Modelling HI and H_2 Gas in L-Galaxies SAMs

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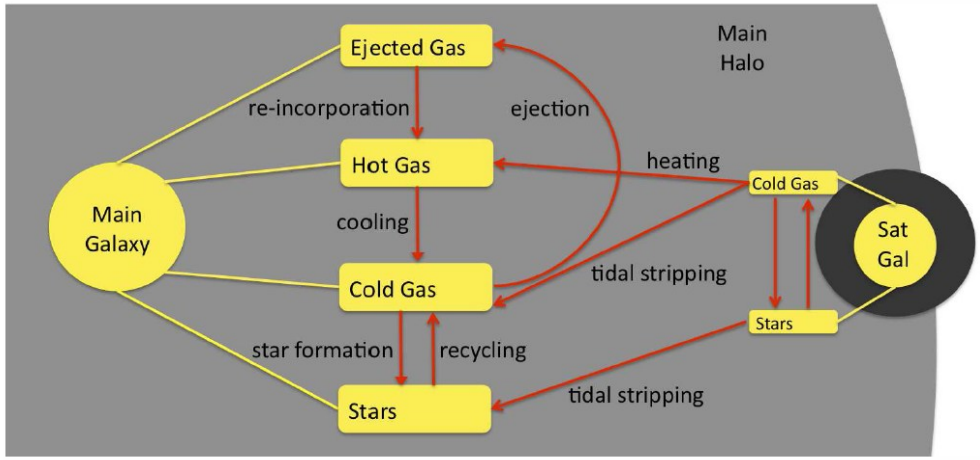
Galaxies in the Simulated Universe

Semi-analytic models

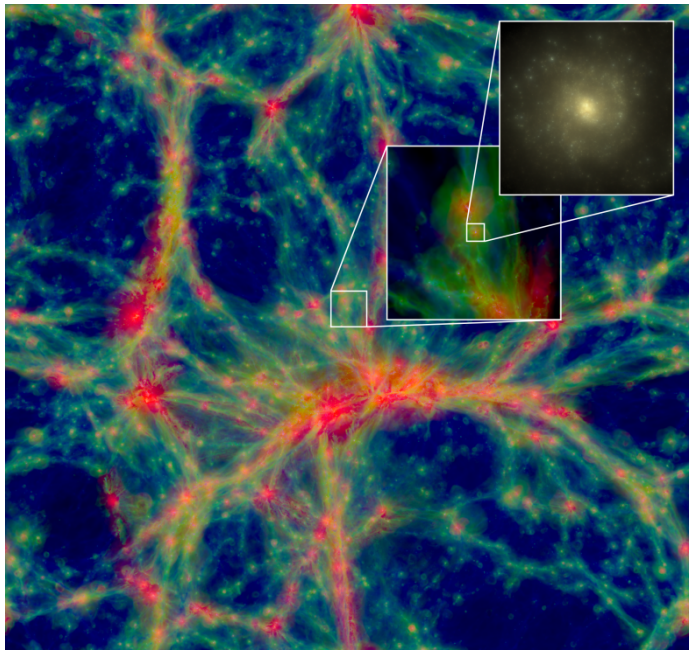
L-Galaxies, GALFORM(Lagos, Kim etc)



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

SAMs vs Hydrodynamic

In one day

Several months

SAMs can study the physical processes more easily.

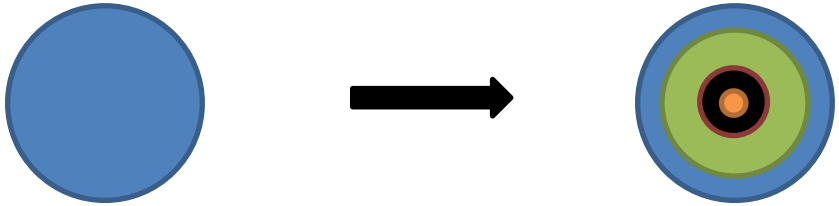
Self-consistent model of atomic & molecular gas partition in ISM

- Models only include one gas phase in ISM (L-GALAXIES, GALFROM etc.)
- Post-processing methods (Obreschkow et al. 2009; Power et al. 2010; Lagos et al. 2015 on EAGLE simulation)

  not self-consistent
- Models with the calculation of H_2-HI-HII transition (Fu et al. on ; Lagos et al. on GALFORM; Popping et al. ; Steven et al. on Dark SAGE …)

  self-consistency on the physical processes of gas/SFR in ISM
- Trace the radial surface density profiles throughout the formation history (Fu et al.; Steven et al.)

The radial resolved disk in SAMs



Similar to the methods in GCE models to trace the radial

- Concentric ... disk formation
- Geometric s... smaller in i... sks
- A lot more n... ion~100GB RAM in largest tr...

RAM is cheaper

Gas profiles and SFR

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

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

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

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

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

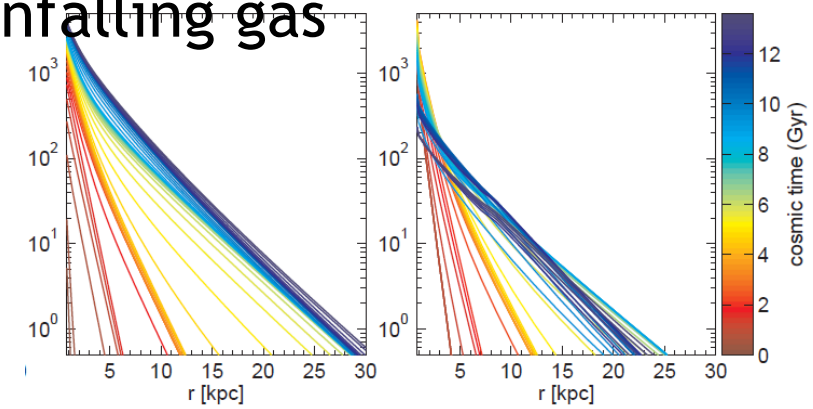
$$f_{\mathrm{HII}}, f_{\mathrm{H_2}}, \Sigma_{\mathrm{gas}}, U_{\mathrm{MW}}, D_{\mathrm{MW}}$$

- H_2 proportional star formation law

$$\Sigma_{\mathrm{SFR}} = \alpha\Sigma_{\mathrm{H_2}}$$

- Exponential infalling gas

$$\Sigma_{\mathrm{HI}} = \Sigma_0 \exp\left(-r / r_s\right)$$



Radial gas inflow and gas surface density profiles

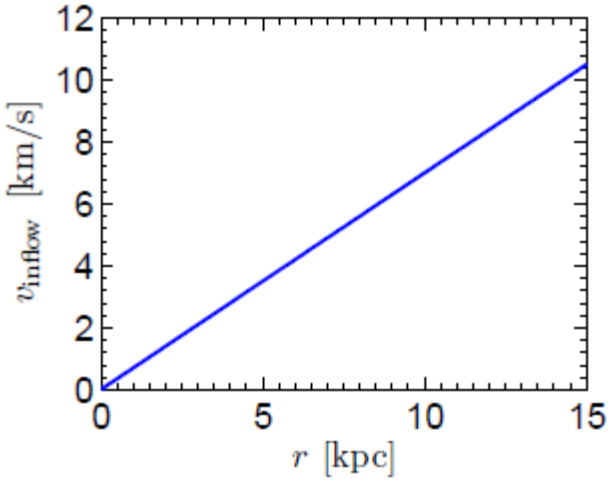
- Galaxy chemical evolution models with radial gas inflow: Lacey & Fall (1985) , Portinari & Chiosi (2000), Spitoni & Matteucci (2011), Schönrich & Binney (2009) etc.
- Physical Mechanisms:
  - The mixing of cooling gas with existant disk gas causes the change of specific angular momentum of gas disk
  - Suppress the increase of specific angular momentum of gas disk caused by the difference of the gas consumption at different radius

