Proceedings of the 16th European VLBI Network Symposium
Ros, E., Benke, P., Dzib, S., Rottmann, I., & Zensus, J.A. (eds.)
September 2nd-6th 2024, Bonn, Germany

Expansion of a subsample of methanol masers rings

A. Bartkiewicz[1], A. Sanna[2], M. Szymczak[1], L. Moscadelli[3], H. J. van Langevelde[4,5,6], A. Kobak[1], P. Wolak[1], and M. Durjasz[1]

[1] Institute of Astronomy, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Grudziadzka 5, PL-87-100 Toruń, Poland; e-mail: annan@astro.umk.pl
[2] INAF - Osservatorio Astronomico di Cagliari, Via della Scienza 5, I-09047, Selargius, Italy
[3] INAF, Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125, Firenze, Italy
[4] Joint Institute for VLBI ERIC (JIVE), Oude Hoogeveensedijk 4, NL-7991 PD Dwingeloo, The Netherlands
[5] Sterrewacht Leiden, Leiden University, Postbus 9513, NL-2300 RA Leiden, The Netherlands
[6] University of New Mexico, Department of Physics and Astronomy, Albuquerque, NM 87131, USA

Abstract. The 6.7 GHz methanol maser distribution showing a circular or elliptical morphology in high-mass star-forming regions was discovered two decades ago using a sensitive European VLBI Network; these targets are so-called: ring-like sources. After multi-epoch observations, we derive the proper motions of single-masing cloudlets at a level of several kilometres per second. The detailed analysis allowed us to state that the motions are directed radially outward from the centres of fitted ellipses indicating that expansion motions dominate. Still, the maser spot distribution alone does not allow for a direct interpretation of the ongoing scenario. With the results, we can not distinguish, if the rings trace the outflows or are related to disc-winds. There is a need for complementary angular resolution images.

1. Introduction

Maser transitions that naturally appear at the interstellar space are an important tool to probe dense regions in our Galaxy especially star-forming regions and circumstellar environments around evolved stars. Uniquely, easily reachable with medium radio telescopes the 6.7 GHz methanol maser line, discovered by Menten (1991), is strongly related to high-mass star-forming regions. This line has been widely observed with the VLBI networks revealing the diversity of structures of masing cloudlets (e.g. Fujisawa et al. 2014). The ring-like structures were also discovered (Bartkiewicz et al. 2009) and due to their symmetry should enable us to answer the general question: *where does the methanol maser emission arise?*. Therefore, we reobserved the selected targets that: 1) were reported as having ring-like structures seen using the European VLBI Network, 2) have shown little or no variation in the single-dish monitoring using the 32 m Torun radio telescope (Szymczak et al. 2018). In this proceeding, we present the results for three targets that show similar characteristics: 1) contain a significant number of masing spots (above 100) and trace a clear elliptical morphology, 2) the single-dish monitoring showed little or no variation of the 6.7 GHz line over years (Szymczak et al. 2018), and 3) maser cloudlets do not move inwards towards the centre of the rings but rather outwards.

The project is presented in detail in Bartkiewicz et al. (2024).

2. Observations

We observed three high-mass star-forming regions: G23.207−00.377, G23.389+00.185 and G23.657−00.127 (the names follow the Galactic coordinates) at the 6668.519 MHz methanol maser transition. In total, three epochs were carried out for each target in 2004, 2013 and 2015. Each observing run lasted for 9 hours in which we grouped nearby targets; the on-source time was ca. 1.5 hours. The phase-referencing mode was used with a switching time 3.25 min+1.75 min. The calibrator 3C345 was observed and used to calibrate the bandpass and instrumental phases. The SFXC software correlator (Keimpema et al. 2015) in JIVE was used with a 2-second integration time; the 2 MHz bandwidth and 1024 channels resulted in 0.1 $\mathrm{km\,s^{-1}}$ resolution.

3. Results and discussion

The clear ring-like morphology can be seen in Fig. 1, where we mark the estimated displacements of single cloudlets over nearly 11 years. The proper motion of the masers was studied in the following way: we determined the maser cloudlets at each epoch (it is defined as a combination of at least three maser spots appearing at consecutive spectral channels and coinciding in position within half the synthesised beam (e.g. Sanna et al. 2017) and we identified the persistent maser cloudlets over the epochs with the linear motion with respect to a bright, compact, and spectrally stable feature. Next, we derived the relative proper motions via linear fits of cloudlet displacements over the three epochs and finally, we subtracted the average proper motion of persistent cloudlets from the proper motion of each cloudlet. This is a method in which we defined a centre of motion approximating the central object rest frame, with respect to which we calculated the proper motions.

