Distribution of H I in galaxies: Semi Analytic Method

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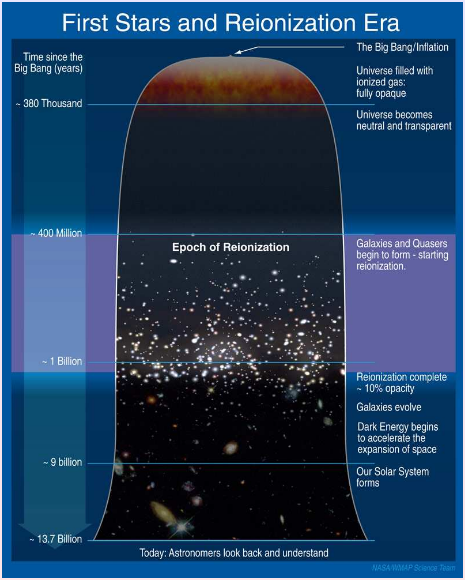
Motivation



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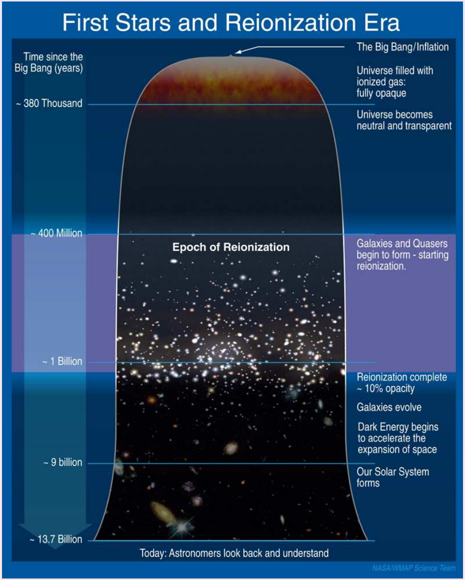

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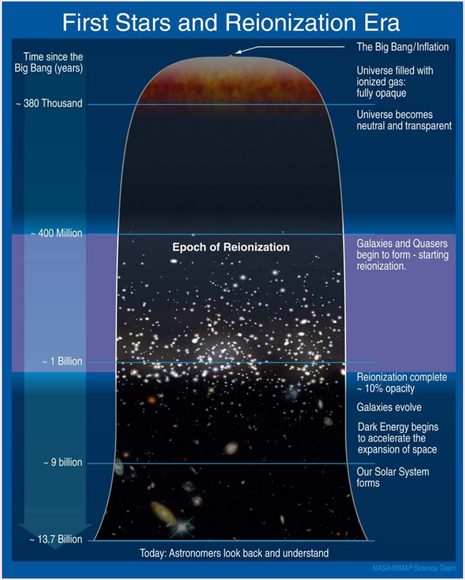

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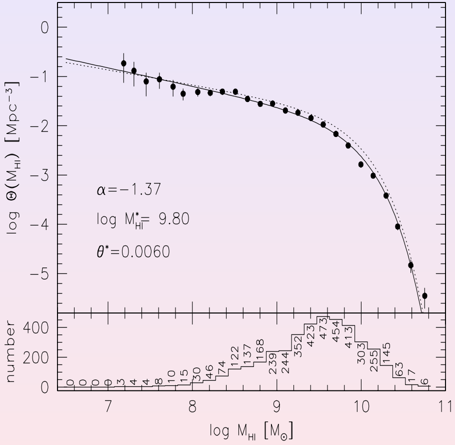
Hence, it is important to know the amount and distribution of cold gas at these redshifts.

