

Maser action in methanol transitions

Maxim Voronkov

Australia Telescope National Facility, Australia

Astro Space Centre, Russia

Andrej Sobolev

Ural State University, Russia

Simon Ellingsen

University of Tasmania, Australia

Andrei Ostrovskii

Ural State University, Russia

Alexei Alakoz

Astro Space Centre, Russia

April 15, 2004

Abstract. We report the detection with the ATCA of 6.7 GHz methanol emission towards OMC-1. The source has a size between 40'' and 90'', is located to the south-east of Ori-KL and may coincide in position with the 25 GHz masers. The source may be an example of an interesting case recently predicted in theory where the transitions of traditionally different methanol maser classes show maser activity simultaneously. In addition, results of recent search for methanol masers from the 25 and 104.3 GHz transitions are reported.

Keywords: masers – ISM: molecules

1. Introduction

Interstellar methanol masers are associated with regions of active star formation and masing transitions are traditionally divided into two classes (Menten, 1991). Although masers of both classes often co-exist in the same star-forming region, Class I masers are normally seen apart from the strong continuum sources, while Class II masers are found close to them. The $5_1 - 6_0$ A⁺ transition at 6.7 GHz (a Class II transition) produces the brightest known methanol maser (up to 5000 Jy). Maser emission from this transition is widespread and to date has been detected towards more than 400 sources. Among the Class I methanol masers there is the $J_2 - J_1$ E series near 25 GHz. The strongest $5_2 - 5_1$ E 25 GHz maser (about 150 Jy) is observed towards the Orion molecular cloud (OMC-1) which is the best studied Class I source. The 25 GHz transitions are seen in absorption towards the archetypal Class II source W3(OH) (Menten et al., 1986) and the general assumption has been that other Class II sources will exhibit similar behaviour. To date only



© 2019 Kluwer Academic Publishers. Printed in the Netherlands.

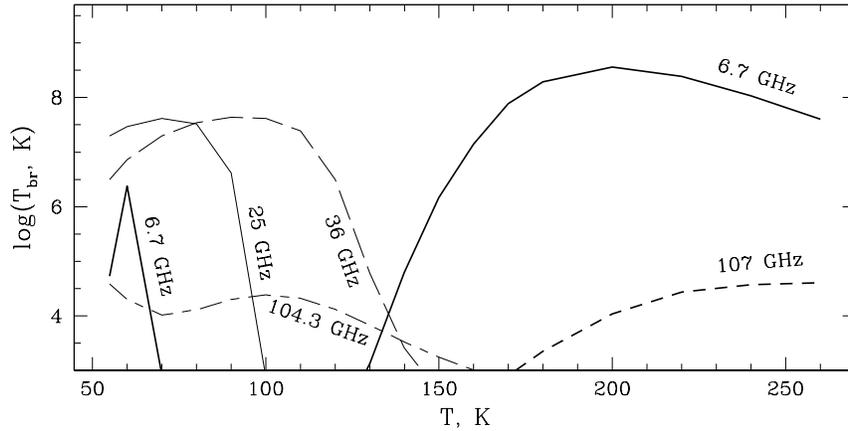


Figure 1. The model dependence of the brightness temperature of various methanol maser transitions on the temperature ($T = T_{gas} = T_{dust}$).

a few 25 GHz methanol masers have been detected and bright 25 GHz masers are thought to be rare (e.g., Menten et al., 1986). However, the survey of Menten et al. (1986) did not cover many sites which subsequent searches in other transitions have been found to be prominent Class I methanol maser sources. In this paper we report results of a pilot survey of 25 GHz masers targeted at Class I masers at 44 GHz with sufficiently well known positions.

The difference between the two traditional classes is due to a difference in the pumping mechanism: strong Class I masers appear when the excitation processes are dominated by collisions while the strong Class II masers appear when the radiative excitation prevails (e.g., Cragg et al., 1992). Therefore, the masers in transitions of different classes are usually seen apart from each other. The work of Cragg et al. (1992) was limited to the case where conditions in the masing region are such that the radiative transitions between different torsionally excited states are not influential.

