Astrophysical Masers:
Unlocking the Mysteries of the Universe
Proceedings IAU Symposium No. 336, 2017
A. Tarchi, M.J. Reid & P. Castangia, eds.

doi:10.1017/S1743921317010055

Expansion of methanol maser rings

Anna Bartkiewicz[1], Alberto Sanna[2], Marian Szymczak[1], Luca Moscadelli[3] and Huib van Langevelde[4,5]

[1]Centre for Astronomy, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Grudziadzka 5, 87-100 Torun, Poland
email: annan@astro.umk.pl

[2] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121, Bonn, Germany
email: asanna@mpifr-bonn.mpg.de

[3] INAF, Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125, Firenze, Italy
email: mosca@arcetri.astro.it

[4]Joint Institute for VLBI ERIC (JIVE), Postbus 2, 7990 AA Dwingeloo, The Netherlands
email: langevelde@jive.eu

[5]Sterrewacht Leiden, Leiden University, Postbus 9513, 2300 RA Leiden, The Netherlands

Abstract. Ring−like sources of 6.7 GHz methanol maser emission were discovered a decade ago with the European VLBI Network. In the past years we have been incessantly working to understand the nature of these rings. In general, the methanol rings do not coincide with H II regions nor they show 22 GHz water maser emission. Here, we present a proper motion study over a time baseline up to 10.5 years for the first sub-sample of methanol maser rings. Our findings suggest that in three targets G23.207−00.377, G23.389+00.185, and G23.657−00.127, such rings form in outflows or even in winds close to the central sources, and the masers trace slow proper motions of a few km s^{-1} typically.

Keywords. masers, stars: formation, instrumentation: high angular resolution

1. Introduction

After the discovery of the ring-like structures of the 6.7 GHz methanol maser emission a decade ago (Bartkiewicz *et al.* 2005), we started complementary studies to answer the question "what are those methanol rings?". The morphology suggests a relation with a disc around a massive proto- or young star, but the velocity signature of the maser spots is not consistent with rotation of a disc (Bartkiewicz *et al.* 2009). In general, we found neither water maser emission towards these sources (Bartkiewicz *et al.* 2011) nor radio continuum emission at cm-wavelength range (Bartkiewicz *et al.* 2009). This evidence suggests that the rings are associated with massive young stellar object at early evolution stages. High-angular resolution infrared observations of four methanol maser rings did not support a scenario where the 6.7 GHz maser emission arises from a circumstellar disc (De Buizer *et al.* 2012). Therefore, we started the most direct investigation of methanol maser emission with ring-like morphology using proper motion measurements obtained with the European VLBI Network†. VLBI observations were successfully demonstrated as a powerful tool to trace the 3D kinematics of the masing gas over a time span of a few years (e.g., Moscadelli *et al.* 2005, 2006; Sanna *et al.* 2010a, 2010b; Goddi *et al.* 2011). Here, we report preliminary results for three methanol maser rings, which are a part of a larger survey towards 12 targets.

† The European VLBI Network is a joint facility of independent European, African, Asian, and North American radio astronomy institutes. Scientific results from data presented in this publication are derived from the following EVN project codes: EN003, EB052.

2. Observations

The first epoch data of three targets, G23.207−00.377, G23.389+00.185 and G23.657 −00.127 were observed on 11 November 2004 (Bartkiewicz *et al.* 2009). The second epoch data were observed on 15 March 2015. The observations were phase−referenced with a switching cycle of 175 s+95 s (maser + phase-calibrator) resulting in a total on-source time of ca. 1.5 hr. The EVN Mk IV Data Processor at JIVE was used in the first epoch data and the SFXC software correlator (Keimpema *et al.* 2015) in the second one; spectral resolution on the maser lines was 0.1 km s^{-1}, i.e. a bandwidth of 2 MHz was divided into 1024 spectral channels. In the project EB052, in order to increase the signal-to-noise ratio on the phase-reference source, we used eight BBCs per polarization for a second correlator pass with 128 channels per BBC (each 2 MHz wide). The data reduction was carried out in AIPS with standard procedures for spectral line observations. Phase calibration was performed on the strongest maser channel from the first epoch observations (Bartkiewicz *et al.* 2009). Finally, we searched the maser emission using the task SAD of AIPS and a cutoff of 7σ for each channel map.

In order to study the displacements of maser spots in time, the following procedures were used: first we selected single maser spots that were visible at both epochs, next we fitted the flux−weighted ellipses to the overall maser spots distributions seen at both epochs using the code by Fitzgibbon *et al.* (1999), and then we aligned the centres of best fitted ellipses. This approach removed any bulk motion of the ring in the plane of the sky. Finally, for each group of maser spots that were clearly separated each one from the other, we constructed the averaged proper motion vector.

3. Results and Discussion

The barycentre of each maser group and its motion vector for three targets G23.207−00.377, G23.389+00.185, and G23.657−00.127 are shown in Fig. 1.

