# EXTRATERRESTRIALS

WADE ROUSH

THE MIT PRESS ESSENTIAL KNOWLEDGE SERIES

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# SERIES FOREWORD

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*Bruce Tidor*
*Professor of Biological Engineering and Computer Science*
*Massachusetts Institute of Technology*

# PREFACE

We live in the middle of a great unfinished story: the tale of humanity's emergence as a planet-dominating but homebound species and our potential transformation into a spacefaring, multiplanetary one.

We know how the story began, as we left the treetops, spread across the continents, and developed language, farming, written culture, and eventually science.

We know where the story stands now. In the current century, we'll be busy confronting the multiple existential challenges we have created for ourselves. But if we can master the forces of global-scale politics and industrial-scale technology, own up to our responsibility to manage Earth's climate and ecosystems, and systematize our exploration of the other planets—all big *if*s, admittedly—then there is not much else to stop us from expanding outward into the galaxy.

What we don't know is which direction the story will go after that. There are only two possibilities. Either we will remain alone in our explorations, or we will find that we have company.

It's conceivable that we are the first intelligent beings in the galaxy ever to consider leaving their home planet. In this scenario, we'll learn that the rest of the Milky Way

is home to microbes and little more. Everywhere we venture, we will find lonely and uninhabited spaces, waiting to be colonized—by us or by our artificially intelligent machines.

Or perhaps we will run into other people as we go, as we always have before. There might be a whole bustling, galaxy-spanning league of planets waiting to welcome us or perhaps a few scattered but nonetheless sociable civilizations.

If and when we do make contact with other cultures, they are likely to be far older than ours, and the interaction is likely to transform us in ways that are hard to imagine now. The astronomer Paul Davies, who chairs the Search for Extraterrestrial Intelligence Post-Detection Task Group, believes contact with extraterrestrials would have "a greater impact on humanity than the discoveries of Copernicus, Darwin and Einstein put together."[1]

But the suspense in this matter may last for a long time. If we are not the first galactic explorers, we might learn this tomorrow or a hundred years from now or a thousand. If the galaxy seems empty, we will have to live with our solitude forever, never knowing whether we are the first (or the last) or whether there are others, but they remain too remote for us to find.

To me, what's interesting is that we've grown up enough as a species to know how to *ask* the question "Are we alone?" but not enough to know how to answer it.

It would be reasonable to assume, for the moment, that we *are* alone. There's no physical evidence that aliens have visited our solar system.[2] We have been listening for radio signals of intelligent extraterrestrial origin for 60 years, and we have not heard a peep. The aliens might be hiding, or they might be too far away, or they might be communicating in ways we can't yet detect—but the most conservative guess right now is that they just aren't there.

But that's only a surmise. We don't know how life arises or exactly how many worlds are suitable for it. We don't know how often simple organisms evolve all the way to the point of sentience and tool making. We don't know how other cultures might try to communicate with us. So far we have chosen to search for their signals on radio and optical frequencies, but the use of those methods in particular, too, is just a guess. Our search may be doomed to futility, or we might just be getting started.

The question of the existence of extraterrestrials is not just one of the most persistent puzzles in science; it is the biggest blank in our own story arc as a species. And it is marvelously, tantalizingly unsettled.

That's what this book is about: the question itself, why it remains unanswered, and how scientists are trying to answer it.

The question has been nagging at my own mind for almost as long as I can remember. I was born in the late 1960s and

devoured pop-culture artifacts such as Stanley Kubrick's *2001: A Space Odyssey* (1968) and Steven Spielberg's *Close Encounters of the Third Kind* (1977) and *E.T.: The Extra-Terrestrial* (1982). The idea that space aliens *might* exist and that it might be our destiny to meet them had long since become part of the zeitgeist.

As we will see in chapter 1, the concept goes back to the ancient Greeks and entered firmly into popular lore in the nineteenth and early twentieth centuries with the help of scientists such as the Mars-obsessed astronomer Percival Lowell and science-fiction writers such as H. G. Wells.

But, for me, it was the work of the renowned astronomer, science communicator, and TV personality Carl Sagan that brought the idea into sharp focus. Sagan was part of a small group of researchers who had been working since the early 1960s to make the search for extraterrestrial intelligence, or SETI, into a respectable scientific discipline. He wrote at length about extraterrestrial life in his book *The Cosmic Connection* (1973),[3] then led the production of the Voyager Interstellar Record. Encoded with audio and photos, the record went into deep space in 1977 aboard the Voyager 1 and Voyager 2 probes as a kind of aspirational message in a bottle. But perhaps most importantly, Sagan electrified my whole generation of budding science geeks with his public-television series *Cosmos: A Personal Voyage* (1980).

