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OH main line masers in the M 82 starburst

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Abstract. A study of the distribution of OH gas in the central region of the nearby active starburst galaxy M82 has confirmed two previously known bright masers and revealed several new main line masers. Three of these are seen only at 1665 MHz, one is detected only at 1667 MHz, while the rest are detected in both lines. Observations covering both the 1665 and 1667 MHz lines, conducted with both the Very Large Array (VLA) and the Multi-Element Radio Linked Interferometer Network (MERLIN), have been used to accurately measure the positions and velocities of these features. This has allowed a comparison with catalogued continuum features in the starburst such as HII regions and supernova remnants, as well as known water and satellite line OH masers. Most of the main line masers appear to be associated with known HII regions although the two detected only at 1665 MHz are seen along the same line of sight as known supernova remnants.

Keywords. masers – galaxies: individual: M82 – galaxies: ISM – galaxies: starburst

1. Introduction

M82 is one of the closest, and therefore best studied, starburst galaxies and radio observations of this galaxy are numerous. An OH maser was first detected in M82 using the Effelsberg telescope by Nguyen-Q-Rieu *et al.* (1976). Using the VLA, Weliachew *et al.* (1984) detected two main line maser regions in the galaxy and noted that, although both spots are an order of magnitude brighter than the most luminous Galactic maser, the emission from those in M82 may be coming from a number of smaller masers within each spot. The resolution of these observations however was not sufficient to detect any velocity structure or spatial extension in either masing region.

Subsequent observations have resulted in further detections of masers at other frequencies. A total of six OH features were detected using the 1612 and 1720 MHz satellite lines by Seaquist *et al.* (1997). Four features were seen in emission at 1720 MHz, two were seen in absorption at the same frequency, while only one feature was detected in emission at 1612 MHz. Several H_2O masers have also been detected in M82 at 22 GHz (Baudry & Brouillet 1996; Hagiwara 2005).

Recently MERLIN and the VLA have been used to probe the OH absorption across the central starburst region in M82 in order to provide a comparison of the distributions of molecular (OH) and atomic (HI) gas with similar resolution. As well as deep absorption features, eleven main line OH masers have been detected to a limit of 3σ, nine of which are new detections.

Unless otherwise stated, all maser positions are given in J2000 coordinates† in the format aa.″aaa bb.″bb corresponding to $09^{\rm h}55^{\rm m}$aa.$^{\rm s}$aaa and $+69^\circ40'$bb.″bb respectively. At the distance of M82 (3.2 Mpc; Freedman *et al.* 1994), one arcsecond corresponds to a linear distance of 15.5 parsecs.

† Note that positions of the continuum features in M82 are quoted in B1950 coordinates following the naming convention of Kronberg & Wilkinson (1975).

Telescope used	Date of observation	Angular resolution	Bandwidth	Velocity resolution
MERLIN	1995 Nov	0.″2	8 MHz	23 km s^{-1}
MERLIN	1997 May	0.″2	2 MHz	1.4 km s^{-1}
VLA	2002 Apr/May	1.″4	6.3 MHz	18 km s^{-1}

Table 1. Summary of the observations of OH masers in M82 discussed here.

ID (J2000)	1995		1997		2002		Nearest feature (B1950)	Nearest feature (J2000)
	S_{1665}	S_{1667}	S_{1665}	S_{1667}	S_{1665}	S_{1667}		
53.62+50.1	<2.6	<2.6	<17	<18	2.44	2.49	44.93+63.9 (HII)	53.65+50.0
53.11+48.0	5.57	<2.6	<17	<18	1.86	<0.77	44.43+61.8 (SNR)	53.14+47.8
52.71+45.8	<2.6	<2.6	<17	<18	5.02	<0.77	44.01+59.6 (SNR)	52.73+45.7
51.87+48.3	<2.6	<2.6	<17	<18	1.71	<0.77	-	-
51.23+44.5	<2.6	<2.6	<17	<18	4.85	5.93	42.48+58.4 (HII)	51.22+44.5
50.97+45.3	8.35	7.83	<17	23.0	13.0	18.5	42.21+59.2 (HII)	50.95+45.2
50.51+45.6	<2.6	<2.6	<17	<18	1.85	1.28	-	-
50.36+44.2	7.01	29.9	<17	57.2	10.7	50.5	41.64+57.9 (HII)	50.39+44.1
50.02+45.8	4.30	5.09	<17	<18	<0.77	<0.77	41.29+59.7 (SNR)	50.06+45.9
49.71+44.4	<2.6	5.29	<17	<18	<0.77	2.34	40.96+57.9? (HII)	49.71+44.1
48.45+42.1	4.15	6.94	<17	<18	2.64	5.97	39.68+55.6 (HII)	48.44+41.9

