NEW DETECTIONS OF SPECTRAL LINES IN THE FREQUENCY RANGE 260-285 GHz

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The upper half of the frequency band lying between the atmospheric water lines at 183 and 323 GHz is virtually unexplored by spectroscopists of interstellar matter. The only published observations are those of Huggins et al. (1979) who detected the J=3-2 lines of HCN, HNC, and HCO^+ in the Orion A molecular cloud (OMC-1). We report here the results of extensive observations made in March and April of 1979 with a University of California (Berkeley) receiver on the Texas 4.9-m antenna.

The receiver had a quasi-optical diplexer for local oscillator injection (Erickson 1977) and a klystron and doubler for a local oscillator source. A Schottky-barrier diode at room temperature was used in the mixer and the system temperature was typically 4500 K (SSB). A room temperature FET amplifier was used for the 1.7-GHz IF signal. The aperture efficiency of the antenna at 282 GHz was roughly 25% from observations of Jupiter. The same planet was used to map the main beam at 267 GHz and we estimate the beam efficiency to be about 40%. The weather during the run was generally excellent with atmospheric optical depths typically 0.3 and occasionally as good as 0.1. The line intensities were calibrated by synchronously detecting a chopper wheel (Penzias and Burrus 1973).

The results of these observations are summarized in Table 1. Except for HCN, HNC, and HCO^+, all of the lines are new detections. The SO_2, HC_3N, and unidentified lines were observed only in OMC-1. The U-lines frequencies are: 278.263, 278.306, 278.889, and 281.958 GHz. Sally Cummins of the NASA Institute for Space Studies has suggested the $8_{17}-7_{16}$ transition of H_2CS at 278.8865 GHz as identification for U278.889. The frequencies agree to within one line width, assuming the U-line occurs at v_{LSR}=9.0 km/s. It might be expected that all four of these relatively strong U-lines are higher transitions of known, relatively abundant interstellar molecules.

The widths of the SO_2 and HC_3N lines are typical of lines associated with the plateau source in OMC-1. Examples are shown in Figure 1

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Table 1

Molecule	Transition	Frequency (GHz)	Comments
SO_2	$11_{3,9}-11_{2,10}$	262.257	detected in OMC-1 (K-L)
	$13_{3,11}-13_{2,12}$	267.537	
	$15_{3,13}-15_{2,14}$	275.240	
	$15_{1,15}-14_{0,14}$	281.763	
	$6_{2,4}-5_{1,5}$	282.037	
	$20_{1,19}-20_{0,20}$	282.293	
HC_3N	30-29	272.885	detected in OMC-1 (K-L)
	31-30	281.977	
H_2CO	$4_{1,4}-3_{1,3}$	281.523	detected in (12) sources
N_2H^+	3-2	279.513	detected in (10) sources
HCO^+	3-2	267.557	detected in (27) sources
HCN	3-2	265.886	detected in (14) sources
HNC	3-2	271.983	detected in (4) sources

