The field "too big to fail" problem

FINDING SOLUTIONS TO A STUBBORN PROBLEM

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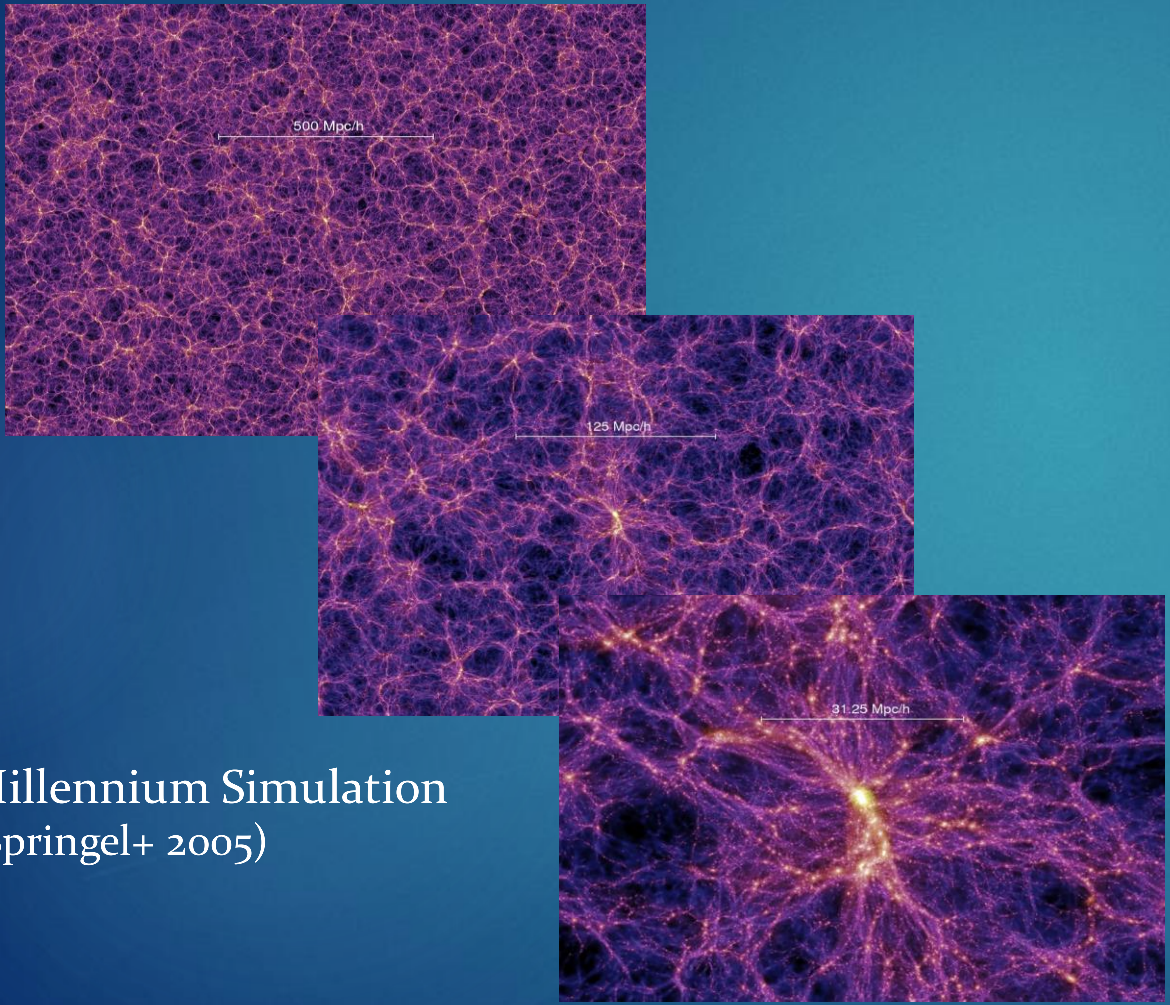
Chalonge Meudon workshop 2015

Meudon, Paris 10 Jun 2015

The Cold Dark Matter paradigm



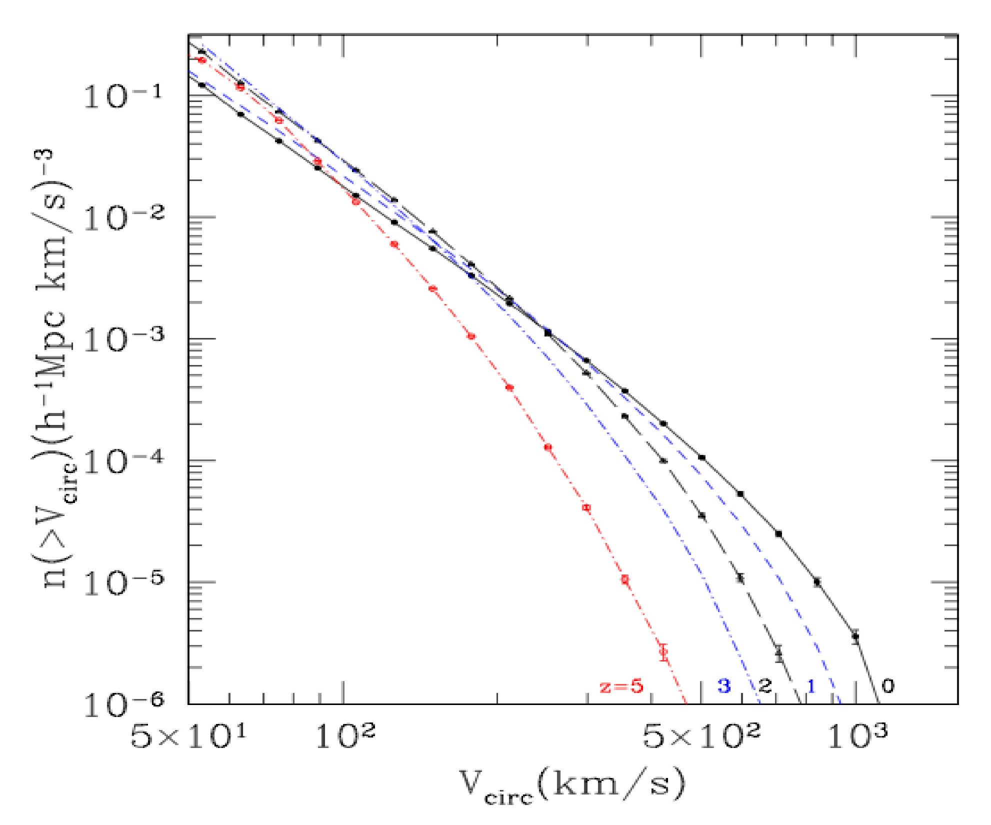
Millennium Simulation
(Springel+ 2005)

(Lovell+ 2012)

The Cold Dark Matter paradigm

(Lovell+ 2012)

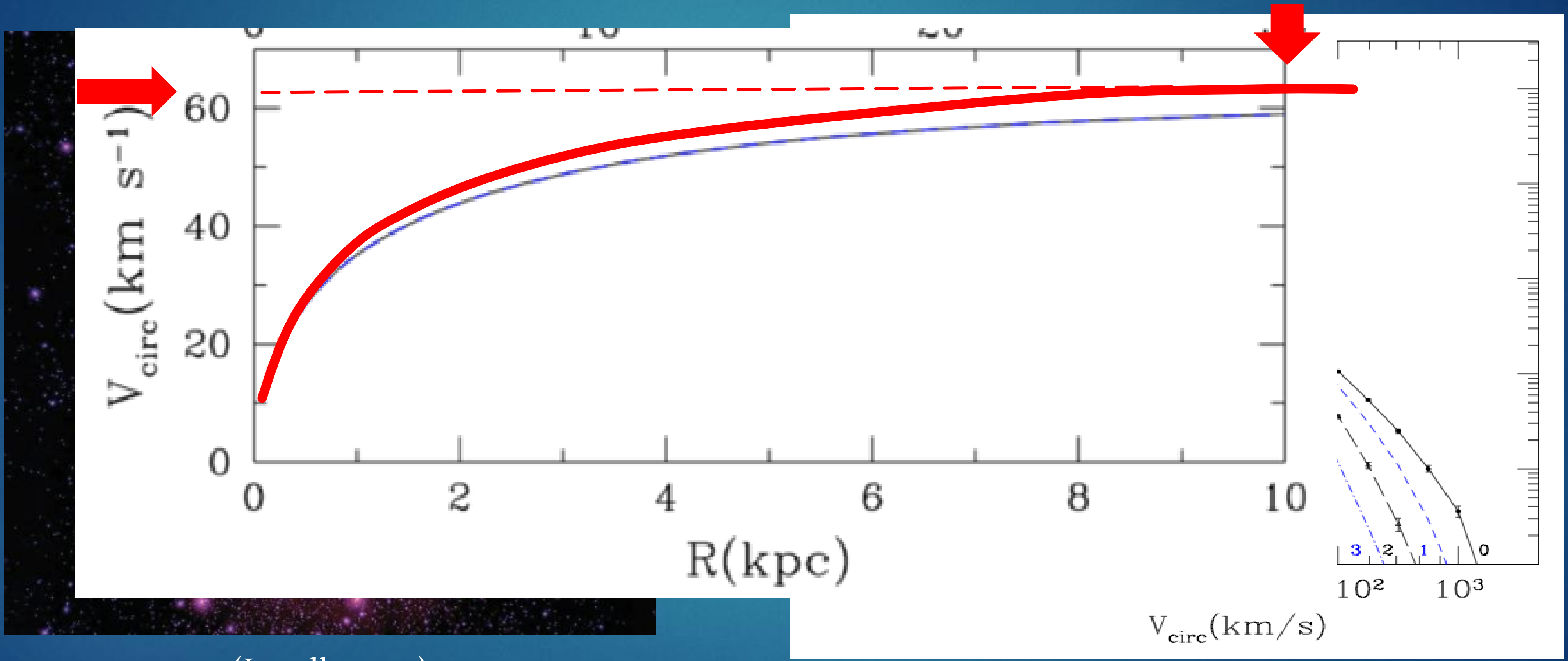
Halo Velocity Function



Bolshoi simulation
(Klypin+ 2011)

The Cold Dark Matter paradigm

Halo Velocity Function



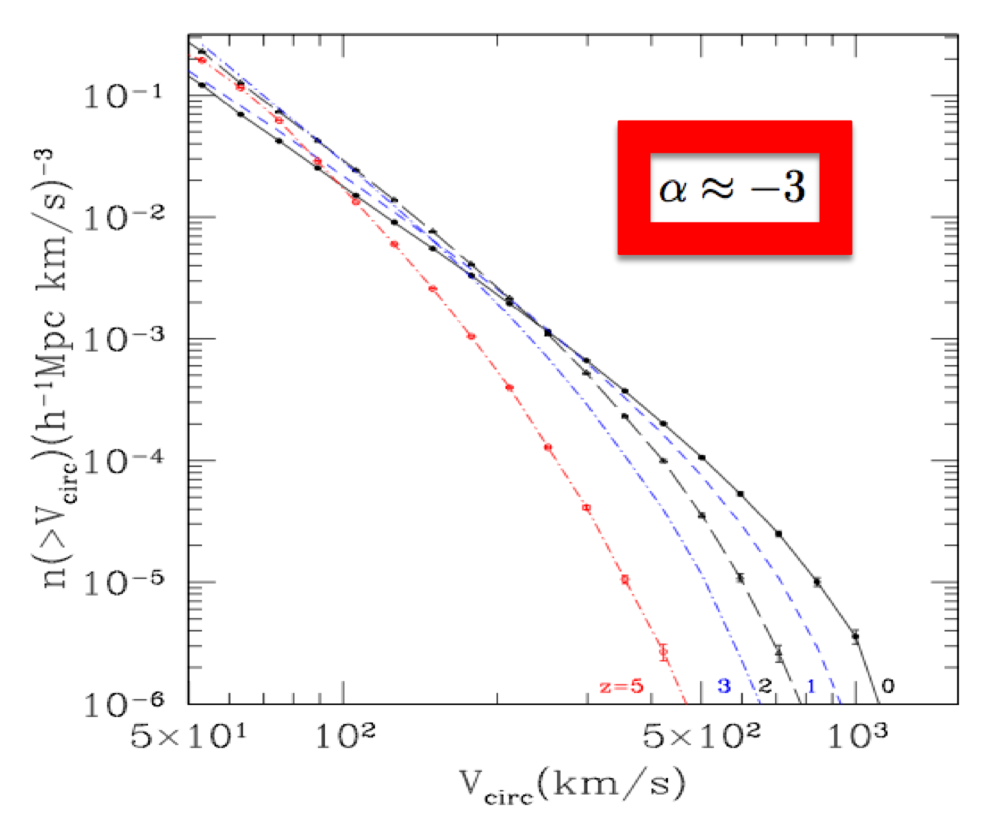
(Lovell+ 2012)

Bolshoi simulation
(Klypin+ 2011)

The Cold Dark Matter paradigm

(Lovell+ 2012)

Halo Velocity Function

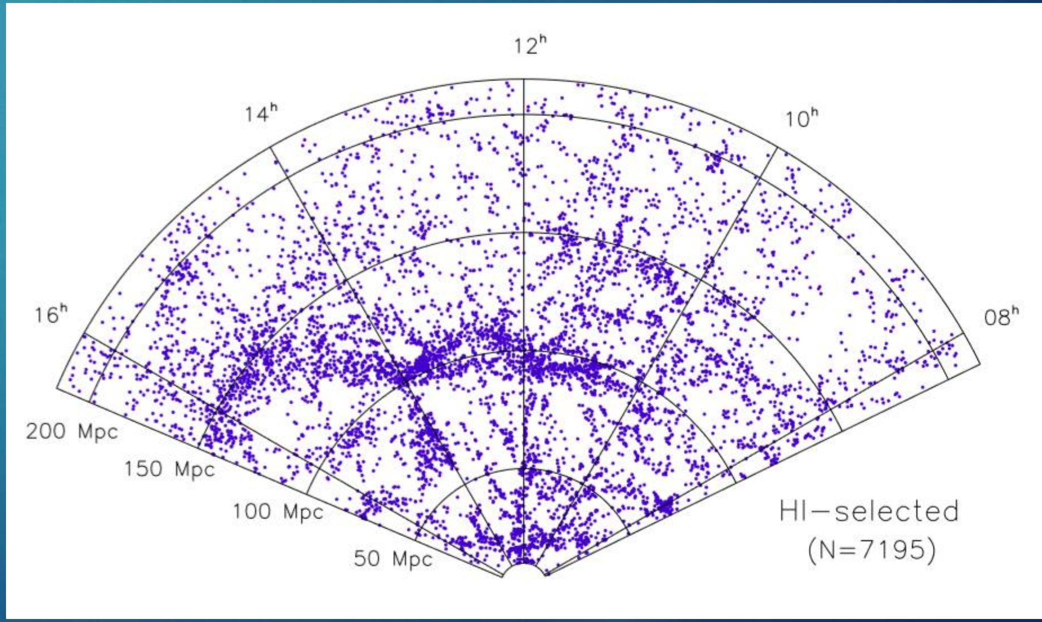


Bolshoi simulation
(Klypin+ 2011)

the ALFALFA survey

http://egg.astro.cornell.edu/alfalfa/

- ALFALFA is a blind, wide area **21-cm line survey** (Giovanelli+ 2005).
- It is done with the **Arecibo** radiotelescope.
- ALFALFA has produced the **largest** HI-selected sample to date:
  - **> 11 000 detected galaxies**
  - **~ 3 000 deg^2 of sky**



the ALFALFA survey

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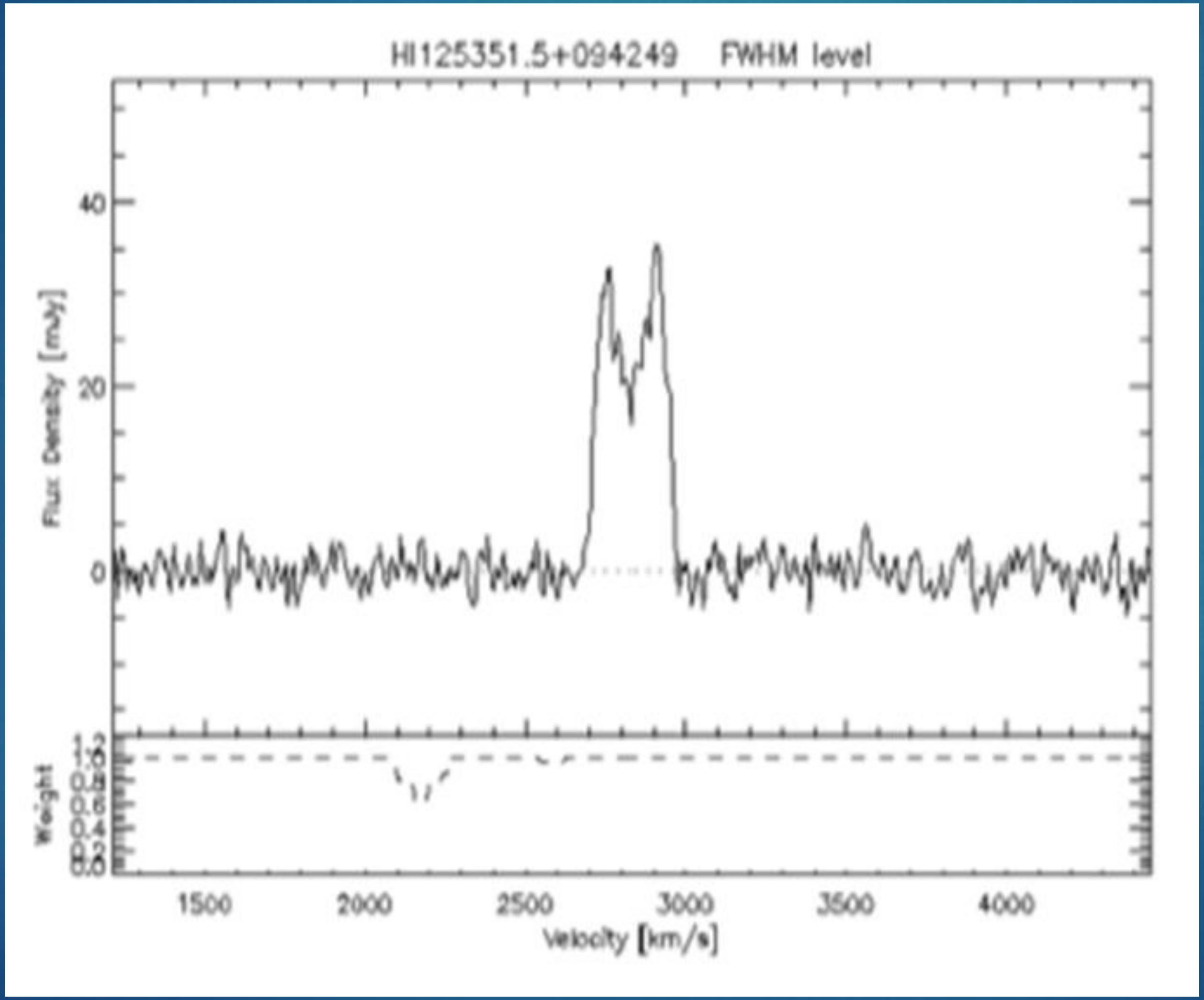

