TianMa Telescope
(Shanghai 65m radio telescope)

Shanghai Astronomical Observatory

Tianma telescope team

Content

1. Construction and performance test

2. Radio astronomical observation

3. Application for tracking deep spacecraft

TianMa Telescope Team

Brief introduction

Tianma Telescope is a steerable radio telescope with a diameter of 65 m, built during 2009-2013. Tianma telescope greatly improves the measurement capabilities of Chinese VLBI network and plays an important role in deep space exploration and astronomy researches.

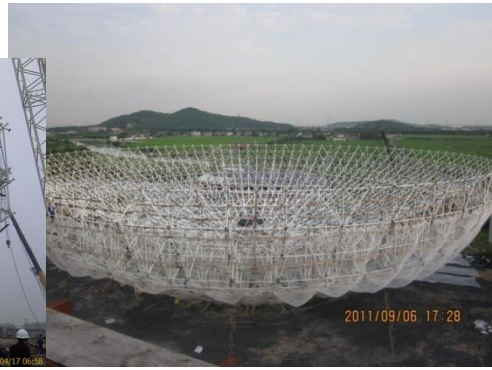
Measurement results of main technical parameters

Antenna diameter	**65m**
Accuracy of main reflector surface (rms)	**0.28 mm**
Best pointing accuracy	**3 arc sec**
Telescope efficiency	**66.6%（L）、62.8%（S)、66.6%（C）、63.0%（X）62.2%（Ku）、54.7%（K）、52.6%（Ka）、52.8（Q）**
Noise temperature of telescope system	**20.8K（L）、20.7K（S）、21.6K（C）、22.5K（X）22.2K（Ku），39.7K（K）、55.8K（Ka），74.3K（Q）**
Switching time between bands	**59.5s**
Maximum speed and acceleration	**0.51°/s，0.277°/s^2（AZ） 0.304°/s，0.166°/s^2（EL）**

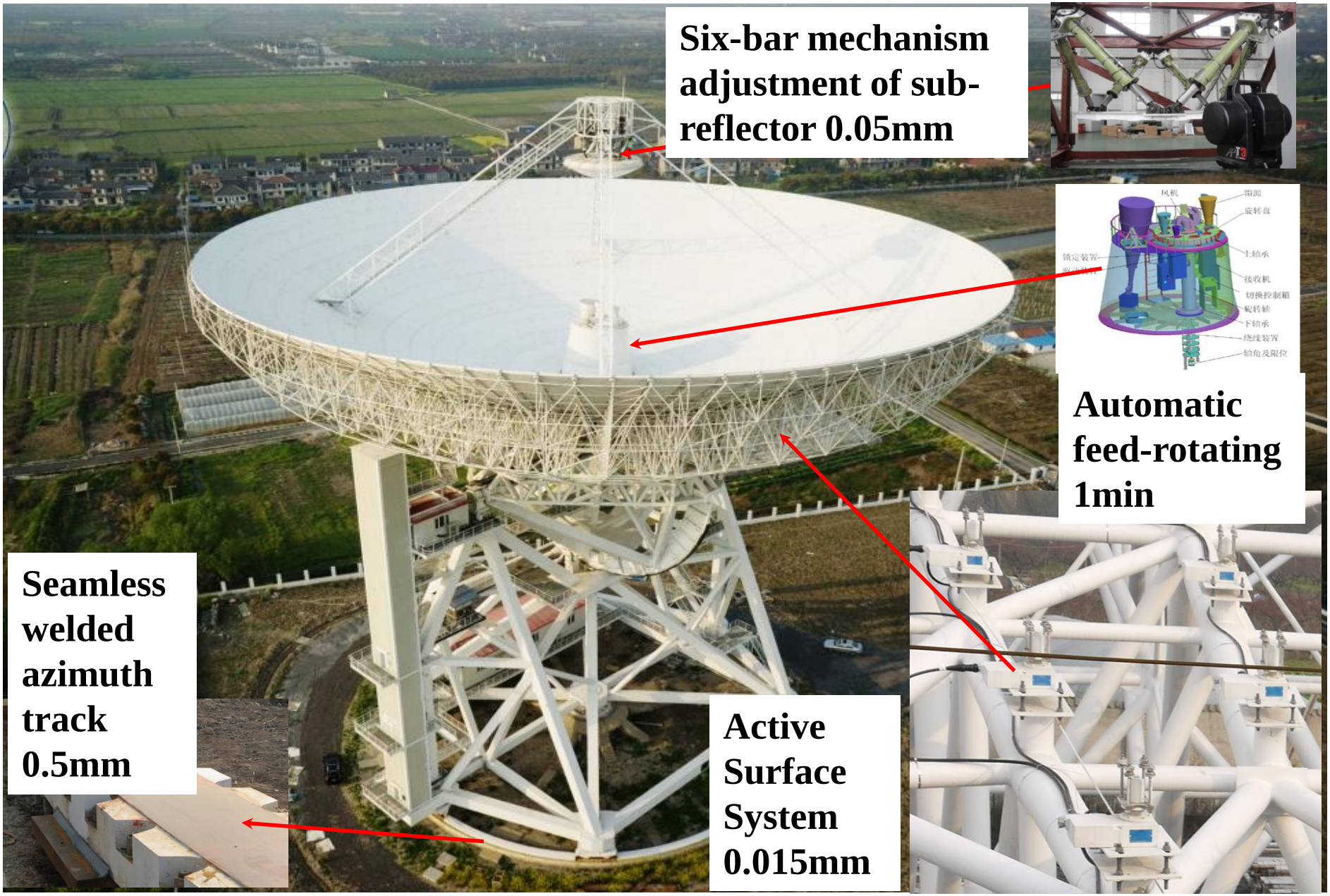
Preliminary results of Tianma telescope

- **Tianma telescope has successful tracked Chinese lunar mission CE-2 in 2012, Lunar soft landing mission CE-3 in 2013, ChangE-5 flight test mission in 2014 , CE- 4 relay satellite in 2018 for VLBI orbit determination.**
- **Tianma telescope successfully carries out observations for spectra lines, pulsar and VLBI radio astronomy, and opened to the outside world.**

Construction of Tianma telescope



Tianma telescope major innovative points



Six-bar mechanism adjustment of sub-reflector 0.05mm

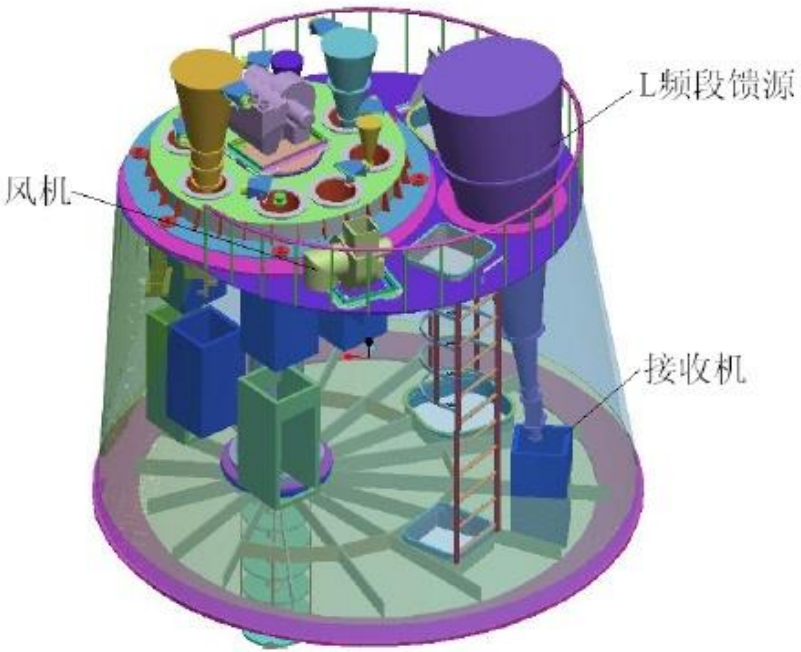
Automatic feed-rotating 1min

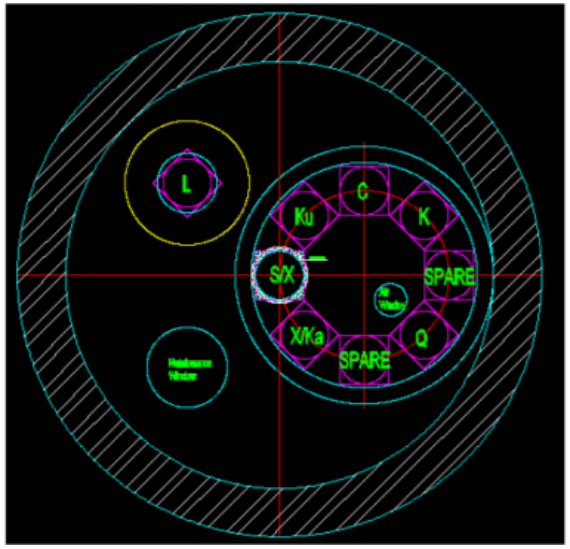
Seamless welded azimuth track 0.5mm

Active Surface System 0.015mm

The azimuth rail of the telescope is welded as a whole, and its surface irregularity is 0.5 mm RMS.

Automatic feed-rotating mechanism

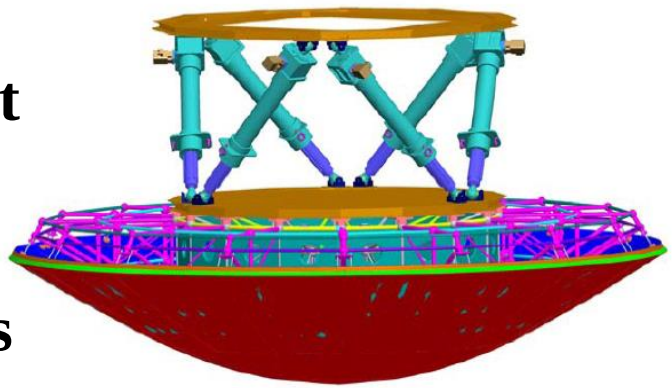


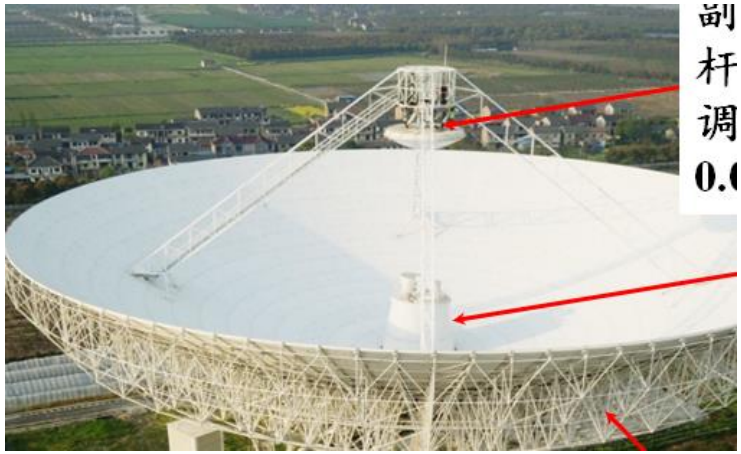


Completing observation band switching within 1 min

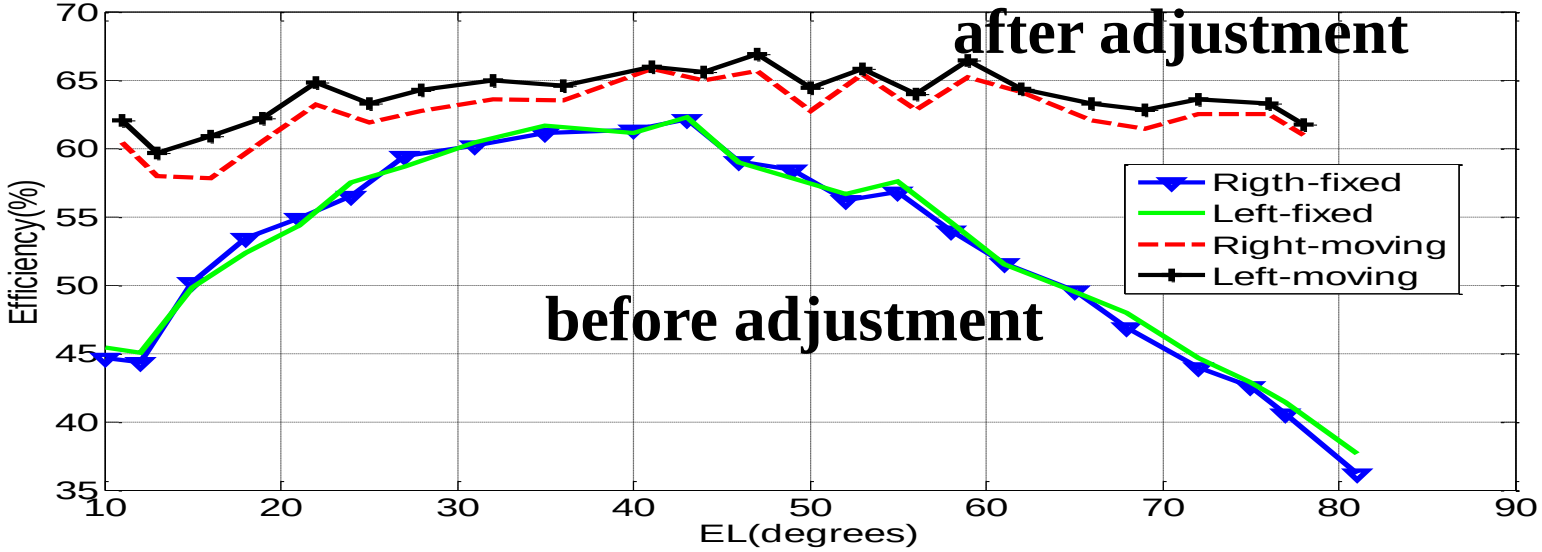
Adjustment of sub-reflector by six-bar mechanism

X、Y、Z Adjustment amount: A few centimeters





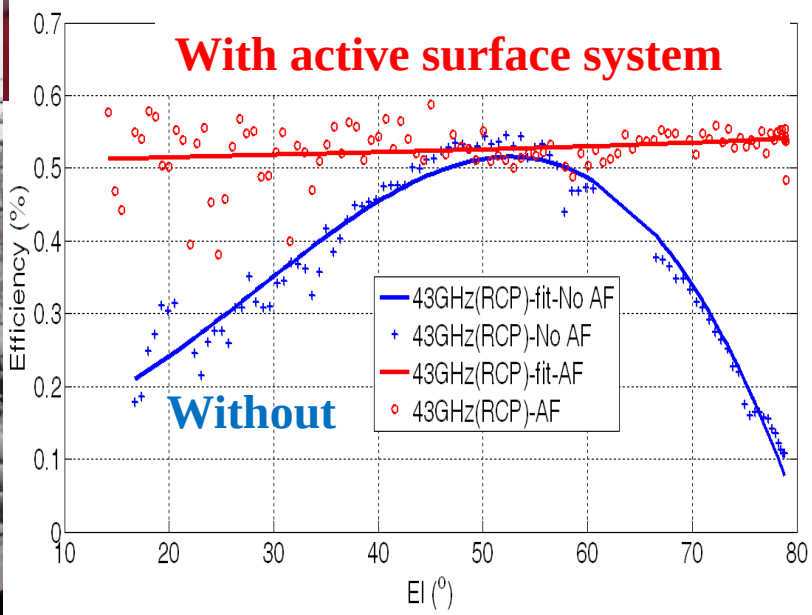
The left- and right-hand circular polarization efficiency of X band before and after adjustment of sub-reflector position and attitude.