Further studies of methanol maser excitation have shown that the strong Class II masers are produced when excitation from the ground to the second torsionally excited state comes into effect (see, e.g., Sobolev & Deguchi, 1994; Sobolev et al., 1997a). Calculations show that the involvement of torsional transitions does not allow masers of different traditional classes to become strong simultaneously. However, the co-existence of inversion in some Class I and II transitions is predicted in some situations (e.g., the Class I $11_2 - 11_1$ E transition is present in the list of Class II methanol maser candidates of Sobolev et al., 1997b).

The general tendencies of methanol maser pumping are demonstrated in Fig.1 showing the dependence of brightness temperature in different masing (i.e., inverted) transitions on the temperature. In this model the collisional excitation is provided by the hydrogen molecules and the pumping radiation is produced by the dust intermixed with the gas within the cloud. The cloud has the following parameters: hydrogen number density 10^5 cm^{-3} , methanol abundance 10^{-5} , beaming factor (ε^{-1}) 10, specific (divided by linewidth) column density $10^{11.5} \text{ cm}^{-3}\text{s}$, temperature of the dust and gas are equal. Increasing the temperature in such a cloud changes the balance of excitation processes in favour of radiative ones. So, one should expect that the Class I masers should appear at low temperatures while at high temperatures the Class II masers should shine brightly. The figure shows that this is correct, at least for well known Class I masers at 25 GHz and 36 GHz and Class II maser at 107 GHz. In addition, the figure shows that there is some transition region when the strong Class I $5_2 - 5_1$ E maser can coexist with the weaker maser in Class II $5_1 - 6_0$ A⁺ transition. This is not expected in the traditional classification scheme and we have attempted to test this prediction through observation. Further, Fig. 1 shows that the maser at 104.3 GHz, which was predicted in theory (Voronkov, 1999), could be a representative of intermediate class. If the maser appears mostly under intermediate conditions then the detection rate in surveys targeted towards either Class I or Class II sources may be low.

2. Observational Results and Discussion

2.1. SEARCH FOR 6.7 GHz EMISSION FROM THE 25 GHz MASER SITE IN OMC-1

The Australia Telescope Compact Array (ATCA) was used to search for 6.7 GHz emission in OMC-1. Observations were made with the array in the compact H75 configuration on 10 June 2003. A weak spectral feature (about 0.2 Jy) has been detected (Fig.2, left). Using the newly installed 12-mm system at the ATCA, the 25 GHz maser was observed quasi-simultaneously with the 6.7 GHz observations. For both frequencies the correlator was configured to split the 4 MHz bandwidth into 1024 spectral channels. The spectral resolution at 25 GHz was 0.047 km s^{-1} . At 6.7 GHz each 8 adjacent channels were averaged together reducing the effective spectral resolution to 1.4 km s^{-1} . Because the spatial resolution of these observations at 6.7 GHz is rather coarse we have compared that data with our 25 GHz measurement, although

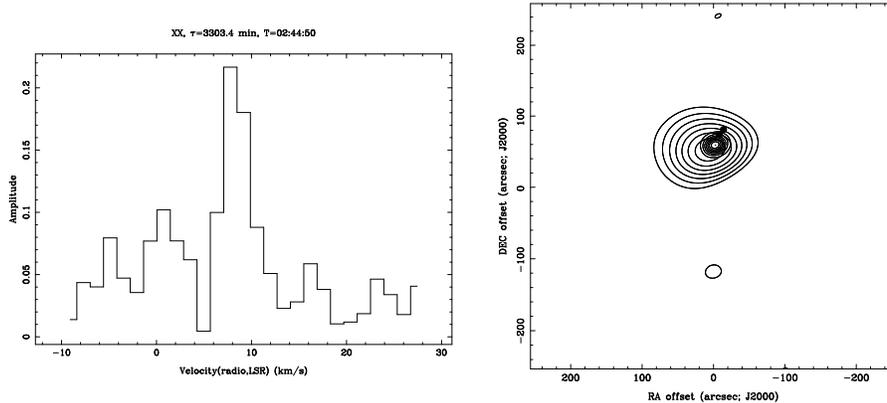


Figure 2. Left. The spectrum of detected 6.7 GHz emission in OMC-1. Amplitude is in Jy. Right. The combined map at 6.7 GHz and 25 GHz (a peak spectral channel corresponding to 8 km s^{-1} was used for imaging). Two filled circles represent the positions of BN and KL objects.

