Title: Re-Examining Astrophysical Constraints on the Dark Matter Model

Date: Dec 09, 2014 01:00 PM

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Abstract: The cosmological model based on cold dark matter (CDM) and dark energy has been hugely successful in describing the observed evolution and large scale structure of our Universe. However, at small scales (in the smallest galaxies and at the centers of larger galaxies), a number of observations seem to conflict with the predictions CDM cosmology, leading to recent interest in Warm Dark Matter (WDM) and Self-Interacting Dark Matter (SIDM) models. These small scales, though, are also regions dominated by the influence of baryons. I will present results from high resolution cosmological galaxy simulations that include both baryons and dark matter to show that baryonic physics can significantly alter the dark matter structure and substructure of galaxies, revolutionizing our expectations for galaxy structure and influencing our interpretation of the Dark Matter model.

Re-Examining Astrophysical Constraints on the Dark Matter Model

Alyson Brooks
Rutgers, the State University of New Jersey

In collaboration with the University of Washington's N-body Shop™
makers of quality galaxies

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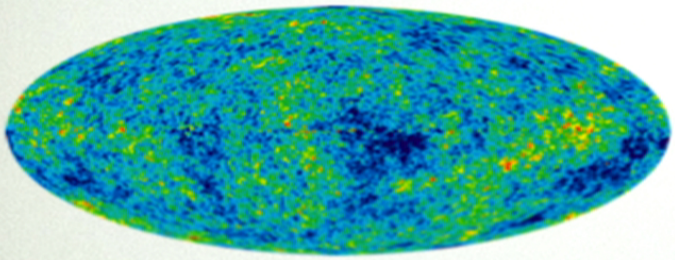
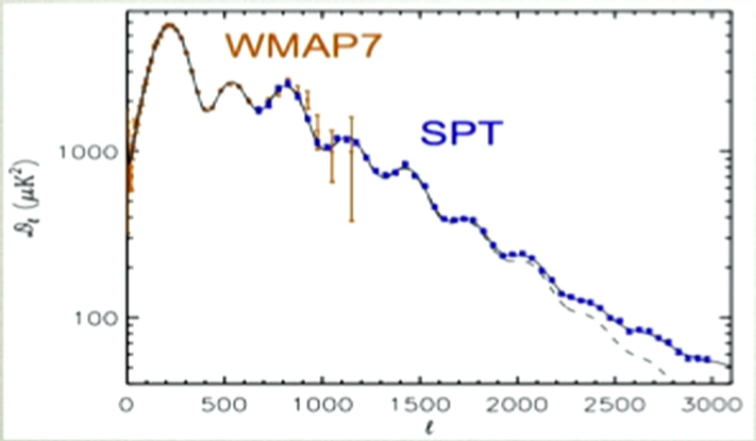
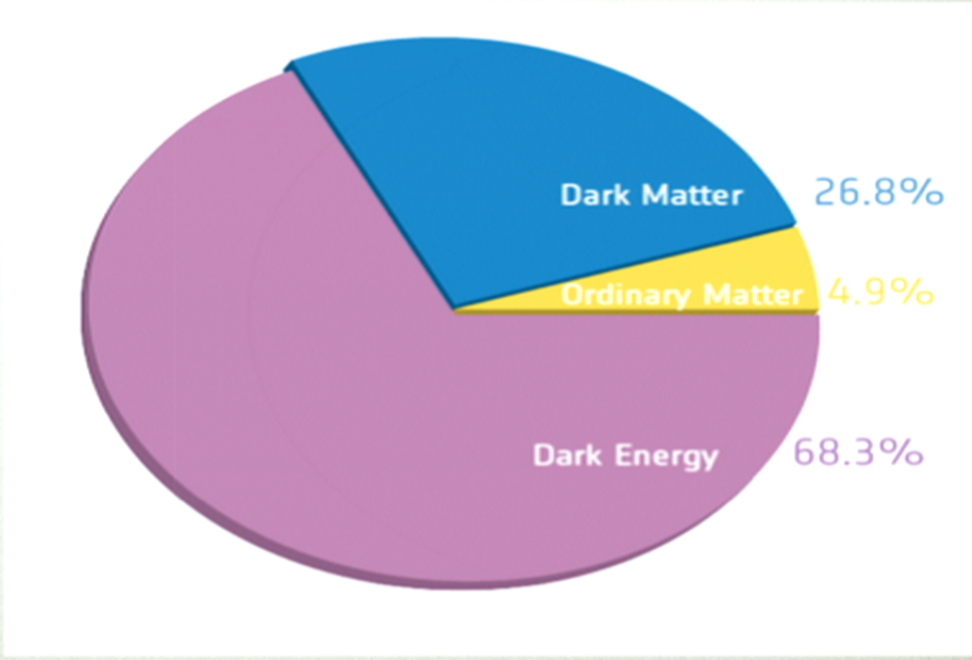
Most of the Universe is Unknown Stuff

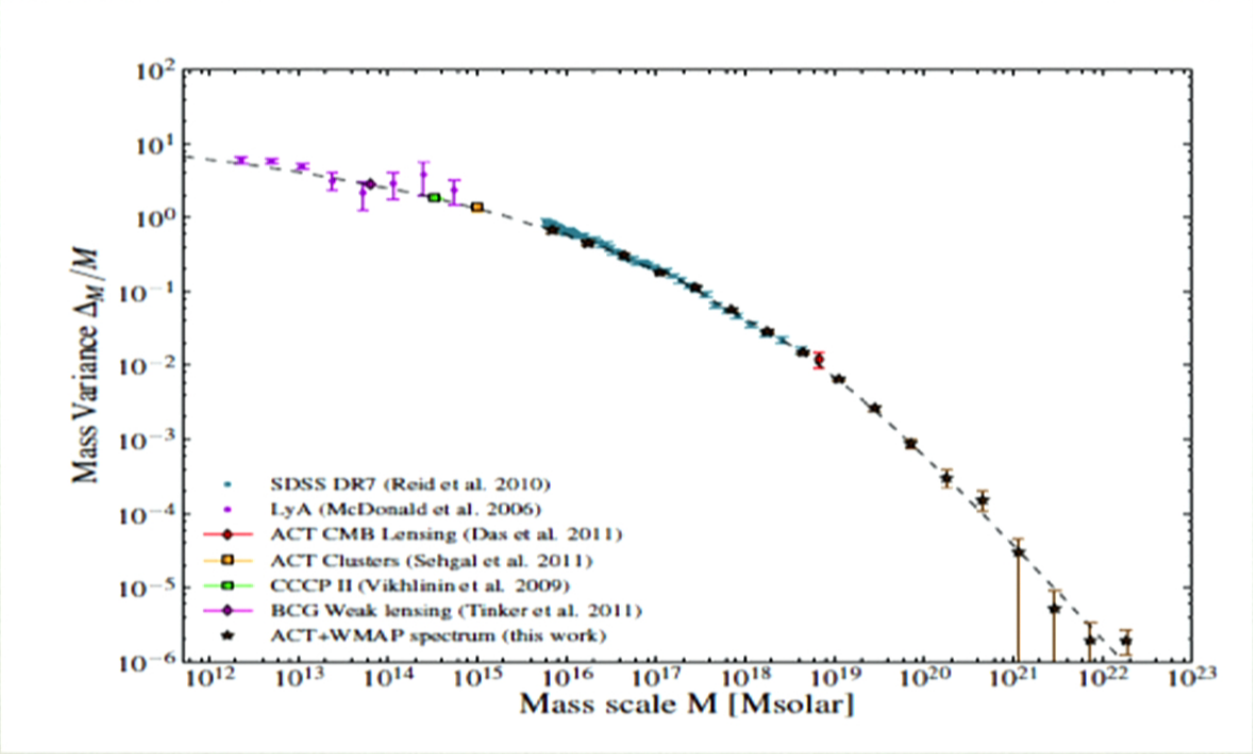






images courtesy of WMAP/Planck webpages

CDM is an Excellent Model for the Large Scale Structure of the Universe



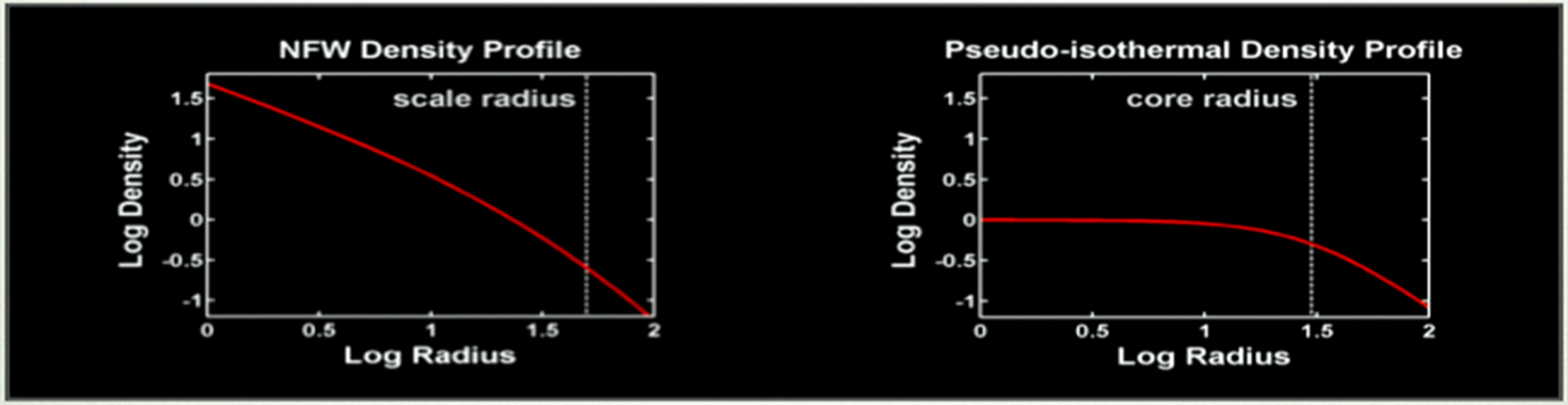
Hlozek et al. (2012)

But...