Active surface system

Actuators: 1104

Range±15mm, accuracy 0.015mm



Phase reference holography technique for measuring surface accuracy of main reflector

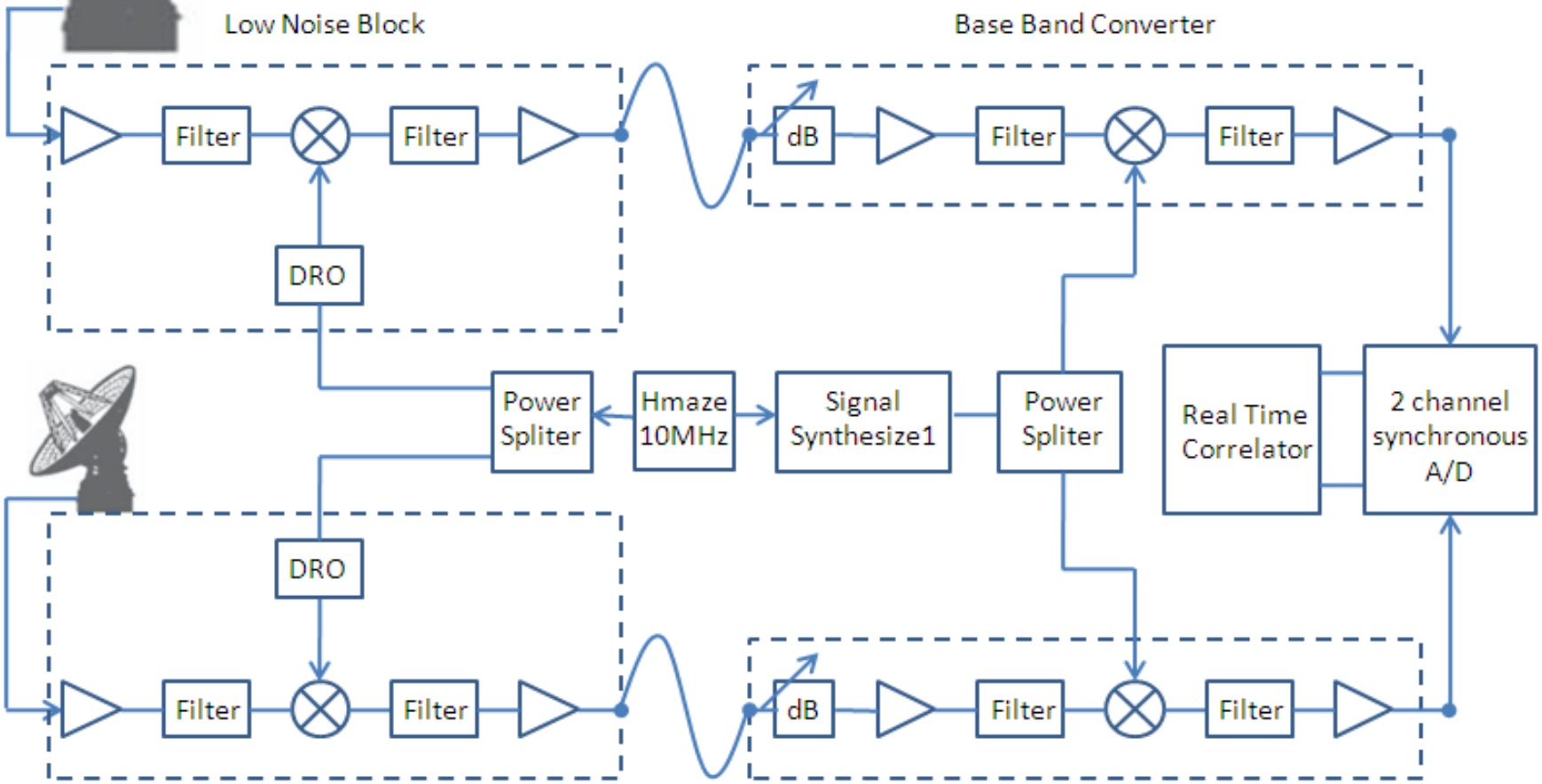
geostationary satellite

Input freq = 12.2GHz ~ 12.75GHz
Output freq = 900MHz ~ 1450MHz
Gain = 60dB
LO = 11.3GHz

Low Noise Block

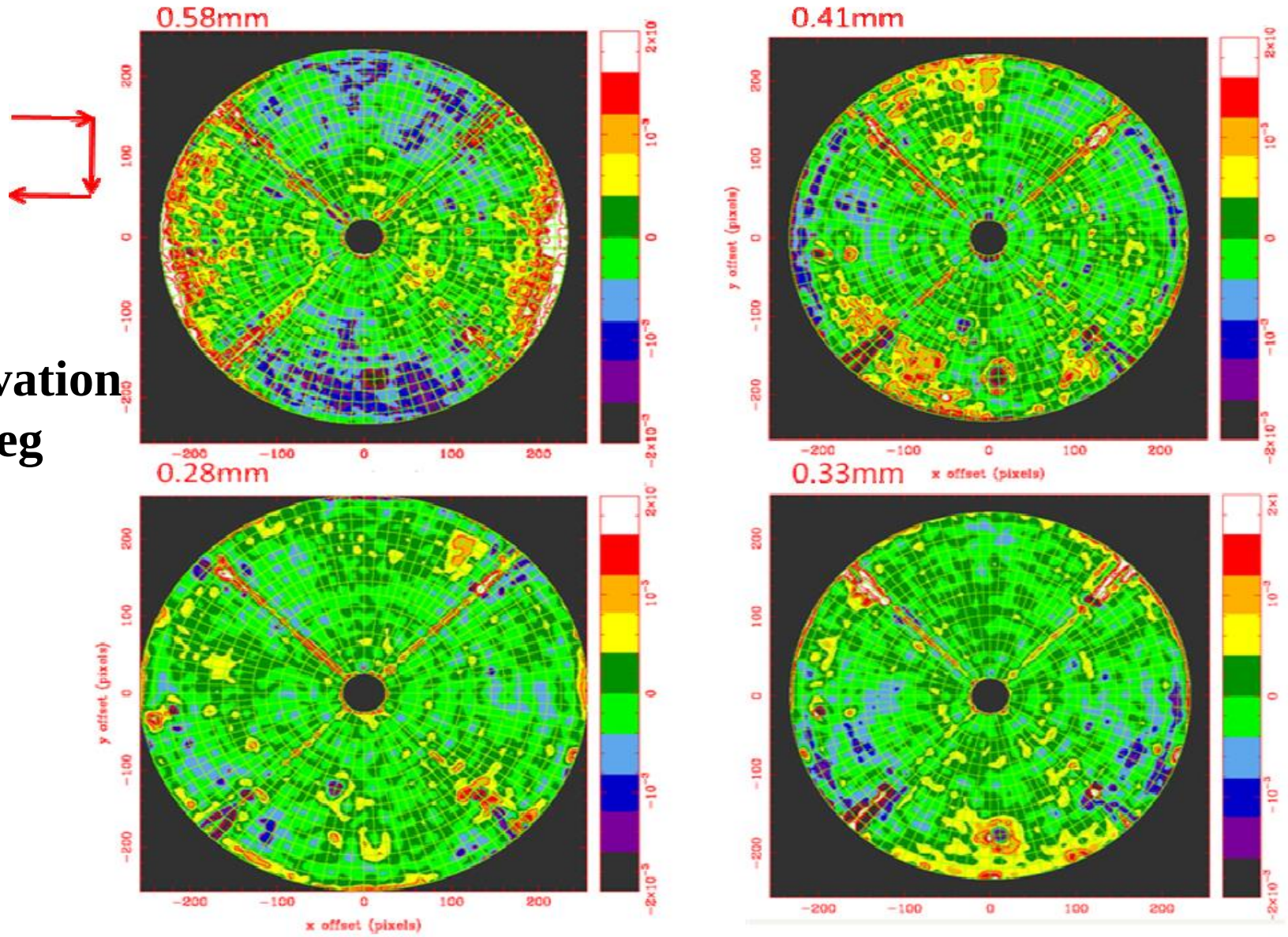
Input freq = 900MHz ~ 1450MHz
Output freq = 100KHz ~ 15MHz
Gain = 30dB
Adjustable Atten = 30dB

Base Band Converter



Surface accuracy of main reflector at 52deg elevation measured by using phase reference holography technique

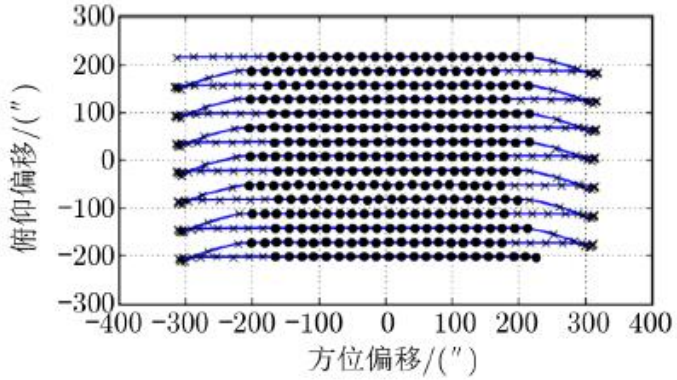
Elevation 52deg

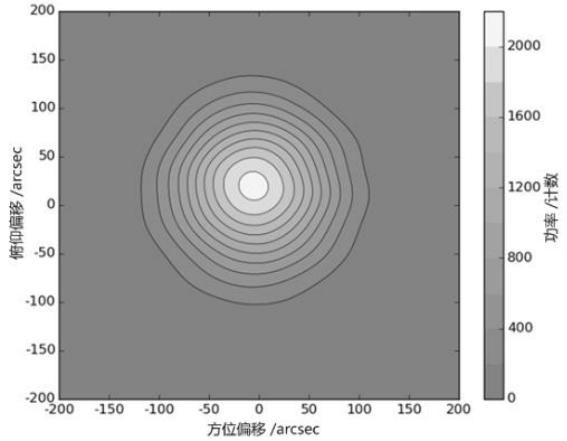


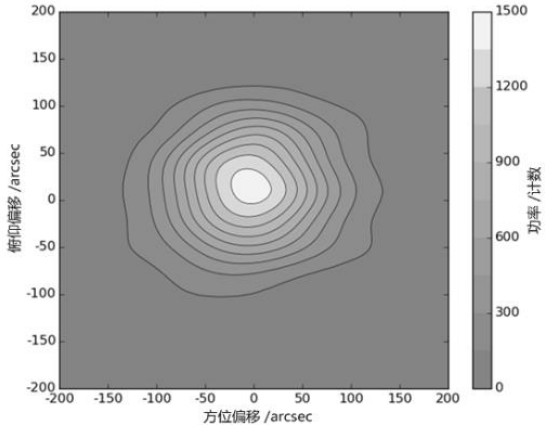
Out-of-focus holographic measurement

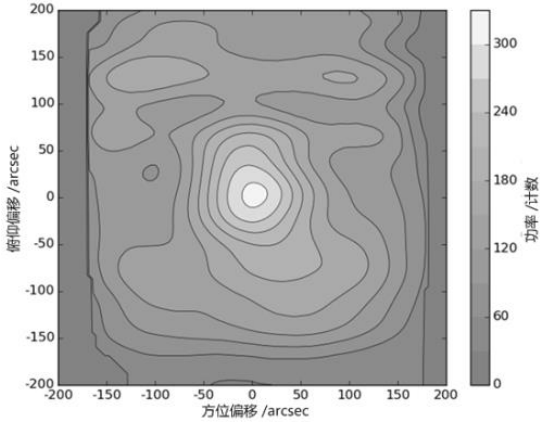
Measuring process: 50 deg elevation, x band, 80 MHz bandwidth, AZ direction OTF scanning

The Z-direction of the sub-reflector is located at (- 25 mm, 0, + 25 mm) to measure the antenna pattern respectively。

