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VERA+ALMA observations of the H_2O maser burst in Orion KL

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We report results of monitoring observations with VERA of the bursting H_2O masers in Orion KL, which has started since 2011 February. The bursting maser consists of two spatially different features at 7.58 and 6.95 km s^{-1}, and are located at the shocked molecular gas called Orion Compact Ridge. Their proper motions are almost perpendicular to the elongation of the maser features along the northwest-southeast direction. We propose that the outflow interacting with the Compact Ridge is a possible origin of the H_2O maser burst. According to our recent observation with ALMA, the bursting maser features are coincident with the 1.3 mm dust continuum emission peak. Detailed physical properties of the dust continuum source will be investigated by the further follow-up observations with ALMA.

11th European VLBI Network Symposium & Users Meeting,
October 9-12, 2012
Bordeaux, France

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PoS(11th EVN Symposium)095

1. Introduction

Orion KL is the nearest massive star-forming region at the distance of 420 pc from the Sun [6, 10, 13, 16], and hence, is the best target for the study of massive star-formation processes. There are complex outflows and high-velocity jets in Orion KL traced by the infrared and radio wavelengths [9, 14, 15, 19, 18]. Part of these outflows/jets are traced by the bright 22 GHz H_2O maser emission [3, 4, 6]. As pointed out in previous literatures listed above, these outflows/jets are closely related to the formation processes of massive stars in Orion KL region.

In February 2011, a burst event of the H_2O maser in Orion KL at 22 GHz has started after 13-year silence [17]. This is the third time to detect such phenomena in Orion KL, followed by those in 1979-1985 and 1998 (see [7] and references therein for details). However, due to the lack of sufficient observational data, it is still an open question what is the origin and pumping mechanism of the bursting masers. In order to explore the detailed properties of such enormous outburst of the H_2O masers, we have carried out astrometric observations of the bursting H_2O maser features in Orion KL with VERA (VLBI Exploration of Radio Astrometry), as well as follow-up observations with ALMA (Atacama Large Millimeter/Submillimeter Array).

2. Observations

2.1 VERA

Monitoring observations of the H_2O maser (6_{16}-5_{23}, 22235.080 MHz) in Orion KL have been done with the four 20 m antennas of VERA [7]. Interval of observations is 2-4 weeks and the monitoring is still ongoing. The maximum baseline length is 2270 km and the FWHM beam size is about 1 mas (milli-arcseconds) on average. We employ the dual beam observation mode, in which Orion KL and an ICRF source J0541-0541 are observed simultaneously. Calibration and imaging are performed using the NRAO AIPS (Astronomical Image Processing System) software package.

2.2 ALMA

We analyzed the ALMA cycle 0 data for the continuum emission at band 6 (240-260 GHz) in the Orion KL region. The observation was done in the extended configuration with 17×12 m antennas. The synthesis imaging was done with the CASA (Common Astronomy Software Applications) package. The uniform-weighted synthesized beam size was about 0.6 arcseconds, and the resultant rms noise level was 7 mJy beam^{-1}. We also analyzed the ALMA Science Verification data of Orion KL at band 6 (215-245 GHz) to investigate the millimeter H_2O line and dust continuum emission. The observation was done in the compact configuration and the synthesized beam size was 1.6 arcseconds. Details of the ALMA data are available in [8].

3. Results and Discussion

3.1 Properties of the bursting H_2O masers at 22 GHz

Based on our astrometry with VERA, the burst event is found to be occurring at two spatially different maser features. We determined the absolute positions of the bursting features for the

first time ever with a submilli-arcsecond accuracy, and found that they are coincident with the shocked molecular gas called the Orion Compact Ridge [1, 11]. The VERA images of the bursting maser features show the elongated structure along the northwest-southeast axis as can be seen in Figure 1. The position, spatial structure, and the line-of-sight velocity ($\sim$8 km s^{-1}) of the bursting masers are similar to those in the previous burst phases, implying a common origin. Their proper motions relative to the radio Source I [5], which is thought to be powering bipolar outflows, are approximately toward west or southwest direction perpendicular to the elongation of the maser features, as shown in Figure 1. There results suggest that the outflow from the radio Source I or another young stellar object interacting with the Compact Ridge is a possible origin of the H_2O maser burst [1, 2, 11].

