

IAU Symposium 336 on Astrophysical Masers: Unlocking the Mysteries of the Universe
In Cagliari, Italy on 7 September 2017

Towards decadal continuous viewing of circumstellar maser sources

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Science and Engineering Area of the Research and Education Assembly
Kagoshima University

Related presentations in IAUS 336 1/3

Water fountains and planetary nebulae (22 GHz H_2O masers)

- **Jose-Francisco Gómez** Water masers as signposts of extremely young PNe
- **Gabor Orosz** Water Fountains and the Formation of Planetary Nebulae
- **Andrés Felipe Pérez-Sánchez**
  Deep into the Water fountains: A detailed study toward IRAS 15445-5449

H_2O and SiO masers associated with long period variables

- **Yoshiharu Asaki** A Intermittent Mass Blowout of the Red Supergiant S Per
- **Mark J. Claussen** Isotopic SiO Maser Emission from the BAaDE Survey
- **Jean-François Desmurs** Missing flux of SiO maser at 7mm in IRC+10011
- **Hiroko Shinnaga** Magnetic field generated by the extreme red supergiant VY CMa
- **Michael Stroh** Simultaneity and Flux Bias between 43 and 86 GHz SiO Masers
- **Tomoaki Oyama** First simultaneous mapping of four 7 mm SiO maser lines using the new broad band VLBI System (OCTAVE)

Time-domain approach to circumstellar H_2O and SiO masers

- **Jan Brand** Variability of water masers in evolved stars on the timescale of decades
- **Jaeheon Kim** Interim Results of Simultaneous Time Monitoring of SiO and H_2O Masers in post-AGB star OH231.8+4.2 (= QX Pup)

Related presentations in IAUS 336 2/3

Simultaneous mapping of circumstellar H_2O and SiO masers with KVN

- **Se-Hyung Cho** → review talk
  A Study of Evolved Stars by Simultaneous Observations of H_2O and SiO Masers Using KVN
- **Richard Dodson** KVN astrometric observations of H_2O and SiO masers in Calabash Nebula
- **Dong-Hwan Yoon** Smultaneous VLBI observations of H_2O and SiO masers toward VX Sgr
- **Youngjoo Yun** KVN imaging results for the H_2O and SiO masers of the evolved stars

Astrometry of circumstellar masers

- **Akiharu Nakagawa**
  Astrometric VLBI observation of the Galactic LPVs; Miras and OH/IR stars
- **Bo Zhang** Verifying Gaia parallaxes of Long period variables via VLBI maser astrometry
- **Maria Rioja** "MultiView" calibration for precise astrometry at low frequencies

Surveys and databases

- **Lorant Sjouwerman** Thousands of Stellar SiO masers in the Galaxy: The Bulge Asymmetries and Dynamic Evolution (BAaDE) survey
- **Jun-ichi Nakashima** The Extensive Database of Astrophysical Maser Sources (eDAMS) First Release on Circumstellar Maser Sources

Related presentations in IAUS 336 3/3

OH masers: major players in SKA era

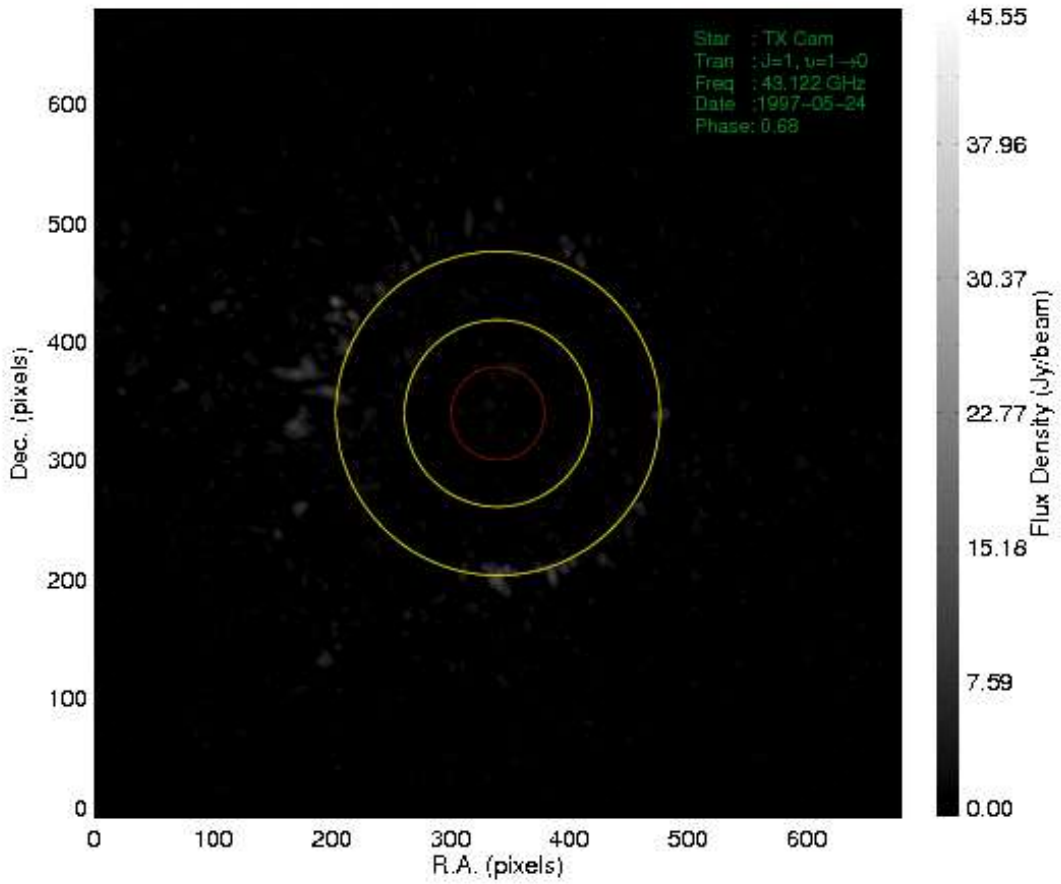
- **Sandra Etoka** Distance of Stars by mean of the Phase-lag Method
- **Dieter Engles**
  OH masers as probes: How does the variability fade away during AGB – post-AGB transition?
- **Angelica Erica Strack** Excited OH Masers in Late Type Stellar Objects
- **Hai-Hua Qiao** Accurate OH maser positions in SPLASH
- **Lucero Uscanga**
  Magnetic fields and radio emission processes in maser-emitting planetary nebulae

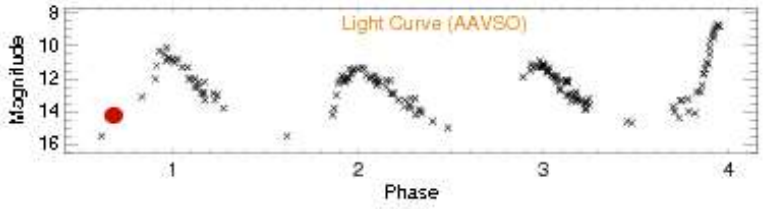
Sub-millimeter masers, infrared

- **Guy Perrin** Perspectives on Evolved Stars
- **Anita Richards** → **Next talk**
  Hot and cold running water: understanding evolved star winds
- **Daniel Tafoya** Sub-millimeter maser emission from warm water fountain nebulae
- **Liz Humphreys** SiO Masers with ALMA Long Baselines

Why is decadal continuous viewing of circumstellar maser sources necessary?

The movie of circumstellar masers





Maser movie visualizes…

- expansion
- contraction /convection
- rotation/ radial acceleration
- **ballistic (matter) and *non-ballistic (signal propagation)* motions**

Maser motions *may(might)* visualize….

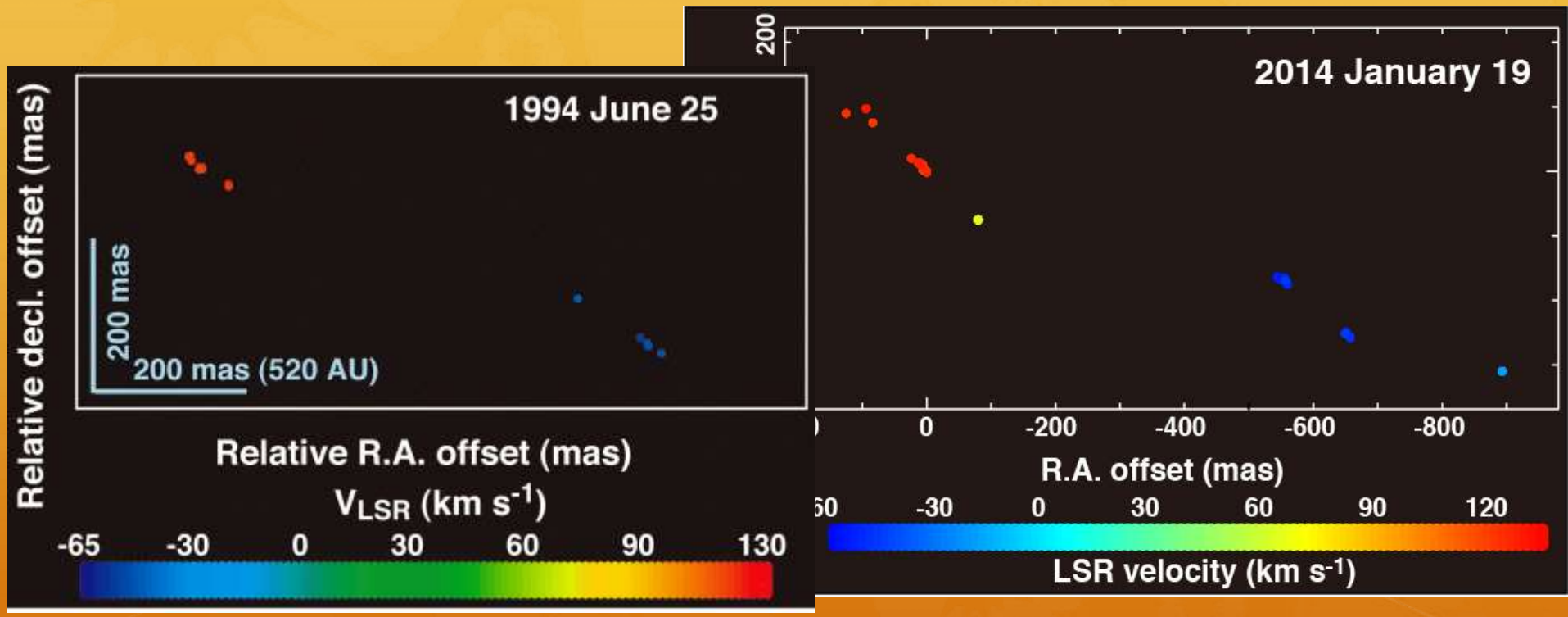
- giant gas clumps floating from giant convective cells
- jets or (non ballistic) spurs
- shock wave transfer

Still homework in ALMA/SKA era

SiO masers around TX Cam
(112 frames from 78 real observations (Gonidakis et al. 2013)

