New Broadband VLBI System for High Precision Delay Measurement

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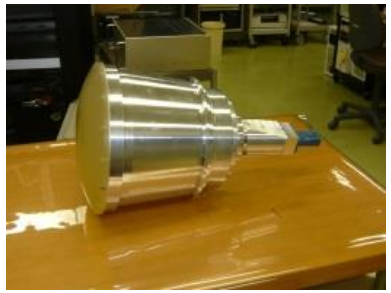
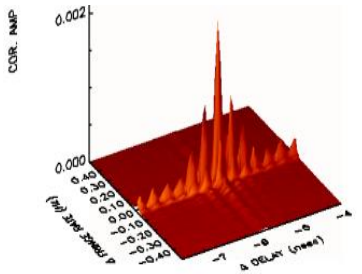
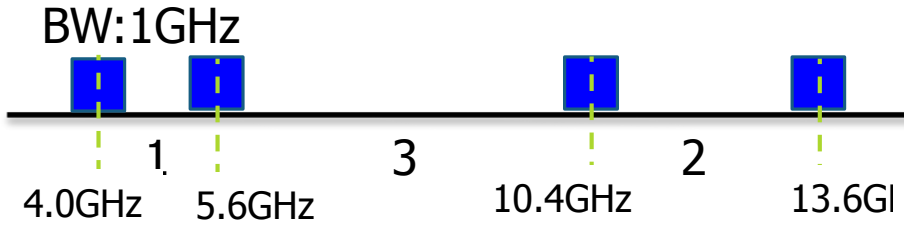
New Broadband VLBI: Gala--V Project Overview

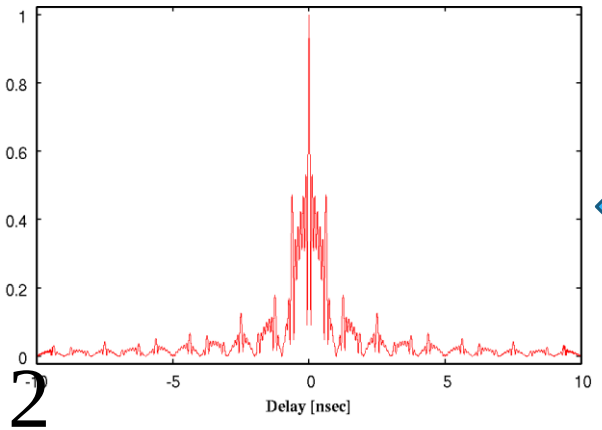
- **Target：** Precise frequency Comparison over Inter--continental distance
- **Concept：** Broadband VLBI Compatible with VGOS for joint Observation.



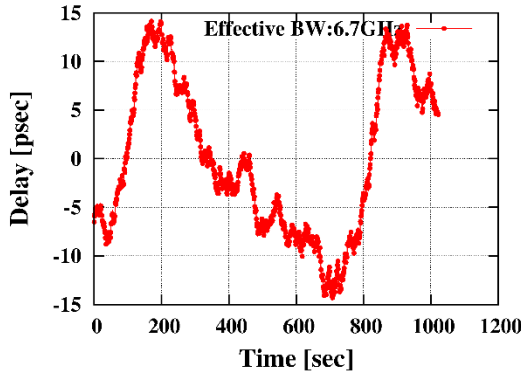
- New Technologies
  - Original Design of Broadband Feed for Cassegrainian Optics
  - RF Direct--Sampling by using high speed Sampler
- Data Acquisition：Four bands(BW:1024MHz) in 3--15GHz Freq, Range.
  - Nominal Array= 4. 0GHz、5. 6GHz、10. 4GHz、13. 6GHz, Non redundancy Interval.
  - Effective Bandwidth：3. 8GHz（10 Times wider than conventional）

