PROCEEDINGS OF SCIENCE

Methanol maser survey using the EVN

Anna Bartkiewicz*
Centre for Astronomy, Nicolaus Copernicus University
Gagarina 11, 87–100 Torun, Poland
E-mail: annan@astro.uni.torun.pl

Marian Szymczak
Centre for Astronomy, Nicolaus Copernicus University
Gagarina 11, 87–100 Torun, Poland
E-mail: msz@astro.uni.torun.pl

Huib Jan van Langevelde
Joint Institute for VLBI in Europe,
Postbus 2, 7990 AA Dwingeloo, The Netherlands
Sterrewacht Leiden, Leiden University
Postbus 9513, 2300 RA Leiden, The Netherlands
E-mail: langevelde@jive.nl

We present the results of a five year campaign observing 6.7 GHz methanol masers towards the Galactic plane using the European Very Long Baseline Interferometer Network (EVN). 31 out of 33 sources were imaged at milliarcsecond scale. Suprisingly, 12 of them showed an elliptical morphology which has not been detected before. We state that the recent increase in sensitivity of the EVN allowed us to detect a new type of masers. We discuss the origin of elliptically shaped methanol masers in massive star forming regions, analysing their detailed structures.

The 9th European VLBI Network Symposium on The role of VLBI in the Golden Age for Radio Astronomy and EVN Users Meeting
September 23-26, 2008
Bologna, Italy

*Speaker.

1. Introducion

Methanol maser emission at 6.7 GHz is known to be associated with high–mass star-forming regions [5]. Because of its brightness and compactness the maser is widely used in investigations of the close ($100-1000$ AU) surroundings of protostars. VLBI observations with milliarcsecond (mas) scale have been carried out for many years to date. The structures of the maser emission range from simple to complex, indicating that they may form in outflows or behind shocks driven by a protostar or in discs/torii around a central object ([4], [6], [8], [9], [13]). Their origin has not been established yet.

Here we present a summary of our project to observe methanol maser sources carried out in 2003–07 using the EVN.[1] The recently increased sensitivity of the EVN enabled us to detect weak features of the maser and consequently to find new morphologies not observed so far. The new maps allowed us to investigate the scenarios of methanol maser emission in great detail.

A full description and discussion of the project are being prepared for publication in *Astronomy & Astrophysics* and parts of the results were presented at the previous EVN Symposia ([1]; [2]).

2. Observations and data reduction

31 sources with 6668.519 MHz methanol maser emission were selected for VLBI observations. They were all discovered using the Toruń 32 m antenna ([10], [11]) and their positions were improved with astrometric measurements using MERLIN (Cm–Mk II). In addition, two sources from the literature ([13], [3]) that are located in the same region on the sky were included. The EVN observations towards all 33 targets were carried out in seven runs in June 2003 (4 antennas), November 2004 (8 antennas), February 2006 (7 or 8 antennas) and June 2007 (8 or 9 antennas). Typically five or six sources were observed in each run. Phase–reference sources were chosen carefully for each group of masers from the VLBA calibrator list. Typically, a total on–source time for each target was about 41 min. The bandwidth was 2 MHz in both circular hands. The data were correlated with 1024 spectral points yielding a velocity resolution of 0.09 km s^{-1}. In the cases when nine antenna observed, the correlation was with 512 points because of the limits set by the correlator (the EVN MK IV Data Processor at JIVE).

The data calibration and reduction were carried out with the standard procedures for spectral line observations using the Astronomical Image Processing System (AIPS). The absolute position of the target, resulting from the phase–referencing, is estimated to be 12 mas in Dec and 10 mas in RA. In the final step the targets were self–calibrated on a strong and point-like maser spot for each target. The analysis was carried out on images 0.5×0.5 arcsec^2 obtained with natural weighting, a typical beam was 6 mas$\times$16 mas elongated along the NS direction. The rms noise level (1σ) in line–free channels was 3–12 mJy beam^{-1} depending on the run.

3. Results

We obtained images for 31 out of 33 targets and were able to apply the phase–referencing scheme in 29 sources, deriving absolute positions. In total almost 2000 maser spots were detected

[1] The European VLBI Network is a joint facility of European, Chinese, South African and other astronomy institutes funded by their national research councils.

above 5σ level. When a spot appeared in at least three consequtive channels we checked its profile manually. 80% of all profiles (265 out 333) showed Gaussian characteristic with the mean FWHM of 0.40$\pm$0.01 km s^{-1}.
We classify the 6.7 GHz methanol maser emission into six morphological types: *simple* (1), *linear* (5), *elliptical* (12), *arched* (3), *complex* (9) and *pair* (1). The number of sources of each type are given in the brackets. This classification is based on the distribution of spots on the sky plane alone. In Fig. 1 we present examples of sources representing each class and in Table 1 we summarize the results for the entire sample. The main parameters are listed for each target: the coordinates of the brightest spot, the range of LSR velocity of the emission, the peak of the flux density, the number of registered spots and the morphology.

