Astronomy 401/Physics 903
Lecture 17
The Intergalactic Medium

There is gas between galaxies: the **intergalactic medium (IGM)**. We see this via absorption lines in the spectra of quasars—absorption lines from gas clouds along the line of sight to the QSO.

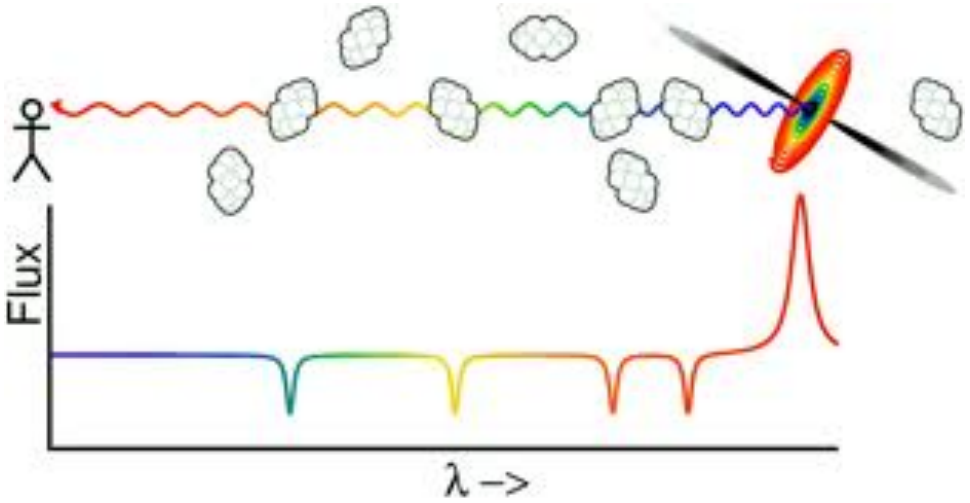

Figure 1: Absorption in the spectrum of a QSO from gas clouds along the line of sight.

Lyman-α (Lyα) is the $n = 2$–1 transition of neutral hydrogen, with a rest wavelength of 1215.7 Å. Because this is a resonance transition, i.e. a transition to or from the ground state, Lyα photons can be easily absorbed by neutral hydrogen gas. This means that if the light from a quasar passes through a cloud of gas on the way from the quasar to us, a Lyα absorption line will be produced in the spectrum of the quasar *at the redshift of the intervening cloud*. There are many clouds along the line of sight, especially for quasars at high redshifts, so this produces a dense series of narrow absorption lines blueward of the Lyα emission from the quasar. This is called the **Lyα forest.**

An example of the Lyα forest is shown in Figure 2. The quasar has a redshift $z = 3.62$, so the Lyα emission from the quasar itself will appear at an observed wavelength of $1215.7 \times (1 + z_{\rm QSO}) = 5616.4$ Å. Lyα absorption from clouds along the line of sight to the QSO will appear at wavelengths $1215.7 \times (1 + z_{\rm cloud})$, where $z_{\rm cloud}$ is the redshift of the cloud. With $0 < z_{\rm cloud} < z_{\rm QSO}$, the Ly$\alpha$ forest will cover the observed wavelength range 1216–5616 Å in this example.

Absorption from ionized metals is also seen: C IV, Mg II, many other elements. This indicates that the material has been processed by stars and enriched. These lines correspond to the stronger Lyα absorption systems, and can be used to determine the metallicity of the gas clouds, which shows a wide range from very low to solar. This variation may depend on how close the line of sight passes to the center of a galaxy.

At least some absorption systems are caused by the line of sight passing through a galaxy or a galaxy halo, but the absorption systems don't seem to have the same large scale structure as galaxies; they are more randomly distributed, rather than grouped into clusters and voids, and probably trace the overall matter distribution more closely than galaxies do.

Absorption systems can also be used to probe the effects of galaxies on the IGM, by studying correlations between the positions of galaxies and absorption systems. This is a way to estimate the distance to which a galaxy enriches its environment. Very much an area of active research.

