Chapter 10

Interstellar Travel

In Chapter 9, we presented the traditional arguments against interstellar travel as a means of communication between civilizations. We now want to reevaluate those arguments. First, we will consider some motivations for interstellar travel. Then we will describe some ways to engage in interstellar travel and consider the possibility that the Galaxy has been colonized. Finally, we will examine the issue of whether the Earth is being visited by extraterrestrials.

Suppose communication by radio fails; this failure could be caused by a variety of things. One explanation is that no other civilization is within the range of our searches, but there are many other possibilities. Perhaps we chose the wrong wavelength range or the wrong specific frequencies; perhaps there are no beacons; perhaps everyone is listening and no one is transmitting; perhaps we failed to recognize the signal; or perhaps the extraterrestrial equivalent of Congress cut off the other civilization's funds. Thus, it would be premature to use the failure, even of a massive and sustained effort, to rule out the existence of relatively nearby civilizations. We would be forced to use interstellar travel to contact such civilizations. By travel, we mean spacecraft with or without human passengers.

There are additional motivations for interstellar travel. Even if no civilization is found, we could explore other planetary systems. Many of these might harbor life, but not technological civilizations. It is possible to use a modified Drake equation to compute the number of planets in our Galaxy with life of some sort. If we use the examples from Chapter 8 for factors through f_ℓ, even the pessimistic student estimated a birthrate of 7.5×10^{-4} planets with life per year. Since life has existed on the Earth for at least 3×10^9 years, we would predict $N_\ell = 7.5 \times 10^{-4} \times 3 \times 10^9 = 2.3 \times 10^6$, where N_ℓ is the number of planets with life in any form in our Galaxy. The optimist and the average student would predict 1.5×10^{11} and 6.7×10^9, respectively. Judging from the fossil record on the Earth, we might expect about three-quarters of these planets to have only microbial life. Nonetheless, the study of even primitive life forms in another solar system would be of extreme interest to biologists. Given Mr. Average Guy's estimate for N_ℓ, we can compute r_ℓ, the average distance to the nearest planet with life using the equations for r in Chapter 8; for $N_\ell = 6.7 \times 10^9$, r_ℓ is only 5 light years. Thus, unless you are very optimistic about the lifetime of civilizations, planets with life will be much more common, and much closer, than planets with civilizations. If only bacteria could make radio telescopes!

If missions with passengers become possible, there is an additional motivation: species immortality. If we colonized planets around other stars, our species could survive even a catastrophe that would destroy all life in our solar system. One such catastrophe is certain to occur in about 5×10^9 years when our Sun becomes a red giant, but others could occur sooner, as noted in Chapter 7.

A final motivation is simply the urge to find out what is out there— to "boldly go where no one has gone before." This motivation overlaps the scientific interest in other planetary systems and possible life forms, but it springs from a less rational and perhaps more powerful portion of the human psyche. This is one of the prime motivations for explorers, but it would have to be communicated effectively to those holding the purse strings, as the example of Columbus can remind us. Assuming that we have established the motivation for interstellar travel, we will now consider the feasibility. We can bear in mind that whatever we can think of doing, a more advanced civilization may have already done.

A. Can We Visit Them?

We can begin with some general considerations. The history of our exploration of the solar system has a clear pattern: first, Earth-based observations were employed; then fly-by missions were sent; these were followed by probes that orbited or landed on the Moon or another planet; finally, astronauts traveled to the Moon and returned to Earth. Permanently occupied bases may be established in the future. This pattern would probably apply also to interstellar exploration. The effort for the next few decades will focus on observations from Earth or Earth orbit to determine characteristics of planets around nearby stars. The next steps will probably follow the rest of the pattern, with one very important exception: there will probably be no missions with human beings that return to Earth. The reason for this difference can be found in the much greater distances to other stars.

The dilemma is the following. At modest speeds (about one-tenth the speed of light), the time to travel to the nearest star and return exceeds the normal human life span. Circumventing this problem by traveling faster (near the speed of light) causes a rapid rise in the mass ratio (R_M, as defined in Chapter 7). Suppose we want to travel at 99% of the speed of light: at this speed, the round-trip to the nearest star would take about 9 years of Earth time, but the occupants would age only about half a year (more on this later). This sounds great, but the mass ratio would have to be 14, even for the most efficient fuel possible, just to achieve a speed of 99% of the speed of light. Unfortunately, it takes an equal amount of fuel to slow down, and this slowing-down fuel must be part of the payload when you are accelerating. Thus, to speed up to 99% of the speed of light and then slow down again requires a mass ratio of $14 \times 14 = 196$. For a round-trip mission, you must have this mass ratio when you get there; thus, when you leave the Earth, you must have a mass ratio of $196 \times 196 = 40{,}000$. For a payload like that of the space shuttle (certainly too small for an interstellar mission), you would need about 10^9 kilograms, or 1.3 million tons, of fuel. (By the way, half of this would have to be antimatter, since the most efficient fuel possible is matter-antimatter annihilation!) Leaving aside the details of this example, the critical point is that round-trip interstellar missions, analogous to the Apollo missions to the Moon, will probably never occur. Tickets to the stars will not be for the round-trip.