4. Discussion

The most unexpected result in this survey is the large number of elliptically shaped methanol maser sources. We suppose that superb sensitivity of EVN enabled us to detect such elaborate structures in relatively weaker targets ($S_p =\leq 28.3\,Jy$). The typical peak flux density in the cross–correlated spectra is 3.6 Jy beam^{-1}, while in the previous surveys it was 10–100 times higher ([8]; [9]; [6]; [13]; [4]).

The elliptical morphology strongly supports the scenario of an inclined disc or torus around a massive protostar or young star. A model of a rotating and expanding water maser ring has been recently tested at the centre of the PN K3-35 [12]. We applied this model to 12 methanol sources from the sample that have elliptical morphology. In general, the best fits obtained suggest that the radial velocity dominates over the rotation component in the majority of the sources, indicating that the maser arises in the zone where rotation exists, but the expansion or infall plays a role. This could take place in the interface between the rotating disc/torus and the outflow.
A similar case towards the well–known object Cep A has been reported during this Symposium (Sugiyama et al. and Torstenson et al. *this volume*). They found that the elliptically distributed 6.7 GHz methanol masers were detected around the H II region HW 2. The plane of the ellipse is perpendicular to the bipolar outflow. The LSR velocity distributions of maser spots show similar characteristic that the expansion/infall dominates over the rotation.
In order to verify if this scenario going on in the targets from the sample we need infrared observations in order to study directly the central protostar. However, the available angular resolution in the infrared wavelenght range is still limited. Proper motion VLBI studies may be a crucial test for these models.

5. Conclusions

We completed the 6.7 GHz methanol line survey in the Galactic plane for a sample of 33 maser sources. High quality EVN images were taken for 31 targets. In most cases the masers show complex structures. The observed morphologies can be divided into six groups. It is suprising that about 40% of the sources exhibit a ring–like spatial distribution of maser spots. This class of methanol sources appears to be consistent with a model of circumstellar disc or torus while their kinematics indicate radial motions, possibly related to outflow/infall phenomena.

Table 1: Results of EVN observations taken at epochs 2003–07

Source	Accurate position (J2000)		$V_s;V_e$	S_p	Number	Morph.
	RA	Dec			of	
Gll.lll±bb.bbb	(h m s)	(°) ' "	(km s^{-1})	(Jy $beam^{-1}$)	spots	
G21.407−00.254	18 31 06.33794	−10 21 37.4108	88.7;91.7	2.76	26	C
G22.335−00.155	18 32 29.40704	−09 29 29.6840	35.3;38.4	1.71	12	L
G22.357+00.066	18 31 44.12055	−09 22 12.3129	79.5;88.7	10.54	31	C
G23.207−00.377	18 34 55.21212	−08 49 11.8926	72.3;85.5	9.30	190	E
G23.389+00.185	18 33 14.32477	−08 23 57.4723	71.8;77.8	21.55	128	E
G23.657−00.127	18 34 51.56482	−08 18 21.3045	77.0;87.8	3.62	315	E
G23.707−00.198	18 35 12.36600	−08 17 39.3577	58.2;81.5	6.06	140	A
G23.966−00.109	18 35 22.21469	−08 01 22.4698	67.2;71.4	5.47	25	L
G24.147−00.010	18 35 20.92949	−07 49 00.1800	17.0;18.6	5.20	22	L
G24.541+00.312	18 34 55.72152	−07 19 06.6504	103.6;110.4	7.75	73	A
G24.634−00.324	18 37 22.71271	−07 31 42.1439	34.7;48.1	3.03	23	E
G25.411+00.105	18 37 16.92106	−06 38 30.5017	93.7;98.9	3.43	30	E
G26.598−00.024	18 39 55.92567	−05 38 44.6424	22.8;26.1	3.04	21	E
G27.221+00.136	18 40 30.54608	−05 01 05.3947	105.2;121.3	12.54	173	C
G28.817+00.365	18 42 37.34797	−03 29 40.9216	87.6;92.8	3.14	28	E
G30.318+00.070	18 46 25.02621	−02 17 40.7539	35.2;37.1	0.52	8	L
G30.400−00.296	18 47 52.29976	−02 23 16.0539	97.9;104.6	2.77	27	E
G31.047+00.356	18 46 43.85506	−01 30 54.1551	77.9;84.2	1.99	27	E
G31.581+00.077	18 48 41.94108	−01 10 02.5281	95.1;99.9	2.72	28	E
G32.992+00.034	18 51 25.58288	+00 04 08.3330	89.6;94.8	6.21	60	C
G33.648−00.224*	18 53 32.551	+00 32 06.525	58.4;63.7	28.3	94	A
G33.980−00.019	18 53 25.01833	+00 55 25.9760	58.6;65.5	3.78	59	E
G34.751−00.093	18 55 05.22296	+01 34 36.2612	50.4;53.5	1.95	30	E
G35.791−00.175*	18 57 16.911	+02 27 52.900	59.9;62.7	9.70	33	L
G36.115+00.552	18 55 16.79345	+03 05 05.4140	69.7;84.5	11.74	169	P
G36.705+00.096	18 57 59.12288	+03 24 06.1124	52.4;63.0	7.58	49	C
G37.030−00.039	18 59 03.64233	+03 37 45.0861	78.3;79.0	0.69	8	S
G37.598+00.425	18 58 26.79772	+04 20 45.4570	82.8;87.3	3.91	31	C
G38.038−00.300	19 01 50.46947	+04 24 18.9559	55.4;59.6	2.17	26	C
G38.203−00.067	19 01 18.73235	+04 39 34.2938	78.3;84.3	0.83	18	C
G39.100+00.491	19 00 58.04036	+05 42 43.9214	14.5;17.8	2.07	31	C

