KVN and E-KVN Project

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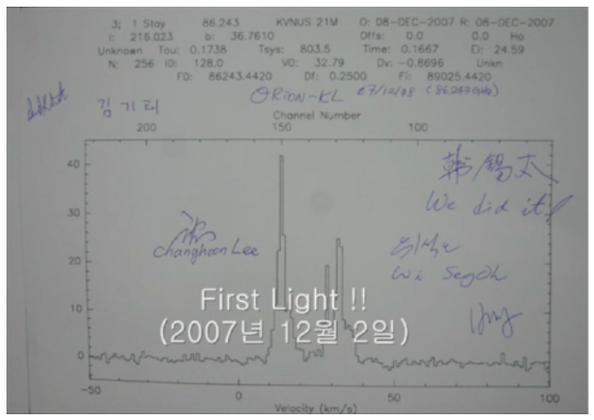
On behalf of KVN Team

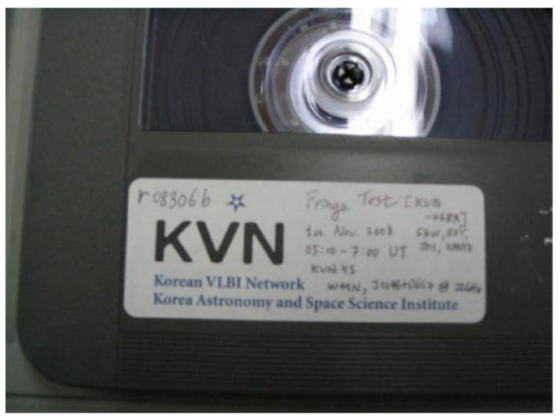
Korea Astronomy and Space Science Institute (KASI)

AGN Jet Workshop 2020 @ Tohoku University, Japan, January 21, 2020

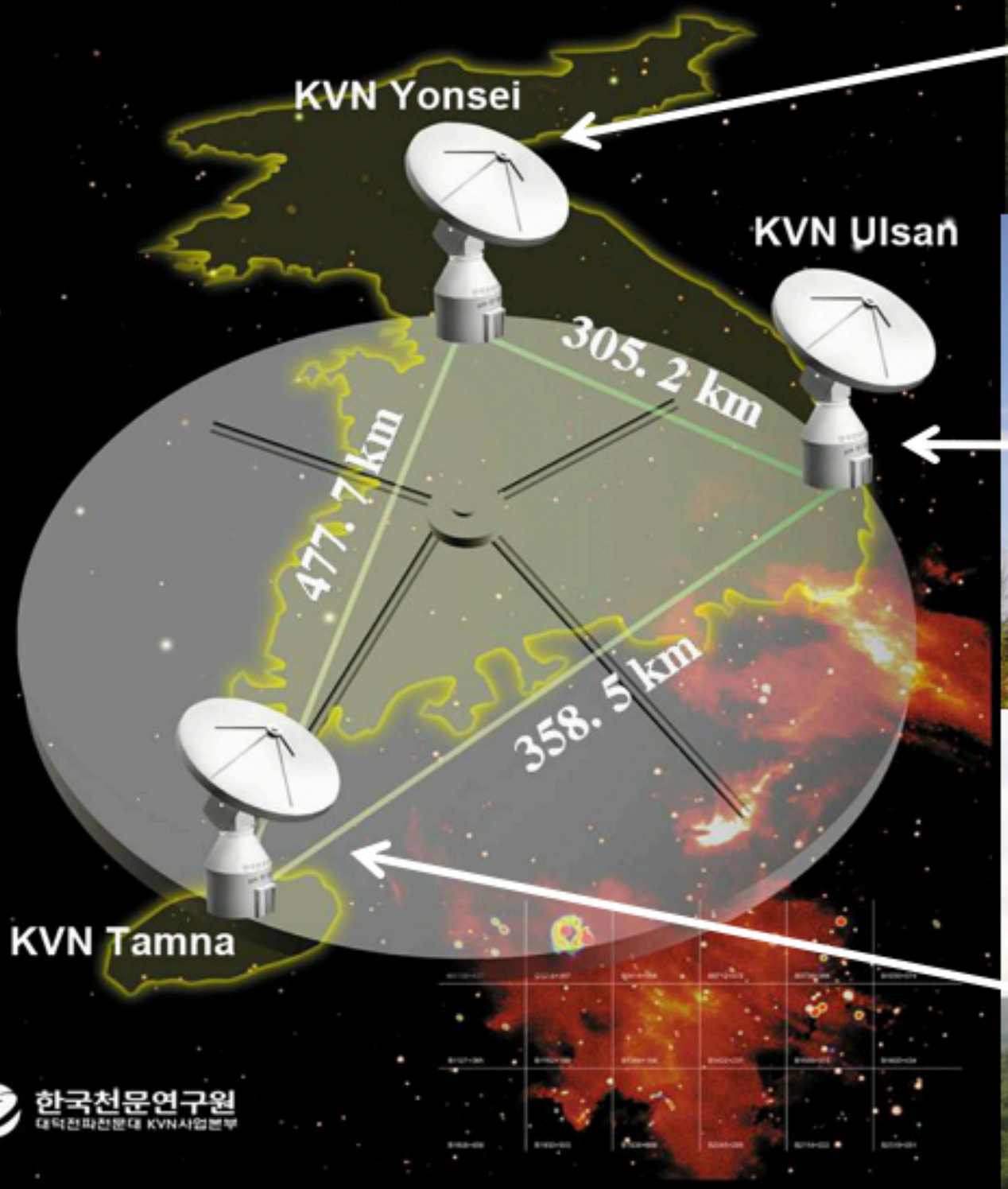
10th Anniversary of Korean VLBI Network

- First three-baseline fringes
  - 2009 OCT 16 (22GHz) NRAO150
  - 2009 OCT 22 (43GHz) ORION-KL
- 2019 OCT 16
  KVN special session
  during the KAS fall meeting
- 2019 OCT 21
  10th anniversary celebration at KASI





