VLBI with the Shanghai 65m Tianma RT

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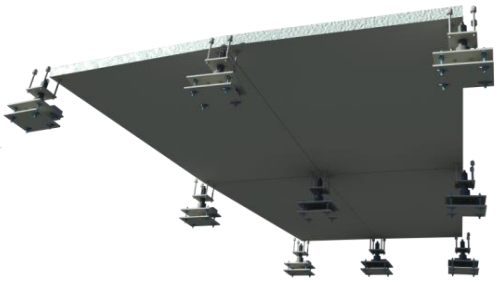
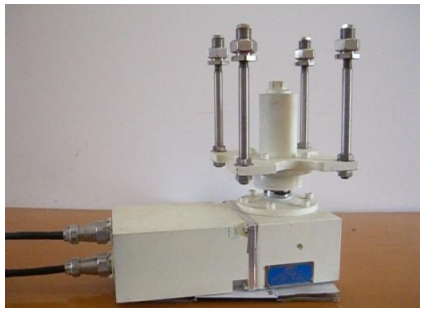
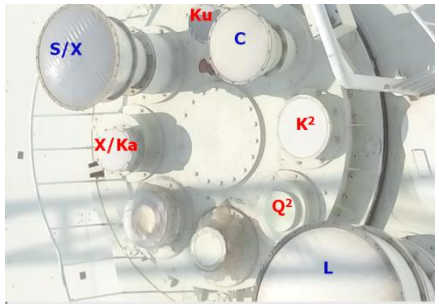
An Introduction to TMRT

TMRT- Shanghai TianMa Radio Telescope

- 65-m in diameter, fully steerable
- Active surface control system
- 7 sets of Rxs covering 8 bands of 1.35 – 50 GHz

  L(1.6 GHz), S/X(2.3/8.4 GHz)
  C(5 GHz), Ku(15 GHz), K(22 GHz)
  Ka(30 GHz), Q(43 GHz)
- General-purpose (radio astronomy, single-dish, VLBI, geodynamics)

Project Timeline
（十年磨一剑）

- 2008: funded; contract to CETC54 for the antenna construction
- 2009: complete design (international review panel); start manufacturing; foundation laying ceremony on December 29
- 2010-11: site construction started on March 19, 2010; foundation completed; antenna construction (wheel-on-track, BUS, alidade, panels, …); active surface system (contract, design, fabrication, installation of actuators)
- 2012-13: L/S/X and C band Rxs in place; first light on October 26, 2012 & inauguration 2 days later; start commissioning; got named (**天马**); participation in the Chinese Lunar Mission; DIBAS installed & tested
- 2014-15: on-site system testing; science observations at L/S/C/X bands;
- 2016-17: active surface tested; Ku/K/Ka/Q band commissioning; on-site acceptance review on Oct 27, 2017!

System Performance

Band	L	S	C	X	Ku	K²	Ka	Q²
Wavelength λ(**cm**)	21/18	13	6/4.5	3.6	2.5/2.0	1.35	0.9	0.7
Frequency ν(**GHz**)	1.35-1.75	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**	**55**	**50***	**50***	**50***
DPFU（**K/Jy, 1.20η_A**）	0.66	0.72	0.72	0.66	0.48	0.60*	0.60*	0.60*
Tsky (**K**)	12	12	10	10	12	25	25	26
Trec (**K**)	14	21	12	22	15	35	35	40
Tsys (**K**)	**26**	**33**	**22**	**32**	**27**	**60**	**60**	**70**
SEFD （**Jy, Tsys/DPFU**）	**39**	**46**	**31**	**48**	**56**	**100***	**100***	**117***
Thermal noise （**mJy, 1σ (B_w=128MHz, T_{on}=10 min**））	**0.142**	**0.165**	**0.110**	**0.175**	**0.202**			

(*: active surface control system on)

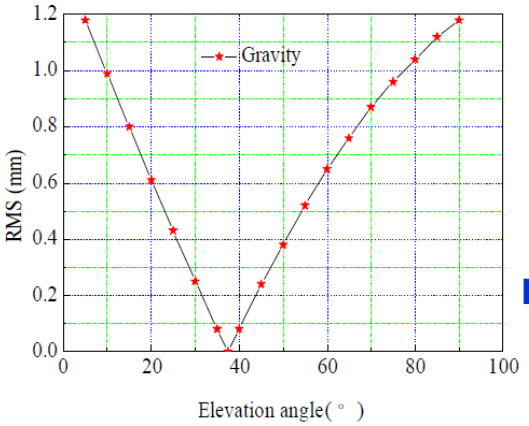
$$\mathrm{SEFD} = \frac{2kT_s}{A_e} = \frac{2kT_S}{\eta_A A_g} = \frac{8kT_S}{\eta_A \pi D^2}$$

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

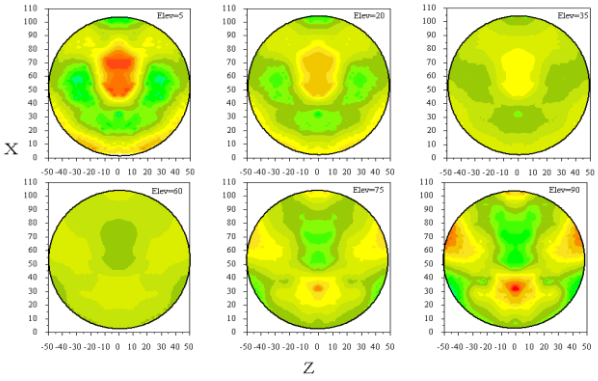
opportunity for mJy science observation!

Active Surface Control System

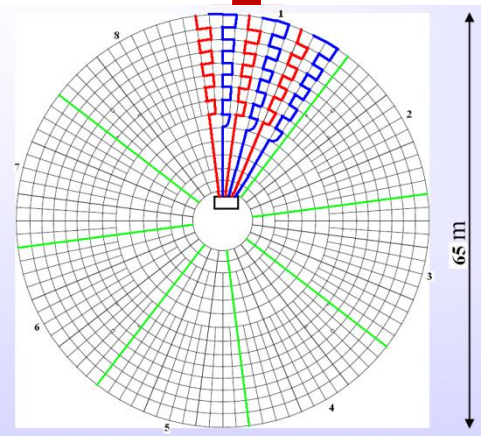
off

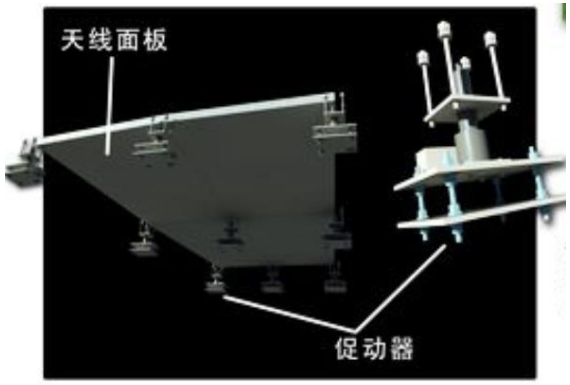


Finite Element Model Predictions

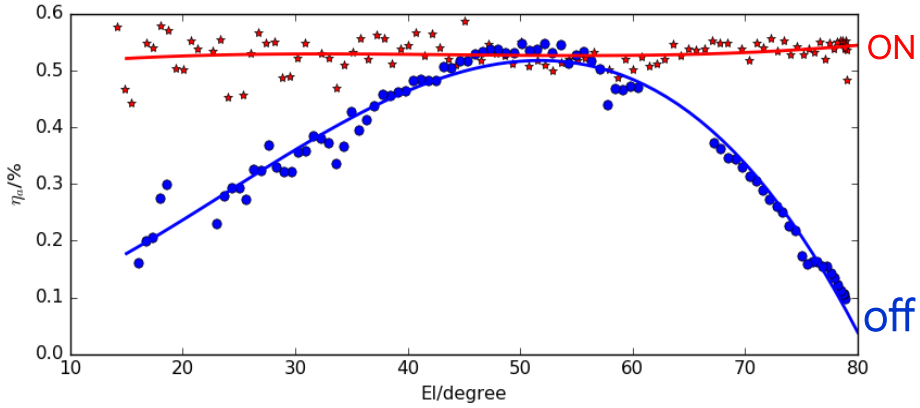


on





Comparison with/without ASCS at 43 GHz



TMRT

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)

