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Detection of new sources of 4765-MHz OH masing

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Abstract. We have used the Australia Telescope Compact Array (ATCA) to make a sensitive search for maser emission from the 4765-MHz transition of OH towards a sample of 55 star formation regions. Maser emission with peak flux densities in excess of 100 mJy were detected in 14 sites, with 10 of these being new discoveries. Unlike the ground-state OH transitions the 4765-MHz transition is not predicted to be circularly polarised and none of the masers observed have detectable levels of linear, or circular polarisation. Combining our results with those of previous high resolution observations of other OH transitions we are able to investigate various theoretical models for the pumping of OH masers.

1. Introduction

Molecular maser emission from the OH molecule has been found to occur in a variety of astrophysical environments, including star formation regions, late-type stars, SNR and the nuclei of distant galaxies. Despite its apparent simplicity the rotational spectrum of the hydroxl radical is complicated by Λ-doubling and hyperfine splitting of the levels. Towards star formation regions OH maser emission is most frequently observed in the main-lines of the ground state $^2\Pi_{3/2}(J = 3/2)$ transitions, in particular the 1665-MHz ($F = 1 \rightarrow 1$) transition. Masing in the other ground state main-line transition at 1667 MHz ($F = 2 \rightarrow 2$) frequently accompanies the 1665-MHz masers, and in some sources the 1612- or 1720-MHz satellite-line transitions also exhibit maser action. Emission has been detected towards star formation regions for all groups of OH transitions with energies less than approximately 500 K above the ground state.

The higher excited OH transitions of 4750 and 6035 MHz ($^2\Pi_{1/2}$, F=1$\rightarrow$1, $^2\Pi_{3/2}$, F=3$\rightarrow$3) (plus their satellites) have also been observed. We have investigated the association of the strongest $^2\Pi_{1/2}$ transition, (F=1$\rightarrow$0 at 4765.562 MHz) with other lines also observed using the ATCA (Caswell 1997, 1998, 1999).

Several previous studies of maser sites have found that the regions of 1720-MHz also have 4765-MHz (Palmer et al. 1984, Masher et al. 1994, MacLeod 1997). Theoretical models of Gray et al. (1992) of maser pumping were developed and found that in regions of higher temperature and medium velocity shift have both strong emission at 1720 and 4765 MHz and 6035 MHz is supressed. The more recent modeling of Pavlakis et al. (1996) do not find any overlap of the 1720 and 4765 masers, yet a common overlap of 6035 and 4765 MHz. Their

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calculations of the 5cm lines are hampered by the fact that some of the theoretical collision rate coefficients have not been calculated. Our work tests the predictions of these models.

2. Observations and Data reduction

All observations were made with the Australia Telescope Compact Array. The configuration of six antennas yielded 15 baselines between 5 and 95 kλ. All pointings had 30 minutes or more of on-source observation, and the primary (and bandpass) calibration was done against PKS 1934-638. The correlator provided a 1024 channel spectrum with all four polarisation products across a 4-MHz bandwidth. The sources were selected from those observed by the ATCA to have 6035-MHz emission (Caswell 1997), or 1720 MHz (Caswell 1999), or those previously reported to have 4765-MHz emission. The observations of the 4765-MHz maser were made in September 2000.

3. Results

Data reduction was done with **miriad** and **karma** following the standard methods. With 1024 channels across 4 MHz the effecitive velocity resolution is 0.3 km s^{-1}. The 1 σ level over this bandwidth is $\approx$ 30 mJy per channel, or 14 mJy per km s^{-1}. The positional accuracy is typically (in comparison with the reference postions) 0.6 arcsecs. We searched an ares of 256 arcseconds centred on the quoted site positions, a velocity range of $\pm$5 km s^{-1} at 0.2 km s^{-1} resolution. Furthermore we searched over 150 arcseconds and $\pm$20 km s^{-1} at a resolution of 1 km s^{-1}. The entire bandpass was searched at the given position.

Fourteen sites of 4765-MHz maser emission were detected, two further sites showed signs of broader thermal emission, or possibly blended maser emission. These are listed in table 1. Ten of the sources are new detections, the remaining previously reported in various papers, as indicated in the table.

