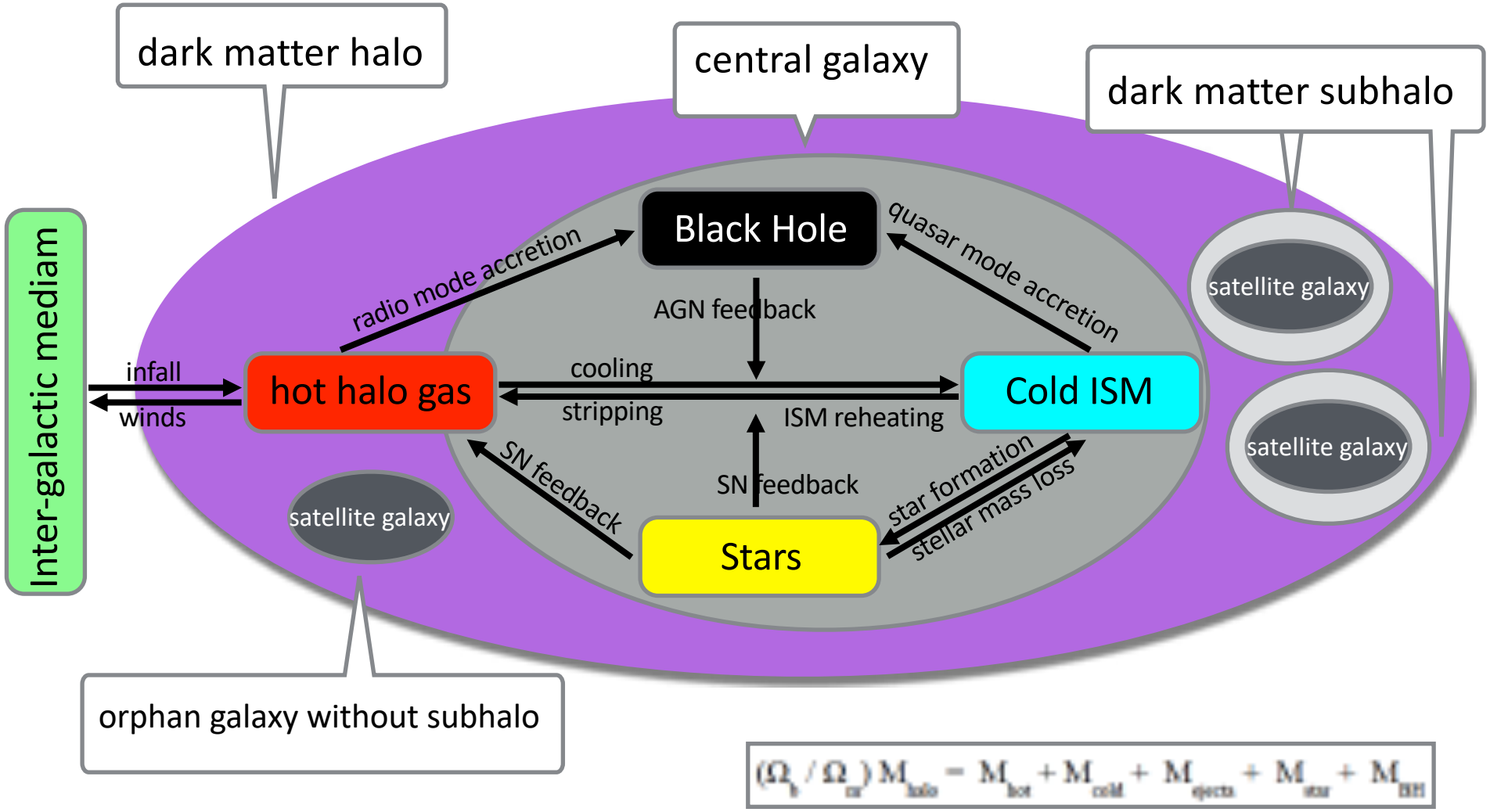
Formation of gas-rich galaxies in the halos

Hong Guo

Shanghai Astronomical Observatory (SHAO)

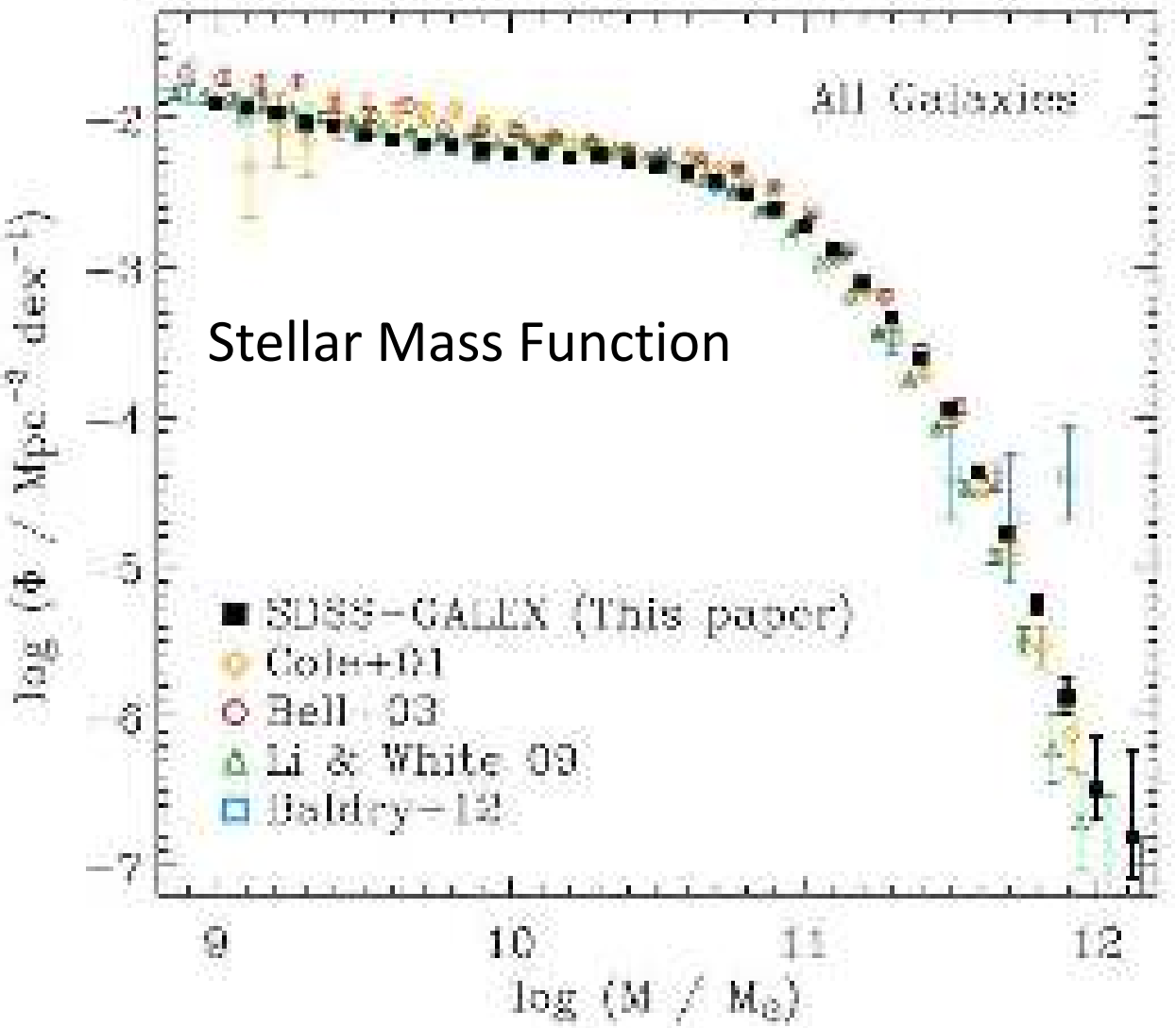
Gas as fuel of star formation plays key roles in galaxy formation



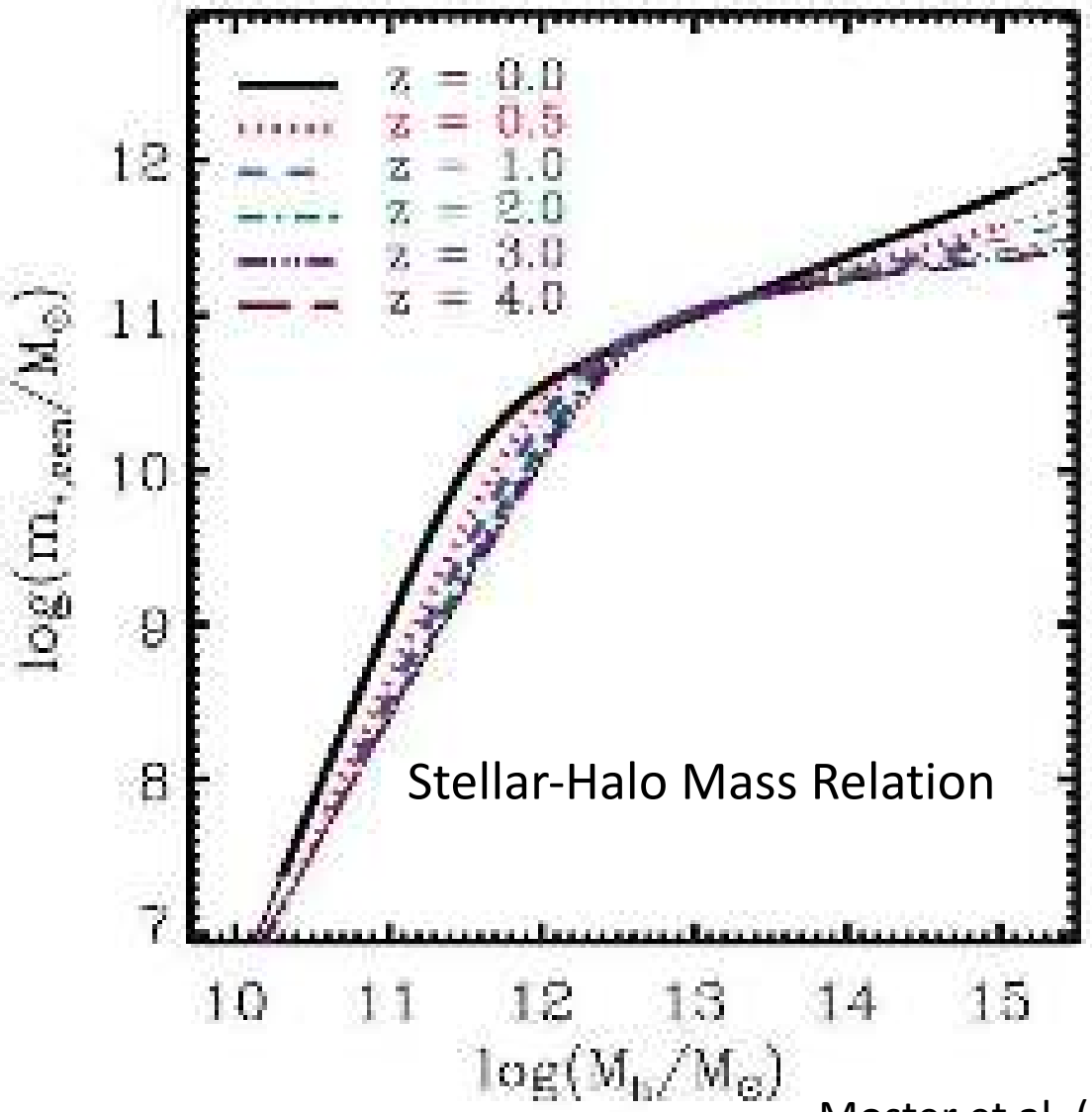
$$(\Omega_b / \Omega_m) M_{halo} = M_{hot} + M_{cold} + M_{ejecta} + M_{star} + M_{IHL}$$

Image Credit: Cheng Li

The Galaxy Stellar Content

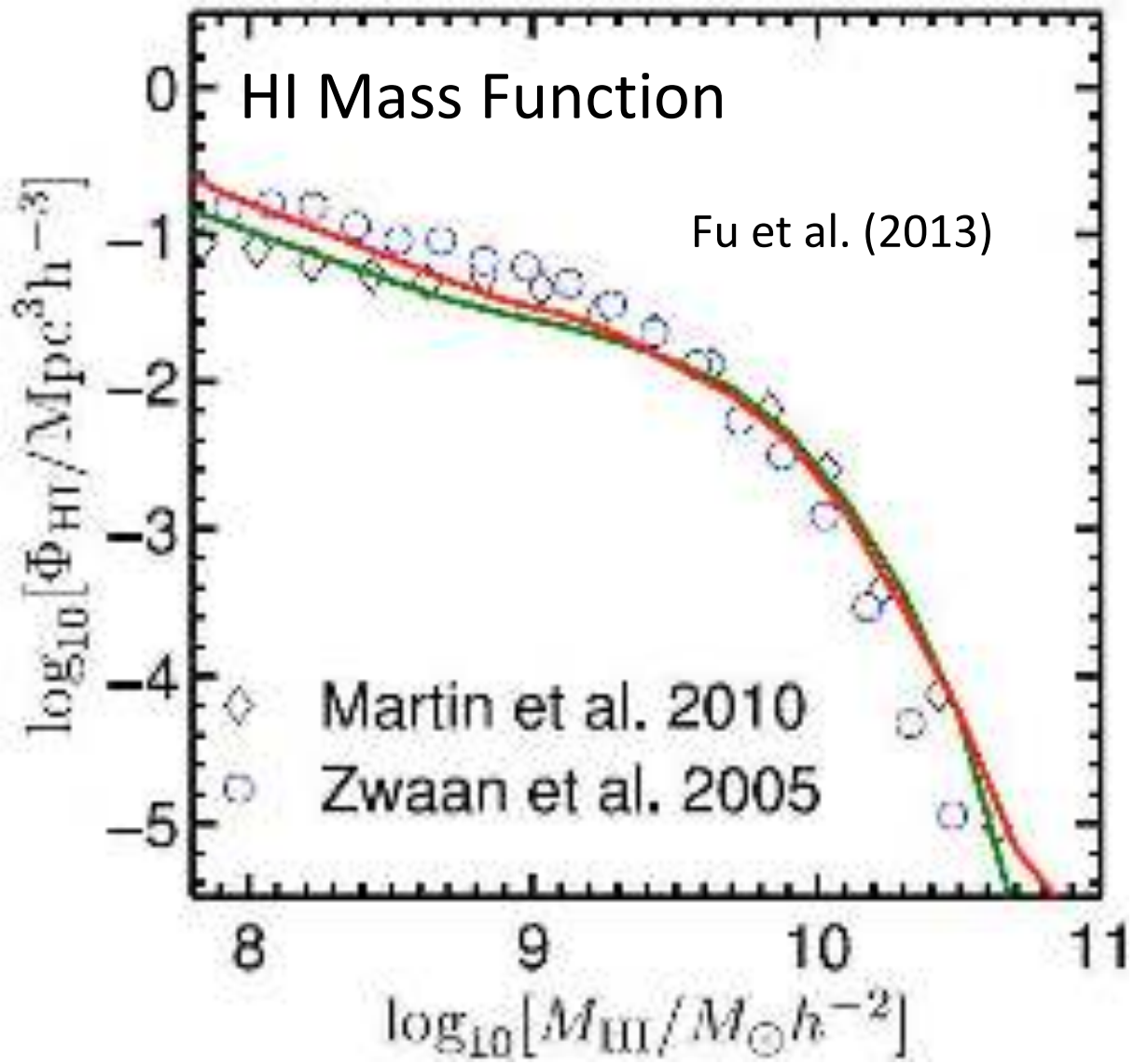


Moustakas et al. (2013)