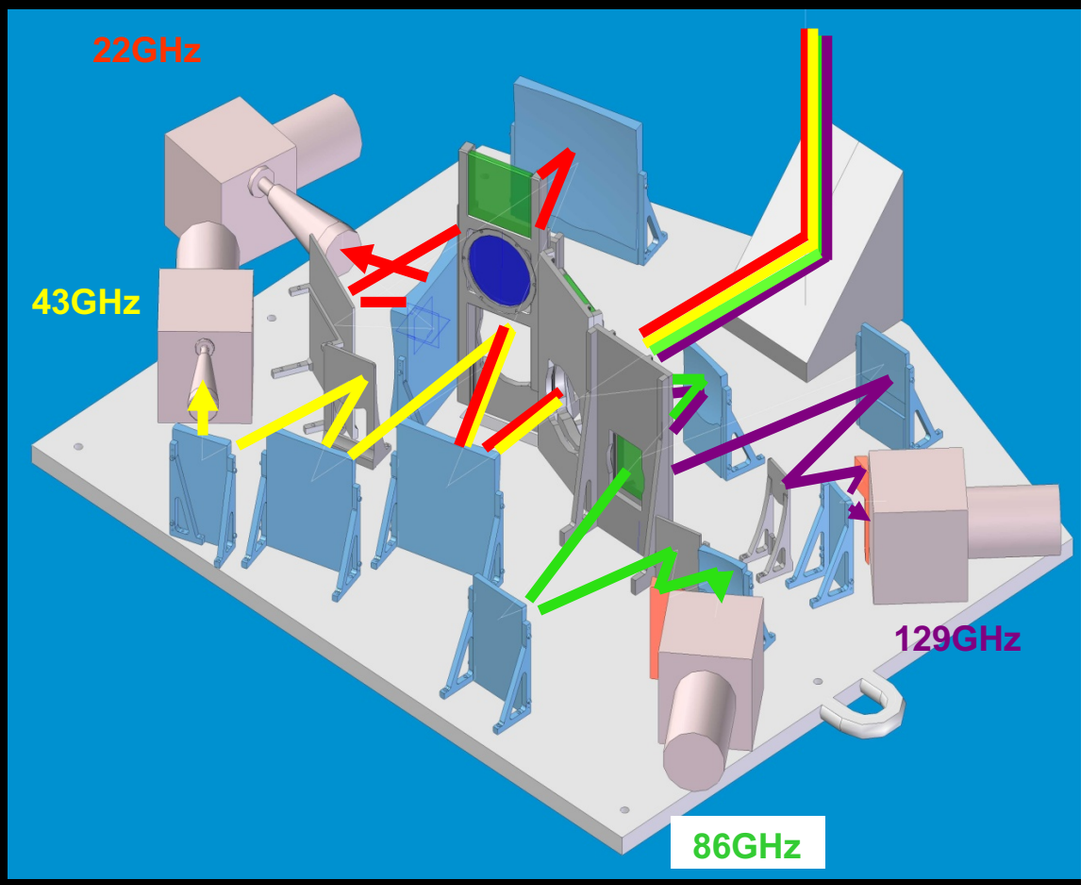
KVN 한국우주전파관측망
Korean VLBI Network



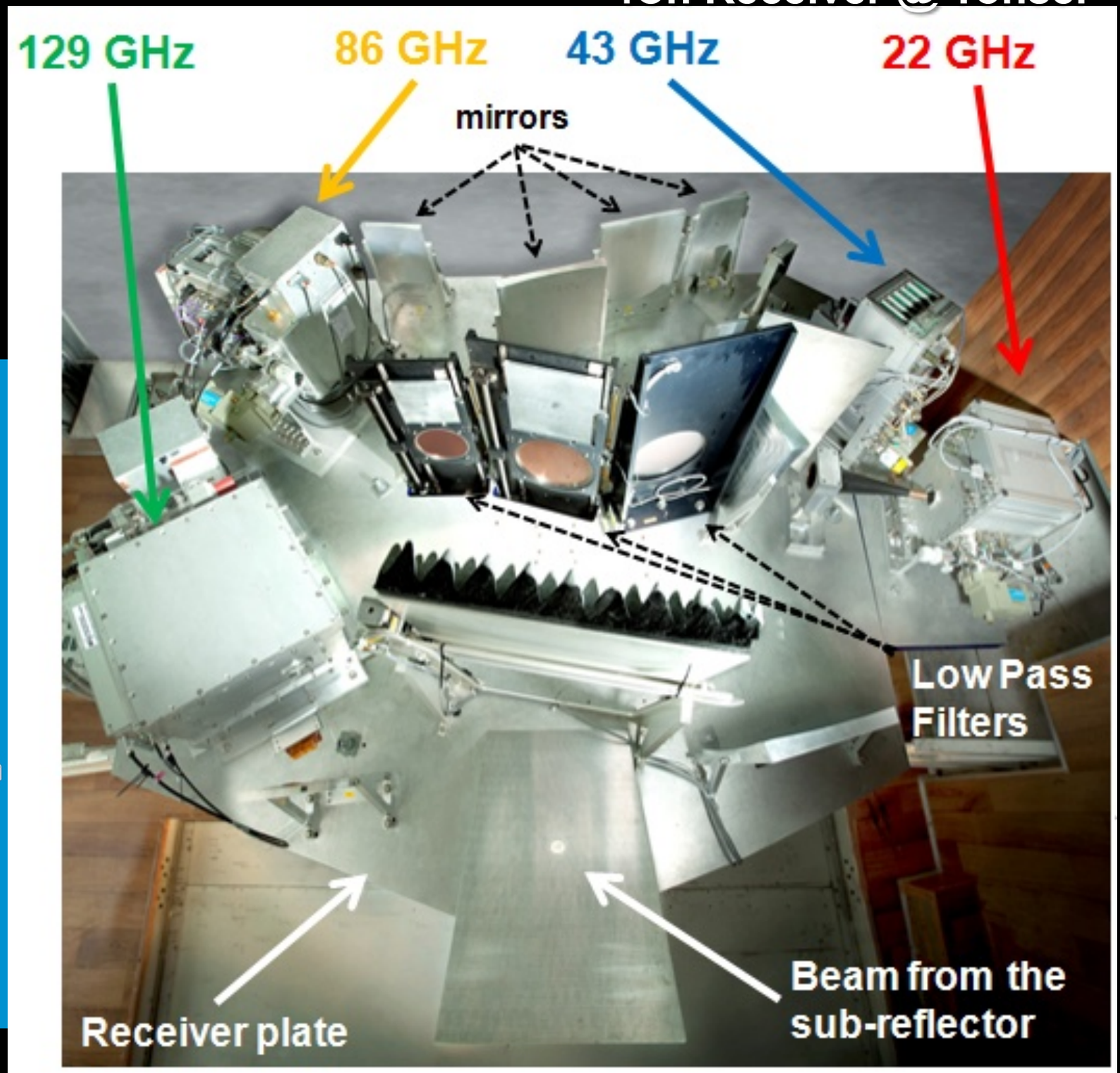
한국천문연구원
대덕전파천문대 KVN사업본부

Multi-Frequency Receiving System

Beams from antenna



4Ch Receiver @ Yonsei



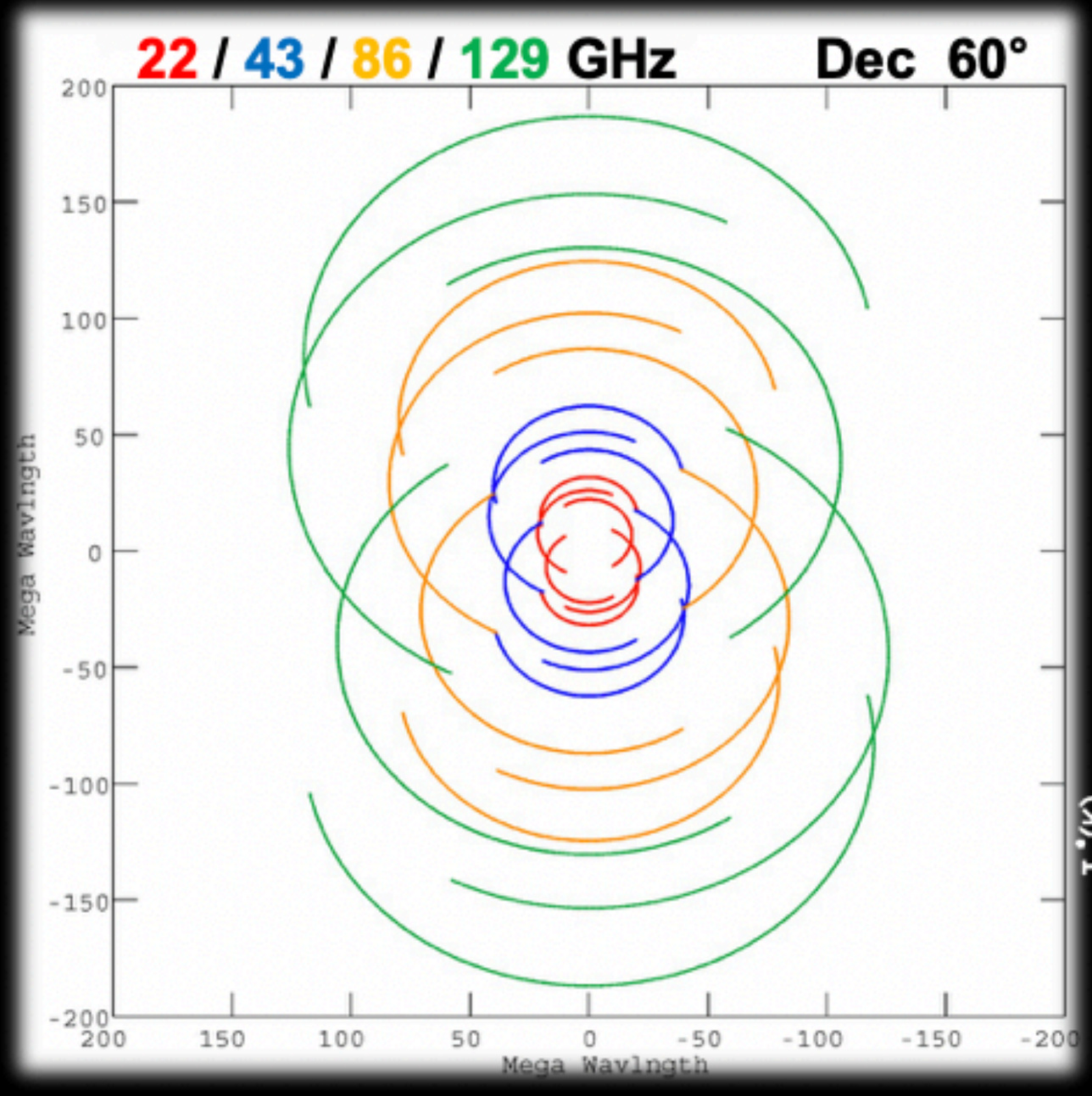
Band	K	Q	W	D
Freq. Range	21.25-23.25	42.11-44.11	85-95	125-142
Trx (K)	30-40	70-80 (40-50 KUS)	80-100	50-80

Full Polarization

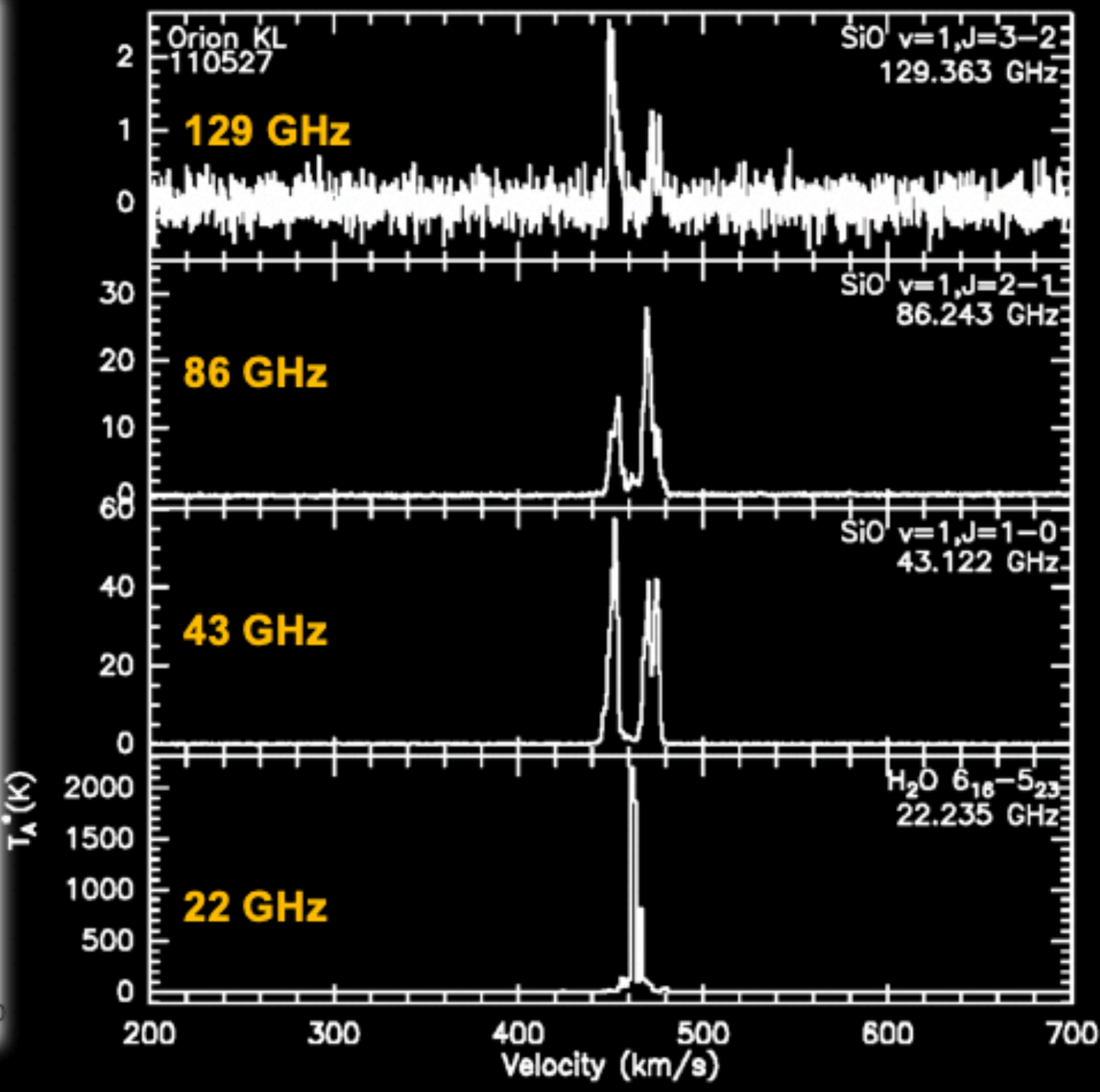
Han et al. (2008)

2011

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



4CH UV Coverage



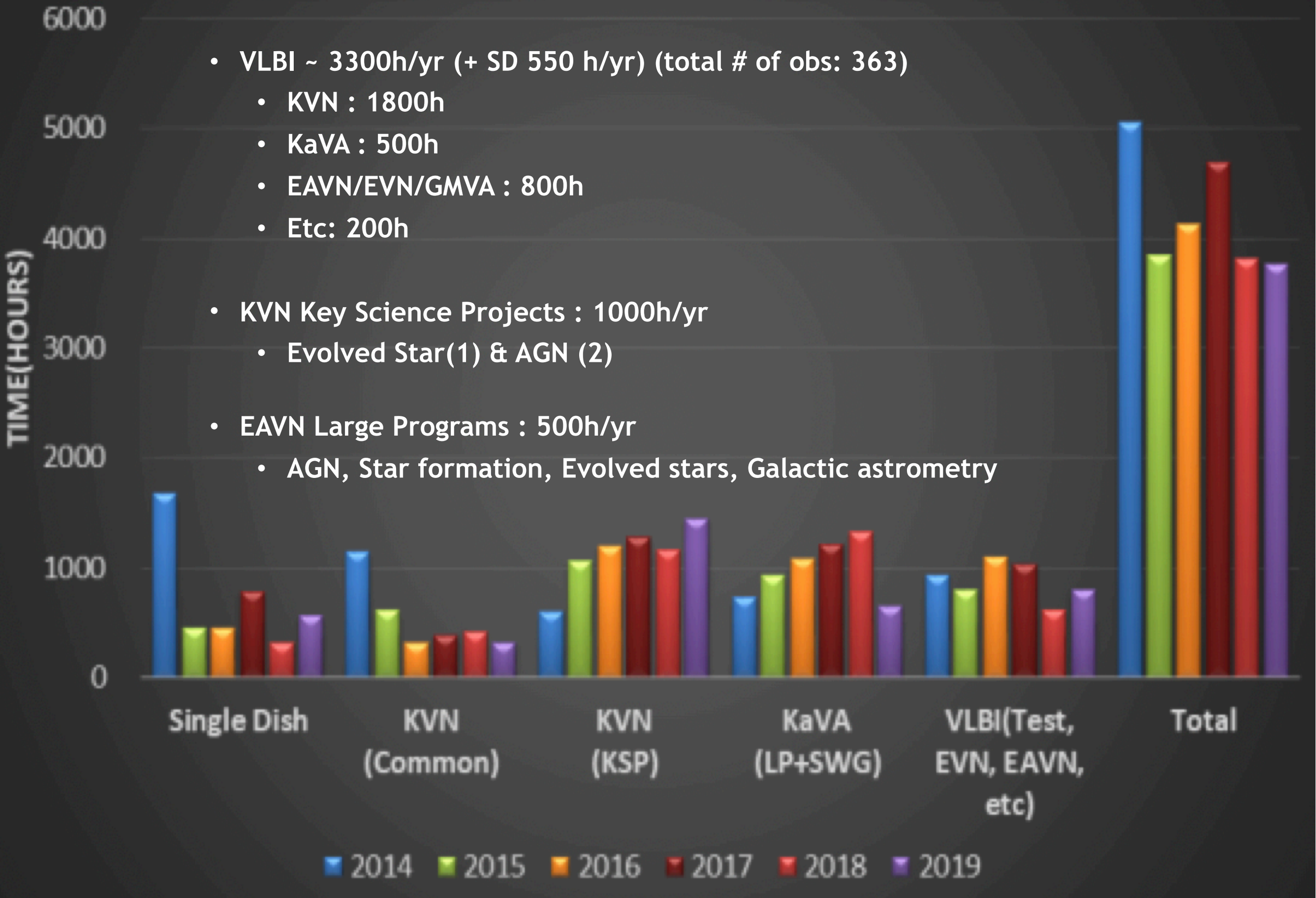
H20/SiO Masers in Orion KL

KVN Operation Status 2019

- VLBI ~ 3300h/yr (+ SD 550 h/yr) (total # of obs: 363)
  - KVN : 1800h
  - KaVA : 500h
  - EAVN/EVN/GMVA : 800h
  - Etc: 200h

- KVN Key Science Projects : 1000h/yr
  - Evolved Star(1) & AGN (2)

- EAVN Large Programs : 500h/yr
  - AGN, Star formation, Evolved stars, Galactic astrometry

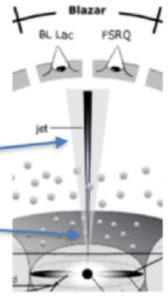


KVN Key Science Projects

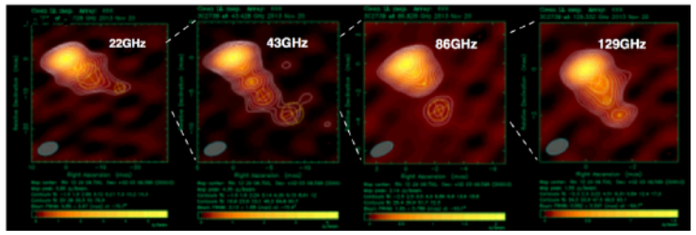
1. Interferometric Monitoring of Gamma-Ray Bright AGN : iMOGABA
2. Simultaneous Monitoring of KVN 4 Bands towards Evolved Stars
3. The Plasma Physics of AGN with KVN : PaGAN

- KVN Institute Program:
  Multi-Frequency AGN Survey with KVN (MASK)

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/

KSP2
Simultaneous Monitoring Observations of KVN 4 Bands toward Evolved Stars

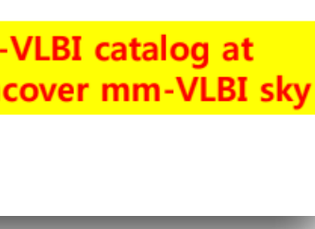
1. Spatial structure and dynamical effect from SiO to 22 GHz H_2O maser regions according to stellar pulsation through simultaneous monitoring obs. of KVN 4 bands

○ 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.

