(E)KVN (Korean VLBI Network): Simultaneous multi-frequency VLBI System

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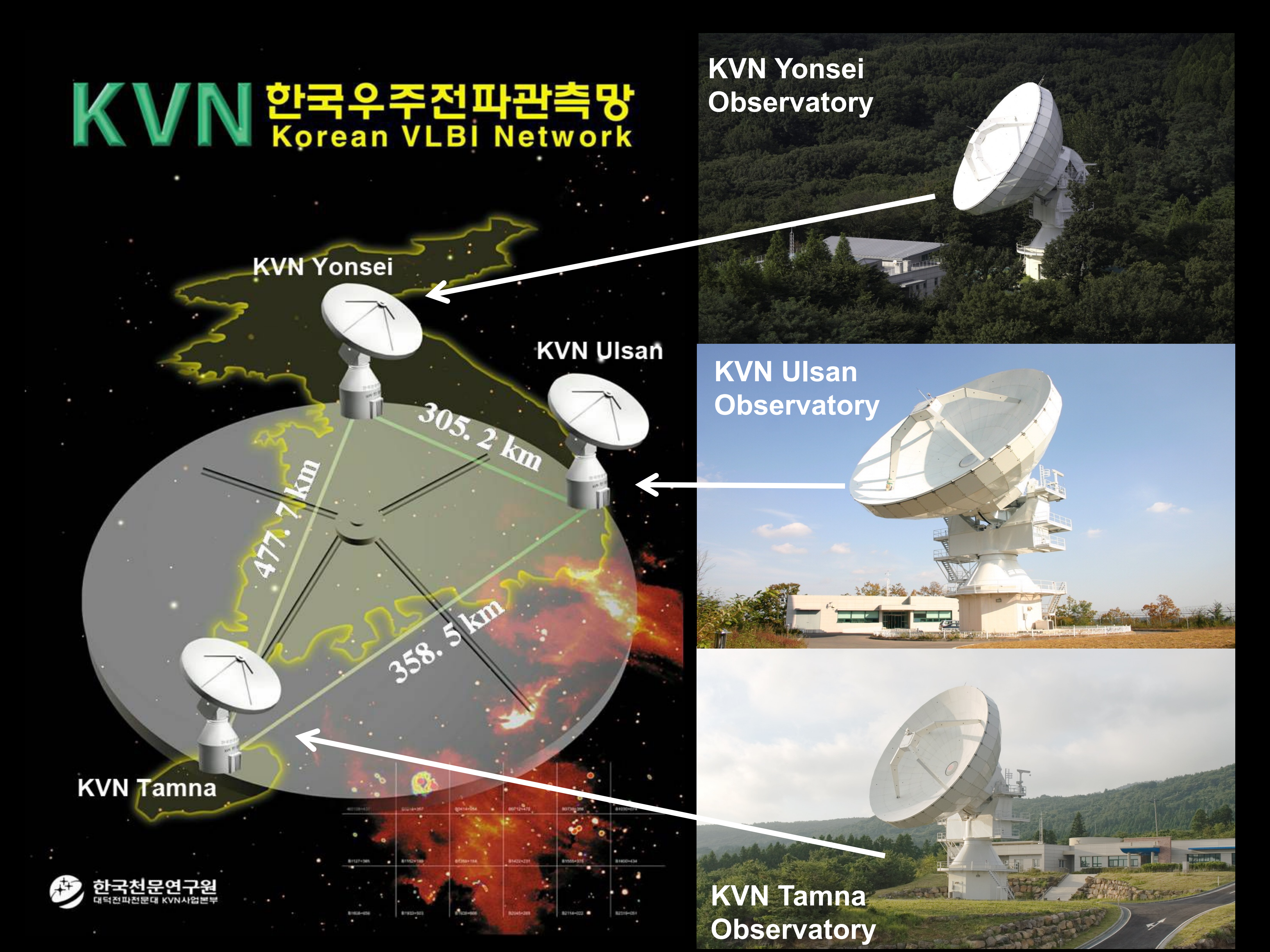
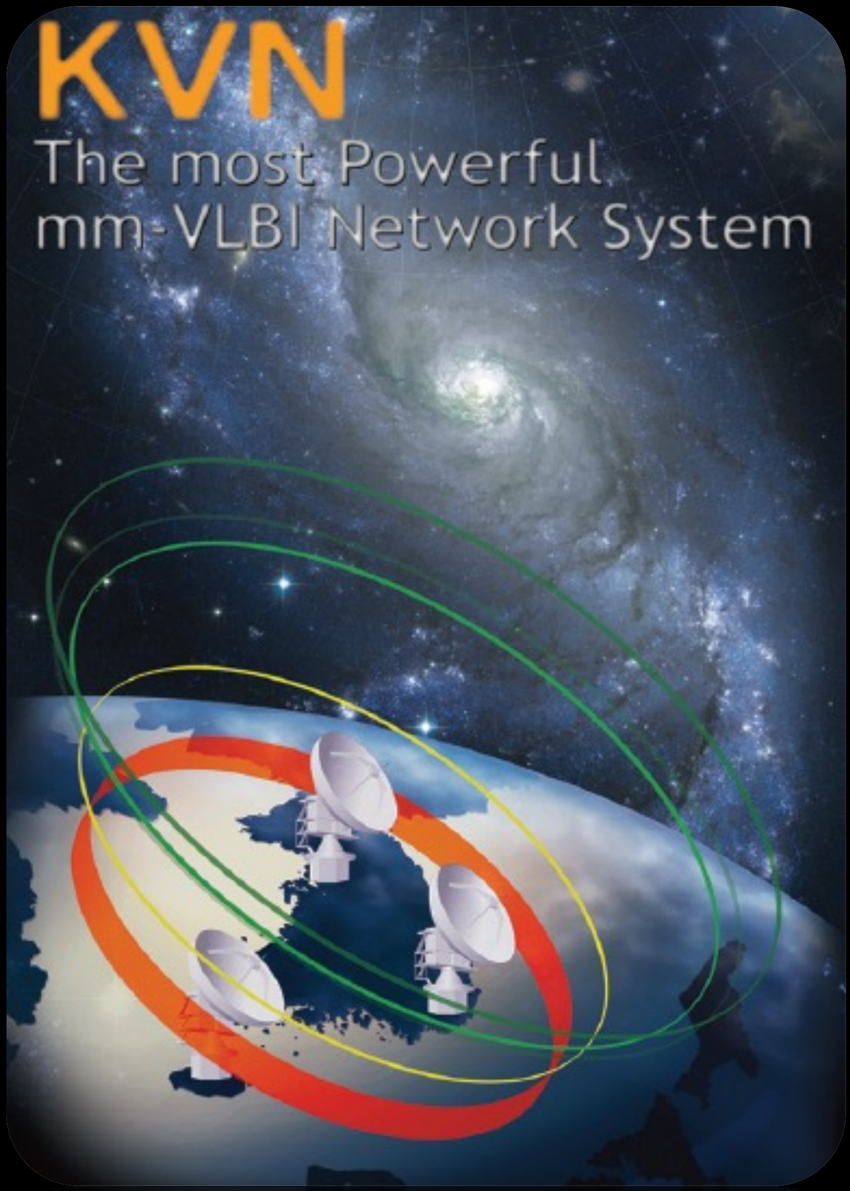
on behalf of KVN team

Korean VLBI Network
Korea Astronomy & Space Science Institute

1st Moscow International Conference on mm/submm Astronomy April 12th, 2021

Korean VLBI Network


KVN 한국우주전파관측망
Korean VLBI Network
KVN Yonsei
KVN Ulsan
KVN Tamna
305. 2 km
477. 7 km
358. 5 km
한국천문연구원
대덕전파천문대 KVN사업본부
KVN Yonsei Observatory
KVN Ulsan Observatory
KVN Tamna Observatory



Specifications

- First VLBI facility in Korea
- 21m x 3 antenna
- First simultaneous multi-frequency receiving system @ 22/43/86/129GHz

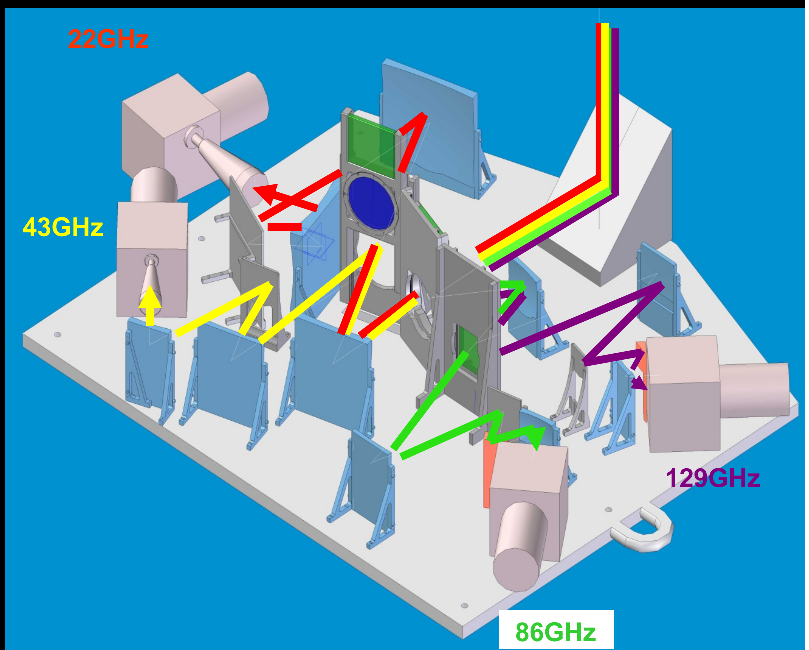
•Slewing speed : 3 deg/sec (AZ/EL)

- Surface accuracy
  ~ panel < 65 micron
  ~ total < 130 micron

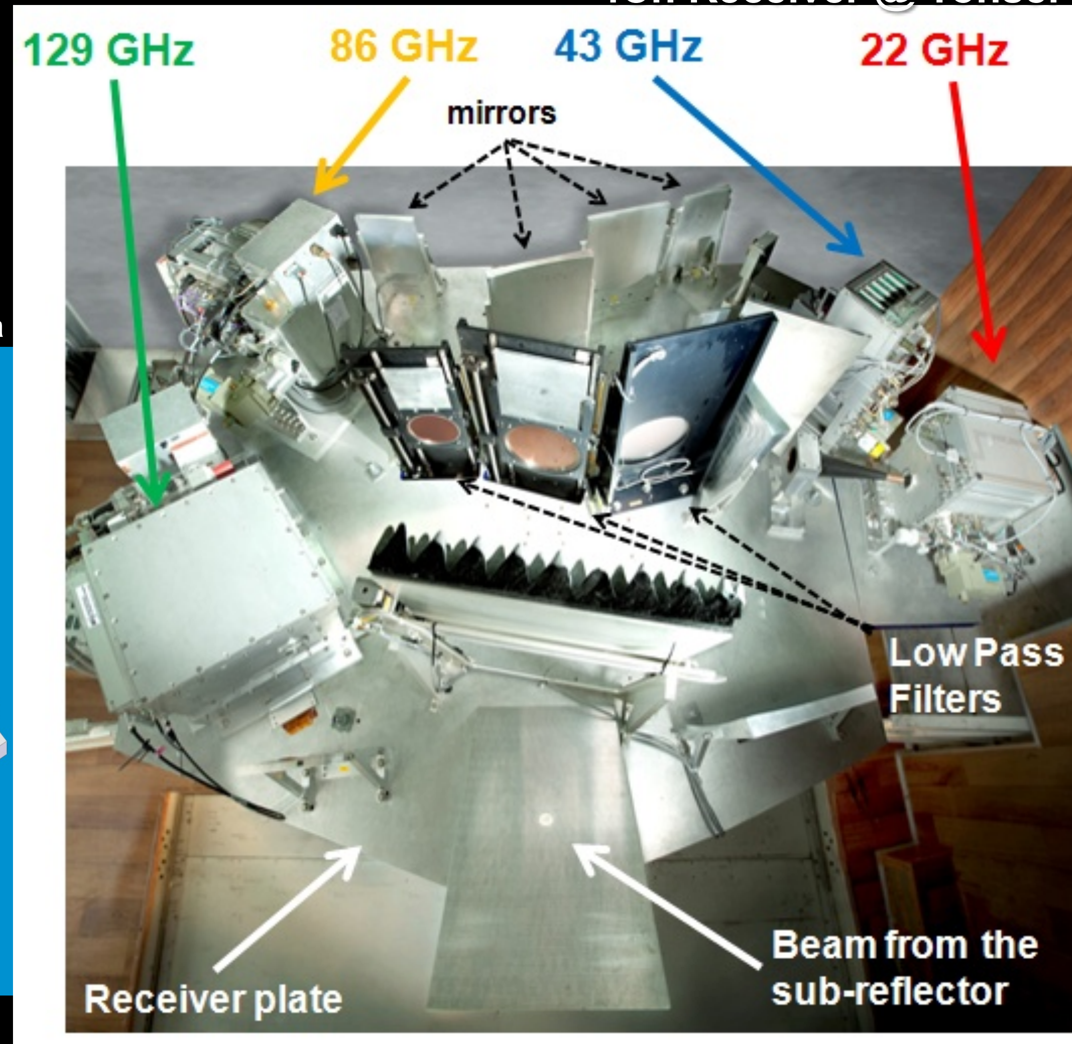
- Pointing accuracy
  ~ < 4 arcseconds in RMS

•Obs frequencies w/ Aeff
- •K-band : 18 – 26 GHz (60%)
- •Q-band : 35 – 50 GHz (60%)
- •W-band : 85 – 116 GHz (50%)
- •D-band : 125 – 142 GHz (40%)

Multi-Frequency Receiving System



4Ch Receiver @ Yonsei



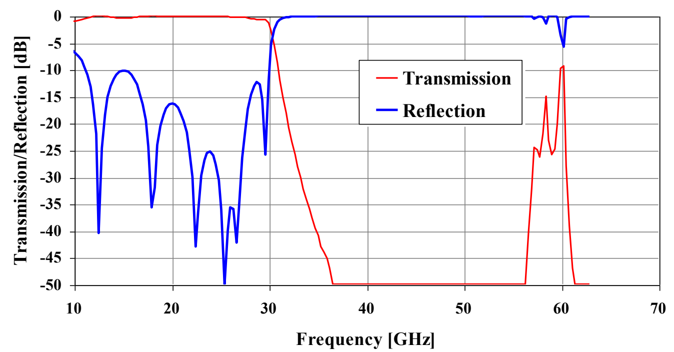
Band	K	Q	W	D
Freq. Range	21.25-23.25	42.11-44.11	85-95	125-142
Trx (K)	30-40	70-80 (40-50 KUS)	80-100	50-80

Full Polarization

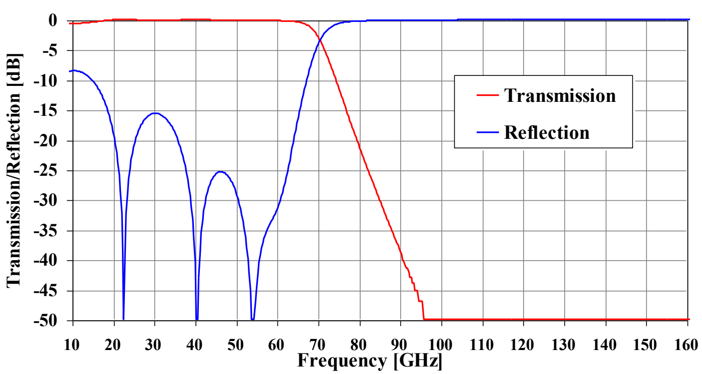
Han et al. (2008)

Low Pass Filters

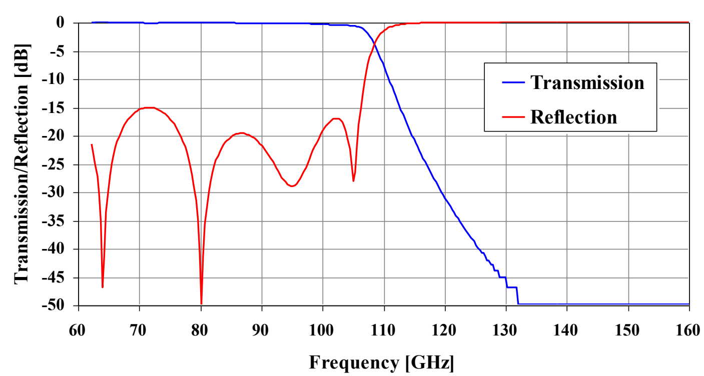
4. Low -pass filters : Meter-mesh (Thomas Keathing)



