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# New detections of OH sources towards the 6.7 GHz methanol masers

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**Abstract.** A sample of 6.7 GHz methanol masers has been searched for OH maser emission at 1665 and 1667 MHz using the 32 m Toruń radio telescope. Eight new OH sources were detected. They are generally weak at radio and infrared wavelengths. In the northern hemisphere sample of 68 methanol sources the OH maser emission is associated with 49 sources. Generally OH masers do not arise in weak FIR sources. The ratio of OH to $CH_3OH$ maser flux densities increases for objects with blue FIR colour and probably reflects evolutionary changes in the star-forming regions.

**Key words:** masers — surveys — stars: formation — ISM: molecules — radio lines: ISM — HII regions

## 1. Introduction

Validity of OH maser emission as a powerful tool to identify protostellar objects has been demonstrated in several surveys (Turner 1979; Caswell & Haynes 1983a, 1983b; Cohen et al. 1988). Those observations are mainly confined to the galactic plane or strong FIR objects. Nevertheless, some galactic plane surveys were not carried out at a uniform grid of positions (Turner 1979), while objects at high galactic latitudes were rarely observed (Cohen et al. 1988; Slysh et al. 1994). With the release of IRAS catalogue the possibility to get a better statistics on sites of star-forming molecular clouds signposted by OH masers greatly increased (Cohen et al. 1988; Slysh et al. 1994; Slysh et al. 1997).

The discovery of the 6.7 GHz methanol maser emission (Menten 1991) has offered another promising way to investigate the very early stages in the formation of massive stars and to obtain more accurate distribution and kinematics of those objects in the Galaxy. The first large surveys of the methanol masers guided by OH maser catalogues quickly established a tight association between maser lines of both molecules (Menten 1991; Caswell et al. 1995). However, a search for the OH 1.6 GHz masers towards the $CH_3OH$ 6.7 GHz masers revealed that the substantial number of methanol sources did not associate OH maser emission (Gaylard et al. 1994). Several new detections of the methanol masers in the northern hemisphere (Slysh et al. 1999; Szymczak et al. 2000) offer a possibility to extend the population of OH masers and to learn more about relationships between the 6.7 GHz methanol emission and the OH maser emission at 1665 and 1667 MHz.

In this paper we report the results of OH mainline observations in the direction of recently discovered methanol sources. The differences in infrared properties of the detections and non-detections are shortly discussed.

## 2. Observations

The observational data were taken between 1999 October and December with the 32 m Toruń telescope equipped with a cooled HEMT dual-channel 1.6 GHz receiver. At this frequency the half-power beam width of the antenna was $22'$. The system temperature at the zenith was about 35 K. The observations were made in the total-power position switching mode with a $2^{14}$-channel autocorrelator as spectrometre. The autocorrelator was divided into 4 banks of 4096-channel each to observe both left and right circular polarizations at 1665 and 1667 MHz simultaneously. The observing bandwidth of 1 MHz provided the velocity extent of $\pm 80$ km s$^{-1}$ relative to the LSR. The band-centre velocities were the same as the central velocities of the methanol emission observed during the Toruń survey (Szymczak et al. 2000). The resulting velocity resolution was 0.1 km s$^{-1}$ after Hanning weighting.

The spectra were obtained alternating every 5 minutes between the source position and the offset position displaced by $60'$ in right ascension. Several scans made for each source were carefully inspected for the possible

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occurrence of radio interferences and edited if necessary. Unfortunately, some scans had to be discarded as they were corrupted by strong interferences. A typical integration time of 2 hours on source yielded the rms noise level of 0.2 Jy. The data were calibrated using a reference noise diode, whose value was determined by comparison observations of W12, assuming unpolarized flux densities of 12.2 and 15.1 Jy at 1665 and 1667 MHz respectively. The absolute flux density calibration is accurate within 20%. All newly discovered sources were reobserved to exclude false detection caused by interferences from satellites or the local ones.

In making up the target list we relied upon our own survey of the 6.7 GHz methanol masers (Szymczak et al. 2000). The sample was confined to the objects with $\delta > 0°$. All new methanol sources and already known ones with no OH observations reported in the literature were searched for. Some known OH sources were observed as well.

## 3. Results

We detected eight new OH masers out of 27 objects searched. In Table 1 we give their IRAS names, the galactic coordinates, the line frequency, the range of velocity where emission is detected $\Delta V$, the velocity of the strongest feature $V_{\rm p}$ and the peak flux density $S_{\rm p}$. $1\sigma$ noise level is given in parentheses and the left and right circular polarizations are designated by L and R respectively. The OH spectra of the newly detected sources are shown in Fig. 1. The IRAS names of non-detections are listed in Table 2. For all of them $3\sigma$ detection limits were 0.4 to 0.7 Jy. Towards the source 19189+1520 a tentative feature near 0 km s$^{-1}$ was seen at 1665 MHz.

