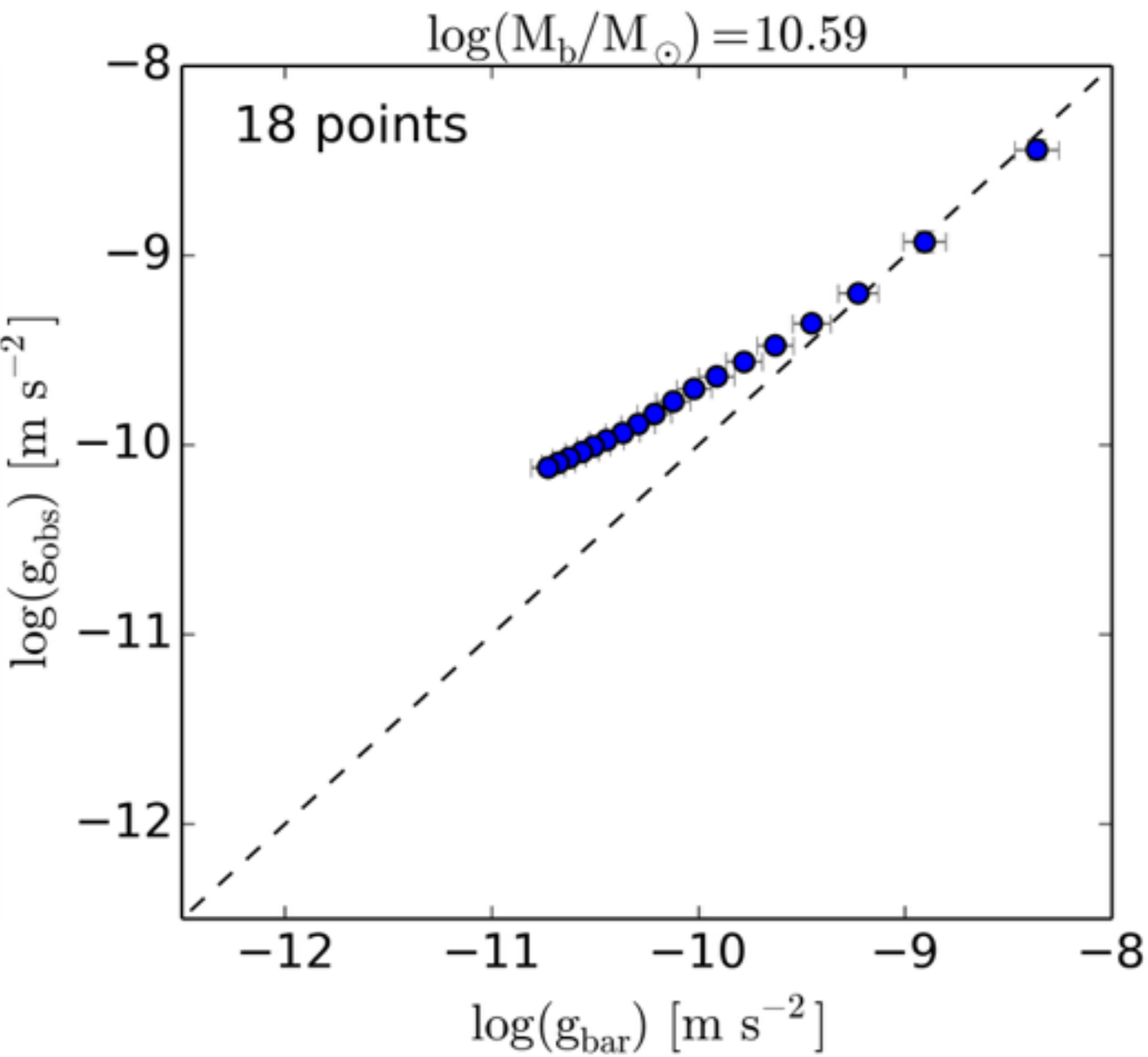




$M_b = 10^{9.8}\ M_{sun}$

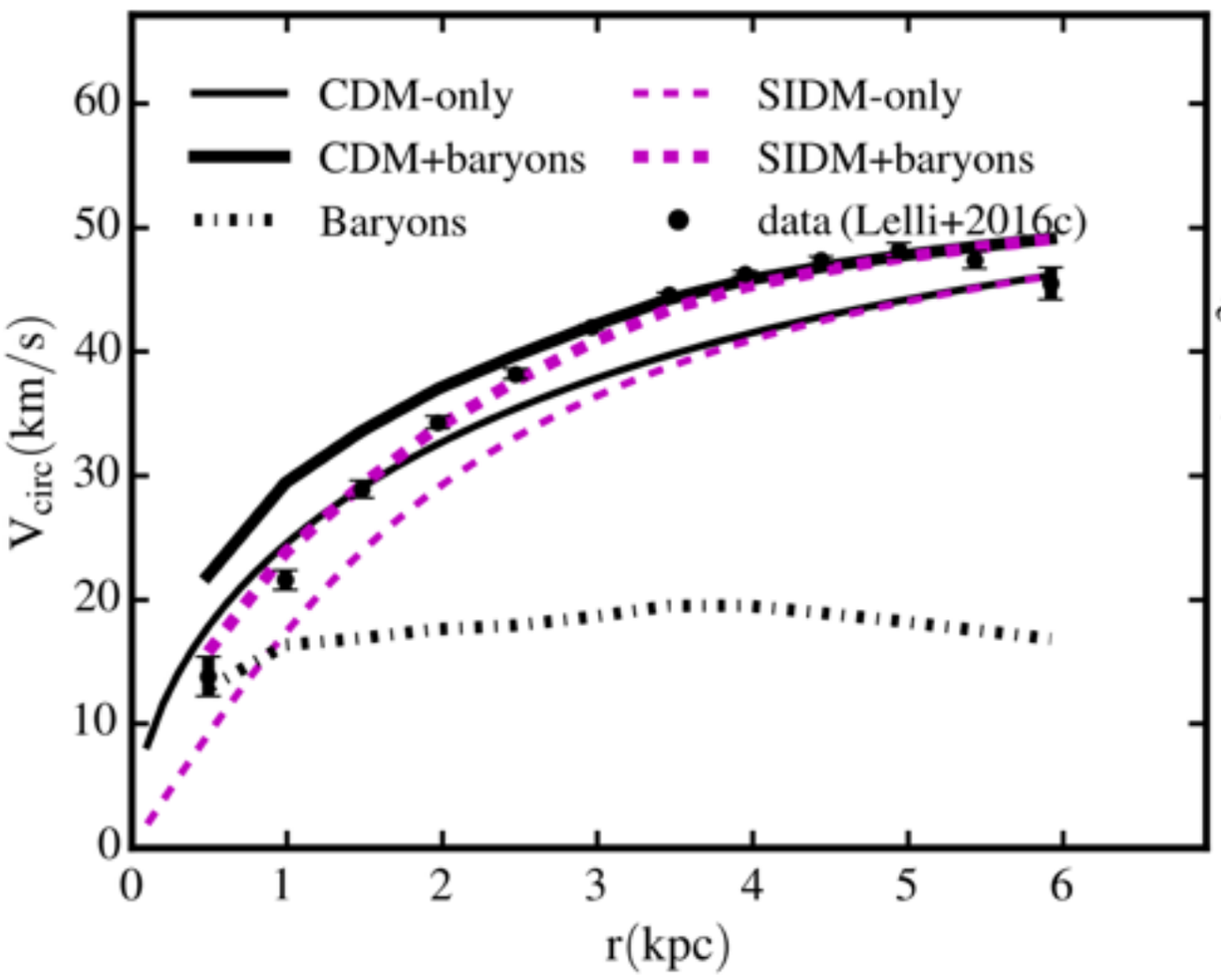
Massive galaxies — no hooks

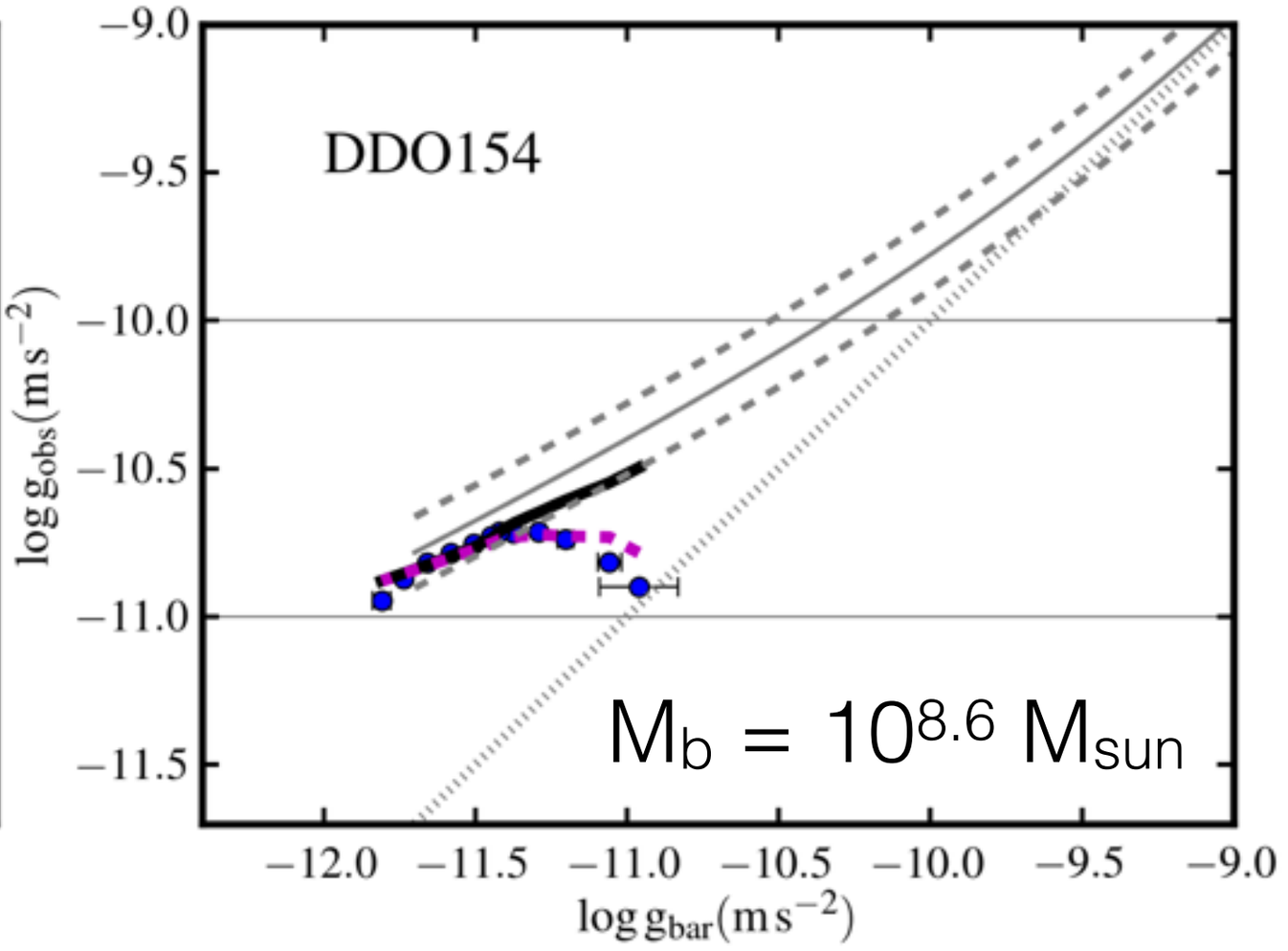




$M_b = 10^{10.6}\ M_{sun}$

