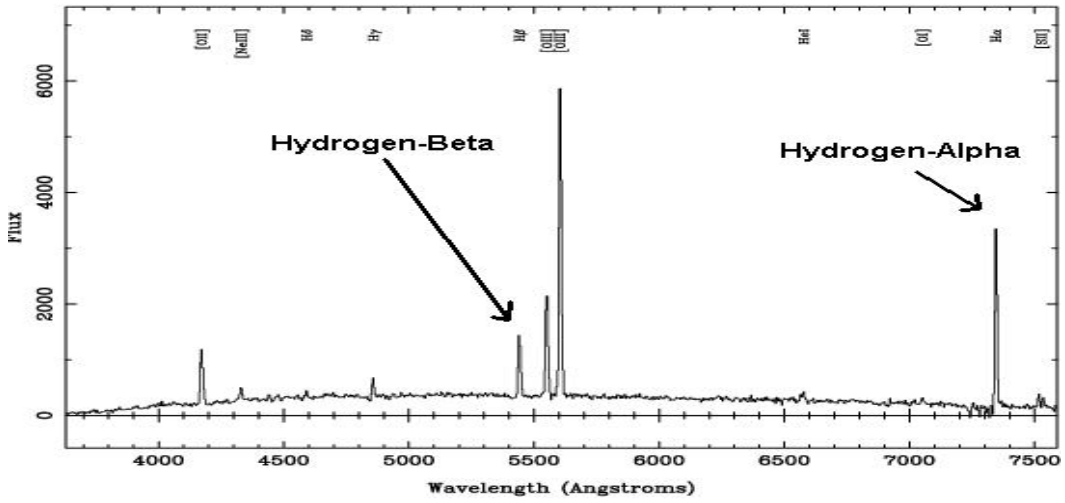
The Doppler Shift is an important physical phenomenon that astronomers use to measure the speeds of distant stars and galaxies. When an ambulance approaches you, its siren seems to be pitched higher than normal, and as it passes and travels away from you, the pitch becomes lower. A careful measurement of the pitch change can let you determine the speed of the ambulance once you know the speed of the sound wave. A very similar method can be used when analyzing light waves from distant stars and galaxies. The basic formula for slow-speed motion (that is, speeds much slower than the speed of light) is:

$$\text{Speed} = 299{,}792 \frac{W_O - W_R}{W_R}$$

The speed of the object in km/s can be found by measuring the wavelength of the signal that you observe (Wo), and knowing what the rest wavelength of the signal is (Wr), with wavelength measured in units of Angstroms (1.0×10^{-10} meters).



This is a small part of the spectrum of the Seyfert galaxy Q2125-431 in the constellation Microscopium. An astronomer has identified the spectral lines for Hydrogen Alpha (Wr = 6563 Angstroms), and Beta (Wr = 5007 Angstroms).

Question 1: From the graph of the spectrum above, use you millimeter ruler to determine the scale of the figure in angstroms per millimeter.

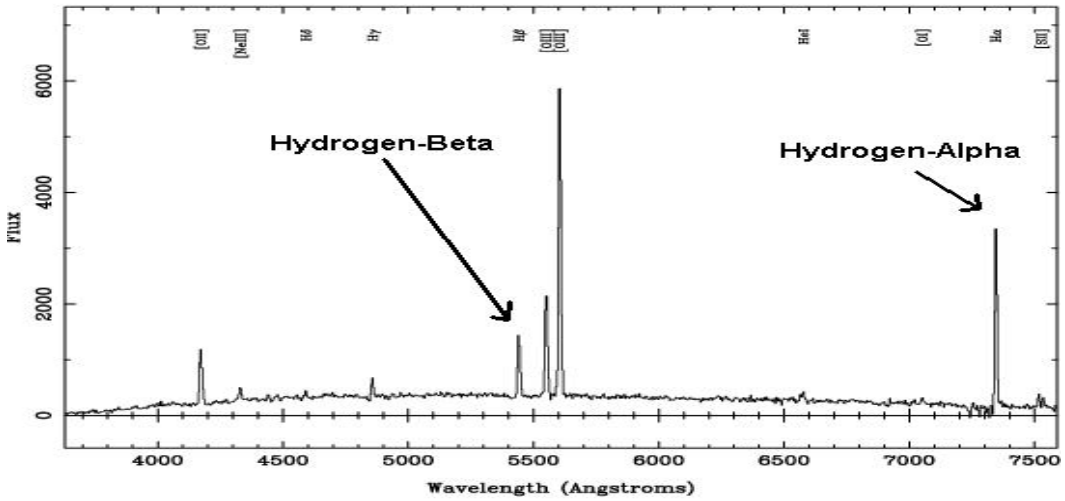
Question 2: What are the observed wavelengths of the Hydrogen-Alpha and Hydrogen-Beta lines?

