PROCEEDINGS OF SCIENCE

Milliarcsecond analysis of the 6.7 GHz methanol maser outburst in HMYSO G24.329+0.145

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An outburst was detected in the high-mass star-forming region G24.329+0.145 at the 6.7 GHz methanol maser line under the monitoring program with the 32 m Torun dish (Wolak et al. 2019). Multi-frequency and multi-epoch studies started immediately under the international M2O cooperation in order to analyze this event and provide some constraints on episodic disc accretion. Using the VLBA and EVN interferometers we observed the methanol maser lines at the 6.7 and 12.2 GHz transitions. We present preliminary results of our detailed variability studies.

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1. Introduction

Recent observations suggest that forming high-mass young stellar objects (HMYSOs) experience variable accretion and this process is accompanied by sudden luminous outbursts (e.g. [4, 7]). These are likely induced by the episodic accretion of gaseous clumps falling from the disk onto the protostar. A unique aspect of that process is a rapid rise in the flux density of the 6.7 GHz methanol maser line which is relatively easily detected during monitoring with a single-dish radio telescope. A prominent outburst of the methanol maser line and appearance of new maser transitions not yet predicted by theoretical models were detected in G358.93−0.03 and widely discussed ([2, 3, 10]).

G24.329+0.145[1] is a young massive protostar known to harbour methanol, water and hydroxyl masers [5]. Its first methanol maser burst was observed in 2011 by the 32 m Torun dish [12]. In 2019, a second burst was noticed and multi-frequency and multi-epoch observations were immediately carried out using VLBI under the international M2O cooperation[2]. Here, we present first results of the VLBA and EVN campaigns.

2. Observations

Target of opportunity VLBA observations were conducted on 27 September, 27 October, and 2 December 2019 for ~8 hours at each epoch under project BB416[3]. Two methanol maser lines were observed at the following frequencies: 6668.519 MHz and 12178.597 MHz. The channel spacings were set to 0.176 (6.7 GHz methanol) and 0.096 km s^{-1} (12.2 GHz methanol), respectively. The 6.7 GHz methanol maser line was also observed with the EVN with channel spacing 0.087 km s^{-1}. The EVN observations were carried out on 7 October 2019 as the target of opportunity project[4]. The target has been continuously observed using the C-band receiver of the Torun 32 m radio telescope once a week as part of the monitoring project [11].

3. Results and discussion

The long-term single-dish monitoring of G24.329+0.145 reveals that the feature has repeatable behavior of bursts in 2011 and 2019 (Fig. 1). The highest increase appears for the two features at velocities 115.3 km s^{-1} (over 75 Jy) and 113.4 km s^{-1} (up to 60 Jy). These features dominated the spectra. The remaining spectral features also increased, but rise was only of a few Jy. The recent burst lasted from July 2019 to January 2020. We also note that the extreme red-shifted features (at ca. 119.8 km s^{-1} LSR velocity) bursted earlier than the extreme blue-shifted ones (at 107.6 km s^{-1}) by ca. 69 days. In Fig. 2 we present different burst stages in 2019 and pre-burst stage from 2009 [1]. We identified three groups of methanol masers that persisted over 10 years. However, it was impossible to derive with reasonable accuracy the proper motions and notice any expansion/rotation/infall.

[1]The name corresponds to the Galactic coordinates.

[2]https://www.masermonitoring.org

[3]The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

[4]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 code: RB006

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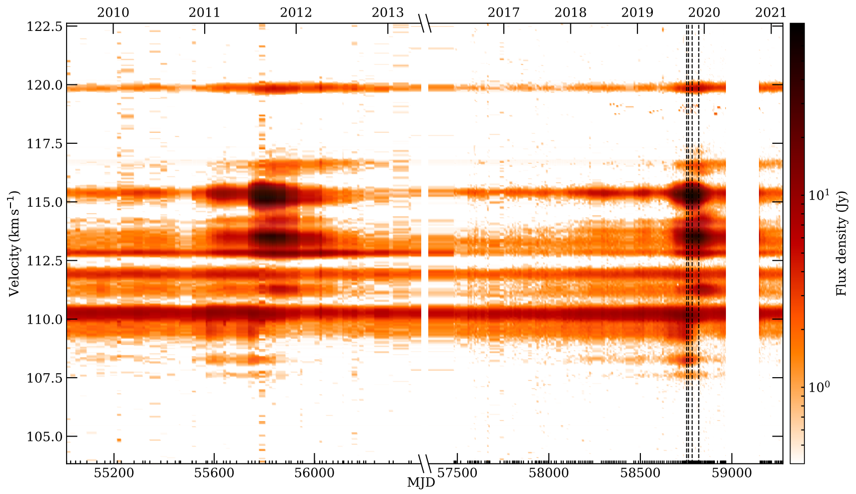

Figure 1: Dynamic spectrum of G24.329+0.145 as obtained from long-term observations using the 32 m Torun dish. The black, dashed lines indicate date of interferometric observations VLBA and EVN.

