Books by Timothy Ferris

The Red Limit
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The Mind's Sky

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Preface

All things without, which round about we see,
We seek to know, and how therewith to do;
But that whereby we *reason, live and be,*
Within ourselves, we strangers are thereto….

We that acquaint ourselves with every zone
And pass both tropics and behold the poles,
When we come home, are to ourselves unknown,
And unacquainted still with our own souls.

—Sir John Davies, 1599

Living matter and clarity are opposites.

—Max Born, letter to Einstein, 1927

Each of us inhabits two equally mysterious universes, one outside the mind and the other within it. Since my youth I have tried to understand the relationship between these two realms. Many a night I sat at the telescope till dawn, marveling at the soft pewter glow of the distant galaxies, the glittering gold and silver star fields of the Milky Way, at sun-hugging Mercury, the pearl-white crescent of Venus, or the parchment-sharp rings of Saturn, and wondered what *we* have to do with all *that.*

I have never shared the sentiment that the enormity of the cosmos need make us feel insignificant. The stars are too involving for that; they stimulate our curiosity, arouse us to reflection, nourish our sense of beauty, and challenge our conception of who we are. We feel connected to them, somehow. I do not think this intuition can be dismissed as mere sentiment, for the simple reason that we are able to some degree to *understand* what goes on out there. We know that iron oxide stains the ruddy sands of Mars, that helium atoms dance in the upper atmosphere of the sun, that storms dot the surface of Aldebaran, and that new stars are being born in the Tarantula nebula; we can predict eclipses of the satellites of Jupiter, weigh the great Catherine wheel of the Andromeda galaxy, take the temperature of Triton, and age-date the craters of the moon. Our knowledge of the universe amounts, of course, to an infinitesimal fraction of the whole, but the fact that we can learn anything at all about the stars suggests that thought—and maybe even "intelligence"—is not a purely parochial phenomenon, the product of our one world alone, but may have universal currency.

I envision our relationship to the universe as symmetrical, hourglass-shaped. On one side is the outer realm, inhabited by galaxies, stars, the plants and animals, and our fellow human beings. Most of us (the solipsists aside) believe that this outer world exists, though we appreciate that our direct perceptions of it are limited and skewed. On the other side is the inner realm of the mind, where each of us is destined to live and die; here resides all we can ever know. Through the neck of the glass flow the sense data by which we perceive the outer realm, and (flowing the opposite way) the models and concepts we apply to nature, and the alterations and abridgments we impose on her. We tip this imaginary hourglass from time to time. In the nineteenth century, when classical physics ruled, we tended to think of the sand as flowing almost entirely from the outer to the inner realm, from an objectively real world to our passively recording minds. In the twentieth century the concept of observer-dependent phenomena in quantum physics has shifted our attention to the ways our observations influence how we perceive nature. But so long as there are thinking beings in the universe, neither bulb of the hourglass will ever be empty.

In this book I offer a few thoughts on the relationship between mind and universe as seen through the lenses of two innovative fields of scientific research—neuroscience, and the search for extraterrestrial intelligence, or SETI.

Neuroscience has begun to reveal some fascinating things about how the brain works, shedding light on the concept of personal identity, the data-handling limitations of the central nervous system, and the way that the brain smooths over its liabilities and discontinuities to sustain a sense of unified consciousness. We are beginning to realize that each of us really does contain multitudes, as Walt Whitman put it, and that the chorus of voices within was built up over eons of evolution, like geological strata in the Burgess Shale or the White Cliffs of Dover.

SETI, meanwhile, has focused attention on what we mean by intelligence, and whether its like is to be found elsewhere in the universe. Regardless of whether we eventually succeed in intercepting an alien signal from space, SETI will have encouraged us to think about thinking in a cosmic context. In so doing it acts as a mirror; our ignorance of the role of life and thought in the universe forms the blacking on the back of the mirror.

This book begins and ends with cosmologically related questions; in between, it examines implications of neuroscience for our understanding of the human brain. Part One examines some of the images we find in the SETI mirror when we think of intelligence in terms of its cosmic context; it outlines how interstellar communications systems might in the long run evolve (or have evolved). Part Two explores the inner world; its thesis is that each of us harbors not one but many minds, which if true suggests that one's individual brain is a galaxy of various intelligences. In Part Three I endeavor to braid these two threads, to see what the outer world can tell us about the inner and vice versa.

The final chapter seeks to demonstrate that science, rather than having to choose either mind or nature as the ultimate reality, can instead be based on the information adduced where mind and nature meet. It is more rigorous than the other chapters, and while I would prefer that it be widely read and discussed, I must in all candor admit that it probably can be skipped without irrevocable harm to one's intellectual development.

Indeed, the reader is invited to pick and choose among these chapters as he or she may prefer. This book is a ramble, not a work of analytic philosophy. It seldom pretends to have said the last word about anything. Much of it takes place far from the palaces of hard science, in lush but jumbled jungles where fact and speculation compete. I expect no one to agree with all that I have to say, and will be content if some care enough to disagree.

