The Cosmic Neutral Hydrogen Mass Density at z=5

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Cosmological mass density of neutral hydrogen

It is required to measure cosmological parameters via HI intensity mapping (e.g. Wyithe & Loeb 2008).

It provides a useful constraint for theoretical models of galaxy formation (Lagos+ 2011, Dave+ 2013, Popping+ 2014, Rahmati+ 2015).

The dense, mostly neutral clouds which dominate the mass density are expected to be closely linked to star formation.

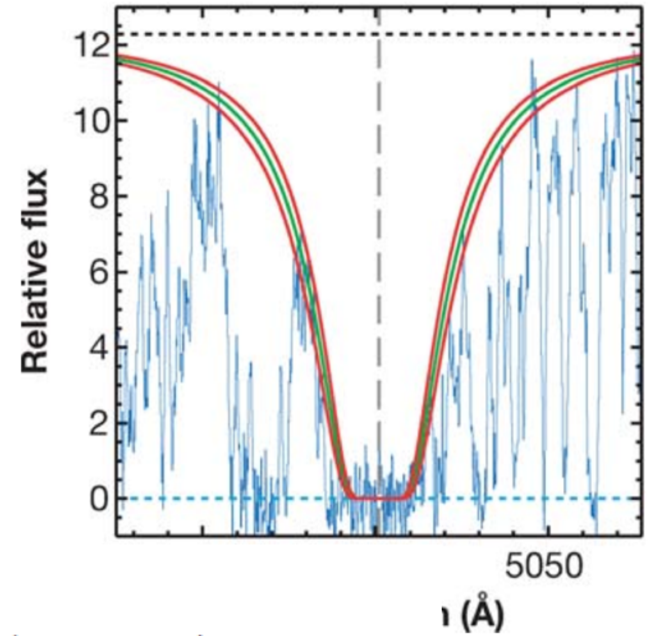
We extend this measurement to z ~ 5: approaching reionization epoch,.

HI cosmic mass density from absorption

Incidence rate of DLAs

$$\ell_{\rm DLA}(X)dX = \int_{N_{\rm HI,min}}^{\infty} f_{\rm DLA}(N_{\rm HI}, X)dN_{\rm HI}dX.$$

N(HI)



physical area of a DLA

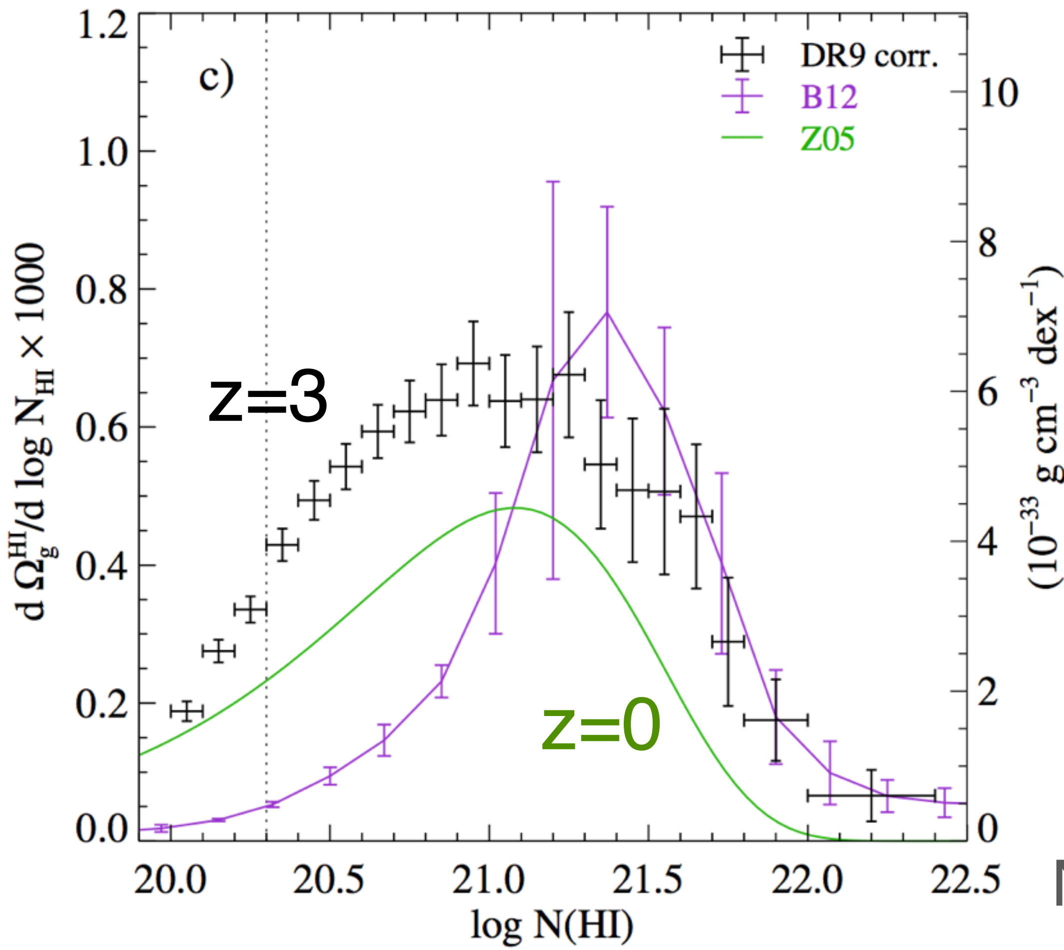
Mass per DLA = $m_{\rm H} N_{\rm HI} A(X)$

$$\ell_{\rm DLA}(X) = \frac{c}{H_0} n_{\rm DLA}(X)A(X)$$

comoving DLA number density

$$\Omega_{\rm HI}^{\rm DLA}(X)dX = \frac{H_0}{c}\frac{m_{\rm H}}{\rho_{\rm crit,0}} \int_{N_{\rm HI,min}}^{\infty} N_{\rm HI} f_{\rm DLA}(N_{\rm HI}, X)dN_{\rm HI}dX$$

critical cosmological density at z=0



Noterdame+ 2012

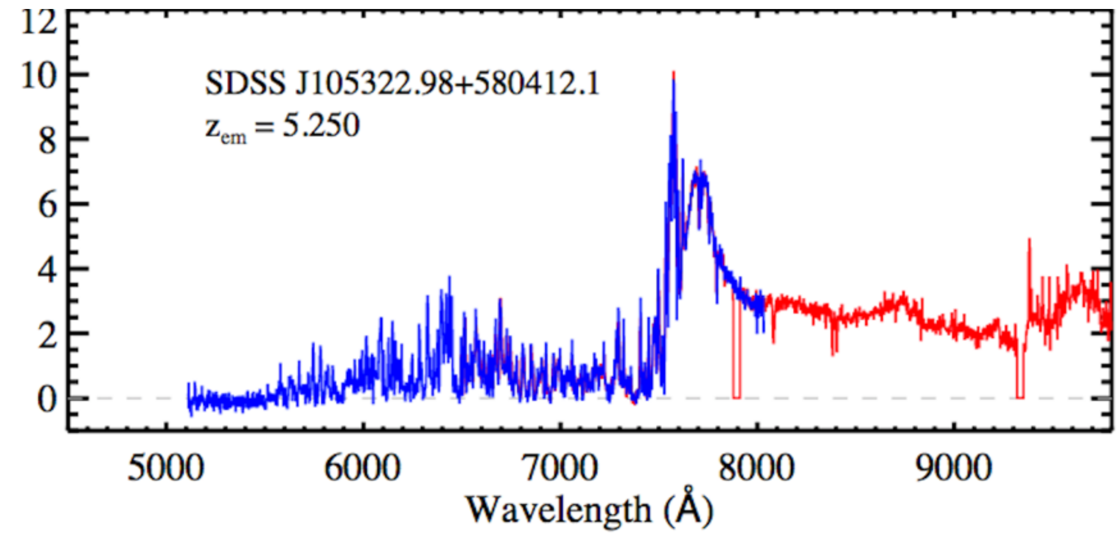
Gas below the DLA threshold contributes < 20% of HI mass.
(O'Meara+ 07, Zafar+ 13)

