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DETECTION OF A STRONG NEW MASER LINE OF METHANOL TOWARD DR 21(OH)

WOLFGANG BATRLA
Astronomy Department, University of Illinois
AND
KARL M. MENTEN
Harvard-Smithsonian Center for Astrophysics
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ABSTRACT

We report the detection of a strong new maser emission line from the 5_{-1}–$4_0\,E$ transition of methanol toward DR 21(OH). Interferometric observations with a resolution of 8".3 × 6".2 show that the line does not coincide in position with any of the known maser or infrared emission features toward this source. This strongly indicates an excitation mechanism for this methanol maser which is different from the physical conditions leading to the excitation of the water and OH masers. In addition, we find maser emission toward a condensation which has been detected in emission in the 2_{11}–2_{12} transition of formaldehyde. Besides maser emission we detect thermal emission lines from several compact sources. Two of these sources are found very close to the OH maser position.

Subject headings: interferometry — interstellar: matter — interstellar: molecules — masers — radio sources: lines

I. INTRODUCTION

Methanol (CH_3OH) displays an extremely rich spectrum of transitions at radio frequencies because of the structure of the molecule, an asymmetric rotor with hindered internal motion. Barrett, Schwartz, and Waters (1971) found the $J_{K=2}$–$J_{K=1}$ ($J = 4$ to 8) series of E-type methanol in maser emission toward Orion A. Over the past 3 yr the number of sources that exhibit maser emission in the J_2–J_1 series (Menten *et al.* 1986) and the number of detected transitions of methanol has rapidly increased (see Menten *et al.* 1988 for a summary). During a survey with the IRAM 30 m telescope of galactic sources in the 5_{-1}–$4_0\,E$ line of methanol Menten *et al.* (1988) found a very narrow, relatively strong emission feature toward DR 21(OH) which indicated the possibility of maser emission as well. In order to determine the nature of the emission and its relation to other molecular line emission features we performed high-resolution, interferometric observations of the 5_{-1}–$4_0\,E$ line toward DR 21(OH).

II. OBSERVATIONS AND DATA REDUCTION

Between 1987 August 7 and December 28, we observed DR 21(OH) in four configurations of the three-element Hat Creek millimeter array of the University of California, Berkeley (Welch and Thornton 1985). The phase tracking center was $\alpha(1950) = 20^h37^m14^s.5$ and $\delta(1950) = 42°12'00"$, the radial LSR-velocity -5 km s^{-1}. Thirty minutes of on-source integration were interspersed with 10 minute integrations on the phase calibrators 3C 345 or BL Lac. Observations of Mars were used to establish the flux density scale while the radio frequency passband corrections were derived from observations of 3C 84. The data sample the *u-v* plane between spacings of 4.6 and 23.2 kilowavelengths at the frequency of the 5_{-1}–$4_0\,E$ line, 84.52121 GHz. The extremely flexible correlator backend (Urry, Thornton, and Hudson 1985) was split into eight sub-receivers of 64 channels with bandwidths of 5 or 20 MHz. This allowed us to observe simultaneously the 18_4–$19_3\,E$ line at 81.65308 GHz in the lower sideband with velocity resolutions of 0.28 and 1.11 km s^{-1} as well as in the upper sideband the 5_{-1}–$4_0\,E$ line in both resolutions and the 19_4–$18_5\,E$ line at 84.74417 GHz with high-velocity resolution. In both sidebands we had one line-free filter of 20 MHz bandwidth for continuum measurements.

The data were processed using the RALINT software package developed by the Radio Astronomy Laboratory at the University of California, Berkeley. The typical rms phase error after editing and phase calibration was 0.25 radians. The flux density scale is estimated to be accurate to better than 20%. The *u-v* data were gridded, convolved, and Fourier-transformed to obtain square maps of 128 pixels with a pixel size of 2", employing uniform weighting. No continuum emission was detected at 84.5 GHz. The upper limit derived from a map utilizing a bandwidth of 18.5 MHz is 47 mJy per beam rms.

Sixty channels each were mapped over the low-resolution and high-resolution filters centered at the 5_{-1}–$4_0\,E$ line. The maps were CLEANed and restored using an elliptical Gaussian approximation to the synthesized beam of 8".3 × 6".2, position angle 56°. The resulting rms noise level in one channel map is 0.72 and 0.36 Jy per beam for the maps with high-velocity and low-velocity resolution. No emission was detected outside the velocity interval $-13.8 \leq$ VLSR ≤ 3.8 km s^{-1} covered by the high-resolution data. So in the following we limit the discussion to results obtained from these data.