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Among the many individuals who have helped me, I should like in particular to express my gratitude to William Alexander, Walter Alvarez, Annie Dillard, Richard S. Dinner, Harriet Fier, Michael Gazzaniga, Stephen Jay Gould, Linda Grey, Owen Laster, Michael McGreevy, Michael Mann, Leslie Meredith, Menno Meyjes, Richard Muller, Thomas Powers, Steve Rubin, David Schramm, John Sepkoski, Alex Shoumatoff, Jill Tarter, and John Archibald Wheeler; to my mother, Jean Baird Ferris, for many enlightening conversations and a constant stream of intriguing articles and news clippings; and to my wife, Carolyn, for contributions any proper allusion to which would fill a book in itself.

PART ONE

This Is Not the Universe

The mind does not understand its own reason for being.

—René Magritte

A picture without a frame is not a picture.

—John Archibald Wheeler

Perhaps you've seen the painting: A pipe, depicted with photographic realism, floats above a line of careful, schoolboy script that reads *Ceci nest pas une pipe*—." This is not a pipe." Rene Magritte painted it in the 1920s, and people have been talking ever since about what it means.

Did Magritte intend to remind us that a representation is not the object it depicts—that his painting is "only" a painting and not a pipe? Such an interpretation is widely taught to undergraduates, but if it is true, Magritte went to an awful lot of trouble—carefully selecting a dress-finish pipe of particularly elegant design, making dozens of sketches of it, taking it apart to familiarize himself with its anatomy, then painting its portrait with great care and skill—just to tell us something we already knew. After all, nobody really confuses paintings with reality, and the danger that people will try to smoke paintings of pipes or eat paintings of pears does not rank high among the hazards confronting the working artist.

Perhaps it was with an eye toward discouraging simplistic explanations of his famous pipe that Magritte returned to the same motif toward the end of his career. In *The Air and the Song,* painted in 1964, just three years before Magritte's death, the pipe is found inside a representation of an elaborate, carved frame, as if to emphasize that it is only a painting—yet smoke from its bowl billows up out of the painted "frame"! In another canvas, *The Two Mysteries,* Magritte is even more insistent: The original pipe painting, complete with caption, is depicted as sitting on an easel that rests on a plank floor; but above it to the left hovers a *second* pipe, larger (or closer) than the painted canvas and its frame. What we have here is a painting of a paradox. Obviously the smaller pipe is a painting and not a pipe. But what is the second pipe, the one that looms outside the represented canvas? And if that, too, is but a painting, then where does the painting end?

We've been set on the road to infinite regress. Suppose, for instance, that Magritte had glued a real pipe to the actual frame of *The Two Mysteries:* Would the genuine pipe qualify as a pipe, or did it become something else once Magritte affixed it to the frame? (The same riddle is posed by Andy Warhol's Brillo Pad boxes, which are indistinguishable from the Brillo boxes on sale in any supermarket. Had Warhol captioned one with the words, "This is not a Brillo Box," would the caption be true or false?)

It seems to me that the roots of the paradox reside in the concept of the frame. When we look at a realistic painting—Raphael's portrait of Pope Leo X and his nephews, say, or Breughel's *Peasant Wedding*—we accept by convention that it represents real people and actual objects. When that convention is denied, as in Magritte's pipe paintings or in the many impossible scenes depicted by his fellow surrealists—locomotives emerging from fireplaces, clocks limp as jellyfish—the point is *not* to remind us that paintings are not real. That much is true, but trivial. The point is to challenge the belief that everything outside the frame *is* real.

The enemy of surrealists like Magritte, and of artists generally, is naive realism—the dogged assumption that the human sensory apparatus accurately records the one and only real world, of which the human brain can make but one accurate model. To the naive realist, every view that does not fit the official model is dismissed as imaginary (for those who "know" that they err when they entertain contradictory ideas) or insane (for those who don't). Naive realism is flattering—to set one's self up as the sole judge of what is actual is to taste the delights of godlike power—but it is also stultifying. Once the realist settles on a single representation of reality, the gate slams shut behind him, and he is doomed to live thereafter in the universe to which he has pledged allegiance. This universe may be elegant and adamantine as the Taj Mahal, but it is a prison nonetheless, and the prisoner's spirit, if it is still awake, will beat its wings against the bars until it weakens and dies.

The truth, of course, is that nobody can grasp reality whole, that each person's universe is to some extent unique, and that this circumstance makes it impossible for us to prove that there is but one true reality. Even if we could free ourselves from fantasy and delusion (not that to do so would necessarily be a good idea), we could at most agree upon small swatches of reality. *Everything* thus is framed, cut from its cosmic context by the limitations and peculiarities of our sensory apparatus, the prejudices of our presuppositions, the multiplicity of each individual mind, and the restrictions of our language. We may feel more comfortable with our own frame of reference than with that of others, and assume it to be more valid, but the frames are there nonetheless. There's no escaping them; the known universe is and always will be in some sense a creation of our (hopefully creative) minds. Magritte made this point overtly in a 1933 painting. It depicts a canvas on an easel that records every detail of the view outside the window it partially obscures, right down to the drifting cumulus clouds. He titled this work *The Human Condition,*