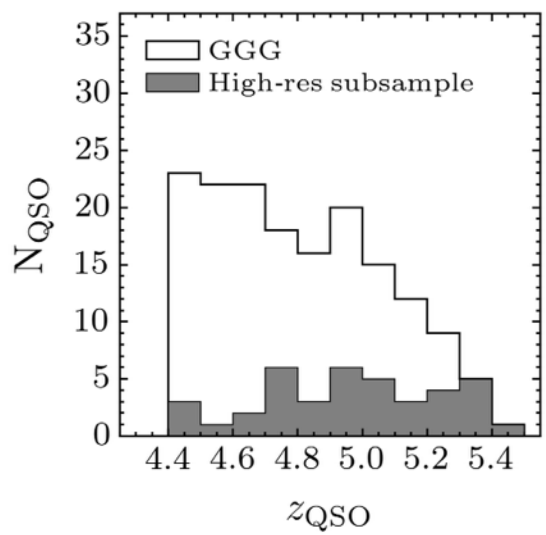
High-redshift QSO Sample

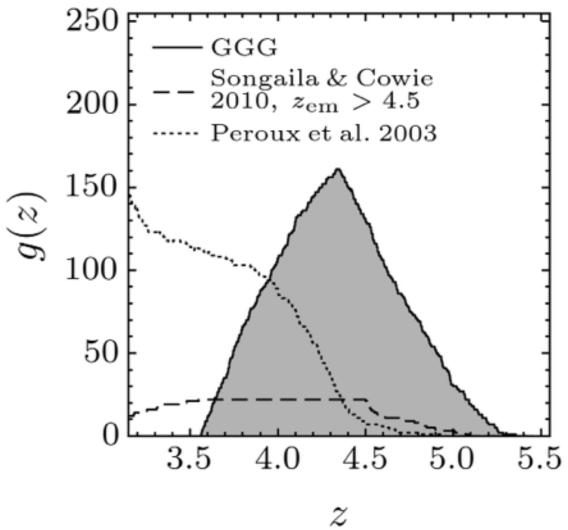
162 QSOs at 4.4 < z < 5.4 with 69 DLAs (The Giant Gemini GMOS survey, Worseck+ 2014)

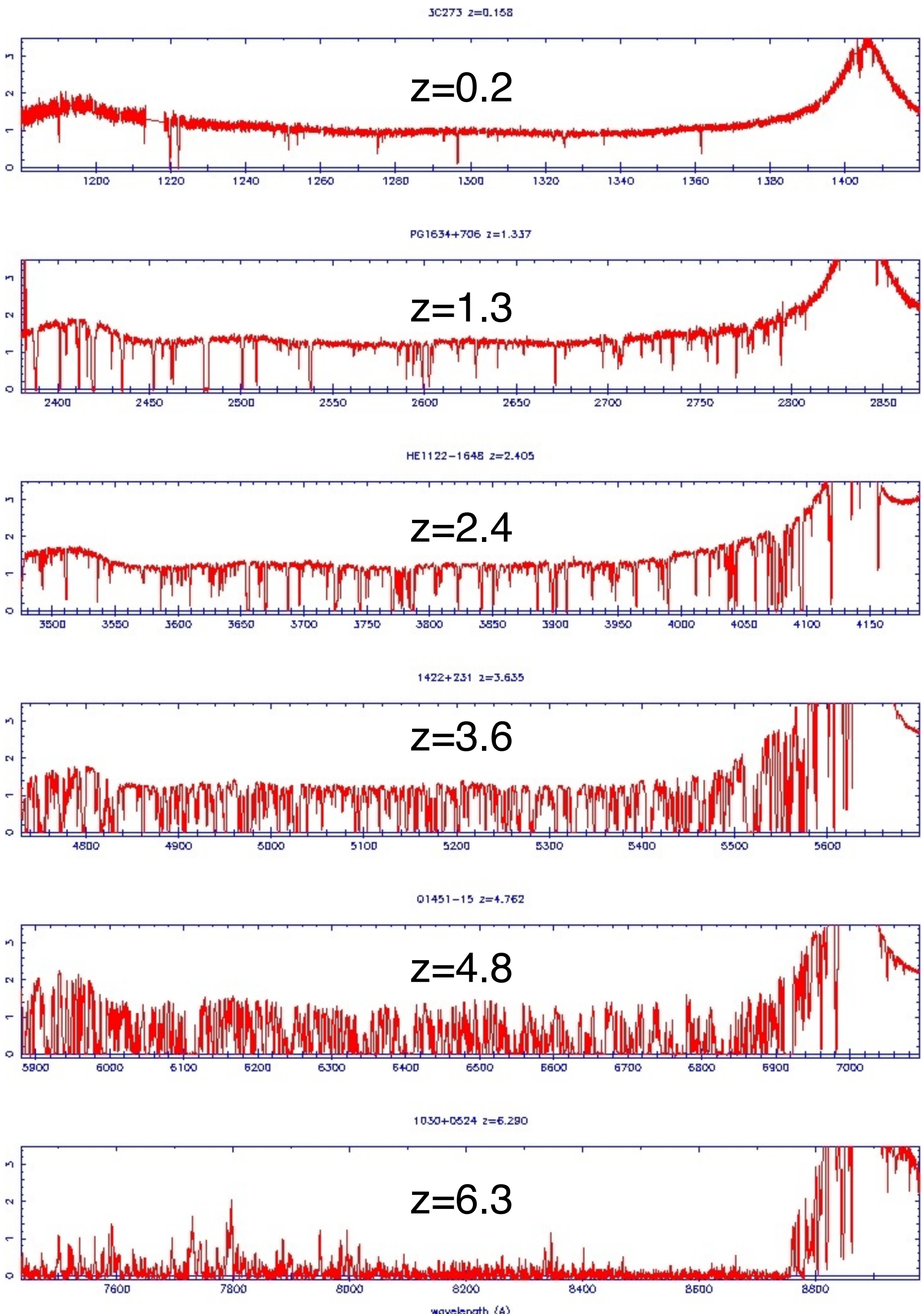
QSOs colour-selected from SDSS (unbiased with respect to the presence of a DLA)

Low resolution spectra (~300 km/s FWHM) covering rest frame 912-1300 A with SNR ~20



