

Image: Hubble Space Telescope

## The Raw Materials

**The chemistry of life is an integral part of the process that births stars.**

**We know, at least, that life somehow arose on Earth. But was it a chance occurrence? Recent research indicates that our makeup of complex molecules based on carbon and hydrogen is no fluke. Precursors to terrestrial life's distinctive chemistry apparently abound in the churning clouds of dust and gas in distant space. Under the right conditions, they could have also fertilized a genesis on myriad distant worlds.**

### **SPAWNING GROUND.**

Turbulent gas and dust in nearby galaxy 283 will engender a new generation of stars. But recent findings indicate that these clouds are also an incubator for primitive organic compounds that can fertilize carbon-based life in the universe.

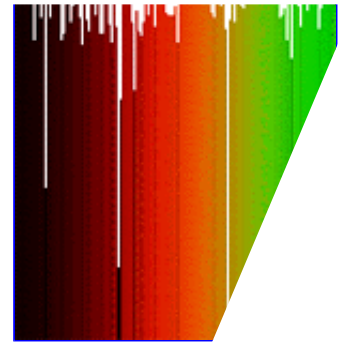
**The growing evidence supporting that conclusion is coming not from distant galaxies but from earth bound laboratories where scientists are simulating the harsh conditions in the vast interstellar clouds. So far, they have demonstrated a mechanism for the formation of molecular hydrogen, induced chemical reactions with carbon to form primitive organic molecules, and found that the substances unique spectral signatures match data that have puzzled astronomers for nearly a century. The results have been reported in recent journal articles and a number of investigators summarized their findings at the 100<sup>th</sup> annual meeting of the American Physical Society in Atlanta.**

**The first clue that organic molecules were adrift in space began as a puzzle in itself. In 1921, Mary Lea Heger, an astronomer at the Lick Observatory in California, observed two absorption lines in the spectra of distant stars that remained stationary while others shifted in wavelengths according to the motion of the stars. Soon afterward, astronomers concluded that these spectral bands came not from the stars themselves but from the gas and dust in space between the star and the observer on Earth.**

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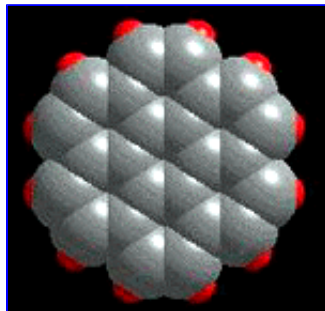
## FEATURES

Astronomers have now detected more than 100 of these "diffuse interstellar bands," or **DIBs**. They appear as gaps in the spectrum of light from distant stars and galaxies because the substances that cause them absorb those frequencies (or colors) of light in the spectral rainbow. But what are those substances? Their spectra do not match those of any known atomic wavelengths.



MISSING S

It took until the 1980s for infrared spectroscopy data to convince **Louis J. Allamandola** of the **Astrochemistry Laboratory** at NASA Ames Research Center that the culprit might be a class of rather gritty organic molecules dubbed **PAHs**, for polycyclic aromatic hydrocarbons. Common--and highly carcinogenic--PAHs are a standard product of combustion found in diesel exhaust, burned pots and pans, charred hamburgers and cigarette smoke. But these components of soot and coal are also very durable. They are flat molecules of carbon and hydrogen in the form of hexagons so that their skeleton looks like chicken wire.



PRECURSORS OF LIFE?

Allamandola had made a neat conjecture, but the interstellar dust clouds are not exactly hospitable places. They are the debris of previous generations of stars and the stuff from which, in time, new stars and solar systems will come. Their average temperature is 10 K (about -440 F; -260 C); air would freeze solid. In a high vacuum, they are bathed in harsh ultraviolet radiation and visible light. Allamandola's idea left some skeptics out in the cold: Would these conditions permit reactions that occur on Earth at high temperatures? Were the necessary reactive elements present? Could the molecules survive without degradation?

To answer these and other questions, investigators had no choice but to try to simulate the conditions of interstellar space in laboratories and compare the data with those collected by the astronomers. Results of these studies indicate that the formation of chemical progenitors of life can indeed form in the interstellar medium because of a fortuitous combination of dust rich in carbon, the presence of hydrogen, and ultraviolet radiation to provide energy.

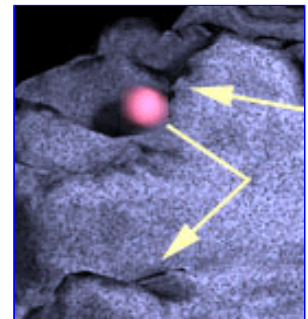
By analyzing the light that passes through interstellar clouds, researchers have determined that they are comprised of tiny sand like grains each covered by a thin layer of ice. The density is very low (about 50 particles per cubic centimeter as opposed to  $10^{19}$  at Earth's surface). Each dust

grain is but one ten thousandth of a millimeter across. The ice is composed primarily of water but often contains some organic molecules. The grains drift in an atmosphere containing atoms of hydrogen.

