中国科学院 上海天文台
Shanghai Astronomical Observatory, CAS

The recent technology development of Chinese VLBI Network

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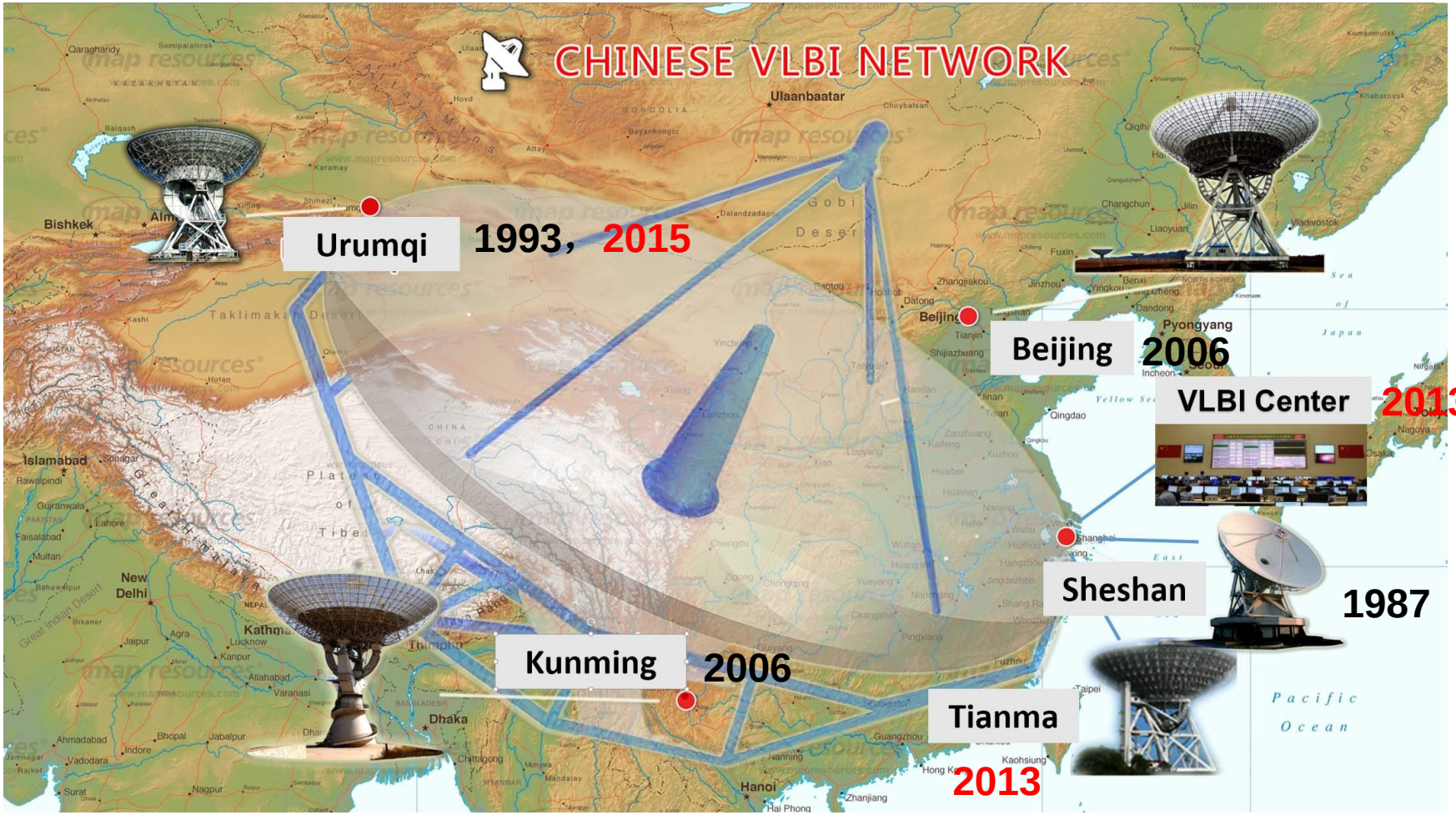
November 23，2015， Auckland

Outline

- CVN Overview
  - VLBI terminal & Correlator
  - Support the lunar missions
  - VOGS antenna
  - Space Millimeter VLBI Array

CVN (5 stations + 1 data center)



CVN data center

Current Status of Tianma Radio telescope

Shanghai 65m RT
(TianMa Telescope)

- L band Rx
- C band Rx
- S band Rx
- X band Rx
- Ku band Rx
- Ka band Rx
- K band Rx (2-beam)
- Q band Rx (2-beam)

VLBI terminal (CDAS) +correlator

General-purpose (DIBAS)

Continuum, line and pulsar + multi-beam

USERS

Multi beam system (2-beam at K- and Q-band)
(+ simultaneous observations of multiple lines)

Open Use of the TianMa Telescope

- **As a VLBI station, join world-wide networks:**
  - **EVN, IVS, VLBA, EA-VLBI, CVN**
- **As a single dish, open to the world**
  - **1st "Call for proposal" for pulsar research made on Sept. 15, 2014**
    - ✓ **22 proposals received,**
    - ✓ **PIs from 7 institutes, co-Is from 12 (domestic) + 3 (oversea)**
  - **2nd "Call for proposal" for spectroscopic observations made on Dec. 29, 2014**
    - ✓ **16 proposals received,**
    - ✓ **PIs from 5 institutes, co-Is from 8(domestic) + 2 (oversea)**
  - **Goal is to operate TM with an open access driven by scientific merit!**

Receiver Frequency Range & Performance

Bands	L	S	C	X	Ku	K	Ka	Q
Wavelength λ(cm)	21/18	13	6/4.5	3.6	2.5/2.0	1.35	0.9	0.7
Frequency f (GHz)	1.25-1.75	2.2-2.4	4.0-8.0	8.2-9.0	12.0-18.0	18.0-26.5	30.0-34.0	35.0-50.0
FWHM（"@CF，1.02λ/D）	628	410	157	110	69	43	29	22
Efficiency η_A (%, best elev=50°)	55	60	60	55	40	≥20 (≥55*)	≥50*	≥45*
Tsky (K)	12	12	10	10	12	25	13	26
Trec (K)	14	21	12	22	15	21	25	40
Tsys (K)	26	33	22	32	27	46	38	66
SEFD (Jy, Tsys/DPFU)	39	46	31	48	56	192 (70*)	63*	122*
Thermal noise (mJy, 1σ (B_w=128MHz, T_{on}=10 min))	0.142	0.165	0.110	0.175	0.202			

$$SEFD = \frac{2kT_s}{A_e} = \frac{2kT_S}{\eta_A A_g} = \frac{8kT_S}{\eta_A \pi D^2}$$

$$\sigma = \frac{SEFD}{\sqrt{T_{on} B_w}}$$

Opportunity for mJy science observation!

SEFD comparison of TM with some others

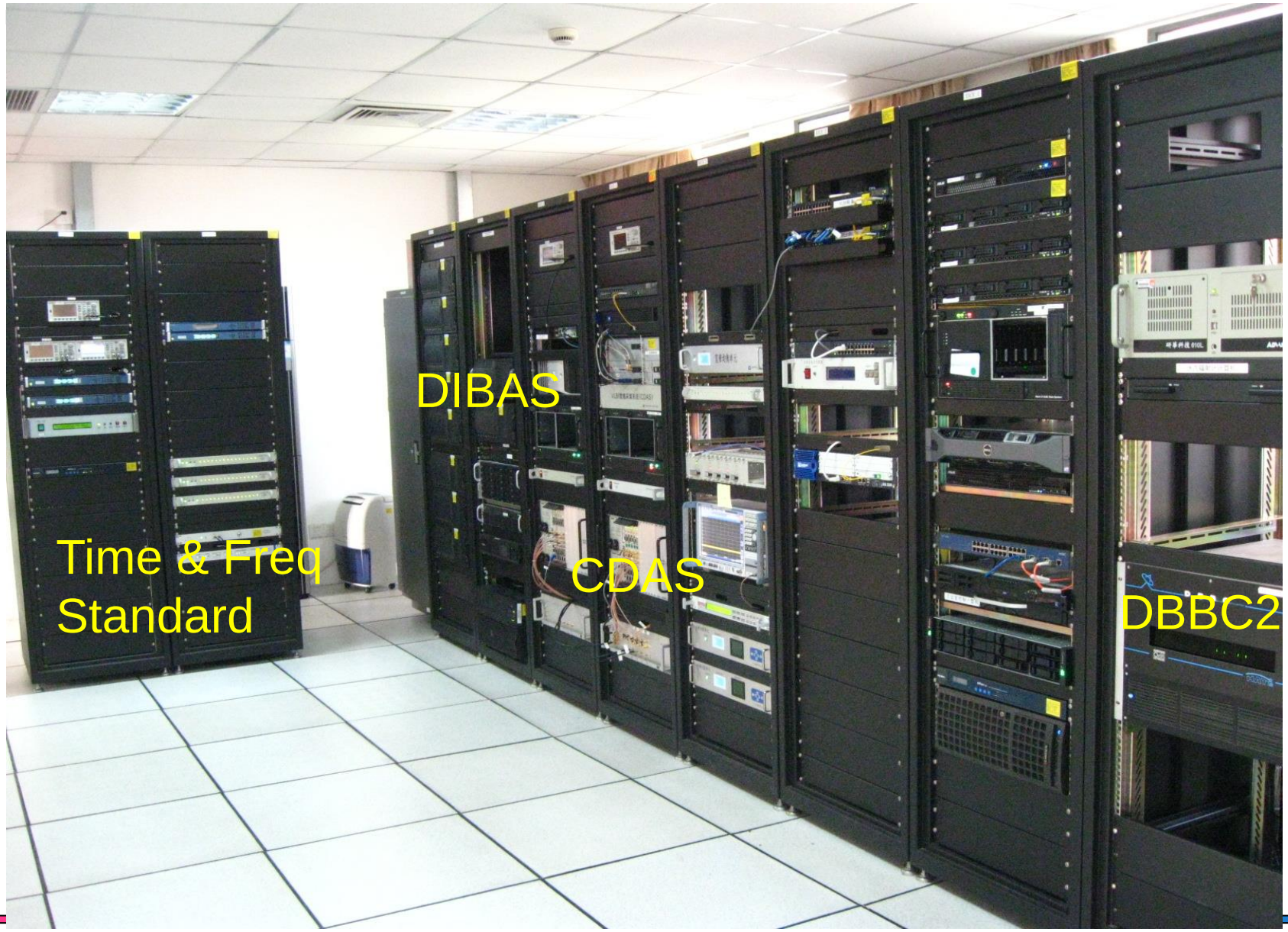
$$SEFD = \frac{2k_B T_{sys}}{A_e}$$

	GBT 100m	Effelsberg 100m	Parkes 64m	Lovell 76m	Tian Ma 65m
L band	1.15-1.73	1.27-1.45, 1.59-1.73	1.2-1.8	1.25-1.50, 1.55-1.73	1.25-1.75
SEFD	**10**	**20, 19**	**31**	**36,65**	**39**
S-band	1.73-2.6	2.2-2.3	2.2-2.5	-----	2.2-2.4
SEFD	**12**	**300**	**25**	**-----**	**46**
C-band	3.95-5.85	5.75-6.75	4.5-5.1	6.0-7.0	4.0-8.0
SEFD	**10**	**25**	**61**	**80**	**31**
X-band	8.00-10.1	7.9-9.0	8,1-8.7	-----	8.2-9.0
SEFD	**15**	**18**	**170**	**-----**	**48**

