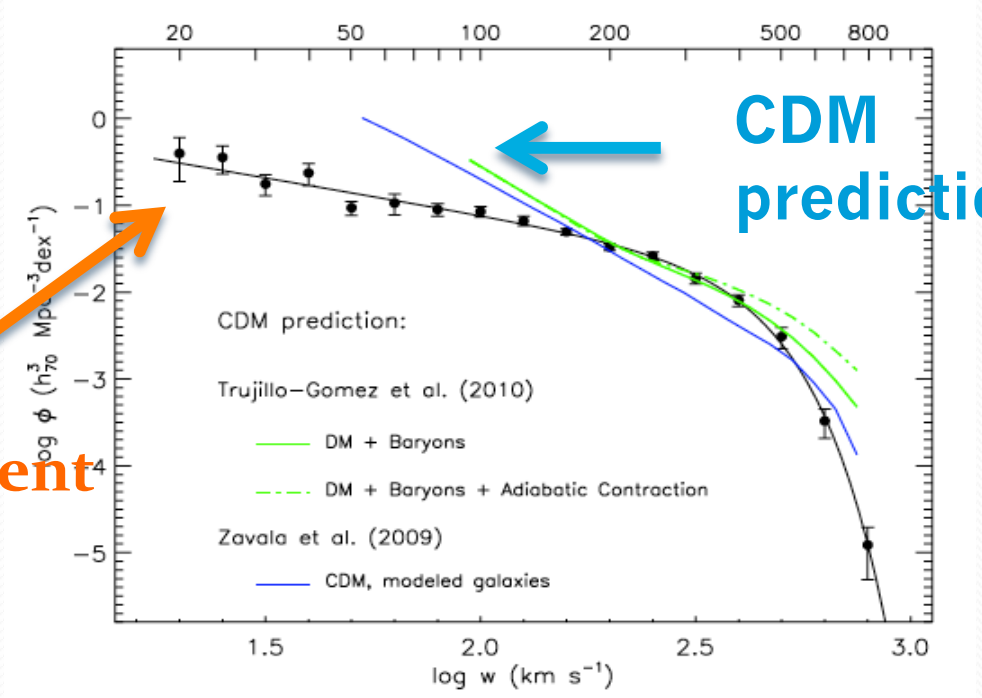
The velocity function of galaxies from the ALFALFA survey & implications for dark matter

Manolis Papastergis, Cornell University

TF35 workshop, 2 April 2012



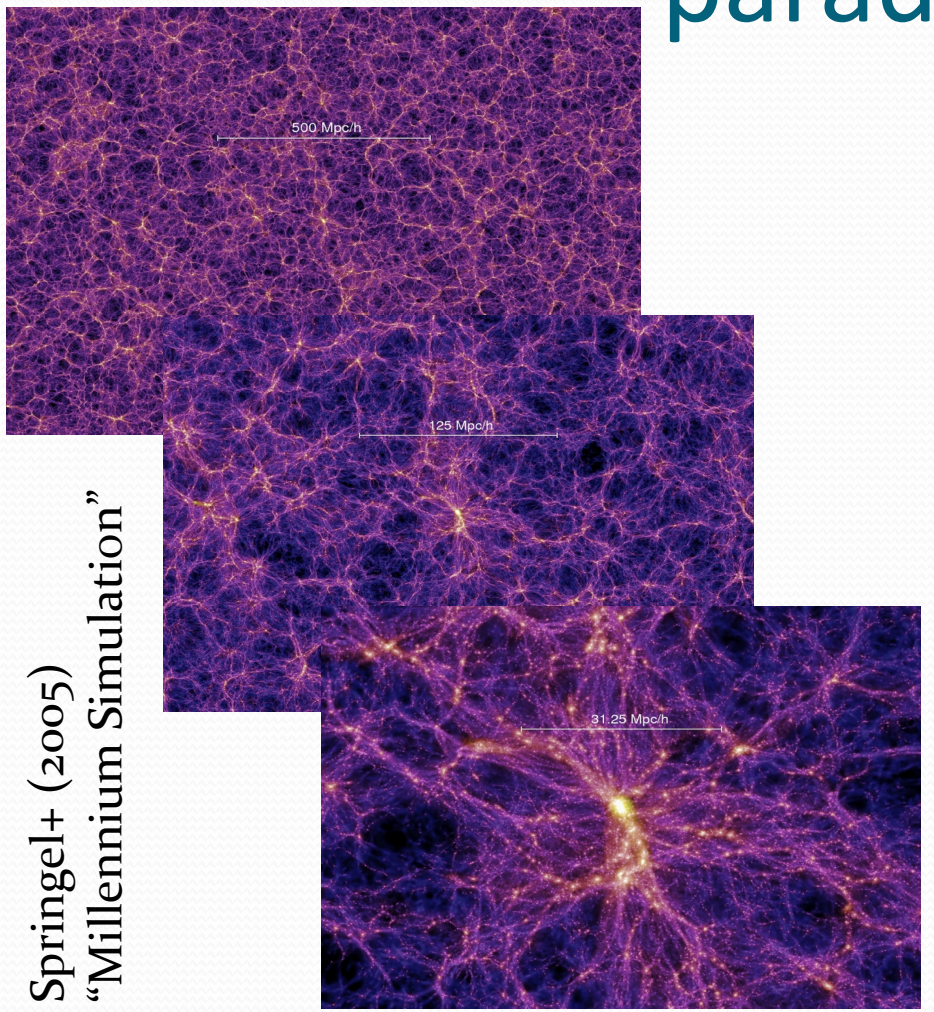
CDM prediction

ALFALFA measurement

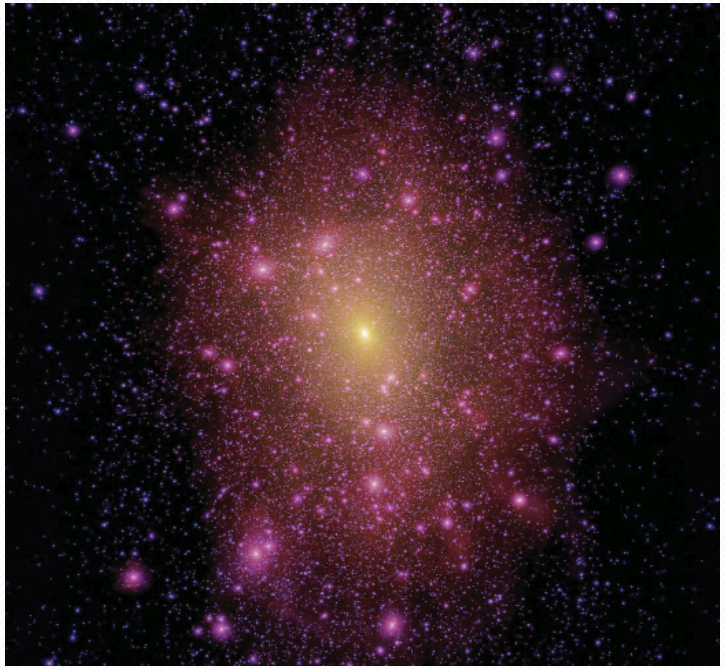
Cornell University

ALFALFA

the cold dark matter (CDM) paradigm



Springel+ (2005)
"Millennium Simulation"



Lovell+ (2012)

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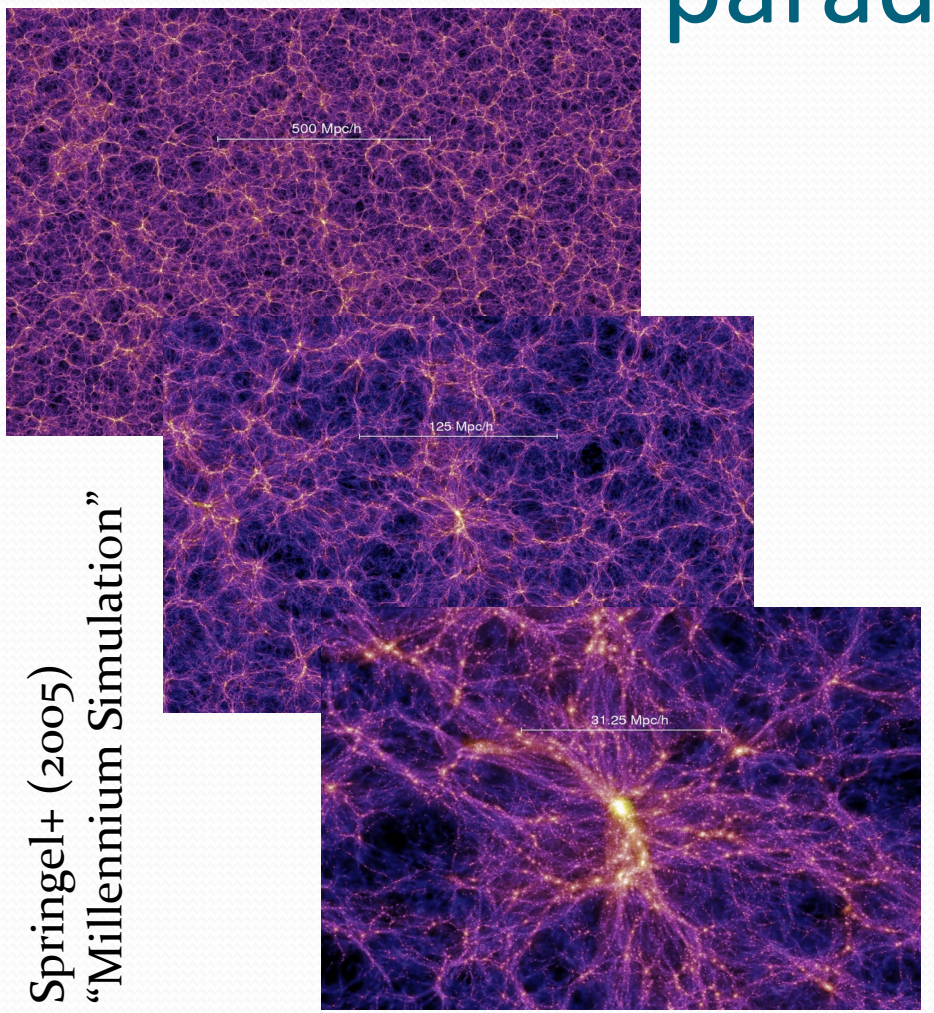

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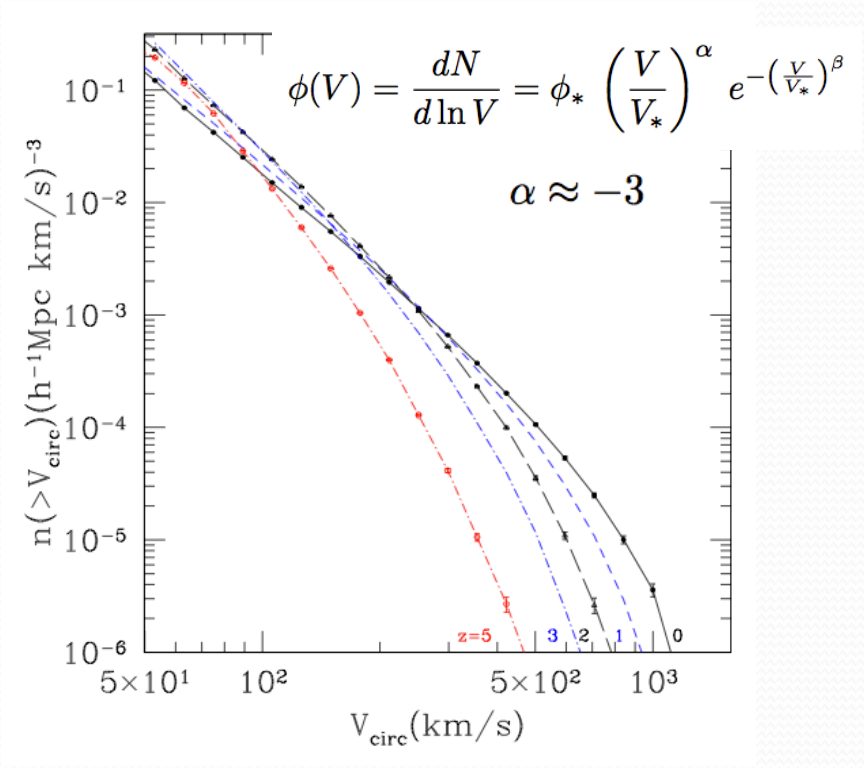


