The view of HI gas size-mass relation in semi-analytic models of galaxy formation

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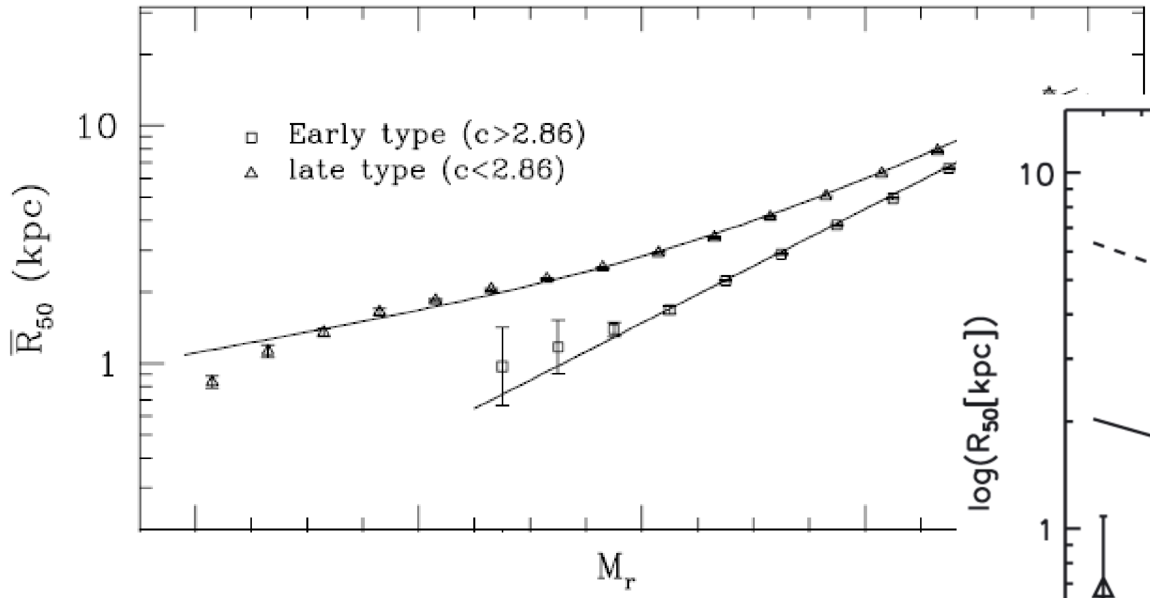
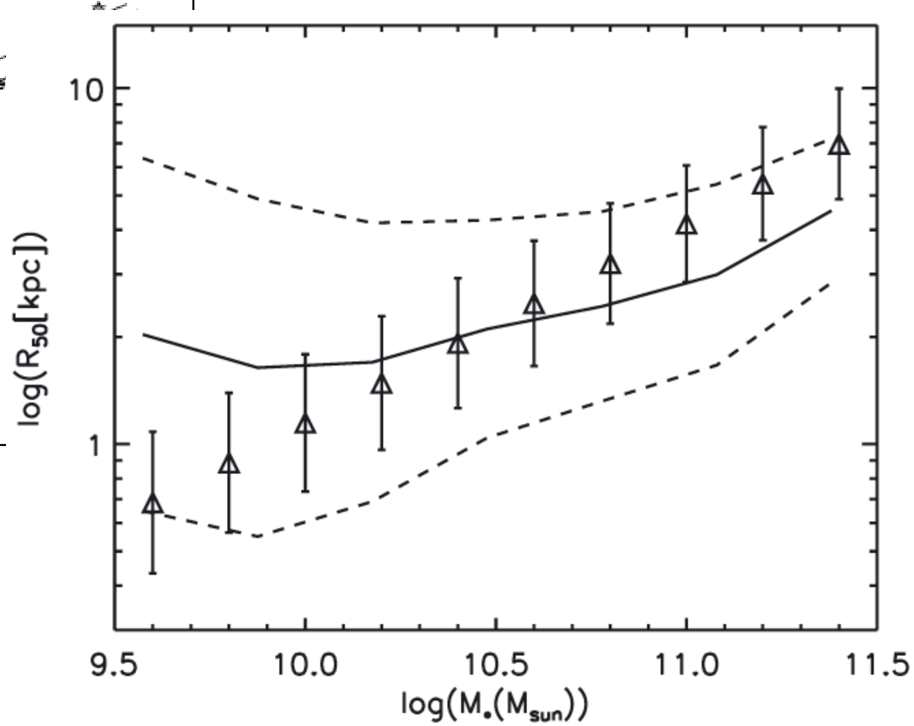
Size-mass relation of galaxies

