Hydrodynamical simulations of galaxies: Distinguishing CDM from non standard DM models the vital role of baryon physics

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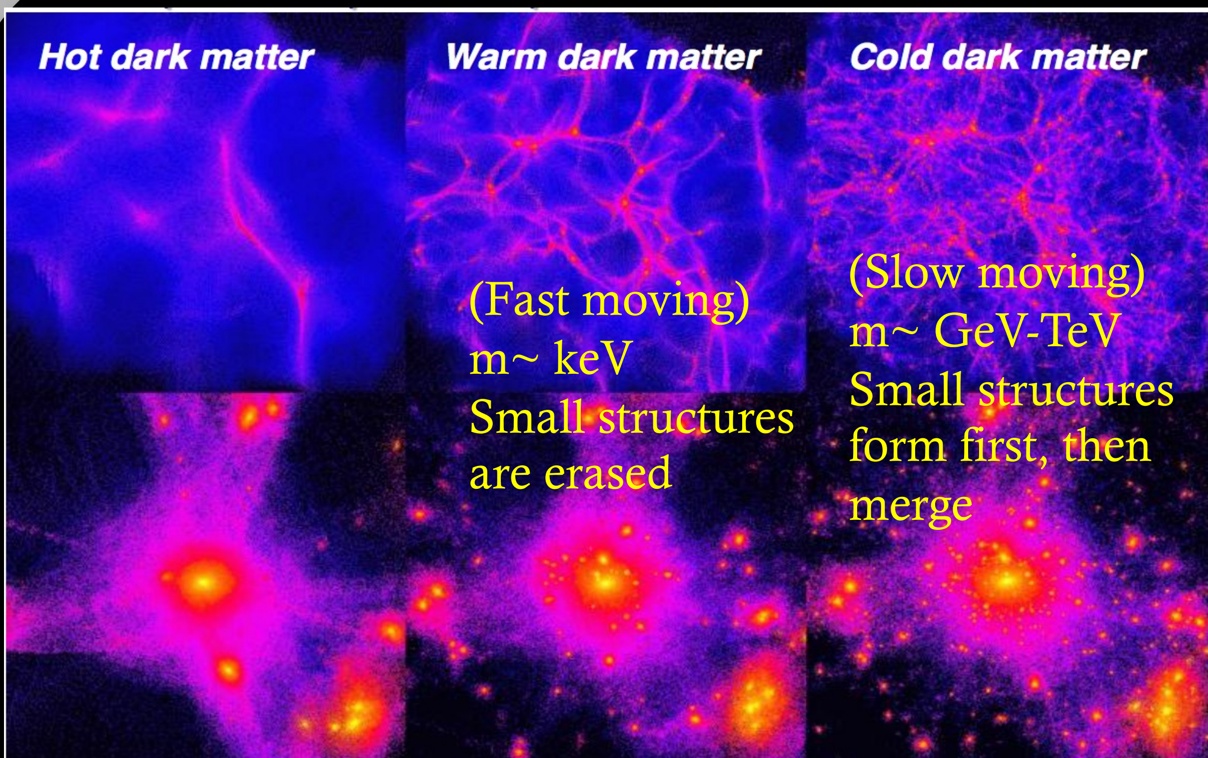
Outline

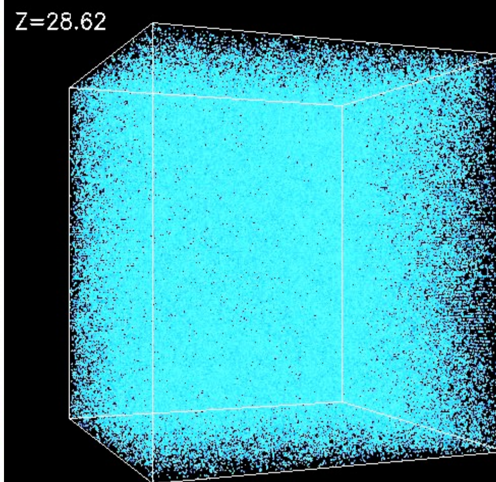
- The LCDM small scale crisis: TBTF-missing satellites-cusp/core-velocity function-RCs- UDGs
- Solution #1: CDM +baryonic physics
- Solution #2: alternative DM models SIDM/WDM
- Solution #3: SIDM/WDM + baryonic physics
- Future perspectives

N-body simulations



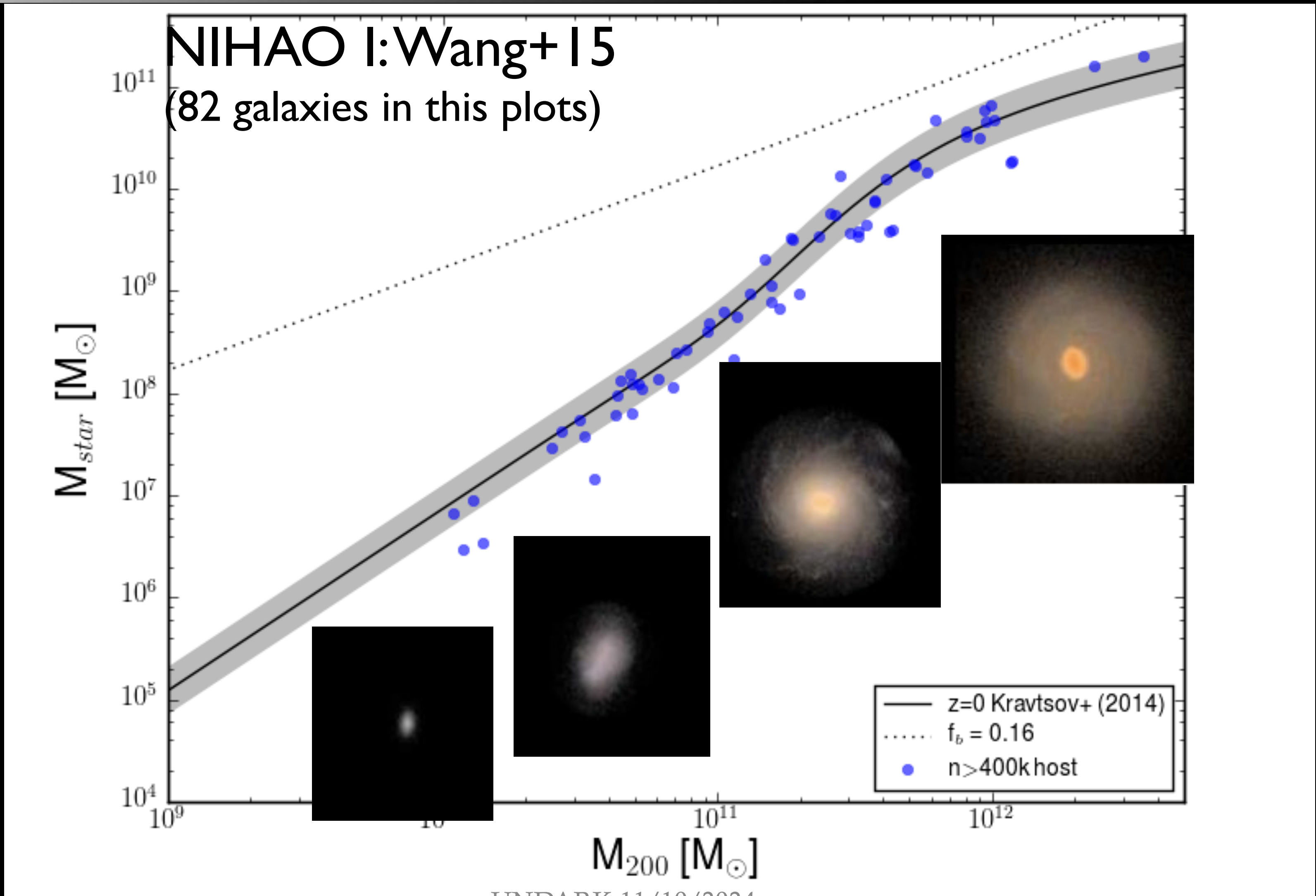
(Fast moving)
m~ keV
Small structures are erased

(Slow moving)
m~ GeV-TeV
Small structures form first, then merge



Credit: A.Kravtsov, A. Klypin

Halo mass – Stellar mass relation

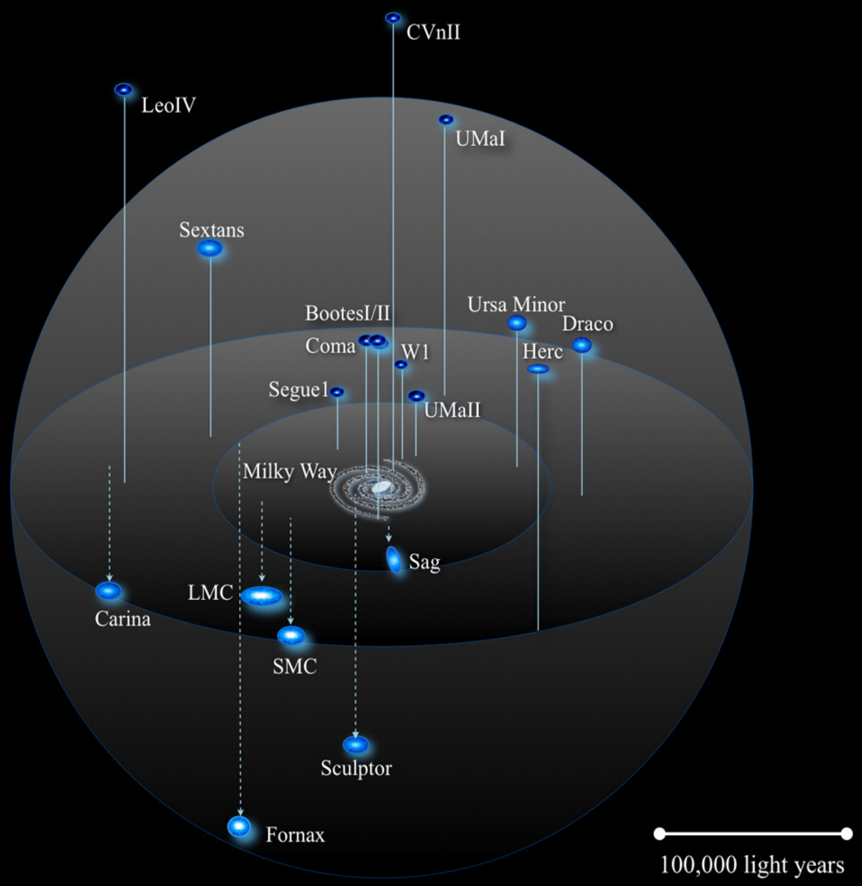


ΛCDM small scale crisis

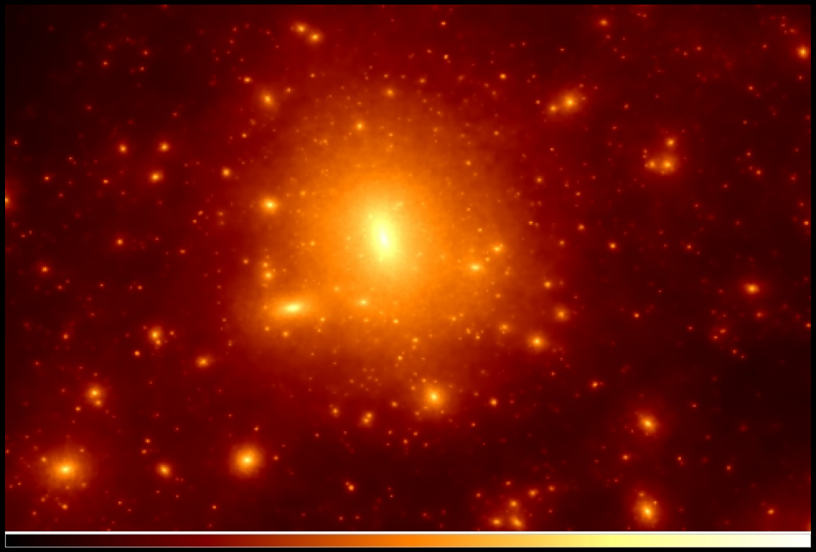
- ✓ Missing satellite problem
- ✓ “Too-big-to-fail” problem
- ✓ Cusp-core discrepancy
- ✓ Velocity function of galaxies
- ✓ Diversity of rotation curves
- ✓ LSB/UDGs galaxies