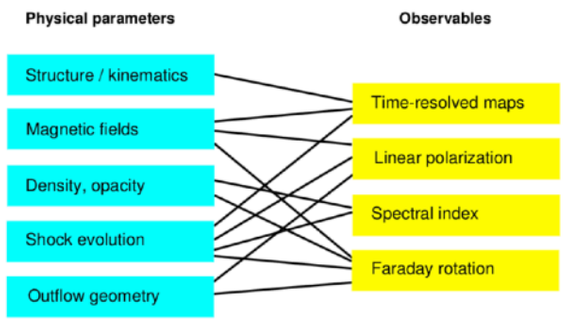


(Credit: S. H. Cho)

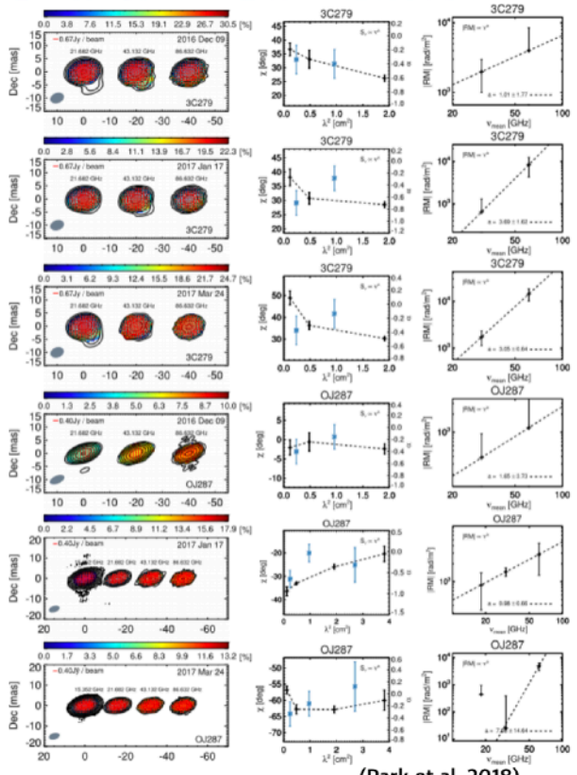
KSP3
The Plasma Physics of AGN with KVN

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

AGN plasma-physics



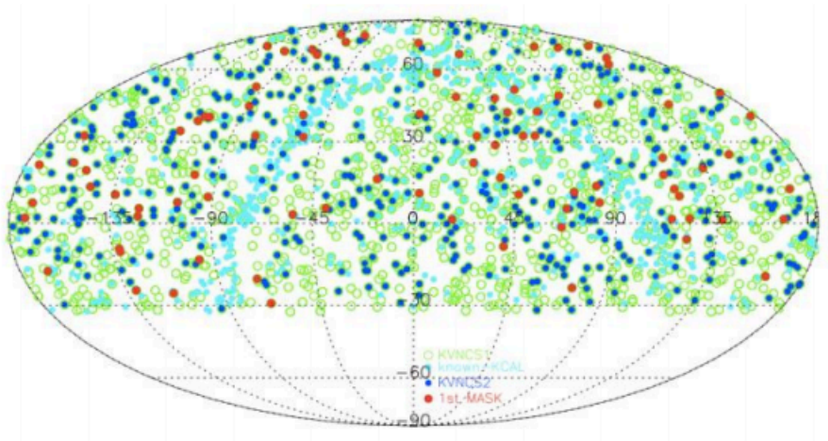
(Credit: S. Trippe)



(Park et al. 2018)

Multi-frequency AGN Survey with KVN

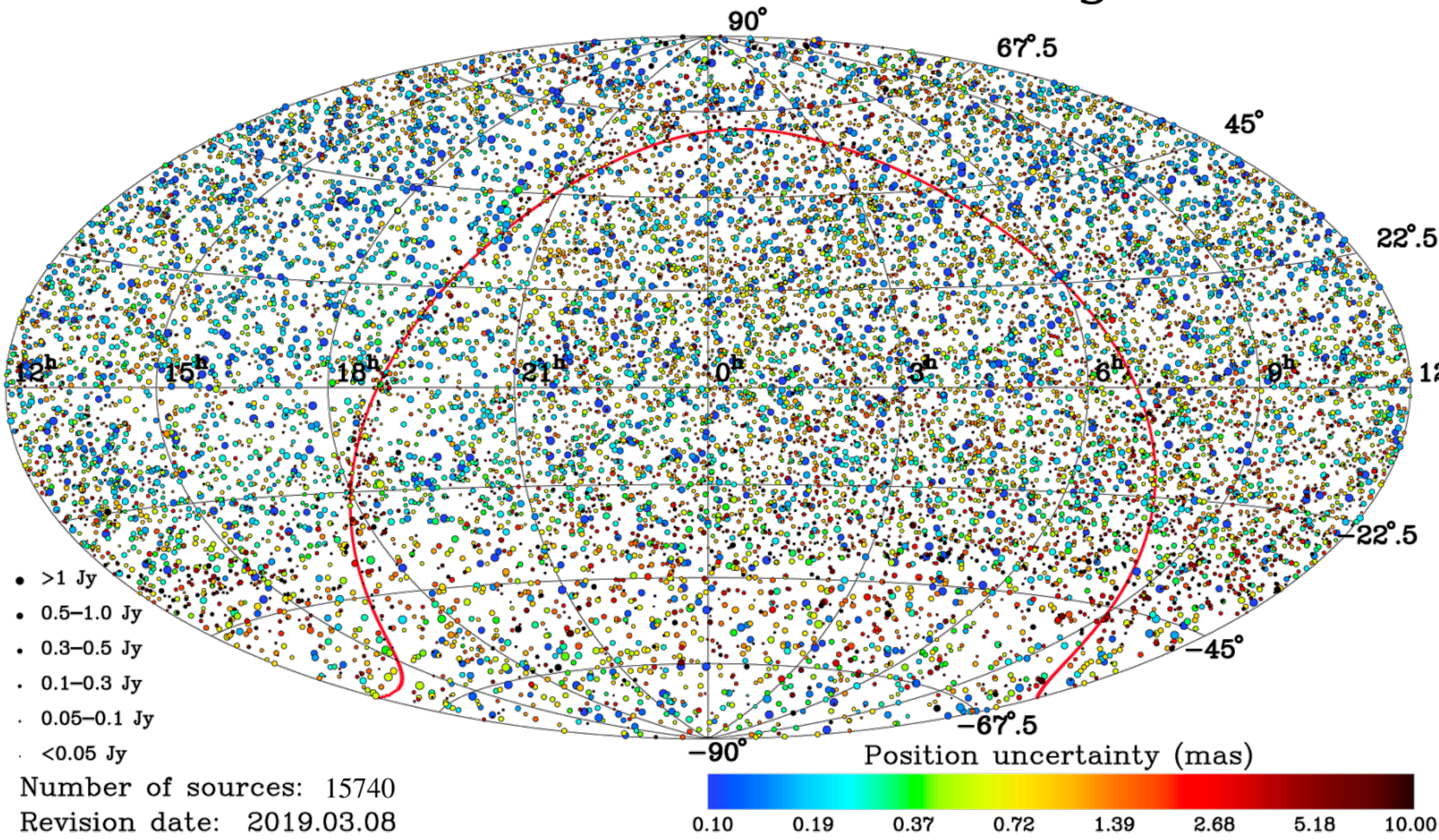
Finding more high-frequency sources & Maximizing the KVN uniqueness



KVN Legacy Program

MASK will be able to provide most extensive mm-VLBI catalog at multiple friquencies and play an important role to uncover mm-VLBI sky

Radio Fundamental Catalogue



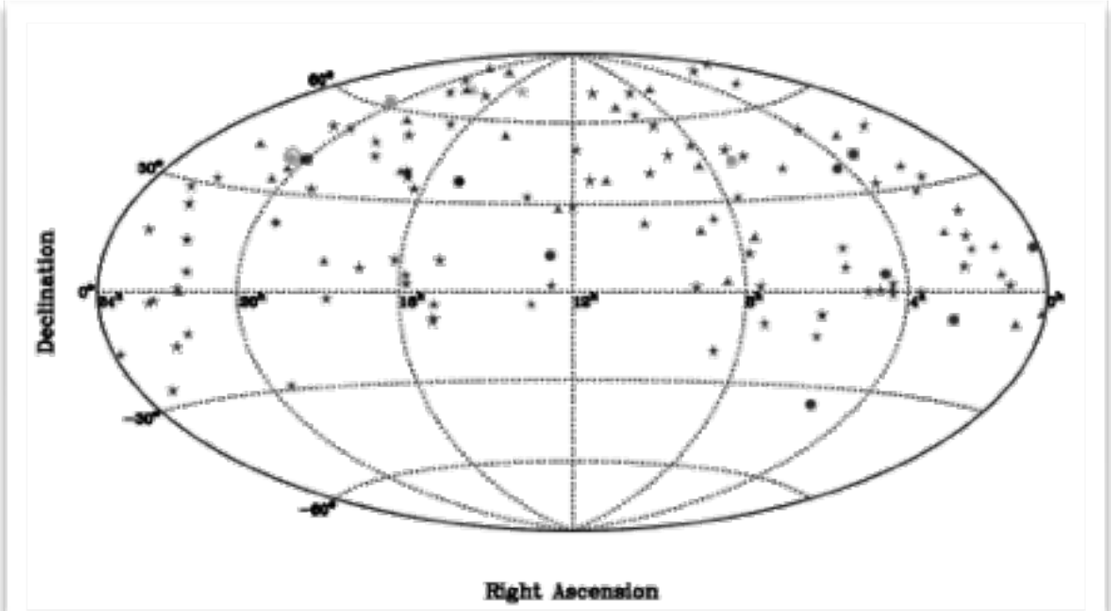
At present, 16,845 sources

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

Number of VLBI sources at mm-wavelengths are very limited

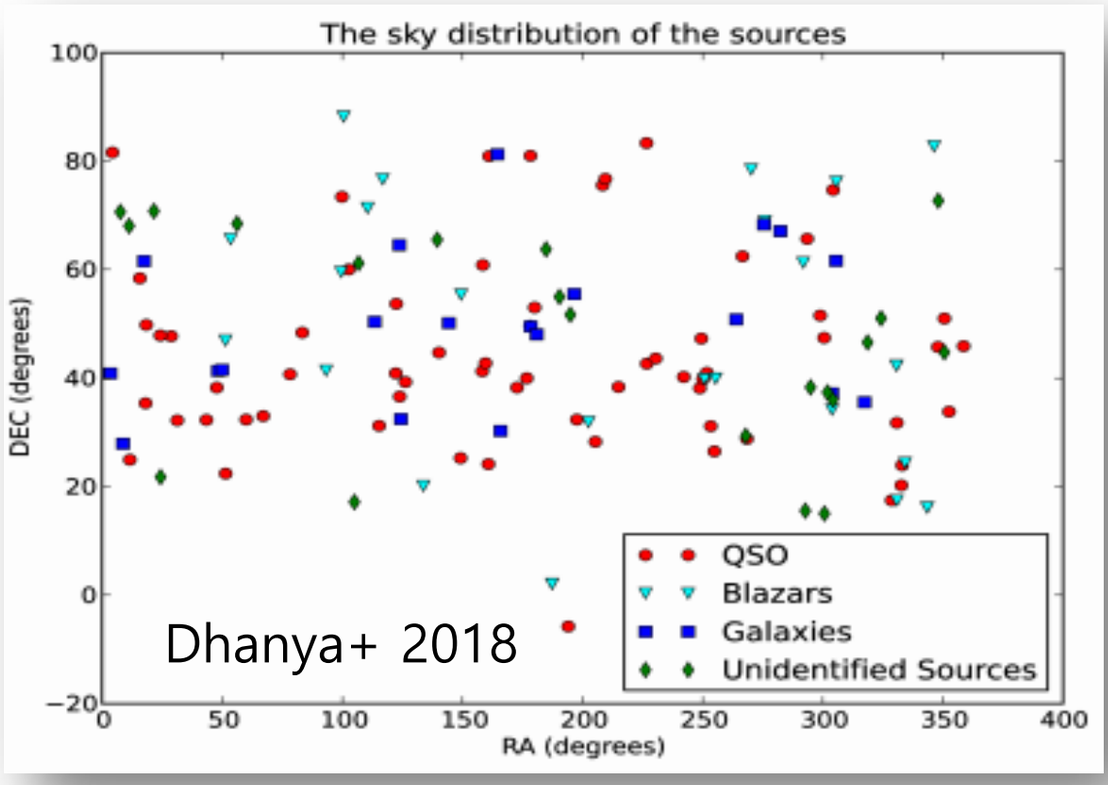
Summary of VLBI Surveys, their wavelengths and the number of sources catalogued. The difference in scale of the number of sources in the cm and mm surveys are clear.

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)

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) ??

