DETECTION OF SUBMILLIMETER LINES OF CO (0.65 mm) AND H_2O (0.79 mm)

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The 91.5 cm telescope of NASA's Kuiper Airborne Observatory has been used, in conjunction with an InSb heterodyne receiver, to detect the J = 4-3 submillimeter transition of CO (461 GHz) and the 4_{14}-3_{21} transition of H_2O (380 GHz). The water emission was detected from the Orion "plateau" region.

1. INTRODUCTION

The submillimeter portion of the spectrum is important for molecular astronomy because it contains the fundamental transitions of many of the simple hydride molecules, and also major cooling lines of abundant molecules such as CO and possibly H_2O. Observations in the submillimeter require low atmospheric water vapor, so that an ideal telescope for initial studies is that of the NASA Kuiper Airborne Observatory. Here we report some line detections with that telescope at wavelengths in the 0.8-0.6 mm range. An InSb heterodyne bolometer receiver was used in conjunction with a diode harmonic generator for local oscillator (LO) power. System temperatures varied from 400-1500 K depending on the amount of LO power available.

2. CO (J=4-3)

Figure 1 shows a spectrum of CO (J=4-3) in the direction of the Becklin-Neugebauer-Kleinmann-Low (BNKL) region of the Orion molecular cloud. As usual for CO both narrow line and broad line components are observed coming from the extended cloud and compact "plateau" region respectively. The line center is found to be at a velocity of 9 km/sec (LSR) using the calculated frequency of 461.0408 GHz (Lovas and Tiemann, 1974). Since our beam size is about 2.5 arc min and the plateau source size for CO is about 50 arc sec (as determined from J = 2-1 measurements using the OVRO 10 m telescope--to be published separately), the broad line is severely diluted. For the narrow line, probably the most immediately striking point is that there is still no

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self-reversal feature, even with the very large opacity in the 4-3 line. It seems that the large cloud is probably heated from the front (or by a not too deeply imbedded source) if there is to be so little foreground cool gas.

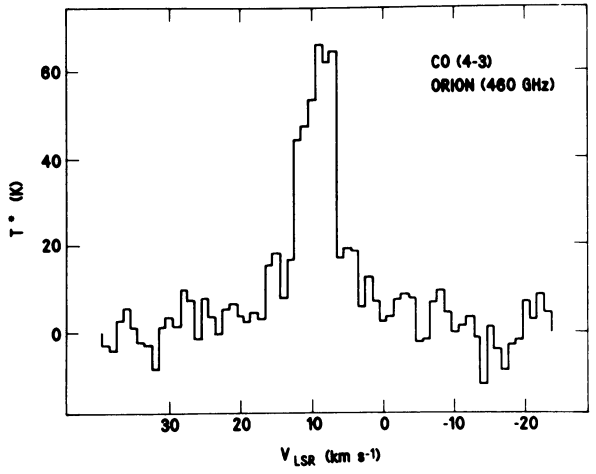

Figure 1. CO (J=4-3) in the direction of BNKL.

3. H_2O (4_{14}-3_{21})

Interstellar water was detected by the powerful masing 6_{16}-5_{23} (22 GHz) transition (Cheung et al, 1968) and has recently been observed in the 3_{13}-2_{20} transition (Waters et al, 1979) and in the $H_2^{18}O$ line (Phillips et al, 1978). The 3_{13}-2_{20} observations have lead to an abundance estimate relative to H_2 of about 10^{-5} and an explanation of this high value has been given by Elitzur (1979) in terms of shock chemistry. That explanation may well be appropriate since the observations were made in the direction of BNKL, where it is currently thought that the observed "plateau" lines and H_2 vibration-rotation lines are due to shock waves (e.g. Kwan, 1977; Hollenbach and Shull, 1977; Kwan and Scoville, 1976).