the ALFALFA survey

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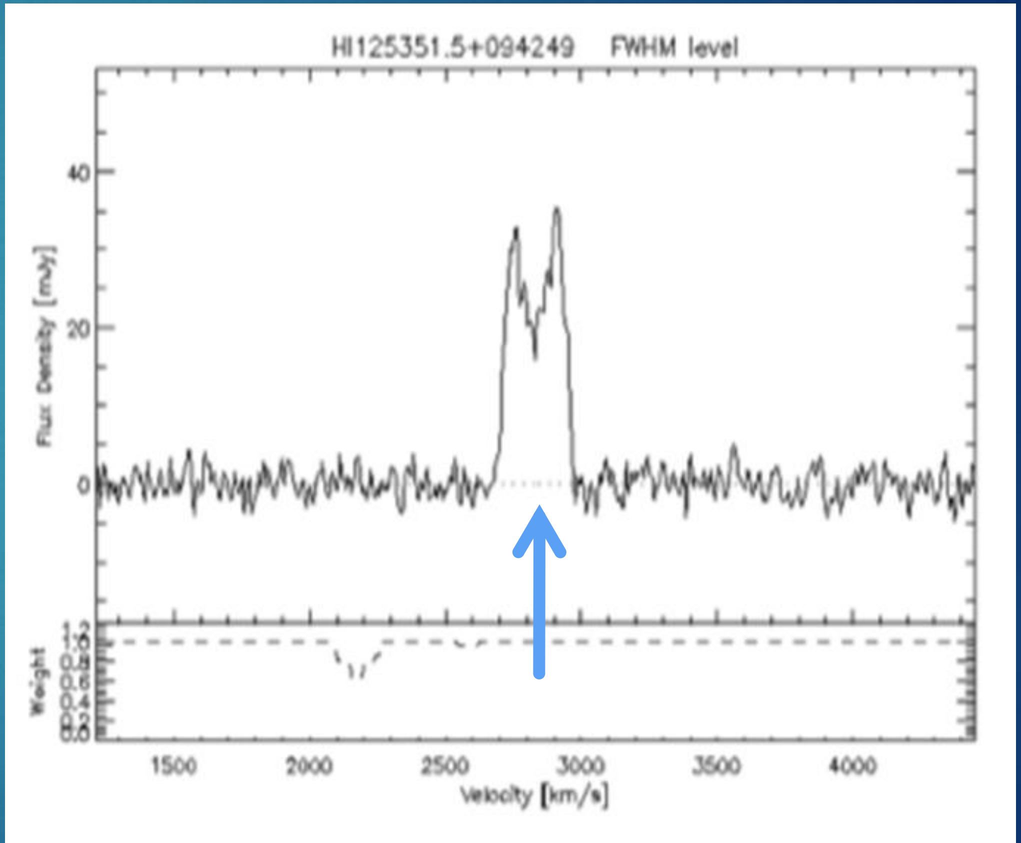
- ALFALFA directly measures:
  - **redshift**



the ALFALFA survey

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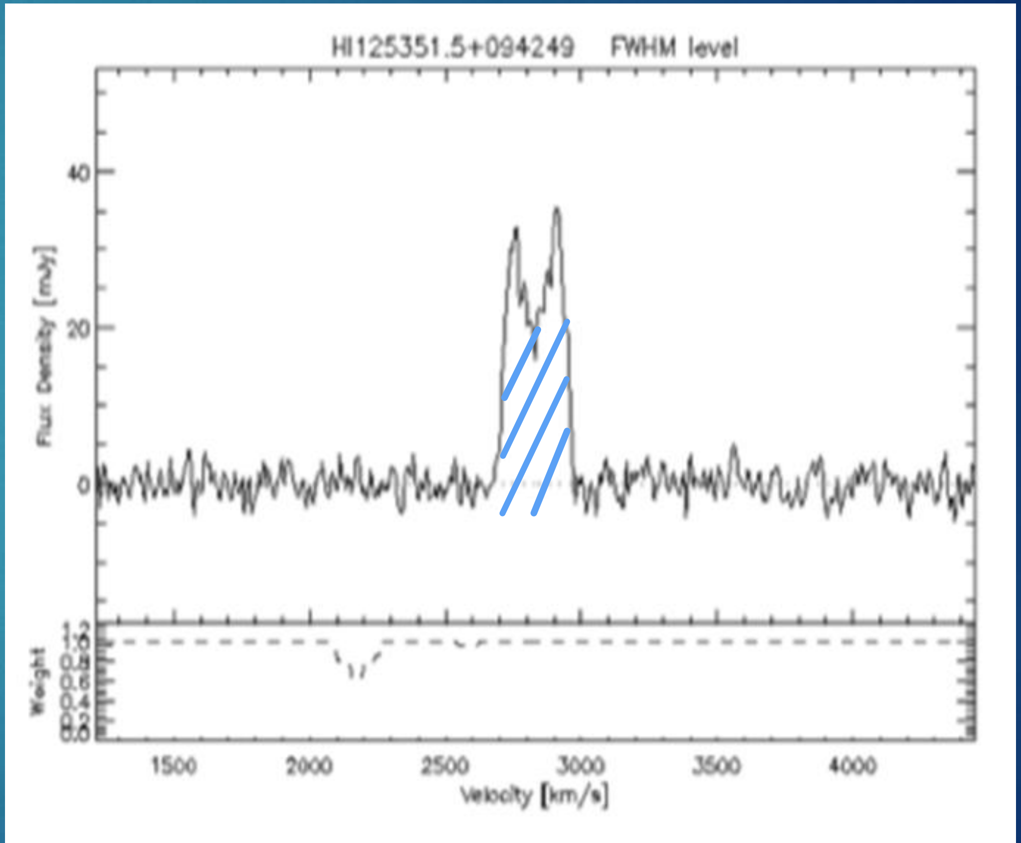
- ALFALFA directly measures:
  - **redshift**
  - **integrated flux (HI mass)**



the ALFALFA survey

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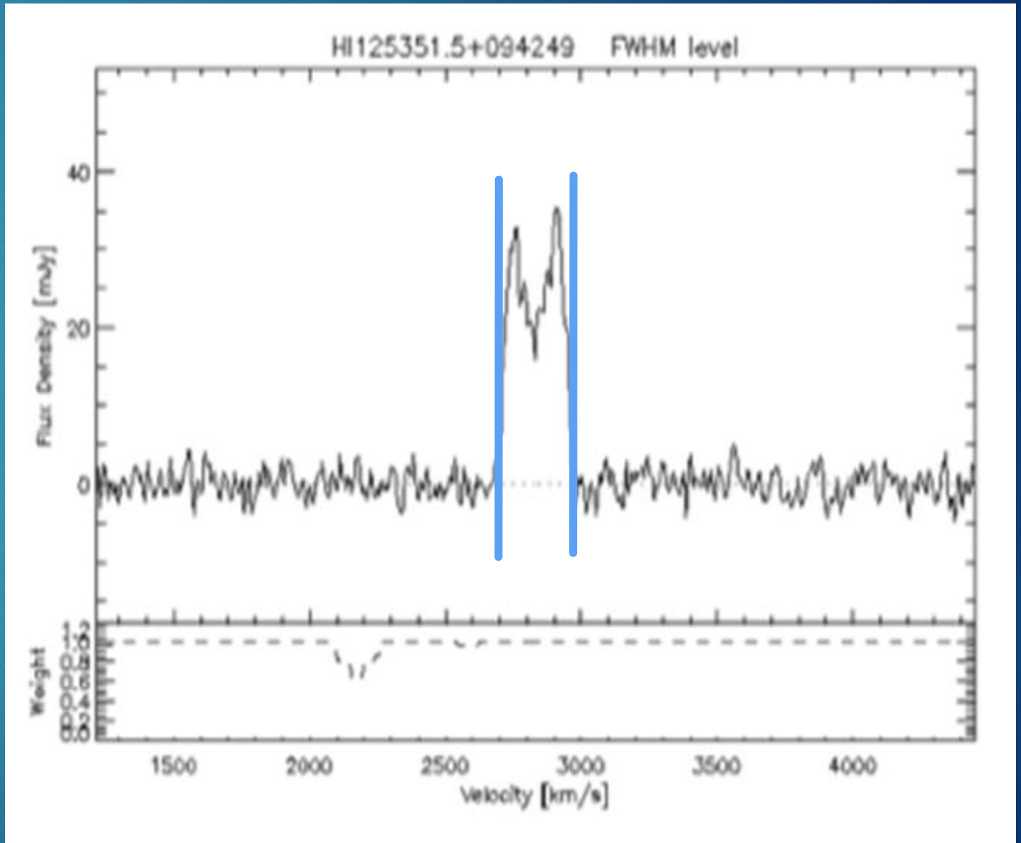
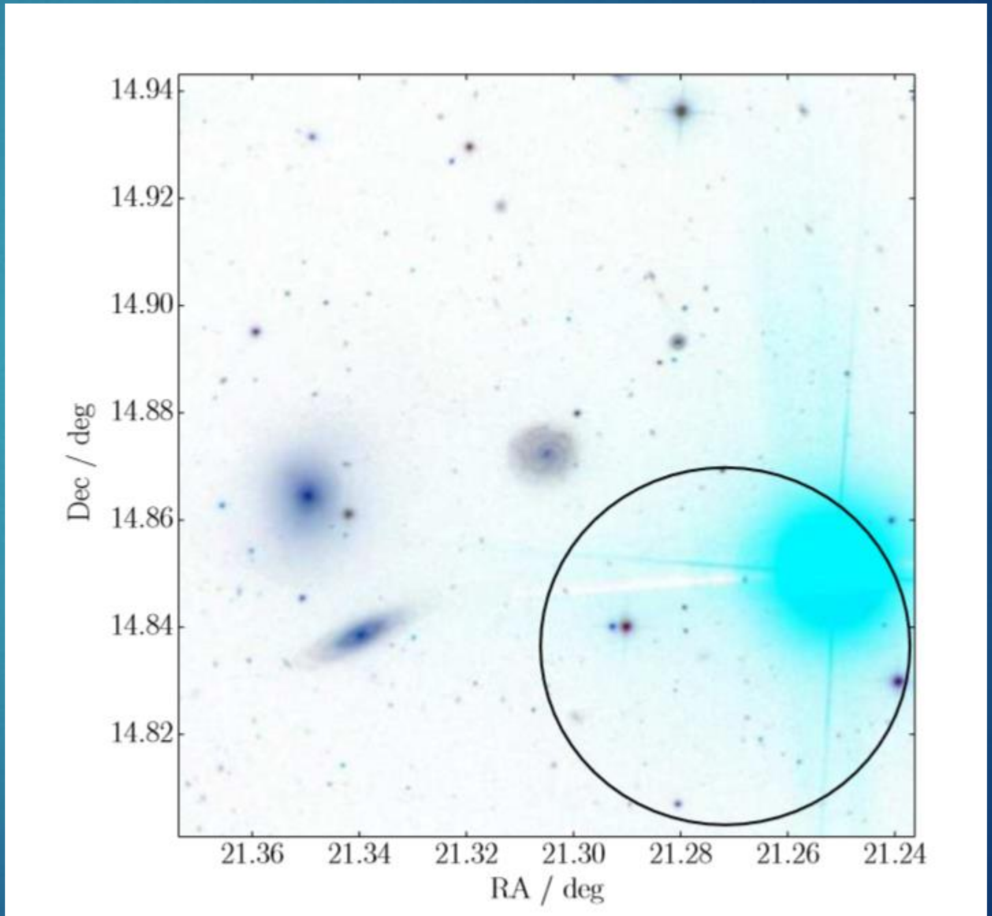
- ALFALFA directly measures:
  - **redshift**
  - **integrated flux (HI mass)**
  - **velocity width**



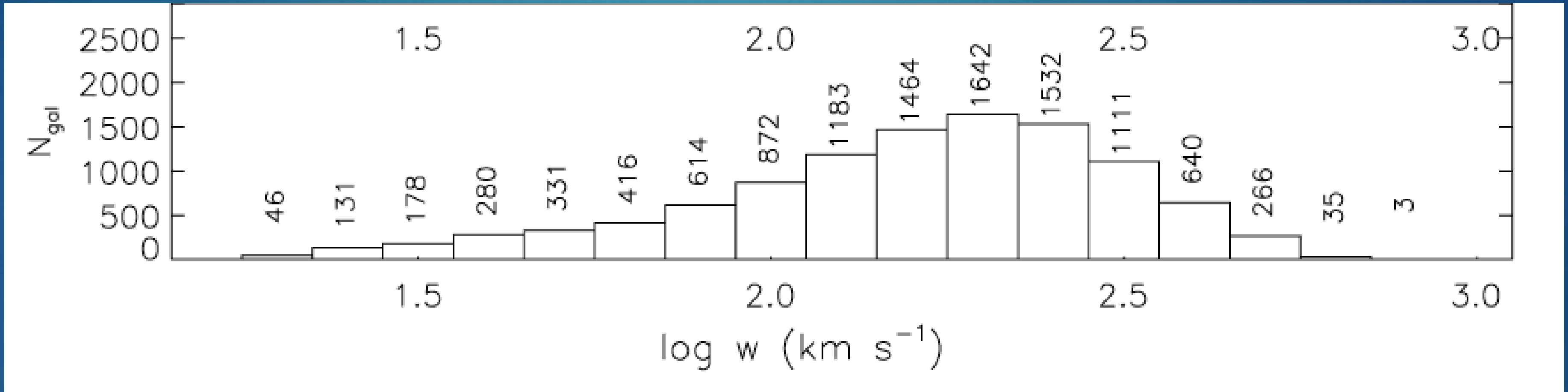
the ALFALFA survey

http://egg.astro.cornell.edu/alfalfa/

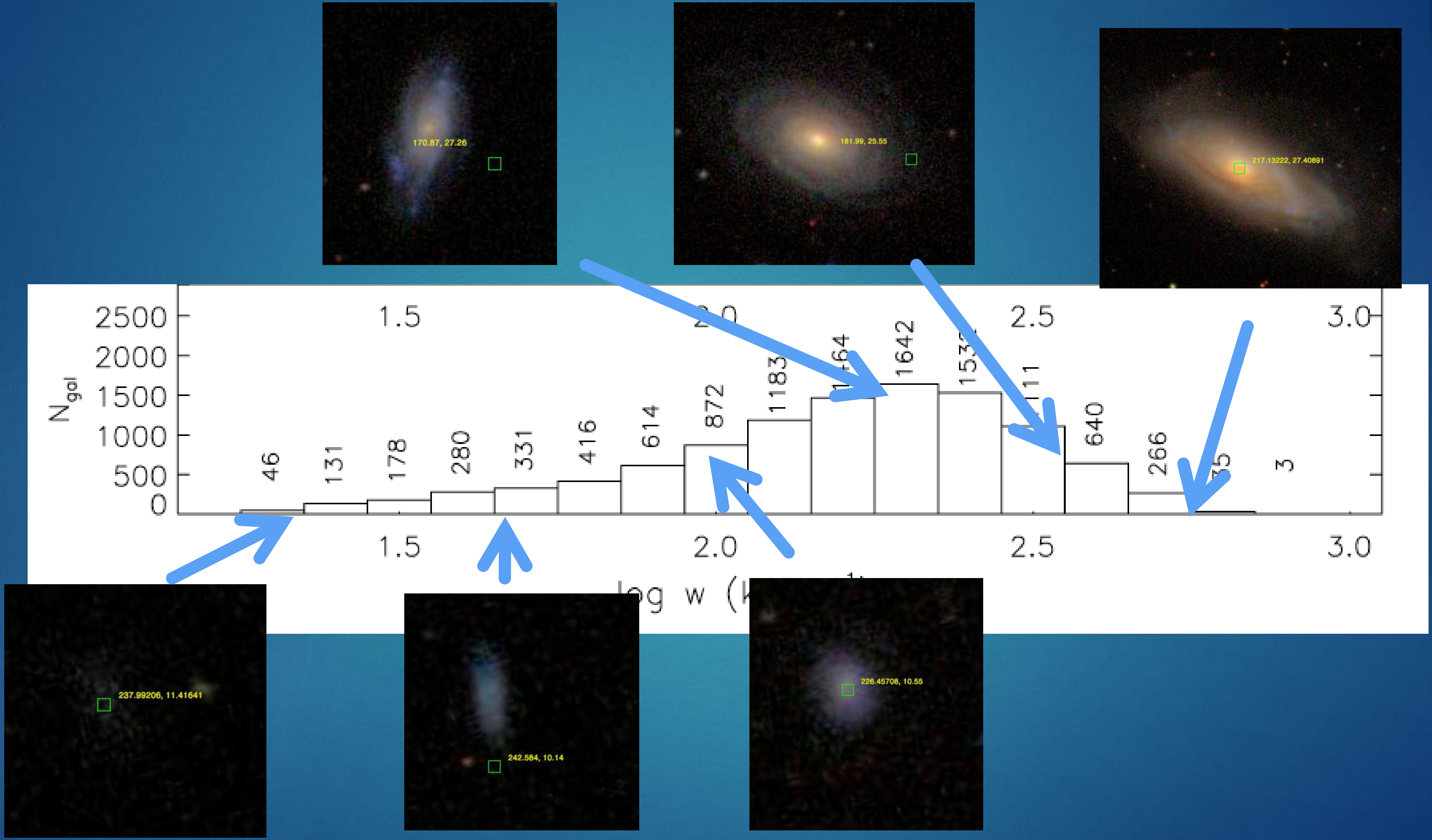
- ALFALFA ***cannot*** measure:
  - **size**
  - **shape, inclination**
  - **rotation curve**