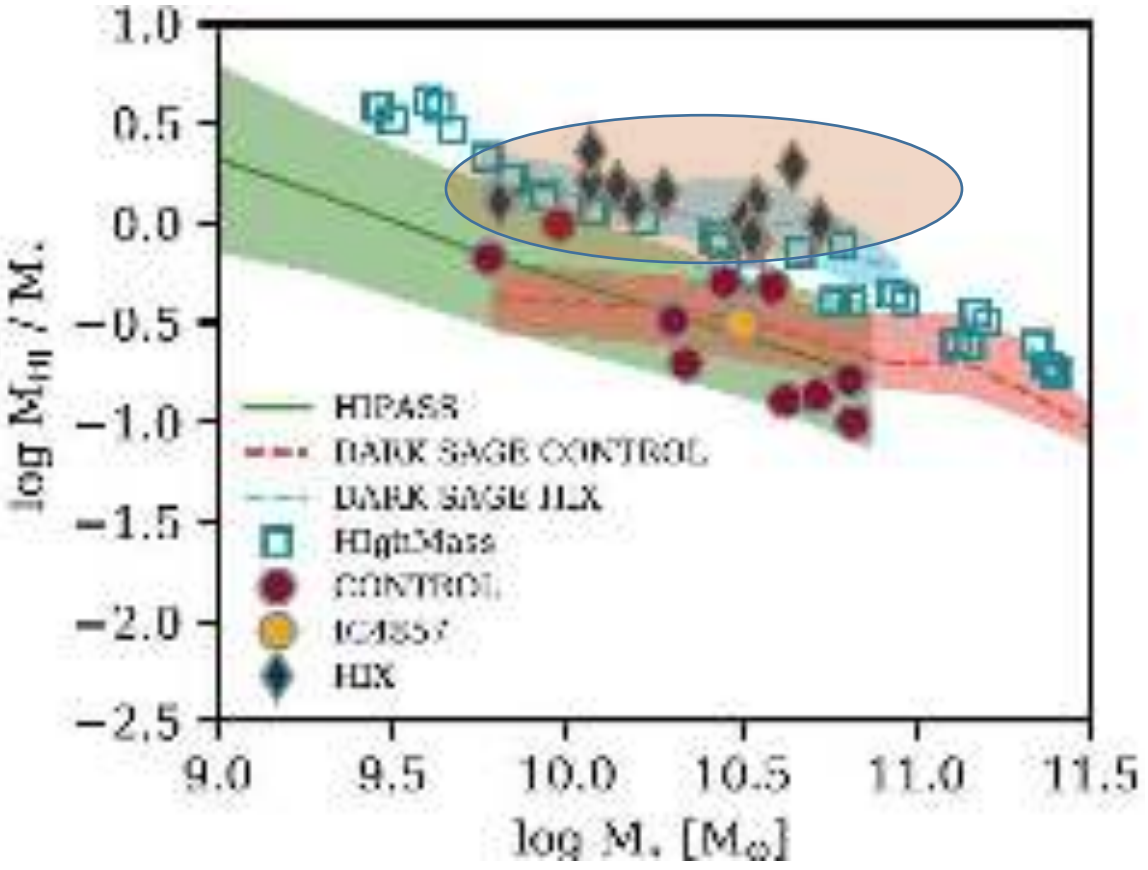
Moster et al. (2013)

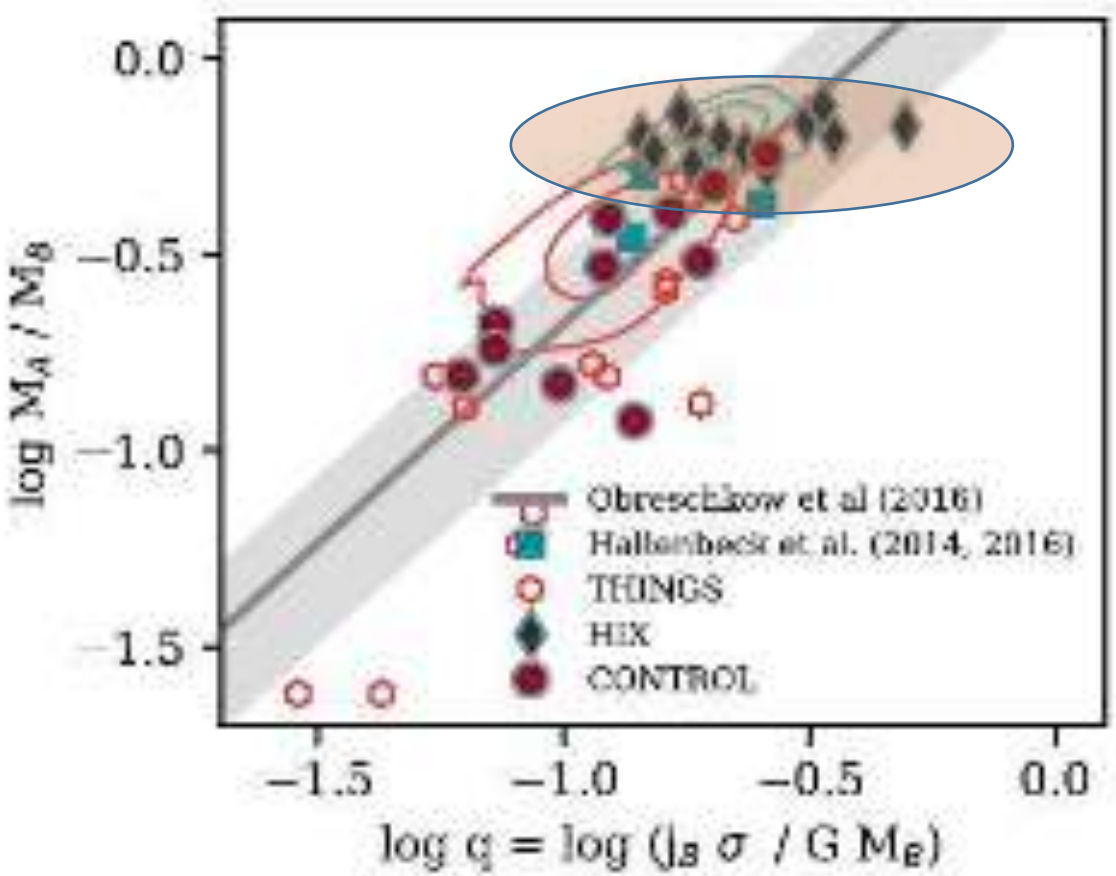
The Gas Content of Galaxies



HI-Halo Mass Relation?

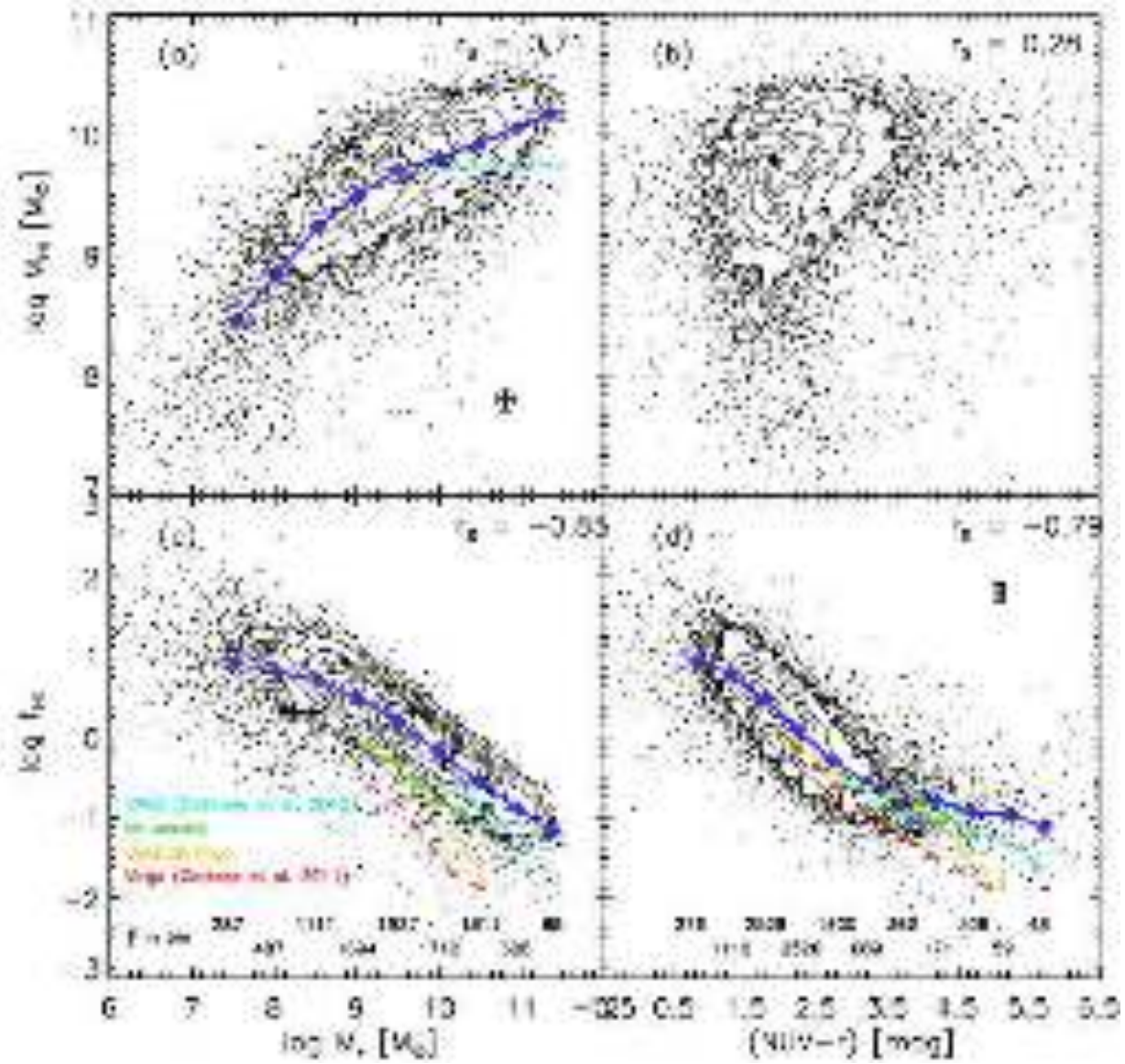
Why do we care about the halos in HI studies?

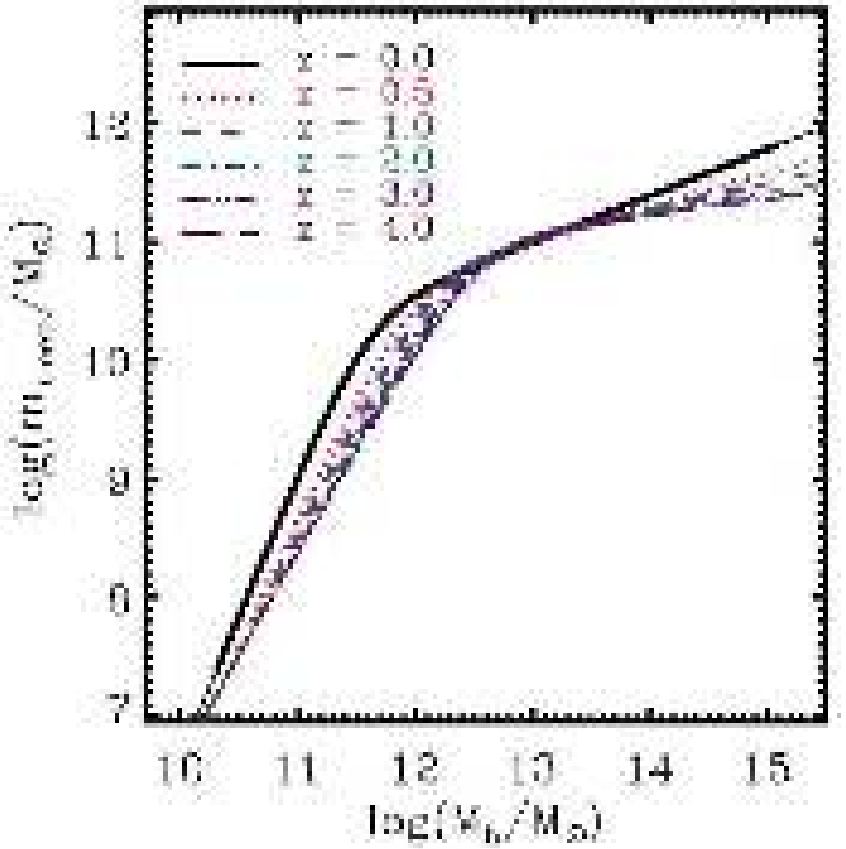




Lutz et al. (2018)

Why do we care about the halos in HI studies?





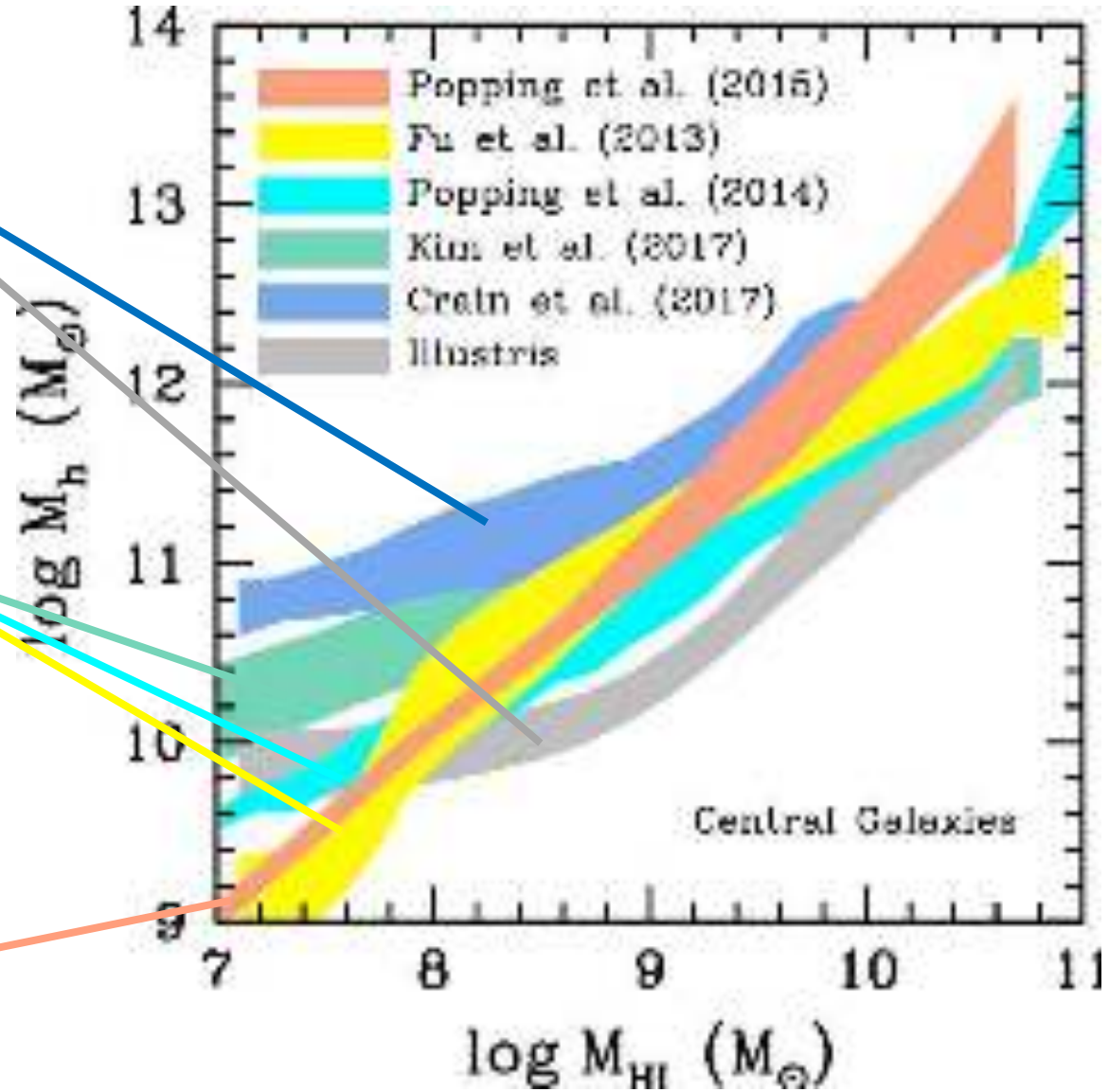
Huang et al. (2012)

