kapteyn astronomical institute

ALFALFA

Too few and too light?

TESTING ΛCDM COSMOLOGY WITH FIELD DWARF GALAXIES

Manolis Papastergis

NOVA postdoctoral fellow

Kapteyn Institute, the Netherlands

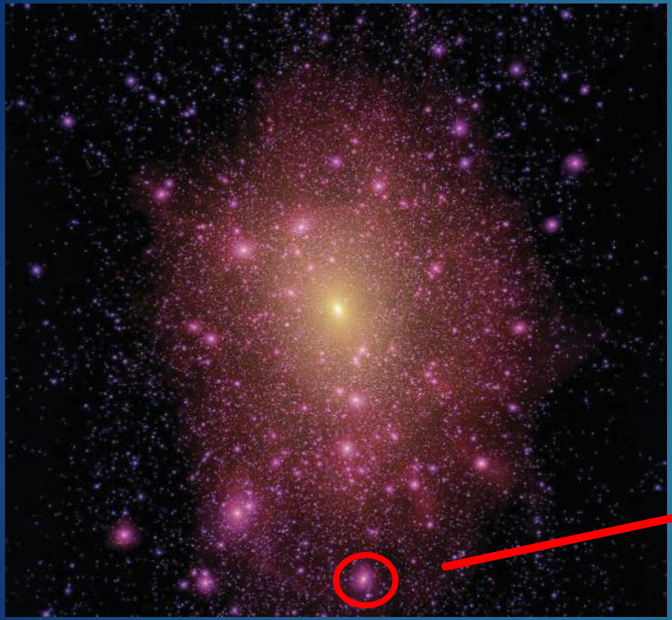
12th Hel.A.S conference

Thessaloniki 29 Jun 2015

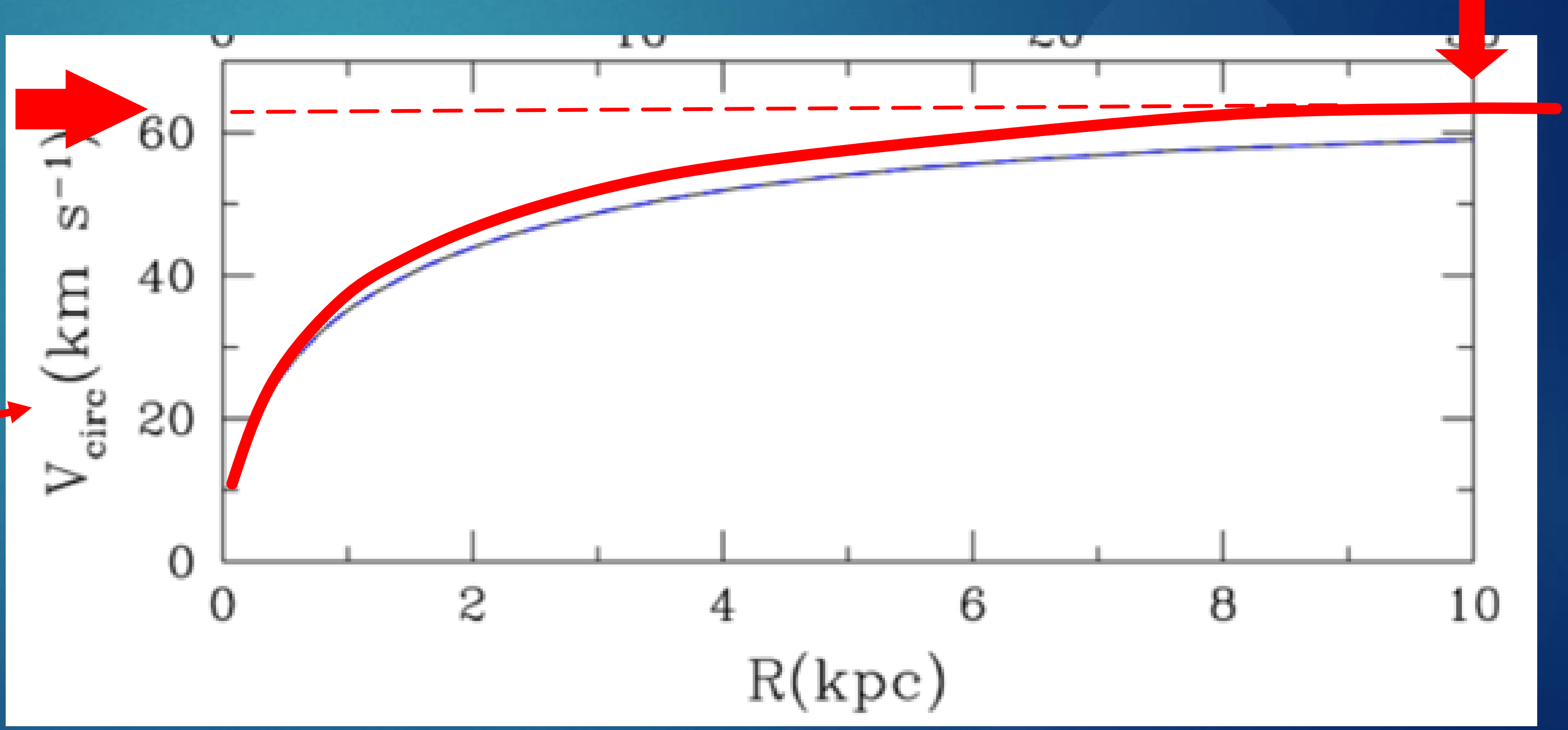
The Cold Dark Matter paradigm

MW-sized halo
(Lovell+ 2012)

The Cold Dark Matter paradigm

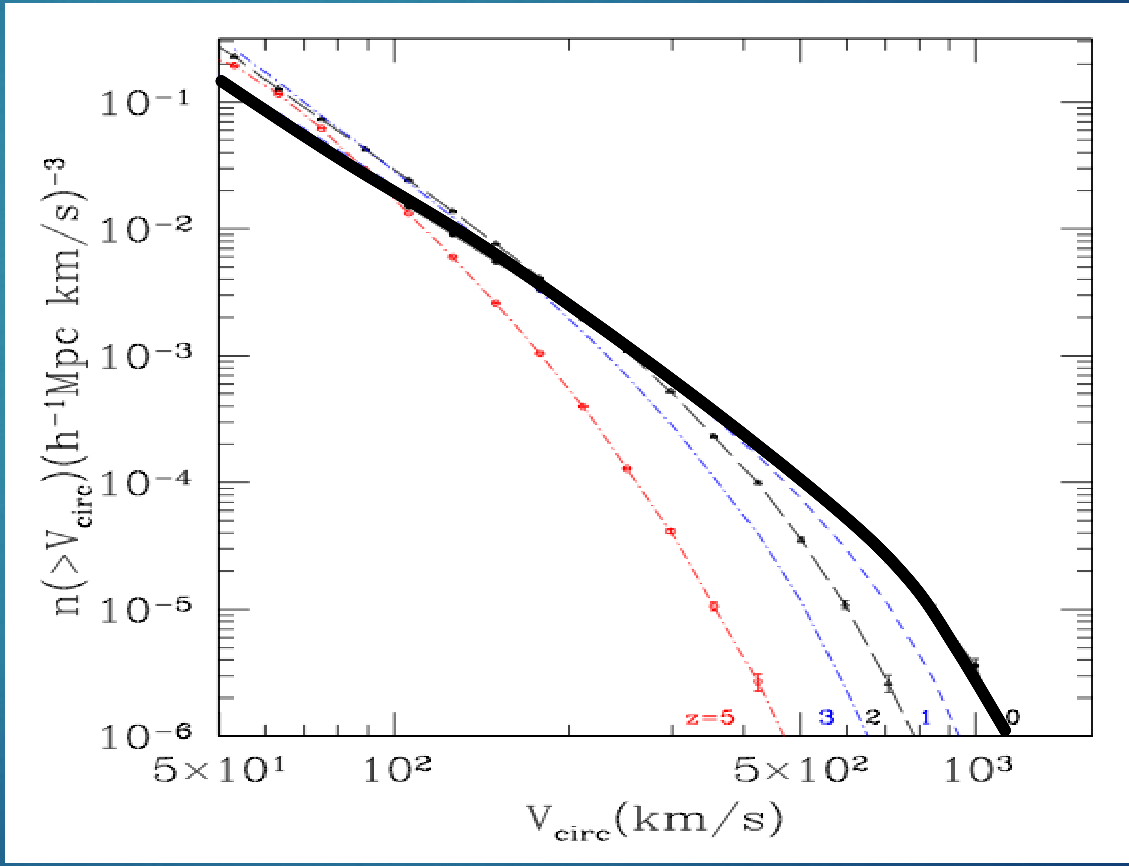


$V_{h,max}$: maximum rotational velocity of halo



The Cold Dark Matter paradigm

Halo Velocity Function



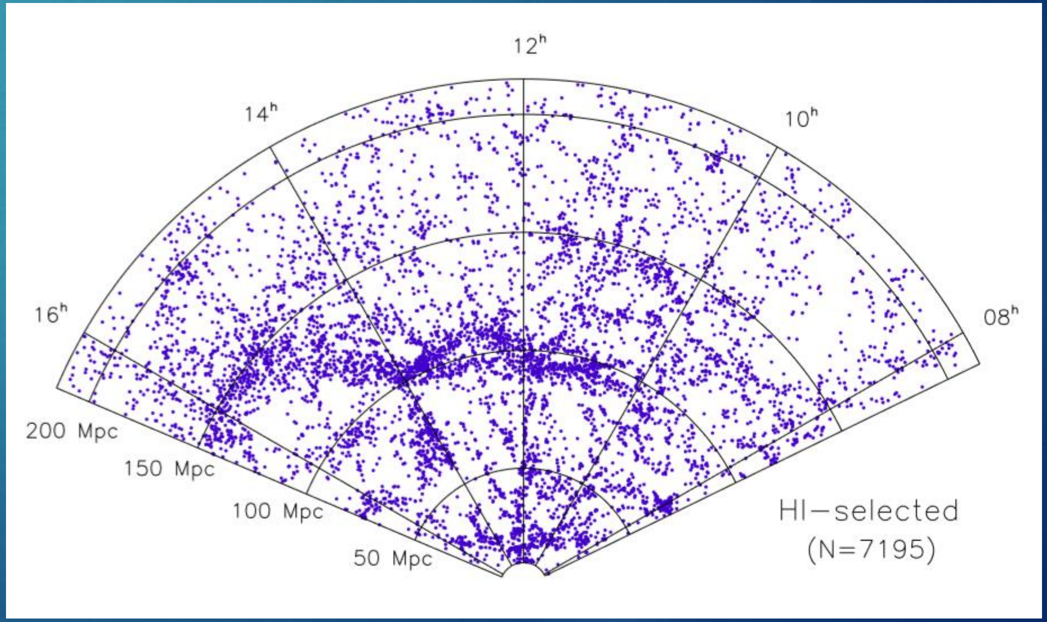
Bolshoi simulation
(Klypin+ 2011)

the ALFALFA survey

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

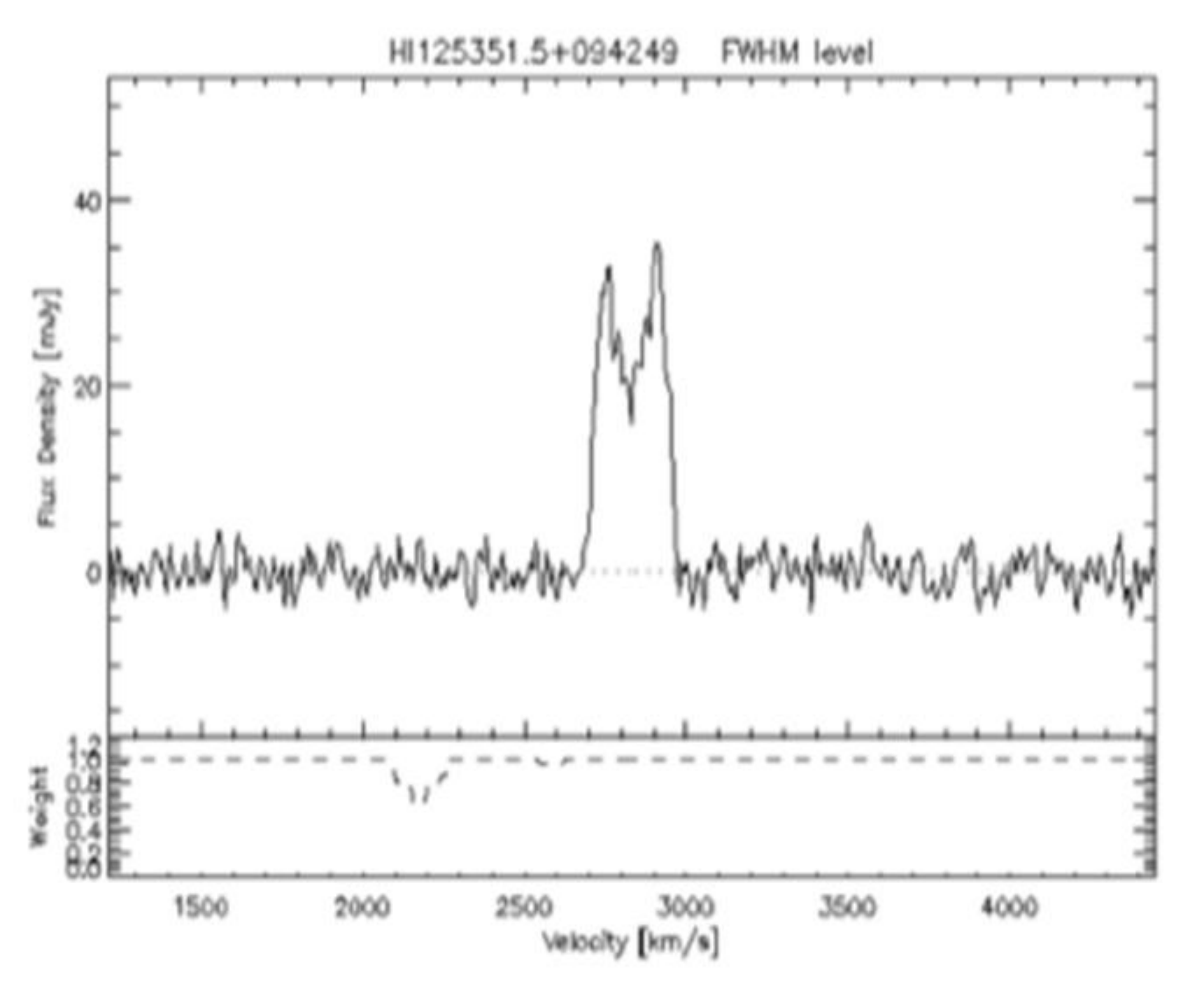
- **ALFALFA** is a blind **21-cm line survey**, performed with the **Arecibo** radiotelescope (Giovanelli+ 2005).

- **Largest HI**-selected sample to date:
  - **> 11 000 galaxies**
  - **~ 3 000 deg^2 of sky**



the ALFALFA survey

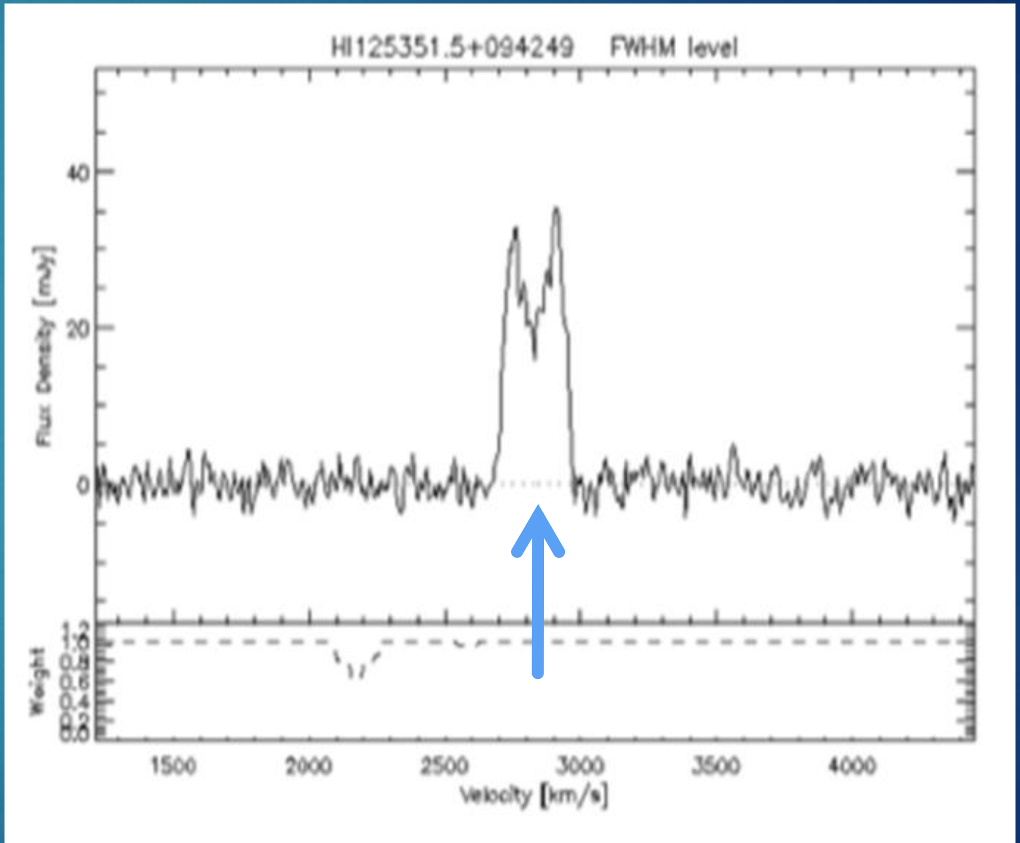
http://egg.astro.cornell.edu/alfalfa/



the ALFALFA survey

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

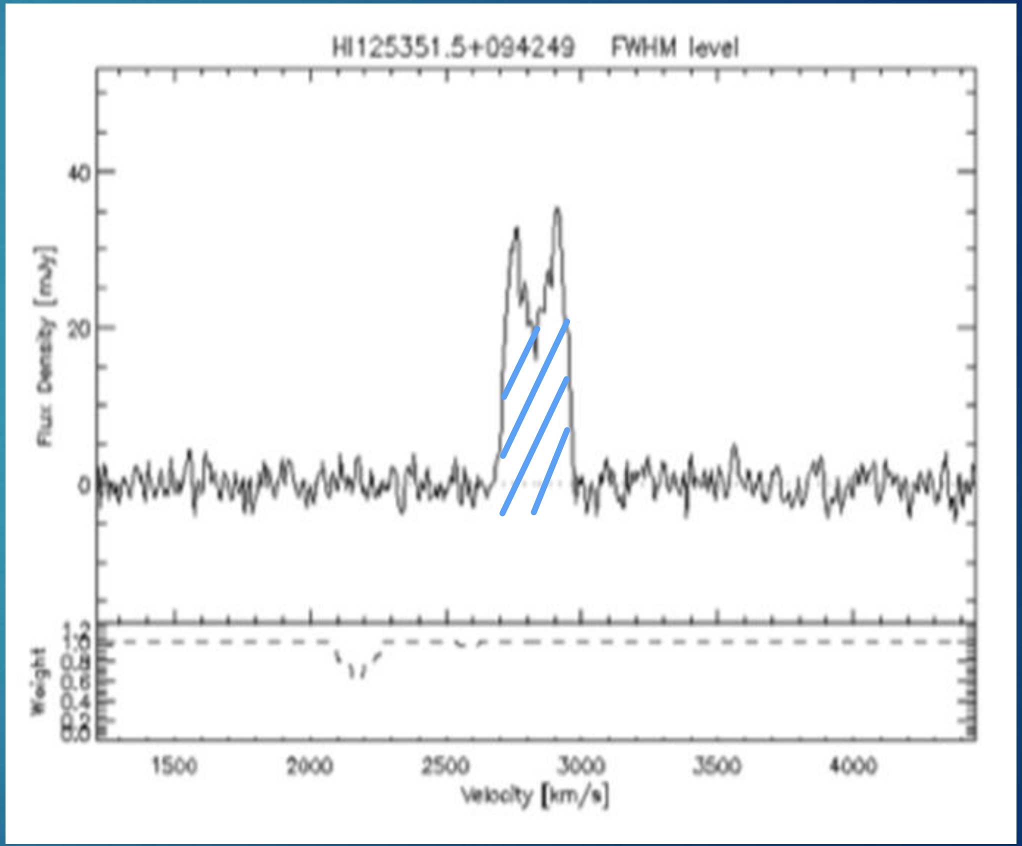
- ALFALFA directly measures:
  - **redshift**



