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RADIO OBSERVATIONS OF COMET BRADFIELD (1979l)

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ABSTRACT

A radio search was conducted for the $F=1-1$ and $F=1-0$ components of OH in the $^2\Pi_{1/2}$, $J=1/2$ state; H111α; the $1_{01}-1_{11}$ transition of H_2CO; the $2_{11}-2_{12}$ E-state transition of $HCOOCH_3$; the $6_{16}-5_{23}$ transition of H_2O; the 3,3–3,3 transition of NH_3; and U8.18883. No spectral lines were detected. Our derived upper limit to the H_2O production rate, $\sim 7.4\times10^{30}$ molecules s^{-1}, is much larger than the rate inferred from observations of OH ultraviolet bands in this comet. This suggests that future searches for neutral water emission from comets should emphasize the $3_{13}-3_{20}$ transition at 183.3 GHz, which must be observed from above all or most of the terrestrial atmosphere.

Subject headings: comets — line identifications — radio sources: lines

I. INTRODUCTION

We searched the radio spectrum of Comet Bradfield (1979l) for specific transitions of the hydroxyl radical, formaldehyde (H_2CO), methyl formate ($HCOOCH_3$), water, ammonia, a hydrogen recombination line, and a previously reported unidentified spectral feature (U8.18883) of possible cometary origin. These observations were intended to elucidate the composition of the coma in terms of parent molecules and daughter radicals and, in the case of the recombination line, perhaps to provide information on ionization-generating processes in the cometary medium (see Brandt and Mendis 1979). While not necessarily abundant in comets, H_2CO and $HCOOCH_3$ certainly are ubiquitous in interstellar molecular clouds (see Zuckerman *et al.* 1970; Hollis *et al.* 1980) and thus may be of special interest in investigating possible relationships between interstellar matter and the nature of comets. An unidentified line, U8.18883, was possibly detected by Giguere and Clark (1975) in Comet Kohoutek (1973 XII). They suggested that this transition might be unique to comets, apparently because J. K. G. Watson (quoted by those authors) tentatively assigned it to NH_2, which would be difficult to observe in a typical interstellar cloud. However, since making the present observations, we learned of a report that invalidates this identification (Cook, Hills, and Curl 1976).

II. INSTRUMENTATION

The OH, H, H_2CO, and $HCOOCH_3$ observations were made with the 43 m telescope of the National Radio Astronomy Observatory during 1980 February 5–9. The NRAO 6 cm cooled parametric amplifier receiver was tunable within the range 4470–5050 MHz; system temperatures ranged from 68 to 77 K during the observations. At 4800 MHz, the half-power beamwidth is $\sim 6\overset{'}{.}2$ and the beam efficiency is $\sim 76\%$. The 413 channel autocorrelation spectrometer was operated in the 384 channel series mode and an offset oscillator was used to enable dual-frequency observations on February 5–6 and 8–9. Transitions of the known interstellar lines of OH, H, and H_2CO that we searched for in the comet were also observed in galactic sources to demonstrate proper system operation. The comet observations utilized the overlapping frequency-switching technique for transitions of H, H_2CO, and $HCOOCH_3$, which allows an observed spectrum to be shifted by the amount of the frequency displacement and folded to gain $\sqrt{2}$ improvement in the peak-to-peak noise. OH was searched for by frequency switching out of the bandpass. The observations were calibrated by measurements of a noise tube. The 43 m antenna temperatures have not been corrected for atmospheric and antenna losses, nor for the elevation dependence of antenna gain.

