HERE BE DRAGONS

The Scientific Quest for Extraterrestrial Life

DAVID KOERNER & SIMON LEVAY

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David Koerner

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Here Be Dragons

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Introduction

* At the Institute for Creation Research in San Diego, California, Duane Gish struggles to demonstrate the literal truth of the story told in Genesis: The universe was created in a week of divine labor, a week that ended with God's masterpiece, the creature made in his own image—Man.
* A few miles away, at the Salk Institute for Biological Studies, chemist Leslie Orgel has a good idea of what God was up against. After a lifetime of trying, Orgel hasn't succeeded in creating anything remotely living. But he has spawned a student who claims it can be done. Within two years.
* From the lifeless salt flats of Death Valley, planetary scientist Chris McKay digs up a spoonful of—life! McKay is impatient to try his prospecting skills on Mars.
* At the summit of Palomar Mountain, in the shadow of the mighty Hale telescope, Ben Lane fiddles with a Tinkertoy contraption of mirrors, lasers, and miniature railways. He is a junior member of a team of scientists who plan to scale up this "optical interferometer" and put it into orbit around the Sun. With it, they hope to see planets around distant stars, and maybe to find life on them.

- Paleontologists Steven Jay Gould and Simon Conway Morris tussle over the interpretation of some odd-looking, half-billion-year-old Canadian fossils. What is Life's guiding principle, they ask: Chance or Necessity?
- At the SETI (Search for Extraterrestrial Intelligence) Institute in Mountain View, California, radio astronomer Jill Tarter listens to the radio babble of the cosmos. Somewhere in the noise, she's convinced, is a message. And the champagne sits ready in her refrigerator.
- On a lonely road in central Nevada, Glenn Campbell sees a string of "golden orbs" light up the night sky. Smoke is rising from them. Do flying saucers have diesel engines?
- At Carnegie Mellon University, roboticist Hans Moravec introduces us to his latest offspring. "This is Uranus," he says proudly. "It may have to tow its brain behind on a trolley." Uranus, Moravec believes, is the ancestor of living machines that will make humans superfluous.
- At UCLA, astronomer Ned Wright measures ripples in the afterglow of the "Big Bang." Was it really just a "Little Bang"—one Creation out of many that, quite by chance, brought forth a life-friendly universe?

These people have little in common, except this: Each is responding in his or her own way—with denial, with fantasy, or with scientific derring-do—to a revolution in human thought. A revolution that knocked us off our throne at the hub of a wheeling universe and exiled us to a remote and humble planet, there to lament our downfall, or perhaps to plot a comeback.

That revolution didn't happen yesterday: it took place gradually over two millennia and more. But it had its grand moments. As when a Greek philosopher saw a curved, eclipsing shadow veil the Moon's face, and understood its meaning: Earth is round. As when Copernicus removed that round Earth from the center of all things and sent it in looping journeys around the Sun. As when Newton saw the apple fall—and saw a mechanical universe in which apples, cannonballs, and planets all moved by the same law. As when Darwin mapped our descent from four-legged, from legless, from microscopic creatures—a descent guided by chance and the struggle to survive. As when Crick and Watson reduced genetics to chemistry.

One of those moments—the discovery that the Earth orbits the

Sun—towers above the others, as far as its intellectual achievement and impact are concerned. Copernicus himself was deeply conservative. He was inclined to minimize the philosophical or religious importance of demoting the Earth to a mere planet. "Although it is not at the center of the universe," he wrote in the first volume of *De revolutionibus orbium coelestium*, published in 1543, "nevertheless its distance from the center is still insignificant, especially in relation to the sphere of fixed stars." And (without his knowledge) a preface was added to the book that made it seem as if Copernicus's theory was intended as a mere mathematical contrivance, not as an actual description of reality. But neither his own caution nor the machinations of his publisher could cushion the shock caused by the book.

That shock crossed all cultures and infiltrated every recess of human thought. "Humanity has perhaps never faced a greater challenge," wrote the poet-scientist Goethe, three centuries after the event. "For by his admission [that the Earth is not at the center of the universe], how much else did not collapse in dust and smoke: a second paradise, a world of innocence, poetry and piety, the witness of the senses, the conviction of a religious and poetic faith.... No wonder that men had no stomach for all this, that they ranged themselves in every way against such a doctrine."

How contrary to our senses, how opposite to our intuition, is the way things really are! Tycho Brahe, the brilliant Danish astronomer, expressed every human's instinctive response to Copernicus when he declared that "the body of the Earth, large, sluggish, and inapt for motion, is not to be disturbed by movement." But our senses and our intuition are the product of our species's brief existence here, at the interface of earth and air, not of a billion-year voyage across the cosmos.

