Simultaneous observations of the H2O and SiO masers toward the late-type stars using KVN

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and KVN KSP members

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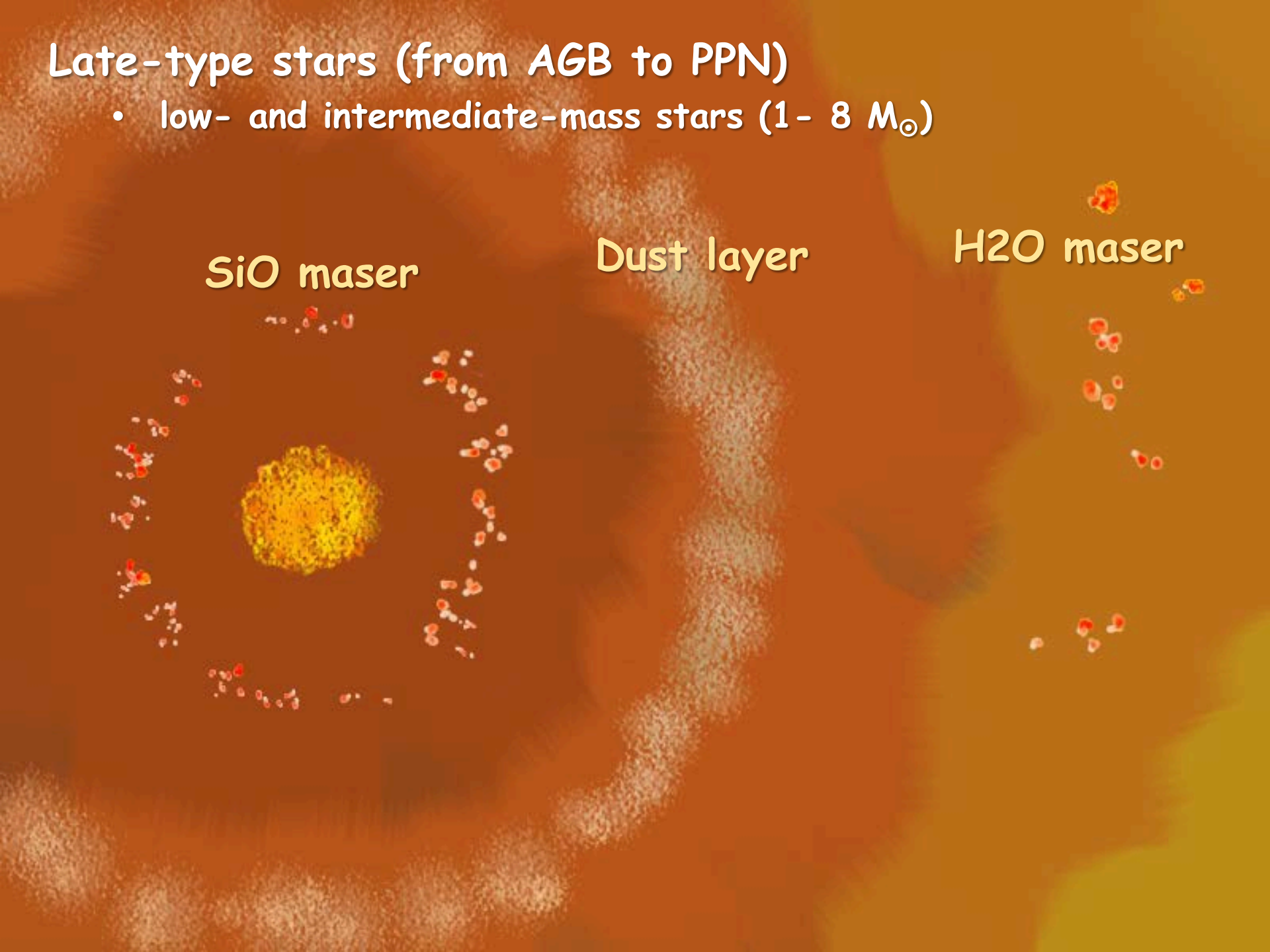
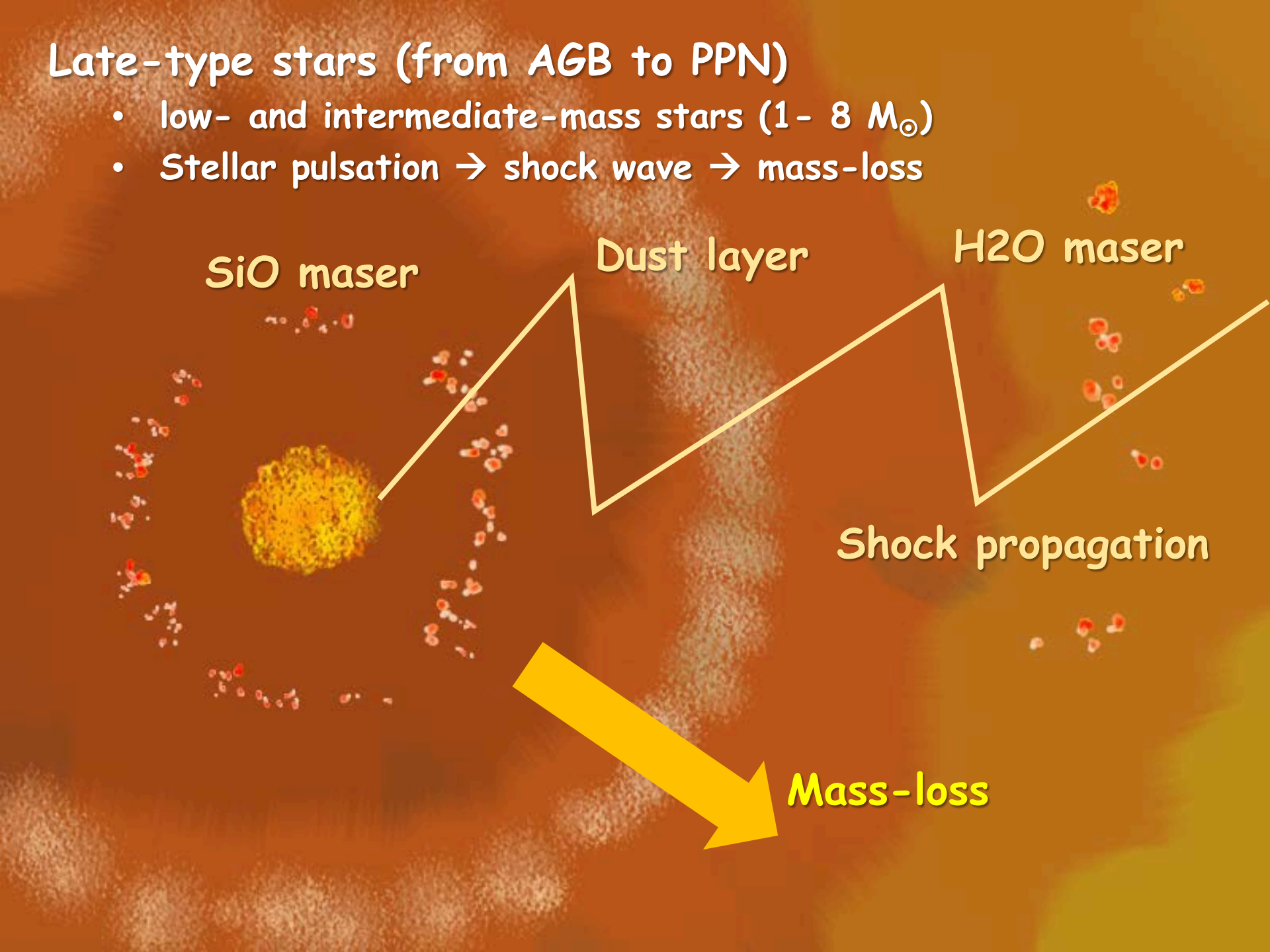
Late-type stars (from AGB to PPN)

- low- and intermediate-mass stars (1- 8 $M_\odot$)



Late-type stars (from AGB to PPN)

- low- and intermediate-mass stars (1- 8 $M_\odot$)
- Stellar pulsation → shock wave → mass-loss