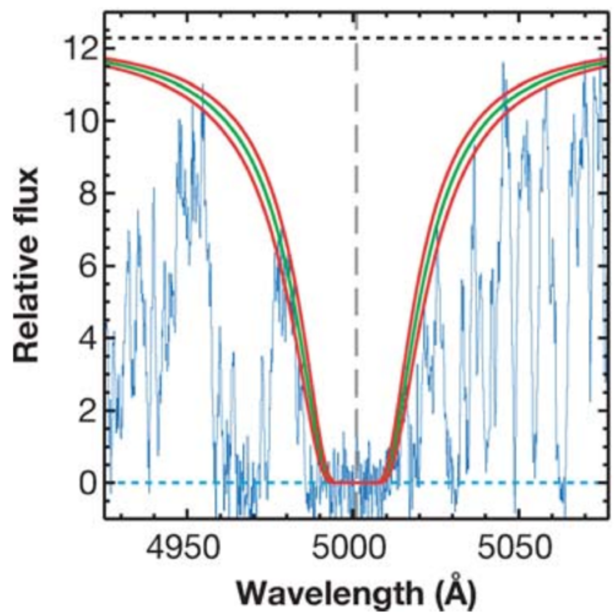






from Bob Carswell

Finding DLAs becomes difficult at high redshift

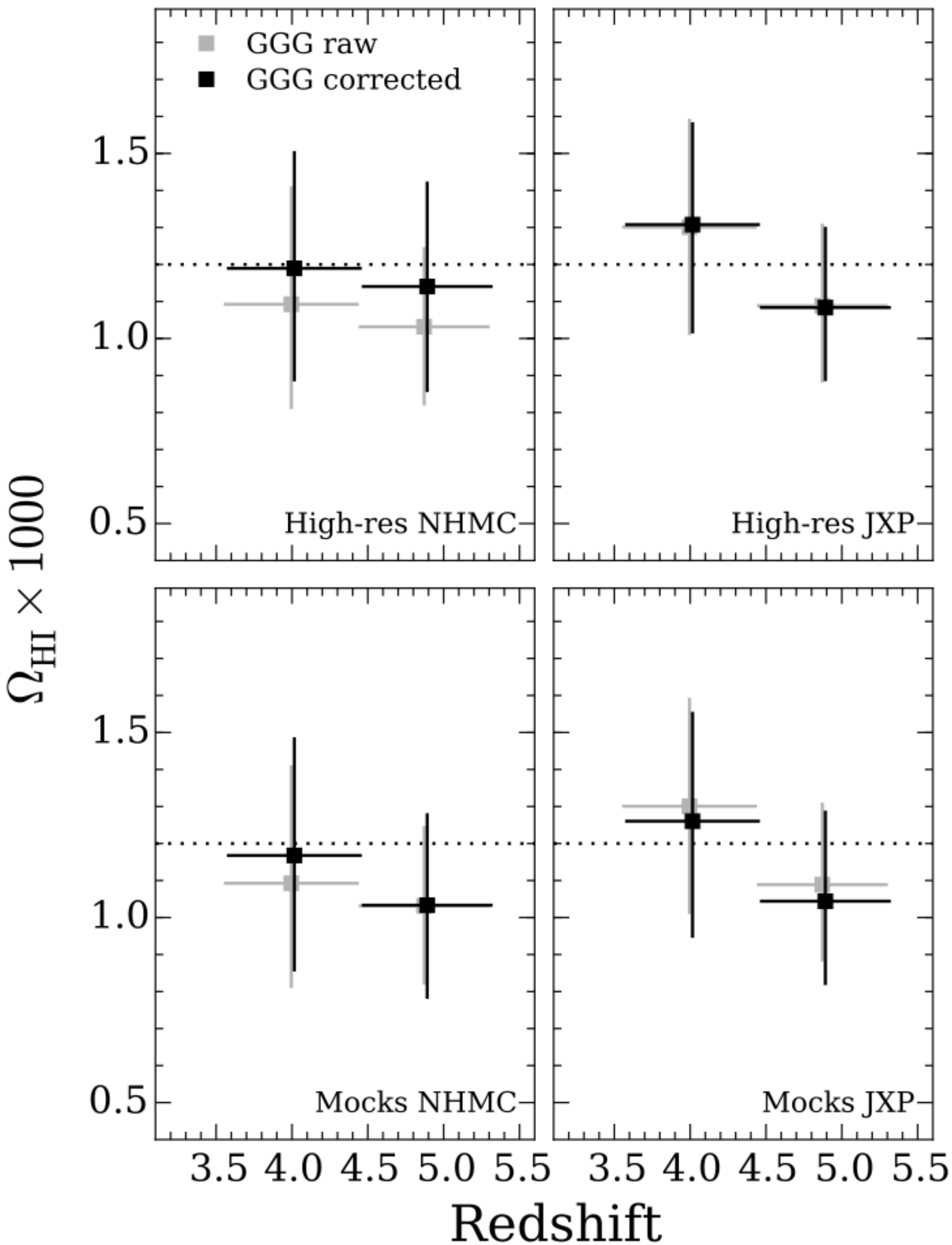


May bias f(N,X) and N(HI)

Dealing with systematics

- Use mock spectra.
- Confirm DLAs with higher resolution spectra.
- Perform independent analyses.

