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Methanol Masers at high Resolution

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Abstract.
We have conducted a follow-up observational campaign towards sources that were detected during the Onsala blind survey of the galactic plane at 6.7 GHz. During that campaign we have used the EVN to map the methanol maser emission at high spatial resolution. Since these observations are prior to the introduction of the 25 m antenna in Cambridge to the 6.7 GHz network, we have observed our list of targets using the single baseline between Cambridge and Jodrell-Bank in a later run, in order to have the information from the short baseline. The analysis of the separated datasets reveals that the EVN shortest baseline spacing (without the Cambridge antenna) is enough to resolve out a significant amount of extended emission from the methanol maser sources.
We present preliminary results from the *missing flux studies* we have conducted by comparing data from the short British single baseline observations with the "basic" EVN network observations at 6.7 GHz. We show how we intend to proceed in the analysis in order to have information about the spatial structure and extent of the observed masing regions.

1. Introduction

Since the time class II methanol masers have been discovered (Batrla et al., 1987 for the 12.2 GHz maser, Menten, 1991 for the 6.7 GHz maser) they have been recognised as very useful tools for studying regions of intense star formation. They are often associated with maser emission of other species e.g. H_2O and OH, as well as with strong IR radiation and ultra-compact (UC) HII regions. These are all signposts for massive star formation. Searches for the strong methanol maser emission at 6.7 and 12.2 GHz have been conducted using different techniques, either by selecting targets according to special criteria or by consistently surveying large regions of sky. The latter way is the one followed at the Onsala Space Observatory, where an extensive search for methanol masers in the northern hemisphere has been running since 1999. The main results are the discovery of new methanol masers at 6.7 GHz, that do not seem to be associated with the usual other observational signposts that characterise most of the known methanol maser sources.

High spatial resolution observations have revealed linear structures having linear velocity gradients. In some cases (e.g. NGC7538 IRS1) this geometry corresponds to circumstellar discs. Assuming a Keplerian rotation, the M/r^3 ratio is deducible and, in cases of the extent of the disc being known, an estimate of the mass of the central object can be given (Minier et al., 1998; Phillips, 1998).

In general, interferometric observations of 6.7 and 12.2 GHz methanol masers led to the discovery of compact, point-like, *maser spots*, which were unresolved and thought to be clumps of gas hosting suitable physical conditions for maser emission to arise. Further observations at 12.2 GHz and 6.7 GHz showed that this hypothesis is not always valid and that instead strong maser emission components are connected through weaker emission at the same frequency. According to Minier et al. (2000) this weaker emission was previously simply averaged together when producing maps over several spectral channels. So methanol masers seemed not to arise in *spots* but the masing emission region was extended.

Recent studies (Minier et al., 2001) have revealed a discrepancy between the total flux density measured with single dish observation and the total flux density in the cross power spectrum of the shortest baselines of both the VLBA and EVN (at 12.2 and 6.7 GHz respectively). The studied sources (e.g. NGC7538 IRS 1, G29.95-0.02, S252) show a clear *core-halo* structure in the spatial distribution of the maser emission (Minier et al. 2002). Thanks to the short British baseline recently equipped with 6.7 GHz amplifiers (a ~ 200 km baseline between Jodrell-Bank and Cambridge, hereafter JB-CB) it is possible to perform detailed studies using the EVN at 6.7 GHz. The missing flux that was resolved out even at the shortest EVN baselines can now be observed. In the following we will presents the still preliminary results of trying to integrate the information from different spatial resolutions.

2. Observations and data analysis

In September 2000 (project EP038) EVN observations of 10 of the 11 newly detected methanol masers were conducted. Two sources were added (W3(OH) and NGC7538) in the list both as test sources and in order to get one more epoch and perform proper motion studies (Minier et al., 2000). The five European antennas equipped with a 6.7 GHz receiver (Eb, Jb, Nt, On, Tr) were used during 24 hours, making it possible to observe every source for 45 minutes on average (*on-source* time) using 2 MHz bandwidth, 1024 channels, dual polarisation. Since the positions of the new methanol masers are accurate to about 15 arcsec, the shortest possible correlation integration time was preferred (1.8 seconds). This fact allowed to fit the fringe rate which is supposed to be high in case of a large offset from the phase centre.