- Assumption: $dL_{\rm gas} / dt = CL_{\rm gas}$

$L_{\rm gas} = m_{\rm gas} r_{\rm gas} v_{\rm cir}$ → $v_{\rm inflow} = \alpha_v r$

$\alpha_v = 0.70 \ {\rm km\ s^{-1}\ kpc^{-1}}$

a constant value in the models



Millennium and Millennium II Simulation

- Millennium Simulation: Springel et al. 2005

- Millennium II Simulation: Boylan-Kolchin et al. 2009
- Rescaling to most update cosmological parameters (Angulo & White 2010)
- The mass resolution of MS-II is 125 larger than MS: use to study dwarf galaxies and small galaxies at high z

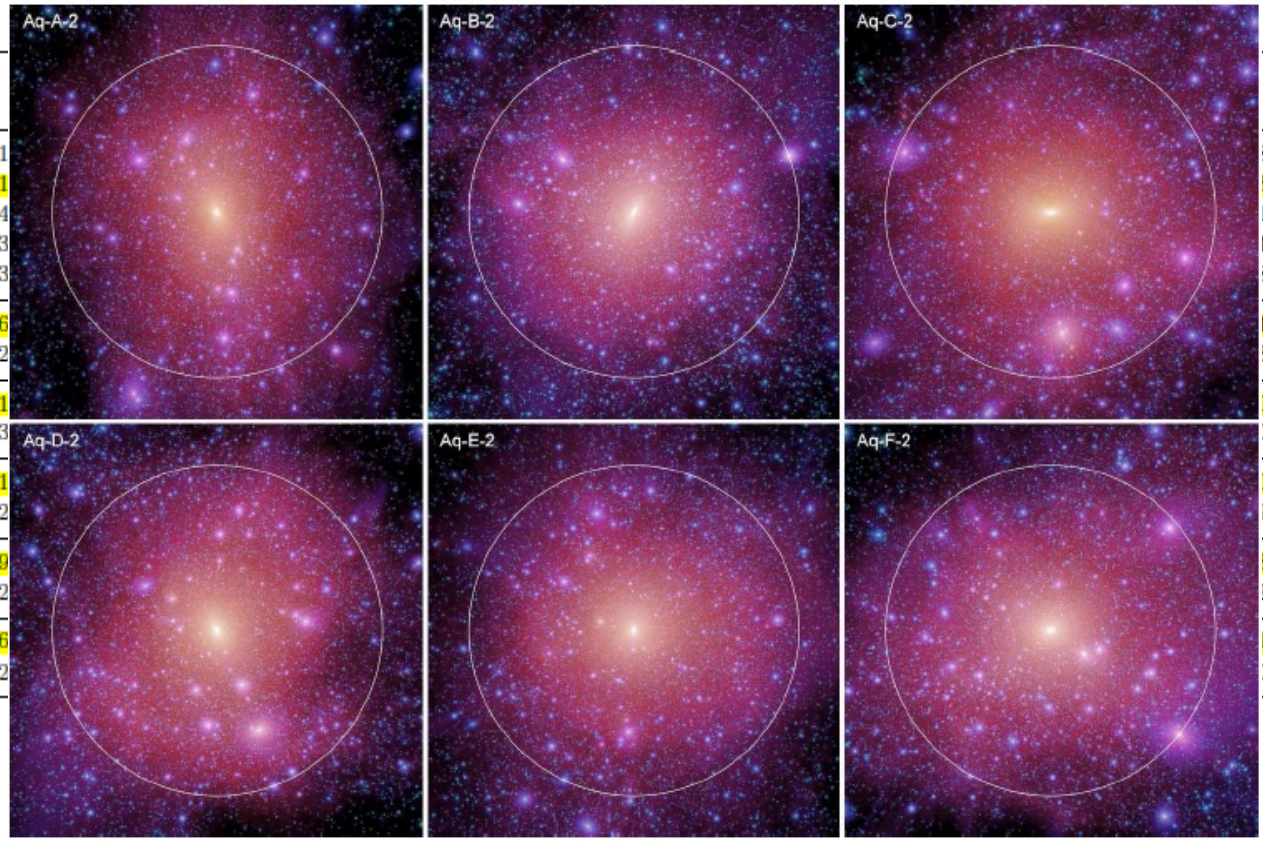
	Millennium I (MS)	Millennium II (MS-II)
Particle number	2160^3	
Particle Mass	$8.6\times10^8 M_\odot h^{-1}$	$6.8\times10^6 M_\odot h^{-1}$
Box size	500 h^{-1} Mpc	100 h^{-1} Mpc
Output snapshots	64 snapshots Between z=0 and 127	68 snapshots Between z=0 and 127
Minimum halo mass	$1.7\times10^{10} M_\odot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

Aquarius Simulation (Springel et al. 2009)

- Six halo merger trees of MW sized galaxies with different resolutions

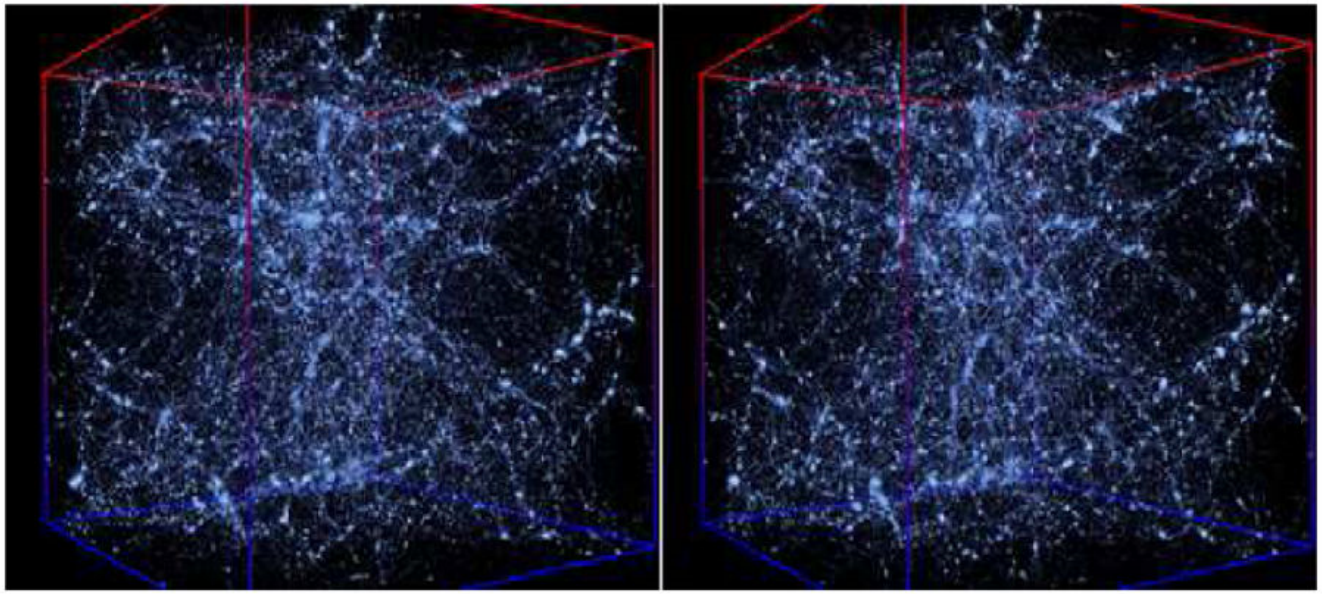
- The formation of MW and its satellites

Name		N_{50}
Aq-A-1	1	,512
Aq-A-2	1	,536
Aq-A-3	4	,468
Aq-A-4	3	,399
Aq-A-5	3	,479
Aq-B-2	6	,992
Aq-B-4	2	,037
Aq-C-2	1	,624
Aq-C-4	3	,775
Aq-D-2	1	,512
Aq-D-4	2	,672
Aq-E-2	9	,676
Aq-E-4	2	,797
Aq-F-2	6	,216
Aq-F-3	2	,572