Problem # 1: missing satellites

Klypin +99, Moore +99

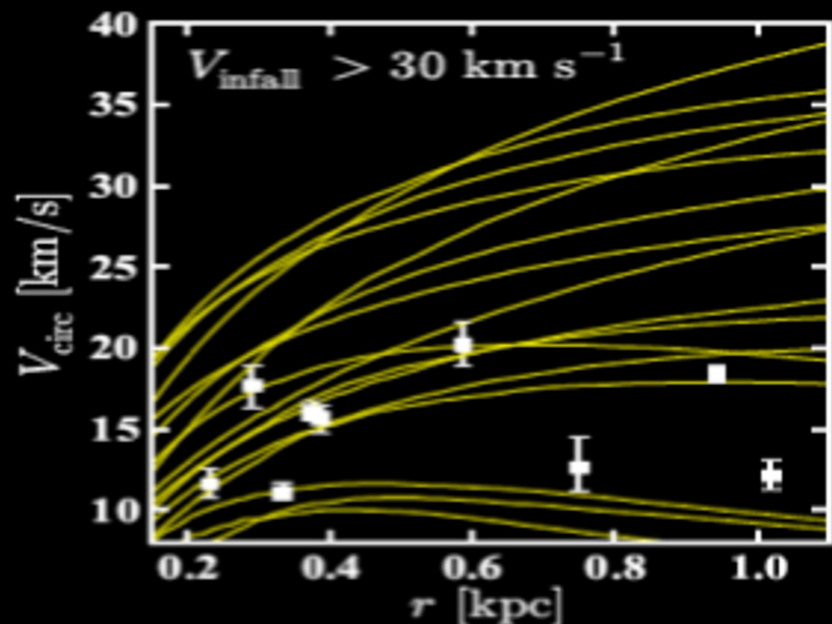


MW halo, CLUES project



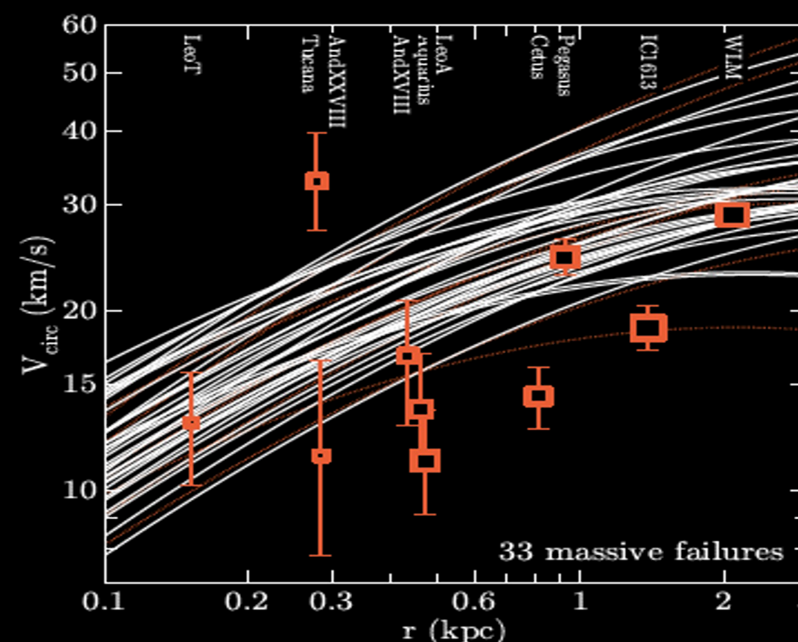
Problem #2 : TBTF in the LG

In satellite galaxies



Boylan-Kolchin +11,+12

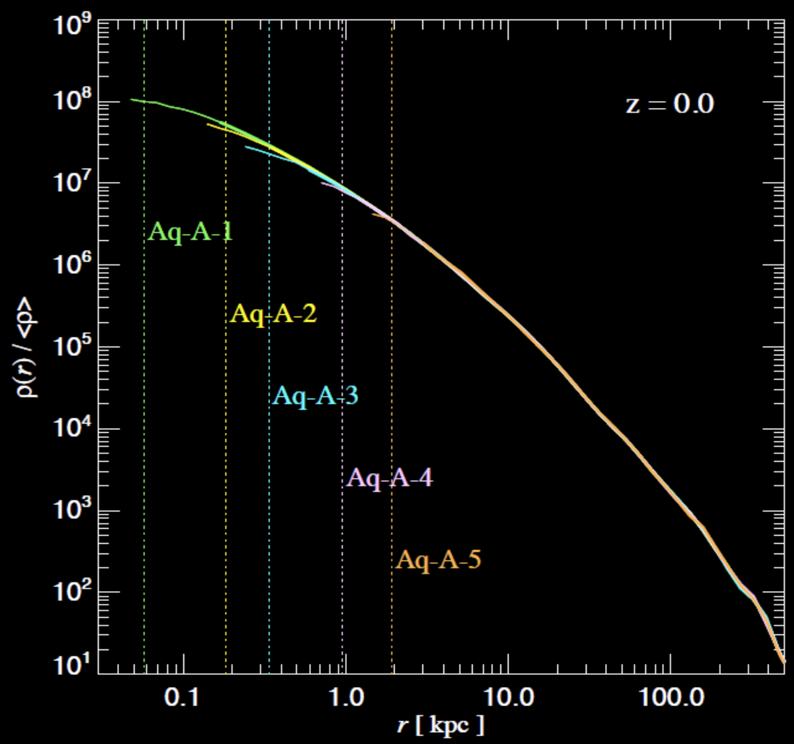
In isolated galaxies



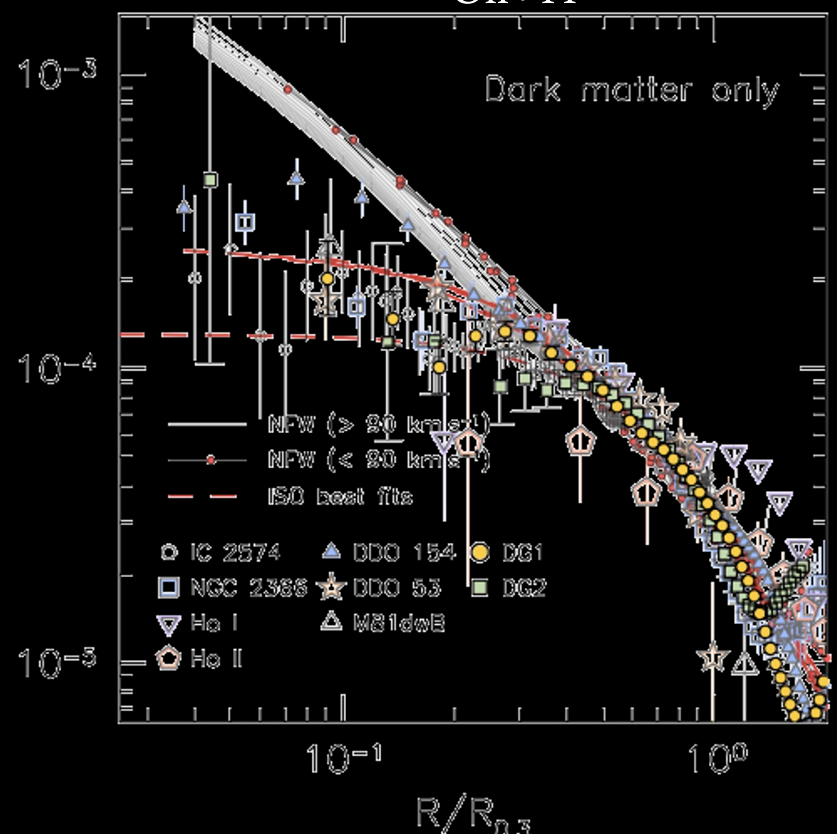
Garrison-Kimmel +14

Problem #3: CUSP-CORE discrepancy

Springel+05



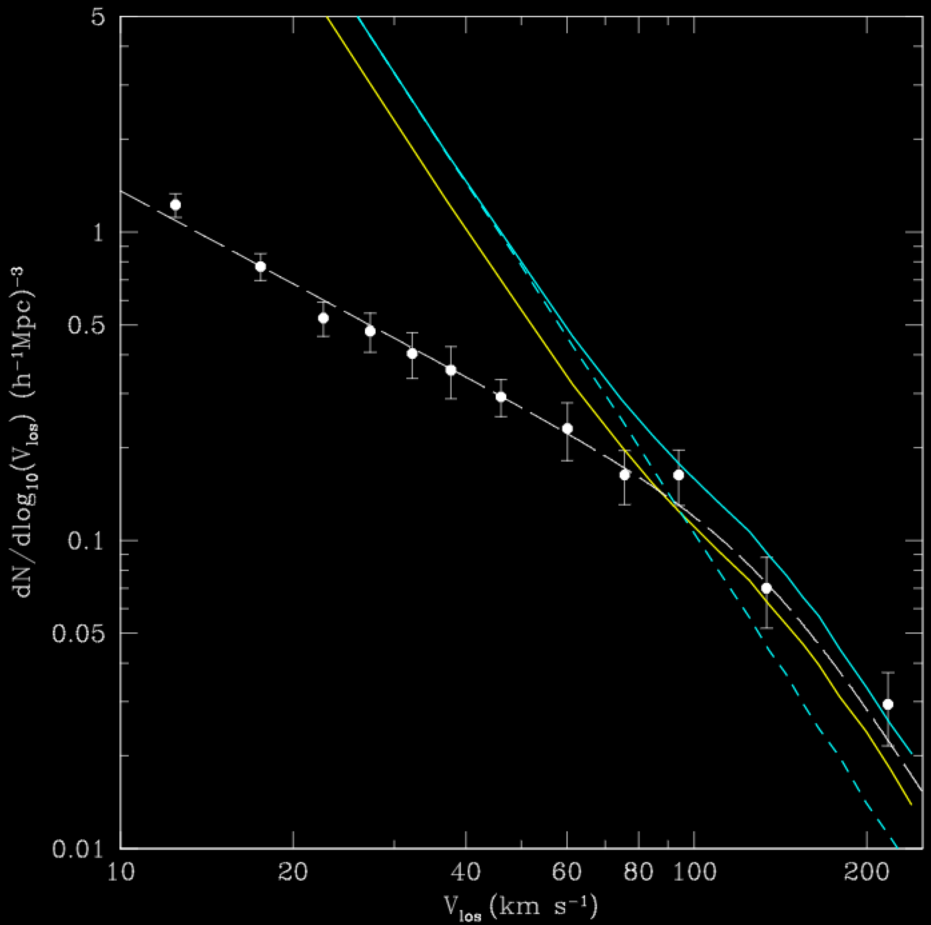
Oh+11



Simulations find 'CUSPY' profiles

Observations show 'CORED' profiles

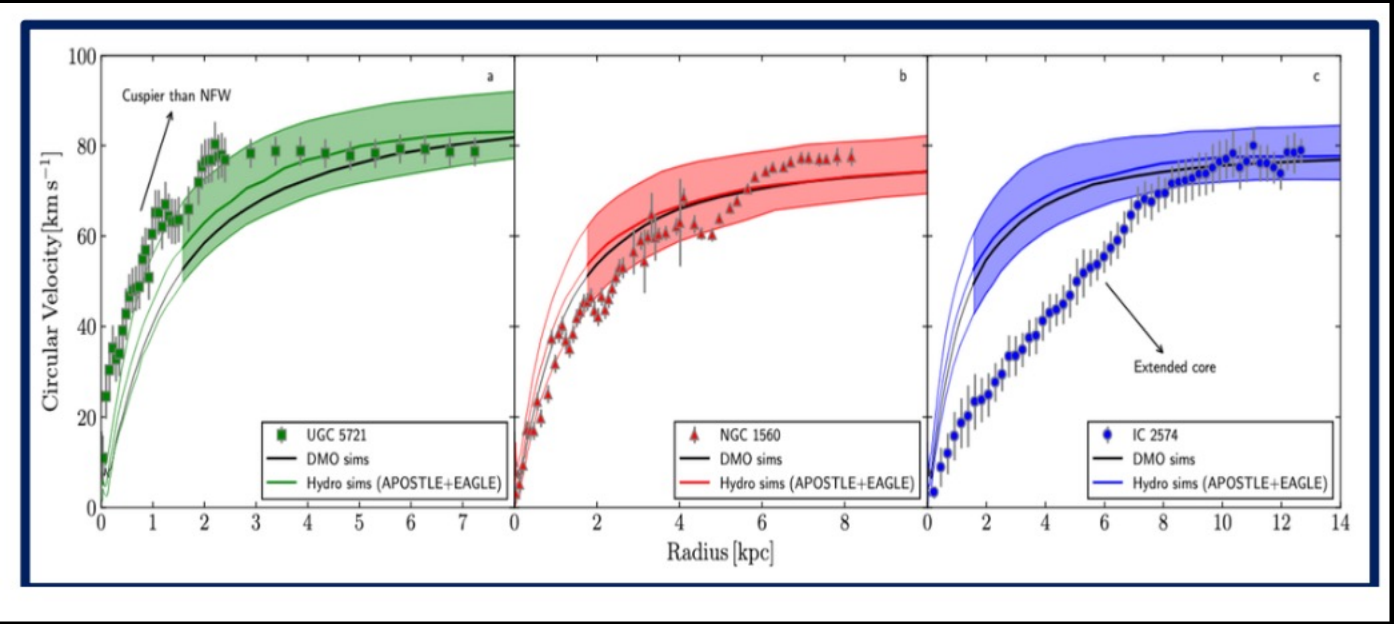
Problem #4 :Velocity function



Klypin+14
Papastergis+11
Zavala+09

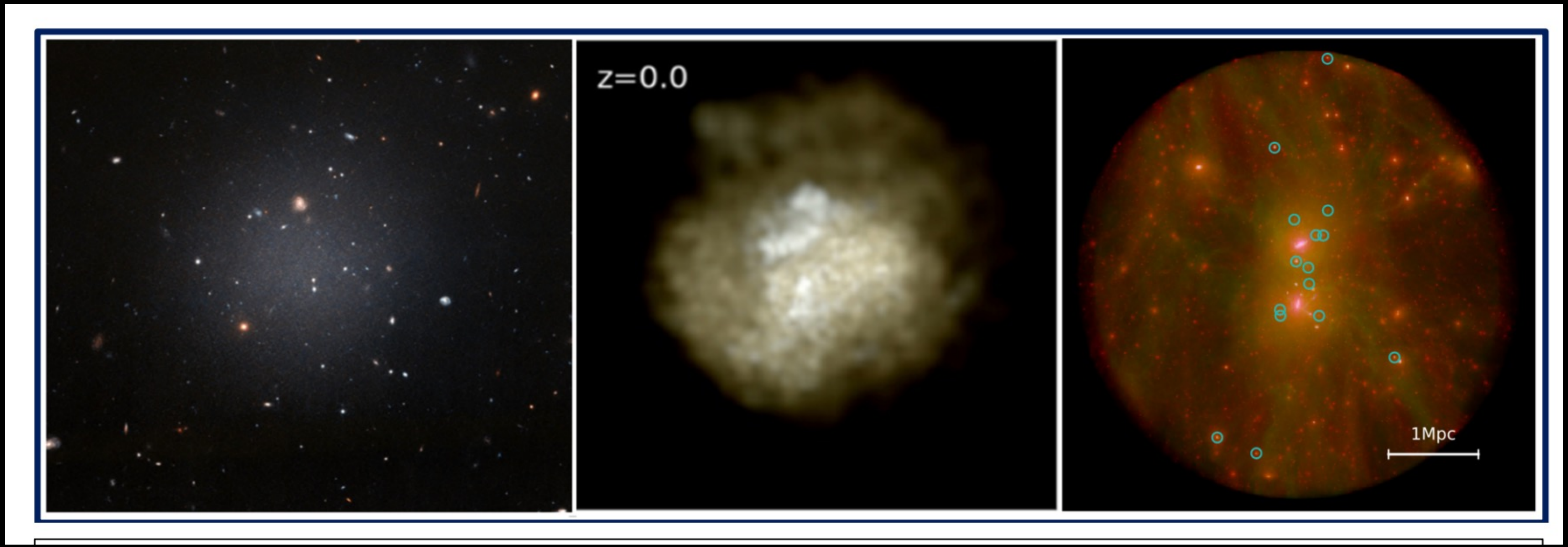
$$V_{rot} = \sqrt{((W50/2/sin(i))^2 - \sigma_v^2)}$$

