Korean Facilities and Instrumentation for Radio Astronomy

Jung-Won Lee, Jongsoo Kim, Jan Wagner (ALMA group)
Radio Technology group, TRAO, KVN group (KASI) & SRAO

EAO/JCMT instrument panel meeting, 8, Mar., ASIAA

TRAO

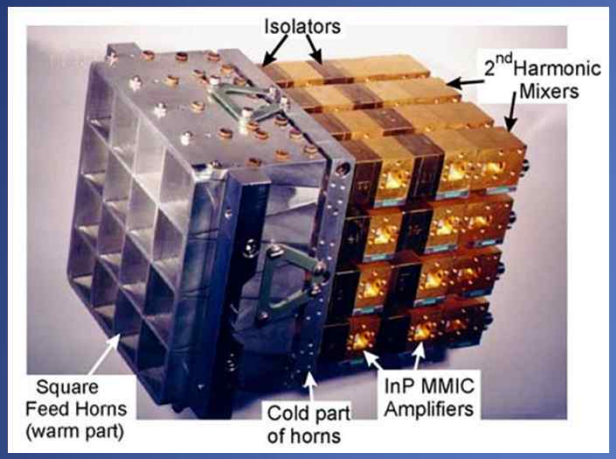
(Taeduk Radio astronomy Observatory)

Site Information	East Longitude	127 22 18.77
	North Latitude	36 23 53.17
	Elevation	109 meters
Telescope	Primary Reflector Diameter	13.716 meters
	Focal Ratio (f/D)	
	Prime Focus	0.3704
	Cassegrain Focus	4.074
	Surface Accuracy	180 μm rma
	Mount	Elevation over Azimuth
	Pointing Accuracy	< 10" rms
	Enclosure (Radome)	ESSCO LAM VI

5% loss@115GHz

- established in 1986, with cryogenic Schottky mixer
- 1990: 100/150 GHz SIS mixer receiver
- large MC survey with 15 beam array receiver since 2009; upgraded in 2015

upgraded TRAO 16 beam array



Sequoia-TRAO frontend

SEQUOIA-TRAO	4X4 arrays
Frequency range	85 - 115.6 GHz
FFT Spectrometer	125 MHz with 8192 channels

- Subreflector upgrade
- Servo upgrade
- Control computer upgrade

- Granted key science programs

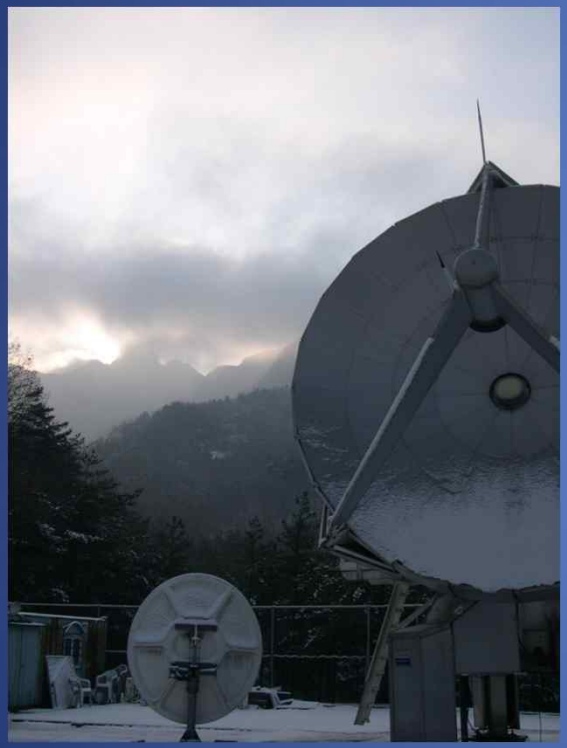
  - C. W. Lee (TRAO Multi-beam Legacy Survey of Nearby Filamentary Molecular Clouds)

  - J. E. Lee (Mapping Turbulent Properties of Star-forming Molecular Clouds down to the Sonic Scale)

  - T. Liu (TRAO Observations of Planck cold clumps (TOP))

SRAO

(Seoul Radio astronomy Observatory)

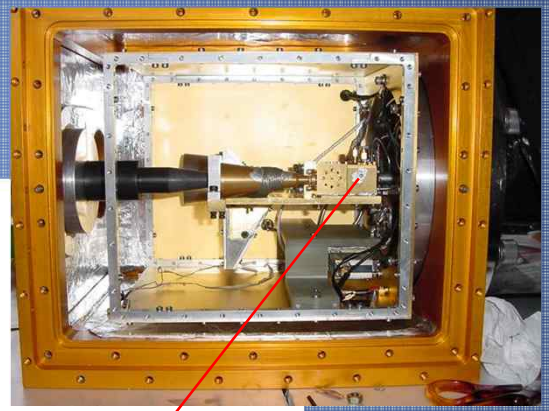


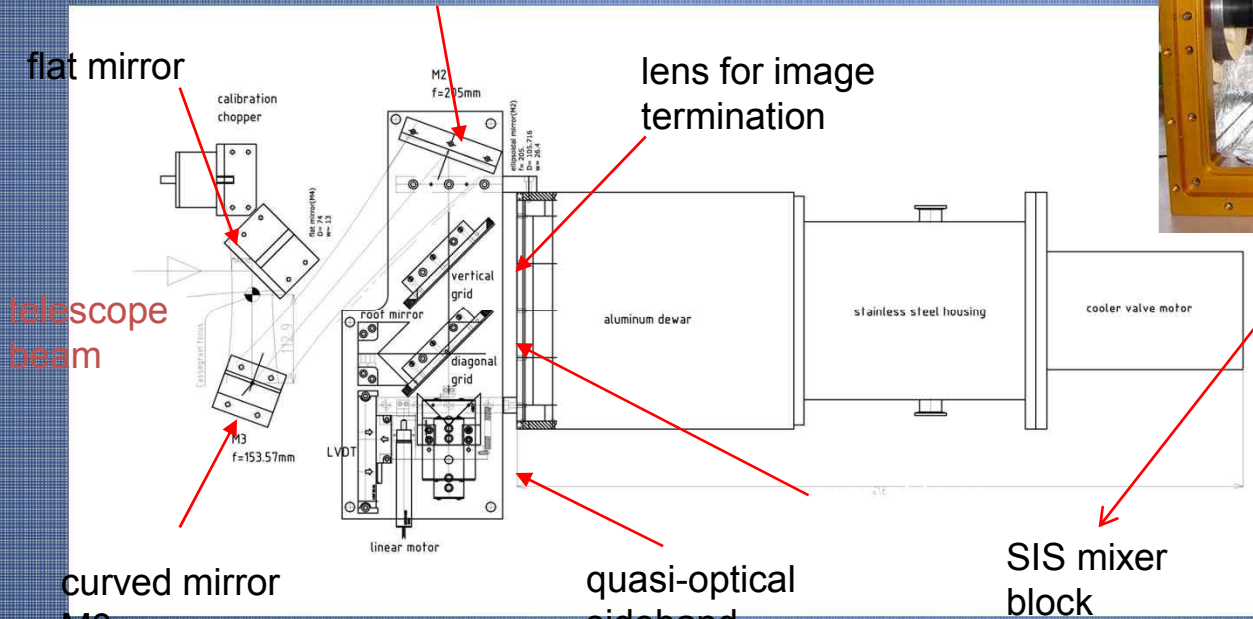
Dec. 2007

- **1 million USD project initiated by SNU astronomy dept. from 1996**
  plus additional collaboration fund granted from KASI
- **SRAO 6m telescope(2001-)**
  rugged structure suited for *mm-wave observation*
  replica antenna of BIMA array
  surface accuracy, drive system : up to 300 GHz
  200m elevation from sea level

SRAO 3mm Receiver(2000)

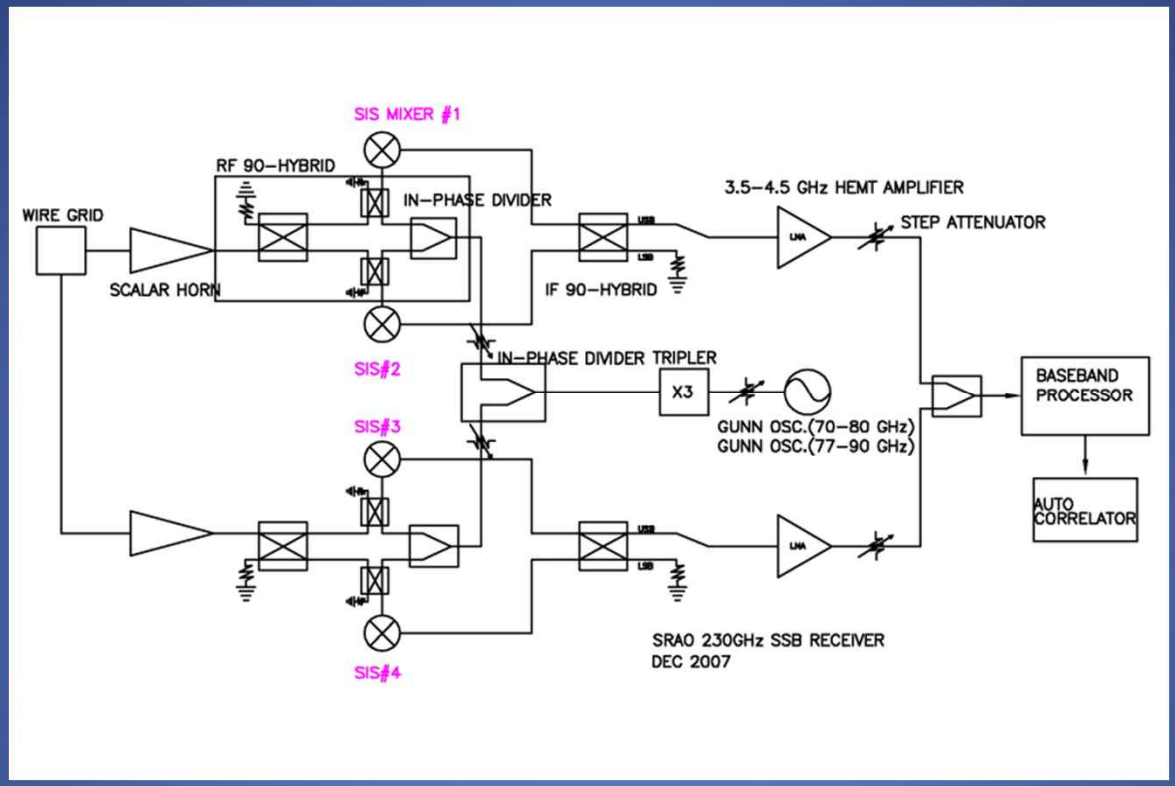
- RF frequency: 85-115 GHz
- DSB noise: 50 K
- 2002-2006





