The VLBI Monitor Project for the 6.7 GHz Methanol Masers Using the JVN/EAVN

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Abstract

We have started a VLBI monitor project of the 6.7 GHz methanol maser sources by using the Japanese VLBI Network (JVN) and the East-Asian VLBI Network (EAVN). The 6.7 GHz methanol maser emission can be one of the best probe to obtain 3-dimensional (3-D) velocity information, particularly on an accretion disk around forming high-mass protostars. The systematic VLBI survey monitor can provide us a chance to understand the evolution of the accretion disk, which is one of the basic issues in the high-mass star formation. Our VLBI monitor project for the 6.7 GHz methanol masers has been started since August 2010 toward 36 sources. In this presentation, we will show a result of the JVN/EAVN imaging survey for all of 36 target sources obtained in 2010-2012 as an initial result of this project. In this imaging survey, spatial distributions of the methanol maser spots in 35 sources were obtained, in which 33 sources provide new VLBI images. The spatial morphology was classified into five categories on the basis of the criteria used in the previous VLBI observations (Bartkiewicz et al. 2009), including elliptical, arched, and linear morphology which could be the best candidates associated with the disk. These spatial distributions were upgraded by comparing to our ATCA observation results, which provided us correct images without missing fluxes. We also present an initial result for a detection of relative proper motions in the elliptical methanol maser sources, G 6.795-0.257.

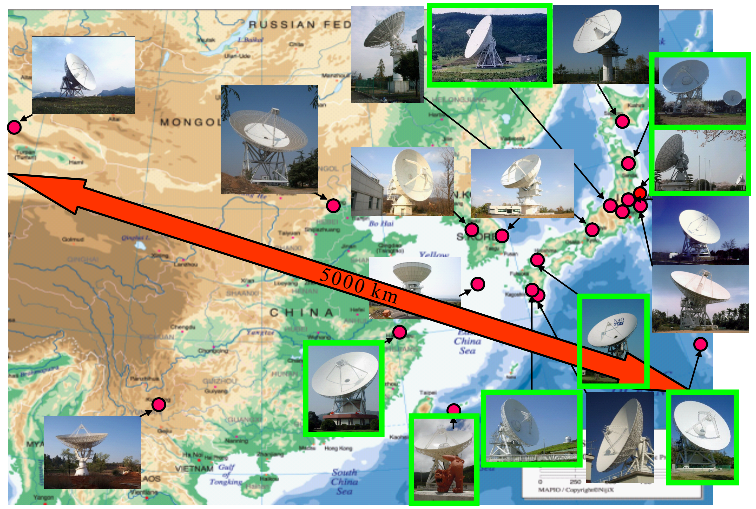

Figure 1. EAVN: 6.7 GHz observable stations are enclosed by Green)

Introduction

Back ground

The process through which high-mass star form has been a matter of debate for many years. However in the last decade, high-resolution interferometric observations at submillimeter and infrared have demonstrated the existence of rotating disks around forming high-mass protostars (e.g., Patel et al. 2005; Kraus et al. 2010; Sanchez-Monge et al. 2013).

Next steps

The evolution of the disk around high-mass protostars must be understood by a combination of VLBI and the ALMA. Studies of the proper motion of individual compact maser spots with VLBI are the only tools to directly provide information about rotation and/or an infall motions of the disk on scales of a few milliarcsecond per year (mas/yr) based on 3-D velocity information.

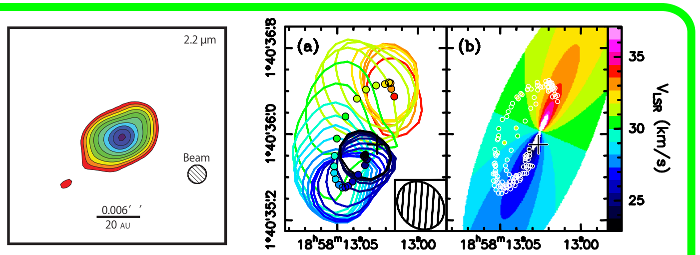

Figure 2. The existence of rotating disks. Left-panel: Observed with the VLTI (Kraus+ 10). The color contours show near infrared dust emissions. Right-panel: Observed with the ALMA (Sanchez-Monge+ 13). The color points indicate peak positions of CH_3CN line emissions. L.o.s. velocity field was well-fitted with an edge-on Keplerian disk in panel (b).