the ALFALFA survey

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

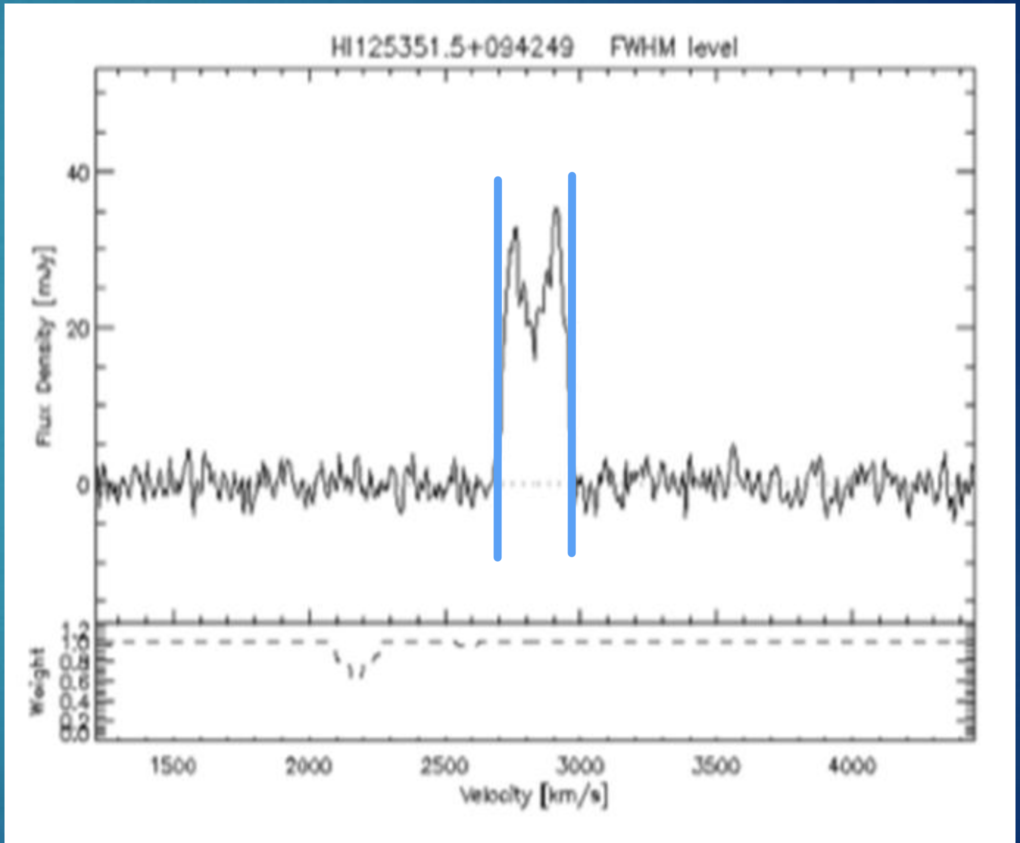
- ALFALFA directly measures:
  - **redshift**
  - **integrated flux (HI mass)**



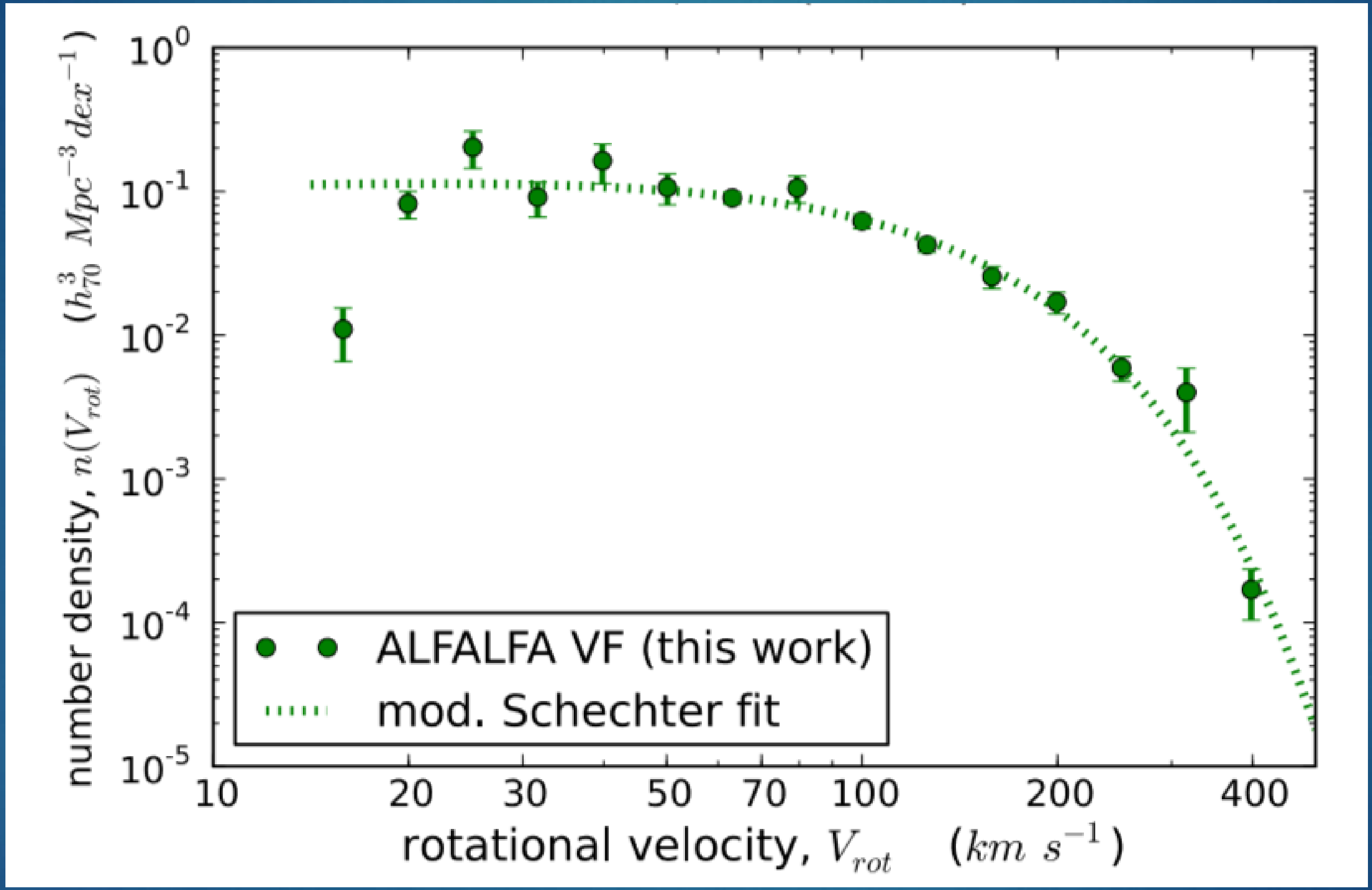
the ALFALFA survey

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

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

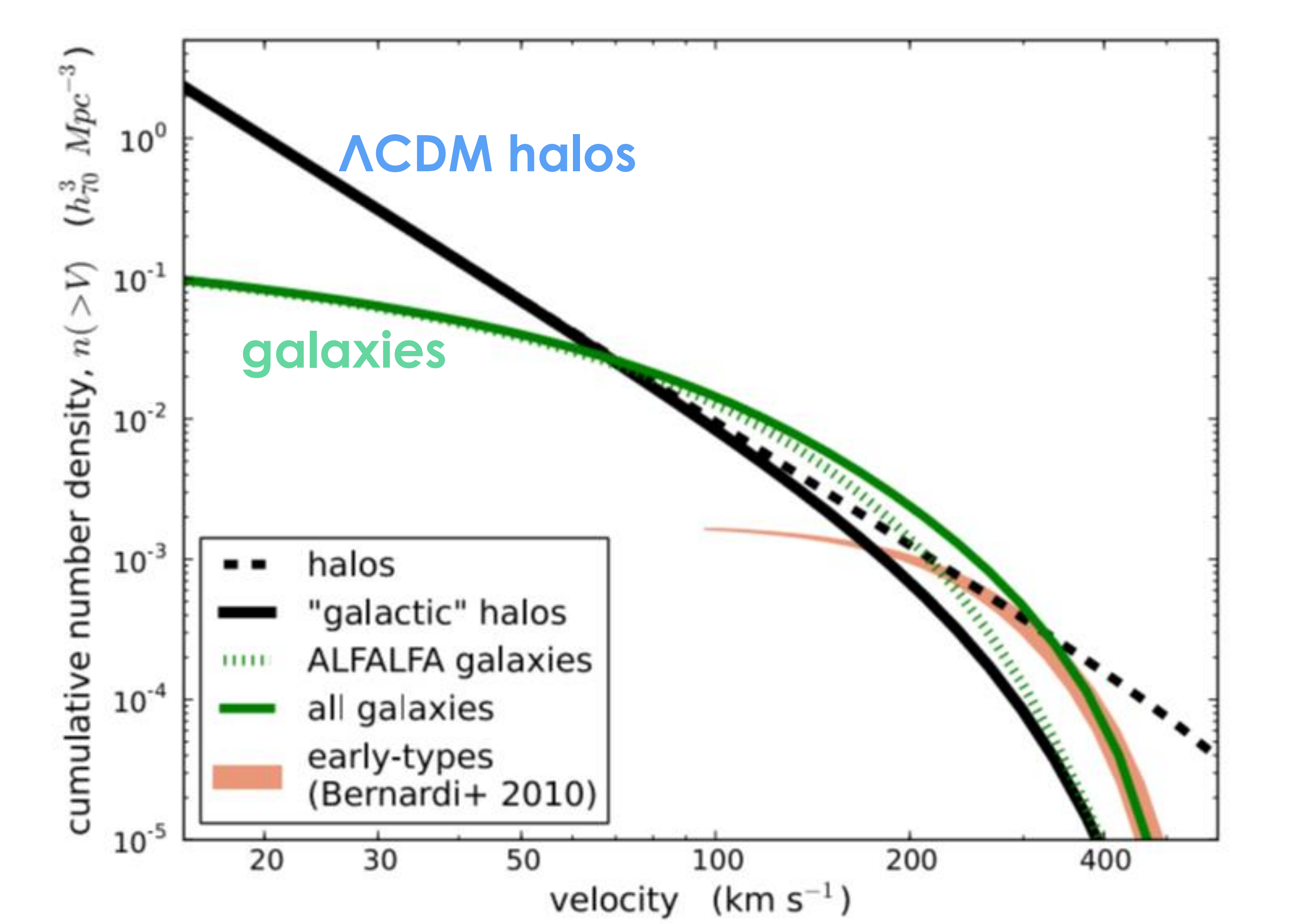


The velocity function of galaxies



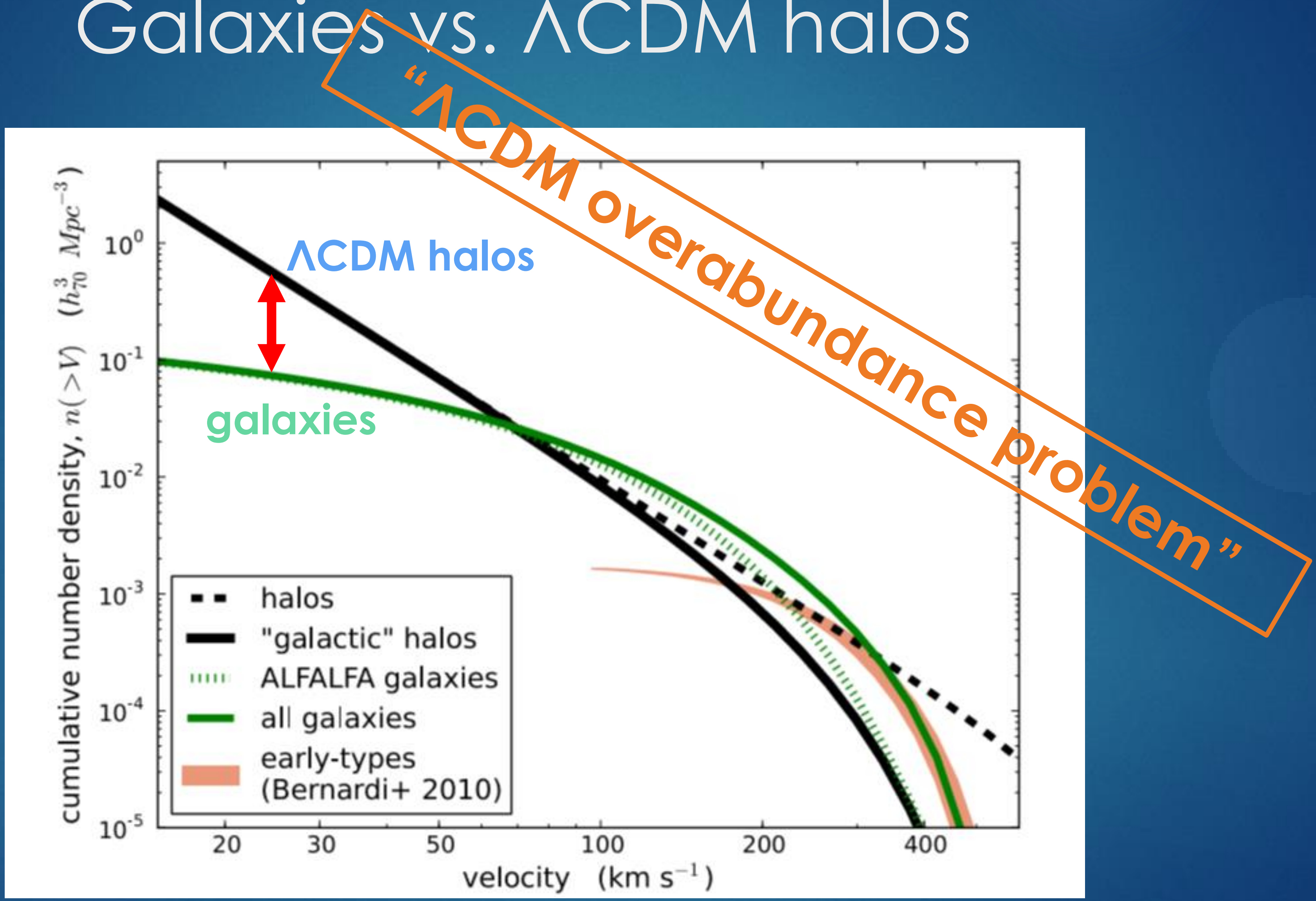
(Papastergis+ 2011,2015)

Galaxies vs. ΛCDM halos



(Papastergis+ 2015)

Galaxies vs. ΛCDM halos

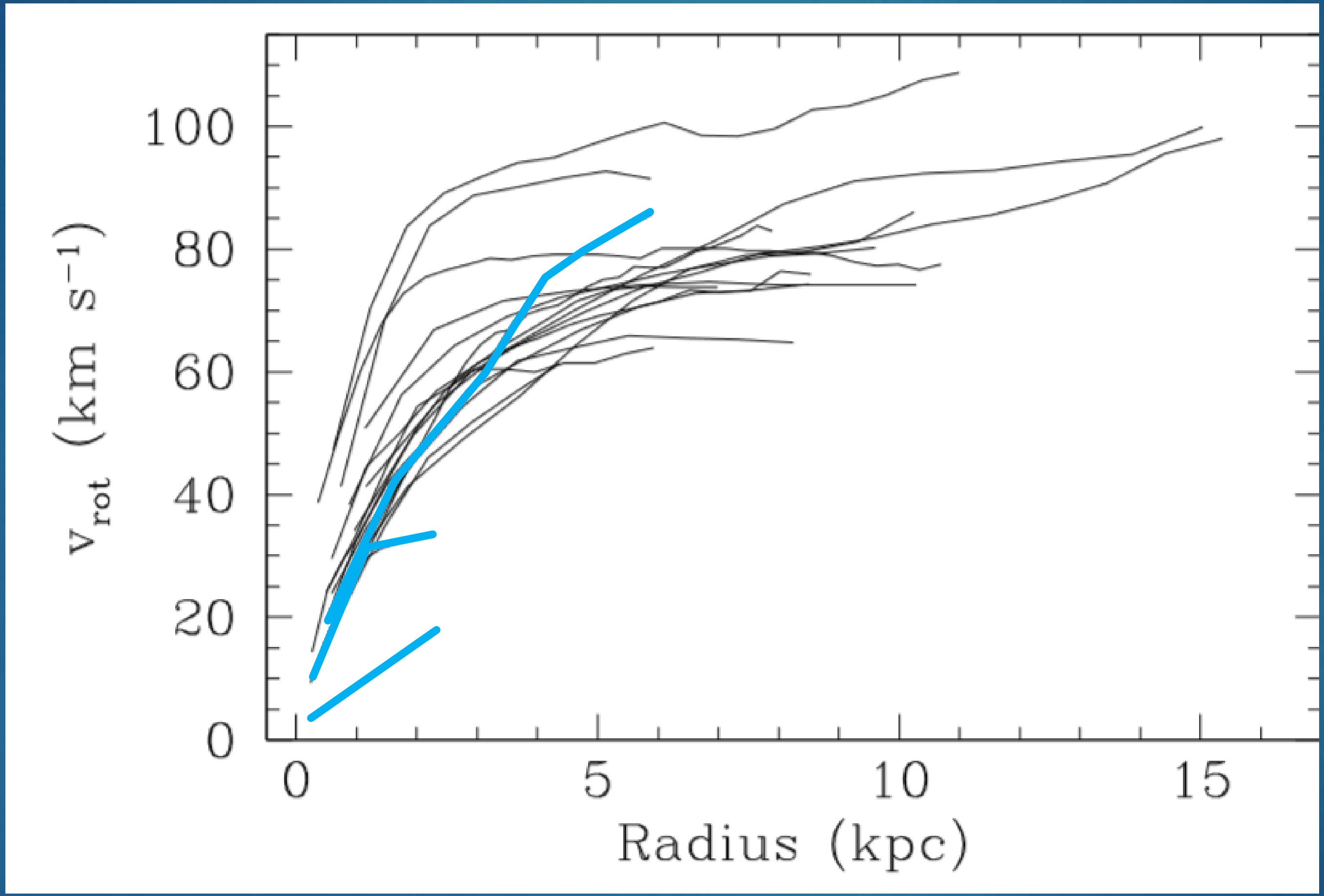


(Papastergis+ 2015)