From the above analysis, it is clear that the lowest mass ratio is for a fly-by mission that does not slow down. Thus, we might expect the first missions to be of this sort, in agreement with the history of solar system exploration. Is even this first step feasible? Pioneer 10 is the fastest moving object produced by our civilization, at a velocity of about 10 kilometers per second. This speed is still only $v = 3 \times 10^{-5}$ c, where c is the speed of light. We will use this unit of velocity because then the time in years to travel a distance r, measured in light years, is simply calculated from $t = r/v$. Consequently, Pioneer 10 would take $t = 4/(3 \times 10^{-5}) = 130{,}000$ years to get to the nearest star, if it were headed in the right direction (which it is not). Fly-bys at current technological levels make little sense. Better propulsion systems are necessary.

In our discussion of solar system colonization, we noted that nuclear fission is the next logical step after chemical fuels. The first serious study of interstellar flight, Project Orion, examined this possibility. The idea was to use nuclear bombs to propel the ship forward. The bombs would be exploded about 30 meters behind the spacecraft and the thrust would be transmitted through a giant pusher plate and shock absorbers. About 60,000 kilograms (65 tons) of shielding would be necessary to protect the rest of the ship from the radiation. By using about 300,000 bombs the size of the one that devastated Hiroshima, exploding one per second for ten days, the Orion spaceship could reach about 10,000 kilometers per second, one thousand times faster than Pioneer 10. However, this great speed is still only 0.03 c, resulting in a 130-year one-way trip to the nearest star. Project Orion was terminated, partly as a result of a 1963 treaty that prohibited nuclear bomb tests in the atmosphere or space. Project Orion might be a more imaginative way to dispose of all the bombs that should be dismantled by the U.S. and Russia.

Project Orion would have been propelled using technology that already exists, as we know all too well. Nuclear fission can convert up to 1.2×10^{-3} of the fuel mass into energy and can thus achieve a maximum specific impulse of about 1.5×10^{6} seconds. However, we have seen that no actual plans exist for achieving s.i. greater than about 1,000 seconds because of problems of melting the confinement vessel. Nuclear fusion, combining light elements into heavier ones, is even more efficient. In principle, fusion can convert up to 9×10^{-3} of the mass into energy and achieve s.i. $= 4 \times 10^{6}$ seconds. Now we are no longer discussing current technology because controlled nuclear fusion has not yet been achieved, except in experimental reactors, where we still get less energy out than is put in. Can we apply nuclear fusion, the power source of the stars, to interstellar propulsion?

To achieve nuclear fusion, we must create conditions similar to those deep inside a star, extremely high temperature being the most critical. Thus, we immediately have a problem similar to that encountered for nuclear fission: how to contain the reaction without melting the walls. One approach is to use magnetic fields, but various instabilities make it difficult to confine the gas for long periods. Another approach is called inertial confinement. In this scheme, tiny frozen pellets of fusion fuel are injected into the reaction chamber where they are struck by intense beams of laser light or charged particles. The pellet is compressed so violently (imploded) that it reaches temperatures high enough to initiate fusion reactions. The resulting explosion would be channeled out the exhaust by magnetic fields, propelling the ship forward. The thrust would be controlled by how many pellets are injected per second. The high temperature results in a large exhaust velocity, which is desirable.

The British Interplanetary Society has sponsored the most detailed study of an interstellar spaceship using nuclear fusion. The study, Project Daedalus, resulted in the design for a fly-by probe, without human occupants, to Barnard's star. This star is 6 ly from the Earth and was thought at the time of the study to show evidence of having other planets. The resulting vehicle would reach a velocity $v = 0.12\,c$, and thus take about 50 years to make the trip. We will examine the results of the Project Daedalus study in some detail because it illustrates many aspects of interstellar travel with foreseeable technology. One of the primary questions was the choice of fuel. Stars fuse protons (hydrogen nuclei) into He^4 (helium) through a series of steps, as discussed in Chapter 2. Unfortunately, the first step of this reaction, the fusion of two protons into a deuteron, positron, and neutrino, is extremely slow and relatively inefficient in energy production. Stars can get away with burning the cheap, low-grade fuel, but it is not suitable for our purposes. Most discussion of nuclear fusion has centered on fusing the deuteron (the nucleus of deuterium) with a nucleus of tritium (a very rare isotope of hydrogen with one proton and two neutrons) to make He^4 plus a neutron. However, the fast neutrons will cause other nuclear reactions in the surrounding materials, and the rest of the ship must be shielded to avoid damage. Neutrons are hard to shield against because, having no electric charge, they cannot be directed by electric or magnetic fields, and they pass through a lot of solid material before stopping. Thus, the shielding requirements were found to be excessive.

