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Life Is an Accident of Space and Time

Even if life existed on every planet that could support it, living matter in the universe would amount to only a few grains of sand in the Gobi Desert.

By Alan Lightman

Erik Carter / The Atlantic; Getty

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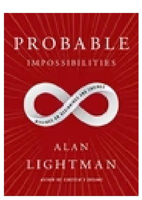
Like many people on planet Earth, I have been spellbound by the first pictures from the James Webb Space Telescope: the lacelike windings of galaxies, the apricot filaments of nebulae, the remnants of exploded stars. A less picturesque, but still revolutionary, part of Webb's mission is the search for signs of life elsewhere in the universe. The telescope goes about this momentous quest by analyzing the starlight passing through the atmospheres of distant planets. Each kind of molecule leaves its own telltale imprints on traversing light, and some molecules, such as oxygen, carbon dioxide, and methane, may indicate life forms on the planet below. Indeed, Webb has already found evidence of carbon dioxide on at least one planet beyond our solar system.

Considering the billions of planets in our galaxy, and the billions of galaxies in the observable universe, few scientists believe that our planet is the only habitat with life. Nonetheless, finding definite evidence of living things elsewhere in the cosmos would have deep emotional and psychological import, as well as philosophical and theological meaning. Such a finding would force us humans to reconsider some of our fundamental beliefs: How do we define “life”? What are the possible varieties of life? Where did we living things come from? Is there some kind of cosmic community?



Probable Impossibilities - Musings On Beginnings And Endings

ALAN LIGHTMAN,
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In fact, recent scientific research suggests that life in the universe is rare. A few years ago, using results from the Kepler satellite to estimate the fraction of stars with possibly habitable planets, I calculated that, even if all potentially habitable planets do in fact harbor life, the fraction of matter in the universe in living form is exceedingly small: about one-billionth of one-billionth. That’s like a few grains of sand on the Gobi Desert. Evidently, we living things are a very special arrangement of atoms and molecules.

Life may be even rarer than that. In the mid-1970s, the Australian physicist Brandon Carter pointed out that our universe seems particularly fine-tuned for the emergence of life. For example, if the nuclear force holding the centers of atoms together were a little weaker, then the complex atoms needed for life could never form. If it were a little stronger, all of the hydrogen in the infant universe would have fused to become helium. Without hydrogen, water (H_2O) would not exist, and most biologists believe that water is necessary for life. As another example of fine-tuning: If the observed "dark energy" that fills the cosmos, discovered in 1998, were a little larger than it actually is, the universe would have expanded so rapidly that matter could never have pulled itself together to make stars, the essential nursery for all the complex atoms thought necessary for life. But with a slightly smaller value of dark energy, the universe would have expanded and recollapsed so quickly that stars wouldn't have had time to form.

Carter's observation that our universe is finely tuned for the emergence of life has been called the anthropic principle. A profound question raised by the principle is: Why? Why should the universe care whether it contains animate matter? The theological answer to this question is a cosmic form of intelligent design: Our universe was created by an all-powerful and purposeful being, who wanted it to have life. Another explanation, more scientific, is that our universe is but one of a huge number of universes, called the multiverse, which have a wide range of values for the strength of the nuclear force, the amount of dark energy, and many other fundamental parameters. In most of those universes, these values would not lie within the narrow range permitting life to emerge. We live in one of the life-friendly universes because otherwise we wouldn't be here to ask the question. Our existence, and our universe itself, is simply an accident, one throw of the cosmic dice.

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A similar line of thinking could explain why planet Earth has such favorable conditions for life: liquid water, moderate temperatures (at the moment), plentiful oxygen for higher-level metabolism. The obvious explanation is that there are many planets, even in our own solar system, that do not have liquid water or pleasant temperatures or oxygen atmospheres. Those planets do not harbor life. We are here, to build houses and write novels and ask questions about our own existence, because we live on one of the small fraction of planets that have the right conditions for life. In sum, animate matter is not only rare in our particular universe, but seems to be nonexistent in most possible universes.

At the time that Carter published his paper, I had recently finished my graduate work and was doing research in astrophysics at Cornell University.

During my two years at Cornell, I lived in an apartment with a large picture window facing Cayuga Lake. Every day, the lake looked different, as if painted by a new artist. I spent hours when I should have been pondering equations staring out at the lake, its fluctuating colors and textures.

At Cornell, I met a number of scientific titans, such as Edwin Salpeter, Thomas Gold, and Hans Bethe. Gold, a theoretical astrophysicist and biophysicist born in Vienna in 1920, I got to know pretty well. Tommy was not particularly adept at mathematical calculations, but he was a brilliant and daring intuitionist. Barrel-chested and ruddy-faced when I knew him, with a broad smile, he had strong opinions about nearly everything and did not shirk from thumbing his nose at the scientific establishment. He rapidly threw out new ideas, like darts at a dartboard. Most of them missed the bull's-eye, but not all.

