THE RADIO SPECTRUM OF THE GALAXY

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The progress of human knowledge often seems to come in sudden bursts of activity, with resting periods in between, when the new concepts are exploited, fitted into existing pictures of the physical world, or the pictures of the world modified to fit the new insights. In astrophysics, radio spectroscopy may well be in the midst of such an active phase. Two decades have passed since van de Hulst suggested, in 1944, that the ground state hyperfine transition in Hydrogen, the celebrated 21-cm line, should be an exceptionally useful tool in studying the galaxy. Several years of laboratory struggle culminated in the almost simultaneous discovery, first at Harvard by Ewen and Purcell, and then by the Leiden and Sydney groups, of the emission line. In a remarkably short time, the broad picture of hydrogen emission was sketched out, the spiral structure of the galaxy demonstrated, and then commenced the assimilation period - not a dull time at all, but a time of hard work, as new and puzzling features of the hydrogen emission and absorption were brought to light. Some of us have brooded over the existing hydrogen models of the galaxy, in many ways so pleasing but still disquieting. A simple glance at the Leiden-Sydney map shows that the galaxy looks very different from the northern and southern hemispheres. Even more striking, however, have been the observations that clearly do not fit, even qualitatively, our pre-existing notions of galactic center, from which hydrogen gas seems to be streaming at velocities ranging to 200 km/sec. and more, in amounts that may be as great as one solar mass per year - a rate high enough to deplete all the mass in the center within the present lifetime of the galaxy.

It is most appropriate, for a location such as the Pereyra Station, that the galactic center passes almost directly overhead, making it a prime target for study.

Another great puzzle is the observation of very high velocity clouds at distances far from the plane of the Milky Way, observed by the Leiden group. So far, all the hydrogen seems to be coming at us, and none streaming away. The sky has been covered most fully in the Northern hemisphere, however, and it will be exciting to see if, in that part of the galaxy that lies invisible to northern observers, the same pattern will hold.

These are subjects of dynamics, however, and not appropriate to my subjects, and I give them as examples only, to illustrate the extent of our ignorance of the interstellar medium. Clearly, the more independent parameters that can be measured, the more complete will be our knowledge; and so the question of studying the interstellar medium by means of other spectral lines becomes important.

Two years ago, Barrett, Meeks, Rogers and Weinreb added the first new lines to the list when they discovered the hydroxyl radical, OH, in absorption in the spectrum of Cassiopeia A. All four lines in the ground-state lambda doublet have now been seen at 1612, 1665, 1667 and 1720 Mc/s - or approximately 18 cm wavelength. Absorption measurements of OH have been particularly exciting in the direction of the galactic center where, as already mentioned, we know that peculiar motions exist. The intensity of the OH absorption lines was far greater than anticipated, by a factor of at least a hundred, and it is ironic to contemplate that these lines are so intense that any of the workers in the field during the past 15 years could have easily detected them. They did not try, however, for two reasons: the existing models predicted only very weak absorption, and the frequencies of the lines were not well known. Here, a partnership between the laboratory worker and the astronomer is essential, and in several laboratories there are now proceeding measurements of the spectra of the radicals CH and SiH. These, too, are made from abundant species of element, and would represent a powerful extension of our knowledge of the state of the interstellar medium.

So far I have only discussed absorption-line spectroscopy, but perhaps the most exciting observations during the past year have been of the OH line in emission by the groups at M.I.T., Harvard and Berkeley. The pattern of OH emission in the sky seems to be entirely different from that of Hydrogen, which can be seen in emission over almost the entire sky. Instead, the OH emission can only be detected near ionized hydrogen, or HII, regions. The observations are less than a year old, but some characteristics are clear.