The study selected instead the reaction of deuterium and ^3He (a rare isotope of helium containing two protons and one neutron). The reaction is

$$d + {}^3He \rightarrow {}^4He + p,$$

where d is a deuteron, ^{4}He is normal helium, and p is a proton. In this case, the products both have positive charges and can be directed by magnetic fields out the exhaust. Therefore, the shielding can be greatly reduced. The reaction is also reasonably efficient, converting 4×10^{-3} of the mass into energy. There is one minor problem. ^{3}He is a rare isotope of an element that is very rare on the Earth, for reasons discussed in Chapter 3. The study group suggested that the fuel be collected from Jupiter, which has large amounts of helium and hydrogen and, hence, reasonable amounts of ^{3}He and deuterium. Thus, exploitation of our solar system on a large scale may have to precede interstellar missions!

The final design of the Daedalus probe involved a two-stage ship beginning its flight from near Jupiter. After accelerating for about 4 years, it would coast for about 50 years to reach Barnard's star. The total scientific payload would be 500 tons; at blastoff, the total mass would be 54,000 tons, of which 50,000 would be fuel, producing an overall mass ratio of about 12, or about 100 if only the scientific payload is considered. The exhaust velocity would be 10^4 kilometers per second, and a specific impulse of about 10^6 seconds would be achieved. The pellets would be injected at a rate of 250 per second. Sophisticated computers would control the mission and robot repair units would be necessary to maintain the ship during its long mission. The study group also considered the problem of erosion of the spaceship caused by impact with interstellar dust grains. From the point of view of the spaceship, it would encounter a hail of dust particles, striking it at a speed of 0.12 c. These would damage the vehicle, so the group proposed a beryllium erosion shield 7 millimeters thick and 55 meters in diameter to protect the second stage. During the encounter with the target planetary system, they might run into larger solid objects, like asteroids. The study group proposed to break up the large objects by projecting a screen of small particles ahead of the ship.

During the encounter, various sub-payloads would be dispersed to study the different planets in the system. The probe would then transmit information back to Earth for 6–9 years after it passed near Barnard's star. (Presumably we would choose a star known to have planets by the time the mission began.) The Galileo mission provided an example of what such a probe could learn, as described in Chapter 5D. As noted there, various "biomarkers" may indicate the presence of life on a planet.

The Daedalus probe would clearly be an impressive undertaking, going well beyond current technology in many areas, most notably propulsion; but it does use technology that is not outlandish (that is, we can reasonably project that such technology might be achieved in this century). It is sobering to realize that Daedalus could be only the first primitive attempt at interstellar travel— a minimal fly-by mission analogous to the Mariner and Pioneer missions in our own solar system. Does it make any sense to consider more advanced missions? Before we address this question, let us stretch our minds a bit by asking whether there are still more advanced technologies that might become available.

In particular, propulsion is clearly a thorny problem. Even the mass ratio and speed that Daedalus would achieve are disappointing in the context of missions with humans, where much larger payloads and shorter travel times are desirable, if not necessary. We have earlier referred to the most efficient possible propulsion system: the annihilation of matter and antimatter. When a particle interacts with its antiparticle, they annihilate each other, turning all their mass into energy, ultimately in the form of photons. If these photons can be properly directed, they would provide the ideal exhaust velocity, $v_e = c$. We have already seen that round trips at speeds near c are unlikely even with this ultimate propulsion system. Now let us examine some of the problems associated with the propulsion system itself. The principal problem is that antimatter does not normally exist in the present Universe, as far as we know. We can create small amounts in giant particle accelerators on Earth; but, using current accelerators, it would take 200 million years to produce even one kilogram of antimatter. Much more energy must be put in to produce the antimatter than could be extracted from it later. Antimatter is not a useful source of energy; it is an incredibly compact way to store energy. It is compact, but difficult; you cannot store it in ordinary containers made of matter. Holding it as a gas in a magnetic field may be possible, but then a large container would be needed to hold enough.

Are there any other ways around the problem of carrying vast amounts of fuel? In 1960, Robert Bussard suggested that the spaceship collect its fuel as it goes, scooping up the interstellar gas, which is primarily hydrogen. After an initial acceleration to about 10^{-4} c, the spaceship would operate as a ramjet, scooping up more and more fuel as it went faster and faster. As we know, the density of interstellar gas is extremely low; on average, there is about 1 atom per cubic centimeter. For a reasonable acceleration (one g), the scoop would have to be 4000 kilometers in diameter. The notion of a physical scoop the size of the United States is clearly ludicrous, so magnetic fields are usually invoked. Nonetheless, the field generators must be supported by material of sufficient strength, and this constraint limits the acceleration eventually. In dense molecular clouds, the scoop could be much smaller, perhaps a mere 100 kilometers in diameter.