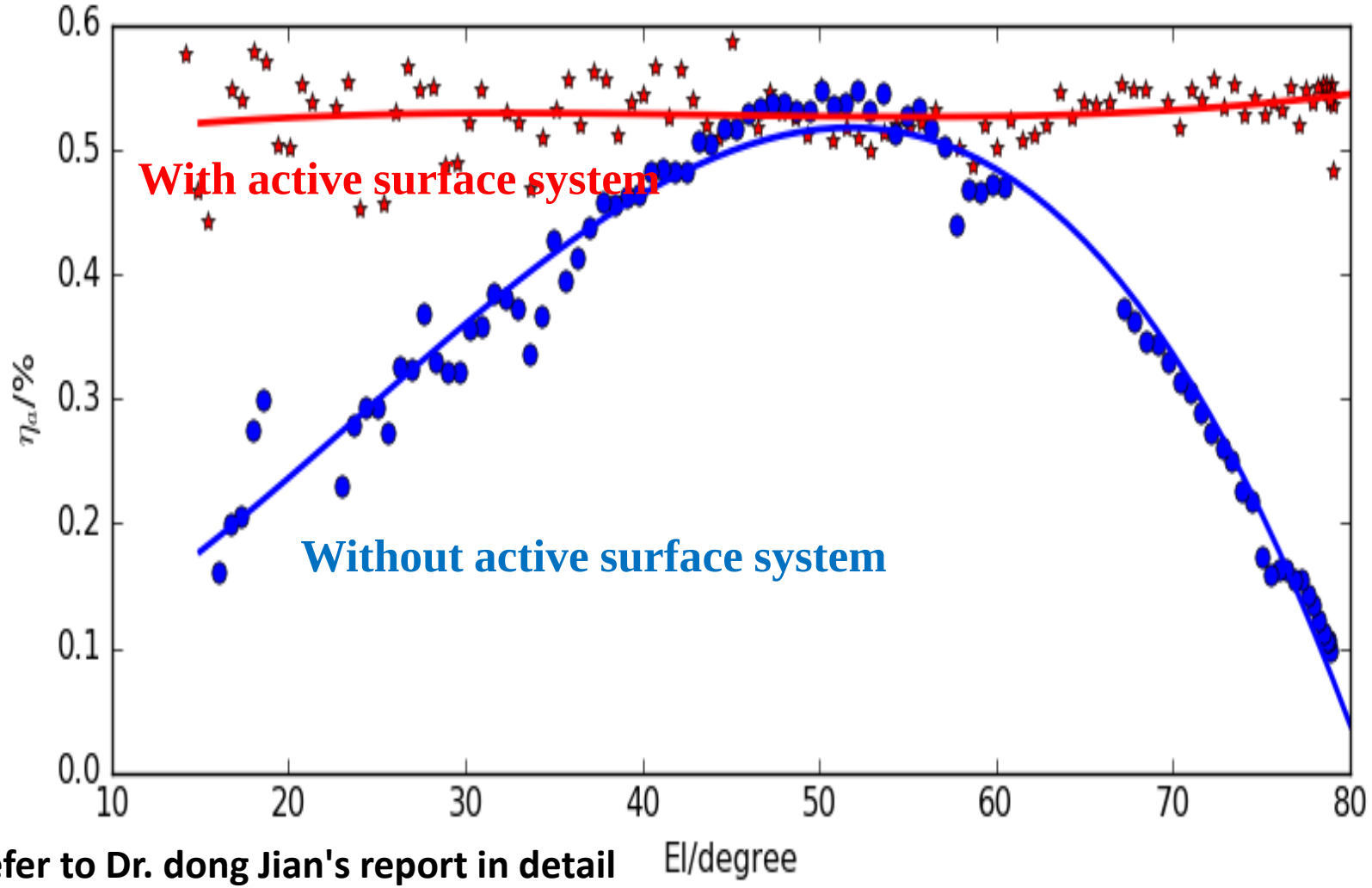








After adjusting with the active surface system, the of Q-band efficiency has reached more than 50 % in all elevation angles



Refer to Dr. dong Jian's report in detail

Receiving system of Tianma telescope

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

VLBI terminal (DBBC/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)

L, K, Q-band receivers developed by SHAO
C and Ku band (NRAO), S/X and X/Ka (CETC 16)

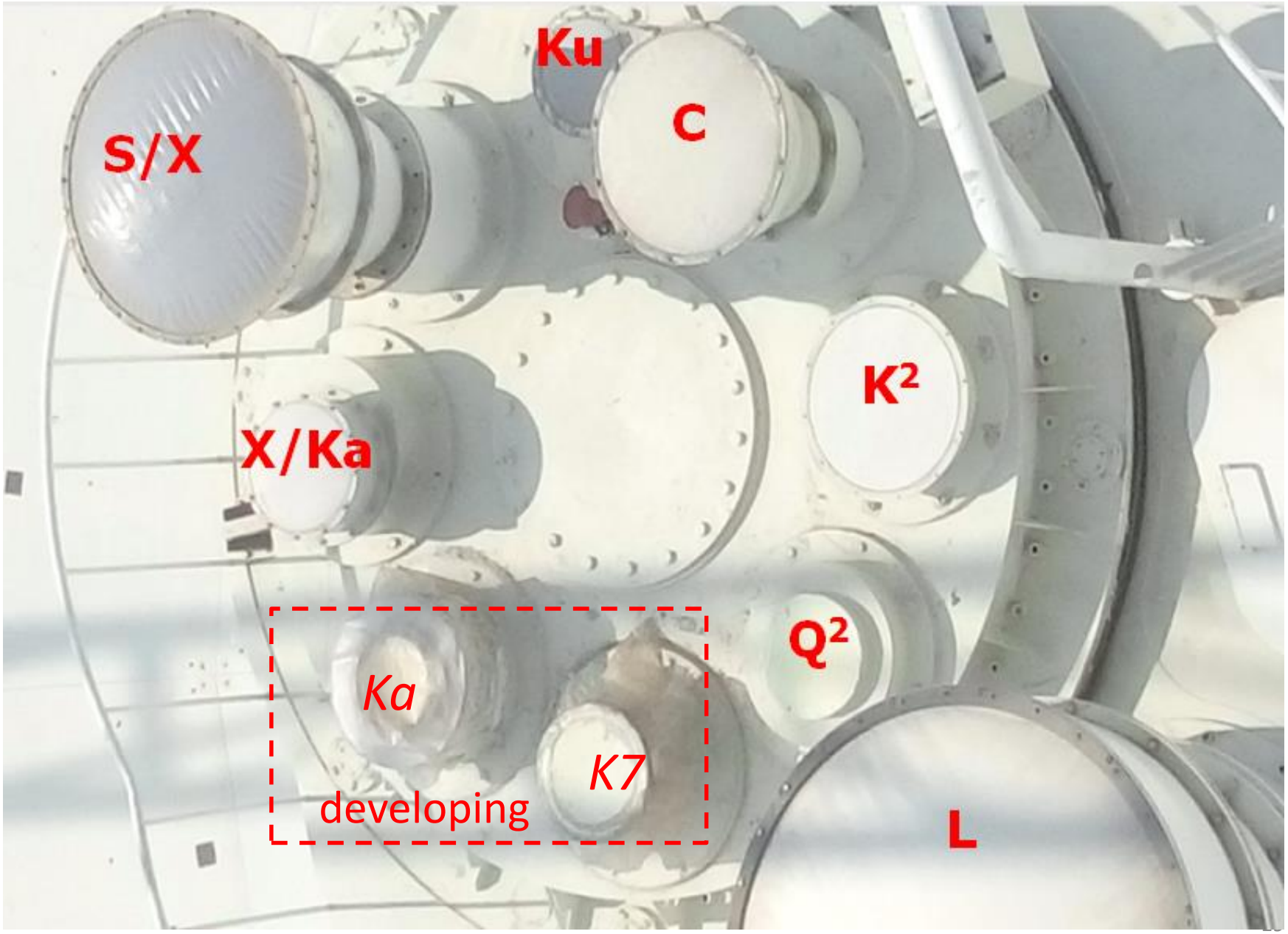
1.25-1.75

18-26.5

35-50 GHz

Refer to Zhong weiyedong's report in detail

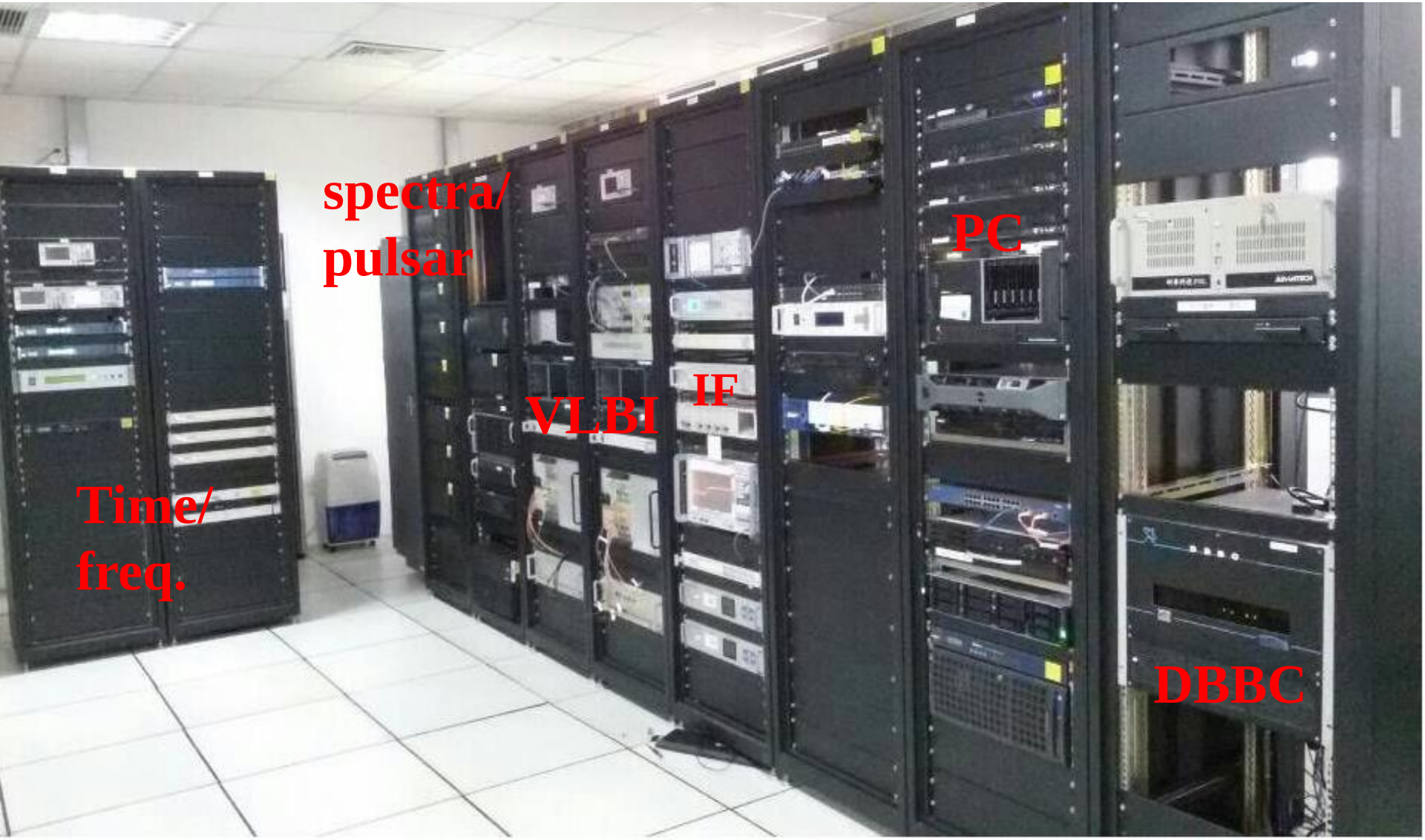
Receiver feed horn



Receiving system parameters

Band	L	S	C	X	Ku	K	Ka	Q
Wavelength	21cm	13cm	6cm	3.6cm	2.2cm	1.3cm	9mm	7mm
Freq(GHz)	1.25-1.75	2.2-2.4	4-8	8.2-9.0	12-18	18-26.5	30-34	35-50
BW(GHz)	0.50	0.20	4.00	0.80	6.00	8.50	4.00	15.00
SEFD（Jy）	39	46	31	48	56	100	100	117
T(Sys)(K)	26	33	20	32	27	60	60	66
Feed Type	Compact	Conical	Conical	Conical	Conical	Compact	Conical	Compact
Efficiency	55%	60%	65%	55%	55%	50%	50%	50%
Polarization	Dual Circ	Dual Circ	Dual Circ	Dual Circ	Dual Circ	Dual Circ	Dual Circ	Dual Circ

Terminals



Terminals

VLBI（CDAS-2,DBBC）

Refer to Wu Yajun's report in detail

Spectra line/pulsar
（DIBAS-NRAO）

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EVN and IVS VLBI observations

- **Tianma telescope has taken part in EVN VLBI observations at L , C and S/X band since 2015, and sometime was selected as the reference telescope in correlation processing.**
- **Tianma telescope also took part in EVN e-VLBI observations with a data transfer rate of 1 Gbps.**
- **Tianma telescope took part in IVS conventional observations for 5 times in 2015, and planning for 7 times in 2016.**

coordinate	position (mm)	Position error (mm)	velocity (mm/yr)	Velocity error (mm/yr)
X	-2826708649.89	7.305	-31.42	5.600
Y	4679237081.85	11.773	-17.47	7.517
Z	3274667547.20	8.408	-16.80	6.114

East Asia VLBI observations（2017）

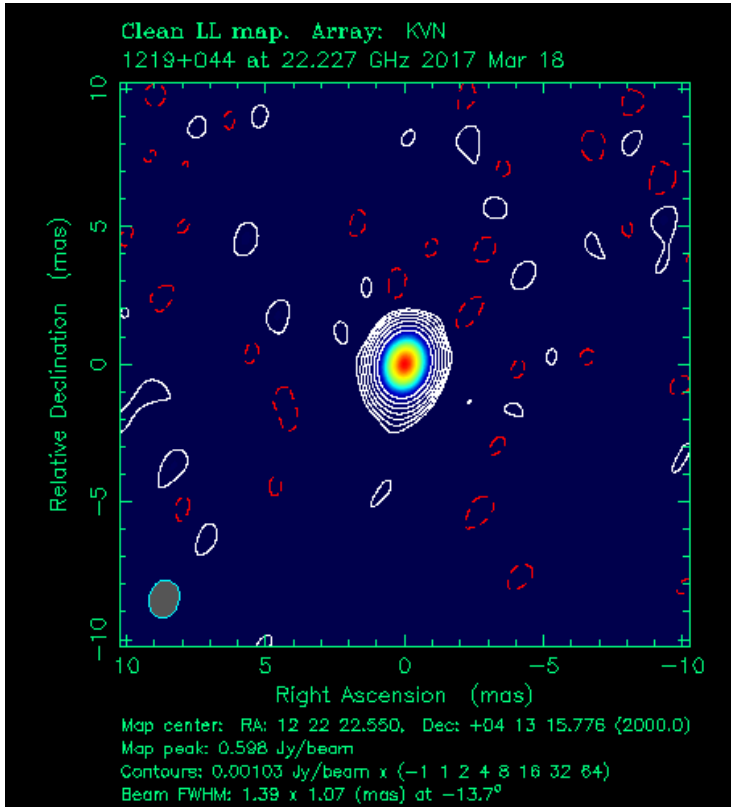
	Date	UT time	Target	Freq.	Stations
1	3/12	18:55 – 00:55 (6hr)	SgrA	43GHz	KaVA7, TM
2	3/18	12:45 – 19:45 (7hr)	M87	22GHz	KaVA7, TM, UR, HT, KS
3	3/19	11:40 – 18:40 (7hr)	M87	43GHz	KaVA7, TM
4	3/27	13:10 – 23:10 (10hr)	M87+SgrA	43GHz	KaVA7, TM
5	4/3	13:20 – 23:20 (10hr)	M87+SgrA	22GHz	KaVA7, TM, UR, HT, KS, MC
6	4/4	12:35 – 22:40 (10hr)	M87+SgrA	43GHz	KaVA7, TM
7	4/9	12:20 – 22:20 (10hr)	M87+SgrA	43GHz	KaVA7, TM, NY
8	4/14	12:00 – 22:00 (10hr)	M87+SgrA	43GHz	KaVA7, TM
9	4/17	11:45 – 18:45 (10hr)	M87	22GHz	KaVA7, TM, UR, HT, KS, SJ, MC, NT
10	4/18	11:40 – 21:45 (10hr)	M87+SgrA	43GHz	KaVA7, TM
11	4/24	09:20 – 16:20 (7hr)	M87	22GHz	KaVA7, TM
12	4/25	09:15 – 16:15 (7hr)	M87	43GHz	KaVA7, TM
13	4/26	15:55 – 21:55 (6hr)	SgrA	43GHz	KaVA7, TM, SJ
14	5/10	08:20 – 17:20 (7hr)	M87	22GHz	KaVA7, TM, MC
15	5/11	08:15 – 17:15 (7hr)	M87	43GHz	KaVA7, TM
16	5/25	14:00 – 20:00 (6hr)	SgrA	43GHz	KaVA7, TM
17	5/26	07:15 – 16:15 (7hr)	M87	43GHz	KaVA7, TM