For the purpose of source statistics our original list of 74 methanol sources above declination 0° is reduced to 68 objects, as we excluded a cluster of three sources 19211+1432, 19216+1429 and 19220+1432 severely contaminated by the OH emission from W51 and source 19078+0901 contaminated by the emission from W49, whereas two sources 18496+0004 and 19230+1341 were missed in the survey. We conclude that 49 sources in this sample i.e. 72% are associated with the OH mainline masers.

## 4. Notes on individual new sources

**05382+3547**. The source lies 36.9′ from the known object 05358+3543 which exhibits both OH and $H_2O$ maser lines (Wouterloot et al. 1988). The OH 1665 MHz and $H_2O$ 22 GHz features from 05358+3543 were observed at velocities higher than −16 and −20 km s$^{-1}$ respectively, but at some epoch the water maser emission was also detected near −30 km s$^{-1}$ (Wouterloot et al. 1988). We made observations of 05382+3547 and 05358+3543 at the same epoch. It appeared that 05358+3543 has only the 1665 MHz right circularly polarized emission with the peak flux density of 3.4 Jy at −10.3 km s$^{-1}$, while 05382+3547 shows the 1665 MHz completely circularly polarized emission at velocities lower than −21 km s$^{-1}$. Therefore, we conclude that 05382+3547 is an OH source. The velocity of the 6.7 GHz methanol maser feature of −24.1 km s$^{-1}$ (Szymczak et al. 2000) is just within the range of the velocities of L and R 1665 MHz features. CO emission at −19.2 km s$^{-1}$ was observed by Wouterloot & Brand (1989). No water maser emission was found towards 05382+3547 at three different epochs (Wouterloot et al. 1993). Furthermore, no ammonia lines were detected (Molinari et al. 1996).

**18512+0029**. This is the strongest new OH source with a high degree of circular polarization up to 100% for 64.6 km s$^{-1}$ feature at 1667 MHz. The adjacent OH source 18507+0110, first discovered by Caswell & Haynes (1983b) as OH34.26+0.15, during our survey had the maser emission blueshifted relatively to the maser features from 18512+0029. Thus, it is unlikely that OH features towards 18512+0029 are sidelobe responses to 18507+0110 source. Turner (1979) did not search for OH emission in the direction of 33.70−0.26. He found an OH mainline emission near 60 and 59 km s$^{-1}$ towards neighbourhood points 33.6+0.0 and 33.9+0.0 respectively. The velocities of most of the OH emission peaks observed in our survey are exactly in the middle of the velocity range of the 6.7 GHz methanol maser (Szymczak et al. 2000).

**19191+1538**. We detected a broad 1667 MHz feature near 42 km s$^{-1}$. It is redshifted relatively to the 6.7 GHz methanol maser and the thermal CS line by about 12 and 16 km s$^{-1}$ respectively (Szymczak et al. 2000; Bronfman et al. 1996). This source is associated with a spherical ultracompact HII region of the flux density of 87.3 mJy at 6 cm (Wood & Churchwell 1989).

**19282+1814**. Towards this source a weak ($\sim 3\sigma$) 1665 MHz emission is seen within the velocity range of about 20 km s$^{-1}$. The 1667 MHz emission peak at about 24 km s$^{-1}$ is redshifted with respect to the 6.7 GHz methanol maser by about 6 km s$^{-1}$ (Szymczak et al. 2000). The CS emission detected at 23.6 km s$^{-1}$ (Bronfman et al. 1996), ammonia emission near 24.1 km s$^{-1}$ (Molinari et al. 1996) and $HCO^+$ emission at 24.4 km s$^{-1}$ (Richards et al. 1987) coincide in velocity with the OH 1667 MHz emission. No $H_2O$ maser emission was detected (Palla et al. 1991). It is unclear whether the 1667 MHz feature near −4.1 km s$^{-1}$ is related to the source. An unresolved HII region with the flux density of 1.5 mJy at 3.6 cm was found by Kurtz et al. (1994).