Those sites for which we have non-detections include some which have been reported as showing emission previously. The most likely reason for the absence is that the 4765-MHz maser is known to be highly variable as reported, for example, by Smits (1997).

The ratio of detections to sites with 6035-MHz emission was 8 out of 38, while for the 1720-MHz it was 2 out of 12, both of which also have 6035-MHz emission. This draws into doubt the claimed predictive power of 1720-MHz, though with few detections the statistics are not compelling.

4. Discussion

The theoretical mechanisms are complicated by some unknown or poorly known excitation rates for the pumping paths. The models of Gray et al. have a well populated combination of 1720 and 4765 MHz with local temperatures of 125K, high densities and large velocity gradients. These are the only conditions under which 4765 MHz is significantly excited. The 6035-MHz line is strongly supressed under these conditions, which is in contrary to our observations in

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Table 1. Sources with detected 4765-MHz OH emission. References: *=new source, a=Cohen, Masheder & Caswell 1995; b=Gardner & Ribes 1971; c=Smits 1997; d=Zuckerman & Palmer 1970.

Source Name	Peak Flux Density (Jy)	Velocity of Peak (km s^{-1})	Width of Peak (km s^{-1})	References
G240.316+0.071	0.31,0.18	65.2,63.0	0.4,0.4	*
G240.31+0.07	0.11	66.7	0.4	*
G294.511-1.621	2.12	-12.0	0.4	c
G309.921+0.479	0.17	-61.0	1.8	*
G328.307+0.430	0.21	-90.6	0.5	*
G328.304+0.436	0.13	-92.0	0.3	*
G328.808+0.633	0.16	-44.8	0.5	*
G328.809+0.633	0.13	-43.5	0.5	*
G333.135-0.431	0.14	-51.4	0.4	*
G333.135-0.431s	0.07	-54.3	6.7	*,Thermal
G353.410-0.360	1.68	-20.9	0.4	a
Sgr B2/G0.666-0.035	0.05	49.4	5.5	b, Thermal
G011.904-0.141	1.0	41.6	0.4	*
W49SW	0.24,0.12	8.4,11.7	0.4,0.2	a
W49N	0.65	2.1	0.5	d
W49NW	0.32	2.5	0.5	*

which 4765- and 6035-MHz masers are commonly present together. The more recent work of Pavlakis et al. find 4765 MHz only excited with *low* velocity gradients, while 1720 MHz is only exited with *high* velocity gradients, in contridiction with that seen in W3(OH) (although most observational papers draw attention to the fact this could easily be a projection effect). They have many more free parameters in their modelling, which complicates the intereptation, as it possible that there is some, unpublished combination that does excite 4765, with 1720 and/or 6035 MHz.

Ideally we would like greater resolution than the 2 arc seconds achieved by the ATCA, as this is not sufficient to separate what could be independant masing regions powered by the same central source.

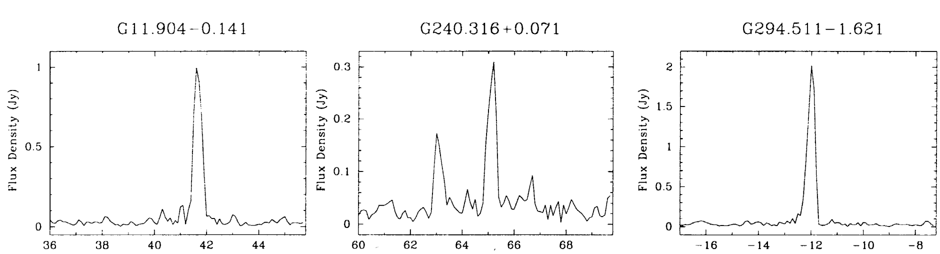

Figure 1. Spectra of some of the 4765 MHz OH masers observed with the ATCA

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5. Conculsions

We report the discovery of ten new $^2\Pi_{1/2}$ maser emission sites, more than doubling the number reported in the southern hemisphere.

We have found that the corespondance of 1720 MHz to 4765 MHz is not as strong as the corespondance of 6035 MHz to 4765 MHz.

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