Evolution of the cosmological mass density of neutral gas from the SDSS

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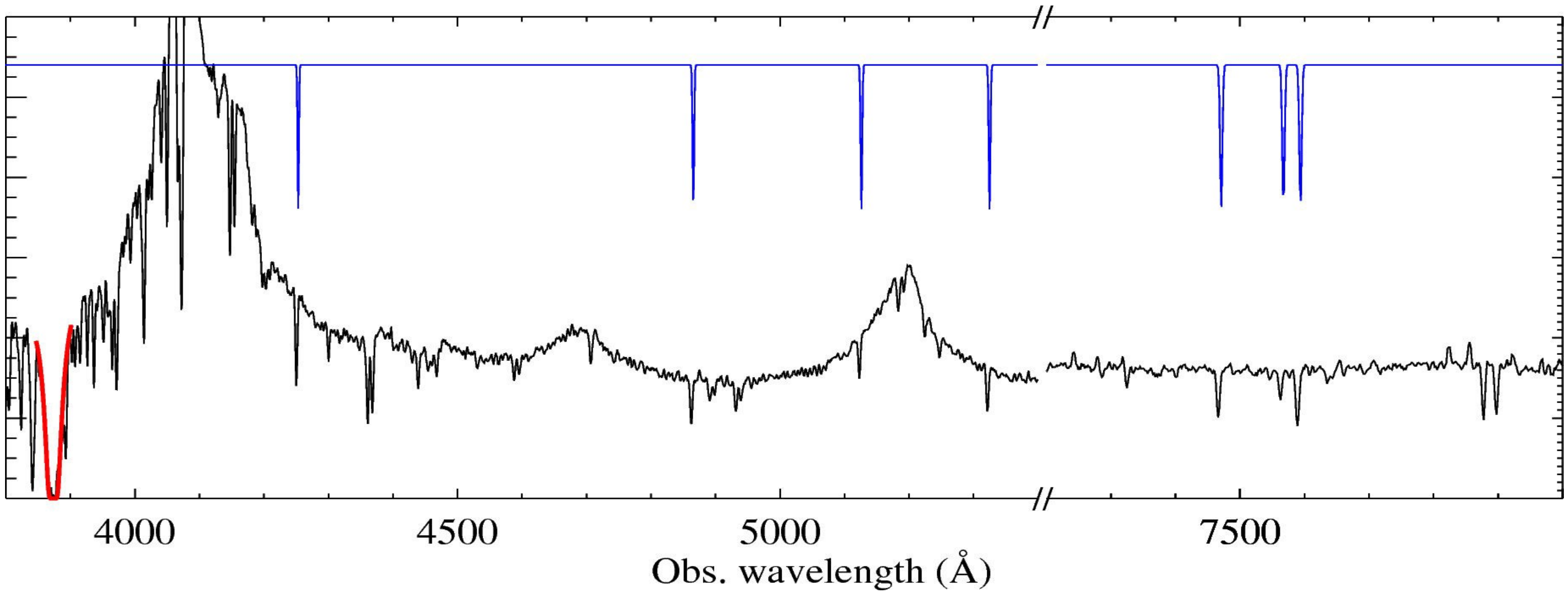
How is neutral gas traced?

z~0: 21-cm (Rao & Briggs 1993, Zwaan et al. 2005a,b)

z~1: MgII-selected DLAs (Rao et al. 2005,2006)

z>1.6: Damped Lyman-α systems (Wolfe et al. 1986, Turnshek et al. 1989, Wolfe et al. 1993, Lanzetta et al. 1991, Wolfe et al. 1995, Lanzetta et al. 1995, Storrie-Lombardie et al. 1996a,b Storrie-Lombardi & Wolfe 2000, Ellison et al. 2001, Péroux et al. 2001, Péroux et al. 2003, Prochaska & Herbert-Fort 2004, Smette et al. 2005, Prochaska et al. 2005, Prochaska & Wolfe 2009, Guimaraes et al. 2009, this work)

Fully automatic search for DLAs in SDSS



DLAs: log N(HI) ≥ 20.3 (Wolfe et al 1986) ---> EW_r ≥ 10 angstrom

SDSS resolution (1800) is sufficient to both detect DLA and measure N(HI)

SDSS: more than 10 000 spectra of z>2.2 quasars

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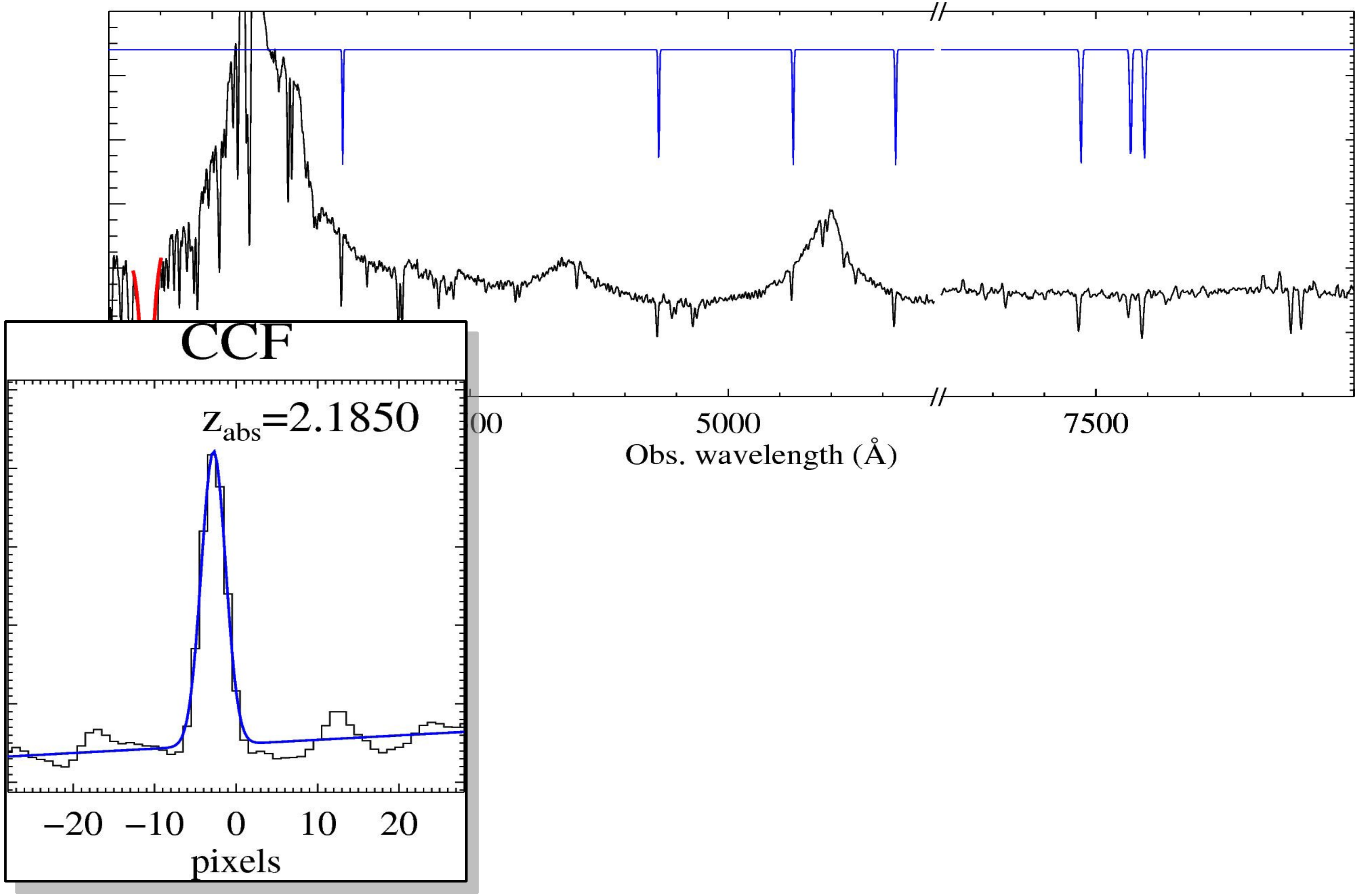

