Astronomical Ideas Fall 2012
Homework 3 Solutions

1. How bright would the Sun appear in the sky to an observer on Pluto (average distance from the Sun ~ 40 AU), compared to an observer on Earth?

The apparent brightness of a star is

\[
\frac{L}{4\pi d^2} \propto \frac{1}{d^2}
\]

Because we are asked to compare the apparent brightness of the Sun at two locations (Earth, \(d = 1\) AU, and Pluto, \(d = 40\) AU), we either want to set-up a ratio (“compare” = ratio) or want to take advantage of the inverse-squared proportionality. Ratio:

\[
\frac{\text{Earth}}{\text{Pluto}} = \frac{L_{\text{Sun}}}{4\pi d_{\text{Earth}}^2} \div \frac{L_{\text{Sun}}}{4\pi d_{\text{Pluto}}^2} = \left( \frac{40\text{AU}}{1\text{AU}} \right)^2 = 1600
\]

The Sun appears 1600 brighter to an Earth-based observer than a Pluto-based observer. Alternatively, we can simply notice that the only difference between the Pluto and Earth calculation is the distance between the planet and the Sun (Pluto is 40x farther than Earth). The apparent brightness of an object is inversely proportional to its distance squared, so the apparent brightness of the Sun is \(40 \times 40 = 1600\) times fainter to a Pluto-based observer than to an Earth-based observer.

2. Calculate the Sun’s luminosity in watts given its observed surface temperature of \(~5800\) K and observed radius of 700,000 km. Use \(\sigma = 5.67 \cdot 10^{-8} \text{Wm}^{-2}\text{K}^{-4}\).

\[
L = \sigma T^4 \ 4\pi R^2 \sim 3.9 \cdot 10^{26} \text{Watts}
\]
3. a. This is an emission line spectrum produced by a heated tube of hydrogen gas. What is the x-axis of this spectrum? What does the black show? What do the colored lines show? (Best to look at this figure on your computer screen rather than a b/w printout.)

The x-axis of a spectrum is wavelength (or color or energy). The black areas show the large range of wavelengths at which hydrogen gas does not emit or absorb energy, and the colored lines show four, distinct wavelengths of light at which hydrogen emits energy. This set of lines shows the part of hydrogen’s fingerprint that resides in the optical part of the spectrum.

b. Explain (briefly) why this pattern of lines can be considered the “fingerprint” of hydrogen.

Every element has its own unique spectrum - unique energies at which it can emit or absorb energy - just like fingerprints are unique. We can thus identify the presence of hydrogen in a gas by observing this pattern of energy lines emitted or absorbed by that gas.

A gas produces spectral lines when its electron’s absorb or emit energy. The energy levels available to the electrons in each element are unique, and are largely determined by the charge of the atom’s nucleus, the number of electrons, and the laws of quantum mechanics and E&M. Each element has a different combination of protons in the nucleus+orbiting electrons, so each element has a different set of energies that its electrons may emit or absorb.

[All of the above is not necessary for full credit, but there needs to be some deeper engagement than the first sentence of this example answer to receive full credit.]
4. Explain (briefly) why the Hubble Space Telescope has been such a revolutionary telescope for astronomers. Explain (briefly) what will be different about the James Webb Space telescope.

The Earth’s atmosphere causes stars to “twinkle”. This effect causes optical astronomical images from the ground to be blurry relative to the optical images that can be obtained above our atmosphere. Because HST is in low Earth orbit above our atmosphere, it can obtain very high resolution images. [Students can also give other reasons, but must say something about the image quality benefit to the telescope being above the atmosphere/in orbit].

The JWST has several differences from HST. The aperture will be much larger (6.5m versus 2.5m), the wavelength of observation will be in the infrared (HST primarily observes at optical wavelengths), and its orbit will be farther than that of HST - meaning that it cannot be serviced. Because this is an infrared telescope rather than an optical telescope, the primary scientific questions that will be pursued are different than HST. One big science goal will be to find the most distant/youngest galaxies in the universe. [Students don’t need to give all of these reasons. Should give two out of the three: aperture, wavelength, orbit location.]