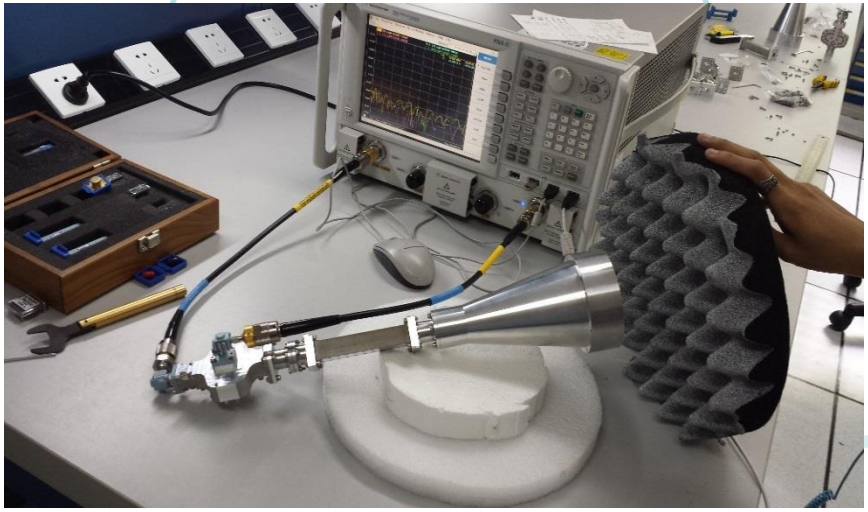
Noise Temperature

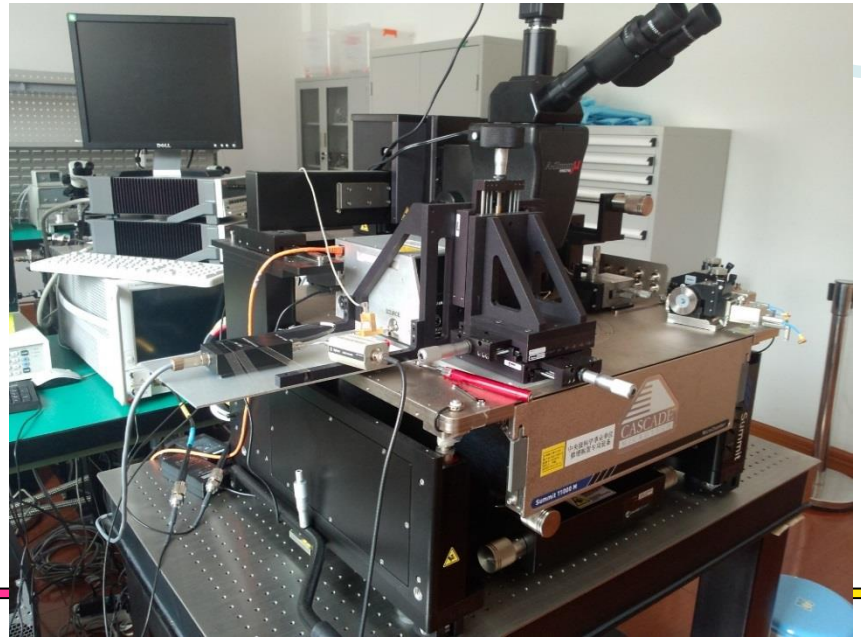
Noise T (K) GHz	Tianma 65m	GBT 110m	Effelsberg 100m	Sardinia 64m
K Band	< 20K Center 75% < 15K 18-26.5GHz	21K 22-26.5GHz	30K 21.6-24.4GHz	21K 18-26.5GHz
Ka Band	< 25K 26-40GHz	20K 36-39.5GHz	18-24K 30-34GHz	25K 26-36GHz
Q Band	<40K 35-50GHz	40-70K 38.2-49.8GHz	73K 41.5-44.4GHz	40K 35-50GHz

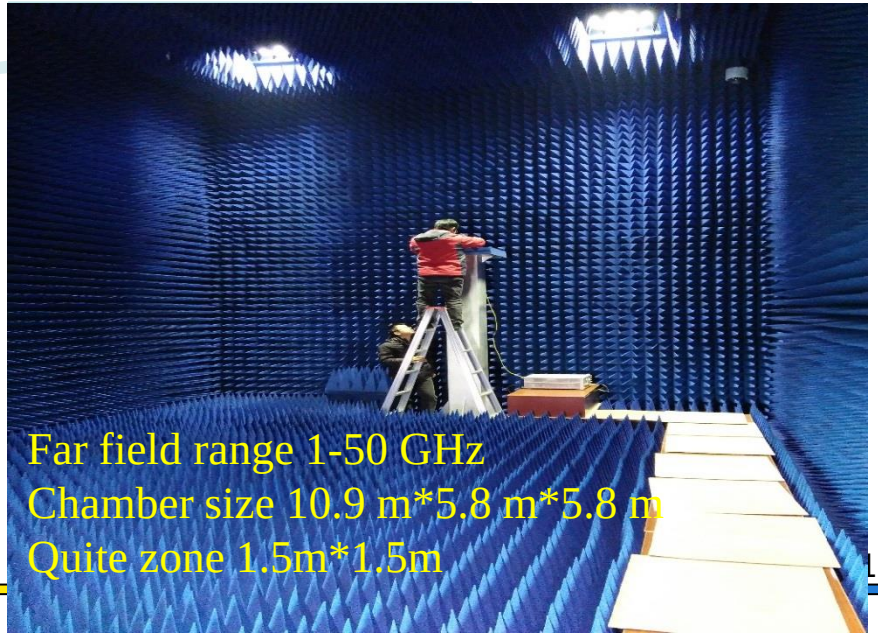
Backend system



Receiver Laboratory



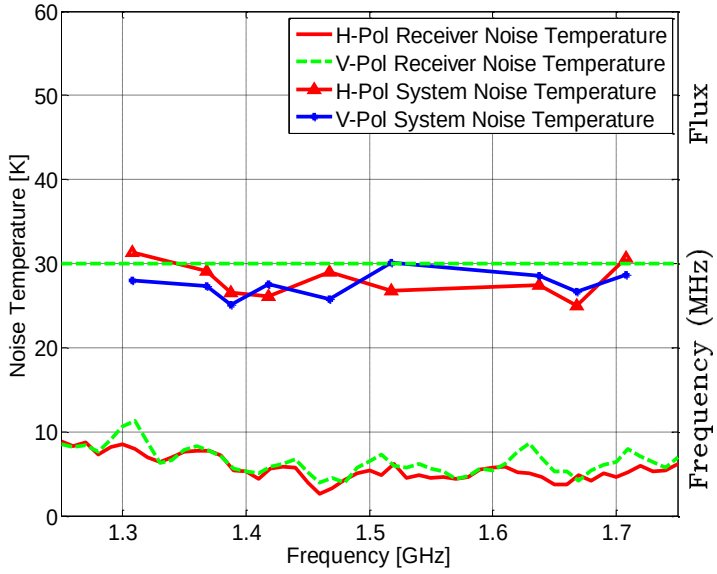


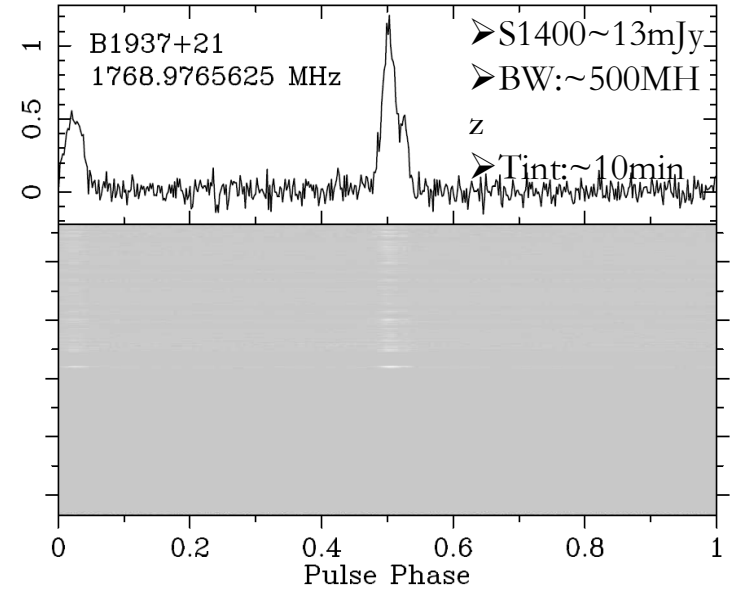


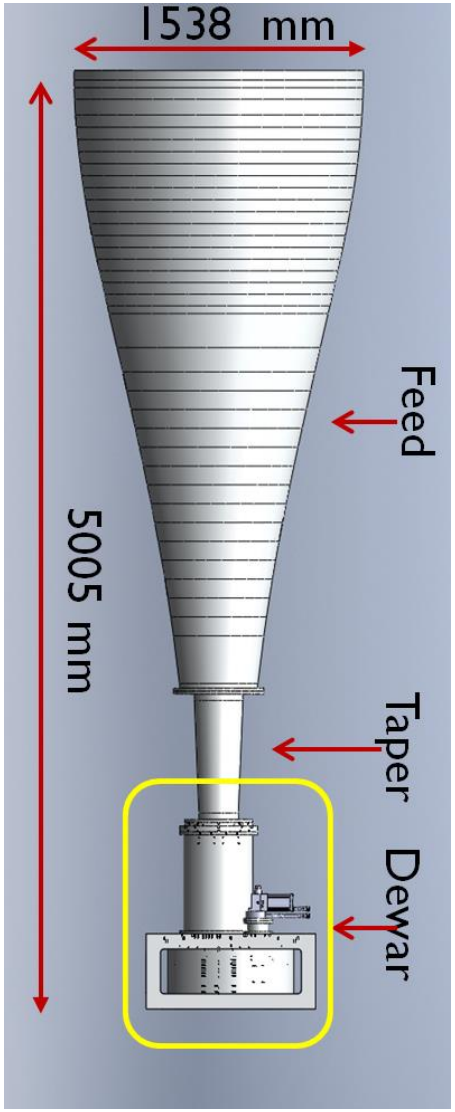
L-band receiver

➢ Features

- 500 MHz BW, 18 & 21 cm observation
- Cooled OMT & hybrid LNA
- Φ270 mm microwave & vacuum window