But wait a second…

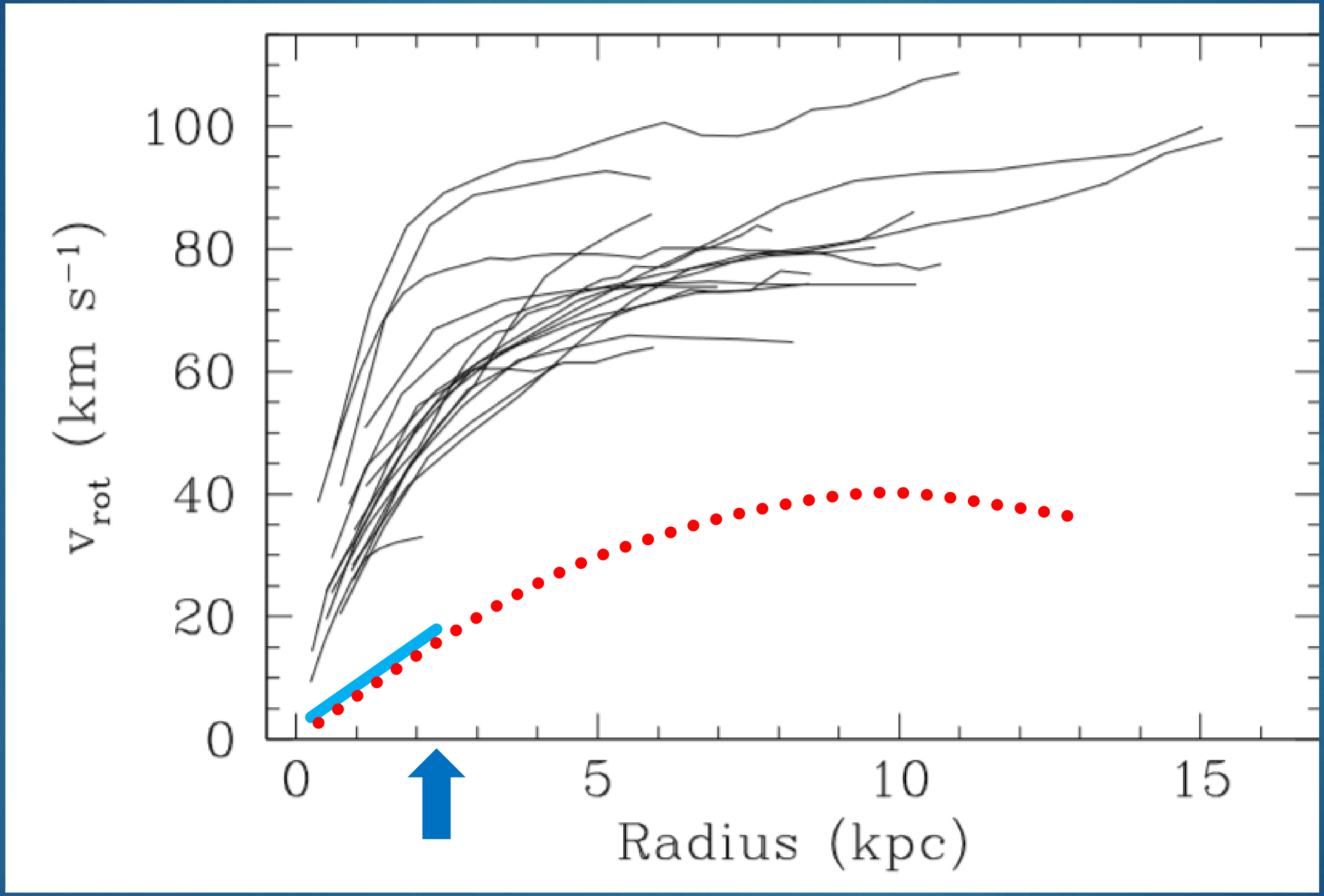
GALAXIES ≠ HALOS

Which velocity?



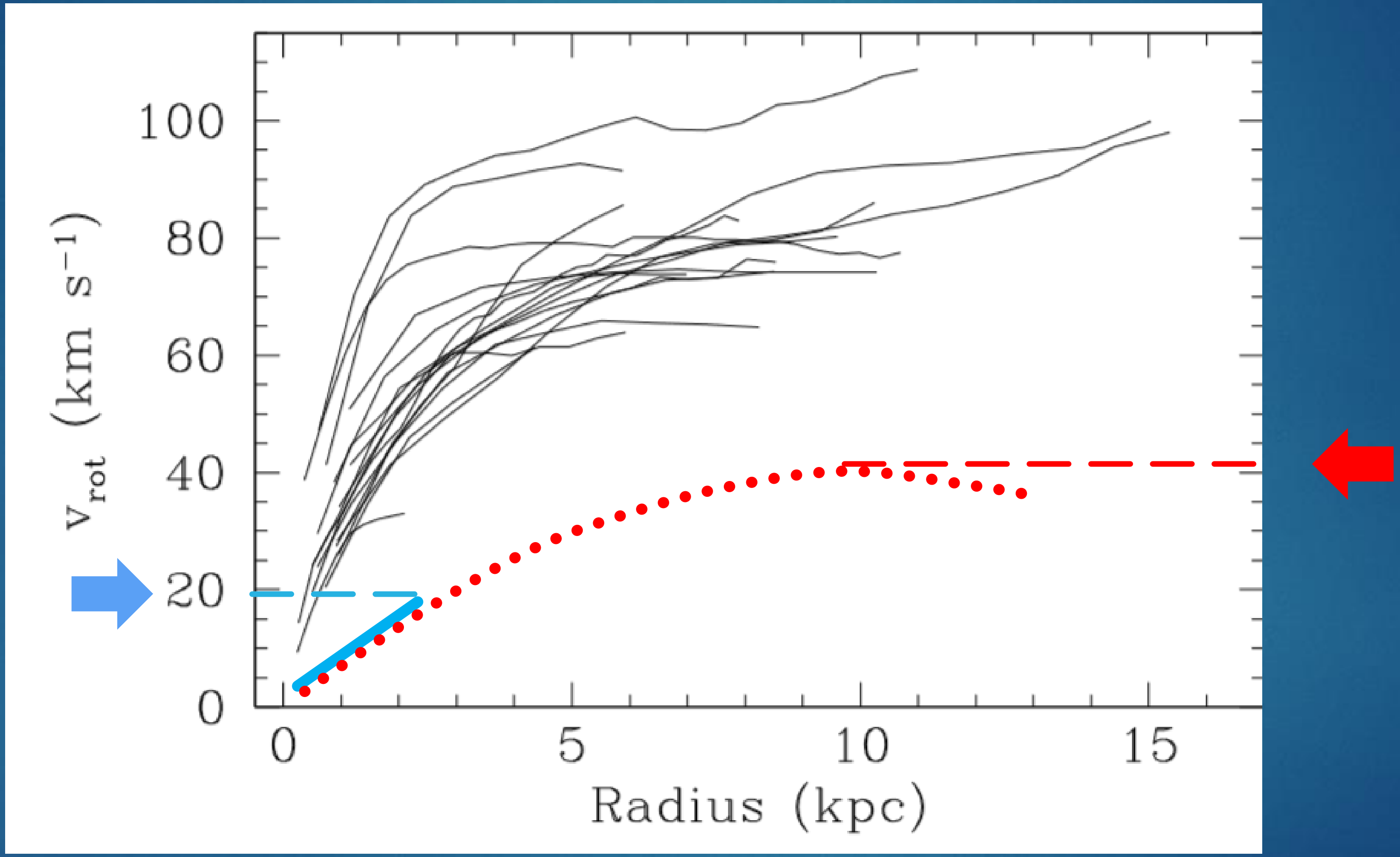
(Swaters+ 2009)

Which velocity?



(Swaters+ 2009)

Which velocity?

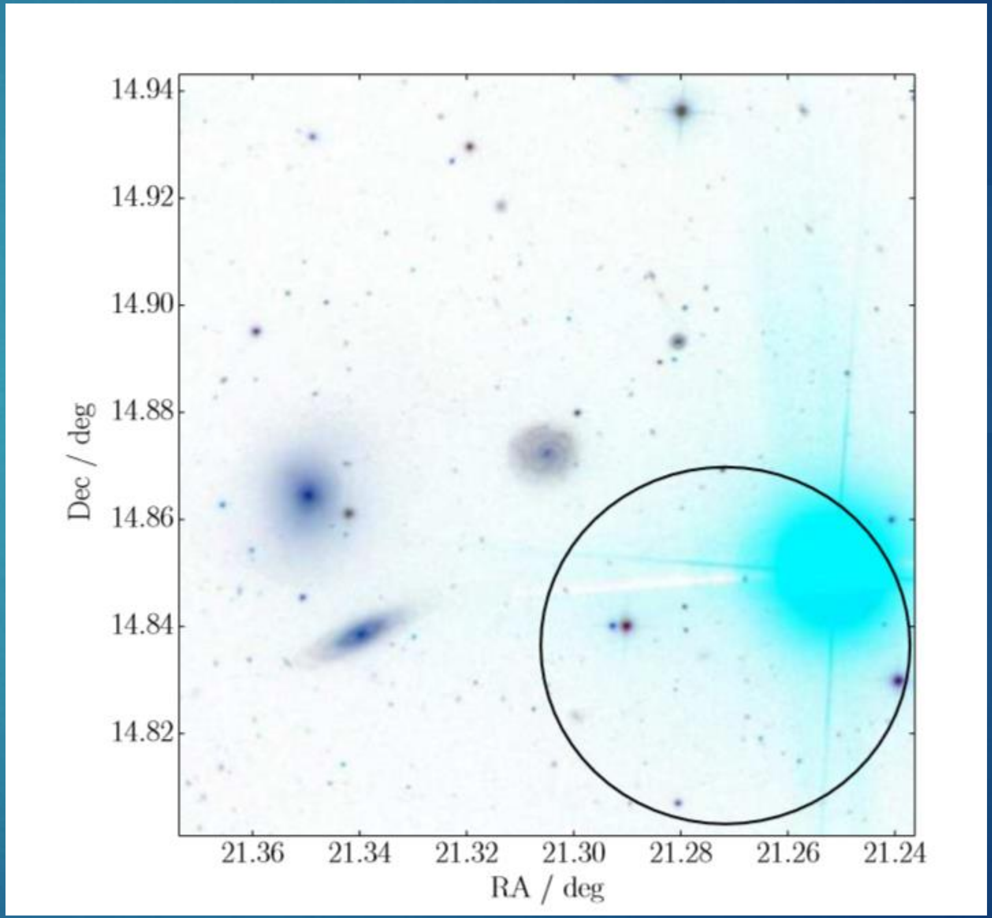


(Swaters+ 2009)

the ALFALFA survey

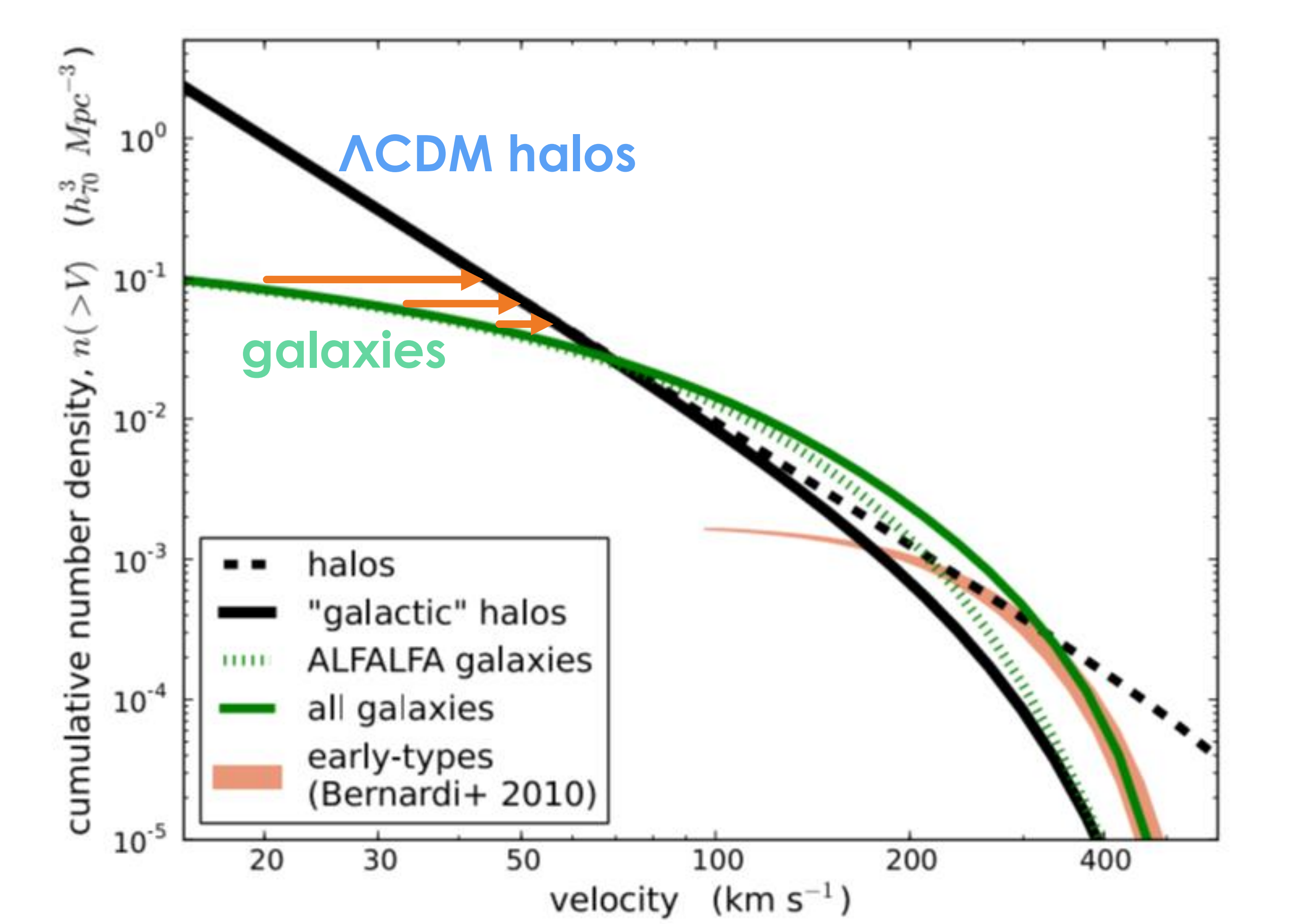
http://egg.astro.cornell.edu/alfalfa/

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



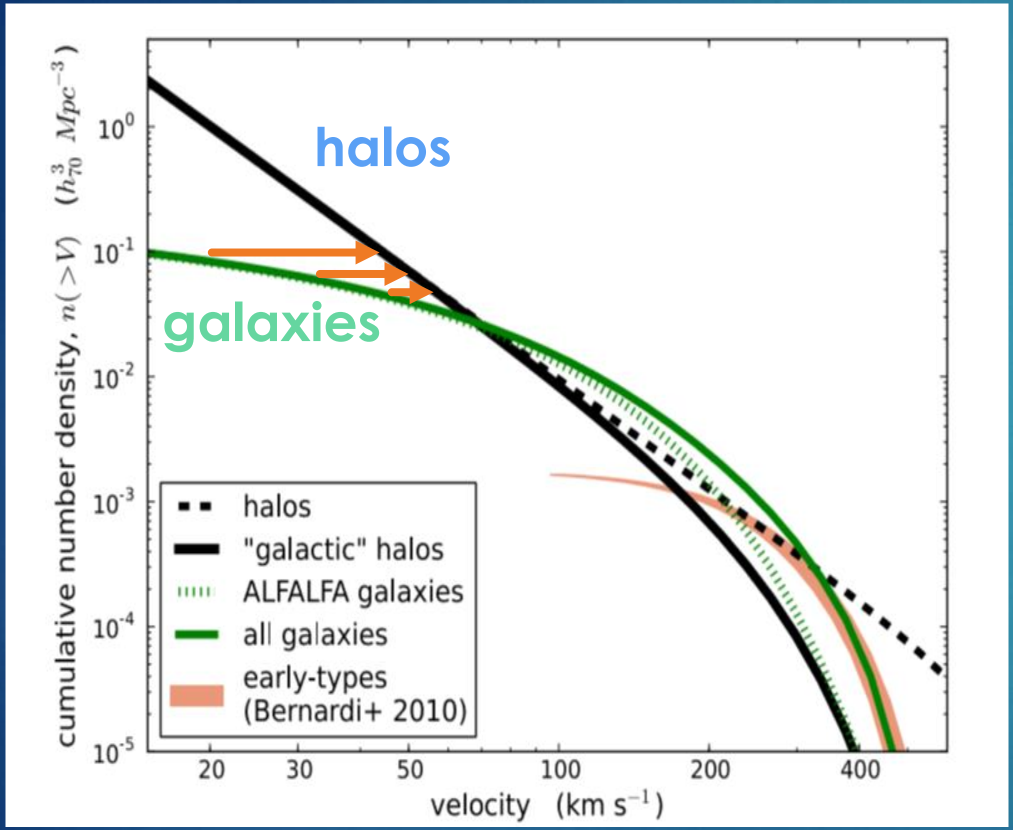
(Image from Jones+ 2015)

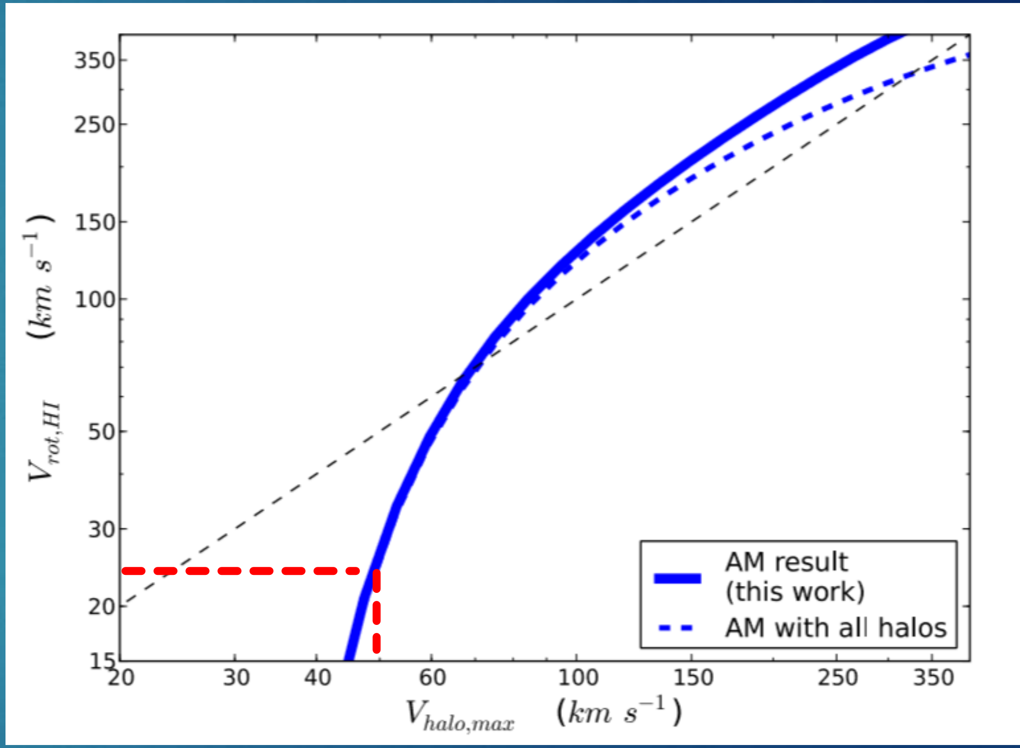
An easy way out?