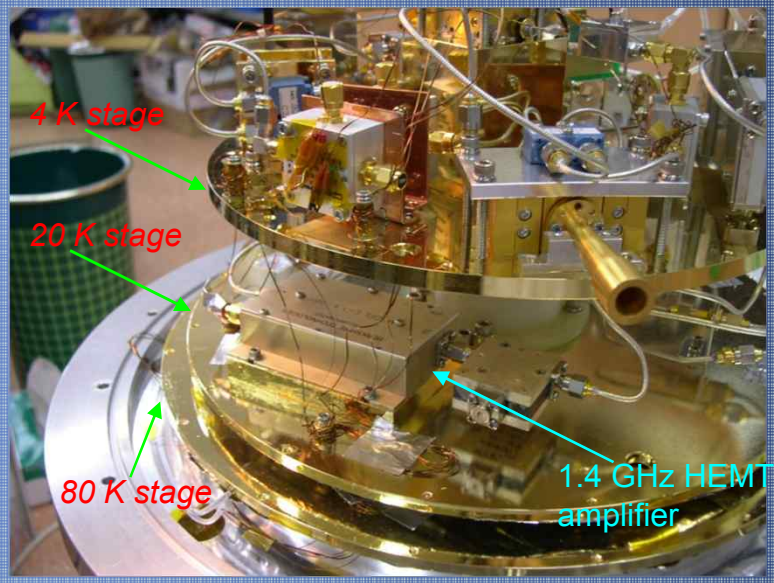
SRAO(SNU) 6m telescope

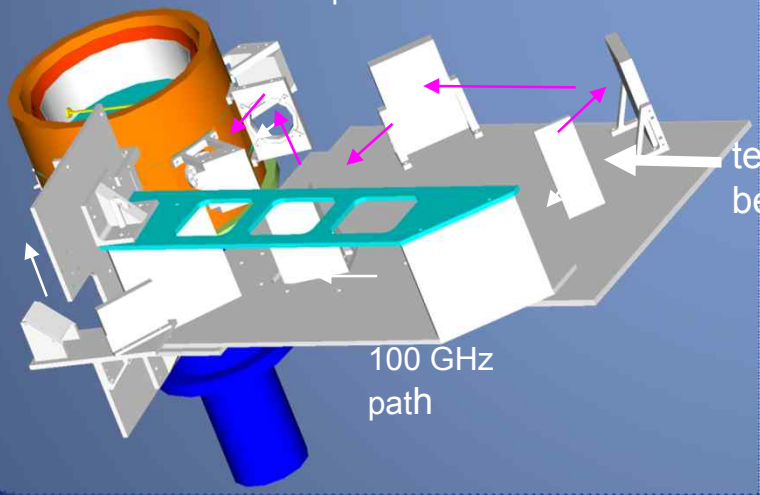
230 GHz Frontend Overview



- A ***wire grid*** adopted for polarization separation
- ***2 mixer chips*** biased separately works for one polarization.
- ***LO signal*** generated from a *WR-4 tripler* is split for each pol. and further divided, coupled to each mixer chip. Separate attenuators adjust LO power to each polarization.
- ***USB IF output*** is amplified by a cryogenic LNA, **with LSB terminated** at each pol. (cf. sideband separation vs. sideband rejection)

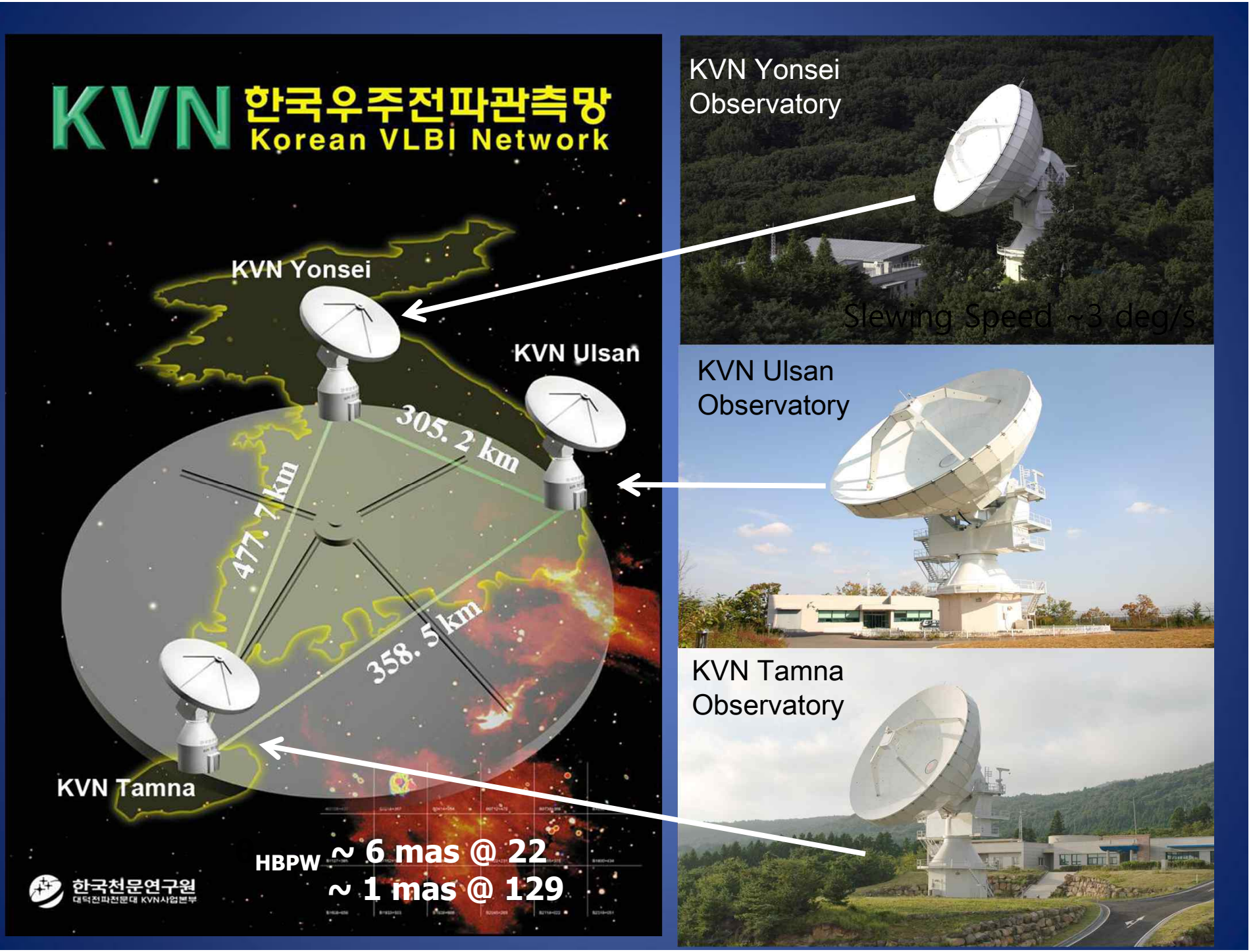
SRAO 230 GHz Receiver(2008)





- RF frequency: 210-265 GHz
- Avg. SSB noise: 80 K (Tsys~150 K best in winter)
- waveguide sideband rejection
- Dual polarization by wire grid
- Facility receiver: 2008-

- 1GHz BW FFT spectrometer (Agilent) 8 bit 2Gs/s, 61 kHz spec. resolution


KVN 한국우주전파관측망
Korean VLBI Network
KVN Yonsei
KVN Ulsan
KVN Tamna
305. 2 km
477. 7 km
358. 5 km
HBPW ~ 6 mas @ 22
~ 1 mas @ 129
한국천문연구원
대덕전파천문대 KVN사업본부
KVN Yonsei Observatory
Slewing Speed ~3 deg/s
KVN Ulsan Observatory
KVN Tamna Observatory

KVN antenna

- D = 21m
- Shaped Cassegrain
- Main reflector
  - 200 panels
  - Four adjusters in each panel
  - Measured and aligned with photogrametry (at EL = 48deg)
- Sub-reflector
  - Controlled by Hexapod to compensate gravitational deformation
  - X,Y,Z,Tip,Tilt

KVN Frontends

Band width = 256MHz

Band	Frequency (GHz)	Tsys (K)	Aeff [Gain] (%) (Jy/K)	SEFD (Jy)	t_int (sec)	ΔS (5σ) (mJy/beam)
K	21.25-23.25	100	60 [0.078]	~1300	120	60
Q	42.11-44.11	150	60 [0.078]	~1900	60	110
W	85-95	200	50 [0.062]	~3200	30	270
D	125-142	250	35 [0.043]	~6000	20	570

- Recording System (Mark6) : 4 x 512MHz

Phase Referencing for Tropospheric Compensation

Middelberg et al. 2005
Rioja&Dodson 2008,2011

"fast-frequency switching"
@ 22/43 GHz

< 5 deg.

