4 Decoding the Arecibo Message

In 1974, the Arecebo radio telescope was used to send a message into space. The message was directed at the globular cluster M13, which is an assembly of hundreds of thousands of stars roughly 25,000 light-years away. The message was sent at a frequency of 2380 MHz, with roughly 1 million Watts of power, and used frequency-modulation (FM) to encode information. Roughly 10 bits of information were sent every second, and the total message contained 1679 bits.

The message was largely ceremonial, but some thought went into encoding a short message that extraterrestrial radio astronomers may have been able to detect and decode. We will be decoding the message in this lab.

The message consisted of 1679 bits of information. Each bit represented either a "0" or a "1" in binary. The number 1679 is significant, because it is a "semiprime" or the product of two prime numbers. Since the bits were meant to be viewed as an image, it was hoped that the alien astronomers would realize that the two primes that make up the length of the signal would be the obvious choice for the *length* and *width* of the array that needed to be made of the data in order to see the image.

This is the string of bits [1]:

0000001010101000000000000101000001010000000100100010001000100101100101010
1010101010100100100000000000000000000000000000000000001100000000000000000
0011010000000000000000000110100000000000000000010101000000000000000000111
1100000000000000000000000000000000110000111000110000110001000000000000011
0010000110100011000110000110101111101111101111101111100000000000000000000
0000001000000000000000000100000000000000000000000000000001000000000000000011
1111000000000000011111000000000000000000000000011000011000011100011000100000
0001000000000100001101000001100011100110101111101111101111101111100000000
0000000000000000010000001100000000010000000000011000000000000000010000110
0000000001111110000011000000111110000000000001100000000000001000000010000 0
0001000001000000110000000100000001100001100000010000000000110001000011000
0000000000001100110000000000000110001000011000000000011000011000000100000 0
0100000010000000100001000000011000000001000100000000110000000001000100000 0
0000010000000100000100000001000000010000000000000011000000000110000 0
0000110000000001000111010110000000000001000000000100000000000100000111110
0000000000010000101110100101101100000010011100100111111101110000111000001
1011100000000010100000011101100100000101000001111110010000001010000011000
0001000001101100000000000000000000000000000000001110000001000000000000001
1101010001010101010100111000000000101010100000000000000000101000000000000000
0111110000000000000000111111111000000000000111000000011100000000011000000
0000011000000011010000000101100000110011000000011001100001000101000001 0
1000100000100010010001001000100000000100010100010000000000010000100001000
0000000001000000000100000000000000010010100000000001111001111101001111000

- **Question 1:** What two prime numbers, when multiplied, equal 1679?

4.1 Displaying the message

On the lab computers there is a file called "arecibo.dat". It contains the string of bits from the Arecibo message.

Using the "SuperMongo" plotting software, you will open this file and display it.

The message is meant to be viewed as a grid of bright (0) and dark (1) points. The grid size must be determined by you.

Since you have determined the two prime numbers that are the factors of 1679, try each of these in turn as the "width" of your grid.

To display the file as a grid:

1. Open an xterm window.
2. Type **sm** on the command line and press return.
3. Type **macro read arecibo.sm** on the command line and press return.
4. You have now loaded a macro file that has the tools to decode the message.

5. Type **message [width] [your name]**, where [width] is the grid width you wish to try, and [your name] is your name (for labeling the plot).
6. A *gv* window will open with your plot. Does this look like a message to you?
7. If not, try another width.
8. If so, type **print_message** to print a paper copy of the plot.

- **Question 2:** What was the appropriate width for the grid?
- **Question 3:** Do you think that an alien looking at this grid would immediately see it as a message, or might they just think that it is strange looking noise?
- **Question 4:** Identify three features on the message and what you think they signify. Is the interpretation of the symbols obvious to you?

4.2 References

1. "The Arecibo Message" Retrieved from http://www.physics.utah.edu/~cassiday/p1080/lec06.html

5 Surviveability: Calculating the Frequency of Civilization-Killing Impacts

5.1 Introduction

There are a lot of ways that a civilization could be wiped out. We will consider one of these that has played out many times in Hollywood films: destruction by massive impact. In the Solar System, there are several reservoirs of small objects that are occasionally nudged into orbits that encounter the Earth. Small impacts occur frequently, with events like the one in 1908 that flattened a huge area of forest near Tunguska, Siberia happening about once every 100 years. Larger impacts occur less frequently, but with far greater effects.

The reason larger impacts occur less frequently is that for every large asteroid or comet, there are many more that are smaller than it. The "size distributions" of asteroids and comets have been measured, and this allows us to estimate how frequently larger impacts occur, given the frequency of smaller ones. Also, the cratering record on the Moon gives us another handle on the frequency of large impacts.