History of the water fountain W43A

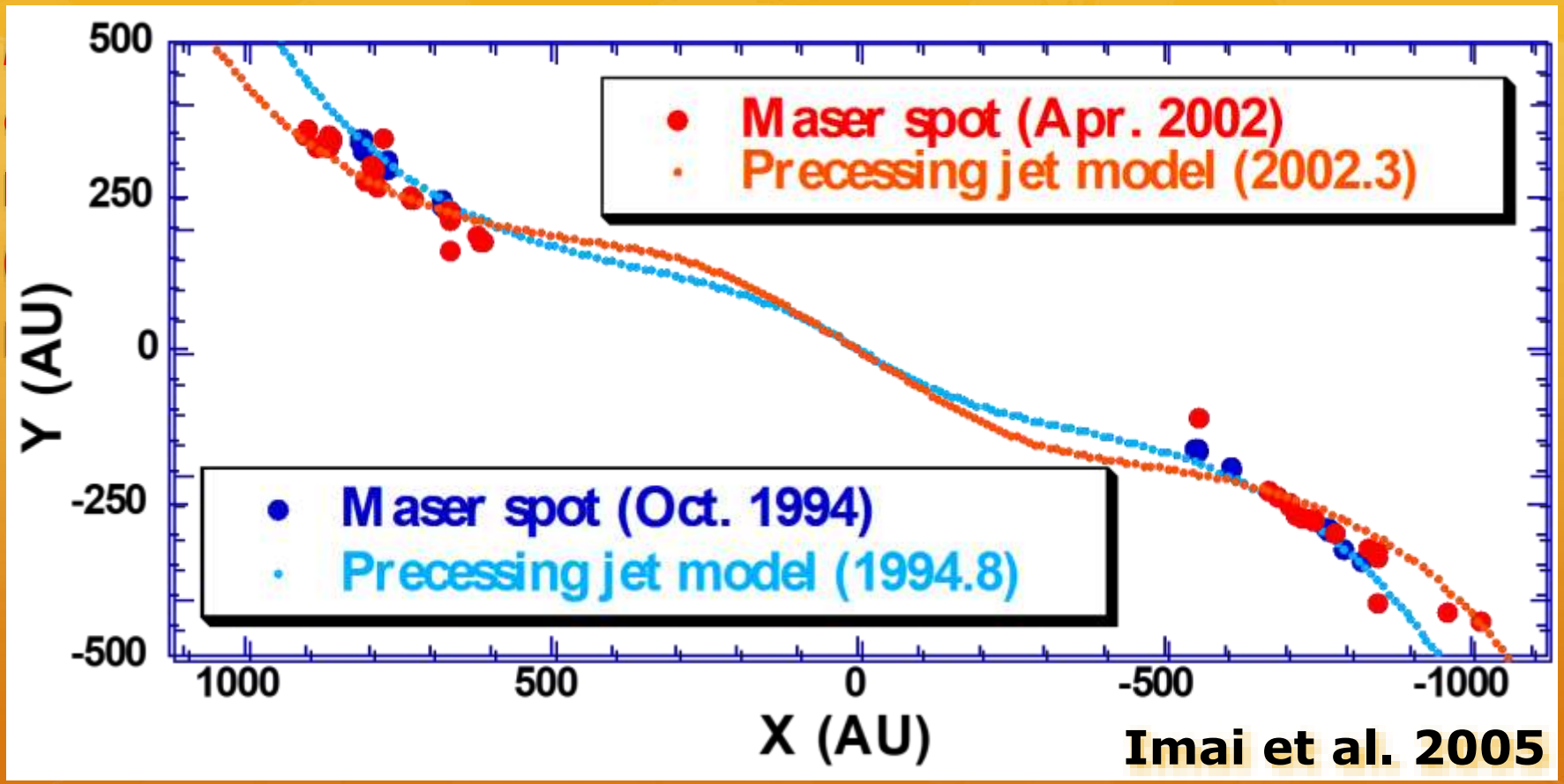
Decadal evolution of maser distribution and its interpretation



- Expansion of maser distribution → growth rate and dynamical age (<< true age of the whole jet)~length/proper motion for W43A
- Recurrent maser generation
- Morphology change: large deviation from a precessing jet model
- Distribution of "outlier" maser features

→ Equatorial, intermediate-velocity flow?

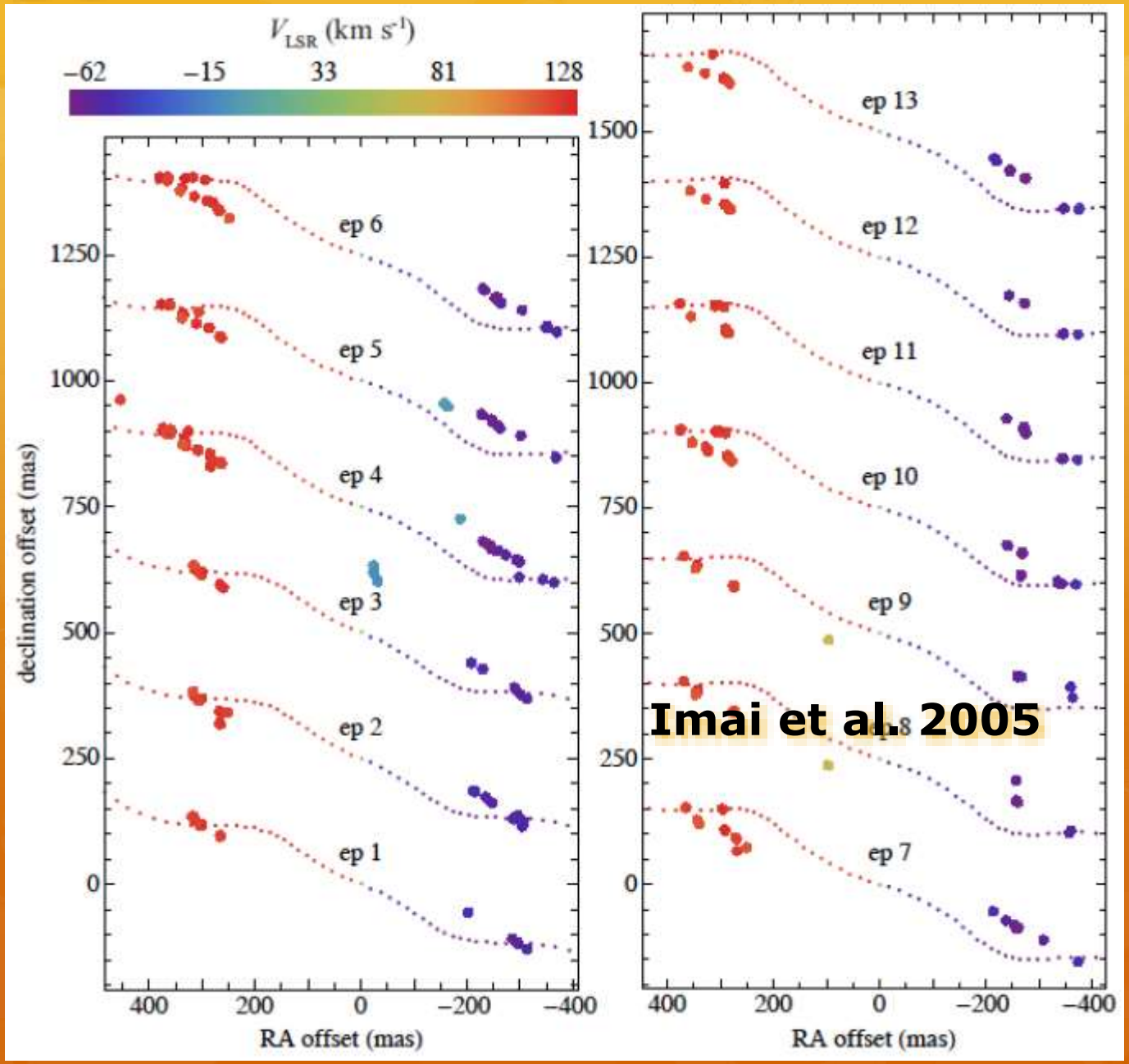
Precessing jet?



Imai (2007, IAUS 242)

Precessing jet ?????

Model parameters and the model Itself by Imai et al. (2002) are probably wrong.

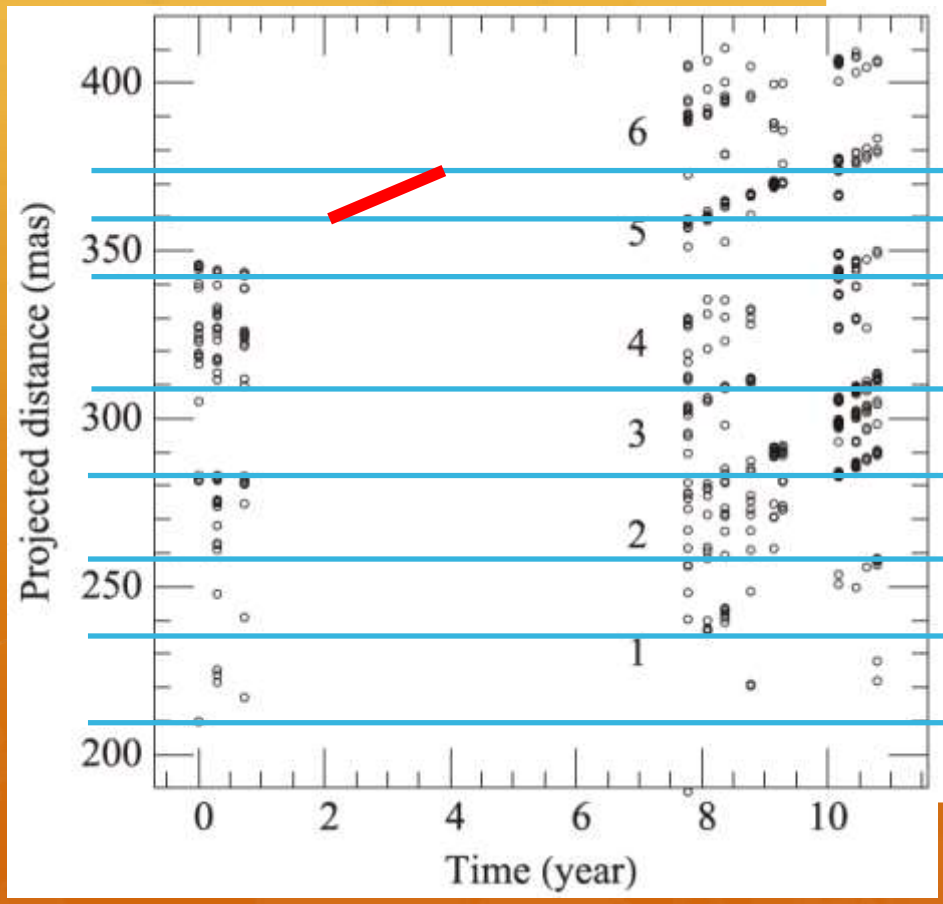


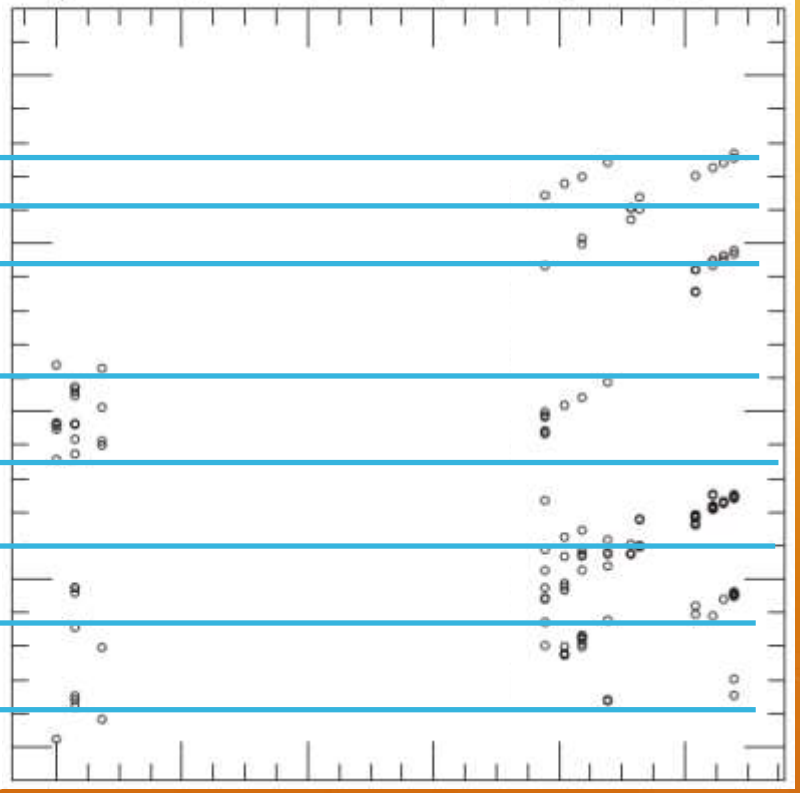
Chong et al. (2015)