Bright Reference Source

Weak Target Source

Target Source
Target Source

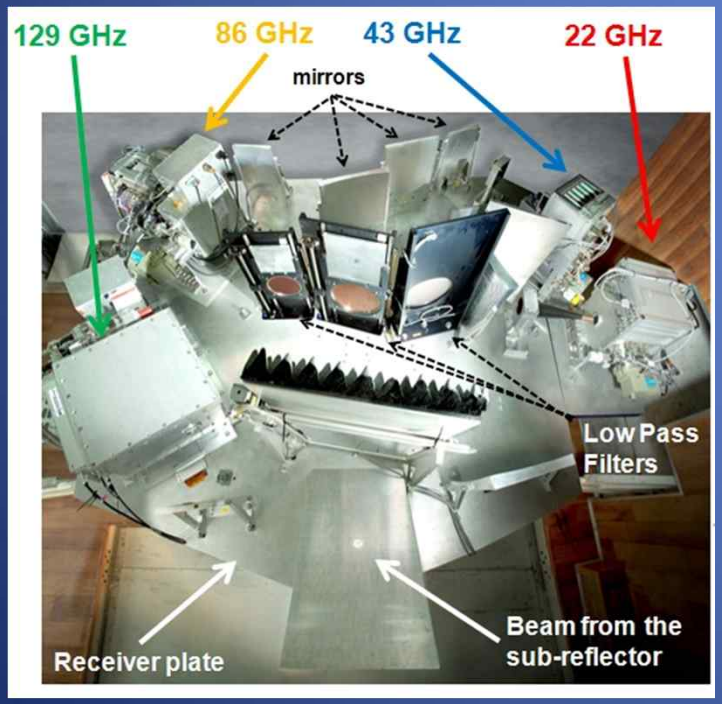
Weak Source & Astrometry

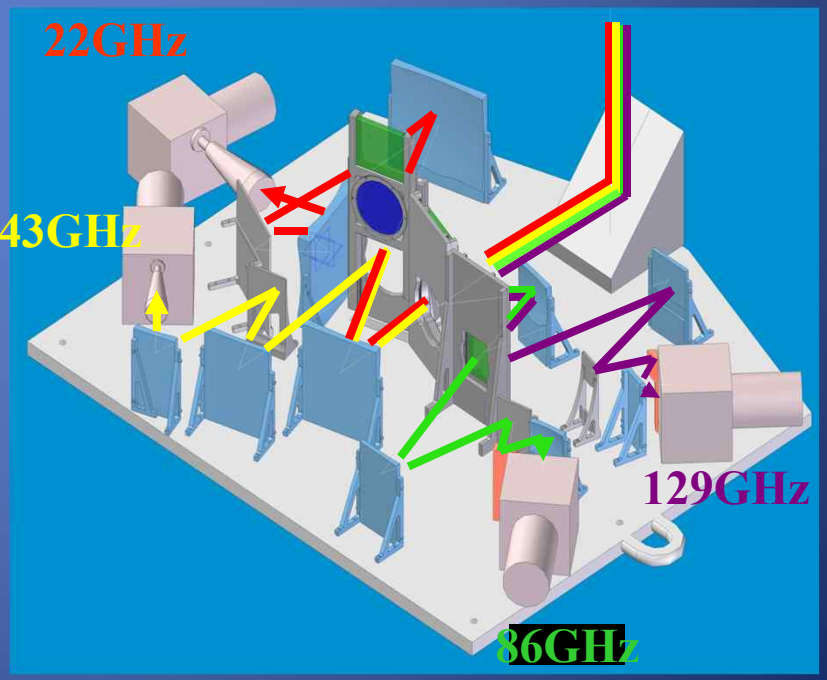
Credit by Rioja

Weak Source

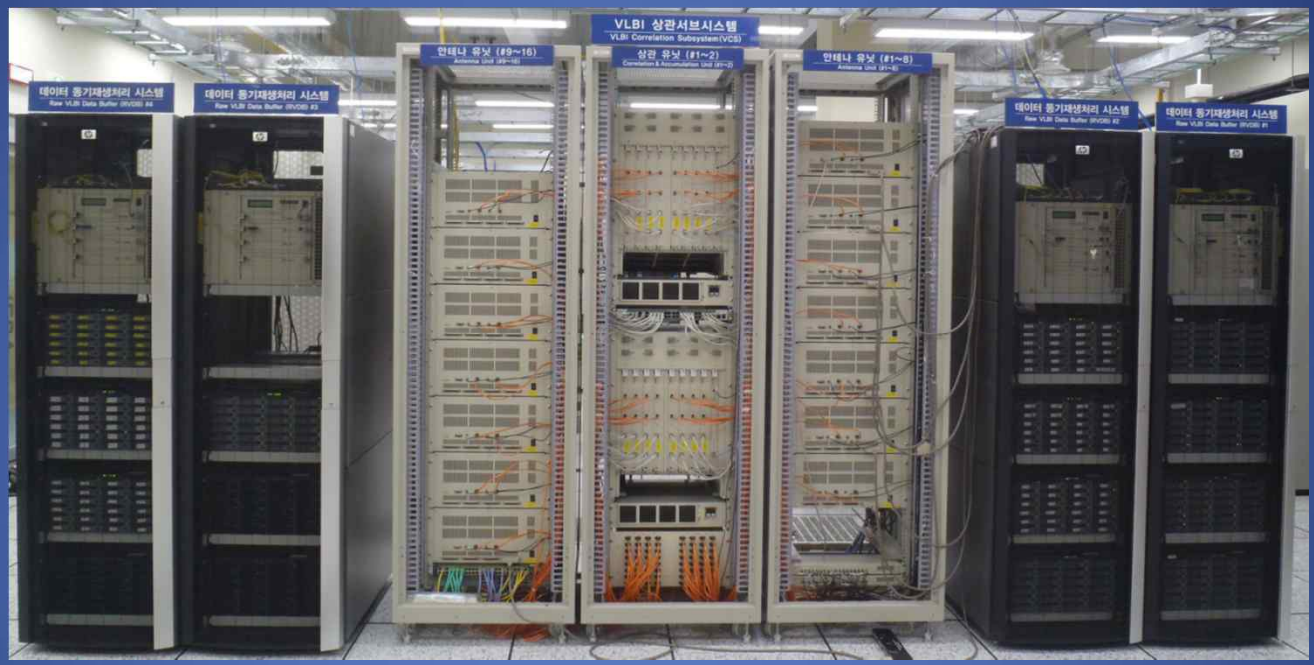
Multi-Frequency Receiving System

- simultaneous Multi-frequency Observation
  - @ 22/43/86/129GHz
- dual Pol : LCP & RCP
  - simultaneous 2 freq bands w/ full stokes
- digital Backend : 256MHz BW (4 x 64MHz) , (4 x 512MHz in 2015)



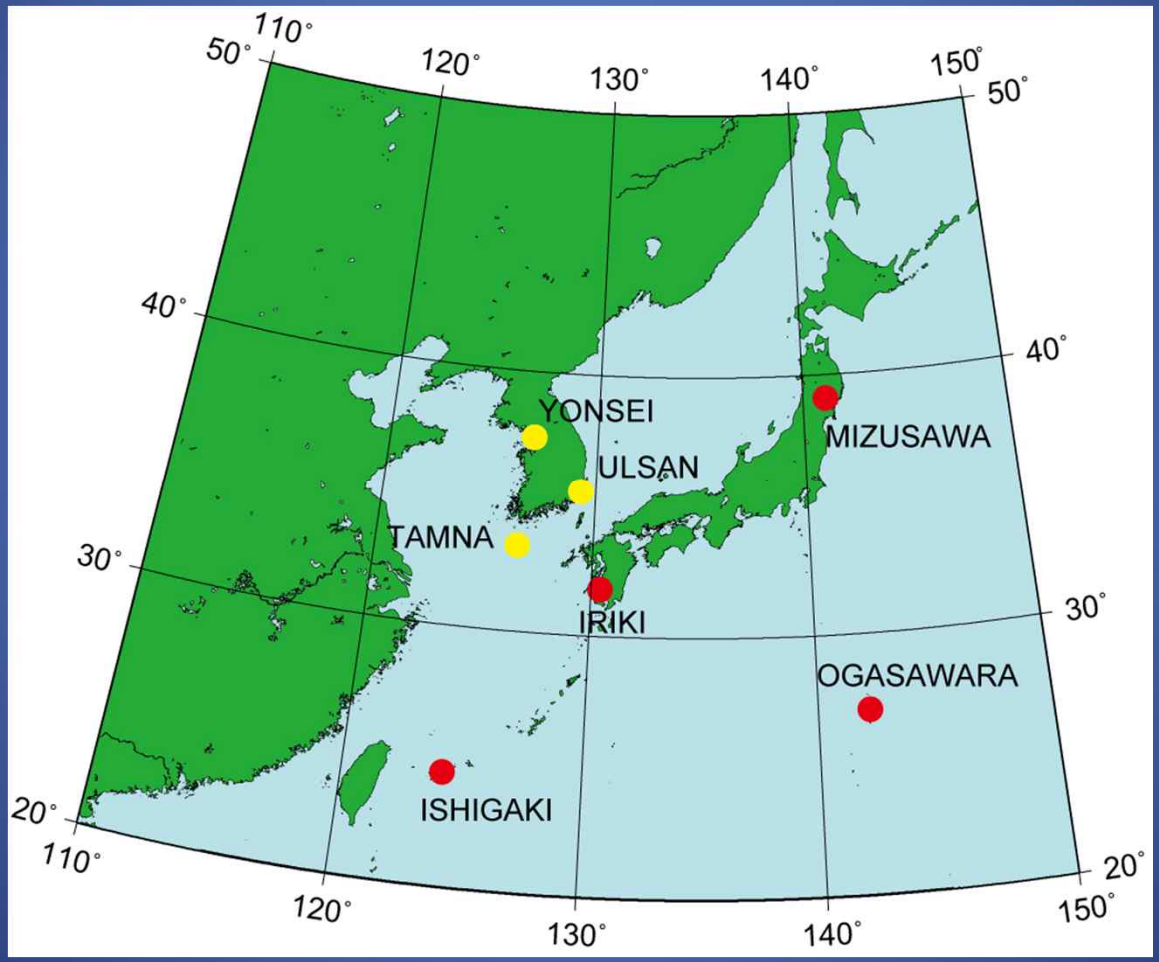


Korea-Japan Correlation Center (KJCC)

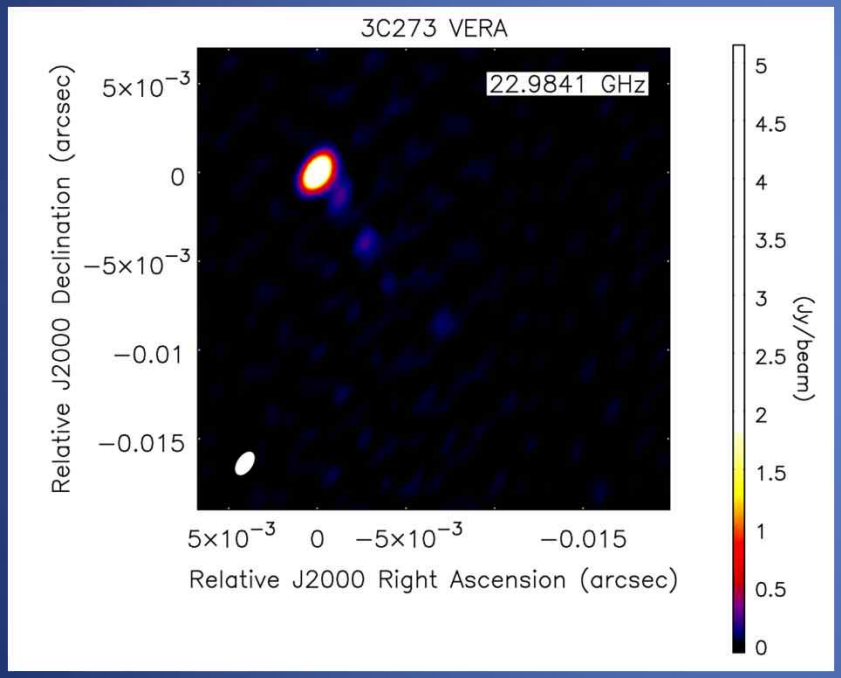


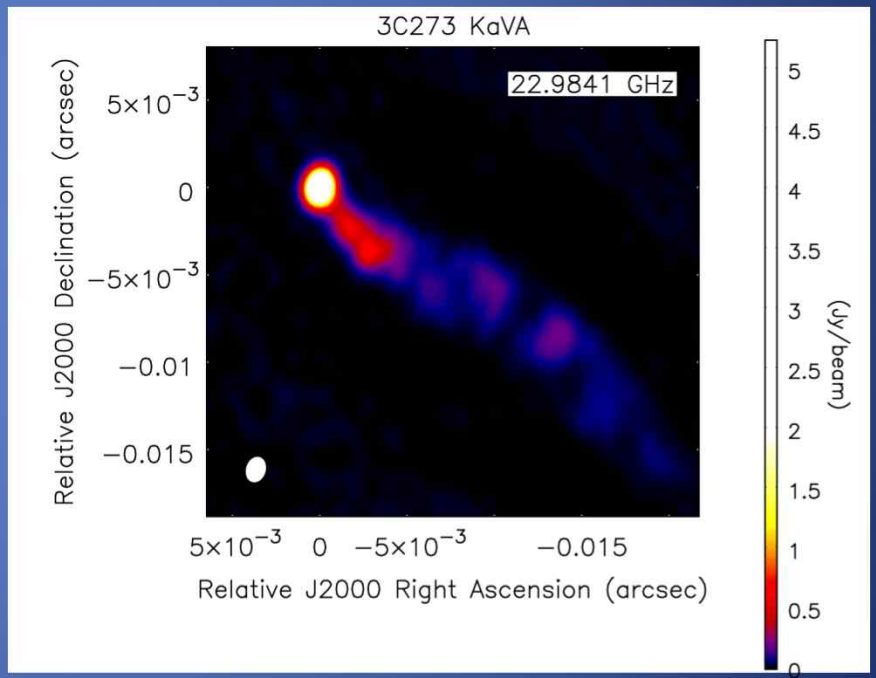
- Daejeon Correlator
  - Joint Development & Joint Operation by KASI & NAOJ
  - Input Data Rate = 4 streams x 2Gbps x 16 stations
- DiFX Software Correlator
  - Linux Cluster
  - KVN only observation

combined VLBI array
KaVA(KVN and VERA Array)

