Chapter 28: Life in the Universe

Are We Alone?

Outline

Summary

"Are we alone?" This topic is perhaps the most interesting of all other topics discussed so far and is likely to be the primary motivation for many of your students in signing up for this course. In this long-awaited chapter, characteristics of life and its development are discussed. The question of life existing elsewhere in our solar system and elsewhere in the universe are addressed. The Drake equation for predicting the number of intelligent, technological civilizations in the Milky Way is examined, and each factor within it is discussed. Finally, the chapter concludes with the search for extraterrestrial life and the difficulties in communicating with other technological civilizations, should they exist.

Major Concepts

- Cosmic evolution
- The definition of life and life "as we know it"
- Candidates for life in the solar system
    - Mars
    - Moons of outer planets—Europa and Titan
    - Cometary and meteoritic debris
- The Drake equation for number of technological, intelligent civilizations in the Milky Way
    - Rate of star formation
    - Fraction of stars having planetary systems
    - Number of habitable planets per system and the habitable zone
    - Fraction of habitable planets on which life arises
    - Fraction of life-bearing planets on which intelligence arises
    - Fraction of planets on which civilization becomes technological
    - Average lifetime of a technological civilization
    - Uncertainties and estimates of factors
- Communication with extraterrestrial, intelligent life
    - Distances
    - Radio leakage from Earth
    - SETI, the search for extraterrestrial intelligence
    - The water hole

Teaching Suggestions and Demonstrations

Asking the question "Are we alone?" is indeed a powerful way to conclude a course! Students may well have thought about this question before, but likely not from the perspective of astronomy or by using a tool such as the Drake equation. In addition to discussing the science involved in attempting to answer this question, be sure to save time for the philosophical implications as well. If we were to find another intelligent civilization, what would it mean for us? How would this knowledge change us, if at all?

Section 28.1

Begin by projecting Figure 28.1, and discuss the **arrow of time**. (Make sure your students recognize that it is not to scale!) It is a powerful statement of how we got to where we are today, and is a nice way to summarize some of the big ideas from the course and add to them what students already know about the development of life on Earth. Make a **timeline** of the about 4.6 billion years of Earth's history, and indicate when life first appeared, when the dinosaurs roamed Earth, and when humans appeared. This can be done on a long strip of paper, such as adding machine or receipt tape. Another common approach is to compress the history of Earth into a single year. If Earth formed on New Year's Day and today is midnight on the next New Year's Eve, when did life appear? When were the dinosaurs around? When did humans appear? When did Galileo use a telescope to view the stars? When were you born? This exercise puts history into perspective; it is amazing how much happens in that last day, and even in the last seconds of the last day.

Before proceeding with the **definition of life** as given in the textbook, ask your students to define life. What conditions must be met in order to classify something as alive? Record responses on the board. There will probably be some disagreement on some of the conditions; open the discussion and get students to try to convince each other of their point of view. When the class is satisfied with the list, play devil's advocate and try to come up with something that meets the conditions but would not be considered "alive." The example of stars given in the book is a good one; stars react to their neighbors, grow, generate energy, and (in a sense) reproduce. The main point of this exercise is to demonstrate that distinguishing between living and nonliving is not as trivial as students probably will think at first. We tend to think of life in terms of things like trees, bugs, giraffes or people. Point out the less clear-cut possibilities as well.

The course so far has covered the first four stages in the arrow of time diagram. Touch briefly on the next two, **chemical evolution** and **biological evolution**, now. Explain the **Urey–Miller experiment** and its significance. In the 1950s, it was believed that the Earth started out with no organic molecules. This is the reason Urey and Miller did their experiments, to see if it was possible to produce organic molecules from an inorganic environment. They succeeded, but the results still allowed for the possibility that Earth was unique in this respect, that organic life was possible only here and maybe nowhere else.