**19366+2301**. A weak ($\sim 3-4\sigma$) OH emission with peaks near 32.5 and 33.7 km s$^{-1}$ at 1665 and 1667 MHz respectively was detected in our survey. These velocities are virtually the same as the velocity of CS emission of 32.9 km s$^{-1}$ (Bronfman et al. 1996) and the central

**Table 1.** New 1.6 GHz hydroxyl masers observed towards 6.7 GHz methanol maser sources

| IRAS | $l$ | $b$ | Line (GHz) | $\Delta V$ (km s$^{-1}$) | $V_{\rm p}$ (km s$^{-1}$) | $S_{\rm p}$ (Jy) |
|---|---|---|---|---|---|---|
| 05382+3547 | 173.70 | 2.89 | 1.665 | −27 | −27.3 | 0.95(0.13)L |
| | | | | −22 | −22.2 | 0.51(0.12)R |
| 18512+0029 | 33.70 | −0.26 | 1.665 | 60, 61 | 60.8 | 7.85(0.19)L |
| | | | | 60, 63 | 60.9 | 9.54(0.21)R |
| | | | 1.667 | 61, 62 | 61.2 | 2.49(0.18)L |
| | | | | 61, 66 | 64.6 | 5.50(0.20)R |
| 19191+1538 | 50.31 | 0.68 | 1.667 | 40, 45 | 42.8 | 1.37(0.18)L |
| | | | | 41, 45 | 42.5 | 1.09(0.23)R |
| 19282+1814 | 53.63 | 0.02 | 1.665 | 2, 21 | 7.2 | 0.47(0.14)L |
| | | | | 3, 21 ? | 3.0 | 0.43(0.15)R |
| | | | 1.667 | −5, 25 | −4.1 | 0.79(0.16)L |
| | | | | | 24.5 | 1.17(0.16)L |
| | | | | −5, 25 | −4.1 | 0.94(0.15)R |
| | | | | | 24.4 | 1.21(0.15)R |
| 19366+2301 | 58.77 | 0.65 | 1.665 | 31, 41 | 32.5 | 0.54(0.18)L |
| | | | | 31 ? | | (0.20)R |
| | | | 1.667 | 30, 43 ? | 33.8 | 0.78(0.20)L |
| | | | | 30, 38 | 33.7 | 0.80(0.21)R |
| 20062+3550 | 73.06 | 1.80 | 1.665 | −2 | −2.4 | 0.76(0.24)L |
| | | | | −2 | −2.4 | 1.57(0.22)R |
| 21074+4949 | 90.92 | 1.51 | 1.665 | −76, −72 | −76.0 | 0.75(0.16)L |
| | | | | | −72.5 | 0.74(0.16)L |
| | | | | −76, −72 | −76.0 | 0.83(0.16)R |
| | | | | | −72.6 | 0.42(0.16)R |
| 22272+6358 | 108.19 | 5.52 | 1.665 | −11 | −10.9 | 1.38(0.21)L |
| | | | | −9 | −8.9 | 0.79(0.25)R |
| | | | 1.667 | −13, −11 | −11.7 | 1.40(0.17)L |
| | | | | −12, −10 | −10.7 | 1.06(0.20)R |

velocity of the 6.7 GHz methanol maser of 34 km s$^{-1}$ (Szymczak et al. 2000).

**20062+3550**. We detected only the 1667 MHz emission at the velocity −2.4 km s$^{-1}$. The strongest methanol maser feature was observed exactly at the same velocity (Slysh et al. 1999; Szymczak et al. 2000). The water maser emission peaks near −1.6 km s$^{-1}$ (Brand et al. 1994). The CS emission was found at 1.1 km s$^{-1}$ (Bronfman et al. 1996).

**21074+4949**. Two peaks of the 1665 MHz emission at −72.5 and −76 km s$^{-1}$ are blueshifted relatively to the velocity of the 6.7 GHz maser (Szymczak et al. 2000). No CS emission was detected (Bronfman et al. 1996).

**22272+6358**. An OH emission was found at both mainlines. In 1993 no OH emission was detected to the 3$\sigma$ upper limit of about 0.15 Jy (Slysh et al. 1994). This suggests considerable variations of the source. The velocity range of the OH emission is similar to that observed for the 6.7 GHz methanol maser (Szymczak et al. 2000). The thermal emission of $HCO^+$ found at the velocity of −9.9 km s$^{-1}$ (Richards et al. 1987) is very close to the velocities of maser lines.

