OVERVIEW:
Dark matter structure and simulations
(Astrophysical Constraints on Dark Matter)

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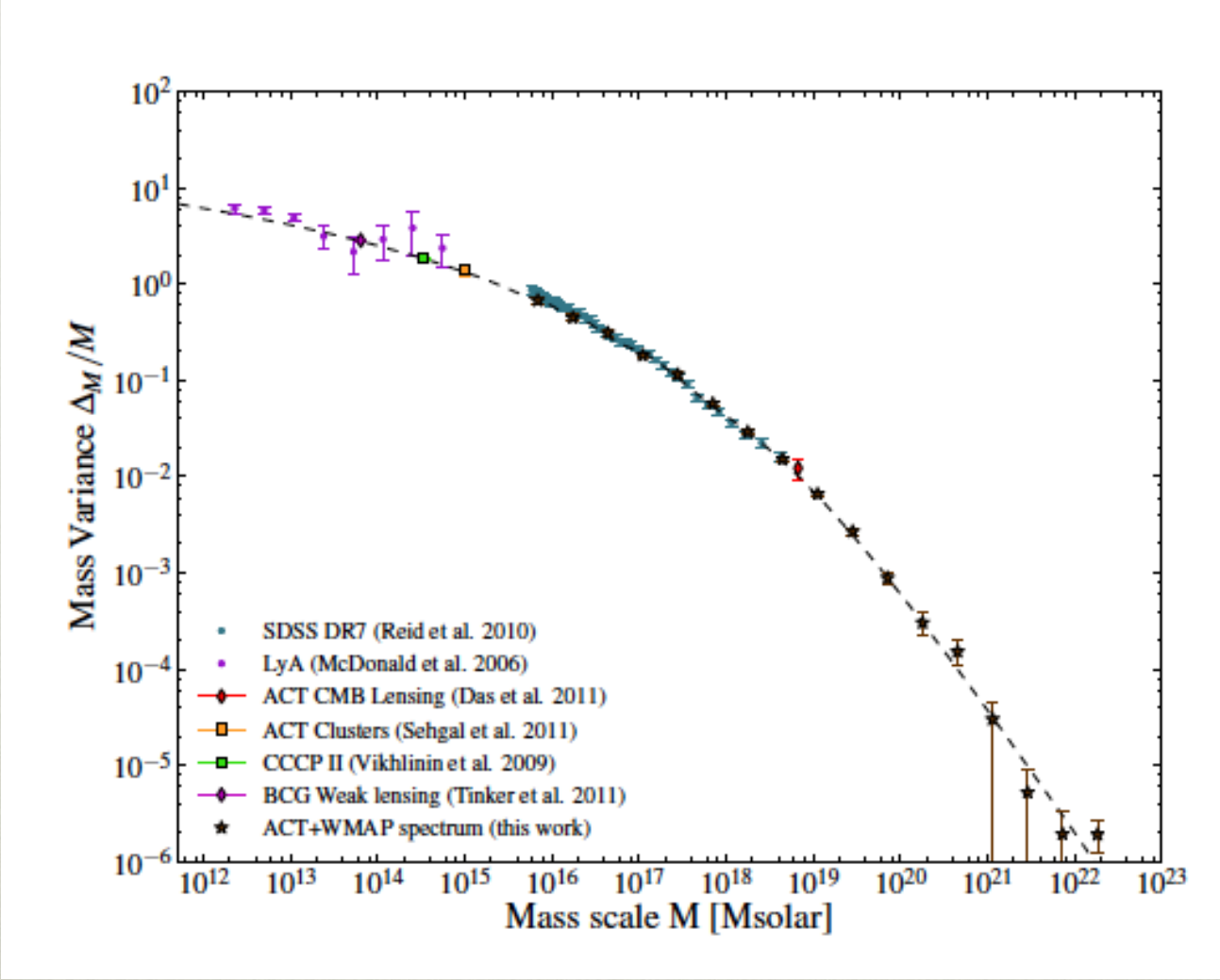
CDM is an Excellent Model for the Large Scale Structure of the Universe



Hlozek et al. (2012)

But...

The Small Scale "Crisis" of CDM

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

My Starting Point:

There is No Small Scale Crisis

there's just a lot of poorly understood physics

But that doesn't rule out new physics

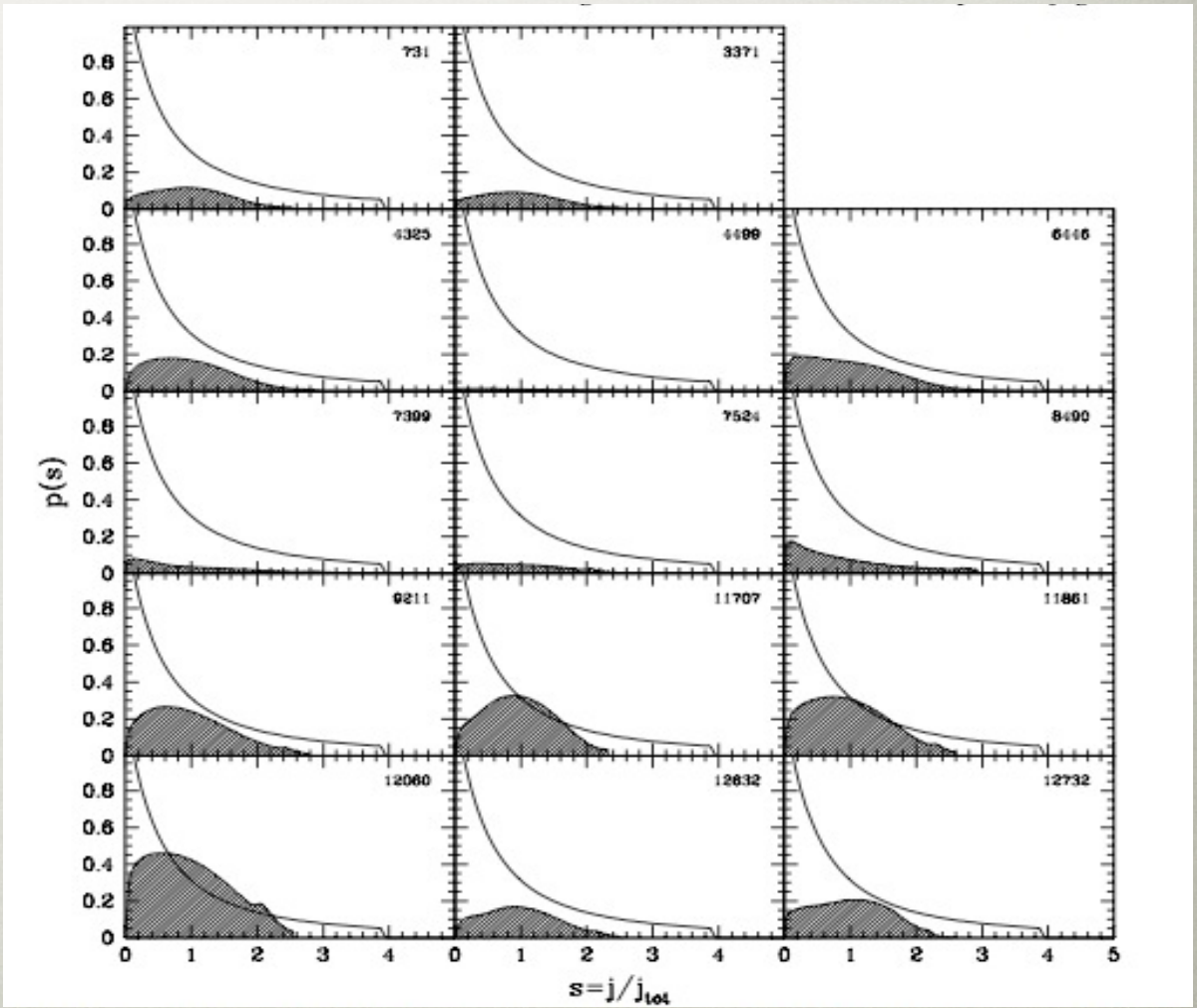
The Importance of Baryonic Physics

A large bulge

A "bulgeless" disk

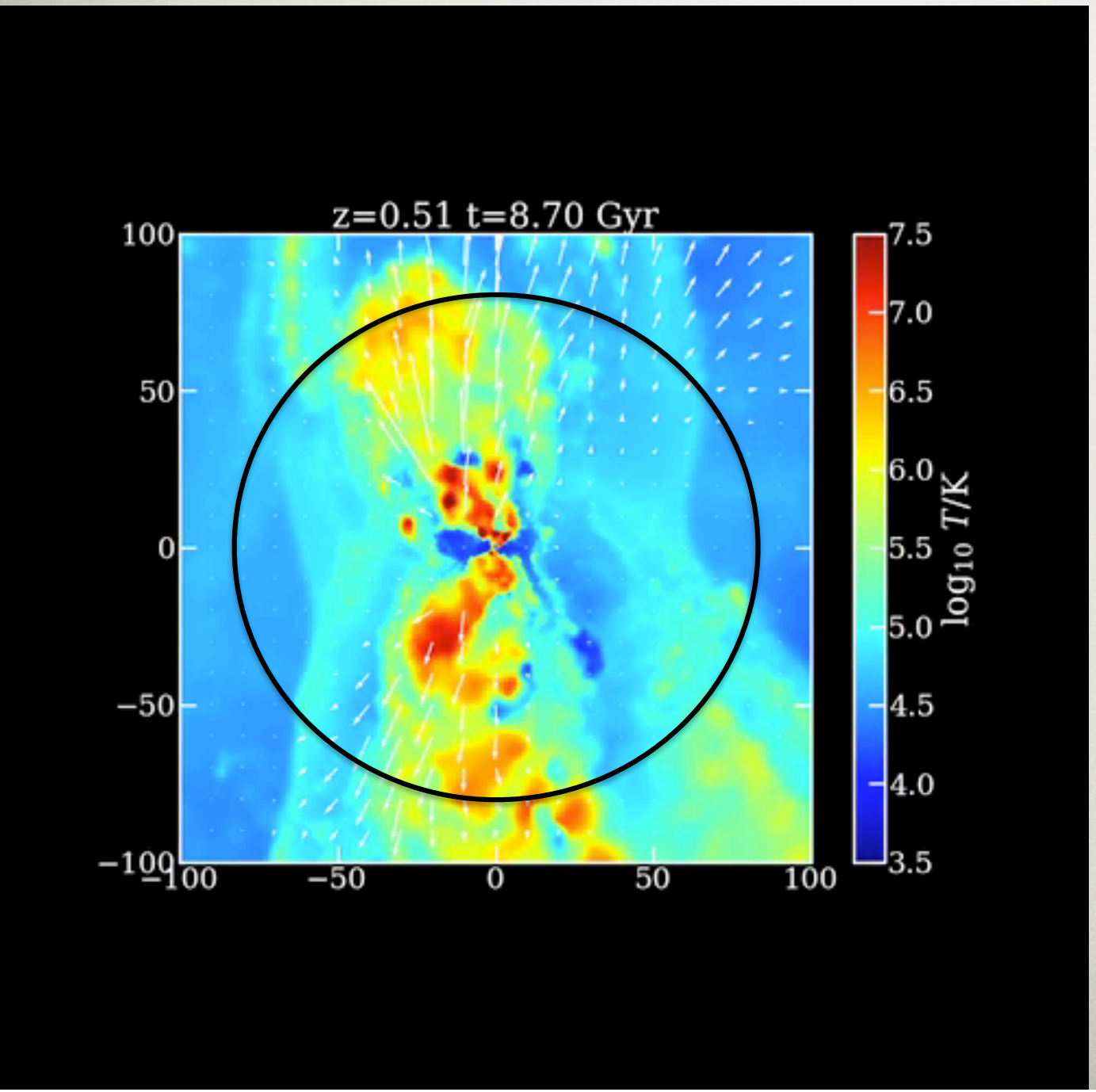
CDM predicts large bulges ...but we rarely see them