The discovery of complex organic molecules in interstellar space (mostly in the 1970s and 1980s) completely changed much of the thinking about the origin of life on Earth. Life on Earth is based on organic chemistry, not because of special or even unique conditions that exist on Earth, but because this is the raw material that was present on the surface of the Earth when it formed. Molecular clouds out of which stars and solar systems form have significant amounts and varieties of organic molecules. Amino acids and genetic bases found in meteorites tell us that some very complex organic chemistry took place in space *before* life developed on Earth. Organic chemistry is very likely one common link we may have with other alien life forms.
The original intent of the Miller–Urey experiments was to produce basic organic molecules from inorganic molecules. Although this chemistry may have taken place on Earth, it is no longer believed essential to the chemical evolution of life. These experiments are now seen as a way very complex organic molecules could further develop from the organic molecules already present.

It was never the intent of Miller–Urey experiments to produce life from inorganic molecules. This is a common mistake made by many students, that, until these experiments produce a living organism, they have failed to "prove" chemical evolution of life. One must remember that even if one of these experiments exactly reproduces the conditions on Earth, there will always be one ingredient missing – a few hundred million years. That is how long the "original" Miller–Urey experiment ran in order to produce life.

There is evidence that life on Earth dates back to at least 3.8 billion years ago. These microfossils are found in some of the oldest Earth rocks known. Certainly the 3.5-billion-year-old blue-green bacteria are well-recognized inhabitants of the youthful Earth. These bacteria form large mats known as stromatolites and were once thought to be algae. They exist even to this day. Early single cell life forms were prokaryotes, meaning non-nucleated cells. They are a much simpler type of cell as opposed to eukaryotes, nucleated cells, which make up most of life today. Although DNA may have been present in these cells, it is very possible that RNA was the original genetic molecule.

All life-forms on Earth are 99% hydrogen, oxygen, carbon, and nitrogen, in order of decreasing abundance. This certainly is not the makeup of Earth's crust or atmosphere. What object(s) have a composition similar to this? It is a good question to ask your students because they have the information to answer it. It is the Sun (and typical stars and interstellar clouds of gas and dust). With the exception of two inert gases, helium and neon, life's elemental abundance reflects that of stars and interstellar matter from which they all formed! This is hardly a coincidence, and is a good topic for discussion.

Section 28.2

As of this writing, we have landed on only three solar system bodies; the Moon, Venus, and Mars (The Huygens Probe is scheduled to land on Titan, Saturn's largest moon, during the Summer of 2004). The Moon and Venus are very poor candidates for having life; Mars, as the text notes, is one of the best places, particularly during its past. Do fly-by missions of the other planets and moons really have the potential to tell us much about life in those environments? Ask your students what those fly-by missions might have detected of life if they had passed by Earth instead. Would the rain forests be obvious? Giant redwood trees, blue whales, elephants, bacteria, and plankton in the oceans? How close to the Earth do you have to get before life is obvious? If we observed Earth from Mars, would there be detectable signs of life on Earth?

Explore with your students places on Earth where life exists under difficult conditions. Where else in the solar system might such conditions exist that would also allow life? Life on Earth exists in some rather inhospitable places; under tremendous pressures and in darkness at the bottom of the ocean around superheated volcanic vents, in the frozen Antarctic, in the driest, hottest, most remote deserts. The enormous ocean of atmospheric hydrogen and helium of Jupiter, which contains some organic molecules, might seem pleasant compared to these places on Earth. What about the interior oceans of water of Europa, Ganymede, and Callisto? It may be a long time before we can penetrate their icy crusts to look for the existence of life in those environments. We can eliminate the very hottest and coldest places in the solar system as being inappropriate for life but there remains many places that are more temperate and which contain all the building blocks of life that have yet to be explored.

When discussing the varieties of life on Earth, amino acids and proteins are a good place to begin. Proteins determine much of the structure, organization, and functions of an organism. Proteins are formed out of hundreds of amino acids strung together in a specific sequence. But there are only 20 amino acids that are used in forming all of life on Earth. (Other amino acids exist but are not used.)

Here is an effective analogy of a protein with its amino acids. Think of a train made up of 20 types of cars; engines, flat cars, tankers, box cars, etc. The train, though, isn't just 20 cars long; as it may be hundreds of cars in length. Thus, there are many box cars in different locations as there are tankers in other locations and so forth. A protein is like the entire train and is composed of hundreds of amino acids in a variety of locations.

