Statistical analysis of ALFALFA galaxies: insights in galaxy formation & near-field cosmology

Manolis Papastergis

NOVA postdoctoral fellow

Kapteyn Institute/University of Groningen

2013 Hel.A.S. Conference Athens, 10 September 2013

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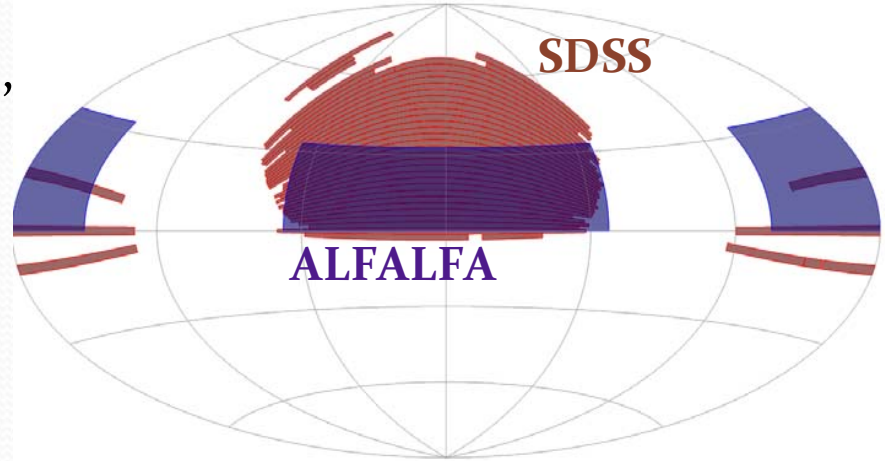
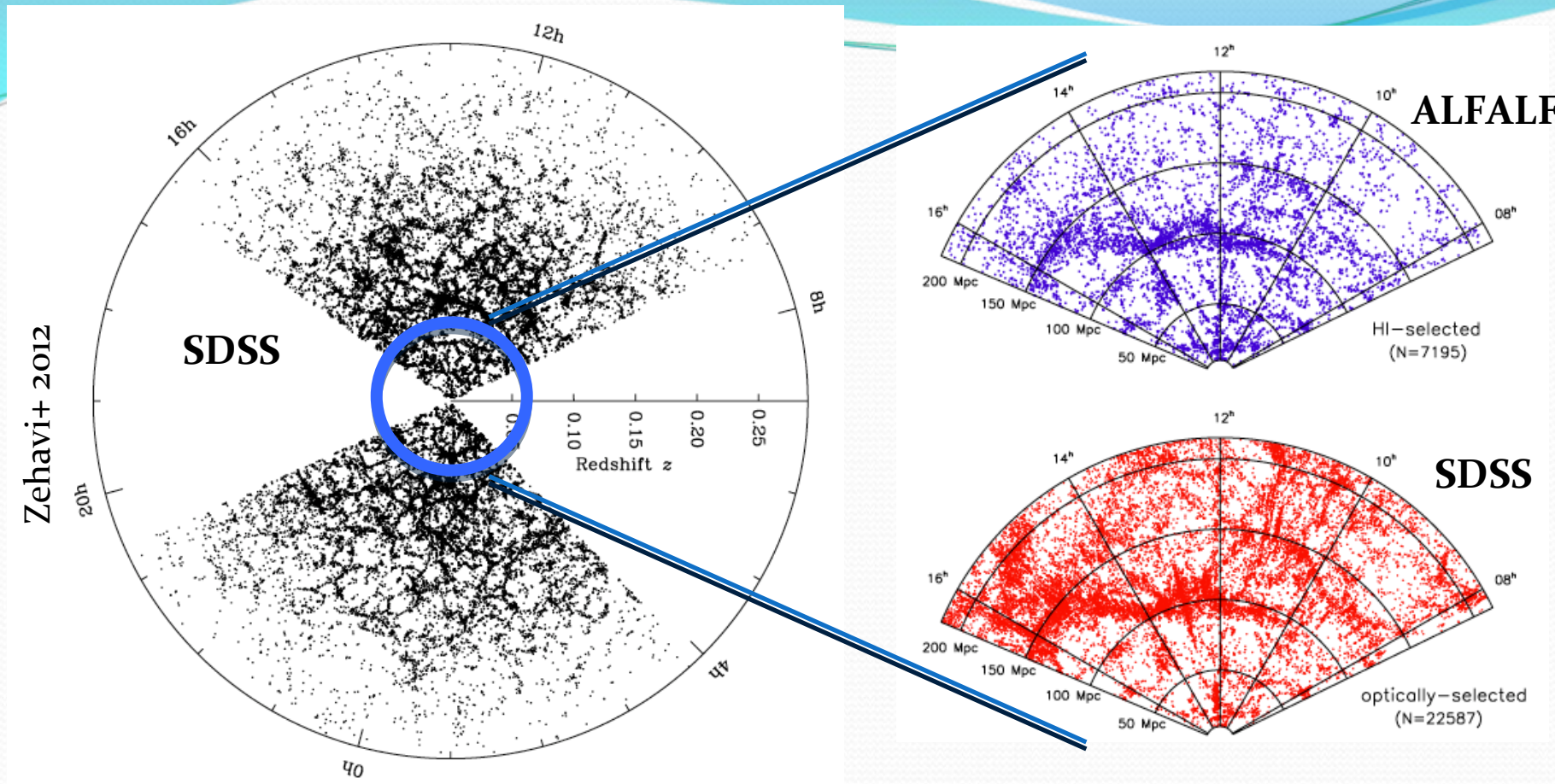
the ALFALFA survey

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

- ALFALFA is a ***21-cm*** survey of ***local galaxies***, done with the ***Arecibo*** radiotelescope (PI: R. Giovanelli, Cornell).
- ALFALFA is a ***blind*** survey, and detects galaxies based on their ***atomic hydrogen (HI)*** content.
- So far, it has detected **15 000+** sources, producing the ***largest HI-selected*** sample to date.





- **ALFALFA**:
  - *7 000 sq.deg.*
  - *median z ~ 0.025, max z = 0.06*
  - *30 000+ sources*
  - *volume ~ 0.003 Gpc³*
- **SDSS**:
  - *9 380 sq.deg.*
  - *median z ~ 0.1, max z ~ 0.3*
  - *~ 930 000 spectr. sources*
  - *volume ~ 0.6 Gpc³*

the ALFALFA survey

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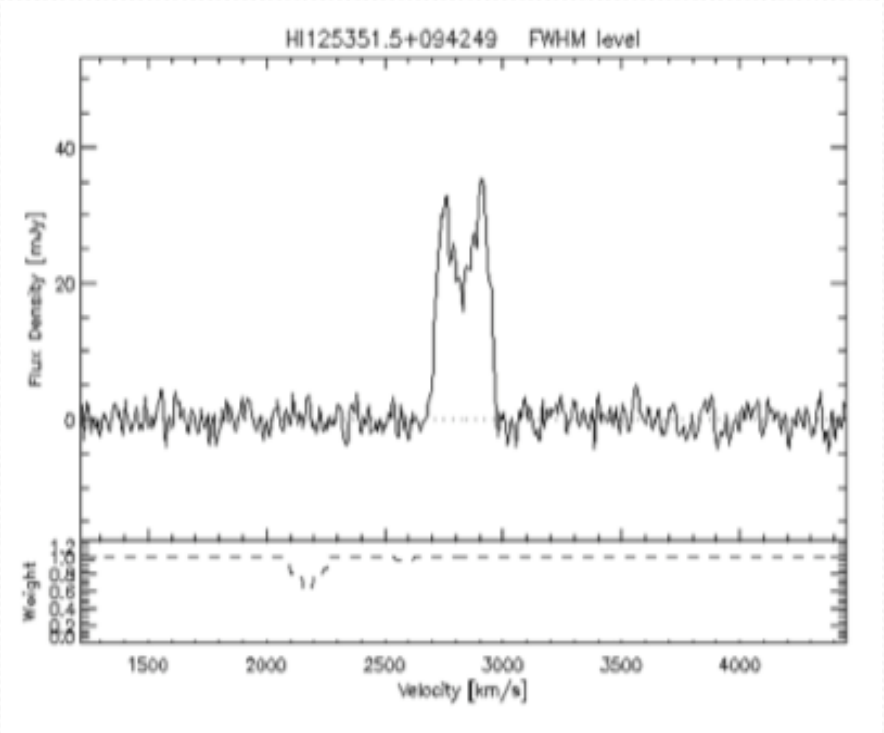
- ALFALFA directly measures three galactic properties:
  - redshift
  - integrated flux (& HI mass)
  - velocity width



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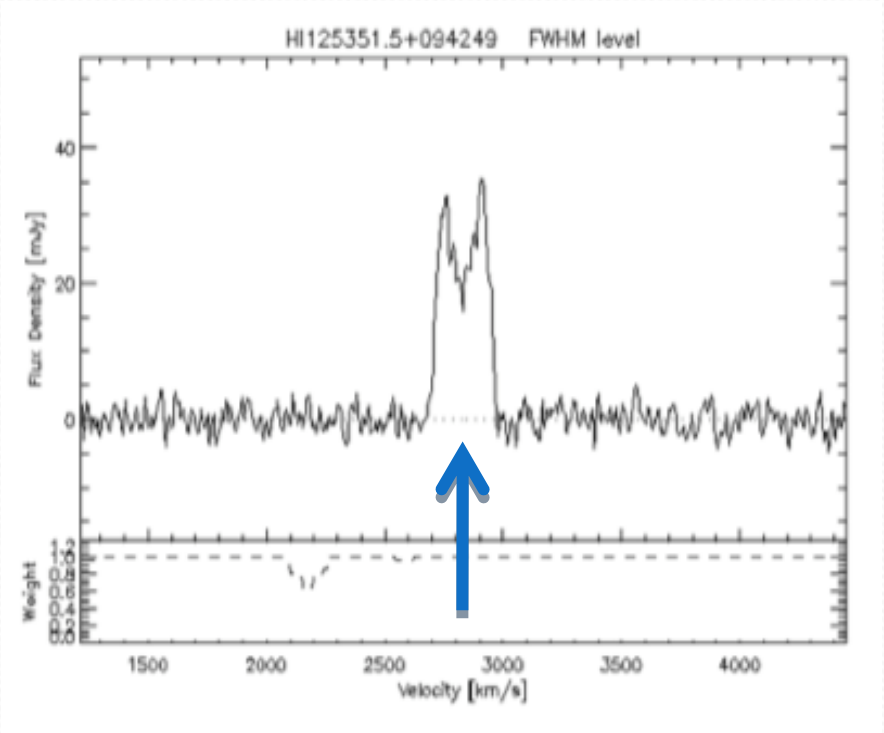

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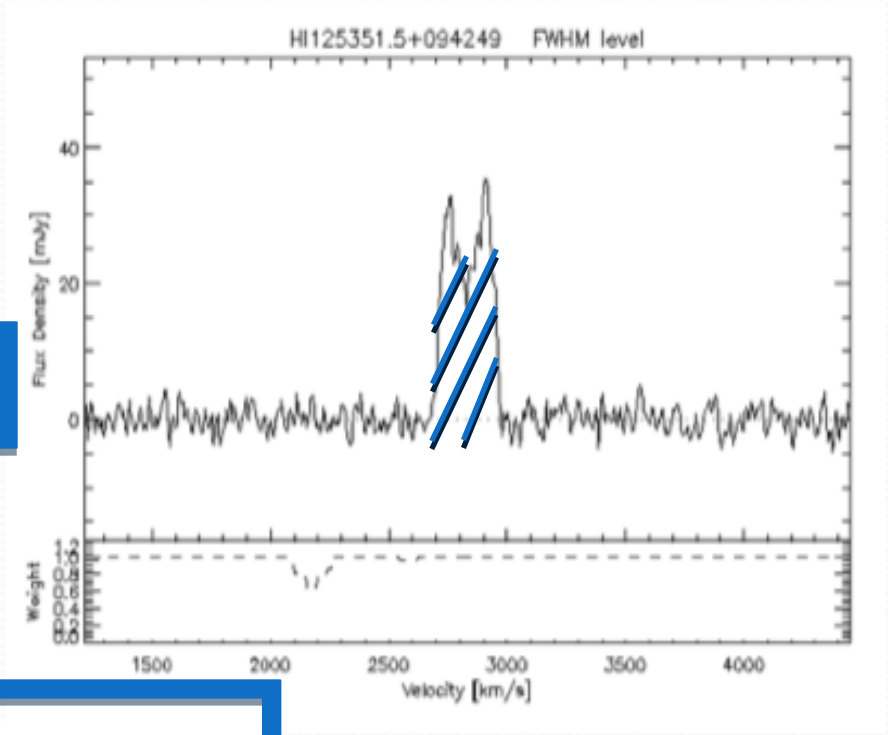

$$M_{HI}(M_\odot) = 2.35\,10^5 \text{ x } D^2 \text{ (Mpc) x } S_{int} \text{ (Jy kmsec}^{-1}\text{)}$$

the ALFALFA survey

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

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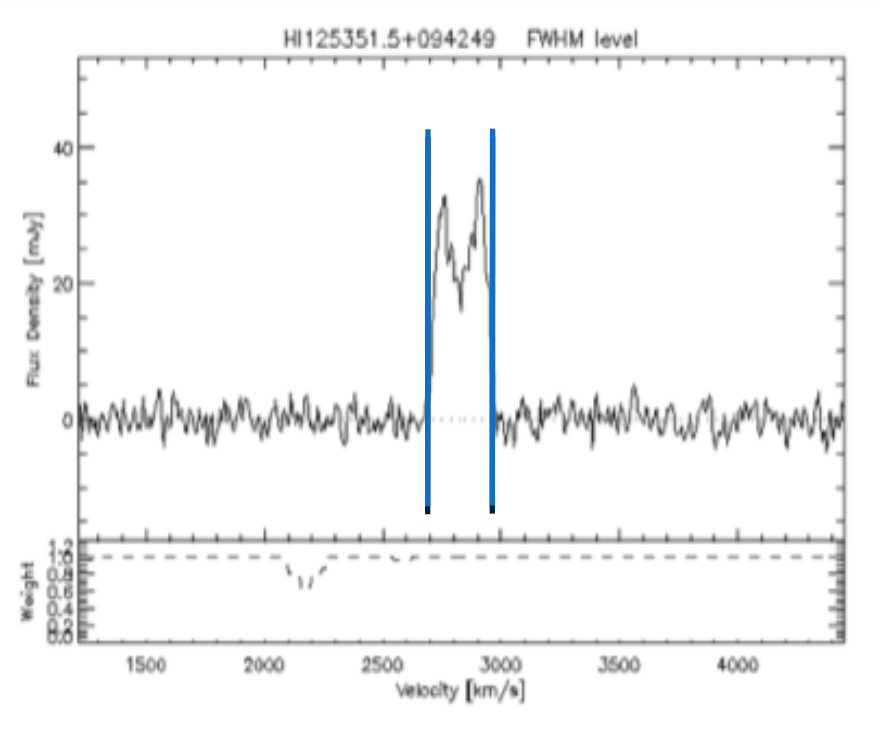
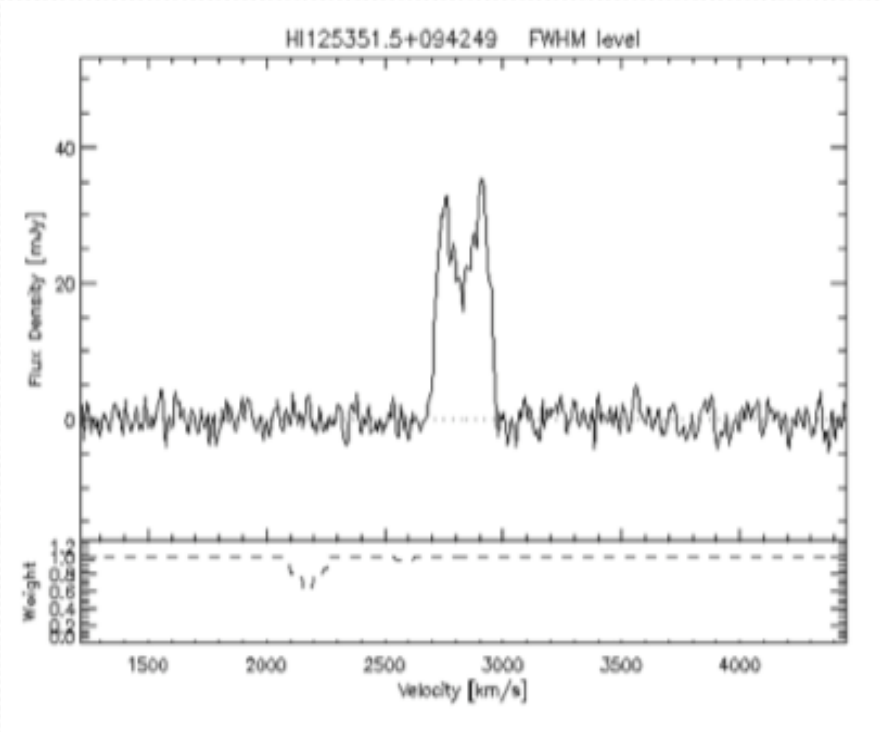


the ALFALFA survey

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

- ALFALFA directly measures three galactic properties:
  - redshift
  - integrated flux (& HI mass)
  - velocity width
- for most exgal sources, ALFALFA *cannot* measure spatially-resolved properties:
  - size, shape, inclination, rotation curve



galaxy formation & evolution

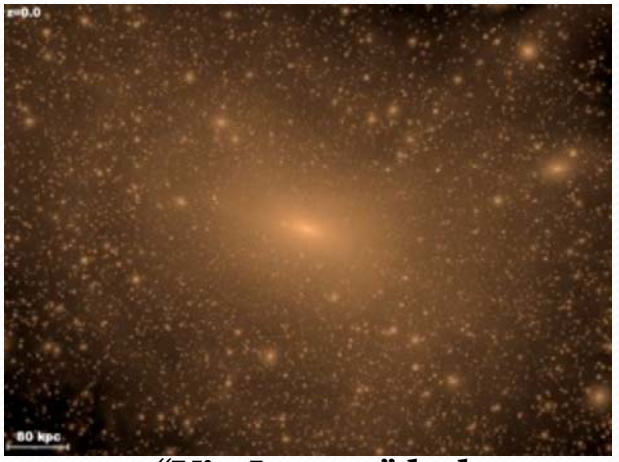
based on:

"*A direct measurement of the baryonic mass function of galaxies & implications for the galactic baryon fraction*", Papastergis E., Cattaneo A., Huang S., Giovanelli R., Haynes M.P., *ApJ*, 759, 138 (2012)

"*The clustering of ALFALFA galaxies: dependence on HI mass, relationship to optical samples & clues on host halo properties*", Papastergis E., Giovanelli R., Haynes M.P., Rodriguez Puebla A., Michael G. Jones *accepted by ApJ* (arXiv: 1308.2661)

galaxy-halo connection

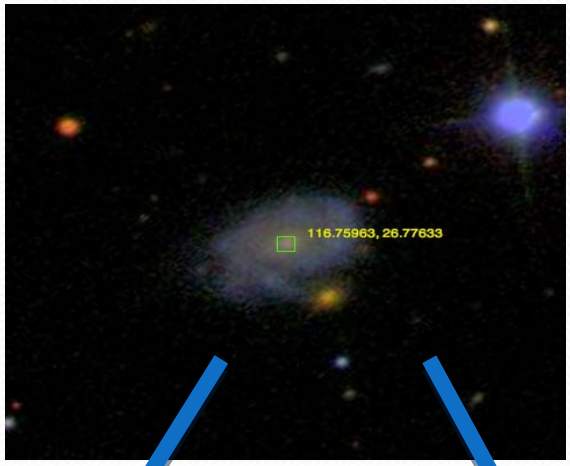
M83 galaxy



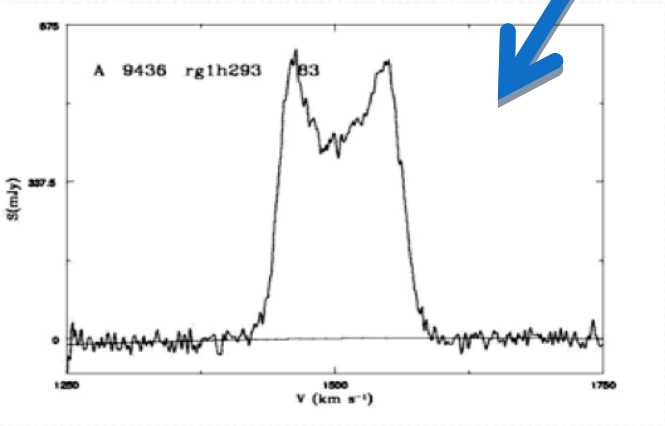
"Via Lactea" halo
(Diemand+ 2007)

- Establishing a **connection** between observed galaxies and dark matter halos is the **key** to understanding galaxy formation.