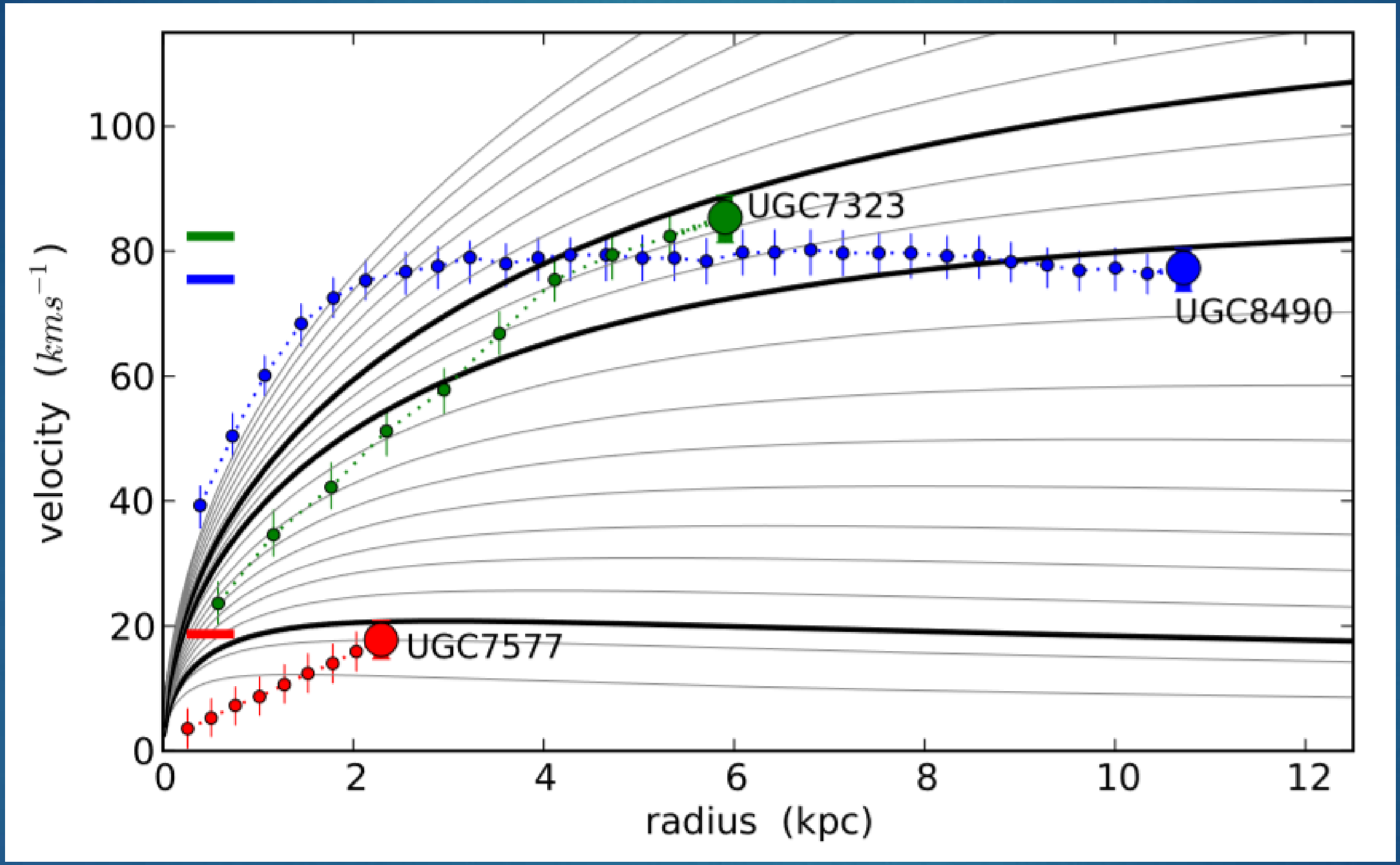
(Papastergis+ 2015)

$V_{rot} - V_h$ relation in ΛCDM

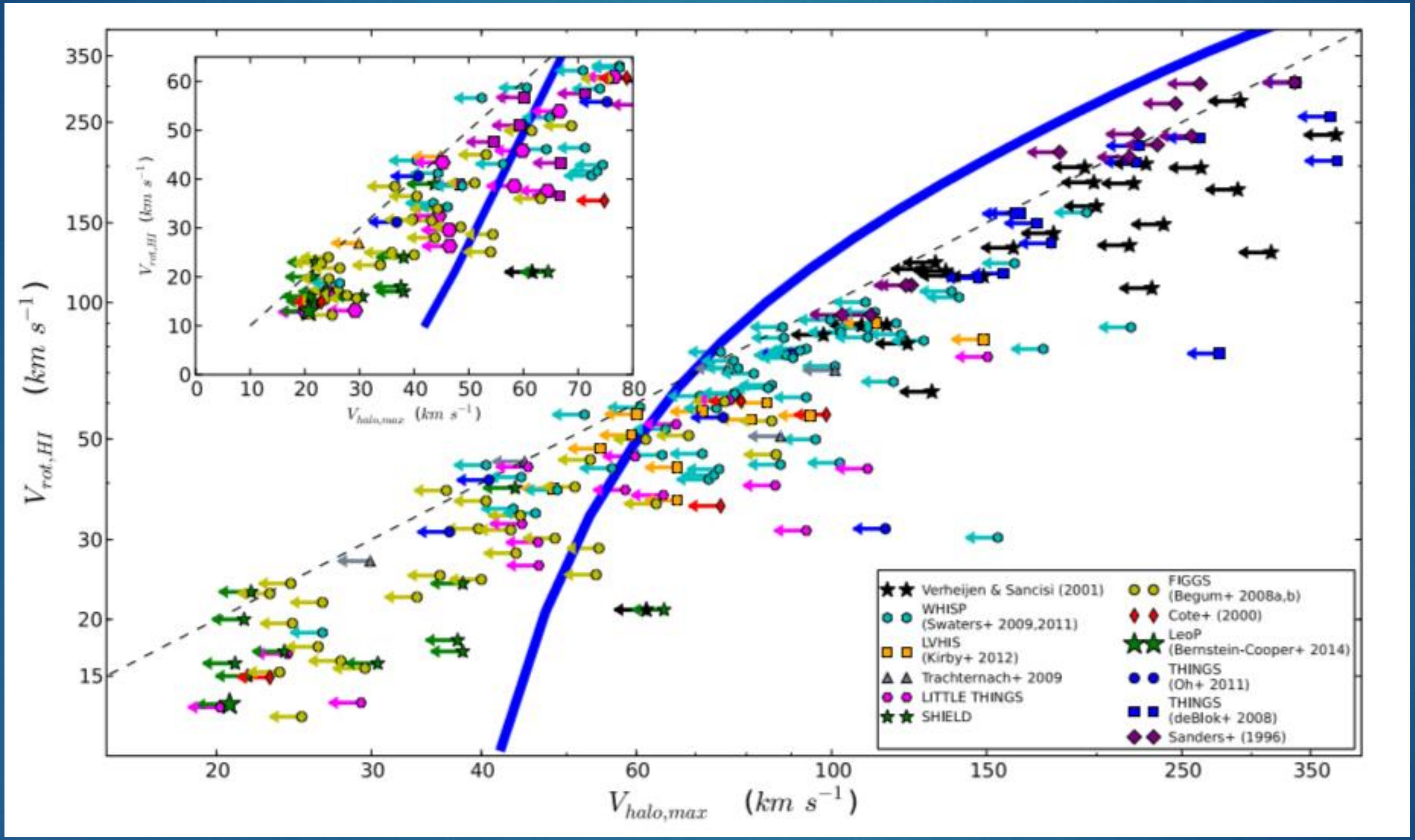




(Papastergis+ 2015)

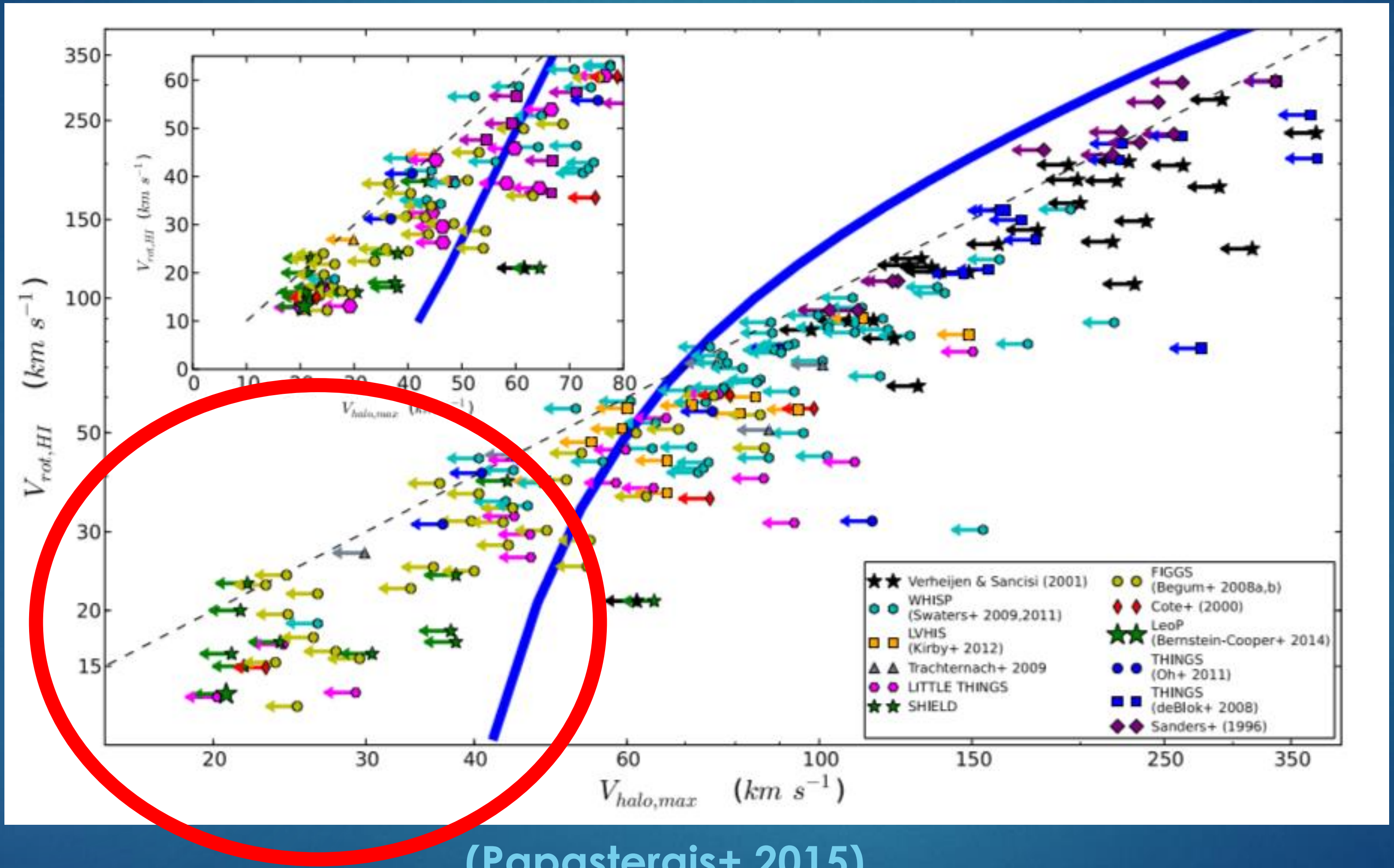


(Papastergis+ 2015)



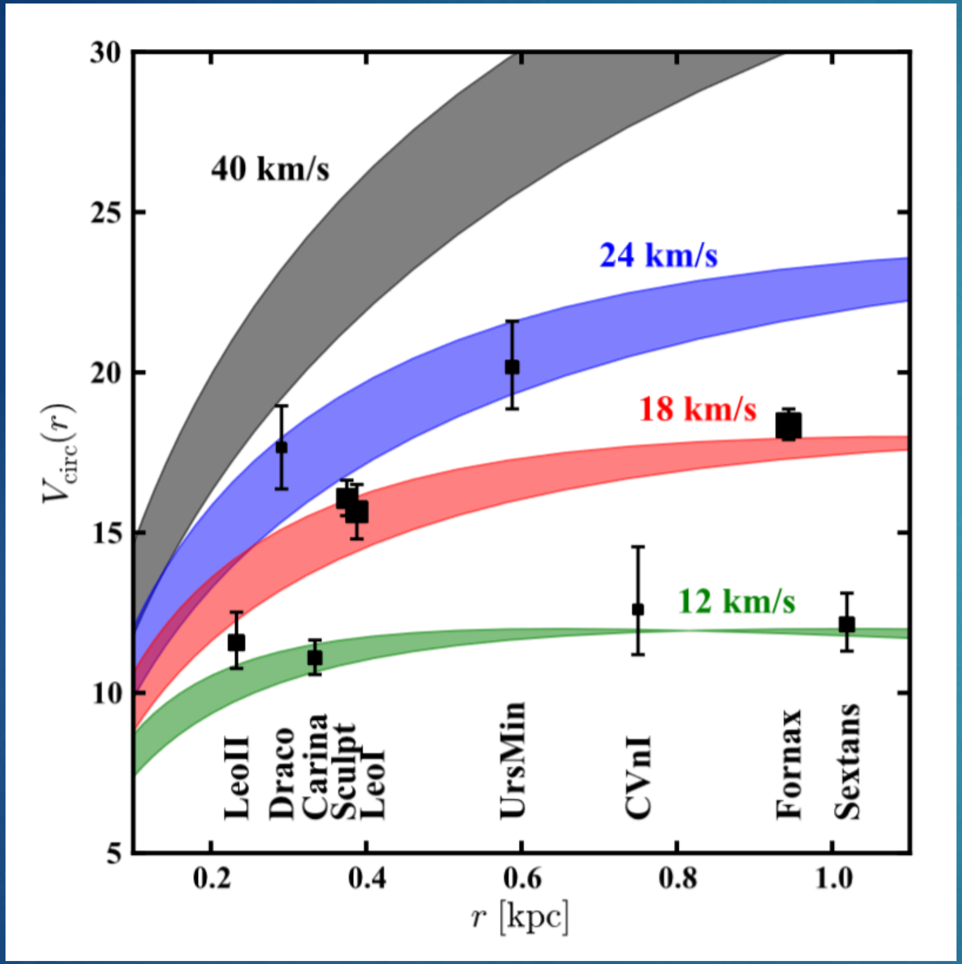
(Papastergis+ 2015)

The *field* "too big to fail" problem



(Papastergis+ 2015)

Not the first to notice…



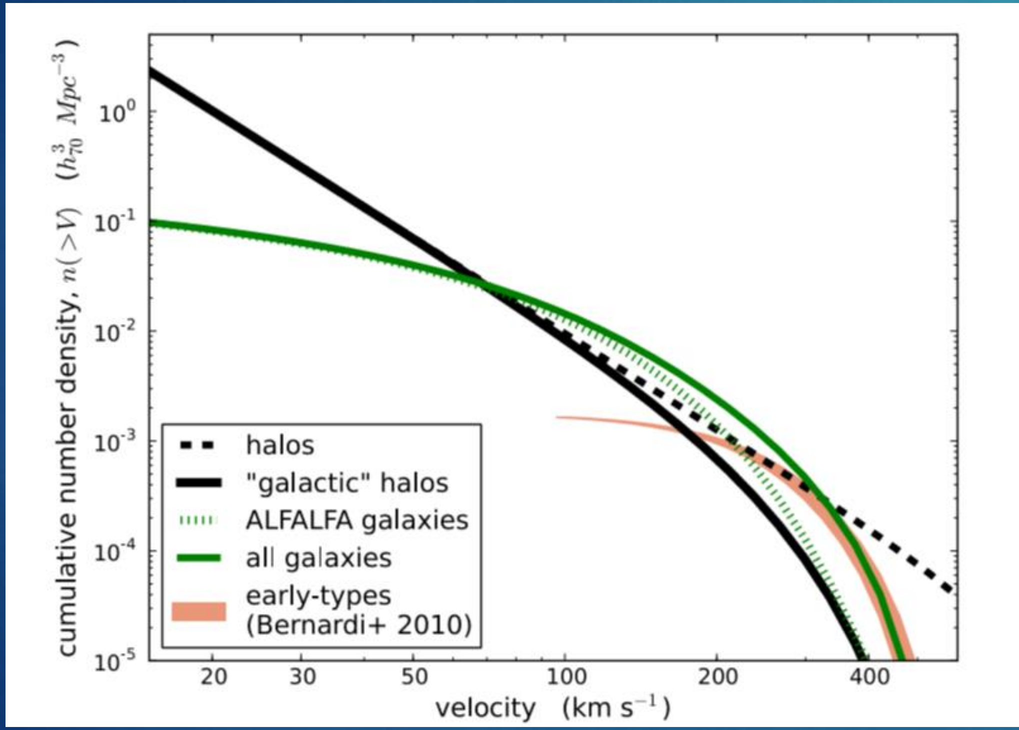
Milky Way satellites
(Boylan-Kolchin+ 2011,2012)

Also for field dwarfs:
Ferrero+ 2012, Garrison-Kimmel+ 2014

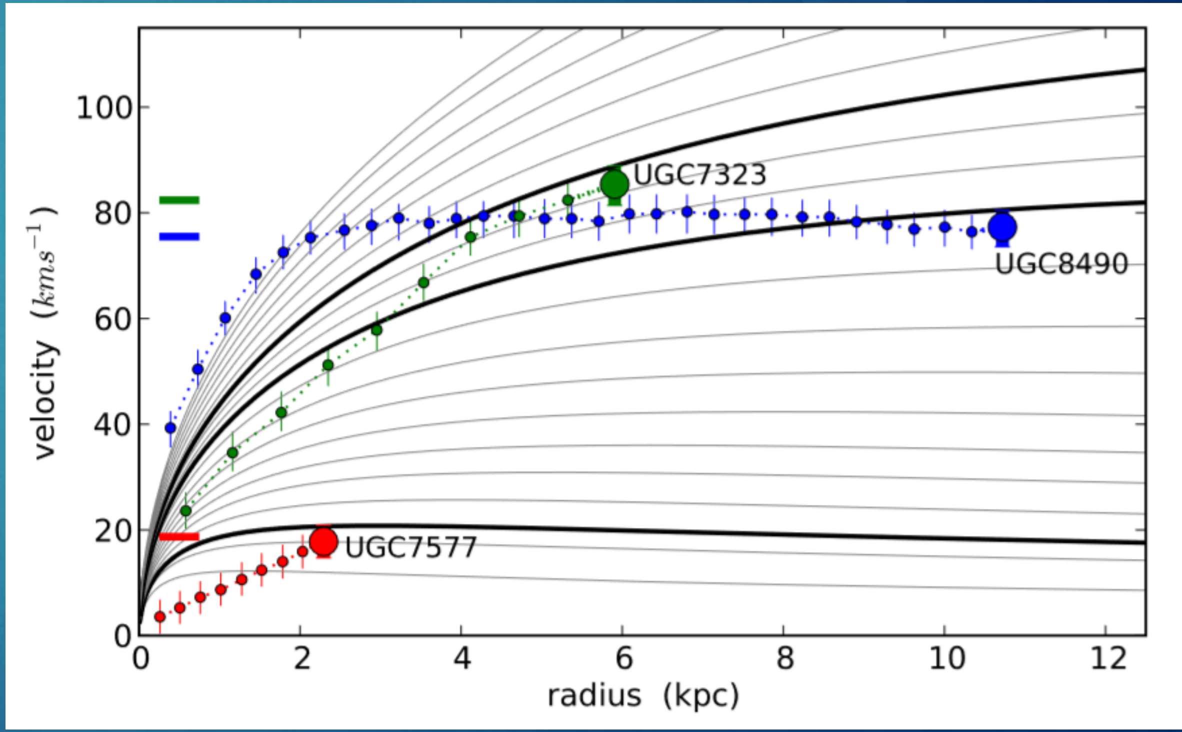
Any solutions?

