Cosmic Masers - from OH to H_0
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VERA Observations of the H_2O Maser Burst in Orion KL

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Abstract. In 2011 February, a burst of the 22 GHz H_2O maser in Orion KL was reported. In order to identify the bursting maser features, we have been carrying out observations of the 22 GHz H_2O maser in Orion KL with VERA, a Japanese VLBI network dedicated for astrometry. The bursting maser turns out to consist of two spatially different features at 7.58 and 6.95 km s^{-1}. We determine their absolute positions and find that they are coincident with the shocked molecular gas called the Orion Compact Ridge. We tentatively detect the absolute proper motions of the bursting features toward the southwest direction, perpendicular to the elongation of the maser features. It is most likely that the outflow from the radio source I or another young stellar object interacting with Compact Ridge is a possible origin of the H_2O maser burst. We will also carry out observations with ALMA in the cycle 0 period to monitor the submillimeter H_2O maser lines in the Orion Compact Ridge region. These follow-up observations will provide novel information on the physical and chemical properties of the mastering region.

Keywords. masers, ISM: individual (Orion KL), ISM: jets and outflows, radio lines: ISM

1. Introduction

An enormous outburst of the 22 GHz H_2O maser in Orion KL (D=420 pc; Hirota *et al.* 2007, Kim *et al.* 2008) is one of the most enigmatic phenomena in terms of cosmic masers. The first H_2O maser burst in Orion KL was discovered in 1979 and the active phase continued until 1985 with several flare-up events (Garay *et al.* 1989). The second burst was detected from 1997 to 1999 and monitoring observations were carried out with single-dish telescopes and VLBI (Omodaka *et al.* 1999, Shimoikura *et al.* 2005). The maximum flux density reached up to an order of 10^6 Jy in both burst phases. Although either a circumstellar disk or a jet/outflow associated with a young stellar object (YSO)

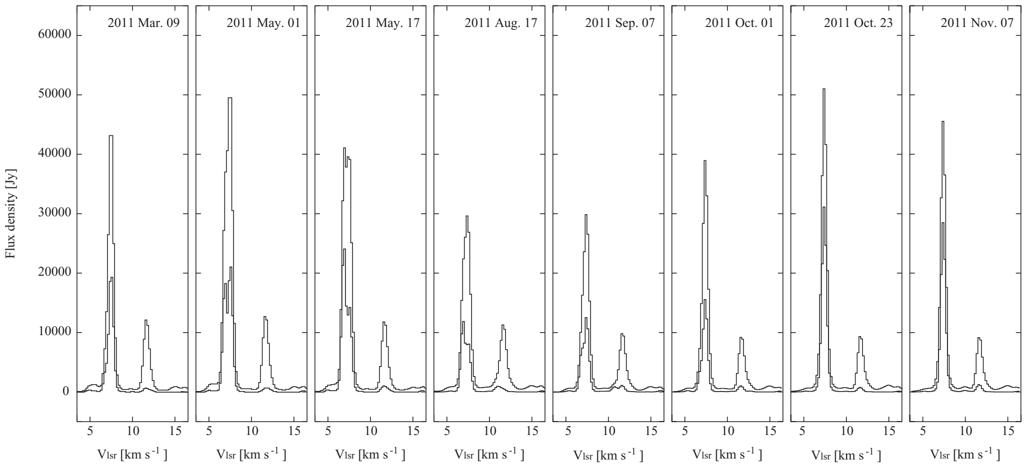

Figure 1. Observed spectra of the H_2O maser in Orion KL. Bold and thin solid lines represent the scalar-averaged cross power spectra and total power spectra, respectively.

is proposed as a possible origin of the maser burst, the origin is still unclear because of the lack of observational evidences other than the H_2O maser itself.

The third-time burst of the H_2O maser in Orion KL has started in February 2011 (Tolmachev 2011, Gaylard 2012). The maser burst appears to be periodic with an interval of 13 years (1985, 1998, and 2011). If the current burst event is the same as those of previous ones, the H_2O maser is expected to flare up to 10^6 Jy again, providing a rare opportunity to investigate the nature of this burst event. With this in mind, we have started astrometric observations of the bursting H_2O maser in Orion KL with VERA (VLBI Exploration of Radio Astrometry), a Japanese VLBI network developed for astrometry. Further details are described in Hirota *et al.* (2011).

