Ay 7A – Fall 2009
Section Worksheet 4
Diffraction Action, Get Some Satisfaction

1. **A Two-Star Household**

   Consider a binary star system. Star A has a radius $R_A = 2R_\odot$ and a temperature $T_A = 5000$ K. Star B has a radius $R_B = 0.5R_\odot$ and a temperature $T_B = 10000$ K. The system is located 20 pc from Earth, and the two stars are separated by 5 AU. Suppose that these two stars are in circular orbits around their barycenter (i.e. center of mass) and that we are observing the orbits edge-on.

   Note that except for part (a), you should not have to do any numerical calculations for this problem.

   (a) Assuming you are observing this binary system with the Keck Telescope (10 m diameter) at a wavelength of 5000 Å, could you resolve the binary system? (In other words, could you tell if this was a binary system just by imaging it with Keck?) Ignore any atmospheric effects.

   (b) If the atmospheric seeing limits resolution to 0.5", can you still resolve the individual stars?

   (c) Draw (qualitatively) the lightcurve (i.e. flux observed versus time) of one full period of the *total* system. In other words, what is the combined flux of this system versus time. You can assume here that flux here means "bolometric flux" (i.e. integrated over all wavelengths).

   (d) If this system were seen face-on instead of edge-on, what would the lightcurve look like?

(e) In the edge-on lightcurve, there should be two dips in brightness for every orbital period (make sure you understand why!). Which dip is bigger (i.e. larger drop in observed brightness) or are they equal in size?

(f) What if Star B had $T_B = 2500$ K?

(g) What if Star B had $T_B = 5000$ K?

2. **Radio Telescopes vs. Mosquitoes**

   The Very Large Array (VLA) in Socorro, New Mexico is a 27 dish radio telescope array. Each dish is 25 meters in diameter. The VLA has been operating since 1976.

   (a) Assume that the VLA has been continuously observing a source with a flux density of 1 Jansky (Jy) using a bandwidth of 10 MHz since 1976 and that it is 100% efficient. Estimate how much total energy it has detected in that time. (Recall that 1 Jy = 10^{-23} erg s^{-1} cm^{-2} Hz^{-1}.)

   (b) Estimate how much energy is expended by a mosquito doing 1 push-up. How many push-ups does the mosquito need to do to match the total amount of energy detected by the VLA?

   (c) (**OPTIONAL**) The VLA can be put into many different configurations which achieve different angular resolutions. In the "A configuration" the maximum separation between the dishes is 36 kilometers. What is the smallest angle that can be resolved by the VLA in this configuration at a frequency of 1 GHz?

3. **How Fat is Your Hair**[1]

Even though we approximate many astrophysical sources (such as stars) as point sources, we know that quantum mechanics won't allow nature to let us observe *exact* point sources. The *diffraction limit* (as referred to in the above problems) is the absolute smallest angle that a telescope can resolve, even under perfect atmospheric conditions.

Recall that the diffraction limit comes from the fact that incoming, parallel light rays from a source diffract when they enter the telescope aperture and cause destructive and constructive interference. Thus the light in your telescope is smeared out in a series of maxima and minima, with the majority of light contained within the first maximum.

In lecture we saw pictures of these so-called Airy Discs or Rings and learned that the pattern can be described by:

$$\sin\theta_m = \frac{m\lambda}{d}$$

where d is the diameter of your diffraction slit (in most cases the diameter of your telescope), λ is the wavelength of the light you are observing, m is the order of the minimum (always an integer), and θ_m is the angle between the principle maximum and m^{th} minimum.

Using the principle of diffraction (along with a laser pointer and a ruler that measures lengths no smaller than 1 cm) we are now going to measure the thickness of your hair. First acquire a hair (please don't pick one up off the ground, that's gross!) by having one person in your group gently run a hand through his or her hair. At least one hair should easily remove itself. That person will hold the hair throughout the experiment.

QUICK LASER SAFETY NOTE: Lasers are incredible devices that produce a stream of coherent photons at a single wavelength. Today we will be working with red laser pointers which have $\lambda \approx 7250$Å. As a coherent light source lasers can be extremely dangerous and should not be treated as a toy. Do not under any circumstances shine the laser at another person, especially another person's face. Even with these lasers, considerable damage could be done to someone's eyes.

(a) Have someone who's *not* holding the hair place the laser on a table a couple meters or so from a wall and point the laser toward the wall. Record the distance from the laser to the wall.

(b) Now, have the person holding the hair slowly pass the hair through the laser beam just in front of the laser pointer. Write a brief description of any changes you see on the wall.

(c) While the hair is in the laser beam, have a third person measure the distance between the principle maximum and the first minimum of the pattern on the wall.

(d) Use the information you've gathered (and that has been given to you) in this problem to calculate the width of your hair.

[1]Thanks to Chat Hull and Adam Miller for coming up with this activity.