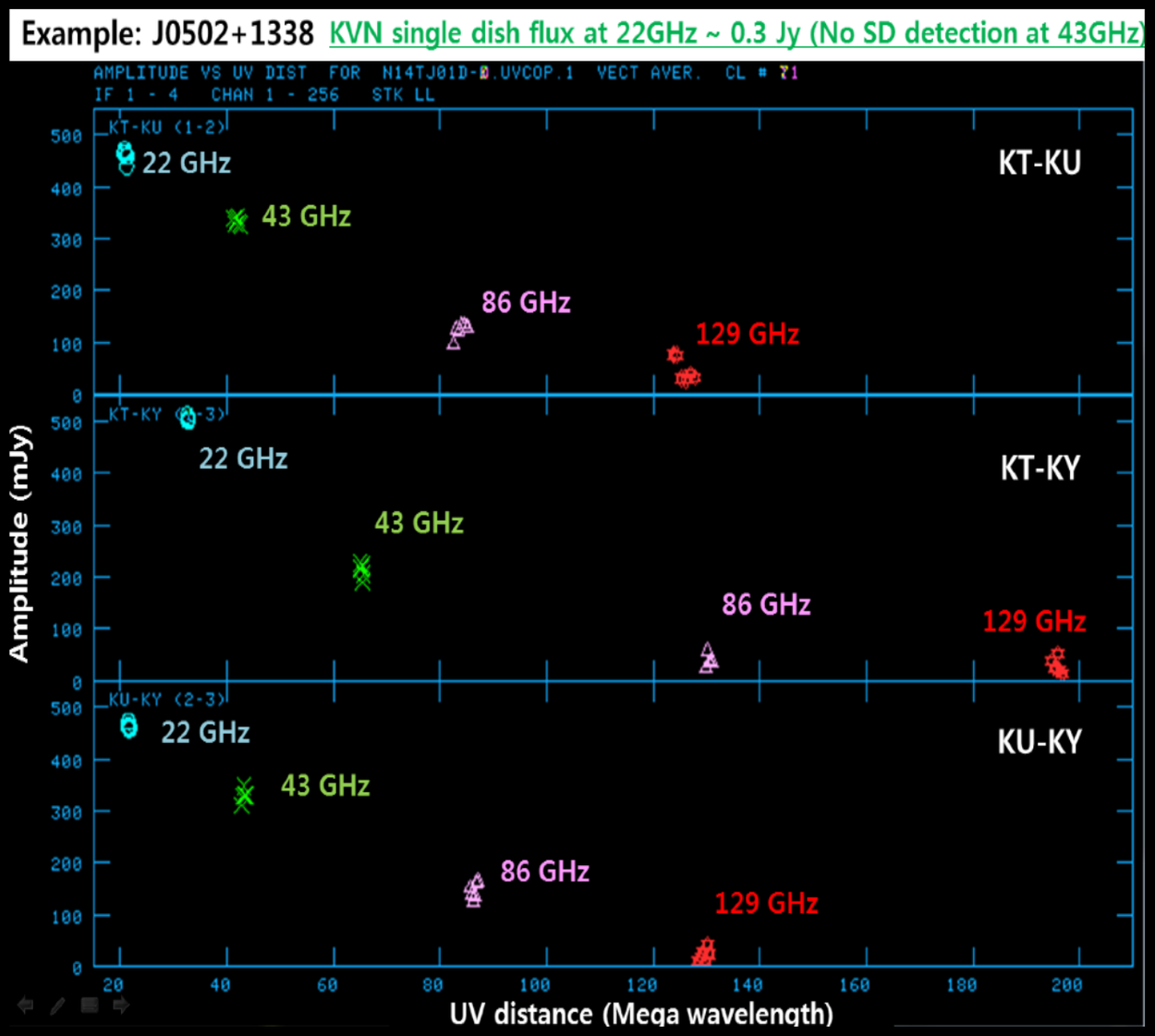


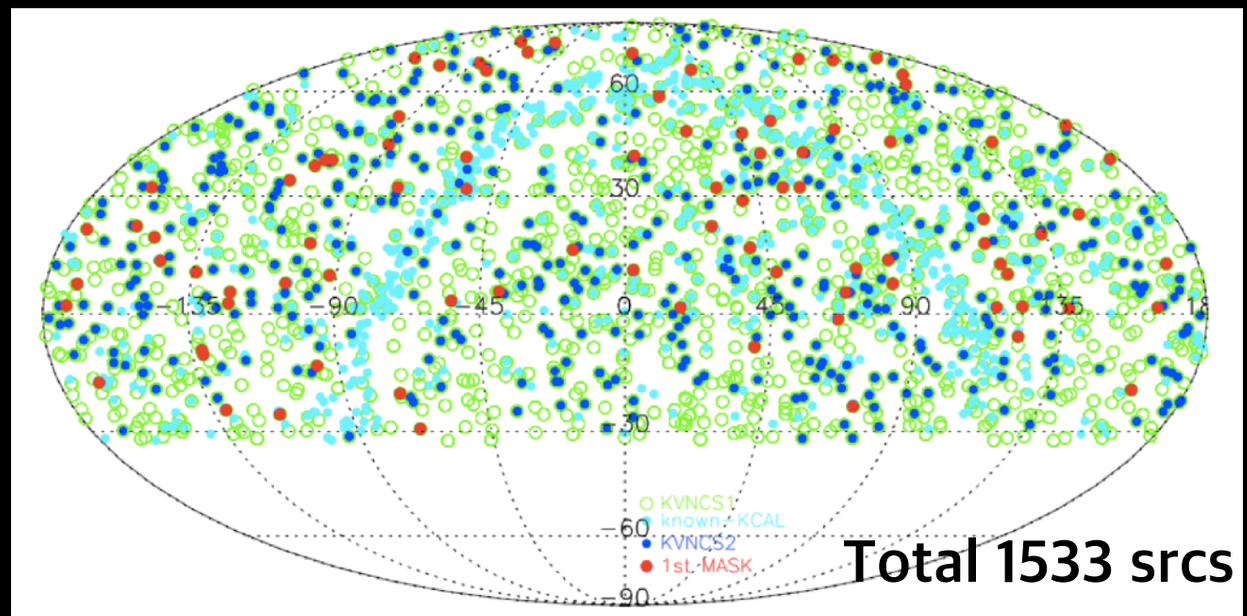
162 sources at 3 mm

KVN's Simultaneous Multi-Frequency VLBI System

- **Excellent calibration of atmosphere**
  → Pefect calibration on troposphere (non-dispersive delays)
  → Superb calibration on Ionosphere (dispersive)
- **Exceptional improvement on coherence time**
  → The largest VLBI source detections at 2-3 mm ever!

MASK: Multi-frequency AGN Survey with the KVN





- To date,
  1273 sources were observed and analyzed

- **Detection Statistics:**
  22GHz (1157, ~91%), 43GHz (950, ~75%),
  86GHz (611, ~48%), 130GHz (308, ~24%)

The 2nd Generation of KVN Key Science Program
Call for Proposal

Call for Proposals 2020B

The Korean VLBI Network (KVN, http://kvn.kasi.re.kr/) invites key science proposals. Principal investigators of the proposals should be affiliated to Korean research institutes and universities. Observations will be scheduled from 2020 August 15. Proposals should be emailed to kvnprop@kasi.re.kr before **the deadline of UT 08:00 (KST 17:00) on 2020 January 15**. The review results of the proposal will be announced until **2020 March 31**.

Important notes for 2020B

1. The available frequency bands are 22/43/86/129 GHz **in 8Gbps and in dual polarization**.
2. The total available time for all KSP proposals is around 1,000 hours per year.
3. The maximum requested time per a proposal is 500 hours per year.
4. The maximum duration of each proposal is 3 years. In case of requesting a total period of more than 2 years, an intermediate evaluation will be performed in late second year of the project.
5. The PI of each proposal is encouraged to establish a research team consisting of experts in international community.
6. For proposals asking for a challenging research topic in observational detection/mode of KVN, it is possible to request in the proposals feasibility-test time (its length is not strictly limited but should be reasonable) for the 2020A season (e.g., 2020 January 15~June 15). The proposal may be accepted conditionally. The final decision of the proposal will be made depending on the results of the feasibility test, whose reports should be submitted to kvnprop@kasi.re.kr no later than 2020 June 30.

OCTAD

- 4 ADC (4 x 16Gsps)
- Input Freq. 8 - 16GHz
- Digital Down Conversion
- Digital Filtering
- 4 x 10GbE output
- VDIF format

KYS

KUS

KTN

Bandwidth (MHz)	Max Num of Channels	Max Data Rate (Gbps)
8192	1	32
4096	2	32
2048	4	32
1024	8	32
512	16	32
256	16	16
128	16	8
64	16	4
32	16	2
16	16	1

KVN 4-Frequency Full Polarization

K-DAS (4 CH)+ OCTAD (4 CH) or OCTAD (8 CH) with Mark6

22/43/86/129 w/ full polarization
Data rate: 1, 2, 4, 8, 16, 32 Gbps

Mark 6

- 16Gbps recording
- 4 disk modules with 8 HDDs each
- 4 10GbE input

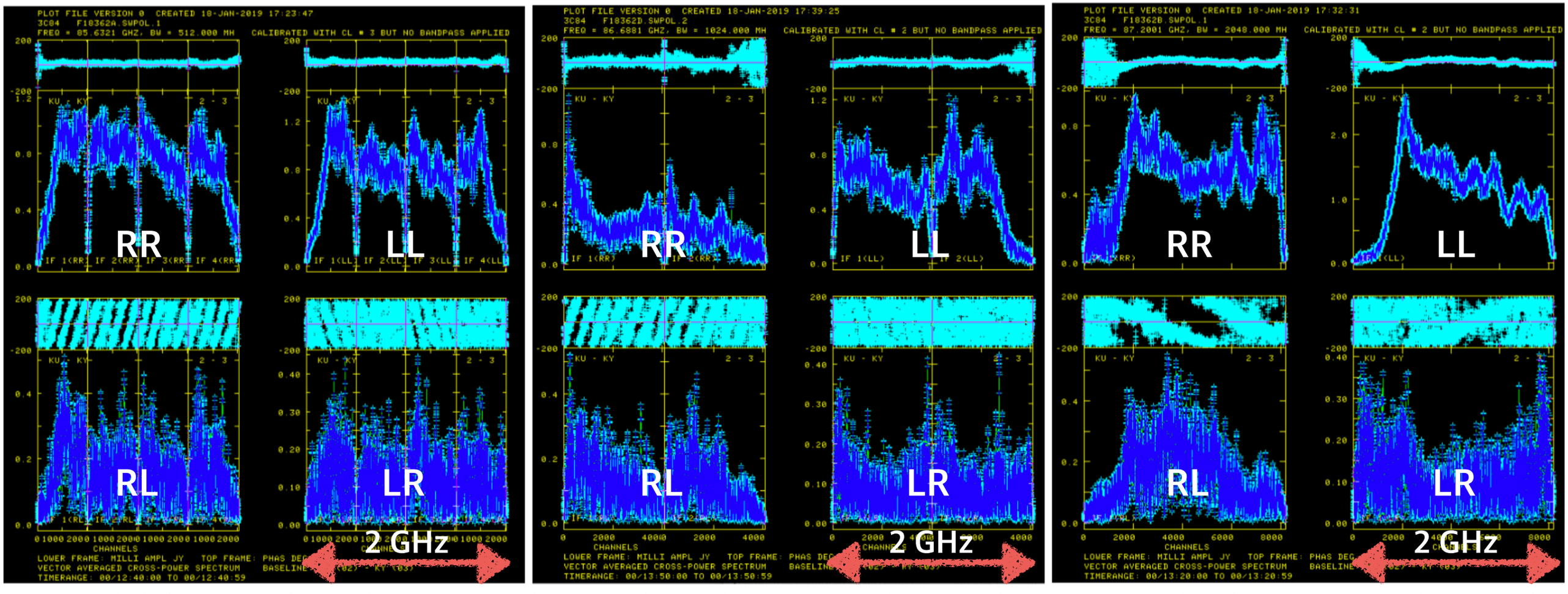
32Gbps mode & 16Gbps Fringes

KYS-KUS with 22/86GHz Dual-Pol (f18324 & f18362)

f18362 fringe test

32Gbps setup in simultaneous K/W observation —> W-band fringes (16Gbps) detected!

512 MHz x 8 Channels x 2 Pols 1024 MHz x 4 Channels x 2 Pols 2048 MHz x 2 Channels x 2 Pols



- On December 28, 2019,
  We have detected **<u>simultaneous 22/43/86/129GHz fringes at full-polarization</u>**
  (16Gbps recording mode, **512MHz x 8 channel**) for the first time !!

