Observations of the 89 GHz Transition of HCO\(^+\) in Orion

R. A. Batchelor, M. G. McCulloch and J. B. Whiteoak,
Division of Radiophysics, CSIRO, Sydney

Observations of CO emission (Kutner et al. 1977) have delineated a molecular cloud extending over several square degrees in the Orion region, and extensive surveys have been made of several other molecules (e.g. CN, CS, HCN, H\(_2\)CO, H\(_3\)H\(^+\)) in the densest regions of this cloud. However, only very limited observations were made for HCO\(^+\) (Turner and Thaddeus 1977), and consequently when a survey with the Epping 4-m radio telescope of the \(J = 1-0\) transition of HCO\(^+\) (rest frequency 89.18855 GHz) in southern molecular clouds was undertaken recently the HCO\(^+\) distribution in the molecular cloud in Orion was also mapped.

The observations were obtained during the period May-July 1979, when the atmospheric attenuation at 89 GHz averaged about 0.7 dB at the zenith. The telescope and its basic instrumentation have been described by Gardner et al. (1978). At 89 GHz the beamwidth is 3'.3 arc. Two main changes have been made since the initial observations of Whiteoak and Gardner (1978). Firstly, an improved cooled-mixer receiver (double-sideband temperature of 750 K) was used, with the feed located on axis instead of in the previous off-axis position. Secondly, the spectra were obtained using a 512-channel acousto-optical spectograph (Cole and Milne 1977) with a bandwidth of 93 MHz (i.e. a radial velocity coverage of 312 km s\(^{-1}\)). To minimize the effects of instabilities in the spectograph a pneumatically-driven quasi-optical beam switch was used to switch between molecular cloud and reference positions at a rate of 0.5 Hz.

Spectra integrated for a total on-source period of 10 min were obtained at 94 positions spaced 2' arc apart and spread across the densest region of the molecular cloud; the errors in telescope pointing were believed to be less than 15" arc. The line intensities were converted into 'corrected antenna temperatures' (corresponding to beam brightness temperatures in the Rayleigh-Jeans limit), assuming equal sideband responses at the signal and image frequencies and a full-beam efficiency of 50%. The results are shown in Figure 1 as a series of maps of HCO\(^+\) emission at different radial velocities. The velocity resolution is 1.2 km s\(^{-1}\).

The maps of Figure 1 contain several interesting features. The HCO\(^+\) emission has a distribution that is elongated north-south (particularly at velocities between +9.4 and 12.5 km s\(^{-1}\)). This also occurs for molecules such as CS (Liszt et al. 1974), H\(_2\)CO (Kutner et al. 1976), CO (Kutner et al. 1977), HCN and CN (Turner and Thaddeus 1977).

To an accuracy with which the telescope can be pointed, Figure 1 shows that the HCO\(^+\) emission peak of about 9 K occurs at the Kleinmann-Low nebula (OMC-1); a similar association also occurs for most other molecules. The concentration has halfwidth dimensions in right ascension and declination of 5'.5, 10' arc respectively. The centre position varies only slightly with velocity; a small north-south variation of position and a north-south elongation of the emission distribution (which is most prominent between +8 and +11 km s\(^{-1}\)) may be the consequence of a small concentration centred 1' arc east and 4' arc south of the main concentration. This second component is clearly resolved in the HCO\(^+\) observations made with higher angular resolution (75" arc) by Turner and Thaddeus (1977). The peak intensity is considerably lower than that measured by Turner and Thaddeus (12.3 K), but this may be due to dilution in the Epping beam.

Near the Kleinmann-Low nebula the velocity distribution is centred at +8.4 km s\(^{-1}\); the halfwidth is 5.0 km s\(^{-1}\). There is little evidence of the broadband emission (velocity halfwidth exceeding 20 km s\(^{-1}\)) which is prominent for some molecules — e.g. SO (Gottlieb and Ball 1973) — but faint in HCO\(^+\). However, Turner and Thaddeus (1977) and Snyder et al. (1977) have pointed out that this emission comes from a small-diameter source and would also be greatly beam-diluted in the Epping observations.

In Figure 1 there is another HCO\(^+\) concentration about 13' arc north of the Kleinmann-Low nebula, centred about 1' arc north of another prominent IR region, OMC-2 (Gatley et al. 1974). Its velocity distribution is centred at +10.6 km s\(^{-1}\); the half-width is 2.9 km s\(^{-1}\). These results are consistent with the observations of other molecules.

Several general conclusions result from the investigation:
(a) With regard to the general kinematics of the Orion molecular cloud, large-scale investigations of CO show a velocity pattern that has been interpreted in terms of an overall rotation of the cloud (see e.g. Kutner et al. 1977). In the small area of the cloud that was surveyed for HCO\(^+\) emission the effects of rotation are not prominent, although the higher velocities of the more northern emission are consistent with the interpretation. The absence of velocity variation across the HCO\(^+\) concentrations provides little support for the claim (see e.g. Kutner et al. 1976) that the dense regions of the cloud are rotating at a rate higher than for the cloud itself.
(b) A comparison of the \(^{13}\)C and \(^{12}\)C isotope species of the \(J = 1-0\) transition of HCO\(^+\) near the Kleinmann-Low nebula (Snyder et al. 1976) suggested that no great saturation effects were present for this transition. However, observations of the \(J = 3-2\) transition of H\(^{12}\)CO\(^+\) (Huggins et al. 1979) yielded an emission temperature somewhat similar to that of the \(J = 1-0\) transition. On the assumption that the populations of the J-states follow a Boltzmann distribution, the equivalent excitation temperature would be around 10 K. However, the assumption does not strictly hold because the observed line temperatures exceed this value. Until more information about the higher J-states becomes available it seems reasonable to adopt a value of 15 K for the excitation temperature, which means that some saturation effects would prevail. This temperature is far less than the kinetic temperature consistent with CO observations (about 100 K). In this case, a minimum HCO\(^+\) projected density \(N\) (cm\(^{-3}\)) can be obtained from the profile areas \(A\) (K km s\(^{-1}\)) shown in the final map of Figure 1, by assuming a low optical depth, a cloud extended with respect...
Figure 1. The distribution of HCO\(^+\) emission with radial velocity (l.s.r.). The contour interval is equivalent to a corrected antenna temperature of 1 K; the first contour is shown dashed. The crosses mark the position of the Kleinmann-Low nebula. The first map includes the beamwidth and positions of observation. The last map shows contours of temperature integrated over each profile; the contour interval is 6.2 K km s\(^{-1}\).

