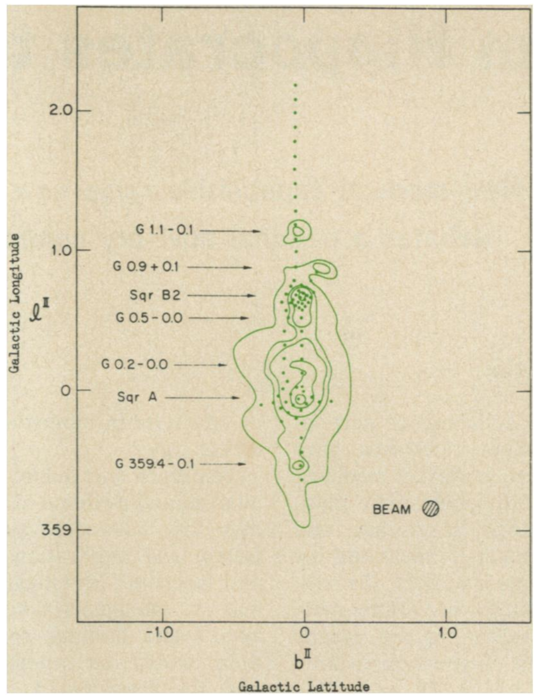
A new look at the galaxy

Interstellar molecules are changing astronomers' impressions of the physics and topography of our galaxy



The galactic center as seen in 6-cm-wave brightness contours. Names of the brightest sources are shown. Solid dots are formaldehyde locations.

P. Thaddeus

by Dietrick E. Thomsen

The first spectral line astronomers discovered in the radio part of the electromagnetic spectrum was for atomic hydrogen. For years it was the only one known. This characteristic emission at a wavelength of 21 centimeters revealed that the galaxy was pervaded by clouds of invisible hydrogen atoms. Astronomers hastened to make contour maps that recorded the brightness of the 21-centimeter radiation in various parts of the galaxy and derived from them a radically different picture from that given by visible light. (Recently an array of radio telescopes at Westerbork in the Netherlands has extended the technique to an external galaxy, the Whirlpool nebula or M51.)

Although the 21-centimeter maps marked a revolutionary change in astronomers' ways of looking at the galaxy, they give a somewhat biased view. As Patrick Thaddeus of Columbia University notes, the 21-centimeter contours show a poor correlation with the clouds of interstellar dust. And it is what goes on in the dust clouds that is of particular interest in attempts to understand the physical and chemical processes going on in the galaxy, especially the formation of stars.

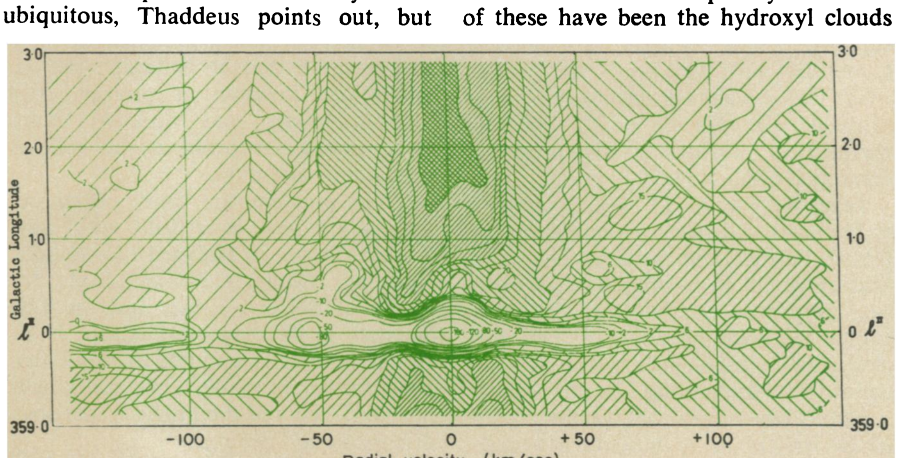
A less biased picture is now evolving, thanks to the large number of new spectral lines discovered in the last few years. Ten years ago reputable astronomers could be heard saying that it was extremely unlikely that any spectral lines beside the 21-centimeter line would be discovered in the radio range. Today, 50 lines are known. They have been used to identify 21 different compounds. Some compounds are known by more than one line. A few are known in more than one isotopic species.