SIDM-type relation for DDO154





But… feedback-driven CDM cores likely create “hooks” — need to explore

SIDM Conclusions

- SIDM is an interesting, predictive alternative to CDM

- Can “solve” cusp/core and TBTF problems naturally

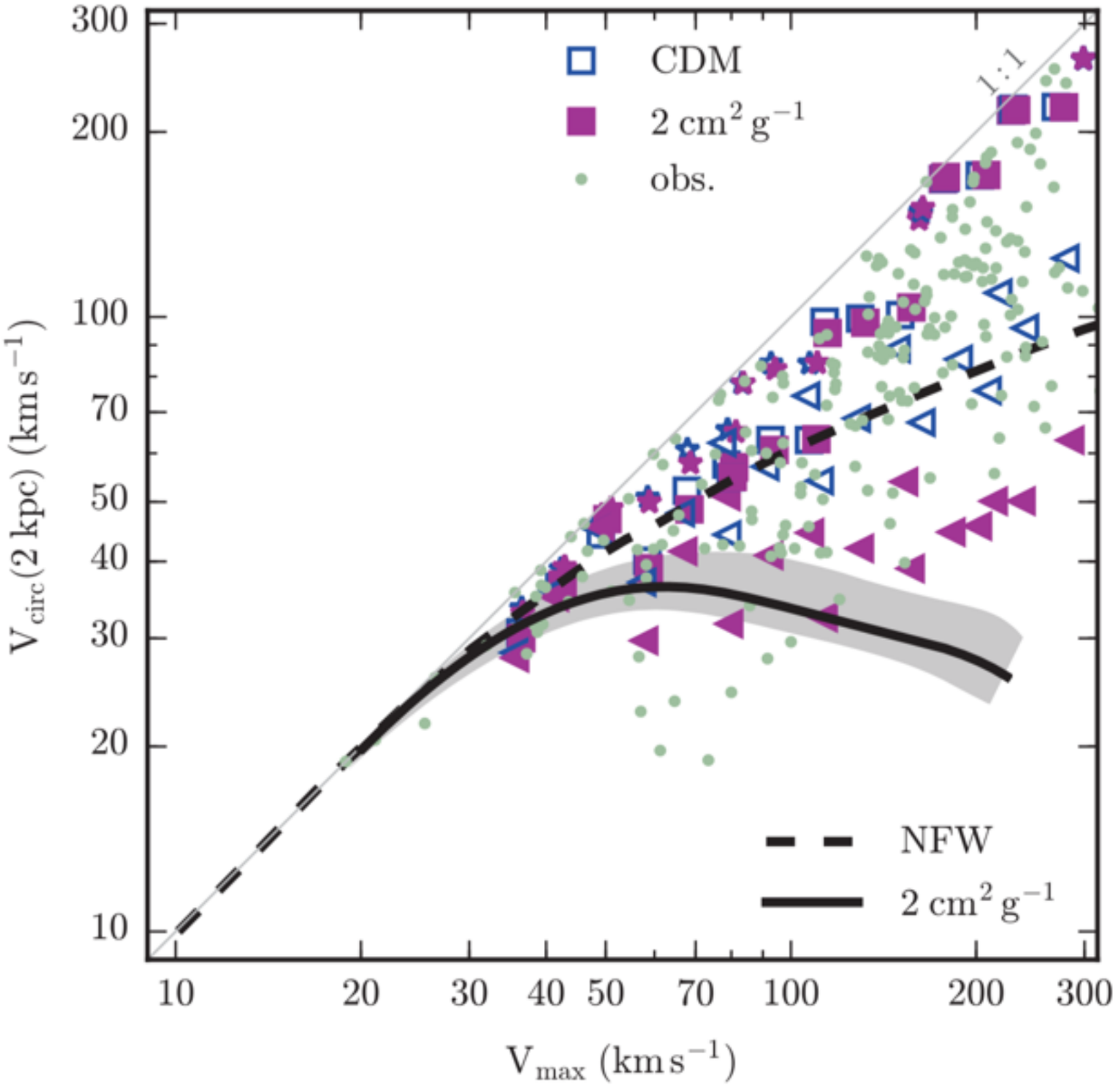
- Predictions are relatively robust to feedback “FIRE proof”

- Predicts cored profiles in the smallest dwarfs
    - unlike many CDM+feedback models

- The galaxy-by-galaxy RAR may provide an interesting avenue for testing SIDM & discriminating from CDM

- Hooks in the RAR?

SIDM <=> baryon cross talk
* much more diversity in rotation curves



Diversity in SIDM correlates with baryonic content

Creasey+16