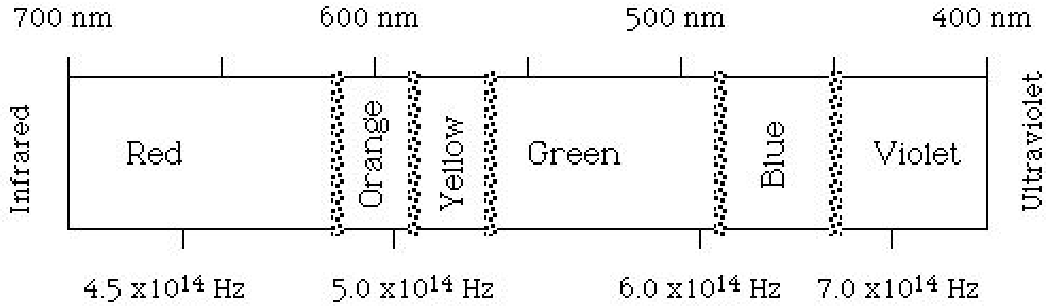
Activity: Cosmic Colors and Spectroscopy

Background:

- The energy of a *photon* of light depends on the wavelength (frequency) of the light
  - higher frequency f = higher energy E = shorter wavelength λ)
  - red light has higher energy / frequency and longer wavelengths than blue light
- Wavelengths of visible light are usually measured in nanometers. One nanometer is one-billionth of a meter (1 nm = 10^{-9} m). The human eye responds to wavelengths between 400 nm & 700 nm.



Visible Light Spectrum

- Electrons within atoms can only be in certain energy levels, with each atom having a *unique* pattern of energy levels
- Photons can be absorbed or emitted by atoms, but ONLY if they have an energy that matches the difference between internal energy levels of the atom
  - If an atom absorbs a photon, the electron jumps up one or more energy levels
  - If an atom emits a photon, the electron falls down one or more energy levels
- Each element can only absorb or emit certain colors of light. The absorption spectrum of each element is like a "fingerprint".
- Split light up according to wavelength (energy) ➔ see a *spectrum* of various colors
  - A *continuous spectrum* is one where all colors are visible. Hot dense objects (like a bulb filament, or the center of a star) emit this kind of spectrum, producing thermal (blackbody) emission:
    - Hotter objects produce more light per unit area ***at every wavelength***
    - Hotter objects produce a larger fraction of their light at shorter wavelengths. This makes them look bluer
  - An *absorption-line spectrum* has a bright background, but dark lines where certain colors (energies) of light have been absorbed by matter. This happens when a cool cloud is in front of a hot dense object.
  - An *emission-line spectrum* has a dark background, with bright lines where certain colors (energies) of light have been emitted. This occurs when a thin, excited cloud is viewed.

Activity: Types of Spectra

Lab Materials:

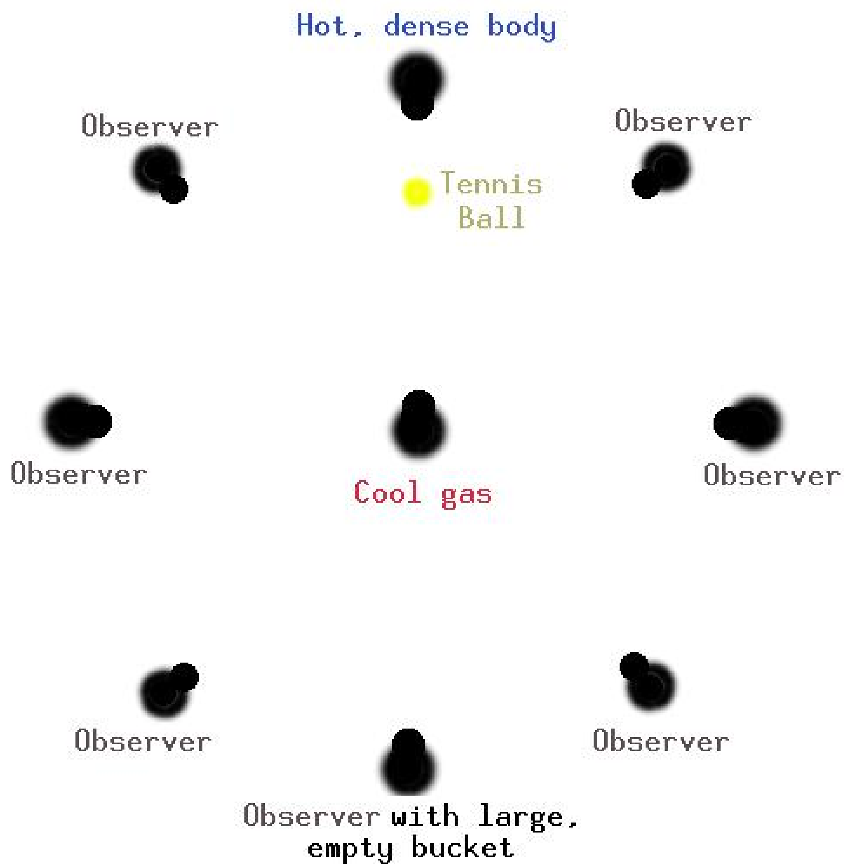
- 60 colored balls: ten each red, orange, yellow, green, blue, violet
- several small buckets, 2 large buckets
- colored markers
- computer with internet access