Just thinking about those distances makes the mind reel. We're designed for close-in stuff—threading needles, hand-to-hand combat, throwing stones. By comparing the inputs from our two eyes, set a couple of inches apart in our heads, our brains figure in a flash what is closer and what is farther away. But no amount of staring tells us what star is closer than another.

Then Copernicus had a bright idea: If the Earth goes around the Sun once a year, he said, let's measure the positions of the stars in January, when the Earth's on one side of the Sun, and in July, when it's on the other. It would be like having eyes spaced as wide as the Earth's orbit. Surely, he thought, we'll see a difference between the two views—parallax, as we call it now. But no one could detect such a difference, even with that giant's gaze. So if the Earth truly orbits the Sun, even the nearest star must be incredibly, absurdly far away. "Consequently I shall not speak now of the vast space between the orb of Saturn and the Eighth Sphere [the fixed stars] left utterly empty of stars by this reasoning," wrote Brahe. (And why did he "not speak" of the thing he spoke of? Because there was an even more persuasive argument against Copernicus's theory: It was against the authority of Holy Writ.)

But the stars *are* incredibly, absurdly far away—even the nearest one. Proxima Centauri, an invisibly dim red star in the southern sky, has that honor: it is 40,000,000,000,000 kilometers away from us. Even if you could travel at the speed of light—which you couldn't—it would be a four-and-a-quarter-year journey. The distance to Proxima Centauri was figured out by the same method that failed the astronomers of the sixteenth century. The idea was right, but the tools weren't up to it. There were no telescopes.

And what about the farthest star? For a long time the Milky Way was the universe, and the farthest star was on the far side of it. But then, in the 1920s, came another shock, almost the equal of the one delivered by the Polish canon. Fuzzy patches in the night sky proved to be other "island universes," other galaxies. And galaxies assembled themselves into clusters, and clusters into superclusters, and these in turn receded to unfathomable distances. The farthest objects we have observed lie about 100,000,000,000,000,000,000,000 kilometers from Earth. 10^{23} kilometers, to squeeze those zeroes to a superscript. A 12-billion-year journey at the speed of light.

"The eternal silence of these infinite spaces frightens me," wrote Blaise Pascal, when only the tiniest fraction of that truth was known. What was the point of so much space? Why, if the universe was made for us, did it stretch so far beyond our reach? What could one fill it with, to take away its fearful emptiness, to give it purpose, human relevance, warmth?

Life!

The search for inhabited worlds began with Copernicus. Not that the notion hadn't been around long before. Lucretius, the Roman disciple of the Greek Atomists, spelled it out in the century before Christ: "We must therefore admit again and again," he wrote, "that elsewhere there are other gatherings of matter such as is this one which our sky holds in its eager embrace.... Now if the atoms are so abundant that all generations of living creatures could not count them, and if the same force and nature remains with the power to throw each kind of atom into its place in the same way as they have been thrown here, you must admit that in other parts of the universe there are other worlds and different races of men and species of wild beasts."[1] And the Scholastic philosophers of the Middle Ages had wrestled with the notion of "other worlds." Aristotle had denied such a possibility, for sure, but how could a Christian do so without limiting God's omnipotence?

But for Lucretius, and for all the pre-Copernican thinkers, "other worlds" were profoundly unreachable. They existed in a "beyond" that was by definition outside the limits of our senses, for everything within those limits was part of "our" world. Perhaps they were merely potential worlds—worlds that God could create (for he could do anything) but in his infinite wisdom chose not to. They were certainly not things one could see or point to. Least of all were they stars, for those were merely the lights in "our" night sky.

It was Copernicus's discovery that breathed life into the visible universe. For if the Earth revolved around the Sun, in an orbit like a planet, might not the planets in turn be like the Earth—large, solid, washed by rivers, fertile, forested, even inhabited? And hard on Copernicus's heels came Galileo with his little telescope, and saw the rocky surface of the Moon, and Jupiter's moons, and the moonlike phases of Venus, and the rings of Saturn. The planets were *places*, not points; that was the electrifying news borne by Galileo's "Starry Messenger" (*Siderius nuncius*, the title of his 1610 book). They were places one could dream of visiting or receiving visitors from.

And the stars? That was Giordano Bruno's work—to make them into "worlds." In 1584, twenty-five years before Galileo built his telescope, the mystical priest published the work whose title said it all: *De l'infinito universo e mondi—Of the infinite universe and worlds.* The stars were suns, made small and faint by distance, and there was no end to them. And around those suns orbited planets, as around our own. And on those planets was life.