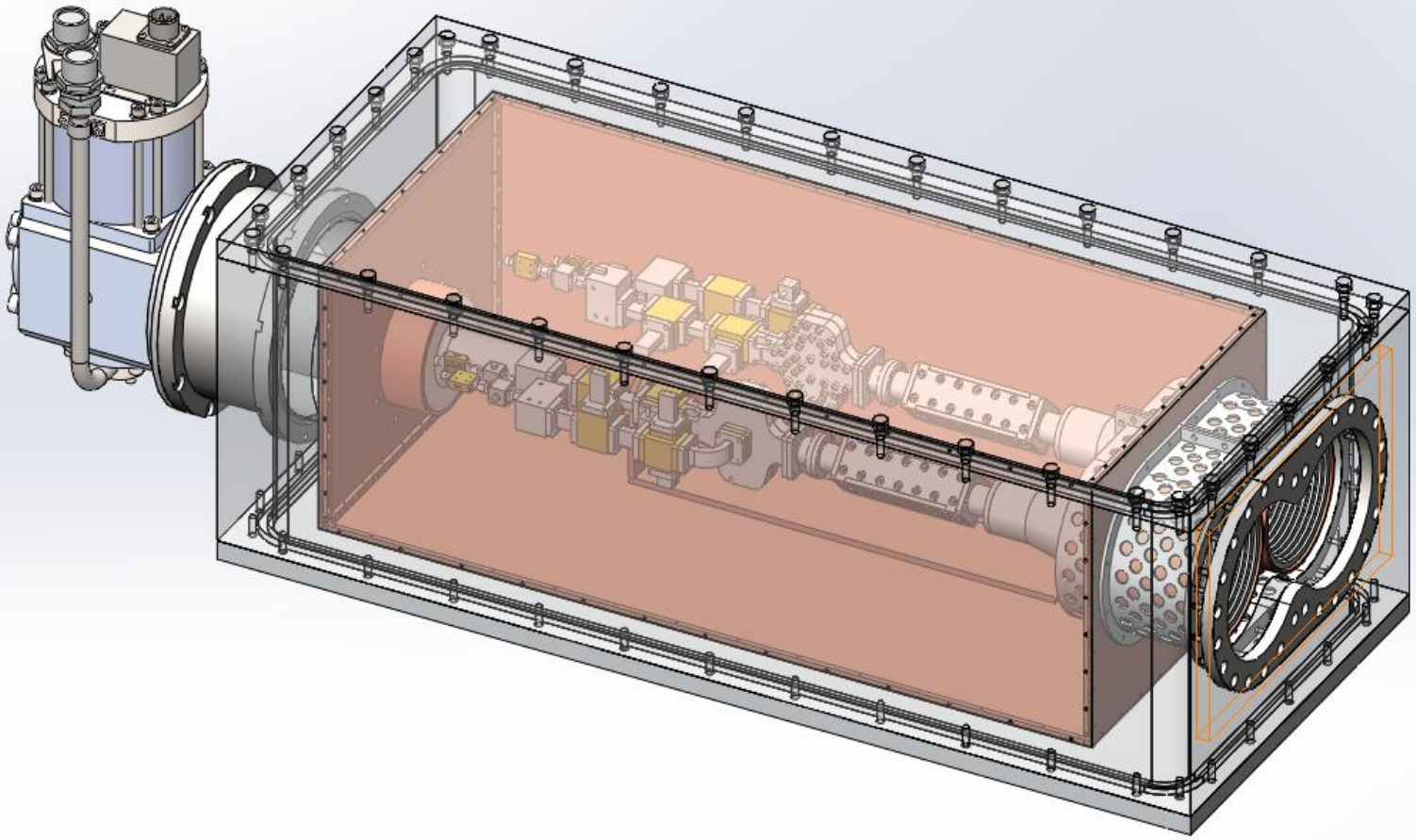




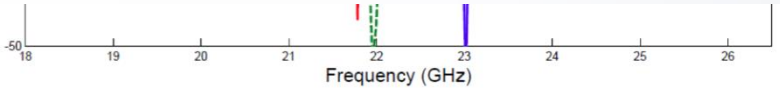
Provided by Dr. Yan Zhen

K-band receiver

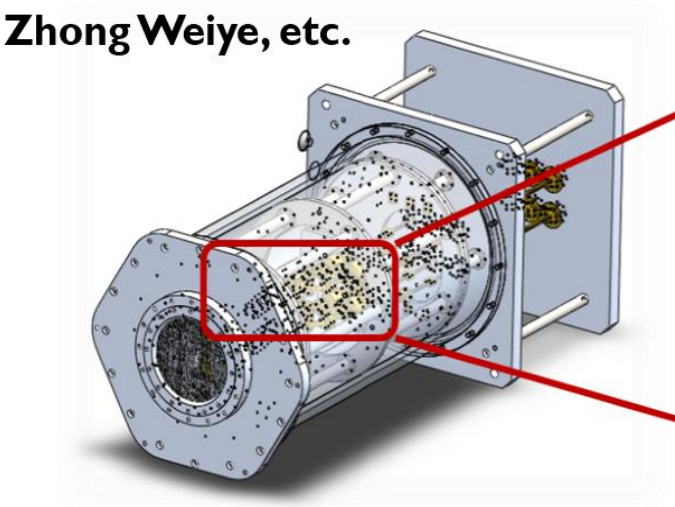
Maximum 110mm beam offset

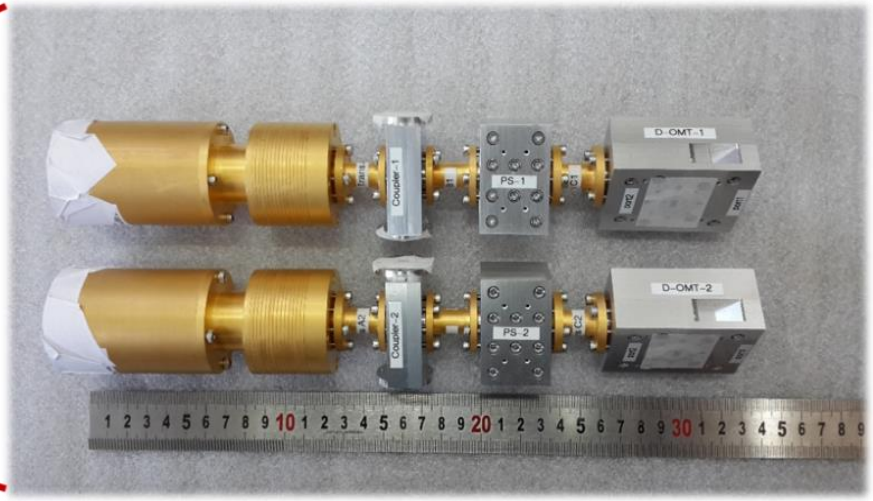


Transducer

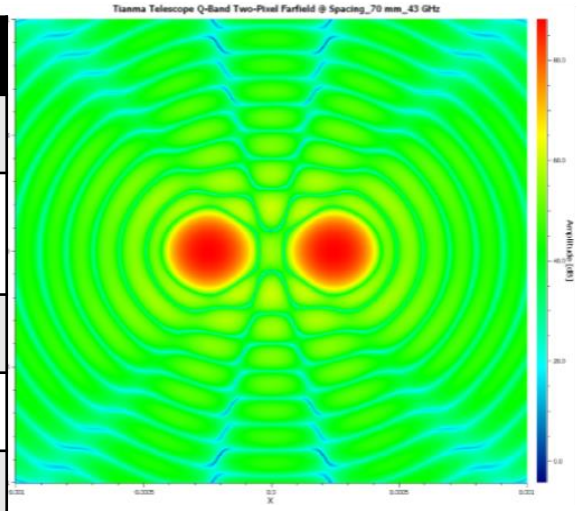


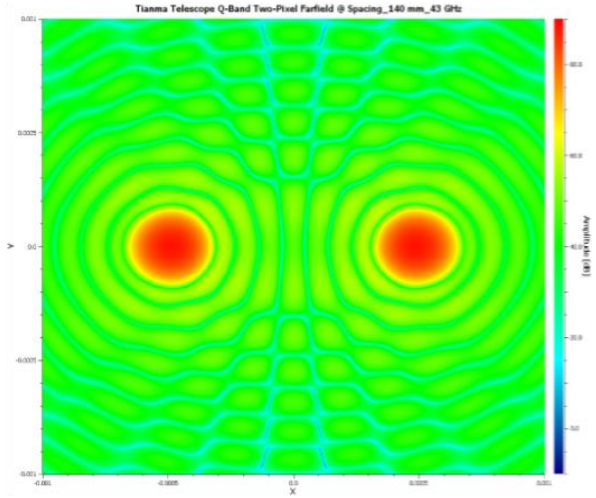
Q-band receiver



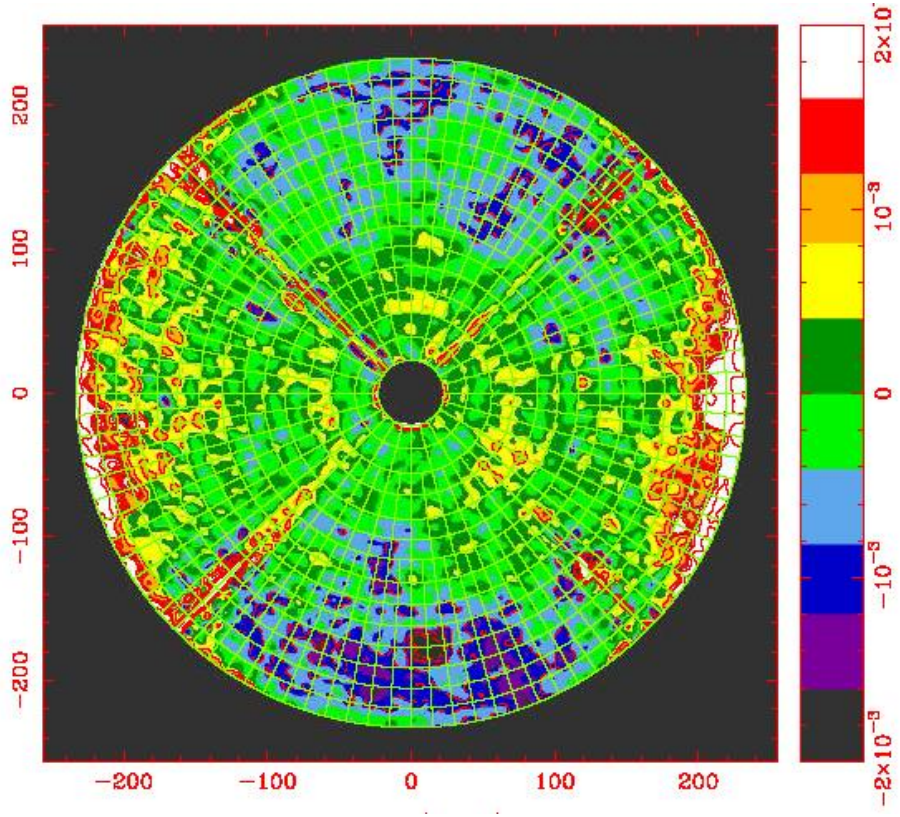


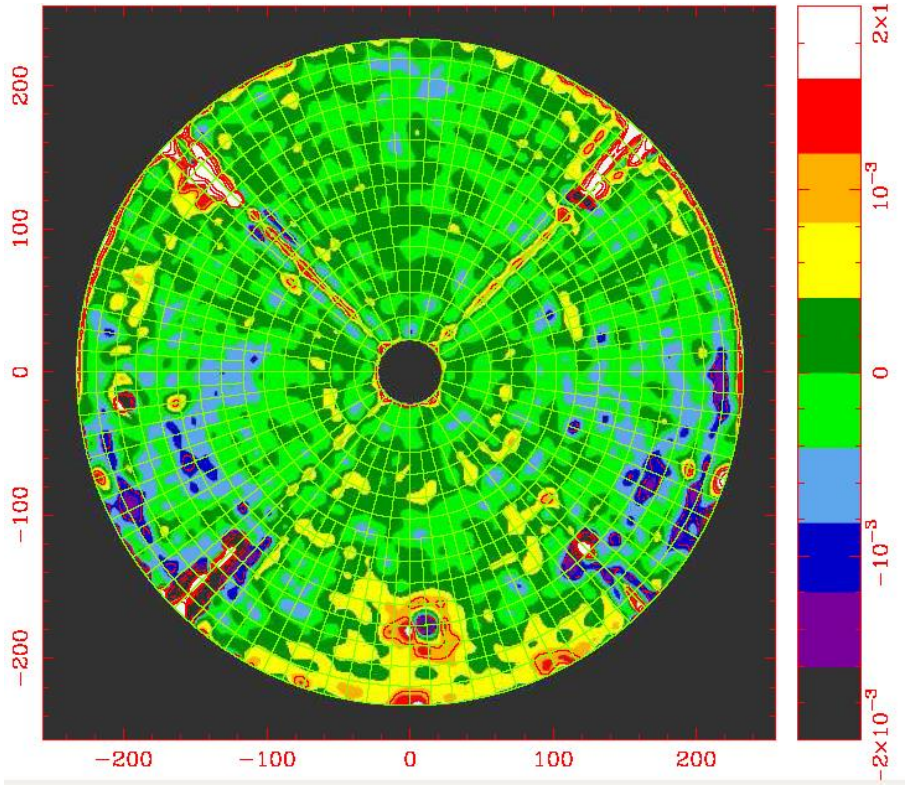
Items	Specifications
Frequency band	35-50 GHz
Number of beams	2
Receiver noise	<35 K
System noise	<60 K
Polarization	Dual circular





Phase coherent holography on TM65m





Before adjustment
Test time: 2015-10-11 16:00-20:00(BT)
Scans:95
Aperture Resolusion:1m
Surface error(RMS):0.58mm

After adjustment
Test time: 2015-10-21 4:10-6:18(BT)
Scans:65
Aperture Resolusion:1m
Surface error(RMS):0.32mm

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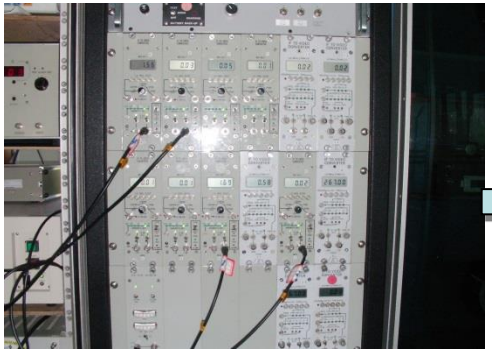
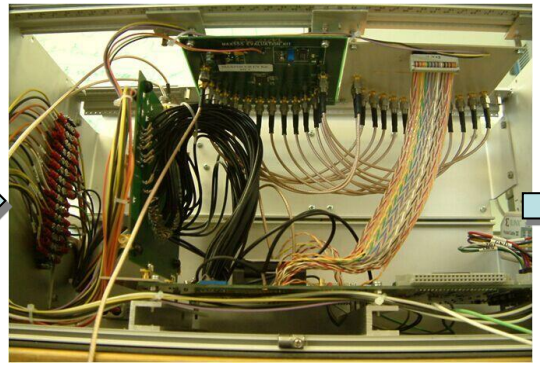
- Space Millimeter VLBI Array

Digital Baseband convertor CDAS



Analog Baseband Converter (ABBC),<2010

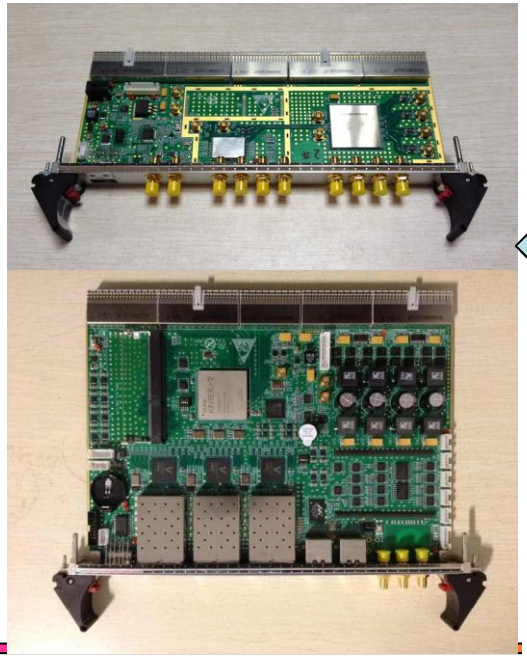


Mini-DBBC (2004)

(2009)

CDAS1 (2010)

CDAS2 (2013)