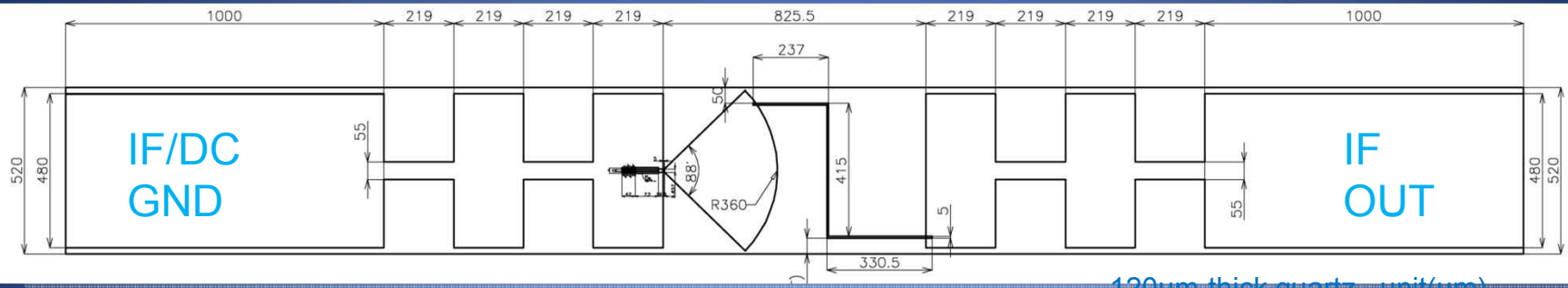


Advantage: combined array

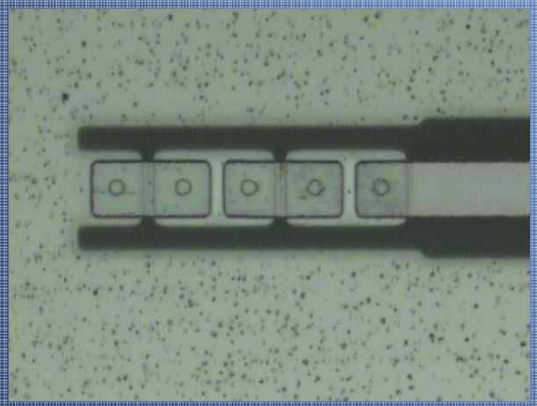


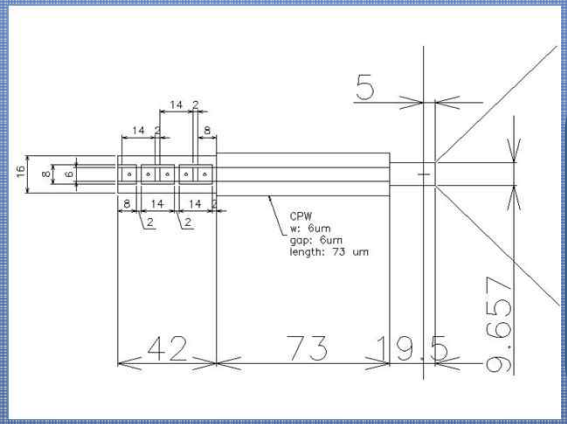


KVN SIS Mixer Chip(2010)



120um-thick quartz, unit(um)



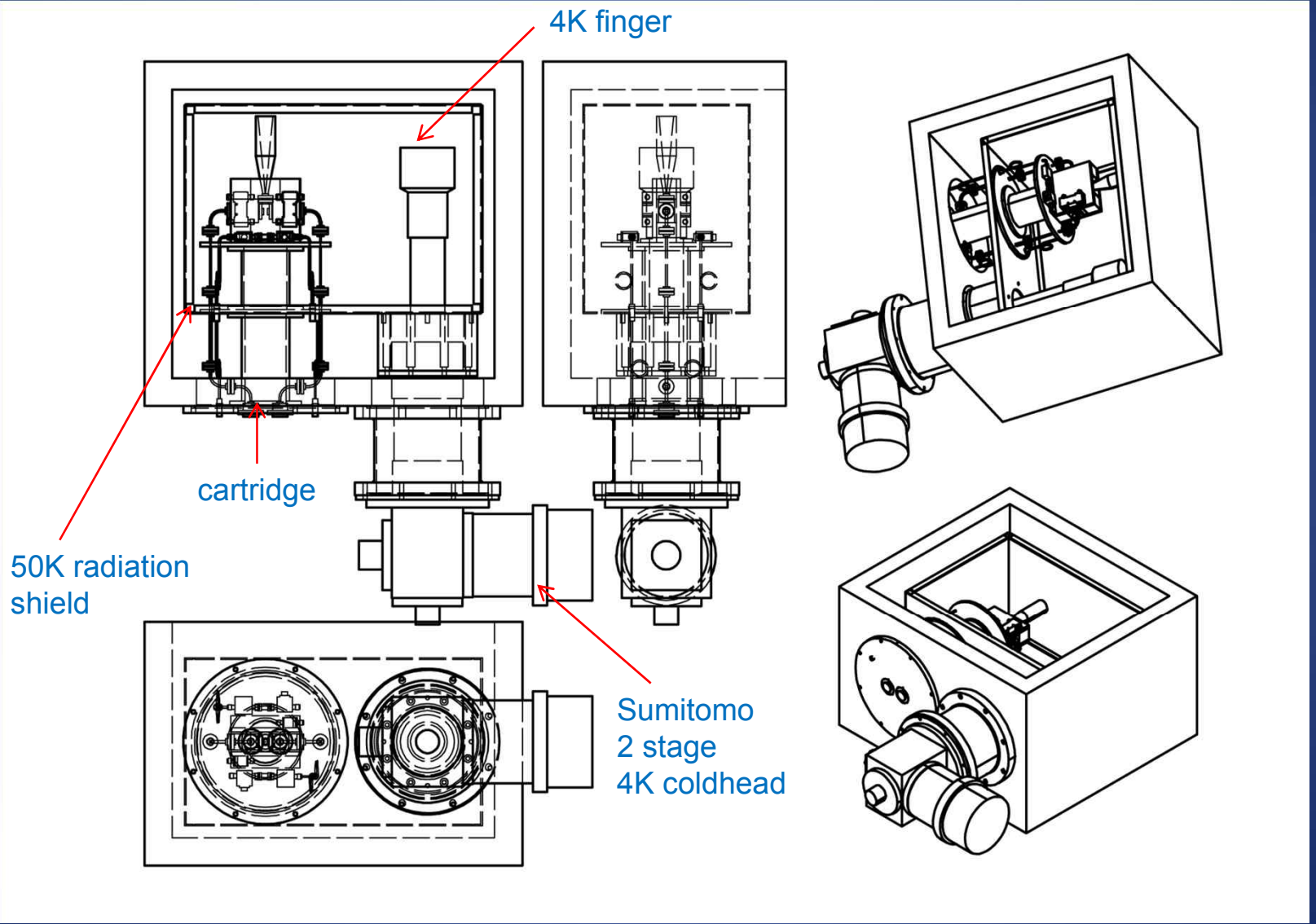


- RF frequency: 120-165 GHz
- Jc~5kA/um^2
- Junction diameter ~1.6 um
- Quartz substrate
- normal Nb tuning
- fabricated in ASIAA

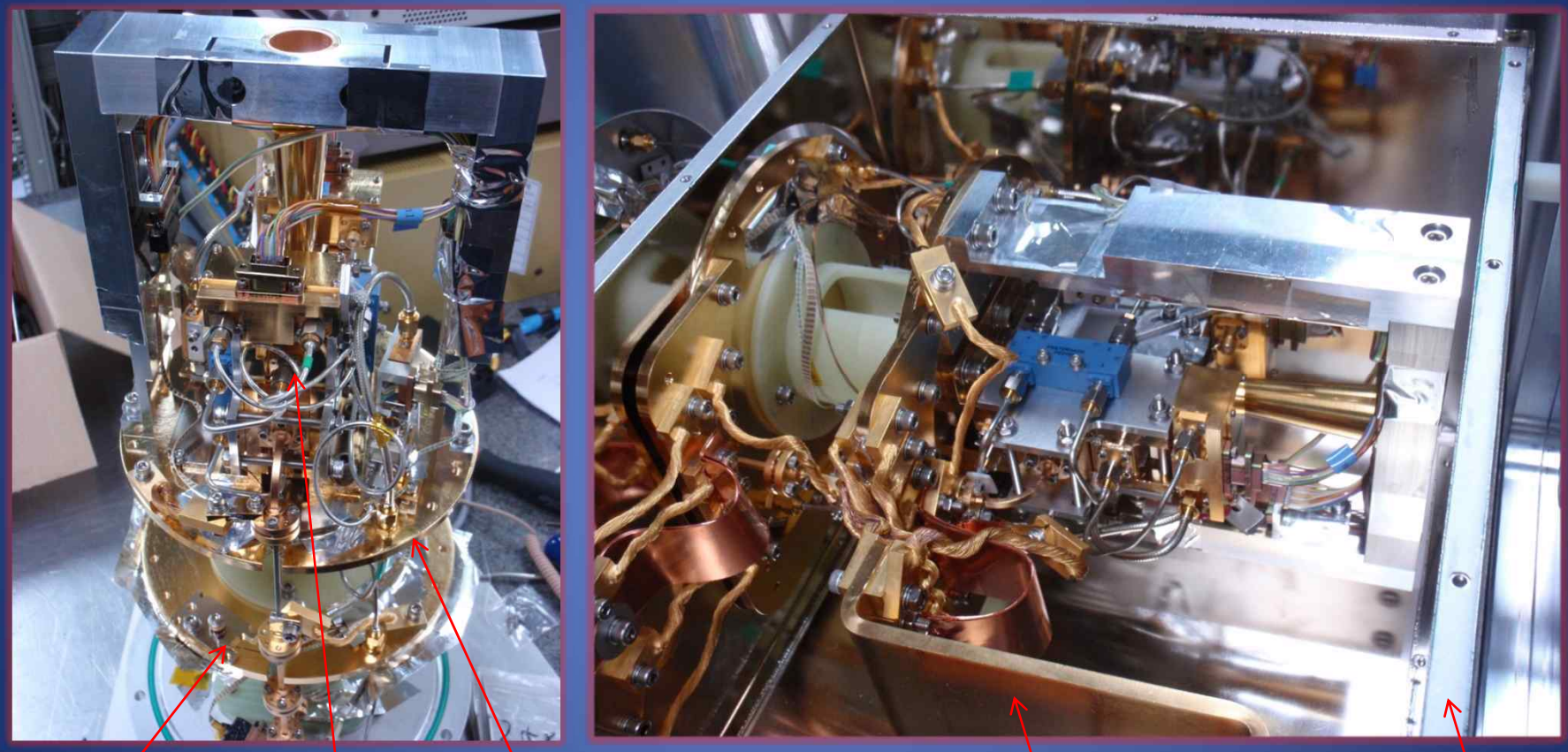
superconducting junction details with
RF tuning circuit