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



van den Bosch et al. (2001)

Outflows!



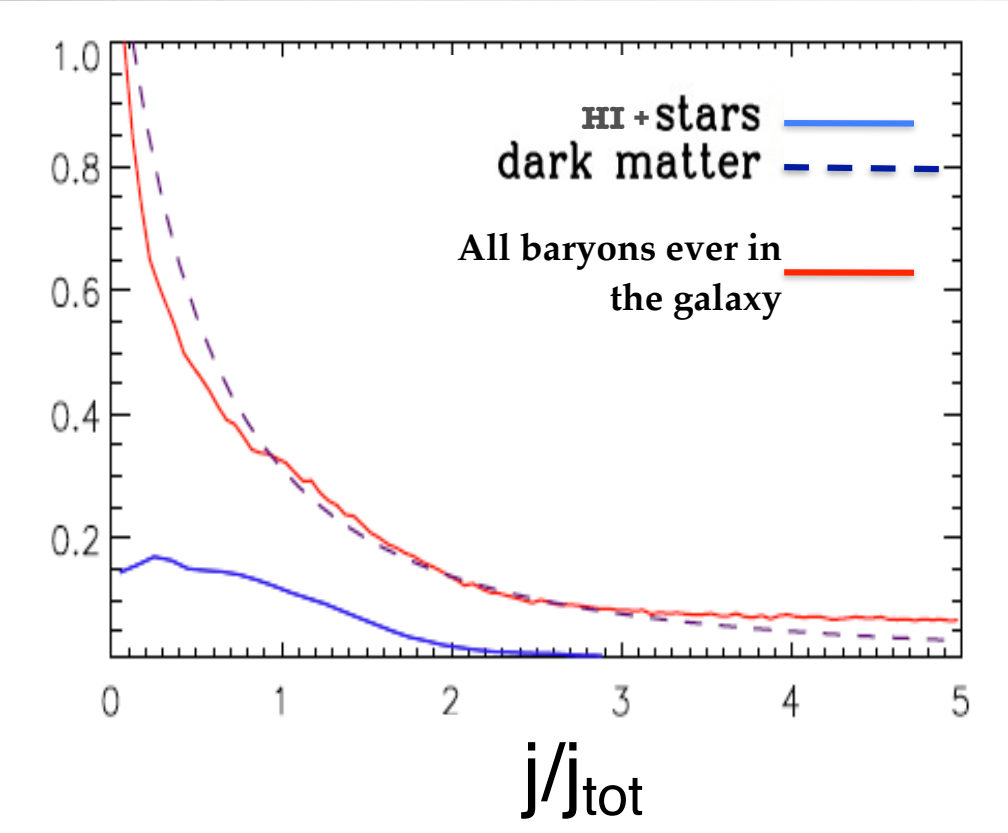
$M_{vir} \sim 10^{10} M_{sun}$
"dwarf galaxy"

Edge-on disk orientation

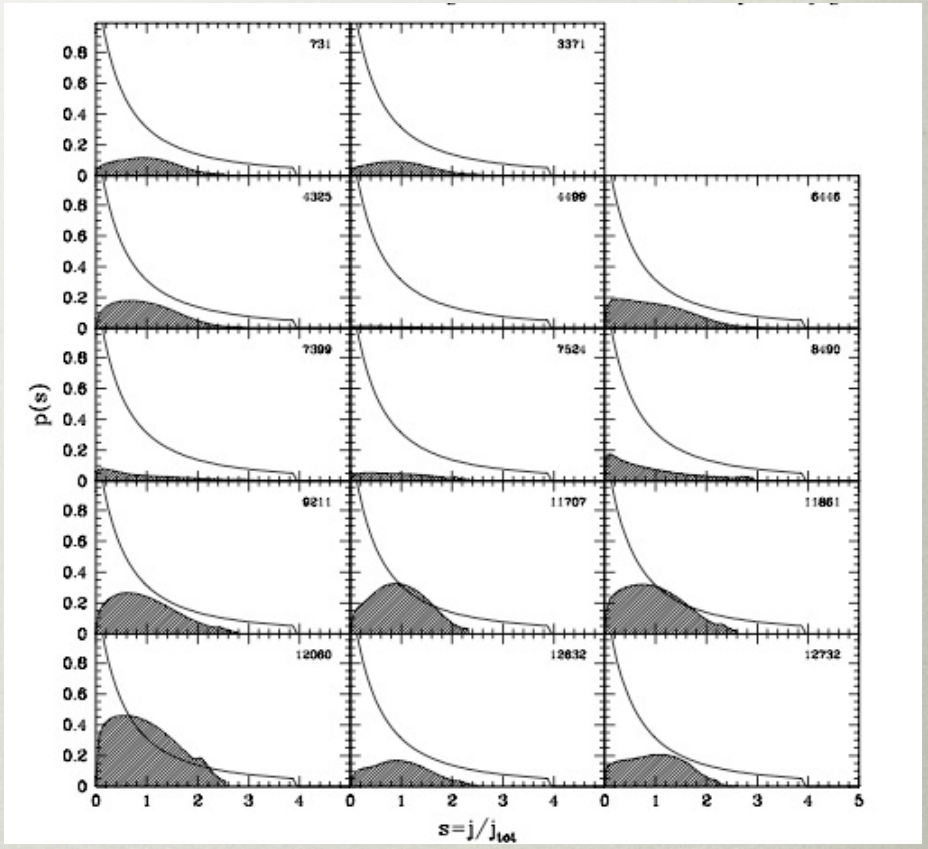
(arrows are velocity vectors)

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

Outflows Remove Low Angular Momentum Gas

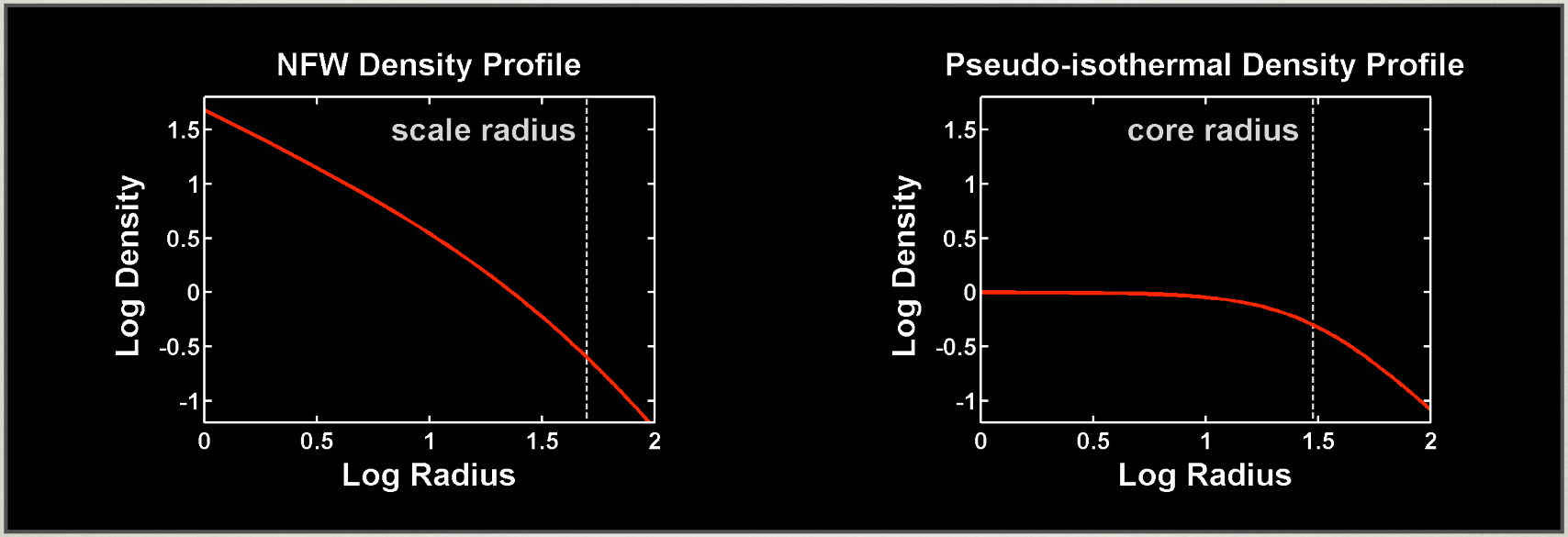


Brook et al., 2011, MNRAS, 415, 1051



van den Bosch et al. (2001)

