

Chapter 1: The Solar System and Beyond



“Insignificance”, artist Lola Chaisson

Introduction

Going out at night to look at the bejeweled and mysterious sky is not something we usually do. People of ancient and prehistoric times turned their eyes to the sky every night because the motions of the Sun, Moon, stars and planets served as their calendar, clock, and compass. The sky told them when to plant and harvest their crops, when the game herds would migrate, and the direction in which to travel. Knowledge of the sky was not only necessary for survival—the sky was also worshipped as the home of the gods. Viewed in this way, the sky gave people mixed feelings of awe, insignificance, and peacefulness. Ever since the first stirrings of consciousness, humankind has lifted its eyes towards the mystery of the heavens and found solace in the contemplation of celestial objects. The heavens seemed so calm and eternal and comforting.

However, the quietude of the universe is an illusion. The stars in the sky are not eternal; they are born from nuclear fires, they live, and ultimately die. Some stars die quietly, some literally tear themselves apart with violent explosions, and still others leave the visible universe when they die to become the most exotic objects in the known universe—black holes.

Beyond the stars in our Milky Way Galaxy are other galaxies—and sometimes one of these galaxies, containing billions of stars, will collide with and consume another galaxy like a cosmic cannibal. Comets and asteroids restlessly roam through space, sometimes crashing into planets and moons with catastrophic results.

The night sky seems so peaceful, yet masks a maelstrom of activity that we are not easily able to detect with our eyes alone. How can we, when we cannot even detect our own motions? The Earth is spinning around at up to 1670 km/hr, depending on latitude, and orbiting around the Sun at 30 km/s; the Sun is orbiting the center of the Milky Way Galaxy at 250 km/s, and the Milky Way Galaxy itself is moving through spacetime. The Sun and Solar System travel 971,000,000 km every year in their orbit around the galactic center. (How many galactic miles have you traveled so far in your lifetime?) We are on a

roller coaster ride of universal proportions, and we feel nothing. How very strange is this world we inhabit!

The rate at which we receive new information and expand our knowledge in astronomy has increased phenomenally. This is due in part to sophisticated technology such as the earthbound Keck Telescope on a mountain top in Hawaii, the Hubble Space Telescope orbiting the Earth, and the Chandra X-Ray Observatory in an extreme orbit that reaches more than one third of the distance to the Moon. When we see the constant stream of beautiful images from these instruments, it is easy to forget that humankind gained an incredible depth of understanding of our local universe by *visual* observation with the aid of a few *simple* astronomical tools. Making observations over periods of time, recording data, and developing predictions from the analysis of the data, is *still* how science works, no matter how glitzy or high-tech, or even how simple, the tools we use are.



Chandra X-Ray Observatory
<http://chandra.harvard.edu/>

You have the ability to travel to the far reaches of space. You can make a journey through your eyes and mind that would otherwise be physically impossible due to the immense distances involved. Traveling at 968 km/hr by 747 jet, it would take 17 years to reach the Sun, and an amazing 4,600,000 years to reach just the nearest star! We cannot travel to the stars, but we can still come to know them well by reading the messages they sent out a very long time ago.

So let the stars get in your eyes and become initiated into the wonders of the universe from your own backyard. Your life will be enriched with a newfound knowledge as you learn how to read the messages encoded within the starlight traveling through spacetime and falling into your eye. You will be able to use this information to understand the unstable and violent nature of seemingly peaceful and stable stars. So look up! Watch the stars! Get to know the stars and constellations, make a quadrant, learn how to use a planisphere, and begin to enjoy the pleasures of the cosmos!

Who is more important?



Tycho Brahe

Tycho Brahe (1546–1601, shown at left) was a nobleman from Denmark who made astronomy his life's work because he was so impressed when, as a boy, he saw an eclipse of the Sun take place at exactly the time it was predicted. Tycho's life's work in astronomy consisted of measuring the positions of the stars, planets, Moon, and Sun, every night and day possible, and carefully recording these measurements, year after year.

Johannes Kepler (1571–1630, below right) came from a poor German family. He did not have it easy growing up. His father was a soldier who was killed in a war, and his mother (who was once accused of witchcraft) did not treat him well. Kepler was taken out of school when he was a boy so that he could make money for the family by working as a waiter in an inn. As a young man Kepler studied theology and science, and discovered that he liked science better. He became an accomplished mathematician and a persistent and determined calculator. His essentially

religious mind drove him to find an explanation for order in the universe. He was convinced that the order of the planets and their movement through the sky could be explained through mathematical calculation and careful thinking.

