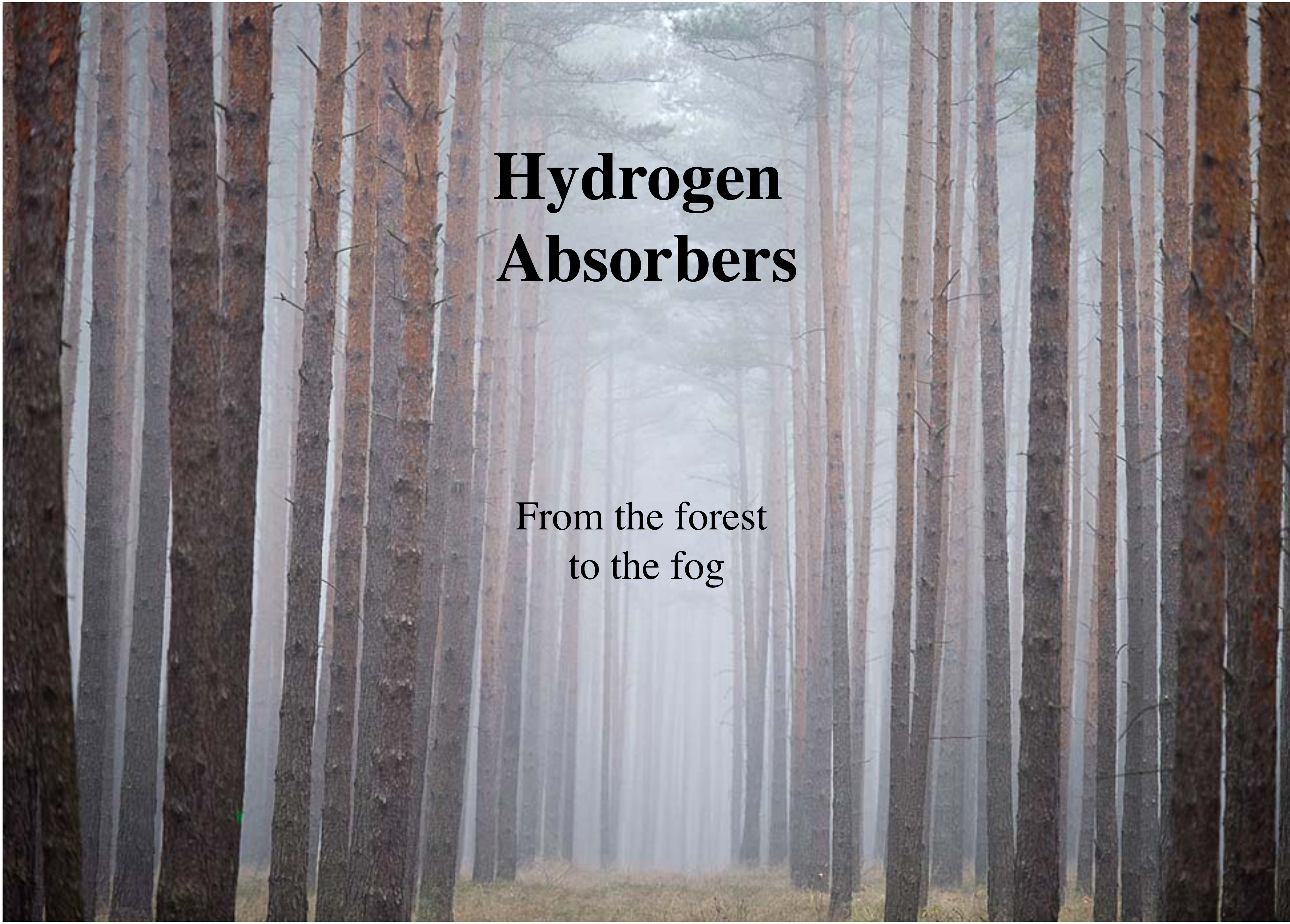


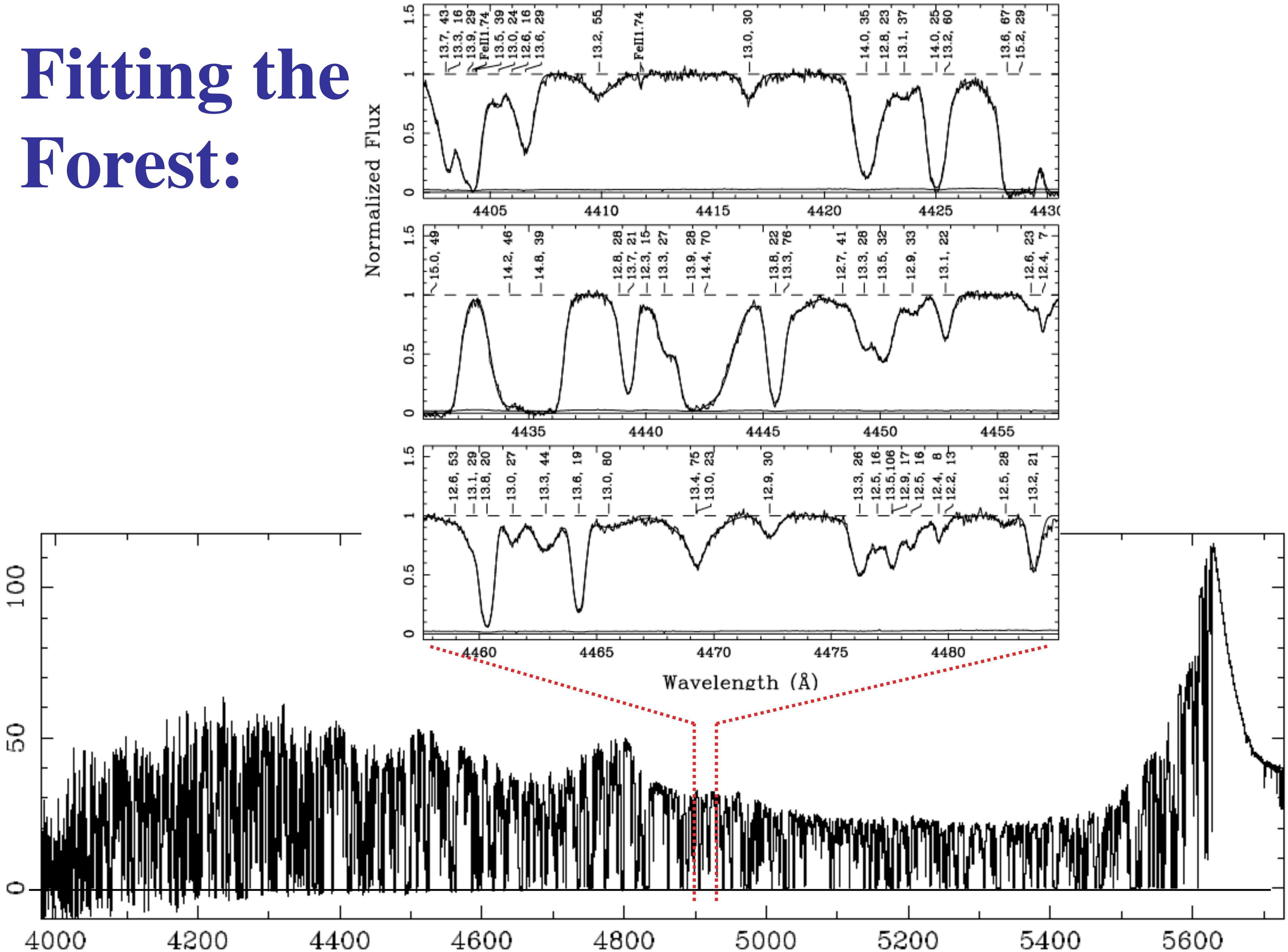
Hydrogen Absorbers

From the forest
to the fog

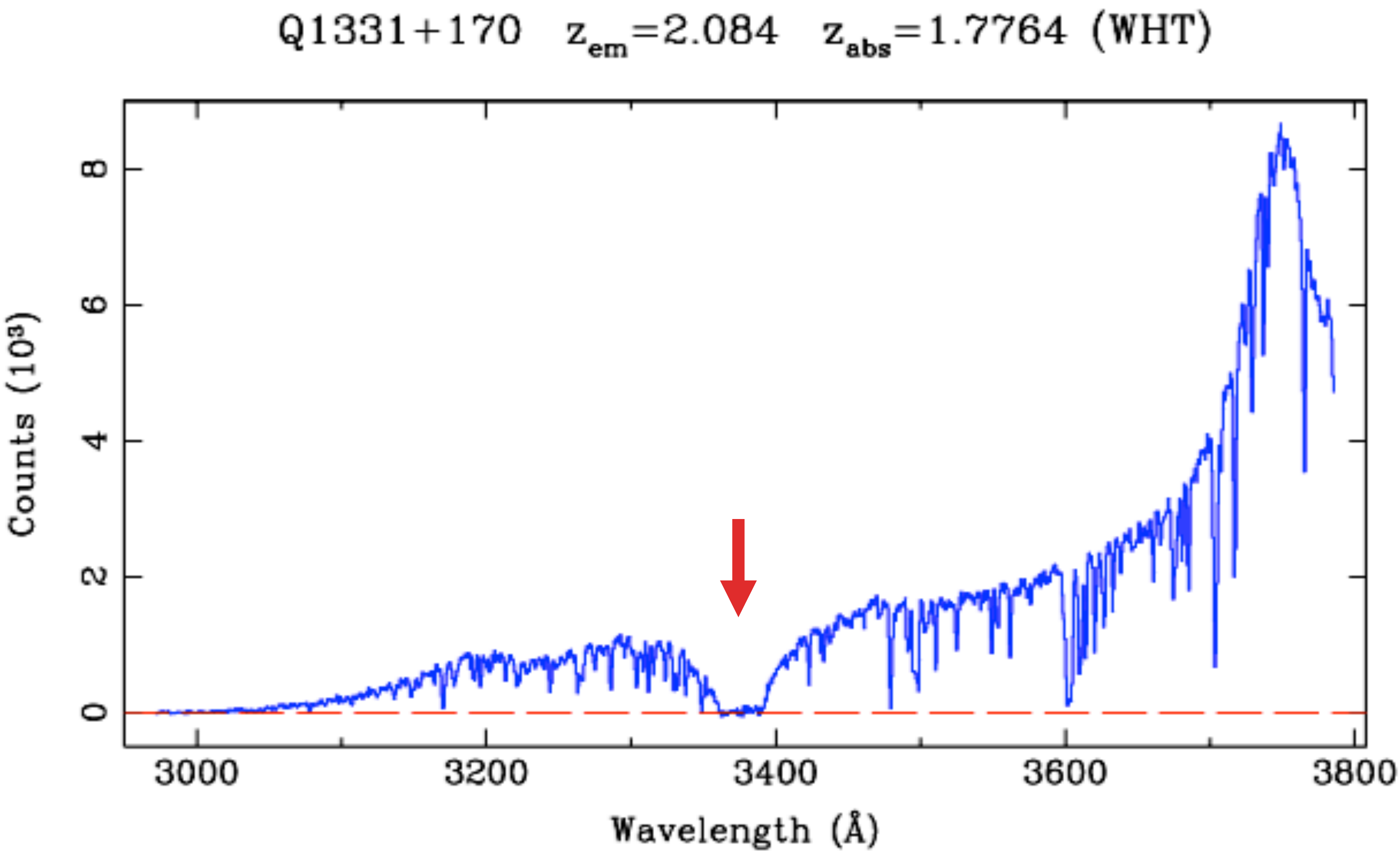
Ly α Absorbers

- **Ly α Forest:** $10^{14} \leq N_{HI} \leq 10^{16}$ cm^{-2}
  - Lines are unsaturated