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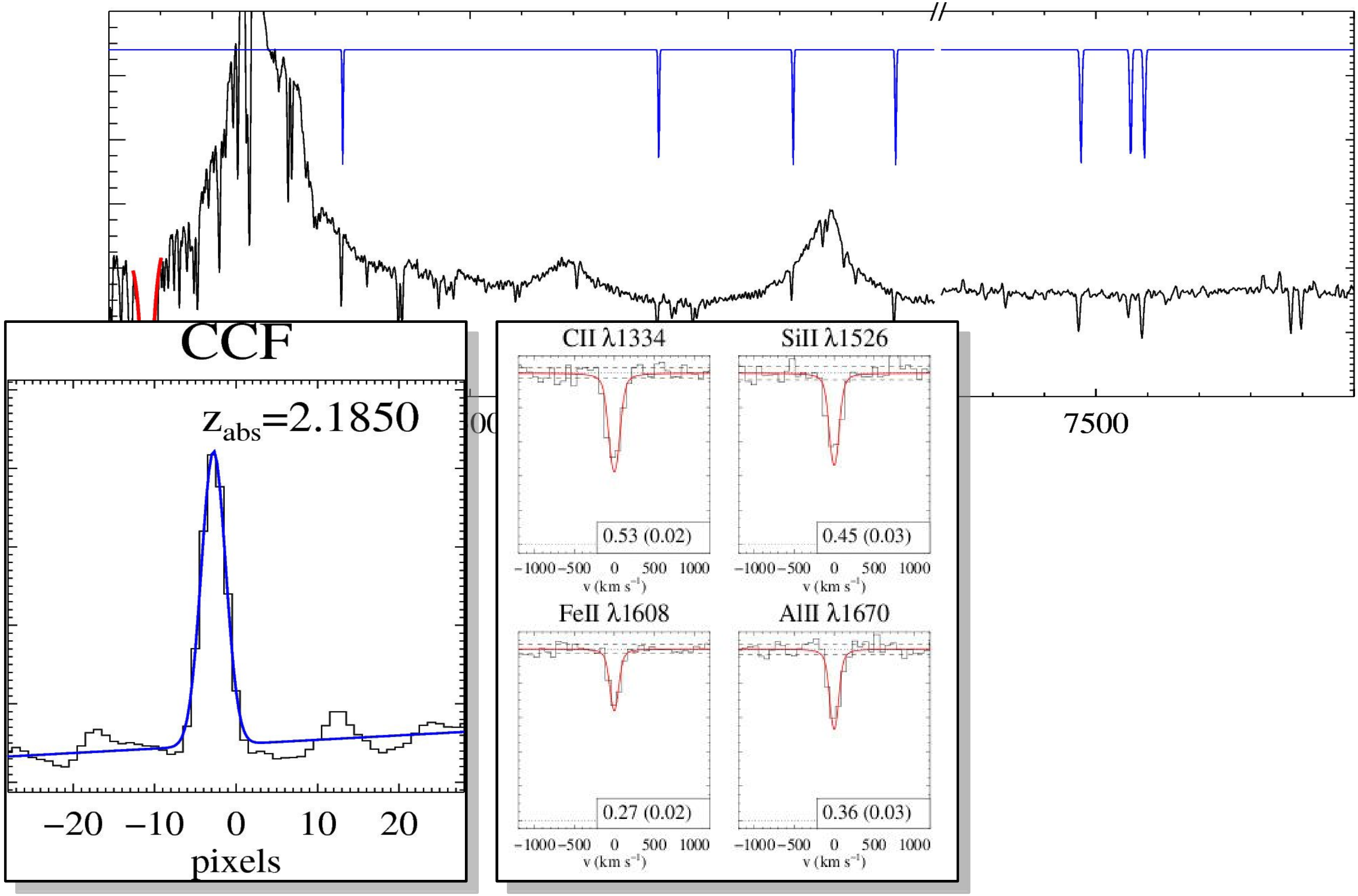

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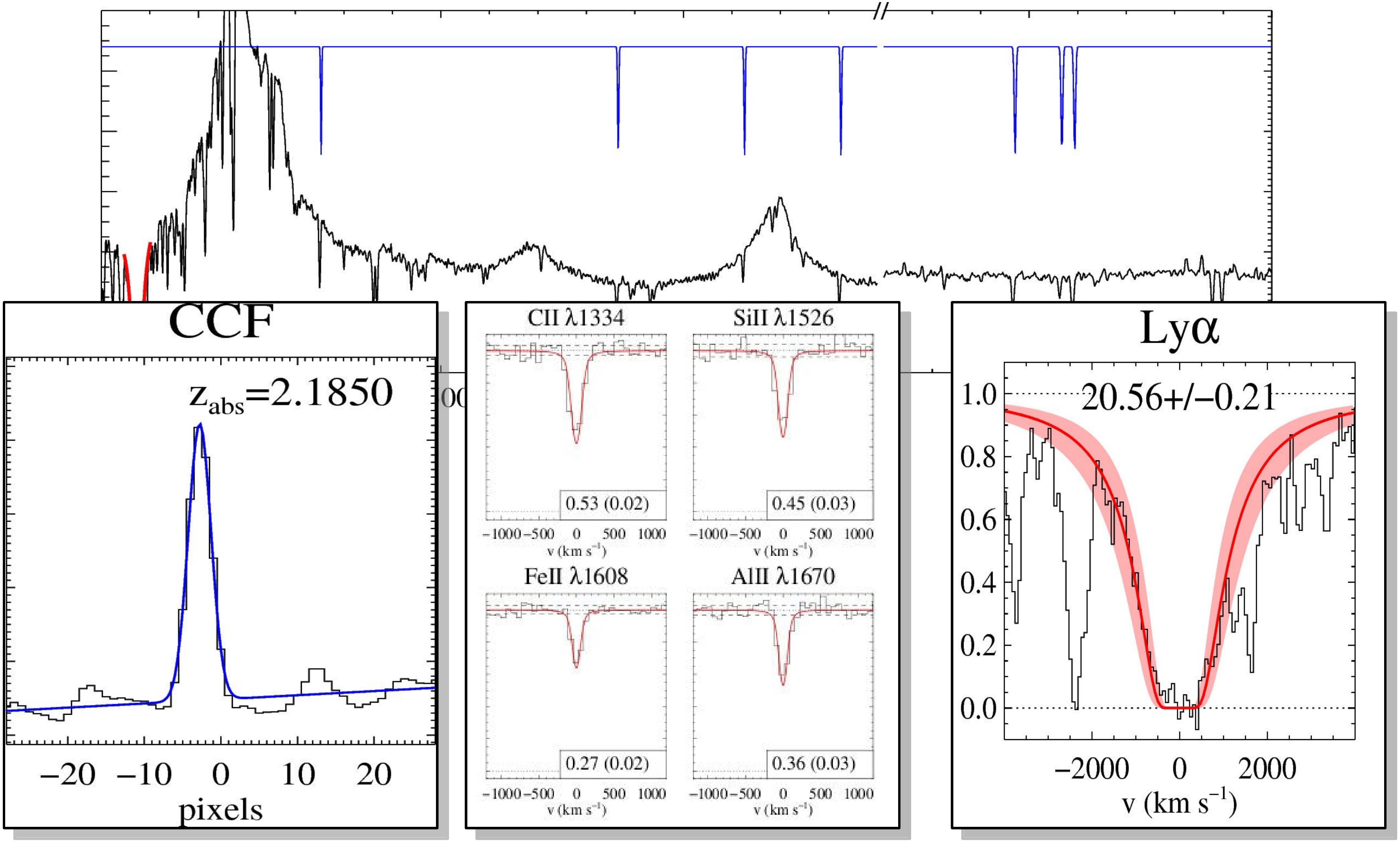


Fully automatic search for DLAs in SDSS

- About a thousand DLAs discovered in the SDSS II – DR7: the largest database to date

Cosmological mass density of neutral gas:

$$\Omega_{DLA} \propto n\sigma l\rho \qquad \Omega_{DLA} \propto N(\mathrm{H\,I})dN/dX$$

$$\Omega_g^{neut.}(X)dX = \frac{\mathrm{H}_0}{c}\frac{\mu m_\mathrm{H}}{\rho_c}\int_{N_{min}}^{N_{max}} N(\mathrm{H\,I})f_{\mathrm{H\,I}}(N,X)dNdX$$

$$\Omega_g^{\mathrm{DLA}}(X) = \frac{\mathrm{H}_0}{c}\frac{\mu m_\mathrm{H}}{\rho_c}\frac{\sum_{N(\mathrm{H\,I})\geq N_{min}} N(\mathrm{H\,I})}{\Delta X}$$

Absorption distance:

$$X(z) = \int_0^z (1+z')^2 \frac{\mathrm{H}_0}{\mathrm{H}(z')dz'}$$

$$\mathrm{H}(z) = \mathrm{H}_0\sqrt{(1+z)^3\Omega_m - (1+z)^2(\Omega_m+\Omega_\Lambda-1)+\Omega_\Lambda}$$

