Before looking at the various proposed solutions to the Fermi paradox, this chapter presents some of the background. I first give a short biography of Enrico Fermi himself, focusing on just a few of his scientific accomplishments (those that I will refer to in later sections of the book). Fermi led an interesting life outside of science, though, and I recommend the interested reader to the biographies of Fermi listed in Chapter 7. I then discuss the notion of paradox, and briefly look at a few examples from various fields. Paradox has played an important role in intellectual history, helping thinkers to widen their conceptual framework and sometimes forcing them to accept quite counterintuitive notions. It is interesting to compare the Fermi paradox with these more established paradoxes. Finally, I discuss how Fermi’s name came to be attached to a paradox that is older than many people believe.
ENRICO FERMI

It is no good to try to stop knowledge from going forward.
Ignorance is never better than knowledge.
Enrico Fermi

Enrico Fermi was the most complete physicist of the last century — a world-class theoretician who carried out experimental work of the highest order. No other physicist since Fermi has switched between theory and experiment with such ease, and it is unlikely that anyone will do so again. The field has become too large to permit such crossover.

Fermi was born in Rome on 29 September 1901, the third child of Alberto Fermi, a civil servant, and Ida DeGattis, a schoolteacher. He showed precocious ability in mathematics, and as an undergraduate student of physics at the Scuola Normale Superiore in Pisa he quickly outstripped his teachers.

His first major contribution to physics was an analysis of the behavior of certain fundamental particles that make up matter. (These particles — such as protons, neutrons and electrons — are now called fermions in his honor.) Fermi showed that, when matter is compressed so that identical fermions are brought close together, a repulsive force comes into play that resists further compression. This fermionic repulsion plays an important role in our understanding of phenomena as diverse as the thermal conductivity of metals and the stability of white dwarf stars.

Soon after, Fermi’s theory of beta decay (a type of radioactivity in which a massive nucleus emits an electron) cemented his international reputation. His theory demanded that a ghostly particle be emitted along with the electron, a particle he called the neutrino — “little neutral one.” Not everyone believed in the existence of this hypothetical fermion, but Fermi was proved correct. Physicists finally detected the neutrino in 1956. Although the neutrino remains rather ghostly in its reluctance to react with normal matter, its properties play a profound role in present-day astronomical and cosmological theories.

In 1938, Fermi won the Nobel Prize for physics. The award was partly in recognition of a technique he developed to probe the atomic nucleus. His technique led him to the discovery of new radioactive elements; by bombarding the naturally occurring elements with neutrons, he produced more than 40 artificial radioisotopes. The award also recognized his discovery of how to make neutrons move slowly. This may seem like a minor discovery, but it has profound practical applications, since slow-moving neutrons are more effective than fast neutrons at inducing radioactivity. (A slow neutron spends more time in the neighborhood of a target nucleus, and so is more likely to interact with the nucleus. In a similar way, a well-aimed golf ball
is more likely to sink into the hole if it is moving slowly: a fast-moving putt can roll by.) This principle is used in the operation of nuclear reactors.

News of the award was tempered by the worsening political situation in Italy. Mussolini, increasingly influenced by Hitler, initiated an anti-Semitic campaign. Italy’s fascist government passed laws that were copied directly from the Nazi Nuremberg edicts. The laws did not directly affect Fermi or his two children, who were considered to be Aryans, but Fermi’s wife, Laura, was Jewish. They decided to leave Italy, and Fermi accepted a position in America.

Two weeks after arriving in New York, news reached Fermi that German and Austrian scientists had demonstrated nuclear fission. Einstein, after some prompting, wrote his historic letter to Roosevelt alerting the President to the probable consequences of nuclear fission. Citing work by
Chapter 2

Fermi and his colleagues, Einstein warned that a nuclear chain reaction might be set up in a large mass of uranium — a reaction that could lead to the release of vast amounts of energy. Roosevelt was concerned enough to fund a program of research into the defense possibilities. Fermi was deeply involved in the program.

