Cosmological Simulations With Self-Interacting DM

Miguel Rocha (UCI)

Santa Cruz 2012

Annika Peter Manoj Kaplinghat James Bullock Shea Garrison-Kimmel's Jose Onorbe





Cosmological Simulations With Self-Interacting CDM

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Cosmological Simulations With Self-Interacting CDM

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With all the good things that "Coldness" brings

- Right Structure
- Right Clustering
- Right Abundances

All large scale properties
> ~1 Mpc

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All large scale properties
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We owe all this to just it being "Cold"!

Cold + ?

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What else can we add?

CDM + Self-Interactions?

Particle Physics Motivations:

Pospelov et al. 2008, Arkani-Hamed et al. 2009, Ackerman et al. 2009, Feng et al. 2009,2010
Loeb & Weiner 2011, Stiele et al. 2011, Peter 2012

CDM + Self-Interactions?

Particle Physics Motivations:

- DM Self-Interactions as strong as the standard model strong interactions are allowed by primordial nucleosynthesis

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CDM + Self-Interactions?

Particle Physics Motivations:

- DM Self-Interactions as strong as the standard model strong interactions are allowed by primordial nucleosynthesis. Wimpless Miracle!
- They are a generic consequences of hidden-sector extensions to the Standard Model
- Even if dark sector particles have no couplings to the Standard Model particles they might experience strong interactions with themselves

Pospelov et al. 2008, Arkani-Hamed et al. 2009, Ackerman et al. 2009, Feng et al. 2009,2010
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CDM + Self-Interactions?

Astrophysical Motivations:

Spergerl & Steinhardt 2000

($\sigma/m = 0.1\text{–}100\ \mathrm{cm}^2\ /\mathrm{g}$)

CDM + Self-Interactions?

Astrophysical Motivations:

- Lower central densities and form constant density cores in DM halos

Spergerl & Steinhardt 2000

(σ/m = 0.1–100 cm^2 /g)

CDM + Self-Interactions?

Astrophysical Motivations:

- Lower central densities and form constant density cores in DM halos
- Reduce the number if subhalos through subhalo evaporation

Spergerl & Steinhardt 2000

(σ/m = 0.1–100 cm^2 /g)

Previous Constraints

Reference	Constraint [cm^2 /g]	From	Problem
Yoshidal et. al 2000	$\sigma/m < \sim 0.1$	Cluster density core	One cluster
Dave et. al 2001	$\sigma/m = 0.1-10$	Dwarfs density Cores	Narrow mass range
Gnedin & Ostriker 2001	$\sigma/m < 0.3$	Subhalo evaporation	Overestimated subhalo evaporation
Miralda-Escude 2002	$\sigma/m < 0.02$	Halo shapes	Overestimated halo sphericity
Randall et al. 2008	$\sigma/m < 0.7-1.25$	Bullet Cluster	High central densities and relative vel.

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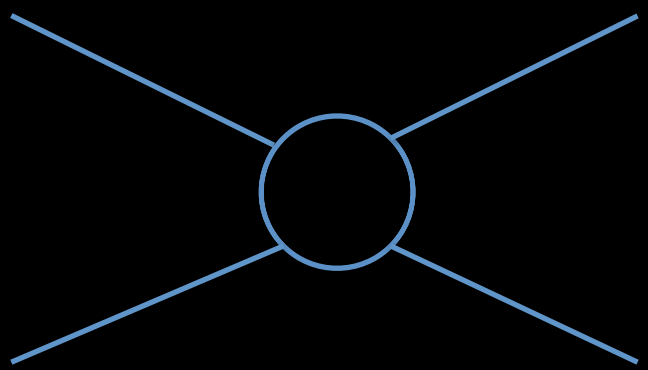
Peter et al. arXiv:1208.3026	$\boldsymbol{\sigma/m < 1}$	Halo shapes	✓
Randall et al. 2008	$\sigma/m < 0.7–1.25$	Bullet Cluster	High central densities and relative vel.

Modeling DM Self-Iteractions

Revisiting the Simplest Model:

- Elastic
- Velocity Independent
- Isotropic



$$\Gamma \simeq \rho \, (\sigma/m) \, v_{rms}$$

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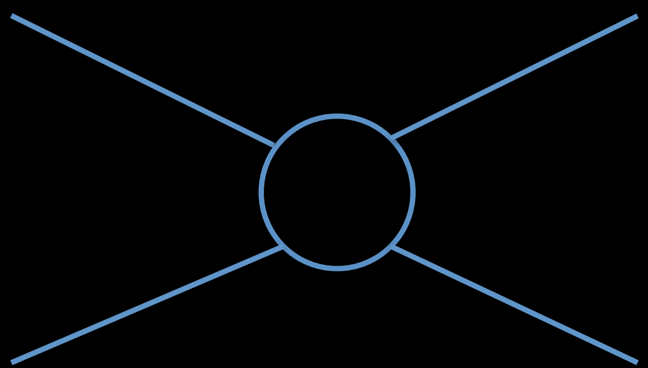

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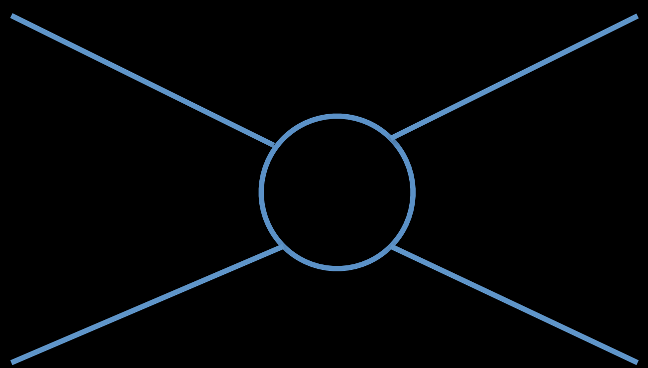


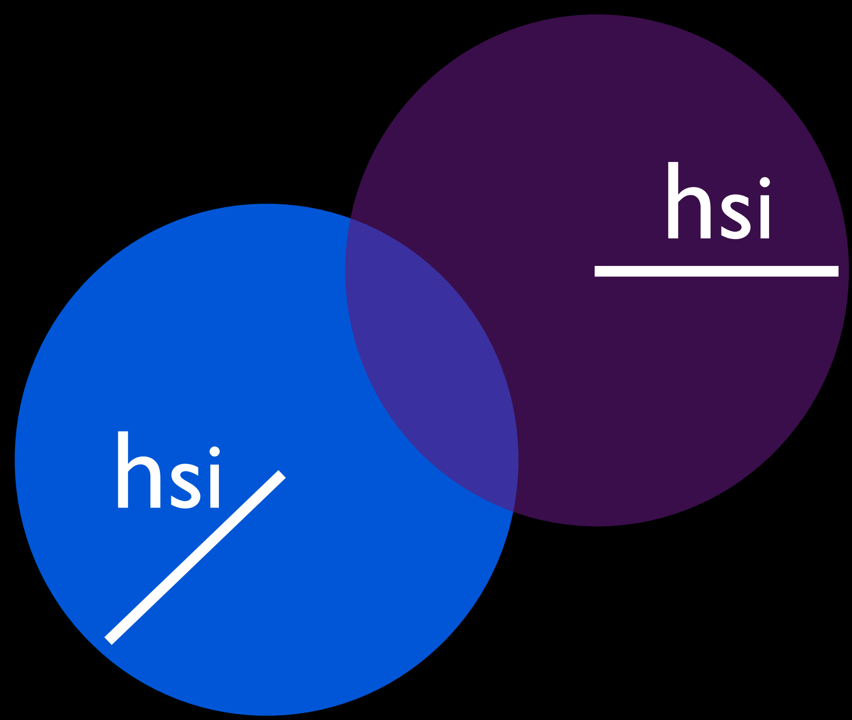
σ/m ~ 0.1, 1 cm^2 /g

$$\Gamma \simeq \rho (\sigma/m) v_{rms}$$

Pair-wise Scattering

New algorithm derived self-consistently from the Boltzmann equation

N-body particles are given a self-interacting smoothing length "hsi" to represent phase-space blobs



