Multi-frequency mm-wave radio telescopes
& other software controlled operations

A quasi-optical system of KVN for millimeter VLBI

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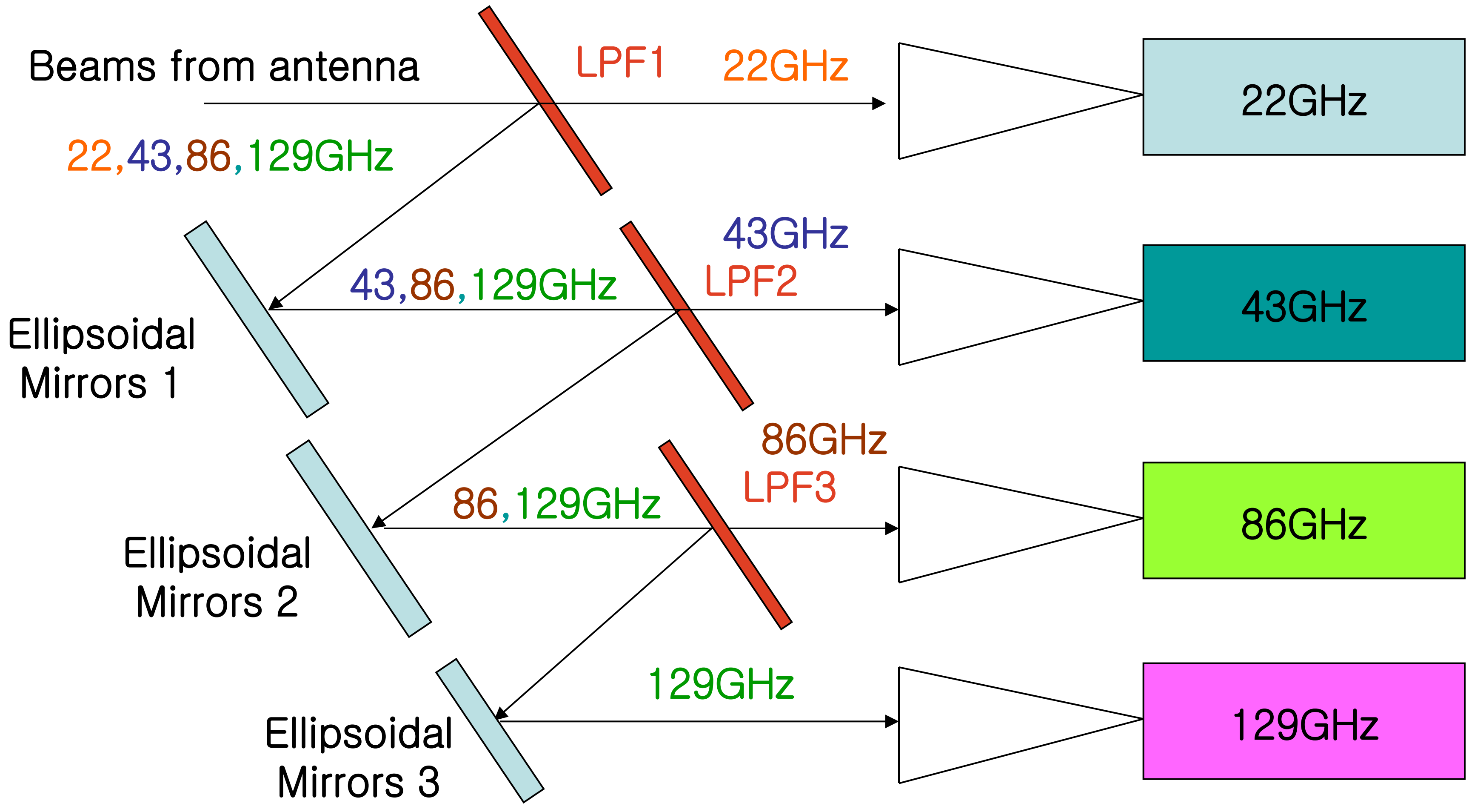
October 6th, 2015

Outline

- Design quasi-optic circuit
- Test results of optical circuit
- Observational results
- Global collaborations for optics design
- Summary

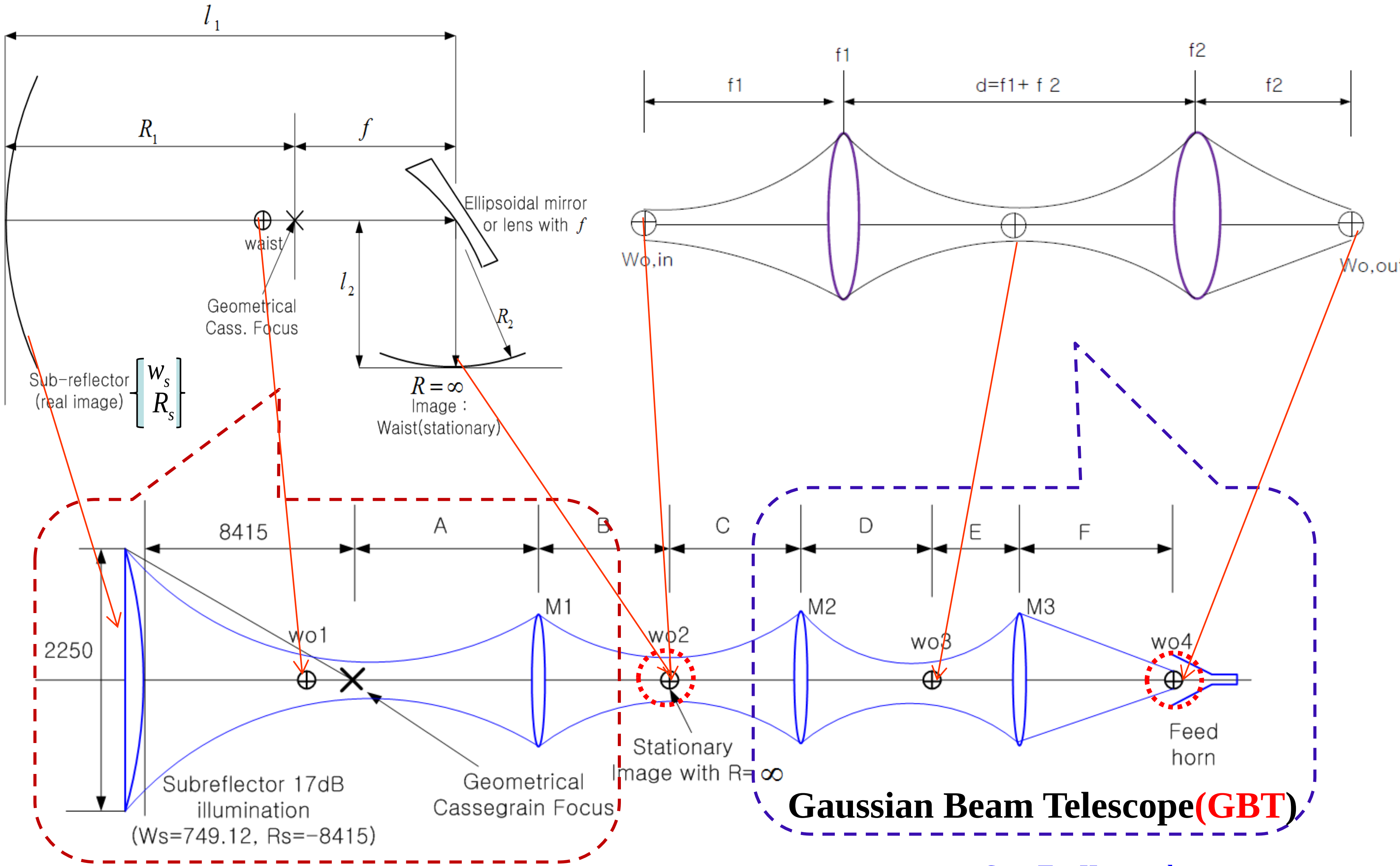
Conceptual design of simultaneous multi-frequency bands millimeter wave receivers

- Conceptual design came out **in April 2003**



Frequency Independent beam waist Image + Gaussian Beam Telescope(GBT)

- Wide band application -

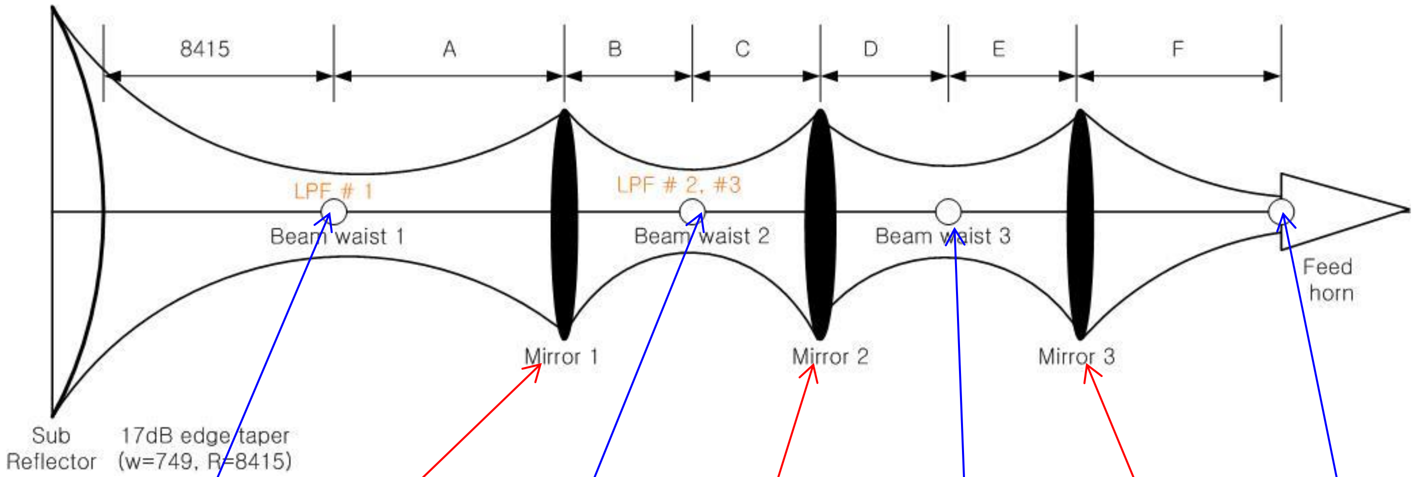


Frequency independent beam waist mage

Detail described the paper

Seog-Tae Han ,et al
"Millimeter-wave Receiver Optics for Korean VLBI Network"
2008. 1. JIMW, Vol. 28, No. 1, pp 69-78

Beam Parameters

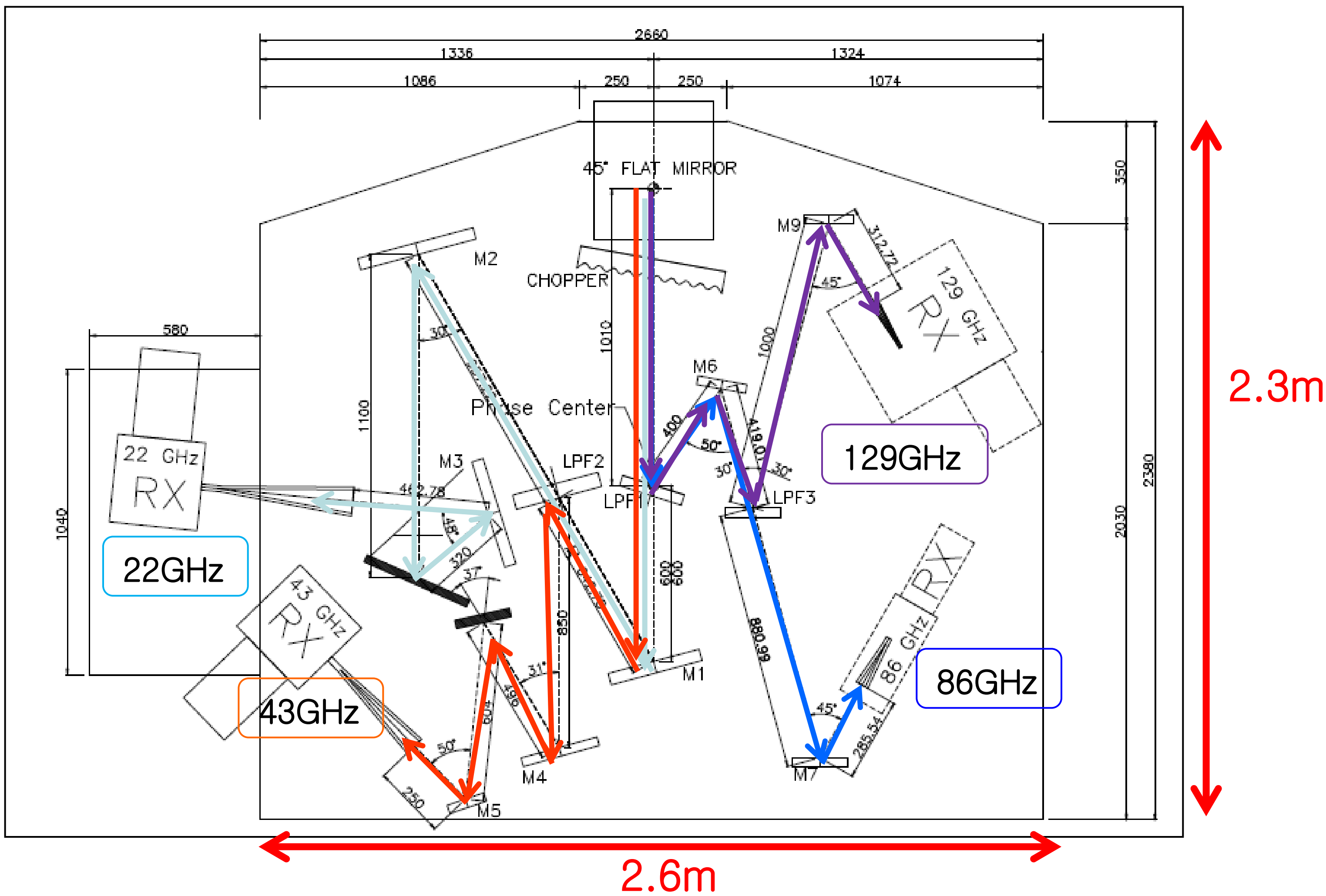


(all units in millimeters unless otherwise noted)