Physicists had many questions to answer before they could build a bomb, and it was Fermi who answered many of them. On 2 December 1942, in a makeshift laboratory constructed in a squash court under the West Stands of the University of Chicago stadium, Fermi’s group successfully achieved the first self-sustaining nuclear reaction. The reactor, or pile, consisted of slugs of purified uranium — about 6 tons in all — arranged within a matrix of graphite. The graphite slowed the neutrons, enabling them to cause further fission and maintain the chain reaction. Control rods made of cadmium (a strong neutron absorber) controlled the rate of the chain reaction. The pile went critical at 2:20 P.M., and the first test was run for 28 minutes.6

Fermi, with his unmatched knowledge of nuclear physics, played an important role in the Manhattan Project. He was there in the Alamogordo desert on 15 July 1945, 9 miles away from ground zero at the Trinity test. He lay on the ground facing in the direction opposite the bomb. When he saw the flash from the immense explosion, he got to his feet and dropped small pieces of paper from his hand. In still air the pieces of paper would have fallen to his feet; but when the shock wave arrived, a few seconds after the flash, the paper moved horizontally due to the displacement of air. In typical fashion, he measured the displacement of the paper; since he knew the distance to the source, he could immediately estimate the energy of the explosion.

After the war, Fermi returned to academic life at the University of Chicago and became interested in the nature and origin of cosmic rays. In 1954, however, he was diagnosed with stomach cancer. Emilio Segré, Fermi’s lifelong friend and colleague, visited him in hospital. Fermi was resting after an exploratory operation, and was being fed intravenously. Even at the end, according to Segré’s touching account, Fermi retained his love of observation and calculation: he measured the flux of the nutrient by counting drops and timing them with a stopwatch.

Fermi died on 29 November 1954, at the early age of 53.
Fermi’s colleagues prized him for his uncanny ability to see straight to the heart of a physical problem and describe it in simple terms. They called him the Pope, because he seemed infallible. Almost as impressive was the way he estimated the magnitude of an answer (often by doing complex calculations in his head). Fermi tried to inculcate this facility in his students. He would demand of them, without warning, answers to seemingly unanswerable questions. How many grains of sand are there on the world’s beaches? How far can a crow fly without stopping? How many atoms of Caesar’s last breath do you inhale with each lungful of air? Such “Fermi questions” (as they are now known) required students to draw upon their understanding of the world and their everyday experience and make rough approximations, rather than rely on bookwork or prior knowledge.

The archetypal Fermi question is one he asked his American students: “How many piano tuners are there in Chicago?” We can derive an informed estimate, as opposed to an uninformed guess, by reasoning as follows. First, suppose that Chicago has a population of 3 million people. (I have not checked an almanac to see whether this is correct; but making explicit estimates in the absence of certain knowledge is the whole point of the exercise. Chicago is a big city, but not the biggest in America, so we can be confident that the estimate is unlikely to be in error by more than a factor of 2. Since we have explicitly stated our assumption we can revisit the calculation at a later date, and revise the answer in the light of improved data.) Second, assume that families, rather than individuals, own pianos and ignore those pianos belonging to institutions like schools, universities and orchestras. Third, if we assume that a typical family contains 5 members, then our estimate is that there are 600,000 families in Chicago. We know that not every family owns a piano; our fourth assumption is that 1 family in 20 owns a piano. We thus estimate there are 30,000 pianos in Chicago. Now ask the question: How many tunings would 30,000 pianos require in 1 year? Our fifth assumption is that a typical piano will require tuning once per year — so 30,000 piano tunings take place in Chicago each year. Assumption six: A piano tuner can tune 2 pianos per day and works on 200 days in a year. An individual piano tuner therefore tunes 400 instruments in 1 year. In order to accommodate the total number of tunings required, Chicago must be home to 30,000/400 = 75 piano tuners. We want an estimate, not a precise figure, so finally we round this number up to an even 100.