The Cusp/Core Problem

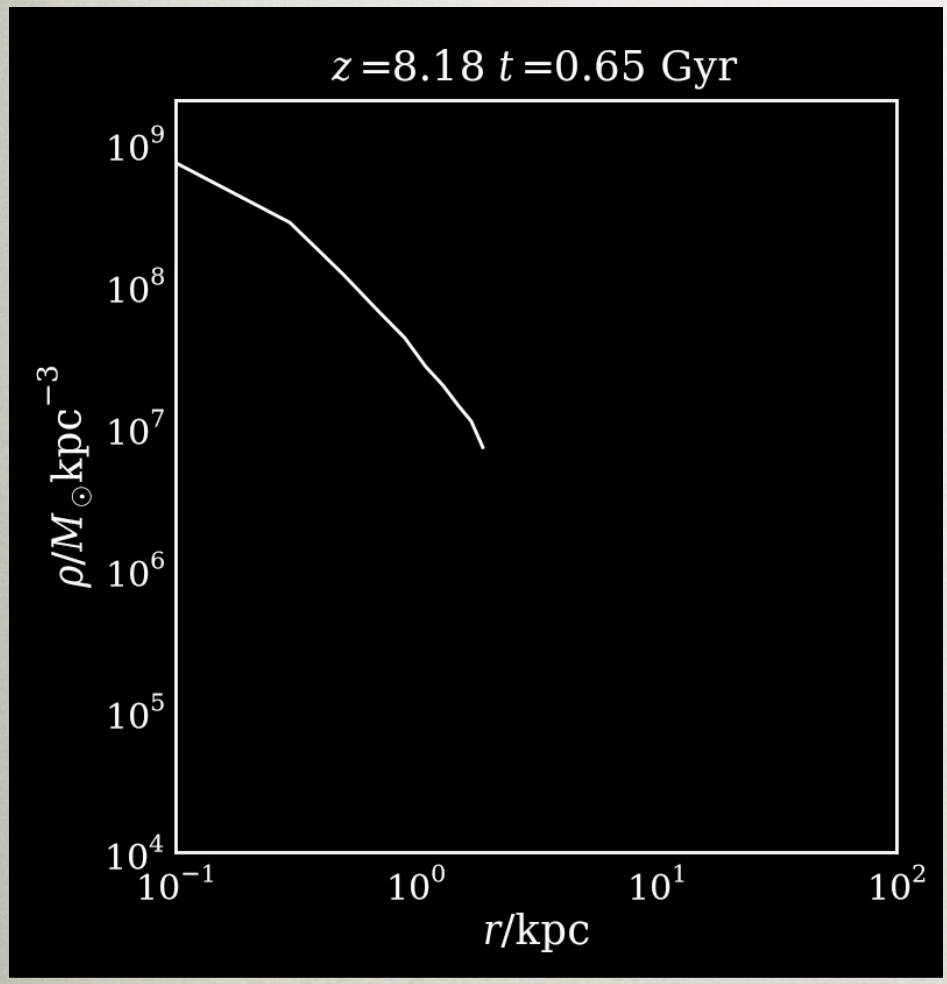


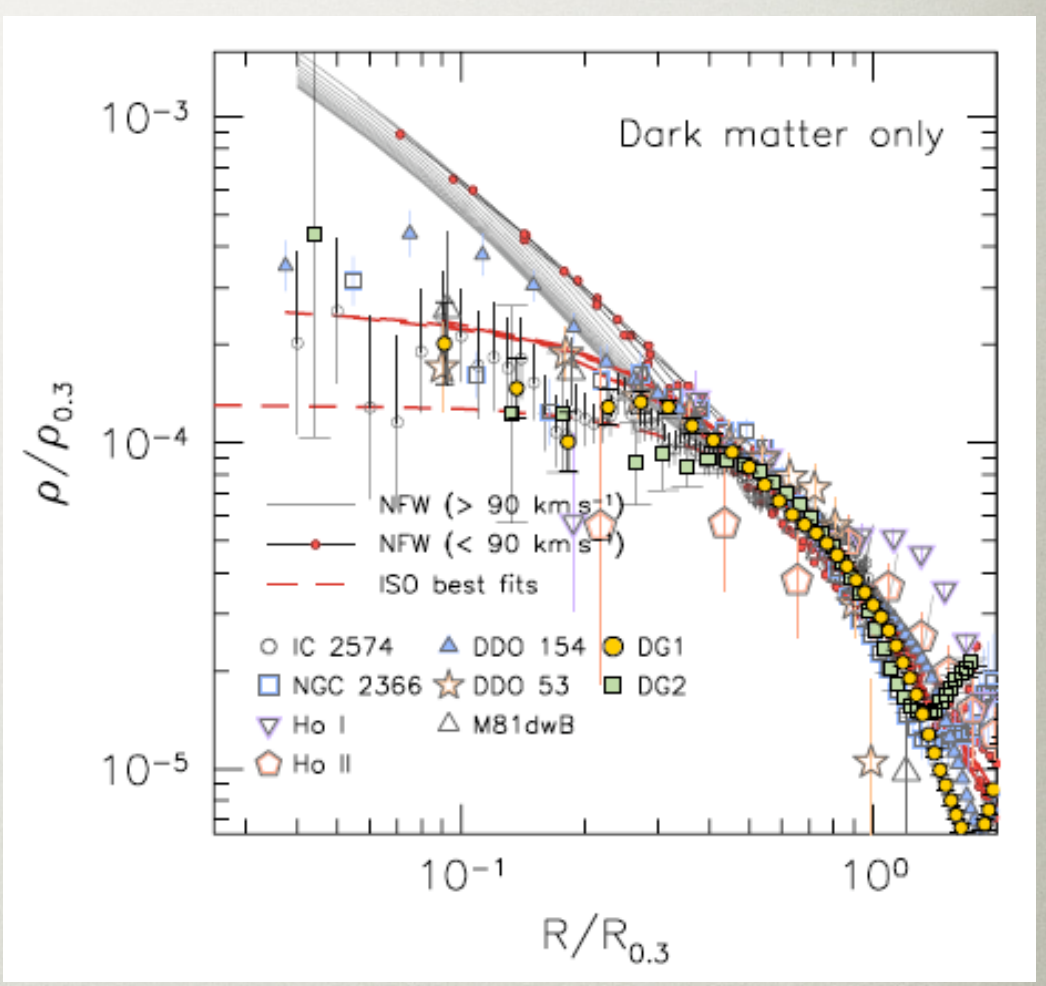
Parameterize density profile as $\varrho(r) \propto r^{-\alpha}$

Simulations predict $\alpha \sim 1$ (a steeply rising central cusp)

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

Creation of a Dark Matter Core

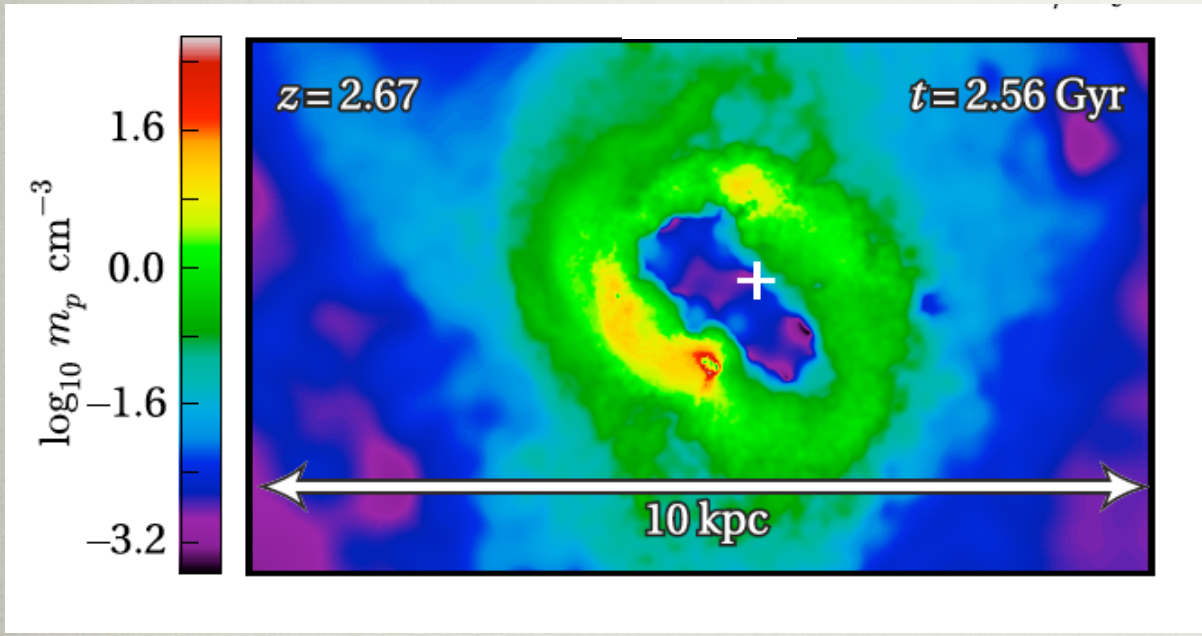


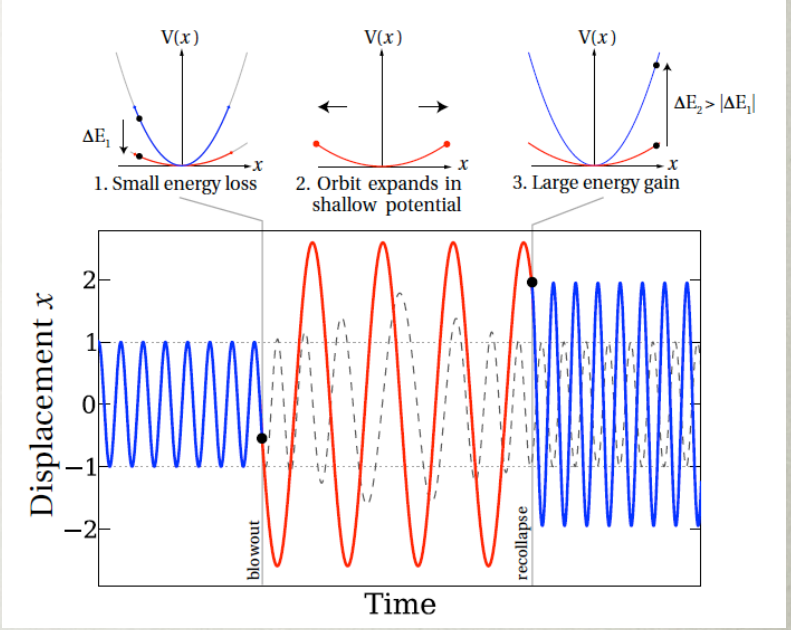


Oh et al., 2011, AJ, 142, 24

Pontzen & Governato (2012)