  - Primordial metalicity < solar
  - Sizes are > galaxies
- **Ly Limit Systems (LLS):** $N_{HI} \geq 10^{17}$ cm^{-2}
  - Ly α Lines are saturated
  - N_{HI} is ufficient to absorb *all* ionising photons shortward of the Ly limit at 912Å in the restframe (i.e., like the UV-drop out or Lyman-break galaxies)
- **Damped Ly α (DLA) Systems:** $N_{HI} \geq 10^{20}$ cm^{-2}
  - Line heavily saturated
  - Profile dominated by "damped" Lorentzian wings
  - Almost surely proto-disks or their building blocks

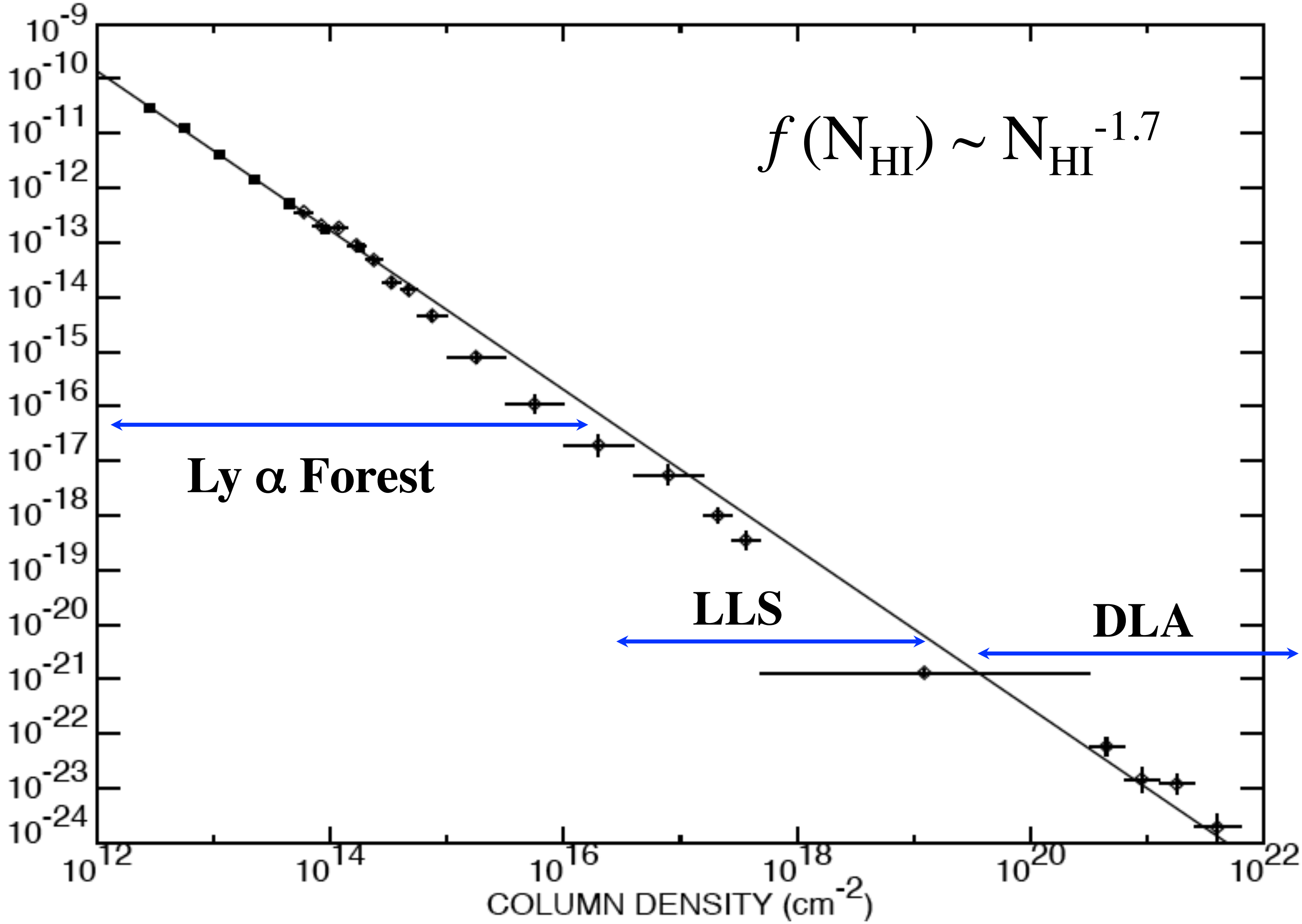
Fitting the Forest:



