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Big Molecules In Space

Prebiotic molecules in interstellar space are hard to detect and study, but astrochemists are closing in

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Space is filled with molecules, even in the yawning gaps between stars. The simple ones are generally pretty easy to spot: CO, for example, or H₂O or HCN. Their spectra, whether from molecular emissions, absorptions, rotations, or vibrations, are relatively simple and well-studied.



Courtesy
of NRAO/AUI and Bob Broilo

STARGAZER The Atacama Large Millimeter Array, under construction in Chile, promises to unveil more interstellar secrets.

Big molecules are another story entirely. As the number of atoms in a molecule increases, generally, so does the complexity of its spectrum. By the time you get to molecules as large as amino acids, the spectra have become an indecipherable mush of lines. Identifying such molecules has proven extremely difficult, and the recent announcements of the detection of two large prebiotic molecules, dihydroxyacetone and glycine, continue to be controversial ([C&EN, Feb. 14, 2005, page 44](#)).

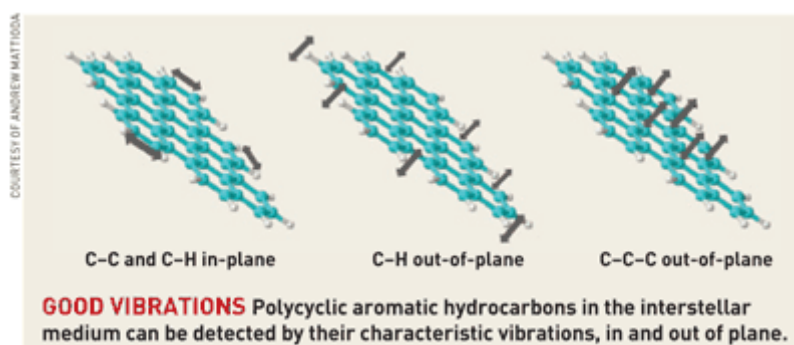
Prebiotic molecules—in particular, simple sugars or precursors to proteins or nucleobases—hold great interest for astronomers. If these molecules were found in space, it would imply that the chemistry to make the building blocks of life can occur throughout the universe. Although the detection of glycine in the interstellar medium doesn't mean that life originated there (the prebiotic molecules that preceded life on Earth were almost certainly produced within our solar system), it would still say much about the complex chemistry of space.

In a symposium sponsored by the [Division of Physical Chemistry](#) at the American Chemical Society national meeting in Atlanta in March, astronomers and chemists reported that they're starting to make headway in the study of large interstellar molecules.

For example, models of interstellar molecular abundances are often based on the assumption that molecules are produced in the gas phase. Research scientist Gregory A. Grieves and chemistry professor Thomas Orlando at [Georgia Institute of Technology](#) have found evidence in support of the theory that surfaces of ice-covered grains, or interstellar dust, may be important reaction mediums. Dust grains tend to be covered first with water ice, which is very sticky. Then, less polar molecules like methane will stick to the ice. The water ice on these grains is also very porous, creating little nanovessels in which organic molecules can pool. Add a cosmic ray or energetic ultraviolet photon, and the organics can polymerize to form more complex molecules. These grain-mediated mechanisms should help modelers devise more accurate predictions, Orlando and Grieves said.

Huge, dense clouds of matter known as hot molecular cores, which

signal the formation of stars, are another spawning ground for relatively large molecules such as formic acid and acetic acid. Anthony J. Remijan, an astronomer at the [National Radio Astronomy Observatory](#), has found some curious patterns in their distributions. Formic acid, for example, tends to exist in areas known as "shocked" regions, where bursts of hot gas hit colder gas. Acetic acid, however, appears to reside in calmer, warm gas just past the shocked region. Acetic acid and formic acid are found in areas rich in nitrogen, suggesting that nitrogen may play a role in their formation. Acetic acid and its isomers— $\text{CH}_3\text{CO}_2\text{H}$, CH_2OHCHO , and HCO_2CH_3 —are seen in different environments, implying that they are formed via different reaction mechanisms. "This puts constraints on formation models people are trying to generate to account for the abundances of big molecules in the interstellar medium," Remijan said. In the future, he said, expect even more detailed pictures from much bigger, more sensitive telescopes, such as the [Atacama Large Millimeter Array](#), now being constructed in Chile.



In addition to their spectroscopic complexity, prebiotic molecules occur only sparsely, because they tend to be readily destroyed by the radiation that suffuses space. Much is made of the implications the discovery of their existence in space could hold for theories of the origin of life. But that connection tends to get overplayed, according to [Pascale Ehrenfreund](#), an astrobiology professor at Leiden University, in the Netherlands. The chance that an amino acid produced in interstellar space could arrive on Earth intact and seed life is almost nil, she believes. Meteorites, on the other hand, can be loaded with prebiotic molecules such as amino acids and nucleobases. Ehrenfreund's studies of the molecules found in the Murchison meteorite indicate that while the building blocks of amino

acids–HCN, ammonia, ketones, and aldehydes–could have some interstellar heritage, the prebiotic molecules themselves "were not formed in the interstellar medium, they were formed in the parent body where the meteorite comes from," she said.

Polycyclic aromatic hydrocarbons, or PAHs, aren't nearly so delicate. These ubiquitous molecules are much more easily able to withstand the rigors of space. "They are the toughest of the bunch," remarked Louis J. Allamandola, head of the astrochemistry lab at the National Aeronautics & Space Administration's [Ames Research Center](#) in Moffett Field, Calif. PAHs are commonly found on Earth as products of combustion. A few decades ago, a pervasive infrared spectral signature was discovered in space, and it's now widely believed to be due to PAHs.

Recently, Allamandola, Andrew L. Mattioli, principal investigator at the [SETI Institute](#) in Mountain View, Calif., and colleagues discovered cosmic PAH-like molecules that contain nitrogen. In Atlanta, they reported that these molecules, known as PANHs, have a number of interesting properties that make them promising new probes for interstellar chemistry. For example, they possess dipole moments, and they can be traced with radio telescopes.

Much less well-characterized are the diffuse interstellar bands (DIBs), a collection of well-defined lines that don't fit any known spectrum. DIBs were first spotted in 1919 at [Lick Observatory](#) in the mountains around Santa Cruz, Calif. They're believed to be due to molecular gases, but which molecules produce them remains unknown. [Benjamin McCall](#), an astronomy and chemistry professor at the University of Illinois, Urbana-Champaign, has found that a subset of DIB lines is strongly correlated with lines from C_2 —that is, molecules responsible for some of the DIBs exist in the same regions as C_2 . Since C_2 is easily photodissociated, it tends to form in denser regions that are more shielded from UV radiation. Perhaps the unknown molecules thrive in a dense, protected environment, McCall said, or perhaps there is a real chemical association, in which they're either formed from C_2 , or C_2 is a building block. "We have no idea at this point," McCall said.

His group has also found two spectroscopic bands that have the same intensity ratio wherever in the sky they're measured. That implies the bands may be caused by the same molecule.

Eventually, this might allow the scientists to identify a molecular characteristic, such as an aromatic C-H stretch. Until then, DIBs may continue to be "the longest standing mystery in all of spectroscopy," McCall said.

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