Statistics of optically thick IGM absorbers – Lessons learnt from SDSS

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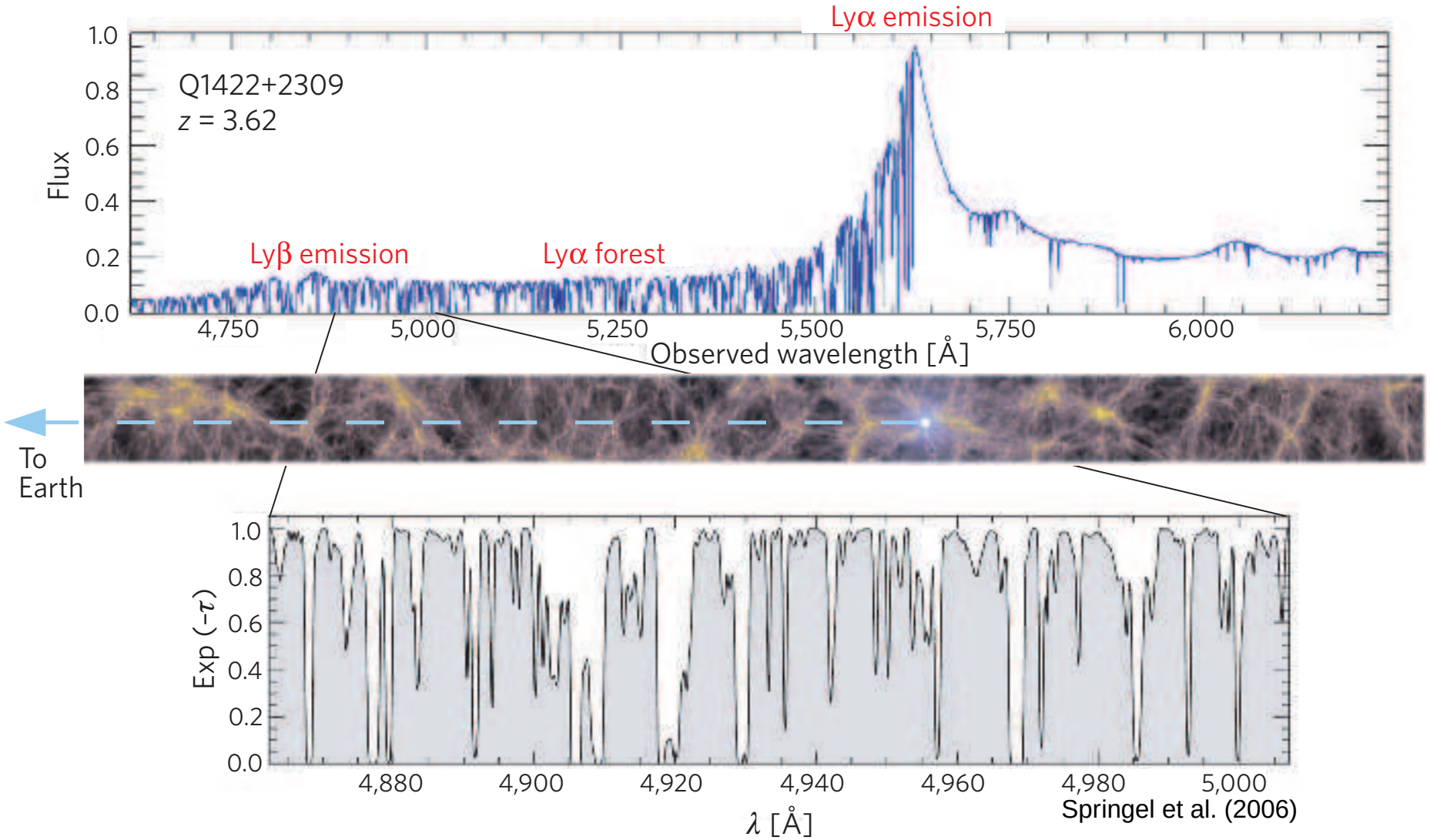
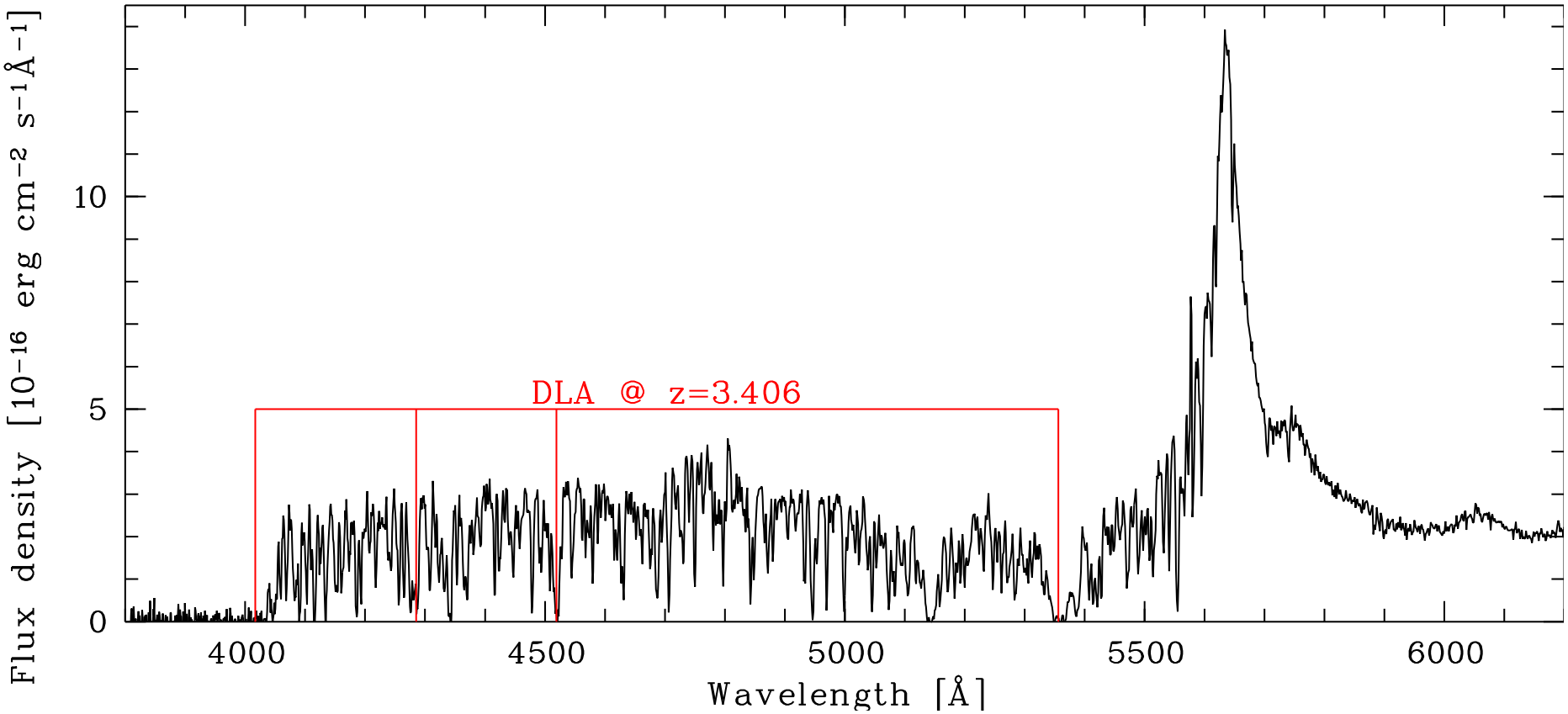
Quasars probe the intergalactic medium