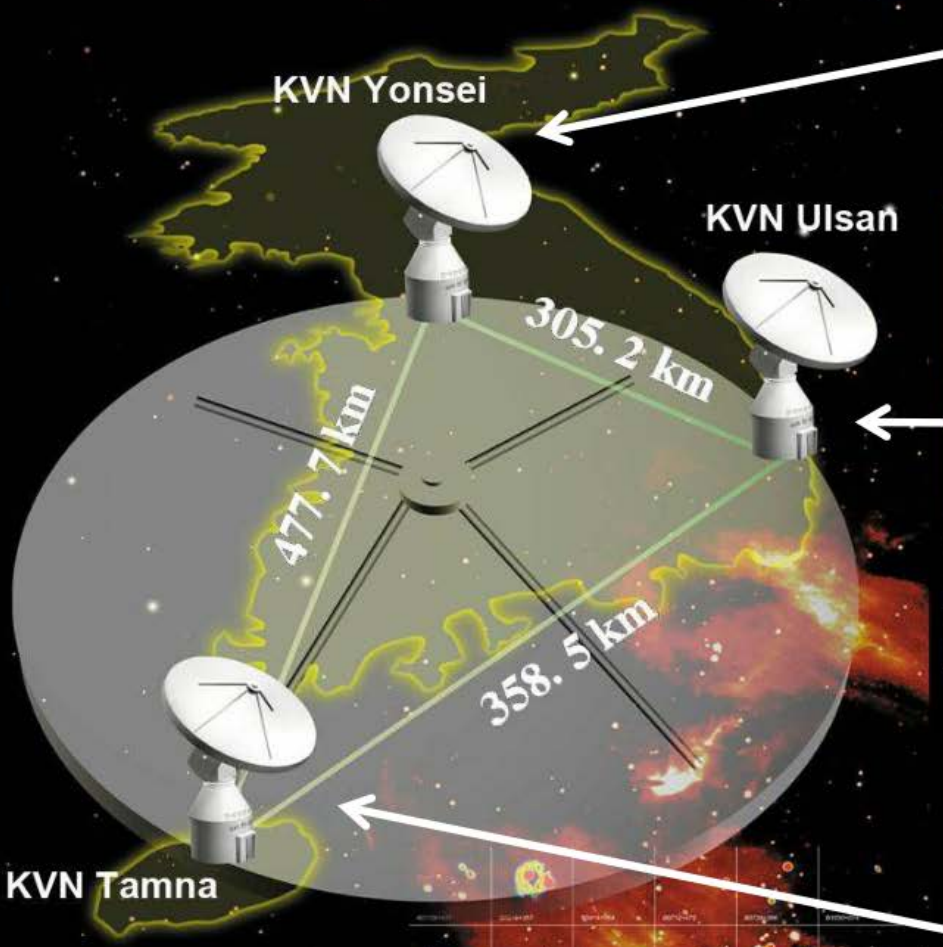


Scientific goals

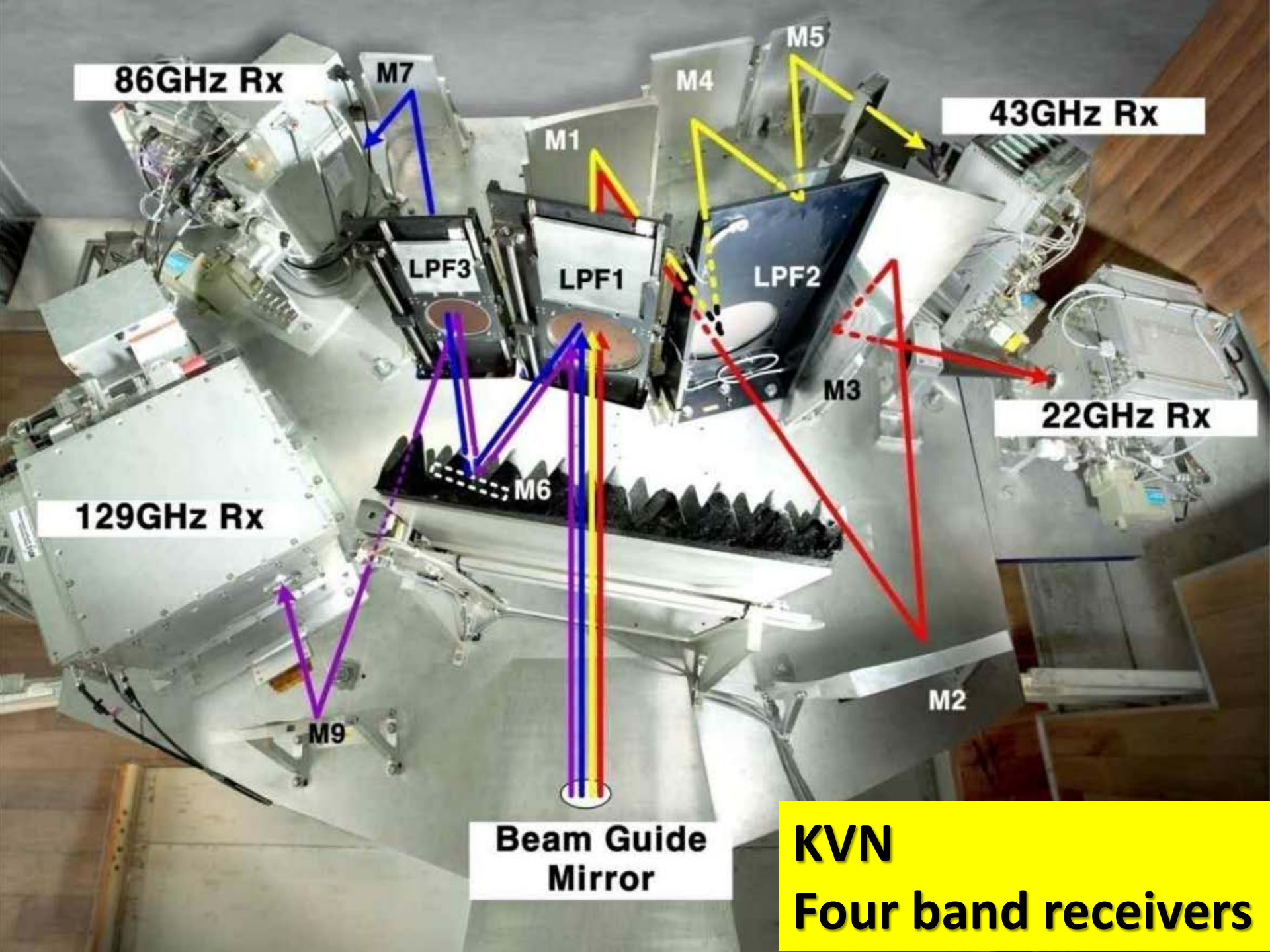
- **Spatial distributions of the different masers**
  - **H_2O and SiO masers**
  - **SiO masers of different rotational states (J=1-0, J=2-1, J=3-2)**
  - **SiO masers of different vibrational states (v=1, v=2, v=3)**

- **To study**
  - ✓ **Physical environments of CSEs**
  - ✓ **Dynamical links between the inner and outer parts of CSEs**
  - ✓ **Maser-variability driven by the stellar pulsation**
  - ✓ **Pumping mechanisms of the stellar masers**
  - ✓ **Mass-loss processes and stellar evolution**

KVN Korean VLBI Network

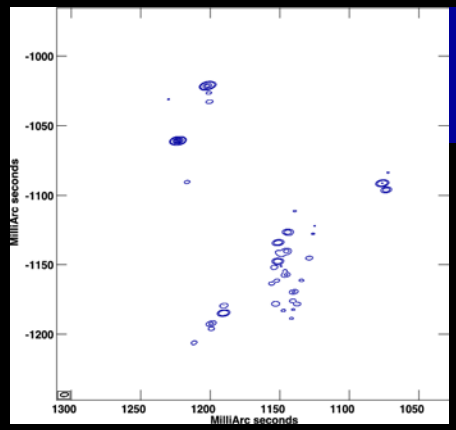


한국천문연구원
대덕전파천문대 KVN사업본부

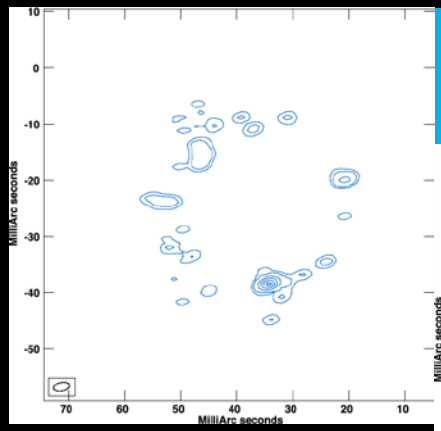


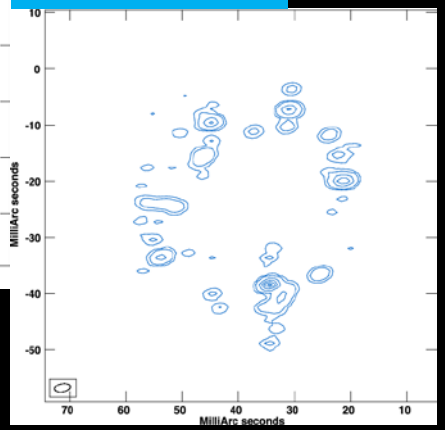
KVN
Four band receivers

Simultaneous observations at four frequency-bands

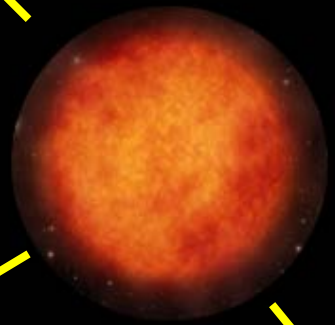


22 GHz
H2O maser

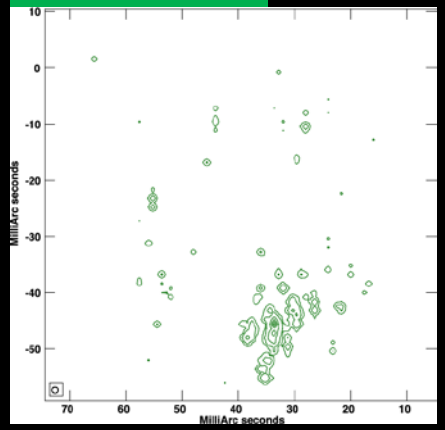


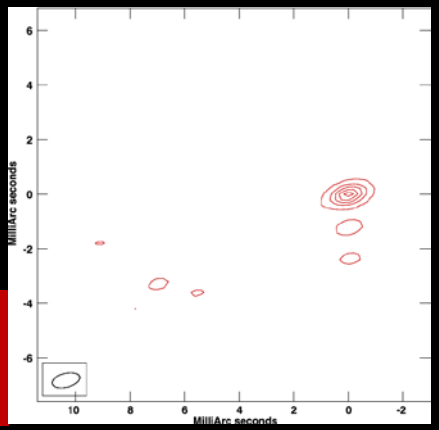


42, 43 GHz
SiO maser



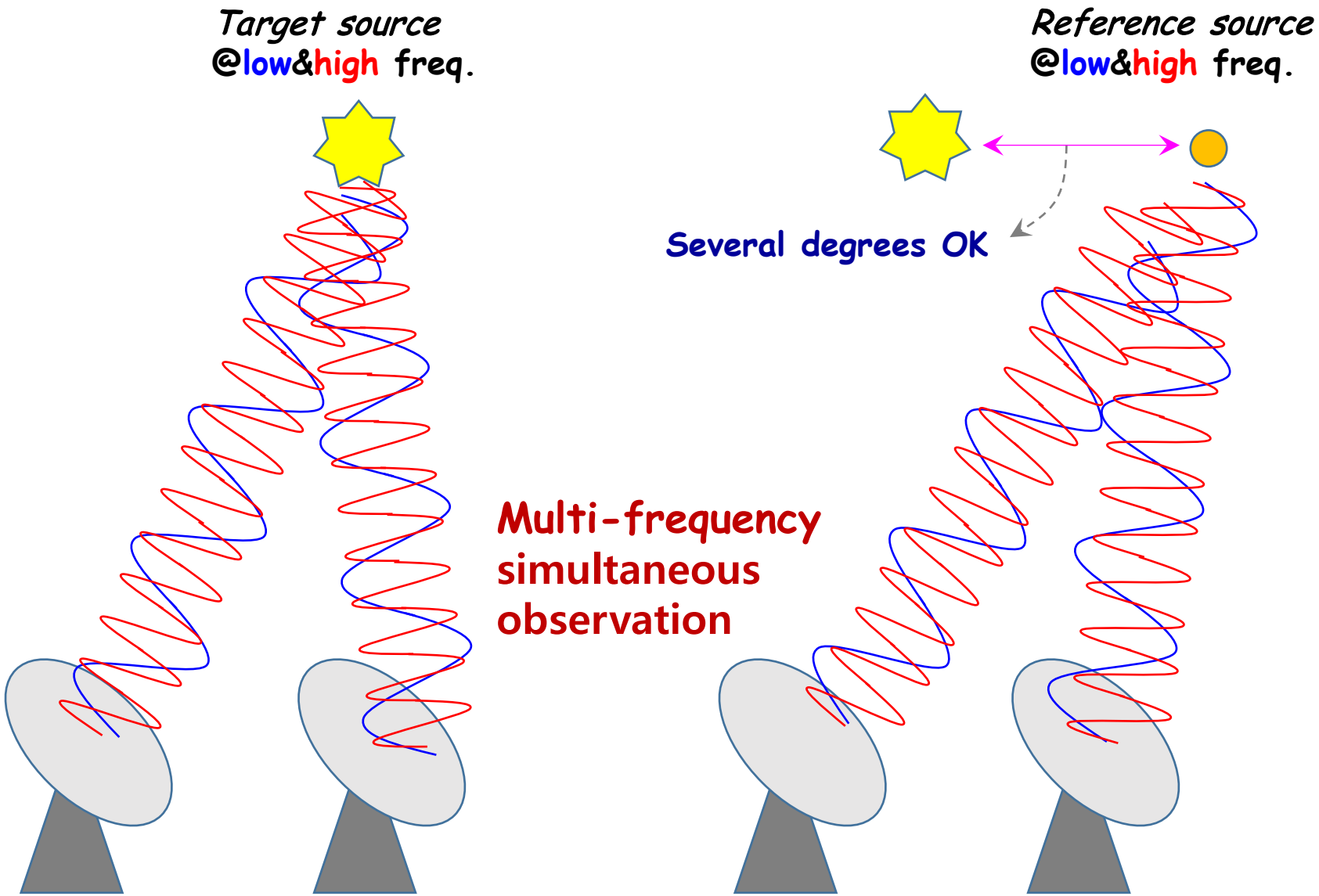
86 GHz
SiO maser





129 GHz
SiO maser

KVN observation under SFPR scheme



Source Frequency Phase Referencing (SFPR) method

For one source A

M. Rioja and R. Dodson 2011
R. Dodson, M. Rioja et al. 2014

High: $\Phi_A = \Phi_{A,GEO} + \Phi_{A,TRO} + \Phi_{A,ION} + \Phi_{A,STR} + \Phi_{A,INST} + 2\pi n_A$

