RADIO DETECTION OF H$_2$O IN COMET BRADFIEL (1974b)

W. M. Jackson, T. Clark and B. Donn

The present authors (Clark et al., 1971) previously attempted to detect the 1.35 cm microwave line of water in Comet Bennett (1969) using the 26 m Maryland Point radio telescope of the Naval Research Laboratory. An upper limit for the H$_2$O column density of $10^{17}$ molec/cm$^2$ was obtained assuming the rotational levels were in thermal equilibrium. A more recent search in Comet Kohoutek using the 37 m radio telescope of the Haystack Observatory with a low noise traveling wave maser preamplifier was also unsuccessful. In this comet the identification of H$_2$O$^+$ in the visible spectrum gave strong support to the idea of water as a major parent molecule. The radio detection of HCN (Heubner et al., 1974) and CH$_3$CH$_2$ (Uhlich and Conklin, 1974) in Comet Kohoutek suggested that the attempt to detect H$_2$O should be repeated in a suitable comet.

The present paper discusses the successful detection of H$_2$O in Comet Bradfield (1974b) using the Haystack telescope when the heliocentric and geocentric distances were 1.22 A.U. and 1.15 A.U. respectively. At 1.35 cm this antenna has a main-beam half-width of 1.5 arc min. and an efficiency of 0.33. The traveling wave maser was used with a 100 channel autocorrelator operating at a 667 KHz bandwidth. The average system temperature for these observations was 158$^\circ$K. An observing sequence of 10 minutes on the comet...
and 10 minutes off was employed. Each off source scan was taken along the azimuth evaluation path on the sky that the comet would traverse ten minutes later. This procedure compensated for gross atmospheric and instrumental effects and sky background. Some on source runs were made with the antenna intentionally displaced one half beam width on the sunward or tailward side of the comet. Cometary positions for pointing purposes were based on ephemerides supplied by B. Marsden.

The results are summarized in Figure 1 for runs taken when pointing at the comet position and in Figure 2 for runs with the telescope pointed one half beam width on the sun or tailward side. All twelve 20 minute on-off scans on the comet show some signal excess at the -0.82 km/sec feature which we identify as the H$_2$O transition. It is therefore unlikely that this feature is an artifact. Figure 2 also shows the H$_2$O feature although the signal is weaker. Because of reduced integration time the noise is worse.

This data supplies strong evidence for the detection of the 1.35 cm (22.2 GHz) emission line of water in Comet Bradfield with a peak antenna temperature of 0.15$^{0}$K and a FWHM of 0.4 km/sec. The -0.82 km/sec line shift from Marsden's ephemeris is several orders of magnitude larger than any possible errors in the calculations. The decrease in signal by $\sim 1/3$ when the telescope is shifted 1/2 beam width from the predicted position of the comet indicates an intrinsic source size of $\lesssim$ 10-15 arc sec.

There are serious difficulties with the interpretation and further analysis of these results. Reliable column
densities and in turn water production rates, Q, can be readily obtained only if the rotational levels are in thermodynamic equilibrium with a Boltzmann distribution over rotational states. This is questionable in the case of comets as the density is low near the nucleus and falls off rapidly. The treatment of Clark et al. (1971) based on the equilibrium assumption yields an average column density \(<N>\) of \(2 \times 10^{16}\) molec/cm\(^2\). A temperature of 240\(^{\circ}\)K calculated from the measured FWHM was used.

Heubner and Snyder (1970) have derived a relationship between \(<N>\) and Q:

\[
Q = \frac{v\Delta^2 \theta^2 <N>}{16r_o}
\]  

(1)