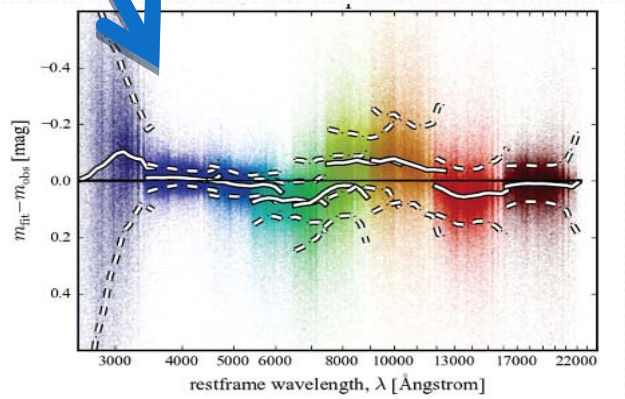
baryonic contents of galaxies



HI mass: ALFALFA flux



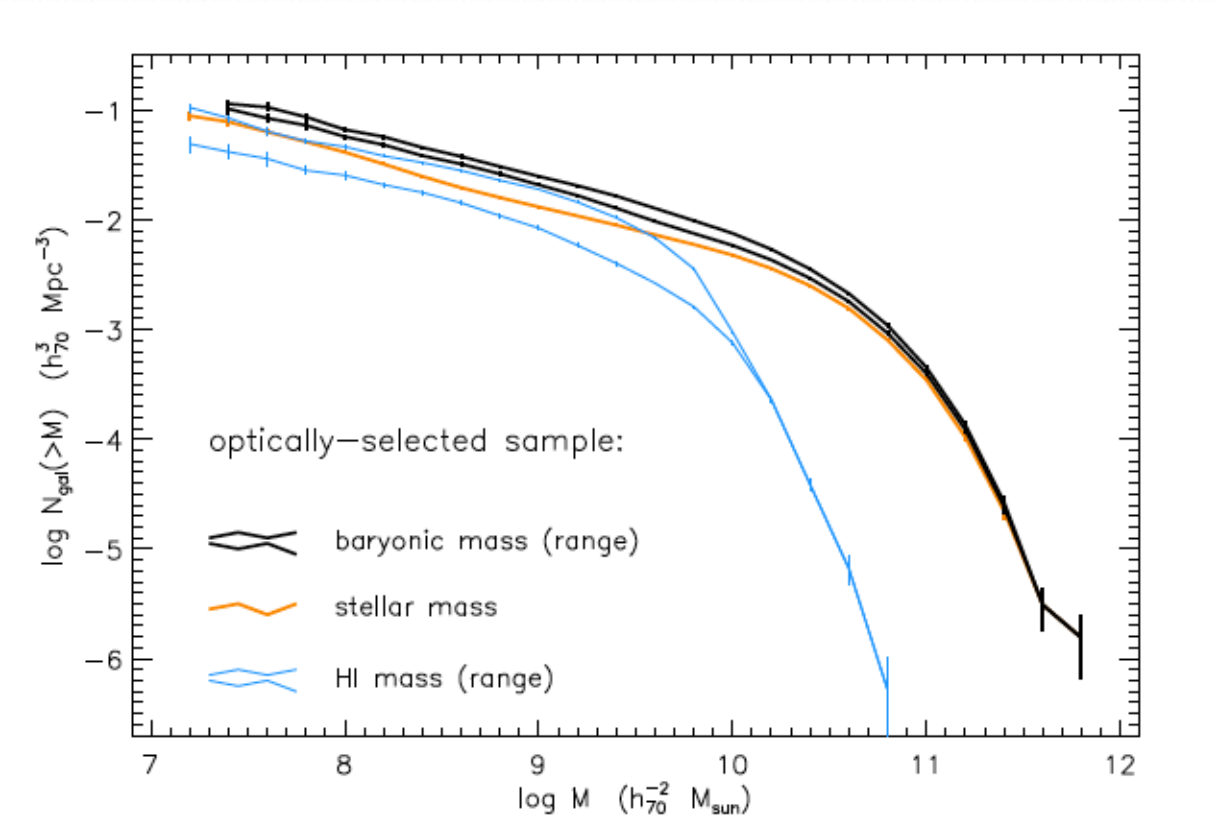
stellar mass: SED-fitting of SDSS *u,g,r,i,z*



Huang+ (2012a)

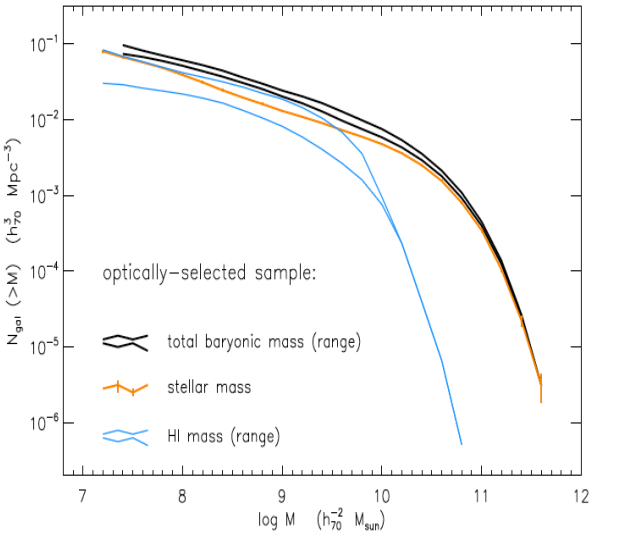
baryonic contents of galaxies

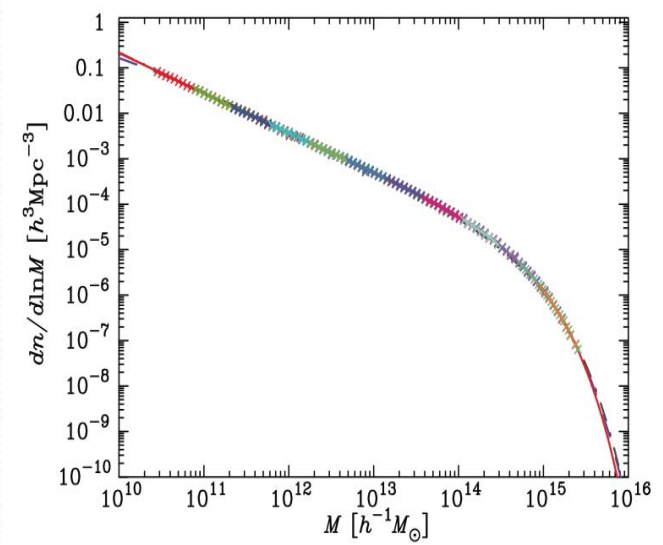
baryonic mass function



Papastergis+ (2012)

abundance matching





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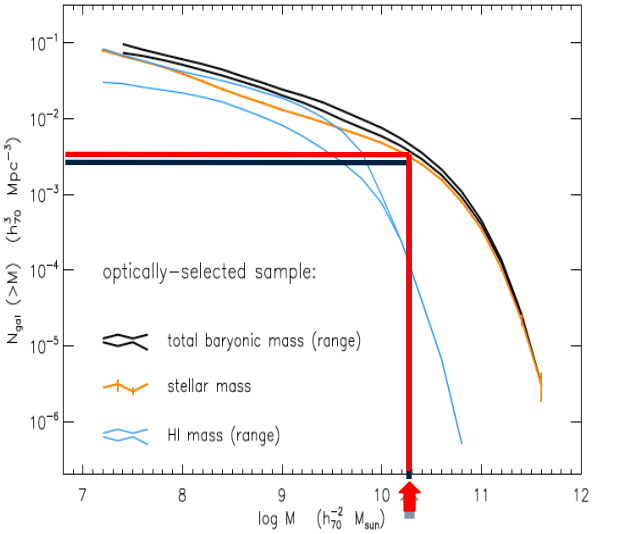

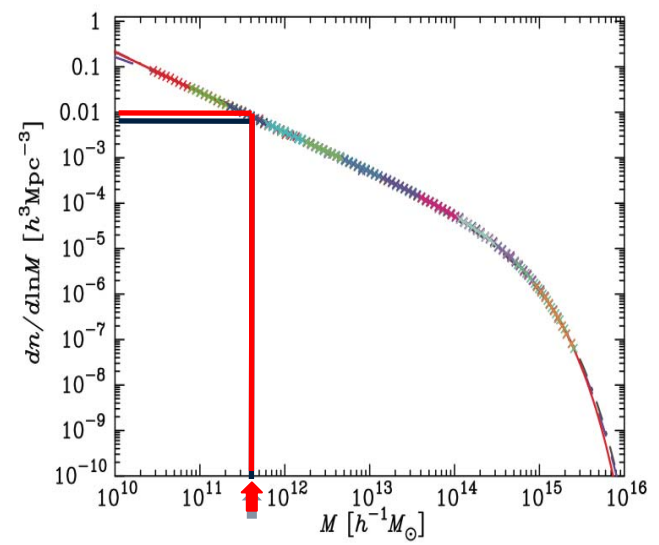

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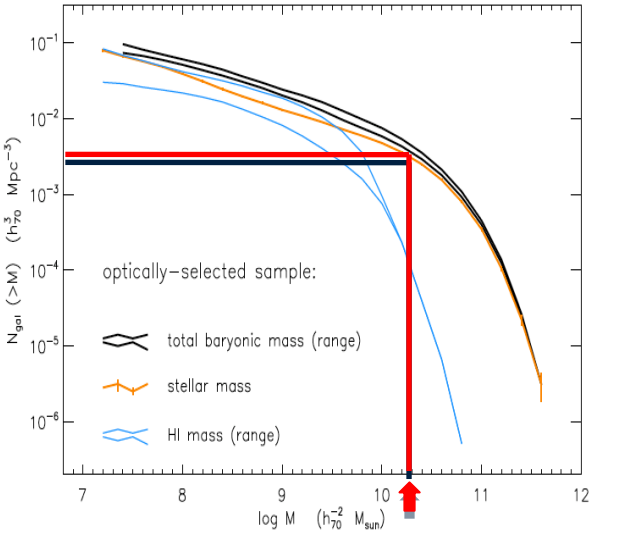

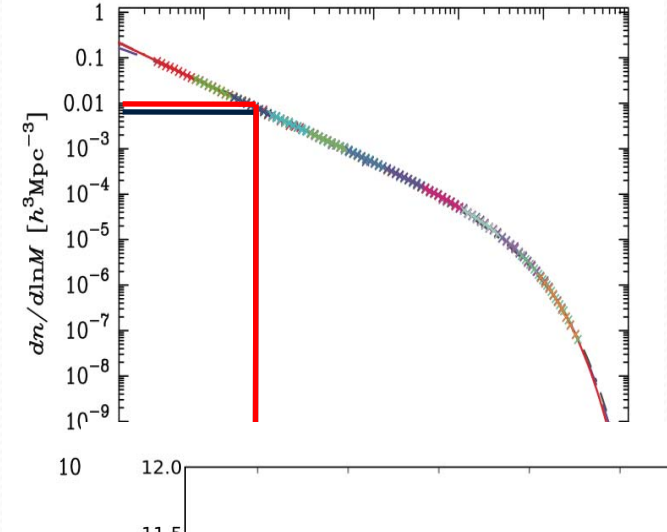

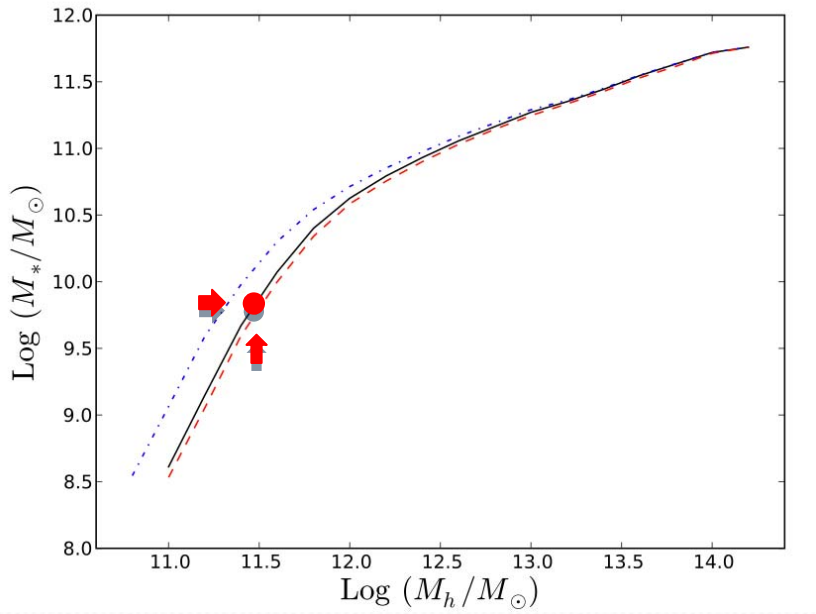

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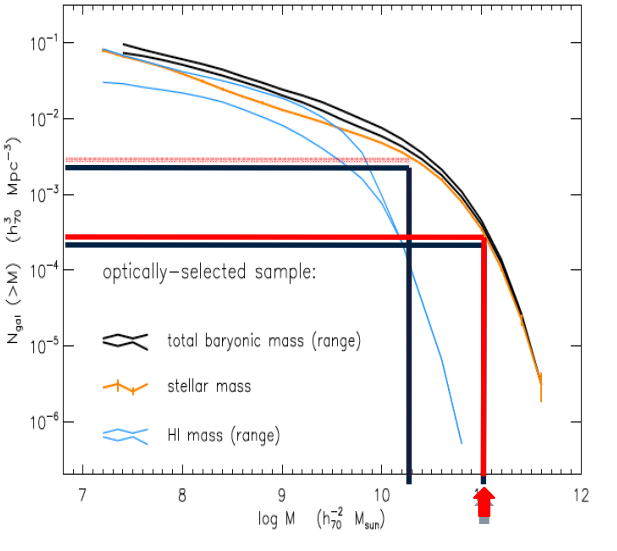

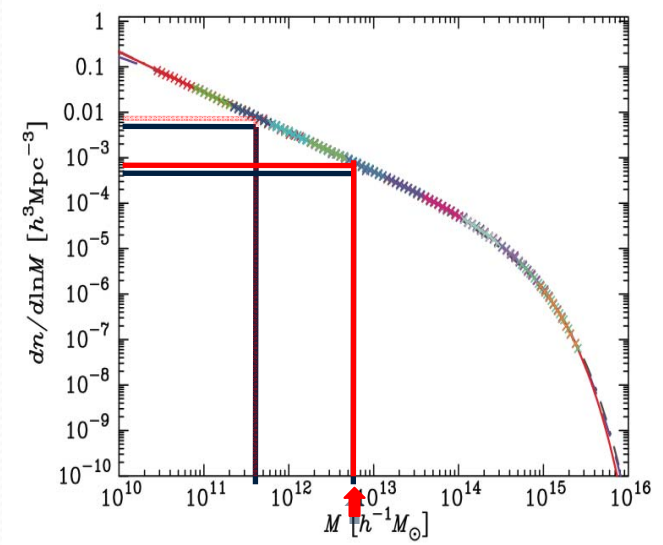

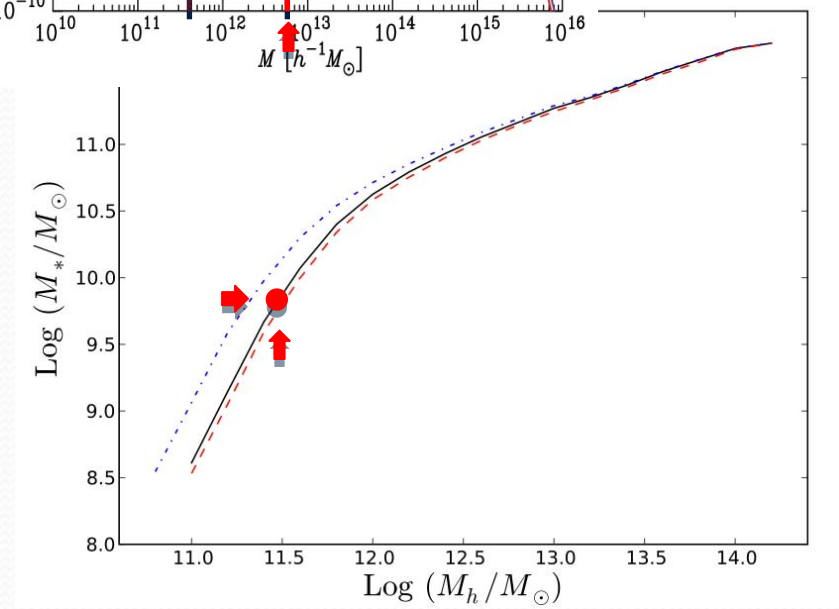

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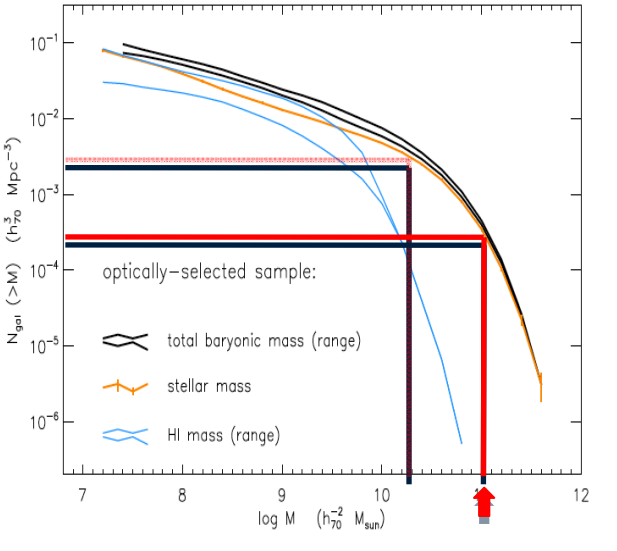