Tycho wanted to study science so that he could be one of those people who could predict eclipses. He studied mathematics and astronomy in Germany. Then, in 1571, when he was 25, Tycho built his own observatory on an island (the King of Denmark gave him the island and some additional money just for that purpose). Tycho named his island observatory Uraniburg-Urania being the muse of astronomy. He lived and worked in his observatory for 20 years with many astronomers and assistants. Tycho's main goal was to determine the positions of the stars and planets as accurately as possible. This could only be done by constructing precision observing instruments and by making and recording many observations of stars and planets night after night.

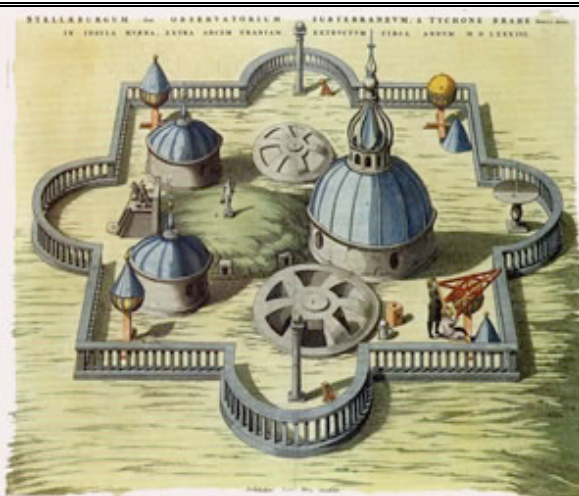


Johannes Kepler

Kepler became interested in science and mathematics when in school at about the age of 18. He was not particularly interested in astronomy until 1600 when Kepler met Tycho Brahe in Prague, and Tycho asked him to be his assistant. Tycho would pay him well. But Tycho died one year later, and even though Kepler was appointed astronomer to the court, he found so little official support for his position that he had to survive by making astrological predictions for noblemen who wanted their fortunes told.

Tycho was a scientist who worked by direct observation. Kepler was a scientist who worked by calculation and testing one idea after another. Tycho's life's work of measuring the positions of objects in the sky was in itself useless without someone like Kepler to come along and make sense of those measurements. In the same way, Kepler's efforts to understand how the planets moved would be nothing but speculation, guessing, and mysticism if he did not have the basic data, the accurate measurements made by Tycho, against which to test his ideas and theories. Each one's work is meaningful because of the other's work.

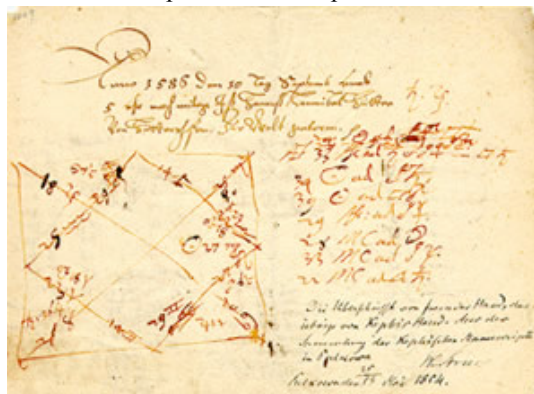
The scientific contributions of these two astronomers from radically different backgrounds are set against a time of great turmoil in European history—the early 1600's. It was a time of upheaval, superstition, and fear—a time when court astrologers were powerful, and the stars were thought to predict and guide one's destiny.



Tycho Observatory on the Island of Ven

Tycho Brahe was a Danish nobleman and held the position of Royal Mathematician at the court-in-exile of the Holy Roman Emperor, Rudolf II, in Prague (in the former Czechoslovakia). He was arrogant, conceited, and obnoxious. While at university he had a duel with a fellow student over which one was the best mathematician. Tycho may have been the superior mathematician, but he was not the better duelist: during the encounter he lost his nose, which he replaced with one made of gold. He had different metal noses which he changed depending upon the occasion (the recent exhumation of his body proved that he did indeed sport a metal nose). At a dinner given by a local Baron, Tycho consumed great quantities of wine but would not leave the table in the presence of the Baron, considering it to be rude behavior. The resulting urinary tract infection, along with Tycho's refusal to stop abusing his body with overdrinking and overeating, led to his death a few months later.