Klypin+ (2011) "Bolshoi simulation"

the “overabundance problem” of CDM

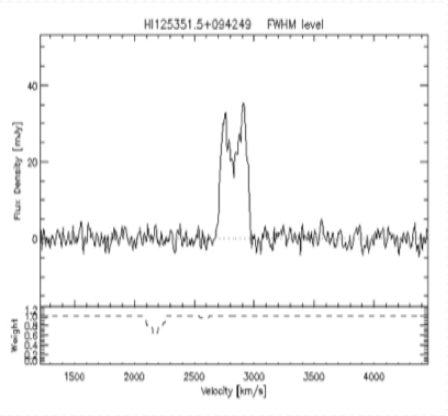
- “missing satellites”
- “void phenomenon”
- flatness of stellar & HI mass functions
- sizes of mini-voids in local volume
- etc…

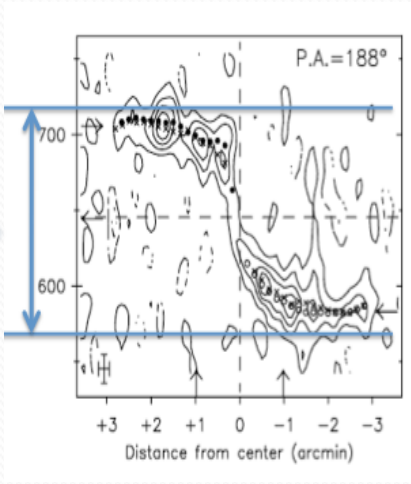
the ALFALFA survey

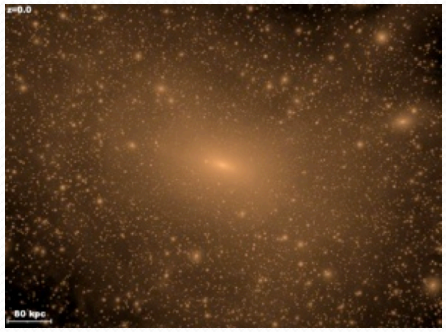
- ALFALFA is a blind, wide area 21-cm line survey done at Arecibo telescope.
- Presently available catalog:
  - ~3,000 deg^2 of sky
  - ~11,000 'Code 1' detections.
- ALFALFA has produced the *largest HI-selected sample to date*.

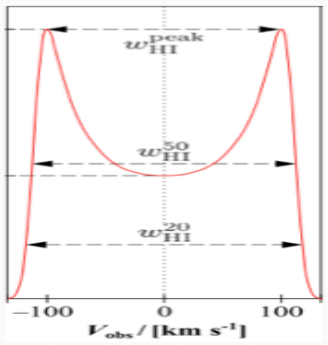
the ‘velocity width function’ of galaxies

- the velocity width of a galaxy is ~twice its maximum circular velocity.
- the ‘velocity width function’ of galaxies should be dynamically related to the halo VF.







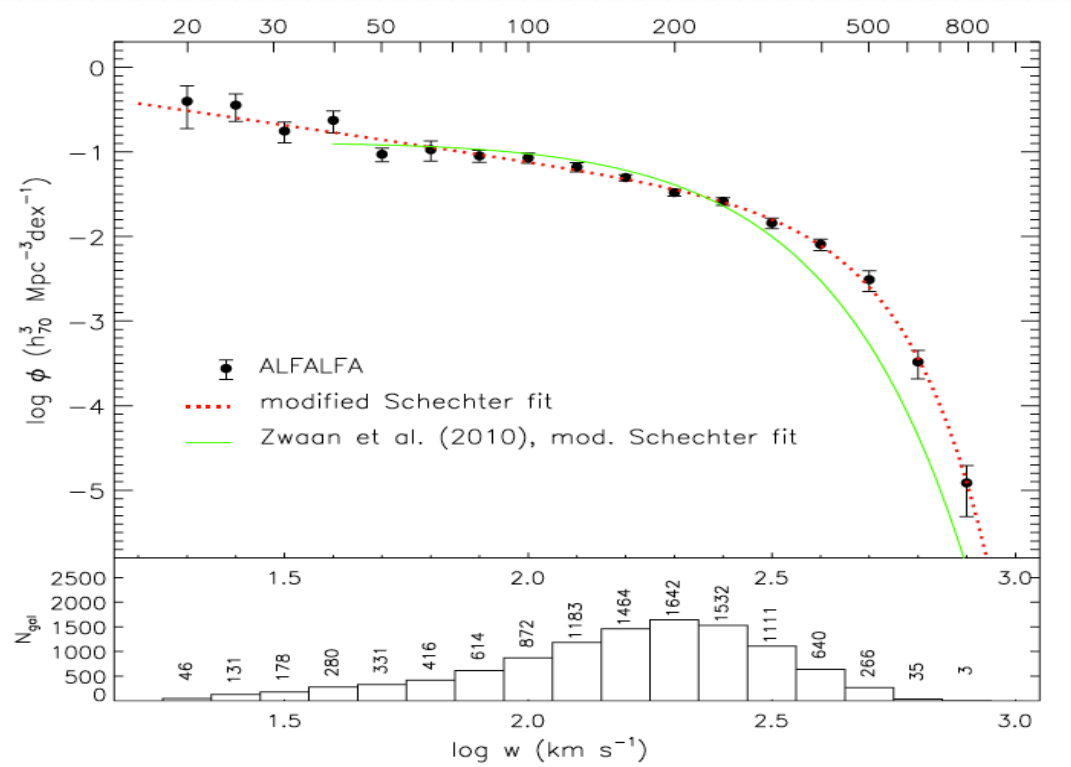


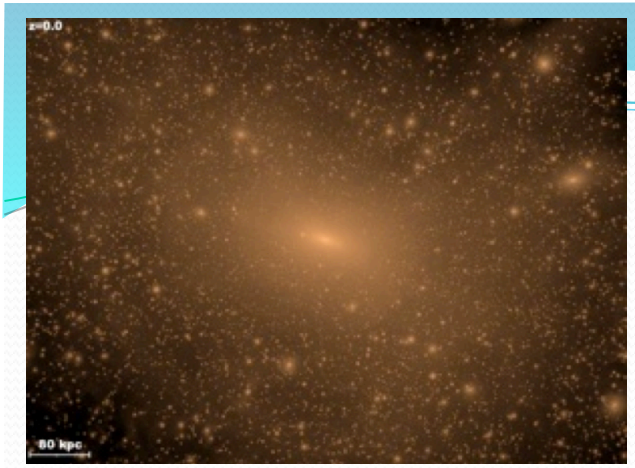
V_{halo} W_{50}

the ALFALFA velocity width function

- Well described by a modified Schechter function, with a "shallow" low-width slope (α = -0.85)

Papastergis+ (2011)





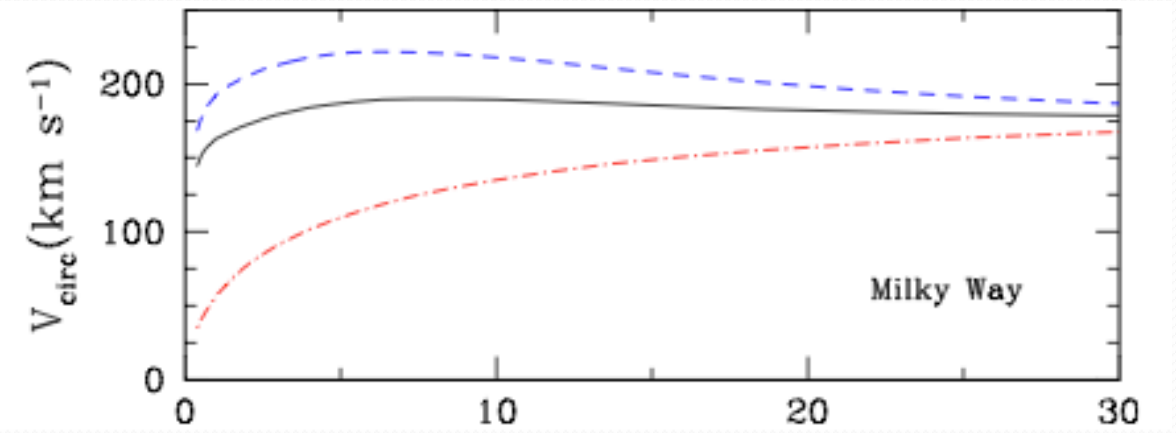
add baryons

does the halo host a single galaxy ?

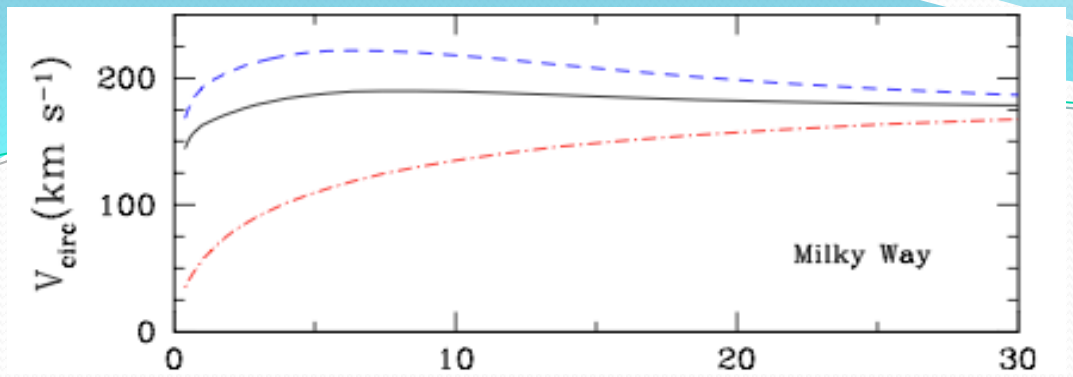
what is the stellar mass of the galaxy ?

what is the gas mass of the galaxy ?

is the DM halo distorted under the influence of the baryons ?



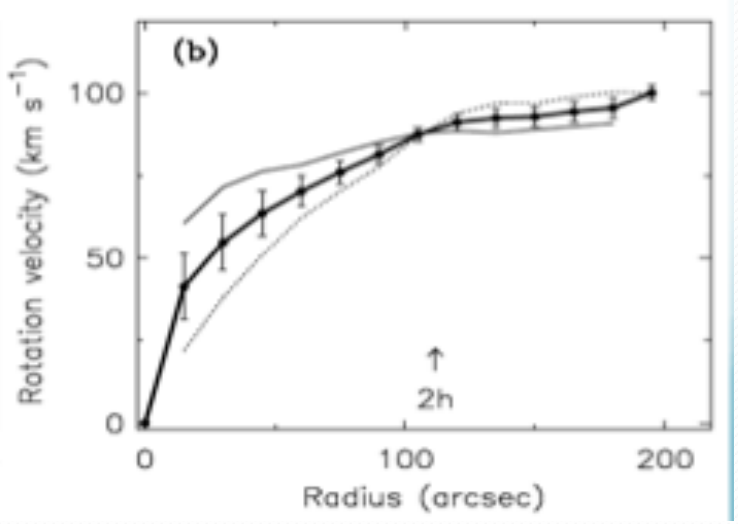
Trujillo-Gomez+ (2011)

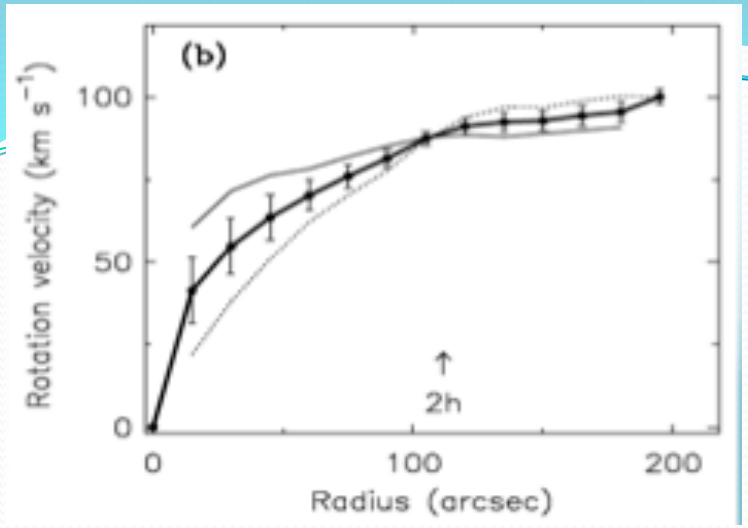


Trujillo-Gomez+ (2011)

add the tracer (HI)

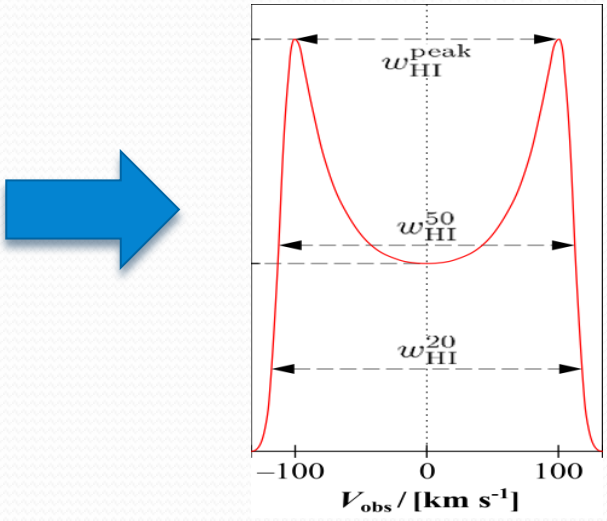
how extended is the HI disk ?