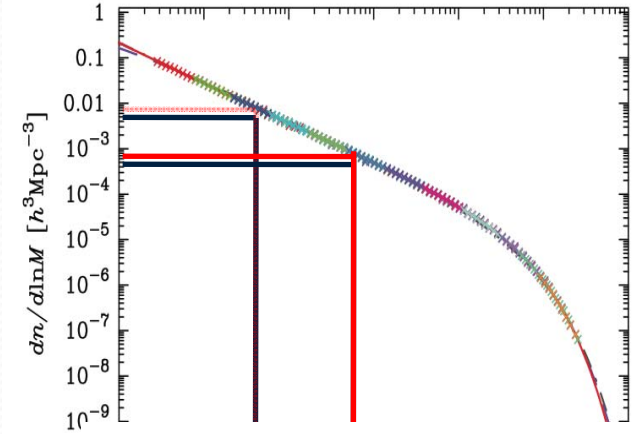

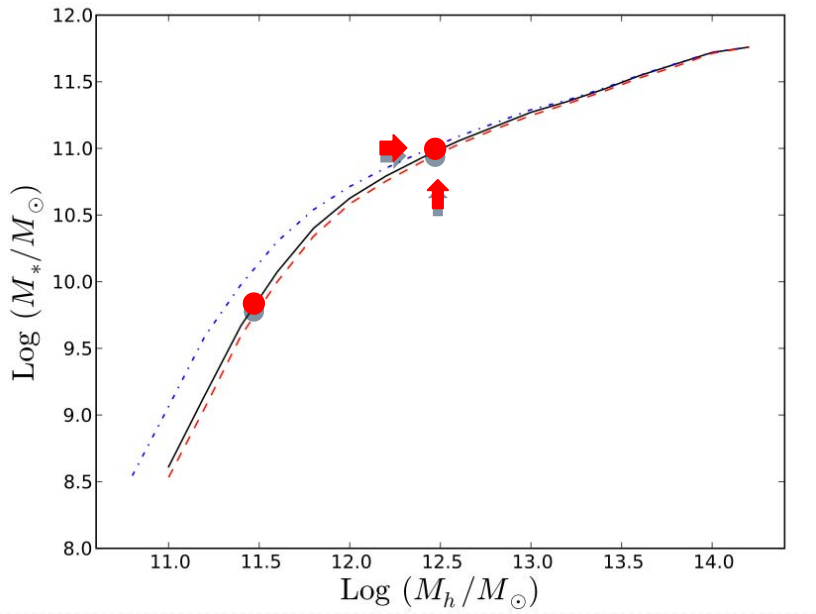

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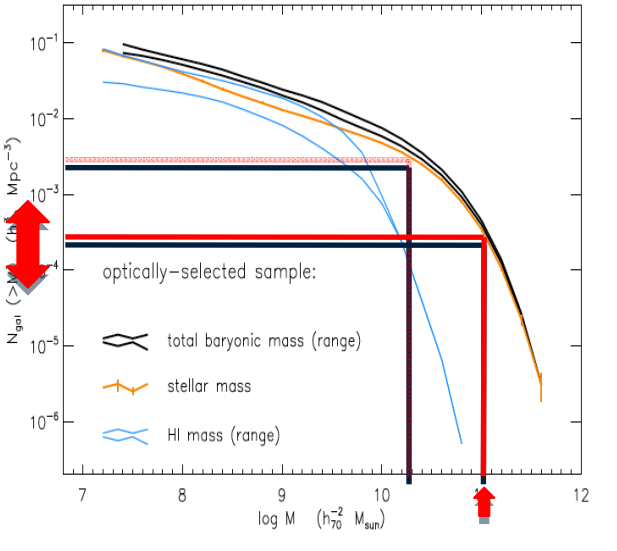
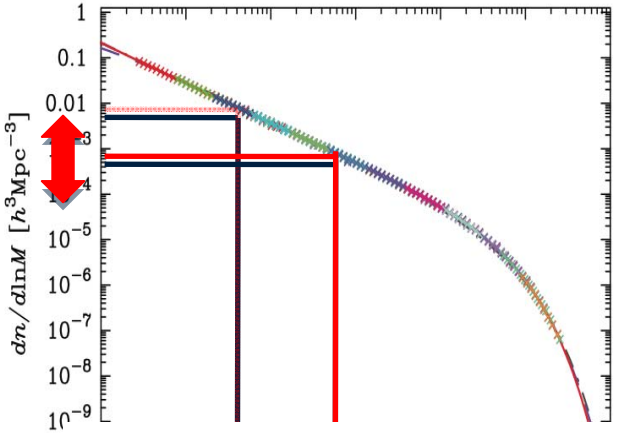
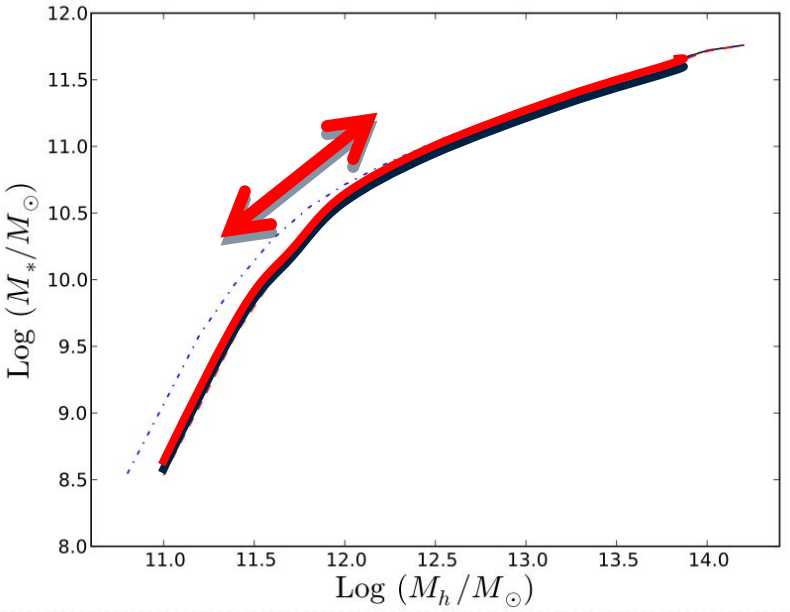
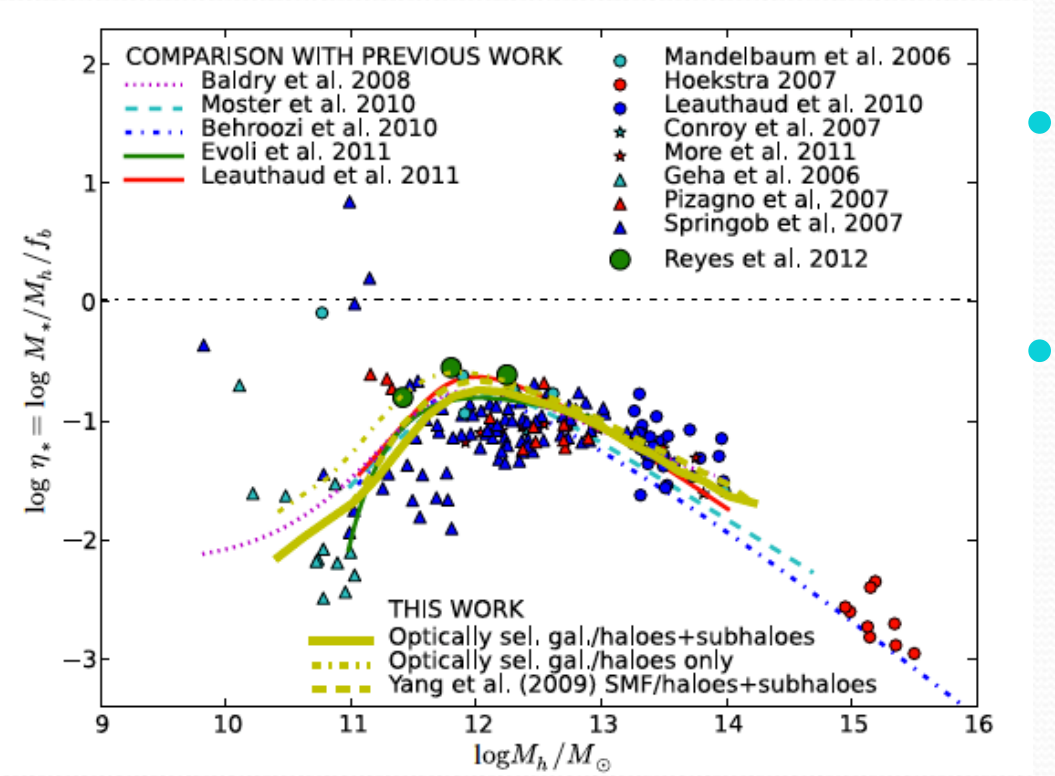






stellar content of galaxies

stellar mass fraction vs. halo mass

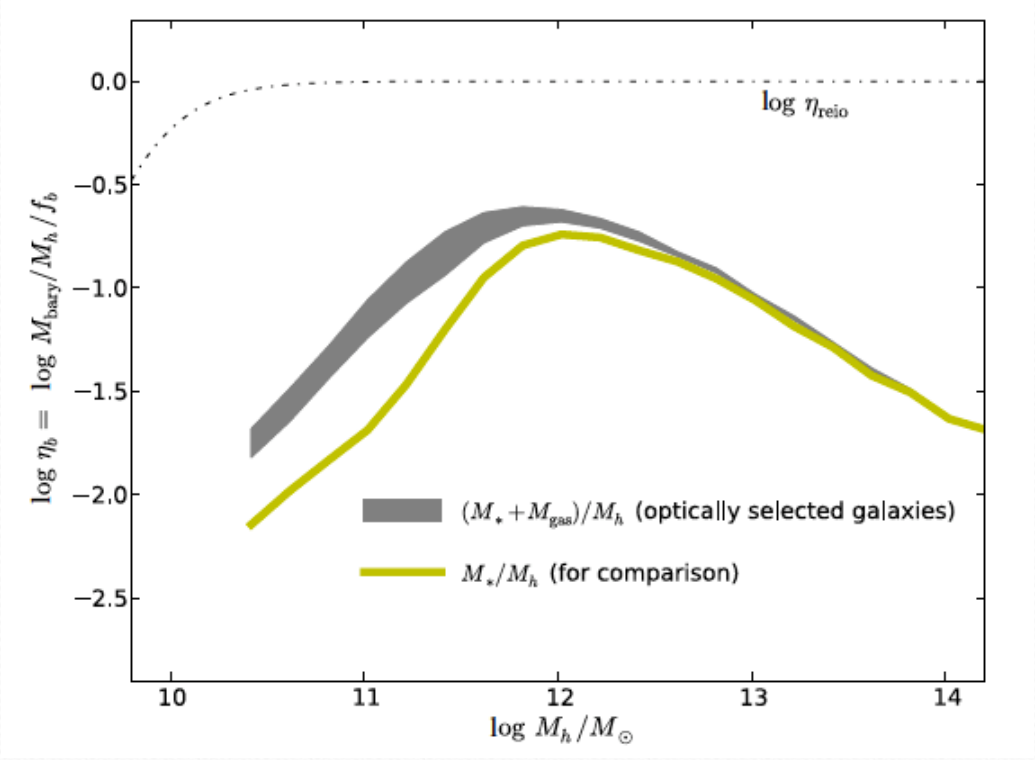


Papastergis+ (2012)

- ***no*** galaxy turns its ***"share"*** of baryons into ***stars***.
- ***MilkyWay***-size galaxies are the ***most efficient***, with stellar conversion efficiency of **30%**.

baryonic content of galaxies

baryonic mass fraction vs. halo mass

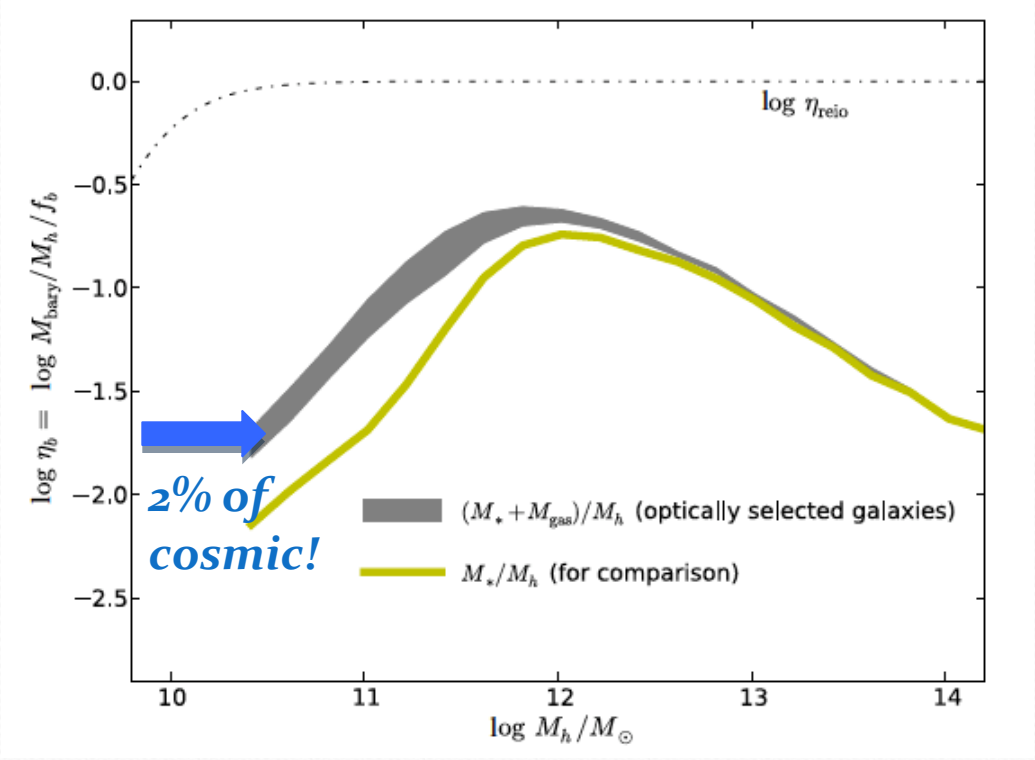


Papastergis+ (2012)

- ***Low mass*** *halos are severely* ***baryon depleted,*** *even when* ***atomic gas*** *content is taken into account*

baryonic content of galaxies

baryonic mass fraction vs. halo mass



Papastergis+ (2012)

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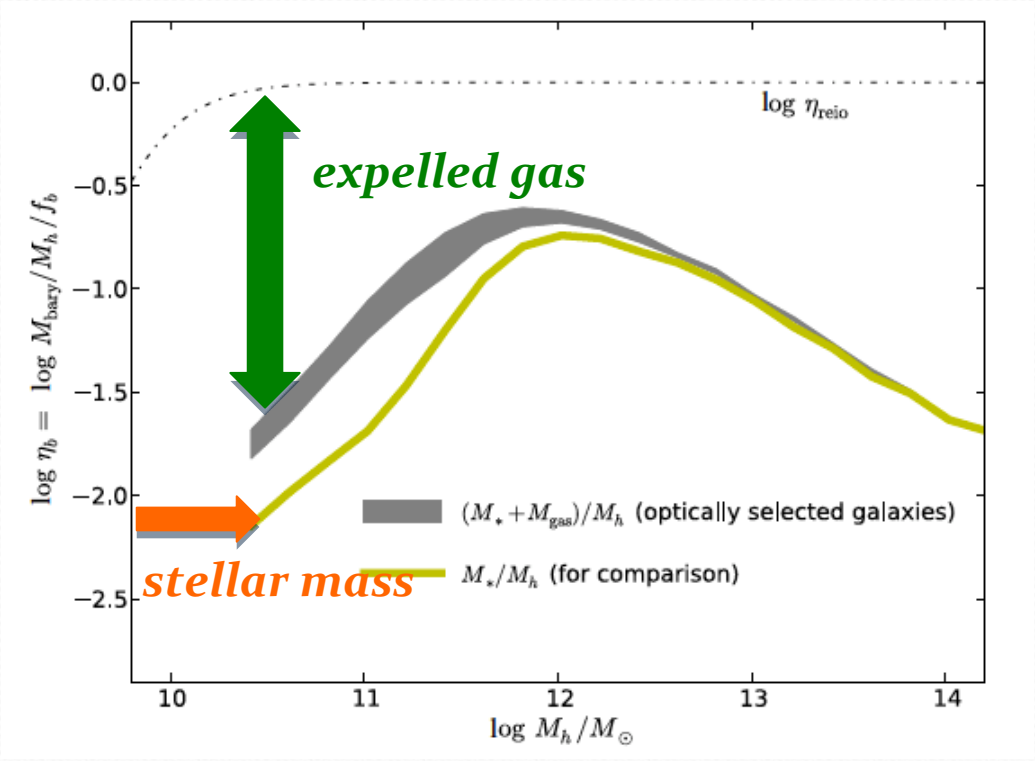
galactic feedback

baryonic mass fraction vs. halo mass



Papastergis+ (2012)

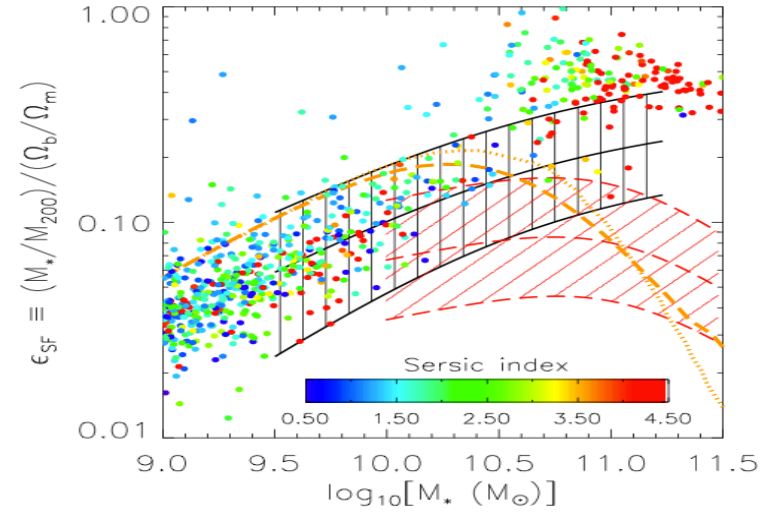
- In low mass halos,

expelled gas mass = 100 x stellar mass

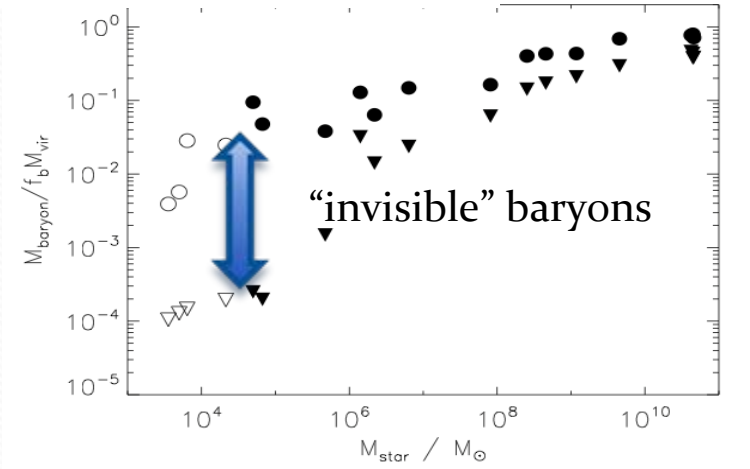
galactic feedback

galactic feedback in hydro simulations

McCarthy+ (2012)



Munshi+ (2012)



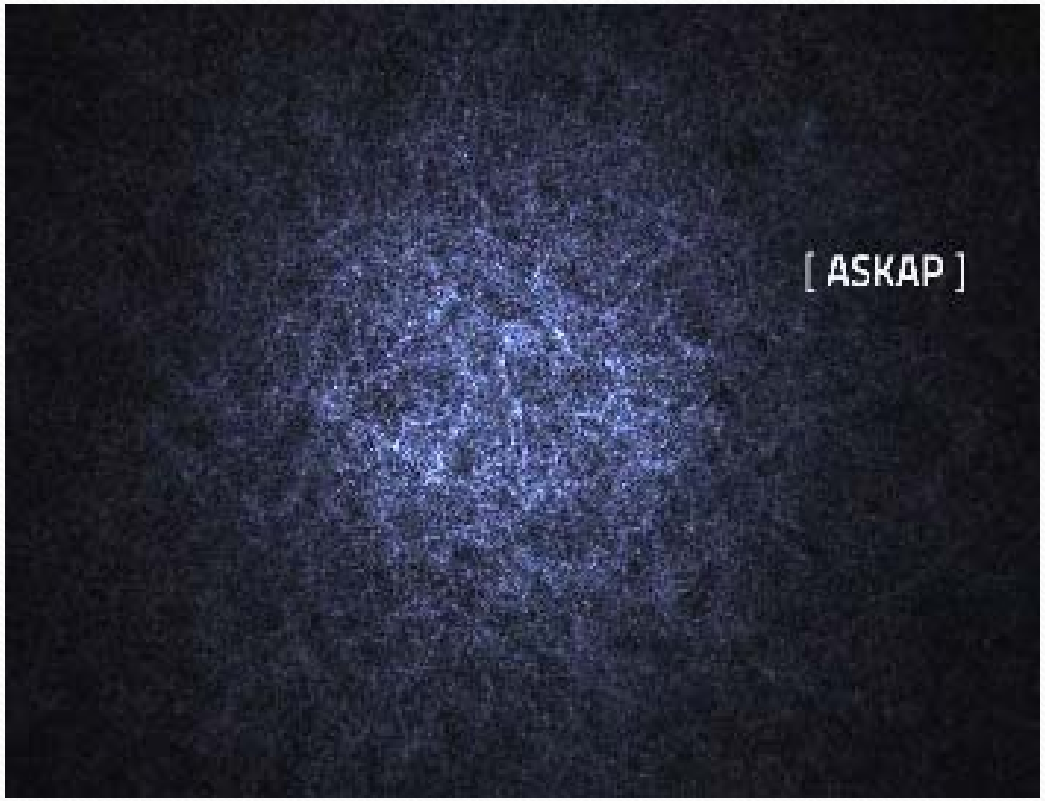
- *Extremely efficient SN feedback?*

... or ...