Rocha et al. 2012
arXiv:1208.3025

Pair-wise Scattering

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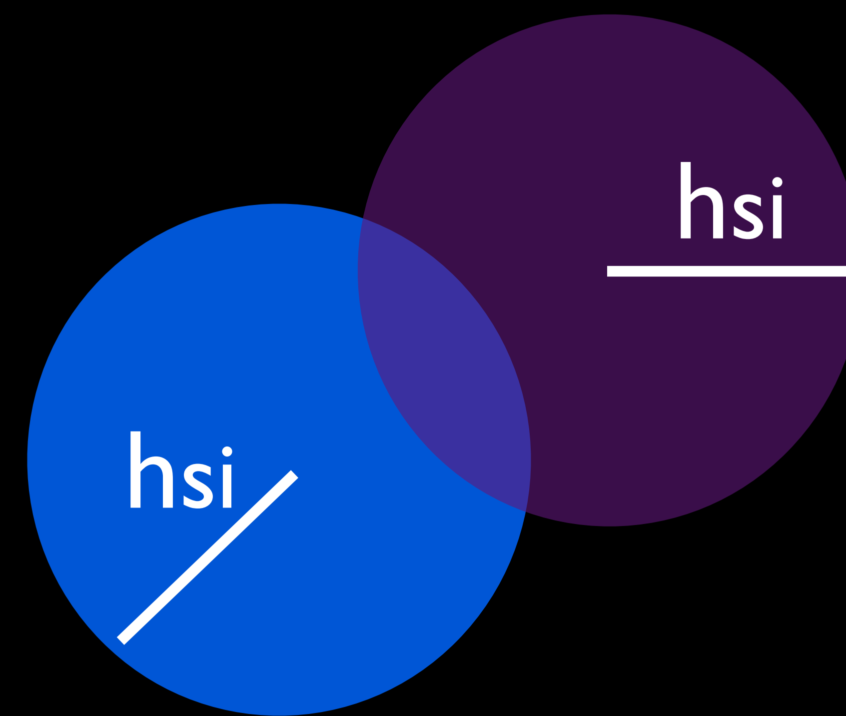
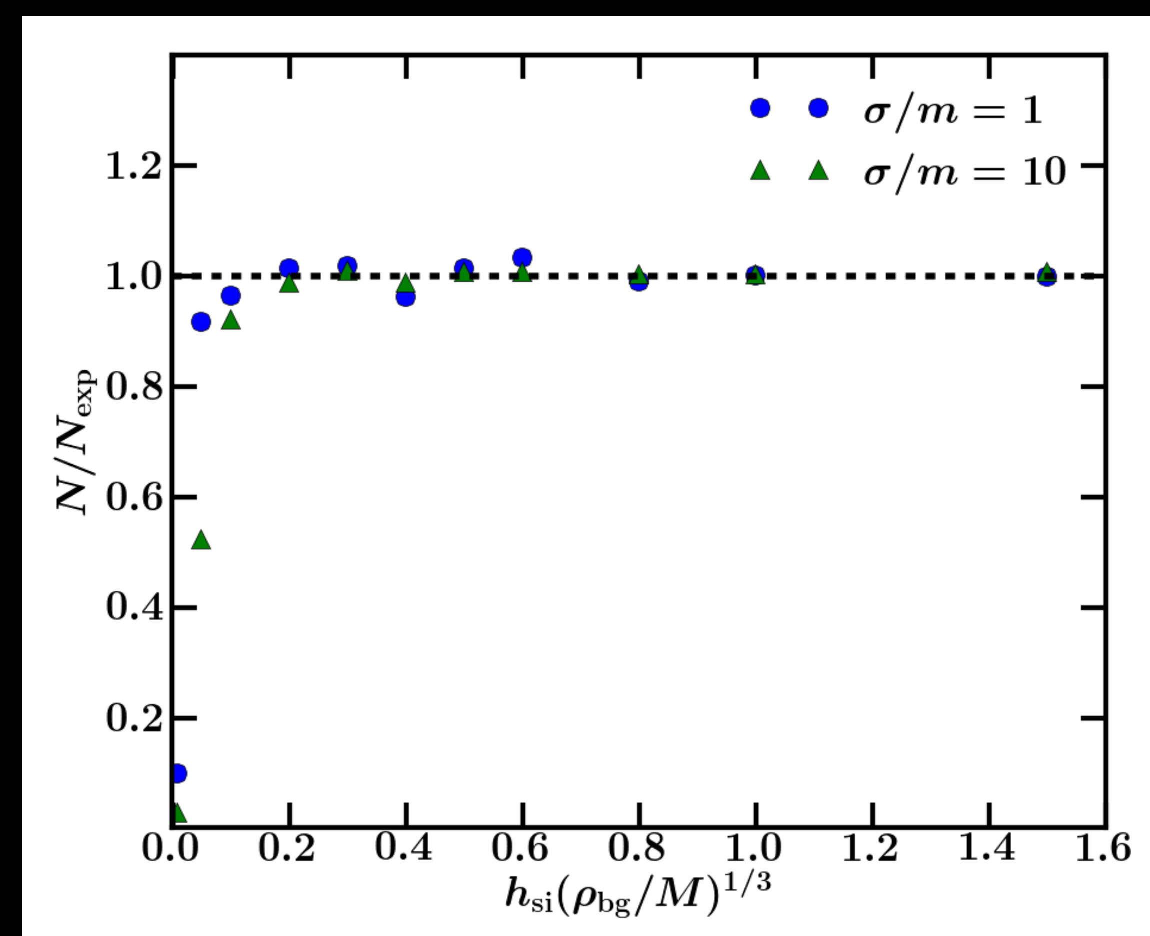
We test it!





Rocha et al. 2012
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Simulation Set

