Redshift of Spectral Lines

Spectral lines are an extremely useful tool in astronomy because they not only tell us about the composition of the gas being observed, but also about its motion. The shift of spectral lines toward the blue or red end of the spectrum reveals whether the gas is moving toward or away from us.

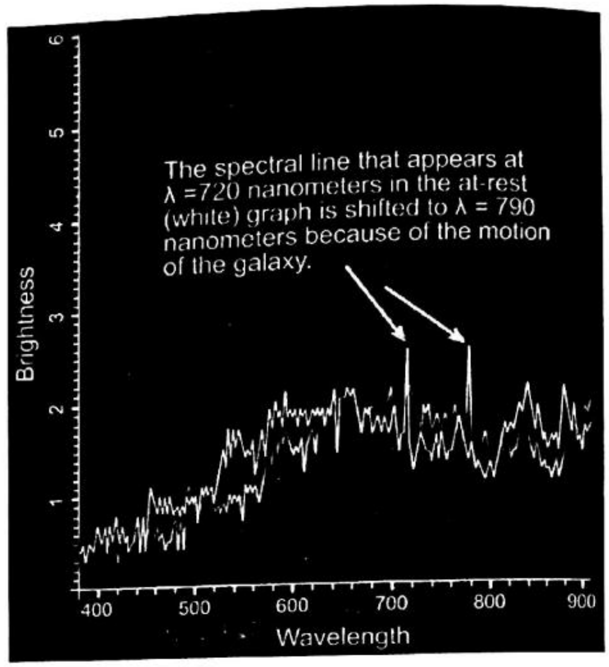

Figure 4-13: Graph of the spectrum of a redshifted galaxy compared with the spectrum of at-rest galaxy

Most galaxies have very recognizable spectral lines such as those identified in Figure 4-13. If this galaxy were moving away from us, the same spectral lines we see in the spectral-line graph would appear, but at different wavelengths. The faster it is moving away from us, the more the lines are shifted toward the red. By comparing the wavelengths of the lines observed from a galaxy to those that would exist if the galaxy were at rest, we can measure the **redshift**, and from that we can determine the motion of the galaxy away from us. Similarly, if a galaxy were moving toward us, the spectral lines would be shifted to shorter, bluer wavelengths.

To better understand redshift, think of the siren on an ambulance. As the ambulance drives away from you, there is a noticeable drop in the pitch of the siren (this is called the Doppler effect for sound). Because the source of the sound (the siren) is moving away from you as it is emitting sound, the wavelength of the sound is stretched out. You hear the increase in wavelength as a decrease in pitch or frequency.

Remember that spectral lines for a particular element have a unique pattern. When the spectrum is shifted, the entire pattern is shifted, but not by the same amount. Longer wavelengths are shifted more than shorter ones. The amount by which a galaxy's spectrum is redshifted is, as you can imagine, dependent on how fast the galaxy is moving away from us. For galaxies that are not receding at a significant fraction of the speed of light themselves, the percentage of shift is equal to the percentage of the speed of light ($c = 3.0 \times 10^8$ m/s) at which the galaxy is receding.

For example, if a line that is known to appear at $\lambda = 400$ nanometers when the galaxy is at rest, is observed to appear at lambda = 440 nanometers, there has been a 10% shift (since 440-400 = 40 and 40 is 10% of the at-rest wavelength, or 400 nanometers). This indicates that the galaxy is moving at 10% of the speed of light, or at 3.0×10^7 m/s.

To calculate the redshift, z, of a galaxy, you can find the ratio of the change in wavelength to the original (at rest) wavelength. If a spectral line would appear at 360 nanometers if the galaxy were at rest, and you observe the spectral line at 364.5 nanometers, you can find the redshift by:

$$z = \frac{(\lambda_{observed} - \lambda_{rest})}{\lambda_{rest}} = \frac{v}{c}$$

$$z = \frac{(364.5 - 360)}{360} = 0.0125$$, which translates to a recession velocity of 12.5% of the speed of light.

Very distant galaxies are moving with such great speed away from us that this simple calculation for redshift does not apply. For them, one must use a relativistic formula for redshift that is beyond the scope of this course.

