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WATER MASER EMISSION TOWARD V788 CYGNI, A CARBON STAR

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ABSTRACT

Radio emission lines of H_2O, SiO, HCN, and CO have been searched in the circumstellar envelopes of carbon stars which exhibit the 10 μm silicate feature in the *IRAS* low-resolution spectra. Water maser emission at 22 GHz has been detected in V778 Cyg. No other emission has been detected in the carbon stars BM Gem, V778 Cyg, and EU And. Two competing interpretations for this curious association of the silicate feature and the water maser with the carbon star, the transient stage hypothesis and the binary one, are examined based upon the present observations. Five other carbon stars and two S stars were also observed for comparison.

Subject headings: masers — stars: carbon — stars: circumstellar shells — stars: individual (V778 Cyg)

I. INTRODUCTION

Inspections of *IRAS* low-resolution spectra (hereafter LRS) (*IRAS* Science Team 1986) have shown that some carbon stars exhibit the 10 μm silicate feature (Willems and de Jong 1986; Little-Marenin 1986). This feature is usually associated with oxygen-rich stars but not with carbon stars. One possible interpretation of this curious combination of the carbon-rich photosphere and the oxygen-rich envelope is that we are observing a transition phase from an M-type star to a C-type star in the stellar evolution (Willems and de Jong 1986). Another possibility is that the 10 μm emission comes from the circumstellar envelope of a hidden M star which is orbiting around the carbon star (Benson and Little-Marenin 1987).

In order to investigate the chemistry of the circumstellar envelope of these peculiar objects, we have searched for H_2O, SiO, HCN, and CO radio lines in three of these sources, V778 Cyg, BM Gem, and EU And. Five other normal C stars and two S stars were added to the program to compare the line intensities. Emission lines of H_2O and SiO were searched to detect the oxygen-rich envelope, while the HCN line was chosen because it is an indicator of the carbon-rich envelope.

Benson and Little-Marenin (1987) independently observed EU And and BM Gem and detected a water maser emission toward EU And. In this *Letter* we report the detection of a water maser emission toward V778 Cyg.

TABLE 1
TELESCOPE PARAMETERS

Frequency (GHz)	System Temperature (K)	Half-Power Beamwidth	Beam Efficiency
22	200	86″	0.85
43	800	44	0.88
86	800	22	0.68
115	1100	18	0.45

II. OBSERVATIONS

Observations were made with the 45 m telescope at Nobeyama Radio Observatory[1] in 1987 April 30 to May 2 and May 23 to May 25. We used a cooled high electron mobility transistor amplifier (Kasuga *et al.* 1987) for the water vapor maser line and a cooled Schottky mixer receiver for SiO, HCN, and CO lines. Data were taken with two types of acousto-optical spectrometers, one with a resolution of 250 KHz and the other with 40 KHz. The observational parameters are listed in Table 1. The observations were carried out in a position switching mode with reference position offset by

[1] This work was carried out under the common use observation program at the Nobeyama Radio Observatory (NRO). NRO, a branch of the Tokyo Astronomical Observatory, University of Tokyo, is a cosmic radio-observing facility open for outside users.

TABLE 2

OBSERVATIONAL RESULTS

STAR NAME	R.A. (1950)	DECL. (1950)	H_2O	SiO					HCN	CO	V_{LSR} (km s^{-1})	TYPE
				$J = 1$–0			$J = 2$–1		$J = 1$–0	$J = 1$–0		
			6_{16}–5_{23}	$v = 0$	$v = 1$	$v = 2$	$v = 0$	$v = 1$	$v = 0$	$v = 0$		
			22.235	43.423	43.122	42.820	86.846	86.243	88.631	115.271		
V778 Cyg	$20^h35^m04^s.0$	+59°54′56″	2.0	< 0.10	< 0.11	< 0.09	< 0.18	< 0.16	< 0.15	< 0.22	−19	C4, 5J
BM Gem	7 17 55.2	+25 05 40	< 0.21	< 0.05	< 0.05	< 0.04	< 0.05	< 0.05	< 0.07	< 0.05	+88	C5,4J
EU And	23 17 37.3	+46 58 02	...	< 0.15	< 0.15	< 0.14	< 0.37	< 0.20	< 0.14	< 0.17	−52	C4,4
R And	0 21 23.0	+38 18 03	...	...	...	...	...	...	< 0.15	0.30 (8.0)	−6	S6,6e
CL Mon	6 52 55.9	+06 26 37	...	...	...	...	...	...	0.12(25.0)	0.18(20.0)	+28	C6,3e
R Gem	7 04 20.0	+22 46 57	...	...	...	...	...	...	< 0.13	0.30(14.6)	−52	S3,9e
RU Vir	12 44 45.8	+04 25 03	...	...	...	...	...	...	< 0.16	0.21(10.6)	+5	C8,1e

NOTE.—Antenna temperatures are given in the fourth to the eleventh columns. Numerals in parentheses are FWHM in km s^{-1}. The conversions from the antenna temperature to the flux density are 3.5, 4.7, and 6.7 Jy K^{-1} for the H_2O, HCN, and CO lines, respectively. Frequencies in GHz are listed below each transition. All the positions are referred to *IRAS Point Source Catalog* (1985). The V_{LSR}'s are the photospheric velocities calculated from Yamashita (1972, 1975), Dean (1976), and Wilson (1963). Types are adopted from Yamashita (1972, 1975), Dean (1976), and Stephenson (1976).