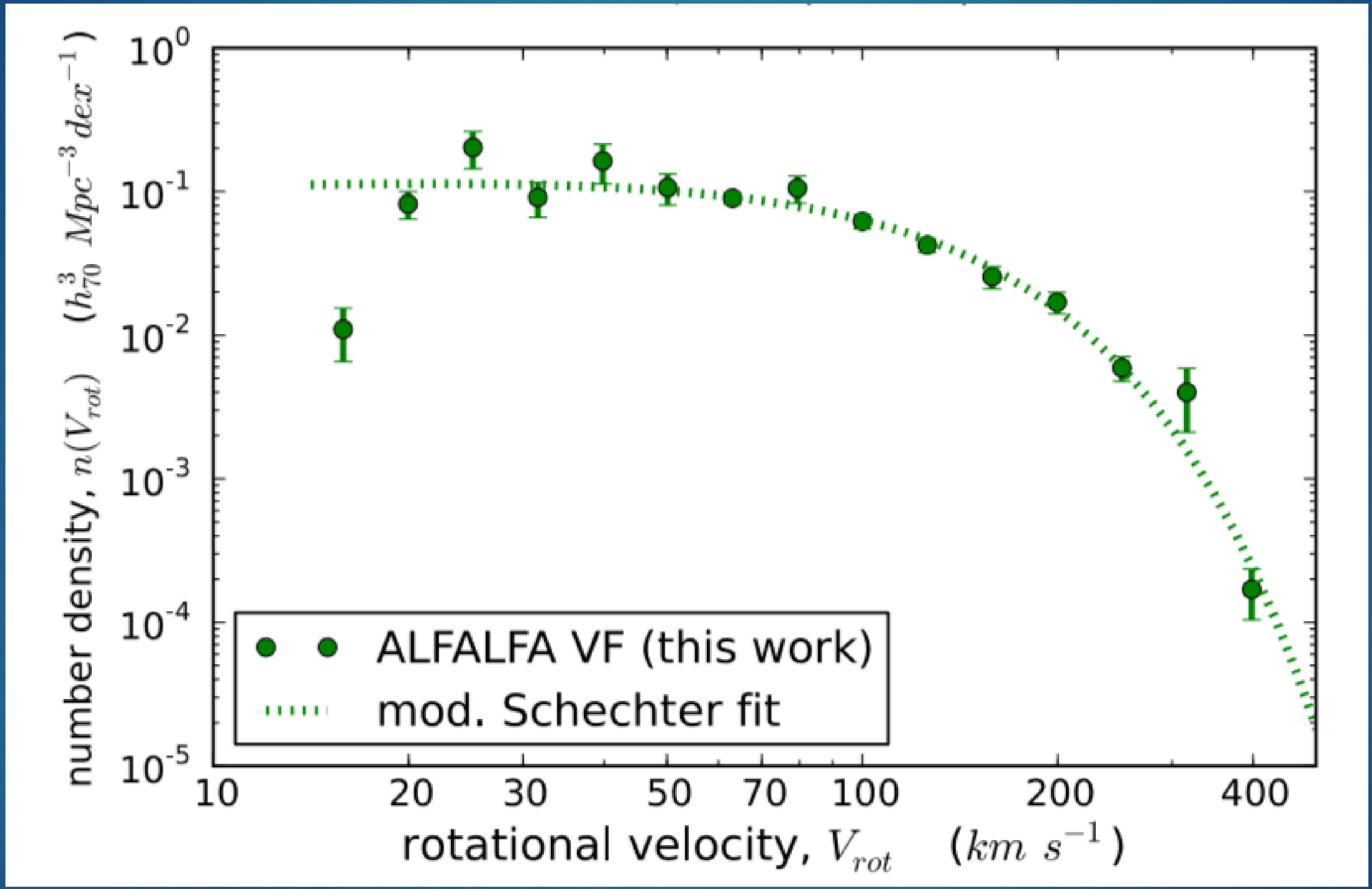
The velocity widths of ALFALFA galaxies



The velocity widths of ALFALFA galaxies

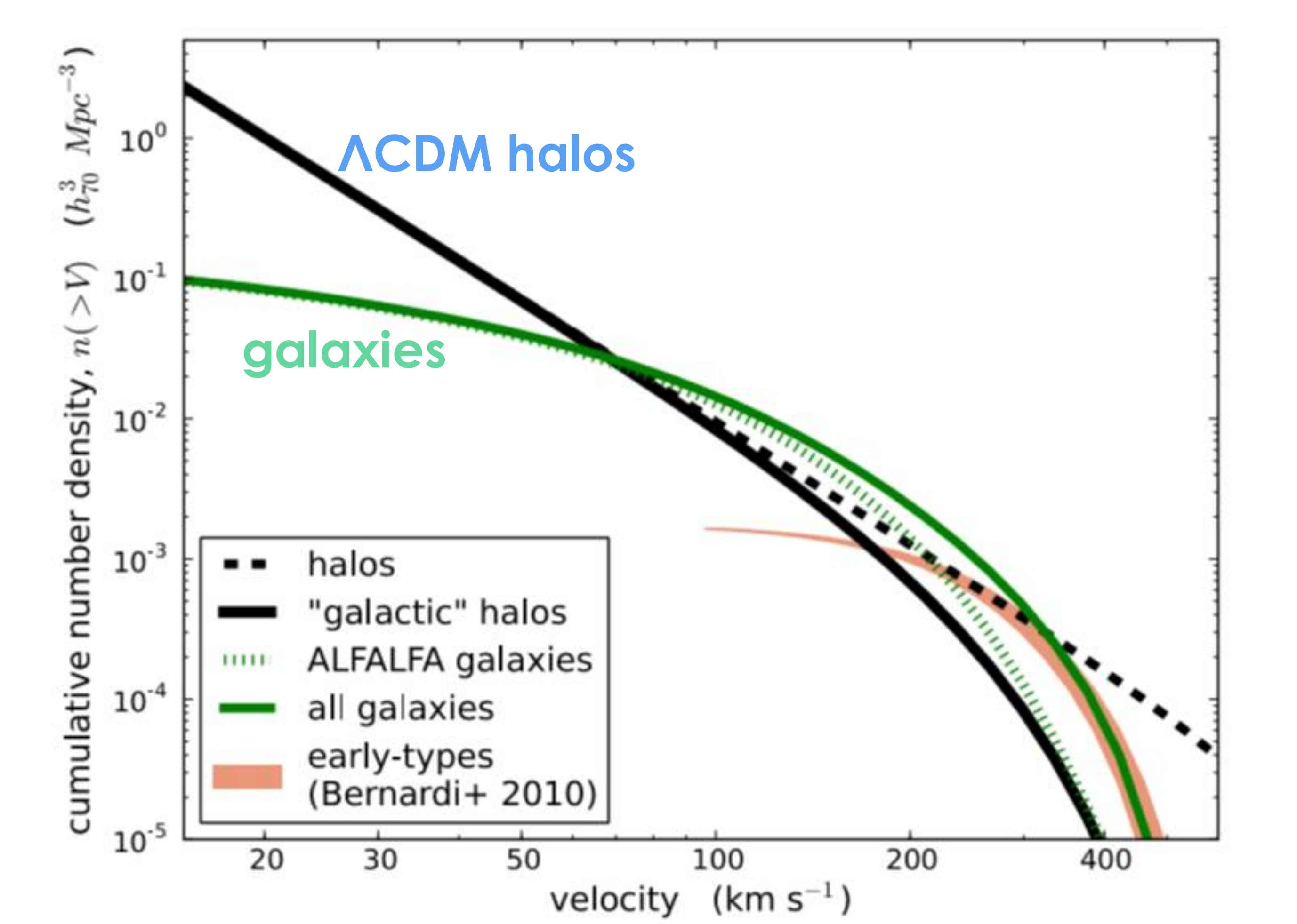


The velocity function of galaxies



(Papastergis+ 2015)

Galaxies vs. ΛCDM halos



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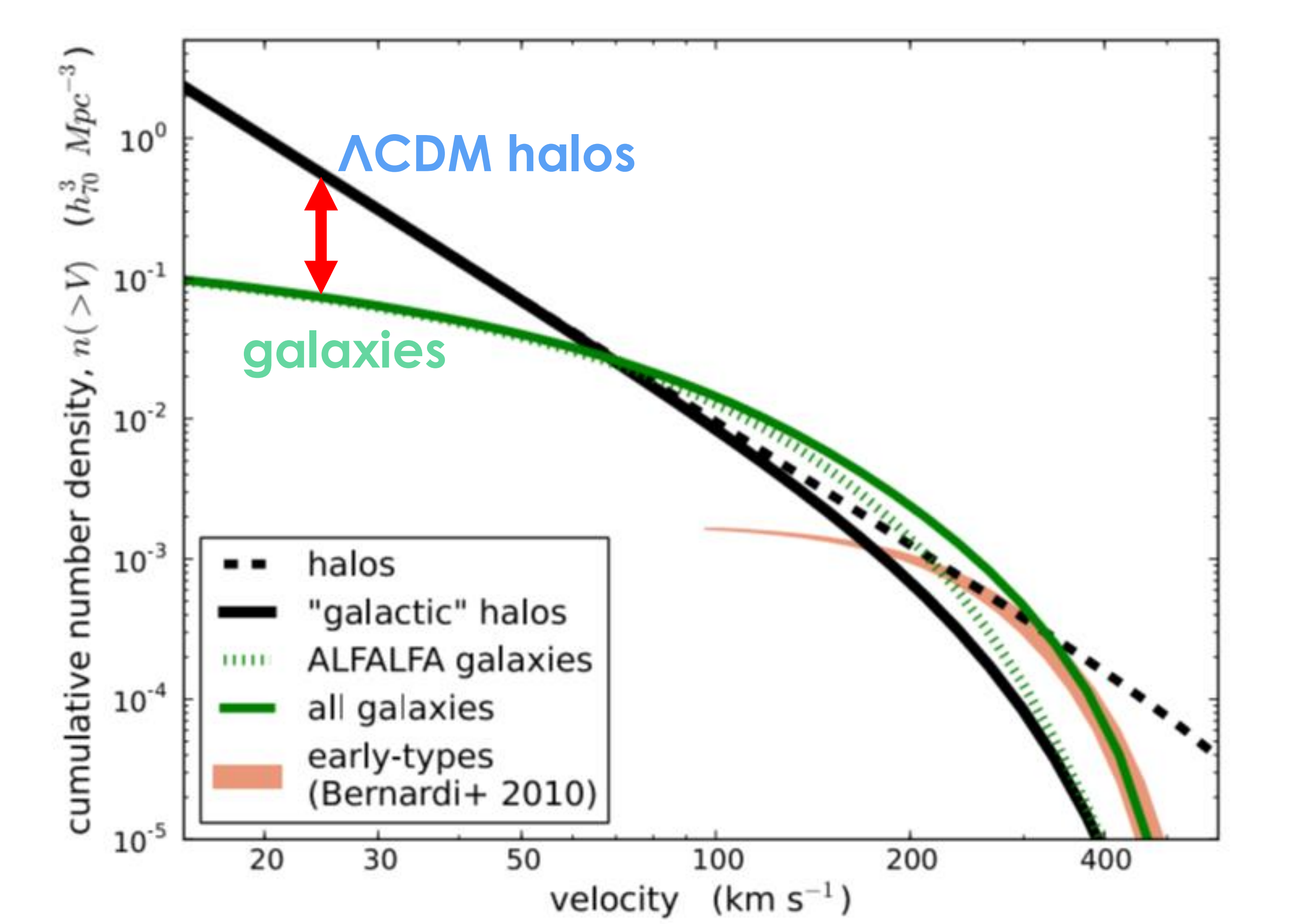
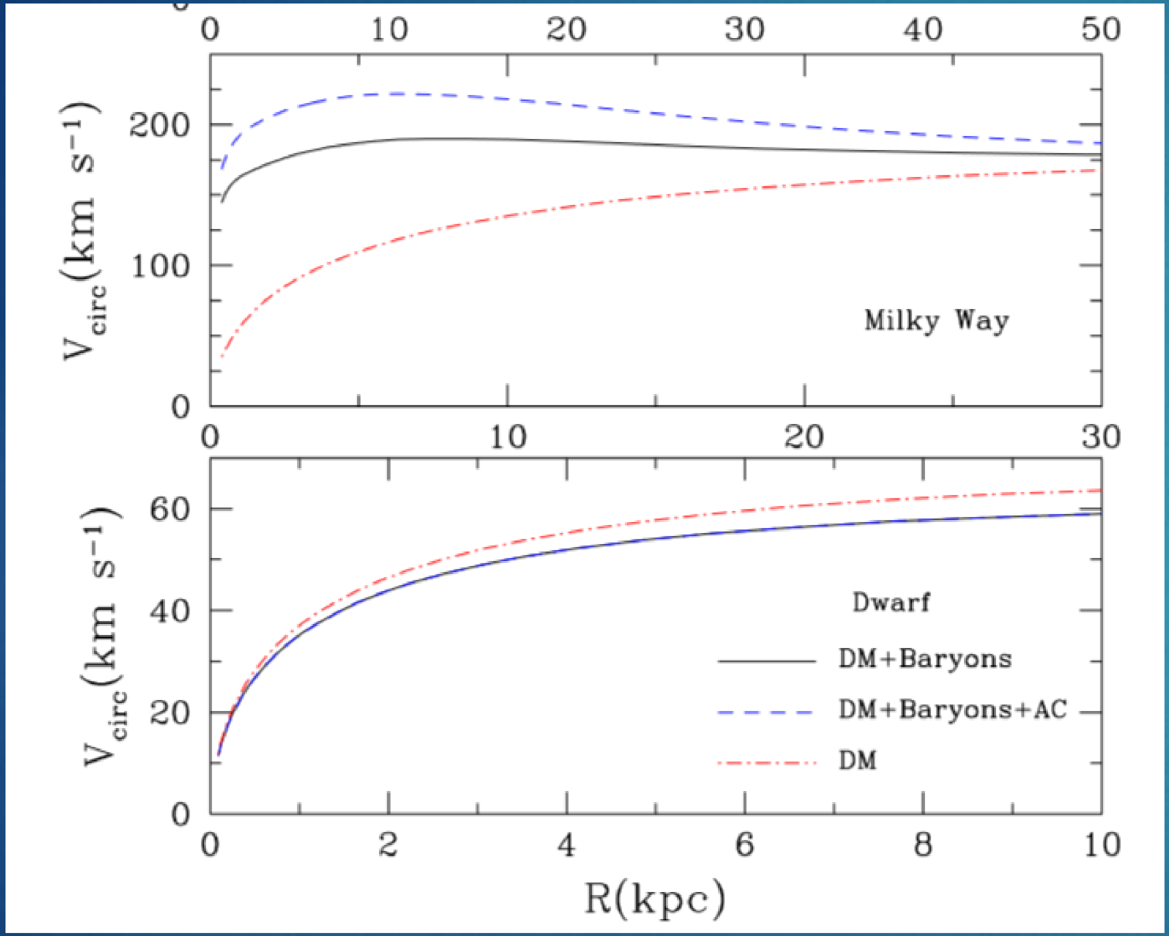


(Papastergis+ 2015)

But wait a second…

GALAXIES $\neq$ HALOS

Galaxies vs. ΛCDM halos

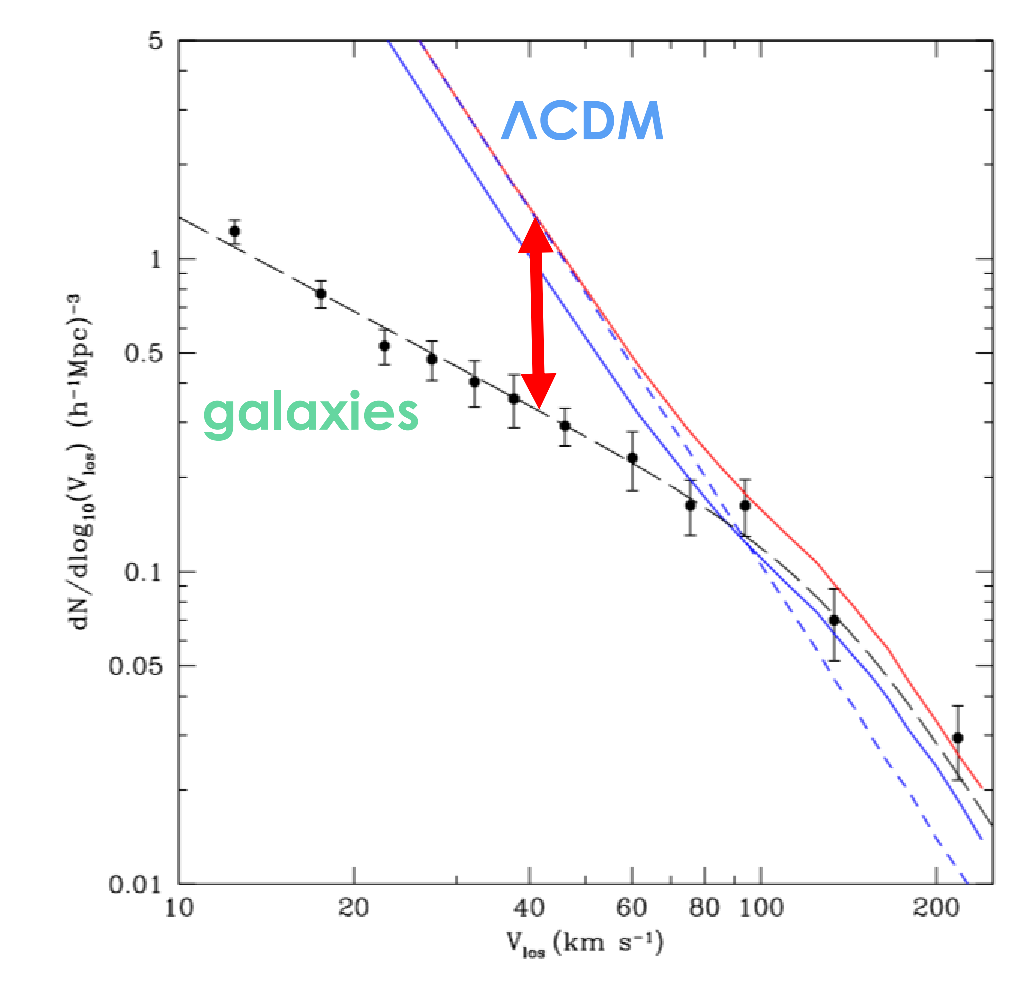


(Trujillo-Gomez+ 2011)

Building a realistic rotation curve:

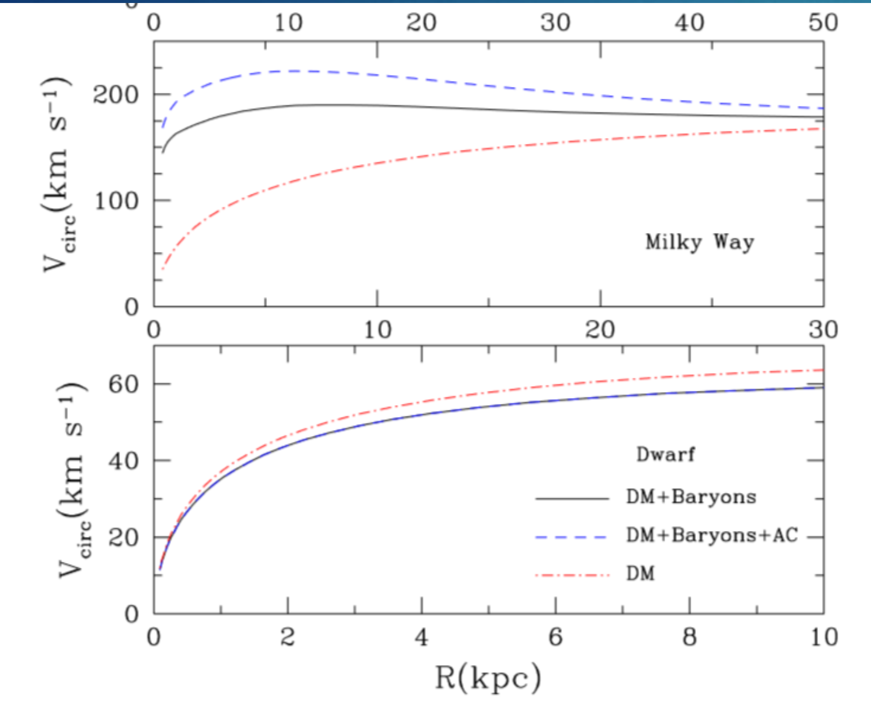
- $\Omega_{DM} \neq \Omega_m$
- Baryons (stars, gas) contribute to RC
- Adiabatic contraction of halo (?)