The Small Scale "Crisis" of CDM

- The cusp / core problem
- Bulge-less disk galaxies
- The "Missing Satellites" problem
- The "Too Big to Fail" (dense satellites) problem

The Cusp/Core Problem



Parameterize density profile as $\varrho(r) \propto r^{-\alpha}$

Simulations predict $\alpha \sim 1$ (central cusp)

Observations show $\alpha \sim 0$ (constant-density core)

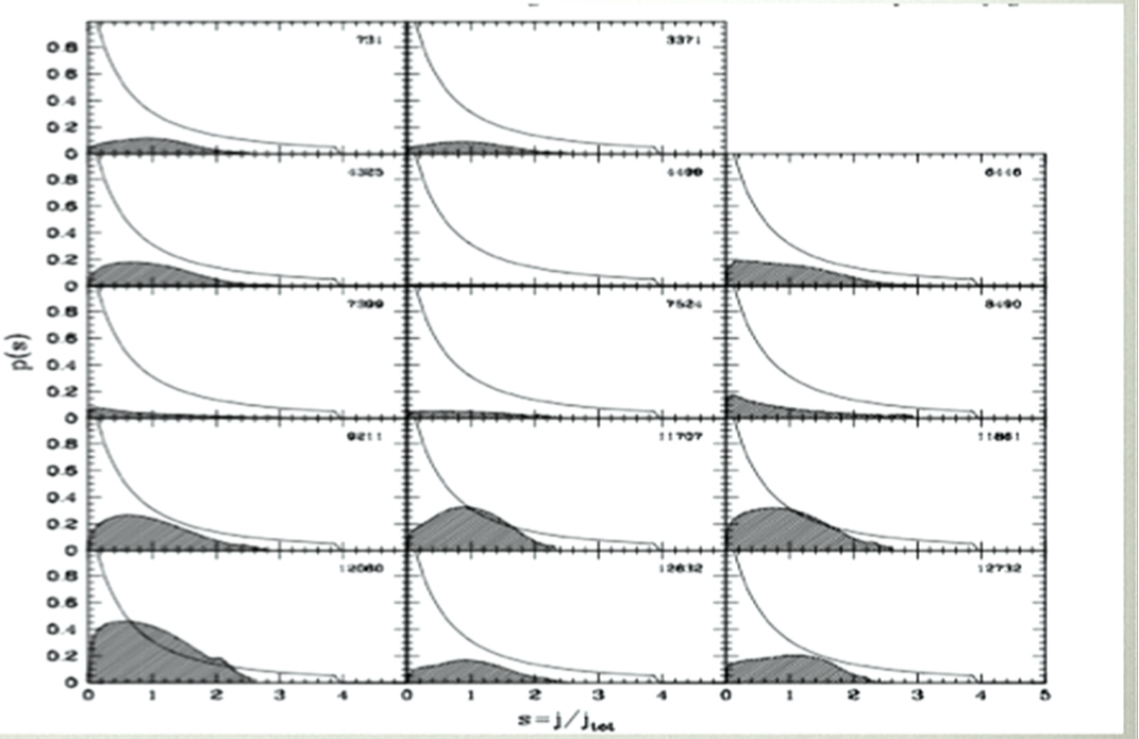
CDM PREDICTS LARGE BULGES
...BUT WE RARELY SEE THEM

A large bulge

A "bulgeless" disk

CDM PREDICTS LARGE BULGES ...BUT WE RARELY SEE THEM

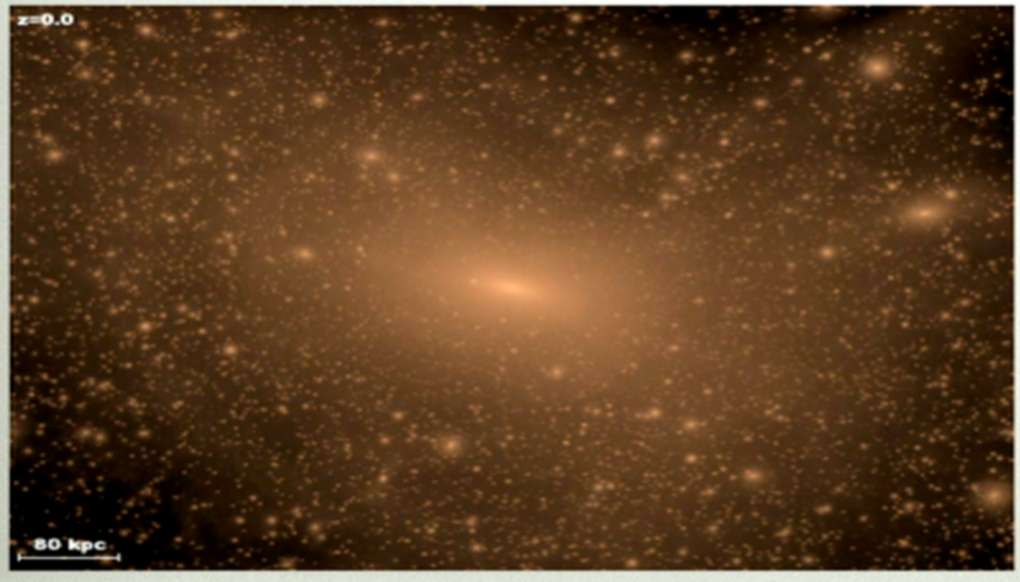
- Tidal torques: predict the sizes of disks well
- But over-predict the amount of low angular momentum gas



van den Bosch et al. (2001)

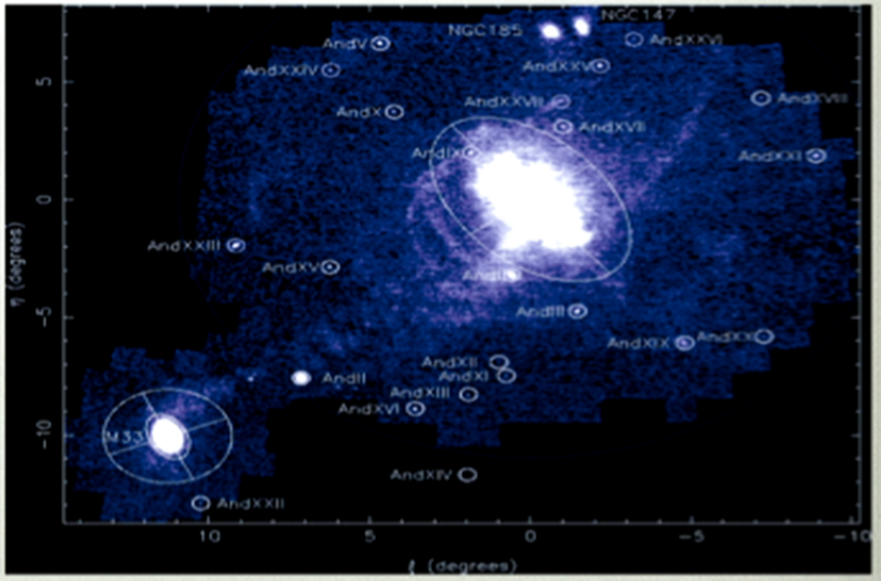
The "Missing Satellites" Problem

1000's of satellites predicted



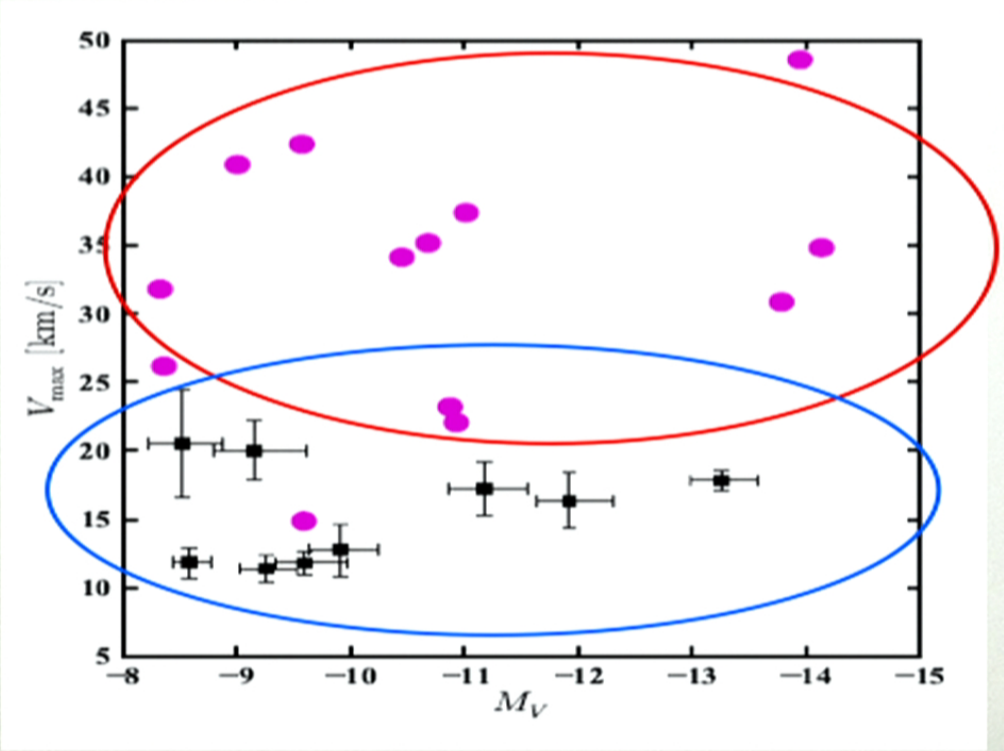
"Via Lactea" Simulation

dozens seen



Pan-ANDromeda Archeological Survey (PAndAS)

THE PREDICTED SATELLITES ARE TOO DENSE



Predicted

Observed

Boylan-Kolchin et al. (2012)

So...

(Vanilla) CDM is Wrong?

So...
(Vanilla) CDM is Wrong?

Maybe it needs to be modified?

Maybe WDM that washes out the small scales?

Maybe DM self-interacts and washes out the small scales?

So...
(Vanilla) CDM is Wrong?

But what about the 5%?

The small scales where there are problems
are also the places dominated by baryons!

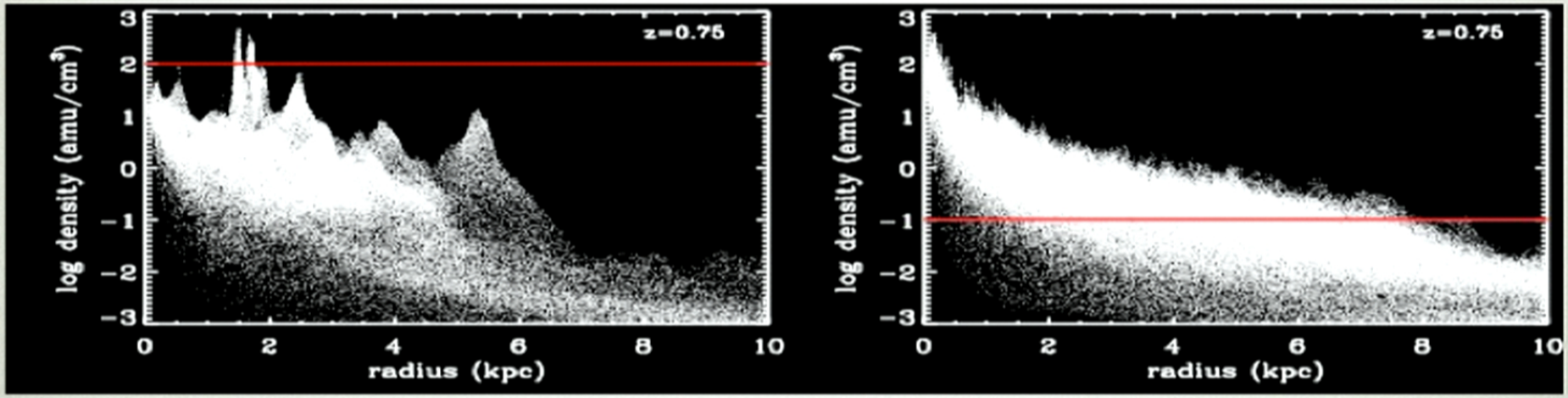
All of the predictions that lead to the small scale crises
are based on Dark Matter-only simulations.

Gas is Much More Complicated (and expensive)!

Greyish-green = gas Blue = young stars Red = old stars

WHY DO RESOLUTION AND FEEDBACK MATTER?