+ thermal broadening

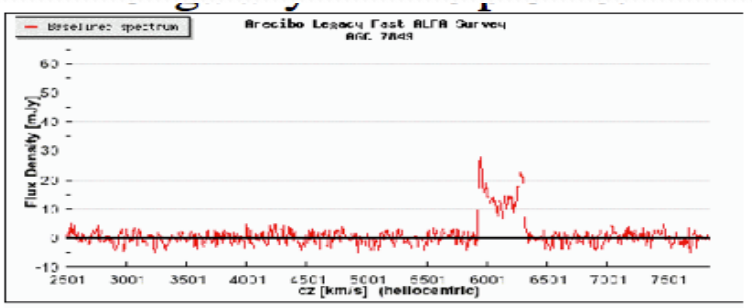
+ spatial integration



+ projection on line-of-sight

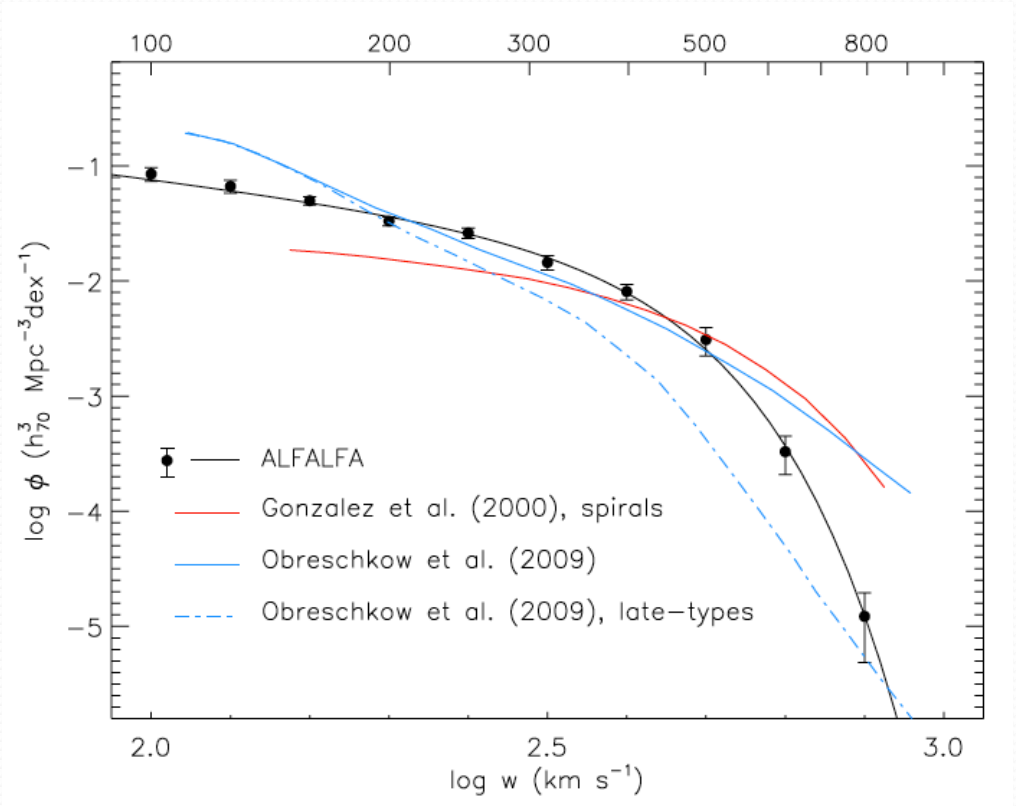
+ Doppler & instrumental broadening

+ noise



observation vs. theory

- the ALFALFA WF is in fair agreement with theoretical predictions for massive galaxies.



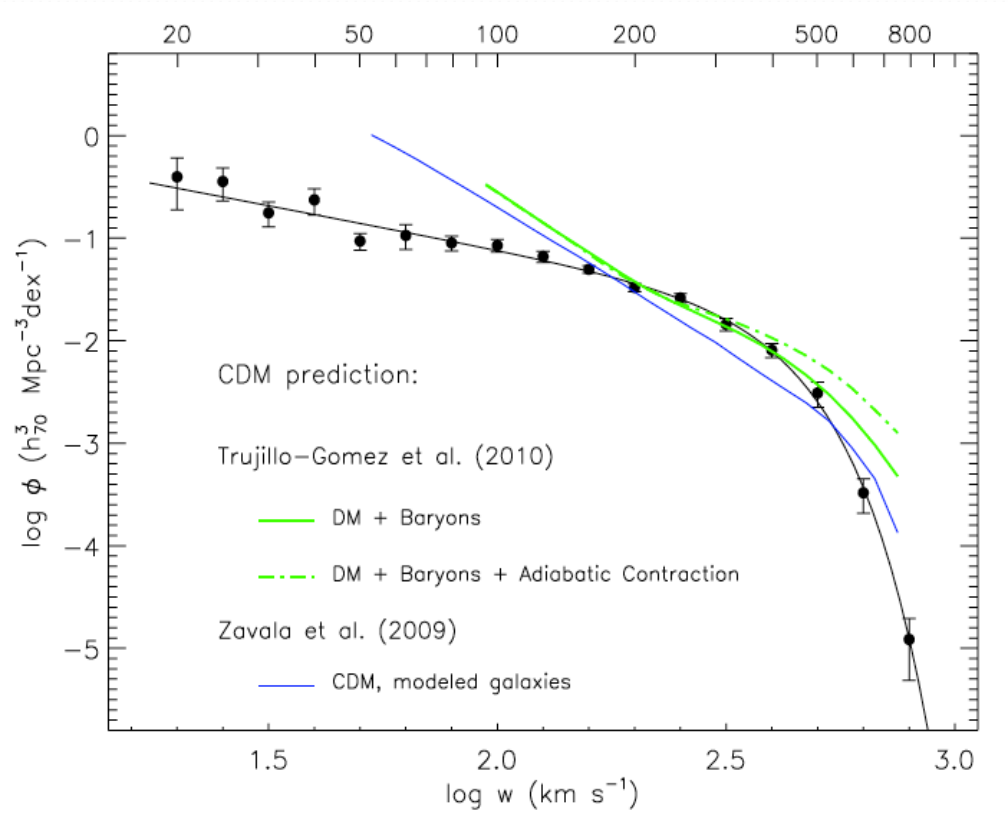
modeling: Obreschkow+ (2009)

Papastergis+ (2011)

observation vs. theory

- at low widths (w < 150 km/sec) the observational and theoretical distributions disagree.

$$w = 2v_{\rm rot} \sin i + w_{\rm eff}$$

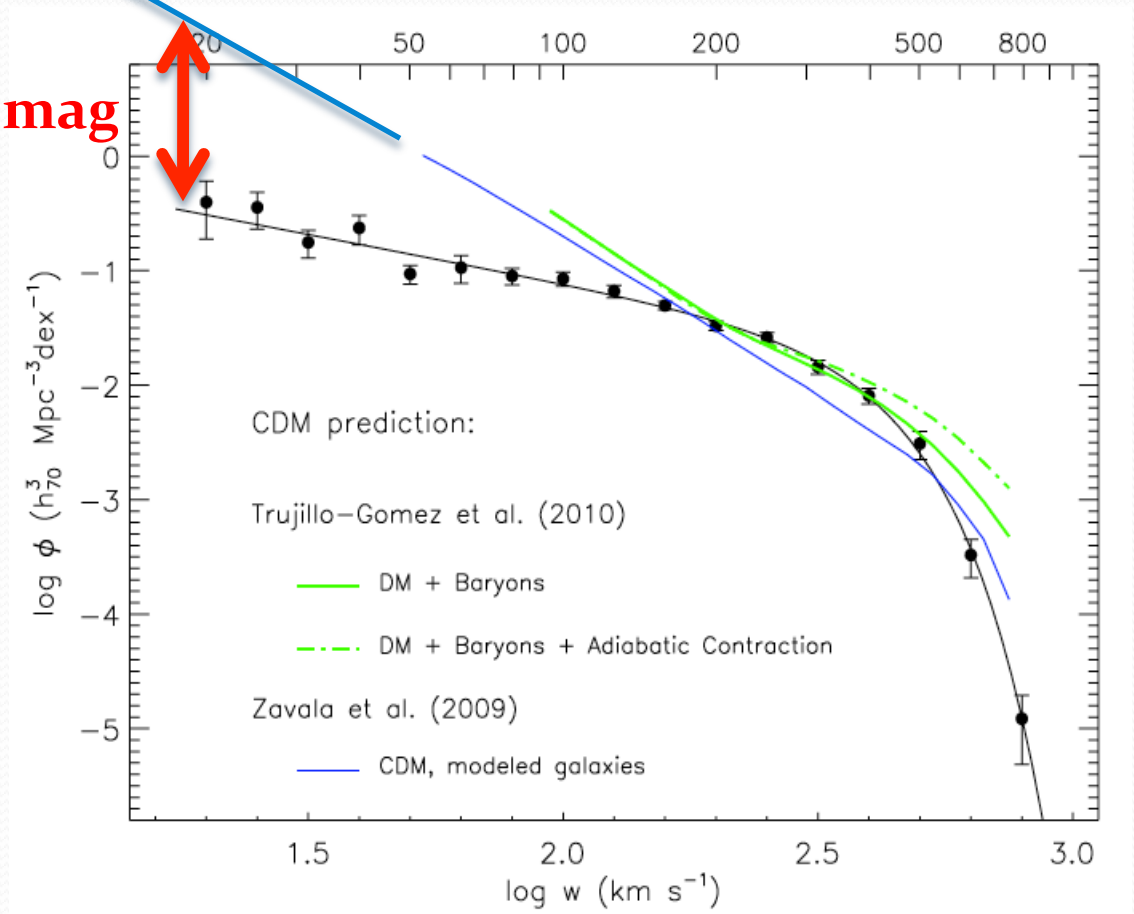


modeling: Trujillo-Gomez+ (2011), Zavala+ (2009)

Papastergis+ (2011)

observation vs. theory

~2 orders of mag

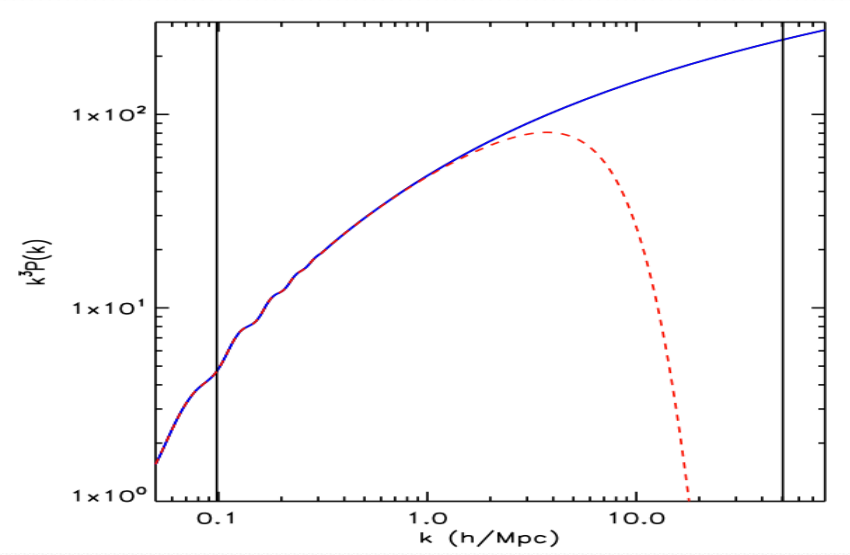


Papastergis+ (2011)

