PROCEEDINGS OF SCIENCE

OH masers in nearby galaxies

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Using the VLA, a series of high velocity resolution observations have been made of the M82 starburst. These observations follow up on previous studies of the main line OH maser emission in the central kiloparsec of this starburst region, but with greater velocity resolution than previous observations. A total of thirteen masers were detected, including all but one of the previously known sources. These new results clearly show velocity structure in spectra from several of the maser regions. Position-velocity plots show good agreement with the distribution of HI including interesting velocity structure on the blue-ward feature in the west of the starburst which traces the velocity distribution seen in the ionised gas as traced by [NeII] for example.

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1. HI is not the only line.

While numerous exciting surveys are planned making use of new facilities to carry out sensitive HI surveys, there are other useful spectral lines at L-band. The ground state main and satellite lines of the OH radical will also be observable with several new facilities and will provide a wealth of useful information. In particular, the Australian SKA Pathfinder, ASKAP, will be capable of surveying OH megamasers and gigamasers out to a redshift of 1.37, tracing their luminosity and number evolution, as well as the galaxy merger rate, over time (see also [1, 2], these proceedings). In nearby galaxies, the wide field and sesitivity of new instruments will make variability studies of single-galaxy OH maser samples much more practical. This contribution describes recent results from a study of OH kilomasers in the nearby starburst galaxy M82, carried out using the existing VLA.

2. The ISM in M82

The nearby galaxy M82 is a well studied starburst system with more than 50 known continuum sources, a variety of molecular species and a turbulent ISM. OH masers in this galaxy were first discovered in the 1980s with the Efflesberg telescope [3] and have been studied in increasing detail as telescopes have improved. Several OH satellite line features have also been detected [4], most apparently associated with HII regions, and water masers are also present in the disk [5]. Previous low velocity resolution observations with the VLA detected ten maser features [6], most of which are apparently co-located with either HII regions or supernova remnants. In recent follow-up observations with the VLA, a total of thirteen OH masers were detected, some of which have been resolved in frequency. The results of these observations are briefly described here.

3. Observations

These observations were carried out in five seperate runs during February and March 2006 using the VLA in its largest A-configuration. The sources 1331+305, 0319+415 and 0954+745 were used as flux, bandpass and phase calibrators respectively. The observations each consisted of scans on the flux and bandpass calibrators as well as alternating scans on M82 and 0954+745 at two frequencies such that the total frequency coverage was sufficient to cover the entire velocity range expected across M82 at both 1665 and 1667 MHz with some overlap between IFs at the band edges. To achieve this, the correlator was used in 4-IF mode with a bandwidth of 1.5 MHz and 128 channels per IF, resulting in a velocity resolution of $\sim 2\,\mathrm{km\,s^{-1}}$. Note that all velocities are quoted relative to $225\,\mathrm{km\,s^{-1}}$, the systemic radio LSR velocity of M82. A more detailed description is given in Argo et al [7].

4. Results

A total of thirteen maser features were detected in these observations, including all but one of the previously known masers. The detections (defined as flux $>3\sigma$ in more than one adjacent channel) are listed in Table 1. While the spatial resolution of the VLA at 1.6 GHz is not sufficient

ID (J2000)	R.A. (J2000)	Dec. (J2000)	S_{1665} (mJy)	S_{1667} (mJy)	Ratio (1667:1665)	Velocity ($\mathrm{km\,s^{-1}}$)
53.64+50.1	$53\overset{s}{.}643$	$50\overset{''}{.}11$	11.4	15.0	1.32	115
53.11+47.9	53.113	47.88	20.2	<2.7	<0.13	46.7
52.73+45.8	52.729	45.77	16.9	<2.7	<0.16	2.7
52.42+49.2	52.416	49.18	11.1	<2.7	<0.24	62.1
51.94+48.3	51.937	48.29	11.5	<2.7	<0.23	-7.3
51.55+48.5	51.543	48.47	<2.7	7.42	>2.75	-26.7
51.27+44.3	51.276	44.29	13.2	32.4	2.44	-113
50.95+45.4	50.950	45.35	29.1	34.4	1.18	-133
50.54+45.5	50.542	45.50	5.15	<2.7	<0.52	-33.7
50.38+44.3	50.381	44.24	22.8	116	5.09	-151
50.07+43.1	50.066	43.06	<2.7	7.66	>2.84	-158
49.71+44.2	49.714	44.21	<2.7	12.1	>4.48	-83.0
48.43+41.9	48.432	41.96	6.18	19.0	3.07	-125

Table 1: Definite maser detections identified from the VLA 2006 data. Limits on the measured *peak* flux densities are given as 3σ. Velocities are quoted relative to the systemic velocity of $225\,\mathrm{km\,s^{-1}}$. Where a line was present in both frequencies, the measured velocities were the same in both frequencies. The maser IDs here are constructed from the J2000 positions measured in this dataset (relative to $09^{h}55^{m}$ +69°40') and are used throughout this paper. Maser IDs in bold are those which are new in these observations. Uncertainties on fluxes are ±2.7 mJy, and $\pm1.1\,\mathrm{km\,s^{-1}}$ on velocities.

to resolve the masers, the high spectral resolution of these observations showed that, while many are still unresolved in frequency, some do have significant velocity structure.