“Resolving” Star Formation Regions



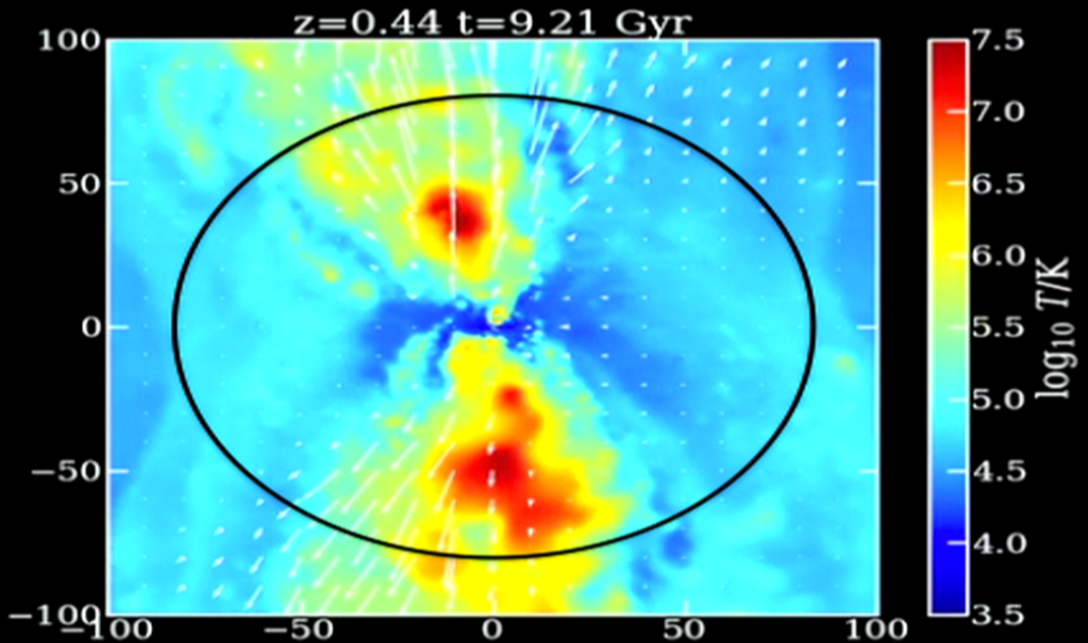
High threshold

Low threshold

Feedback becomes more efficient (more outflows per unit mass of stars formed)

See also: Mashchenko et al. (2006, 2008), Ceverino & Klypin (2008)
Robertson & Kravtsov (2008), Tasker & Bryan (2008)

Outflows!



$M_{vir} \sim 10^{10} M_{sun}$
"dwarf galaxy"

Edge-on disk orientation

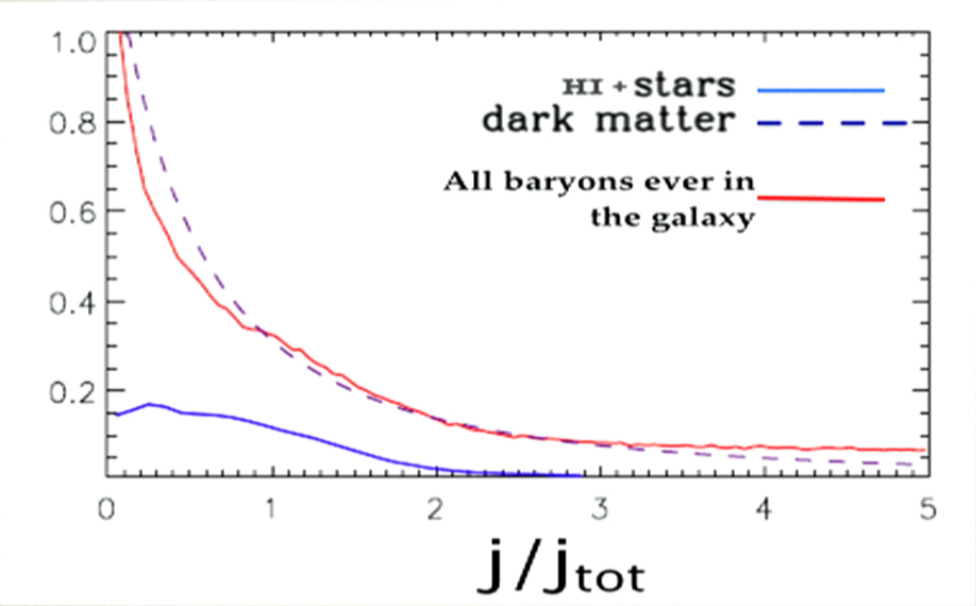
(arrows are velocity vectors)

Brook et al., 2011, MNRAS, 415, 1051

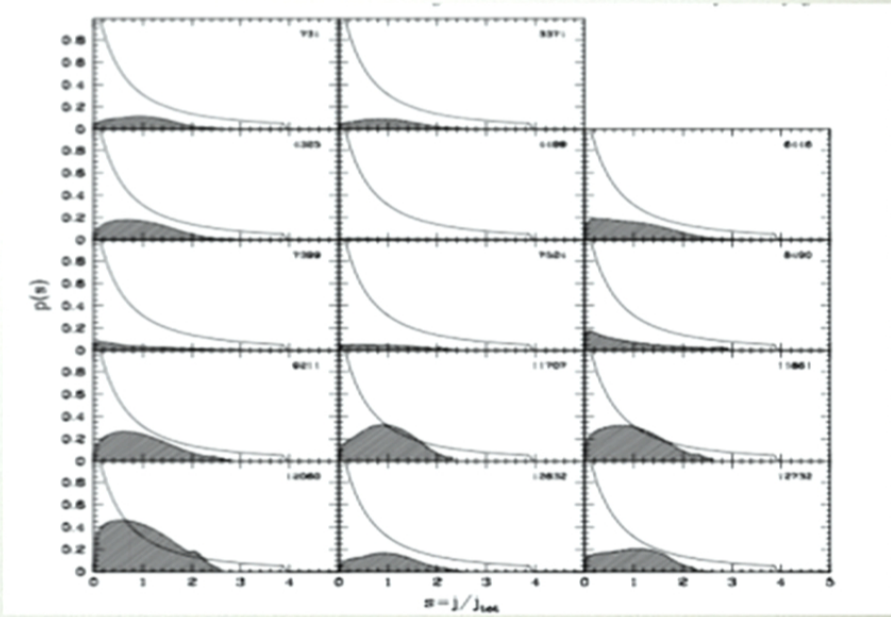
The Bigger Picture:
The Small Scale "Crisis" of CDM

	Baryons	WDM	SIDM
Bulge-less disk galaxies			
The Cusp/ Core Problem			
Too Big to Fail			
Missing Satellites			

Outflows Remove Low Angular Momentum Gas



Brook et al., 2011, MNRAS, 415, 1051



van den Bosch et al. (2001)

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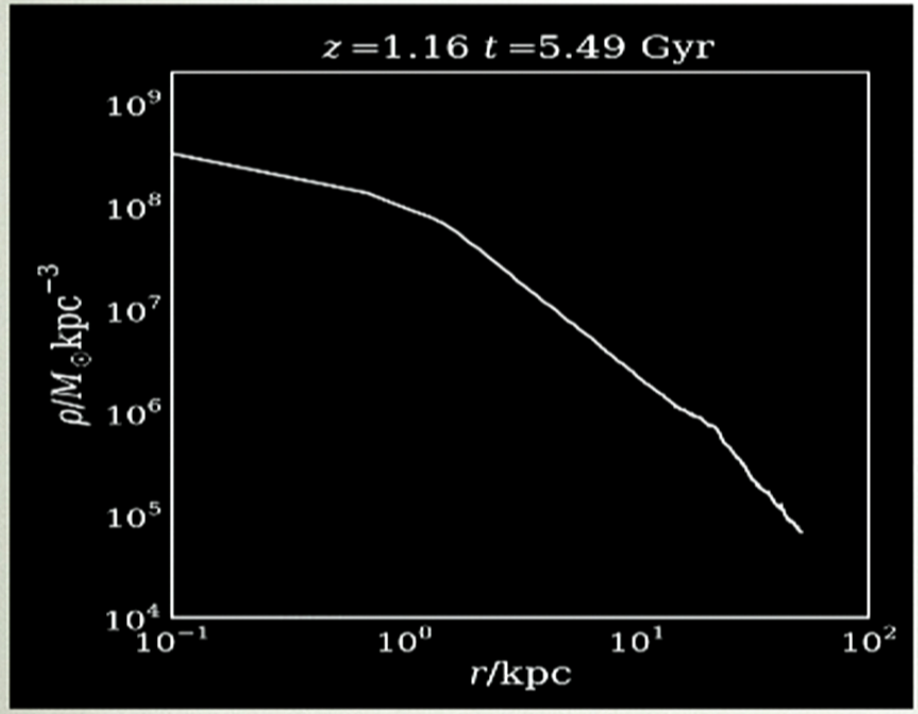
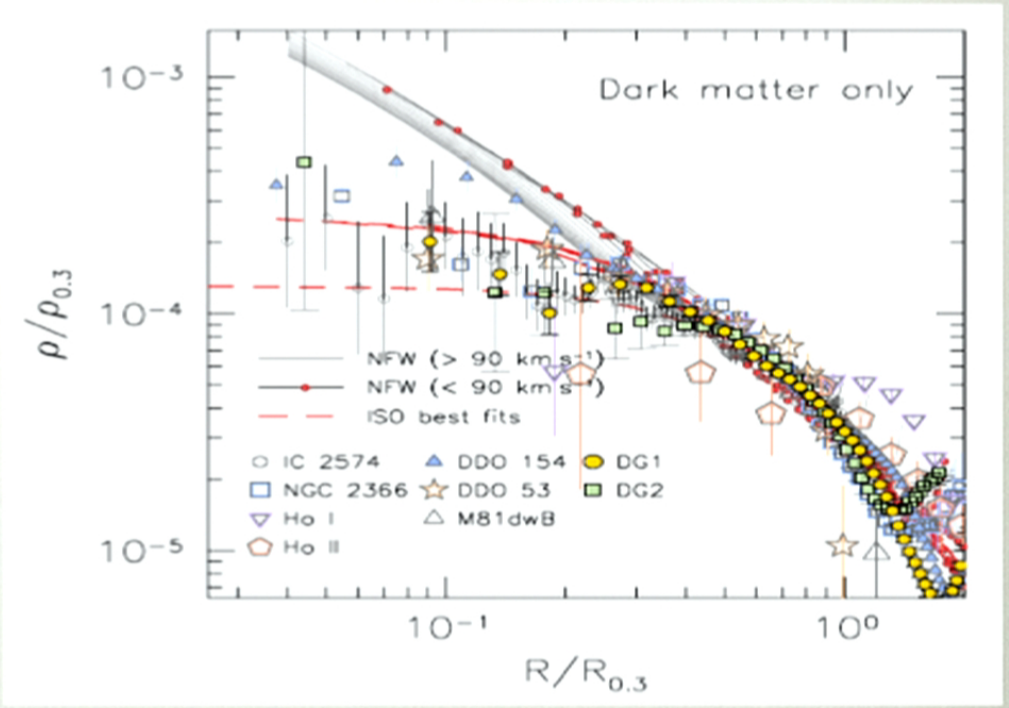
Creation of a Dark Matter Core