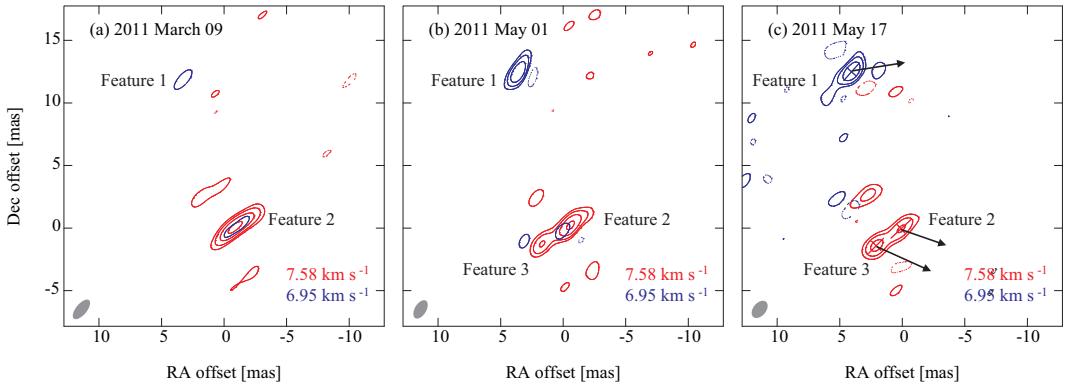

Figure 1: The VERA images of the bursting maser features [7]. The synthesized beam pattern is indicated by grey ellipse at the bottom left corner in each panel. Blue and red contours represent the 6.95 km s^{-1} and 7.58 km s^{-1} features, respectively. The contour levels are -1600, 1600, 3200, 6400, and 12800 Jy beam^{-1}. Proper motions with respect to the Source I [5] are shown in the panel (c).

To investigate physical properties of the bursting H_2O masers, we analyzed the ALMA cycle 0 data of the dust continuum emission at band 6 (240-260 GHz). As shown in Figure 2, the 22 GHz H_2O maser features are coincident with the dust continuum peak in the Compact Ridge. The position agrees well with the molecular peak of the Methyl Formate ($HCOOCH_3$) line labeled as MF1 [1]. The detailed nature of this dust continuum source will be investigated by the follow-up observations with ALMA at other frequency bands.

3.2 Millimeter/submillimeter H_2O masers with ALMA

In addition to the 22 GHz H_2O maser burst, we analyzed the ALMA Science Verification data of Orion KL to study a possible relationship with other millimeter/submillimeter H_2O line. As a result, we found a spectral signature of the vibrationally excited H_2O line at 232 GHz (ν_2=1, $5_{5,0}$-$6_{4,3}$, 232686.70 MHz; E_l=3451 K) [8]. This line has been detected in circumstellar envelopes of late-type stars so far [12] but not in star-forming regions including Orion KL. The distribution of the 232 GHz H_2O feature is concentrated at the position of the radio Source I, which is remarkably different from other molecular lines. The spectrum of the 232 GHz line toward the Source I shows a double-peak structure as shown in Figure 3. It appears to be analogous to the 22 GHz H_2O masers and 43 GHz SiO masers observed around Source I. Thus, the 232 GHz H_2O line around