Problem #5: Diversity of dwarfs RCs



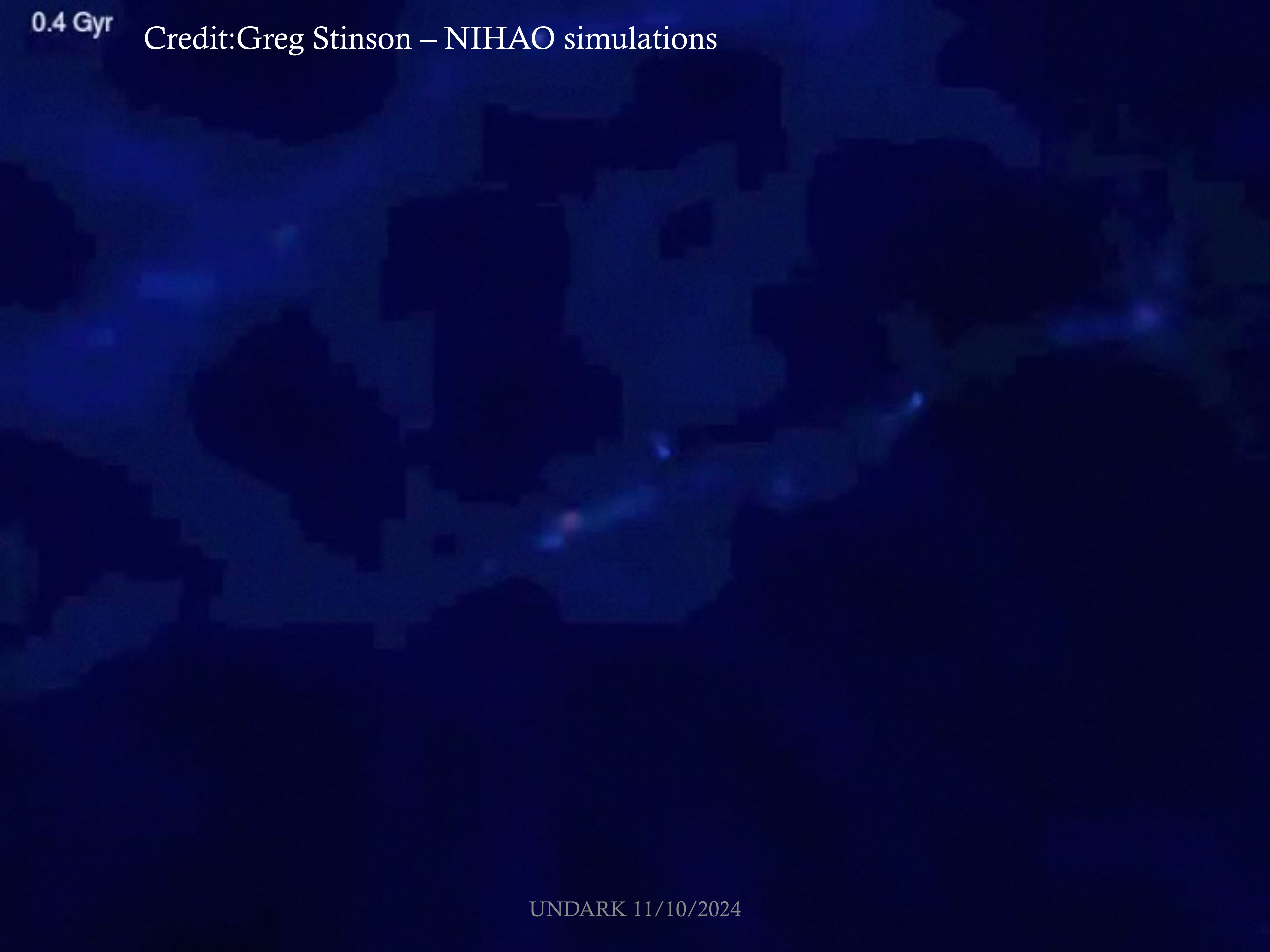
Oman+15

Problem #6: Emergence of UDG/LSB



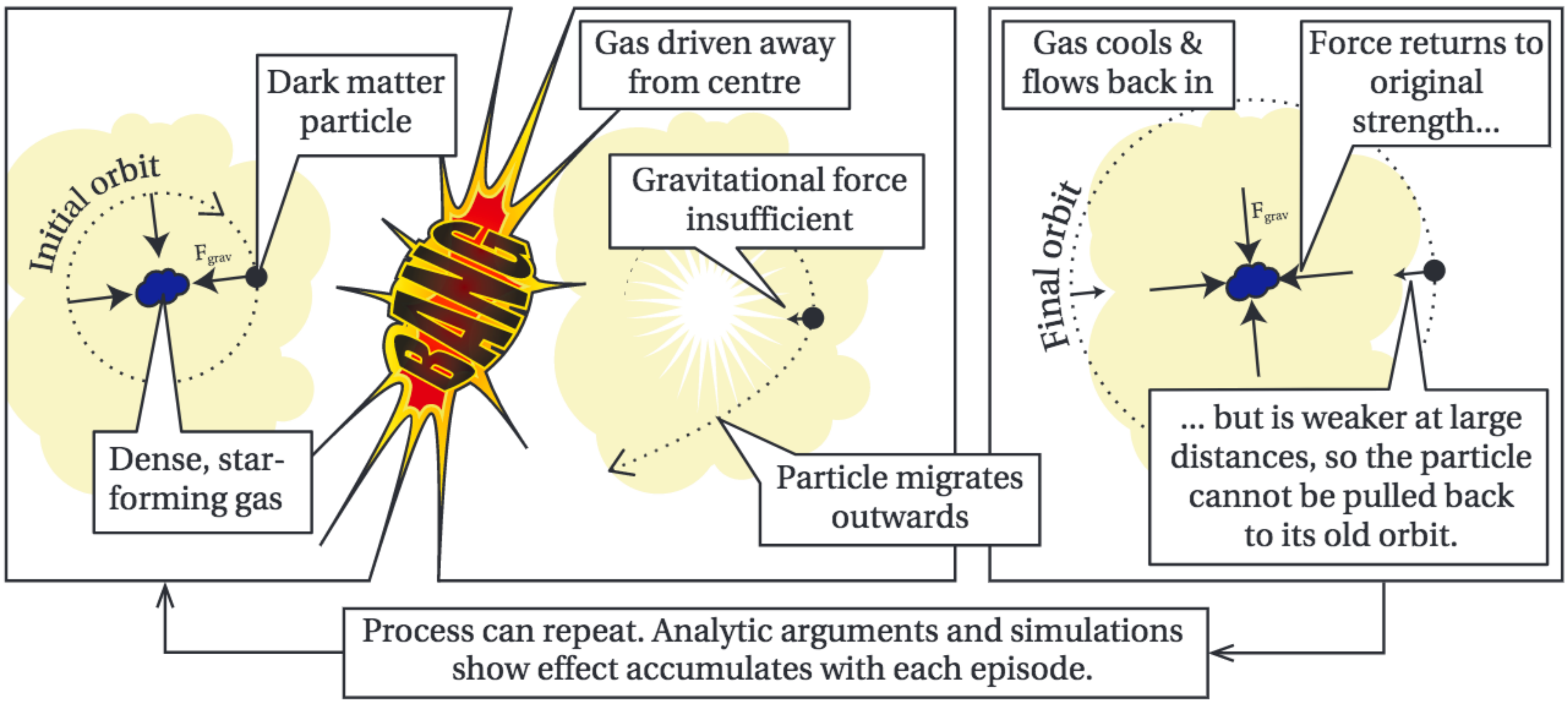
Van Dokkum+15, Trujillo+16,Di CIntio+17

Solution #1:
CDM +baryonic physics



Credit:Greg Stinson – NIHAO simulations

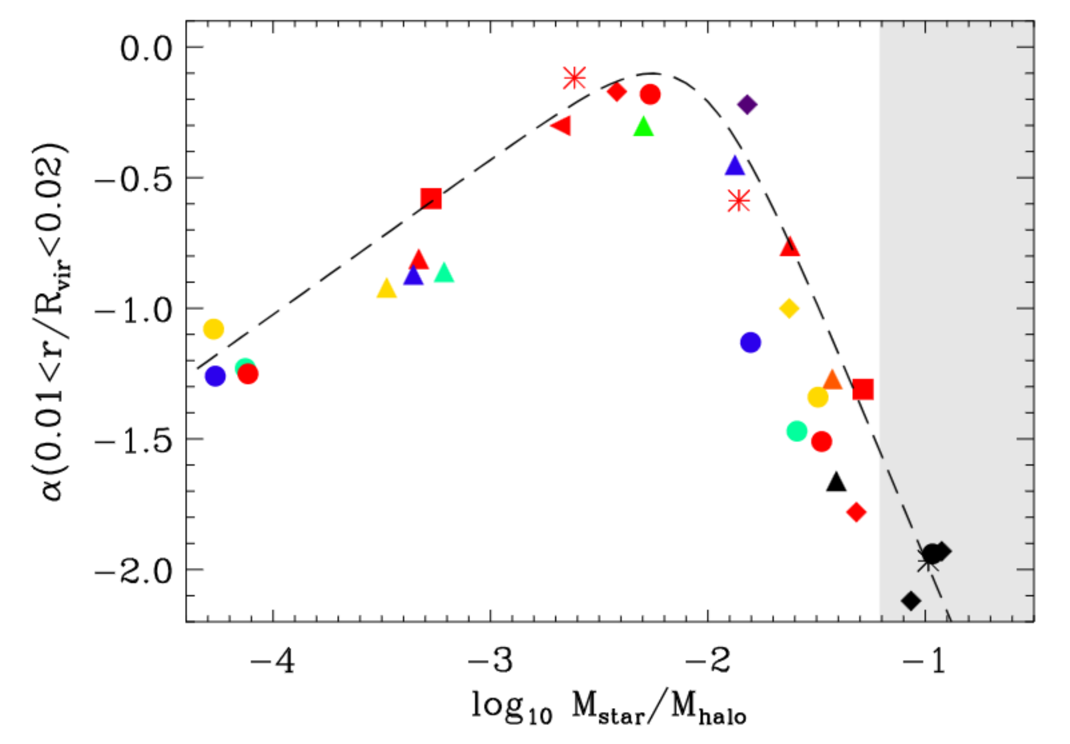
SNae feedback: From gas outflows to DM 'cores'



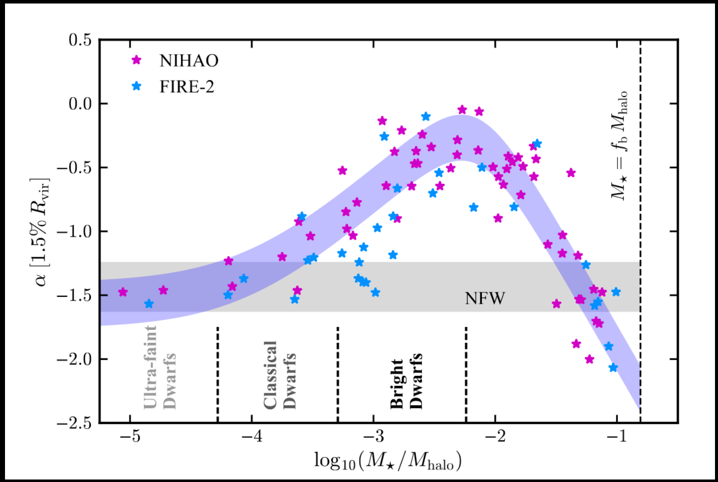
Pontzen & Governato 14

Core formation mechanism -> outflows driven by SNae feedback
Core created during starburst events that launch powerful gas outflows

Sweet spot of core formation



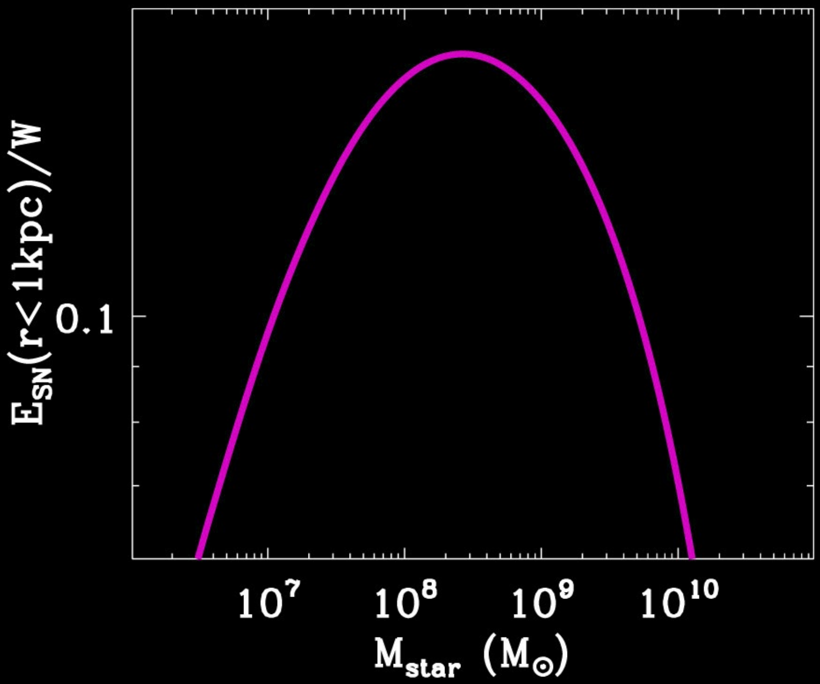
Di Cintio+14 a,b
Chan +15,
Tollet+16
Review by
Bullock & MBK 2017



Small dwarfs not enough energy from stellar feedback to modify NFW halo
Intermediate dwarfs/LSBs correct amount of energy from Snae
Large spirals can not 'win' the large grav potential of $\gamma 10^{12}$ halo with SNae alone