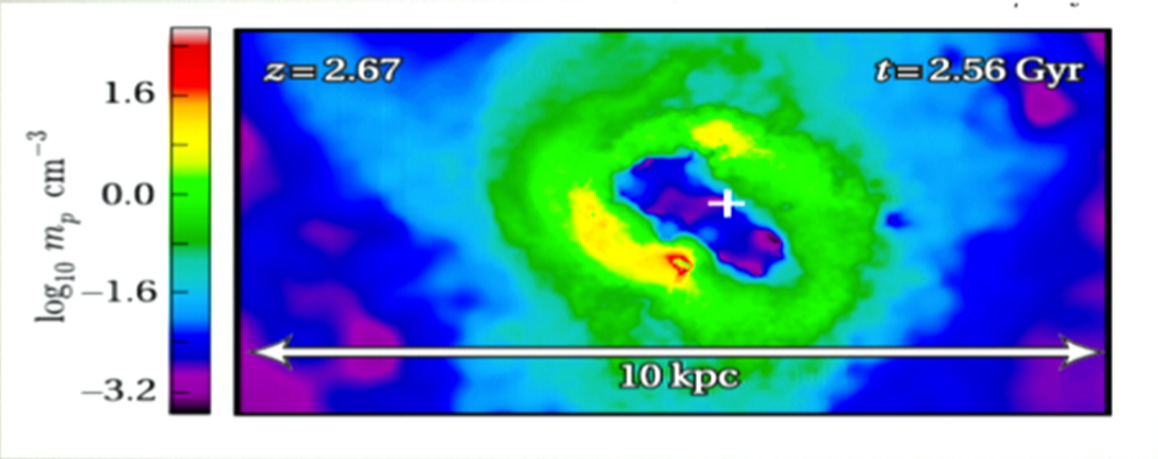


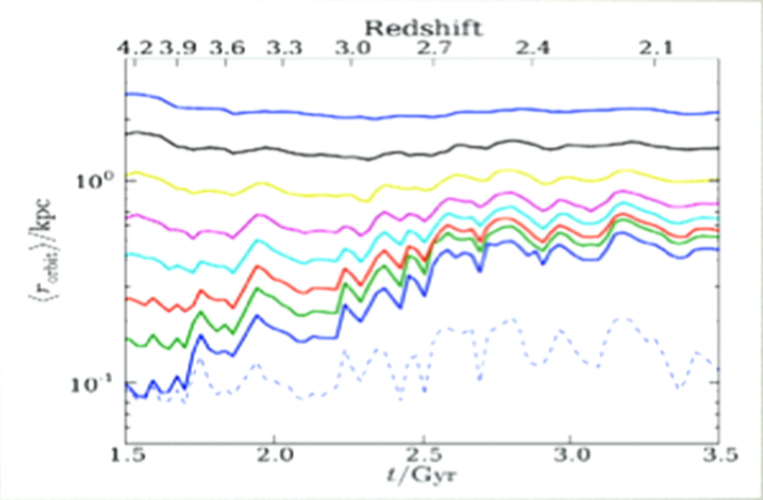


Oh et al., 2011, AJ, 142, 24

See also: Navarro et al. 1996; Read & Gilmore 2005; Mashchenko et al. 2006, 2008; Pasetto et al. 2010; de Souza et al. 2011; Cloet-Osselaer et al. 2012; Maccio et al. 2012; Teyssier et al. 2012; Ogiya & Mori 2012

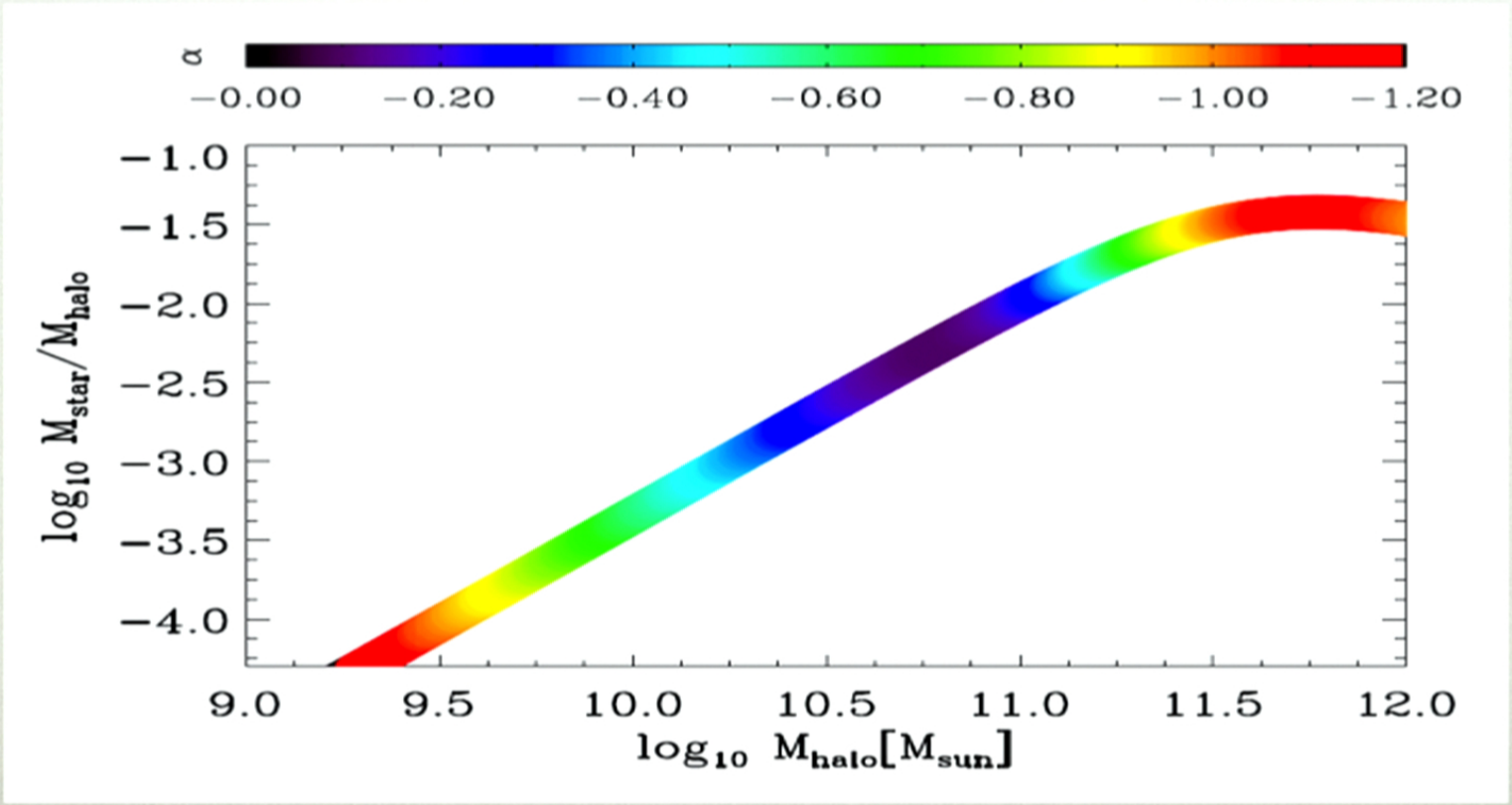
How are Cores Created?





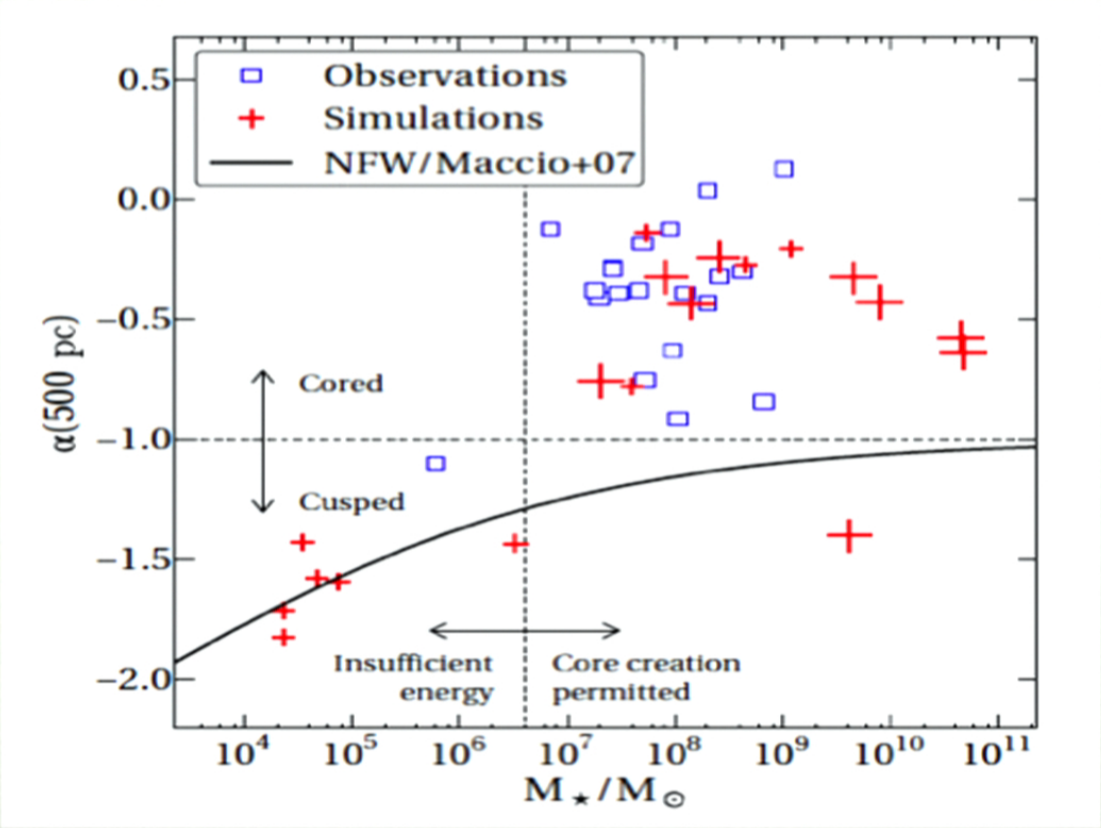
Pontzen & Governato (2012), MNRAS, 421, 3464, arXiv:1106.0499

Density Slope as a Function of Stellar/Halo Mass



di Cintio et al. (2014)

Core Creation varies with Mass!