In G23.207−00.377 we detected tangential displacements of 0.13–5.6 mas between 2004 and 2015. For a distance of 4.17 kpc, obtained from a parallax measurement within the BeSSeL Survey† (Reid priv. comm.), these offsets correspond to velocities in the sky plane from 0.24 to 10.6 km s^{-1}. In the second source, G23.389+00.185, displacements were from 0.5 to 7.5 mas in the same period. For a distance of 5 kpc (Reid priv. comm.) this range corresponds to velocities from 1.1 to 17.0 km s^{-1}. The methanol maser spots in the third target, G23.657−00.127, are the most circularly distributed; the ellipticity of the best fitted ellipse is 0.39 (Fig.1). The registered shifts are from 0.6 to 3.8 mas corresponding to the velocities from 0.9 to 5.5 km s^{-1} for a distance of 3.19 kpc (Bartkiewicz *et al.* 2008). The proper motion vectors of 33 maser groups in G23.657−00.127 do not show any obvious sign of expansion or rotation, furthermore there is neither a particular direction where the motion would be greater or smaller relatively to the mean value of 2.7 km s^{-1} (Bartkiewicz *et al.* 2014). The width of “the shell” of methanol maser emission was established as 29 mas, corresponding to 92 AU (Bartkiewicz *et al.* 2005). The proper motion of each maser group do not seem to depend on a radius; the further from the centre of the best-fitted ellipse the shift is larger (Fig. 1). This points the possible expansion. De Buzier *et al.* (2012) detected a source towards this target at near- and mid-infrared. The peak emission coincided with the centre of the methanol ring to within 2.5σ. However, the 2.12 μm morphology was fan-shaped; this evidence argues in favor of scattered and/or reflected emission from the walls of the outflow cavity. Both morphologies, of methanol