Different proteins have both different sequences of these amino acids and different numbers of amino acids. For simplicity, let us say that proteins are formed out of 200 amino acids. How many different combinations or arrangements are possible with 20 amino acids linked to form a sequence of 200? It is simply 20^{200} ($=10^{260}$). For proteins with 500 amino acids in sequence, it would be 20^{500} ($=10^{650}$). These numbers are virtually infinite in size.

This suggests that there may be an infinite number of varieties of life possible for just the Earth. (Once a life form becomes extinct, there is essentially zero probability that it will ever occur again on Earth or anywhere in the universe!) Each life form, including human, is unique, not only on Earth but in the universe. Imagine the possibilities for the varieties of alien life, even if they are all based on organic chemistry. The diversity may truly be unimaginable!

Section 28.3

The **Drake equation** addresses the question at the other extreme: the possible existence of *intelligent* life. It calculates the number of technological, intelligent civilizations now present in the Milky Way Galaxy. Point out to students that the certainty of the result of an equation is no better than the certainty of the data entered into it. In this case, the values of some of the factors of the Drake equation are far from certain. However, it is still a useful tool because it helps us to examine the factors necessary for the development of advanced civilizations and to address them individually.

When examining the Drake Equation, have the students come up with their own estimation for each value. You can present the "liberal" view given in the text; students typically enjoy being very conservative with some of their estimates. Have a discussion on each of the factors and let the students provide the pros and the cons. Let the lifetime, L, remain an open question after it has been thoroughly discussed (and this term usually produces the liveliest discussion). Putting all the factors together, the number of technical civilizations in the galaxy, N, will be N = L from the text and maybe something like N = 0.000000001 L from your students (depending on how unlikely they feel some of the factors are).

The Drake Equation cannot, at this time, tell us N because the value of L has such an enormous potential range, i.e., $100 < L < 10^{10}$. But which form of the Drake Equation is closer to reality? There is one additional piece of information we can use to narrow down the possibilities. Since we exist, $N \geq 1$. Now put this value of N into the equation and solve for L. The first form of the equation is trivial, $L \geq 1$ year, which we already know is true. For the second form, $L \geq 1$ billion years. But we know this must be incorrect. We know that L could be very short because of the many ways we know that human civilization might come to an end (asteroid impacts, global natural disasters, nuclear war, over-population, destruction of the environment, running out of natural resources, etc.). A mandatory large value for L cannot be justified. The result is the N = L must be closer to the truth than the highly conservative case. An open discussion of L and its possible values is an excellent way of involving students in discussions "outside" of astronomy and yet highly relevant to the issue of N.

Section 28.4

As done in the text, take the result from the Drake equation and assume these civilizations are spread reasonably uniformly throughout the Milky Way Galaxy, then calculate the distance to the closest one. Clearly, the greatest obstacle in communicating with other intelligent civilizations is **distance**. Discuss the limitations of space travel, science fiction notwithstanding! Even the travel time of a *message*, sent at the speed of light, is enormous. Nevertheless, we are putting effort into looking for extraterrestrial life. Discuss SETI (the Search for ExtraTerrestrial Intelligence) and its implications. What if we find extraterrestrial, intelligent, technologically competent beings? Will they be more advanced than us? (Most likely, the answer is yes. We have been technological for only 100 years; chances are, any civilization communicating with us would have been at it a lot longer.) Ask your students how they, individually, would react to such a discovery. How do they think our planet's civilization as a whole would react? What is the value in conducting SETI with, say, radio telescopes, as currently funded by NASA? What does society get out of this search and any potential discoveries? Would the discovery of ETI be beneficial to society? These are excellent questions to pose to your students.

In addition to listening for messages, we have transmitted our own messages both in the form of radio waves escaping from Earth and as plaques and records with interstellar probes, as shown in Figure 28.13 and discussed in the context of the *Voyager* spacecraft.

Concerning "peopled" exploration, it is generally considered highly inefficient and an unlikely method to make contact with alien civilizations. Discuss with students the energy requirements for space flight and/or the time necessary for such trips. Obviously to resolve the problem of time, flight velocities must be very high; in fact, they must be relativistic. If such flights are possible, and the energy requirements are truly astronomical, time dilation allows onboard crews to survive lengthy journeys. However, point out that time still passes at the same rate on Earth, so the crew returns to a much older Earth than they left; maybe hundreds or thousands of years older!

