On Detecting HI in Emission at $z \sim 1$

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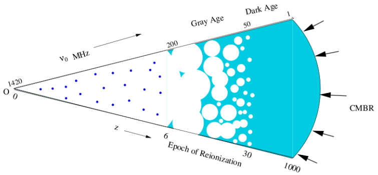
Outline

- Motivation
- Modeling the HI distribution
- Prospects for Detection: Statistical and Direct
- Detecting by Stacking the Spectra
- Conclusions and Future Prospects

Motivation

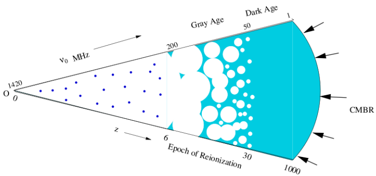
Evolution of Neutral Hydrogen (HI)



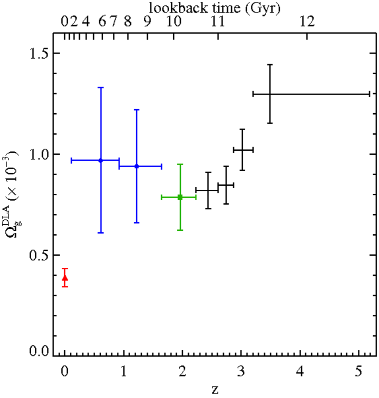
Ali & Bharadwaj 2005

Motivation

Evolution of Neutral Hydrogen (HI)



Ali & Bharadwaj 2005



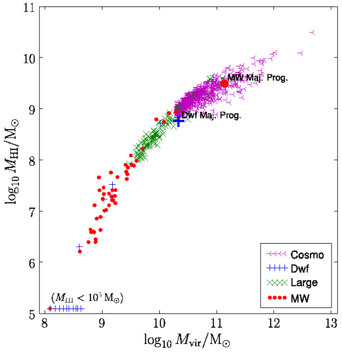
Noterdaeme et al. 2009

- Post-reionisation, a tiny fraction of neutral hydrogen (HI) survives ionization and is locked in dense clumps through self-shielding : DLAs.
- The neutral fraction has remained consistent with a constant value of $\Omega_{HI} \sim \mathcal{O}(10^{-3})$ $z > 1$ with large errors.
- A census of cold gas is crucial for galaxy formation models at moderate redshifts.
- Clustering properties of HI selected galaxies (HI bias, mass function), will give key insights into the clustering of their host halos.
- 21-cm cosmology (Ue-Li Pen's talk), will also put independant constraints on cosmological parameters.

- We focus in the post-reionization era and make predictions for the distribution of HI in this regime, using the 21cm hyperfine transition of HI as a probe.
- $T_s \gg T_{CMB}$ at these redshifts hence the signal will be seen in emission.
- We will see that a direct detection for HI in emission with an existing radio interferometer (GMRT) is not feasible.
- Noise is too large, flux is diluted at higher redshift.
- A statistical detection would be possible: low-σ detection at $z = 1.33$.
- Strategy for direct detection: Stack the signal with known estimates galaxy redshift from another survey: DEEP2.
- Independent constraint on Ω_{HI}

Modeling the HI Distribution

Simulation of DLAs at z=3

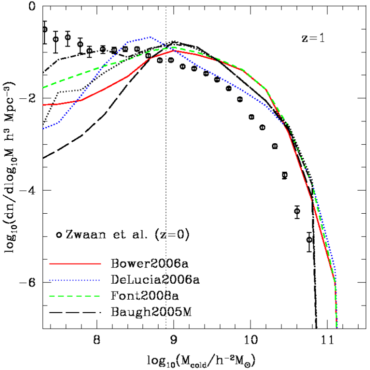


Pontzen et al 2008

- Bimodality at $M \sim 10^{10.5}$
- Suppression in HI at $M > 10^{11} M_\odot$
- $10^{13} M_\odot$ halo also host the most significant HI.

$$M_{vir} \simeq 10^{10}\ \mathrm{M}_\odot \left(\frac{v_{circ}}{60\mathrm{km/s}}\right)^3 \left(\frac{1+z_c}{4}\right)^{-3/2}$$

$$V_{circ}^{min} \sim 30\mathrm{km/s} \qquad V_{circ}^{max} \sim 200\mathrm{km/s}$$