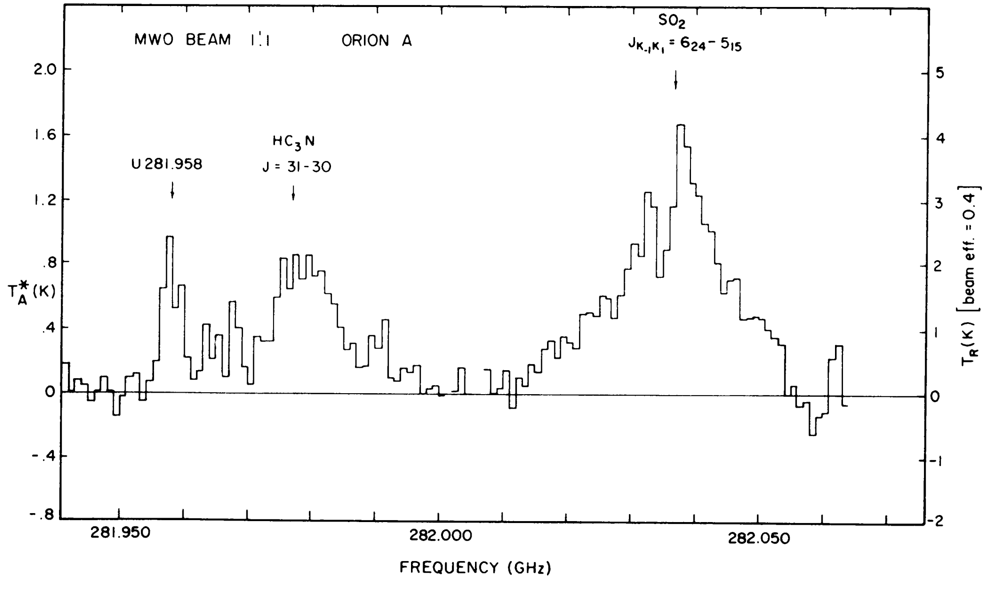

Figure 1. Sample OMC-1 spectra: HC_3N, SO_2, and an unidentified line near 282 GHz.

where very roughly one 10-MHz division on the horizontal axis is 10 km/s. The spike component which can be seen in the 6_{24}-5_{15} SO_2 line is not present in any of the other SO_2 spectra. This is expected because the 5_{15} level lies only 10.9 cm^{-1} above the ground state whereas the other observed SO_2 transitions have lower levels lying 48.8 to 128.8 cm^{-1} above the ground state.

The plateau source apparently has several components. The central velocity of HC_3N line is 7 km/s whereas the spike source has a velocity of 9 km/s and typically the central velocity of other plateau lines lie even farther to the red. This is in agreement with the velocity of 5 km/s found by Wannier and Linke (1978) for broad J=9-8 HC_3N emission and the velocity of the emission from vibrationally excited HC_3N detected by Clark et al. (1976) at 4 and 6 km/s. (Our spectra demonstrate one advantage of observing at higher frequencies: the broad HC_3N lines we observed are ten times stronger ($T_A^* \sim 1K$) than those observed by Wannier and Linke ($T_A^* \sim 0.1K$) as a result of both the narrower antenna beam and greater optical depth of the higher frequency transition.) Further evidence for multiple plateau components can be seen in Figure 2 which shows that the broad HCO^+ emission can be seen 1'N of the K-L position and is, therefore, more extended than the SO_2 emission which is seen only at the K-L position.

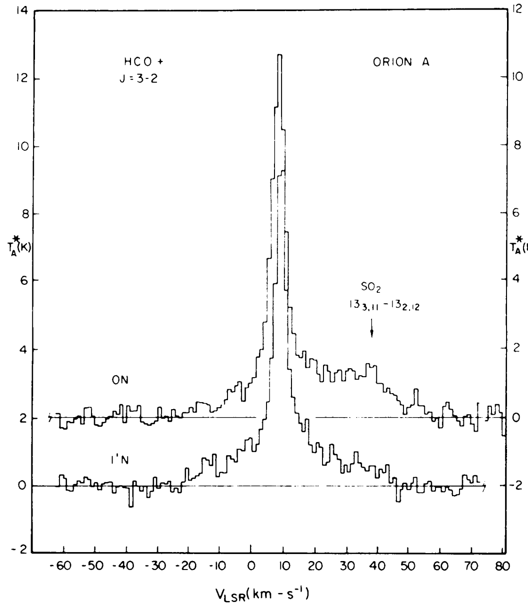

Figure 2. HCO^+ J=3-2 lines observed at the K-L position and 1'N in OMC-1. Both scales are for T_A^*.

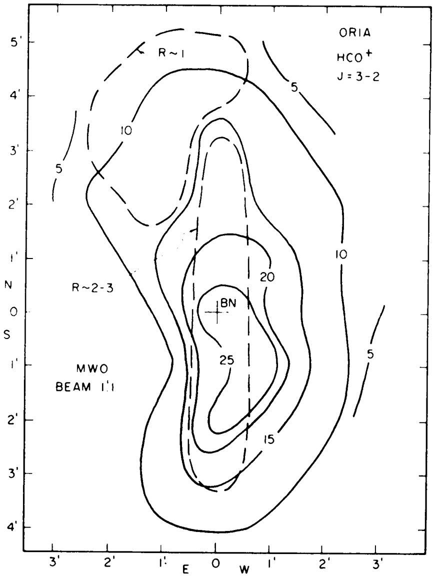

Figure 3. A map of HCO^+ J=3-2 emission in OMC-1. Contours are of T_R. $R \equiv T_R(3-2)/T_R(2-1)$.