The observations were scheduled in blocks, alternating scans of 8 minutes *on-source* and 3 minutes on a (bright) calibrator. For practicality we have chosen the same calibrator for sources nearby each other. With this tight alternation of source and calibrators we were hoping to get absolute positions by performing phase referencing (Beasley and Conway, 1995). This hasn't been the case for all targets, because some calibrators were too faint and consequently not detected. The coarse position accuracy available for the data correlation of the EVN experiment encouraged us to use the JB-CB inteferometer to constrain the searching field in the EVN phase referenced maps. Furthermore the visibilities of this 200 km baseline complete very well the EVN *u,v*-coverage whose shortest baseline is 800 km, providing the opportunity to study the suggested *core-halo* structure that methanol maser sources are likely to show (as in Minier et al., 2001).

EVN data was correlated in Socorro, and because of differences in the recording format, the autocorrelation spectra for each antenna were not usable for the amplitude calibration. A priori calibration has been tried, but at this stage of the data analysis a clear result has not yet been obtained.

In order to get a preliminary idea of the shape of the masing regions, phases were calibrated by self-calibration on the strongest spectral feature of the maser signal (Fig. 1). Maps of the channels showing emission were produced and cleaned around the spots of emission. The resulting fits for positions and intensity (using the AIPS task IMFIT) on the maps of the resulting data cube were then read in `msplot`[1] to produce the relative position maps. The gray scale codes the radial velocity and the size of the maser spot indicates the strength of the emission. Channels were averaged together if the distance between the different emission points was not larger than the beam, which in this case was 7.8 x 3.4 mas.

3. Results

The `msplot` position plots of G 41.34-0.14 and G 85.40-0.07 are shown in Fig. 1. JB-CB data is not included in those maps. These two sources are new detections. The first is associated to a faint IRAS source; the second does not have any listed IRAS counterpart, though in that region there is clear diffuse IR emission. Due to the simplicity of the spectra, the analysis of the VLBI data did not reveal the expected structures seen towards other known objects like outflows or discs. Using the estimated kinematical *far* distance (11.8 and 6.05 kpc for G 41.34-0.14 and G 85.40-0.07 respectively), attempts of determining the separation between the emission points were carried out. For G 41.34-0.14 the angular distance of 11 mas corresponds to about 110 AU, for G 85.40-0.07 31 mas indicate a distance of about 180 AU. These distances cannot be considered as conclusive for some kind of size of the source powering the methanol maser.

Since these results are still preliminary, we do not include a *0-moment* JB-CB map of the two sources mentioned, reserving it for a later publication. These maps show that there is maser emission connecting the two masing sites seen with the "basic" EVN. This speaks surely for an extended emission.

To illustrate the way in which we analyse the spatial structure of the source, we present here the first plots of high resolution observations at 6.7 GHz toward a strong source of the Onsala survey, G 43.80-0.15. The 6.7 GHz methanol maser hosted by this source has been detected by Menten (1991), and seems to be co-spatial with a strong UC HII region.

The idea with our analysis is to look at the correlated flux versus *u,v*-distance both through the spectrum and the time scans. We plot one point per baseline in every scan, giving plots like the one in the bottom panel of Fig. 2. We assume that the source does not vary in flux over a scan (unity of time in which source and calibrator are observed alternatively, in our case about 11 minutes long), allowing us to coherently average over time. In this way we are able to follow the correlated flux detected at every time, or at every baseline length.

In Fig. 2 an example is given. The top panel illustrate how the spectrum varies in function of baseline, at scan 4. Since such a plot summary can be made at every scan on the source, we can follow the spectral features over the complete *u,v*-range covered by the experiment. The spectra in the figure have been produced by coherently averaging in time over one scan, and the spectra show the amplitudes of the visibilities at every channel. Spectra showing no emission are the result of a noisy baseline: the coherent average of the noise gives zero. The amplitudes at every channel can then be plotted versus *u,v*-distance, where we can see if a particular spectral feature shows spatial extention. In this case, the correlated flux at that channel should decrease when increasing the baseline length. This is what we can see in the bottom panel, where the amplitudes of channel 483 are shown (the strongest visible spectral feature from the top panel). Every point in each plot corresponds to a baseline. The points are in some cases spread in a not ordered way. This has to do with the probably not yet accurate calibration of each antenna.

We can estimate the extention of the emission in the strongest channel, assuming it is a circular symmetric Gaussian-shaped emitting object, and e.g. in scan 3 we get the half of the flux at about 20 Mega-lambda, which would correspond to 260 mas. This size seems to change in time (e.g. scan 4 and 6) and this will be matter of future investigation.

