

Station 1: Examples of Redshifted Spectra from Galaxies

Link to original website:

https://imagine.gsfc.nasa.gov/features/yba/M31_velocity/spectrum/doppler_galaxies.html

The images below show historic spectra and images of several galaxies captured by Milton Humason in the 1930's. Each galaxy was observed to be traveling toward or away from Earth with different velocities. By convention, negative velocities indicate motion toward the observer and a positive velocity indicates motion away from the observer. The velocities are determined by the shift of the spectral lines.

In the image of each spectrum, the middle section shows the observed galactic spectrum. The lines shown on the top and bottom of each spectrum are the spectral lines of hydrogen for comparison. The red arrow in each spectrum indicates the segment of the galaxy's spectrum that is of interest – the "bright" hydrogen line. For each galaxy, that line is compared to the hydrogen spectrum. The horizontal arrow in the other spectra indicates the extent of the spectral shift due to motion. Study the diagrams carefully, and you will notice that the galaxies displaying higher velocity show the greatest Doppler shift (AKA wavelength shift).

In the raw data, the horizontal axes of the spectra would be labelled "wavelength" or "energy."

NGC 221



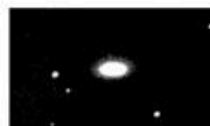
$v = -200 \text{ km/s}$

NGC 4473



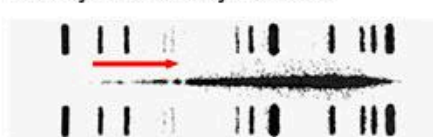
$v = +2,300 \text{ km/s}$

NGC 379



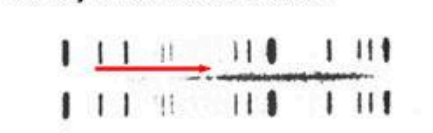
$v = +5,500 \text{ km/s}$

Galaxy in Ursa Major Cluster



$v = +15,400 \text{ km/s}$

Galaxy in the Gemini Cluster



$v = +23,000 \text{ km/s}$

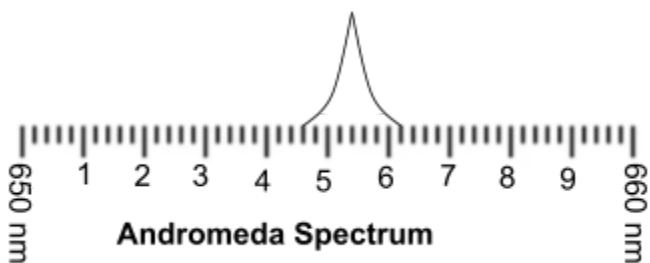
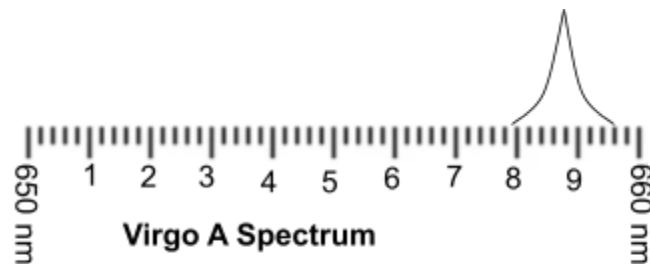
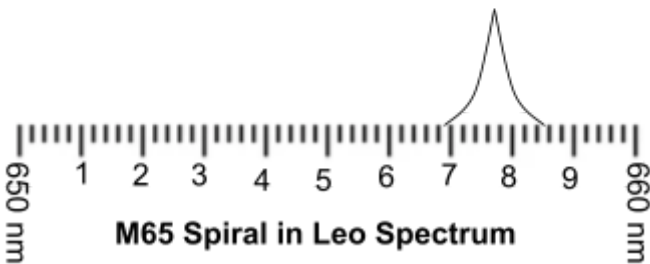
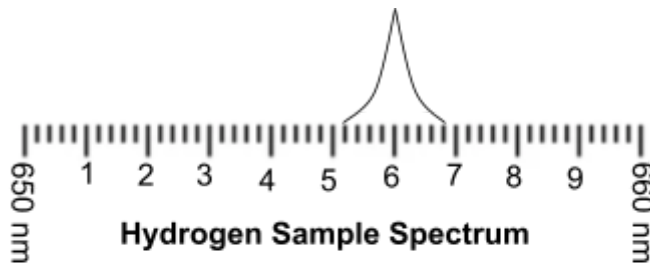
Measuring the shift in wavelength from the laboratory frame enables you to calculate the galaxy's velocity.

