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Methanol and excited OH masers in HMYSOs at milliarcsecond scales

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Significant contributions to our knowledge of high-mass star formation came from interferometric observations of cosmic masers, mostly from OH, methanol and water molecules. Using the European VLBI Network, our team in Torun has been studying high-mass young stellar objects by imaging the maser lines for over 13 years. Here, we present first milliarcsecond images of G20.237+00.065 and G24.148−00.009 at the excited OH maser line at 6.035 GHz. These regions were mapped at the 6.7 GHz methanol maser transition earlier as well. Radial velocities of methanol and excited OH spectral features overlapped, as it was noticed in the single-dish spectra. This suggests that both lines arise in the same volume of gas, and VLBI data are necessary to verify this hypothesis.

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1. Introduction

Observational studies of high-mass young stellar objects (HMYSOs) at radio wavelengths are necessary to answer the question about high-mass star formation. Significant contributions to our knowledge of the formation of HMYSOs came from interferometric observations of cosmic masers, mainly methanol, water and OH transitions. They allow to map the neutral gas in the vicinity of HMYSOs at scales of a few tens of AU and to study its structure and kinematics (e.g. [5, 7]). Unfortunately, the physical conditions from observations of individual maser transition are commonly poorly constrained, but mapping of two or more lines satisfactorily constrain the kinetic temperature and density in regions that cannot be studied by other means (e.g. [3, 4]). For example, we carried out a project using MERLIN in 1999–2000 concerning the coincidence of the OH lines 1720 and 4765 MHz in the well-known high-mass star-forming regions Cep A and W75N [8]. Based on the model by [6], physical conditions were derived.

Using the European VLBI Network, we aim to image a sample of HMYSOs where the excited OH maser line at 6.035 GHz (ex-OH hereafter) exists as well as the 6.7 GHz methanol maser line as it was shown in the single-dish studies using the Torun 32-m dish [10, 11]. With new data, we plan to find the likely coincidence of maser spots at both transitions or their avoidance. Since the images of both maser lines were separated by more than 10 yr, we can only make a crude estimation of the physical conditions in structures surrounding HMYSOs (e.g. [3, 4]) and select targets for simultaneous observations at both transitions.

2. Observations

We observed the following targets at the 6.035 GHz OH transition: G20.237+00.065 and G24.148− 00.009 (the names correspond to the Galactic coordinates) under the EVN project[1] on 2020 October 16. The spectral mode (4 MHz bandwidth with 2048 correlator channels yielding the spectral resolution of 88 m s^{-1}) was used with the phase-referencing technique; the nearby phase-calibrator J1825−0737 was used with the cycle-time of 195 s+105 s (maser+phase-calibrator). The calibration was done in a standard way as it was applied in previous C-band projects concerning the 6.7 GHz methanol maser transition (e.g. [2]). The rms and synthesized beams on the final images in two circular polarizations (RHC, LHC) were 8 mJy and 15×5 mas with a position angle of −5°, respectively.

The typical astrometric accuracy of single-maser spots is ca. 5 mas in both coordinates as it was clearly explained in [2] for the 6.7 GHz methanol masers.

3. Results and discussion

We present the first images of ex-OH masers in two HMYSOs. We describe the main results shortly and present them in Fig. 1. The (0,0) points in the figures correspond to the coordinates of the brightest spots of the 6.7 GHz methanol masers as in [1, 2].

[1]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: EB079.

G20.237+00.065: Two ex-OH maser groups appeared in close surroundings of the 6.7 GHz methanol masers, but they do not coincide in space. A shift of 20 mas corresponding to a distance of 88 AU (assuming the near kinematic distance of 4.4 kpc [9]) is not significant considering the astrometric accuracy and the 11-year difference between these two observations of maser lines (assuming a motion of masing spots of an order of 10 km s^{-1}). The high-angular resolution and simultaneous (at both transitions) observations are planned for this target.

In the vicinity (0.18 pc) of G20.237+00.065 lies G20.239+00.065 with methanol emission [1]. The source G20.239+00.065 showed the 6.7 GHz methanol emission in the LSR velocity ranges from 60.1 to 63.3 km s^{-1} and from 70.1 to 71.1 km s^{-1}. While the maser spots in G20.237+00.065 showed a complex distribution over ~880 AU×880 AU without any regularity in velocity, the methanol emission in G20.239+00.065 was extended in the east–west direction over an area of ~220 AU×880 AU. None ex-OH masers were found in G20.239+00.065 with a 3σ limit of 24 mJy.

G24.148−00.009: The ex-OH maser emission is blue-shifted relatively to the methanol masers, as imaged in 2007 [2], and displaced by ~0.1" corresponding to 164 AU for a near kinematic distance of 1.64 kpc [9]. The ex-OH emission covered the LSR velocity range from 16.3 to 17.6 km s^{-1}, while the methanol masers appeared from 17.1 to 18.5 km s^{-1}. Assuming that both maser lines are not variable, they are likely not coinciding in the space. However, simultaneous observations are again needed to verify this statement.