Point symmetric, periodic (3—4 years) gas clump ejection?

c.f. Pulsation period ~400 d (Herman & Habing 1985)

Chong et al. (2015)

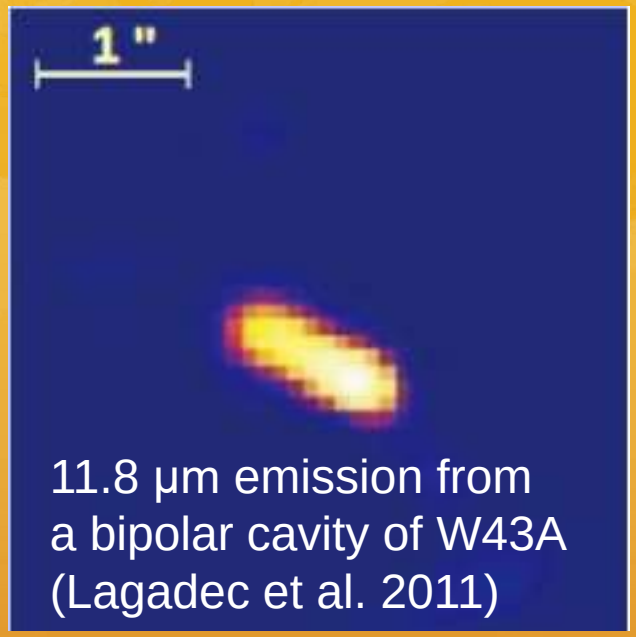




Blue -shifted (south-west) lobe

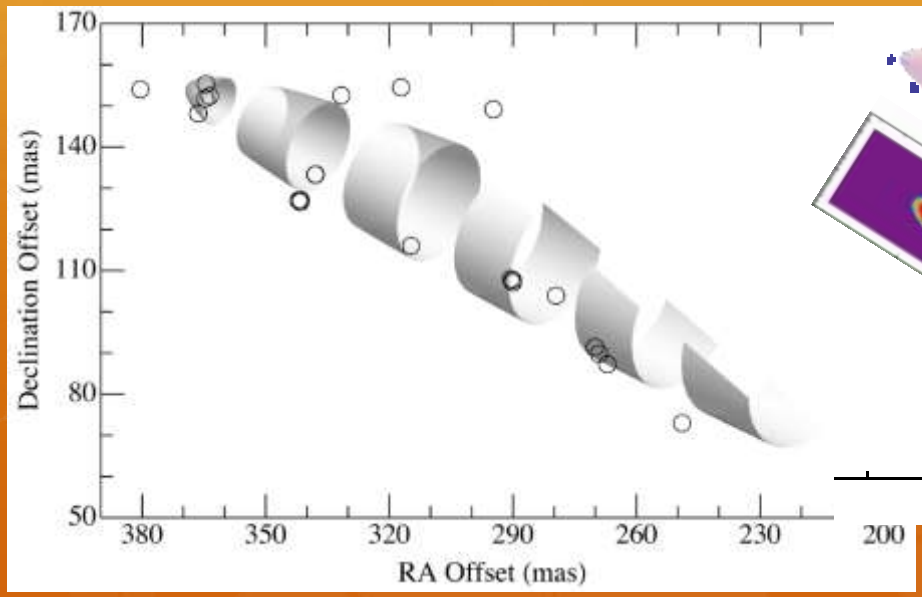
Red-shifted (north-east) lobe

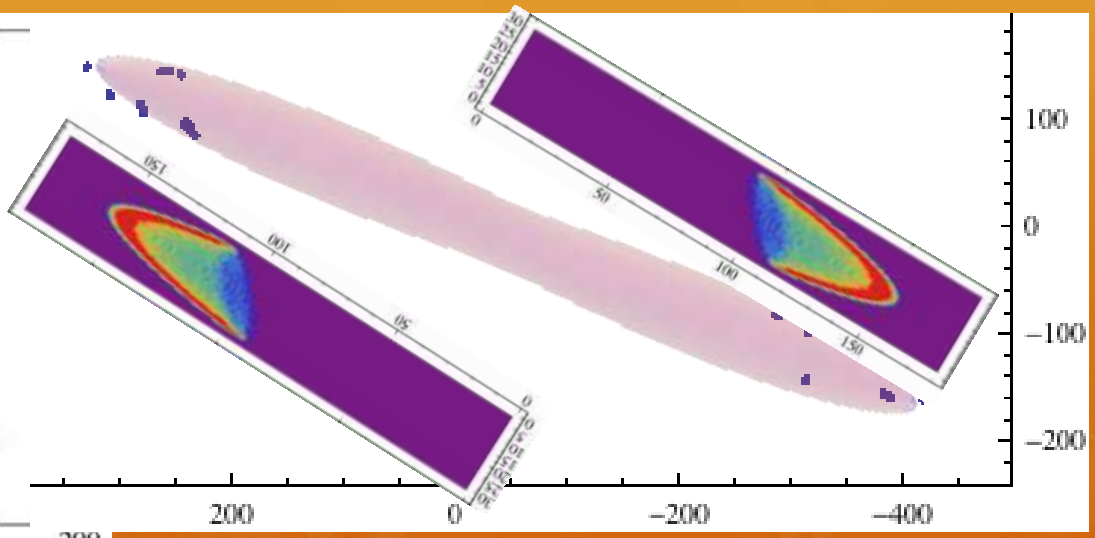
A new model of H_2O maser excitation region (Chong et al. 2015)



11.8 μm emission from a bipolar cavity of W43A (Lagadec et al. 2011)

- Bipolar cavity formed by past jet ejection
- New interaction of newly ejected jet at the cavity wall
- Periodic pattern of maser region produced by discontinuous ejection of jet or envelope

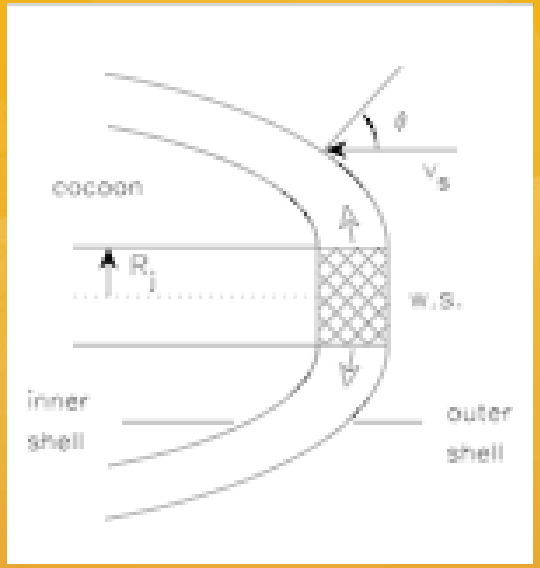




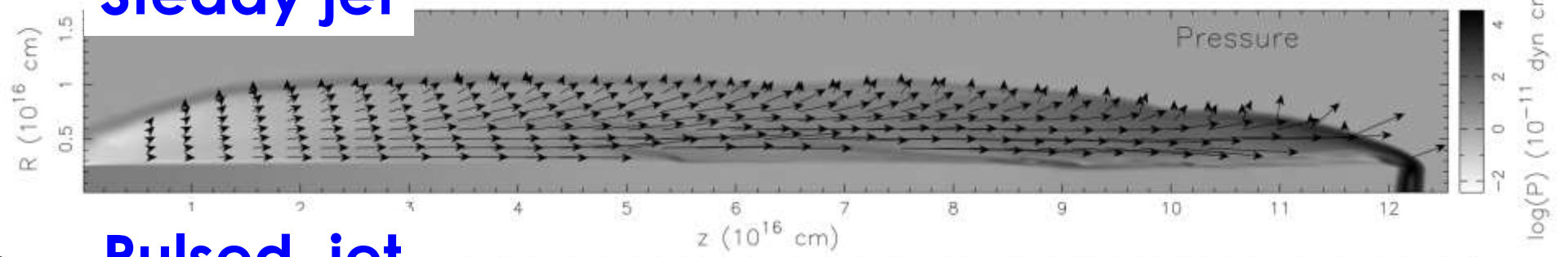
Ballistic bow shock model

- Formalization (Ostriker 2001)
- Simulations (Lee et al. 2001)
  steady v.s pulsed jets
- Application to water fountain jet to explain directions of maser motions and thickness of maser distribution

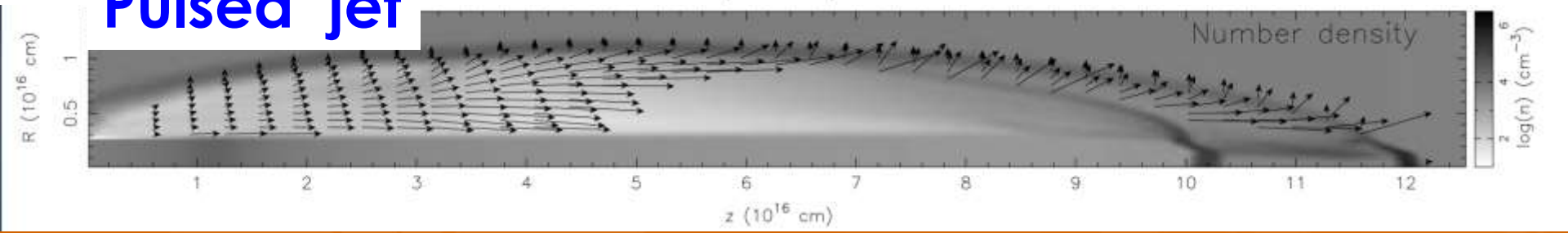
(Orosz et al. 2017 in prep.)