Johannes Kepler was born into much humbler surroundings. He expected to enter the clergy, but instead became a mathematics teacher in Graz, Austria. His belief in the Copernican concept of a heliocentric universe was a dangerous one. With the coming of the 30 Years' War, Kepler and his wife were exiled due to their Protestant beliefs. During his time in Prague, he fought continually with Tycho, who refused to share his meticulous observations with him. These were observations which Kepler desperately needed for his continuing quest to establish the true orbital motions of the planets.



Kepler manuscript

After Tycho's death, Kepler stole the data. Eventually the war reached Prague, and Kepler was once again persecuted for his religious beliefs. He also lost his wife and son to a plague, and his mother was convicted of witchcraft and imprisoned. Eventually, however, Kepler was able to have her death sentence commuted to one of exile. During this time Kepler wrote one of the first science fiction stories, entitled "Somnium," or "The Dream." This story probably contributed to his mother's persecution as she resembled one of the characters, an old woman who had dealings with demons and devils. Kepler finished his days in poverty, writing horoscopes for noblemen in order to survive.

Tycho Brahe and Johannes Kepler had totally disparate backgrounds and temperaments. In spite of this, Tycho's painstaking and detailed observational data, combined with Kepler's mathematical genius, allowed Kepler to derive the following three laws of planetary motion:

1. The planets move in an ellipse with the Sun at one focus.
2. The orbit of a planet sweeps through equal areas in equal times (see diagram just above Kepler's picture on other side).
3. The square of the period in years is equal to the cube of the mean distance (with the unit of measurement in Astronomical Units [AU]).

Investigation 1.1: Sizes and Distances of the Sun, Earth, Moon, and Planets

Models can be extremely useful in helping us understand relationships, but they can also be misleading. To use models effectively, it is important to understand how a model may be different from what it represents. To begin your investigation of the sizes and distances of the objects in the Solar System, your instructor will give you some materials to work with and some activities to do. Later on, you will construct your own scale models of the Sun and planets.

You are familiar with models—they exist everywhere. We make models to help us “see” things that are too large for us to see—such as the Solar System and the Milky Way Galaxy—and things that are too small, such as the structure of an atom or a bacterium. Models can also help us to understand what happens when the time it takes for things to happen is very long—the movements of the continents caused by plate tectonics, for example. Models can take many forms. Some are physical models, such as maps and globes. Others are mental models, such as the “Bohr” model of the atom that comes to mind when we think of atoms. Still other models are mathematical, such as the equations that model the curvature of spacetime, which is impossible to make into a physical model, or even into a mental image.

All of these models have distortions. Flat maps of the Earth get more exaggerated towards the edges—putting a round shape onto a flat surface causes some of the countries to look larger than they really are. However, they are still useful because they help us see relationships and because they are convenient. A flat map may be folded up and put in your pocket. So there are trade-offs between accuracy and convenience whenever you construct a model.

Portraying the Solar System is also difficult to do with complete accuracy. All pictures and models are inaccurate. We are so used to seeing pictures that are not drawn to scale that we have no sense of distances or sizes in relation to ourselves. And if we cannot even feel how far 150,000,000 kilometers is (the distance from Earth to the Sun), how can we even begin to imagine the enormous distances to the stars and other galaxies?

We are misled by every representation of the Solar System that we see, yet we would be unable to understand the structure of our planetary family without these same models. So as you begin your exploration of sizes and distances and construct your own models, remember that not only is it important to develop a model to show some aspect of the Solar System, it is also important to understand what aspects of your model are not correct.

Your instructor will now provide you with the materials necessary for you to begin your investigation of the sizes and distances within the Solar System.