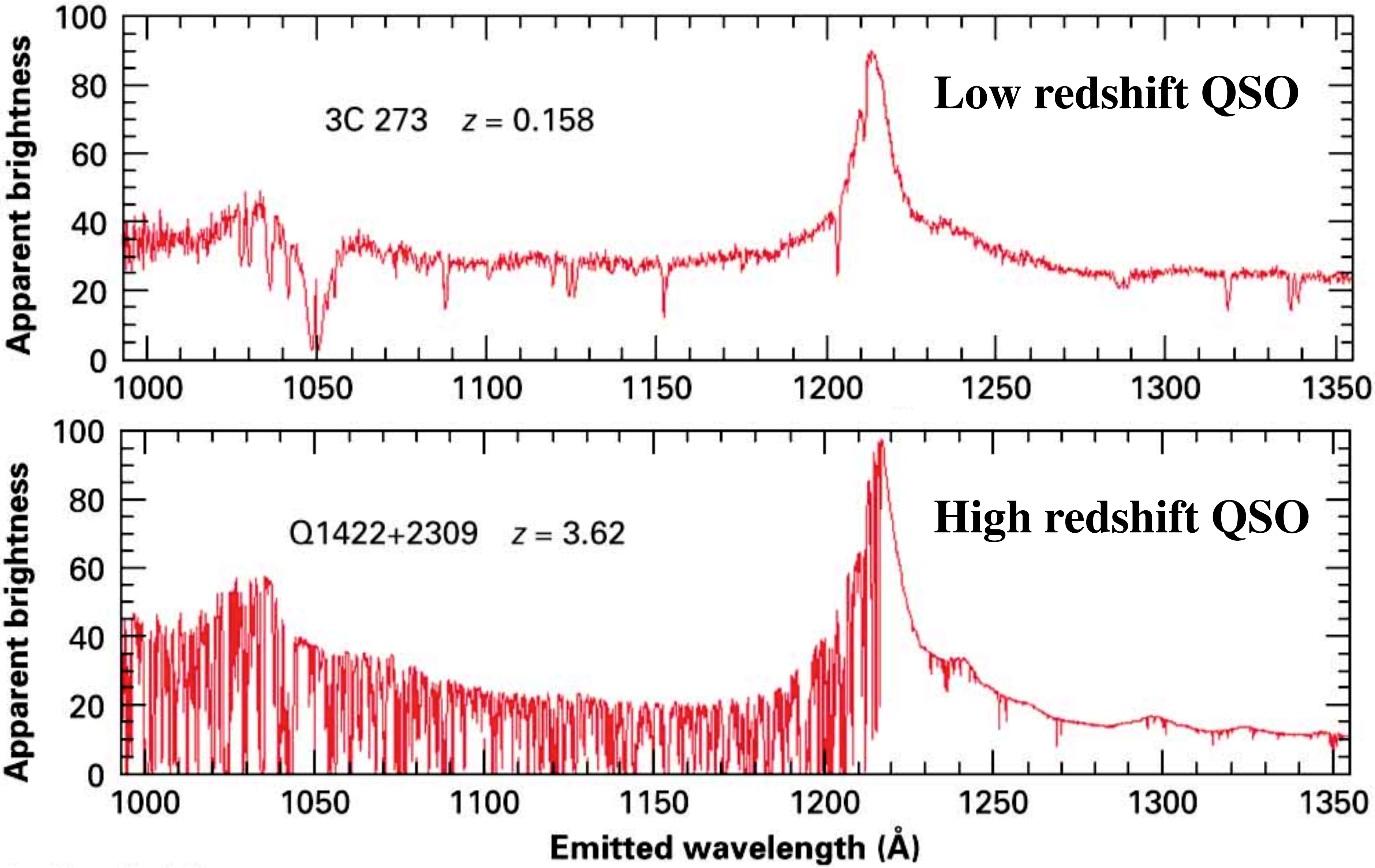
A Damped Lyman α System



Distribution of Column Densities



Evolution of the Hydrogen Absorbers



Evolution of Ly α Absorbers

(from Rauch 1998, ARAA, 36, 267)

EVOLUTION OF THE LINE DENSITY An analytic expression (Wagoner 1967, Bahcall & Peebles 1969) can be given for the number of absorption systems per unit redshift, $d\mathcal{N}/dz$, in terms of the comoving number density $n_0(z)$ of absorbers, the geometric absorption cross section $\sigma(z)$, and the Hubble constant H_0:

