

Hydroxyl Molecules in Space Puzzle Radio Astronomers

Investigations of emission and absorption of radiation by hydroxyl (OH) radicals in interstellar space have turned up many puzzles and anomalies. The newly developed long-baseline interferometers may provide a solution. They may in fact reveal a galactic maser, and further observations may tell us more about the structure of our own planet.

The presence of the hydroxyl molecule was first shown in 1963 by a group at MIT (Alan Barrett, Sandy Weinreb, Litt Meeks and John Henry). They saw OH lines in absorption when observing emission from the strong radio source Cassiopeia A, and these observations were quickly confirmed by other groups around the world. The calculated intensity in the direction of Cassiopeia A is 10^{14} mol per cm^2 , which indicates an OH/H abundance ratio in this part of the galaxy of 10^{-7} . In the direction of the galactic center the OH/H ratio is 10^{-4} . The emission lines were first seen in 1964 but were not immediately recognized as OH; the main feature is a strong line at 1665 MHz (18-cm microwave band) with other weaker lines nearby. Unlike the 21-cm atomic hydrogen emission, which is observed with wide distribution throughout the galaxy, the OH lines are only seen in areas near very hot stars called HII regions, where the hydrogen is almost completely ionized. These regions are all close to the galactic equator.

The four OH 18-cm lines that have been observed in absorption and emission arise from fine and hyperfine splitting of the rotational levels of the molecule. Interaction of the unpaired electron with the molecule as a whole splits each state into two, called the Δ -doublet; further splitting by nuclear magnetic-moment coupling results in each rotational level having four hyperfine components in all. The four allowed transitions between these components have wavelengths in the 18-cm band.