Core Activity 1.2: Unit Conversion

You will be constructing scaled-down models, which always require conversion from large-scale measurements to smaller ones. There is a simple but powerful method which can be applied to any type of unit conversion you need to calculate. Units are **always** included with the numerical value in scientific calculations. Consider the following examples:

EXAMPLE 1:

How many seconds are there in one year? You already know all of the parts you need to easily calculate the answer:

1. There are 60 seconds in a minute;
2. 60 minutes in an hour;
3. 24 hours in a day;
4. 365.24 days in a year.

There are two things you need to know; *identical units cancel* each other in the same way that identical numbers do. If you have:

$$\begin{array}{r} 3 \times 2 \\ 3 \end{array}$$

you can cancel the 3's and know the answer is 2 without multiplying and dividing. The same method applies to units. Also, two values can be equal to each other even if the units are different. Since 60 minutes is the same amount of time as one hour, then 60 minutes divided by one hour (which is a fraction) is equal to one. Let's now calculate how many seconds there are in a year. We want all units except seconds and year to cancel.

$$\frac{60 \text{ seconds}}{1 \text{ minute}} \times \frac{60 \text{ minutes}}{1 \text{ hour}} \times \frac{24 \text{ hours}}{1 \text{ day}} \times \frac{365.24 \text{ days}}{1 \text{ year}} = 31,556,736 \text{ seconds/year}$$

Maybe you already know there are 3600 seconds in an hour (by looking at the number in the conversion table provided following Example 5). Then the conversion will be shorter:

$$\frac{3600 \text{ seconds}}{1 \text{ hour}} \times \frac{24 \text{ hours}}{1 \text{ day}} \times \frac{365.24 \text{ days}}{1 \text{ year}} = 31,556,736 \text{ seconds/year}$$

EXAMPLE 2:

You throw a baseball at 85 miles/hour and want to know how many inches the ball is traveling each second; that is, you want to convert miles/hour to inches/second. We will start with miles/hour and keep going until all units have cancelled out except for inches in the numerator and seconds in the denominator.

This is a two-part problem. First we will convert miles into inches. Then we will convert hours into seconds.

1. Miles into inches:

From the conversion table you find the following information:

1 mile = 5280 feet; 1 foot = 12 inches

$$\frac{85 \text{ miles}}{\text{hour}} \times \frac{5280 \text{ feet}}{1 \text{ mile}} \times \frac{12 \text{ inches}}{1 \text{ foot}}$$

2. Hours into seconds:

We have now converted the miles into inches. Now we need to convert the hours into seconds by extending from what we have already converted.

$$\frac{85 \text{ miles}}{\text{hour}} \times \frac{5280 \text{ feet}}{1 \text{ mile}} \times \frac{12 \text{ inches}}{1 \text{ foot}} \times \frac{1 \text{ hour}}{3600 \text{ s}} = \frac{5,385,600 \text{ inches}}{3600 \text{ seconds}}$$

$$= 31,556,736 \text{ inches/year}$$

In other words, once all the units have cancelled except the ones you want, multiply all numbers in the numerator, all the numbers in the denominator, and divide the numerator by the denominator to calculate your answer.

$$\frac{85 \times 5280 \times 12}{3600} = \frac{5,385,600}{3600} = 1496 \text{ inches/second}$$

EXAMPLE 3:

1. 150 kilometers(km)/hour is how many miles/hour?
2. From the table, 1 km = 1000 meters (m); 1609 meters (m) = 1 mile;
- 3.

$$\frac{150 \text{ km}}{\text{hour}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{1 \text{ mile}}{1609 \text{ m}} = \frac{150,000}{1609} = 93 \text{ miles/hour}$$

EXAMPLE 4:

1. 150 km/hour is equal to how many meters/second?
- 2.

$$\frac{150 \text{ km}}{\text{hour}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{1 \text{ hour}}{3600 \text{ seconds}} = \frac{150,000}{3600} = 41.7 \text{ meters/second}$$

EXAMPLE 5:

1. 5000 kilometers is how many miles?
- 2.

$$5000 \text{ km} \times \frac{0.62 \text{ miles}}{1 \text{ km}} = 3100 \text{ miles}$$

Conversion Table

1. 1 kilometer (km) = 1000 meters (m) = .62 mile (mi)
2. 100 centimeters (cm) = 1 meter
3. 1 mile = 5280 feet (ft) = 1609 meters
4. 1 inch = 2.54 centimeters
5. 1 hour = 3600 seconds (s)

Practice Problems for Unit Conversion:

1. Recalculate Example 3 above, using a different (and shorter) conversion.
2. 3,000 miles is how many kilometers?
3. 3,655,000 centimeters is how many miles?
4. 7 miles/second is how many
 - a. miles/hour?
 - b. kilometers/hour?
 - c. feet/hour?
 - d. meters/hour?
5. How many hours are there in 35 years?
6. Calculate a rough estimate of how many hours of your life you have spent sleeping.

