

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

1. 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, and yes, this is the second worksheet in the last three weeks that has involved 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.

Penzias and Wilson detected blackbody radiation that peaked at a wavelength of about 1.1mm. What part of the electromagnetic spectrum does this correspond to? What is the temperature of the CMB photons that they detected?

Astronomers like to relate many quantities to **redshift**, represented by the letter  $z$ . This is the same redshift that came up when we talked about Doppler shifts, but here we’re applying it to the fact that the Universe is expanding and that galaxies appear to be racing away from us. The redshift today,  $z_0$ , is defined to be 0 and  $z$  increases as we go further back in time. Also, a photon’s temperature scales as  $(1 + z)^{-1}$ . Furthermore, particle physicists and astronomers have shown that CMB photons were emitted with an initial temperature of about 3000K. 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  $t \approx 13.7 \times 10^9 * (1 + z)^{-3/2}$ , where  $t$  is in years. Note that today  $z = 0$  and so the age of the Universe today is about 13.7 billion years. Using this equation, calculate how old the Universe was when the CMB photons were emitted.

2. 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:

$$N = N_s * f_p * n_e * f_l * f_i * f_c * f_L$$

The equation can be thought of as seven questions where scientists have more accurately determined some answers more than others<sup>1</sup>. 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.

$N_s$  represents the number of stars in the Milky Way Galaxy.

Question: How many stars are in the Milky Way Galaxy?

$f_p$  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  $n_e$  where life evolves.

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

$f_i$  is the fraction of  $f_l$  where intelligent life evolves.

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

$f_c$  is the fraction of  $f_i$  that communicate.

Question: What percentage of intelligent races have the means and the desire to communicate?

$f_L$  is fraction of the planet's (or moon's) life during which the communicating civilizations live.

Question: For each civilization that does communicate, for what fraction of the planet's (or moon's) life does the civilization survive?

Now multiply your answers to the above questions and get  $N$ , the current number of communicating civilizations in the galaxy.

Many people say that  $N$  must be at least 1. Why would they say this? 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 guess work involved when filling in the variables. As we learn more from astronomy, biology, and other sciences, we'll be able to better estimate the answers to the above questions.

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<sup>1</sup>Thanks to the Active Mind website for the questions based on the Drake Equations  
<[http://www.activemind.com/Mysterious/Topics/SETI/drake\\_equation.html](http://www.activemind.com/Mysterious/Topics/SETI/drake_equation.html)>.

The Search for Extraterrestrial Intelligence (SETI) gives the following values:

$N_s$  represents the number of stars in the Milky Way Galaxy.

Answer: Current estimates are 100 billion.

$f_p$  is the fraction of stars that have planets around them

Answer: Current estimates range from 20% to 50%.

$n_e$  is the number of planets per star that are capable of sustaining life

Answer: Current estimates range from 1 to 5.

$f_l$  is the fraction of planets in  $n_e$  where life evolves

Answer: Current estimates range from 100% (where life can evolve it will) down to close to 0%.

$f_i$  is the fraction of  $f_l$  where intelligent life evolves

Answer: Estimates range from 100% (intelligence is such a survival advantage that it will certainly evolve) down to near 0%.

$f_c$  is the fraction of  $f_i$  that communicate

Answer: 10% to 20%

$f_L$  is fraction of the planet's life during which the communicating civilizations live

Answer: This is the toughest of the questions. If we take Earth as an example, the expected lifetime of our Sun and the Earth is roughly 10 billion years. So far we've been communicating with radio waves for less than 100 years. How long will our civilization survive? Will we destroy ourselves in a few years like some predict or will we overcome our problems and survive for millennia? If we were destroyed tomorrow the answer to this question would be  $10^{-8}$ . If we survive for 10,000 years the answer will be  $10^{-6}$ .

Using SETI's average values we get  $N$  equal to about 40.