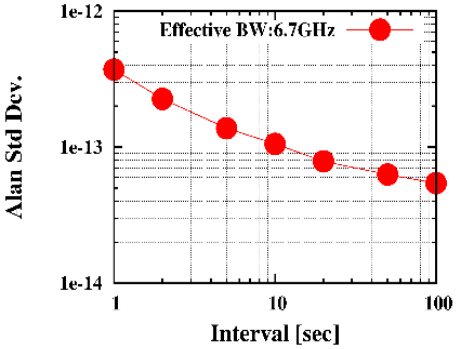






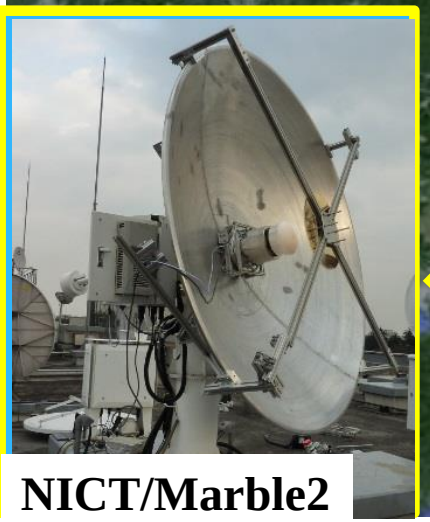
Delay Resolution Function
10 Times precise delay determination can be achieved without ambiguity





Broadband VLBI Stations in Japan

NMIJ/Marble1

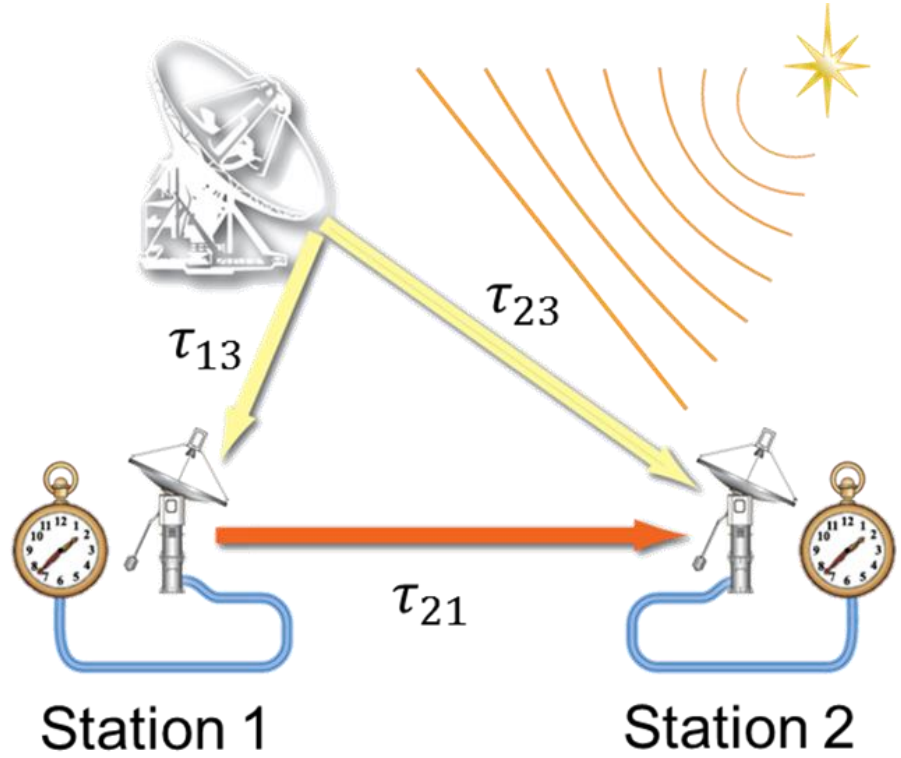


NICT/Marble2

GSI/Ishioka13m

NICT/Kashima34

GALA--V Project is targeting distant frequency comparison between small diameter transportable VLBI stations. Disadvantage of small aperture is compensated by **Broadband** and **joint observation with Large diameter antennas**.