The penultimate episode of the show, "Encyclopaedia Galactica," was all about SETI. It explained that the question of extraterrestrial life was one that scientists, not just science fiction authors, could examine. By the time I reached Harvard College in the fall of 1985, I not only shared Sagan's optimism that extraterrestrials must exist but had become a full-fledged Sagan wannabe, choosing to major in astronomy and taking a work-study job at the Harvard-Smithsonian Center for Astrophysics, where he had once worked.

Imagine my excitement, then, when Sagan himself showed up on campus. He was there to participate in a symposium to christen the Megachannel Extraterrestrial Assay, a radio-frequency SETI project spearheaded by the Harvard physicist Paul Horowitz. I attended the symposium and approached Dr. Sagan afterward to share all my fanboy enthusiasm. He was as gracious and engaging as I could have hoped.

At the very same time, I was trying out for the news section of the weekly campus paper, the *Harvard Independent*. Thanks to the symposium, I had a story to pitch. The resulting piece about Horowitz's project, which had been made possible by a $100,000 gift from none other than Steven Spielberg ("I thought it was time that I got involved in a little science reality," Spielberg said at the symposium[4]) appeared in print the next week. It was my first published

article of any kind, and it left me with a passion for writing about science and technology that has never let up.

Within a couple of years, my interest in journalism and the history of science had overtaken my interest in astronomy. I went on to get a PhD from MIT in the history and social study of science and technology, and I have spent my adult life working as a technology journalist for print, Internet, and audio outlets.

But I have long felt that my I owe my career, in some small way, to Spielberg, Horowitz, Sagan, and SETI. The funny thing is that after that first clip for the *Independent*, I never returned to writing about the subject—until the MIT Press invited me to contribute this book.

For me, then, this project has offered both a chance to complete an important life circle and a welcome opportunity to immerse myself, more than 30 years after that Harvard symposium, in historical and current thinking about the search for extraterrestrial life and alien civilizations.

Before going on to share what I have learned, I would like to thank Susan Buckley, my editor at the MIT Press on this project and a previous one, the hard-science-fiction anthology *Twelve Tomorrows* (2018). She solicited the proposal for this book and has been a creative and patient counselor.

In the fall of 2018, while I was doing the research for this book, it was also my honor to coteach a seminar on SETI for MIT's Experimental Study Group. My friend

and coinstructor, the MIT astrophysicist Paola Rebusco, made that experience a joy and inspired me with her creative teaching ideas. Paola also took the time to review the manuscript for this book. The MIT first-years in the seminar—Annalisa Broski, Juliana Drozd, Raquel Garcia, Sarah Lincoln, Joshua Rodriguez, Elena Romashkova, and Talia Spitz—asked hard questions that also helped me sharpen all of the ideas here. My deep thanks to Paola and all of the students. I am also grateful to our guest speakers, especially Paul Horowitz, who remembered my article and spent two generous hours discussing SETI's modern prospects with our students.

In addition, I would like to thank the Experimental Study Group director Leigh Royden and associate director Graham Ramsay for buying into the seminar idea in the first place. Leigh also secured my appointment as a research affiliate in MIT's Department of Earth, Atmospheric, and Planetary Sciences, which came with a crucial benefit: library access.

Thanks as well to Mark Pelofsky for reading the manuscript and to my friends and colleagues at the Hub & Spoke audio collective for their support and encouragement.

In October 2018, Paola and I took our MIT seminar students to Harvard's Radcliffe Institute to attend "The Undiscovered," a day-long seminar organized by my friend the Harvard astronomer Alyssa Goodman. The event concluded with a talk by the astronomer Jill Tarter, the retired

cofounder of the SETI Institute in California. Dr. Tarter is a celebrated SETI pioneer and was the model for the Ellie Arroway character in Carl Sagan's novel *Contact* (1985).[5] (Jodie Foster played the part in the film adaptation in 1997, the year after Sagan died.) Dr. Tarter's talk held us all rapt, and in a remarkable replay of my experience in October 1985, I was able to speak with her afterward and to tell her about this book. She was as gracious and engaging as I could have hoped.

