

# SPACE-DUST SCIENCE

**ACS MEETING NEWS:** Elucidating the chemistry of interstellar dust particles is key to understanding early planets

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**TO MAKE A PLANET,** start with an interstellar cloud of ice-covered dust and gas. Then add random turbulent processes to create structure within that cloud. A portion of the mixture can become dense enough to collapse under its own weight and begin star formation. The material that doesn't collapse forms a disk that rotates around the protostar. Eventually, the dust and gas in the disk start to aggregate, forming planets, as well as asteroids and comets.

The dust grains have carbonaceous or silicate cores encased by ices composed of frozen compounds such as water and carbon dioxide, and the chemistry that occurs on their surfaces is key to understanding the chemistry of newborn planets. But "it's

only recently that the astronomy and astrochemistry communities have embraced the role of grain surfaces," said Thomas Orlando, a chemistry professor at Georgia Institute of Technology and co-organizer of a symposium on astrochemistry at the American Chemical Society national meeting in San Francisco last month. "There's now a full realization that the grain surface is very important in the formation of even the simplest molecules and could be at the heart of the formation of bigger molecules," such as polyaromatic hydrocarbons (PAHs), Orlando said.

The molecular species that astrochemists look at tend to be simple—H<sub>2</sub>, CO, HCN, CH<sub>4</sub>, C<sub>2</sub>H<sub>2</sub>, and NH<sub>3</sub>, for example—



**PLANETARY GESTATION**  
As shown in an artist's rendition, a brown dwarf star is surrounded by a protoplanetary disk.

but groups are also working to identify and understand more complex compounds. Much chemistry on interstellar dust particles is driven by radiation, in particular ultraviolet light and X-rays from protostars and cosmic-ray particles. Astrophysicists and astrochemists both observe the compounds present in space—princi-

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### Enabling Chemistry Experiments In Space

Most astrochemical research is done either by analyzing spectroscopic data from space or by conducting laboratory experiments on Earth. A third avenue is to experiment in the space environment, which is the goal of a new "nanosatellite" project called Organism/Organic Exposure to Orbital Stresses (O/OREOS).

The nanosatellite isn't exactly "nano," but it is small: It is roughly the size of a shoebox and weighs about 5.5 kg, said Andrew L. Mattioda, deputy chief of the astrophysics branch at the National Aeronautics & Space Administration (NASA) Ames Research Center, in Moffett Field, Calif. Mattioda described the project at the ACS national meeting in March. O/OREOS is part of a NASA Astrobiology Institute program to develop

payloads with off-the-shelf, modular technology and make them small enough to be easily piggybacked onto other missions.

O/OREOS includes two 10-cm<sup>3</sup> experimental cubes. The biology cube contains two microbes, *Halorubrum chaoviatoris* and *Bacillus subtilis*, that will be rehydrated and fed at three different time points in space to evaluate the effects of microgravity and space radiation on the organisms.

The chemistry cube contains four organic compounds, each encased in four different environments of interest for studying chemistry in the universe: the compound alone in interstellar space, a mineral setting similar to a dust grain or a lunar surface, an atmosphere akin to that on Mars, and a

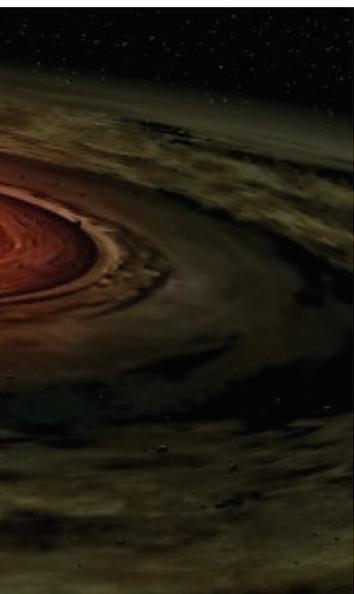
water environment. To observe the effects of sunlight and cosmic radiation on the compounds, researchers will monitor them with a spectrometer covering ultraviolet, visible, and near-infrared wavelengths, from 200 to 1,000 nm.

Each experimental cell is a small cylinder about 9 mm across and capped with MgF<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> windows. The windows can be coated with, for example, a silica layer to mimic the mineral nature of a lunar environment. The "wet" cell incorporates a wire mesh ring with a hydrated salt to maintain the water vapor inside the cell.

The compounds chosen for O/OREOS are isoviolanthrene, anthrurufin, tryptophan, and iron tetraphenylporphyrin. They were picked, Mattioda said, to represent what might

be found in environments astrobiologists want to emulate, but narrowing down the chemical library to a mere four molecules wasn't easy. Among the considerations was that the molecules had to be robust enough to sit for months without sublimating or otherwise degrading while awaiting a flight. The researchers also wanted chemicals with spectral features that they could easily monitor.

Although O/OREOS is technically a demonstration mission, Mattioda and colleagues expect it will also yield some interesting scientific results. The satellite is currently scheduled to lift off on an Air Force rocket from Alaska in August. "We're testing the viability of low-cost spaceflight science experiments," Mattioda said. If the technology works, it could be used to do chemistry experiments on future missions to the moon or Mars.



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pally through ground-based and satellite telescope observations—and try to emulate astronomical conditions in laboratory experiments.

