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Spatially resolving the OH masers in M82

Megan Argo

Jeremiah Horrocks Institute, University of Central Lancashire, UK
email: margo@uclan.ac.uk

Abstract. With luminosities between those of typical Galactic OH masers and more distant OH megamasers, the masers in the nearby galaxy M82 are an interesting population which can be used to probe the physical conditions in the central starburst region of this irregular galaxy. Following on from previous low spatial resolution studies, here we present the initial results of two high-resolution observations separated by eight years. We find that some of the maser spots are resolved into multiple spatial components when observed with the EVN, as predicted by our previous studies, but that significantly less flux is recovered that that seen with the previous VLA observations. We conclude that some of this flux difference is likely due to variability but that, in common with the results seen in Arp220, there may also be a significant diffuse component.

Keywords. masers, galaxies: individual (M82)

1. Introduction

M82 is a nearby starburst galaxy, located 3.6 Mpc away (Freedman *et al.* 1994) in the constellation of Ursa Major. As it is inclined almost edge-on to our line of sight, little in the way of spiral structure can easily be seen in this galaxy, and the thick dust lanes caused by the starburst activity obscure much of the optical centre of the galaxy. Numerous radio studies of this galaxy have shown large amounts of gas, as well as over fifty compact radio sources which can be separated into HII regions and supernova remnants based on their radio spectra and/or their VLBI morphology (e.g. McDonald *et al.* 2002, Fenech *et al.* 2010, Muxlow *et al.* 2010, Brunthaler *et al.* 2010).

Bright OH main line emission was first detected using the Effelsberg telescope in the 1970s (Rieu *et al.* 1976), while Weliachew *et al.* (1984) looked at the HI and OH within the disk of M82 and made the suggestion that the masers, while bright, were not necessarily brighter than Galactic maser spots if each region contained many individual spots. Maser emission in the OH satellite lines was also detected (Seaquist *et al.* 1997).

Wills *et al.* (2000) used radio observations of the 21cm line of HI to investigate the motions of the atomic gas in this galaxy, finding evidence for motions that they modelled as being due to an inner bar. In 2002, in an effort to compare the atomic and molecular gas at the same spatial resolution, the OH lines at 1665 and 1667MHz were

Year	Array	Spatial resolution	Velocity resolution	Reference
2002	VLA	1.4”	17 km/s	Argo *et al.* (2007)
2004	EVN	0.03”	1.4 km/s	in prep
2006	VLA	1.4”	1.4 km/s	Argo *et al.* (2010)
2012	EVN	0.03”	1.4 km/s	in prep
2017	e-MERLIN	0.15”	1.4 km/s	in prep

Table 1. Observations of the masers in M82.

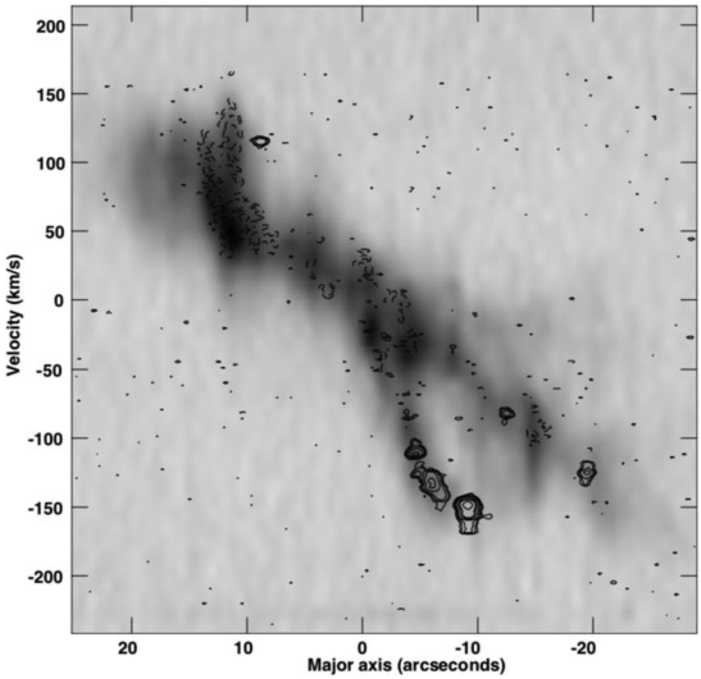

Figure 1. Position-velocity plot of the OH distribution in M82 from the VLA 2006 observations (contours) overlaid on the HI distribution from Wills *et al.* (greyscale) across the central ∼1-kpc starburst of the galaxy. The two masers with significant velocity structure here at around −150 km/s also have significant spatial structure in the EVN 2012 observations in Fig. 2.

observed with the VLA in the same configuration as the HI observations. These observations were designed to probe the absorption, rather than maser emission, but several previously-undetected OH main line masers were serendipitously discovered, even in the broad frequency channels of this observation (Argo *et al.* 2007). All of the maser spots were significantly brighter than typical Galactic masers, an effect likely due to the superposition of several masing clouds along a particular line of sight. This conclusion was supported by later VLA observations at higher velocity resolution, showing significant velocity structure in several of the maser spots (Fig 1; Argo *et al.* 2010).

In order to investigate the maser population further we obtained EVN observations at high spatial and velocity resolution, which showed that several of the maser spots are indeed resolved into multiple spatial components on scales of a few milliarcseconds, with one spot splitting into a spectacular 3.5-parsec ring at these resolutions (Argo *et al.* 2012).