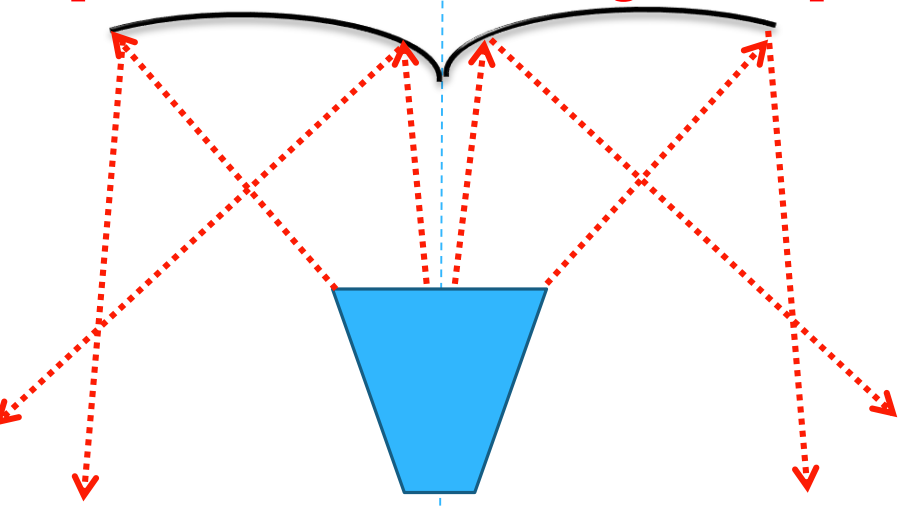


$$\tau_{21} = \tau_{13} - \tau_{23}$$

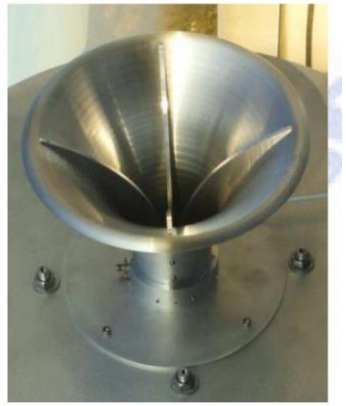
New Technology 1

Requirement of original Broadband Feed

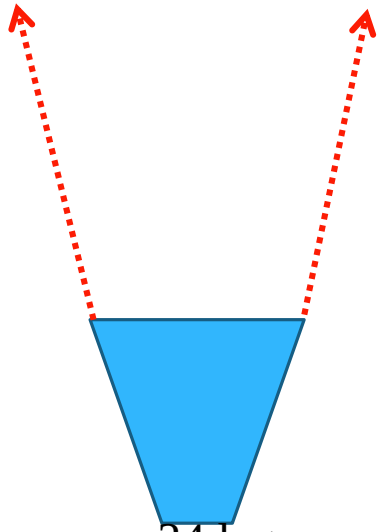
Beam widths of known Broadband Feeds are more than 120 deg. It requires **Special antenna with Ring focus optics**



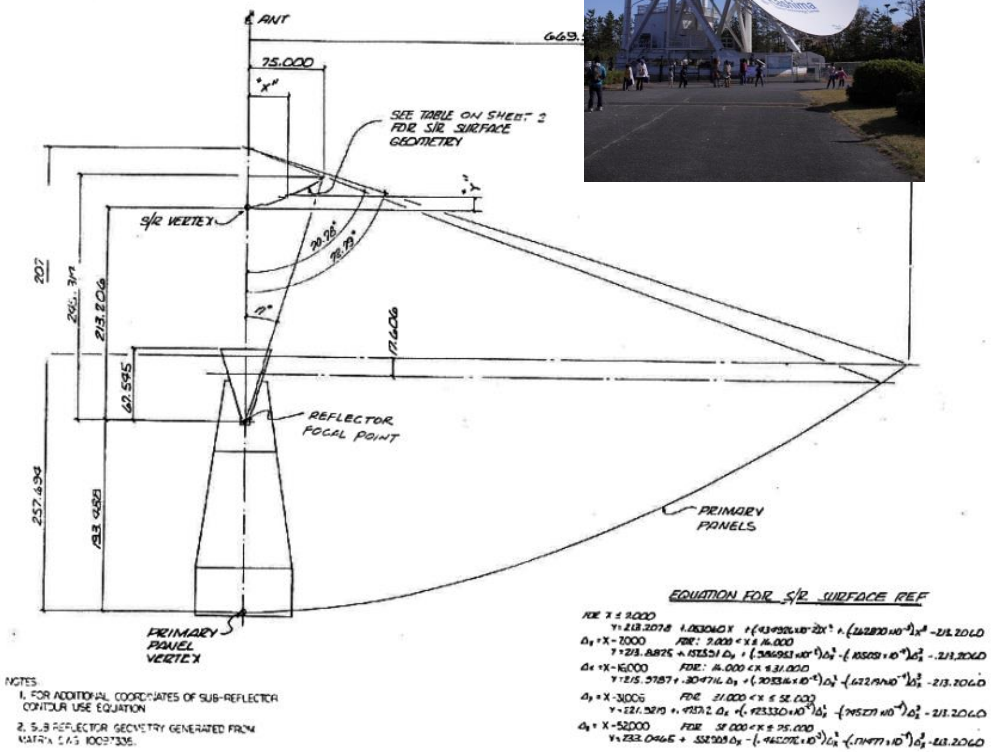
~120deg.