Here we will estimate how frequently two kinds of events occur. These events, " comet showers" and the formation of asteroid families, lead to a large influx of comets and asteroids into the inner Solar System and may therefore lead to large extinction events. We will also use an online "impact calculator" to learn about the effects of different kinds of impacts.

If civilizations are destroyed by these kinds of events, we can estimate the upper limit for the length of time a civilization can survive before being destroyed by natural processes (as long as they don't invent a way to stop asteroids). We can use this number in the last term of the Drake Equation, the lifetime of technological civilizations. With our calculated timescales, we will estimate the number of civilization-hosting planets that we might discover with the Kepler space telescope.

5.2 Stellar Close Encounters and Comet Showers

The sun is encircled by a vast, distant reservoir of comets called the Oort cloud. These comets have orbits that stretch out nearly halfway to the nearest star. Sometimes, if another star passes close by the Solar System, a number of these comets can be dislodged and come raining down on the planets in what is called a "comet shower." These comet showers may be linked to extinction events on the planet Earth.

In order to calculate how often a comet shower occurs, we need to know how often other stars pass close by the Sun. We will estimate how frequently this occurs.

If the stars in the neighborhood of the Sun have some random distribution of velocities, then we can estimate the *"Mean Free Time"* between close encounters with other stars. We will use the following equation:

$$\text{Time Between Close Encounters} = T = 1/(\sqrt{2} \times v \times A \times n) \tag{8}$$

where v is the random velocity (in parsecs / year), A is the cross-sectional area (in square parsecs) around the Solar System that counts as a "close encounter," and n is the number of stars per cubic parsec in the Galaxy.

- The random velocity of stars in the solar neighborhood is on the order of $v \simeq 1 \times 10^{-5}$ parsec/year.
- There are $\sim$ 400 billion stars in the galaxy.
- The galaxy is shaped like a thin disk. So we can estimate the total volume of the galaxy by Volume= $\pi \times R^2 \times H$. The radius of the galaxy is $R \simeq 20,000$ parsecs, and the thickness is $H \simeq 300$ parsecs.
- A star passing within $\sim$ 0.1 parsec of the Sun will dislodge a large number of comets from the Oort cloud. The cross-sectional area is then $A = \pi \times (0.1)^2 \simeq 0.03$ square parsecs.
- The number of stars per cubic parsec is therefore $n = \frac{\text{Number}}{\text{Volume}}$
- **Question 1:** Using the above equations and values, estimate the *Time Between Close Encounters* and therefore between comet showers for a Sun-like star in the Milky Way.

5.3 Asteroid Showers from Family Formation

Another event that can cause a large influx of objects into the inner Solar System is the breakup of a large asteroid. When a large "parent" asteroid is destroyed by a collision in the asteroid belt, it creates a group of smaller objects on similar orbits, called an "asteroid family." If this group forms near an unstable orbit (like a resonance with Jupiter), some of the newly-created objects can get injected into the inner Solar System, potentially colliding with the inner planets. In fact, it is thought that the formation of the Baptistina family created the asteroid that wiped out the dinosaurs 65 million years ago [1].

There are roughly 40 large asteroid families in the main asteroid belt [2]. Since the families have formed over the age of the Solar System (4.6 billion years), we can estimate how often an asteroid family forms by:

$$\text{One asteroid family forms every } T \text{ years, where } T = \frac{\text{Age of Solar System}}{\text{Number of Families}} \tag{9}$$

- **Question 2:** Using the above equations and values, estimate the time between asteroid family formation events.

5.4 Caveats

You should find that by these estimates, comet showers should occur much more frequently than asteroid showers. This is not exactly correct, since we used the average density of stars in the galaxy to estimate the frequency of comet showers, whereas the Sun is not in a very dense region of the galaxy (so the comet shower timescale should be greater for the Solar System). However, *for the average star in the Milky Way*, this might be the case.

We are somewhat protected from comet showers by the presence of Jupiter, which acts like a gravitational shield against comets for the inner planets. Also, it is thought that the size distribution of comets is steeper than for asteroids, so there are fewer large comets for every small one. Therefore, asteroid showers are probably more dangerous than comet showers.

5.5 Impact Calculator

There are online tools to estimate the effects of various kinds of asteroid or comet impacts. We will be using one to explore these effects and the frequency at which various kinds of impacts occur.

- Open **Firefox** on a lab computer.
- Go to the web address **http://simulator.down2earth.eu/index.html**
- Select **English** for your language, and then select **Start**
- You are presented with a control panel to set up your impact type.

We will explore two kinds of impacts. First, we will simulate the impact of a 1-km Iron object from the Asteroid belt. We will then simulate the impact of a 1-km Ice object from the Oort cloud. Since most of the planet is covered in water, we will simulate all of our impacts as though they occur 100 km off the coast of Vancouver Island, in deep water (1000 m). The angle of impact matters for these calculations, but for consistency we will set the angle to the most probable value of 45°.