Springel et al. (2006)

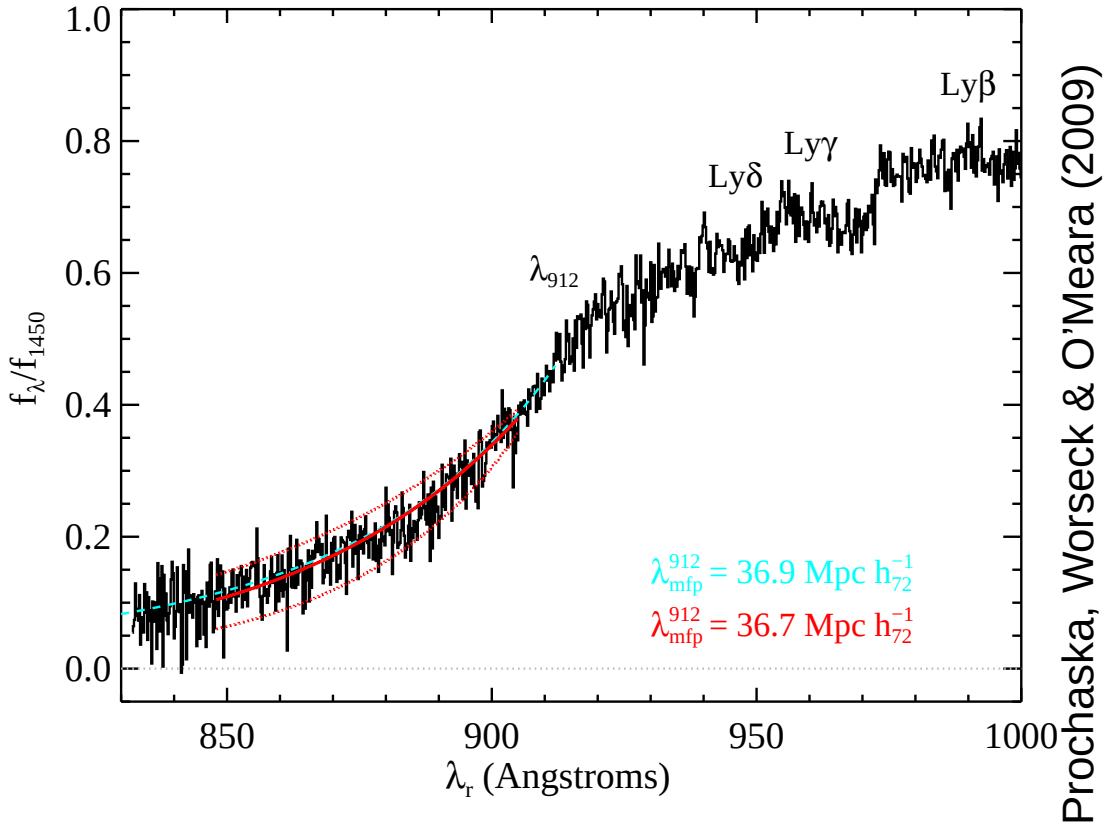
SDSS: Statistics of rare absorbers

- DLAs ($\log(N_{\mathrm{H\,I}}) \geq 20.3$) rare but easy to identify
- SLLS ($19 \leq \log(N_{\mathrm{H\,I}}) < 20.3$) less rare but quite easy to identify
- LLS ($17.2 \leq \log(N_{\mathrm{H\,I}}) < 19$) numerous but hard to identify



Stacked spectra: The mean free path of H I ionizing photons

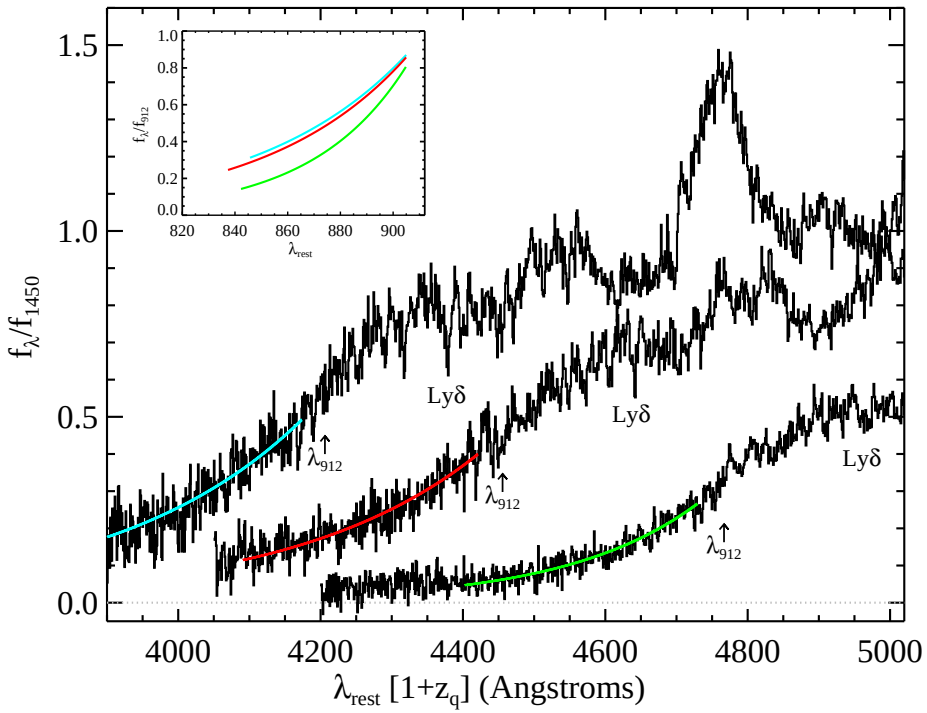
- $\tau_{\mathrm{eff,LL}}\left(z_{\mathrm{obs}}, z_{\mathrm{em}}\right) = \int_{z_{\mathrm{obs}}}^{z_{\mathrm{em}}} \int_0^{\infty} f\left(N_{\mathrm{H\,I}}, z\right) \times \left[1 - \mathrm{e}^{-N_{\mathrm{H\,I}}\sigma_{\mathrm{LL}}(z)}\right] \mathrm{d}N_{\mathrm{H\,I}}\mathrm{d}z$
- $\tau_{\mathrm{eff,LL}}\left(z_{\mathrm{obs}}, z_{\mathrm{em}}\right) \approx \frac{c\kappa}{H_0\sqrt{\Omega_{\mathrm{m}}}}\left(1 + z_{\mathrm{obs}}\right)^3 \int_{z_{\mathrm{obs}}}^{z_{\mathrm{em}}} \left(1 + z\right)^{-11/2} \mathrm{d}z$
- mean free path: proper distance where $\tau_{\mathrm{eff,LL}} = 1$, $\lambda_{\mathrm{mfp}} = 1/\kappa$

