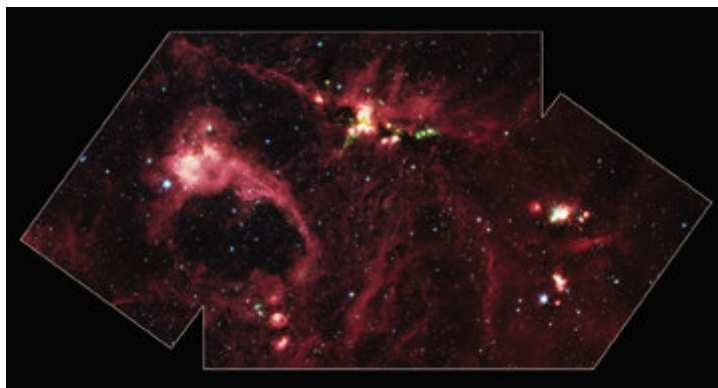


Space Invaders—The stuff of life has far-flung origins

Alexandra Goho

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When most people look up at the night sky, they see emptiness. Stars, to be sure, but mostly a black void. When Louis Allamandola, an astrochemist based at NASA's Ames Research Center in Moffett Field, Calif., looks up, he sees life. Everywhere. Perhaps not life in the literal sense, but its building blocks—materials just like those delivered to Earth via comets or meteorites some 4.5 billion years ago. Understanding how these molecules formed within the interstellar medium, he says, could offer scientists a rare glimpse of our chemical heritage and the complex processes that gave rise to life on Earth.



FOG OF LIFE. The red streaks in this image taken from NASA's Spitzer Space Telescope indicate organic molecules called polycyclic aromatic hydrocarbons, which are ubiquitous in the interstellar medium.

A. Marston (ESTEC/ESA)NASA, JPL-Caltech

Until recently, "space was perceived as a sterile environment, and there was nothing of any significant molecular complexity out there," says Allamandola. Only in the past several years has a new picture emerged of interstellar space—one that portrays it as chemically diverse and complex. That view is now beginning to take hold in the scientific community.

Buried in the Milky Way are interstellar clouds that block out distant stars, thereby creating the effect of dark patches on the night sky as viewed by the naked eye. These clouds arise when stars, nearing the ends of their lives, eject their outer shells into the surrounding space. This fog of gas and dust particles then coalesces into cold, dense clouds that eventually give rise to a new generation of stars. From observations by ground-based telescopes and satellites, scientists have identified in interstellar clouds and cooling stars hundreds of molecules, most of which contain carbon and so are classified as organic.

"We know there are a lot of these molecules present in space, but we don't know what kind of molecules were delivered to the Earth or to Mars," says Alexander Tielens of the University of Groningen in the Netherlands. "If we are to understand the origin of life, we have to know what it is we started with."

Laboratory experiments under simulated-space conditions have shown that the environment within these clouds can foster an array of chemical reactions that result in organic molecules even more complex than those so far observed in space. Such experiments not only serve to confirm what astronomers have found in our galaxy but also provide clues as to what other molecules might be present in the interstellar medium.

Complex organic molecules readily forming in space could have contributed to life's beginnings on Earth some 3.5 billion years ago. Scientists have long assumed that combinations of simple molecules on Earth eventually formed individual cells that replicated on their own. Some scientists have argued that the time between when Earth became habitable and when life emerged was too short to have generated the complexity required of self-replicating cells. However, if precursor molecules for making proteins, RNA, and DNA came from space, life-creating chemical reactions within Earth's primordial soup could have greatly accelerated.

What's more, if complex organic materials are forming in space and being delivered to the planet even now, it's conceivable that these same materials are also being delivered to other planets. Says Allamandola: "The fact that life could be widespread now seems to me is inescapable."

They're everywhere

A star emits an enormous amount of radiation in all directions. When that radiation passes through the dust in a molecular cloud or surrounding a dying star in the Milky Way, organic molecules absorb some of the emissions and release that radiation at different wavelengths. As a result, the molecules display a unique optical spectrum that researchers can detect and compare with the spectra of similar molecules measured in the lab. By detecting the emissions of specific wavelengths of light from space, astronomers can identify types of organic molecules in the interstellar medium. Some 30 years ago, astronomers discovered a series of spectra dubbed the unidentified infrared bands. They suspected that these spectra came from simple molecules on interstellar dust particles, but it wasn't until the late 1990s that scientists confirmed the source of these bands: polycyclic aromatic hydrocarbons (PAHs). These extremely stable organic molecules contain rings of carbon atoms and are widespread on Earth. For instance, they're a standard by-product of gasoline combustion in automobiles.