freq.	w01	A	w(M1) 4w f Ri/Ro	B	w02	C	w(M2) 4w f Ri/Ro	D	w03	E	w(M3) 4w f Ri/Ro	F	w04
22	48.62	600	74.68 298.72 600 1102.93 -1315.81	642.78	53.41	957.22	94.32 377.28 957.22 1409.17 -2984.61	957.22	77.73	462.78	81.91 327.64 462.78 4656.25 -513.85	462.78	25.82
43	24.92	600	59.72 238.88 600 737.72 -3213.92	642.78	53.41	850	64.03 256.12 850 2794.33 -1221.59	850.00	15.71	250	38.65 154.6 250 1513.42 -299.47	250	15.71
86	12.46	400	37.93 151.72 400 451.03 -3535.43	419.01	35.61	880.99	44.96 179.84 880.99 2363.21 -1404.62	880.99	27.45	200.01	28.62 114.48 200.01 2506.45 -217.35	200.01	8.08
129	8.31	400	36.66 146.64 400 422.76 -7431.00	419.01	35.61	900	40.22 160.88 900 4164.56 -1148.12	900	18.70	150	19.62 78.48 150 1638.71 -165.11	150	5.93

Optical circuit lay out

April 2003 ~ November 2005 (2 and half years)

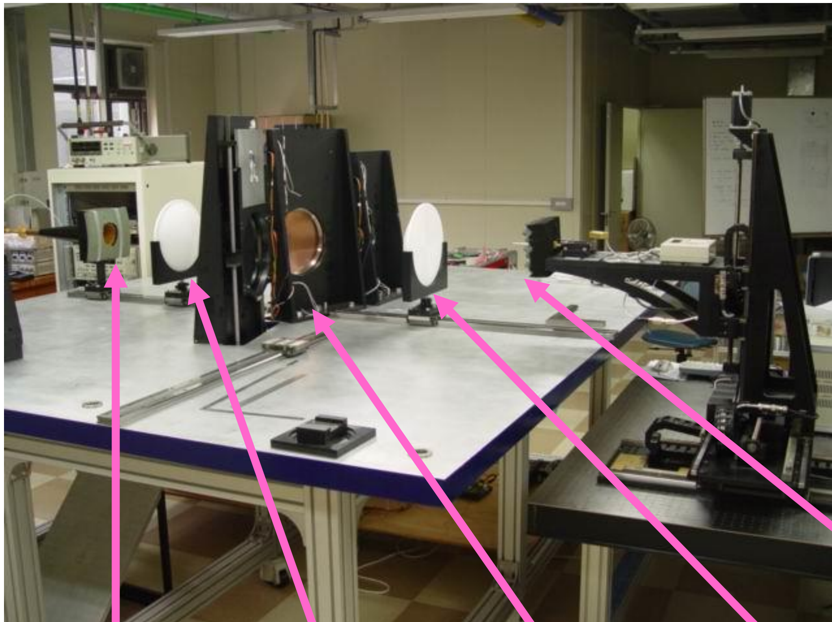


Test of Quasi-optical circuit

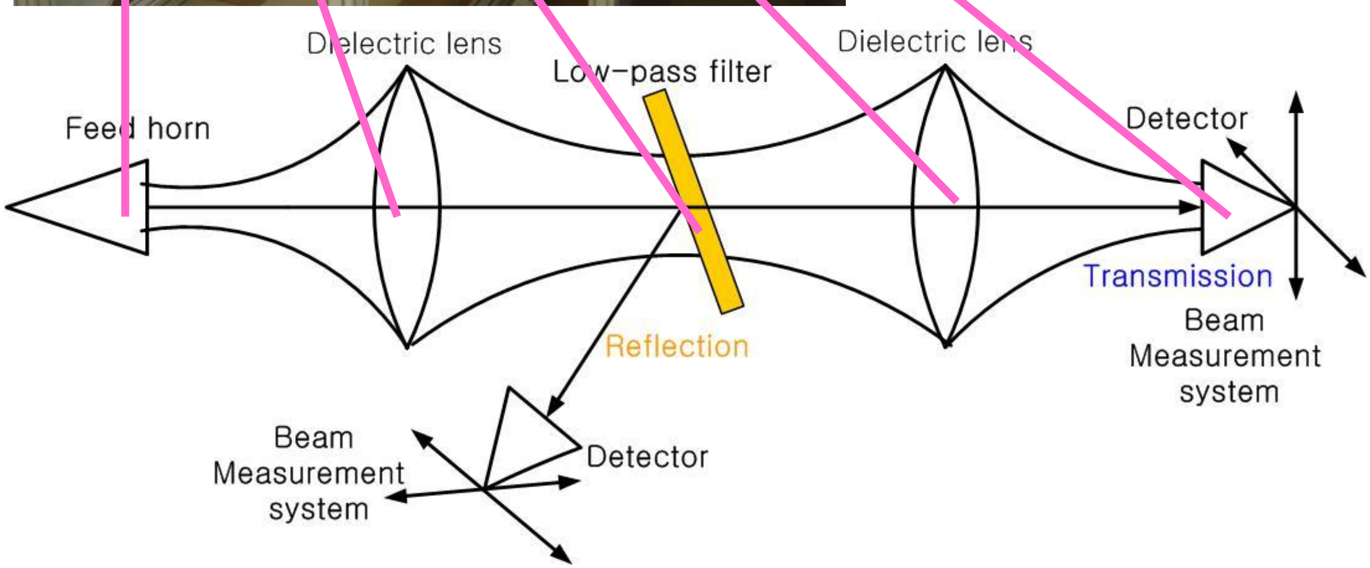
Gaussian beam measurement system

- Homemade to be used quasi-optics test only

- Radiation patterns of feed horns
- Ellipsoidal mirrors
- Dielectric lens
- LPF(Dicroic filter)

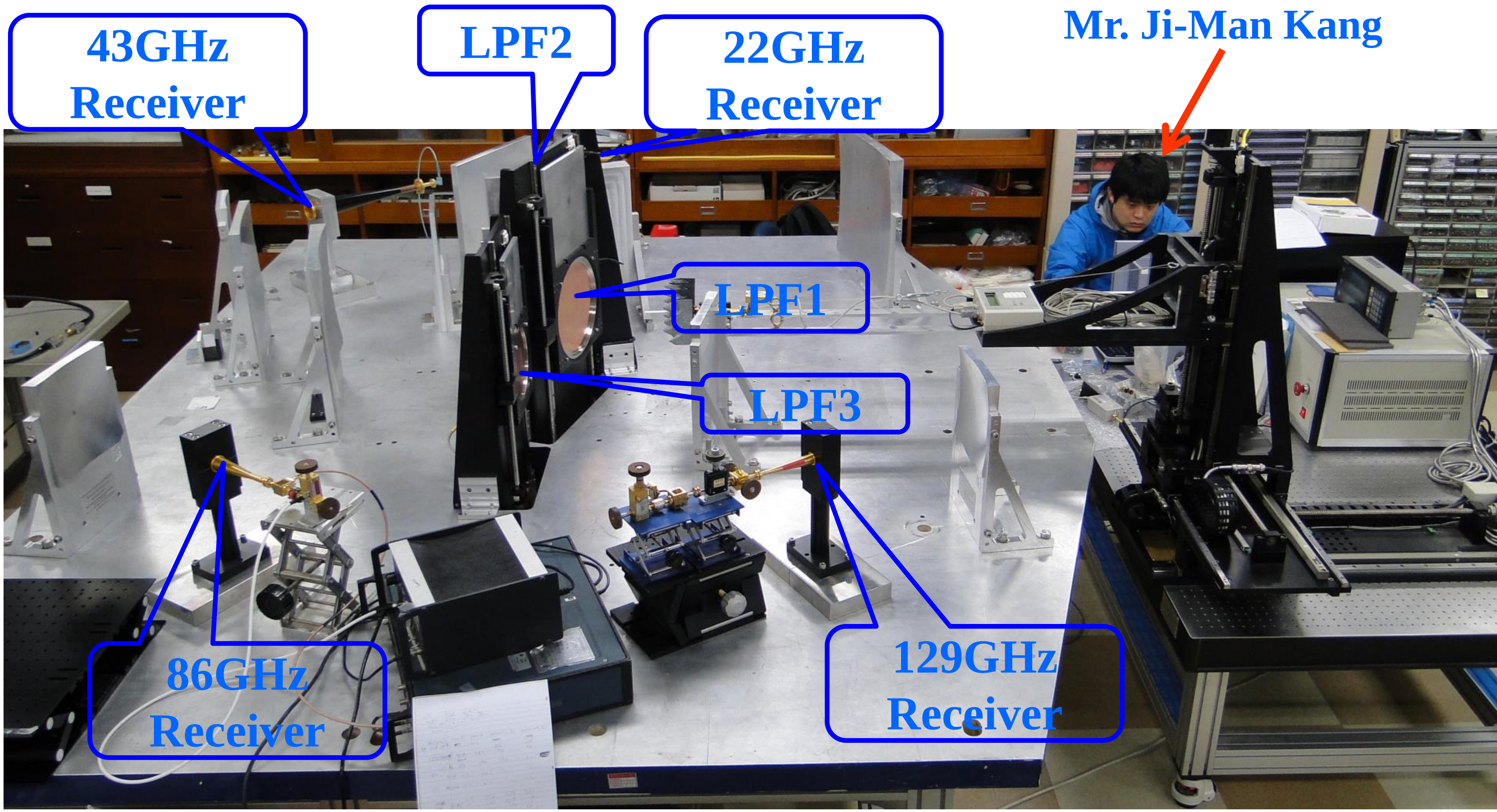


- Beam pattern
- Transmission Loss
- Reflection Loss
- Cross-polarization



Quasi-optics circuit test

December 2005 ~ May 2011 (5 and half years)



Comparison theoretical and experimental beam radii near the focus

- Differences between two values(measure-design) are less than 2mm of beam radius
- Optical circuit and its components are properly designed.
- Gaussian beam transmission theory is very powerful tool to be used quasi-optics design