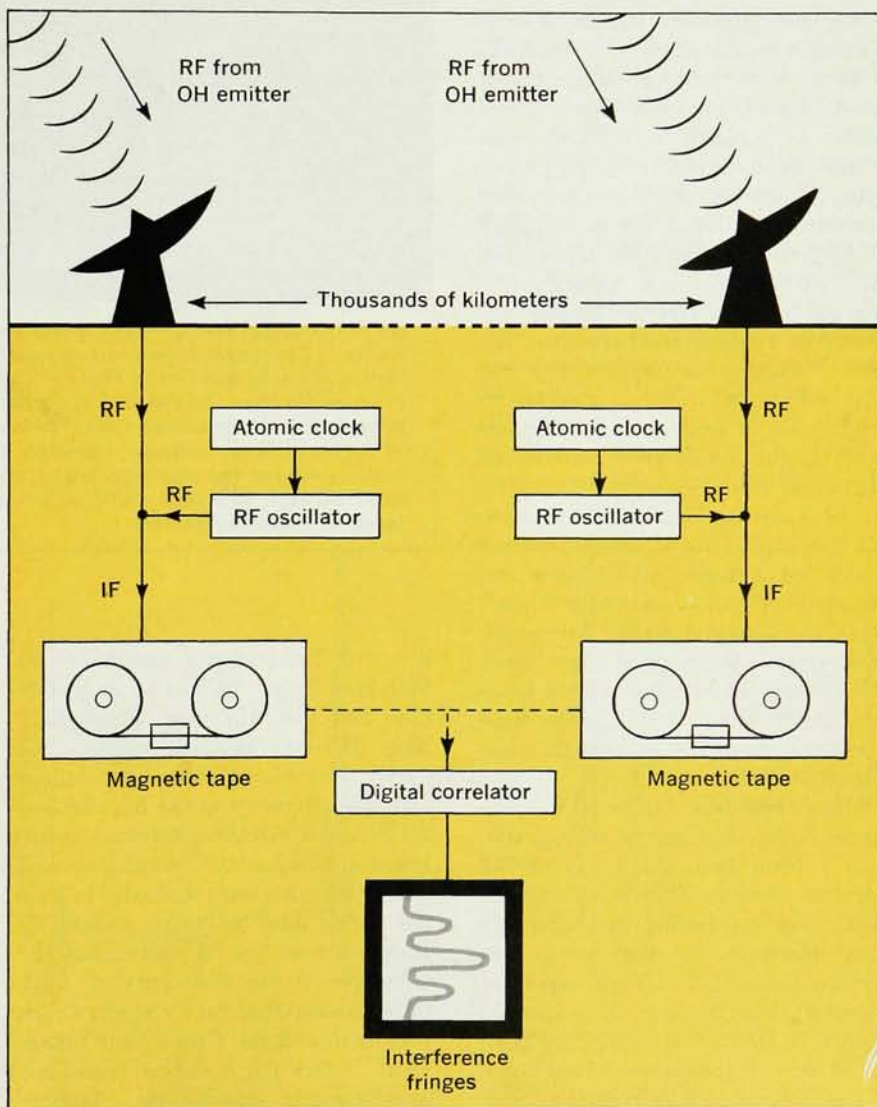
A puzzling feature of the galactic

hydroxyl emission and absorption lines is that the relative intensities of the four components of the group are not in agreement with quantum-mechanical calculations. Another strange property appears when the line-of-sight velocity component of the OH molecules is computed from the Doppler shift in the absorption observations; these molecules are found to be moving toward the center of the galaxy at about 40 km per sec. In contrast, observations on atomic hydrogen in the

same region show that these atoms are moving away from the galactic center with a velocity of 50 km per sec.

Further anomalies have appeared. Among them is an apparent time variation in the emission intensity, with random periods of the order of hours, days or weeks. It is not known whether these fluctuations arise at the emitter or during propagation.

Long baselines. The physical size of OH emitters appears to be very small—certainly smaller than the HII



LONG-BASELINE INTERFEROMETER uses two radio telescopes thousands of kilometers apart. Magnetic tape recordings synchronized by atomic clocks are correlated by computer to show interference fringes.

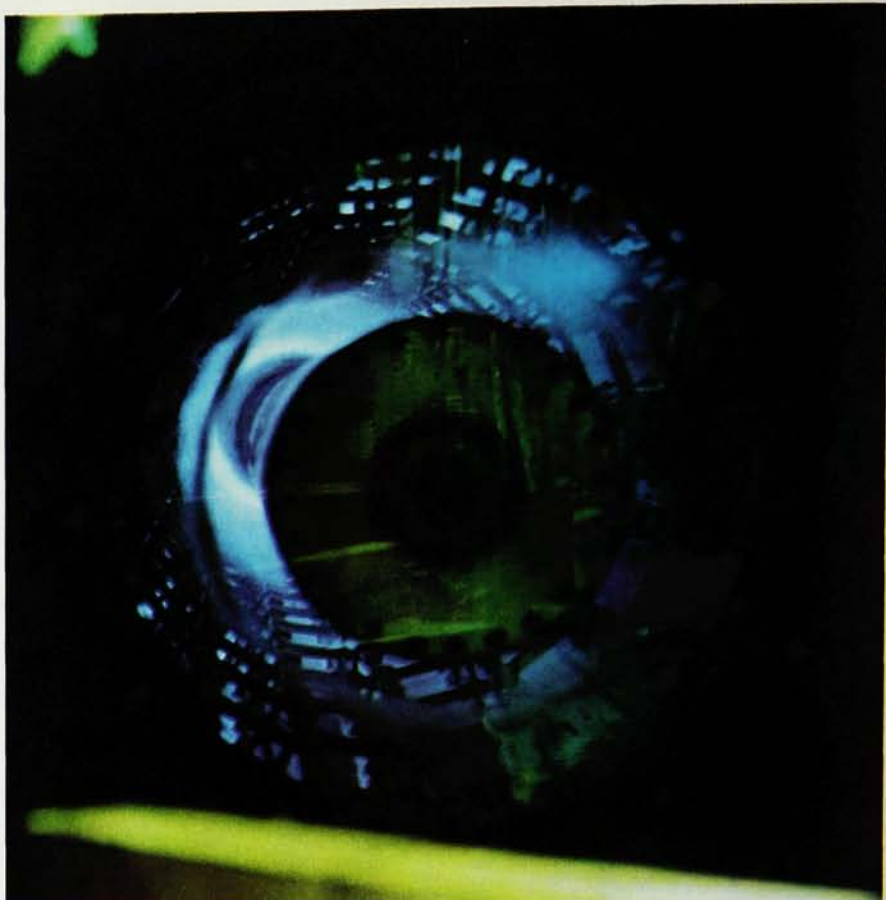
regions in which they are found. Early efforts to measure their angular diameters showed that they are too small to be resolved by any single radio telescope or interferometer array. Much excitement has been generated this summer by new techniques of long-baseline interferometry exploited by several radio-telescope groups working in collaboration.