If modern artists have labored to call attention to the fact that our understanding of reality is limited and variegated, so too have modern scientists. Many people are surprised to hear this. They think of science as a collection of hard facts mined from bedrock reality, through a process as uncreative as coin collecting. The scientists, however, have come to know better. Astronomers understand that each act of observation—photographing of a galaxy, taking an ultraviolet spectrum of an exploding star—extracts but a small piece of the whole, and that a montage of many such images is still only a representation, a painting if you will. The quantum physicists go further: They appreciate that the answers they obtain through experiment depend to a significant degree on the questions they ask, so that an electron, asked if it is a particle or a wave, will answer "Yes" to both questions. (I will say more about this in the final chapter of this book.) Neuroscientists studying the other side of the mind-nature dialogue have learned that the brain is no monolith, either. Each of us harbors many intelligences, and insofar as my various minds take varying views of reality—in terms, say, of spatial relationships versus language, or of sentimental versus rational education—I can no more legitimately impose a single model on myself than I can expect to impose it on others.

This is not to say that every opinion about the universe deserves equal attention—as if schoolteachers, in much the same way as they are being urged by fundamentalists to teach biblical creation myths alongside Darwinism, should also be enjoined to give equal weight to the flat-earth theory, ESP, or the notion that little Sally in the back row was empress dowager of China in a former life. That no one theory of the universe can deservedly gain permanent hegemony does not mean that all theories are equally valid. On the contrary: To understand the limitations of science (and art, and philosophy) can be a source of strength, emboldening us to renew our search for the objectively real even though we understand that the search will never end. I often reflect on a remark made to me one evening over dinner in a Padua restaurant by the English astrophysicist Dennis Sciama, teacher of Roger Penrose and Stephen Hawking. "The world is a fantasy," Sciama remarked, "so let's find out about it." To me, that heroic statement encapsulates the spirit of science: to seek to learn something while accepting that one will never know everything.

Science is young—it has been a going concern for only about three hundred years, and the word *scientist* itself was unknown before about 1825—yet it has already transformed our world view. Thanks to science, educated men and women can contemplate an astonishing array of invigorating facts—that we are kin to the animals, that the tenure of our species has amounted to but a moment compared to the age of the earth, that the sun is one star among many, and that seemingly solid objects are themselves as empty as cosmic space, strewn with atoms lonely as stars.

Owing to its great prestige, however, science often is given credit for understanding more than it really does about what things really are. Actually, science seldom has much to say about what something "is." Science studies and predicts phenomena, not essences, and to attempt to use it to assert, for instance, that living organisms "are" machines is to choose the wrong tool to do the job. A scientific theory provides a model that enables us to reason about unfamiliar phenomena by translating them into terms with which we are familiar. It is a kind of language, and as such itself exemplifies the dialogue between mind and nature.

To clarify what I mean, consider that science rests on a tripod whose legs are hypothesis, observation, and faith.

A scientific *hypothesis* (which aspires to become a *theory,* which if extraordinarily successful and far-reaching might attain the status of a *law)* begins as an idea about how something works. A scientist may come up with a hypothesis more or less inductively, by working with raw data for many days or years before it occurs to her. That's the hard way, much esteemed by the work-ethic Victorians: it's more or less how Darwin arrived at his theory of evolution, which is one reason that the Victorians found it impossible to dismiss Darwin even though many were repelled by his idea that we share an ancestor with the apes and chimps. Alternately, a hypothesis may arise suddenly and intuitively. That's more romantic, and we tend to lionize "pure" theorists like Richard Feynman, who got a Nobel Prize for a line of thought that began when he was idly watching a waiter toss a plate in the air in a cafeteria, or Stephen Hawking, a victim of paralysis who thought up his theory of black hole evaporation while his nurse was putting him to bed. But chance, as Pasteur said, favors the prepared mind; the theorist may work with only a pencil and paper, but she is immersed in her field of research, and that field in turn depends on the work of the experimentalists.

Scientific ideas live or die by the verdict of *observation.* An observation may be overtly intrusive, as when a physicist slams clouds of protons together in a particle accelerator, or relatively passive, as when an astronomer takes the spectrum of a star to learn its chemical composition. In either case the goal is to obtain objectively reliable data. By "objectively reliable" I mean that the result should be *replicable:* Another experimenter, using another particle accelerator or telescope, should achieve essentially the same result.

Precisely because observation is so important, we need to appreciate its limits.

The most conspicuous of these is observational error. It's easy to make a mistake when measuring, say, the velocity of a faint galaxy near the edge of the observable universe, or differences in the thickness of cortical tissue in laboratory rats that have been raised in enriched and deprived environments. In practice, the observer relies to some extent on the guidance of a promising theory that predicts what he *ought* to find, even though this may mean disregarding at least some data that contradict a persuasive theory. Albert Einstein ignored the results of an early experiment that seemed to invalidate the special theory of relativity. Einstein happened to be right in this instance (the experimental data were wrong) but there are obvious dangers in leaning too heavily on theory—in discarding, as "noise," those data that deny a theory while retaining, as "signal," those that confirm it. In practice one keeps muddling along, experimenting and observing, hoping that the truth will emerge.