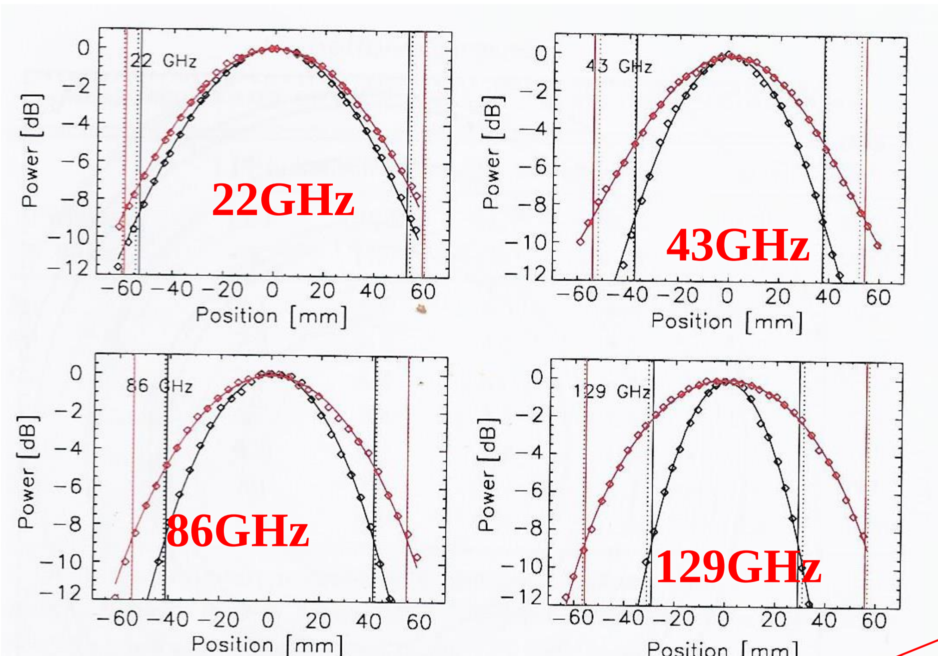
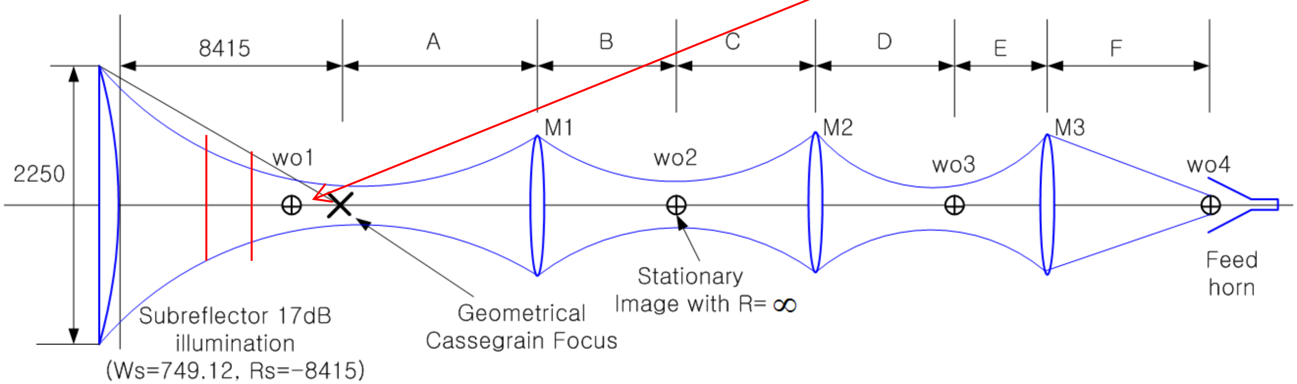


TABLE 1

COMPARISON BETWEEN THE DESIGNED AND MEASURED BEAM RADII

Frequency (GHz)	Distance from focus (mm)	Measured beam radius (mm)	Designed beam radius (mm)	Difference (mm)
22	223	53.0±0.4	54.3	1.3
	373	59.1±0.7	60.0	0.9
43	322	37.3±0.3	37.8	0.5
	522	54.0±0.3	52.0	2.1
86	462	41.2±1.1	42.1	0.9
	612	54.4±1.5	54.6	0.2
129	340	29.1±0.3	30.9	1.8
	640	55.6±0.8	56.6	1.0

NOTE.—Due to mechanical interference with mirror mounts, each band has a different measurement plane.



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"Korean VLBI Network Receiver Optics Simultaneous Multi-frequency Observation
PASP ,2013, 5. Vol. 225, pp 539~547

Beam axises alignment for among 4 beams(22/43/86/129GHz)

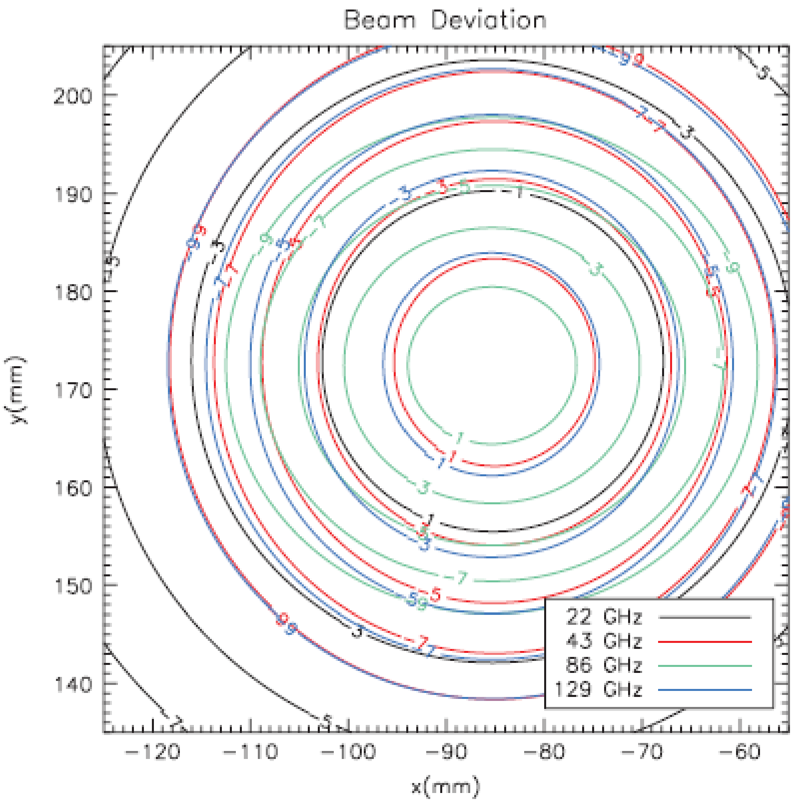
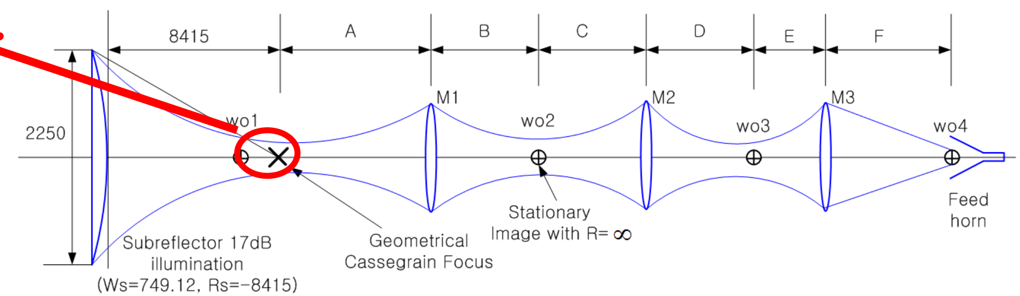


TABLE 2

BEAM CENTER DEVIATION

Frequency (GHz)	Δx (mm)	Δy (mm)	$(\Delta x^2 + \Delta y^2)^{0.5}$ (mm)	Angle deviation (arcmin)
22	-0.57 ± 0.03	0.30 ± 0.03	0.65 ± 0.03	7.35 ± 1.76
43	-0.32 ± 0.05	0.16 ± 0.06	0.36 ± 0.05	4.07 ± 3.00
129	-0.80 ± 0.03	0.07 ± 0.03	0.81 ± 0.03	9.17 ± 1.81

NOTE.—Measured at a distance of 200 mm displacement from the Cassegrain focus (toward the secondary). All offsets are referred to the beam center at 86 GHz.



- Circular shaped of beam pattern : alignment is correct
- Lateral offsets are within less than 1mm among 22/43/129GHz beam centers referred to beam center at 86GHz
- Can make simultaneous observation four channels such 22, 43, 86 and 129GHz bands

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PASP ,2013, 5. Vol. 225, pp 539~547

Losses of transmission and reflection at at LPFs

TABLE 3

MEASURED LOSSES OF LPF1 AND LPF2 IN THE 22/43 GHz BANDS

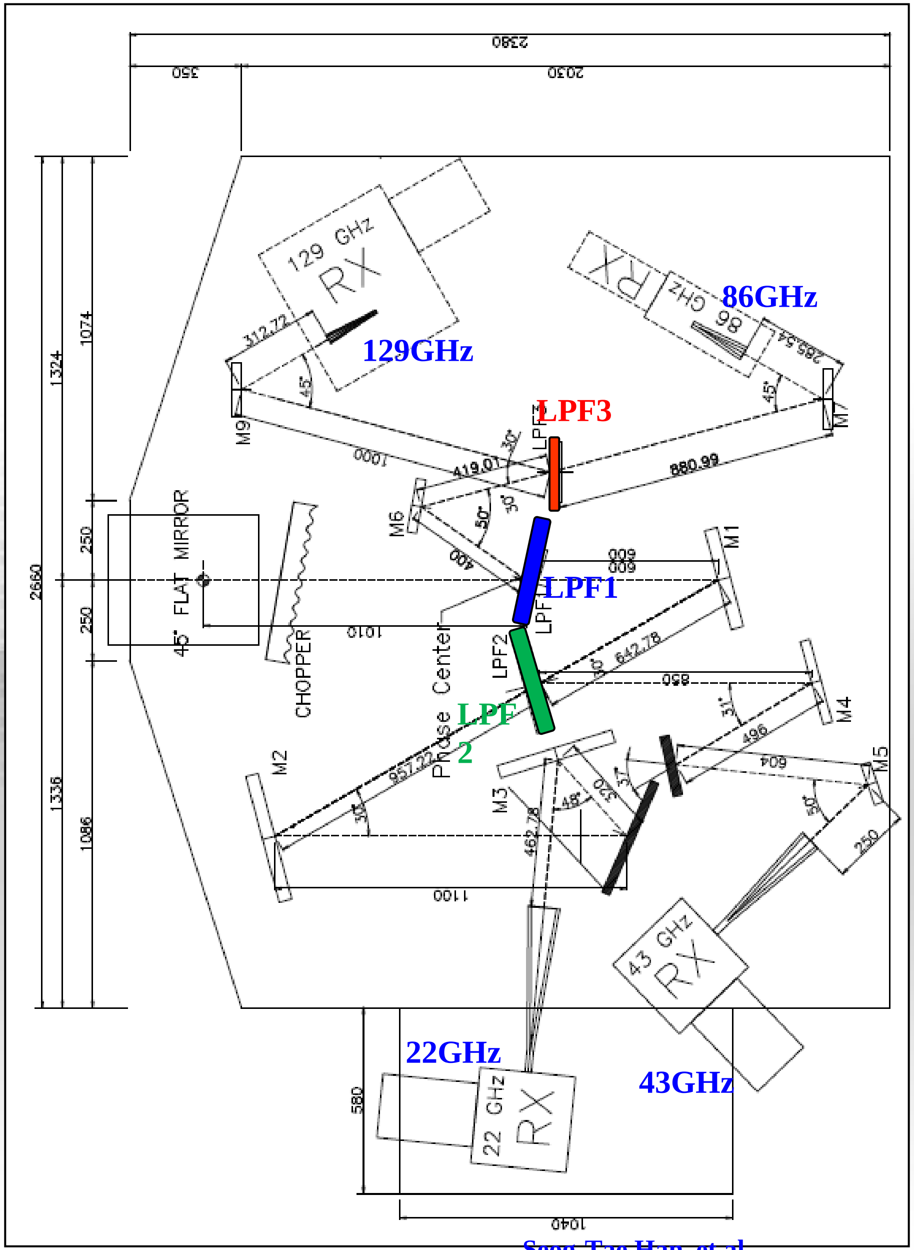
Frequency (GHz)	LPF1 LCP (%)	LPF1 RCP (%)	LPF2 LCP (%)	LPF2 RCP (%)	LPF1+LPF2 LCP (%)	LPF1+LPF2 RCP (%)
21.5	0.70	1.16	2.48	3.11	3.15	4.20
22	0.80	0.80	2.53	2.57	3.30	3.32
23	0.47	0.46	2.63	2.57	3.07	3.01
42.36	1.08	1.08	3.02	5.38	4.03	6.35
43.11	1.29	0.88	3.01	2.90	4.23	3.74
43.86	1.48	1.15	1.82	1.82	3.24	2.93