Controversial predictions of HI-halo mass relation in current models

Hydrodynamical simulations + empirical models of HI and H2 partitioning

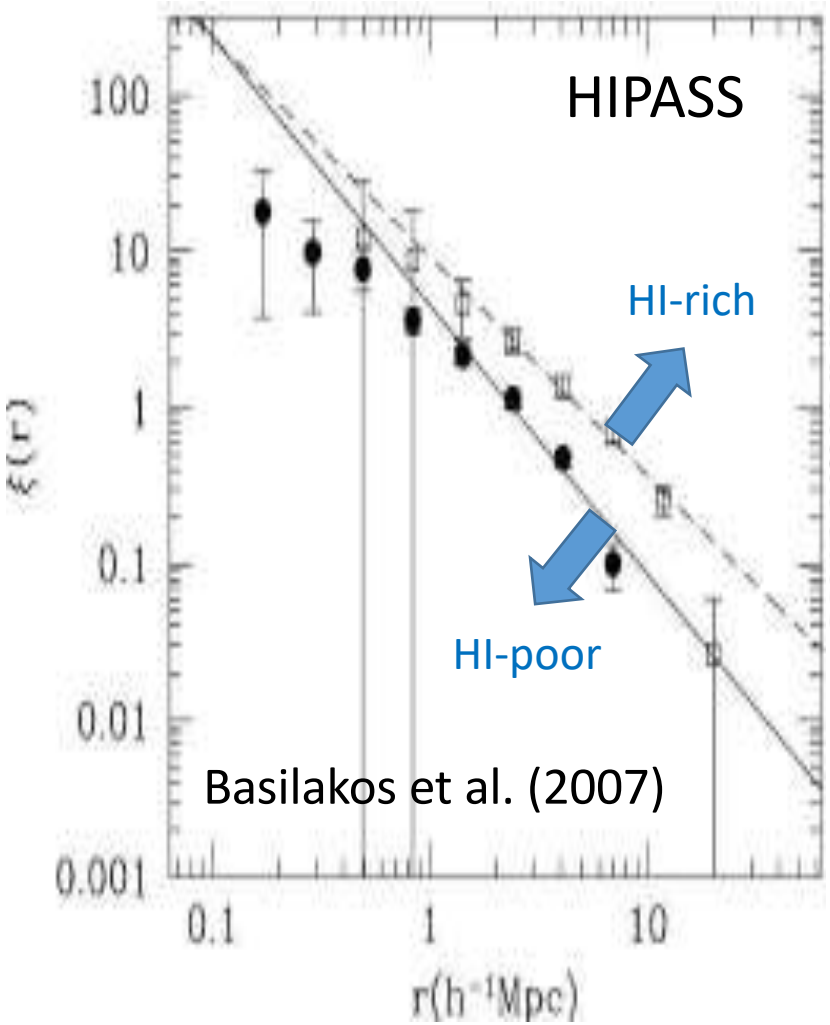
Semi-analytical models of galaxy formation

Abundance matching model + SFR vs gas mass relation



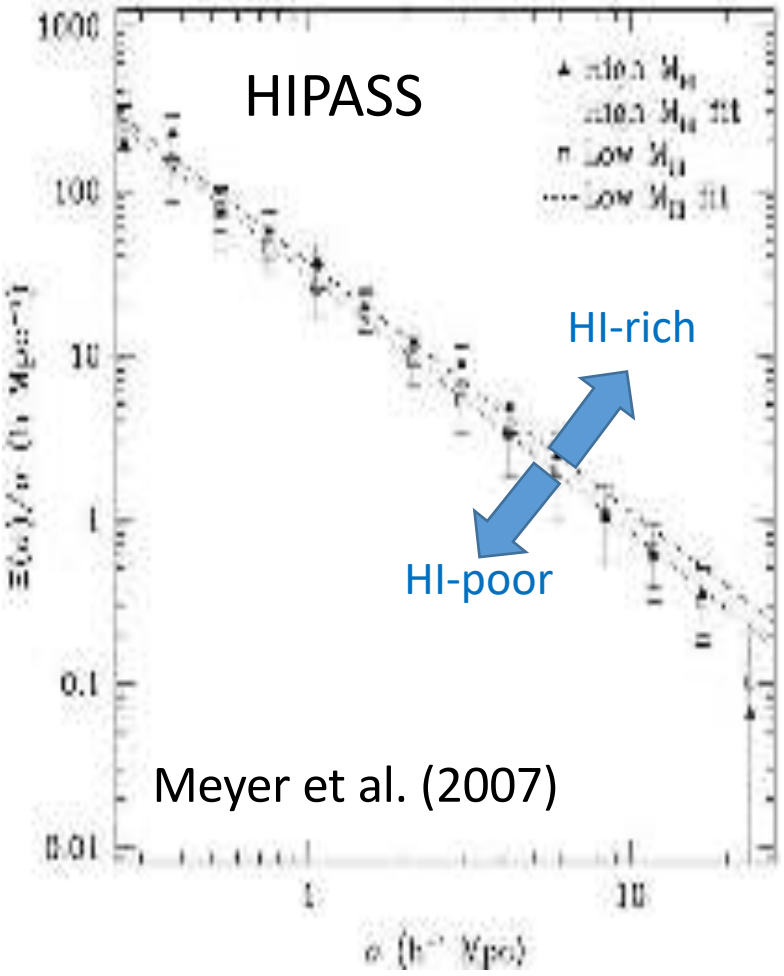
Contradictory measurements of clustering of HI-selected galaxies

Strong Dependence!



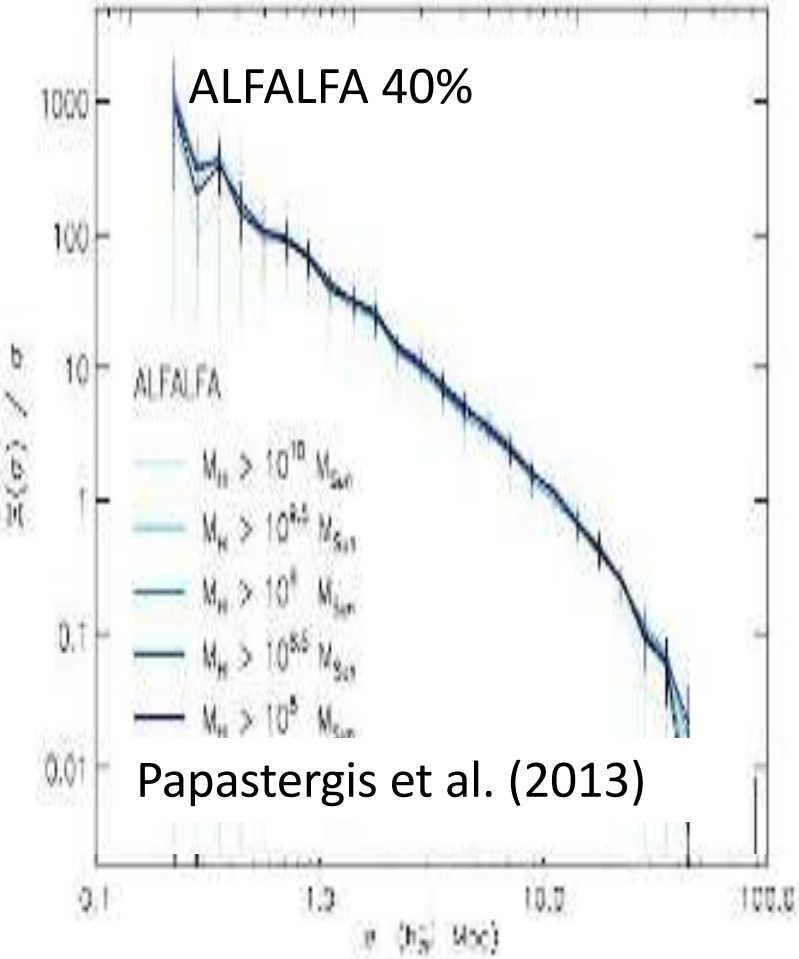
Basilakos et al. (2007)

Weak Dependence!



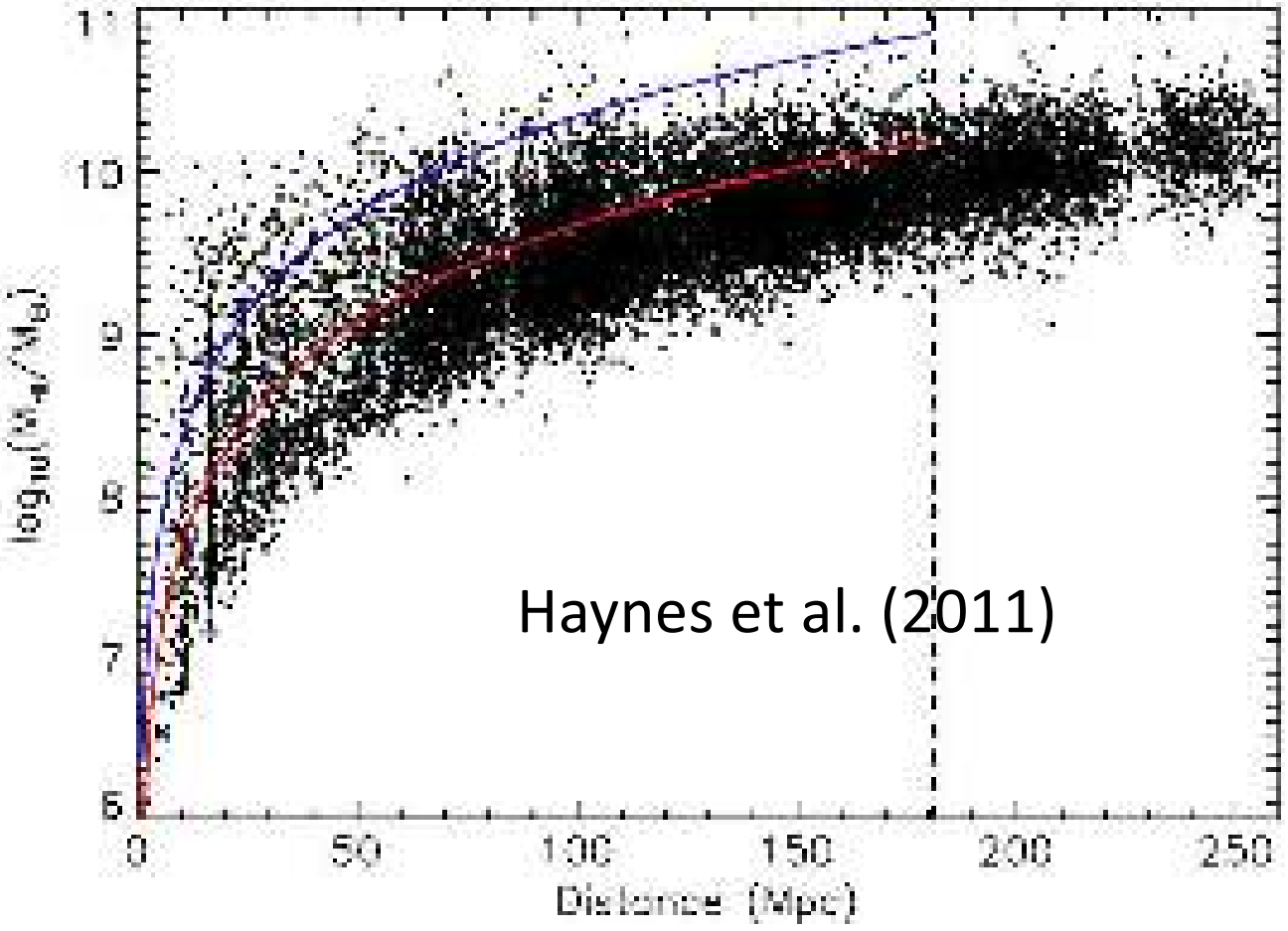
Meyer et al. (2007)

NO Dependence!

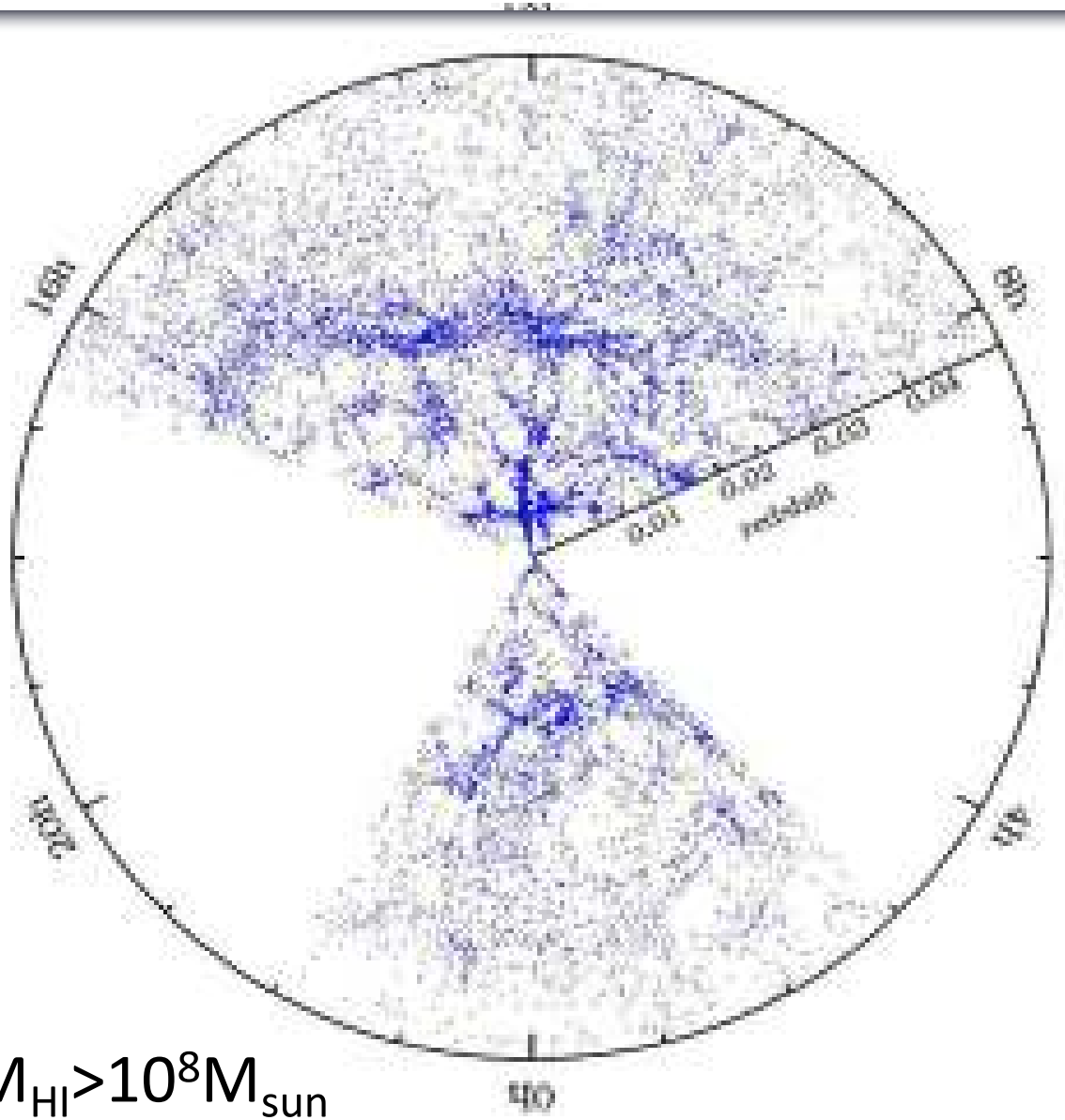


Papastergis et al. (2013)

