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Multiwavelength OH observations of Mon R2 during 4765 MHz OH maser flaring

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Abstract. During the spectacular 4765 MHz excited OH maser flaring episodes observed in Mon R2 from 1994 to 1998 (Smits et al. 1998), observations were made at the line frequencies of other OH transitions. No excited OH lines were detected, nor were any 1612 or 1720 MHz OH masers found in Mon R2. 1665 and 1667 MHz OH masers were present and underwent small changes. With a peak flux of $\sim$ 75 Jy, the null detections and small variations at other wavelengths put strong constraints on models of OH masers.

1. Introduction

Maser emission from rotationally excited levels of OH has only been found in star-forming regions. The most common excited OH masers are the 6035 MHz line from the first excited rotational level and the 4765 MHz line from the lowest level of the $^2\Pi_{1/2}$ chain. A theoretical treatment of radiative transfer applied to a multilevel OH system by Field & Gray (1988) showed that the growth and saturation of any one maser line is intimately linked to the behaviour of other OH maser lines. Observations have indicated that the 4765 MHz masers might be associated with 1720 MHz ground-state OH masers and 6035 MHz masers. MacLeod (1997) listed the numbers of 1720, 6035 and 4765 MHz masers detected towards those sources which had been observed at all three frequencies. Eight of the eleven 4765 MHz maser sources in his sample also had detections at 1720 and 6035 MHz at some stage (not necessarily simultaneously). This suggests that the three different maser species could occur in regions with similar physical conditions, or they could change from one type to another as the region evolves. The 4765 MHz excited OH maser flaring reported by Smits, Cohen & Hutawarakorn (1998) in Mon R2 provided an opportunity to test correlations between the lines of OH from different rotational levels.

Single dish monitoring and a MERLIN observation of Mon R2 showed that the 4765 MHz emission consisted of multiple maser spots located in the region known as IRS3. The spots had about 15% linear polarization aligned at a position angle of 14°. With a peak flux density of $\sim$ 75 Jy the Mon R2 4765 MHz maser emission was twenty times stronger than any other known 4765 MHz source, and hence sets strong limits on the strengths of other OH maser lines.

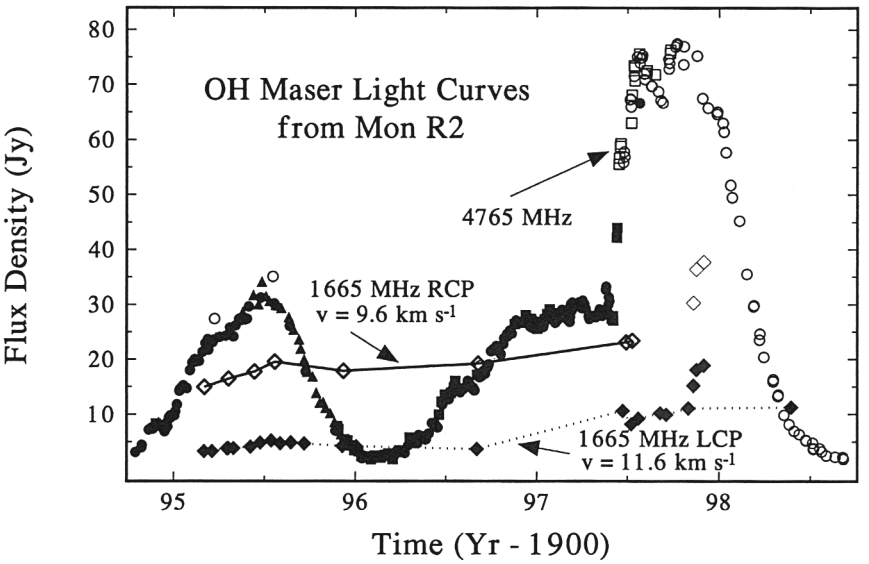

Figure 1. Temporal variations of the peak flux density at 4765 MHz and of one peak each in the 1665 MHz LCP and RCP spectra.

2. Observations

Observations using the 26m radio telescope of the Hartebeesthoek Radio Astronomy Observatory (HartRAO) were made at frequencies of the four 18 cm groundstate transitions, the four 6 GHz transitions from the first excited rotational level and the three 4.7 GHz transitions of the lowest level in the $^2\Pi_{1/2}$ chain of OH. One observation was made at 8.189 GHz, the frequency of the $F = 3 \Rightarrow F = 3$ transition of the $^2\Pi_{1/2}\, J = 5/2$ level.

The complete light-curve for the single, broad line of 4765 MHz excited OH maser emission from Mon R2 is shown in Figure 1. The last observation shown in this figure was made on 03 September 1998, by which time the flux density had dropped below 2 Jy. When observations commenced again on 06 December 1998 there was no detectable signal (to a 3σ limit of at least 0.5 Jy). Monitoring of Mon R2 has continued approximately every two weeks since then, but no sign of any further activity had been found up to February 2001.