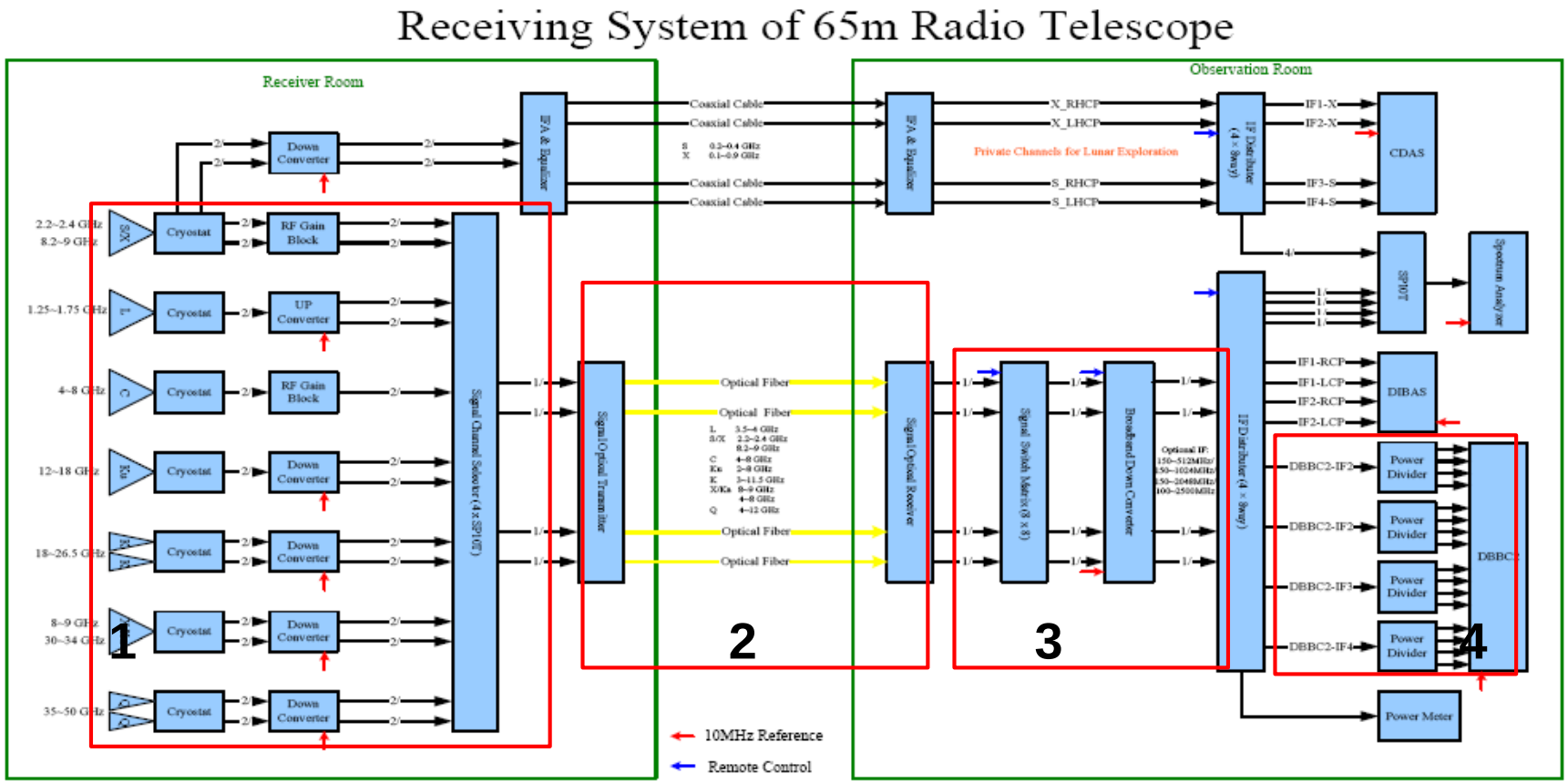
DIBAS: DIgital BAckend System

- An updated version of the NRAO-VEGAS (Versatile GBT Astronomical Spectrometer), customized with the addition of NRAO-GUPPI (Green Bank Ultimate Pulsar Processing Instrument)
- Support two types of observing modes
  - Spectral line modes: support 29 modes, including wideband up to 16,384 channels, narrowband up to 524,288 channels and, sub-band modes (higher spectral-resolution over multiple narrow bands (sub-bands) within the sampled bandwidth)
  - Pulsar modes: support the incoherent/coherent search and pulsar timing modes.

Open Use of the TMRT

- **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" on Sept. 15, 2014
  - 2nd "Call for proposal" on Dec. 29, 2014
  - 3rd "Call for proposal" on Dec. 29, 2016
  - 4th "Call for proposal" on Oct. 27, 2017
- **Goal is to operate TMRT with an open access driven by scientific merit!**

VLBI Receiving System



馈源舱微波开关分配表

微波开关 A		IP 地址：178.1.65.74	
编号	信号	编号	信号
1-1	X1-R	2-1	X1-L
1-3	Ku-R	2-3	Ku-L
1-5	Ka-R	2-5	Ka-L
1-7	K1-R	2-7	K1-L
1-9	Q1-R	2-9	Q1-L

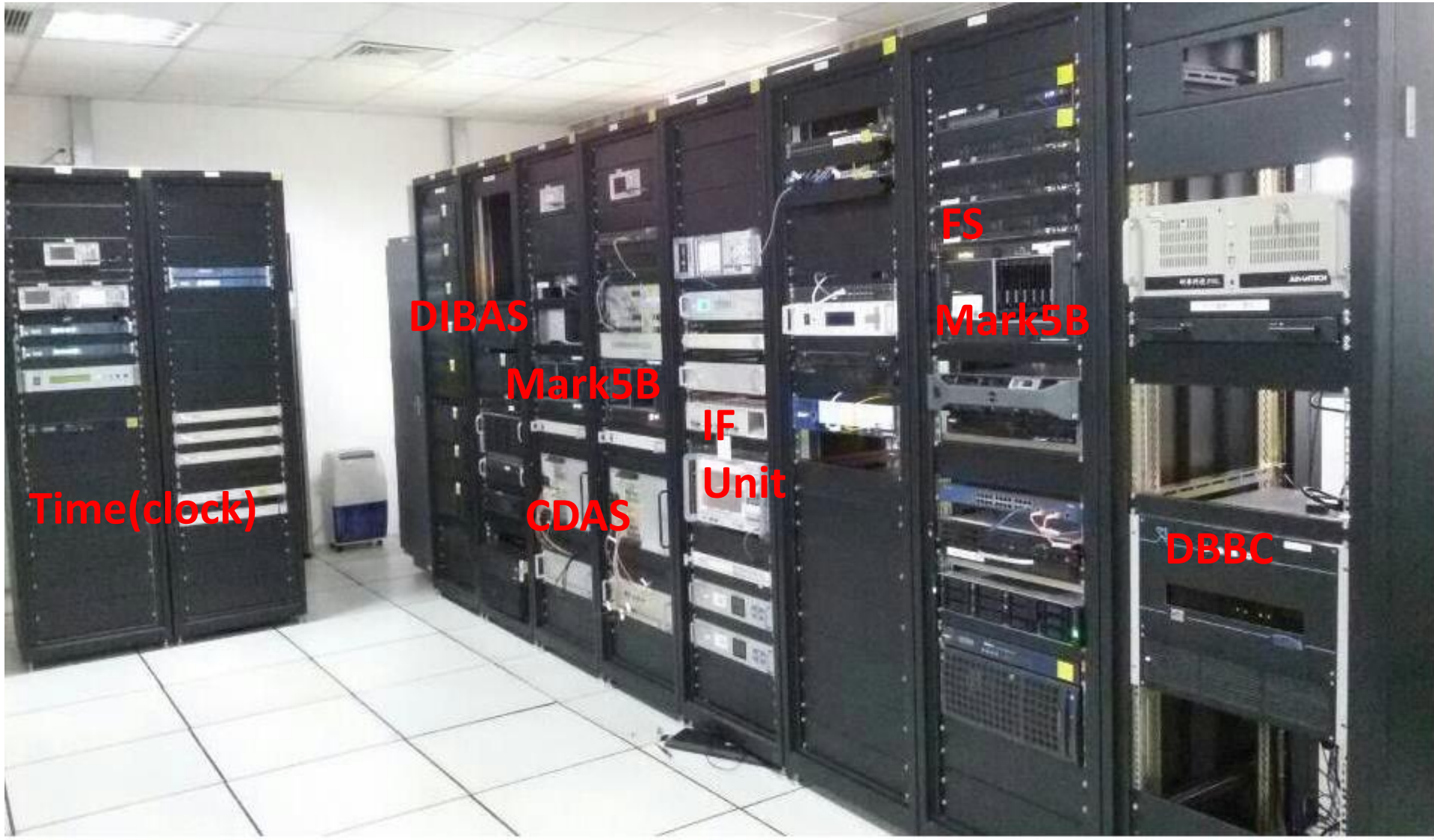
微波开关 B		IP 地址：178.1.65.78	
编号	信号	编号	信号
1-1	L-R	2-1	L-L
1-3	S-R	2-3	S-L
1-5	C-R	2-5	C-L
1-7	X2-R	2-7	X2-L
1-8	K2-R	2-8	K2-L
1-9	Q2-R	2-9	Q2-L

终端室频谱监测切换开关分配表

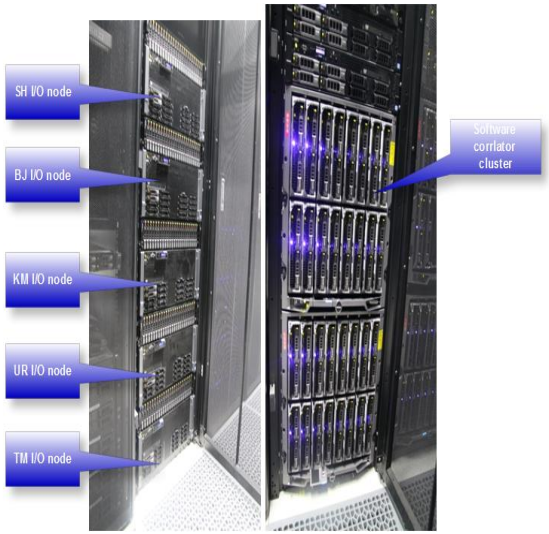
编号	信号	编号	信号
1-1	S(c)-R	1-2	S(c)-L
1-3	X1(c)-R	1-4	X1(c)-L
1-5	L/S/C/X2/K1/Q1-R	1-6	L/S/C/X2/K1/Q1-L
1-7	X1/Ku/Ka/K2/Q2-R	1-8	X1/Ku/Ka/K2/Q2-L

注：1）(c)为同轴传输；(f)为光纤传输
2）X1：S/X接收机X波段；X2：X/Ka接收机X波段
3）K1：K接收机1波束；K2：K接收机2波束
4）Q1：Q接收机1波束；Q2：Q接收机2波束