Low: $\Phi_A = \Phi_{A,GEO} + \Phi_{A,TRO} + \Phi_{A,ION} + \Phi_{A,STR} + \Phi_{A,INST} + 2\pi n_A$

Non-dispersive errors:

$\Phi_{A,TRO} - R \cdot \Phi_{A,TRO} \approx 0$

$\Phi_{A,GEO} - R \cdot \Phi_{A,GEO} \approx 2\pi\nu/c(D \cdot \Theta_{A,SHIFT})$

Dispersive errors:

$\Phi_{A,ION} - R \cdot \Phi_{A,ION} = (1/R - R) \cdot \Phi_{A,ION}$

$\Phi_A - R \cdot \Phi_A = \Phi_{A,STR} - 2\pi\nu/c(D \cdot \Theta_{A,SHIFT}) + IONO_A + INST_A$

Source Frequency Phase Referencing (SFPR) method

For one source A

$$\Phi_A - R\cdot\Phi_A = \Phi_{A,STR} - 2\pi\nu/c(D\cdot\Theta_{A,SHIFT}) + IONO_A + INST_A$$

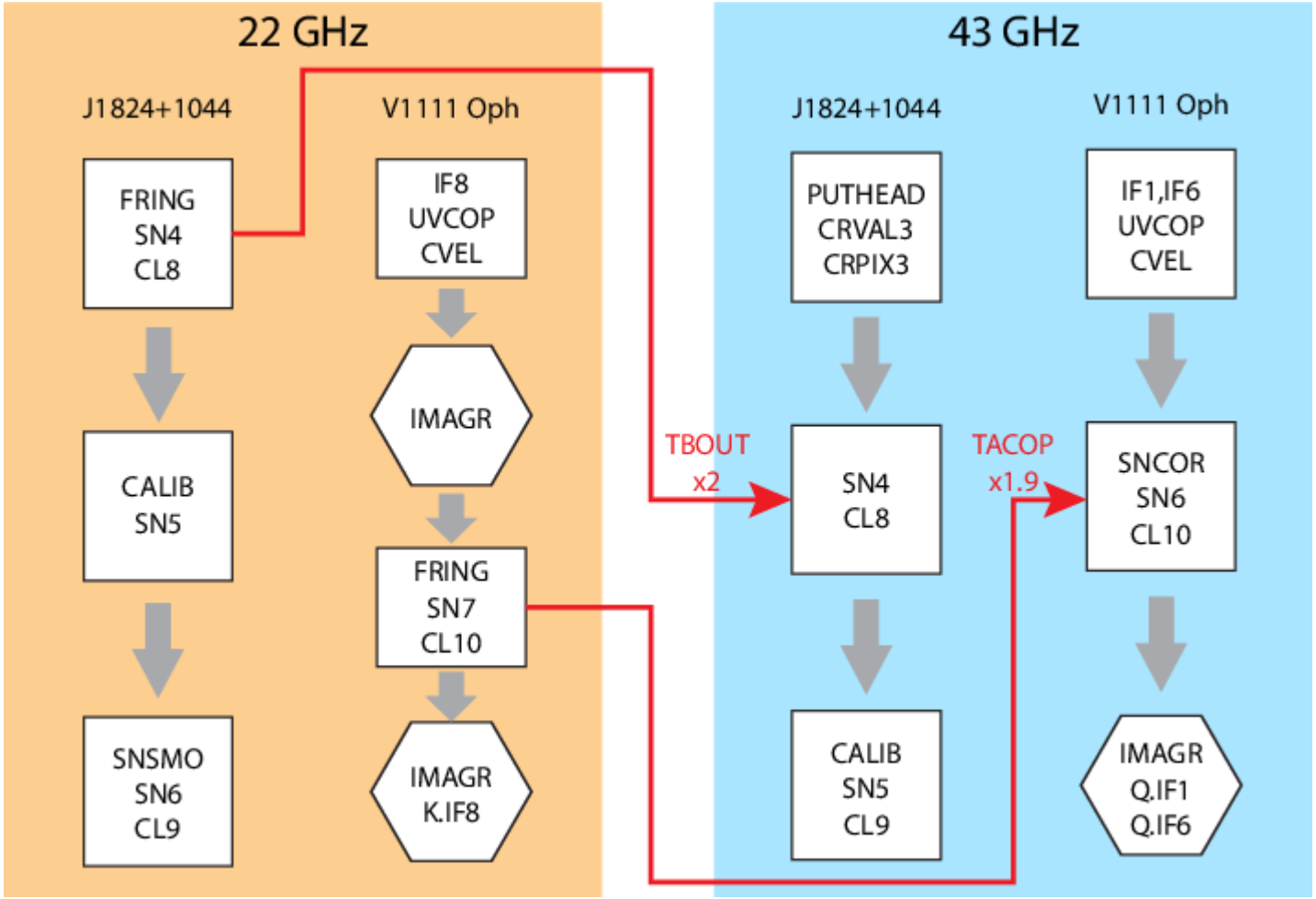
For another source B

$$\Phi_B - R\cdot\Phi_B = \Phi_{B,STR} - 2\pi\nu/c(D\cdot\Theta_{B,SHIFT}) + IONO_B + INST_B$$

Source / Frequency referenced visibility phase:

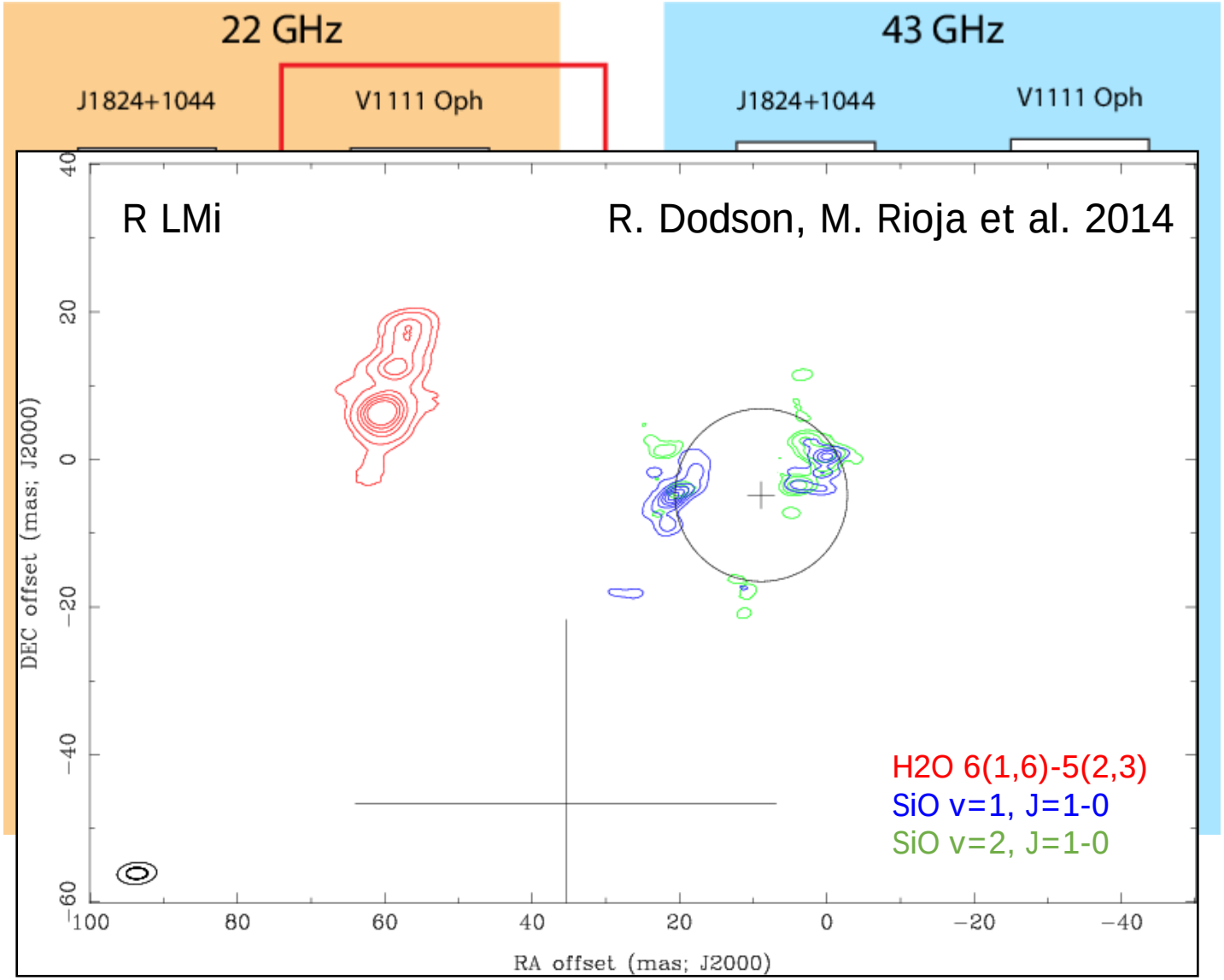
$$\Phi_{A,STR} + 2\pi\nu/c(D\cdot\Theta_{A,SHIFT} - D\cdot\Theta_{B,SHIFT})$$

Schematic of data reduction using SFPR method



Calibration solutions determined from the lower frequency data are transferred to the higher frequency data.

Schematic of data reduction using SFPR method



Introduction to Key Science Program (KSP) of KVN

Target sources of KSP

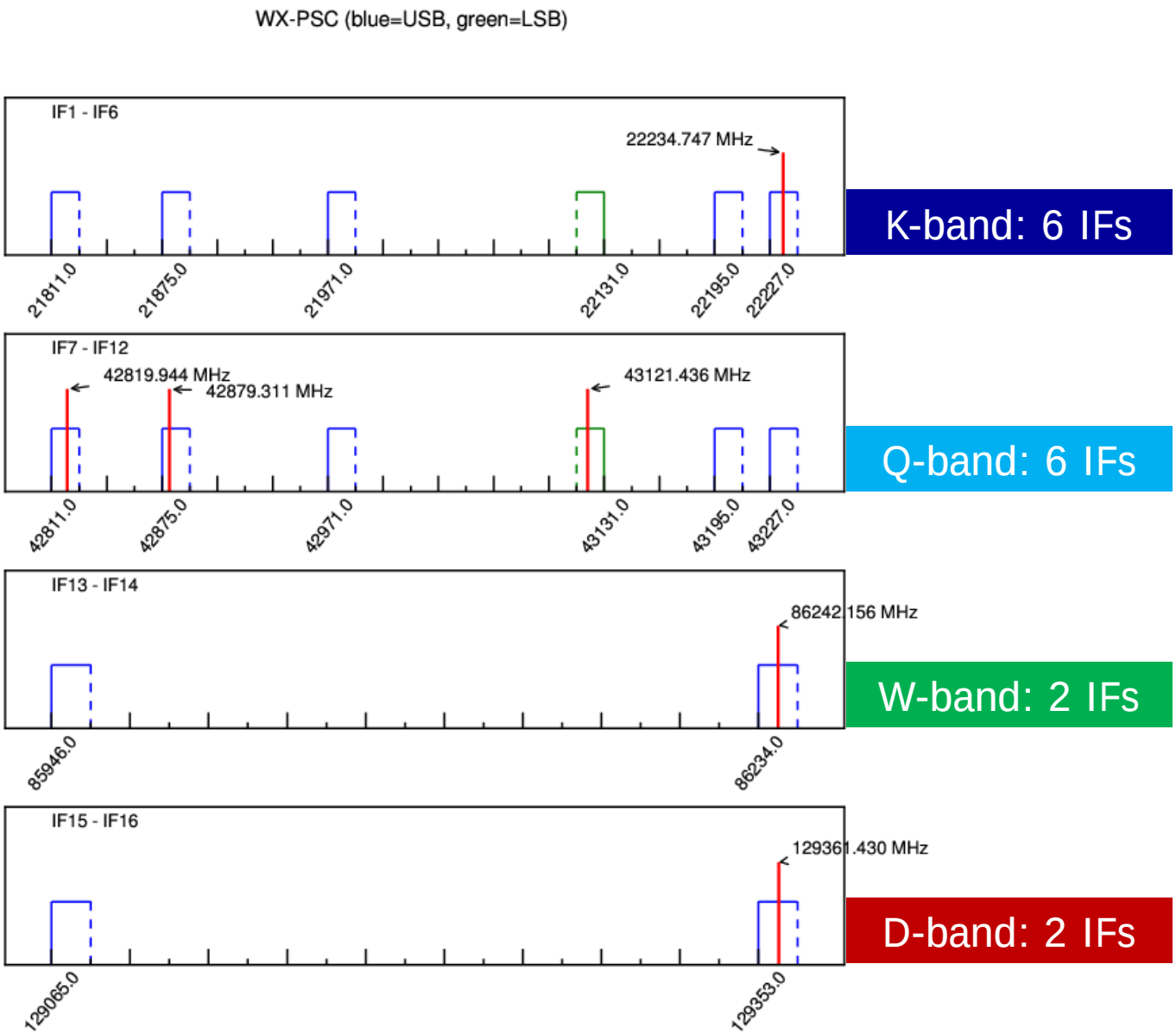
Target	Reference	Sep. (deg)	Observation frequency				
			22/43 GHz	43/86 GHz	22/43/86 GHz	22/43/129 GHz	22/43/86/129 GHz
IK Tau	J0345+1453	4.04	3				12
NV Aur	J0514+5602	3.19	4				2
R Cas	J2322+5057	5.65	2				1
R Crt	J1048-1909	3.06	2				9
R Leo	J1007+1356	5.52		3			2
RR Aql	J2015-0137	4.42	1				2
V627 Cas	J2231+5922	3.43	2				5
V1111 Oph	J1824+1044	3.28	3		1	1	8
V1366 Aql	J1830+0619	7.07					2
V2108 Oph	J1722+1013	2.45	1				1
V5102 Sgr	J1833-2103	5.99	1				4
VX Sgr	J1833-2103	6.06	2			1	9
VY CMa	J0731-2341	2.78	3		1		17
W Hya	J1339-2401	4.89	3				10
WX Psc	J0121+1149	3.81	2				4
χ Cyg	J2015+3710	6.65		1			2

