Toruń Maser Group Highlights

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Maser action, i.e., microwave amplification by stimulated emission radiation occurs naturally in the interstellar medium and traces regions under non-LTE conditions with sufficient velocity coherence in the line of sight. Methanol, water and hydroxyl are well known masing molecules which occur in vicinity of high-mass young stellar objects (HMYSOs) and evolved stars. Observations using the Torun 32-m radio telescope together with the European Very Long Baseline Interferometer Network (EVN) are important inputs for the models of maser radiation and theory of high-mass star formation. Recent highlights of the work of our Maser Group are presented.

1 Introduction

The Toruń 32-m radio telescope is equipped with five cryogenically cooled heterodyne receivers. It is mostly used for spectral line observations, especially of the maser lines which arise in dense molecular clouds. The 32 m dish is also a vital component of the EVN[1]. The following frequency bands (with observed species) are covered by the receivers: **Band L:** 1.2–1.7 GHz (OH), **Band C1:** 4.3–5.1 GHz (OH, H_2CO), **Band C2:** 6.0–6.8 GHz (CH_3OH), **Band X:** 8–16 GHz (CH_3OH), and **Band K:** 20.5–25 GHz (H_2O, CH_3OH, NH_3). Some recent findings of unexpected behaviour of the maser lines are presented.

2 Results and Discussions

A sample of 140 methanol maser sources have been monitored with the 32-m radio telescope since 2009 (Szymczak et al., 2018). Several of them exhibit cyclic changes with periods of 120 to 416 days. Recently, a new source with periodic variability (149 days) was discovered in G59.63−0.19 (named based on its galactic coordinates). Changes in the maser flux density are synchronous with the infrared flux density (Fig. 1). The 3D structure recovered using the EVN observations and single dish data implies that the emission traces an accretion disc (Olech et al., 2019).

The intermediate-mass protostar G107.298+5.639 shows periodic flares, with a period of 34.4 days at the diverse transitions: 22 GHz H_2O, 6.7 GHz CH_3OH, 1.665 and 1.667 GHz OH lines. This is the only known source displaying anticorrelated flares of CH_3OH and H_2O vapour masers. This type of behaviour is most likely driven by periodic accretion onto a binary protostar (Fig. 2, Szymczak et al. 2016, Olech et al. 2020).

What causes the maser variability? To answer this question we compared the light curves of the maser lines with the infrared photometry of the WISE telescope

[1] https://www.evlbi.org/

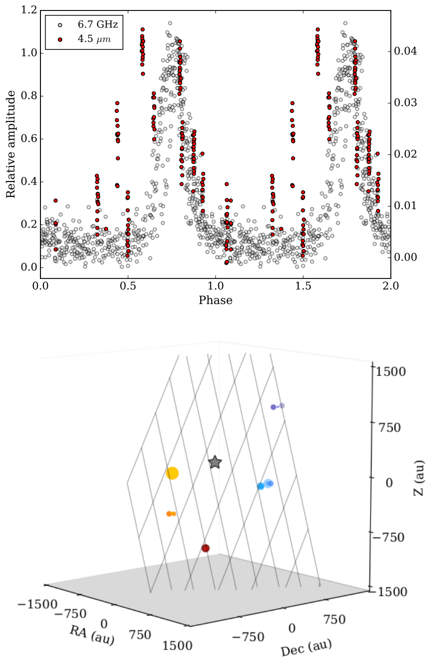

Fig. 1: G59.63−0.19. *Top:* Phased light curves of the 6.7 GHz methanol maser and 4.5 μm emission. *Bottom:* 3D structure of the maser emission derived from time delays of maser features and the EVN map.

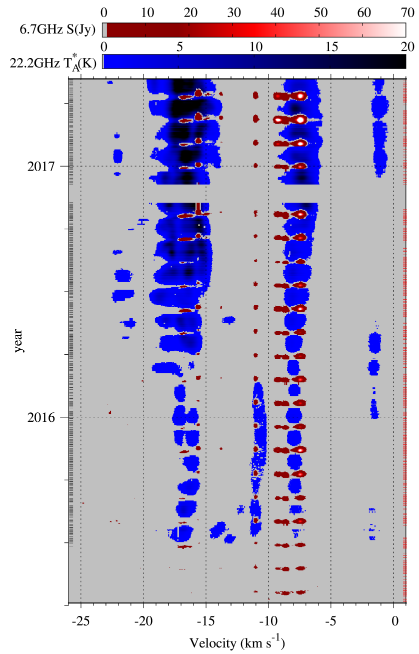

Fig. 2: Dynamic spectra of the methanol and water maser lines in G107.298+5.639. There is clear evidence of anti-correlated variability of both masers.

