Results of KVN observations toward evolved stars

SiO v=1 J=1-0
IK Tau

Youngjoo Yun, Se-Hyung Cho, Dong-Hwan Yoon,
Haneul Yang, Dong-Jin Kim

12th East Asian VLBI Workshop
Ibaraki, 23 – 27 September 2019

Outline

- **Introduction to KVN Key Science Project**
- **Results of KVN observations**
- **Summary and future works**

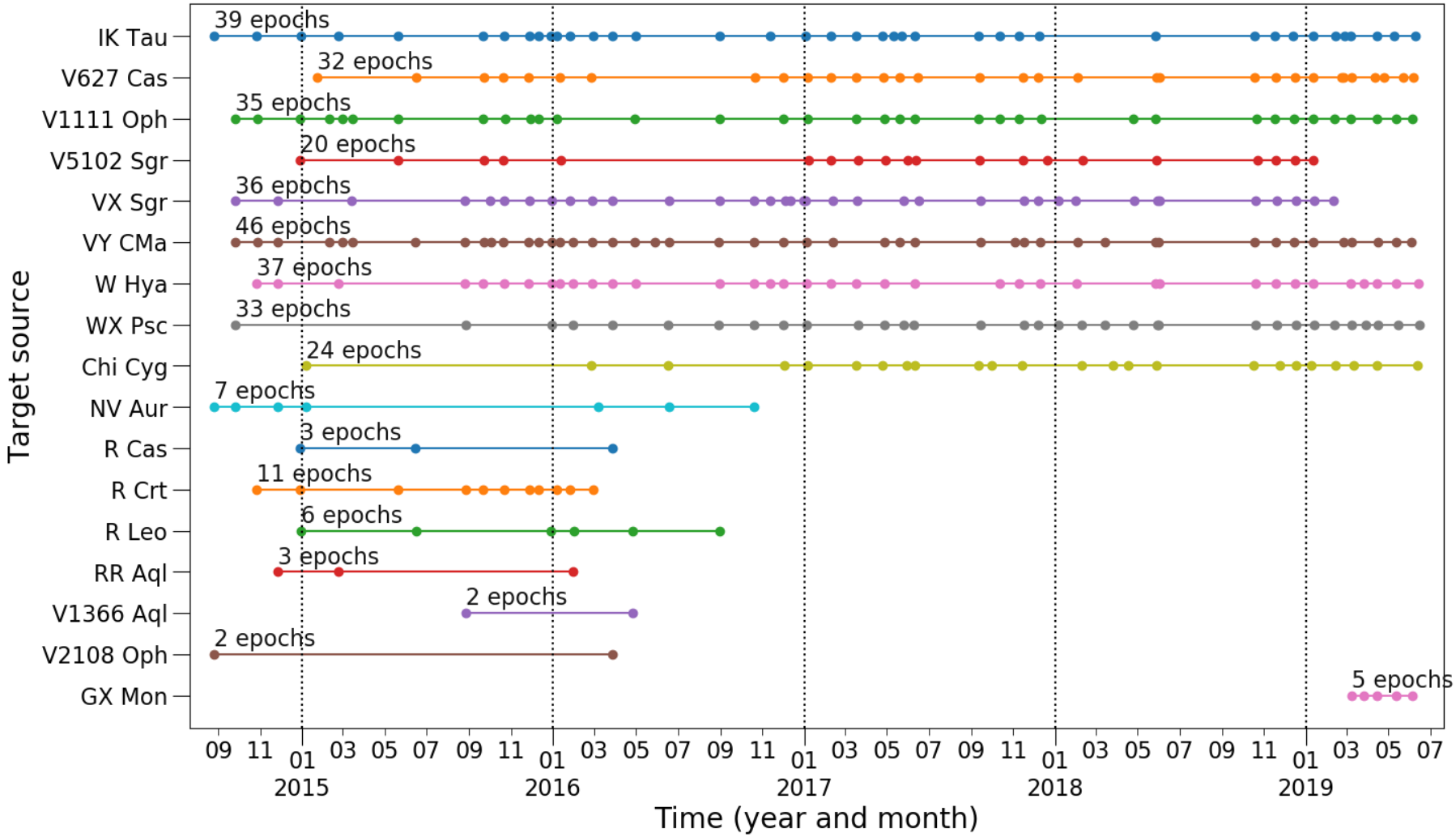
Scientific goals of KSP

To Study

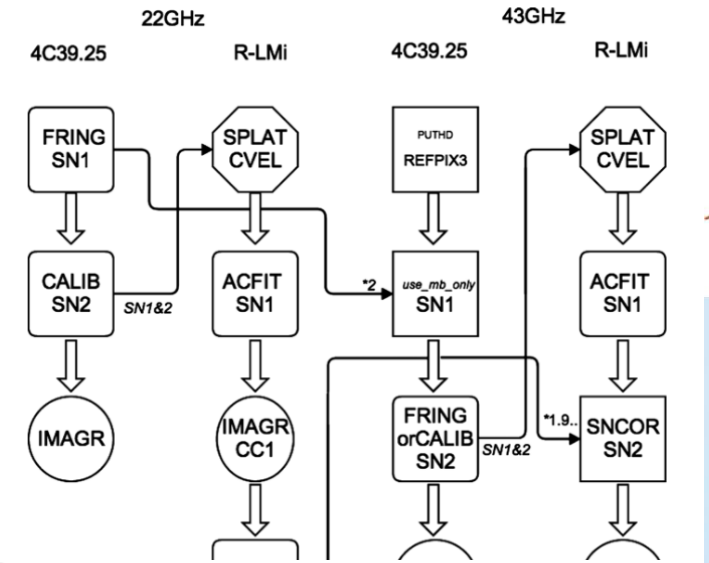
- **Characteristics of stellar masers**
  - Spatial structure, relative location, intensity
  - Temporal variability
  - Masing conditions
- **Kinematic and chemical properties of circumstellar envelopes**
  - Pulsation and shock propagation
  - Molecular abundance
  - Dust condensation
- **Mass-loss mechanism and history**
  - Dust-driven stellar wind
  - Shell morphology: spherical, bipolar, irregular, …
  - Mass-loss rate and stellar evolution

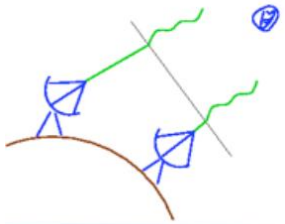
Total 341 VLBI observations in KSP

Aug. 2014 – Jun. 2019

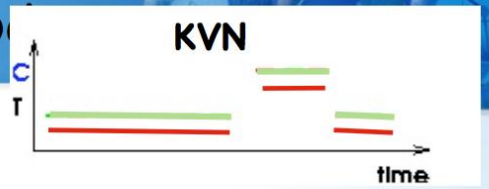


Key technique of KSP observations
Source Frequency Phase Referencing method





new metho



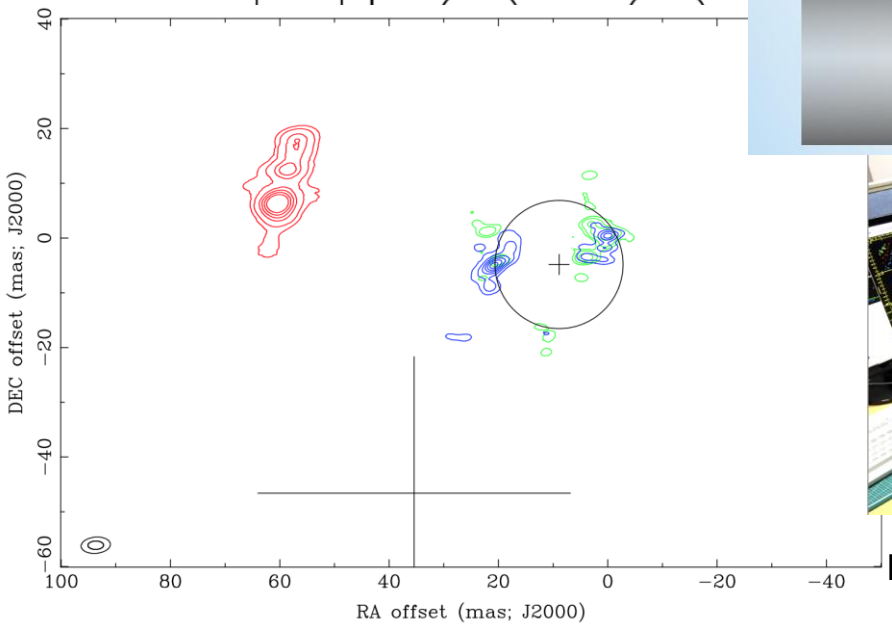
Introduce a Second Source B

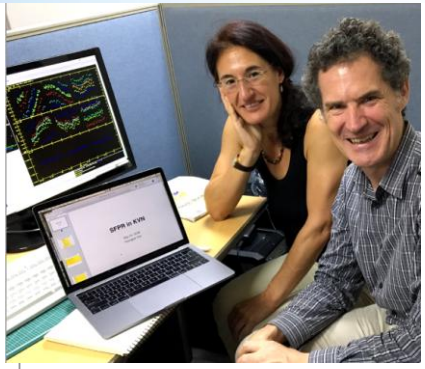
$$\phi_B - R*\phi_B = 2\pi\nu/c\ (\bar{D}\ .\ \bar{\theta}_{B,shift}) + ION + INST$$

Same as for A

Source/freq. referenced Visibility phase:

$$\phi_{A,STR} + 2\pi\nu/c * \bar{D}\ (\bar{\theta}_{A,shift} - \bar{\theta}_{B,shift})$$





May the SFPR be with you!

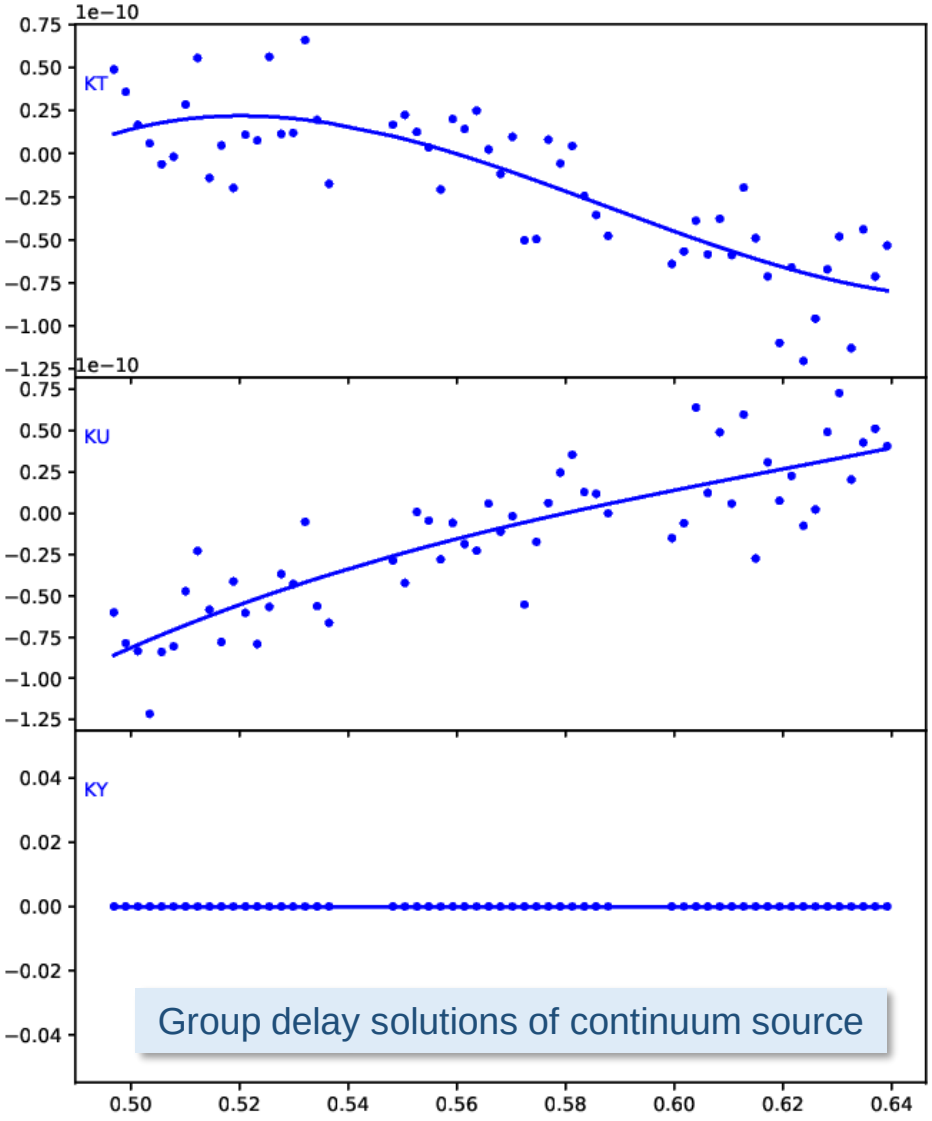
Richard Dodson and Maria J. Rioja (2014)

Development of KVN pipeline

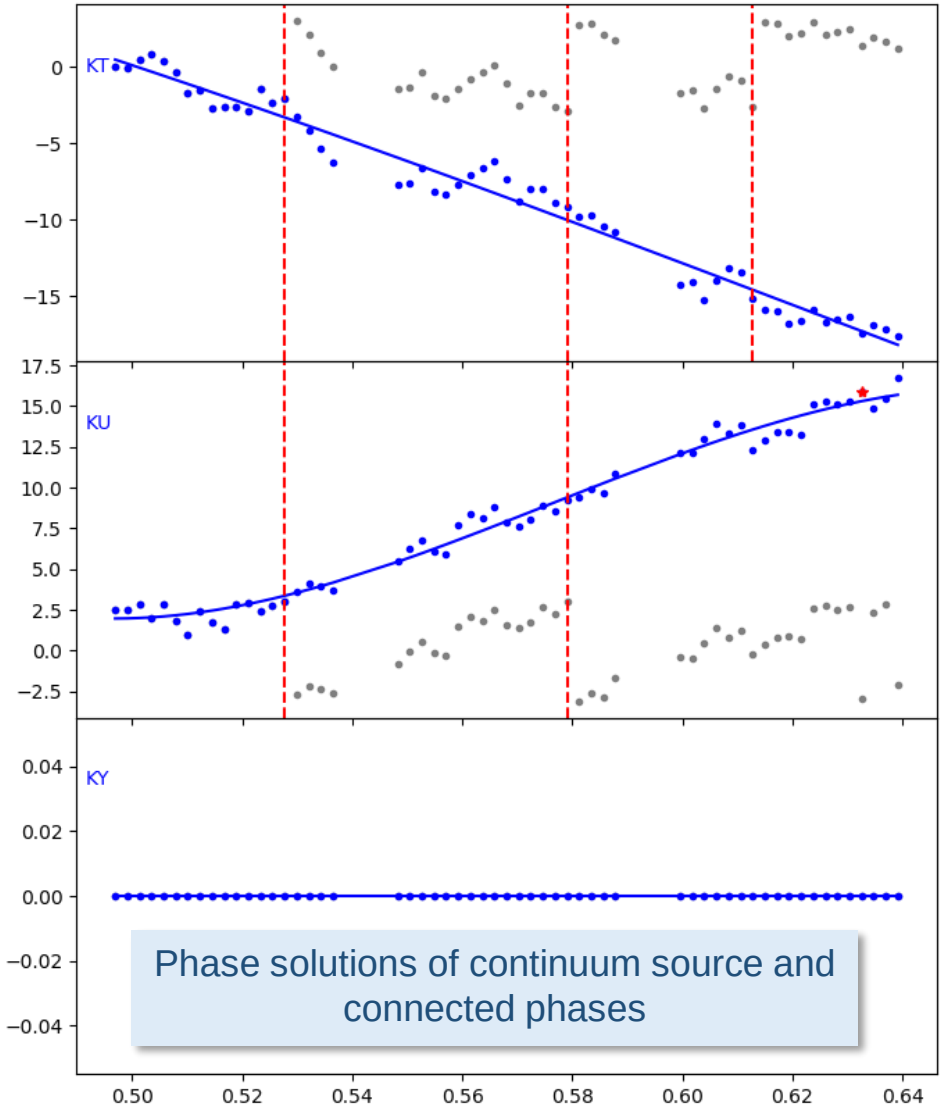
- SFPR method for KVN observations is completely implemented.
- Fully-automated procedures of pipeline save a huge amount of time by replacing human eye inspection.
- Consistency and repeatability of data reduction can be achieved by using the pipeline along the multi-epoch observations.

Examples of KVN pipeline

Procedures for continuum reference source for phase referencing



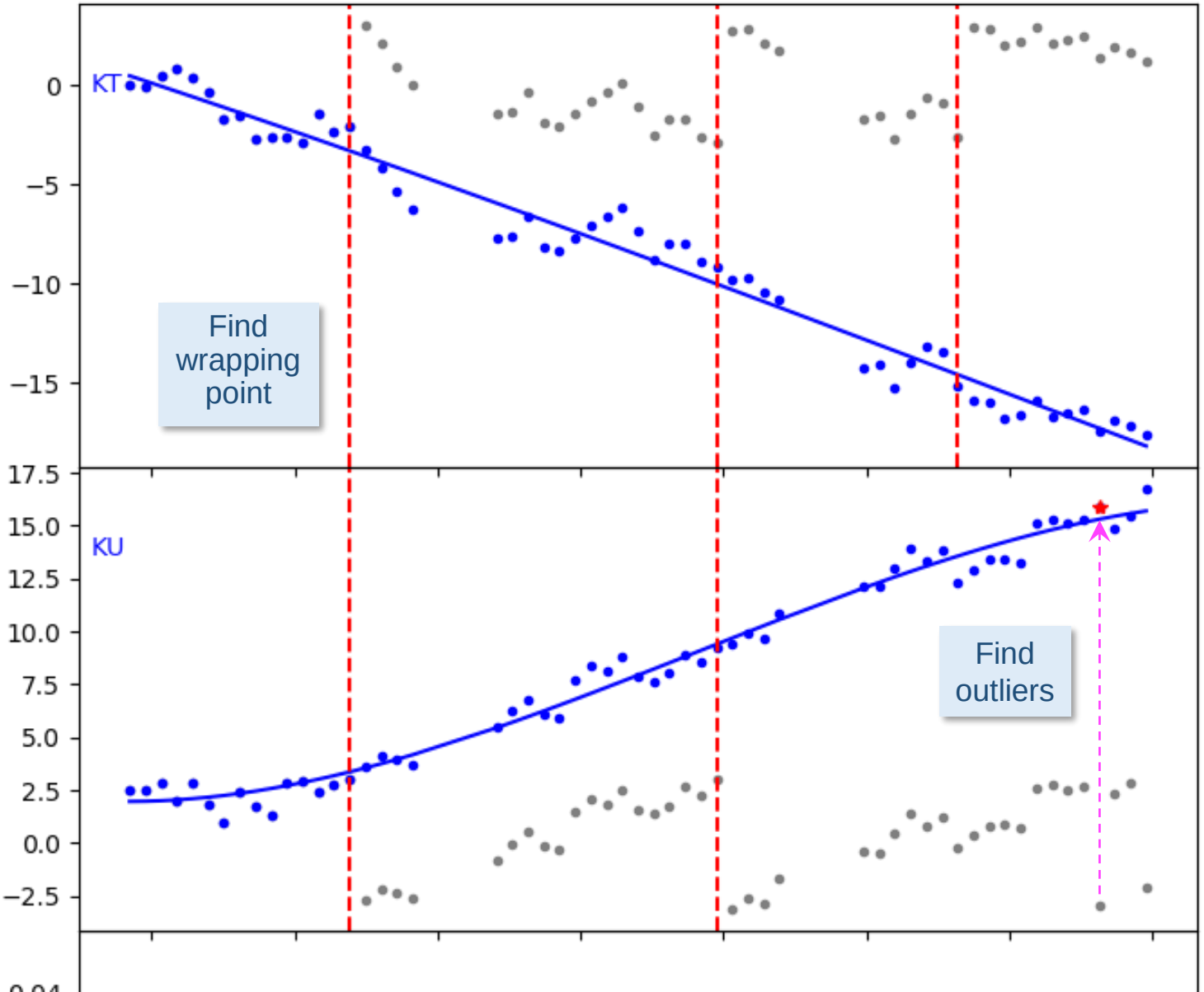
Group delay solutions of continuum source



Phase solutions of continuum source and connected phases

Examples of KVN pipeline

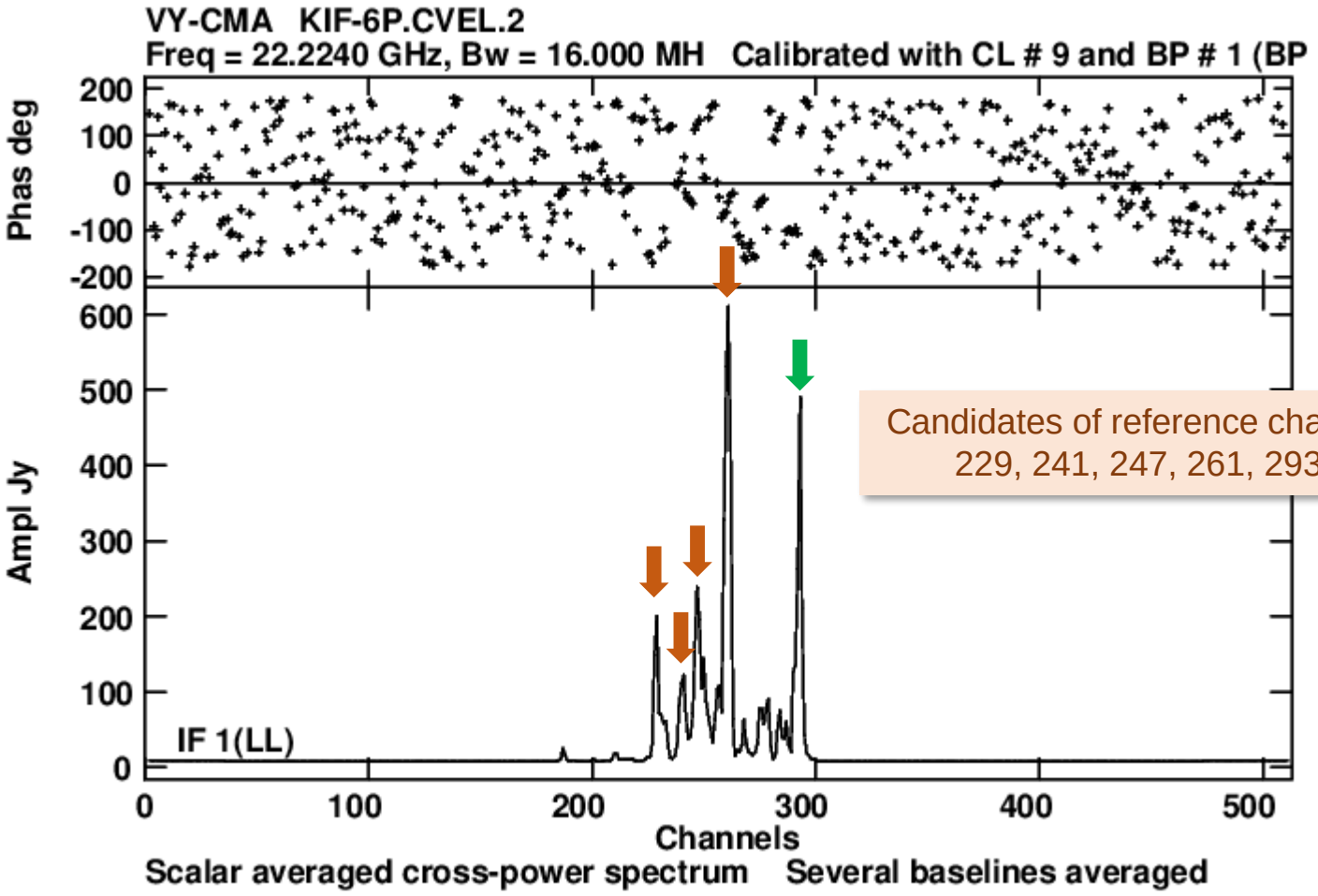
Procedures for continuum reference source for phase referencing



Examples of KVN pipeline

Procedures for maser line source for fringe fitting

Spectrum of 22 GHz H2O maser of VY CMa

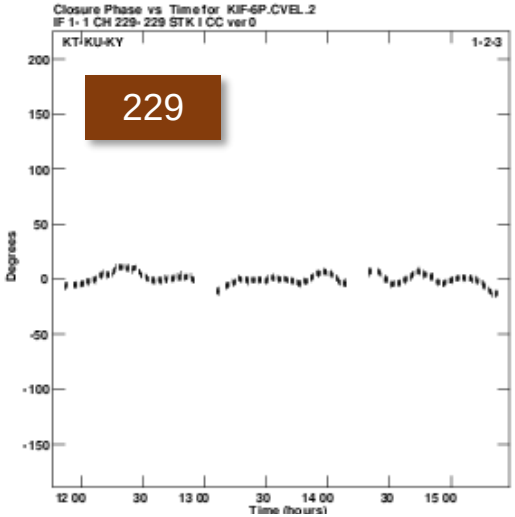


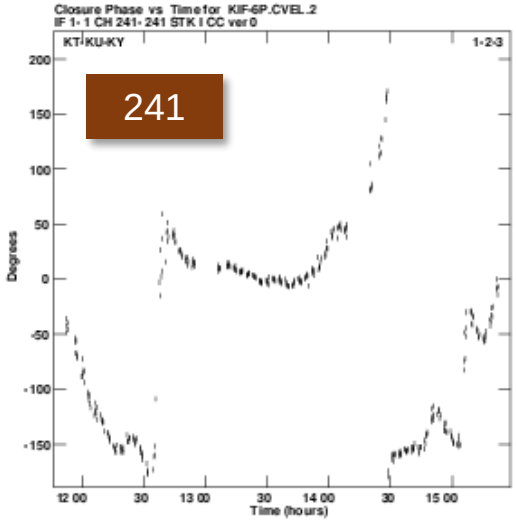
Candidates of reference channel
229, 241, 247, 261, 293

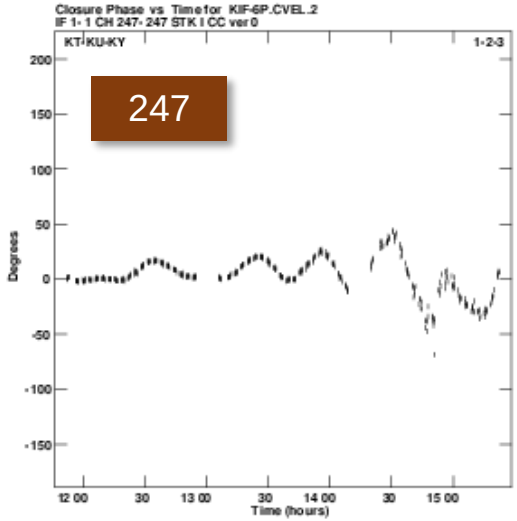
Examples of KVN pipeline

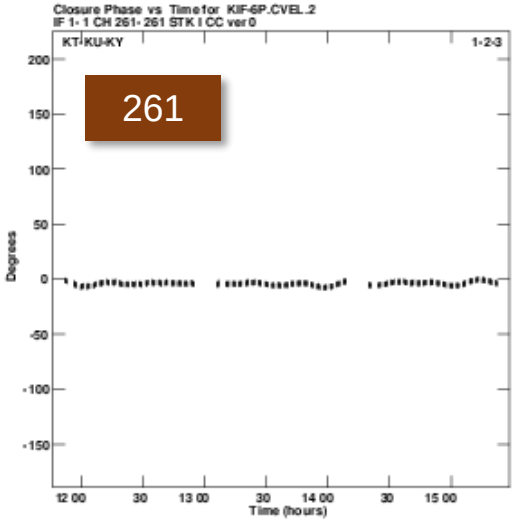
Procedures for maser line source for fringe fitting

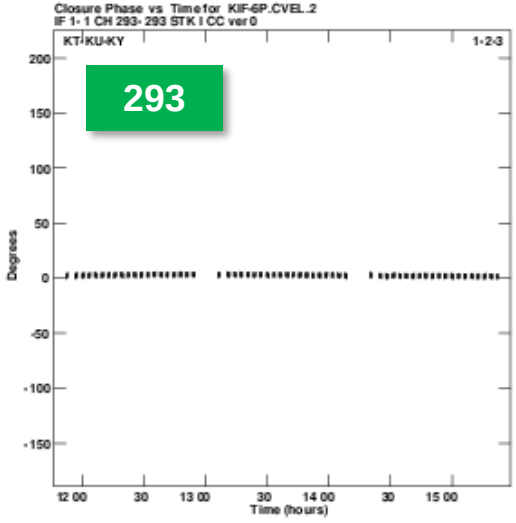
Closure phases of maser line channels





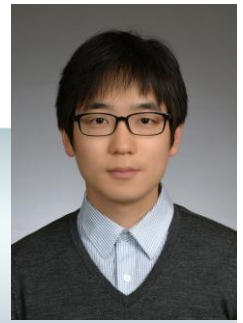






Reference channel of maser line can be automatically determined from the qualities of fringe phase solutions and closure phases.

Results of VX Sgr by Dong-Hwan Yoon



nature COMMUNICATIONS

ARTICLE

DOI: 10.1038/s41467-018-04767-8 OPEN

Astrometrically registered maps of H_2O and SiO masers toward VX Sagittarii

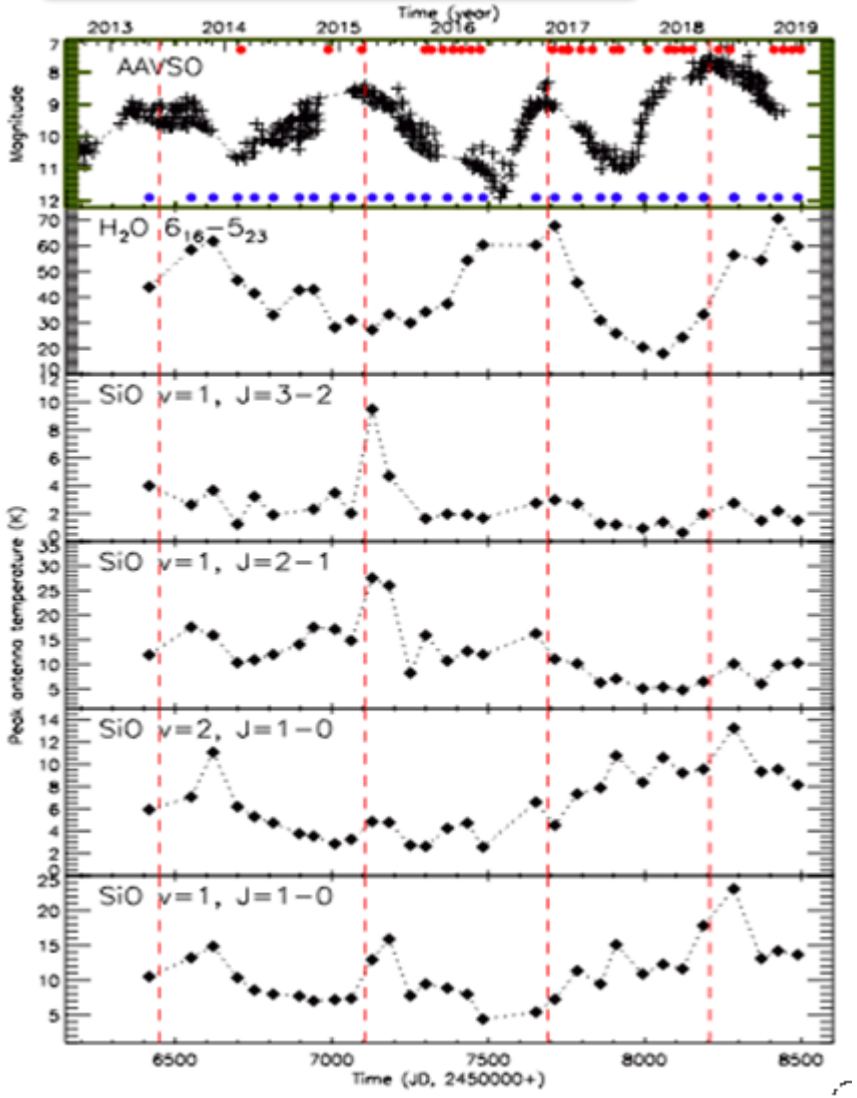
Dong-Hwan Yoon[1,2], Se-Hyung Cho[2,3], Youngjoo Yun[2], Yoon Kyung Choi[2], Richard Dodson[4], María Rioja[4,5], Jaeheon Kim[6], Hiroshi Imai[7], Dongjin Kim[3], Haneul Yang[1,2] & Do-Young Byun[2]

The supergiant VX Sagittarii is a strong emitter of both H_2O and SiO masers. However, previous VLBI observations have been performed separately, which makes it difficult to spatially trace the outward transfer of the material consecutively. Here we present the astrometrically registered, simultaneous maps of 22.2 GHz H_2O and 43.1/42.8/86.2/129.3 GHz SiO masers toward VX Sagittarii. The H_2O masers detected above the dust-forming

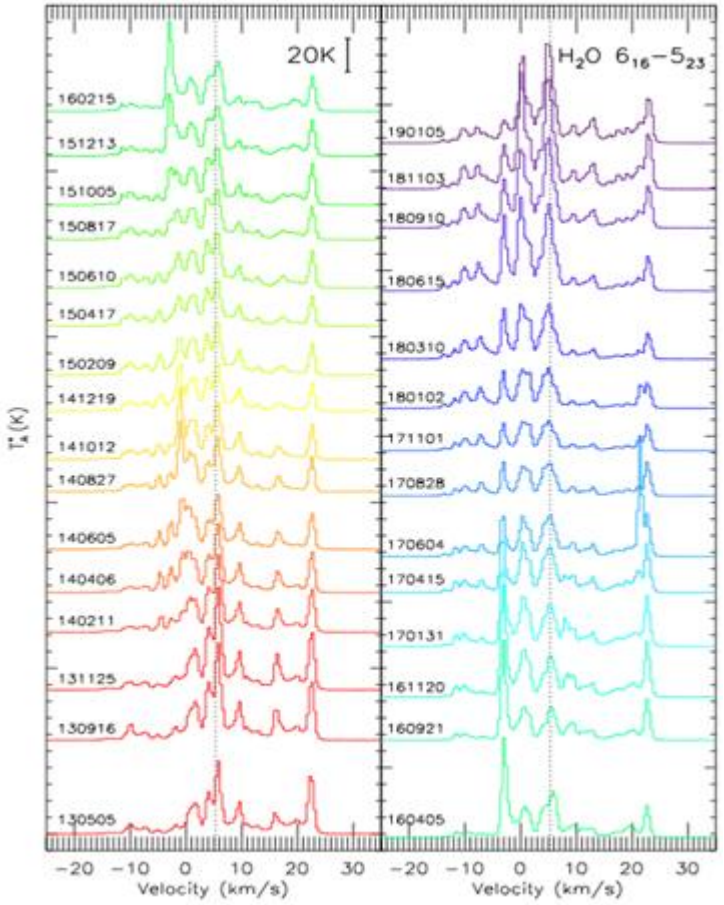
Single dish monitoring observations of KVN

Result of VX Sgr reduced by Dong-Hwan Yoon

Light curve and maser intensity

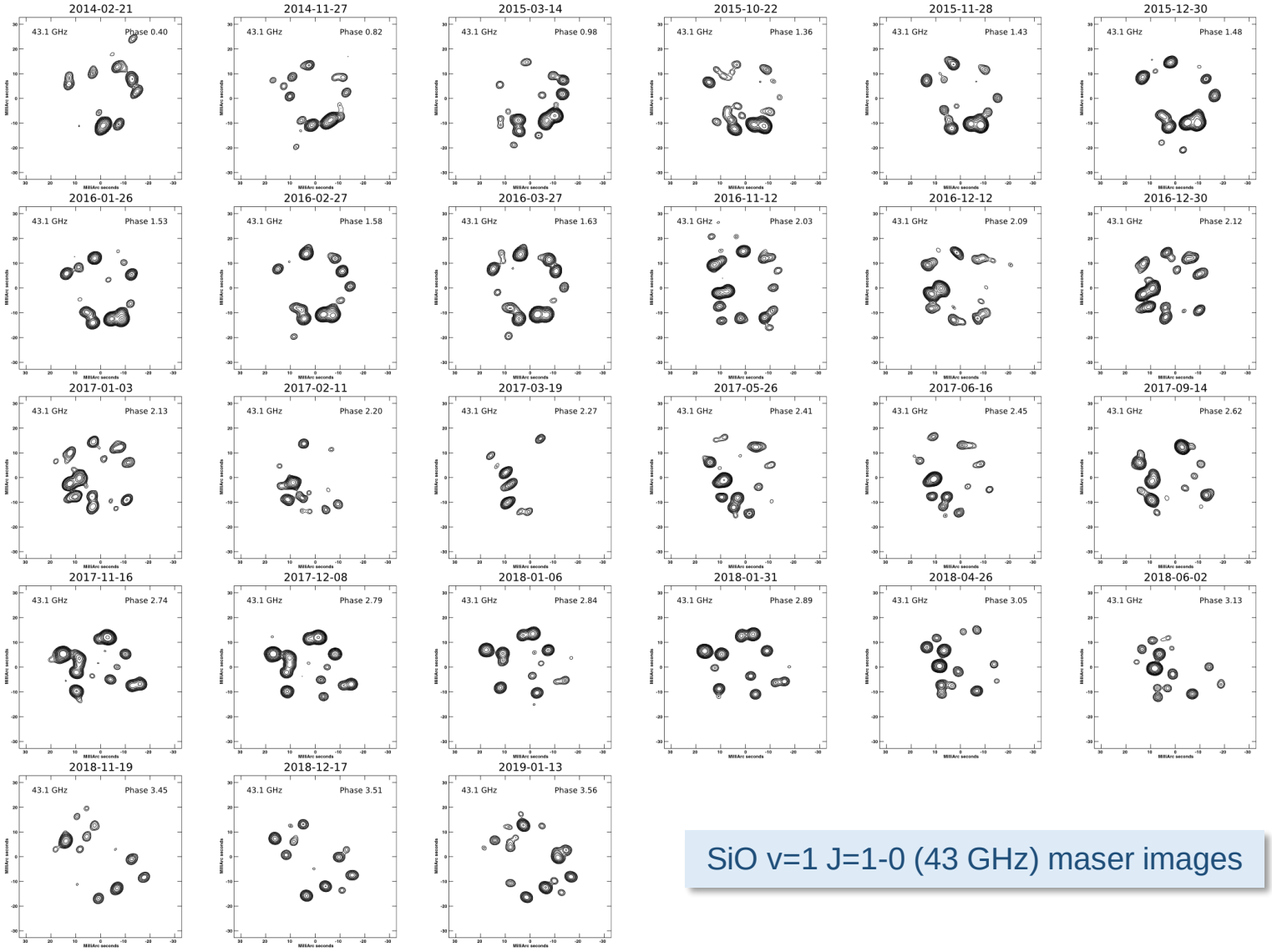


Spectra of 22 GHz H2O maser



VLBI monitoring observations of KVN

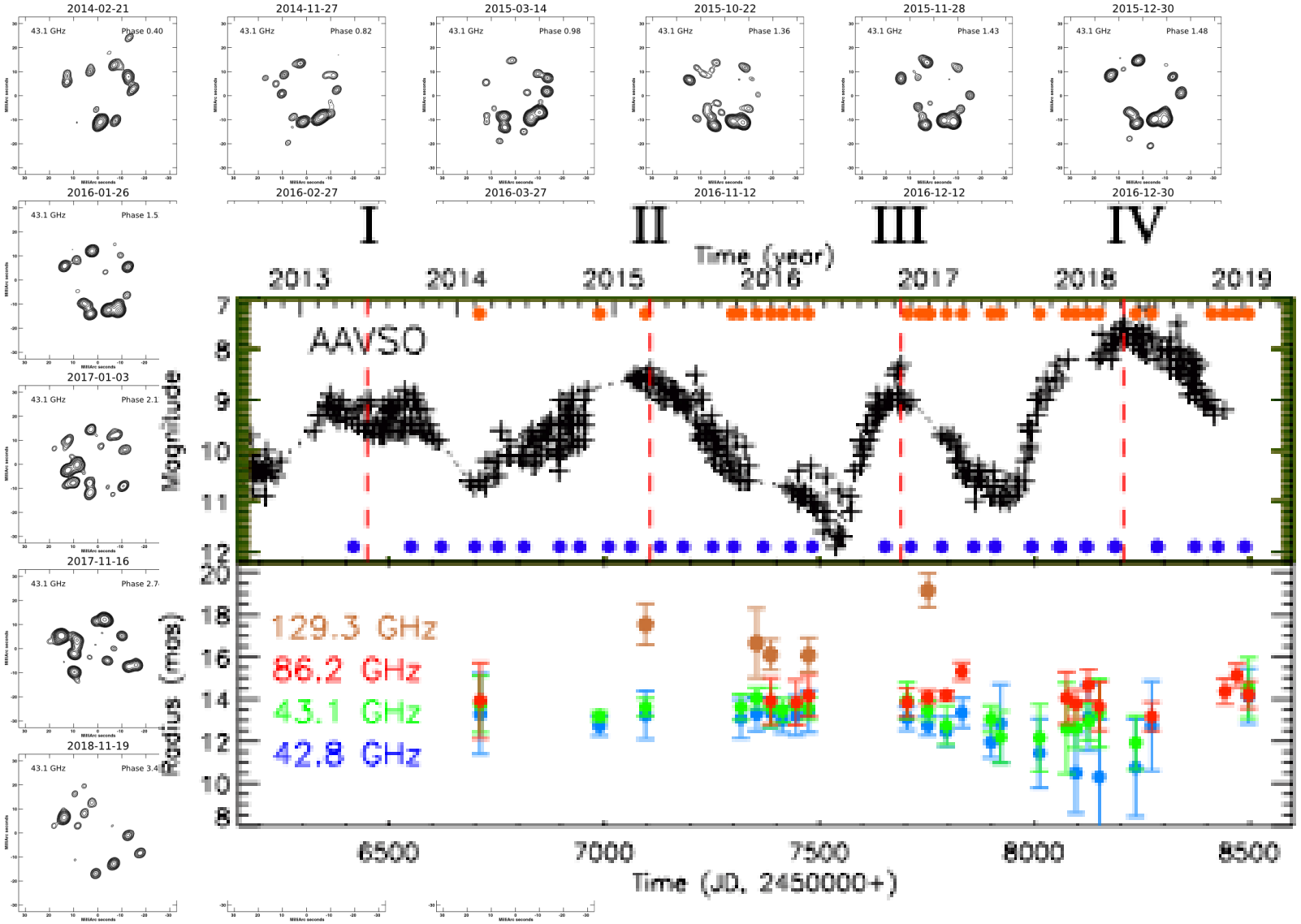
Result of VX Sgr reduced by Dong-Hwan Yoon



SiO v=1 J=1-0 (43 GHz) maser images

VLBI monitoring observations of KVN

Result of VX Sgr reduced by Dong-Hwan Yoon



Results of R Crt by Dong-Jin Kim

The Astrophysical Journal Letters, 866:L19 (6pp), 2018 October 20

https://doi.org/10.3847/2041-8213/aae58b

CrossMark

Simultaneous VLBI Astrometry of H_2O and SiO Masers toward the Semiregular Variable R Crateris

Dong-Jin Kim[1,2,3], Se-Hyung Cho[1,2], Youngjoo Yun[2], Yoon Kyung Choi[3], Dong-Hwan Yoon[2,4], Jaeheon Kim[5], Richard Dodson[6], María J. Rioja[6,7,8], Haneul Yang[2,4], and Suk-Jin Yoon[1]

[1] Department of Astronomy, Yonsei University, 50 Yonsei-ro Seodaemun-gu, Seoul, 03722, Republic Of Korea
[2] Korea Astronomy and Space Science Institute, 776 Daedeok–daero, Yuseong–gu, Daejeon 34055, Republic Of Korea; cho@kasi.re.kr
[3] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
[4] Astronomy program, Department of Physics and Astronomy, Seoul National University, 1 Gwanakro, Gwanakgu, Seoul 08826, Republic Of Korea
[5] Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030, People's Republic of China
[6] International Center for Radio Astronomy Research, M468, The University of Western Australia, 35 Stirling Hwy, Crawley, Western Australia, 6009, Australia
[7] Observatorio Astronómico Nacional (IGN), Alfonso XII, 3 y 5, E-28014 Madrid, Spain
[8] CSIRO Astronomy and Space Science, 26 Dick Perry Avenue, Kensington WA 6151, Australia
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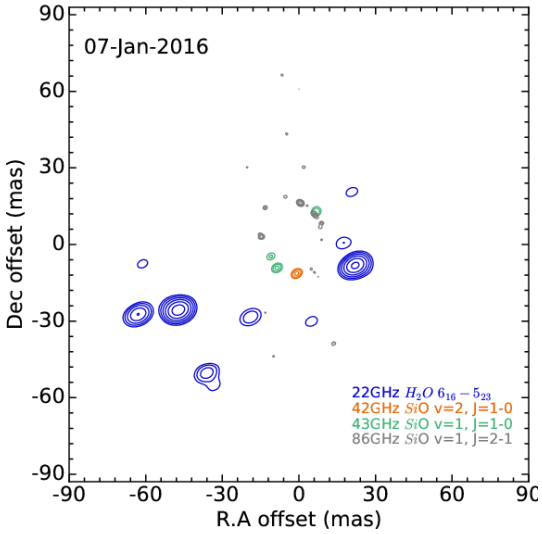
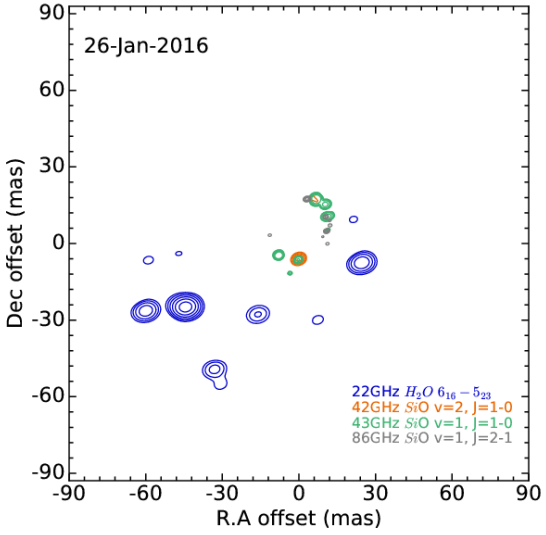
Abstract

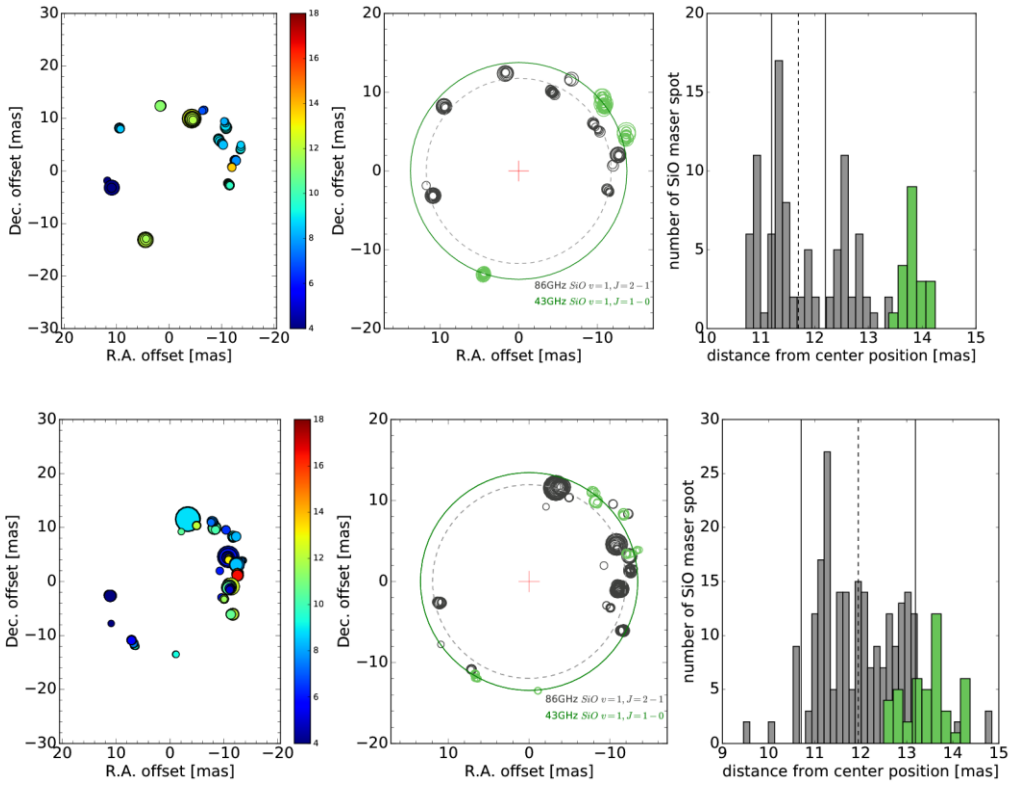
We obtained, for the first time, astrometrically registered maps of the 22.2 GHz H_2O and 42.8, 43.1, and 86.2 GHz SiO maser emission toward the semiregular b-type variable (SRb) R Crateris, at three epochs (2015 May 21, and 2016 January 7 and 26) using the Korean Very-long-baseline Interferometry Network. The SiO masers show a

VLBI monitoring observations of KVN

Result of R Crt reduced by Dong-Jin Kim







Relative spatial distribution of 7mm and 3 mm SiO masers

Average ring size
3 mm < 7 mm

Opposite case to the common ones

Results of V627 Cas by Haneul Yang

In preparation

Asymmetric distributions of 22 GHz H_2O and 43, 42 and 86 GHz SiO masers toward the symbiotic star V627 Cas

Haneul Yang,[1,2] Se-Hyung Cho,[2,3] Youngjoo Yun,[2] Dong-Hwan Yoon,[1,2] Dong-Jin Kim,[4] Hyosun Kim,[2] Sungchul Yoon,[1] Richard Dodson,[5] María J. Rioja,[5,6] and Hiroshi Imai[7]

[1] *Astronomy program, Department of Physics and Astronomy, Seoul National University, Gwanakgu, Seoul 08826, Korea*

[2] *Korea Astronomy and Space Science Institute, Yuseong–gu, Daejeon 34055, Korea*

[3] *Astronomy program, Department of Physics and Astronomy, Seoul National University, Gwanakgu, Seoul 08826, Korea; cho@kasi.re.kr*

[4] *Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany*

[5] *International Center for Radio Astronomy Research, M468, The University of Western Australia, 35 Stirling Hwy, Crawley, Western Australia, 6009, Australia*

[6] *Observatorio Astronmico Nacional (IGN), Alfonso XII, 3 y 5, 28014 Madrid, Spain*

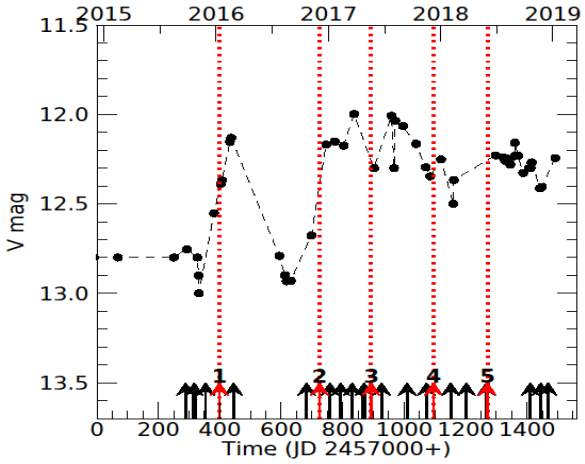
[7] *Institute for Comprehensive Education, Kagoshima University, Korimoto 1-21-30, Kagoshima 890-0065, Japan*

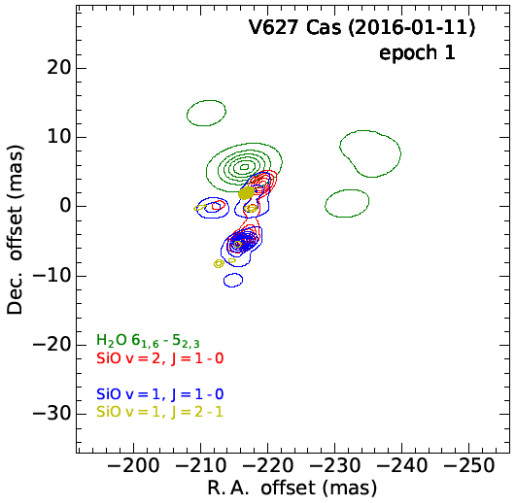
ABSTRACT

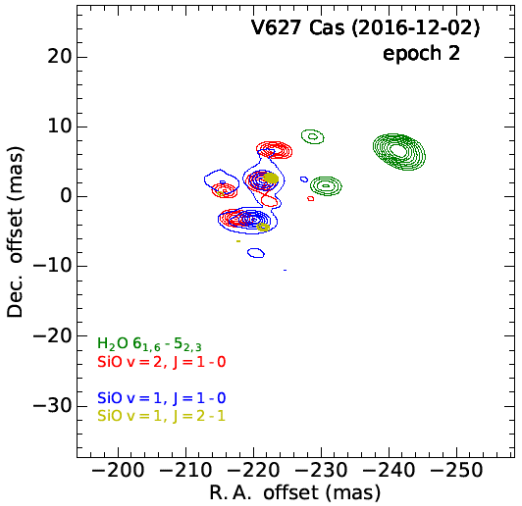
We have performed simultaneous observations of the 22 GHz H_2O and 43/42/86/129 GHz SiO masers toward the D-type symbiotic star V627 Cas using the Korean VLBI Network (KVN). Here, we present astrometrically registered maps of the 22 GHz H_2O and 43/42/86 GHz SiO masers from five epochs from Jan. 2016 to Jun. 2018. Distributions of the SiO maser spots did not show the usual ring-like

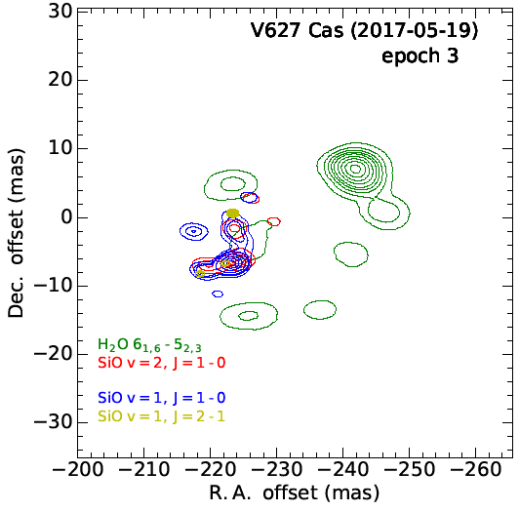
VLBI monitoring observations of KVN

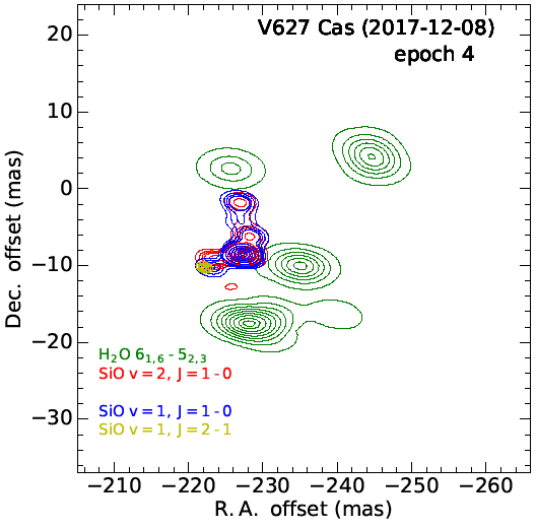
Result of V627 Cas reduced by Haneul Yang

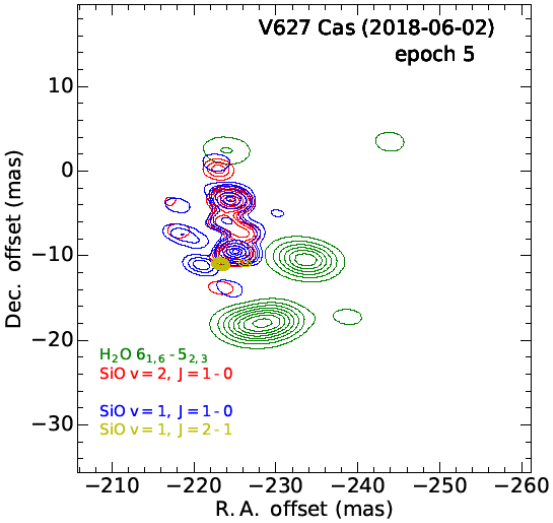








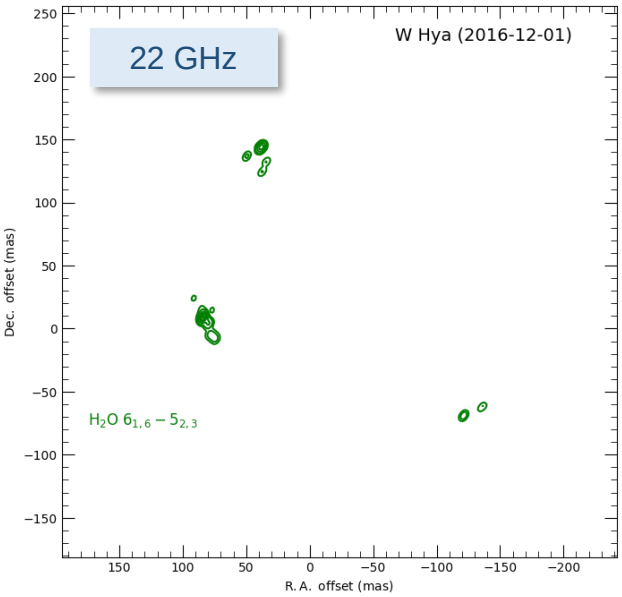


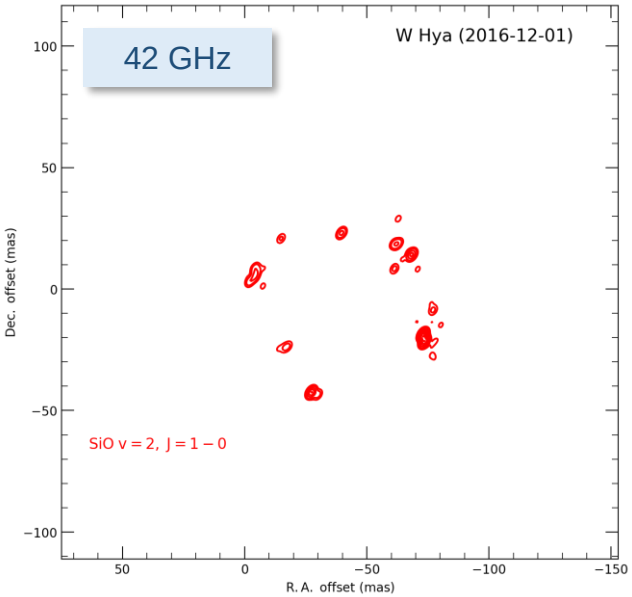


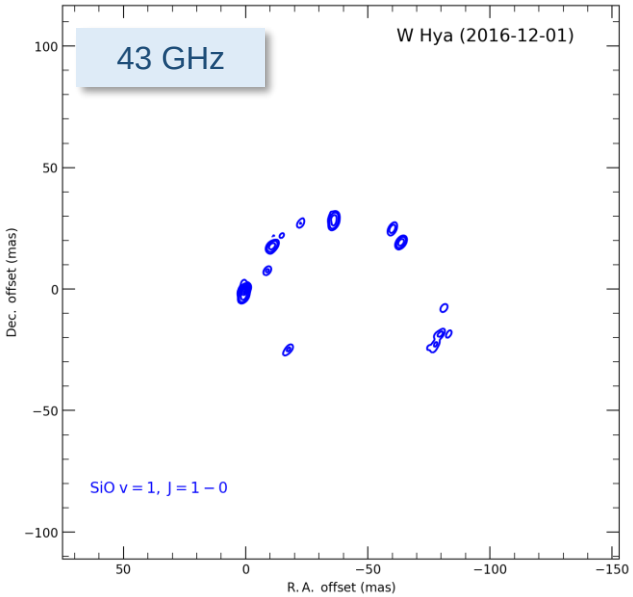
Need to know how the spatial distribution of H2O and SiO masers are associated with the orbital motion of hot companion.

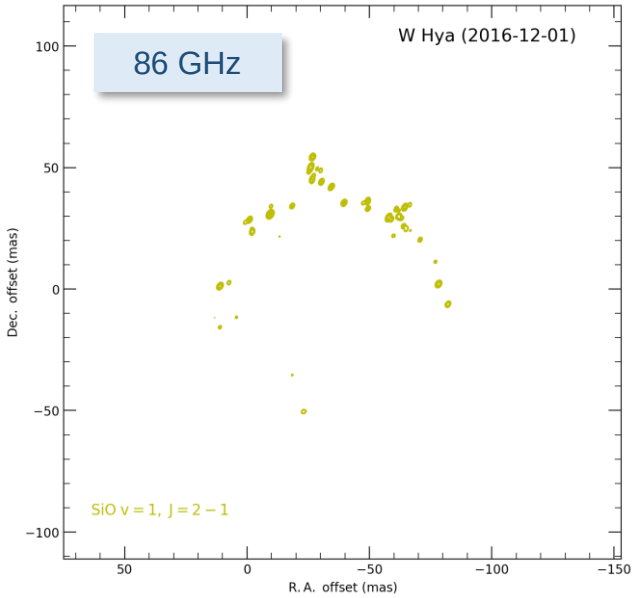
Spatial distributions and structures of masers

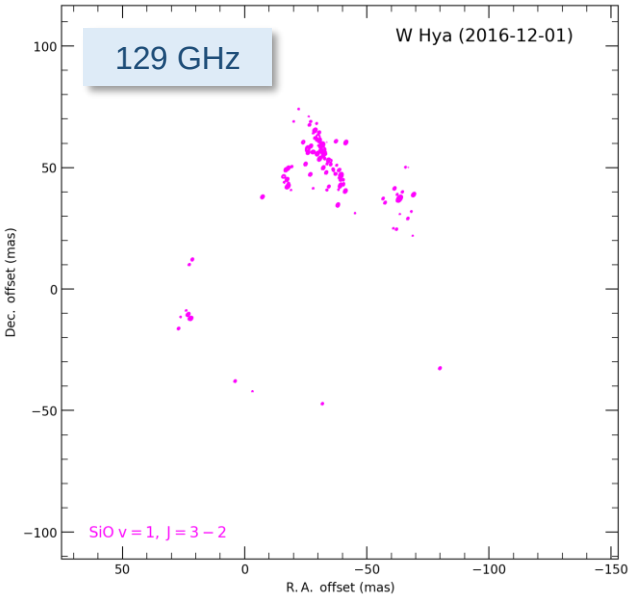
W Hya





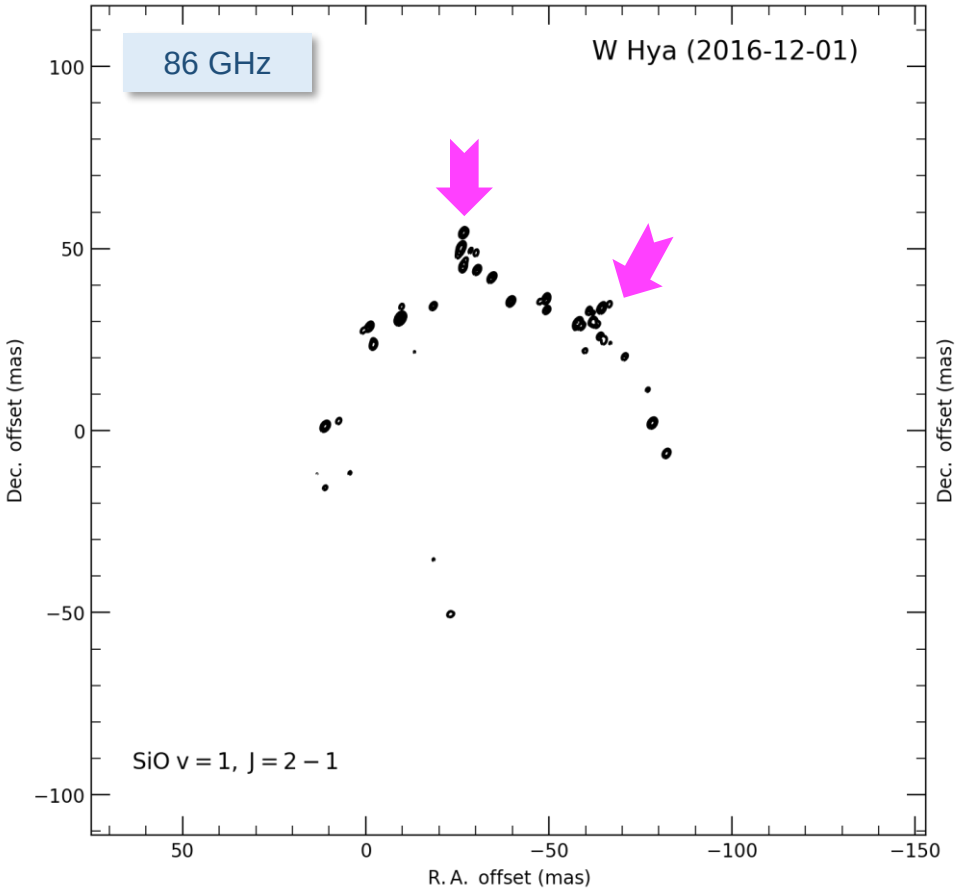


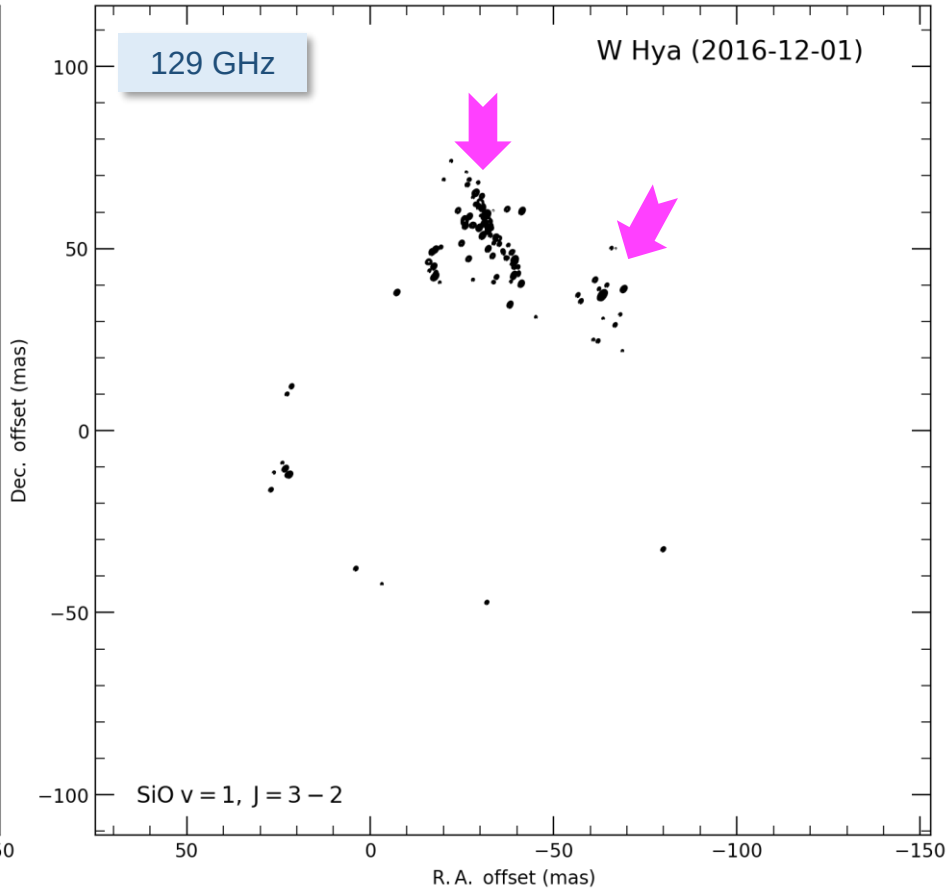




Spatial distributions and structures of masers

W Hya



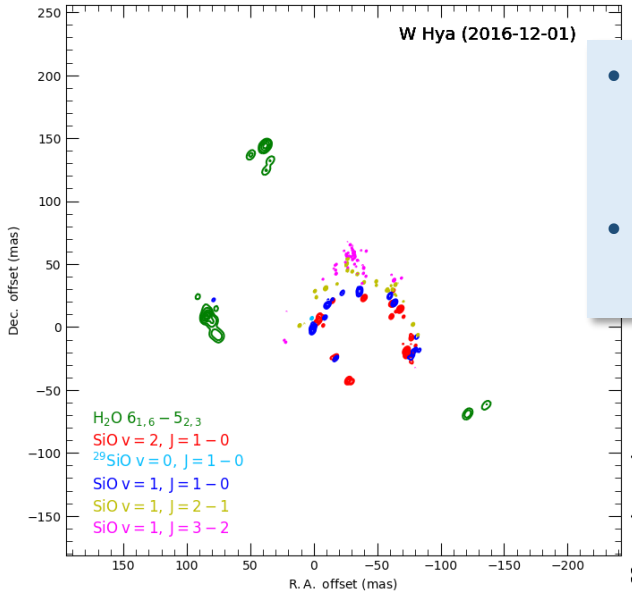


Clear arc structure with bumps in northern part of 3 mm SiO maser

Largely bumped features in northern part of 2 mm SiO maser

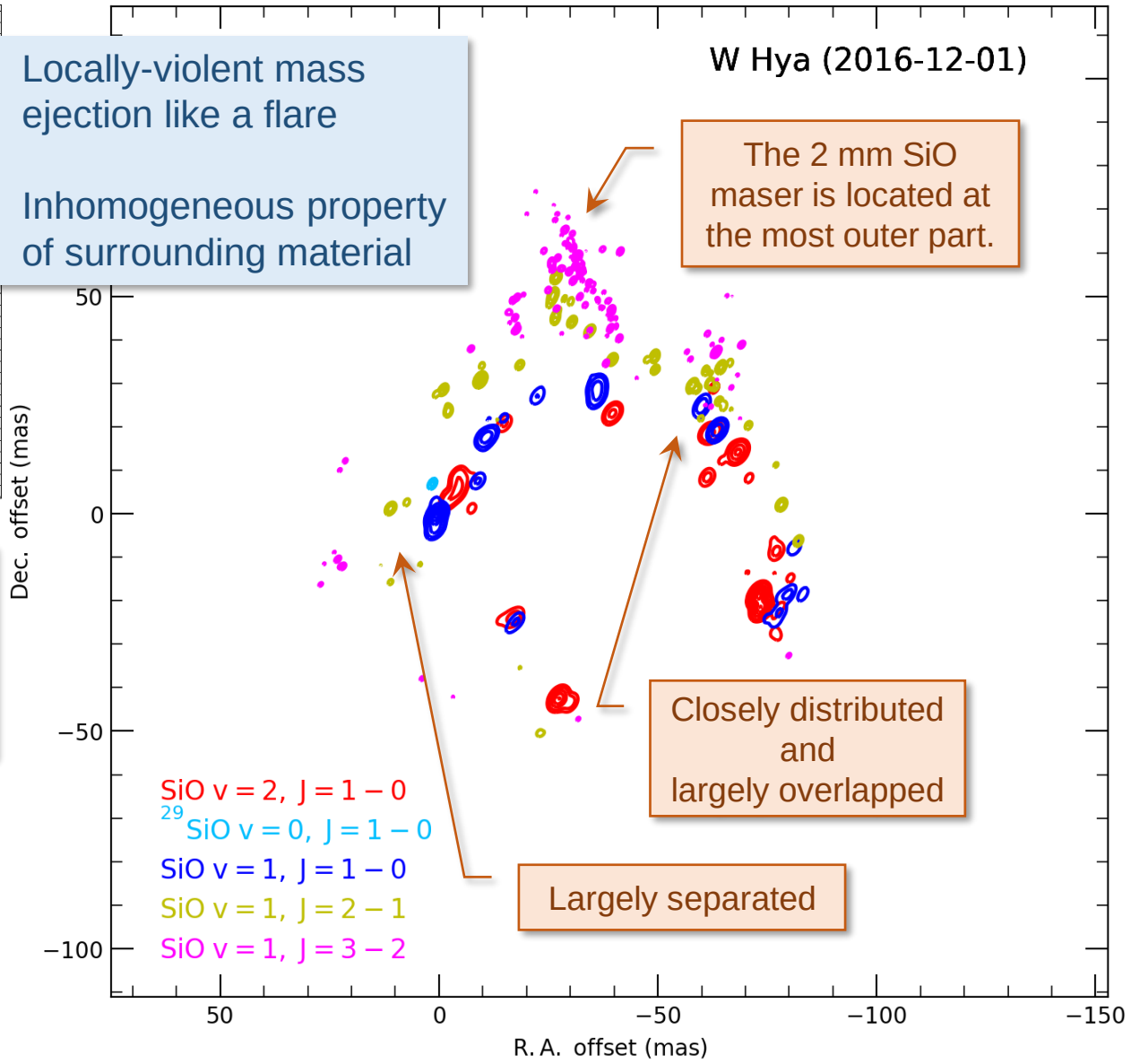
Spatial distributions and structures of masers

W Hya

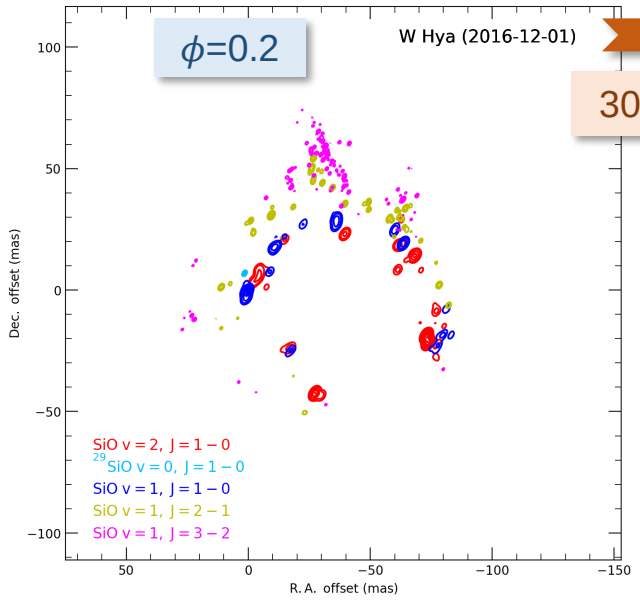


- Asymmetric spatial distribution of water maser
- SiO masers are located in the middle of water maser

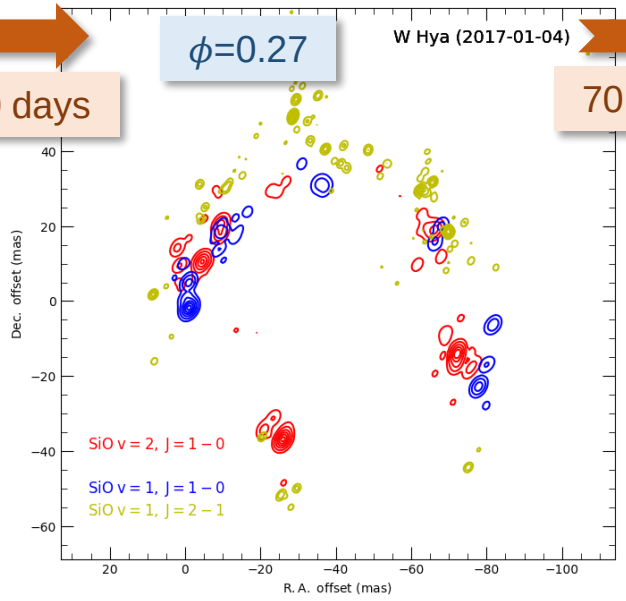
- Locally-violent mass ejection like a flare
- Inhomogeneous property of surrounding material



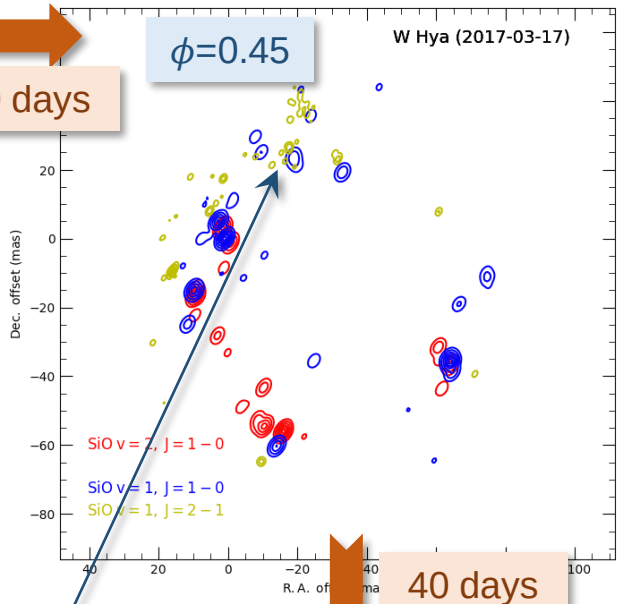
Spatial distributions and structures of masers
W Hya



30 days



70 days



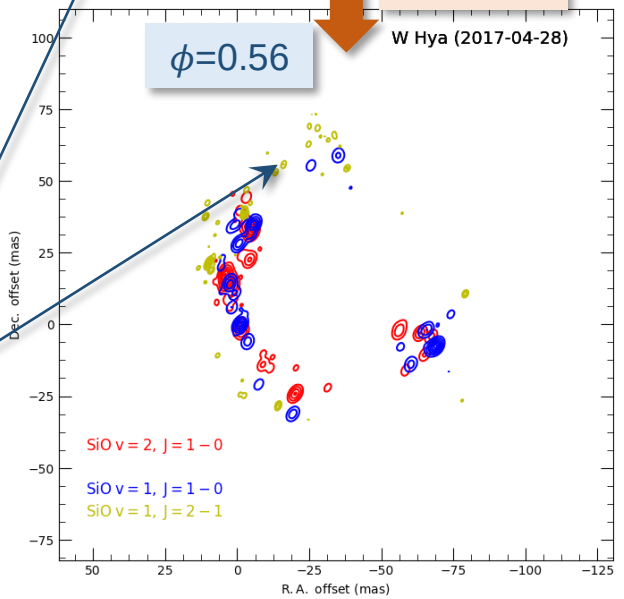
40 days

Observations of 2 mm SiO maser failed.

7 mm SiO maser follows and catches up the 3 mm SiO maser.

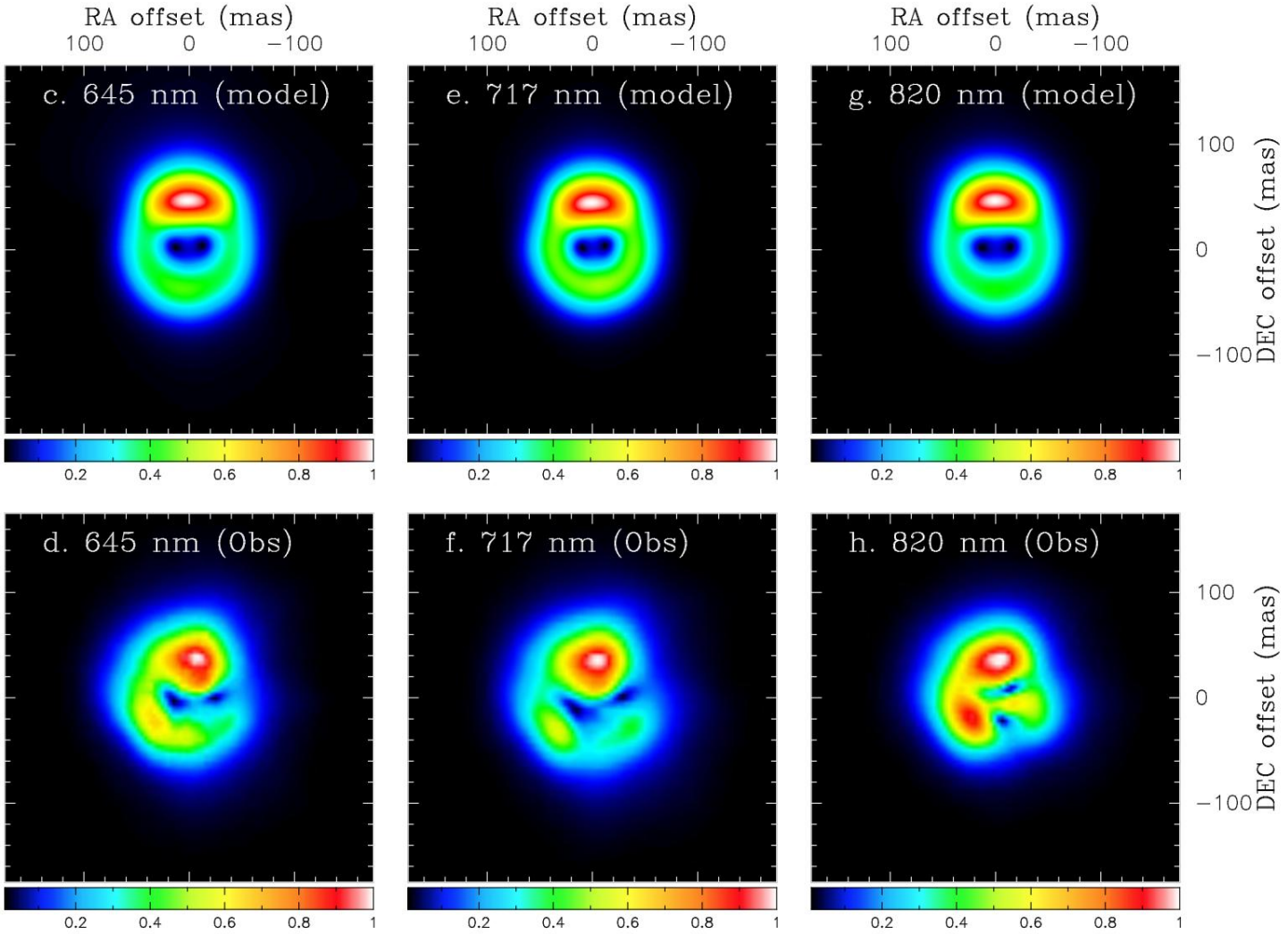
Weakened and disappearing bumped features of 3 mm SiO masers

Episodic mass-loss phenomena in local region of CSEs



Clumpy structure of dust
W Hya

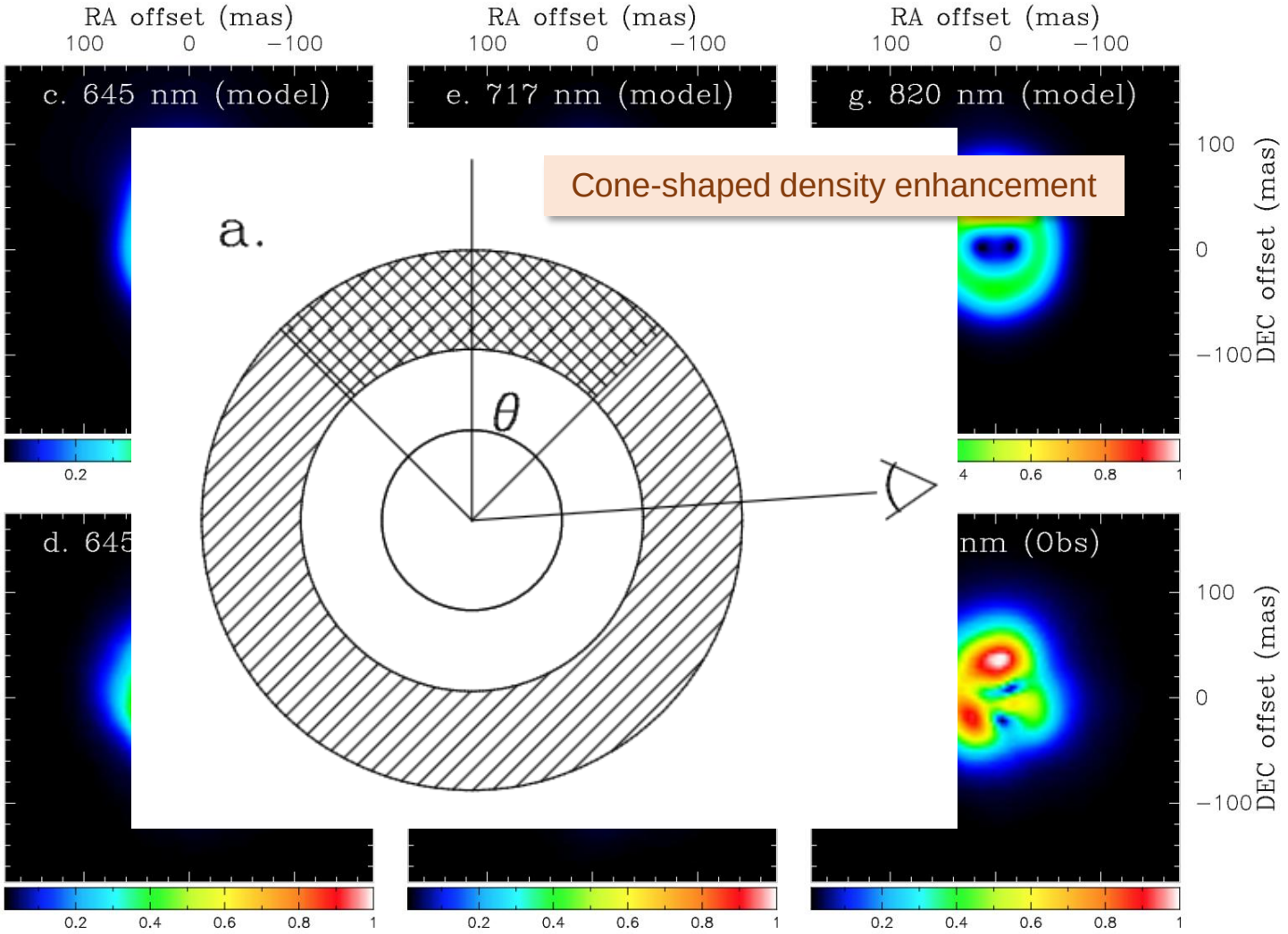
2015-7-8
ϕ=0.9



Visible polarimetric imaging of W Hya observed with VLT/SPHERE-ZIMPOL
Ohnaka et al. (2016)

Clumpy structure of dust
W Hya

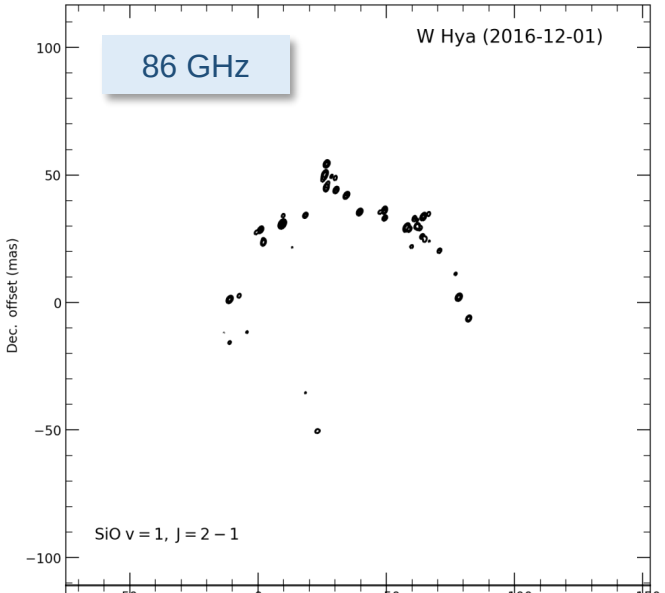
2015-7-8
ϕ=0.9

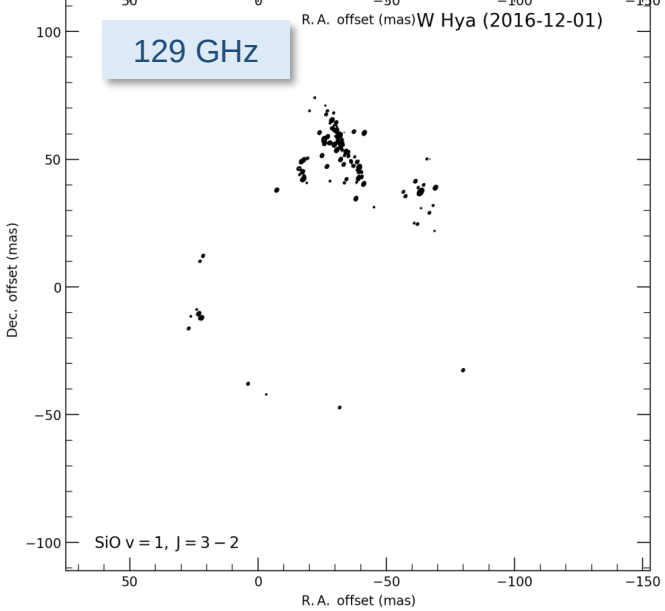


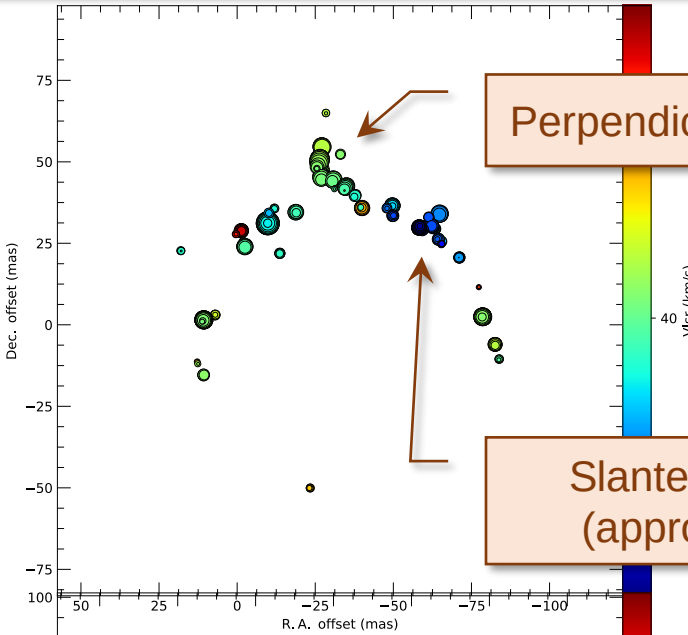
Visible polarimetric imaging of W Hya observed with VLT/SPHERE-ZIMPOL
Ohnaka et al. (2016)

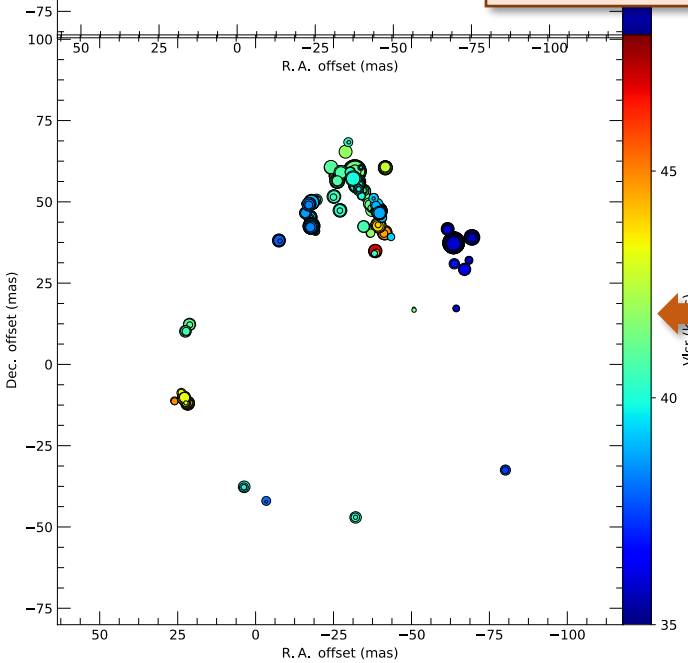
Spatial distributions and structures of masers

W Hya









Summary and future works

- **Successful operation of the 1st KSP providing important results for the study of late stage of stellar evolution**
  - Spatial distributions, clumpy structures, intensities of stellar masers observed at four frequency bands
  - Mass-loss phenomena indicated from the temporal variabilities of the maser properties
- **Planning the 2nd phase of KSP**
  - New target sources (GX Mon, R Aqr)
  - Intensive monitoring for the strong maser sources
  - Including polarization observation for a few sources
- **Further physical interpretation**
  - Combining other facilities (EAVN, ALMA, VLA, …)
  - Theoretical research by using numerical simulations