Systematics: correction factors

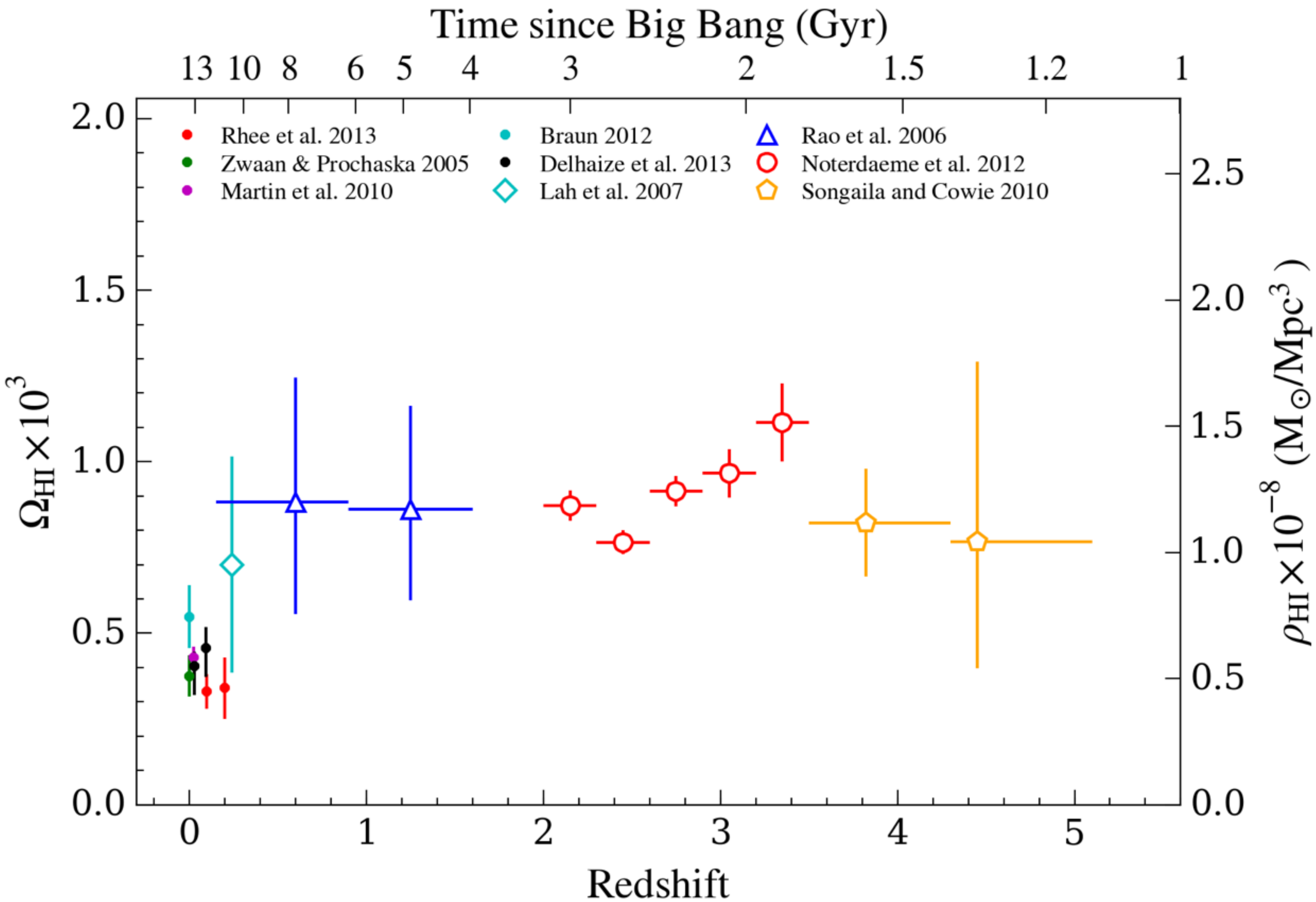


We do all of this twice, for two authors: NHMC and JXP.

None of the systemics are as large as the statistical uncertainty, estimated using bootstrapping.

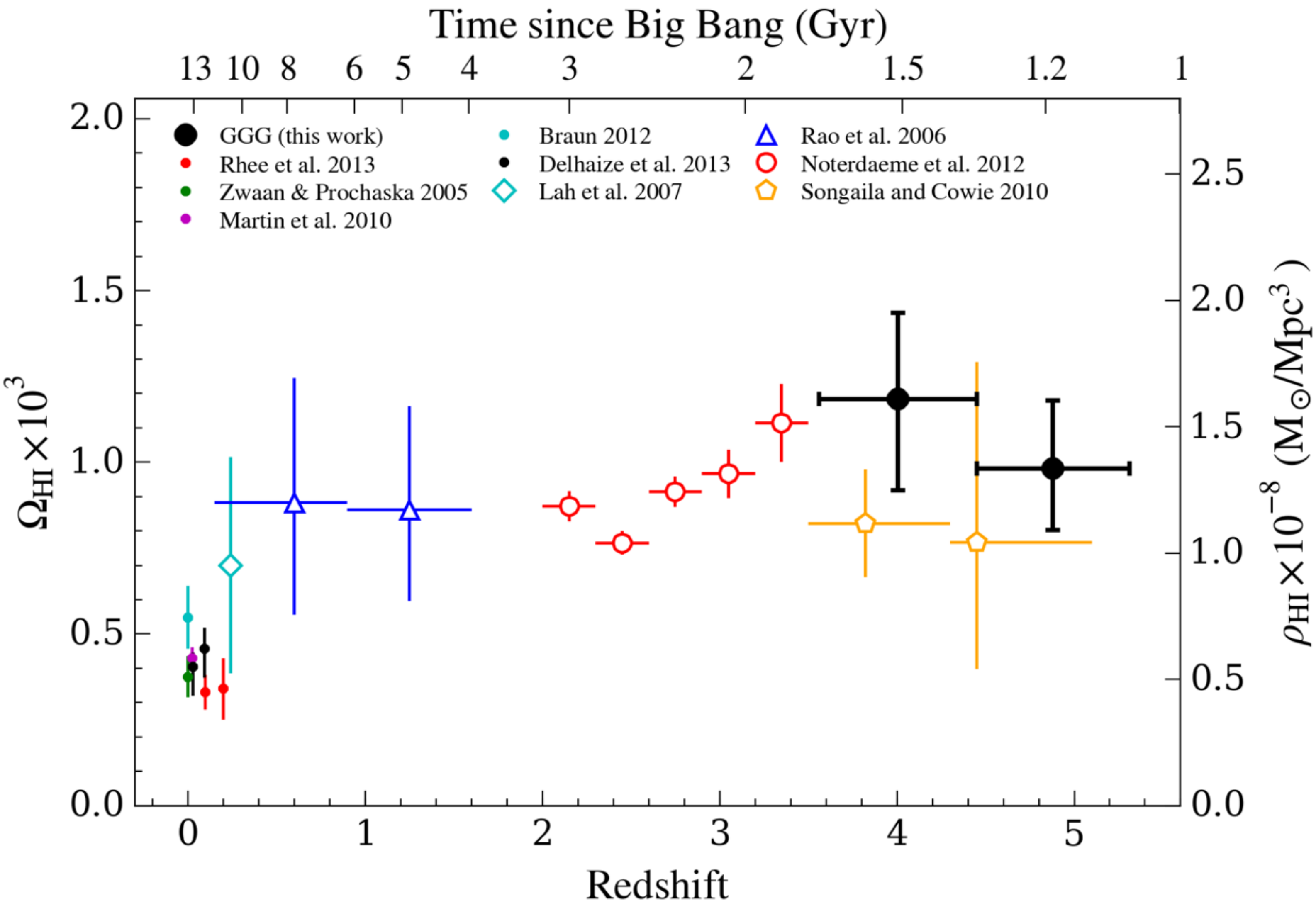
There is an increase of 30 ± 20% in the DLA incidence towards bright QSOs (z mag <19.2) compared to fainter QSOs (see also Prochaska+ 2005). This is probably a statistical fluctuation (Menard+ 2008).