$$\frac{d\mathcal{N}}{dz} = \frac{cn_0(z)\sigma(z)}{H_0}\frac{1+z}{(1+q_o z)^{1/2}}. \tag{6}$$

For absorbers with no intrinsic evolution,

$$\frac{d\mathcal{N}}{dz} \propto \begin{cases} 1+z, & q_0 = 0 \\ (1+z)^{1/2}, & q_0 = \frac{1}{2} \end{cases}. \tag{7}$$

(NB: this is for $\Lambda = 0$ cosmology!)

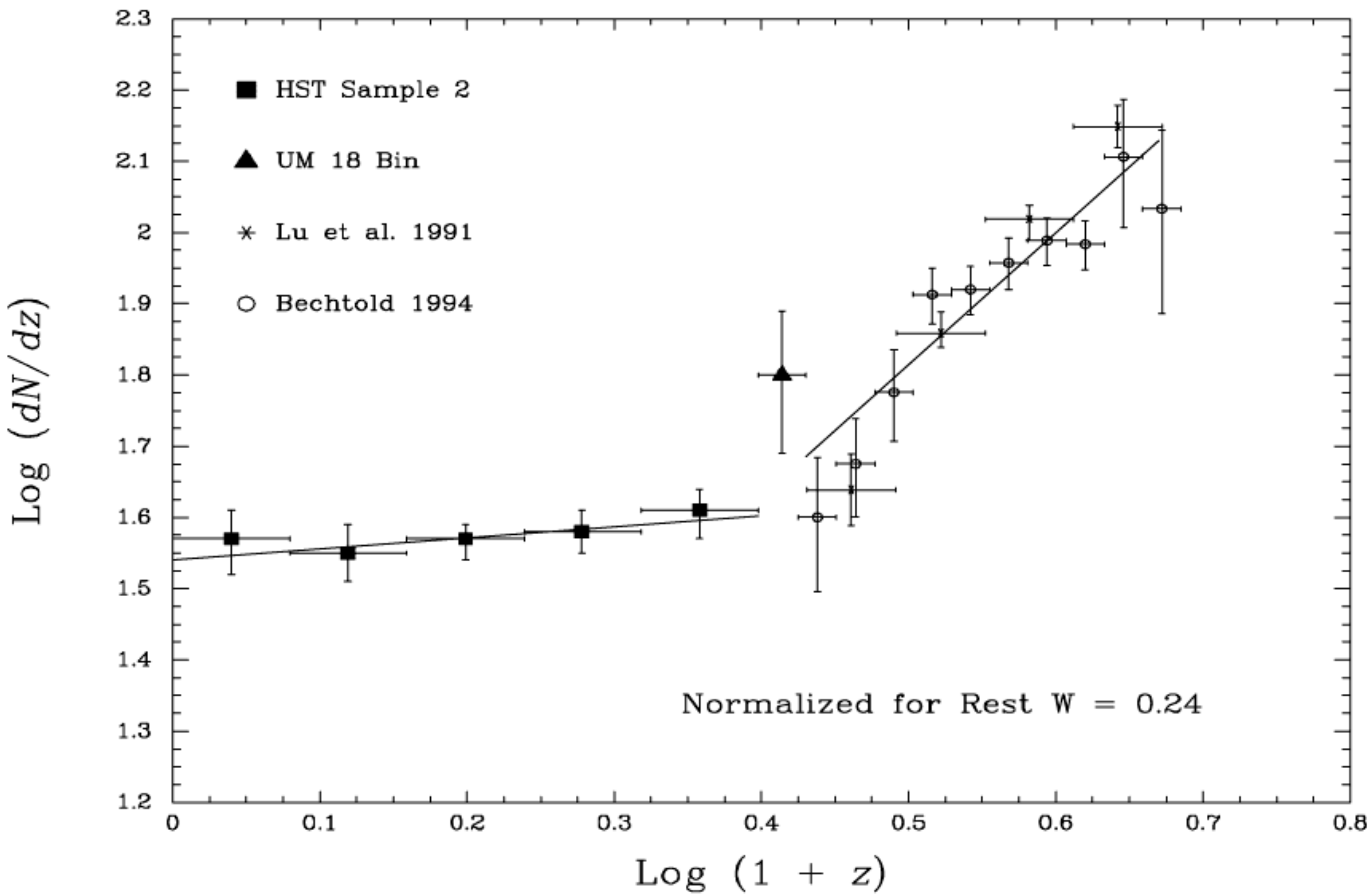
The observationally determined evolution in the number of absorbers above a certain column density threshold is usually expressed in the form