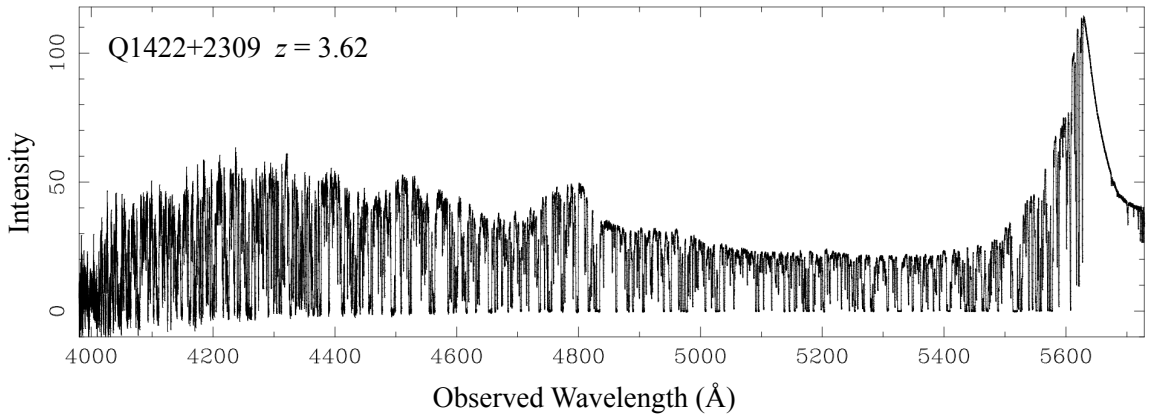

Figure 2: The spectrum of a quasar at redshift $z_{\rm QSO} = 3.62$ showing the Lyα forest. Lyα emission from the quasar itself is the strong line at 5616 Å, and intervening clouds of gas along the line of sight produce a forest of narrow absorption lines at bluer wavelengths.

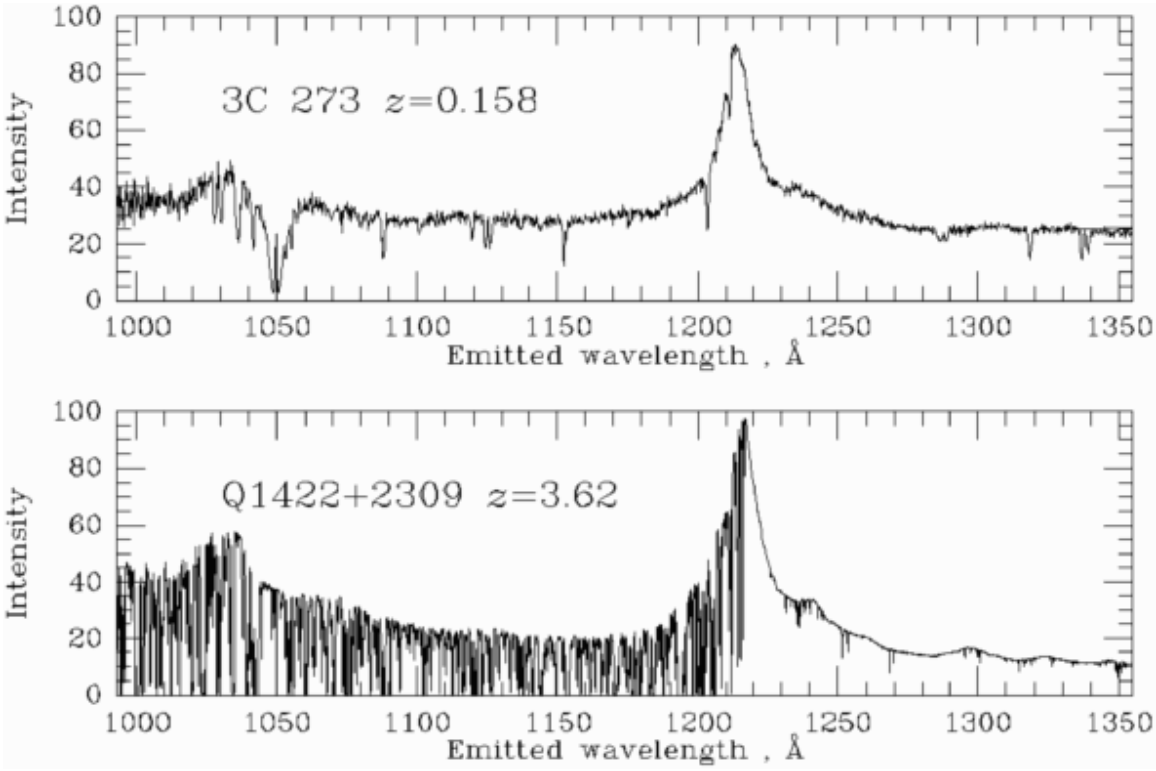

Figure 3: The spectra of two QSOs. Both are shifted into the rest frame of the quasar, meaning that the wavelength scale has been divided by $(1 + z_{\rm QSO})$. The QSO shown in the top spectrum, with a redshift $z = 0.158$, is much closer than the QSO shown in the lower panel, which has $z = 3.62$ (this is the same quasar shown in the figure above). This means that the line of sight to the more distant QSO is much longer and there are many more opportunities for absorption from intervening neutral hydrogen. Therefore the Lyα forest is seen in the spectrum of the high redshift QSO. The strength of the absorption depends on the amount of gas in the absorbing system. The strong, broad absorption line in the spectrum of 3C 273 is Lyα absorption from the Milky Way.

Note: most of the gas in the universe is ionized, was ionized by the light from the first galaxies sometime around $z \sim 7$. Absorption comes from the small neutral fraction.