Astrophysical Masers and their Environments
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Towards constraining the environments of methanol masers

M. Szymczak[1], A. Bartkiewicz[1] and A. M. S. Richards[2]

[1] Toruń Centre for Astronomy, Nicolaus Copernicus University, Poland
email: msz@astro.uni.torun.pl, annan@astro.uni.torun.pl

[2] Jodrell Bank Observatory, University of Manchester, UK
email: amsr@jb.man.ac.uk

Abstract. Observations of 10 transitions of HCO^+, CO and CS isotopomers were taken with the IRAM 30 m telescope for a sample of 28 methanol maser sources detected in the Torun unbiased survey of the galactic plane. About 64% of the sources show line wings in one or more transitions, indicating the presence of molecular outflows. Two sources show evidence for infall motion. Comparison of the widths of line wings and methanol maser emission suggests that the 6.7 GHz maser line traces the environment of massive young stellar objects of various kinematic regimes. Calculations based on the CO and HCO^+ lines and the CS line intensity ratios refine the physical parameters. Specifically, a gas density of $< 10^7$ cm^{-3} is sufficient for strong maser emission and a high methanol fractional abundance ($> 5 \times 10^{-7}$) is required.

Keywords. masers, ISM: molecules, radio lines: ISM, stars: formation

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Unbiased surveys of the 6.7 GHz methanol maser line appear to provide an efficient method of forming complete samples of candidates of on-going or recently formed massive stars (Ellingsen *et al.* 1996; Szymczak *et al.* 2002; Pandian *et al.* 2007). Homogeneous samples are important for understanding when and where the methanol masers arise. However, due to the non-linear nature of maser amplification it is quite difficult to extract information about physical conditions in the maser environments from the maser data alone. In this report we present the main results of our observations of candidate massive stars in thermal molecular lines in order to constrain the range of environments probed by methanol masers.

A sample of 28 sources were selected from Szymczak *et al.* (2002); 25 of them were undetected prior to the Torun survey. Therefore, our selection excludes previously known objects associated with OH masers or with IRAS-selected bright ultra-compact HII regions. The astrometric positions of the targets were measured with the Mark II – Cambridge baseline of MERLIN (Niezurawska *et al.* 2005). The absolute positions of the objects were determined with an accuracy of 0.18″ and 0.53″ in right ascension and declination, respectively. The sample were observed in ten transitions of HCO^+, CO and CS isotopomers using three receivers at 3, 2 and 1.3 mm of the IRAM 30 m telescope. The half power beam widths ranged from 10–27″ and the spectral resolutions were 0.10–0.16 km s^{-1}.

In 18 targets the wing emission was identified at least in one of the optically thick ($^{13}CO(2-1)$, $HCO^+(1-0)$, CS(2–1), CS(3–2)) and/or thin ($C^{18}O(2-1)$, $H^{13}CO^+(1-0)$) lines. The source G25.410+0.105 is the best example of sources which show evidence for the line wings in several transitions (Fig. 1). Because the line wings are considered as signatures of outflow motion we suggest that the maser emission may be associated with molecular outflows in about 64% of the sources in our sample. A second source, G26.598–0.024, is one of the two objects in the sample with an excess of blue-shifted

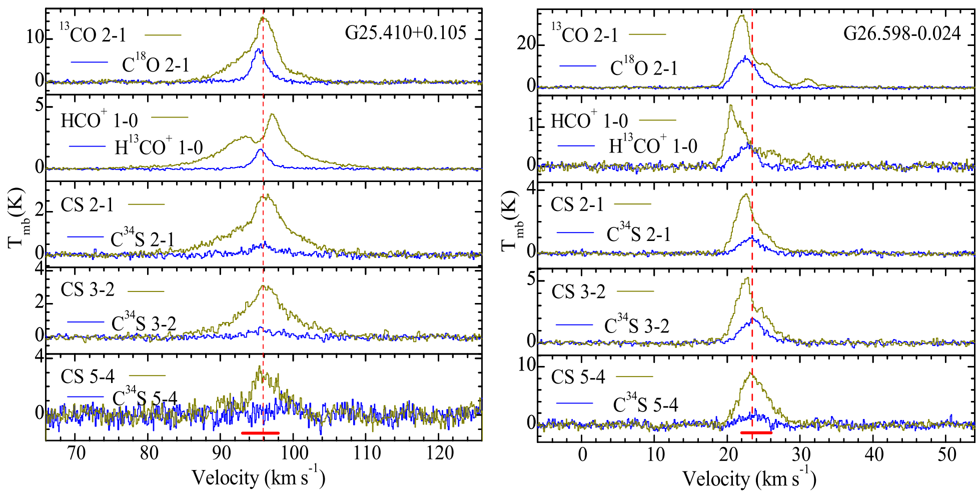

Figure 1. Molecular spectra of selected sources. The main beam brightness temperature (T_{mb}) is plotted against velocity (V_{LSR}) for one of the eighteen outflow candidates (left) and one of the two infall candidates (right). Source names, molecules and transitions are indicated. The dashed vertical line shows the systemic velocity (inferred from a Gaussian fit of one of the optically thin transitions) for each target. The thick bottom bar indicates the velocity range of the 6.7 GHz methanol maser emission (Szymczak *et al.* 2002) for each source.

emission in the optically thick lines (Fig. 1). Such a blue asymmetry of line profiles was postulated as evidence of inward motion of the gas and we suggest that the minority of the methanol maser sources may be infall candidates. The systemic velocity determined from the optically thin lines agrees within $\pm 3\,\mathrm{km\,s^{-1}}$ with the central velocity of the methanol maser emission for almost all the sources.

Using an escape-probability model we calculated the density and temperature of the gas required for the observed line intensity ratios of CS and $C^{34}S$. For the 16 sources for which all three CS transitions were detected, we found that the range of gas density is $10^5 - 10^7\,\mathrm{cm^{-3}}$ while the H_2 column density is between 10^{22} and $2 \times 10^{23}\,\mathrm{cm^{-1}}$ and the kinetic temperature varies from 30 to 100 K. The H_2 column density range is consistent with that inferred from our data for two pairs of molecular lines HCO^+ (1–0), $H^{13}CO^+$ (1–0) and ^{13}CO(2–1), $C^{18}O$(2–1) using the method outlined in Purcell *et al.* (2006) and references therein. This provides a significant refinement to the input parameters of methanol maser models.

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