Or hope that *part* of the truth will emerge, given that the universe is vast and the conclusions of scientific theories and observations almost absurdly narrow. This nasty little fact often gets overlooked in popular accounts that stress the grandeur of the scientific world view. Science does not customarily pose big questions. It poses *small* questions. As the thermodynamicist Ludwig Boltzmann put it:

> The scientist asks not what are the currently most important questions, but "which are at present solvable?" or sometimes merely "in which can we make some small but genuine advance?" As long as the alchemists merely sought the philosopher's stone and aimed at finding the art of making gold, all their endeavors were fruitless; it was only when people restricted themselves to seemingly less valuable questions that they created chemistry. Thus' natural science appears completely to lose from sight the large and general questions.

Yet it is by such peephole-squinting that science, more than any other discipline, has cast fresh light on the big questions. Research into the family relationships of subatomic particles has produced insights into the early evolution of the entire universe, while studies of the chemistry of radioactive isotopes have made it possible to age-date moon rocks and pre-Columbian Indian campsites. Boltzmann again: "But all the more splendid is the success when, groping in the thicket of special questions, we suddenly find a small opening that allows a hitherto undreamt of outlook on the whole." Never more resoundingly than in modern science have we seen demonstrated the truth of Lao Tzu's and Jesus' dictum that the great and transcendent is to be found in the small and ordinary.

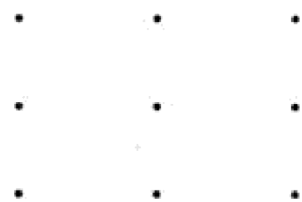
What one gets from science, generally speaking, are *relations.* Ask a particle physicist what happens when a quark is knocked out of a proton, and she will tell you without hesitation that the result will most likely be the creation of a meson. Ask her what a quark *is,* however, and the only genuinely honest answer will be no answer at all. (Or, perhaps, a relational answer—"Quarks are the building blocks of hadrons"—which defines these particles in terms of other particles.) Ask an astronomer what a star "is," and the result will be similarly unsatisfying if viewed from the old metaphysical perspective: The astronomer is likely to explain "star" in terms of its relationship to other astronomical bodies, or merely to offer a definition, which *by definition* will say more about the word than the star. ("A star is a celestial object massive and dense enough for thermonuclear process to have taken place at its core.") Science is silent about the essences of quark-ness or star-ness.

Lost, too, is the comfort of absolute certitude. The philosophers of old could claim with assurance to have discovered exactly how nature works; they did not have to worry about contradictory experimental results, and in any event their formulations typically were too vague to be wrong. Scientists today enjoy no such luxury. They must live with the knowledge that even their most esteemed theories may in the long run turn out to be flawed. The philosopher of science Karl Popper made this point when he argued that no observation can prove a theory true, but can at best permit it to survive until it is tested again.

What science does, then, is to construct mental models of natural processes. These models must make sense; it is the *faith* of science that nature is rationally intelligible. The models should be efficient; the scientist believes that nature, given the choice, will elect a simple, economical process over a complex and inefficient one. The models should also have predictive power, which is another way of saying that they should remain vulnerable to disproof by observation.

What has all this to do with Magritte's pipe? Just this: that each act of observation, and each scientific model based on observation, puts a frame around a piece of nature. We may then extrapolate, projecting the model onto a larger screen. We are encouraged if it holds up (every star and planet ever observed obeys Newton's and Kepler's laws) but our belief in the model remains forever tentative (Newton's and Kepler's laws fail inside black holes). The model is not reality; it is but a painting, and it has a frame.

The tendency to put imaginary frames around things is not unique to science. We all do it all the time, usually without thinking about it. Here is a little puzzle that illustrates what I mean. Try to connect all nine dots, using only four straight lines, without retracing or lifting up your pencil.



Most people have trouble with this riddle until they are given a hint—that the straight line may extend *beyond* the box described by the dots. The problem is that we automatically and often arbitrarily frame the problem. Often that helps, but in this case it makes the puzzle harder to solve.

The way we interpret a physical process can similarly be altered by the size of the frame we put around it. Suppose we view a videotape showing an area one inch square. On the tape we see a wooden hammer striking a wire and producing sound waves in the surrounding air. We would be inclined to describe this process as strictly deterministic: There is a cause, the hammer blow, and an effect, the sound waves. Now pull the camera back, enlarging the reference frame, and we see that the hammer is one of eighty-eight in a piano. *Now* the process begins to look voluntary; we assume the piano is being played by a pianist, who can choose to play whatever she wants. Pull back farther, though, and we see that it's a *player* piano: The keys are being struck not by a pianist but by a machine. The system looks deterministic again. Pull back farther still, in time as well as space, and we see a composer writing a piece for the player piano; now the situation looks volitional once more.

Never is the danger of distortion greater than when we extrapolate from a limited reference frame to the infinite universe. Yet all cosmological models do just that, and all, therefore, should be taken with a grain of salt. (Or with a trainload of salt, which is about enough salt grains to equal the number of stars in the Milky Way galaxy.) A cosmologist can describe the shape of the universe in terms of a few numbers—the Friedmann-Robertson-Walker metric, for instance—and if in a rash mood may declare: "There! *That* is the universe." But it is not. It is at best only one cut through the universe, and a paper-thin cut at that. The real universe glides on about its business, without stopping to read the scientific journals.