One of the most important scale relations of galaxy

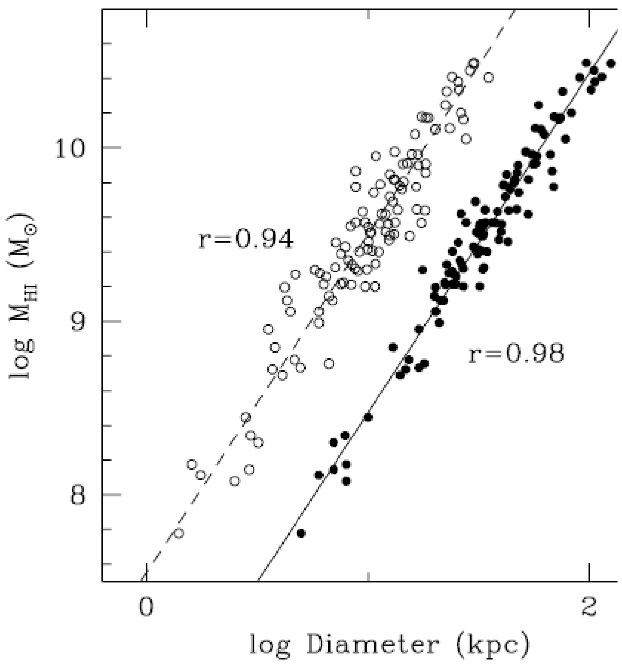


Shen et al. 2003

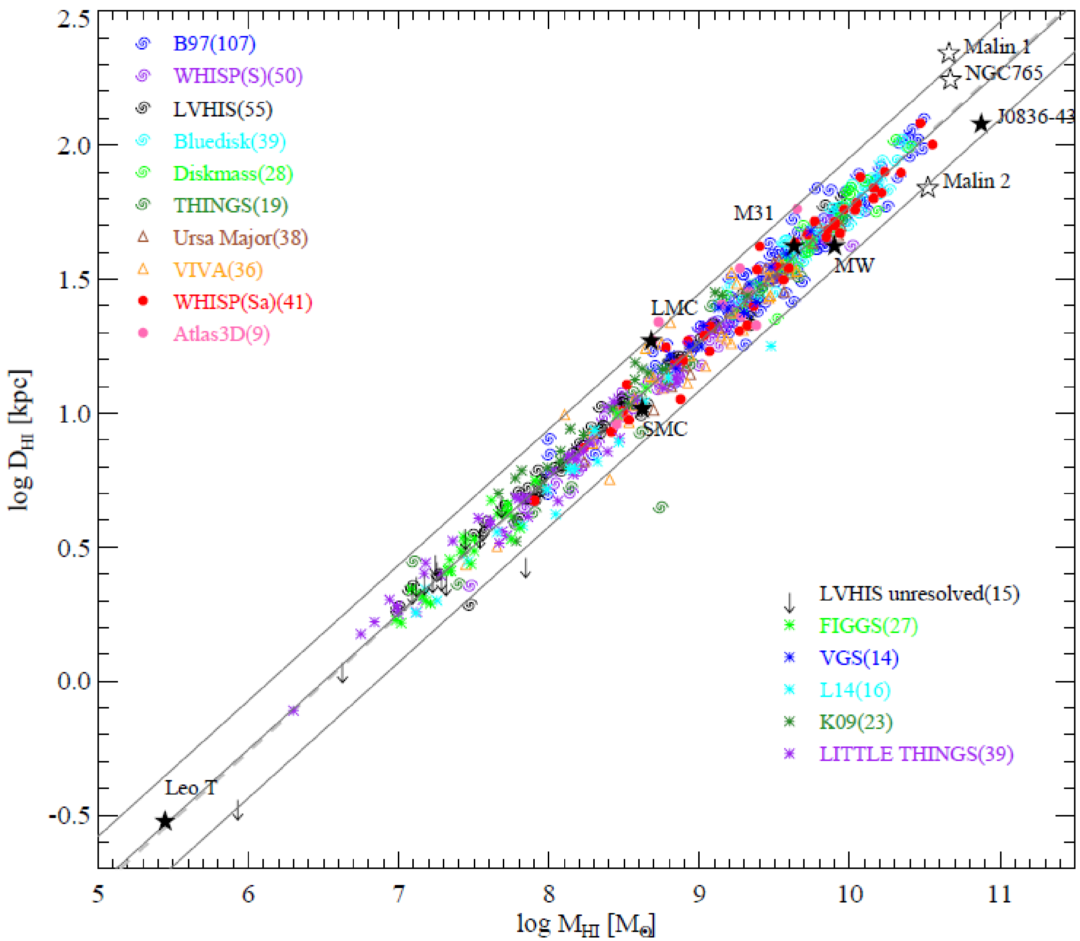


Guo et al. 2013

Size-mass relation HI gas in galaxies



Broeils & Rhee 1997



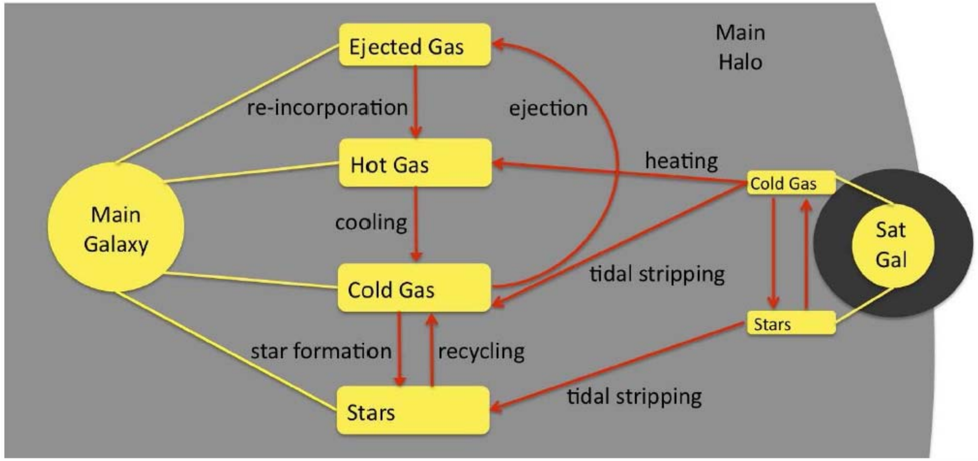
Wang et al. 2016

$$\lg M_{\mathrm{HI}} = (1.96 \pm 0.04) \lg D_{\mathrm{HI}} + (6.52 \pm 0.06)$$

Galaxies in the Simulated Universe

Semi-analytic models

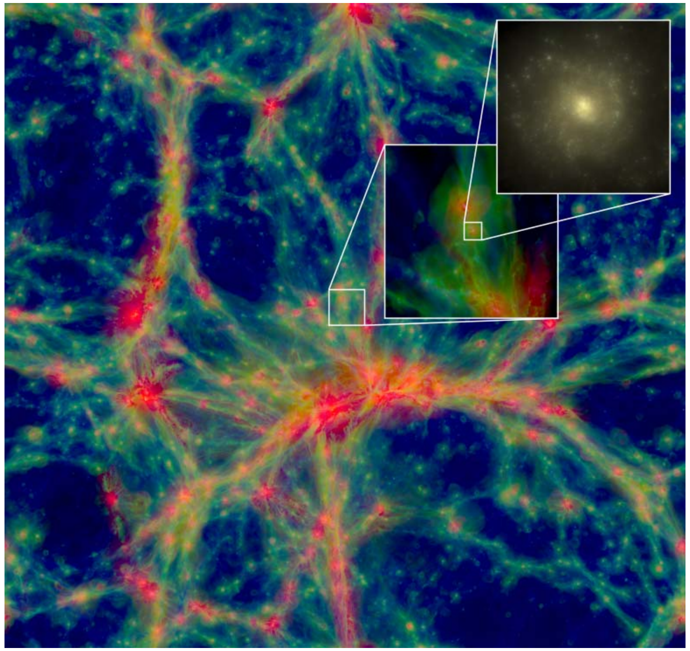
L-Galaxies, GALFORM



Describe the physical processes of baryonic matter based on dark matter simulation ouputs

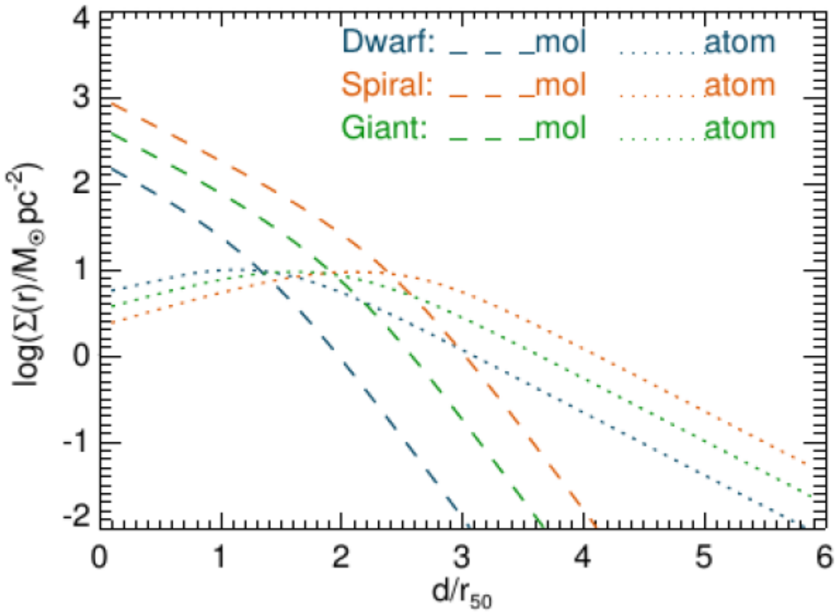
Hydrodynamic Simulations

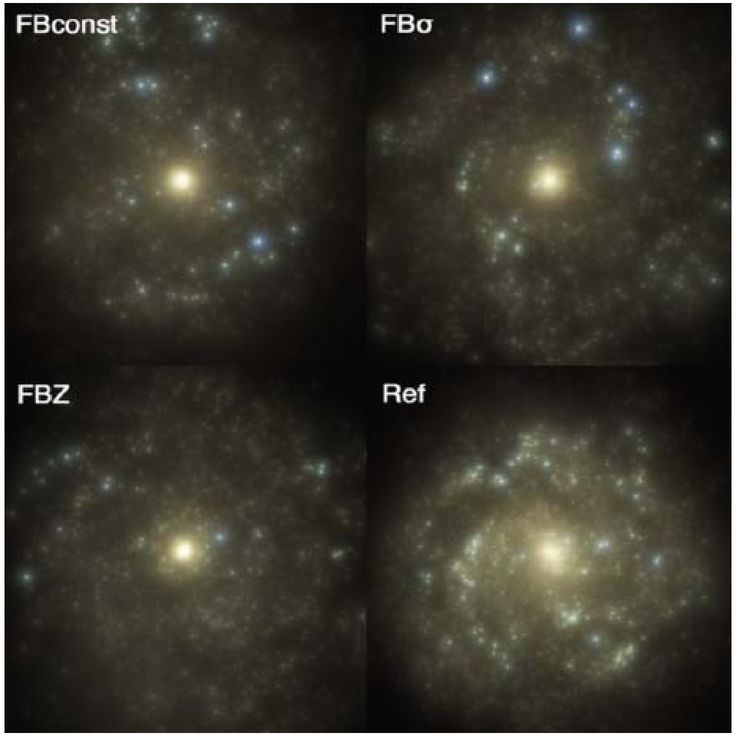
- EAGLE, Illustris, Horizon-AGN



Simulation combining both dark matter and baryonic matter

Radial profiles in SAMs & Hydro





Galaxy data and properties vs galaxy structure and image

Millennium and Millennium II Simulation

- Millennium Simulation: Springel et al. 2005
- Millennium II Simulation: Boylan-Kolchin et al. 2009
- The mass resolution of MS-II is 125 larger than MS: use to study dwarf galaxies and small galaxies at high z