Besides the problem of low density, the interstellar gas consists mostly of low-grade hydrogen fuel. We have noted that the first stage in hydrogen-to-helium fusion, the fusion of two protons, is very slow. This problem has led to the suggestion of the catalytic ramjet. In this scheme, the CNO cycle is used to catalyze the hydrogen to helium fusion, just as it does in some stars (see Chapter 2). This would allow efficient usage of interstellar hydrogen, but the technology needed to realize this scheme is considerably beyond that required for the deuterium and ^{3}He fusion.

Other schemes have been proposed, such as using a fixed laser to bounce light off a huge sail, keeping the fuel to power the laser in one place instead of having to accelerate it. Alternatively, the laser could ignite propellant pellets, the hot gas then being exhausted. With our present state of knowledge and technology, it is virtually impossible to decide whether any of these schemes might ever be realized. This uncertainty makes it harder still to decide if other, very advanced civilizations might develop efficient means of interstellar travel.

We can provide some general considerations, which, being based solely on the laws of physics, will apply to any civilization. One consequence of the theory of relativity is that time is not uniform for all observers. Time appears to "slow down" in a rapidly moving object. Consider the following famous example. One of a pair of twins sets out on an interstellar journey, her sister remaining on the Earth. The traveler journeys to Alpha Centauri at 86.6 percent of the speed of light. The sister on Earth knows that the traveler will make the 4.34 ly trip in five years. However, the onboard clock indicates that only 2.5 years have elapsed. Since all clocks, including biological ones, run "slower" on the ship, the sister who went to Alpha Centauri has actually aged by only 2.5 years. If she turns right around and returns home, she will find herself 5 years younger than her stay-at-home twin sister! This effect, known as time dilation, is a favorite of science fiction writers because it allows short travel times from the traveler's point of view. The theory of relativity gives us the formula, $t = \gamma t_0$, where t is time interval measured by the sister at home, t_0 is the traveler's time interval, and

$$\gamma = \frac{1}{\sqrt{1-(v/c)^2}},$$

where v is the velocity of the traveler.

At speeds closer and closer to c, the factor inside the square root sign becomes closer to zero, and γ grows toward infinity. If one could travel at the speed of light, time would appear to stop! Travel at speeds very close to the speed of light allows very long trips in times that are short, as measured by the crew of the spacecraft. For example, if you could accelerate at 1 g (Earth gravity) for the first half of the journey and decelerate at 1 g for the second half, you could reach the center of our Galaxy, 3×10^4 ly distant, in about 20 years. Thus one could make a trip around our Galaxy in one human lifetime. Of course, the Earth would have aged by over 60,000 years, so the homecoming celebration might have been forgotten.

What price does one pay for this relativistic time dilation? The price is paid in the increasing difficulty in accelerating the ship as v approaches c. The source of the difficulty is that the mass that must be accelerated increases by the same factor, γ, which occurred in the time dilation formula: $M = \gamma M_0$, where M is the mass of the moving object, which has mass M_0 when it is at rest. This equation helps us see that travel at the speed of light is impossible; the mass would become infinite, requiring infinite energy to accelerate. This factor also makes it very difficult to reach speeds at which the time dilation factor even starts to make the travel time reasonable. This is also why the mass ratio gets so large for relativistic (v near c) travel. Other problems arise at high speeds. Since the interstellar dust grains now strike the ship at relativistic speeds, their mass is larger by the same formula, and the erosion of the shield becomes staggering. For $v = 0.99$ c, 5.5 meters will be eroded every year from every square meter of surface.

The great distances between stars, typically a few light years, coupled with the absolute speed limit of c, have forced most science fiction writers dealing with interstellar travel to resort to a fictional device: faster-than-light travel. "Warp drive" allowed the Star Trekkers to visit a new star system each week, instead of spending long, boring years in space. While it is a fine fictional device, faster-than-light travel is impossible in the context of the laws of physics. The laws have changed before as we learned more, and may well change again; in this fact some find hope for actual warp drives. The history of physics is not encouraging; most changes in physical theories consist of new restrictions (such as Einstein's imposition of c as the absolute speed limit) and new theories usually include the restrictions of the old.

One far-out possibility, implicit in the name, warp drive, is the recognition that space and time can be warped by sufficiently strong gravitational fields. Rotating black holes may form wormholes, which might serve as rapid-transit conduits to "elsewhen" in the Universe. The term "elsewhen" implies that both space and time travel are involved. Such ideas are quite fanciful, since the very field that might create a wormhole would normally tear apart anything that ventured into it. Nonetheless, some physicists have been exploring, theoretically, ideas for stabilizing wormholes with exotic matter, a possible product of attempts to create more unified theories of physics. Wormholes have provided interesting puzzles for physicists and useful plot devices for science fiction writers, but there is no evidence that they actually exist. Another possible way around the speed limit involves the use of "exotic matter", which is invoked in some physics theories. At this point, no one knows if such matter exists, nor how to create or control it.