* – coordinates estimated using single baseline of MERLIN (Cm–Mk II)

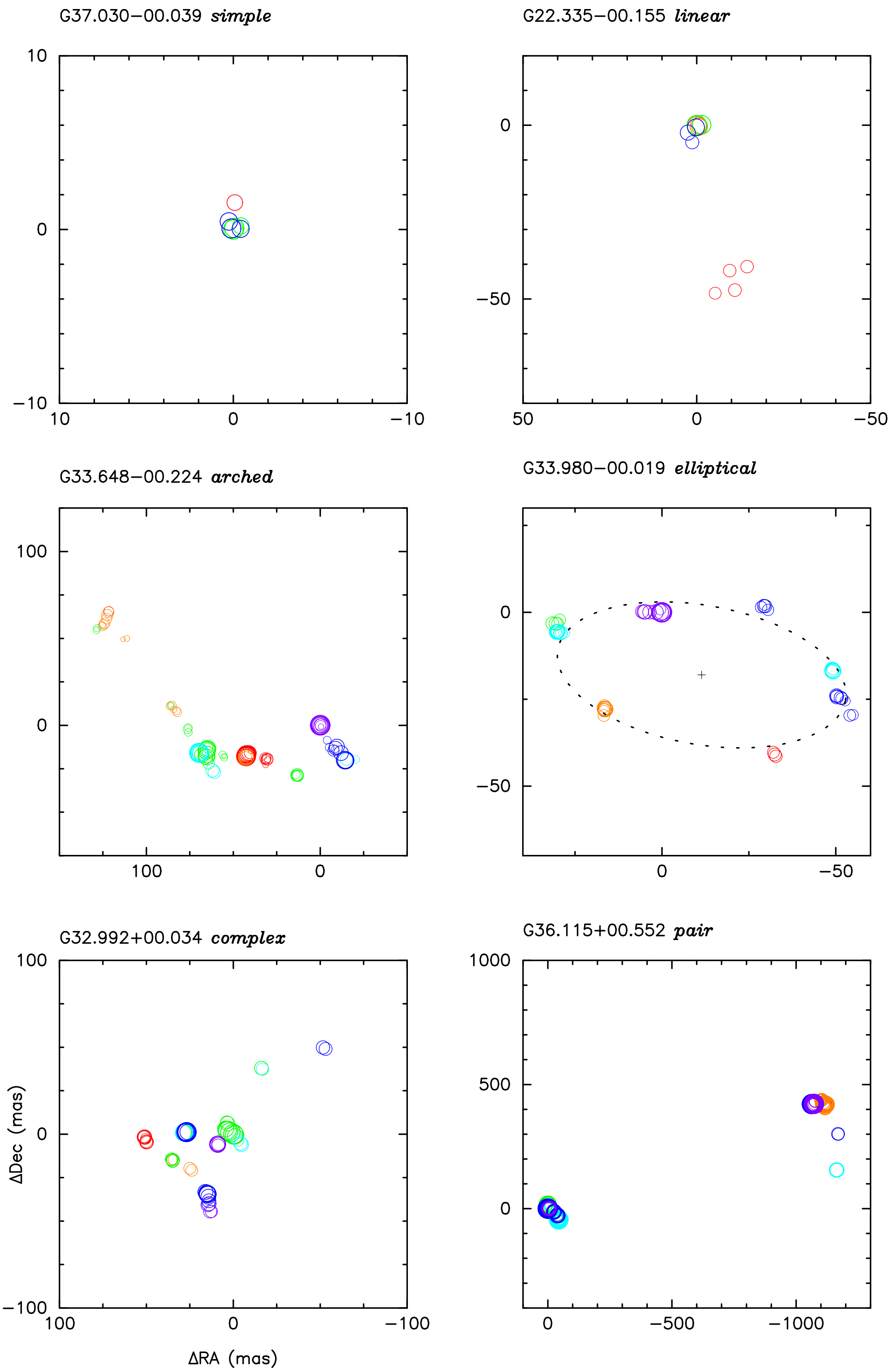

Figure 1: Examples of distribution of 6.7 GHz methanol maser emission. The coordinates are relative to the brightest spots (Table 1). The sizes of circles are proportional to the logarithm of the flux densities. The dashed line traces the best fitted ellipse to the spot distribution in G33.980−00.019.

Acknowledgements

This work was supported by the MNiI grant 1P03D02729 and UMK grant 407–A.

References

[1] A. Bartkiewicz, M. Szymczak & H.J. van Langevelde, *Methanol masers in environments of three massive protostars*, Proceedings of the 7th European VLBI Network Symposium held in Toledo, eds. R. Bachiller, F. Colomer, J.-F. Desmurs, P. de Vicente, **2004**, 187–190

[2] A. Bartkiewicz, M. Szymczak & H.J. van Langevelde, *EVN imaging of Methanol masers towards massive protostars*, Proceedings of the 8th European VLBI Network Symposium held in Toruń, ed. A. Marecki, **2006**, 274–278

[3] H. Beuther, A. Walsh, T.K. Sridharan, K.M. Menten & F. Wyrowsky, *CH_3OH and H_2O masers in high–mass star–forming regions*, A&A, **2002**, 390, 289–198

[4] R. Dodson, R. Ojha & S.P. Ellingsen, *High-resolution observations of 6.7-GHz methanol masers with the Long Baseline Array*, MNRAS, **2004**, 351, 779–790

[5] K.M. Menten, *The discovery of new, very strong and widespread interstellar methanol maser transition*, ApJ, **1991**, 380, L75–78