Table 1 lists the properties of each of the masers detected in the 2006 observations. Figure 1 shows the spatial distribution of the masers across the disk in M82 and Figure 2 shows the location of the masers on a p-v diagram, overlaid on the corresponding distribution of HI absorption from previous VLA observations by Wills et al [8], for both 1665 and 1667 MHz.

4.1 Associations

As has been noted in previous studies, most of the masers are apparently associated with known continuum features in M82. Most are apparently associated with HII regions, while some are close to supernova remnants. Given the high gas density, the large number of compact sources, the fact that we observe M82 almost edge-on, and the need for a source of photons for the maser process to occur, it is not surprising that many of the maser sources are apparently associated with other features. In some cases the masers may be physically associated with continuum sources, but it is likely that many of the associations are purely line-of-sight effects. The resolution of these observations is insufficient to determine which is the case. Note that, of the three new sources, none are coincident with known continuum sources to a sensitivity limit of 17 μJy/bm [9].

4.2 Velocity distribution

Previous observations of M82 have shown a velocity distribution typical of a rotating disk

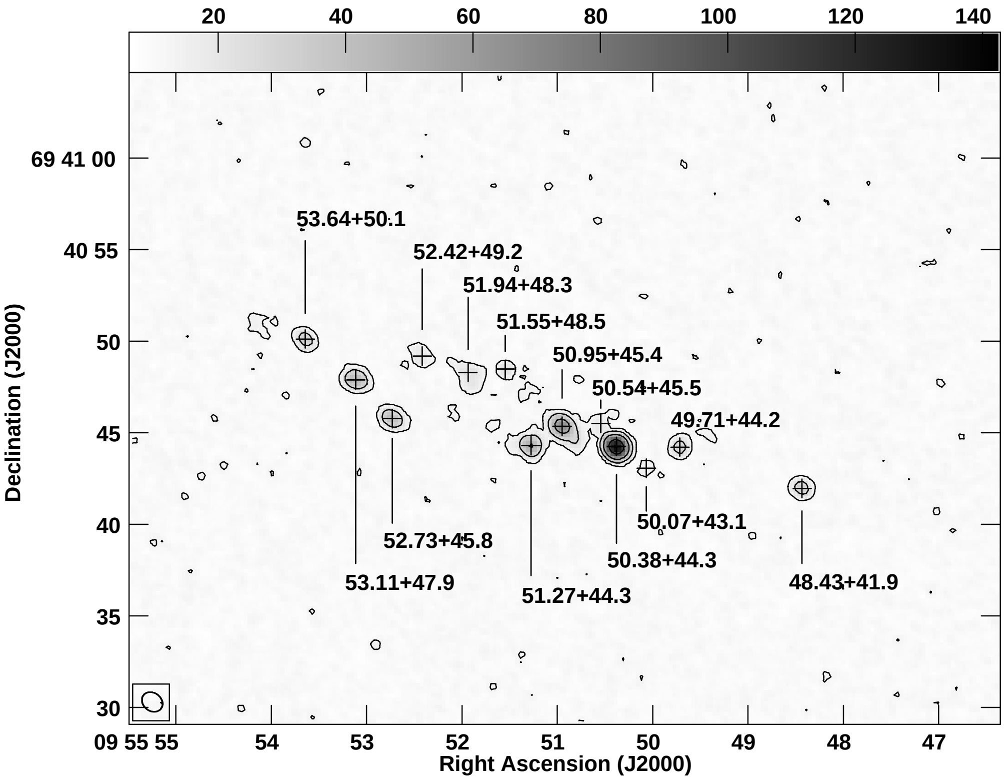

Figure 1: All masers detected in the VLA 2006 observations at $>5\sigma$. The image is a combination of both frequencies showing masers at both 1665 and 1667 MHz. The contours are $(-1,1,2,4,8,16,32) \times 3$ mJy/beam and the labels correspond to the maser IDs given in Table 1.

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with particularly strong HI and OH absorption at the eastern end of the distribution. Wills et al [8] compared p-v plots of HI, CO and [NeII] gas and noted a blue arc on the western side of the dynamical centre with velocities blueshifted compared to the main distribution in both HI and CO. They also noted that the [NeII] gas has a steeper distribution (with a gradient of $\sim$20 km s^{-1} arcsec^{-1} compared to $\sim$6 km s^{-1} arcsec^{-1} for the main distribution) which matches the eastern side of the blue feature quite well. Previous low velocity resolution observations showed that there is also significant OH absorption in this blueshifted region [6].