- *"Invisible" baryons?*

the era of cosmological HI surveys

Wallaby survey virtual sample

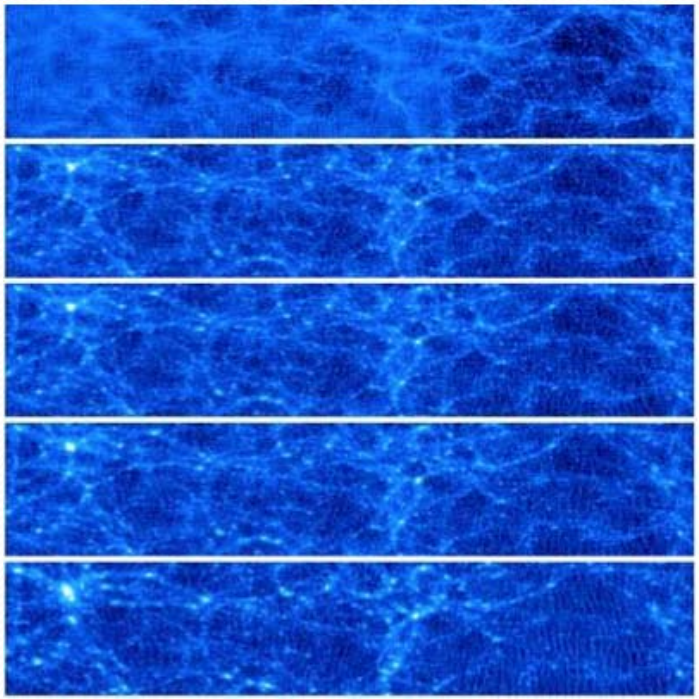


credit: Alan Duffy (ICRAR)

- Near-future HI surveys
  - **Wallaby** (ASKAP, Australia)
  - **WNSHS** (WSRT, Netherlands)
  - **FAST** (China)
- Will measure **>500 000** galaxy redshifts

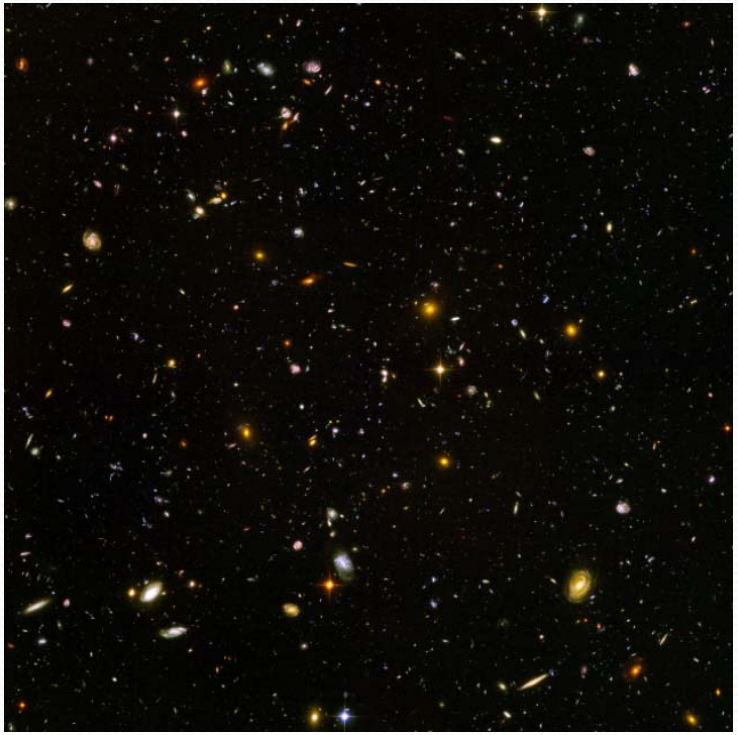
advanced galaxy modeling & cosmology

we predict this…



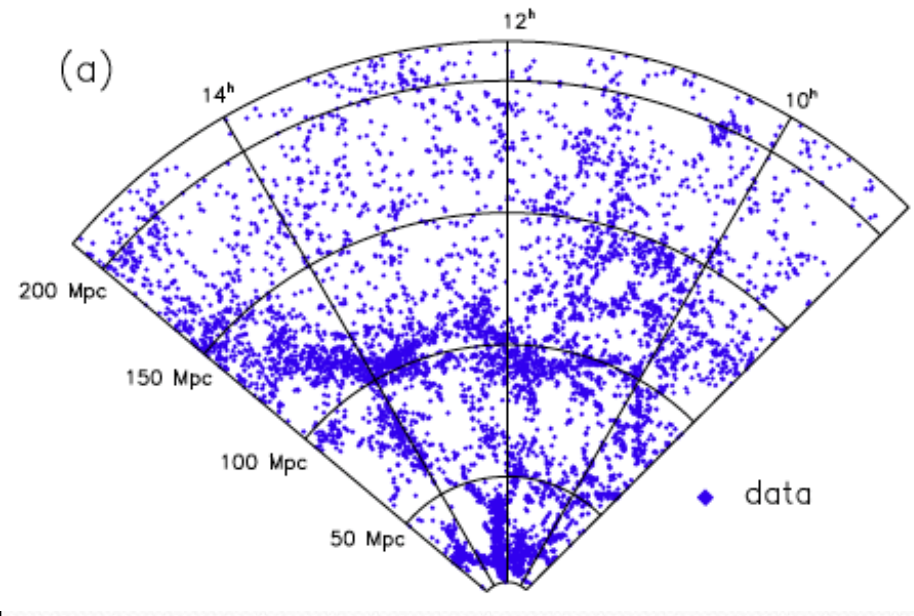
Dalal+ (2008)

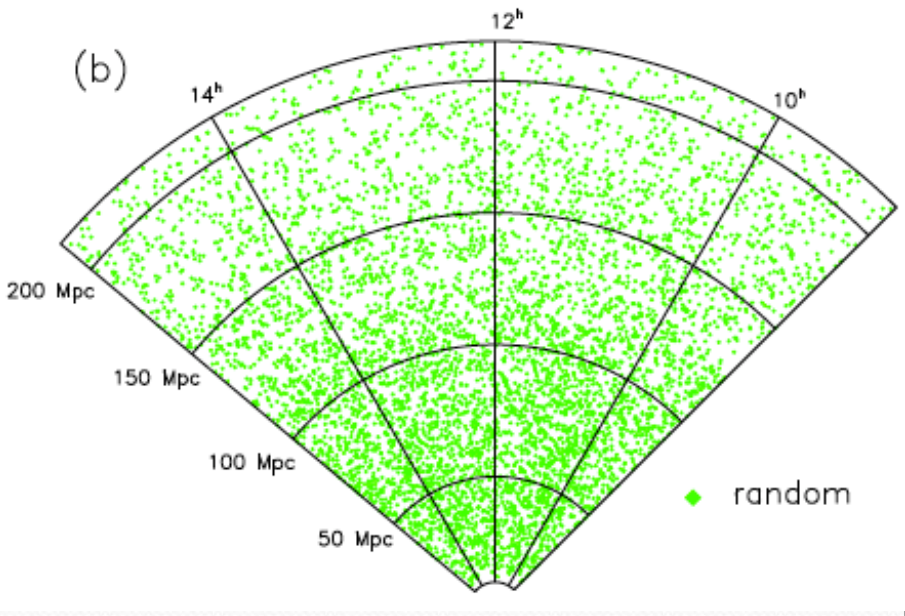
… but we measure this



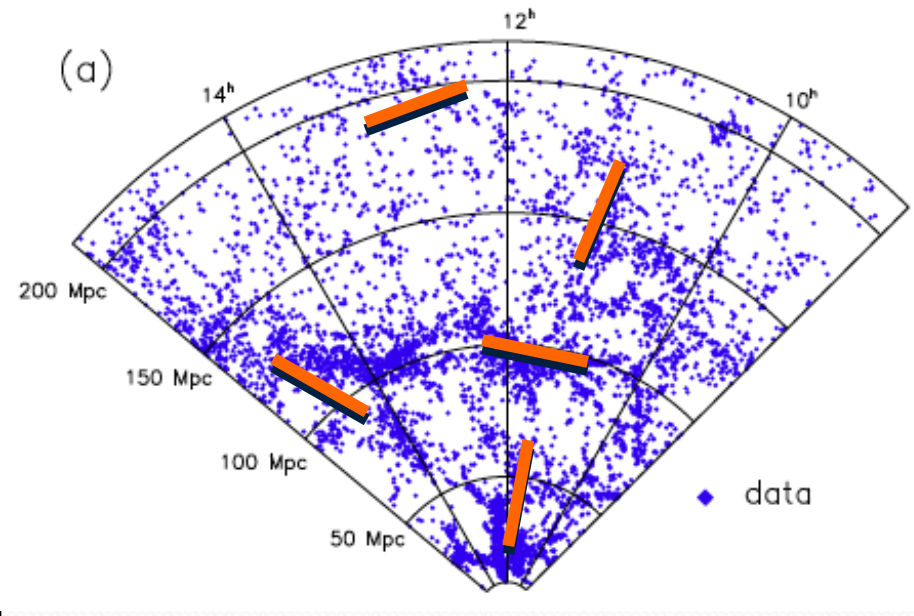
A **detailed model** of the galaxy-halo connection is necessary for using **galaxy surveys** for **cosmology**