Observation Front



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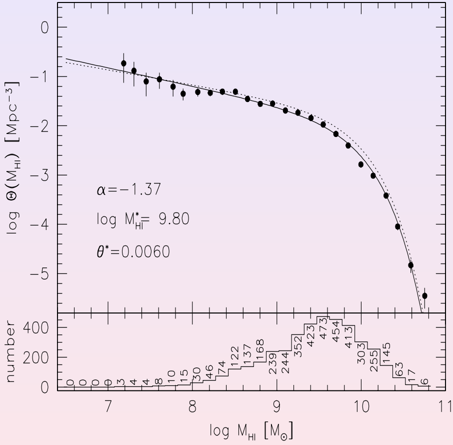

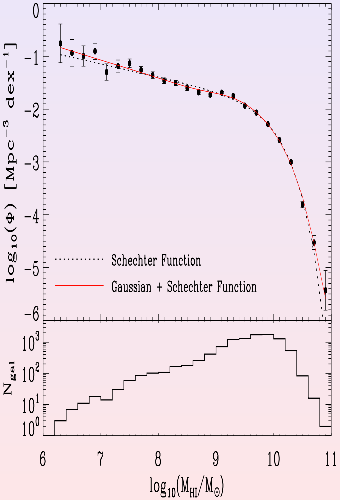

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Future H I surveys will have deep impact on our understanding of galaxy formation and evolution, hence it is theoretically important to understand the outcome of currently favoured galaxy formation models w.r.t. H I in high redshift Universe.

Galaxy Formation

Objects like galaxies form when gas collapses at the center of dark matter halos after radiative cooling of baryons.(see e.g. White & Rees, 1978). There are mainly three methods to study formation and Evolution of galaxies and hence H I in ISM:

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- **Semi Analytic Modelling** : In this technique we take advantage of high resolution N-Body simulation and simple prescription for evolution of baryons in dark matter halos

$L_{\rm box}$	$N_{\rm part}$	$m_{\rm part}$	z^f	$n_{\rm snap}$
23.04	512^3	6.7×10^6	5.0	24
51.20	512^3	7.0×10^7	3.0	29
76.80	512^3	2.3×10^8	1.0	19
153.6	512^3	7.5×10^9	0.0	23

FoF algorithm used to identify halos.

- Index of the *central particle* of each halo, which is the most-bound particle in the halo.
- The *virial mass* of the halo $\mathbf{M}_{\rm vir} = \mathbf{m}_{\mathbf{part}} \times \mathbf{N}_{\mathbf{part},\mathbf{Halo}}$
- The *virial radius* of the halo $\mathbf{R}_{\rm vir} = (\mathbf{G}\mathbf{M}_{\rm vir}/\mathbf{100H^2})^{\mathbf{1/3}}$.
- The *circular velocity* of the halo at virial radius $\mathbf{V}_{\mathbf{c}} = (\mathbf{G}\mathbf{M}_{\rm vir}/\mathbf{R}_{\rm vir})^{\mathbf{1/2}}$.

Results Model

SAM Calibration : Local TF Relation

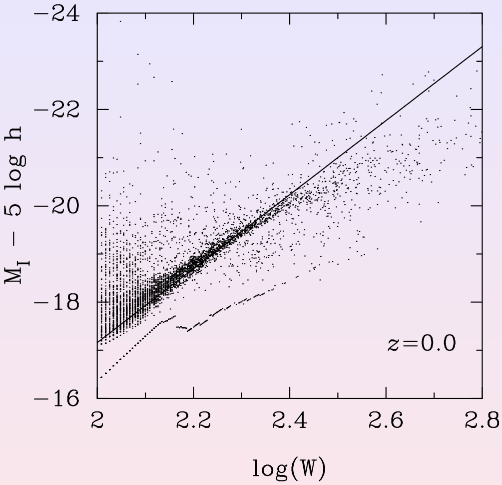


Figure: Local Tully-Fisher Relation for model galaxies compared with observation of Giovanelli et al. 1997 (Kulkarni,JKY,Bagla; In preparation)

SFR density

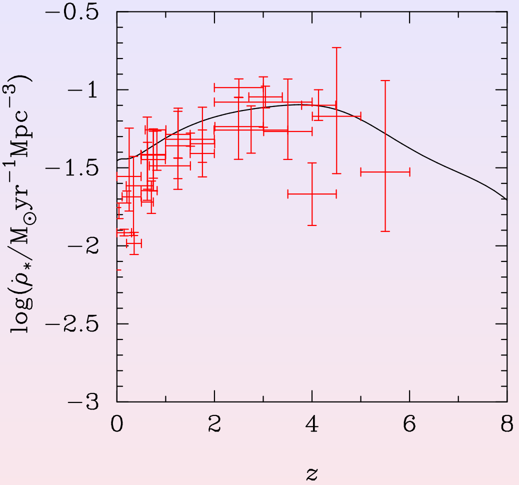


Figure: Data points with error bars are from a compilation of observations as in Springel & Hernquist 2003