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The most extensive map made during this observing run was of J=3-2 HCO^+ emission from OMC-1. Figure 3 shows the map which consists of 36 points with 1' spacings. Our map is similar to the map of J=1-0 emission published by Turner and Thaddeus (1977) in that the familiar N-S ridge can be seen in both maps. However, the J=3-2 map does not show a strong secondary peak at the 4'N 1'E position as is seen in the J=1-0 map. Both lines have comparable strengths at this position whereas the J=3-2 line is 2 to 3 times stronger than the J=1-0 line at the K-L position and along the N-S ridge. The two regions in question are labelled $R=T_R(3-2)/T_R(1-0)=1$ and $R=2\rightarrow3$ in Figure 3.

The strong HCO^+ J=3-2 lines by themselves indicate the presence of high density gas in OMC-1. The characteristic density, n, for this transition, defined by $nR_{23}\equiv A_{32}$, is $n\simeq5(+6)$ cm^{-3}, where the rate coefficient R_{23} for a kinetic temperature of 70K was estimated by extrapolating those given by Green (1975). A more realistic density estimate can be derived from the ratio R. Simple large-velocity-gradient (LVG) calculations show that R=1 corresponds to $n\simeq5(+5)$ cm^{-3} for a wide range of abundances $[n(HCO^+)/n=5(-12)\rightarrow10(-10)]$. The ratio has values larger than one only for optically thin lines. For $n(HCO^+)/n=5(-12)\rightarrow10(-11)$, $R=2\rightarrow3$ corresponds to $n\simeq10(+6)$ or greater. Densities of this order have been reported previously for the N-S ridge based on HC_3N (Morris et al. 1977) and H_2CO (Evans et al. 1979) observations. The validity of this density estimate depends on the accuracy of the line strengths. Our HCO^+ line temperature is 2.5 larger than that of Huggins et al. (1979). It is possible that there are significant contributions to the signal from extended HCO^+ lying outside the main beam of the 4.9-m antenna. Until these data are more carefully calibrated, the density estimate is tentative.

Figure 4 shows OMC-1 spectra of N_2H^+, H_2CO, HNC, and HCN. Our J=3-2 line intensities for HCN and HNC, after correction for beam efficiency, are in good agreement with those of Huggins et al. (1979). The N_2H^+ line shown in Figure 4 is for a position 4'N 1'E of K-L; the line is weaker for the K-L position. Again, as for HCO^+, the J=3-2 and J=1-0 N_2H^+ lines are comparable in strength at the 4'N 1'E position and the J=3-2 line is 2 to 3 times stronger than the J=1-0 line at the K-L position. The similar behavior in the OMC-1 maps of the ratio R for both N_2H^+ and HCO^+ is not unexpected. Both molecules have little optical depth in OMC-1 and the ratio R reflects the excitation, which should be similar for the two molecules because their collisional cross sections are similar. The fact that the line strengths themselves for both transitions of N_2H^+ are stronger at the 4'N 1'E position than at K-L, with the reverse true for HCO^+, means the N_2H^+/HCO^+abundance ratio changes between these two positions in OMC-1, as concluded by Turner and Thaddeus (1977).

The plateau component is just visible at roughly 20% of the spike component strength in the H_2CO 4_{14}-3_{13} profile for the K-L position. We have not yet incorporated this line in a model of all the observed H_2CO lines in OMC-1. The 4_{14}-3_{13} line strength seen in S140 is roughly consistent with our model for that source.