Figure 2 shows the velocity distribution of the masers detected here with that of the HI gas observed by Wills et al [8]. Following their method, before producing the p-v plots each cube was first rotated 17° anticlockwise so that the major axis of the galaxy was horizontal. Each cube was then compressed to one plane along the Declination axis, ignoring the five channels at either end of the band where the response was poor. As the figure shows, most of the masers in M82 lie on the main velocity distribution seen in the HI gas, however there are several which are located on the blue arc. Interestingly, the masers in this region also tend to be the brighter masers in M82. The two brightest masers, those originally detected in observations with the Efflesberg telescope, are

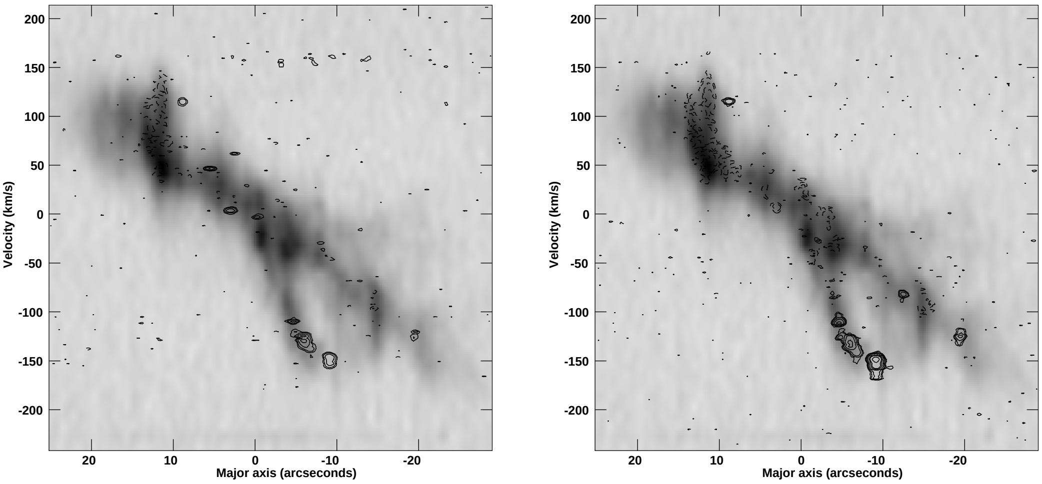

Figure 2: A comparison between the OH and HI datasets. The 1665 MHz $p-v$ plot is on the left, 1667 MHz on the right. The greyscale shows the HI absorption while the contours show the OH absorption and emission. The greyscale range is from 0 to -28 mJy/bm, while contours are drawn at (-4,-2,-1,1,2,4,8,16,32,64) × 2.4 mJy/bm (left) and 1.5 mJy/bm (right). The centre of M82 is taken to be 09$^{\rm h}$55m52$^{\rm s}$.132 +69°40’46$''$.14 (J2000) and the velocity has been corrected for a systemic velocity of 225 km s^{-1}.

located on this feature.

4.3 Velocity structure

Most of the masers continue to be unresolved, even in these higher velocity resolution observations. Some of the masers, however, are resolved in these observations. The fact that most of the masers are spatially unresolved is not surprising: given the typical physical sizes of Galactic maser spots, it is highly likely that each feature seen by the 1$''$.4 beam of the VLA contains several physical maser regions.

The masers which are resolved in velocity are mostly located on the blue arc, with the exception of 48.43+41.9 which is on the main distribution and only mildly resolved in frequency. Some of these, notably 50.95+45.4, show considerable velocity structure which is likely due to numerous closely-spaced maser regions.

5. The blue arc

The blue arc to the west of the dynamical centre of M82 is the location of the brighter masers. On the sky, they are located in an arc north of the enigmatic source 41.95+575 [10]. Interestingly, a comparison with MERLIN 408 MHz data of Wills et al [11] shows that the masers tend to avoid the peaks of low frequency emission and, in particular, several of the masers are actually located within the ‘hole’ feature noted by Wills et al. This feature is ∼100 pc in diameter, roughly centered on the compact object 41.95+57.5, and has been suggested to be due to free-free absorption by gas in a giant HII region ionised by a large stellar cluster. The masers located in this region however are not typical of Galactic masers found in star forming regions as they all (except 50.54+45.5) have line ratios >1.

6. Final comments

M82 contains many OH maser features with interesting properties, and questions involving their structure, association with continuum sources and their variability still remain. While similar samples will be easily visible in nearby galaxies, to date, there are only a small number of galaxies where such sources are known. With new facilities such as ASKAP, surveys of nearby galaxies will discover many more examples of such sources. Planned HI surveys with upcoming facilities are likely to detect numerous OH emitters and absorbers in their samples. Galaxies with masers of the sort detected in M82 will be visible in OH in the local universe and, in some cases, this emission may be confused with HI where only one line is present. Further out, more distant galaxies containing stronger megamasers and even gigamasers will be detected in deep HI surveys. Good optical redshift measurements of these galaxies will be required to discriminate between HI and OH detections in these cases to reduce mis-identifications and sample contamination.

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