The black hole M - σ relation

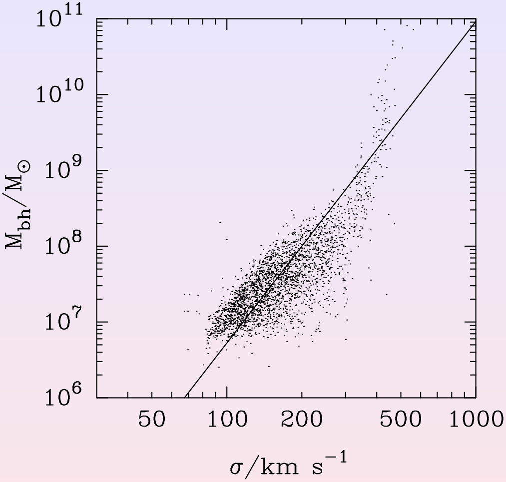


Figure: The $M_{\rm bh} - \sigma$ relation of our model galaxies compared to observations by Kayhan et. al 2009

Luminosity function (without dust extinction)

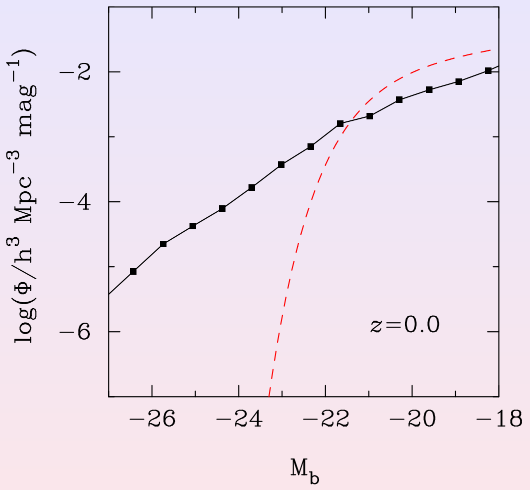
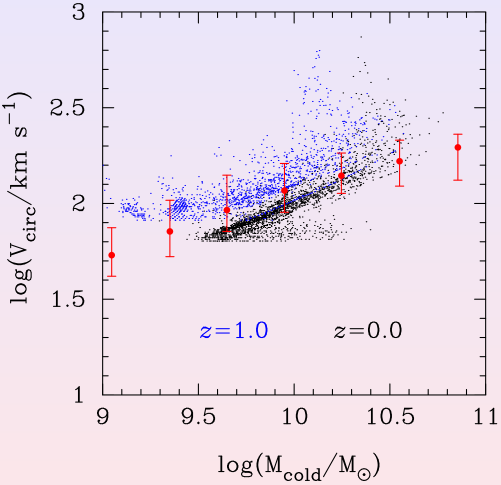