During the burst, i.e. in September–December 2019, a more complex morphology emerged in comparison to the 2009 data. Spots are spread over 0.6"×"0.6 area corresponding to ca. 4320 AU× 4320 AU at the assumed kinematic distance of 7.20±0.76 kpc as estimated using the Bayesian distance calculator by [8]. The time-span of burst observation is 66 days. The maximum brightness increases over 6 times (from 3.5 in 2009 to 21.5 Jy in 2019) for the brightest feature at 115.3 km s^{-1}, and gradual decreases during burst to 11.5 Jy. The observations by 32 m Torun dish show much more flux. The largest value was 75 Jy on 27/10/2019. The ratio of the integral flux as observed using VLBA and the Torun dish is 23.5%, 16.3% and 20% at the first, second and third epoch, respectively. And for the EVN was 45%. Clearly, the interferometric observations resolved the majority of the emission. The 12.2 GHz methanol maser transition was observed and imaged for the first time in this target. The 12.2 GHz masers are spread about 0.06"×"0.06 (i.e., 432 AU×432AU), much less than the 6.7 GHz emission. The maximum brightness of 12.2 GHz maser reached 4 Jy on 27/10/2021. We note, we have detected the co-propagation of both methanol lines. They overlapped in the sky plane within 1.3 mas and in the velocity domain within 0.2 km s^{-1}. It indicates that both methanol masers appear in the same gas volume. Co-propropagation of both methanol maser transitions was predicted within a range of physical conditions of gas temperature (30-150 K), density (10^3-10^8 cm^{-3}) and density of methanol molecules (10^{-7}-10^{-9} cm^{-3}) [6, 9]. Detailed analysis is underway.

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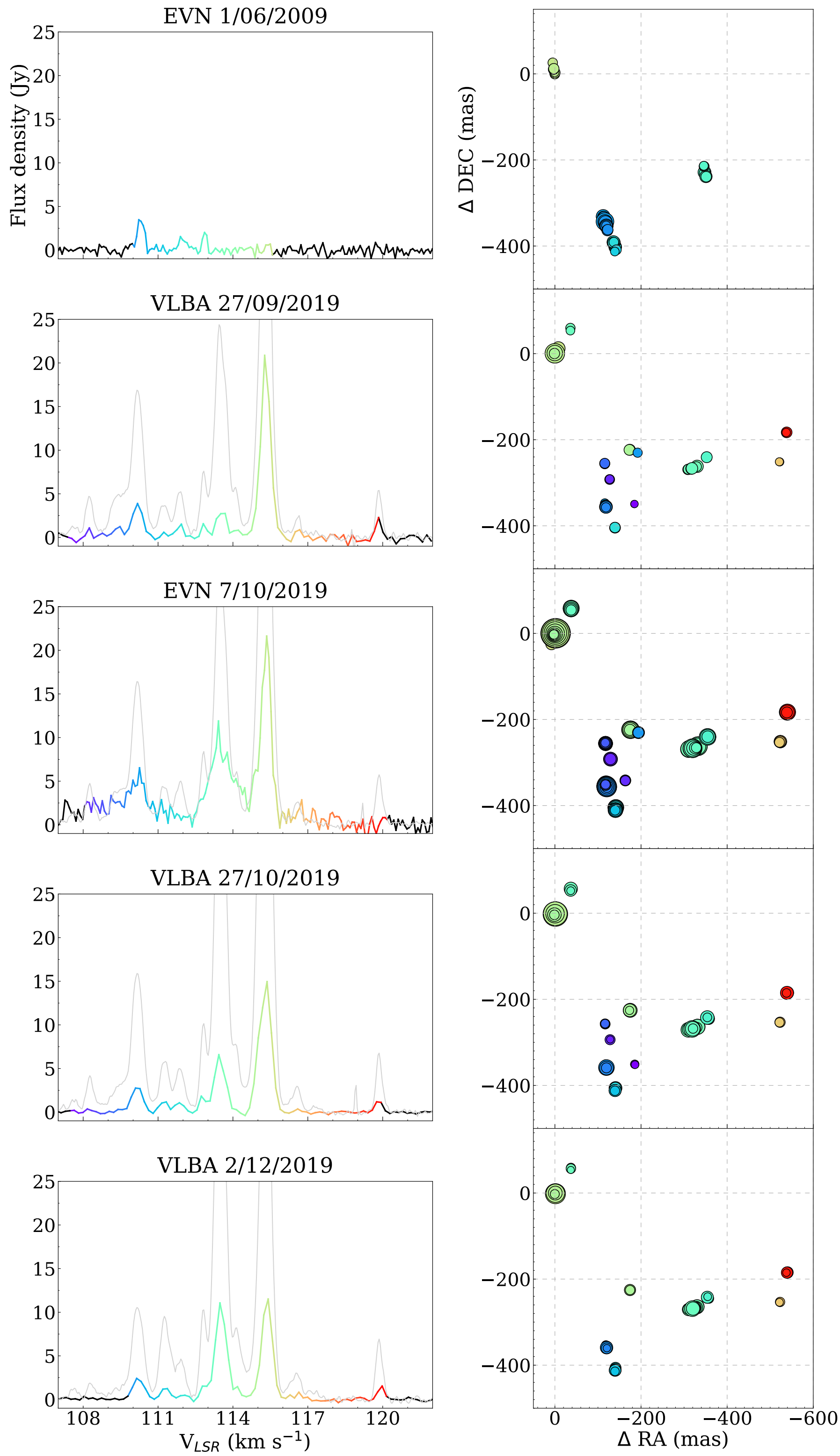