50 Mpc/h Box: Np = 512^3, mp ~ 7e7 Msun

25 Mpc/h Box: Np = 512^3, mp ~9e6 Msun

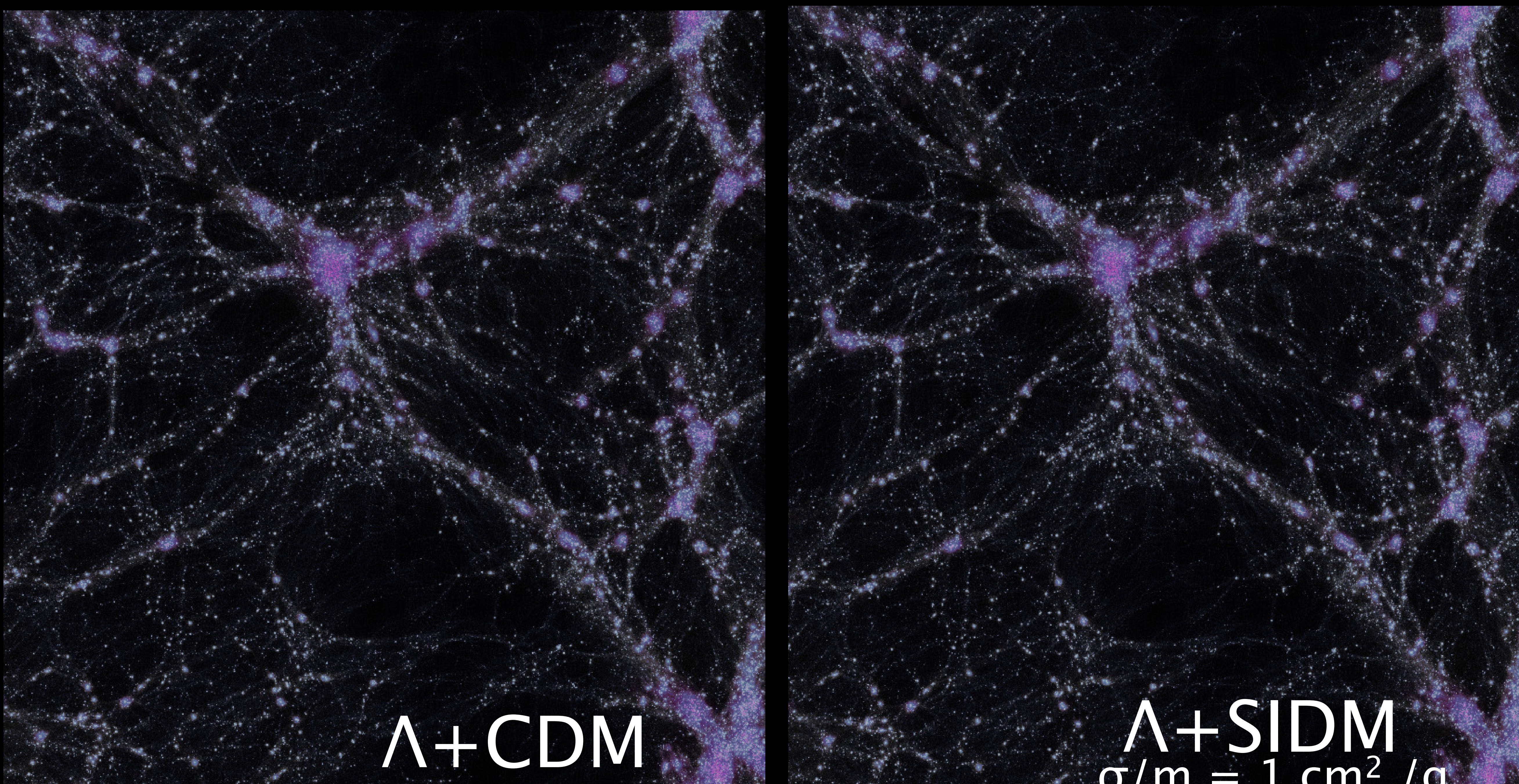
Zoom halo Mvir = 5e11 Msun, mp ~ 1.5e6 Msun