TABLE 4

MEASURED LOSSES OF LPF1 AND LPF3 IN THE 86/129 GHz BANDS

Frequency (GHz)	LPF1+flat mirror[a] LCP (%)	LPF1+flat mirror[a] RCP (%)	Flat mirror+LPF3 LCP (%)	Flat mirror+LPF3 RCP (%)	LPF1+LPF3 LCP (%)	LPF1+LPF3 RCP (%)
86	5.1	5.9	4.1	4.0	8.3	9.6
90	7.3	8.2	4.7	4.7	11.4	12.7
94	7.5	8.8	6.0	6.4	13.2	14.9
129	4.7	5.3	1.7	1.7	5.3	5.6
134	6.5	6.3	1.6	1.8	6.5	6.6
138	7.3	7.2	1.7	1.5	7.7	7.9
142	8.7	8.9	1.9	1.5	10.4	10.6

Freq. [GHz]	Transmission and/or Reflection Loss [%] (LPF1+ LPF2/LPFs)	Tnoise @300K [K]
22	3.30 (Transmission only)	9.90
43	3.74 (Transmission + Reflection)	11.1
86	9.60 (Reflection + Transmission)	28.8
129	5.60 (Reflection only)	16.8



Needed cooling down to cryogenic temperature

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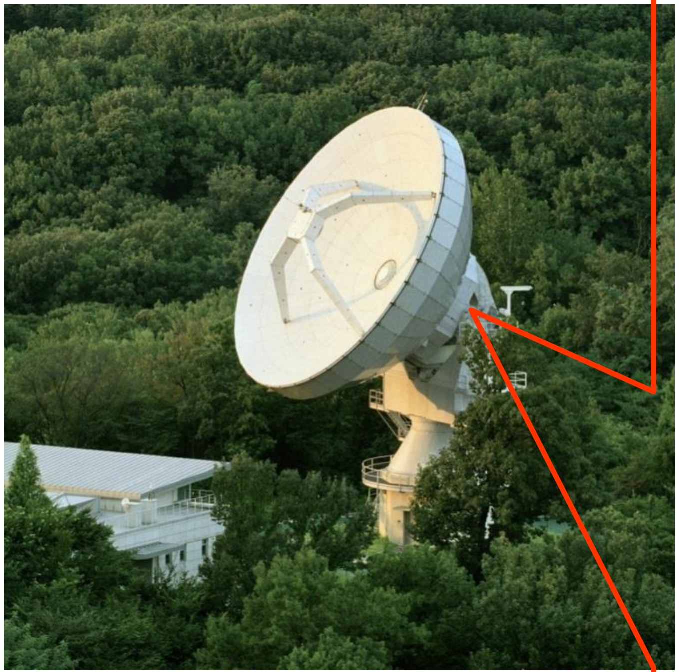
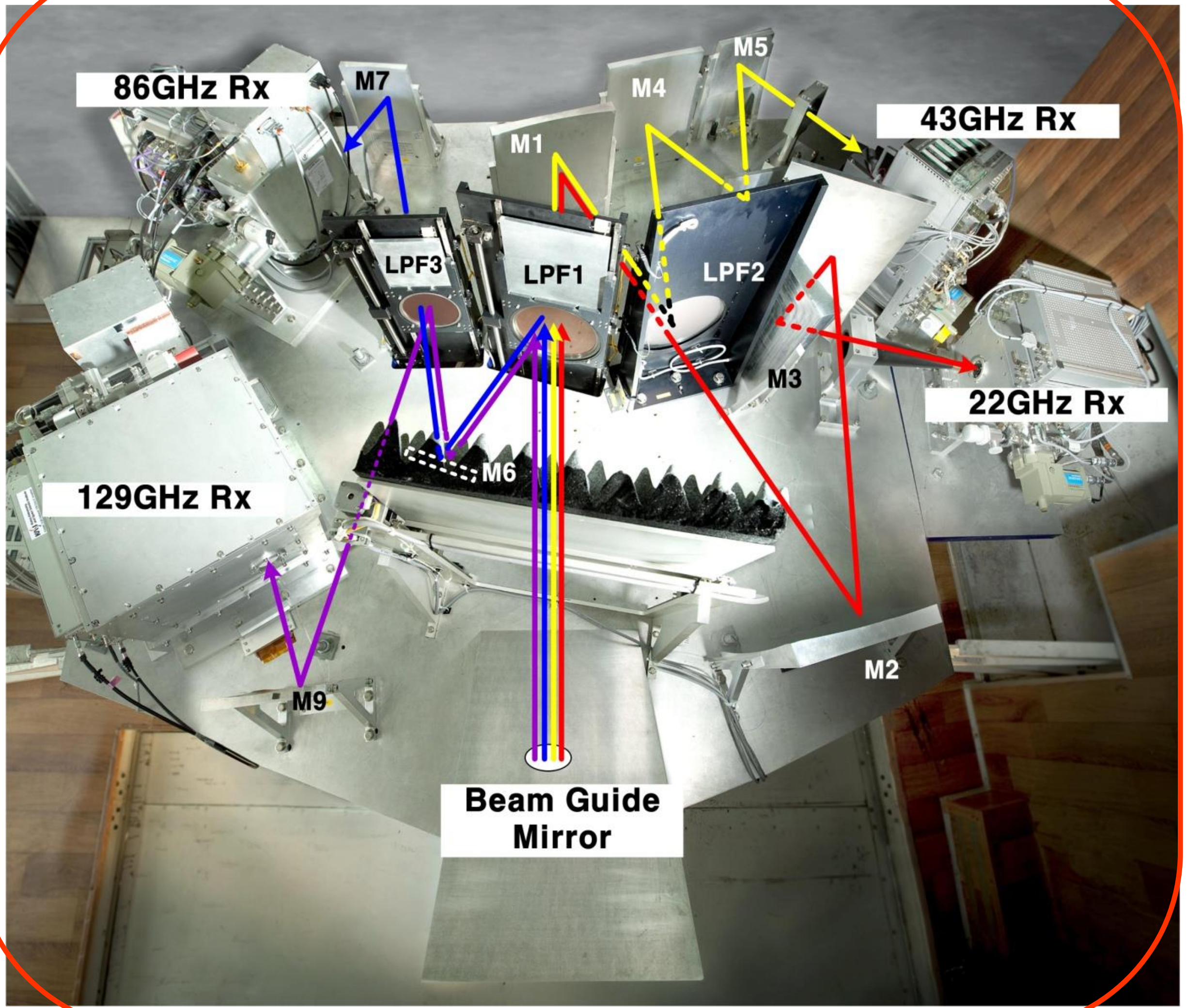
Test Observation Results

Simultaneous observation receiver systems



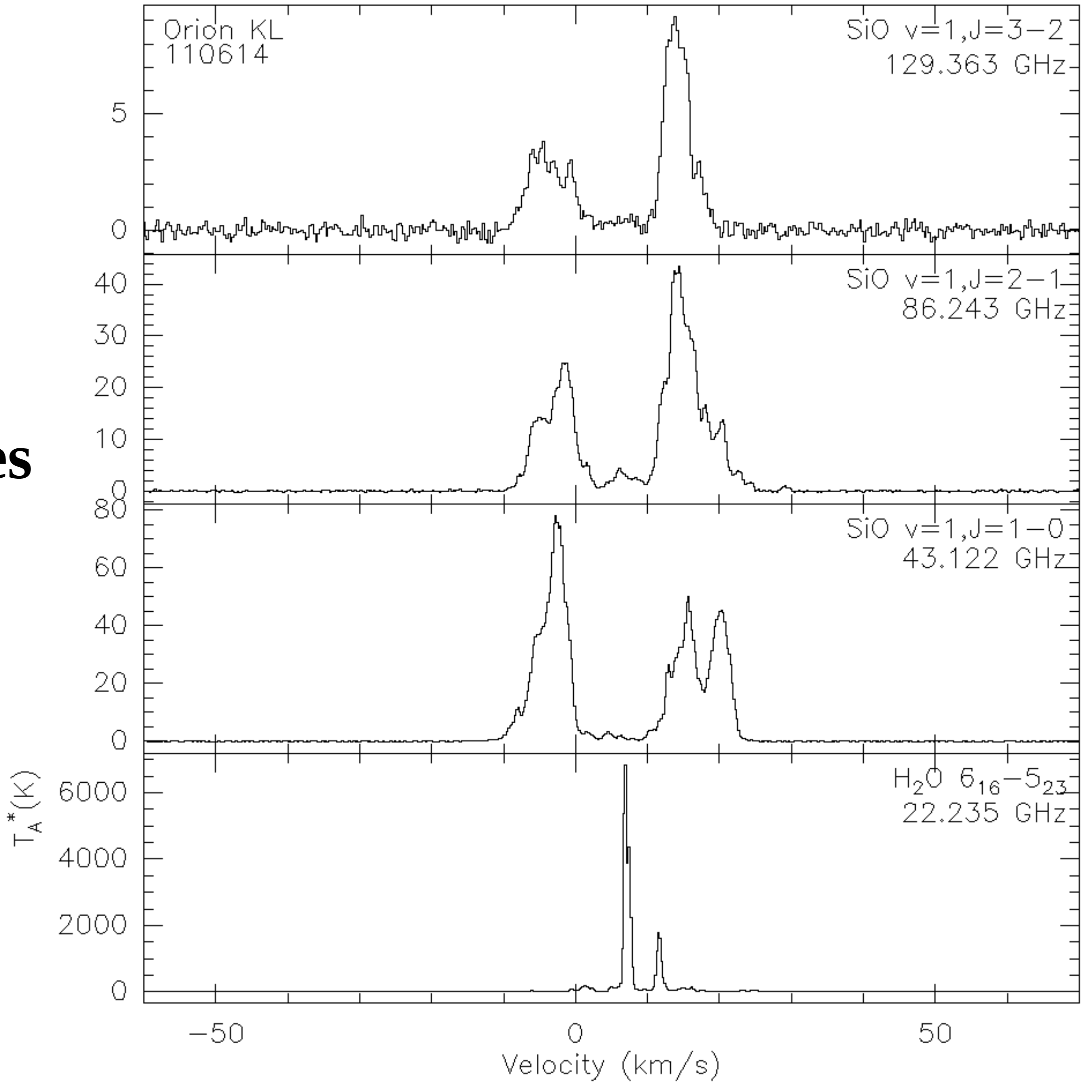


KVN Yonsei Radio Observatory

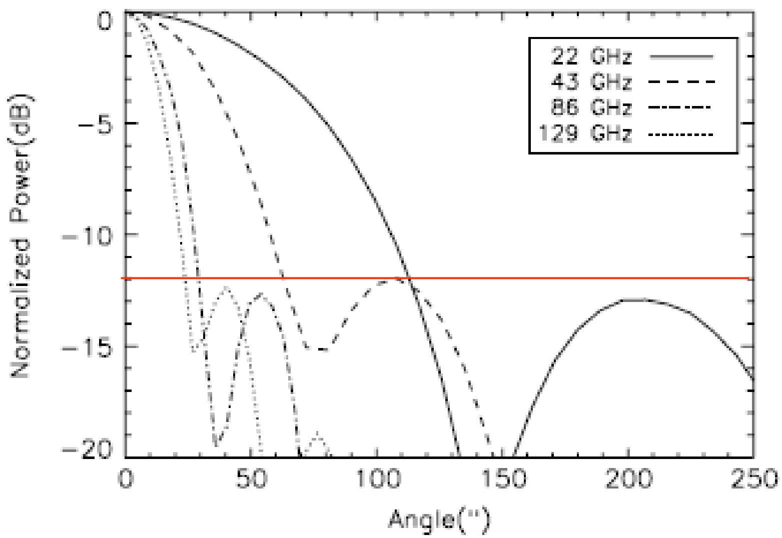
Simultaneous observation results at Orion KL for 22GHz, 43GHz, 86GHz and 129GHz receivers