Power et al 2010

- Observations: HIPASS galaxies at $z = 0$ (Zwaan et al. 2005)

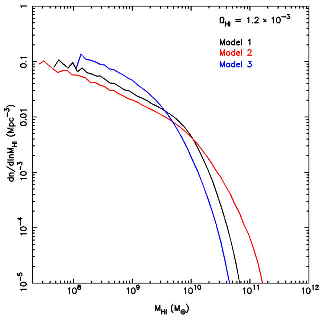
  $$\frac{dn}{dlnM} = 0.006 \left(\frac{M_{HI}}{M^*_{HI}}\right)^{-0.37} \exp\left(-\frac{M_{HI}}{M^*_{HI}}\right)$$

  $$M^*_{HI} = 10^{9.8} M_\odot$$

- Shift due to larger $\Omega_{HI}(z = 1)$
- Finite resolution: Mismatch at low masses

Simulation Details

- Gadget3: Dark Matter Simulation
- $N_{part} = 2448^3$, $L_{box} = 400h^{-1}Mpc$,
  1.5 larger than Millenium.
- Cosmology: $\sigma_8 = 0.8, n_s = 0.96, \Omega_\Lambda = 0.74, \Omega_m = 0.26$
  $P(k) \Rightarrow$ Eisenstein and Hu.
- Halofinder: SUBFIND with 20 bound particles.
- Mass resolution: $M_{DM} = 3 \times 10^8 M_\odot$,
  3 times finer than Millenium.
- Large volume will probe effects of cosmic variance on Ω_{HI}

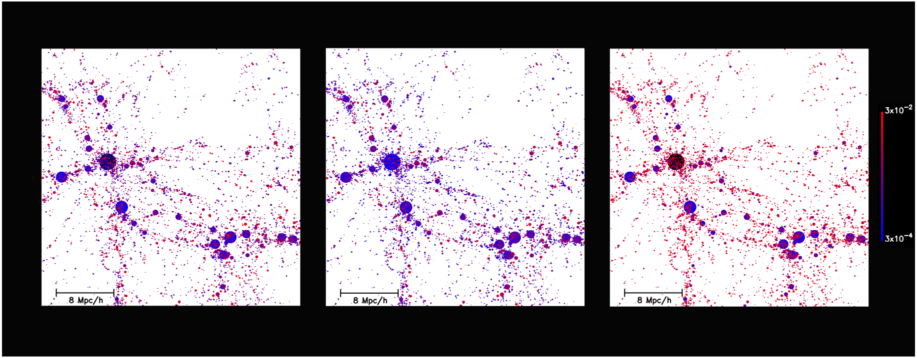


- $M_{HI} \propto \dfrac{(M_{halo})^m}{1 + \left(\frac{M_{halo}}{M_{min}}\right)^n + \left(\frac{M_{halo}}{M_{max}}\right)^p}$
- Model 1: Fits Zwaan mass function but normalised to $\Omega_{HI} = 1.2 \times 10^{-3}$
- Model 2: HI suppression in low mass halos.
- Model 3: HI suppression in high mass halos.

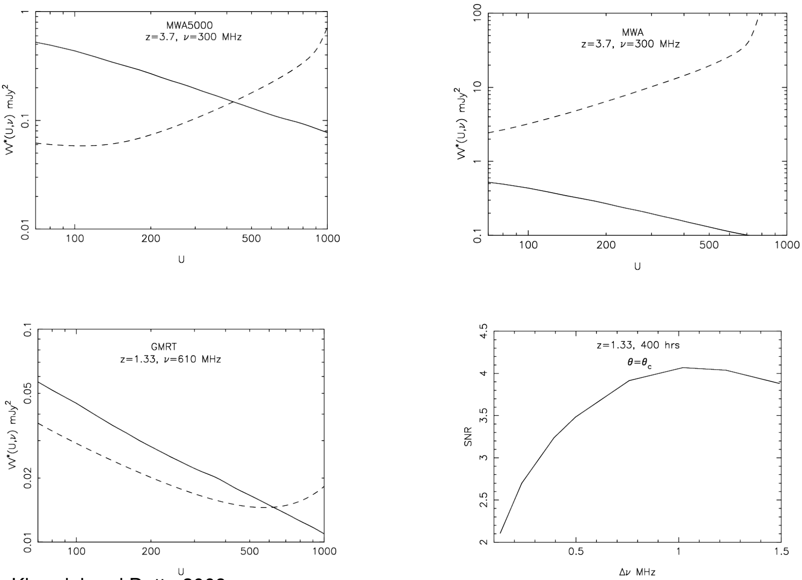
Table: Model Parameters

Model	$M_{min}(10^{10} M_\odot)$	$M_{max}(10^{10} M_\odot)$	m	n	p
1	12	143	1.8	1.36	1.8
2	12	143	2.0	1.36	2.0
3	5	143	1.6	1.15	1.7