KVN 129 GHz Receiver Cartridge

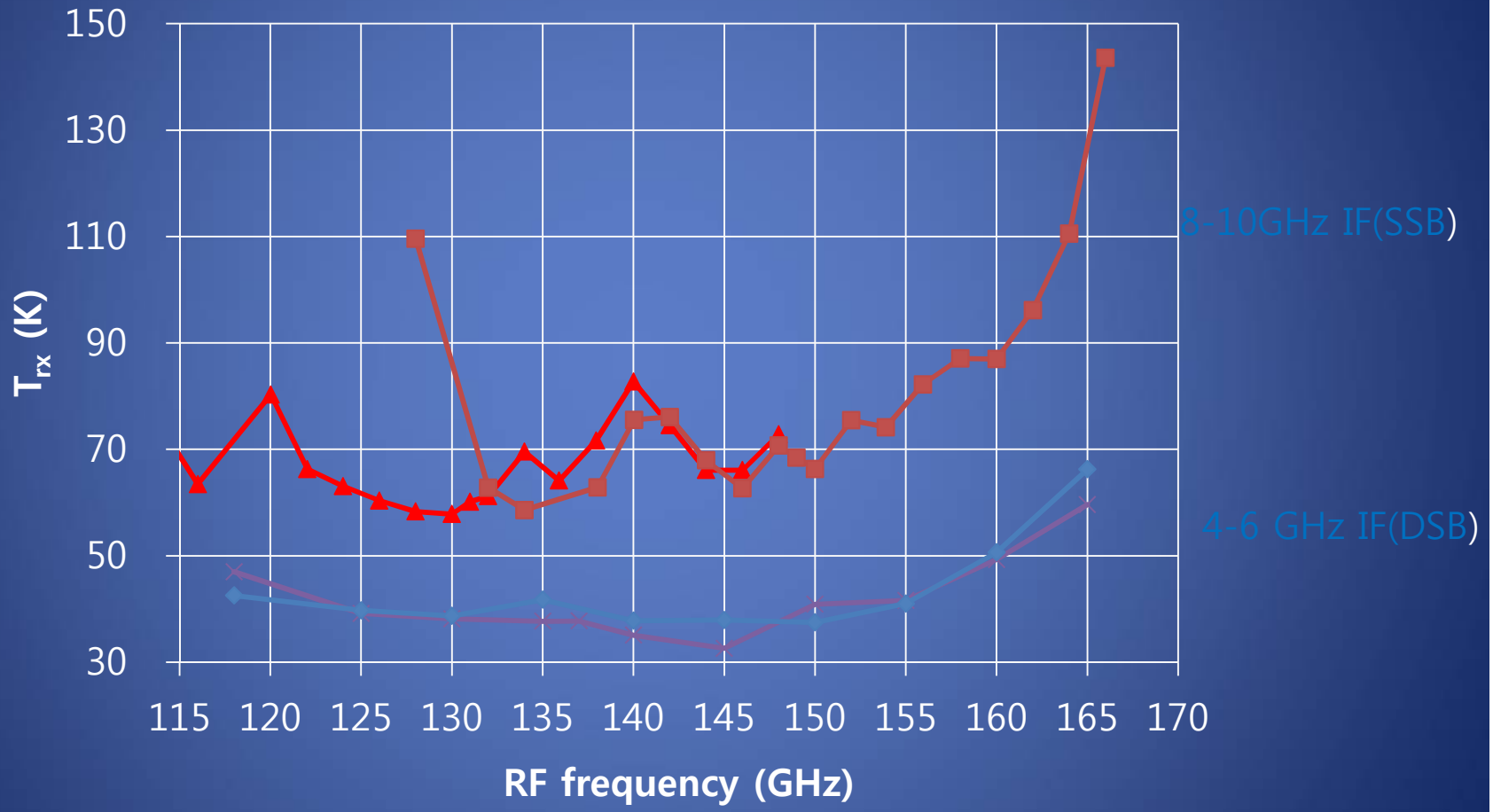
- RF band : 124 -142 GHz (band limited by circ. Polarizer)
- IF band : 8 GHz- 10 GHz (KVN system standard)