Question 3: What are the rest wavelengths of the Hydrogen-Alpha and Hydrogen-Beta lines?

Question 4: If Wr is defined by your answers to question 3, and Wo is defined from your answers to question 2, what velocity do you calculate for each line from the formula above?

Question 5: From your answer to question 4, what is the average of the two velocities?

Question 6: Is the galaxy moving towards or away from the Milky Way? Explain.



This figure was obtained from the paper "Naked Active Galactic Nuclei" by M. Hawkins, University of Edinburg, Scotland. (Astronomy and Astrophysics, 2004, vol. 424, p. 519)

This is a small part of the spectrum of the Seyfert galaxy Q2125-431 in the constellation Microscopium. An astronomer has identified the spectral lines for Hydrogen Alpha (Wr = 6563 Angstroms), and Beta (Wr = 5007 Angstroms).

Question 1: From the graph of the spectrum, use you millimeter ruler to determine the scale of the figure in angstroms per millimeter. Answer: On the Student's page, the wavelength scale from 4000 to 7000 Angstroms measures 100 millimeters, so the scale is (7000-4000)/100 = 30 Angstroms/mm.

Question 2: What are the observed wavelengths of the Hydrogen-Alpha and Hydrogen-Beta lines? **Answer:** Alpha: 7000 A + 30 x (11.5mm) = 7345 A. Beta: 5000 A + 30 x (14.5 mm) = 5435 A.

Question 3: What are the rest wavelengths of the Hydrogen-Alpha and Hydrogen-Beta lines? **Answer:** Alpha = 6563 Angstroms; Beta = 5007 Angstroms.

Question 4: If Wr is defined by your answers to Question 3, and Wo is defined from your answers to question 2, what velocity do you calculate for each line from the formula above? **Answer:** For the Alpha line; Wr=6563 A, Wo = 7345 A. so from the formula Speed = 299792 x (7345-6563)/6563 = 35721 km/s. For the Beta line: Wr = 5007 A, Wo = 5435 A. so Speed = 299792 x (5435-5007)/5007 = 25626 km/s.

Question 5: From your answer to Question 4, what is the average of the two velocities? **Answer:** (35721 + 25626)/2 = 30,700 km/s. **Note to Teacher:** Because it is hard to measure the wavelengths of these lines to less than 1 mm accuracy, the line wavelengths will be uncertain to about 30 Angstroms. This works out to a speed uncertainty of 299792 x (30/5007) = 1,800 km/sec. The actual difference in the two speeds is 35721-25626 = 10,095 km/sec which is <u>much higher</u> than the measurement uncertainty, and may mean that the regions of gas producing the H-Alpha and H-Beta emission are not moving at the same speeds within the galaxy.

Question 6: Is the galaxy moving towards or away from the Milky Way? Explain. **Answer:** Because the observed wavelength of each line is LONGER then the wavelength for the gas at rest, the source is moving away from the observer (just as the pitch of an ambulance siren is lower as it moves away from you).