The root of the problem

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

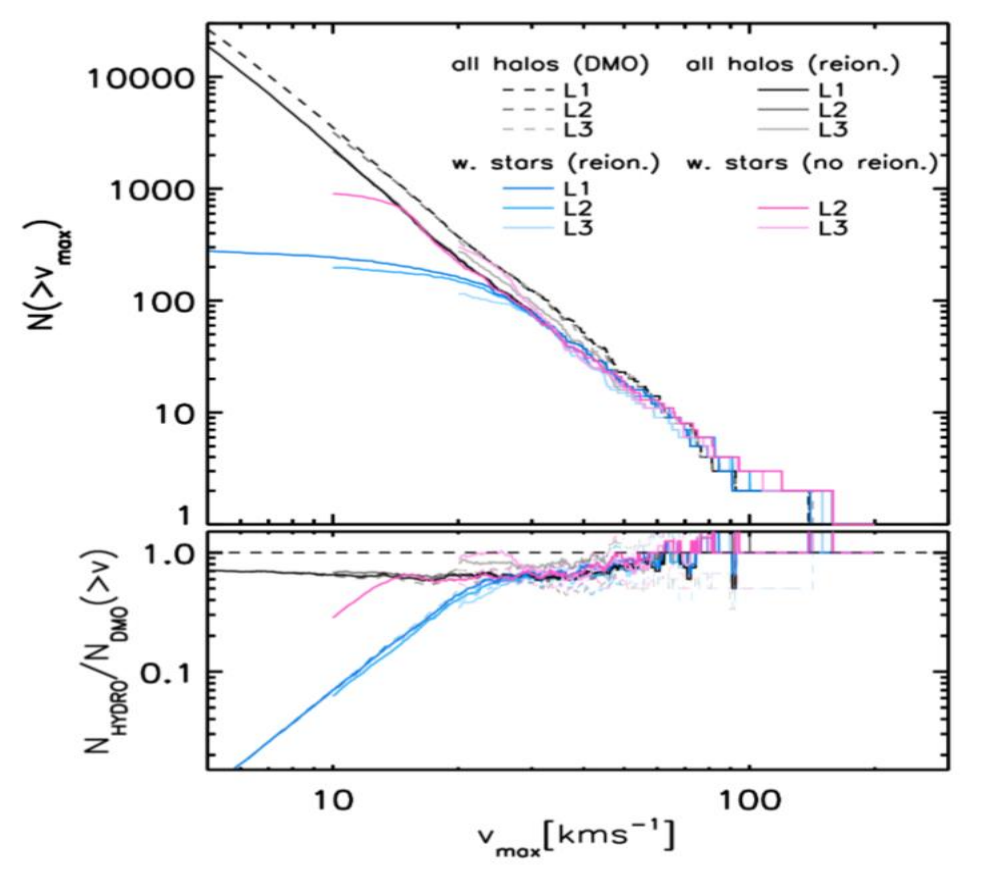


2. Impossible to fit dwarf kinematics with massive halos



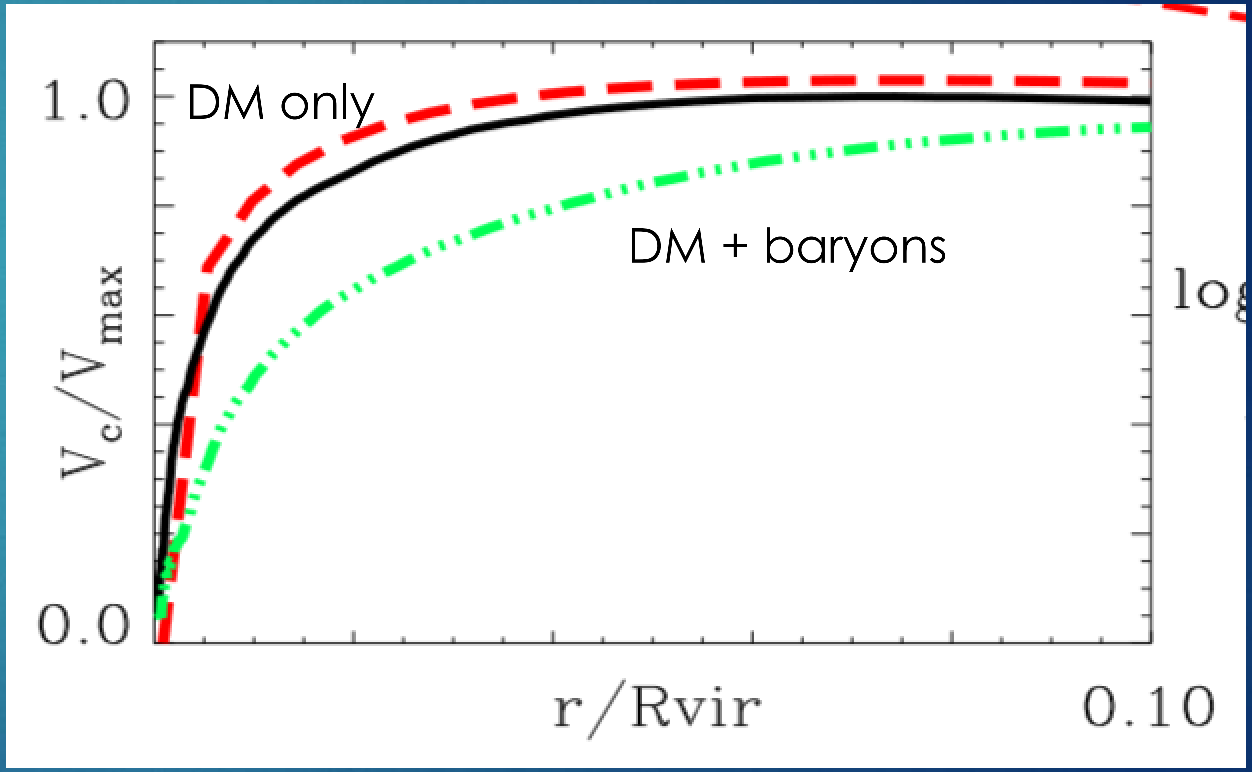
Baryonic solutions in ΛCDM?

1. Reionization feedback



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

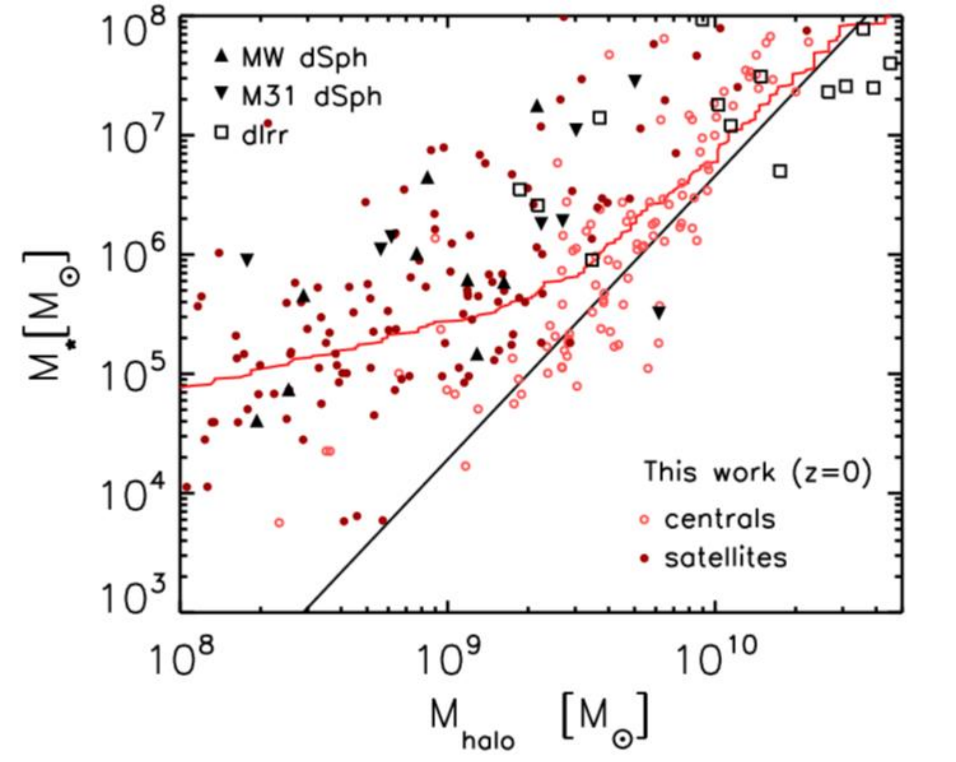
2. Core creation through star-formation feedback

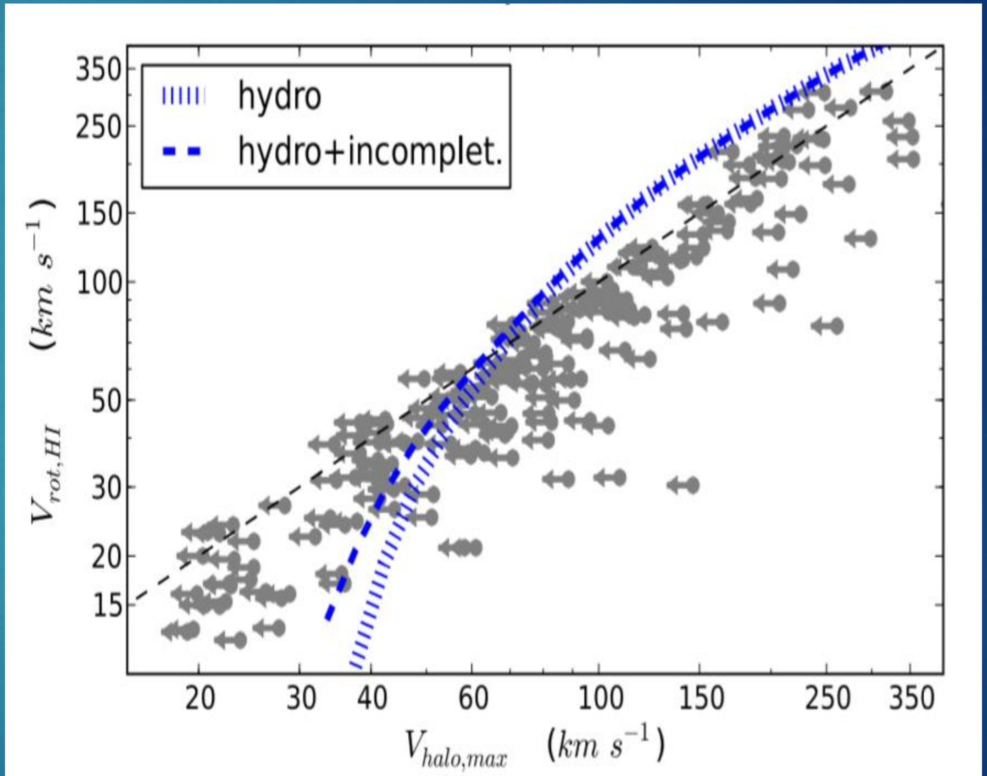


(di Cintio+ 2015; also Governato+ 2010, Brooks+Zolotov 2014, Onorbe+ 2015, etc.)

Do baryonic solutions work?

1. Reionization



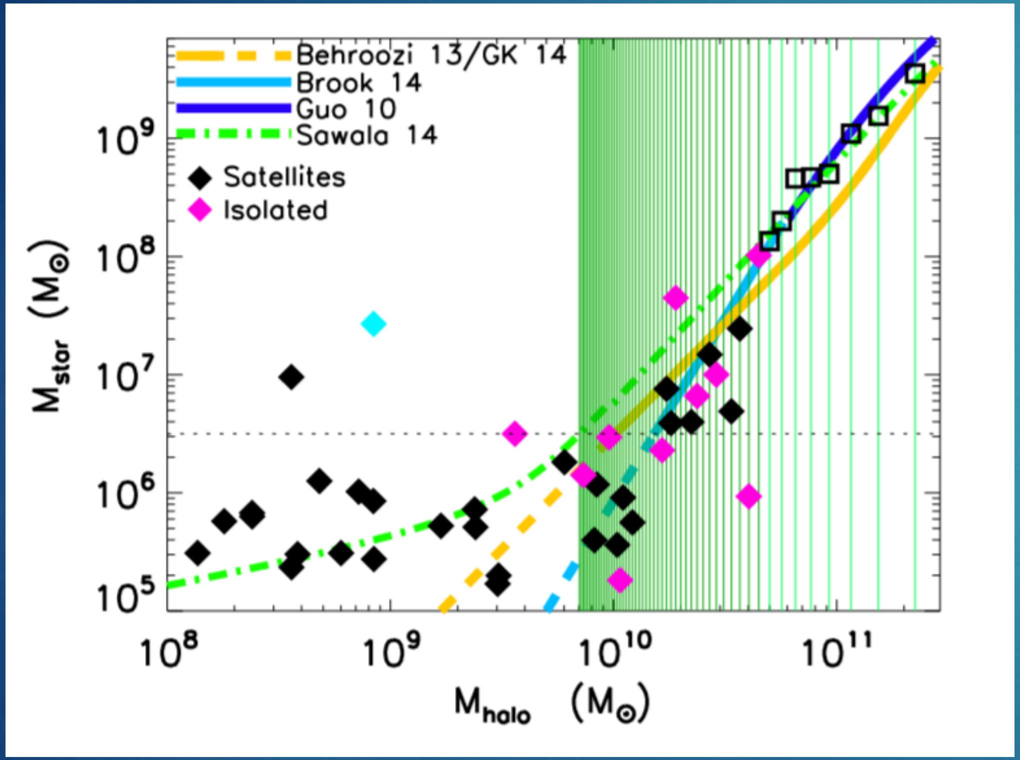


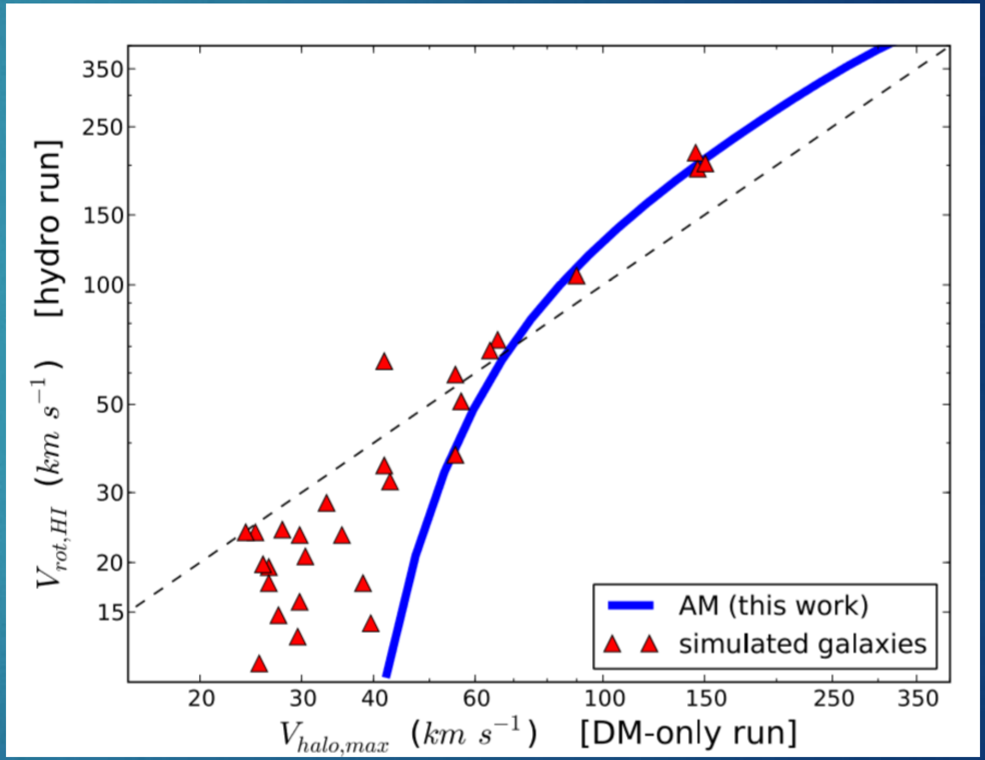
Sawala+ 2015: yes

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)

Conclusions

- **"Too big to fail" problem**: it is challenging to reproduce simultaneously the **number density** and **internal kinematics** of dwarf galaxies in ΛCDM