Our project

We have started a VLBI monitor project of 36 sources for the 6.7 GHz methanol maser sources using the JVN/EAVN to systematic investigate the 3-D velocity on the disk.

Observations

	JVN / EAVN	ATCA
Obs. date	2010/08, 2011/10,11 2012/09 (for G6.795)	2012/02/11-19
Stations	8 antennas (Green in Fig.1)	6 antennas (CA01-06)
Sources	see Table 1	
Polarization	LHCP	Linear
Synth. beam	∼ 15 x 5 milliarcsec^2	∼ 2 x 1.5 arcsec^2
Integ. time	~ 1 hour/source	~ 2-3 hour/source
Vel. resol.	0.176 km/s	0.088 km/s
Image rms (1σ)	~ 60 mJy/beam	~ 100 mJy/beam

JVN/EAVN Imaging Observation

- **Source selection**
  - From the 6.7 GHz methanol maser catalog and the Methanol MultiBeam survey;
  - Criteria: 1) -40 < Dec < +30 deg; 2) Total flux > 65 Jy; 3) No previous VLBI
  - Listed in Table 1 (note that 31.28+0.06 and 49.49-0.39 were already observed, and used for checking image capabilities)
- **Results**
  - Obtained VLBI images of the 6.7 GHz methanol maser spots for 35 sources
  - Showed new VLBI images in 33 sources, which provide an increase of the VLBI imaged sample of this maser by 1.5 times compared to that so far.
- **Spatial distribution** (: Fujisawa et al. to be submitted soon)
  - Classified into five categories: elliptical, arched, linear, pair, and complex (on the basis of the classification by Bartkiewicz et al. 2009)
  - At least, we could 13 sources as candidates associated with the disks, possibly showing elliptical, arched, and linear spatial morphology

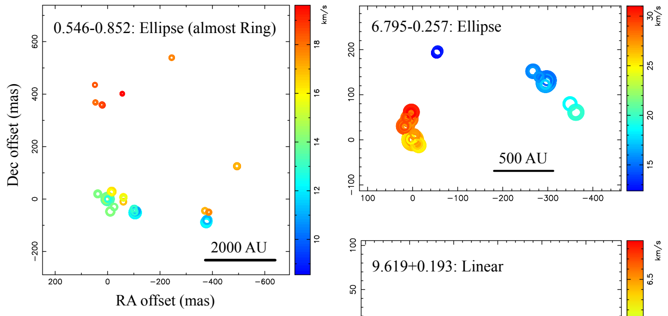

Figure 3. A part of JVN/EAVN images classified into elliptical and linear spatial morphology. Spot size and color indicates the peak intensity and l.o.s. velocity, respectively. The origin of the image corresponds to the brightest maser spot.

Table 1. Observed source list with the JVN/EAVN.