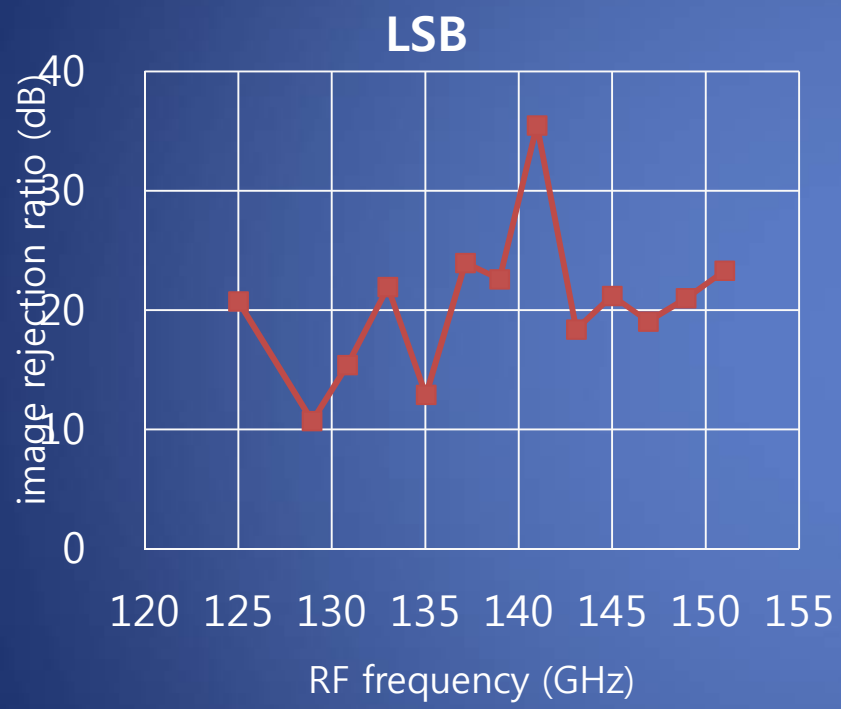
KVN 129 GHz Receiver Cartridge

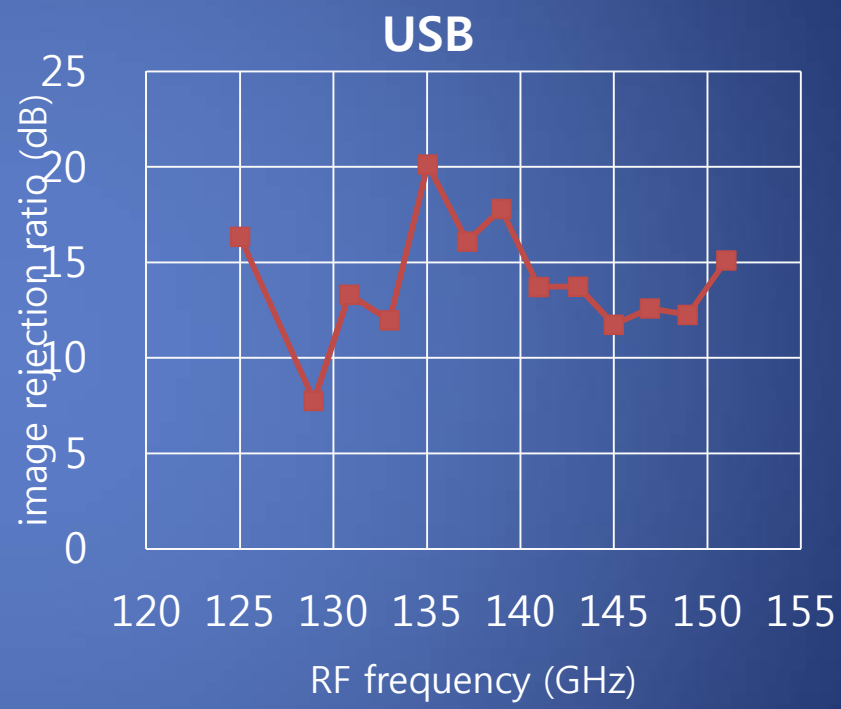


KVN 129 GHz Receiver Performance

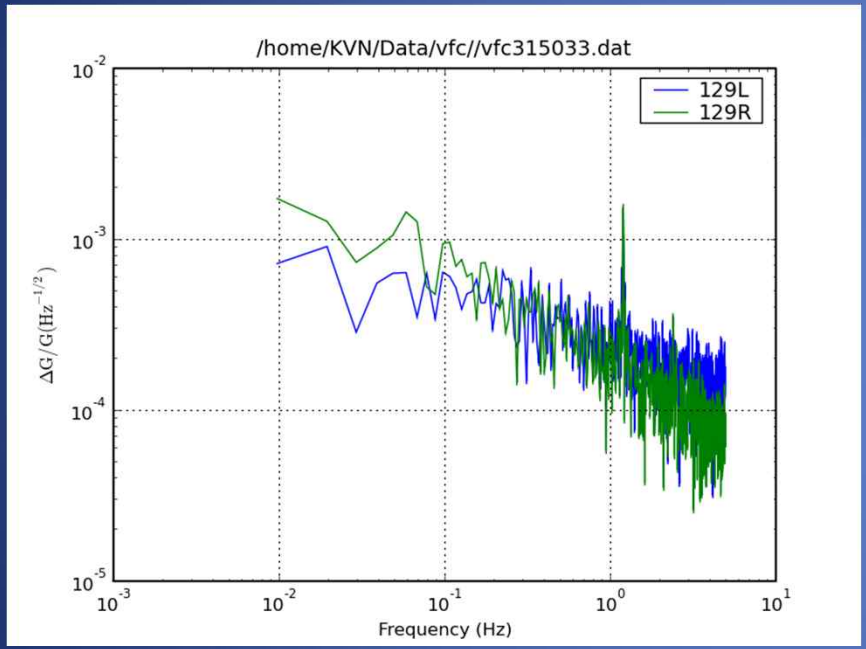


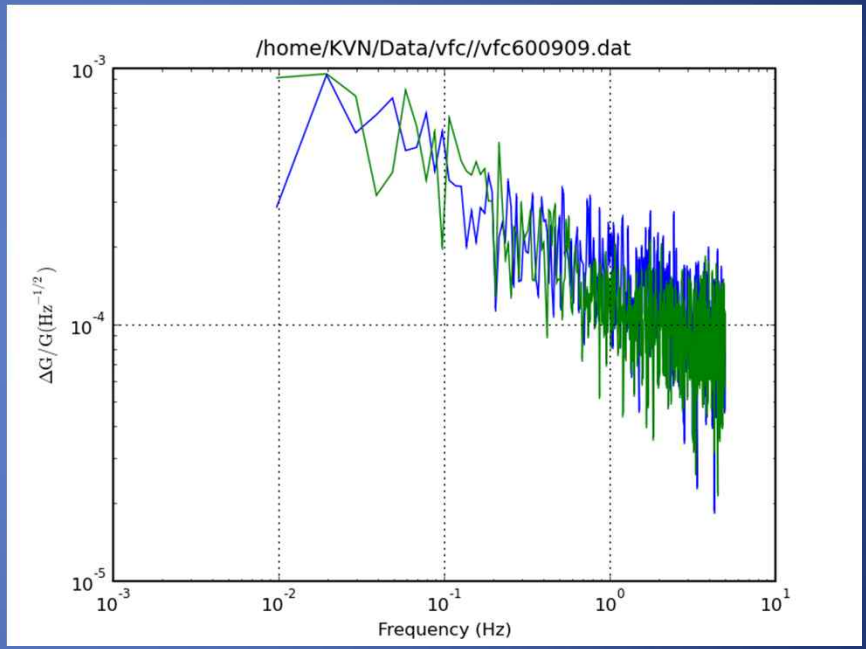
KVN 129 GHz Receiver Performance



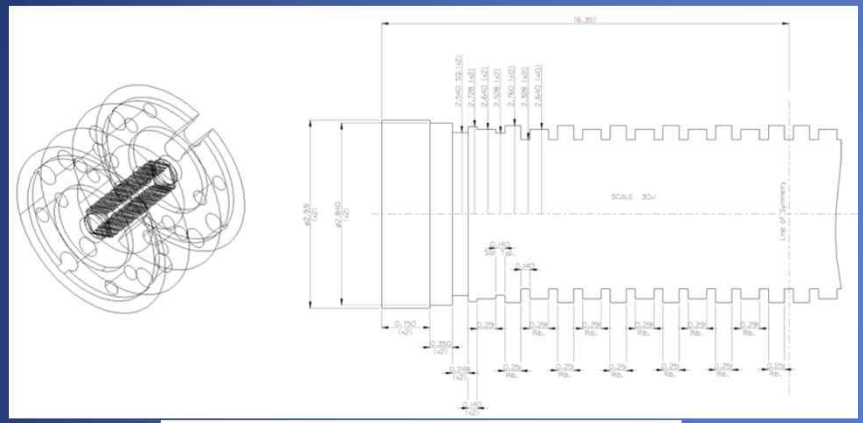


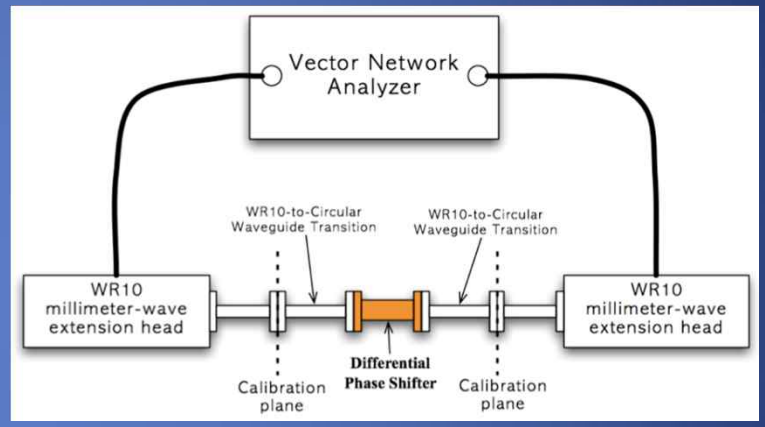
KVN 129 GHz Receiver Performance

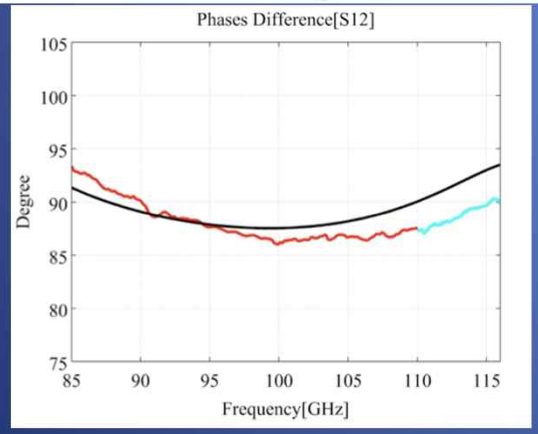


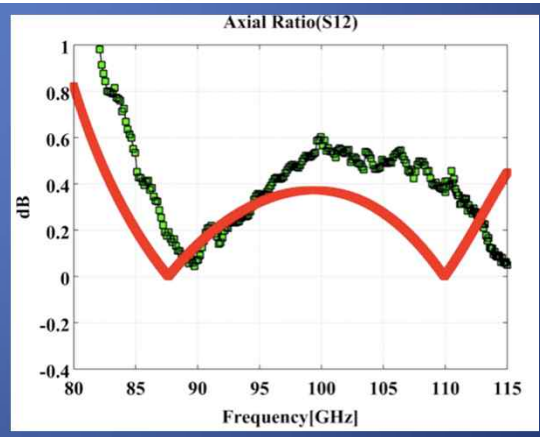


Phase shifter for circular polarizer

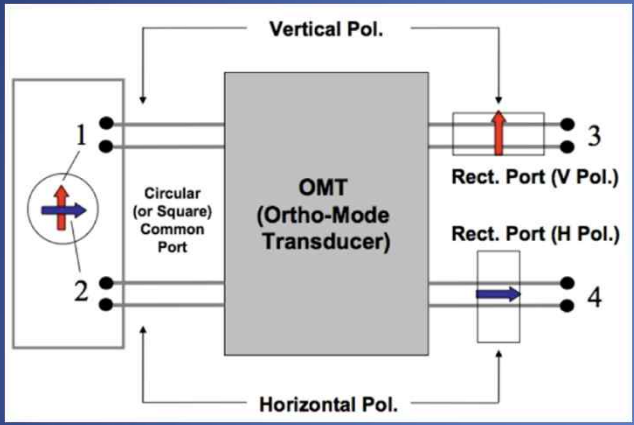


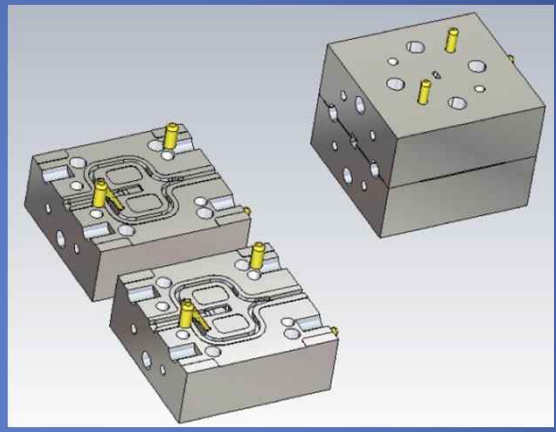


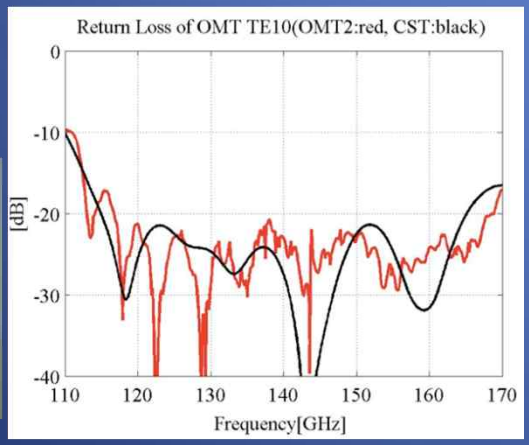


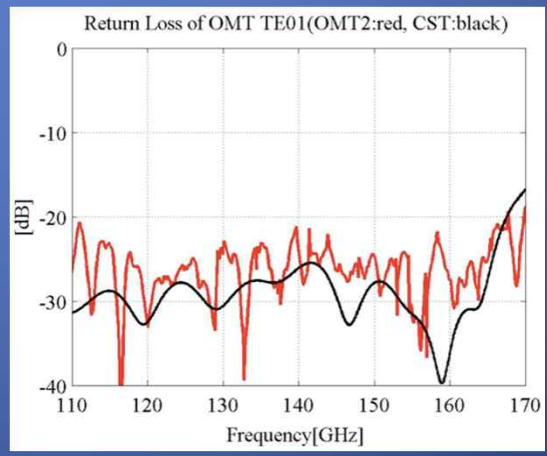


Orthomode transducer









Chronicles of ASTE FPA Development

- Sep., 2012 KASI started initial study on Korean participation in East Asia ALMA consortium
- June, 2014 ALMA/ASTE Development Workshop (NAOJ, Japan)
  → request for 300-500 GHz focal plane array for ASTE telescope
  by radio community
  ALMA-EA endorsement to development of similar FPA for ALMA TP array
  as future ALMA enhancement

- Aug., 2014 call for development proposal
  Korean participation in ALMA announced officially

- Nov., 2014 KASI submits a proposal for ASTE focal plane array
- Feb., 2015 Proposal accepted