As we shall see later, Fermi’s ability to grasp the essentials of a problem manifested itself when he posed the question: “Where is everybody?”
These are old fond paradoxes, to make fools laugh i’ the alehouse.
William Shakespeare, Othello, Act II, Scene I

Our word paradox comes from two Greek words: 
\textit{para}, meaning “contrary to,” and \textit{doxa}, meaning “opinion.”

It describes a situation in which, alongside one opinion or interpretation, there is another, mutually exclusive opinion. The word has taken on a variety of subtly different meanings, but at the core of each usage is the idea of a contradiction. Paradox is more than mere inconsistency, though. If you say “it is raining, it is not raining,” then you have contradicted yourself, but paradox is more than this. A paradox arises when you begin with a set of self-evident premises and then, from these premises, deduce a conclusion that undermines them. If you have a cast-iron argument that proves it \textit{must} certainly be raining outside, and then you look out of the window and see that it is \textit{not} raining, then you have a paradox to resolve.

A weak paradox or fallacy can often be clarified with a little thought. The contradiction usually arises because of a simple mistake in a chain of logic leading from premises to conclusion. In a strong paradox, however, the source of a contradiction is not immediately apparent; centuries may pass before matters are resolved. A strong paradox has the power to challenge our most cherished theories and beliefs. Indeed, as the mathematician Anatol Rapoport once remarked: “Paradoxes have played a dramatic part in intellectual history, often foreshadowing revolutionary developments in science, mathematics and logic. Whenever, in any discipline, we discover a problem that cannot be solved within the conceptual framework that supposedly should apply, we experience shock. The shock may compel us to discard the old framework and adopt a new one.”

Paradoxes abound in logic and mathematics and physics, and there is a type for every taste and interest.
A Few Logical Paradoxes

An old paradox, contemplated by philosophers since the middle of the 4th century BC and still much discussed, is the liar paradox. Its most ancient attribution is to Eubulides of Miletus, who asked: “A man says that he is lying; is what he says true or false?” However one analyzes the sentence, there is a contradiction. The same paradox appears in the New Testament. St. Paul, referring to Cretans, wrote: “One of themselves, even a prophet of their own, said the Cretans are always liars.” ¹⁰ It is not clear whether St. Paul was aware of the problem in his sentence, but when self-reference is allowed paradox seems almost inevitable.

One of the most important tools of reasoning we possess is the sorites. In logicians’ parlance, a sorites is a chain of linked syllogisms: the predicate of one statement becomes the subject of the following statement. The following is a typical example:

all ravens are birds;
all birds are animals;
all animals require water to survive.

Following the chain, we reach a logical conclusion: all ravens need water.

Sorites are important because they allow us to make conclusions without covering every eventuality in an experiment. (So we do not need to deprive ravens of water to know they may die of thirst.) But sometimes the conclusion of a sorites can be absurd: we have a sorites paradox. For example, if we accept that adding one grain of sand to another grain of sand does not make a heap of sand, and given that a single grain does not itself constitute a heap, then we must conclude that no amount of sand can make a heap. And yet we see heaps of sand. The source of such paradoxes lies in the intentional vagueness of a word like “heap”; politicians, of course, routinely take advantage of these linguistic tricks.¹¹

As well as sorites, when reasoning we all routinely employ induction — the drawing of generalizations from specific cases. For example, whenever we see something drop, it falls down: using induction we propose a general law, namely that when things drop they always fall down and never up. Induction is such a useful technique that anything casting doubt on it is troubling. Consider Hempel’s raven paradox.¹² Suppose that an ornithologist, after years of field observation, has observed hundreds of black ravens. The evidence is enough for her to suggest the hypothesis that “all ravens are black.” This is the standard process of scientific induction. Every time the ornithologist sees a black raven it is a small piece of evidence in favor of her hypothesis. Now, the statement that “all ravens are black” is logically equivalent to the statement that “all non-black things are non-ravens.” If
the ornithologist sees a piece of white chalk, then the observation is a small piece of evidence in favor of the hypothesis that “all non-black things are non-ravens” — but therefore it must be evidence for her claim that ravens are black. Why should an observation regarding chalk be evidence for a hypothesis regarding birds? Does it mean that ornithologists can do valuable work whilst sat indoors watching television, without bothering to watch a bird in the bush?

