Interstellar clouds: A new kind of chemistry

Hale Observatory

The lack of formaldehyde in the Orion nebula remains a mystery to be solved.

Larger and more complex molecules are being found in space, and their reactions are different from those in the lab

by Dietrick E. Thomsen

In the past two or three years astronomers have discovered more and more complicated chemical molecules in interstellar clouds. The series now includes such relatively complicated structures as formaldehyde, and there are astronomers who even harbor the hope of finding simple amino acids.

All this has been something of a running surprise to astronomers. "One thought the interstellar medium primitive," says Dr. David Buhl of the National Radio Astronomy Observatory. Radiation, he says, was expected to destroy any molecules that found their way there, and furthermore the density of matter there was so thin that the chances of any molecules forming were very slim. Nothing more complicated than diatomic molecules was expected.

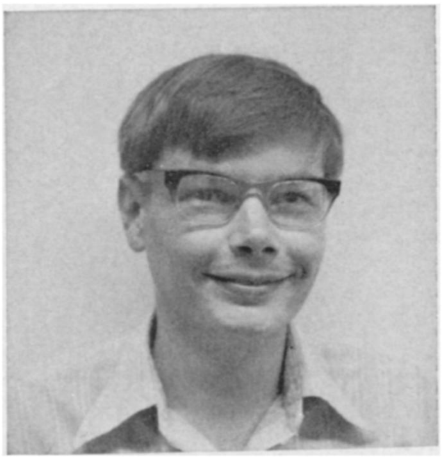
Now, says Dr. Buhl, it looks as though processes in interstellar space can produce fairly large quantities of things thought ridiculous before the current discoveries.

The existence of compounds is not a special freak of an unusual part of the galaxy; they are quite widespread. Formaldehyde, for example, is found in widely separated parts of the galaxy. About 50 formaldehyde clouds are now known, says Dr. Buhl, and there may be many unseen ones: The only detectable ones are those that have a radio source behind them, since the molecules can be detected only by the frequencies they absorb from the radio signals that come through them.

The clouds in which one compound is found generally harbor others, as well as cosmic dust, solid grains that according to different astronomers may be graphite, silicate or ice flakes, or perhaps a combination of any of these. The presence of more and more complicated compounds indicates that somewhere in the galaxy chemical reactions are going on, either in the clouds at large or in the envelopes of young stars that are found in the clouds.

One of the most recent discoveries is hydrogen cyanide (HCN), and, says Dr. Buhl, "HCN tends to be a by-product of complex reactions." This would suggest that some sort of chemical evolution is going on in the clouds, but, he goes on, "It is difficult to say which way the evolution is going.

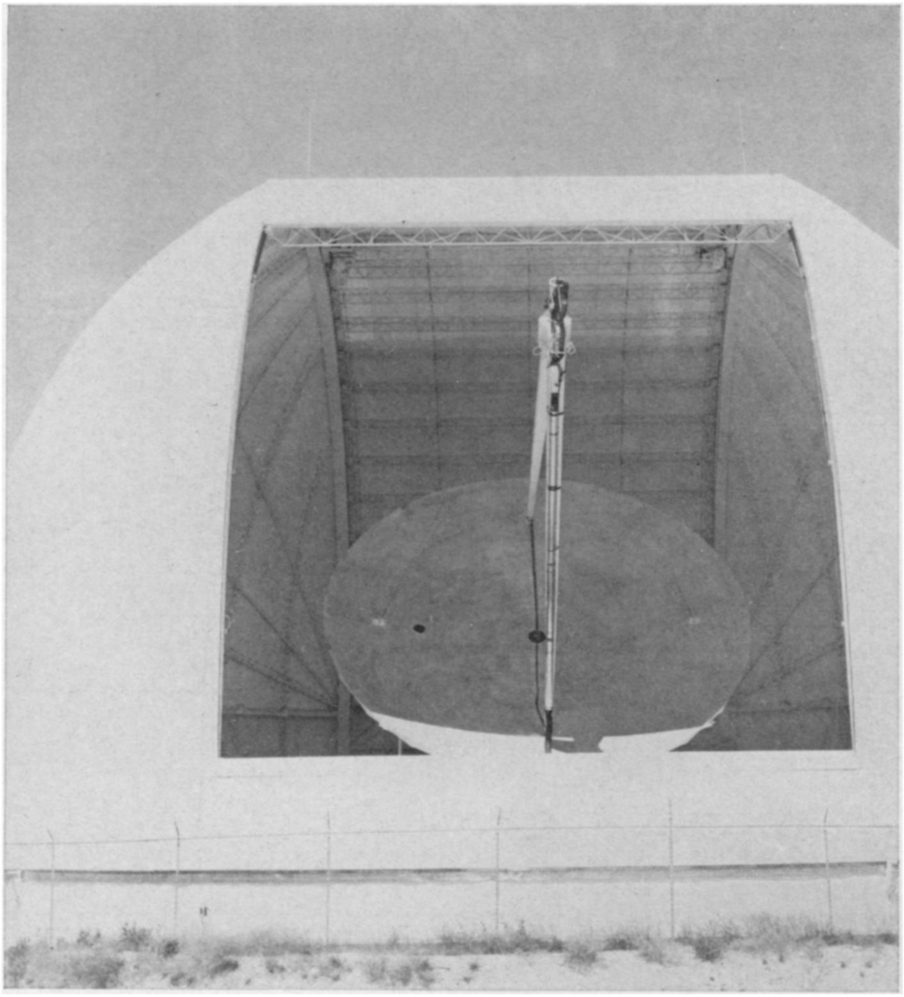
"The compounds don't form in midspace," he says. If they are manufactured in the clouds, it is because the dust is sufficiently thick both to capture flying atoms, bringing them together to form compounds, and to shade the molecules from the ultraviolet radiation that would break them up. On the other hand the compounds may be made in the relatively cool envelopes of the young stars and drift out into the clouds.