Steady jet



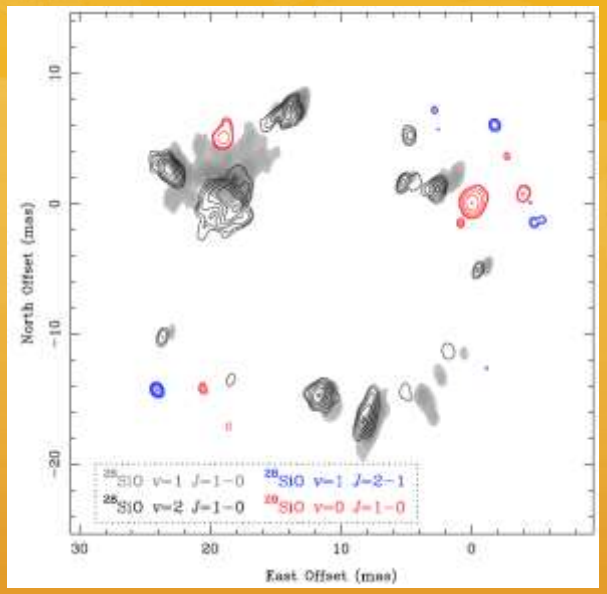
Pulsed jet



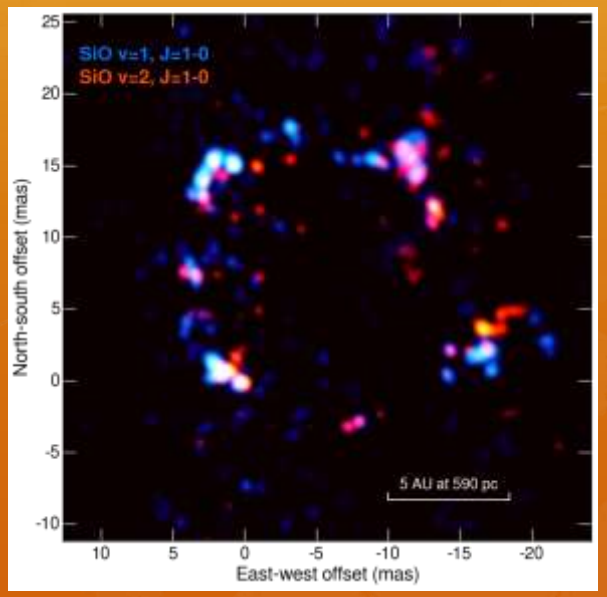
More confident examples!

See amazing results presented later in this session!

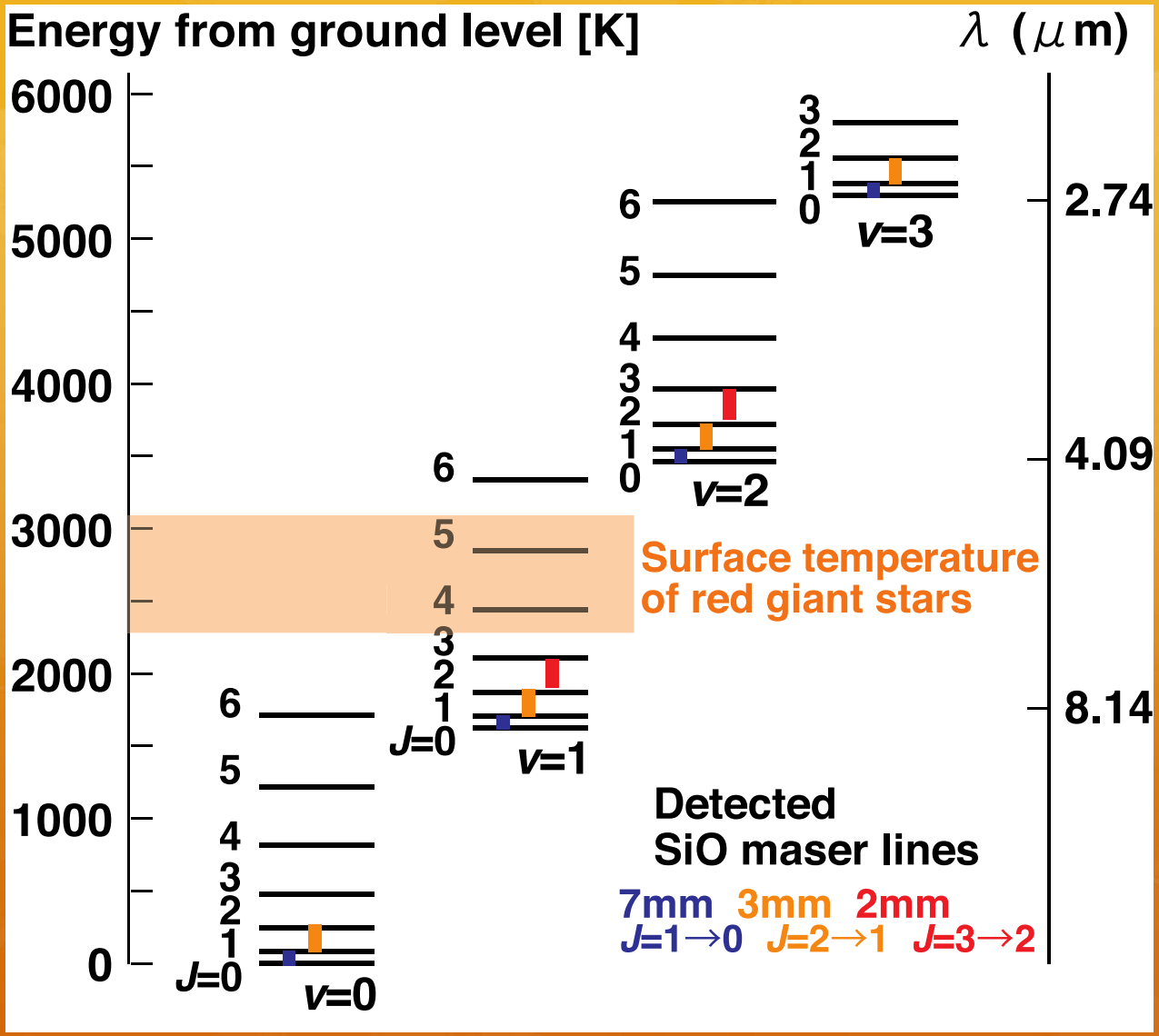
From monochromatic to colorful maser mapping



Soria-Ruiz et al. (2004)



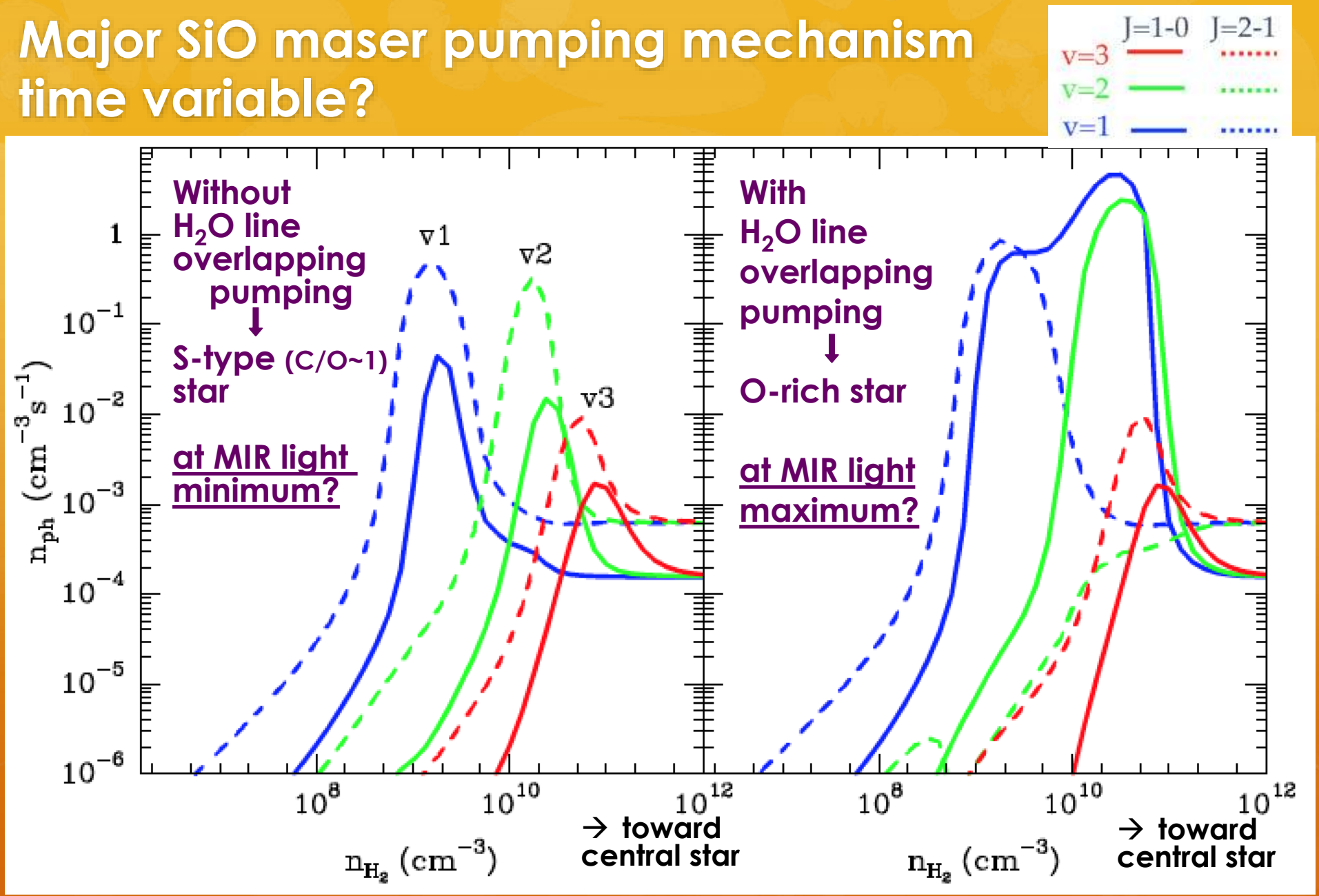
Yun et al. (2016)



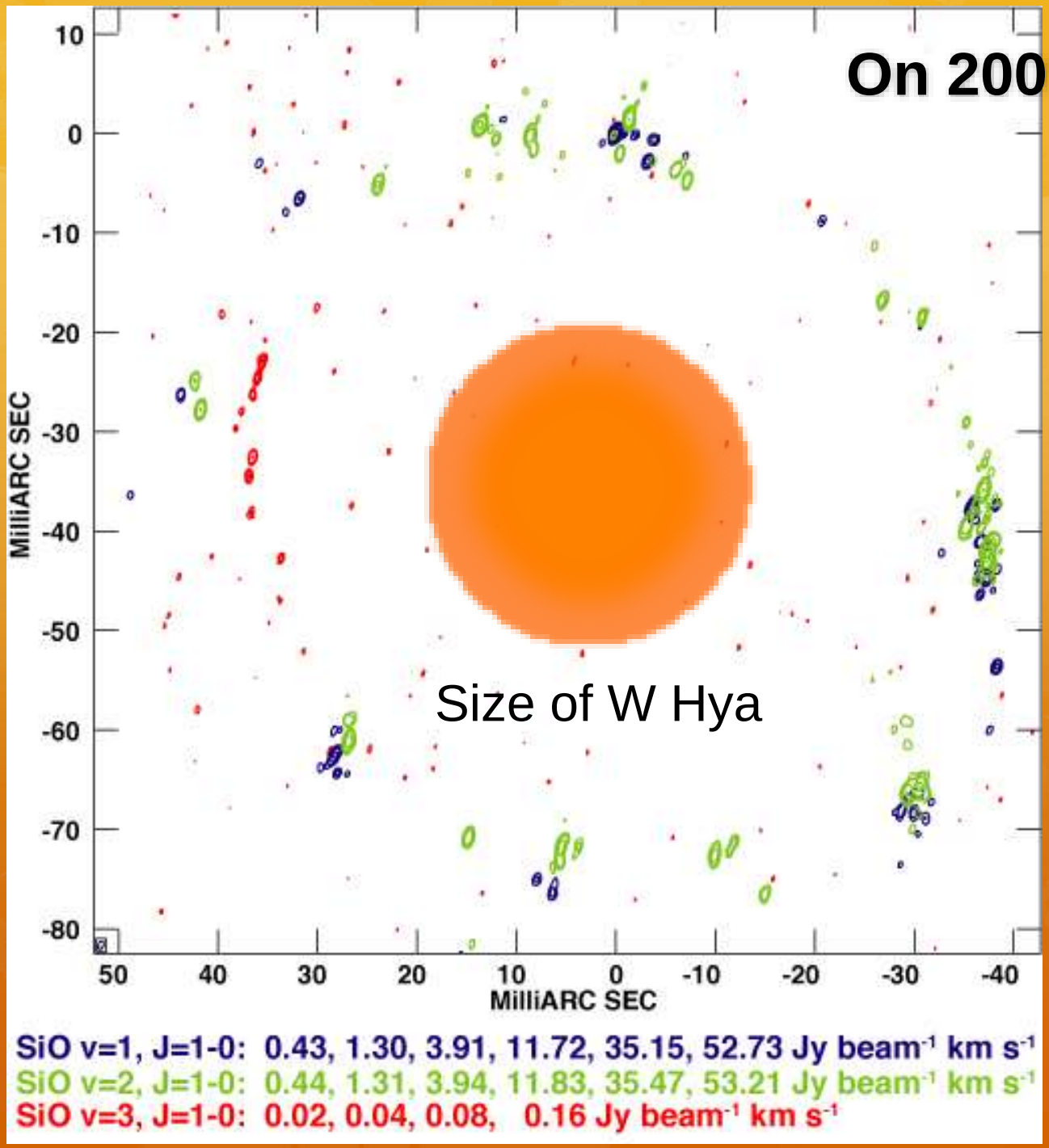
See presentations by Cho, Yoon, Yun (multi-band)

See poster by Oyama (wide-band)

Major SiO maser pumping mechanism time variable?