G-Name*	RA(J2000)	Dec(J2000)	catalog	epoch	Morph†
232.621+0.996	07 32 09.79	-16 58 12.4	Pesta	1st	P
351.775-0.536	17 26 42.57	-36 09 17.6	MMB	1st	C
352.630-1.067	17 31 13.91	-35 44 08.7	MMB	1st	L
353.410-0.360	17 30 26.18	-34 41 45.6	MMB	1st	C
354.615+0.472	17 30 17.13	-33 13 55.1	MMB	1st	E
359.436-0.104	17 44 40.60	-29 28 16.0	MMB	1st	P
0.546-0.852	17 50 14.35	-28 54 31.1	Pesta	2nd	E
0.645-0.042	17 47 18.67	-28 24 24.8	Pesta	2nd	C
2.536+0.198	17 50 46.47	-26 39 45.3	Pesta	1st	E
6.189-0.358	18 01 02.16	-23 47 10.8	MMB	1st	C
6.795-0.257	18 01 57.75	-23 12 34.9	MMB	1st	E
8.683-0.368	18 06 23.49	-21 37 10.2	MMB	1st	C
8.832-0.028	18 05 25.67	-21 19 25.1	MMB	1st	E
9.619+0.193	18 06 14.92	-20 31 44.3	MMB	2nd	L
9.986-0.028	18 07 50.12	-20 18 56.5	MMB	2nd	C
10.323-0.160	18 09 01.46	-20 05 07.8	MMB	2nd	C
11.497-1.485	18 16 22.13	-19 41 27.1	MMB	2nd	C
11.904-0.141	18 12 11.44	-18 41 28.6	MMB	2nd	P
12.025-0.031	18 12 01.86	-18 31.55.7	MMB	1st	A
12.681-0.182	18 13 54.75	-18 01 46.6	Pesta	1st	C
12.889+0.489	18 11 51.40	-17 31 29.6	MMB	2nd	P
14.101+0.087	18 15 45.81	-16 39 09.4	MMB	2nd	
20.237+0.065	18 27 44.56	-11 14 54.2	Pesta	2nd	P
23.437-0.184	18 34 39.25	-08 31 38.5	Pesta	1st	P
25.650+1.050	18 34 20.91	-05 59 40.5	Pesta	1st	L
25.710+0.044	18 38 03.15	-06 24 15.0	Pesta	1st	C
25.826-0.178	18 39 03.63	-06 24 09.5	Pesta	2nd	E
28.832-0.253	18 44 51.08	-03 45 48.5	Pesta	1st	C
29.86-0.04	18 45 59.53	-02 44 47.0	Xu	2nd	A
30.70-0.07	18 47 36.9	-02 01 05	Pesta	1st	P
30.76-0.05	18 47 39.73	-01 57 22.0	Pesta	2nd	P
30.91+0.14	18 47 15.0	-01 44 07	Pesta	1st	L
31.28+0.06	18 48 12.39	-01 26 22.6	Pesta	2nd	C
32.03+0.06	18 49 37.3	-00 45 47	Pesta	1st	P
37.40+1.52	18 54 10.5	+04 40 49	Pesta	1st	L
49.49-0.39	19 23 43.949	+14 30 34.45	Pesta	1st	C

Pesta=Pestalozzi+ (2005); Xu=Xu+ (2009);
MMB=Methanol Multi Beam survey(Caswell+ 2010,Green+ 2010)
*: Galactic source name (also observed with the ATCA marked by blue color)
†: E: Ellipse, A: Arched, L: Linear, P: Pair, C: Complex

ATCA Imaging Observation

- **Motivations with the ATCA obs.**
  - Detected just 20% flux on average in the JVN/EAVN observation
  - Possibly prevent us to understand correct spatial Morphology and Size
  - Observed with the ATCA for 24 sources in table 1. (except for -5 < Dec < +5 deg)
- **Results**
  - Obtained ATCA images without missing fluxes, which could provide us to understand correct spatial morphology;
    - e.g., for G 2.536+0.198, we could detect new maser spots at NW part, making the elliptical morphology more clear (in figure 4.)
  - Increased candidates associated with the disk listed in table 2.

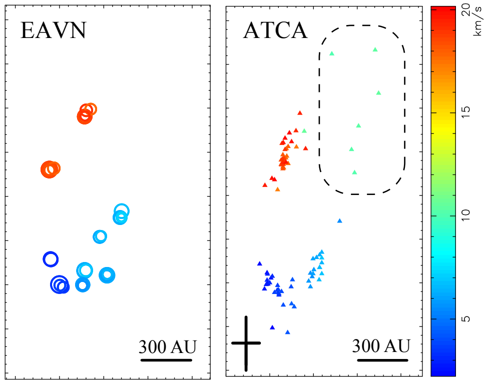

Figure 4. Spatial distribution of the G 2.536+0.198 methanol maser spots obtained with the JVN/EAVN and ATCA. The dash rectangle surrounds new detected spots in the ATCA obs.. The cross at bottom-left corner indicates a relative positional accuracy in the ATCA obs..