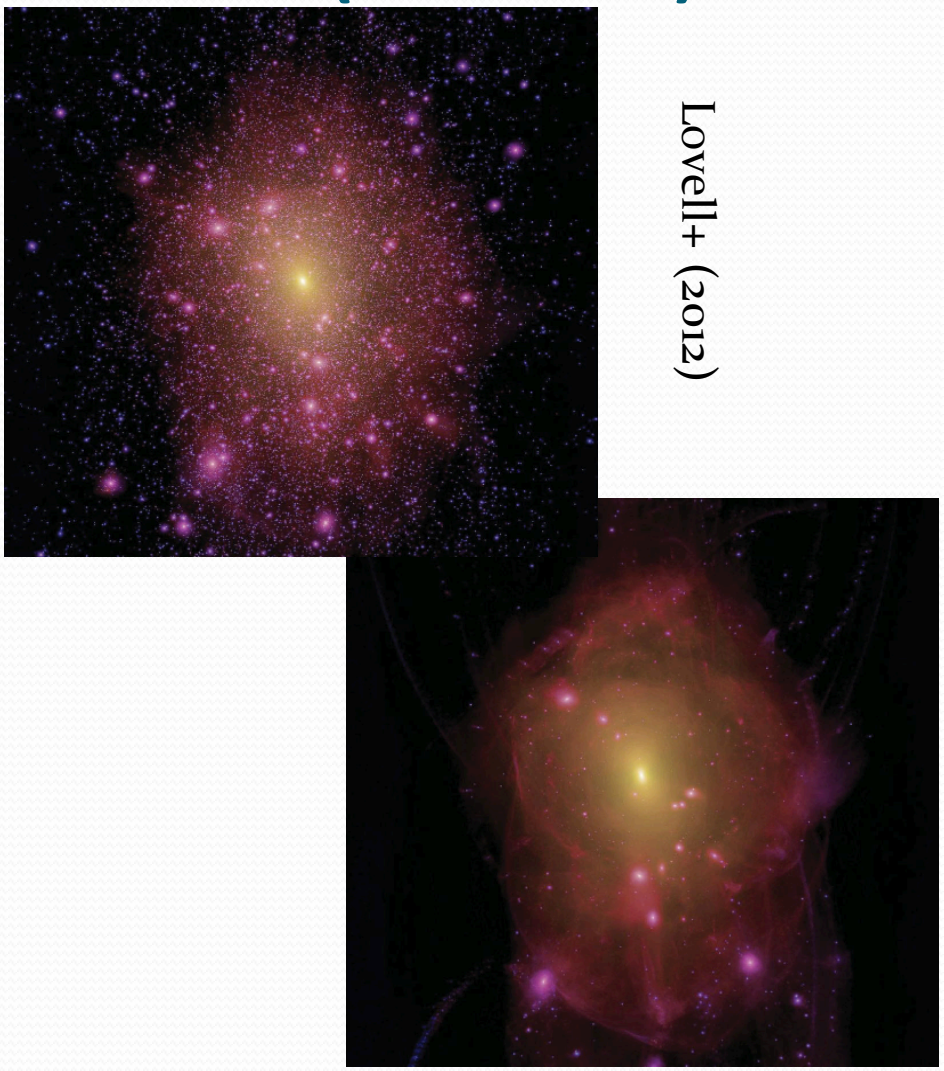
Possible solutions ?

warm dark matter (WDM)

- in a ~keV warm dark matter universe, far less low-mass halos would be formed.



Zavala+ (2009)



Lovell+ (2012)

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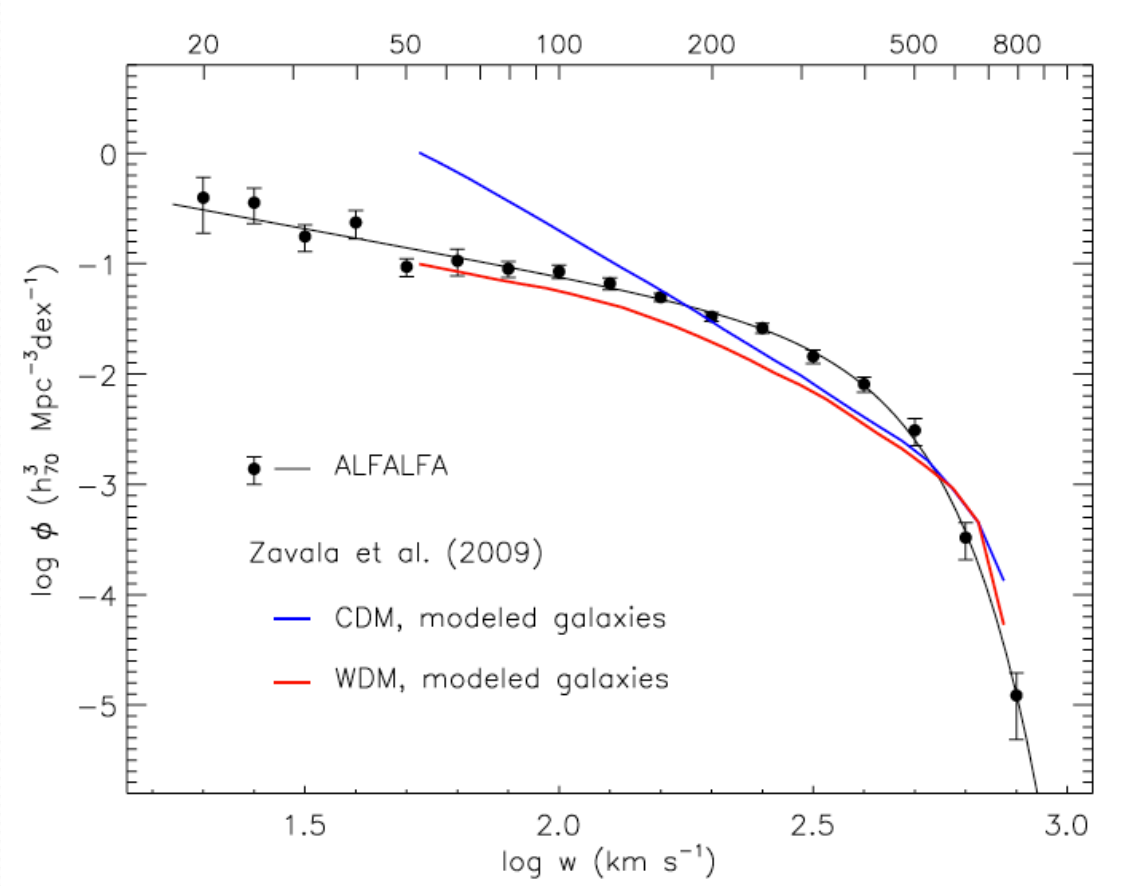
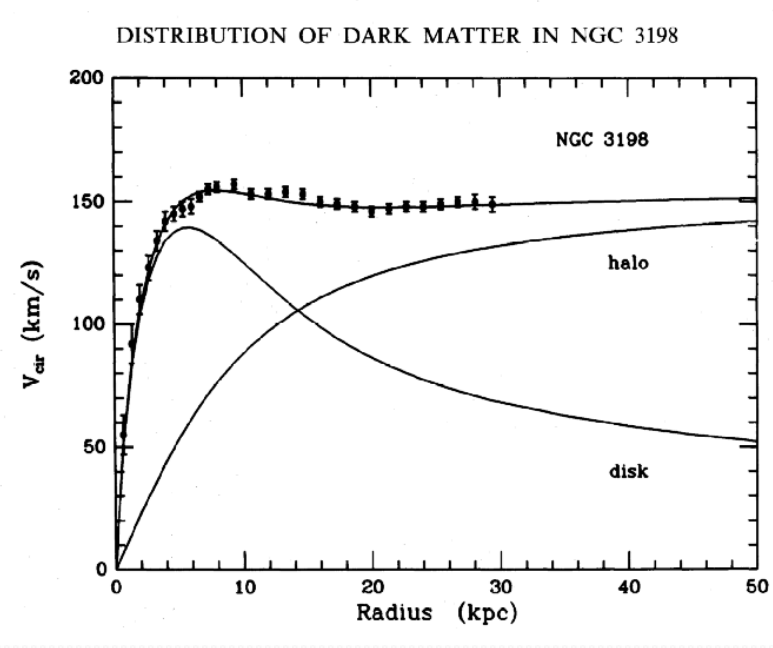


modeling: Zavala+ (2009)

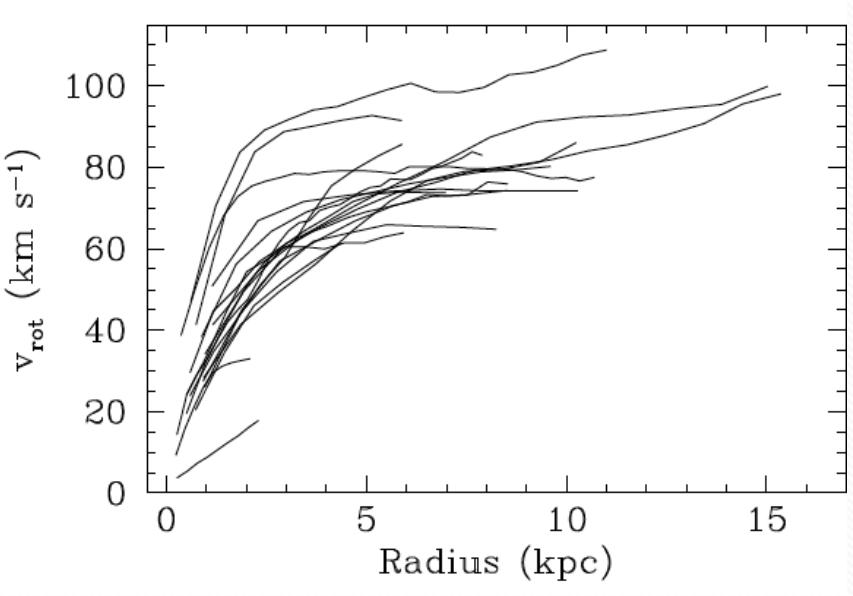
Papastergis+ (2011)

HI disk extent

- HI disks in dwarf galaxies are often rising to the last measured point.