Originally, scientists thought that PAHs in outer space existed only around the edges of dense clouds or dying stars. Recent observations suggest that these molecules also reside in the diffuse interstellar medium and in galaxies beyond the Milky Way. For example, NASA's Spitzer Space Telescope has revealed PAHs in the Milky Way and more-distant regions (SN: 12/20 & 27/03; p. 387: <http://www.sciencenews.org/articles/20031220/fob1.asp>).

Now, astronomers' big challenge is to determine the size and structure of these molecules. They have recently begun the arduous task of creating a detailed inventory. For instance, Adolf Witt at the University of Toledo and his colleagues this year determined the nature of some PAHs by looking at the Red Rectangle nebula, a star located 1,000 light-years away and surrounded by a cloud of dust and gas.

The star is in the very late stages of its life and is firing off large amounts of material from its outer shell. Although emissions in the infrared range can identify a class of molecules, they can't describe its chemical structure. So, Witt looked instead at the ultraviolet part of the spectrum. The type of ultraviolet radiation that an organic molecule emits corresponds to its size.

Using observations made with telescopes in Chile and in Arizona, the researchers identified ultraviolet spectra characteristic of PAHs such as anthracene and pyrene, which have three and four carbon rings, respectively. Anthracene contains 24 atoms of which 14 are carbon, and pyrene has

26 atoms, including 16 carbons, says Witt. He presented his findings in January at the American Astronomical Society meeting in Atlanta.

"These nebulae are like chemical factories," says Witt. They start off producing simple molecules, such as acetylene, which has just two carbons and two hydrogens. These molecules, in turn, combine and grow into more-complicated structures, such as single-ring benzene and multiring pyrene. "Eventually, you have very large organic molecules," says Witt.

This delicate process takes place only because the nebula, which is cooling, provides a protective environment for small molecules. Only after the organic molecules reach a certain size—perhaps 40 atoms or so, says Witt—can they survive ejection from the nebula into the harsh ultraviolet light of the diffuse medium and stay there for millions of years.

Increasing complexity

If organic molecules such as PAHs can form in space, Allamandola wondered, what other kinds of complex molecules might arise? To answer that question, he and his colleagues have been re-creating molecular clouds in the laboratory to simulate the different chemical reactions that might occur within that extremely frigid environment.

One of his group's first findings was that, inside a cold vacuum chamber, photochemistry takes place within the tiny ice mantles that form on microscopic grains of dust. When the researchers create ice particles containing simple molecules and irradiate them with ultraviolet light, the molecules begin to interact.

Using this irradiation technique, the NASA team and scientists at the University of California, Santa Cruz converted simple molecules—water, methanol, ammonia, and carbon monoxide—into compounds that form vesicles with cell-like membranes. When the scientists exposed the vesicles to ultraviolet light, the membranes glowed. The researchers speculate that the glowing molecules guard the membrane against ultraviolet radiation, a protection that would be required for a cell to survive.

In simulated molecular clouds, the NASA team has also created amino acids, the main components of proteins (SN: 3/30/02, p. 195: <http://www.sciencenews.org/articles/20020330/fob1.asp>). The researchers trapped three simple compounds—methanol, ammonia, and hydrogen cyanide—inside an ice particle and exposed it to ultraviolet light. After warming the particles to room temperature, the researchers detected three different amino acids: alanine, serine, and glycine. The process might underlie the origins of amino acids that have been found in meteorites that have landed on Earth. "There's a driving force, even under harsh conditions, to make molecules like these," says Allamandola.

Most recently, Allamandola has found that replacing one of the carbons in a PAH compound with a nitrogen atom yields molecules with absorption spectra similar to some recently observed unexplained spectra from space. Intriguingly, these nitrogen-containing molecules resemble components of DNA and its cousin RNA. "It's almost as if in this simple simulation of interstellar particles, which are widespread throughout our galaxy, you have all the basic building blocks of life," says Allamandola.