The OH emissions is strongly polarized, with circular polarization predominating, although there is some linear polarization, as well. The pattern is complex, for at each line frequency in the multiplet one sees several components, corresponding, presumably, to different discrete clouds, each with its appropriate doppler shift. Since each discrete cloud should exhibit all four multiplet components, the patterns observed at the four line frequencies should all be similar, each doppler component appearing at the correct doppler shift. This regularity is not observed, and the observed patterns at 1612, 1665, 1667, and 1720 Mc/s bear little or no resemblance to one another. Since each doppler component is strongly polarized, the Zeeman effect is suspected, with magnetic fields of the order of a milligauss required to destroy the similarity in patterns. The individual Zeeman components should still be identifiable, however, and the patterns related to one another. Unfortunately, this has not been possible so far, although one can make a pseudo-fit for any given member of the multiplet. Different doppler components, and different magnetic fields are required to fit all the observations, however, and while many are conviced that the Zeeman effect is somehow responsible, the solution has not yet been given. (A recent attempt by the Manchester group seems to be such a pseudo-fit - they were unable to observe the weaker members of the multiplet.)

The relative intensities of the OH lines are especially striking when one compares observation with theory. The relative intensities can be worked out by standard quantum mechanical calculations, which predict that the lines at 1612, 1665, 1667 and 1720 Mc/s should be in the ratios 1 : 5 : 9 : 1. In many of the observations to date, however, the 1665 Mc line is by far the most intense, reaching an intensity 50 or 100 times that of the 1667 Mc line - an intensity anomaly of at least 100. The emission lines are often extraordinarily sharp, and Barrett and his coworkers have an example in which the line breadth corresponds to a kinetic temperature of only 5°K, although the intensity of the line suggests a radiation temperature of at least 15°. Some doppler components are even more intense, and in the direction of the galactic center, one emission component must have a brightness temperature of at least 1500°K.

These anomalous intensities, and in particular the anomalous ratios, suggest highly non-thermal state distributions, and it appears likely that we are viewing some sort of cosmic maser, excited by the radiation from the neighboring HII, amplifying the galactic background radiation.

Another category of spectral line has recently been brought to light. The Russian astrophysicist Kardashev several years ago predicted that in an ionized hydrogen region, the hydrogen atoms as they recombine could emit discrete lines in the radio region. These are simply the lines arising from transitions between very highly excited states in the energy level diagram, with enormous Bohr orbits corresponding to n = 100-200 -- enormous floppy atoms a micron or so in size. A year ago two Russian groups reported discovery of one of these lines, and confirmation at the NRAO by Hoglund and Metzger followed shortly. Such transitions as n=109-108 (near 6000 Mc/s) and n = 167-166 (close to the hydrogen line) have already been observed, and these lines promise to be a powerful tool in probing the physical condition of HII regions. At very low frequencies, the line intensities and widths should be determined by the Stark effect and thus give a direct measurement of the local electron densities. At higher frequencies, the line widths are determined mostly by internal velocities, and their use will be more closely related to conventional hydrogen line analyses.

Before closing, I wish to make some remarks on a radio line that may never be observed at all. The cyanogen molecule CN is known to exist in interstellar space because optical absorption lines can be observed from electronic transitions within the molecule. The ground state of the molecule consists of a series of rotational levels, only the lowest of which should be populated. In some cases, however, two optical absorption lines are seen, corresponding to the transitions from both the lowest and first excited rotational states. Field has suggested, on the basis of a footnote in Herzberg's classical work on diatomic molecules, that the second line should be expected, since Penzias and Wilson's measurement recently of a finite background temperature at 4000 Mc/s. Their measurement has been interpreted as direct evidence of the initial explosive formation of the cosmos -- an inference of such importance that alternate tests must be sought. Field remarked that the second CN line would be expected from radiation equilibrium with a 3°K blackbody temperature, and thus would regard the CN absorption lines as direct confirmation of a 3°K background temperature at 3 mm wavelength. If the first two levels are in radiative equilibrium, the microwave rotational line could never be seen, and thus one can state that failure to observe the CN microwave line at 3 mm (116,000 Mc/s) would be a confirmation of the 3°

blackbody temperature of space. It would be misleading, however, to imply that this is the only explanation at this time, since Sciama has calculated that electronic collisions are equally effective and that the second optical absorption line is thus an indication, not of the blackbody temperature of space, but of the ionization condition to be found in those regions where CN exists. We can perhaps be encouraged that, far from the cosmos being explained, we are simply confronted with another puzzle that only further observations can shed light on.