$$\frac{d\mathcal{N}}{dz} = \left(\frac{d\mathcal{N}}{dz}\right)_0 (1+z)^{\gamma}, \tag{8}$$

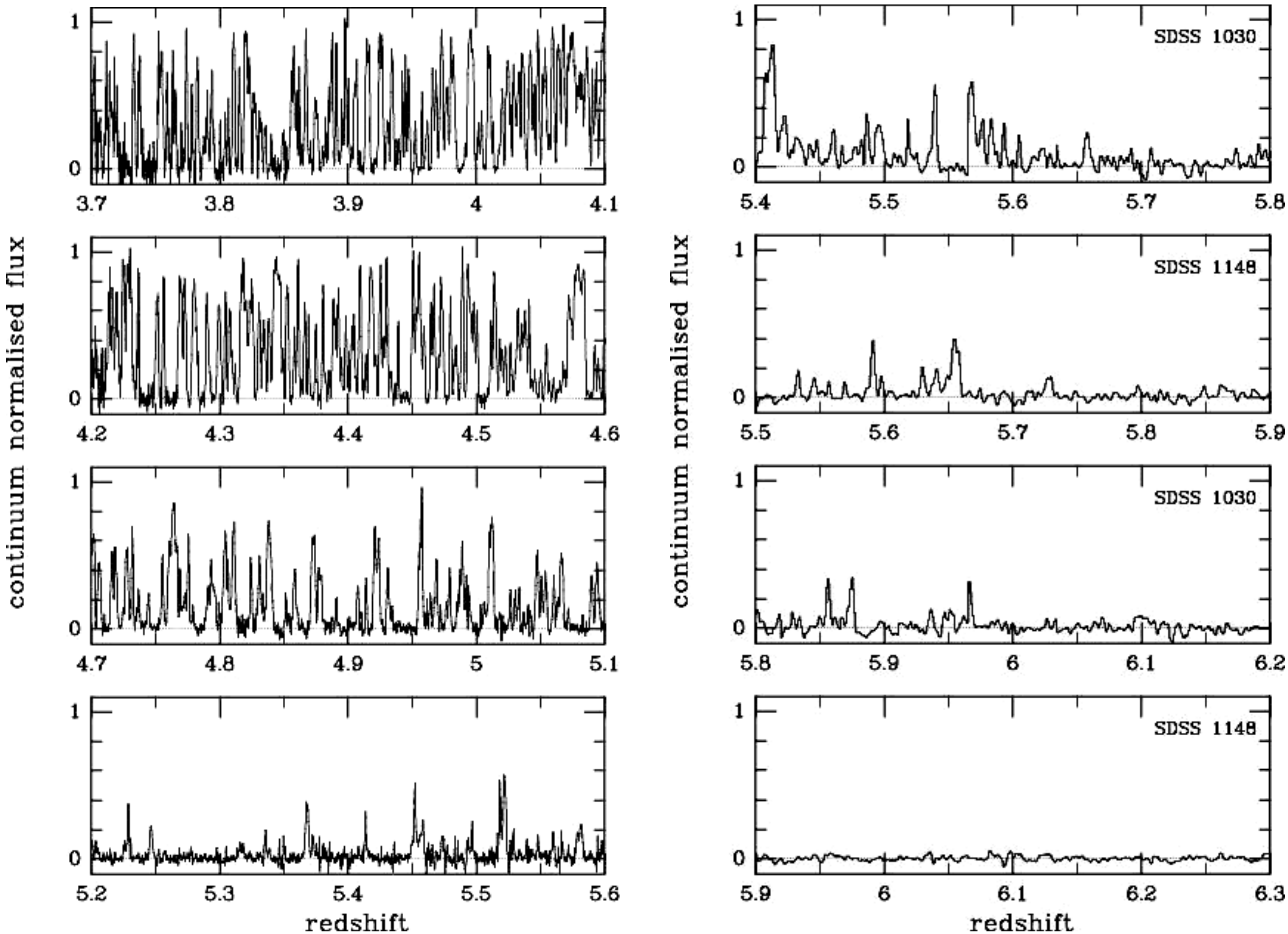
Typical $\gamma \sim 1.8$ (at high z's)

