Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
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Catching unusual phenomena with extensive maser monitoring

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Abstract. High brightness and low interstellar extinction allow the 6.7 GHz methanol (CH_3OH) masers to carry the information about what happens in the vicinity of the High-Mass Young Stellar Objects (HMYSOs). Monitoring this transition provides an only one opportunity to catch rare, unusual phenomena. In this paper, I describe three of them: quasi-periodic flares of the red-shifted emission in Cep A HW2, accretion burst in S255-NIRS3 and reappearance of the methanol maser flare in G24.329+0.144.

Keywords. masers, stars: massive, stars: formation, ISM: molecules, radio lines: ISM

1. Introduction

The 6.7 GHz CH_3OH maser is the second brightest interstellar emission line (Menten 1991). It originates in the vicinity of high-mass young stellar objects (HMYSOs) and is highly sensitive to variations of the physical conditions in their environment. Theoretical models (Sobolev *et al.* 1997; Cragg *et al.* 2005) show that the maser emission comes from the regions of number density lower than $10^9\,\mathrm{cm}^{-3}$ and dust temperatures higher than 100 K. There are theoretical and recent observational evidences that IR photons are essential in the pumping of the class II methanol masers (e.g. Olech *et al.* 2020, 2022). These attributes make the 6.7 GHz methanol maser a fairly good indicator of the protostellar activity.

2. Observations

The Torun maser research team has been using the 32-meter radio telescope of the Nicolaus Copernicus University, located in Piwnice to monitor regularly the 6.7 GHz methanol masers since June 2009. The number of observed sources varied between 70 to 250 throughout the monitoring period. The main parameters of the spectral observations are as follows: the RMS pointing error is estimated to be $10''$, T_{sys} in a range from 25 to 40 K, spectral resolution: $0.09\,\mathrm{km\,s^{-1}}$, the typical ($1\sigma$) noise level was 0.25 Jy.

3. Results

Here, we describe some results from Torun's 13-year monitoring program for selected targets:

Cep A HW2. This well-known HMYSO lies at the distance of 700 pc (Moscadelli *et al.* 2017) and shows 5-year quasi-periodic variability of the most red-shifted spectral features at -0.5 and $-1.3\,\mathrm{km\,s^{-1}}$. Anti-correlation between -4.7 and $-2.6\,\mathrm{km\,s^{-1}}$ features during the periods of activity of the blue-shifted component is also visible. Such behaviour suggests a radiative connection between the masing cloudlets as proposed by Cesaroni

(1990). The measured delay between the cloudlets was 4.5 d, corresponding to a distance of ∼800 AU. The anti-correlation was presented initially by Sugiyama *et al.* (2008), and new data confirm it (see also Szymczak *et al.* 2014 and Durjasz *et al.* 2022). Red-shifted flaring features originate near the edge of a dust disc, reported in Patel *et al.* (2005). Proper motions of the flaring cloudlets show sub-Keplerian orbital velocity combined with infall motion. These results confirm previous reports (Sugiyama *et al.* 2014; Sanna *et al.* 2017). We expect the next flares of -0.5 and $-1.3\,\mathrm{km\,s^{-1}}$ features to occur in the first quarter of 2025 and the increase of the $-4.7\,\mathrm{km\,s^{-1}}$ feature activity in the last quarter of 2027. The monitoring will be continued.

S255-NIRS3. The distance is estimated to be ∼1.8 kpc (Burns *et al.* 2016) and the central star mass to $\sim 20\,\mathrm{M_\odot}$ (Zinchenko *et al.* 2015). The accretion burst at the 6.7 GHz transition started in 2015 and lasted for 2 years. It is one of the most extensively studied HMYSO accretion burst to date (Caratti o Garatti *et al.* 2017; Szymczak *et al.* 2018; Moscadelli *et al.* 2017). Our 13-year monitoring shows that the overall 6.7 GHz profile has not recovered to the pre-burst state from before 2015. Detection of the emission lines, typical for the young eruptive low-mass stars (Caratti o Garatti *et al.* 2017) suggest a rapid increase in the accretion rate.

G24.329+0.144. The 6.7 GHz methanol flare was detected in 2011 and it reappeared in 2019 (Wolak *et al.* 2019). The overall emission profile recovered after each burst to its previous shape. Also, the weakest features in the pre-burst spectra appear to be the strongest when a flare occurs. Interferometric observations of diverse maser lines and dust continuum towards this source were described in Kobak *et al.* (2023) and Hirota *et al.* (2022). It is important to monitor this target and confirm the ca. 8 year periodicity.

4. Conclusions

Extensive monitoring of the 6.7 GHz transition not only provides a significant amount of information about variations of the physical conditions in the vicinity of the emerging, massive stars but also extends scientific output from the high-resolution VLBI observations and allows for early detection of the accretion bursts.

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