Pontzen & Governato, 2014, Nature

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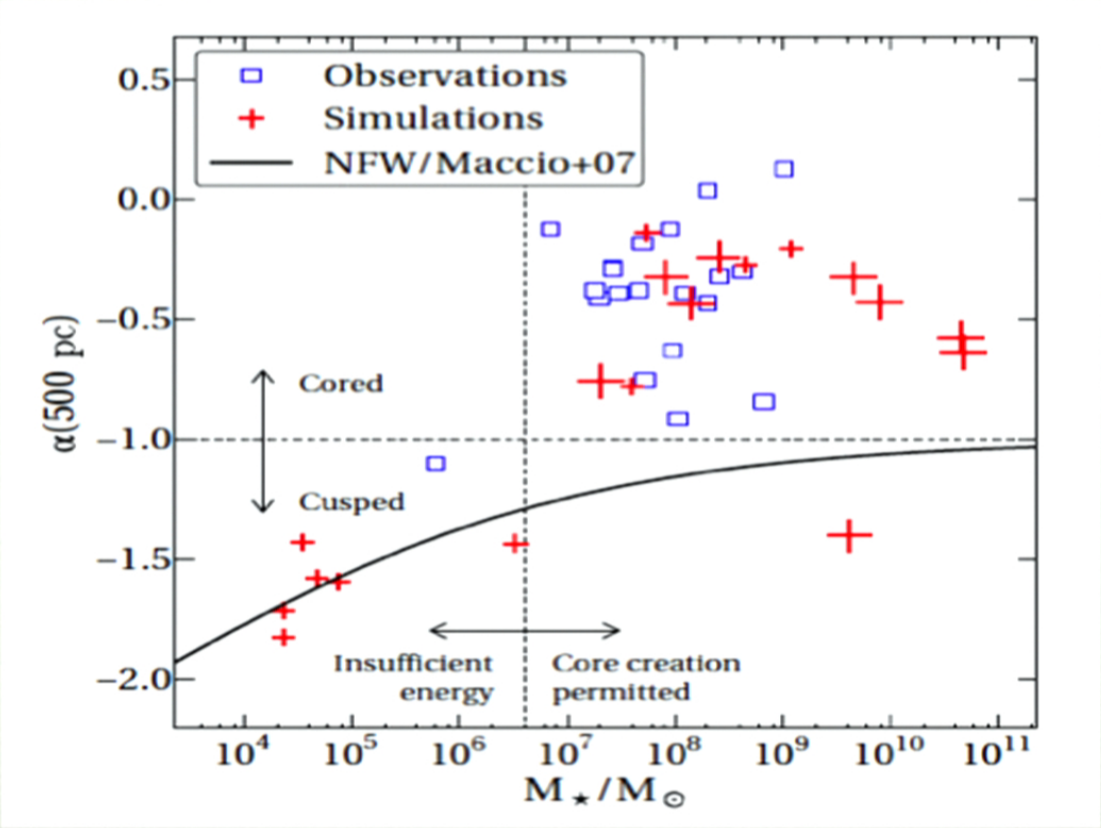
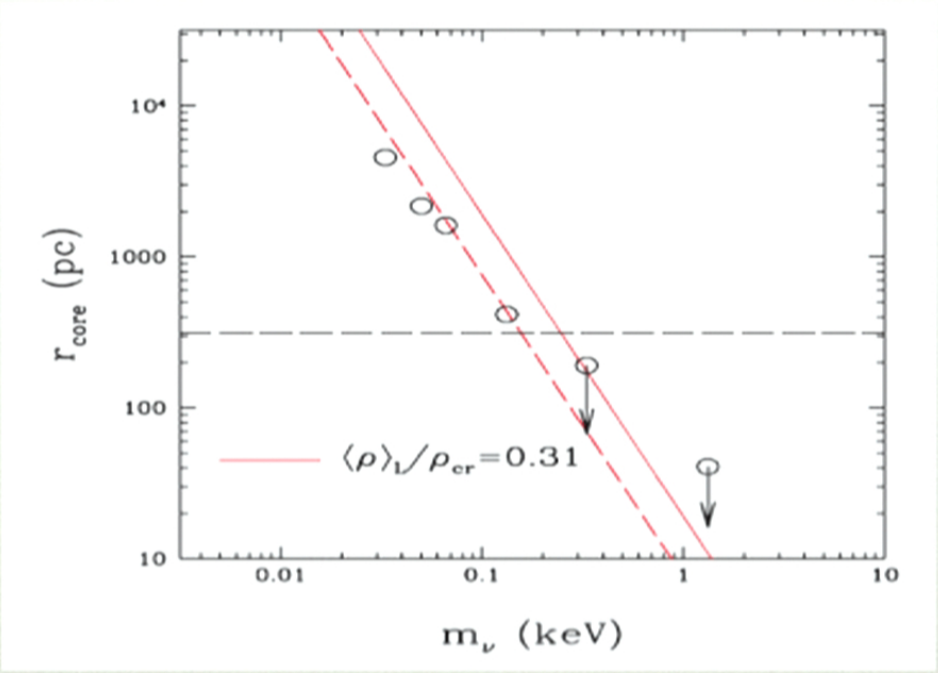


Pontzen & Governato, 2014, Nature

WDM DOESN'T CREATE CORES

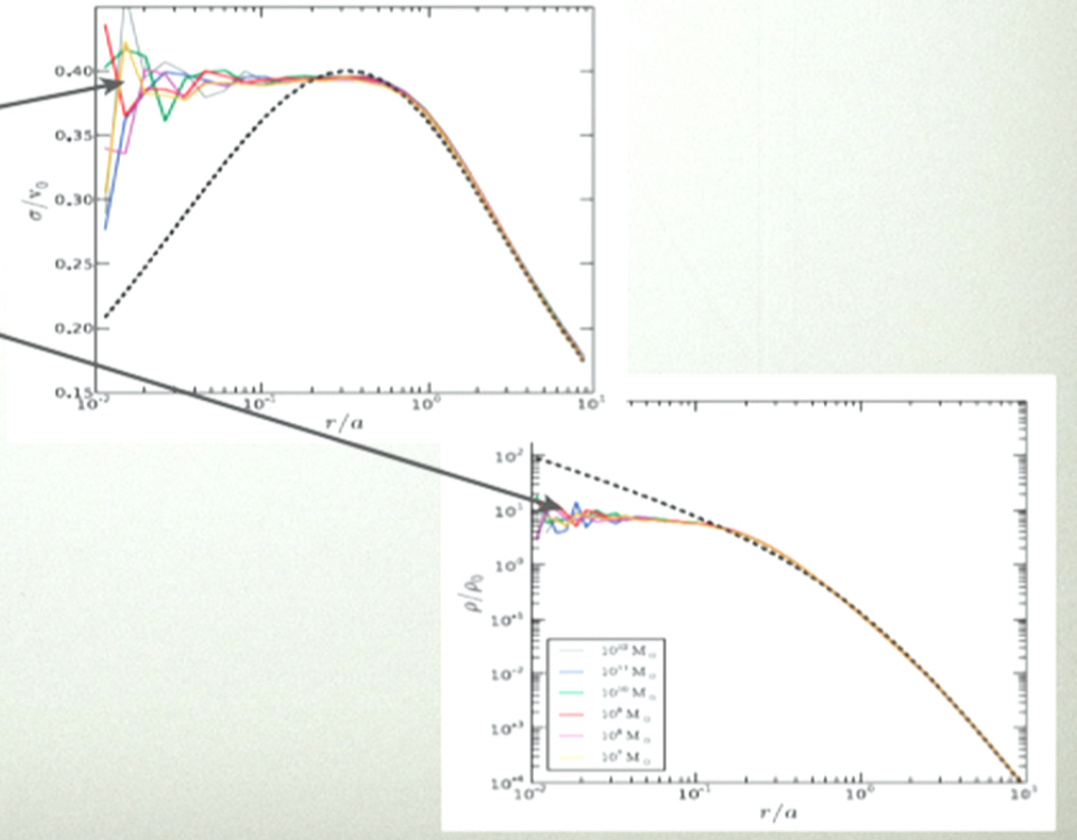


Maccio et al. (2012)

SIDM

SCATTERING CREATES CORES

- SIDM
- repeated elastic collisions equalize the velocities



Vogelsberger, Zavala, & Loeb (2012)

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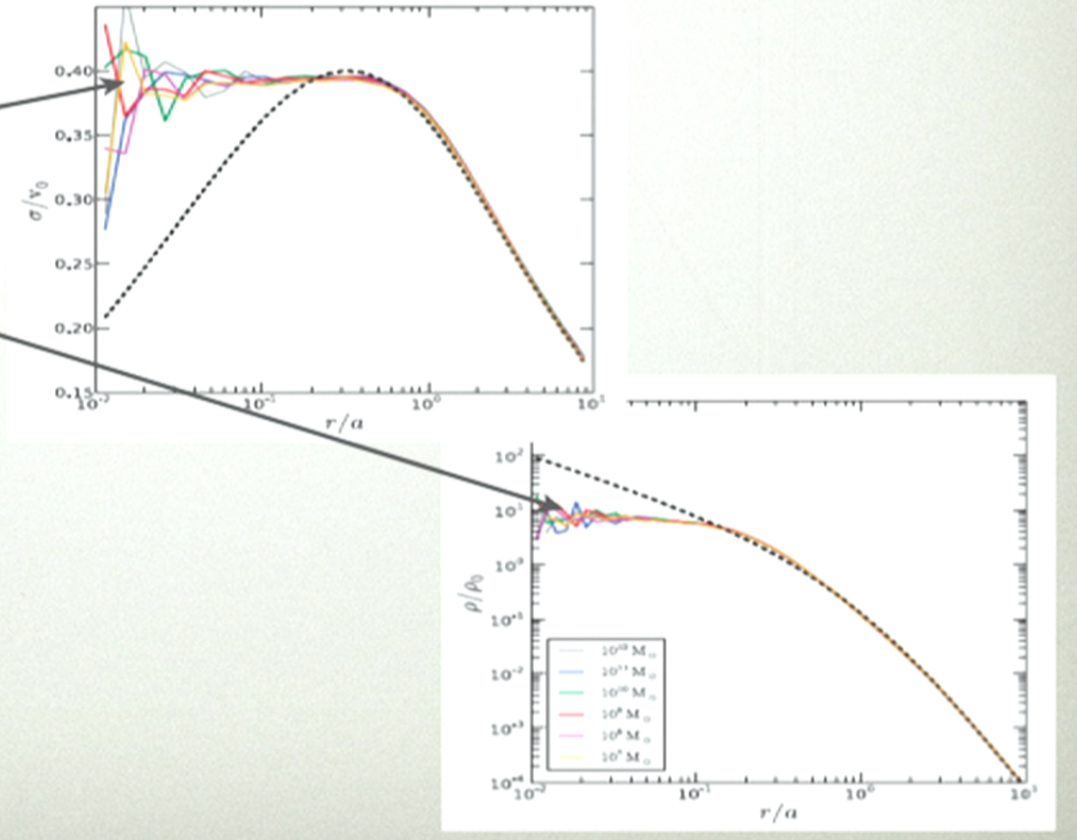

Vogelsberger, Zavala, & Loeb (2012)