Evolution of Ly α Absorbers

The numbers are higher at higher z's, but it is not yet clear how much of the effect is due to the number density evolution, and how much to a possible cross section evoluton - nor why is there a break at $z \sim 1.5$



The Forest Thickens



The Gunn-Peterson Effect

Even a slight amount of neutral hydrogen in the early IGM can completely absorb the flux blueward of Lyα

The Gunn-Peterson (1965) optical depth to Lyα photons is

$$\tau_{\rm GP} = \frac{\pi e^2}{m_e c} f_\alpha \lambda_\alpha H^{-1}(z) n_{\rm HI}, \tag{1}$$

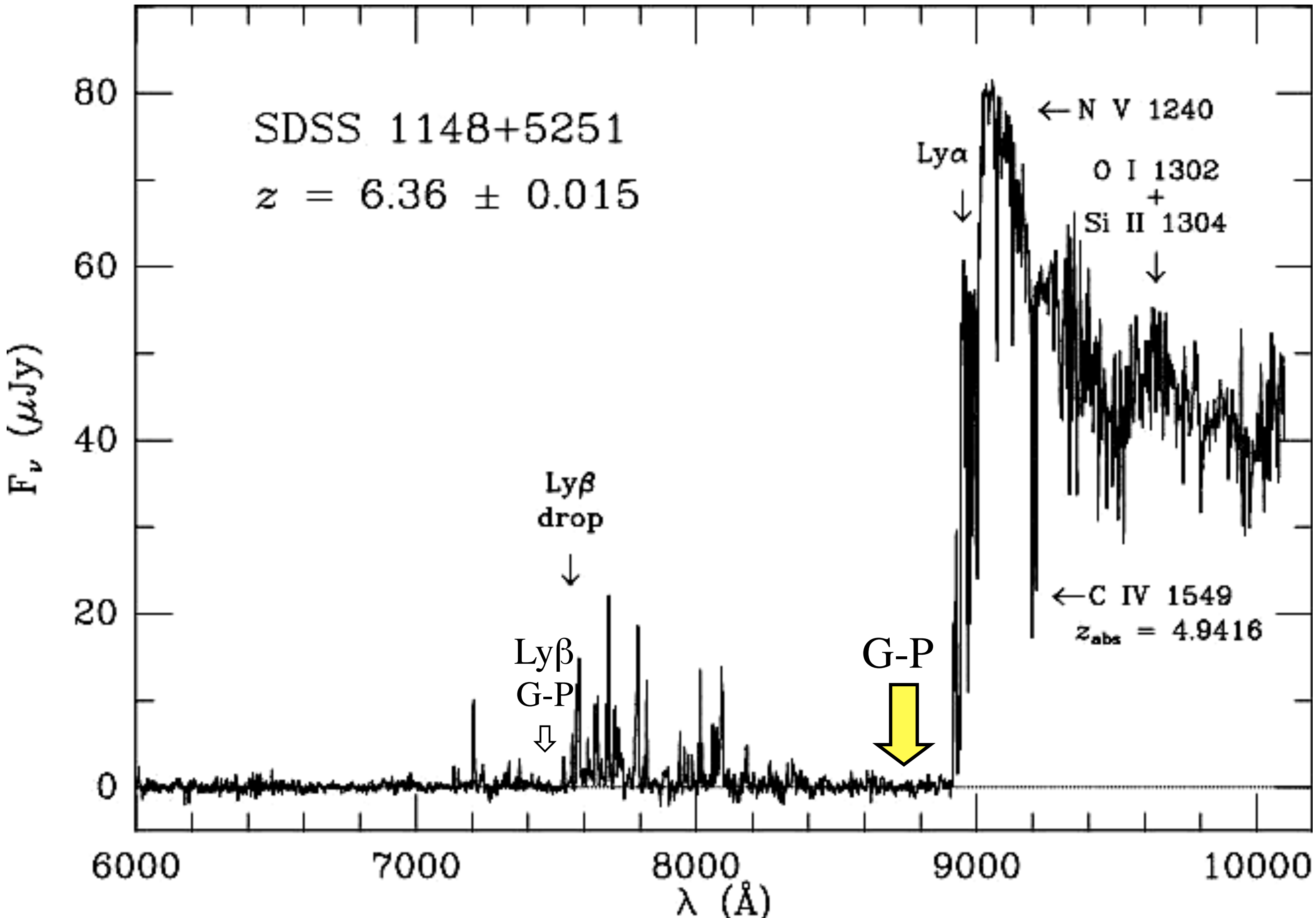
where f_α is the oscillator strength of the Lyα transition, $\lambda_\alpha = 1216$ Å, $H(z)$ is the *Hubble* constant at redshift z, and $n_{\rm HI}$ is the density of neutral hydrogen in the IGM. At high redshifts,

$$\tau_{\rm GP}(z) = 4.9 \times 10^5 \left(\frac{\Omega_m h^2}{0.13}\right)^{-1/2} \left(\frac{\Omega_b h^2}{0.02}\right) \left(\frac{1+z}{7}\right)^{3/2} \left(\frac{n_{\rm HI}}{n_{\rm H}}\right) \tag{2}$$

for a uniform IGM. Even a tiny neutral fraction, $x_{\rm HI} \sim 10^{-4}$, gives rise to complete GP absorption. This test is only sensitive at the end of the reionization when the IGM is already mostly ionized, and the absorption saturates for the higher neutral fraction in the earlier stage.