	Millennium I (MS)	Millennium II (MS-II)
Particle number	2160^3	
Particle Mass	$8.6\times10^8 M_\odot h^{-1}$	$6.8\times10^6 M_\odot h^{-1}$
Box size	500 h^{-1} Mpc	100 h^{-1} Mpc
Output snapshots	64 snapshots Between z=0 and 127	68 snapshots Between z=0 and 127
Minimum halo mass	$1.7\times10^{10} M_\odot h^{-1}$	$1.4\times10^8 M_\odot h^{-1}$

L-Galaxies Semi-analytic models

Cooling
- temperature
- Metallicity
- …

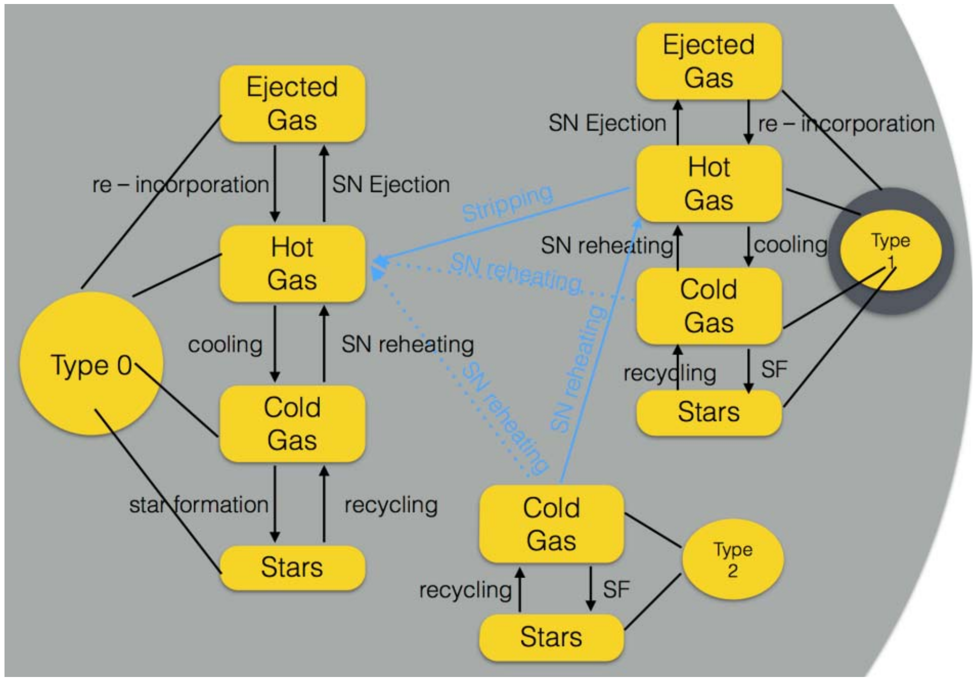
Star formation and evolution
- Threshold
- IMF
- Recycling
- …

Feedback
- SN feedback
- AGN feedback
- …

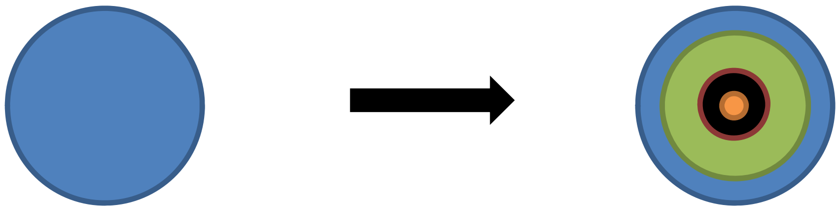
Chemical evolution
- metals' production
- ejection
- Mixing
- …

Mergers
- Morphology
- Star bursts
- AGN
- …

Black Hole AGN
- BH growth
- Feedback
- …



The radial resolved disk in SAMs



Concentric rings in galaxy disks to trace the disk formation

$$\Sigma_*(r), \Sigma_{\rm gas}(r), \Sigma_{\rm HI}(r), \Sigma_{\rm H_2}(r), {\rm SFR}(r)$$

- Atomic-molecular gas transition
  - Prescription 1: Krumholz et al. 2009; Mckee & Krumholz 2010

$$f_{\rm H_2}\left(\Sigma_{\rm gas}, [{\rm Z/H}]_{\rm gas}\right)$$

  - Prescription 2: Pressure related H_2 fraction recipe (B&R 2006)

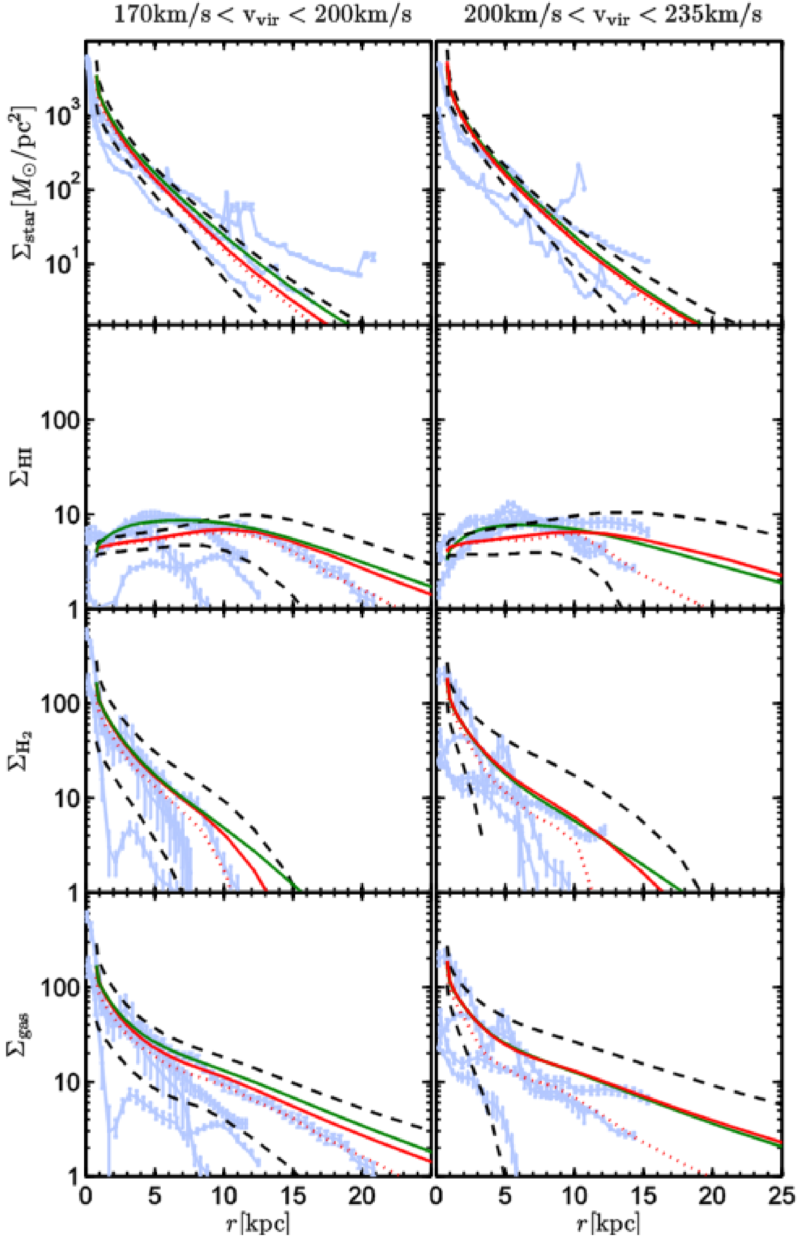
$$R_{\rm mol} \equiv M_{\rm H_2} / M_{\rm HI} = \left[P / P_0\right]^{\alpha} \qquad P(r) = \frac{\pi}{2} G \Sigma_{\rm gas}(r)\left[\Sigma_{\rm gas}(r) + f_{\sigma}(r)\Sigma_*(r)\right]$$