Energetic of core formation

$$\frac{E_{SN}}{W} = \frac{M^{\star}(<1Kpc) \times f_{SN}/\bar{m} \times 10^{51} erg \times \epsilon}{-4\pi G \int_0^{rvir} \rho(r) M(r) r dr}$$



Energy balance between SNe energy and potential energy of NFW halo.
Flattest profiles expected at $M_* \sim 10^{8.5} M_{\odot}$.

Brook & Di Cintio2015a
(see also Penarrubia +2012)

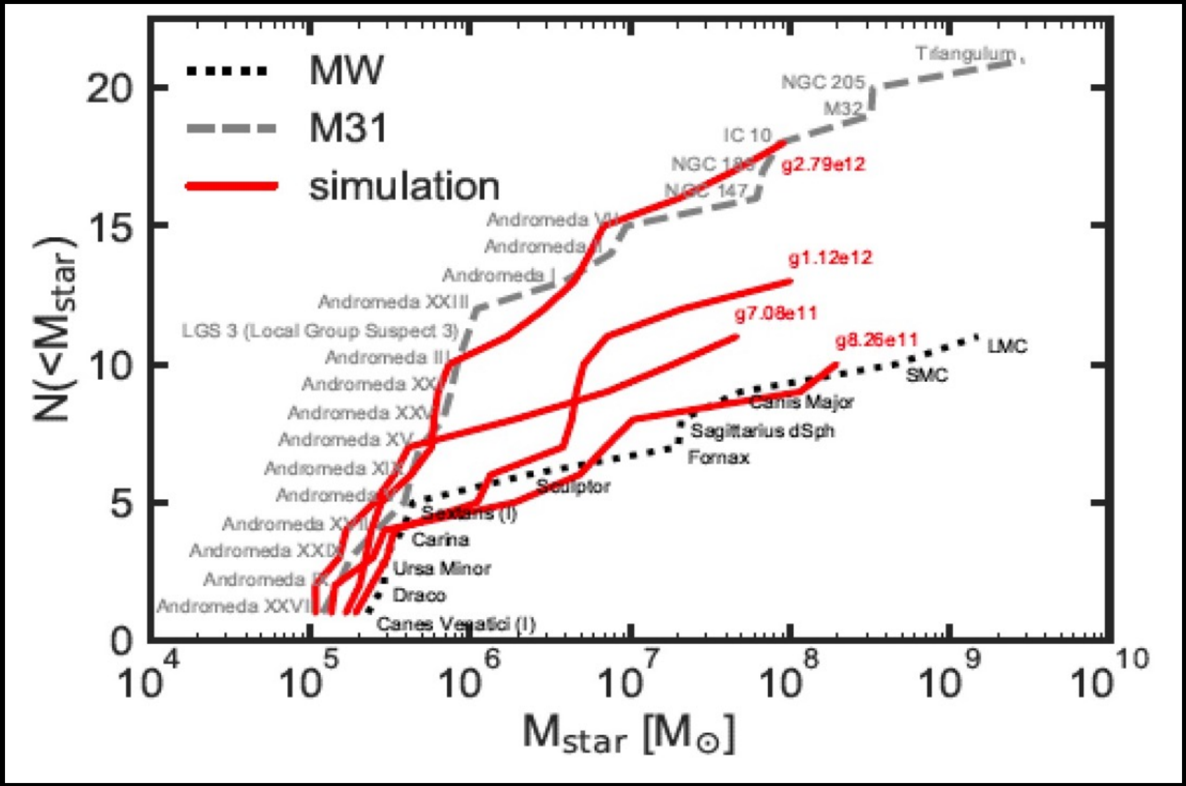
My understanding on core-formation in galaxy sims

CENTRAL dark matter cores from in every hydrodynamical-baryonic simulation that :

- includes SNae feedback
- resolve the star forming regions with high density (n~10-100 amu/cm3)
- has a realistic amount of gas – stars - DM (it follows scaling relations!)
- Has enough resolution to resolve the central 100s of pc of dwarf galaxies

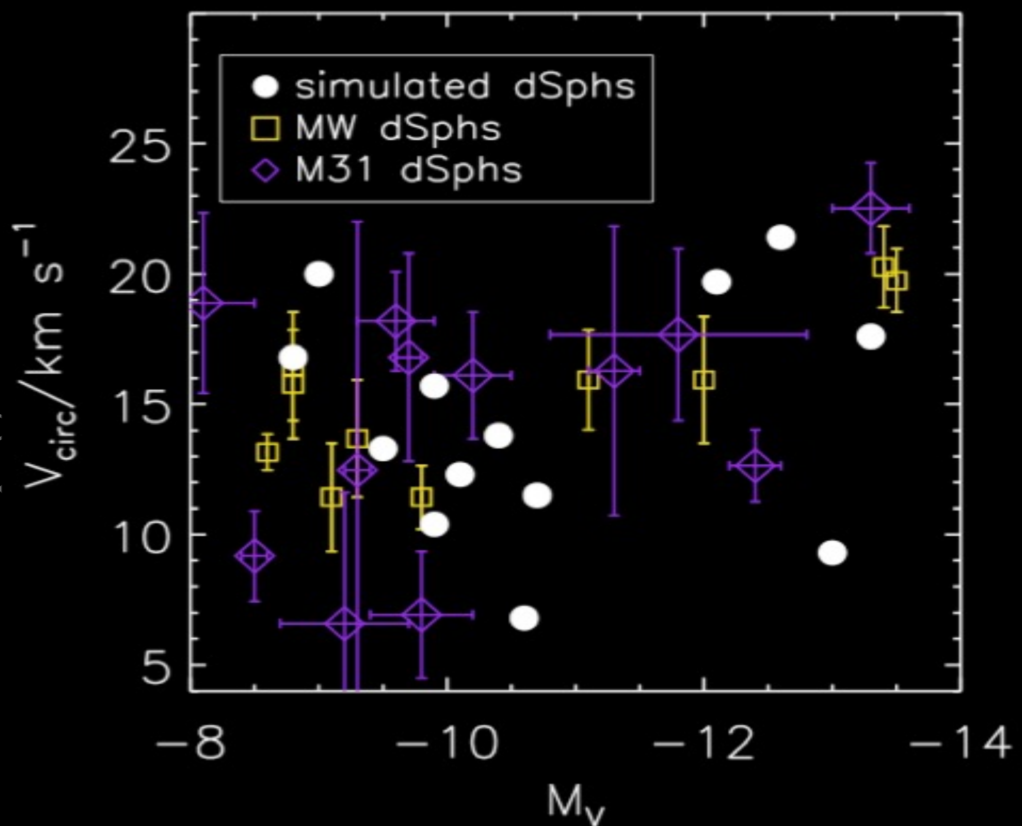
- …some simulations still do not produce cores.. usually because they do not fulfill some of the requirements above