+10′ in azimuth. The telescope pointing was checked about every two hours on nearby SiO maser sources.

III. RESULTS

The observational results are summarized in Table 2, where the antenna temperatures have been corrected for the atmospheric attenuation and the gain loss.

a) H_2O

The H_2O maser emission was detected toward V778 Cyg on 1987 April 30. The five-point mapping with the 40″ offset from the center was carried out next day to check the possible contamination by other sources in this direction. The peak position was found to agree within 20″ of the *IRAS* position. A more accurate determination of the position was carried out later by the five-element interferometer at Nobeyama. The position is confirmed to coincide with the optical star position within 1″ (Deguchi *et al.* 1987). The spectrum is shown in Figure 1. The emission consists of three peaks, which indicates that the outflow in the envelope is not very smooth. Line parameters of the central peak are $F_{peak} = 7.0$ Jy, $V_{LSR} = -16.9$ km s^{-1}, and $\Delta V(\mathrm{FWHM}) = 1.0$ km s^{-1}.

H_2O emission was not detected toward BM Gem. The upper limit was 0.21 K. EU And was not included in the present program due to the limited observation time, but was later observed with the interferometer. Though the precise analysis is under way, the preliminary result indicates that the emission was below the detection limit. The vanishing of the maser in this object is probably in accordance with the intensity decline reported by Benson and Little-Marenin (1987).

It has been indicated that most carbon stars with the silicate feature are *J*-type carbon stars (Willems and de Jong 1986). Another common property among them is that they mostly have *IRAS* infrared color of $\log(F_{60}/F_{25}) < -0.8$, implying the silicate-like composition of the dust in their circumstellar shells. Therefore we have observed three carbon-rich objects Y CVn (C4, 5J) GL 2392 [$\log(F_{60}/F_{25}) = -0.80$], and GL 2881 [$\log(F_{60}/F_{25}) = -0.89$] to see if the H_2O maser emission was present toward them. None of them showed the H_2O 22 GHz emission. The upper limits are 0.35, 0.14, and 0.14 K for Y CVn, GL 2392, and GL 2881, respectively.

b) SiO, HCN, *and* CO

Because CO radio lines are good indicators of the mass loss and HCN of the carbon-rich chemistry, we have searched for these lines in BM Gem, V778 Cyg, and EU And to investigate the molecular envelopes of these stars.

We did not find any emission of CO or HCN in BM Gem, EU And, and V778 Cyg. The 3 σ detection limits are given in Table 2. Two S stars, R And and R Gem, and two C stars with thick carbon-rich envelopes, CL Mon and RU Vir, were also observed. The CO emission has been detected in all the four sources, while HCN was only seen in CL Mon.

We have searched for the SiO $J = 1$–0, $v = 0$, 1, and 2, and $J = 2$–1, $v = 0$, and 1 emissions. None of the lines were detected in the present program stars.

IV. DISCUSSION

The detection of water maser emission confirms that the circumstellar gas is oxygen-rich toward V778 Cyg, being consistent with the 10 μm silicate feature seen in the *IRAS* LRS of this object. This star has been classified from the optical spectroscopy as a *J*-type carbon star with high $^{13}C/^{12}C$ ratio (Yamashita 1975). The water maser emission has also been detected in EU And, another carbon star which exhibits the 10 μm silicate feature (Benson and Little-Marenin 1987). The excitation of the water maser has been explained by the collisional pumping (Deguchi 1977; Cook and Elitzur 1985). It is observed in an expanding shell between 10^{14} and 10^{15} cm from the star with a mass-loss rate of 5×10^{-7}–1×10^{-4} $M_\odot$ yr^{-1} (Reid and Moran 1981; Bowers and Hagen 1984; Johnston, Spencer, and Bowers 1985).