- 22GHz/43GHz channel



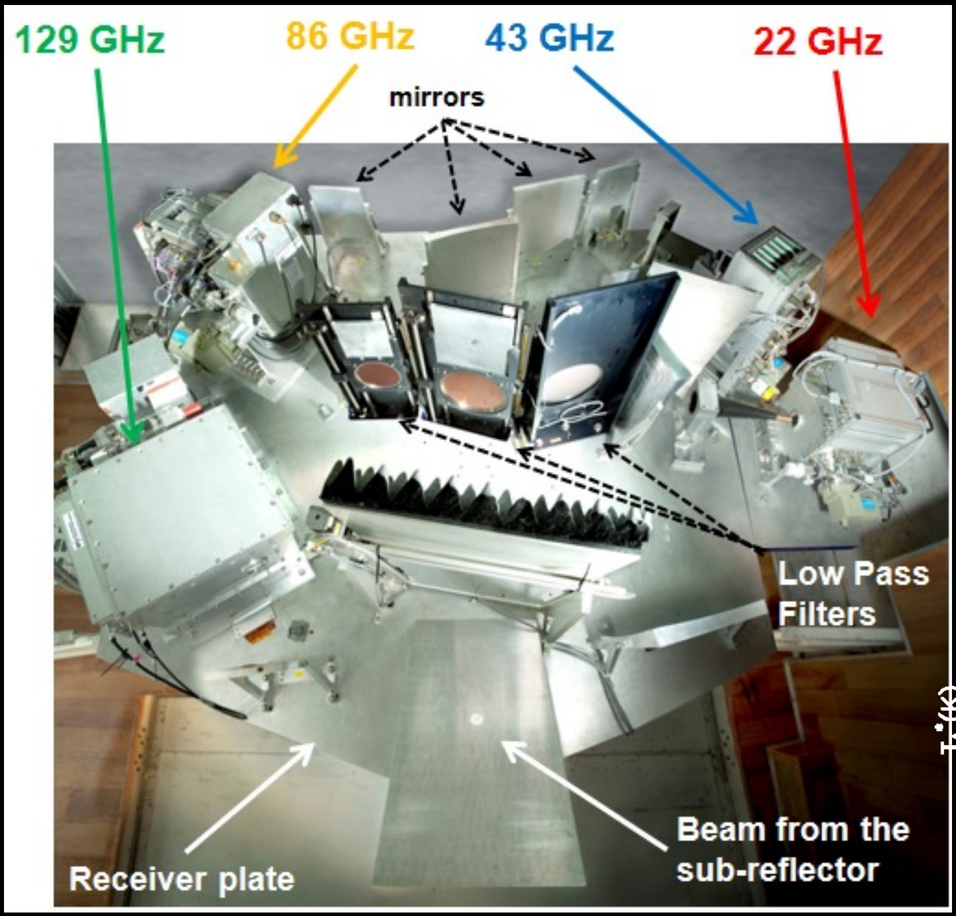
- 22 and 43GHz/86 and 129GHz channel



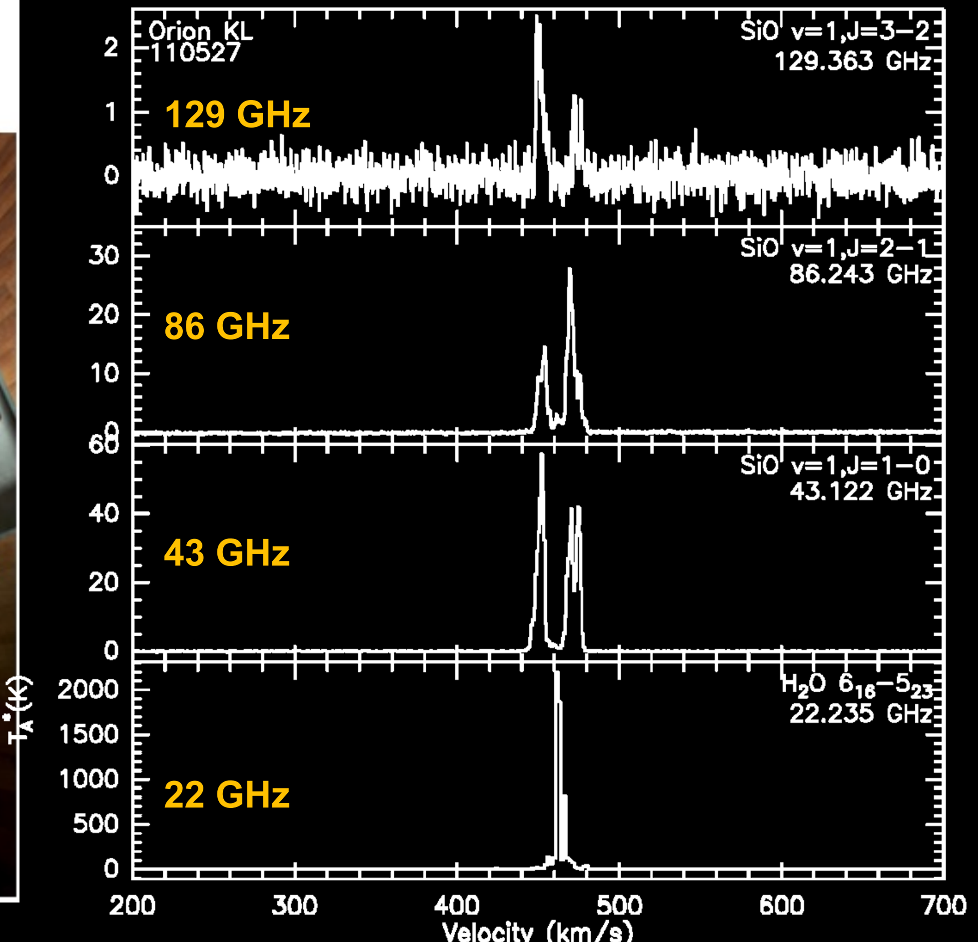
- 86GHz/ 129GHz channel

From S. T. Han

First Light from 22/43/86/129 GHz Simultaneous Single Dish Observation

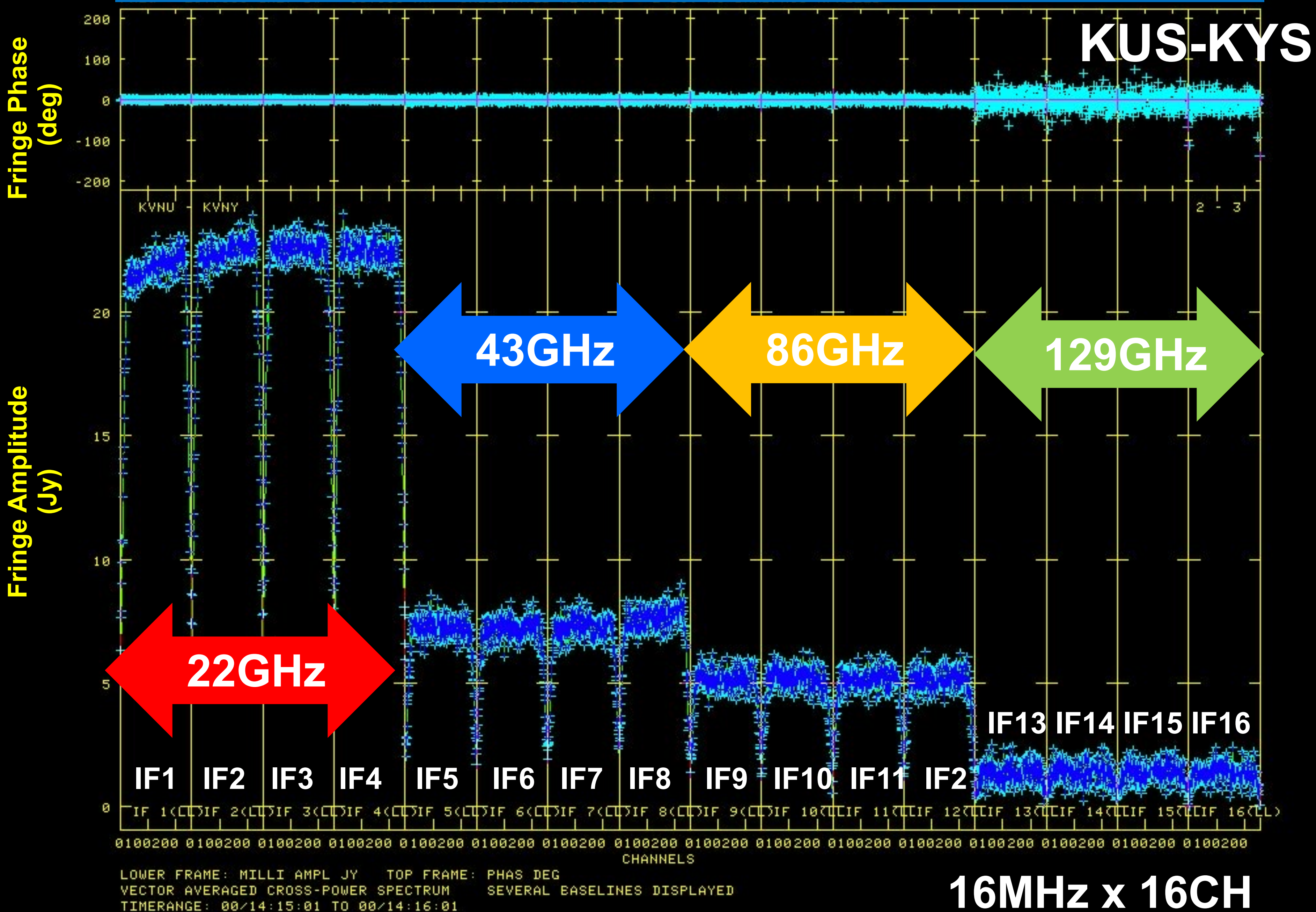


4 channel Rx at KVN Yonsei station
(Han et al. 2008)



H20/SiO Masers in Orion KL

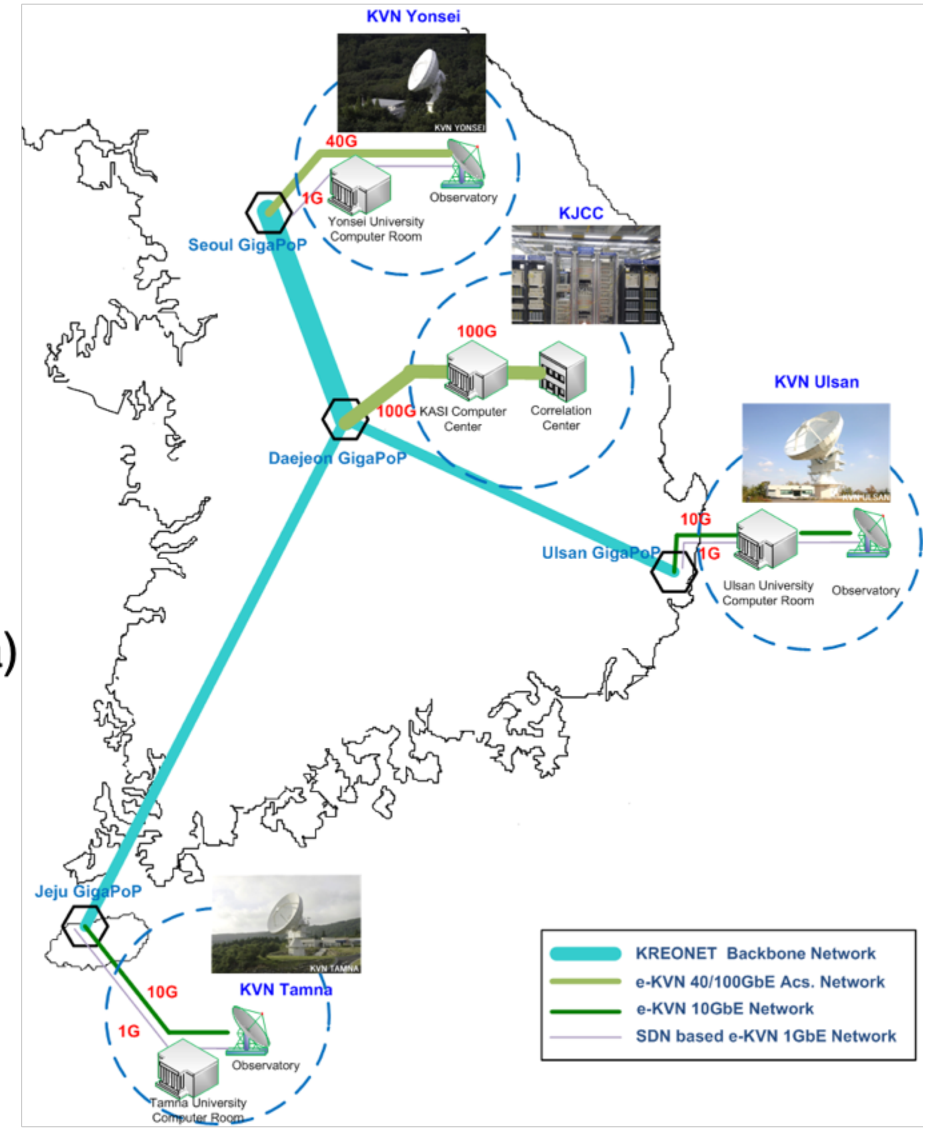
1st KVN VLBI 4-band Fringes (2012 April)



High Speed Network Connection

Korea
Research
Environment
Open
NETwork

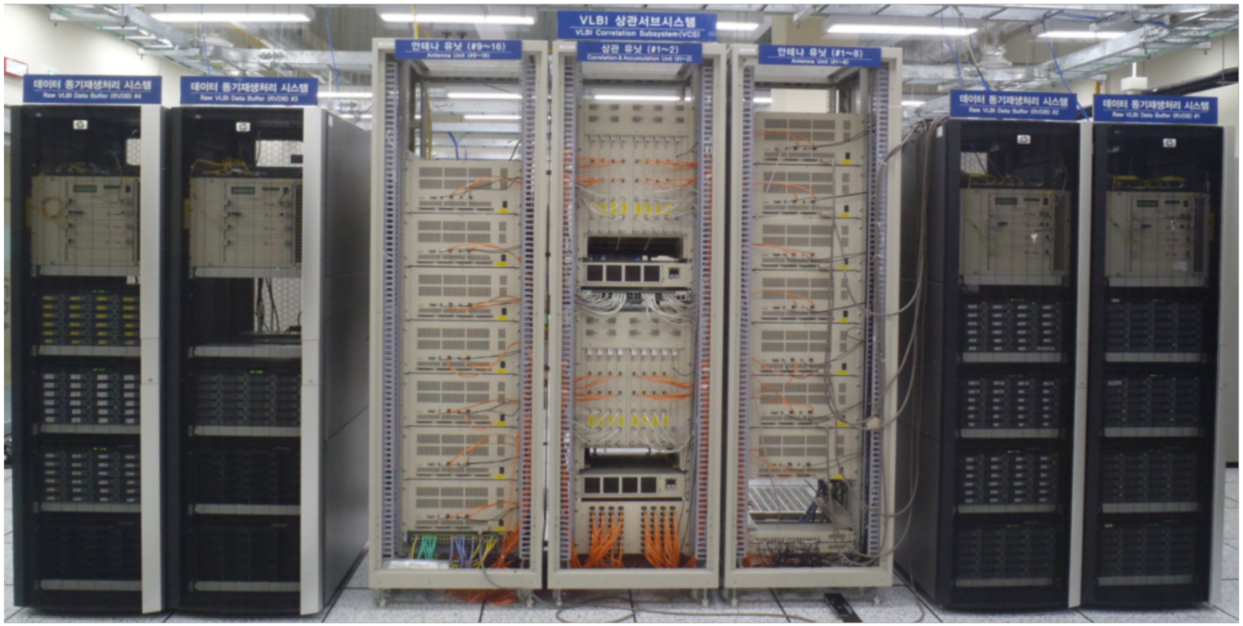
(dedicated science network in Korea)



- KVN Sites : 10 – 40 GbE
- Daejeon : 100GbE
- Remote Operation
- e-Transfer & e-VLBI

Daejeon Correlation Center @ KASI

Daejeon HW Correlator

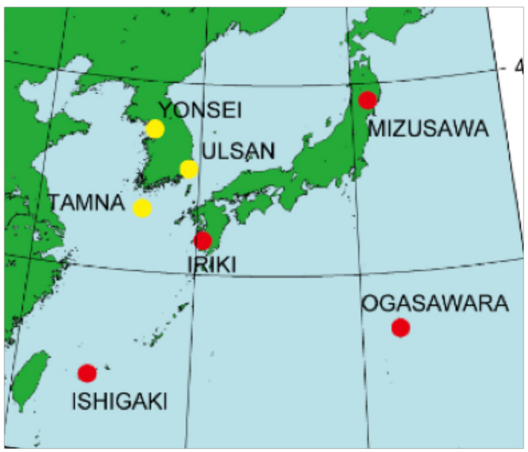


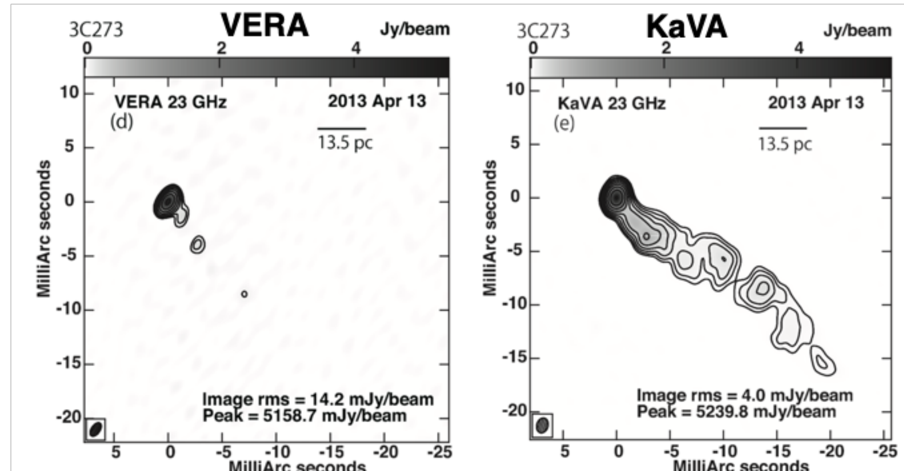
- Korea-Japan Joint Development (2005-2010)
- Target Array : EAVN + Int'l campaig
- Correlation of 16 Stations

DIFX SW Correlator

- Linux Cluster
- KVN data
- e-VLBI
- Operation from 2012
- Storage ~ 1.5 PB

KaVA : KVN and VERA Array





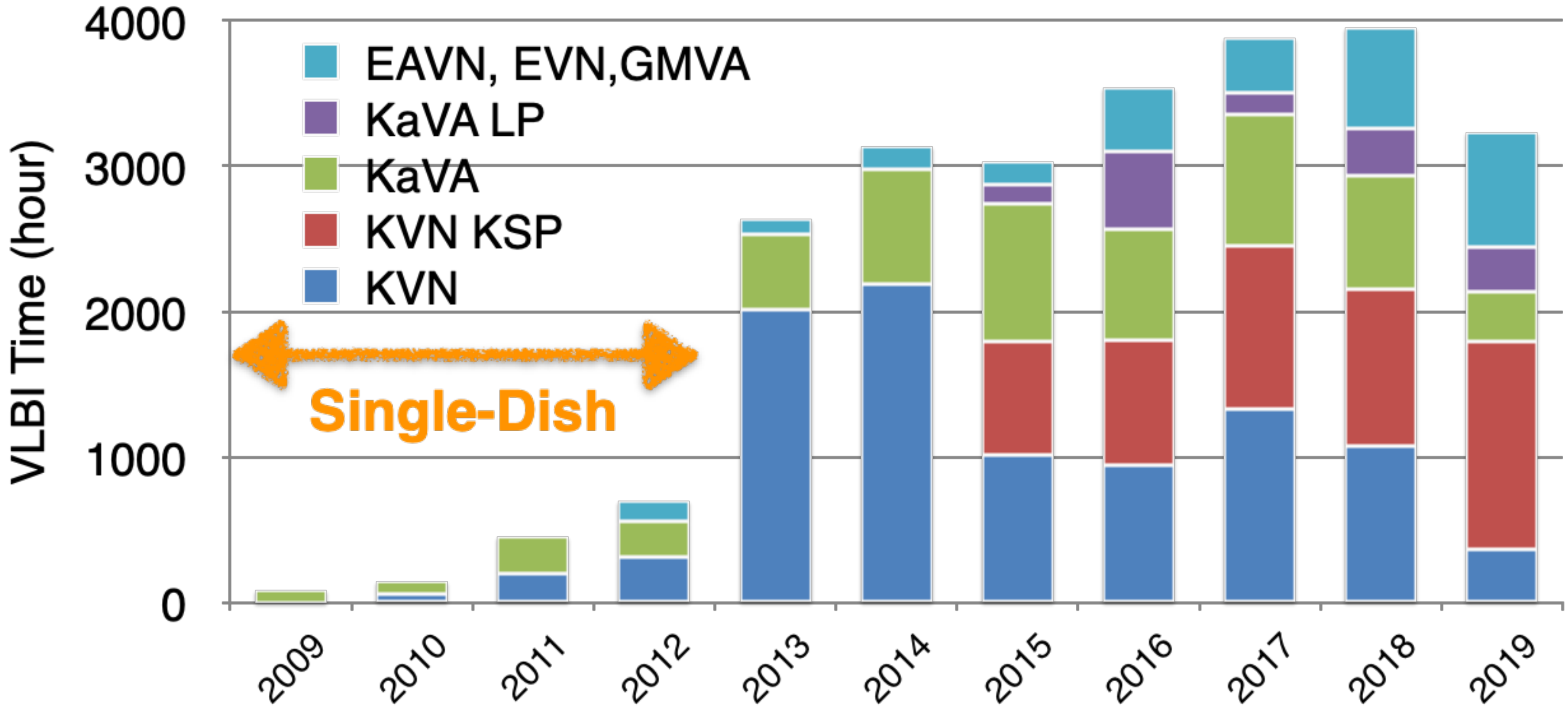
Niinuma+ 2014 PASJ

- Frequency : 22 & 43GHz
- Baseline : 300 - 2300 km
- Formed in 2010
- ~1000 hr /yr from 2013
- High Cadence (2-week)