The H_2O, NH_3, and U8.18883 observations were made with the 36.6 m telescope at the Haystack Observatory during 1980 February 13–16. The Haystack

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K-band traveling wave maser radiometer (used for H_2O and NH_3 observations) was tunable within the range 21.8–25.0 GHz; system temperatures ranged from 90 to 180 K during the observations. At 22 GHz, the half-power beamwidth is ~1'.4 and the beam efficiency is ~25%. The two-stage cooled parametric amplifier used for the U8.18883 observations was tunable within the range 7.7–8.6 GHz; system temperatures ranged from 90 to 120 K during the observations. At 8 GHz, the half-power beamwidth is ~4'.2 and the beam efficiency is ~48%. The 1024 channel spectrometer was used in all Haystack observations. Transitions of known interstellar lines of H_2O and NH_3 that we searched for in Comet Bradfield were observed in galactic sources to demonstrate proper system operation. The 22 GHz and 8 GHz cometary observations were made in the total power mode, integrating off-source followed by an equal-duration integration on-source. The observations were calibrated by measurements of a noise tube. The 36.6 m antenna temperatures have not been corrected for antenna losses.

III. OBSERVATIONS

The specific transitions searched for in Comet Bradfield are the $F=1-1$ and $F=1-0$ components of OH in the excited doublet $\Pi_{1/2}, J=1/2$ state; the H111α recombination line; the $J_{K-K+}=1_{10}-1_{11}$ line of H_2CO; the $J_{K-K+}=2_{11}-2_{12}$ E-state transition of $HCOOCH_3$; the $J_{K-K+}=6_{16}-5_{23}$ line of H_2O; the $J, K=3,3-3,3$ transition of NH_3; and the U8.18883 (unidentified) line. The results of the search are summarized in Table 1. Columns (1), (2), (3), (5), (7), and (8) are self-explanatory. No transition was detected. The antenna temperatures in column (4) are the line detection limits corresponding to the peak-to-peak noise in the spectra. Column (6) gives the autocorrelator resolution per channel. Column (9) gives the geocentric radial velocity search range. All of the search ranges were broad, since comets typically have multiple velocity-component spectral features in OH emission, at least one of which is centered at the cometary geocentric radial velocity (see Snyder *et al.* 1976). A typical OH emission line in a comet has a FWHM ~2.5 km s^{-1} (Bowers and A'Hearn 1976; Webber and Snyder 1977).

IV. DISCUSSION

The present negative results may be due to the beam dilution (where appropriate) or to low column density of emitting species. The latter situation might arise from a low dust-to-gas ratio in Comet Bradfield (Feldman *et al.* 1980); the circumstance that the comet was well past perihelion during our observations may also be relevant. Finally, the species sought may in some cases simply be absent from the comet, or the excitation conditions may be nonconducive to emission of the searched-for lines.

Although more precise models are available (Haser 1957; Festou 1978), the simple fluid dynamical approach of Huebner and Snyder (1970) will suffice to derive a conservative upper limit to the water production rate. This model assumes a species radial density distribution that varies as the inverse square of the distance from the center of the source. For the H_2O source, which should be comparable to the beam size in the present observations, the production rate in units of molecules s^{-1} is

$$Q=\frac{\langle N\rangle \pi v \Delta^2 \theta^2}{4r_0}, \quad (1)$$

where $\langle N\rangle$ is the column density of water averaged over the beam, v is the mean thermal expansion velocity, Δ is the geocentric distance, θ is the beamwidth (1'.4), and r_0 is the characteristic distance from the

TABLE 1

COMET BRADFIELD DATA SUMMARY

Species (1)	Transition (2)	Frequency (MHz) (3)	T_A[a] (K) (4)	1980 Date Feb. (5)	Spectral Resolution (kHz) (6)	Geo. Dist.[b] (AU) (7)	Helio. Dist.[b] (AU) (8)	Velocity Observed[c] (km s^{-1}) (9)
OH.........	$^2\Pi_{1/2}$ $J=1/2$ $F=1-1$	4750.656	<0.06	5, 6	6.510	0.48	1.12	+21.3→+ 99.9
OH.........	$^2\Pi_{1/2}$ $J=1/2$ $F=1-0$	4765.562	<0.06	5, 6	6.510	0.48	1.12	+21.3→+ 99.9
H	111α	4744.183	<0.04	7	52.083	0.54	1.15	−96.2→+219.9
H_2CO.......	$1_{10}-1_{11}$	4829.664	<0.05	8, 9	6.510	0.58	1.17	+43.0→ +81.8
$HCOOCH_3$..	$2_{11}-2_{12}$E	4827.926	<0.06	8, 9	6.510	0.58	1.17	+43.0→ +81.8
H_2O........	$6_{16}-5_{23}$	22235.080	<0.09	13, 14	10.851	0.76	1.25	+33.4→ +93.3
NH_3........	3,3–3,3	23870.128	<0.08	14, 15	10.851	0.80	1.27	+35.5→ +91.3
U8.18883....	...	.8188.83	<0.10	15, 16	4.883	0.84	1.28	+36.0→+100.0

[a] Peak-to-peak noise level.