Core Activity 1.3: String Model of the Solar System

You are going to build your own scale model of planetary distances in the Solar System. The longest distance you can use will determine the scale of the model.

| Longest Usable Distance (meters) | Distance to Pluto (AU) | Scaling Factor (m/AU) |
|----------------------------------|------------------------|-----------------------|
| | 39.4 | |

1. Measure this distance to the nearest meter and record it in Table 1.1a. This number represents the distance between the Sun and Pluto (39.4 AU or 5.9×10^9 km.) You will begin using a unit that may be unfamiliar, the *Astronomical Unit* (AU). The distance from Earth to the Sun is about 150 million kilometers, which is assigned the value of 1 AU.
2. To calculate the distance from the Sun to the planets, you need to determine the scaling factor. Divide the largest usable distance by the distance to Pluto in AU's. This is the scaling factor. Your scaling factor is _____ m/AU. Enter this number into Table 1.1a.

TABLE 1.1b

| Planet/Star | Distance from the Sun (AU) | Scale Distance from Sun (meters) | Actual Average Distance(kilometers) | Actual Diameter (kilometers) |
|-------------|----------------------------|----------------------------------|-------------------------------------|------------------------------|
| Sun | | | | 1,391,980 |
| Mercury | 0.39 | | 58,000,000 | 4,880 |
| Venus | 0.72 | | 108,000,000 | 12,100 |
| Earth | 1.00 | | 150,000,000 | 12,800 |
| Mars | 1.52 | | 228,000,000 | 6,800 |
| Jupiter | 5.20 | | 778,000,000 | 142,000 |
| Saturn | 9.54 | | 1,430,000,000 | 120,000 |
| Uranus | 19.2 | | 2,870,000,000 | 51,800 |
| Neptune | 30.1 | | 4,500,000,000 | 49,500 |
| Pluto | 39.4 | | 5,900,000,000 | 2,300 |

3. Multiply the scaling factor by the distance from the Sun to each of the planets in AU's, and record in the column labeled "Scale Distance from Sun" in Table 1.1b.
4. Measure out a length of string equal to the scaled distance from the Sun to Pluto. Mark the points along the string where the planets are located and attach a flag or marker at these points.

Questions:

1. Does your model resemble the mental picture you had of the spacing between the planets? If not, how does it differ?
2. If different scale models have been produced, are some inaccurate? Can they all be "correct"? If so, then are some more "useful" than others? Why or why not?
3. Is it possible to have the same scale model for the sizes of the planets? Why or why not?
4. What are some of the inaccuracies of your scale model? If there are "wrong" aspects to your model, is it still useful?
5. The nearest star to Earth is Proxima Centauri, 266,000 AU away. Where would this star be placed in your scale model of the Solar System?

| |
|--|
| 1 kilometer (km) = 1000 meters (m) (10^3) 1 centimeter (cm) = 1/100 meter (m) (10^{-2}) 1 millimeter (mm) = 1/1000 meter (m) (10^{-3}) |
|--|

Core Activity 1.4: Mathematical Estimation of Sizes and Distances



1. If the Sun is represented by the dot shown in the right corner of the box above, what is your best estimate for the size of the Earth and its distance from the Sun? Draw the Earth to scale and place it on the page at your estimated location.
 - a. The average distance from the Earth to the Sun is about 15×10^7 km (150 million km), and the approximate diameter of the Sun is 14×10^5 km (1 million, 400 thousand km). How many solar diameters is the Earth from the Sun?— that is, how many Suns can fit between the Earth and the Sun?
 - b. The circle representing the Sun has a diameter of 2 millimeters (mm). How far away is the Earth from this scale model Sun? Measure the distance and mark the location. Does it agree with your estimation?
 - c. The diameter of the Earth is 13×10^3 km (13,000 km). The Sun's diameter is how much larger than that of the Earth?—that is, how many Earths would fit across the diameter of Sun's disk?
 - d. What would be the Earth's diameter if it was on the same scale as the circle above? Does this agree with your estimation? Can you draw this diameter on this page?
2. For a different scale model, the Sun is represented by a soccer ball having a diameter of 25 cm.
 - a. How far from the Sun is the Earth in centimeters? In meters?
 - b. What is the Earth's diameter using this scale?
 - c. The farthest planet from the Sun, Pluto, is 40 times farther away from the Sun than the Earth. How far from the Sun is Pluto in the soccer ball Solar System?
 - d. What would be the diameter of the entire Solar System on this scale?
 - e. Calculate the diameter of the star Betelgeuse (actual diameter of 420×10^6 km, or 420 million kilometers) on this same scale.