Student Writing Questions

1. Assuming contact has been made with another civilization at a distance of, say 100 light years, what sort of information would you like to know about them? What would you like or want to say about us to them in return? Keep in mind that a question and answer format is not really practical with a 200-year wait between question and answer.

2. What impact would the discovery of an advanced alien civilization have on civilization here on Earth? Assume the contact is made through radio communications with a civilization on their home planet at a distance of 100 light years or more. Consider the effects, if any, on our political, social, and religious institutions.

3. Reflect on the word "alien" in terms of how it is used when referring to extraterrestrial life forms and its current use in reference to people from countries other than our own. Keep in mind the varieties of environments and evolutionary possibilities when thinking about life on planets around other stars. Consider, too, the differences among humans on Earth that make one group "alien" from another. What is the significance of the differences in these two cases?

4. Look up the meaning of "panspermia." Write a scenario in which life on Earth is seeded from life on Mars. How unlikely a possibility is this? Can this "new panspermia" be easily dismissed? If this is actually how life began on Earth, what effects do you think this would have on our way of thinking about ourselves?

5. The Drake Equation tells us the Galaxy could contain as few as one technical civilization (us!) or possibly some other, potentially large number. Take the latter number to be

something not too large, like 100,000. What are our responsibilities, if any, with regard to either of these two situations: we are the lone technical civilization in the entire Galaxy or we are among 100,000 other civilization? Keeping in mind that N = L, what is the implication with regard to our lifetime as a civilization? In the case of N = L = 100,000, how would our technology compare to most other technologies?

Answers to End of Chapter Exercises

Review and Discussion

1. Characteristics of life are reaction, growth, reproduction, and evolution. Although other characteristics might be listed, much of life has these four in common. Life is difficult to define because not all forms of life share the same characteristics.

2. Chemical evolution is a process by which life develops from the natural environment of the Earth (or anyplace else, for that matter). The chemistry of life, to some degree, depends on the material present on the Earth's surface and on the environment of the surface.

3. The Urey–Miller experiment tries to recreate the conditions on Earth before life existed, with the purpose of producing molecules necessary for life. Using ingredients like water, methane, ammonia, and carbon dioxide, and by adding energy, essential organic molecules for life, such as amino acids and nucleotide bases, have been formed.

4. Experiments have shown that organic molecules can form in the interstellar environment. An icy mixture of water, methanol, ammonia, and carbon monoxide were exposed to ultraviolet light. When the results were later placed in water, droplets, surrounded by membranes and containing complex organic molecules, were found.

5. The basic ingredients are water, methane, carbon dioxide, and ammonia.

6. It is possible that the Earth's atmosphere and surface environment were not suited for forming lots of organic molecules. If this took place in space, as suggested by Question 4, then the origin of life is the interstellar matter.

7. The fossil record dates back to at least 3.5 billion years ago, when the Earth was just over one billion years old. The fossil record, although unclear at times, is continuous up to the present time.

8. Language may be the direct result of the development of human intelligence. With language, information could be passed on from generation to generation. Ideas could be developed and exchanged. Cultural evolution are the changes in ideas and behavior of society and are likely linked to the appearance of language.

9. Organic molecules have been found in meteorites and in molecular clouds of interstellar matter. Comets and the surface of Triton likely contain some organic molecules. Many other solar system objects may also, but have not been sufficiently explored.

10. The possibility of life cannot be excluded from places such as Jupiter's atmosphere, Europa's liquid ocean, or the surface of Triton.

11. The *Viking* landers on Mars found no evidence of life as we know it. However, several possibilities remain before anyone can say for certain that life does not exist on Mars. The

landers were in very desolate, mid-latitude sites that may be quite inhospitable for life. Better locations might be near the poles where water, mostly frozen, exists in greater abundance. Life might also exist below the immediate surface of Mars, deeper in the soil where water may be abundant and life is shielded from the harsh surface environment. The landers could only look for life as we know it to be and could not look for alternate forms of life. Fossil evidence of life might also exist, telling of times in the past when the Martian environment was favorable for life. These questions have yet to be investigated.