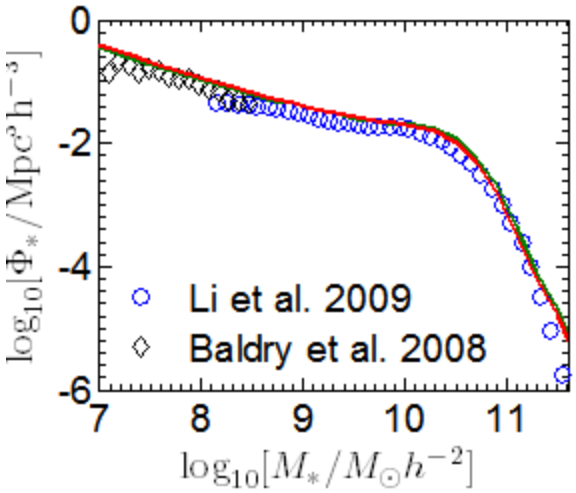


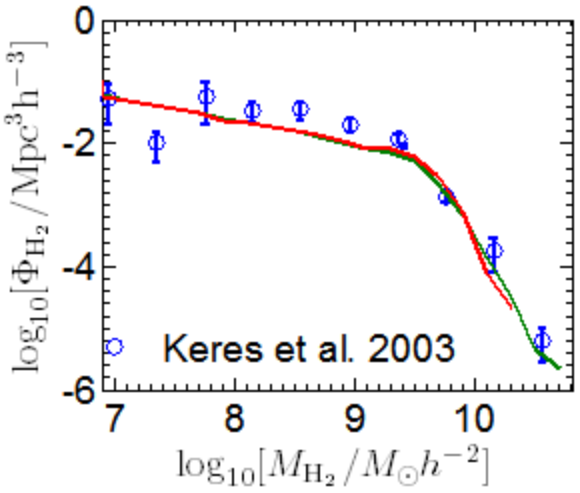
Plan: Cold Gas components in local universe

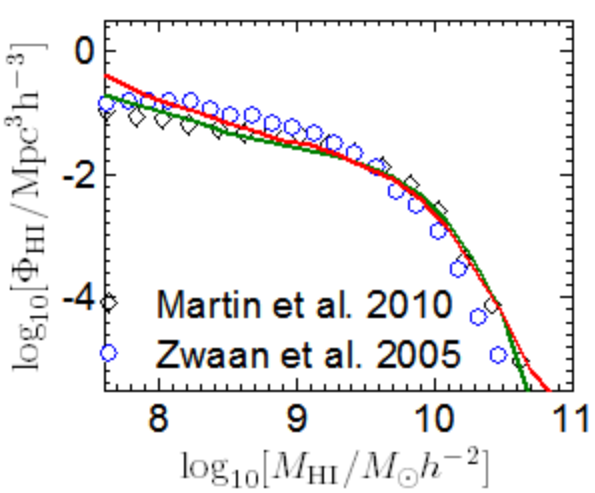
- ELUCID simulation (Wang, Mo, Yang et al. 2014)



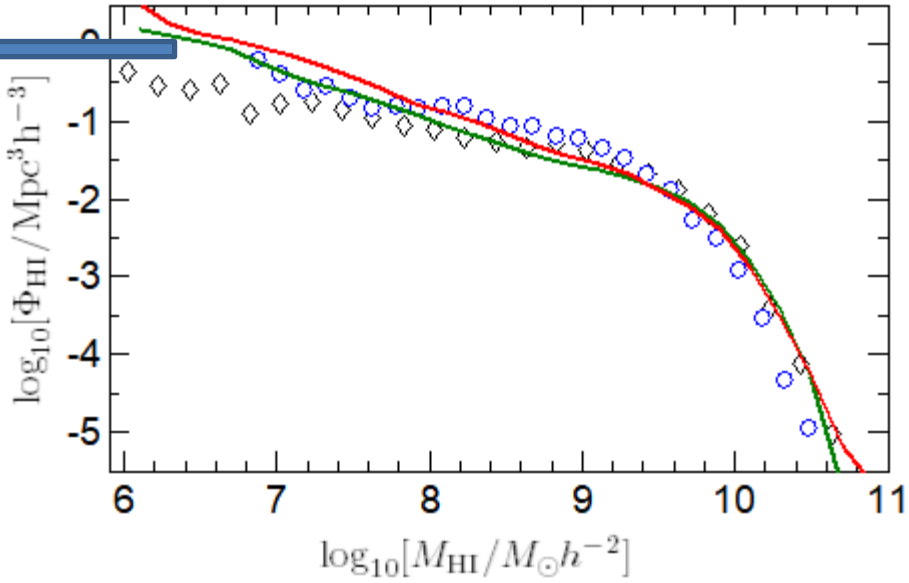
Mass functions at z=0







- Too much Galaxies with low HI mass
- HI version of Missing Satellite?



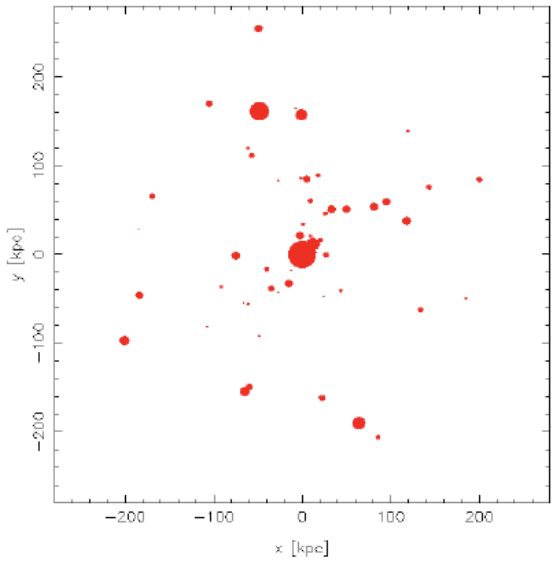
The HI gas in MW satellites

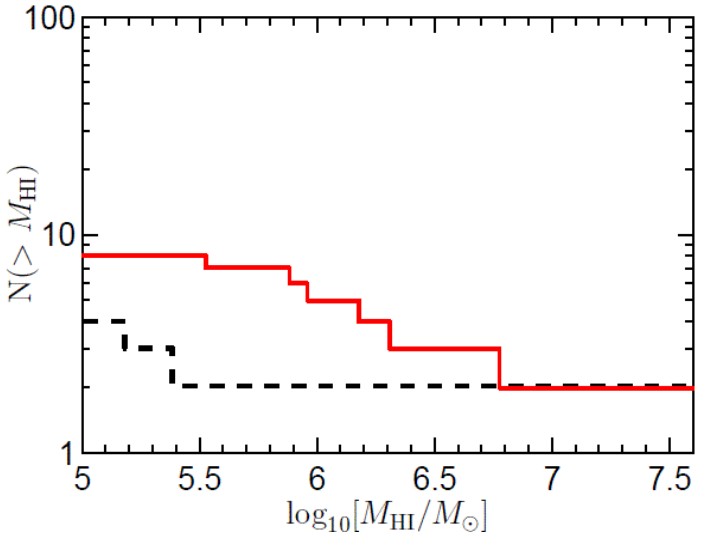
Collaborators: Lincheng Li, Jie Wang, Bo Qin

- Models based on Aquarius haloes
- 4 MW satellites with HI detected within 280 kpc (Grcevich & Putman 2009)

- Neutral gas ionized by UV background (Gnedin 2012)

$\Sigma_{\mathrm{HI+H_2}} < 0.4 M_{\odot}\,\mathrm{pc}^{-2}$ ⟹ HII

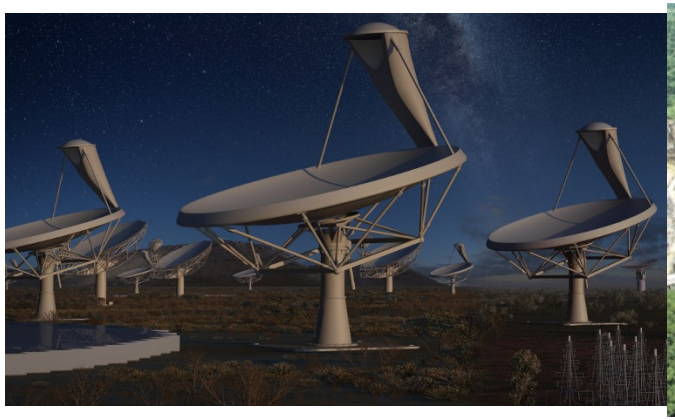




- Warm dark matter?
- Change baryonic processes in dwarf satellites?