Outside our frame of reference forever hovers something else—the larger reality, embracing every bird's egg and mud puddle, every star and planet, every poem and crime in the gigantic and eternally incomprehensible universe. *This*—this equation, this theory, the finest model concocted by the wisest mind in the universe, or the sum total of all the scientific models, and all the artistic and philosophical ones, too—*this* is not the universe.

The other night I had a dream about frames. In the dream, a man and his wife, on a stroll near the outskirts of a small town, stop to look into the window of a dusty antiques shop. The man becomes fascinated by an odd object he sees in the window: It is a model of a cottage, fashioned painstakingly if inexpertly with tiny individual slate tiles on the roof, checked curtains at the windows, a painted front door with brass knocker and keyhole. A figurine of a man is kneeling at the stoop, peeking through the keyhole at a couple who are sitting inside by a fire, she knitting, he reading a newspaper.

The man tries to interest his wife in buying this little model. She's not interested. Over her objections, the husband takes her into the shop and asks the price. He is told the cottage is not for sale. The husband presses the shop owner to name a price, but the old man won't budge. The couple leaves. Over lunch they quarrel about his insistence on buying the toy cottage. She goes back to their hotel. He returns to the antique shop and finds it closed.

The early afternoon sun bakes the empty street. Water trickles from a fire hydrant valve that has been left slightly ajar, a wrench still affixed to the bolt on top. The man knocks on the shop door but there is no reply. After pondering the situation for a few moments, he removes the wrench from the fire hydrant and throws it through the shop window. A burglar alarm goes off. The man steps up through the shattered window and reaches for the model of the cottage.

A police patrolman in a blue serge uniform arrives to investigate the alarm. He finds the window intact and unbroken. The wrench is on the fire hydrant; the policeman tightens it to stop the trickle of water, then pockets the wrench. He rattles the doorknob on the front door of the shop and the alarm stops ringing. He looks in the window, and his eyes come to rest on the little cottage. He bends down to look more closely. Inside the cottage, instead of the couple, now sits the figure of a solitary man. Kneeling outside the front door, peering through the keyhole, is a figurine of a policeman in a blue serge uniform.

A psychiatrist might place other interpretations on it, and I wouldn't argue with them, but to my way of thinking this is a dream about how the mind frames its relationship with the wider universe. We look through a peephole at nature, as Boltzmann said, and interpret the whole in terms of what little we have been able to see. But we, too, are part of the whole—and we, like the universe, are more than the sum of the observations made of us. All swim in an ocean of enigma. "Science cannot solve the ultimate mystery of Nature," wrote Max Planck, the founder of quantum physics. "And it is because in the last analysis we ourselves are part of the mystery we are trying to solve."

The artists have long understood this. "When I look at my work I think I'm in the heart of mystery and there's nothing in the world which can explain it," Magritte said. He added, on another occasion, that "the feeling we experience while we look at a picture is not to be distinguished from the picture or from ourselves. The feeling, the picture, and ourselves are united in our mystery." Magritte's words are echoed by the American physicist and philosopher of science John Archibald Wheeler, who writes, "The vision of the universe that is so vivid in our minds is framed by a few iron posts of true observation—themselves resting on theory for their meaning—but most of the walls and towers in the vision are of papier-mâché, plastered in between those posts by an immense labor of imagination and theory."

We are confronted, then, not with *the* universe, which remains an eternal riddle, but with whatever model of the universe we can build within the mind. Every thinking creature in the universe shares this predicament; for all, the ultimate subject of inquiry is not the outer universe but the nature of its dance with the mind. In searching for signs of extraterrestrial intelligence, our aim is to better understand the dance by learning how others dance. We hope to widen our perspective, to broaden the base of our perceptions and analysis, to improve the little universes of mind and make them answer more smartly to the vast whole. And what is the emblem of a sound mind, if not conformance between the inner model and the outer reality? What we seek among the stars is sanity.

The Enormous Radio

> Maybe we're here only to say: *house, bridge, well, gate, jug, olive-tree, window*—at most, *pillar, tower* … but to say them, remember, oh to say them in a way that the things themselves never dreamed of existing so intensely.
>
> —Rainer Maria Rilke

> Flout 'em and scout 'em—and scout 'em and flout 'em; Thought is free.
>
> —Shakespeare

The universe has four remarkable properties that encourage us to investigate whether we are alone in the universe.

The first is that space is *transparent.* A ray of starlight can speed unfettered through space for thousands of millions of years, bringing news of events long ago and far away, and the sailing is even clearer for radio waves. Natural radio noise—the chatter of hydrogen atoms adrift in space, the scream of electrons trapped in the magnetic fields of distant galaxies—can pass not only through the virtually perfect vacuum of interstellar space, but also though the clouds of gas and dust that clutter the disk of our galaxy and block the visible light of many stars beyond. These naturally occurring radio emanations need not be especially powerful for us to pick them up; all the energy gathered by all the world's radio telescopes over the past thirty years amounts to less than the kinetic energy released by a snowflake falling gently to the ground. This suggests that artificial radio signals, too, could in principal be detected across interstellar distances, even if broadcast at modest levels of power. Radio telescopes in operation today could receive signals transmitted by similar instruments throughout much of our galaxy; a hundred billion stars and perhaps half a trillion planets lie within their range. And, since radio waves travel at the speed of light, three hundred thousand kilometers per second, their velocity of transmission is as fast as can be.