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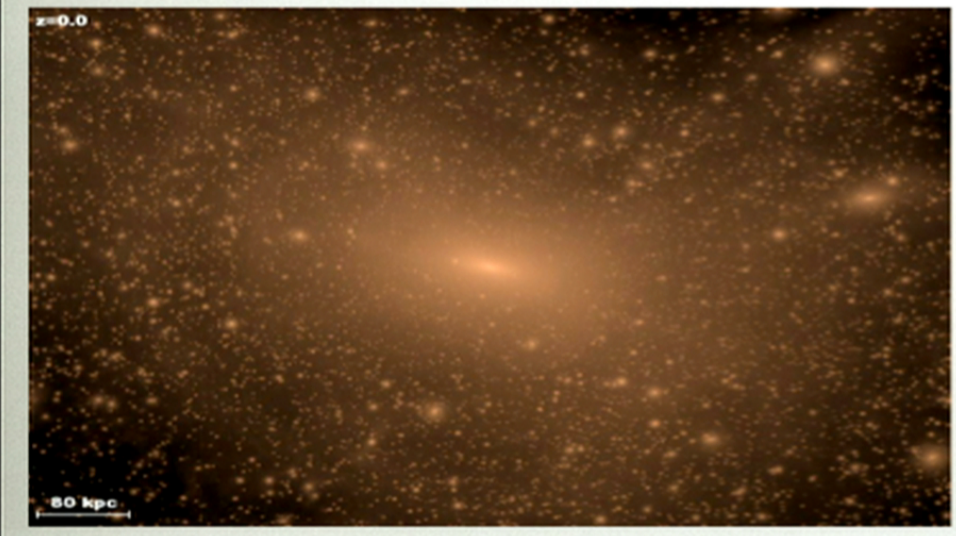
	Baryons	WDM	SIDM
Bulge-less disk galaxies	✓		
The Cusp/ Core Problem	✓		✓
Too Big to Fail			
Missing Satellites			

Also: Baryons Make a Disk (Dark Matter Doesn't)



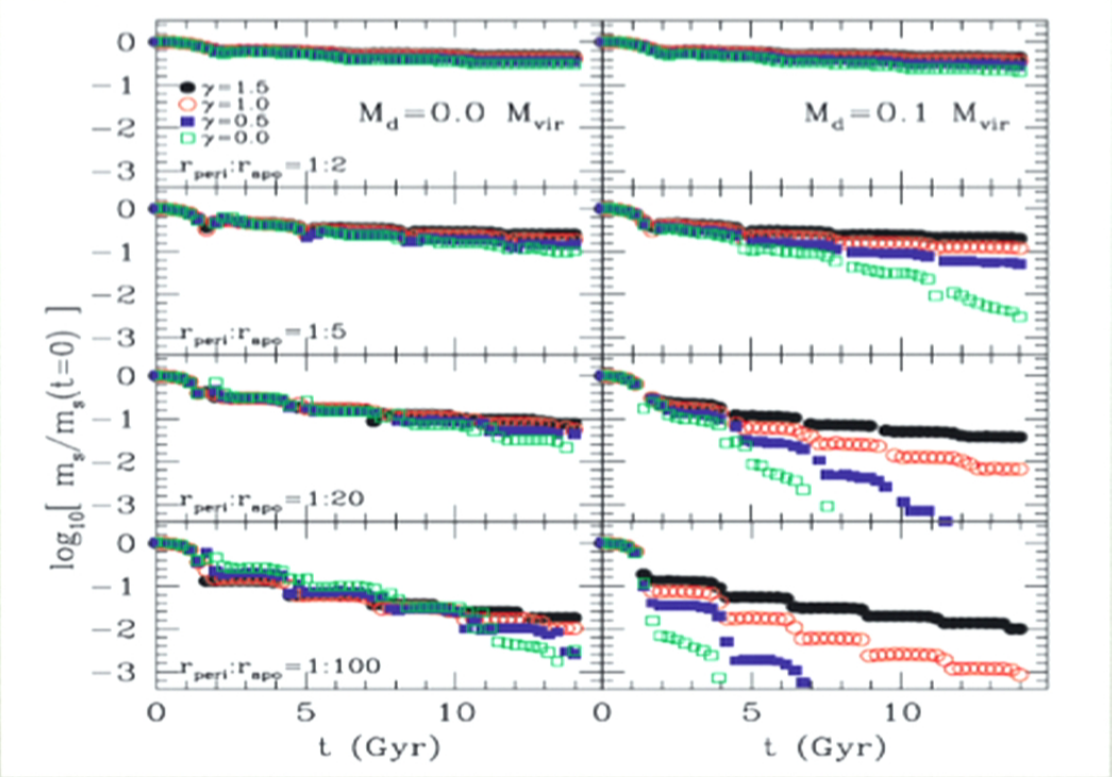
Dark Matter

Baryons

(or any central baryonic concentration)

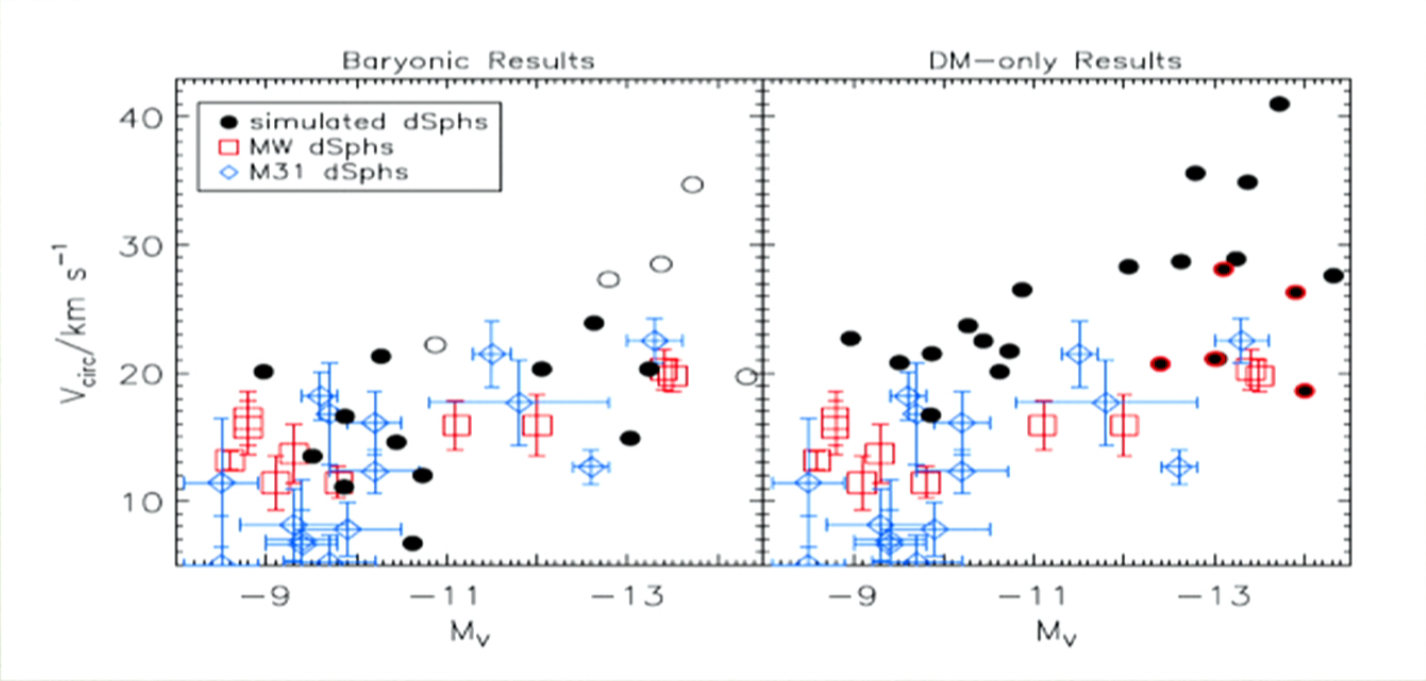
Chang et al. (2012)

Not Just Core Creation: The Tidal Effect of the Disk



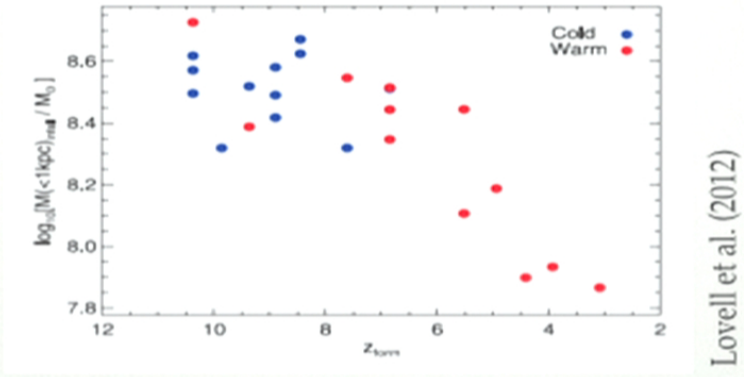
Penarrubia et al. (2010), see also Arraki et al. (2012)