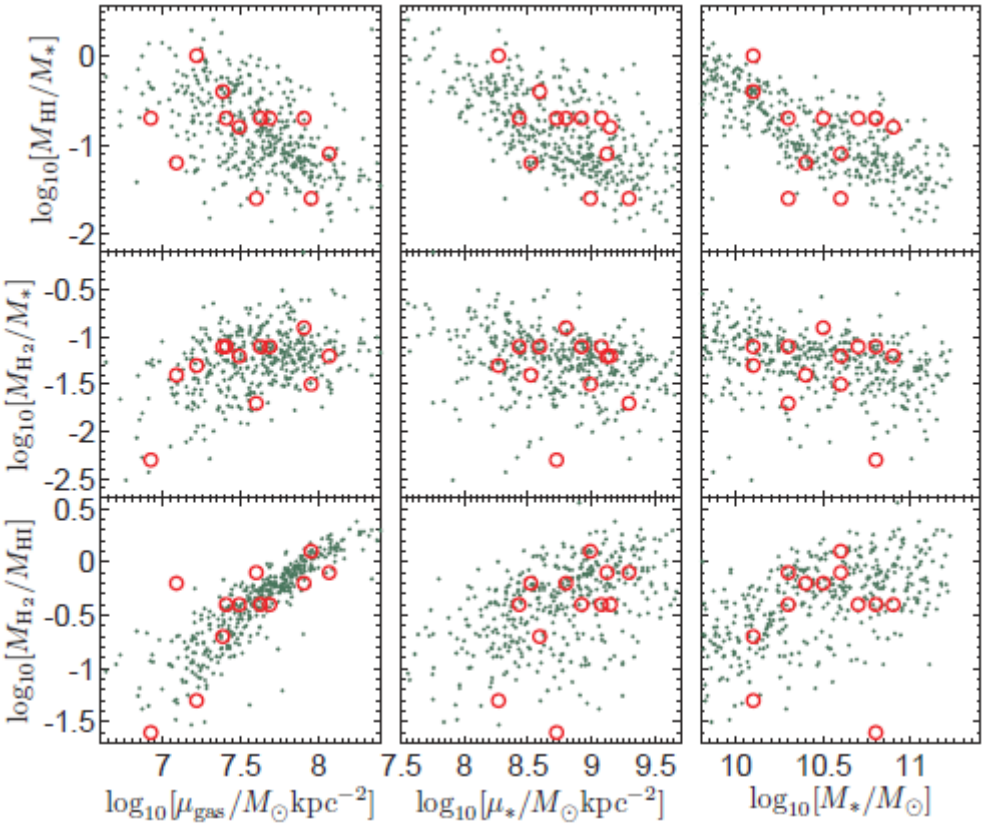
The upcoming extragalactic HI and H_2 (CO) observations

- ASKAP (WALLABY: HI All-Sky Survey)
- MeerKAT (MHONGOOSE: nearby HI observations)
- SKA (all sky HI survey after 2020)
- FAST (Large-Scale Surveys for HI Emission from Galaxies
- ALMA (CO survey in galaxies at high redshift)