Table 2. All masers detected in the data-sets discussed here. Maser IDs are constructed from the VLA 2002 position with the exception of 50.02+45.8 which was only detected in the MERLIN 1995 observations. Fluxes are given for each maser in each line in which is was detected in each epoch (lower limits are the 3σ noise levels in each dataset), along with the closest continuum feature from McDonald *et al.* (2002) given in both B1950 and J2000 coordinates.

2. Observations

Data from the MERLIN archives, as well as more recent VLA observations, have been used to investigate the maser population in M82. A summary of the observations discussed here is given in Table 1. Some of these observations were carried out with the primary aim of investigating the molecular gas distribution across the M82 starburst via OH absorption in order to provide a comparison with that seen in HI for example. The low velocity resolution which resulted from this setup is clearly not ideal for maser studies, however useful results were obtained from these data.

3. The masers

A total of eleven main line OH masers were detected in the observations outlined above, nine of which are new detections. Table 2 lists the masers and their properties while Figure 1 shows the velocities of each maser along with the OH absorption on a position-velocity diagram constructed using the VLA 2002 data.

In the MERLIN 1995 observations, four of the six masers are detected in both main lines, while 53.11+48.0 is detected only at 1665 MHz and 49.71+44.4 is present only at 1667 MHz. In 1997, the two masers detected were seen only at 1667 MHz. In 2002 six of ten are seen in both lines, 53.11+48.0, 52.71+45.8 and 51.87+48.3 are seen only at 1665 MHz, while 49.71+44.4 is again seen only at 1667 MHz.

Of those which appear to be associated with HII regions, most are brighter at 1667 MHz than at 1665 MHz. The only exception to this is 50.97+45.3 which is reversed only in the 1995 observations. The difference in magnitude between the two lines is, however, less

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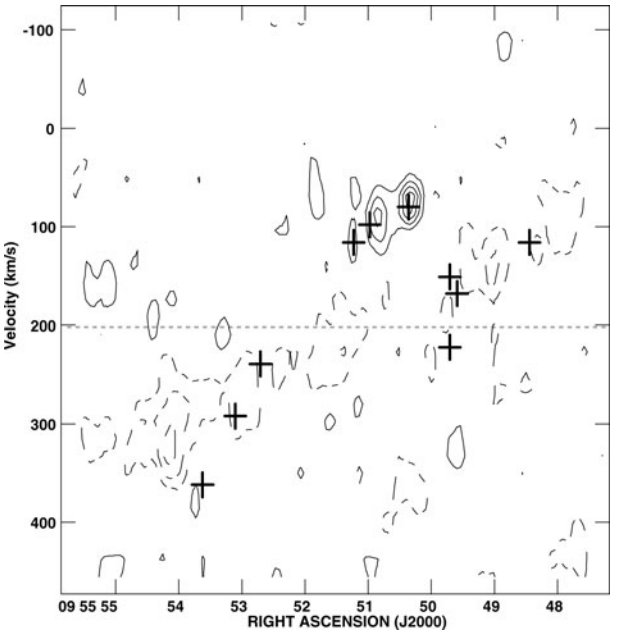

Figure 1. A comparison between the maser velocities and the absorption. Crosses represent measurements of maser velocities from the 2002 data. The contours represent the OH absorption (and emission) from the VLA 2002 dataset and the dashed line represents the systemic velocity of M82.

than 1σ. Two of the masers, 53.11+48.0 and 52.71+45.8, appear to be associated with supernova remnants. These two masers are both detected only at 1665 MHz, if they are detected at all, with no emission apparent at 1667 MHz.