Observations vs. theory



(Klypin+ 2015)

Which velocity?



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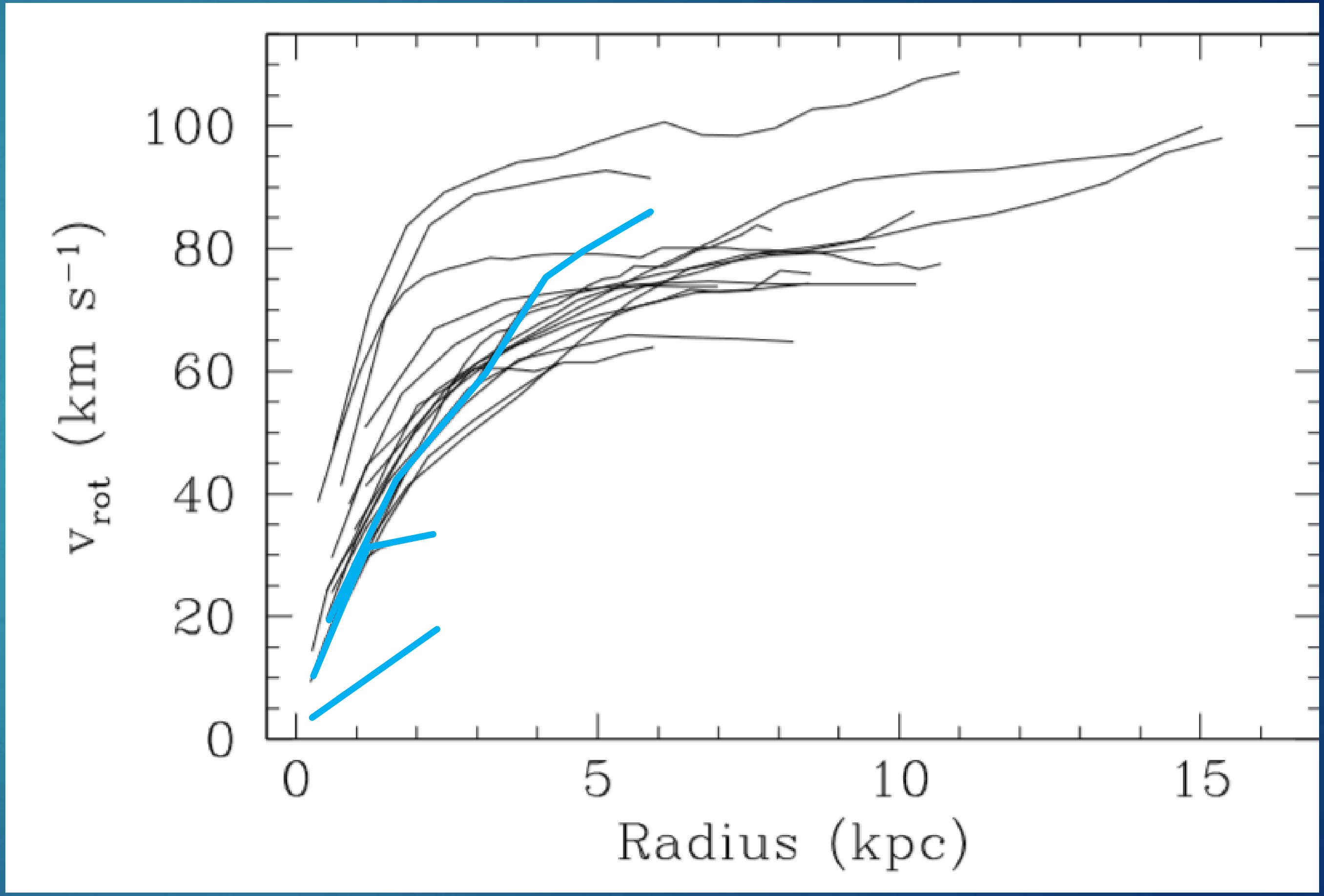

(Swaters+ 2009)

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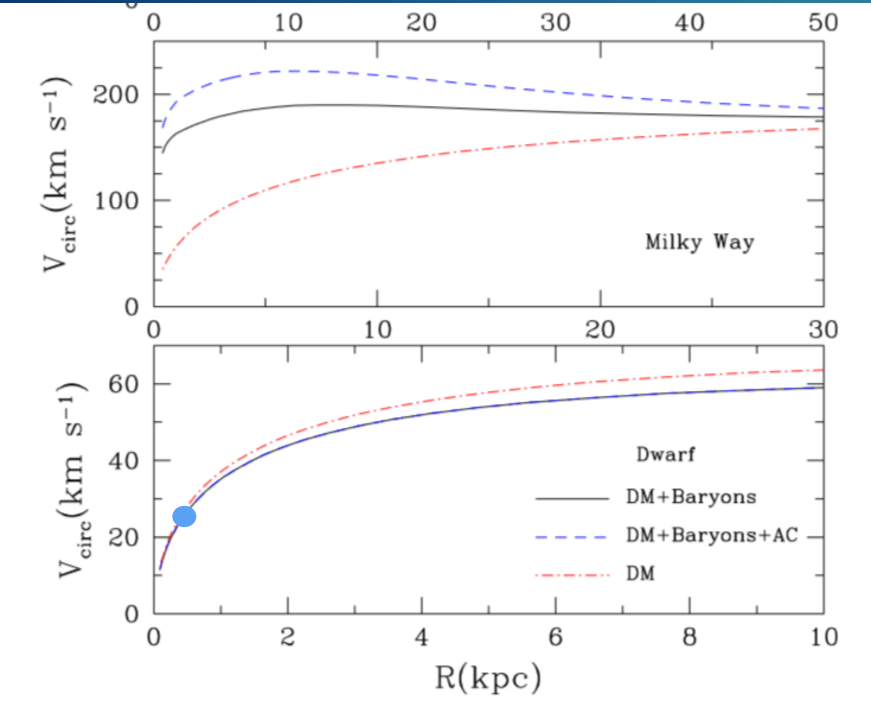

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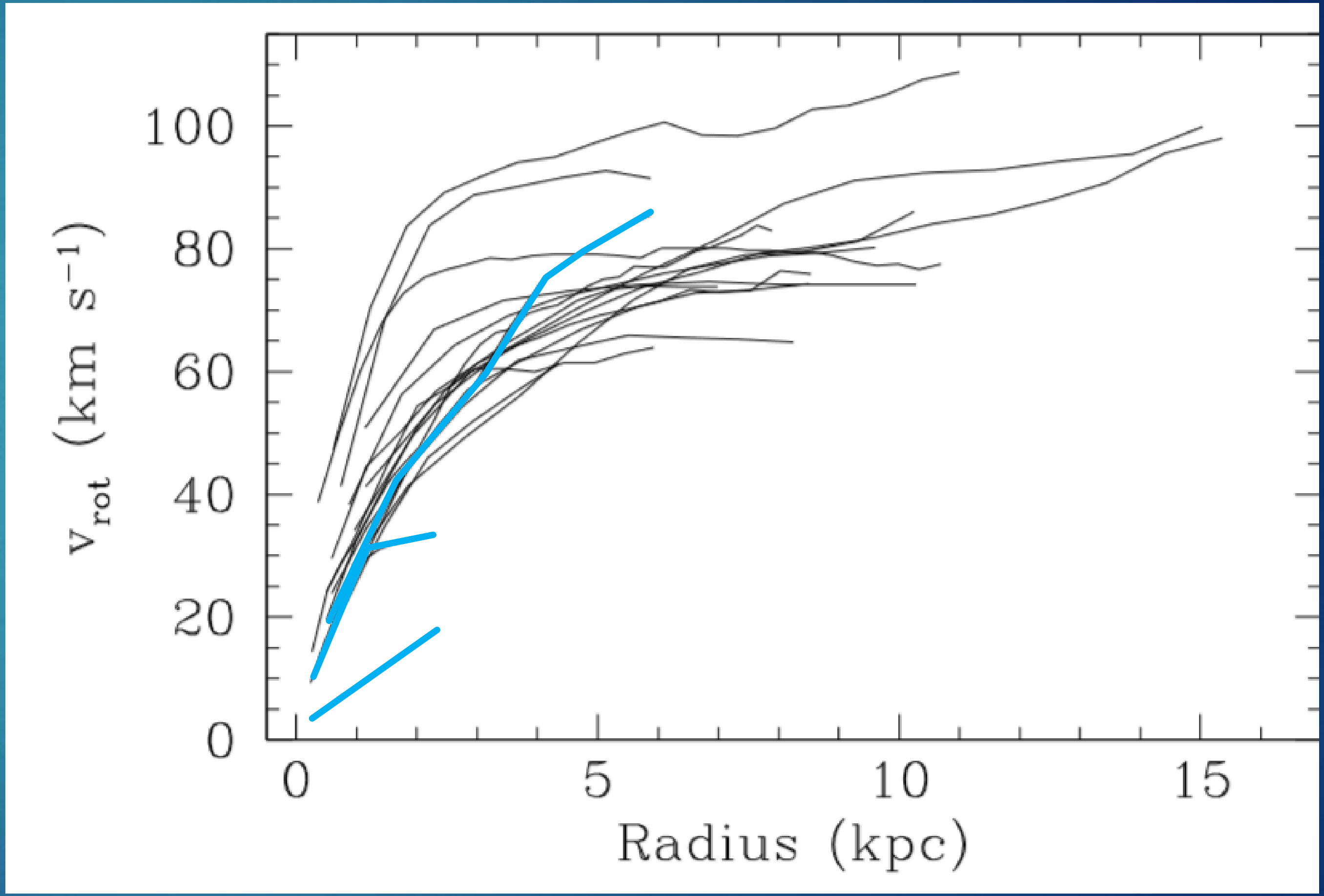

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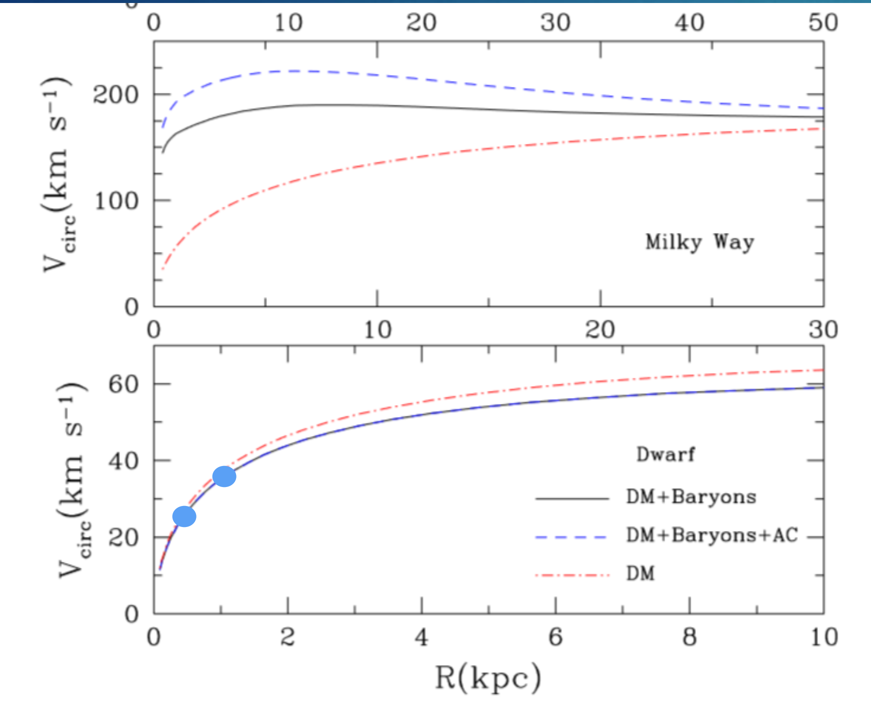

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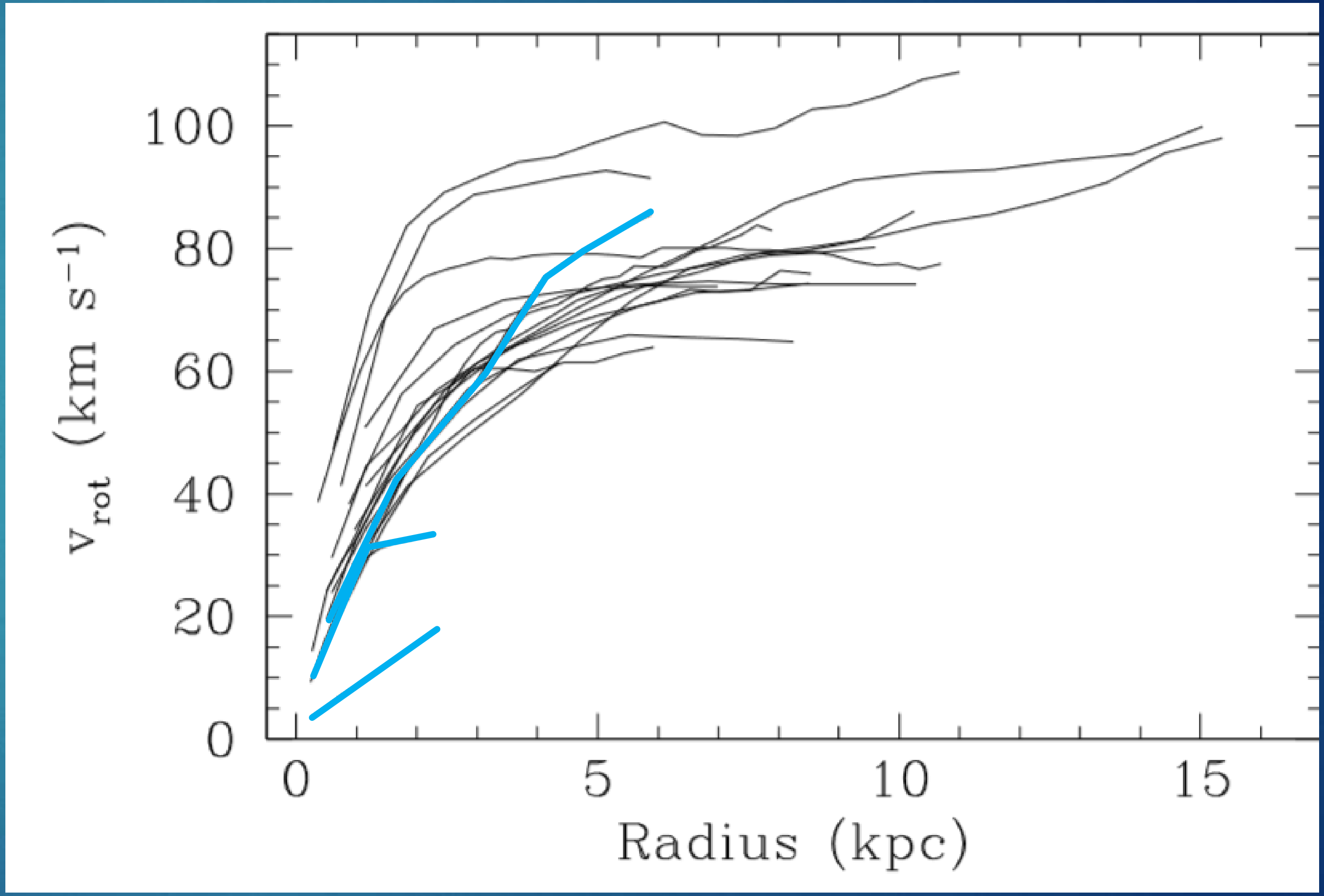

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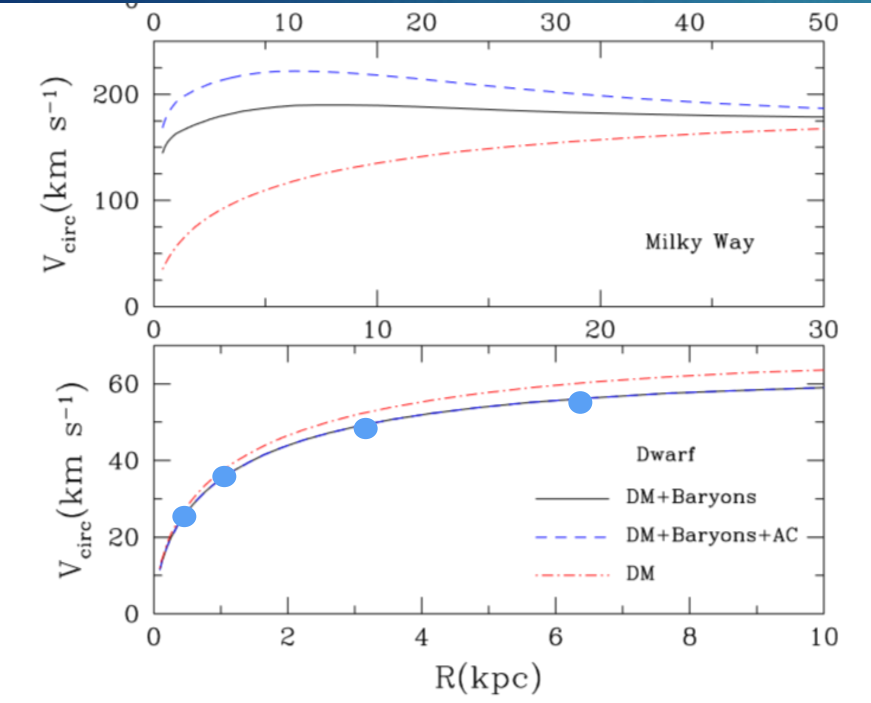