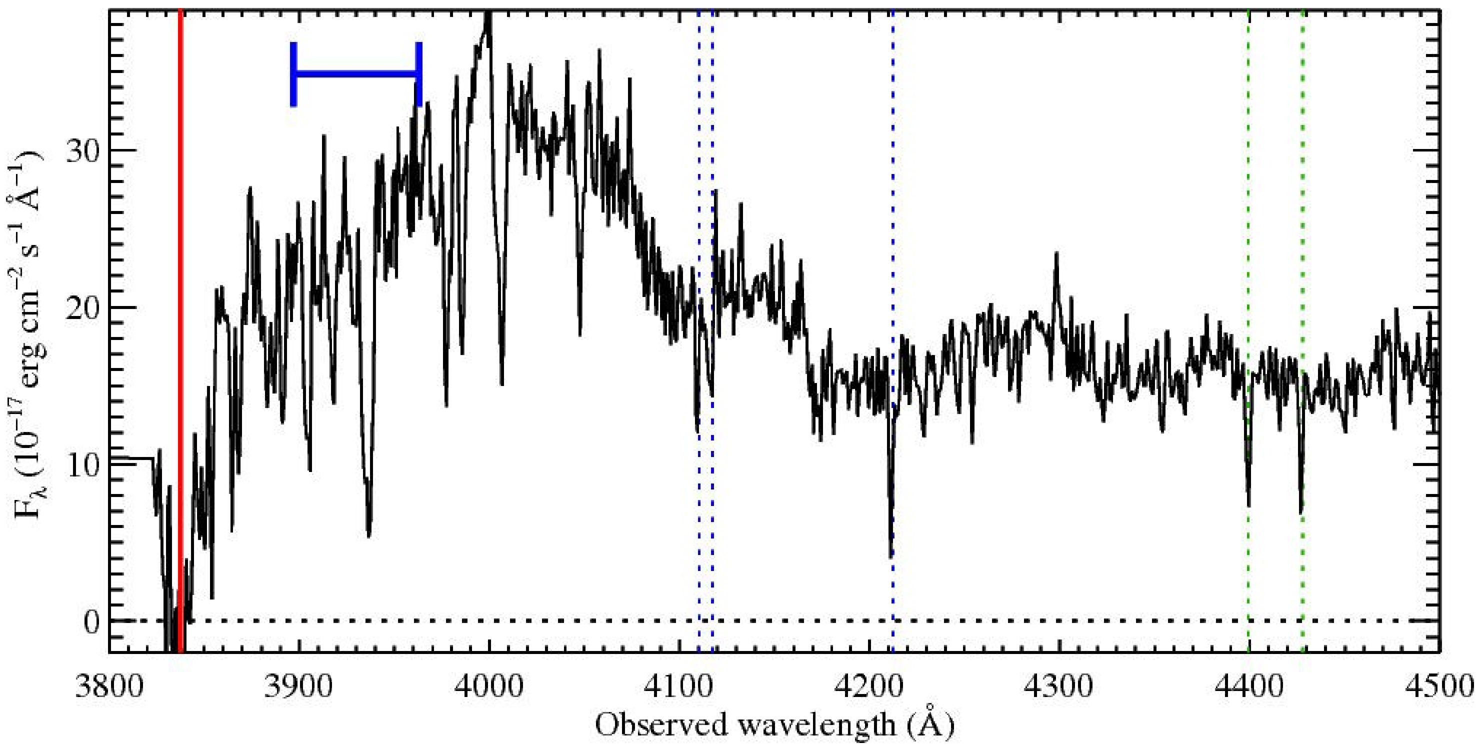
For each line of sight:

In the red: zmax a few thousand km/s from quasar

In the blue: zmin defined when SNR reaches sufficient value

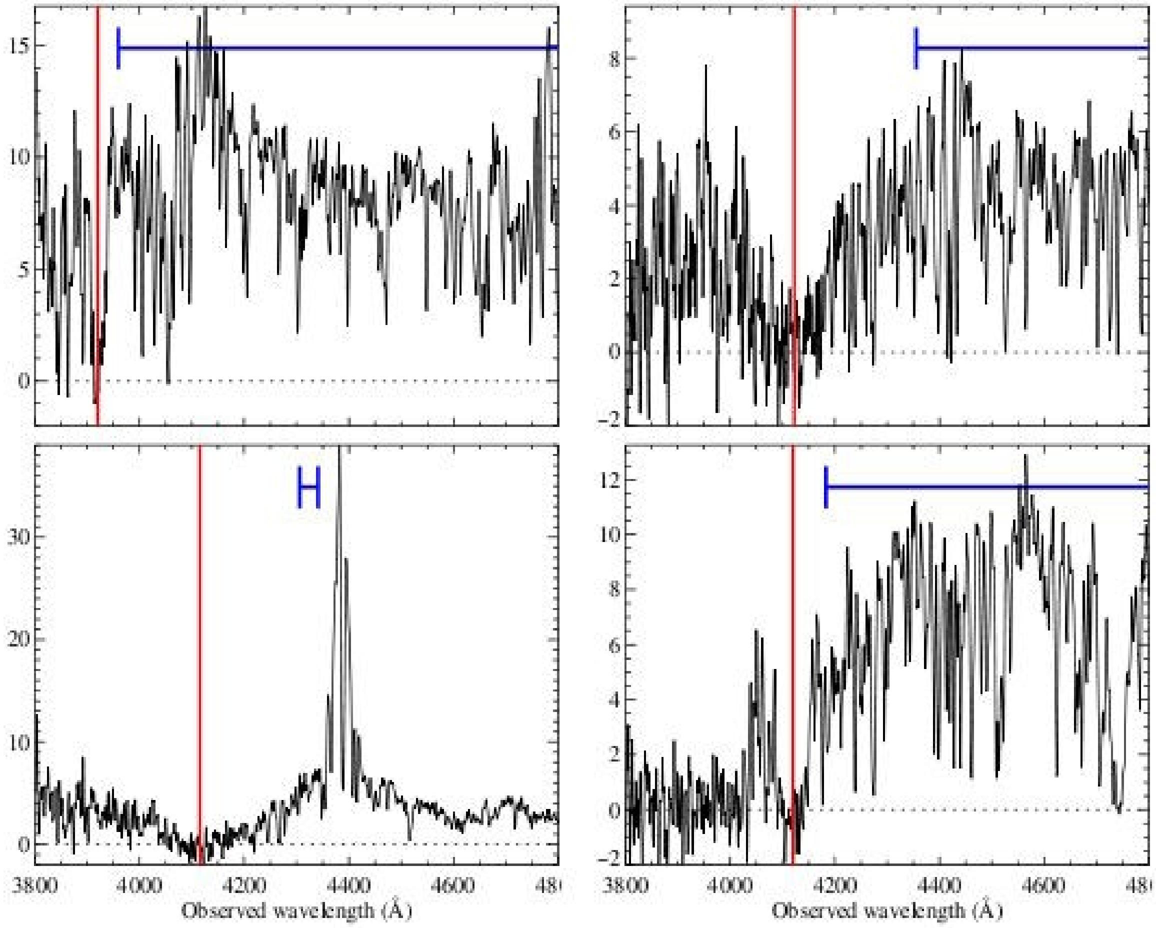
Evidence for a bias

What happens if a DLA is present at the blue end of the spectrum?