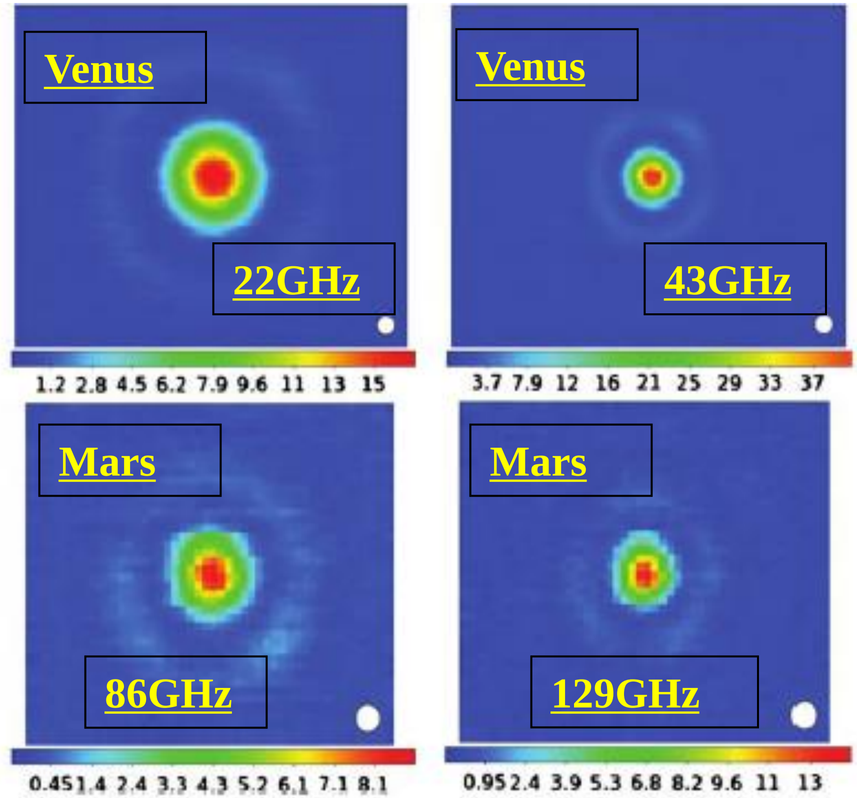
April 2003 ~ May 2011 (8 years)

simultaneous 4 spectral lines



Radiation patterns for 22GHz, 43GHz, 86GHz and 129GHz





Beam sizes and side lobes levels

TABLE 6

BEAM SIZES AND FIRST SIDELOBE LEVELS OF KVN YONSEI TELESCOPE

Frequency (GHz)	Obs. date	Source name	Elevation (degree)	Source size (arcsec)	Beam size (arcsec)	First sidelobe level (dB)
22.235	2012 Apr 27	Venus	70	35.5	125	−12.9
43.122	2012 Apr 27	Venus	70	35.5	63	−12.0
86.243	2012 Mar 12	Mars	42	13.8	33	−12.6
129.363	2012 Mar 12	Mars	42	13.8	23	−12.6

- **The measured beam sizes at 22GHz, 43GHz, and 129GHz are 5-8% are smaller than those of theoretical ones.**
- **The first side-lobe levels of about 12 -13dB due to shaped reflector both sub- and main reflectors**

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➢ Beam offsets among four bands and aperture efficiencies

TABLE 5

BEAM ALIGNMENTS OF THE 22/43/129 GHz BANDS

	22 GHz		43 GHz		129 GHz	
	Offset (Az) (arcsec)	Offset (El) (arcsec)	Offset (Az) (arcsec)	Offset (El) (arcsec)	Offset (Az) (arcsec)	Offset (El) (arcsec)
Before	>5	>5	>5	>5	>5	>5
After	−3.1 ± 0.7	+3.1 ± 0.7	+1.7 ± 0.1	+2.0 ± 0.3	+0.8 ± 0.4	−0.9 ± 0.5

NOTE.—With respect to the center of the 86 GHz beam on the KVN Yonsei telescope.

- ➢ **Pointing accuracy ~ 1/10 of HPBW (30arcsec at 130GHz)**
- ➢ **Can do simultaneous observation with four bands!!!!!**

➢ Aperture efficiencies

TABLE 7

APERTURE EFFICIENCIES OF KVN YONSEI TELESCOPE

Frequency (GHz)	Obs. date	Source name	Elevation (deg)	Source size (arcsec)	Brightness temperature (K)	Aperture efficiency (%)
22.235	2012 Oct 25	Jupiter	30–60	46.1	134 ± 4 (P03)	65 ± 1
43.122	2012 Oct 25	Jupiter	30–60	46.1	150 ± 15 (G94)	62 ± 2
86.243	2012 Oct 25	Venus	30–60	13.7	357.5 ± 13 (U80)	57 ± 2
129.363	2012 Oct 25	Venus	30–60	13.7	331 (F92)	38 ± 3

NOTE. —Errors of aperture efficiencies are 1σ, not including systematic errors arising from uncertainties in the brightness temperatures.
References.—(F92) Fahd 1992; (G94) Greve et al. 1994; (P03) Page et al. 2003; (U80) Ulich et al. 1980.

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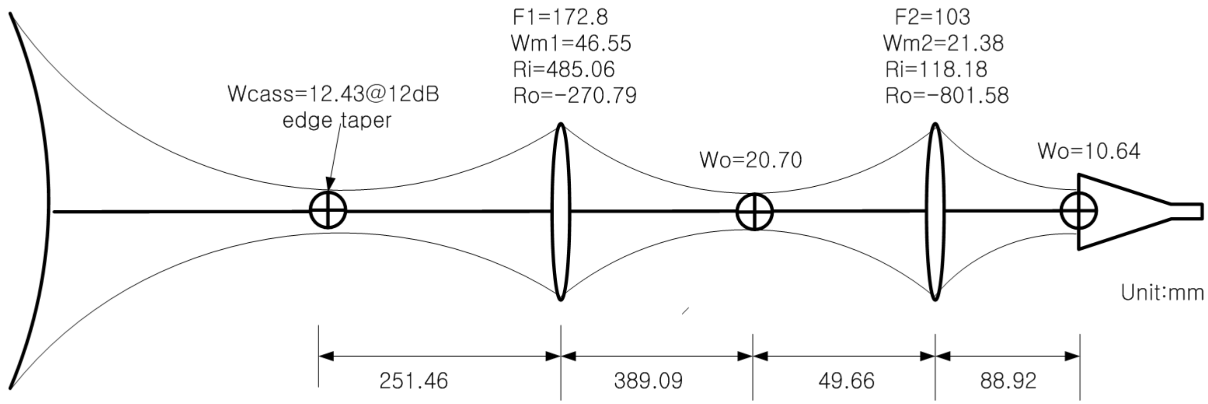
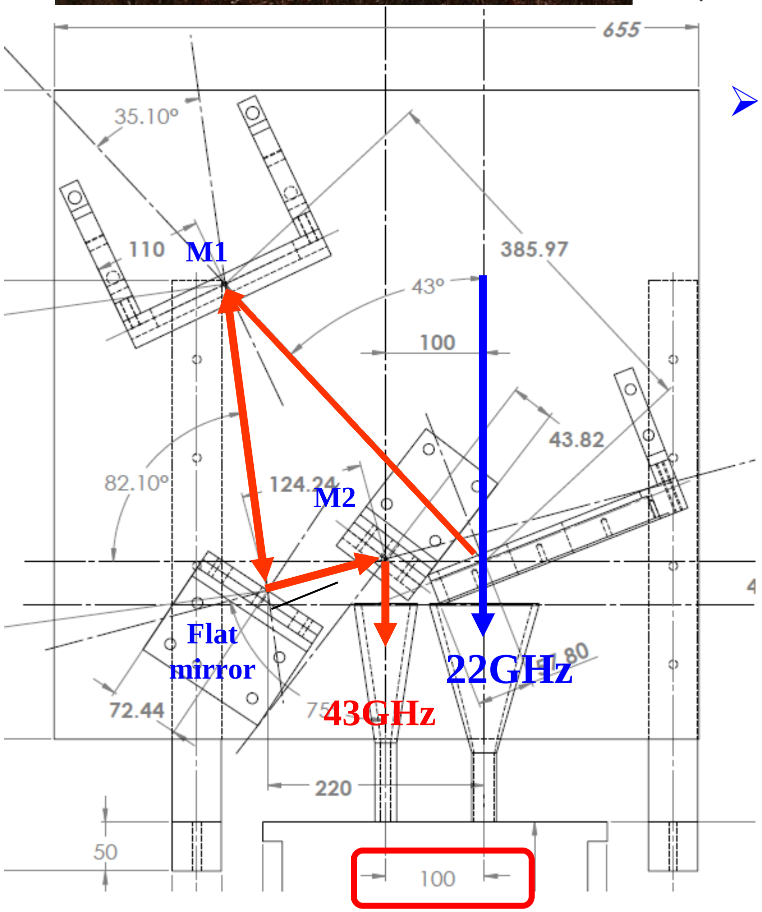
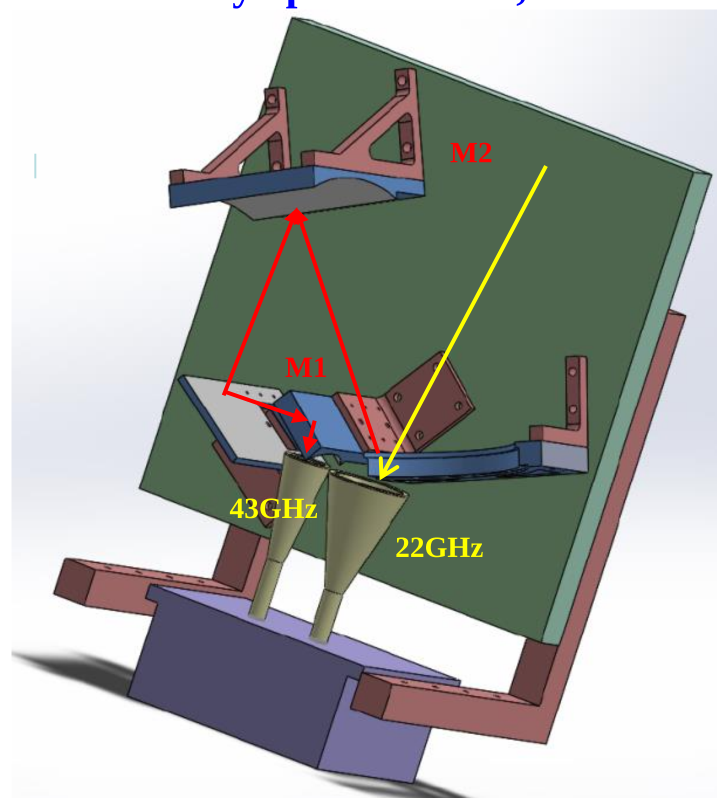
Global collaborations for optics design