Earlier collaborations between telescopes separated by up to a few hundred kilometers were made possible by cable or microwave transmission links between the instruments, but this becomes impossible for the greater separations needed for higher resolution. The new technique utilizes atomic clocks and radio time signals to keep the stations in phase and synchronized, so there is no physical or electronic link between them. Baselines are now limited in principle only by the size of the earth. The radio-frequency signal is heterodyned down to video frequencies so that it can be recorded on magnetic tape, and the tapes from the two stations are subsequently brought together and the signals correlated in a digital computer (see figure). A baseline of 1000 km, or about 5×10^6 wavelengths in the 18-cm band, gives a resolution (one fringe width in the interference pattern) of 0.02 sec of arc.

These ideas go back about ten years, but the availability of suitable atomic clocks led Kenneth Kellermann and Marshall Cohen to decide to go ahead, using the National Radio Astronomy Observatory's telescope at Green Bank and Cornell's at Arecibo. David Jauncey, Barry Clark and Claude Bare joined the team, and construction was started in 1966.

Meanwhile Jack Locke of the National Research Council of Canada, with a team from the University of Toronto, Queen's University and the NRC were proceeding independently with telescopes at Algonquin, Ont. and Penticton, B.C. Their report of observations on quasar radio sources in *Nature*, 1 July 1967, is the first published work on the successful operation of a long baseline interferometer.

The Cornell-NRAO group tested their technique in May, with the Green Bank telescope and the Naval



ASTRON E LAYER. 4-MeV electrons trapped in helical paths inside Astron facility (Lawrence Radiation Laboratory, Livermore) are made visible by ionization of background gas. Photo is a time exposure of about 300 pulses. Astron experiments have yielded 6% of current density needed to make a linear magnetic bottle for controlled fusion (*PHYSICS TODAY*, Aug., page 49). Light blue at 2:00 o'clock is probably Cerenkov radiation from the head of the electron bunch escaping the magnetic mirror and reaching the lucite end window; dark band between 8:00 and 10:00 o'clock is caused by radiation darkening of the lucite by this bombardment.

Research Laboratory's instrument at Maryland Point. It was at about this time that the MIT team (John Ball, Alan Barrett, Bernard Burke, Joe Carter, Mrs Pat Crowther, Jim Moran and Alan Rogers) joined in, and two MIT-Cornell-NRAO collaborations followed in which both OH radiation and quasar emission were studied. In June the Green Bank telescope and MIT's Haystack were paired, and in July the telescope of the University of California Radio Observatory at Hat Creek was used with the Green Bank instrument. Later the Arecibo-Green Bank interferometer was set up. Jauncey says that successful observations were made in August, and the tapes are now being processed.

The very high angular resolution obtainable with these interferometers is still not sufficient to determine the size of OH emitters. For example, the Haystack-Green Bank work showed that the emitter known as Radio Source W3 has a component less than 0.02 sec of arc in diameter. For the estimated distance from the earth of 1700 parsec that implies an apparent diameter less than 34 astronomical units; this would mean the source is smaller than the solar system.

An interesting suggestion has been made by Thomas Gold of Cornell that these long-baseline interferometers should enable measurements to be made of the period of the earth's revolution to a better accuracy than is

possible by visual observations. Conventional optical measurements are limited in accuracy, by variations in refraction by the atmosphere, to a resolution of about 0.4 sec of arc. 18-cm microwave radiation is not affected so much by atmospheric refraction, and we have seen that 0.02 sec of arc resolution is possible. The OH emitters like W3, and some of the quasars are of sufficiently small size to be good fiducial marks for measurements of the length of the day. The improvement in accuracy should be from 5 msec to less than 0.25 msec. The earth's rotational period varies with regular annual, semiannual, monthly, fortnightly, daily and semidaily components, plus irregular variations. The increased accuracy of radio interferometers would lead to better measurements of short-term fluctuations that in turn would give information on the tidal motion of the earth's solid mantle and on fluid motion within the atmosphere, oceans and core.