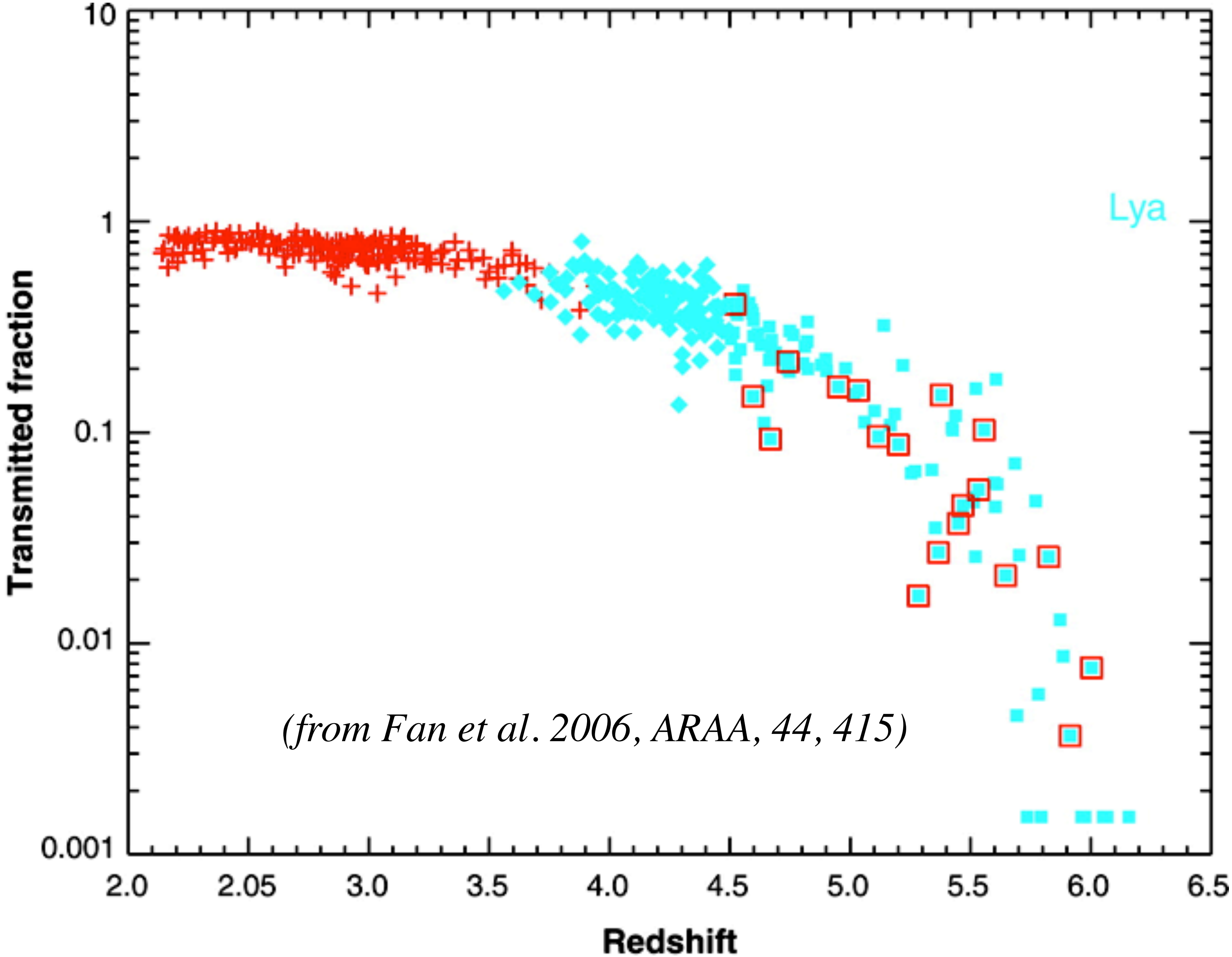
(from Fan et al. 2006, ARAA, 44, 415)

"Gunn-Peterson like" troughs are now observed along all available lines-of-sight at at $z \sim 6$



(Djorgovski *et al*.)

Transmitted Lyα Flux vs. Redshift



(from Fan et al. 2006, ARAA, 44, 415)


Next:
The Absorber - Galaxy Connection