images with a better spatial resolution exist for 25 GHz maser in OMC-1 (Johnston et al., 1992). In Fig.2(right) the combined image at the two frequencies is shown. A peak spectral channel corresponding to $V_{\text{LSR}} = 8.0 \text{ km s}^{-1}$ was used for imaging at both frequencies. It follows from this image that the detected 6.7 GHz emission may come from the same region of space as the 25 GHz maser emission. The peak pixels in the 6.7 GHz and 25 GHz images have offsets from the phase centre ($\alpha_{2000} = 5^{\text{h}}35^{\text{m}}15^{\text{s}}$, $\delta_{2000} = -5^{\circ}23'43''$) equal to (5, 50) and (-11, 67) arcseconds respectively. This gives a displacement of about $23''$. The estimate of the displacement 3σ accuracy is about $60''$ (the synthesized beam size is about $2'$ and the signal to noise ratio is about 3 at 6.7 GHz). The peak of the 25 GHz emission tends to move towards that at 6.7 GHz if a spectral channel corresponding to lower velocity is used for imaging. A minimum separation of about $10''$ achieved at $V_{\text{LSR}} = 7.3 \text{ km s}^{-1}$. This behavior is in agreement with the 25 GHz map of Johnston et al. (1992), where the maser has been resolved into a number of spots at close velocities spread across the region of about $30''$ in extent. Due to a poor spatial resolution of the ATCA measurement the position we measure is a weighted (with flux) averaged position of individual maser spots. A higher resolution study is desirable to measure the position of the 6.7 GHz emission with respect to individual 25 GHz maser spots (say from the map of Johnston et al., 1992). However, it is difficult to do this with existing interferometers because the source is very weak at 6.7 GHz and possibly resolved.

On the basis of these observations we cannot prove that the emission detected at 6.7 GHz is a maser (brightness temperature $T_b > 1 \text{ K}$).

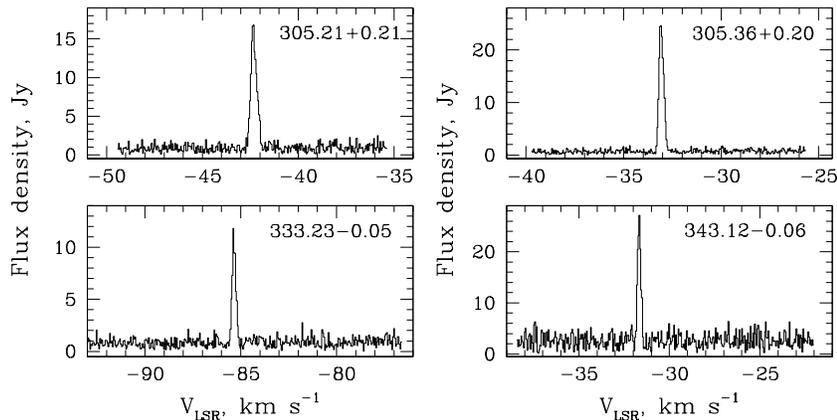


Figure 3. New 25 GHz masers. The phase was self-calibrated and all baselines were averaged together decreasing the noise level in the spectra.

However, this is not in contradiction with the theory. Fig.1 shows that the bright 25 GHz masers are not necessarily accompanied by the maser emission at 6.7 GHz. So, the actual physical parameters (density, temperature, etc) of the source may be different from the interesting pumping regime where the two maser transitions of different classes do coexist. If the emission is quasi-thermal its detection towards the Class I maser position in OMC-1 is interesting because according to traditional reasoning the Class II transitions at such locations should be overcooled (i.e. the upper level population should be less than the equilibrium value). So, it is expected that the corresponding lines will be undetectably weak or in absorption. The source appears to be unresolved on all short baselines, although it was not detected on the baselines including the 6km antenna. We reobserved the source at 6.7 GHz using the 1.5D configuration, which contains a greater number of large baselines. These observations can be used to place limits on the brightness temperature at 6.7 GHz, which are helpful for understanding the nature of the detected emission. However, the signal was detected on the shortest baseline only, which implies the source size less than about $90''$ and greater than about $40''$ ($0.6 \text{ K} < T_b < 3.4 \text{ K}$). It is worth noting that an extended source can indicate either a thermal or maser nature, while a compact source must be a maser.