Maser? Many of the puzzling features of the hydroxyl emission and absorption have been tentatively explained as arising from a natural maser action in interstellar space. The high-intensity, narrow-bandwidth lines could arise from maser amplification, and the apparent small size of the OH sources could be due to coherent, parallel emission from a region that is very much larger. The problem is to devise a mechanism by which the excited states are "pumped" to produce the population inversion that is necessary before stimulated emission can occur. Radiation pumping by the ultraviolet continuum from hot HII regions has been suggested, but Philip Solomon of Columbia University believes that if his guess for the hydroxyl internuclear potential-energy curves is right this radiation would dissociate the molecule. Solomon's alternative theory is based on a form of chemical pumping arising from formation of the molecule by pre-association, or in more familiar language, inverse pre-dissociation: $O + H \rightarrow OH^*$. The kinetic energy of the atoms all goes into excitation of the molecule. Solomon says that when the electronically excited state decays to the ground state, a population inversion of the Λ -doublet results that would give maser action. The hydroxyl radical is destroyed by

collisions with atomic hydrogen: $OH + H \rightarrow H_2 + O$. Solomon has calculated the equilibrium concentration of OH from these two processes, and his value of 10^{-7} for the OH/H abundance ratio is in good agreement with the absorption measurements.

Another explanation of the OH emission anomalies that has been advanced—perhaps with tongue firmly located in cheek—is that someone "out there" is trying to speak to us. The properties desired in an interstellar communication network are all here; the signals are of good intensity, narrow bandwidth, they fluctuate in an apparently random manner and originate from a small region in space. Perhaps the intensity anomalies in the four OH lines have been deliberately introduced to draw attention to them!

Of more serious concern to radio astronomers at this time is the possibility that they may not be able to work at the OH frequency indefinitely. International agreements on the allocation of radio-frequency bands for commercial use have left the 21-cm atomic hydrogen band free for scientific observation—listening instead of talking. But the future of the 18-cm OH frequency is still in doubt. Wouldn't it be disappointing if the residents of a distant planetary system were desperately trying to communicate with us and all we could hear were baseball scores?

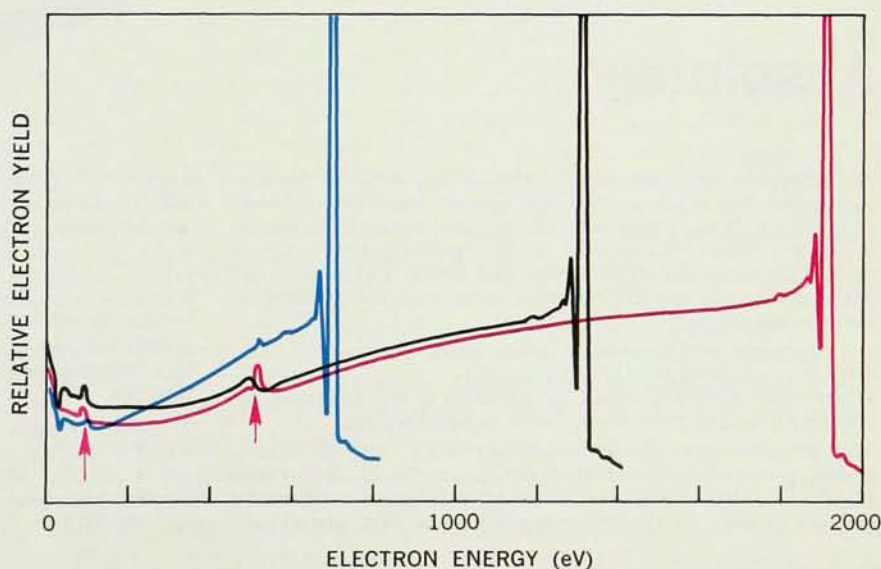
—JTS

Auger Electron Emission Can Identify Surface Impurities

Auger electron emission can be used to detect and identify contaminants on solid surfaces, with some advantages over the customary x-ray method. Lawrence Harris, of the G. E. Research Center at Schenectady, developed the technique, and at the University of Minnesota Roland Weber and William Peria demonstrated that 1% of a monolayer of cesium can be detected on substrates of either germanium or silicon.

The atoms of a specimen bombarded with electrons of 2–3 keV energy may be excited by the ejection of an inner-shell electron, with x-ray emission if this electron returns to its place and the atom is left in its ground state. Alternatively the energy may go to ionize the atom by ejection of an outer-shell electron; this is the Auger ionization process.

In Harris's technique the kinetic energy of all electrons leaving the surface is measured over the range 0–2 keV, and that part of the energy spectrum due to the Auger process is examined and correlated with the known Auger spectra of the elements. The electron energy is analyzed in an electrostatic selector with focusing at 127 deg, and the signal is detected by an electron multiplier. The Minnesota experimenters used standard low-



ENERGY DISTRIBUTION OF AUGER ELECTRONS emitted from pure beryllium bombarded with 695-eV (blue), 1310-eV (black) and 1910-eV (red) electrons. The two vertical arrows show Auger levels.