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RADIO DETECTION OF H_2O IN COMET BRADFIELD (1974b)

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The present authors (Clark et al, 1971) previously attempted to detect the 1.35 cm microwave line of water in Comet Bennett (1969i) using the 26 m Maryland Point radio telescope of the Naval Research Laboratory. An upper limit for the H_2O 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_2O^+ 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_3CH (Uhlich and Conklin, 1974) in Comet Kohoutek suggested that the attempt to detect H_2O should be repeated in a suitable comet.

The present paper discusses the successful detection of H_2O 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°K. An observing sequence of 10 minutes on the comet

D13

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_2O transition. It is therefore unlikely that this feature is an artifact. Figure 2 also shows the H_2O 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 $0.15^{\circ}K$ 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 $\leqslant$ 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 questionnable 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 x 10^{16} molec/cm^2. A temperature of 240°K calculated from the measured FWHM was used.

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

$$Q = \frac{v\Delta^2 \theta^2 <N>}{16 r_o} \qquad (1)$$

Where Δ = geocentric distance, v = expansion velocity, θ = 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 τ 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 x 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 CH_3CN result. The two other water results are based on ultraviolet 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 1

Production Rates of Parent Molecules

Molecule	A.U.	Molec/sec sterad.	Comet	Method	Reference
H_2O	1.0	2.6×10^{28}	Bennett (1969i)	OGO-5 H atom profiles	Bertaux et al (1974)
H_2O	0.43	2×10^{28}	Kohoutek (1973f)	Sky Lab	Carruthers et al (1974)
H_2O	1.2	3.4×10^{29}	Bradfield (1974b)	Radio Observation	This work
CH_3CN	0.8	10^{30}	Kohoutek (1973f)	Radio Observation	Uhlich & Conklin (1974)
HCN	0.4	$\sim 5 \times 10^{26}$	Kohoutek (1973f)	Radio Observation	Heubner et al (1974)

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_2O transition lies 447cm^{-1} above the ground rotational level. In order to maintain thermodynamic equilibrium, collosional 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 τ_c of collisional processes:

$$\tau_c = (v\sigma n)^{-1} \lesseqgtr 1 \text{ sec} \qquad (2)$$

where v 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$\overset{\circ}{A}{}^2$ (Levine and Bernstein, 1974).

With $v = 10^4$ cm/sec, the water density must be greater than 2.5×10^8 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 H_2O and CH_3CN 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 (δ=87°) 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.