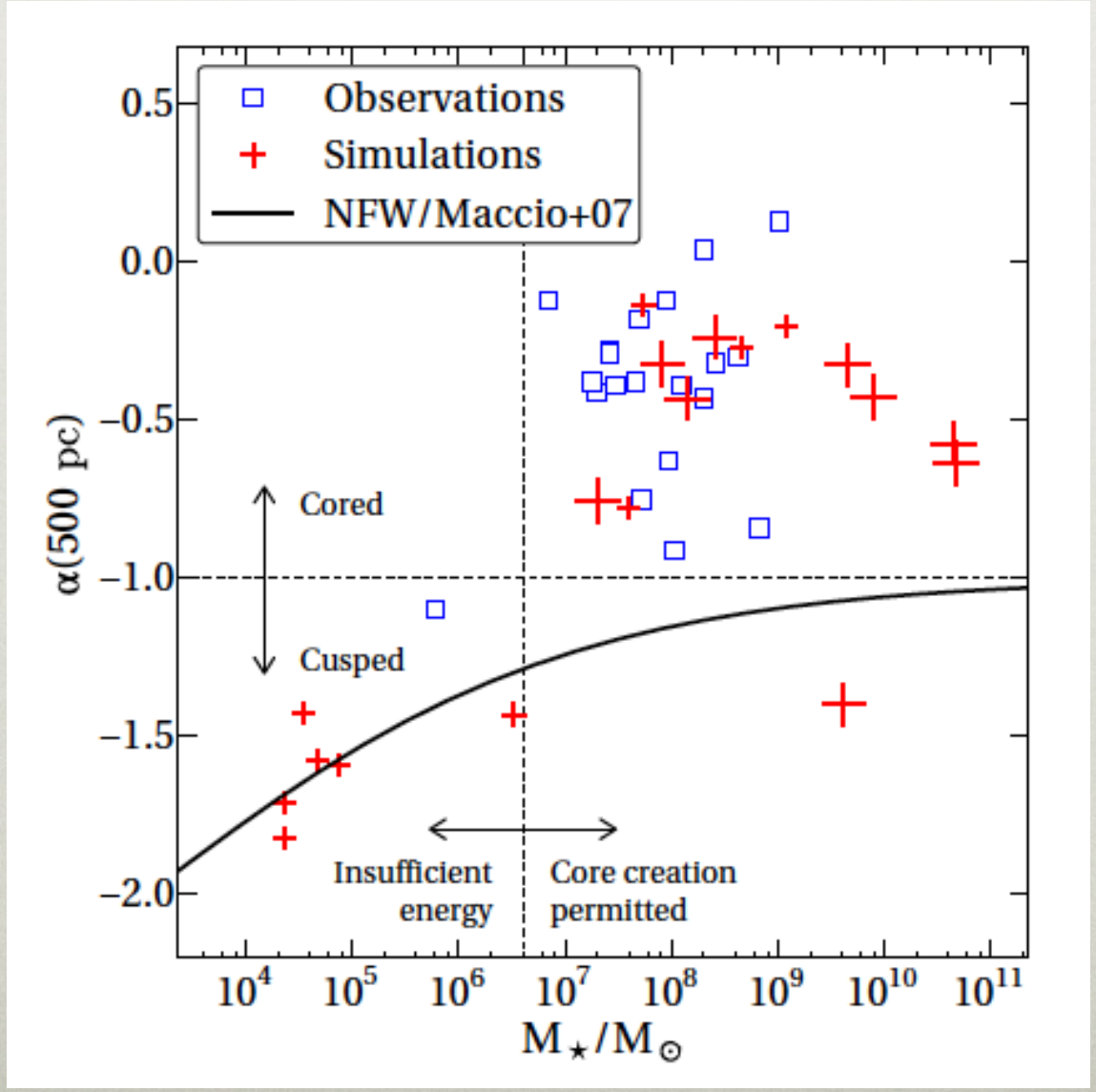
How are Cores Created?





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

Core Creation Varies with Galaxy Mass



Starting Assumption:
There is No Small Scale "Crisis"

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

Starting Assumption:
There is No Small Scale "Crisis"

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

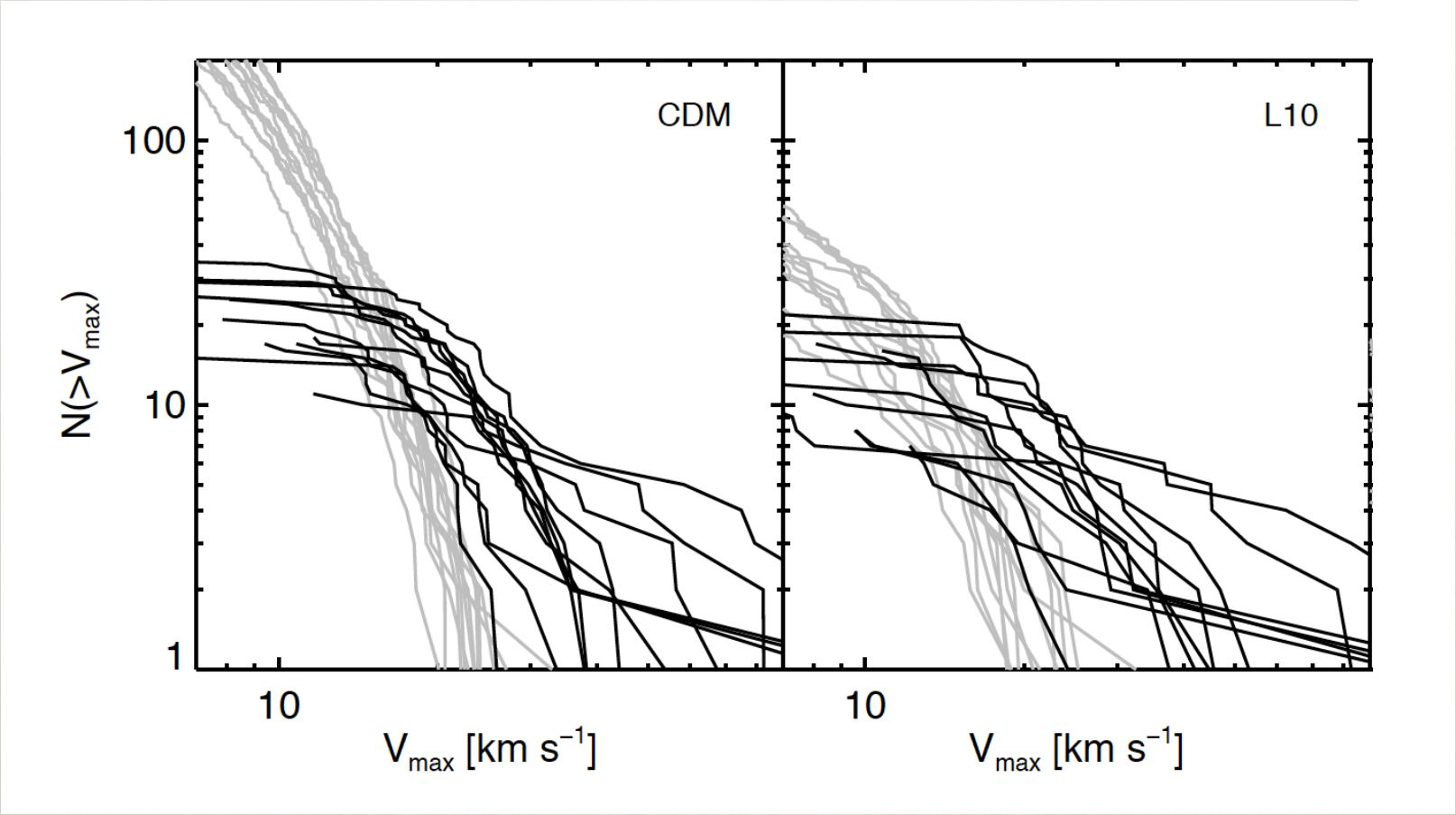
Starting Assumption:
There is No Small Scale "Crisis"

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

We need baryons in alternative DM models

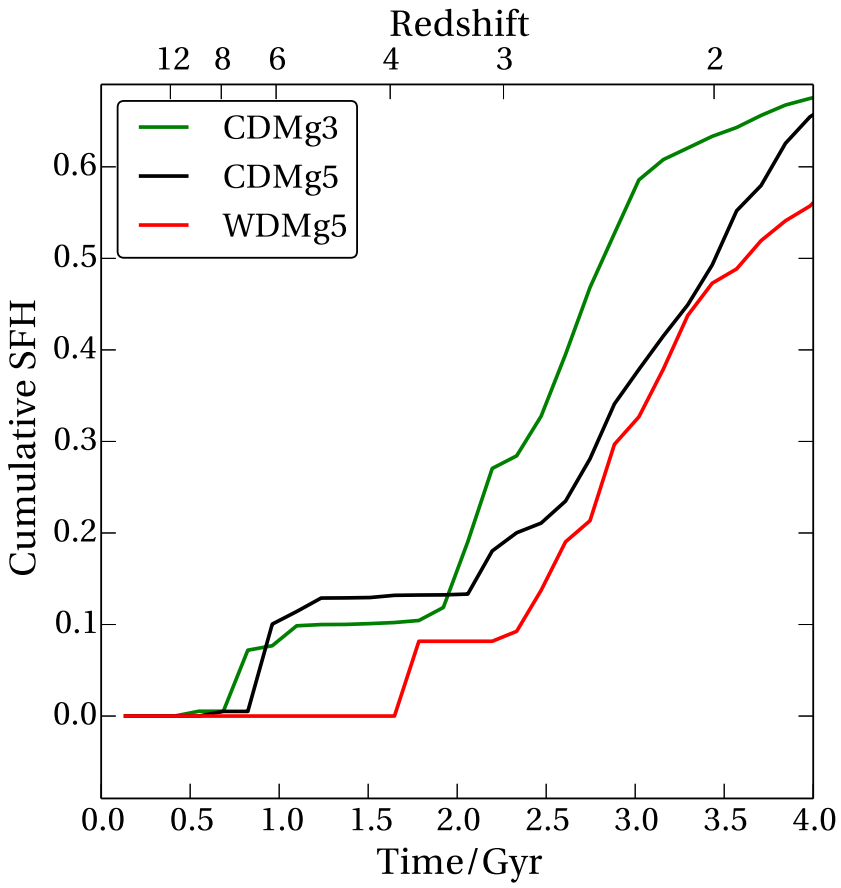
What is the smoking gun that points to a given DM model?