Checking In

1. Suppose we observe spectral lines from a galaxy that are redshifted by 3% . At what speed would you estimate that the galaxy is moving away from us?
2. Suppose you measure spectral lines at 318 nanometers and 339.2 nanometers from a galaxy that emits lines that would appear at rest at 300 nanometers and 320 nanometers. How fast is the galaxy moving away from us?

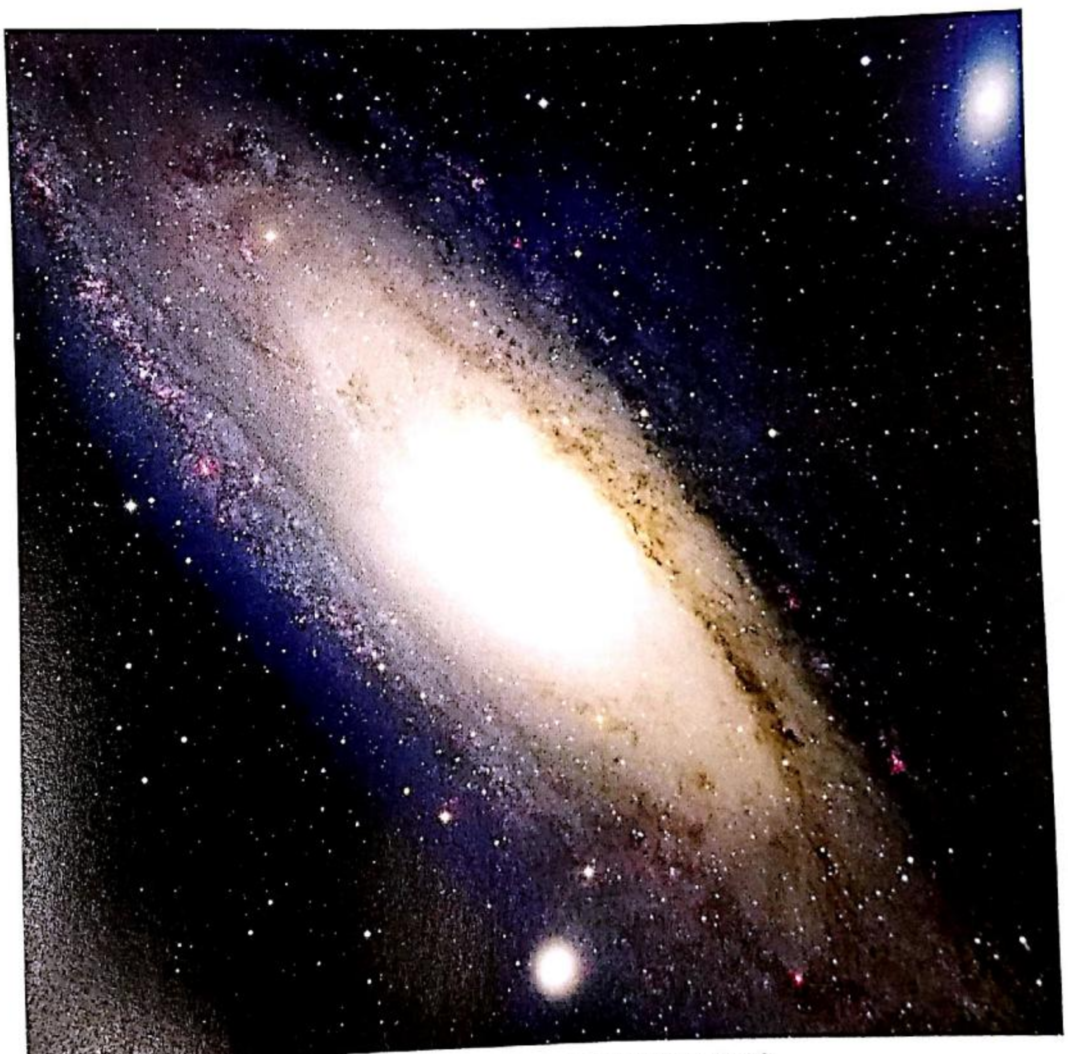

Image of M31 (Andromeda), the closest large spiral galaxy to Earth