Solution #1: Missing satellites



Buck+18

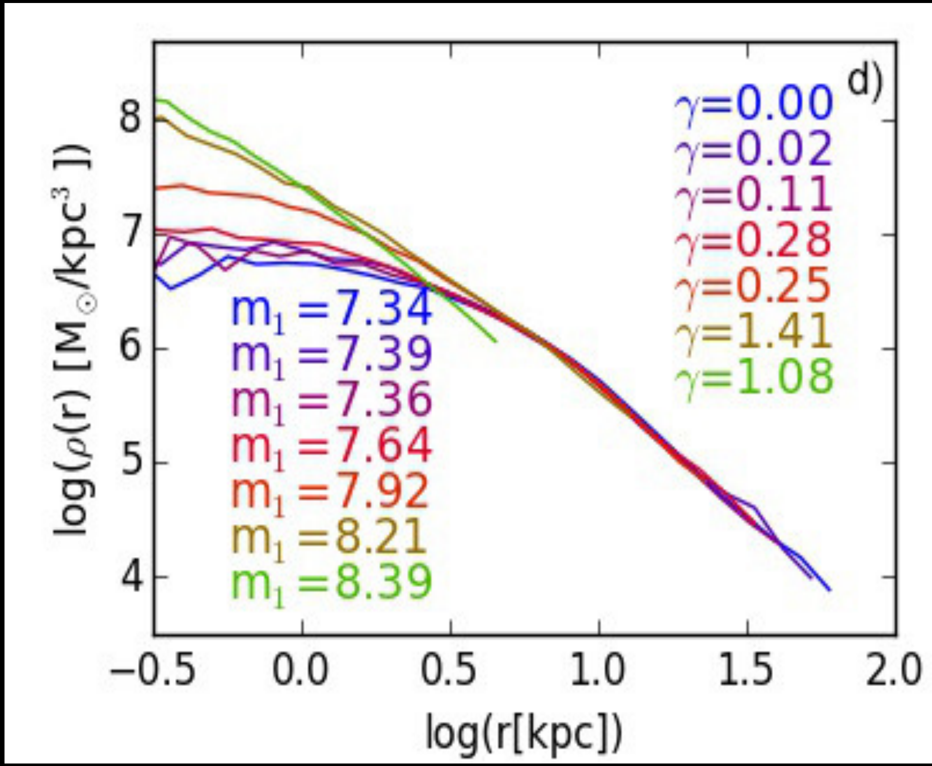
Solution #1: TBTF



Review b
Bullock &

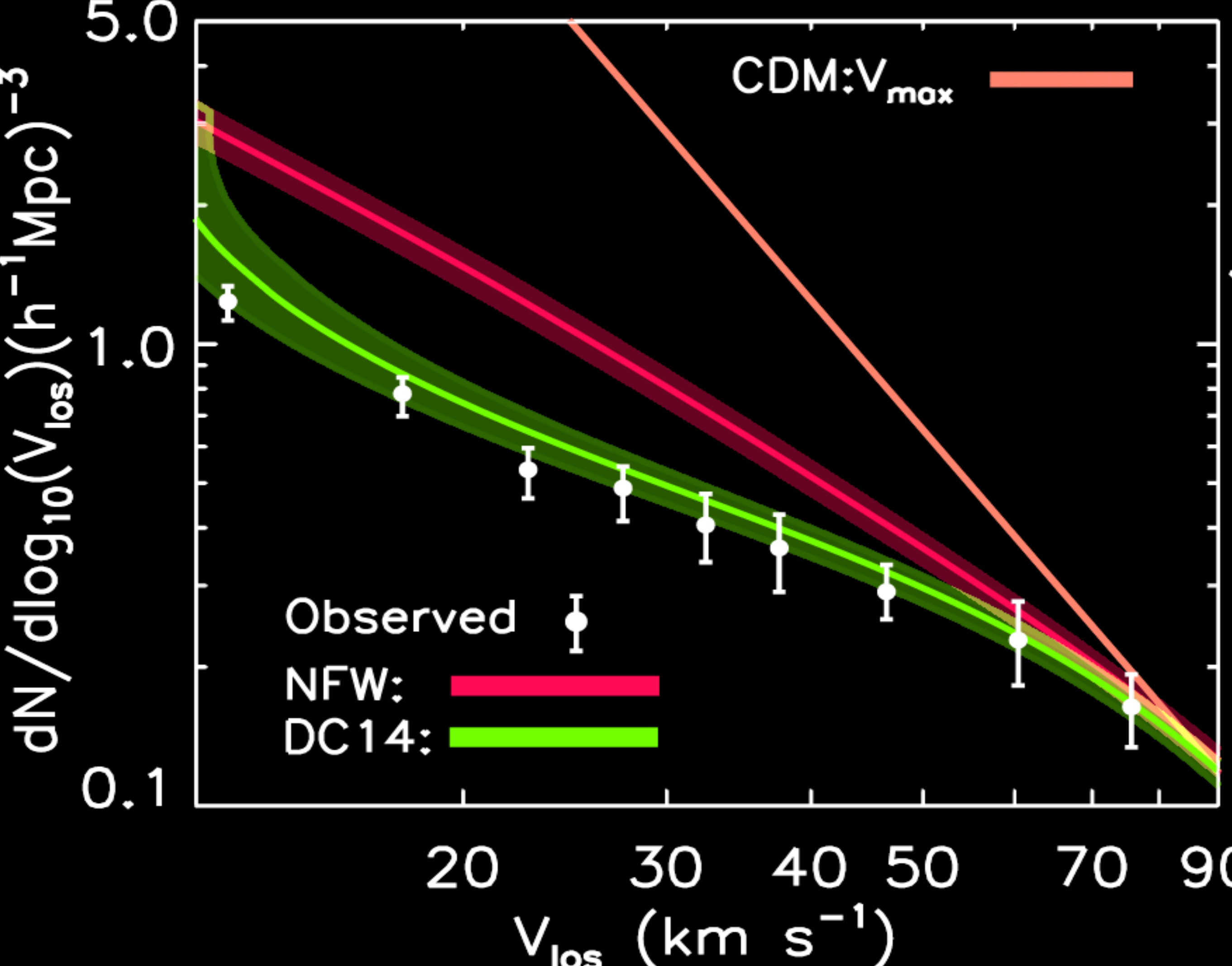
Brooks & Zolotov2014, Brook & Di Cintio 2015a

Solution #1: cusp-core



Governato,Brook+10 Nature
Di Cintio 2014a,b
Chan+18 etc.

Solution #1: galaxy velocity function



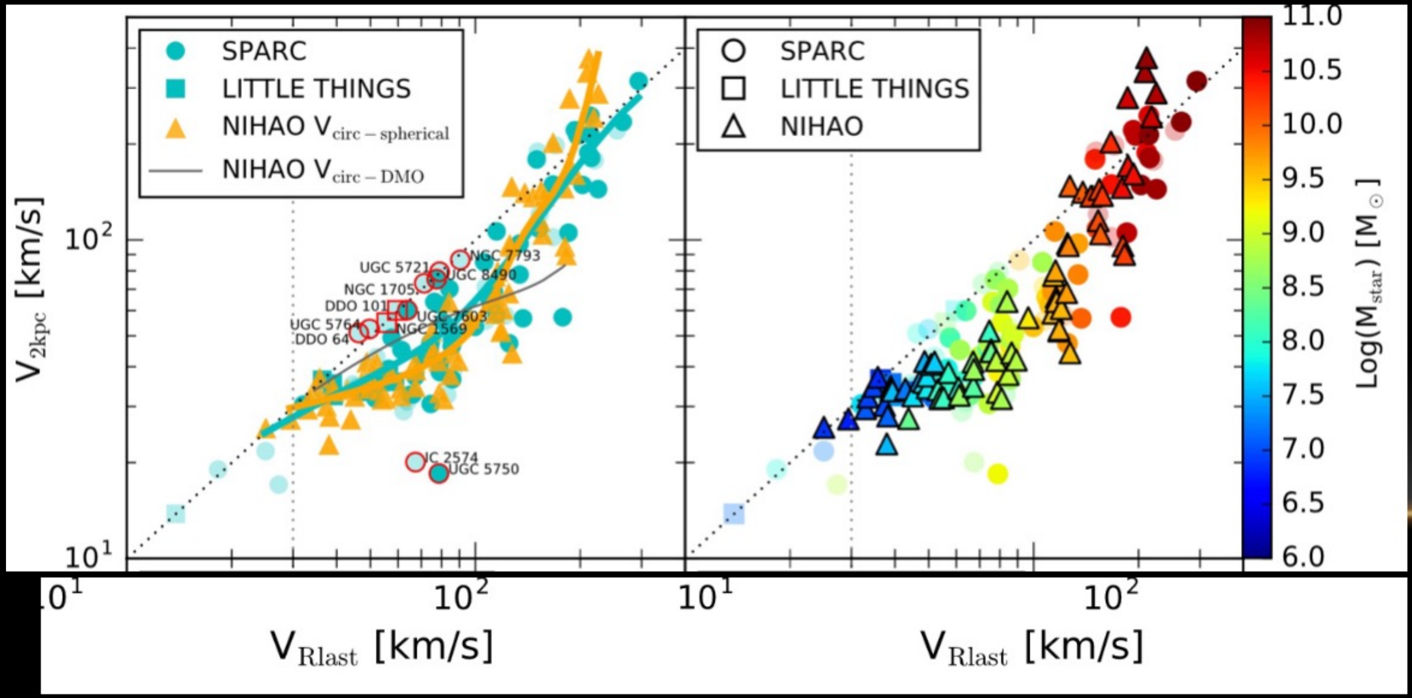
Brook & Di Cintio 15b
Di Cintio 14b

Modelling DM haloes with a mass dependent profile (DC14)