Figure 2: Spectra and spot distributions of the 6.7 GHz methanol masers in all five epochs, EVN and VLBA observations. Color of a circles corresponds to LSR velocity as it is presented in the spectra. The size of the circles is proportional to the square root of the intensity of a given spot. Spectra given by 32 m Torun dish are marked grey lines.

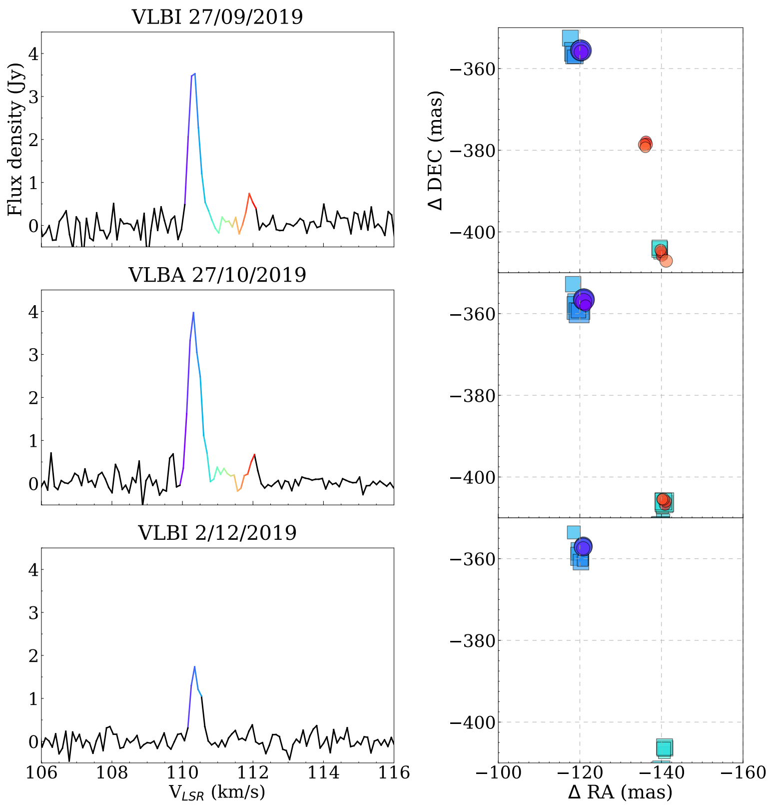

Figure 3: Spectra and spot distributions of the 12 GHz methanol maser in all three epochs as observed using VLBA. Color of a circles corresponds to LSR velocity as it is presented in the spectra. The size of the circles is proportional to the square root of the intensity of a given spot. The 6.7 GHz methanol masers are marked by squares with which colors corresponding to spectra in Fig.2.

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