  - Prescription 3: Molecular-atomic-ionized gas (Gnedin& Kravtsov 2011)

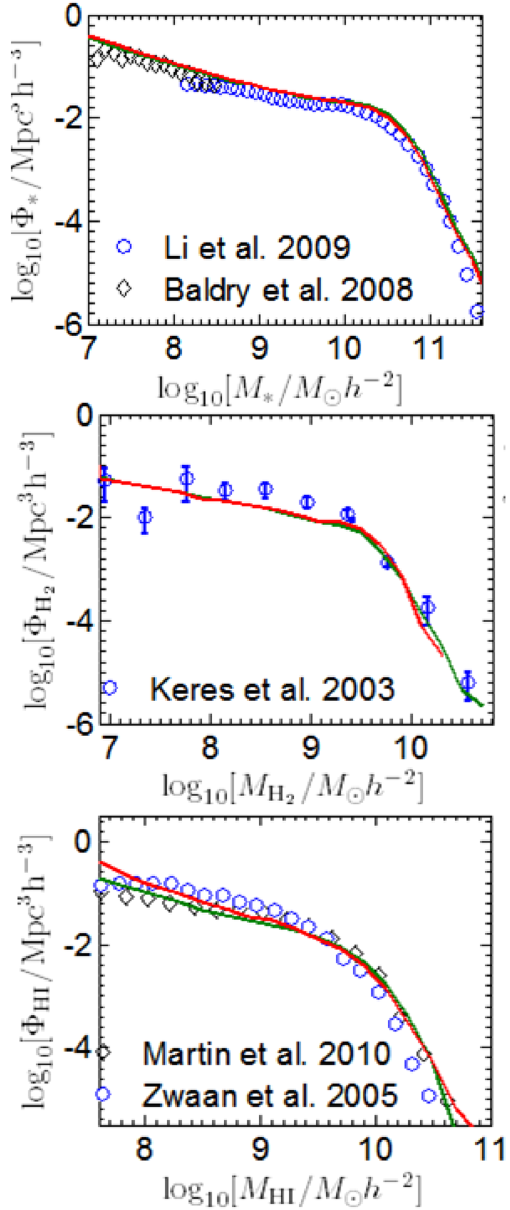
$$f_{\rm HII}, f_{\rm H_2}, \Sigma_{\rm gas}, U_{\rm MW}, D_{\rm MW}$$

- H_2 proportional star formation law $\quad \Sigma_{\rm SFR} = \alpha \Sigma_{\rm H_2}$