Beam parameters of VERA: 22/43GHz simultaneous observation optical circuit



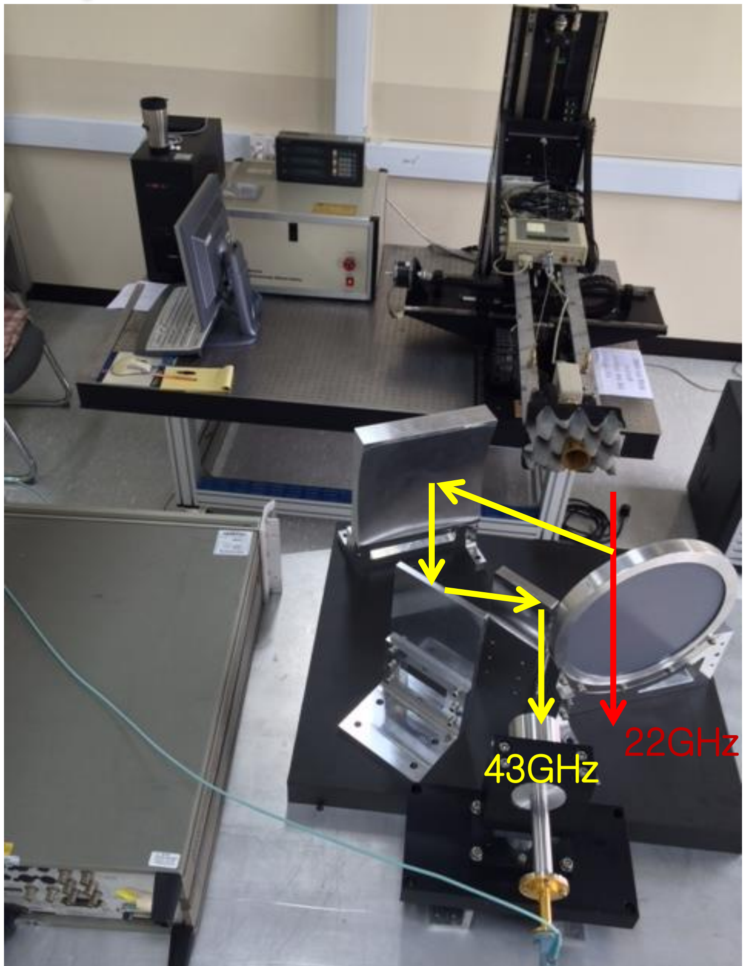


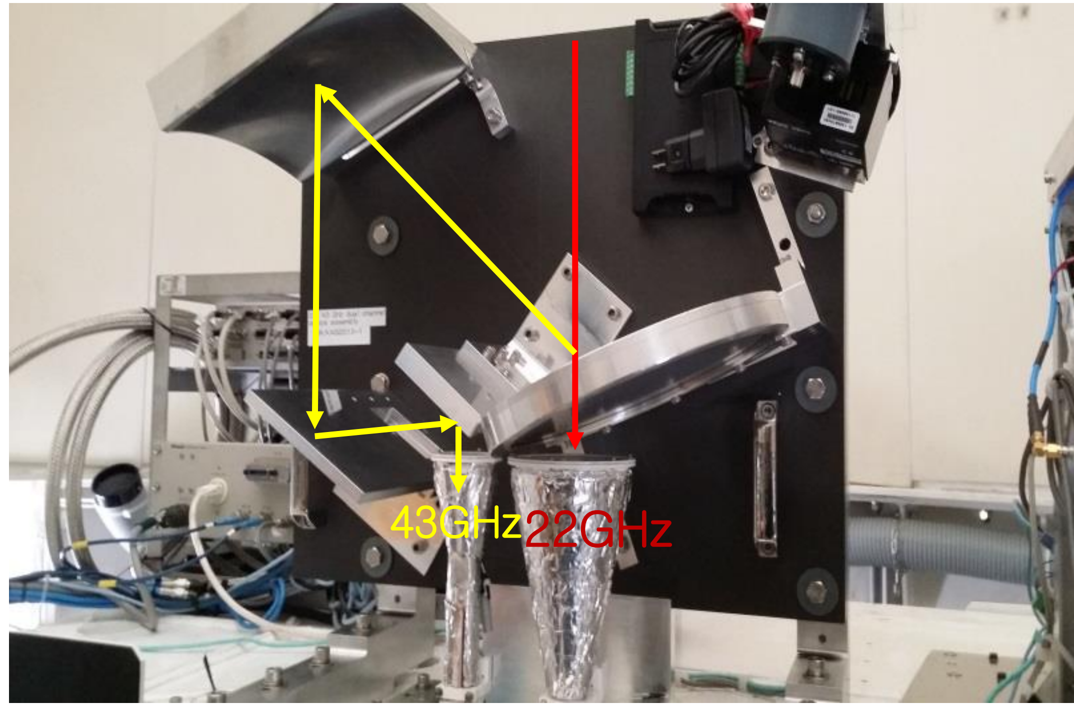
- Designed and installed only optical circuit, Not receivers



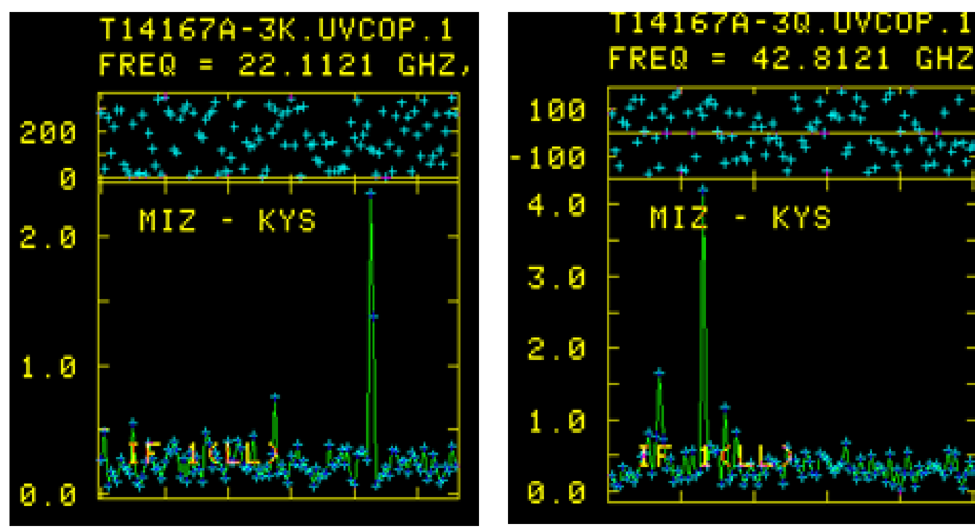
Quasi-Optics for VERA Mizusawa site

Optical circuit test as KASI' Lab, Korea



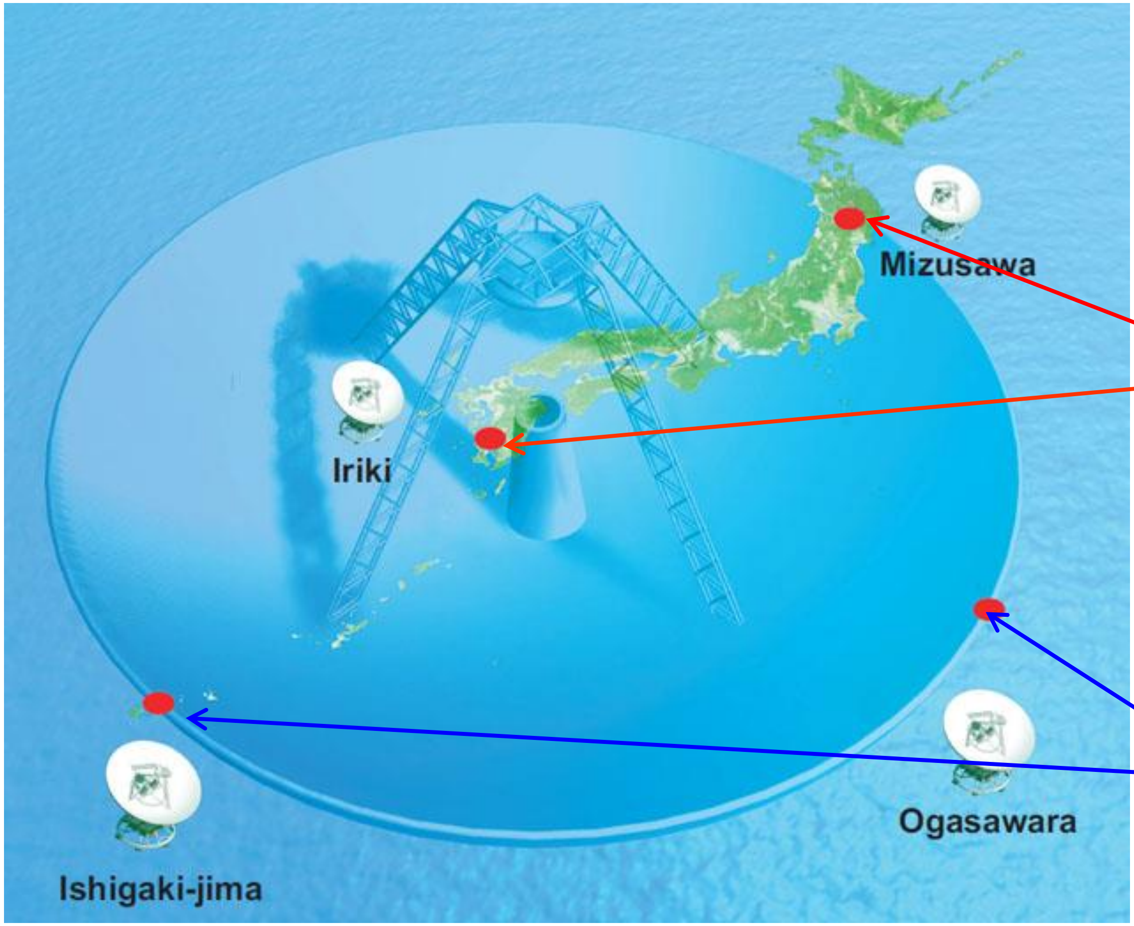


Installed on Mizusawa observatory of VERA



H_20/SiO Simultaneous fringes of ORION-KL

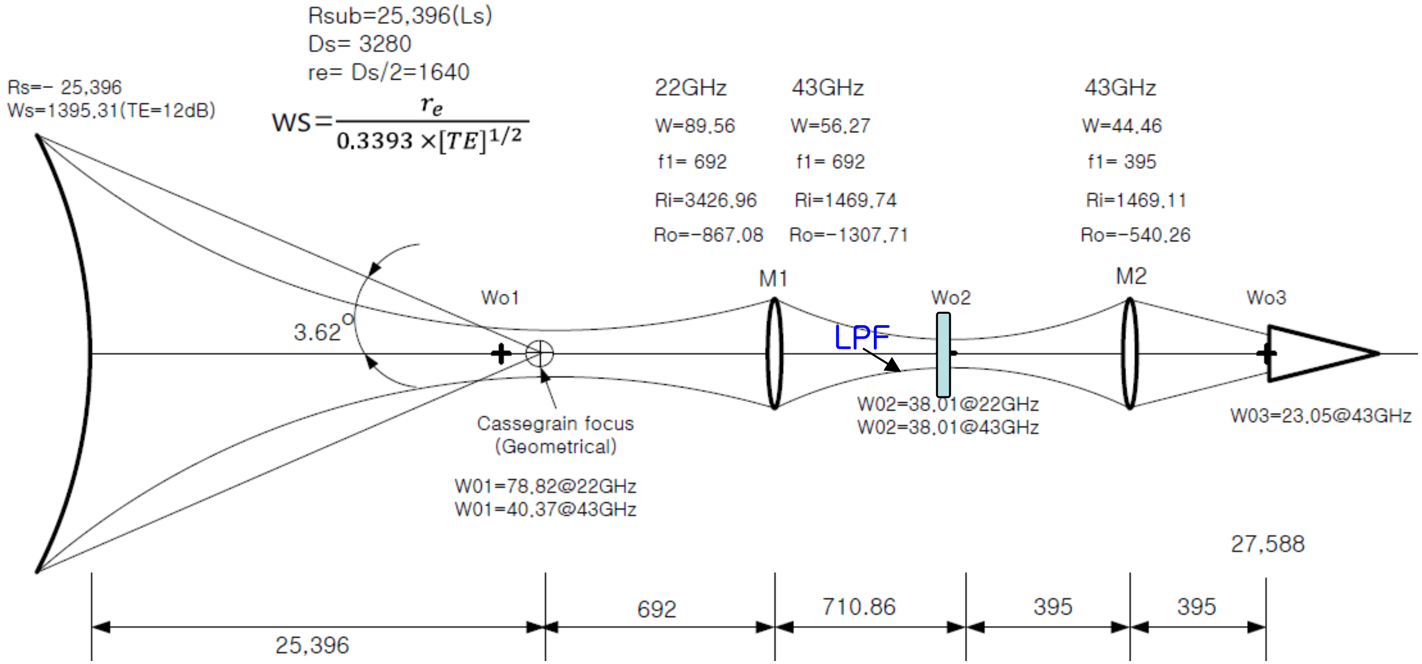
Quasi-optical circuit of K/Q-band simultaneous observation for VERA, Japan



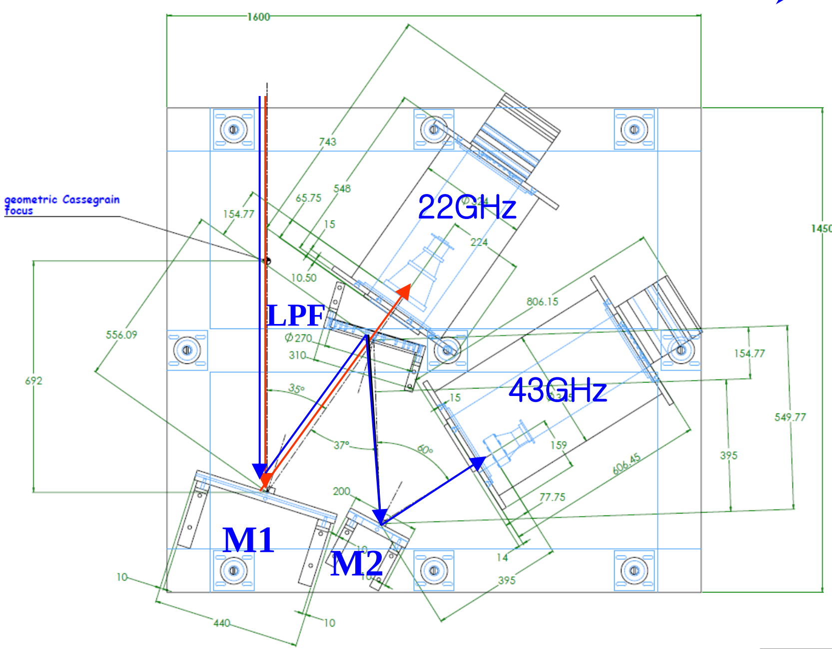
Installed
October 2015
* Under the installing just now