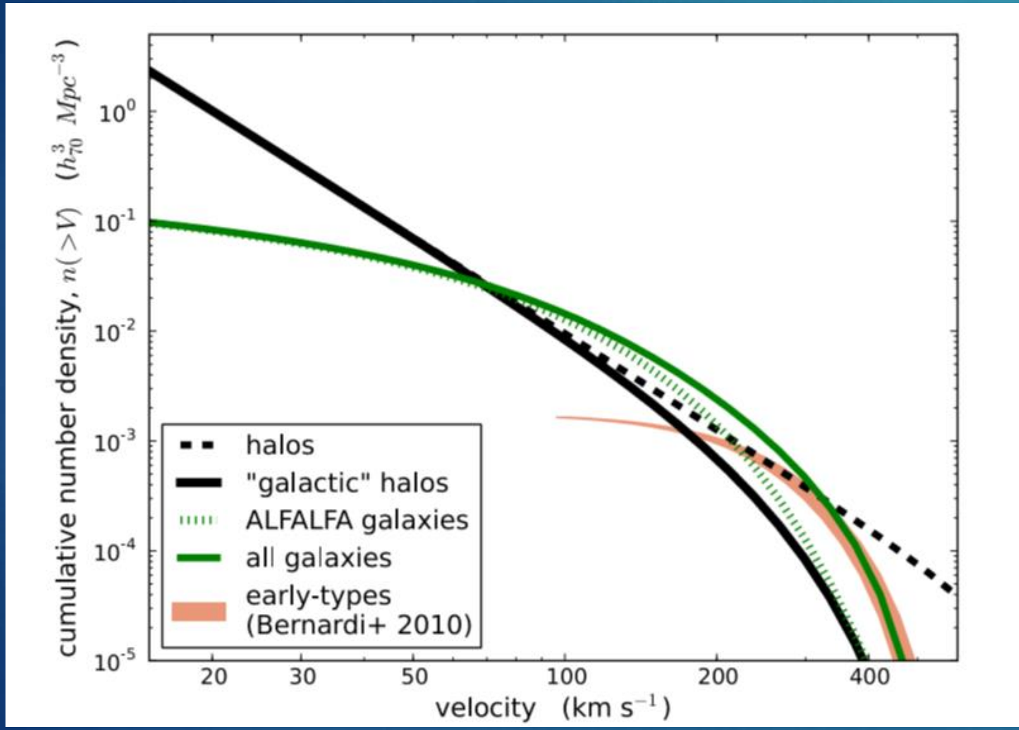
- A solution must have the following characteristics:
  - **Lower the number** of low mass halos
  - **Lower the velocity** in the central parts of small halos

- **Within ΛCDM**, there exist potential **baryonic solutions**. However, it is **not yet clear** whether they work or not

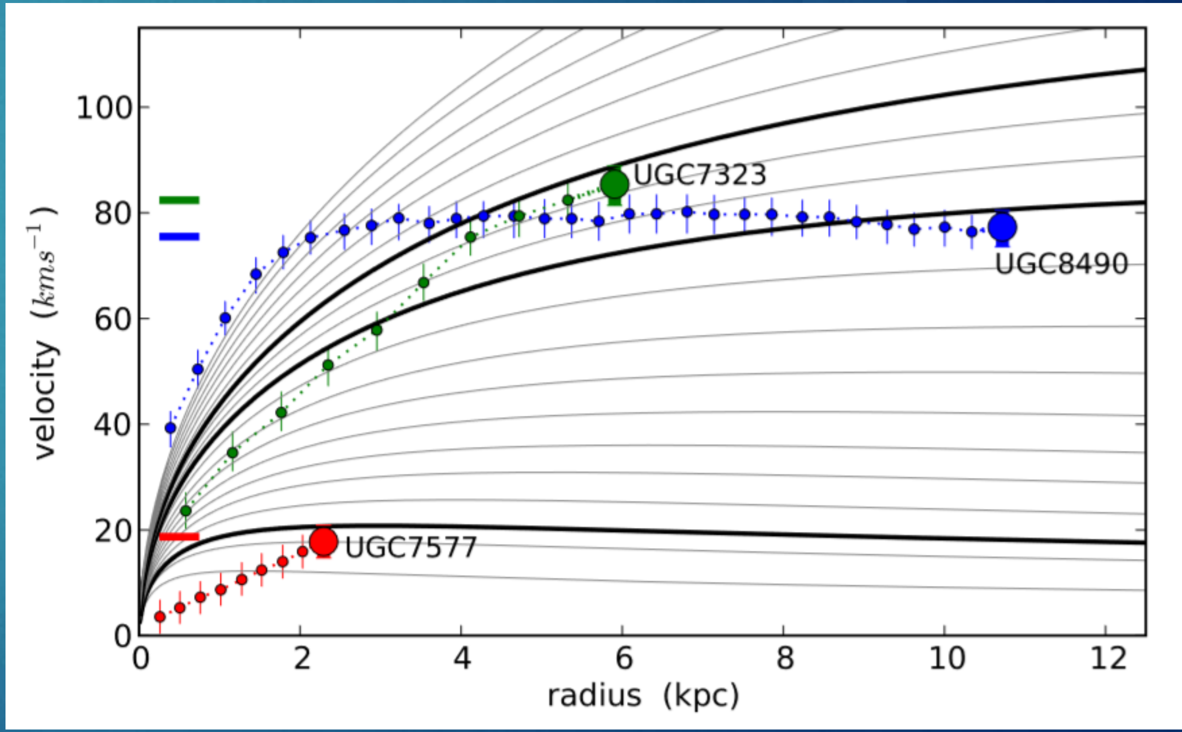
Ευχαριστώ για την προσοχή σας!

The root of the problem

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



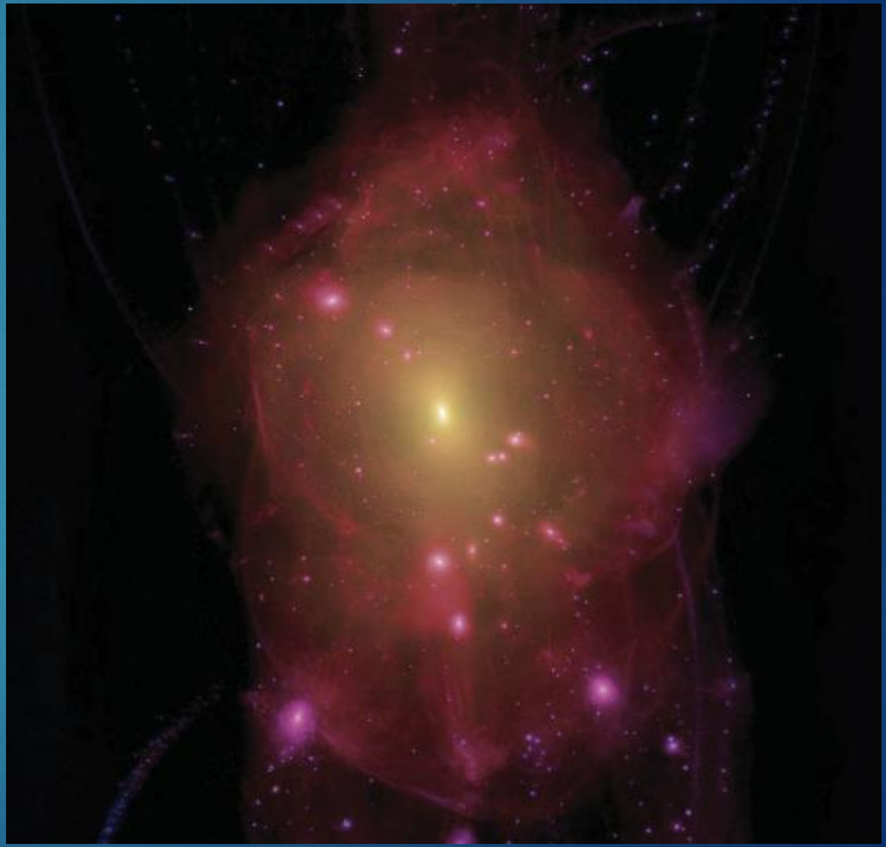
2. Impossible to fit dwarf kinematics with massive halos



CDM

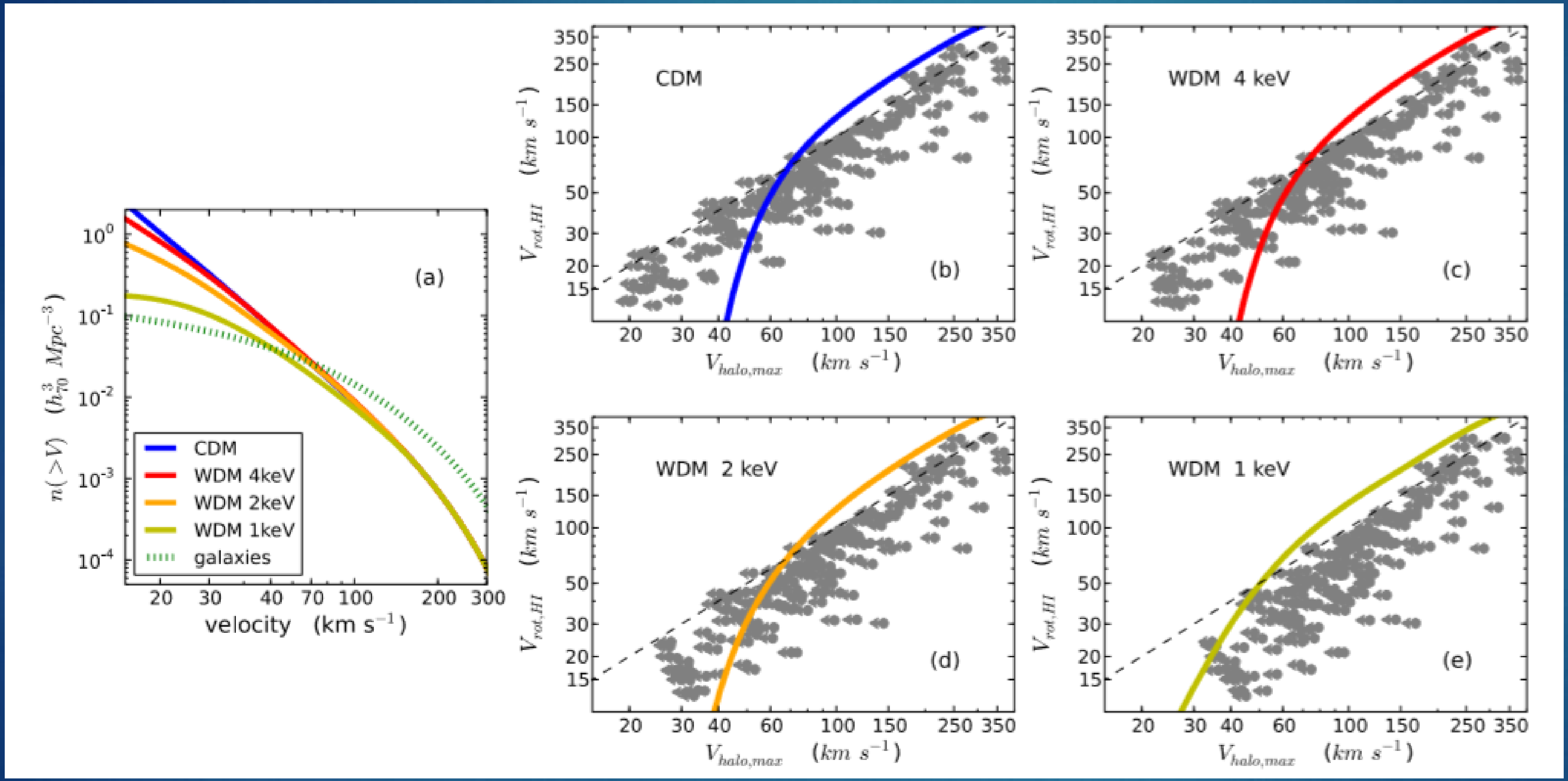
(Lovell+ 2012)

WDM



(Lovell+ 2012)

Warm dark matter?

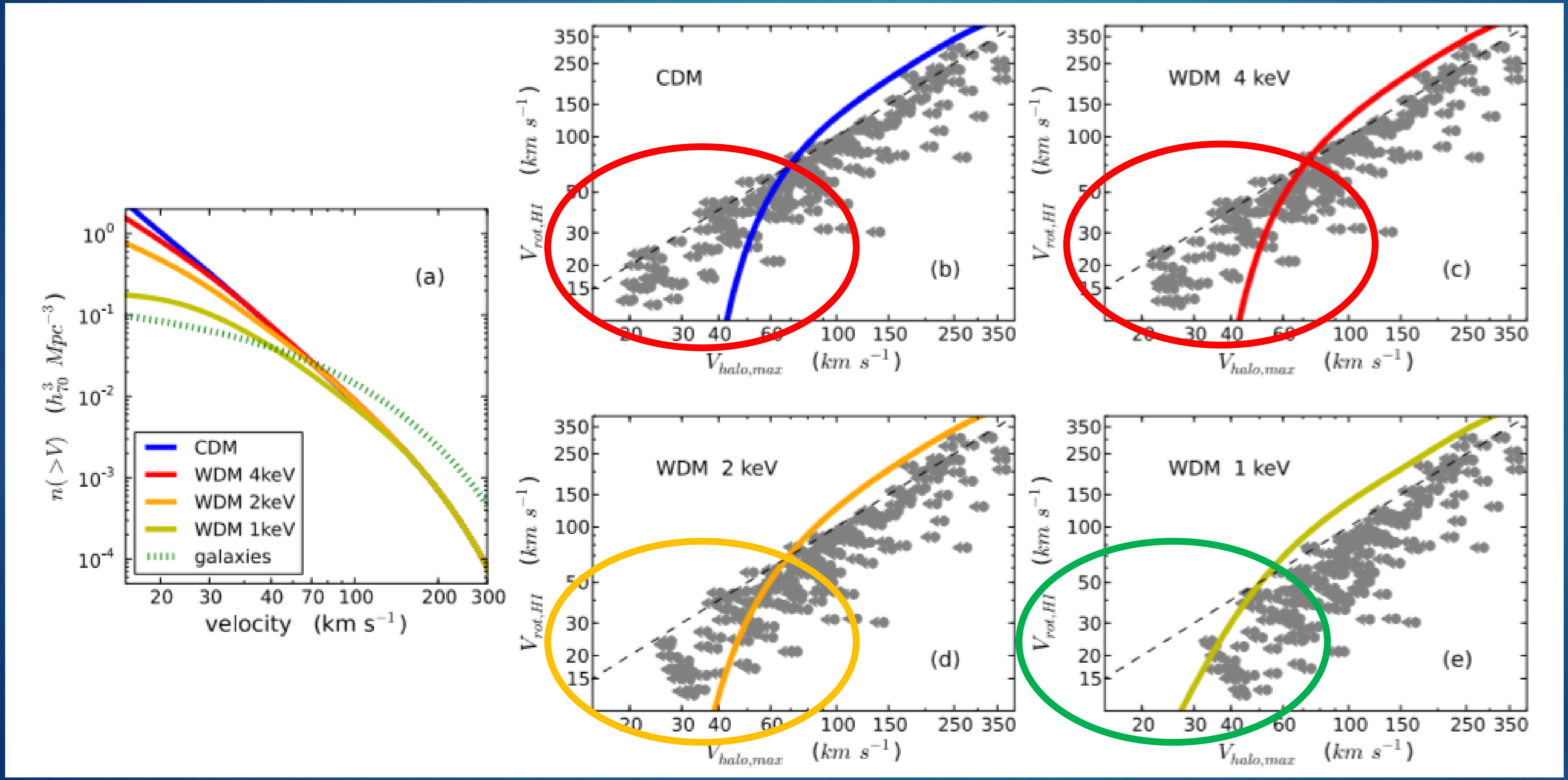


WDM advantages:

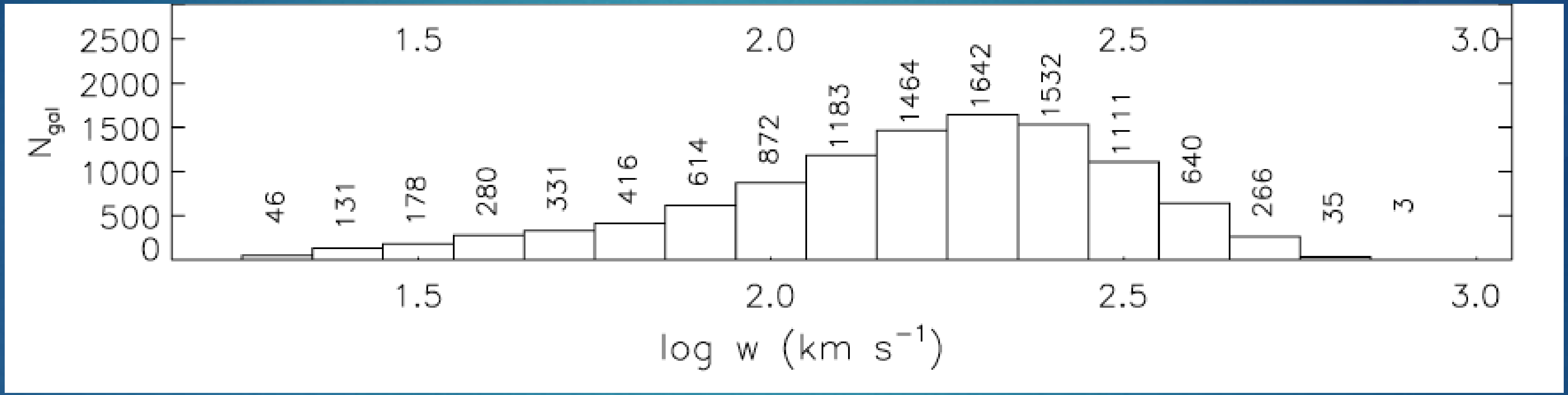
1. Fewer low-mass halos
2. Less concentrated halos

Warm dark matter?