Bruno died at the stake, and Galileo recanted when he was shown the rack. But there was no getting this genie back into the bottle. Kepler—he who took the perfect circles of Copernicus and bent them into impure ellipses—claimed to make out the caves where the moon people dwelled, and he wrote a whole fantastical book about their lives. And he wasn't the last astronomer to spot the work of extraterrestrials. In the eighteenth century, William Herschel—the discoverer of Uranus—saw cities, thoroughfares, and pyramids where Kepler had seen only caves. At the end of the nineteenth century came the canals of Mars. They were originally described as indistinct "channels" by an Italian, Giovanni Schiaparelli; but an American, Percival Lowell, later identified them as a complex system of artificial waterways, the work of a civilization fighting to survive on a desiccating planet.

This was what the astrononomers—the professionals—had to say. What laypeople had to say would fill many books, many genres, fact and fiction. Martians attacking the Earth or bringing otherworldly wisdom. Close encounters of the first, second, and third kinds. Contact. And governments became involved. In an astronomical folie à deux, the mad King George gave Herschel ever-larger telescopes, the better to see the cities on the Moon. Lunatics chasing Lunarians! Fast-forward two hundred years, and extraterrestrial life has become a leitmotiv of the US space program, a central justification for expenditures in the billions of dollars.

Let us make our own positions clear. As two scientists—an astronomer and a biologist—we are professional skeptics. We know of no direct evidence that a single living organism exists or has ever existed anywhere in the universe, outside of Earth. We doubt that any intelligent extraterrestrial has ever visited our planet in the past or will do so in the foreseeable future. As much as humanity may yearn for an end to its cosmic loneliness, that yearning alone will not turn gray planets green or spark chatter from silence. We must admit the possibility that we are alone forever.

But from that safe haven of skepticism, may we not venture out a way into the rough seas of speculation? For while nothing is certain, the possibilities are extraordinary—surely great enough to hazard a voyage or two. And even a negative result would be extraordinarily significant.

As a scientific discipline, the study of life in the cosmos is sometimes known as *exo*biology—"the study of life *outside*." But because our knowledge of terrestrial life is so crucial to the broader question of life in the universe, the term *cosmic biology* may be a better one. That way, terrestrial life is included, not excluded. It becomes an example, a specimen, not just an analogy or model. It gives us an "*n* of 1," as scientists like to say. Not a cornucopia, certainly, but far better than an "*n* of zero." The task, then, is to deduce from what we know of life on Earth the truly general principles of biology—principles that have shaped us in ways we now barely understand, and that apply wherever life may arise.

So terrestrial biology is one foundation of cosmic biology, and the other is astronomy, along with its infant child, space exploration. For it is astronomy's task to describe the habitats of cosmic life, and perhaps eventually to find life in those habitats. Cosmic biology means putting biology and astronomy together and forging a new science.

We will start our quest by asking: How does a Life get started? (And by the capitalized word 'Life' we mean an entire system of interdependent living things, linked by common descent, such as our own here on Earth.) What are the building blocks from which a Life is born, where do those building blocks come from, and how do they put themselves together to make the first fledgling creatures? Then, in Chapter 2, we explore the range of environments which our terrestrial Life can tolerate, to gain a feeling for the adaptibility of life and for the kinds of environments in which we may hope to find life elsewhere.

Bearing that knowledge in mind, we finally take off from Earth, in Chapter 3, to explore the solar system. We look for possible homes for life, and examine the evidence for and against the idea that a Life exists or once existed on at least one body in our solar system besides Earth. In Chapter 4, we leave the solar system behind and enter the dusty clouds where stars are born. Is it possible, we ask, that nascent stars gather the raw materials of life from the emptiness of deep space? And does the process of starbirth regularly give rise to planets too? Then, in Chapter 5, we describe the search for planets around other stars—a search that has just recently been rewarded, though in the most unexpected ways.

Complexity and evolution are the themes of Chapter 6: How do simple organisms get more complicated? Are there "rules" that guide a Life's development, here on Earth or elsewhere? And if so, do such rules tend toward complexity, interdependence, and intelligence? Or are we, as intelligent social beings, merely another example of Nature's penchant for creating oddities?

The thought that intelligence might be widespread in the universe leads inevitably to the desire to communicate—to SETI (the *s*earch for *e*xtra*t*errestrial *i*ntelligence). That enterprise is the theme of Chapter 7. Then, in the following chapter, we ask: Are aliens visiting Earth right now? What, in other words, are UFOS?