BackEnds



CVN-VLBI Center



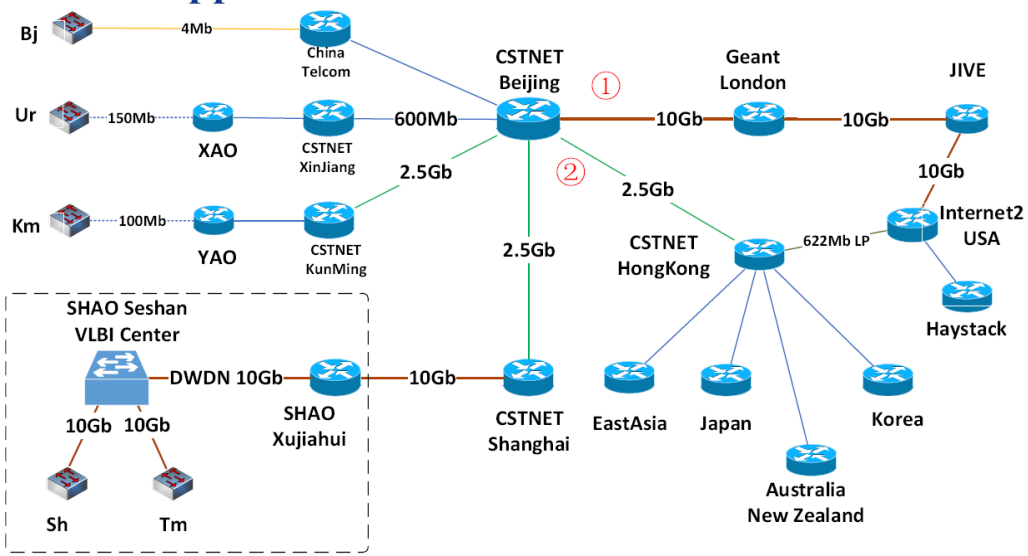
Hardware Correlator

CVN software correlator

DiFX correlator

DiFX Correlator

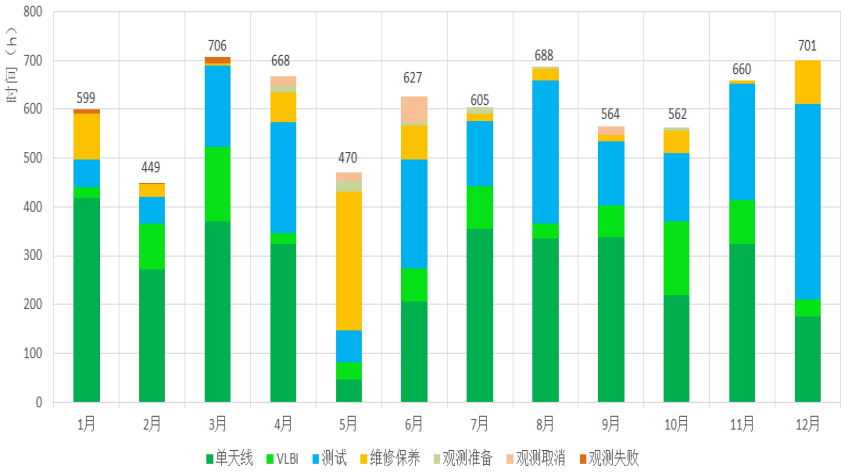
- Via CSTNET(Chinese Science&Technology Network, CAS)
- IPv6 supported in CVN



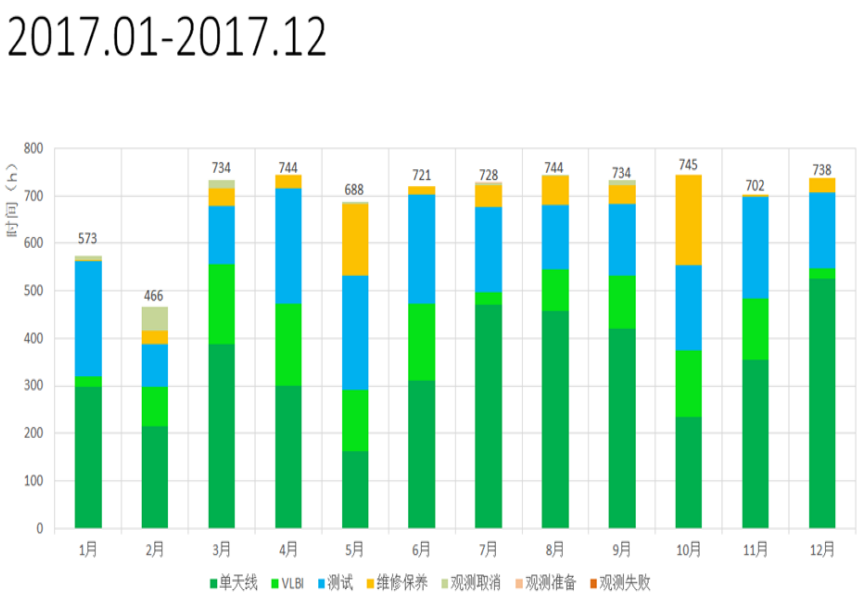
	CVN	Joint	IVS
2015	10 Continuum, Pulsar, Geodesy	10 EAVN(FT), Astrometry	10 AOV, APSG, CRF
2016	20 T6 Rx test, Continuum, Geodesy	8 EAVN(FT), FT, Astrometry	26 AOV, APSG, AUA, AUG, CRDS, CRF, R&D
2017	Astrometry, Geodesy, Pulsar	EAVN, FT	31 AOV, APSG, AUA, CRDS, CRF, R&D

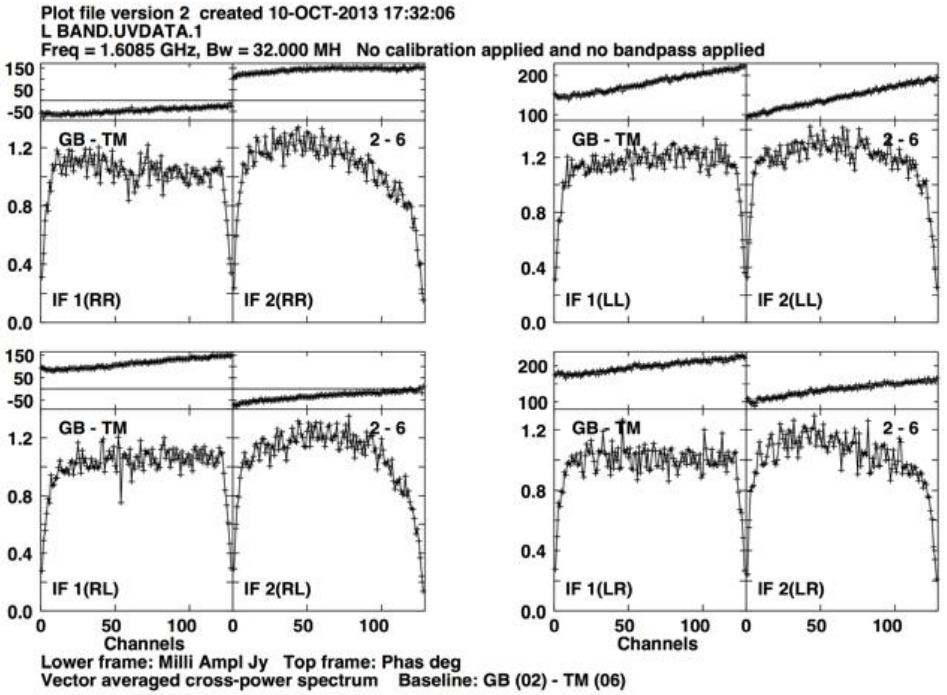
Routine Operations

2016: 855 hr VLBI (7300 hr)



2017: 1258 hr VLBI (8300 hr)



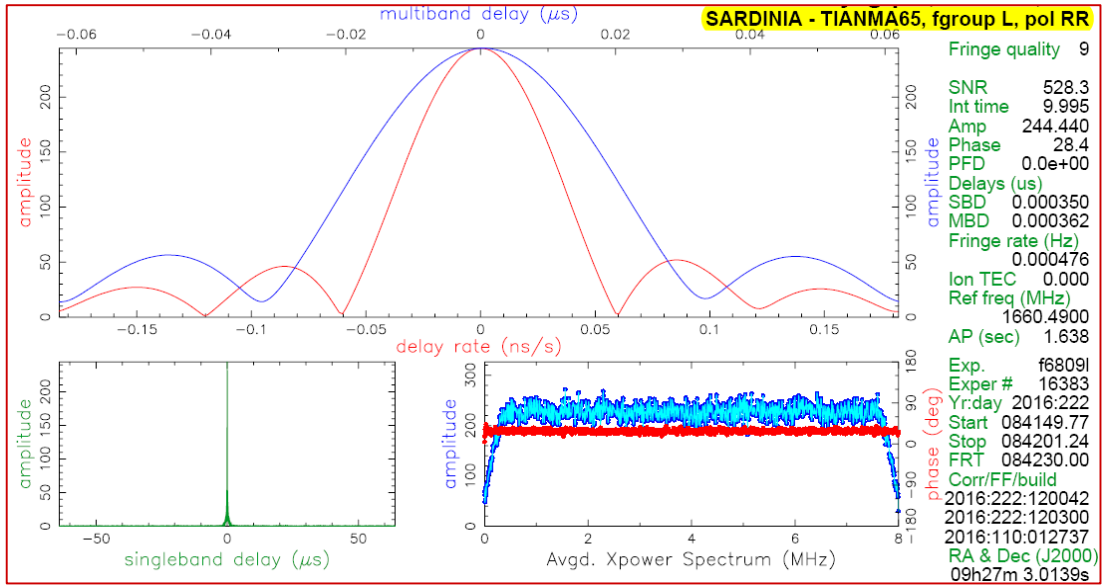


(VLBI fringes with the GBT on 2013 Aug 30)

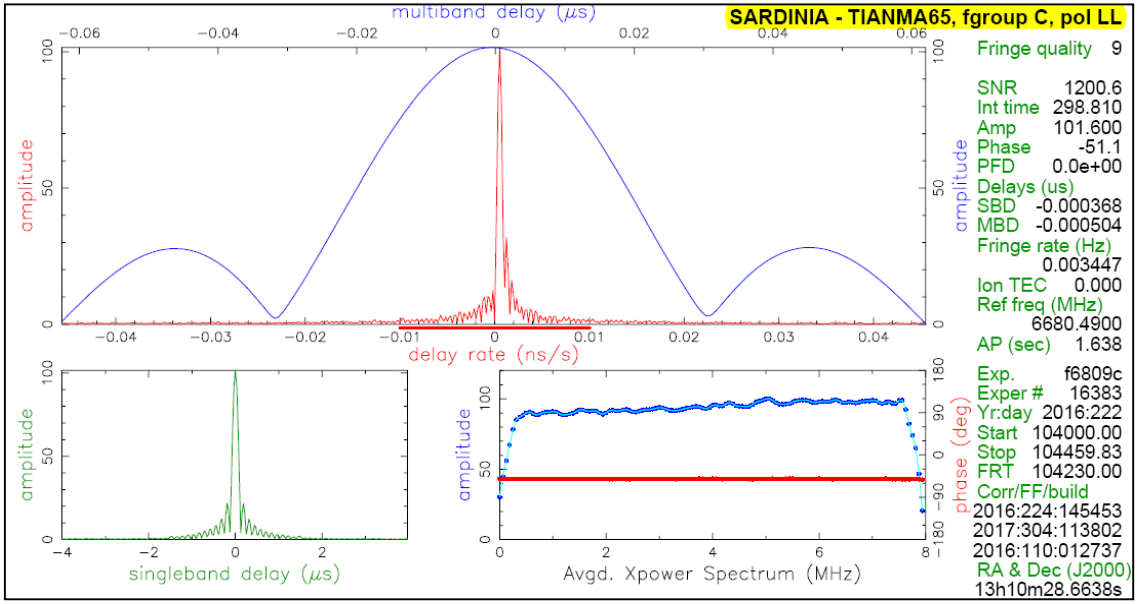
VLBI Related Activities

FT @ L & C：TMRT – SRT

(2016 Aug 9)

