Please write neatly and show your work. Write down the governing equation first, being careful with units and specifying what units you’re using (and especially what units your answer is in). Unless stated otherwise, answers correct to two decimal places will receive full credit, and so you should be able to do most computations by hand. Also, big magnitude answers should be given in scientific notation. Please put a box around all your final answers. Answers without a box may not receive credit.

You are allowed (even encouraged) to work together. But make sure the work you hand in is your own. That is, you should write up your solutions in (virtual) isolation; you can discuss a problem with a classmate and even solve it together, but you shouldn’t look at each other’s write-ups as you’re writing up your own solutions). Finally, at the top of your front page, near your own name, I ask that you explicitly list the name of all persons with whom you consulted in solving the problem.

1. Energy flux and magnitude:
   a. Suppose two objects have energy fluxes of $f$ and $f + \Delta f$, where $\Delta f \ll f$. Derive an approximate expression for the magnitude difference $\Delta m$ between these two objects that depends only on the ratio $\Delta f / f$. (Hint: note that $\ln(1 + x) \approx x$ for $x \ll 1$.)
   b. What magnitude difference do you get for a flux difference of 10%?

2. Angles, magnitudes, inverse square law:
   a. How far from the Earth would the Sun have to be moved so that its apparent angular diameter would be 1 arc second? (Express your answer in AU.)
   b. How far away (in km) would a Frisbee of diameter 30 cm have to be to subtend the same angle?
   c. At the distance you calculated in (a), by what factor would the solar flux at earth be reduced?
   d. What would the Sun’s apparent magnitude be? (Use $m_\odot = -26.7$ for the actual Sun, the one that’s at 1 AU.)
3. **Galaxies: distance, magnitude, and solid angle:**
   a. What is the apparent magnitude of a galaxy that contains $10^{11}$ stars identical to the Sun (i.e., assume its luminosity is equal to $10^{11} \, L_\odot$) if it’s at a distance of 10 million parsecs?
   b. If the galaxy is circular in shape, as seen from the Earth, and has a diameter of 50,000 pc, what is its apparent angular diameter, in both radians and degrees?
   c. What solid angle does it subtend (in steradians and in square degrees)?
   d. How does the galaxy’s surface brightness (energy/time/area/solid angle) compare to the Sun’s (express this as a ratio)?

4. **Equilibrium Temperature of Earth:**
   a. Assuming Earth is a blackbody, use the known luminosity and distance of the Sun to estimate Earth’s average equilibrium surface temperature if the solar energy it intercepts is re-radiated to space according the Stefan-Boltzman law. Compare this to the temperature on a moderate spring day in Delaware.
   b. According to [http://en.wikipedia.org/wiki/Earth](http://en.wikipedia.org/wiki/Earth), Earth’s has an “albedo” of $a = 0.633$, meaning the fraction of received light that is reflected by, e.g. clouds, snow, etc., without contributing any heat to Earth. So now redo the calculation in (a) reducing the solar input energy by $1 - a$.
   c. Which result seems more “reasonable”? Briefly discuss what other physics might be important to include to understand the actual surface temperature of Earth.

5. **Parallax of Mars:**
   In 1672, an international effort was made to measure the parallax angle of Mars at opposition, when it was on the opposite side of the Earth from the Sun, and thus relatively close to Earth.
   a. Consider two observers at the same longitude but one at latitude of 45 degrees North and the other at 45 degrees South. Work out the physical separation $s$ between the observers given the radius of Earth is $R_E \approx 6400 \, \text{km}$.
   b. If the parallax angle measured is 22 arcsec, what is the distance to Mars? Give your answer in both km and AU.