ALFALFA α.70 Sample: the largest HI sample of galaxies

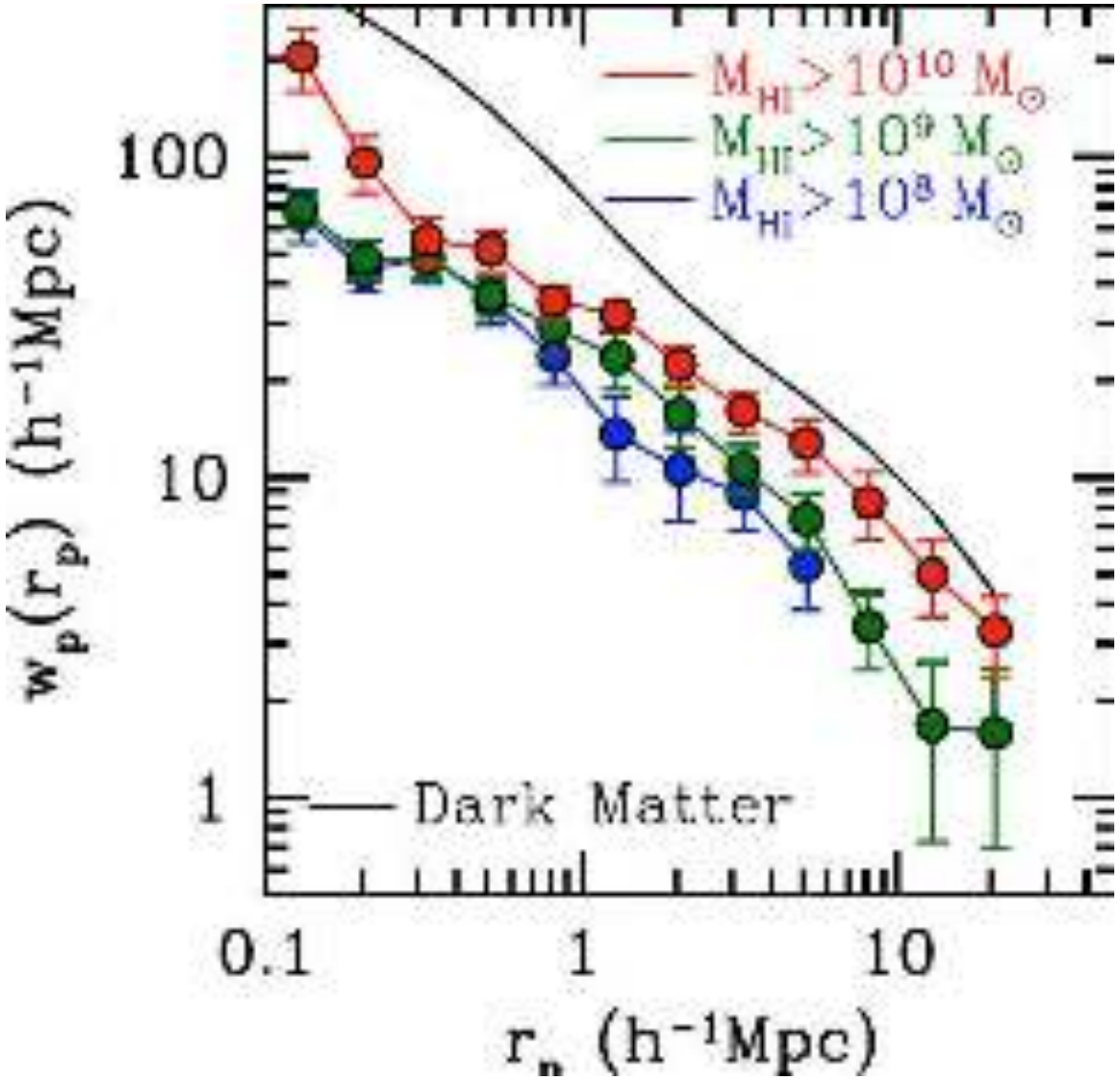


Haynes et al. (2011)



16,000 galaxies with $0.0025<z<0.05$ and $M_{HI}>10^8 M_{sun}$

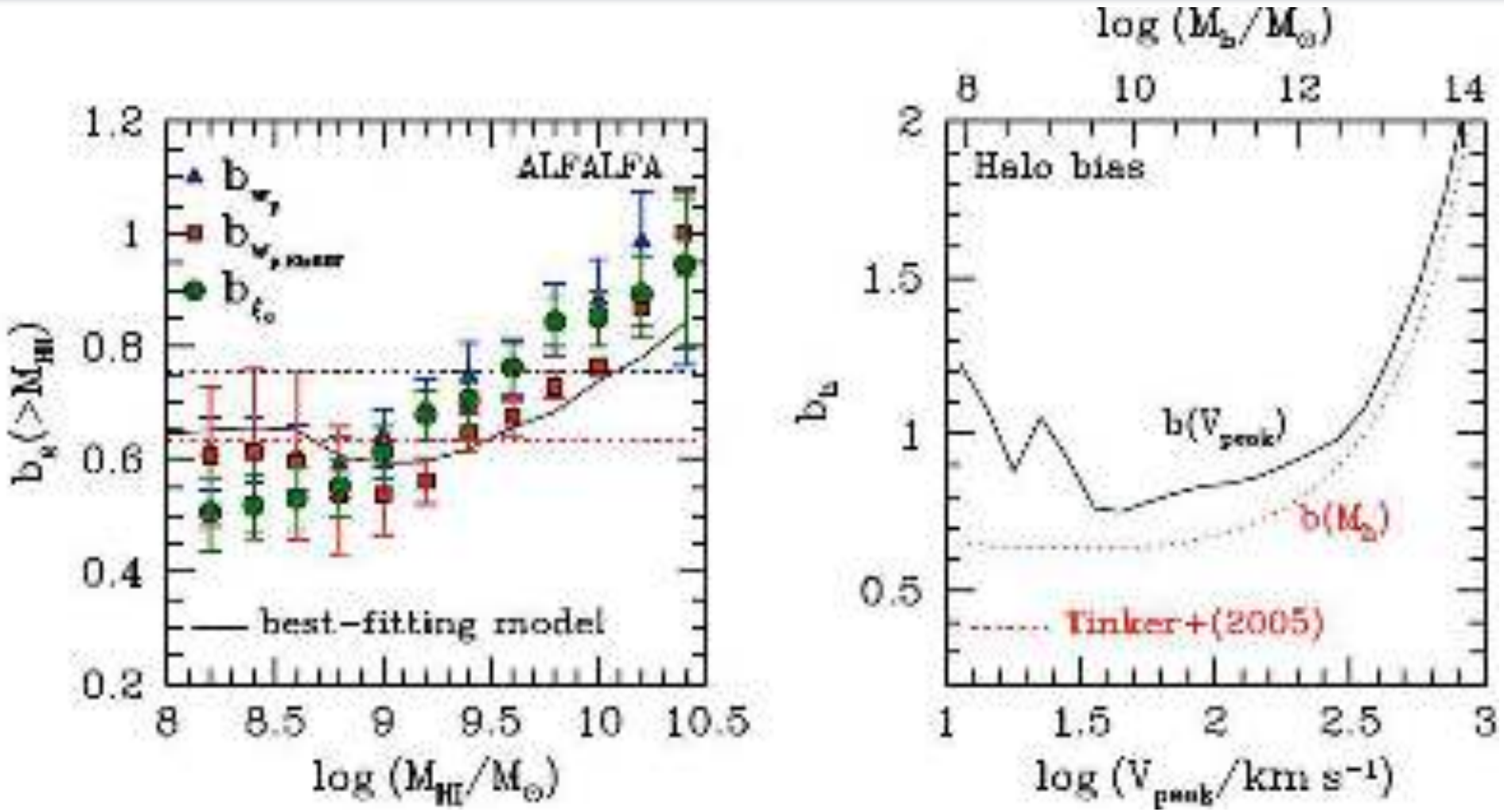
Our Measurements of projected 2PCF with ALFALFA a.70 sample



- Larger sample, better S/N
- Careful corrections of sample selection effects
- Multiple statistical methods to test the reliability of the results

Strong dependence on HI mass at r_p above a few Mpc

Galaxy bias as a function of HI mass from various statistics



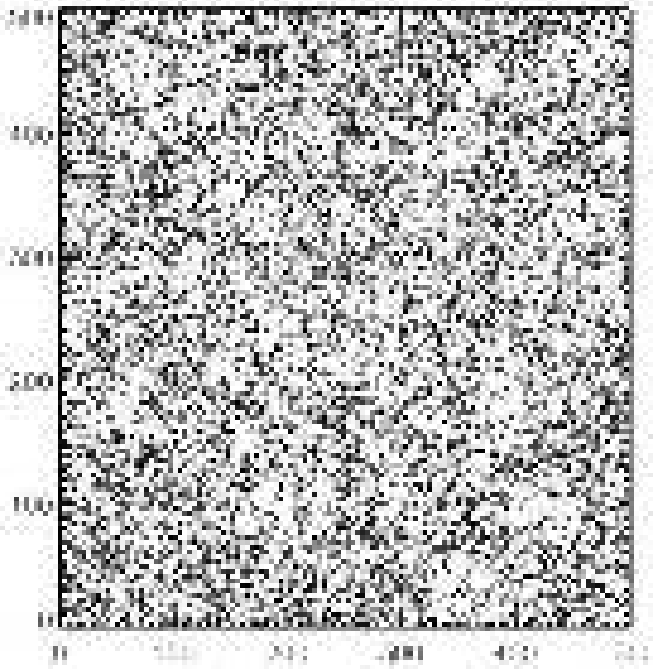
Bias of HI-rich galaxies is smaller than the minimum bias of dark matter halos!

The clustering cannot be solely explained by halo mass

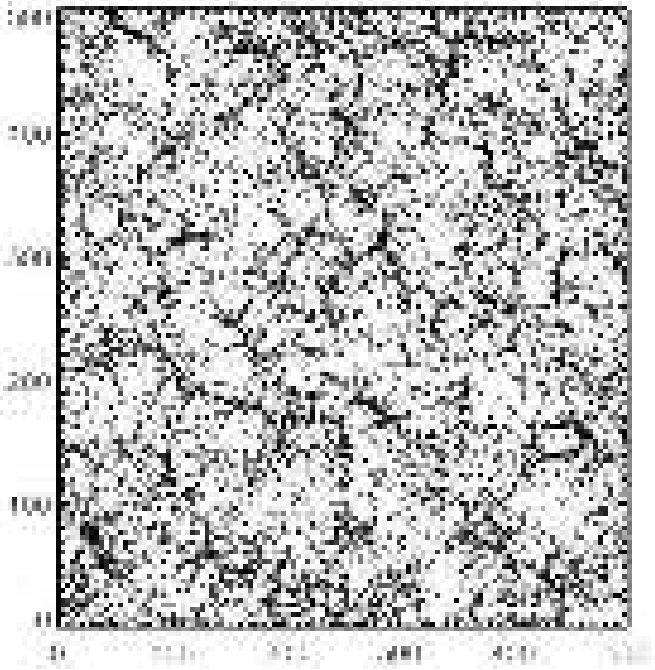
Additional halo parameters must be included in the modelling

- Halo Assembly Bias: halos at fixed mass can be clustered differently due to different assembly histories
- Assembly history is likely a driving parameter of galaxy color and gas content for galaxies hosted by halos of same masses

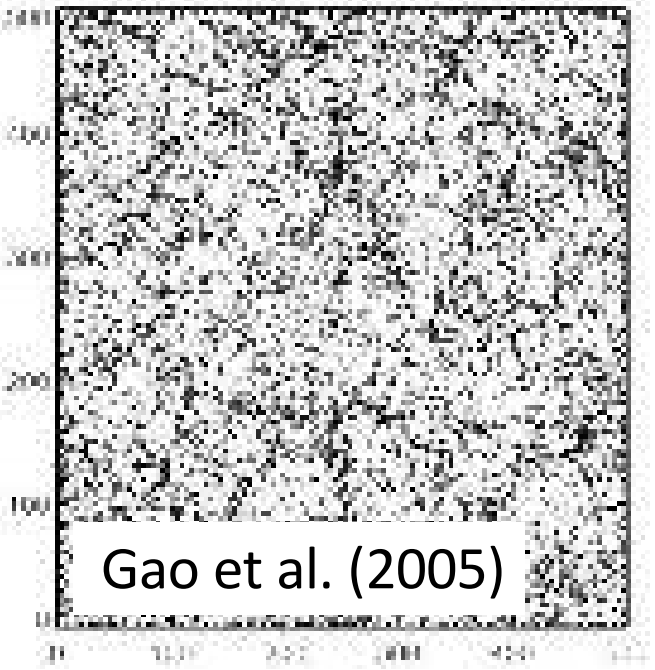
Young Halos



Old Halos



Dark Matter



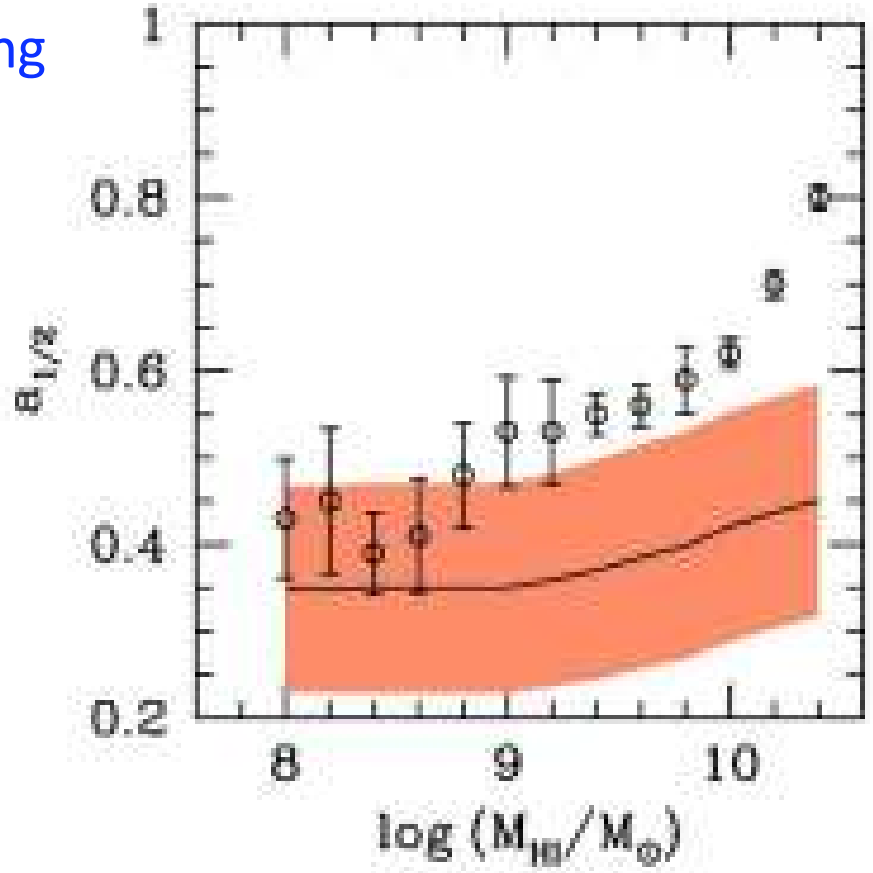
Gao et al. (2005)