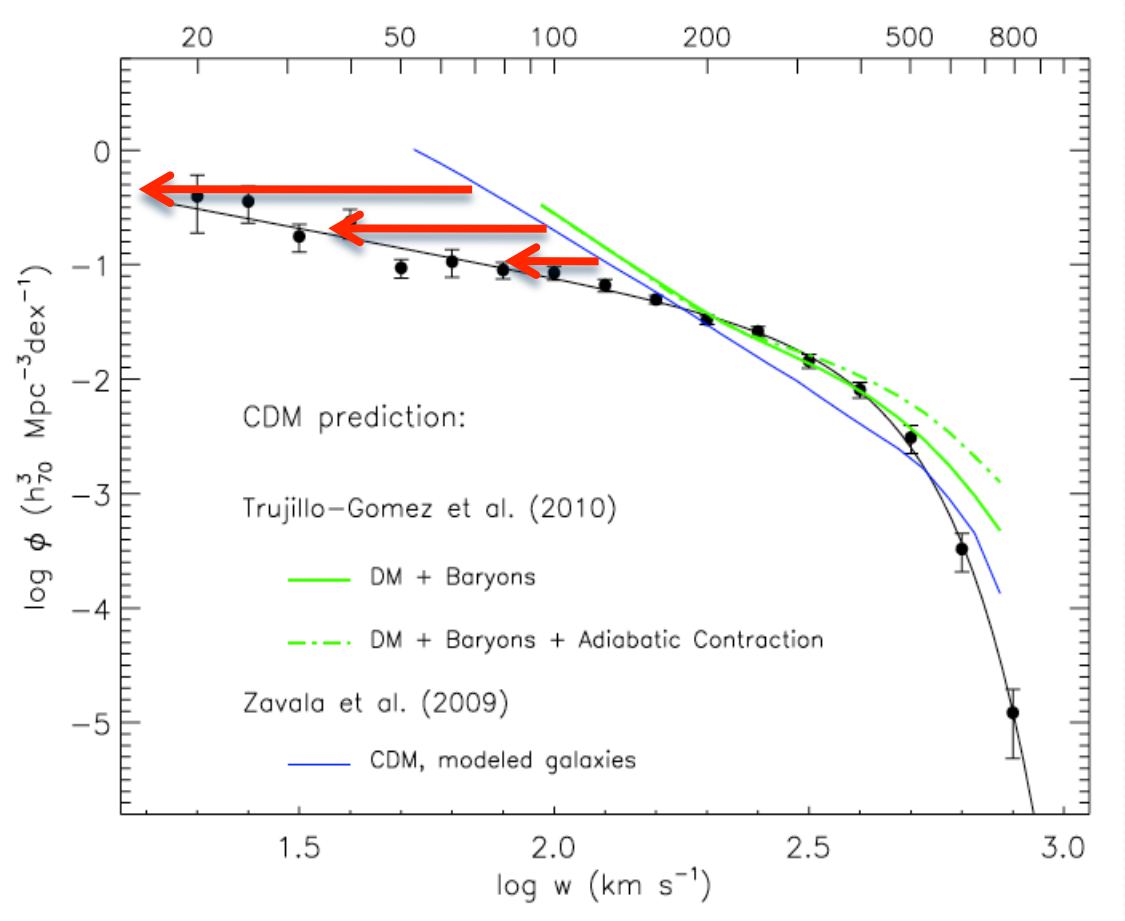
'flat' rotation curve



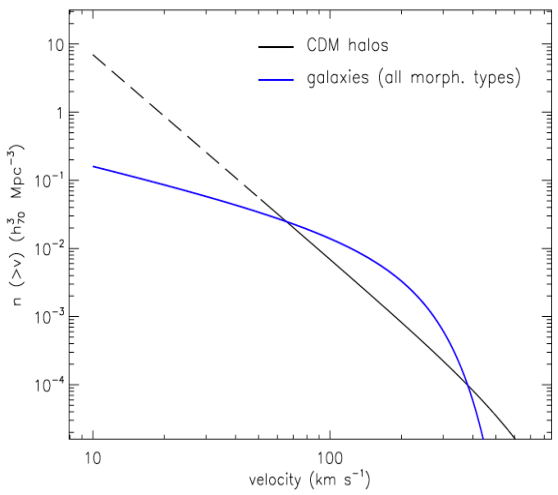
'rising' rotation curves

Swaters+ (2009)

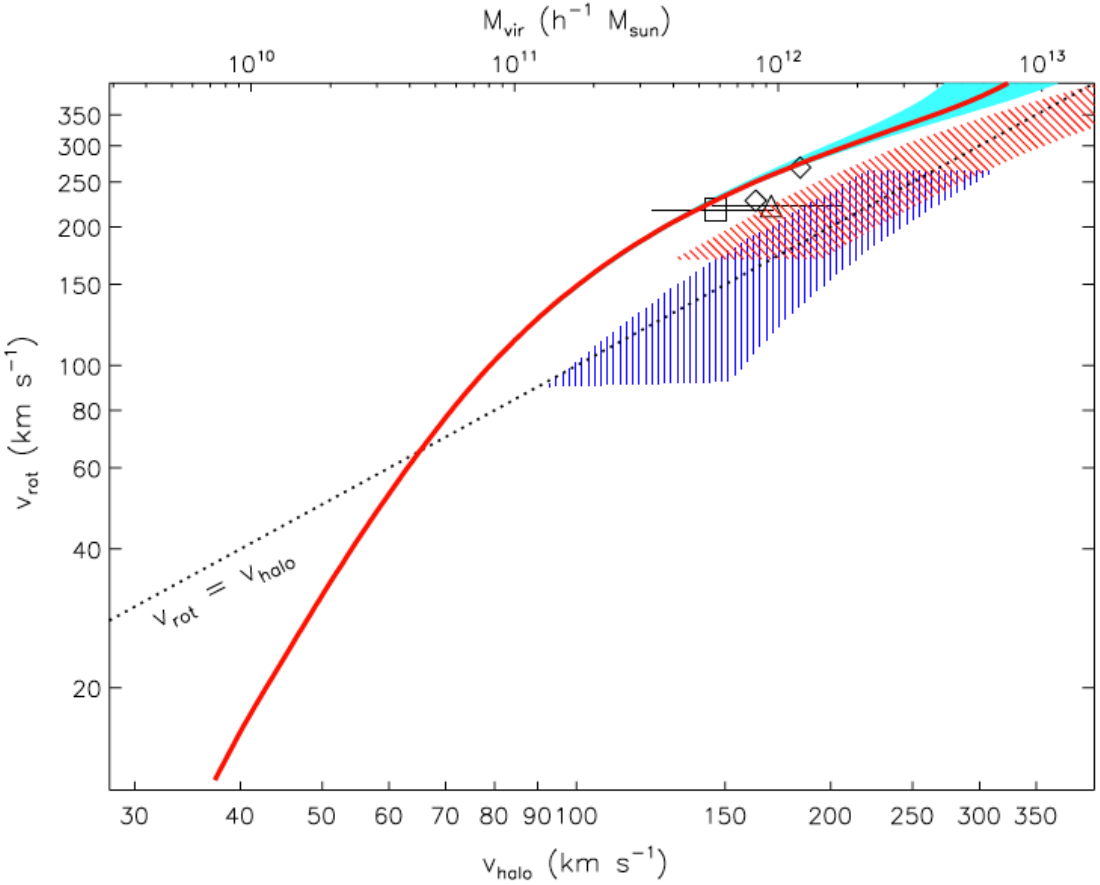
HI disk extent



$v_{rot} - v_{halo}$ relation in CDM universe



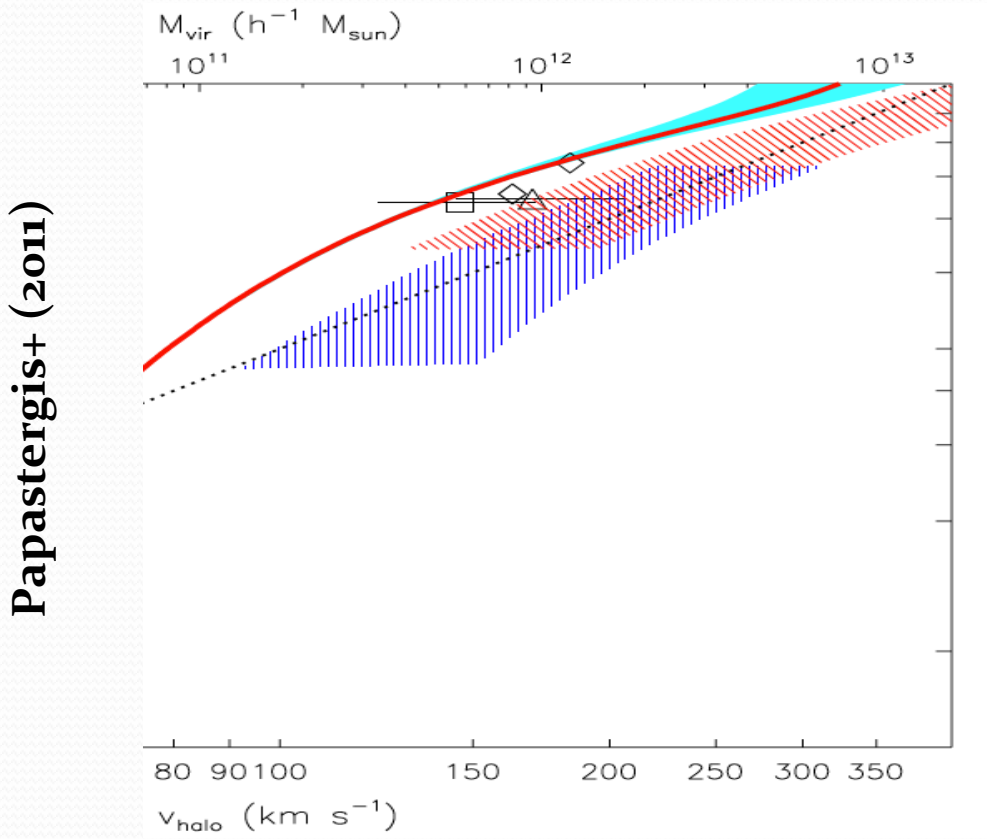
'abundance matching'



Papastergis+ (2011)

$v_{rot} - v_{halo}$ relation in CDM universe

- $v_{rot} \approx 1.5\, v_{halo}$ for MW-sized galaxies



external datasets:

MW mass:
Klypin+ (2002), Xue+ (2008),
Smith+ (2007)

Andromeda mass:
Klypin+ (2002)

stacked weak lensing & satellite kinematics:
Dutton+ (2010)

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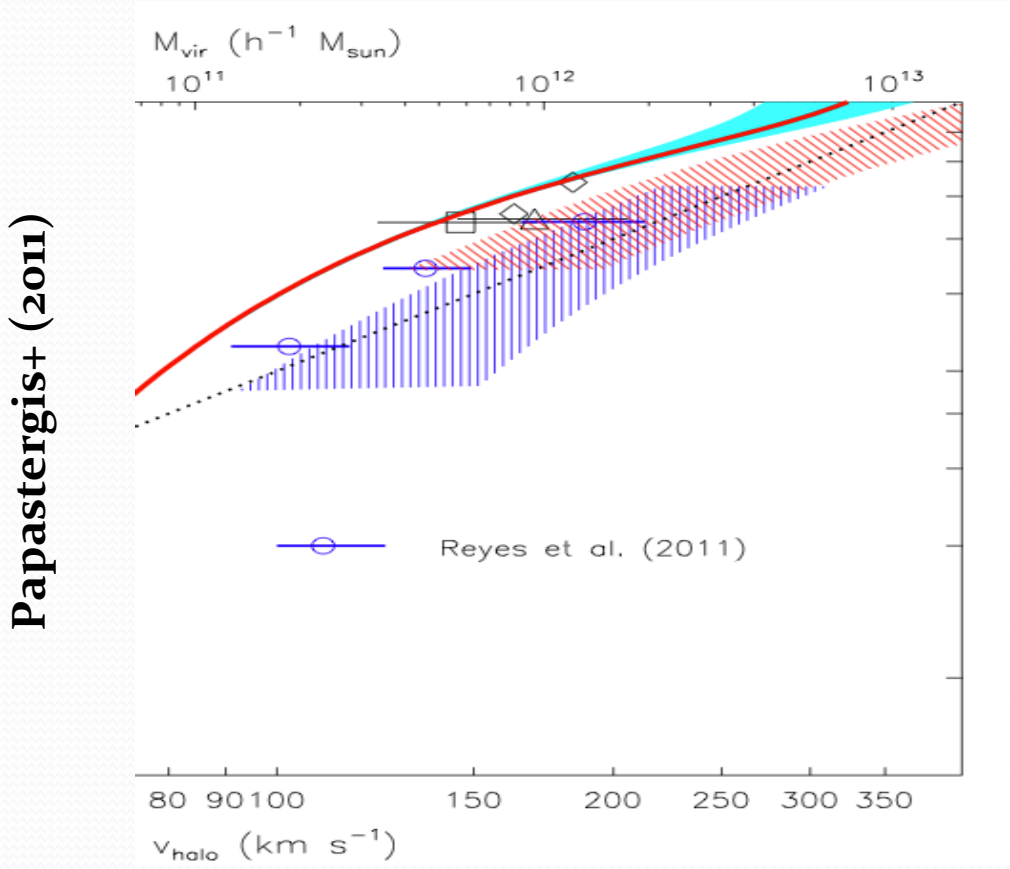

