Observations of Infrared-identified Protostars in Molecular Maser Lines

Miju Kang[1], Jeong-Eun Lee[2], Minho Choi[1], Yunhee Choi[3], Kee-Tae Kim[1], James Di Francesco[4], Yong-Sun Park[5]

[1]Korea Astronomy and Space Science Institute, [2]Kyung Hee University, [3]Kapteyn Astronomical Institute SRON, [4] Herzberg Institute of Astrophysics, [5]Seoul National University

ABSTRACT

Many protostars were recently identified from the infrared data from the Spitzer space telescope. We present the results of a maser survey toward 99 protostars in the Orion molecular cloud complex. Observations were carried out in the water maser line at 22 GH z and three class I methanol maser lines at 44, 95, and 133 GHz. Five water maser sources were detected, and they are excited by HH 1-2 VLA 3, HH 1-2 VLA1, L1641N MM1/3, NGC 2071 IRS 1/3, and an object in the OMC 3 region. The water masers showe d significant variability in intensity and velocity with time scales of a month or shorter. Four methanol emission sources were dete cted, and those in the OMC 2 FIR 3/4 and L1641N MM1/3 regions are probably masers. The methanol emission from the other tw o sources in the NGC 2071 IRS 1-3 and V380 Ori NE regions are probably thermal. For the water maser, the number of detections per protostar in the survey region is about 2%, which suggests that the water maser of low-mass protostars is rarely detectable. Th e methanol class I maser of low-mass protostars is an even rarer phenomenon, with a detection rate much smaller than 1%.

1. INTRODUCTION

Orion giant molecular cloud complex

- One of the nearest active star-forming region at ~ 420 pc from the Sun.
- 3479 young stellar objects (YSOs) were identified in the Orion region based on t he *Spitzer* observations, 488 of which were protostars.

→ *Herschel* Orion Protostar Survey (HOPS) project (Megeath et al. 2012)

Maser emission

- An important signpost of star formation in the early stage of evolution.
- Useful for studying the environment of deeply embedded YSOs.
- Water and methanol maser lines have been detected toward many star-forming re gions (Elitzur et al. 1989; Kurtz et al. 2004; Torrelles et al. 1998) .

2. OBSERVATIONS

The KVN 21m radio telescopes

Target sources

- 99 protostars in the Orion molecular cloud (HOPS sources)

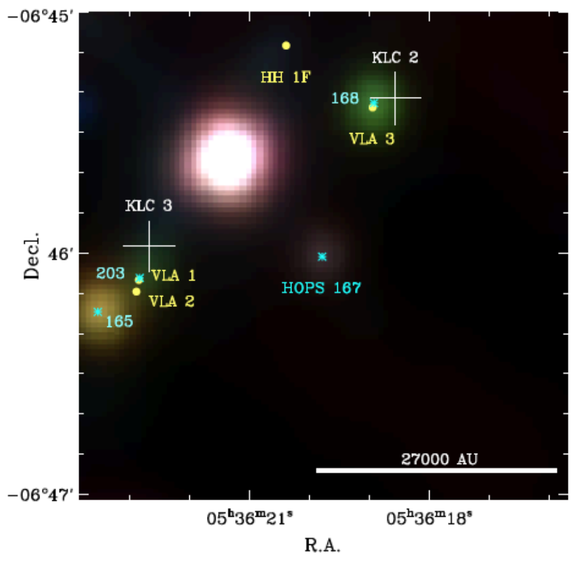
Target lines

- H_2O $6_{16} - 5_{23}$ (22 GHz)
- CH_3OH $7_0 - 6_1$ $A+$, $8_0 - 7_1$ $A+$, and $6_{-1} - 5_0$ E (44, 95, and 132 GHz)
- Angular resolutions : 121″, 63″, 33″, 23″, respectively

Mapped the area around the detected HOPS sources to identify the respons ible YSOs in the 22 GHz H_2O and 95 GHz CH_3OH maser lines.

