Studies on Evolved Stars Using KVN

The 12th East Asian VLBI Workshop
September 23-27, 2019 , Ibaraki University, Mito, Ibaraki, Japan

Se-Hyung Cho[1,2], Youngjoo Yun[1], Dong-Hwan Yoon[1], Haneul Yang[1,2], Jaeheon Kim[3], Dong-Jin Kim[4], Richard Dodson[5], Maria Rioja[5] and Hiroshi Imai[6]

[1]KASI, [2]Seoul Nat. Univ., [3]Chungbuk Nat. Univ., [4]MPI, [5]ICRAR, [6]Kagoshima Univ.

Abstract

At the commissioning phase of KVN from 2009 to 2013, single dish survey performed toward about 1000 evolved stars and monitoring observations also toward about 60 relatively strong SiO and H_2O maser sources. Based on these single dish results and VLBI feasibility test observations at K/Q/W/D bands in 2014, KVN Key Science Project (KSP) centered on VLBI observations has started from 2015 and will be completed in 2019 as phase I. Here we report the overview of studies on evolved stars using KVN. In KSP phase I, we have focused on nine KSP sources which show a successful astrometrically registered maps of SiO and H_2O masers using the Source Frequency Phase Referencing (SFPR) method. We aim at investigating the spatial structure and dynamical effect from 43/42/86/129 GHz SiO to 22 GHz H_2O maser regions associated with a stellar pulsation and development of asymmetry in circumstellar envelopes.

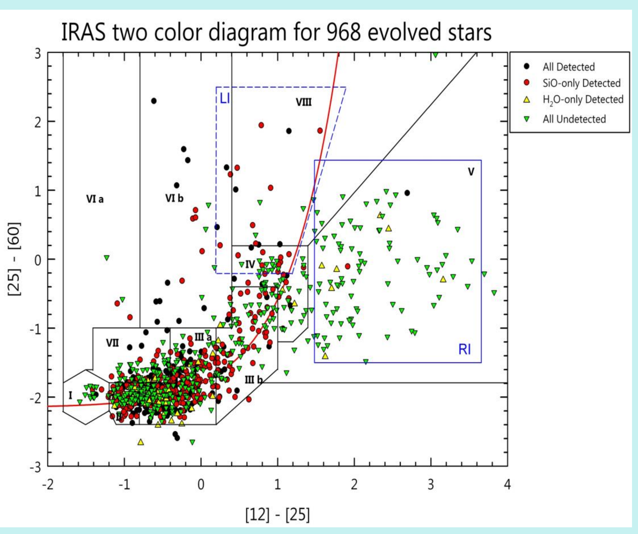
Introduction

- The maser emission plays an important role for investigating the atmosphere and envelope of the central stars according to their different chemical and excitation conditions. It is important to perform simultaneous observations of both SiO and H_2O masers because their spatial distributions may be connected from the innermost region to the radially accelerating region of the circumstellar envelope.
- The Korean VLBI Network (KVN) equipping a simultaneous observation system of 22/43/86/129 GHz bands enables us to combined studies of SiO and H_2O masers.
  ► We have performed single dish survey at commissioning phase of KVN and the Key Science Project of evolved stars since 2015A (SH Cho et al. 2018).

■ As a science goal, (1) we aim at investigating the spatial structure and dynamical effect from SiO to 22 GHz H_2O maser regions and the development of asymmetry via dust formation layer according to stellar pulsation.
(2) Combined models of SiO and H_2O masers will be studied.
(3) The correlation and difference of SiO maser properties among J=1-0, J=2-1, and J=3-2 masers are investigated for constraining SiO pumping models.

Observations and Data Reduction

Target Sources for KVN Single Dish and VLBI Obs.



No	Objects	No of Obs	2015	2016	2017	2018	2019A
1	IK Tau	41	5/7	5/8	11/11	4/8	3/7
2	VY CMa	45	8/10	10/11	6/9	4/9	2/6
3	VX Sgr	34	3/6	7/9	6/8	4/9	2/2, Fin
4	R Crt	11	8/8	3/3	Fin	Fin	Fin
5	V1111 Oph	35	7/8	3/4	8/9	1/8	3/6
6	W Hya	38	3/5	7/10	7/8	2/9	4/6
7	V627 Cas	34	5/5	4/4	8/9	2/9	1/7
8	V5102 Sgr	24	3/4	2/2	8/9	8/8	1/1, Fin
9	WX Psc	31	1/2	5/6	6/8	6/8	4/7
10	X Cyg	25	1/1	1/3	6/8	2/8	1/5

Number of monitoring obs. & obs. success rate

KVN Single Dish and VLBI Monitoring Obs.