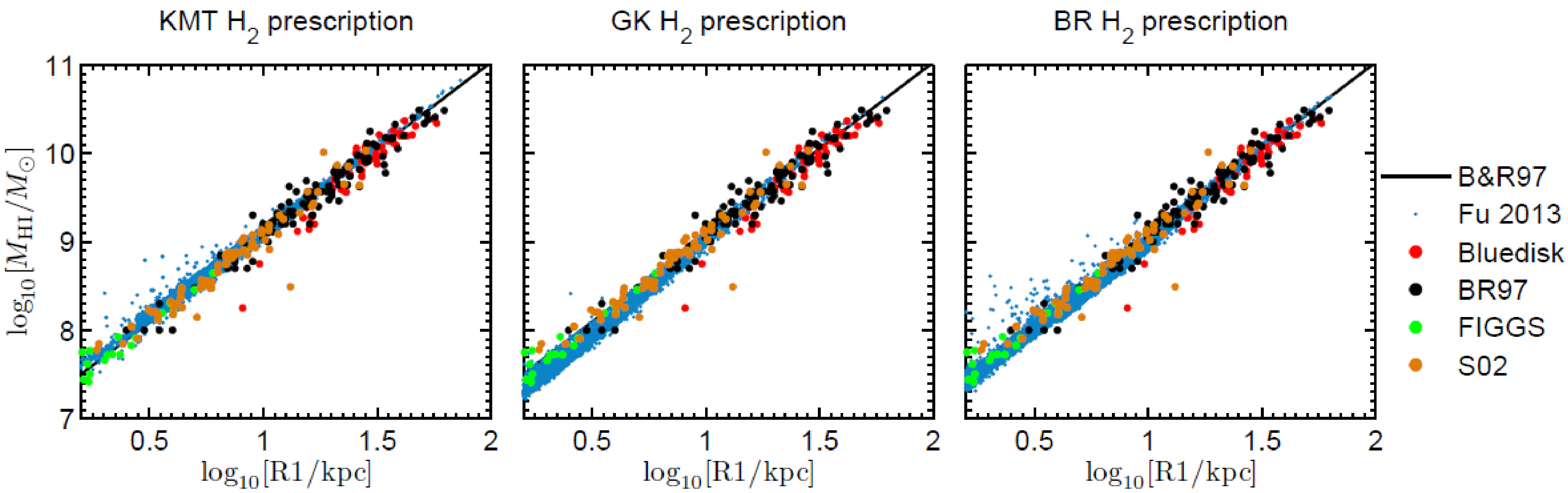
Radial profiles of nearby disk galaxies

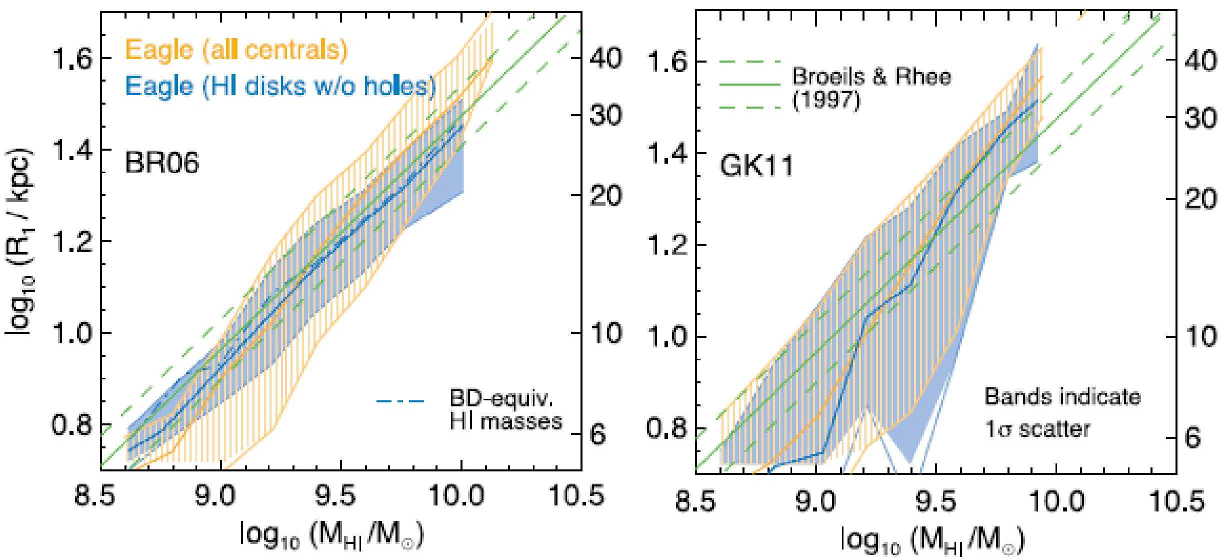


mass functions at z=0



HI size-mass relation in the model results

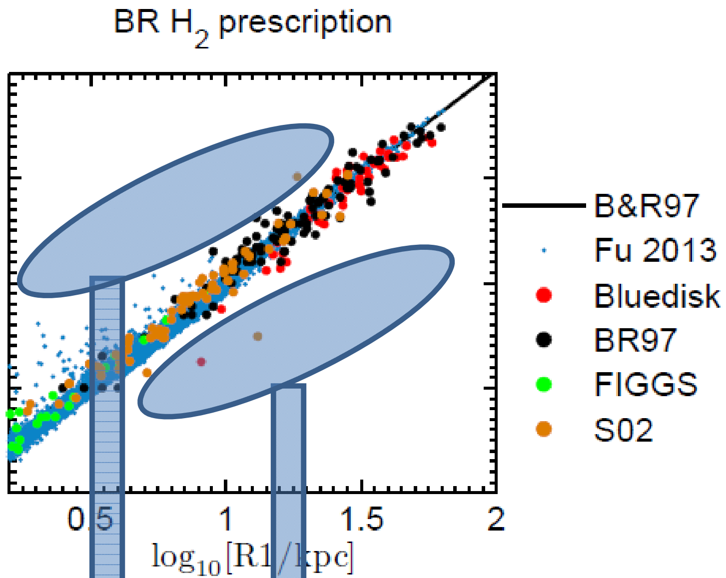


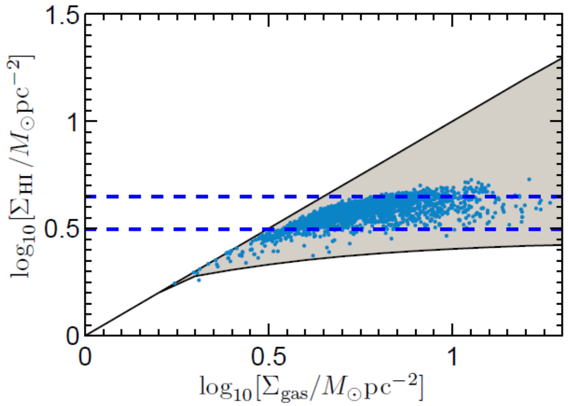


EAGLE simulation
Bahé et al. 2016

HI size-mass relation in the model results

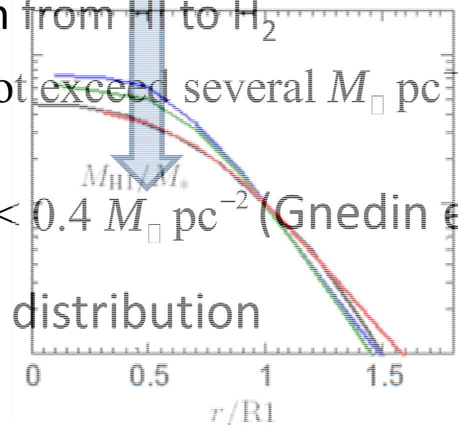
$$M_{\rm HI} \propto R1^2 \Rightarrow \overline{\Sigma}_{\rm HI} = \frac{M_{\rm HI}}{\pi R1^2} \sim \text{constant}$$





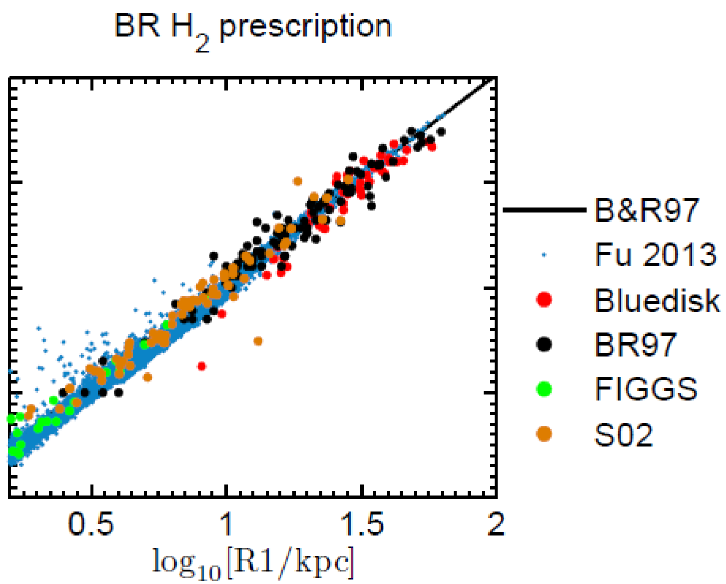
Transition from HI to H_2

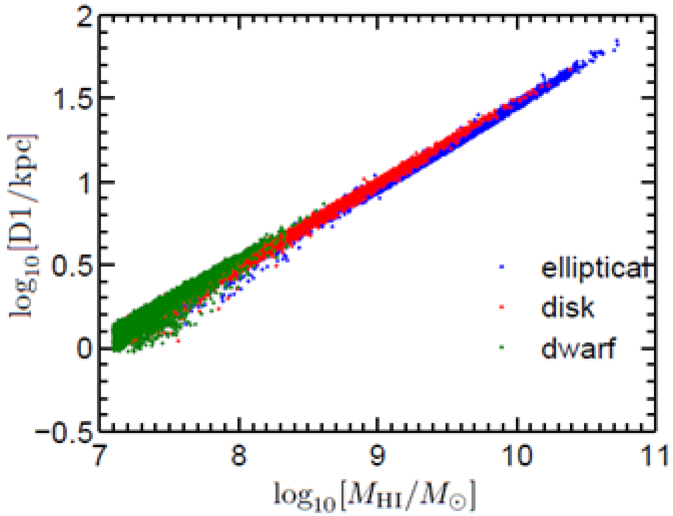
$\Sigma_{\rm HI}$ cannot exceed several $M_\odot\ {\rm pc}^{-2}$

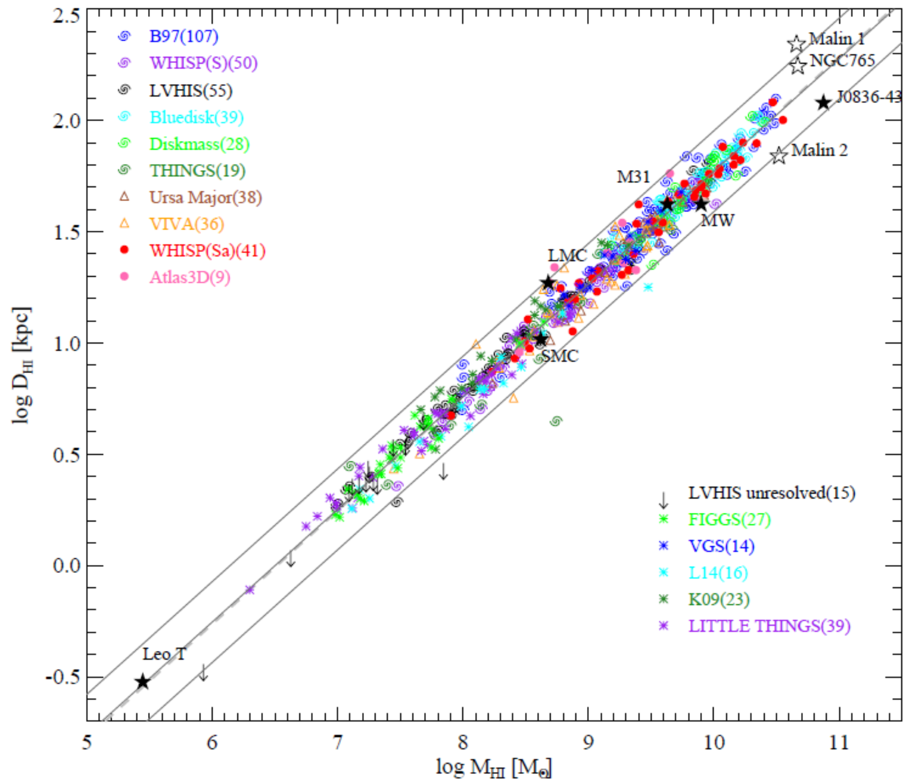


- UV ionization, $\Sigma_{\rm HI} < 0.4\ M_\odot\ {\rm pc}^{-2}$ (Gnedin et al. 2012)
- Outer disk similar distribution