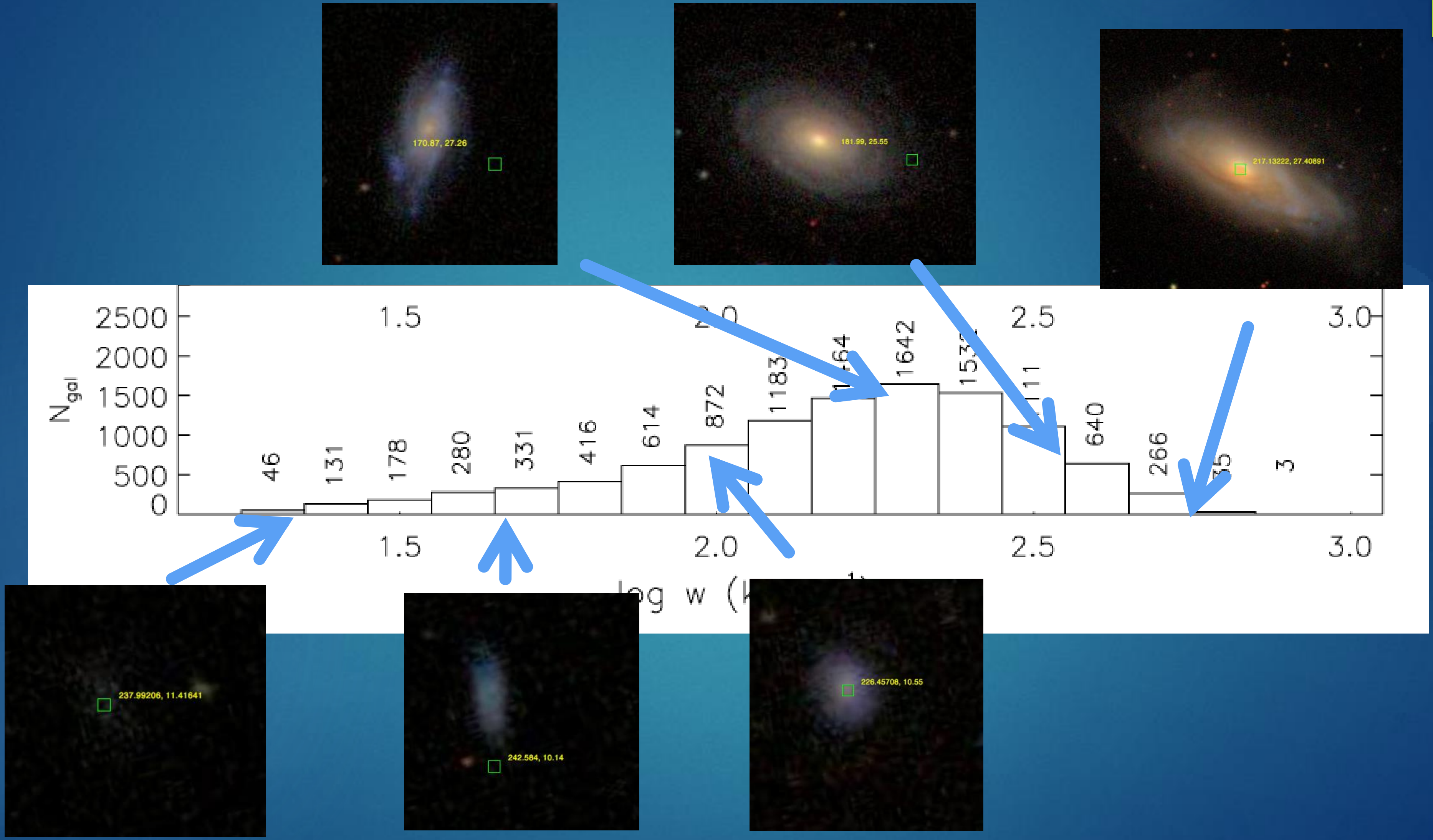
**** The WDM particle mass must be ≲ 2 keV ****



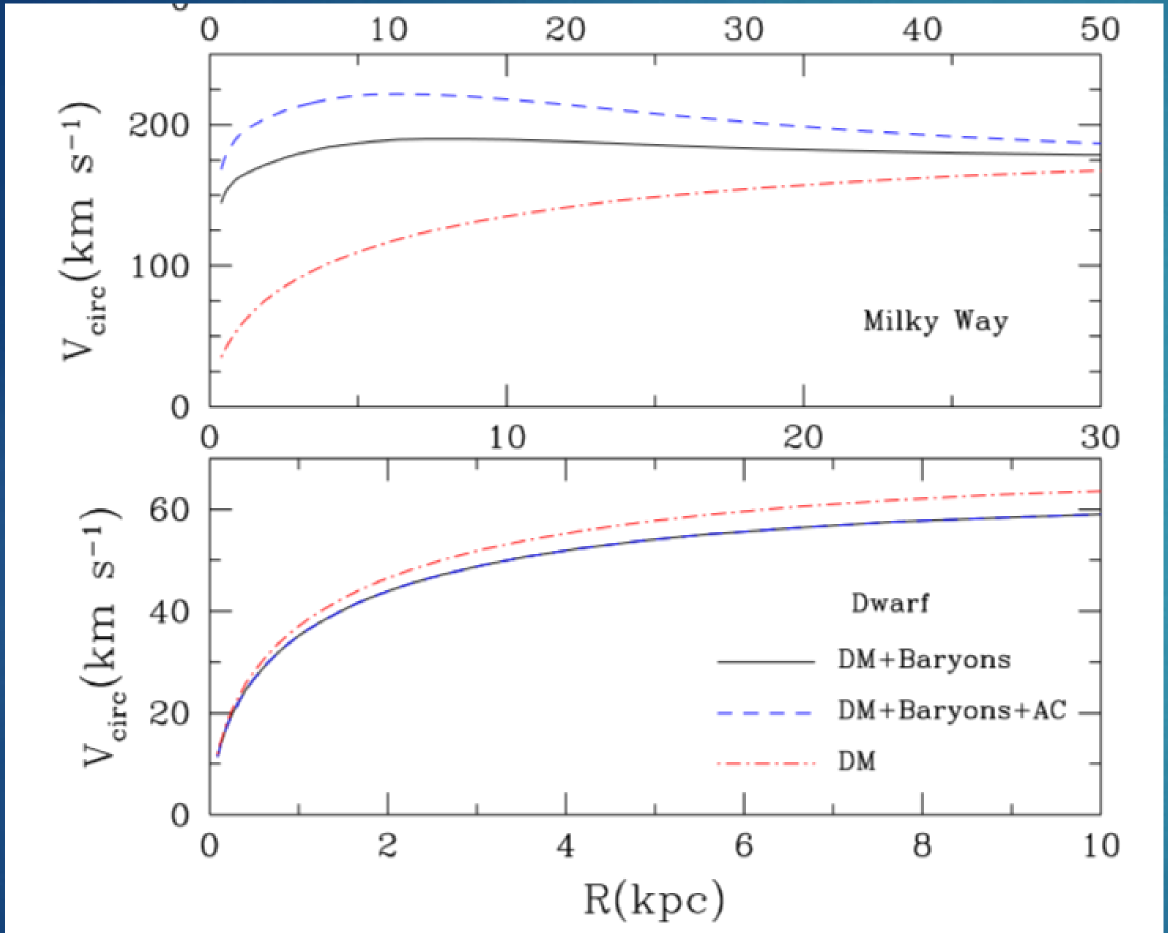
The velocity widths of ALFALFA galaxies



The velocity widths of ALFALFA galaxies



Galaxies vs. ΛCDM halos

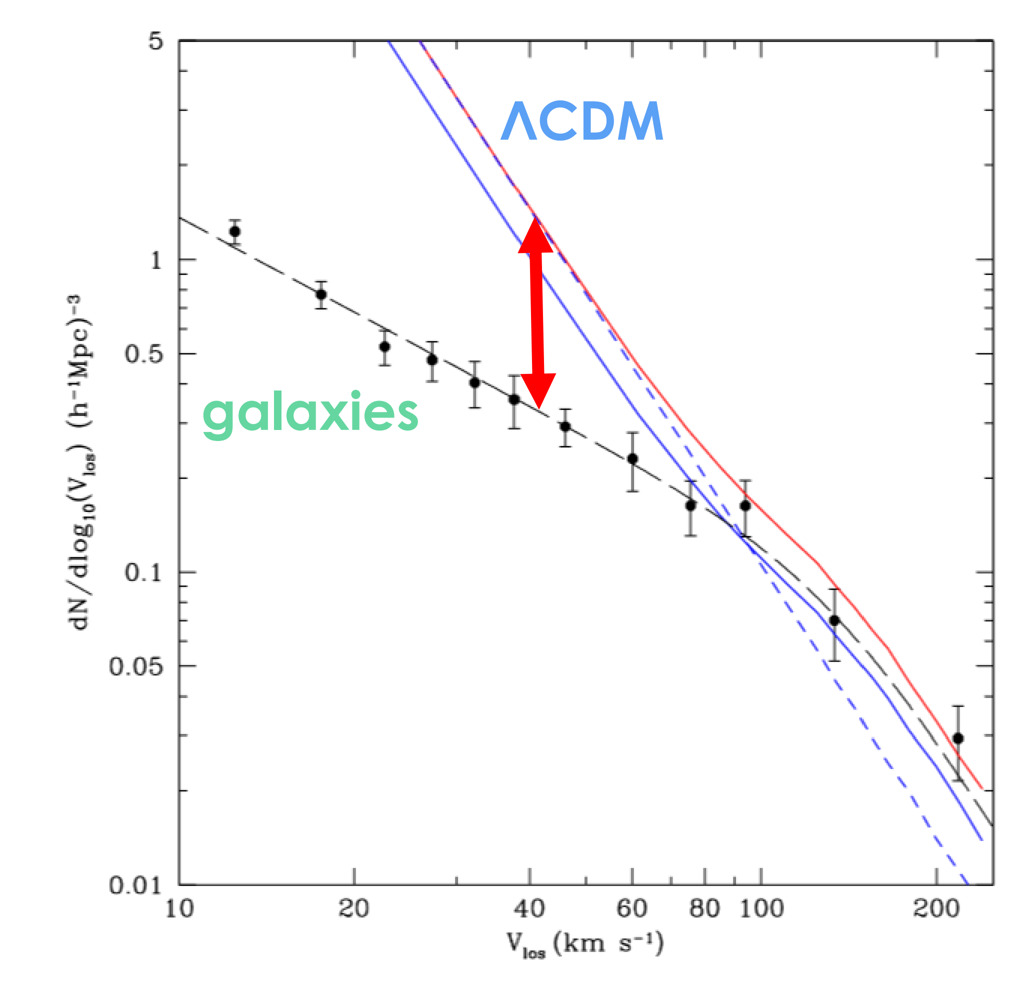


(Trujillo-Gomez+ 2011)

Building a realistic rotation curve:

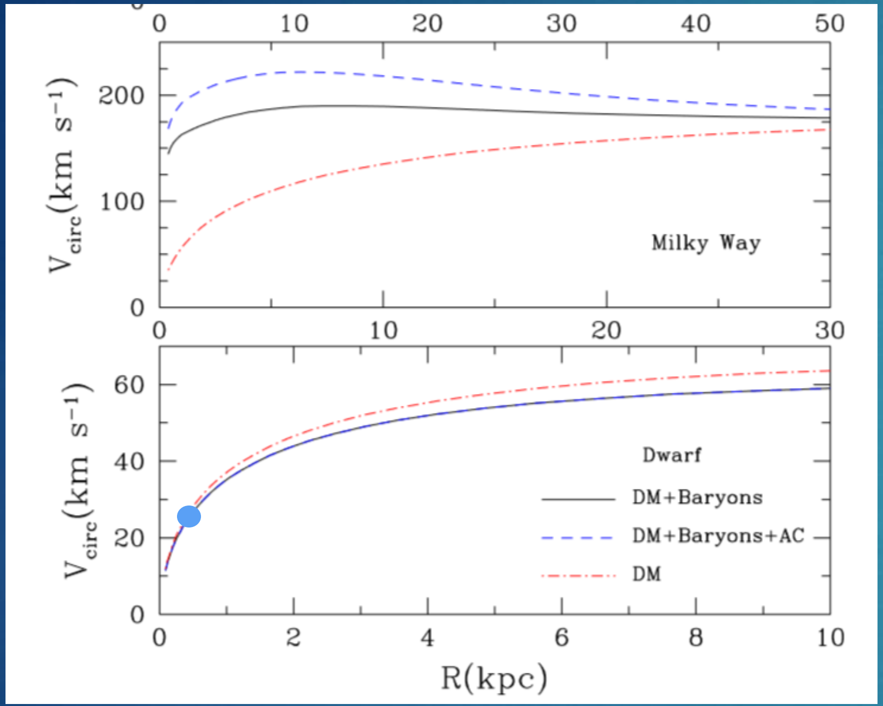
- $\Omega_{DM} \neq \Omega_m$
- Baryons (stars, gas) contribute to RC
- Adiabatic contraction of halo (?)

Observations vs. theory

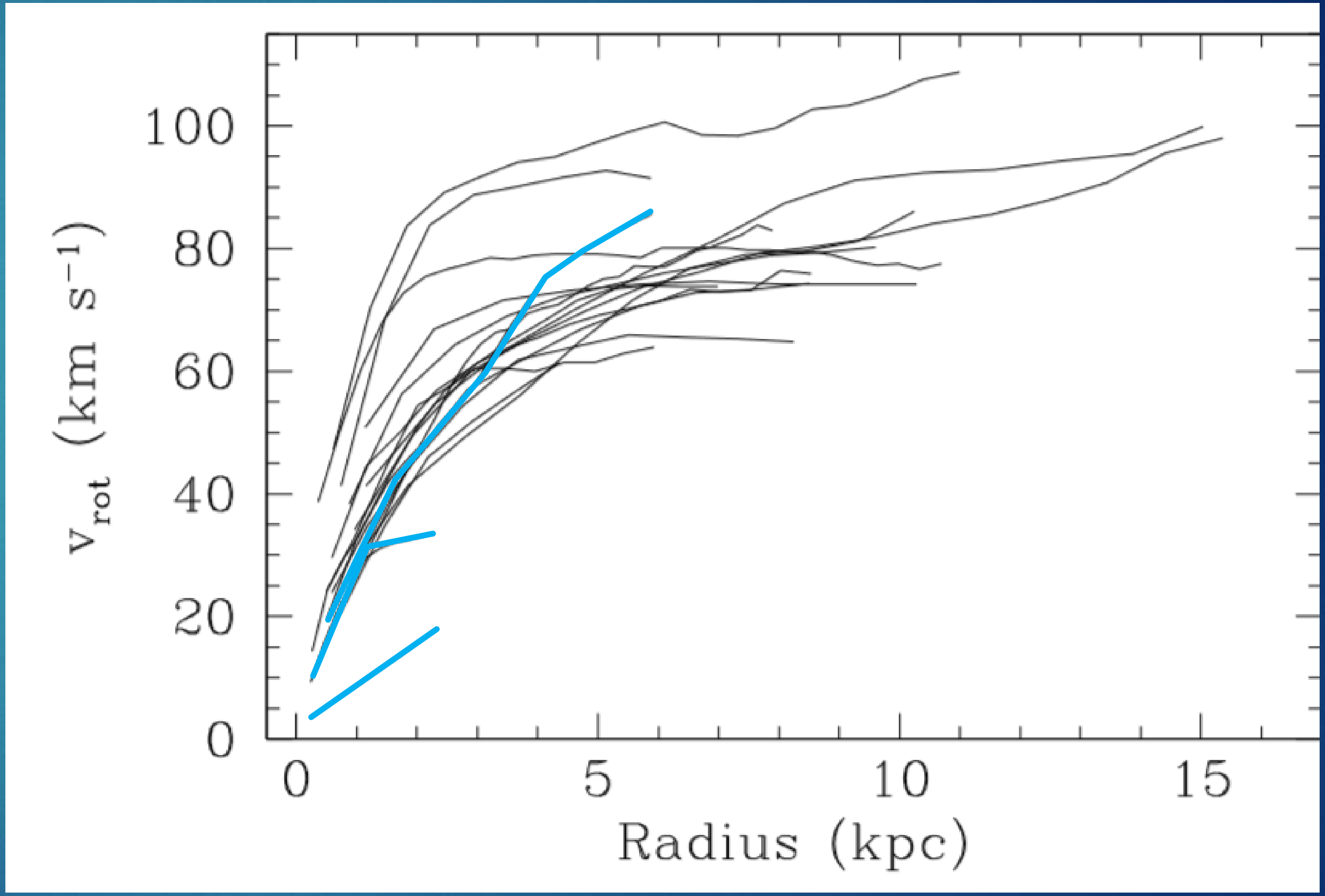


(Klypin+ 2015)

Which velocity?

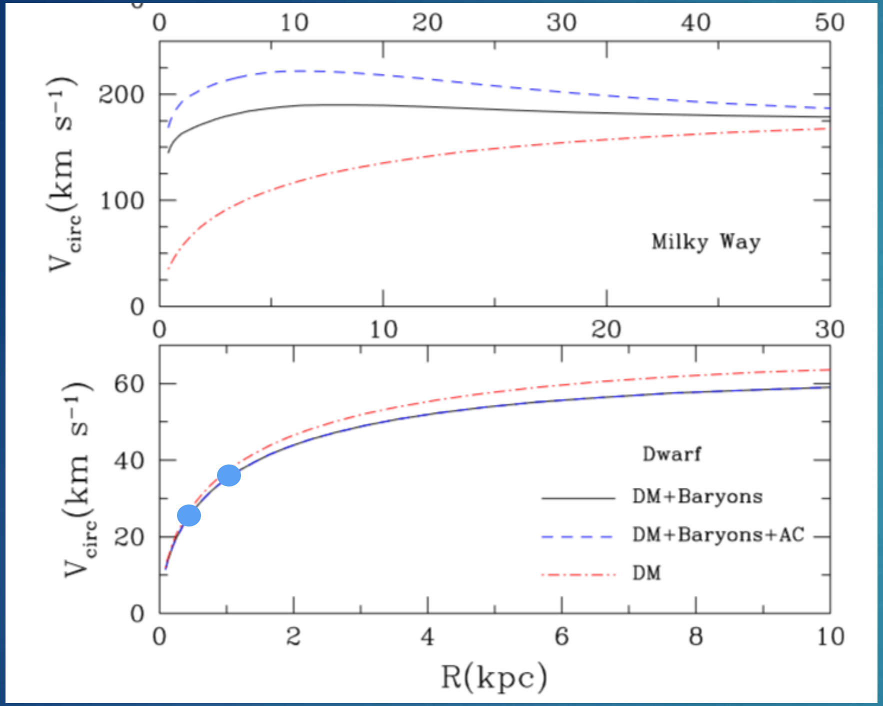


(Trujillo-Gomez+ 2011)

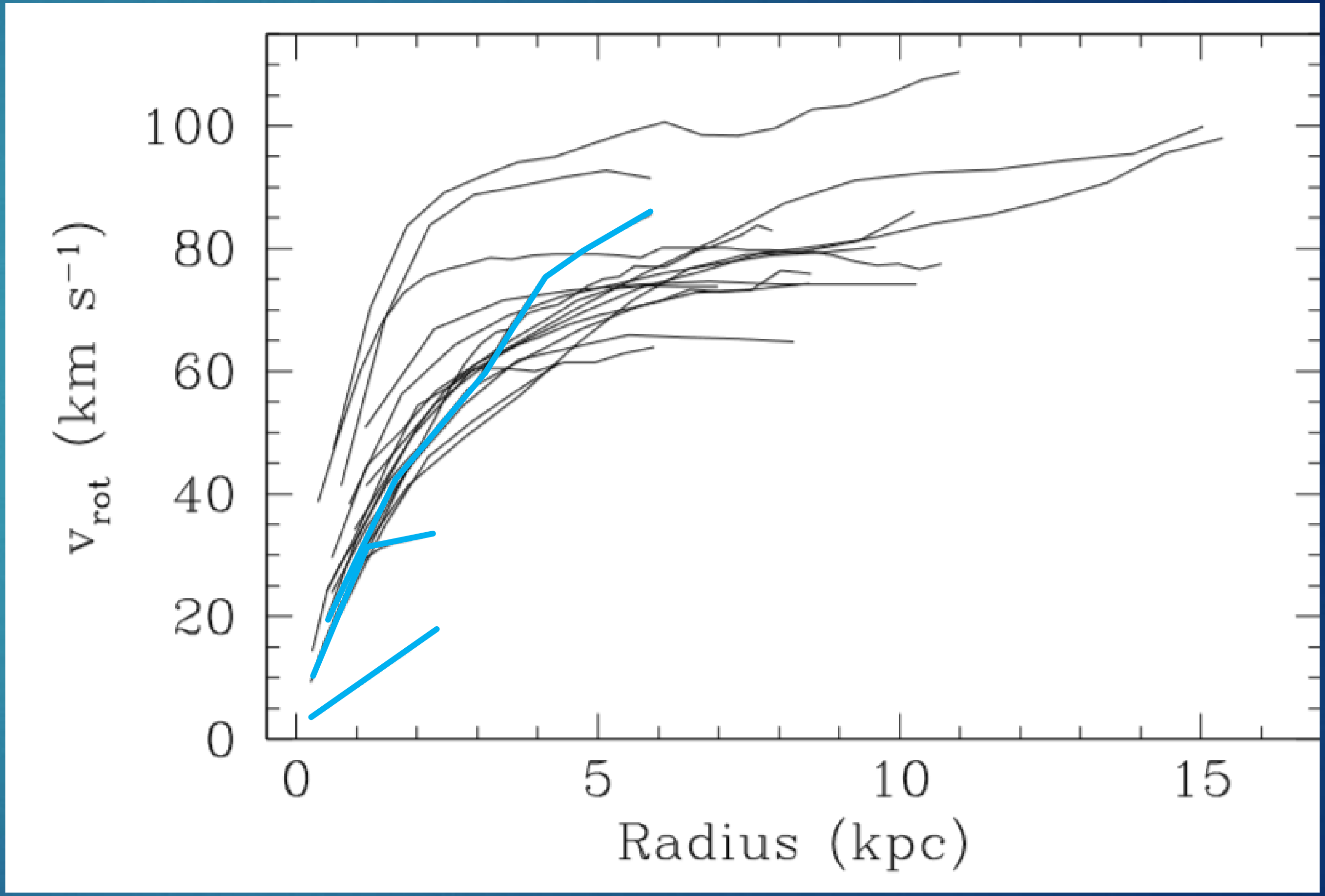


(Swaters+ 2009)

Which velocity?