2. Observations

Observations of the H_2O maser (6_{16}-5_{23}, 22235.080 MHz) in Orion KL were carried out on 2011 March 09, May 01, and May 17 with VERA and are still ongoing. The maximum baseline length was 2270 km and the uniform-weighted synthesized beam size (FWMH) was 1.7 mas$\times$0.9 mas with a position angle of 143 degrees on average. We employed the dual beam observation mode, in which Orion KL and an ICRF source J054138.0-054149 were observed simultaneously. The data were recorded onto magnetic tapes at a rate of 1024 Mbps, providing a total bandwidth of 256 MHz. One IF channel with 16 MHz bandwidth was assigned to Orion KL and the remaining 15 IF channels were assigned to ICRF J054138.0-054149. For the H_2O maser lines, the spectral resolution was set to be 15.625 kHz, corresponding to a velocity resolution of 0.21 km s^{-1}. A bright continuum source, ICRF J053056.4+133155, was observed every 80 minutes for bandpass and delay calibration. Calibration and imaging were performed using the NRAO Astronomical Image Processing System (AIPS) software package.

3. Results

The H_2O maser burst is detected at the peak LSR velocity of 7.58 km s^{-1} in our first epoch of observation on 2011 March 09, as shown in Figure 1. The total flux density of (4.4$\pm$0.3)$\times 10^4$ Jy is three orders of magnitude larger than that in the quiescent phase in

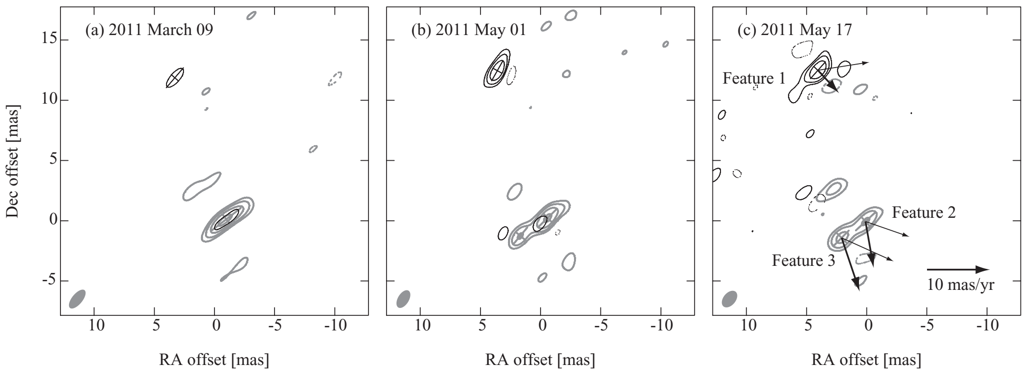

Figure 2. Phase-referenced images of the bursting maser features. The delay tracking center position (0, 0) is α=05^{h}35^{m}14^s.1255 and δ=−05°22'36".475 (J2000). Gray and black contours represent the 6.95 km s^{-1} and 7.58 km s^{-1} features, respectively. The contour levels are -1600, 1600, 3200, 6400, and 12800 Jy beam^{-1}. The bold and thin arrows in panel (c) represent the absolute proper motion vectors and those with respect to source I, respectively.

2006 (e.g. Hirota *et al.* 2007). Due to the lack of short baselines in VERA, the correlated flux, $(2.2 \pm 0.2) \times 10^4$ Jy, recovers 50% of the total flux density. On 2011 May 01, another new velocity component at 6.95 km s^{-1} appears while the flux density of the 7.58 km s^{-1} component gradually decreases. Two weaks later, the total flux density of the 6.95 km s^{-1} component becomes comparable with that of the 7.58 km s^{-1} component on 2011 May 17. These two velocity components are consistent with those detected during the first burst event (Garay *et al.* 1989) while they are slightly shifted toward lower velocity compared to that reported for the second event, 7.64 km s^{-1}(Shimoikura *et al.* 2005).

Phase-referenced images of the bursting H_2O maser features are shown in Figure 2. The maser features show elongated structure along the northwest-southeast direction. It is consistent with that observed with VLBA during the previous burst in 1997-1999 (Shimoikura *et al.* 2005). In the first epoch of observation in March 2011, the 7.58 km s^{-1} feature shows single-peaked structure while it splits into double peaks in May 2011. In addition, another spatially distinct feature at the LSR velocity of 6.95 km s^{-1} appears at 12 mas north. The variation of the spatial structure is consistent with that seen in the H_2O maser spectra shown in Figure 1.

The absolute position of the target maser source is measured with respect to the extragalactic position reference source J054138.0-054149 with the dual-beam astrometry observations with VERA. Compared with the absolute positions reported for the previous burst events (e.g. Greenhill *et al.* 1998), the current position of the bursting maser is shifted by ∼200 mas. Although this could be due to the much better astrometric accuracy of VERA (∼1 mas, see Hirota *et al.* 2007) than that previously achieved with VLA in A-configuration. The positions of the bursting masers are thus almost consistent with each other. We have also measured the absolute proper motions of three bursting maser features as shown in Figure 2. Taking into account the annual parallax of Orion KL of 2.39 mas (Kim *et al.* 2008), we obtain the absolute proper motions of 4-9 mas yr^{-1} or 8-18 km s^{-1} toward southwest direction.

