COLUMN DENSITY OF AN ABSORPTION LINE

The column density of a line is a measure of the total number of atoms or ions that are responsible for producing an absorption or emission line. This within unit cross-section over the entire line of sight through a gas column that finally results in the absorption or emission line. Column density is related to the number density $n_{\rm H}$ as

$$N = \int_0^L n_{\rm H}\, dl \tag{1}$$

The dimensions of column density are particles per cm^{-3}.

There are two ways to measure the column density of an atomic or ionic species from the absorption line that it casts in the continuum of a background source (most of what is going to be said is also true for emission lines). One of them is by fitting a Gaussian profile to the absorption feature. The other is by integrating the column density corresponding to the *apparent optical depth* in each absorbing pixel. In this lab, you have to generate a routine that would compute the column density of a line using the apparent optical depth method (famously known as the AOD method, first enunciated in Savage & Sembach 1991). The method is as follows.

Let's say that an absorption feature is centered at wavelength λ_0, with the profile extending from λ_- to λ_+. The optical depth at each wavelength λ, within the wavelength interval λ_- to λ_+, is given by

$$\tau_a(\lambda) = \ln\left[\frac{f_c(\lambda)}{f(\lambda)}\right] \tag{2}$$

where $tau_a(\lambda)$ is the *apparent optical depth* at that wavelength, and f_c and f are the continuum and observed flux levels at the same wavelength.

We can now convert this apparent optical depth at each wavelength along the absorption into an *apparent column density* at those wavelengths, using the following expression

$$N_a(\lambda) = \frac{m_e c}{\pi e^2} \frac{\tau_a(\lambda)}{f \lambda_0} \tag{3}$$

In the previous expression, m_e and e are the mass and charge of an electron, c is the speed of light in vacuum, f is the oscillator strength, a dimensionless quantity that represents transition probability and λ_0 is the wavelength at the core of the absorption (this should be in the rest-frame of the absorbing cloud).

If c is in cm/s and wavelength in Å, then the apparent column density will have units of cm^{-3} Å^{-1}. The above equation assumes that the absorption line is weak and unsaturated. For saturated line the equation will only give a lower limit on the column density.

Once we do this from the beginning to end of an absorption line, we have a column density *profile* of that absorption line. The total column density is then obtained by integrating the column density profile.

$$N_a = \int_{\lambda_-}^{\lambda_+} N_a(\lambda)\, d\lambda \tag{4}$$

where $d\lambda$ is the size of the wavelength bin across the absorption profile. This will be a constant value only if the spectrum is uniformly binned. The integrated apparent column density will have units of cm^{-3}.

The task for this lab is as follows:

1. In the spectrum that was given to you in the previous lab session, the transition at 1150 Å is a Lyβ absorption line (H I 1026 Å) produced by a gas cloud sitting at $z = 0.1212$ along the line of sight to a background quasar (whose spectrum you are analyzing).

2. Calculate the equivalent width in the rest-frame of the absorbing cloud of this particular line.

3. Calculate the apparent column density of H I using this line in units of cm^{-3}. Given that the oscillator strength of Lyβ is $f_{osc} = 0.079120$, and the wavelength of a Lyβ transition in the laboratory frame is $\lambda = 1025.7223$ Å.