

# Observations of H<sub>2</sub>O maser sources in Orion-Monoceros Molecular Clouds with VERA

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**Abstract.** We present results of phase-referencing VLBI observations of H<sub>2</sub>O maser sources in Orion-Monoceros Molecular Clouds with VERA (VLBI Exploration of Radio Astrometry), which is newly constructed Japanese VLBI network. Main topics of this poster are (1) the aim of one of the first scientific projects for VERA "3-Dimensional Structure and Kinematics of Orion-Monoceros Molecular Cloud Complex"; (2) current status (sensitivity and astrometric accuracy) of phase-referencing VLBI observations with VERA; and (3) results of VLBI observations of H<sub>2</sub>O maser sources in Orion-Monoceros Molecular Clouds with VERA.

## 1. Introduction

VERA is a newly constructed Japanese VLBI network dedicated to phase-referencing VLBI observations (Kobayashi et al. 2003). The main goal of the VERA project is to reveal 3-dimensional Galactic structure and kinematics based on the precise astrometric VLBI observations of annual parallax and proper motion of H<sub>2</sub>O and SiO maser sources with an accuracy of 10 $\mu$ as. For the purpose of this, we at first plan to carry out 3 projects as test observations of VERA to measure distance to (1) the Galactic center, (2) Mira-type variables to establish period-luminosity relation, and (3) Orion-Monoceros molecular cloud complex, which is the nearest giant molecular cloud (GMC) complex. In this poster, we introduce details of one of the first VERA project observations "3-Dimensional Structure and Kinematics of Orion-Monoceros Molecular Cloud Complex".

Orion-Monoceros molecular cloud complex is the nearest GMC at the distance of about 400-800 pc (e.g. Genzel et al. 1981). Therefore, it has been recognized as an important object to study star-formation processes. Using VERA, we aim to measure the distance and proper motion of each GMC to reveal kinematics of Orion-Monoceros molecular cloud complex. Because more than 20 H<sub>2</sub>O maser sources associated with young stellar objects have been detected, Orion-Monoceros molecular cloud complex is the best target for our systematic VLBI observations. In addition, Orion-Monoceros molecular cloud complex is located in one of the Galactic arms, Local arm, and hence, this project would be the first step to complete the 3-D map of our Galaxy.

## 2. Observations

VLBI observations of H<sub>2</sub>O maser sources in Orion-Monoceros molecular cloud complex were carried out in several observing sessions in 2003 and 2004. All the 4 VERA stations were used in most of observing sessions, although only 3 stations were used in part of observing sessions due to bad weather condition.

For phase-referencing observations, all the observations were made in the dual beam mode; a H<sub>2</sub>O maser source and its reference source with a separation angle of 0.3-2.2 degree were observed simultaneously with the dual beam receivers on VERA using a dual-beam phase calibration based on the horn-dish method (Kobayashi et al. 2003; Honma et al. 2003). Left-handed circular polarization was received and sampled with 2-bit quantization, and filtered using a digital filter before being recorded onto magnetic tapes. The data were recorded at a rate of 128Mbps. In several observing sessions, we used wide band recording system at a rate of 1Gbps. Observations of strong continuum source, J0530+1331, were made every 1-2 hours for calibration purposes. Typical system temperature measured with the chopper-wheel method were 100-600 K, depending on weather conditions at each station.

Correlation process was carried out on Mitaka FX correlator located at the NAO Mitaka campus with a spectral resolution of 15.625kHz (1024 channels per 16MHz band). Data reduction was performed in the standard way using the NRAO AIPS. In the analysis, fringe fitting and self calibration were performed on the reference source, and the solutions were applied to target maser source.

## 3. Results

### 3.1. A Survey of H<sub>2</sub>O maser sources with VERA

It is difficult to survey and continue long-term monitoring observations of H<sub>2</sub>O maser sources with VLBI, especially for low-mass star-forming regions because of their variability (Claussen et al. 1996). In addition, H<sub>2</sub>O maser sources in nearby molecular clouds are heavily resolved out with the VLBI observations (e.g. Migenes et al. 1999). Therefore, we at first carried out a survey observations of H<sub>2</sub>O maser sources in Orion-Monoceros molecular cloud complex and their reference sources with VERA. Observations were carried out with the VERA 3 stations (Mizusawa, Iriki, and Ishigaki) on 2003 October 15 UT16-20h. A maser source and a continuum source

were observed simultaneously, and the data were recorded at a rate of 128 Mbps (16 MHz bandwidth for each source).

