Dynamics of jet/outflow driven by high mass young stellar object revealed by KaVA 22 GHz water maser observations.

JUNGHAS KIM (SOKENDAI, NAOJ)

SUPERVISORS: MAREKI HONMA (NAOJ), TOMOYA HIROTA (NAOJ), KATSUNORI SHIBATA (NAOJ)

COLLEAGUES: KA VA SCIENCE WORKING GROUP FOR STAR-FORMING REGIONS
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High-mass Star Formation

- High-mass star formation is still far from understanding observationally.
- Evolutionary Sequence of high-mass young stellar objects (HMYSOs)
High-mass Star Formation

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Beltrán 2011
Astrophysical Masers

- **Water (H$_2$O) masers** at 22 GHz
  - Tracing shocked gas associated with dynamical structures such as high velocity jets, outflows etc

- **Methanol (CH$_3$OH) masers**
  - Class I at 44 GHz (Menten 1991)
    → Low-velocity outflows
  - Class II at 6.7 GHz (HMYSOs only?)
    → Rotating disks or outflows (under debating)

Masers are useful tracers of the dynamical signpost of HM star formation.
KaVA (KVN and VERA Array)

- Combined VLBI array with three 21-m radio telescopes of KVN (Korean VLBI Network) and four 20-m radio telescopes of VERA (VLBI Exploration of Radio Astrometry)
- The highest angular resolution: ~1.2 mas @ 22 GHz

Base line range: 200 km ~ 2300 km

Observable bands: 22 GHz and 44 GHz
Motivations

- To establish an evolutionary scenario using different maser species to enlarge samples of HMYSOs having VLBI images.
- To investigate the dynamics of jet/outflow+disk systems driven by HMYSOs by analyzing 3D velocity field and spatial structure of water masers.
- To reveal their launching and mass accretion processes.
RESULTS

OVERALL SPECTRA
Results – Examples of Water maser Spectra

Dashed vertical lines indicate systemic velocities of each source.
Results – Examples of Water maser Spectra

Dashed vertical lines indicate systemic velocities of each source.

- **S255N**
  - Blue only
  - Blue and Red

- **RMS2547**
  - Red only

- **AFGL 5142**
  - Blue and Red

- **G28.37**
  - Large velocity distribution

- **G357.967–0.163**
RESULTS

TOWARD INDIVIDUAL SOURCES
Similar distribution of water maser features is shown to that from Goddi+2011 obtained with the VLBA.

This study

Proper motion of water maser at 22 GHz from Goddi, Moscadelli, and Sanna 2011
Magnified distribution maps of AFGL 5142 - Red shifted spots at northwest of the center show arc-shaped feature with velocity gradient within the arc.
G25.82-0.17

D $\sim$ 5.1 kpc (Green & McClure-Griffiths 2011)

↑ Water maser spectrum at 22 GHz obtained with the KaVA.

↑ Spatial distribution of water masers. (green: systemic velocity of 91 km s$^{-1}$; shirley+2013)
G25.82-0.17

D ~ 5.1 kpc (Green & McClure-Griffiths 2011)

↑ Water maser spectrum at 22 GHz obtained with the KaVA.

↑ Spatial distribution of water masers. (green: systemic velocity of 91 km s\(^{-1}\); shirley+2013)
No 22 GHz water maser distribution map from the previous work. 

-> The first imaging result at this position.
DISCUSSIONS & FUTURE WORKS
Preliminary results from ALMA cycle 3 observations (PI: Mikyoung Kim, 2015.1.01571.S) at band 6 (239 GHz)

Integrated intensity map of SiO 5-4 overlaid onto dust continuum emission

Spatial distribution map of water maser features

The inner most part near HM-YSOs can be investigated by 3D velocity structure of water maser emission obtained with the KaVA.
Future works

- Target sources for the VLBI monitoring in the second year of KaVA LP is selected based on the first year results and further snap-shot imaging survey with KaVA and/or VERA (archival data).

- Dynamical properties of the water masers will be revealed by measuring proper motions with KaVA.

- Physical properties of the jets/outflows and their driving sources will be investigated by the follow-up observations such as ALMA.
Summary

- The first year project of water maser survey at 22 GHz using KaVA has been done.
- Summarization of 22 GHz water maser observations in the first year project is in progress in the same manner.
- Both blue and red shifted components were apparently detected toward 9 sources among 21 detected sources.
- Comparison with the previous work and verification of detectability have been done.
- Preliminary results from ALMA suggest that measuring proper motion with KaVA is important to understand the innermost part of the jet/outflow+disk system.