Ay 10 - Section Worksheet 8

The Big Bang(!) and Alien Encounter(?)

The Cosmic Microwave Background

The Big Bang predicts that the early universe was a very hot place and that as it expands, the gas within it cools. This means that the universe should be filled with radiation that is literally the remnant heat left over from the Big Bang, called the **cosmic microwave background radiation**, or **CMB**.

The existence of the CMB was first predicted by George Gamow in 1948. It was first observed inadvertently in 1965 by Arno Penzias and Robert Wilson at the Bell Telephone Laboratories in Murray Hill, New Jersey.

The radiation was acting as a source of excess noise in a radio receiver they were building. At first they couldn't find an explanation for their observations and they even considered the possibility that it was due to "a white dielectric substance" on their receiver (*i.e.* bird poop). It was soon realized that the signal they had accidentally detected was actually photons left over from the Big Bang. Penzias and Wilson went on to share the 1978 Nobel Prize in physics for their discovery.

Today, CMB observations are a huge part of modern observational cosmology and much cutting edge research is still going on this area. In fact, this year's Nobel Prize in Physics went to John C. Mather (from the NASA Goddard Space Flight Center) and Cal's own physics professor George F. Smoot "for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation."

1. Now back to Penzias and Wilson. Back in the 60's they detected blackbody radiation that peaked at a wavelength of about 1.1mm. What part of the electromagnetic spectrum does this correspond to?

2. What is the temperature of the CMB photons that they detected?

Recall that the redshift today, z_0, is defined to be 0 and that z increases as we go further back in time. Also, a photon's temperature scales as $(1+z)$. Furthermore, astronomers have shown that CMB photons were emitted with an initial temperature of about 3000 K.

3. Using this information, along with the current CMB temperature that you calculated above, at what redshift were the CMB photons emitted?

The age of the Universe, t, can be roughly calculated from the equation $t \approx 13.7\times10^9\,(1+z)^{-3/2}$, where t is in years. Note that today $z = 0$ and so the universe today is about 13.7 billion years old.

4. Using this equation, calculate how old the universe was when the CMB photons were emitted.

The Drake Equation

The **Drake Equation** was developed by American astronomer Frank Drake (now a professor at UC Santa Cruz) in 1961 as a way to focus on the factors which determine how many intelligent, communicating civilizations there are in our galaxy at any given time. The Drake Equation is:

$$N = R_s * f_p * n_e * f_l * f_i * f_c * L$$

The equation can be thought of as seven questions where scientists have more accurately determined some answers more than others[1]. Discuss each question with your group and come up with an answer (*i.e.* a number for each variable in the equation). At the end you will multiply all your answers together to calculate the number of communicating alien civilizations in the Milky Way.

- R_s is the rate of star formation in the galaxy (in stars per year).

  Question: How many stars per year are formed in the Milky Way?

- f_p is the fraction of stars that have planets around them.

  Question: What percentage of stars have planetary systems?

- n_e is the number of planets (or moons) per star that are capable of sustaining life.

  Question: For each star that has a planetary system, how many planets (or moons) are capable of sustaining life?

- f_l is the fraction of planets (or moons) of the above that actually go on to develop life.

  Question: On what percentage of the planets (or moons) that are capable of sustaining life does life actually develop?

- f_i is the fraction of the above where intelligent life develops.

  Question: On the planets (or moons) where life does develop, what percentage develops intelligent life?

- f_c is the fraction of the above that communicate.

  Question: What percentage of intelligent beings have the means and the desire to communicate with other civilizations?

- L is the expected lifetime of such a civilization (in years).

  Question: (This is the toughest of the questions.) For each intelligent civilization that communicates, how many years does the civilization survive (*i.e.* for how many years does it communicate)?

[1]Thanks to the Active Mind website for the questions based on the Drake Equation <http://www.activemind.com/Mysterious/Topics/SETI/drake_equation.html>.

1. Now multiply your answers to the above questions to calculate N, the current number of communicating civilizations in the galaxy.

2. Many people say that N must be at least 1. Why would they say this?

3. Is your answer greater than or equal to 1?

The real value of the Drake Equation is not in the answer itself, but in the questions that are prompted when attempting to come up with an answer. Obviously there is a tremendous amount of guesswork involved when assigning actual values to the variables. However, as we learn more from astronomy, biology, and other sciences (and social sciences for that matter), we'll be able to better estimate the answers to the above questions.

"Answers" for GSIs

Some current (and Drake's original) estimates according to Wikipedia:

- R_*, the rate of star formation in our galaxy

  Estimated by Drake as 10 per year. Latest calculations from NASA and the European Space Agency indicate about 6 per year.

- f_p, the fraction of those stars which have planets

  Estimated by Drake as 50%, might be as low as 20%.

- n_e, the average number of planets (or moons) which can potentially support life per star that has planets

  Estimated by Drake as 2. Current estimates range rom 1 to 5.

- f_l, the fraction of the above which actually go on to develop life

  Estimated by Drake as 100%. Current estimates range from 100% (where life can evolve it will) down to close to 0%.

- f_i, the fraction of the above which actually go on to develop intelligent life

  Estimated by Drake as 1%. Current estimates range from 100% (intelligence is such a survival advantage that it will certainly develop) down to near 0%.

- f_c, the fraction of the above which are willing and able to communicate

  Estimated by Drake as 1%. Current estimates range from 10% to 20% (note that these numbers are given with no support whatsoever).

- L, the expected lifetime of such a civilization

  Estimated by Drake as 10,000 years. Current estimates range from 100 to 10,000 years. The value of L can be estimated from the lifetime of our current civilization from the advent of radio astronomy in 1938 (dated from Grote Reber's parabolic dish radio telescope) to the current date. In 2006, this gives an L of 68 years. In an article in *Scientific American*, Michael Shermer estimated L as 420 years, based on compiling the durations of sixty historical civilizations. Using twenty-eight civilizations more recent than the Roman Empire he calculates a figure of 304 years for "modern" civilizations. Note, however, that the fall of most of these civilizations did not destroy their technology, and they were succeeded by later civilizations which carried on those technologies, so Shermer's estimates should be regarded as lower limits.

- N, the current number of communicating civilizations in the galaxy

  Drake originally calculated 10. Current estimates are all over the place, ranging from 0 all the way up to a few thousand! If your students are getting relatively large values of N and are confused, then you might want to be vaguely familiar with the **Fermi paradox**. According to Wikipedia it is "the apparent contradiction between [some] high estimates of the probability of the existence of extraterrestrial civilizations and the lack of evidence for or contact with such civilizations". Basically, in 1950, Fermi supposedly asked astronomy colleagues over lunch one day, "Where are they?" The Wikipedia page has a whole bunch of possible explanations and is quite interesting actually, I encourage everyone to take a look at it.