Not only do these experiments explain some space observations, they're also influencing astronomical observations. "The lab studies are getting better at predicting what we should be looking for," says Steven Charnley of NASA's Ames Research Center.

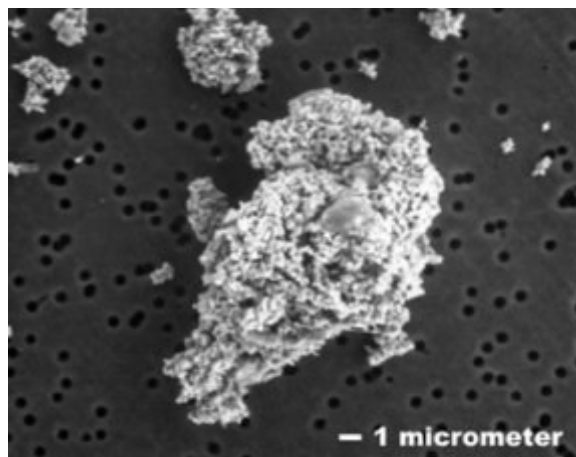
In the Aug. 20, 2003 *Astrophysical Journal*, Charnley and researchers from Taiwan and Poland reported evidence of the amino acid glycine in space. Between 1997 and 2001, the international team carried out a series of observations with the University of Arizona's Arizona Radio Observatory telescope near Tucson. The researchers found signs of the amino acid in the radio-wave region of the spectra from three giant molecular clouds.

Charnley adds that his group is now in hot pursuit of a pyrimidine, a particular component of DNA and RNA.

Unsettling dust

Many scientists have suspected that life on Earth stems from complex organic molecules delivered via meteorites, comets, and the dust particles that populate space. Cosmic dust containing carbon continues to enter Earth's atmosphere and settle on the planet's surface. However, chemical evidence pinpointing the extraterrestrial origins of this organic material has remained elusive.

But recently, when scientists at Washington University in St. Louis and Lawrence Livermore (Calif.) National Laboratory analyzed an interplanetary dust particle collected by a NASA aircraft from Earth's stratosphere, they discovered organic material older than the solar system. The researchers say in the Feb. 27 *Science* that the particle must have formed in an interstellar molecular cloud.



COLLECTING DUST. An interplanetary dust particle found in Earth's stratosphere includes carbon-containing material that predates the birth of the solar system 4.5 billion years ago.

F. Stadermann/Washington University

Other researchers had reported finding isotopic signatures of hydrogen and nitrogen indicative of an interstellar origin, but never of carbon. However, Christine Floss of Washington University and her colleagues succeeded in finding an isotopic signature both in the nitrogen and the carbon elements.

When the researchers analyzed the ratio of carbon isotopes in the sample, they found an isotopic signature that arises only in the extremely cold environment of interstellar molecular clouds. This signature differs from that of anything found on Earth or in the solar system, says Floss. The researchers' analysis so far hasn't determined whether the organic material is a PAH or some other type of hydrocarbon. They plan tests to further elucidate the sample's molecular structure. Floss says that there's growing evidence to suggest that dust particles spill onto Earth from comets. These icy bodies predate the solar system and bear the chemical signatures of their interstellar environment.

The NASA Stardust mission to Comet Wild 2 has already collected dust particles near a comet and is scheduled to return to Earth in January 2006 (SN: 1/10/04, p. 19: <http://www.sciencenews.org/articles/20040110/fob1.asp>). Researchers hope to find a wealth of organic molecules in these particles.

"That's something we're all very excited about," Floss says. "I think it's going to be a big step forward for this field."

Allamandola, for one, says he won't be surprised if the comet-dust samples contain wildly complex molecules. Perhaps not an entire bacterium, virus, or even strand of DNA. "That's pushing it," he admits. Still, he notes, "just in the last 5 years, we've opened up this whole new magical world. I think in the next 10 years, it's going to get more and more incredible."

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For more information on organic molecules in the interstellar medium, visit NASA Astrochemistry Lab's website at: <http://www.astrochem.org/>.

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