In Chapter 9, we row into a Sargasso of speculation, asking whether life as we know it is all there is. Are there Lifes based on quite different chemical principles than our own, or perhaps not based on chemistry at all? And what about 'artificial life'? Is a computer conscious? Are digital organisms alive? Will robots take over the biosphere from "squishy" creatures like ourselves?

In the final chapter, we delve briefly into the arcane world of modern physics. As we broaden the horizons of "our" world, embracing first the Moon and planets, then the stars, and finally the entire observable universe, are we seeing everything there is, or are there worlds that are truly and forever beyond our ken, as the ancients believed—worlds whose existence follows, not from direct observation, but from cosmological theories? And if so, does our world have some special status as a possible home for life?

At the root of the search for life is the tension between two ideas. One idea is what Carl Sagan called the "principle of mediocrity." This is the idea, deriving from the Copernican Revolution, that there is nothing special about our view of the universe; that what we see around us, including life, is likely to be replicated over and over, not in detail but in wonderful diversity. The universe, according to this notion, is a starlit garden to which we need only find the gate.

The opposing idea is that we do indeed have a privileged view of the universe—a view conditioned by our role as viewers. At the extreme, this idea can include Creationism, but it can also simply be the awareness that we should not infer conditions elsewhere from what we see here, because life *must* exist here. Earth is not a random sample of all planets, but a planet that had to have life, in order that we be here to think about it. If there were only one inhabited planet in the whole wide universe, we would be on it! And it would not seem unusual to us until we had searched the rest of space and failed to find our peers.

Although the Copernican viewpoint seems to favor the principle of mediocrity, there have been scientific findings that are not entirely supportive of it, at least in its most general application. In the 1930s, Edwin Hubble, perched on a rickety chair on a mountaintop behind Los Angeles, took the measure of the stars and found them to be in flight from us and from each other. Later that expansion was understood as the residue of a Big Bang that happened a mere 15 billion or so years ago. This discovery raises a difficulty that did not exist when it was possible to believe in an infinitely old universe, for if we are not special in space, we do at least seem to be special in time. Of course, one can get around this difficulty. It is possible, for example, that our cosmos is not all there is—that we are a mere momentary bubble in a froth of endless Becoming. But a timeless cosmos would have been easier.

No amount of learned discussion, only observation, can tell us which idea is closer to the truth. And that is where the excitement is today. Whether the rationale is right or wrong, the search for life in the cosmos has become Big Science and Big Engineering, involving our brightest minds and most expensive hardware.

Hic sunt dracones—"Here be dragons"—wrote the cartographers of old, to fill in the still unexplored lands of Earth. The same sense of mystery, the same lure to adventure, now colors the unexplored lands of the cosmos. Welcome to the dragon hunt.

SUGGESTED READING

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1

Origins

How Life on Earth Began

The Museum of Creation and Earth History stands on a freeway frontage road in Santee, California, a nondescript suburb tucked among the low hills east of San Diego. We pull into the museum's forecourt and park backward in our space, thus concealing the "Darwin fish" that adorns the rear of the car. We feel a slight anxiety.

The receptionist is a pleasant elderly gentleman, who nevertheless increases our unease by asking, "You're not reporters, are you?" "No, no," we assure him truthfully, but it feels perilously close to a falsehood. A sense of transparent culpability, not experienced since Sunday school decades ago, accompanies us into the exhibition rooms. For this museum raises one of the most profound questions that humanity can ask—Where do we come from?—and offers an unambiguous answer: Scientists like ourselves have got it all wrong, and the Bible has got it exactly right.

We move through a series of small halls, named for the Six Days of Creation. In the first, light is divided from the darkness; in the second, a firmament appears; in the third, the seas are divided from the dry land. All this is visualized with the help of rather schematic artwork, to the accompaniment of classical music. Things get a little more animated on the Fourth Day with the appearance of the heavenly bodies: NASA-supplied color photographs reveal the beautiful and unexpectedly diverse faces of the planets and their moons. But the hall of the Fifth Day really comes alive: there's an aquarium with real fish and an aviary with real birds, although the birds' trills and warbles are piped in. The next hall has even more living creatures: a poisonous-looking frog, a snake (or its shed skin, at least), and even a herd of giant Madagascan cockroaches. And humans, of course—represented by their skulls. For the Sixth Day was the culmination of Creation, when God created Man in His own image and gave Man dominion over the Earth. In the next hall, the significance of the Seventh Day is explained: God rested from His labors, thus marking the end of the period in which He created the universe and the beginning of the period, still continuing today, in which He actively upholds His Creation.