The First Simulated Dwarf Spheroidals to Match Observed Kinematics

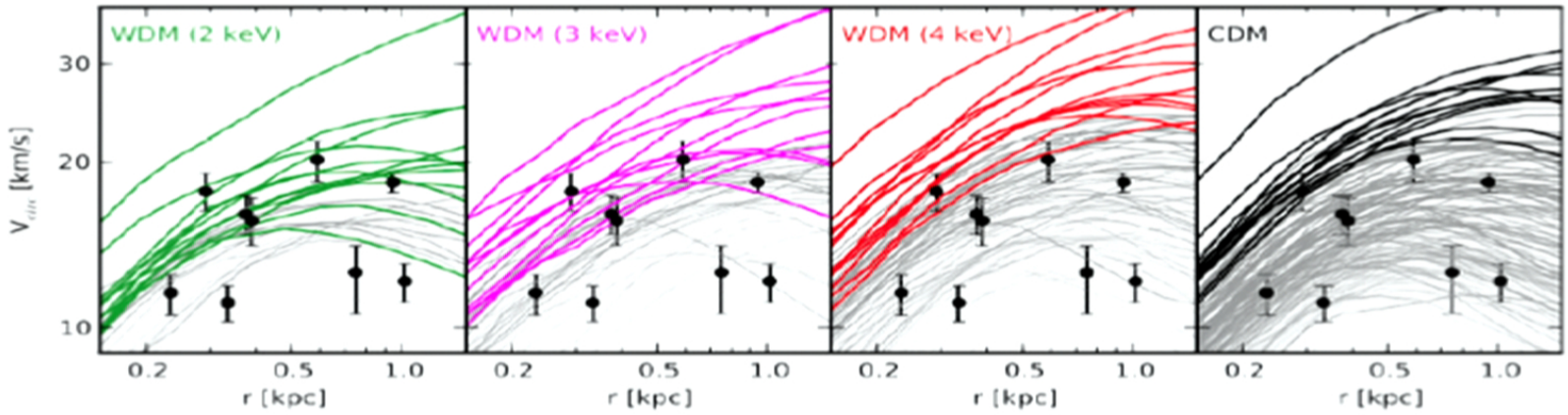


Brooks & Zolotov (2014), ApJ, 786, 87, arXiv:1207.2468

WDM may also solve the Too Big to Fail Problem



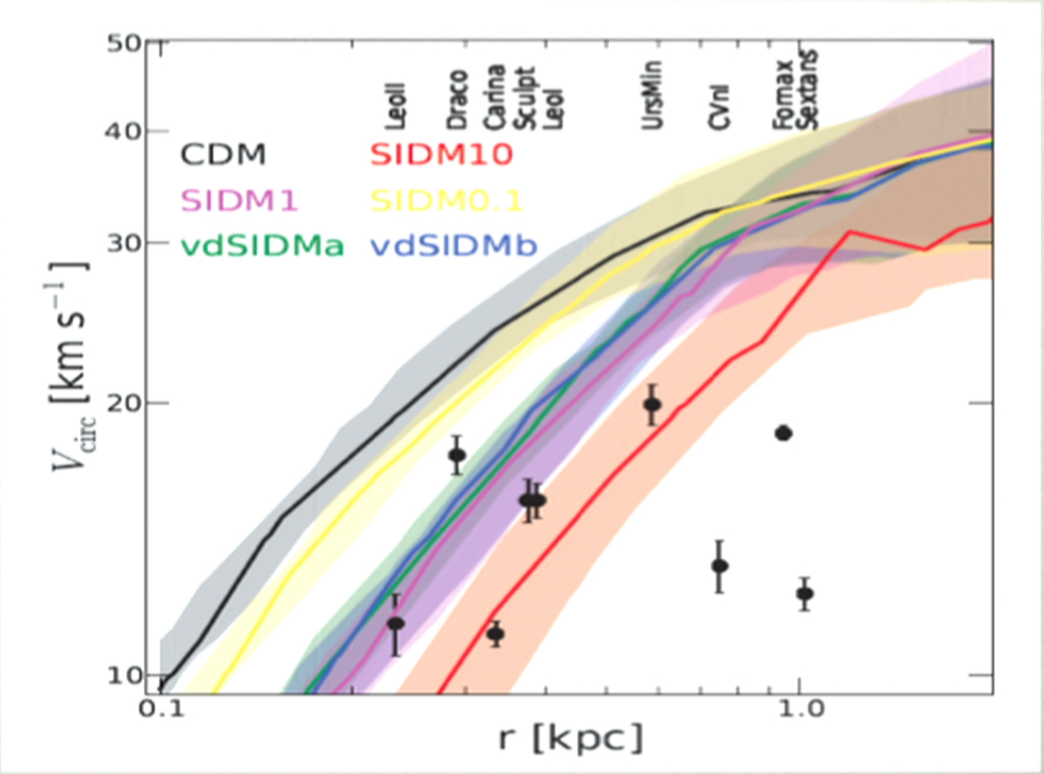
Lovell et al. (2012)



Schneider et al. (2013)

Can SIDM Solve the Too Big to Fail Problem?

- depends who you ask

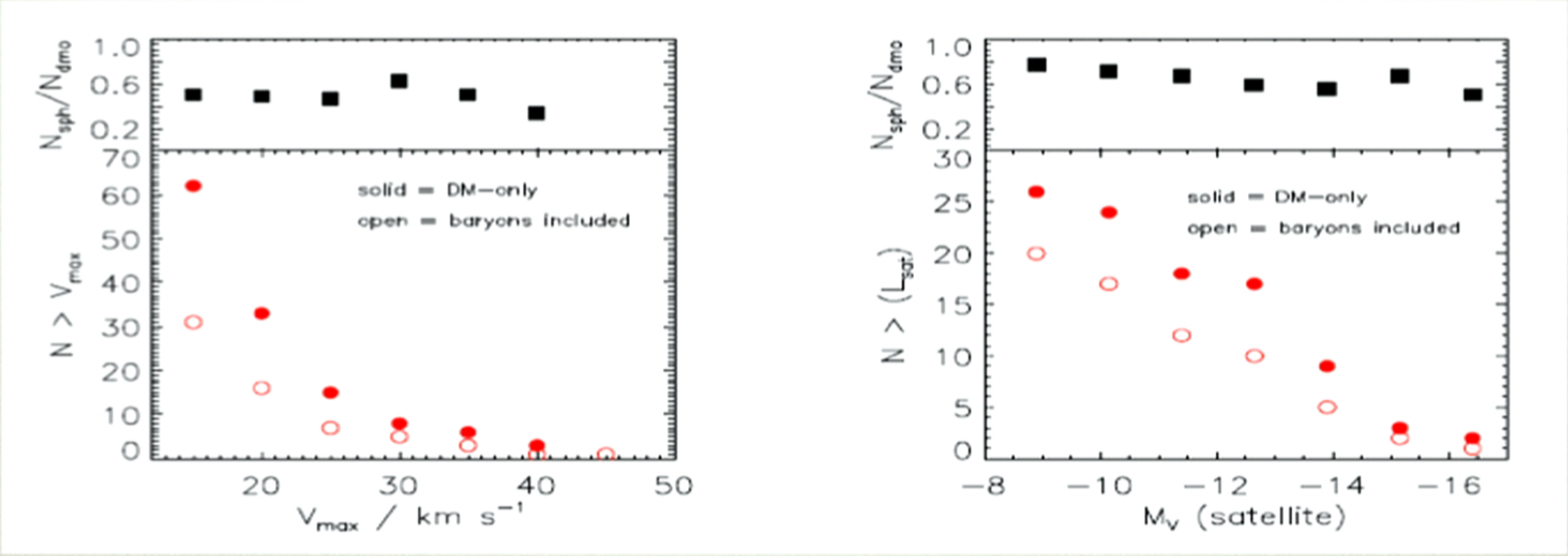


Zavala et al. (2013)

THE BIGGER PICTURE:
THE SMALL SCALE "CRISIS" OF CDM

	Baryons	WDM	SIDM
Bulge-less disk galaxies	✓		
The Cusp/ Core Problem	✓		✓
Too Big to Fail	✓	✓	✓
Missing Satellites			

The Change to Mass and Luminosity Functions



Brooks & Zolotov (2014), ApJ, arXiv:1207.2468

But...

What About the Number of Luminous Satellites?

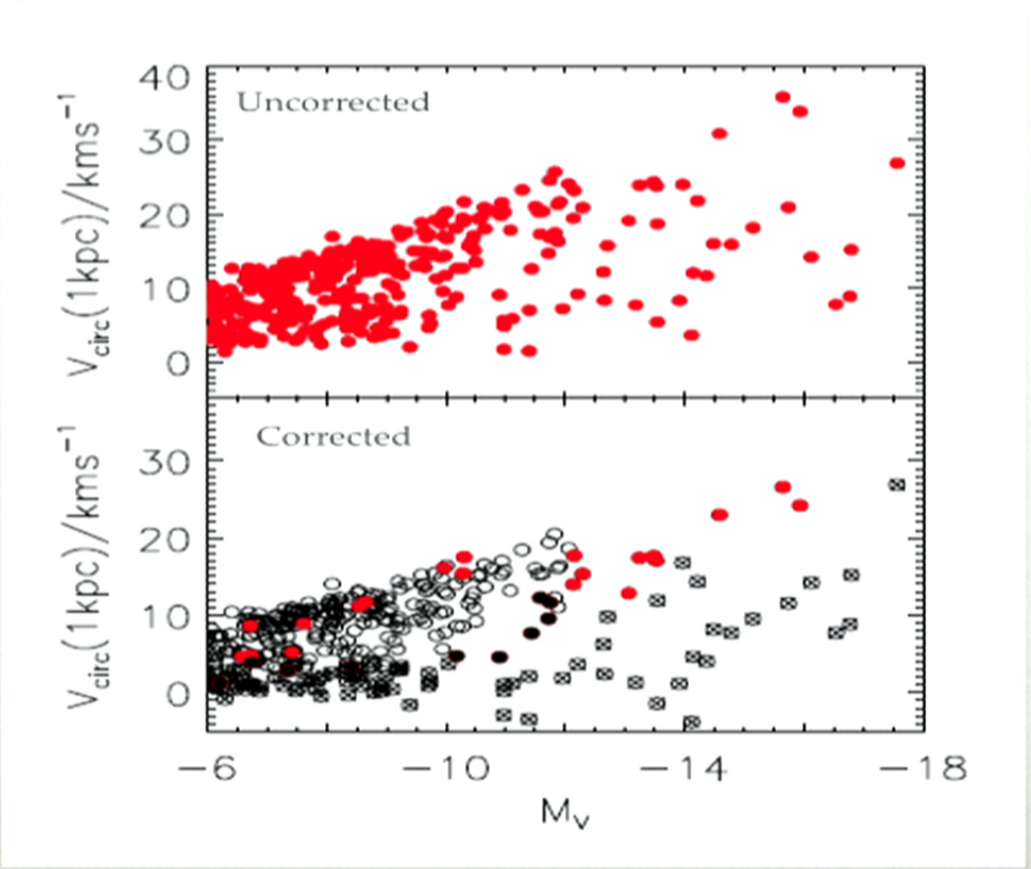
1000's of satellites predicted

dozens seen

"Via Lactea"

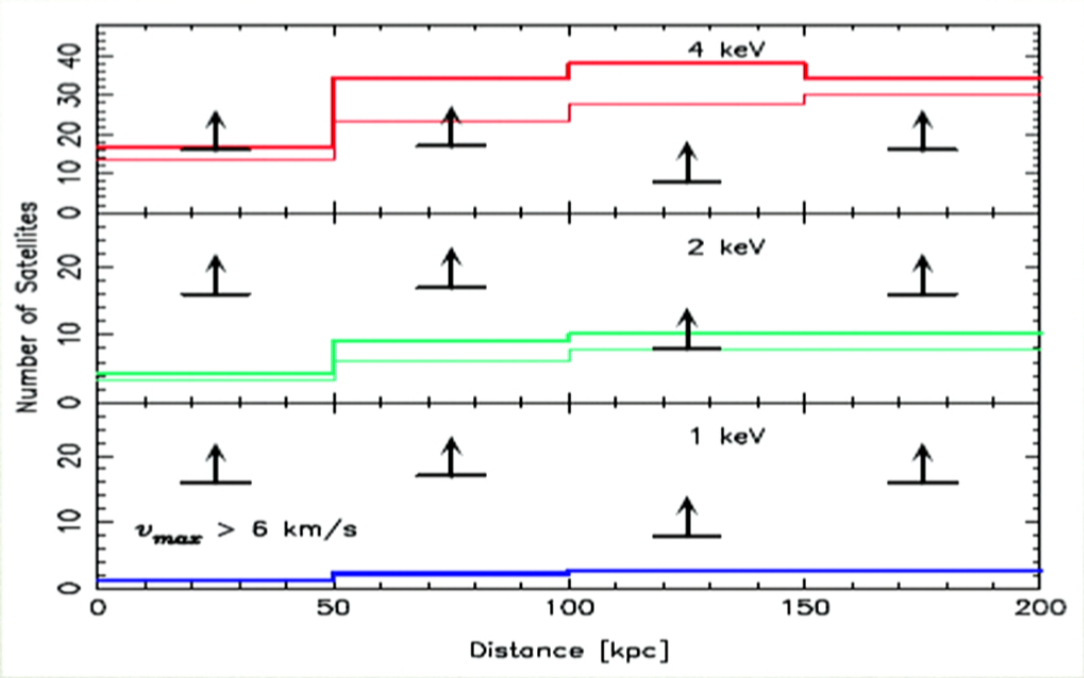
So the Number of Massive Satellites is Reduced...

but what about Luminous Satellites?