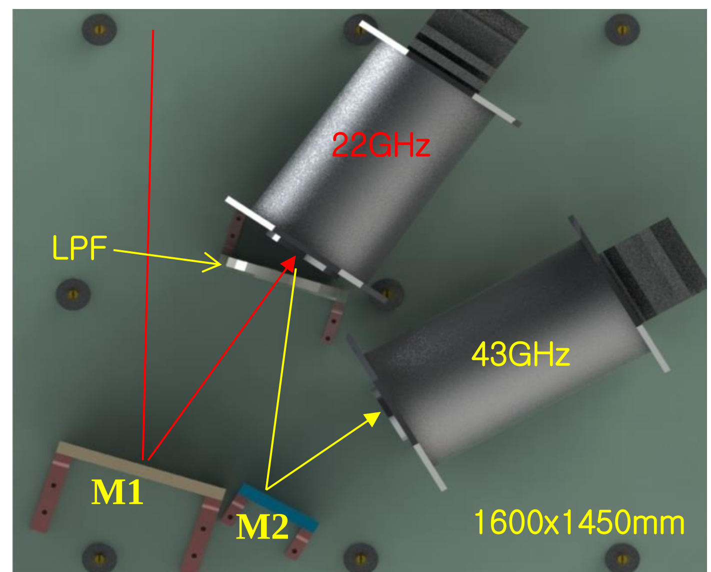
Will be Installed
2016

Optical circuit and its beam parameters for Yebes 40m radio telescope

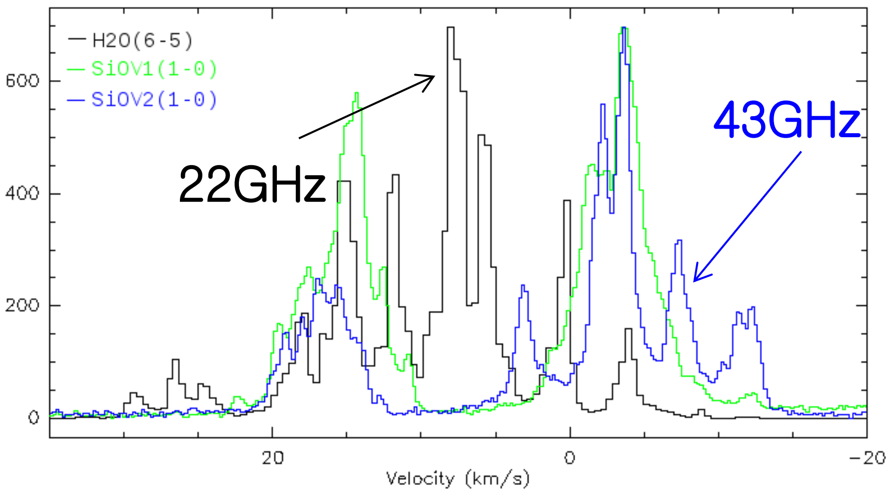


➢ **Designed and installed only optical circuit, Not receivers**

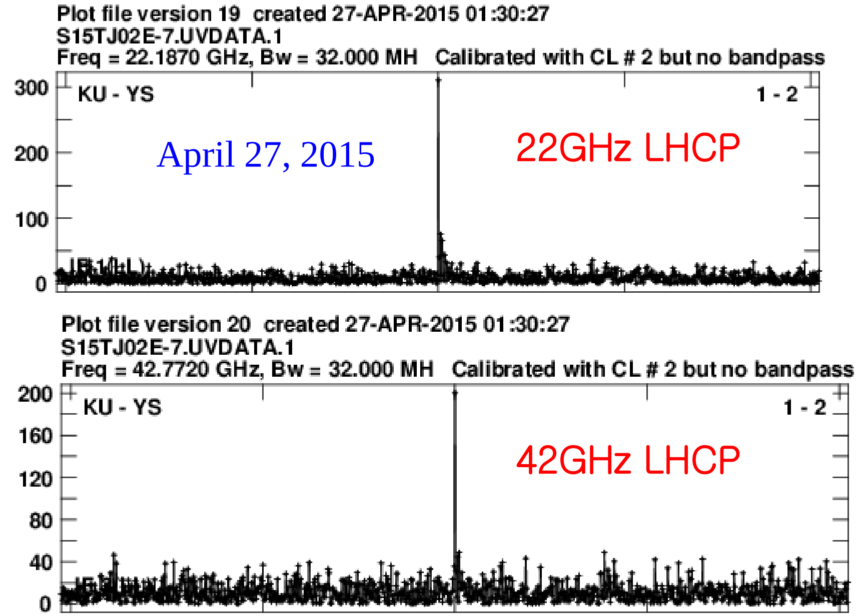


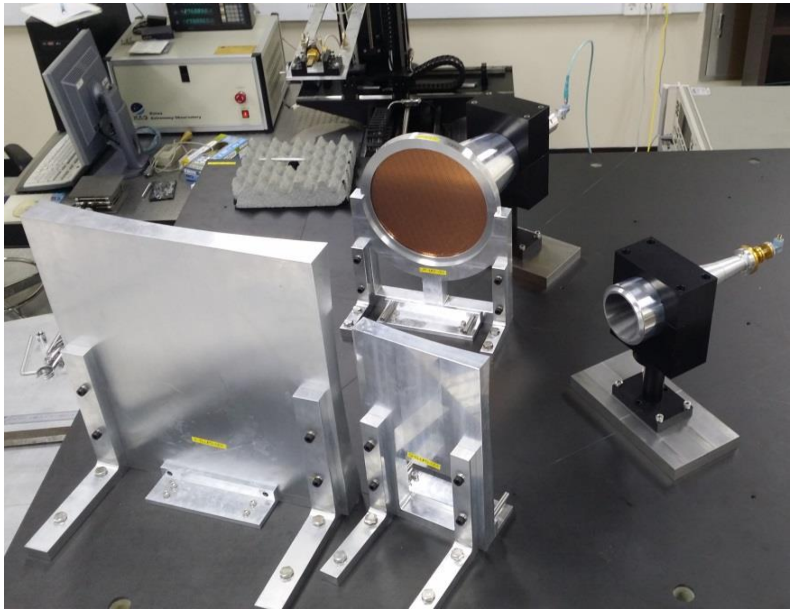


Quasi-Optics for Yebes 40m Radio Telescope, Spain

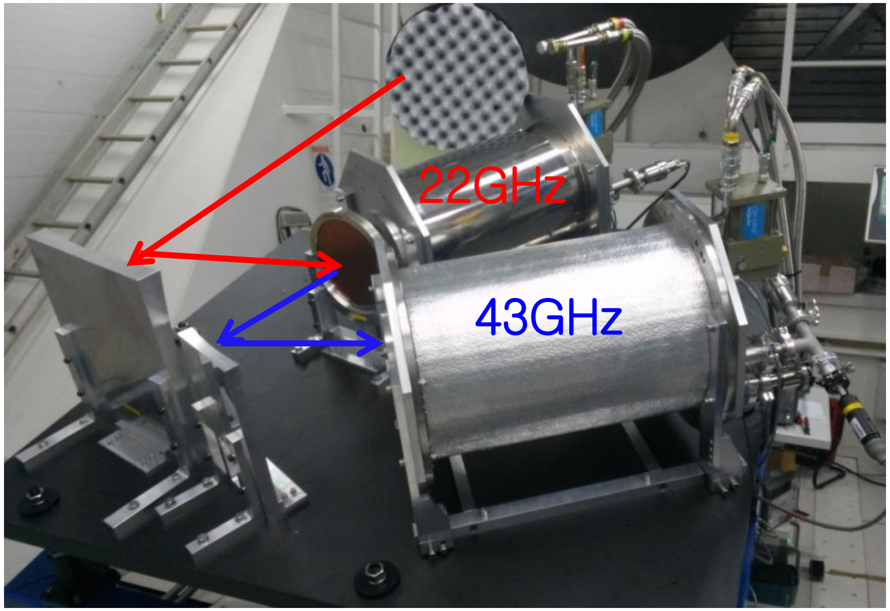


Simultaneous observation at Orion-KL Jan.12/2015



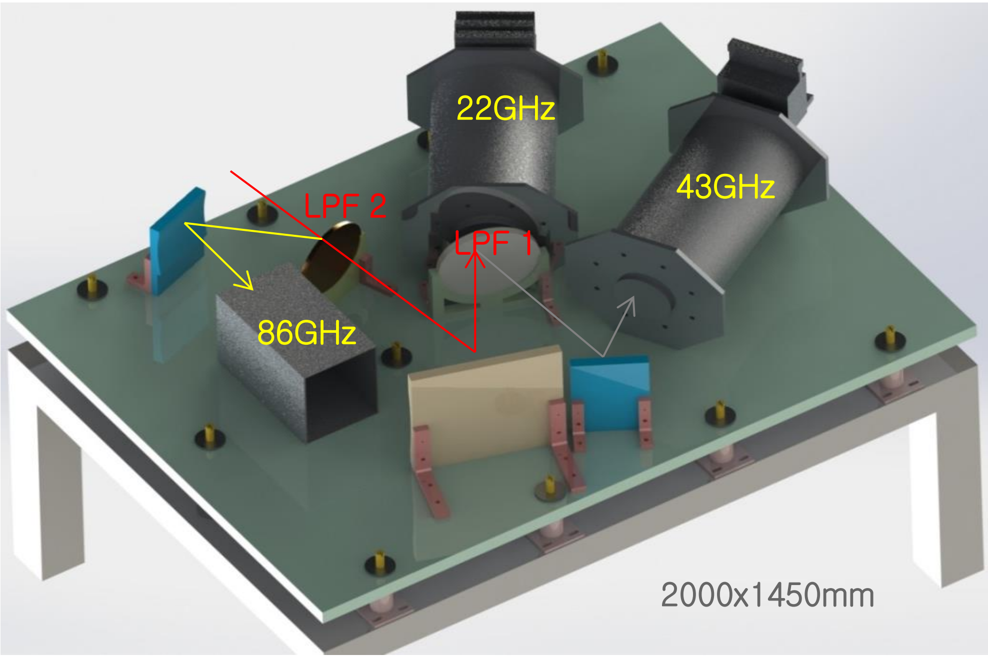


Optical circuit test at KASI's Lab,, Korea.