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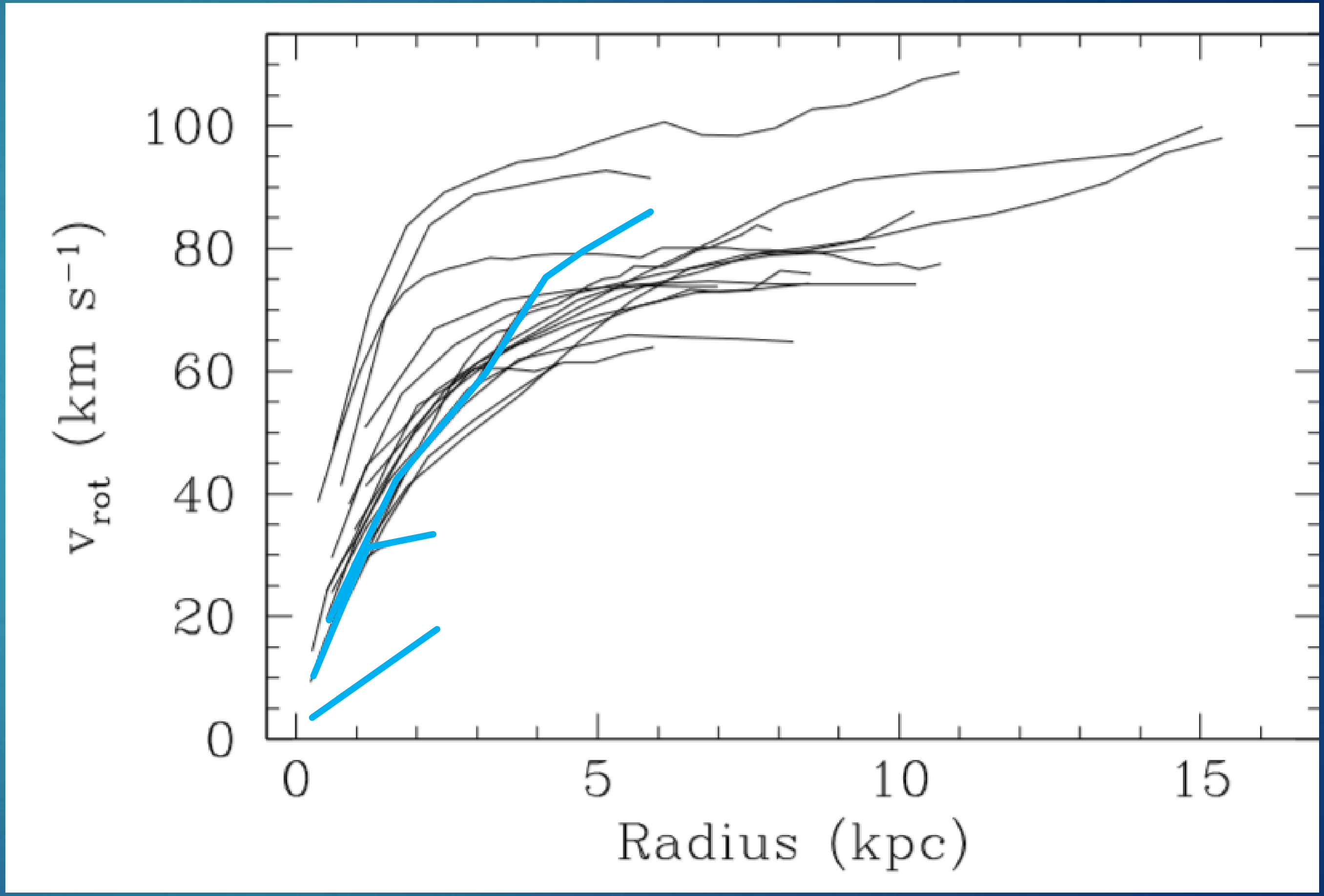

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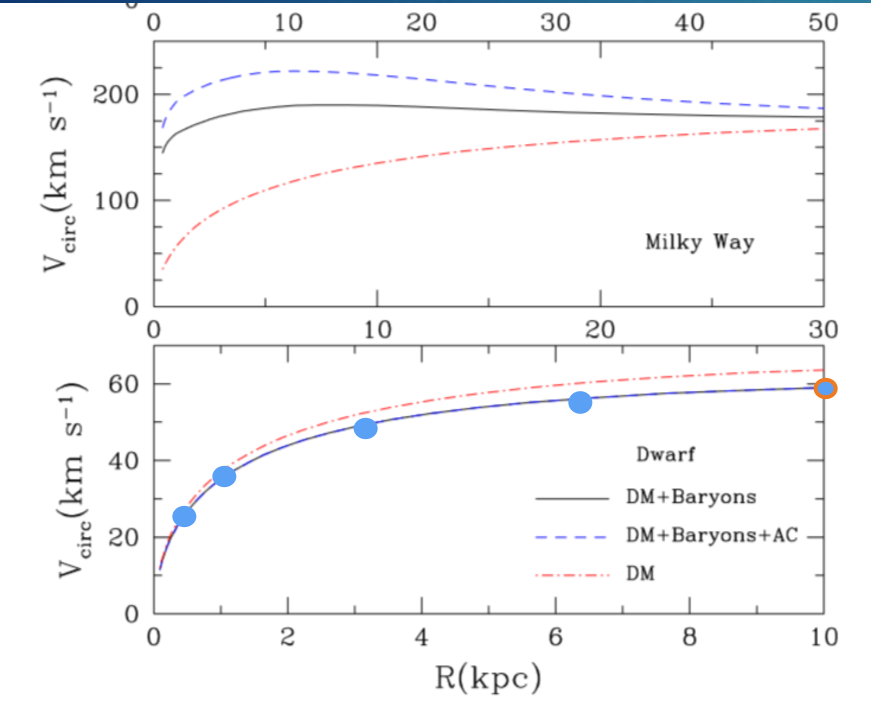

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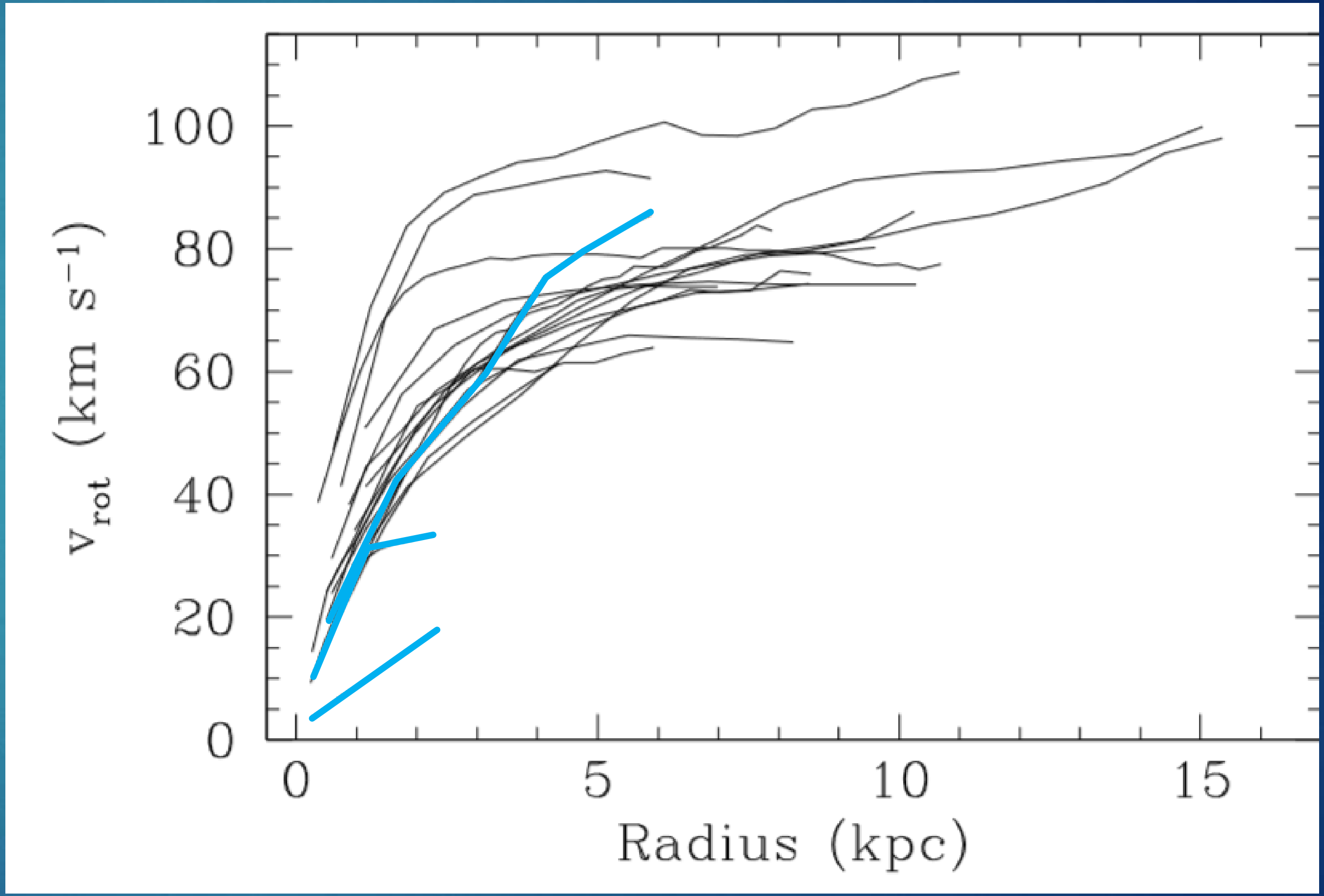
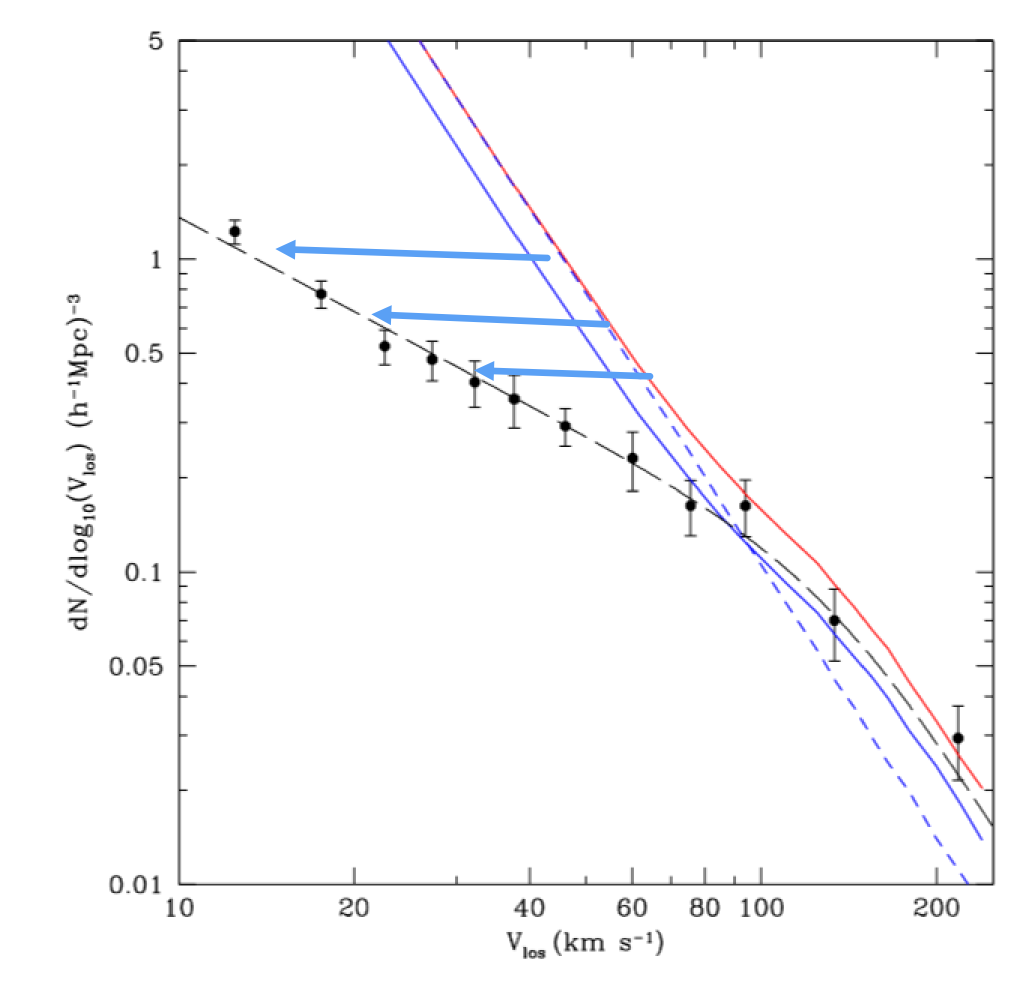


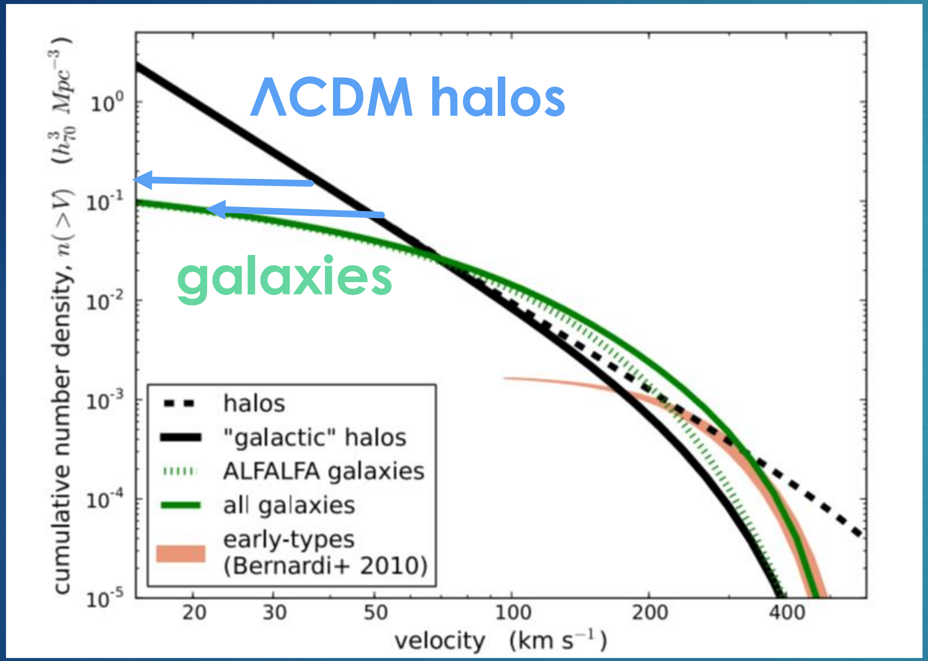
(Swaters+ 2009)

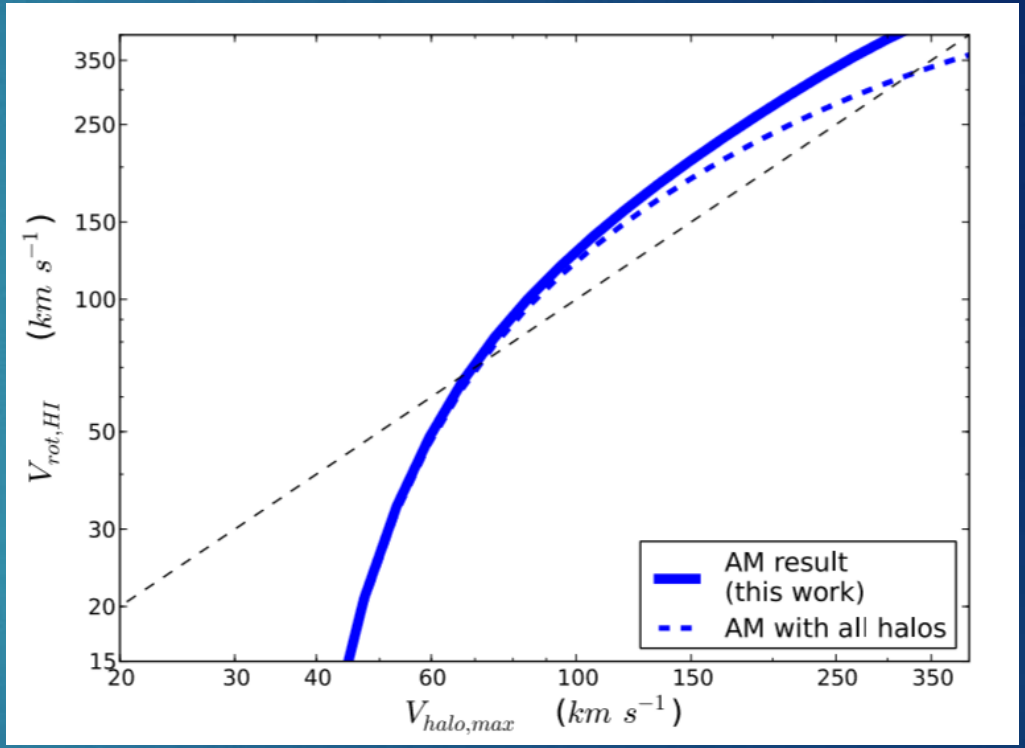
An easy way out?



(Klypin+ 2015)

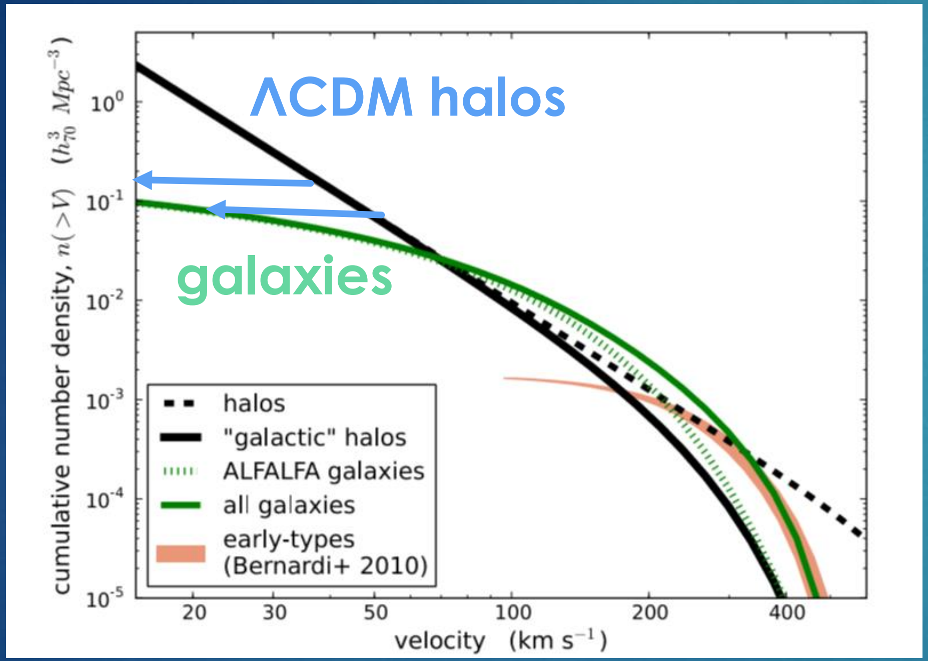
Which velocity?