- f. Proxima Centauri, the star closest to the Sun, is 266,000 times farther from the Sun than the Earth in this model and has the same diameter as our Sun. How far away is Proxima Centauri?
- g. If the soccer ball Sun is placed in your house, determine the geographical location where Proxima Centauri would be found.
3. Create your own scale model by setting the size of the Earth to be that of any object you choose. Using the size of your object, calculate the scale values for the objects in the following table.

The diameter of your object is _____.

TABLE 1.2a

| Star or Planet | Scale Diameter (meters) | Scale Distance (meters) | Scale Distance (km) |
|------------------------------------|-------------------------|-------------------------|---------------------|
| Sun | | | |
| Moon* | | | |
| Jupiter | | | |
| any other planet (see chart below) | | | |
| Proxima Centauri | | | |
| Betelgeuse** | | | |

* The moon is 1/4th the diameter of the Earth and is $\sim 38 \times 10^4$ km away.

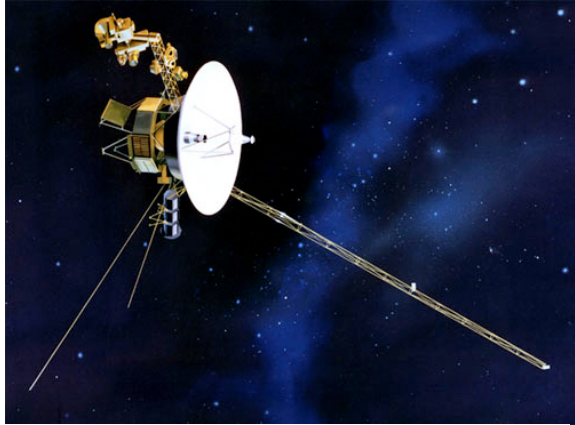
** Distance from Sun to Betelgeuse is $\sim 4.1 \times 10^{15}$ km

TABLE 1.2b

| Planet | radius (km) |
|---------|-------------|
| Mercury | 2,440 |
| Venus | 6,052 |
| Earth | 6,378 |
| Mars | 3,397 |
| Jupiter | 71,492 |
| Saturn | 60,268 |
| Uranus | 25,559 |
| Neptune | 24,764 |
| Pluto | 1,151 |

An Arm's-Length Reach into the Universe

In 1977 NASA launched the twin spacecraft Voyager 1 and Voyager 2. The Voyagers explored the giant outer planets of our Solar System, their moons, and the systems of rings and magnetic fields of those planets. These two spacecraft are now beyond the orbit of Pluto and heading for interstellar space.



Voyager - <http://voyager.jpl.nasa.gov/>

Voyager 1 encountered Jupiter in 1979, and Saturn in 1980. Voyager 2 encountered Jupiter in 1979, Saturn in 1981, Uranus in 1986, and Neptune in 1989.

Voyager 1 is now leaving the Solar System, rising above the ecliptic plane at an angle of about 35 degrees at a rate of about 520 million kilometers (about 320 million miles) each year. Voyager 2 is also headed out of the Solar System, diving below the ecliptic plane at an angle of about 48 degrees and a rate of about 470 million kilometers (about 290 million miles) a year.

Eventually, Voyager 1's instruments may be the first of any spacecraft to sense the heliopause—the boundary between the end of the Sun's magnetic influence and the beginning of interstellar space.

The heliopause is the outermost boundary of the solar wind, where the interstellar medium restricts the outward flow of the solar wind and confines it within a magnetic bubble called the heliosphere. Exactly where the heliopause is has been one of the great unanswered questions in space physics. By studying radio emissions, scientists now theorize the heliopause exists some 90 to 120 astronomical units (AU) from the Sun.