EAVN : East Asian VLBI Network

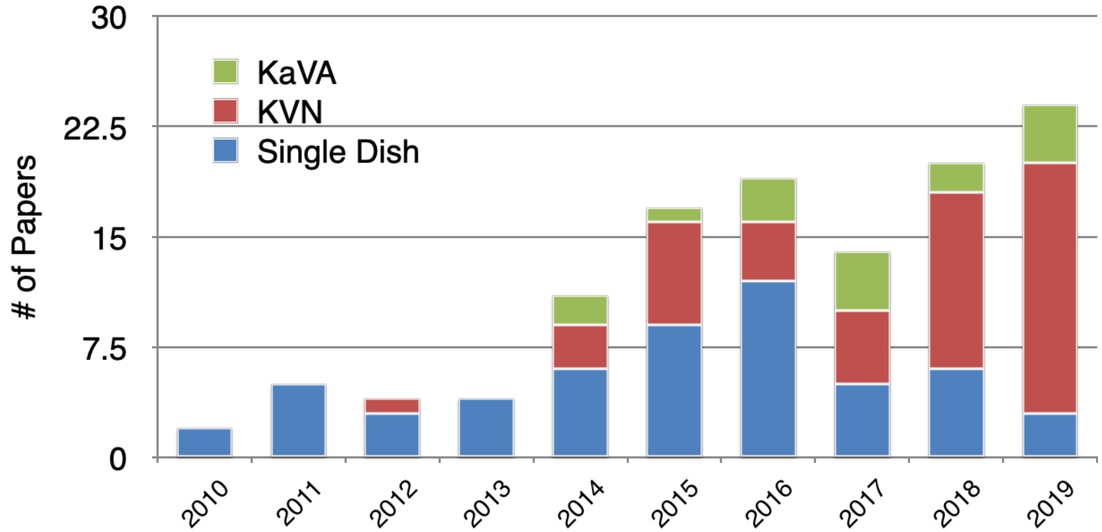
- KVN + VERA + NRO 45m + Tianma 65m (SHAO) + Nanshan 26m (XAO)
- MOU for EAVN Collaboration in 2018
- Regular Operation from 2018
- 22/43GHz (+ 6.7/8GHz)

VLBI Operation

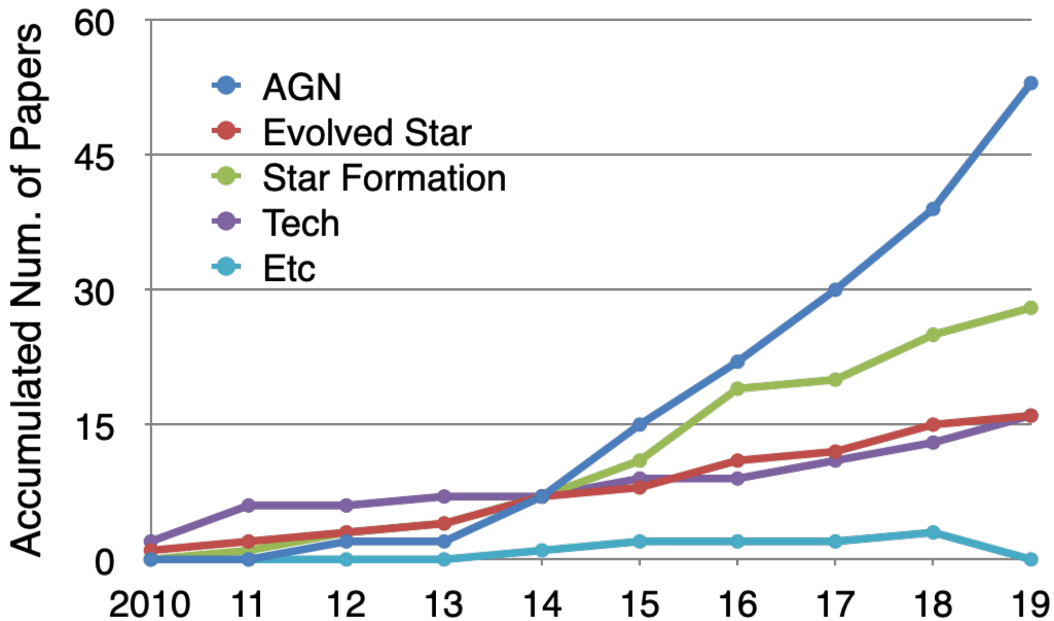


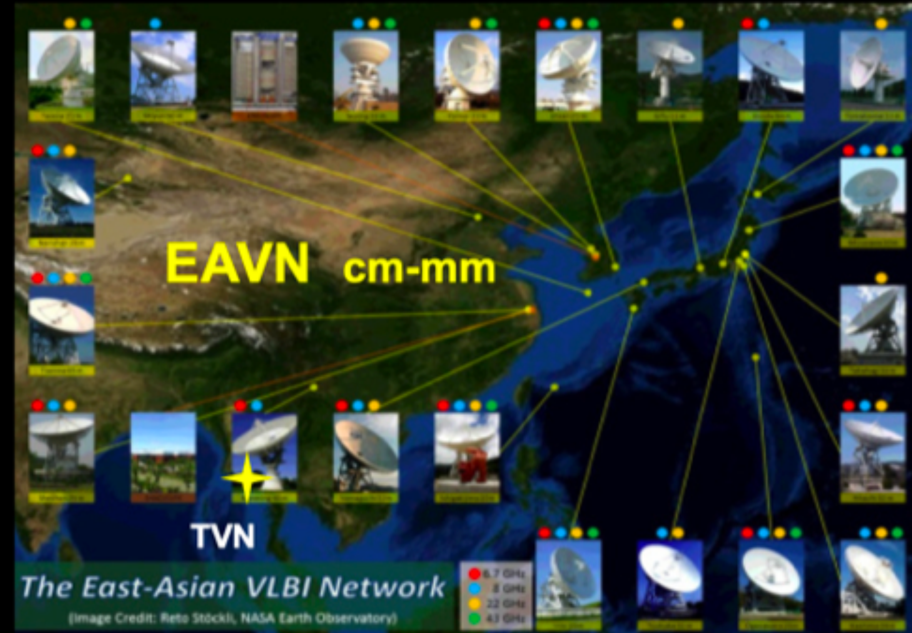
- ~4000hr/yr , ~40 proposals/yr
- Active International Collaboration
- KVN-Sejong Geodetic VLBI from 2016 (~200hr/yr)

Publications

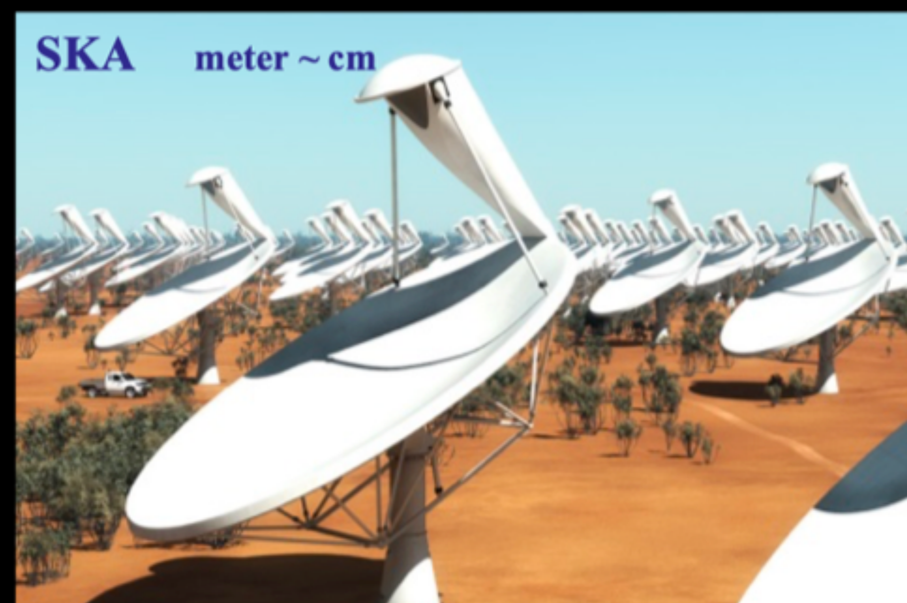


- Total 107 SCI(E) papers
- 11 PhD & 17 Master Theses

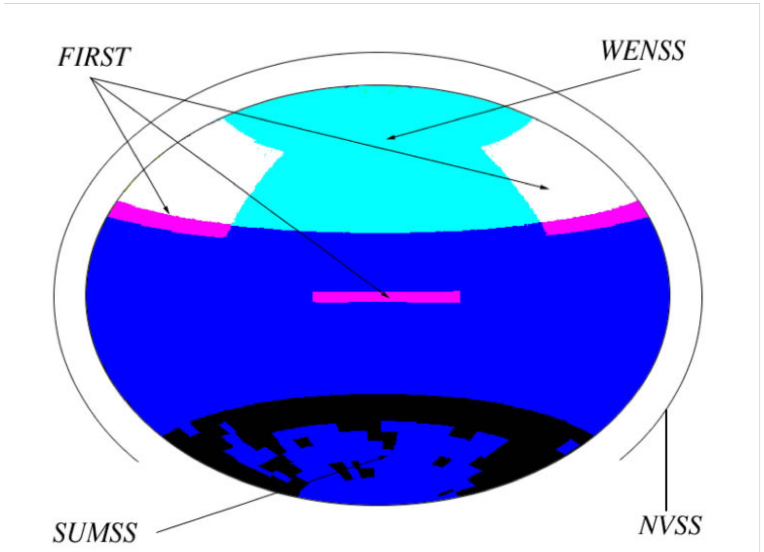




Big Radio Interferometers in Global



High Resolution Radio Surveys



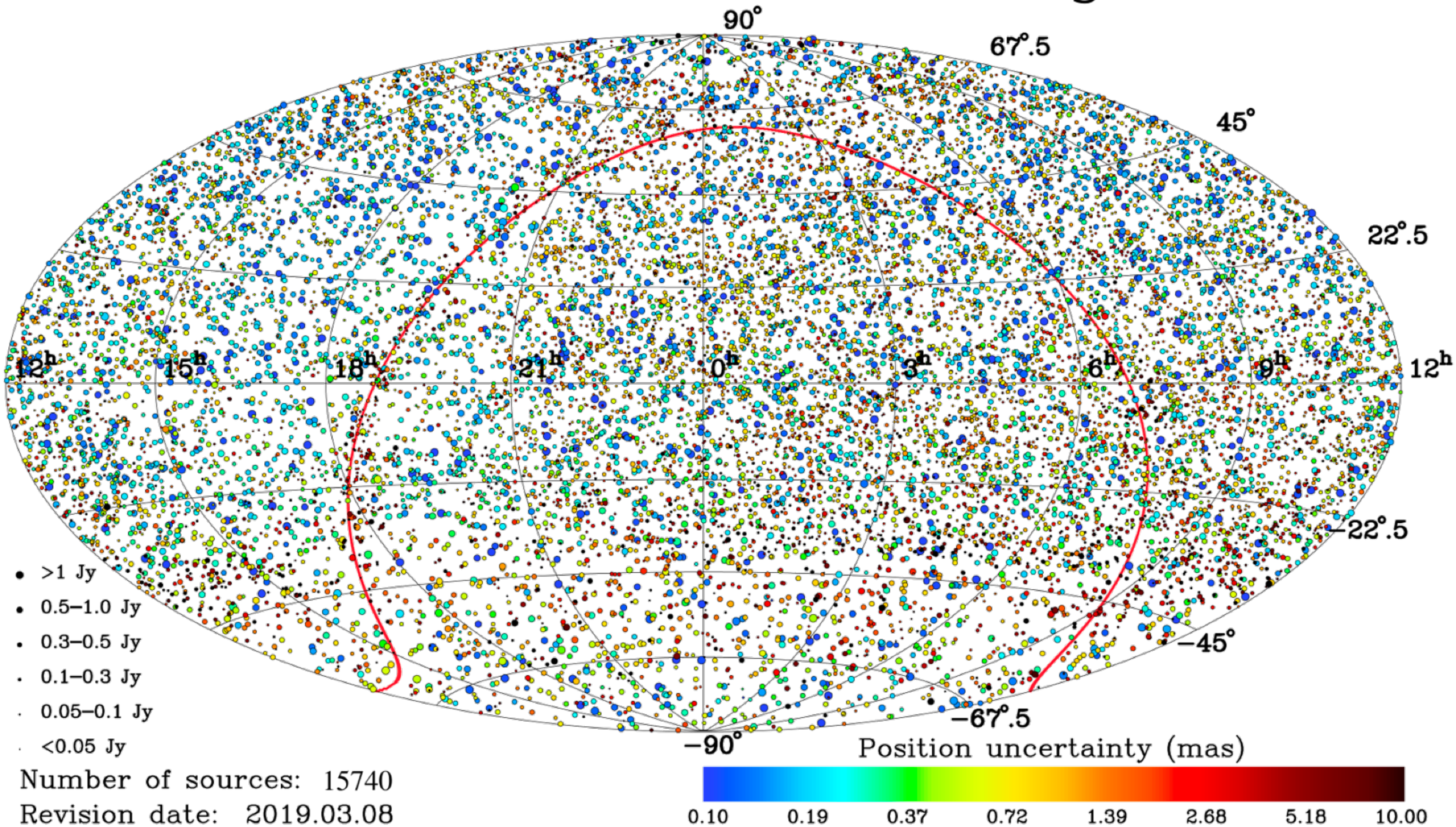
High Resolution Radio Survey Coverage

WENSS: Westerbork Northern Sky Survey
FIRST: VLA Faint Images of the Radio Sky at Twenty centimeters survey
NVSS: NRAO VLA Sky Survey
SUMSS: Sydney University Molonglo Sky Survey

Low frequency surveys **(20cm ~ 1m)** using the **connected interferometers**

	FIRST	NVSS	SUMSS	WENSS
Frequency	1400 MHz	1400 MHz	843 MHz	325 MHz
Area (deg^2)	10,000	33,700	8,000	10,100
Resolution	5”	45”	43”	54”
Detection limit	1 mJy	2.5 mJy	3.5 mJy	15 mJy
Coverage	$\delta > +22°$	$\delta > -40°$	$\delta > -30°$	$\delta > +30°$
Sources/deg^2	90	60	50	20
# of Sources	946,432	1,773,484	211,050	229,420
References	Becker+1995	Condon+1998	Bock+1998	Rengelink+1997

Radio Fundamental Catalogue



At present, 16,845 sources

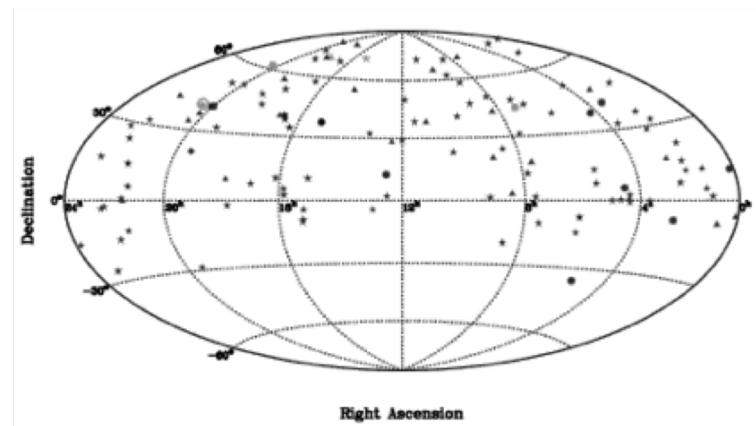
Credit: L. Petrov (http://astrogeo.org)

Astrometry surveys **(1.3cm ~ 15cm)**
using the **Very Long Baseline Interferometry (VLBI)**

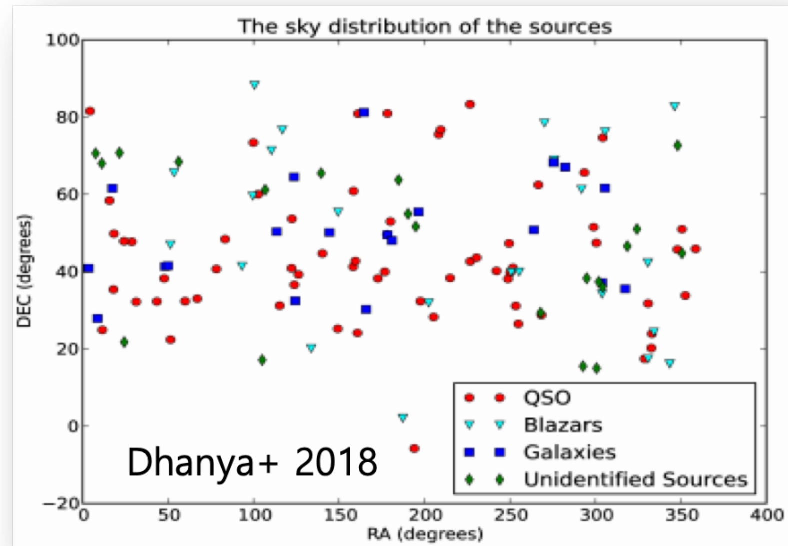
Number of VLBI sources at mm-wavelengths are very limited

Summary of VLBI Surveys, their wavelengths and the number of sources catalogued. The difference in scale of the number of sources in the cm and mm surveys are clear.