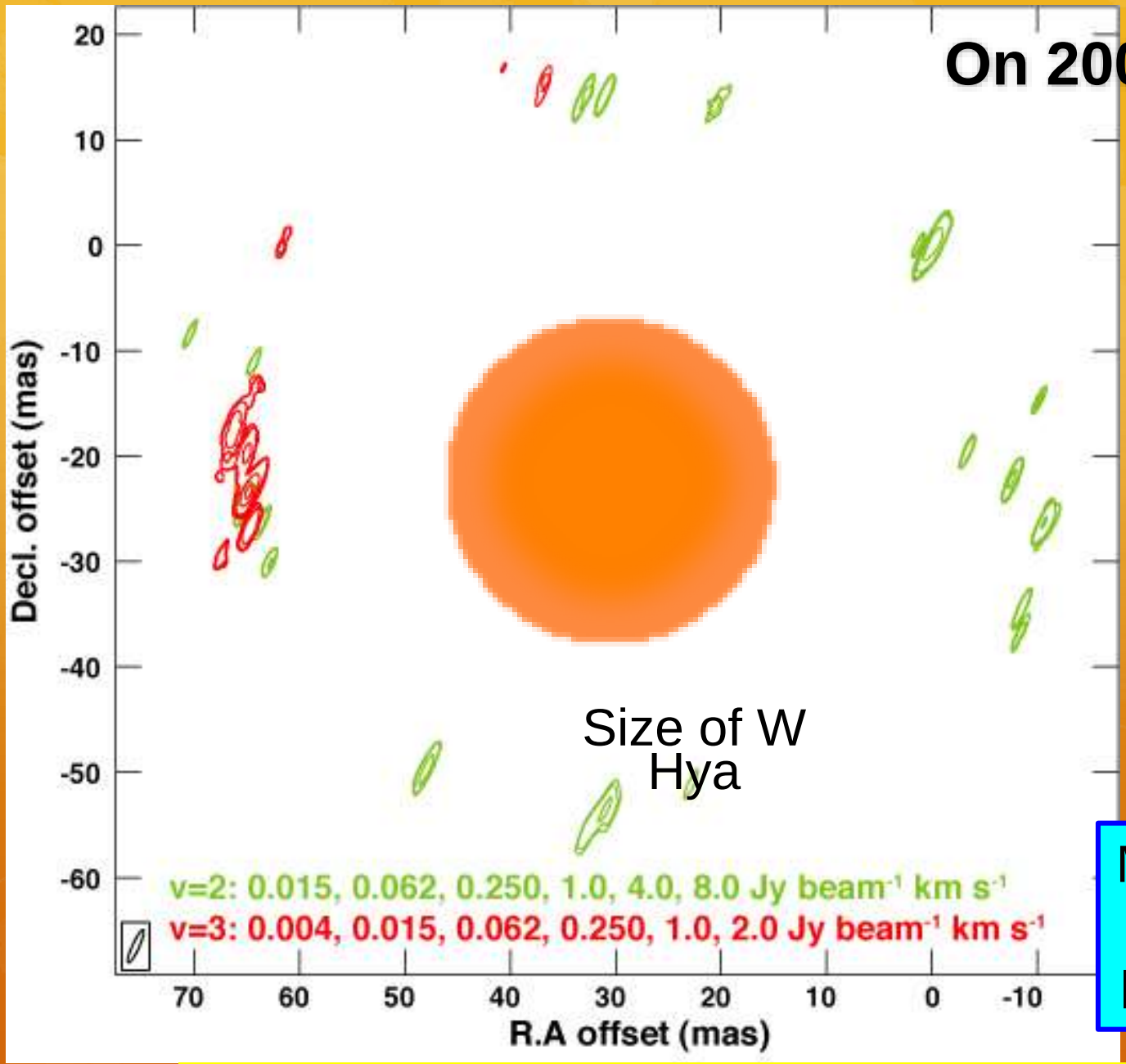


SiO *J*=1→0 models (Desmurs et al. 2014)



Imai et al. 2010

Map registration uncertainty less than 2 mas



On 2009 April 11-12

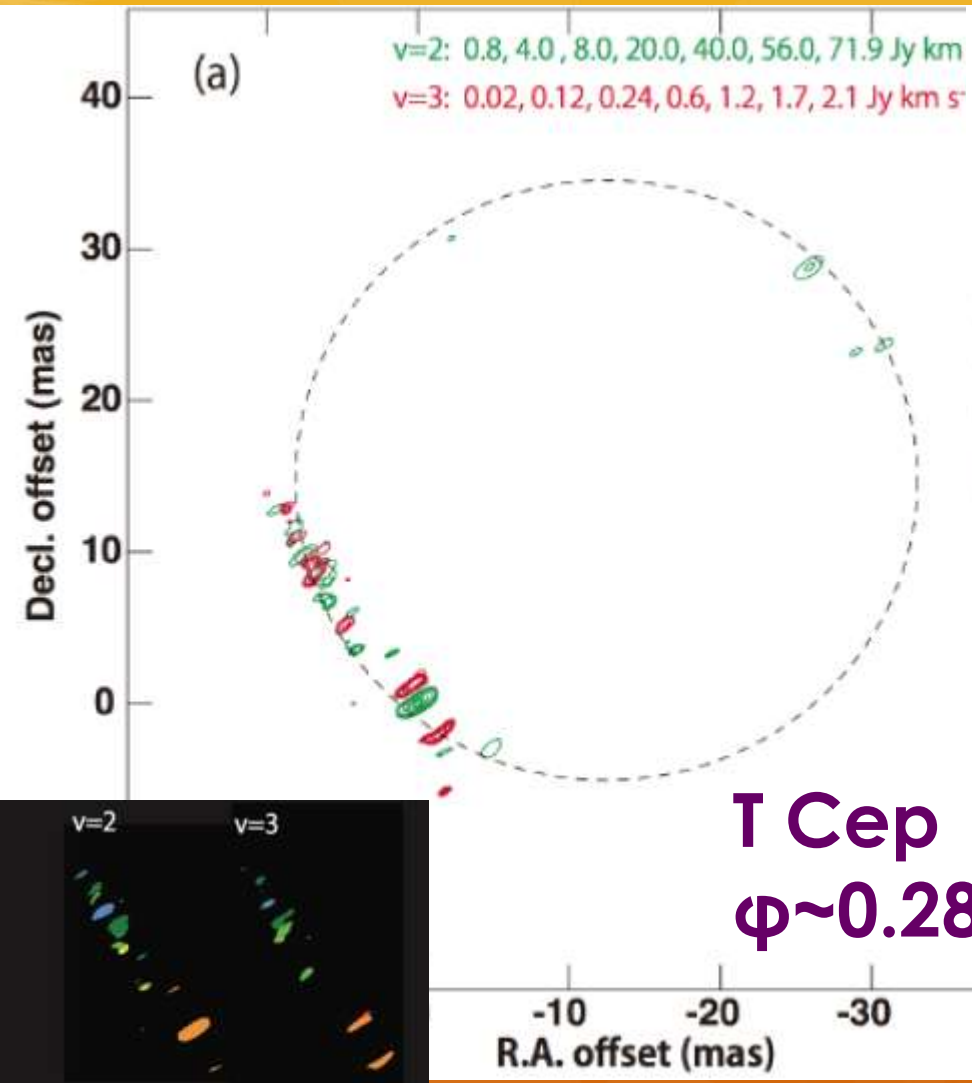
φ~0.22

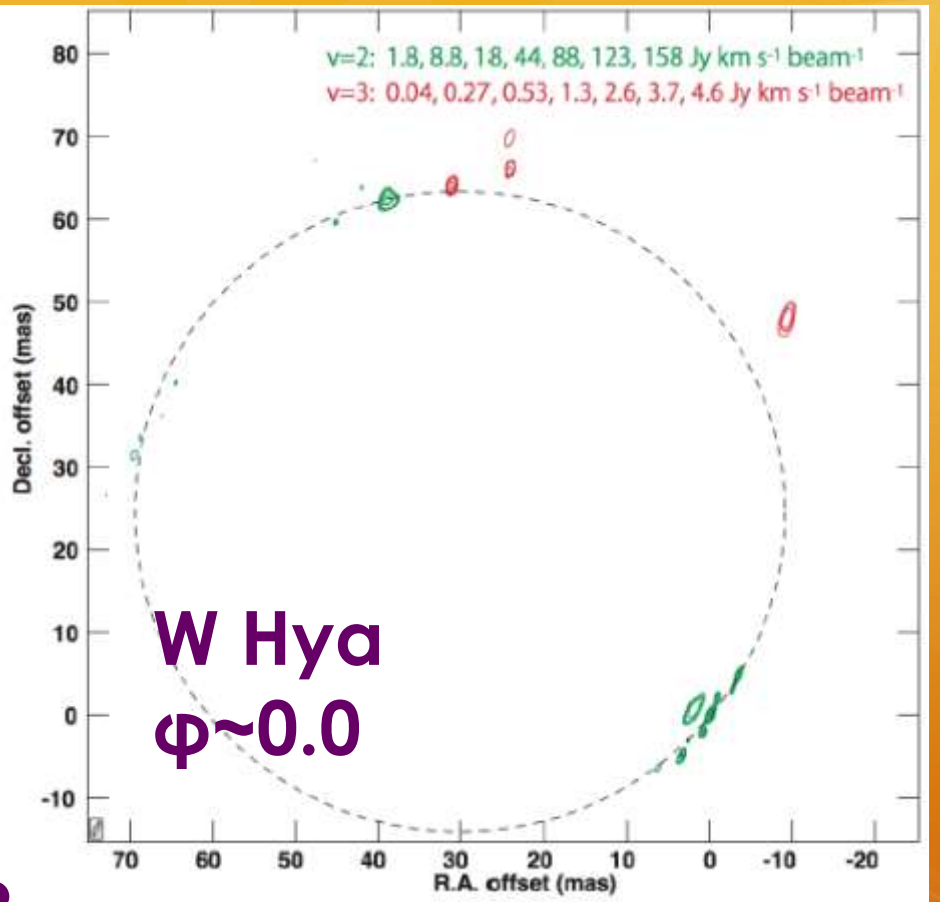
Imai et al. 2010

Map registration uncertainty less than 2 mas

Only the size of v=2 maser ring looks changed.