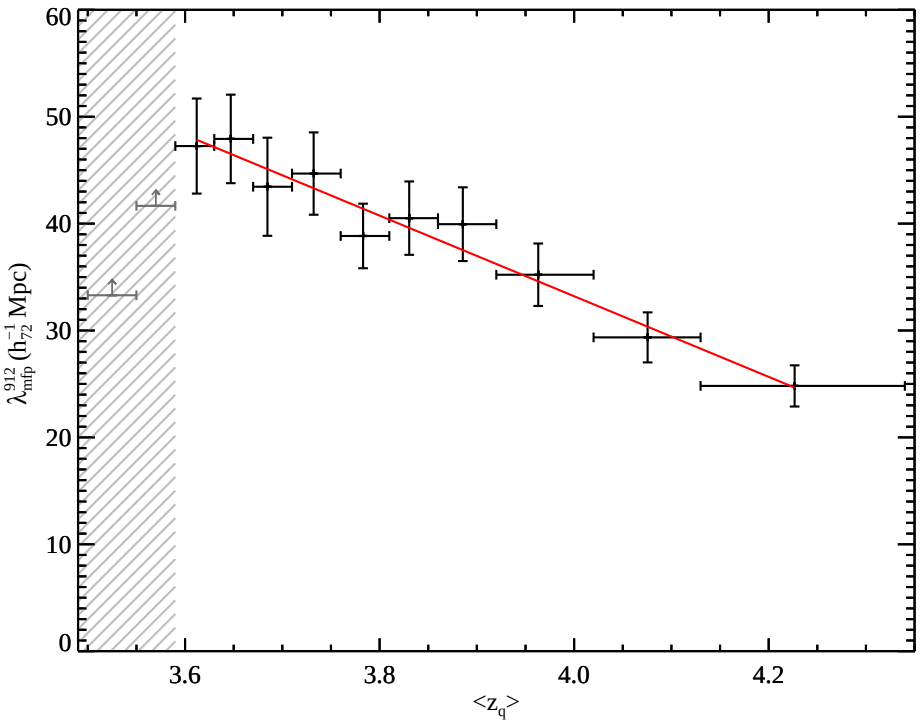


Prochaska, Worseck & O'Meara (2009)

The first direct measurement of the mean free path

- method: normalize, stack in rest frame, determine f_{912}, $\tau_{\mathrm{eff,LL}} \approx -\ln\left(f/f_{912}\right) \propto 1/\lambda_{\mathrm{mfp}}$
- 150 SDSS spectra per redshift bin