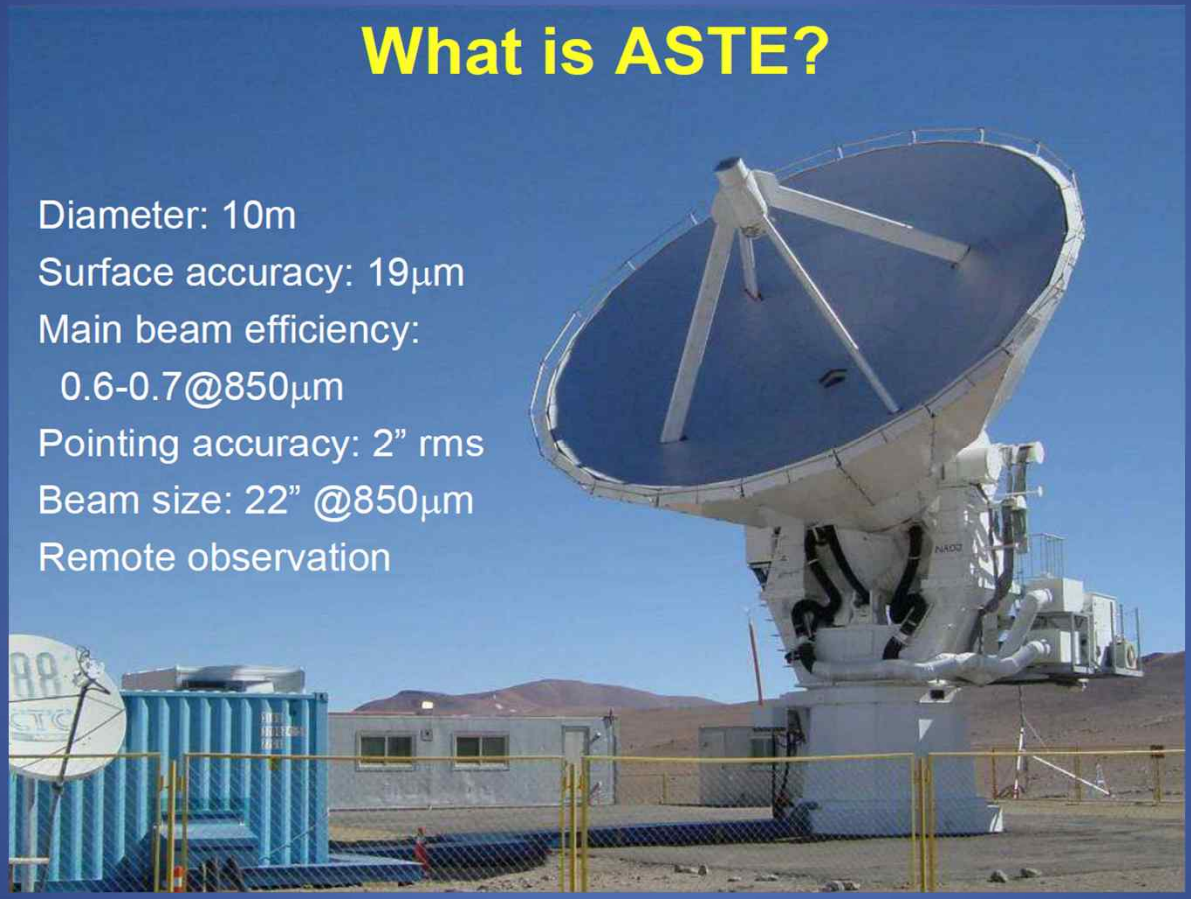
- May, 2015- Dec., 2015:1st- 4th KASI-NAOJ f2f meeting (Osaka, Japan)-will finalize scheduling and work scopes

Instrument Overview

45 % wideband, compact focal plane array

- stacked Silicon feedhorn array pending test
- wideband Nb-AlN-Nb SIS mixers (NAOJ lead fabrication)
- balanced sideband separation configuration
- low-power consumption cryogenic LNAs (~1mW, 39 dB, 2K noise)
- 8 GHz digitizer+ GPU-based FFT spectrometer (with polyphase digital filter & ring buffer)
- Single pixel engineering model delivery ~2017
  4 pixel FPA delivery ~ 2019
- Proposal to ALMA board for TP array receiver~2020

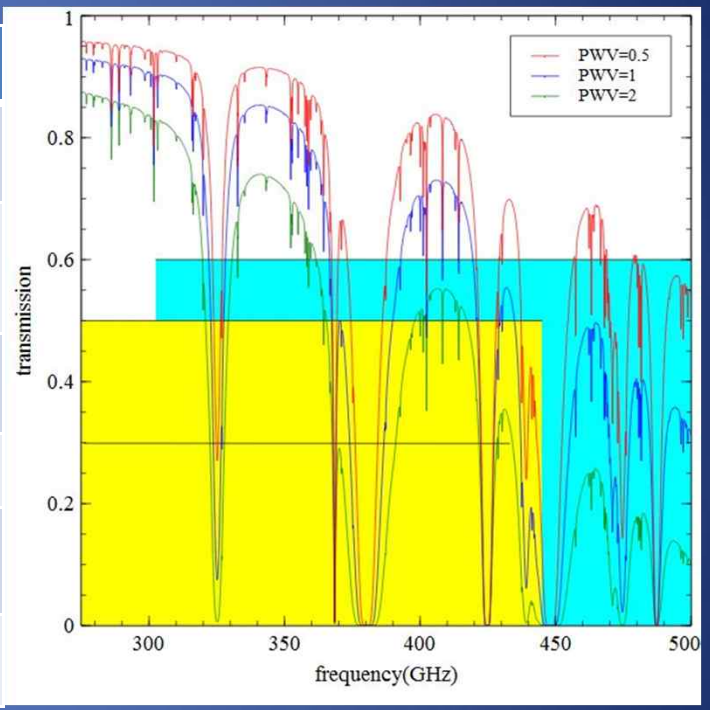
Focal Plane Array for TP array: Testbed at Chile, ASTE Observatory



- Initial feasibility study on 300-500 GHz receiver architecture : 2015
- Proof of concept: single-pixel cartridge Q2 2017
- 4 pixel cartridge: Q2 of 2019

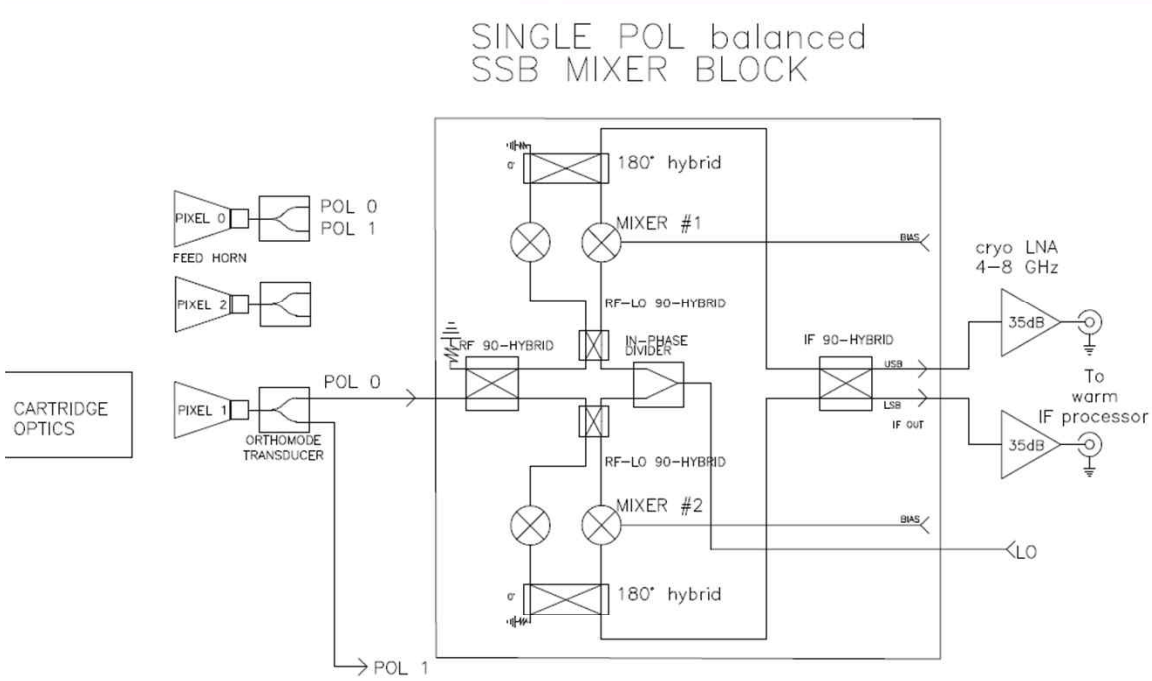
Specification of ASTE FPA

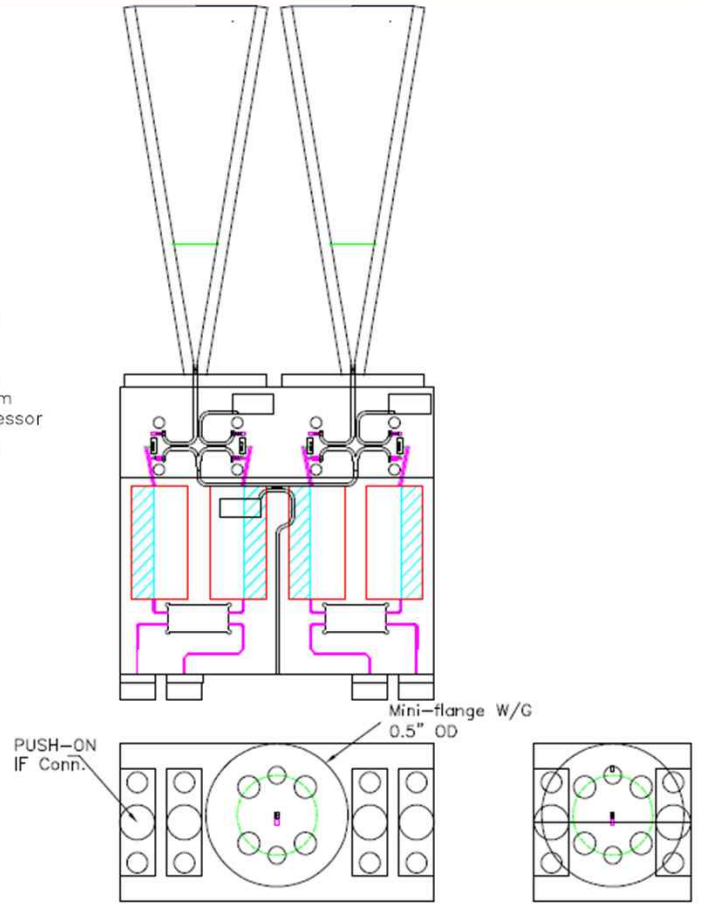
	Specifications
Number of focal plane pixels	4 pixels(min.) for ASTE cartridge cryostat
Operation RF frequency	300-500 GHz (nominal 45% fractional BW)
Receiver noise temperature	<70 K(300-370 GHz), <130 K(385 GHz-500 GHz)
IF frequency	4-8 GHz (USB, LSB)
Spectrometer BW/ channel width	4 GHz/7.6 kHz
Polarization	dual polarization using waveguide OMT