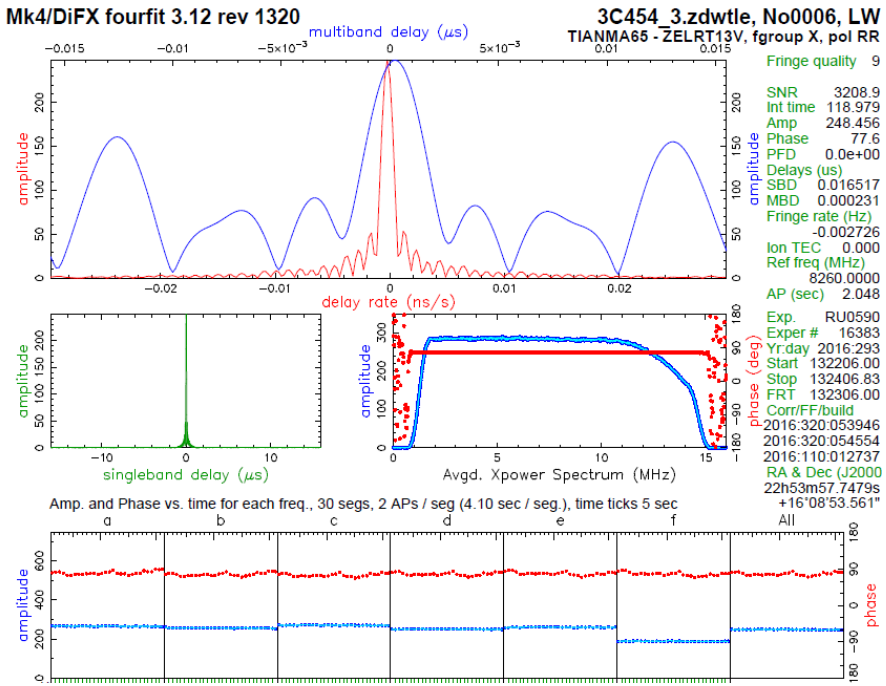


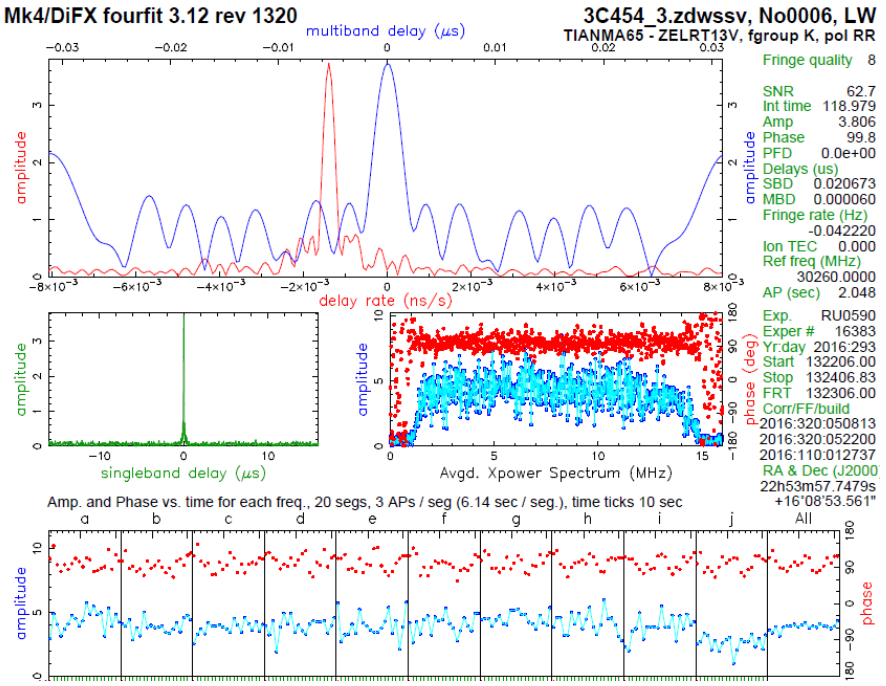
L band



C band

FT @ X/Ka：TMRT - Russia13m

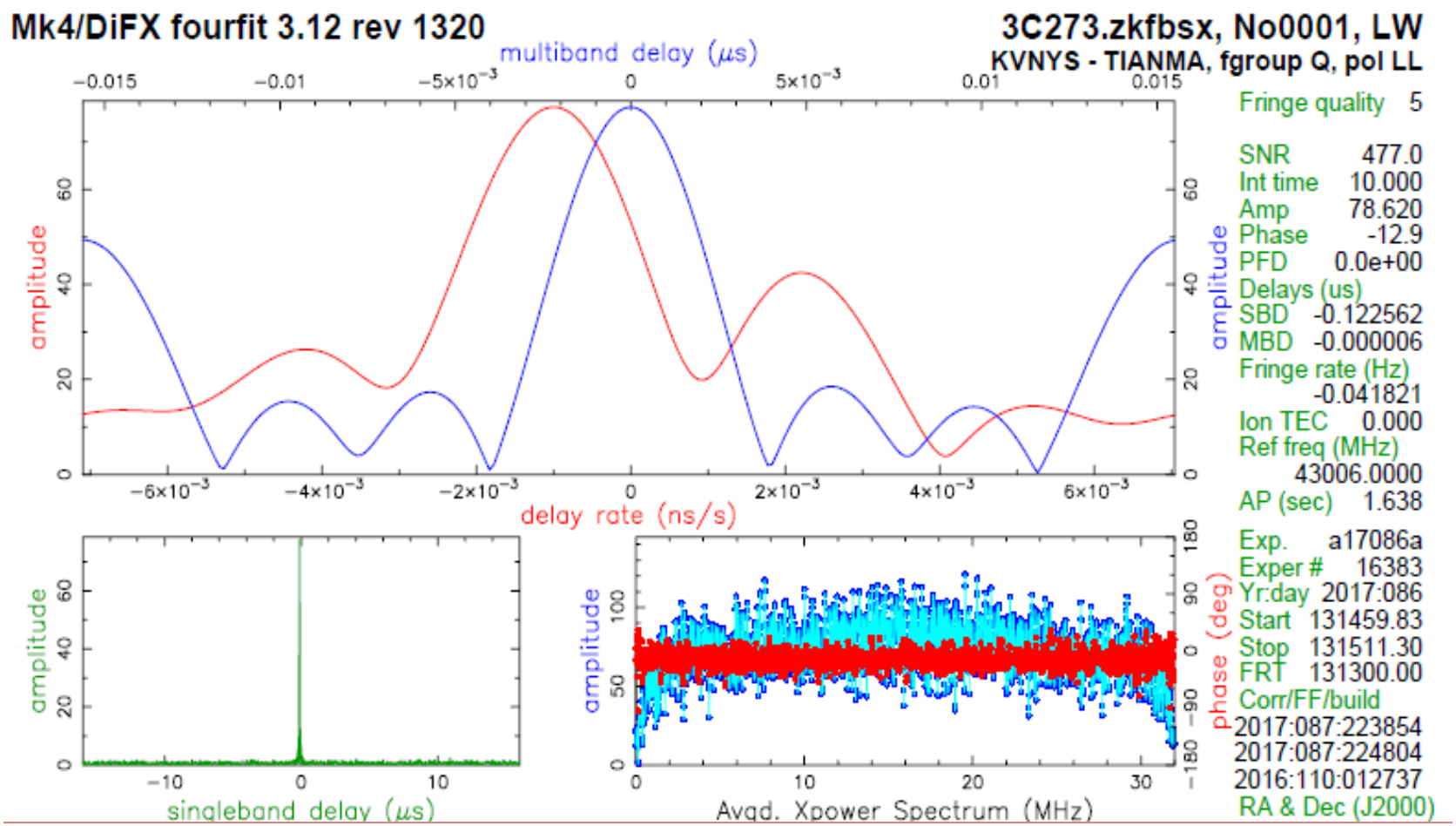




6X+10Ka channels in geodesy mode at 1Gbps on 2016 October 19

FT @ Q：TMRT – KVNYs21m

64MHz (BW), 3C273, 10s integration, 2017 March 27



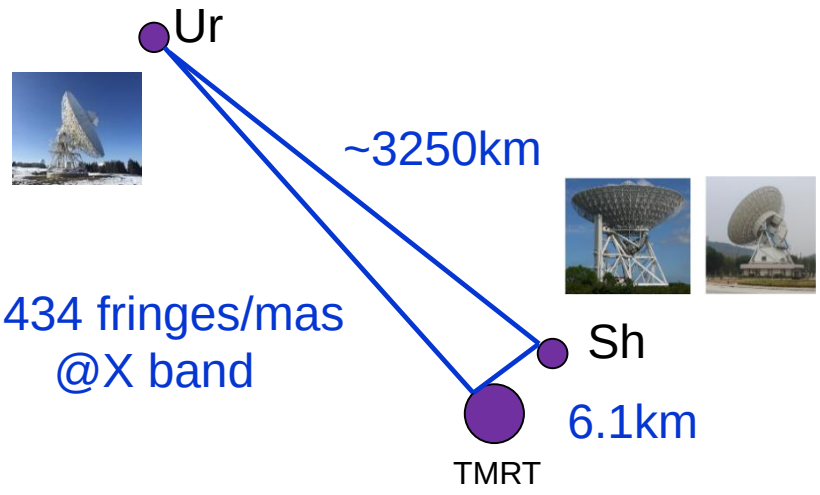
unique two stations in CVN (EAVN) — short spacing