Zoom halo Mvir = 1e12 Msun, mp ~ 2e5 Msun

All of them run with $\sigma/m = 0,\ 1,\ 0.1\ \mathrm{cm}^2\ /\mathrm{g}$

Rocha et al. 2012
arXiv:1208.3025

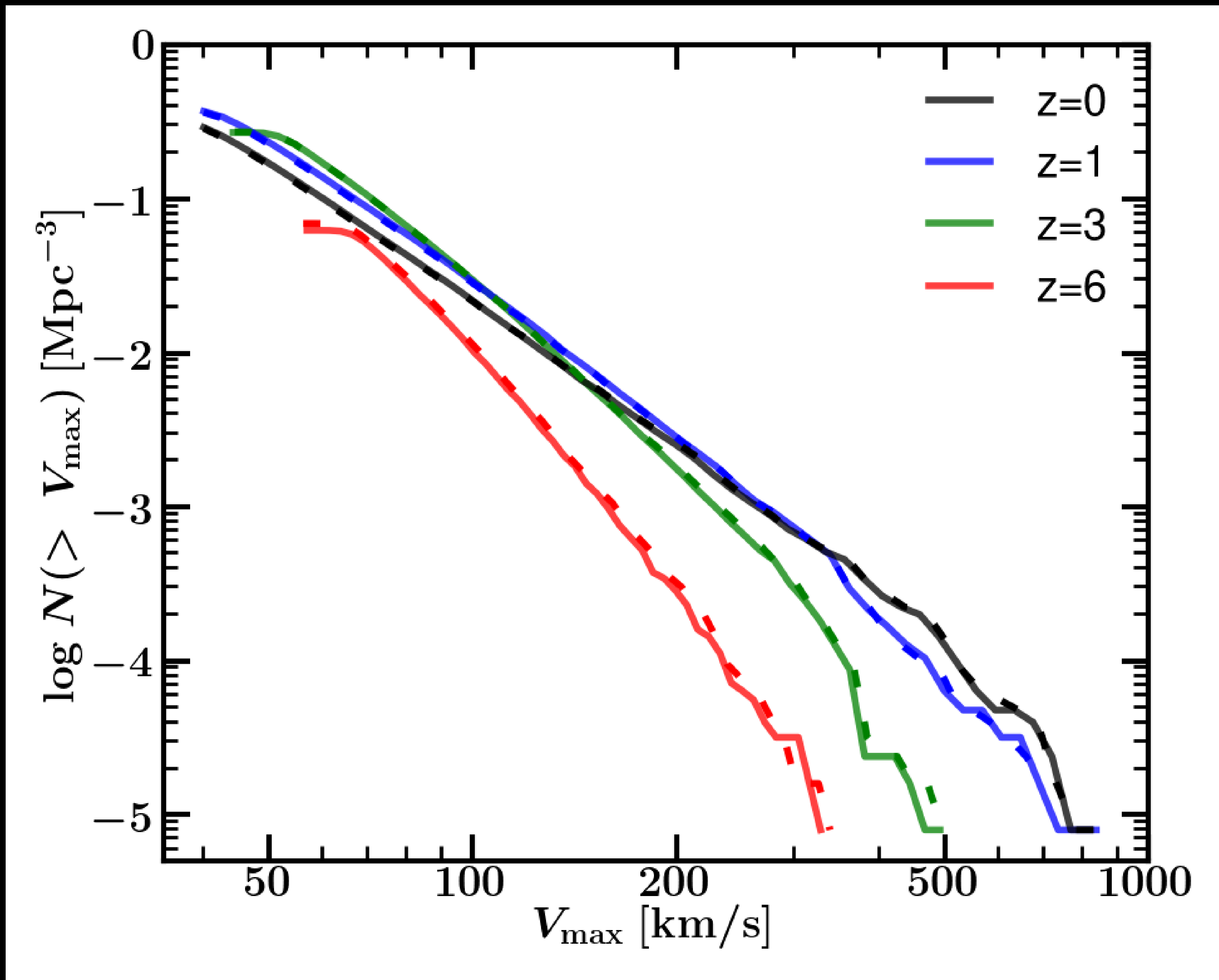
Identical Large-Scale Sturcture



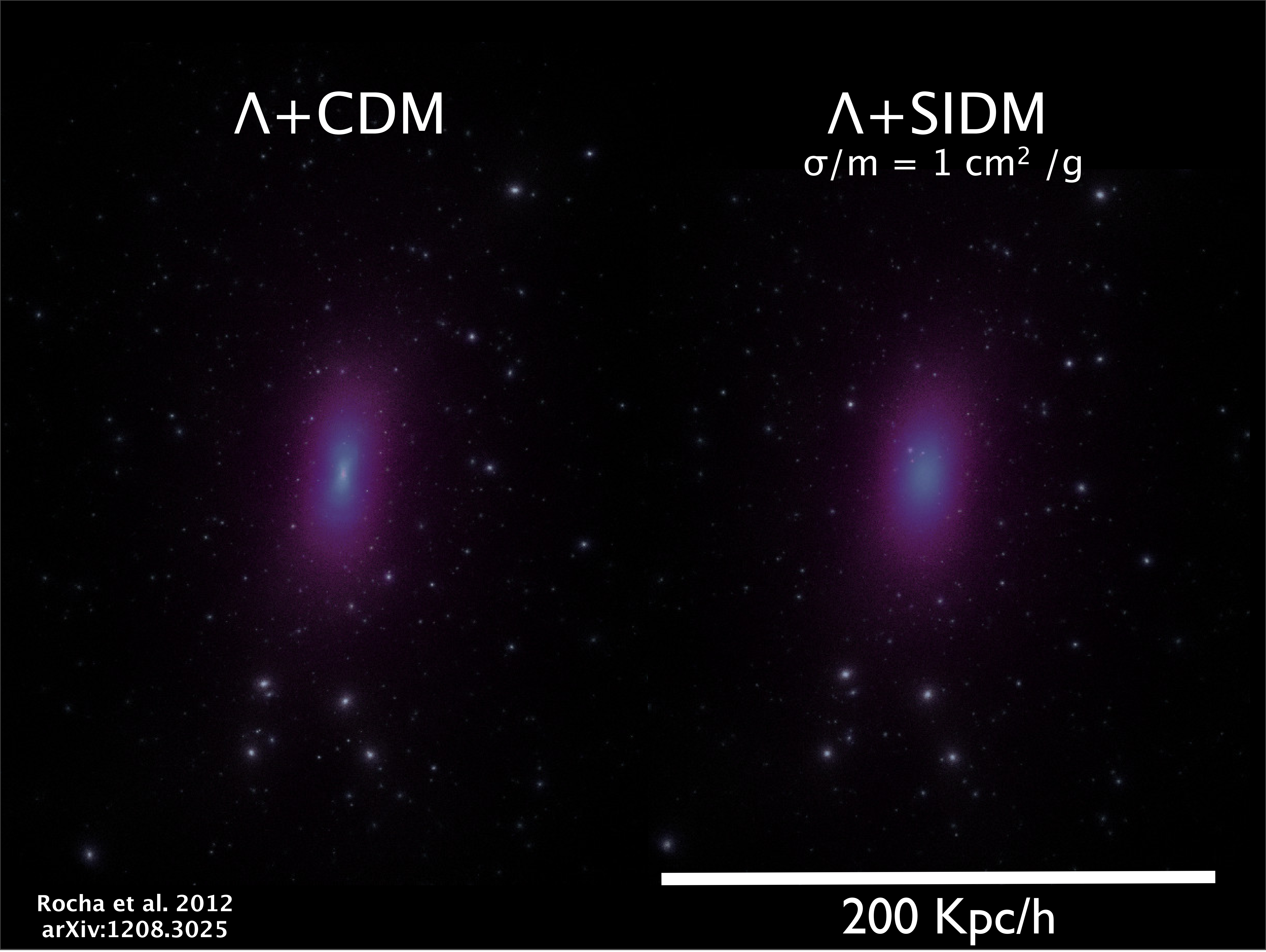
50 Mpc/h

Rocha et al. 2012
arXiv:1208.3025

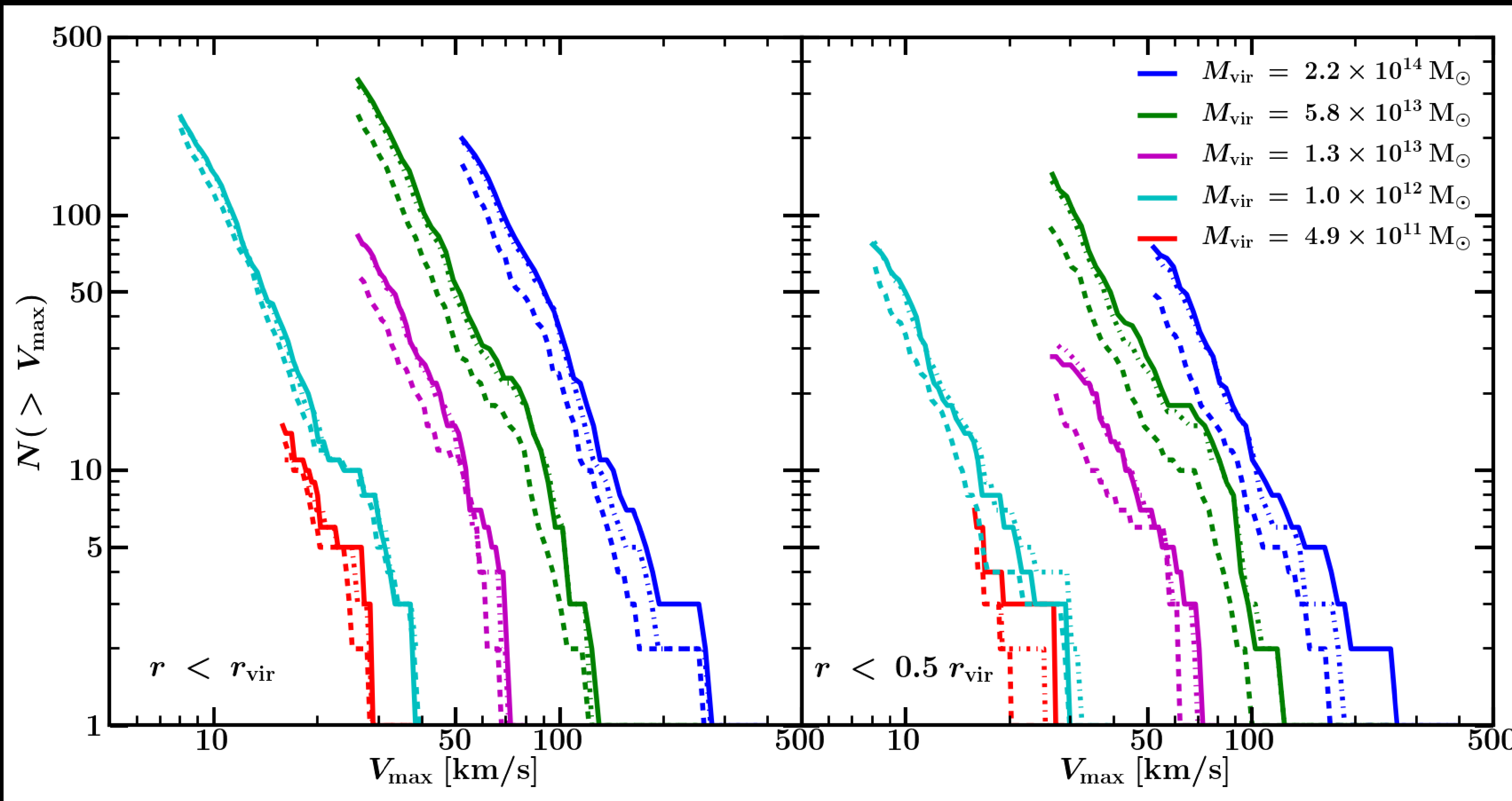
Identical abundance of halos at all redshifts