12. "Life as we know it" means life based on organic molecules in a mostly water environment. When searching for life we must remember that "Life as we know it" may not be the only possibilities for life to have. Life might be based on other atoms than carbon or it may have a carbon base but function radically differently than our own forms of life.

13. The Drake equation has been devised as a way to estimate the abundance of life outside of the solar system. The result depends on seven factors: (1) rate of star formation, (2) fraction of stars having planetary systems, (3) number of planets in a solar system with a suitable environment for life, (4) fraction of suitable planets on which life actually develops, (5) fraction of life-bearing planets on which intelligence evolves, (6) fraction of intelligent life planets that develop a technology, and (7) average lifetime of a technological civilization.

    Factors 1 and 2 are fairly well known. Factor 3 could also be included in this group, although it is not as well known as 1 and 2. Factors 4, 5, and 6 really require some guess work. We really have no examples other than ourselves. Factor 7 has the widest range of values possible and is therefore the least well-known.

14. For a star to be suitable for life on one of its planets it is preferably not part of a binary system. It cannot be a spectral type O, B, A, or possibly F because these stars are too short-lived and O and B stars are too luminous, which would make the solar system too hot. M-type stars are probably not suitable either because they are under-luminous.

15. When the lifetime of a civilization approaches the time it takes for one two-way communication, then such communication becomes impractical if not impossible. This occurs for lifetimes of less than about 3000 years. If these civilizations were separated by 1500 light years, then one two-way communication would require 3000 years. By the time one of the civilizations sent a message by radio waves to the other and receives a reply, it would be just dying out.

16. Radio transmissions from Earth would vary significantly over a 24-hour period. This is the result of the Earth's rotation and various groups of transmitters coming into view. Most of the transmissions would be in the FM and television frequencies.

17. An advanced civilization would probably not continue to "leak" large amounts of radio radiation. We would expect their efficiency to improve and new technologies to be used that would prevent this leakage. Hopefully, though, they might transmit radio waves in order to communicate with other civilizations or in an effort to locate new civilizations.

18. The advantages of radio waves for interstellar communication are several. Radio waves travel just as fast as all other electromagnetic waves—the speed of light. They can penetrate dust clouds and can reach anywhere in the Galaxy. Being the lowest energy waves, they are cheap to produce and do not require a high level of technology to produce or receive. The background noise level at radio wavelengths is minimal, allowing signals to be detected over large distances.

19. The water hole is a section of radio wavelengths between 18 and 21 cm. This region of the radio spectrum would be the best for interstellar communications because it has the least amount of naturally occurring radio noise. These wavelengths also pass easily through interstellar dust clouds and are least affected by planetary atmospheres.

20. The best parts of the sky to monitor for SETI would probably be the Milky Way. The direction towards the Galaxy's nuclear bulge would also be preferred because so many more stars are in that direction.

Conceptual Self-Test

1. F
2. F
3. F
4. T
5. F
6. T
7. T
8. F
9. T
10. T
11. A
12. B
13. C
14. C
15. C
16. B
17. D
18. D
19. B
20. A

Problems

1. Use an age of 20 years for an example. In 46 years there are $46 \times 3.2\times10^7\ s = 1.47\times10^9$ s. Dividing this by the 4.6-billion-year age of the Earth gives 0.32 s/yr. For a 20-year-old person, this would be equivalent to 6.4 s.

   WWII ended 60 years ago, which would be 19 seconds on this scale. The declaration of independence was signed 73 seconds ago, Columbus sailed 2.7 minutes ago and the dinosaurs became extinct about 240 days ago.

2. The inner boundary of the habitable zone is where the temperature is at the boiling point of water, 373 K; the outer boundary is where water freezes at 273 K. The following proportionality will be used; it equates the inverse square law to Stefan's law. $L / d^2 \propto T^4$. But the temperature will be the same for any planet on either the inner or outer boundary. So, $L \propto d^2$. Comparison will be made to the Sun and its habitable zone. L will be in solar luminosities and d will be in A.U. $1 / 1 = (0.6 / d)^2$, $d = 0.6$ A.U.

   Similarly for the outer boundary, $1 / 1 = (1.5 / d)^2$, $d = 1.5$ A.U.

3. Use the same approach as in the previous question but with a new luminosity of 4.
   For the inner boundary, $1 / 4 = (0.6 / d)^2$, $d = 1.2$ A.U.