III. RESULTS AND DISCUSSION

Figure 1 shows the average emission over the 34 channels from the high-resolution filter that contain line emission. In addition we present spectra at selected positions in Figure 2. The circled numbers in Figure 1 indicate the positions of the spectra from Figure 2 and point toward the corresponding entries in Table 1, which summarizes the spectral line parameters obtained from Gaussian fits to the spectra.

The new maser line was detected at a position ($\Delta\alpha$, $\Delta\delta$) = ($-24"$, $11"$) with respect to the center of the map. The line is extremely narrow, $\Delta V_{\rm FWHP} = 0.53$ km s^{-1} and displays a peak brightness temperature, T_R*, of 136 K. The emission region is

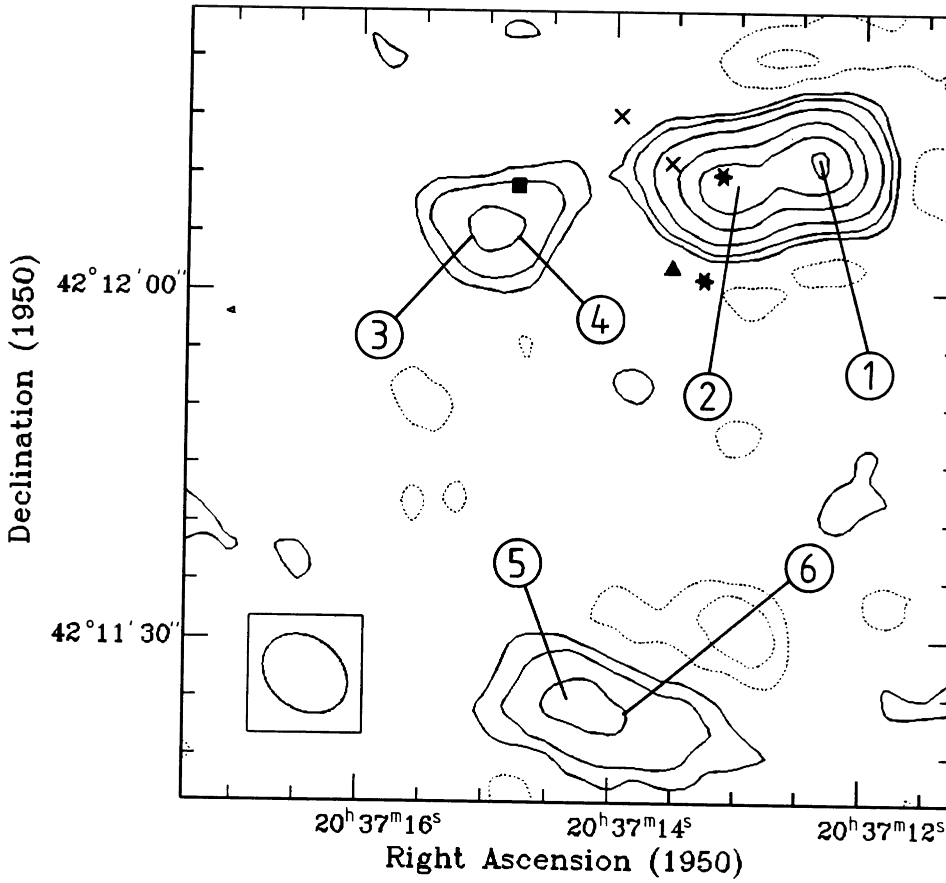

FIG. 1.—Contours show the average emission over 34 channels in the high-resolution filter that have line emission. The square gives the OH maser position (Norris *et al.* 1982) as well as the 20 μm infrared source (Wynn-Williams *et al.* 1974). The triangle shows the position of the 53 μm infrared source (Harvey *et al.* 1977). Two crosses depict the water maser emission centers 2a, b of Genzel and Downes (1977). The two filled stars are at the positions of the condensations found in emission in the 2 cm line of formaldehyde (Johnston *et al.* 1985). The numbers in circles point to the positions corresponding to the spectra in Fig. 2 and correspond to the numbers of the entries in Table 1. The insert at lower left shows the size of the synthesized beam.

