Problem Set 9 Solutions, AST 205, Fall 2003

1. (6 points total).
If 13.7 billion years is to be shrunk down to one year, then one month of the Cosmic Calendar corresponds to just under a billion years, one day is 37 million years, and one second is 441 years.
With this under our belt, let's go through the list:

- First stars and quasars formed about 200 million years after the Big Bang, or 5 days. *January 5.*
- The Sun formed about 4.5 billion years ago, or 9.2 billion years after the Big Bang. This is 248 days, or roughly *mid-August*.
- The earliest known life is about 3.8 billion years old, about 19 days later, or *early September*.
- An oxygen atmosphere formed on Earth about 2 billion years ago, or 53 days before the end of the year; roughly *November 7*.
- Land animals appeared about 300 million years ago, or eight days before the end of the year, *December 23*.
- Dinosaurs came into their own soon thereafter, about 50 million years later, or just about on *Christmas day.*
- The asteroid impact that wiped out the dinosaurs happened 65 million years ago, or in the *early morning hours of December 30.*
- Homo Sapiens appeared on the scene around 130,000 years ago, or 300 seconds before New Years; that is, *11:55 PM on December 31.*
- 0 AD was 2000 years ago, or 5 seconds before midnight, *11:59:55 PM on December 31.*
- Princeton University was founded 250 years ago, or about 1/2 second before midnight: *11:59:59.5 PM on December 31.*

2. (9 points total)
We're asked here for the peak wavelength of light reflected and reradiated by Venus, Earth, Mars, and the Moon. The reflected light part is easy: this is sunlight being reflected, so the peak wavelength for all four bodies must be the peak wavelength of sunlight, roughly 5000 Å.
For the reradiated light, we need to figure out the effective temperatures at the top of the clouds of each of these planets. I'll use the formula in the solutions to Problem 2 in problem set 7 for the equilibrium temperature of a planet:

$$T_{planet} = T_{star}(1-A)^{1/4}\left(\frac{R_{star}}{2\,D}\right)^{1/2}$$

For each of Venus, Earth, Mars, and the Moon, we know:

- T_{star} is the temperature of the Sun, 6000 K.
- R_{star} is the radius of the Sun, 7×10^{10} cm.

- D is the distance from the Sun to the object in question, namely 0.7, 1, 1.5, and 1 AU.
- A is the albedo, given as 0.75, 0.60, 0.15, and 0.07, respectively.

Now it is plug-and-chug: we find the temperature of each of these bodies to be:

- Venus has a temperature of 250 K (this is the surface of the clouds; *not* the surface temperature under the clouds!)
- Earth has a temperature of 230 K (remember we haven't included the Greenhouse effect).
- Mars has a temperature of 230 K as well.
- The moon has a temperature of 285 K.

Now, we know that the peak wavelength emitted by a black body of a certain temperature is inversely proportional to the wavelength: $\lambda_{peak} = 2.9\, mm/T$. With this equation in hand, it is straightforward to calculate the peak wavelength of the reradiated emission in each case:

- Venus' radiation peaks at 11.6 microns.
- Earth and Mars peak at 12.6 microns
- The moon peaks at 10 microns.

To a very good approximation, all four peak at roughly the same wavelength, in the infrared part of the spectrum.
There were two common misconceptions here. The first was to assume that the reflected light also followed a blackbody curve, and calculated the temperature and peak wavelength corresponding to that. That is not the case. The more serious problem that some of you had was pulling an equation out of another branch of physics: you calculated the total amount of energy per second absorbed by the planet, and calculated what is called the de Broglie wavelength corresponding to that amount of energy: $\lambda = hc/E$. This is the wavelength of a *single* photon containing all the energy absorbed by the planet each second! That is not the way planets radiate, needless to say...