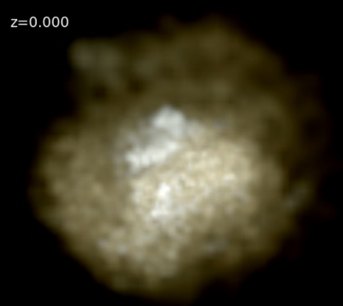
See also Papastergis+15

Solution #1: diversity of RCs

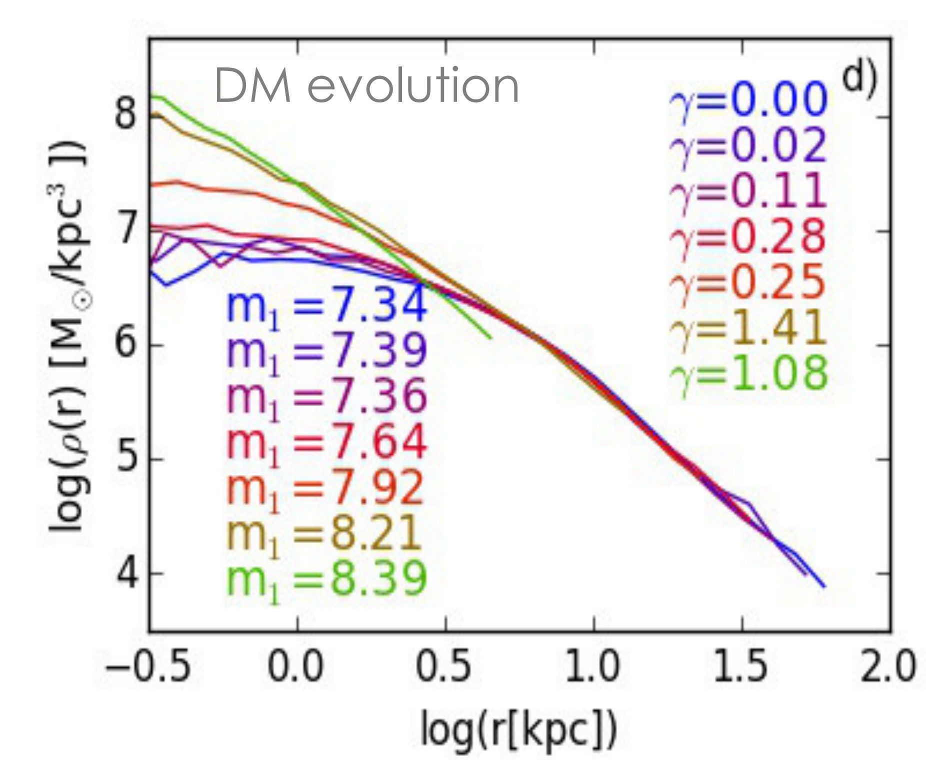
- Santos-santos,ADC et al, 2018

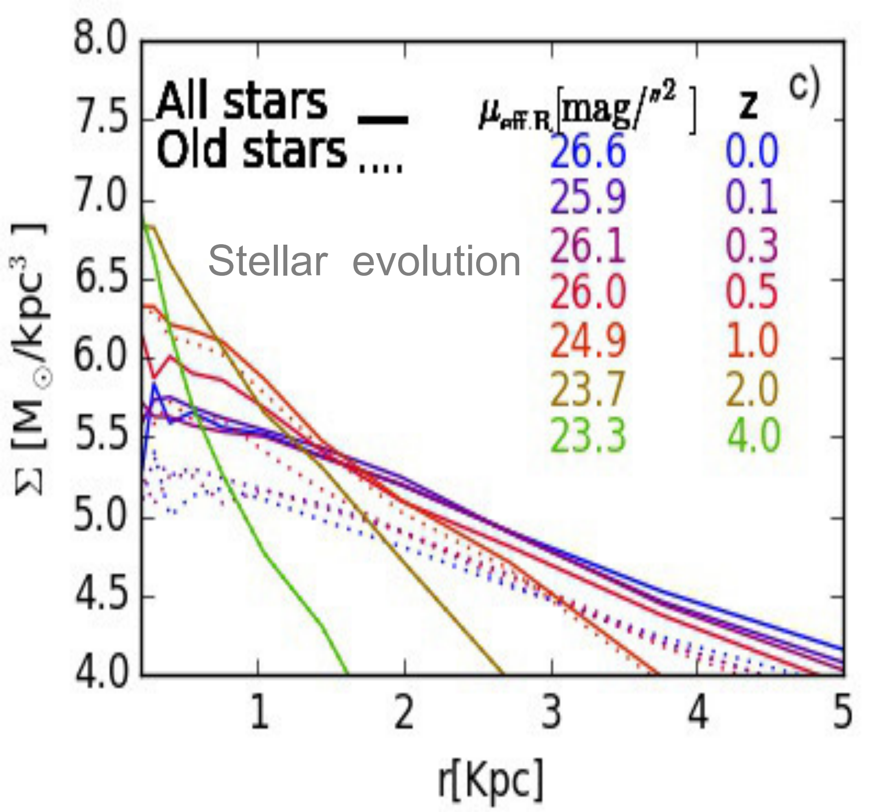


Solution #1: emergence of UDGs



Solution #1: emergence of UDGs

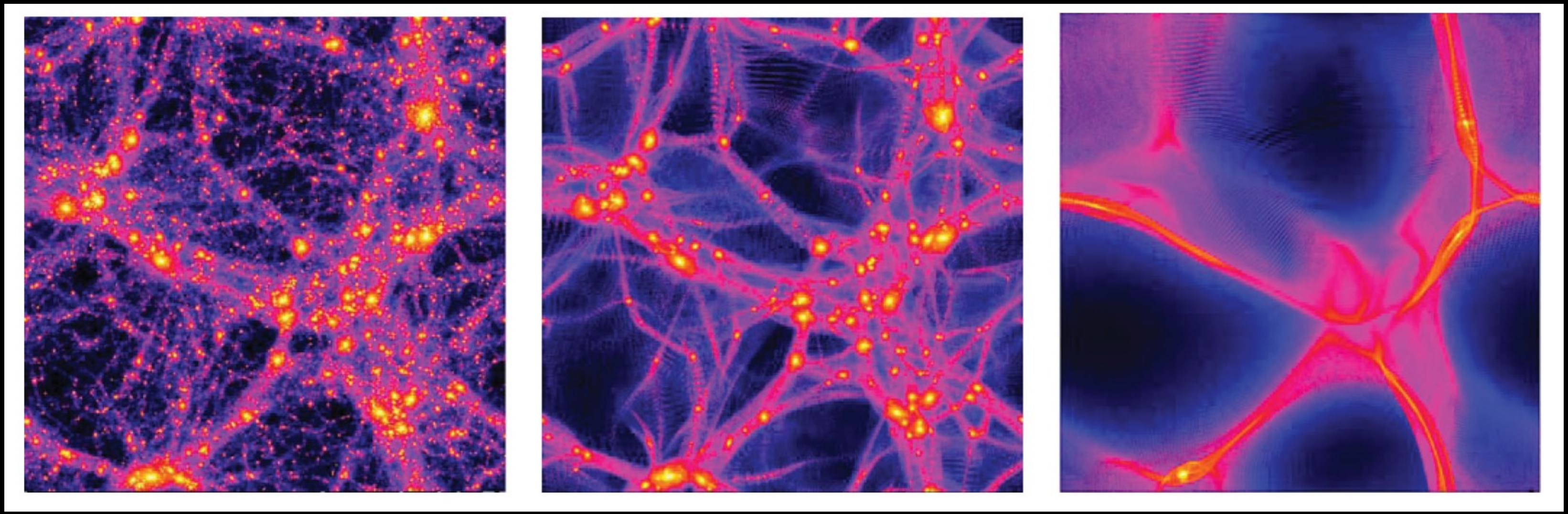




Di Cintio +17 using NIHAO sims

Solution #2: Alternative DM models

TBTF & cusp-core in Warm Dark Matter



To solve the TBTF problem with WDM we need to create cores of ~Kpc size, which requires a thermal candidate with a mass below 0.1 keV, ruled out by all large scale structure constraints => This would fully prevent the formation of the dwarf galaxy in the first place (see Schneider+15, Maccio'+12)

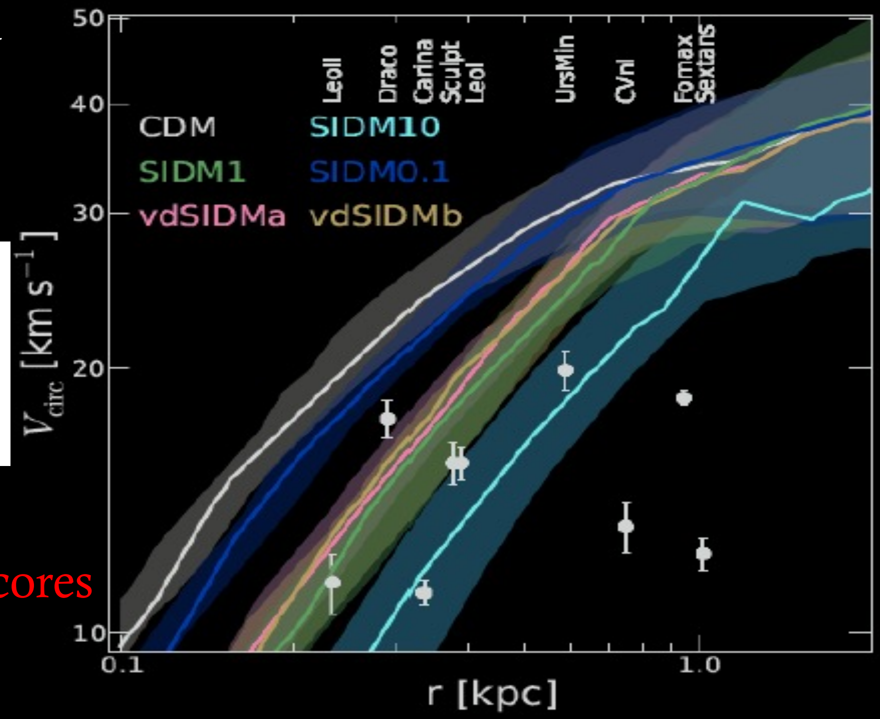
Solution #2: Alternative DM models

TBTF in Self Interacting Dark Matter

Zavala+13

Self-interactions lower the central density alleviating TBTF problem
Vogelsberger+12, Zavala+13, Rocha+12