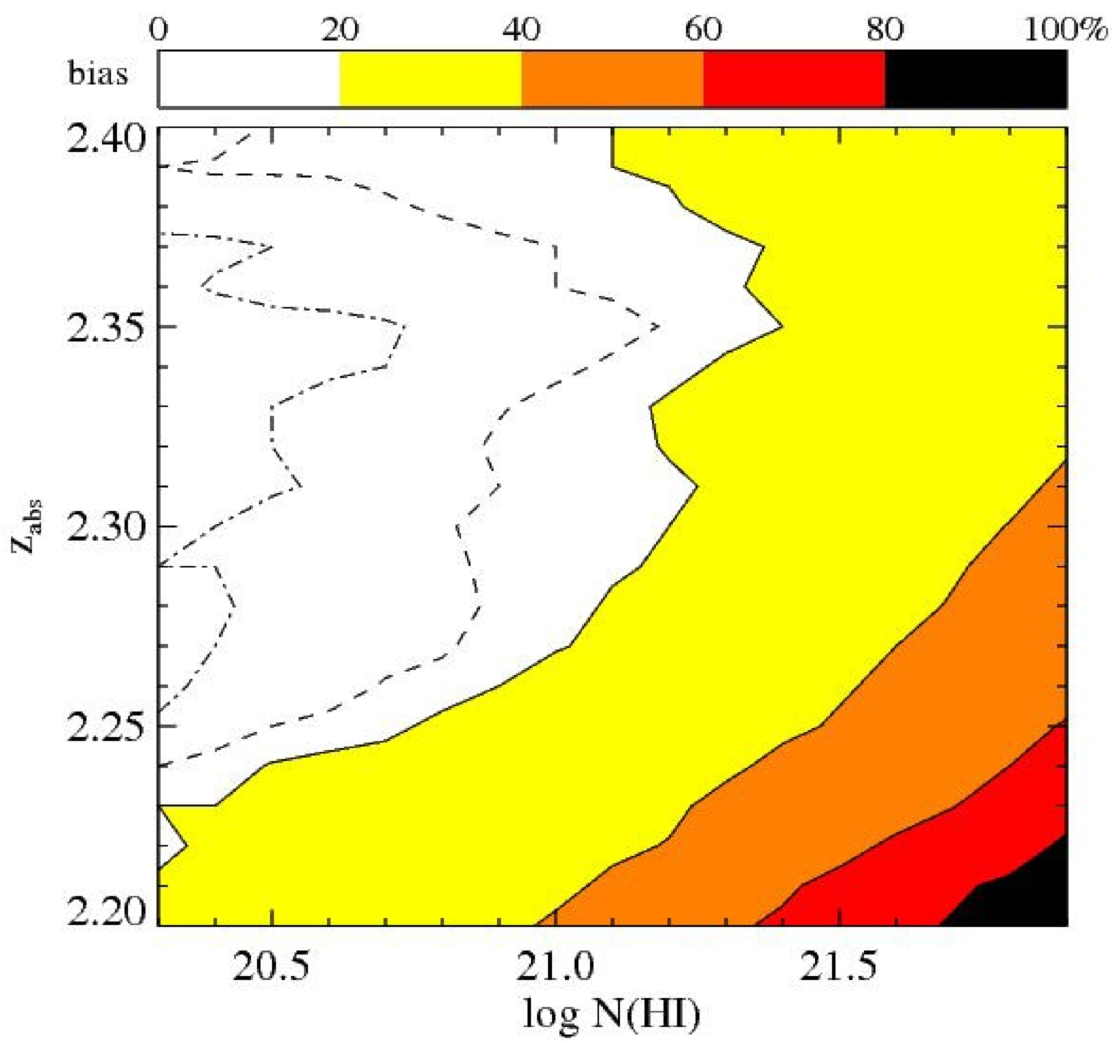


Z_{min} set redwards of DLA

Evidence for a bias



Evidence for a bias

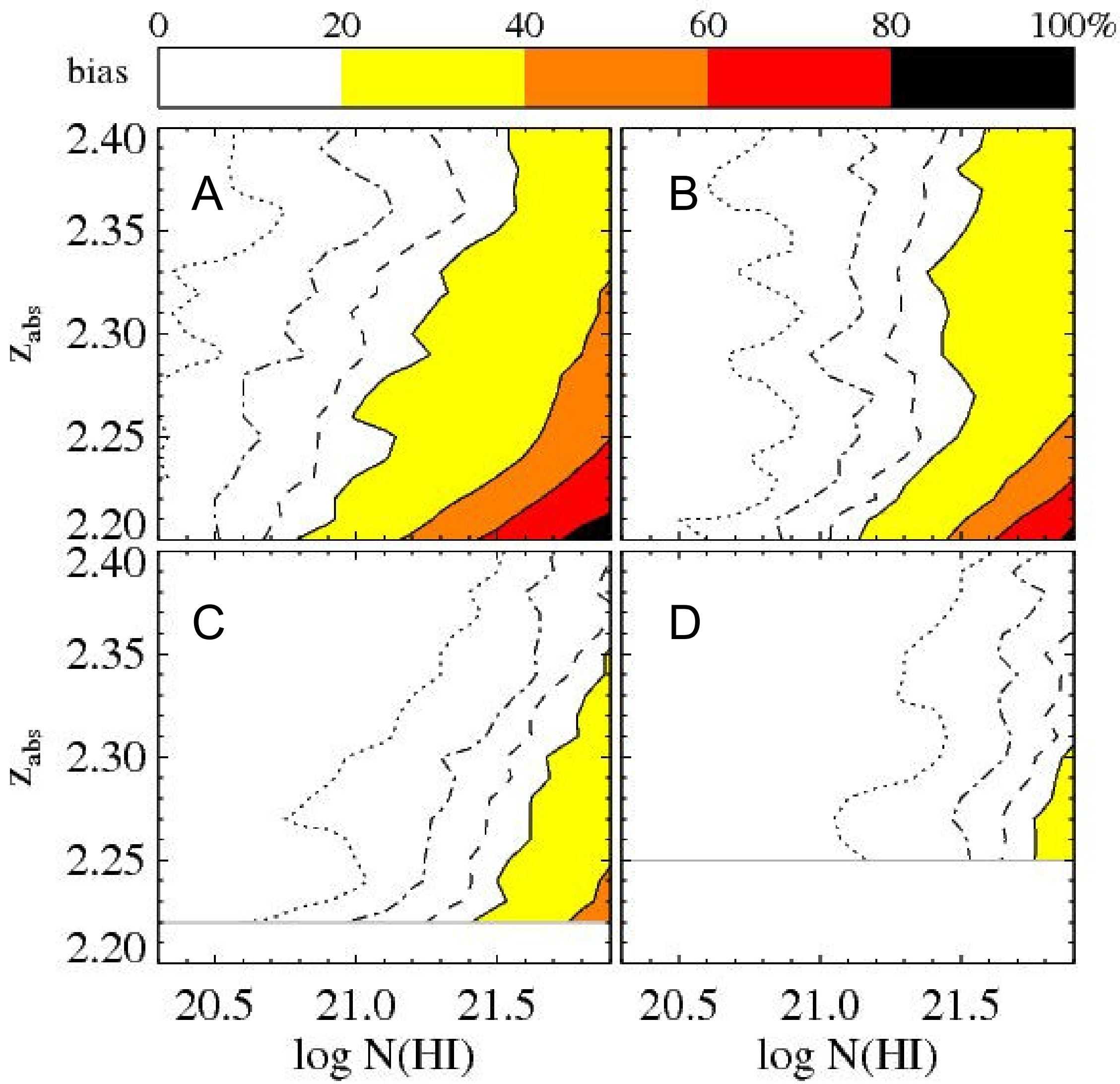


Fraction of DLAs missed

Bias is more severe when

- z_{abs} is low : we are closer to the edge of the spectrum
- N(HI) is large: the signal-to-noise ratio is decreased over a large velocity range

Avoiding the bias



Apply a shift to zmin, independently of the presence of a DLA

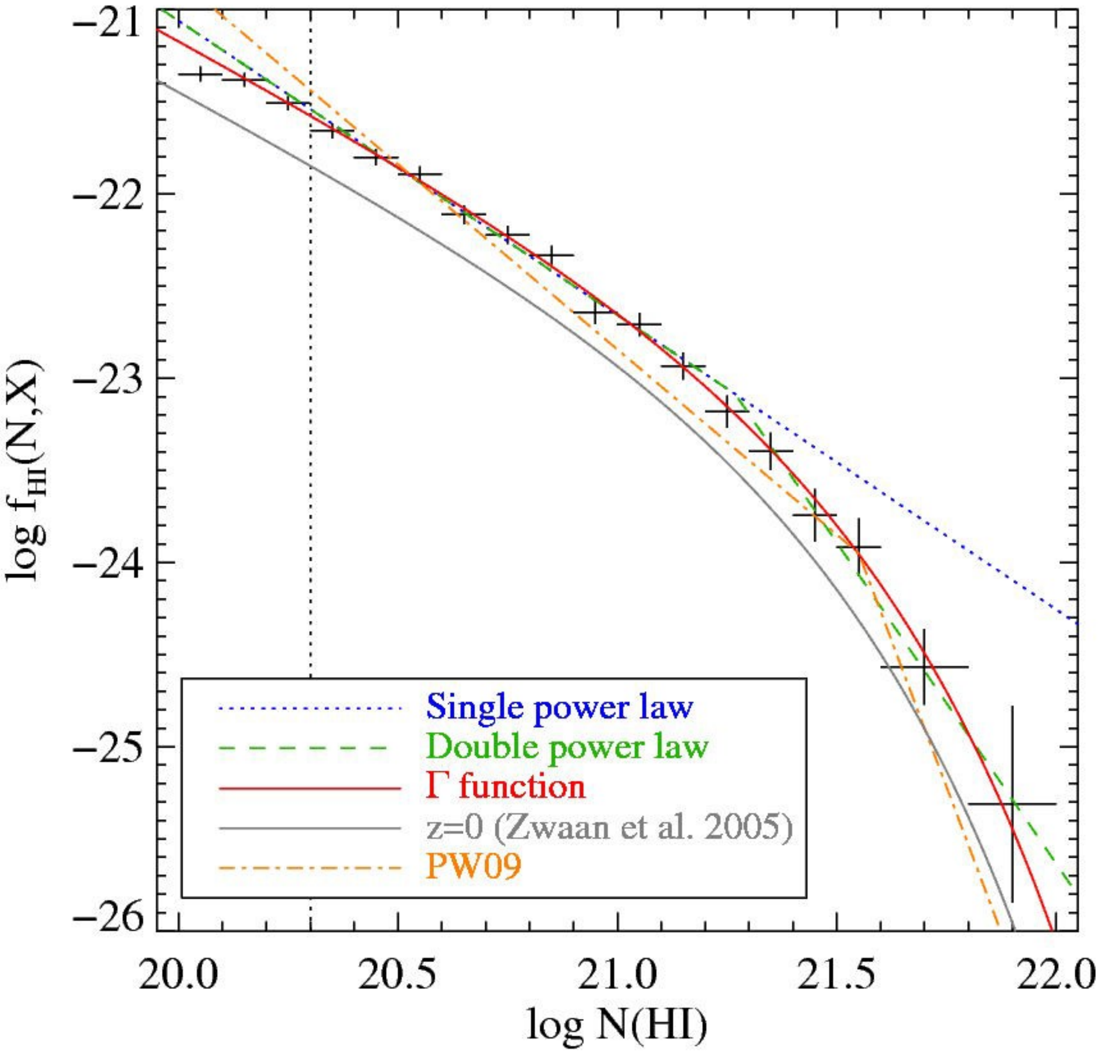
$$z_{\min} = z^0_{\min} + \frac{\delta v}{c}(1 + z^0_{\min}).$$