The Seven Days of Creation by no means exhaust the museum's exhibits. Other rooms take us inside Noah's Ark, to the eruption of Mount St. Helens, to the Grand Canyon, to the interior of a glacier. We see the tower of Babel and pass through the Ishtar Gate, and we file down a corridor between portraits of creationists on the left, and evolutionists on the right—the saints and sinners of the Great Debate.

If the museum based its case simply on a divinely inspired faith in what the Bible says, it would be of limited interest to us. But far from it: The museum's whole purpose is to show how we can deduce the truth of the Bible story from objective study of the world around us—from science, in fact. It could properly be called the Museum of Natural Theology, for that is the name of the venerable branch of philosophy that seeks to recognize God through Reason and the study of His Works.

In making this case, of course, the museum has to face serious obstacles. Because of the detailed genealogies recounted in Genesis, the museum needs to place the beginning of all things no more than about 10,000 years in the past, while most astronomers and cosmologists claim that our universe is a million times older. The museum must compress into a mere six days processes that, in the view of the majority of scientists, took more than ten billion years. And it must make intentional what most scientists consider, in a deep sense, accidental.

The museum does not shirk this challenge. It expresses open antipathy toward Christians who try to smooth over the gulf by, for example, asserting that the "days" of Creation were metaphors for longer periods of time: that they were in fact "ages" or "eons." No, "days" were days—periods of 24 hours.

It also rejects the strategy, favored by some Christian groups, of pushing God's creative role backward in time, allowing the latter part of Creation to go forward by purely natural processes. Some believe, for example, that God lit the spark of life on Earth but allowed natural selection to do the job of getting from microbes to humans. This, in fact, was the view publicly espoused by Charles Darwin, though his private beliefs, as we shall see later, were different. With discoveries in physics and astronomy, there has been pressure to push God's role back even further. The British cosmologist Stephen Hawking, in his book *A Brief History of Time*, tells how he attended a scientific meeting at the Vatican at which the Pope admonished the conferees not to discuss what happened before the Big Bang, because that was God's province. Yet Hawking's lecture at the conference concerned the possible circularity of time, a hypothesis that, if true, would make the phrase "before the Big Bang" meaningless![1] The Museum of Creation wisely refuses to set foot on the slippery slope of biblical revisionism.

How then, does the museum propose to explain the apparent discrepancies between the Bible story and the usual teachings of science? There are several basic points. One is that, according to the museum, God created all things, including living creatures, in a fully functioning, mature state. Thus, Adam and Eve were created as normal adults, in possession of navels, for example—just as they are portrayed by Dürer and a hundred other artists. But seeing their navels, we think of umbilical cords and therefore assume that Adam and Eve were once fetuses—which they were not. And seeing the Tree of Knowledge, we assume that it was once a seed, and so on. There is the deceiving appearance of a past.

The same phenomenon, the museum argues, could explain how stars appeared in the sky on the Fourth Day, even though it would take many years for photons, traveling at the speed of light, to reach us from the newly created stars. God may have created a "functionally mature" state, including both the stars and the entire stream of photons traveling from it to us, in a single act. But seeing the photons, we naturally imagine that they originated from the star many years previously.

Of course, this line of thought can lead us into dangerous territory. Is it not equally possible that the universe is much younger than the Bible tells us? Perhaps God created the universe just a few hours or minutes ago, rather than 10,000 years ago? That vivid memory we have of reading this morning's newspaper, and every earlier memory—were they perhaps implanted in our brains to make us "functionally mature"? Do our past lives resemble those wildlife dioramas we loved as children: a couple of stuffed gazelles up front, and the rest painted on the backdrop? How to distinguish reality from illusion becomes an insoluble dilemma, once one posits the intentional creation of "mature" systems.

The museum presents a second line of argument to explain the discrepancies between creationism and conventional science. Most scientists, it argues, assume that natural processes have always occurred at the same rate. If the half-life of a radioactive isotope (the time required for half of the atoms to decay into other atoms) is now a million years, it was always a million years, because the physical laws that control radioactive decay have not changed since atoms first existed. But, the museum reminds us, we can't go back into the distant past and measure the decay rate then; therefore, the assumption of a constant rate is unjustified, and so is any finding based on that assumption, such as the age of a rock or of a fossil embedded in that rock. The Seventh Day of Creation, when God rested, was one particular time when the rates of physical processes might well have changed. Before then, light may have traveled at infinite speed, for example, thus providing an alternative explanation for how stars were seen on the day they were created.