EHT period

TM: Tianma, UR: Urumqi, SJ: Sejong, HT: Hitachi,
KS: Kashima, NY: NRO45, MC: Medicina, NT: Noto

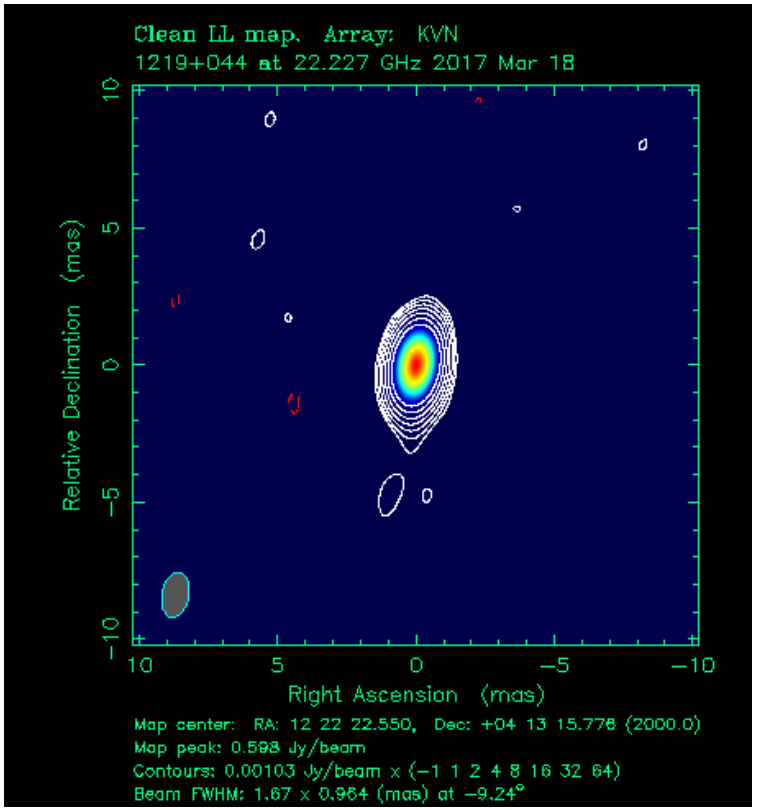
Snapshot images on a point source (22GHz, 10min integration)

Only KaVA



Peak: 598mJy; Rms: 0.52mJy; DR: 1150

KaVA + Tianma



Peak: 598mJy; Rms: 0.34mJy; DR: 1758

~50% increase in image dynamic range

Tianma pulsar observation

The DIBAS pulsar observation modules were finished and installed at Tianma telescope in June 2014. This backend supports four principal pulsar observation modes:

[1] coherent dedispersion search;

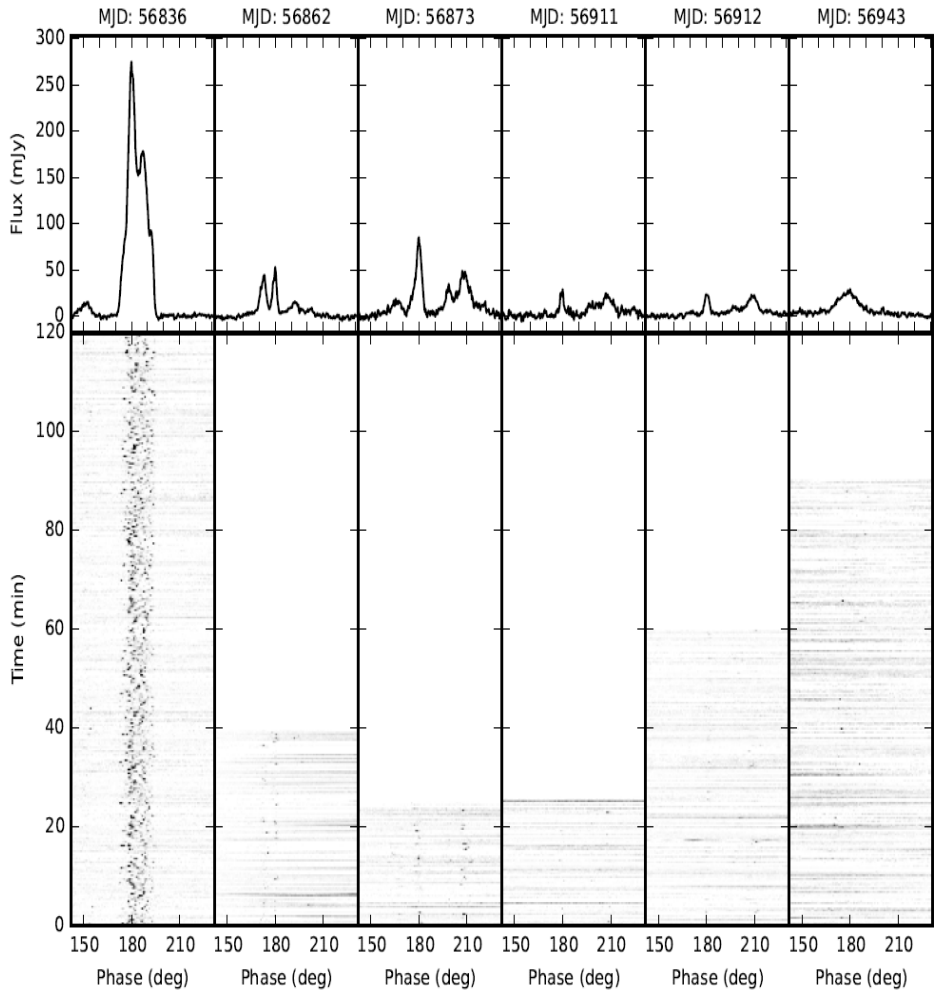
[2] incoherent dedispersion search;

[3] coherent online folding;

[4] incoherent dedispersion online folding.

Pulsar observation

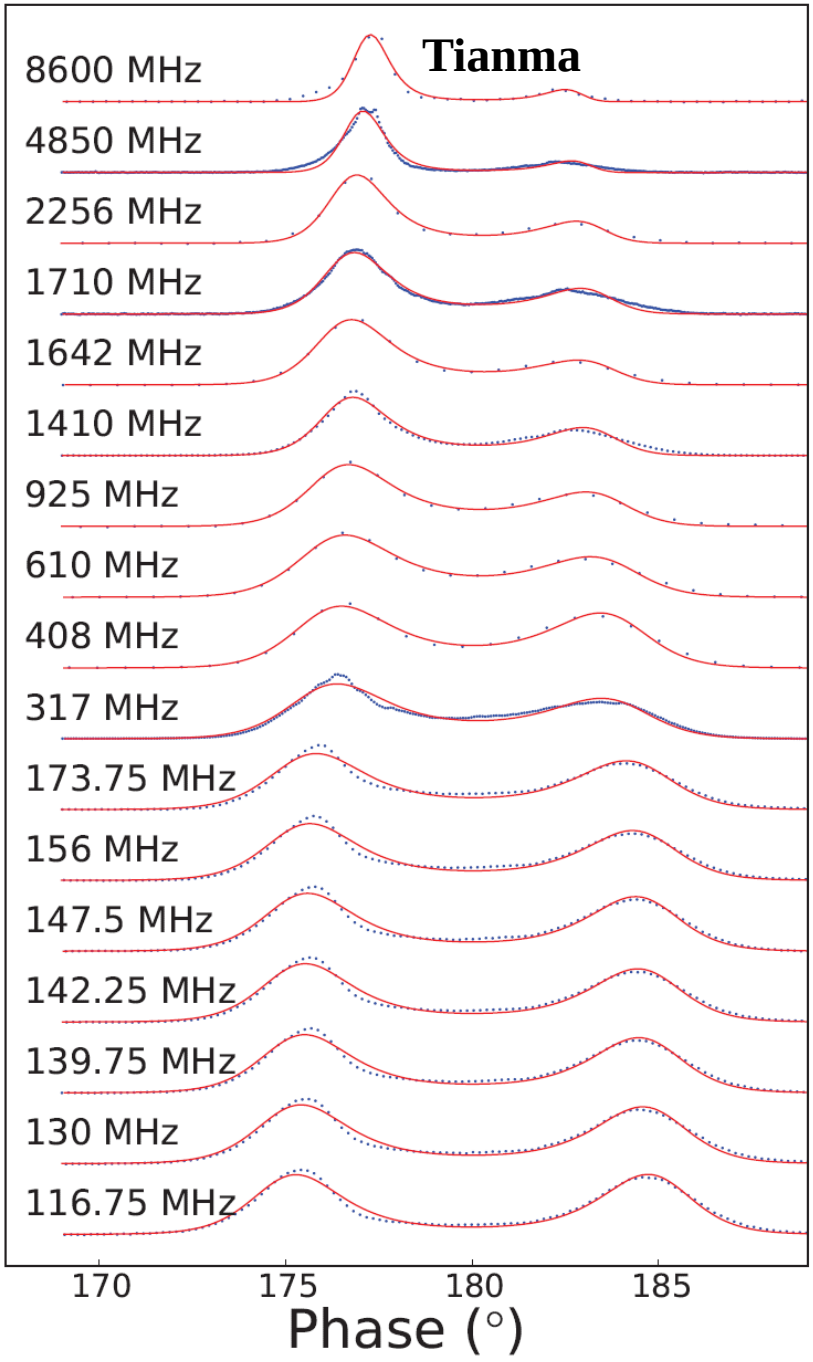
A batch of pulsars have been detected at L、S、C and X band, including the pulsar with the shortest rotational period on the northern sky and the Magmetar around the Galactic center. One case of strong radio flare of the magmetar PSR J1745-2900 was detected by the TMRT at X-band.



Integrated profiles and phase–time plots of magnetar J1745–2900

Pulsar observation

The pulsar PSR B1133 + 16 multi-frequency integral profiles. The highest frequency (8600 MHz) results were obtained by using Tianma telescope.



DIBAS spectra line observation model

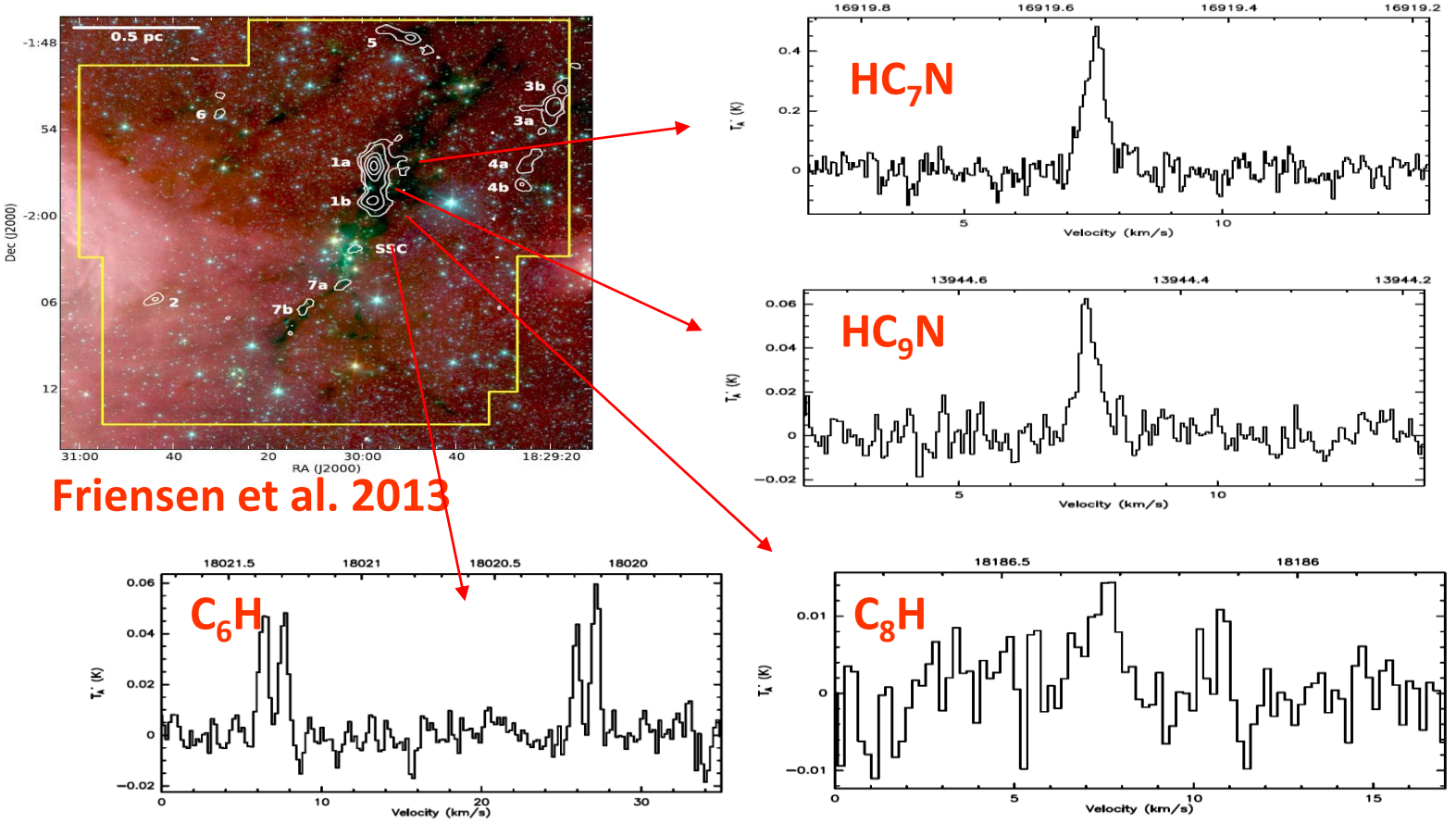
- Total support 29 observation model
- The highest resolution is 20Hz
- The maximum bandwidth is 1.5GHz

