LECTURE 3

QSO ABSORPTION LINES AND THE IGM

1. Damped Lyα absorption
2. Lyman limit absorption
3. Thermal/ionization/enrichment history of the IGM
4. Physics of the Lyα forest
5. HeII absorption

QSO Absorption

- Damped Lyα systems: $N_{\rm HI} > 10^{20.3}$ cm^{-2}, $Z \sim 0.01 Z_\odot - 1 Z_\odot$
- Lyman limit systems: $N_{\rm HI} > 10^{17.2}$ cm^{-2}, $Z \sim ?$
- Lyα forest: $N_{\rm HI} < 10^{17}$ cm^{-2}, $\tau_c = 2.52 \left(\frac{N_{\rm HI}}{10^{14}\ {\rm cm}^{-2}}\right) \left(\frac{30\ \ {\rm km\ s}^{-1}}{b}\right)$

  Most systems with $N_{\rm HI} > 10^{14.5}$ cm^{-2} have $Z \sim 0.001 Z_\odot - 0.01 Z_\odot$
- HeII Lyα absorption (304 Å) detected in several QSOs.

Damped Lyα Absorption

- Arises in neutral ISM of forming galaxies.
- Predicted population of absorbers is diverse.
- Roughly 50% in systems with $v_c < 100$ km s^{-1} (SCDM).
- Complex structure $\Longrightarrow$ can produce Prochaska & Wolfe signatures without large, rotating disks.
- Models with small scale power similar to SCDM can roughly produce observed $n(z)$.
- Models with much less small scale power likely to fail.
- Numerical resolution effects still a big uncertainty.

Lyman Limit Absorption

- LL absorbers roughly like DLAs, but less massive, younger systems or larger impact parameters.
- However, all (?) simulations underproduce observed abundance.

  Possible solutions:
  - More small scale power than SCDM.
  - $\Omega_b > 0.1$
  - Resolution of simulations inadequate for LL predictions.
  - Additional population from other physics.

Thermal, Ionization, and Enrichment History of the IGM

Recombination at $z = 1100$.

Gas temperature drops below CMB at $z \sim 500$.

First star-forming objects condense and

- reionize IGM, $5 < z_{\rm reion} < 50$
- heat IGM to $T \sim 10^4$ K
- enrich IGM to $Z \sim 10^{-2.5} Z_\odot$ (?)

Reionization may temporarily suppress, or regulate, "galaxy" formation.

By $z \sim 5$, hydrogen neutral fraction is very low.

By $z \sim 3$, QSOs may dominate UV backround.

HeII reionization may happen long after HI reionization, at $z \gtrsim 3$.

Clustering of Lyα forest lines

Observations

$\xi(\Delta v) \approx 0$ at large scales; weak or zero at small scales.
Associated CIV lines have $\xi(\Delta v) \sim$a few at small scales.
(See, e.g., Fernandez-Soto et al. 1996.)

Simulations

$\xi(\Delta v) \approx 0$ at large scales; weak, zero, or negative at small scales, depending on line identification method, spectrum S/N.
Associated CIV lines have $\xi(\Delta v) \sim$a few at small scales.
Difference is due to *line blending.*
(Gaudi, Davé, Hellsten; see also Cen et al. 1997.)

Large scale structure in Lyα forest can be measured much more robustly by working directly with the flux instead of with lines (lecture 4).

Properties of "typical" forest absorbers

- Low density,

$$\left(\frac{\rho_b}{\bar{\rho}_b}\right) \approx \left(\frac{\rho_d}{\bar{\rho}_d}\right) \sim 2\left(\frac{N_{\rm HI}}{10^{14}{\rm cm}^{-2}}\right) \qquad \text{at } z = 2$$

- Broadened mainly by Hubble flow

Implications

- uncollapsed
- large ($\sim$ 100 kpc coherence scale)
- low neutral fraction $\longrightarrow$ large fraction of cosmic baryons
- out of dynamical and thermal equilibrium
- thermal state driven by photoionization heating, adiabatic cooling
- no sharp division between lines and background
- evolution driven by expansion of universe, change in $H(z)$
- to a first approximation,

$$\tau = \left[\frac{\pi e^2}{m_e c} f_\alpha \lambda_\alpha\right] H^{-1}(z) n_{\rm HI}(z)$$