Survey ID	Wavelength	No. Sources	Reference
CJF survey	6 cm	293	Taylor et al. (1996)
VSOP VLBApls	6 cm	374	Fomalont et al. (2000)
CJF Polarimetry survey	6 cm	177	Pollack et al. (2003)
ICRF	3.6 cm	~ 500	Ojha et al. (2004); 2005) and references therein
MOJAVE	2 cm	> 133	Lister and Homan (2005)
2 cm Survey	2 cm	250	Kovalev et al. (2005)
VLBA Calibrator survey	13 & 3.6 cm	> 3400	Kovalev et al. (2007)
VIPS	6 cm	1127	Helmboldt et al. (2007)
VERA FSS / GaPS	1.35 cm	500	Petrov et al. (2007)
VSOP Survey	6 cm	~ 300	Dodson et al. (2008)
TANAMI	3.5 & 1.3 cm	80	Ojha et al. (2010)
mJIVE-20	20 cm	> 4300	Deller and Middelberg (2014)
GMVA 3 mm	3 mm	123	Lee et al. (2008)
ICRF 22 & 43-GHz	13.7 & 7 mm	~ 100	Lanyi et al. (2010)
KVN Q-CAL survey	7 mm	638	Petrov et al. (2012)



Lee+ 2007 (108 sources at 3 mm)



162 sources at 3 mm

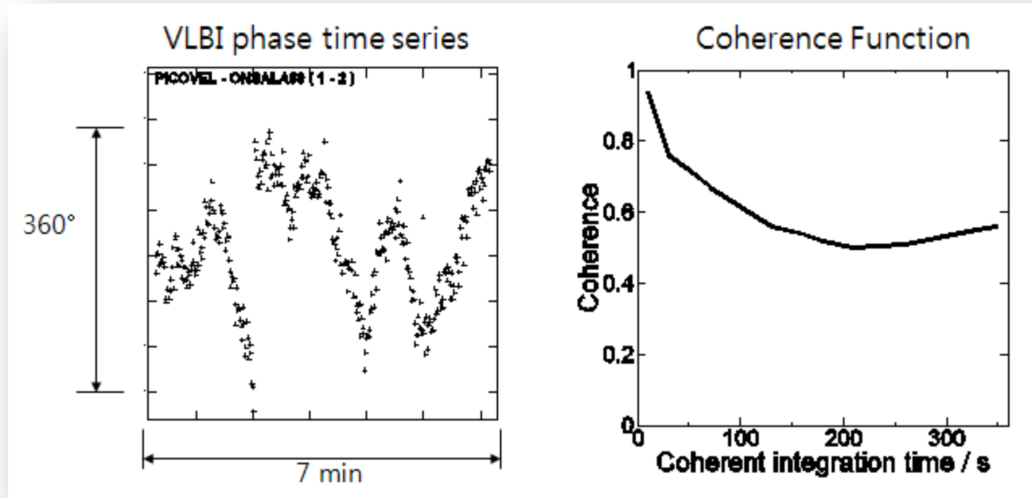
Only ~5% of RFC is available at 7 mm (43 GHz)
Only ~1% of RFC is available at 3 mm (86 GHz)
How about 1 mm (230 GHz) ??

cm VLBI vs mm-VLBI

	cm-VLBI	mm-VLBI
Instrument & Technology	Good performance	Relatively poor performance
Atmospheric condition	Relatively stable (longer coherence)	Rapid change (short coherence)
Sensitivity	~ micro Jy (e.g. Garret 2005)	> 100 mJy
# of Sources	>10,000 (e.g. Petrov, RFC)	~ 160 @ 3mm (86GHz)
Phase Referencing	Well established (e.g. Beasely 1995)	Not very successful (mostly < 43GHz)
Astrometry	tens of micro arcsec (Reid & Honma 2014)	Limited success > 40 GHz

Errors coming from the **ATMOSPHERE** are still remain the most serious difficulty which significantly degrade the sensitivity and imaging capability of mm and sub-mm VLBI observation

Coherence



Pico Veleta – Onsala baseline
Source : BL Lac
Frequency : 86 GHz

(A. Roy)

Coherence Function

$$C(T) = \left| \frac{1}{T} \int_0^T e^{i\phi_t} dt \right|,$$

VLBI Sensitivity

$$S_\nu = (SNR) \frac{8k}{\pi \eta_c} \frac{\sqrt{T_{S_1} T_{S_2}}}{\sqrt{\eta_{A_1} \eta_{A_2}} D_1 D_2 \sqrt{2B\tau_a}}$$

Coherence Time

Frequency (GHz)	2	8	15	22	43	86	129
Coherence Time (sec)*	800	200	100	73	37	19	12

*Typical value of atmospheric phase stability ~ 10^{-13}

Multi-Frequency Phase Referencing (MFPR)

$$\Phi^h = \Phi^h{}_{str} + 2\pi\nu^h(\tau_g + \tau_C + \tau_{inst} + \tau_{trop} + \tau_{ion}) + \Phi^h{}_{LO}$$

$$\Phi^l = \Phi^l{}_{str} + 2\pi\nu^l(\tau_g + \tau_C + \tau_{inst} + \tau_{trop} + \tau_{ion}) + \Phi^l{}_{LO}$$

Self-calibration at lower frequency

$$\Phi^l{}_{str} \qquad 2\pi\nu^l(\tau_g + \tau_C + \tau_{inst} + \tau_{trop} + \tau_{ion}) + \Phi^l{}_{LO}$$

$$\Delta\Phi = \Phi^h - r\Phi^l \qquad r = \nu_h / \nu_l$$

slow varying term

$$\Delta\Phi = \Phi_h - \frac{\nu_h}{\nu_l}\Phi_l = \Phi_h{}^{str} + 2\pi\nu_h(\tau_h{}^g - \tau^g{}_l) - 2\pi\left(1 - \frac{\nu_h^2}{\nu_l^2}\right)\frac{\nu_0^2}{\nu_h^2}\tau^{ion} + (\Phi_h{}^{LO} - \frac{\nu_h}{\nu_l}\Phi_l{}^{LO})$$

Source Structure

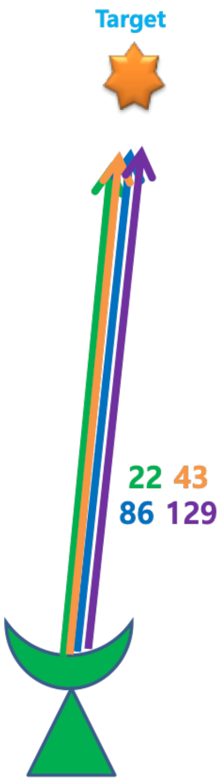
Core-shift or Diff. in maser lines

ionosphere

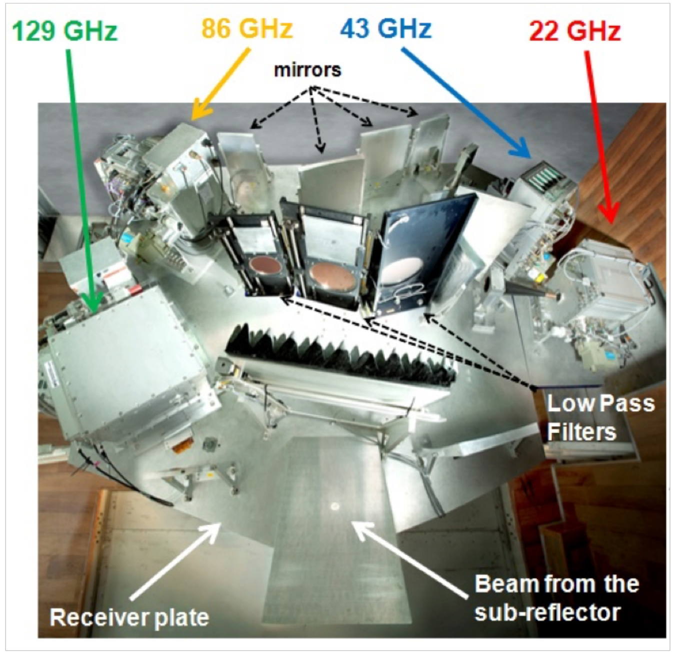
instrument

Jung et al. (2011)

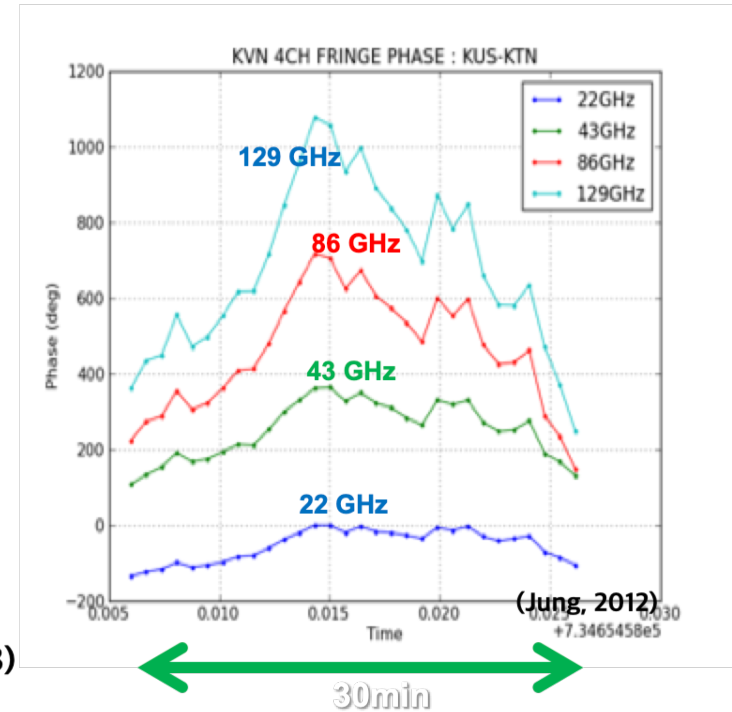
KVN Simultaneous Multi-frequency VLBI System

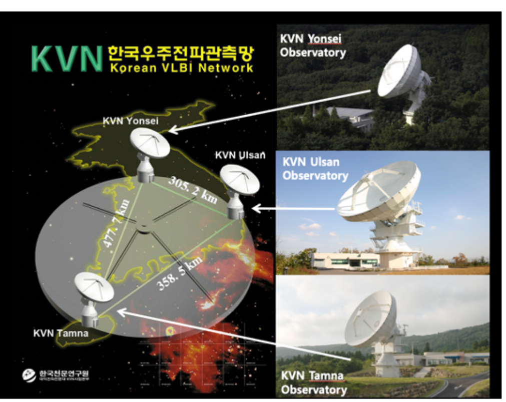


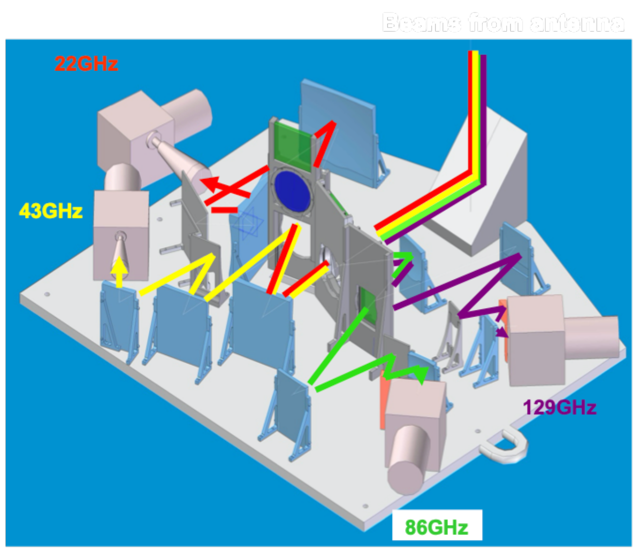
Multi-Frequency System



KVN Multi-Frequency System (Han et al. 2008)







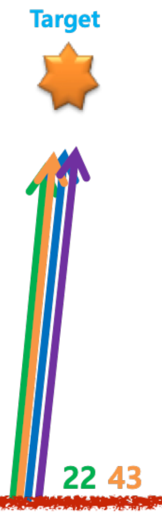
$$\frac{\partial \phi_{high}}{\partial t} = \left(\frac{\nu_{high}}{\nu_{low}} \right) \times \frac{\partial \phi_{low}}{\partial t}$$

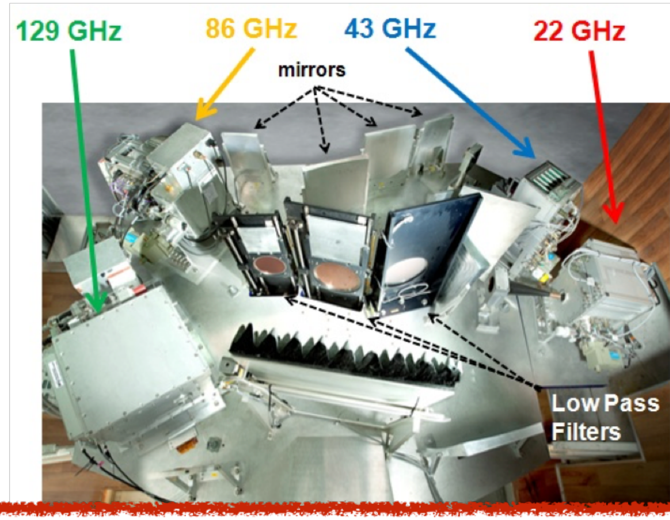
Non-dispersive nature of troposphere

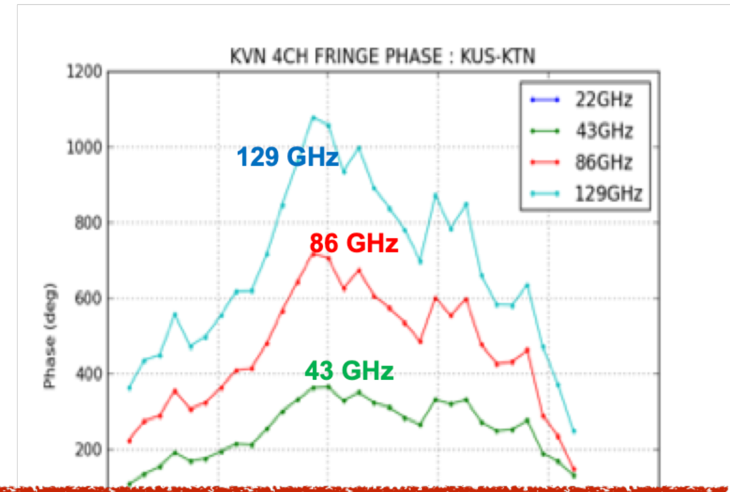
- No observing time loss
- No Calibrator (target = calibrator)
- No coherence loss
- Lower frequency detection needed

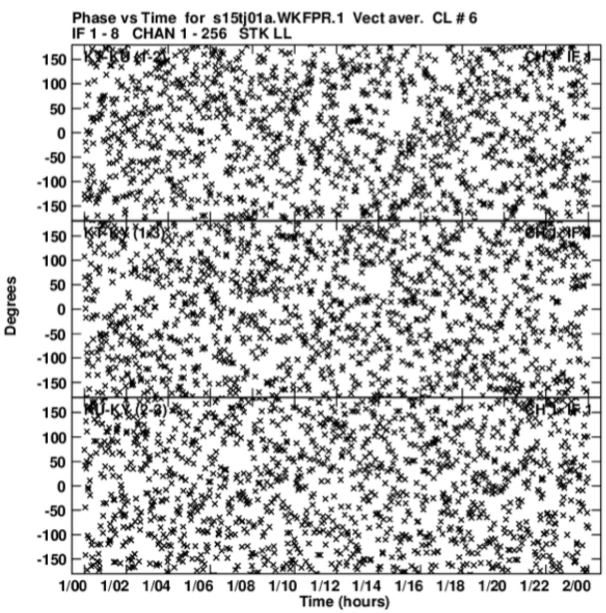
Excellent Atmospheric Calibration!!

KVN Simultaneous Multi-frequency VLBI System

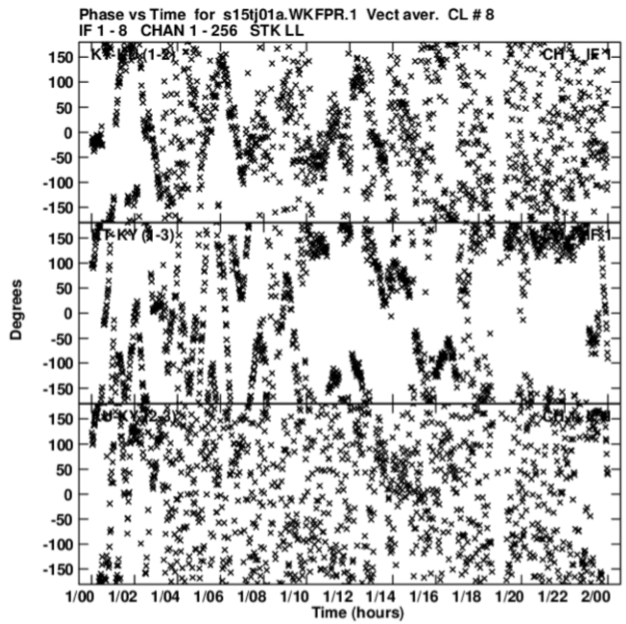




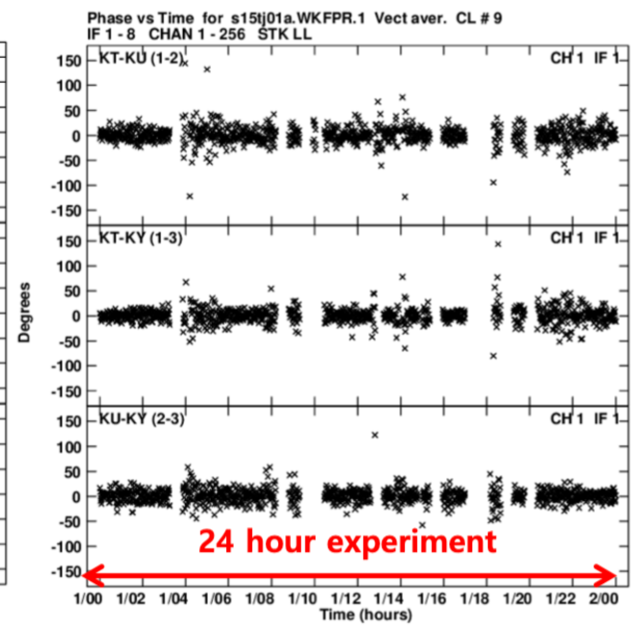




Raw 86GHz Phase



FPTed 86GHz Phase



Calibrated 86GHz Phase

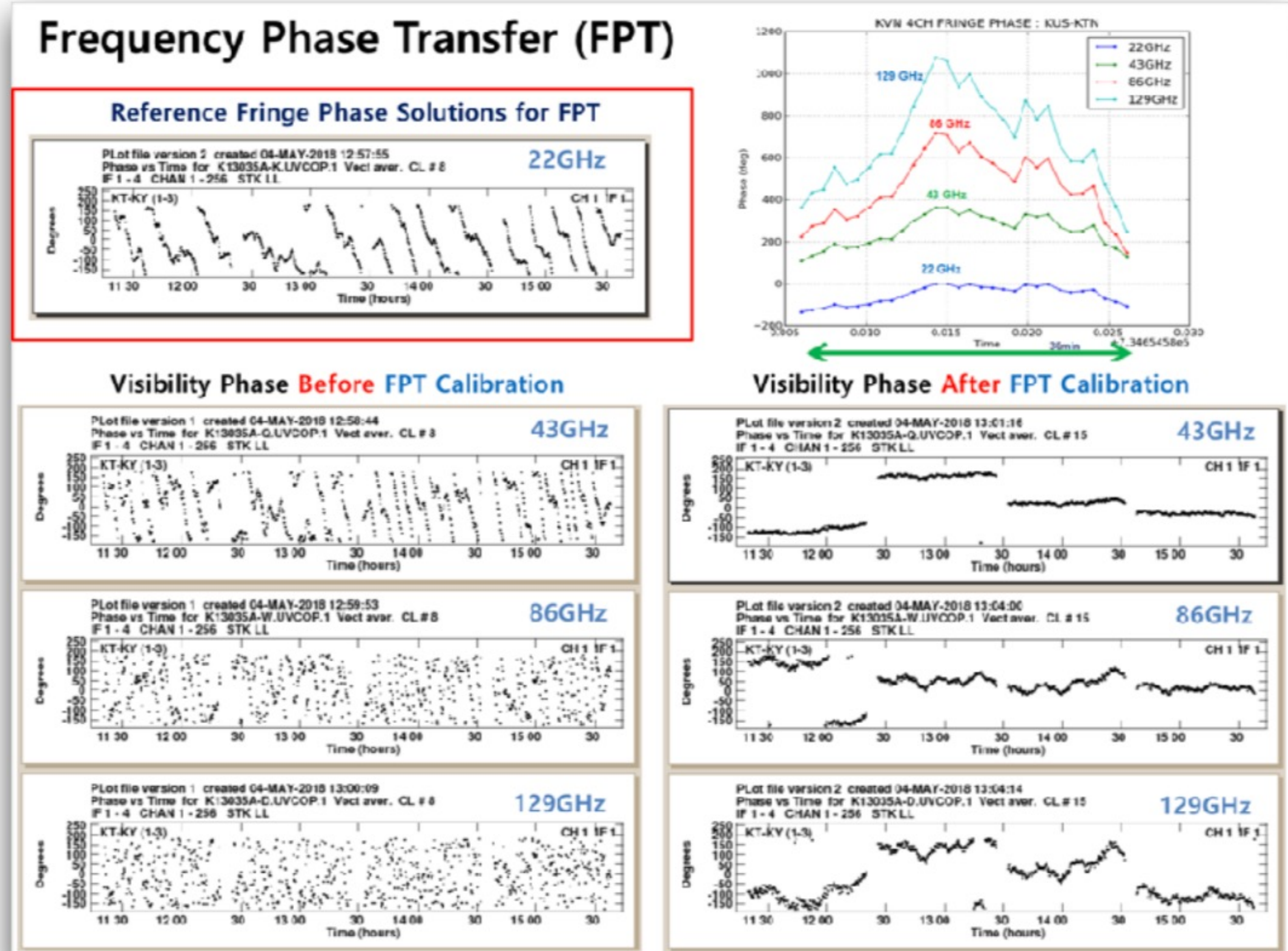
Excellent Atmospheric Calibration!!