Historic spectra of selected galaxies as taken by Milton Humason at the Mount Wilson Observatory in the 1930s.

(Credit: Humason, 1936, The Astrophysical Journal, 83:10)

Station 2: Calculating Velocities of Galaxies

The math to calculate how fast galaxies or stars are moving is not very complex. You need to know how much the galaxy spectrum has shifted, and then compare that shift to the speed of the wave (speed of light). Use the spectra at this station, and the instruction below, to fill out the table on your handout, and find the velocities of the example galaxies.



Step 1 Use the spectra on the left to estimate the location of each galaxy's hydrogen spectrum peak.

Step 2 Each galaxy's spectral peaks have shifted. You will need to compare the position of the galaxy's peak to the original Hydrogen sample peak. Subtract the two numbers to find their **wavelength shift**.

Step 3 Next you will calculate how fast the galaxies are moving based on their wavelength shift. The "regular" hydrogen peak is located at 656 nm. We will find what percent the galaxy wavelengths have shifted and then compare that to the speed of the waves using the speed of light. So we use this formula:

$$\text{Velocity} = (\text{wavelength shift} / 656) \times 300,000$$

Step 4 Galaxy wavelength shift and velocity can both be positive or negative. Positive numbers mean the galaxy is moving away from Earth, while negative numbers mean they are moving towards Earth. Fill in the direction for each of the galaxies.

Step 5 Most human eyes can at best barely perceive a 1 nm difference in

color; I can't. Let's see how fast an object (like a galaxy) needs to travel in order for a human eye to begin to see a color change. Use the equation above to find the speed required for a human to maybe see a color difference.

Station 3: Redshifting Galaxies from Universe Expansion

The slow and steady expansion of the Universe pulls galaxies apart from each other and this also causes redshifting of light. The rate of the Universe expanding is fairly well studied, and while we're not completely sure why and how the Universe is stretching, we do know the rate of expansion pretty well. We now use redshift of distant galaxies caused by universal expansion to calculate how far away galaxies are from Earth. Hubble's Law helps show the relationship between a galaxy's distance and its redshift.

$$\text{Hubble's Law states } v = H D$$

where v is redshift, H is Hubble's constant (64.5), and D is distance in Mpc

Step 1 Use the formula above and a calculator to convert each of your galaxy's redshift into their distance from Earth in Mpc (Mega Parsec)

Step 2 Now that you've found how far these galaxies are, we should make some sense of these numbers. You probably don't know what a Mega Parsec is or how large and far they are. One Mega Parsec is equal to 3,260,000 light years, and a light year is pretty far. Calculate how far your galaxies are in lightyears and fill in that column.

Step 3 Like station 2, we're going to find the limit of human perception. Most people can see a 5 nm difference in wavelength, this corresponds to a speed of roughly 2280 km/s. Use Hubble's Law above to find how far an object would have to be in order for the redshift from the universe expanding to be apparent to the human eye.

Step 4 The farthest we can use telescopes to see individual stars is about 100 million light years. Can we use telescopes to see stars that are noticeably affected by Universal Expansion? (You can decide by comparing to the last step)

Station 4: Finding Exo-planets through Redshift - Blueshift

As you saw within the star spectra gizmo simulation, sometimes planets can have enough gravitational pull on their stars that they move enough to redshift and blueshift. **Exoplanets** are planets that orbit stars outside our solar system. Astronomers are increasingly interested in finding exoplanets and studying other solar systems. We have found a variety of methods for locating exoplanets. The one you will learn about today is called, "Radial Velocity Method".

Please go to Schoology and open the "Radial Velocity Method Article". *Please read the article, and use it to answer the questions on your handout.*