Figure 2 is a spectrum of the 4_{14}-3_{21} line towards BNKL. The rest frequency is given by DeLucia et al (1972) as 380.1974 GHz. The shape and width of the line are more typical of the plateau source rather than the large cloud, so that a discussion of excitation under the physical conditions of the plateau region is appropriate. To get a value for the brightness temperature of the source we need to know the beam dilution factor. The beam size at 380 GHz is 3 arc min

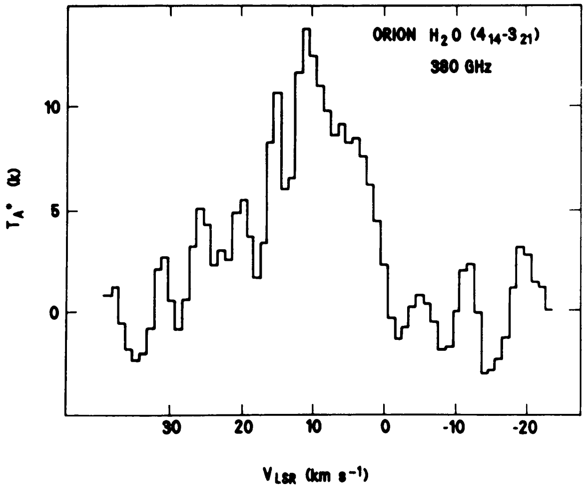

Figure 2. H_2O $(4_{14}$-$3_{21})$ in the direction of BNKL.

and the source size presumably lies in the range between 50 arc sec found for CO (see above) and 30 arc sec found for SO_2 (Phillips et al, 1980). Consequently the brightness temperature for H_2O $(4_{14}$-$3_{21})$ would be between 160 and 430 K. Assuming a source density of 10^7 H_2 molecules per cm^3, a velocity gradient of 50 km s^{-1} per 3×10^{17} cm and a gas temperature of 100 K, we find from an excitation calculation a brightness temperature of > 160 K in the abundance range $[H_2O]/[H_2] = 10^{-6}$-2×10^{-5}. Within that range the brightness temperature peaks at $\sim$ 500 K. The observations and calculations are consistent with peak maser ($-\tau \lesssim 3$) action for both the 4_{14}-3_{21} and 3_{13}-2_{20} lines from the plateau source.

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DISCUSSION FOLLOWING PHILLIPS

Hollenbach: There seems to be some disagreement in the literature about the theoretical gas-phase abundance of H_2O in *cold* molecular gas. Is it well established that the H_2O in Orion is necessarily produced behind the shock in the *hot* gas?

Phillips: In the case of $H_2{}^{16}O$ the smallest beamwidth used is 3 arc min so that there is no direct proof that H_2O is confined to the hot region. However, the deduced brightness temperatures of >160 K and the observed linewidths of ∿50 km/sec imply that the H_2O is produced behind the shock. Attempts to observe $H_2{}^{16}O$ lines in cold gas regions have been unsuccessful.

Black: What is the ratio of abundances of ortho and para species of H_2O?

Phillips: Lines of both species have been detected in the Orion plateau source. The observations seem to be consistent with an ortho to para ratio of 3:1, but the errors are at least a factor of 2.

Kuiper: The shock chemistry depends largely on the effect of increased temperature on temperature-sensitive reactions. The SO_2 plateau observations of Pickettt and Davis (Ap.J. 1979, 227, 446), as well as those reported by you, indicate that SO_2 in the plateau is in thermodynamic equilibrium at 70 K. Even if the plateau region was originally shocked, the absence of any residual temperature effects makes it doubtful whether an H_2O enhancement could be attributed to a shock.

Phillips: The current temperature of the region is not relevant to the temperature at the time of the formation of the molecules. Once formed, the water will obviously remain until chemically converted into something else. The time scale for the conversion would have to be worked out.

Kuiper: A search with a typical sensitivity of 0.2 K was made on the Kuiper Airborne Observatory for the 380 GHz line of water by de Graouw, Lidholm, van Vliet, Nieuwenhuyzen, van de Stadt (U. of Utrecht), and myself. The sources included the molecular clouds M17, W51, W49, Sgr B2, ρ Oph, and L134, the star χ Cygni, and the galaxy M101. The line was not detected. This result, coupled with the detection reported here by Phillips et al., suggests that the excitation of this transition bears some similarity to that of the 183 GHz transition (Waters et al., Ap.J., 1980, in press).