Large spatial offsets of *v*=3 SiO masers





Note: unseen extended maser components (See Desmurs's poster)

Oyadomari et al. (in prep.)

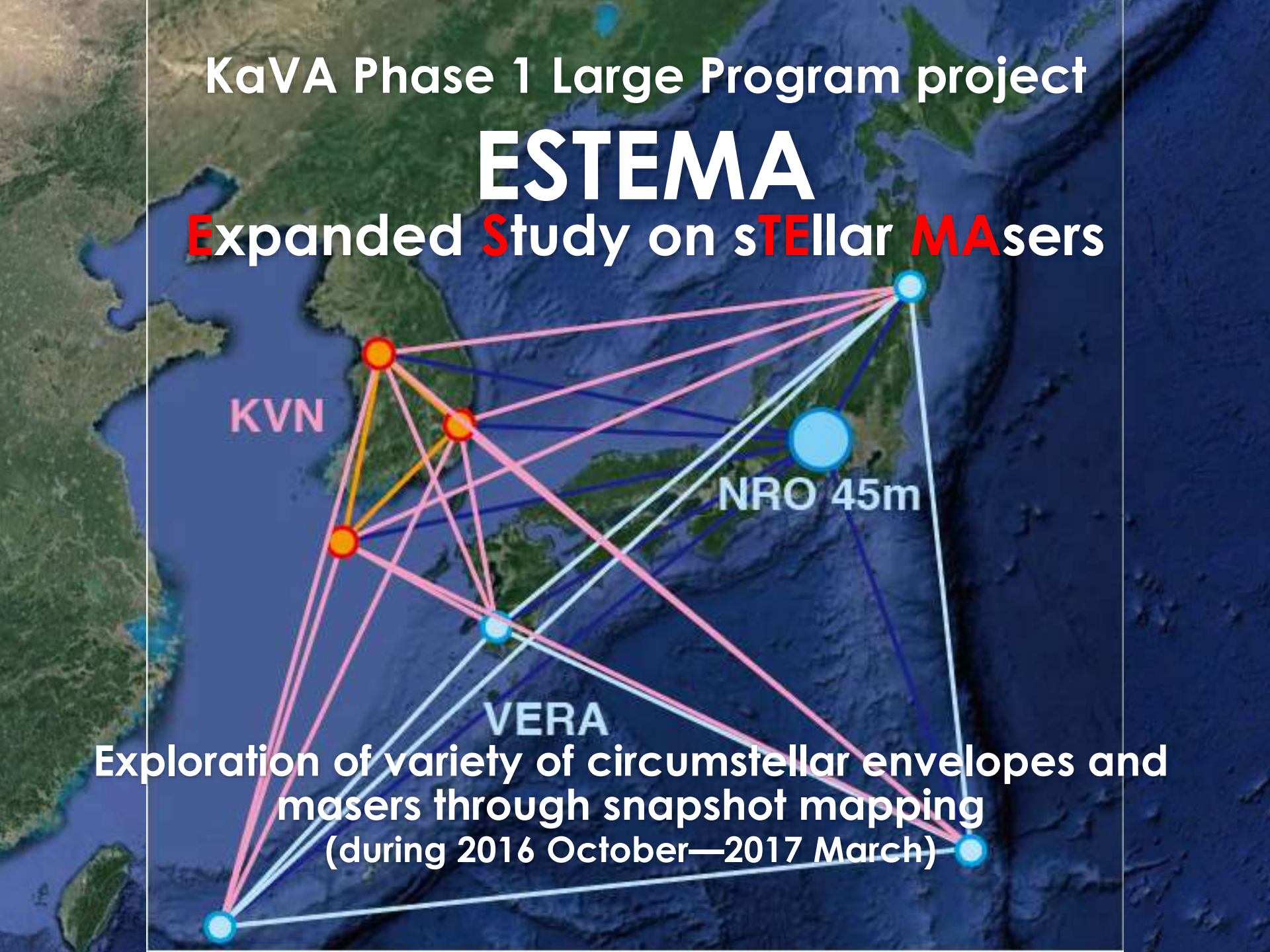
Which star should be a target of intensive monitoring VLBI observations?

Will the findings of their results universal?

KaVA Phase 1 Large Program project

ESTEMA

Expanded Study on sTEllar MAsers



Exploration of variety of circumstellar envelopes and masers through snapshot mapping

(during 2016 October—2017 March)

Target 80 stars in KaVA ESTEMA

See KaVA HP

ESTEMA source list (1st year)

No.	Maser source (Type)	Priority	R.A. (J2000)	Dec. (J2000)	*V*star (km/s)
41	RS Vir (Mi*)	A	14 27 16.39	+04 40 41.1	−14
46	U Her (Mi*)	A	16 25 47.47	+18 53 32.9	−15
51	AH Sco (SG)	A	17 11 17.02	−32 19 30.7	−13
53	RW Sco (Mi*)	A	17 14 51.68	−33 25 54.6	−70
86	V1111 Oph (Mi*)	A	18 37 19.26	+10 25 42.2	−30
99	RT Aql (Mi*)	A	19 38 01.60	+11 43 18.2	−33
111	OH83.42−0.89 (OH*)	A	20 50 58.60	+42 48 11.0	−39
116	IRC+60370 (Mi*)	A	22 49 59.20	+60 17 55.0	−54
118	MY Cep (SG)	A	22 54 31.71	+60 49 38.9	−50
119	V627 Cas (Sy*)	A	22 57 40.99	+58 49 12.5	−52
1	Y Cas (Mi*)	A	00 03 21.47	+55 40 51.8	−17
34	R UMa (Mi*)	A	10 44 38.47	+68 46 32.7	38
122	R Cas (Mi*)	A	23 58 24.87	+51 23 19.7	21
32	R Leo (Mi*)	A	09 47 33.49	+11 25 43.7	−1
57	OH358.23+0.11 (OH*)	A	17 40 53.40	−30 23 09.0	−10
70	V4201 Sgr (sr*)	A	17 53 18.80	−26 56 37.0	−4
103	IRAS 19422+3506 (OH*)	A	19 44 07.00	+35 14 08.2	−49
79	V5102 Sgr (sr*)	A	18 16 26.03	−16 39 56.4	48
88	IRC+00363 (Mi*)	A	18 41 25.00	−04 20 36.0	55
93	OH38.10−0.13 (pA*)	A	19 01 20.05	+04 32 31.6	53
100	IRAS 19371+2855 (OH*)	A	19 39 07.77	+29 02 38.6	24
52	V2108 Oph (Mi*)	A	17 14 19.39	+08 56 02.6	16
56	IRC−30308 (OH*)	A	17 38 40.49	−31 57 18.2	5
71	V4120 Sgr (Mi*)	A	18 03 56.54	−20 19 00.4	15
80	OH16.1−0.3 (pA*)	A	18 21 06.44	−15 03 29.8	22
16	U Ori (Mi*)	A	05 55 49.17	+20 10 30.7	−45
22	Z Pup (Mi*)	A	07 32 38.06	−20 39 29.1	3
27	R Cnc (Mi*)	A	08 16 33.83	+11 43 34.6	18
42	S CrB (Mi*)	A	15 21 23.93	+31 22 02.4	−1
4	*o* Cet (Mi*)	A	02 19 20.79	−02 58 37.4	47
15	S Col (Mi*)	A	05 46 56.31	−31 41 28.4	65
24	QX Pup (pA*)	A	07 42 17.16	−14 42 49.9	29
120	R Peg (Mi*)	A	23 06 39.17	+10 32 36.1	23
25	V353 Pup (sr*)	A	07 46 34.15	−32 18 16.3	28
26	HU Pup (sr*)	A	07 55 40.16	−28 38 54.8	44
30	IW Hya (Mi*)	A	09 45 15.24	−22 01 45.3	46
20	IRC−10151 (OH*)	A	07 07 49.38	−10 44 05.9	45
36	R Crt (sr*)	A	11 00 33.85	−18 19 29.6	11
37	RT Vir (sr*)	A	13 02 37.98	+05 11 08.4	15
40	RX Boo (sr*)	A	14 24 11.84	+25 42 21.1	1

Group 1
Group 2
Group 3 *
Group 4
Group 5
Group 6
Group 7
Group 8
Group 9 *
Group 10 *

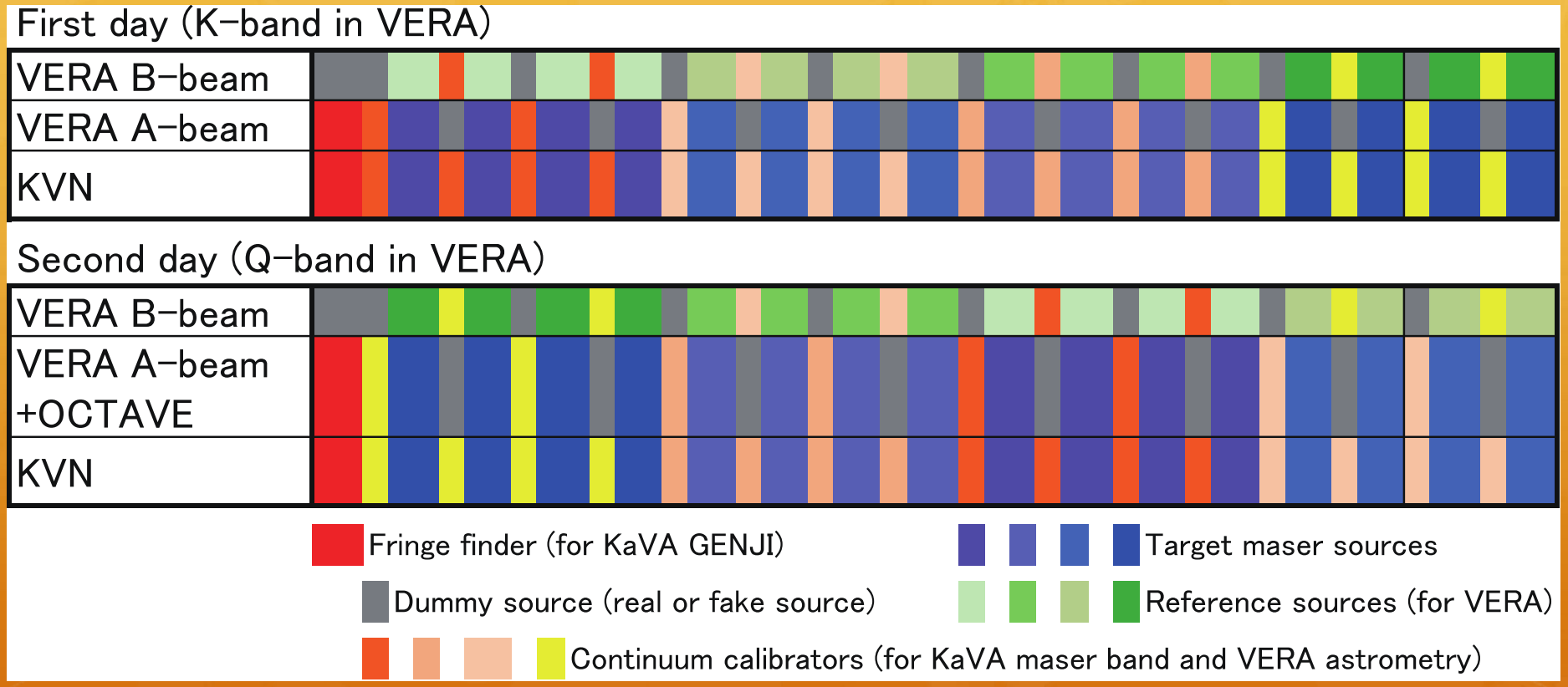
* Group 3, 9, 10 can be grouped together in a 2x15h session