KVN Baseline/Image Sensitivity

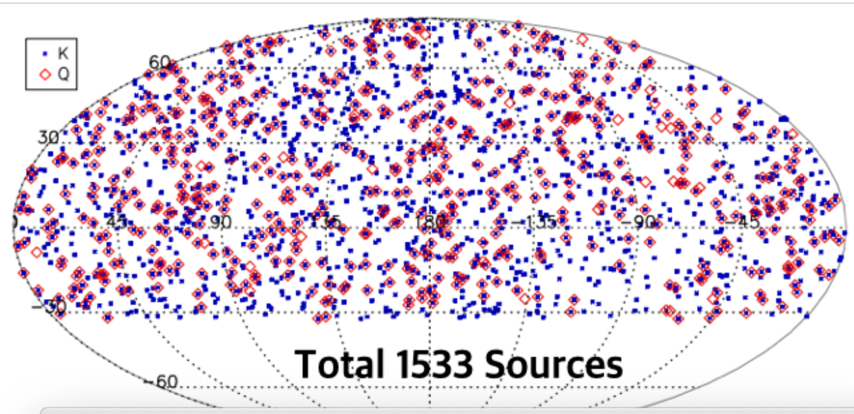
Frequency	22 GHz	43 GHz	86 GHz	129 GHz
SEFD (Jy)	1500	1800	3400	5000
Sensitivity (mJy, 1-sigma)	T_int=100s / T_int=1hr	T_int=60s / T_int=1hr	T_int=30s / T_int=1hr	T_int=30s / T_int=1hr
1 Gbps (Max 256 MHz)	9.6 / 1.28	14.9 / 1.53	39.8 / 2.89	58.5 / 4.25
2 Gbps (Max 512 MHz)	6.8 / 0.90	10.5 / 1.08	28.1 / 2.05	41.3 / 3.01
4 Gbps (Max 1024 MHz)	4.8 / 0.64	7.4 / 0.77	19.9 / 1.45	29.2 / 2.13
8 Gbps (Max 2048 MHz)	3.4 / 0.45	5.3 / 0.54	14.1 / 1.02	20.7 / 1.50
16 Gbps (Max 4096 MHz)	2.4 / 0.32	3.7 / 0.38	9.9 / 0.72	14.6 / 1.06
32 Gbps (Max 8192 MHz)	1.7 / 0.23	2.6 / 0.27	7.0 / 0.51	10.3 / 0.75

- Note: (baseline) / (image) sensitivity in the unit of mJy
- Big improvement on the baseline sensitivity when FTP is applied (i.e., ~30 min)

Simultaneous Multifrequency Receiving System



Multi-Frequency AGN Survey with KVN

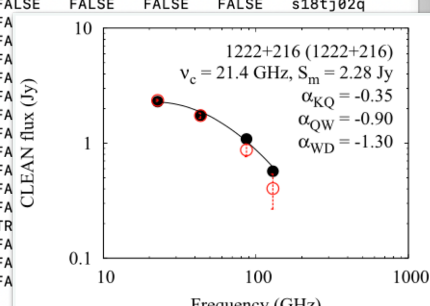


- Simultaneous multi-frequency VLBI catalogue (22/43/86/130GHz)
- All 1533 srcs were observed and 1273 srcs were analyzed
- VLBI Detection Statistics (each BW: 64MHz)
  - 22GHz (1157, ~91%), 43GHz (950, ~75%), 86GHz (611, ~48%), 130GHz (308, ~24%)

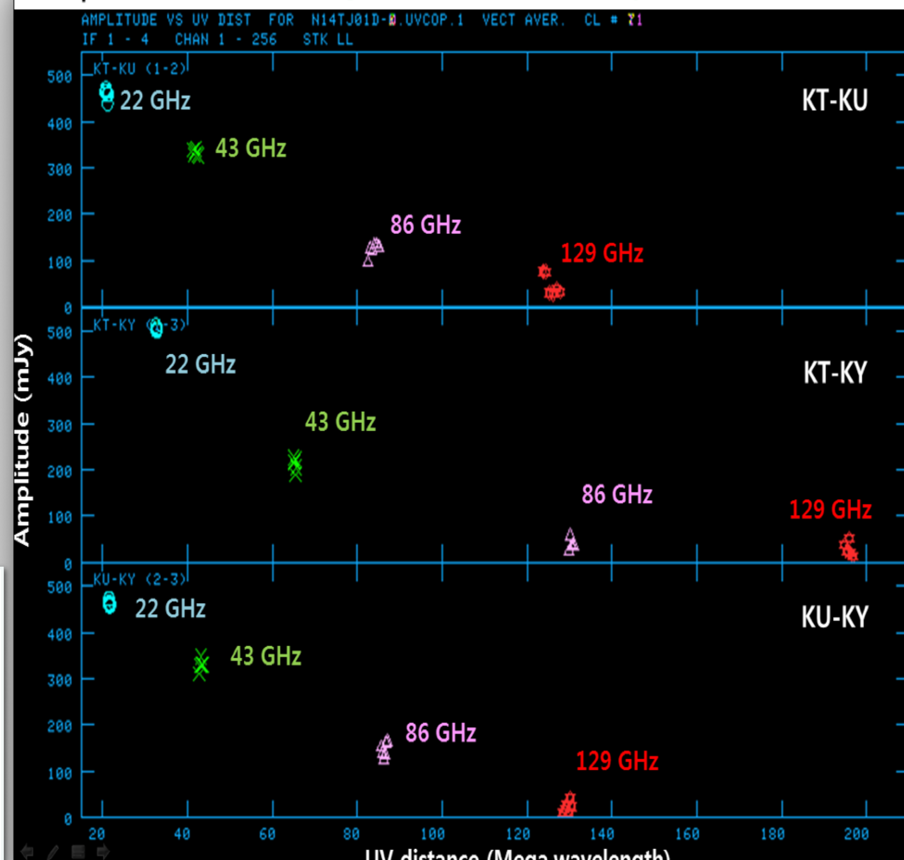
thjung — kvnuser@KVNAOC: /home/KVN/Resource/Vex/2019a — vim mask-detec.txt — 93×45

~ — kvnuser@KVNAOC: /home/KVN/Resource/Vex/2019a — vim mask-detec.txt

1	J0001-1551	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	s18tj01f
2	J0006-0623	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	s16tj02c
3	J0006-0623	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	FALSE	s16tj02s
4	J0008-2339	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	s18tj01a
5	J0008-2339	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	s18tj02x
6	J0008+6837	TRUE	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE	s18tj02a
7	J0009+4001	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	s18tj02a
8	J0010-2157	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	s18tj01f
9	J0010+1058	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	s16tj02a
10	J0010+1058	TRUE	FALSE	TRUE	FALSE	TRUE	TRUE	TRUE	s16tj02l
11	J0010+1058	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	s16tj02s
12	J0011-2612	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	FALSE	s18tj01a
13	J0011+0823	TRUE	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE	s18tj02a
14	J0011+7045	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	s18tj02s
15	J0012+3353	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	s18tj02a
16	J0013+1910	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	s18tj02c
17	J0013+4051	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	s16tj02a
18	J0013+4051	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	s16tj02l
19	J0014+6117	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	s16tj02c
20	J0014+6117	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	s16tj02s
21	J0016-0015	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	s18tj01x
22	J0016-0015	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	s18tj02y
23	J0017-0512	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	s18tj01x
24	J0017+5312	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	s18tj02c
25	J0017+8135	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	FALSE	s18tj02s
26	J0019+7327	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	s16tj02a
27	J0019+7327	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	s16tj02k
28	J0022+4525	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	s18tj02c
29	J0024-0412	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	s18tj02q
30	J0025+3919	FALSE	FALSE	FALSE	FA				
31	J0028+2000	TRUE	TRUE	TRUE	FA				
32	J0029-0113	TRUE	TRUE	FALSE	FA				
33	J0029+0554	TRUE	TRUE	TRUE	FA				
34	J0038+1227	FALSE	FALSE	FALSE	FA				
35	J0039+1411	TRUE	FALSE	FALSE	FA				
36	J0040-0146	TRUE	TRUE	FALSE	FA				
37	J0042+2320	TRUE	TRUE	TRUE	FA				
38	J0042+5708	TRUE	TRUE	TRUE	FA				
39	J0047+2435	TRUE	TRUE	FALSE	FA				
40	J0047+5657	TRUE	TRUE	FALSE	FA				
41	J0048+3157	TRUE	TRUE	TRUE	TR				
42	J0049+0237	TRUE	TRUE	FALSE	FA				
43	J0049+5128	TRUE	TRUE	FALSE	FA				
44	J0050-0929	TRUE	TRUE	TRUE	FA				



Example: J0502+1338 KVN single dish flux at 22GHz ~ 0.3 Jy (No SD detection at 43GHz)



KVN Key Science Projects

1. Interferometric Monitoring of Gamma-Ray Bright AGN : iMOGABA (Sang-Sung Lee/KASI)
2. Simultaneous Monitoring of KVN 4 Bands towards Evolved Stars (Se-Hyung Cho/KASI)
3. The Plasma Physics of AGN with KVN : PaGAN (Sascha Trippe/SNU)

- KVN Legacy Program:

  Multi-Frequency AGN Survey with KVN : MASK (Taehyun Jung)

KSP1

iMOGABA (Interferometric Monitoring of Gamma-Ray Bright AGN)

- Studying the origins of the gamma-flares
  - What is the location of the gamma-ray flares?

  : Down stream the relativistic jets?

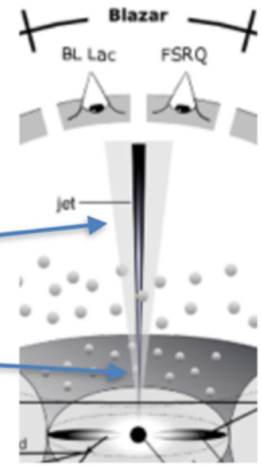
  : much inner region of the jets?

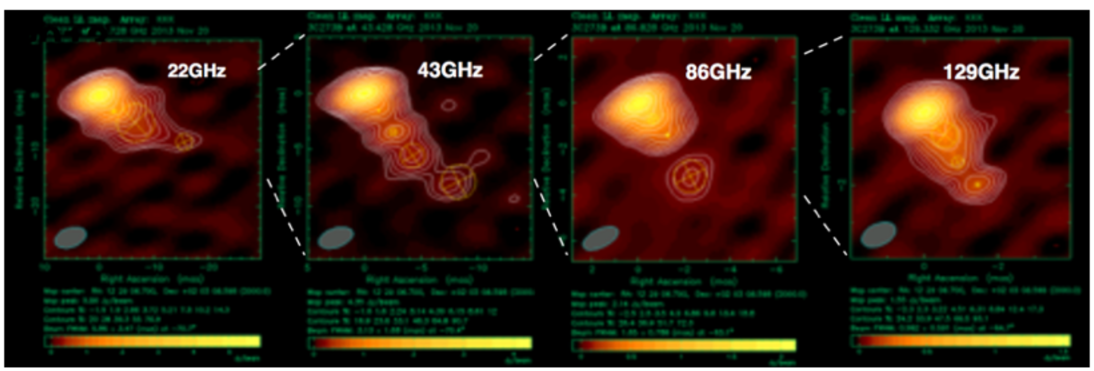
  - What cause the gamma-ray flares of AGNs?

  : A relativistic jet of high energy plasma (a shock) (e.g., Marscher et al. 2008)

  : Doppler boosting of synchrotron radiation of the jet (e.g., Dermer 1995)

  : Inverse Compton scattering by relativistic electrons (upscattered g-ray photons)



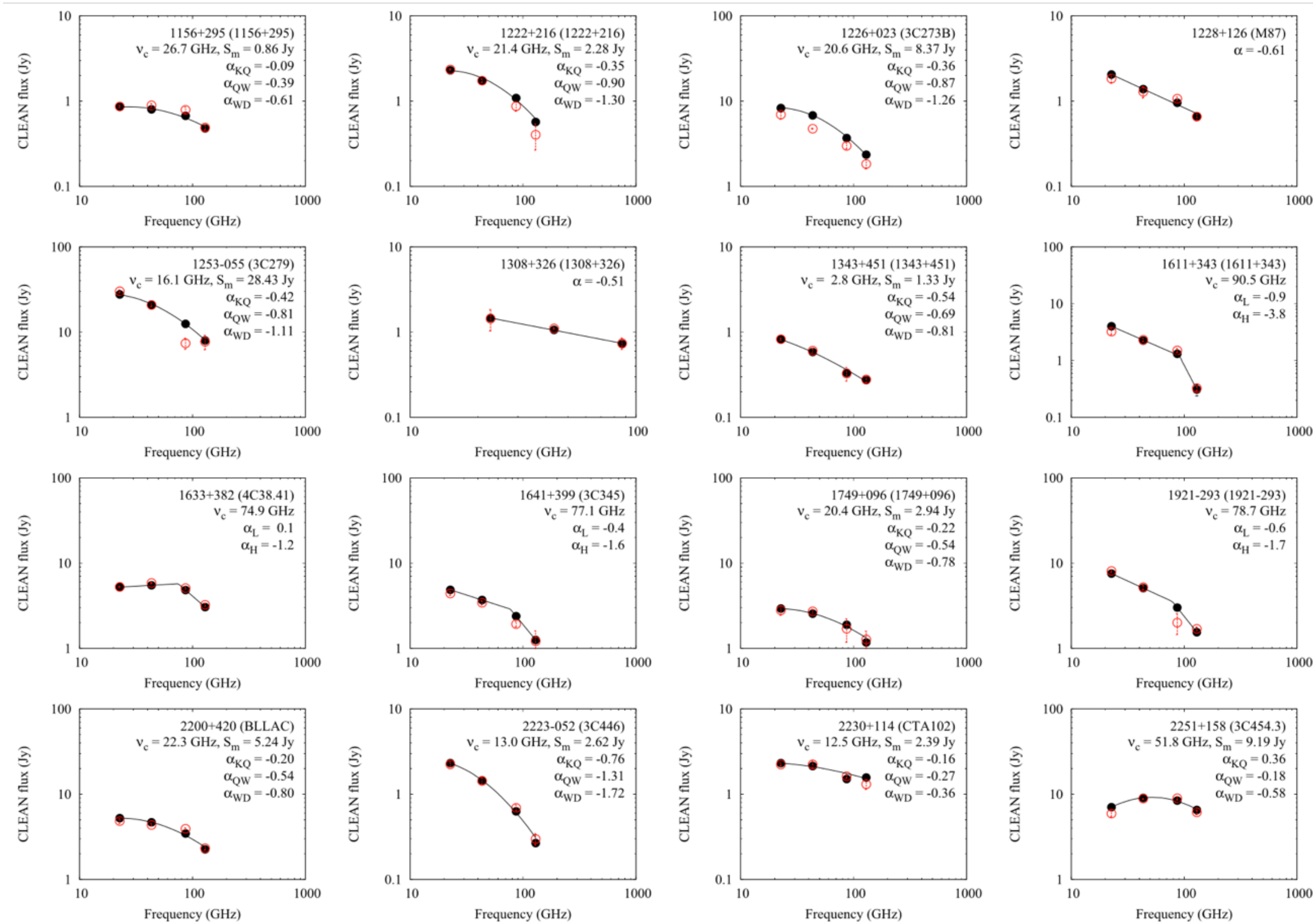


- Monthly VLBI monitoring of the MOGABA sources (**~35**)
- correlated flux of inner-jet structure after gamma-ray flare
- Multi-freq. (22/43/86/129GHz) monitoring

(Credit: S-S Lee)

http://radio.kasi.re.kr/sslee/

Interferometric Monitoring of Gamma-Ray Bright AGNs.
I. The Results of Single-epoch Multifrequency Observations



Spectra over 22GHz-129GHz can be fitted with a power-law or a curved power-law

(Lee et al. 2016)

KSP2

Simultaneous Monitoring Observations of KVN 4 Bands toward Evolved Stars

1. Spatial structure and dynamical effect from SiO to 22 GHz H_2O maser regions according to stellar pulsation through simultaneous monitoring obs. of KVN 4 bands

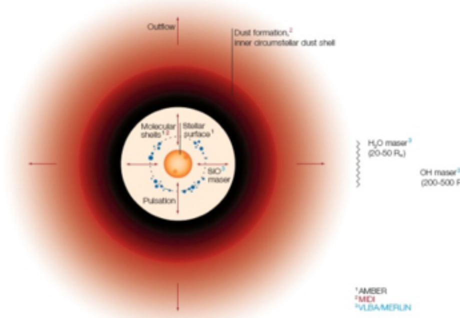
○ Pulsation and shock wave propagation effect from SiO to H_2O maser region via dust layer : **development of outflow motion and asymmetry ► Mass loss mechanism** based on combined studies of SiO and H_2O masers.

No.	Source	R. A.	Dec.	V_{LSR} (km s^{-1})	Period (days)	S. A. (°)	Calibrator
1	WX Psc	01h06m25.98s	12d35'53.0	8.5	660	3.81	J0121+1149[3]
2	IK Tau	03h53m28.87s	11d24'21.7	35.0	470	4.04	J0345+1453[1]
3	NV Aur	05h11m19.44s	52d52'33.2	3.0	635	3.19	J0514+5602[1]
4	VY CMa	07h22m58.33s	-25d46'03.2	18.0	-	2.78	J0731-2341[2]
5	R Leo	09h47m33.49s	11d25'43.7	−1.0	310	5.52	J1007+1356[3]
6	R Crt	11h00m33.85s	-18d19'29.6	10.7	160	3.06	J1048-1909[3]
7	W Hya	13h49m02.00s	-28d22'03.5	42.0	390	4.89	J1339-2401[3]
8	V2108 Oph	17h14m19.39s	08d56'02.6	16.0	395	2.45	J1722+1013[1]
9	VX Sgr	18h08m04.05s	-22d13'26.6	3.0	732	6.06	J1833-2103[2]
10	V5102 Sgr	18h16m26.03s	-16d39'56.4	48.0	250	5.99	J1833-2103[2]
11	V1111 Oph	18h37m19.26s	10d25'42.2	−30.2	-	3.28	J1824+1044[1]
12	V1366 Aql	18h58m30.09s	06d42'57.8	20.4	1424	7.07	J1830+0619[3]
13	χ Cyg	19h50m33.92s	32d54'50.6	12.0	408	6.65	J2015+3710[3]
14	RR Aql	19h57m36.06s	-01d53'11.3	26.0	395	4.42	J2015-0137[3]
15	V627 Cas	22h57m40.99s	58d49'12.5	−52.0	-	3.43	J2231+5922[3]
16	R Cas	23h58m24.87s	51d23'19.7	21.0	430	5.65	J2322+5057[3]

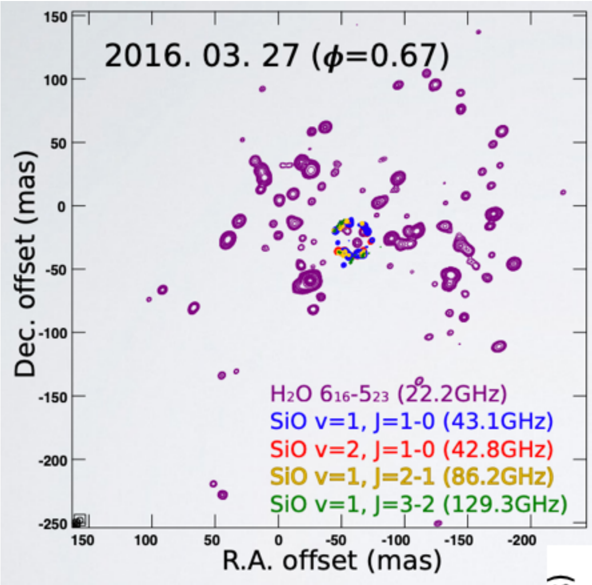
2. Correlation and difference of maser properties (spatio-kinematic properties etc) among SiO J=1-0, J=2-1, J=3-2 masers

► Constraints on SiO maser excitation and pumping models (collisional and/or radiative)

▶ Synergy with KaVA (KVN+VERA) Evolved Star Large Program and ALMA Observations.