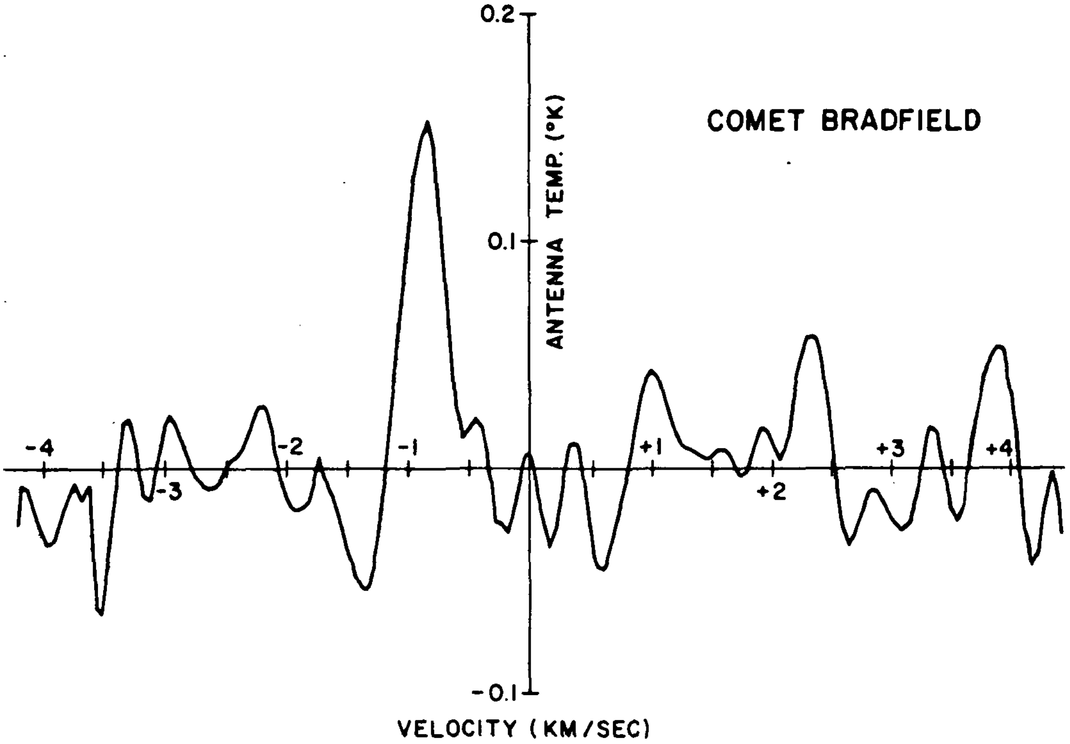

Figure 1. 1.35 cm (22.2 GHz) water transition. Sum of all scans centered on comet position.

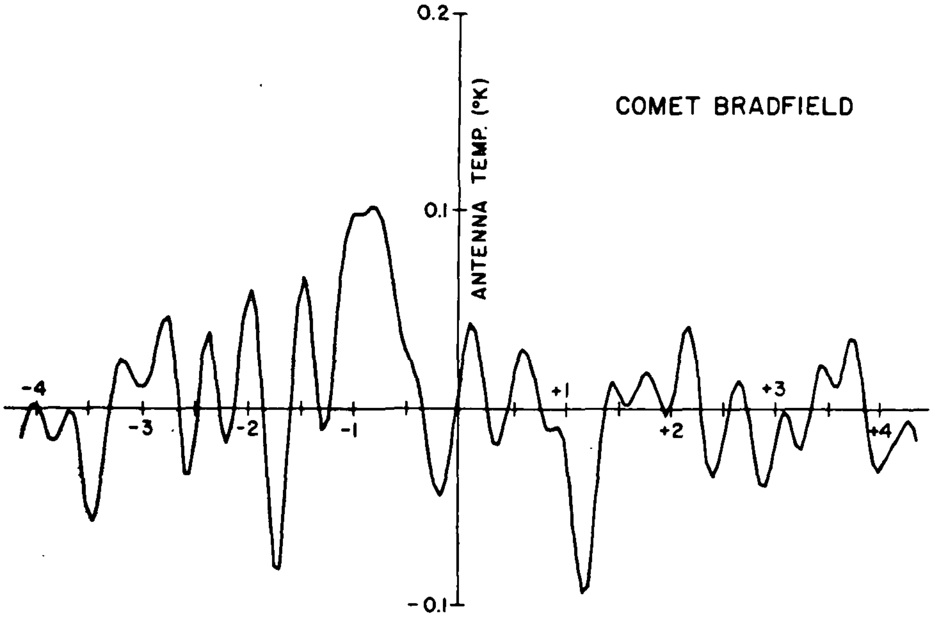

Figure 2. 1.35 cm (22.2 GHz) water transition. Sum of scans displaced 1/2 beam width in sun or tail direction.

REFERENCES

1. Bertaux, J.L., Blamont, J.E., and Festou, M., 1974. Astron. and Astrophys., 25, 415.
2. Buhl, D., Snyder, L., Schwartz, P.R., and Barrett, A.H., 1969, Ap. J., 158, L97.
3. Carruthers, G.R., Opal, C.B., Page, T.L., Meier, R.R., and Prinz, D.K., 1974, Icarus, 23, 526.
4. Clark, T.A., Donn, B., Jackson, W., Sullivan, W.T., and Vanderberg, N., 1971, Astron. J., 76, 614.
5. Heubner, W.F., and Snyder, L.F., 1970, Astron. J., 75, 759.
6. Heubner, W.F., Snyder, L.S., and Buhl, D., 1974, Icarus, 23, 580.
7. Itikawa, Y., 1972, J. Phy. Soc. Japan, 32, 217.
8. Jackson, W.M., and Donn, B., 1966, Colloque Int. Astrophys., Liege, 1965, p. 133.
9. Levine, R.D., and Bernstein, R.B., 1974, "Molecular Reaction Dynamics", Oxford University Press, p. 152.
10. Litvak, M.M., 1972, in Molecules in the Galactic Environment, ed. M.A. Gordon and L.E. Snyder (New York, Wiley), p. 267.
11. Snyder, L.E., 1975, These Proceedings.
12. Uhlich, B.L. and Conklin, E.K., 1974, Nature, 248, 121.