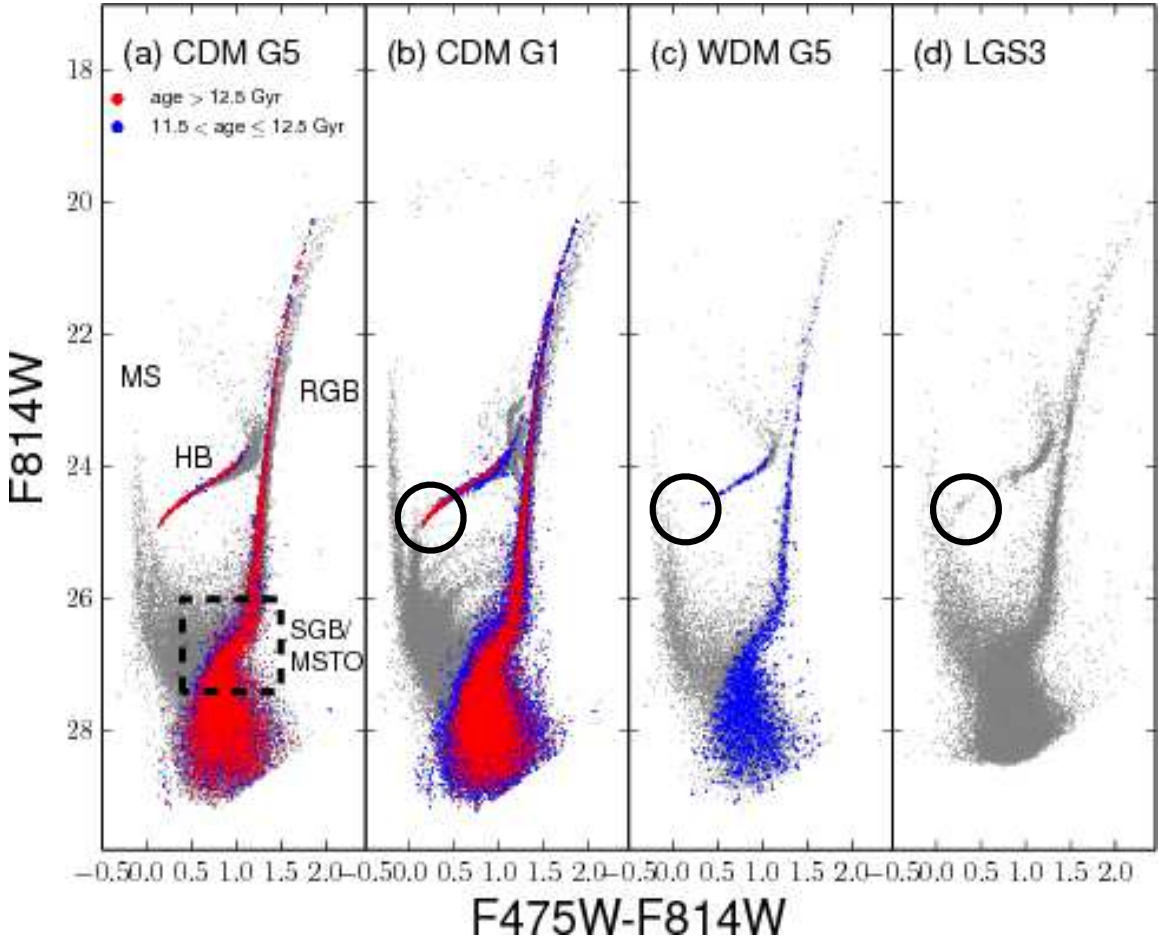
WDM: Walking a Fine Line



Lovell et al. (2016)

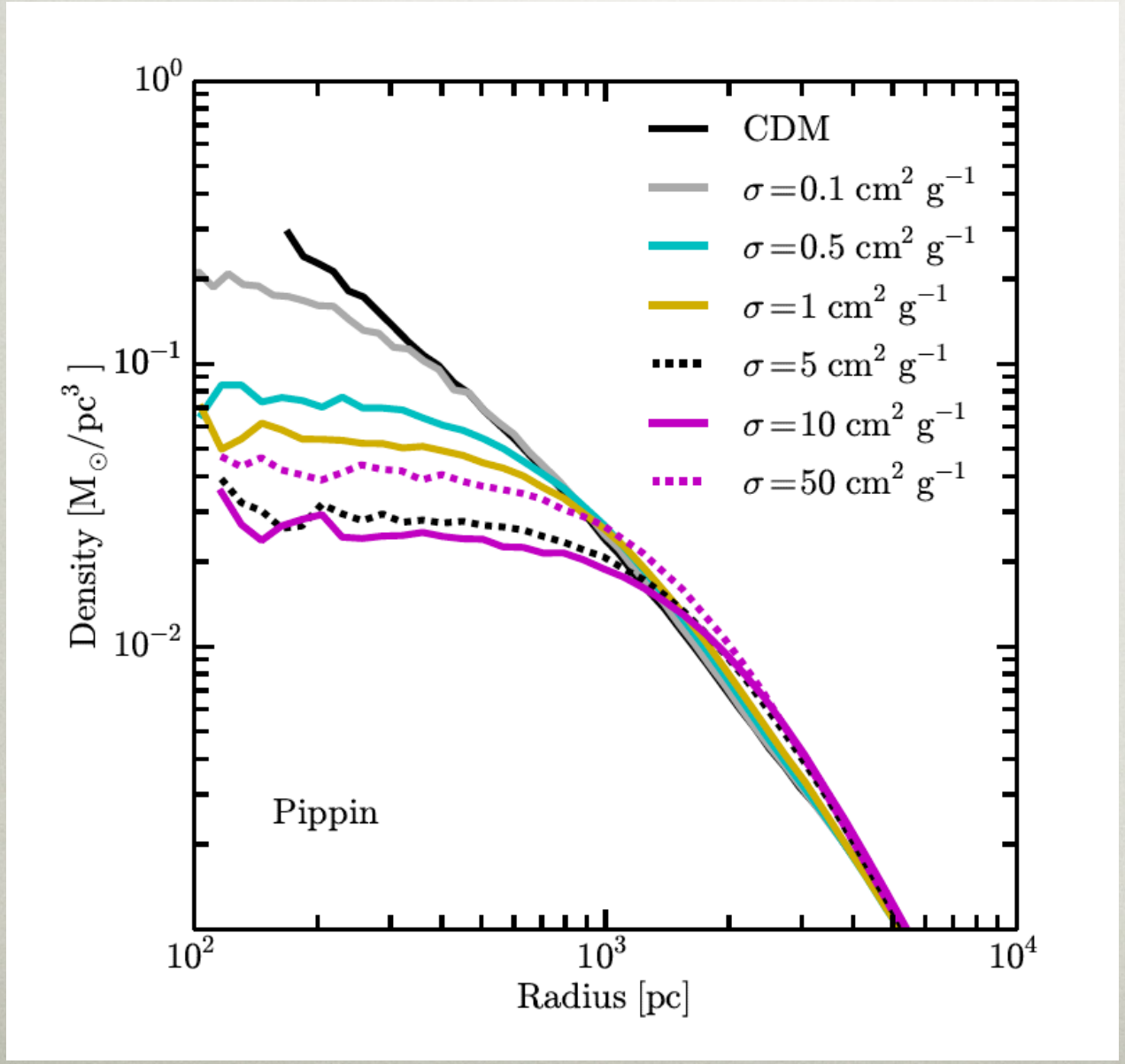
A Testable Prediction of delayed structure formation





Governato et al. (2014)

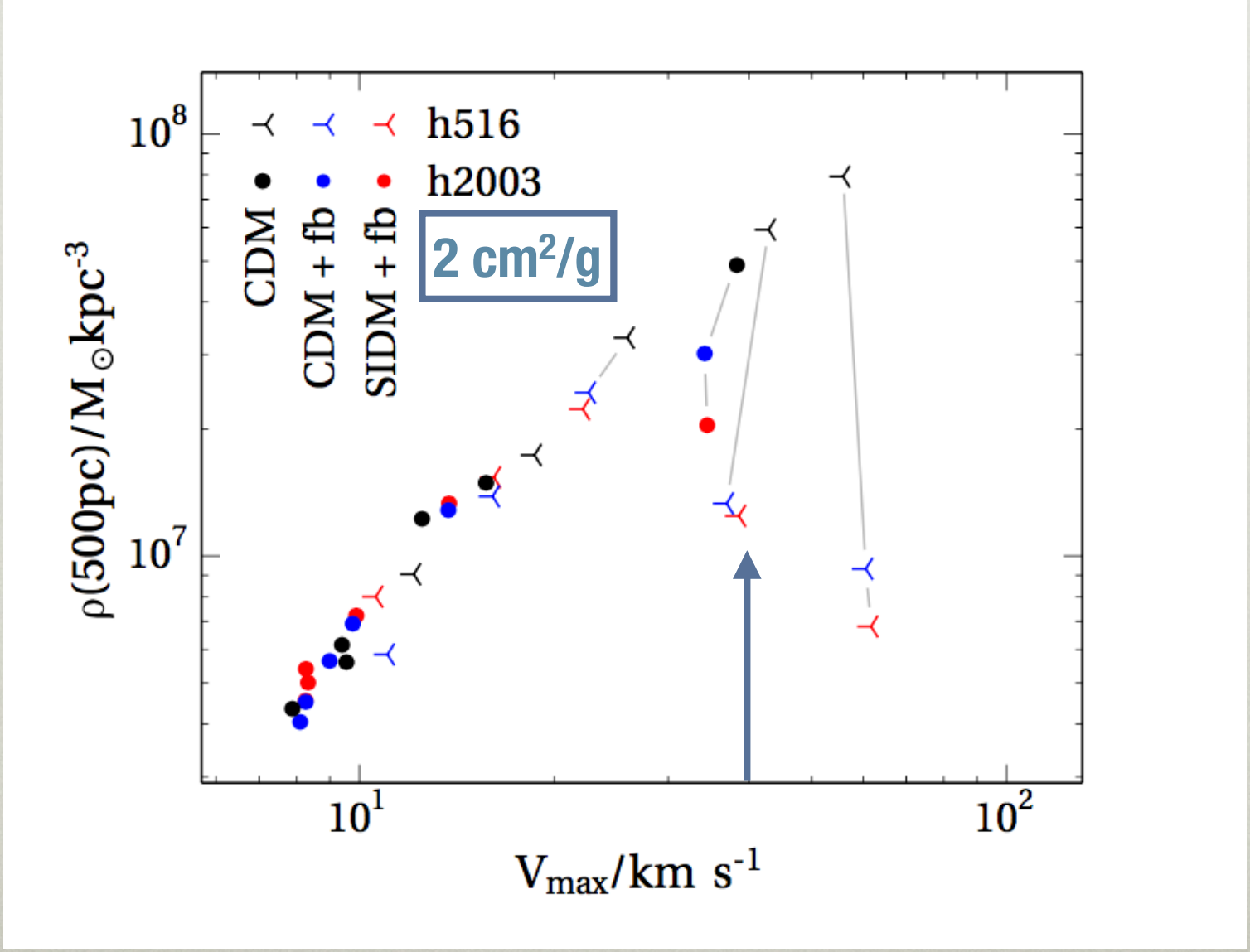
SIDM: the Constraints Are Weakening



results for a 9×10^9 M_{sun} halo

Elbert et al. (2015)