Second, the universe is *uniform.* Wherever we look, across millions of light years of space and eons of time, everything appears to be built out of the same chemical elements we find at home, functioning in accordance with the same natural laws. The carbon atoms of which diamonds and orchids are made are identical with the carbon atoms of the Pleiades star cluster. If life here on Earth arose through the operation of natural law—and there is no evidence to suggest otherwise—then it seems reasonable to suppose that life may have appeared elsewhere, too.

Third, the universe is *isotropic,* which is to say that on the large scale it looks pretty much the same in every direction. Every observer in the universe sees galaxies stretching off into all parts of the sky, just as we do. Contrary to what the ancient philosophers assumed, the earth does not sit at the center of the universe; indeed, there *is* no center of the universe. (Let a two-dimensional sheet represent three-dimensional cosmic space; bend it into a sphere, like the earth, as gravitation can curve space; there is no center to the universe, as there is no center to the *surface* of the earth.) Nor is there anything unique about the sun, which is one among many such stars in one of many galaxies. If nothing is strikingly special about our situation, then we have no particular reason to assume that the events that transpired early in the history of our planet—one of which was the advent of life—could not also have happened elsewhere.

Finally, the universe is *abundant.* Within the range of our telescopes lie perhaps one hundred billion galaxies, each home to a hundred billion or so stars. Astronomers estimate that at least half those stars have planets. If so, there are as many planets in the observable universe as there are grains of sand in all the beaches of the earth. In so rich a universe, many improbable things can happen: If intelligent life has arisen on but one planet in a billion, then fully ten thousand billion planets have given birth to intelligent species.

From such considerations has arisen the venturesome endeavor called SETI—the search for intelligent life in the universe.

Humans have long speculated about life on other worlds. Anaxagoras, Democritus, Aristotle, Epicurus, Philolaos, and Plutarch entertained the notion that the moon and planets were inhabited, as did Lucretius, Lambert, Locke, and Kant. Democritus's student Metrodorus of Chios mused that "it would be strange if a single ear of corn grew in a large plain or there were only one world in the infinite." Similar sentiments were expressed by the thirteenth-century Chinese philosopher Teng Mu, who wrote that "upon one tree there are many fruits, and in one kingdom many people. How unreasonable it would be to suppose that besides the heaven and earth which we can see there are no other heavens and no other earths." None of these thinkers, of course, had any genuine evidence of extraterrestrial life, nor do we have any such evidence today. The difference is that SETI, rather than merely pondering the question, proposes to investigate it.

The modern SETI effort began in 1959, with a brief paper published in the British journal *Nature*. Titled "Searching for Interstellar Communications," it was written by two scientists, Philip Morrison and Giuseppe Cocconi, who noted that beings capable of broadcasting and receiving radio signals could communicate all the way across the galaxy. Morrison and Cocconi reasoned that since interstellar signals can be transmitted without any great cost, and by means of relatively primitive technology, perhaps someone, somewhere, was doing it. If so, we might hear from them—provided we listen.

Though many scientists believe for various reasons that SETI is but a dream, there have from the outset been dreamers willing to give it a try. A few months after the Morrison-Cocconi paper appeared, the American astronomer Frank Drake pointed a radio telescope with a dish twenty-six meters in diameter at two sunlike stars and listened to them at a single frequency for a total of one hundred fifty hours. He heard nothing out of the ordinary, and the dish was returned to service in less speculative research endeavors, but the ice had been broken. SETI projects have proceeded in fits and starts ever since. By 1991 approximately fifty radio searches had been conducted, principally in the United States and the Soviet Union. Some, the "dedicated" searches, diverted radio telescope time to pure SETI work; others, called "parasitic," sifted through data accumulated in normal astronomical observations, looking for unnatural patterns. Some enjoyed government support. Others were privately funded. A retired electronics technician stood a lonely SETI vigil for two years on the shores of Great Slave Lake in northern Canada, using swap-meet electronics hooked up to the military antennae of a decommissioned Distant Early Warning (DEW) line station built to warn of a Soviet missile attack. A Berkeley astronomer

SETI's advocates are mostly astronomers and physicists. They marshal astronomically large numbers to argue on statistical grounds that intelligence probably occurs frequently on the panstellar scale. The SETI skeptics are mainly biologists. They use similar statistics to conclude that intelligence is unlikely to have evolved anywhere else, and that SETI is therefore a waste of time and money. Their debate revolves around how each camp views life and intelligence.