Finding the carbon in stardust is pretty easy. It's the first of the lighter elements that is exclusively formed in the interiors of stars and appears to be a major component of space dust. In a [paper](#) in the December 18, 1998, issue of *Science*, [Farid Salama](#) of the Ames Research Center [Space Science Division](#) and Thomas Henning of the Astrophysikalisches Institut und Universitäts-Sternwarte in Jena, Germany, identified a veritable menagerie of space-borne forms of carbon, including diamond nanocrystals, graphite, fullerenes, carbynes (long chains of carbon atoms) and amorphous carbon.

It's also not hard to locate hydrogen, the lightest and most abundant element in the universe and the fuel for the fires of stars. The trouble is, atomic hydrogen does not engage in chemical reactions; two atoms must first combine to form molecular hydrogen, H<sub>2</sub>. But the odds of two hydrogen atoms simply bumping into each other in the ether seems pretty low, so about 30 years ago, Erwin Salpeter and his student David Hollenbach of Cornell University proposed that a surface is required to initiate the reaction, an interstellar dust grain, for example. As hydrogen atoms that have landed on a dust grain move about, there is a greater chance they will bump into each other and form a chemical bond.

A team headed by [Gianfranco Vidali](#) of the [Laboratory of Surface Physics and Astrophysics](#) at Syracuse University and [Valerio Pirronello](#) from the Istituto di Fisica at the University of Catania, Italy set out to test the theory. Vidali, who [reported](#) the results at the APS meeting on March 22, and his colleagues, directed beams of hydrogen atoms at two candidates for space dust--silicate olivine and amorphous carbon--in a vacuum chamber evacuated to one trillionth of atmospheric pressure and chilled to 10 degrees above absolute zero. They found that the efficiency of the reaction on amorphous carbon was higher than on olivine.



**BINDING HYDROGEN**

Further experimental evidence comes from Salama and [Douglas M. Hudgins](#) (also from NASA Ames), who also provided an [overview](#) of recent work to the APS on March 23. Salama and his co-workers [simulated](#) the space environment in a vacuum chamber at about one tenth of a billionth of atmospheric pressure and temperatures as low as -270 C; starlight was simulated.

When the PAH molecules were frozen in a cage of inert-gas (neon) atoms, which ensured that the trapped molecules were cold and fully isolated, the researchers measured the spectra in the ultraviolet and visible light

bands and compared it to astronomical data from Kitt Peak and other observatories. They matched. Similarly, Hudgins and his colleagues--measuring the infrared spectrum of ionized PAHs, this time frozen in solid argon--showed that they also match the infrared spectra measured by ground-, air-, and space-based telescopes, indicating that PAHs are common and abundant throughout the entire interstellar medium

To check the hypothesis from another direction, NASA Ames scientists [Max Bernstein](#), [Scott A. Sandford](#), and Allamandola created PAHs in a simulated interstellar medium, froze them into ice under conditions like those in dark dust clouds and exposed them to UV radiation. "We made a bunch of oxidized PAHs, including aromatic ketones, alcohols, and ethers. These kinds of molecules are in cosmetics and medicine that will be familiar to many. For example, they are found in aloe, henna, and St. John's wort," says Bernstein, who is working at NASA Ames through a cooperative agreement with the [SETI Institute](#), which is dedicated to finding intelligent life elsewhere in the universe.

The investigators then sent the stuff they made to [Richard Zare](#) at Stanford University. Zare and his colleagues recorded spectrographs of the compounds and compared them to similar data from PAHs found in carbonaceous meteorites found on Earth. The data, as the researchers reported in the February 19 issue of *Science*, correlated.

"These oxidized PAHs are made in the interstellar medium and brought to Earth in interplanetary dust particles that drift down to Earth by the ton every day," says Allamandola. "These compounds are similar to those ubiquitous in living systems today, and play important roles in essential biological processes. Perhaps such molecules were exploited by Earth's earliest organisms, and that is how these kinds of compounds become incorporated into our biochemistry."

If the new astronomical data and experimental results continue to withstand scrutiny, the conclusion is a reassuring affirmation of our origins. The vast interstellar clouds that spawn new generations of galaxies, stars and planets are also the incubators of life. The prebiotic compounds that they produce sift down in a cosmic rain, not just on Earth but on any hospitable planet in the cosmos. The stuff of life is stardust and we are born of it--and, yes, we are probably not alone.

--By *Alan Hall*

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