ESTEMA source list (2nd semester, Priority B)

Group	No.	Maser source (Type)	Priority	R.A. (J2000)	Dec. (J2000)	*V*star (km/s)
B1	6	RR Per (Mi*)	B	02 28 29.40	+51 16 17.3	9
B1	11	BW Cam (Mi*)	B	05 19 52.56	+63 15 55.8	50
B1	19	GX Mon (Mi*)	B	06 52 47.04	+08 25 19.2	−8
B1	23	OZ Gem(Mi*)	B	07 33 57.75	+30 30 37.8	7
B2	2	V524 Cas (Mi*)	B	00 46 00.12	+69 10 53.4	−27
B2	109	IRAS 20381+5001 (Mi*)	B	20 39 39.60	+50 12 15.0	−38
B2	115	AM Cep (Mi*)	B	21 41 27.08	+76 23 11.3	−50
B2	117	V386 Cep (sr*)	B	22 53 12.33	+61 17 00.4	−49
B3	17	AP Lyn (Mi*)	B	06 34 33.92	+60 56 26.2	−23
B3	18	U Lyn (Mi*)	B	06 40 46.49	+59 52 01.6	−16
B3	29	X Hya (Mi*)	B	09 35 30.27	−14 41 28.6	27
B3	33	V Ant (Mi*)	B	10 21 09.11	−34 47 18.7	−18
B4	35	VX UMa (Mi*)	B	10 55 39.88	+71 52 09.8	−50
B4	40	RX Boo (sr*)	B	14 24 11.84	+25 42 21.1	1
B4	44	WX Ser (Mi*)	B	15 27 47.38	+19 33 42.9	7
B4	47	T Oph (Mi*)	B	16 33 43.54	−16 07 54.3	−33
B5	66	MHSOM100	B	17 48 18.11	−28 07 38.9	111
B5	76	OH10.1−0.1 (pA*)	B	18 08 16.38	−20 16 11.6	52
B5	87	V438 Sct (Mi*)	B	18 41 14.33	−06 15 00.7	71
B5	89	IRC+00364 (IR)	B	18 42 08.43	−02 45 15.4	50
B6	49	V446 Oph (sr*)	B	16 46 39.11	−11 38 53.1	10
B6	54	IRAS 17187−3750 (IR)	B	17 22 11.20	−37 53 13.0	−26
B6	82	UY Sct (sr*)	B	18 27 36.53	−12 27 58.9	26
B6	102	V1415 Aql (Mi*)	B	19 43 45.29	+03 44 30.4	−31
B7	55	IRAS17313−1531	B	17 34 10.80	−15 33 02.0	−49
B7	62	MHSOM75	B	17 46 12.46	−28 07 05.3	−39
B7	68	V2211 Oph (Mi*)	B	17 51 09.95	−08 01 21.3	−20
B7	90	V837 Her (Mi*)	B	18 43 36.47	+13 57 22.8	−9
B8	72	IRC−20427 (Mas)	B	18 05 35.49	−21 13 42.2	17
B8	73	IRC−10395 (IR)	B	18 06 42.88	−08 13 12.0	20
B8	77	V2302 Oph (Mi*)	B	18 09 18.55	+09 12 15.6	−13
B8	84	OH24.7+0.2 (OH*)	B	18 35 29.20	−07 13 08.0	42
B9	92	V1366 Aql (Mi*)	B	18 58 30.09	+06 42 57.8	20
B9	98	UV Cyg (sr*)	B	19 31 13.28	+43 38 13.6	33
B9	105	OH65.4+1.3 (OH*)	B	19 51 21.20	+29 13 01.3	−21
B9	108	V1828 Cyg (Mi*)	B	20 36 57.04	+37 52 33.9	−2
B10	101	V391 Cyg (Mi*)	B	19 40 52.39	+48 47 41.5	−20
B10	106	V468 Cyg (Mi*)	B	19 55 38.15	+32 45 33.8	−45
B10	112	UX Cyg (Mi*)	B	20 55 05.52	+30 24 52.1	2
B10	121	R Aqr (Sy*)	B	23 43 49.46	−15 17 04.1	−21

Scan pattern in KaVA/ESTEMA observations

First two hours of schedule block



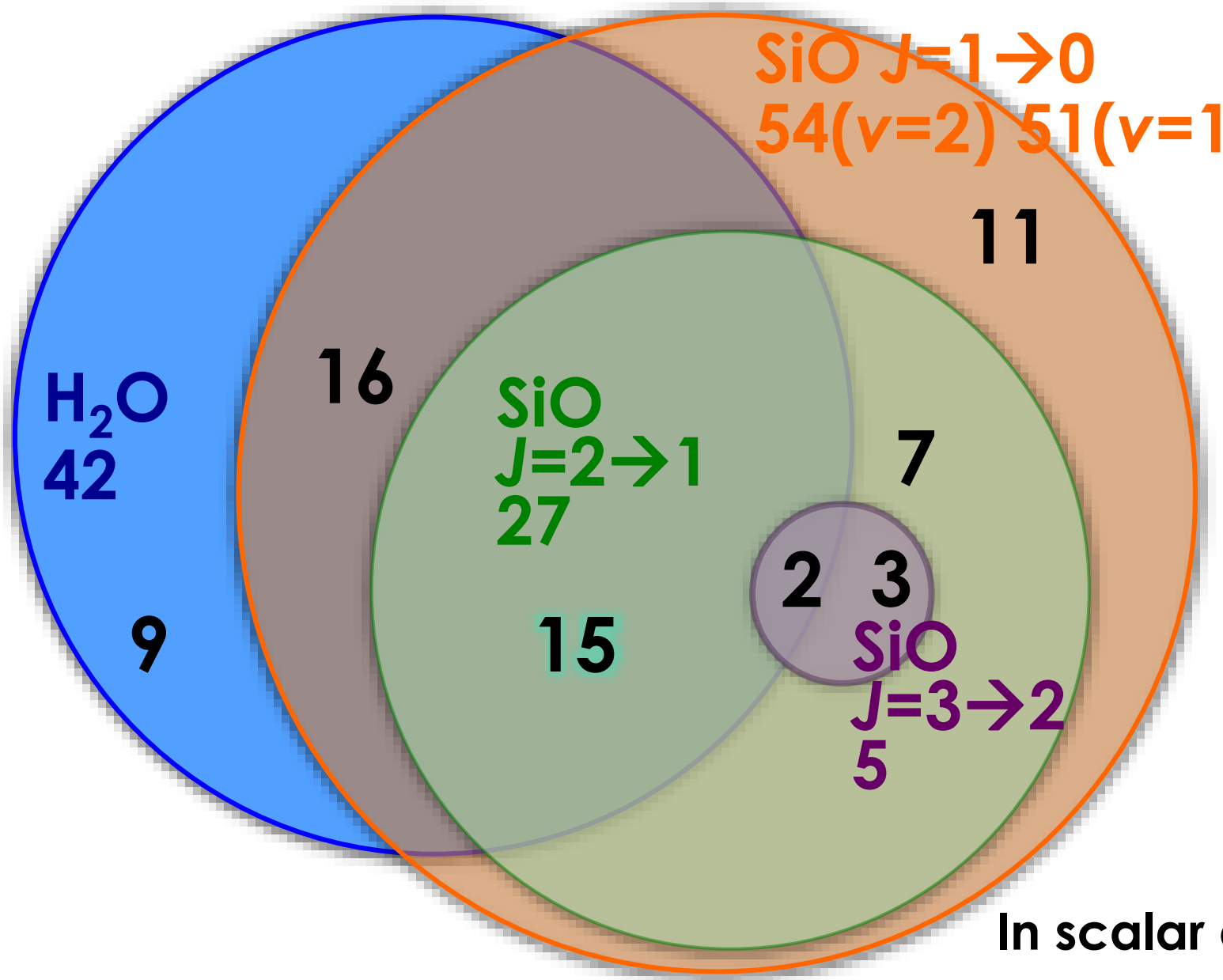
6-9 hours of schedule block per session observing 4—6 sources

20 pairs of K/Q-band sessions with VERA

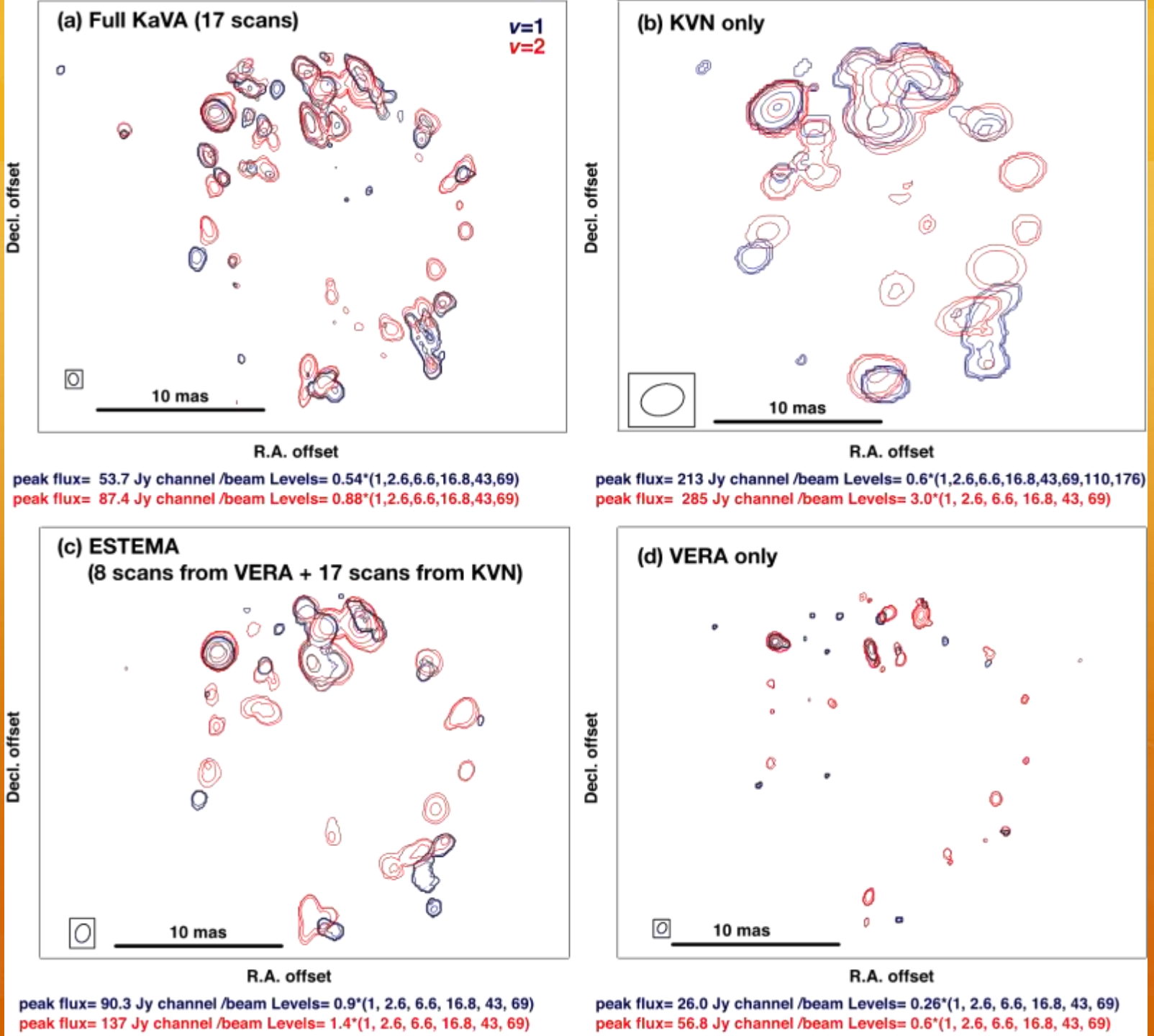
Data concatenation between two-day sessions in KVN