Results



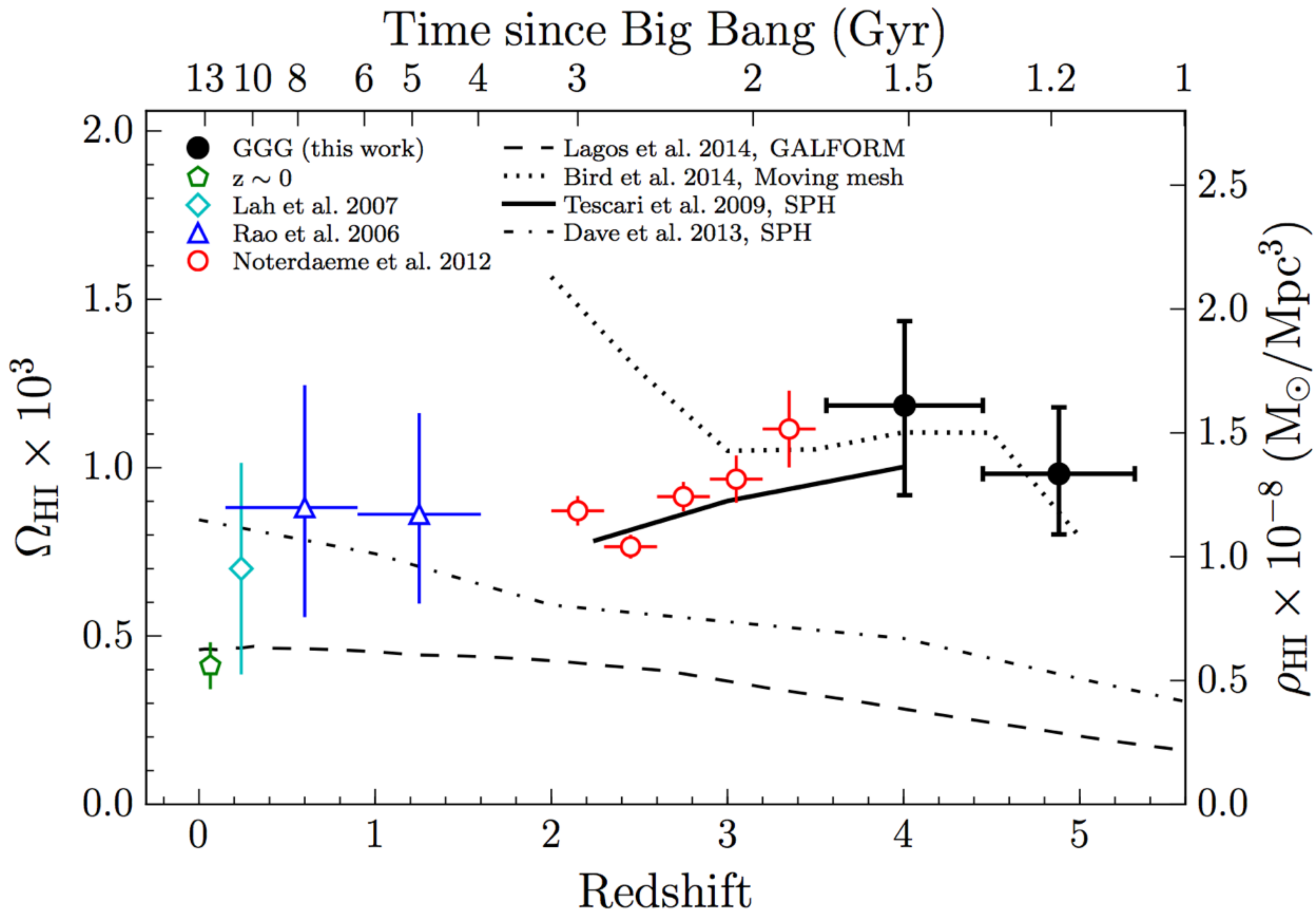
See also Zafar+ 2013, Prochaska+ 2009

Results



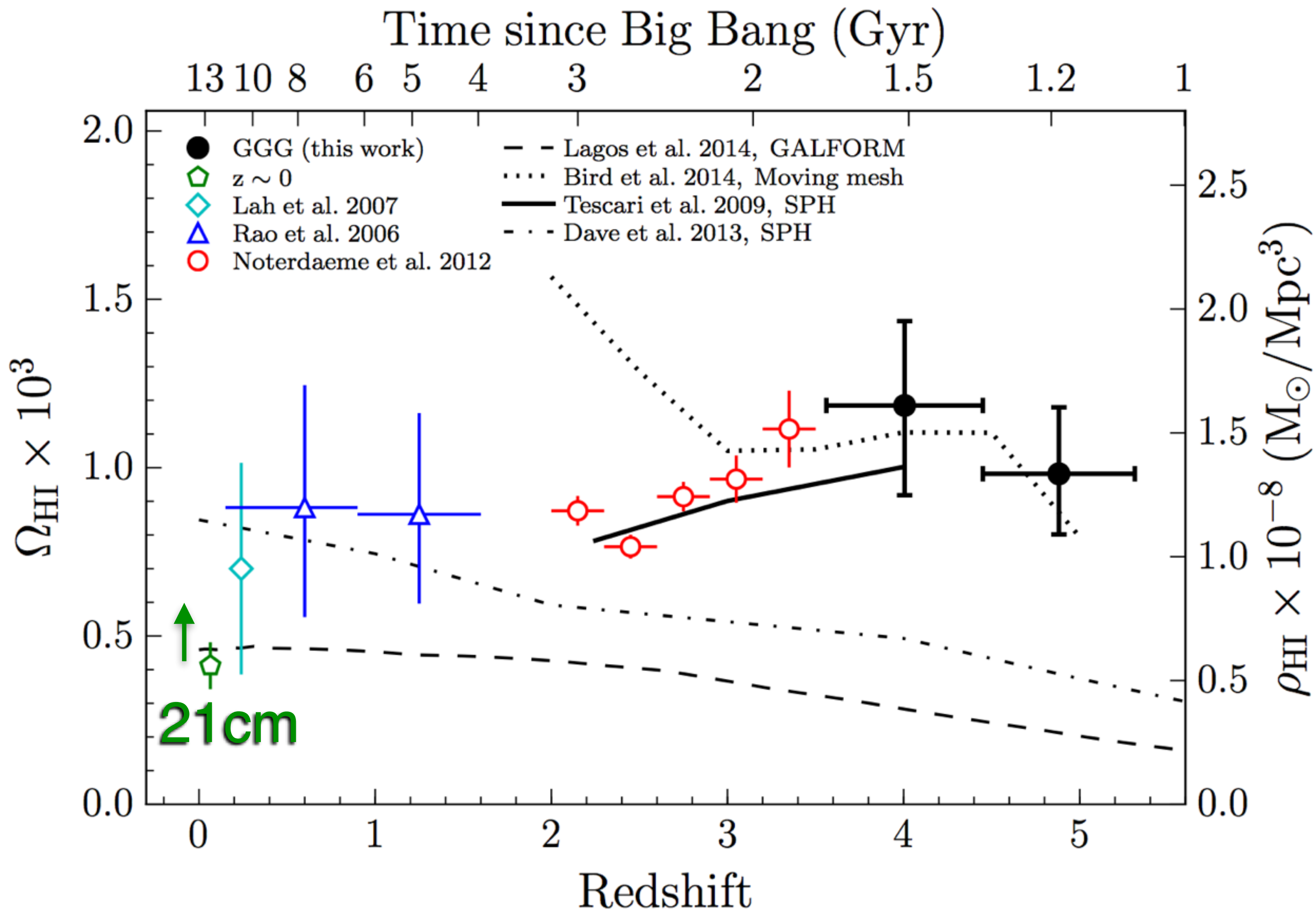
See also Zafar+ 2013, Prochaska+ 2009

Comparison to theory



See also Duffy+ 2012, Popping+ 2014, Rahmati+ 2015