Good news: the bias can be avoided

Bad news : we loose some statistics at lowest z

A: 2500 km/s, B:5000 km/s,
C: 7500 km/s, D:10 000 km/s

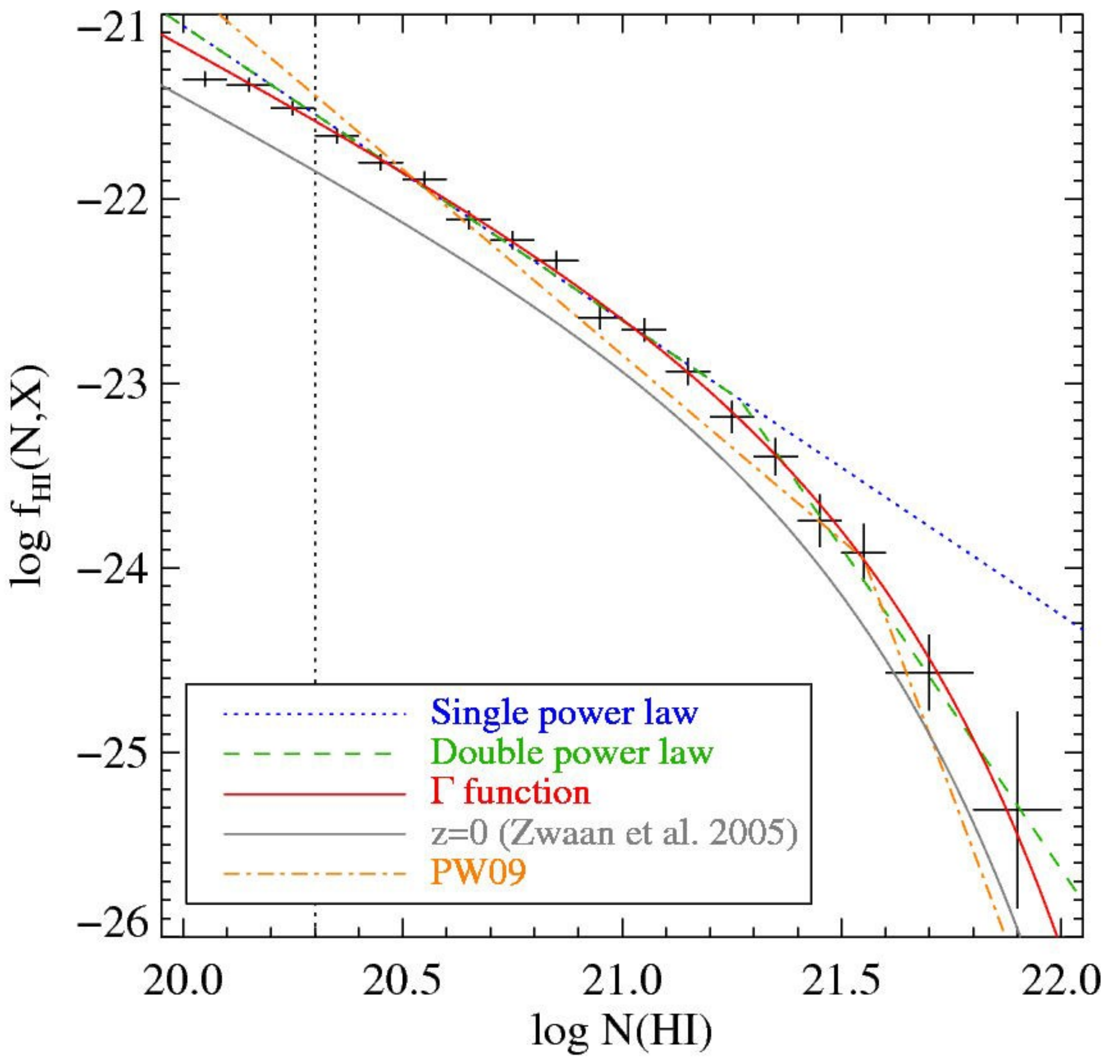
The HI frequency distribution



- steep slope at large N(HI)

- flattening at small N(HI)

The HI frequency distribution



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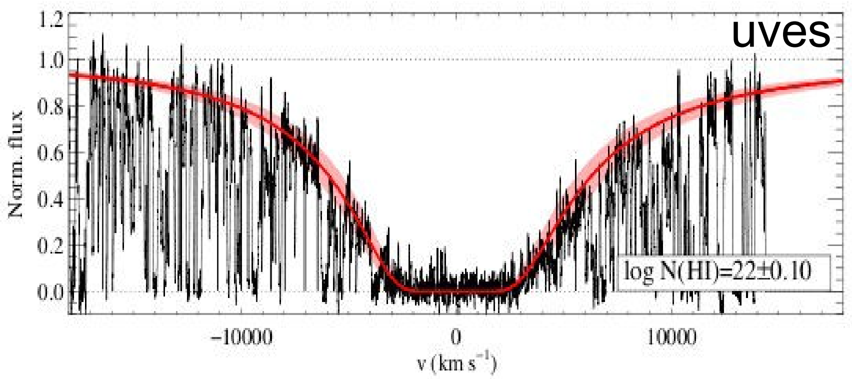
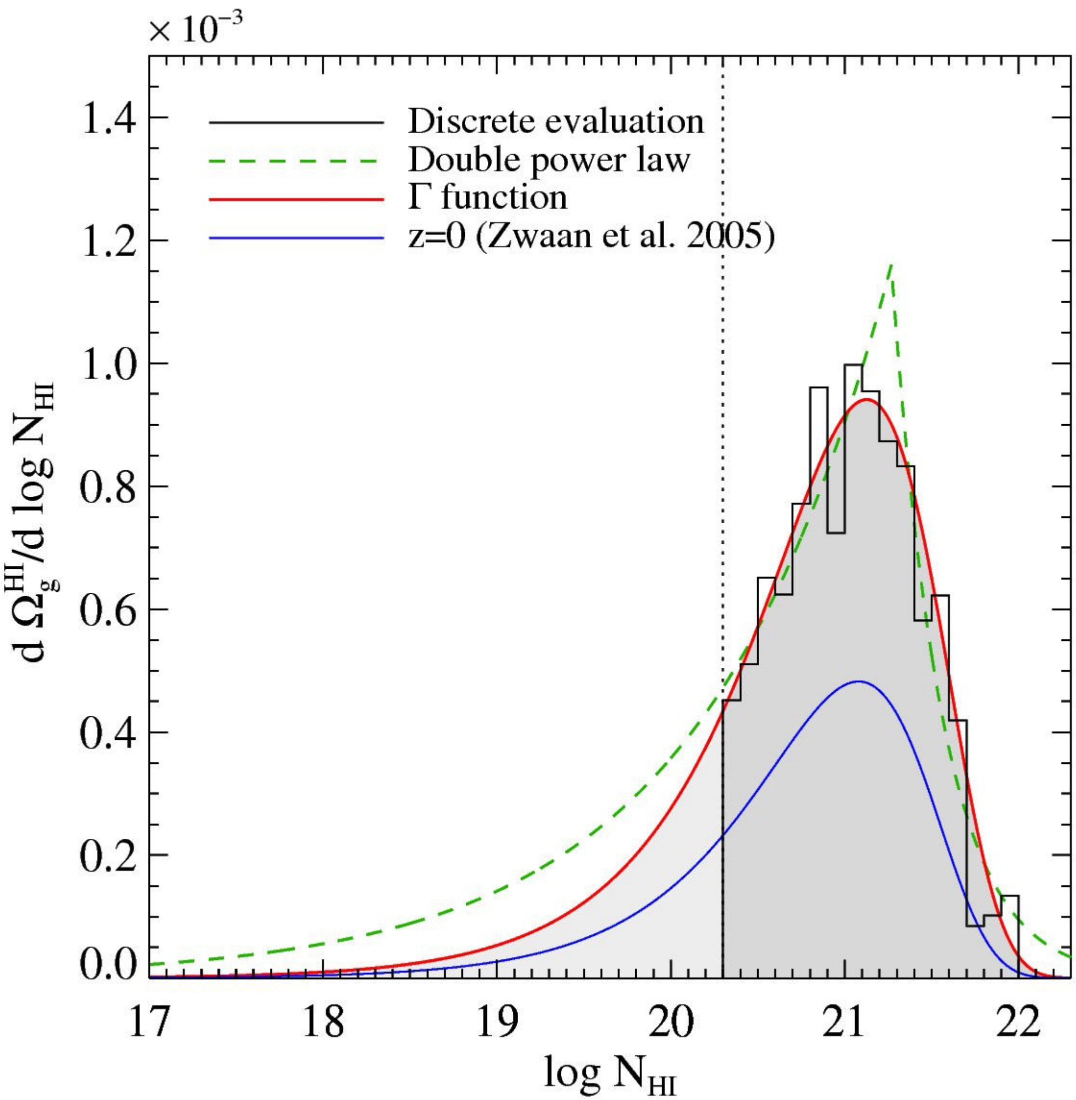