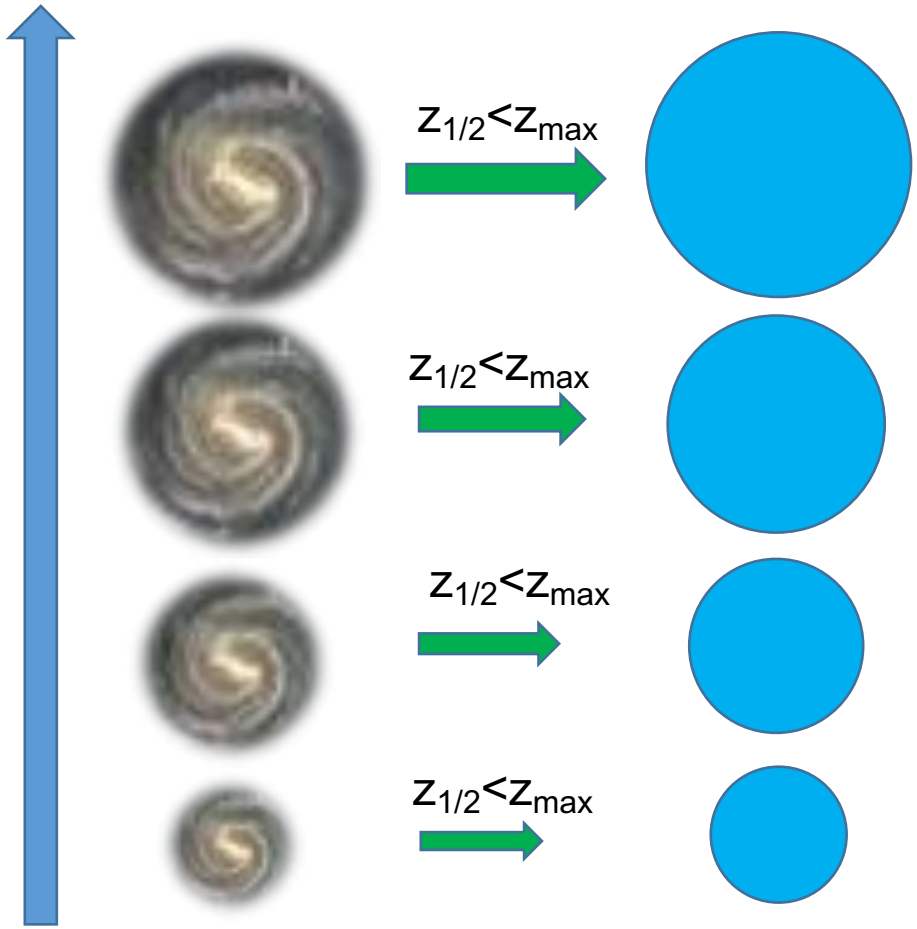
Model Construction: abundance matching + age matching

Only one free parameter:
Maximum halo formation time, z_{max}, determined through fitting the clustering measurements

young

old

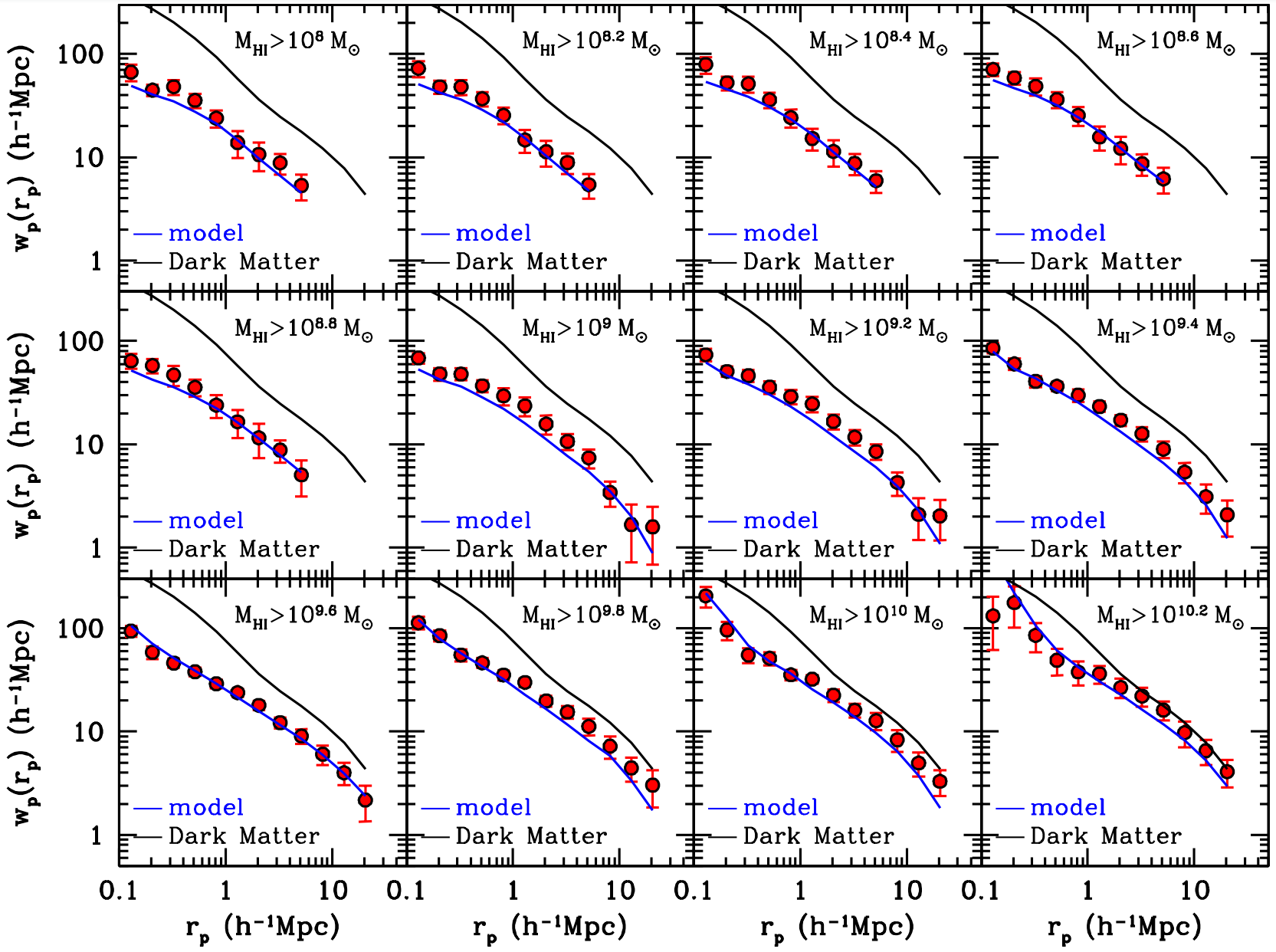




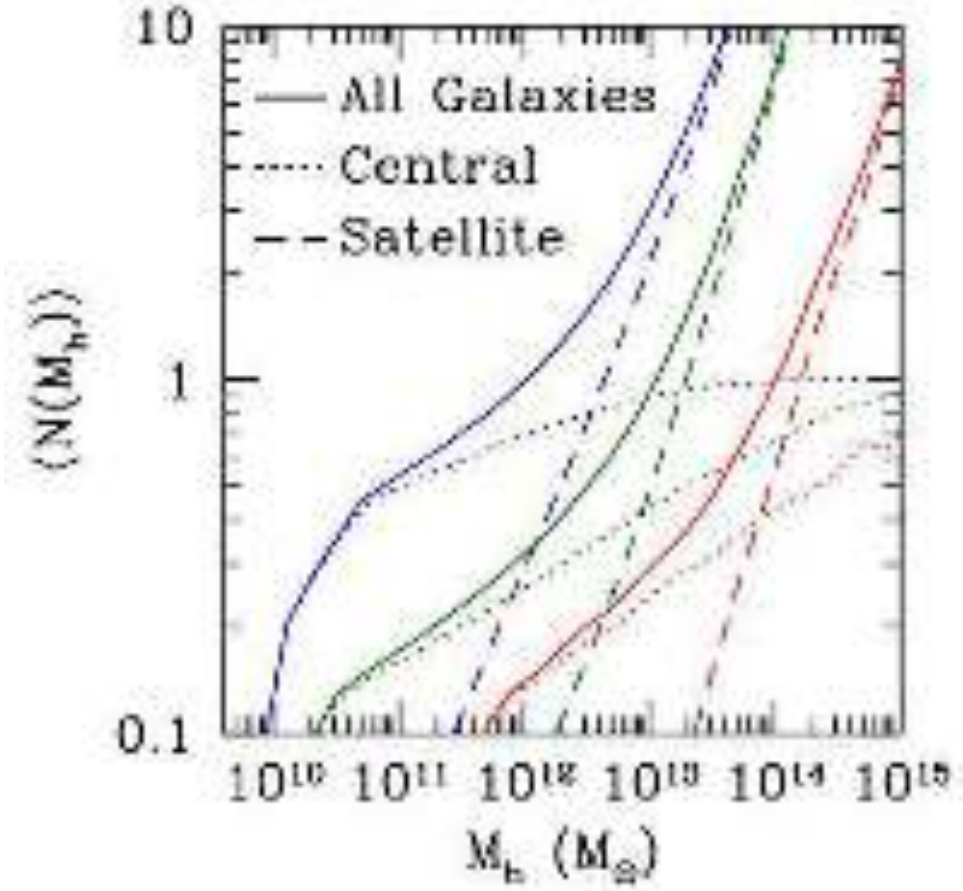
Rank order by HI Mass

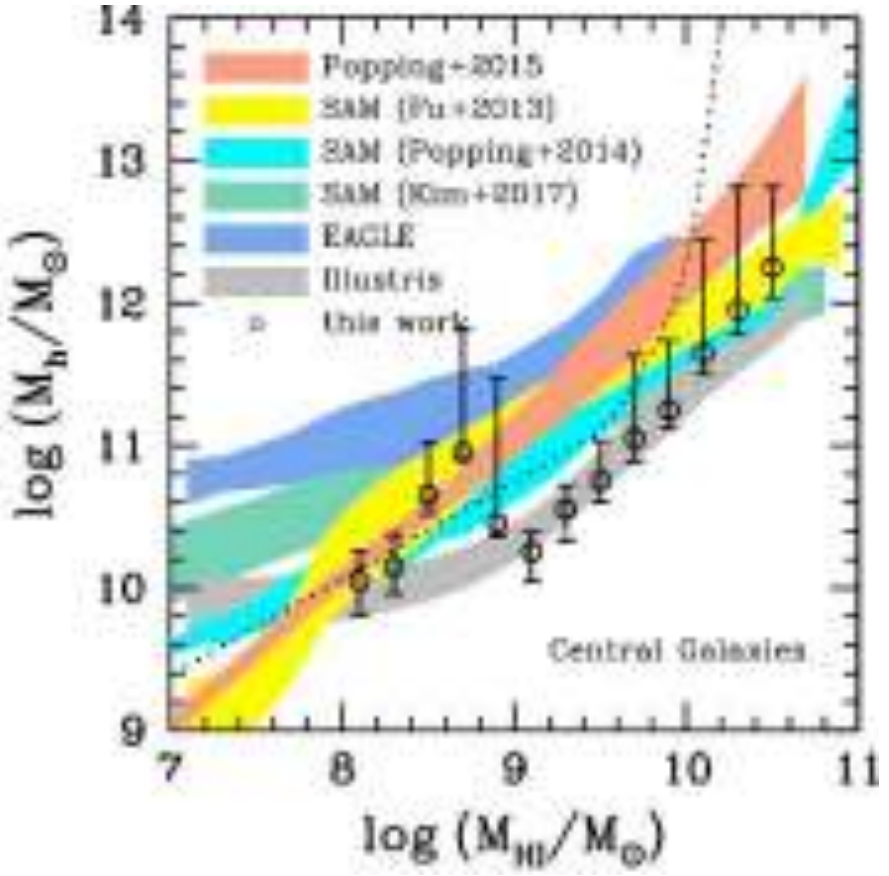
Rank order by halo maximum circular velocity