The interferometric observation (Deguchi *et al.* 1987) has shown that position of the water maser coincides with that of

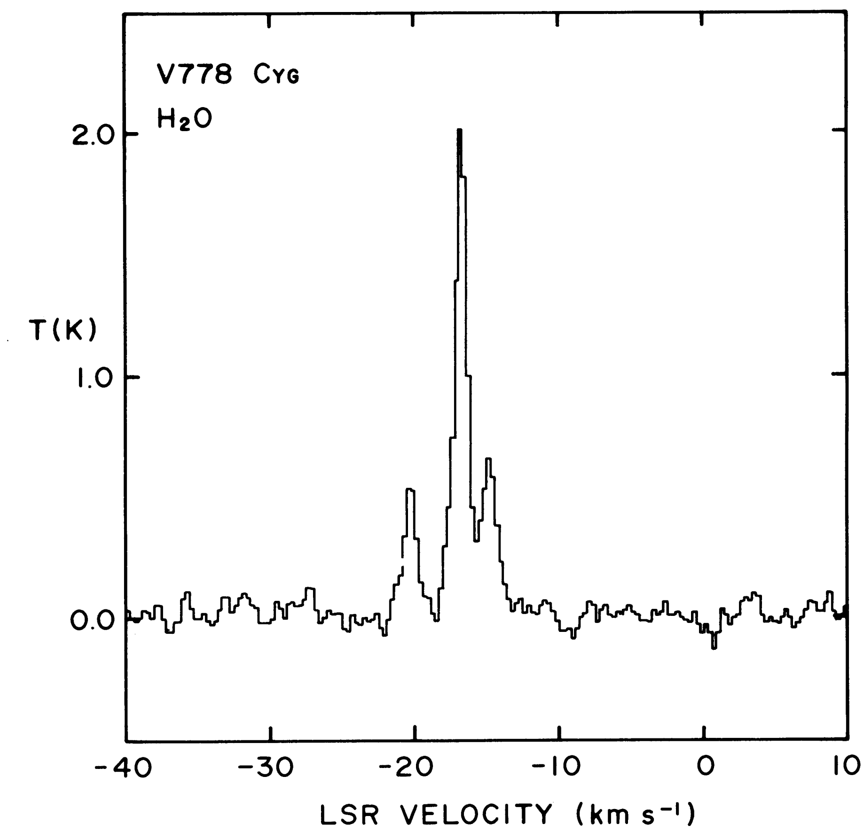

FIG. 1.—Spectrum of the H_2O maser emission in V778 Cyg at JD 2,446,916.12. The velocity resolution is 0.58 km s^{-1}

the optical star within 1″. Although the distance to V778 Cyg is uncertain, the derived value of 1″ seems consistent with the scale of the maser-emitting shell. The presence of three components in the water maser emission suggests that the mass flow in V778 Cyg may be turbulent. The velocity of the major maser peak ($V_{LSR} = -16.9$ km s^{-1}) is redshifted by only 2 km s^{-1} relative to the optical photometric velocity ($V_{LSR} = -19$ km s^{-1}; Sanford 1944). The photospheric velocity of stars usually falls within the range of 0 to 8 km s^{-1} relative to the stellar velocity which is determined from the thermal radio lines (Dickinson *et al.* 1978). Therefore, the radial velocity of oxygen-rich material would be 2 to 10 km s^{-1} relative to V778 Cyg. Contrary to the case of EU And, it is a moderate value for the outflow velocity.

There are now two competing interpretations for the curious association of the H_2O maser and the 10 μm feature with the carbon star. One is a straightforward interpretation that the carbon star is surrounded by the oxygen-rich envelope, and the other is that the visible carbon star forms a binary with an invisible M star which is brighter in the infrared. In the following we will discsuss the implications of our observations for the two interpretations.

According to the former interpretation, the strange chemistry of the circumstellar envelope can be understood if the star is in a transient state of evolution from an M star to a C star. In this case, the "silicate" feature and the water maser originate from the remnant shell of the past oxygen-rich stage of the star (Willems and de Jong 1986). The absence of the 11 μm "SiC" feature in these C stars is explained by a subsequent pause of the mass loss immediately after the transition (Willems 1987). Therefore there is no continuous change of the chemical composition in the envelope. The system consists of a newly born carbon star and a detached envelope of oxygen-rich material. Benson and Little-Marenin (1987) pointed out that the large relative velocity of water maser (24 km s^{-1}) in EU And is not typical for C stars. However, if the molecular envelope has been ejected from an M-type progenitor, the expansion velocity might have been large.

We have not detected either CO or HCN lines toward BM Gem, V778 Cyg, or EU And. Though little can be said from the present upper limit, the negative detection is at least consistent with the above idea that the mass loss stops for some time after the transition. Our negative detection of SiO maser emission also supports this interpretation, since the vicinity of the star, where the SiO maser emerges, is expected to have already turned into carbon-rich composition.

The second possibility is that the object is composed of a binary system of a carbon star and an M-type star (Benson and Little-Marenin 1987). The oxygen-rich material is provided by mass loss from the M star. This hypothesis could be confirmed observationally as a periodic change of the radial velocity. Molecular radio emission, in particular SiO lines, can also be used to detect the hidden M star. However, the present detection limits of this emission were higher than the strength of the thermal emission expected from their infrared fluxes.

The SiO maser is often found in mass-losing M stars and is usually stronger than the H_2O maser in stars with low mass-loss rate (Bowers 1985). However, both masers usually show large variabilities. Thus, the present negative detection of the SiO maser cannot be regarded immediately as evidence against the binary model. The continual monitoring of SiO as well as H_2O maser is desirable to study the nature of these peculiar objects.

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