How will we know alien life if we see it? It depends on whom you ask.

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Science Writer

Before NASA launched its Viking landers to Mars in 1975, Carl Sagan suggested that the Red Planet might harbor “organisms ranging in size from ants to polar bears.” Afterward, he acknowledged that nothing in the landers’ images could be taken as a sign of advanced life.

There was one rock, however, that appeared to be inscribed with the letter “B.” But Sagan held off on any sort of celebration. “It is clear that a single letter by itself is not sufficiently improbable to force the hypothesis of intelligent origin,” he wrote in Journal of Geophysical Research (1). “This is in addition to the unlikely universality of the Roman alphabet.”

After more than 50 unrewarding years of searching for extraterrestrial life using spacecraft and radio telescopes, it seems that if aliens exist, they are unwilling to wave at us or shout out their presence—unless they are simply unable. Most life in the universe may be like the microbes that have populated Earth for billions of years: too small for ordinary cameras to spot and too simple to produce their own radio shows.

Hence, the many scientists eagerly awaiting the first hints of alien life are preparing for the microbial sort.

Different scientific disciplines propose different searches for such primitive life-forms (2). Astronomers suggest scanning planetary atmospheres for gases redolent of earthly life, chemists favor sending probes to look for a preponderance of right- or left-handed molecules, and physicists say we should hunt for the tiny vibrations of metabolism or the still more subtle footprints of self-replicating information. Researchers are now developing the tools and techniques to root out each one. However, cross-disciplinary attempts to probe the essence of life provoke not only difficult and divisive philosophical questions but incredibly practical ones: With numerous researchers studying all aspects of life, terrestrial and potentially otherwise, how would we actually know alien life if we found it?

Atmospheric Signatures

Life has no standard scientific definition. University of California, Berkeley, biochemist Daniel Koshland, a former editor-in-chief of PNAS and of Science, once recalled how researchers at a meeting were focusing on the ability to reproduce as the main requirement for life—until someone pointed out that an isolated rabbit would therefore be considered dead, while a female/male pair would be alive. “At that point, we all became convinced that although everyone knows what life is, there is no simple definition,” he wrote (3).

This can lead to confusion. The Viking mission included three experiments to search for signs of metabolism in Martian soil. All three found these signs, but the results were not taken as proof of alien life because another experiment failed to detect organic molecules, the building blocks of terrestrial life. The debate about these findings simmers on today (4).

The nearest we have to a mainstream view is the guess that aliens will be broadly similar to Earth-like life, with carbon-based chemistry and water as a solvent. This assumption allows a very expansive search, as we can scan extrasolar planets for some of the atmospheric gases produced by life on Earth.

Ours is the only planet known to harbor life—thus far. This recent image of the sunlit side of the Earth, taken from one million miles away, comes from NASA’s Deep Space Climate Observatory satellite. Image courtesy of NASA.
Hands can be used to demonstrate how amino acid molecules are mirror images of each other, a phenomenon, known as chirality, that represents a key characteristic of Earthly life. Image courtesy of NASA.

Finding a combination of molecular oxygen, ozone, and methane would end up strong evidence for life, according to simulations run by Shawn Domagal-Goldman of NASA’s Goddard Space Flight Center in Greenbelt, Maryland, and his colleagues (5). Although nonbiological processes can create these gases too, they would only make oxygen slowly—and any methane would end up reacting with the oxygen atoms before they could bind together into O₂ or O₃. Biology can produce oxygen fast enough to outrun this destructive process, says Domagal-Goldman.

The first instrument to have a chance of detecting these gases on Earth-like worlds will be the James Webb Space Telescope, due for launch in 2018. Future missions now on the drawing board might also be powerful enough to glimpse surface features that change as an exoplanet rotates, such as continents, oceans, or hints of vegetation. These, along with the right combination of biosignature gases that vary seasonally, would be enough to show that we are not alone, Domagal-Goldman says. “I’d be comfortable sending a paper in ... saying, ‘Evidence of life on planet ATLAST5b,’” he says.

Others disagree. “The word ‘indisputable’ would not apply to that paper,” says Steven Benner, an astrobiologist at the Foundation for Applied Molecular Evolution in Alachua, Florida.

