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THE DETECTION OF A NEW METHANOL MASER TRANSITION AT 9.9 GHz

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ABSTRACT

A search for the 9_{-1}–8_{-2} E, 4_3–5_2 A^+, and 4_3–5_2 A^- methanol lines at 9.94, 9.98, and 10.06 GHz, respectively, was undertaken with the 43 m radio telescope at Green Bank. From a sample of 11 sources three were detected in emission for the 9_{-1}–8_{-2} E line, Orion-KL, Sgr B2, and W33-Met. The line in W33-Met shows maser properties; in Orion-KL and in Sgr B2 the line is thermal.

Subject headings: ISM: molecules — masers — radio lines: ISM — stars: formation

1. INTRODUCTION

Class I methanol masers (Menten 1991) have been observed in transitions where the upper level has $K = 0$ for A methanol, and $K = -1$ or $K = 2$ for E methanol. The radiation lifetimes of these levels are much larger than for the lower levels of the class I maser transitions, which lie in neighboring ladders—the $K = 1$ ladder for A methanol and the $K = 0$ or $K = 1$ for E methanol. Thus, in the 7_0–6_1 A^+ transition, at 44 GHz, the radiation lifetime of the upper level, 7_0, is 7.6 times longer than the lifetime of the lower, 6_1, level. In the 4_{-1}–3_0 E maser transition, at 36 GHz, the ratio of the lifetimes of the upper and lower levels is 2.9. The whole $K = 0$ ladder of A methanol and $K = -1$ and $K = 2$ ladders of E methanol have larger lifetimes compared with neighboring ladders. Therefore, after excitation of the rotational levels (for example, by collisions) and subsequent radiative decay, the levels of these neighboring ladders will be depopulated first, while the level population of the $K = 0$ ladder of A methanol and the $K = -1$ and $K = 2$ ladders of E methanol will remain high. As a result of this, population inversion arises and maser emission may occur (see also Lees 1973).

If this simplified excitation scheme of class I masers is correct, then one can make predictions for other methanol maser lines. For example, in E methanol the inversion may be established not only between levels of the $K = -1$ and $K = 0$ ladders, but also between levels of the $K = -1$ and $K = -2$ ladders. The 9_{-1}–8_{-2} E transition at the frequency 9.94 GHz is one such transition with a ratio of lifetimes of 6.5. Observations of the 9_{-1}–8_{-2} E transition are reported in this *Letter*. Apparently the first observations of this transition were made by W. Batrla (see Menten 1991), but no details of the sources observed were reported.

In A methanol, along with the levels of the $K = 0$ ladder, the levels of the $K = 3$ ladder also have a sufficiently long lifetime for population inversion of the $K = 3$ ladder levels to be established relative to the levels of the neighboring $K = 2$ or $K = 4$ ladders. The 4_3–5_2 A^+ and A^- transitions belong to this type (lifetime ratio 3.4) and maser emission may also be expected from these transitions. To check such a possibility, observations of the A methanol 4_3–5_2 A^+ and 4_3–5_2 A^- transitions at the frequencies of 9.98 and 10.06 GHz, respectively, were also carried out. The frequencies of these transitions are close to the frequency of the 9_{-1}–8_{-2} E transition, so it was possible to observe them simultaneously with the same receiver.

2. OBSERVATIONS AND RESULTS

The observations were made during 1992 April 2–3 with the NRAO 43 m radio telescope at Green Bank, West Virginia.[2] The aperture efficiency was 0.5, the main-beam efficiency was 0.7, and the system noise temperature was about 40 K. The half-power beamwidth was 3′.4, and the rms pointing accuracy 20″. The spectra were taken using a 1024 channel digital autocorrelator in the frequency-switching mode. Table 1 gives information on the observed transitions. The autocorrelator was split into four sections tuned to the three methanol frequencies and to the frequency 9.82 GHz of the H87β hydrogen recombination line. The latter was used as an overall check of the telescope pointing and receiver performance. Eleven Galactic sources with known methanol masers in other transitions were observed in the three methanol lines and in the recombination line. The recombination line was reliably detected in every source observed. Of the methanol lines, the 9_{-1}–8_{-2} E line was detected in only three sources. The 4_3–5_2 A^- line was marginally detected in Sgr B2, and the 4_3–5_2 A^+ line was possibly detected in W33-Met. In Figures 1–3 the spectra of the 9_{-1}–8_{-2} E line are shown. The measured line parameters are given in Table 2, and in Table 3 the list of nondetected sources is given.