Another paradox in logic is that of the unexpected hanging, wherein a judge tells a condemned man: “You will hang one day next week but, to spare you mental agony, the day that the sentence will be carried out will come as a surprise.” The prisoner reasons that the hangman cannot wait until Friday to carry out the judge’s order: so long a delay means everyone will know the execution takes place that day — the execution will not come as a surprise. So Friday is out. But if Friday is ruled out, Thursday is ruled out by the same logic. Ditto Wednesday, Tuesday and Monday. The prisoner, mightily relieved, reasons that the sentence cannot possibly take place. Nevertheless, he is completely surprised as he is led to the gallows on Thursday! This argument — which also goes under the name of the “surprise examination paradox” and the “prediction paradox” — has generated a huge literature.\footnote{13}

\section*{A Few Scientific Paradoxes}

Although it is often fun, and occasionally useful, to ponder liars, ravens and hanged men, arguments involving logical paradoxes too frequently — for my taste at least — degenerate into a discussion over the precise meaning and usage of words. Such discussions may be fine if one is a philosopher. But for my money the really fascinating paradoxes are those that can be found in science.

Consider one of the oldest of all paradoxes: Zeno’s paradox of Achilles and the tortoise.\footnote{14} Achilles and the tortoise take part in a 100-m sprint. Since Achilles runs 10 times faster than the tortoise, he gives the animal a head start of 10 m. The two sprinters set off at the same instant; so when Achilles has covered the first 10 m, the tortoise has moved on by 1 m. In the time it takes Achilles to cover 1 m, the tortoise has moved on by 10 cm; in the time it takes Achilles to cover that 10 cm, the tortoise has moved on by a further 1 cm. And so on \textit{ad infinitum}. Our senses tell us a fast runner will always overtake a slow runner, but Zeno said Achilles cannot catch the tortoise. There is a contradiction between logic and experience: there is a paradox. It took 2000 years to resolve the paradox — but the mathematical machinery for doing so found a host of other uses.\footnote{15}
The twin paradox, which involves the special relativistic phenomenon of time dilation, is one of the most famous in physics. Suppose one twin stays at home while the other twin travels to a distant star at close to the speed of light. To the stay-at-home twin, his sibling’s clock runs slow: his twin ages more slowly than he does. Although this phenomenon may be contrary to common sense, it is an experimentally verified fact. But surely relativity tells us that the traveling twin can consider himself to be at rest? From his point of view, the clock of the earthbound twin runs slow; the stay-at-home twin should be the one who ages slowly. So what happens when the traveler returns? They cannot both be right: it is impossible for both twins to be younger than each other! The resolution of this paradox is easy: the confusion arises from a simple misapplication of relativity. The twins’ situations are not interchangeable: the traveling twin accelerates to light speed, decelerates at the half-way point of his journey, and does it all again on the trip back. Both twins agree that the stay-at-home twin undergoes no such acceleration. So the traveler ages more slowly than the earthbound twin; he returns to find his brother aged, or even dead. An extraterrestrial visitor to Earth would observe the same phenomenon when it returned to its home planet: its stay-at-home siblings (if aliens have siblings) would be older or long-since dead. It is a sad fact of interstellar travel, and it is contrary to our experience, but it is not a paradox.16