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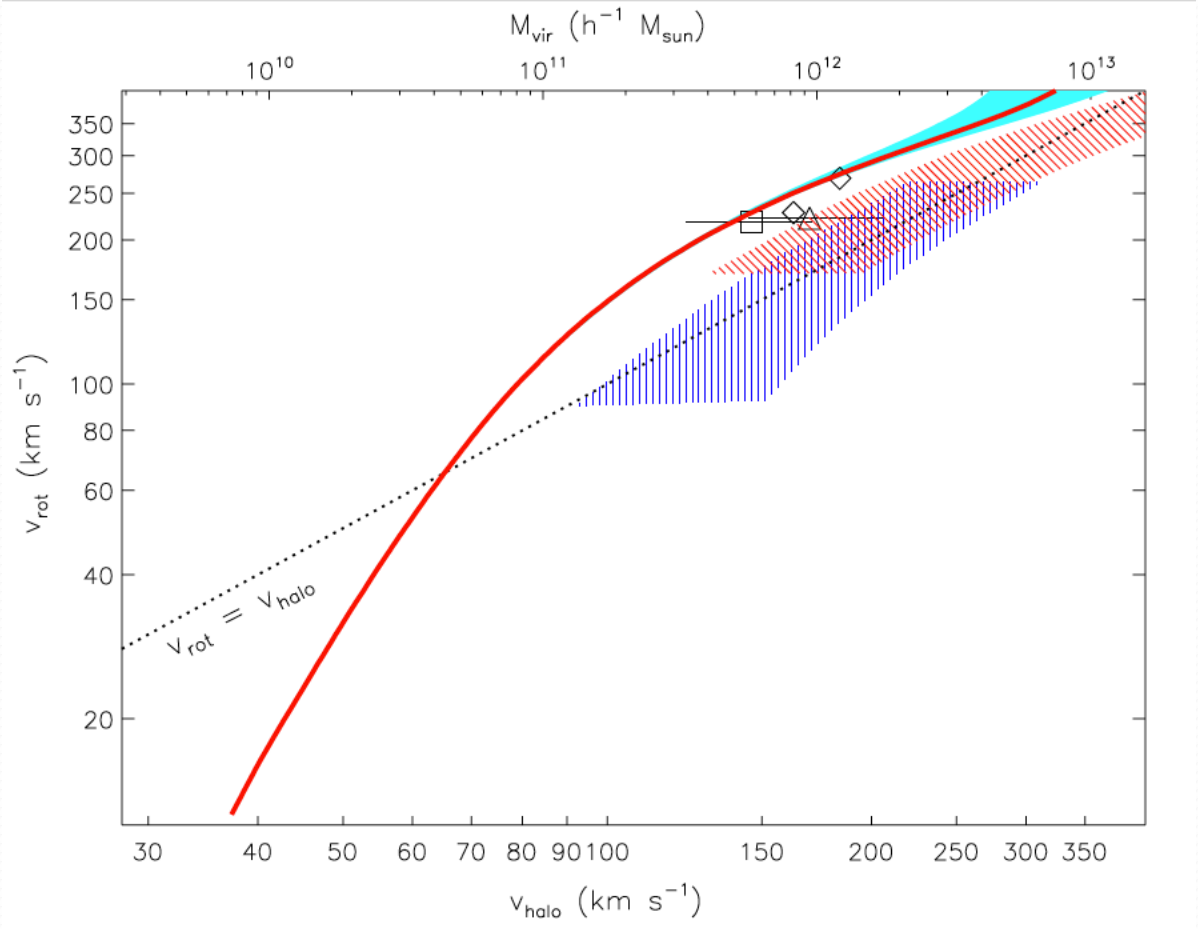
stacked weak lensing & satellite kinematics:
Dutton+ (2010), Reyes+ (2011)

$v_{rot} - v_{halo}$ relation in CDM universe

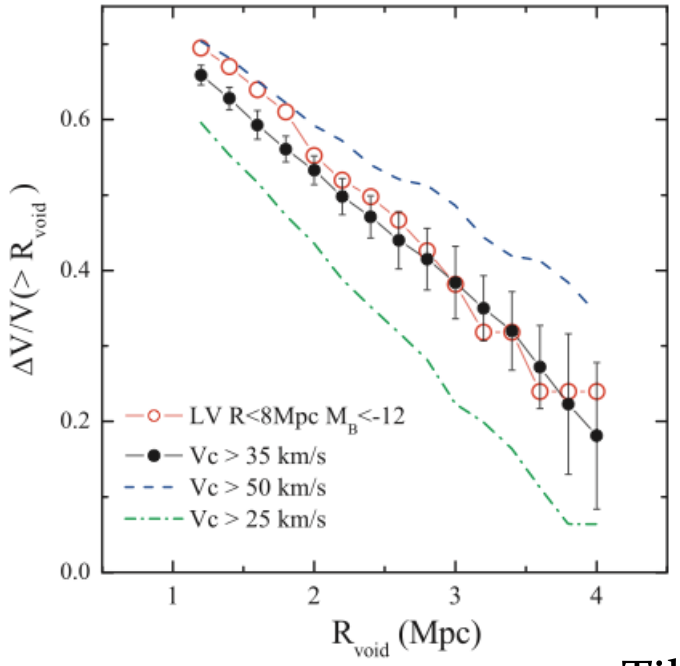
- HI rotational velocities *must* underestimate the true halo mass.
- The underestimate is **a factor of ~2** at **v_{rot} = 20 km/sec**.



Papastergis+ (2011)

the “mini-void” size problem

- Galaxies brighter then M_B = -12 should be hosted by halos with v_{max} > 35 km/sec.



Name	M_B	Axial ratio	W_{50}	V_{rot}
E349-031,SDIG	−12.10	0.82	20.0	17.5
KKH5	−12.27	0.62	37.0	23.6
KKH6	−12.38	0.60	31.0	19.4
KK16	−12.65	0.37	24.0	12.9
KKH18	−12.39	0.57	34.0	20.7
KKH34,Mai13	−12.30	0.56	24.0	14.5
E489-56,KK54	−13.07	0.53	33.8	19.9
KKH46	−11.93	0.86	25.0	24.5
U5186	−12.98	0.23	42.0	21.6
E321-014	−12.70	0.43	39.8	22.0
KK144	−12.59	0.33	44.0	23.3
E443-09,KK170	−12.03	0.75	29.0	21.9
KK182,Cen6	−11.89	0.60	16.0	10.0
DDO181,U8651	−12.97	0.57	42	23.7
DDO183,U8760	−13.13	0.32	30.0	15.8
HIPASS1351-47	−11.88	0.60	38.8	24.2

Tikhonov & Klypin (2009)

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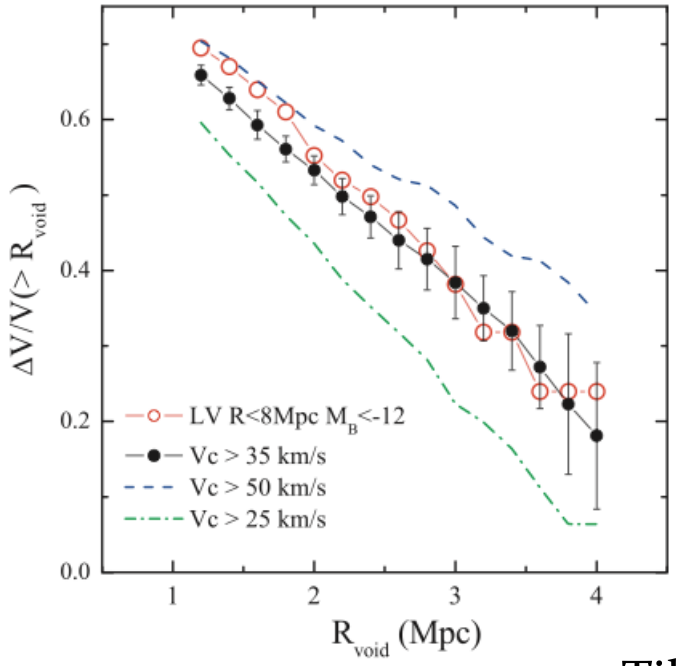

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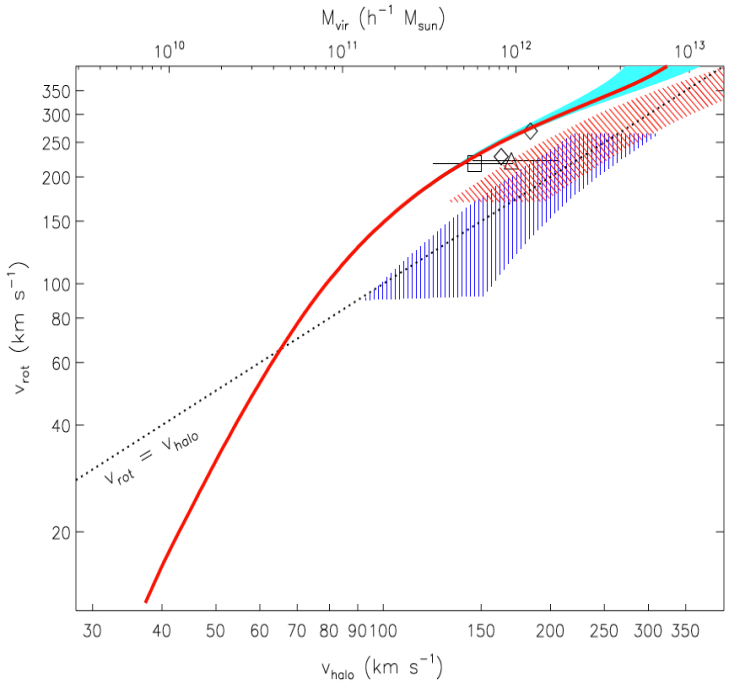
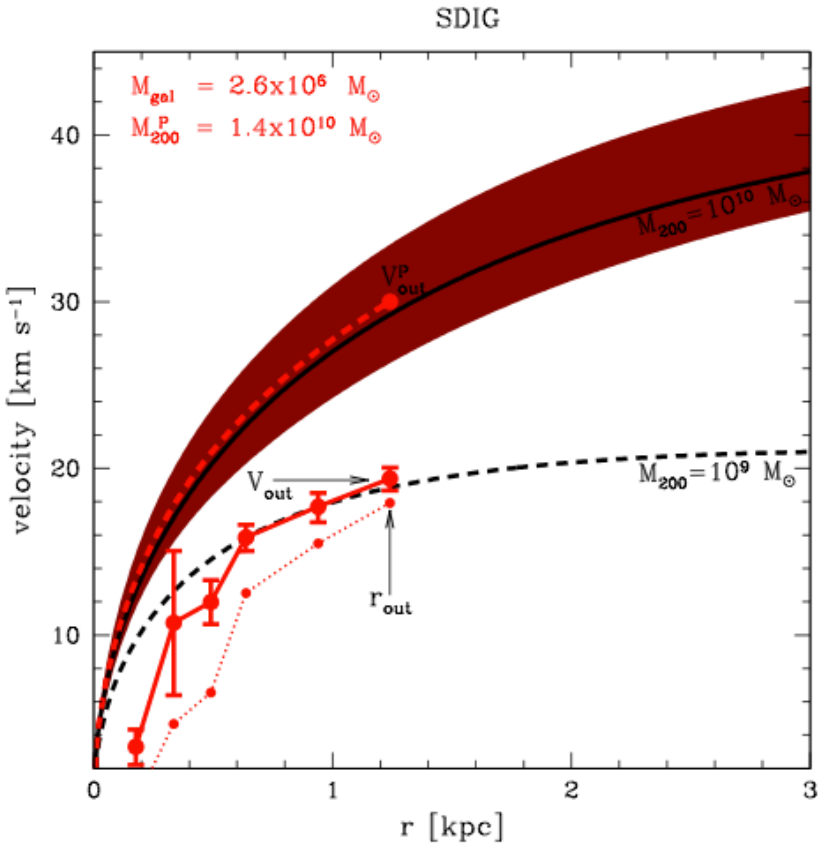
Tikhonov & Klypin (2009)

dwarf galaxy rotation curves

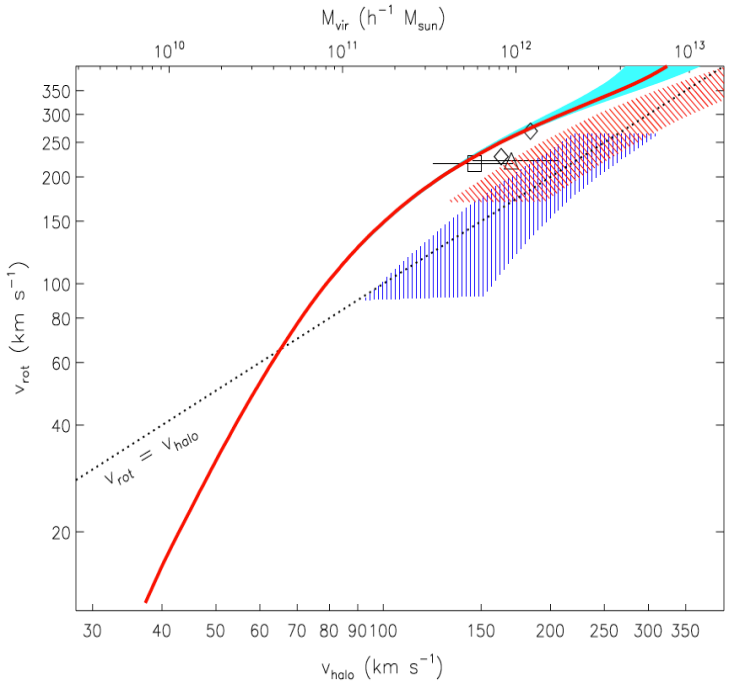


Papastergis+ (2011)