**Table 2.** List of non-detections

| | | | |
|---|---|---|---|
| 02455+6034 | 06061+2151 | 18494+0002 | 18527+0301 |
| 18572+0057 | 18577+0358 | 19012+0505 | 19031+0621 |
| 19048+0705 | 18049+0712 | 19097+0847 | 19120+0917 |
| 19186+1440 | 19189+1520 | 19266+1745 | 19270+1750 |
| 19388+2357 | 22566+5830 | 23139+5939 | |

## 5. Discussion

Although the number of new OH masers detected in our survey does not allow to make a firm statistical analysis of their physical properties, we can point out some interesting characteristics. In five sources the differences between the velocities of methanol and hydroxyl maser peaks are less than 3 km s$^{-1}$. Furthermore, in several cases the radial velocities of maser peaks are the same or very close to the systemic velocities of host molecular clouds traced by thermal CO and/or CS lines. This may suggest that the maser emission of both molecules comes from common regions and the excitation of masers is achieved in the clouds of high gas density. All new masers are associated

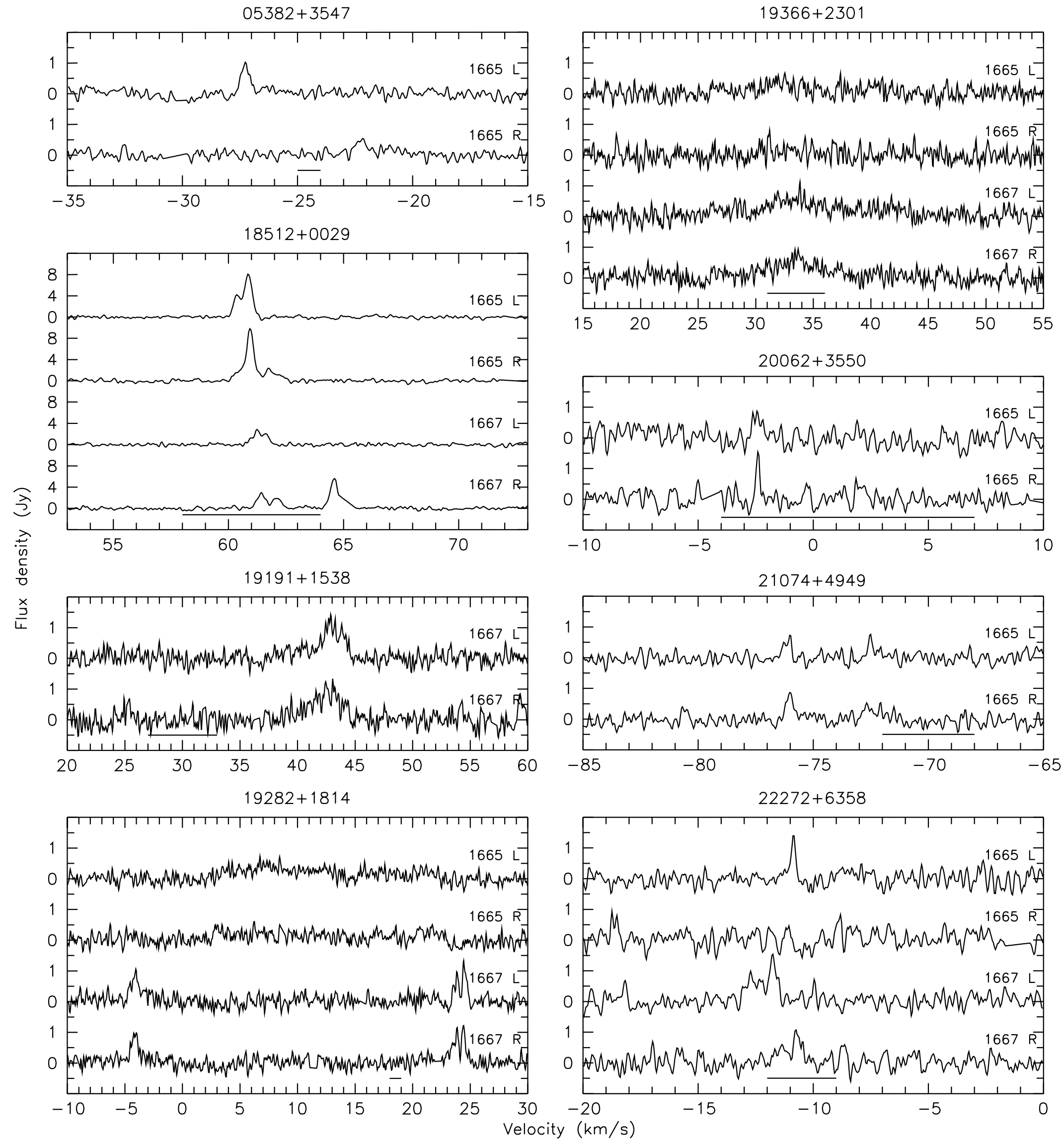


**Fig. 1.** 18 cm spectra of new OH masers. L and R means the left and right circular polarizations respectively. The lower bar in each panel indicates the velocity range of the 6.7 GHz maser emission

with relatively weak FIR sources; the median flux density at 60 $\mu$m is 360 Jy. The OH emission of these objects is generally weak. It seems that the correlation found between the OH maser flux density and infrared flux density (Cohen et al. 1988) is held for new sources and the infrared photons are likely to be involved in the pumping scheme of OH molecule. The detections reported in this paper were missed in previous survey biased towards bright IRAS sources (Cohen et al. 1988). On the other hand, six OH sources are located at galactic latitudes higher than 0.6°, so that they were not observed during the surveys of the galactic plane (Turner 1979; Caswell & Haynes 1983b).