Color code: HI fraction f_{HI}



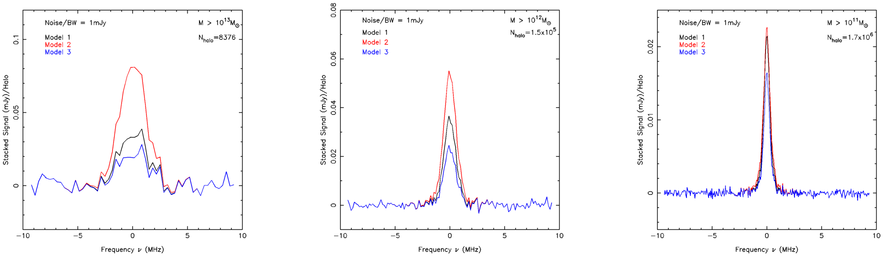
Statistical and Direct Detection Estimates



Bagla, Khandai and Dutta 2009

- Observation time (statistical and direct) too large.
- Individual detection: no constraints on Ω_{HI}
- Signal $\mathcal{O}(10\mu Jy)$, Noise $\mathcal{O}(mJy)$
- Beat noise by stacking sources, with independant redshift estimate.

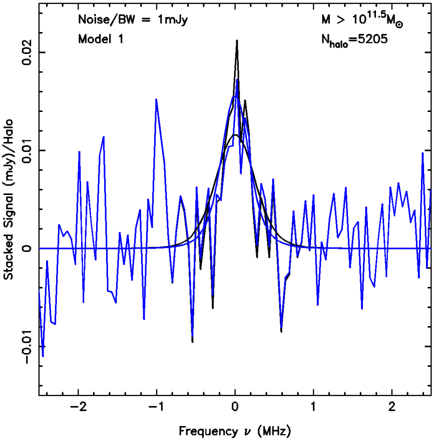
Stacked Spectra



$$S_\nu = \frac{3}{4} A_{12} h\nu \frac{M_{HI}}{m_H} \frac{(1+z)}{4\pi D_L(z)^2} \phi(\Delta\nu) \quad (1)$$

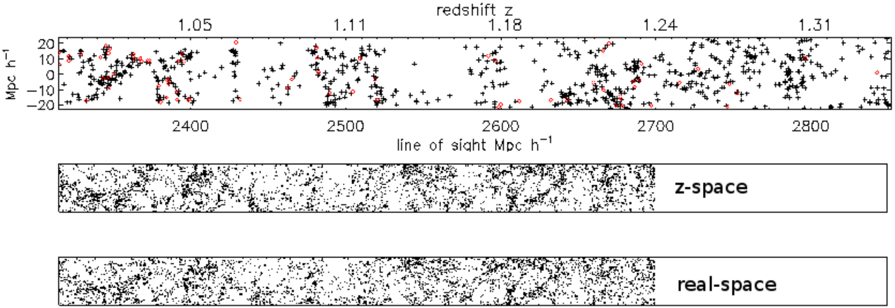
$$\Delta\nu = \frac{\Delta v}{c} \nu \quad (2)$$

Effect of z-errors in DEEP2



Spectral resolution in DEEP2: 68km/s

DEEP2 (top) and GMRT common field of view



Summary and Ongoing Efforts

- We have modelled HI in a Dark Matter Simulation and seen how the signal can be extracted by stacking sources.
- In a preliminary estimate we find that DEEP2 and GMRT have around 2000 sources in common.
- Redshift errors might dilute the expected signal.
- By combining different subsets in the sample we can expect (in principle) to constrain the HI mass function at $z \sim 1$.
- We will also be estimating whether such a strategy can be carried out with photo-z in a survey like LSST (larger sample but larger z-errors).