TABLE 1

SOURCE PARAMETERS DERIVED FROM GAUSSIAN FITS

Number	$\Delta\alpha$[a,b]	$\Delta\delta$[a,b]	Amplitude[b] (K T_R*)	VLSR[b] (km s^{-1})	ΔV_{FWHP}[b] (km s^{-1})
			Maser Emission Lines		
1.........	−24".12(0.06)	11".22(0.04)	136.21(2.55)	0.53(0.01)	0.53(0.01)
2.........	−16.84(0.28)	8.86(0.20)	41.16(3.25)	0.07(0.02)	0.51(0.06)
	−16.06(0.14)	8.62(0.12)	20.90(3.68)	−0.51(0.11)	0.66(0.27)
	−15.24(0.24)	8.88(0.18)	14.90(1.86)	−1.56(0.10)	0.97(0.23)
			Thermal Emission Lines		
3.........	5.84(0.30)	5.74(0.22)	9.77(0.48)	−4.70(0.05)	1.92(0.11)
4.........	2.04(0.22)	5.64(0.28)	6.43(0.70)	−6.37(0.04)	0.76(0.10)
5.........	−4.02(0.76)	−35.42(0.52)	8.53(0.88)	−3.97(0.18)	1.54(0.36)
6.........	−5.74(0.52)	−36.16(0.38)	4.73(1.17)	−5.46(0.13)	0.93(0.28)

[a] Offsets relative to the phase tracking center $\alpha(1950) = 20^h37^m14^s.5$, $\delta(1950) = 42°12'00''$, obtained by fitting elliptical Gaussians to the channel map of the peak channel of the line.
[b] Numbers in parentheses give the formal 1 σ errors from the fit.

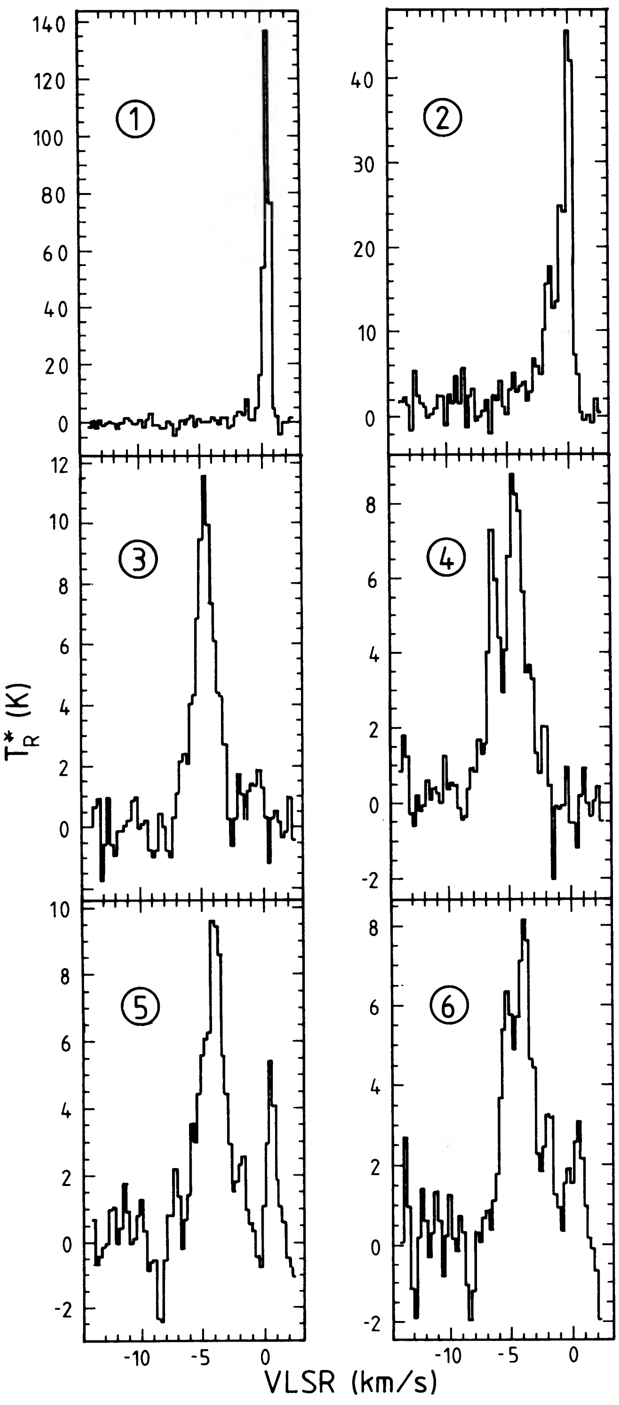

FIG. 2.—Spectra at selected positions in Fig. 1. The spectra were obtained by integrating over an array of 3 × 3 pixels. Spectra 1 and 2 show the newly detected maser emission lines. Spectra 4–6 are thermal emission lines. For positions, see Fig. 1 and Table 1.

