Astronomy 350 Fall 2012
Homework #3

Due in class: Friday, Sept. 21

1. *Dark Matter*. In the previous homework you showed that measuring orbits in a gravitating system allows one to calculate the mass giving rise to the system's gravity. Namely, if the mass inside radius r is given by

$$M(r) = \frac{v^2 r}{G} \quad (1)$$

where v is the speed of objects at radius r, and G is the constant in the universal gravitation law. We will now apply this result.

   (a) [**5 points**]. The Large Magellanic Cloud (LMC) is a small galaxy that orbits as a satellite of the Milky Way. The LMC lies at a distance of about $R = 50$ kpc and moves with a speed of about $v = 200$ km/s around the Galactic center. Using these data, calculate the mass M of material inside the orbit of the LMC. Be careful with units! Probably the best thing is to convert everything to meters, kg, and seconds first. Finally, express your answer in terms of the mass $M_\odot = 2.0 \times 10^{30}$ kg of the Sun, i.e., find $M/M_\odot$. Comment on the significance of this result.

   (b) [**5 points**]. How can the result from part (a) be used to tell that our Galaxy contains dark matter? What other information is needed to come to this conclusion?

   (c) [**5 points**]. What tells us dark matter is "dark"? What tells us it is "matter"?

   (d) [**5 points**]. What is a possible candidate for dark matter? What about it makes it a good candidate–that is, how does it fit the definition of dark matter from part (c)?

   (e) [**5 points**]. It is possible dark matter does not exist. If so, what is an alternate scientific explanation of the observations that led to the idea of dark matter?

   (f) [**5 bonus points**]. The solar system may contain dark matter. But if so, the mass in the form of dark matter is much less than the mass in the Sun. To appreciate how we know this, imagine the opposite–imagine that the solar system contained large amounts of dark matter, say in the form of ghostly invisible particles. For simplicity, imagine they are spread uniformly, so that the dark matter has a constant density throughout the solar system. Imagine further that the dark matter density is large enough a sphere of radius 5 AU would contain as much mass in dark matter as the ordinary mass of the Sun.

   Explain how we could observe the effects of this large density of dark matter even if we don't detect the particles? You need not do any calculations, but be specific about what observations would be needed to infer the presence of the solar system dark matter. *Hint:* you might think about the effect on the orbits of the planets, asteroids, comets, etc.

2. *Thermal Radiation.* [**5 points**] Celsius and Fahrenheit temperatures are related by $T_{\rm C} = (5/9)(T_{\rm F} - 32)$. Using this, calculate the temperature of a healthy human in

Kelvin units. Then go on to use Wien's law to calculate the peak wavelength of thermal radiation from a human. What kind of light is this (see for example Fig. 2.20 of Duncan & Tyler). Is your result consistent with the familiar result that you don't see people glowing in the dark?

3. *Telescopes as Time Machines.* It is crucial for astronomy and especially cosmology that the speed of light, c, is finite. Because of this, telescopes are time machines. Indeed, even your naked eye is a time machine.

   Note: all of these questions require you to comment on your answers. As with all such questions, your comments are necessary to receive full credit–do not just give a number, but use it to respond to the question you are asked to remark on.

   (a) [**3 points**]. Estimate the length, in meters, of the ASTR350 classroom (Astronomy 134). Then compute the time it takes for light to travel from the front to the back of the room. About how far back in the past is the lecture, as seen by someone seated in the front row? the middle row? the back row? Comment on why these different delays don't make for enormous confusion.

   (b) [**3 points**]. The Moon orbits the Earth at a radius of $360,000$ km. How long does light take to go from the Moon to the Earth? Comment on how this delay figures into the radio transmissions with lunar astronauts. (If you are curious to test your answer, audio for these can be found online in various NASA sites!)

   (c) [**3 points**]. Now compute the time delay to Mars, when it is at its closest and most distant distances from the Earth (note that $a_{\rm Mars} = 1.4$ AU). Comment on implications for the Mars rovers (e.g., imagine one driving near the edge of a cliff!) and for future Mars astronauts.

   (d) [**3 points**]. Find the light travel time to the nearest star, α Centauri, located at 1.3 parsec (see HW 1 for conversion to meters). Imagine there are space aliens on αCen, then (i) sketch one, and (ii) comment on what they see going on here when they look at us with high-power telescopes and/or tune in to our TV transmissions (which leave Earth as radio waves).

   (e) [**3 points**]. The nearest galaxy like our own is the Andromeda galaxy (nickname: M31), which is 0.7 Mpc $= 0.7 \times 10^6$ parsecs away. What would a space alien in M31 see if they looked today at the Earth with a high-powered telescope?

   (f) [**5 points**]. Explain how we can uncover (most of) the past history of the universe by looking out across the cosmos.