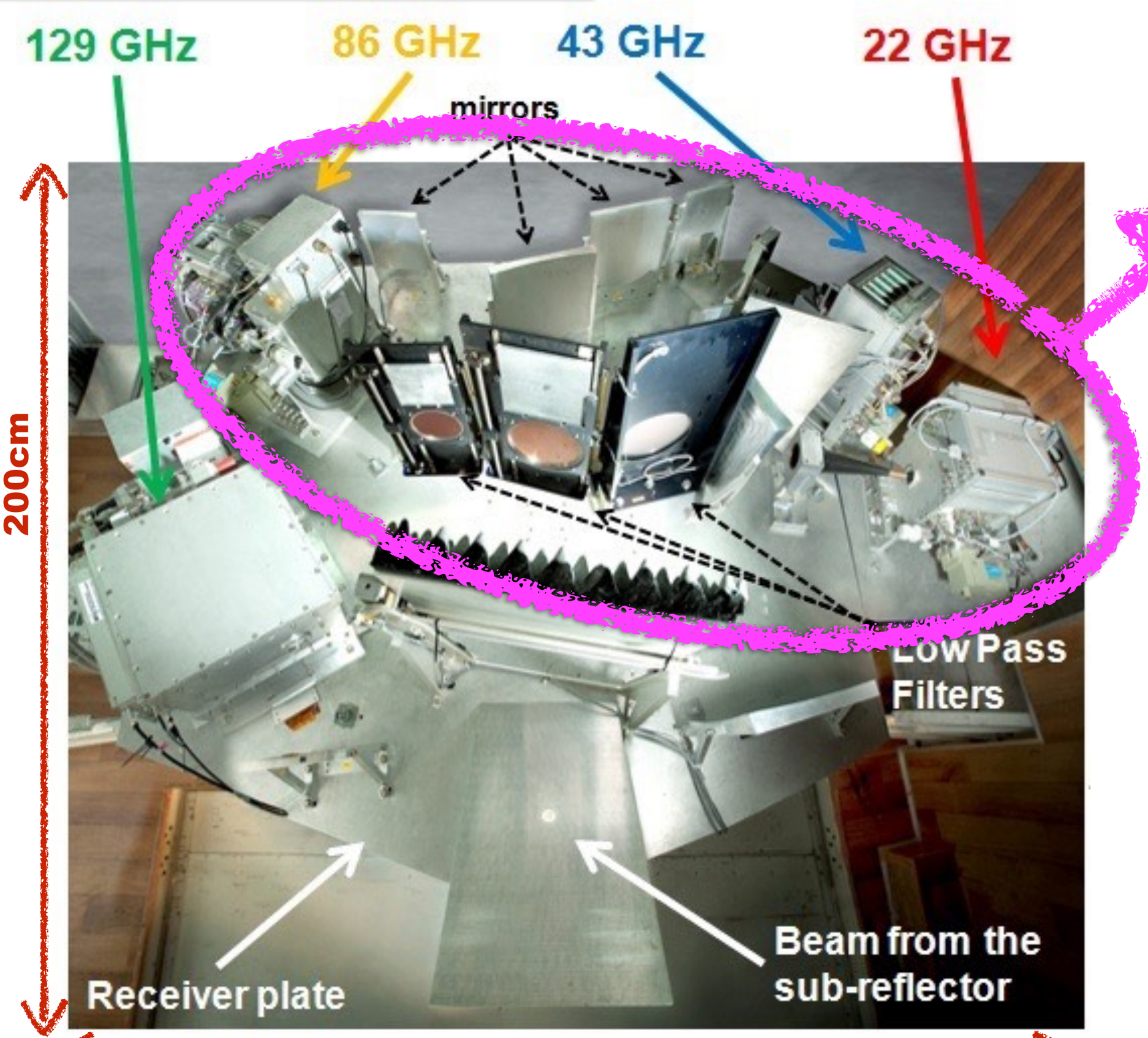
KVN Baseline/Image Sensitivity

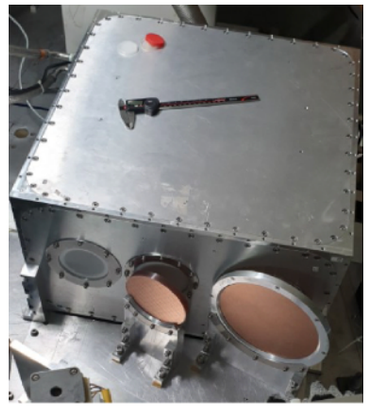
Frequency	22 GHz	43 GHz	86 GHz	129 GHz
SEFD (Jy)	1500	1800	3400	5000
Sensitivity (mJy, 1-sigma)	T_{int}=100s / T_{int}=1hr	T_{int}=60s / T_{int}=1hr	T_{int}=30s / T_{int}=1hr	T_{int}=30s / T_{int}=1hr
1 Gbps (Max 256 MHz)	9.6 / 1.28	14.9 / 1.53	39.8 / 2.89	58.5 / 4.25
2 Gbps (Max 512 MHz)	6.8 / 0.90	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

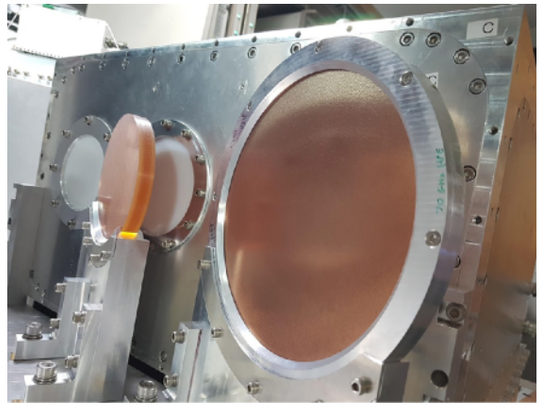
- Note: (baseline) / (image) sensitivity in the unit of mJy
- Big improvement on the baseline sensitivity when FTP is applied (i.e., ~30 min)

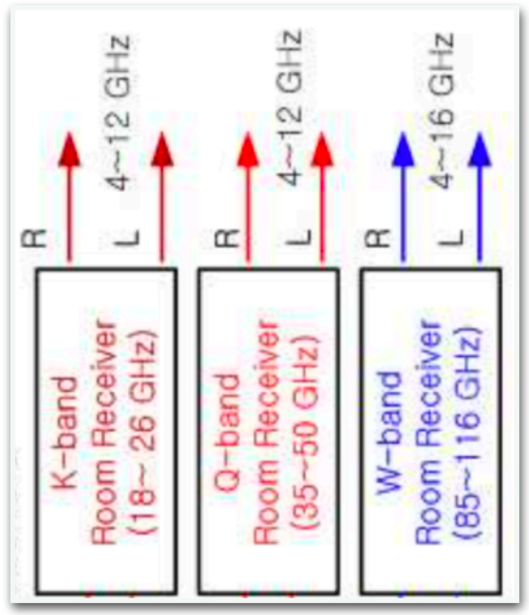
Compact Triple-band Receiver (CTR)

Installed on Sep. 2~3 at KYS









RF: 18-116GHz

Global Simultaneous MF Network

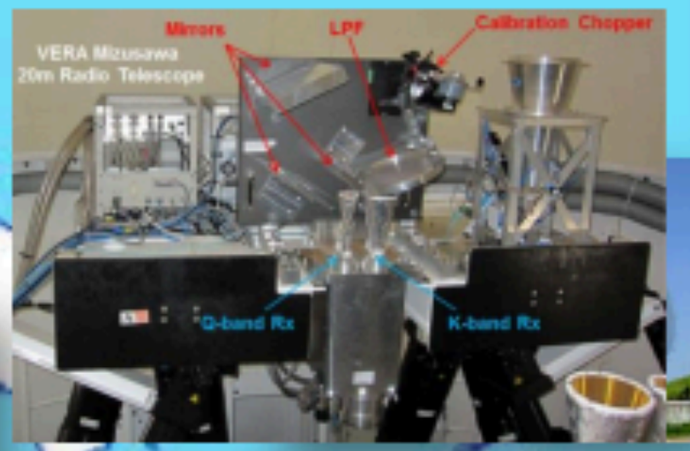
Yebes 40m (K/Q/W)

Sardinia 64m (K/Q/W)

Xinjiang 26m (K/Q)

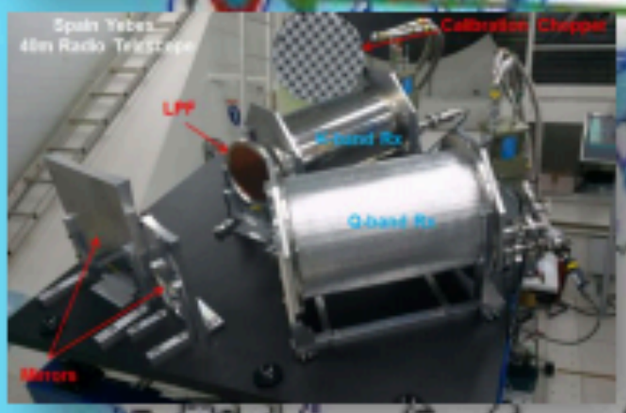
KVN 21m x 3 (K/Q/W/D)

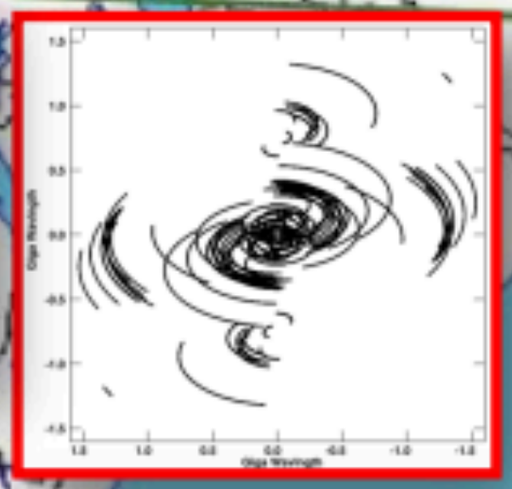
KASI: 500km



VERA 20m x 4 (K/Q)

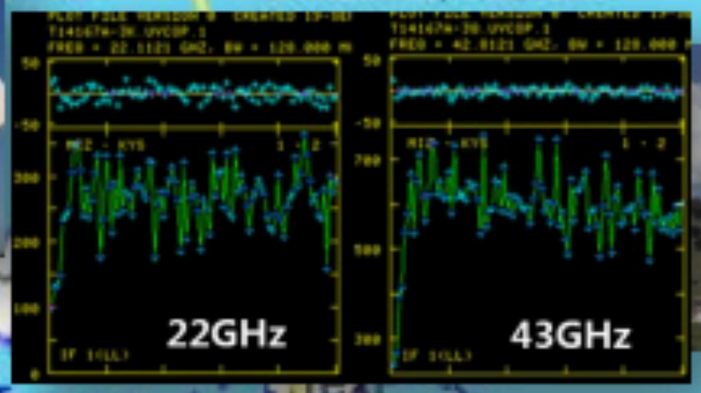
NRAO: 7,300km



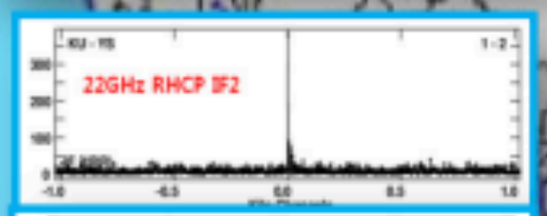


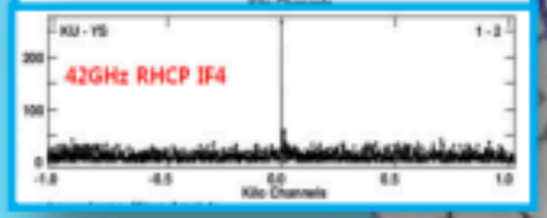
Tianma 65m (K/Q)

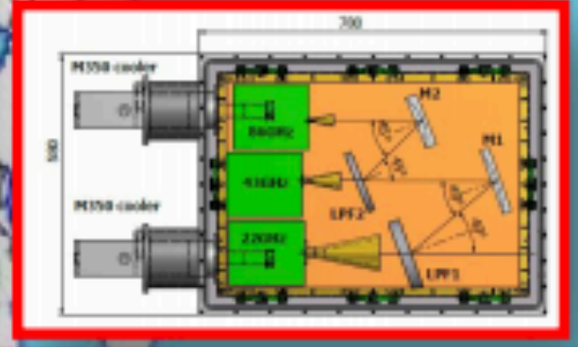
NAOJ: 2,400km



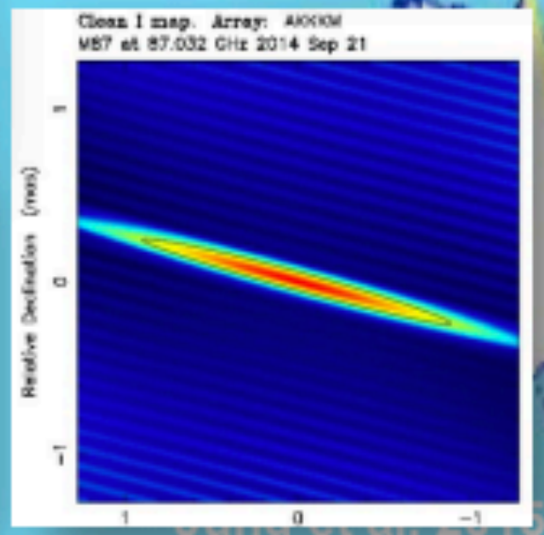
VLBA MK 25m (K/Q/W/D)







Frequency (GHz)	Resolution (mas)		Accuracy (μas)	
	KVN	x-KVN	KVN	x-KVN
22	6	0.33	346	12
43	3	0.16	173	6
86	1.5	0.08	87	3
129	1.0	0.05	58	2



ATCA 22m x 6 (K/Q/W)

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)

E-KVN
(K/Q/W/D+230GHz)

"Standard System" in mm-VLBI

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

Tianma 65m
(China, K/Q)