表2　谱线模式参数表

Table 2　The parameters of molecular line observing modes

模式	N_{band}	BW (MHz)	N_{chan}	Δf (kHz)	Δv (km s^{-1}) 45GHz	22.5GHz	9GHz	6.7GHz	1.7 GHz
1	1	1500	1024	1465	9.8	19.5	49	66	259
2	1	1500	16384	92	0.6	1.2	3.1	4.1	16.2
3	1	1000	16384	61	0.4	0.8	2.0	2.7	10.8
4	1	187.5	32768	5.7	0.04	0.08	0.19	0.26	1.01
5	1	187.5	65536	2.9	0.02	0.04	0.10	0.13	0.51
6	1	187.5	131072	1.4	0.01	0.02	0.05	0.06	0.25
7	1	100	32768	3.1	0.02	0.04	0.1	0.14	0.55
8	1	100	65536	1.5	0.01	0.02	0.05	0.07	0.26
9	1	100	131072	0.8	0.005	0.01	0.03	0.036	0.14
10	1	23.44	32768	0.7	0.005	0.009	0.023	0.031	0.124
11	1	23.44	65536	0.4	0.003	0.0053	0.013	0.018	0.07
12	1	23.44	131072	0.2	0.0013	0.0026	0.0067	0.009	0.035
13	1	23.44	262144	0.1	0.0007	0.0013	0.0033	0.0045	0.018
14	1	23.44	524288	0.05	0.00035	0.00065	0.00165	0.00225	0.009
15	1	11.72	32768	0.4	0.003	0.0053	0.013	0.018	0.07
16	1	11.72	65536	0.2	0.0013	0.0026	0.0067	0.009	0.035
17	1	11.72	131072	0.1	0.0007	0.0013	0.0033	0.0045	0.018
18	1	11.72	262144	0.05	0.00035	0.00065	0.00165	0.00225	0.009
19	1	11.72	524288	0.02	0.00013	0.00026	0.00067	0.0009	0.0035
20	8	23.44	4096	5.7	0.038	0.076	0.19	0.26	1.01
21	8	23.44	8192	2.9	0.02	0.04	0.1	0.13	0.51
22	8	23.44	16384	1.4	0.01	0.02	0.05	0.06	0.25
23	8	23.44	32768	0.7	0.005	0.009	0.023	0.031	0.124
24	8	23.44	65536	0.4	0.003	0.0053	0.013	0.018	0.07
25	8	15.625	4096	3.8	0.025	0.051	0.13	0.17	0.67
26	8	15.625	8192	1.9	0.013	0.025	0.063	0.085	0.34
27	8	15.625	16384	0.95	0.006	0.013	0.032	0.043	0.17
28	8	15.625	32678	0.48	0.0032	0.0064	0.016	0.021	0.085
29	8	15.625	65536	0.24	0.0016	0.0032	0.008	0.011	0.042

Detection of long carbon-chain molecules in Serpens South with TMRT (Li et al. 2016, ApJ, 824, 136)

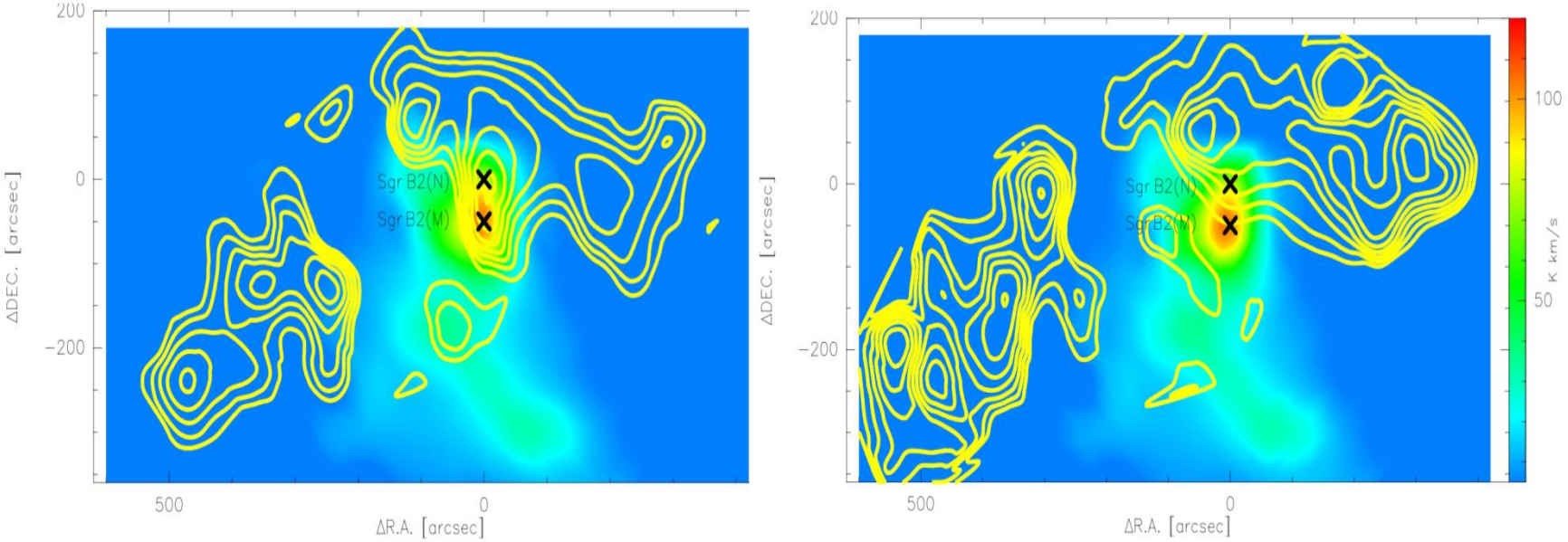


We detect several long carbon-chain molecules, including HC_5N, HC_7N, HC_9N, C_6H, C_8H, HC_3N and its ^{13}C isotopes toward Serpens south 1a with TMRT. This is the third molecular cloud detected in HC_9N and C_8H.

Observation of Former life molecules in the galactic center

TMRT carried out nearly 200 hours of highly sensitive mapping observation of the giant molecular cloud Sgr2 in the center of the galaxy in Ku band.

The emission of ethanol aldehyde and ethylene glycol molecules was detected for the first time. It is found that the spatial distribution of these two molecules is very extensive.

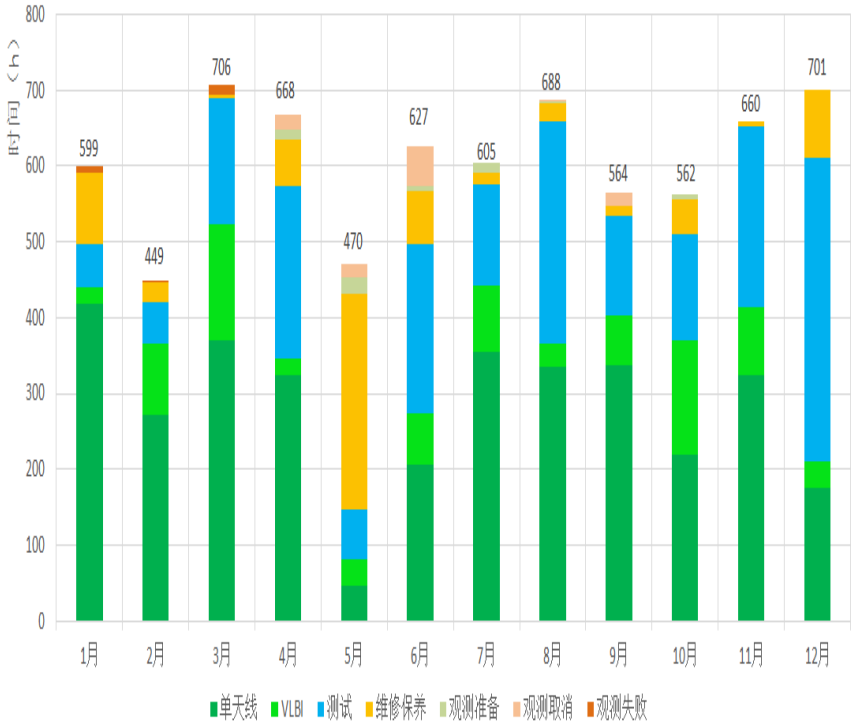


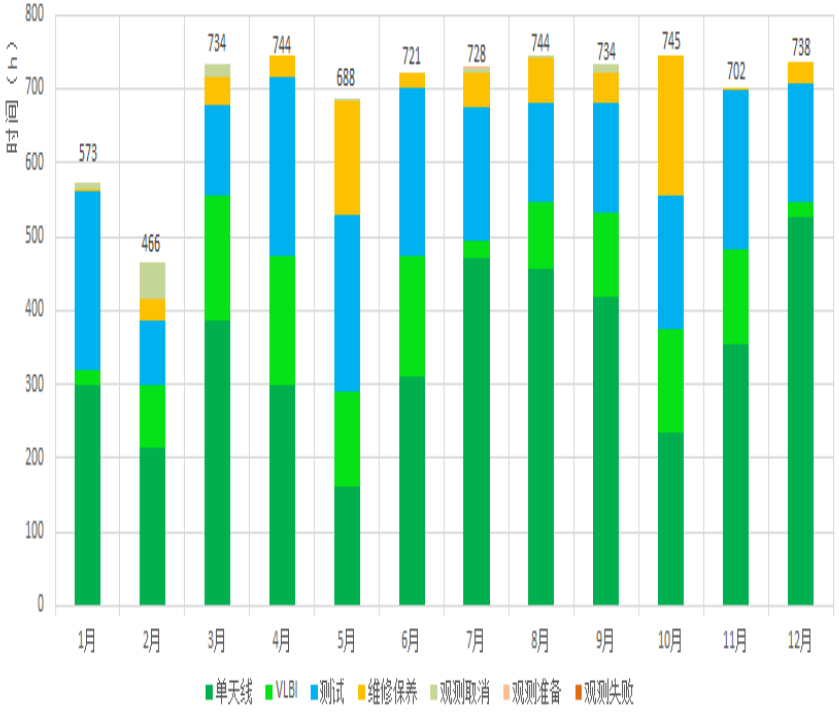
CH_2OHCHO and $HOCH_2CH_2OH$ (Li et al. 2017, ApJ)

Tianma Running time (2016.1-2017.12)

The total operating time in 2016 is 7300 h (single dish 3385h, VLBI 855h,measurement 2129h, maintenance 733h, other 175h)
Total operating time in 2017 is 8317 hours (single dish 4136h, VLBI 1258h,measurement 2183h, maintenance 639h , others101h)

Running time (h)





Tianma telescope is open to researchers

- **As VLBI antenna, join international VLBI cooperation, including::**
  - EVN, IVS, VLBA, EA-VLBI, CVN
- **As a single dish, it applies to domestic and foreign researchers to develop observation time**
  - 1st "Call for proposal" on Sept. 15, 2014 [L, S/X, C]
    - ✓ 22 proposals received,
  - 2nd "Call for proposal" on Dec. 29, 2014 [L, S/X, C]
    - ✓ 16 proposals received,
  - 3rd "Call for proposal" on Dec. 29, 2016 [L, S/X, C, Ku]
    - ✓ 17 proposals received,
  - 4th "Call for proposal" on Dec. 1, 2017 [L, S/X, C, Ku,K,Q]

    26 proposals received,

We built RFI monitoring platform at Tianma telescope. RFI is strong at L and S band, very little at X and above bands. C band has a little interference.