The basic case for SETI goes like this:

Life is a natural; it's "in the cards." The chemicals required to make living organisms—e.g., carbon and water—are abundant in the universe, suggesting that there are quite a few planets where conditions favor the appearance of life. And where the environment is right, it may not take long before the first organisms start wiggling in the ooze: Terrestrial life arose within the first billion years of the planet's 4.5 billion year history. So prompt an origin implies that life appears more or less routinely, on earthlike planets at least. This hypothesis gains support from experiments in which conditions thought to replicate those widespread on the young Earth—a primitive atmosphere of methane, ammonia, water vapor, and molecular hydrogen, bathed in ultraviolet light and charged by electrical shocks like those produced by lightning—are reproduced in laboratories. These conditions, the experimenters find, lead readily to the formation of amino acids like glycine and alanine, the so-called "precursor" molecules on which life as we know it is based. So it seems reasonable to suppose, as a working hypothesis if nothing else, that there is life elsewhere in the universe.

As for intelligence, the standard argument is that while we don't know how or why intelligence arose on Earth (something to do with the ice ages, perhaps), once it does appear on any given planet it may be expected to flourish, since it bestows considerable advantages upon the species endowed with it. “We say that because in the fossil record, there is only one category of thing that constantly improved and that is brain size, which we associate with intelligence,” Drake once told me. “There have been larger creatures in the past, higher flying birds, but the one thing that has consistently improved survival value has been intelligence.” The American astronomer Carl Sagan reasons similarly. “The adaptive value of intelligence and of manipulative ability is so great—at least until technical civilizations are developed—that if it is genetically feasible, natural selection seems likely to bring it forth,” he writes.

As a long-standing SETI enthusiast myself, I’m emotionally inclined to accept the conclusions of these arguments. I’m willing, in other words, to “believe” that there is life on other planets—though it makes not an iota of difference to the universe whether I choose to believe that it’s lively as a cloud forest or sterile as a surgeon’s scalpel. But I have to admit that the case for SETI, if evaluated as a scientific hypothesis, really doesn’t hold much water. Its weakness lies in the assumption that what we regard as intelligence will have been selected for in the course of biological evolution on other planets. Why should this be so?

The answer cannot be that we expect the anatomy of alien brains to resemble our own. As I will discuss later in this book, the brain is a ramshackle concatenation, slapped together through the course of millions of years of evolution in which many chance events, from the swift hammer-blows of meteor impacts to the slow advance and retreat of glaciers, appear to have played important roles. So unpredictable are all these twists and turns of fortune that our neuroanatomy almost certainly has been duplicated nowhere else in the universe. We are led, then, to speculate that intelligence is somehow universal even though the physical brain that gave rise to *our* intelligence is unique. By these lights, intelligence is akin to a computer program ("software") that can run on many different sorts of computers ("hardware"). But who wrote the program, and how did He load it into our brains? This line of argument, I fear, is freighted with heavier theological implications than many of the scientists who employ it would feel comfortable supporting.

Suppose we try to avoid the problem by defining "intelligence" narrowly, as meaning nothing more than the ability to send radio signals across interstellar space. That seems fair enough—it reduces to a bare minimum the requisite overlap between alien minds and our own—but it leads to the curious conclusion that intelligence has existed on Earth for only sixty years. (The first radio telescope was built in 1931, by an engineer studying the effects of lightning on long-distance telephone lines.) Whereupon the same statistics that previously supported the SETI case suddenly turn against it: If there has been life on Earth for four billion years, and "intelligent" life for but sixty years, then how can we say that intelligence has been selected for in the course of biological evolution? One could just as readily argue that intelligence is *not* selected for, precisely because it has *not* appeared more often in terrestrial history.

Personally, I feel that there is something nonparochial about human intelligence—something cosmic about a brain that can chart the galaxies and fly itself to the moon. But I can't prove it, and a hard lesson taught by science, as by life more generally, is that the broad emotional appeal of a hypothesis has nothing whatever to do with the likelihood that it is true. So I am forced to conclude that SETI, just as its critics maintain, has not been justified scientifically.

But if SETI is not yet a science, it may nevertheless be justifiable as a campaign of exploration.

The precepts of exploration are, after all, distinct from those of science. Science survives by making accurate predictions. Exploration does not; an explorer who could predict what his voyage of discovery would find would not be much of an explorer. Some of the most heroic voyages in human history were made for insupportable reasons: The ancient Chinese navigated the Pacific in search of the elixir of immortality, as did Ponce de León in Florida; and Columbus thought he could sail west all the way to the Indies, an impossibility, because he insisted against all evidence that the earth was a third of its true size. Explorers, like poets, often succeed by making fantastic leaps of the imagination, free from reason's fetters. In that sense exploration is even more imaginative than science—which is to say that it is very imaginative indeed.

Shakespeare, who understood this perfectly well, had little use for science but was infatuated with exploration. *The Tempest,* his last play, was inspired by his reading of a contemporary account of a shipwreck that stranded one hundred fifty English seafarers in the mid-Atlantic. They were colonists bound for the New World, and the manuscript Shakespeare read had just been written by one of their number, the adventurer William Strachey. It told a stirring tale of how the flagship *Sea Venture,* her hull splitting apart in heavy seas and St. Elmo's fire dancing through her rigging, was wedged onto the rocks of an uninhabited island in the Bermudas and miraculously prevented from sinking, just as those aboard were toasting one another's fortunes in the next life. It detailed how they survived there for nearly ten months, from July 1609 through May 1610, during which time four men and a woman died, two babies were born (a boy, named Bermudas, and a girl, Bermuda), and a mutineer—one Henry Paine, who stole a sword, beat up a guard, and invited the governor to kiss his ass—was executed. Strachey's memoir recounted how the colonists fashioned two makeshift longboats from the timbers of island cedars, christened them *Deliverance* and *Patience,* and sailed them across six hundred miles of open ocean to Jamestown, Virginia, only to find that their fellow colonists, near starvation in a fort surrounded by hostile Indians, were in worse shape than their shipwrecked confederates had been in Bermuda.