CDAS3

CDAS：

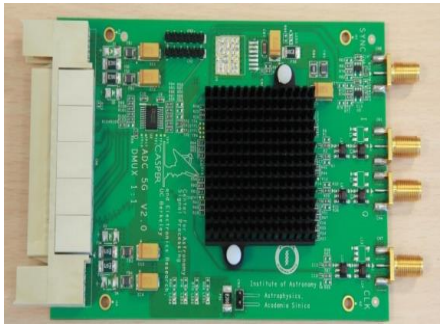
Chinese VLBI Data Acquisition System

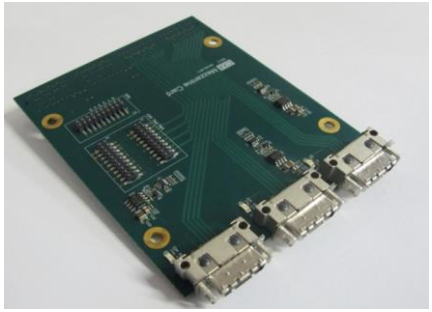
Comparison

Platform	CDAS1	CDAS2	CDAS3
Number of inputs IFs for each board	1	2	4
Sample mode	1CH@1024Msps	2CH@2048Msps 1CH@1024Msps	4CH@1024Msps 2CH@2048Msps 1CH@4096Msps
Type of FPGAs	4 x Virtex4 LX160	2 x Kintex7 480T	1 x Kintex7 480T
Data Interface	VSI (interface board needed)	10GE x 2 VSI(interface board needed)	10GE x 6
Memory	No	No	8GB DDR3
DAC	No	No	Yes
Schedule	Finished	Firmware and software testing	2016 or later

Future work: General purpose backend

- **VLBI (SHAO)**
  - **512MHz BW x 4 (depend on the resources in FPGA)**
  - **16 channels with PFB algorithm**
  - **VDIF Data frame**
  - **10GE output**
- **For Pulsar (XAO)**
  - **2Gsps x 1 @ 8-bits**
  - **Minimum BW : <0.25KHz**
  - **PSRFITS supported**
  - **10GE output**
- **Platform**
  - **Roach2 + GPU**



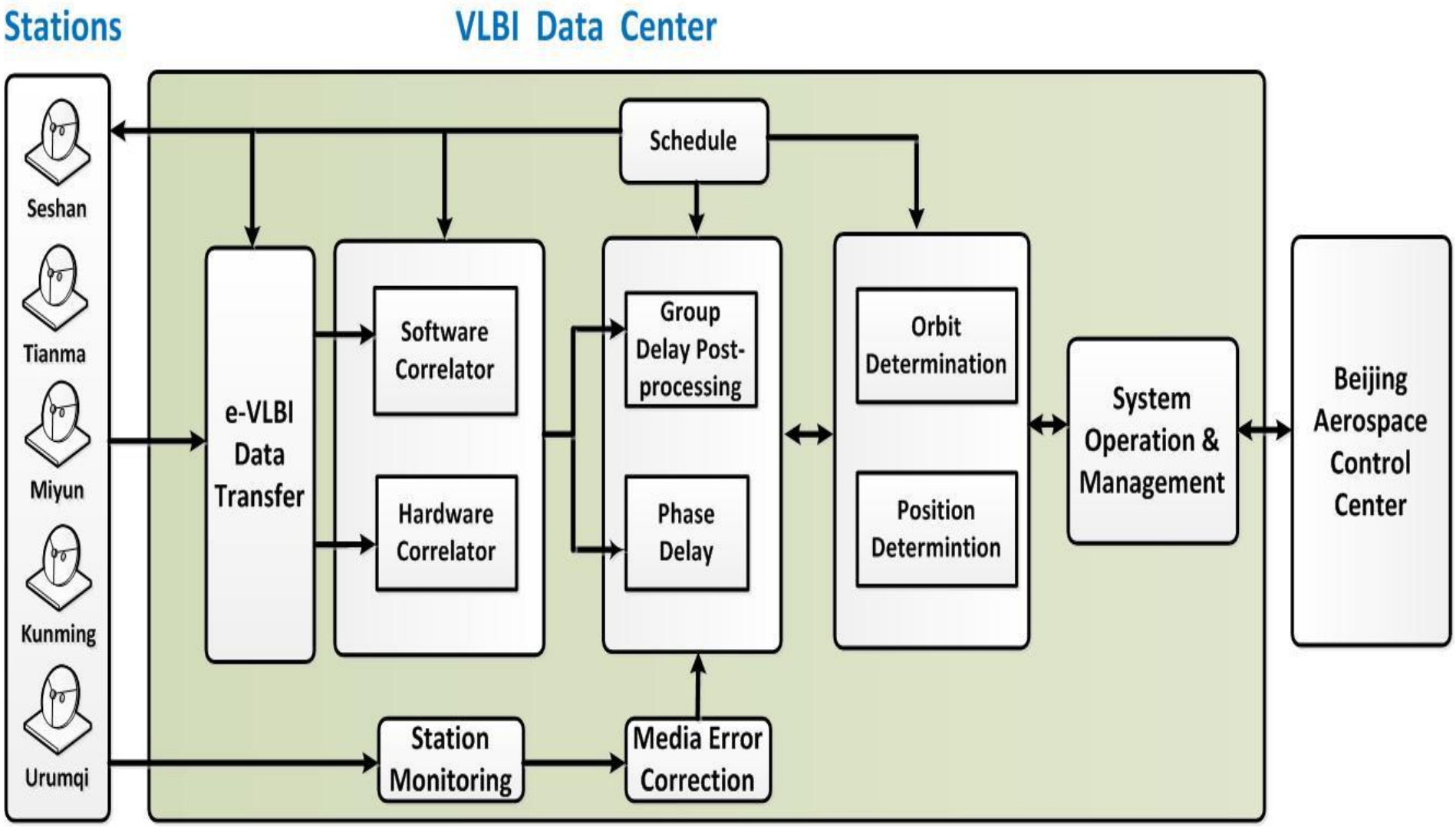


CVN correlator status

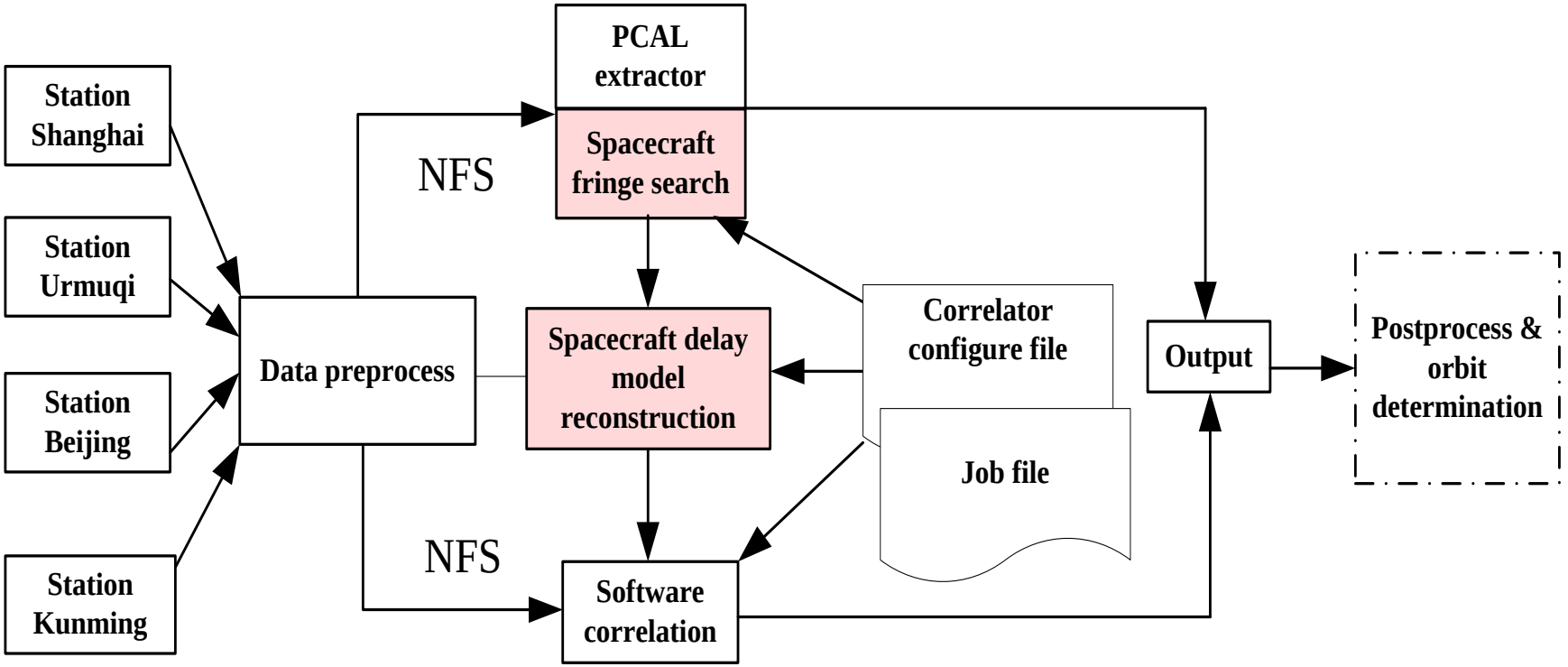
1. Self-developed correlator:
lunar mission & CVN geodesy observations

2. DiFX was installed for IVS data processing (> 2014)

CVN data center real-time pipelines in CE-3



Block diagram software correlator

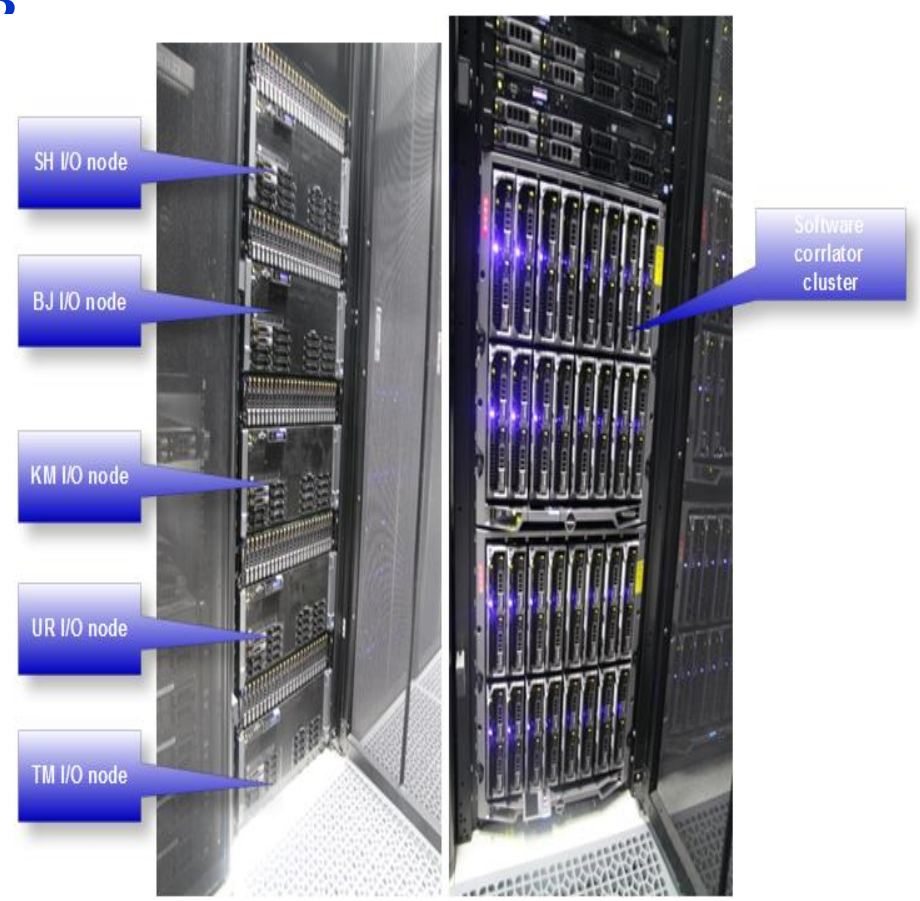


NFS: Network File System

Computing platform

Standard Linux cluster

- **Five I/O nodes**
  - **E7-4820*4/ 128GB/ 300GB+12TB**
- **32 compute nodes*12 cores:**
  fringe search (192 cores)
  + correlation (192 cores)
  - **E5-2640*2/ 32GB/ 300GB**
- **2 manage nodes**
  - **E5-2620*2/ 24GB/ 900GB+214GI**
- **Management network**
  - **10G Ethernet**
- **Compute network**
  - **InfiniBand**



Specifications of CE-3 software correlator

Processing Mode	Real-time & post-processing
Station number	1~20
Real-time fast fringe search	4 stations
IF number	1,2,4,8,16
Frequency channel	24~16384/IF
Integration period	0.1~60 second
Maximum data speed (192 CPU cores)	About 1.9Gbps/station, totally 4 stations
Output format	CVN, FITS-IDI

Development status

- **Increase correlation speed by MPI+Pthreads**

  6 stations * 1.1Gbps/station->2.0Gbps/station

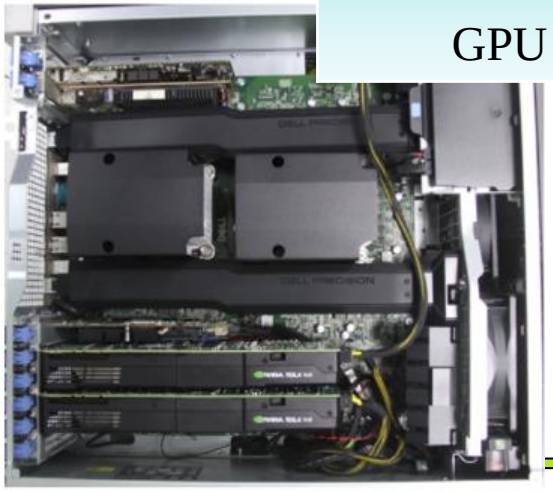
  192 CPU cores
- **GPU acceleration: VGOS application**
- **Geodesy application: Output format CVN--> Mk4,**
- **Pulsar correlation: Pulsar gate**