Rocha et al. 2012
arXiv:1208.3025


Λ+CDM
Λ+SIDM
σ/m = 1 cm² /g
200 Kpc/h
Rocha et al. 2012
arXiv:1208.3025

Modest suppression of subhalo numbers

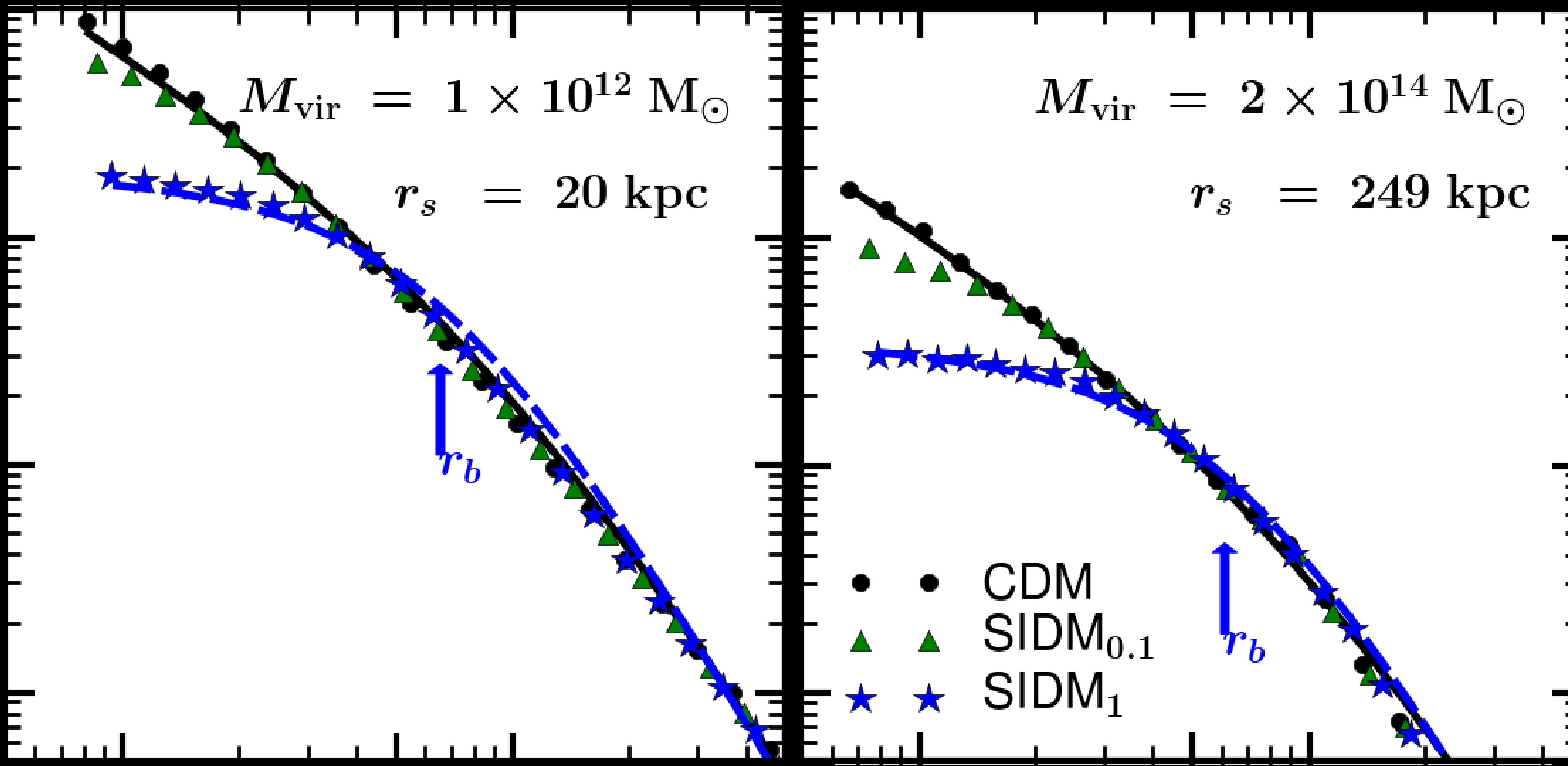


Rocha et al. 2012
arXiv:1208.3025

"Cold" Dark Matter + Self-Interactions

Astrophysical Motivations:

- Lower central densities and constant density cores in DM halos
- ~~Subhalo Evaporation~~ → This is good!!