As a matter of fact, it is not quite right to say that scientists simply assume the constancy of process rates. Many processes on Earth, such as the rate of deposition of sedimentary rocks, have been shown to vary greatly over time. Even the constancy of the great "constants," such as the strength of the gravitational force, is open to scientific debate: there are cosmologists who have developed models in which the force of gravity has changed since the Big Bang. But we can study process rates in the past with the same kinds of certainties and uncertainties with which we study them today. Some kinds of radioactive decay, for example, leave permanent tracks in rocks—rocks whose age can be estimated by other means, such as their degree of weathering or chemical transformation, their position in a sedimentary series, and so forth. One can count these tracks and thus determine whether the process of radioactive decay took place at the same rate in ancient times as it does today. In the end, our knowledge of process rates in the past is built on the mutual consistency of events that happened then, just as our knowledge of process rates today is built on the consistency of events happening now. To believe that the apparent great age of the universe is an illusion caused by decreasing process rates is really to say that time itself ran faster in the past—an assertion that belongs to metaphysics, not science.

Finally, the museum confronts the findings of conventional science by contesting the findings on science's own terms—by getting into the nitty-gritty of the data and challenging every piece of evidence, and every interpretation, that runs counter to the Bible story. Does radiometric dating of rocks at the bottom of the Grand Canyon prove them to be a billion years old? No, because if one applies the same technique to obviously recent lava flows near the canyon's rim, one gets an even earlier date—or so the museum's experts allege. Therefore the dating technique is patently untrustworthy. Did the dinosaurs go extinct 65,000,000 years ago, as the fossil record suggests? No, because dinosaurs were frequently and unambiguously sighted by humans—they called them "dragons"—as recently as the Middle Ages. Dinosaur fossils, like all other fossils, are merely the remains of the animals that drowned in Noah's Flood. Others survived, either by swimming or by being taken on board the Ark. At the museum, a painting of the Ark's interior shows what seems to be a stegosaurus lounging peaceably in its stall. The accompanying panel goes through the arithmetic to show that the Ark was plenty big enough to hold all 50,000 "kinds" of animals.

The Museum of Creation is an offshoot of the Institute for Creation Research,[2] whose offices are located in the same building, and the Institute's Senior Vice President, Duane Gish, is a Berkeley-trained biochemist who yields to no one in the discussion of scientific minutiae, whether it be the proper interpretation of an indistinct band in a sedimentary rock or the assessment of transitional forms between various fossil hominids. Woe to the "evolutionist" who agrees to debate Gish on a college campus or at a church meeting: he or she will be buried under an avalanche of particularities that collectively obliterate the conventional scientific worldview. Gish and the institute's founder, Henry Morris, have written a series of books that promote creationism as a science and label the theory of evolution a "religion"—and a false one, to boot. Of course, creationism should be taught in schools.

Where does the institute stand on extraterrestrial life? Bill Hoesch, the institute's Public Relations Officer, tells us that nonintelligent life—such as microbes—poses no problems. Creationists do not have the same need for them that "naturalists" do, since the Creator might well have chosen to put life on the Earth alone. But there is nothing to say that microbes do not exist elsewhere. With intelligent life it's a different story, especially if that life is in an "unfallen" state. In retribution for mankind's Original Sin, God put His Curse on the entire universe, Saint Paul tells us in Romans 8:22 ("For we know the whole creation groaneth and travaileth in pain together until now"). If innocent extraterrestrial creatures are laboring under this Curse, it would raise the question of whether God had acted unjustly. "That would raise some hoary theological problems for us," Hoesch says. So creationists doubt that such beings exist.

As we leave the museum and stand blinking in the afternoon sunlight, we have the sense of having torn ourselves free from a dark web of unreason, a web that might have held us in its threads until the brains were sucked out of our skulls. We feel the impulse to flag down one of those trucks hurtling by on Route 67, to breathlessly recount our trip to Eden and the saurian Ark, as if we had just returned from an alien abduction. Surely the driver would comfort us with the assurance that everything we saw and heard was an illusion?

Perhaps not. Creationism, in one form or another, is the majority worldview. Most people believe that the universe was brought into existence by divine intention, and about 40 percent of the population of the United States, according to a 1991 survey by *U.S. News and World Report*, believes in the literal truth of the Genesis story. Henry Morris, Duane Gish, and their colleagues at the Institute for Creation Research are unusual only in the fervor with which they explore the ramifications of that belief.