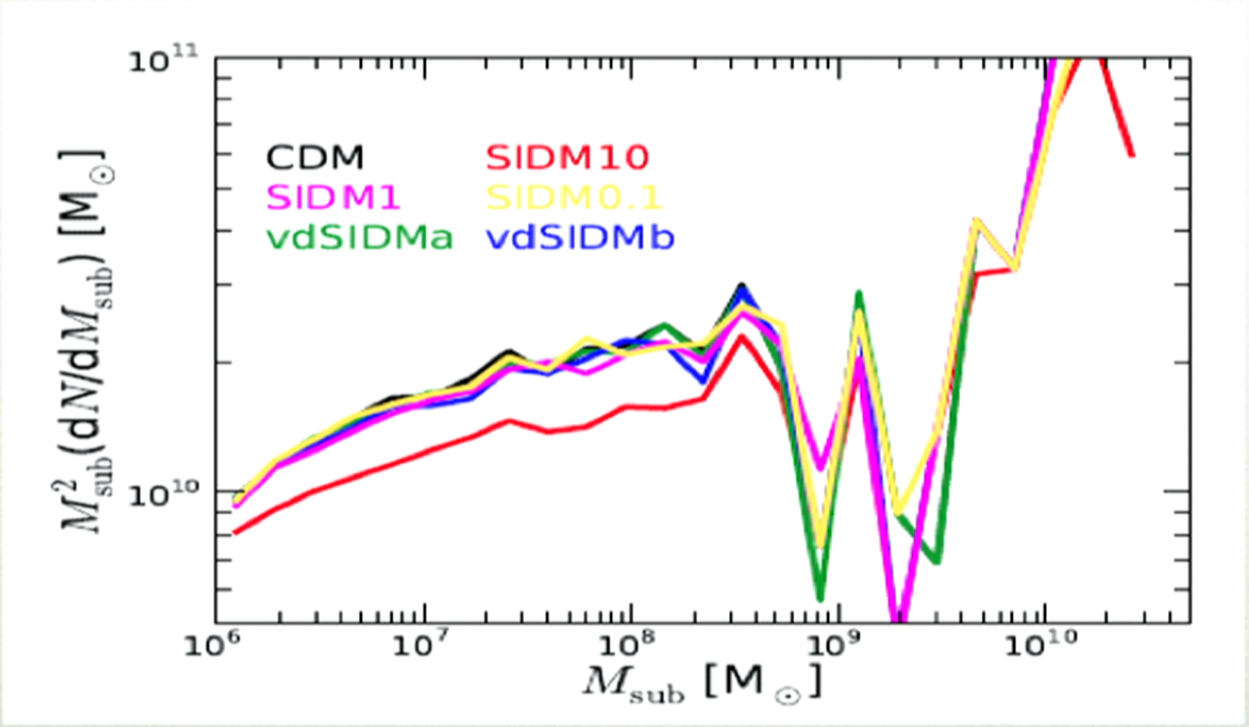
Brooks, Kuhlen, Zolotov, & Hooper (2012), ApJ, 765, 22, arXiv:1209.5394

Missing Satellites & WDM



Polisensky & Ricotti (2011)

Missing Satellites & SIDM



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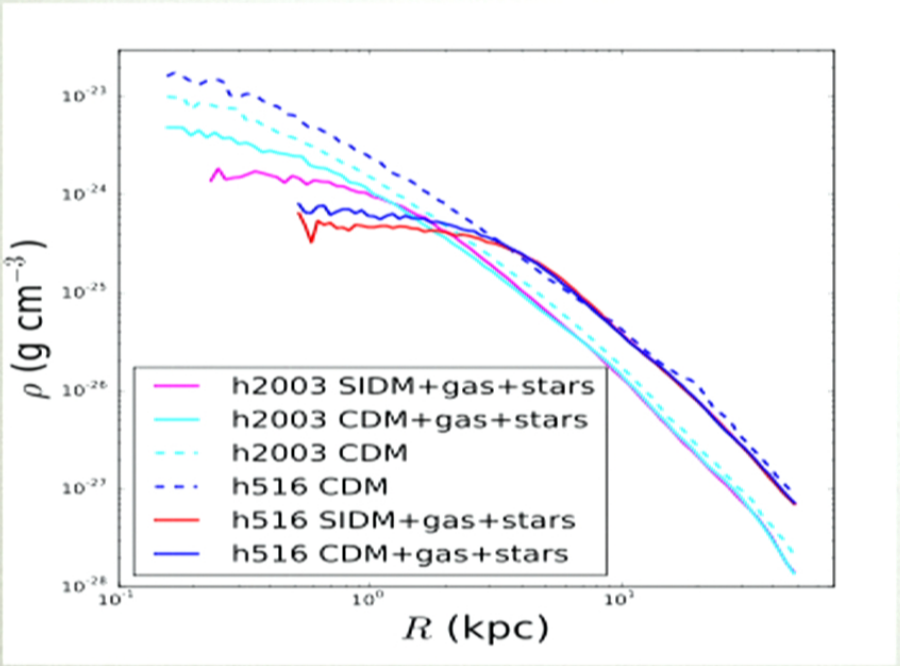
Bulge-less disk galaxies	✓		
The Cusp/ Core Problem	✓		✓
Too Big to Fail	✓	✓	✓
Missing Satellites	✓	✓	

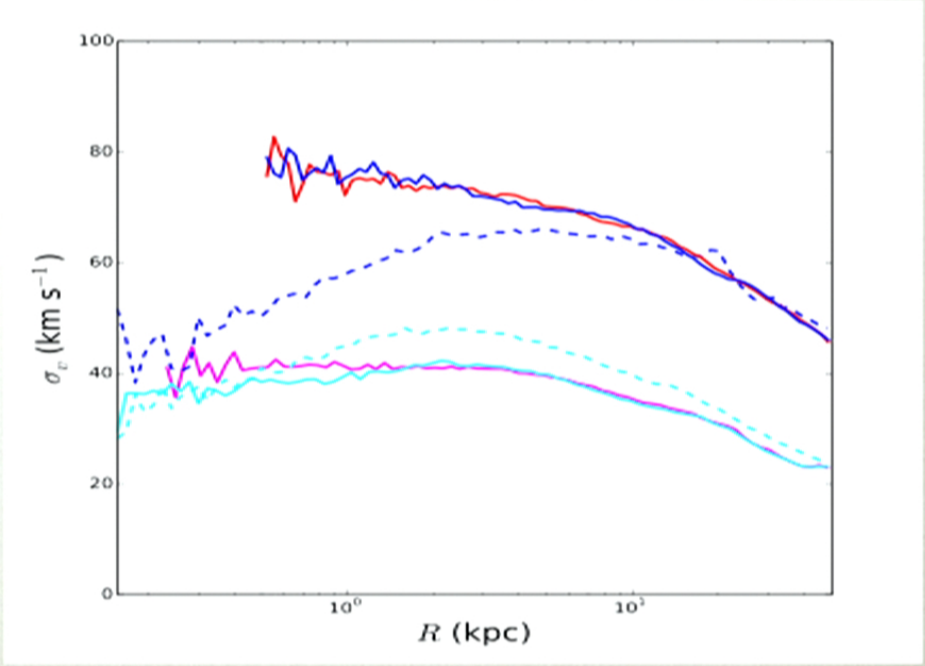
Future Work

(1) Baryons in Alternative DM Models

(2) Quantifying the role of SN Feedback

SIDM with Baryons





Fry et al. (in prep)
see also Vogelsberger et al. (2014)

Conclusions

A better treatment of baryonic physics may alleviate the small scale crisis of CDM

WDM: no cores without baryons, but current mass limits make it nearly indistinguishable from CDM

SIDM: core size vs galaxy mass may distinguish from vanilla CDM

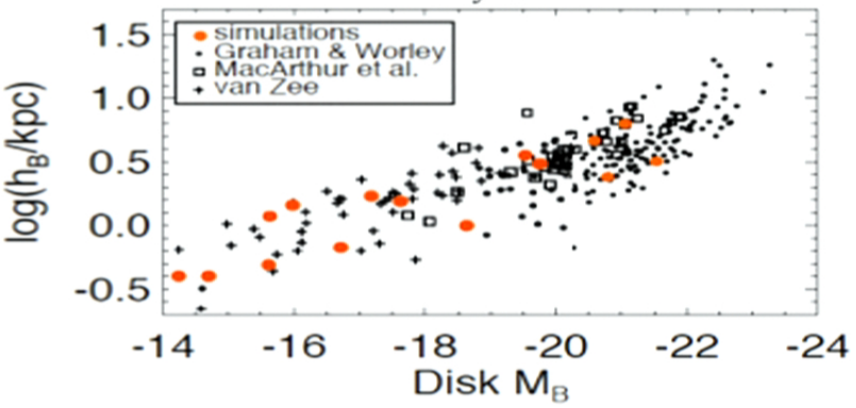
SIDM: need predictions that include baryons!!!

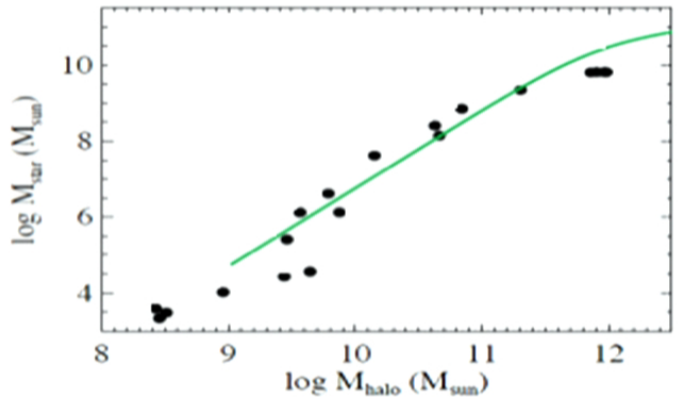
We must understand the impact of baryonic physics on galaxy formation (in any model)!

Review article that summarizes this talk — arxiv:1407.7544

Resulting Galaxies Match Observed Scaling Relations

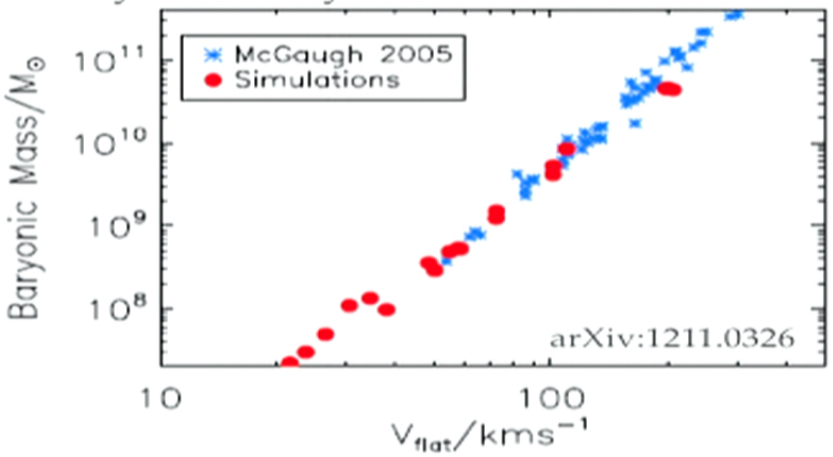
Size-Luminosity (Brooks et al. 2011)





Stellar-to-Halo Mass (Munshi et al. 2013)

Baryonic Tully-Fisher (Christensen et al., 2013)



...and Mass-Metallicity (Brooks et al. 2007)

...and HI gas fractions (Munshi et al. 2013)

...etc