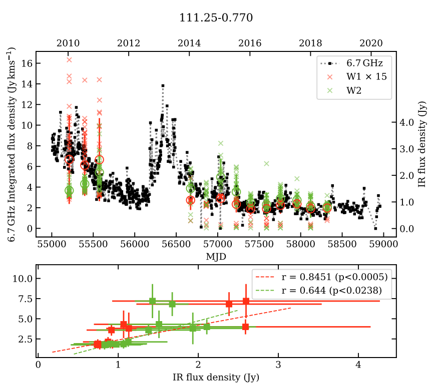

Fig. 3: *Top:* The light-curves of the 6.7 GHz methanol maser lines with the infra-red photometry of the WISE telescope. *Bottom:* There is a correlation between infra-red and 6.7 GHz methanol maser flux for variable sources.

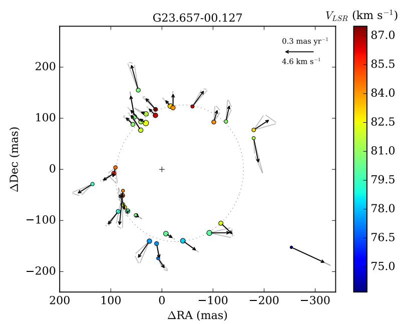

Fig. 4: Vectors of proper motion of 6.7 GHz methanol maser clouds in G23.657−00.127 (Bartkiewicz et al., 2020). The clouds are marked by filled circles, their sizes are proportional to their peak brightness at the first epoch. The colours correspond to the local standard velocity scale presented in the vertical wedge. The black arrows indicate the best fits of the relative proper-motion for the three epoch data with the uncertainties marked by the grey triangles.

available from 2011 to 2019. This allowed us to relate the maser characteristics with those of the infrared radiation from the high-mass young stellar objects. A correlation between infrared and 6.7 GHz methanol maser flux was found for variable sources (Fig. 3) supporting a radiative pumping scheme (Durjasz et al., 2019).

Owing to the high-astrometric precision achieved using the EVN and compactness and brightness of Galactic masers, it is possible to derive the proper motions of gas clouds with a precision of a few km s^{-1} over a few years. When the elliptical, so called ring-like, structures were discovered in the methanol maser emission at 6.7 GHz it was not obvious if they originate in a disc or torus around a proto- or young massive star, or are related to an outflow or infall (Bartkiewicz et al. 2005, Bartkiewicz et al. 2009). Therefore multi-epoch observations were carried out on a time baseline up to 10 years. These data allowed for direct measurements of single maser cloud displacements excluding the systemic motions of the system. Expansion of the ring-like maser structures was clearly detected, suggesting the existence of very young outflows from a massive young star (Fig. 4, Bartkiewicz et al. 2018, Bartkiewicz et al. 2020).

A sample of 63 methanol maser sources were observed with the EVN with the milliarcsecond angular resolution (i.e. 30 AU at a distance of 5 kpc), SED-fits were obtained based on 33 infra-red bands from diverse catalogues (e.g. WISE, GLIMPSE, Herschel) for each source. A few preliminary results from these detailed studies are: a typical size of a maser cloud is 14 au, masers are related to objects actively accreting matter, the maser emission is mostly associated with high-mass young stellar objects of total luminosity of 10^4 $L_\odot$ (Sarniak et al., 2018).

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References

Bartkiewicz, A., Szymczak, M., van Langevelde, H. J., *A&A* **442**, 3, L61 (2005)

Bartkiewicz, A., et al., *A&A* **502**, 1, 155 (2009)

Bartkiewicz, A., et al., in A. Tarchi, M. J. Reid, P. Castangia (eds.) Astrophysical Masers: Unlocking the Mysteries of the Universe, *IAU Symposium*, volume 336, 211–214 (2018)

Bartkiewicz, A., et al., *A&A* **637**, A15 (2020)

Durjasz, M., Szymczak, M., Olech, M., *MNRAS* **485**, 1, 777 (2019)

Olech, M., et al., *MNRAS* **486**, 1, 1236 (2019)

Olech, M., et al., *A&A* **634**, A41 (2020)

Sarniak, R., Szymczak, M., Bartkiewicz, A., in A. Tarchi, M. J. Reid, P. Castangia (eds.) Astrophysical Masers: Unlocking the Mysteries of the Universe, *IAU Symposium*, volume 336, 321–322 (2018)

Szymczak, M., et al., *MNRAS* **459**, 1, L56 (2016)

Szymczak, M., et al., *MNRAS* **474**, 1, 219 (2018)