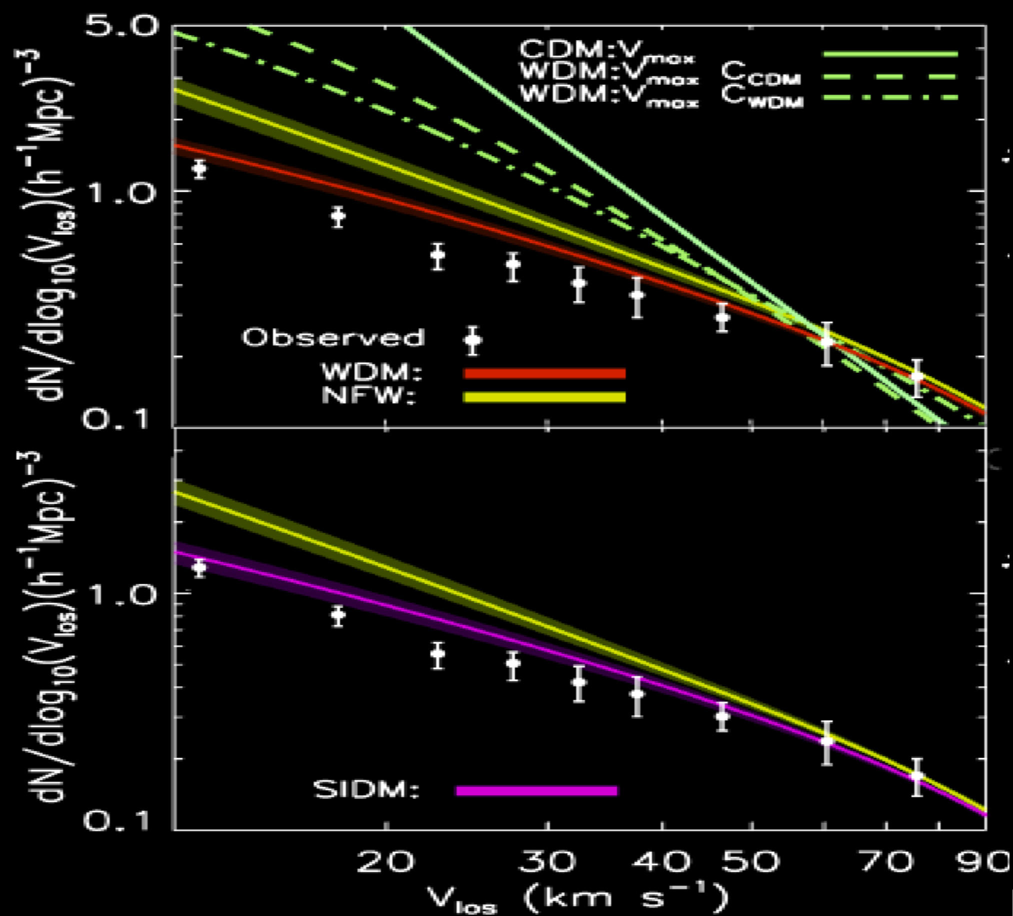
$$\rho v \sim 1/(t\sigma)$$



σ/m>=1 cm²/g in dwarf galaxy to create cores

Solution #2:Alternative DM models

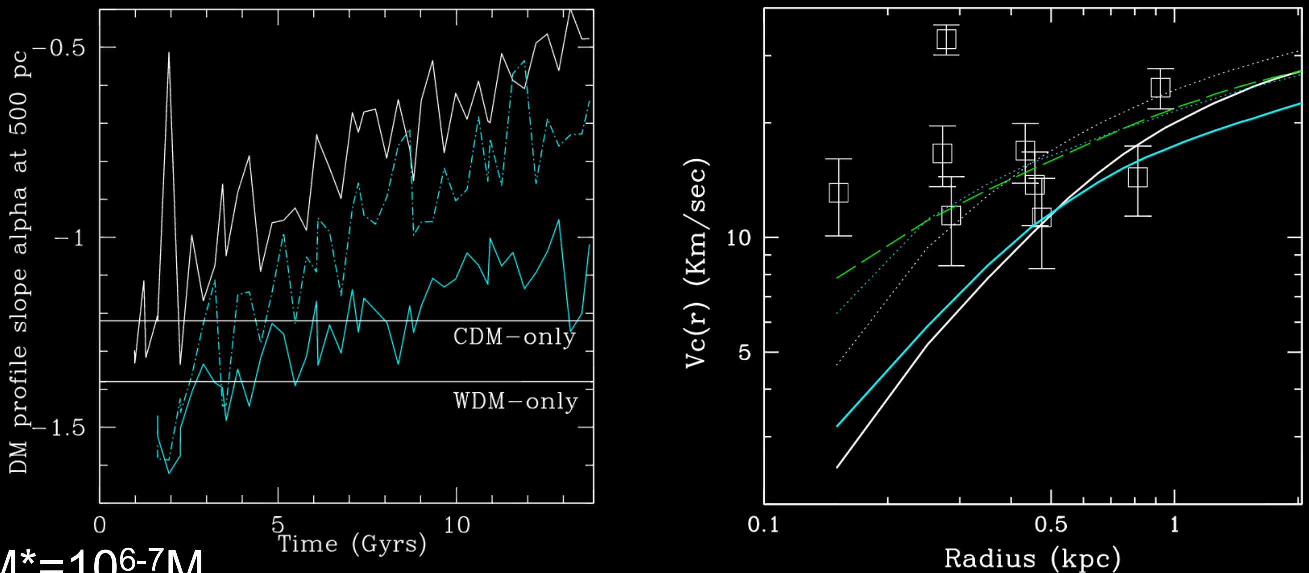
Velocity Functions and TF relation in 2 keV WDM and SIDM model



Brook & Di Cintio 15

Solution #3: WDM+baryons

WDM-2 keV- model. → Same Vcirc distribution in CDM and WDM solving TBTF



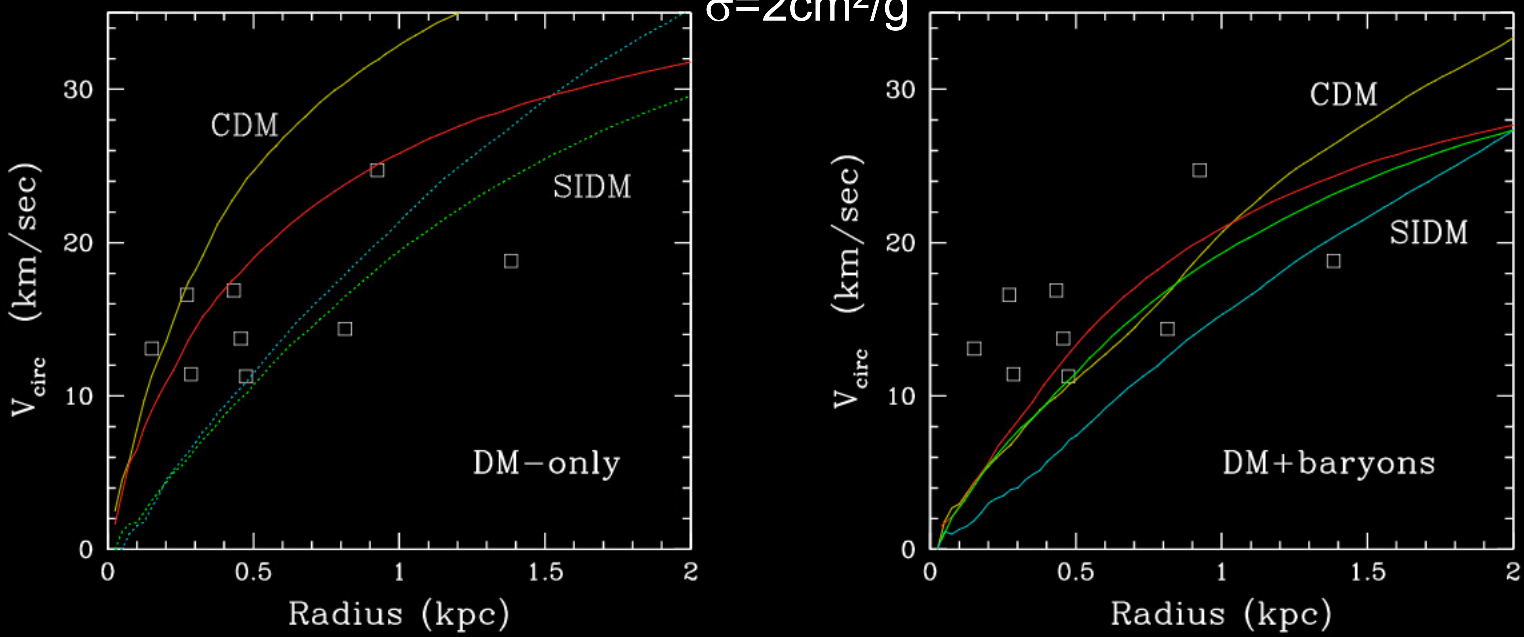
$M^* = 10^{6\text{-}7} M_{sun}$
$M_{halo} = 10^{10} M_{sun}$

Governato +15

Solution #3: SIDM+baryons

SF and resulting feedback dominates over SI: dm inner slope, SFH, star and gas content are indistinguishable between CDM and SIDM+baryons

σ=2cm²/g

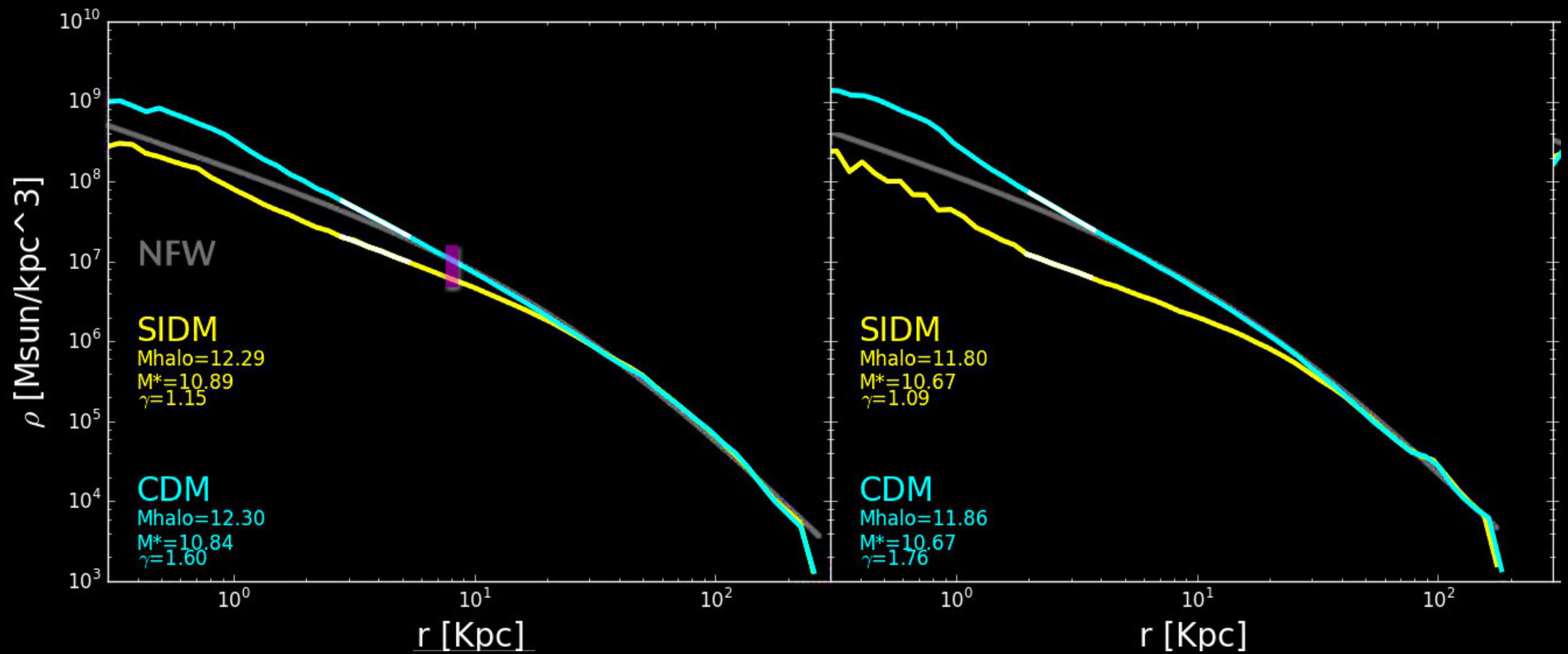


Bastidas-Fry, Governato +15

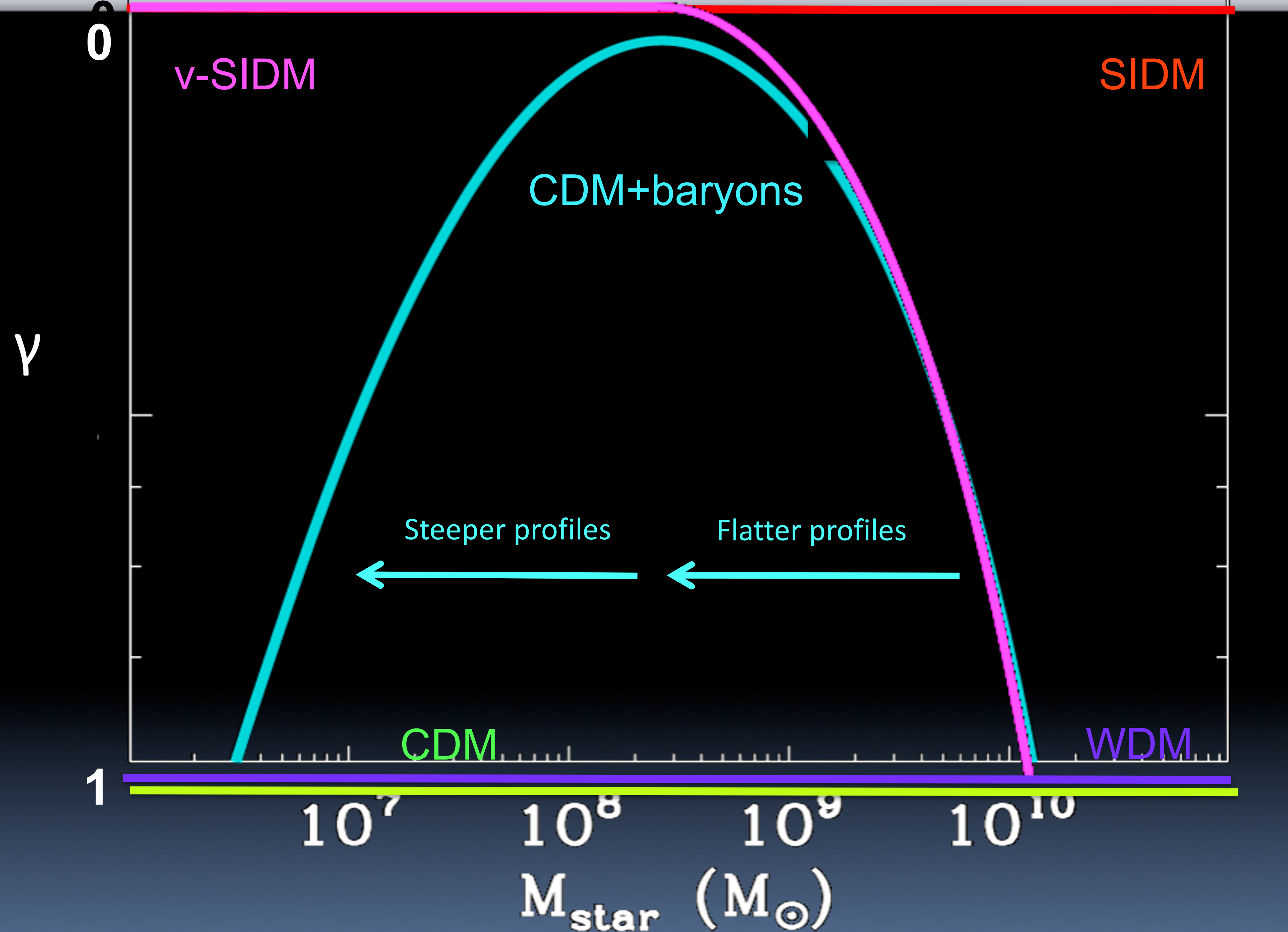
Solution #3: SIDM+baryons

SIDM cores wins over adiabatic contraction in MW galaxies
Massive spirals have a lower DM density in SIDM at 20 kpc!