Thaddeus points out that there is little or no redundancy in all these data. "Each measurement gives new information," he says, different lines representing different parts of the puzzle. Even when more than one line of a given compound is known, each line represents a different energy change within the molecule, and each is thus a clue to a different physical activity.

Thus astronomers can now make maps of the distribution of various molecules in the galaxy, and the results are beginning to show significant differences from the hydrogen maps. First there is a greater correlation between molecules and dust than between hydrogen atoms and dust. Two of the dustiest parts of the sky, the nebula in Orion and the galactic center region in Sagittarius, are particularly rich sources of molecules. Many molecules, including most of the complex ones, have so far been found only in one or both of these sources. Other molecules are more widespread. Formaldehyde is ubiquitous, Thaddeus points out, but the chemical reason why it should appear in so many places is completely unknown. Of particular interest are detailed maps of the galactic center, where radiations of various molecules are uncovering structural detail.

The second difference is that molecular clouds are denser than hydrogen ones—on the average 10 to 100 hydrogen atoms per cubic centimeter versus 10^{14} to 10^{16} molecules per cubic centimeter.

One of the most curious physical phenomena brought to light by the molecular investigations is that most of the molecular clouds are not in thermodynamic equilibrium. If a cloud of gas is not subject to energetic disturbances from outside, all of its molecules will eventually come to the same temperature and to equilibrium with its surroundings. The most spectacular examples where this is not true are certain clouds of hydroxyl radical (OH), water and formaldehyde. The longest known and most frequently discussed of these have been the hydroxyl clouds



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Atomic hydrogen distribution parallel to the plane of the galaxy.

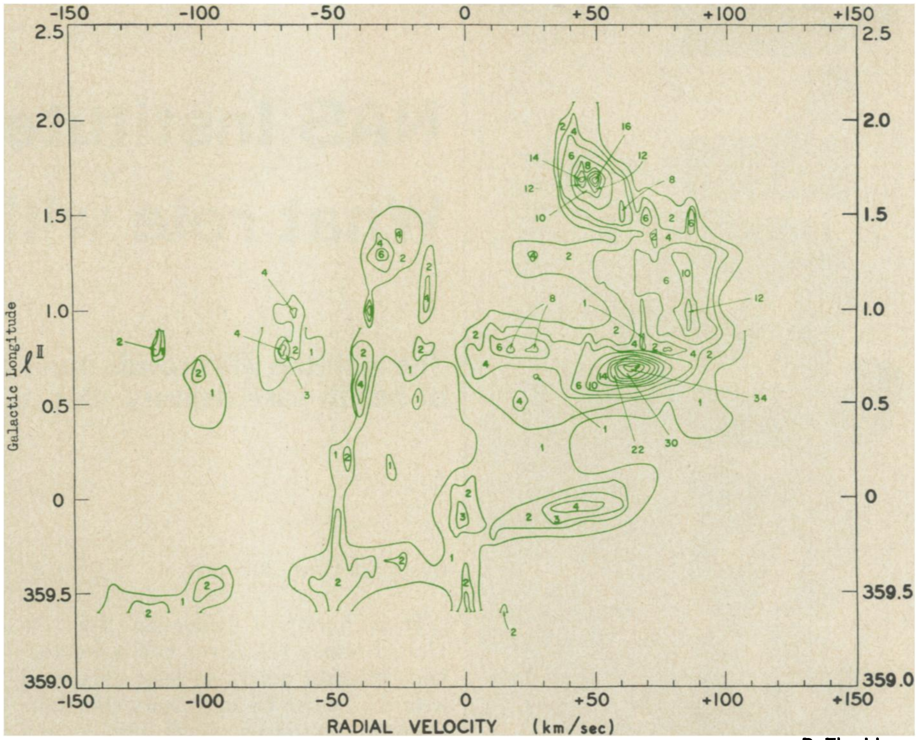
that are sometimes called natural masers. Some process is continually raising the energy of some of the hydroxyl molecules. These excited molecules then cool back to the equilibrium temperature and in so doing emit the radio frequency that informs astronomers of this activity.

Speculation about the pumping mechanisms that keep raising the energy of significant numbers of molecules in the clouds generally points to collisions with other bodies, either neutral particles or electrons. William J. Welch of the University of California at Berkeley tends to favor neutral particles because electrons are not likely to remain free in such dense surroundings long enough to be effective.