One of the most important of scientific paradoxes is that named after Heinrich Olbers.17 He considered a question asked by countless children — “Why is the night sky dark?” — and showed that the darkness of night is deeply mysterious. His reasoning was based upon two premises. First, that the Universe is infinite in extent. Second, that the stars are scattered randomly throughout the Universe. (Olbers did not know of the existence of galaxies — they were not recognized as stellar groupings until some 75 years after his death — but this does not affect his reasoning. His argument works in exactly the same way for galaxies as it does for stars.) From these premises we reach an uncomfortable conclusion: in whichever direction you look, your line-of-sight must eventually end on a star — the night sky should therefore be bright.
Suppose all stars have the same intrinsic brightness. (The following argument is simpler under this assumption, but the conclusion in no way depends upon it.) Now consider a thin shell of stars (call it shell A) with Earth at its center, and another thin shell of stars (shell B), also centered on Earth, with a radius twice that of shell A. In other words, shell B is twice as distant from us as shell A.

A star in shell B will appear to be \( \frac{1}{4} \) as bright as a star in shell A. (This is the inverse-square law: if the distance to a light source increases by a factor of 2, the apparent brightness of the light source decreases by a factor of \( 2 \times 2 = 4 \).) On the other hand, the surface area of shell B is 4 times larger than that of shell A, so it contains 4 times as many stars. Four times as many stars, each of which is \( \frac{1}{4} \) as bright: the total brightness of shell B is exactly the same as the total brightness of shell A! But this works for any two shells of stars. The contribution to the brightness of the night sky from a distant shell of stars is the same as from a nearby shell. If the Universe is infinite in extent, then the night sky should be infinitely bright.

This argument is not quite correct: the light from an extremely distant star will be intercepted by an intervening star. Nevertheless, in an infinite Universe with a uniform distribution of stars any line of sight will eventually run into a star. Far from being dark, the entire night sky should be as dazzling as the Sun. The night sky should blind us with its brightness!

How can we resolve the paradox? The first explanation you are likely to think of is that clouds of gas or dust obscure the light from distant stars. The Universe does indeed contain dust clouds and gaseous regions, but they cannot shade us from Olbers’ paradox: if the clouds absorb light, they
will heat up until they are at the same average temperature as the stars themselves. It turns out that the paradox is explained by one of the most dramatic discoveries made by astronomers: the Universe has a finite age. Since the Universe is only about 13 billion years old, the part that we can see is only about 13 billion light years in size. For the night sky to be as bright as the surface of the Sun, the observable Universe would have to be almost 1 million times bigger than it is. (That the Universe is expanding also helps to explain the paradox: light from distant objects is redshifted by the expansion, and so distant objects are less bright than one would expect from the inverse-square law. The principal explanation, though, comes from the finite age of the Universe.)

It is fascinating that in pondering such a simple question — “Why is the night sky dark?” — one could infer that the Universe is expanding and that it (or at least the stars and galaxies it contains) has a finite age. Perhaps the simple question that Fermi asked — “Where is everybody?” — leads to an even more important conclusion.

**THE FERMI PARADOX**

*Sometimes I think we’re alone. Sometimes I think we’re not. In either case, the thought is staggering.*

Buckminster Fuller

Thanks to detective work by the Los Alamos physicist Eric Jones, whose report I draw heavily upon in this section, we know the genesis of the Fermi paradox.18

* * *

The spring and summer of 1950 saw the New York newspapers exercised over a minor mystery: the disappearance of public trash cans. This year was also the height of flying saucer reports, another subject that filled the column inches. On 20 May 1950, *The New Yorker* published a cartoon by Alan Dunn that made amusing reference to both stories.