Comparison to theory



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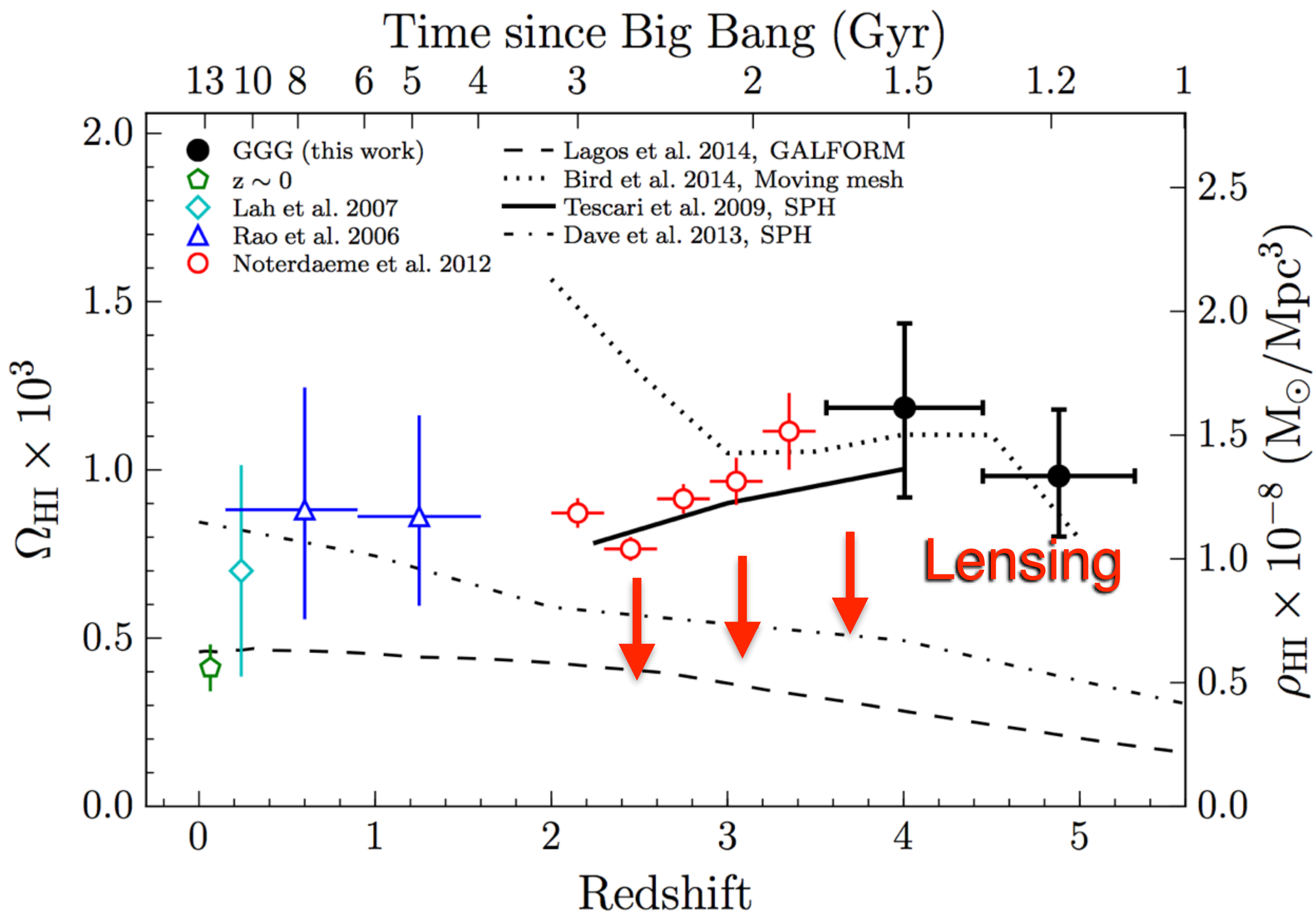

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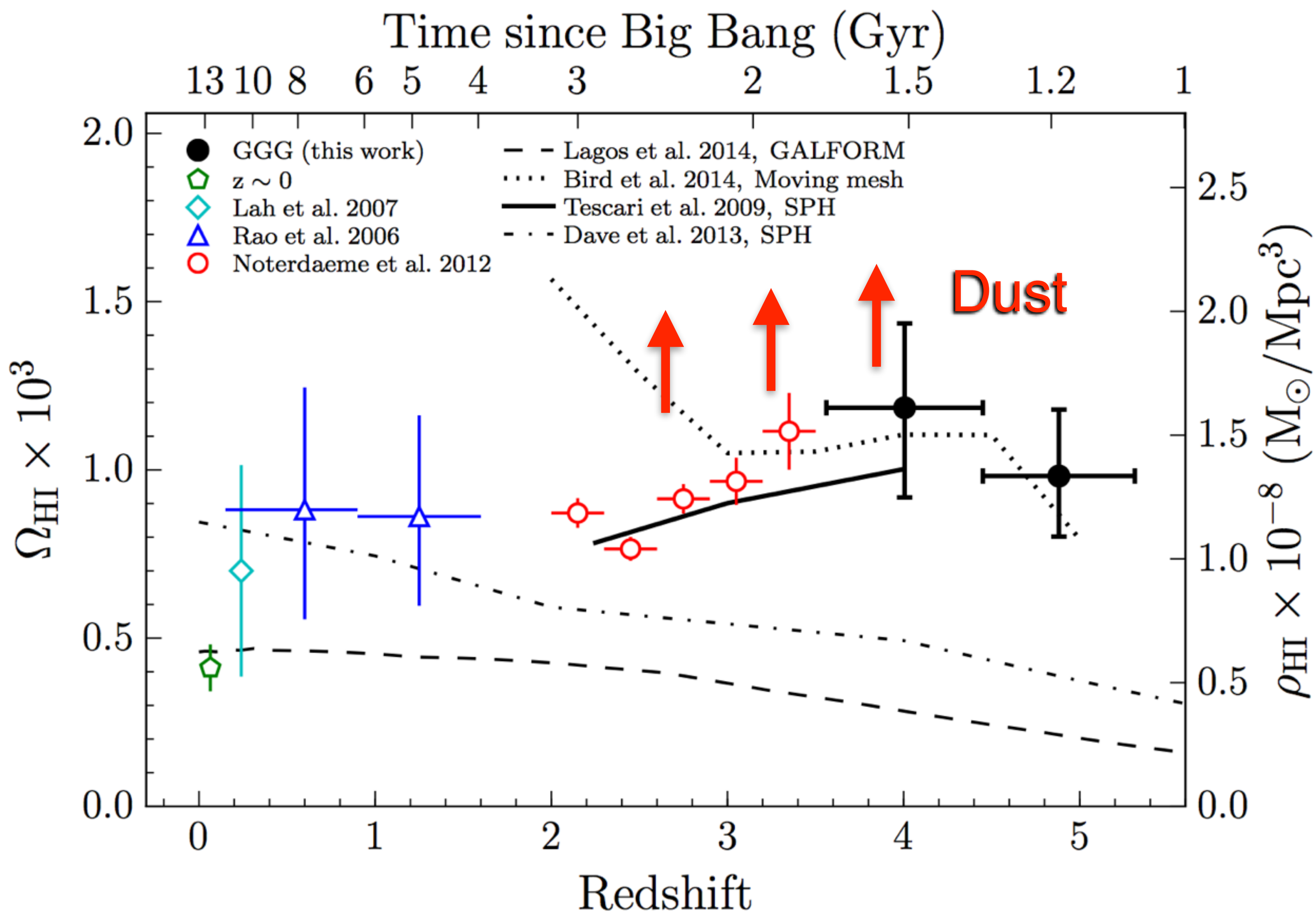
Comparison to theory