The Solar System does not end at the orbit of Pluto, the ninth planet. Nor does it end at the heliopause boundary, where the solar wind can no longer continue to expand outward against the interstellar wind. It extends over a thousand times farther out where a swarm of small cometary nuclei, known as the Oort Cloud, is barely held in orbit by the Sun's gravity.

But even at speeds of over 35,000 mph, it will take nearly 20,000 years for the Voyagers to reach the middle of the comet swarm, and possibly twice this long for them to pass the outer boundaries of cometary space. By then, they will have traveled a distance of two lightyears, equivalent to half of the distance to Proxima Centauri, the nearest star.

Once the Voyager spacecraft leave the Solar System (by 1990, both were beyond the orbit of Pluto), they will find themselves in empty space. What can they do out there then? For the next 20 to 30 years, the Voyagers will continue to send information about ultraviolet light from the stars, and data about magnetic fields, radio emissions, cosmic rays, and charged particles in space.

The Voyager spacecraft will be the third and fourth human artifacts to escape entirely from the Solar System (the first two were Pioneer 10 and 11, launched in 1973 and 1974).

Plaques identifying the time and place of origin were mounted on the Pioneer spacecraft, should any other spacefarers find them in the future.

Think of it: it took about 13 years for the Voyagers to reach the orbit of Pluto, but it will be 40,000 years before they make a close approach to any other possible planetary system.

The message affixed to the Voyagers is much more elaborate: in addition to information about the spacecrafts' origin, there is a 12-inch gold-plated copper disk containing sounds and images selected to portray the diversity of life and culture on Earth. Among these are sounds of surf, wind, birds, and whales; music from many cultures and eras, from ethnic, to classical, to rock-and-roll; and spoken greetings from Earth-people in 55 languages.

As astronomer Carl Sagan pointed out, the spacecraft will be encountered only if there are advanced spacefaring civilizations in interstellar space. But the launching of this bottle into the cosmic ocean says something very hopeful about life on this planet.

(Adapted from NASA information files.)

What is the probability that life other than our own exists in the universe? How many galaxies, how many stars, how many civilizations? The Drake equation is an attempt to estimate how many others, similar to ourselves in technological advancement, there may be in just one galaxy-the Milky Way:

$$N = (N^*) (f_p) (n_e) (f_i) (f_l) (f_c) (f_L)$$

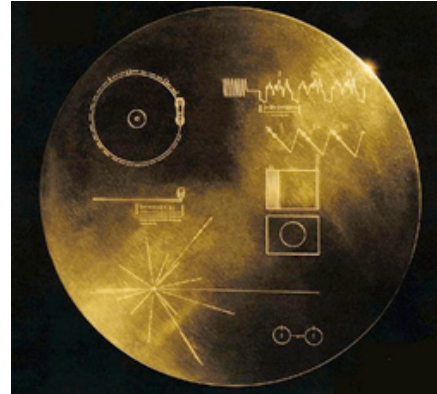
where

1. N^* is the number of stars in the Milky Way Galaxy;
2. f_p is the fraction of stars that have planetary systems;
3. n_e is the number of planets in a system ecologically suited for life;
4. f_i is the fraction of suitable planets on which life actually evolves;
5. f_l is the fraction of inhabited planets on which intelligent life evolves;
6. f_c is the fraction of planets on which advanced technology develops;
7. f_L is the fraction of a planetary lifetime inhabited by a technical society.

This equation involves physics, chemistry, biology and earth science. It attempts to quantify complex factors. Is the equation adequate? How would you derive the best estimates for the quantities within the equation? How many civilizations do you get?

What would you have sent on Voyager to try and summarize millions of years of human evolution on planet Earth? How do you explain the human condition to alien eyes and ears? What music? What sounds? What artifacts? Music is an expression of the human spirit. Is it important to other life forms? Will it reveal more or less about us than the mathematics of prime numbers and the cryptic lines and diagrams engraved on Voyager? What would you send on a spacecraft about to be launched into forever?

The calculator on your desk is more powerful than the computers on board the Voyagers. When the computers fail, only the information inscribed on the spacecraft and on the record will remain. Will these lonely space travelers reach other stars? In what condition? Will the record still work? Would others understand how to play the record? Can robotic travelers adequately replace humans in the exploration of space? Should we continue projects such as SETI (the Search for Extra Terrestrial Intelligence)? We climb the tallest mountains, submerge ourselves into the depths of the ocean chasms, and even hope to travel to distant worlds to see what is there; we have never ceased from exploration and discovery-only the destinations of our journeys have changed.