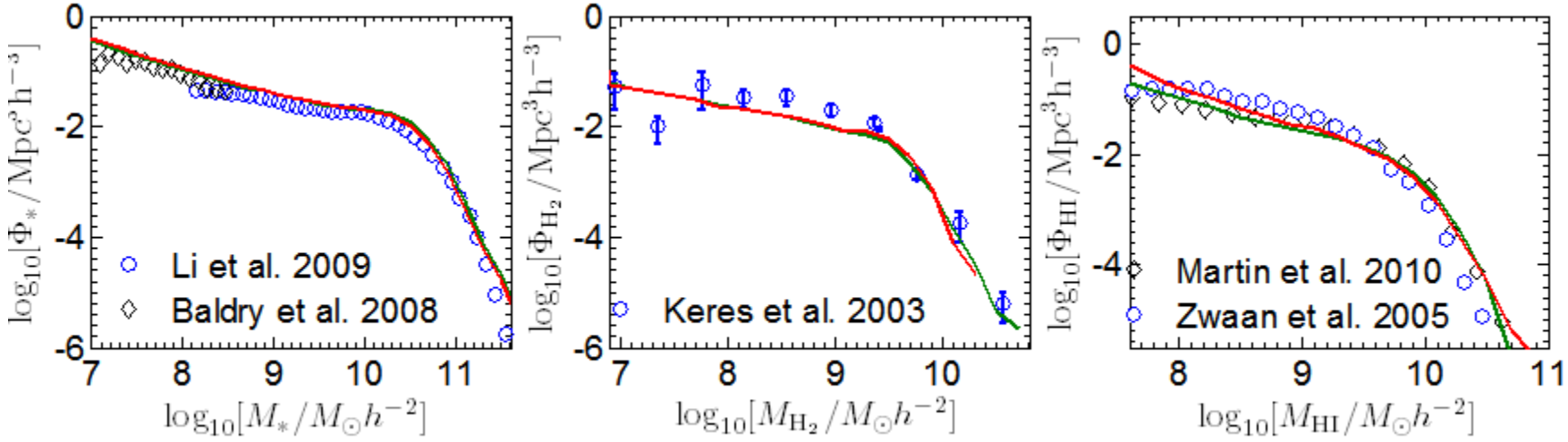
scale relations at z=0

Fu et al. 2010



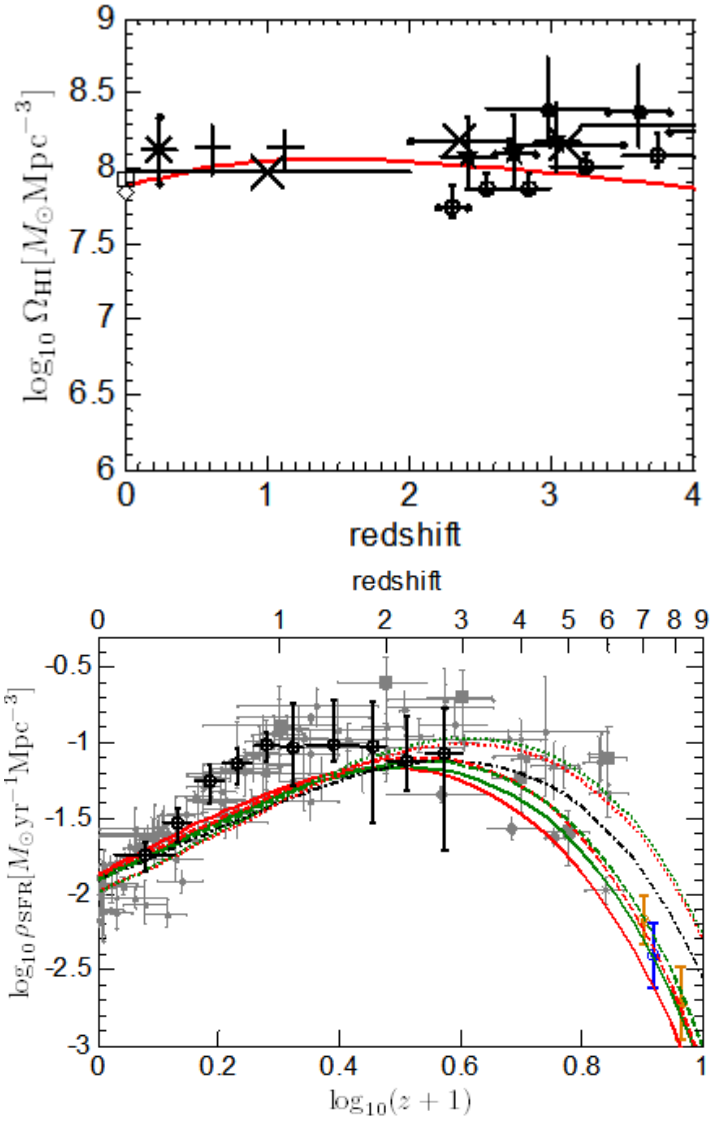
mass functions at z=0

Fu et al. 2013

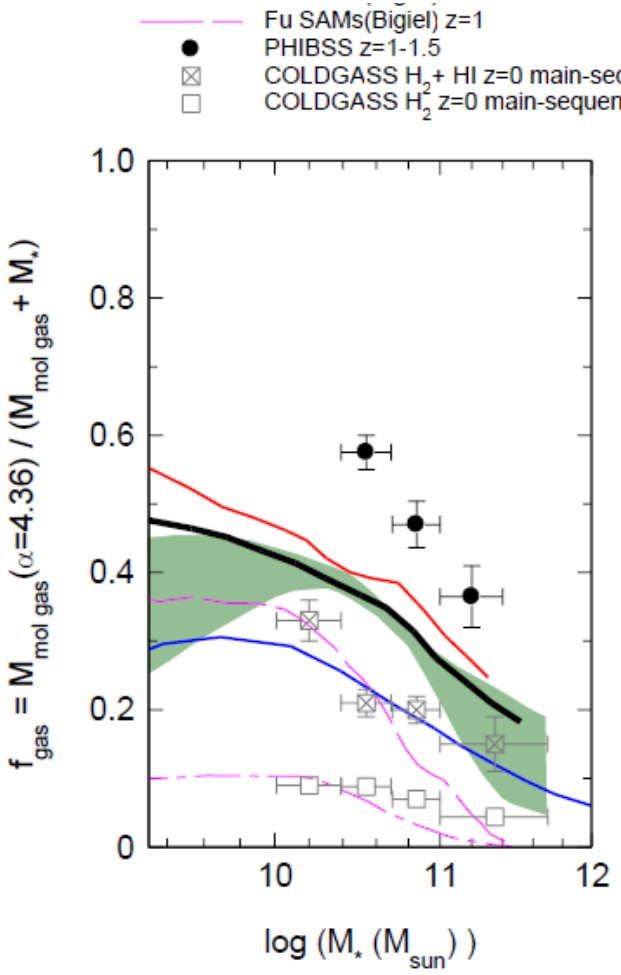


The redshift evolution of H2 and HI

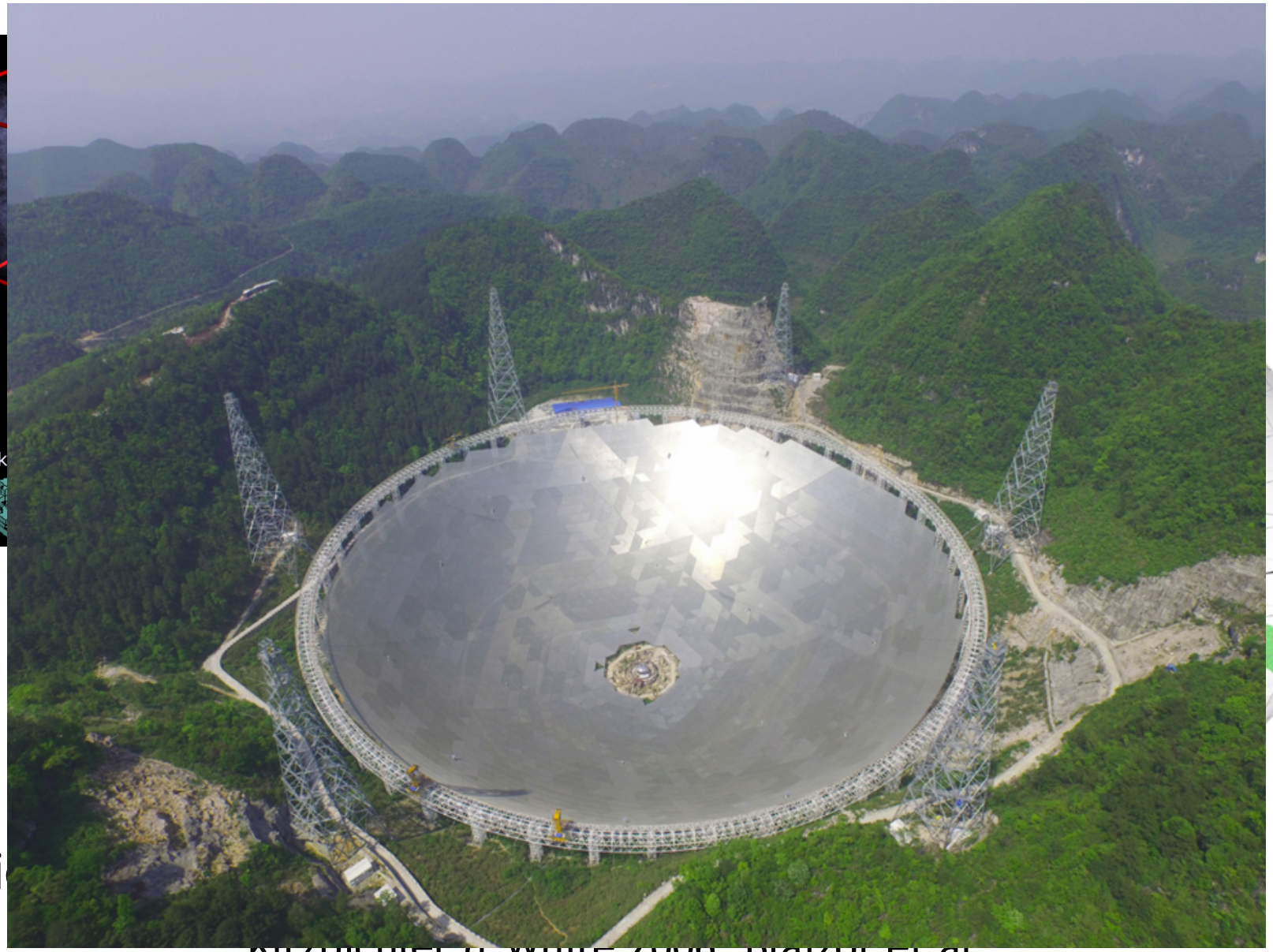
Fu et al. 2012



PHIBSS (Tacconi et al. 2013)