So this volume is dedicated to Jill Tarter, Paul Horowitz, Carl Sagan, and all of the kind, lonely, and visionary scientists who have taught us how to look for extraterrestrials—and why the search itself connects us to the cosmos.

*Cambridge, Massachusetts*
*Summer 2019*

# INTRODUCTION

Let's begin with a little counterfactual story. Imagine that the year is 1491. The place is somewhere south of Lake Ontario, in what is now upstate New York. Dozens of sachems, or chiefs, from a great league of Native American tribes, the Haudenosaunee, have convened a Grand Council meeting, and there is a startling item on their agenda.

They have learned from their shamans that a ceremonial pole of standard length casts a midday shadow that differs in length depending on whether the measurement comes from a village at the far northern edge of the league's territory or from a village at the far southern edge.

In each location, the pole points straight up—perpendicular to the ground. Such a difference could arise, the shamans reason, only if "up" is slightly different at

each location on a north–south line, meaning that the poles are, in fact, oriented at slightly different angles to the sun's rays. The unavoidable implication is that the world is curved, forming a very large sphere. (The Greek mathematician Eratosthenes used the same reasoning to figure out Earth's circumference in the third century BCE.[1])

So large is this sphere that it must extend far beyond the lands known to the Five Nations and their neighbors. In fact, some of the shamans have observed, it's so big that there might be room for entirely new lands elsewhere on the sphere, occupied by unknown tribes—tribes who might want to trade with the Haudenosaunee or to fight them.

The conclusion seems incredible to the gathered sachems. But just in case, some of them argue, it might be worth preparing for the arrival of these supposed people from other lands.

No, others say. If other lands truly exist, their inhabitants would already have come across the oceans in boats to offer tribute or to make war. They have not. So surely the Haudenosaunee and the peripheral tribes are the only people in the world, and there is no cause for alarm.

Did I mention that the year is 1491?[2]

## Where Is Everybody?

And now a second story, one retold so often among SETI scientists that it has entered into the realm of legend. It's the summer of 1950. In Los Alamos, New Mexico—site of the development of the first atomic bomb—a clutch of prominent nuclear physicists, including Hans Bethe, Edward Teller, Emil Konopinski, and Enrico Fermi, has reassembled to work on an even more powerful weapon, a hydrogen bomb.

The scientists gather daily for lunch at the Fuller Lodge, the main building of the old boys' school purchased by the US Army in 1943 to make way for the bomb laboratory. One day Herbert York, a visitor from the Physics Department at Berkeley, joins a table inside the lodge where Konopinski, Teller, and Fermi are in the middle of a conversation.[3]

Fermi possesses a brilliant and playful mind, and he enjoys posing semirhetorical questions that can be answered through rough estimation and back-of-the-envelope calculations. It's such a habit with him that his brain teasers—such as "How many piano tuners are there in Chicago?"—would come to be known as Fermi Problems or Fermi Questions. (The answer to the Chicago puzzler is a few hundred.)

On this particular day, the topic is not pianos, but flying saucers. Starting in 1947, there had been a series

of highly publicized sightings of these unidentified objects. Press coverage had generated enough lighthearted buzz to inspire a cartoon in the *New Yorker*, showing aliens returning to their home planet toting trash cans stolen from the New York Department of Sanitation. (The cartoon was a tongue-in-cheek solution for two mysteries at once: UFOs and a rash of missing trash cans in New York.) Earlier in the day Konopinski had noticed this cartoon and mentioned it to Fermi, sparking the conversation.

Just as York sits down, Fermi bursts out: "Don't you ever wonder where everybody is?" Everyone at the table understands that Fermi is talking about extraterrestrials.

It's easy enough for the scientists to laugh off the popular idea that flying saucers are spaceships from other star systems, piloted by actual aliens. But that begs a larger question: If flying saucers aren't real and nobody has traveled through interstellar space to visit us, why not?

Fermi does some quick math, estimating quantities such as the age and size of the Milky Way, the number of stars and planets it contains, and the odds of intelligent life evolving on each planet. His calculation shows that our galaxy ought to be rife with civilizations. If no one has visited us, Fermi concludes, it's probably not because they don't exist; it's more likely that Einstein's universal speed limit—the speed of light, $3 \times 10^8$ meters/second—makes interstellar travel difficult or impossible.

The lunch companions nod and agree that the question is a deep and important one. But on this day they fail to resolve it. After lunch, they go back to designing their bomb.