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

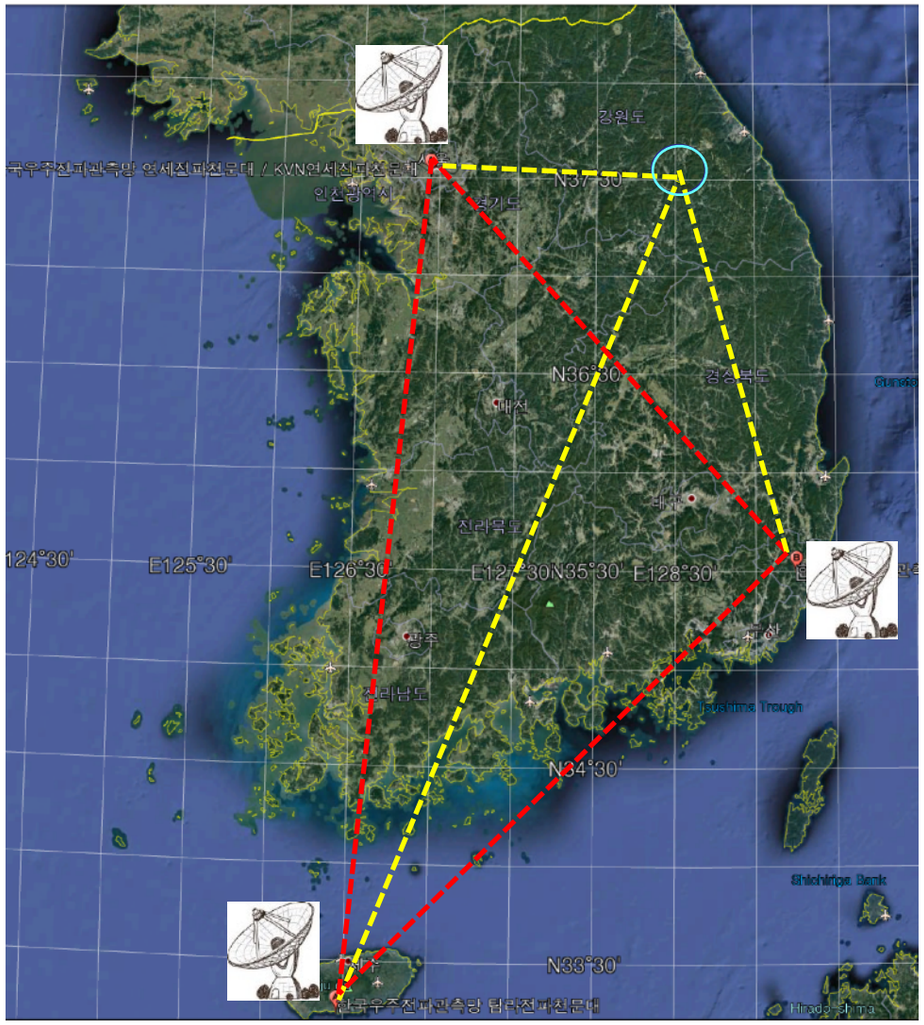
Sardenia 64m, Noto 32m, Medicina 32m (Italia, K/Q/W)

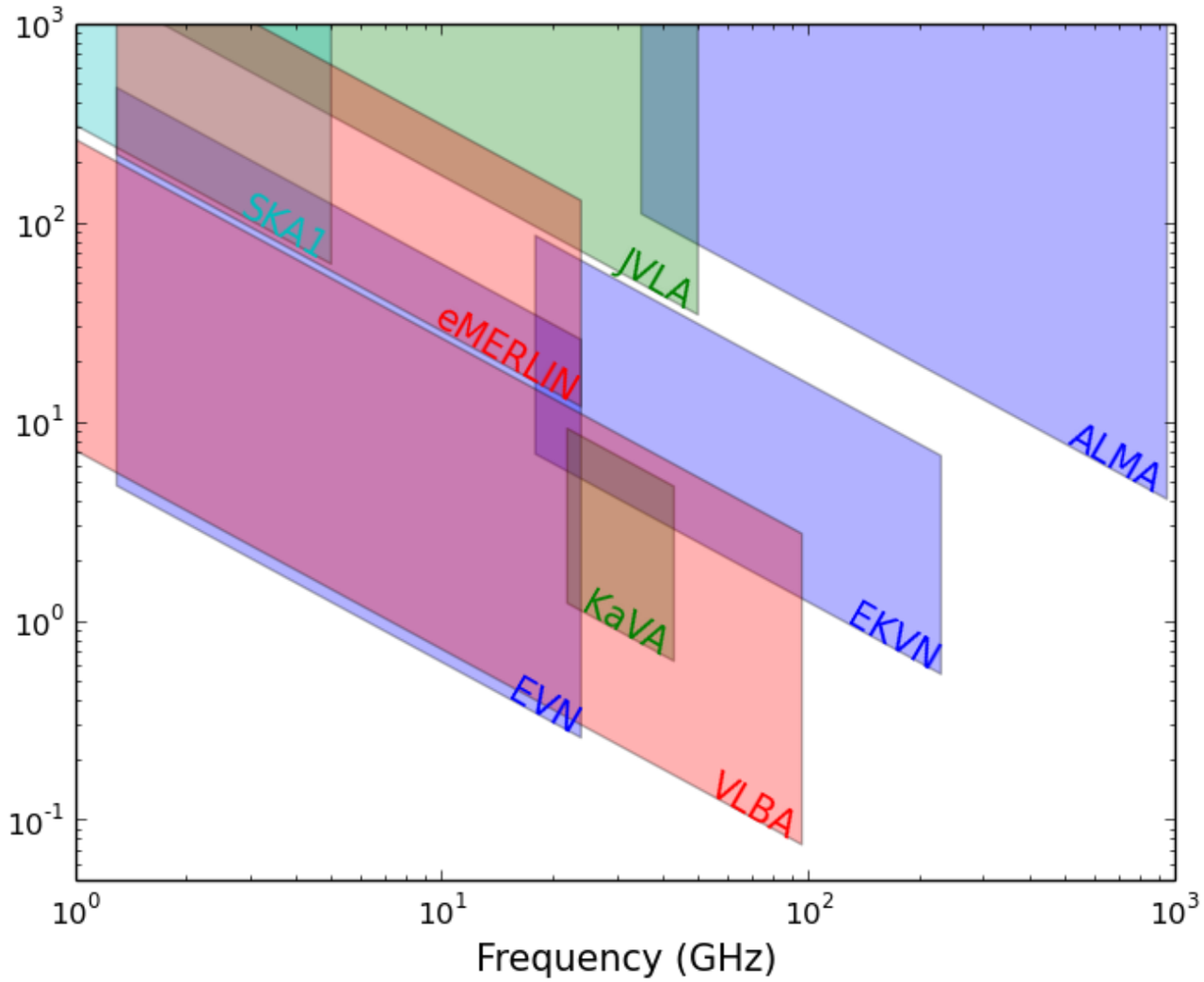
Mopra 22m (Australia, K/Q/W)

ATCA 22m x5
(Australia, Q/W)

E-KVN Project: Construction of A New Telescope

- ❖ Almost same Telescope (D = 21m)
  - Kangwon Province (~130 km E-W baseline)
  - better surface accuracy (~80 um) for 230GHz operation



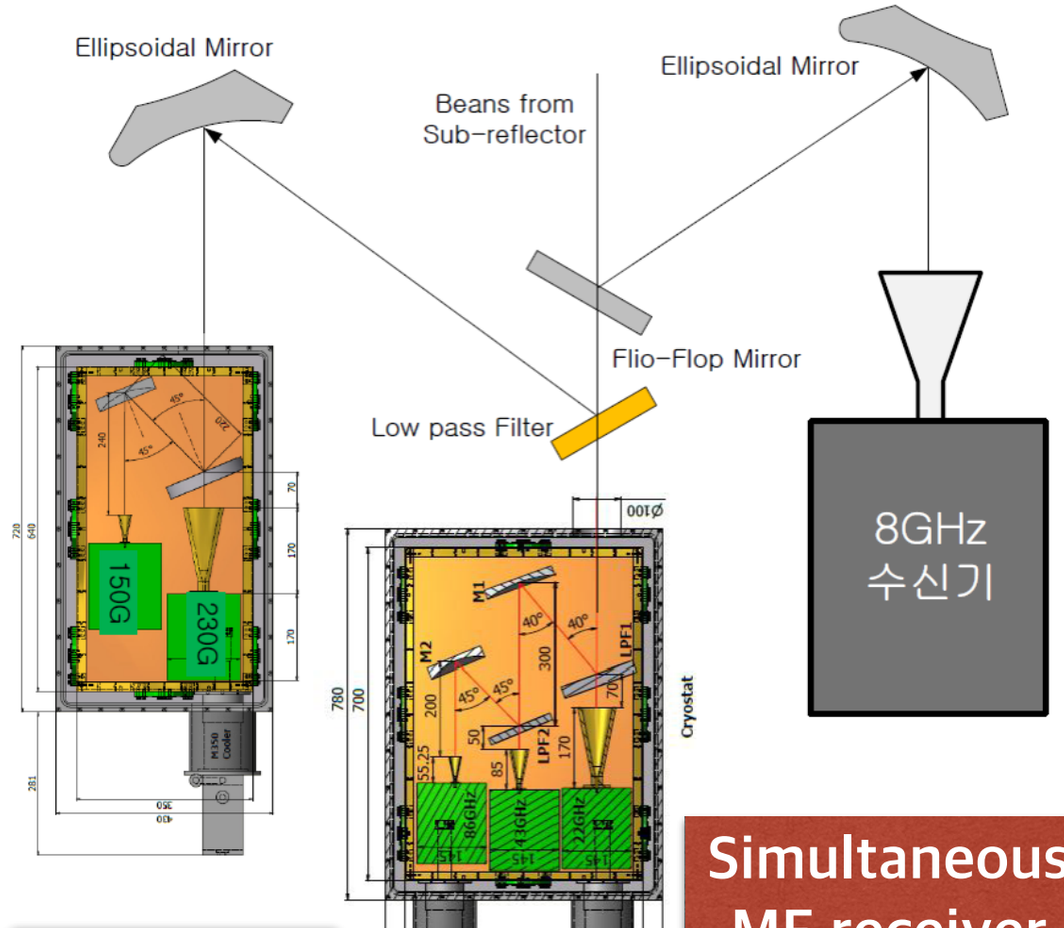


E-KVN Project (2020 - 2023)

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

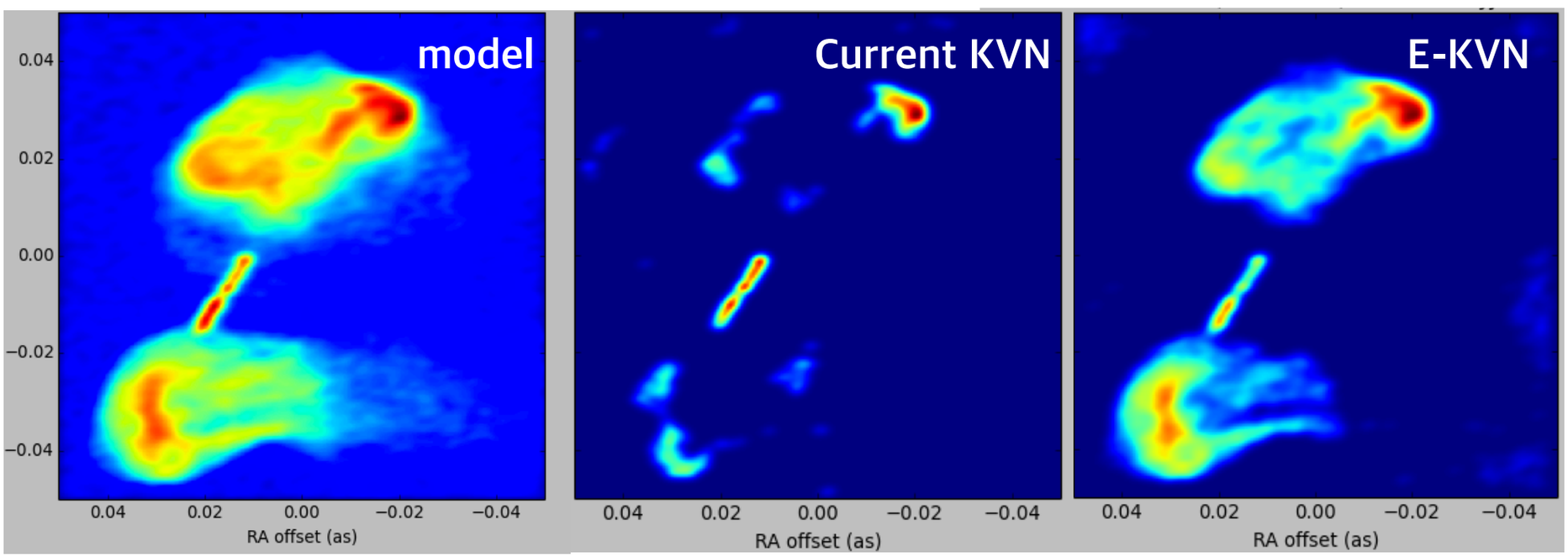
- ❖ Recording Bandwidth
  - 64Gbps (2GHz x 8 IFs)