Finally we have to take into account that the maximum flux registered at the shortest EVN baselines does

[1] software by C. Phillips, JIVE

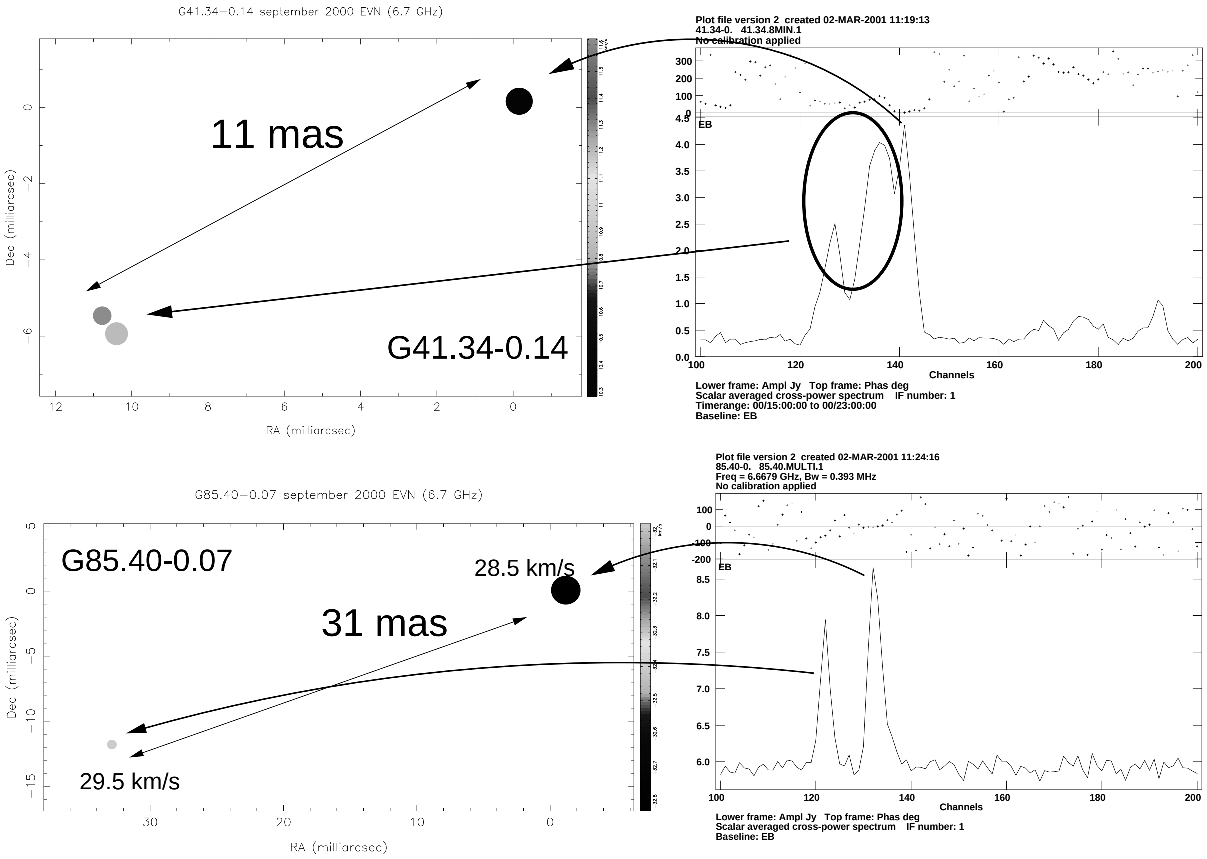

Fig. 1. Relative position maps of G41.34-0.14 (top) & G85.40-0.07 (bottom), two newly detected 6.7 GHz methanol masers. Notice that the simplicity of the spectra is reflected in the simplicity of the spatial structure.

not correspond to the zero spacing value for G 43.80-0.15. The conclusion we can sketch here is that undoubtedly, there is extended emission. Depending on the shape of the plot we will be able to tell whether there are one or more Gaussian feature to fit. Our refined analysis will take this aspect into account.

4. Conclusions

We are not yet able to make concrete conclusions about the ultimate outcomes of the analysis of our high spatial resolution data, like extention of the different regions appearing in the different channels, relative location of the spectral features, etc. We can confirm the existence of *missing flux*, which seems to be resolved out at the shortest "basic" EVN baselines, as seen in Fig. 2. A better amplitude calibration and the estimate of the error on each point, as well as the integration of the JB-CB data will give us insights on the spatial structure of the masing region. Nevertheless, care has to be used when integrating two different data sets taken in different epochs, because of variability. The investigation technique has been used in previous experiments and gave high quality results (Pestalozzi et al., 2000, Smith et al., 2002, in prep.). This makes us confident of being soon able to precisely study the spatial extent of methanol masers.