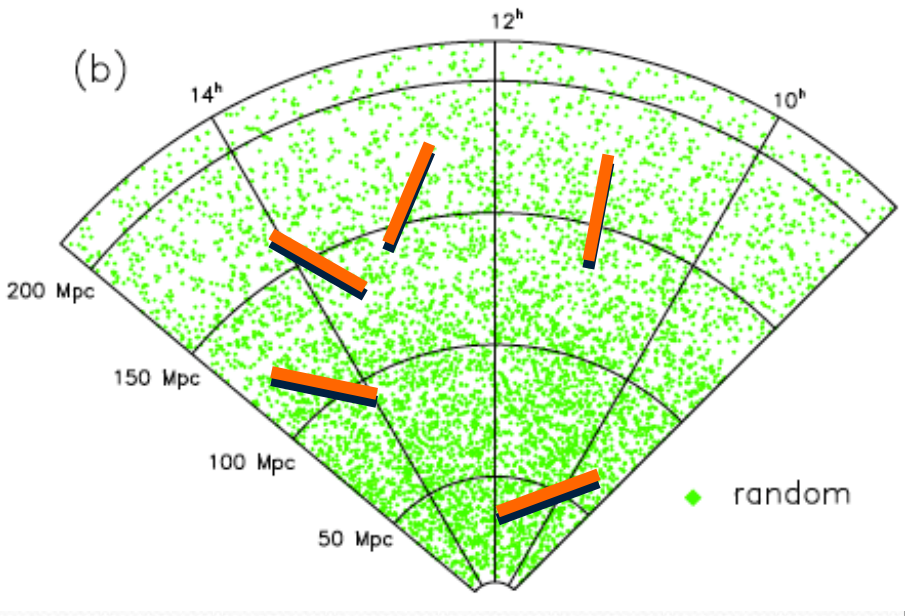
galaxy clustering



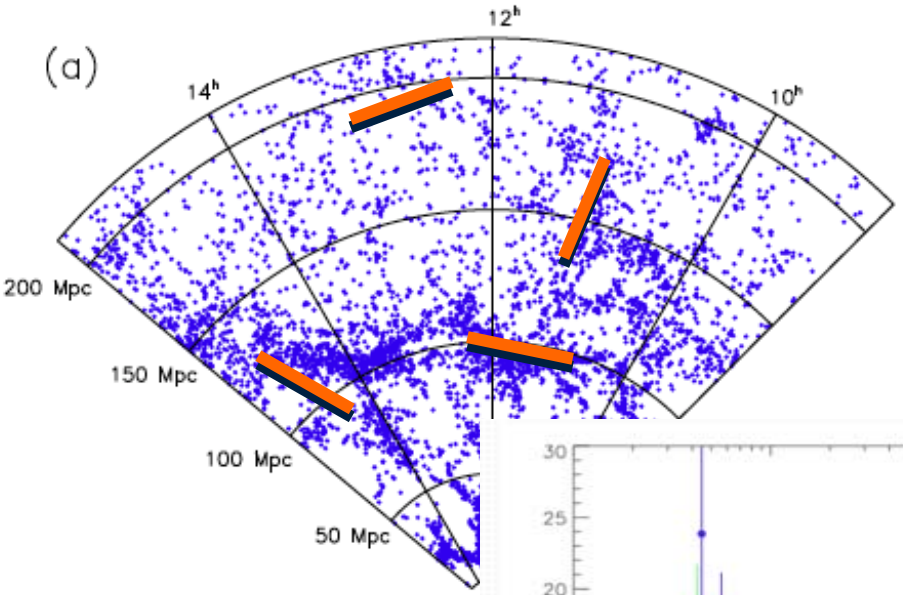


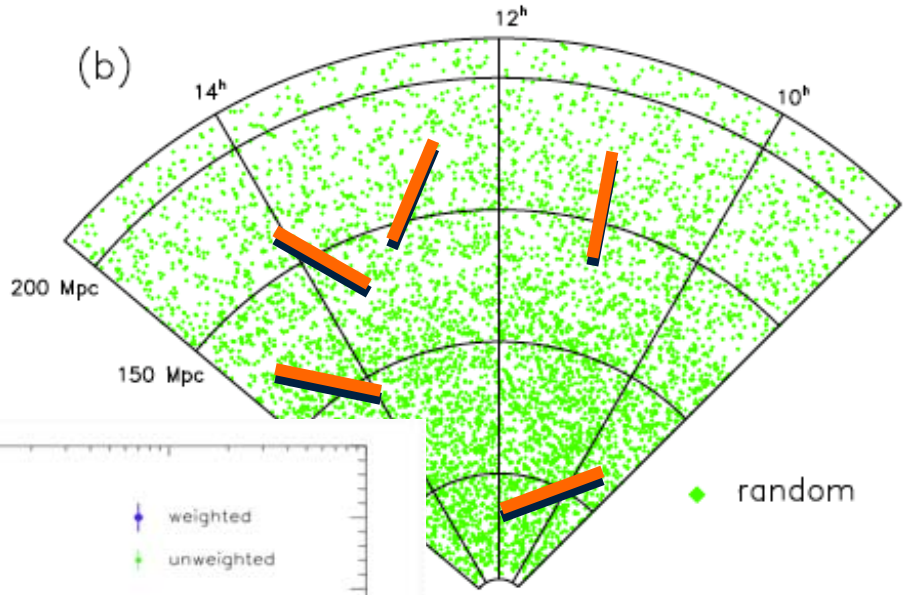
galaxy clustering

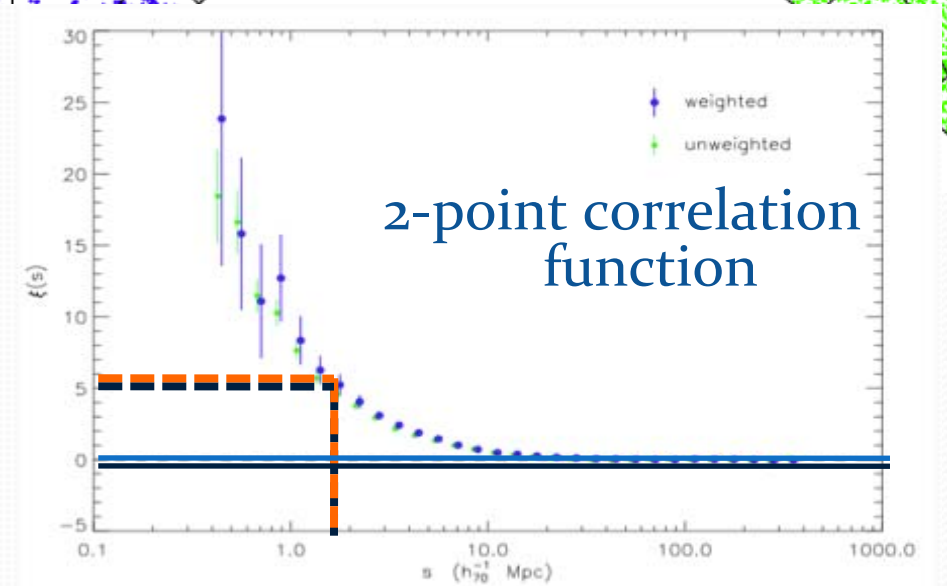




galaxy clustering



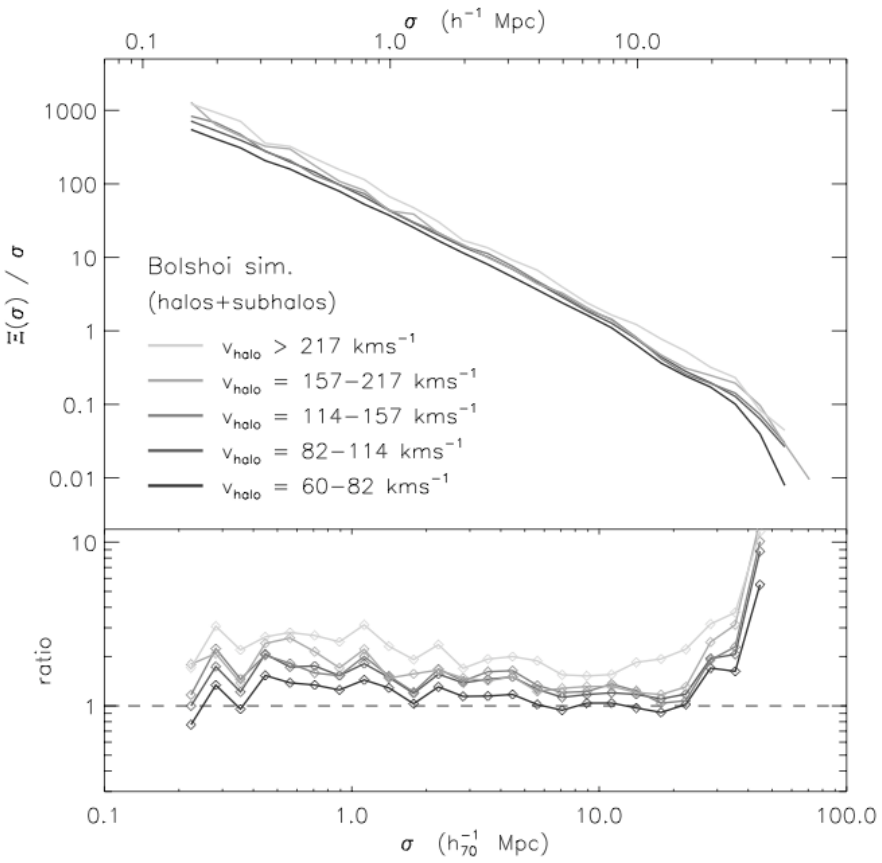




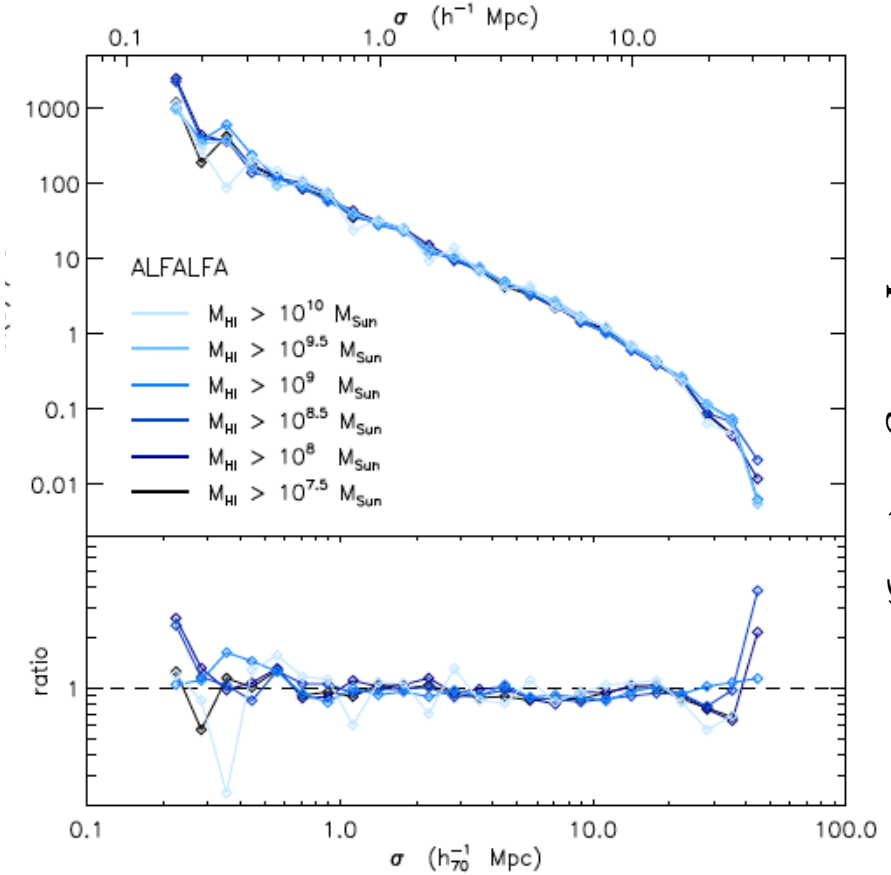
2-point correlation function

dependence of clustering on mass

ΛCDM halos



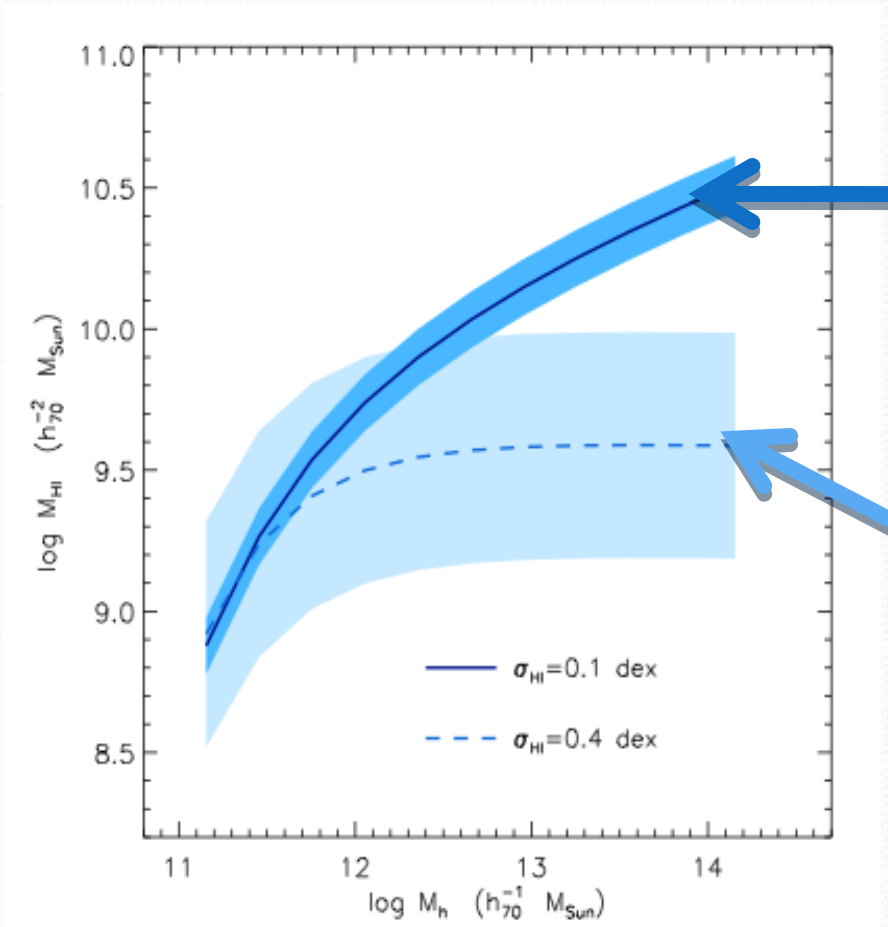
ALFALFA galaxies

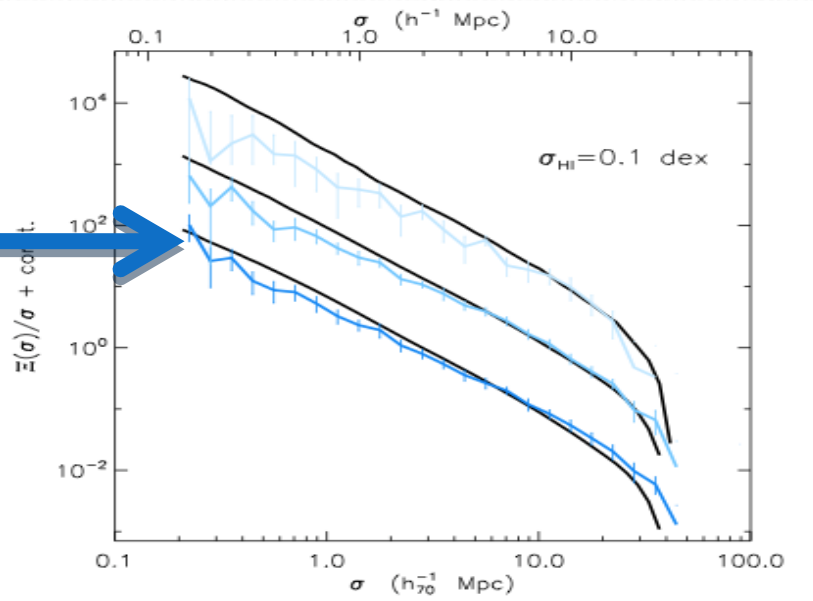


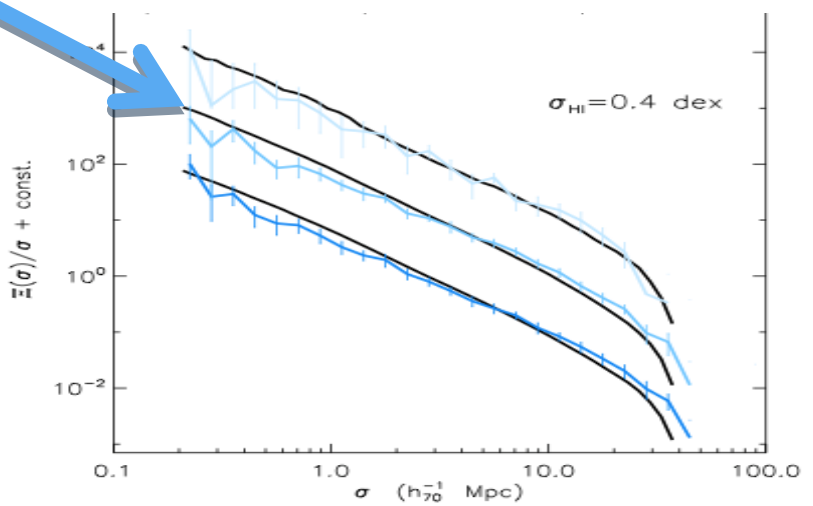
Papastergis+ (2013)

- HI mass is **not tightly** related to host halo mass

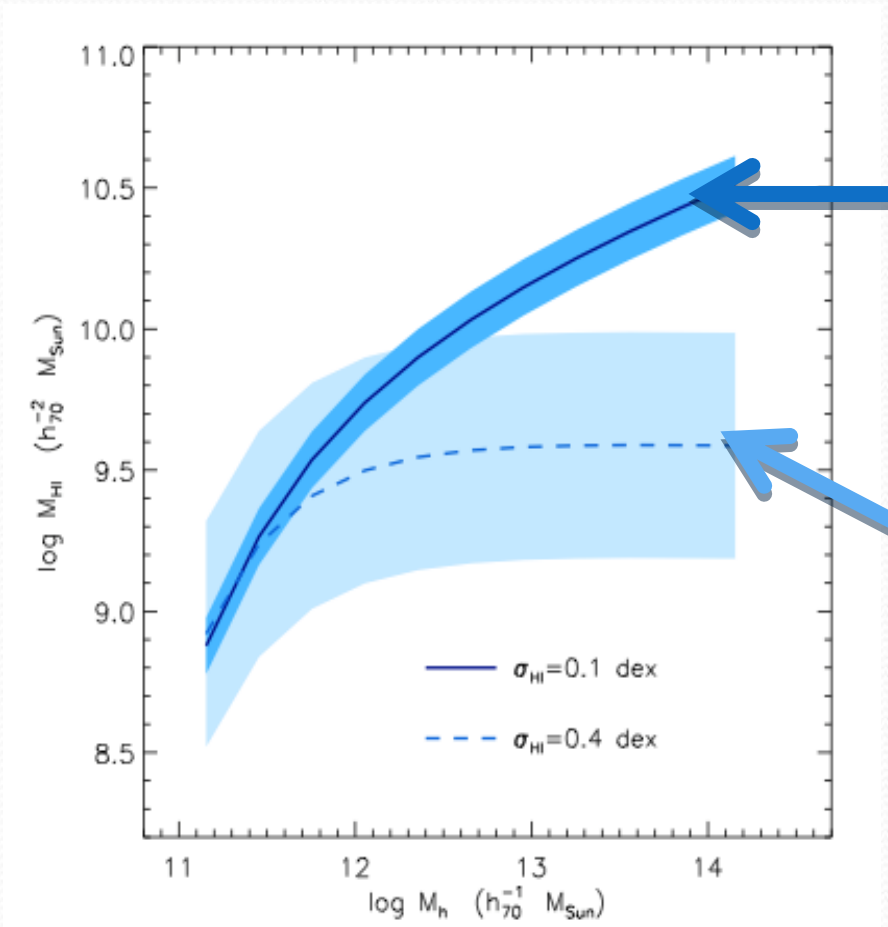
$M_{HI} - M_{halo}$ relation

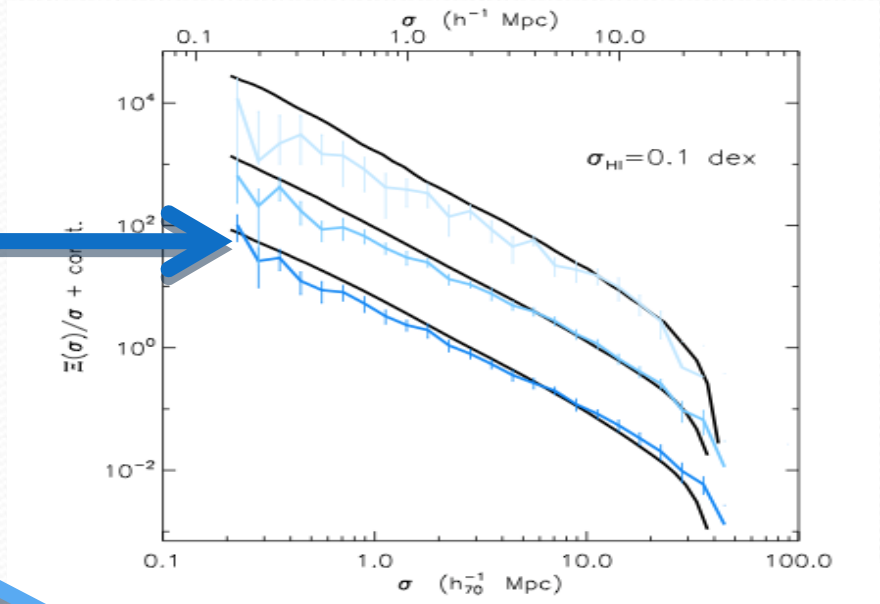


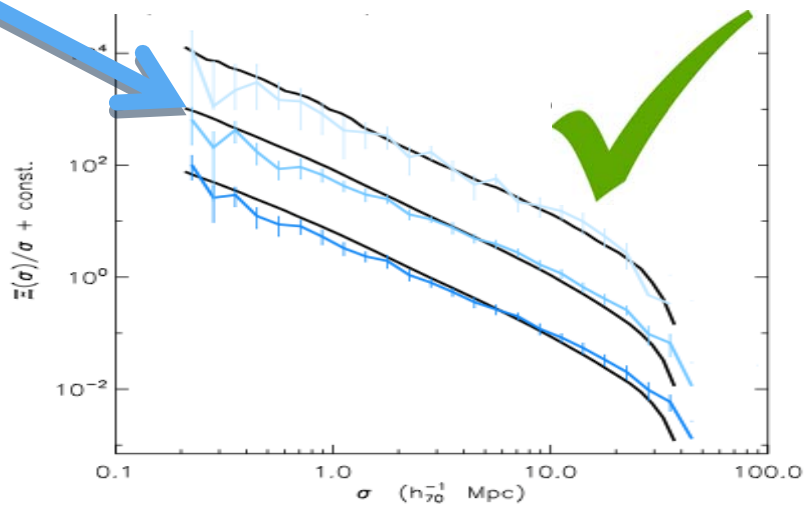




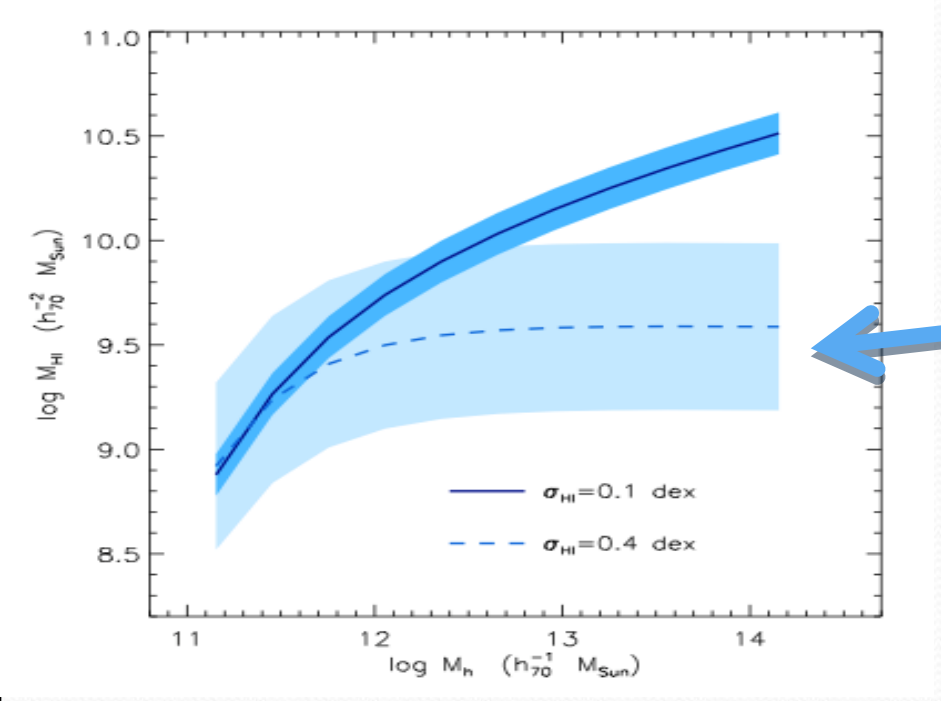
$M_{HI} - M_{halo}$ relation

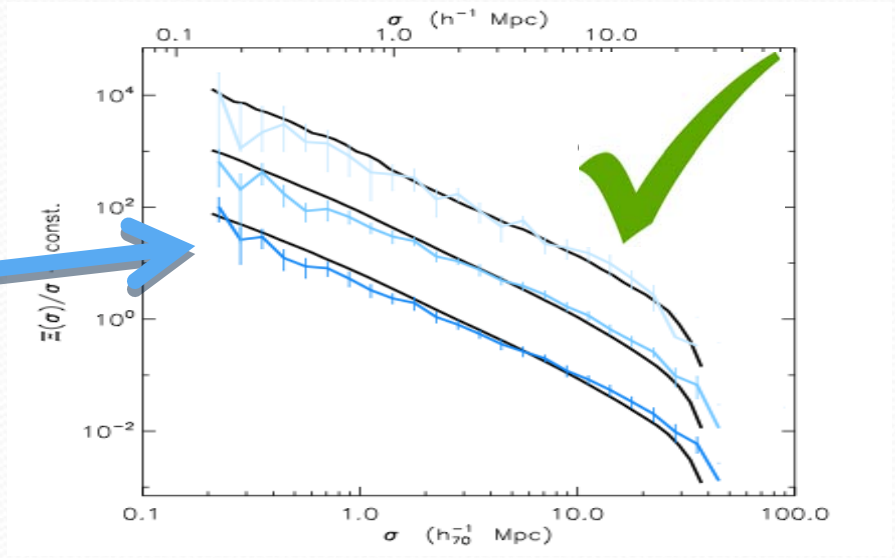






$M_{HI} - M_{halo}$ relation





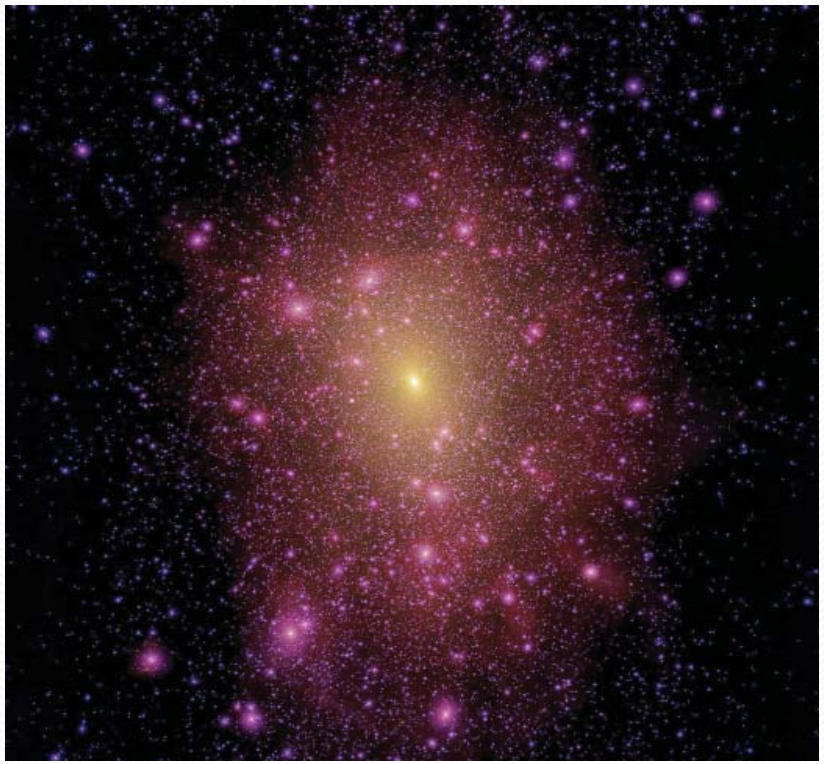
- In conclusion:
  - The $M_{HI} - M_{halo}$ relation has **large scatter**
  - **Not all**, but **some** subhalos host HI galaxies

near-field cosmology

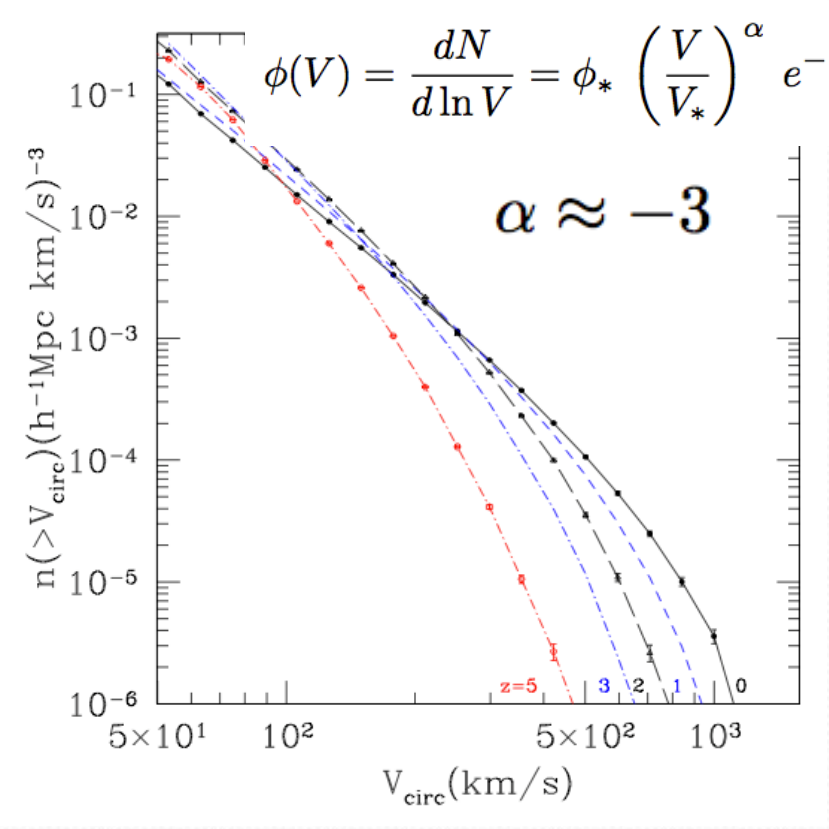
based on:

"*The Velocity Width Function of Galaxies from the 40% ALFALFA Survey: Shedding Light on the Cold Dark Matter Overabundance Problem*", Papastergis E., Martin A.M., Giovanelli R., Haynes M.P., *ApJ*, 739, 38 (2011)

HI cosmology with ALFALFA

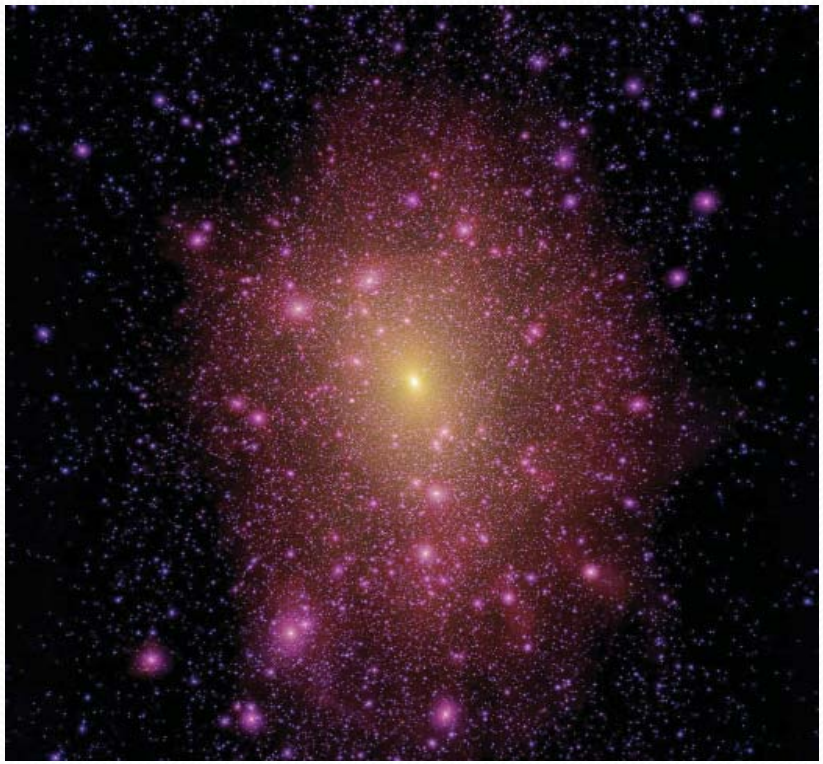


Lovell+ (2012)

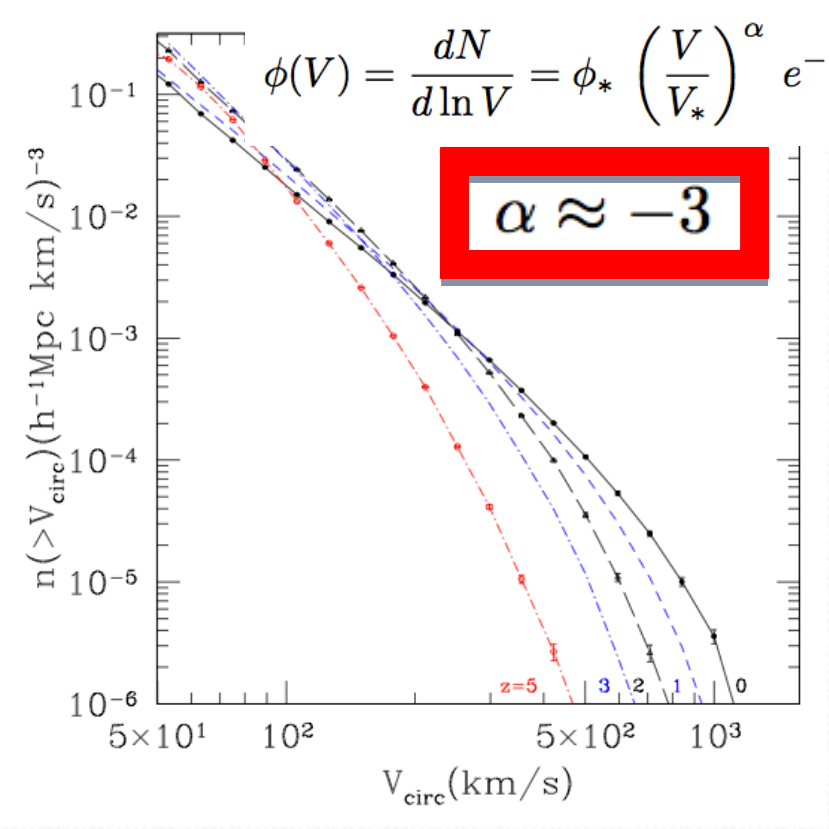


Klypin+ (2011) “Bolshoi simulation”

HI cosmology with ALFALFA



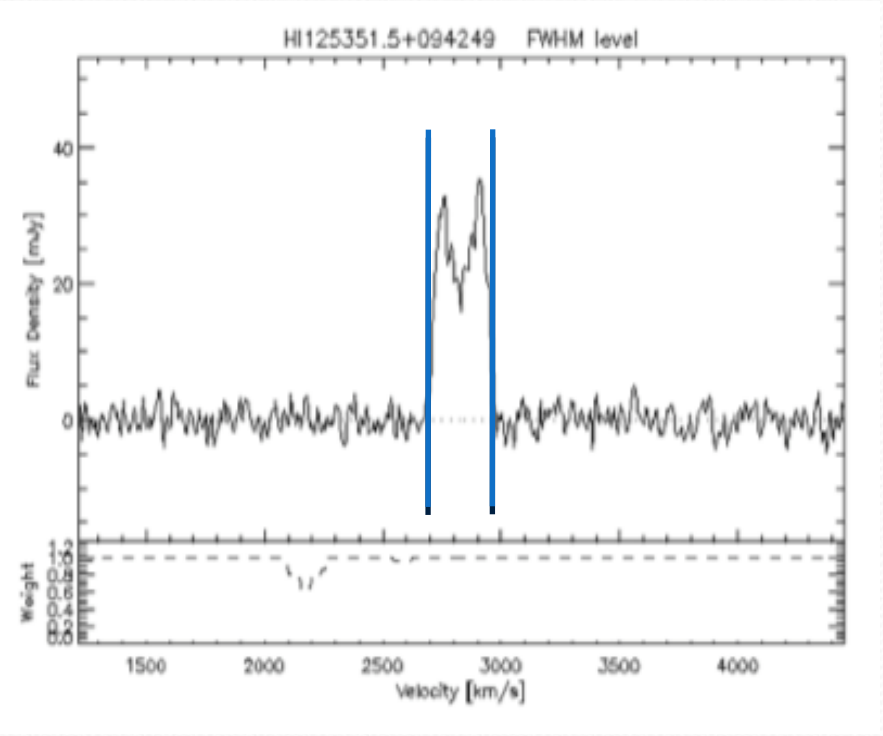
Lovell+ (2012)

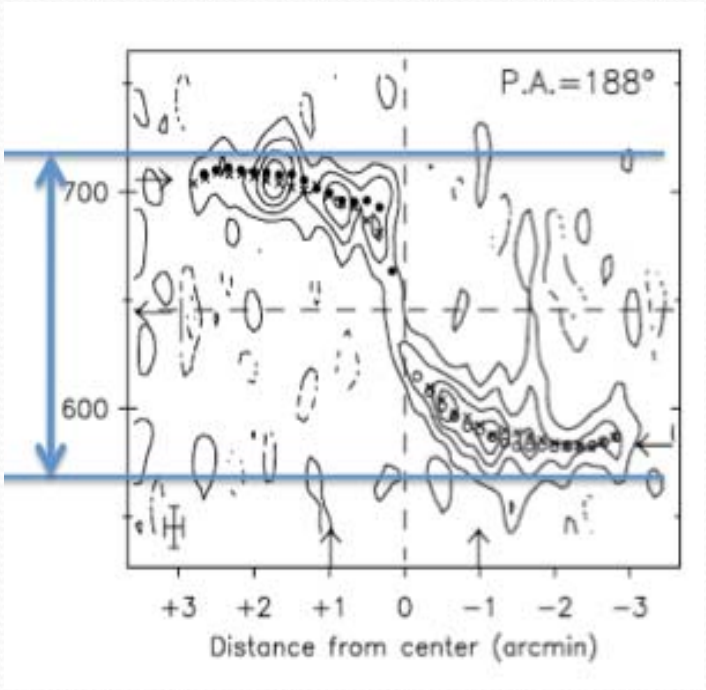


Klypin+ (2011) “Bolshoi simulation”

HI cosmology with ALFALFA

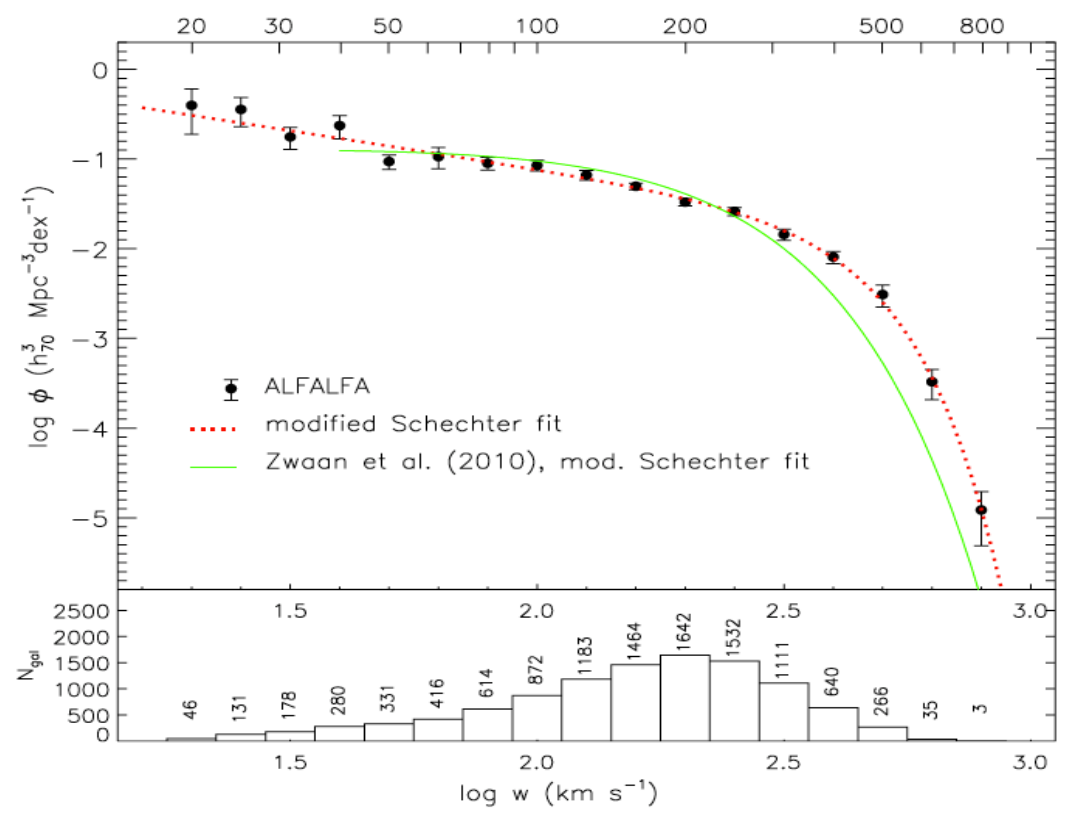
- The ***velocity width*** of a galaxy is a direct indicator of ***dynamical mass***.





the ALFALFA velocity width function

- "shallow" low-velocity slope, $\alpha = -0.85$



Papastergis+ (2011)

the ALFALFA velocity width function

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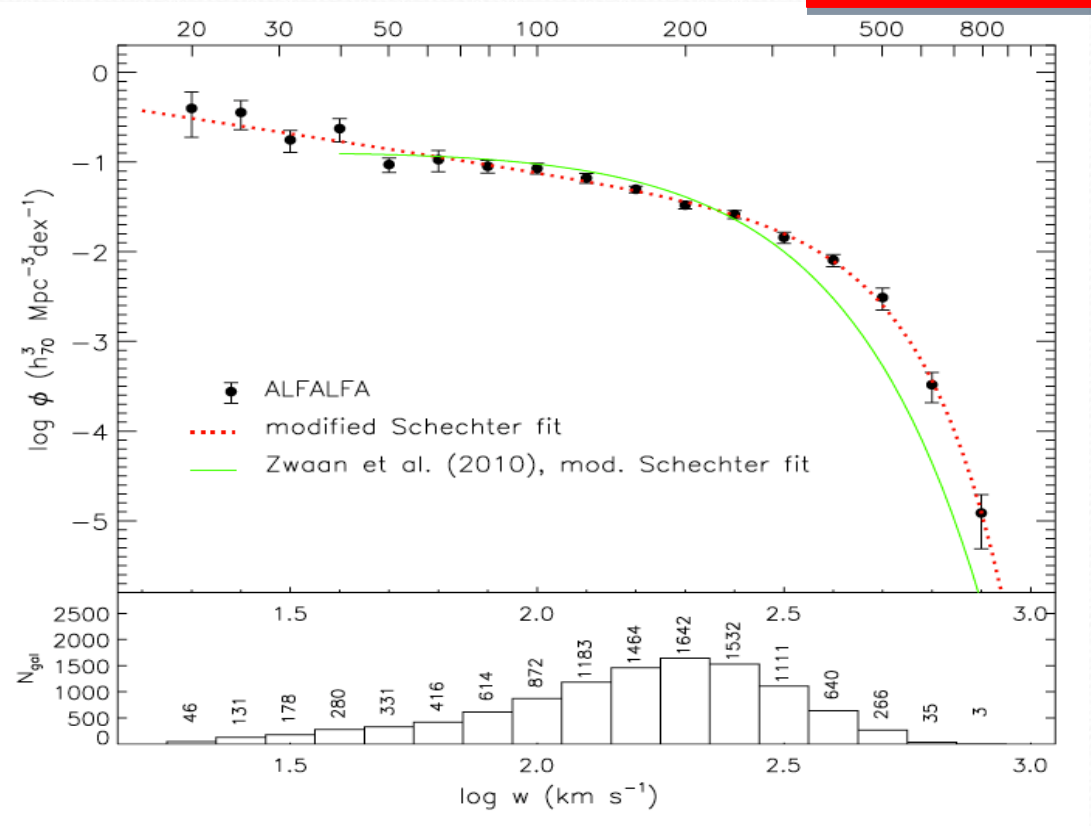


Papastergis+ (2011)

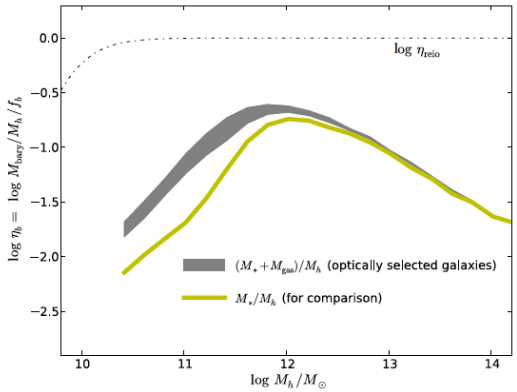
dark matter only rotation curve

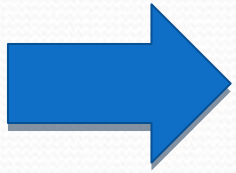
add baryons

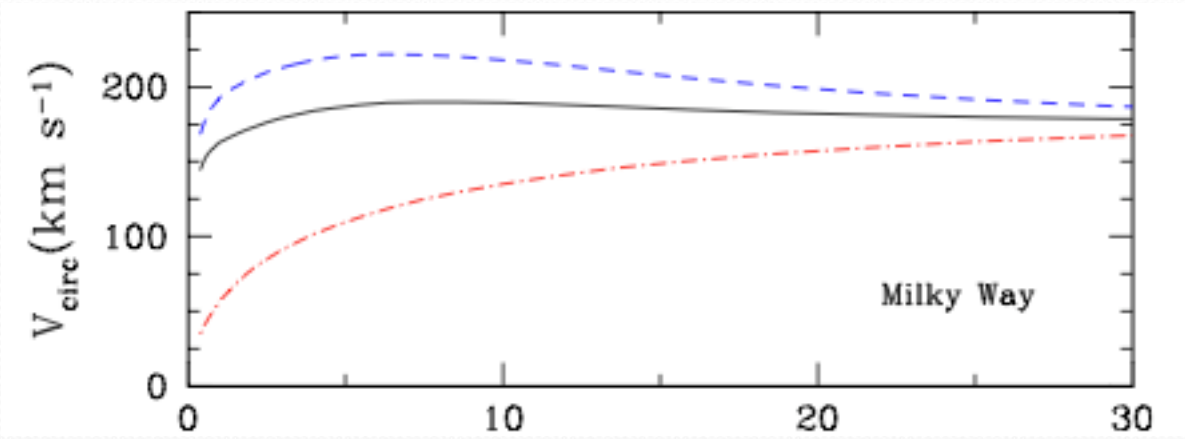
Stellar mass of the galaxy

Gas mass of the galaxy

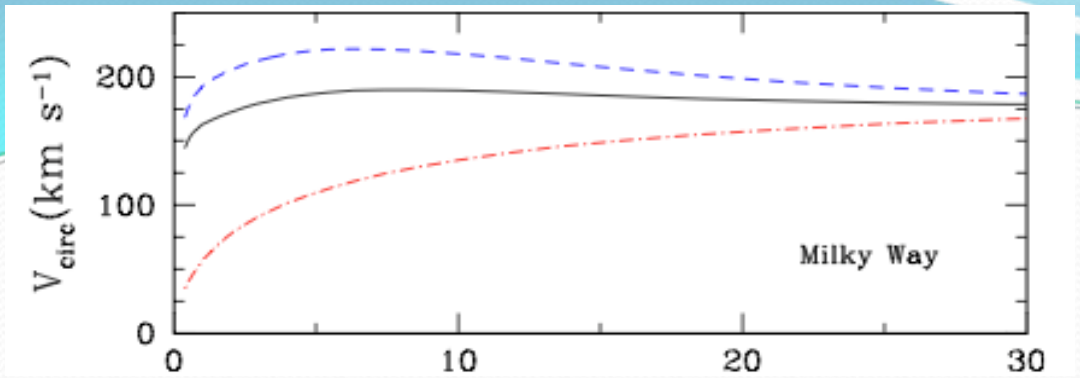
Adiabatic contraction?