Arguments have raged for decades over whether certain Australian rocks contain the oldest fossilized life on Earth (6). Given such disagreements about life on our own planet, Benner says, “You will not see any consensus emerging from any extrasolar planet experiment in our lifetime.”

Lopsided Life

Instead, could the shape of molecules reveal alien life? Some molecules such as amino acids can arrange themselves in two mirror-image, or chiral, configurations. When amino acids are made in the laboratory, they form equal numbers of left- and right-handed versions. However, life uses left-handed amino acids exclusively.

Why? Amino acids build enzymes and other proteins, which fold in a complicated way. This requires that the amino acids all be of the same handedness, otherwise the proteins could not fold properly, explains Jeffrey Bada, a geochemist at the University of California, San Diego.

If an excess of chiral amino acids were found on another planet, that would indicate life, says Bada. Also, the left-handedness of Earth life may have been an accident, so extraterrestrial life may have chosen left- or right-handed amino acids. “My great hope would be to go to Mars and find right-handed amino acids in abundance,” says Bada. “That would mean not only that we had life but we had unique life because it couldn’t be related to Earth in any way.” Finding two independent origins of life in the same solar system would suggest that life is common elsewhere in the universe too, says Daniel Glavin, an astrobiologist at NASA Goddard.

The drawback is that chirality would be extremely difficult to detect with a telescope unless the chiral compounds were abundant and exposed. Scientists would almost certainly need to send a lander, which restricts the search to our own solar system. Bada has developed an instrument called Urey to look for chiral molecules on Mars, but so far it has not been given the green light for launch—in part because the version that meets NASA’s requirements costs $75 million, which the agency has deemed too expensive, says Bada.

Live to Eat

In any case, looking for chirality or for particular gases may just be too parochial. Other worlds with different temperatures and pressures may hold a strange biochemical brew. Researchers have pondered the possibility of life based on silicon instead of carbon, or using liquids besides water as solvents—such as the methane/ethane mixtures that fill seas on Saturn’s moon Titan.

“How do we detect life if we don’t know what to look for?” says Christoph Adami, a physicist who simulates evolving life at Michigan State University in East Lansing. “You really need to have some understanding of what makes life universal before you can be confident that you’re not going out there looking with a prejudice, like, ‘All life has to look like a lion,’ or, ‘All life needs amino acids,’” he says.

Perhaps a more universal property is the need to eat. “All living systems metabolize,” says Benner. “Life is life because it captures resources that are not ‘it’ from the environment ... and makes more of ‘it’ from these resources.”

Metabolism creates vibrations, for example, from the opening or closing of ionic channels in a cell’s membrane. “Anything that is alive moves,” says Giovanni Longo, a physicist at the Swiss Federal Institute of Technology in Lausanne. Longo and his colleagues have developed a sensitive probe for these faint vibrations. Samples are placed on a diving board less than a millimeter long, and a laser reveals shifts in the board’s position of just a nanometer (7).

Studying the frequency of these motions can distinguish life from nonlife. Nonliving things vibrate due to the thermal energy in their atoms, which should cause the diving board to shake at its resonant frequency, whereas life should vibrate at lower frequencies too.

Single mammal and plant cells, groups of bacteria, and even the contortions of proteins have been detected with this method. Motion alone would probably not be enough to prove alien life, as noise could potentially create a life-like signature, says Longo, but this kind of sensor could “be used in parallel to identify any kind of energy-consuming system.”

Longo’s goal is to use this system on an interplanetary probe, but Benner points out a practical snag. “The hazard is getting the living thing into the detection instrument without killing it,” he says. Sensing motion this way requires a fluid medium, and flushing, say, a Martian soil sample with liquid water might kill any organisms it contains.

Unless, of course, a microscope or high-powered camera shows something that is clearly beetling around. “If it’s keeping its form and scurrying around, I think that we would conclude that it’s life,” says Carol Cleland, a philosopher who studies astrobiology at the University of Colorado Boulder.