2.2. SEARCH FOR NEW BRIGHT 25 GHz MASERS

The southern sky is very attractive for Class I maser searches because the most widespread Class I methanol maser line at 44 GHz has been searched for in southern sources (Slysh et al., 1994) giving a good target

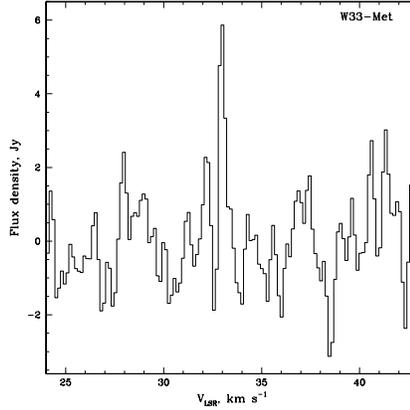


Figure 4. The 104.3 GHz spectrum of W33-Met.

list. The ATCA in the 1.5D configuration was used to search for new $5_2 - 5_1$ E 25 GHz masers. The resulting detection limit was about 5 Jy and we observed the following 10 sources: $305.21+0.21$, $305.36+0.20$, $333.23-0.05$, $343.12-0.06$, M8E, $333.13-0.43$, $335.59-0.29$, $337.91-0.47$, $338.92+0.56$, $351.78-0.54$. The first 4 sources listed are new detections (Fig.3). The results of this pilot survey mean that the 25 GHz masers may be rather common. There is no simple correlation between the flux densities at 25 GHz and 44 GHz. Interestingly, the brightest known 44 GHz maser in M8E showed no emission in the 25 GHz transition.

2.3. THE 104.3 GHz MASER SEARCH

A search for new methanol masers in the $11_{-1} - 10_{-2}$ E transition at 104.3 GHz was carried out with the Onsala radiotelescope. The maser in this transition was predicted in theory (Voronkov, 1999) and can be bright at Class I maser positions. Our target list included all known 44 GHz masers visible from the high latitude of the Onsala observatory. In addition to them two Class II maser sources, W3(OH) and GL2789, were also observed as they can have a thermal emission and they were above the horizon almost all the time. The only obvious maser (i.e. a source with a very narrow line) detected was W33-Met (Fig.4). In addition to this source, 6 sources showed broad line emission, which is probably thermal (Fig.5). Slysh et al. (1993) searched for the $9_{-1} - 8_{-2}$ E masers at 9.9 GHz. This maser transition belongs to the same series $(J+1)_{-1} - J_{-2}$ E and should have a similar behavior. Slysh et al. (1993) have found 9.9 GHz maser also towards W33-Met only. It appears that, the masers at both 9.9 GHz and 104.3 GHz are rare and may be representatives of an intermediate class of methanol masers.