unresolved with the given angular resolution. Menten *et al.* (1988) measured a T_R* of 17.5 K with an angular resolution of 28″. This value is consistent with our finding of a spatially unresolved source. The brightness temperature is unphysically high compared to the kinetic temperature derived for the molecular clouds toward DR 21(OH). Linke and Goldsmith (1980) find a kinetic temperature, T_K, of 27 K from CO data. Mauersberger *et al.* (1985) derive a value of 58 K from measurements of metastable and nonmetastable lines of ammonia while Menten *et al.* (1986) deduce a T_K of 29 K from their observations of *thermal* emission of the J_2–J_1E series of methanol. The source size, the unphysical line temperature, and the narrow linewidth lead to the conclusion that the 5_{-1}–$4_0\,E$ line of methanol is seen in maser emission. The radial velocity of the maser agrees with velocities quoted for H_2O maser features by Genzel and Downes (1977) and OH masers detected by Norris *et al.* (1982). However, we find the position of the methanol maser offset from the positions of H_2O as well as OH maser spots with identical radial velocity. This strongly indicates an excitation mechanism for methanol maser emission which is different from the physical conditions leading to the excitation of the water and OH masers. The maser position does not coincide with the positions of the infrared sources found by Wynn-Williams, Becklin, and Neugebauer (1974) and Harvey, Campbell, and Hoffmann (1977). Therefore, infrared radiation does not seem to play a role in the excitation of the line.

At a second position offset (−17″, 9″) relative to the center of the map we measure a spectrum which displays three velocity components. Again the lines have very narrow width and high brightness temperature, and the emission region is unresolved with the given resolution. Following the arguments given above we again find strong indications of maser emission. However, the measured brightness temperatures of the lines are still in agreement with the kinetic temperatures quoted earlier. The position of these features agrees with the position of the northern condensation seen in emission in the 2_{11}–2_{12} line of formaldehyde by Johnston, Henkel, and Wilson (1984). Since the 2 cm line of formaldehyde is expected in emission only at densities in excess of $n(H_2) = 10^6$ cm^{-3} (Garrison *et al.* 1975), high density, leading to an overpopulation of $K = -1$ rotational ladder of E-type methanol, could be important for the excitation of the maser emission lines. This argument is supported by the detection of maser emission in the 4_{-1}–$3_0\,E$ transition of methanol toward DR 21(OH) by Haschick and Baan (1987) and the statistical equilibrium calculations of Walmsley *et al.* (1988) who detected the 2_0–$3_{-1}E$ line in absorption against the microwave background radiation toward TMC-1 and L183. In addition Batrla *et al.* (1987) have detected the 2_0–$3_{-1}E$ line in absorption toward DR 21(OH) at radial velocities consistent with the radial velocities of the maser lines. During the five months of our observations we could not find any variability of the maser components within the accuracy of the calibration.

We find thermal emission lines immediately to the south of the OH maser position (Norris *et al.* 1982) at offset (6″, 6″). The radial velocity is −4.7 km s^{-1} with a velocity width of 2 km s^{-1}. A second rather narrow component ($\Delta V = 0.76$ km s^{-1}) peaks at the position (2″, 6″). This feature is at lower velocity, $V_{LSR} = -6$ km s^{-1}. Currently we cannot separate these two features spatially, and their size is unresolved. About 36″ to the south we find two lines at velocities of −3.97 and −5.46 km s^{-1}. From fits of elliptical Gaussians to the line channel of the peak emission we find that both components are extended; the source sizes are approximately 12″. No other sources of emission are known at the position of the latter two features. The physical conditions in all of these clumps are not determined, since no observations of comparable resolution are available in other molecular lines, and single-dish observations sample all of the clumps in one resolution element. This fact explains the high line width detected in single-dish observations and emphasizes the need for future molecular line observations with high spatial resolution toward DR 21(OH).

We have made interferometric observations with high resolution in the 5_{-1}–$4_0\,E$ line of methanol. These data show that the position of the detected, strong maser in DR 21(OH) does not coincide with any previously known source. The absence of any centimeter-maser lines of methanol toward DR 21(OH) (Menten *et al.* 1988) leads to the conclusion that the excitation mechanism must be different from that responsible for the class A or B methanol masers described by Batrla *et al.* (1987). However, the detection of an absorption line and two masers from consecutive J-levels in the same K-ladder of one species of methanol opens for the first time the possibility for understanding the underlying excitation mechanism.

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WOLFGANG BATRLA: University of Illinois, Department of Astronomy, 349 Astronomy Building, 1011 West Springfield Avenue, Urbana, IL 61801

KARL M. MENTEN: Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138