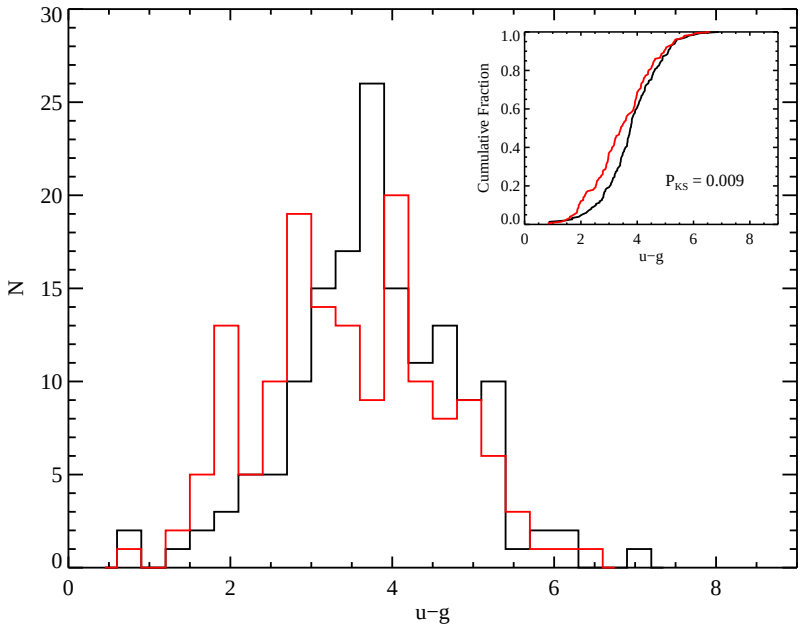


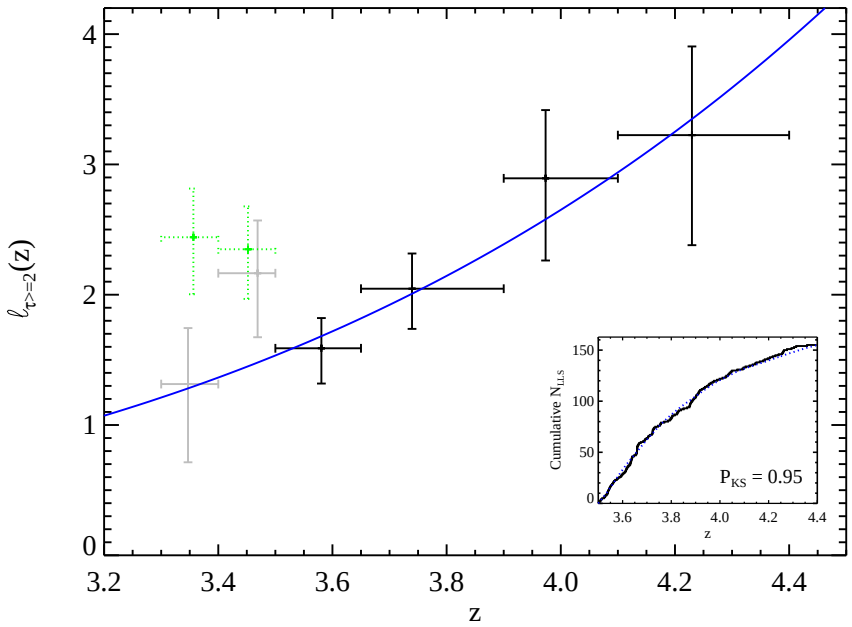


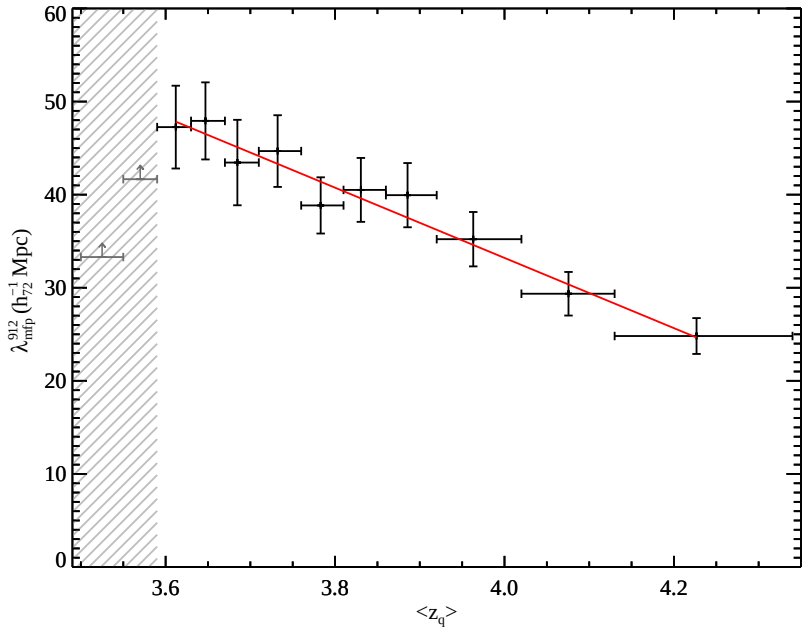
Prochaska, Worseck & O'Meara (2009)

The high abundance of Lyman limit systems at $z \lesssim 3.6$

- $\lambda_{\rm mfp}$ decreases
- incidence of Lyman limit systems increases
- quasar colors redder at $z \sim 3.5$ than at $z \sim 3.6$