While experts disagree on whether relativistic interstellar travel would be possible for advanced civilizations, it is clear that formidable obstacles exist from our vantage point as one of the youngest communicable civilizations. Let us restrict ourselves in what follows to physics as we know it, and to technology that we can at least project as possible. I will interpret this restriction as meaning the ability to travel at speeds around 0.1 c, as would be achieved by the Daedalus probe. The next logical step would then be a probe that could decelerate and go into orbit around another star. This idea leads us to the subject of Bracewell probes.

Ron Bracewell has suggested that under some circumstances, unmanned probes could be more efficient in contacting other civilizations than radio searches. In particular, if r is about 100 light years, then there are more than 1,000 candidate stars, and we have discussed how unlikely contact is unless someone has set up a beacon. Also, there is a 200-year delay between question and answer, making communication hard to interpret. It would be essentially a one-way conversation. Bracewell prefers an automated robot space probe that would wait in orbit around a star until it is triggered by the reception of radio signals from a planet (or other signs of life). It would then notify us and initiate contact with the planet. This could be a two-way exchange between the probe and the planet, given a sufficiently sophisticated computer program on the probe. Bracewell suggests repetition as a way of attracting attention. Suppose the probe hears a particular message at the end of a news broadcast and broadcasts back that message. After some delay, depending on where the probe is, the listeners would hear an echo. The transmitter could test this by repeating it again. This could go on until there was no question about the source of these echoes. Then a code could be established and real communication begun. Advantages of Bracewell probes are the following: we could be checking out many stars simultaneously; we could send out one probe at a time, as funding permits; and two-way communication makes it much easier to recognize the artificial origin and establish a code. The Bracewell probe also has some disadvantages. It takes a long time to get to the other star. Even if we achieved a speed of 0.1 c, it would still take 1,000 years to get to a star 100 light years away. Considerable advances in technology would be needed to build the probe: higher speed, internal navigation, computer advances, etc. It must be reliable for 10^3 years just to get to the star. It would have to last longer if it had to wait for a civilization to arise on a planet.

Is there such a probe in our solar system? Long-delayed echoes are echoes of radio signals, with delays of 1-30 seconds; no good explanation has been found for them. Duncan Lunan, a Scottish science fiction writer, tried an analysis in 1973. He claimed to find a pattern in the echoes, interpreting it as a map of constellation Boötes, with Epsilon Boötes as the home star. Lunan thought that this star was 103 light years away, fitting into Bracewell's ideas. However, the star is actually 230 light years away and is a binary star (and thus not a good candidate for life). Lunan's interpretation is not convincing. Attempts to initiate contact with the alleged probe were unsuccessful, and this idea is now generally discounted.

If we used Daedalus-level technology for a Bracewell probe, the mass ratio would be raised to about 150 by the need to decelerate. This is high, but not much worse than the space shuttle. Even if Bracewell probes are not effective in establishing communication, they could be used to collect much more detailed information about a planetary system than could be collected by a fly-by mission. Such information could pave the way for a mission with people aboard. Since the mission would be one-way, adequate information about what to expect would be essential. This would probably be a mission not to explore, but to colonize.

B. Colonization of the Galaxy

Let us now consider the possibility of sending human passengers, with the goal of colonizing a planet around another star. If we again assume the propulsion methods of the Daedalus study, the speed and mass ratio of a colonization mission would be $v = 0.1$ c and $R_M = 150$. Of course, the payload of a colonization mission would have to be much larger, raising the fuel requirement dramatically. Alternatively, one could travel more slowly and lower the mass ratio. Notice that even at 0.1 c, the travel time to nearby stars will be about 50 years, so the intrepid 20-year-olds who start out will be doddering 70-year-olds when they arrive to "seek out brave new worlds." It will be up to their descendants to do the colonizing; once you are forced to multi-generation missions, slower travel does not seem so unreasonable. Would anyone undertake such a mission, knowing that only his or her descendants will ever see the promised land? When I ask for volunteers, every class has a few. If we were to develop space colonies, we could attach a propulsion system and send one to another star. Various "world-ships" of this type have been suggested, ranging up to giant structures containing a million colonists traveling for thousands of years.

Whether or not our civilization ever does this, we can imagine that other, very long-lived civilizations might. If so, what are the consequences? Kuiper and Morris considered this question; they concluded that colonization is quite reasonable for advanced civilizations with plenty of time to spare. Assume that each new colony becomes the center of a new expansion after some time of regeneration. Traveling at $v = 0.1$ c and waiting 500 years to regenerate, the effective expansion velocity would be 0.016 the speed of light. In this way an advanced civilization could colonize the entire Galaxy in 5×10^6 years (which is less than 10^{-3} of the age of the Galaxy). If the birthrate of technological civilizations is modestly high, then many civilizations have arisen during the history of the Galaxy, the great majority of them arising more than 5×10^6 years ago. Even the pessimist of Chapter 8, with her very low birthrate of 7.5×10^{-8}, would predict that in 5×10^9 years 375 civilizations would have arisen ($7.5 \times 10^{-8} \times 5 \times 10^9 = 3.75 \times 10^2$).