This model can well explain the clustering at all M_{HI} masses



HI – Halo Mass Relation and Halo Occupation Distribution

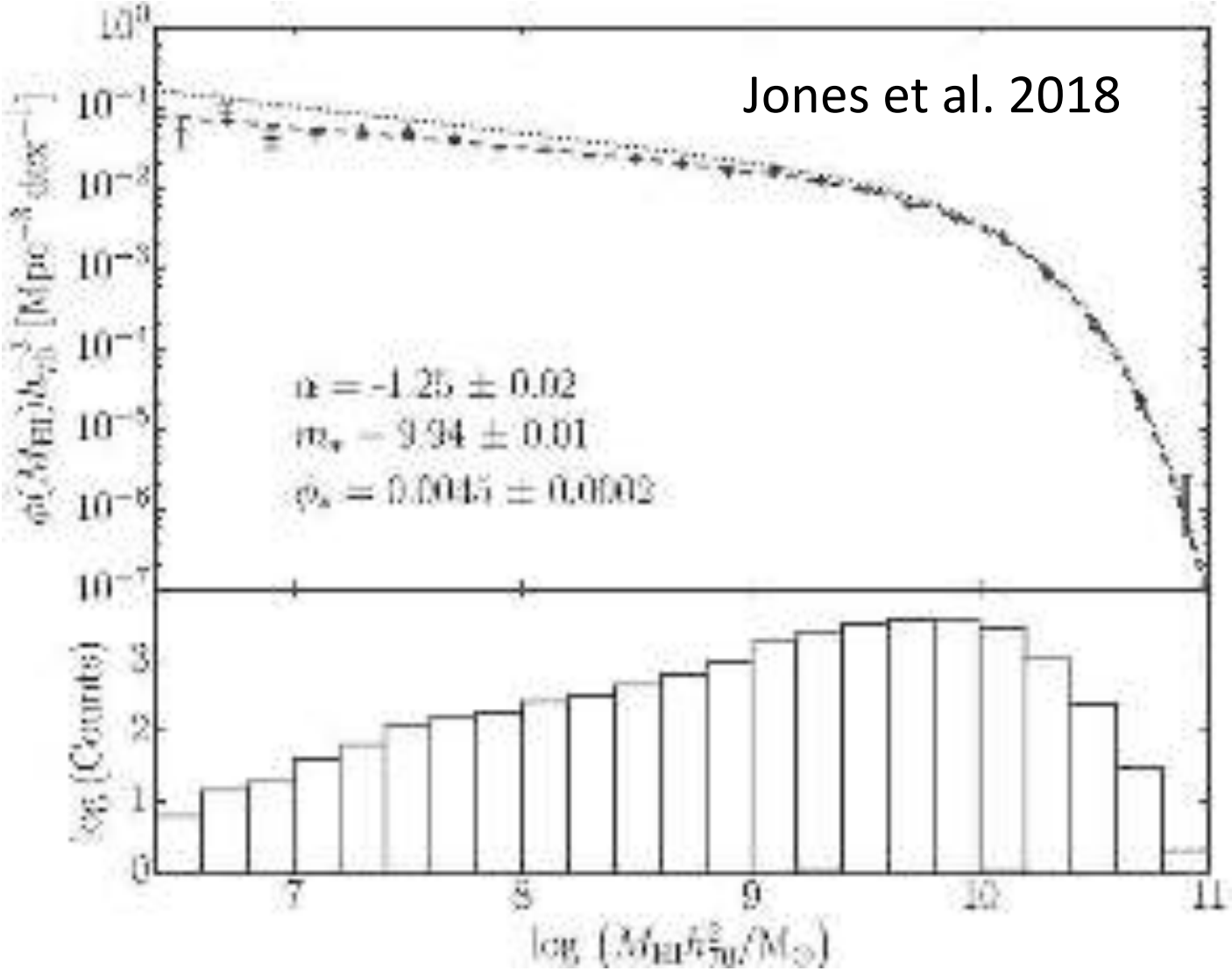


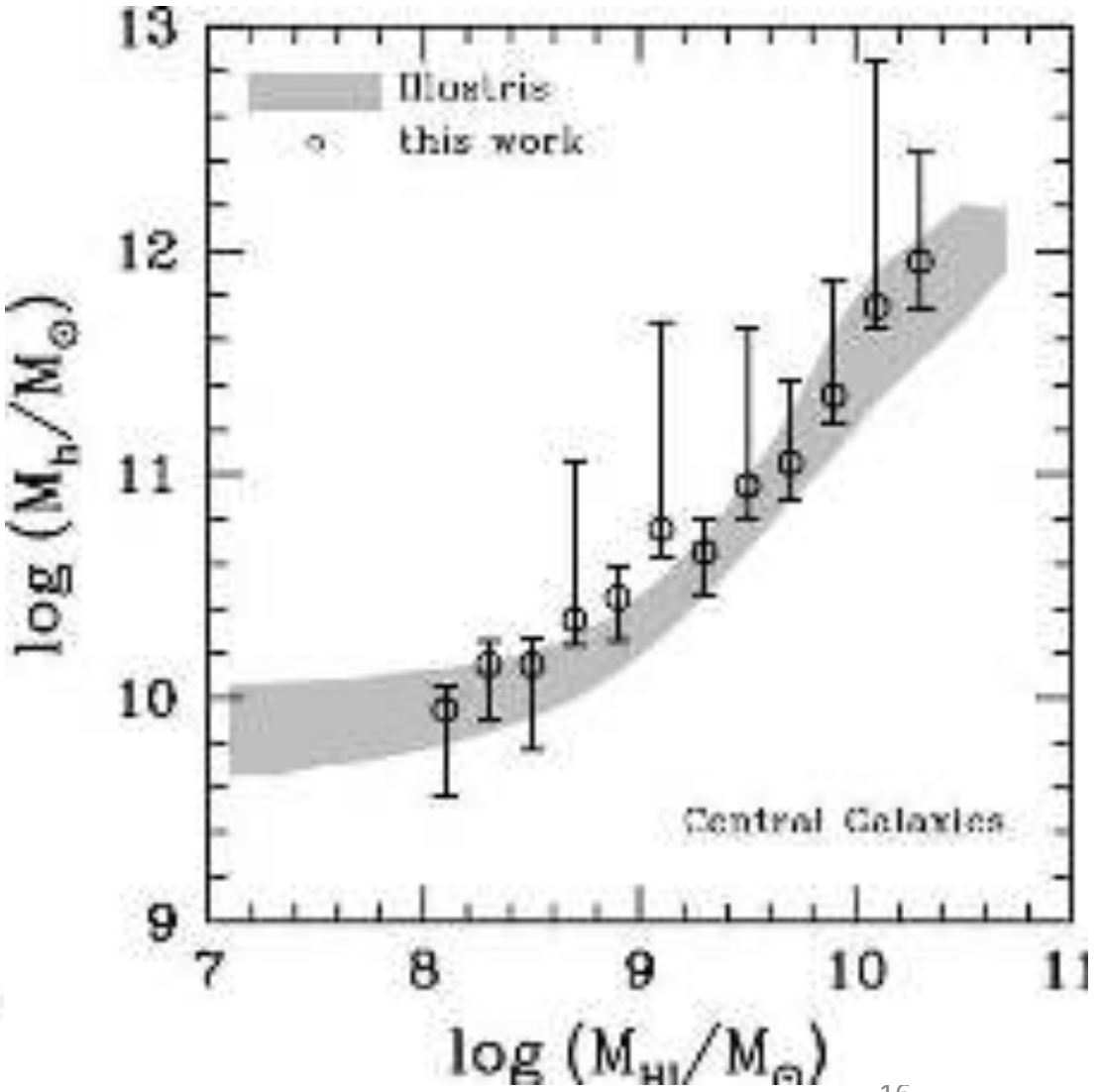


- HI-rich galaxies can be hosted by massive halos, if the halos formed late
- Current simulations and semi-analytic models predict contradictory HI-halo relations, which can be constrained by the clustering of gas-rich galaxies

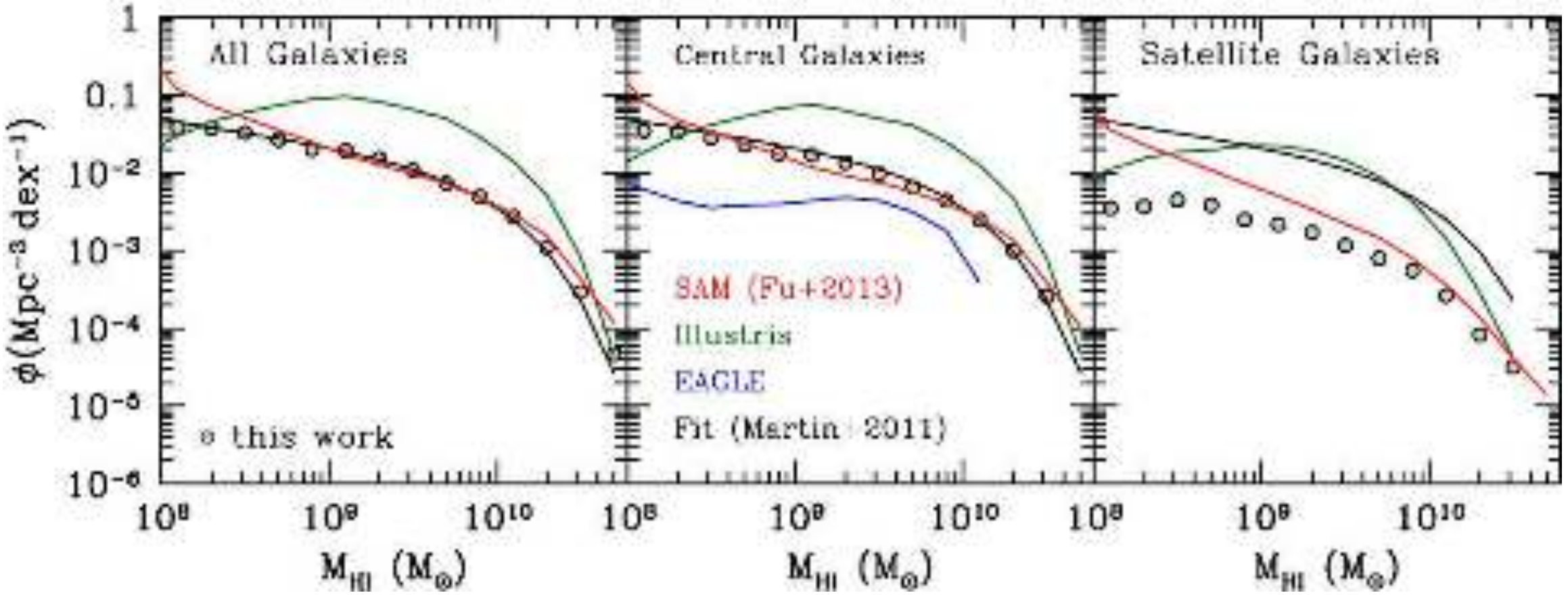
Updated with ALFALFA 100% DATA

Jones et al. 2018





Predicted HI Mass Functions

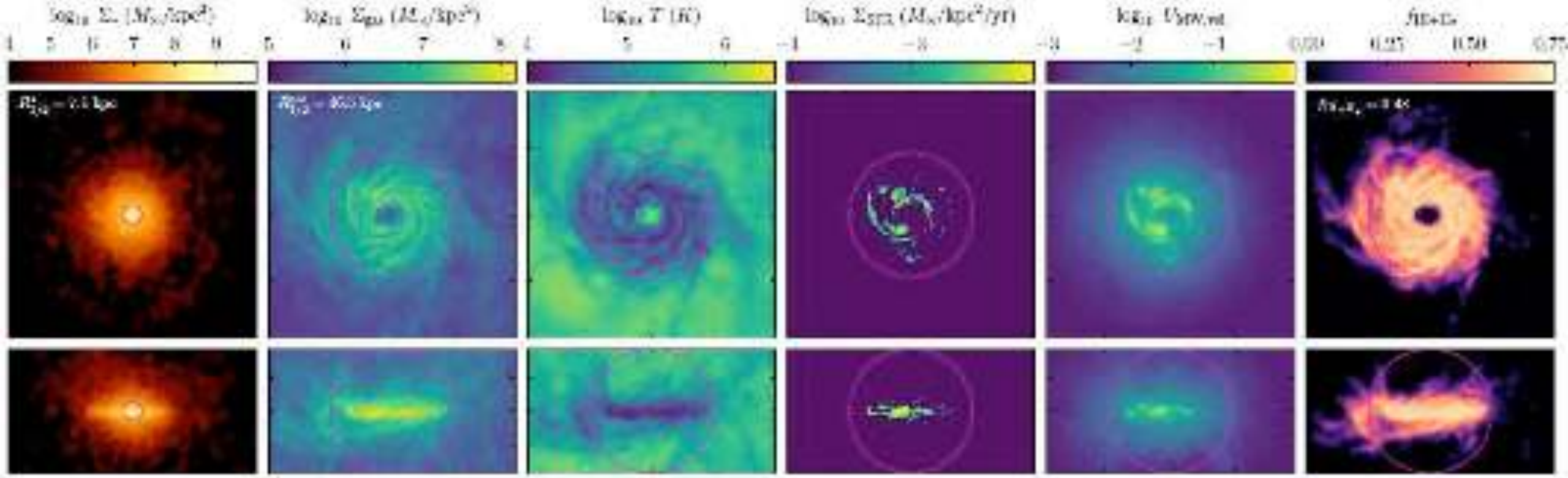


- The Illustris simulation overpredicts the abundance of gas-rich galaxies
- Our HIMFs for central/satellite galaxies can be tested using galaxy groups/clusters with deep HI observation (science case for FAST?)

IllustrisTNG Simulations

	Illustris	TNG100	TNG50	TNG300
Overview:				
Specs	L75n1820FP	L75n1820TNG	L35n2160TNG	L205n2500TNG
MHD	no	yes	yes	yes
Cosmology	WMAP7	Planck 2015	Planck 2015	Planck 2015
Box and Resolution:				
Lbox [Mpc]	106.5	110.7	51.7	302.6
# res elements	2 x 1820^3	2 x 1820^3	2 x 2160^3	2 x 2500^3
gas mass in the initial conditions [Msun]	1.26e6	1.39e6	8.47e4	1.1e7
DM mass [Msun]	6.26e6	7.46e6	4.54e5	5.88e7
~EpsilonBaryons [kpc]	0.7	0.7	0.3	1.5

HI+H2 Modeling in IllustrisTNG



Post-processing of the neutral gas into HI and H2 component

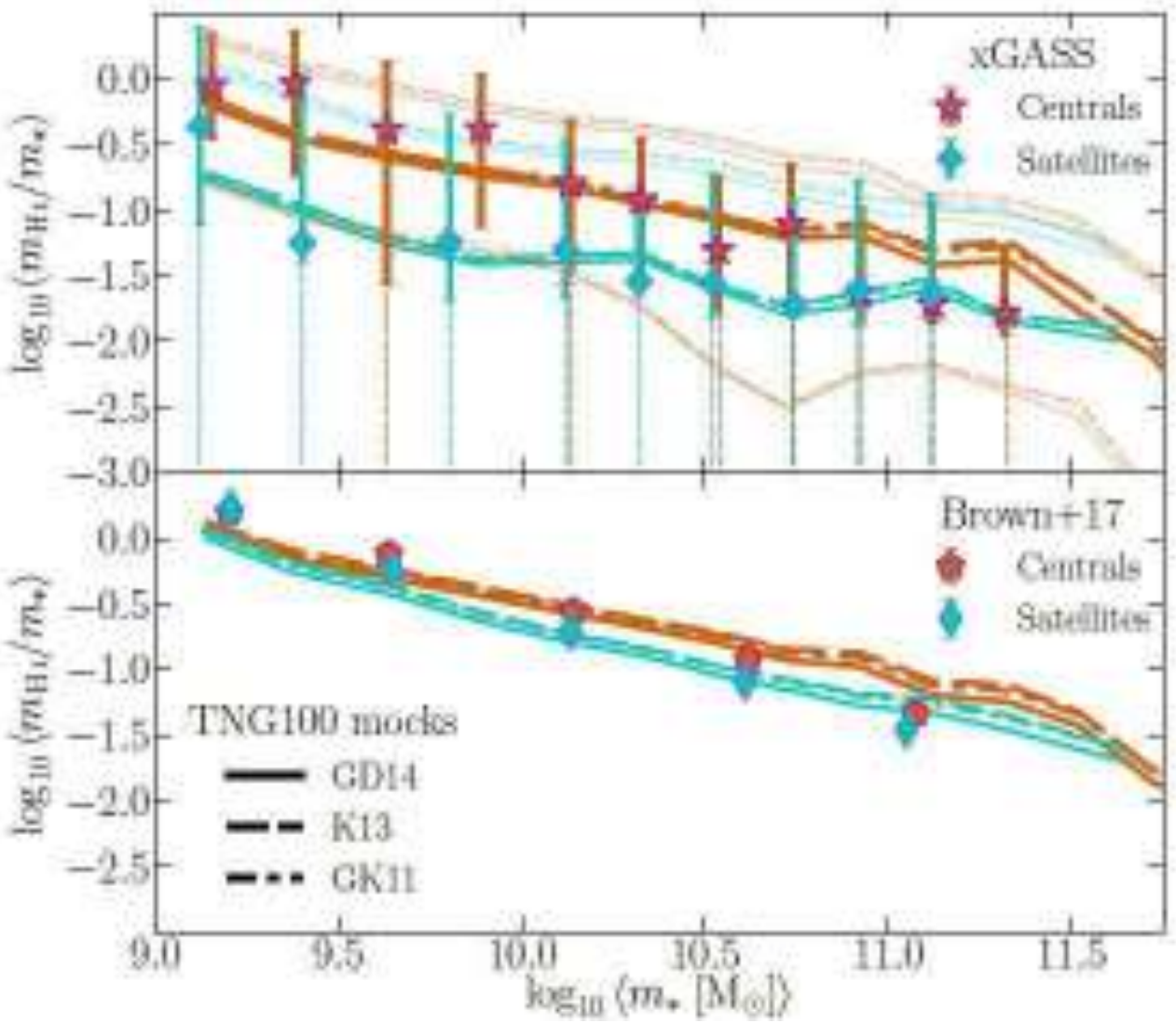
Diemer+2018

$$f_{\rm mol} = \begin{cases} 1 - 3s/(4+s) & \text{if } s < 2 \\ 0 & \text{if } s \geq 2 \end{cases}, \qquad \text{(C11)}$$