SIDM $\sigma/m=10\ cm^2/g$ vs CDM
Baryons +BH physics + SNae

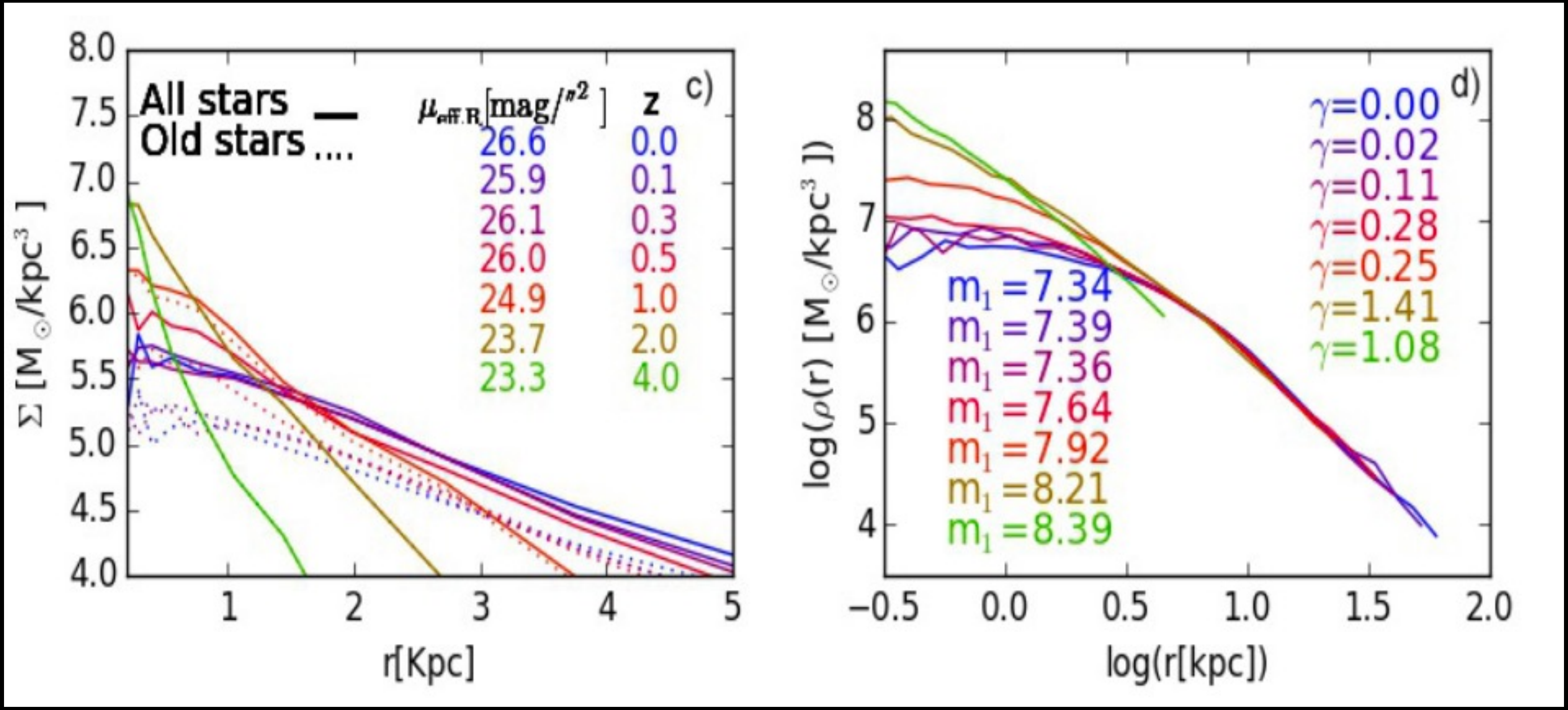


Di Cintio+ 17 b



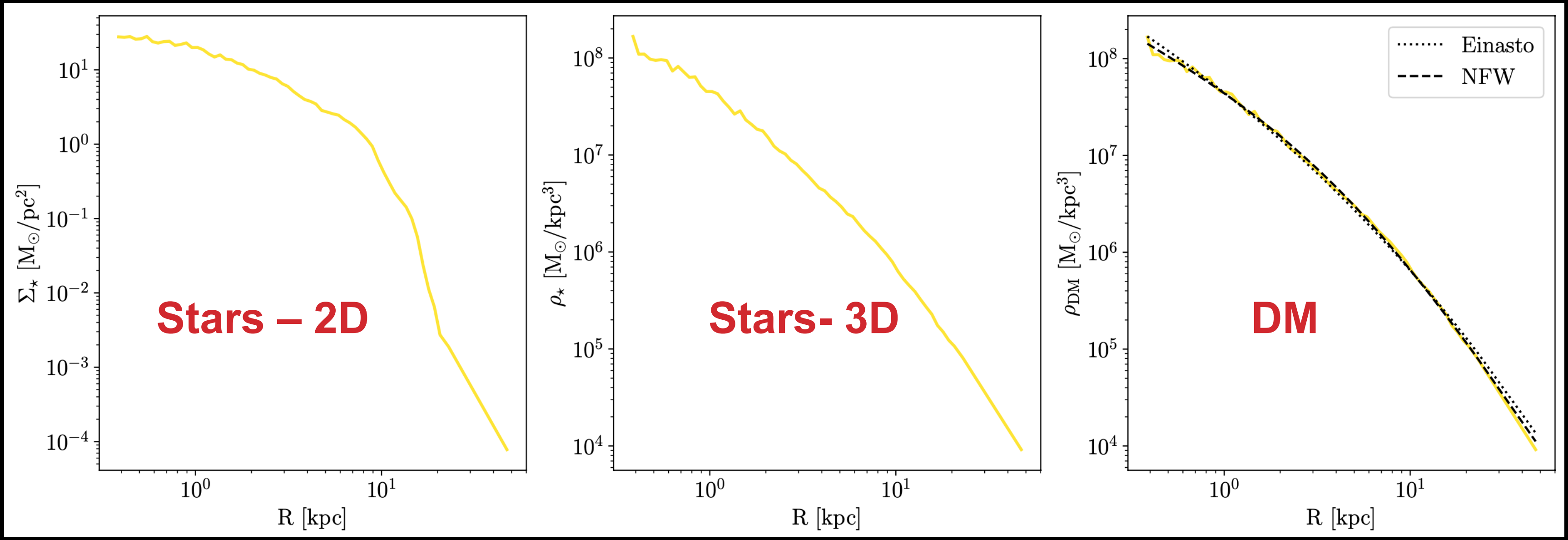
Study the mass dependence of cusp/core over the full galaxy mass

Does light follow the potential of DM?



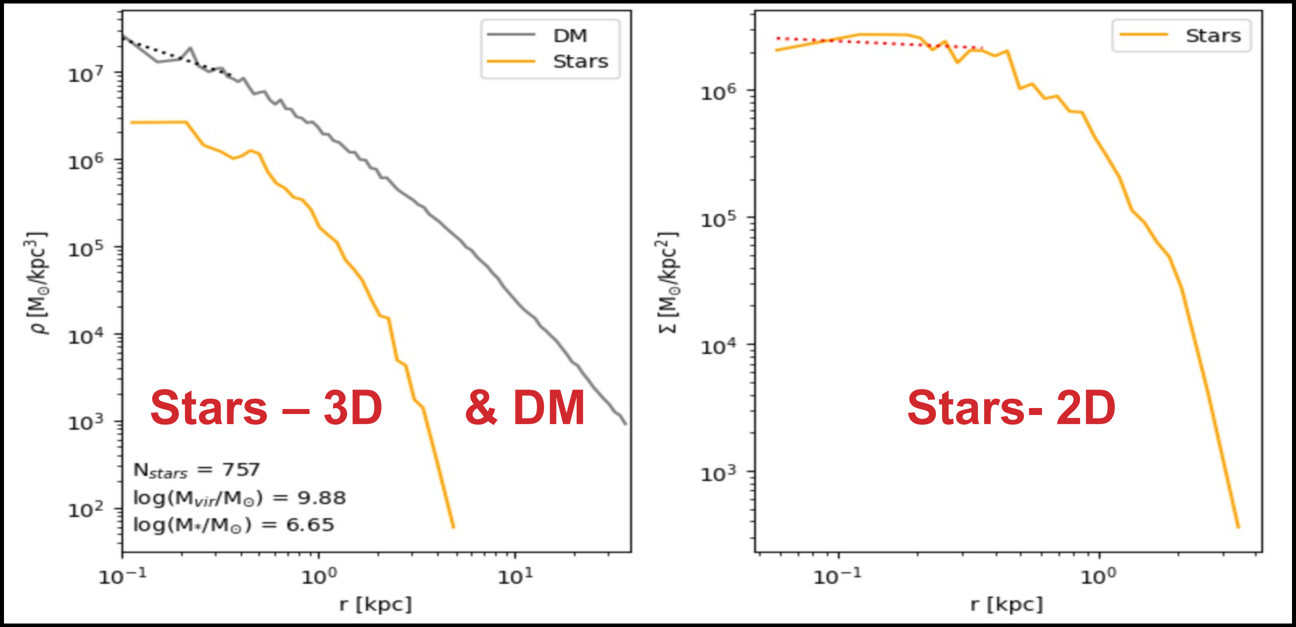
Di Cintio+17

Can stellar "cores" live in DM "cusps"?



HESTIA sims=>produce UDG galaxies with large Reff but central DM cusps
Yet stellar cores are visible in 2d projected light distribution
Arjona-Galvez +in prep

Can stellar “cores” live in DM “cusp”?



FIRE sims=> Sarrato + in prep
stellar cores are visible in 2d projected light distribution

Take home points

- Finding **cores in 2d stellar distributions** is not a smoking gun of having a central DM core!

It can be **explained by projection effects** within a standard ΛCDM + baryonic simulation

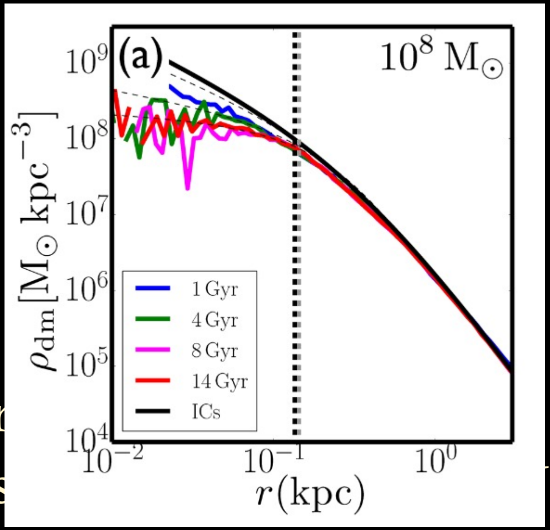
Take home points

- To invalidate CDM + baryonics physics we need a **bona-fide DM core in UFD galaxies**, where the effect of baryonic physics are negligible

- BUT!!

Dark matter cores all the way down

J. I. Read,[1★] O. Agertz[1★] and M. L. M. Collins[1,2★†]



Dark matter cores of size comparable to the stellar radius r1/2 always form if star formation proceeds if SMALL haloes – 10^8 with 10^4 stars!!

'pristine' dark matter cusps will be found either in systems that have truncated star formation and/or at radii r > r1/2

Conclusions

- Global properties of galaxies to get the mass dependence of core formation → help disentangle DM models?

- **So far NO sign at all of ΛCDM failing at small scales=> no need for alternative DM physics!**