NRAO

Buhl: Chemical evolution going on.

Molecular astronomy at present is a science that has many loose ends and open questions besides the basic one of where the molecules are made. One such question is whether the same chemical processes are going on everywhere. As an anomalous example, Dr. Buhl cites



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Many of the interstellar compounds were found with the 36-foot Kitt Peak dish.

the Orion nebula, which has hydrogen cyanide, hydroxyl radicals, water, carbon monoxide and cyanogen radicals, but no formaldehyde. Formaldehyde is found elsewhere in association with these compounds, so it may be either that the chemistry of the Orion nebula is somehow different or that formaldehyde is there but cannot be detected because it is not properly illuminated. Neither theory nor observation can settle the question at present.

Another puzzle is the relative abundance of complex compounds to simple ones. Knowing the abundances of the various elements that go into the compounds and the rates at which different reactions take place under given conditions of temperature and pressure, scientists can calculate the amounts of different compounds that are likely to form. But for the interstellar dust clouds the calculation does not match the observation.

Heavier molecules, says Dr. Buhl, tend to be more abundant compared to light ones than calculation says they ought to be. One example is the ratio of formaldehyde to hydroxyl. Calculation says there should be one formaldehyde molecule to 3,000 hydroxyls; observation shows densities between one to 10 and one to 30. "There does seem to be something peculiar about the densities we're deriving," he says.

To solve the problems of molecular astronomy it will "take a new type of chemistry," says Dr. Buhl, "not what we're used to in the lab."

Most chemical research has been done at room temperature (300 degrees K.) or higher and at pressures on the order of that of the atmosphere. The temperatures of interstellar clouds range from one to 100 degrees K., and pressure is almost nonexistent.

Dr. Bertram Donn, a chemist with the National Aeronautics and Space Administration agrees with Dr. Buhl: "You can't just carry over chemistry experiments. Most theory is not applicable to the pressures and temperatures in the interstellar medium."

Under interstellar conditions chemical reaction rates may differ from those found under ordinary laboratory conditions. Laboratory chemistry, says Dr. Donn, usually takes place under thermodynamic equilibrium: the kinetic energy associated with the motion of the atoms is equal to the energy associated with their vibrations, and it is possible to speak of a single temperature.

But in interstellar space there are not enough collisions among atoms to equalize the two kinds of energy, and one must distinguish between kinetic temperature and vibrational temperature. It is possible, says Dr. Donn, to have a gas with a high vibrational temperature and a low kinetic temperature. He is studying the reactions of vibrationally excited hydrogen to see what differences the excitation makes.

One major difficulty for laboratory astrochemistry, says Dr. Donn, is that if interstellar conditions are precisely simulated in the laboratory, reactions are so rare in any feasible volume that they cannot be observed. What he does instead is to approximate such conditions as closely as practical and extrapolate the findings. He is now working especially on the optical properties and photochemistry of molecules at very low temperatures and densities.

So far there has not been much interest in astrochemistry among chemists, but Dr. Donn attributes this to the extreme youth of the science. "Chemists are realizing that much more chemistry is going on in interstellar space than anywhere else," he says. "It will be a developing field."

Meanwhile astronomers keep looking for different molecules. So far the most fruitful observations have been in the millimeter radio range because molecular spectra are simpler here than in other parts of the electromagnetic spectrum. What an observer gets, says Dr. Buhl, is a spectrum with a lot of lines in it, and he tries to see what molecules the lines represent.

In radio two or three or half a dozen lines may suffice to identify a substance. In the optical range molecular spectra are so complex that sorting out the pattern of one molecule from all the others is a formidable task. Now that radio observation has given indications that such efforts may pay off, Dr. Buhl expects to see more and more optical identification done.

Dr. Buhl and others have looked for ketane and formic acid but so far found neither. Amino acids may be in the future since the molecules now known are one level of chemical complexity below simple amino acids, and the reactions they engage in are the sort that produce amino acids.

If amino acids should turn up, molecular astronomy might have something to say about the evolution of life. A young star surrounded by a gas cloud, says Dr. Buhl, represents what the sun and solar system may have looked like 4 billion or 5 billion years ago. If the earth and the other planets condensed out of such a cloud, they may have been endowed at their creation with more complex organic compounds than used to be supposed, and, according to some suggestions, even with very primitive forms of life. □