Setup: (see figure on next page)

- We will shortly be doing an activity involving a group of students.
- The group of students will form a circle around a student in the center, about 5m across.
- One student is a hot dense object, and takes a large bucket with ALL the balls in it, and a small bucket.
- The center student is the cool, thin, gas cloud.
- The other students are observers from various angles. Each of these students is given a small bucket, except the student directly opposite the 'hot dense object', who takes the large (empty) bucket.

Plan:

- The *hot dense* object will emit photons (colored balls; one ball at a time!) of all colors (wavelengths) equally towards the person in the center and the observer beyond.
- The cool *thin cloud* (center student) will catch the orange and blue balls (absorbing photons with a particular energy/wavelength), *becoming excited,* then toss the orange/blue balls (re-emitting photons with those same energies/wavelengths) in ***RANDOM*** directions (including the student behind them, and the hot dense object), *becoming de-excited.*
- The cool *thin cloud* (center student) will let all other balls pass to the observer behind him/her (these photons don't have the right energy for him/her to absorb).
- All observers will catch their balls and place them in their containers.
- After all the balls have been thrown (and caught!), the students each make a spectrum on the board representing the number of balls of each color. Have the spectra drawn in locations representing where the students were in the circle.
- If there are too many students, the others can either watch, and make sure everyone's doing it right, or form a separate circle (if there are enough balls).



<u>Predictions:</u> (write on board)

1. Observer with large, empty bucket:
   a. What color balls will this observer have?

   b. Will this observer have an equal number of each color?

   c. What type of spectrum would this observer see, when looking at a hot, dense body through the cloud of gas?

2. Other observers:
   a. What color balls will these observers have?

   b. What type of spectrum would these observers see, when looking at the thin, excited gas?

<u>Do the activity</u>

<u>Discussion:</u>

3. Compare the results of the 'experiment' with the predictions.

4. Ask the students to predict what an observer would see if they were BETWEEN the hot dense body and the gas cloud:
    a. looking towards the hot dense object

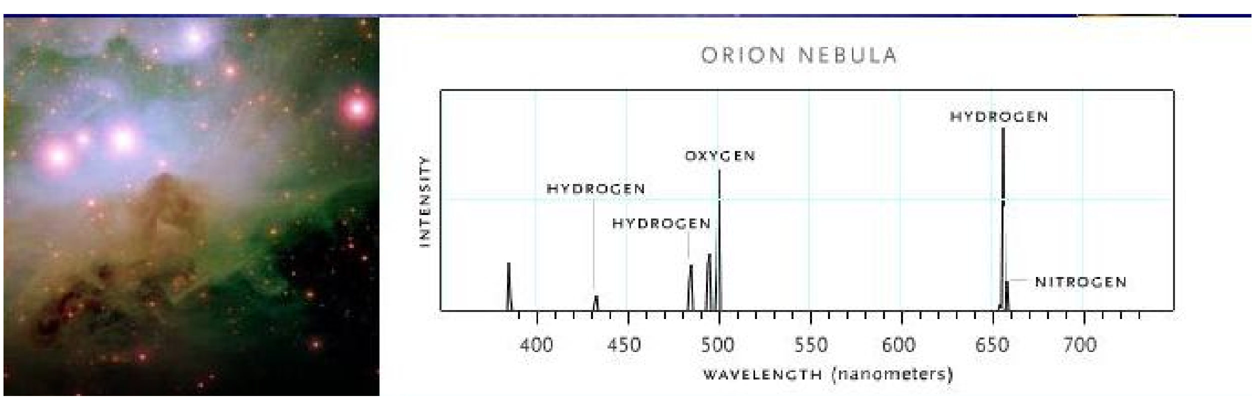
    b. looking towards the gas cloud.