Monitoring observations have been performed since August 2014.

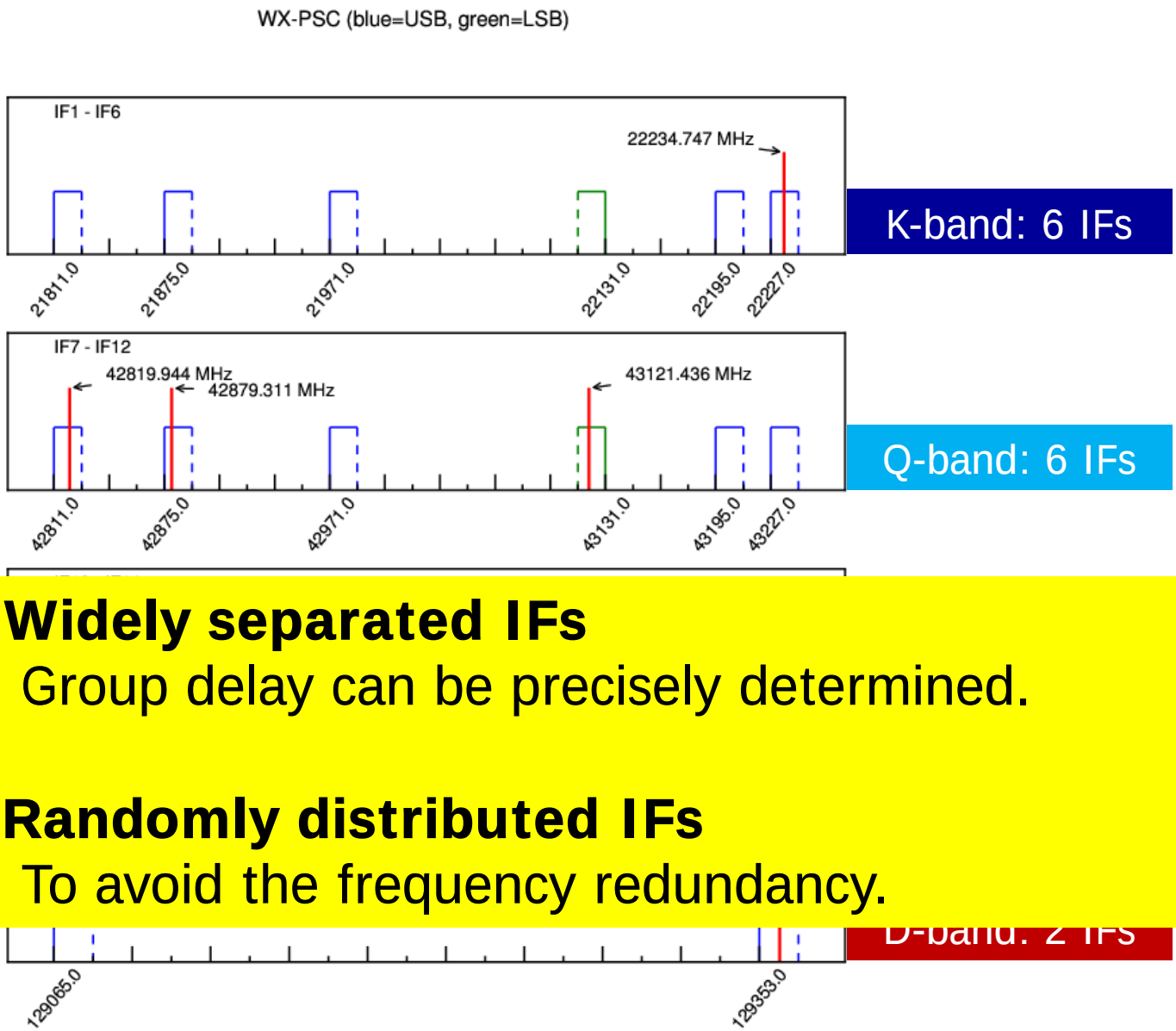
Example of KSP observations

- Target source: **WX Psc**
- Obs. date: **2015.12.30 (~7 hours)**
- Fringe finder: **J0136+4751**
- Position reference source: **J0121+1149 (3.81° from TS)**
- Scan pattern: **TS (2 min.) – PR (2 min.) – TS (2 min.)**
- Obs. frequencies: **22/43/86/129 GHz**

Frequency setting of BBCs (base band channels)



Frequency setting of BBCs (base band channels)



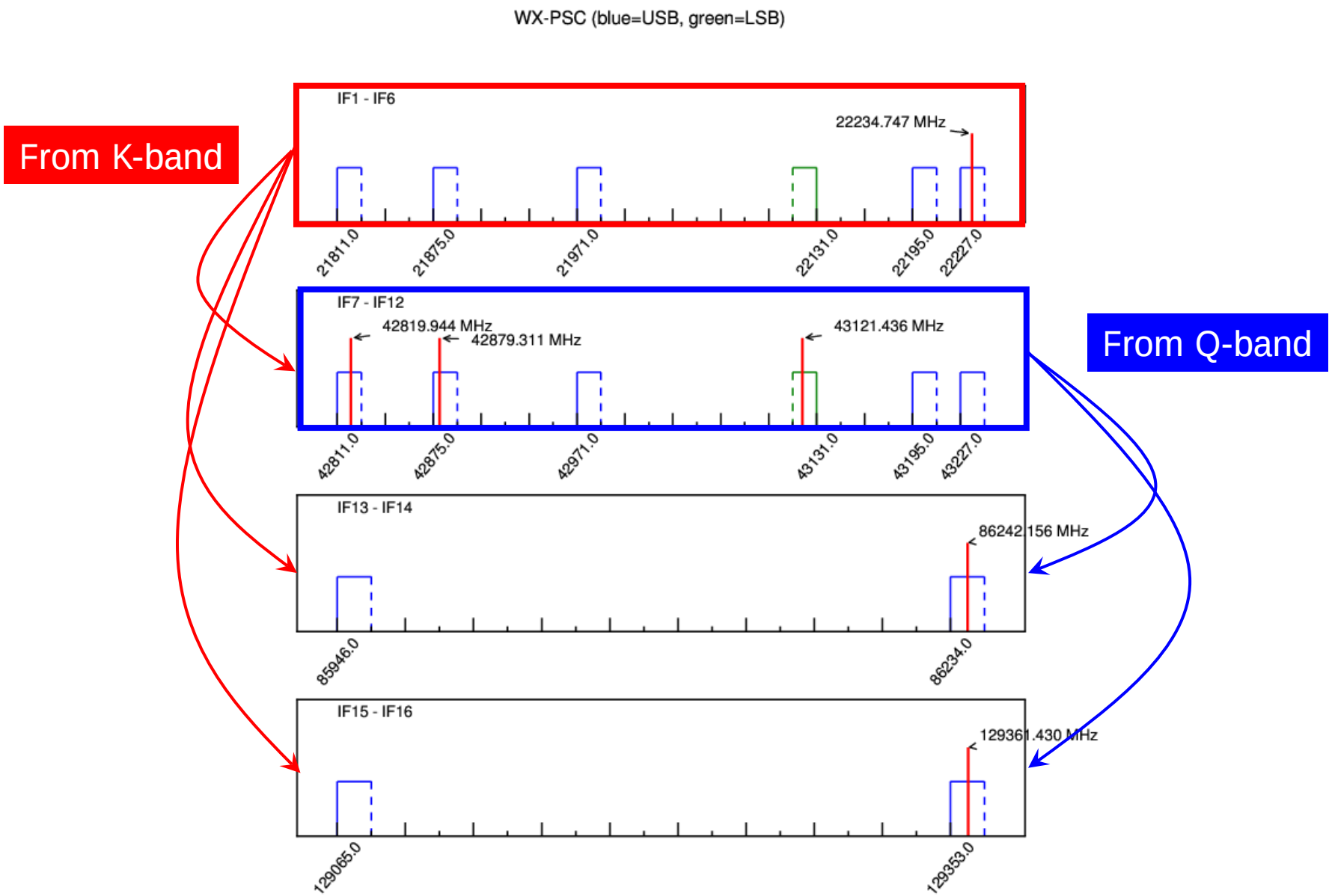
- **Widely separated IFs**

→ Group delay can be precisely determined.