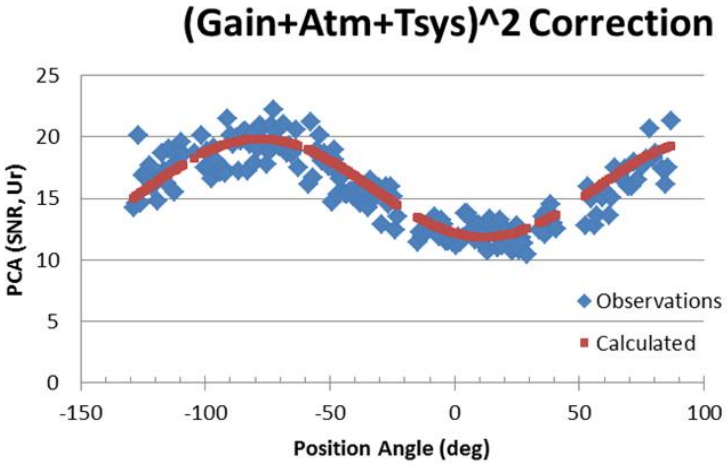
Baseline ~ 6.1 km

Tianma 65 m telescope

Sheshan 25 m telescope

CVN





Pseudo Closure Amplitude (PCA) measurement

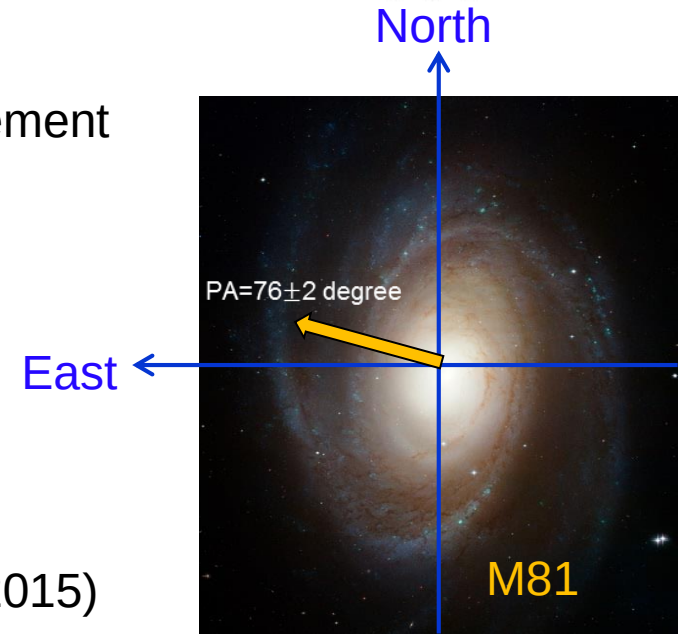
$$PCA_{Ur} = \frac{\rho_{SU} \bullet \rho_{TU}}{\rho_{ST}} \approx S_o \bullet r^2 \bullet S_{Ur}$$

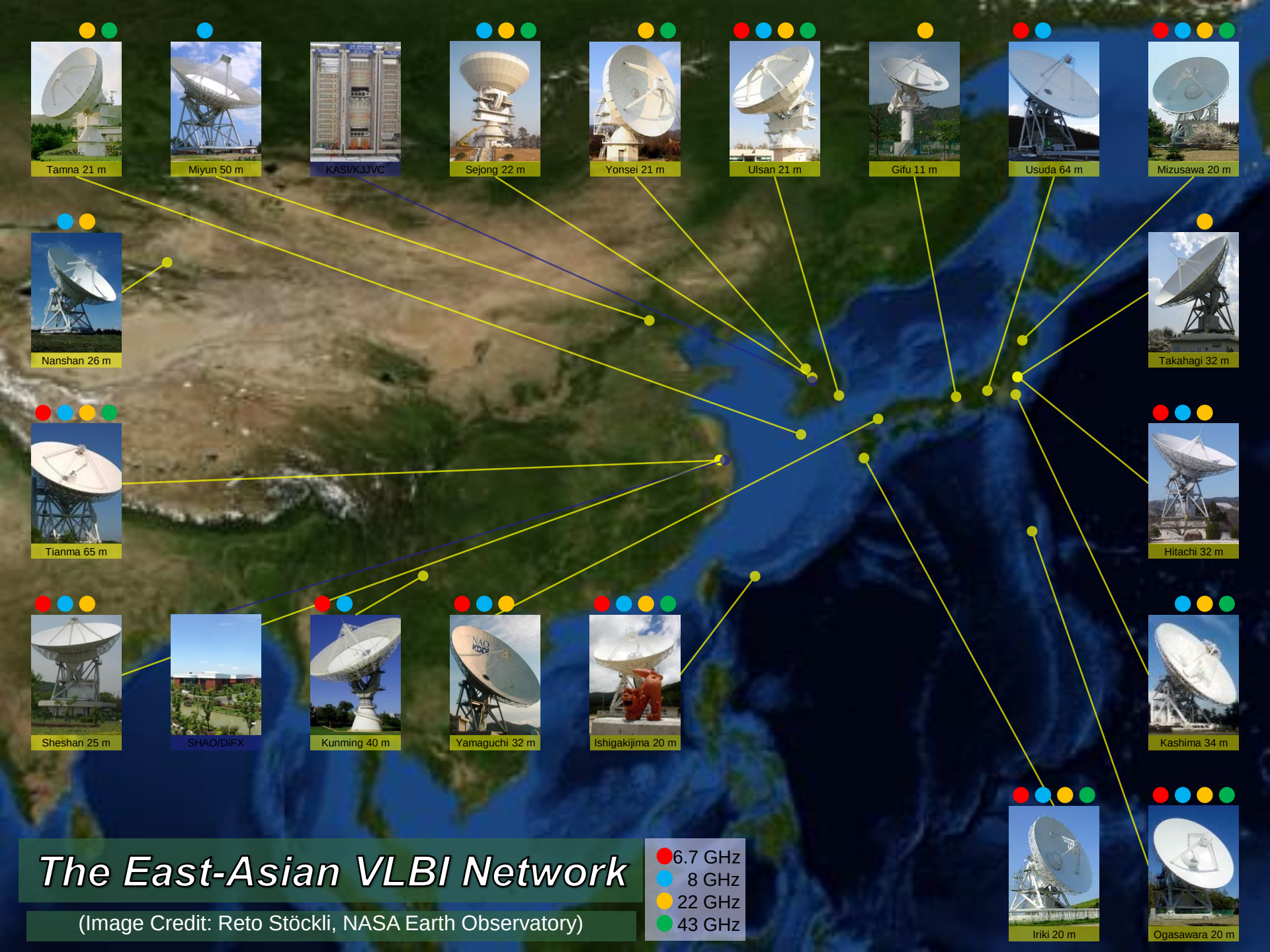
S_0: Source Flux, S_{UR}: Station Sensitivity

small dish (Sh) – calibration assistant

big dish (TMRT) – sensitivity booster

(Kawaguchi et al. PASJ, 2015)




Tamna 21 m
Miyun 50 m
KASI/KJJVC
Sejong 22 m
Yonsei 21 m
Ulsan 21 m
Gifu 11 m
Usuda 64 m
Mizusawa 20 m
Nanshan 26 m
Takahagi 32 m
Tianma 65 m
Hitachi 32 m
Sheshan 25 m
SHAO/DiFX
Kunming 40 m
Yamaguchi 32 m
Ishigakijima 20 m
Kashima 34 m
Iriki 20 m
Ogasawara 20 m
The East-Asian VLBI Network
(Image Credit: Reto Stöckli, NASA Earth Observatory)
6.7 GHz
8 GHz
22 GHz
43 GHz

EAVN

2017 Mar –May (K and Q band), contemporized with the EHT (April 4-11) campaign.

A good start!

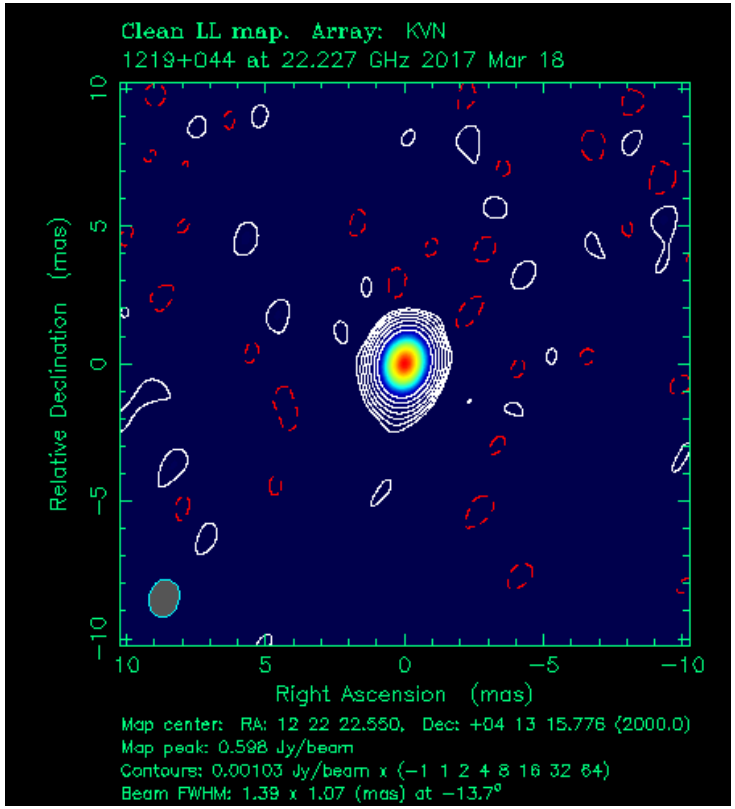
Obs. Code	Date	Sources	Freq. Band	Stations
a17077a	Mar 18 UT12:45-19:45	M87	K	KaVA, Tm, Ur, Ht, Ks
a17078a	Mar 19 UT11:40-18:40	M87	Q	KaVA, Tm
a17086a	Mar 27 UT13:10-23:10	M87+SgrA	Q	KaVA, Tm
a17093a	Apr 3 UT13:20-23:25	M87+SgrA	K	KaVA, Tm,Ur,Ht,Ks,Mc
a17094a	Apr 4 UT12:35-22:35	M87+SgrA	Q	KaVA, Tm
a17099a	Apr 9 UT12:20-22:20	M87+SgrA	Q	KaVA, Tm, Ny
a17104a	Apr 14 UT12:00-22:00	M87+SgrA	Q	KaVA, Tm
a17107a	Apr 17 UT11:45-18:45	M87	K	KaVA, Tm,Ur,Sj,Ht,Ks,Mc,Nt
a17108a	Apr 18 UT11:40-21:40	M87+SgrA	Q	KaVA, Tm
a17114a	Apr 24 UT09:20-16:20	M87	K	KaVA, Tm
a17115a	Apr 25 UT09:15-16:15	M87	Q	KaVA, Tm
a17116a	Apr 26 UT15:55-21:55	SgrA	Q	KaVA, Tm, Sj
a17130a	May 10 UT08:20-17:20	M87	K	KaVA, Tm, Mc
a17131a	May 11 UT08:15-17:15	M87	Q	KaVA, Tm
a17145a	May 25 UT14:10-20:12	SgrA	Q	KaVA, Tm
a17146a	May 26 UT07:20-14:20	M87	Q	KaVA, Tm

EAVN campaign 2018, Mar –May. (K and Q band) during EHT (April 20-29)