The mock catalogue based on model results



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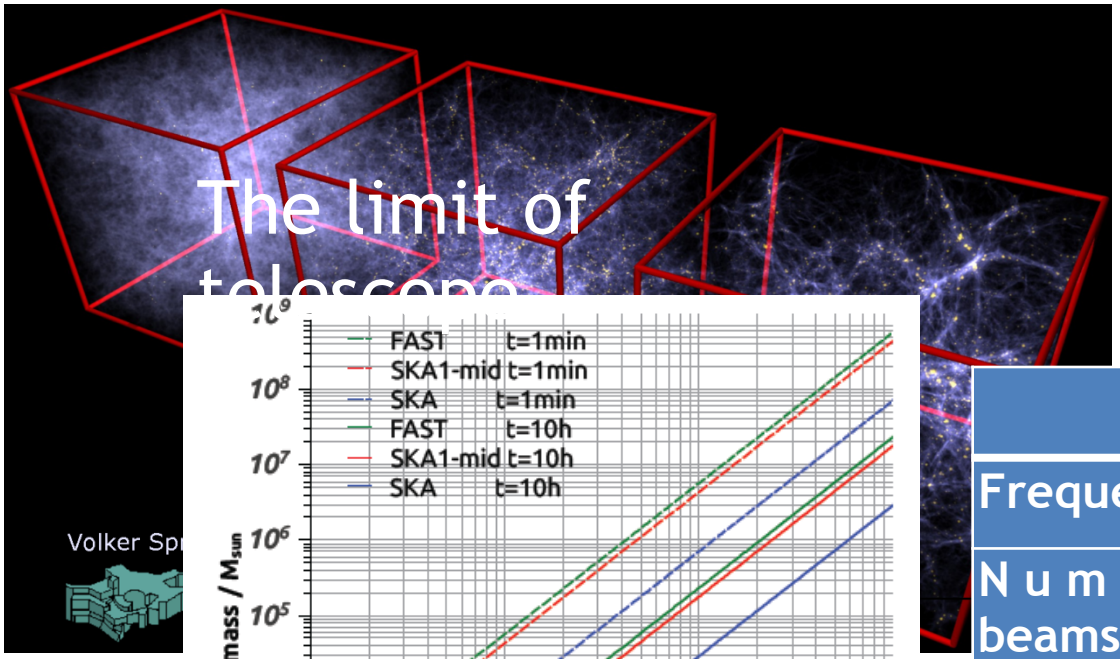
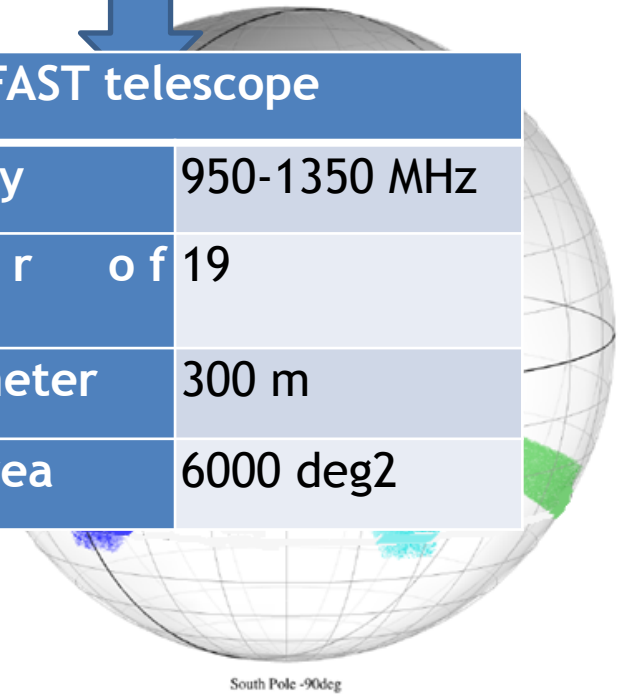
Kitzbichler & White 2006, Blaizot et al. 2005

The mock catalogue based on model results



FAST telescope	
Frequency	950-1350 MHz
Number of beams	19
Dish diameter	300 m
Survey Area	6000 deg2



Periodic box at different z → Observers framework

Kitzbichler & White 2006; Blaizot et al. 2005

The mock galaxy catalogue for HI survey

- Mock method: Kitzbichler & White 2006; Blaizot et al. 2005

$$\mathrm{RA},\ \mathrm{Dec},\ z,\ M_*,\ M_{\mathrm{HI}},\ M_{\mathrm{H_2}},F_{\mathrm{HI}},W_{\mathrm{HI}}^{50},\ L$$

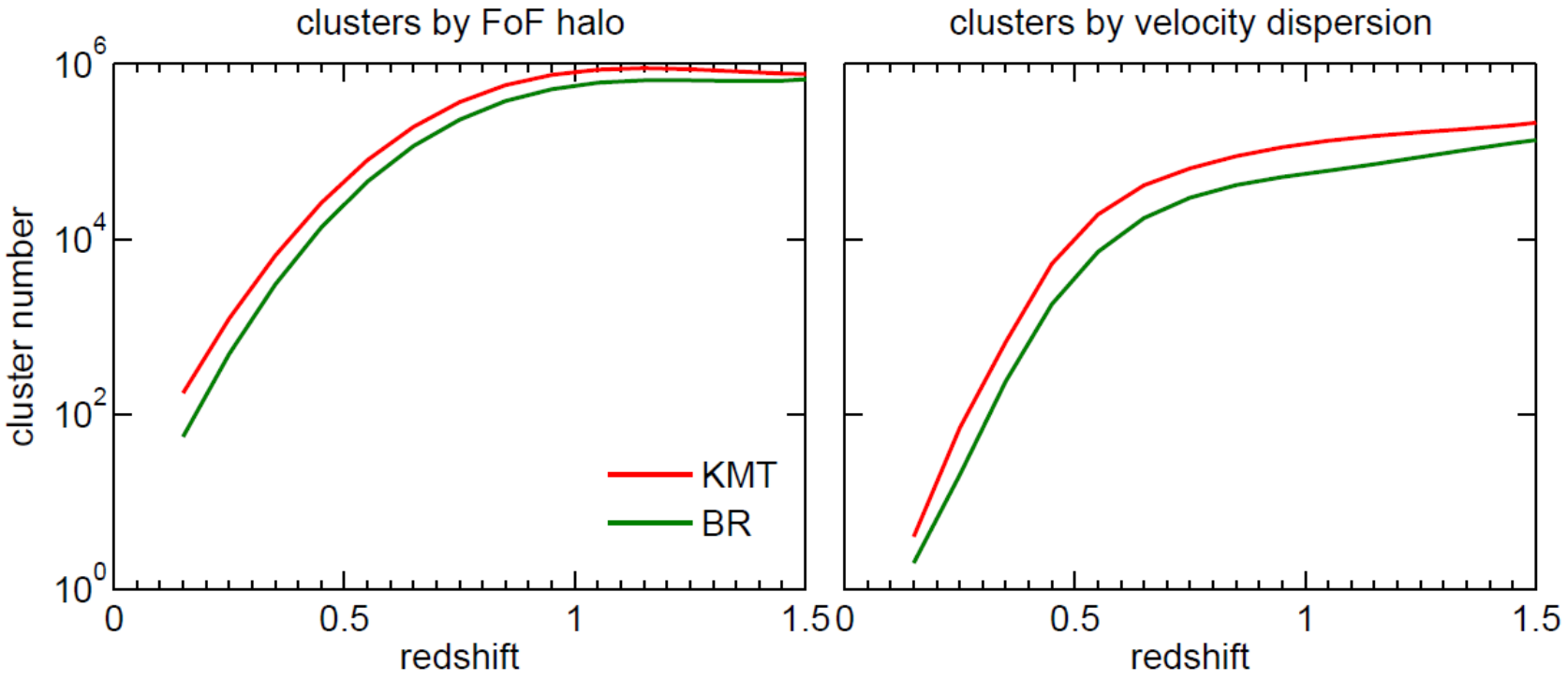
$$\frac{F_{\mathrm{HI}}}{\mathrm{Jy\ km/s}} = \frac{1}{2.36\times10^5 D^2}\frac{M_{\mathrm{HI}}}{M_{\boxed{?}}}$$

- HI gas in low redshift (z<0.3) galaxies
- HI gas in dwarf satellite galaxies in local group
- HI gas mock for high redshift HI survey

$$\frac{L_{\mathrm{CO}}}{\mathrm{Jy\ km\ s^{-1}\ Mpc^2}} = 3.2\times10^{-3}\frac{M_{\mathrm{H_2}}}{M_{\boxed{?}}}\left(\frac{X}{10^{20}\ \mathrm{cm^{-2}\ K^{-1}km\ s^{-1}}}\right)^{-1}$$