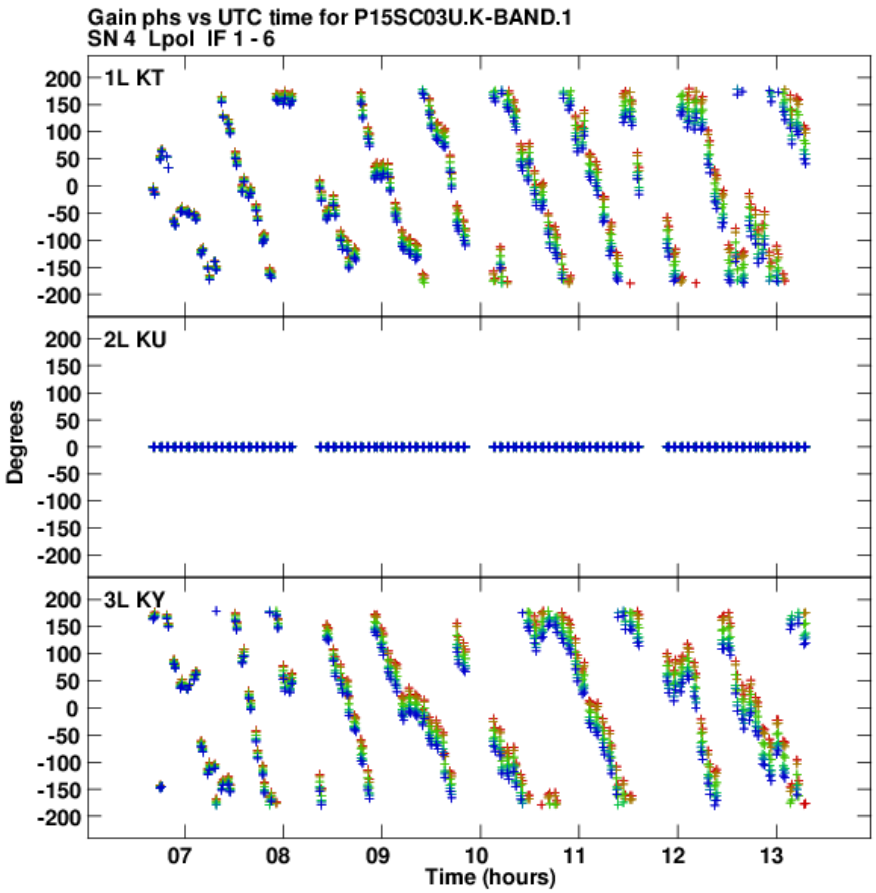
- **Randomly distributed IFs**

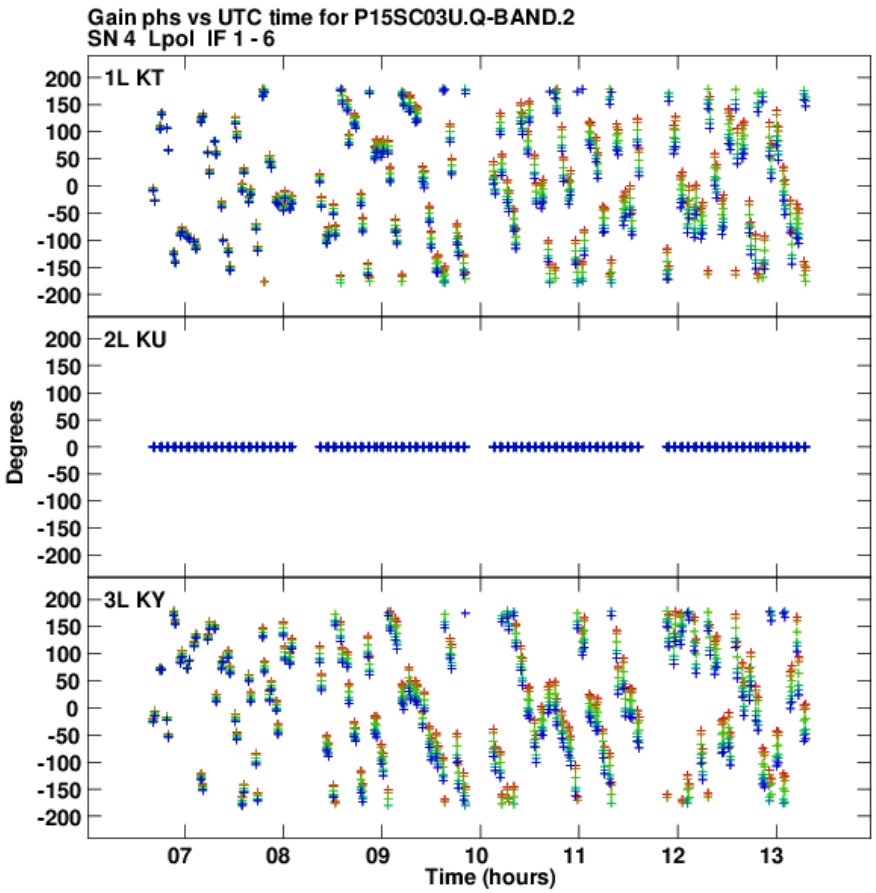
→ To avoid the frequency redundancy.

Phase transfer from LOW to HIGH frequency band



Frequency phase transfer from K-band to Q-band

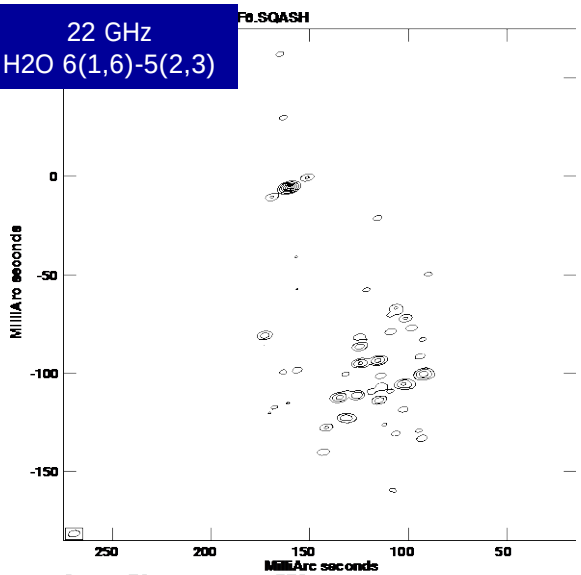




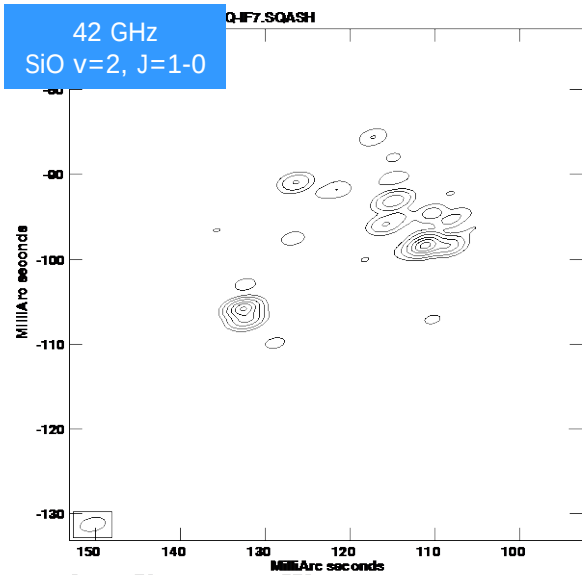
Phase of K-band → Phase of Q-band

Final image of H2O and SiO masers at four bands

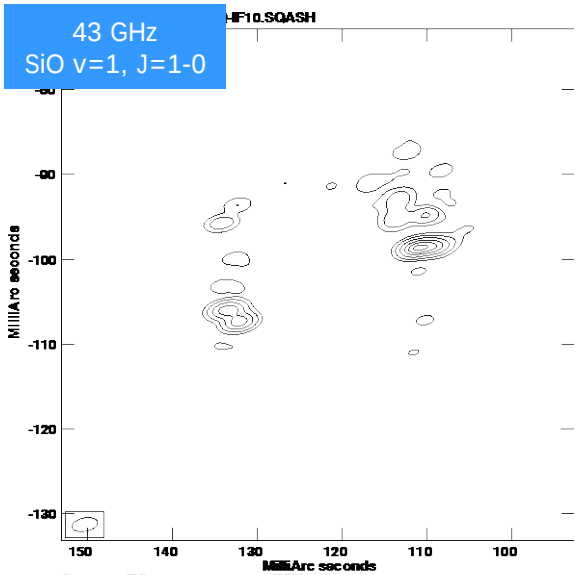
22 GHz
H2O 6(1,6)-5(2,3)