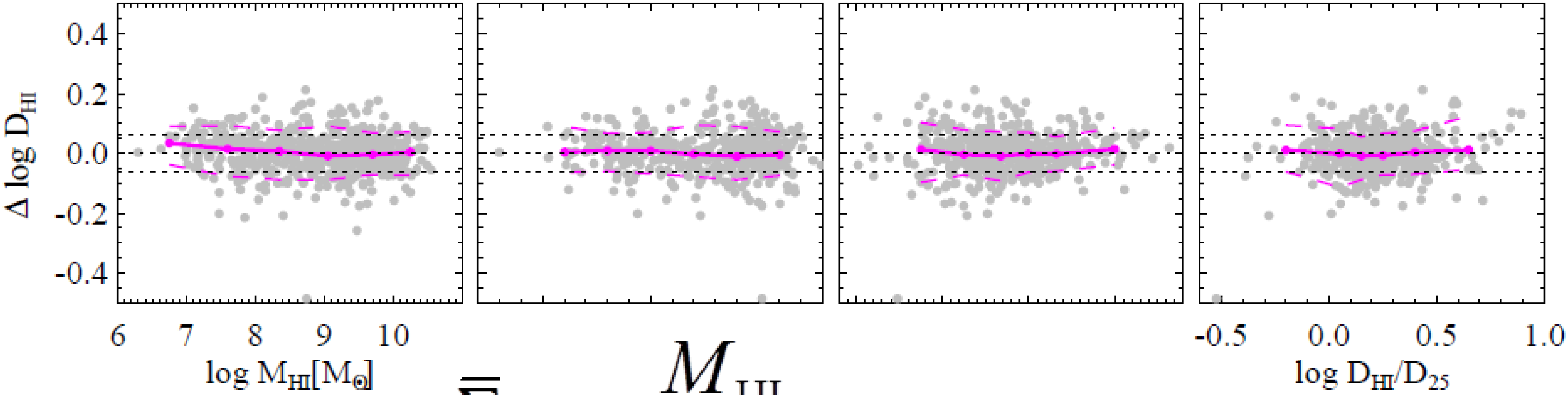
Size-mass relation in different types of galaxies