(Credit: S. H. Cho)

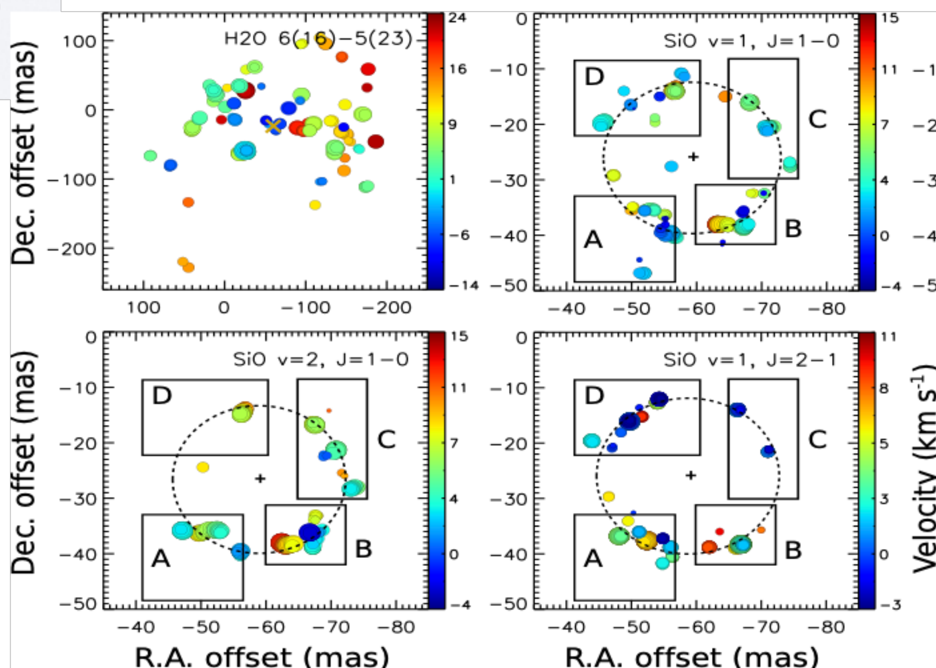


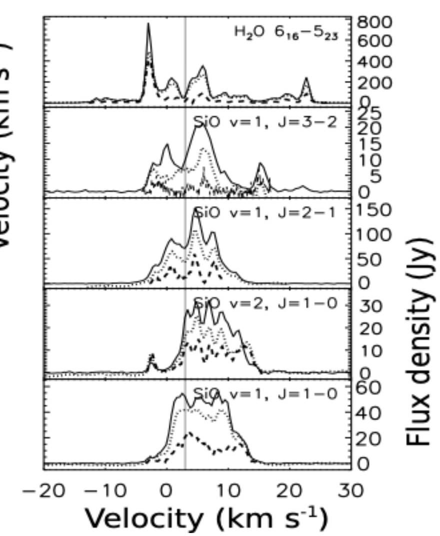
Velocity-integrated intensity map

Astrometrically Registered Maps of H2O and SiO Masers Toward Vx Sagittarii

SiO masers is an almost complete, nearly circular ring, suggesting spherically symmetric mass loss within a few stellar radii although the H2O maser shown an asymmetric structure.

Astrometrically Registered Maps In Vx-Sgr

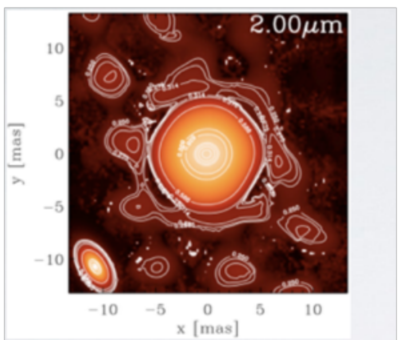




(Yoon et al. 2018)
Nature Communications 2018

2016. 03. 27 (ϕ=0.67)

Observational evidence for a break in spherical symmetry between the SiO and H2O maser zone

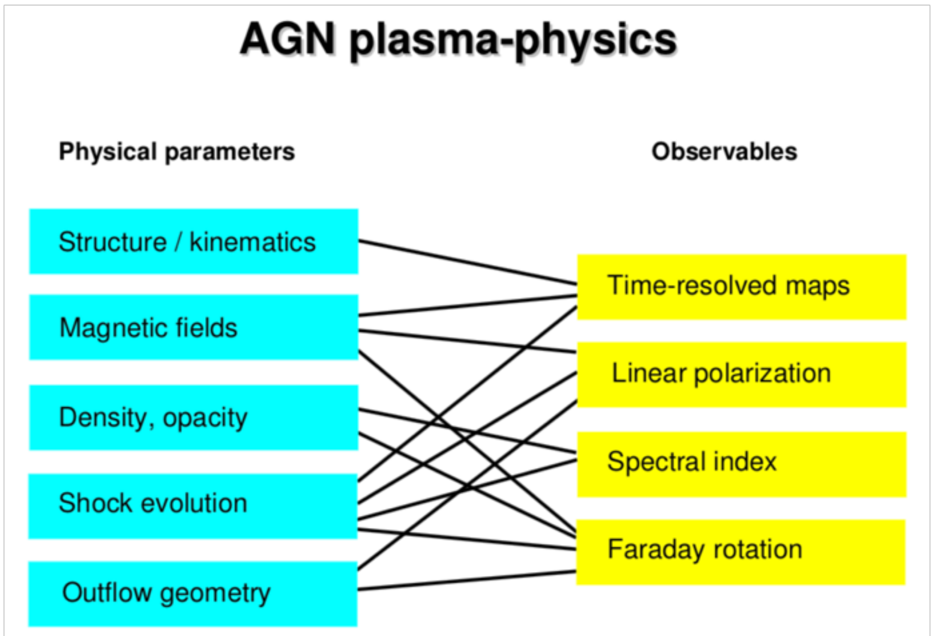


VLTI/AMBER spectro-interferometry
(Chiavassa et al. 2010)

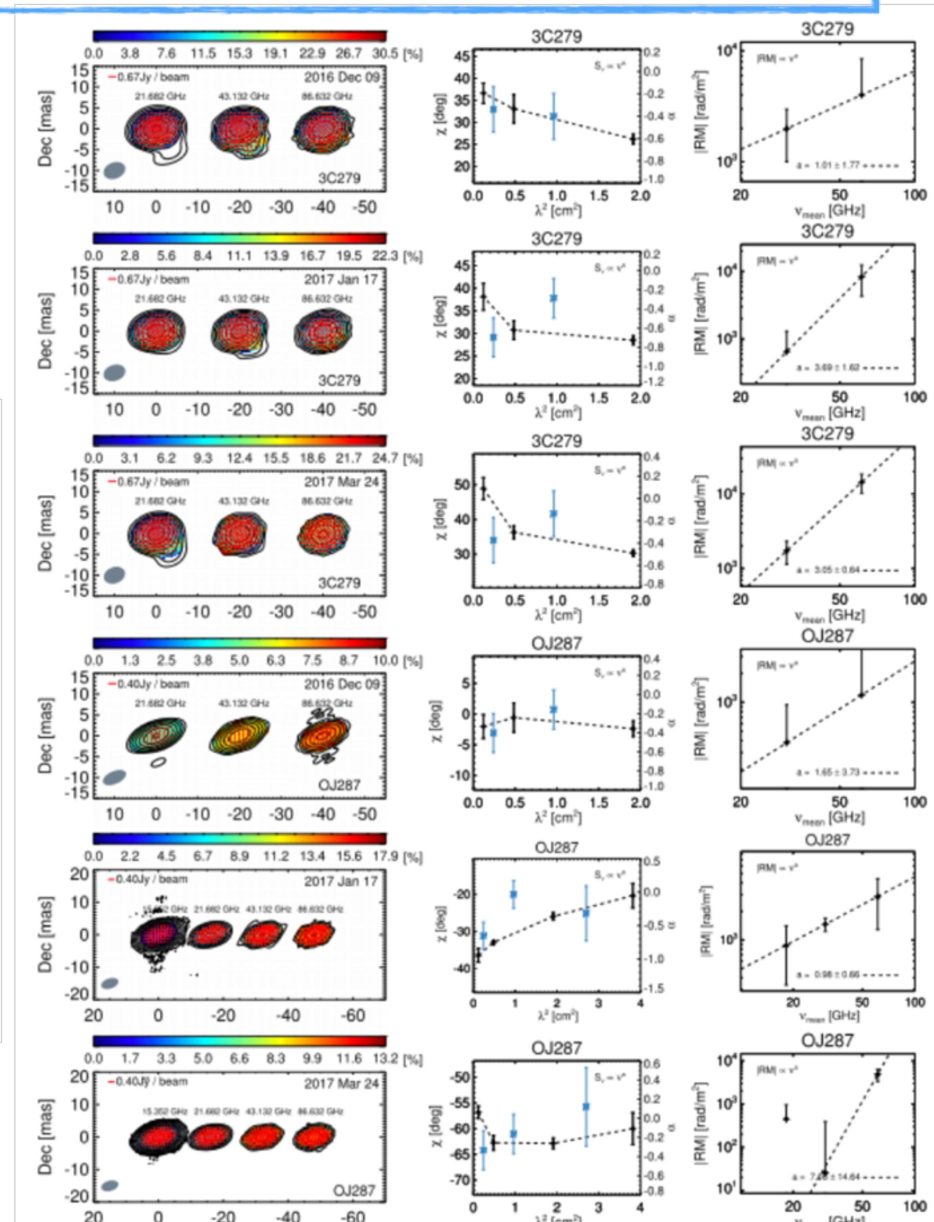
KSP3

The Plasma Physics of AGN with KVN

- Geometry and Magnetic field structure of AGN Jets from ν-dependent Rotation Measure
- Polarization Monitoring of ~14 Bright AGNs
- Polarization Calibration up to 130GHz



(Credit: S. Trippe)



(Park et al. 2018)

2nd KVN Key Science Projects

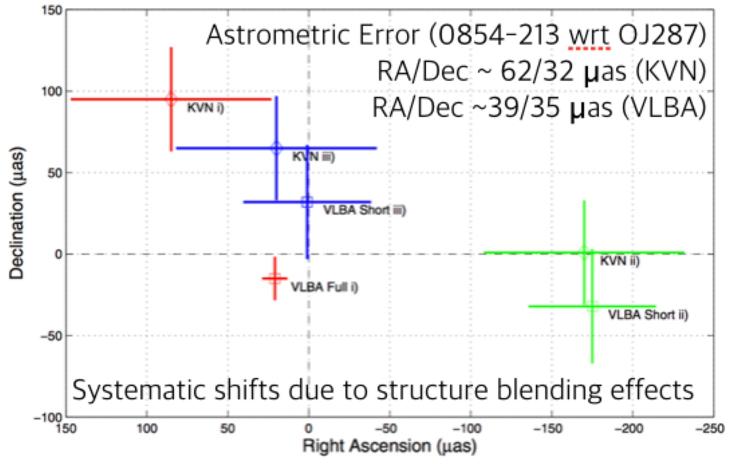
1. The Plasma Physics of AGN with KVN : PaGAN (Sascha Trippe/SNU)
2. Simultaneous Monitoring of KVN 4 Bands towards Evolved Stars (Youngjoo Yon/KASI)

16Gbps + simultaneous dual-pol @22/43/86/129GHz

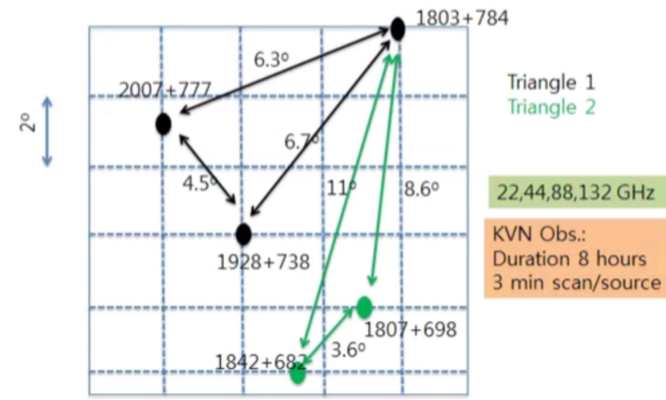
Starting from October 2020

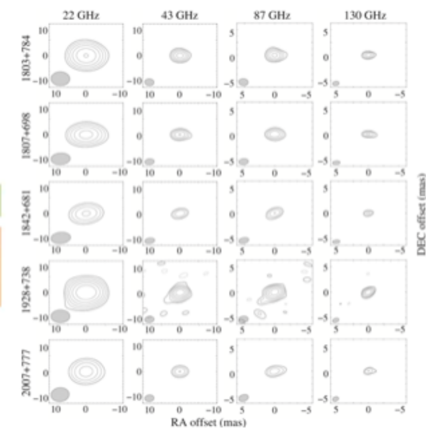
SFPR and Astrometry with KVN

Verification of Astrometric Performance of KVN with VLBA at 14/7 mm (Rioja+ 2014)

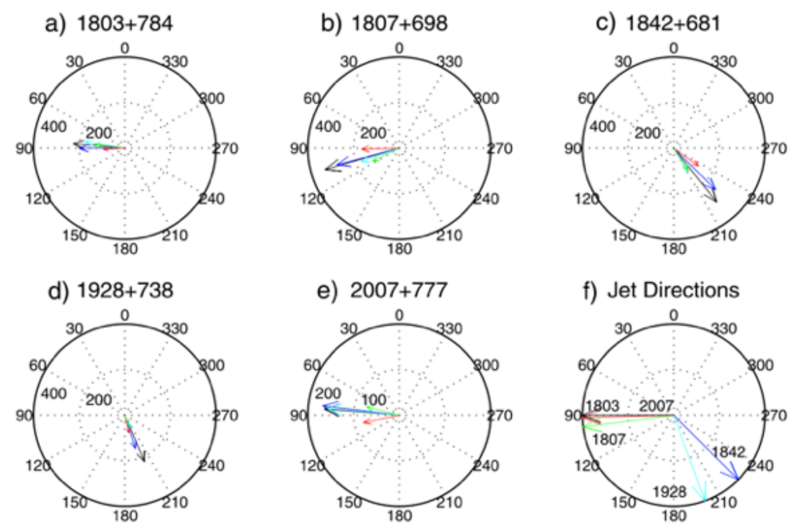


KVN SFPR demonstration using Polar Cap samples (Rioja+ 2015)

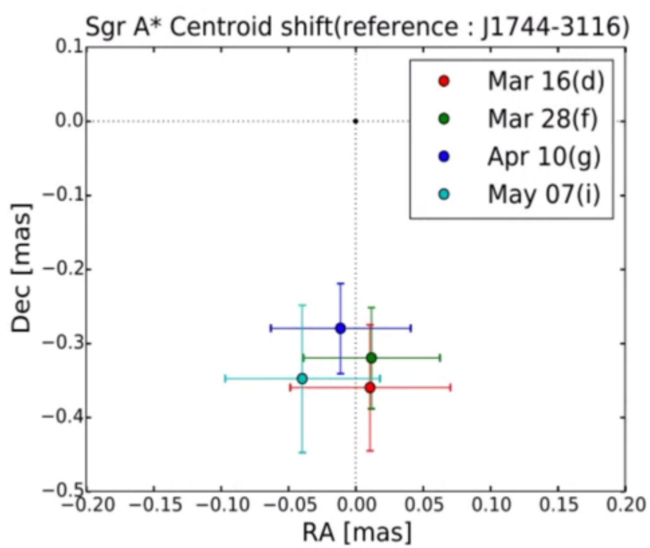




- Demonstration of high-precision astrometry up to 130GHz



Coreshift measurement of SgrA* (I-J Cho)



Continuum Studies

- Weak sources
- Astrometry
- Faraday rotation studies
- Opacity core-shifts, γ-ray flares, and nature of the VLBI core

The science case for simultaneous mm-wavelength receivers in radio astronomy

Richard Dodson[*,a], María J. Rioja[a,b,c], Taehyun Jung[d,e], José L. Goméz[f], Valentin Bujarrabal[c], Luca Moscadelli[g], James C.A. Miller-Jones[h], Alexandra J. Tetarenko[i], Gregory R. Sivakoff[i]

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Instrumentation: Interferometers
Methods: Observational
Telescopes
Quasars: General
Astrometry
Quasars: Jets
Stars: AGB and post-AGB
Stars: Formation
X-rays: Binaries

ABSTRACT

This review arose from the European Radio Astronomy Technical Forum (ERATec) meeting held in Firenze, October 2015, and aims to highlight the breadth and depth of the high-impact science that will be aided and assisted by the use of simultaneous mm-wavelength receivers.

Recent results and opportunities are presented and discussed from the fields of: continuum VLBI (observations of weak sources, astrometry, observations of AGN cores in spectral index and Faraday rotation), spectral line VLBI (observations of evolved stars and massive star-forming regions) and time domain observations of the flux variations arising in the compact jets of X-ray binaries.

Our survey brings together a large range of important science applications, which will greatly benefit from simultaneous observing at mm-wavelengths. Such facilities are essential to allow these applications to become more efficient, more sensitive and more scientifically robust. In some cases without simultaneous receivers the science goals are simply unachievable. Similar benefits would exist in many other high frequency astronomical fields of research.