## The Power of Paradox

The point of these two stories—one a fable, the other true—is that we don't know what we don't know.

For thousands of years, the Native people of the Americas were safe in their isolation. It would have been natural to dismiss worries about rapacious, slave-driving, disease-carrying invaders—right up to the moment Columbus arrived.

Even today, there's no way to disprove Fermi's conclusion that we on Earth are safe in our isolation. He may have been right that the vast distances between the stars will keep us from ever meeting extraterrestrials. But Fermi was thinking only about *physical* contact. His conclusion would become moot if we were to detect an electromagnetic signal of intelligent extraterrestrial origin or notice some obvious sign of engineering elsewhere in the galaxy.

Over the years, Fermi's question "Where is everybody?" has ripened into a larger intellectual conundrum that students of SETI call the Fermi Paradox. The problem

isn't really about the speed of light or whether the hypothetical aliens are too lazy or short-lived to visit us. It can be framed this way: everything we know about how planets form and how life arises suggests that human civilization on Earth should not be unique. In fact, our galaxy is old enough to have been thoroughly colonized, perhaps several times over. So we ought to see abundant evidence of extraterrestrial activity. But we don't see anything, not even radio blips and certainly not derelict spaceships or the monuments of dead civilizations. We should not be alone—yet apparently we are. How is that possible?

This question has fueled decades of debate, speculation, and, lately, some actual science. "It is hard to conceive a scientific problem more pregnant and richer in meaning and connection with the other 'Grand Questions' of science throughout the ages," writes Milan Ćirković in *The Great Silence*, a masterful new book showing how deep the problem really goes.[4]

Part of what makes the problem so deep is that it is in fact a formal paradox. The word *paradox* comes from the Greek term *paradoxon*, "contradictory opinion." It usually means "a proposition that proceeds from seemingly sound premises to a senseless or illogical conclusion."

Paradoxes can be seen as useful irritants. They beg for resolution. The key phrase in the definition is "*seemingly* sound premises." When a paradox pops up, it's often an indication that the premises are *not* as sound as

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supposed or that there's something wrong in the chain of reasoning.

So what's the truth hiding behind the Fermi Paradox? Which flawed assumption would have to be excised to resolve it? What are we missing?

One possibility is that life, especially intelligent life, is less common than Fermi originally calculated. That's the idea favored by Peter Ward and Donald Brownlee, authors of *Rare Earth: Why Complex Life Is Uncommon in the Universe*.[5] We may find microbial life on many planets, Ward and Brownlee concede. But advanced, multicellular life can emerge, they propose, only when a planet enjoys an unusual combination of advantages, such as a Jupiter-size neighbor (to clear the neighborhood of debris), a large moon, plate tectonics, and a magnetic field.

Another possibility is that intelligent extraterrestrials do exist, but we just haven't met them yet. This is the answer offered by Carl Sagan in *Contact,* both the novel and the movie. In Sagan's fictional treatment, TV signals from Earth reach an alien detector near the star Vega, 25 light years away. This prompts an elaborate coded response that includes the blueprints for a kind of stargate; most of the suspense in the movie version is about who will get to go through it. The story amounts to an argument that we are not alone and that signs of intelligent life may lie just outside our grasp. We should keep looking for them because if we succeed, what we discover could change everything.

That's the solution to the Fermi Paradox that most SETI proponents still embrace today. But there are many, many other possible answers. In fact, one extremely useful book in this field is entitled *If the Universe is Teeming with Aliens … Where Is Everybody? Seventy-Five Solutions to the Fermi Paradox and the Problem of Extraterrestrial Life*.[6]

The book you're holding is meant as a general introduction to the debate over the existence of intelligent extraterrestrials, and in the pages ahead we will encounter many ideas about how the Fermi Paradox may ultimately be resolved. In chapter 4, I boil the potential solutions down into general categories—fewer than 75, I promise—and review the arguments for and against each. Ward and Brownlee think that we *seem* to be alone because we *are* alone. Others, myself included, feel it's too early to come to that conclusion. At this point, we're still sorting out what former US Secretary of Defense Donald Rumsfeld, in a very different context, called the "known knowns," the "known unknowns," and the "unknown unknowns."