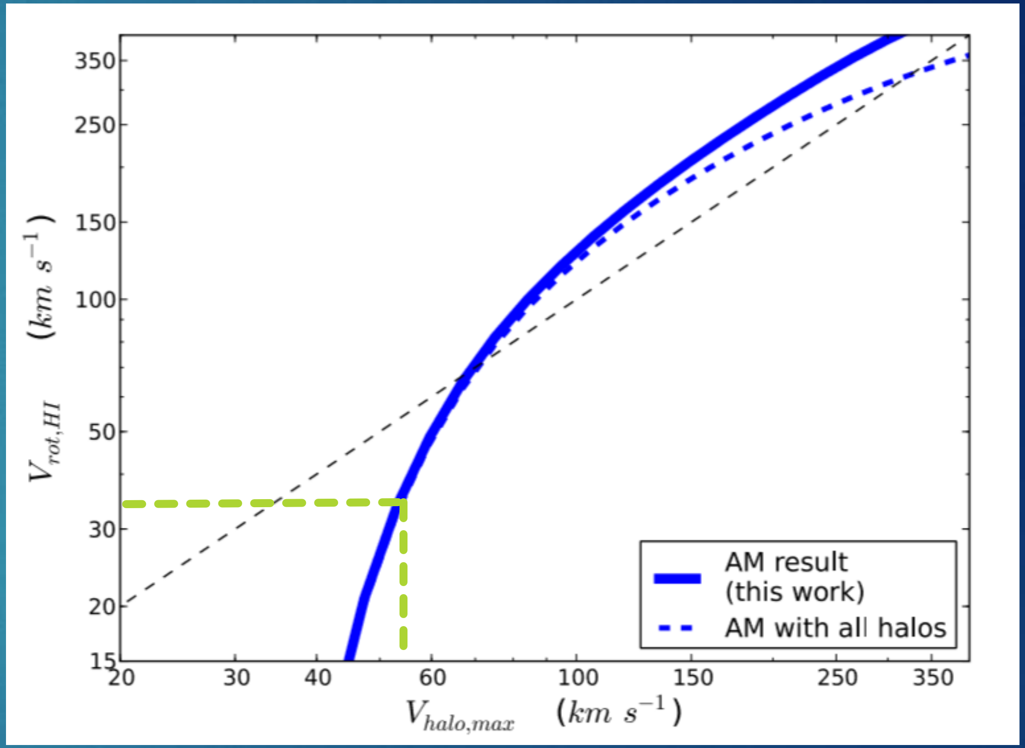




(Papastergis+ 2015)

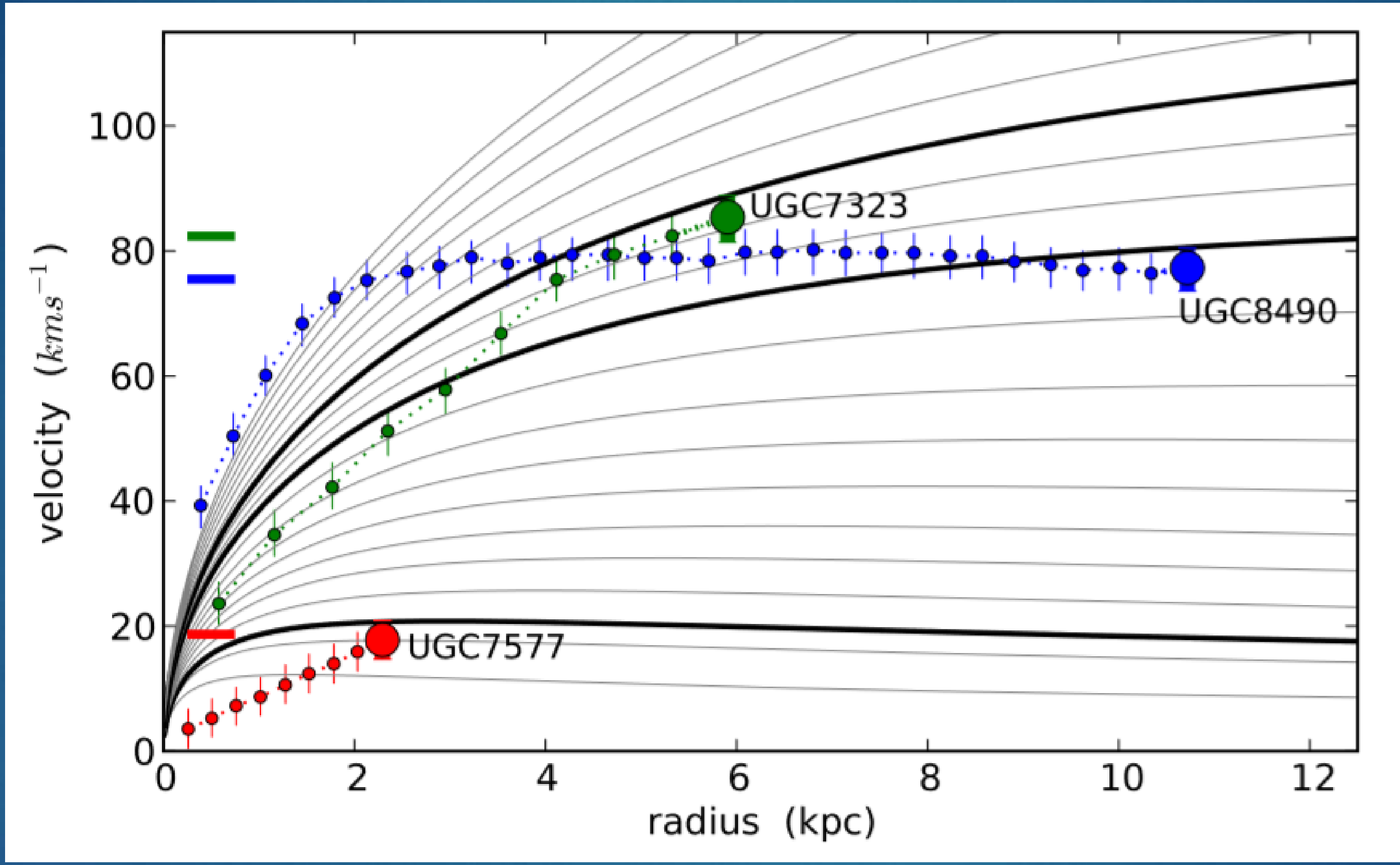
Which velocity?



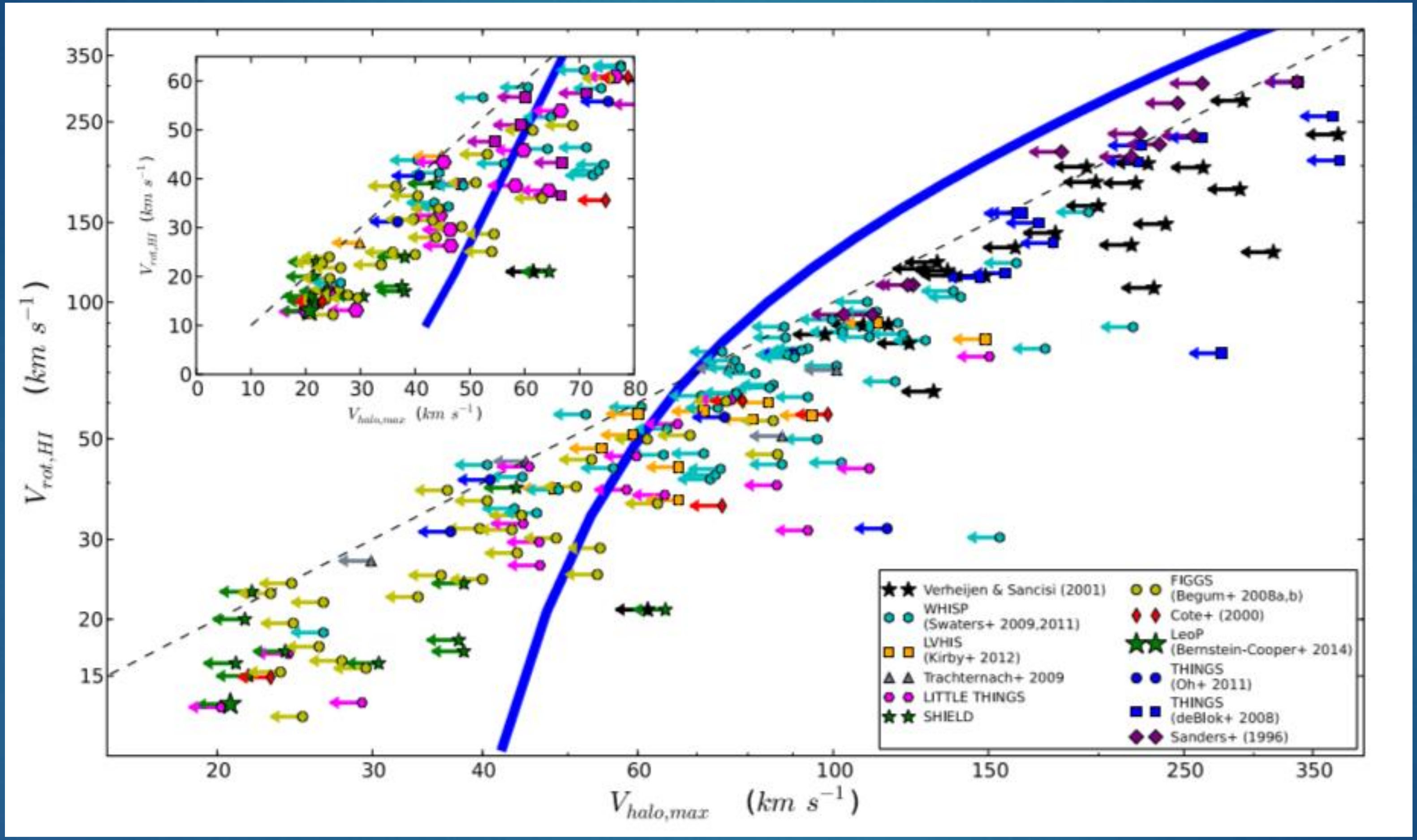


(Papastergis+ 2015)

Constraining the halo of a galaxy

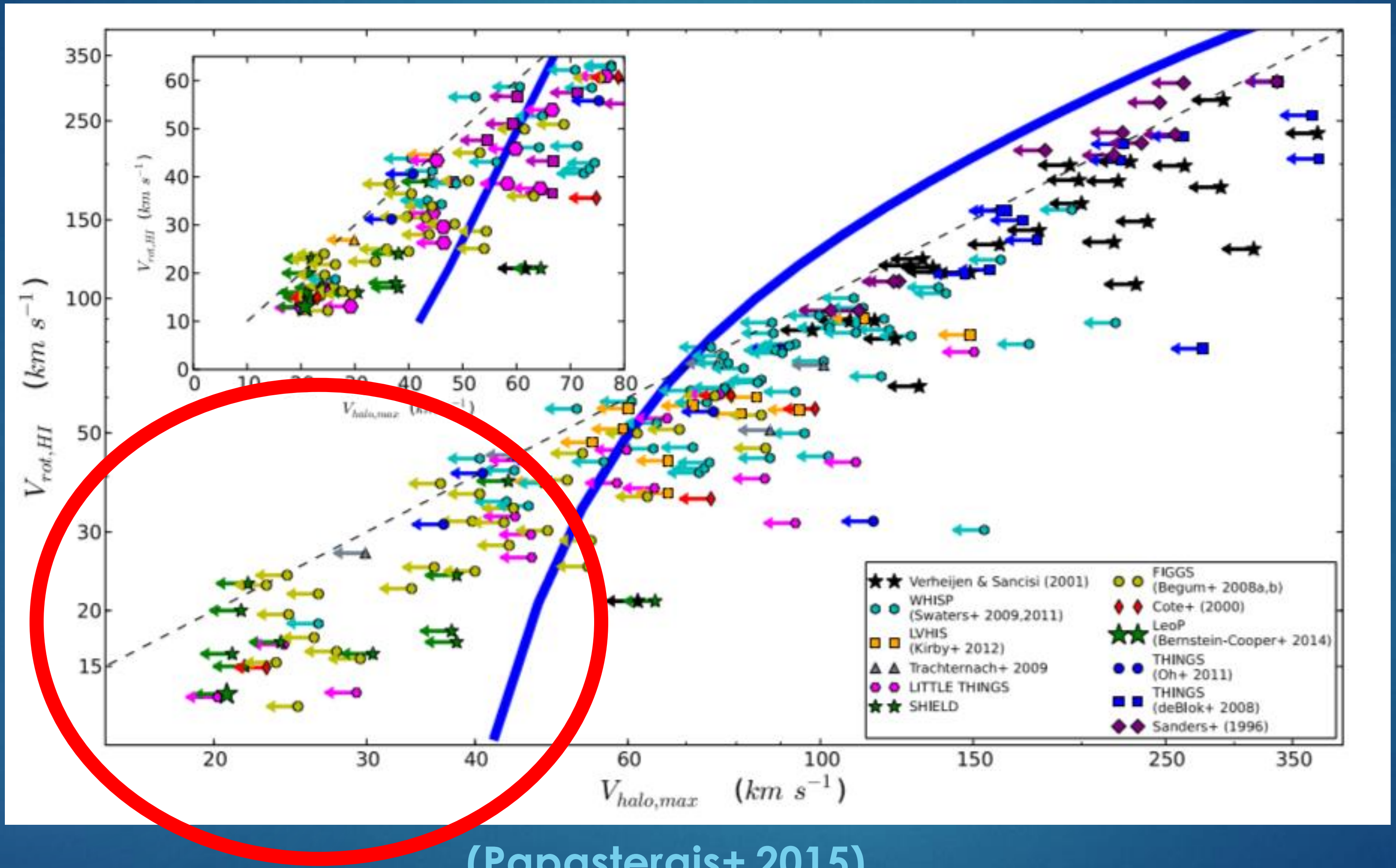


(Papastergis+ 2015)



(Papastergis+ 2015)

The *field* "too big to fail" problem

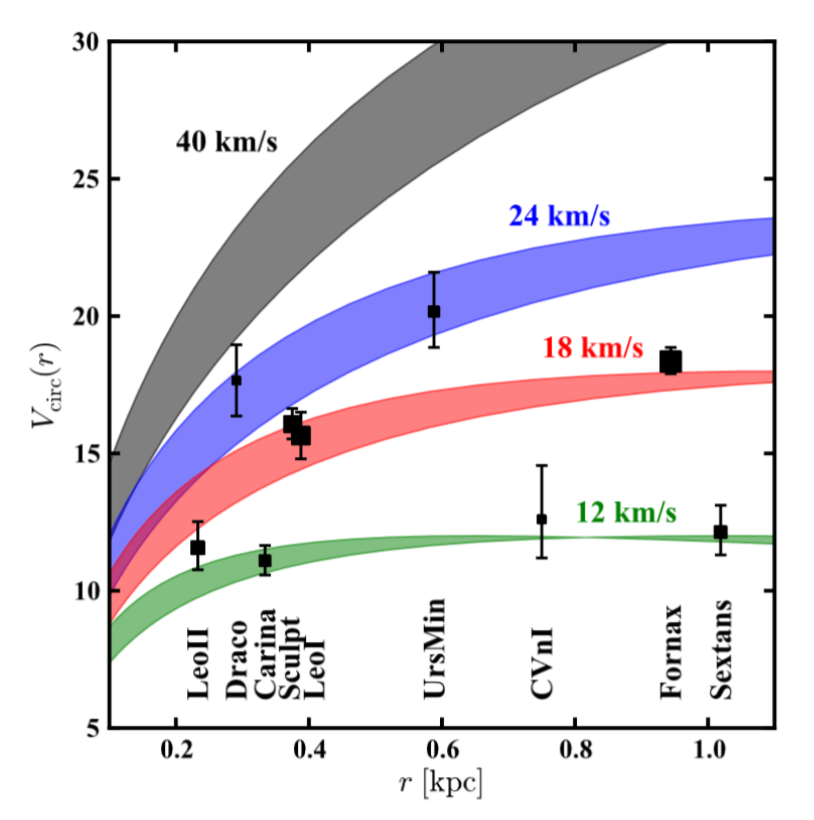


(Papastergis+ 2015)

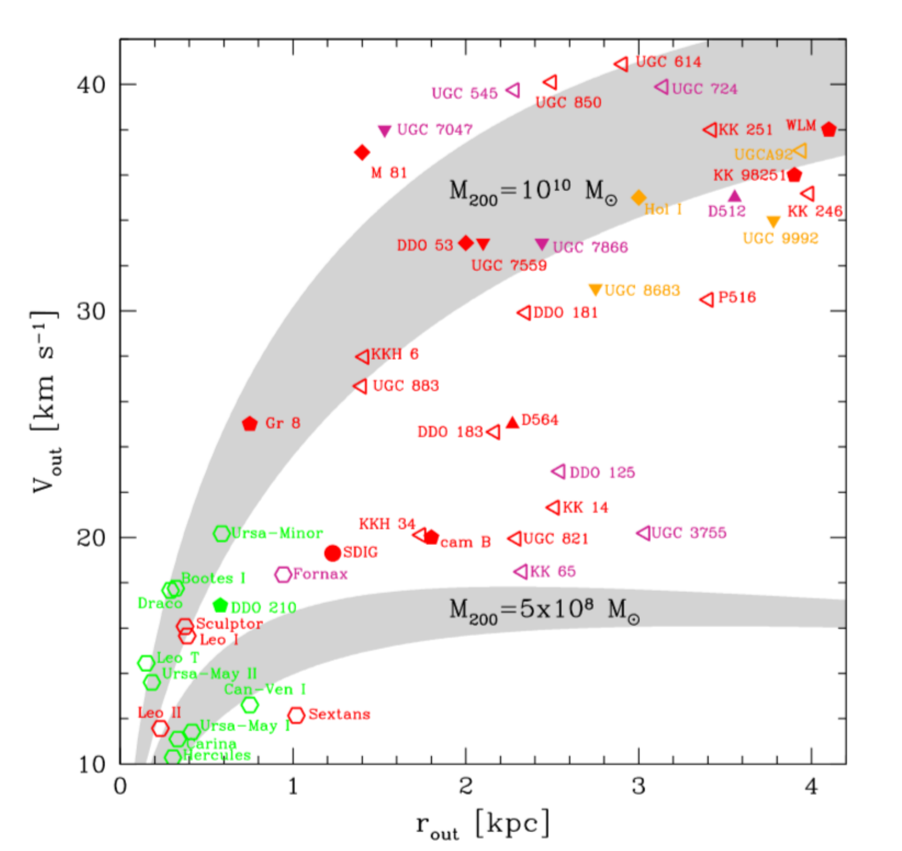
The *field* “too big to fail” problem in simple terms:

The rotation curves of dwarf galaxies in the field indicate that their host halos are quite ``light’’ ($V_{h,max} \approx$ 20-40 km/s). However, in a CDM universe there are so many halos of this mass that we should be observing many more dwarf galaxies than we are.