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



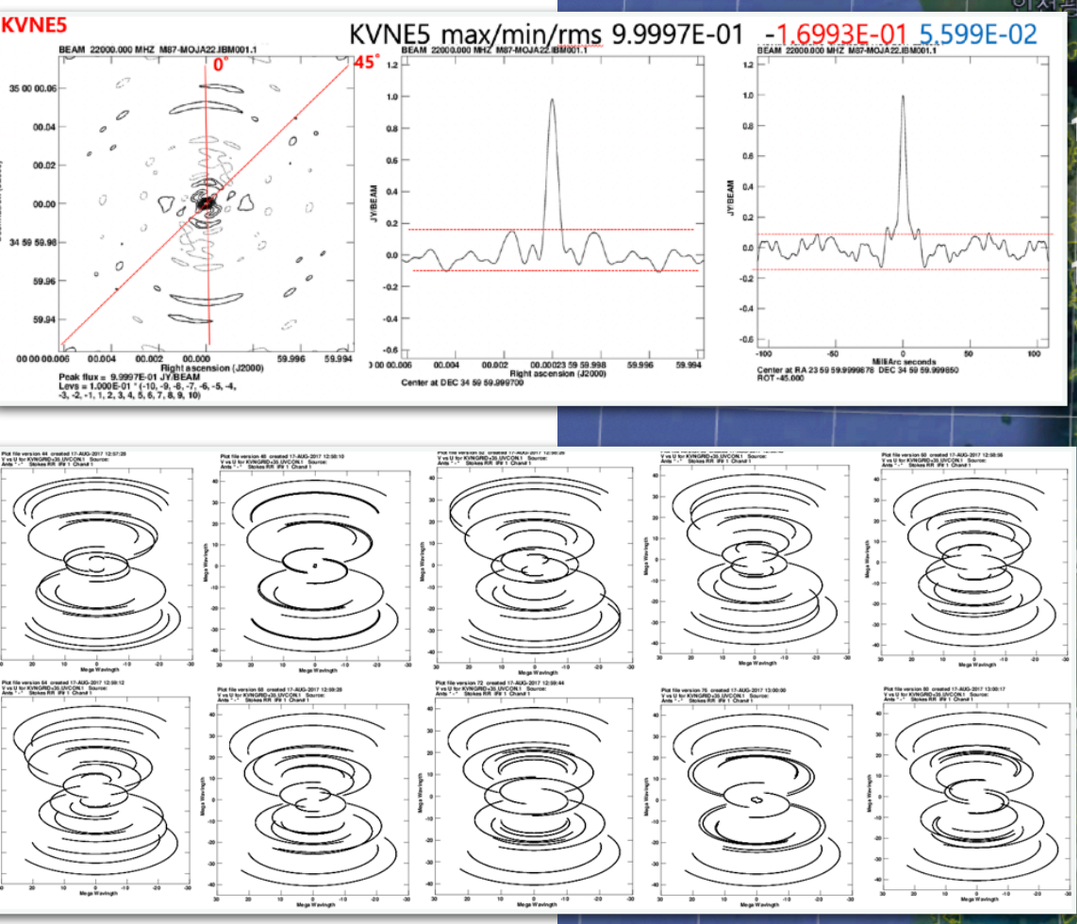
See details
(Dr. Han's Talk)

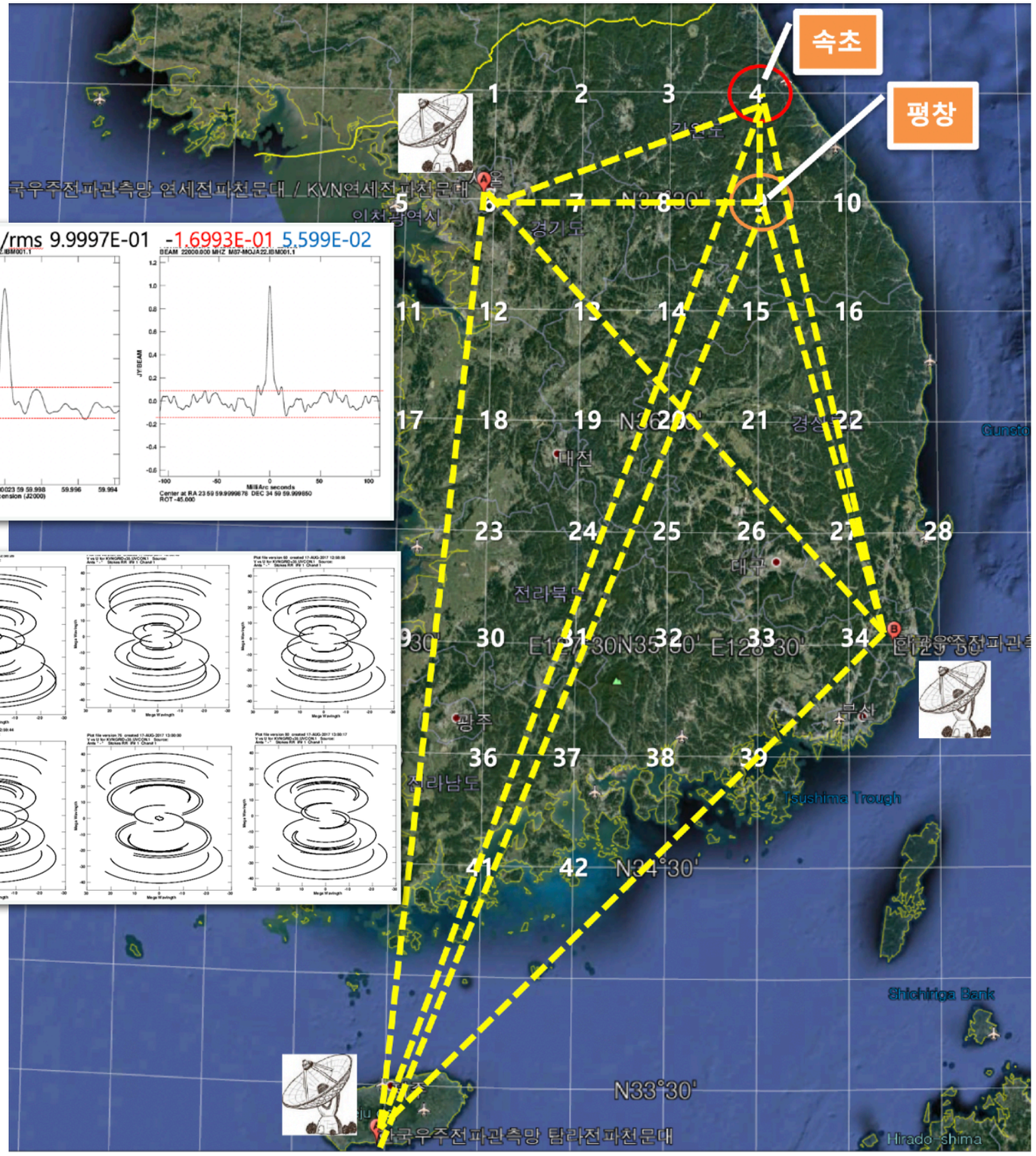
Simultaneous MF receiver (18 - 230 GHz)



Simulation assuming flat spectrum over 18- 150GHz

Baselines, Synthetic beams and UV coverages





KVN확장
GRID UV 시뮬레이션

```
2 38.0  -127.0  100  21  0.6  50  4  0 # 1
2 38.0  -127.5  100  21  0.6  50  4  0 # 2
2 38.0  -128.0  100  21  0.6  50  4  0 # 3
2 38.0  -128.5  100  21  0.6  50  4  0 # 4

2 37.5  -126.5  100  21  0.6  50  4  0 # 5
2 37.5  -127.0  100  21  0.6  50  4  0 # 6
2 37.5  -127.5  100  21  0.6  50  4  0 # 7
2 37.5  -128.0  100  21  0.6  50  4  0 # 8
2 37.5  -128.5  100  21  0.6  50  4  0 # 9
2 37.5  -129.0  100  21  0.6  50  4  0 # 10

2 37.0  -126.5  100  21  0.6  50  4  0 # 11
2 37.0  -127.0  100  21  0.6  50  4  0 # 12
2 37.0  -127.5  100  21  0.6  50  4  0 # 13
2 37.0  -128.0  100  21  0.6  50  4  0 # 14
2 37.0  -128.5  100  21  0.6  50  4  0 # 15
2 37.0  -129.0  100  21  0.6  50  4  0 # 16

2 36.5  -126.5  100  21  0.6  50  4  0 # 17
2 36.5  -127.0  100  21  0.6  50  4  0 # 18
2 36.5  -127.5  100  21  0.6  50  4  0 # 19
2 36.5  -128.0  100  21  0.6  50  4  0 # 20
2 36.5  -128.5  100  21  0.6  50  4  0 # 21
2 36.5  -129.0  100  21  0.6  50  4  0 # 22

2 36.0  -127.0  100  21  0.6  50  4  0 # 23
2 36.0  -127.5  100  21  0.6  50  4  0 # 24
2 36.0  -128.0  100  21  0.6  50  4  0 # 25
2 36.0  -128.5  100  21  0.6  50  4  0 # 26
2 36.0  -129.0  100  21  0.6  50  4  0 # 27
2 36.0  -129.5  100  21  0.6  50  4  0 # 28

2 35.5  -126.5  100  21  0.6  50  4  0 # 29
2 35.5  -127.0  100  21  0.6  50  4  0 # 30
2 35.5  -127.5  100  21  0.6  50  4  0 # 31
2 35.5  -128.0  100  21  0.6  50  4  0 # 32
2 35.5  -128.5  100  21  0.6  50  4  0 # 33
2 35.5  -129.0  100  21  0.6  50  4  0 # 34

2 35.0  -126.5  100  21  0.6  50  4  0 # 35
2 35.0  -127.0  100  21  0.6  50  4  0 # 36
2 35.0  -127.5  100  21  0.6  50  4  0 # 37
2 35.0  -128.0  100  21  0.6  50  4  0 # 38
2 35.0  -128.5  100  21  0.6  50  4  0 # 39

2 34.5  -126.5  100  21  0.6  50  4  0 # 40
2 34.5  -127.0  100  21  0.6  50  4  0 # 41
2 34.5  -127.5  100  21  0.6  50  4  0 # 42
```