† http://bessel.vlbi-astrometry.org

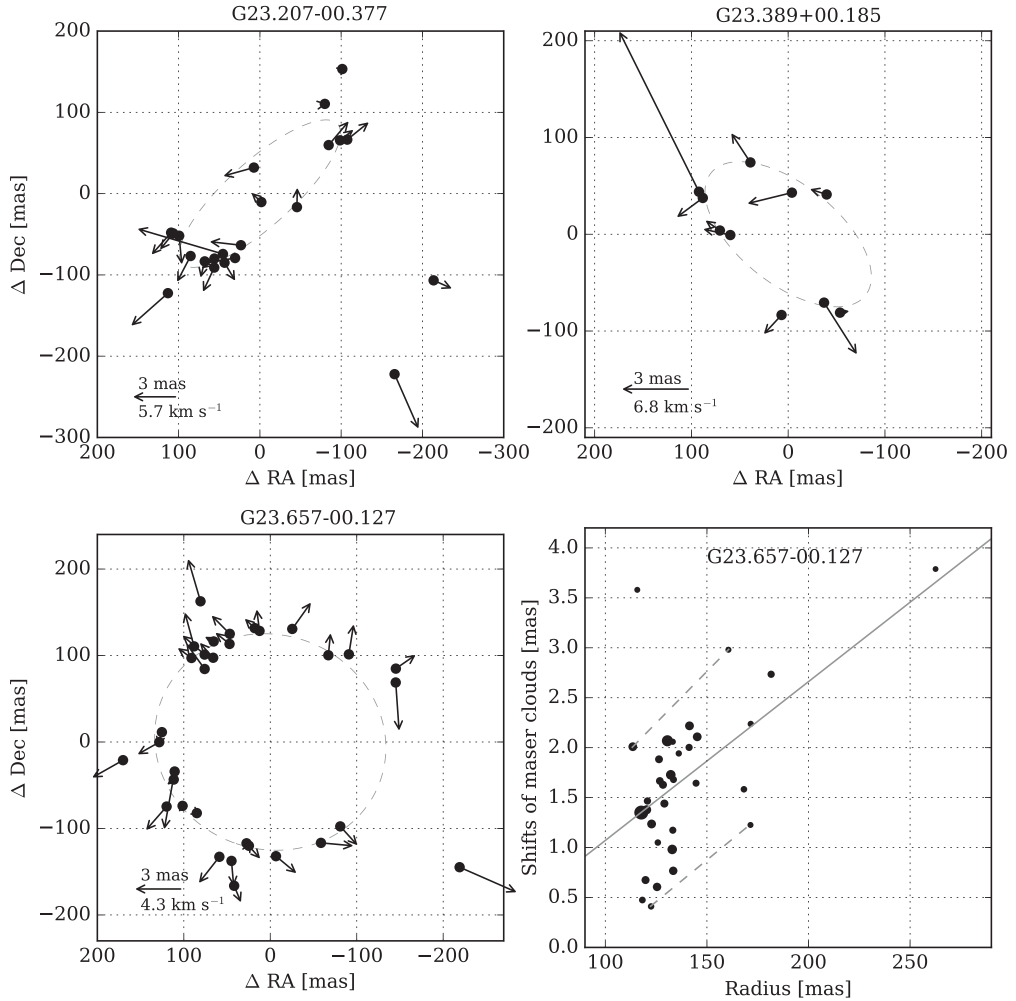

Figure 1. In the first three panels proper motion vectors of the 6.7 GHz methanol maser groups in G23.207−00.377, G23.389+00.185, and G23.657−00.127 as derived from two epoch observations (2004 and 2015), are presented. The (0,0) points correspond to the centres of the best fitted ellipses to the data from 2004. **In the bottom right panel**, for G23.657-00.127 between 2004 and 2015, we show maser shifts versus their radii from the center of the ellipse. The sizes of dots are proportional to the intensities of the brightest spots within each maser groups (a logarithmic scale). The solid line shows the least square fit with following coefficients: a=−0.52, b=0.0159. The dashed lines connect the most outer data points at both side of the fitted line, but in close position to the majority of data.

maser and near-infrared, were not consistent with a scenario where the maser ring arises from a face-on circumstellar disc.

One can see that in all three sources the proper motions are not consistent with radial motions of maser spots from the centre of the ellipse.. That is opposite to the result for the well−known high-mas star-forming region Cep A, where a combination of infall and rotation were reported (Sugiyama *et al.* 2014, Torstensson *et al.* 2011, Sanna *et al.* 2017). We rather observe an expansion and possible rotation as reported for G23.01−0.41 (Sanna *et al.* 2010b). We also note a similarity to the proper motions of SiO masers in Orion Source I, where they arise from a wide-angle bipolar wind emanating from a rotating, edge-on disc (Matthews *et al.* 2010). The extended disc wind has been recently seen by ALMA using CO lines in the TMC1A low-mass protostellar system (Bjerkeli *et al.* 2016). We therefore want to explore the possibility that methanol maser rings may be a part of a disc wind close to the central sources (rings are relatively small in sizes 400−1000 AU in diameter). In order to locate the position of the central objects we are planning high-angular resolution observations with the most sensitive interferometers such as the Jansky VLA and ALMA.

Acknowledgements
AB and MS acknowledge support from the National Science Centre, Poland through grant 2016/21/B/ST9/01455. The research leading to these results has received funding from the European Commission Seventh Framework Programme (FP/2007-2013) under grant agreement No. 283393 (RadioNet3).

References

Bartkiewicz, A., Szymczak, M., & van Langevelde, H. J. 2005, *A&A*, 442, L61
Bartkiewicz, A., Brunthaler, A., Szymczak, M., van Langevelde H. J., & Reid, M. J. 2008, *A&A*, 490, 787
Bartkiewicz, A., Szymczak, M., van Langevelde, H. J., Richards, A. M. S., & Pihlström, Y. M. 2009, *A&A*, 502, 155
Bartkiewicz, A., Szymczak, M., Pihlström, Y. M., van Langevelde H. J., Brunthaler, A., & Reid, M. J. 2011, *A&A*, 525, A120
Bartkiewicz, A., Sanna, A., Szymczak, M., & Moscadelli, L. 2014, Proceedings of 12th European VLBI Network Symposium and Users Meeting (EVN 2014) at http://pos.sissa.it/, 039
Bjerkeli, P., van der Wiel, M. H. D., Harsono, D., Ramsey J. P., & Jørgensen J. K. 2016, *Nature*, 540, 406
De Buizer, J. M., Bartkiewicz, A., & Szymczak, M. 2012, *ApJ*, 754, 149
Fitzgibbon, A., Pilu, M., & Fisher, R. B. 1999, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 21, 476
Goddi, C., Moscadelli, L., & Sanna, A. 2011, *A&A*, 535, L8
Keimpema, A., Kettenis, M. M., & Pogrebenko, S. V. *et al.* 2015, *ExA*, 39, 259
Matthews, L. D., Greenhill, L. J., Goddi, C., Chandler, C. J., Humphreys, E. M. L., & Kunz, M. W. 2010, *ApJ*, 708, 80
Moscadelli, L., Cesaroni, R., & Rioja, M. J. 2005, *Astronomy and Astrophysics*, 438, 889
Moscadelli, L., Testi, L., Furuya, R. S., Goddi, C., Claussen, M., Kitamura, Y., & Wootten, A. 2006, *A&A*, 446, 985
Sanna, A., Moscadelli, L., Cesaroni, R., Tarchi, A., Furuya, R. S., & Goddi, C. 2010a, *A&A*, 517, 71
Sanna, A., Moscadelli, L., Cesaroni, R., Tarchi, A., Furuya, R. S., & Goddi, C. 2010b, *A&A*, 517, 78
Sanna, A., Moscadelli, L., Surcis, G., van Langevelde, H. J., Torstensson, K. J. E., & Sobolev, A. M. 2017, *A&A*, 603, 94
Sugiyama, K., Fujisawa, K., Doi, A., Honma, M., Kobayashi, H., *et al.* 2014, *A&A*, 562, 82
Torstensson, K. J. E., van Langevelde, H. J., Vlemmings, W. H. T., & Bourke, S. 2011, *A&A*, 526, 38