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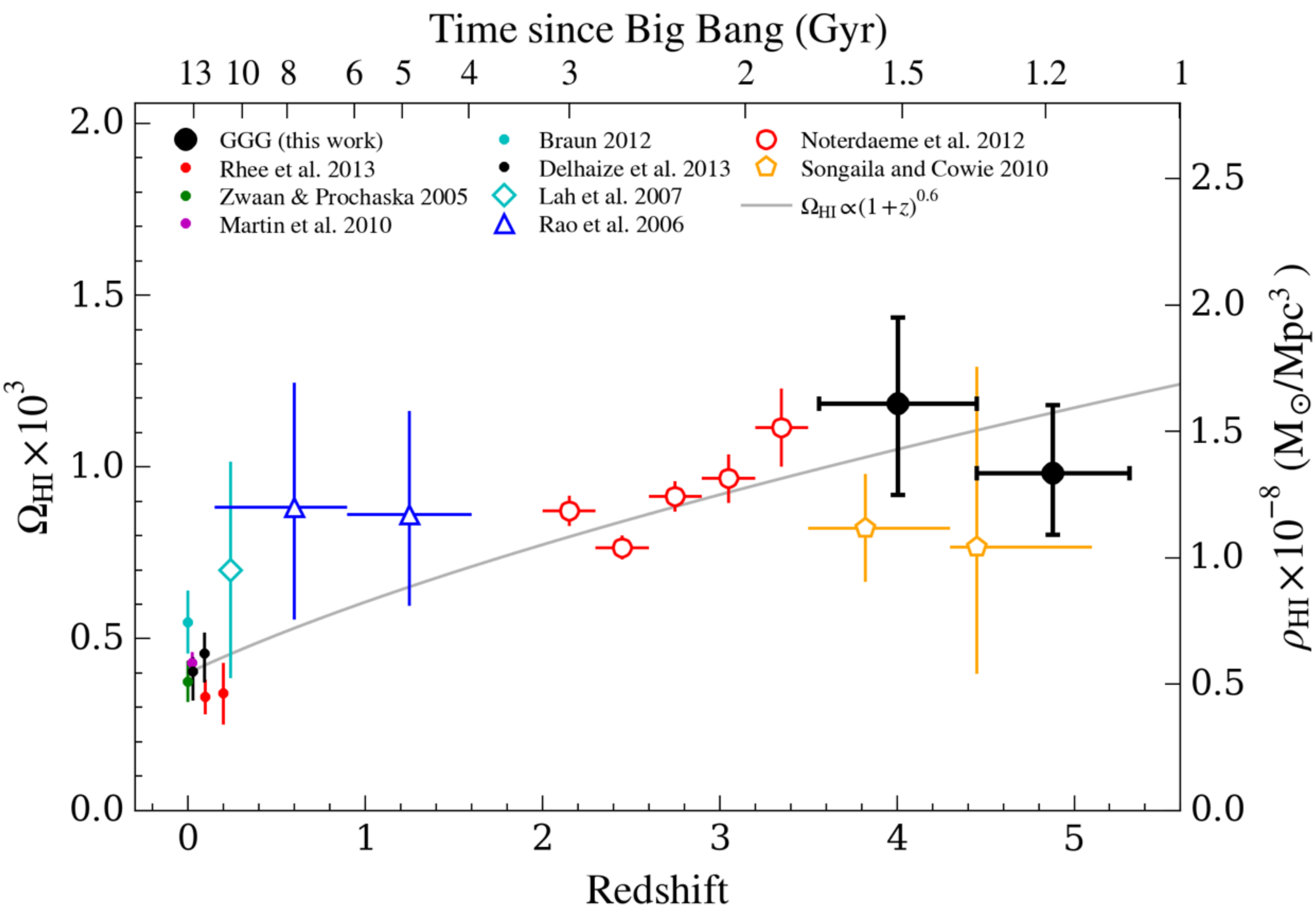
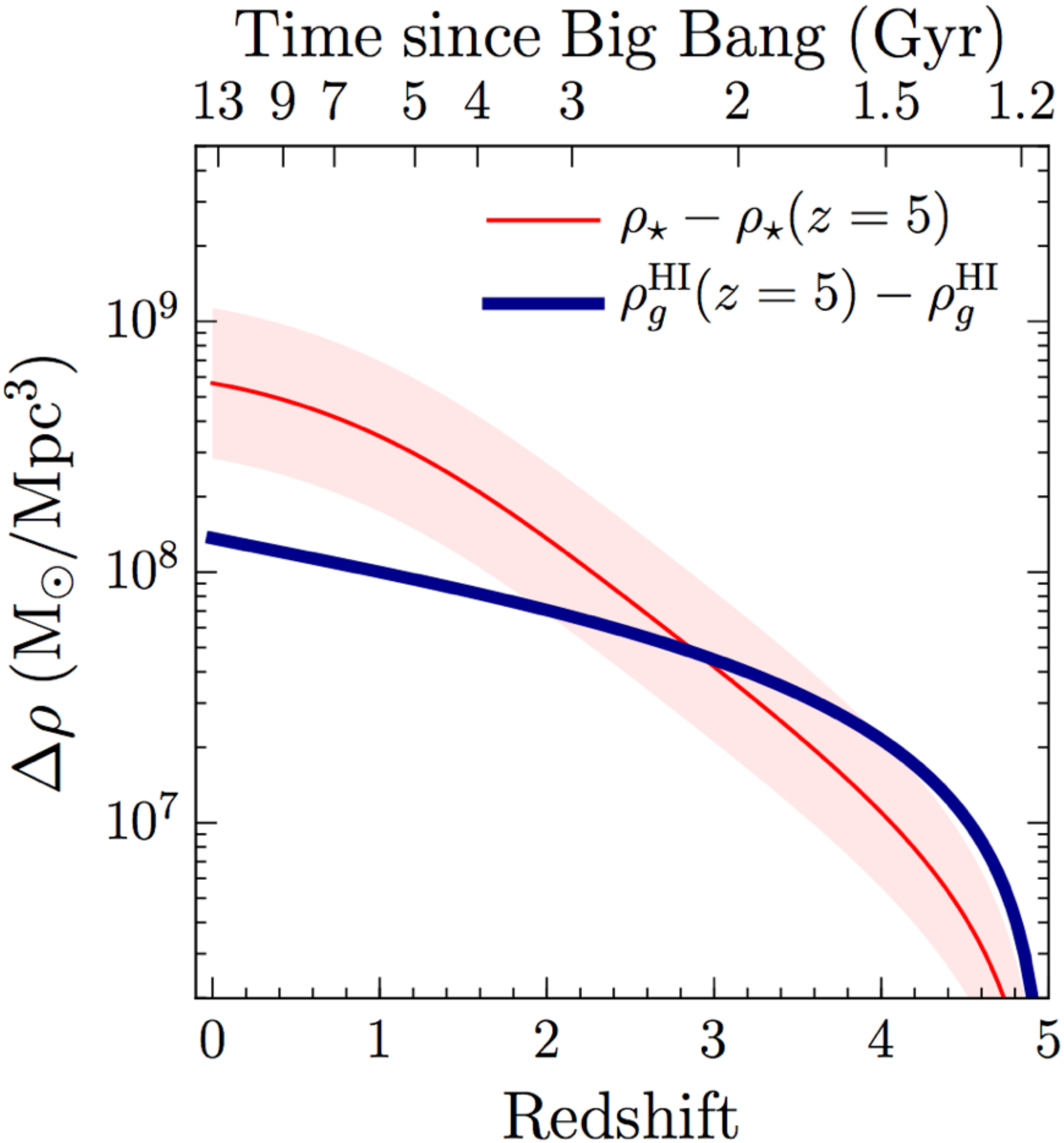
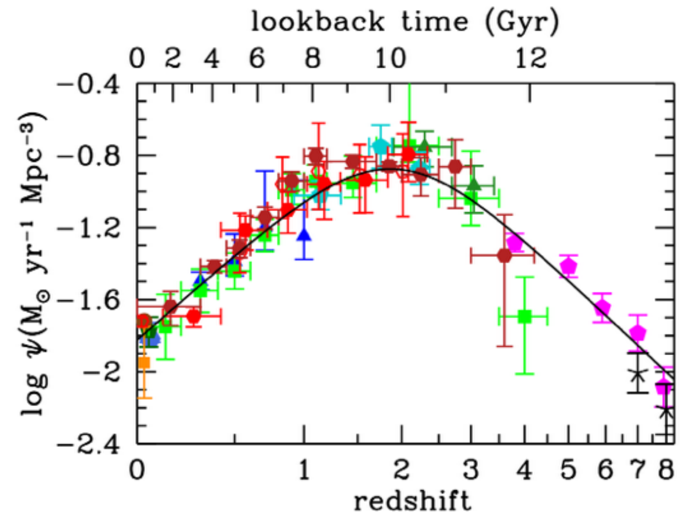