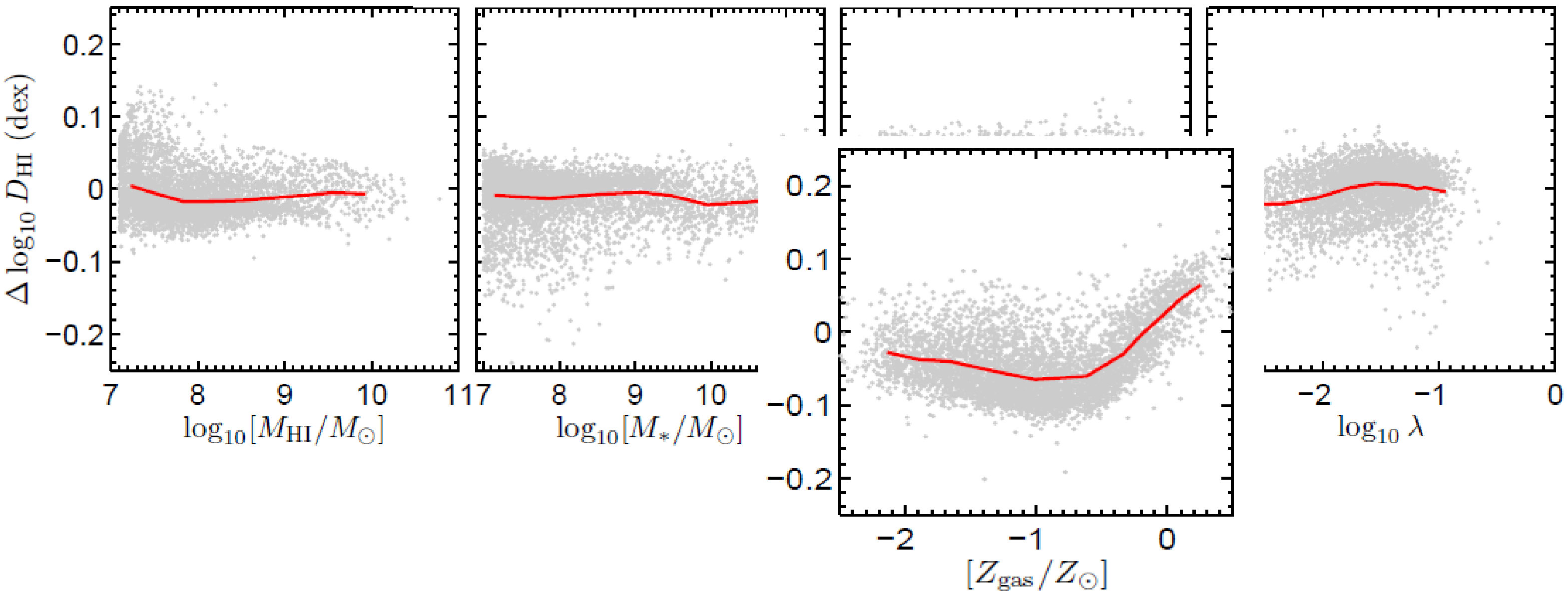




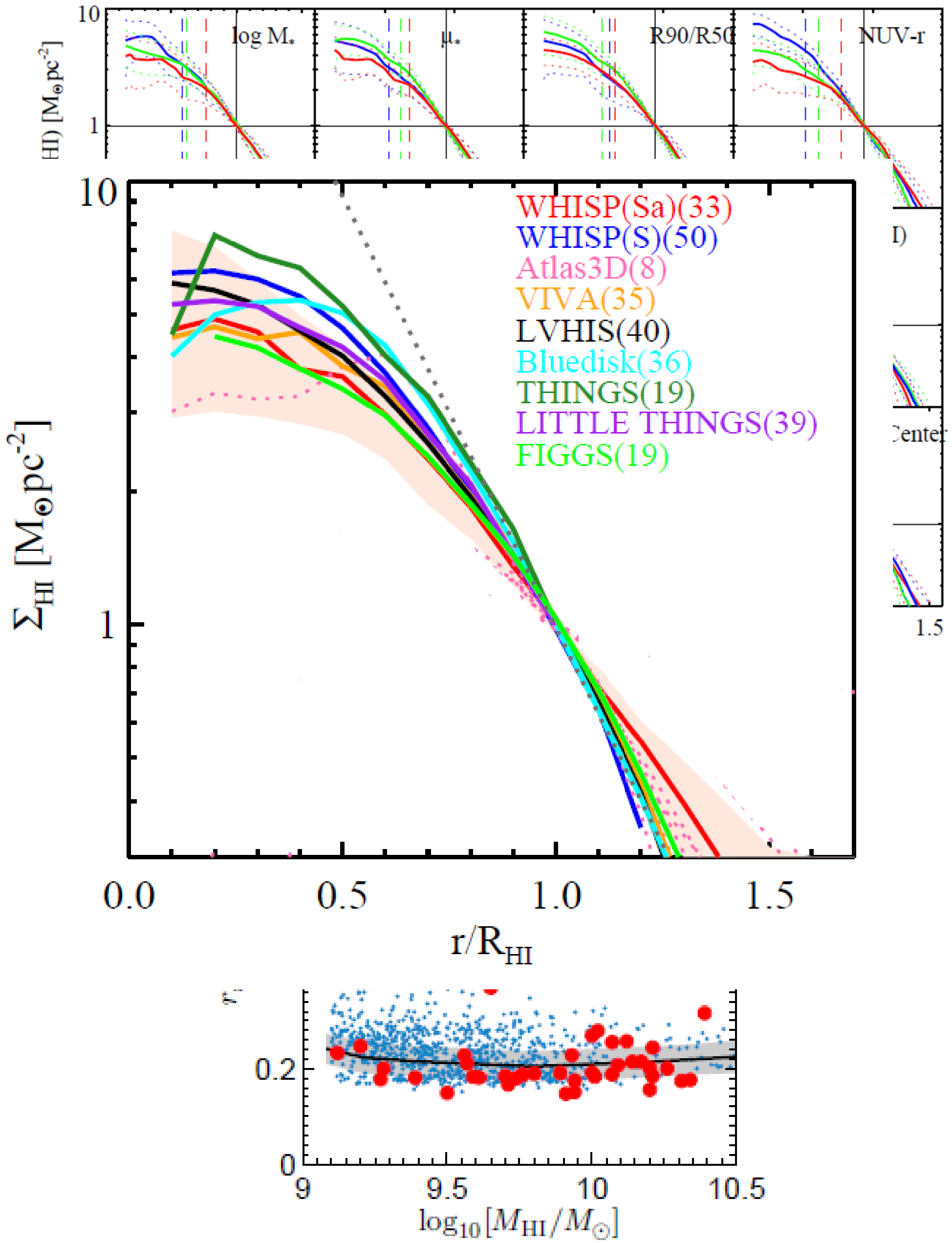
The scatters of HI size-mass relation

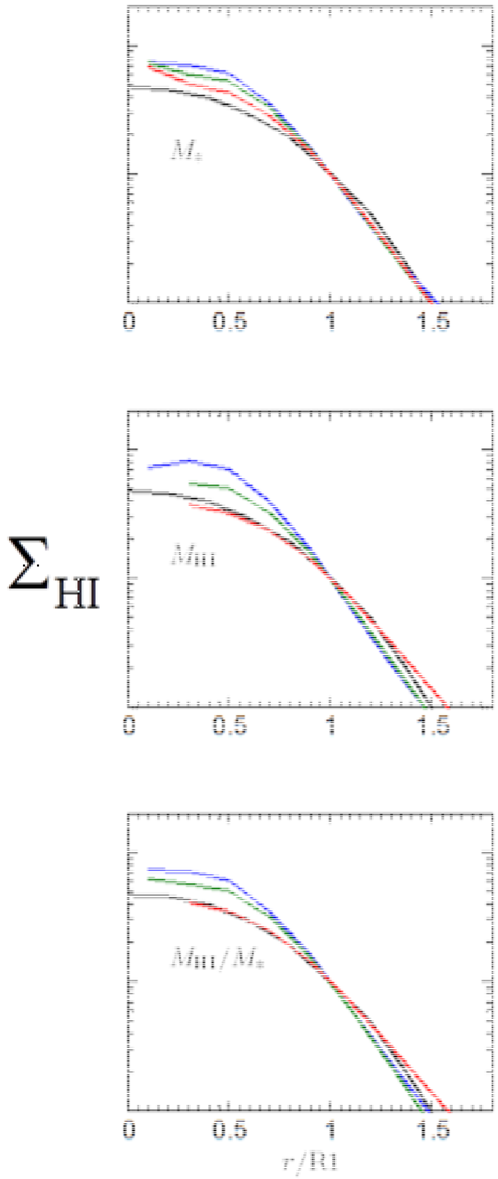


$$\bar{\Sigma}_{HI} = \frac{M_{HI}}{\pi R1^2} \sim \text{constant}$$



Similar distribution of HI radial profiles

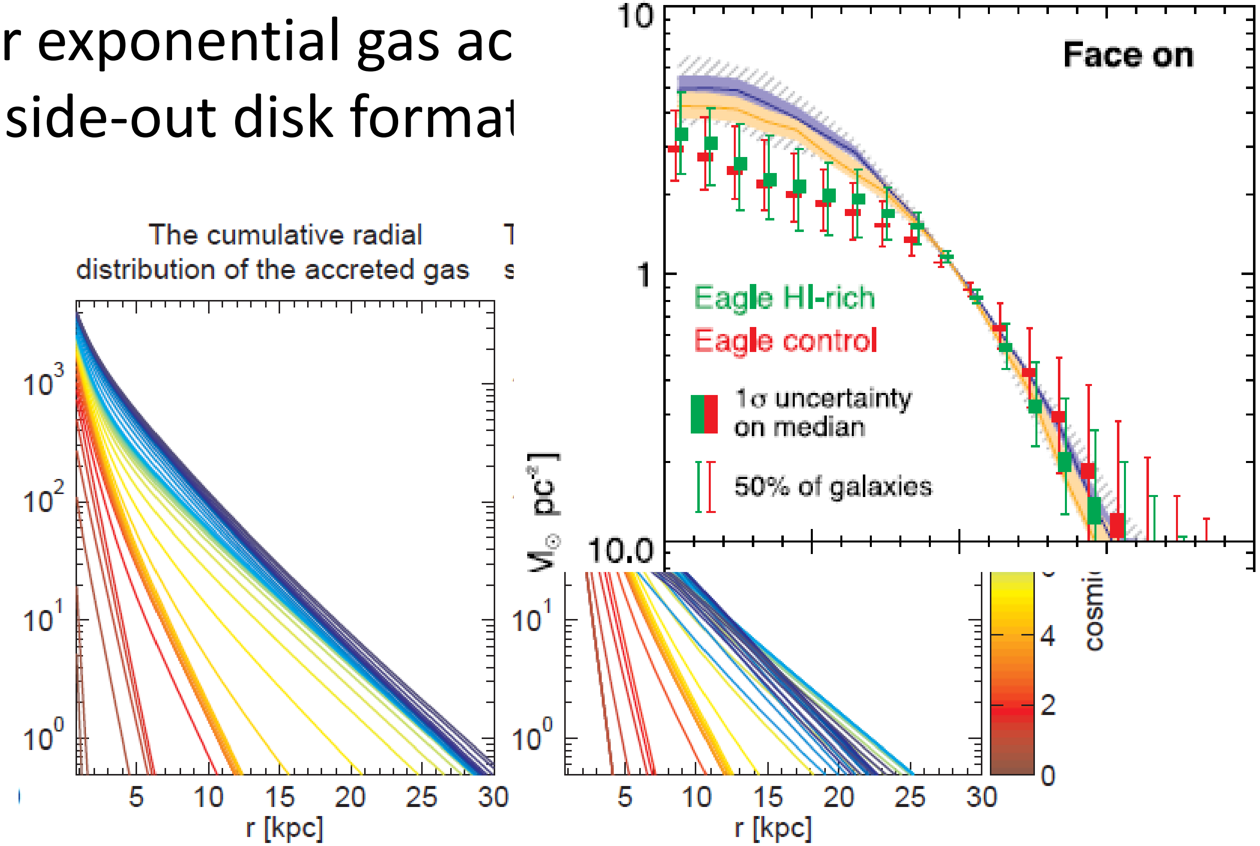




The scale length of HI in outer disk r_s

Similar distribution of outer disk HI gas

- The slope outer disk HI profiles represent the recent gas
- The similar distribution of outer disk:
1. Similar exponential gas ac
2. The inside-out disk format