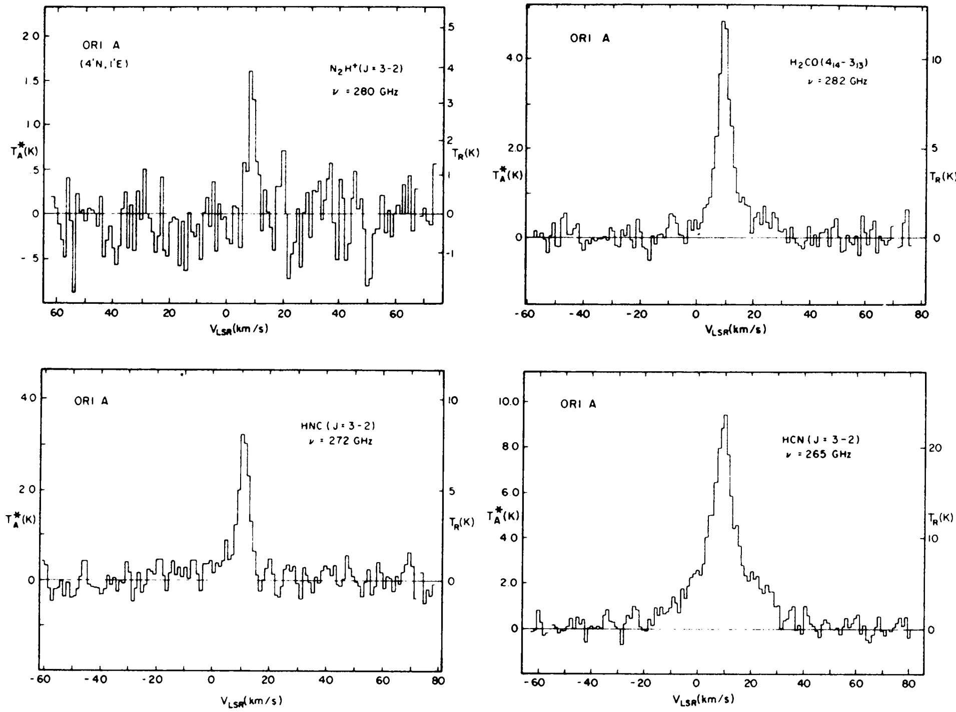

Figure 4. Spectra of N_2H^+, H_2CO, HNC, and HCN emission from the K-L position in OMC-1 except the N_2H^+ line is for a position 4'N 1'E of K-L. The T_R scale assumes a beam efficiency of 40%.

The HCN J=3-2 line profile for the K-L position clearly shows both spike and plateau components; only the spike component is visible in the HNC J=3-2 profile. The ratio R is about R=2 for both spike and plateau components of HCN and for the spike component of HNC, using the J=1-0 data of Gottlieb et al. (1975) for HCN and of Snell and Wootten (1979) for HNC. Again, a ratio larger than unity is indicative of small optical depths. The ratio is less than that observed for HCO^+ but this is expected because the characteristic density for excitation of the HCN J=3-2 line is roughly ten times larger than that for HCO^+.

These initial observations and results indicate both the richness of the spectrum in this band and the possibilities high-frequency observations offer for determining the properties of galactic molecular clouds. This work was supported by NSF Grant AST 75-13511 and AST 77-28475.

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DISCUSSION FOLLOWING VANDEN BOUT

Kuiper: Do you have any information on the extent and position of the "plateau" source in Orion? Besides the one spectrum taken 1' north of KL, is there any other evidence for extended HCO^+ "plateau" emission?

Vanden Bout: The other positions in our HCO^+ map have sufficient signal to noise to define the spike component intensity but not to reveal weak plateau-component emission, so we cannot say if the broad emission is extended beyond KL and 1' north.

Guelin: An HCN 2-1 strip map in Orion A made by Thaddeus and myself shows the plateau to fall down very quickly off the KL position ($\lesssim$2').

Goldsmith: High velocity dispersion emission in the $J=3\rightarrow2$ transition of CS has been detected with the 14-m FCRAO antenna near the KL position. The center is between 0" and 30" north of KL, and the size $\lesssim$40", but signal to noise ratio is the limiting factor.

Winnewisser: Do you have any idea of the optical depth of the 280 GHz lines. How useful are these lines for isotopic substitution?

Vanden Bout: Given the line strengths and kinetic temperature of OMC-1, it is difficult to see how these lines can be optically thick unless the excitation is severely sub-thermal. Our LVG calculations indicate that it is not, and the lines are optically thin, so they may be suitable for isotopic abundance measurements in Orion; other HCO^+ sources may well have optically thick J=3-2 lines because several self-reversed J=1-0 profiles are known.