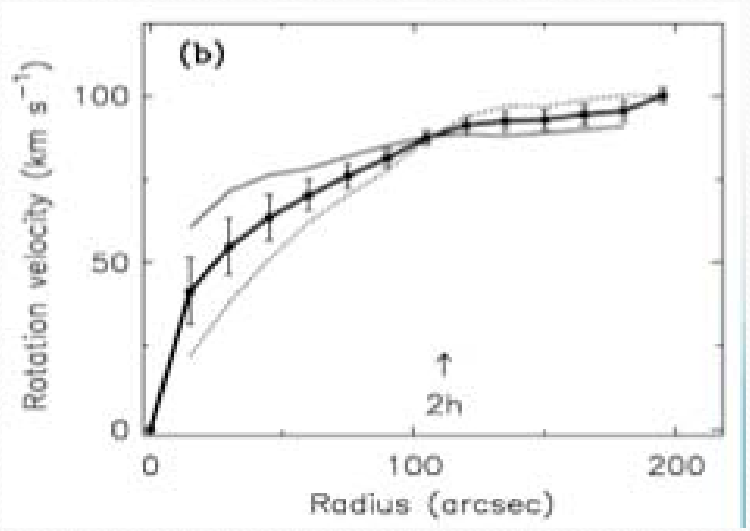
Trujillo-Gomez+ (2011)

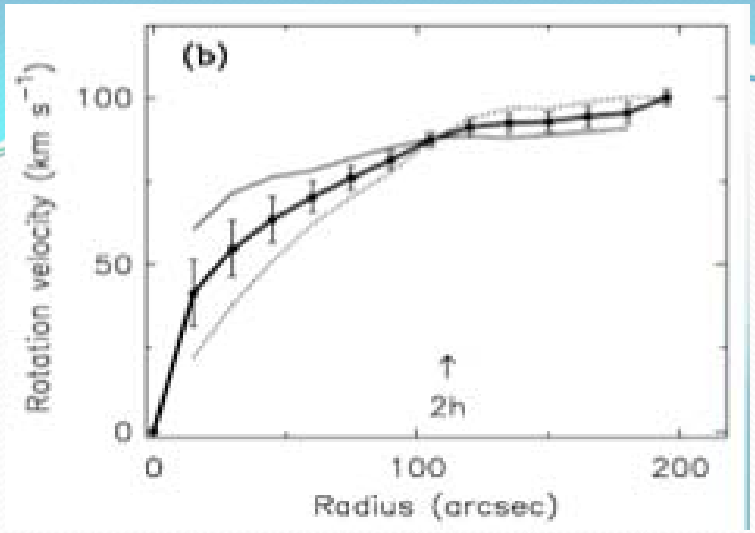


Trujillo-Gomez+ (2011)

add the tracer (HI)

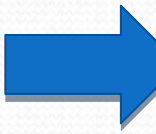
HI disk extent

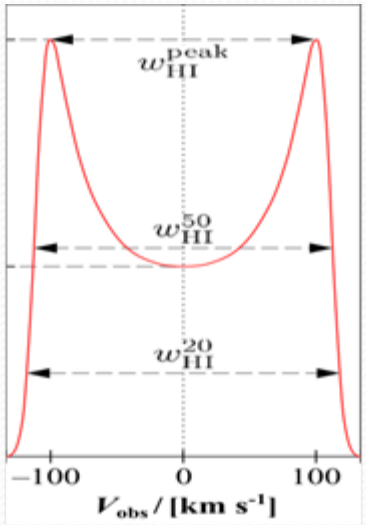




+ thermal broadening

+ spatial integration

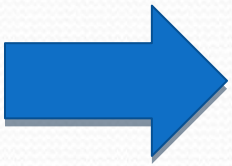


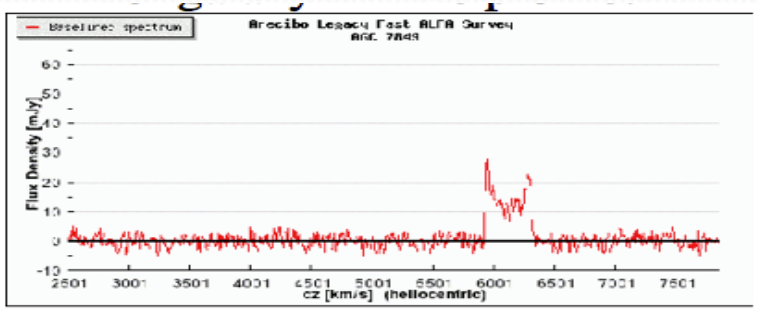


+ projection on line-of-sight

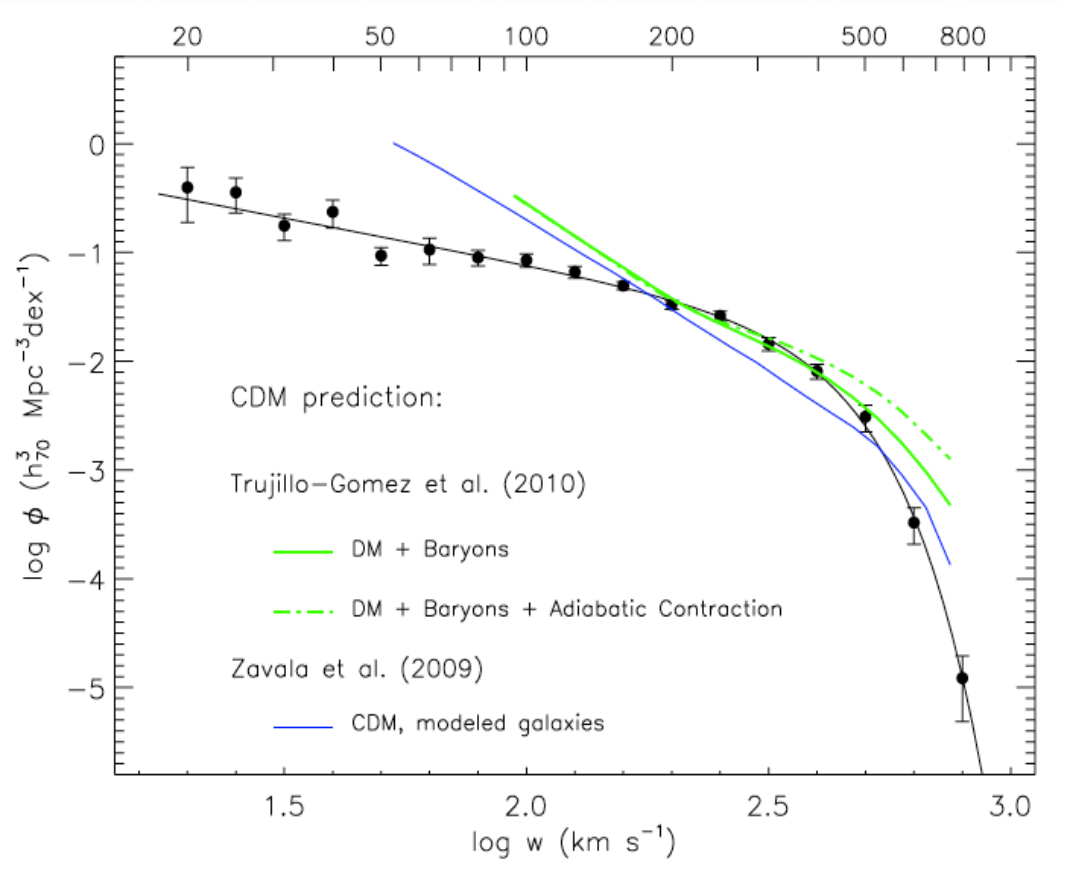
+ Doppler & instrumental broadening

+ noise





observation vs. theory

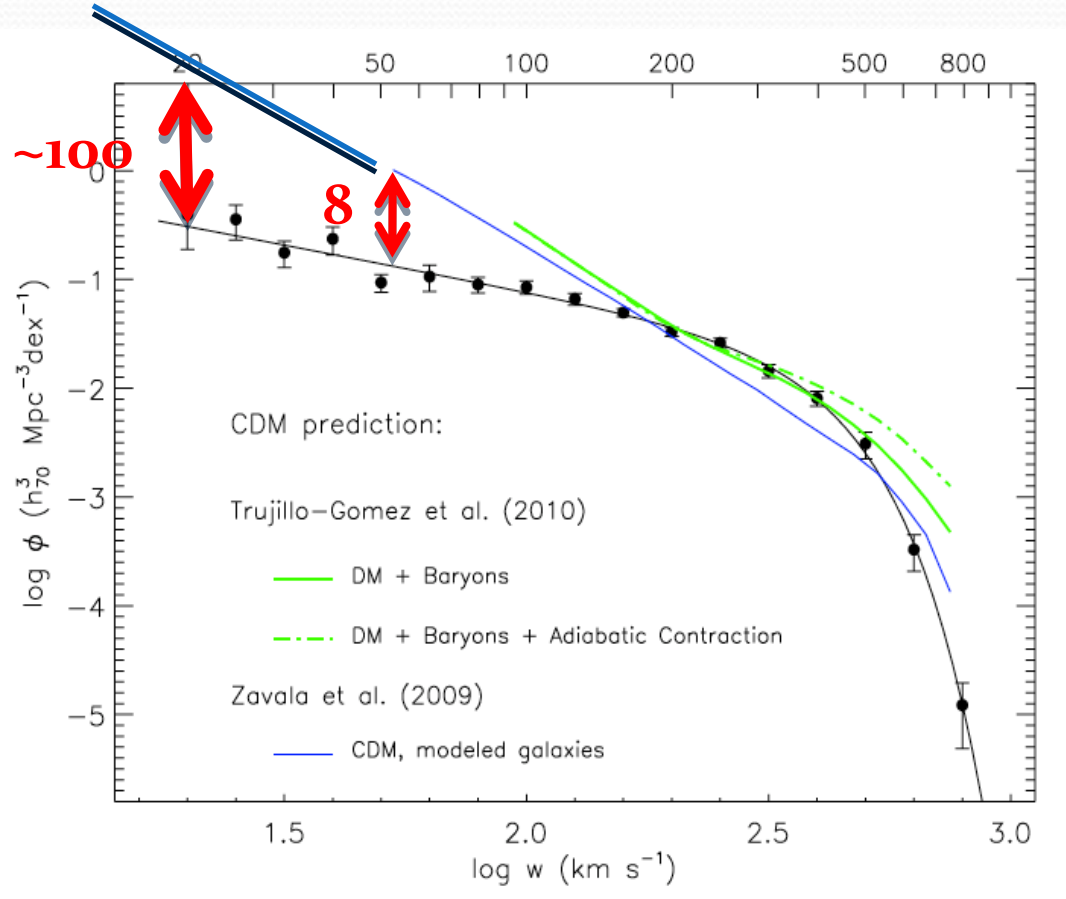


Papastergis+ (2011)

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

- the theoretical and observational distributions ***disagree at low widths*** (w < 100 km/s).
- a factor of **8 at w=50 km/s**, a factor of **~100 at w=20 km/s**.

observation vs. theory



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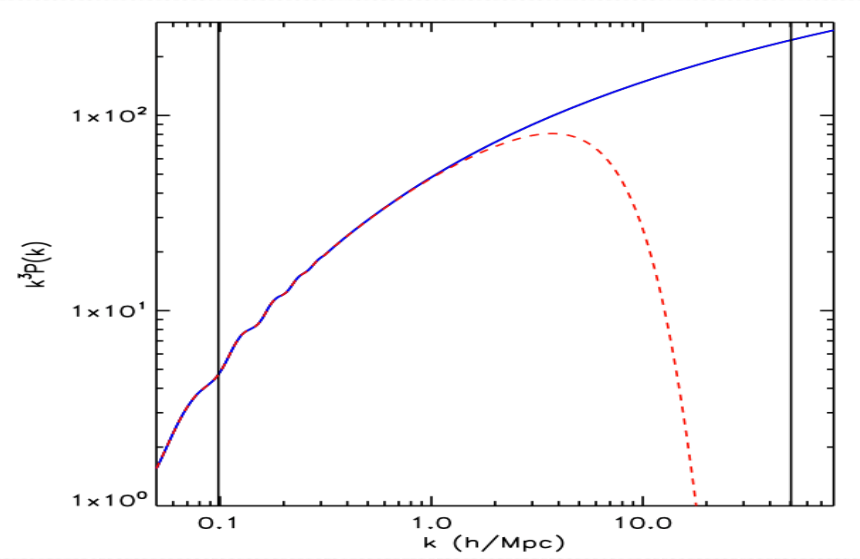
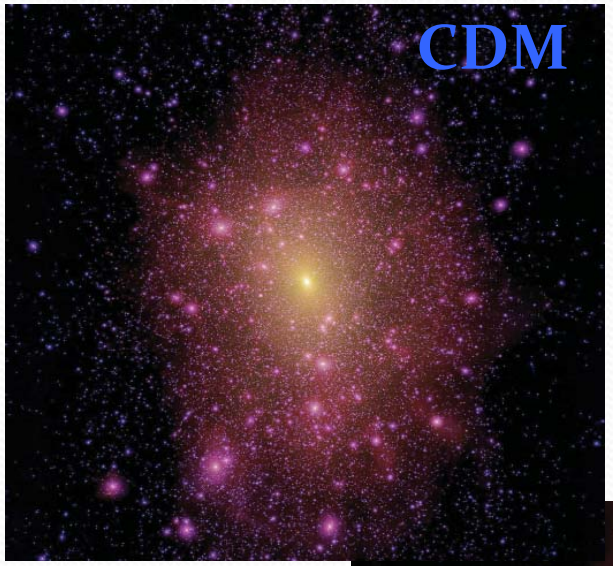
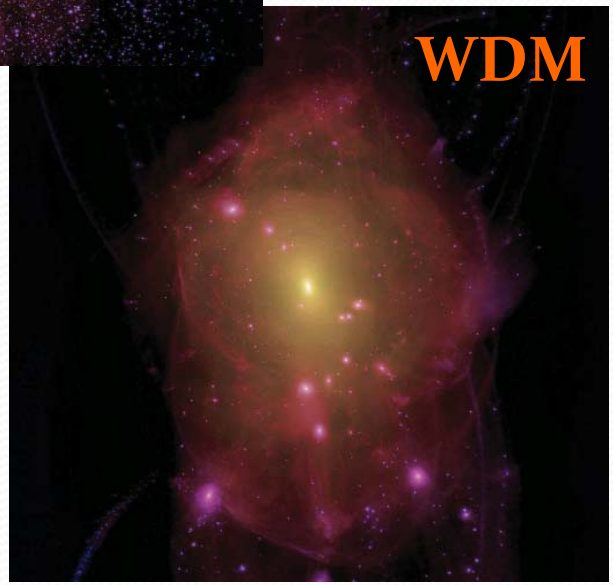
Warm Dark Matter ?

- in **WDM** universe number of **low-mass** halos **suppressed**.



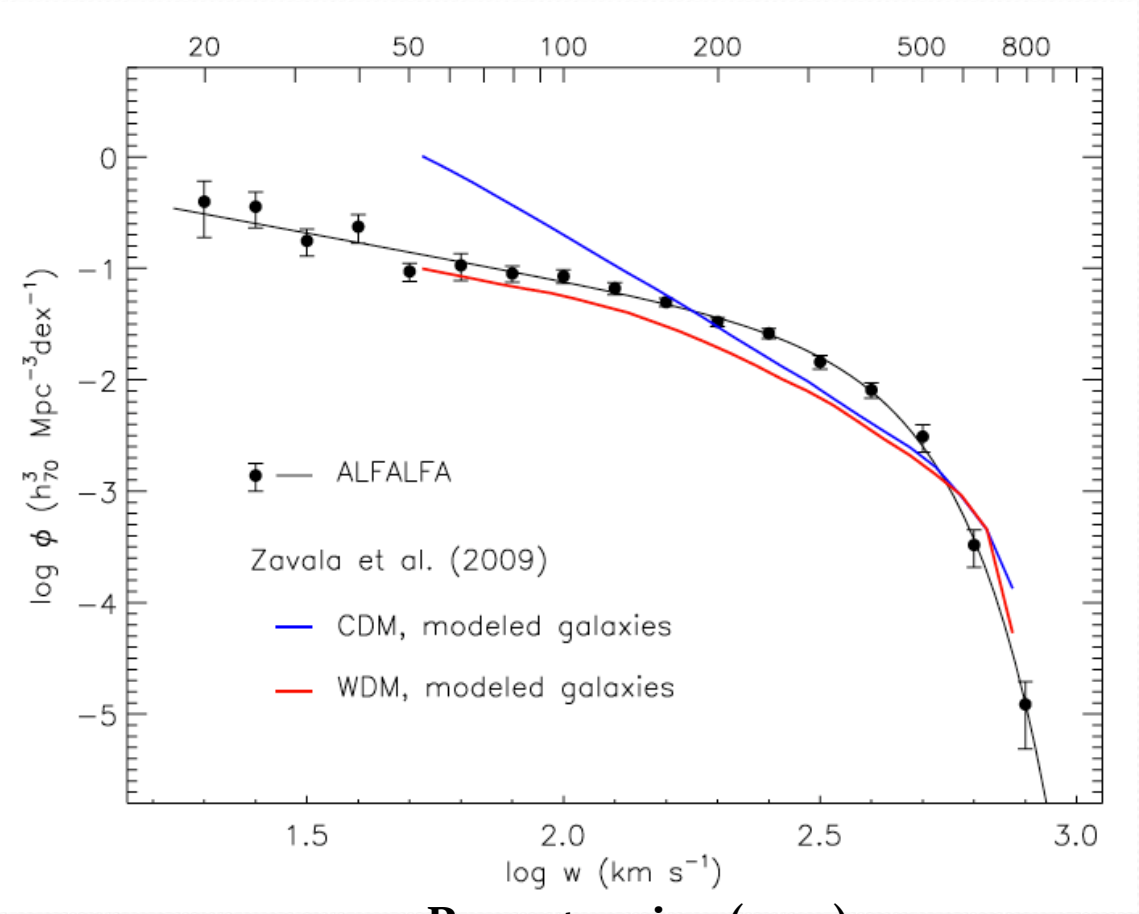
Zavala+ (2009)





Lovell+ (2012)

Warm Dark Matter ?

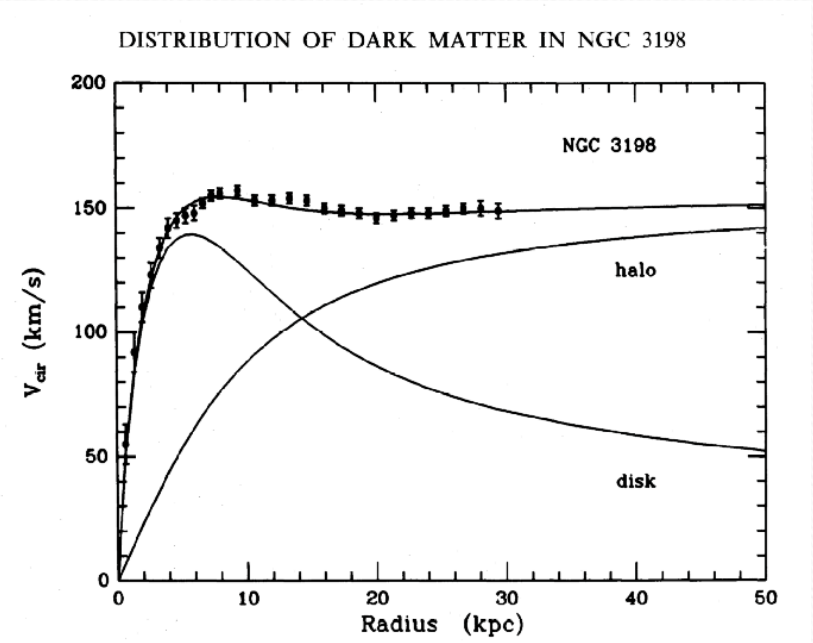


modeling: Zavala+ (2009)

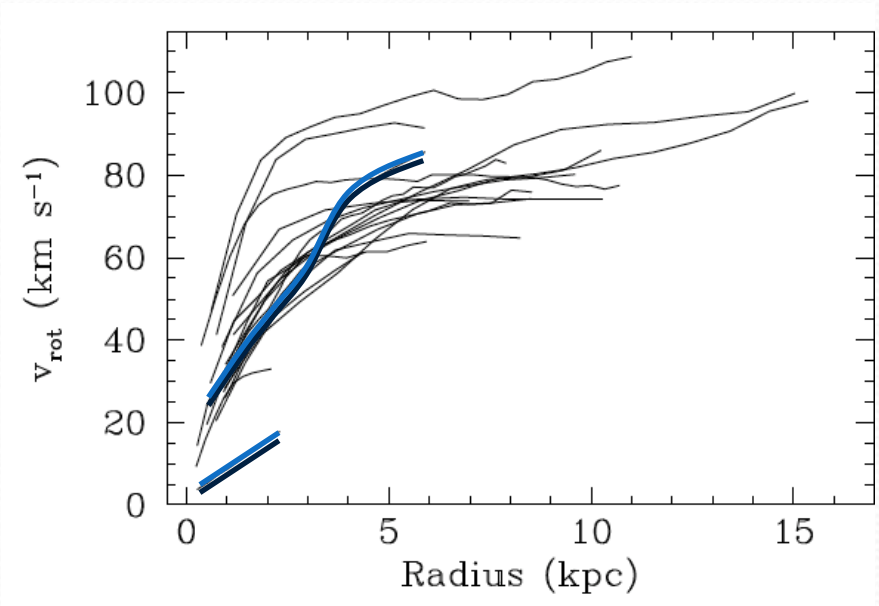
Papastergis+ (2011)

rotation curve shape?