EKVN Candidate Site

KVN서울

세종

KVN울산

KVN탐라

속초 - 잼보리

속초 - 경동대

양양 - 송이밸리

YangYang

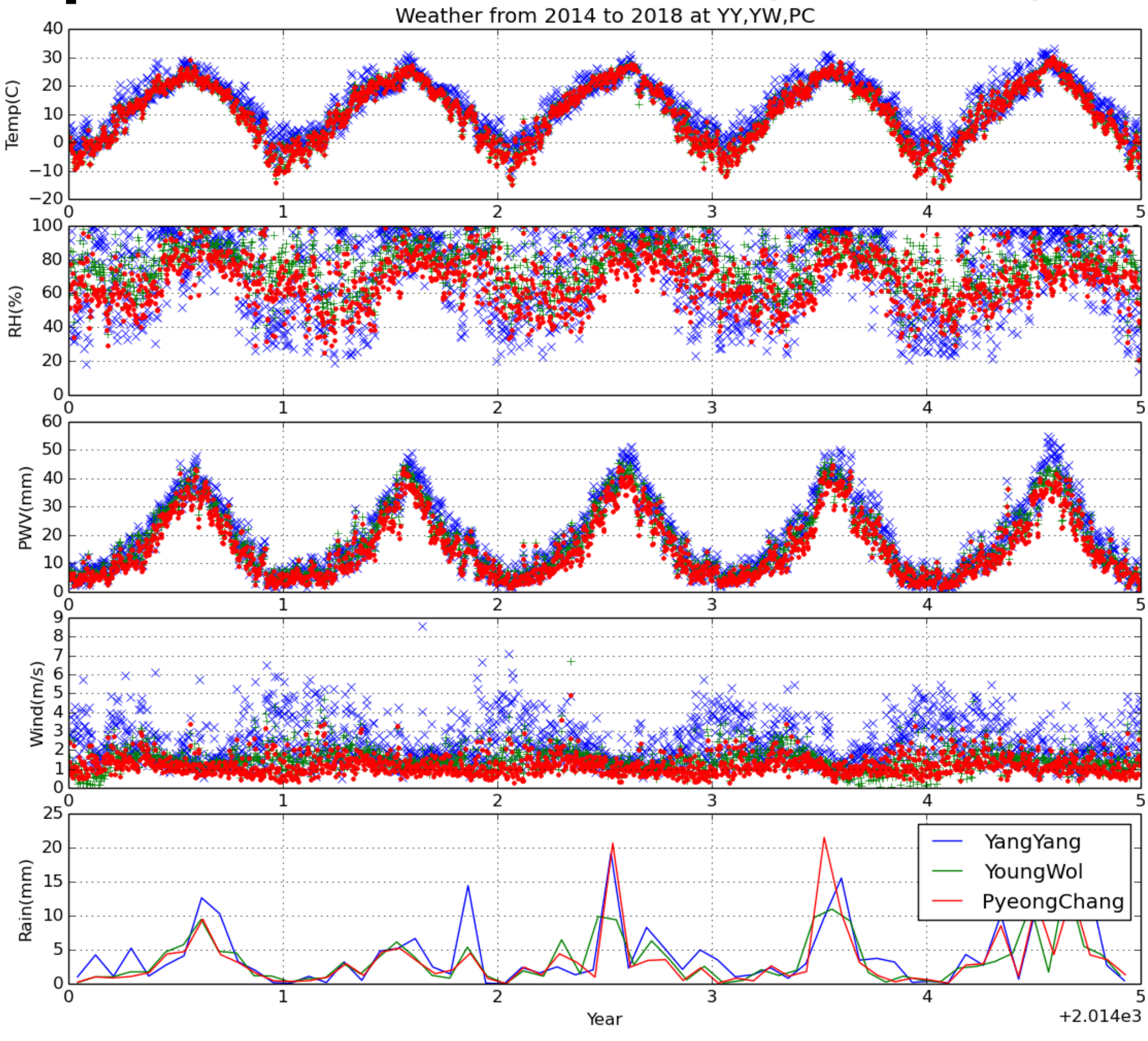
평창 - 서울대

PyeongChang

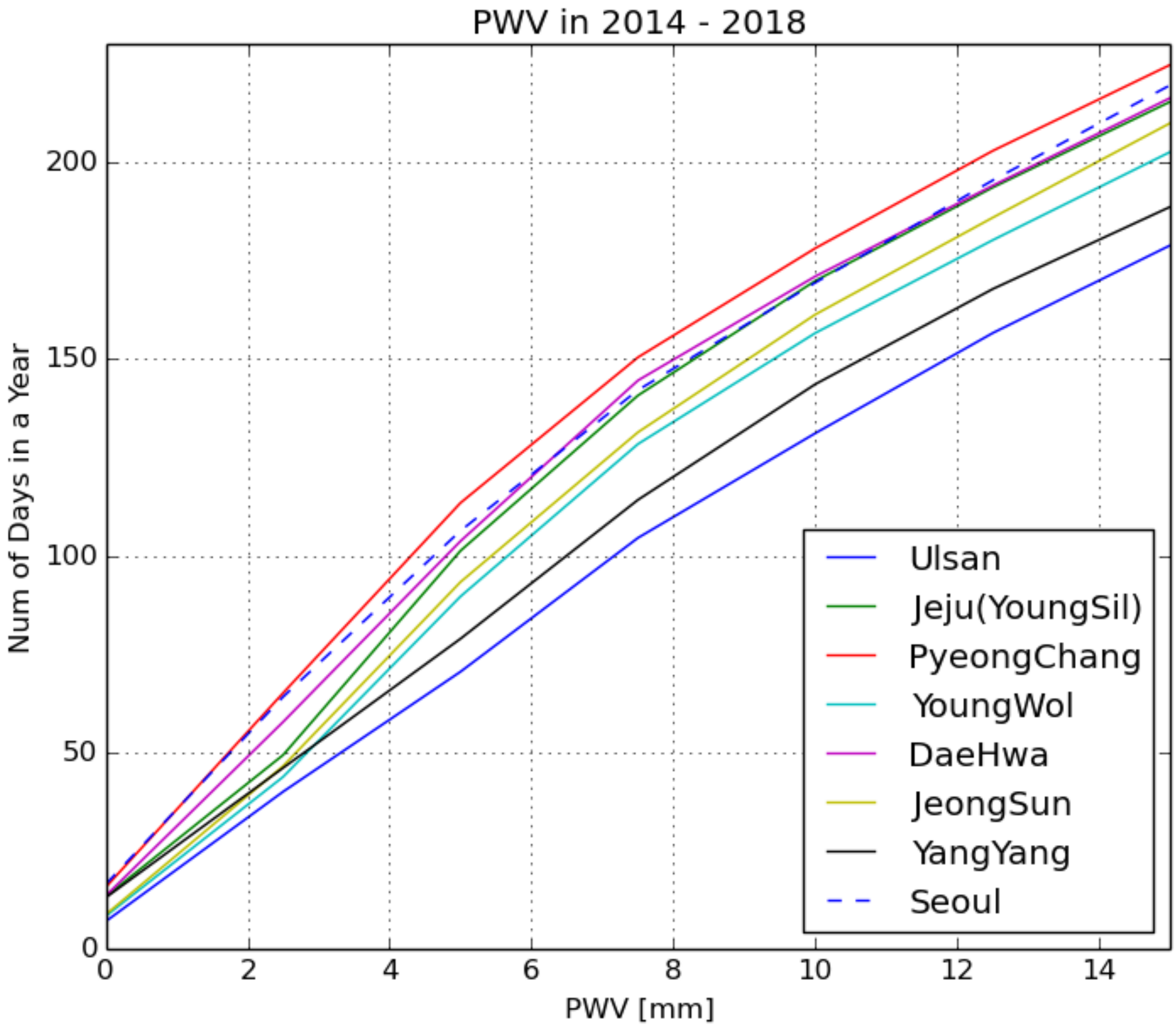
영월 - 봉래산

YoungWol

Atmospheric Conditions (5 years, daily averaged)

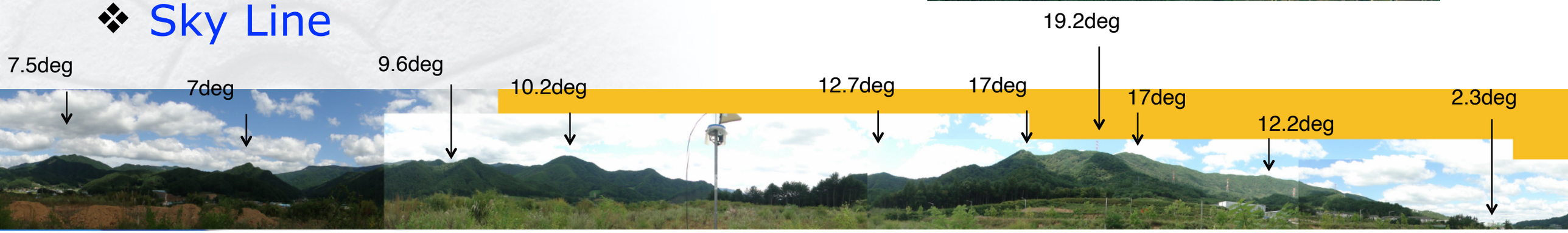


Atmospheric Conditions (5 years, daily averaged)



PyeongChang Campus as a candidate site

- Good Baselines
- Enough Space
- Less Groundwork
- Easy to Access (KTX)
- Weather Condition
  - ~600m above sea level
  - low Temp /mild Wind
  - daily Temp variation
- Active User Group
- Sky Line



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]

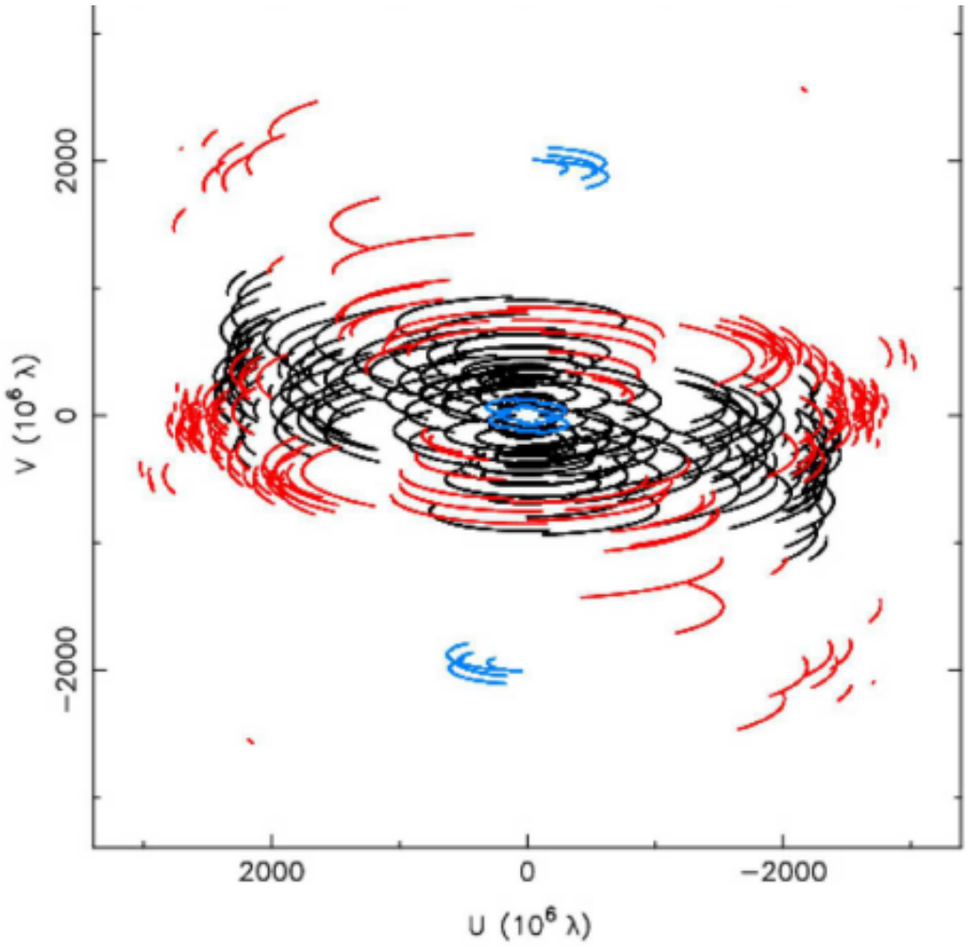
Authors

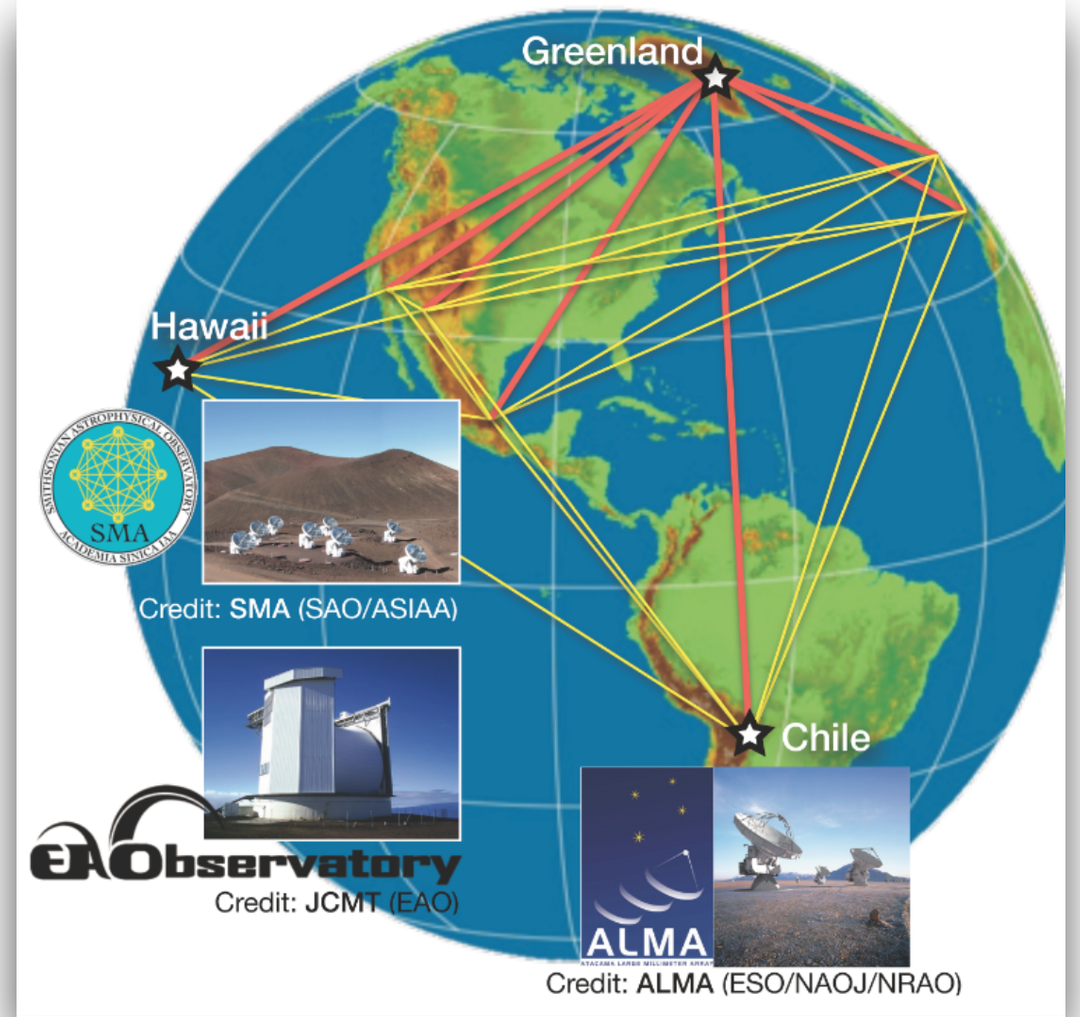
Akiyama, K.[3,8], Algaba, J-C.[2], An, T.[4], Bower, G.[1], Byun, D-Y.[2], Dodson, R.[9], Doi, A.[10], Edwards, P.G.[11], Fujisawa, K.[12], Gu, M-F.[4], Hada, K.[3], Hagiwara, Y.[13], Jaroenjittichai, P.[15], Jung, T.[2,6], Kawashima, T.[3], Koyama, S.[1,5], Lee, S-S.[2], Matsushita, S.[1], Nagai, H.[3],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

<<1mm>>
- EKVN
- SRAO
- JCMT
- GLT
- SMA
- SPART

Expected UV-coverages with Extended EAVN at 3mm





The Most Powerful Eyes in the Universe

서울~울산~제주 삼각관측 우주와의 '소통' 한걸음 더

12일 새벽 제주도 서귀포 하늘에서 북극성을 중심으로 궤적을 그리며 움직이는 별들을 향해 지름 21m 크기의 접시 안테나가 우뚝 솟아 있다. 서울 연세대·울산 울산대·제주 탐라대를 3각으로 연결하는 한국우주전파관측망(KVN) 사업의 마무리 단계로 서귀포 탐라대 탐라전파천문대의 전파망원경이 지난 1일 성령식을 마치고 시험 가동에 들어갔다. 전파망원경 석 대가 연결되면 서울에서 제주 한라산의 쌀 한 톨도 식별할 수 있는 정밀도를 갖게 된다. 한국우주전파관측망을 가동하면 우리도 우주의 블랙홀을 정밀 계측해 별의 탄생과 사멸을 연구할 수 있고, 태반도 지각변동도 정밀 모니터링할 수 있게 된다. 이 사진은 디지털카메라에 14㎜ 렌즈를 부착해 1시간 동안 셔터를 열어 찍었다.

서귀포/김동균 기자 bong8@hani.co.kr

Thank you !