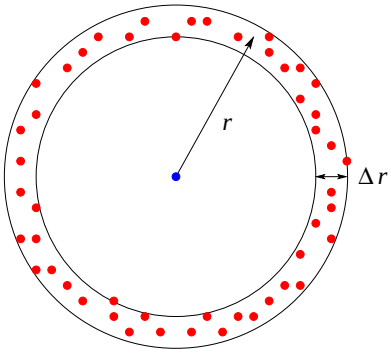
Astronomy 350 Fall 2011
Homework #9
Due in class: Friday, Nov. 18

1. *Olber's Paradox and the Dark Night Sky.* There is important cosmological information encoded in the simple observation that the night sky is dark.

   To appreciate this, imagine a pre-modern view of the universe: static, infinitely large, infinitely old, filled with stars of unchanging luminosity. Let's call this the "naïve cosmology." Already in the 1700's, it was realized that such a universe can't be the one we live in.

   (a) [**5 points**]. In this "naïve cosmology," let's assume the universe is everywhere filled with a constant density $n_\star$ of stars per volume, each with the same luminosity $L_\star$.
   Consider a thin shell of such stars, centered on us, with radius r and thickness Δr; see diagram on right. Show that

   i. each star will be seen with flux $F_\star = L_\star/4\pi r^2$,
   ii. the number of stars in the shell is $N_{\star,\mathrm{shell}} = 4\pi r^2\ \Delta r\ n_\star$, and
   iii. the total flux coming from the shell is $F_{\mathrm{shell}} = L_\star n_\star \Delta r$.

   Explain why F_{shell} does not depend on the shell distance r.

   (b) [**5 points**]. In part (a) we found the flux one sees coming from one shell of cosmic stars. But in the naïve cosmology, space is everywhere filled uniformly with stars, which means there are many such shells; imagine they are all of the same thickness. Each shell has flux $F_{\mathrm{shell}} = L_\star n_\star \Delta r$, and so the total flux one sees (i.e., the brightness of the sky F_{sky}) is the sum from adding up the fluxes from *all* shells. Show that in the naïve cosmology, this sum leads to a total flux F_{sky} which is in violent contradiction with the darkness of the night sky. This contradiction is known as Olber's paradox, named after one of the first people to notice it.

   (c) [**5 points**]. The real universe differs from the naïve universe in several respects, several of which alleviate Olber's paradox. In fact, even if the universe is infinitely large (as we think it may be!) it is enough that the universe has a finite (not infinite) age. Explain how this gets us out of Olber's paradox. *Hint*: recall that light moves at finite speed c, and reconsider part (b) in view of this.

   In light of your answer, comment on the cosmological significance of the dark night sky.

2. *The Cosmic Microwave Background and Prizewinning Cosmology*

   (a) [**5 points**]. How can we see the CMB if the photons were released 14 billion years ago? Shouldn't those photons be billions of light years away by now?

   (b) [**5 points**]. Who was awarded the 2006 Nobel Prize for Physics? What was the prize for–what were the results, and how were they obtained?

   (c) [**5 points**]. What is the importance of the results you discussed in part (b)?

3. *Primordial Nucleosynthesis.*

   (a) [**5 points**]. Why is helium (i.e., ^{4}He) the most abundant complex nucleus (i.e., containing more than one proton or neutron) in the universe? Why doesn't the big bang go on to make all heavy elements?

   (b) [**5 points**]. Why can't the composition of the Earth and/or the Sun be used to test the predictions of big bang nucleosynthesis? What is the problem, and why is this problem alleviated in the systems that *are* used to test primordial nucleosynthesis?

   (c) [**5 points**]. What is a baryon? How does big bang nucleosynthesis show that there must be two kinds of dark matter today: baryonic and non-baryonic?

   (d) [**5 points**]. What is the significance of the existence of non-baryonic dark matter? Give a known (i.e., already confirmed to exist) example of non-baryonic dark matter.