Density

σ/m = 1

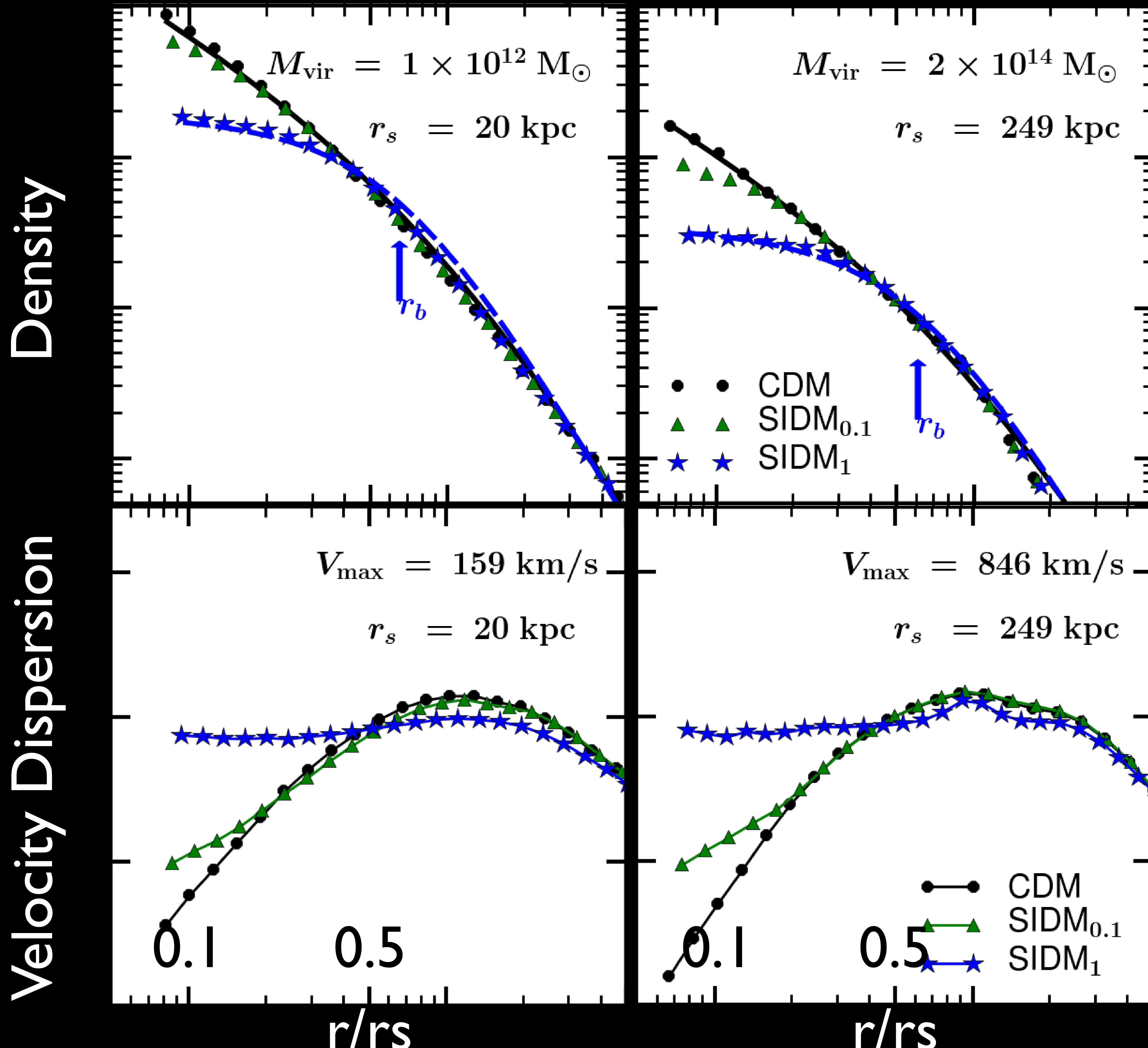
σ/m = 0.1

r/rs

r/rs

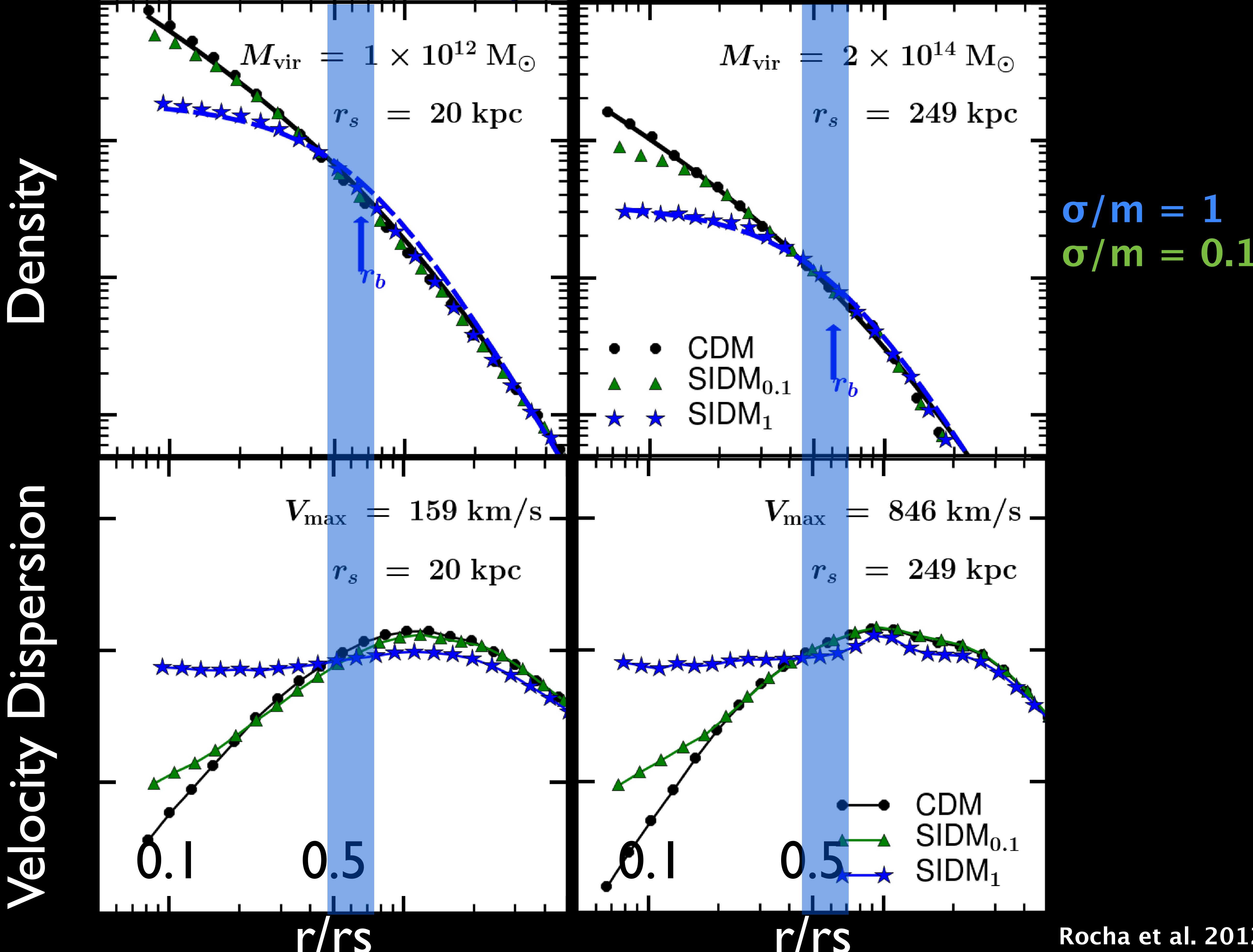
Rocha et al. 2012
arXiv:1208.3025

Thursday, August 16, 2012



σ/m = 1
σ/m = 0.1

Rocha et al. 2012
arXiv:1208.3025



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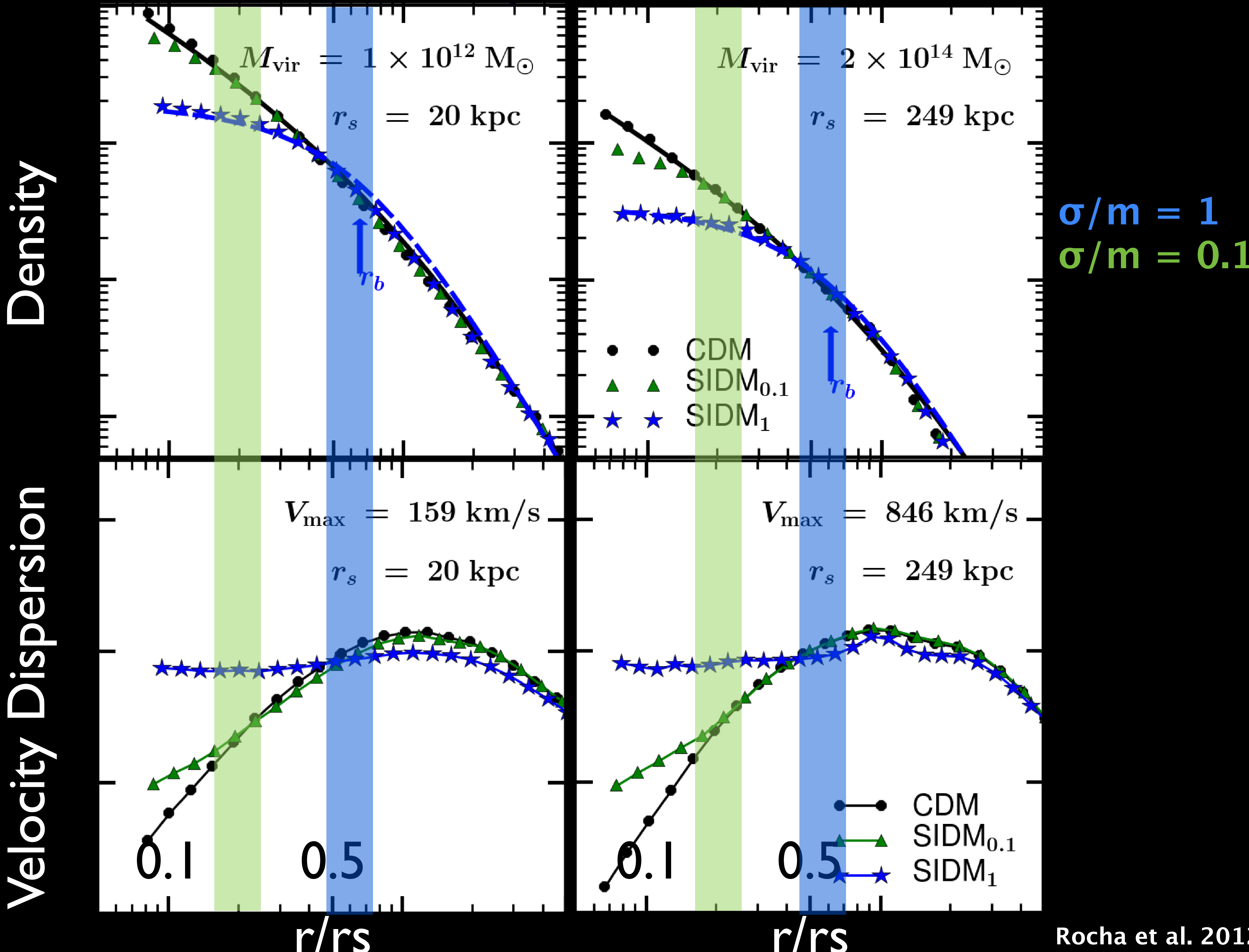