In 1948, Gold partnered with other astrophysicists to challenge the Big Bang theory with a counter theory called the "steady state" theory of cosmology. That theory proposed that the universe never had a beginning. It appears unchanging, even while expanding, because of a hypothesized constant creation of new matter. Steady state was eventually proved wrong. In 1968, Gold correctly hypothesized that the newly discovered pulsing radio waves from space were produced by rapidly rotating neutron stars. In the 1970s, Gold argued that the oil found on Earth did not originate from the decomposition of organic material, as most geologists believe, but was present deep underground when the planet first formed. He even persuaded the Swedish national power company to drill an exploratory well in a meteor crater. The interpretation of the sludge brought forth was highly controversial, and the company went bankrupt.

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I have vivid memories of standing in Tommy's office, attempting to solve a problem with equations on the blackboard, when he would brush me away with exasperation and pronounce the answer simply by visualizing the problem in his head. Such physical intuition can be found in most scientists, but Tommy possessed it to an astounding degree.

Tommy was also good with his hands. He once showed me a beautiful, three-legged chair he'd designed and built, and he explained that all chairs should be made that way. Even if the three legs are not the same length, their ends will sit stably on the floor because three points (the ends of the legs of the chair) define a unique plane (the floor). Add a fourth leg—a fourth point—and, unless it is cut exactly to the right length, its end will not lie in the same plane as the first three. The chair can then wobble back and forth among its four legs, the ends of any three of them lying in the plane of the floor, but the fourth being out of place. In other words, three legs allow only one solution for the position of the chair, but four allow for several.

Thinking back on Tommy's three-legged chair, I realize that it was a perfect metaphor for the single and unique universe that most scientists dreamed of. Physicists, and especially theoretical physicists, would like to think that there is only one possible universe consistent with the fundamental laws of nature, like one unique solution to a crossword puzzle or a chair with only three legs. If so, we would be able to calculate why our universe *must* be as it is.

The possibility that there may be many other universes with different properties, many different solutions to the same fundamental laws of nature, deeply disturbs many scientists. It's a bit like going into a shoe store and finding that size 3 fits you, but sizes 6 and 11 fit equally well.

Modern physicists take great pride in being able to calculate everything from "first principles"—that is, from a few fundamental laws. For example, a physicist can calculate how fast a ball hits the floor when dropped from a height of three feet using a principle known as the "conservation of energy": The total energy in a closed system is constant, even though that energy may change form. The conservation of energy, in turn, follows from an even deeper principle called "time invariance": The laws of nature do not change from one moment to the next.

Using basic principles, physicists have been able to calculate the color of the sky, the detailed orbits of planets, the strength of magnetism in an electron, and many other phenomena. But if there are many different universes consistent with the same starting principles and laws, then the fundamental nature of our universe is *incalculable*. Some basic properties of our universe would have to be accidents. Physicists hate accidents. If there were too many accidents, nothing would be predictable. Wheelbarrows might suddenly float in the air. The sun might come up some days and not others. The world would be a frightening place.

There's one more disturbing aspect of the multiverse idea. Even if this multitude of other universes are real, there may well be no way to prove or disprove their existence. By definition, a universe is a self-contained region of space and time that cannot send a signal to another such region even into the infinite future. Thus, a universe cannot communicate with another universe. The hypothesized boatload of universes must be accepted or rejected as a matter of faith. Just as scientists do not like accidents, they dislike being forced to accept things they cannot prove. But the multiverse, and other aspects of this strange cosmos we find ourselves in, may be not only not unknown to us at this moment, but fundamentally *unknowable*. Although such a notion goes against the long tradition of science, it does offer a bit of humility, which is good medicine for any profession.

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The multiverse hypothesis is not accepted by all scientists. But one thing is almost certain: Life in our universe is extremely rare. I have already explained that life is rare in space—only a small fraction of matter exists in living form. Life is also rare in time, in the long unfolding history of the universe. At some point in the future, in perhaps a few hundred billion years, after all of the stars have burned out and all sources of energy have been exhausted, life in our universe will end—not just life similar to that on Earth, but life of all kinds. The "era of life" will have passed.

What should we make of this realization? For me, it offers a feeling of kinship with all living things. We living things are the only mechanism by which the universe can observe itself. We living things, a few grains of sand on the desert, are that special arrangement of atoms and molecules that can attempt to fathom and record this dazzling spectacle of existence. In a limited but real sense, we living things help give the universe meaning. Without us, the cosmos would merely be.

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Alan Lightman teaches at MIT. He is the host of the upcoming miniseries *Searching: Our Quest for Meaning in the Age of Science*, premiering on public television in January 2023.

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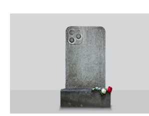

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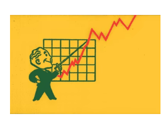

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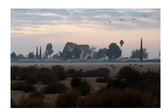

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