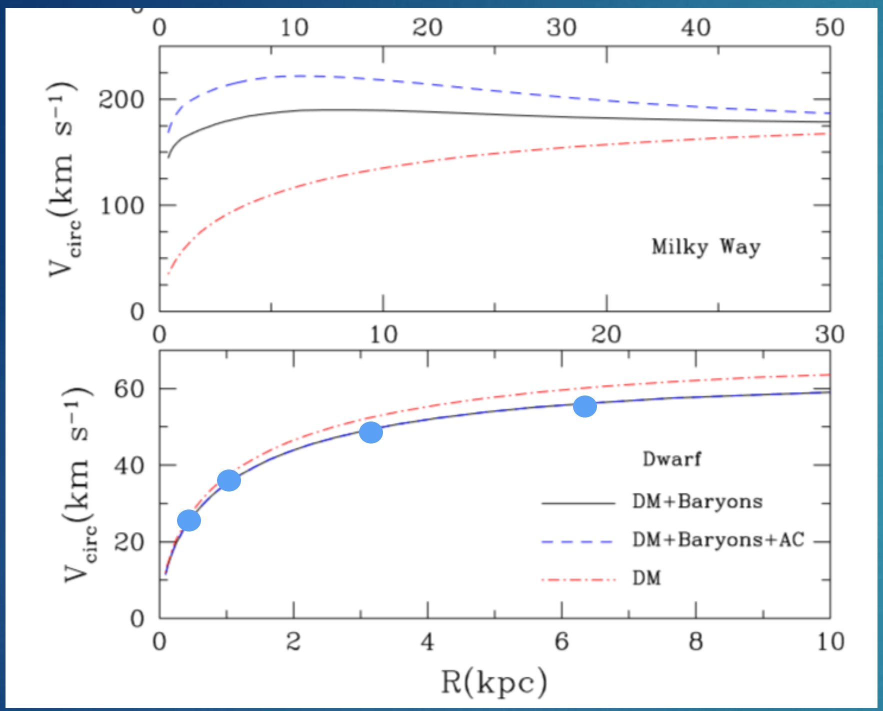


(Trujillo-Gomez+ 2011)

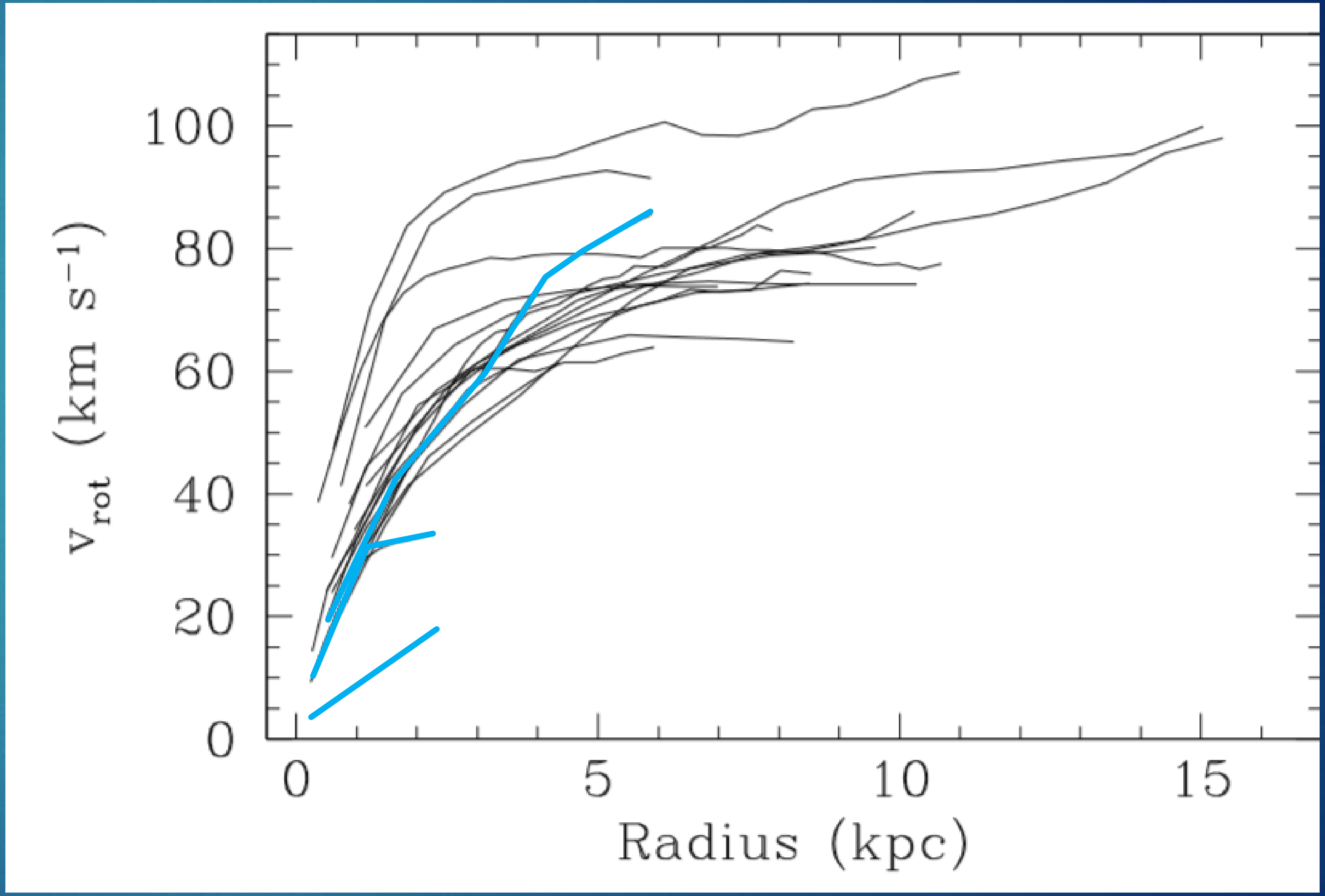


(Swaters+ 2009)

Which velocity?

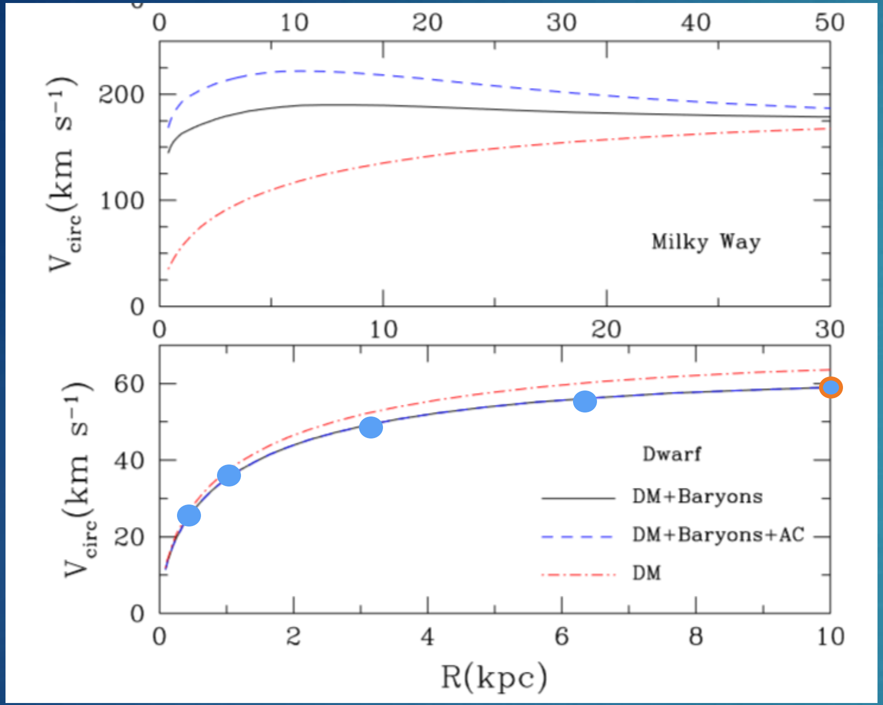


(Trujillo-Gomez+ 2011)

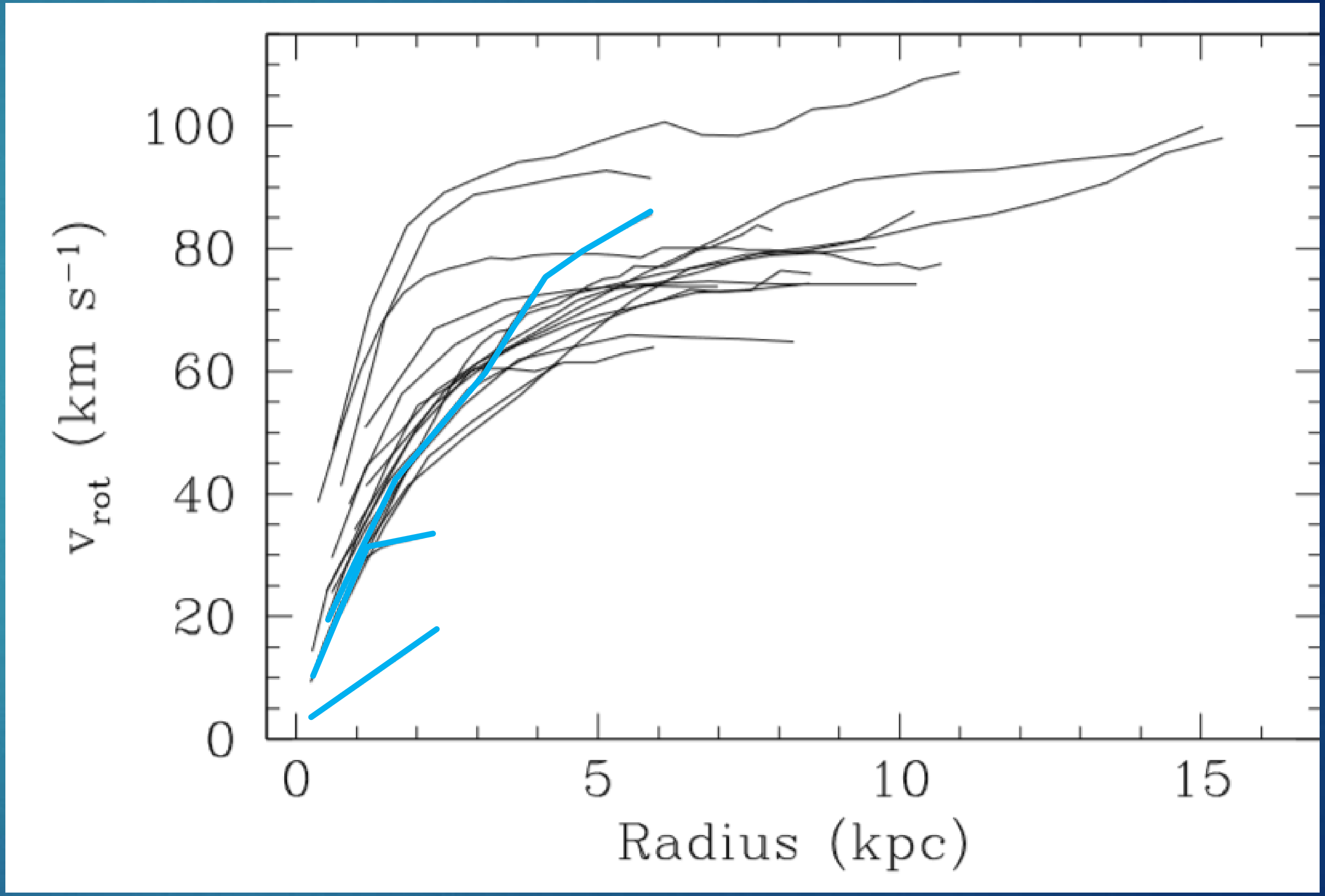


(Swaters+ 2009)

Which velocity?

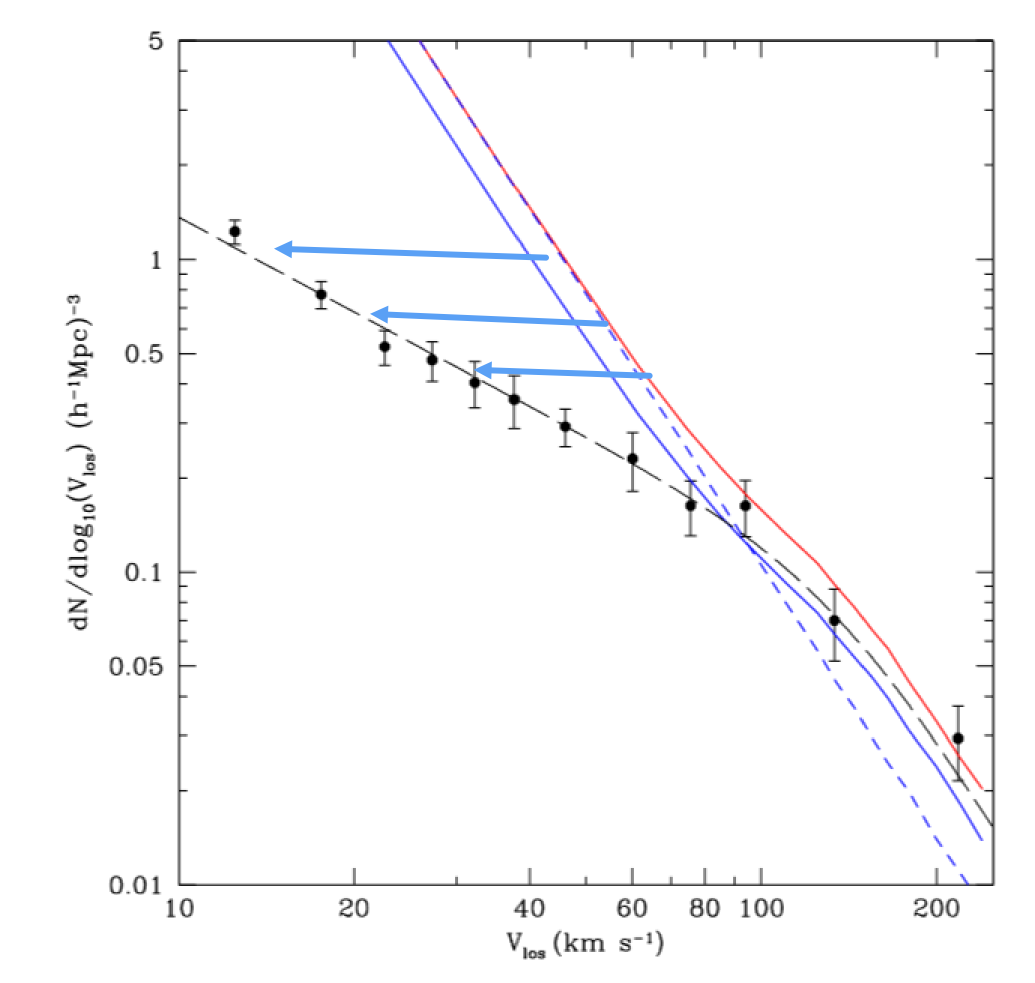


(Trujillo-Gomez+ 2011)



(Swaters+ 2009)

An easy way out?



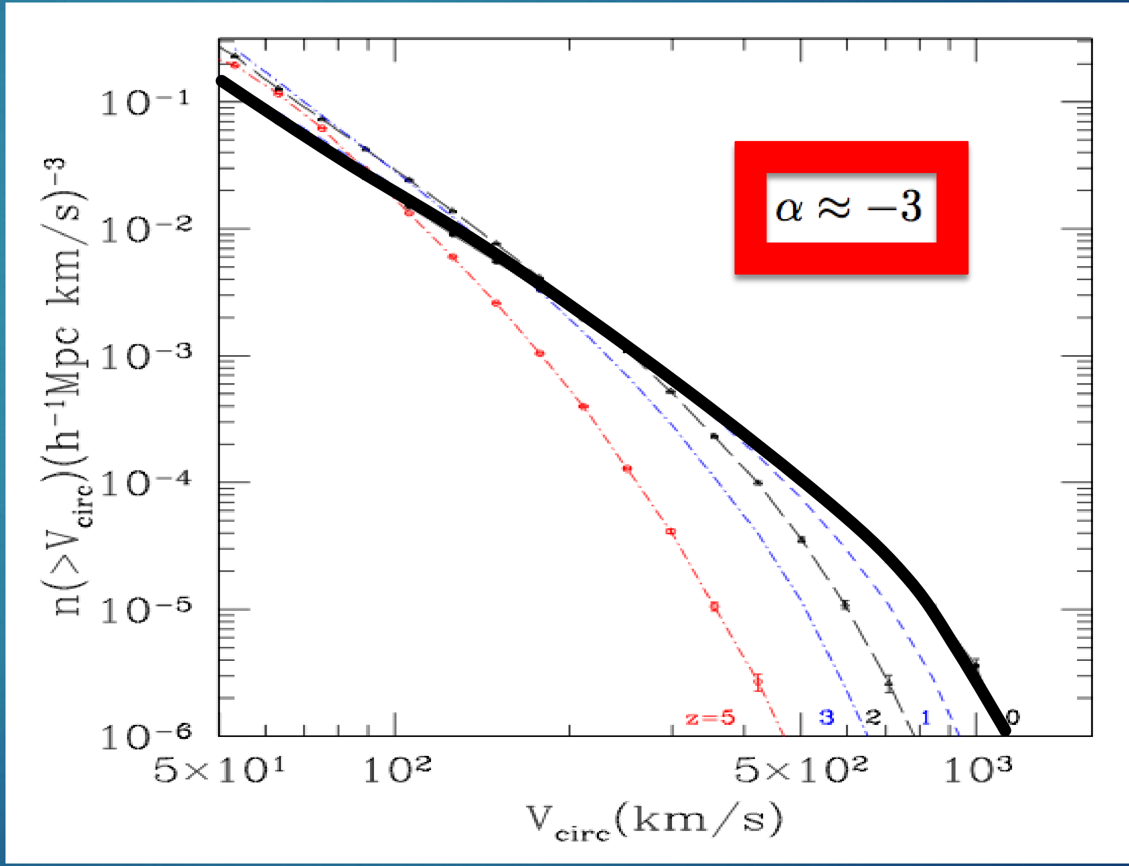
(Klypin+ 2015)

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.

The Cold Dark Matter paradigm

Halo Velocity Function



Bolshoi simulation
(Klypin+ 2011)