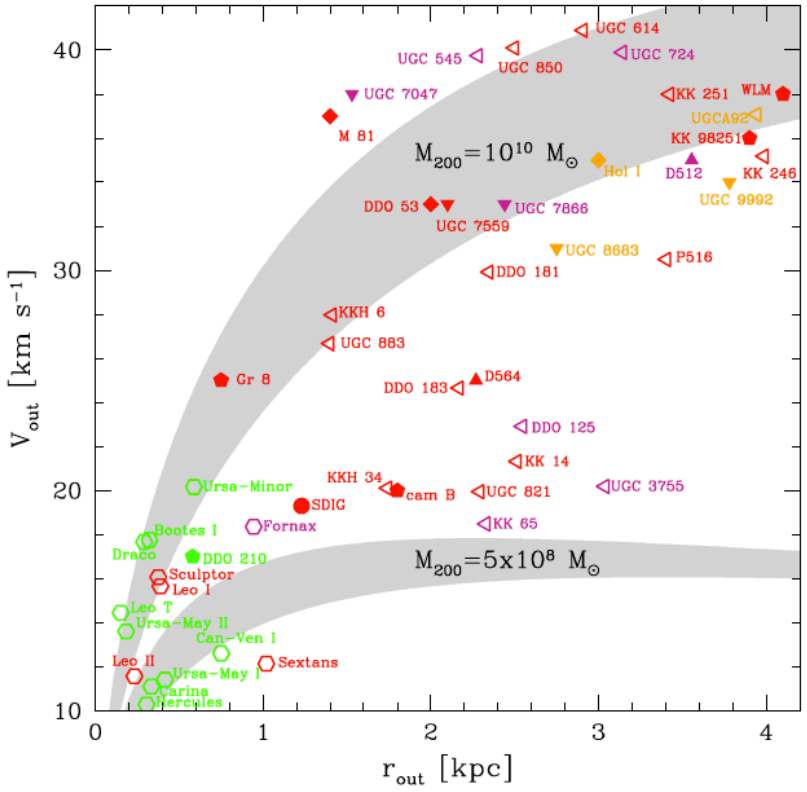


Ferrero+ (2011)

dwarf galaxy rotation curves



Papastergis+ (2011)



Ferrero+ (2011)

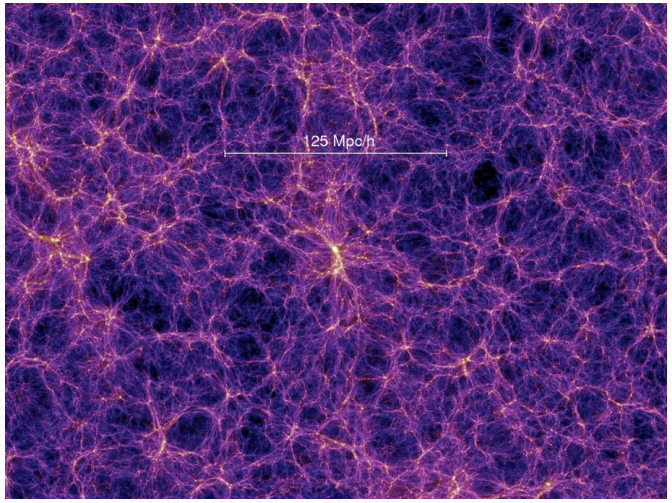
Summary

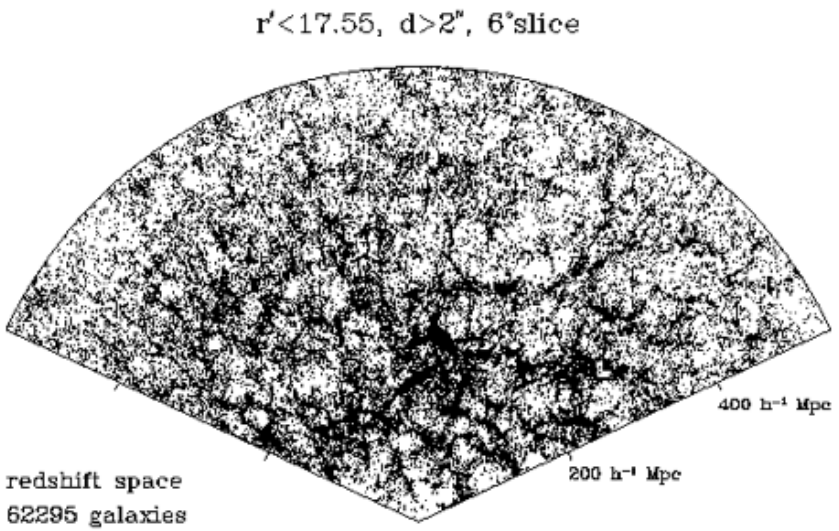
- The HI velocity width function is the galactic distribution which is most directly related with the DM halo mass function.
- There is a large discrepancy at low velocities between the observed and theoretically expected distribution.
- There are 2 possible solutions:
  - warm dark matter
  - HI velocity ≠ halo velocity
- In the latter case, the HI velocity *must* underestimate the host halo velocity by a factor of ~2.5 at v = 20 km/sec.
- A quantitative $v_{rot} - v_{halo}$ relation in a CDM universe has been statistically obtained, through abundance matching.

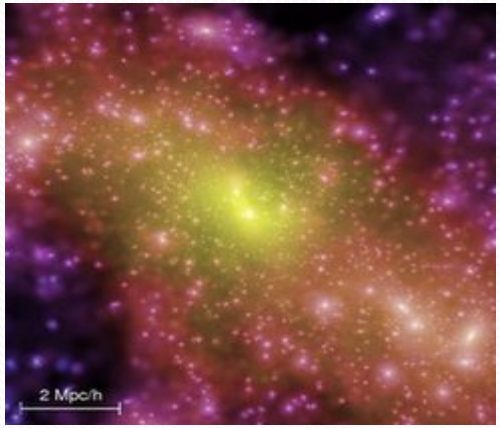
thank you!

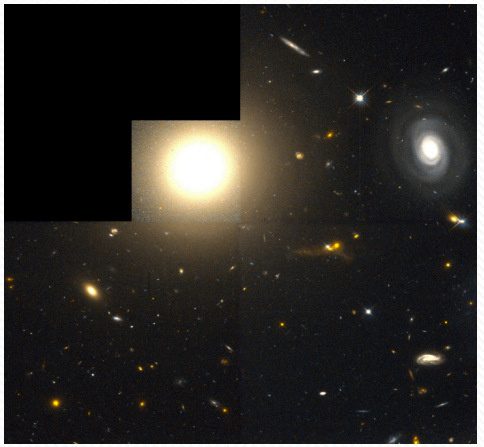
Questions?

CDM is (still) just a model!



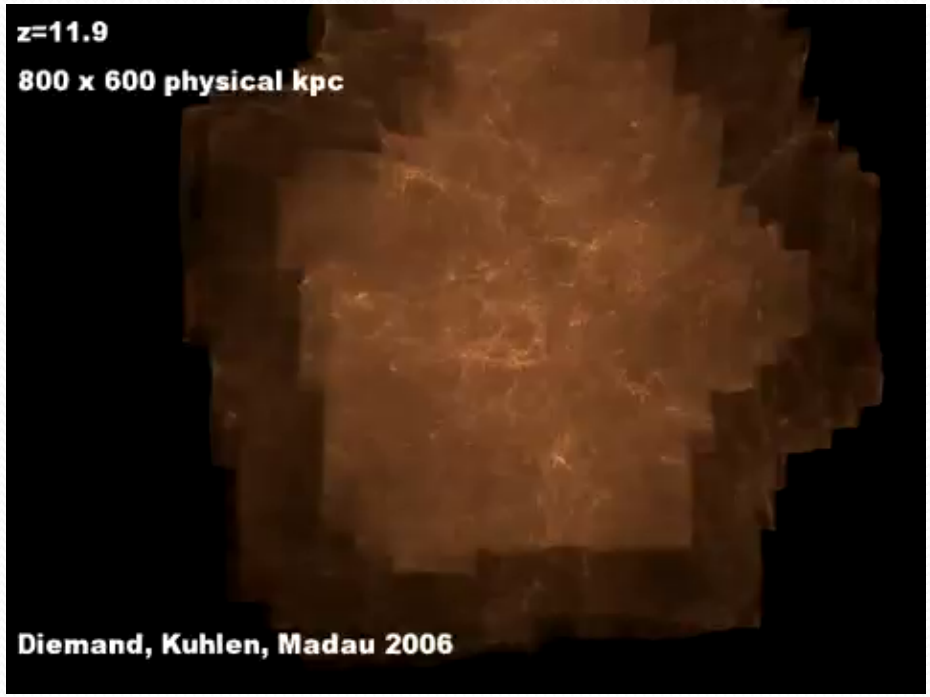






The CDM 'velocity function'

- cold dark matter clumps quickly and effectively, creating a large number of low-mass halos
- larger halos grow hierarchically through mergers, but most low mass halos are left behind



Diemand, Kuhlen & Madau (2006)
"Via Lactea simulation"

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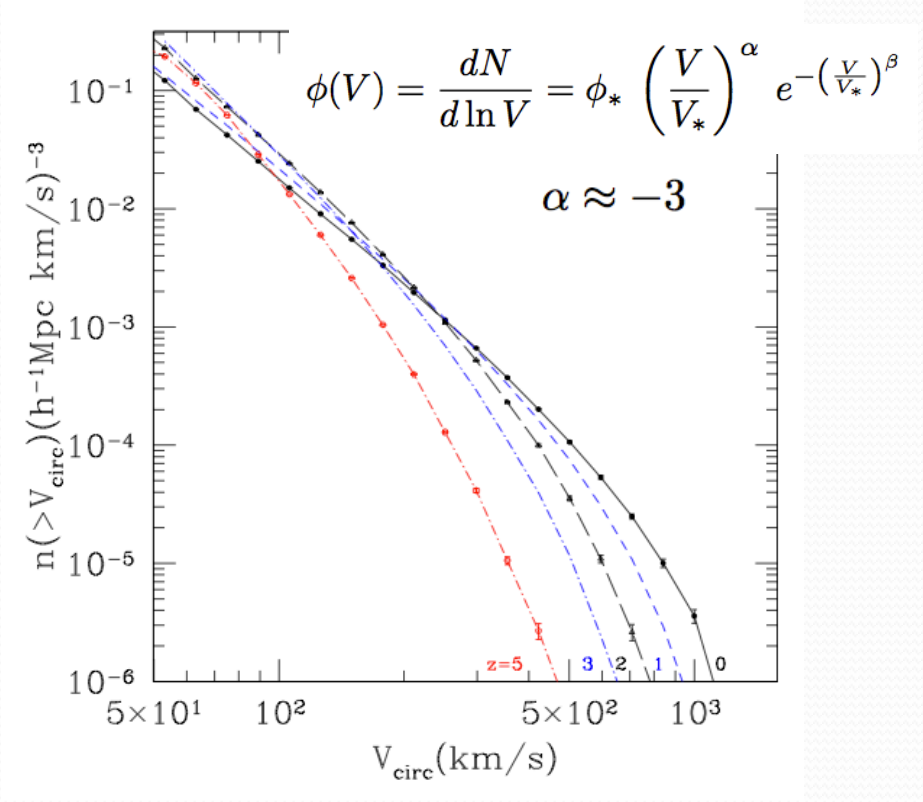
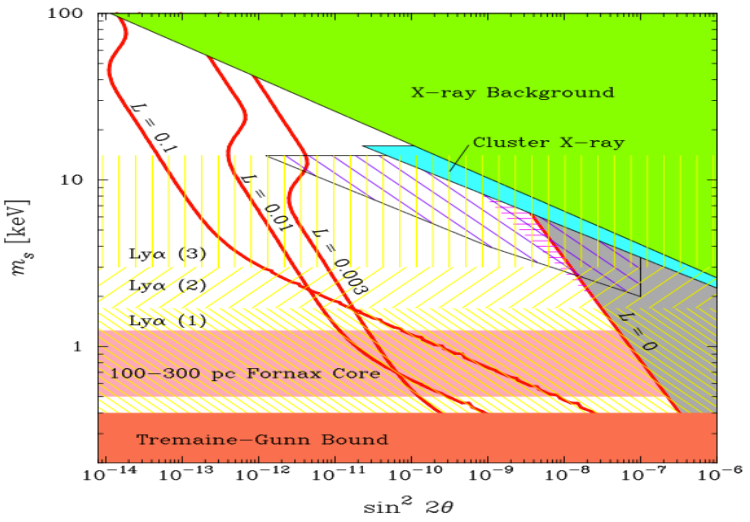