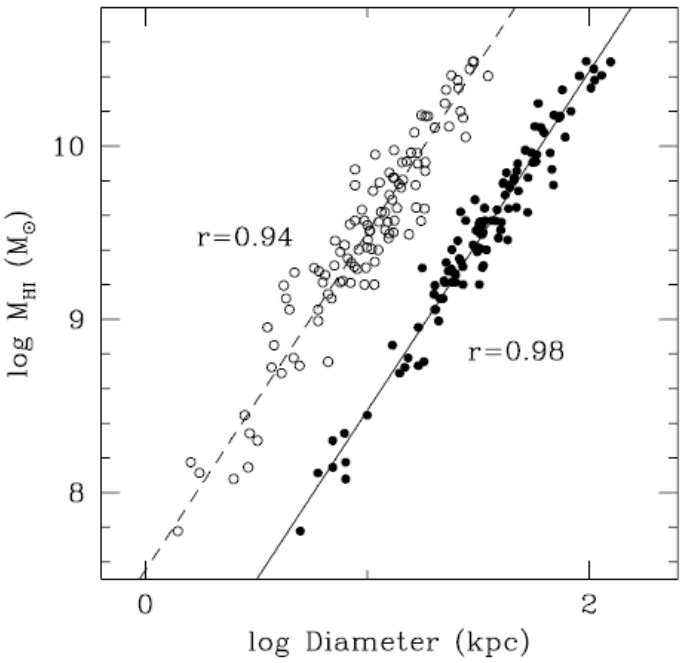
CO(1→0) luminosity

Predictions of Galaxy cluster numbers for FAST HI gas survey

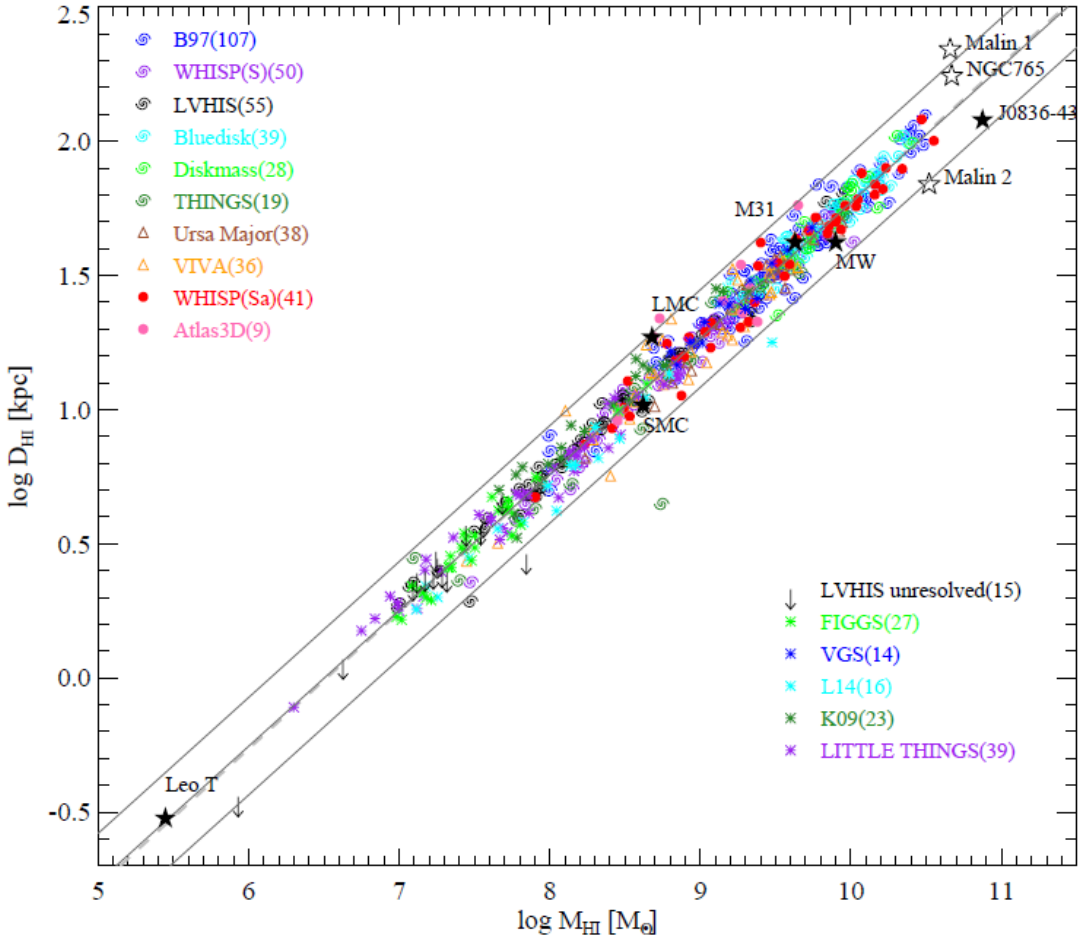


Ai et al 2017

Size-mass relation HI gas in galaxies



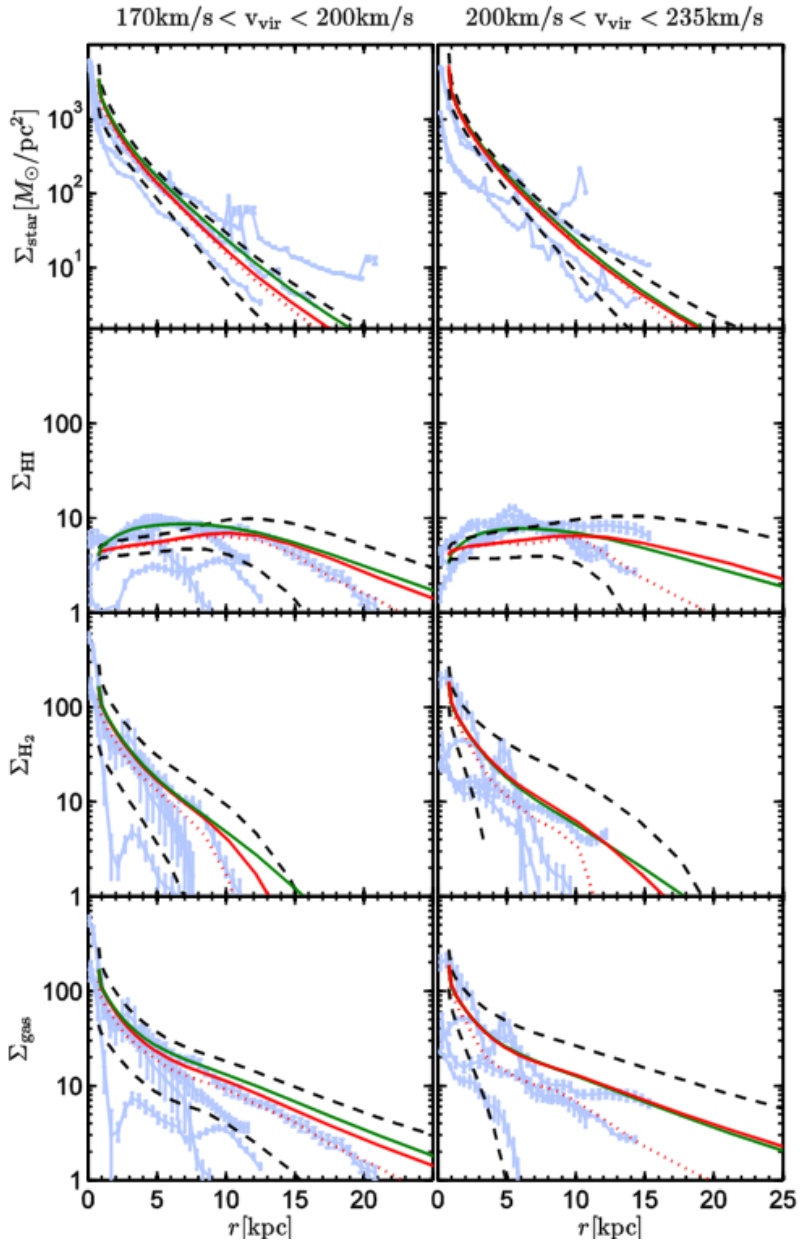
Broeils & Rhee 1997



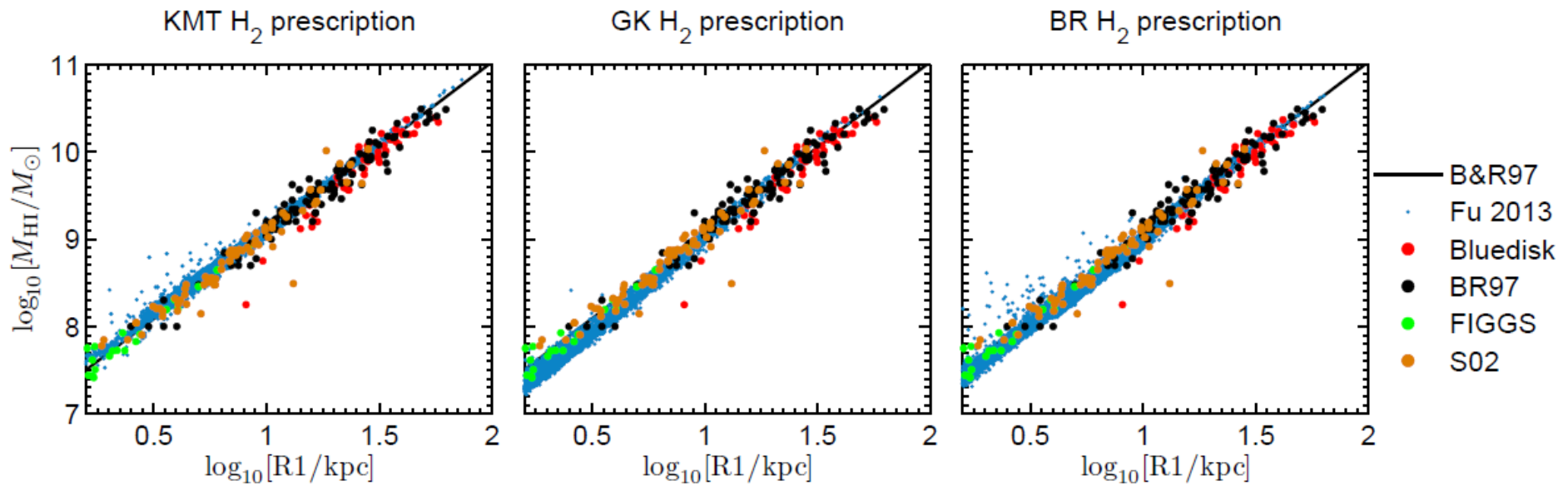
Wang et al. 2016

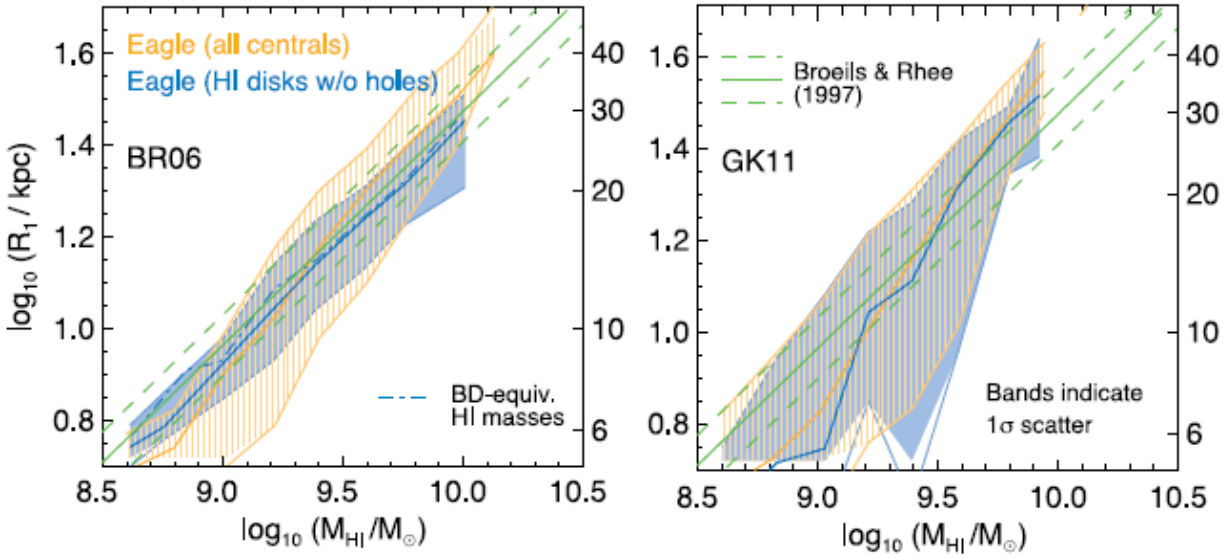
$$\lg M_{\mathrm{HI}} = (1.96 \pm 0.04)\lg D_{\mathrm{HI}} + (6.52 \pm 0.06)$$

Radial profiles of nearby disk galaxies



HI size-mass relation in the model results