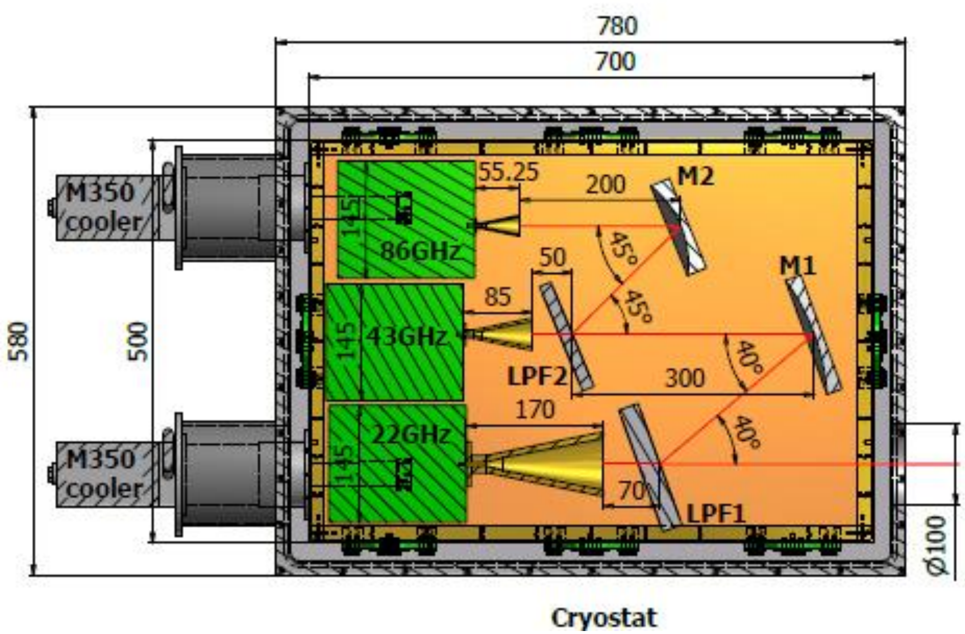


Installed on Receiver cabin of Yebes antenna

Nobeyama 45m radio telescope, Japan



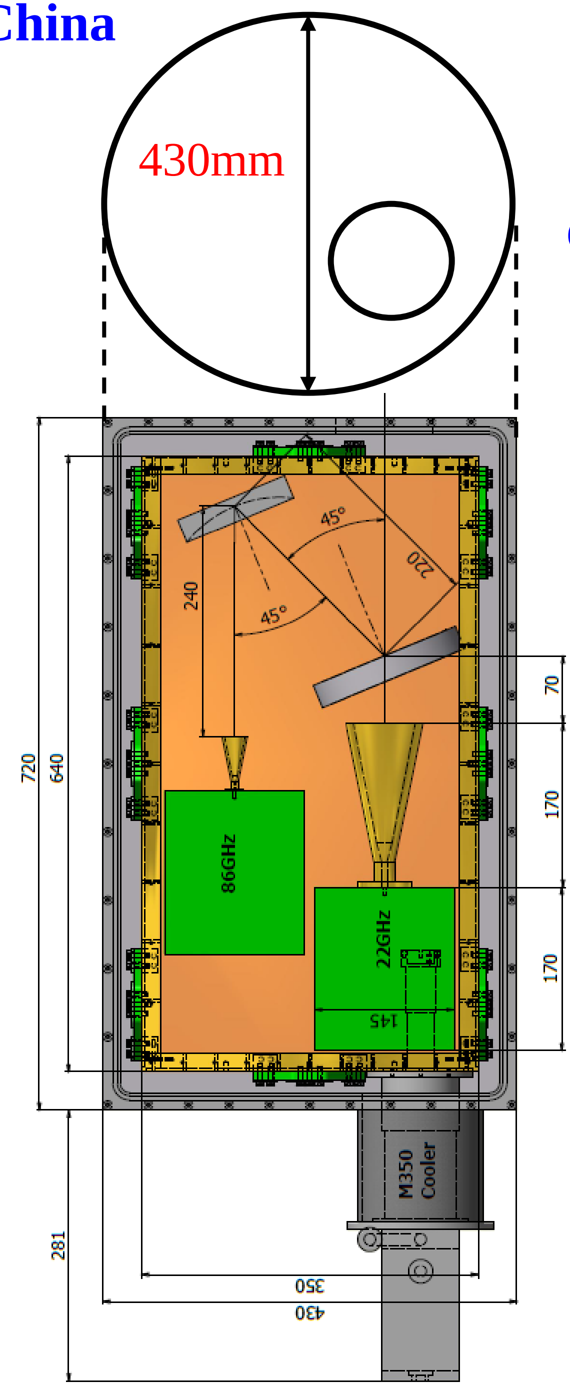
➡ Optical circuit only will be designed like Yebes observatory did.

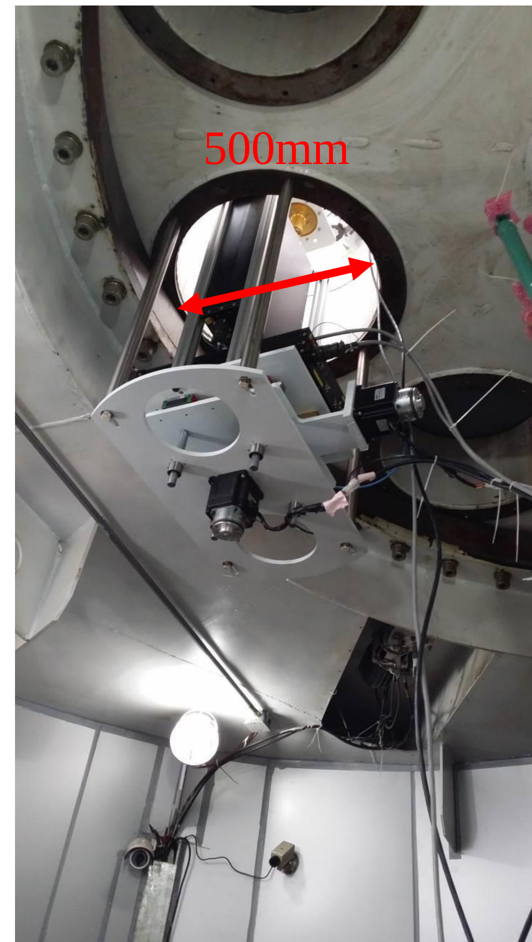


➡ Both Optical circuit and receivers will be designed

- Considering both ways.
- Be powerful tools 86GHz VLBI with KVN + Nobeyama 45m antenna

Shanghai 65m radio telescope, China





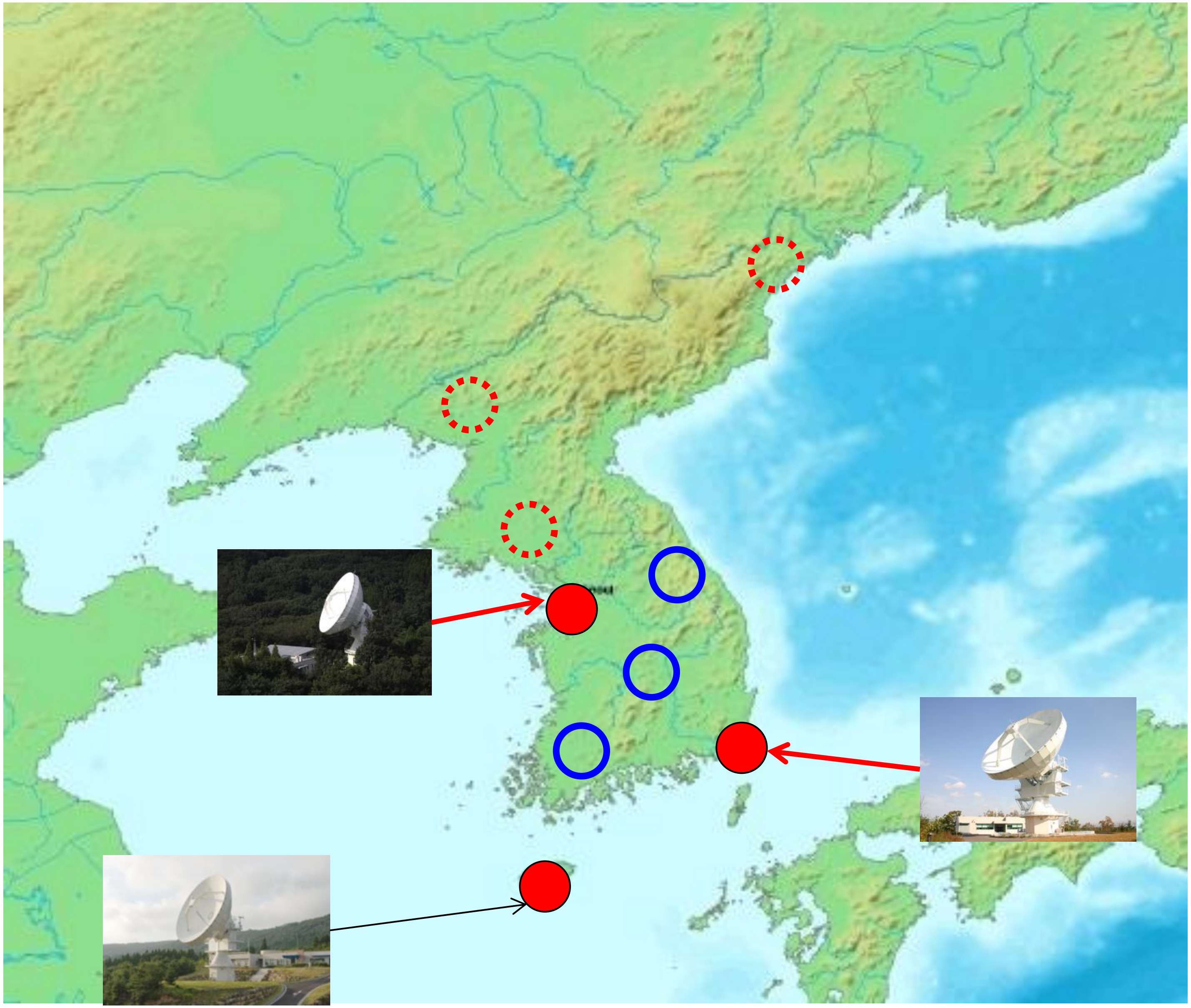
- Quasi-optical circuit and 22/43GHz Receivers

9. Summary

My dream

3 more 21m radio telescope for E-KVN

Dream comes true !!!!!



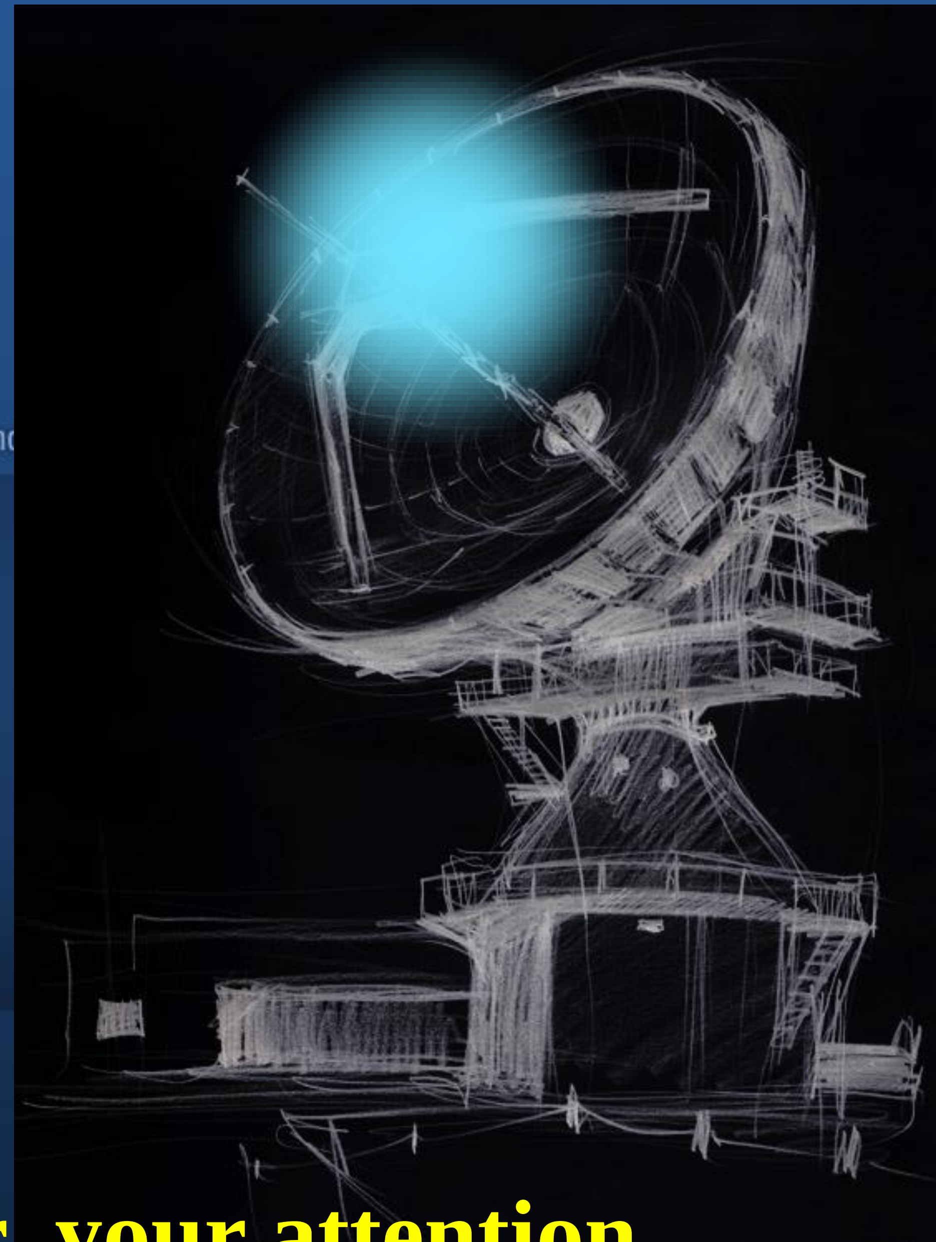
Summary

- **Beam alignment among several channels**
  - Has to be aligned at least 1/10 of HPBW of antenna

- **Losses at quasi-optical circuit**
  - Mainly due to LPFs0.1 ~ 0.2dB
  - Cooled down to 20K to improve receiver noise temperature

- **Incident angle of LPF**
  - less than 20 degree
  - To avoid cross-pol. and reflection and transmission losses

- **Required more compact system design**
  - compact, reduce receiver noise temperature
  - Introduce to compact cryogenic optical circuit, next my talk in this afternoon



Thanks for your attention