Discovery of the largest N(HI) DLA along QSO line of sight

- flattening at small N(HI)

The HI frequency distribution



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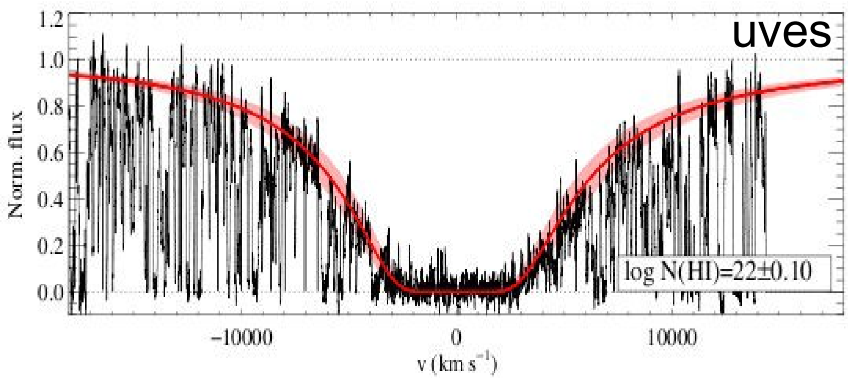
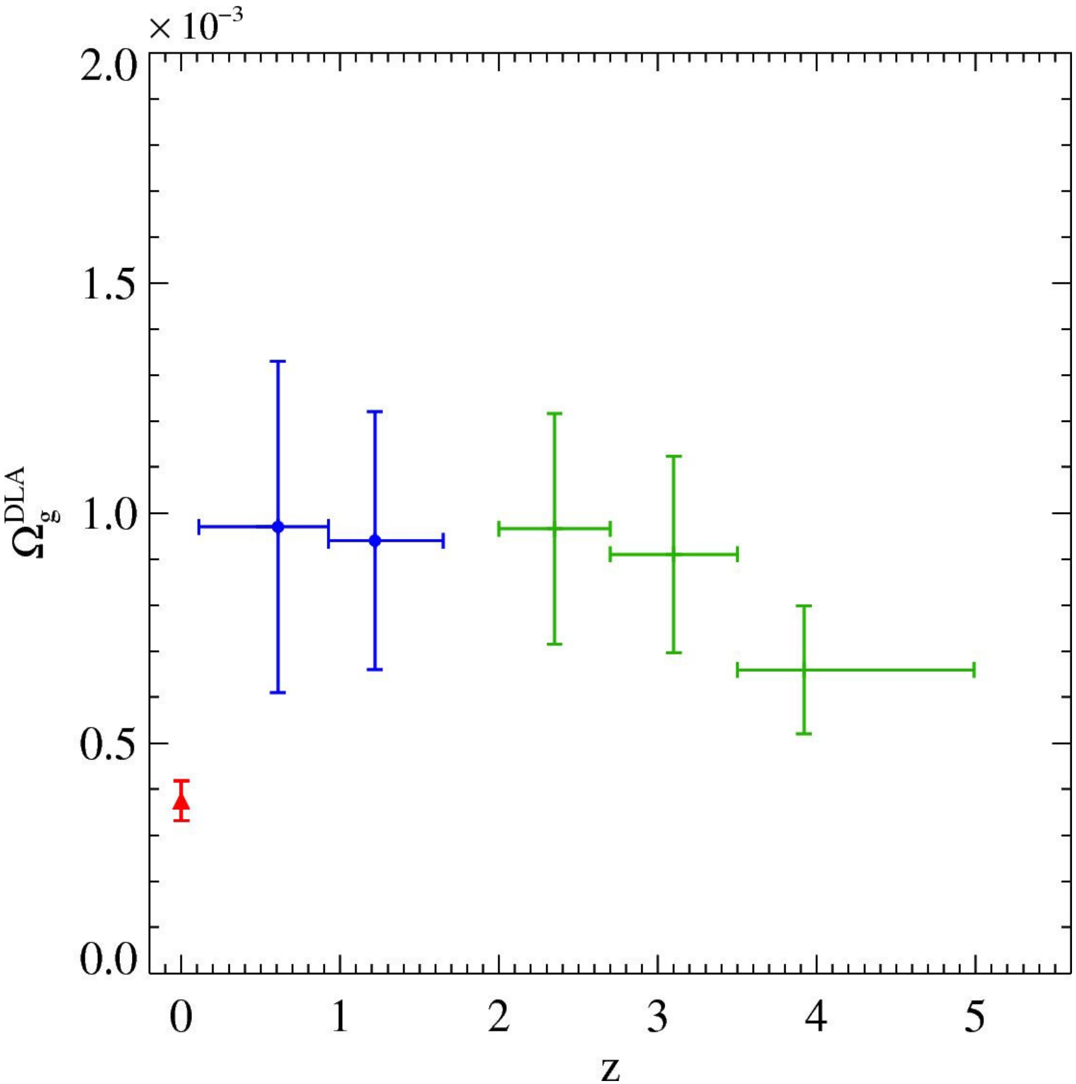


Discovery of the largest N(HI) DLA along QSO line of sight

- flattening at small N(HI)
  (see also Péroux et al. 2005)

Sub-DLAs contribute ~20% of neutral gas

The cosmological mass density of neutral gas



$$\Omega_g^{\rm DLA}(X) = \frac{\rm H_0}{c}\frac{\mu m_{\rm H}}{\rho_c}\frac{\sum_{N(\rm H\,I)\geq N_{min}} N(\rm H\,I)}{\Delta X}$$

Zwaan et al. 2005 (21cm)

Rao et al. 2006 (MgII)

Péroux et al. 2003 (DLAs)