Not the first to notice…



Milky Way satellites
(Boylan-Kolchin+ 2011,2012)

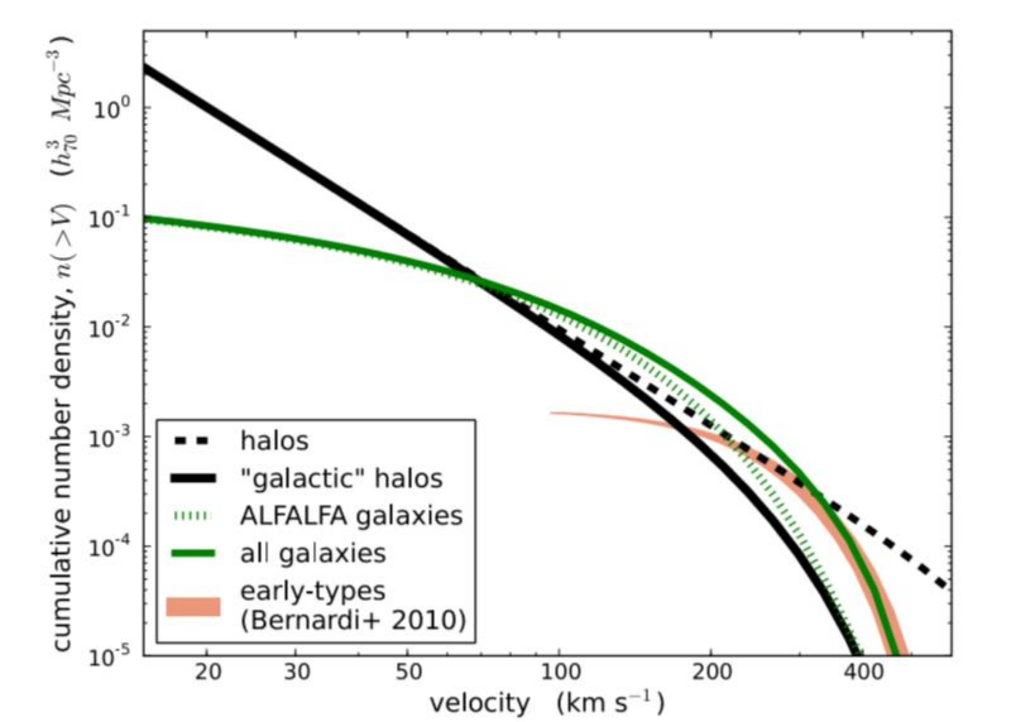


field dwarfs
(Ferrero+ 2012, Garrison-Kimmel+ 2014)

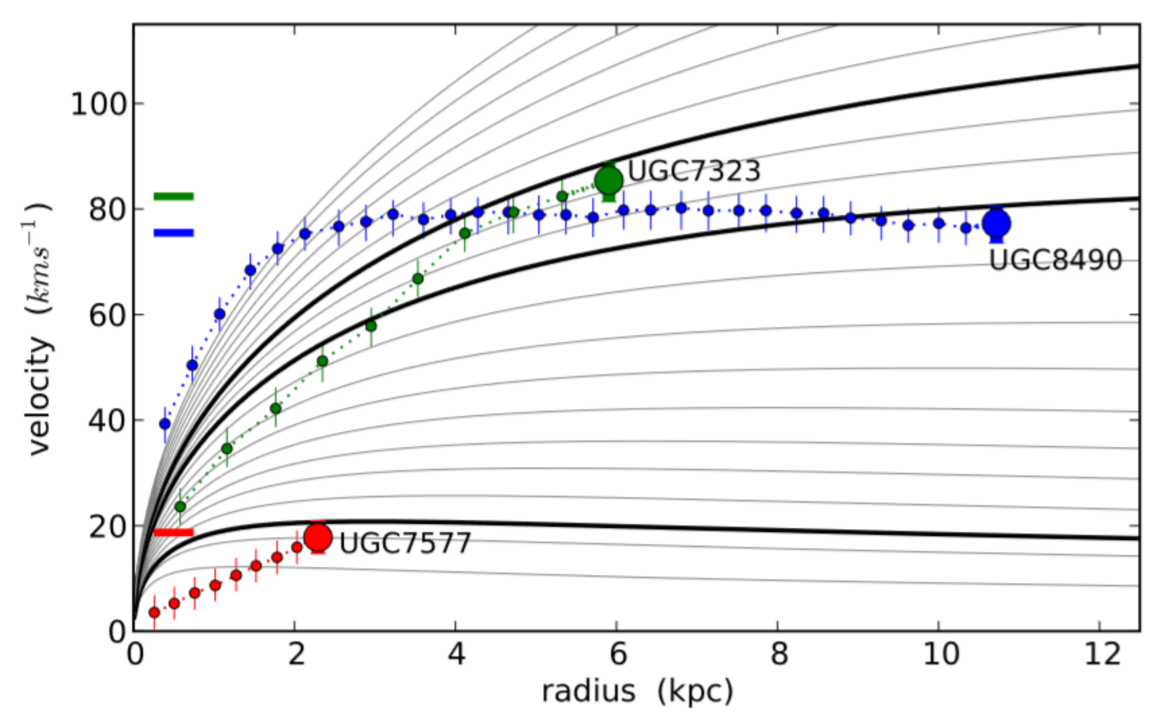
Any solutions?

The root of the problem

1. Large difference between abundance of small halos and dwarf galaxies

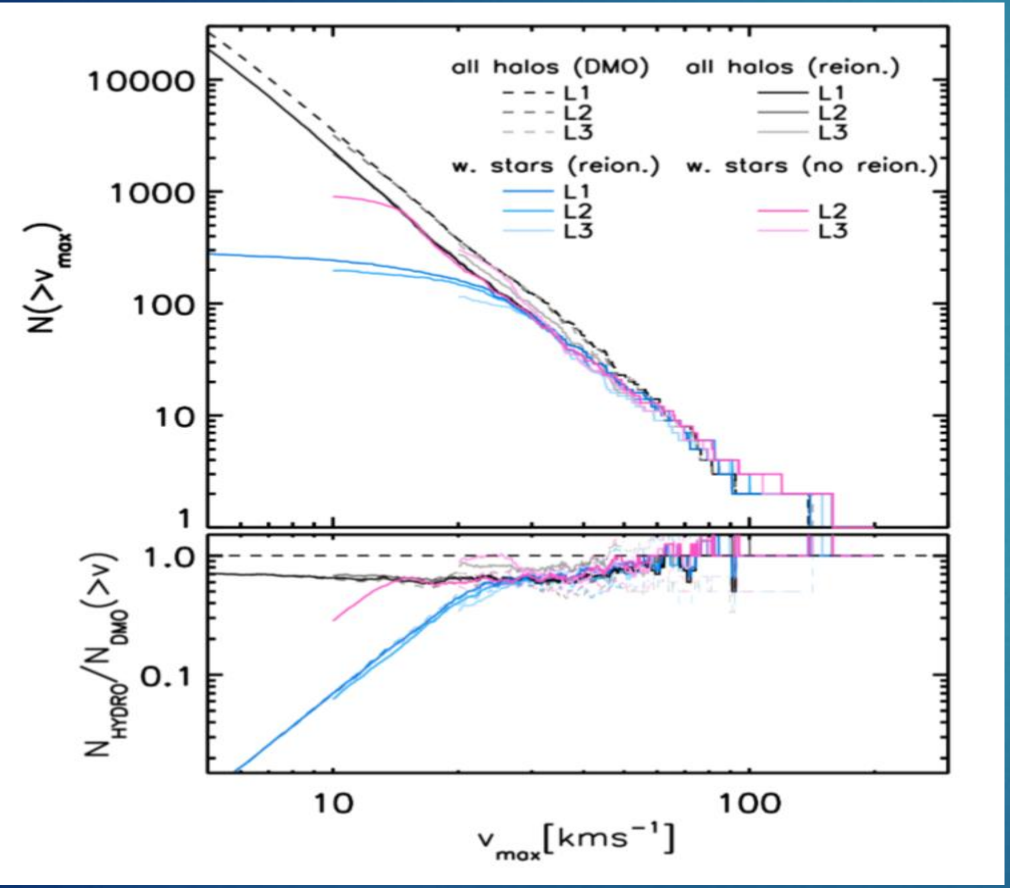


2. Impossible to fit dwarf kinematics with massive halos



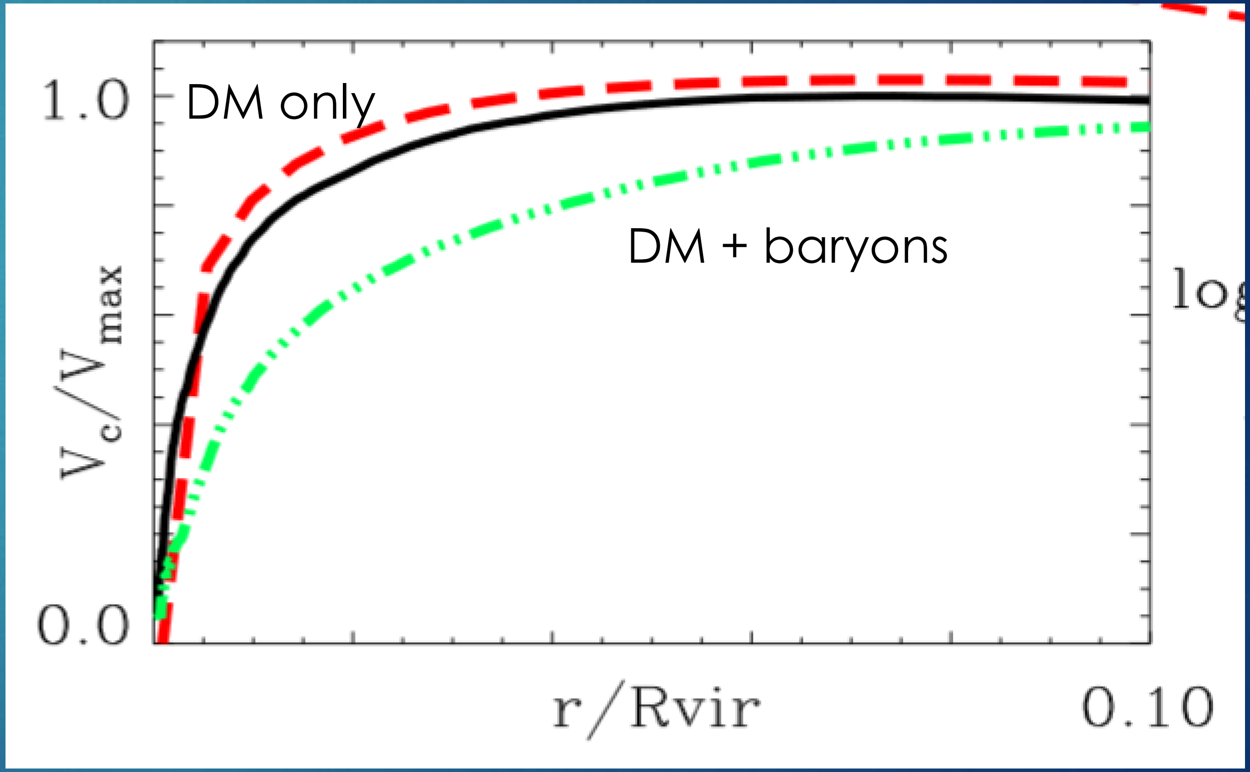
Baryonic solutions in ΛCDM?

1. Reionization feedback



(Sawala+ 2015; also Okamoto+ 2008, etc.)

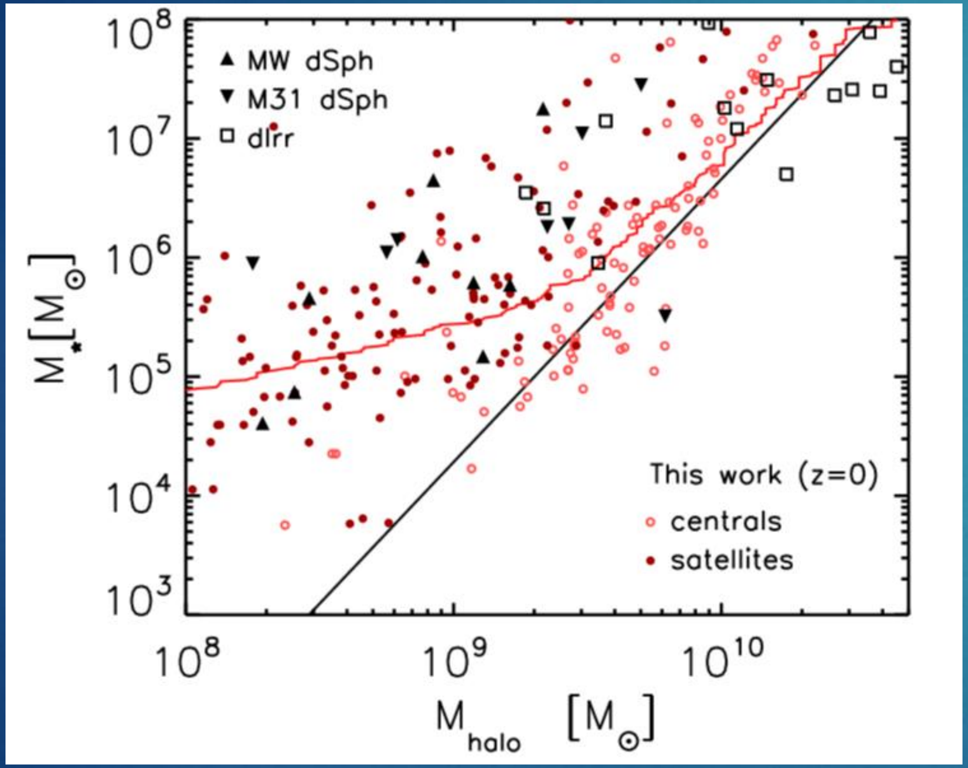
2. Core creation through star-formation feedback



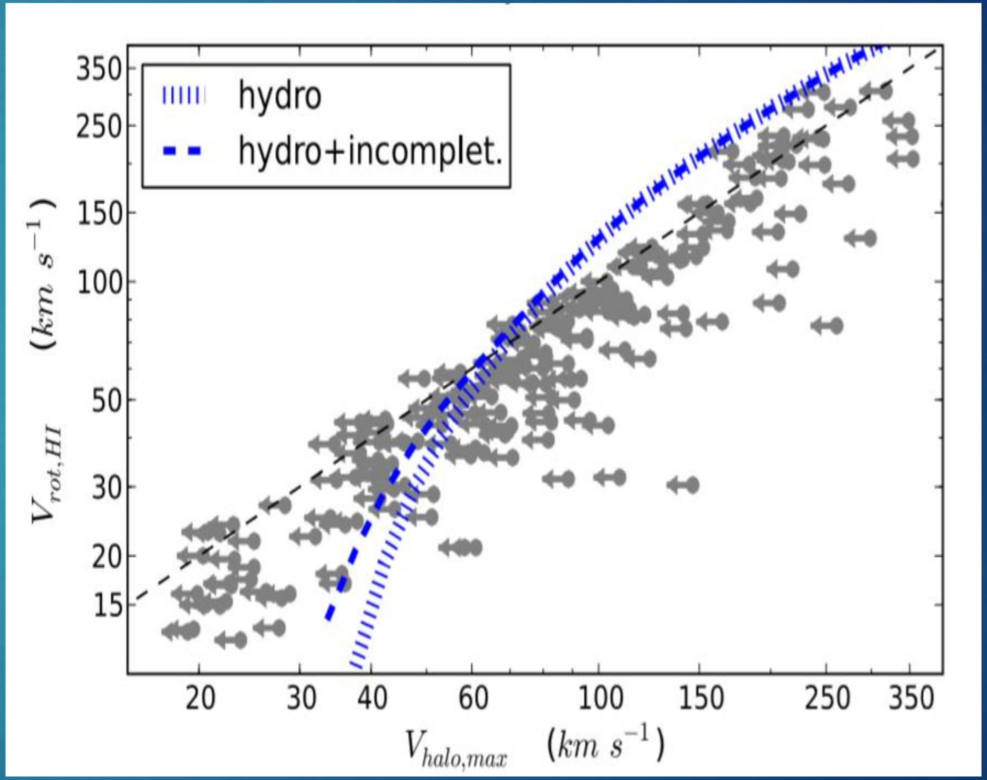
(di Cintio+ 2015; also Governato+ 2010, Brooks+Zolotov 2014, Onorbe+ 2015, etc.)

Do baryonic solutions work?