APEX site transmission

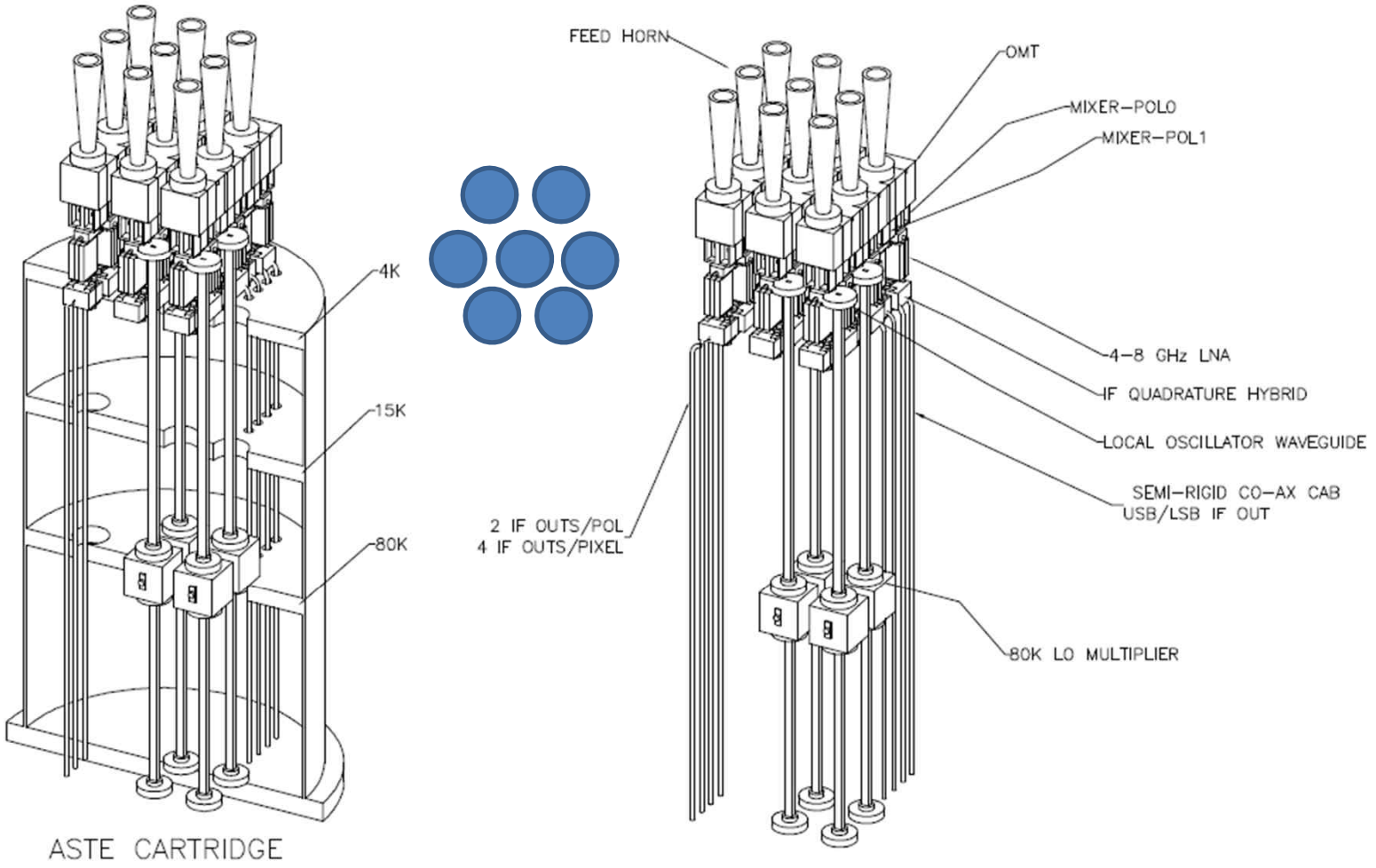
Focal Plane Array: blocks for balanced mixers





a strawman half-block layout of balanced sideband-separation mixer: block fits within 14(W)mm X 14(H) mm. (This is a prior design to OMT version)

Focal Plane Array: cartridge compatible to ALMA's



We indeed considered *possible component sizes* for this layout

OMT: double ridge type with additional E-bend

GPU spectrometer for ALMA TP array

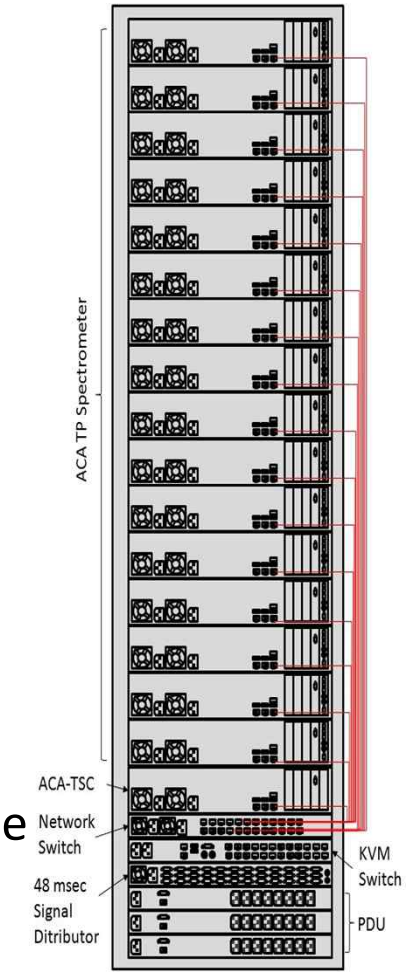
- Development background
  - One of the Korean contribution to the ALMA project
  - Sub-array mode of 7m and TP arrays of the ACA hasn't operated.
  - No full polarization has been done using the TP array
  - Spectrometer for a future multi-beam receiver of the TP array
- Requirements: current ALMA spec
  - Input data rate/antenna: 2 GHz x 4 BB x 2 pol x 3 bit x 2 Nyquist = 96Gbit/sec
  - Full polarization, …

Jongsoo Kim's slide

The “kfftspec” Spectrometer

- Multi-GPU cross-power spectrometer for nVidia GPU
- Development setup
  - Dell PowerEdge T630, nVidia Tesla K40m, 2 x TITAN X
  - Sample data from file or 10G/40G (KVN; 2-bit)

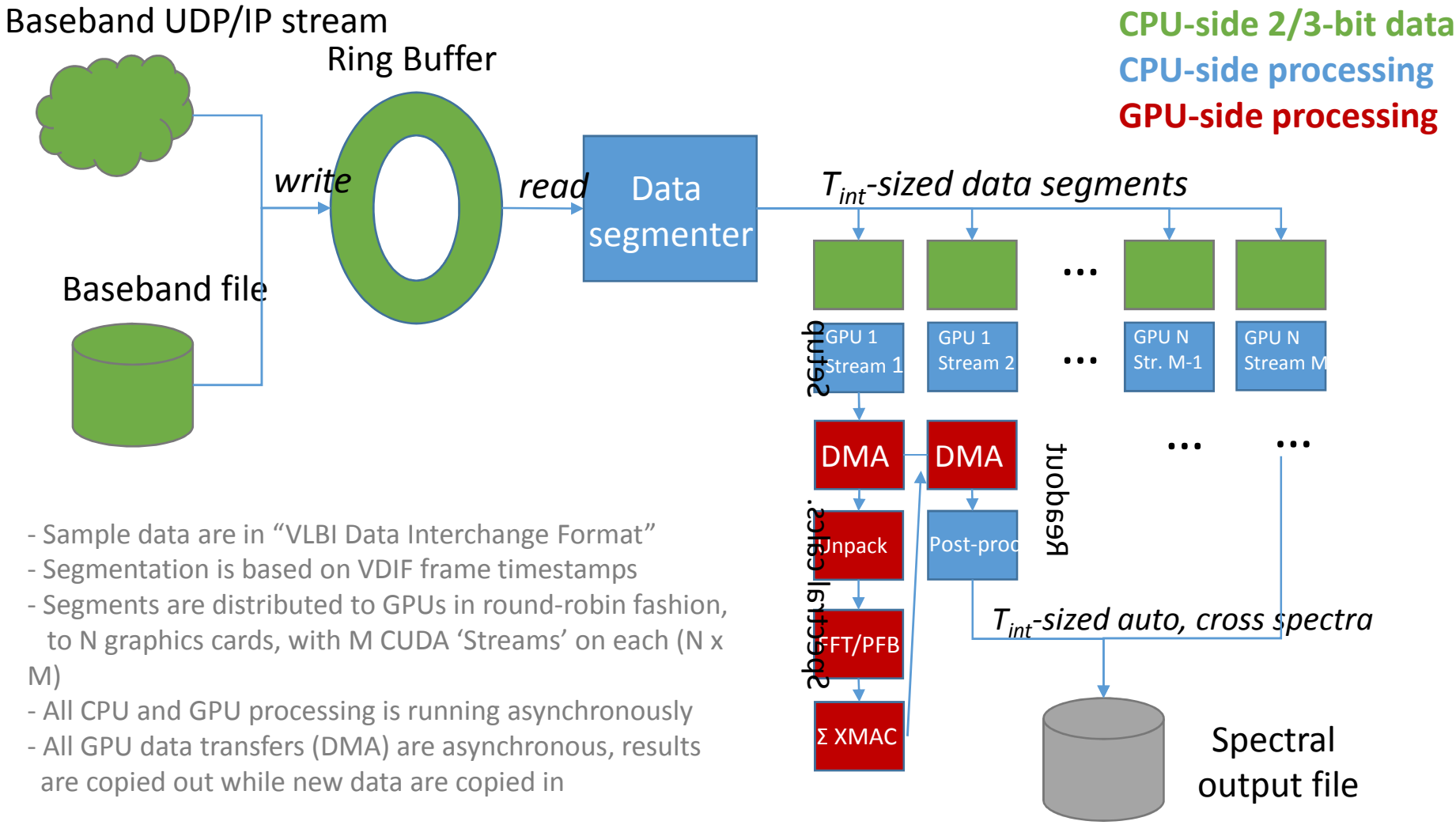
- Possible ACA spectrometer rack setup
  - Four to eight GPU in each node , 1-2 nodes per band
  - Sample data from “OC-192” (ALMA; 3-bit) via DXRP PCIe board



Plan: GPU spectrometer rack for ACA TP (Iguchi, Asayama)

Jan Wagner’s slide

Data Flow in "kfftspec" Spectrometer



- Sample data are in "VLBI Data Interchange Format"
- Segmentation is based on VDIF frame timestamps
- Segments are distributed to GPUs in round-robin fashion, to N graphics cards, with M CUDA 'Streams' on each (N x M)
- All CPU and GPU processing is running asynchronously
- All GPU data transfers (DMA) are asynchronous, results are copied out while new data are copied in

Jan Wagner's slide

Summary

- *TRAO, SRAO, KVN system have been introduced but tried to focus on KVN engineering researches.*
- Brief introduction to commenced *ASTE FPA project* as Korean ALMA-EA contribution to future ALMA enhancement