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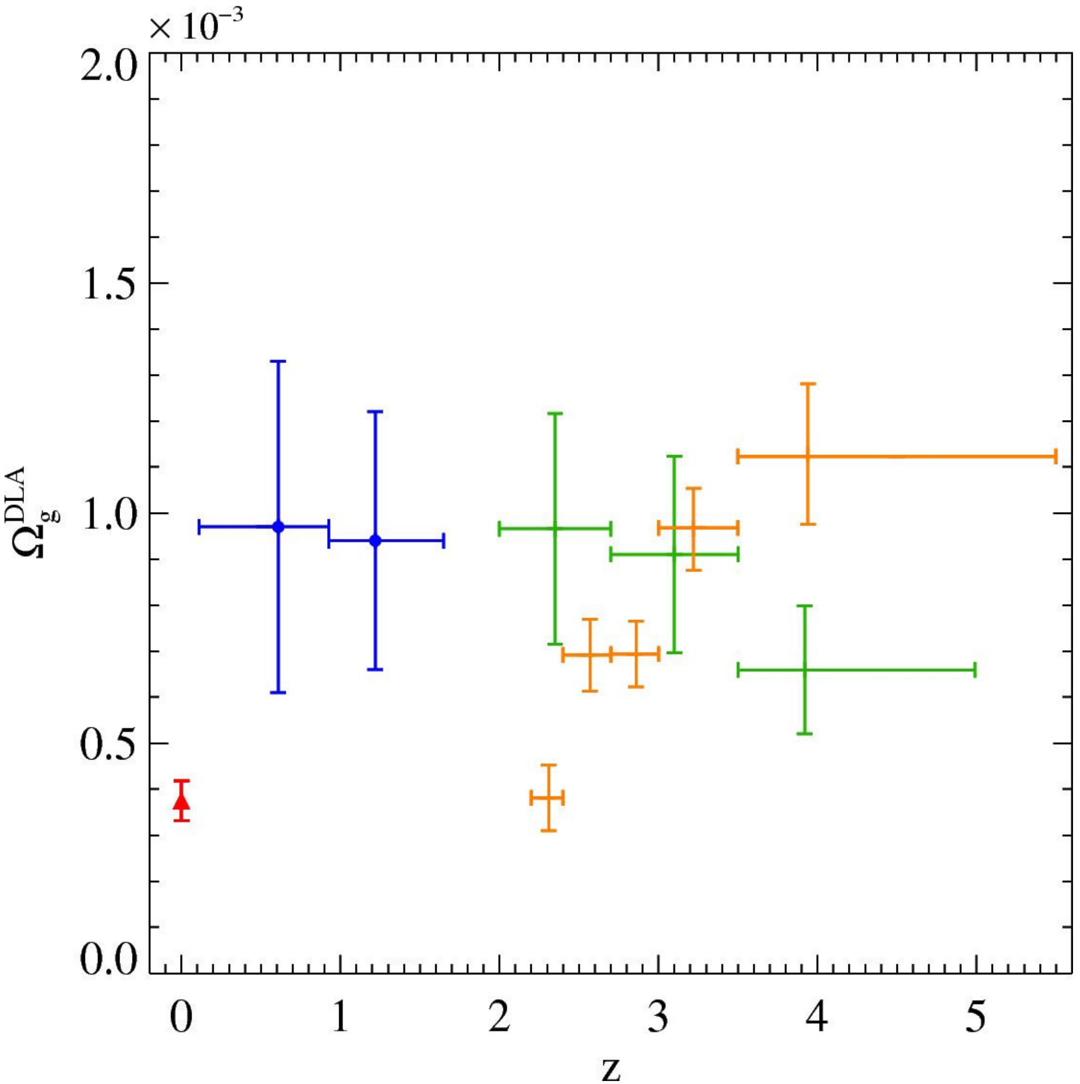

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Prochaska & Wolfe. 2009

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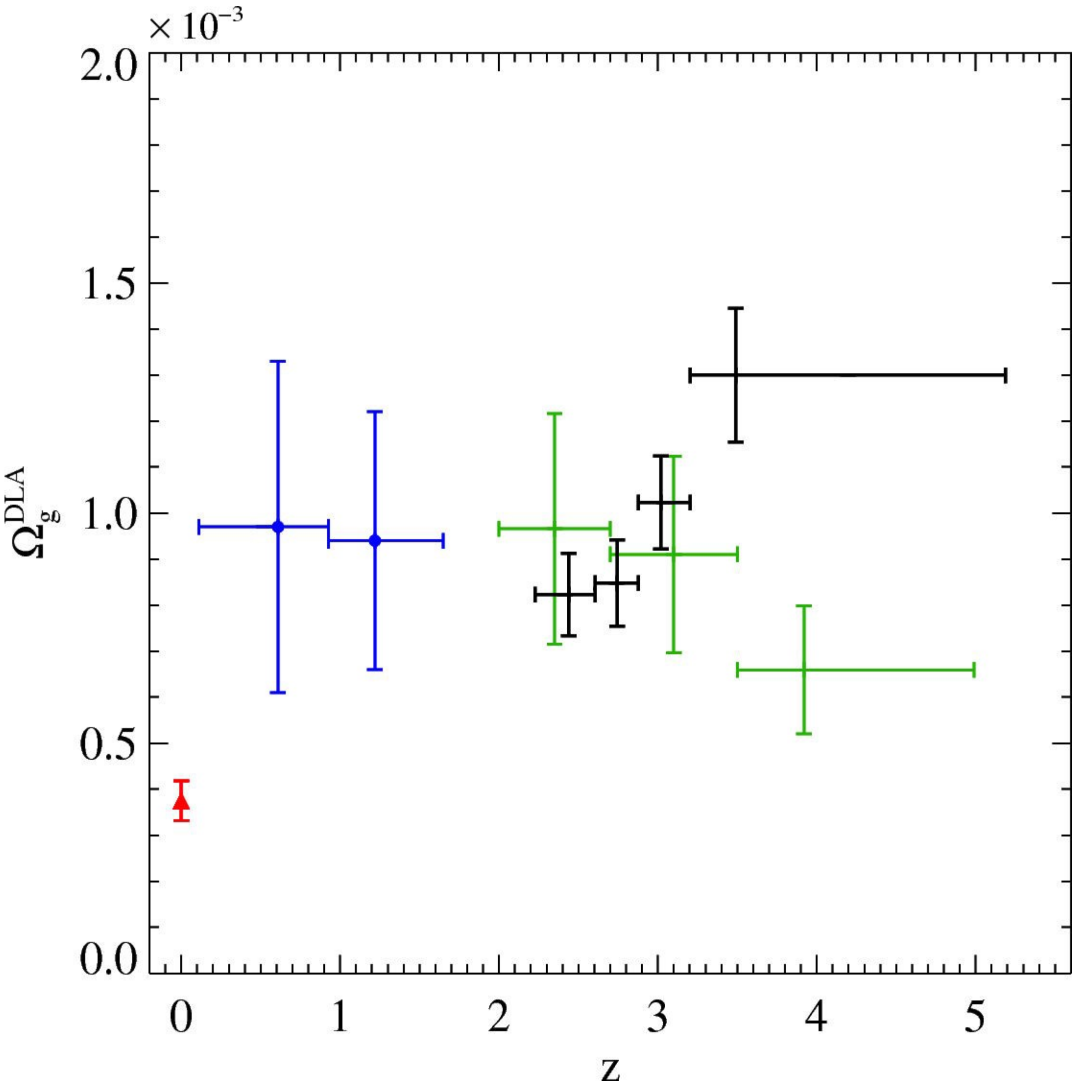

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This work

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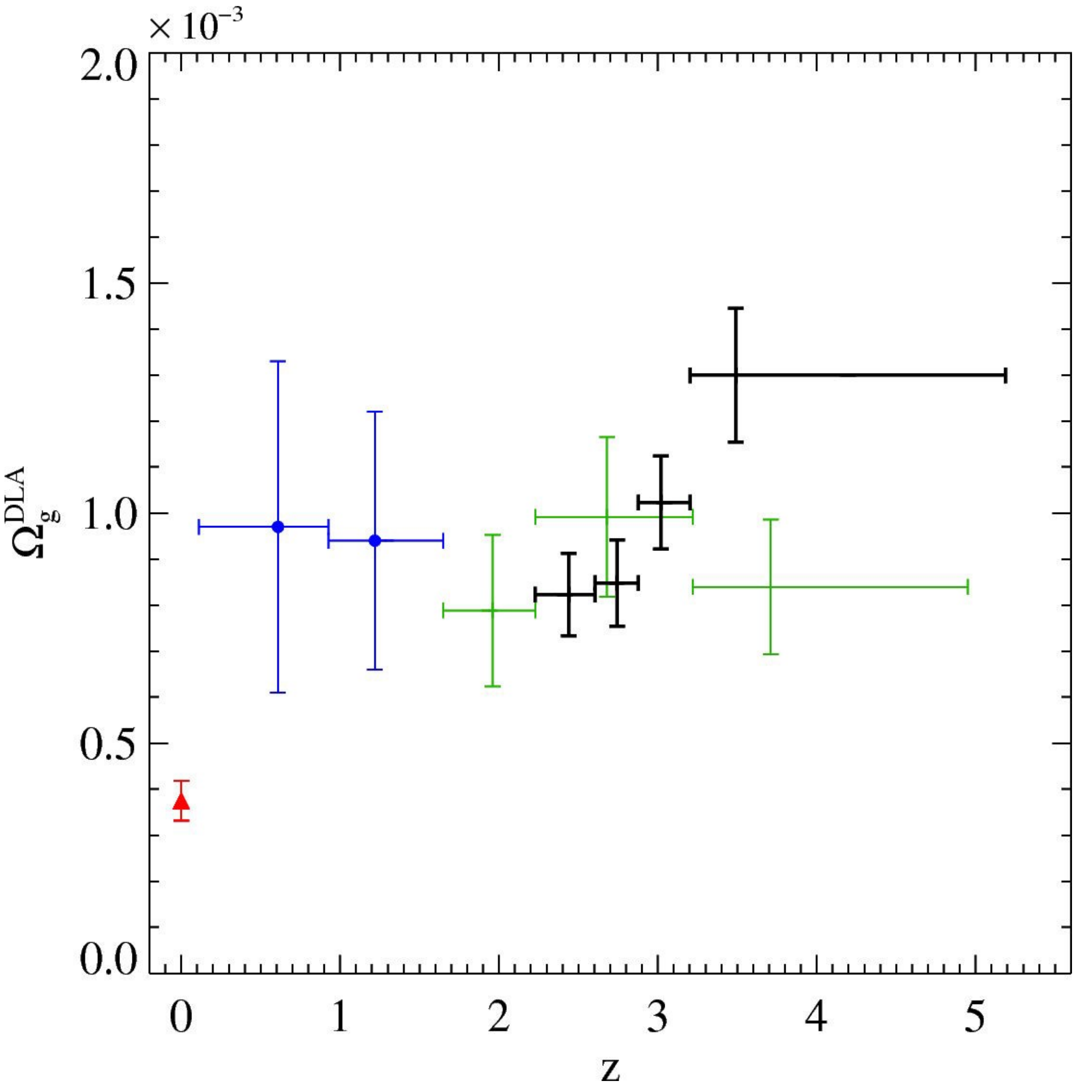