Of course, the Museum of Creation does represent something of an extreme position within theology. Natural theology, as practiced today, has many different perspectives on the identity of God and His role in the creation of the universe and life. For example, one school of liberal theology speaks of God as a process that is coming into being, rather than as a substance coexistent with but transcendent over matter. Process theologians, and many other liberal theologians, would not dream of contesting the date that dinosaurs went extinct, or any other scientific findings related to our origins. Our purpose in visiting the museum was not to gain an overview of current theological perspectives, but to sample the least naturalistic among them, in order to provide a contrast with what follows: The effort to explain the origins of life by natural processes.

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Lucretius, whose belief in extraterrestrial life we mentioned in the Introduction, had an uncompromisingly naturalistic view of Creation. The gods exist, he said, but they are irrelevant. Our world assembled itself spontaneously, by the aggregation of atoms moving through a boundless extent of space. No Prime Mover was needed. Nor did the origin of life require divine intervention. "As I believe," he wrote, "no golden rope let down living things from on high into the fields ... rather, this same earth that now nourishes them from herself gave them birth."[3]

To explore this alternative vision, we visit the beachside community of La Jolla, 15 miles and a world away from the Museum of Creation. For La Jolla is home to the science-focused University of California, San Diego (UCSD) and to a host of satellite institutes and research corporations. Here we call on a group of five scientists—Jeff Bada, Stanley Miller, Gustav Arrhenius, Leslie Orgel, and Gerald Joyce—who are the closest thing to disciples of Lucretius that one may hope to find in the world today. Not that they are concerned with the entire panoply of Creation. It's that "golden rope" part that obsesses them. Can one explain the origin of life without it? It turns out to be a Herculean undertaking.

The group is called the NASA Specialized Center of Research and Training in Exobiology, one of a pair of such centers in the US. Yet the La Jolla scientists actually devote the bulk of their attention to terrestrial life—to "endobiology," if you like. "Certainly, our effort is to figure out how life began on Earth," the center's Director, Jeff Bada, tells us. "But of course that provides a model for everything else. Admittedly, we're biased by what we know about life on Earth. But I think the consensus is, if we can understand the processes that lead up to the origin of life, then given the proper conditions, it will probably be a universal process."

Jeans clad, with weather-beaten face and graying beard, Bada could be mistaken for an aging sailor. In fact, his research has taken him onto the high seas—he has sampled fluids emitted by deep-sea volcanic vents, for example. His office is no more than a few hundred feet from the ocean, at the Scripps Institution of Oceanography. And the ocean, Bada and his colleagues believe, is where life most probably originated.

"Water is best," said the first philosopher, Thales of Miletus, about six centuries before Christ. Water gave rise to all things, he claimed, including life—and certainly, water seems like the most natural place for a Life to get started: it's an excellent solvent, and there's plenty of it, on Earth at least. But water alone isn't enough. Terrestrial life is made of carbon-containing molecules—organic compounds—many of which also contain nitrogen, oxygen, and other elements. And assembling these molecules takes energy.

As mentioned earlier, Charles Darwin publicly expressed a belief that Earth's first creatures were divinely made. Perhaps he felt that he had rocked the boat sufficiently with his theory of evolution—that he would endanger the seaworthiness of his whole enterprise if he went further. But in a private letter, written in 1871, he did put forward the idea that life arose spontaneously, "in some warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity, etc. present."

If so, what were these chemicals and where did they come from? In 1936 the Russian chemist A.I. Oparin suggested an answer.[4] The Earth's early atmosphere, he proposed, was rich in ammonia (NH_3) and methane (CH_4), and lacked oxygen. In this "reducing" (hydrogen-donating) atmosphere, a large variety of organic molecules formed and were washed by rain into the ocean, gradually building up a "prebiotic soup." (The "soup" metaphor was actually introduced by the British geneticist J.B.S. Haldane, who had been thinking independently along the same lines.) The very first organisms, Oparin believed, were extremely simple: they didn't need to have complex metabolic pathways because everything was available in the soup—both molecules to make up their structure (such as amino acids) and molecules to break down for energy. It was the ultimate free lunch. Eventually, of course, the goodies ran out, and organisms had to learn how to make an honest living. However long that initial period may have lasted—a hundred thousand years, a million years, ten million years—it could have been no more than a moment in the Earth's history.

One of the La Jolla scientists, Stanley Miller of the UCSD Chemistry Department, tested Oparin's ideas in the laboratory. In 1952, as a graduate student working in the laboratory of Harold Urey at the University of Chicago, Miller performed an experiment that made him famous and established origin-of-life research as an experimental science.[5] He tested Oparin's hypothesis by (1) filling a flask with a "reducing atmosphere" (he chose a mixture of methane, ammonia, and hydrogen gas—H_2) over an "ocean" (a cupful or so of water) and (2) subjecting the milieu to "lightning strikes" (electrical discharges).