GPU acceleration correlator prototype

- **Two GPU Nodes**
- **Each node:1 x Nvidia K40c**

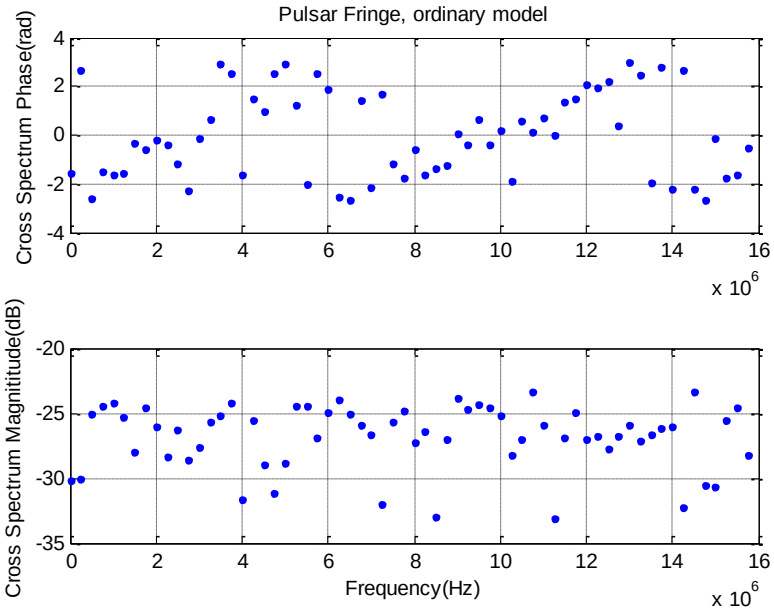
GPU	Speed/station
1 node	337Mbps
2 nodes	670Mbps

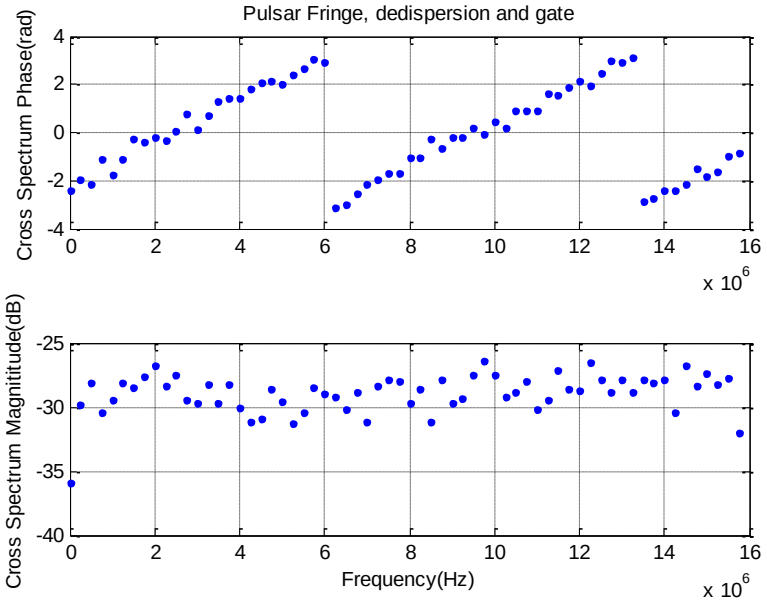
GPU Workstation	DELL T5600
Chipset	Intel C600
CPU	Intel E5-2600 @ 2.00GHz
Memory	64GB
Ethernet	Intel 82579 1Gb NIC
Infiniband	Mellonax ConnectX 40Gb/s QDR
GPU	NVIDIA Kepler K40c



Four station speed test
NVIDA K40C

Pulsar B0329+54 preliminary result

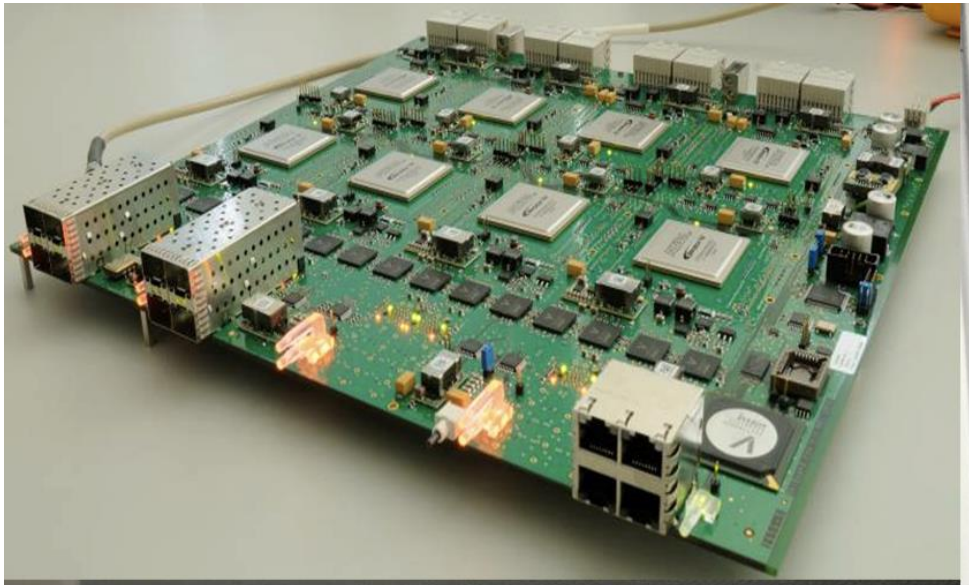


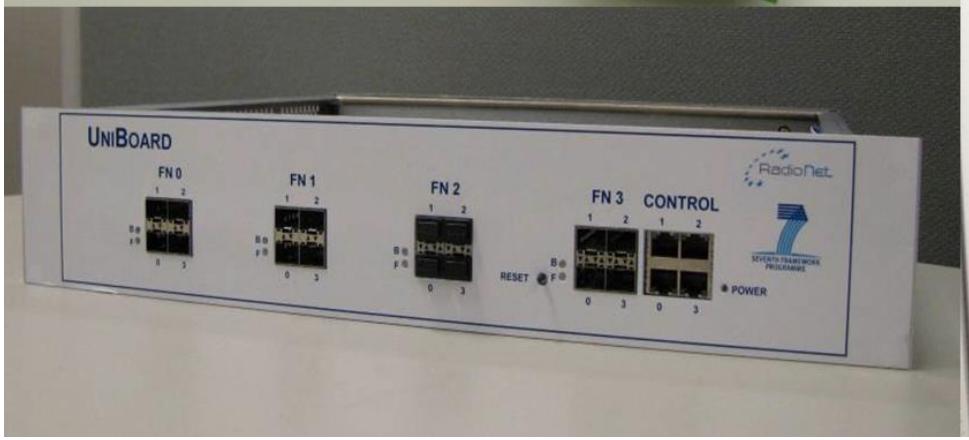


20s integration without pulsar gate and dispersion correction

20s integration with pulsar gate and dispersion correction

Hardware correlator: based on Uniboard





Near Real-time Vs Real-time Mode

Mode	Near Real-time	Real-time
10GbE Interface	4Gbps	8Gbps
IO Interface	6.25Gbps	6.25Gbps
Delay Tolerate	~20s	1s
Buffering	Disk	Memory
Design Difficulty	10GbE, high speed IO	DDR3, system design
Applications	Deep space exploration	VGOS..

Future work

CVN needs a general purpose correlator:

- **Lunar and deep space exploration mission**
- **Geodesy and astronomy data processing**
- **Pulsar binning, multi-phase center ability**
- **VGOS broadband ability**

New correlator

- **CVN, IVS(VGOS), EVAN, AOV**

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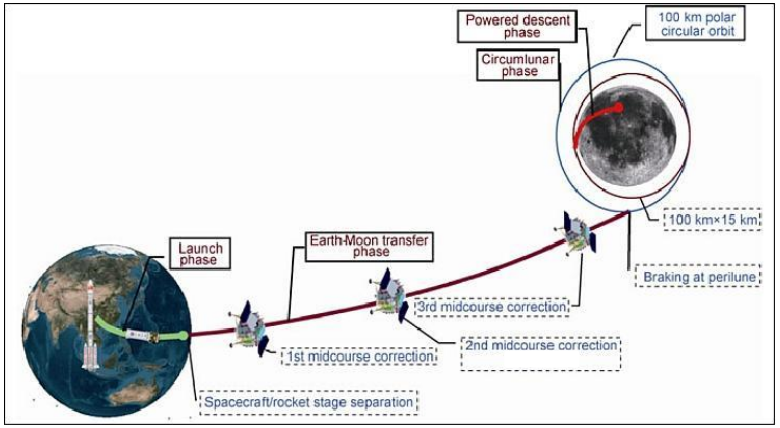
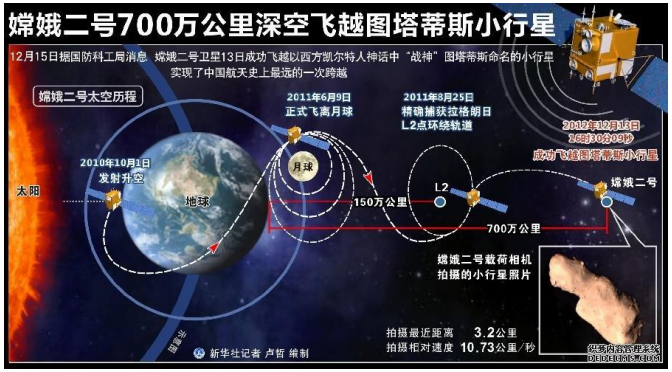
Supported CE Lunar missions