The entire field of astrobiology, for example, is dedicated to determining how life might arise in non-Earth-like environments. When the discipline was born several decades ago, scientists had little sense of the range of environments in which life might flourish, even here on Earth, let alone elsewhere in our solar system or elsewhere in the galaxy. But over the past 40 years, the field has advanced in fundamental ways. For one thing, we have discovered

many types of "extremophiles," organisms thriving around undersea thermal vents and other places so inhospitable that no one would have expected to find life there, right up to the moment they did. On top of that, astronomers keep adding to the catalog of extrasolar planets, or exoplanets. As of this writing, there are 4,025 of them.[7] So far none are precisely Earth-like, but many do seem to orbit within the habitable zones of their star systems.

The point is that the more extremophiles and exoplanets we discover, the more room there is for exploration by astronomers and astrobiologists and the more unknown unknowns become known unknowns. With hard work, funding, and a little luck, we might even be able to convert some of them into known knowns. Watching this process fills me with wonder and hope.

## Organizing Our Ignorance

Despite these discoveries, SETI remains an unusual corner of science, one where the blanks are even blanker than usual. The only hard piece of data we have is that the skies, so far, are silent. In 1975, the astronomer Michael Hart, in a famously skeptical article about SETI, called this silence "Fact A."[8] It's the observation that leads to the Fermi Paradox, and any serious argument for doing SETI research must grapple with it.

To restate the paradox: we don't see aliens, but we *should*, given a few seemingly reasonable assumptions. What are those assumptions? In the coming pages, we will meet the Drake Equation, first proposed by radio astronomer Frank Drake in 1960 as a way to estimate $N$, the number of technologically advanced and communicative civilizations there should be in the Milky Way. The equation helps to quantify the inputs that lead to the Fermi Paradox—in fact, Fermi used the same approach in his back-of-the-envelope calculations over lunch in Los Alamos. In the classic form of the Drake Equation, $N$ is the product of seven factors, such as the number of stars in the galaxy, the fraction of stars that have planets, and the probability that simple life on a given planet will evolve into intelligent life. As we will see in the chapters ahead, we have learned a great deal about the first four factors in the equation, but we're still in the dark about the last three. The variable $N$ could be exactly 1 (it certainly can't be less than that because we exist), or it could be much greater. We just don't know.

The Drake Equation isn't a traditional scientific equation, in the sense of a formula expressing how physical properties relate, like $E = mc^2$. But it was useful to Drake and his early SETI peers as a roadmap—a way to kick-start the discussion of the known unknowns. Indeed, the SETI pioneer Jill Tarter has called the equation "a wonderful way to organize our ignorance."[9]

This book proceeds in that same spirit, attempting to sort out the known knowns, the known unknowns, and the unknown unknowns. A conversation about aliens and the Fermi Paradox is by necessity partly conjectural. I won't hide my own opinions, and I'll try to make it clear when we're crossing the line from evidence-based reasoning to informed speculation—but I won't let that slow us down.

In a way, talking about SETI is like cooking stone soup. We're forced to start with little more than an idea. But if we borrow a bit of broth from the philosophers who have debated the plausibility of extraterrestrial life, some carrots from the oceanographers studying extremophiles, some seasoning from the astronomers seeking more exoplanets, and so forth, then we can probably make something intellectually nourishing.

Here's my list of ingredients. In chapter 1, I examine the surprisingly long history of speculation about aliens. When Aristotle said that nature abhors a vacuum, he was wrong; most of the universe is a near vacuum. But humans do seem to abhor the idea that we might be alone, and we have been debating the idea for thousands of years.

Scientists eventually realized that they could go beyond talk. Chapter 2 looks at the birth of SETI as a serious discipline in the 1960s. We'll learn how scientists turned to radio and optical techniques to begin the practical

search for signals from extraterrestrial civilizations and how that search has evolved over the past 60 years.

Chapter 3 is about the revolutions in astrobiology and exoplanet research since 1977 as well as how the unexpectedly rapid progress in these areas has altered the way scientists think about the possibility of extraterrestrial life.

In chapter 4, armed with all this additional information, I return to the Fermi Paradox. Many intriguing solutions have been proposed, and I review them and assess their plausibility.

Finally, in chapter 5, I zero in on my favorite solutions and look at some new ideas for refocusing SETI work to increase the chances of resolving the paradox and finding extraterrestrials.

By the end, I hope you will agree that SETI is one of the most exciting and potentially world-changing research questions of our day and will feel inspired to keep exploring the subject on your own. You can do that with help from the sources cited in the notes, the glossary, and the list of further reading materials at the back of the book.