Any variability between epochs could be due either to variability of a few strong sources in a particular spot, the creation/destruction of many weaker maser sources within a spot, or a combination of both. Whether the masers are varying between epochs is not trivial to determine since each observation was carried out using a different setup.

4. Two interesting sources

49.71+44.4: Despite the velocity resolution being more suited to absorption studies in the VLA 2002 and MERLIN 1995 observations, some evidence of velocity structure was seen in this maser source. Two components were observed in the 1667 MHz line in both observations. The spectra from these two observations is shown in Figure 2. Preliminary results from a further VLA dataset obtained in 2006 at higher velocity resolution also show two well-separated peaks in the 1667 MHz line with one of these further split into several components.

50.97+45.3: The only maser to show evidence of spatial structure in any of the observations examined to date. The VLA 2002 data shows an extension to the south west at a position angle almost aligned with the direction of the peculiar continuum source 41.95+57.5. The higher spatial resolution 1995 MERLIN observations show an unresolved component at the position of the peak seen in the 2002 data, as well as a 3σ component located to the SW along the same position angle as the extension seen with the VLA in 2002, see Figure 3.

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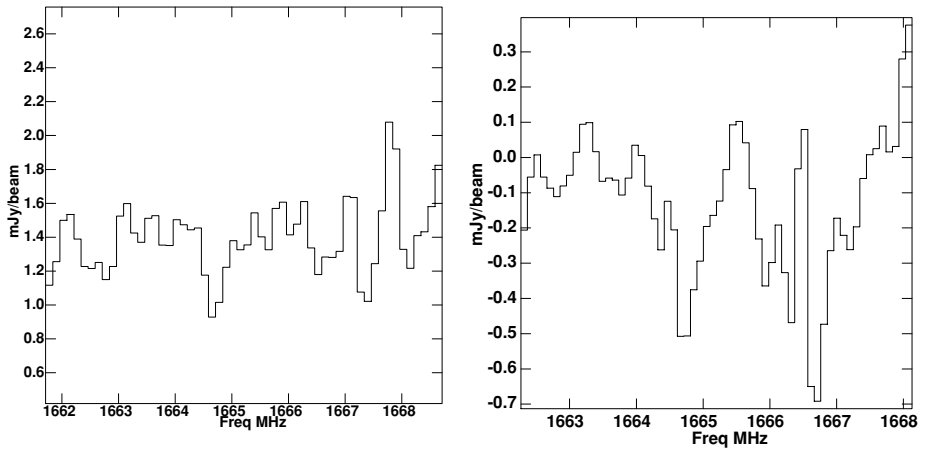

Figure 2. Spectra of 49.71+44.4 from the 1995 MERLIN observations (left) and 2002 VLA observations (right). Two components are detected at 1667 MHz separated by of order 70 km s^{-1}. A component is also visible in the absorption at 1665 MHz in the VLA 2002 data.