CE-1

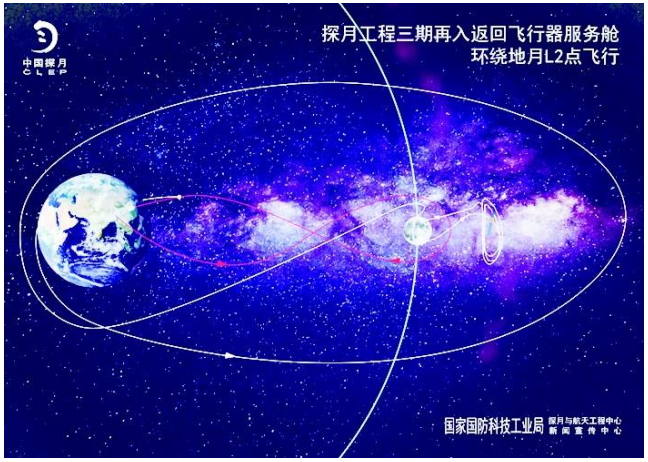
CE-3



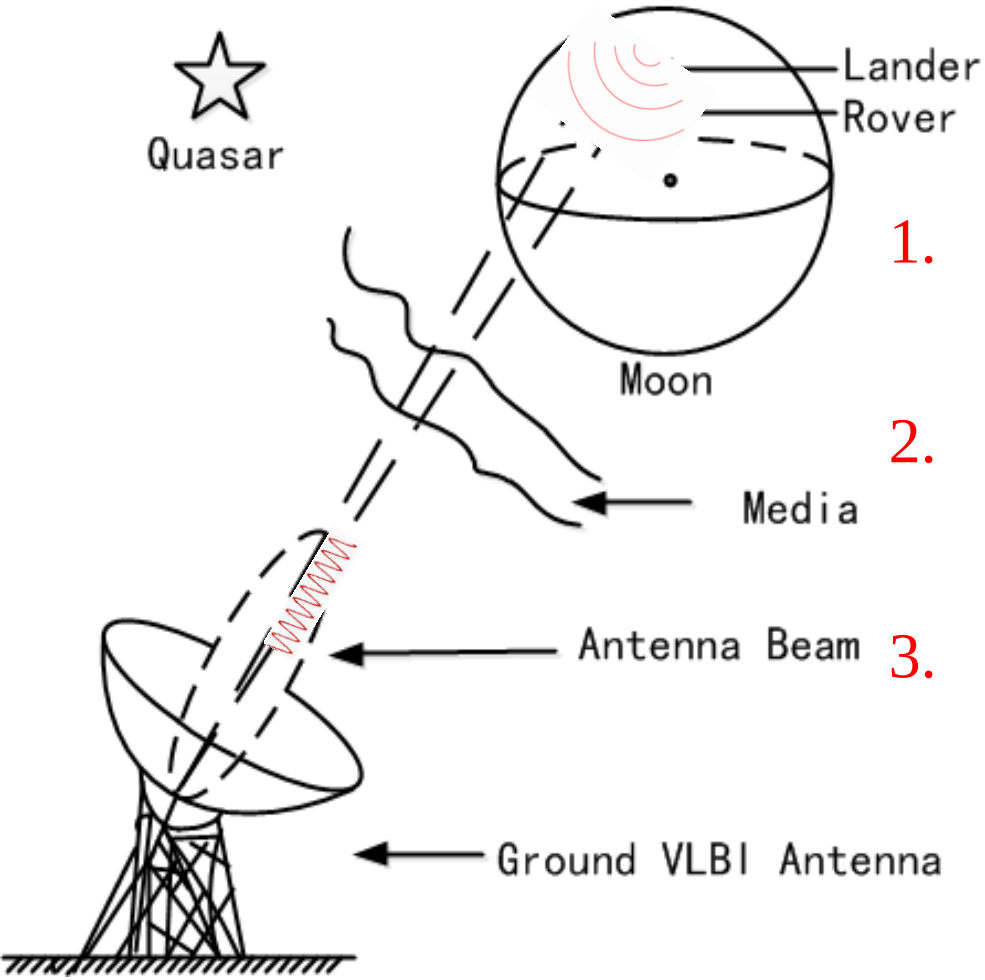
CE-2



CE-5T1



Rover positioning by same-beam VLBI

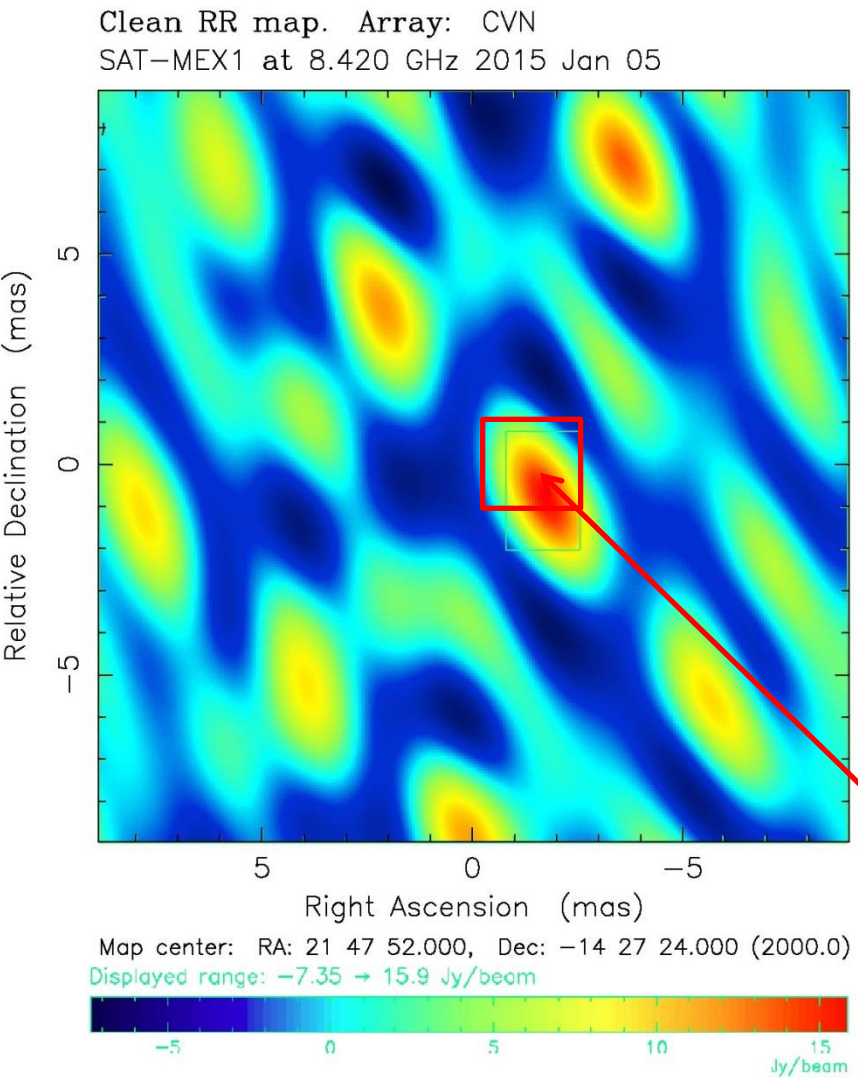


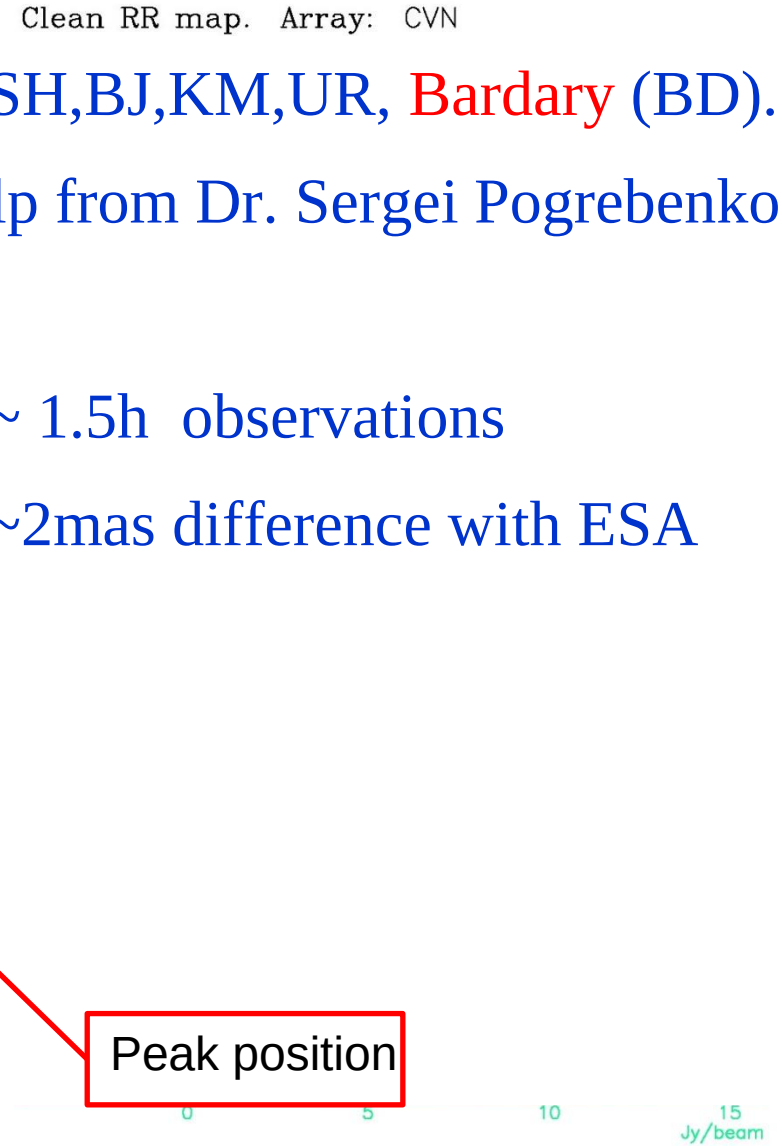
1. Differenced VLBI group delay Real time mode
2. Same beam phase reference image postprocess mode
3. Differenced VLBI phase delay, postprocess

Great improvement over CE-1/2

	Chang'E 3		Chang'E 1/2	
	realization	requirement	realization	requirement
ΔDOR technique	yes	yes	no	no
Same beam VLBI	yes	yes	no	no
Delay error	0.5 ns	4 ns	6 ns	12 ns
Lander position error	< 100m	1000m	N/A	N/A
YuTu relative position error	~1 m	500m	N/A	N/A
Data latency	15-40 seconds	1 minute	6minutes	10 minutes

MEX imaging





- SH,BJ,KM,UR, Bardary (BD).

Help from Dr. Sergei Pogrebenko

- ~ 1.5h observations
- ~2mas difference with ESA

Outline

- Overview
- VLBI terminal & Correlator
- Support the lunar missions
- VOGS antenna
- Space Millimeter VLBI Array

VGOS Station

ShVGOS station located near Tianma 65m telescope

Seshan25 VLBI station location

Antenna Construction

- The antenna is being constructed by a Chinese company CETC 54.

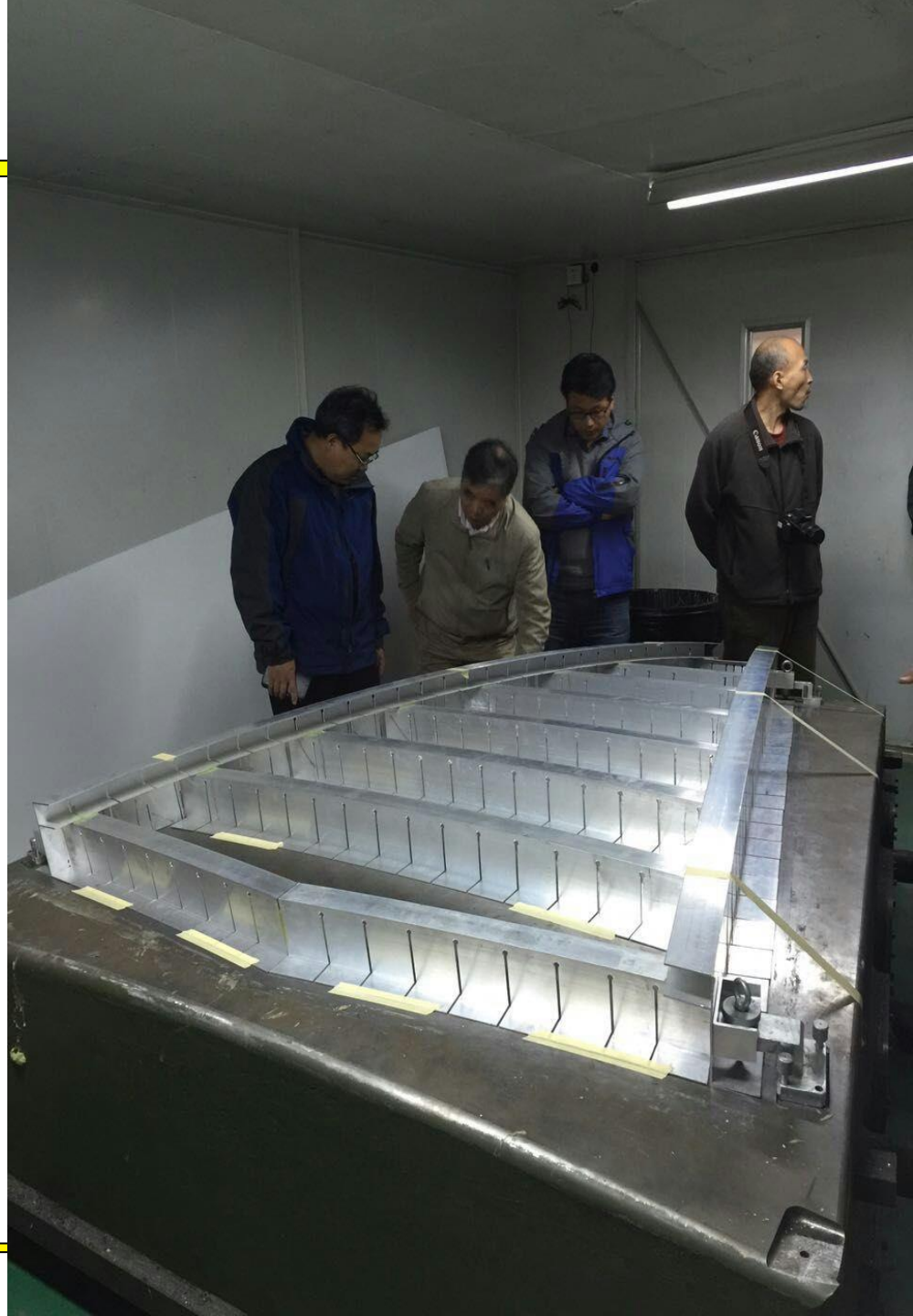
- Similar design as Onsala VGOS station with some modifications considering geological difference.