Table 2. Comparison between the EAVN and ATCA.

	Ellipse	Arched	Linear	Pair	Complex
EAVN*	5	1	2	5	11
ATCA	9	1	5	2	7

* Selected sources observed also with the ATCA obs.

Discussion: Spatial Size

- **Investigation item**
  - Relationship between spatial SIZE and l.o.s. velocity range
  - Whether associated with the disk or not
- **Results**
  - Moderately positive slope in the VLBI sources
  - Almost flat in the ATCA sources
  - VLBI sources spread wider than ATCA ones
  - Not well-fitted by simple Keplerian rotation ...
- **Possibilities**
  - × Resolved out: apparent spatial size
  - ? Expansion/infall: large velocity dispersion
  - ? Not associated with disk basically

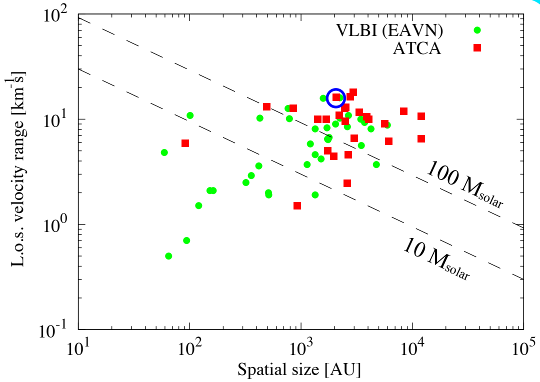

Figure 5. The relationship between the spatial size and l.o.s. velocity detected in the VLBI (green) and ATCA (red) sources. The dashed lines indicate equations of simple Keplerian rotation in the case of 10 and 100 solar masses, respectively.

Relative proper motions

- **Investigation item**
  - Understanding 3-D velocity in the elliptical source, G 6.795-0.257 (blue circle in fig. 5)
  - Investgate a possibility of not simple rotation
- **Results & model fit** (rotation + expansion)
  - Detected rotations in 3-epoch JVN/EAVN obs.

$$V_{x'}^{calc} = V_{rot}\sin\theta + V_{exp}\cos\theta$$
$$V_{y'}^{calc} = -(V_{rot}\cos\theta - V_{exp}\sin\theta)\cos i$$
$$V_{z}^{calc} = -(V_{rot}\cos\theta - V_{exp}\sin\theta)\sin i + V_{sys}$$

$V_{x,y,z}$: 3-D Vel.
V_{rot} : Rotation
V_{exp} : Expansion
θ : Azimuth on disk
i : Incli. of disk

⇨ Vrot = +2.5 km/s, Vexp = +4.2 km/s

◎ Elliptical source can be associated with rotation disk, and the large velocity dispersion can be caused by expansion!

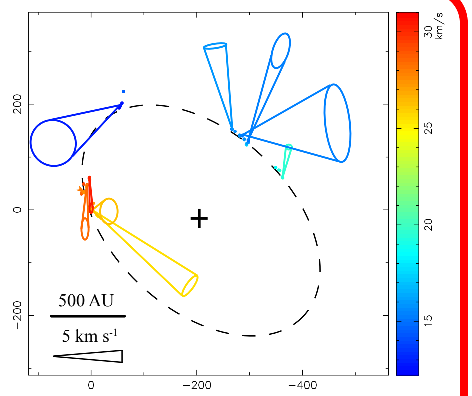

Figure 6. Relative proper motions of the maser spots in G 6.795-0.257, shown by cone (the bottom of one corresponds to the uncertainty). The dashed ellipse corresponds to the fitted elliptical structure for the methanol maser spots.