Obs. Code	Date		Sources	Freq. Band	Stations
a18068a	03/09	UT13:20 - 20:20	M87	K	KaVA, Tm, Ur, Mc
a18069a	03/10	UT12:15 - 19:15	M87	Q	KaVA, Tm
a18085a	03/26	UT12:45 - 19:45	M87	K	KaVA, Tm, Ur, Mc
a18087a	03/28	UT11:05 - 18:05	M87	Q	KaVA, Tm
a18088a	03/29	UT17:45 - 23:50	SgrA	Q	KaVA, Tm
a18101a	04/11	UT10:40 - 17:40	M87	Q	KaVA, Tm
a18110a	04/20	UT09:35 - 21:35	M87+SgrA	K	KaVA, Tm, Ny, Ur, Ib, Mc
a18111a	04/21	UT09:30 - 21:30	M87+SgrA	Q	KaVA, Tm
a18117a	04/27	UT09:05 - 21:10	M87+SgrA	K	KaVA, Tm, Ny
a18118a	04/28	UT09:00 - 21:05	M87+SgrA	Q	KaVA, Tm, Ur, Ib, Mc
a18124a	05/04	UT08:15 - 20:15	OJ287, CenA	Q	KaVA, Tm
a18127a	05/07	UT08:25 - 20:30	M87+SgrA	Q	KaVA, Tm, Ny
a18128a	05/08	UT08:25 - 20:25	M87+SgrA	K	KaVA, Tm

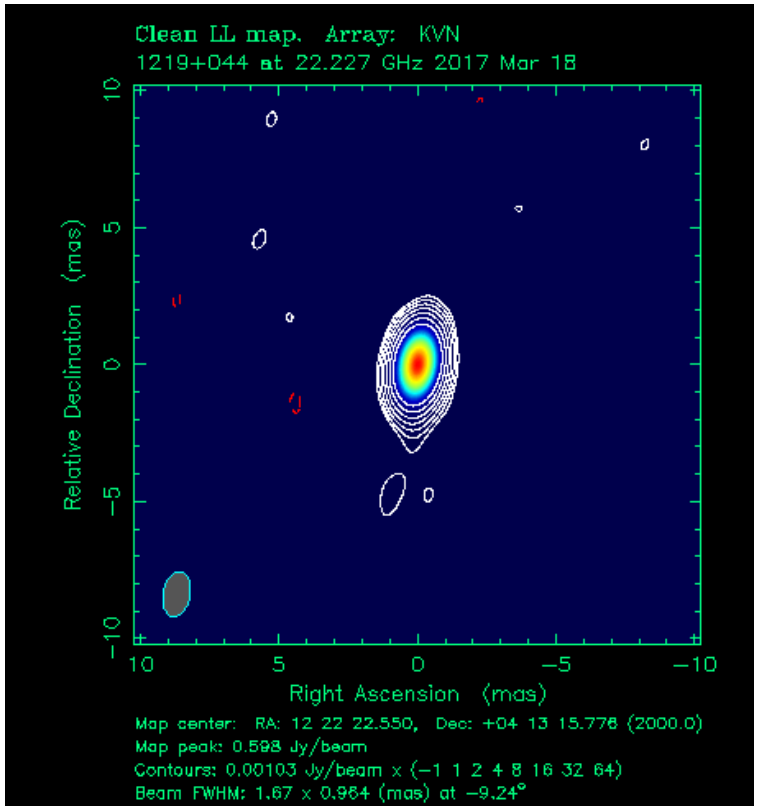
Snapshot images on a point source (22GHz, 10min integration)

Only KaVA



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

KaVA + Tianma



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

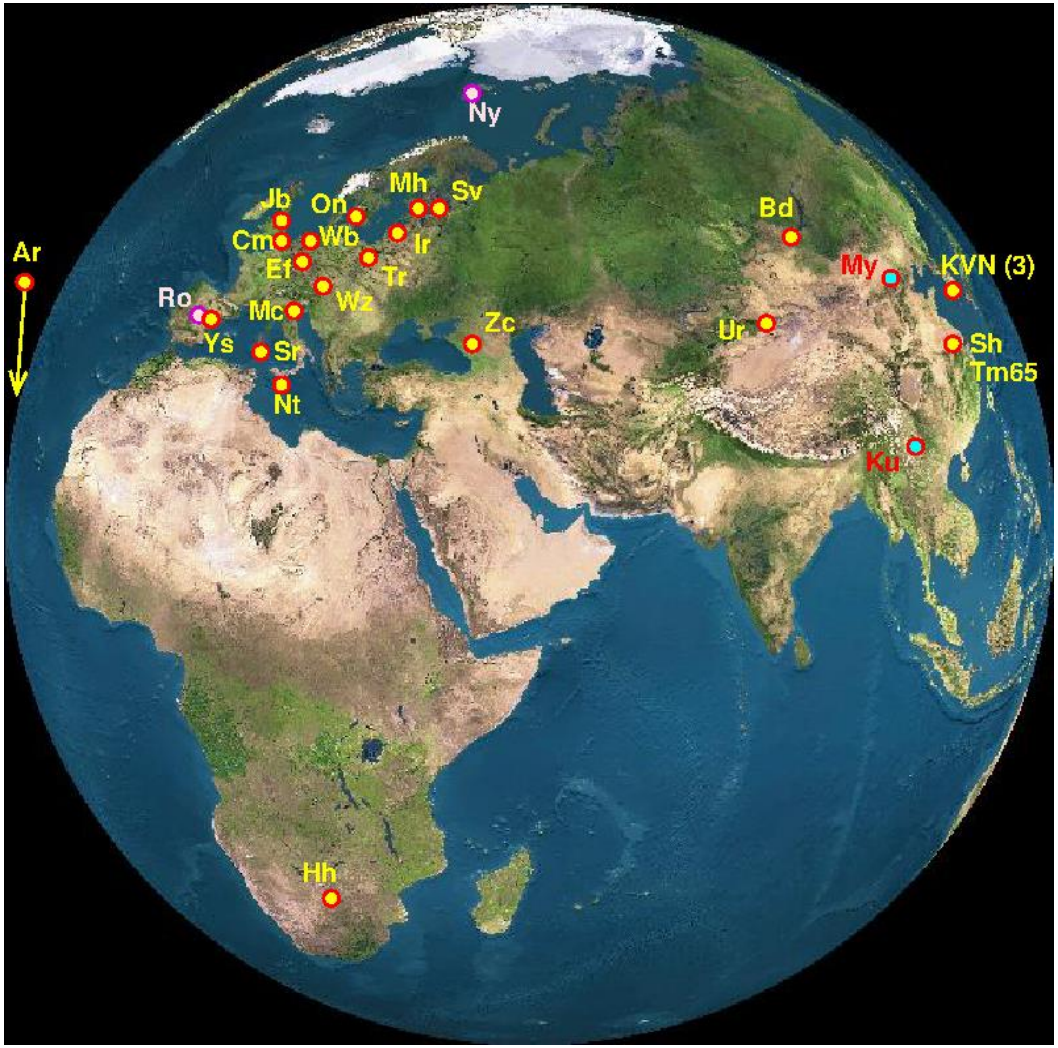
~50% increase in image DR

(Courtesy： Kazuhiro Hada)

EVN

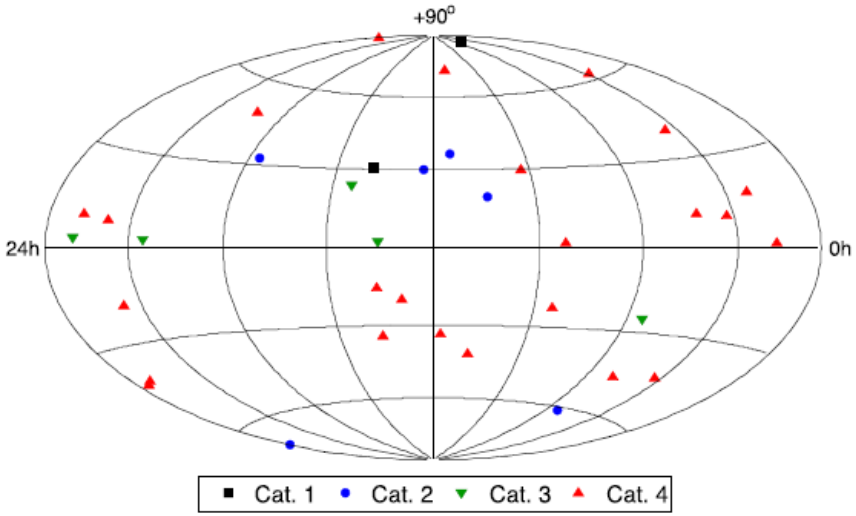
As a member of EVN, TMRT participates the EVN, e-VLBI, Global VLBI and RadioAstron sessions, at various bands: L/C/X (2014-), K (2017.10-), Q (2018-).

Reference antenna for the EVN!



TMRT for radio-optical frame connection

- TMRT has been observing 37 ICRF2-Gaia transfer sources in some IVS-R&D sessions since 2014
- The goal is to improve the position accuracies to better than 200 μas for both R.A. and decl.
- Table 4: # of successful observations when using TMRT or not.