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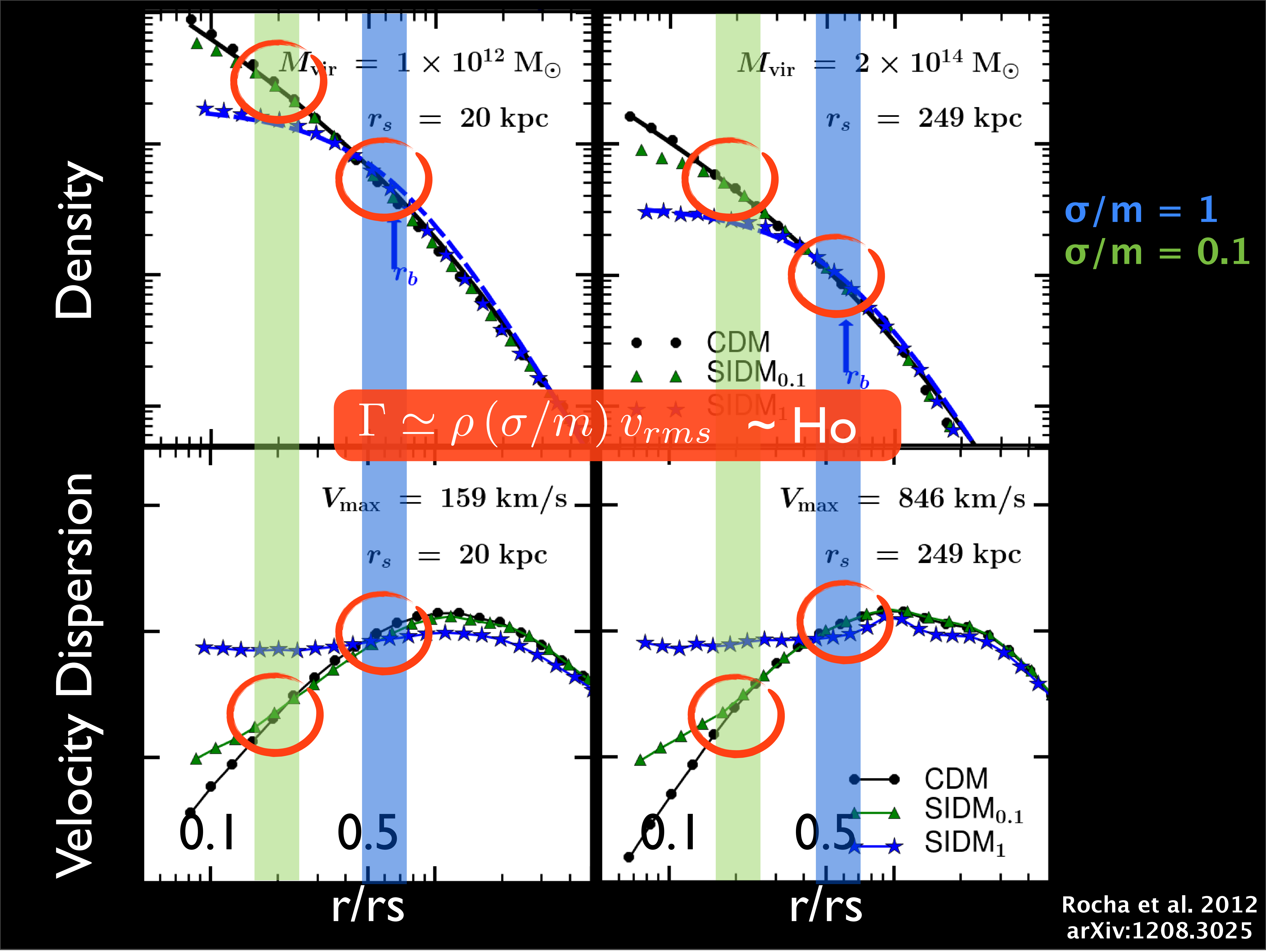
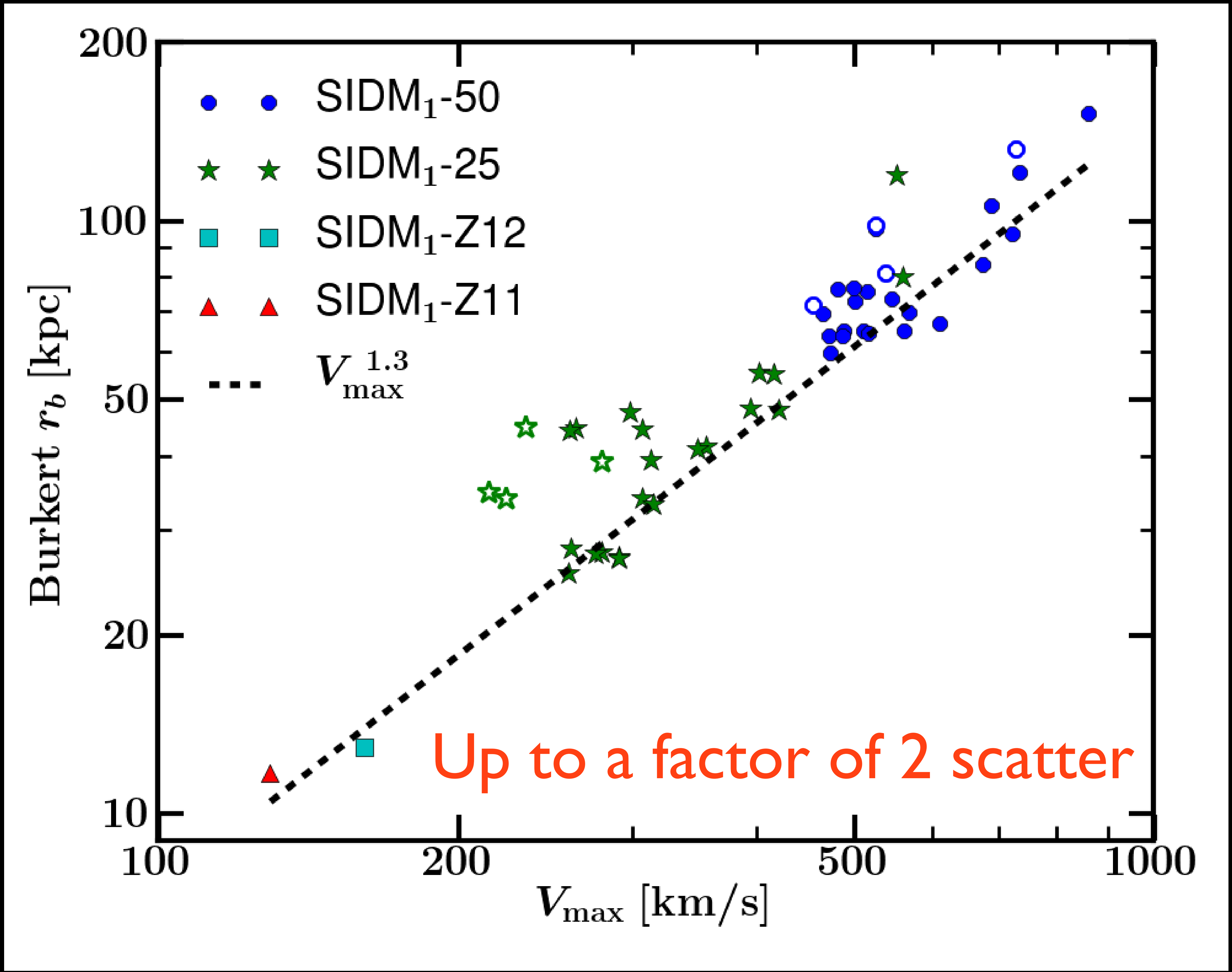