3. DISCUSSION

Maser emission was found in only one source, W33-Met, and in only one transition, 9_{-1}–8_{-2} E. That this is maser emis-sion is evident from the narrowness of the line (0.4 km s^{-1}); from its radial velocity of 33.5 km s^{-1}, which is close to the radial velocity of the maser feature in 7_0–6_1 A^+ and 6_2–6_1 E methanol transitions (Haschick, Menten, & Baan 1990; Menten et al. 1986a); and from the relatively high intensity as compared with the thermal lines in Orion-KL and Sgr B2. Apparently only this source meets the requirements needed to populate the 9_{-1} level, which lies 109 K above the ground state: a kinetic temperature of about 100 K and particle density of about 10^6 cm^{-3} or higher, if collisional excitation is taking place. Other sources which were observed are probably too cold and have too low a molecular density to populate the 9_{-1} E level. A similar situation is found with the J_2–J_1 E masers. At $J = 9$ only W33 and DR 21(OH) were found (Menten et al. 1986a) to show maser emission. For the excita-

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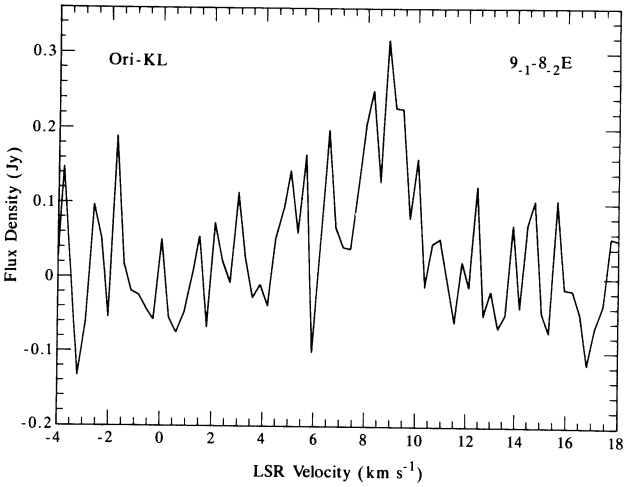

FIG. 1.—Spectrum of the 9_{-1}–8_{-2} E methanol transition observed toward Orion-KL. Velocity resolution is 0.29 km s^{-1}.

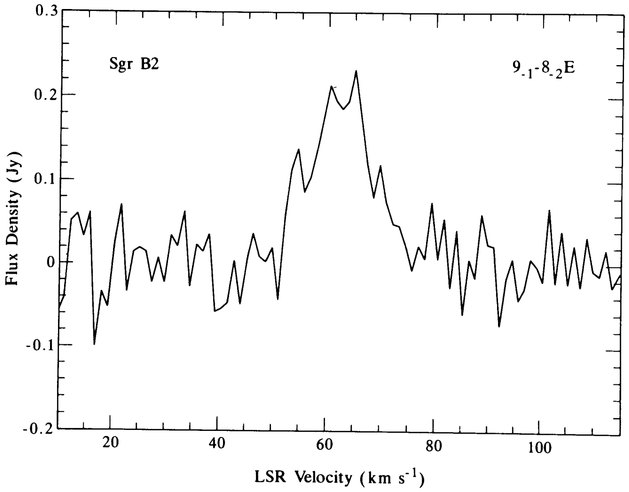

FIG. 2.—Spectrum of the 9_{-1}–8_{-2} E methanol transition observed toward Sgr B2. Velocity resolution is 1.2 km s^{-1}.

tion of the 9_2 level, still higher temperature and density are required, but a lower column density of methanol molecules is necessary because of the larger line strength of the 9_2–9_1 E transition.

In the 4_3–5_2 A^+ transition a weak line was possibly detected in W33-Met at a velocity of 37 km s^{-1}, which is close to the velocity of the second maser component seen in the 3_2–3_1 E (Menten et al. 1986a) and 7_0–6_1 A^+ transitions (Haschick et al. 1990). No maser lines were seen in the 4_3–5_2 A^- transition. In Orion-KL and Sgr B2 the 9_{-1}–8_{-2} E emission is probably thermal with broad weak lines similar to the thermal emission

TABLE 1

OBSERVED METHANOL TRANSITIONS

Transition	Frequency[a] (MHz)	E/k[b] (K)	S[c]
9_{-1}–8_{-2} E	9936.229	109	1.50
4_3–5_2 A^+	9978.732	73	0.27
4_3–5_2 A^-	10058.304	73	0.27

[a] Rest frequencies are taken from Anderson, De Lucia, & Herbst 1990.

[b] Excitation energy of the upper level, in kelvins.

[c] Line strength (Lees et al. 1973).

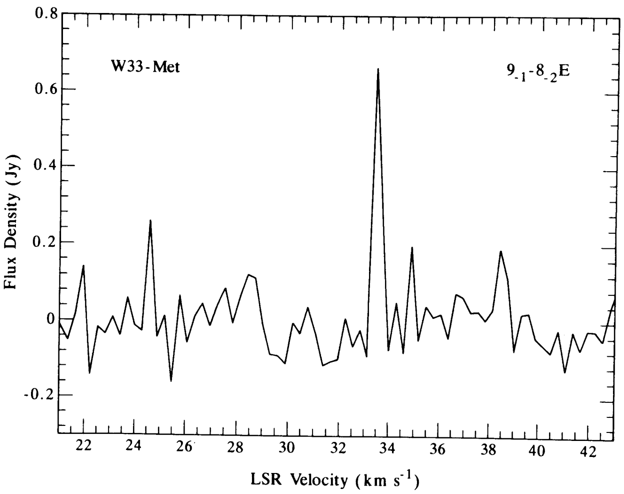

FIG. 3.—Spectrum of the 9_{-1}–8_{-2} E methanol transition observed toward W33-Met. Velocity resolution is 0.29 km s^{-1}.