We Are Data

But perhaps there’s a better definition. That supposed letter “B” on Mars may have offered a hint at the right recipe for defining life after all. “Life is information that replicates,” Adami asserts. The information encoded in life gives it a particular signature, he says. Human languages, for example, each have their own alphabetical “fingerprint,” with certain letters and letter combinations used much more often than others. This, Adami says, is a sign that the letters are conveying information (8). Life on Earth also uses an uneven distribution of letters in a molecular
alphabet: our 20 amino acids. Thousands of these molecules are theoretically possible, so nonliving chemistry should not favor a particular set of 20.

Searching for similar patterns on alien worlds could reveal otherwise unrecognizable forms of life, he says. This could include creatures that do not use nucleic acids to transmit hereditary information, or that are not chemical-based at all. “Adami [is] describing excellent and elegant ways of showing that life’s information could be detected with an algorithm,” says Chris Impey, an astronomer at the University of Arizona in Tucson. “The weakness is that it requires a high level of measurement.”

Adami agrees. “To be able to detect information, you have to reliably characterize what is not information,” he says. That means surveying an extraterrestrial environment well enough to understand its chemistry, so that the molecular alphabet of life can stand out against the nonliving background. This is not only beyond telescopic observation, it is probably beyond even an automated probe, says Impey. Bringing rock samples back to laboratories on Earth might be good enough, he says, “but Mars is the only place from which we can get the rocks back any time soon.”

**Aliens on Earth**

Or maybe there is one other place we could look. Paul Davies, a physicist at Arizona State University in Phoenix, suggests there could be life on Earth unrelated to the kind we know—a “shadow biosphere” that arose independently and has gone unnoticed because it cannot be grown in a culture or genetically sequenced. If, as many researchers argue, life should emerge readily on Earth-like planets, why wouldn’t it have started more than once on Earth? “It could be right under our noses—or in our noses,” says Davies.

“It’s an interesting concept,” says Tanja Woyke, head of the Microbial Genomics Program at the Joint Genome Institute in Walnut Creek, California. Although she is reluctant to comment on the likelihood of completely alien Earthlings, her research has shown that our DNA-based life is more diverse than previously thought (9). She found two new phyla of bacteria that use a different dialect in their genetic codes. Instead of reading certain sequences as commands to halt production of a protein, as other organisms do, these creatures interpret them as commands to make the amino acid glycine. Woyke’s team has also found another potential new phylum, Kryptonia, with substantial

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differences in a gene that appears spectacularly similar in all other known life. “It is reasonable to speculate that undiscovered and highly divergent branches of life may exist,” she wrote in *Science* in November (10). If so, maybe we will need information theory to recognize it.

**Indefinite Definitions**

Cleland argues that even information theory is “too crude” a definition for extraterrestrial life, however. Any attempt at defining life, she says, is too limiting. “You only find what you’re looking for,” she says. “If you want to find alternative forms of life, you’re not going to find them with a definition.”

Instead, she suggests using more tentative criteria that provide grounds for suspicion. “What you’re looking for is a system—that given your knowledge of abiotic chemistry and physics—doesn’t seem like it should be there,” Cleland says.

That might include unexpected ratios of different atomic isotopes, she says, pointing out that on Earth, life uses more carbon-12 than carbon-13, a measurement that can be done with automated probes. “Life is lazy; it likes to haul around one less neutron,” says Cleland.

According to Cleland, who coined the term “shadow biosphere,” we may already have an example of life as we do not know it here on Earth. Some canyon walls in deserts around the world are coated in a hard, dark glaze enriched in manganese and iron, even though the underlying rocks are not. The glaze evades a purely geological explanation, she argues, raising the possibility that it’s a form of life or perhaps a byproduct thereof. These “desert varnish” coatings are more than a million years old, which leads some to argue that they could not be alive. “But why not?” asks Cleland. “Who’s to say that all life is based on our particular time frame?”

We may never find alien life even if we look under every rock on Mars and analyze the air of a million exoplanets. In the end, perhaps the definition of life itself—alien or otherwise—will actually stem from our own efforts to create it. Already, there are various projects underway to create life from scratch here on Earth—part of the burgeoning field of synthetic biology (11). In the last several years, biologists have attempted to create exotic life-forms, using, for example, new nucleotides (12).

“Research agendas are proceeding away from natural towards the unnatural,” says Benner. “I have a suspicion the first time you discover an alien life-form, it will be one that’s created in the laboratory.”

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