By the way, I'm going to assume that as of the moment you're reading this, aliens have *not* been discovered. If they have been, then the book is now a useless artifact of the precontact era. I would love nothing more, but I'm not that much of an optimist. So the paradox remains—and still begs to be unraveled.

# NOTES

**Preface**

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**Introduction**

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2. For a more serious treatment of Native American culture in the pre-Columbian moment, see Charles Mann, *1491: New Revelations of America before Columbus* (New York: Knopf, 2005).
3. The account here comes mainly from the Harvard physicist and SETI scientist Paul Horowitz, who heard it from York. See "The Fermi Paradox," late 1998, http://seti.harvard.edu/unusual_stuff/unpublished/fermi.htm. But there are several other versions; in some, the conversation took place in 1943, not in 1950. See David Grinspoon, *Lonely Planets: The Natural Philosophy of Alien Life* (New York: Harper Collins, 2003), 311.
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**Chapter 1**

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3. Karl Popper, *Conjectures and Refutations: The Growth of Scientific Knowledge* (New York: Routledge, 2014), 186.
4. Richard McKirhan, "Anaximander's Infinite Worlds," in *Essays in Ancient Greek Philosophy VI: Before Plato*, ed. Anthony Preus (Albany: State University of New York Press, 2001), 49–66.
5. Bertrand Russell, "The Atomists," in *History of Western Philosophy: Collectors Edition* (New York: Routledge, 2009), chap. 9.
6. This version of the Metrodorus quote comes to us via Aëtius and the unknown authors grouped under the name "Pseudo-Plutarch." See Plutarch, *Morals*, chap. 5, https://ebooks.adelaide.edu.au/p/plutarch/nature/book1.html#chapter5.
7. Epicurus to Herodotus, in Epicurus, *The Epicurus Reader: Selected Writings and Testimony*, ed. Lloyd P. Gerson (Indianapolis, IN.: Hackett, 1994), 8.
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15. Johannes Kepler, *Kepler's Conversation with Galileo's Sidereal Messenger*, trans. Edward Rosen (New York: Johnson, 1965), 42.
16. Galileo Galilei, *Letters on Sunspots*, in *Discoveries and Opinions of Galileo*, trans. Stillman Drake (New York: Doubleday, 1957) 137.
17. One valuable book that does attempt such a comprehensive overview is Steven J. Dick, *Plurality of Worlds: The Origins of the Extraterrestrial Life Debate from Democritus to Kant* (Cambridge: Cambridge University Press, 1984). For another thorough tour of discussions of extraterrestrials in the seventeenth, eighteenth, and nineteenth centuries, see Michael J. Crowe, *The Extraterrestrial Life Debate, 1750–1900* (Cambridge: Cambridge University Press, 1986).
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22. Giovanni Schiaparelli, *La via sul pianeta Marte: Tre scritti di Schiaparelli su Marte e i "marziani,"* ed. Pasquale Tucci, Agnese Mandrino, and Antonella Testa (Milan: Mimesis, 1998), 76; translation courtesy of Paola Rebusco.
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25. A. R. Wallace, *Is Mars Habitable?* (London: Macmillan and Co., 1907), 38–77.
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**Chapter 2**

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6. Drake and Sobel, "The Origin of the Drake Equation," 3.
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10. NASA, *Project Cyclops: A Design Study of a System for Detecting Extraterrestrial Intelligent Life*, NASA Report no. CR 11445 (Washington, DC: NASA, 1971), 1.
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14. Quoted in Bill Steele, "It's the 25th Anniversary of the First Attempt to Phone E.T.," *Cornell Chronicle*, November 12, 1999, http://news.cornell.edu/stories/1999/11/25th-anniversary-first-attempt-phone-et-0.
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**Chapter 3**

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9. Leonard David, "NASA's Mars Rover Curiosity Had Planetary Protection Slip-up," *Scientific American*, December 1, 2011, https://www.scientificamerican.com/article/nasas-mars-rover-curiositt/, and Jyoti Madhusoodanan, "Microbial Stowaways to Mars Identified," *Nature*, May 19, 2014, https://www.nature.com/news/microbial-stowaways-to-mars-identified-1.15249.