Time since Big Bang (Gyr)
13 10 8 6 5 4 3 2 1.5 1.2 1
GGG (this work)
Rhee et al. 2013
Zwaan & Prochaska 2005
Martin et al. 2010
Braun 2012
Delhaize et al. 2013
Lah et al. 2007
Rao et al. 2006
Noterdaeme et al. 2012
Songaila and Cowie 2010
$\Omega_{HI} \propto (1+z)^{0.6}$
$\Omega_{HI} \times 10^3$
$\rho_{HI} \times 10^{-8}$ ($M_\odot/Mpc^3$)
0.0 0.5 1.0 1.5 2.0
0.0 0.5 1.0 1.5 2.0 2.5
0 1 2 3 4 5
Redshift



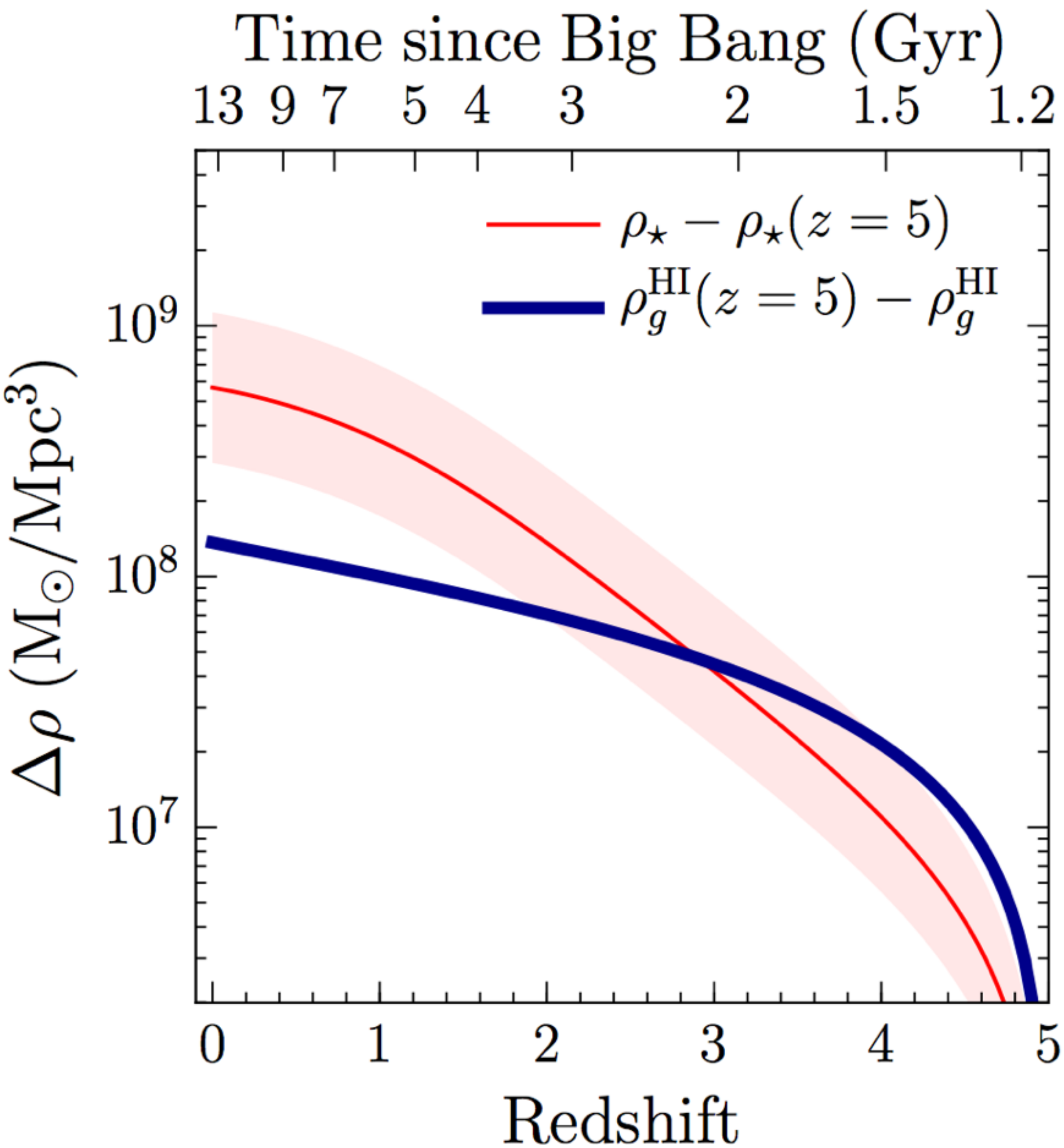
Madau+ 2014



HI is a short-lived buffer, not a large reservoir.

Is the IGM driving star formation?

See also Peroux+ 2003, Prochaska+ 2005, Dave+ 2013, Zafar+ 2013



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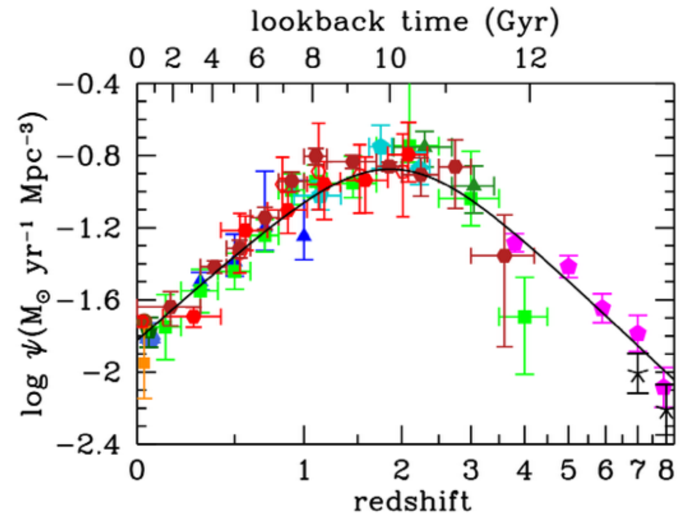

HI is a short-lived buffer, not a large reservoir.

Is the IGM driving star formation?

YES!

See also Peroux+ 2003, Prochaska+ 2005, Dave+ 2013, Zafar+ 2013

Summary

We assemble the largest survey of DLAs at z~5, and measure the cosmological HI mass density.

Systematic uncertainties do not significantly affect our results.

Theoretical models do not currently match the observations.

The HI mass density consistent with a gradual decrease from z=5.5 to z=0, and we interpret the HI phase as a short-lived ‘buffer’.