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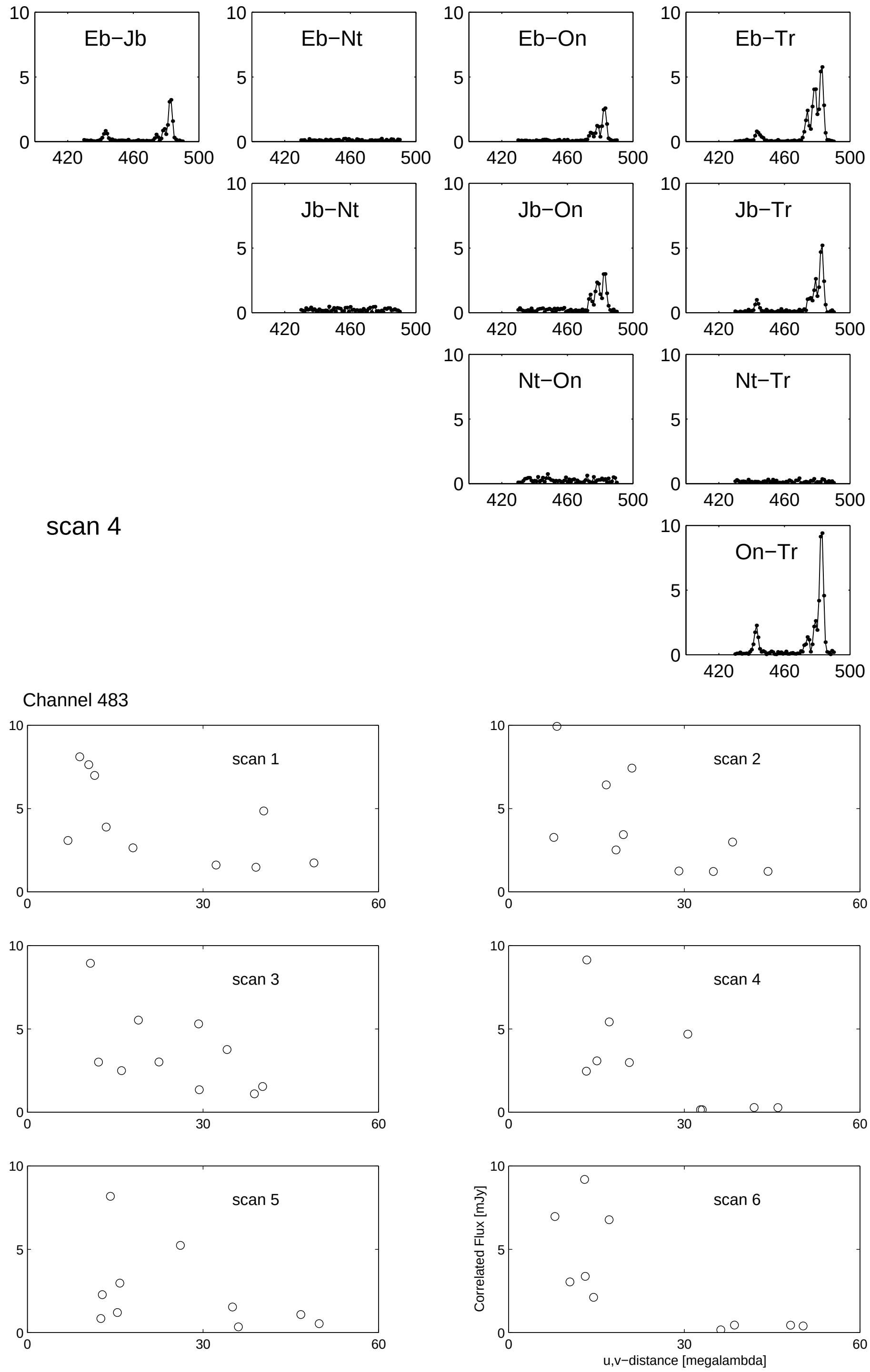

Fig. 2. An complete explanation of this figure appears in the text. Top panel: Spectra of the 6.7 GHz methanol maser of G 43.80-0.15. Every plot is named by the baseline. Bottom panel: correlated flux versus *u,v*-distance for channel 483, corresponding to the stronger spectral feature. Every plot is named by the scan number.