After a week, he analyzed what was in the water and found glycine and alanine—two of the amino acids that are building blocks of proteins. Subsequent experiments of a similar kind have revealed that a wide variety of amino acids, as well as the nucleosides that are the building blocks of DNA and RNA, are readily formed in experiments of this kind. Thus, Miller's work suggested that the building blocks of life were indeed there, free for the taking, in the Earth's primordial ocean. It was just a matter of putting them together into an organism.

Asked what it was like to have performed such a famous experiment while a graduate student, Miller tells us: "I'm sure it helped my career. But in terms of famousness—I don't know. A lot of people felt that it wasn't really science. It was attacking a problem that people didn't think about."

With the passage of the years, however, Miller has evolved from radical wunderkind to conservative defender of a possibly outmoded theory. This is on account of changing views about the composition of the Earth's early atmosphere. To understand this change, we must take a look at how scientists think the Earth and its atmosphere were created. According to current consensus, the Earth formed by the gathering together ("accretion") of smaller objects, or "planetesimals," in the disk of gas and dust orbiting the evolving Sun, 4.6 billion years ago. The main period of accretion lasted about 100 million years. During this period, the heat generated by frequent impacts kept the Earth in a molten state. For several hundred million years after that, sporadic large impacts probably prevented life from establishing itself. One such impact—by an object at least as large as Mars—is thought to have kicked a large amount of material from the Earth's mantle into orbit around the remainder of the planet. This orbiting material eventually accreted to form the Moon.

It was once generally believed that the Earth's original atmosphere was drawn directly from the disk of gas and dust from which the solar system formed. If so, it would have resembled the present atmosphere of Jupiter and Saturn, being rich in hydrogen and hydrogen-containing molecules, such as ammonia and methane, and lacking molecular oxygen (O_2). This would have been a strongly reducing atmosphere and would have been appropriate for the synthesis of organic compounds by the methods that Urey and Miller proposed. But according to the majority of contemporary researchers, the Earth was too small to attract or hold on to such a primordial atmosphere. Instead, the first atmosphere was composed of volatiles that were released from infalling planetesimals as they crashed into the magma ocean and were vaporized, or of volatiles that were outgassed from volcanoes. The main gases produced by these processes would probably have been water vapor, nitrogen, carbon monoxide (CO), carbon dioxide (CO_2), and hydrogen. Hydrogen, however, is light enough to escape from the atmosphere into space and, therefore, would not have accumulated in significant concentrations. Compounds such as methane and ammonia, if they were generated at all, would likely have been kept at very low concentrations by the destructive effect of the Sun's ultraviolet radiation.

Geochemists have had a much harder time figuring out how organic molecules could have been generated in this neutral or mildly reducing atmosphere, compared with the strongly reducing atmosphere favored by Oparin, Urey, and Miller. It's not completely impossible. Miller himself, for example, has shown that electrical discharges in a mildly reducing $CO_2/N_2/H_2O$ atmosphere can give rise to formaldehyde, and hydrogen cyanide can be produced in a similar atmosphere by ultraviolet irradiation. These compounds can go on to build larger organic molecules. Still, the process is not very efficient. "If you're going to make enough organic compounds," says Miller, "it has to be methane or ammonia, or else hydrogen and carbon dioxide and nitrogen."

So Miller tries to find ways to rescue the original scheme. He suggests to us, for example, that methane might have been released from the deep-sea volcanic vents. The vents don't release methane now, admittedly, but they might have done so, Miller says, when the Earth's atmosphere and oceans lacked oxygen. There would still be the problem of how to protect that methane from the Sun's ultraviolet radiation once it entered the atmosphere. But by happenstance, the Cornell astronomer Carl Sagan (shortly before his death in 1996), along with Chris Chyba, came up with a theory to explain how methane might have been protected.[6] They suggested that a layer of organic haze high in the Earth's atmosphere—smog, in effect—filtered out the ultraviolet radiation before it could reach the deeper layers where methane would be located. Sagan and Chyba came upon this idea because just such a smog layer does surround another body in the solar system—Saturn's largest moon, Titan (see Chapter 3).

We say "by happenstance" because Chyba and Sagan had not set out to rescue the Miller-Urey hypothesis. They wanted methane in the Earth's early atmosphere for a quite different reason. Early in the