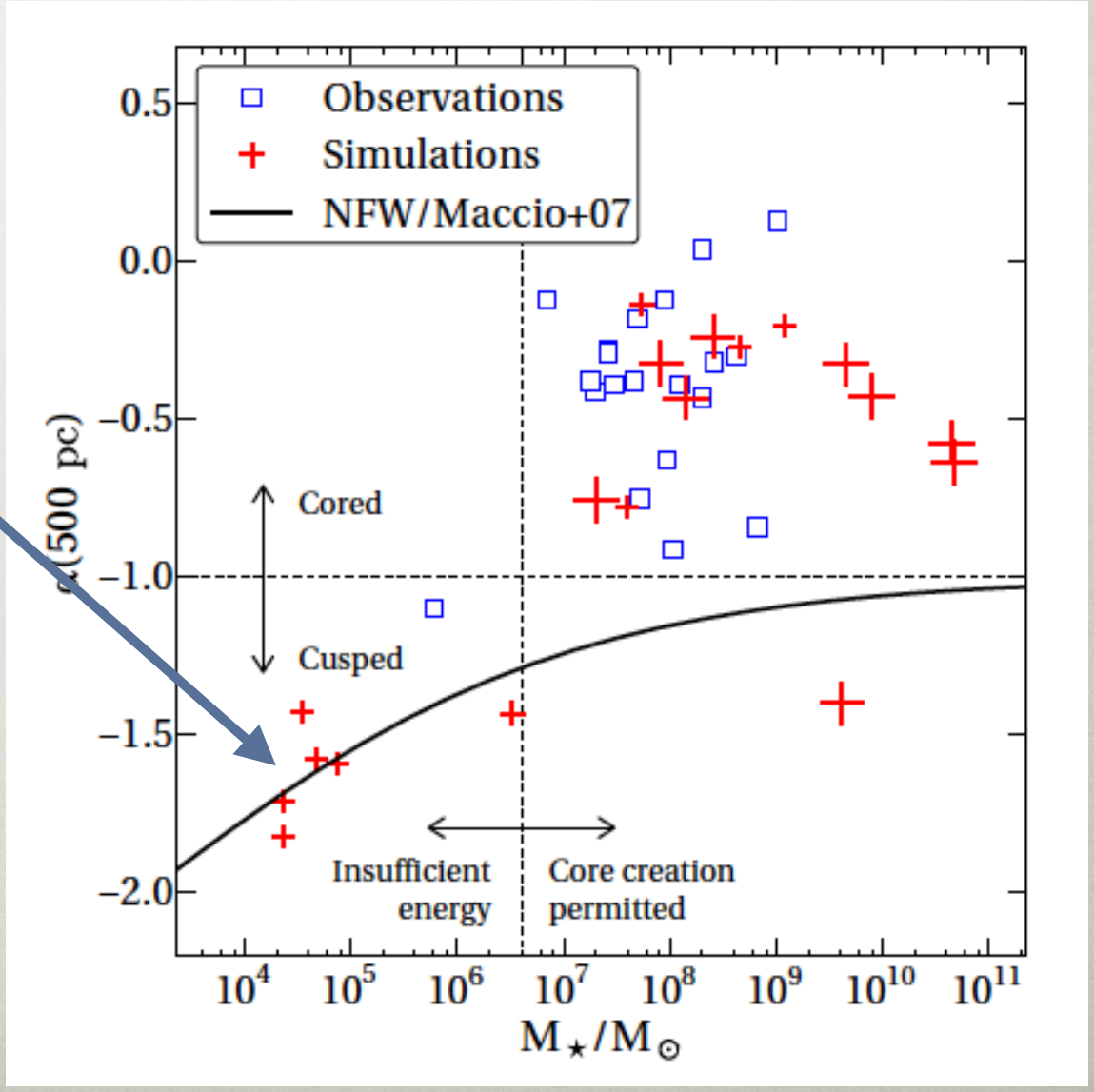
But... baryons win first



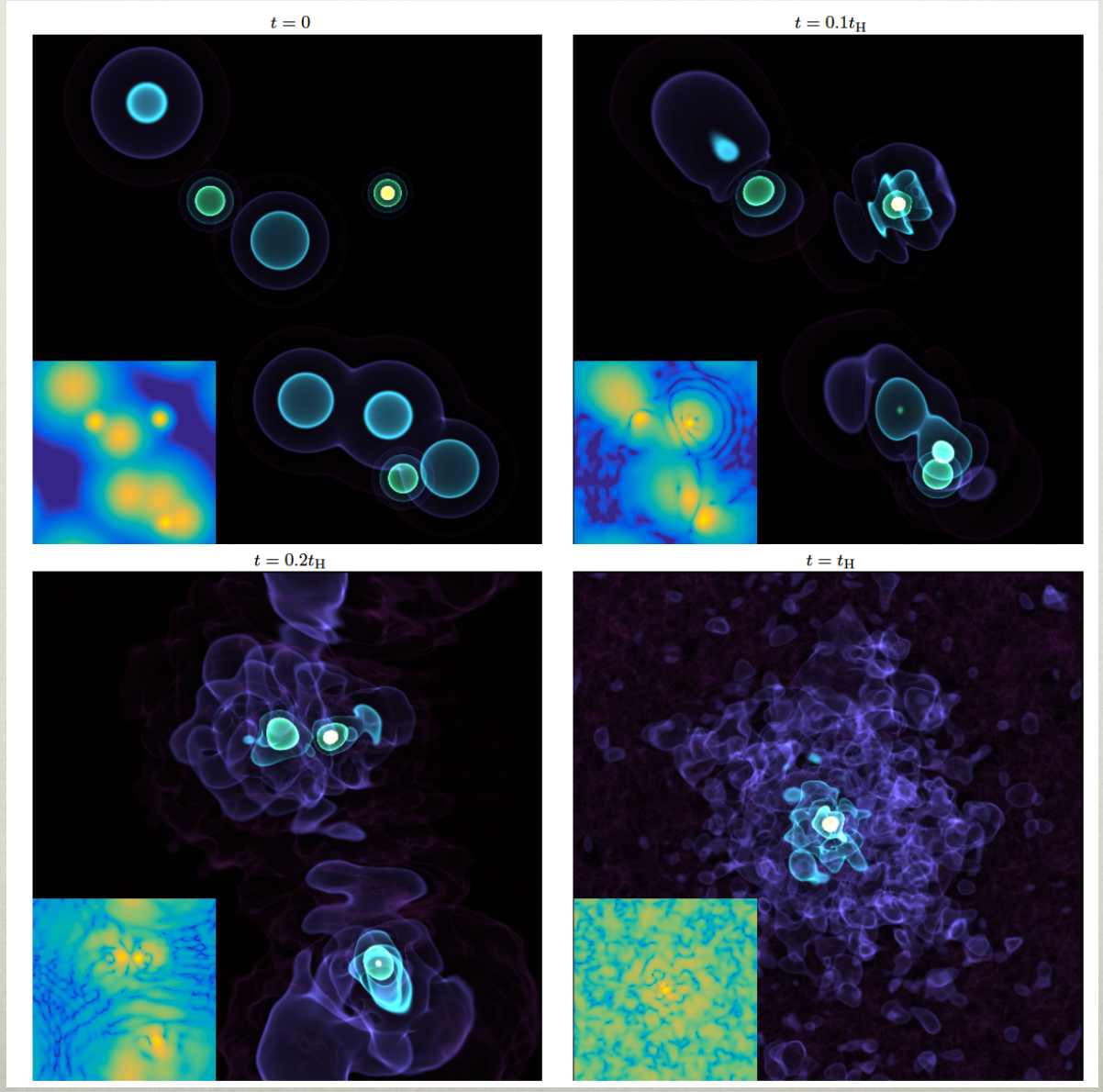
Bastidas-Fry et al. (2015)

An Observational Test

If galaxies in this mass range are observed to have large cores, then something beyond CDM is necessary