Judging from the similarities in peak LSR velocity, position, and structure in all of the bust events, they could be attributed to the common origin. However, it is unlikely that the bulk of the bursting gas clump would be identical throughout every burst events because the typical life time of the H_2O masers in Orion KL is much shorter than that of the bursting phase. In fact, we can see significant time variation of velocity and spatial

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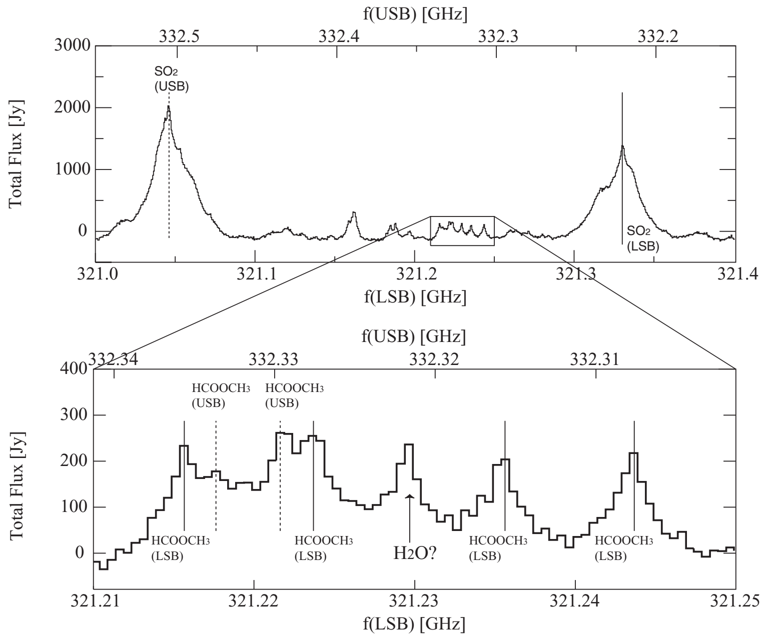

Figure 3. A single-dish 321 GHz spectrum toward Orion KL taken with the Atacama Submillimeter Telescope Experiment (ASTE) 10 m telescope. Note that the spectrum was taken with the double side-band (DSB) receiver.

structure of the bursting maser features even within the present monitoring observations for only two months from March to May 2011.

4. Discussion

Here we discuss a possible powering source of the bursting maser features. One of the most plausible interpretations is related to the outflow from a YSO in the Orion KL region as proposed by Garay *et al.* (1989). It has long been established that the H_2O masers in Orion KL are excited by interaction with outflow and ambient dense gas (Genzel *et al.* 1981, Liu *et al.* 2002). The most plausible powering source is the radio source I, which drives a northeast-southwest low-velocity outflow (Plambeck *et al.* 2009). The bursting maser features are located at 8” or 3400 AU southwest from source I, and are coincident with the interacting region named as Orion Compact Ridge. The elongation of the bursting maser features, which is perpendicular to the direction to source I, would suggest a shocked layer between the low-velocity outflow and the Compact Ridge. The magnitude of the proper motions of the bursting maser features are 16-20 km s^{-1} pointing toward the west to southwest direction when we subtract the absolute proper motion of source I (6.3 mas yr^{-1}, -4.2 mas yr^{-1}) recently reported by Goddi *et al.* (2011). Interestingly, they are roughly consistent with the low-velocity outflow from source I (Genzel *et al.* 1981). Thus, the H_2O maser burst may occur at a different part of the shocked layer when the episodic or possibly 13 year-periodic outflow from source I interacts with Compact Ridge.

Nevertheless, it is still unclear why only the $\sim$8 km s^{-1} components show such anomalous amplification phenomena episodically or with a possible 13 year-periodicity. It may imply a special condition to stimulate such maser burst. One of the possibilities is an existence of another pre-existing YSO in Compact Ridge interacting with the powerful

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outflow from source I (Garay *et al.* 1989). In fact, there are number of closer infrared, radio and X-ray sources around the bursting maser features than source I (see discussion in Hirota *et al.* 2011 and Favre *et al.* 2011). Because of the lack of high resolution observations resolving these continuum sources as well as their velocity structures, the powering source of the bursting maser features is still debatable. Higher-resolution observations with ALMA of the dust continuum and thermal molecular line emissions will be helpful to reveal physical properties of the bursting maser features and its origin. In addition, observational studies on submillimeter H_2O maser lines (see Figure 3) in parallel to the monitoring with VLBI of the 22GHz maser lines will also provide information on pumping mechanism of the bursting H_2O maser features. Follow-up observations will be carried out in the ALMA early sciences (cycle 0).

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