The results of modelling by [3] show: (1) the 6.7 GHz methanol maser line is excited in a broad range (30-250 K) of kinetic temperature while the ex-OH maser emission is quenched at above 70 K, (2) the methanol maser operates at low gas density, and is independent of gas density up to 10^8 cm^{-3}, where its intensity falls abruptly, while the ex-OH line requires the gas density of $10^6 - 10^8$ cm^{-3}, (3) the column density of methanol molecule ranges from 10^{16} to $10^{18.5}$ cm^{-2} and that for OH molecule is predicted to be an order of magnitude lower. Our EVN imaging implies a likely coincidence of both maser lines in the G20.237+00.065 and a likely avoidance in G24.148−00.009.

We note that no Zeeman pairs have been found to confirm the results from single-dish studies [10]. That indicates the magnetic field strength below 0.1 mG.

4. Summary

We have successfully imaged the ex-OH masers using EVN C-band receivers. The results will help us to study gas properties in the environment of HMYSO where the 6.7 GHz methanol and 6.035 GHz ex-OH masers exist. The first results indicate the coincidence in G20.237+00.065 and avoidance in G24.148−00.009 of both maser lines. Since the VLBI ex-OH emission is significantly resolved out with EVN, we have also used e-MERLIN to image more extended emission at both maser lines (A. Kobak's proceeding from this Symposium). However, the VLBI data taken simultaneously are needed to verify the milliarcsecond coincidence and for kinematic studies.

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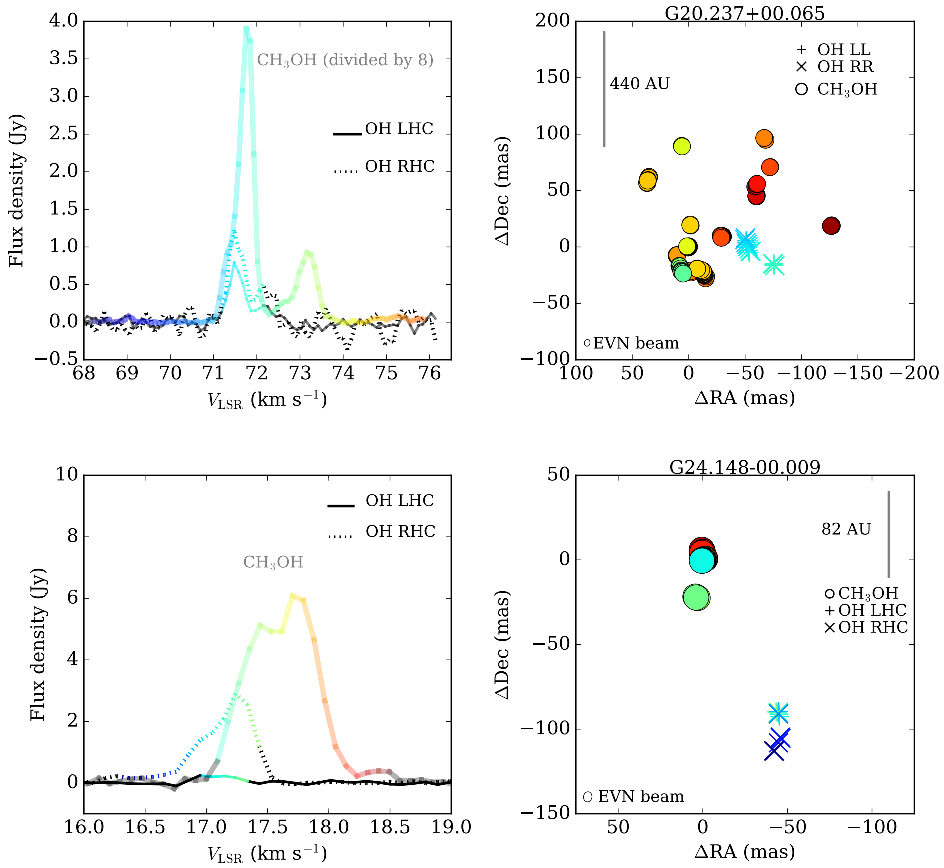

Figure 1: Left panels: The spectra of 6.035 GHz ex-OH RHC (dotted) and LHC (solid thin) polarized and 6.7 GHz methanol (thick transparent line) emission in G20.237+00.065 and G24.148−00.009. For clarity, the methanol spectrum of G20.237+00.065 is divided by a factor of 8. **Right panels:** The distribution of ex-OH and methanol maser spots n G20.237+00.065 and G24.148−00.009. The (0,0) points corresponds to RA =18^{h}27^{m}44.56429^s, Dec=11^{o}14'54.0938" (top panel) and RA =18^{h}35^{m}20.94266^s, Dec=07^{o}48'55.6745" (J2000) (bottom panel). The beam sizes are indicated by ellipses in the left bottom corners. The colours of circles (6.7 GHz maser spots), crosses (ex-OH RHC polarized spots) and plus symbols (ex-OH LHC polarized spots) correspond to the LSR velocities as in the spectra. The linear scales are presented assuming the near kinematic distances using the BeSSeL calculator [9].

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