The present survey revealed that about 28% of methanol maser sources are not associated with the 1.6 GHz mainline masers. It is interesting to look for any differences in infrared properties of OH sources and non-OH sources. Figure 2 shows the distributions of the 60 $\mu$m flux density $F_{60}$ in both sets of objects. 52 objects were included in this figure as we neglected objects with the upper limits for $F_{60}$. It is clear that the methanol masers without any OH emission are generally weaker 60 $\mu$m objects than those with the OH emission. The occurrence of OH emission preferentially in objects with stronger infrared emission appears to be consistent

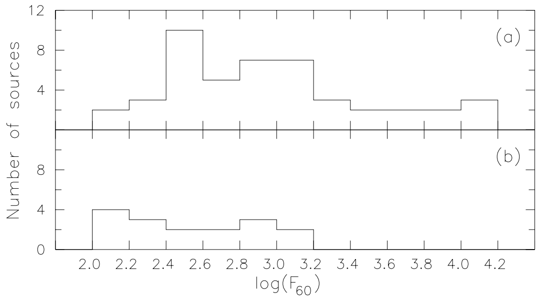


**Fig. 2.** Distributions of the 60 $\mu$m flux density in OH detections **a)** and non-detections **b)**

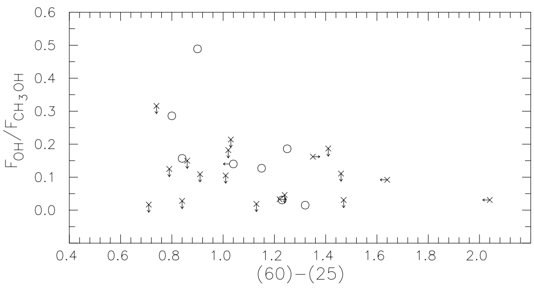


**Fig. 3.** Ratio of the OH peak flux density to the $CH_3OH$ peak flux density versus IRAS colour. The circles designate OH detections, the crosses non-detections (upper limits). The horizontal arrows indicate the upper or lower limits for the colour

with the correlation between OH and FIR flux densities mentioned above. In turn, the methanol masers without any OH emission are associated with weak FIR sources. This suggests that the infrared photons are less involved in pumping of $CH_3OH$ masers (Walsh et al. 1997) than in pumping of OH masers. Figure 3 illustrates the ratio of OH to $CH_3OH$ maser peak flux densities against the (60)−(25) colour, defined as $\log(F_{60}/F_{25})$. The peak flux densities of the 6.7 GHz methanol masers were taken from Szymczak et al. (2000). Figure 3 suggests that the intensity of OH masers increases for objects with bluer (60)−(25) colour. The above observational evidence suggests that the OH mainline masers are not sustained in sources with weak FIR emission and OH masers can appear later than the 6.7 GHz methanol masers, when a massive star-forming region evolves from the red to blue infrared colours.

The large scale surveys of OH masers (Turner 1979; Caswell & Haynes 1983a, 1983b; Cohen et al. 1988) provided the most complete inventory of star formation regions. The present observations however, suggest that the number of sites of star formation derived from OH data can be underestimated by about 30%. Gaylard et al. (1994) based mainly on the observations of the southern hemisphere sources also concluded that there is a substantial population of the 6.7 GHz methanol masers without any OH maser emission. A sensitive survey of selected galactic areas in both methanol and hydroxyl maser lines would yield a more quantitative result.

## 6. Conclusions

The survey of the OH 1.6 GHz mainline emission in the direction of the $CH_3OH$ 6.7 GHz maser sources provided eight new detections. For most sources the radial velocities of flux peaks in both maser lines differ by less than 3 km $s^{-1}$. In the sample of 68 northern methanol sources there are 19 objects not associated with OH masers. The sources without any OH emission have low 60 $\mu$m flux densities (<1100 Jy). The peak flux ratio of OH to $CH_3OH$ masers increases in sources with blue (60)–(25) colour possibly due to the evolution of star-forming regions.

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