- ***rotation curves*** in dwarf galaxies are often ***rising*** to the last measured point.



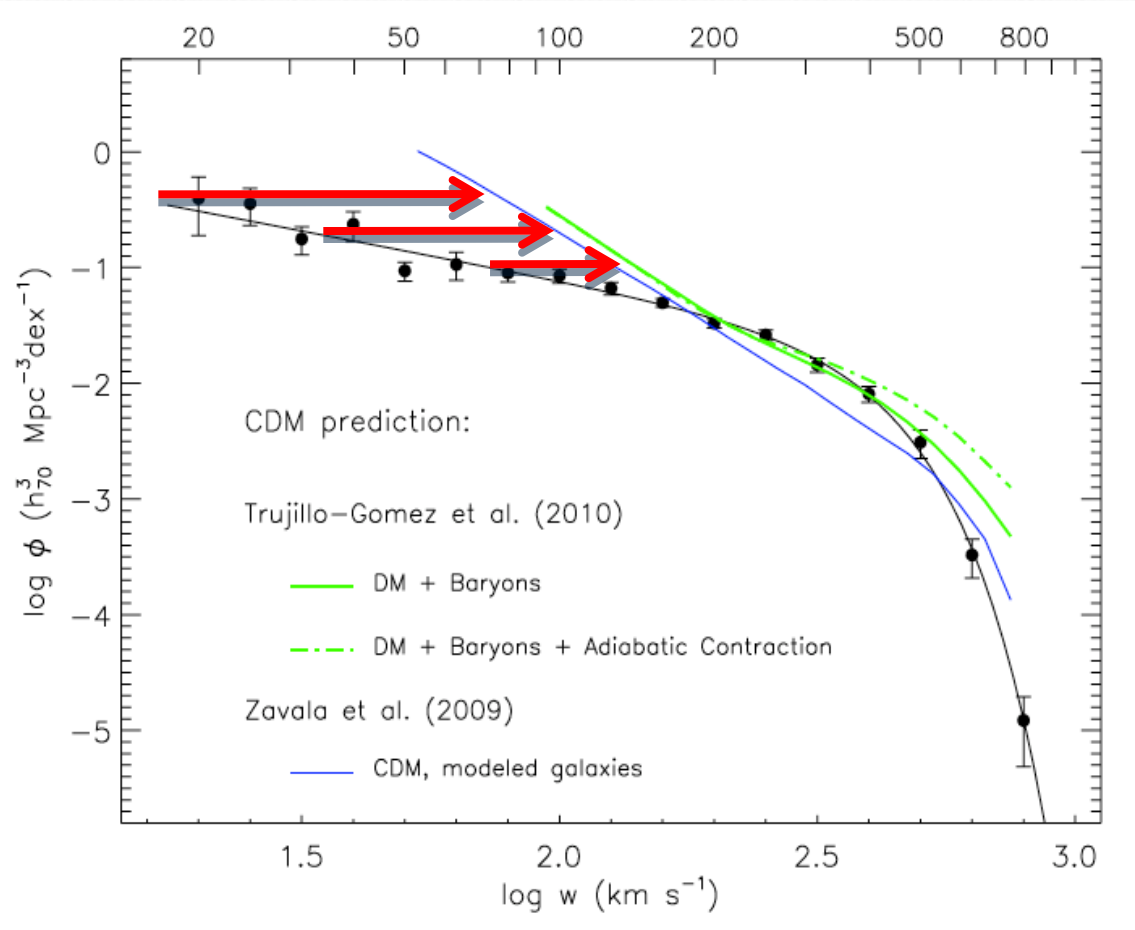
'flat' rotation curve



Swaters+ (2009)

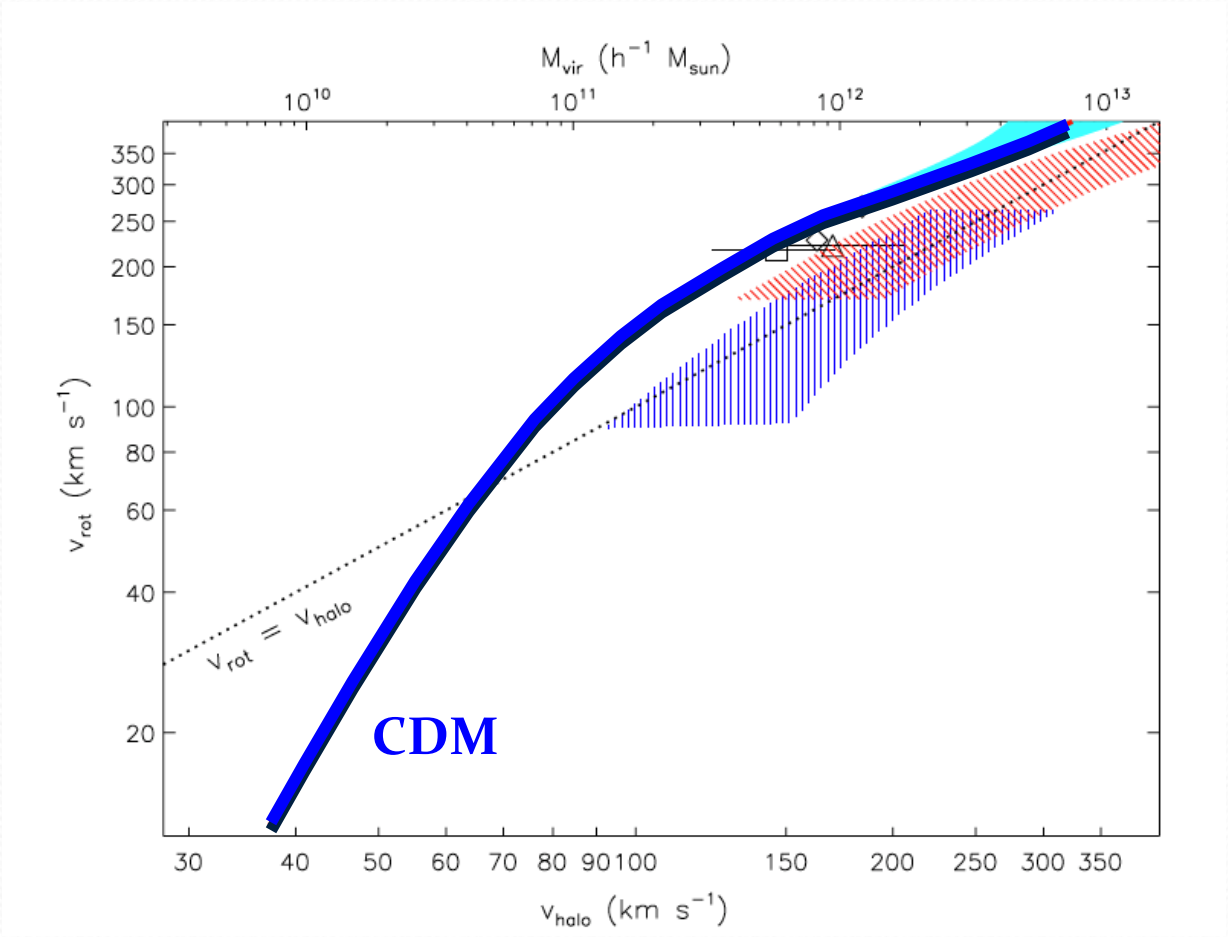
'rising' rotation curves

rotation curve shape?



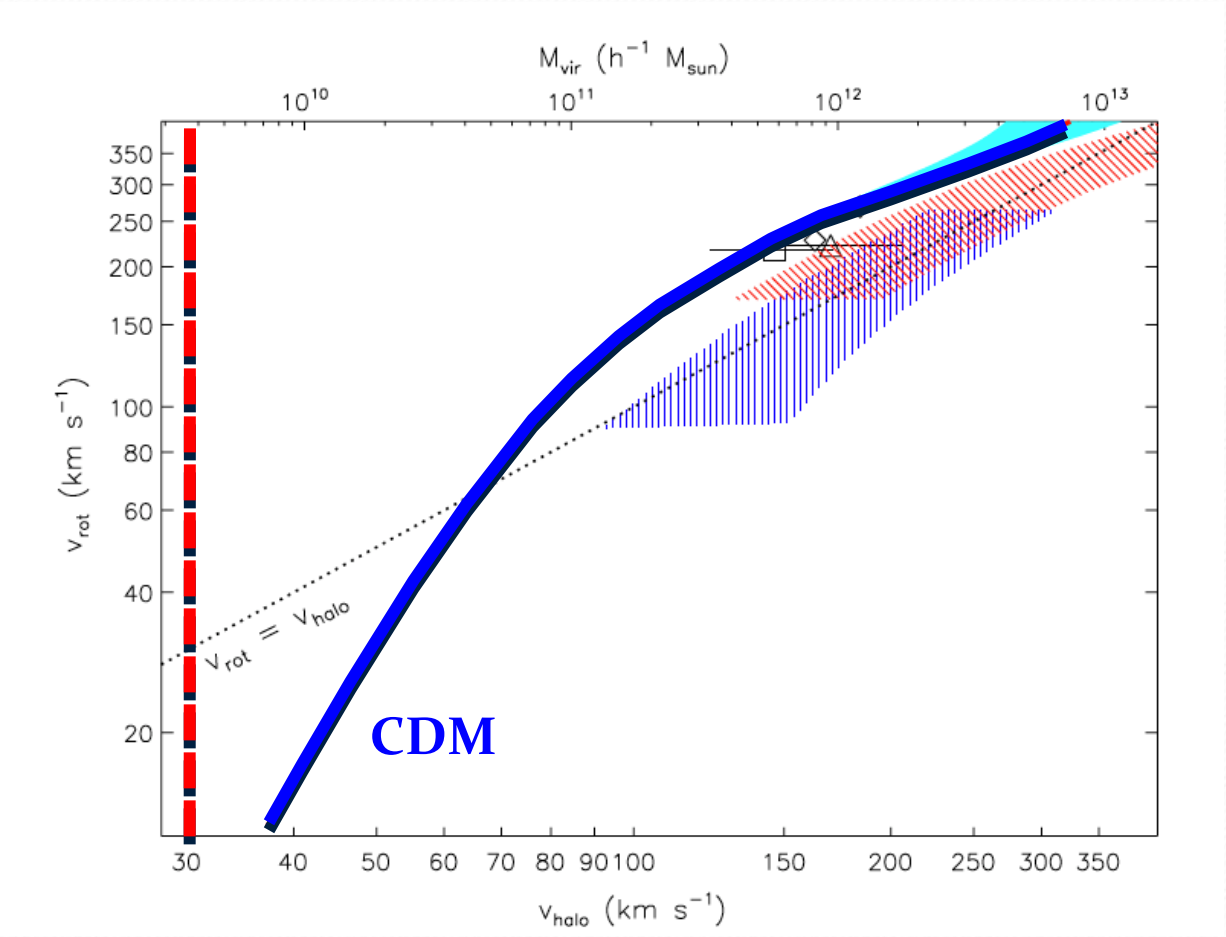
- for dwarfs, ***HI velocities*** may systematically ***underestimate*** true ***halo masses***.

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



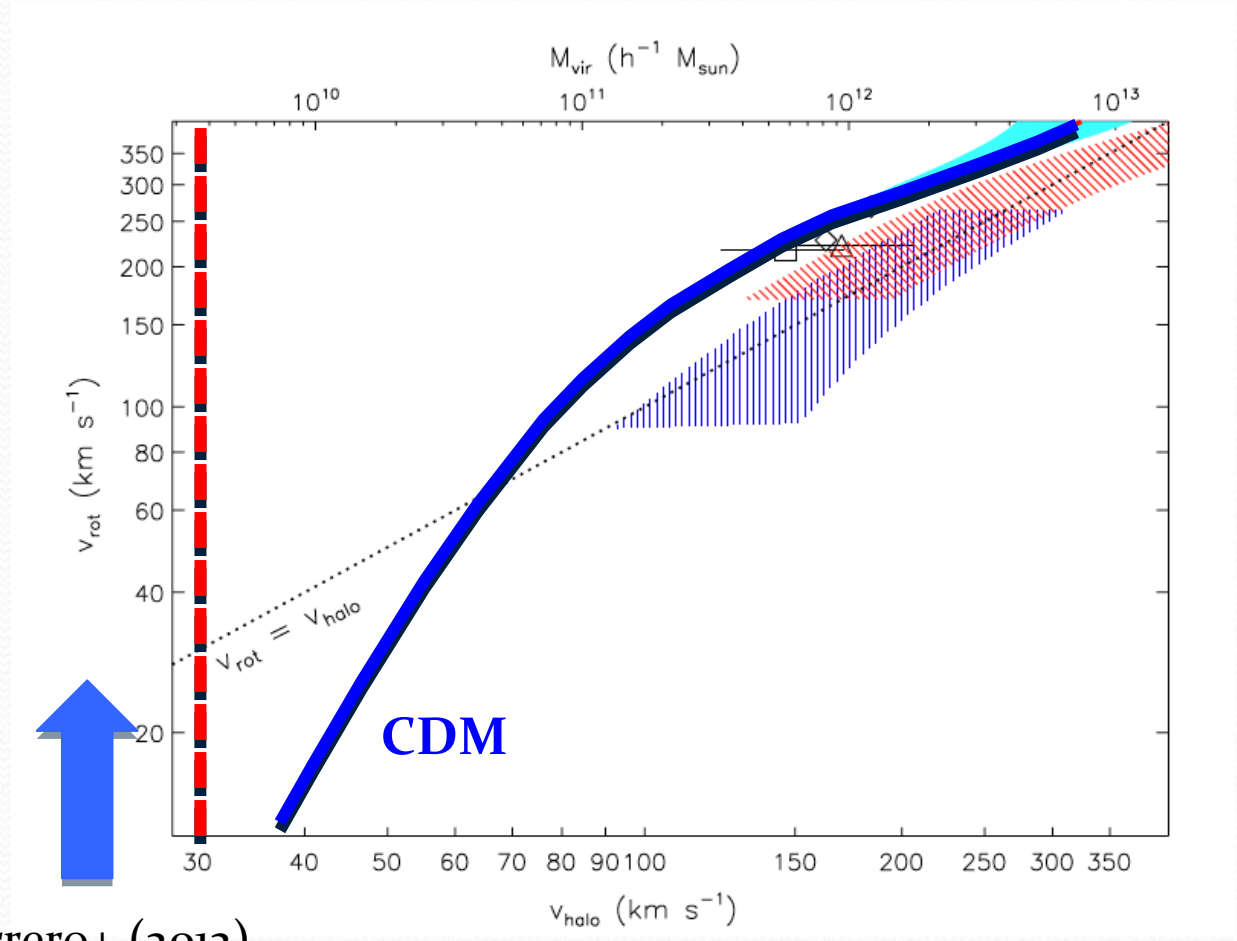
Papastergis+ (2011)

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



Papastergis+ (2011)

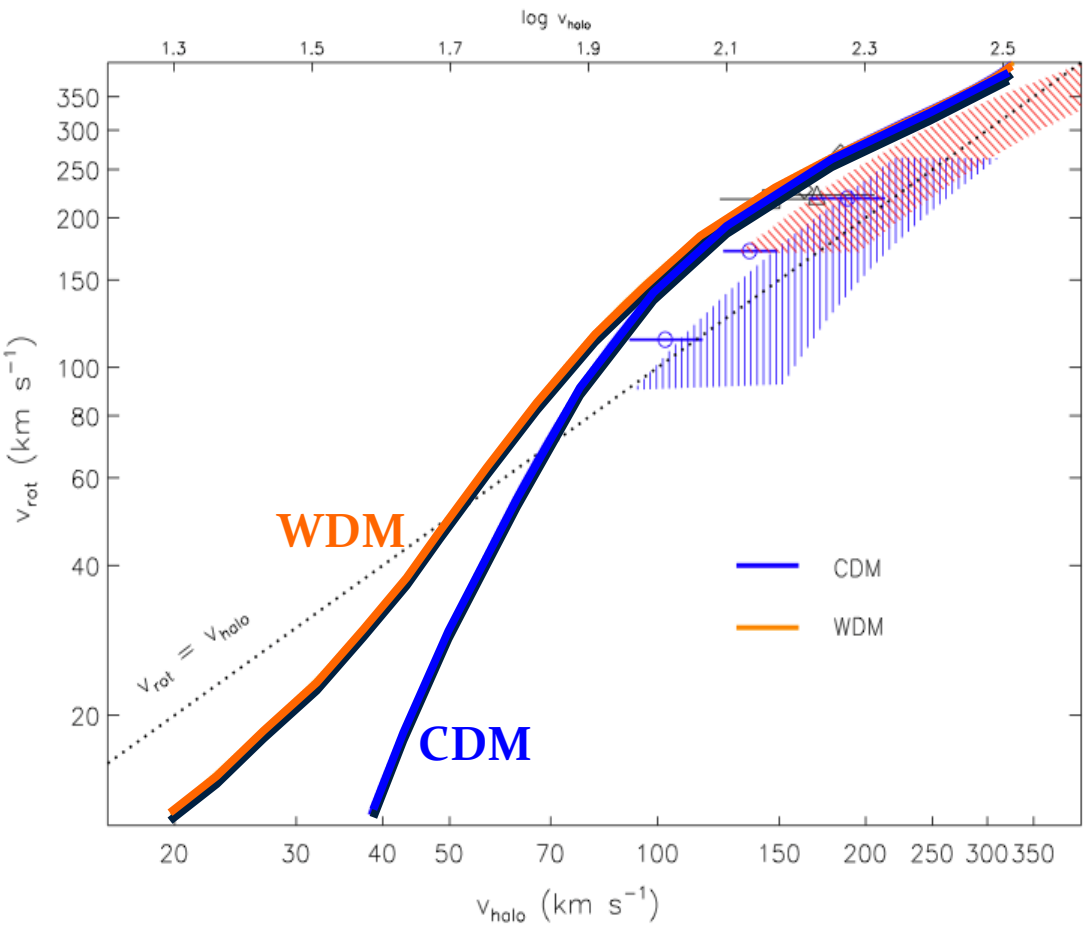
$v_{rot} - v_{halo}$ relation in CDM universe



Ferrero+ (2012)

Papastergis+ (2011)

Warm dark matter or baryonic physics?



- placing data for ***individual galaxies*** on the $v_{rot} - v_{halo}$ diagram, can distinguish between ***alternative dark matter*** and ***baryonic effects***.

thank you for your attention!

questions?