If even one of these decided to colonize, then the Galaxy should already be colonized. What would be the consequences of Galactic colonization? First, a Galactic community would exist, and one or several different civilizations would be communicating from planet to planet. If so, then we may be close to a communication station. Second, the solar system would have been visited. Third, advanced civilizations would probably have representatives somewhere near the Sun; for example, there might be a Bracewell-type probe waiting for us to reach some level of development before contacting us. Fourth, it would be likely that the Galactic community knows of our existence because of our leakage radiation. Thus, there may be a nearby beacon. If they have decided not to contact us, we still might intercept a signal. In each case, searches with existing telescopes would suffice; something much more ambitious, like Project Cyclops, would not be necessary.

The conclusions of Kuiper and Morris challenged many of the prevailing views on this subject. Michael Hart has made a more radical suggestion, which we will refer to as the Hart Hypothesis. This argument starts with a fact: there are no intelligent beings from space on Earth now. Hart claims that there are only five possible explanations for this fact:

(1) Space travel is not feasible.
(2) Other civilizations have chosen not to colonize.
(3) Other civilizations have not had time to colonize the Galaxy
(4) The Earth has been visited in the past, but we do not observe any visitors now.
(5) There are no other advanced civilizations in the Galaxy.

Hart argues against explanations one and three in the same way that Kuiper and Morris did. What about the second possibility? Hart argues that, even if a given society chooses not to colonize at one time, at another time it may choose to colonize. Consider your Drake equation; unless your estimate for the birthrate of civilizations is very small, many will have arisen in the 5×10^9 years available. If even *one* of these decided to colonize, it could have colonized the entire Galaxy. Next, Hart considers the fourth possibility, that they have been here in the past and have visited us, but are not doing so now. He argues that the Earth is very suitable for colonization. This argument seems to negate the fourth possibility, leaving only number five. Note that this argument is constructed so that the five proposed explanations include all possible explanations; thus, if all but one can be rejected, then the remaining one must be the correct explanation. So, in the end, Hart concludes that we are alone in the Galaxy. More precisely, he argues that we are essentially alone, and that the value of N is not nearly as great as optimists like Sagan and Drake would like to believe. Hart thinks that L is long, so he believes that some other factor in the Drake equation must be overestimated (f_ℓ, f_i, f_c). Hart, you will recall, was also the person who did the calculations that indicated a low n_e in the Drake equation, but he does not think it is low enough to explain the absence of extraterrestrials on Earth.

If you have calculated a large number for N, Hart's argument is a direct challenge to your conclusions; you will need to present a convincing counter-argument. To help you, we will re-examine our assumptions about colonization. Let us consider some things that may be wrong in the arguments that colonization will be easy and fast. First, colonization may be much slower and more careful than we have assumed. Civilizations may first send a robot space probe, then establish a colony slowly, methodically, and solidly before moving on to colonize other areas of the Galaxy (this seems entirely reasonable, since they may need to terraform). If the regeneration time is 10^6 years rather than 500 years, then the time to cover the Galaxy is longer than the present age of the Galaxy.

Second, perhaps the space travelers become nomads and explorers who are more interested in analyzing new planets than colonizing them (as in **Star Trek**); this type of space search mission may be much more prevalent than colonization. If the pressure to colonize comes from overpopulation, we have seen that there is no way that it can succeed. Long-lived civilizations will have to learn to control their population, removing that motive for extensive colonization. Since we anticipate long journeys in space colonies to a new star, people would be adapted to space, not a planet (especially not to a new planet that they know little about). Thus, space explorers may not want to land on a new planet, but merely analyze it for scientific purposes. Also, they would have to go from a tightly controlled population during the voyage to rapid population expansion to colonize the planet.

Third, other planets may be suitable for life, but not our life (that is, our civilization may not find the planet all that pleasant or inhabitable). Consider our case if we were to colonize a planet around another star; if even one of the 20 amino acids was not used in the life on that planet, then food could be a problem. Thus, it may simply be harder to colonize than we assumed.

Fourth, even the optimistic estimate for the time to spread across the Galaxy is 10^6 years; this is comparable to the time scale for significant biological evolution, which may cause the travelers to become space creatures who are ill-adapted to life on planets. Even if colonization has occurred, it is plausible that an ecological ethic will develop— that is, there may be a rule against interfering with life on any planet if it is reasonably advanced (that is the Prime Directive of **Star Trek**).