For the outer boundary, $1 / 4 = (1.5 / d)^2$, $d = 3.0$ A.U.

So, they each increase by a factor of 2.

4. From Problem 2. $L / d^2 \propto T^4$ or $d \propto 1 / T^2$. $d / 1.5 = (273 / 150)^2$, $d = 5$ A.U. or just about to the orbit of Jupiter.

5. First, calculate the outer boundary as in the previous question. $1 / 5 = (1.5 / d)^2$, $d = 3.35$ A.U. Calculate the orbital period using Kepler's third law. $P^2 = 3.35^3 / 1.5$, $P = 5$ years.

6. If 10 stars per year is the average formation rate of stars, each is able to form a planetary system, and 1 in 10 have a suitable environment for habitability, then over 5 billion years there should now be $10 \times 1 \times 0.1 \times 5$ billion = 5 billion habitable planets in the Galaxy.

7. The ratio of the gravitational force due to the parent star and the tidal force due to both stars is given to be 0.0001.

$$\frac{F_{tidal}}{F_{parent}} = \frac{GMm/R^2}{2GMmR/r^3} = \frac{2R^3}{r^3} = 0.0001.$$

Solving for r gives:

$$r = \sqrt[3]{\frac{2}{.0001}} = 27 \text{ A.U.}$$

8. (a) $N = 20 \times 0.1 \times 1 \times 0.1 \times 0.1 \times 0.1 \times 100$, $N = 0.2$ technological civilizations.

(b) $N = 20 \times 0.1 \times 1 \times 0.1 \times 0.1 \times 0.1 \times 10{,}000$, $N = 20$ technological civilizations.

(c) $N = 20 \times 0.1 \times 1 \times 0.1 \times 0.1 \times 0.1 \times 1{,}000{,}000$, $N = 2000$ technological civilizations.

9. Let A be the area of the Galaxy, R its radius in light years, and N the number of civilizations. The area per civilization will be A/N. If r is the radius of the civilization's area, the $A/N = \pi r^2$. Solving for r gives $r = \sqrt{(R^2/N)}$. From the Drake Equation, $N = L$, so $r = \sqrt{(R^2/L)}$.

The distance to the nearest neighbor will be $2r$ and for a round-trip conversation, the total distance will be $4r$. The communication will be at light speed, $c = 1$ ly/yr and must be completed in the liftetime of the civilization, L. So, $L = 4r/c$ and $r = Lc/4$.

Set the two equations for r equal to each other and solve for L. $Lc/4 = \sqrt{(R^2/L)}$, $L^3 = 16R^2/c^2$. For $R = 50{,}000$ ly, $L = 3400$ yrs.

10. Traveling at 50 km/s is 6000 times slower than light speed. Replace c^2 with $2.8\times10^{-8}\, c^2$. $L = 1$ million years.

11. Taking twice the distance of 1.3 pc is 8×10^{13} km. 80 years is 2.6×10^9 s. The average speed would be 31,000 km/s, which is about 10% of the speed of light.

12. 10,000 stations × 50,000 W/station = 5×10^8 W. This is 5×10^8 W / 10^6 W = 500 times more power radiated than the Sun in this same frequency range.

13. The water hole ranges from 18 to 21 cm in wavelength. $c = \lambda f$, so 3×10^{10} cm / 18 = 1.7×10^9 Hz and 3×10^{10} cm / 21 = 1.4×10^9 Hz. Subtracting these two frequencies gives 2.7×10^8 Hz. Dividing

by a 100 Hz per channel gives 2,700,000 channels. This is how many channels have to be searched when observing throughout the water hole. Talk about channel surfing!

14. The microwave background has an effective temperataure of 2.7 K. From *More Precisely 3–2*, λ_{max} = 0.29 cm / 2.7, λ_{max} = 0.107 cm = 0.00107 m. Calculate the frequency, $0.00107f = 3\times10^8$, $f = 2.8\times10^{11}$ Hz = 2.8×10^5 MHz = 280 GHz. Compare to Figure 28.14. The Water Hole is from 1.4 to 1.7 GHz, so this frequency is about 200 times higher.