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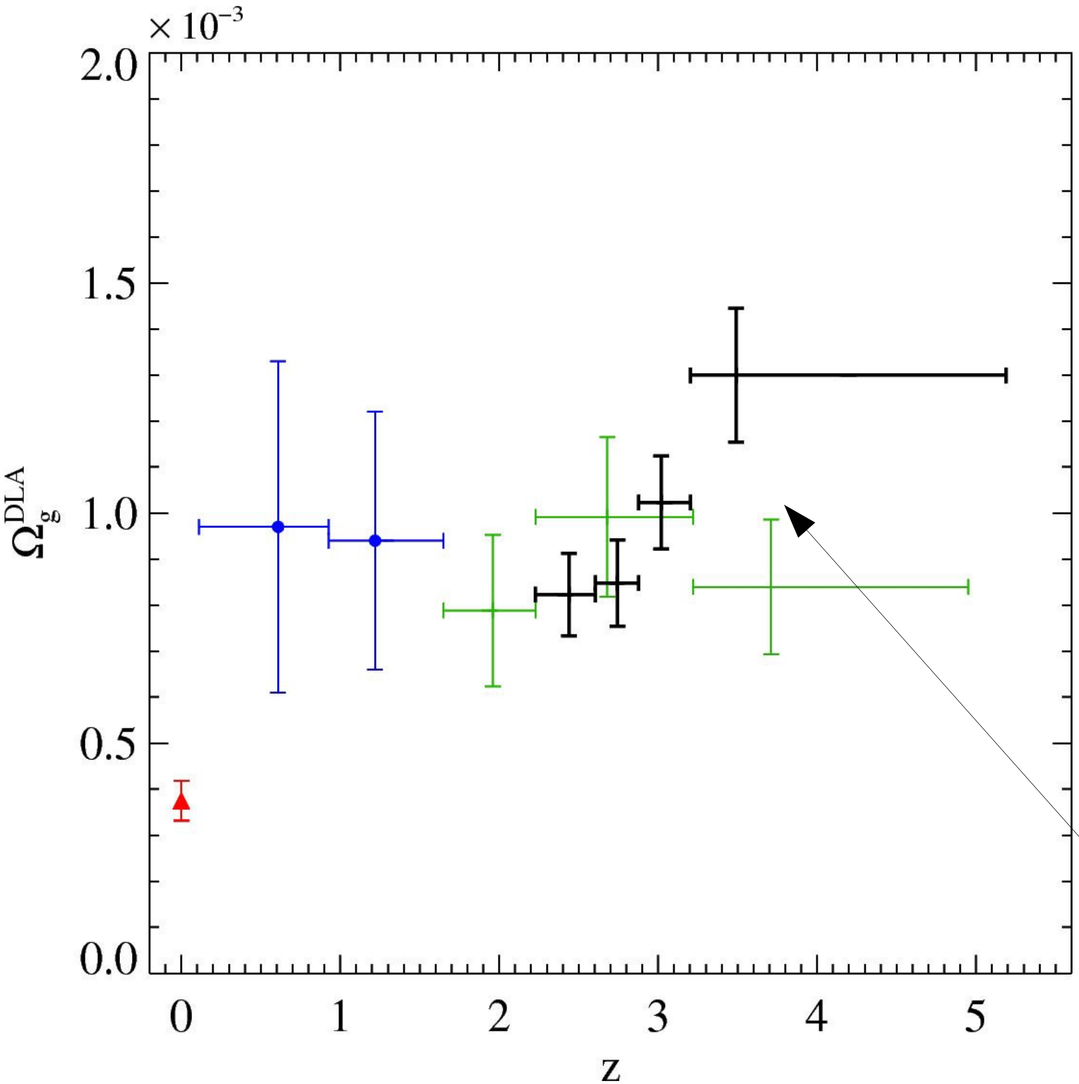

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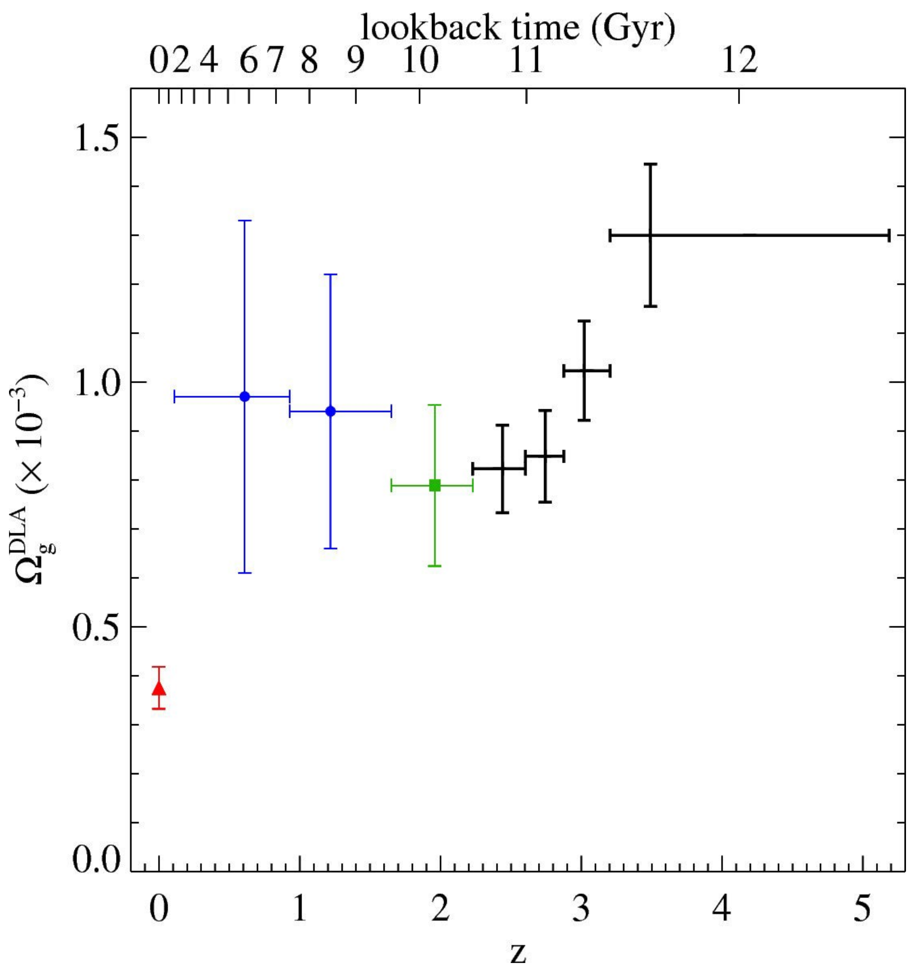
R. Guimaraes et al. 2009, see poster

Conclusion



Fully automatic search and analysis are feasible

Presence of bias that can be avoided

N(HI) frequency distribution now well constrained at large column densities.

Sub-DLAs account for ~20% of neutral gas.

Ω_g^{DLA} decreases from z~3.2 to z~2.2

Neutral gas mass density at z=2.2 twice that at z=0

Amount of baryons in DLAs at all z is less than the amount of baryons in stars at z=0

z~1 and z>4 (Guimaraes et al. 2009)