The story was still incomplete, however. The total flux recovered in the EVN observations is much less than that observed in the VLA observations at the same velocity resolution. To test whether this flux reduction is due to variability, or to a diffuse component to which the EVN is not sensitive, we obtained a second epoch of EVN data, as well as intermediate spatial scale e-MERLIN observations at matched velocity resolution. Table 1 shows a summary of all observations of the OH masers carried out as part of this investigation.

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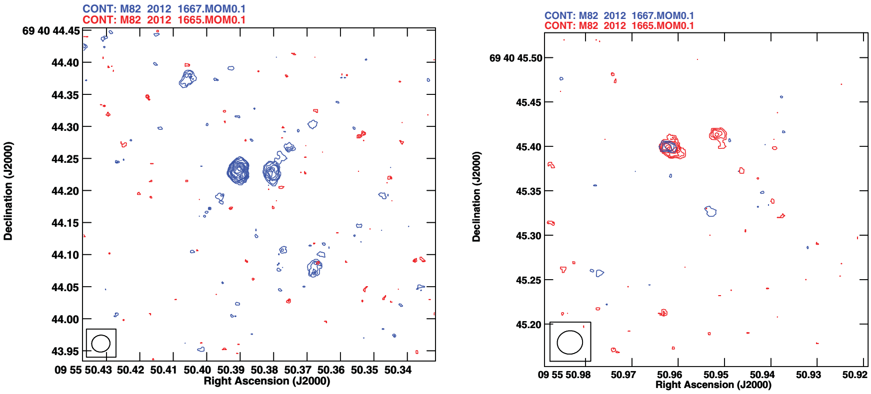

Figure 2. Comparison of 1665 (red) and 1667 MHz (blue) emission for the masers 50.37+44.3 (left panel) and 50.95+45.4 (right panel) in the 2012 EVN observations, illustrating the difference in line ratios for the different spatial components within these maser regions.

2. New observations

Since the EVN observations were carried out eight years apart, it is inevitable that there are significant changes in the hardware available between the two epochs. The 2004 observation used eight EVN stations, the 2012 observation included an additional three Russian and two Chinese stations. Both observations lasted for 18 hours, using the same phase calibrators (J0958+6533 and 0955+697A) with the same switching cycle, and the same velocity resolution. Despite the smaller beam in the 2012 observations, due to the longer baselines, this dataset was imaged with the same beam as the 2004 dataset so that the observations would be directly comparable.

The newer e-MERLIN observations were carried out in summer 2017 using the same phase calibrators as the EVN observations. They included all available antennas of the array, with 8 IFs covering a total bandwidth of 512 MHz, as well as additional spectral windows covering the HI line and each of the OH lines with the same spectral resolution as the EVN and VLA2006 observations. This dataset is currently being analysed and will be discussed further in an upcoming paper.

3. Results so far

In the earlier VLA studies, many of the masers have narrow spectral widths, however the maser regions located at 50.37+44.3 and 50.95+45.4 were both clearly resolved into multiple velocity components in the high-velocity resolution VLA study (see Fig. 1). The feature at 50.37+44.3 split into several velocity components, but was unresolved spatially at a resolution of 1.4”, whereas 50.95+45.4 was resolved in both parameters with the spatial extent stretching over several arcseconds (Argo *et al.* 2010). While many of the masers remain compact at VLBI resolution, both of these features are clearly resolved into multiple spatial components, matching the prediction from the high velocity VLA observations. Interestingly, in the 2012 EVN data, the feature at 50.37+44.3 is extended over a larger physical region than 50.95+45.4, although it is important to note here that any extended diffuse maser emission would be resolved out in these observations. A careful analysis of the velocities of each of the VLBI components is underway, with comparisons being made between the two EVN epochs, and with the spectral peaks seen in 2006 with the VLA.

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A comparison of the two VLBI datasets shows that there is considerable variation in the line ratios of the maser spots, with some being visible in only the 1665-MHz line, others only appearing in the 1667-MHz line, and some individual spots showing clear differences in line ratios between the two EVN epochs. The lack of continuum emission at the maser locations in the EVN images is expected from previous high-resolution VLBI observations of the galaxy (e.g. Fenech *et al.* 2010) - the long baselines resolve out all but the most compact emission within the galaxy. This results in limits to the amplification factors of between 40 and more than 200, again comparable with the results from Arp220 (Lonsdale *et al.* 1998).

4. To be continued

The results presented here are from the preliminary study of the high resolution data. The question of whether the apparent associations of any of the maser spots with continuum sources is being investigated by a careful comparison of the EVN images with continuum datasets at similar resolution; indications are that compact OH maser emission is offset from the continuum, demonstrating that high-gain maser action is responsible for at least part of the maser emission in M82. Observations at the same velocity resolution but intermediate angular resolution have recently been carried out with e-MERLIN. These observations should allow us to search for a more diffuse maser component such as that observed in Arp220.

One question it has so far been impossible to answer is that of variability: are changes in spot brightness between observations due to variability, or because each observation has used dramatically different parameters in either spectral or angular resolution, making both a comparison of brightnesses between epochs and a search for morphological changes impossible. The two EVN epochs, together with the new e-MERLIN data, should allow us to answer these questions.

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