- Single dish survey toward ~1000 stars from 2009 : SRs, Miras, SGs, OH/IR stars (252), Post-AGB stars (182), Symbiotic stars
- Single dish monitoring toward about 10-15 strong SiO and H_2O maser sources together with VLBI every 1- 3 months regularly
- VLBI monitoring focused on 10 successful SFPR objects
- Obs. lines : H_2O 6_{16}-5_{23} , SiO v=1, 2, J=1-0, v=1, J=2-1, & v=1, J=3-2

● KVN home page ► http://radio.kasi.re.kr/kvn/kvn.php

◈ Source Frequency Phase Referencing (SFPR) technique (Dodson et al. 2014) and SFPR pipeline (2019 YJ Yun) were adopted.

Observational Results

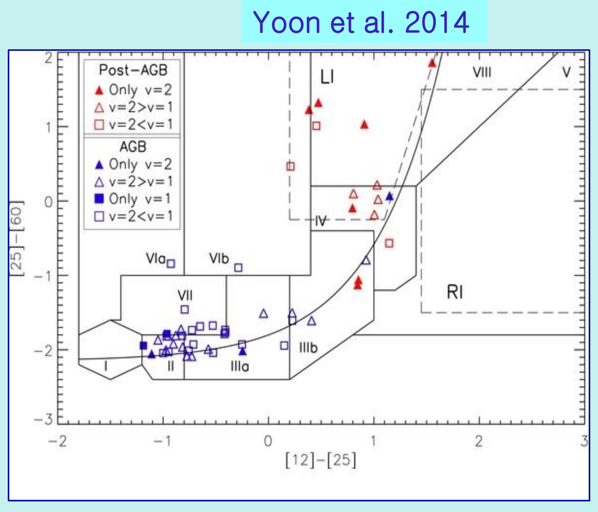
Summary of KVN Single Dish Observations

■ Both SiO and H_2O masers are detected from a large number of AGB stars (SR, Mira, SG: 188/401, OH/IR: 50/252) at one-epoch obs. ◄ Both H_2O & SiO masers are detected from known SiO-only and H_2O-only detected sources (Kim et al. 2010, 2013, Cho et al. 2012).

■ Intensity variations of SiO and H_2O masers show similar patterns for several stars (Ref: H_2O maser maximum are scattered in the range of phase, 0.7~1.5; Shintani et al. 2008) (Kim et al. 2014).

■ SiO maser intensities are stronger than H_2O maser in most evolved stars and at most optical phases. However, peak intensities of H_2O are stronger than those of SiO around maximum phases in several stars (Kim et al. 2014).

Yoon et al. 2014



■ FWZP of SiO maser shows a similar value in both Mira variables and OH/IR stars, while FWZP of H_2O maser is large in OH/IR stars compared with that in Mira variables (Kim et al. 2012, 2014, Cho et al. 2017).

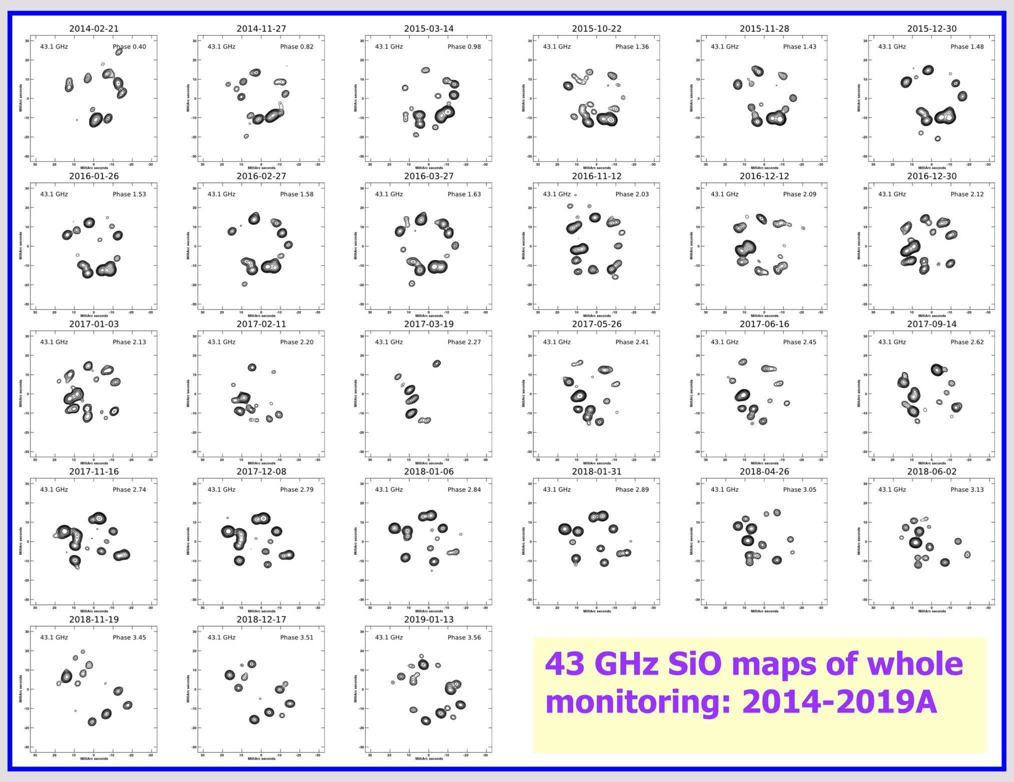
■ One-way, double peaks of H_2O masers, and SiO v=2-only masers appear at late stage of AGB evolution and at post-AGB stage (Yoon et al. 2014, Cho et al. 2017).

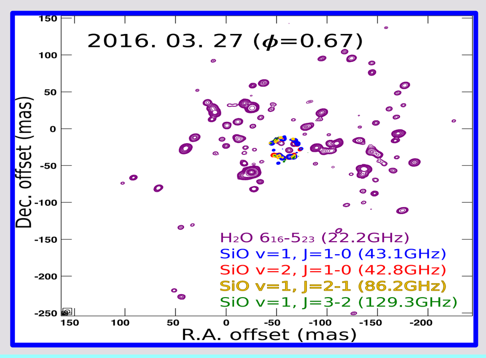
■ Different detection rates between SiO and H_2O masers at post-AGB stage (Yoon et al. 2014).

Observational Results

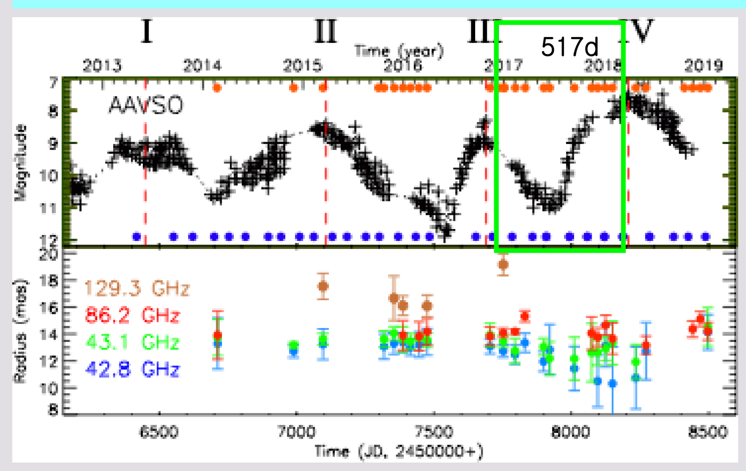
■ Successful SFPR maps of H_2O and SiO masers were obtained from KSP 9 stars : VX Sgr, VY CMa, IK Tau, R Crt, W Hya, V1111 Oph, V627 Cas, V5102 Sgr, WX Psc.

Supergiant Star VX Sgr (PhD thesis of DH Yoon 2019)



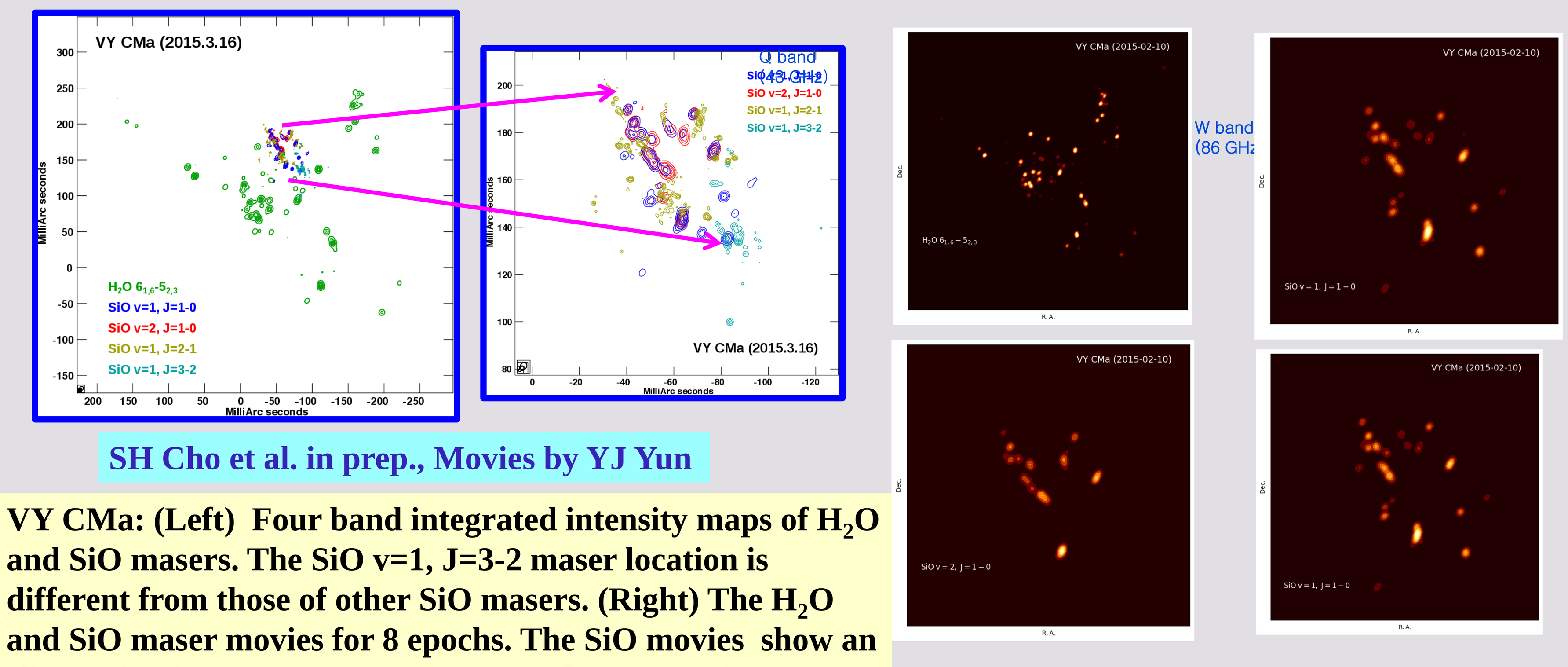


DH Yoon et al. 2018 Nature Comm. 9:2534



VX Sgr: (Left) NE-SW transformations appeared from 2017 Feb. which shows the shortest period, 517 days (green box in the light curve). ◄ probably caused by the variations of pulsation motion (Right) Variation of SiO ring radius with optical light curve. ● Ring radius of 129 GHz maser increases near optical max. ► Radiative pumping is dominant.

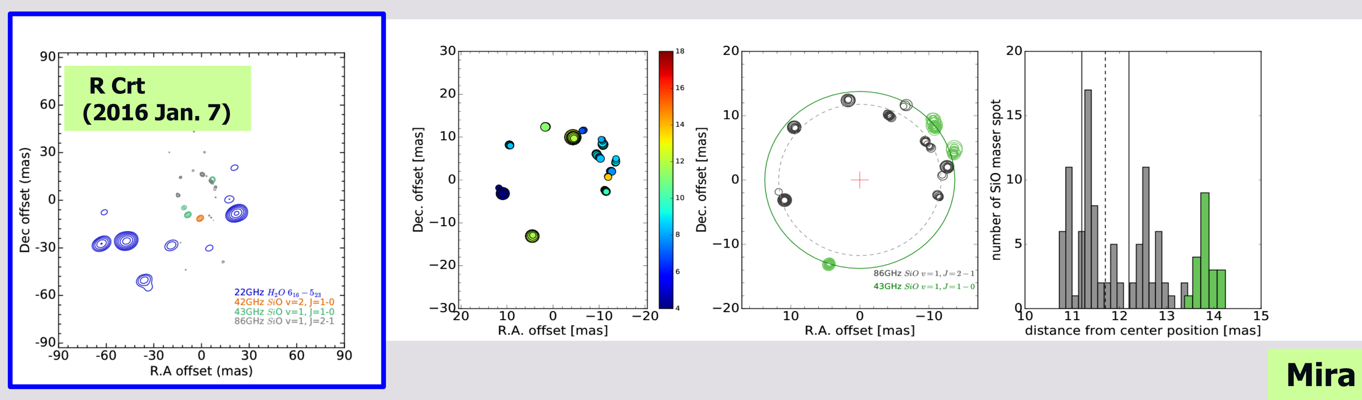
4 Band SFPR Maps (Movie) of H_2O and SiO Masers toward VY CMa



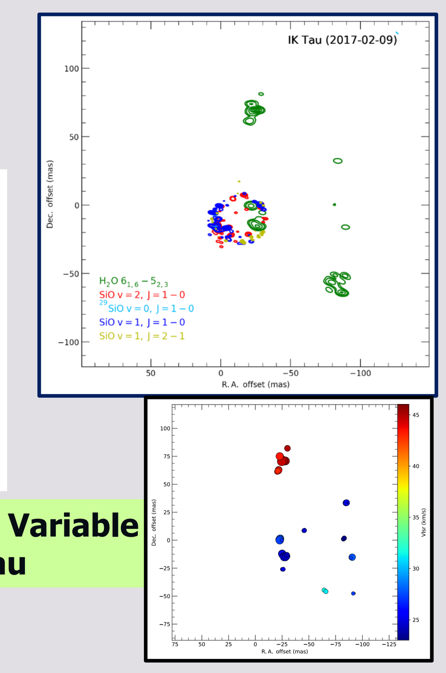
SH Cho et al. in prep., Movies by YJ Yun

VY CMa: (Left) Four band integrated intensity maps of H_2O and SiO masers. The SiO v=1, J=3-2 maser location is different from those of other SiO masers. (Right) The H_2O and SiO maser movies for 8 epochs. The SiO movies show an elliptical pulsation motions (NE-SW pulsation motion).

Semiregular b-Type Variable R Crt : P~160 days



Ring size of SiO v=1, J=2-1maser in R Crt is smaller than that of v=1, J=1-0 different from known results (DJ Kim et al. 2018).

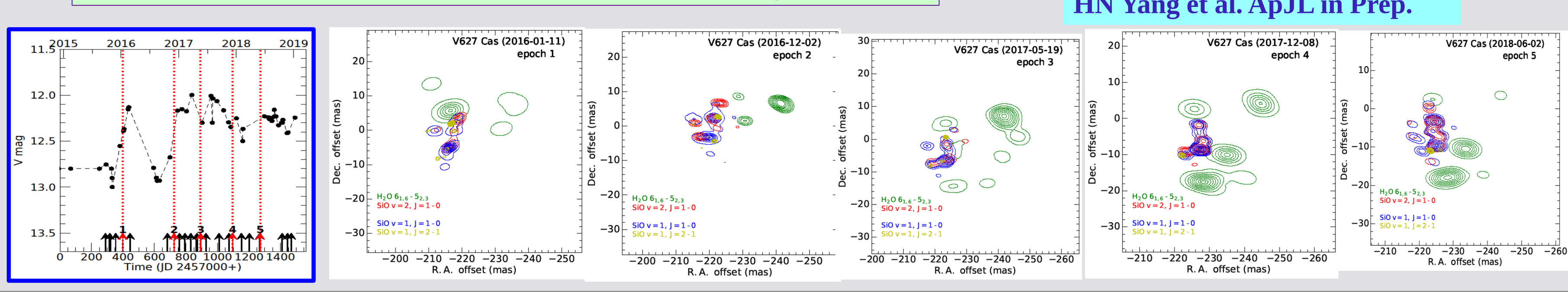


Mira Variable IK Tau

OH/IR star: WX Psc, V1111 Oph ►YJ Yun's presentation

Symbiotic star: V627 Cas ► HN Yang's pres.

HN Yang et al. ApJL in Prep.



We investigated that the variations of H_2O & SiO masers are associated with the orbital motion of hot companion.

Discussion and Future Works

◆ What is the development process for changing from ring (elliptical)-like structure of SiO masers to highly asymmetric structure of H_2O maser via dust formation layer including the transformations of SiO ring-like structure ?
◆ Differences of pumping mechanism among SiO masers. ◆ Completion of movies and polarization obs. ◆ Hydrodynamical model combining SiO and H_2O maser propagation ◄ Gray et al. 2009

References

Cho et al. 2018, Proceedings IAU Sym. 336
Dodson et al. 2014, AJ, 148, 97
Gray et al. 2009, MNRAS, 394, 51
Yoon et al. 2014, ApJS, 211, 15