With the exception of the 4765 MHz emission, no other OH maser activity was found from excited levels of OH to a limit of $\sim 0.5 - 1$ Jy (i.e. to about 1% of the 4765 MHz flux density). Observations at 4660 and 4750 MHz were made about every two months from late 1994 to September 1996, and once in August 1997 when the 4765 MHz flux was about 75 Jy. The 6 GHz lines were looked for

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once early in 1995 at both circular polarizations, and on three occasions when the 4765 MHz flux was above 60 Jy. At no stage were any of the 6 GHz OH lines detected above the RMS noise. In November 1996 (Yr = 96.87) 9 hrs of data were obtained at 8189.587 MHz towards Mon R2. Nothing was found to a level of 0.3 Jy.

Ground-state OH 1612 MHz emission consists of two broad peaks with fluxes of 1.0 and 1.2 Jy at velocities of 9.1 and 11.5 km s^{-1} respectively extending over a velocity range from 6.5 to 12.5 km s^{-1}. This emission appears to have remained constant since 1973 when it was first detected by Downes et al. (1975). A similar pattern occurs at 1720 MHz, but in absorption rather than in emission. Such conjugate behaviour of the OH satellite lines is common in star-forming regions and is due to quasi-thermal emission from the molecular cloud surrounding the region. 1720 MHz observations have been made since 1995 up to February 2001, but no maser signatures have been seen in the spectra at any stage.

Absorption troughs are also present over the same velocity range in the 1665 and 1667 MHz spectra, but the shape of the absorption features are obscured by maser emission sitting in the absorption trough. At 1667 MHz the dominant maser lines occur at velocities of 9.8 km s^{-1} in RCP and 10.6 km s^{-1} at LCP. The emission from these two features has a high degree of circular polarization. These lines are broad enough to indicate that they consist of multiple, unresolved spots of emission. From February 1995 to February 1996 the 1667 MHz masers underwent no noticeable changes. Two observations made in mid-1997 showed that the RCP component had increased from its 1995 value of 1.7 Jy to about 3.5 Jy. The flux of the LCP component ($\sim$ 1 Jy) did not change.

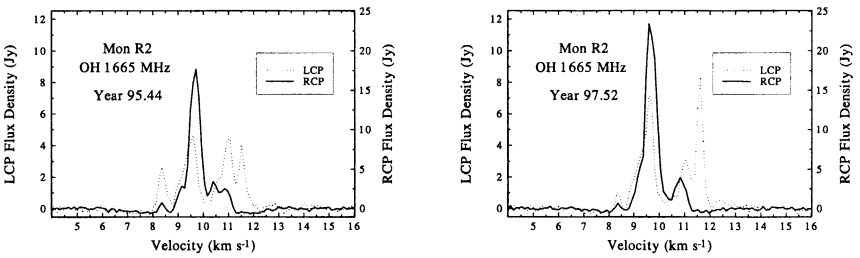

Figure 2. 1665 MHz LCP (dotted line) and RCP (solid line) spectra of Mon R2 taken 2 years apart. The scale for LCP is on the left of the plot, and that for RCP on the right.

The 1665 MHz maser emission in Mon R2 has been known to vary since its discovery by Downes et al. (1975). LCP and RCP spectra taken in June 1995 and August 1997 are shown in Figure 2 (note that the LCP and RCP fluxes use different scales). Variations of the spectra at the two epochs are clearly visible. The lines were broad and the peaks shifted channels during the observation period. This suggest that the lines are blends of more than one maser component which grow and die out at different times.

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A plot of the temporal variations of the flux density in the RCP channel at 9.6 km s^{-1} and the LCP channel corresponding to 11.6 km s^{-1} are shown in Figure 1 superimposed on the 4765 MHz light curve. The points connected by lines (dotted and solid) are from HartRAO, the other three points are from Nançay radiotelescope. The observations were made on 10 and 17 November, and 01 December, and show that the 1665 MHz fluxes of these two peaks underwent an impulsive increase at this time.

A second epoch of 4.7 GHz MERLIN observations with full polarization was obtained in December 1997 when the 4765 MHz flux density was $\sim$ 60 Jy. The maps revealed that most of the emission came from a new maser spot which also had about 15% linear polarization at a position angle of 14°. Observations at 4660 and 4750 MHz showed no maser emission to a level of 30 mJy, which is 2000 times weaker than the 4765 MHz flux density.

3. Discussion

Multiline pumping models of OH masers do not account for the behaviour of the OH masers observed in Mon R2 during the large 4765 MHz excited OH flaring episodes from 1994 to 1998. No other excited OH masers were found in this region throughout the flaring episodes, nor was there any sign of 1720 MHz groundstate OH maser activity. Groundstate 1665 and 1667 MHz OH masers have been present in this source since at least 1973 (Downes et al. 1975). Although variable, the changes were generally slower and smaller than those seen in the 4765 MHz spectra. On occassions, the 4765 MHz intensity was more than four times stronger than the 1665 MHz groundstate emission. The impulsive increase seen in the 1665 MHz Nançay radiotelescope data occurred about 5.5 months after that at 4765 MHz, indicating clearly that the 1665 and 4765 MHz lines are formed in distinctly different regions. The OH masers in Mon R2 do not appear to have any connection with each other, and therefore must be pumped independently.

All spots of 4765 MHz maser emission had linear polarization of 15% lying at a position angle of 14°. This is the only 4765 MHz maser known to have any polarization. Knapp & Brown (1976) reported a high degree of linear polarization in at least two of the 1665 MHz maser lines. Full polarization 1665 MHz MERLIN observations of Mon R2, made on 7 May 1998, are being processed.

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