Universal outer HI profiles in the unit of r/R1

$$\Sigma_{\rm HI} = \Sigma_0 \exp\left(-r / r_s\right)$$
$$1 M_{\odot}\,{\rm pc}^{-2} = \Sigma_0 \exp\left(-R1 / r_s\right)$$

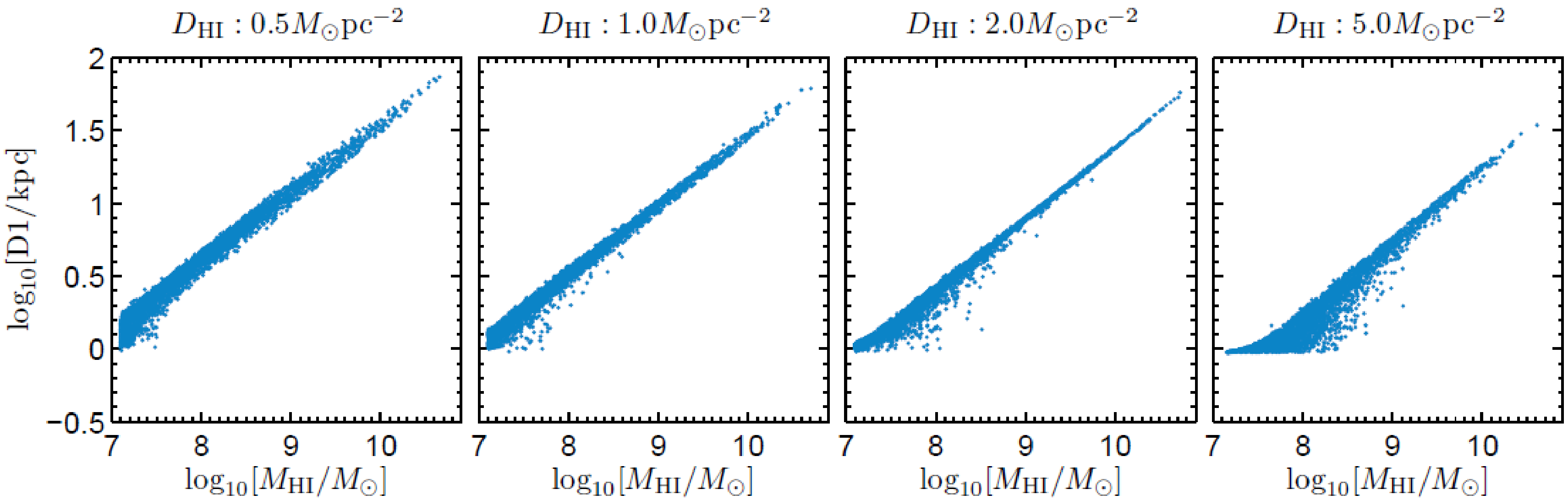
$$\Rightarrow \quad \frac{r_s}{R1} = \frac{1}{\ln\left[\Sigma_0 / M_{\odot}\,{\rm pc}^{-2}\right]}$$

• The slope outer disk HI profiles represent the recent gas accretion in the disk center

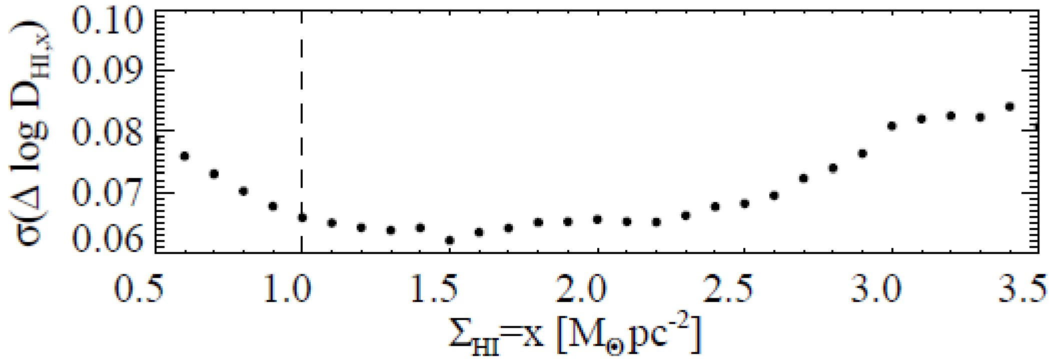
• The universal HI profiles in the model results are from:
1. The exponential gas accretion
2. The inside-out disk formation

• Observations and SPH indicate HI accreted in the form of "rings"

Different definition of D_{HI}



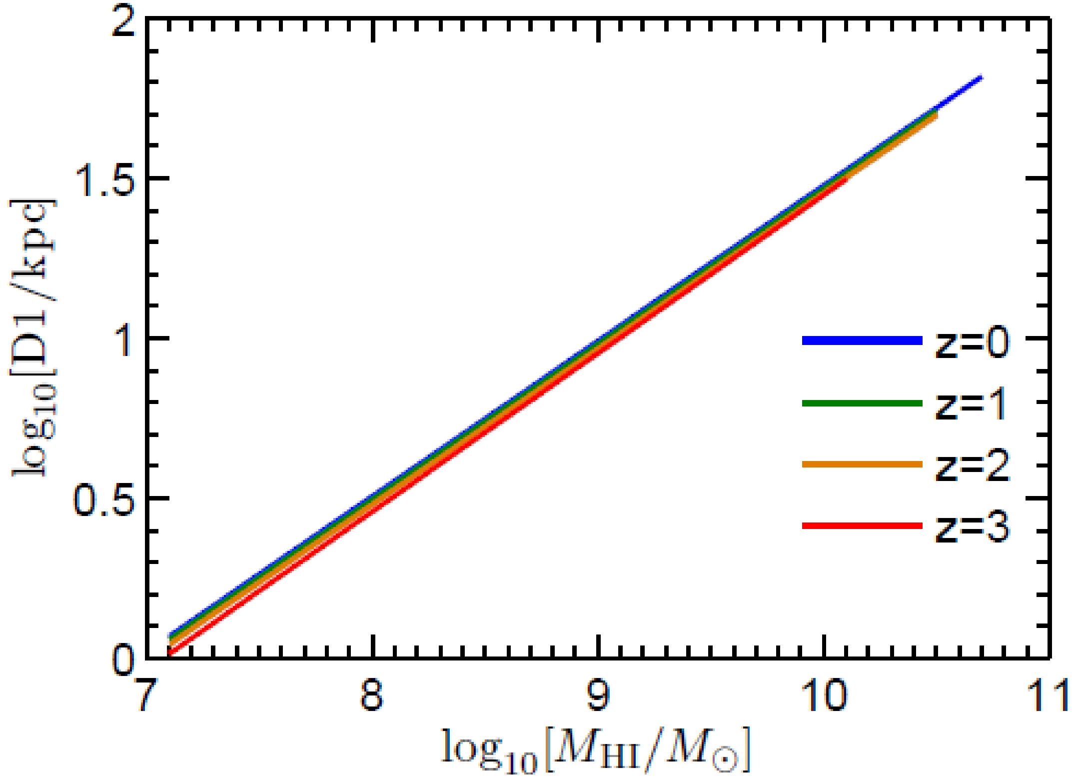
D_{HI}: $0.5 \sim 2\ M_{\odot} pc^2$



$$2 \times 10^{20} cm^{-2} \sim 1.6 M_{\odot} pc^{-2}$$

Wang et al. 2016

The redshift evolution of HI size-mass relation



- The size of HI disk from 21cm emission flux
- The mass of HI absorbers at high redshift

Conclusions

- The size-mass relation of HI gas in galaxies are mainly caused by atomic-molecular gas conversion
- The small scatter of size-mass relation is the result of similar HI gas radial profile
- Universal outer disk HI exponential profiles are from recent similar gas accretion
- HI size-mass relation are nearly universal for different galaxies at different redshift

Thank you!