The formation of H<sub>2</sub> in interstellar space is one example of a chemical process in which dust plays a critical role. Hydrogen is the most abundant element in the universe, and H<sub>2</sub> is the most abundant molecule in space. Hydrogen plays a key role in reactions leading to bigger molecules.

The association of two hydrogen atoms to form H<sub>2</sub> is an exothermic reaction, and a third atom or molecule takes up the excess energy under typical conditions. In the interstellar medium, however, hydrogen-

atom densities can be as low as 1–10 atoms/cm<sup>3</sup> in diffuse clouds. “It’s improbable to have three atoms interact in the gas phase because of the low density,” said Gianfranco Vidali, a physics professor at Syracuse University, during the symposium.

Instead, the likely mechanism of H<sub>2</sub> formation involves hydrogen atoms sticking to interstellar dust grains, where the hydrogens can move about and interact. Vidali is studying these reactions by using atomic and molecular beams to irradiate amorphous silicates at 10–15 K. By developing a better understanding of how atoms and molecules adsorb onto, diffuse around, react with, and desorb from the surface (in some cases, a single photon can cause enough of a temperature jump to get an atom to desorb), he aims to provide a better model for how these reactions occur.

The ices that build up on dust also come from surface reactions, said Eric Herbst, a physics professor at Ohio State University. The simple picture of an interstellar dust particle is one of silicates or carbonaceous material in the middle and water, CO, and CO<sub>2</sub> ices on the surface, along with more

complex organic species. Even though CO might be made in the gas phase and accreted onto the dust, “you don’t have much water in the gas phase,” Herbst said. Instead, water comes from the reaction of oxygen and hydrogen atoms on grain surfaces. The same would be true for turning atomic carbon into CH<sub>4</sub> or CO into formaldehyde. As with H<sub>2</sub> formation, adsorption and desorption processes are critical to understanding the species present in the ices and how they react, he said.

**RESEARCHERS ARE ALSO** studying how to identify different ice mixtures—say, water, methanol, and CO<sub>2</sub> in varying ratios—to see what happens when compounds are deposited onto surfaces or when mixtures are heated. The goal is to build a database of spectroscopic profiles that can be compared with telescope observations to help scientists pinpoint what mixtures of species they might be looking at and how those compounds originated, said Perry A. Gerakines, a physics professor at the University of Alabama, Birmingham.

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its early stages of formation. Near the protostar, temperatures can be hot enough to put silicates into the gas phase. Particles at a distance retain their icy nature.

Karin I. Öberg, currently a postdoctoral researcher at the Harvard-Smithsonian Center for Astrophysics, described experimental work she did as a graduate student aimed at deducing the chemistry triggered

in methanol-rich ices irradiated with UV light. She and colleagues at the Raymond & Beverly Sackler Laboratory for Astrophysics at Leiden University, in the Netherlands, found that some molecules, such as ethanol and dimethyl ether, form in a constant ratio. This is the type of information that can be used to determine whether gas-phase molecules in astrophysical environments have an

icy origin. Other mixtures of molecules have varying ratios that depend on initial conditions, such as ice composition and temperature; these properties can be used as clues to explain astrophysical observations.

Not all of the interest in ice chemistry focuses on simple organic molecules. For some, these compounds are merely building blocks of chemicals of greater interest: PAHs. Over the past 15 years, observations have shown that interstellar clouds “all have a skin of PAH emission glowing all around them,” said Louis J. Allamandola, director of the Astrophysics & Astrochemistry Laboratory at the National Aeronautics & Space Administration (NASA) Ames Research Center, in Moffett Field, Calif. As a class, PAHs are more abundant than all other known interstellar polyatomic molecules combined. Until now, researchers have rarely considered PAH species in ices within interstellar clouds, “but it’s hard to imagine that they surround clouds but are not in the clouds,” Allamandola said.

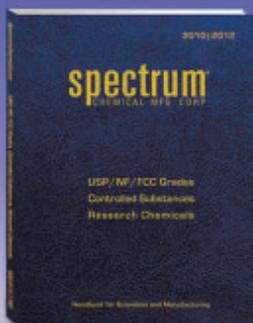
Experiments show that the ionization potentials of PAHs are lower in water ice, Allamandola said, making ionization-driven reactions an important component of modeling ice chemistry. In experiments with pyrene, he and colleagues have found that ion chemistry dominates in ices below 50 K, and at higher temperatures radical chemistry takes over.

**TEMPERATURE CHANGES** might also be critical for PAH chemistry in ices, noted Murthy S. Gudipati, a principal scientist at NASA’s Jet Propulsion Laboratory, in Pasadena, Calif. When naphthalene, for example, is ionized, it gets oxidized to naphthol—but only when it is warmed to 125 K. “This shows that ionized molecules may form some kind of complex with available radical and ionic species in ice at lower temperatures,” but mobility of molecular species at higher temperatures is needed to form other products, Gudipati said. He and his coworkers are studying laboratory reactions of such species in an effort to model what happens to them in space.

Ultimately, one of the goals of astrochemistry research is to better understand the compounds available during and after the formation of stars and what roles they might play in a prebiotic world on Earth and other planets, both in our solar system and around other stars. “Understanding the chemistry of solar system ices is an integral part of understanding the evolution of stars and galaxies,” Gudipati said. ■

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