The proper motions of single maser cloudlets have been estimated to range from 16.1 $\mathrm{km\,s^{-1}}$ to 0.5 $\mathrm{km\,s^{-1}}$relating to their distances of: 4.2 kpc for G23.207−00.37, 4.8 kpc for G23.389+00.185 and 3.19 kpc for G23.657−00.127 (Reid et al. 2019). Considering the directions of shifts of maser cloudlets, we can not propose only one scenario going on in these high-mass star-forming regions. The methanol rings can be related to the outflows or/and disc-winds. Inspection of mid-infrared data from the Spitzer IRAC maps, GLIMPSE, and MIPSGAL revealed that these targets coincide with unresolved and bright sources. De Buizer et al. (2012) presented the NIR and MIR emission peaks are located northward (ca. 0.″25) from the methanol maser G23.389+00.185 and slightly shifted southward from the G23.657−00.127. No support of the hypothesis that methanol masers resided in circumstellar discs was found. Hu et al. (2016) reported weak (0.38 mJy) continuum emission at 6 GHz towards G23.389+00.185, the elongated morphology could be interpreted as a jet associated with the methanol masers. However, more sensitive observations at 8.4 GHz resulted in non-detection (Bartkiewicz et al. 2009). Therefore, we have started an ALMA project with a complementary angular resolution to VLBI observations (Kobak et al. in prep.) and also an eVLA multi-frequency survey with 10 μJy per beam sensitivity (Bartkiewicz et al. in prep.).

In summary, we report the first proper motions of the ring-like 6.7 GHz methanol masers in our Galaxy. Three-epoch observations using the EVN over eleven years enabled us to detect velocities on the order of a few kilometres per second. We find that the internal motions of maser cloudlets clearly suggest expansion from a common centre. The overall morphology of the maser emission has remained stable. The multi-frequency studies at a complementary angular resolution are needed.

Acknowledgements. The European VLBI Network (www.evlbi.org) 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, EB031, EB034 and EB052. AK, AB, MSz acknowledge support from the National Science Centre, Poland through grant 2021/43/B/ST9/02008.

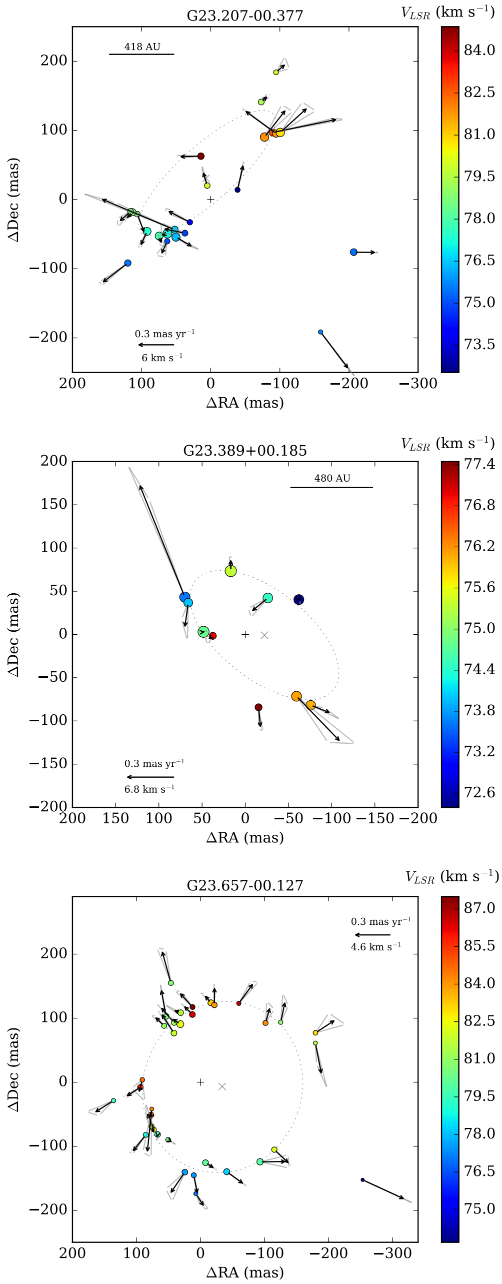

Fig. 1. Proper motions of 6.7 GHz methanol maser cloudlets in three methanol maser rings over a time span from 2004 to 2015 as seen using the EVN. The black arrows indicate the proper motions and the uncertainties are marked by the grey triangles. The centre of motion (the (0,0) point) is marked by the plus sign. The dotted ellipse traces the best flux-weighted fit to all cloudlets from the epoch of 2004 , and its centre is marked with a cross.

References

Bartkiewicz, A., Szymczak, M., van Langevelde, H.J., et al. A&A, 2009, 502, 155
Bartkiewicz, A. Sanna, A., Szymczak, M., et al. A&A, 2024, 686, A275
De Buizer, J., Bartkiewicz, A., Szymczak, M., ApJ, 2012, 754, 149, 15
Fujisawa, K., Sugiyama, K., Motogi, K., et al. , PASJ, 66, 31
Hu, B., Menten, K.M., Wu, Y., et al. ApJ, 2016, 833, 18
Keimpema, A., Kettenis, M. M., Pogrebenko, S. V., et al. Experimental Astronomy, 2015, 39, 259-279
Menten, K. M. 1991, ApJ, 380, L75
Reid, M. J., Menten, K. M., Brunthaler, A., et al. ApJ, 2019, 885, 131
Sanna, A., Moscadelli, L., Surcis, G., et al. A&A, 2017, 603, A94,
Szymczak, M., Olech, M., Sarniak, R., et al. MNRAS, 2018, 474, 219