37 ICRF2-Gaia transfer sources

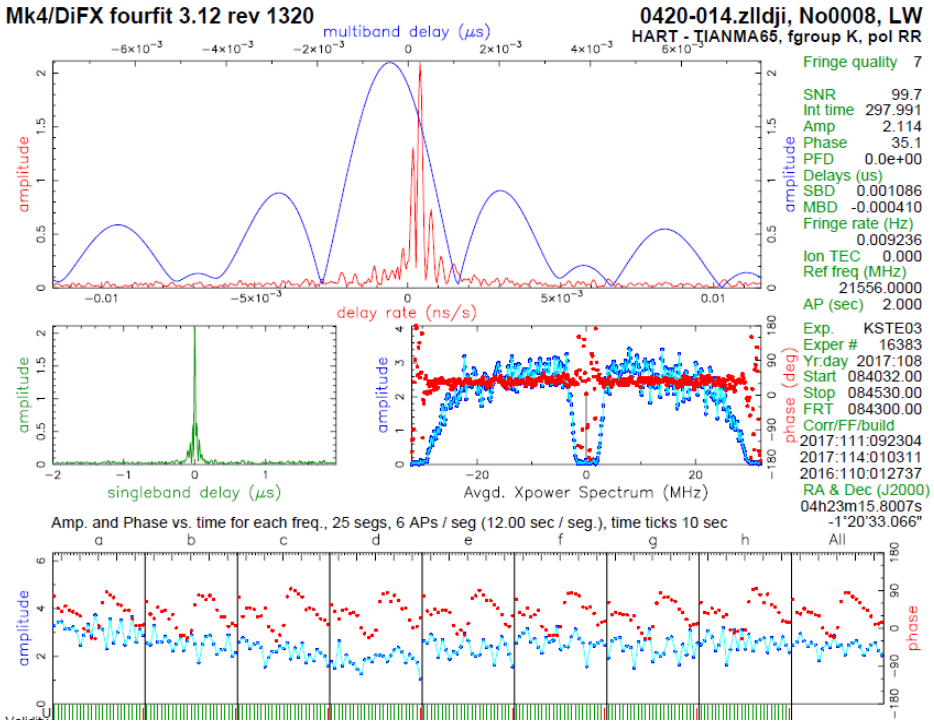
Table 4
Number of Successful Observations of the 24 ICRF2-*Gaia* Transfer Sources in Category 4 When Using Tianma (T6) in the Network or Not

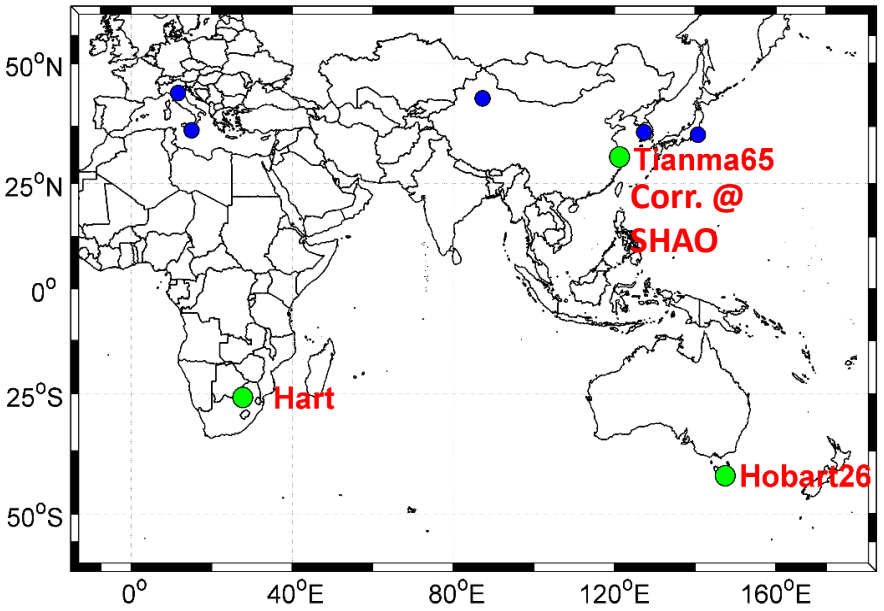
	Number of Observations			Flux (Jy)	
Sources	w/ T6	w/o T6	Ratio	S Band	X Band
2135–184	[illegible]	[illegible]	…	0.03	0.10
0316–444	4	0	…	0.05	0.05
0211+171	10	3	3.3	0.06	0.06
1251–197	22	7	3.1	0.07	0.07
1333–152	28	9	3.1	0.07	0.10
0325+395	9	0	…	0.07	0.33
0912+297	43	22	2.0	0.08	0.07
0137+012	57	34	1.7	0.08	0.17
0312+100	74	57	1.3	0.09	0.10
1046–409	7	2	3.5	0.09	0.12
1333–337	20	6	3.3	0.09	0.17
1908+484	69	39	1.8	0.10	0.06
1143–332	15	5	3.0	0.13	0.16
2329–415	7	2	3.5	0.14	0.13
1104+728	84	56	1.5	0.16	0.12
0410+110	102	76	1.3	0.16	0.15
0812+020	99	68	1.5	0.20	0.13
2145+082	23	10	2.3	0.22	0.09
0241+622	20	18	1.1	0.24	0.52
2314–409	10	1	10.0	0.30	0.15
2239+096	59	45	1.3	0.33	0.23
0823–223	20	11	1.8	0.40	0.76
2353+816	106	89	1.2	0.49	0.36
0454–463	3	0		0.74	0.50
Average	…	…	2.6	…	…

(Le bail et al. 2016, AJ)

K band Astrometry

In collaborations with HartRAO, SHAO, UTAS etc.
Fringe test on April 18, 2017 (Hart26m-TMRT).
The first 24 h session already done on August 28, 2017!

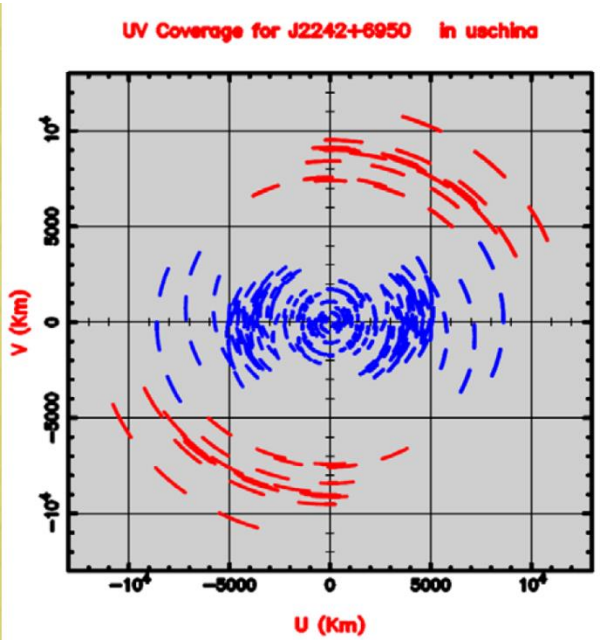


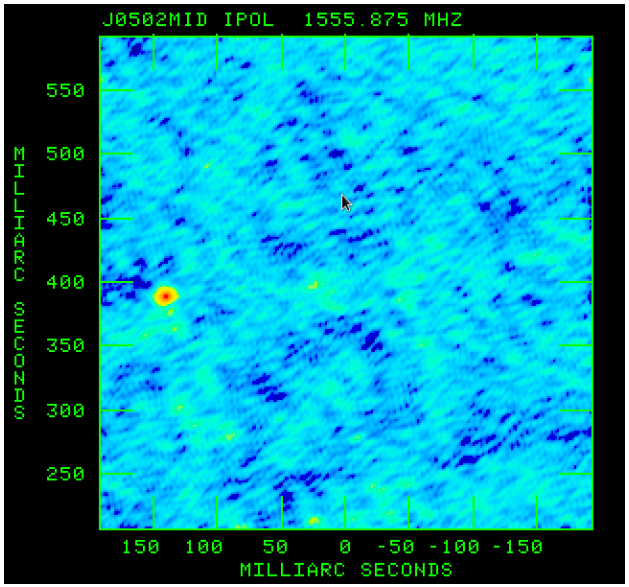


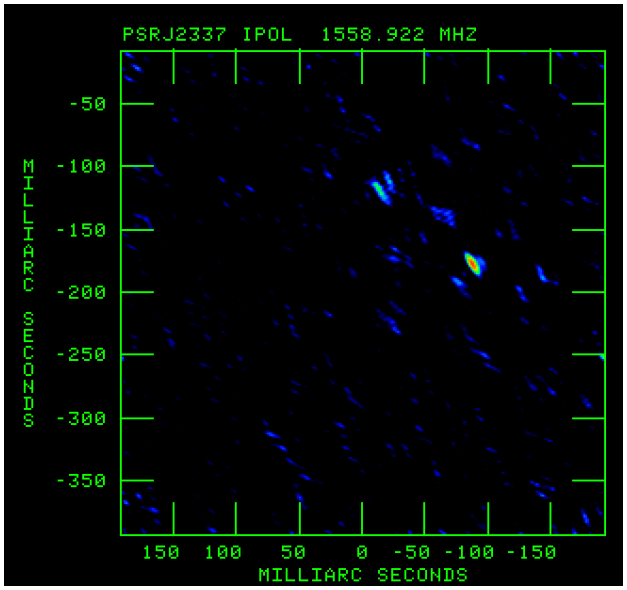
2Gbps K-band fringe Hh-T6!

Pulsar Astrometry with VLBA+TMRT

- **pulsar parallaxes via relative astrometry (differential astrometry) to get distances and transverse velocities (proper motion)**





