Astronomy 350 Fall 2011
Homework #3
Due in class: Friday, Sept. 16

1. *Alternative Universes: A New Gravity Law* [**10 points**]. In class we saw that Newtonian gravity provides an incredibly successful theory of motion in the solar system and in many other astronomical systems To get an appreciation for how Newton's gravity affects our lives, let's imagine a universe with a different gravity law. In this "bizarro" universe, the gravity force between two masses (call them m_1 and m_2) is still attractive, is still directed along a line between them, and is still proportional to each of the masses, and still depends on the distance R between the two masses.

   In our real universe, Newton's gravity force depends on the inverse square of the disance, so we have a gravity force $F_{\rm grav,us} = G_{\rm us} m_1 m_2 / R^2$. However, in the alternate bizarro universe, the gravity force depends *directly* on the distance, so that the gravity force is $F_{\rm grav,bizarre} = G_{\rm bizarre} m_1 m_2 R$, where $G_{\rm bizarre}$ a constant number measured by the bizarro universe cosmologists. What are some ways in which the bizarro universe be different from ours? Do not do any calculations, but think about what would happen as a result of the difference in the gravity force law. Hint: you might think about what (if anything) be different for planets, the Sun, the solar system, or our Galaxy).

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.

   (a) [**5 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) [**5 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) [**5 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) [**5 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) [**5 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.

4. *The Doppler Effect.*

(a) [**5 points**] After an Astronomy 350 exam, you blow off steam by driving to Chicago for concert. Please indicate who you are going to hear. As luck would have it, you are running a bit late, and have a bit of a lead foot as you zoom up I-57. You pass a stationary law enforcement officer. Officer Grumpy uses a radar gun that emits radio waves and detects their reflection which has bounced off your motor vehicle (please specify type). If the radar gun operates with wavelength $\lambda_{\rm emit} = 3$ cm, calculate the wavelength shift $\Delta\lambda$ caused by speed of $v = 80$ mph $= 130$ km/hr (*hint*: be careful that you put all speeds in the same units!). Express $\Delta\lambda$ in cm. Comment on the wavelength measurement accuracy needed for the radar gun to reveal your having won a ticket.

Will the measured shift be bigger or smaller if the Officer Grumpy is not parked on the roadside but following behind you?

(b) [**5 points**] Show that for wavelength shifts with $\Delta\lambda > \lambda_{\rm emit}$, the approximate (low-speed) Doppler formula gives speeds larger than the speed of light.

As we will discuss, Einstein frowns on this result. But more than just complaining, he did something about it, by giving a formula which is exact and good for all speeds:

$$\frac{\Delta\lambda}{\lambda_{\rm emit}} = \sqrt{\frac{c+v}{c-v}} - 1 \tag{1}$$

where c is the speed of light. Find the speed v needed to create a wavelength shift $\Delta\lambda = 2\lambda_{\rm emit}$, and the speed needed to create a shift $\Delta\lambda = 1000\lambda_{\rm emit}$. Show that in both cases, $v < c$, in contradiction of the approximate formula. On the other hand, show that for $\Delta\lambda = 0.001\lambda_{\rm emit}$, the result from the approximate formula is almost identical to the exact answer. In all of your answers, you my express speeds in terms of the speed of light, for example, $v = 10c$, $v = 0.99c$, etc.