The Hart Hypothesis can also be found in slightly modified forms. One variation involves the concept of a Von Neumann device, a theoretically possible, self-repairing, self-replicating machine. Frank Tipler has argued that such devices, once built, could colonize the Galaxy much more cheaply than could people (or the extraterrestrial equivalent). Each machine, sent to a nearby star, would replicate itself, sending out more and more machines until the Galaxy was completely populated by the machines. The absence of such machines on the Earth can be used to argue against the existence of other civilizations, as in the original Hart Hypothesis. The Tipler Variation suffers from a severe motivational problem. One can perhaps imagine a civilization sufficiently megalomaniac to want to spread its population over the entire Galaxy, but manifest destiny for machines seems a little unlikely. What's the point? Besides, you might worry about them returning in some mutated form to take over the home planet!

A second variation, suggested by Ben Zuckerman, notes that sending primitive organisms is a great deal easier than sending advanced life forms. Following an initial fly-by mission, we could breed or genetically engineer a strain of microbes suited to conditions on another planet. In this way, we could easily seed the planets around the nearest 10^4 stars. The Zuckerman variation might be called the poor man's colonization: you don't get to go, but you can send your bacteria. This variation is also a form of directed panspermia, reminding us of the idea that life on Earth began this way. As we noted earlier, it only transfers the question of the origin of life somewhere else. Once again, the question of motivation arises. Random interstellar bacterial warfare hardly seems worthy of an advanced civilization.

In some sense, the Hart Hypothesis and all its variants are more detailed treatments of the concise question attributed to Enrico Fermi: upon hearing a discussion of ETI, he simply asked, "Where are they?" This question was taken as the title of a book edited by Hart and Zuckerman that examines these questions in some detail. The extent to which this question challenges the view implicit in much of this course depends on the likelihood of extensive interstellar travel. Looking over the difficulties and expense of interstellar travel, one may be tempted to answer Fermi's question by saying, "They stayed home." Let us now turn to the possibility that they **have** been here.

C. Have They Visited Us?

If we return to Hart's argument, we can see two other branches to take. Suppose that possibility number 4 is right, that we have been visited by extraterrestrials in the past. Did these visitations leave any traces? Or we can reject Hart's original "fact" and say that the extraterrestrials are here now, a path which will lead us to the topic of UFOs.

If we maintain the view that space travel is feasible for very advanced civilizations, but reject the notion that colonization of every suitable planet is necessary, then a visit to Earth by aliens becomes plausible. If the visit was fairly recent, the aliens may have left some evidence behind. Perhaps seeing Homo erectus at the threshold of human-level intelligence, or human beings at the threshold of technology, they left a gift of knowledge and technology to be found when our civilization became sufficiently advanced to find it. This idea, suggested by **2001, A Space Odyssey**, has been elaborated by various writers into incredibly complex schemes. In one, the dimensions of the Great Pyramid in Egypt are used to deduce the location of a data bank on Phobos, a small moon circling Mars. The theme of extraterrestrial visitors, perceived as gods by our befuddled ancestors, directing the construction of great monuments, landing fields, and statues, has been explored exhaustively by Erich Von Daniken. After riding a tremendous crest of popularity, Von Daniken's ideas have been thoroughly debunked. Since his stock, measured by the number of term papers on the subject, has plummeted, we will not spend time detailing the problems with his ideas. Suffice it to say that the common thread is an insufficiently appreciative view of the abilities of ancient civilizations.

What about UFOs? The term **UFO** stands for Unidentified Flying Object and was introduced as a neutral bureaucratese term to replace the emotionally charged term "flying saucer." Calling something a UFO was supposed to mean simply that it had not been identified yet, with no suggestion that it had anything to do with extraterrestrials. Of course, this strategy did not work; the term "UFO" quickly took on all the connotations that were originally carried by "flying saucer."

An incredibly large number of people believe that UFOs represent extraterrestrial visitors. National polls consistently find that 40% to 50% of people hold this belief. My own polls in this class give higher results. At the start of the semester, 68% of students believe that UFOs exist, and 76% of those believe that they are controlled by extraterrestrials. By the end of the class, these percentages drop to 40% to 50% believing in UFOs, with 45% to 55% of those believing they are controlled by extraterrestrials. One might argue that I get higher percentages than the national surveys because the course naturally attracts UFO believers. Several students have conducted polls outside the class, but still in Austin, for term papers for this class. In surveys in 1983 and 1995, nearly 80% of those polled by the students believed in UFOs. Since Austin has a high level of education, this result seemed surprising at first. In the 1995 poll, the student asked about education level. Those with below average education (high school or less) were *less* likely to believe (62%) than those with above average education, defined as working on or having a doctorate (88%). Perhaps the high credulity rate in Austin is caused by the high education level: 72% of those surveyed had at least some college education. This is certainly a sobering thought for my academic colleagues. Credulity does not extend to the government, however; exactly half the respondents believed that the government covers up UFO sightings.