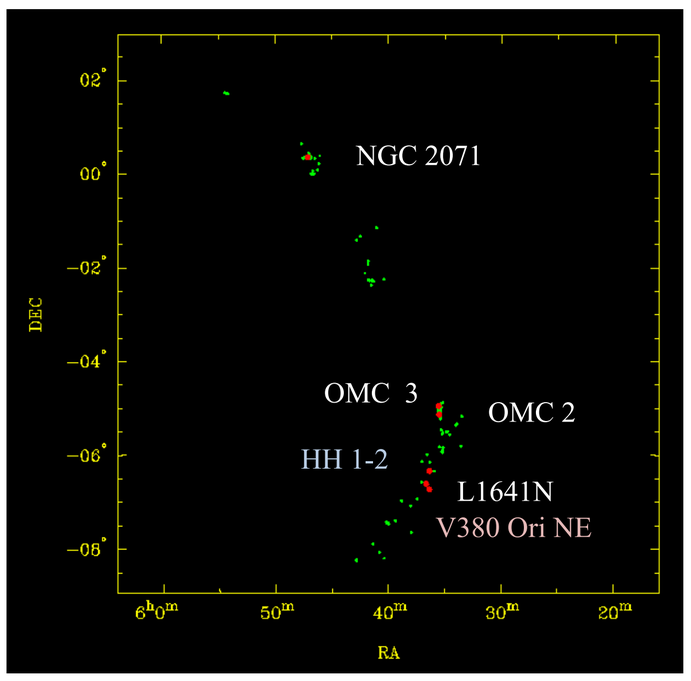
3. RESULTS & DISCUSSION

- The H_2O maser line was detected toward four target sources (HOPS 96, 167, 182, and 361). The H_2O masers showed significant variability in intensity and veloc ity. The detection rate of H_2O masers, defined as number of detections per survey field, is 5-7 %. The detection rate, defined as detections per protostar, is ~2%. T his small rate suggests that the H_2O maser of low-mass protostar is a rarely detectable phenomenon.
- The CH_3OH 44, 95, and 133 GHz lines were detected toward four target sources (HOPS 64, 182, 361, and 362). The CH_3OH lines did not show a significant var iability and have peak velocities within ~ 1 km s^{-1} relative to the systemic velocities of the ambient dense clouds. The per-field detection rate of CH_3OH class I m asers is 1-2%. The per-protostar detection rate may be much smaller than 1 %.



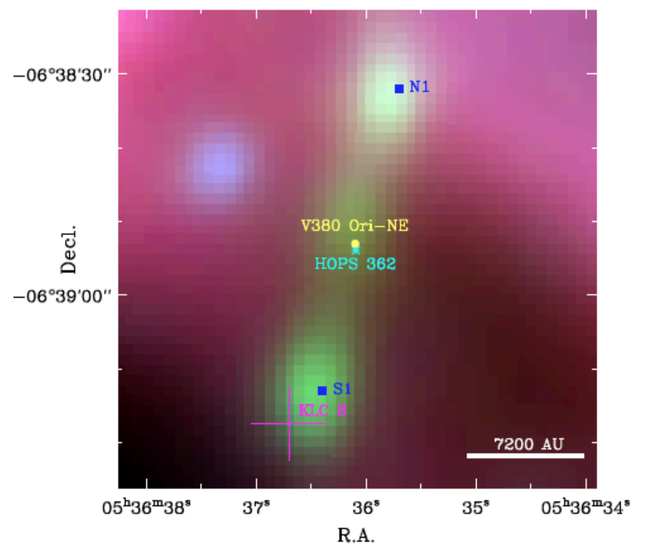
KLC 2/3 in the HOPS 167 Field (HH1)

The HH 1 region on the three-color image composed of WISE 12 μm (red), 4.6 μm (green), and 3.4 μm (blue). Asterisks mark the positions of HOPS 165, 167, 168, a nd 203. The white plus signs represent the H_2O maser s ource positions. The size of the plus sign corresponds t o the position uncertainty. The filled circles mark radio continuum sources (Rodriguez et al. 1990).



Protostars in Orion

Distribution of the 99 protostars in the Orion molecular cloud for KVN observations. Green dots are the target sources and red dots are the detected sources in the maser line observations using KVN .



KLC 8 in the HOPS 362 Field (V380 Ori NE)

The V380 Ori NE region on the three-color image compos ed of WISE 12 μm (red), 4.6 μm (green), and 3.4 μm (blue). Asterisks mark the positions of HOPS 362. The magenta plus signs represent the CH_3OH source positions. The siz e of the plus sign corresponds to the position uncertainty. The filled circles mark V380 Ori NE and two filled square s are the H_2 knots in the V380 Ori NE outflow (Davis et al . 2000).

Line Emission Source Positions Determined by Mapping

KLC Source	HOPS ID	Line	Mapping Date	v_p (km s^{-1})	R.A. (J2000.0)	Decl. (J2000.0)	Associated Object
1	64	CH_3OH	2012 May 7	11	5 35 27.7	-5 09 46	OMC 2 MIR 23
2	167	H_2O	2011 Nov 25	-1,1	5 36 18.6	-6 45 24	HH 1-2 VLA 3
3		H_2O	2012 Jan 22	13	5 36 22.5	-6 46 01	HH 1-2 VLA 1
4	182	H_2O	2012 Jan 11	6	5 36 18.4	-6 22 11	L1641 N MM1/3
5		CH_3OH	2012 May 7	7	5 36 17.7	-6 22 20	L1641 N MM1/3
6	361	H_2O	2011 Nov 25	-3, -1, 3, 6, 9, 11, 13	5 47 04.2	0 21 44	NGC 2071 IRS 1-3
7		CH_3OH	2012 Jan 30	10	5 47 04.9	0 21 44	NGC 2071 IRS 1-3
8	362	CH_3OH	2012 May 11-12	9	5 36 36.7	-6 39 17	V380 Ori NE

REFERENCES:

Davis et al. 2000, MNRAS, 318, 952
Elitzur et al. 1989, ApJ, 346, 983
Kurtz et al. 2004, ApJS, 155, 149
Megeath et al. 2012, AJ, 144, 192
Rodriguez et al. 1990, ApJ, 352, 645
Torrelles et al. 1998, ApJ, 706, 244

KVN Telescopes