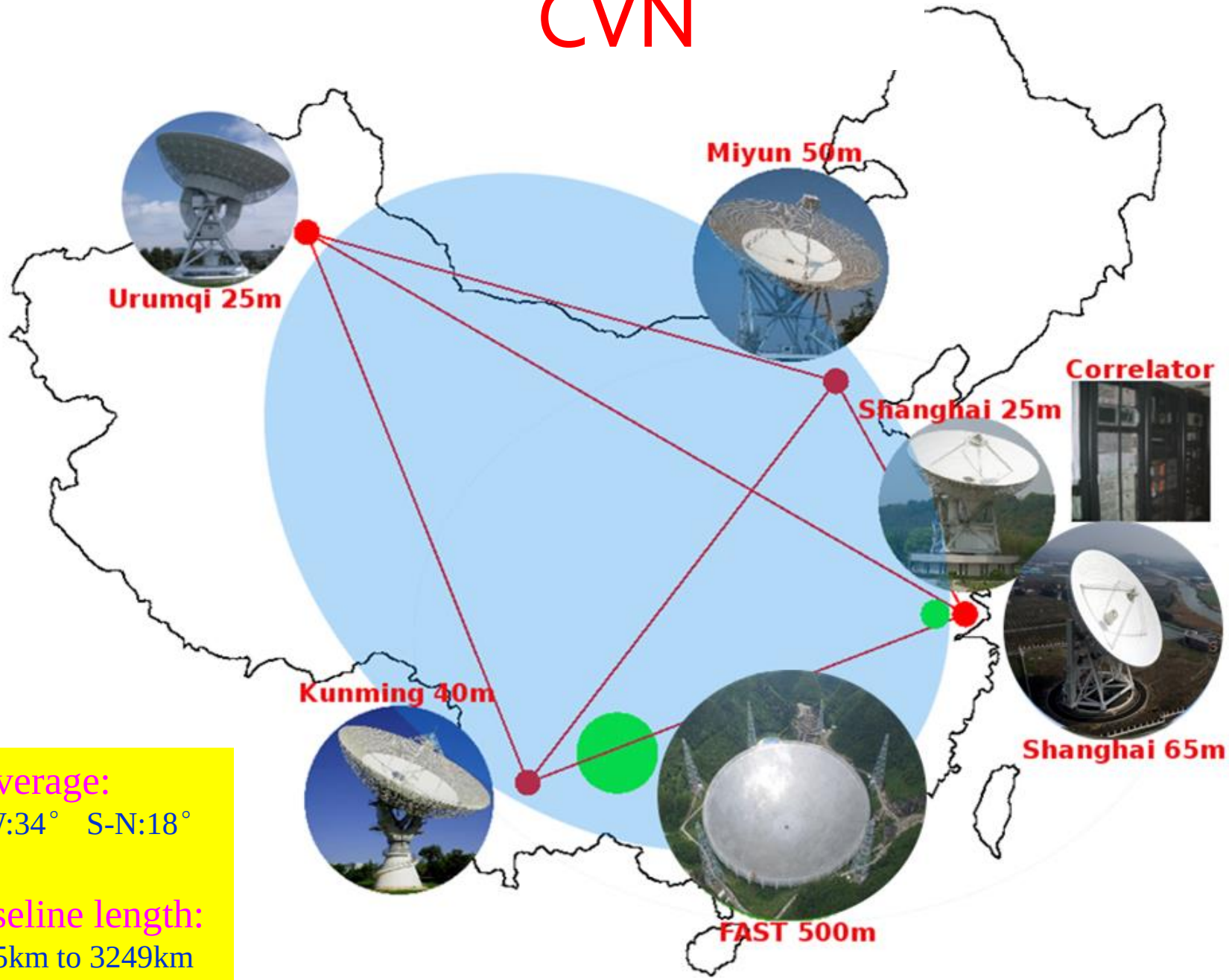


NAME	PSRJ	P0	DM	S1400
B0458+46	J0502+4654	0.638565 s	42.19 cm^-3 pc	2.50 mJy
B2334+61	J2337+6151	0.495370 s	58.41 cm^-3 pc	1.40 mJy

(Yan et al.)

Chang'E National Project (2004-)

CVN

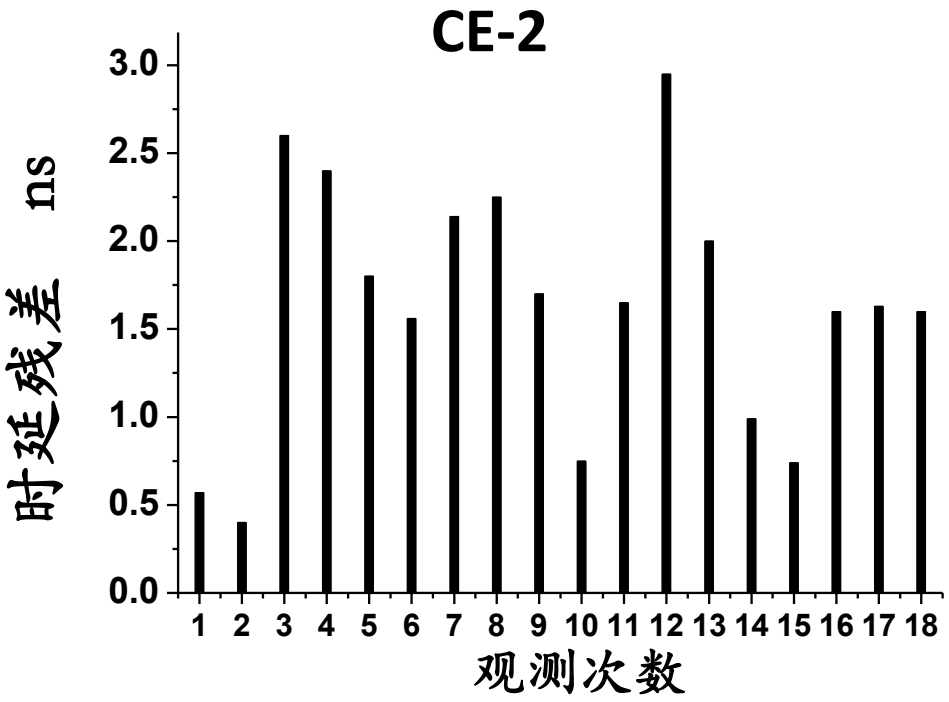


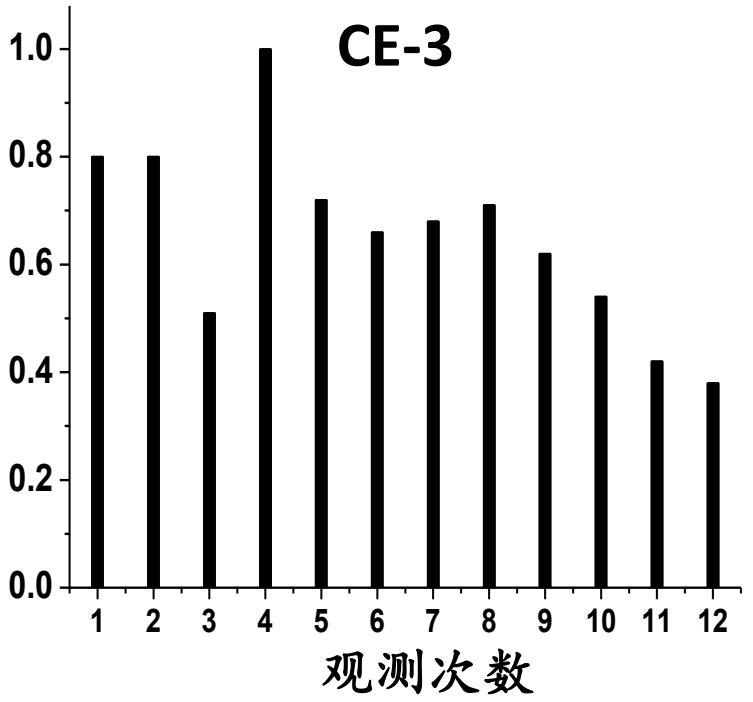
Coverage:
E-W:34° S-N:18°

Baseline length:
1115km to 3249km

Chang'E National Project (in 2013)

Delay precision was greatly improved with TMRT in CE 3!



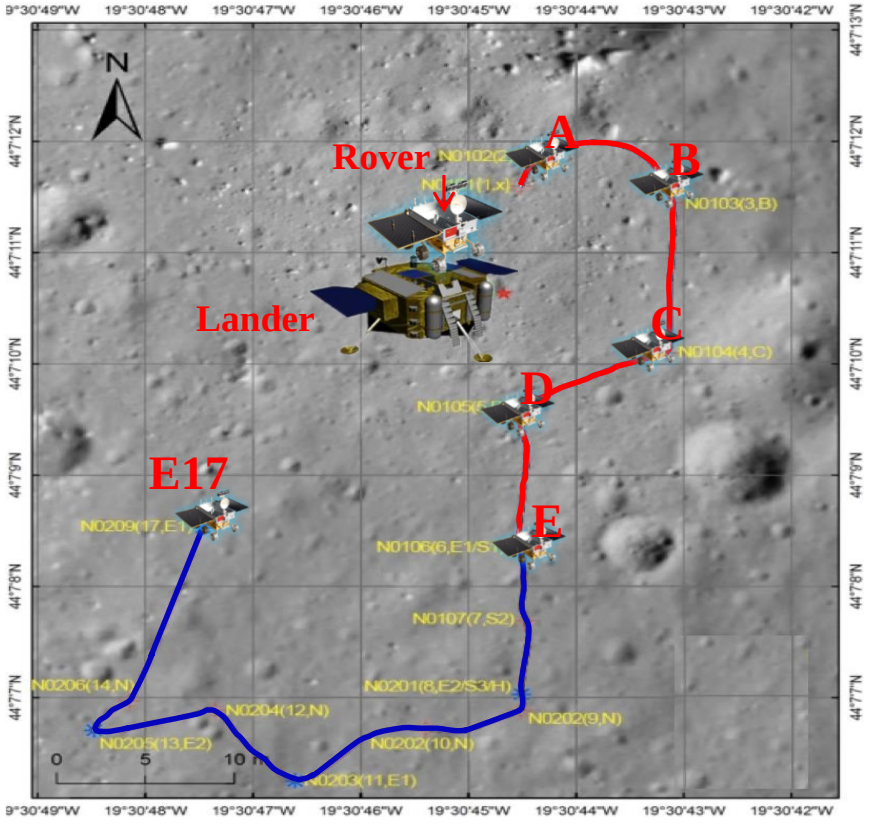


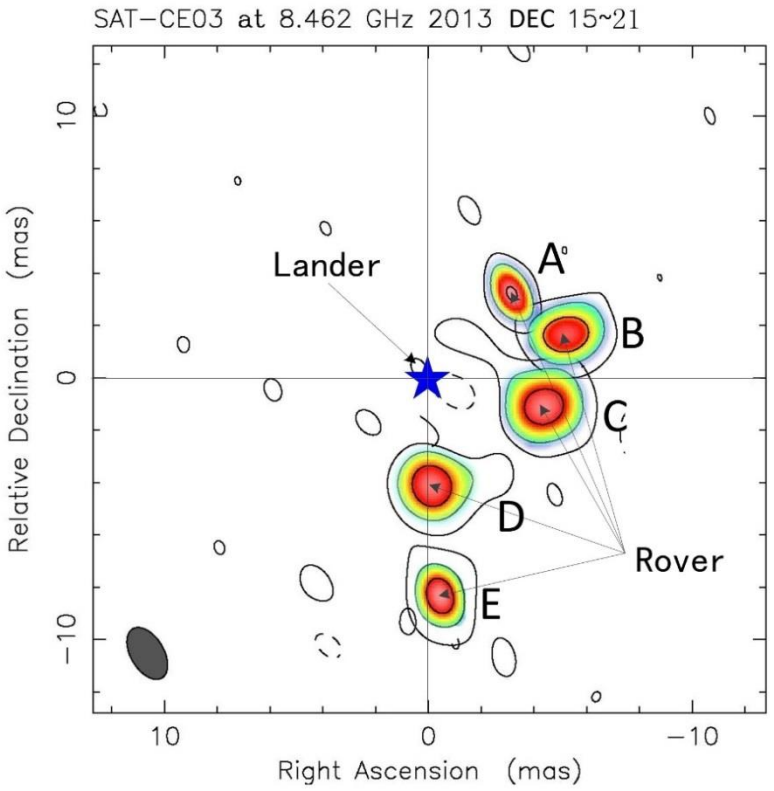
Residual delay error 1.77ns with Sheshan 25 in CE 2.

Residual delay error improved to 0.67ns with Tianma in CE 3.

Phase-reference results of CE-3 Rover

- Target: Rover using the Lander as the Calibrator.
- The accuracy of the relative position between Lander and Rover is ~1m (0.5mas).





Thanks!