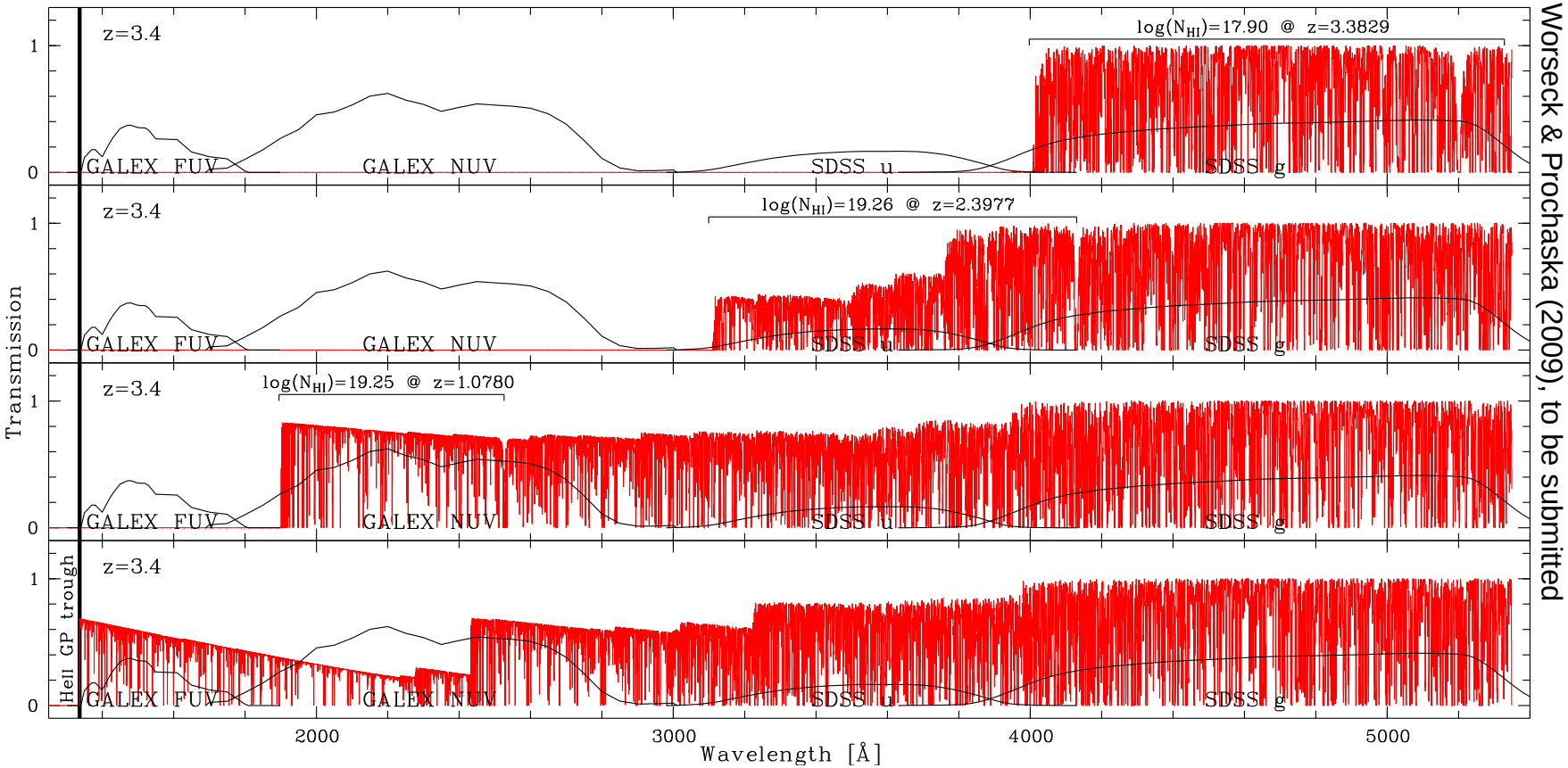






Monte Carlo simulations of quasar spectra

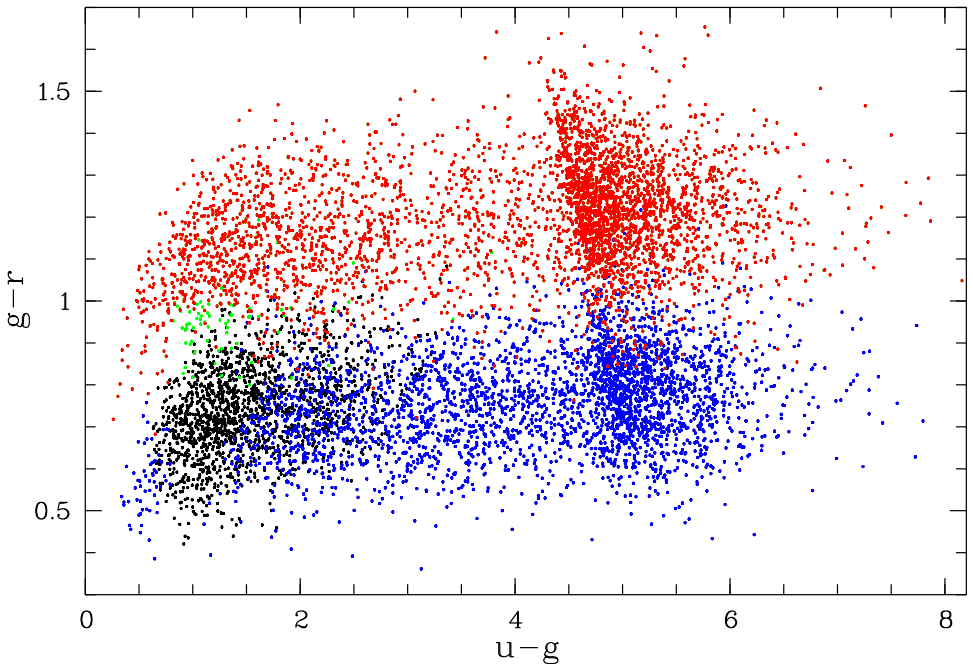
- IGM: line defined by $(z, N_{\mathrm{H\,I}}, b)$ from empirical line distributions
- simulations reproduce $\tau_{\mathrm{eff},\alpha}(z)$, $\lambda_{\mathrm{mfp}}(z > 3.6)$, number density of LLSs
- quasar SEDs (broken power law continua with emission lines)