We observed 15 H<sub>2</sub>O maser sources and 11 continuum sources. Integration time for each source is 10 minutes. Table 1 shows the observed maser sources. Only 5 sources were detected with one of the baselines of VERA. Low detection rate of H<sub>2</sub>O maser sources is mainly due to their variability (Claussen et al. 1996), while it is also likely that some of the maser sources (e.g. Mon R2) were completely resolved out even with the shortest baseline of VERA (1000 km). For continuum sources, we detected only 2 known sources, J0541-0541 and J0607-0834. In order to detect more reference sources, we are planning to carry out further VLBI observations at a rate of 1Gbps.

**Table 1.** Observed H<sub>2</sub>O maser sources

H <sub>2</sub> O maser Source	$F_{tot}^a$ (Jy)	$F_{cor}^b$ (Jy)	Reference Source
Orion KL	2500	600	J0541-0541
OriA-W	5	<2	NO
OMC-2	40	6	J0541-0541
HH1	60	16	J0541-0541
L1641-MMS1	<2	<2	J0541-0541
NGC2024 FIR5	15	<2	NO
IRAS 05413-0104	<2	<2	NO
NGC2071	200	50	NO
NGC2071N	<2	<2	NO
IRAS 05393-0156	15	<2	NO
IRAS 05445+0016	6	<2	NO
B35	<2	<2	NO
Mon R2 IRS3	150	<2	J0607-0834
HH12-15	90	60	NO
HH19-27	<2	<2	NO

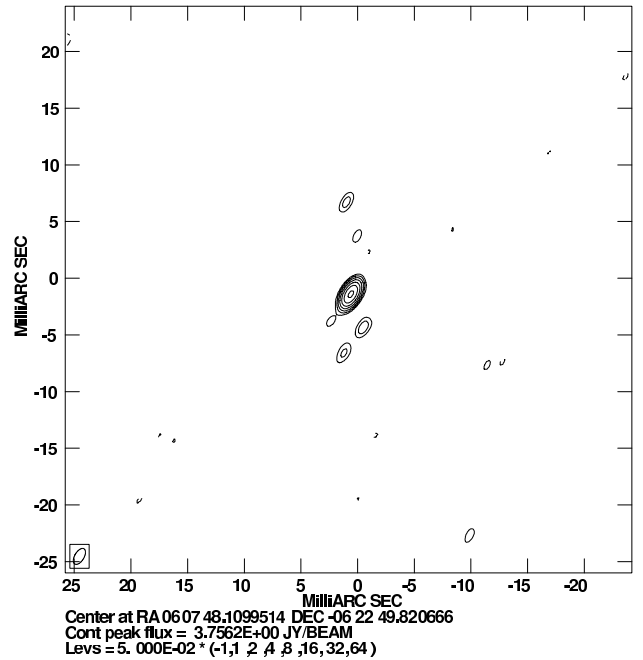
<sup>a</sup> Total power flux observed with the 20 m antenna.

<sup>b</sup> Correlated flux observed with the VERA Mizusawa-Iriki baseline.

### 3.2. Monitoring of H<sub>2</sub>O Masers Sources with VERA

According to our survey observations, 5 sources (Orion KL, OMC-2, HH1, NGC2071, and HH12-15) were detected with VERA. Among them, 3 sources (Orion KL, OMC-2, and HH1) are associated with the reference source (J0541-0541) within 2.2 degree and hence, they would be good candidates for monitoring observations with VERA. In addition, intense H<sub>2</sub>O maser was detected toward Mon R2 in the total power spectra. Since Mon R2 was detected with previous VLBI observations (Migenes et al. 1999), it is also a possible candidate for our project.

Therefore, we have started to carry out monitoring observations of 4 maser sources (Orion KL, OMC-2, HH1, and Mon R2) with VERA since 2004 January. Average interval of observation is 1 month. The total observing time was 4 hours for each source including calibration. At present, 7 epochs of ob-



**Fig. 1.** A phase-referenced image of H<sub>2</sub>O maser sources in Mon R2. The LSR velocity is 5.9 km s<sup>-1</sup>.

servations have been made and correlation processes have been done for 4 epochs.

Figure 1 shows an example of a phase-referenced image of the H<sub>2</sub>O maser source Mon R2 observed with VERA. A natural weighted map was produced using the AIPS task "IMAGR". The synthesized beam was 1.6×0.8 mas with the position angle of -31 degree. In this epoch, another maser feature (11.4 km s<sup>-1</sup>) is also detected in Mon R2, although it seems to be resolved out. On the other hand, we could not detect the same maser feature at the LSR velocity of 5.9 km s<sup>-1</sup> in other 3 epochs. In order to detect annual parallax and proper motion, further observations and data analysis including other sources (Orion KL, OMC-2, and HH1) are now in progress.

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