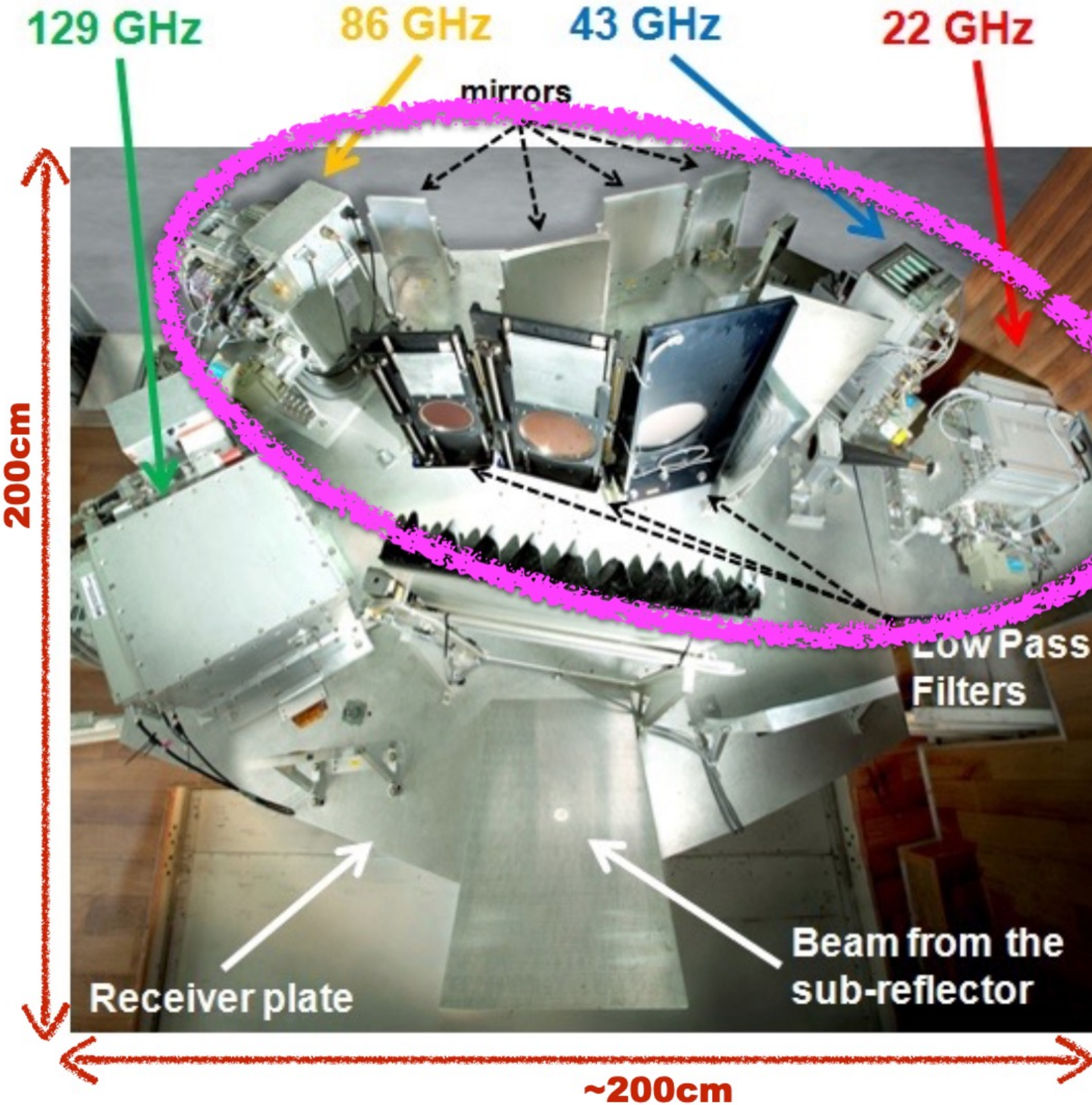
http://www.sciencedirect.com/science/article/pii/S1387647317300209

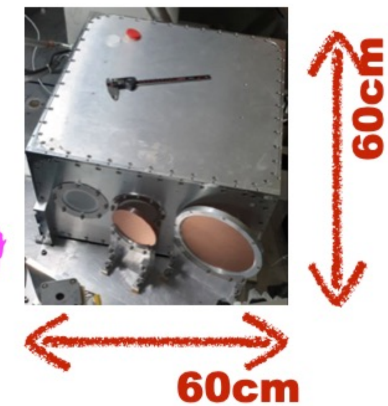
Spectral Studies

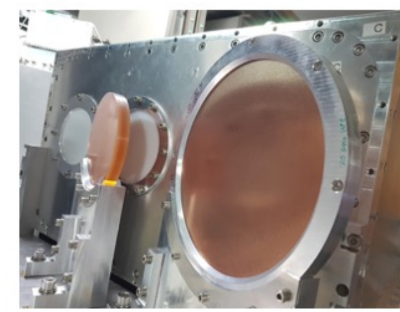
Multi-frequency VLBI observations of maser emission in evolved starts
Massive star formation

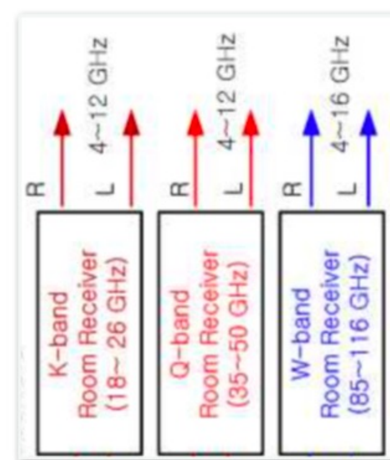
Compact Triple-band Receiver (CTR)

Installed on Sep. 2~3 at KYS



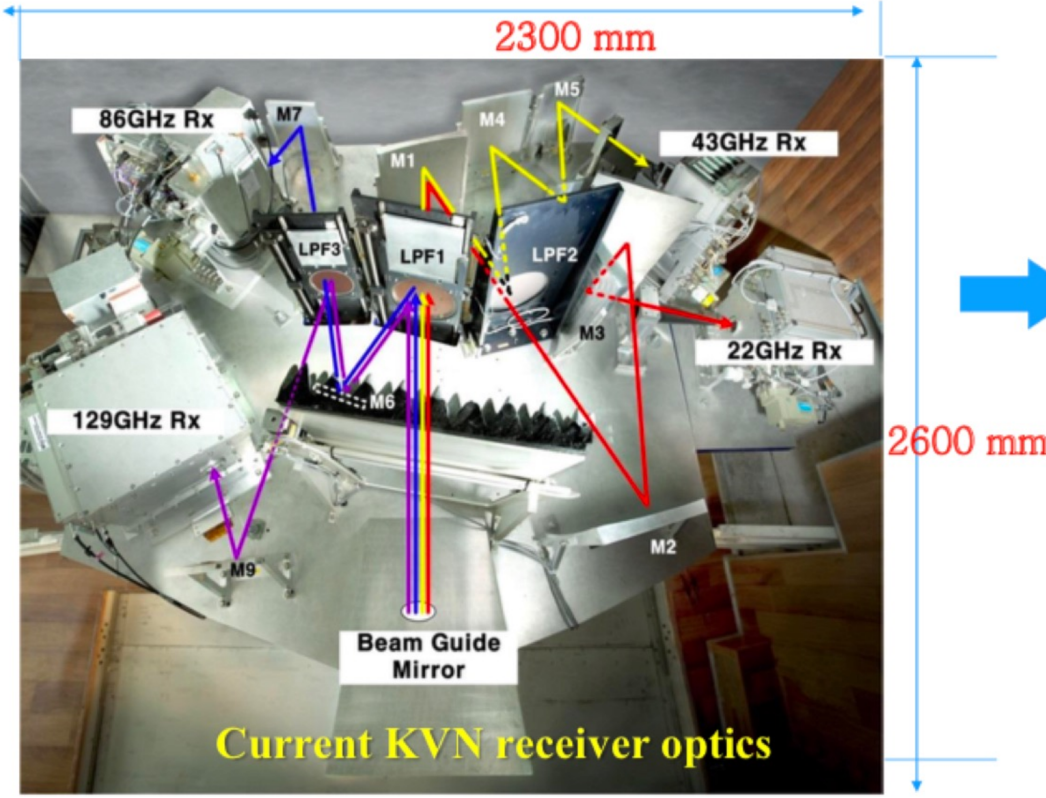


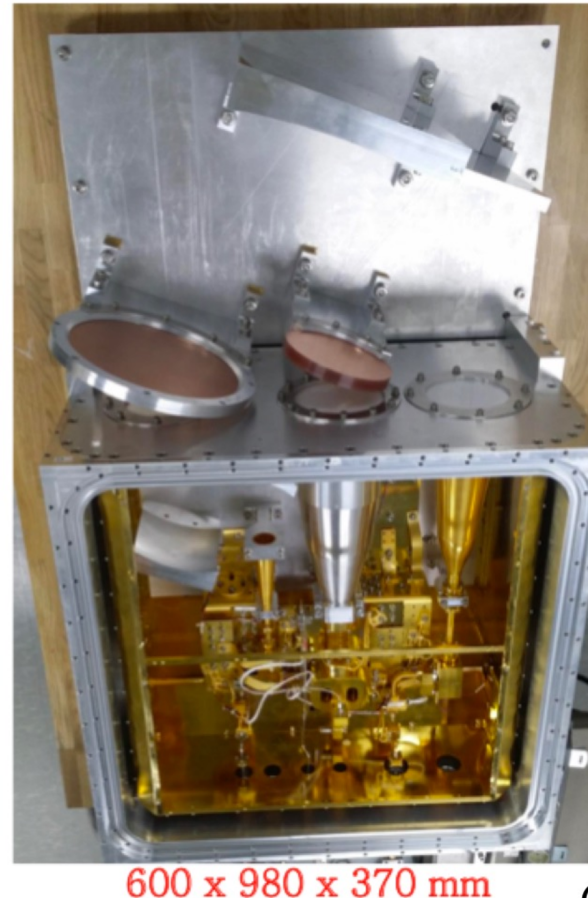




RF: 18-116GHz

Compact Triple-band Receiver (CTR)





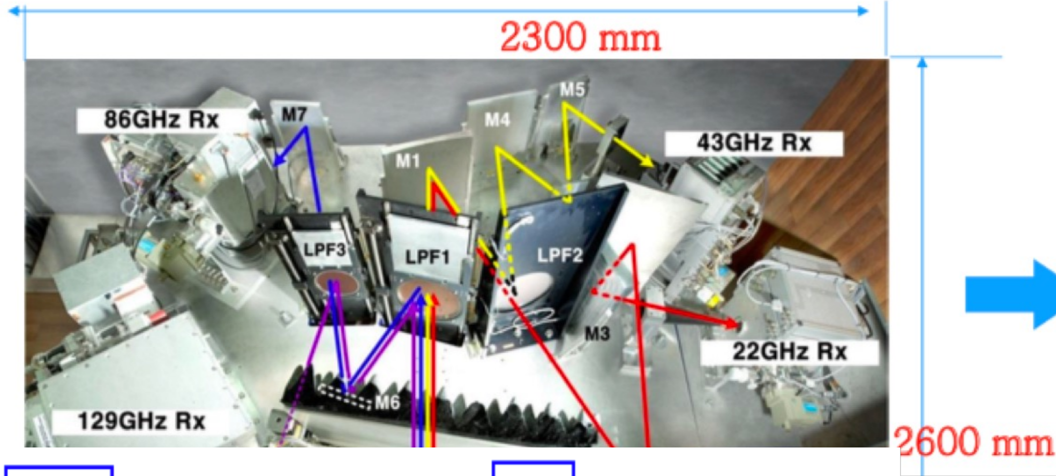
(S. T. Han)

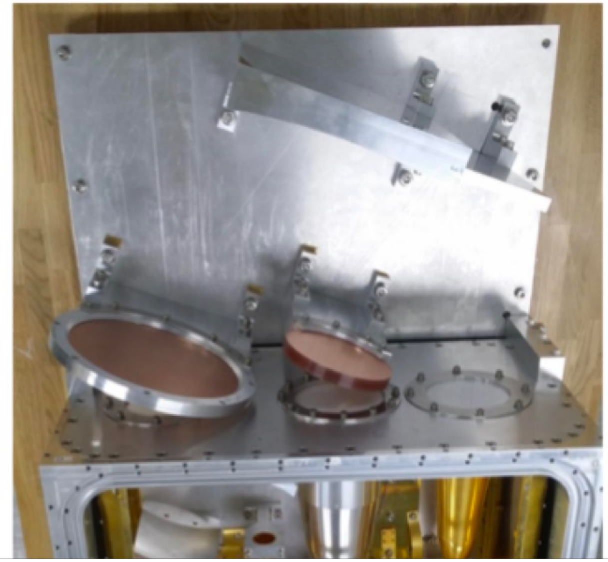
- Pointing offset among 3 channels : less than 3 arcsec to conduct simultaneous observations
- Aperture efficiencies : Obtained as much as we could (K- : 68 %, Q-: 66 %, W-band : 50%)
- Receiver noise temperatures : Not bad, but have to be improved (OMT, Polarizer and LNA)

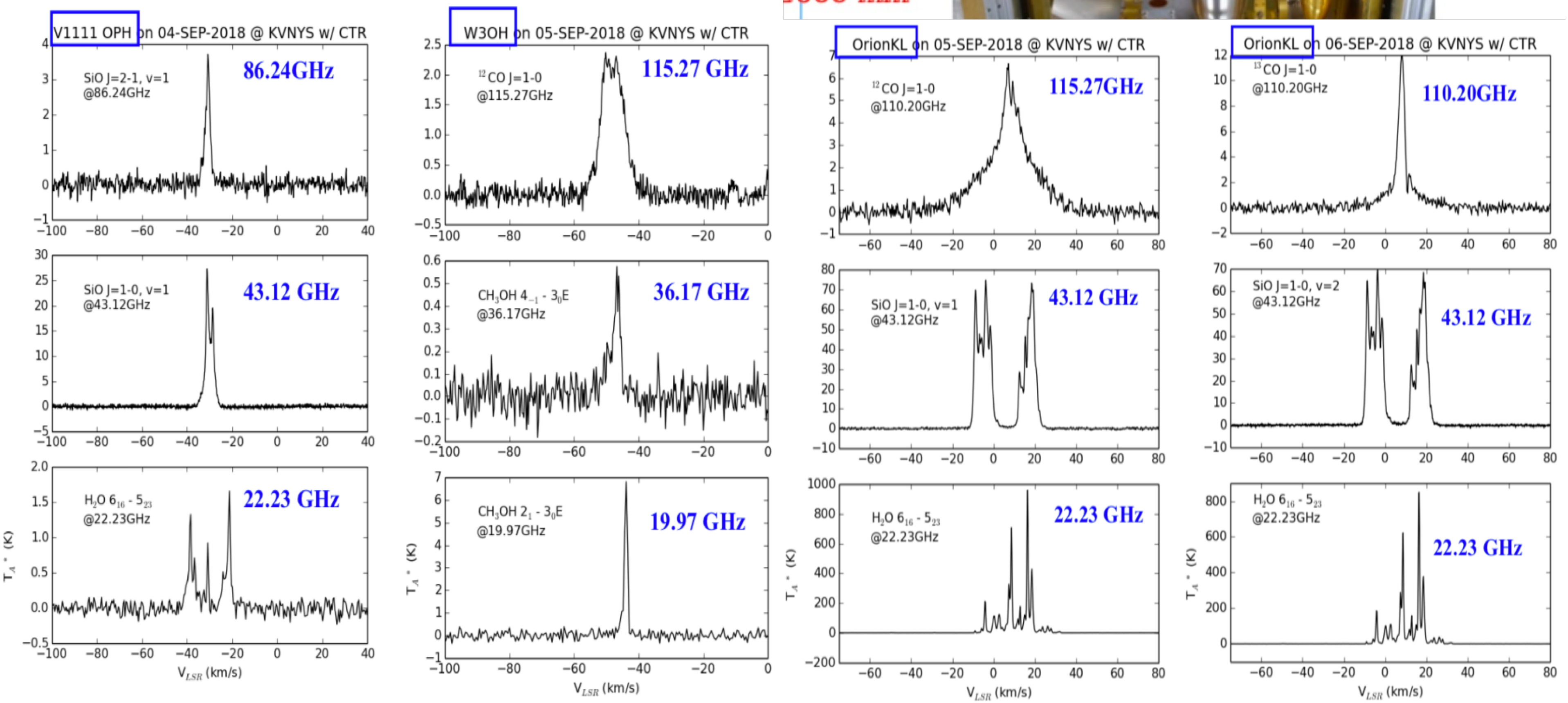
❖ CTR is tailorable for use in telescopes with a small receiver cabin.

❖ Ultimately this concept may lead to development of much more compact multi-frequency receiver systems for mm-wave and sub-mm radio telescopes

Compact Triple-band Receiver (CTR)







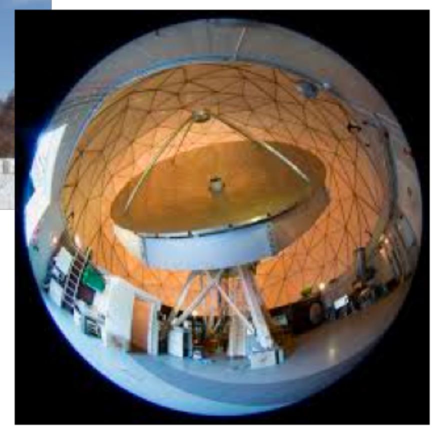
Simultaneous Multi-Freq. VLBI System in Globe

KVN (K/Q/W/D)
VERA (K/Q)
Sejong (K/Q/W)

Yebes 40m (Spain, K/Q/W)

Nobeyama 45m (Japan, K/Q/W)

Metsahovi 14m
(Finland, K/Q/W)



Tianma 65m
(China, K/Q)

VLBA MK 25m
(USA, K/Q/W)
Future?

(K/Q/W/D+230GHz)

Common MF System for
mm-VLBI in Globe

Sardenia 64m, Noto 32m, Medicina 32m (Italia, K/Q/W)

Mopra 22m (Australia, K/Q/W)

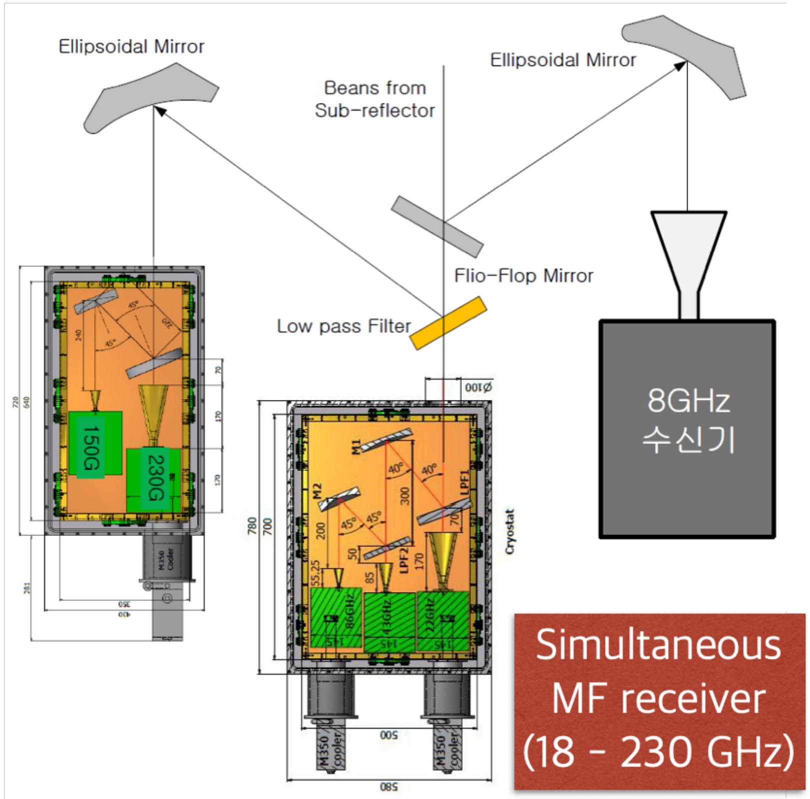
ATCA 22m x5
(Australia, Q/W)

E-KVN Project (2020 - 2023)