[b] Based on the following ecliptic (1950.0) orbital elements obtained from Marsden 1980: $T=2444229.10888$, $\omega=257^\circ.59705$, $\Omega=102^\circ.50788$, $i=148^\circ.60420$, $q=0.5452940$ AU, $e=0.9880083$.

[c] Comet radial velocity relative to Earth monotonically increased from 60.6 to 63.5 km s^{-1} during these observations.

center at which the molecules are destroyed by photodissociation ($\sim 5\times 10^4$ km). For a thermal equilibrium temperature of 150 K (Snyder, Huebner, and Buhl 1975), $v(H_2O)\approx 0.3$ km s^{-1}. If the source fills the beam and is optically thin,

$$T_a=\eta_B T\bar{\tau}, \qquad (2)$$

where $\eta_B=0.25$ is the antenna beam efficiency and the optical depth at line center for an asymmetric molecule such as H_2O, averaged over the beam, is

$$\bar{\tau}=\frac{8\pi^{5/2}h^{3/2}(\mathrm{ABC})^{1/2}e^{-\varepsilon/kT}}{3ck^{5/2}}\frac{\langle N\rangle \mu^2 S\nu^2}{T^{5/2}\Delta\nu}, \qquad (3)$$

according to Snyder (1972). The H_2O rotational constants A, B, C, are 836, 435, and 278 GHz, respectively. The electric dipole moment $\mu=1.85$ Debyes; the transition strength, $S=0.06$; and the 5_{23} state energy, $\varepsilon=0.0554$ eV. The line width, $\Delta\nu$, which is broadened due to bulk and thermal motions, corresponds to $\sim$2.5 km s^{-1}. Solving for $\langle N\rangle$ from equations (2) and (3), we derive $Q(H_2O)<7.4\times 10^{30}$ molecules s^{-1} from our observations of the $6_{16}-5_{23}$ transition at 22,235.08 MHz. Since OH arises from the dissociation of H_2O, this is also an upper limit to the hydroxyl production rate, and it should be compared with the rate $Q(\mathrm{OH})\approx 2.5\times 10^{28}$ molecules s^{-1} at the same heliocentric distance, derived from IUE observations of OH emission in the ultraviolet (Weaver, Feldman, and Festou 1980). The highest cometary production rate derived from hydroxyl observations in the ultraviolet is $\sim 1\times 10^{30}$ molecules s^{-1} for Comet West (Opal and Carruthers 1977). This, coupled with the fact that our H_2O production rate upper limit is almost three orders of magnitude higher than that derived from observations of Comet Bradfield in the ultraviolet, underscores the difficult nature of ground-based radio observations of putative parent molecules in comets.

V. CONCLUSIONS

The literature assures us that complex molecules must be present in comets (*cf.* Potter and Del Duca 1964; Jackson 1976). Although detections of HCN (Snyder, Huebner, and Buhl 1975), CH_3CN (Ulich and Conklin 1974), and H_2O (Jackson, Clark, and Donn 1976) in earlier comets have been reported, all remain unconfirmed by independent work. With Comet Bradfield (1979l) as our target, an extensive radio search for previously unobserved or unconfirmed cometary emission lines was made. None was detected. Note that although the $3_{13}-3_{20}$ transition of H_2O at 183.3 GHz is not observable through the Earth's atmosphere, it is a more readily excitable transition than the $6_{16}-5_{23}$ line that we attempted to observe. Thus, barring substantial improvements in ground-based instrumentation, a suitably equipped space mission may be required to detect many of the parent molecular species such as H_2O in comets.

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