Other aspects of the issue are more variable. Years ago, before the release of several movies about aliens (**Close Encounters of the Third Kind** and **E.T.**), a student asked 100 people if they personally had seen a UFO; only 12% answered yes. A few years later, after these very popular movies had been released, 60% answered yes. In the same poll, 84% thought that the extraterrestrials would be friendly. Also, 85% of those polled said they would be willing to travel with an extraterrestrial! Yes, 4 people who thought they would be unfriendly were still willing to travel with them. Go figure.

The fervent interest in UFOs has stimulated several government studies. A prominent advisor on one study, Allen Hynek, has written a book on the subject, developing much of the standard terminology. UFOs are divided into the following four categories.

1. **Nocturnal lights** are seen in clear weather, usually between 8 and 11 p.m.
2. **Daylight disks** are seen in the daytime. While usually disks or saucer-shaped, they sometimes are cigar-shaped.
3. **Radar-visuals** are objects that show up on radar and are also seen visually. Those that are not explicable as aircraft or balloons may be quite puzzling. Some may be enormous swarms of insects illuminated by atmospheric electrical effects.
4. Finally, we have **Close Encounters.** This category is subdivided into three kinds. Close encounters of the first kind indicate that the UFO is seen at a distance of less than 500 feet. In the second kind, some physical effects occur, such as burnt vegetation, trouble with electrical systems, etc. Close encounters of the third kind involve the observation of actual aliens, and contact with them may even be involved. The aliens are usually humanoid in form. If not a hoax or a delusion on the part of those who report them, these are the hardest to explain through conventional means.

While many objects in categories one and two can be attributed to optical illusions, bright planets, aircraft, weather balloons, blimps, or inebriation, the third category is more interesting. Most close encounters of the third kind have been investigated in some detail; generally they turn out to rest on the testimony of one person or of a few related people. Hypnosis has sometimes been used to decide if the reports are truthful, but this procedure is highly suspect. In one experiment recounted by Ian Ridpath, a group of test subjects with no involvement in UFO cases were hypnotized and asked to describe imaginary UFO abductions. Their accounts bear striking resemblances to those of people claiming to have had such close encounters. Hypnosis is no "truth serum." The common threads running through many accounts of UFO abductions suggest that we have all absorbed details of stories from newspapers, television, and movies. Under the proper conditions, these details may be recalled without remembering their origin. If the sighting of a strange but natural object stimulates the imagination of a receptive person, that person may develop a fantasy that becomes difficult to separate from reality. This appears to be the explanation of a number of famous cases.

More generally, the common appearance of certain male (cigar-shaped) and female (disk-shaped) symbols in UFO accounts and the close resemblance to common dream images suggests that UFO observers are projecting images from their unconscious onto normal objects and events. The psychoanalyst Carl Jung explored this problem in some detail in his book on flying saucers. Researchers have also noted that the experiences of those who report alien abductions are similar to experiences during sleep paralysis. Sleep paralysis has not been well studied, but as many as half of all people may experience it at some time. It seems to occur when a person becomes conscious while the brain is still "disconnected" from the body, as occurs during REM sleep, to avoid dangerous activity during REM sleep.

Finally, one can ask whether the explanation of UFOs as carrying alien visitors is plausible. We have seen that the barriers to interstellar travel are formidable. If interstellar travel becomes easy for very advanced civilizations, visits may be possible. However, it can be argued that we could see them coming. The most plausible energy sources for rapid travel are nuclear fusion or annihilation of matter and antimatter. Either would produce copious gamma rays. Numerous sources of gamma rays exist, many of which vary in time. A spacecraft would be distinguished from natural sources by a change of position over time. Since 1991, we have had a gamma ray telescope that could detect the kind of fuel use needed for deceleration. Michael Harris has considered the possibility of detecting distant spacecraft using matter-antimatter annihilation. Spacecraft decelerating from speeds near c anywhere within 1 AU of the Earth would have been detected as long as the mass of the spacecraft exceeded a few tens of grams, about the mass of a few sticks of spaghetti. Unless the aliens and their spacecraft are microscopic, we can rule out any recent arrivals. Even before 1991, military satellites monitored nuclear weapons testing, and these would probably have detected earlier arrivals of any significant mass, but I lack specific numbers on their capabilities.

Even if we ignore the technical objections, the great flood of extraterrestrial visitors suggested by all the UFO reports indicates an inordinate interest in our little planet. A civilization advanced enough to travel between stars would certainly be expected to behave more intelligently than the aliens described in most accounts. Indeed, the alien behavior seems pretty clearly a filtered reflection of our own attitudes, as was beautifully illustrated in the movie **E.T.** The scene in which Earthly scientists perform medical experiments on the little visitor is hauntingly reminiscent of many UFO abduction stories. While opinions will continue to differ, the conclusion seems clear to me: the "aliens" reported in UFO accounts are images from our own psyches.