- 2016, Nov

  Join international observation experiments

Main technical Specifications of Antenna

- Diameter: 13.2m
- RF frequency range: 2.7-15.5GHz, upgradable to Ka band
- Polarization: H&V Linear polarizations
- Optics: Ring focus
- Aperture efficiency: >50%
- Surface accuracy: <0.3mm
- Pointing accuracy： <18”
- Antenna mount: az-el turntable mount
- Slew rate: az 12^{o}/s, 2.5^{o}/s^{2} ; el 6^{o}/s, 2.5^{o}/s^{2}
- Slew range: az -270^{o}~+270^{o}; el 0^{o}~90^{o}
- Reference point stability: ＜0.3mm
- Signal path length stability: ＜0.3mm



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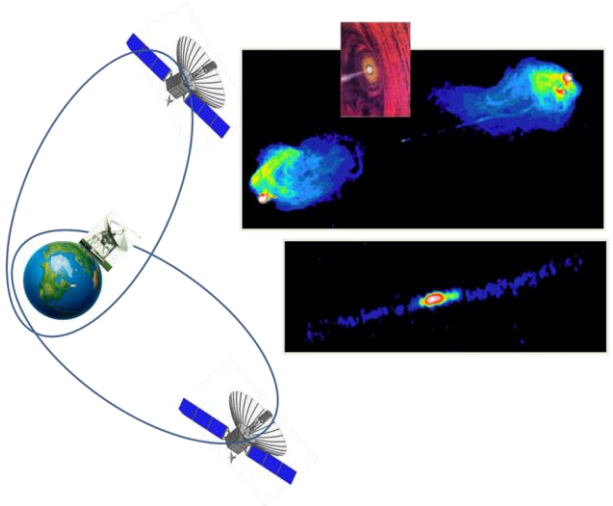
Space Millimeter VLBI Array (SMVA)

Main Scientific Objectives:

- Black Hole Shadow (e.g. M87)
- Astrophysical Jet in Active Galactic Nuclei (AGN)
- Disk structure & dynamics, SMBH mass (water mega-masers)

Specifications:

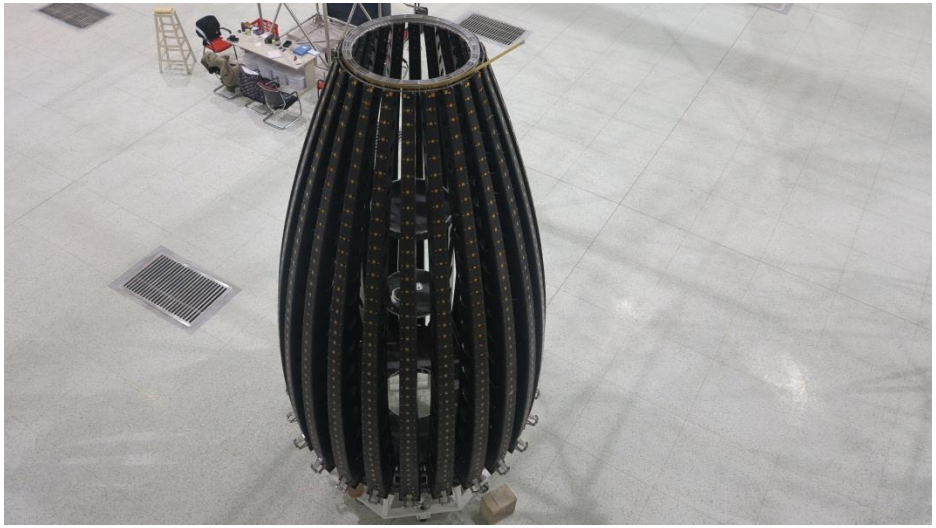
- Two 10-m (in diameter) antennas
- Three frequency bands (8, 22 & 43 GHz)
- Dual polarization (LCP/RCP)
- Angular resolution: 20 micro-arc-second
- Optimized orbits for a better (u,v) coverage
  - ✓ Apogee: 60,000 km
  - ✓ Perigee: 1,200 km
  - ✓ Inclination: 28.5°
- Life time: 3 year



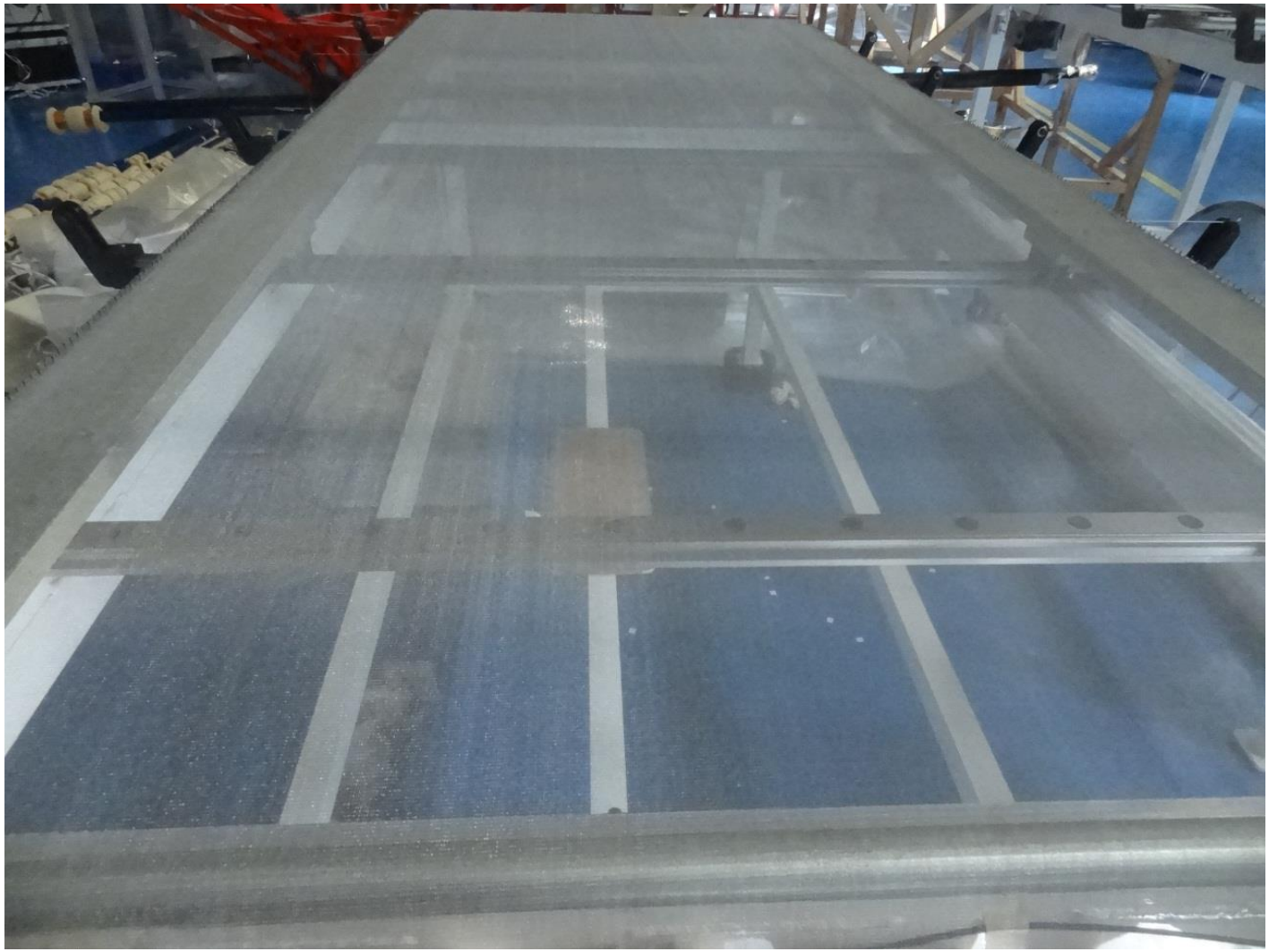
Background research project of CAS:

- Prototype research will complete 2015

Completed prototype antenna structure assembly



The mesh

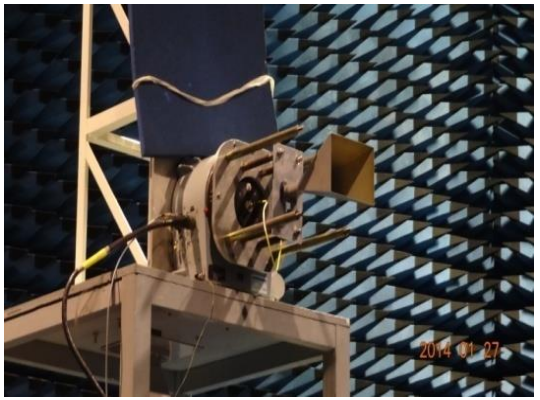


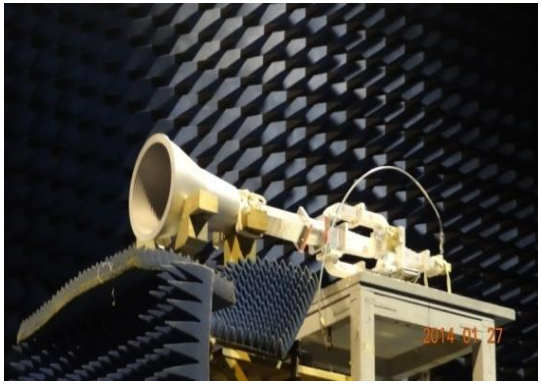
Feed horn

K/Q-band light-wall horn

X-band corrugated horn

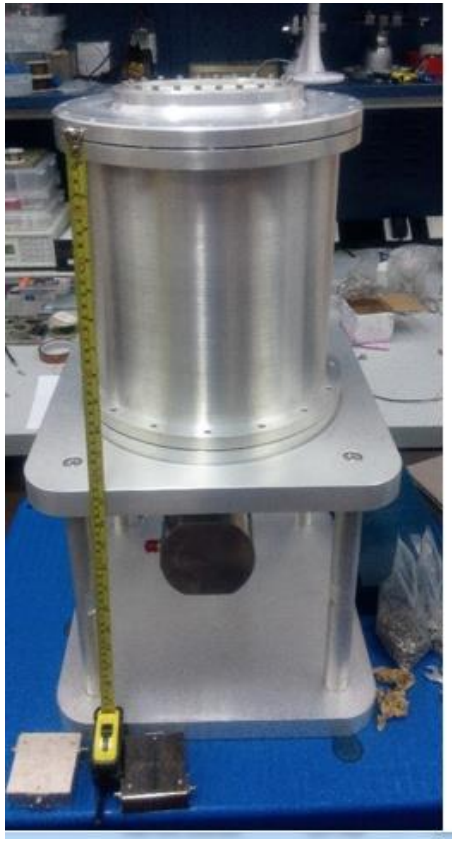
Horn test

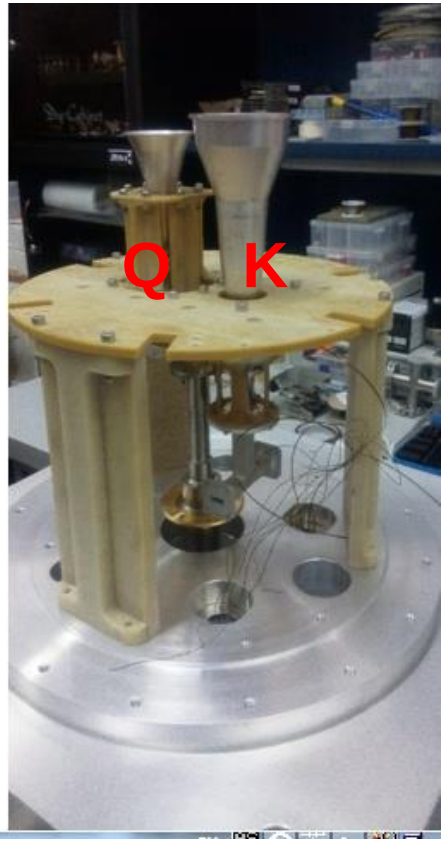


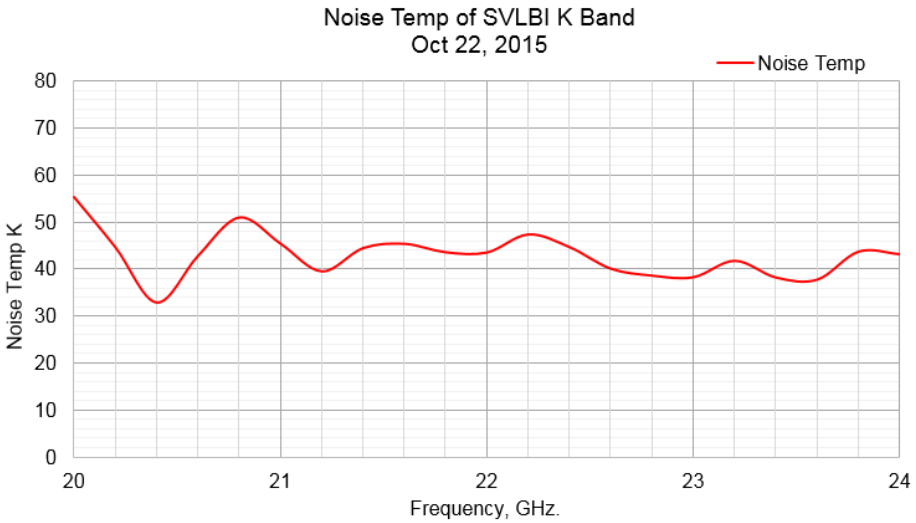


K and Q band cooler receiver

K and Q band cooler receiver prototype

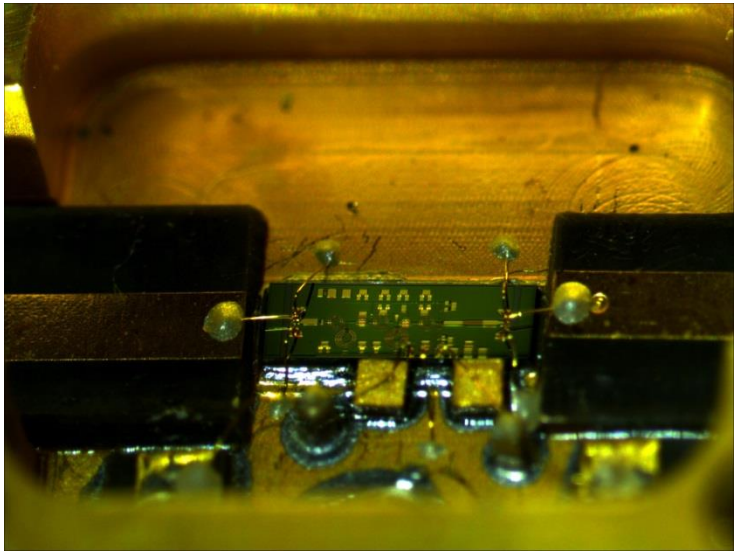


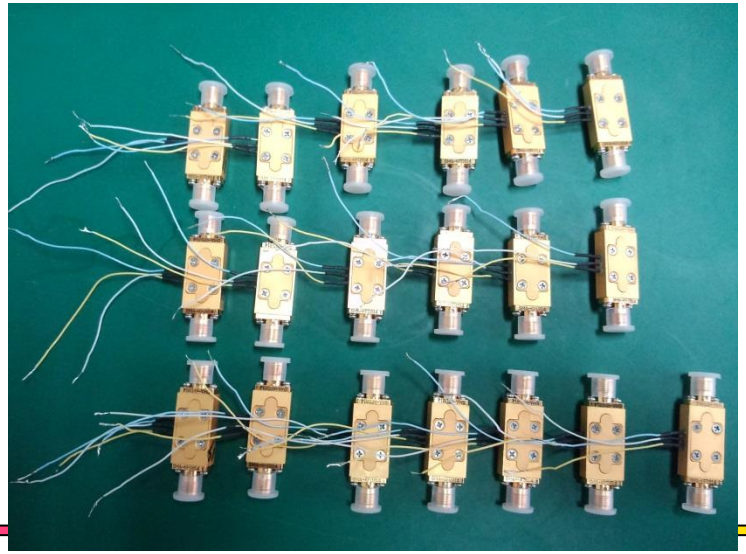


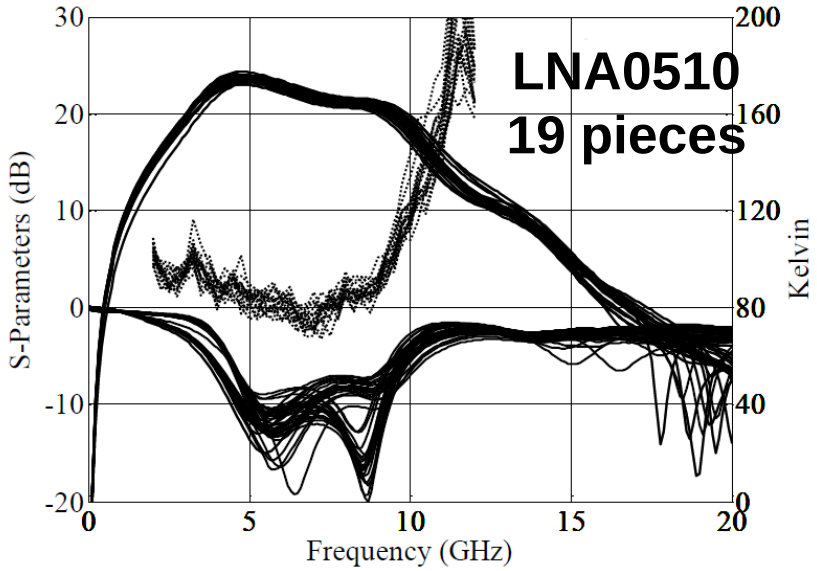


K noise temperature Tc=45 k

LNA



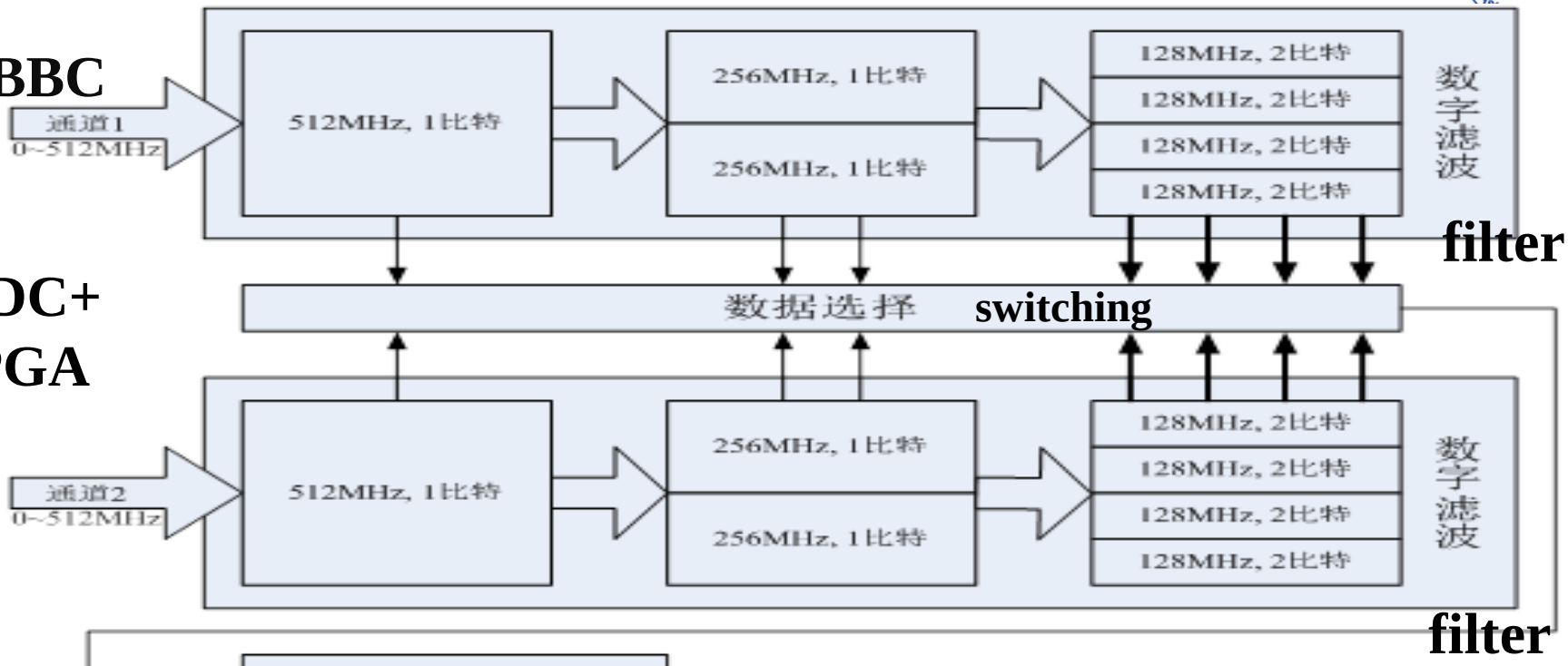



LNA0510
19 pieces
S-Parameters (dB)
Kelvin
Frequency (GHz)
30
20
10
0
-10
-20
200
160
120
80
40
0
0
5
10
15
20

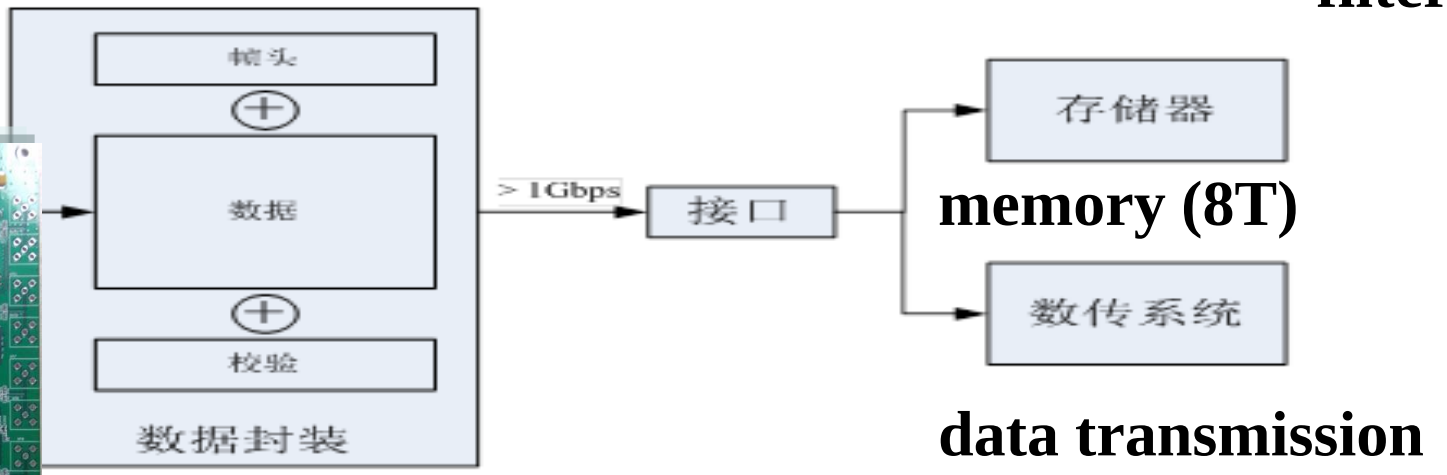
Onboard DBBC

DBBC

ADC+
FPGA



1Gbps

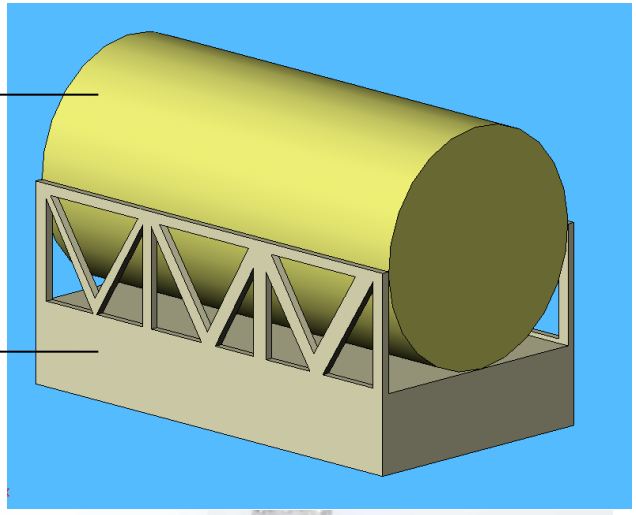


data package

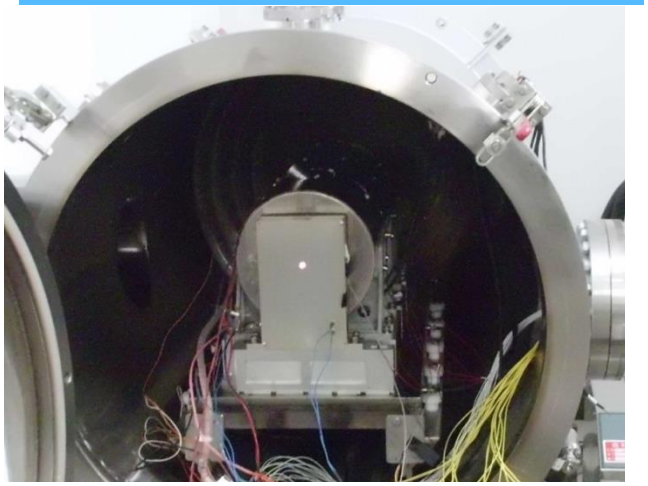
Onboard hydrogen maser

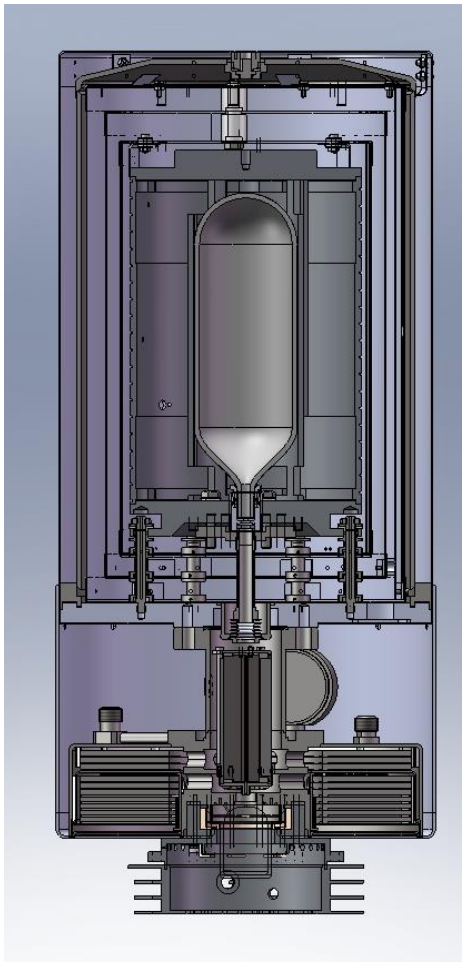
Physical part

Circuit part



Onboard H-Maser





Thanks for your attention!