Exercise 2: Detecting Interstellar Reddening

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In this exercise, you will learn how interstellar reddening affects the spectrum of a planetary nebula. Comparing the spectra of several nebulae, you will be able to determine which are more or less affected by interstellar reddening. Combining these results with the galactic latitudes of these planetary nebulae, you will be able to conclude something about the distribution of interstellar dust in our Milky Way Galaxy.

The Balmer Decrement

In the Bohr model of the hydrogen atom there are many distinct energy levels, between which electrons can transfer if they emit or absorb the proper amount of energy. Upward moves require absorption of energy, while downward ones release energy. Downward electron transitions that end on the second energy level are called the Balmer series, and are important in optical astronomy, since these are the only transitions that involve visible light. The first three of these are called $H\alpha$, $H\beta$, and $H\gamma$, for the transitions from 3-2, 4-2, and 5-2, respectively. When many ionized hydrogen atoms are recombining, as in a planetary nebula where atoms are being ionized and recombining all the time, the captured electrons cascade down through the energy levels, emitting photons of the appropriate wavelengths as they fall. The likelihood of any particular downward jump is dictated by atomic constants, and thus the ratios of all possible transitions can be calculated. This leads to the "Balmer decrement," the well known ratios among the intensities of the Balmer lines, where $H\alpha$ is the strongest line, $H\beta$ is weaker, $H\gamma$ is weaker still, and so on. Under typical conditions in planetary nebulae these ratios are (from Osterbrock, Astrophysics of Planetary Nebulae and Active Galactic Nuclei, University Science Books, 1989):

$$H\alpha/H\beta = 2.86 \text{ and } H\gamma/H\beta = 0.47$$

The Phenomenon of Interstellar Reddening

Thus, the Balmer decrement, the intensity ratios of Balmer lines in all planetary nebulae, should be roughly the same. However, this is not what is observed. Interstellar reddening produced by micron-sized dust particles selectively dims shorter-wavelength, bluer light more than it does longer-wavelength, redder light, leading to Balmer line ratios that differ systematically from the theoretical predictions. A planetary nebula lying behind a cloud of interstellar dust will be observed to have the intensity ratios $H\alpha/H\beta$ **more** than 2.86, and $H\gamma/H\beta$ **less** than 0.47. The more dust, the greater the disparity between the observed and theoretical Balmer decrements. Turning this concept around, from the size of the discrepancy between observed and theoretical Balmer decrements, astronomers can infer the amount of interstellar reddening, and therefore, dust, between us and a given planetary nebula.

The Milky Way Galaxy and Galactic Coordinates

Our solar system and all of the planetary nebulae in this database reside in the Milky Way Galaxy. The Milky Way is a flattened spiral of stars, gas, and dust, surrounded by a more spheroidal, extended, and much more diffuse region, called the galactic halo. Locations in the Milky Way are conveniently specified by galactic coordinates, similar to latitude and longitude as seen by someone viewing from the center of the Earth. The origin of the galactic coordinate system, though, is not at the center of the Milky Way, but rather, is located at the sun's position, because that's where we are as we view the heavens.