Message aboard Voyager

SPACE TALK

Planets, referred to as “wandering stars” by the ancient Greeks, are celestial bodies that orbit stars, have sufficient mass for self-gravity to assume a nearly round shape, and have cleared away the debris in the vicinity around their orbits.



A **satellite** (or **moon**) is a small body in orbit around a planet. If mathematical calculations show that an object is more gravitationally bound to the Sun than the planet it is orbiting, then that object is a planet, technically speaking. This is the situation with the Earth and its Moon. Several characteristics of the Earth-Moon system distinguish it from the satellite systems of most other planets in the Solar System, including the unusually large relative size of the Moon, its great orbital distance from Earth, and the

fact that the Moon's path around the Sun is always concave to the Sun, like that of the Earth (but unlike that of most other satellites in the Solar System). As a result, some observers hold that the Earth-Moon system is a *double planet* rather than a planet with a satellite. Several possible planetary systems have been discovered orbiting other stars. We are not unique in the galaxy; we have only just developed the technology to detect such small objects so very far away. The planets and moons within our **Solar System** exhibit an extraordinary range of temperature, meteorology, size, and composition. Each is unique, from the sulfuric acid-laden clouds and lead-melting temperature of Venus, the vulcanism driven by tidal forces on Io, the methane lakes of Titan, to the giant hurricanes of Jupiter and the dust storms of Mars.

Other inhabitants of our Solar System which attract our attention are **comets**, referred to as “hairy stars” by the ancient Greeks. Once considered omens of impending disaster, these occasional visitors to our night sky now dazzle and delight us with their ghostly beauty as they shed dust and debris for millions of kilometers across the sky. Comets are composed of frozen ices such as water, carbon dioxide, methane and ammonia, along with fragments of minerals. Since it is not known if they have a higher percentage of minerals or ices, they can be thought of as either dirty iceballs or icy dirtballs! Long-period comets begin their journey towards the Sun from the **Oort cloud**, thought to exist at the farthest reaches of the Solar System and extending two light-years into space, halfway to the nearest star. Shorter-period comets come from the **Kuiper belt**, located

beyond the orbit of Uranus. Comet Halley comes from the Kuiper belt; Hyakutake and Hale-Bopp probably originated from the inner Oort cloud.

Asteroids, also called **planetoids** or **minor planets**, are chunks of rock which are confined to the **asteroid belt** between Mars and Jupiter. However, some asteroids have Earth-crossing orbits and others, the Trojan asteroids, occupy the orbit of Jupiter. Sometimes asteroids get knocked out of the asteroid belt and travel through space. These stray asteroids are then called **meteoroids**, as are other chunks of rocky debris from sources such as Mars. If meteoroids should enter the Earth's atmosphere and heat up due to friction so we can see them, they are called **meteors**. Meteors that are large enough or have a high iron content can survive their fiery journey through the Earth's atmosphere and reach the ground. Then they are called **meteorites**. Very large ones gouge craters on the Earth's surface, such as the Barringer Crater in northern Arizona. So asteroids, meteoroids, meteors, and meteorites are all chunks of rocky materials; what they are called depends upon where you find them.

That leaves **meteor showers**, which are not meteors at all! Meteor showers are actually the debris left behind in the orbits of comets—the dust and metals left after the Sun's radiation unlocked them from the icy prison of the comet. When the Earth travels through the orbit the debris occupies, the debris heats up due to friction as it encounters the Earth's atmosphere, and is referred to as a meteor shower. Meteor showers are named after the constellations from which they seem to originate, such as the **Perseid** shower in August, which appears to come from the constellation Perseus.

Stars radiate their own energy because they have enough mass for thermonuclear fusion to take place in their core. Stars are unique, differing in color, temperature and mass. Stars are born and stars die; some are just emerging from their stellar nurseries, while others are in the later chaotic stages of life. Some stars are unstable and vary in temperature and brightness.



Milky Way Galaxy

And now we begin our journey from our star, the Sun, with its family of planets, moons, comets and asteroids, to learn about other stars. There are more stars in the **Milky Way Galaxy** than grains of sand on the surface of a beach. We shall learn to decipher the messages encoded within the light they radiate, as well as appreciate their eternal grace and beauty.