We requires **Narrow beam width in broad frequency range for enable Cassegrain antenna.**

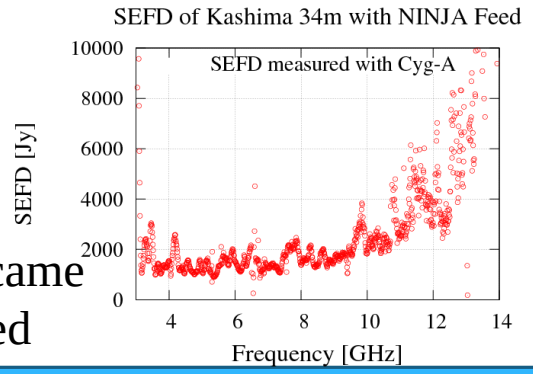


~34deg.



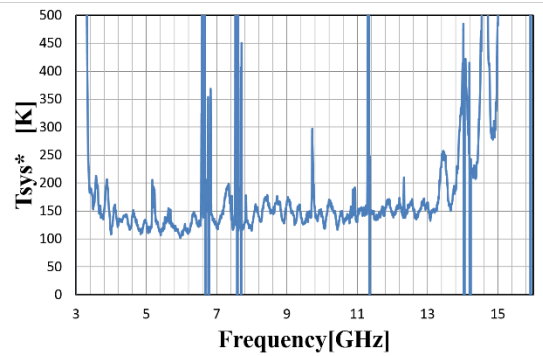
New Technology 1

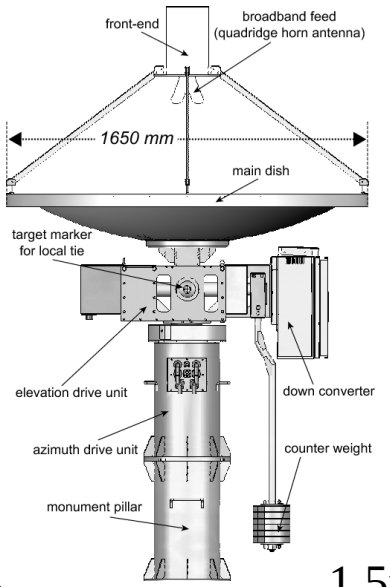
Application of Original Broadband Feed



3--13GHz observation became available with NINJA--feed

NINJA Feed with Room Temperature LNA





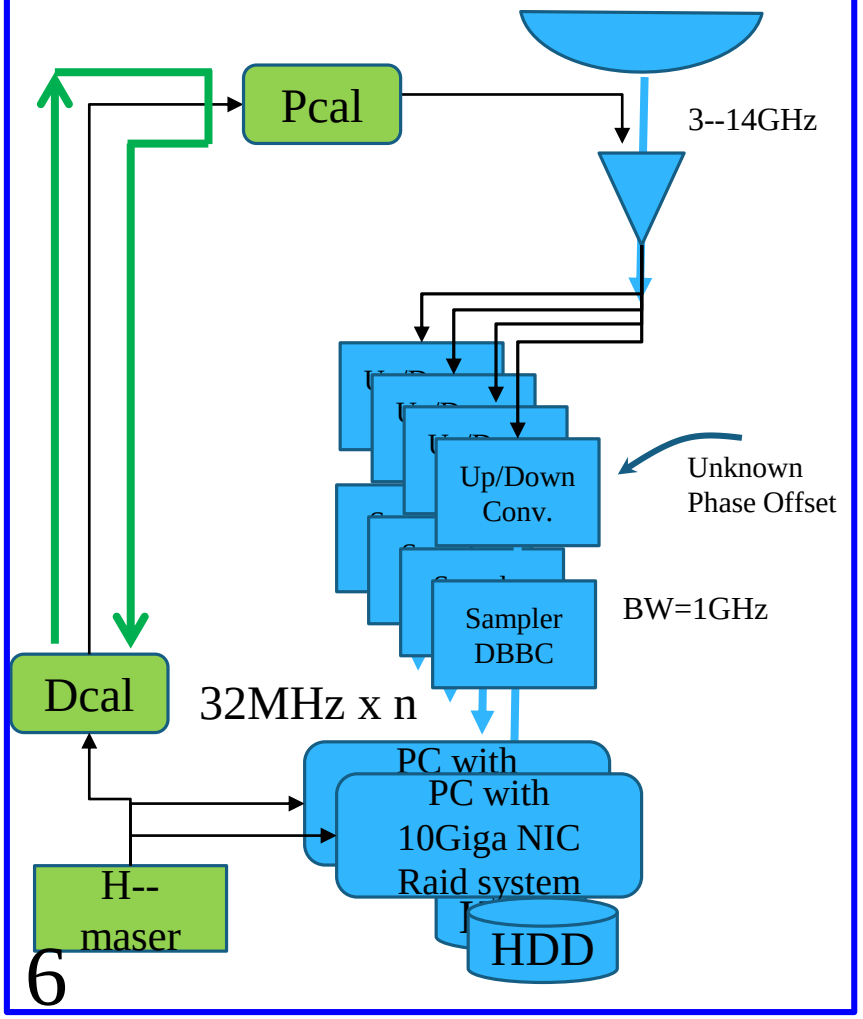
1.5m MABRL1 Antenna