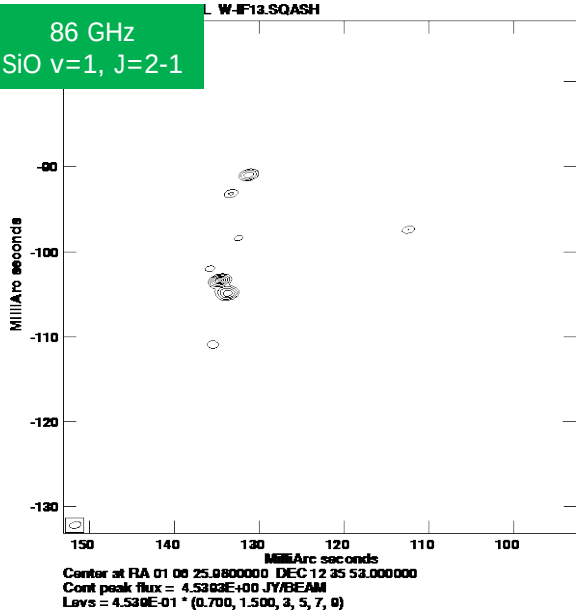
42 GHz
SiO v=2, J=1-0



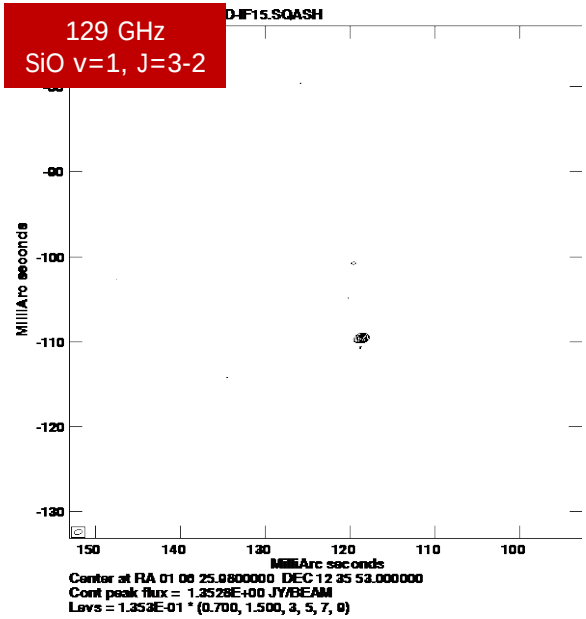
43 GHz
SiO v=1, J=1-0



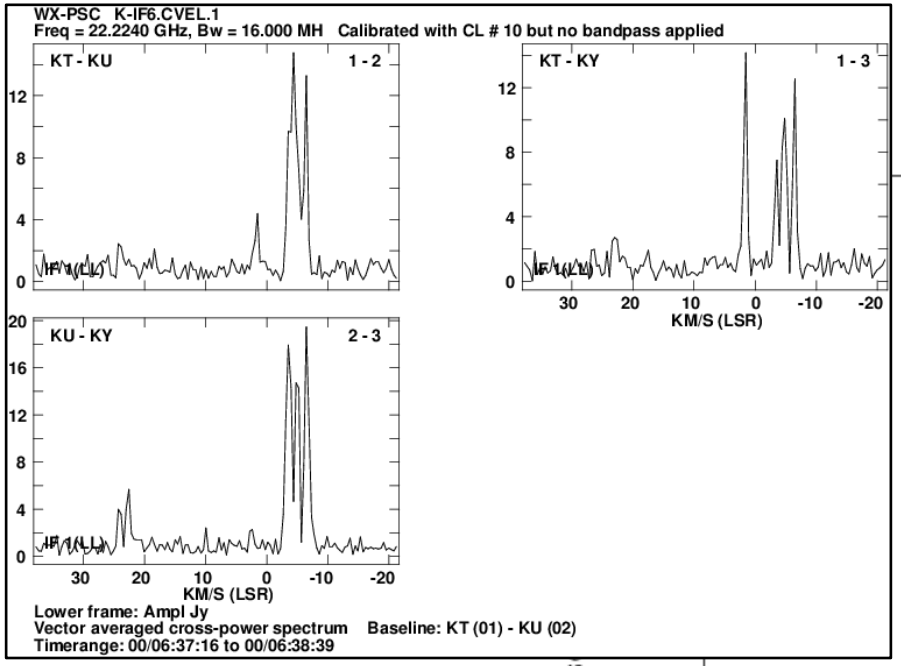
86 GHz
SiO v=1, J=2-1

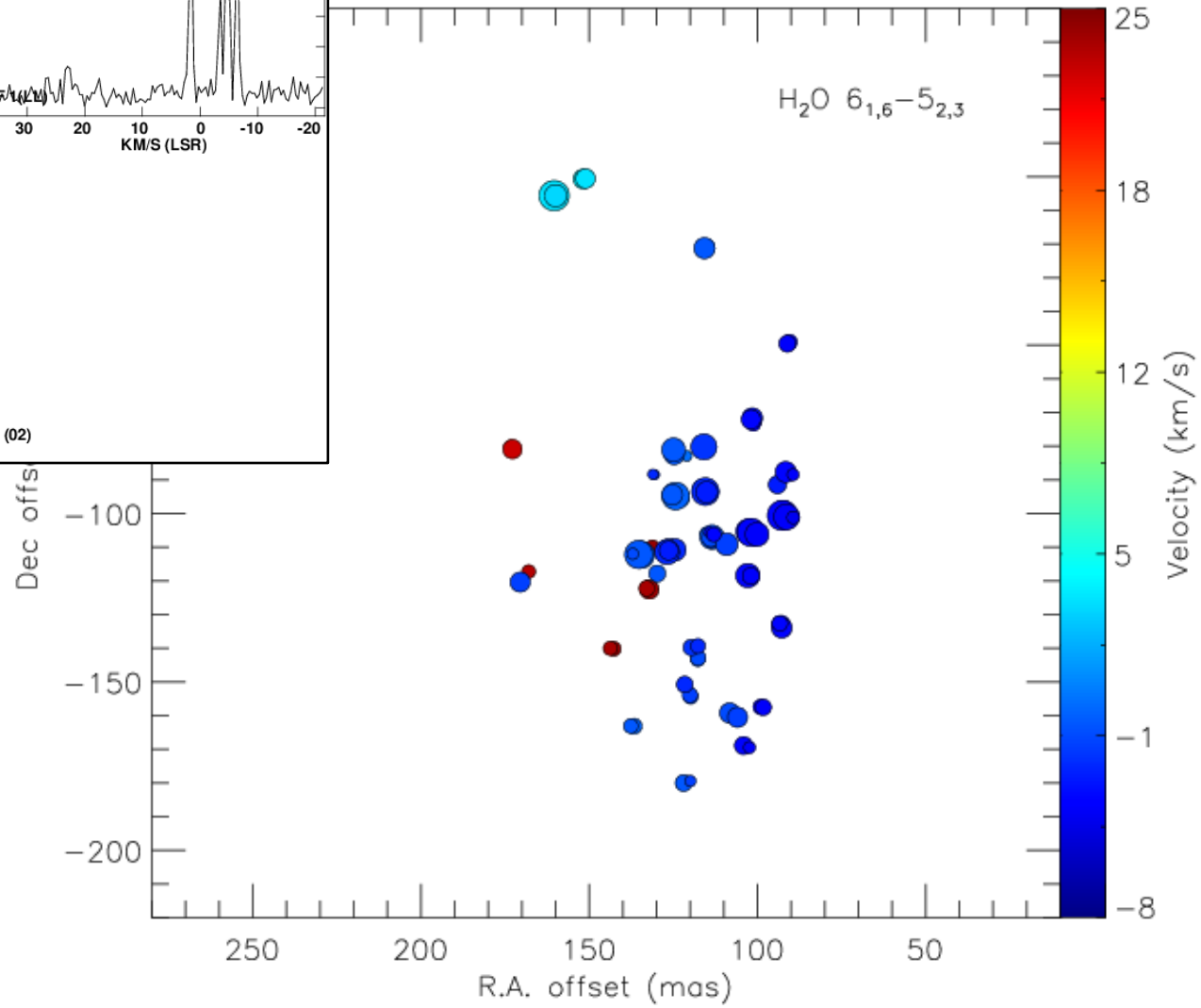


129 GHz
SiO v=1, J=3-2

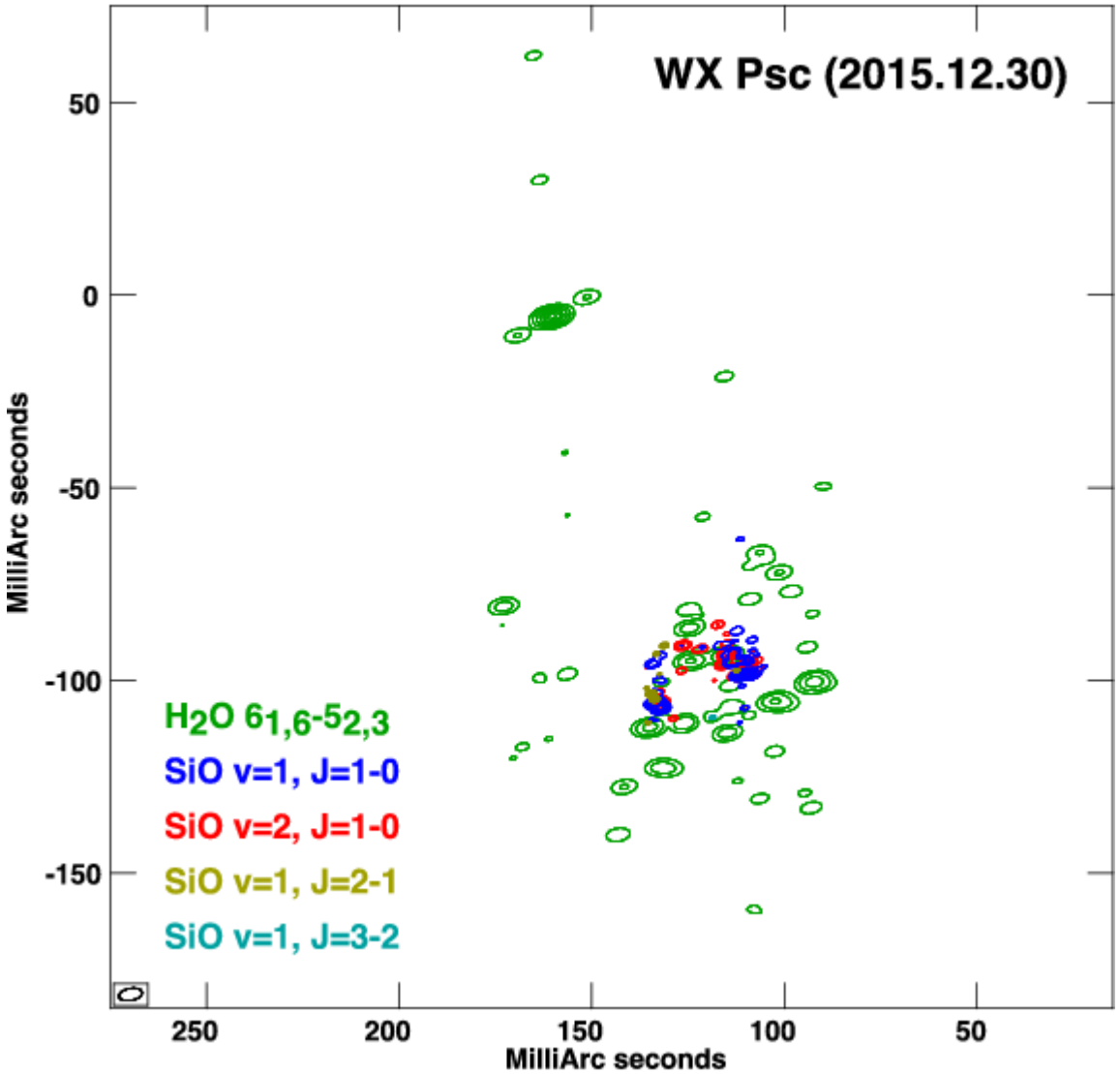


Final image of H2O maser (22 GHz)





Superposed map of H2O and SiO masers at four bands



Location of the central star

→ Center of the SiO maser ring

Asymmetric morphology of the H2O maser@22 GHz

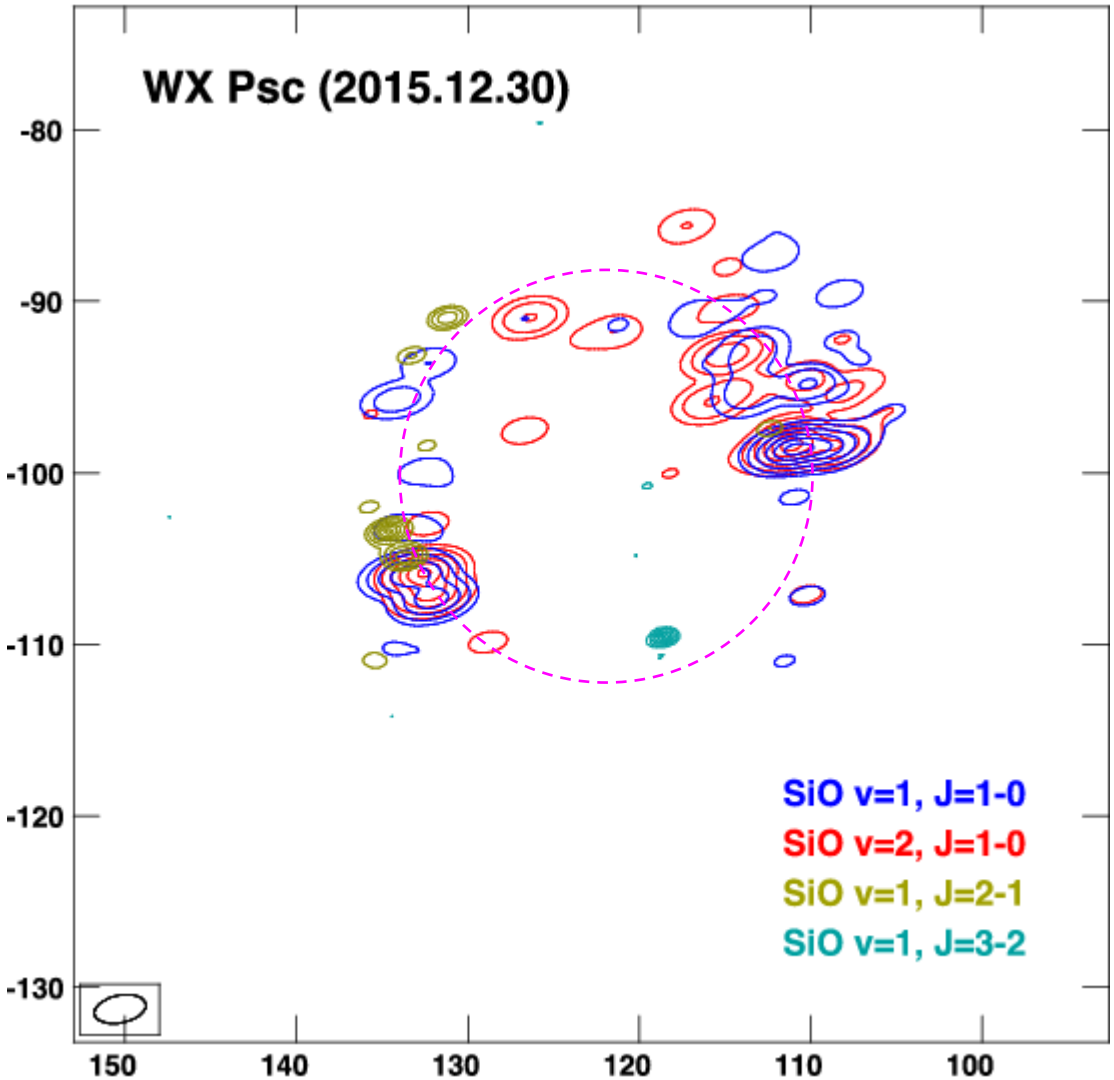
→ Outflow (bipolar?) motion in CSEs

Spatial distribution of SiO masers

→ Similarity and difference imply the pumping mechanisms of the SiO masers.