So, for all impacts, the following parameters will always be the same:

- **Trajectory Angle** = 45°.
- **Target Density** = Water, with a depth of 1000m.
- **Distance from crash site** = 100 km.

Note that the lowest velocity any impact can have on Earth is 11 km/s (escape velocity).

Impactor type	Material Type	Typical Velocity	Diameter
Asteroid	Iron	17 km/s	1000 m
Comet	Ice	51 km/s	1000 m

Table 5.5.1: Table of values for impact calculator.

5.5.1 Procedure

For each impact type in Table 5.5.1, set up the conditions in the impact calculator, select **Submit**, and answer the following questions:

- **Question 3:** From the Crater Size panel: How wide is the resulting crater? How deep?
- **Question 4:** From the Data View panel: How much Kinetic Energy is released? How frequently does this calculator estimate this kind of collision occurs? Note down the damage that would occur in Victoria (100 km from the crash site).

As of 1996, the total destructive power of all (known) tested nuclear devices summed up to roughly 510.3 Megatons of TNT, or 2.1×10^{18} joules [3]. Thats over 42,000 times more destructive energy than the single bomb that was dropped on Hiroshima.

- **Question 5:** Set up the same impact parameters as for the "Asteroid" case. Reduce the **Asteroid Diameter** until the **Impact Energy** is roughly equal to the sum of the energy released by all nuclear tests. How small is the impactor that will generate this much energy? How frequently do these kinds of impacts occur?

  Note that the 8-km wide Iturralde Crater in Bolivia is thought to be the youngest "large" impact crater on Earth. It is estimated to be between 11,000-30,000 years old [4]. Are we due for another impact of this size?

5.6 Number of civilizations in the Kepler field

The Kepler mission is surveying 100,000 stars for Earth-like planets. The project scientists estimate that it might discover up to 650 planets with masses less than 2.2 times the mass of the Earth [5]. What are the chances that one of those planets might currently be home to a technological civilization?

We will make a rough estimate based on some of the terms of the Drake Equation. The form that we will be using is below:

$$N_c = 100\% \times N_* \times F_P \times F_L \times F_T \tag{10}$$

where N_c is the number of civilizations currently detectable in the survey, N_* is the number of stars under consideration, F_P is the fraction of those stars that have Earth-like planets, F_L is the fraction of those planets that produce intelligent life, and F_T is the fraction of the age of the galaxy that those civilizations exist for. The Kepler scientists have already created an estimate for the combination of the terms $N_* \times F_P$ based off of their observing method and the fraction of stars currently known to have planets - this is how they arrived at their estimate of 650 Earth-like planets. So we now have:

$$N_c = 100\% \times 650 \times F_L \times F_T \tag{11}$$

So how can we estimate the other terms? In our own planetary system, there are three "Earth-like" planets. Only one of them (that we know of) has ever given rise to intelligent life. So, for this Solar System, $F_L \simeq \frac{1}{3}$.

What about F_T? In your previous exercises, you have determined upper limits for the lifetimes of civilizations based on extinction from 1) comet showers, and 2) asteroid showers. If the galaxy is roughly 13 billion years old, you can calculate the fraction of the age of the galaxy any civilization can reach before it is destroyed by either a comet shower or an asteroid shower by the following:

$$F_T = \frac{T}{\text{Age of Galaxy}} \tag{12}$$

5.7 Drake Equation Exercises

- **Question 3:** Based on the timescale T you estimated for comet showers, calculate F_T and use that to calculate N_c for the Kepler survey. What are the chances that a civilization-hosting planet will be discovered based on these estimates?
- **Question 4:** Based on the timescale T you estimated for asteroid showers, calculate F_T and use that to calculate N_c for the Kepler survey. What are the chances that a civilization-hosting planet will be discovered based on these estimates?

5.8 References

1. Bottke, W. F., Vokrouhlický D., & Nesvorný, D. (2007) “An asteroid breakup 160Myr ago as the probable source of the K/T impactor” *Nature* Vol. 449, pp. 48-53.
2. Parker, A. H., Ivezic, Z., Juric, M., Lupton, R., Sekora, M. D., & Kowalski, A. (2008) “Size Distributions of Asteroid Families in the Sloan Digital Sky Survey Moving Object Catalog” *Icarus* Vol. 198, pp. 138-155.
3. Norris, R. S., & Arkin, W. M. (May 1996) “Known Nuclear Tests Worldwide, 1945-1995.” *Bulletin of the Atomic Scientists* Vol. 52, No. 3., pp. 61-63.
4. Baxter, K., & Taliaferro B. “NASA Educational Brief on the Iturralde Structure” http://education.gsfc.nasa.gov/experimental/all98invProject.Site/Pages/science-briefs/ed-taliaferro/iturralde.html
5. “Overview of the Kepler Mission” (2009): http://kepler.nasa.gov/about/