Krumholz et al. (2013)

where

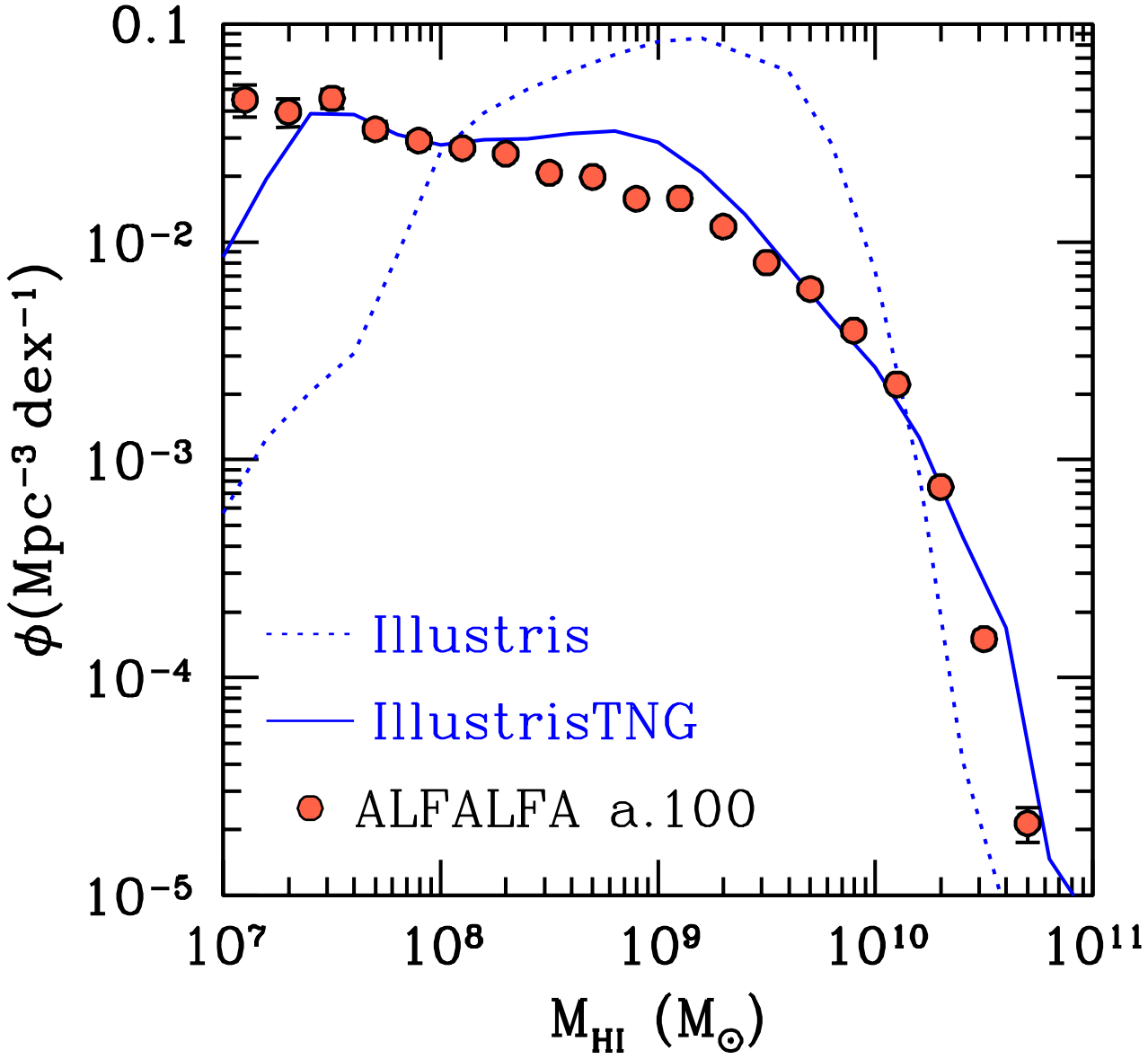
$$s = \frac{\ln(1 + 0.6\chi + 0.01\chi^2)}{0.6\tau_c}. \qquad \text{(C12)}$$

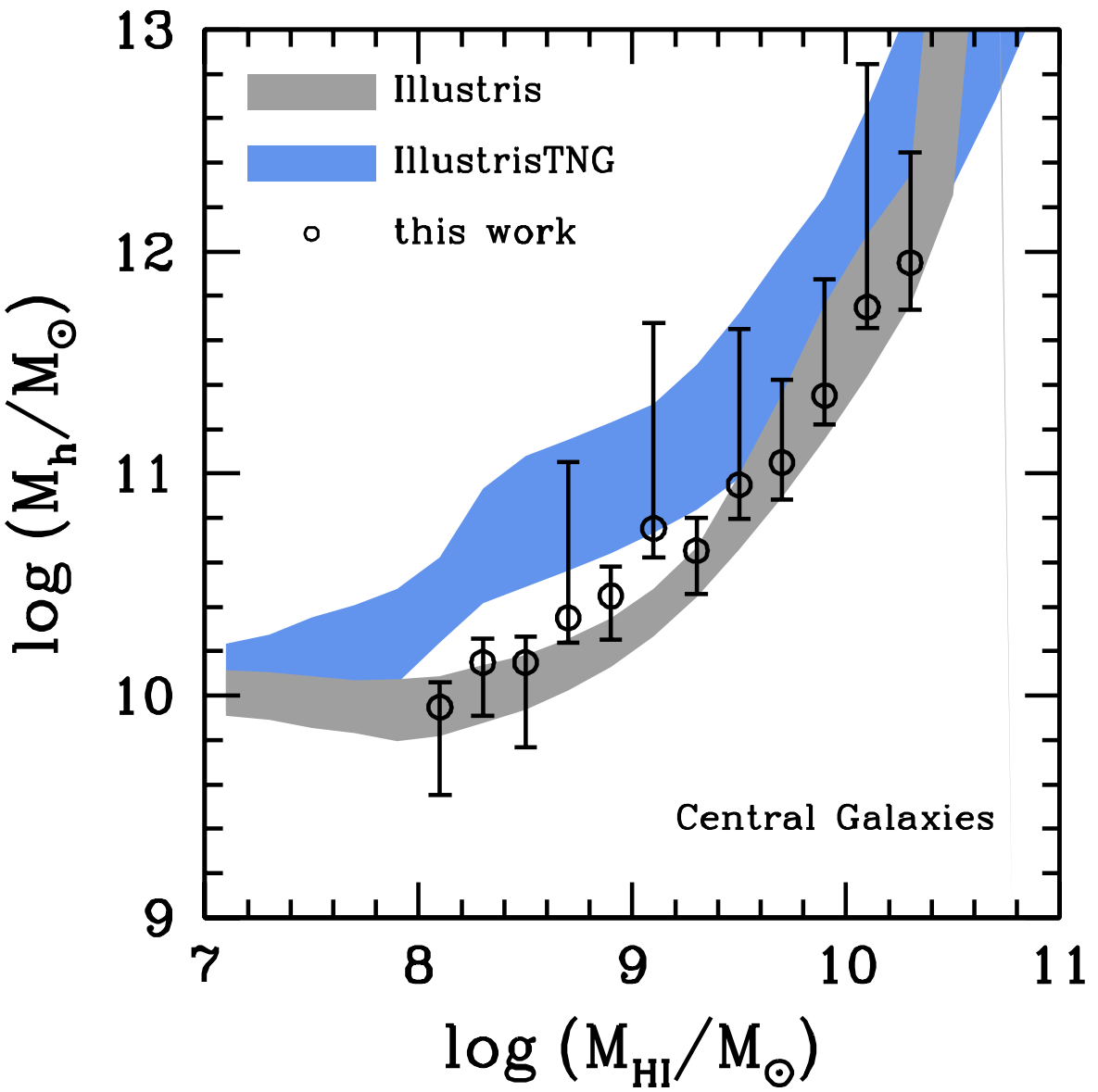


- Comparisons to observations of xGASS
- Good agreement with literature

Stevens et al. (2018)