None of this, however, found its way into *The Tempest.* What caught Shakespeare's eye was the alien mystery of the Bermudas, remote and unexplored and much feared, known in those days as the "Isles of Devils." The islands lay beyond the firelight of the known, as the allegedly inhabited alien planets do today, and Shakespeare took full advantage of our love for the unknown. He peopled his fictional version of the island with fairies and beasts, and with a native, Caliban, who in a heartbreaking passage blurts out his regret at having been cajoled into trading his useful knowledge of the place for such trivia as the English names of the sun and moon:

… When thou camest first
Thou did strok'st me, and made much of me; wouldst give me
Water with berries in't, and teach me how
To name the bigger light and how the less,
That burn by day and night; and then I lov'd thee
And show'd thee all the qualities o'th' isle,
The fresh spring, brine-pits, barren place and fertile.
Cursed be I that did so! …
For I am all the subjects that you have,

The Central Nervous System of the Milky Way Galaxy

> I have loved my fellow men,
> And lived to learn that they are neither
> fellow nor men
> But machine robots.
>
> —D. H. Lawrence

> Heaven and earth shall pass away, but my words shall not pass away.
>
> —Jesus of Nazareth

Suppose that one day we detect a radio signal transmitted by an extraterrestrial intelligence. Where might it come from?

The customary assumption in SETI circles is that the signal would have been dispatched by the inhabitants of a solitary planet who were broadcasting in hopes of finding another intelligent species somewhere in space. I call this the lonely-hearts scenario. In it, the alien civilization plays a role akin to that of a seeker after romance in the personals columns: "Lonesome, technically proficient species seeks same. Object: Communication." In a variant version the alien civilization has lost its virginity—is already in touch with other worlds—but still strives to widen its contacts.

Maybe something like this will prove to be the case. But there are problems with the lonely-hearts scenario, and when we take them into account we arrive at a rather different conception of interstellar communication—one that implies that the first signal we intercept might not come from living beings at all, but from some form of artificial intelligence.

The lonely-hearts scenario requires virgin worlds to broadcast. But for all they know, broadcasting might betray their presence to a powerful, hostile civilization that would respond by enslaving or exterminating them. We humans certainly feel the need for caution; we listen with radio telescopes but seldom use them to transmit. When Frank Drake dispatched a single, brief message to a star cluster twenty-four thousand light years away, the British Astronomer Royal, Sir Martin Ryle, implored him in strong language never again to do something so rash. To the best of my knowledge, none of the approximately thirty SETI searches conducted since the Drake-Ryle incident has involved transmitting. So persuasive is the argument for prudence that one wonders whether everybody in the galaxy is listening and nobody broadcasting.*

Caution aside, broadcasting is more expensive than listening. If you don't know in which direction to send your signals, the best strategy is to send them in all directions at once ("omnidirectionally"), and that can take a lot of power. And you must be prepared to keep broadcasting for a very long time: If your very first message is received on a planet a thousand light years away, by sociable beings who reply at once, you will have to wait two thousand years before receiving an answer. This might not bother aliens who live millions of years, but certainly would pose a problem for beings with lifespans like ours.

But while the vastness of space and the resultantly long Q&A times are routinely acknowledged by SETI writers, more troubling still is the longevity, not of individual creatures, but of the communicating worlds to which they belong. The Milky Way galaxy is more than ten billion years old, and contains a great many stars older than the sun. As there is no compelling reason to assume that technologically competent civilizations began to appear in the galaxy only recently, we may presume that most civilizations would have arisen and subsequently declined long before we came on the scene. In that case the universe, viewed on a cosmic time scale, is mainly a necropolis.

Suppose that there are ten thousand communicative worlds in our galaxy today, and that each flourishes for an average of ten thousand years before going off the air due to war, disaster, loss of interest, or some other cause. That's a fairly sanguine scenario—if ten thousand worlds were beaming signals our way right now, a SETI search capable of scrutinizing one star per hour at every plausible frequency could be expected to hit paydirt by the middle of the twenty-first century—yet it has a tragic side, for it implies that something like a million civilizations have died out since the galaxy was born. Unless alien civilizations normally survive for a very long time relative to the age of the galaxy, most will already be gone. And this is true not only for us but for every world engaged in SETI today: Each will find that most of the information exchanged among worlds came from societies that perished long ago. A SETI endeavor, then, has less information to gain by contacting a living world today than by acquiring the records left behind by worlds that have gone off the air.

How, then, might this information have been preserved?

Surely the communicating worlds themselves would keep records of the messages they received from alien societies. If we received a lengthy SETI signal, we'd do all we could to preserve its contents for as long as possible. But this approach

THE MIND'S SKY

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