Figure: The B-Band Luminosity function

Cold gas versus Circular Velocity



Cosmic density of H I

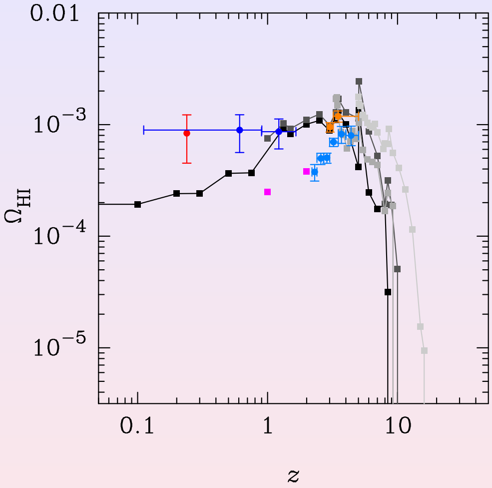


Figure: Evolution of HI mass density

Cold gas fraction of haloes in our simulation

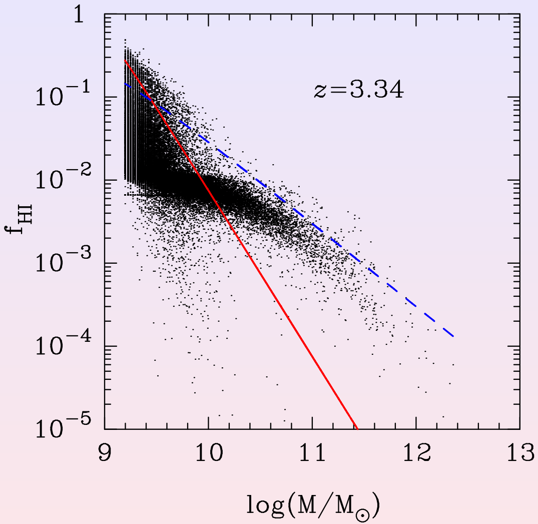


Figure: Model comparison with previous works

Power Spectrum and Bias

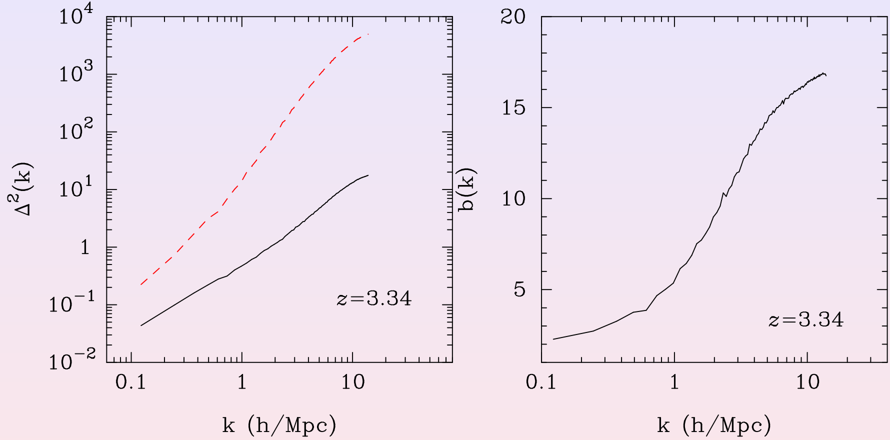


Figure: Power spectra in our model at $z = 3.34$. Black solid is dark matter and red dashed is HI. Right panel is HI bias

Power Spectrum and Bias Evolution

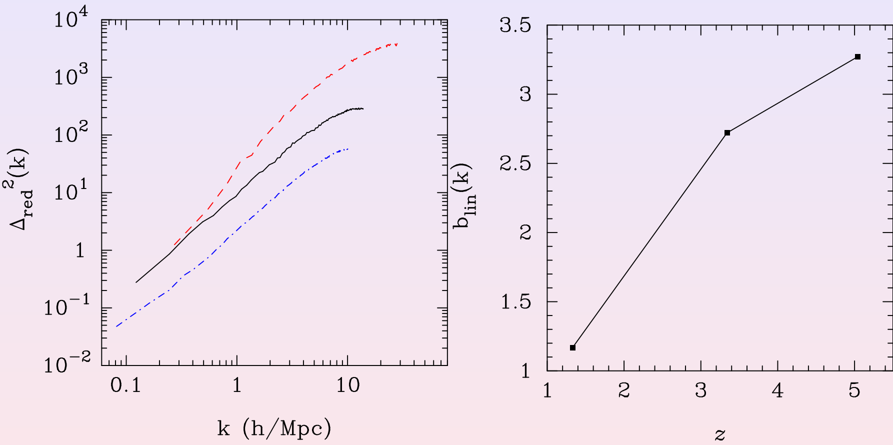


Figure: Blue is z=1.3, black is z=3.34 and red is z=5.1

Conclusions

- An improved and self consistent calculation of H I in galaxies is presented using a semi analytical code of galaxy formation (Kulkarni,JKY & Bagla, In preparation)
- We find that the clustering of HI at small scales is very strong, stronger than what was found in simple models presented earlier.
- This reinforces the point that direct detection of rare peaks in the HI distribution may require less time that statistical detection at larger scales.
- Further studies are required to refine strategies for HI detection in the post-reionization epochs.