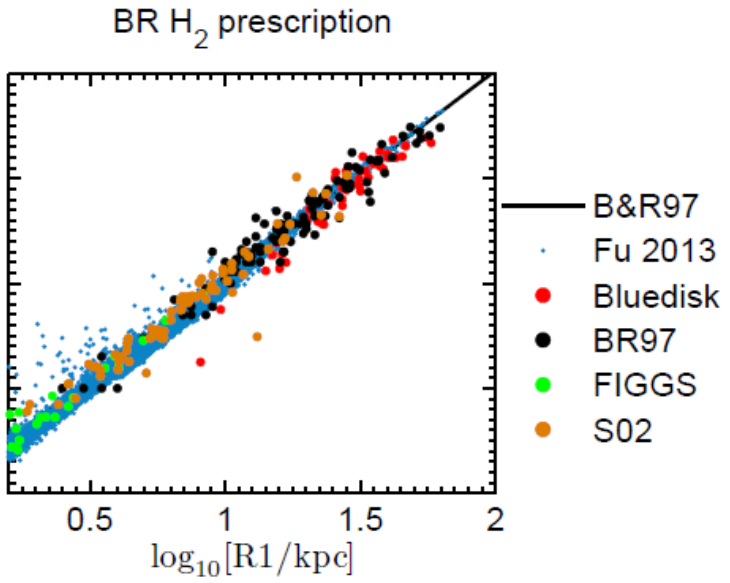


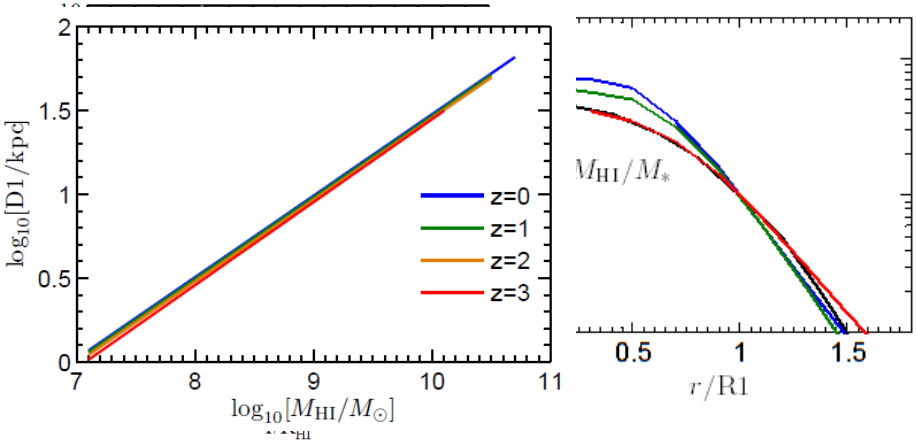


EAGLE simulation
Bahé et al. 2016

HI size-mass relation

- 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 redshifts





Conclusions

- Advantages for study HI and H_2 based on SAMs
- Our model can give fit the results of nearby galaxies and also some results for high redshift

→ mock catalogue for 21 cm survey for radio telescopes

- The missing satellite problem exists in HI gas components
- HI size-mass relation: the atomic-molecular transition

Thank you!