1. Reionization



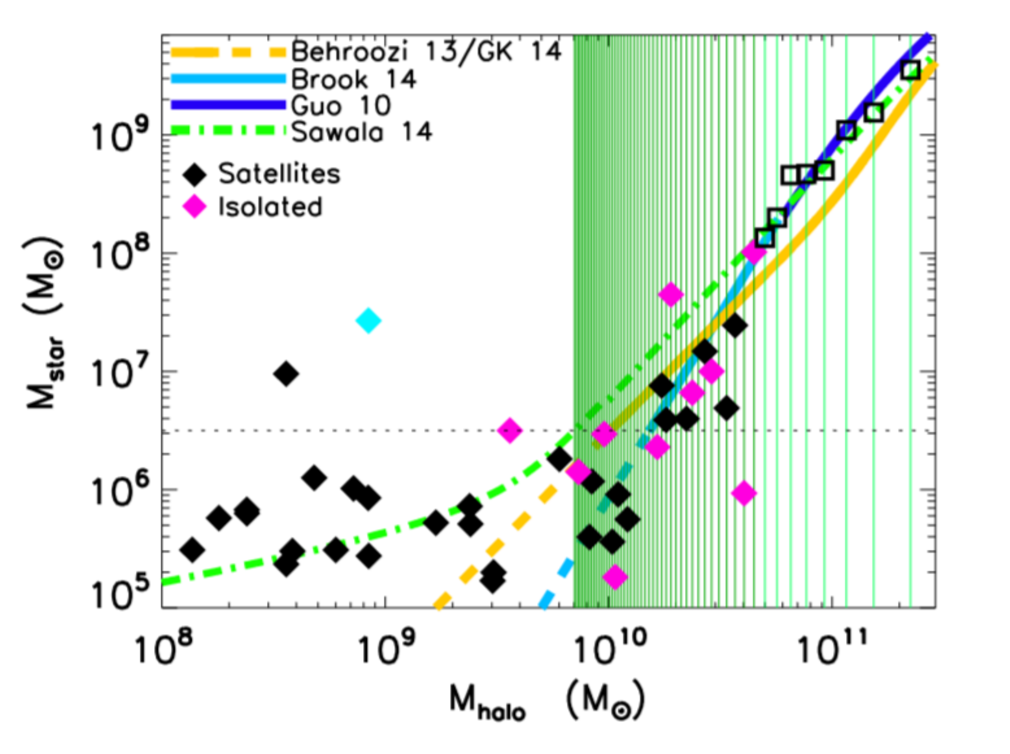
Sawala+ 2015: yes

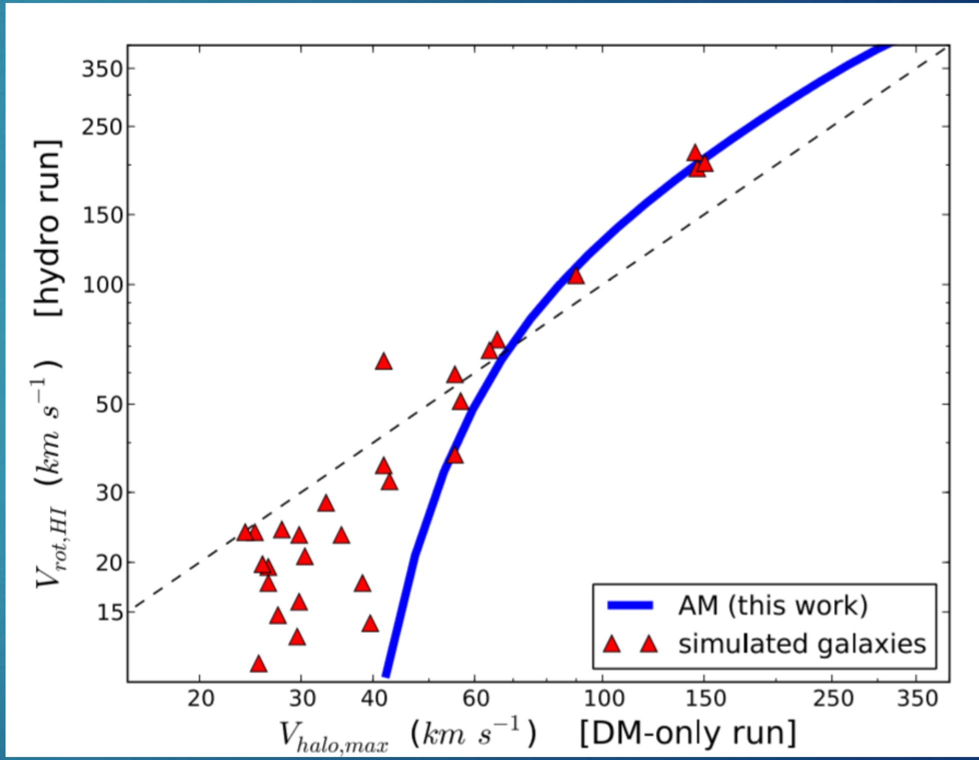


Papastergis+ 2015: no

Do baryonic solutions work?

2. Reionization + cored profiles



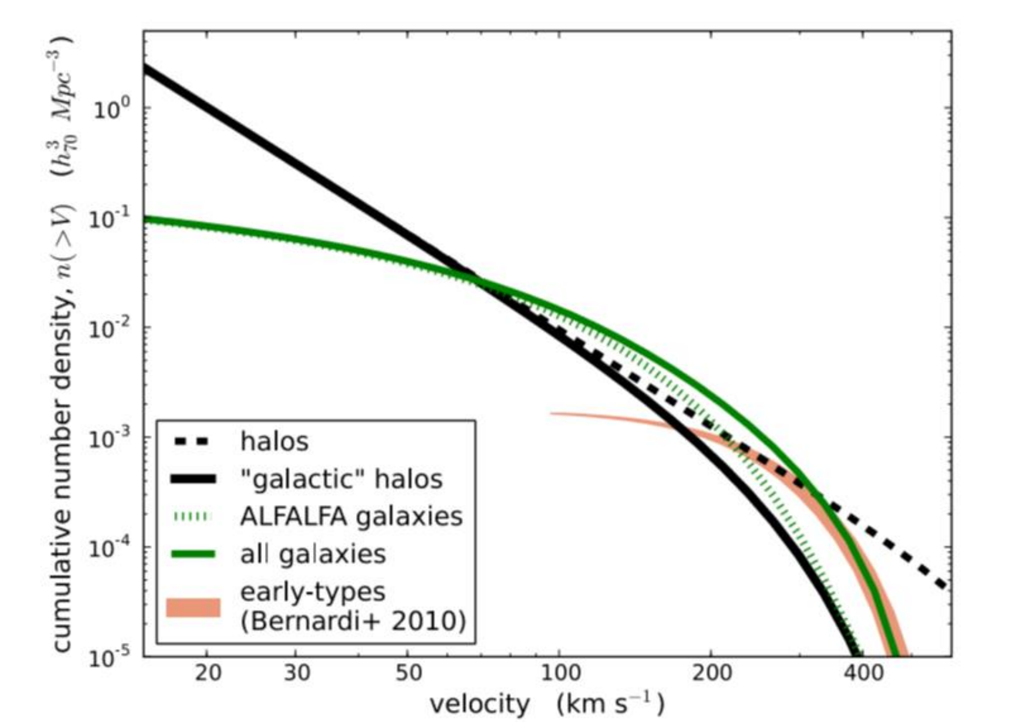


Brook+diCintio 2014: yes

Papastergis+ 2015: no
(based on hydro sims of Governato+ 2012, Brooks+Zolotov2014, Christensen+ 2014)

The root of the problem

1. Large difference between abundance of small halos and dwarf galaxies



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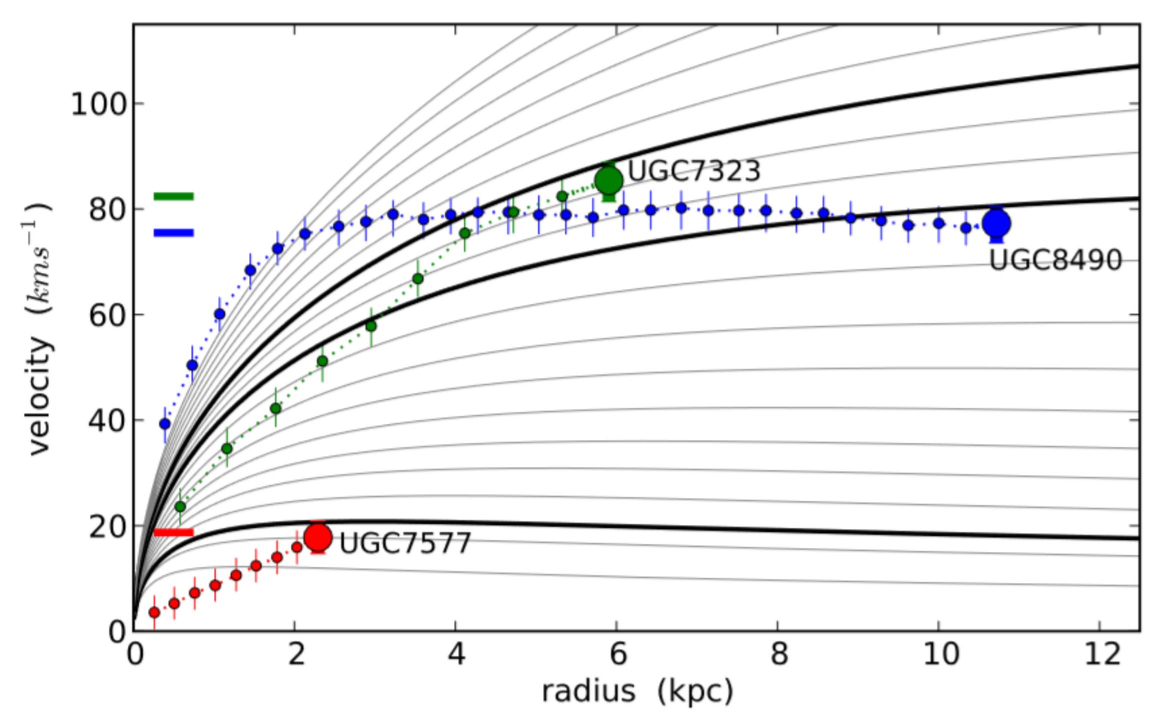
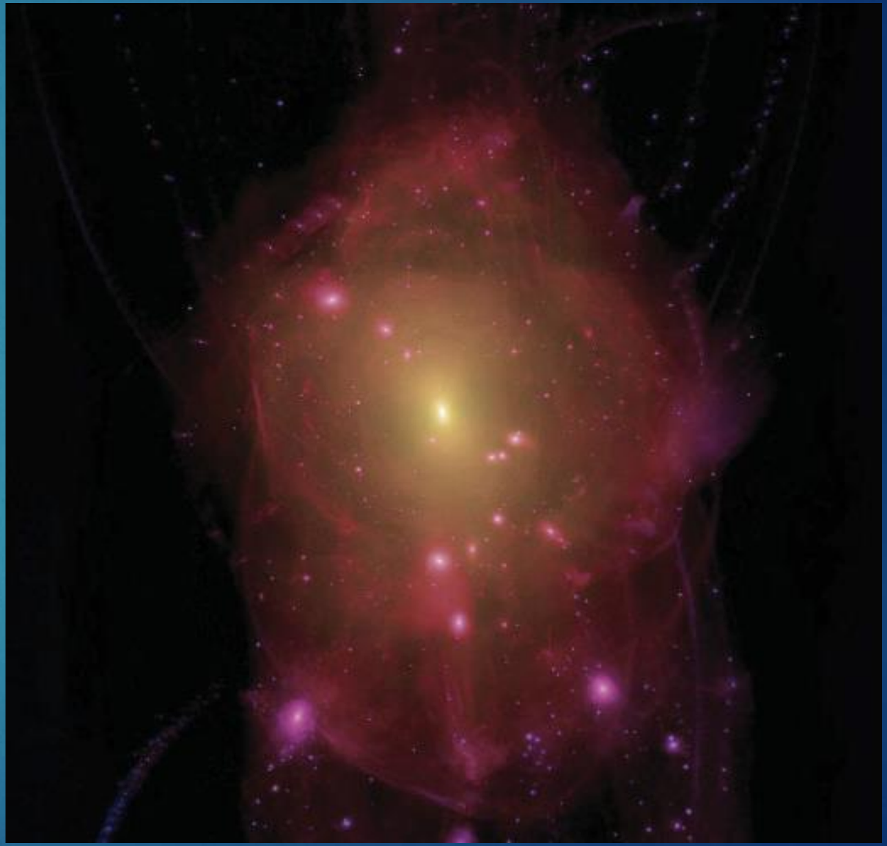


CDM

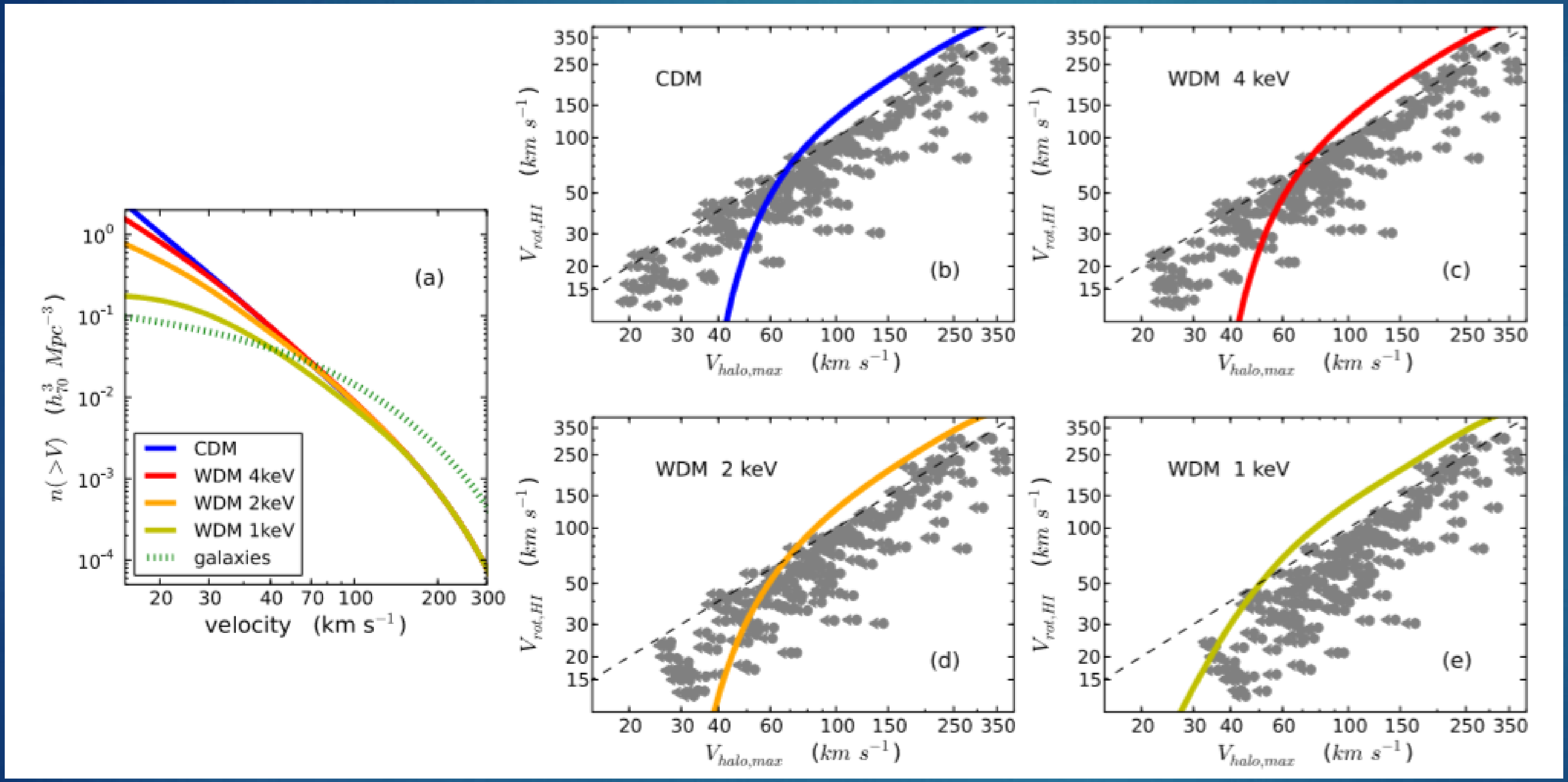
(Lovell+ 2012)

WDM



(Lovell+ 2012)

Warm dark matter?

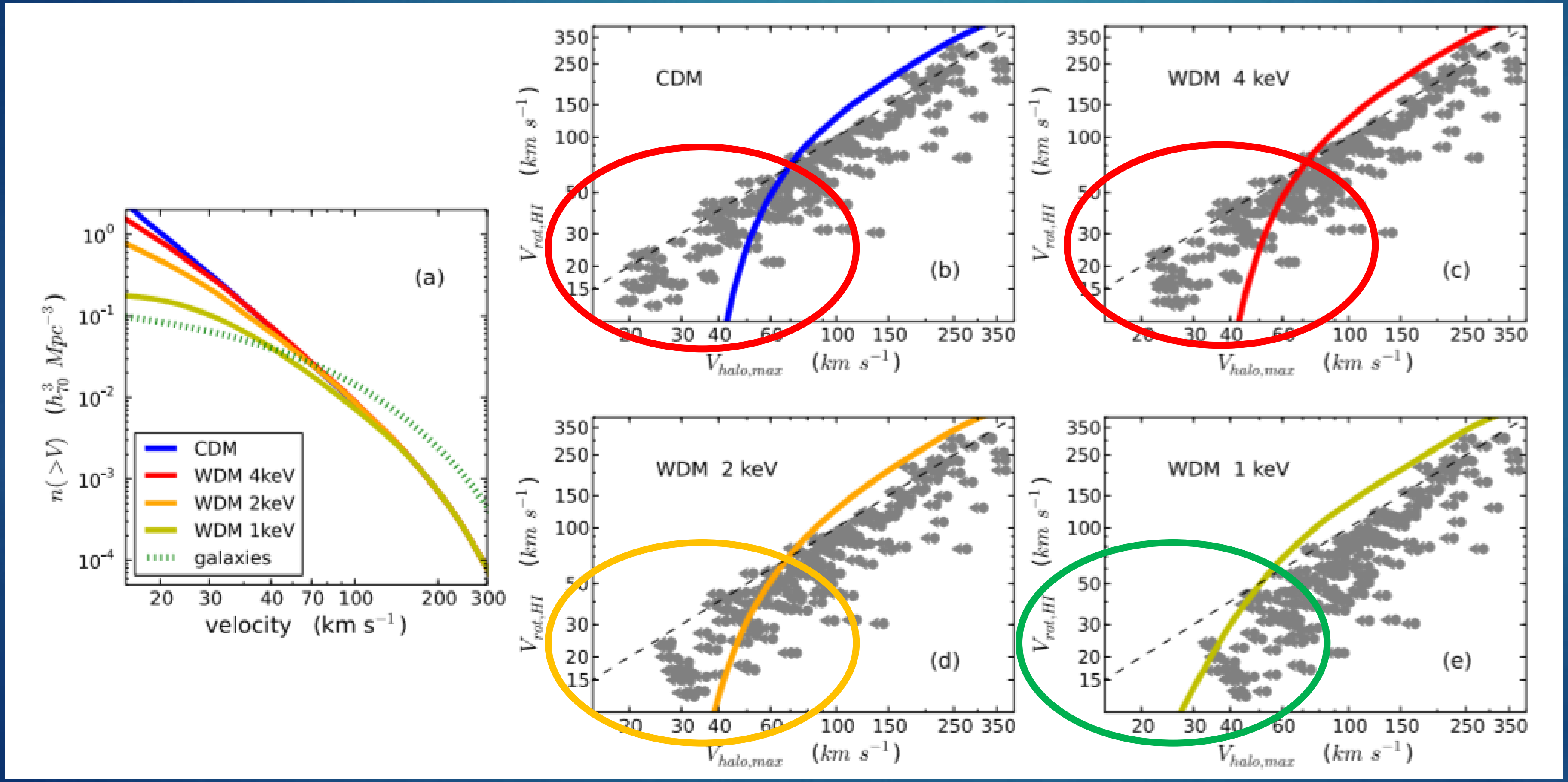


WDM advantages:

1. Fewer low-mass halos
2. Less concentrated halos

Warm dark matter?

** The WDM particle mass must be ≤ 2 keV **



Conclusions

- **"Too big to fail" problem**: it is challenging to reproduce simultaneously the **number density** and **internal kinematics** of dwarf galaxies in ΛCDM
- Even though the TBTF problem was first identified in the population of **MW satellites**, now it is clear that concerns **all dwarfs** (satellites + field objects)
- A solution must have the following characteristics:
  - **fewer** low mass halos than in ΛCDM
  - **less concentrated** halos than in ΛCDM
- **Within ΛCDM**, there exist potential **baryonic solutions**. However, it is **not yet clear** whether they can work.
- **WDM** can **help solve** the TBTF problem. However the particle must be **light, < 2 keV**