SAM Implementation

- A merger tree is constructed by connecting DM Halos across different epochs of simulation.
- Starting from the highest redshift, on each branch of merger tree the simple recipes of SAM are applied.
- The main processes to model are Cooling,SFR and Feedback mechanisms.

Gas Cooling

Before the structure forms the gas has the same distribution as DM.

$$T_v = 35.9(V_c/kms^{-1})^2 K \tag{1}$$

1. Cooling by IC scattering of CMB photons by electrons. Not effective at late times.
2. $T_v < 10^4 K$: Deexcitation of fine structure lines of heavy elements and rotational levels of molecules.
3. $10^4 K < T_v < 10^{7.5} K$: Decay through the recombination of electron and ions. Much dependent on metallicity.
4. $T_v > 10^{7.5} K$: Bremsstrahlung emmision. Cooling dominated by free-free transition in elctron-ion collision.

Cooling efficiency also depends on size of Halos.

Star Formation

$$\dot{M}_* = \alpha M_{cold}/t_{dyn} \qquad (2)$$

In Spherical Collapse Model
$R_{vir} \propto V_c(1+z)^{-3/2}$

- Halos are smaller and Denser at Earlier Epochs
- SFR is higher in Halos at Earlier z, even for same cold gas

Feedback From Supernovae

Supernovae reheat the cold gas and may drive a wind.

$$\Delta m_{\rm reheated} = \epsilon_{\rm gal} \Delta m_* \tag{3}$$

Energy in SN ejecta

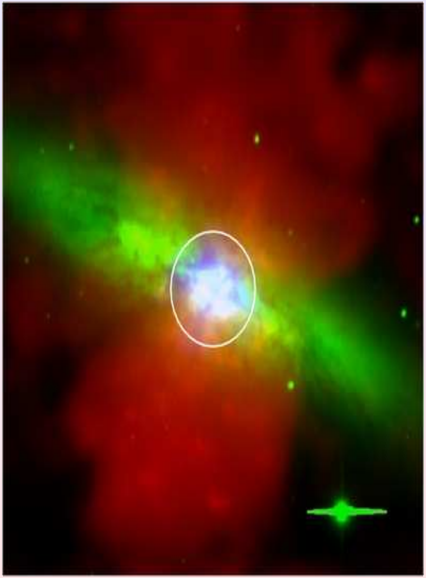
$$\Delta E_{\rm SN} = 0.5 \epsilon_{\rm halo} \Delta m_* V_{\rm SN}^2, \tag{4}$$

Change in thermal Energy of halo

$$\Delta E_{\rm hot} = 0.5 \Delta m_{\rm reheated} V_{\rm vir}^2. \tag{5}$$

Condition for reheated gas to eject from the hot component

$$\Delta E_{\rm excess} = \Delta E_{\rm SN} - \Delta E_{\rm hot}. \tag{6}$$



Feedback From AGN

Increase in mass of BH in mergers

$$\Delta m_{\rm BH,Q} = \frac{f'_{\rm BH} m_{\rm cold}}{1 + (200\,{\rm km\,s^{-1}}/V_{\rm vir})^2} \quad (7)$$

Accretion due to Radio mode of feedback

$$\dot{m}_{\rm BH} = \kappa \left(\frac{m_{\rm BH}}{10^8 {\rm M}_\odot}\right) \left(\frac{f_{\rm hot}}{0.1}\right) \left(\frac{V_{\rm vir}}{200\ kmps}\right)^3$$

Mechanical heating generated by this mode

$$L_{\rm BH} = \eta \dot{m}_{\rm BH} c^2, \quad (8)$$

This modifies the cooling rate to

$$\dot{m}'_{\rm cool} = \dot{m}_{\rm cool} - 2 L_{\rm BH}/V_{\rm vir}^2 \quad (9)$$

Thank You for your Attention.