Fermi was at Los Alamos in the summer of 1950. One day, he was chatting to Edward Teller and Herbert York as they walked over to Fuller Lodge for lunch. Their topic was the recent spate of flying saucer observations. Emil Konopinski joined them and told them of the Dunn cartoon. Fermi remarked wryly that Dunn’s was a reasonable theory because it accounted for two distinct phenomena: the disappearance of trash cans and the reports of flying saucers. After Fermi’s joke, there followed a serious discussion about whether flying saucers could exceed the speed of light. Fermi
asked Teller what he thought the probability might be of obtaining evidence for superluminal travel by 1960. Fermi said that Teller’s estimate of one-in-a-million was too low; Fermi thought it was more like one-in-ten. The four of them sat down to lunch, and the discussion turned to more mundane topics. Then, in the middle of the conversation and out of the clear blue, Fermi asked: “Where is everybody?” His lunch partners Teller, York and Konopinski immediately understood that he was talking about extraterrestrial visitors. And since this was Fermi, perhaps they realized that it was a more troubling and profound question than it first appears. York recalls that Fermi made a series of rapid calculations and concluded that we should have been visited long ago and many times over. Although neither Fermi nor the others ever published any of these calculations, we can make a reasonable guess at his thought processes. He must first have made an estimate of the number of ETCs in the Galaxy, and this is something we can estimate ourselves. After all, the question “How many advanced communicating extraterrestrial civilizations are there in the Galaxy?” is a typical Fermi question!
A Fermi Question: How Many Communicating Civilizations Exist?

Represent the number of communicating ETCs in the Galaxy by the symbol \( N \). To estimate \( N \) we first need to know the yearly rate \( R \) at which stars form in the Galaxy. We also need to know the fraction \( f_p \) of stars that possess planets and, for planet-bearing stars, the number \( n_e \) of planets with environments suitable for life. We also need the fraction \( f_l \) of suitable planets on which life actually develops; the fraction \( f_i \) of these planets on which life develops intelligence; and the fraction \( f_c \) of intelligent life-forms that develop a culture capable of interstellar communication. Finally, we need to know the time \( L \), in years, that such a culture will devote to communication. Multiplying all these factors together will provide us with an estimate for \( N \). We can write it as a simple equation:

\[
N = R \times f_p \times n_e \times f_l \times f_i \times f_c \times L.
\]

The equation \( N = R \times f_p \times n_e \times f_l \times f_i \times f_c \times L \) is no more a “proper” equation for the number of communicating ETCs than \( N = p_c \times n_i \times f_p \times n_t \times R \) is the equation for the number of piano tuners in Chicago. But if we assign reasonable values to the various factors in the equation — always with the understanding that such values can and will change as our knowledge
increases — we will arrive at an estimate for the number of ETCs in the Galaxy. The difficulty we face is in our varying degrees of ignorance for the various terms in the equation. When asked to provide values for these terms, astronomers would provide responses ranging from “We’re reasonably certain” (for the factor $R$) to “We’re close to pinning it down” (for the factor $f_p$) to “How the hell should we know?” (for the factor $L$). At least when we try to estimate the number of Chicago-based piano tuners, we can be reasonably confident that our various sub-estimates are not wildly in error; there can be no such confidence with our estimate for the number of communicating ETCs. Nevertheless, in the absence of any definite knowledge of ETCs, it is our only way to proceed. (The equation above has reached a certain iconic status in science; it is known as the Drake equation, after the radio astronomer Frank Drake who was the first to make explicit use of it.\textsuperscript{19} The Drake equation was the focal point of an extremely influential conference on the search for extraterrestrial intelligence, held at Green Bank in 1961 — 11 years after Fermi’s remark.)

In 1950, Fermi would have known far less about the various factors in the above “equation,” but he could have made some reasonable guesses
— guided, as he would have been, by the Principle of Mediocrity: there is nothing special about Earth or our Solar System. If he guessed at a rate of star formation of 1 star per year he would not have been too wrong. Values of $f_p = 0.5$ (half the stars have planets) and $n_e = 2$ (stars with planets on average each have 2 planets with environments conducive to life) seem to be “reasonable.” The other factors are much more subjective; if he were an optimist, Fermi might have chosen $f_l = 1$ (every planet that can develop
life will develop life), \( f_i = 1 \) (once life develops, intelligent life will certainly follow), \( f_c = 0.1 \) (1 in 10 intelligent life-forms will develop a civilization capable and willing to communicate) and \( L = 10^6 \) (civilizations remain in the communication phase for about 1 million years). Had he argued like that, he would have arrived at the estimate \( N = 10^6 \). In other words, there could right now be a million civilizations trying to communicate with us. So why do we not hear from some of them? In fact, why are they not already here? If some of the civilizations are extremely long-lived, then we might expect them to colonize the Galaxy — and have done so before multicellular life even developed on Earth. The Galaxy should be swarming with extraterrestrial civilizations. Yet we see no sign of them. We should already know of their existence, but we do not. Where is everybody? Where are they? This is the Fermi paradox.