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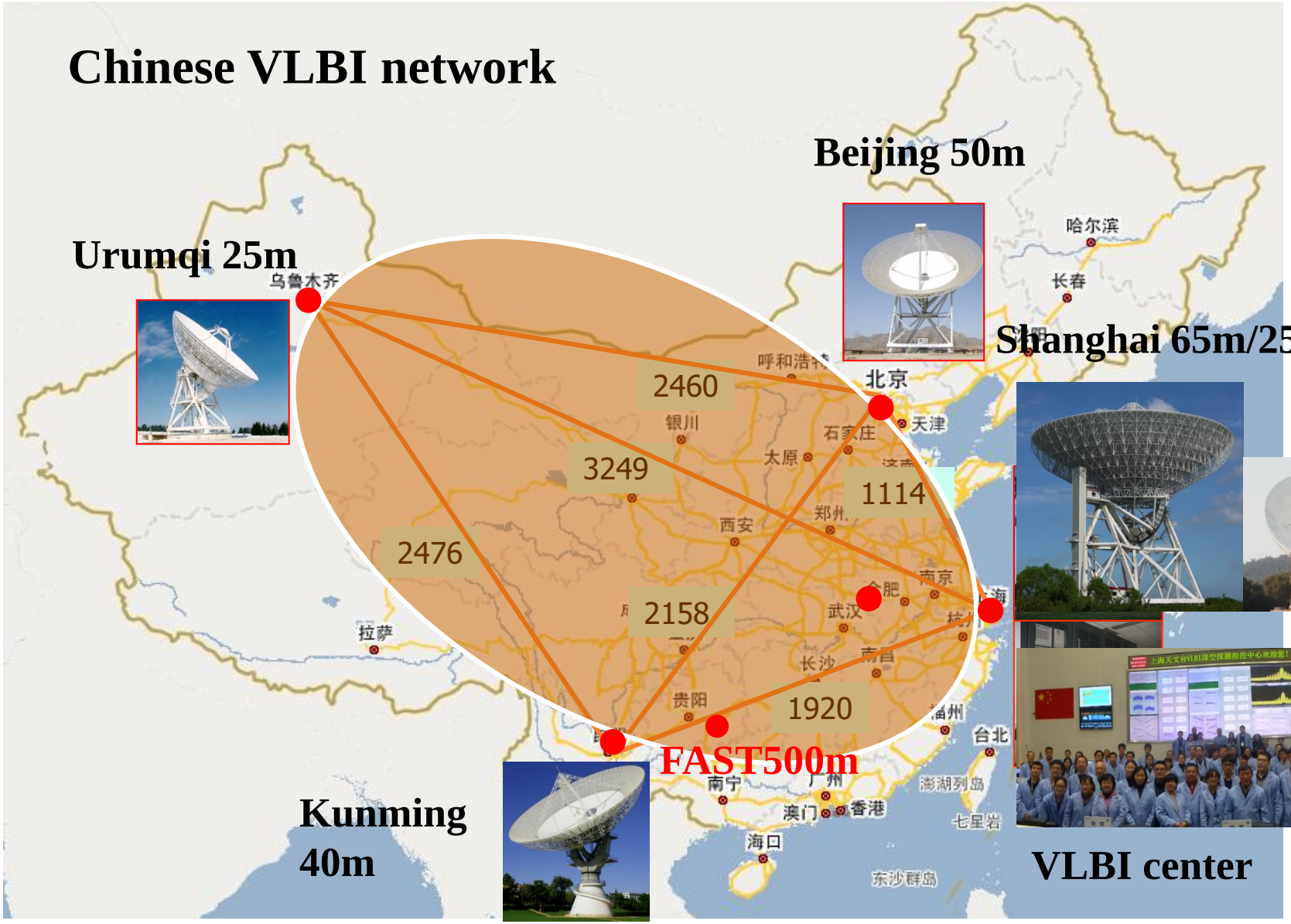
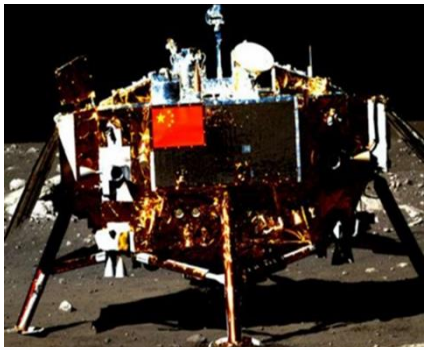
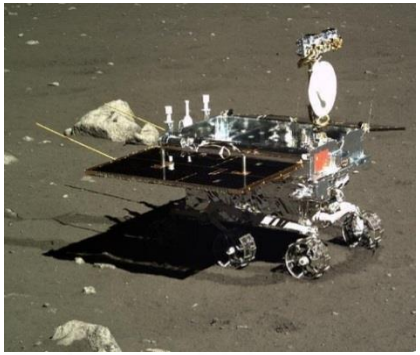
Chinese VLBI network



CE-3 Orbit

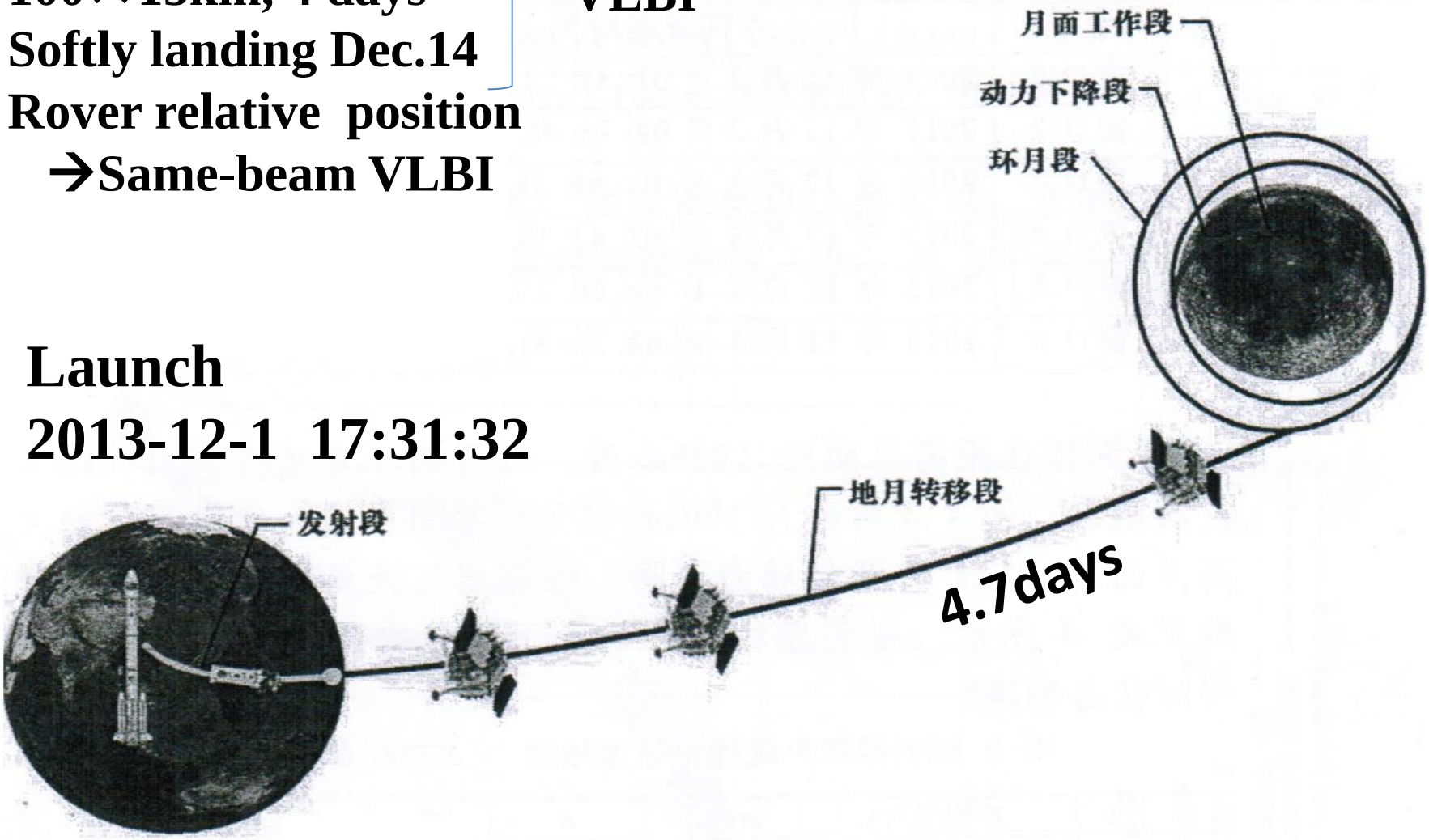




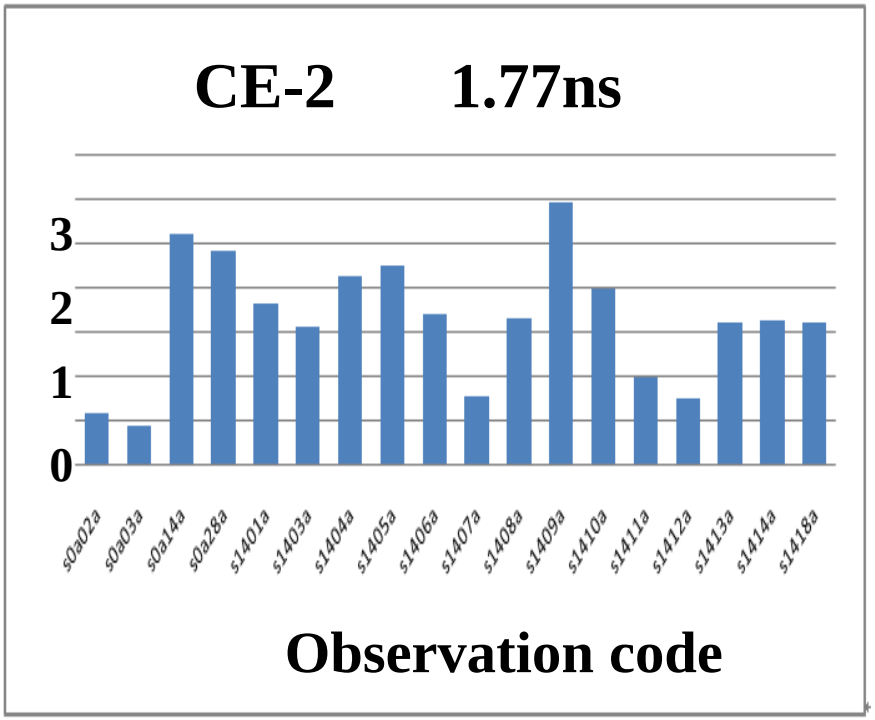
Flying to moon
100×100km, 4 days.
100×15km, 4 days
Softly landing Dec.14
Rover relative position
→Same-beam VLBI

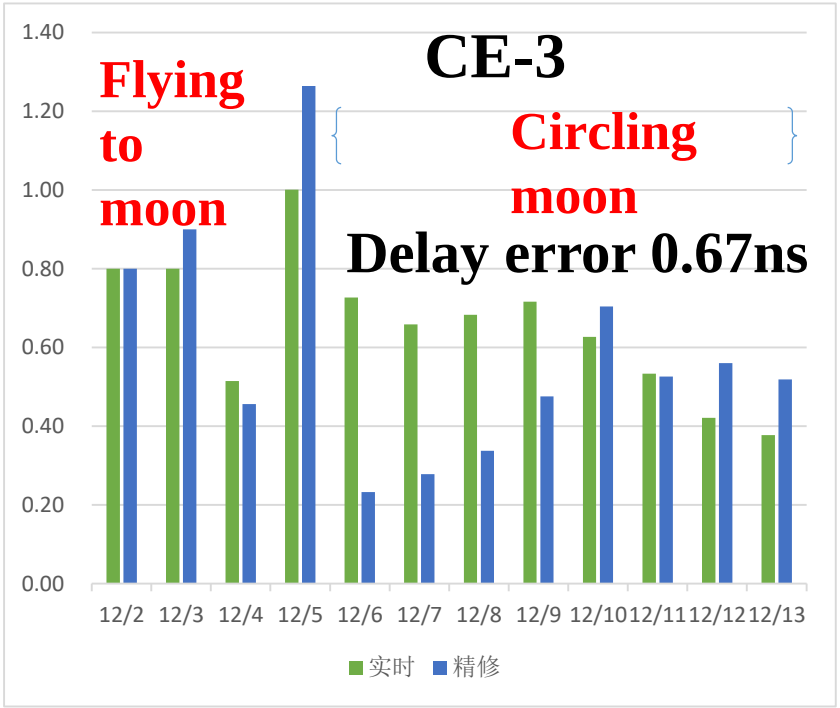
ΔDOR
VLBI

Launch
2013-12-1 17:31:32



CE-2 and CE-3 VLBI delay residual after orbit determination

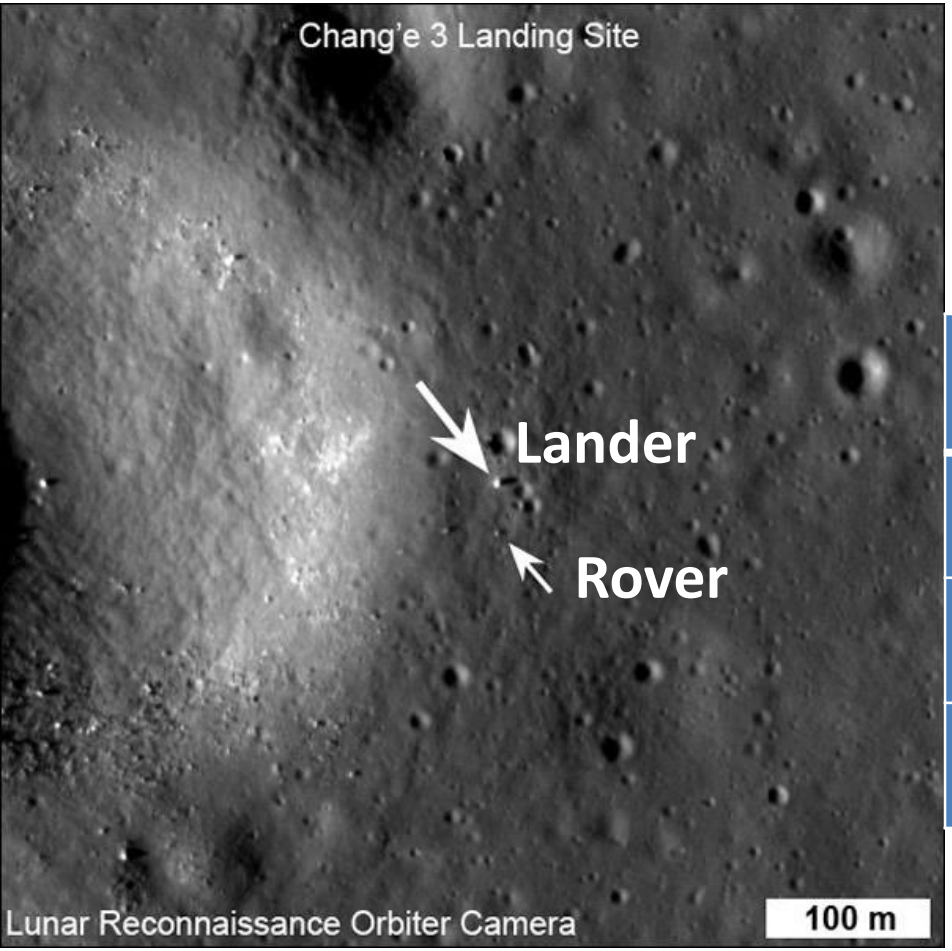




Orbit determination error (VLBI+Doppler/Range)

- **Flying to the moon: hundreds meters**
- **Circling the moon: tens meters**
- **Landing site: tens meters**

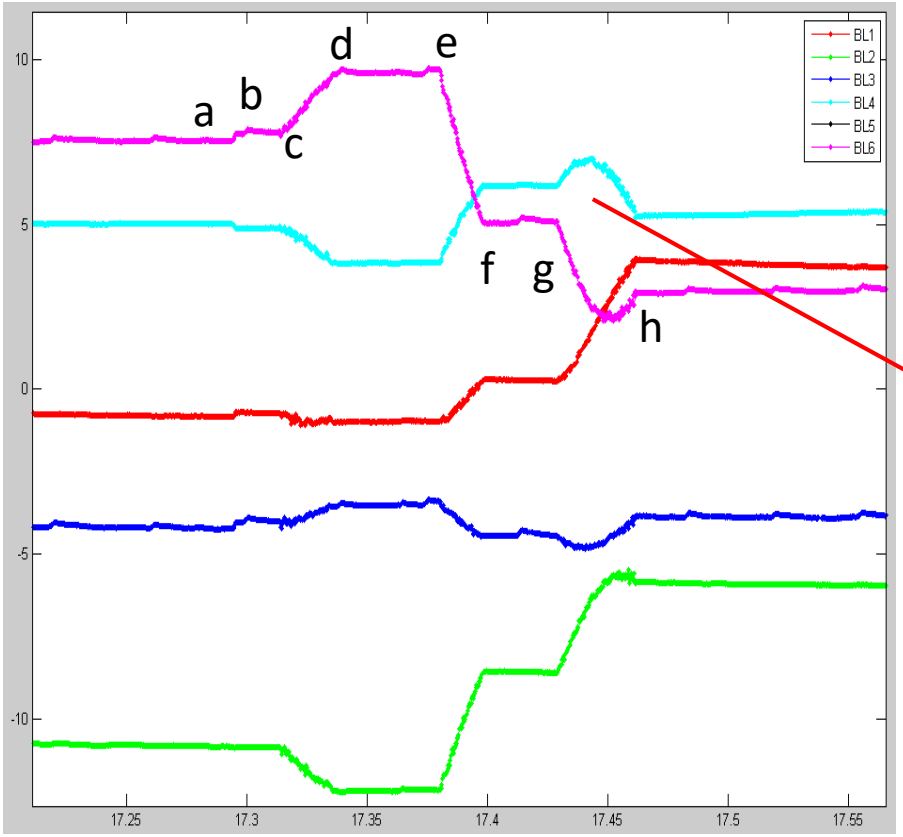
CE-3 landing site

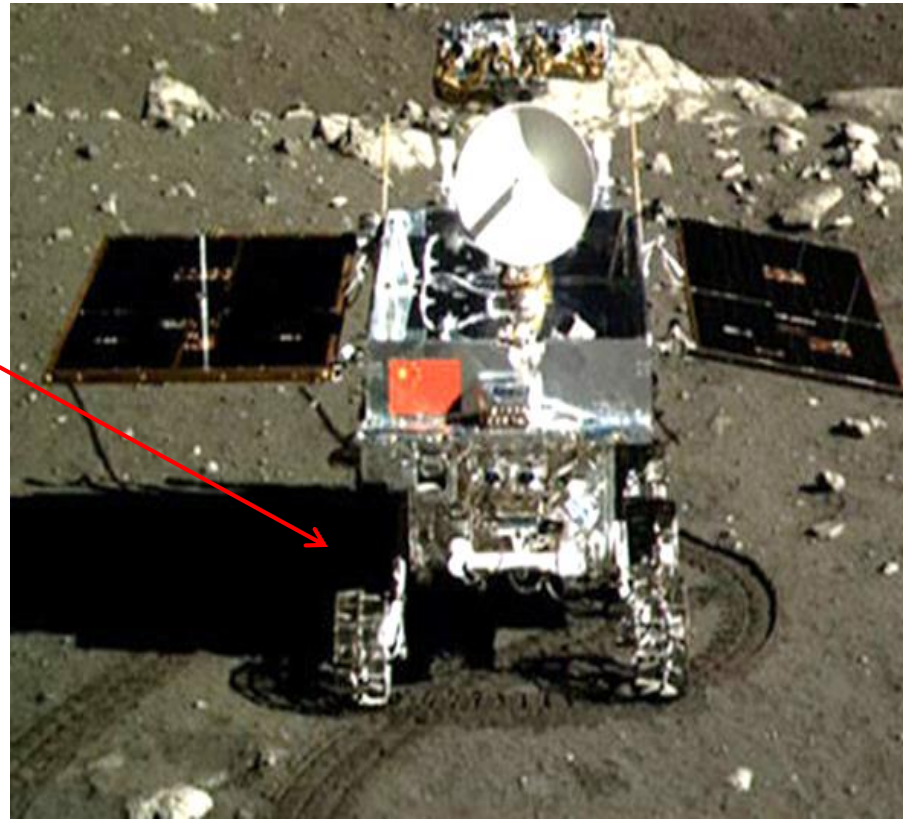


Position difference measured by SHAO and NASA was less than 50m

	longitude	latitude	height
NASA	-19.5116	44.1214	-2640.0
SHAO	-19.5124	44.1206	-2632.0
Position	17m	24m	8m

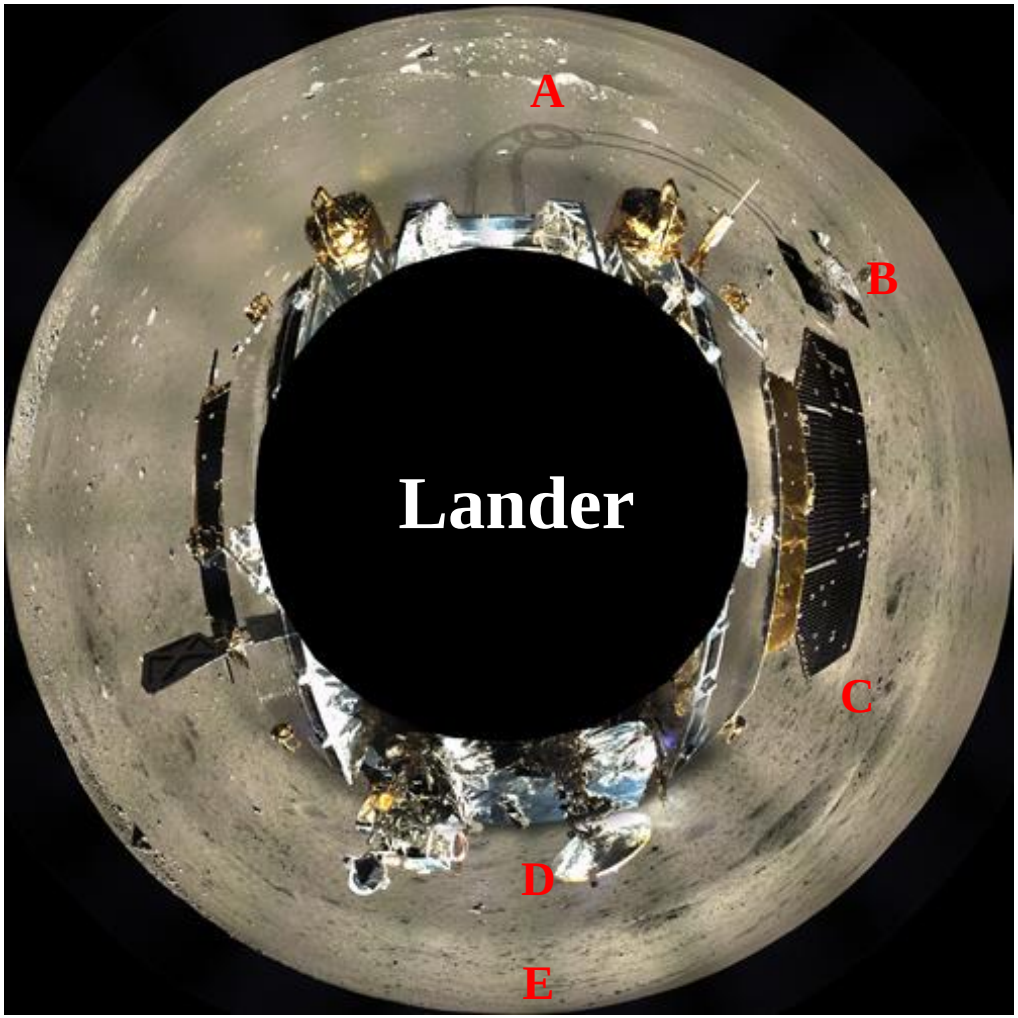
Monitor rover movement with a sensitivity of 5 cm

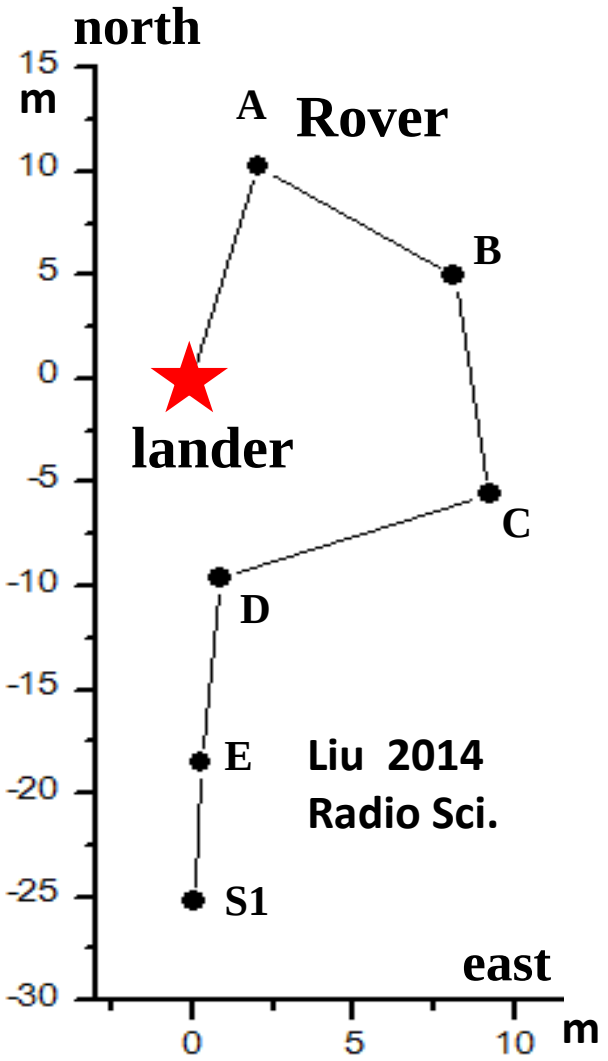




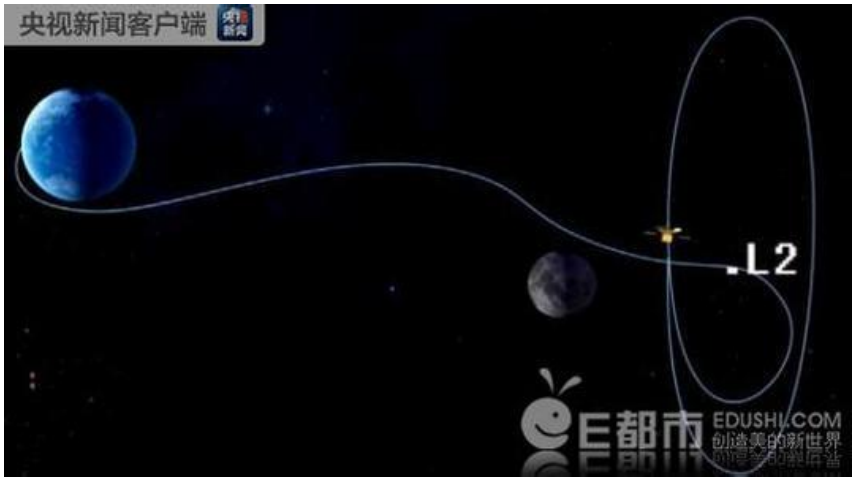
a-b: a little movement, c-d: several meter movement
e-f: several meter movement ,
g-h: make a turn

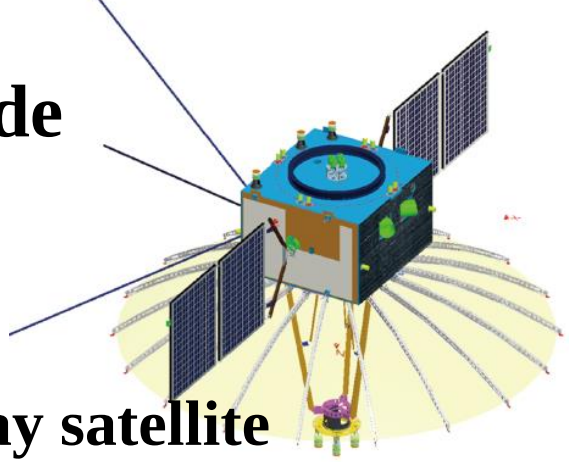
Rover relative position determination with an accuracy of 1m.





Chang' E-4, will land on the lunar far side





Relay satellite

L2

Halo Orbit

CE-4

Lander on the far side

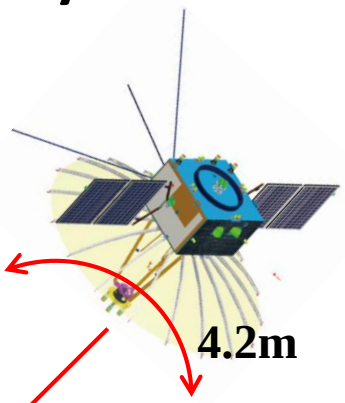
Lunar orbit

Earth

Chang' E-4, will land on the lunar far side

Measuring relay satellite antenna pointing with several arcsec accuracy

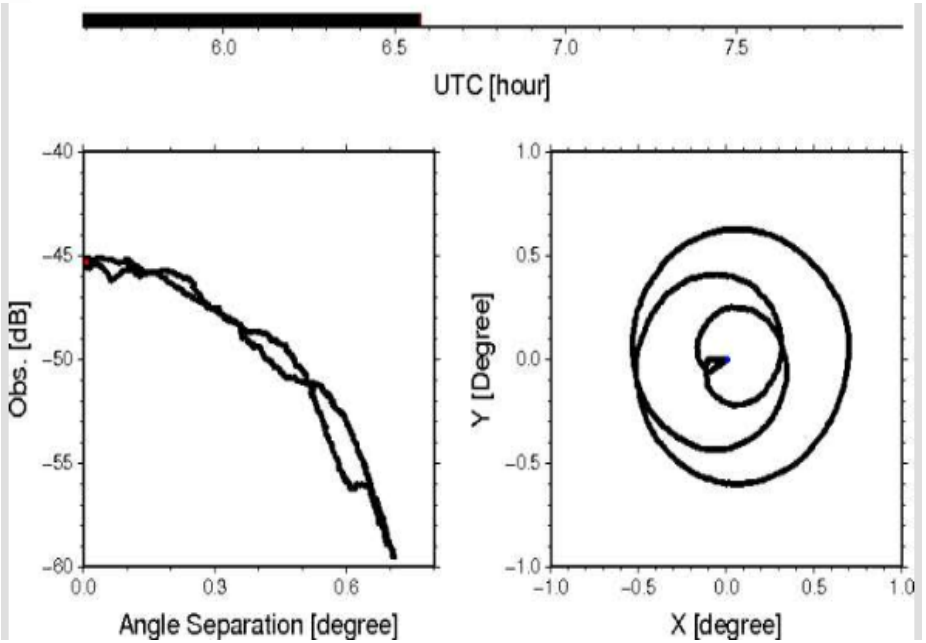
CE-4 ralay satellite scanning



4.2m

7.2GHz

Tianma telescope

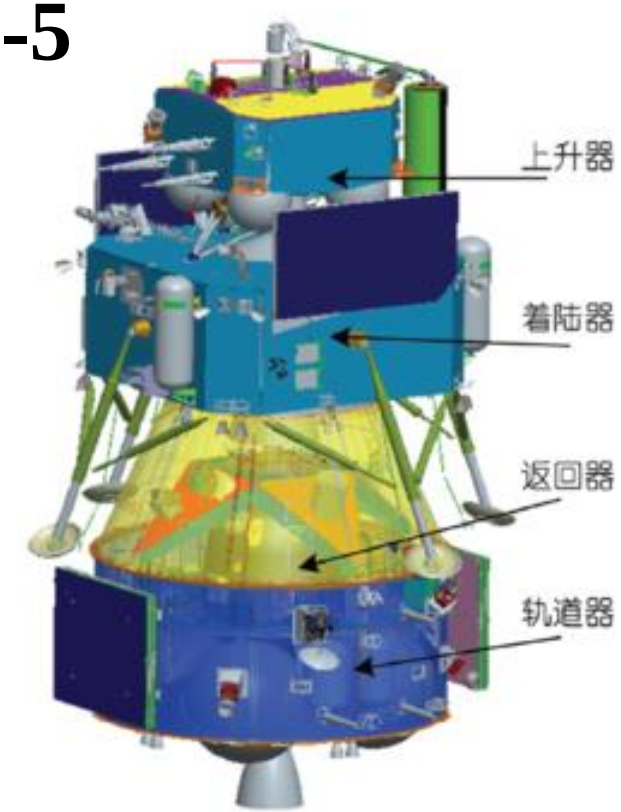


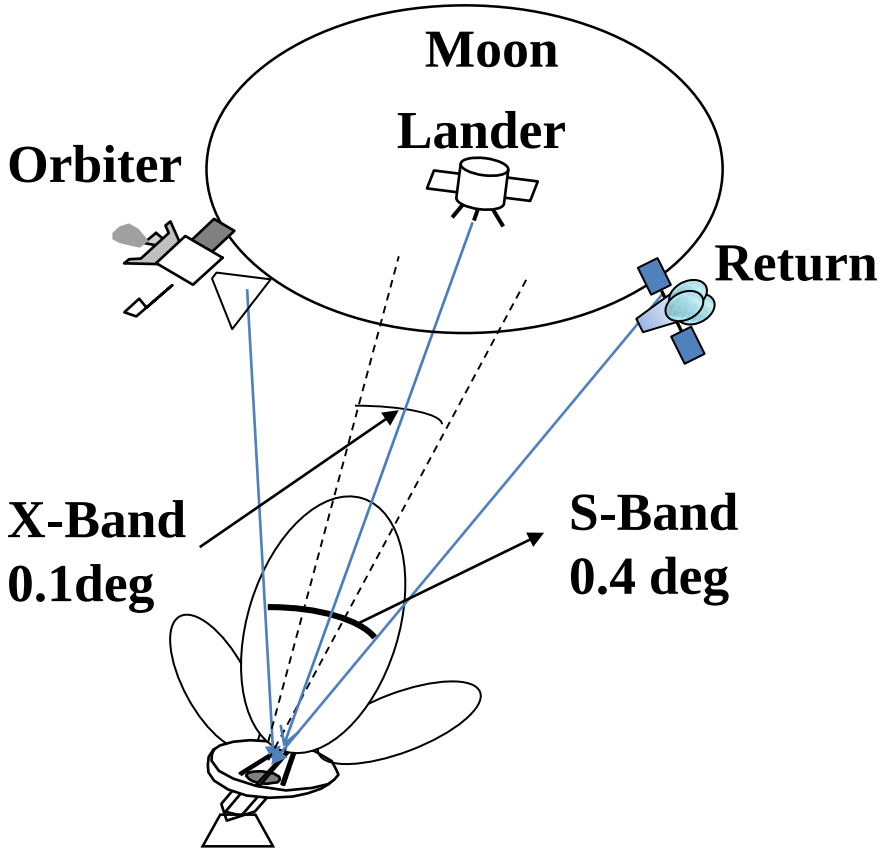
Same-beam VLBI in a sampler-return mission

It is very useful in the docking for two lunar spacecrafts

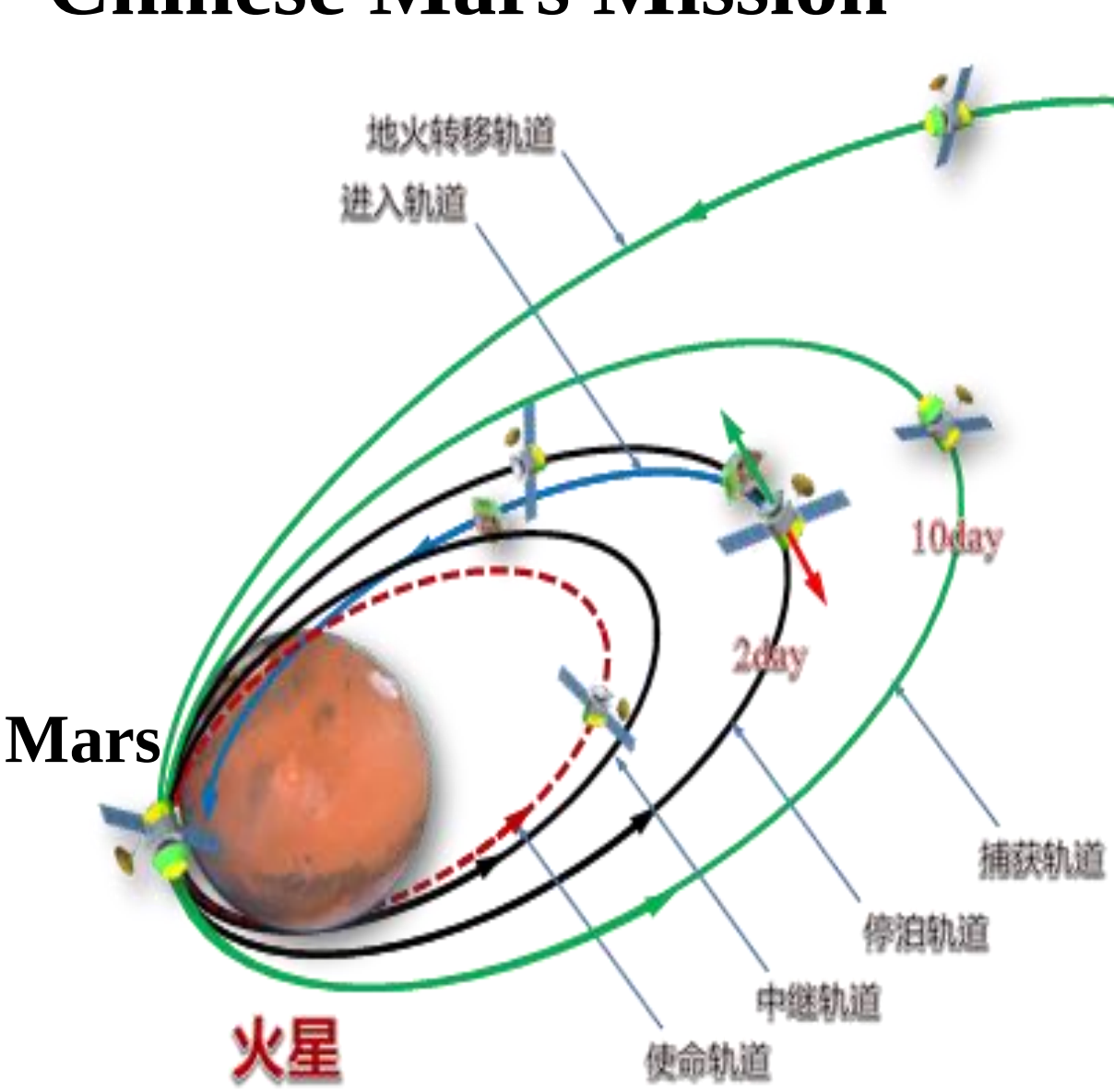
Differential phase delay accuracy: 1mm
Corresponding to relative distance accuracy: 1m

CE-5



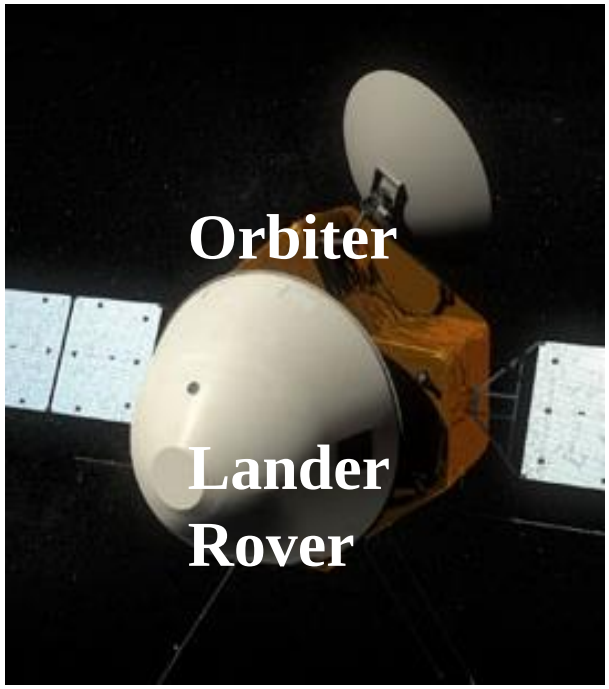


Chinese Mars Mission

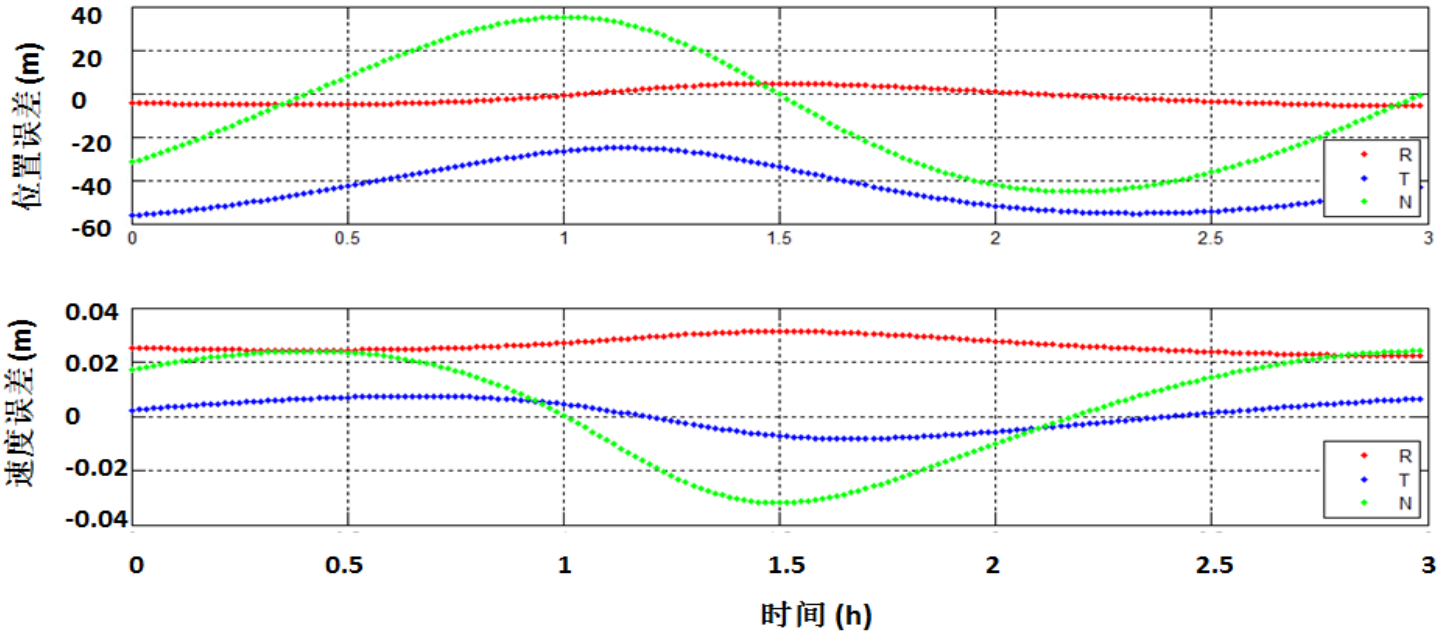


Earth

Mars



Simulation results of the orbit determination error of a Mars orbiter: tens meters



Simulation results of positioning error of a Mars rover: Hundreds meters

	Latitude (deg)	Longitude (deg)	elevation （m）
True value	45.00000	-30.00000	-3000.0
Calculation	45.00244	-29.99555	-3225.7
error	0.00244	0.00444	-225.7
	125.5m	263.5m	-225.7m

What service can Tianma telescope team provide for you?

- Overall telescope research and development technology
- Active surface research and development technology
- Phase reference holography and out-of-focus holography
- Receiver research and development technology
- Testing technology of telescope's comprehensive performance
- Research and development technology of telescope control software
- Application technology of telescope in VLBI and single dish observation
- Many research and development experiences and improving methods that are not willing to openly exchange


Tianma telescope team will continue to work in all aspects of radio astronomy, deep space exploration, science research and education, welcome to use Tianma telescope