Comparison between TNG and ALFALFA100 data

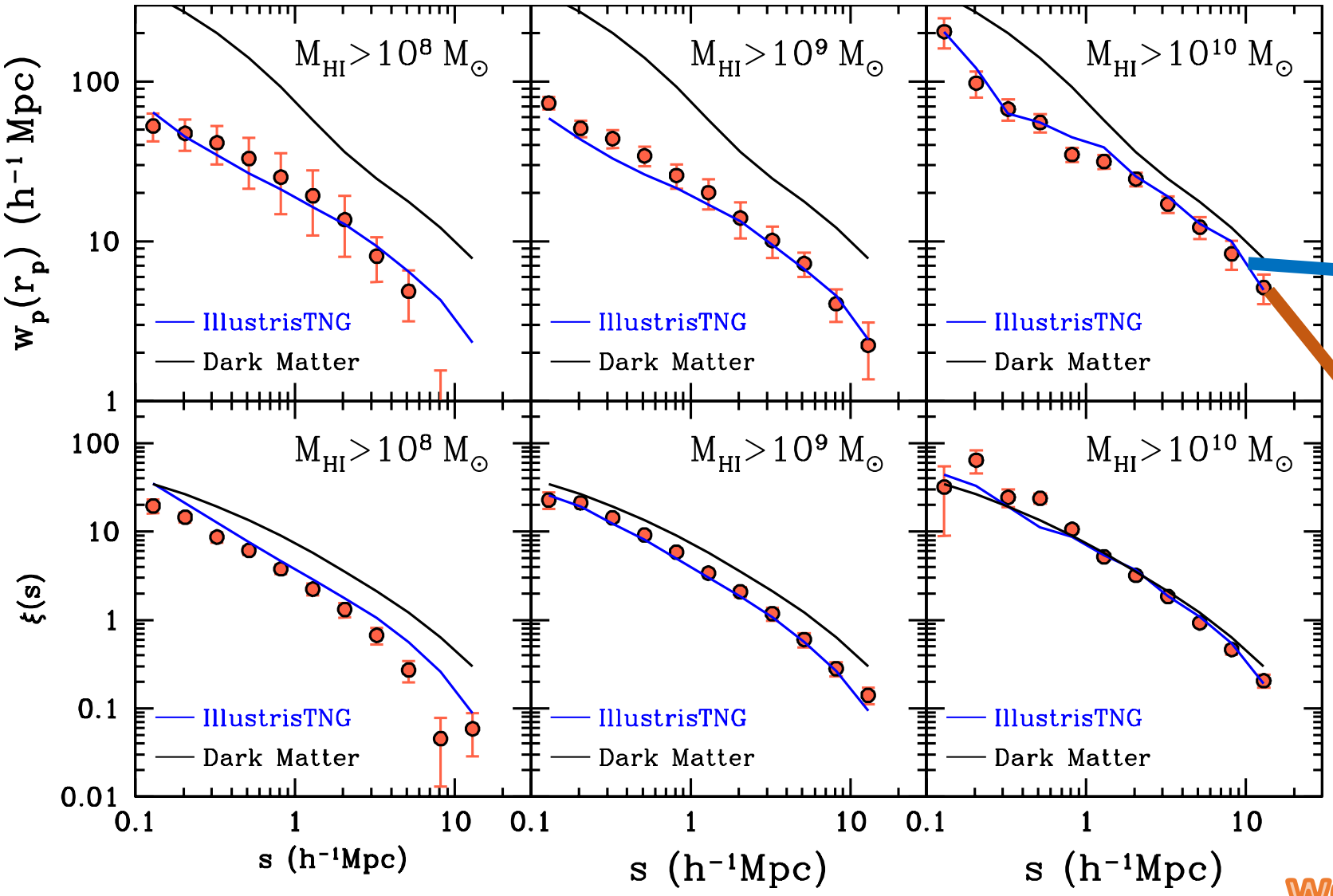




Comparison between TNG and ALFALFA100 data

Projected two-point function

Redshift-space two-point function

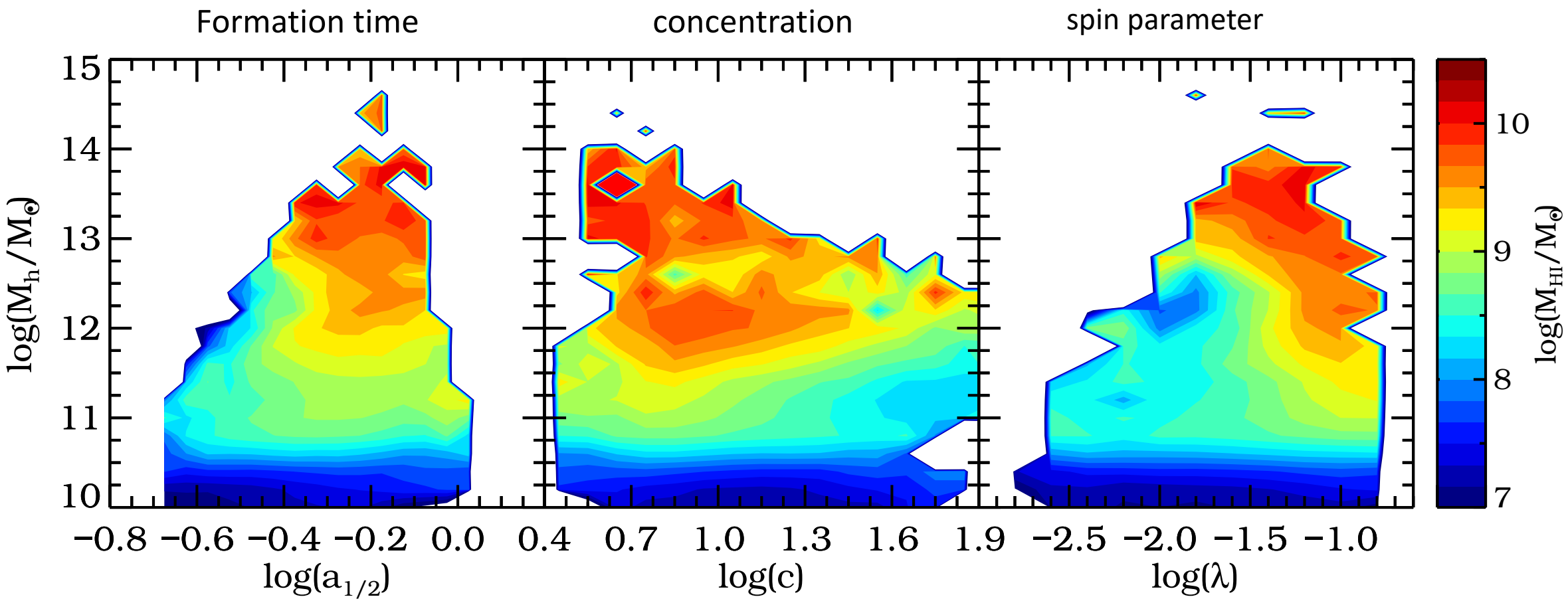


IllustrisTNG

ALFALFA 100 measurements

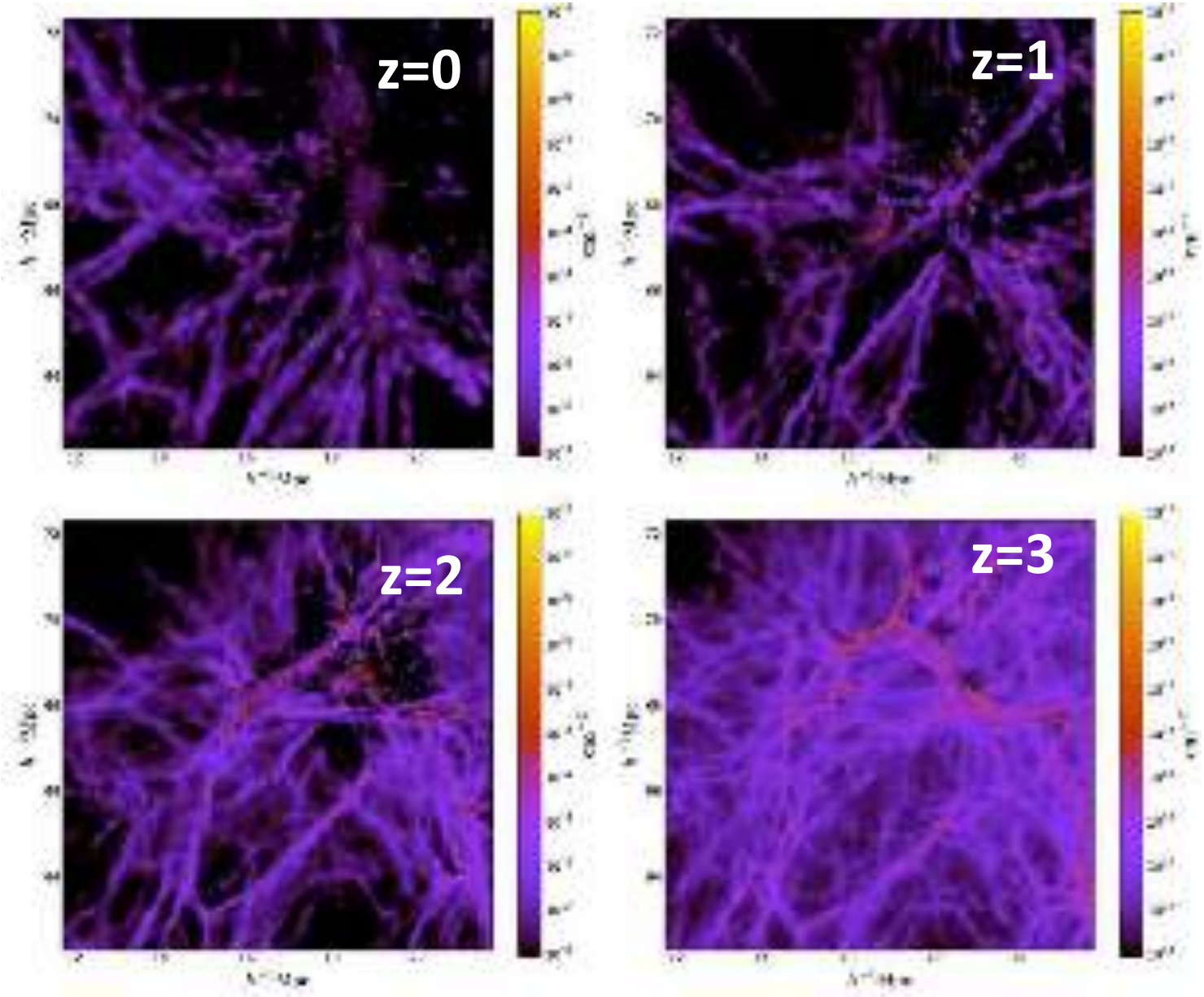
work in progress

Halo Assembly Effect in TNG



HI-rich galaxies tend to live in young, low-concentration, and high-spin halos

Halo assembly bias confirmed in TNG!

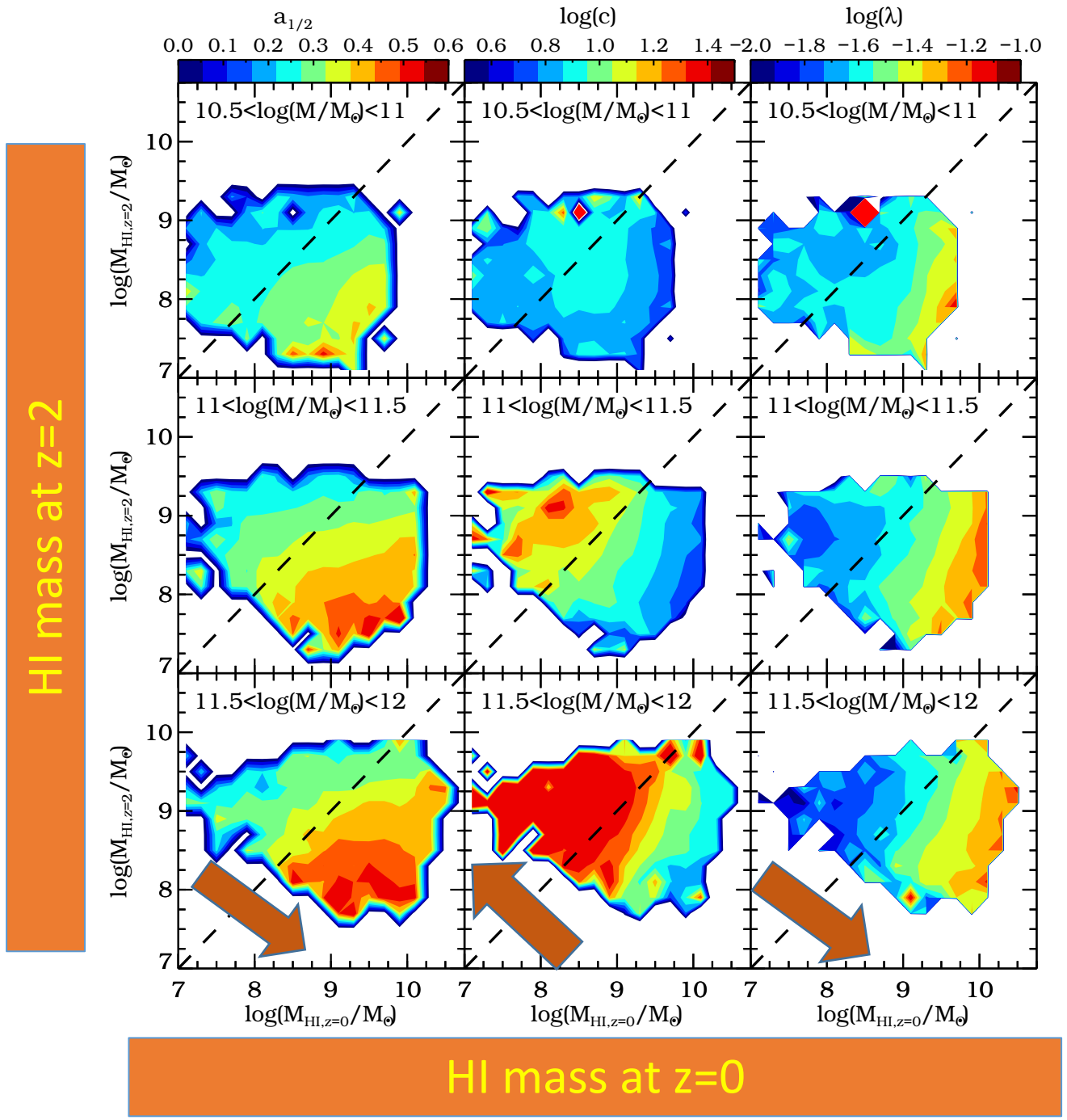


- Distribution of HI gas in the large scale structure
- At low redshift the HI is mostly locked inside galaxies.

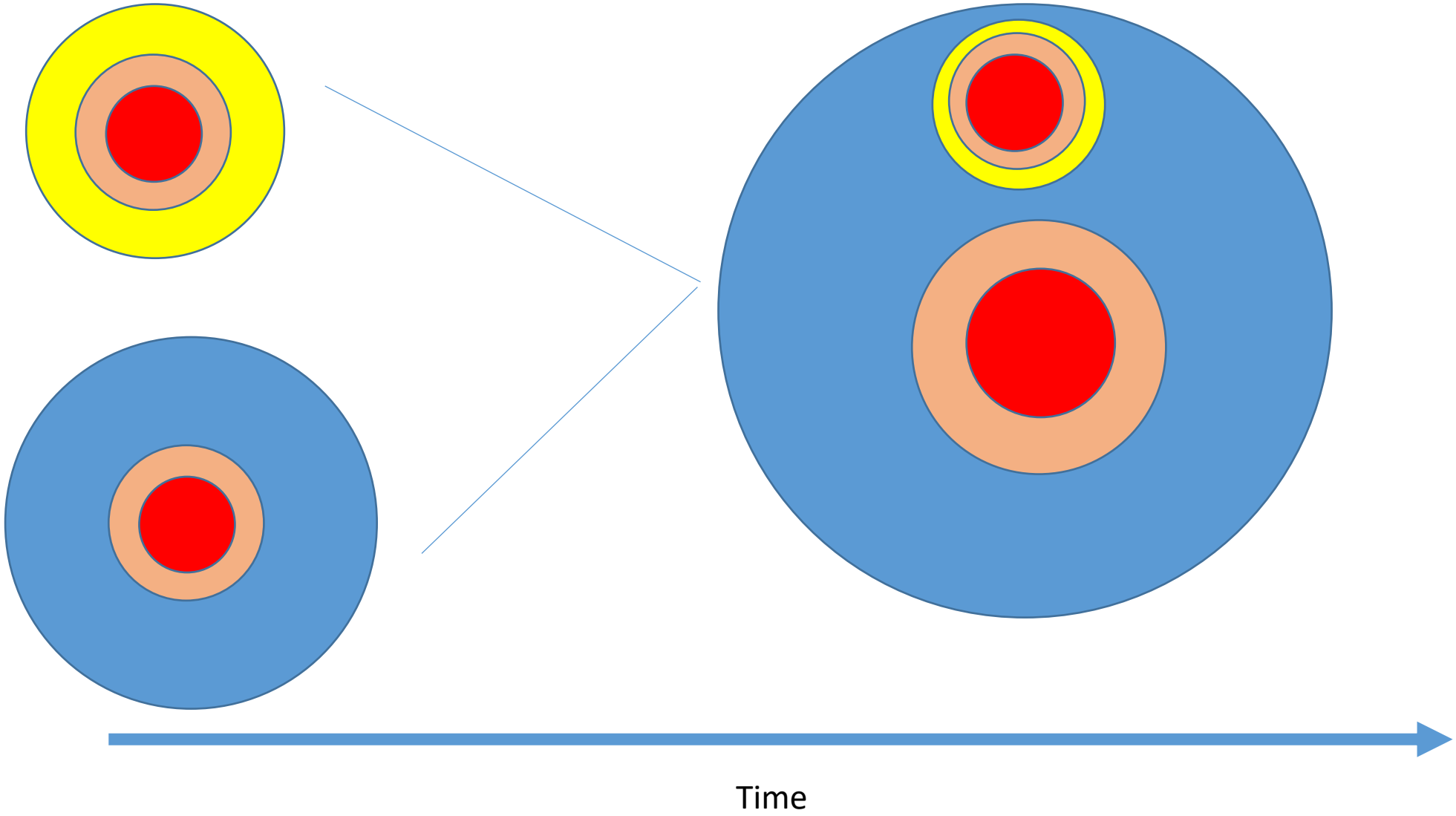
Villaescusa-Navarro et al. (2018)

Evolution of the HI content in halos

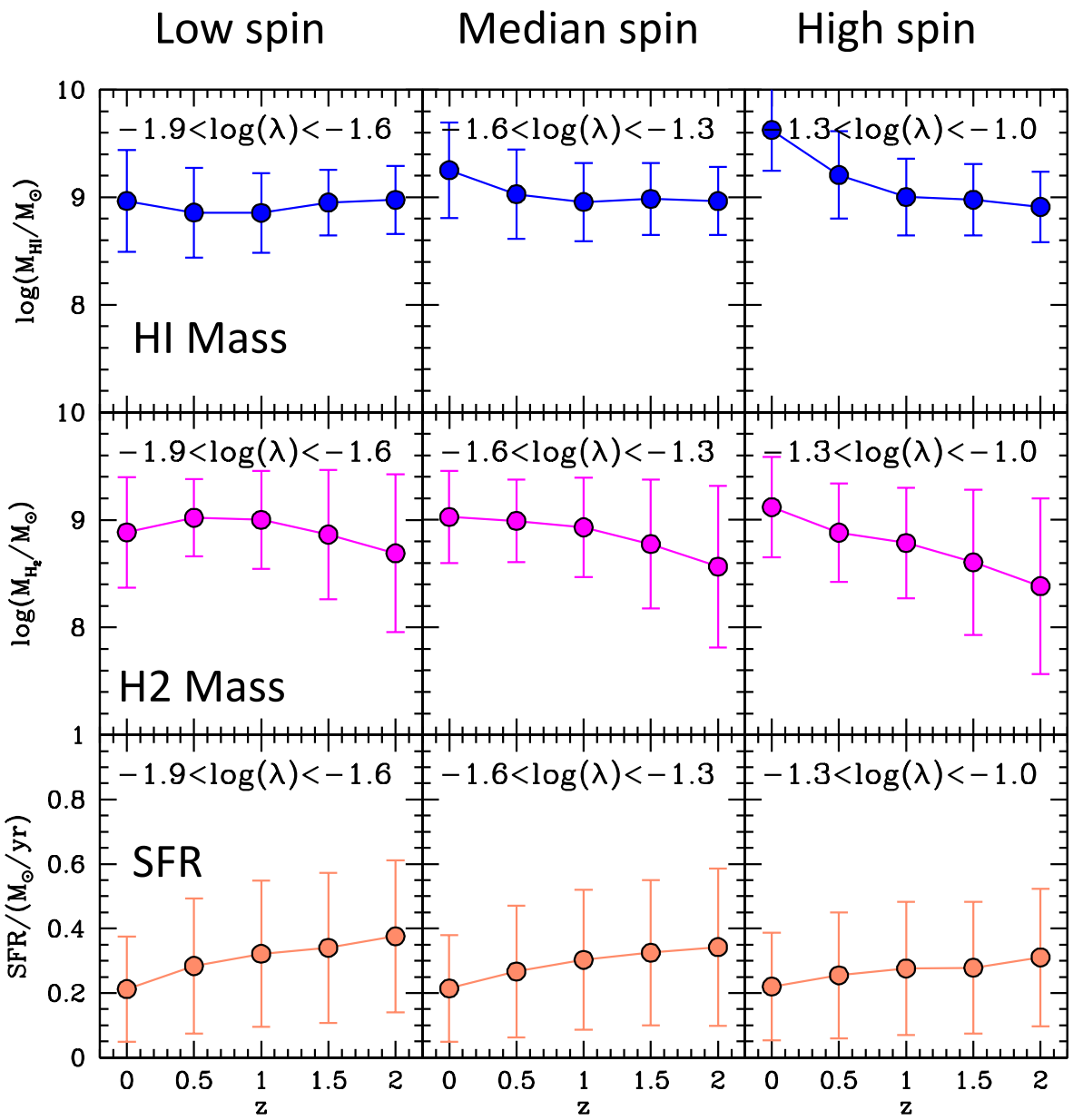
There is strong growth of HI mass in young, low-concentration, and high-spin halos



Merger-driven Formation Scenario for Gas-rich Galaxies



Gas Mass evolution



Large HI mass is recently accreted into high-spin halos

Summary

- Galaxy clustering strongly depends on HI mass, with stronger clustering at higher HI masses
- Abundance matching combined with halo age matching model can successfully explain the observed clustering
- HI-rich galaxies can be hosted by massive halos, provided that the halos formed late
- Current simulations and semi-analytic models predict contradictory HI-halo relations, which can be constrained by the clustering of gas-rich galaxies

Thank you!