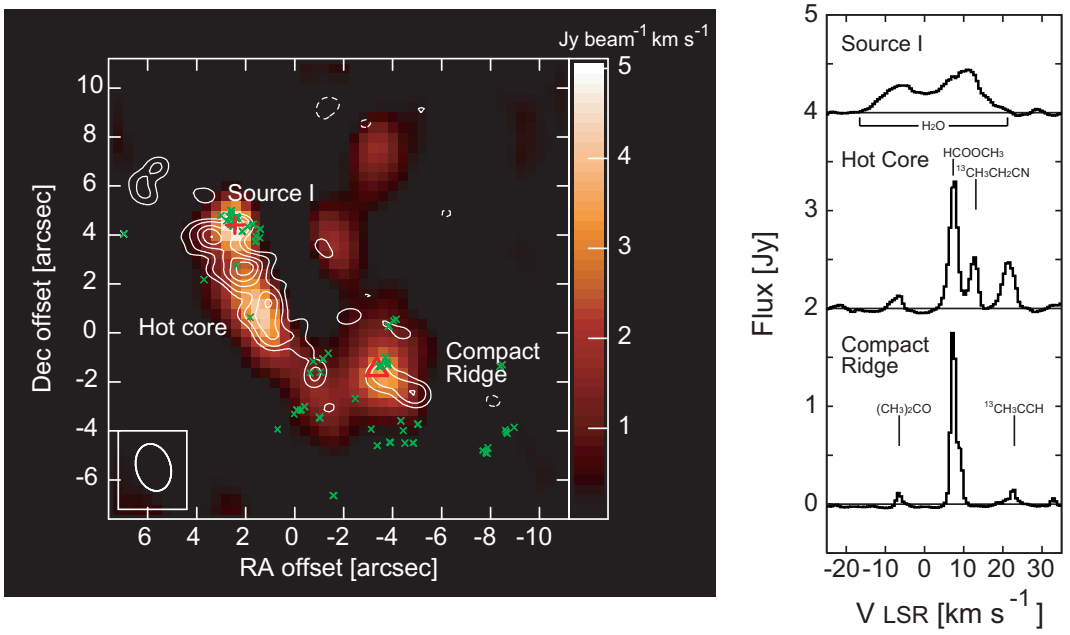

Figure 2: (Left) Integrated intensity map of the 232 GHz H_2O line (blended with $HCOOCH_3$ line) [8]. The positions of the 22 GHz H_2O maser spots [3] are superposed as indicated by green X-marks. A red cross and triangle represent the positions of Source I and the bursting 22 GHz H_2O maser features in the Compact Ridge, respectively. The dust continuum image of ALMA band 6 is shown as white contours. The contour starts at 5σ level and its interval of 5σ, with the 1σ noise level of 7 mJy beam^{-1}. (Right) Spectra of the 232 GHz H_2O feature toward the dust continuum peaks [8].

Source I would be a maser emission excited by the internal heating by an embedded protostar, being associated with either the root of the outflows/jets or the circumstellar disk around Source I, as traced by the 22 GHz H_2O masers or 43 GHz SiO masers, respectively. On the other hand, no emission feature of the 232 GHz H_2O line is identified at the position of the 22 GHz bursting maser feature in the Compact Ridge, partly due to the confusion with the Methyl Formate ($HCOOCH_3$) line at almost the same frequency.

Using ALMA, we will observe other submillimeter H_2O maser lines in Orion KL at bands 6, 7, and 9. Further higher resolution observations will provide novel information about excitation and pumping mechanism of the H_2O lines including the bursting H_2O maser features at 22 GHz.

Acknowledgments

This paper makes use of the following ALMA data: ADS/JAO.ALMA#2011.0.00009.SV and 2011.0.00199.S. ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada) and NSC and ASIAA (Taiwan), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ. We thank the staff at ALMA for making observations and reducing the Science Verification data. This study is partly supported by the Grant-in-Aid for Young Scientists (A) (24684011).

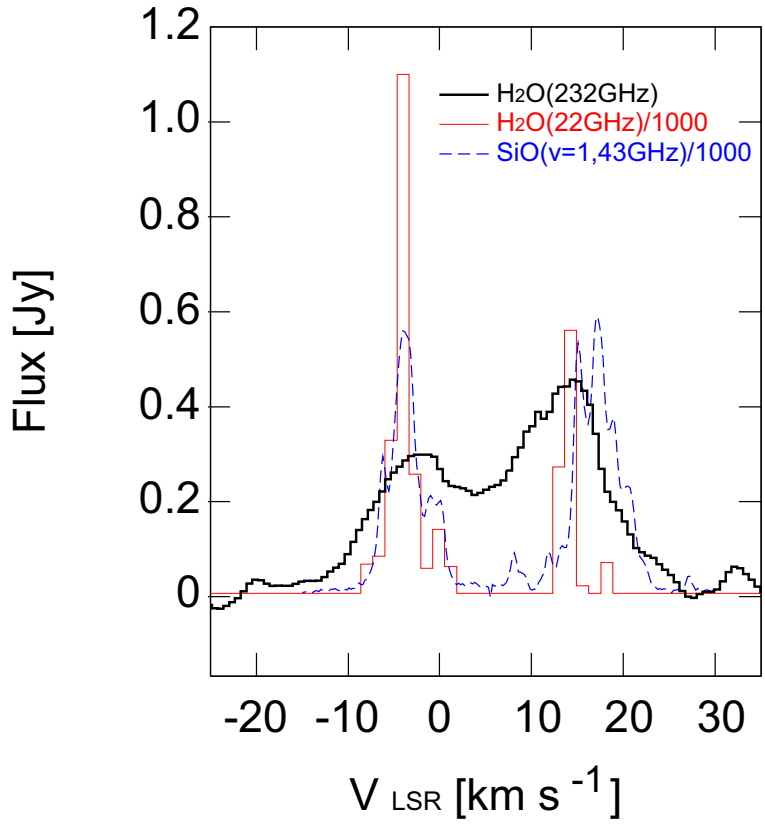

Figure 3: Spectra of the 232 GHz H_2O line [8], 22 GHz H_2O shell maser [3], and 43 GHz SiO (v=1) maser [10] associated with Source I. These lines are observed with ALMA, VLA, and VERA, respectively. Note that the flux scales of the 43 GHz SiO maser and the 22 GHz H_2O masers are multiplied by a factor of 1/1000.

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PoS(11th EVN Symposium)095