5. Have the students suggest ways to improve the accuracy of this representation. For example, having the 'gas cloud' step up onto books of different heights depending on which ball they've caught, and then step down when they throw the ball would more accurately represent the changing energy state of the atoms in the cloud.

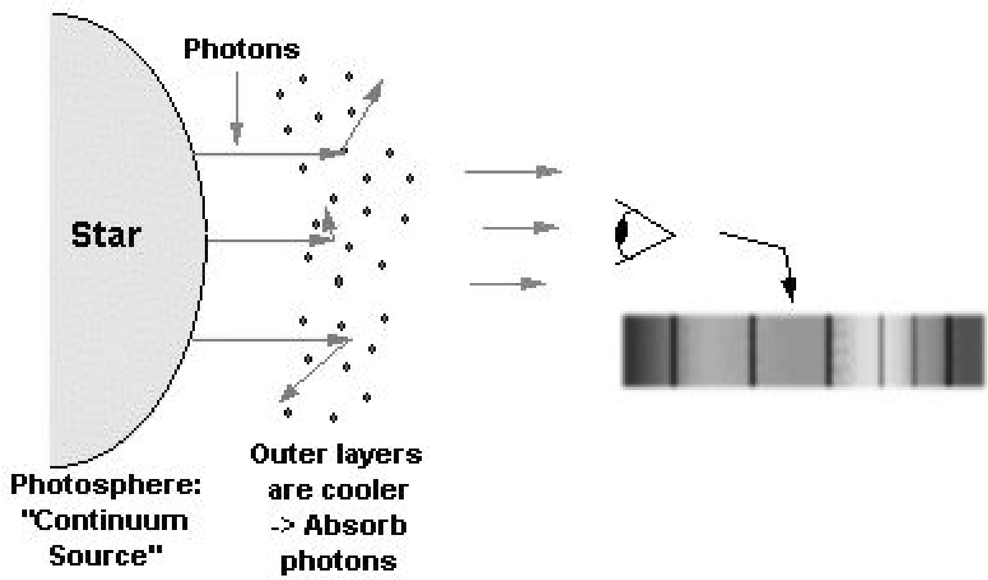
Applications:

1. The Orion nebula is a bright cloud of gas and dust. It is visible to the naked eye as a fuzzy patch in the constellation of Orion. Hot stars form inside the nebula, and excite the thin gas of the nebula.
    a. What type of spectrum (continuous, emission-line, or absorption-line) would you expect the Orion nebula to have? Explain.

    b. The following spectrum of the Orion nebula was taken from: http://www.pbs.org/wgbh/nova/origins/spectra.html. Does this match your expectation?



2. The centers of stars are hot and dense, but the outer layers are much cooler and thinner.
    a. What type of spectrum would you expect the Sun to have?



This image showing why stars have absorption-line spectra comes from: http://www.astro.columbia.edu/~archung/labs/spring2002/lab01.html

b. Explain why the Sun's spectrum has absorption lines.

3. Each element can only absorb certain colors of light. The absorption spectrum of each element is like a "fingerprint".
   - Go to: http://www.ioncmaste.ca/homepage/resources/web_resources/CSA_Astro9/files/multimedia/unit2/stellar_spectra/stellar_spectra.swf
   - Choose the "Classify Spectra" Activity

   a. What elements are present in the simplified spectrum of the Sun?

   b. What elements are present in the spectrum of Star A?

   c. What elements are present in the spectrum of Star B?

   d. What elements are present in the spectrum of Star C?