The relation is:

\[ N \approx 5.2 \times 10^{11} A/f, \]

where \( f \) is the fraction of HCO\(^+\) molecules in level \( J = 1 \). For \( A = 56 \) K km s\(^{-1}\), \( f = 0.3 \) (appropriate to a temperature of 15 K), then \( N \approx 9 \times 10^{13} \) cm\(^{-3}\).
The amplitude scintillations of pulsars and the broadening of the signal by fine structure in the ionized interstellar gas. The profiles are different manifestations of the scattering of their signal. The authors are indebted to Mrs G. Manefield and Mrs R. E. Otrupcek for their assistance with the reduction of the observations.


(c) The HCO$^+$ distribution in Figure 1 reinforces the conclusions of Turner and Thaddeus (1977) and Snyder et al. (1976) that HCO$^+$ is overabundant compared with N$_2$H$^+$ in the Kleinmann-Low nebula. This is a prediction of the current ion-molecule formation theory (see e.g. review by Watson 1976), because in high-density clouds the reaction

$$N_2H^+ + CO \rightarrow N_2 + HCO^+$$

dominates, thereby reducing the abundance of N$_2$H$^+$ relative to HCO$^+$.

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Pulsars, X-rays, Cosmic Rays

Culgoora Radioheliograph Measurements of Interstellar Scattering of Pulsar Signals

O. B. Slez, George A. Dulk* and Robena E. Otrupcek,
Division of Radiophysics, CSIRO, Sydney

Introduction

The amplitude scintillations of pulsars and the broadening of their profiles are different manifestations of the scattering of the signal by fine structure in the ionized interstellar gas. The frequency bandwidth $\Delta \nu$ over which the amplitude scintillations remain correlated is related to a measure of the delay time $\tau$ due to scattering by a Fourier transform such that $2\pi \tau \Delta \nu = 1$, the exact value of the numerical value on the right of the equation depending upon the spectrum of the turbulence in the interstellar gas. In addition, $\Delta \nu$ varies as approximately the fourth power of the frequency, the exact value for the power-law index again being somewhat dependent on the spectrum of the turbulence.

It happens that for the more distant (presumably more scattered) pulsars $\Delta \nu$ becomes only a few hertz at say 80 MHz and is thus not measurable with any practicable radiometer; on the other hand, $\tau_0$ may reach a value of several tens of milliseconds, which becomes detectable as a broadening of the pulse, provided the emitted pulse is of short enough duration. At high frequencies the pulse broadening is not detectable but the correlation bandwidth is often large enough to be measurable. For the closer pulsars the scattering is seldom strong enough to give measurable values of $\tau$, even at the lowest observing frequencies, but in these cases the frequency correlation bandwidth $\Delta \nu$ is large enough to be measurable at frequencies $>200$ MHz.

In this report we describe a newly developed pulsar-observing system at Culgoora and give our first results on the pulse shapes of 11 highly scattered pulsars at 80 and 160 MHz. Our results are then combined with other published measurements of $\tau$ and $\Delta \nu$ to: (i) establish the validity of the theoretical expression $2\pi \tau \Delta \nu = 1$; (ii) obtain more accurate expressions for the observed variation of $\tau$ with $\nu$ and to relate these to the various turbulence spectra which have been proposed; (iii) obtain a more accurate expression for the variation of $\tau$ with dispersion measure (distance) and use this information to test the hypothesis that the scattering properties of the interstellar medium are invariant within a distance of $\sim 15$ kpc of the Sun.

Equipment and Observational Techniques

The Culgoora radioheliograph was described by Wild (1967) and the subsequent conversion to three-frequency operation was described by Sheridan et al. (1973). Briefly, the array consists of 96 aerials forming a 3 km aperture; it has an effective area of 6400 m$^2$; it can be switched to 43, 80 or 160 MHz within milliseconds. For the present pulsar observations we used the instrument in its total power mode, i.e. without the normal sidelobe suppression by the J$^2$-synthesis technique. The integration time on individual pulsars can be as much as 5 h, although for most cases reported here we observed for about 1 h at each of two frequencies, alternating between the two frequencies each minute.

In order to remove the pulse dispersion the observations are made using two sets of filters: (a) a set of 15 filters, each 10 kHz wide, spaced 10 kHz apart, and followed by a 4 ms RC time constant; (b) a set of nine filters, each 90 kHz wide, spaced 110 kHz apart, and followed by an 8 ms RC time constant. The output of the 10 kHz filters is sampled each 3.9 ms.

*Also Department of Astro-Geophysics, University of Colorado, Boulder, U.S.A.