Another version of NINJA--feed was used for upgrading prime--focus 1.5m antenna to 2.4m Cassegrain antenna.

New Technology 2

Simple and Stable DAS via RF Direct Sampling

VGOS Proof of Concept(PoC) Broadband VLBI System



The New RF Direct--Sampling system has several advantages.

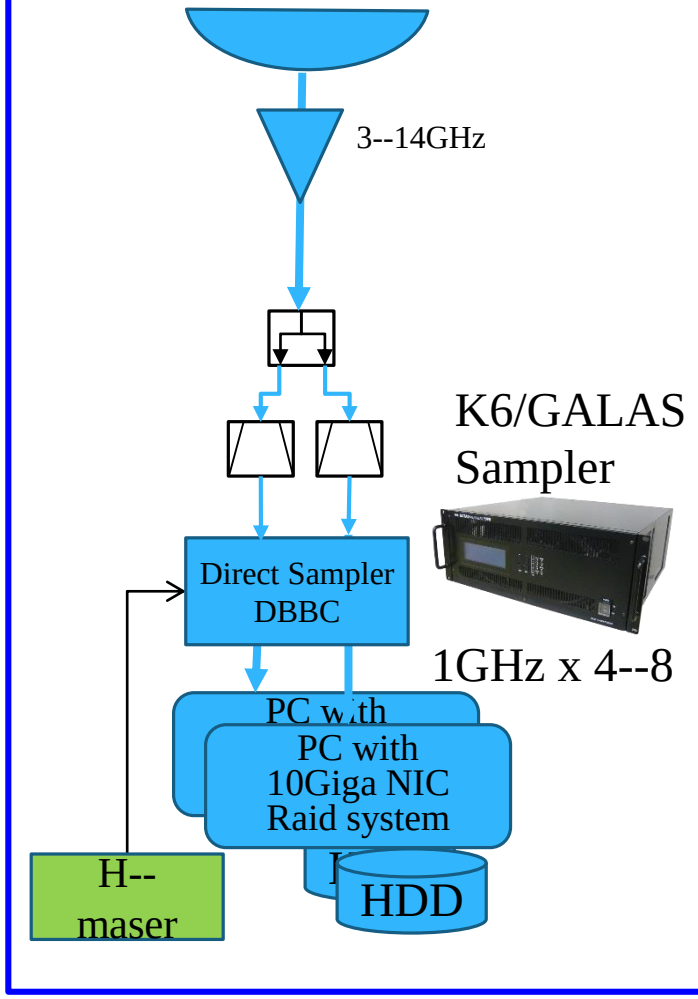
A) It is free from "unknown phase offset", which is inserted by analog frequency conversion in case of PoC VLBI system.