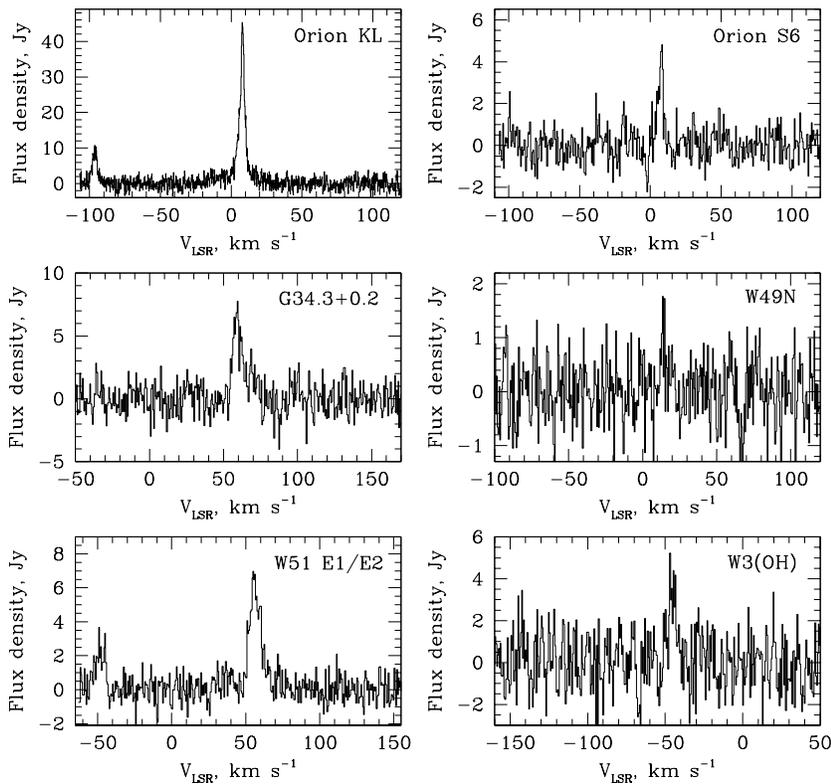


Figure 5. Sources with a broad line emission detected at 104.3 GHz. A weaker feature which is present in the left hand side of some spectra belongs to CH_3OD (the same transition).

3. Conclusions

1. 6.7 GHz emission which may be associated with the 25 GHz maser has been detected towards OMC-1. The source has a size between $40''$ and $90''$.
2. New 25 GHz methanol masers were discovered in 305.21+0.21, 305.36+0.20, 333.23-0.05, 343.12-0.06.
3. 104.3 GHz methanol emission has been detected towards Orion KL, Orion S6, G34.3+0.2, W49N, W51 E1/E2, W3(OH) and W33-Met. In the last source the emission is a maser.

Acknowledgements

We would like to thank the local staff of Narrabri and Onsala observatories for the help during observations. The Australia Telescope is funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO. Maxim Voronkov and Alexei Alakoz were partially supported by the RFBR grant no. 01-02-16902 and by the program "Extended objects in the Universe-2003". Andrej Sobolev and Andrei Ostrovskii were supported by the RFBR grant no. 03-02-16433.

References

- Cragg D. M., K. P. Johns, P. D. Godfrey and R. D. Brown. Pumping the interstellar methanol masers. *MNRAS*, 259, 203–208, 1992.
- Menten K. M., C. M. Walmsley, C. Henkel, T. L. Wilson. The centimeter transitions of E-type methanol. *A&A*, 157, 318–328, 1986
- Menten K. M. In A. D. Haschick, P. T. P. Ho, editors, *Proceedings of the Third Haystack Observatory Meeting*, 119, 1991
- Johnston K. J., R. Gaume, S. Stolovy, T. L. Wilson, C. M. Walmsley and K. M. Menten. The distribution of the $6_2 - 6_1$ and $5_2 - 5_1$ E-type methanol masers in OMC-1. *ApJ*, 385, 232–239, 1992
- Slysh V. I., S. V. Kalenskii and I. E. Val'tts. The detection of a new methanol maser transition at 9.9 GHz. *ApJ*, 413, L133–L135, 1993
- Slysh V. I., S. V. Kalenskii, I. E. Val'tts and R. Otrupcek. The Parkes survey of methanol masers at 44.07 GHz. *MNRAS*, 268, 464–474, 1994
- Sobolev A. M. and S. Deguchi. Pumping of Class II methanol masers. I. The $2_0 - 3_{-1}$ E transition. *A&A*, 291, 569–576, 1994
- Sobolev A. M., D. M. Cragg and P. D. Godfrey. Pumping of Class II methanol masers. II. The $5_1 - 6_0$ A^+ transition. *A&A*, 324, 211, 1997a
- Sobolev A. M., D. M. Cragg and P. D. Godfrey. Class II methanol maser candidates. *MNRAS*, 288, L39, 1997b
- Voronkov M.A. A modification of the Monte Carlo method for simulation of radiative transfer in molecular clouds. *Astron. Lett.*, 25, 149–155, 1999 (astro-ph/0008476)