Where \(\Delta = \) geocentric distance, \(v = \) expansion velocity, \(\theta = \) half power beam width and \(r_o = \) radius of molecular cloud. All of these are known or may be reliably estimated except \(r_o\). They defined \(r_o\) as \(v\tau\) where \(\tau\) is the photodissociation lifetime. Bertaux et al. (1974) obtained a value of approximately 30 hours which makes \(r_o = 5.7 \times 10^4\) km. Equation (1) yields a water production rate of \(3.4 \times 10^{29}\) molec/ster sec. A comparison with other derivations of production rates of parent molecules is given in Table 1. It is seen that our value is an order of magnitude larger except for the \(\text{CH}_3\text{CN}\) result. The two other water results are based on ultra-violet observations of H and OH fragments. As the photochemistry of water and the optical excitation of the fragments are well understood, it seems likely that these results are substantially correct. HCN is detected by the \(J = 1-0\)
<table>
<thead>
<tr>
<th>Molecule</th>
<th>A.U.</th>
<th>Molec/sec sterad.</th>
<th>Comet</th>
<th>Method</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_2O$</td>
<td>1.0</td>
<td>$2.6 \times 10^{28}$</td>
<td>Bennett (1969i)</td>
<td>OGO-5, H atom profiles</td>
<td>Bertaux et al (1974)</td>
</tr>
<tr>
<td>$H_2O$</td>
<td>0.43</td>
<td>$2 \times 10^{28}$</td>
<td>Kohoutek (1973f)</td>
<td>Sky Lab</td>
<td>Carruthers et al (1974)</td>
</tr>
<tr>
<td>$H_2O$</td>
<td>1.2</td>
<td>$3.4 \times 10^{29}$</td>
<td>Bradfield (1974b)</td>
<td>Radio Observation</td>
<td>This work</td>
</tr>
<tr>
<td>CH$_3$CN</td>
<td>0.8</td>
<td>$10^{30}$</td>
<td>Kohoutek (1973f)</td>
<td>Radio Observation</td>
<td>Uhlich &amp; Conklin (1974)</td>
</tr>
<tr>
<td>HCN</td>
<td>0.4</td>
<td>$\sim 5 \times 10^{26}$</td>
<td>Kohoutek (1973f)</td>
<td>Radio Observation</td>
<td>Heubner et al (1974)</td>
</tr>
</tbody>
</table>
transition and no excitation problem occurs. Methyl cyanide is detected by emission from excited state comparable to that of water and a similar, as yet unknown, excitation process occurs.

A more careful analysis of the excitation of water and methyl cyanide in comets is required and preliminary considerations are now given. The upper level of the 6_{16} - 5_{23} H_{2}O transition lies 447 cm\(^{-1}\) above the ground rotational level. In order to maintain thermodynamic equilibrium, collisional pumping rates of all levels must be larger than the radiative decay rates. The principal mode of radiative decay of the 6_{16} level is via the 6_{16} - 5_{05} transition with a lifetime of about 1 sec (Buhl et al., 1969).

To a first approximation the steady state condition is given by equating radiative and collisional lifetimes. The approximation neglects the details of the system in which there are numerous rotational levels with radiative and collisional transitions among them. It also cancels Boltzmann factors for rotational and translational populations. We write for the lifetime \(\tau_c\) of collisional processes:

\[
\tau_c = (\nu_{\text{col}})^{-1} \lesssim 1 \text{ sec}
\]  

where \(\nu\) is the thermal velocity.

As the principle constituent is assumed to be water, rotational excitation will be governed by a dipole-dipole potential. This leads to cross-sections for rotational excitation of the order of 1000\(\AA^2\) (Levine and Bernstein, 1974).
With $v = 10^4$ cm/sec, the water density must be greater than $2.5 \times 10^8$ cm$^{-3}$. The fluid dynamic model of comets (Jackson and Donn, 1966) predicts densities of this order at 1600 km from the nucleus for water production rates of $10^{29}$ molec/sec ster. This radius for the cloud is a factor of 40 less than that used to calculate the water production rate from Equation (1). The assumption of thermodynamic equilibrium leads to an inconsistency and production rates for molecules detected in excited rotational states may not be calculated on such an assumption.

Some other mechanism of rotational excitation than molecular collisions is required. Recent calculations by Itikawa (1972) have yielded cross-sections for rotational excitation of water by 0.01 ev electrons of the order of $10^{-13}$ cm$^2$. Even this large cross-section would require an electron density comparable to the particle density. An anomalous excitation of the $6_{16} - 5_{23}$ water transition is observed in the interstellar water masers requiring a non-equilibrium excitation mechanism. A suggestive process is infra-red pumping as described by Litvak (1972). Such a scheme may also work for comets. The cometary system is known in considerable detail and a comprehensive analysis for cometary $\text{H}_2\text{O}$ and $\text{CH}_3\text{CN}$ emission would be very valuable.

The more favorable observing conditions with Comet Bradfield compared to Comet Kohoutek appear to account for the detection of water in Bradfield for the first time. Comet Bradfield was nearly circumpolar ($\delta=87^\circ$) at the time of our observations. Hence we were able to observe for
longer times without suffering extensive atmospheric attenuation. Comet Halley will also be favorably located and will be a good candidate for further water observations.
Figure 1. 1.35 cm (22.2 GHz) water transition. Sum of all scans centered on comet position.

Figure 2. 1.35 cm (22.2 GHz) water transition. Sum of scans displaced 1/2 beam width in sun or tail direction.
REFERENCES

11. Snyder, L.E., 1975, These Proceedings.