Mapping 6 (+2) H_2O and SiO maser lines

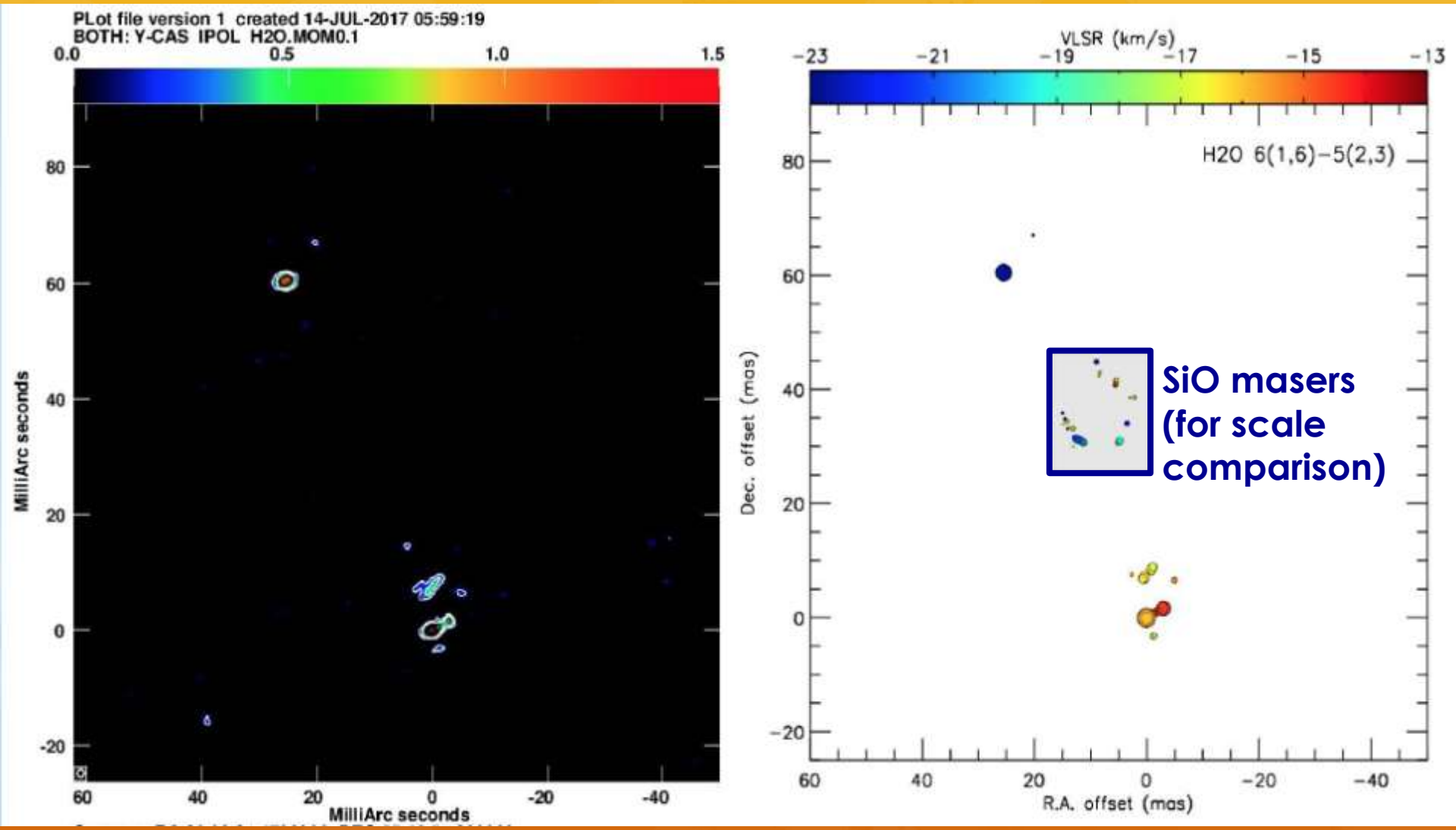
Venn diagram of VLBI fringe detections of ESTEMA circumstellar maser source



In scalar averaging

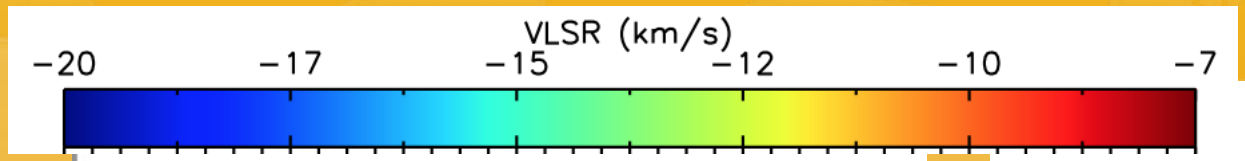

(a) Full KaVA (17 scans)
v=1
v=2
10 mas
Decl. offset
R.A. offset
peak flux= 53.7 Jy channel /beam Levels= 0.54*(1,2.6,6.6,16.8,43,69)
peak flux= 87.4 Jy channel /beam Levels= 0.88*(1,2.6,6.6,16.8,43,69)
(b) KVN only
10 mas
Decl. offset
R.A. offset
peak flux= 213 Jy channel /beam Levels= 0.6*(1,2.6,6.6,16.8,43,69,110,176)
peak flux= 285 Jy channel /beam Levels= 3.0*(1, 2.6, 6.6, 16.8, 43, 69)
(c) ESTEMA
(8 scans from VERA + 17 scans from KVN)
10 mas
Decl. offset
R.A. offset
peak flux= 90.3 Jy channel /beam Levels= 0.9*(1, 2.6, 6.6, 16.8, 43, 69)
peak flux= 137 Jy channel /beam Levels= 1.4*(1, 2.6, 6.6, 16.8, 43, 69)
(d) VERA only
10 mas
Decl. offset
R.A. offset
peak flux= 26.0 Jy channel /beam Levels= 0.26*(1, 2.6, 6.6, 16.8, 43, 69)
peak flux= 56.8 Jy channel /beam Levels= 0.6*(1, 2.6, 6.6, 16.8, 43, 69)

ESTEMA imaging performance



H_2O masers around Y Cas (Mapped by Jaeheon Kim)

ESTEMA imaging performance



10 mas

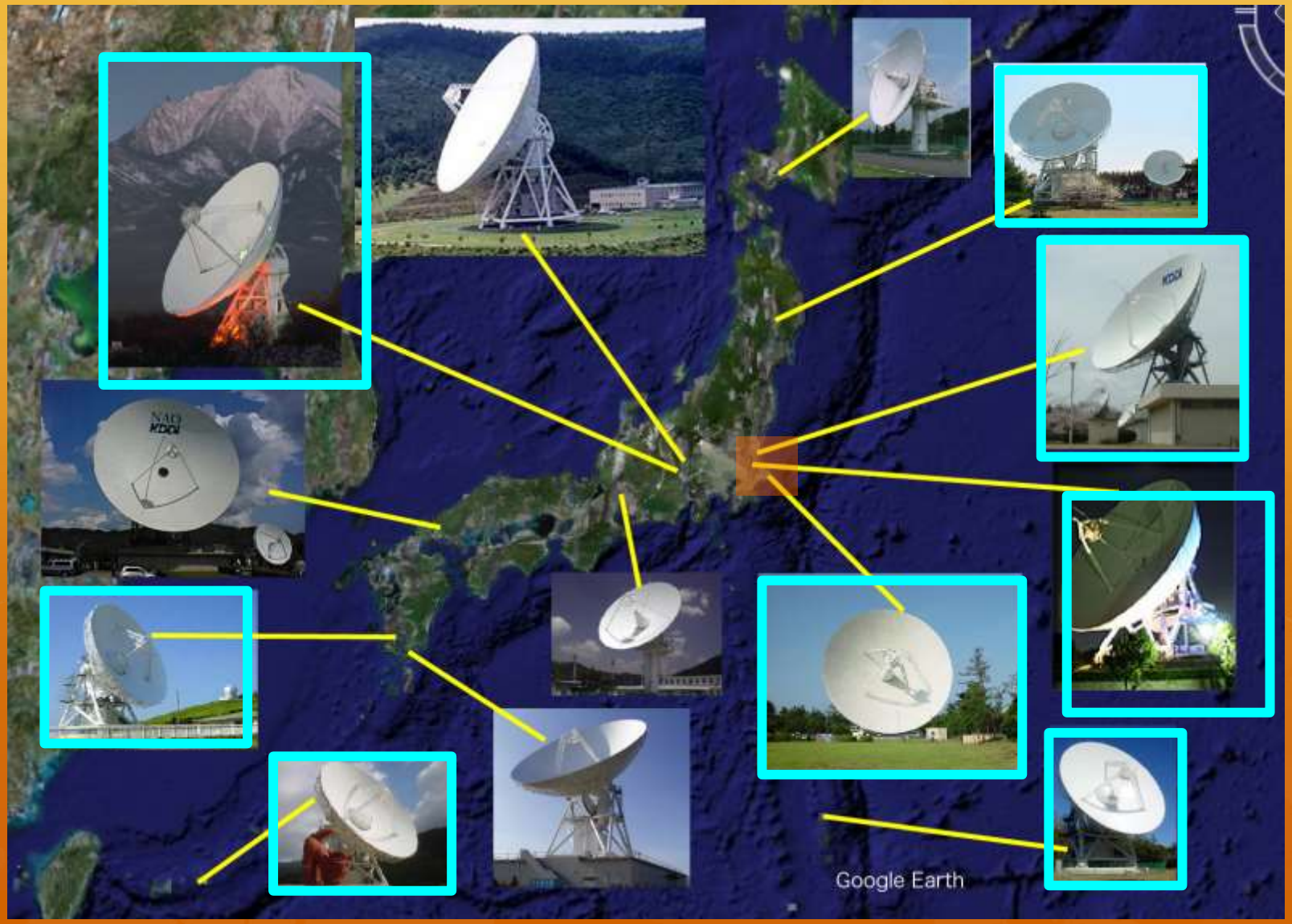
SiO
v=2 *J*=1→0

SiO
v=1 *J*=1→0

SiO *J*=1→0 masers around Y Cas (mapped by Jaeheon Kim)

H_2O maser distributions always biased?

JVN Campaign of circumstellar H_2O masers (2016 May 15—16, 50 hours, 20 stars)



Summary

Towards decadal continuous viewing of circumstellar maser sources: one science case of time-domain astronomy

- Episodic outbursts and/or intermittent mass ejections of AGB and post-AGB stars with stellar pulsation are seen in decadal scale, comparable to lifetimes of VLBI observatories and astronomers.
- ESTEMA provides a sufficient number (~20) of target sources for decadal intensive VLBI monitoring observations of circumstellar masers.
- Tracing motions of individual tiny and clumpy structures of CSEs enables us to explore the origins of the motions leading to understand the microscopic physics of mass loss and internal evolution of pulsating stars.
- Time domain astronomy in VLBI on circumstellar masers will be a unique application in the era of ALMA/SKA/ngVLA.

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  - EAVN Science Working Group on Evolved Stars
  - HINOTORI team
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