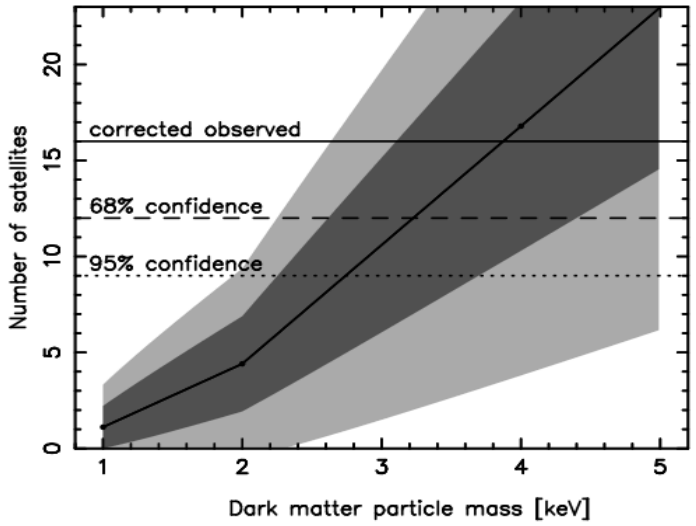
Klypin+ (2011) "Bolshoi simulation"

warm dark matter

- The mass of the sterile neutrino can be constrained by:
  - small scale power from below
  - X-ray line fluxes from above
  - the cosmic density of DM in conjunction with their production mechanism



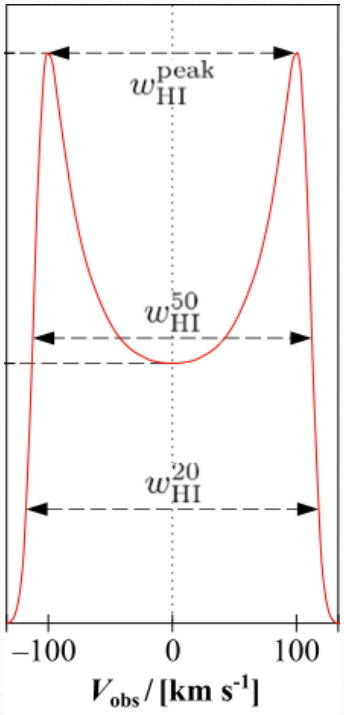
Abazajian & Koushiappas (2006)



Polisensky & Ricotti (2011)

the velocity width function

- We want to link observed galaxies to their halos *dynamically*…



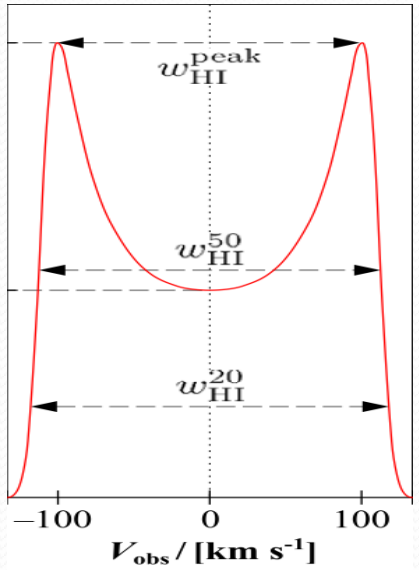
V_{halo} ⟺ W_{50}

the ALFALFA survey

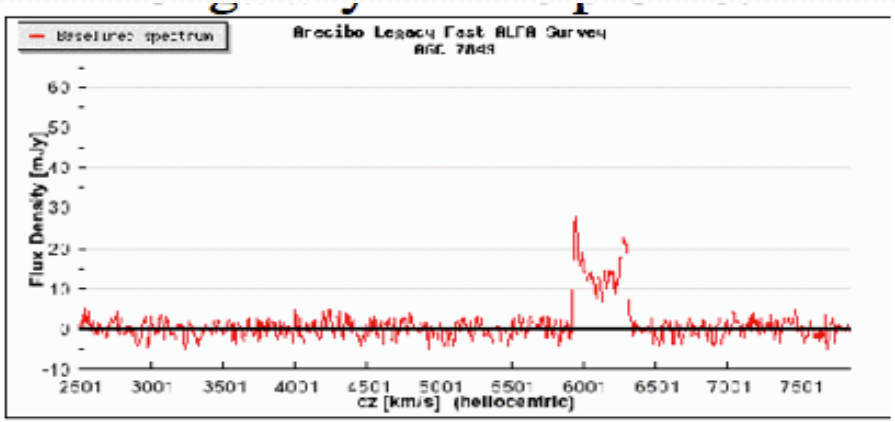
- ALFALFA can directly measure 3 properties of a galaxy:
  - **21-cm flux**
  - **redshift**

$$M_{HI}(M_\odot) = 2.35\,10^5 \text{ x } D^2 \text{ (Mpc) x } S_{int} \text{ (Jy kmsec}^{-1})$$

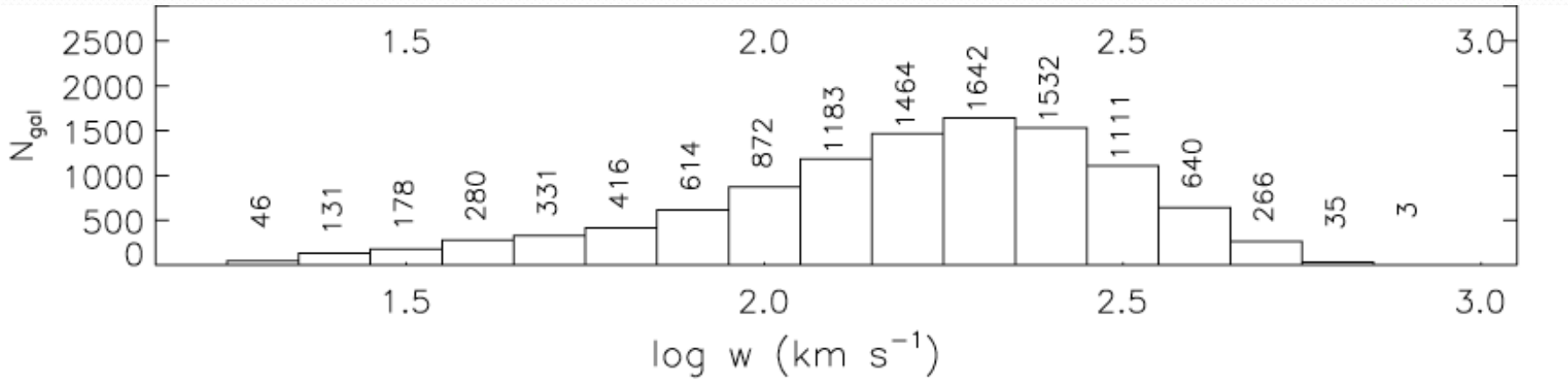
  - **velocity width**



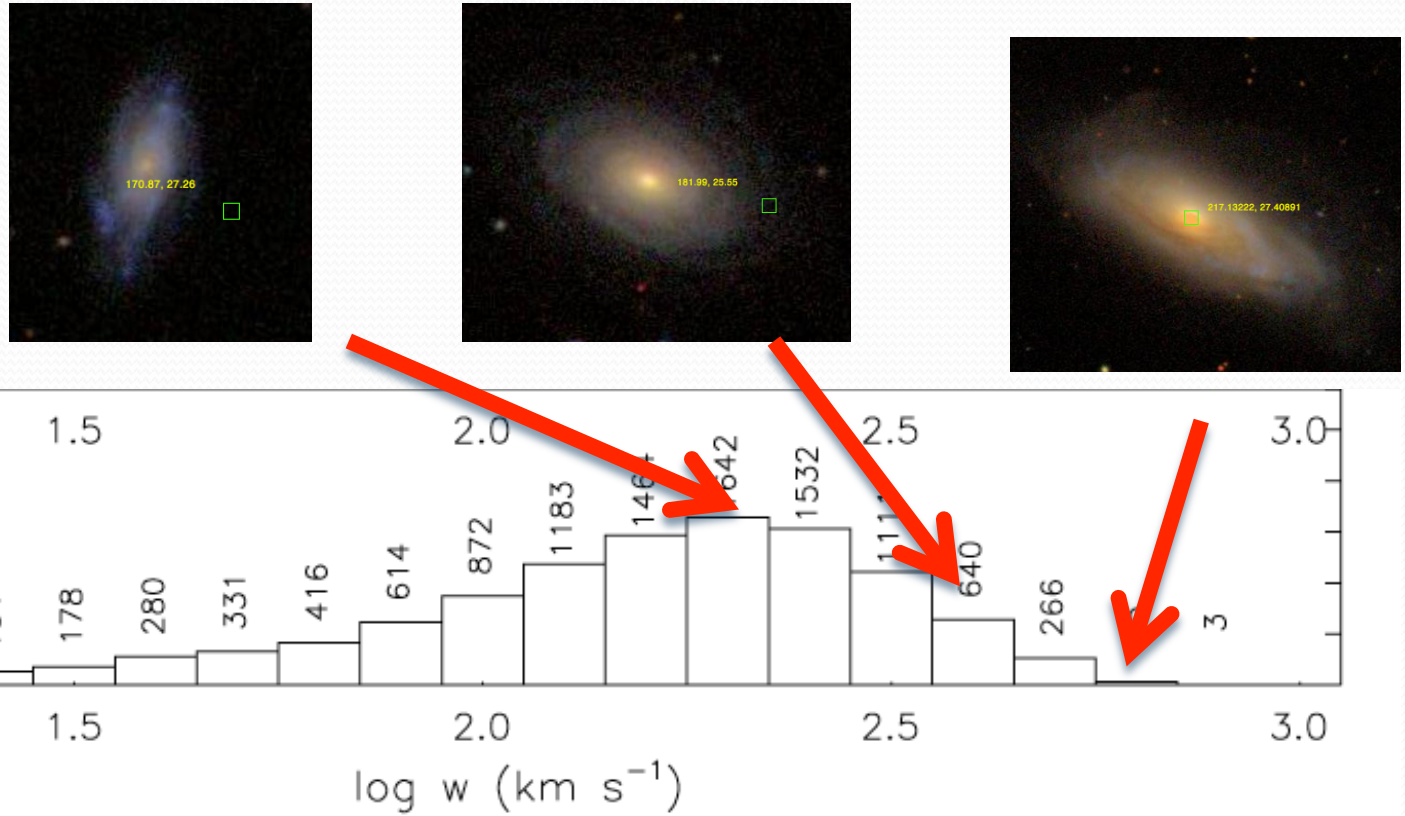
- ALFALFA *cannot* directly measure any spatially resolved property:
  - galaxy size
  - inclination
  - rotation curve
  - surface density



how do we make a WF?



how do we make a WF?



how do we make a WF?