15. 20,000 hours is the equivalent of 833 days or 2.3 years. 20,000 days is the equivalent to 55 years. This suggests that such a search must be conducted in such a way that each star can be searched in under an hour, otherwise the search would take too long.

Resource Information

Student CD Media

Movies/Animations
None

Interactive Student Tutorials
None

Physlet Illustrations
Drake Equation and Number of Intelligent Civilizations

Transparencies

T-269	Figure 28.1	Arrow of Time	p. 744
T-270	Figure 28.2	Urey-Miller Experiment	p. 746
T-271	Figure 28.9	Drake Equation	p. 751
T-272	Figure 28.10	Stellar Habitable Zones	p. 752
T-273	Figure 28.11	Galactic Habitable Zone	p. 753
T-274	Figure 28.13	*Pioneer 10* Plaque	p. 756
T-275	Figure 28.14	Earth's Radio Leakage	p. 757
T-276	Figure 28.15	The Water Hole	p. 758

Materials

Two interesting videos which deal with the possibility of finding life elsewhere in the galaxy are *Contact: The Search for Extraterrestrial Intelligence* (Space Viz Productions), and *Hunt for Alien Worlds* (NOVA).

Another excellent film is *Life Beyond Earth* by Timothy Ferris, PBS Home Video, 2001. This film is very well written, contains many beautiful images, quotes from scientists and has pleasant music. Students are typically captivated through the entire two hours.

Suggested Readings

Alper, J. "It Came From Outer Space." *Astronomy* (November 2002). p. 36. Discusses the idea that the building blocks for life are manufactured in space and delivered via cometary debris.

Crawford, Ian. "Where are they?" *Scientific American* (July 2000). p. 38. Examines possible explanations for the absence of detected signals from extraterrestrial civilizations.

Davies, Paul. "Interplanetary infestations." *Sky & Telescope* (Sept 1999). p. 32. Discusses the hypothesis that life is brought to planets by microbes from space.

Dick, S. "They aren't who you think." *Mercury* (November/December 2003). p. 20. Excellent discussion of the Drake Equation, cultural evolution and the implications for what an alien race might consist of (or what it might not consist of).

Joseph, T., Lazio; W. "Hello? Are You Still There?" *Mercury* (May/June 2003). p. 27. Discusses recent detection of 11 tantalizing signals and the methods used to try to confirm their origin.

LePage, Andrew J. "Where they could hide." *Scientific American* (July 2000). p. 40. Displays diagram summarizing the SETI search results in terms of distance from Earth and total radiated power.

Lubick, N. "Goldilocks and the Three Planets" *Astronomy* (July 2003) p. 36. Compares Venus, Earth and Mars from the standpoint of the ultimate ability to grow life.

Marchand, Peter J. "Windows on the desert floor: desert life may give hint of what extraterrestrial life may be like." *Natural History* (May 1998). p. 28. Describes microbes that exist under harsh conditions on Earth.

McInnis, Doug. "Wanted: life-bearing planets." *Astronomy* (Apr 1998). p. 38. Describes plans to search for Earth-like extrasolar planets.

Naeye, Robert. "OK, where are they?" *Astronomy* (July 1996). p. 36. Takes a look at all the conditions necessary for a planet to harbor an advanced civilization.

Schilling, Govert. "The chance of finding aliens: reevaluating the Drake equation." *Sky & Telescope* (Dec 1998). p. 36. Reevaluates the factors in the Drake equation.

Swenson, George W., Jr. "Intragalactically speaking." *Scientific American* (July 2000). p. 44. Discusses the transmission of radio signals and the limitations on communication with extraterrestrial civilizations.

Tyson, Neil de Grasse. "Goldilocks and the three planets." *Natural History* (May 1999). p. 92. Discusses the many factors that affect the suitability of a planet for life.

Zuckerman, B. "Why SETI Will Fail." *Mercury* (September/October 2002). p. 14. Discusses NASA's proposed *Terrestrial Planet Finder* (TPF) program. Explores issues, both pro and con with regard to the efforts of SETI, related to searching out extraterrestrial intelligence.

Notes and Ideas

*Class time spent on material: Estimated:*_______ *Actual:*______________

Demonstration and activity materials:

Notes for next time: