Results of KVN Key Science Program for evolved stars

Youngjoo Yun

collaborators
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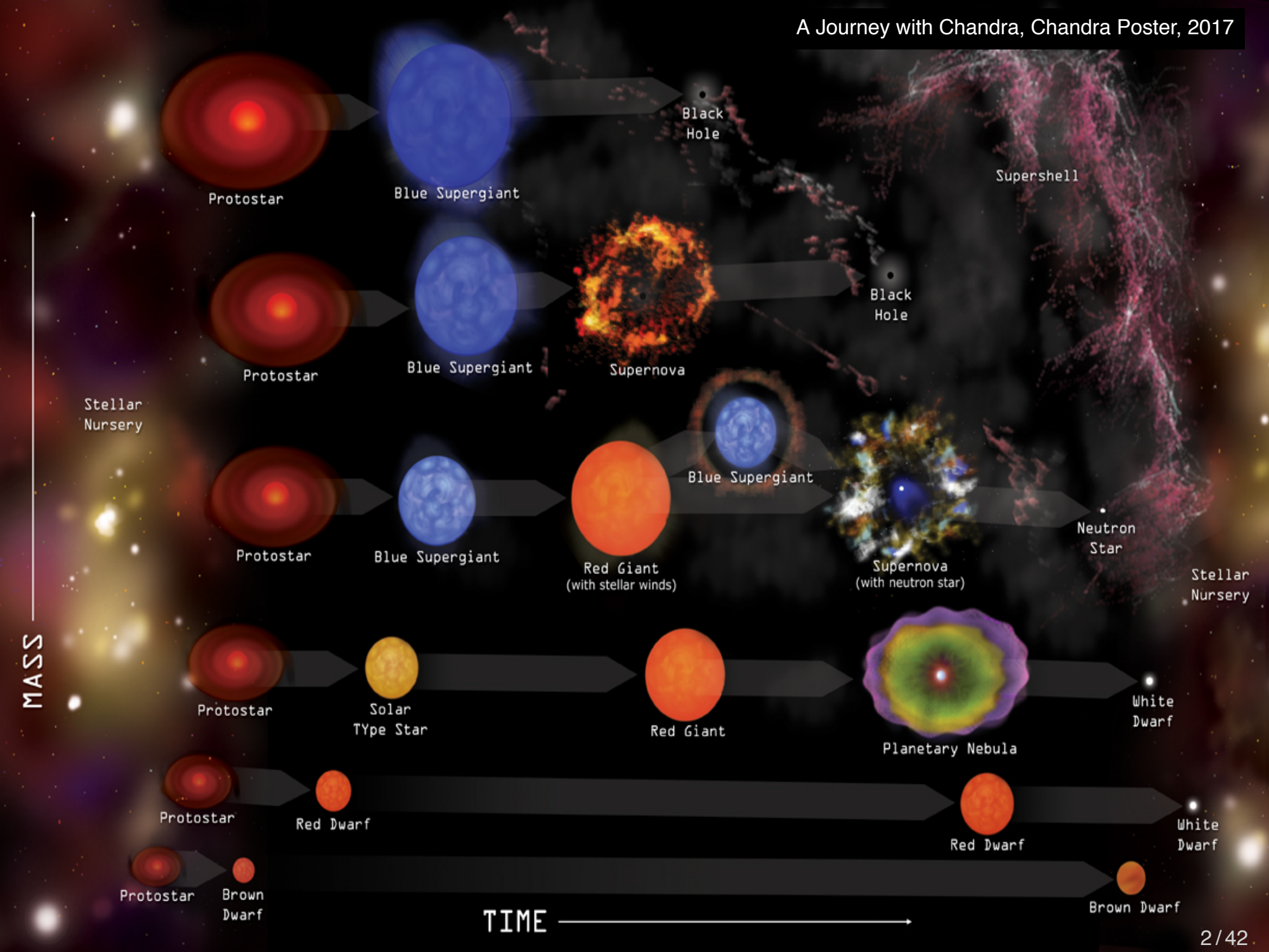
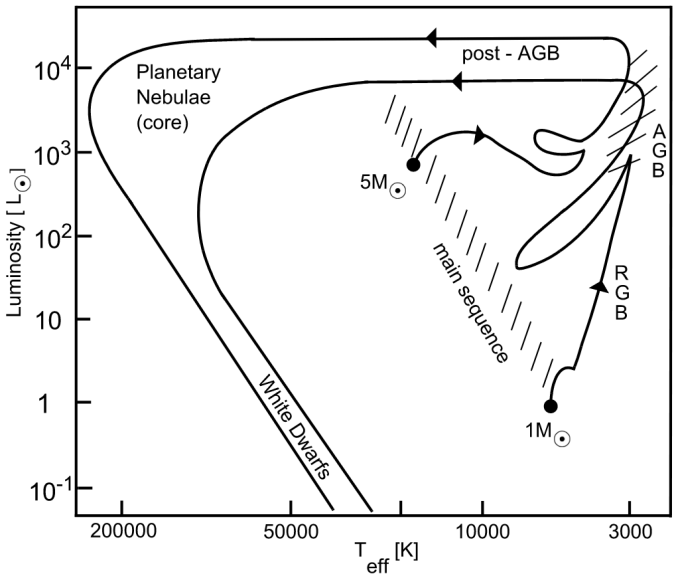
special thanks to
María J. Rioja & Richard Dodson

also thanks to
KVN correlator center & AOC members

East-Asian VLBI Workshop 2021
March 4, 2021


A Journey with Chandra, Chandra Poster, 2017
Protostar
Blue Supergiant
Black Hole
Supershell
Protostar
Blue Supergiant
Supernova
Black Hole
Stellar Nursery
Protostar
Blue Supergiant
Red Giant (with stellar winds)
Blue Supergiant
Supernova (with neutron star)
Neutron Star
Stellar Nursery
MASS
Protostar
Solar TYpe Star
Red Giant
Planetary Nebula
White Dwarf
Protostar
Red Dwarf
Red Dwarf
White Dwarf
Protostar
Brown Dwarf
Brown Dwarf
TIME

Evolution of AGB stars



AGB phase

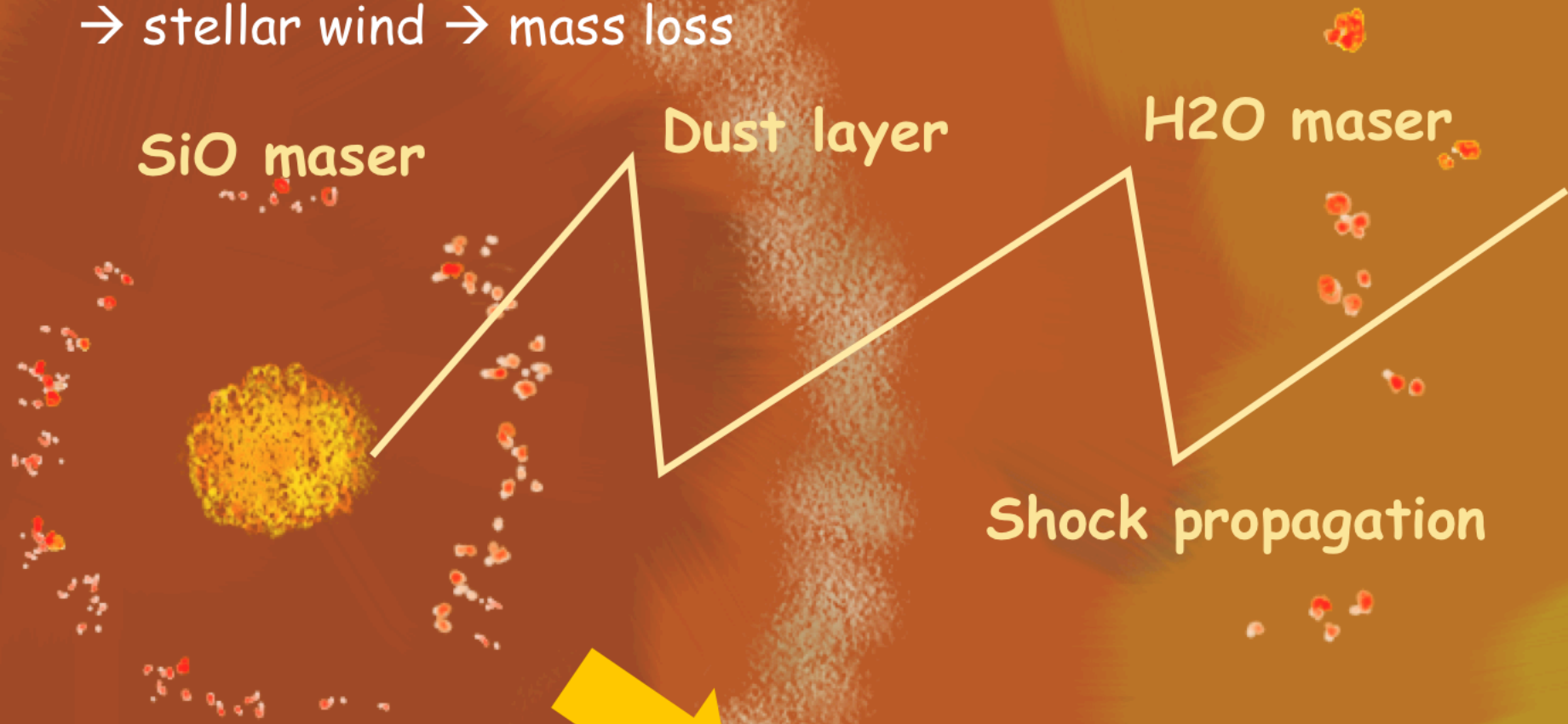
- Central degenerate core (C+O)
- He and H-shells (nuclear-burning)
- Large H-rich stellar envelope
- Cool ($T_{eff} < 3000$ K)
- High luminous ($\sim 10^4\ L_\odot$)
- Dusty, spherical expanding envelopes at low speeds (5 - 20 km/s)
- High mass-loss rate (10^{-8} - $10^{-5}\ M_\odot/yr$)

Post-AGB and Planetary Nabula (PN) phase

- Mass-loss rate decreases
- Stars become hot $\rightarrow$ ionize CSE material
- Stellar envelope shrinks $\rightarrow$ T_{eff} increases up to 30000 K $\rightarrow$ ionize detached circumstellar nebula
- End of stellar evolution for stars with mass of 0.8 - 8 $M_\odot$

Physical characteristics of AGB stars

- Low- and intermediate-mass stars (1- 8 $M_\odot$)
- Stellar pulsation → stellar radiation + dust + gas → stellar wind → mass loss

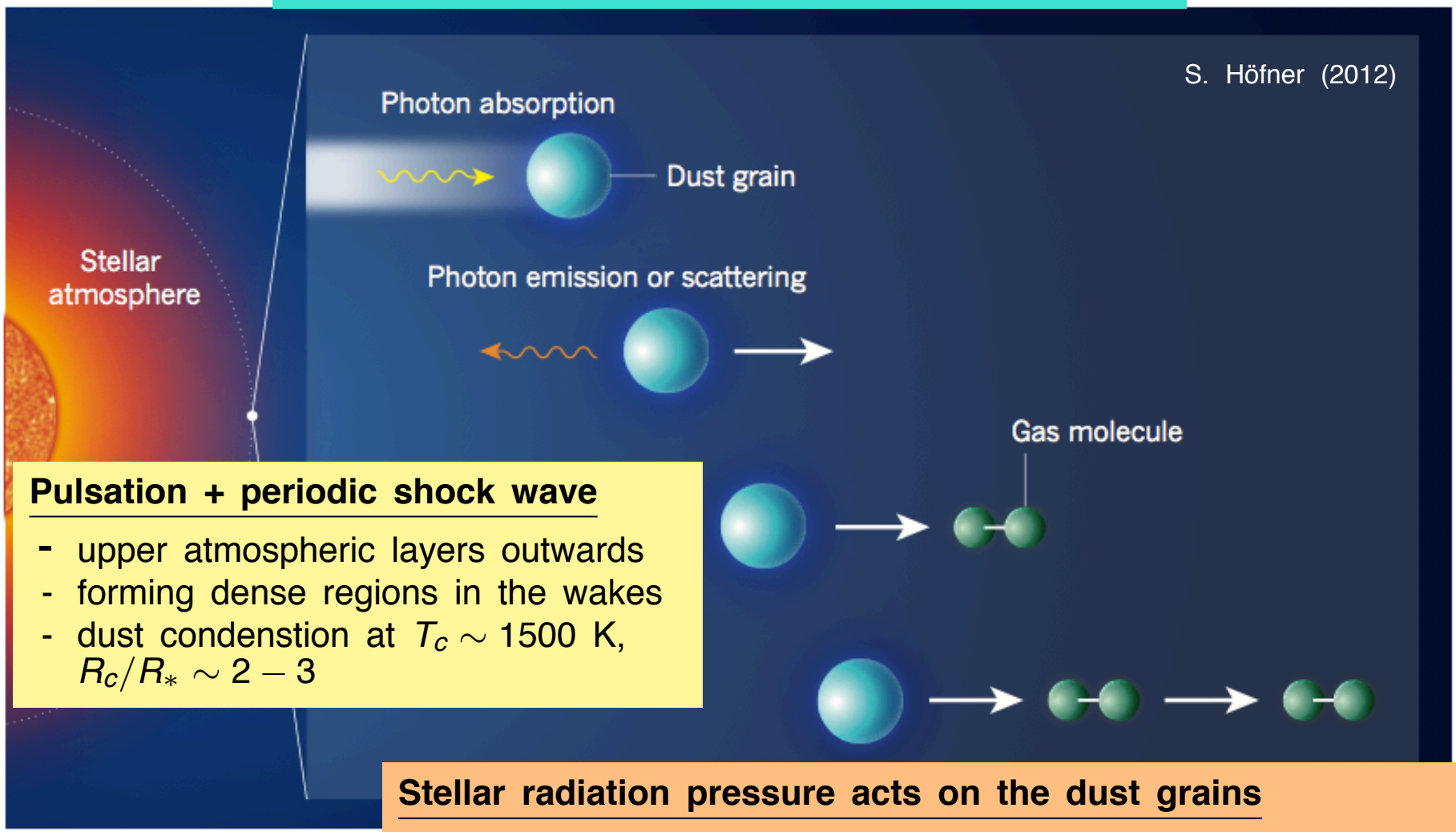


C/O < 1: O-rich (M-type)
C/O > 1: C-rich (C-type)
C/O ~ 1: S-type

Mass-loss rate
10^{-8} - 10^{-5} $M_\odot$ yr^{-1}

Driving mechanism of Mass loss of AGB stars

Pulsation-enhanced dust-driven stellar wind

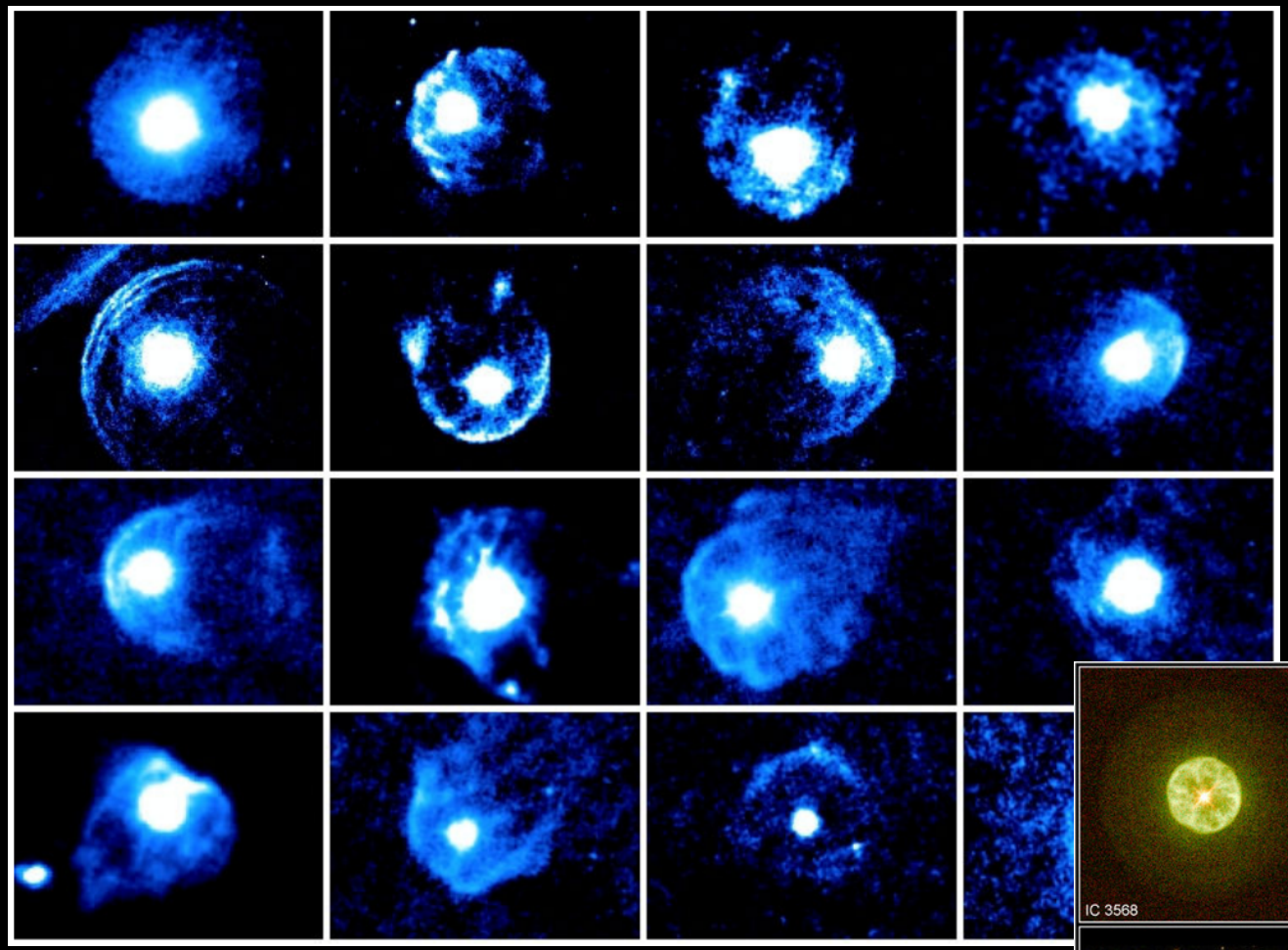


Pulsation + periodic shock wave

- upper atmospheric layers outwards
- forming dense regions in the wakes
- dust condenstion at $T_c \sim 1500$ K, $R_c/R_* \sim 2-3$

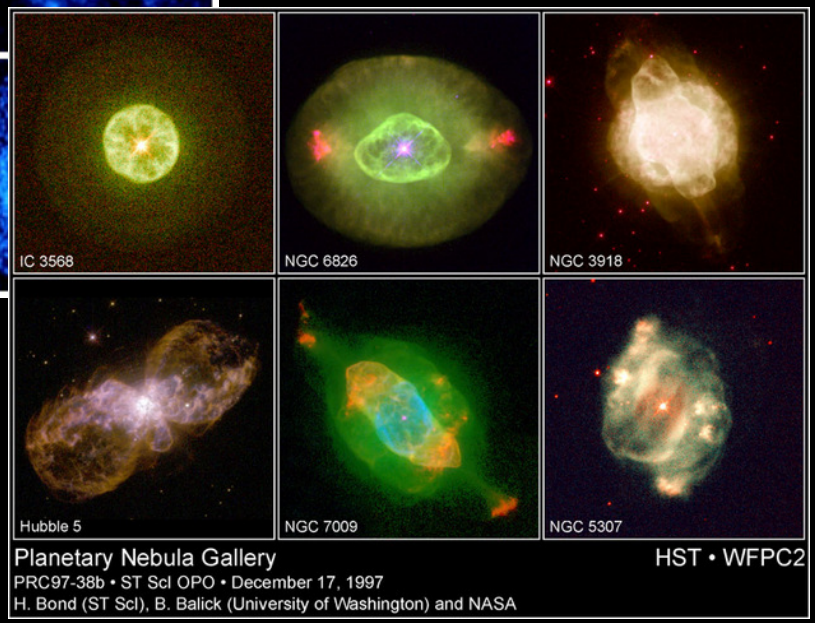
Stellar radiation pressure acts on the dust grains

- dust grains acquire momentum from stellar photon
- transfer momentum to the surrounding gas via collisions
- momentum transfer by collisions between gas molecules
- resulting in a net outwards momentum, driving stellar wind



HERSCHEL/PACS images of the ISM/CSM interaction seen around many mass-losing AGB and red supergiant stars (N. Cox 2012)

Planetary nebulae
(HST - WFPC2, NASA)



Properties of circumstellar envelopes

- Dynamical + chemical properties
- Stellar fusion reaction, convection, thermal pulse $\rightarrow$ molecular abundance
- Pulsation and shock propagation $\rightarrow$ outward motion $\rightarrow$ dust nucleation

Mass-loss mechanism and history

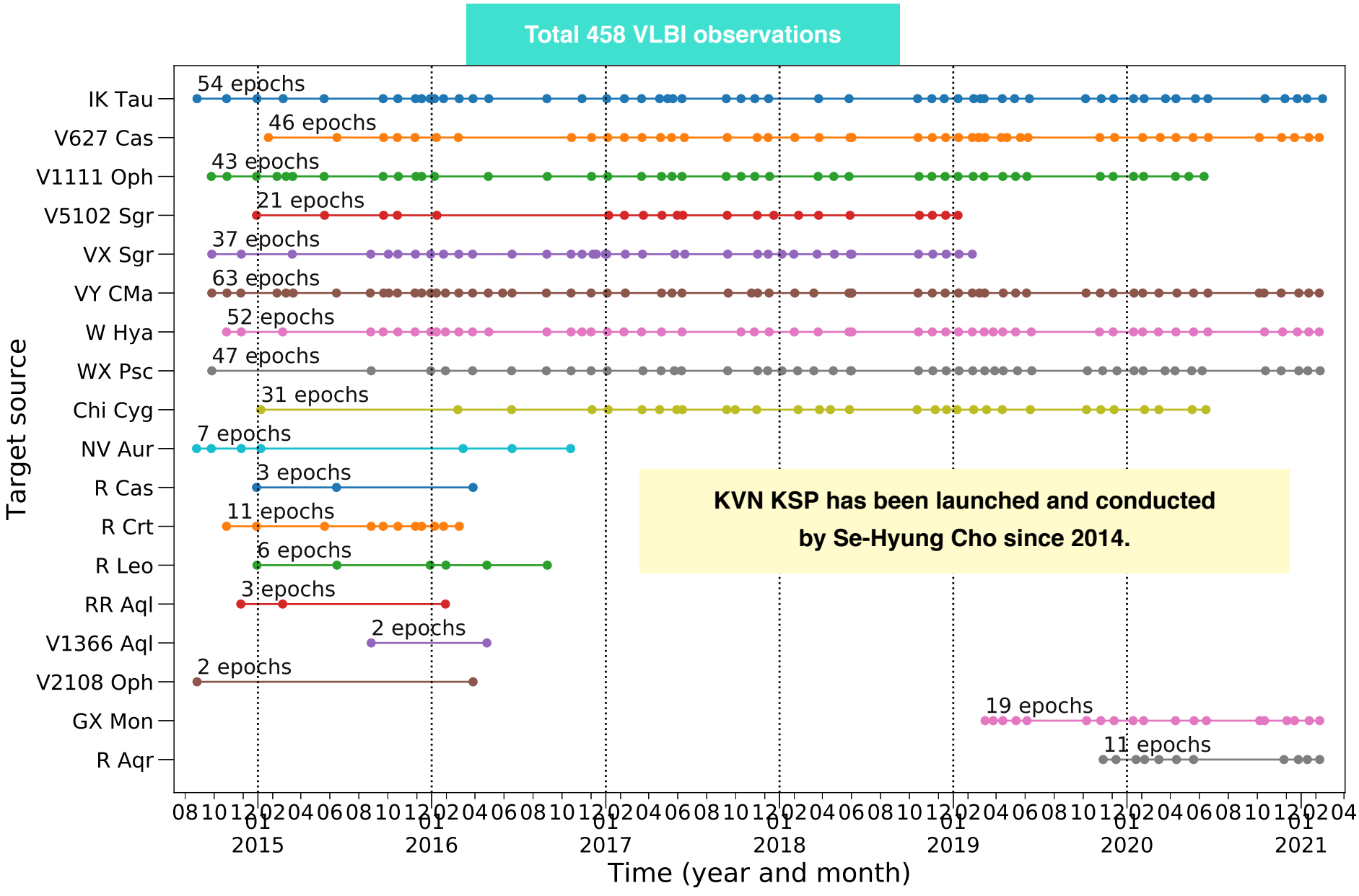
- Pulsation-enhanced dust-driven stellar wind
- Mass-loss rate and stellar evolution
- Morphological changes of CSEs: spherical, bipolar, irregular

Stellar masers show us their

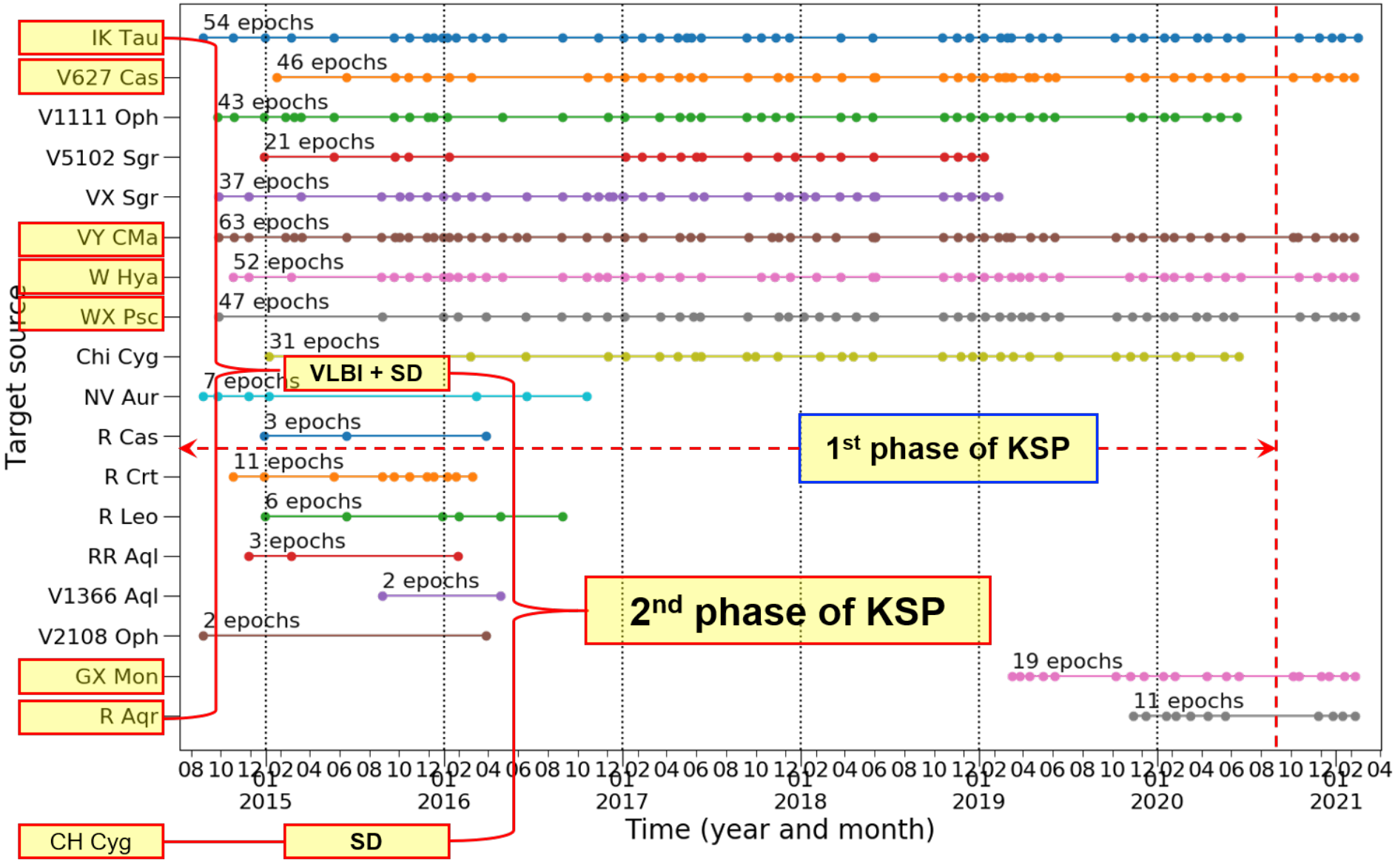
- Spatial distribution: clumpy structure, bipolar feature
- Temporal viaribility: kinematic information
- Polarization

Monitoring VLBI observation is the best way to follow the maser story along the stellar evolution.

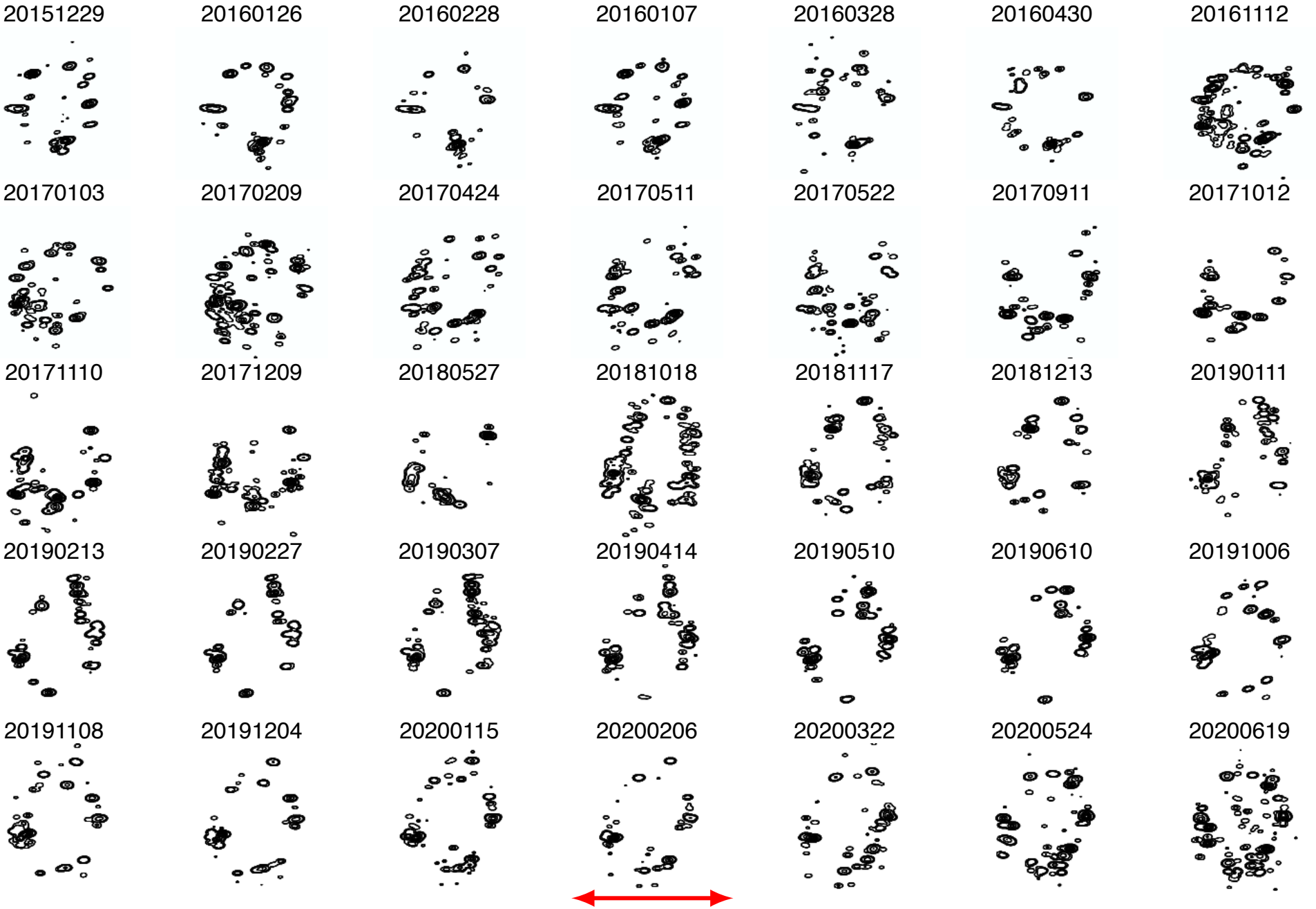
KVN KSP observations



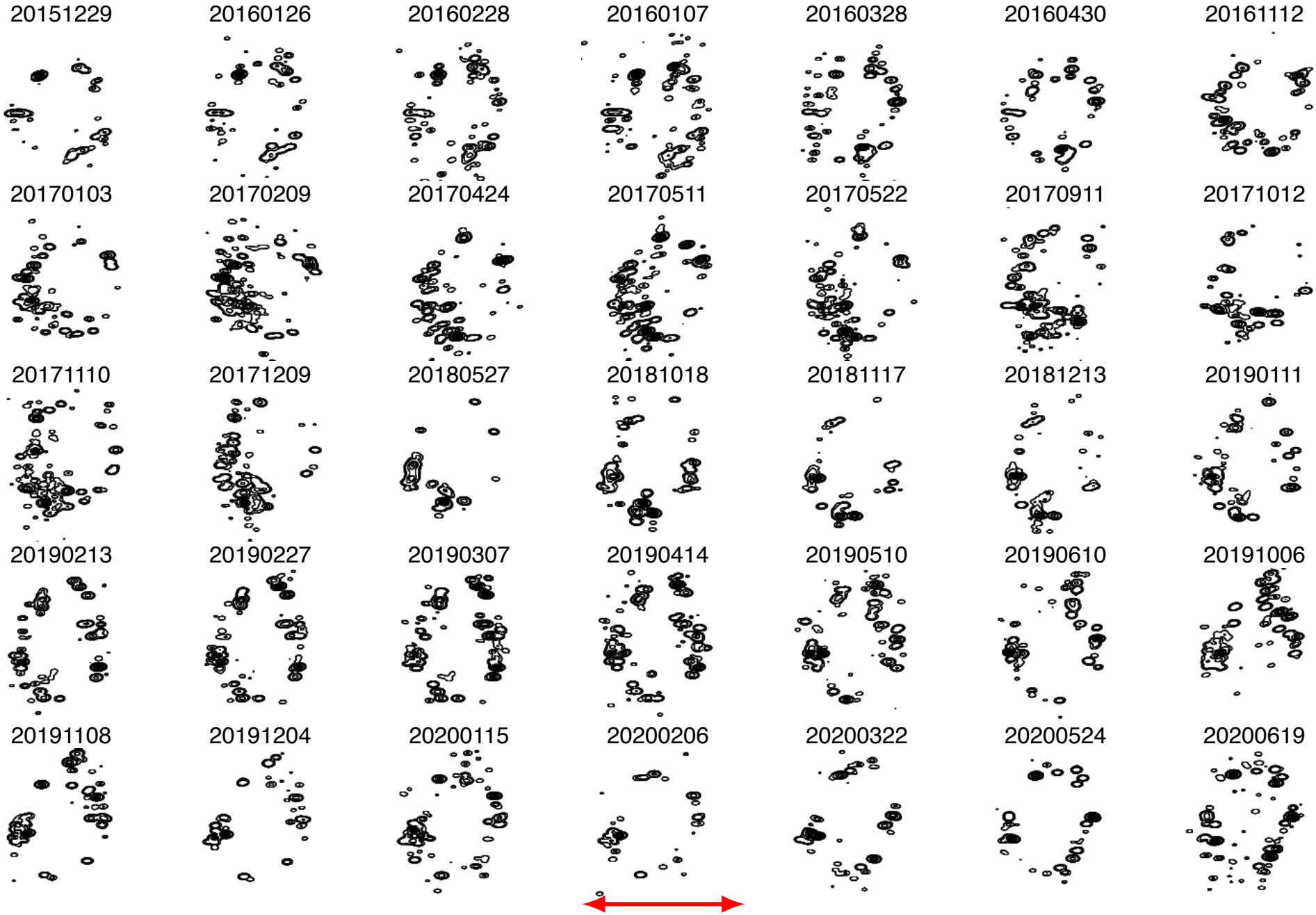
KVN KSP observations



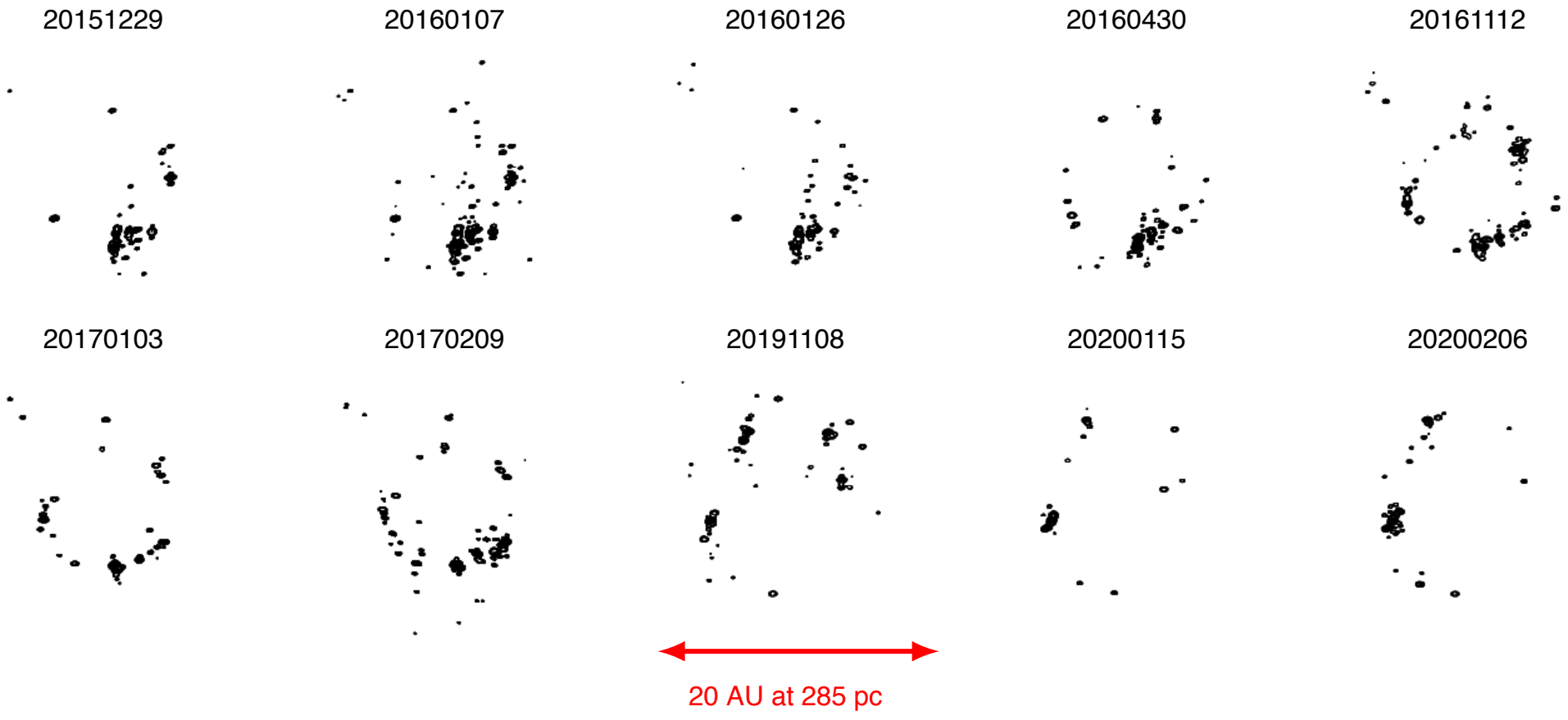
IK Tau: SiO v=2 J=1-0 maser at 42 GHz



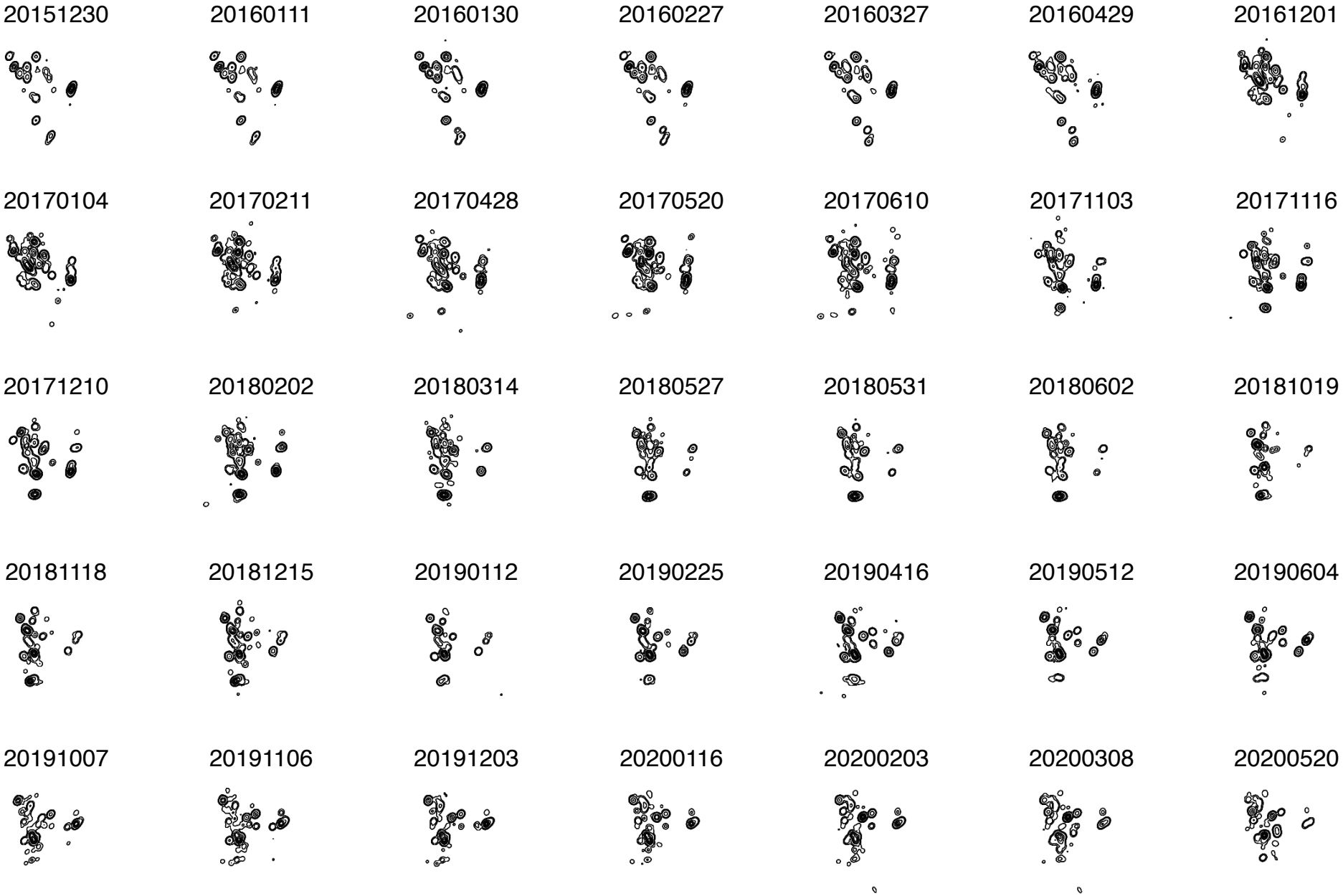
IK Tau: SiO v=1 J=1-0 maser at 43 GHz



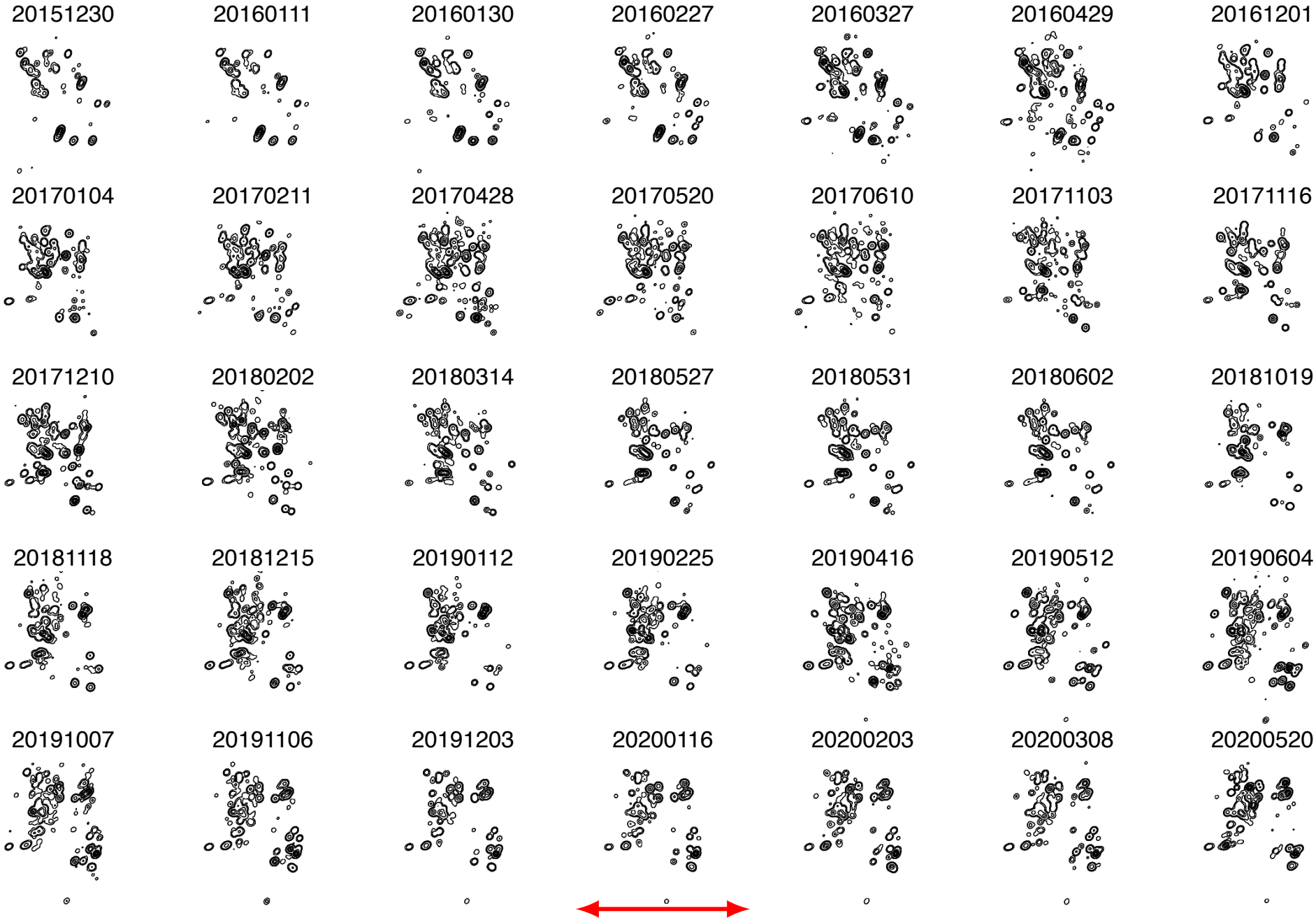
IK Tau: SiO v=1 J=2-1 maser at 86 GHz



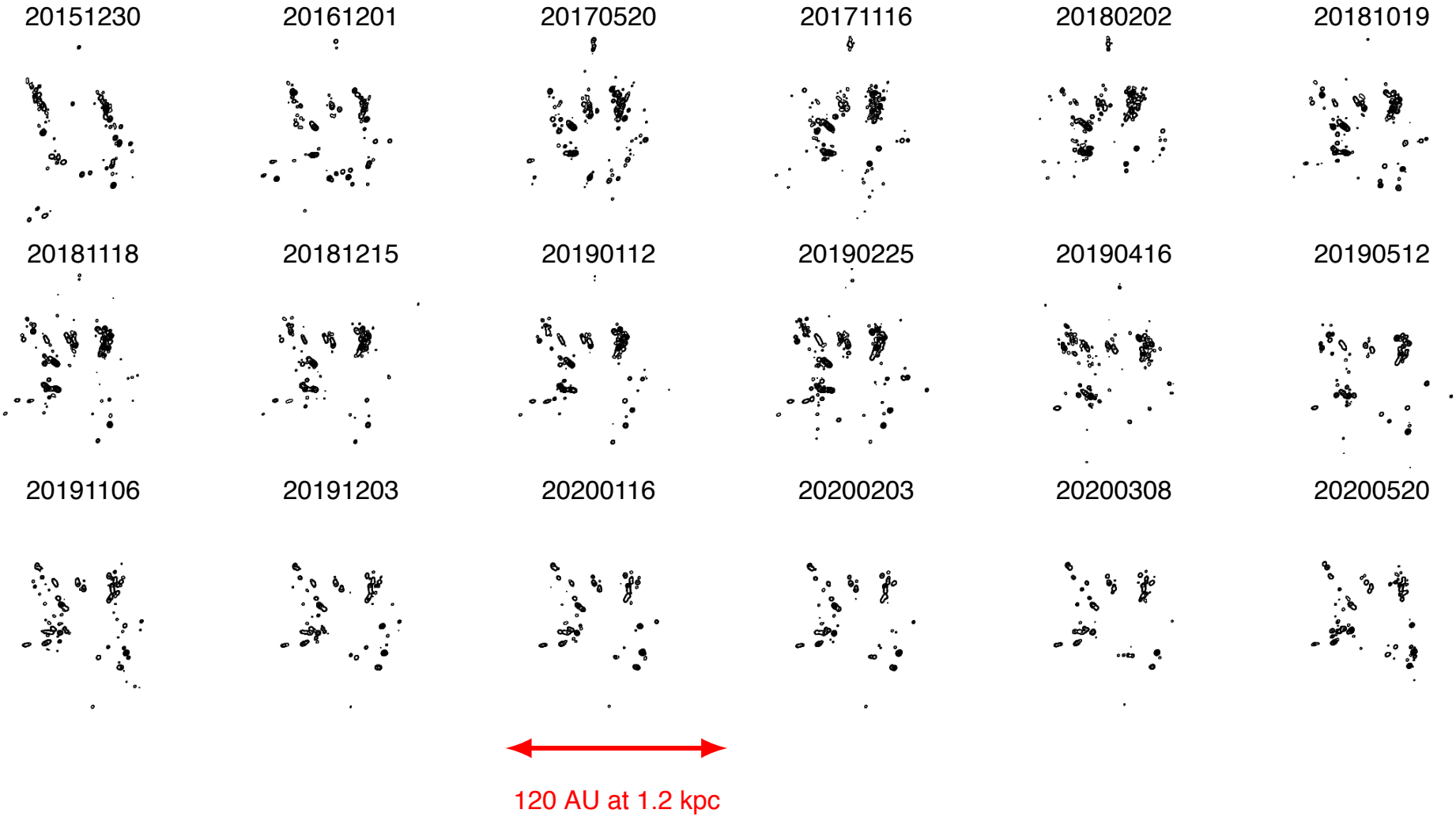
VY CMa: SiO v=2 J=1-0 maser at 42 GHz



VY CMa: SiO v=1 J=1-0 maser at 43 GHz



VY CMa: SiO v=1 J=2-1 maser at 86 GHz



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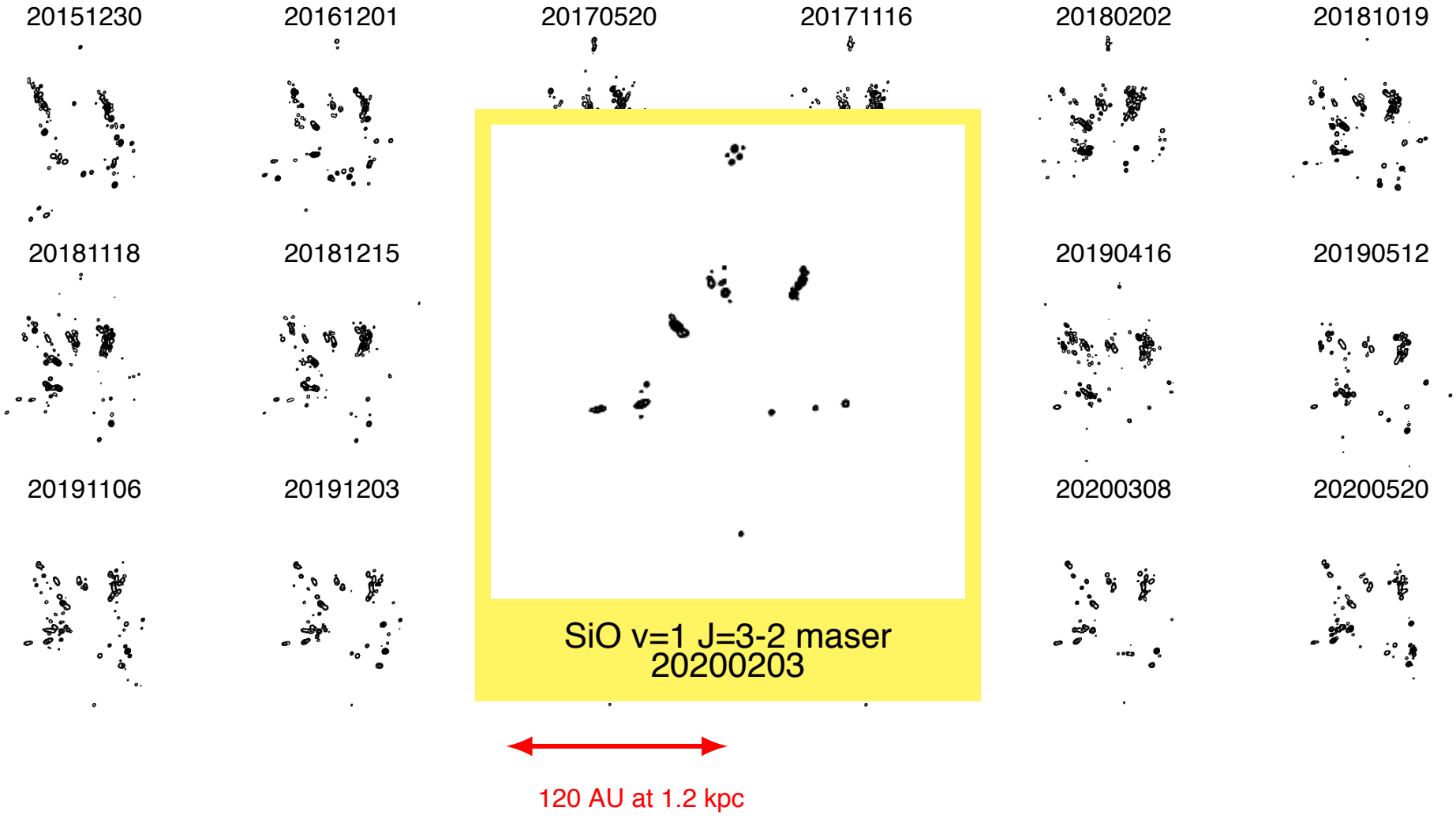
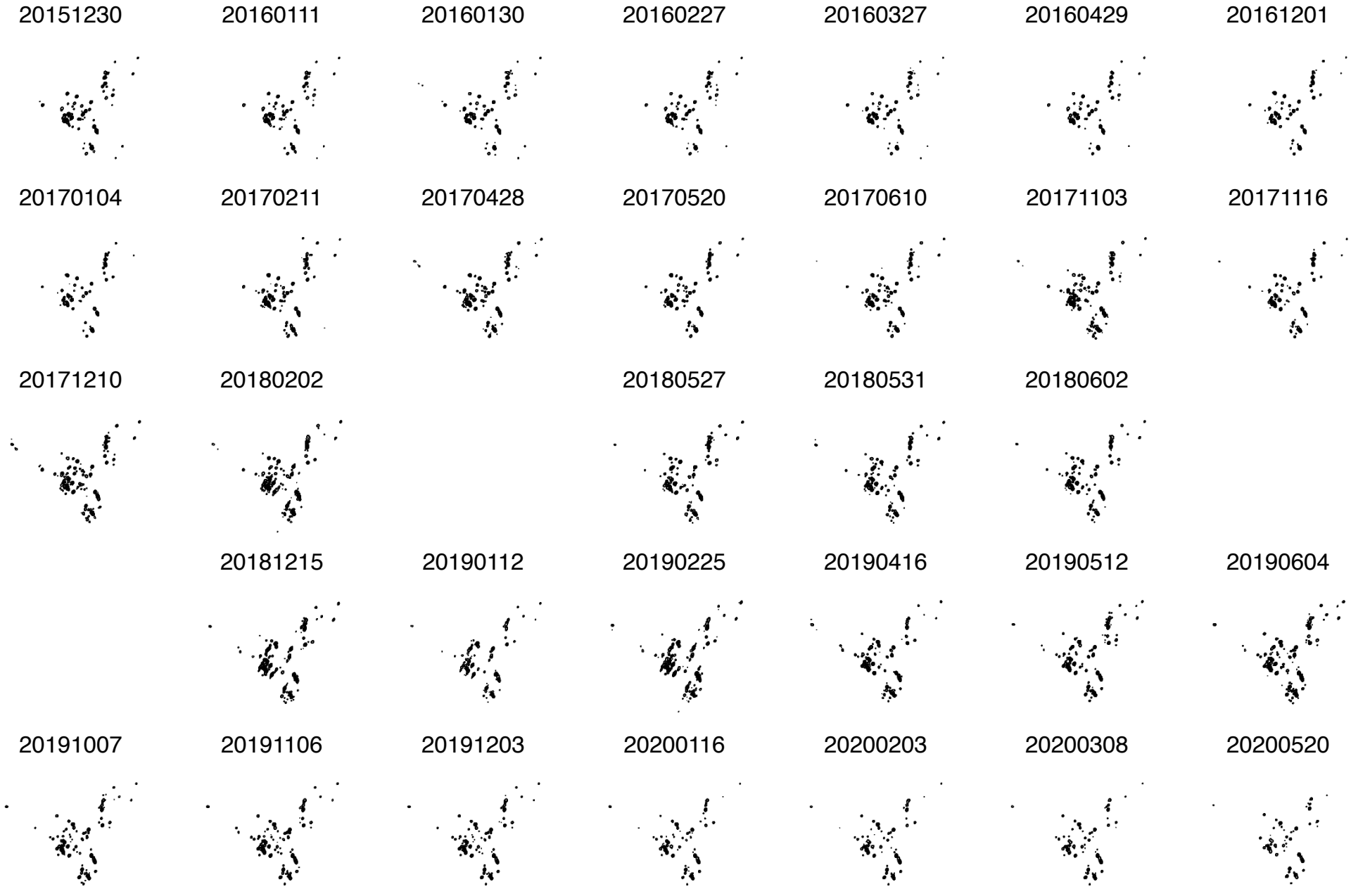
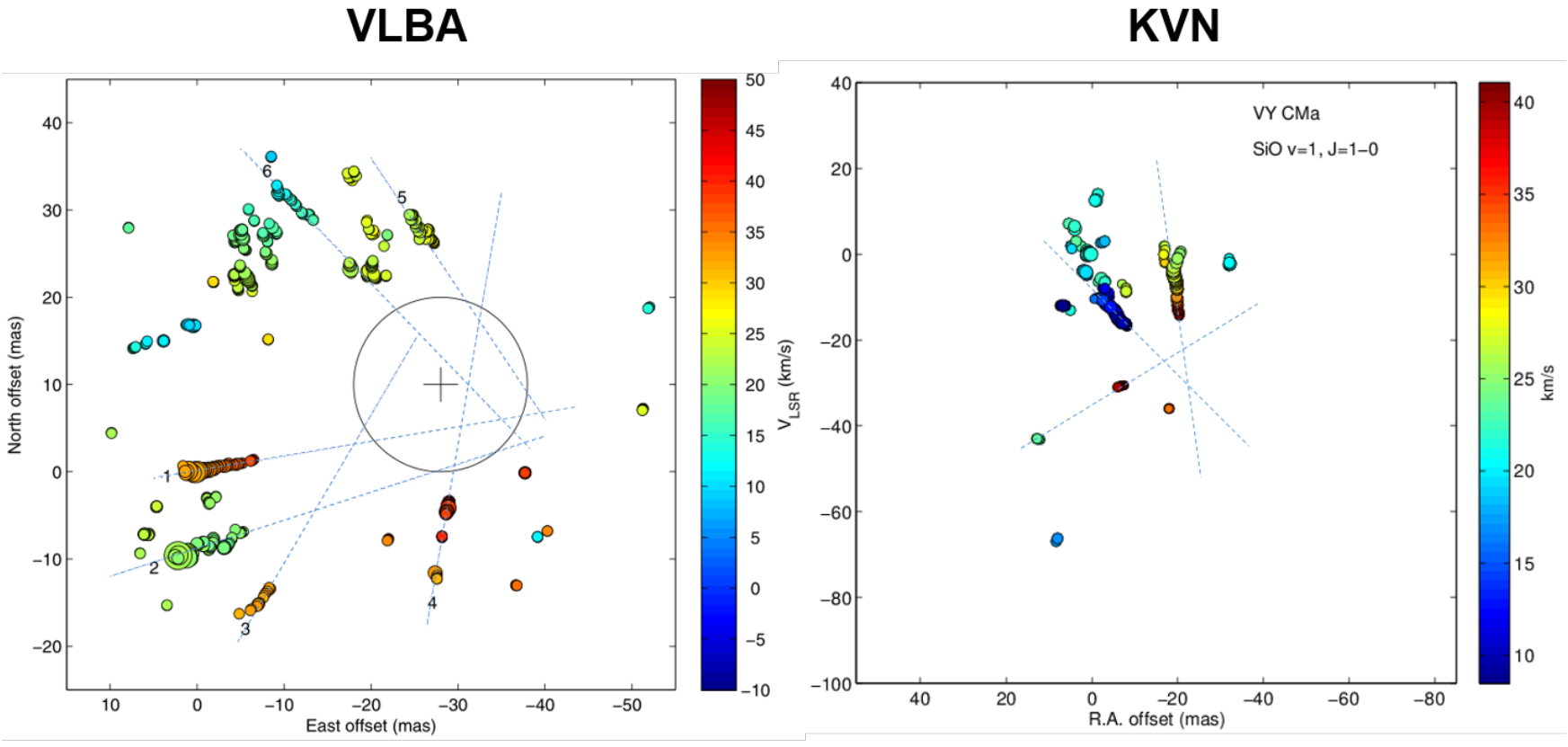


VY CMa: H_2O 6(1,6)-5(2,3)maser at 22 GHz



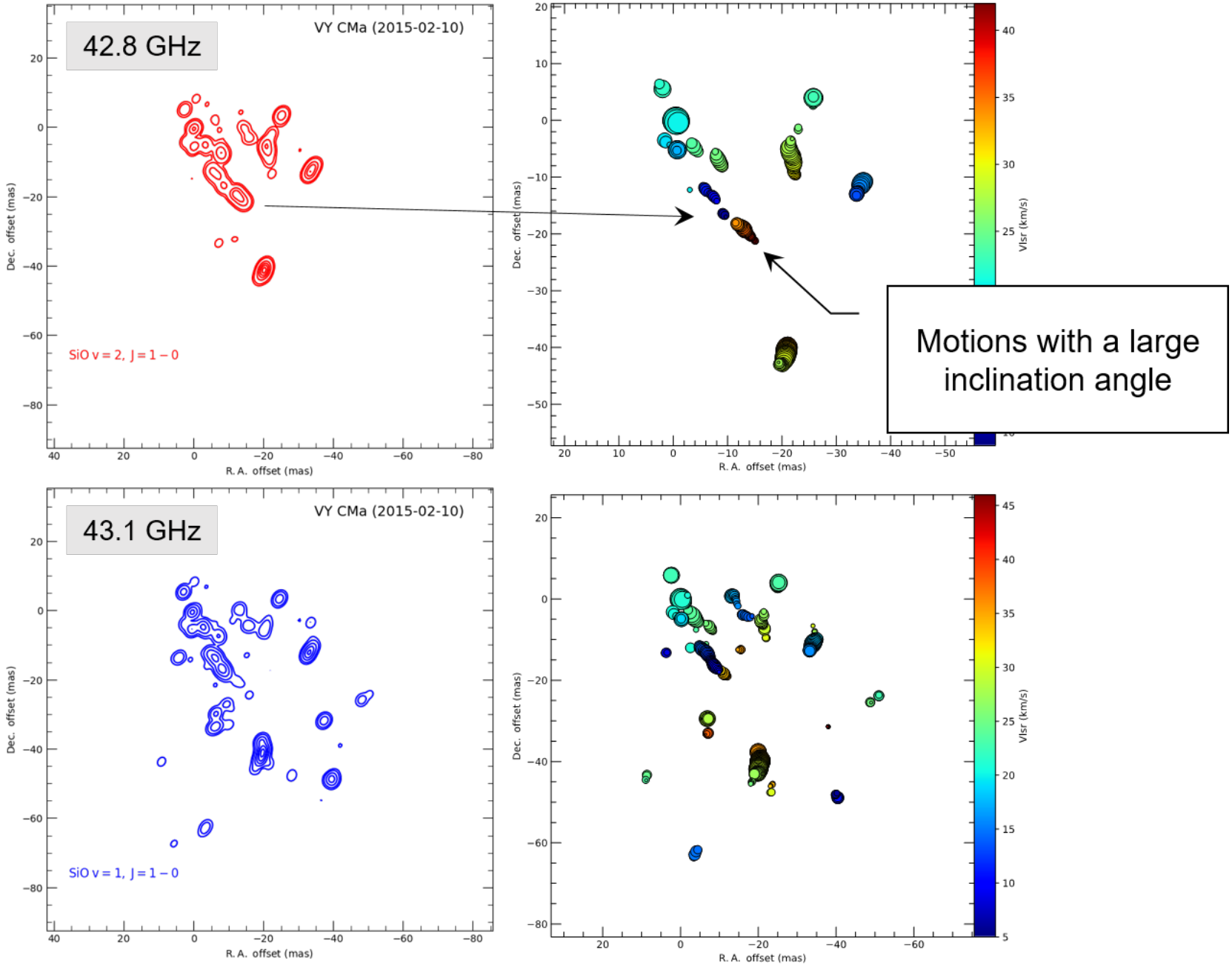
VY CMa: spatial distributions of SiO masers



Zhang et al. 2012

“Spoke-like” maser features
→ radial motions of stellar material

VY CMa: kinematic properties of SiO masers



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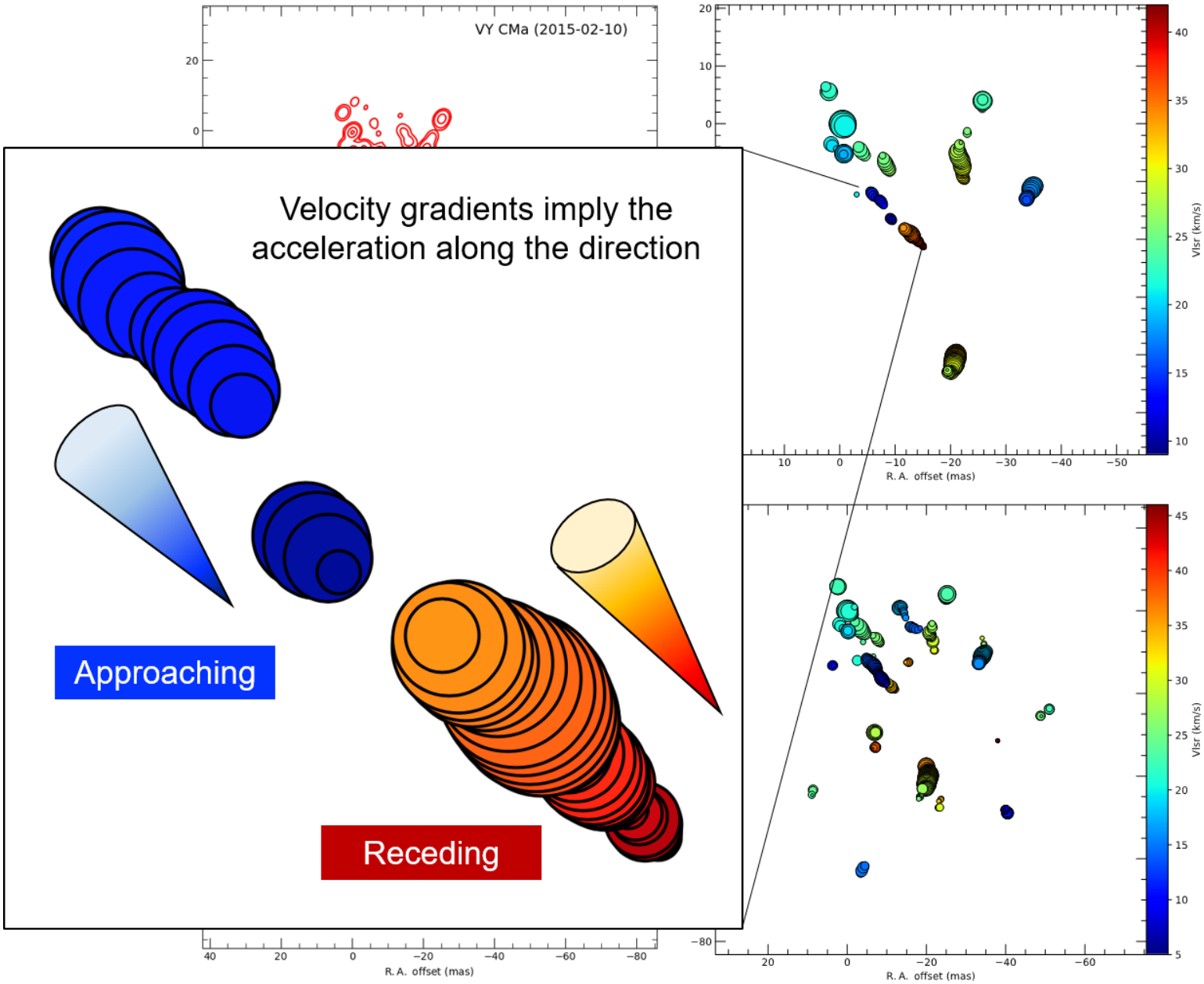
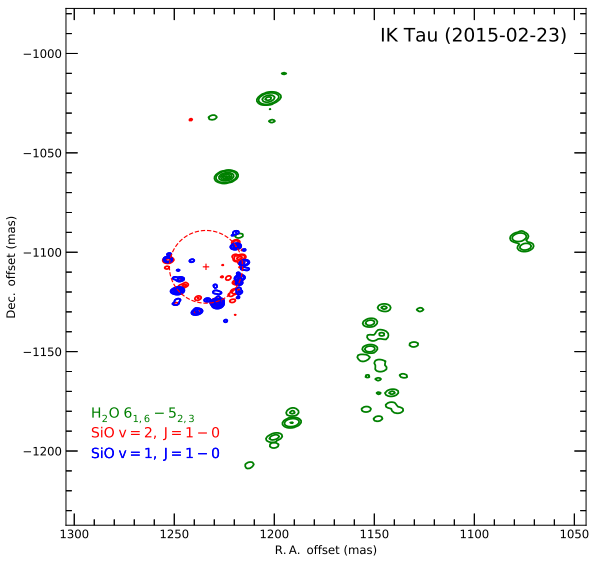
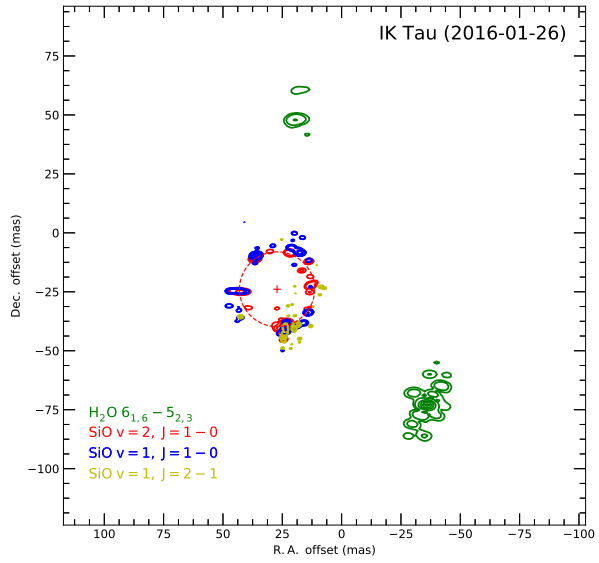
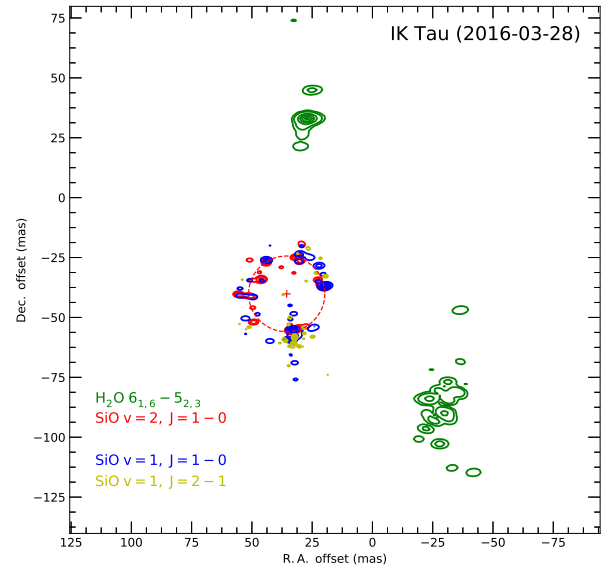
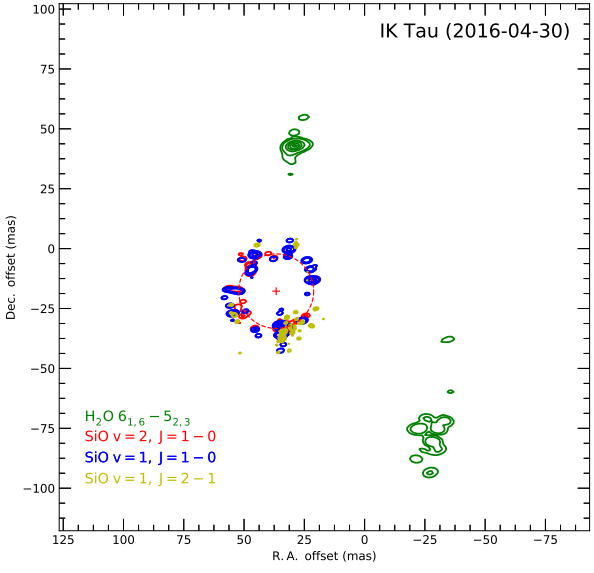


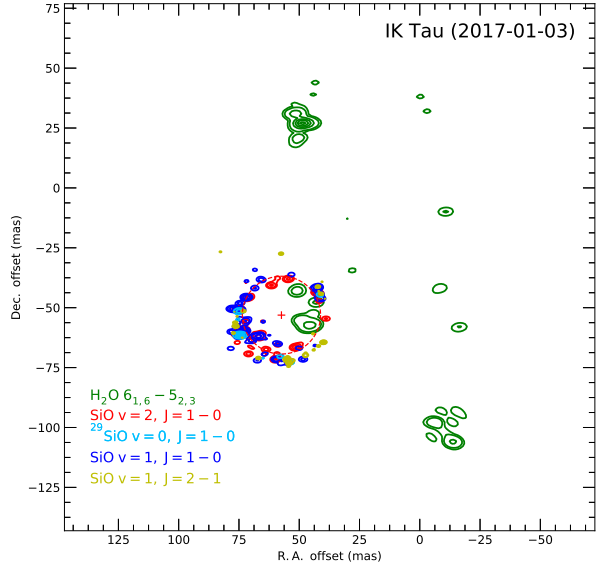
IK Tau: relative spatial distribution of stellar masers

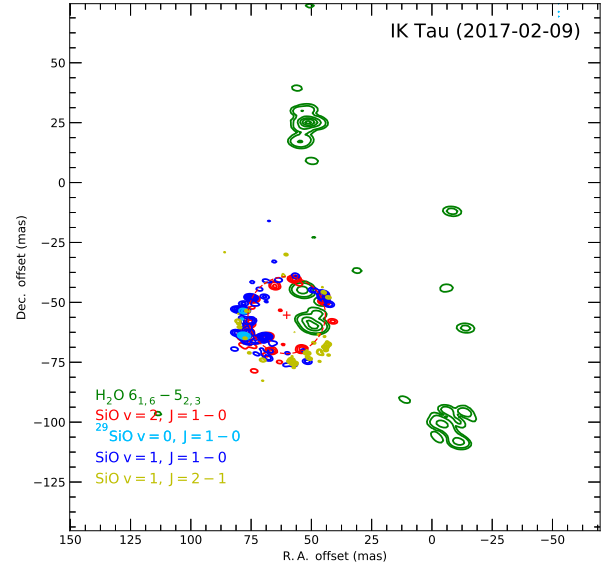












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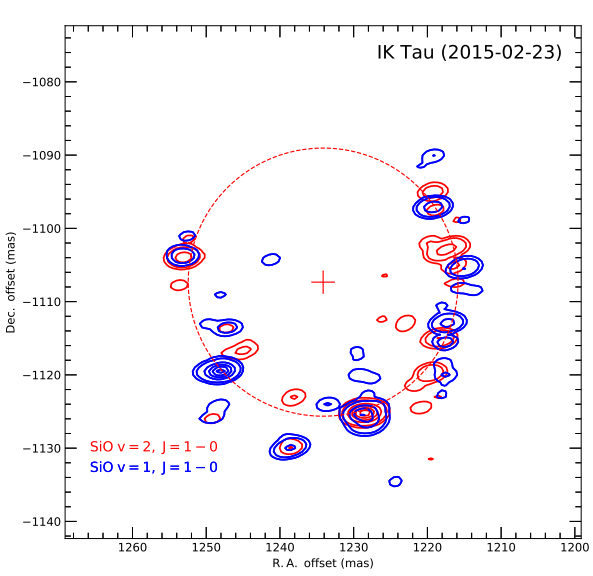
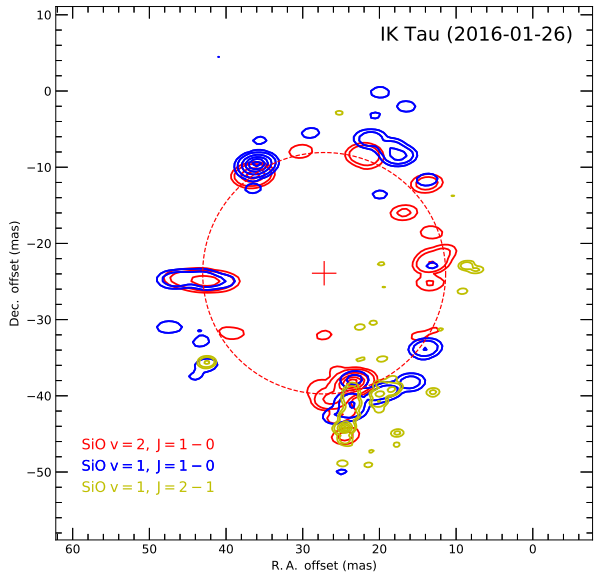
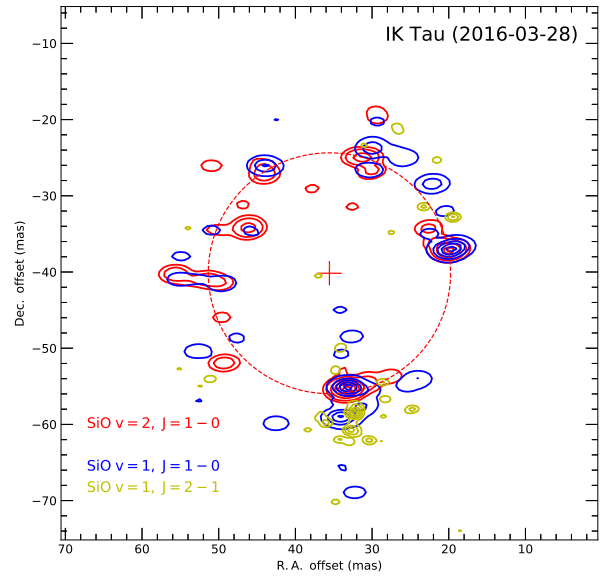
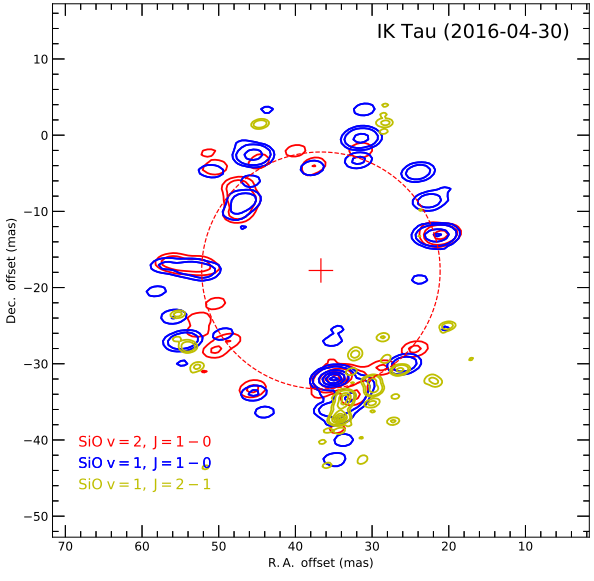
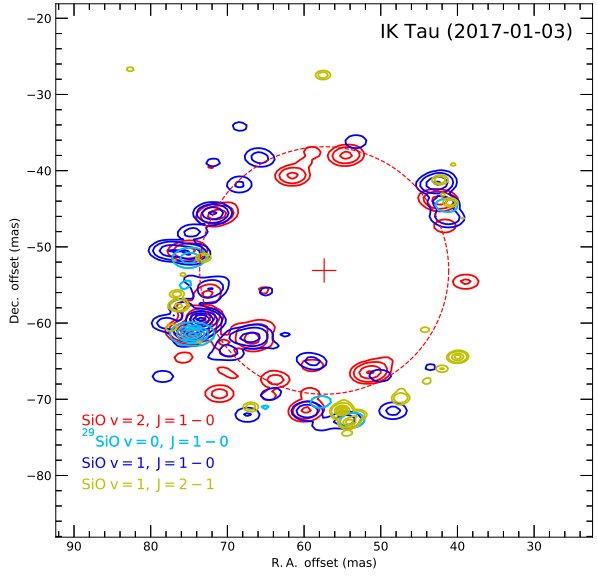
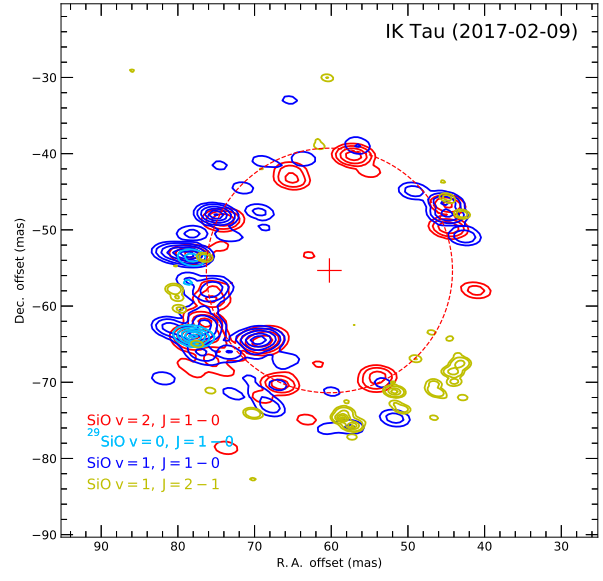




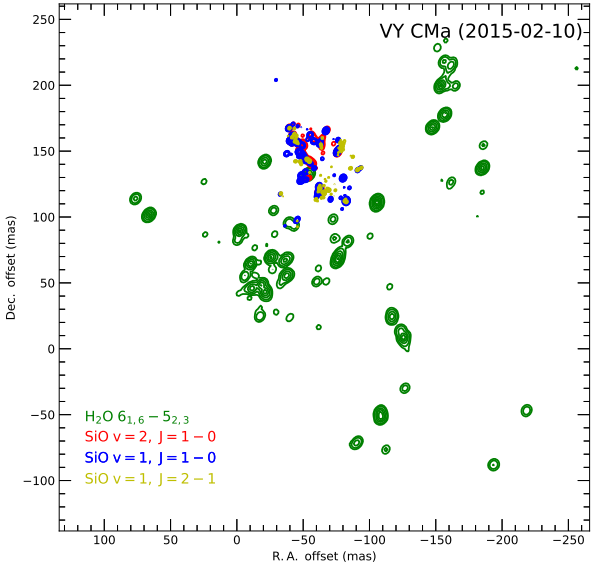


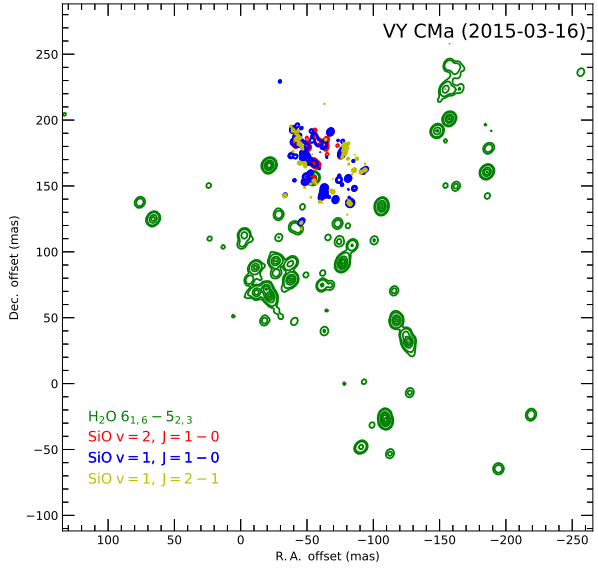


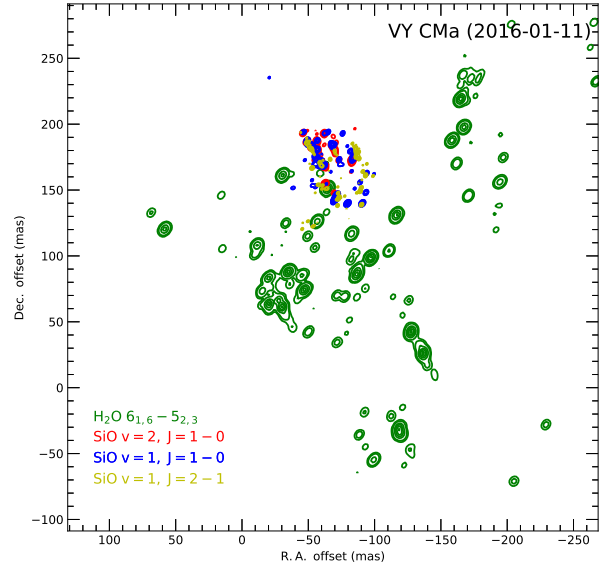


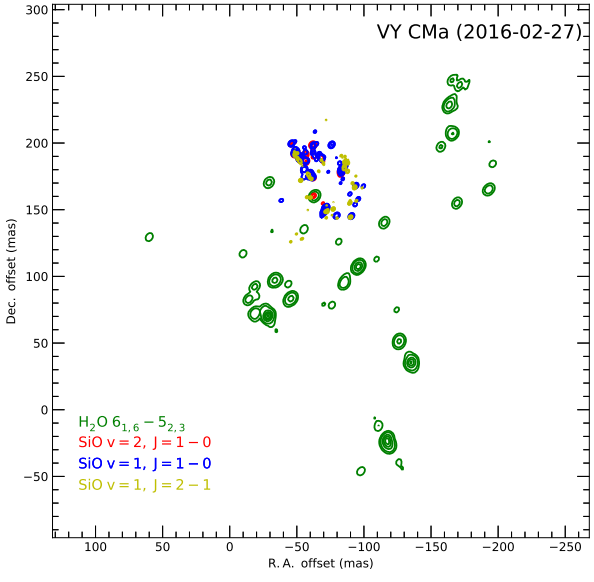


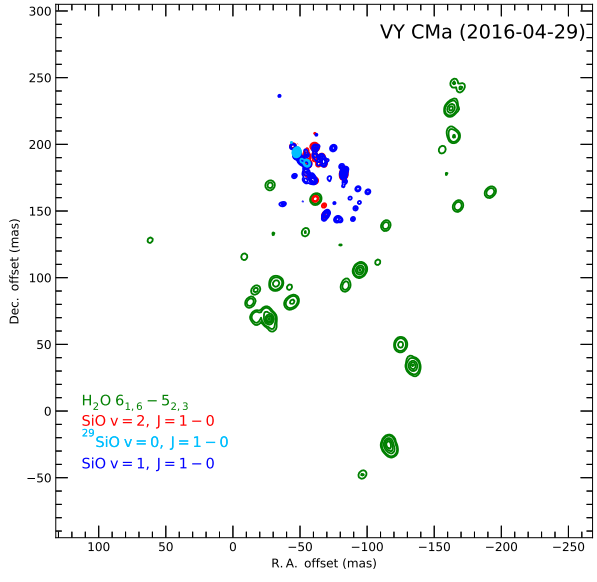
VY CMa: relative spatial distribution of stellar masers

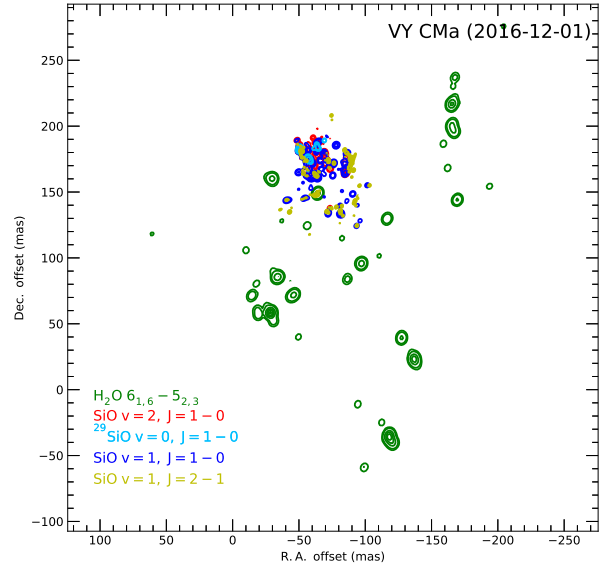












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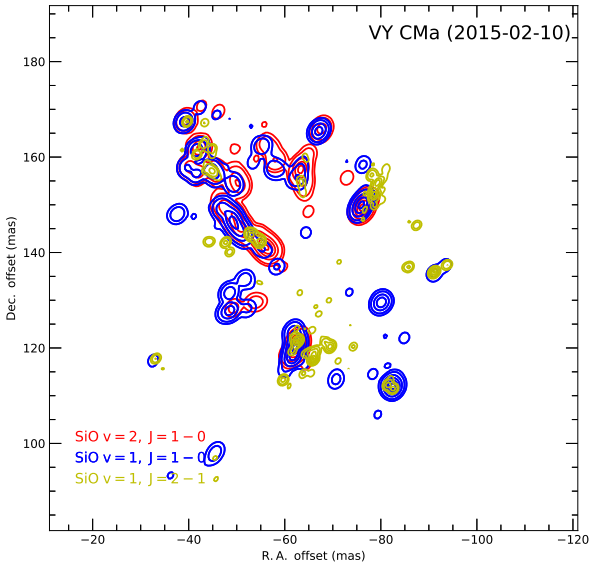
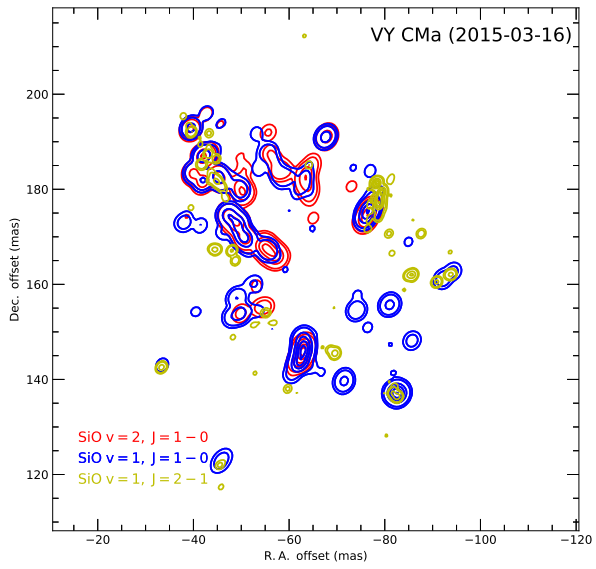
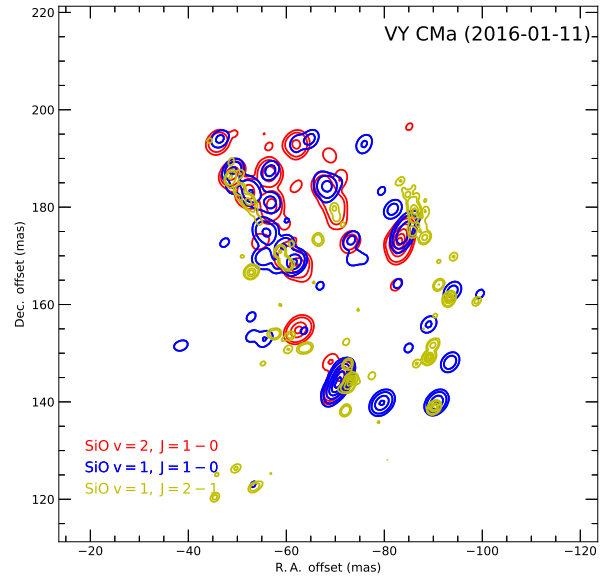
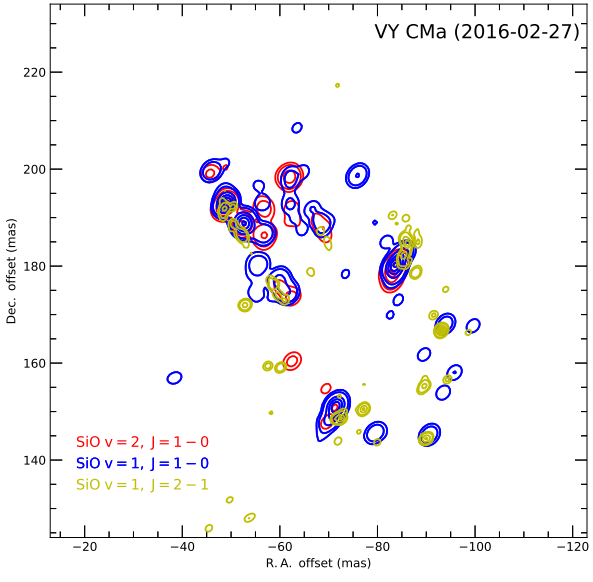
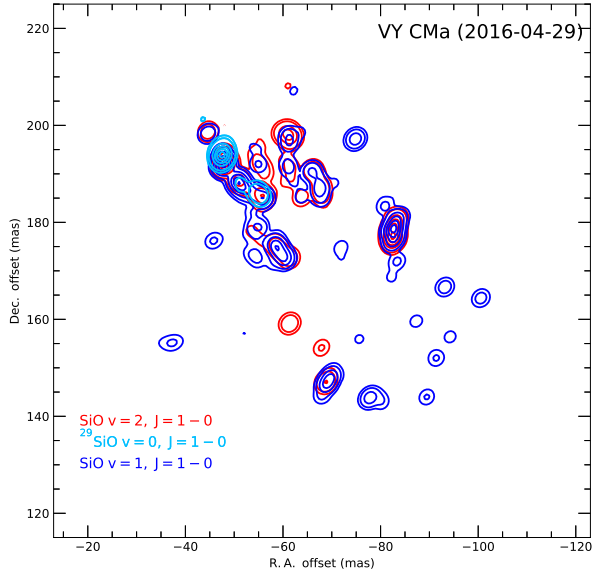
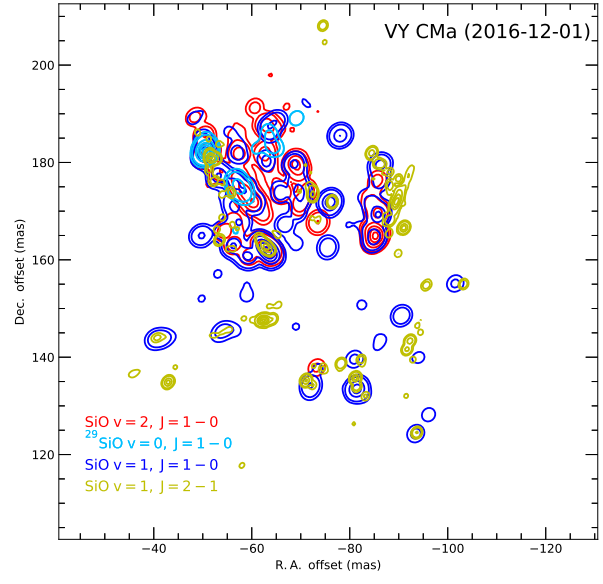




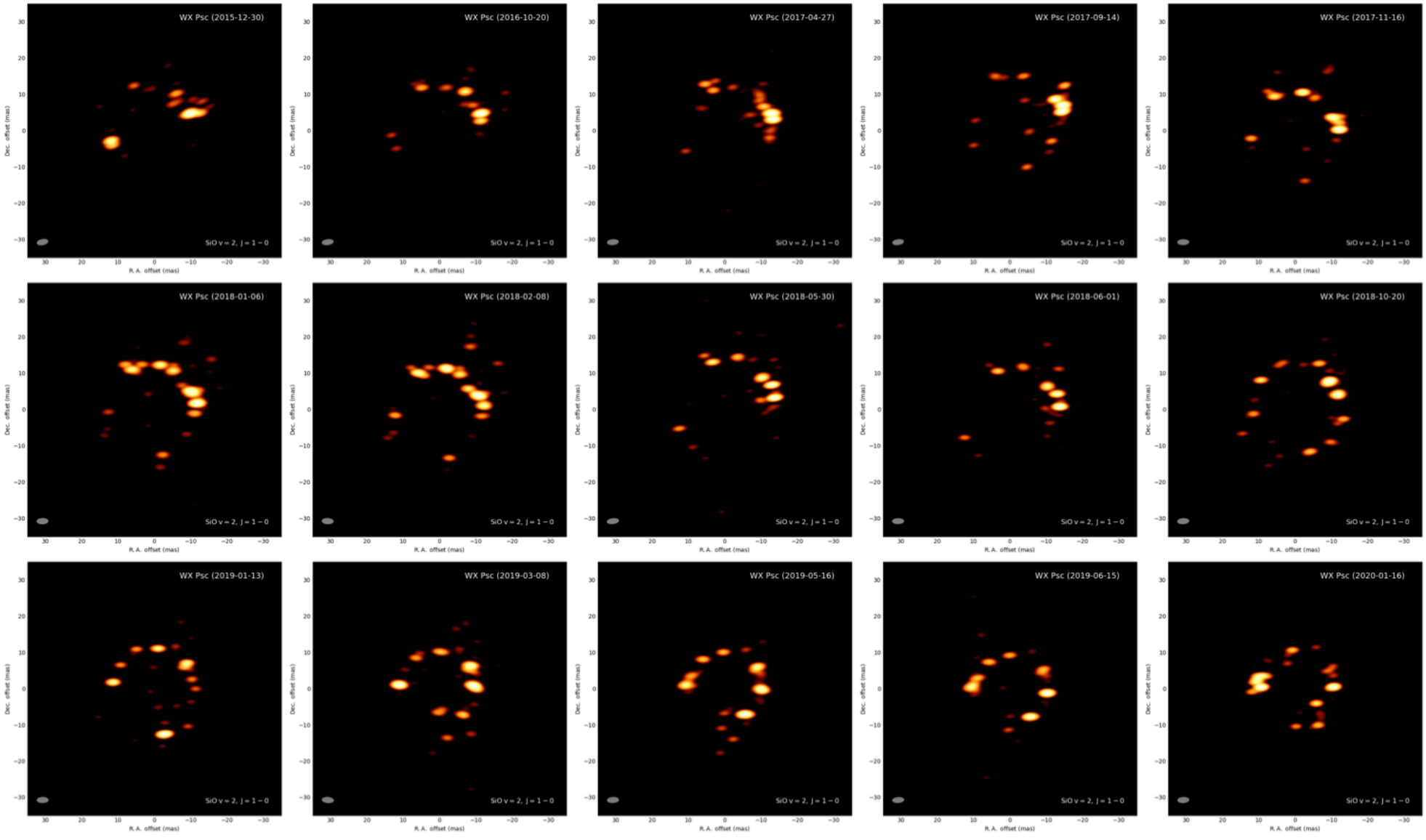








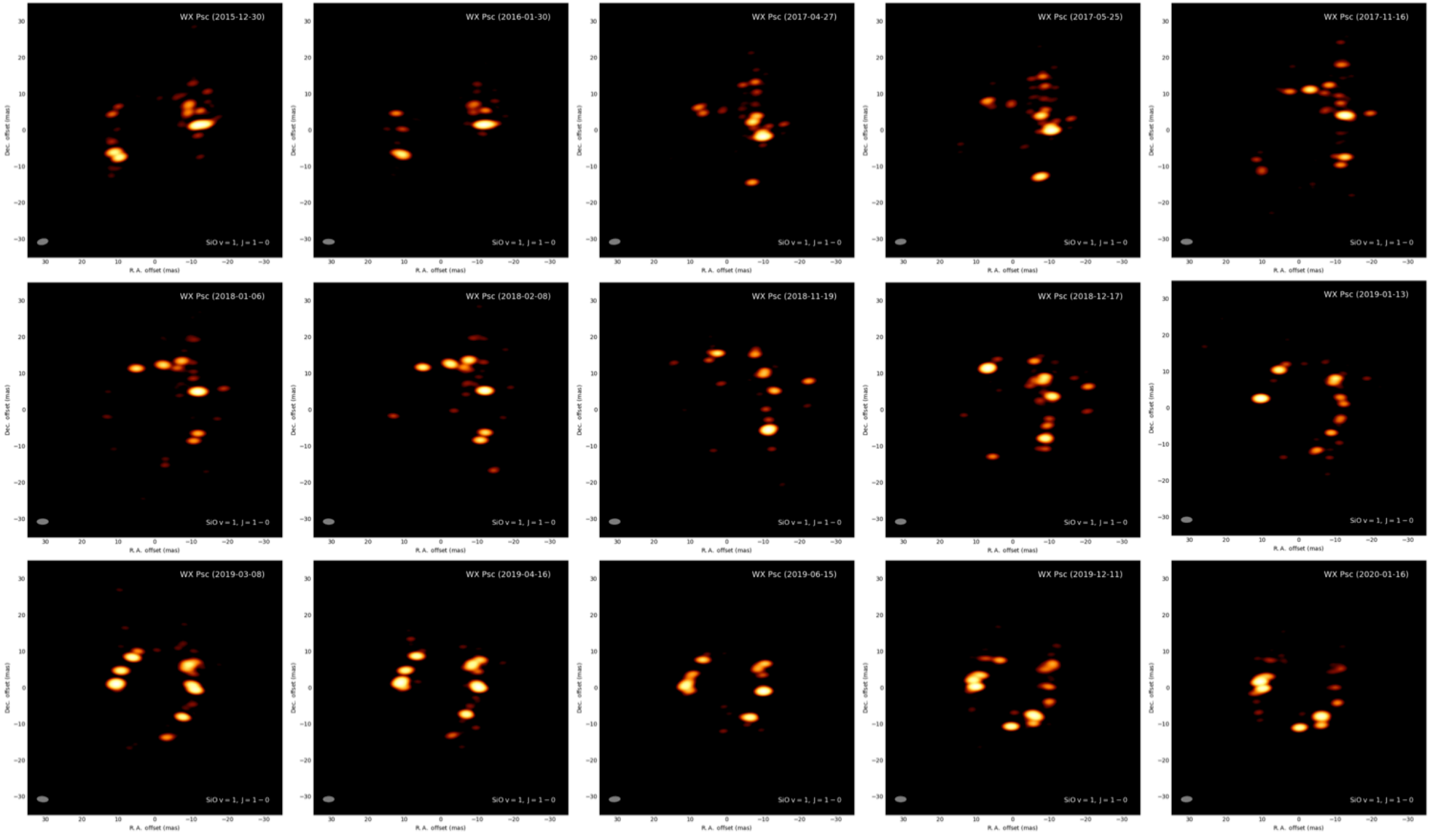
WX Psc: KVN monitoring VLBI observations



VLBI maps of SiO v=2 J=1-0 (42.8 GHz) maser around WX Psc

Dec. 30, 2015 – Jan. 16, 2020

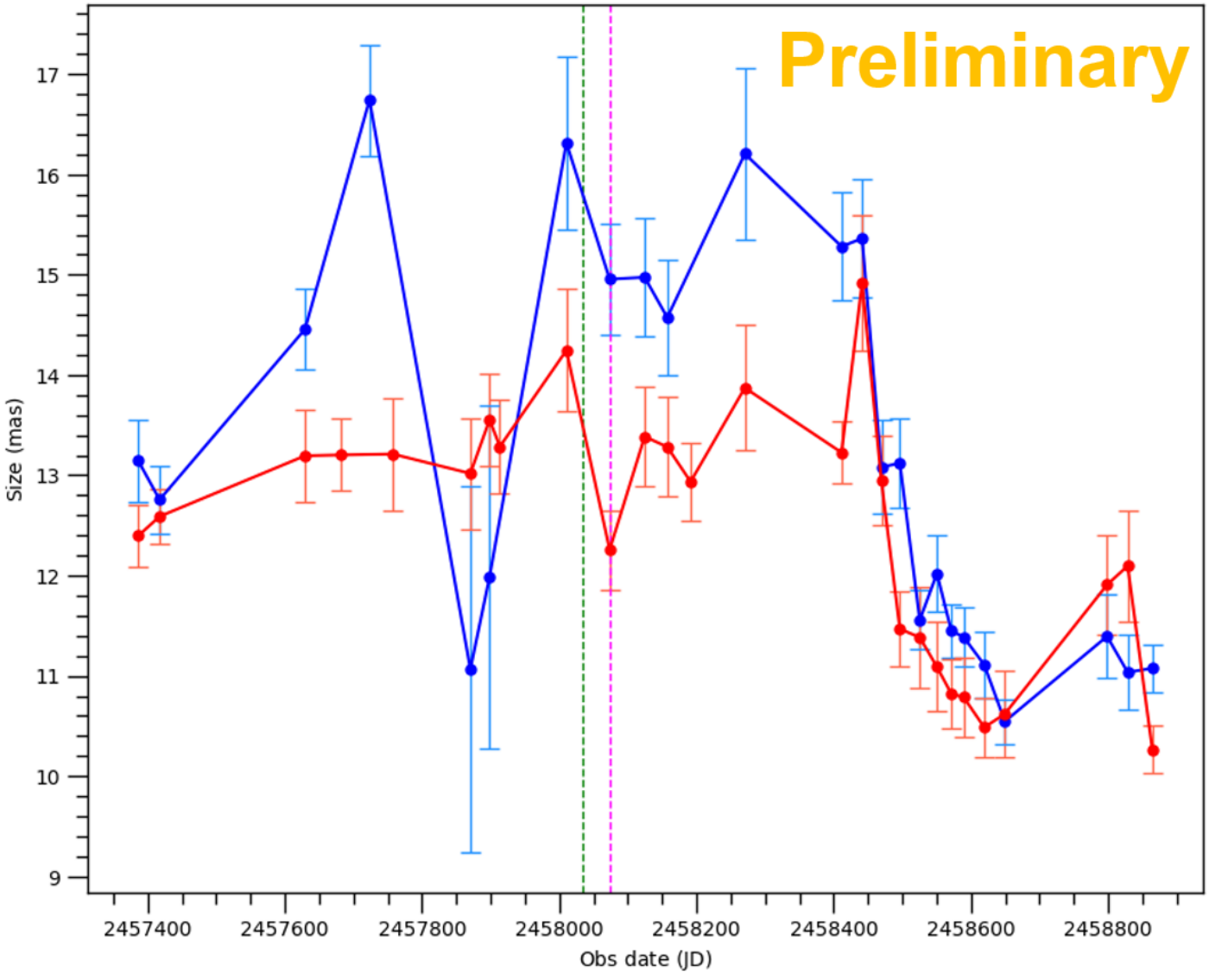
WX Psc: KVN monitoring VLBI observations



VLBI maps of SiO v=1 J=1-0 (43.1 GHz) maser around WX Psc

Dec. 30, 2015 – Jan. 16, 2020

WX Psc: KVN monitoring VLBI observations

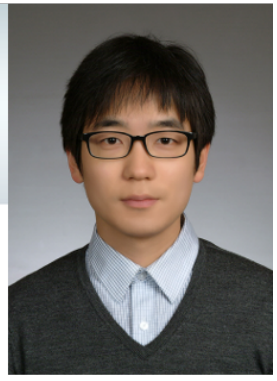


Change of SiO maser ring size (red: SiO v=2, blue: SiO v=1)

Dec. 30, 2015 – Jan. 16, 2020

Publications of KSP results: VX Sgr

KVN four bands astrometry for VX Sgr by Dong-Hwan Yoon



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ARTICLE

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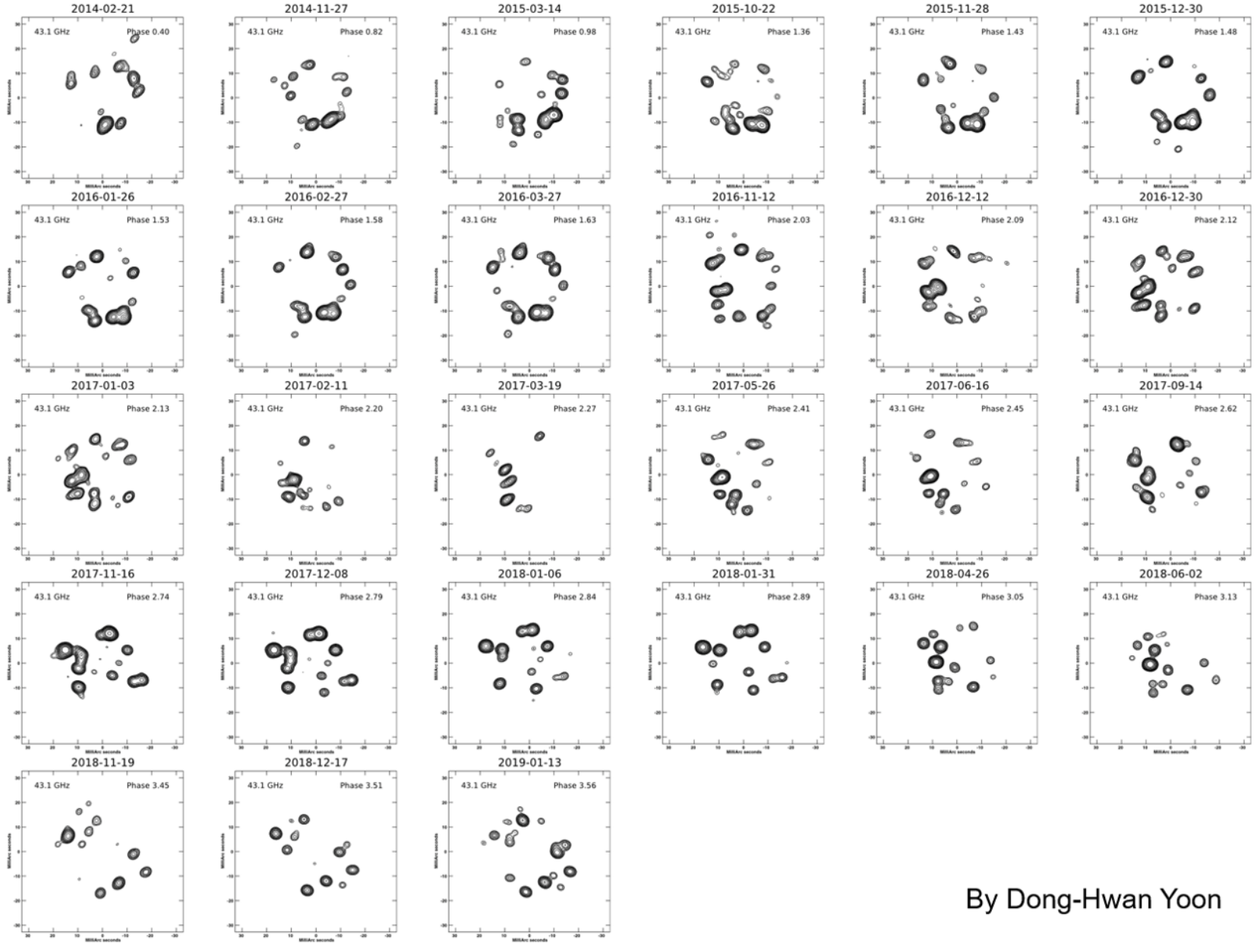
Astrometrically registered maps of H_2O and SiO masers toward VX Sagittarii

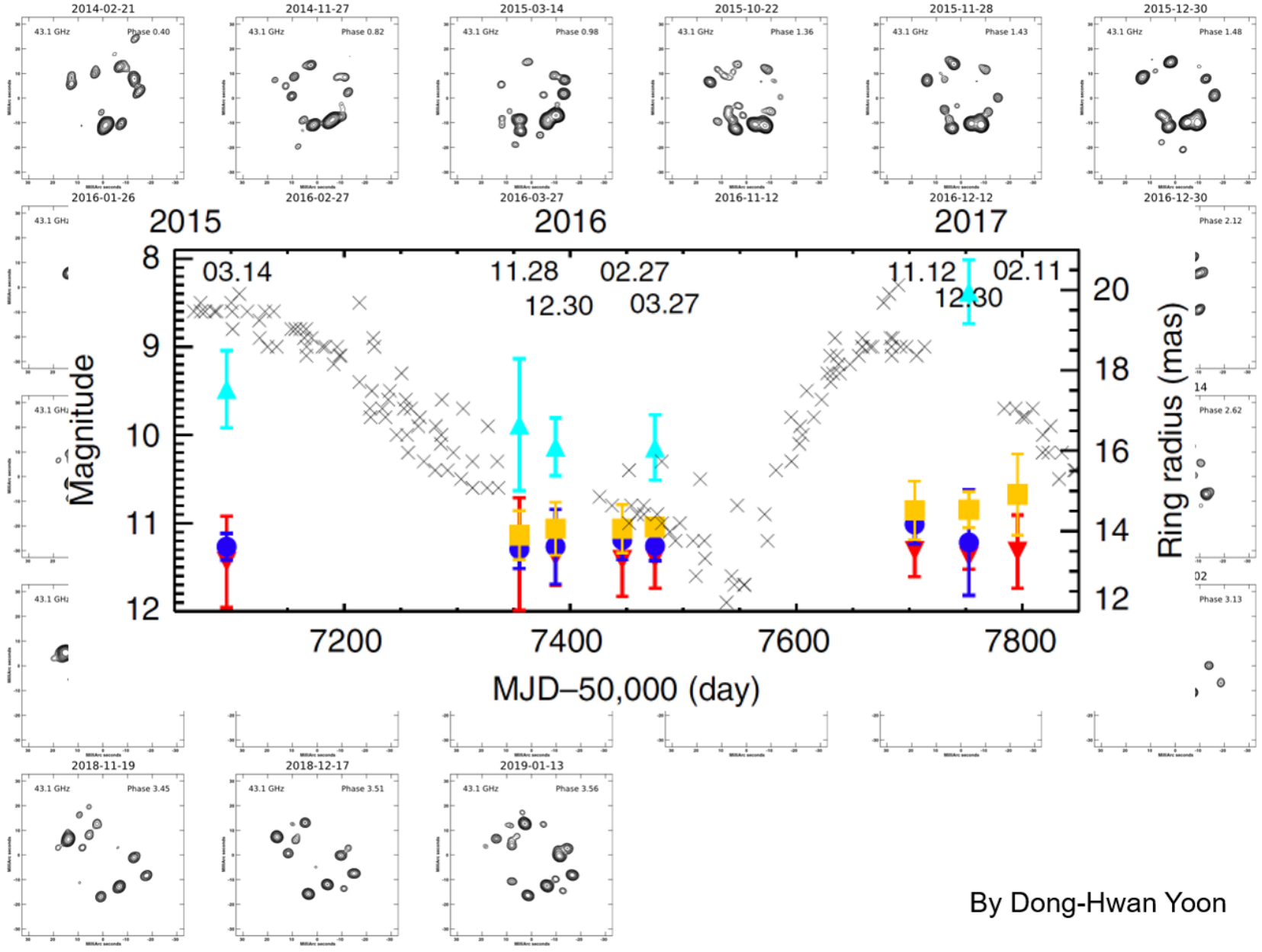
Dong-Hwan Yoon[1,2], Se-Hyung Cho[2,3], Youngjoo Yun[2], Yoon Kyung Choi[2], Richard Dodson[4], María Rioja[4,5], Jaeheon Kim[6], Hiroshi Imai[7], Dongjin Kim[3], Haneul Yang[1,2] & Do-Young Byun[2]

Publications of KSP results: VX Sgr



By Dong-Hwan Yoon

Publications of KSP results: VX Sgr



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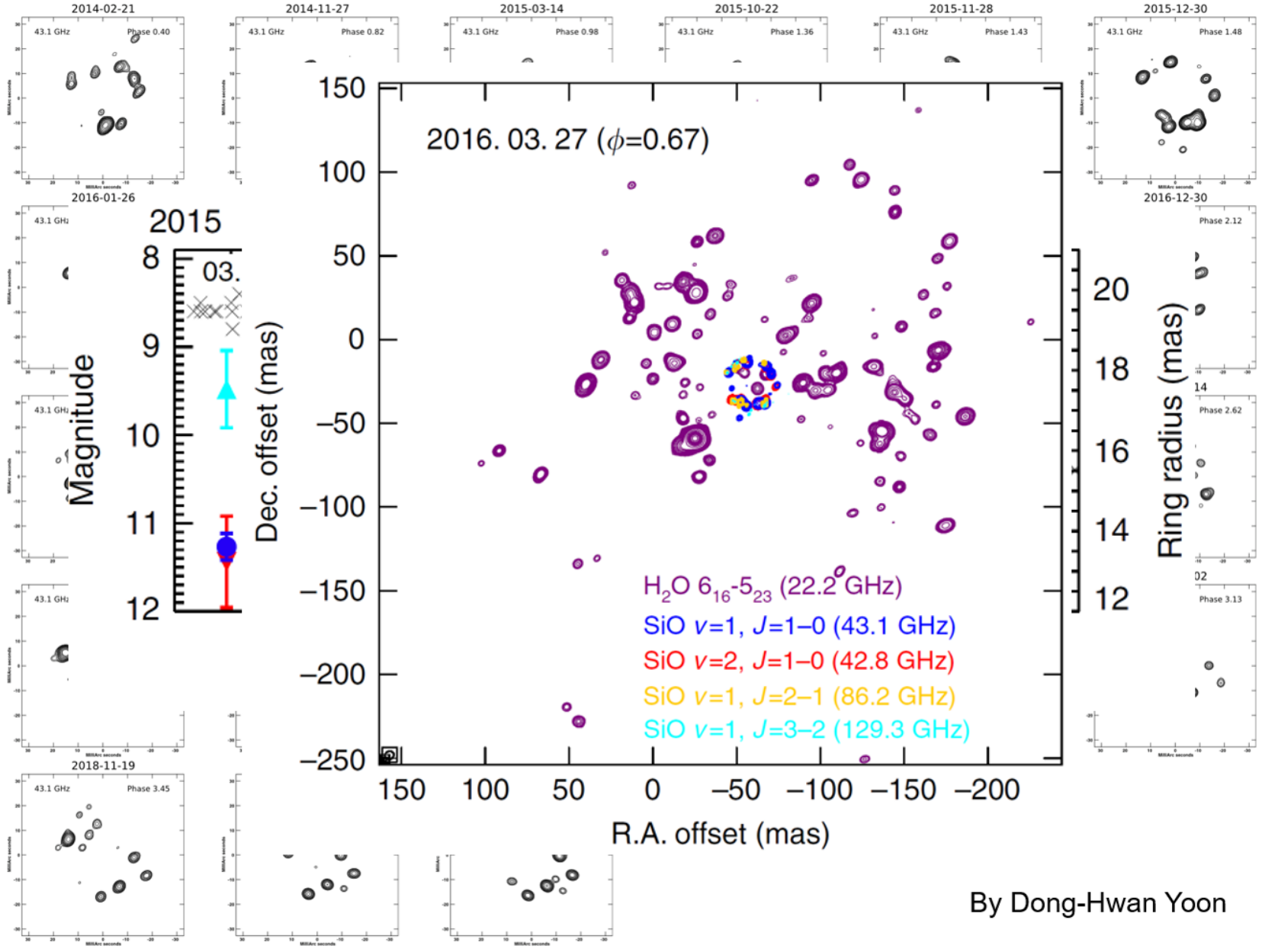
Publications of KSP results: VX Sgr



By Dong-Hwan Yoon

Publications of KSP results: R Crt

Atypical ring sizes of SiO masers around R Crt by Dong-Jin Kim

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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]

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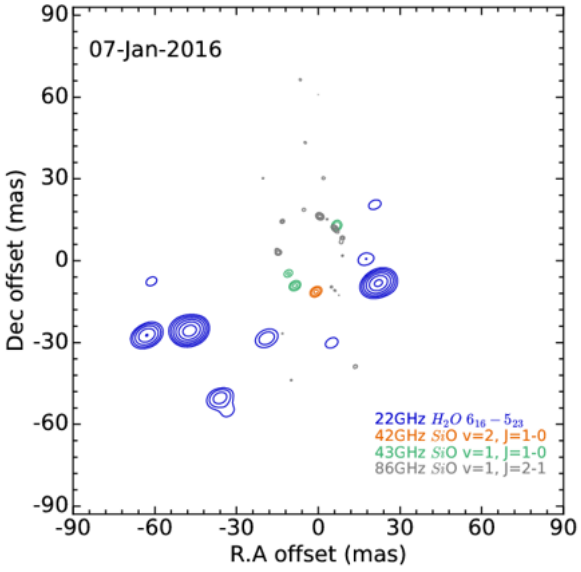
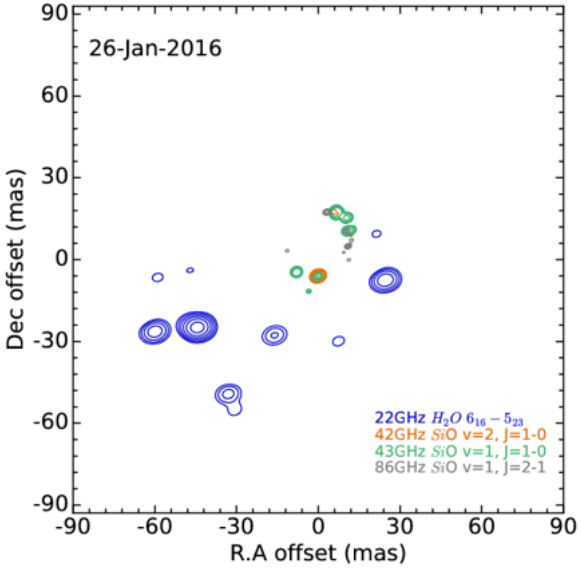
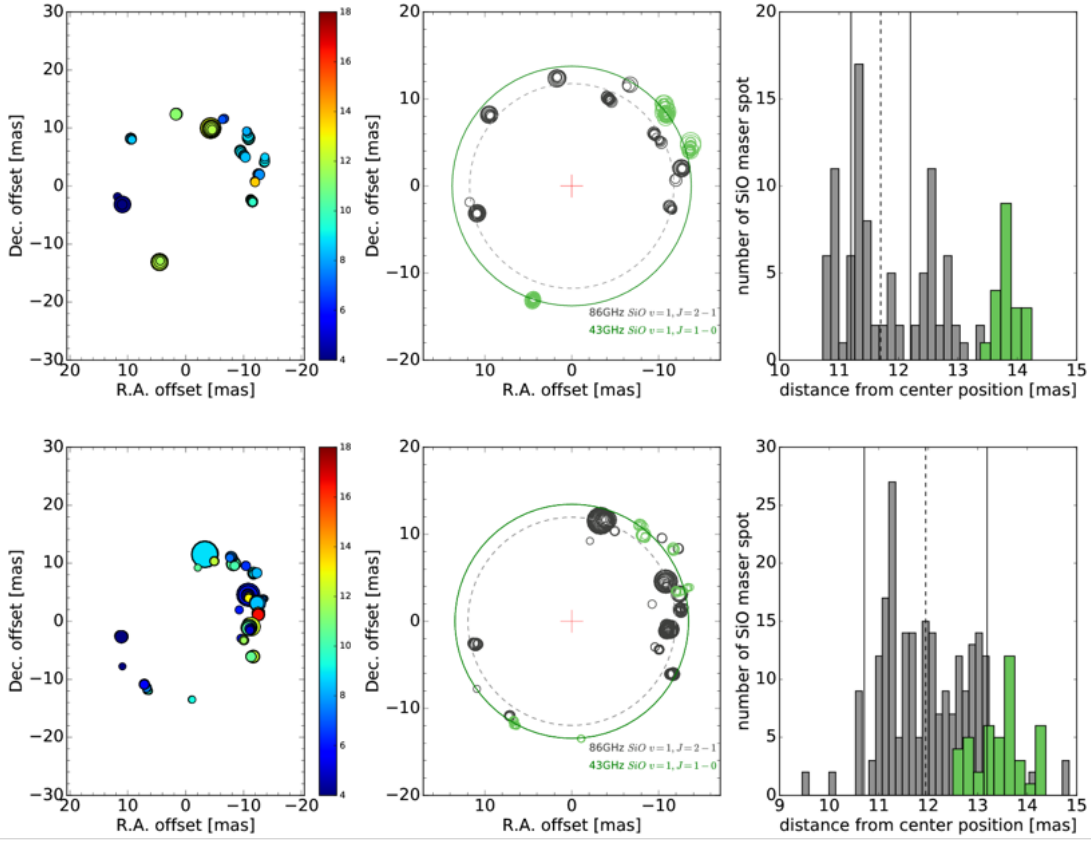
Received 2018 June 29; revised 2018 September 27; accepted 2018 September 30; published 2018 October 15

Publications of KSP results: R Crt







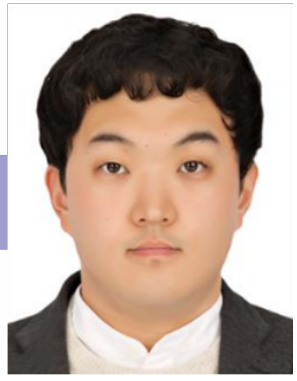
Relative spatial distribution of 7mm and 3 mm SiO masers

Average ring size 3 mm < 7 mm → Opposite to the common cases

By Dong-Jin Kim

Publications of KSP results: V627 Cas

First VLBI imaging of symbiotic V627 Cas by Haneul Yang



Monthly Notices
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ROYAL ASTRONOMICAL SOCIETY

MNRAS **495,** 1284–1290 (2020)
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Asymmetric distributions of H_2O and SiO masers towards V627 Cas

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

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[2]*Radio Astronomy Division, Korea Astronomy and Space Science Institute, Yuseong–gu, Daejeon 34055, Korea*
[3]*Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, Bonn D-53121, Germany*
[4]*International Center for Radio Astronomy Research, M468, The University of Western Australia, 35 Stirling Hwy, Crawley, WA 6009, Australia*
[5]*Observatorio AstronÃşmico Nacional (IGN), Alfonso XII, 3 y 5, Madrid E-28014, Spain*
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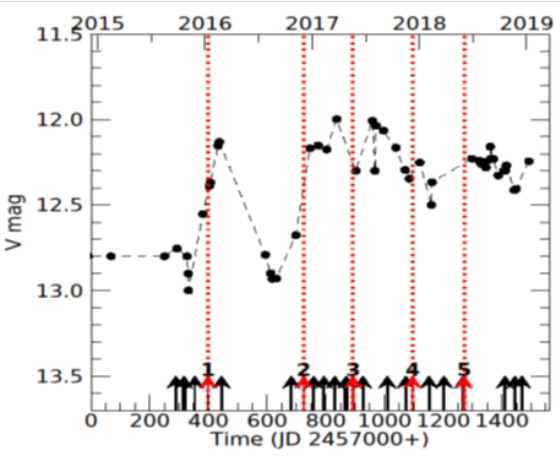
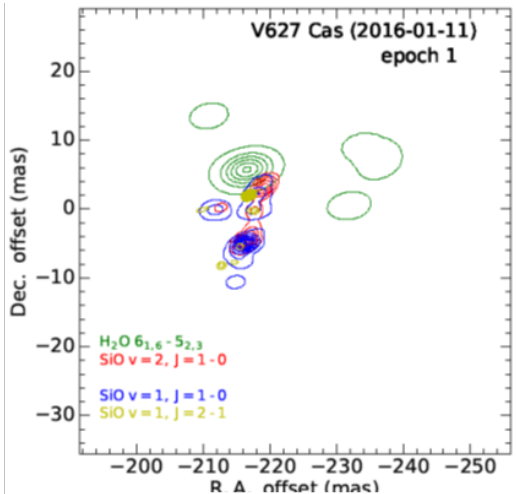
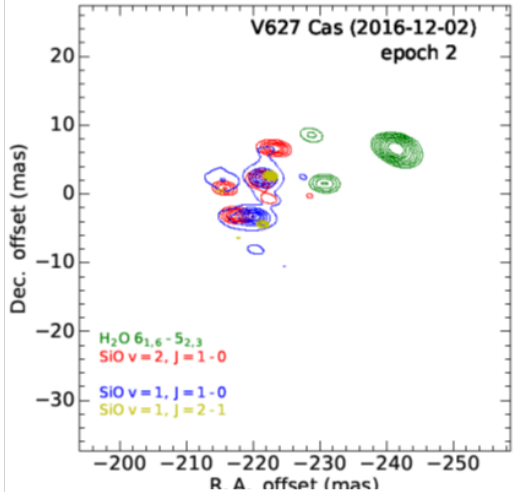
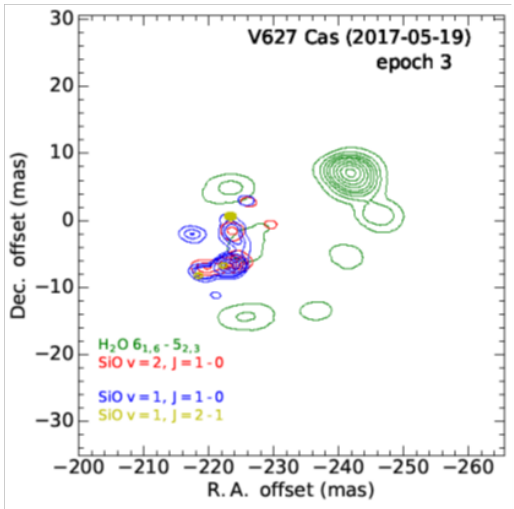
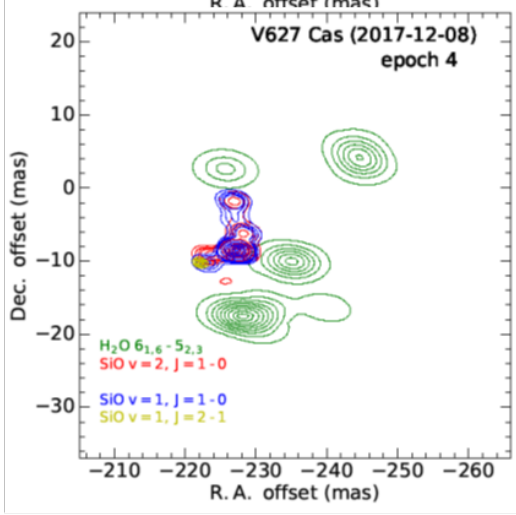
Publications of KSP results: V627 Cas

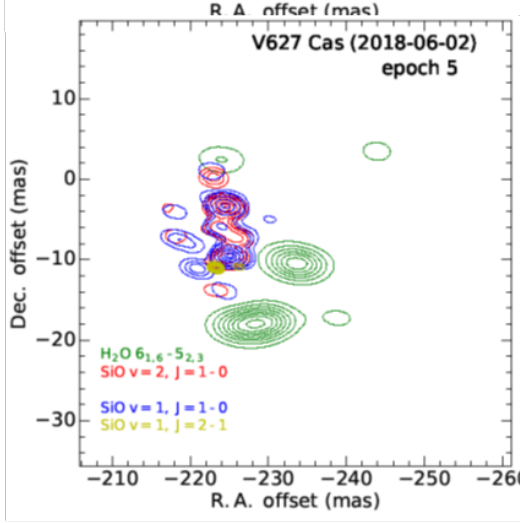








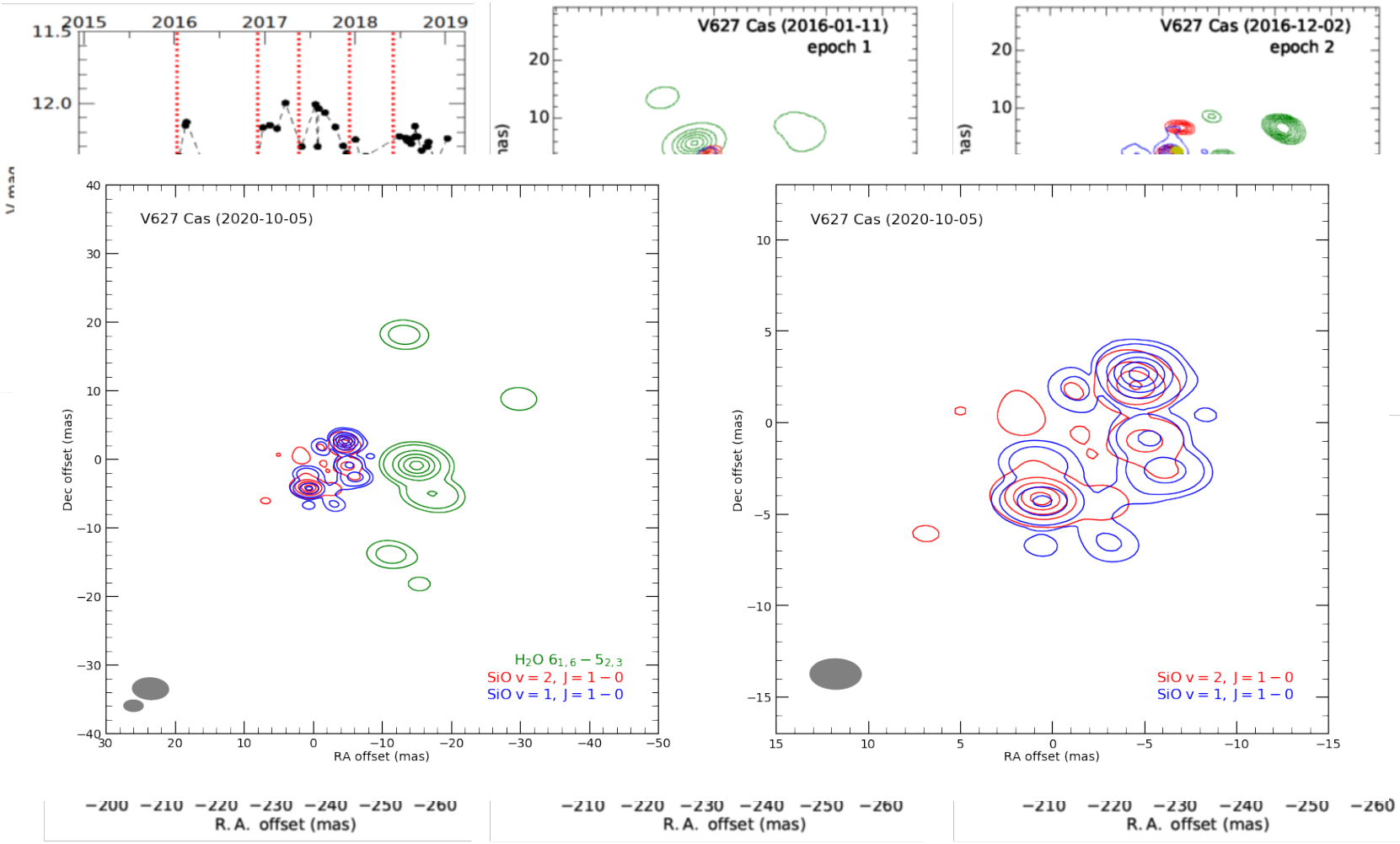




The spatial distribution of H_2O and SiO masers might be affected by the orbital motion of hot companion.

By Haneul Yang

Publications of KSP results: V627 Cas



The spatial distribution of H_2O and SiO masers might be affected by the orbital motion of hot companion.

By Haneul Yang

Publications of KSP results: V627 Cas

Monitoring observations toward symbiotic V627 Cas by Haneul Yang

Eight-year simultaneous monitoring observations of H_2O and SiO masers toward V627 Cas

Haneul Yang,[1,2] Se-Hyung Cho,[3,1] Youngjoo Yun,[2] Dong-Hwan Yoon,[2] and Jaeheon Kim[2]

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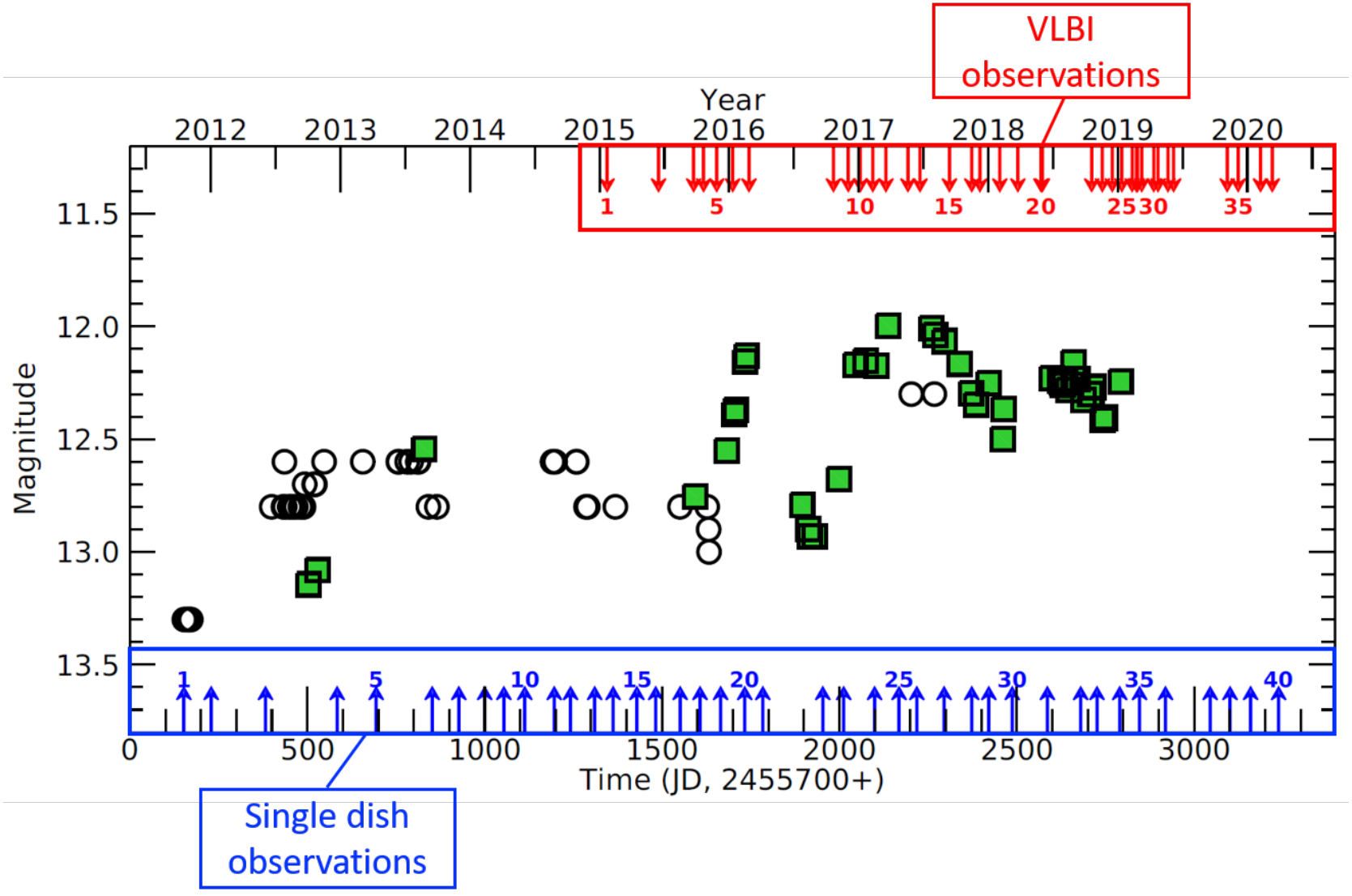
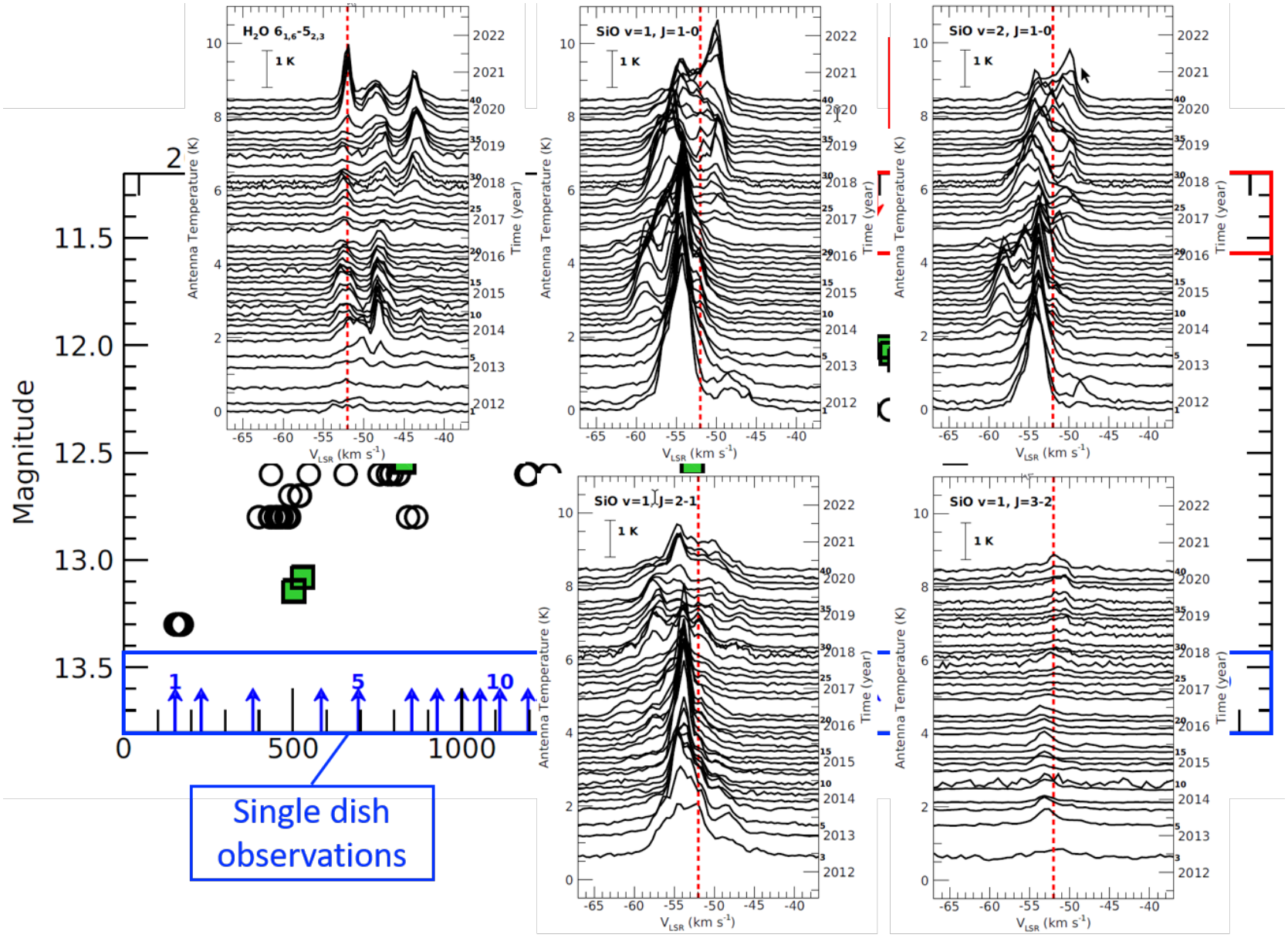


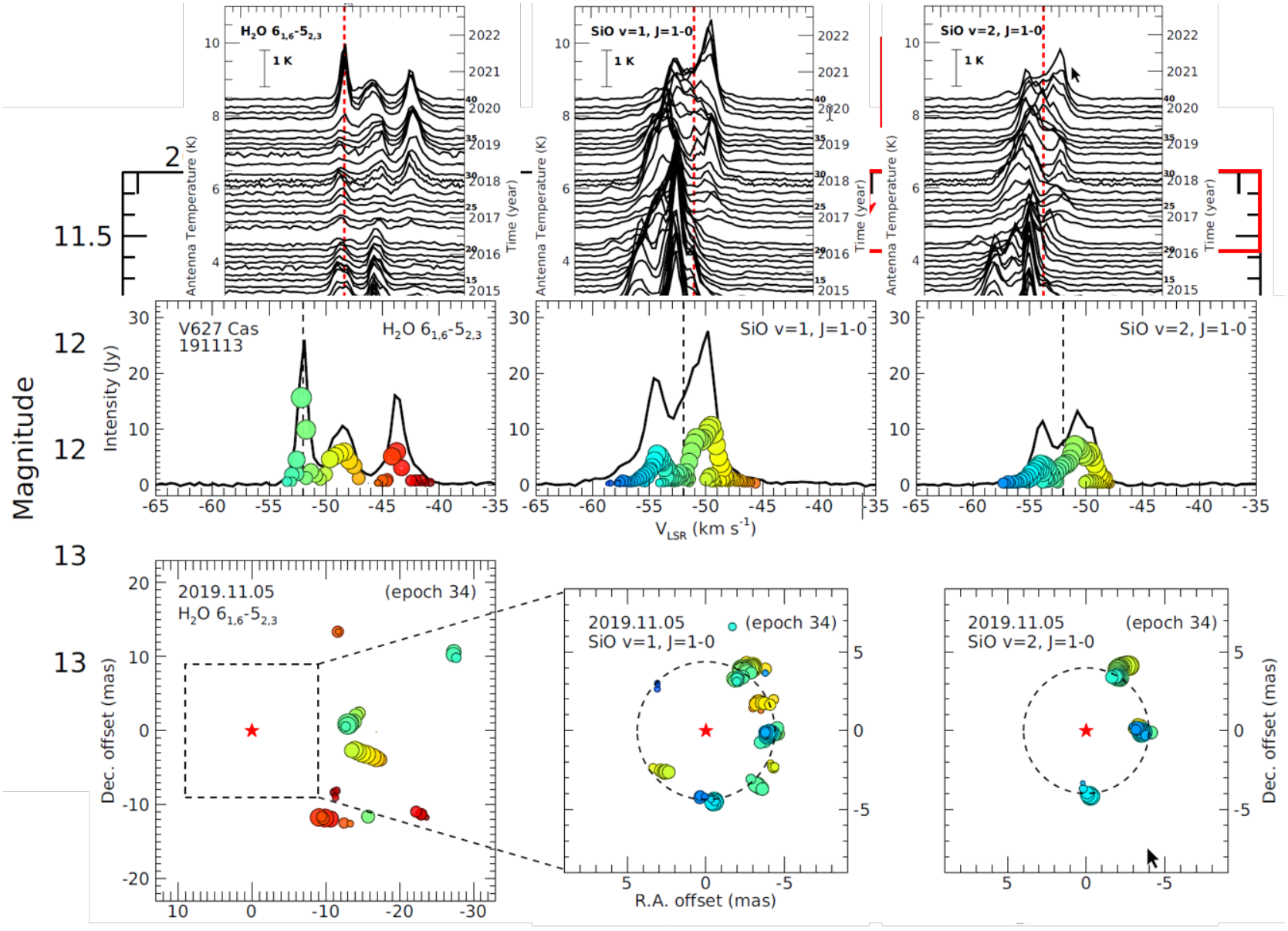
By Haneul Yang

Publications of KSP results: V627 Cas



By Haneul Yang

Publications of KSP results: V627 Cas



By Haneul Yang

Publications of KSP results: CH Cyg

Spectral characteristics of SiO maser around CH Cyg by Se-Hyung Cho

The Astrophysical Journal Letters, 897:L26 (6pp), 2020 July 10 https://doi.org/10
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CrossMark

Detection of Periodicity in SiO Maser Intensity and Velocity Shift of the Symbiotic Star CH Cyg

Se-Hyung Cho[1,2], Haneul Yang[2], Youngjoo Yun[2], Dong-Hwan Yoon[2], Jaeheon Kim[3], and Dong-Jin Kim[4]
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Abstract

We performed simultaneous monitoring observations of H_2O 6_{16}–5_{23} and SiO $v = 1, 2$, $J = 1 \rightarrow 0$, SiO $v = 1$, $J = 2 \rightarrow 1$, $3 \rightarrow 2$ maser lines toward the symbiotic star CH Cyg from 2012 December to 2019 November using the Korean very long baseline interferometry Network single-dish telescope. SiO $v = 1, 2$, $J = 1 \rightarrow 0$ and $v = 1$, $J = 2 \rightarrow 1$ maser lines were detected for the first time. A periodicity of about 2.5 yr in the SiO maser intensity was found, showing its association with the pulsation of the M giant in CH Cyg. Only the SiO $v = 2$, $J = 1 \rightarrow 0$ maser, without detections of the $v = 1$, $J = 1 \rightarrow 0$ maser, was detected in 6 epochs out of 15 $v = 2$, $J = 1$–0 maser detected epochs. In addition, the SiO $v = 1$, $J = 2 \rightarrow 1$ maser intensity was always stronger than that of the $v = 1$, $J = 1 \rightarrow 0$ maser except for one epoch, providing a critical constraint on the different masing conditions by different transitions, according to changes of the CH Cyg symbiotic system. We also found the gradual redshifted peak velocities of the SiO masers had about a 2.5 yr periodicity corresponding to the period of peak intensities (redshifted up to about $+40$ km s^{-1} with respect to the stellar velocity of the M giant). Two possible explanations can be suggested for the 2.5 yr period of the SiO maser intensity and velocity behaviors, although their actual causes remain uncertain.

Successful operation of the 1st phase of KSP

- Accumulating sufficient experiences of astrometric analysis with four band KVN observations → **great contribution from the SFPR method**
- Providing many important results for the late stage of the stellar evolution
  - Spatial distribution of the stellar masers and their temporal variability
  - Physical/dynamical properties of the inner CSEs
    → related to the dust condensation and mass loss process

New launch of the 2nd phase of KSP

- New target sources (GX Mon, R Aqr)
- Wide band observations (e.g. 512 MHz/band)
- Polarization observations for a few epochs

Future works

- Need to enhance KVN astrometric accuracy (atmospheric model, antenna position)
- Combining results from other facilities (EAVN, ALMA, VLA)
- More works on the polarization of the stellar masers
- Introduction numerical works