→ Important information of the physical environments of the CSEs

Superposed map of SiO masers



Location of the central star

→ Center of the SiO maser ring

SiO v=1 and v=2, J=1-0 masers

→ Largely overlapped

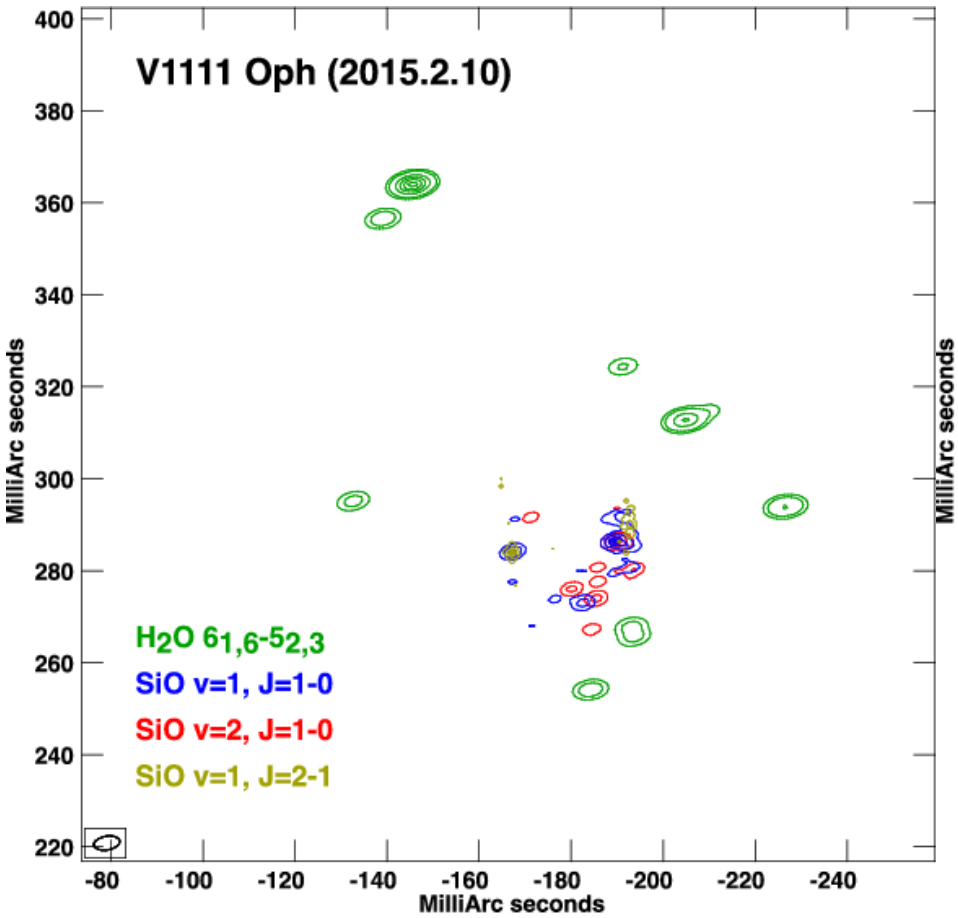
→ Slightly different

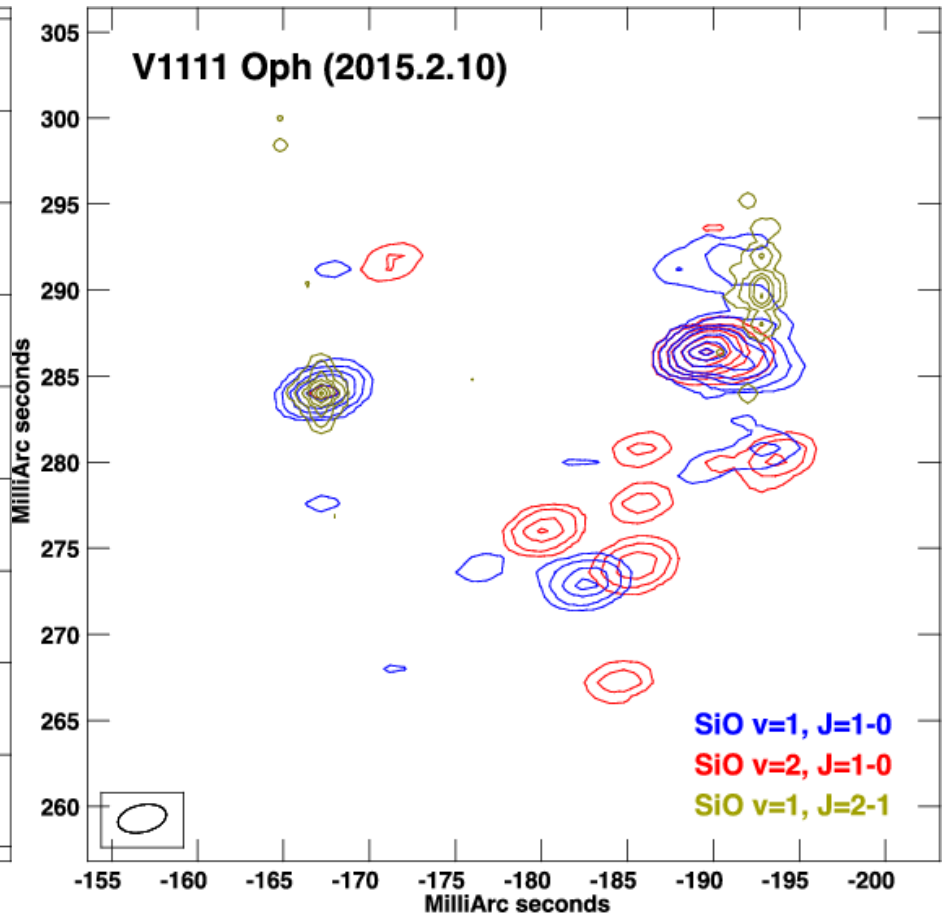
→ Radiative/collisional pumping

SiO v=1, J=2-1 and J=3-2 masers

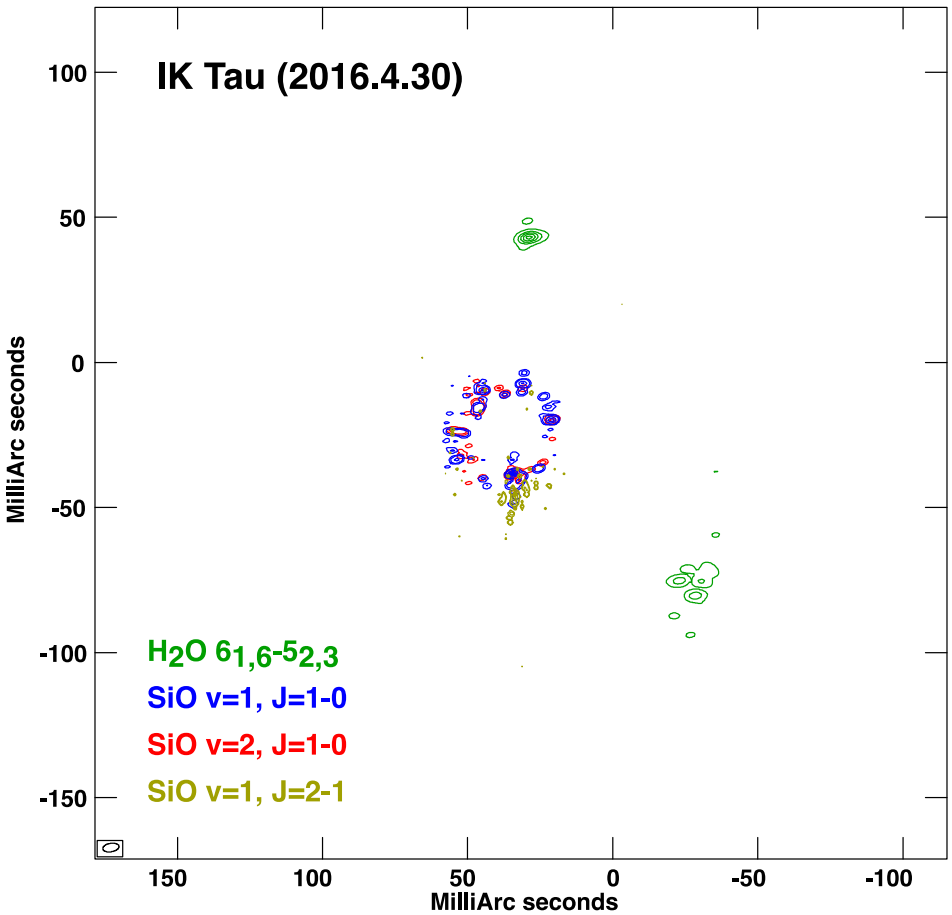
→ Different spatial distribution from 42/43 GHz SiO masers

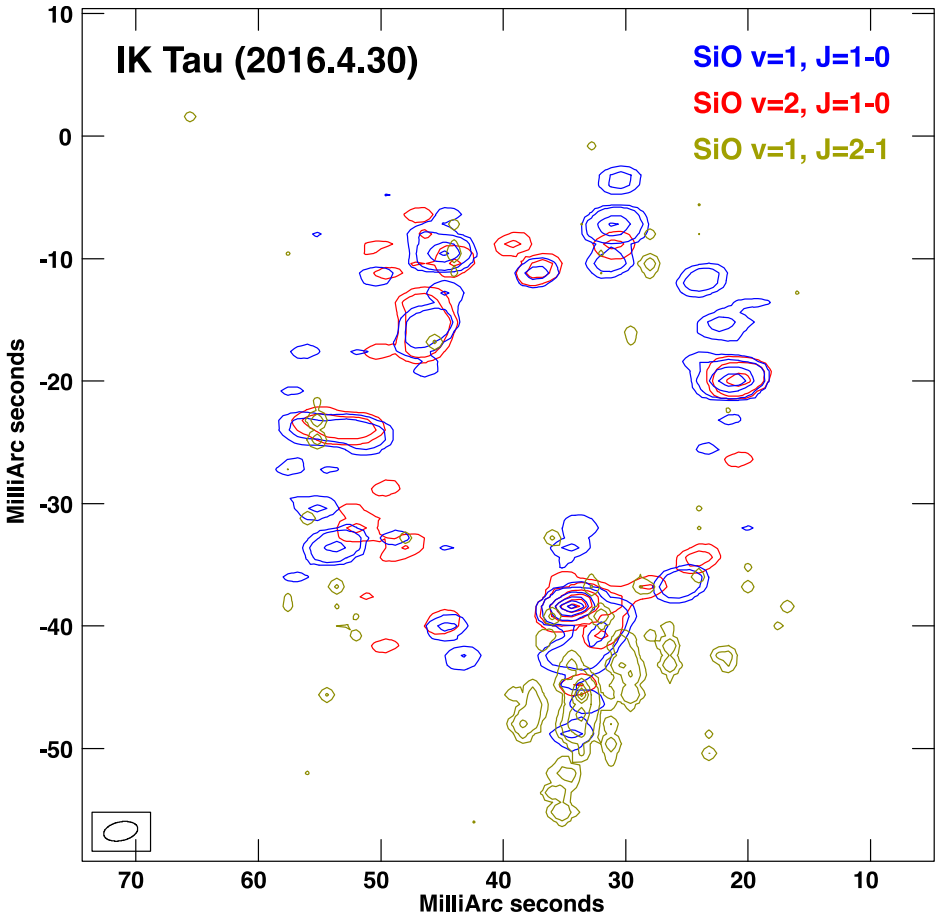
Superposed map of H2O and SiO masers at four bands