TABLE 2

MEASURED LINE PARAMETERS

Source	α_{1950}	δ_{1950}	Transition	Flux (Jy)	v_{LSR} (km s^{-1})	Δv (km s^{-1})	N_{CH_3OH} (10^{17} cm^{-2})
Orion-KL	05^{h}32^{m}47^s.0	−05°24′20″	9_{-1}–8_{-2} E	0.25 (0.04)	8.7 (0.2)	2.4 (0.3)	5.3[a]
			4_3–5_2 A^+	<0.11[b]			<9.5[b]
			4_3–5_2 A^-	<0.11[b]			<9.5[b]
Sgr B2	17 44 10.3	−28 22 02	9_{-1}–8_{-2} E	0.19 (0.03)	62.5 (0.1)	14.3 (0.2)	0.76[c]
			4_3–5_2 A^+	<0.019[b]			<0.36[b]
			4_3–5_2 A^-	0.04[d]	65	15	0.84
W33-Met	18 11 15.3	−17 56 49	9_{-1}–8_{-2} E	0.80 (0.10)	33.5 (0.02)	0.4 (0.01)	
			4_3–5_2 A^+	0.17[d]	37	0.5	
			4_3–5_2 A^-	<0.13[b]			

NOTE.—Errors are 1 σ deviations determined by Gaussian fits.

[a] Assuming source diameter 30″ and rotational temperature 140 K (Menten et al. 1986b).

[b] 3 σ upper limit determined with a velocity resolution of 0.29 km s^{-1}.

[c] Assuming rotational temperature 204 K from the two-component model of Turner 1991 and diameter of the source larger than the beamwidth.

[d] Marginal detection.

TABLE 3

NONDETECTION OF METHANOL LINES

Source	α_{1950}	δ_{1950}	v_{LSR}[a] (km s^{-1})	3 σ Upper Limit[b] (Jy)
W3(OH)	$02^{h}23^{m}17^{s}.0$	61°38′54″	−46.5	0.19
NGC 6334-I(N)	17 17 33.0	−35 42 04	−4.8	0.23
Sgr A[c]	17 42 27.9	−29 04 00	15.0	0.11
W31C	18 07 30.5	−19 56 28	−2.6	0.23
W51 e_1/e_2	19 21 26.2	14 24 43	48.9	0.21
DR 21–West	20 37 07.6	42 08 50	−2.5	0.25
DR 21(OH)	20 37 13.8	42 12 13	0.4	0.23
NGC 7538	23 11 36.7	61 11 53	−55.0	0.25

[a] Velocity interval ±15 km s^{-1}.

[b] Determined with a resolution of 0.29 km s^{-1}.

[c] Velocity interval ±60 km s^{-1}, resolution 1.2 km s^{-1}.

seen in the 1_0–0_0 A^+ transition (Barrett et al. 1972; Val'tts et al. 1991). The column density of methanol derived from the present observations in Orion-KL is consistent with the results of Menten et al. (1988). In Sgr B2 the derived column density is in agreement with the column density of the hot component (Turner 1991).

The two other methanol transitions, 4_3–5_2 A^+ and 4_3–5_2 A^-, were also searched for but not found, except for a marginal detection of the 4_3–5_2 A^- line in Sgr B2 and the probable detection of the 4_3–5_2 A^+ maser line in W33-Met mentioned above. The 4_3 A^+ level is 26 K lower than the 9_{-1} E level but requires a higher particle density for excitation. The reason for nondetection of these transitions most probably lies in their lower, by a factor of 5, line strengths (cf. Table 2). This factor is important in the present observations, since the lines actually detected are weak, and weaker lines could have been missed in the noise.

The present low detection rate of masers in the three transitions is in contrast to the widespread nature of the class I masers. The 7_0–6_1 A^+ and 4_{-1}–3_0 E transitions are detected in many sources. As was mentioned above, for the excitation of the 9_{-1}–8_{-2} E and 4_3–5_2 A^+ and 4_3–5_2 A^- transitions temperatures of 75–100 K and densities of 10^6 cm^{-3} are required. It seems that few sources can have such high values of temperature and density. On the other hand, for the 7_0–6_1 A^+ maser, a temperature of 50 K and a density of 3×10^5 cm^{-3} are sufficient, and for the 4_{-1}–3_0 E maser a still lower temperature of 25 K and a density of 3×10^4 cm^{-3} are needed. Certainly many more sources can provide such an environment. This difference may explain why more masers were found in these lower excitation transitions.

4. SUMMARY

1. A new methanol emission line, 9_{-1}–8_{-2} E, was detected at 9.94 GHz.
2. In W33-Met a maser line, apparently of class I, was found but in Orion-KL and Sgr B2 the emission is thermal.
3. In the 4_3–5_2 A^+ and 4_3–5_2 A^- transitions, which, according to theoretical predictions, might show maser emission, no lines were detected, probably because of lower line strength.

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