Note that the paradox is not that extraterrestrial intelligence does not exist. (I do not know whether Fermi believed in the existence of extraterrestrial intelligence, but I suspect that he did.) Rather, the paradox is that we see no signs of such intelligence when we might expect to. One explanation of the paradox is indeed that we are the only advanced civilization — but it is only one of several explanations.

Asking why we see no evidence of extraterrestrial civilizations may seem like a trivial question but, as we might expect from a remark by Fermi, it is a profound puzzle. We can appreciate the strength of the paradox when we realize that it has been independently discovered four times: it might more properly be called the Tsiolkovsky–Fermi–Viewing–Hart paradox.

Konstantin Tsiolkovsky, a scientific visionary who worked out the theoretical basis of spaceflight as long ago as 1903, believed deeply in the monistic doctrine that ultimate reality is entirely of one substance. If all parts of the Universe were the same, it followed that there must be other planetary systems similar to our own, and that some of those planets would possess life. However, not unnaturally given his interest in the details of spaceflight, Tsiolkovsky also firmly believed that mankind would construct habitats in the Solar System and then move out into space. His feelings were revealed in his famous phrase: “Earth is the cradle of intelligence, but it is impossible to live forever in the cradle.” The monist in him impelled him to argue that if we expand into space, then all those other species must do the same. The logic is inescapable, and Tsiolkovsky was aware that this led to a paradox when maintaining both that mankind will expand into space and that the Universe is brimful with intelligent life. In 1933, long before Fermi asked his question, Tsiolkovsky pointed out that people deny the existence
Of Fermi and Paradox

of ETCs because (i) if such civilizations existed, then their representatives would have visited Earth, and (ii) if such civilizations existed, then they would have given us some sign of their existence. Not only is this a clear statement of the paradox, Tsiolkovsky offered a solution: he believed that advanced intelligences — “perfect heavenly beings” — consider mankind to be not yet ready for a visitation.  

Tsiolkovsky’s technical works on rocketry and spaceflight were widely discussed, but the rest of his output was generally ignored in the Soviet era. An appreciation of his discussion of the paradox therefore came only recently. (Fermi’s own contribution did not fare much better. In their influential 1966 book Intelligent Life in the Universe, Sagan and Shklovsky introduce a chapter with the quote “Where are they?”; they attribute it to Fermi, but they incorrectly state that it was uttered in 1943. In a later paper, Sagan says that Fermi’s quote was “possibly apocryphal.”)

In 1975, English engineer David Viewing clearly stated the dilemma. A quote from his paper encapsulates it nicely: “This, then, is the paradox: all our logic, all our anti-isocentrism, assures us that we are not unique — that they must be there. And yet we do not see them.” Viewing acknowledges that Fermi was first to ask the important question — “Where are they?” — and that this question leads to a paradox. To my knowledge, then, this paper is the first that refers directly to the Fermi paradox.