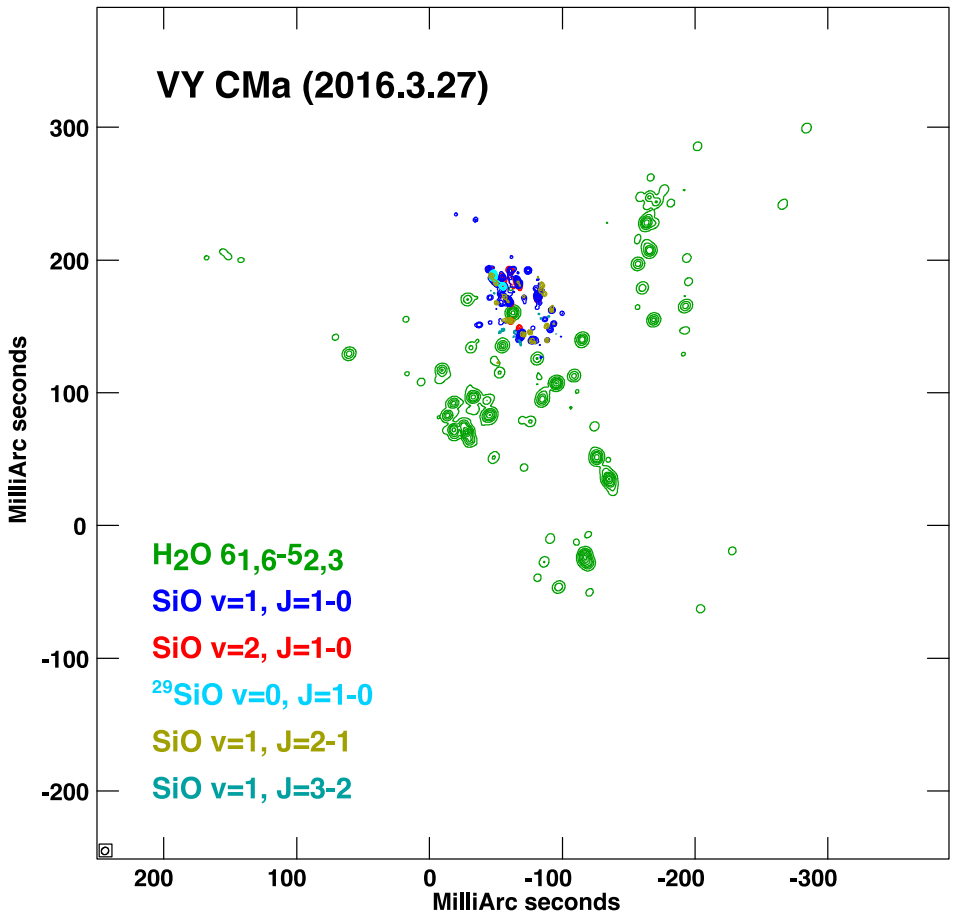


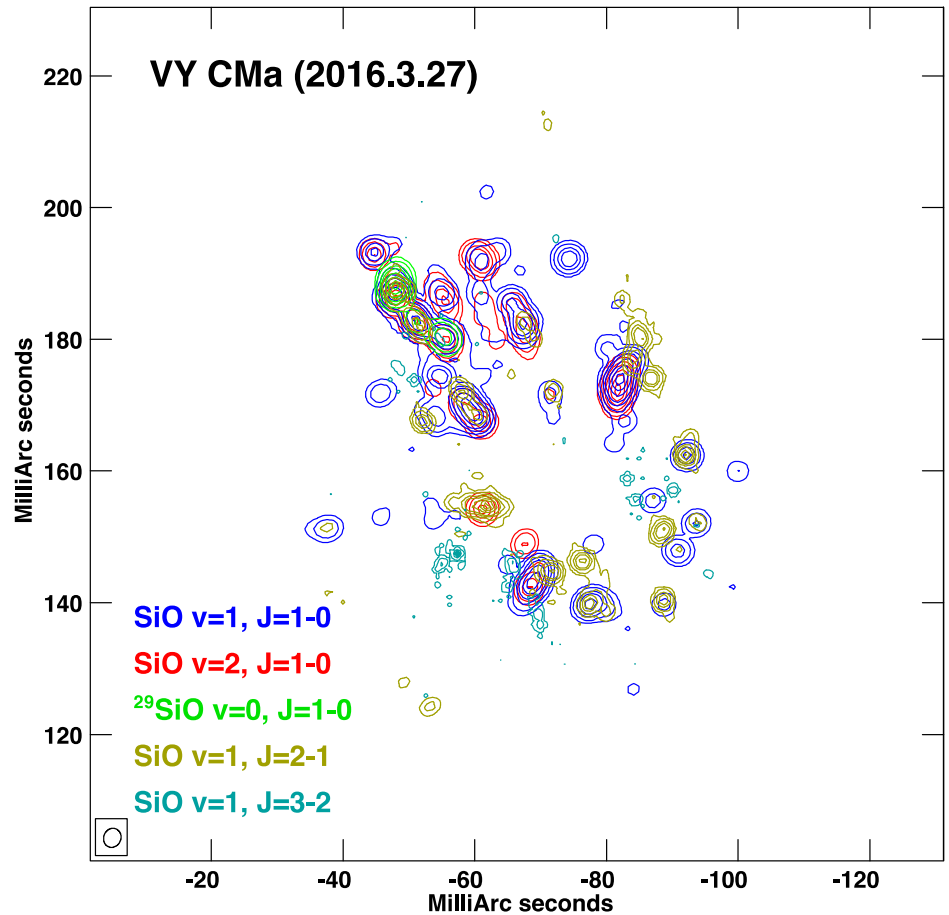
Superposed map of H2O and SiO masers at four bands



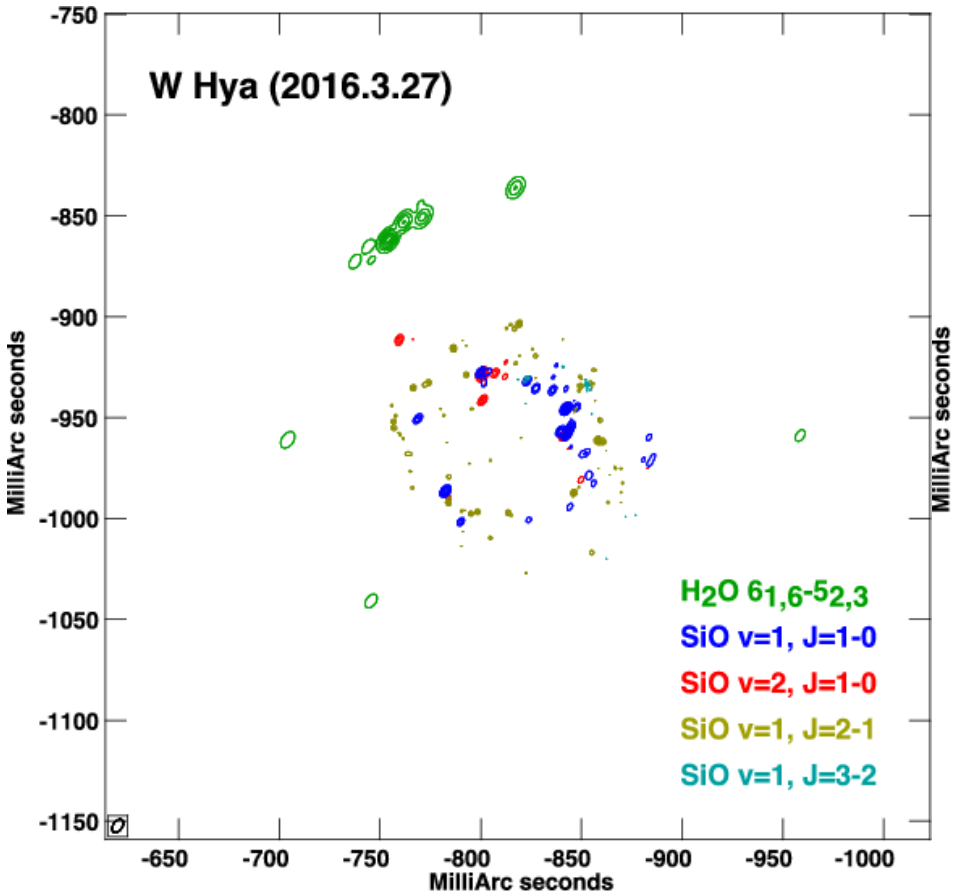


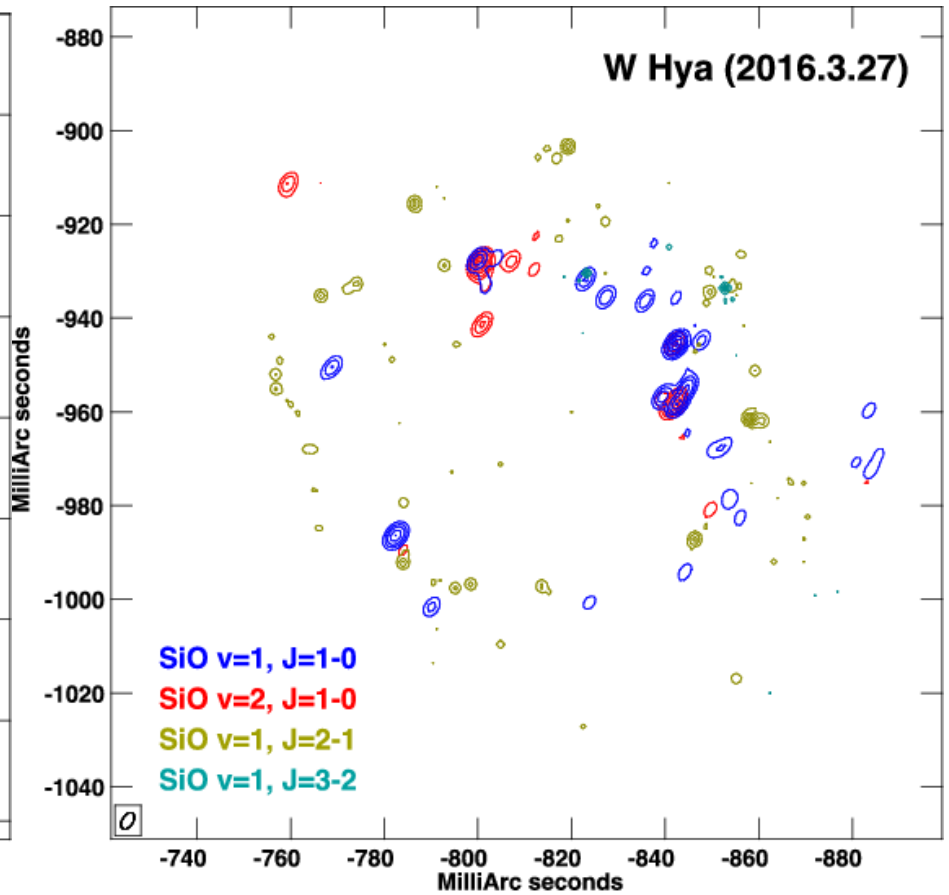
Superposed map of H2O and SiO masers at four bands





Superposed map of H2O and SiO masers at four bands





Summary

- **Simultaneous observations of KVN at four frequency-bands have succeeded and are now very promising for studying the stellar masers.**
- **Relative spatial distributions between the SiO masers obtained from the KVN observations can give a good evidence for the maser pumping study.**
- **Monitoring-observational results of the SiO masers and the H2O masers can be used to trace the dynamical evolution of the CSEs together with the stellar pulsation.**
- **POSTER section of #15 shows more information of this study.**

Come and enjoy KVN!