Density
Velocity Dispersion
$M_{vir} = 1 \times 10^{12} M_\odot$
$r_s = 20$ kpc
$M_{vir} = 2 \times 10^{14} M_\odot$
$r_s = 249$ kpc
r_b
CDM
$SIDM_{0.1}$
$SIDM_1$
$\Gamma \simeq \rho(\sigma/m) v_{rms}$ ~ Ho
$V_{max} = 159$ km/s
$r_s = 20$ kpc
$V_{max} = 846$ km/s
$r_s = 249$ kpc
0.1
0.5
r/rs
σ/m = 1
σ/m = 0.1
Rocha et al. 2012
arXiv:1208.3025

$\sigma/m = 1\ cm^2\ /g$



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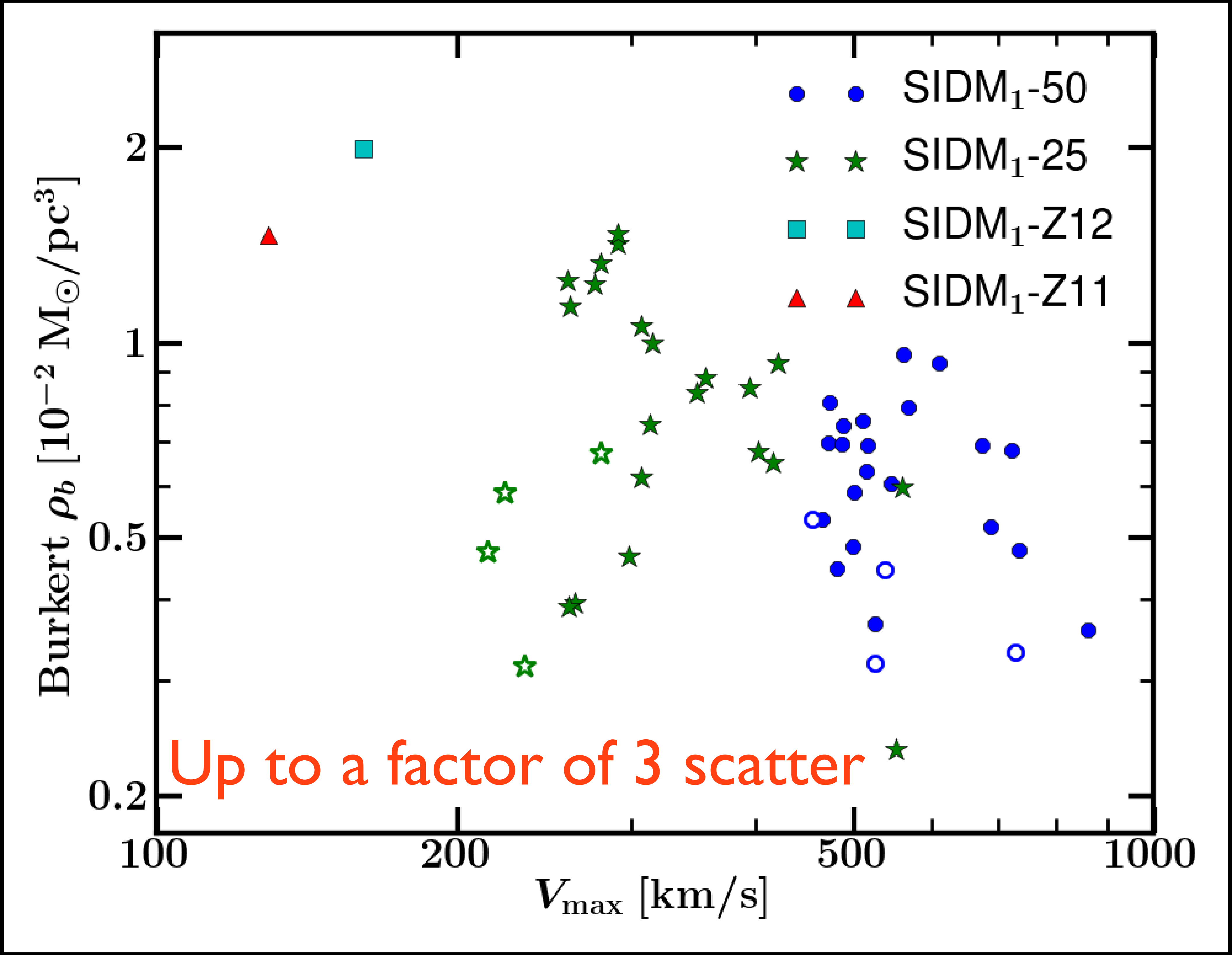

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Comparison to observed core sizes

	Observed	$\sigma/m = 1\ cm^2/g$	$\sigma/m = 0.1\ cm^2/g$
Clusters 700-1000 km/s	10-75 kpc Arabadjis et al. 2002, Sand et al. 2004, 2008, Saha et al 2006, Saha & Read 2009 Newman et al. 2009,2011	95-155 kpc	16-20 kpc
Low-Mass Spirals 50-130 km/s	0.5-8 kpc de Blok et al. 2001, Simon et al. 2005, Sanchez-Salcedo 2005, Kuzio de Naray et al. 2008,2010, Oh et al . 2011, Salucci et al. 2012	3-10 kpc	0.6-2.5 kpc
MW dSphs 20-50 km/s	0.2-1 kpc Walker & Penarrubia 2011	0.9-3 kpc	0.2-0.6 kpc

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Comparison to observed core densities

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Clusters 700-1000 km/s	6-2.5 $10^{-2}\ M_{sun}/pc^3$ Arabadjis et al. 2002, Sand et al. 2004, 2008, Saha et al 2006, Saha & Read 2009 Newman et al. 2009,2011	0.5-0.4 $10^{-2}\ M_{sun}/pc^3$	4 $10^{-2}\ M_{sun}/pc^3$
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MW dSphs 20-50 km/s	~10 $10^{-2}\ M_{sun}/pc^3$ Strigari et al. 2008, Wolf et al. 2010, Walker & Penarrubia 2011, Amorisco & Evans 2012, Wolf & Bullock 2012	4-2 $10^{-2}\ M_{sun}/pc^3$	50-20 $10^{-2}\ M_{sun}/pc^3$

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Conclusions

- It is interesting to look at the astrophysical effects of DM properties other than it being cold, if nothing else to provide constraints to particle physicist.
- Past constraints on SIDM are weaker than previously thought. Our simulations suggest that $\sigma/m = 1\ cm^2/g$ is ruled out by the high DM central densities observed.
- With $\sigma/m \sim 0.1\ cm^2/g$ we find that SIDM predicts central densities and core sizes consistent with observations at all scales, from MW dSphs to large galaxy clusters. And is an alternative possible solution to the cusp/core problem and TBTF.
- Higher resolution simulations are necessary to determine the scatter in our scaling relations and verify what our analytical model predicts for $\sigma/m \sim 0.1\ cm^2/g$