[6] V. Minier, R.S. Booth & J.E. Conway, *VLBI observations of 6.7 and 12.2 GHz methanol masers toward high mass star-forming regions*, A&A, **2000**, 362, 1093–1108

[7] L. Moscadelli, R. Cesaroni & M.J. Rioja, *Tracing the root of the bipolar jet in IRAS 20126+4104: VLBA observations of H_2O masers*, A&A, **2000**, 360, 663–670

[8] R.P. Norris, S.E. Byleveld, P.J. Diamond *et al.*, *Methanol masers as traces of circumstellar disks*, ApJ, **1998**, 508, 275–285

[9] C.J. Phillips, R.P. Norris, S.P. Ellingsen & P.M. McCulloch, *Methanol masers and their environment at high-resolution*, MNRAS, **1998**, 300, 1131–1157

[10] M. Szymczak, A.J. Kus, G. Hrynek, A. Kepa & E. Pazderski, *A survey of the 6.7 GHz methanol maser emission from IRAS sources. I. Data*, A&AS, **2000**, 143, 269–301

[11] M. Szymczak, A.J. Kus, G. Hrynek, A. Kepa & E. Pazderski, *6.7 GHz methanol masers at sites of star formation. A blind survey of the Galactic plane between $20^o \leq 40^o$ and $|b| \leq 0.^o52$*, A&A, **2002**, 392, 277–286

[12] L. Uscanga, Y. Gómez, A.C. Raga, J. Cantó, G. Anglada, J.F. Gómez, J.M. Torrelles & L.F. Miranda *Kinematics of the H_2O masers at the centre of the planetary nebula K3–35*, MNRAS, **2008**, 390, 1127–1132

[13] A.J. Walsh, M.G. Burton, A.R. Hyland & G. Robinson, *Studies of ultracompact H II regions*, MNRAS, **1998**, 301, 640–698