Even Lighter DM?
Fuzzy DM Simulations



Mocz et al., arXiv:1705.05845

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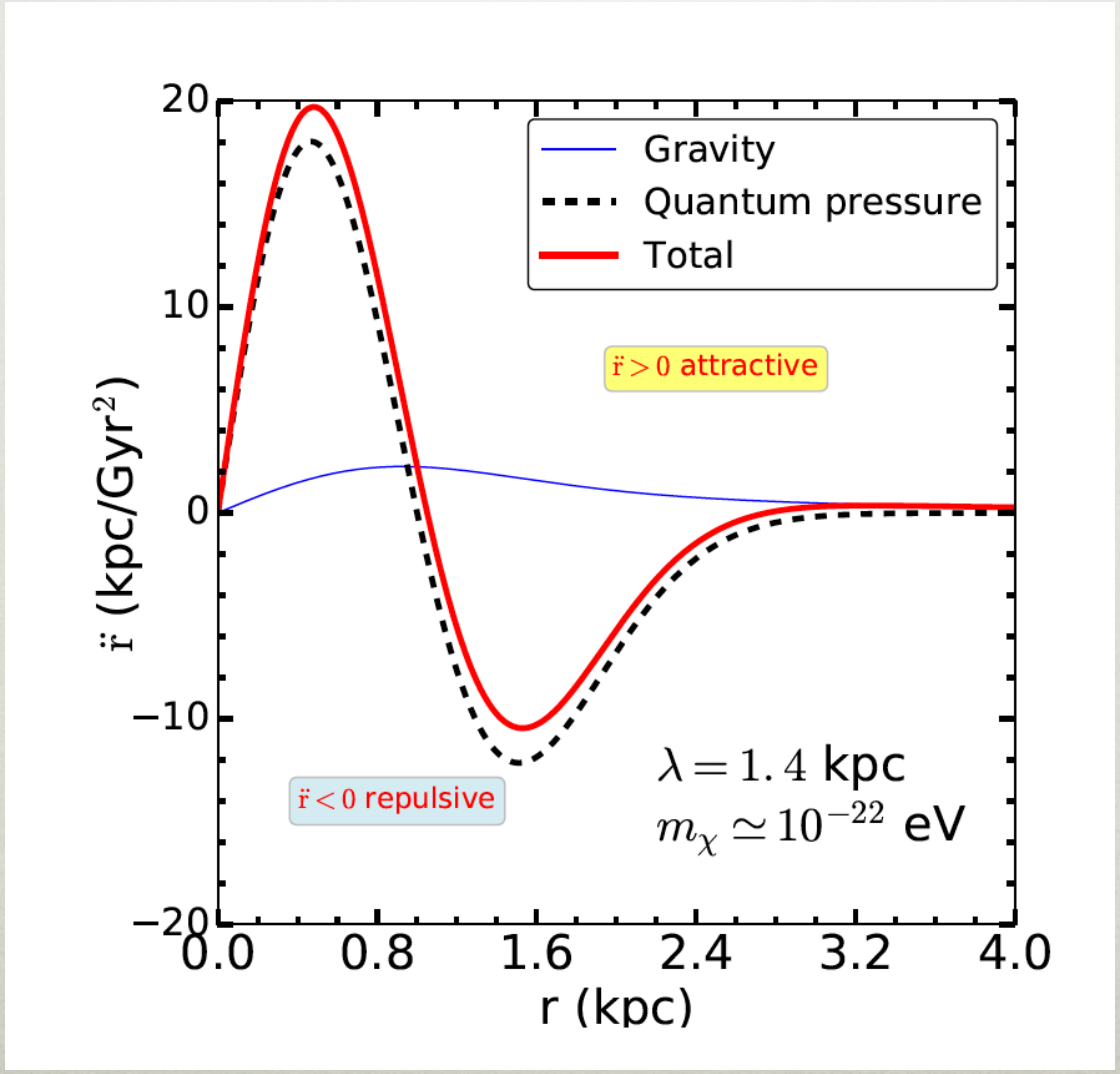

Zhang et al., arXiv:1611.00892

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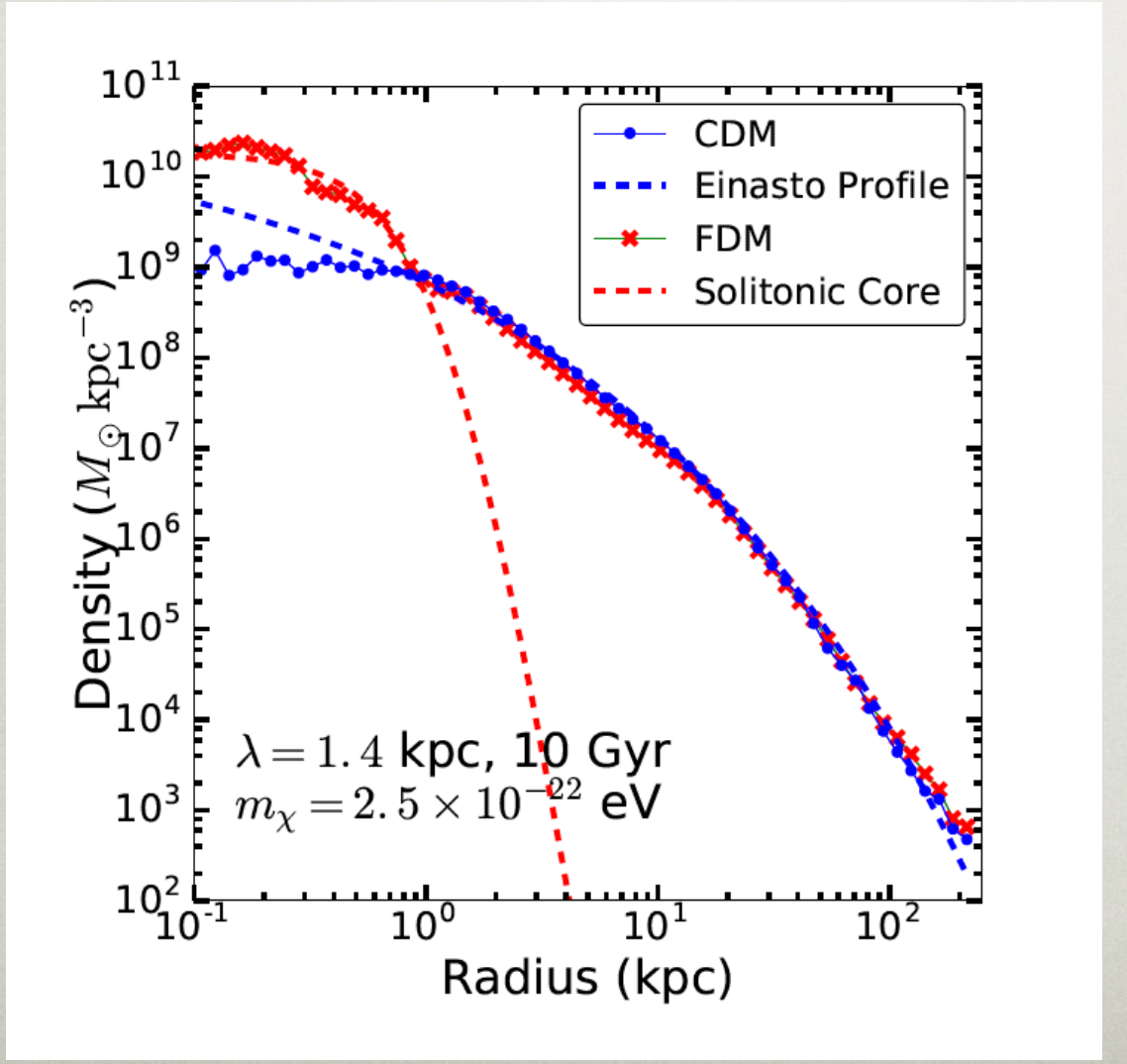
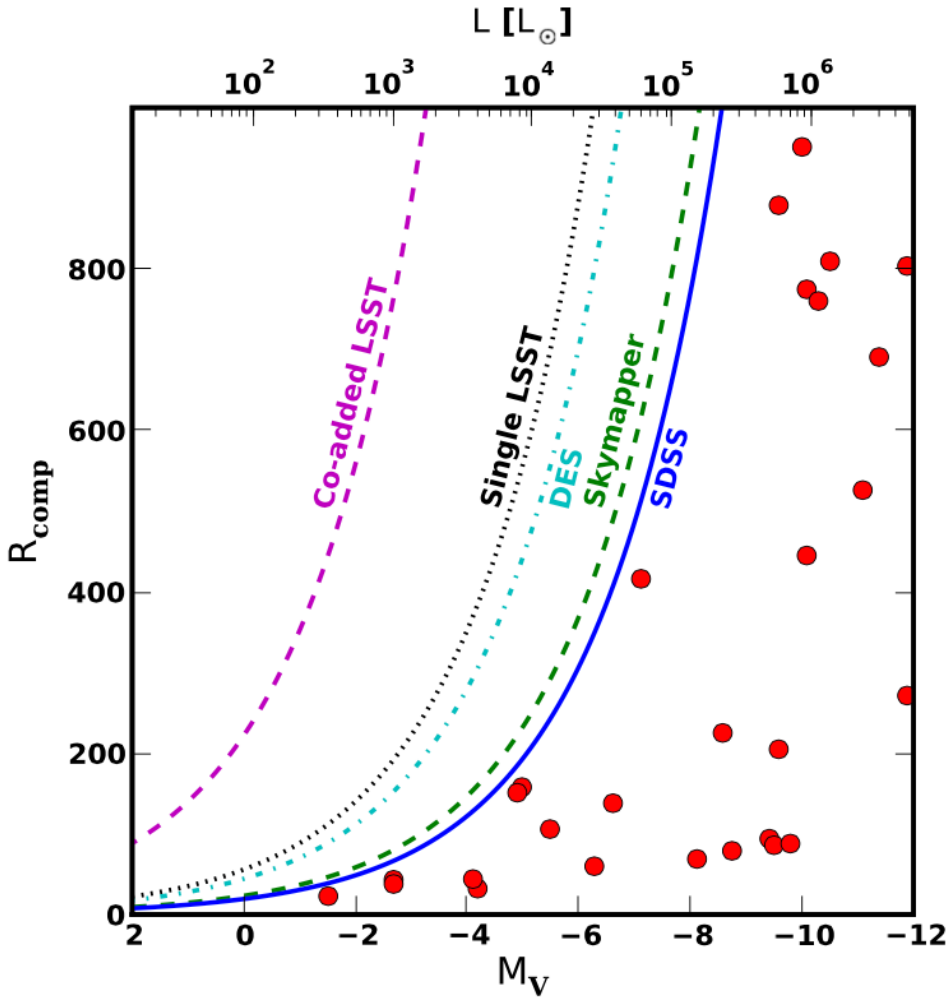
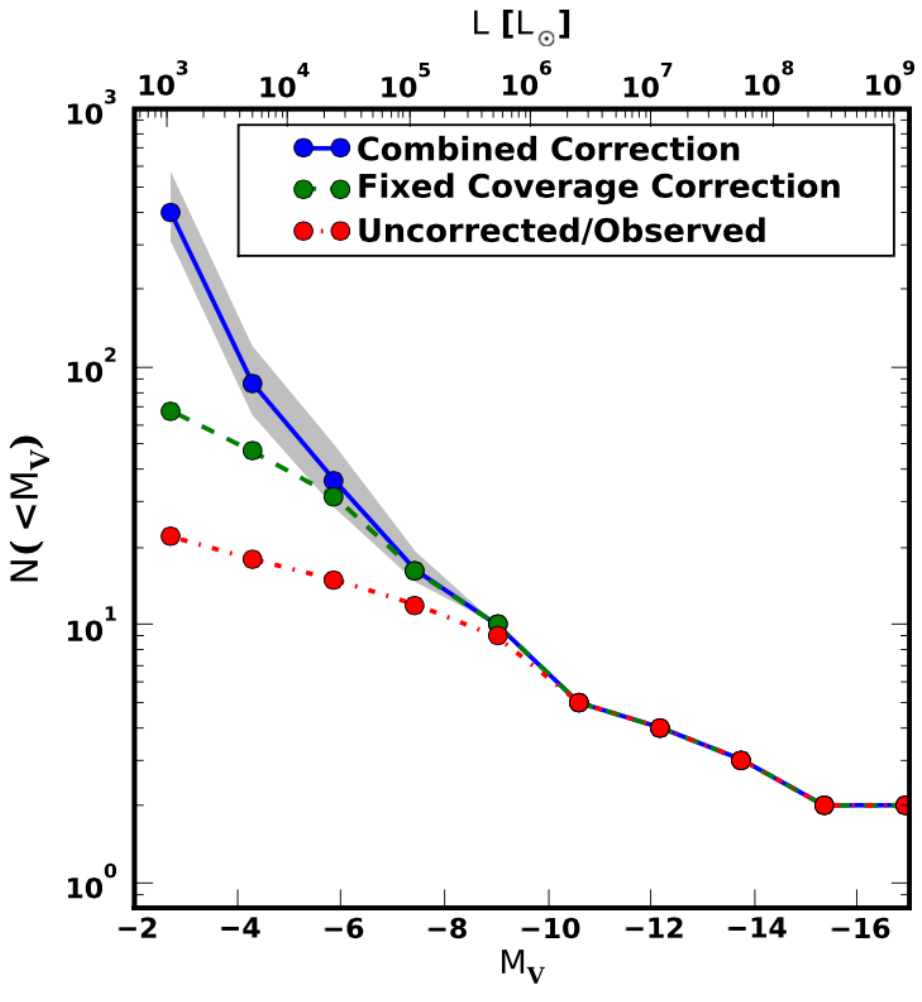