- mock *ugriz* photometry of $\sim$ 200000 quasars at $2.6 < z < 4.6$

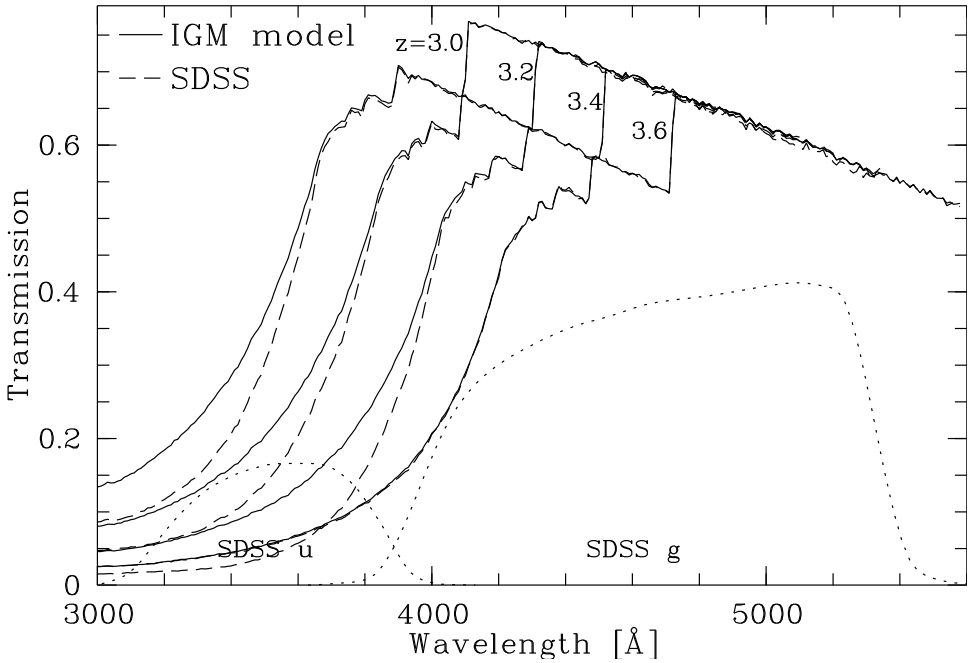


Worseck & Prochaska (2009), to be submitted

SDSS color selection favors Lyman limit systems

- mock quasar photometry run through SDSS target selection algorithm (thanks to Gordon Richards)
- significant fraction of $z < 3.6$ quasars in stellar locus
- SDSS is biased against sightlines without Lyman limit systems (blue $u - g$ colors)