However, it was a 1975 paper by Michael Hart in the Quarterly Journal of the Royal Astronomical Society that sparked an explosion of interest in the paradox. Hart demanded an explanation for one key fact: there are no intelligent beings from outer space on Earth at the present time. He argued that there are four categories of explanation for this fact. First, “physical explanations,” which are based on some difficulty that makes space travel unfeasible. Second, “sociological explanations,” which in essence suppose that extraterrestrials have chosen not to visit Earth. Third, “temporal explanations,” which suggest that ETCs have not had time to reach us. Fourth, there are explanations arguing that perhaps they have been on Earth, but we do not see them now. These categories were meant to exhaust the possibilities. Hart then forcefully showed how none of these four categories provide a convincing account of the key fact, which led him to offer his own explanation: we are the first civilization in our Galaxy.

Hart’s paper led to a vigorous debate, much of it appearing in the pages of the Quarterly Journal. It was a debate that anyone could enter — one of the earliest contributions came from the House of Lords at Westminster! Perhaps the most controversial offering came from Frank Tipler, in a paper with the uncompromising title “Extraterrestrial Intelligent Beings Do Not Exist.” Tipler reasoned that advanced ETCs could use self-replicating probes to explore or colonize the Galaxy cheaply and in a relatively short...
time. The abstract to Tipler’s paper sums it up: “It is argued that if extraterrestrial intelligent beings exist, then their spaceships must already be present in our Solar System.” Tipler contended that the SETI program had no chance of success, and was therefore a waste of time and money. His argument poured oil on the fires of the debate and led to a further round of argument. The coolest and best summary of the arguments came from David Brin, who called the paradox the “great silence.”

In 1979, Ben Zuckerman and Michael Hart organized a conference to discuss the Fermi paradox. The proceedings were published in book form, and although the volume contains a variety of views it is difficult to read it without concluding that ETCs have the means, motive and opportunity to colonize the Galaxy. The means: interstellar travel seems to be possible, if not easy. The motive: Zuckerman showed how some ETCs would be forced into interstellar travel by the death of their star, and in any case it seems a wise idea for a species to expand into space to guard against the possibility of planetary disaster. The opportunity: the Galaxy is 13 billion years old, but colonization can take place over a period of only a few million years. Yet we do not see them. If this were a murder mystery, we would have a suspect but no body.

Not everyone was struck by the force of the argument. A recent book by the mathematician Amir Aczel makes the case for the probability of extraterrestrial life being 1. The physicist Lee Smolin wrote that “the argument for the non-existence of intelligent life is one of the most curious I have ever encountered; it seems a bit like a ten-year-old child deciding that sex is a myth because he has yet to encounter it.” The late Stephen Jay Gould, referring to Tipler’s contention that ETCs would deploy probe technology to colonize the Galaxy, wrote that “I must confess that I simply don’t know how to react to such arguments. I have enough trouble predicting the plans and reactions of people closest to me. I am usually baffled by the thoughts and accomplishments of humans in different cultures. I’ll be damned if I can state with certainty what some extraterrestrial source of intelligence might do.”

It is easy to sympathize with this outlook. When considering the type of reasoning employed with the Fermi paradox, I cannot help but think of the old joke about the engineer and the economist who are walking down a street. The engineer spots a banknote lying on the pavement, points to it, and says, “Look! There’s a hundred-dollar bill on the pavement.” The economist walks on, not bothering to look down. “You must be wrong,” he says. “If there were money there, someone would already have picked it up.” In science it is important to observe and experiment; we cannot know what is out there unless we look. All the theorizing in the world achieves nothing unless it passes the test of experiment.
Of Fermi and Paradox

Nevertheless, surely Hart’s key fact does require an explanation. We have been searching for E.T.C.S. for more than 40 years. And the continuing silence, despite intensive searches, is beginning to worry even some of the most enthusiastic proponents of SETI. We observe a natural universe when we could so easily observe an artificial universe. Why? Where is everybody? Fermi’s question still demands an answer.

FIGURE 10  Enrico Fermi, sailing off the island of Elba. The photograph was taken shortly before his death.
If the Universe Is Teeming with Aliens ... WHERE IS EVERYBODY?
Fifty Solutions to the Fermi Paradox and the Problem of Extraterrestrial Life
Webb, S.
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