solitonic cores denser than CDM?

Zhang et al., arXiv:1611.00892

The Future is Dwarfy





Tollerud et al. (2009)

Conclusions

Baryonic physics alleviates the current problems with CDM

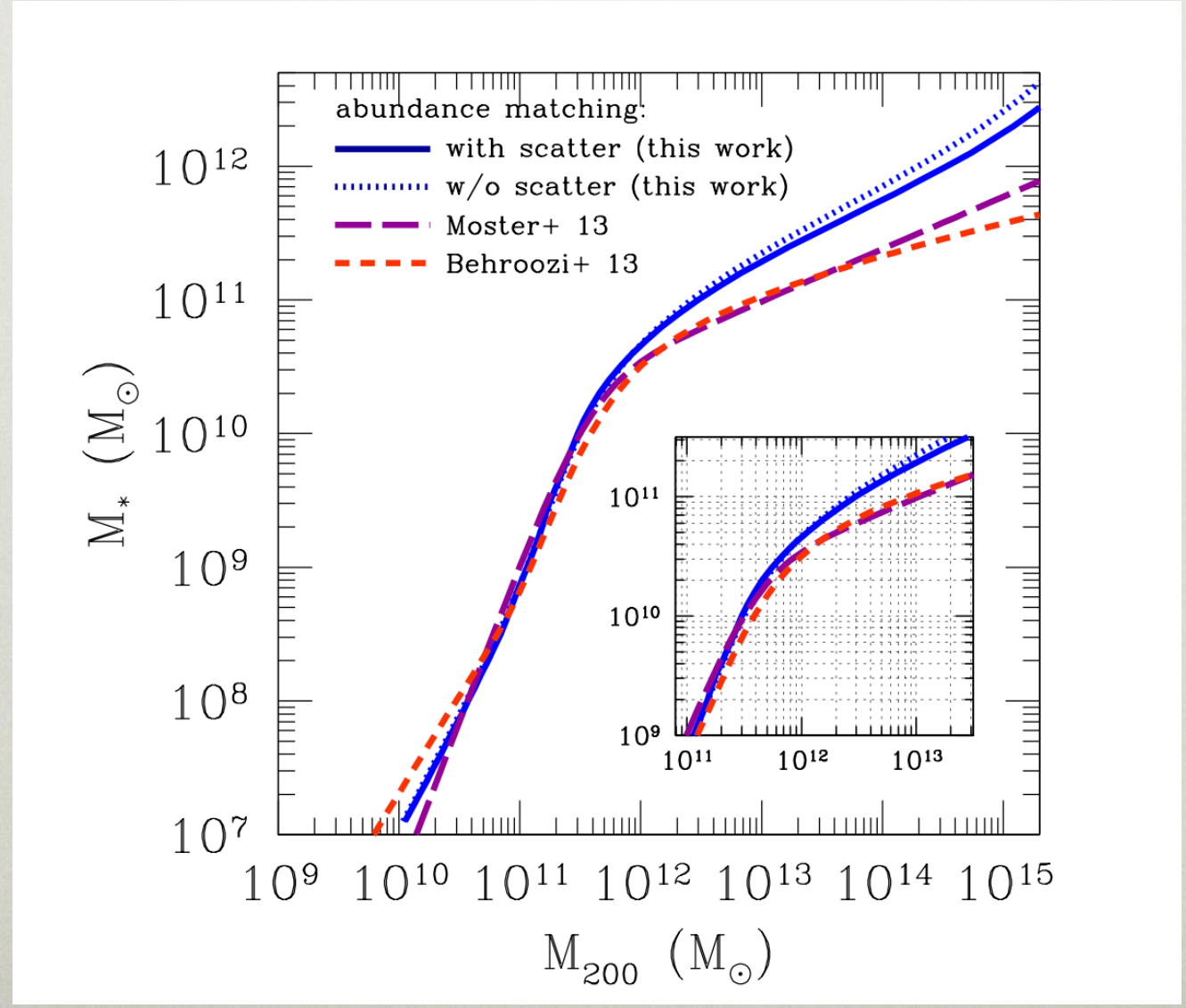
But that doesn't mean CDM is the correct model. All dark matter models must also include baryons!

Future observations of dwarf galaxies ($M_{star} < 10^7 M_{sun}$) are the best probes of non-vanilla CDM

To constrain the Dark Matter model, we must understand the impact of baryonic physics on galaxy formation!

see arXiv:1407.7544 for a review

The Stellar Mass — Halo Mass Relation



Kravtsov et al. 2014

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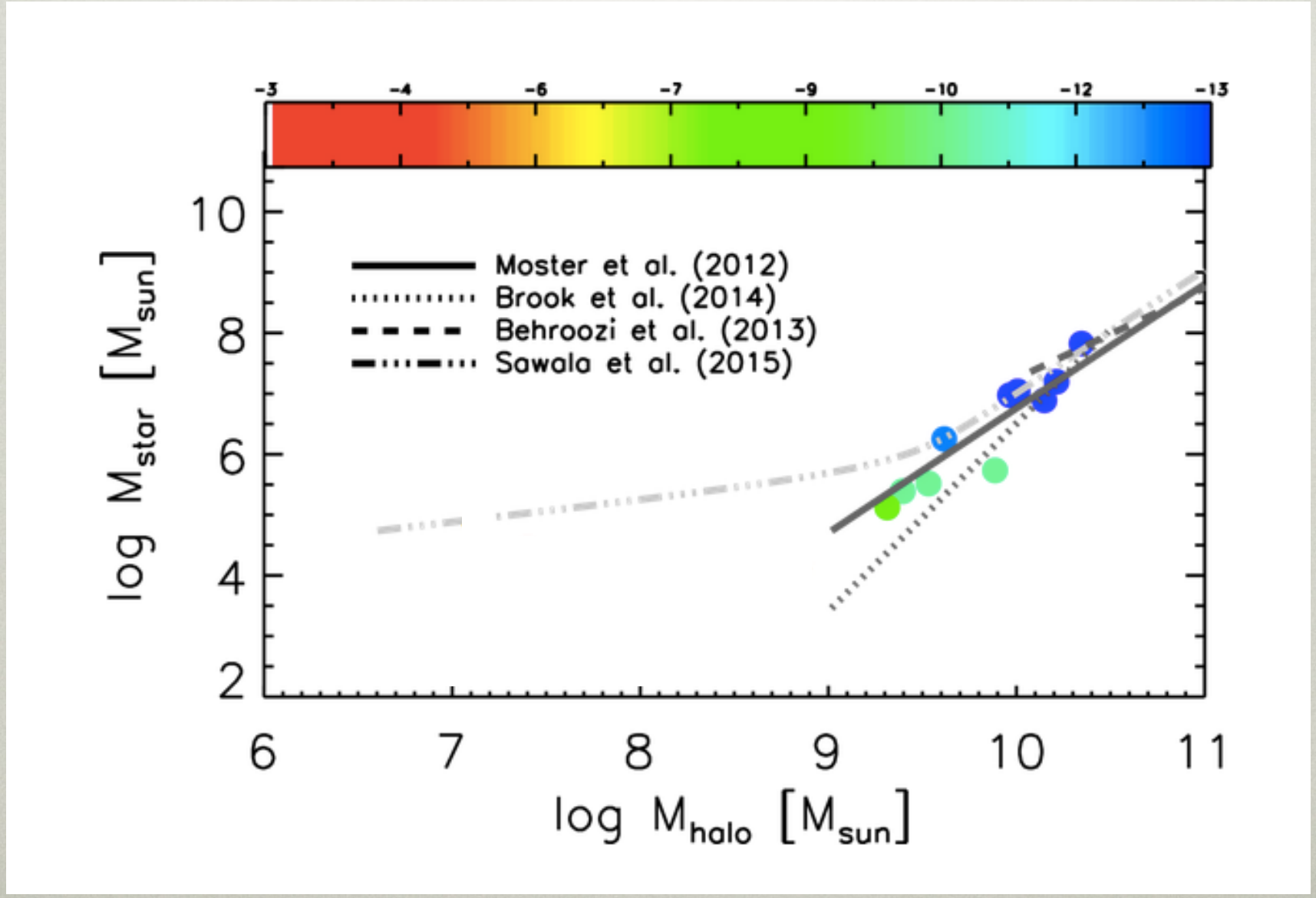

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