Even stranger is the apparent reverse maser action of the formaldehyde. In a number of the formaldehyde clouds located some distance from the central plane of the galaxy some mechanism is making formaldehyde molecules colder than their surroundings. They exhibit this by absorbing a line of about 6 centimeters wavelength from the three-degree K. blackbody background radiation that permeates the galaxy. The absorbed wavelength represents about 1.7 K. degrees of cooling. The amount, says Thaddeus, requires a cooling-pump mechanism that works quite fast, but what it is nobody knows.

Another physical question concerns the origin of the atoms that make up the interstellar molecules. Do they represent matter that has been processed through stars? Have the nuclei of these atoms been manufactured by the thermonuclear fusion processes that go on in stars? Because certain compounds are known in more than one isotopic variety, an answer can be sought. The ratios of different isotopic varieties can be compared to the ratios that ought to be produced by the fusion processes in stars.

Benjamin M. Zuckerman of the University of Maryland has compared ratios of carbon 12 and 13, nitrogen 14 and 15 and sulfur 32 and 34 in the galactic clouds with their respective ratios in the solar system as determined from terrestrial measurements. He finds the ratios similar enough to conclude that "whatever nuclear processes have determined the isotopic mix in our solar system, this mixture is typical of many regions in our galaxy in spite of the fact that our solar system is representative of matter that was last burned in a star at least 5 billion years ago."



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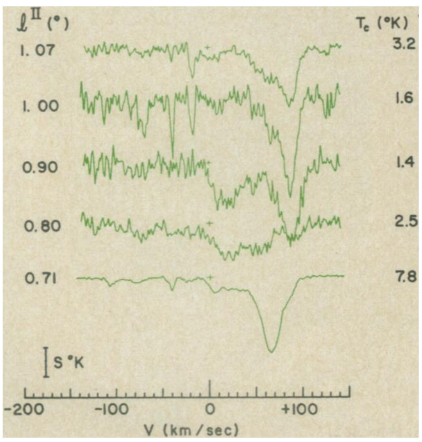
View along the galactic plane from measurements of 6-cm formaldehyde line.



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Sample 6-cm-absorption spectra.

One abundance ratio especially important for theories of how the universe originated and of how nucleosynthesis proceeds is that between hydrogen and deuterium. So far deuterium has not been detected by radio, but Arno Penzias of the Bell Telephone Laboratories at Holmdel, N.J., has hopes of finding it with new equipment being developed at Holmdel. The equipment continues the present exploitation of the rotational energy changes of the interstellar molecules. Rotation around their centers of gravity is a characteristic kind of motion that many molecules indulge in. Each molecule that rotates has a particular set of discrete rotational energies. To change from one to another (altering the rotation by a quantum jump) requires only small amounts of energy, and therefore is a process likely to happen in interstellar space. When the change occurs, radiation or absorption of a particular radio frequency takes place. Most of these lines fall into ranges around two or three millimeters wavelength, a window region where the radiation can get through the earth's atmosphere without being absorbed.

"Thus," says Penzias, "it was natural that when the first millimeter line receiver was built at Bell Labs last year, it would lead to an explosion in the number of molecules detected." Bell Lab's plans for the future are to stretch the reception band of highly sensitive receivers ever more and more toward shorter millimeter wavelengths. By December they plan to be using a receiver that goes to 180 gigahertz. Sometime in the future they hope to get to 270 gigahertz (a frequency of 300 gigahertz corresponds to a wavelength of one millimeter). With these they hope to find more interesting molecules. One of them could be deuterium. □

MOLECULE	WAVELENGTH
H_2	1000 A
CH	4000 A
CH^+	4000 A
CN	4000 A
OH hydroxyl	18 cm
SiO silicone monoxide	0.23
H_2O water	1.35
NH_3 ammonia	1.25
CO carbon monoxide	0.26
CS carbon monosulfide	0.20
HCN hydrogen cyanide	0.31
OCS carbonyl sulfide	0.28
H_2CO formaldehyde	6
HNCO isocyanic acid	0.3
HCOOH formic acid	18
HC_3N cyanoacetylene	3
CH_3OH methyl alcohol	36
CH_3CN methyl cyanide	0.29
$HCONH_2$ formamide	6
CH_3CH_2 methylacetylene	0.31
$HCOCH_3$ acetaldehyde	30
X-ogen	0.3
'HNC' 'hydrogen isocyanide'	0.3

W. W. Welch