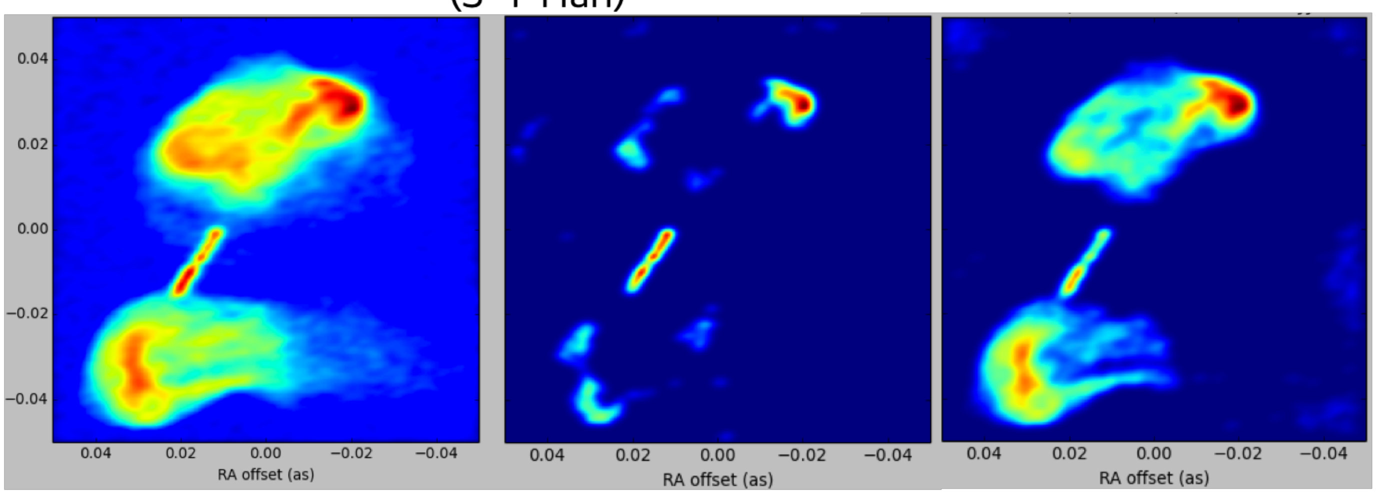
❖ Target Frequency Range : 18 - 250GHz (+ 8GHz)
- Compact Triple band Receiver (18 - 115GHz)
- 2-Channel SIS Mixer Receiver (125 - 250GHz)
- X-band Receiver (6-12GHz)

❖ Recording Bandwidth
- 64Gbps (2GHz x 8 IFs)

❖ Two times more baselines from 3 to 6
❖ Amplitude self-calibration
❖ M/F Image Synthesis

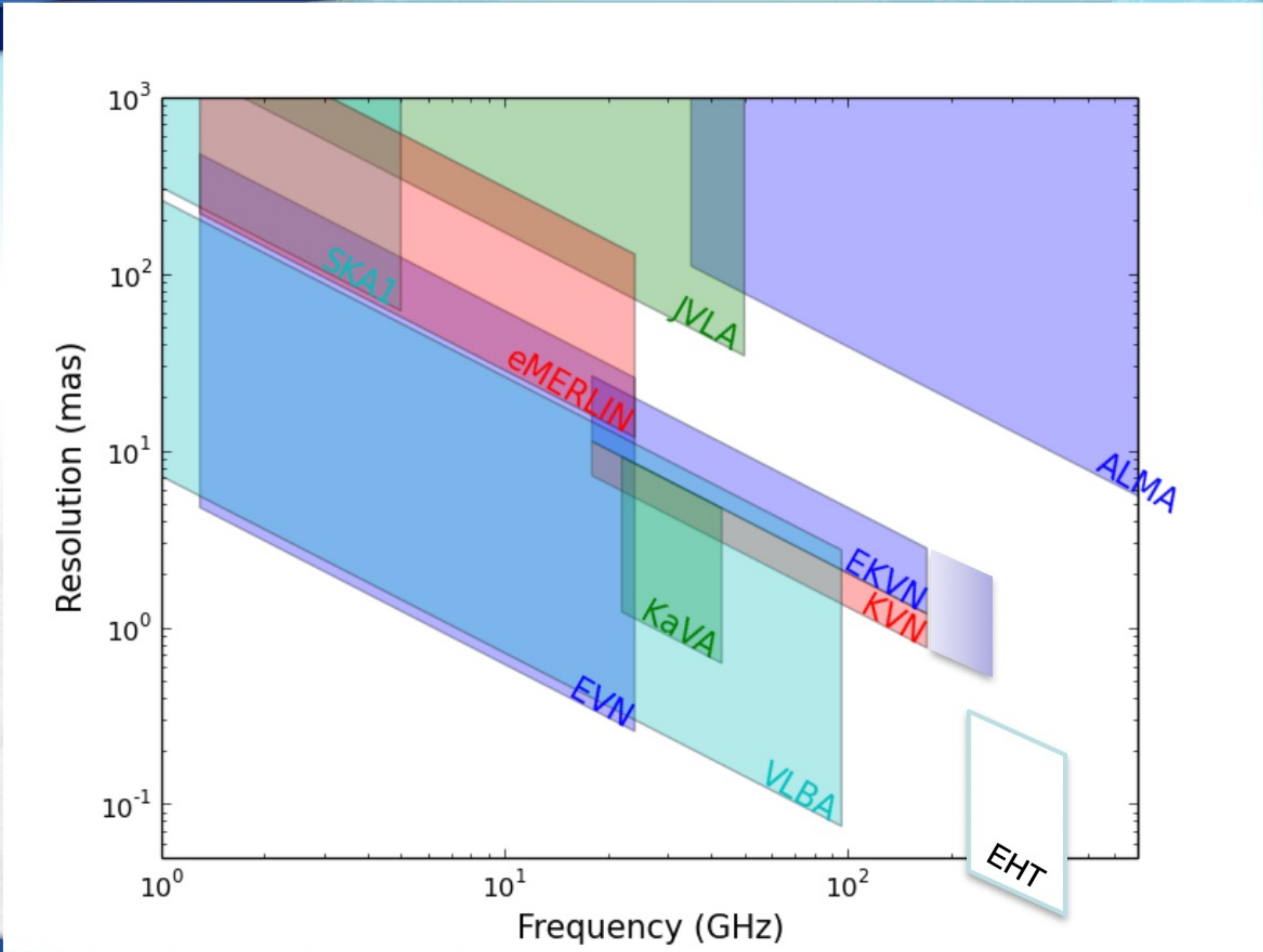


(S-T Han)



Simulation assuming flat spectrum over 18- 150GHz

Frequency - Angular Resolution Diagram



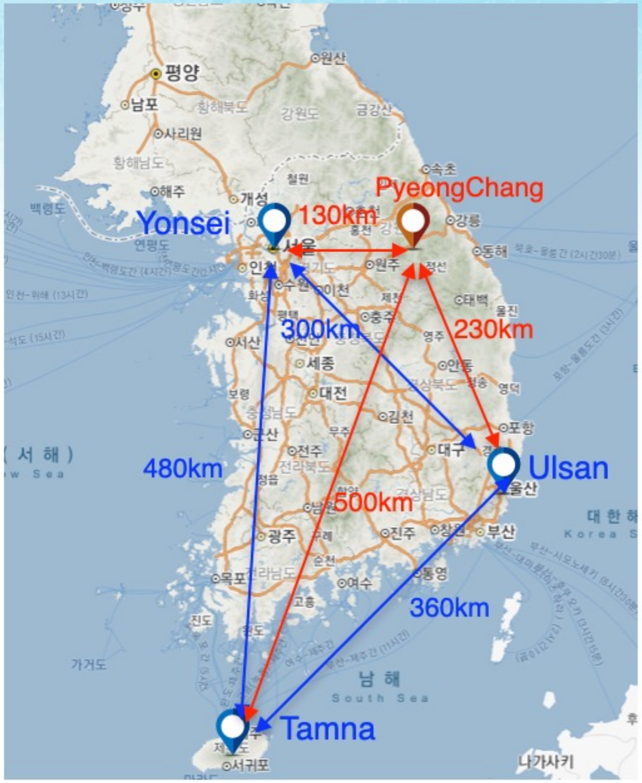
Specification of a New Telescope

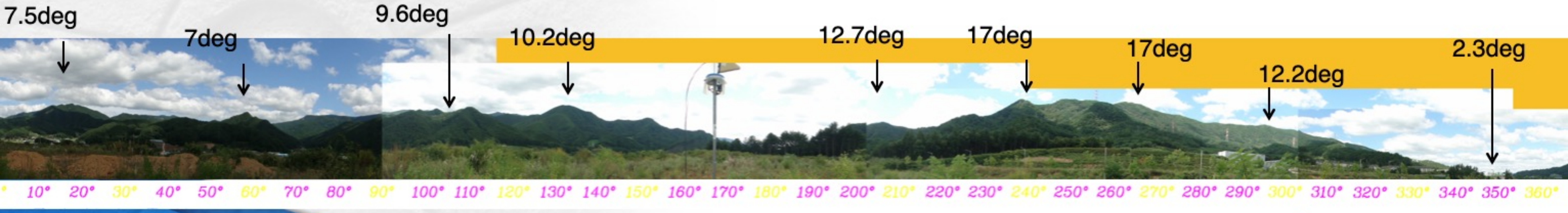
- D = 21m (Shaped Cassegrain)
- Frequency : 18 - 250GHz, 6-9GHz
- Aperture Efficiency
  - ≥ 60% @100GHz
  - ≥ 30% @230GHz
- Surface accuracy ≤ 100㎛
  - Main reflector panel ≤ 60㎛
- Pointing accuracy < 3″
- Construction Period : 2021 - 2023

KVN Ulsan Telescope

PyeongChang Site

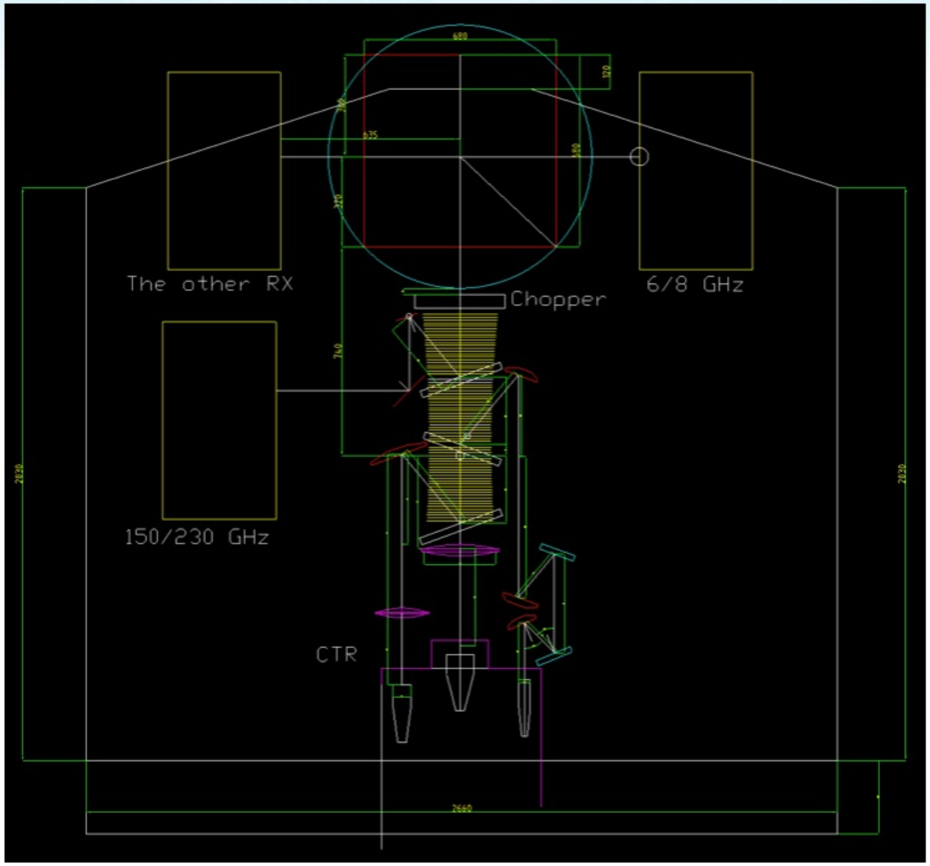
- PyoengChang Campus of Seoul National University
- 130-500km baselines
- Weather Condition
  - ~500m above sea level
  - low temperature / mild wind





M/F Receivers for KVN PyeongChang

- Frequency Range : 18-270GHz (+ 8GHz)
  - Compact Triple band Receiver
    - 18-26GHz
    - 35-50GHz
    - 85-116GHz
  - 2-Channel SIS Mixer Receiver
    - 125-174GHz
    - 210-270GHz
  - X-band Receiver (6-9 GHz)



- VLBI Backends
  - 2 OCTAD + 4 Mark6
  - 64Gbps (2GHz x 8 IFs)

Expected SEFD at 230GHz with KVN

PWV (mm)	tau0	trans-parency	Tsys* (K) (Trx = 50)	SEFD (KJy) (A.E.~ 30%)
3.0	0.25	0.8	150	4.0
5.0	0.36	0.7	200	5.3
7.0	**0.50**	**0.6**	**280**	**7.4**
10.0	0.70	0.5	380	10.0

- 230GHz with SRAO 6m telescope (from Y.-S. Park)
  - tau0 ~ 0.16 (trans ~ 0.86) in cold winter
  - tau0 ~ 0.6 (trans ~ 0.55) in April

Surface Accuracy

unit : μm

Error Source	KVN EL = 48 (25)	New Telescope EL = 48 (25)	KVN w/ new SubR + align
Panel	65	60	65
Sub Reflector	50	20	20
Panel Align	65	47	47
Wind(@5m/s) + Thermal (ΔT =1 C)	23	23	23
Gravity	19 (63)	19 (57)	19 (63)
Measurement	21	11	16
Total RSS	111 (126)	86 (100)	89 (107)
A.E. at 230GHz [%]	22 (15)	38 (30)	36 (26)

❖ Efficient way to improve surface accuracy
- Replacement of sub-reflector
- Photogrammetry (or Holography) to improve panel alignment accuracy
- Redesign of BUS to reduce gravitational deformation

White Paper on East Asian Vision for mm/submm VLBI:

Toward Black Hole Astrophysics down to Angular Resolution of 1 R_S

Editors

Asada, K.[1], Kino, M.[2,3], Honma, M.[3], Hirota, T.[3], Lu, R.-S.[4,5], Inoue, M.[1], Sohn, B.-W.[2,6], Shen, Z.-Q.[4], and Ho, P. T. P.[1,7]

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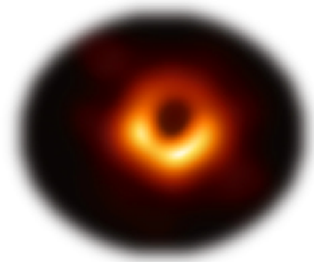
Akiyama, K.[3,8], Algaba, J-C.[2], An, T.[4], Bower, G.[1], Byun, D-Y.[2], Dodson, R.[9], Doi, A.[10], Edwards, P.G.[11], Fujisawa, K.[12], Gu, M-F.[4], Hada, K.[3], Hagiwara, Y.[13], Jaroenjittichai, P.[15], Jung, T.[2,6], Kawashima, T.[3], Koyama, S.[1,5], Lee, S-S.[2], Matsushita, S.[1], Nagai, H.[3], Nakamura, M.[1], Niinuma, K.[12], Phillips, C.[11], Park, J-H.[15], Pu, H-Y.[1], Ro, H-W.[2,6], Stevens, J.[11], Trippe, S.[15], Wajima, K.[2], Zhao, G-Y.[2]

<<3mm>>

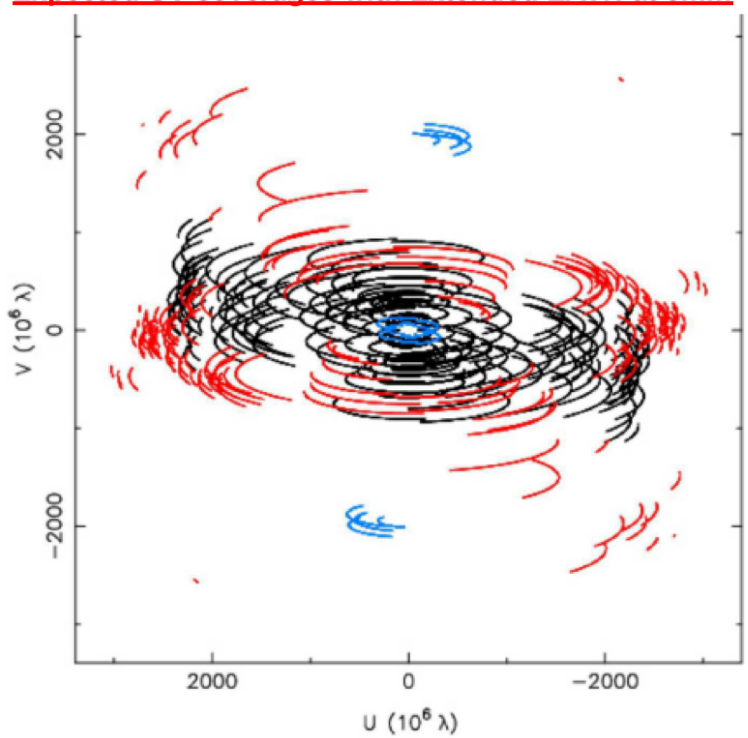
- SEJONG
- NRO
- QTT
- KVN

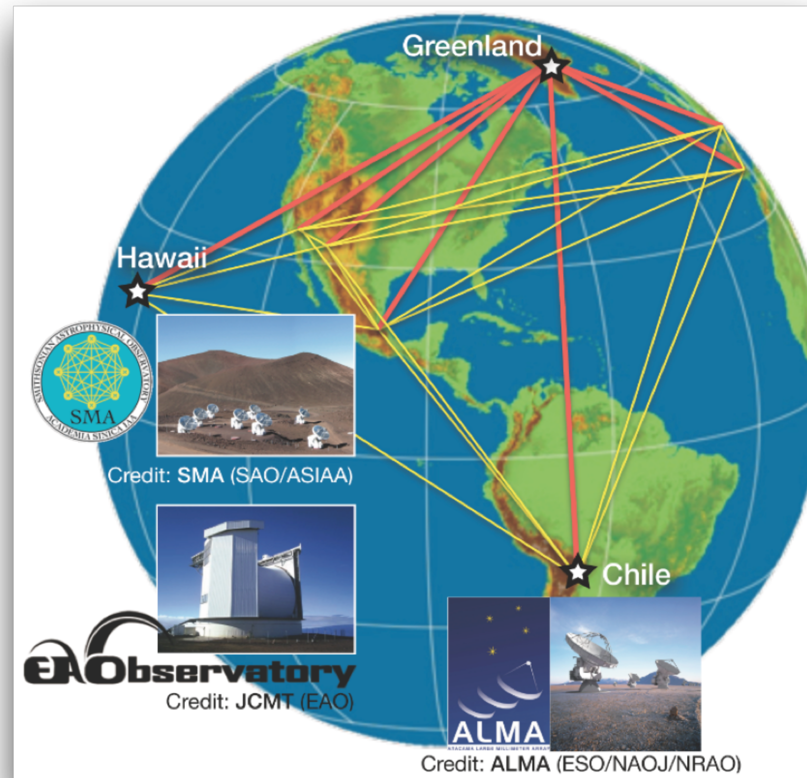
<<1mm>>

- EKVN
- SRAO
- JCMT
- GLT
- SMA
- SPART

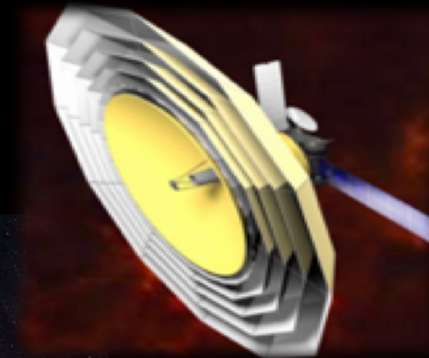


Expected UV-coverages with Extended EAVN at 3mm





The Most Powerful Eyes in the Universe



An ideal mm-VLBI system for Earth and Space

Thank you for your attention!