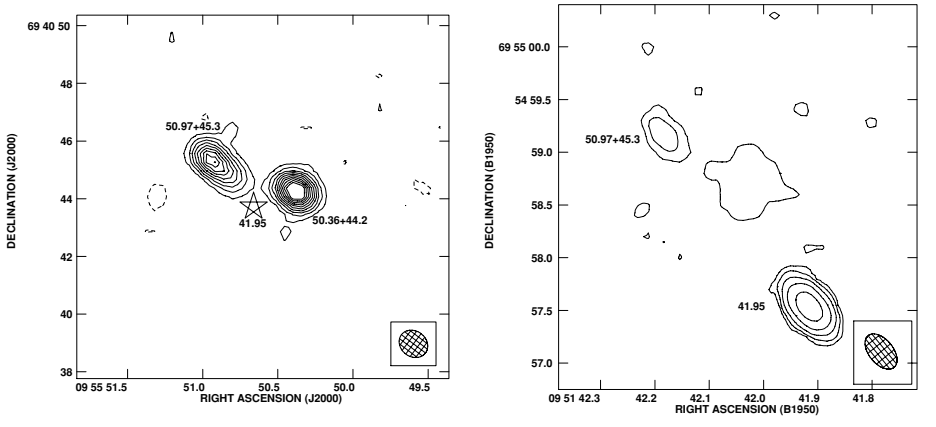

Figure 3. Images from the 2002 VLA observations (left) and 1995 MERLIN observations (right). Both maps show the maser at 50.97+45.3 relative to the continuum source 41.95 and show the extension of the maser, see main text. Note that the VLA data have been continuum subtracted while the MERLIN data have not.

5. Some conclusions

Nine new OH main line masers have been detected in the central starburst region of the nearby galaxy M82. On a position-velocity plot of the galaxy, most of the masers lie along the same axis as the gas. Four of the masers are blue-shifted from the main distribution and could possibly be on the edge of an expanding shell or orbiting within a bar.

The apparent association of most maser features with HII regions is not surprising given the results of surveys carried out in our own Galaxy, although the comparative strength of the 1667 MHz line is more characteristic of late-type stars than HII regions. The association of two masers with known supernova remnants, while unusual, is not unique. Higher resolution imaging of these sources will help determine whether these

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associations are real or just chance close alignments along a line of sight. A more sensitive survey for emission at 1612 and 1720 MHz would also help determine the nature of the maser sources.

Due to the spectral resolution of the 2002 VLA observations the masers were not resolved in frequency, with most only visible in two channels. As the individual spots are an order of magnitude more luminous than typical Galactic masers, it is likely that they are made up of more than one individual masing region, so would have structure both spatially and in frequency. In order to investigate this further, observations have recently been made using the EVN in order to provide higher spatial resolution, and the VLA at higher spectral resolution. It is hoped that further investigation using these two observations will show evidence of both spatial and velocity structure.

It is likely that there are more main line OH masers in M82 but, due to the depth of absorption and the low velocity resolution, faint or narrow masers could be buried to the extent that they are undetectable in the VLA 2002 observations. The recent high spectral resolution VLA observations will have a gain in sensitivity over the 2002 observations which should enable the detection of weaker masers.

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References

Baudry, A. & Brouillet, N. 1996, *A&A* 316, 188
Caswell, J. L., Haynes, R. F. & Goss, W. M. 1980 *Australian Journal of Physics* 33, 639
Freedman, W. L., Hughes, S. M., Madore, B. F., Mould, J. R., Lee, M. G., Stetson, P., Kennicutt, R. C., Turner, A., Ferrarese, L., Ford, H., Graham, J. A., Hill, R., Hoessel, J. G., Huchra, J. & Illingworth, G. D. 1994, *ApJ* 427, 628
Hagiwara, Y. 2005, *Ap&SS* 295, 125
Kronberg, P. P. & Wilkinson, P. N. 1975, *ApJ* 200, 430
McDonald, A. R., Muxlow, T. W. B., Wills, K. A., Pedlar, A. & Beswick, R. J. 2002, *MNRAS* 334, 912
Nguyen-Q-Rieu, Mebold, U., Winnberg, A., Guibert, J. & Booth, R. 1976, *A&A* 52, 467
Seaquist, E. R., Frayer, D. T. & Frail, D. A. 1997, *ApJ* 487, L131
Shen, J. & Lo, K. Y. 1995, *ApJL* 445, L99
Weliachew, L., Fomalont, E. B. & Greisen, E. W. 1984, *A&A* 137, 355
Wills, K. A., Das, M., Pedlar, A., Muxlow, T. W. B. & Robinson, T. G. 2000, *MNRAS* 316, 33
Wills, K. A., Pedlar, A. & Muxlow, T. W. B. 2002, *MNRAS* 331, 313