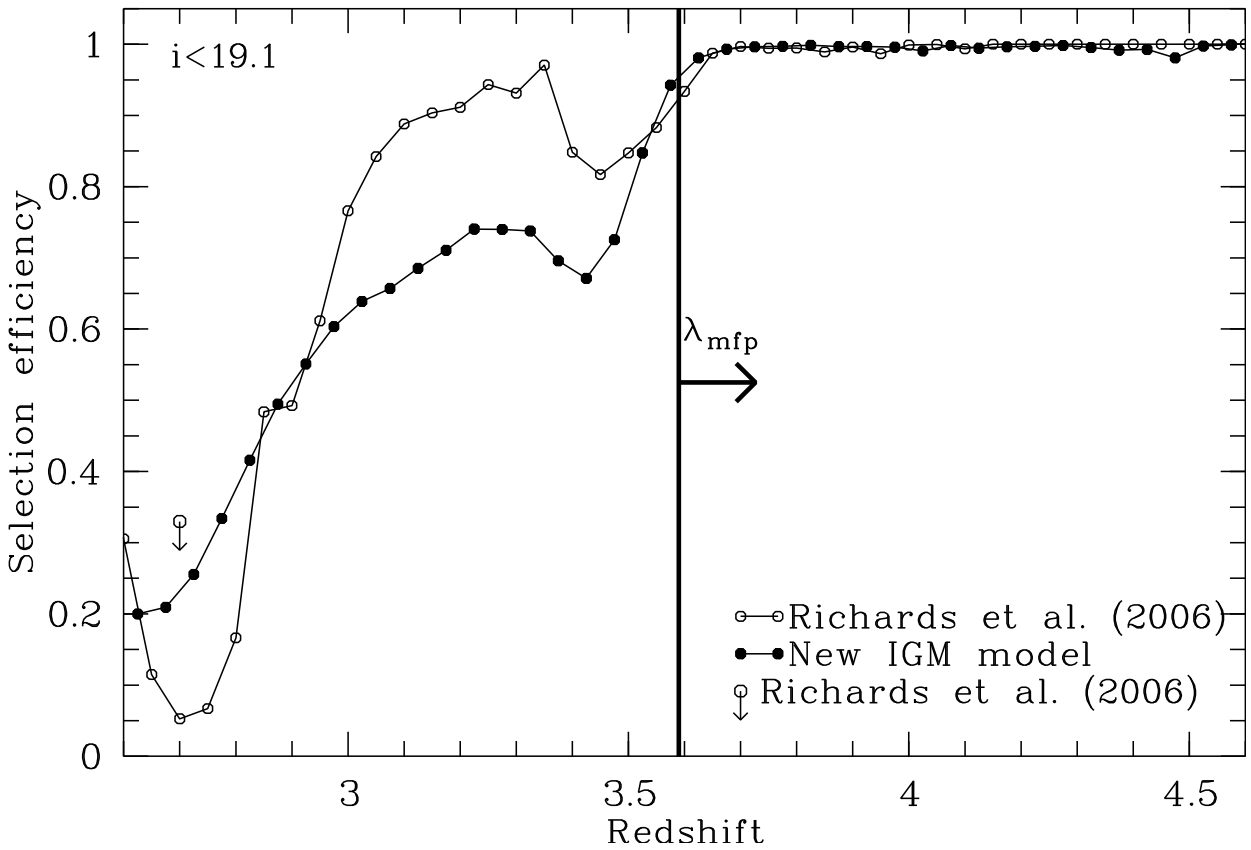




Worseck & Prochaska (2009), to be submitted

A lower SDSS selection efficiency at $2.9 < z < 3.5$

- previously: SDSS selection efficiency low at $2.7 \lesssim z \lesssim 3.0$
- our analysis: SDSS selection efficiency low at $2.9 \lesssim z \lesssim 3.5$
- quasars are bluer $\longrightarrow$ UV-excess selection possible at $z \lesssim 2.9$



Worseck & Prochaska (2009), to be submitted

Conclusions

- Large spectroscopic surveys provide sufficient statistics of high column density systems in the IGM
- absorbers are prominent in $R \sim 2000$ survey confirmation spectra (large equivalent width, Lyman continuum absorption)
- stacking of spectra in Lyman continuum region: mean free path of ionizing photons in the 'average' IGM
- $z < 3.6$ SDSS quasar sightlines are biased towards a higher incidence of Lyman limit systems
- reason: SDSS selects outliers from the stellar locus
- IGM folks have to know much more about their background targets

BigBOSS must target the stellar locus