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**Chapter 4**

1. I'm referring mainly to Milan Ćirković, who considers the Drake Equation to be not just outmoded but also dangerous: "In the SETI field, invocation of the Drake equation is nowadays largely an admission of failure … to develop a real theoretical grounding for the search" (*The Great Silence*, 95).
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3. "On the Shores of the Cosmic Ocean," episode 1 of *Cosmos*, PBS, September 28, 1980.
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5. Webb, *If the Universe Is Teeming with Aliens*, 230–234.
6. Michael Hart, "Habitable Zones about Main Sequence Stars," *Icarus* 37, no. 1 (January 1979): 351–357.
7. Erik Petigura, Andrew Howard, and Geoffrey Marcy, "Prevalence of Earth-Size Planets Orbiting Sun-Like Stars," *Proceedings of the National Academy of Sciences* 110, no. 48 (November 26, 2018): 19273–19278.
8. Ward and Brownlee, *Rare Earth*, 190–220.
9. Webb, *If the Universe Is Teeming with Aliens*, 288–290. To be clear, although Ward and Brownlee were aware of the Mars hypothesis, it wasn't a big part of their argument.
10. Ward and Brownlee, *Rare Earth*, 243.
11. Ward and Brownlee, *Rare Earth*, 250.
12. US National Research Council, *Limits of Organic Life in Planetary Systems*, 1.
13. David J. Darling, *Life Everywhere: The Maverick Science of Astrobiology* (New York: Basic Books, 2001), 103.
14. Ćirković, *The Great Silence*, 152.
15. John G. Cramer, "The Pump of Evolution," *Analog Science Fiction & Fact*, January 1986, https://www.npl.washington.edu/av/altvw11.html.
16. Ćirković, *The Great Silence*, 172.
17. This is known as the Adaptationist or Permanence Hypothesis, after a story by science-fiction author Karl Schroeder. See Ćirković, *The Great Silence*, 158–162.
18. Ross Andersen, "What the Crow Knows," *Atlantic*, March 2019, https://www.theatlantic.com/magazine/archive/2019/03/what-the-crow-knows/580726.
19. Sagan, *Cosmos*, 301. Note that Sagan's version of the Drake Equation was slightly different from the standard one. He used $N^*$ (the absolute number of stars in the galaxy) instead of $R^*$ (the rate of star formation), and $f_L$ ("the fraction of a planetary lifetime graced by civilization") instead of $L$. But the math comes out the same. Note also that Earth will become uninhabitable in about one billion years, long before the sun dies.
20. The Light-Cage Hypothesis: see Webb, *If the Universe is Teeming with Aliens*, 101–103.
21. The Galactic Stomach Ache Hypothesis: see Ćirković, *The Great Silence*, 222–228.
22. The Thoughtfood-Exhaustion Hypothesis: see Ćirković, *The Great Silence*, 163–164.
23. The Deadly Probes Hypothesis: see Ćirković, *The Great Silence*, 187–193.
24. The Astrobiological Phase Transition Hypothesis: see Ćirković, *The Great Silence*, 174–178.

25. Nick Bostrom, *Anthropic Bias: Observation Selection Effects in Science and Philosophy* (New York: Routledge, 2010).
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27. Robin Hanson, "The Great Filter—Are We Almost Past It?" September 15, 1998, http://mason.gmu.edu/~rhanson/greatfilter.html.
28. David Deutsch, *The Beginning of Infinity: Explanations That Transform the World* (New York: Penguin Books, 2011), 446.
29. Ćirković explores the Hermit Hypothesis and finds it wanting (*The Great Silence*, 27–30). It assumes that every individual in a hermit species feels the same way and that the species has figured out how to avoid leaking any transmissions or other information about themselves.
30. Webb, *If the Universe Is Teeming with Aliens*, 183–185.
31. The Sustainability or Aliens Are Green Hypothesis: see Ćirković, *The Great Silence*, 220–222, and Webb, *If the Universe Is Teeming with Aliens*, 106–109.
32. The Resource-Exhaustion Hypotheses: see Ćirković, *The Great Silence*, 185, and Webb, *If the Universe Is Teeming with Aliens*, 103–104.
33. Webb, *If the Universe Is Teeming with Aliens*, 111–113.
34. The Distance-Learners Hypothesis: see Webb, *If the Universe Is Teeming with Aliens*, 187–189.
35. Ćirković calls this the "Introvert Big Brother" Hypothesis: see *The Great Silence,* 182–185.
36. The Persistence Hypothesis, also known as the Percolation Hypothesis: see Ćirković, *The Great Silence*, 212–214, and Webb, *If the Universe Is Teeming with Aliens*, 92–98.
37. Jonathan Carroll-Nellenback, Adam Frank, Jason Wright, and Caleb Shaw, "The Fermi Paradox and the Aurora Effect: Exo-civilization Settlement, Expansion, and Steady States," ArXiv preprint, February 13, 2019, https://arxiv.org/pdf/1902.04450.pdf.
38. The average distance between any two communicating civilizations is calculated using a standard formula for the number of spheres of a given volume that fit into a space of a given volume. The formula is ((space-volume/sphere-volume)/packing-density), where the packing density is the optimal 0.74048 for cubical or hexagonal packing. We know the number of spheres, 16,875 in this case, and the volume of the galaxy, so we can solve for sphere volume and hence the sphere radius. The distance between any two communicative civilizations in this idealized scenario will be twice this radius.
39. "Kepler-1229b," *Wikipedia*, n.d., https://en.wikipedia.org/wiki/Kepler-1229b.

40. Douglas Adams, *The Hitchhiker's Guide to the Galaxy* (London: Pan Books, 1979), chap. 8.
41. Ćirković calls this the "Eternal Wanderers" Hypothesis: see *The Great Silence*, 214–220.
42. This is sometimes called the Berserker Hypothesis: see Grinspoon, *Earth in Human Hands*, 348–351, and Webb, *If the Universe Is Teeming with Aliens*, 122–123.
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44. Quoted in Johnson, "Greetings, E.T. (Please Don't Murder Us)."
45. John A. Ball, "The Zoo Hypothesis," *Icarus* 19 (1973): 347–349.
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47. Stephen Baxter, "The Planetarium Hypothesis—a Resolution of the Fermi Paradox," *Journal of the British Interplanetary Society*. 54 (2001): 210–216.
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50. For more discussion of the Delta-T argument, see Webb, *If the Universe is Teeming with Aliens*, 178–183. For a recent book on Gott's idea, see William Poundstone, *The Doomsday Calculation: How an Equation That Predicts the Future Is Transforming Everything We Know about Life and the Universe* (Boston: Little, Brown Spark, 2019).
51. Webb, *If the Universe Is Teeming with Aliens*, 208–211.
52. The Transcension Hypothesis: see Ćirković, *The Great Silence*, 195–199, and Webb, *If the Universe Is Teeming with Aliens*, 196–198.
53. Ćirković, *The Great Silence*, 133.

**Chapter 5**

1. Thomas Levenson, the head of MIT's science-writing program, tells the Vulcan story in compelling detail in *The Hunt for Vulcan … and How Albert Einstein Destroyed a Planet, Discovered Relativity, and Deciphered the Universe* (New York: Random House, 2015).
2. Ćirković calls this the "Paranoid Style in Galactic Politics" Hypothesis; see *The Great Silence*, 124–126.
3. Webb, *If the Universe Is Teeming with Aliens*, 160.

4. Marek Abramowicz, *How to Search for a Signal from an Alien Civilization*, video, December 4, 2018, https://www.youtube.com/watch?v=P-XE7DOFLo0.
5. A double-size DVD-RAM disk holds 9.4 gigabytes of data. Assume that it flies for one second in a small room. You have just sent data at 9.4 gigabytes per second or 75,200 megabits per second. Compared to a maximum download speed for most home broadband services (circa 2020) of 300 megabits per second, the flying disk offers a 250-times improvement.
6. Webb, *If the Universe Is Teeming with Aliens*, 161–163.
7. Shmuel Bialy and Abraham Loeb, "Could Solar Radiation Pressure Explain 'Oumuamua's Peculiar Acceleration?" accepted for publication in *Astrophysical Journal Letters*, November 6, 2018; Abraham Loeb, "6 Strange Facts about the Interstellar Visitor 'Oumumua," *Scientific American*, November 20, 2018, https://blogs.scientificamerican.com/observations/6-strange-facts-about-the-interstellar-visitor-oumuamua.
8. Quoted in Josh Swartz, "Harvard Astronomer on Why Aliens Aren't Science Fiction," WBUR, January 30, 2019, https://www.wbur.org/endlessthread/2019/01/30/oumuamua-alien-probe-avi-loeb.
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12. Cabrol, "Alien Mindscapes," 669.
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14. See Carl Jung, *Flying Saucers: A Modern Myth of Things Seen in the Skies* (Princeton, NJ: Princeton University Press, 1979).