B) Radio frequency signal is captured by direct sampling without frequency conversion. Then four 1GHz bands are extracted by digital baseband conversion. Thus phase relation among the captured signal is stable.

C) Due to these reasons, phase--calibration (Pcal) signal and related delay calibration system can be avoidable.

Simpler and stable

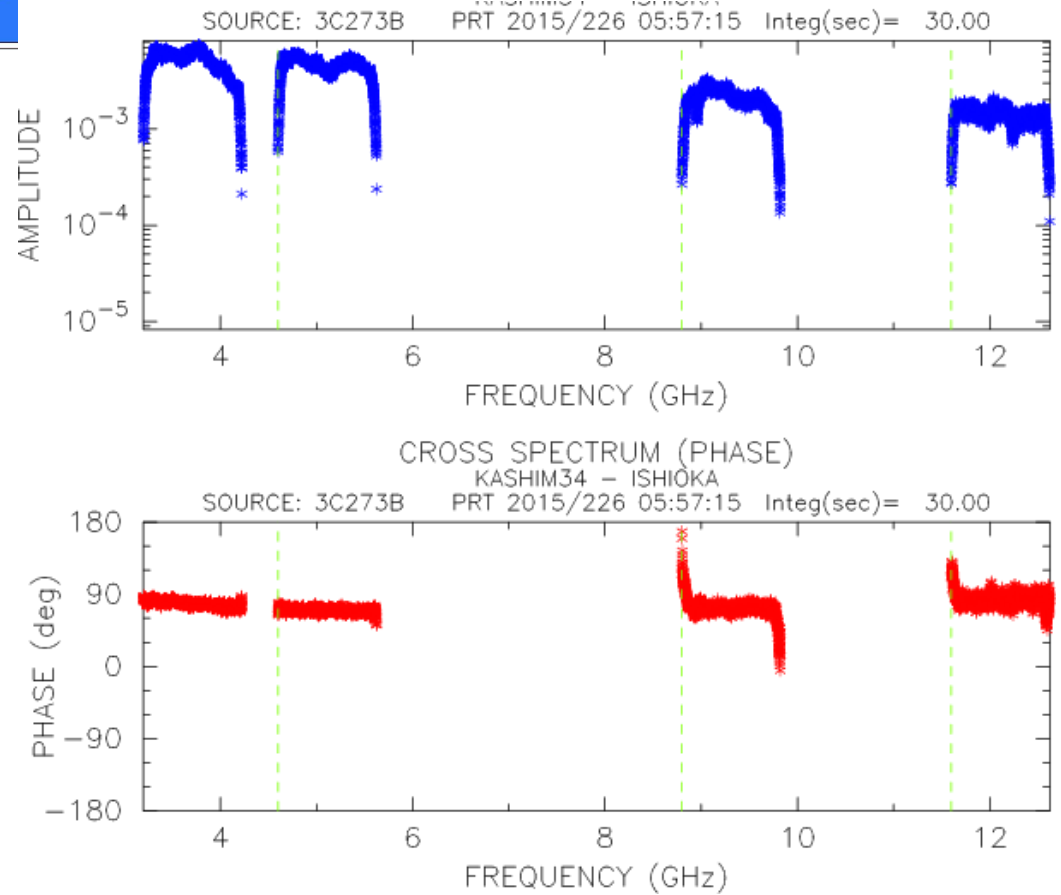
GALA--V RF Direct Sampling Broadband VLBI System



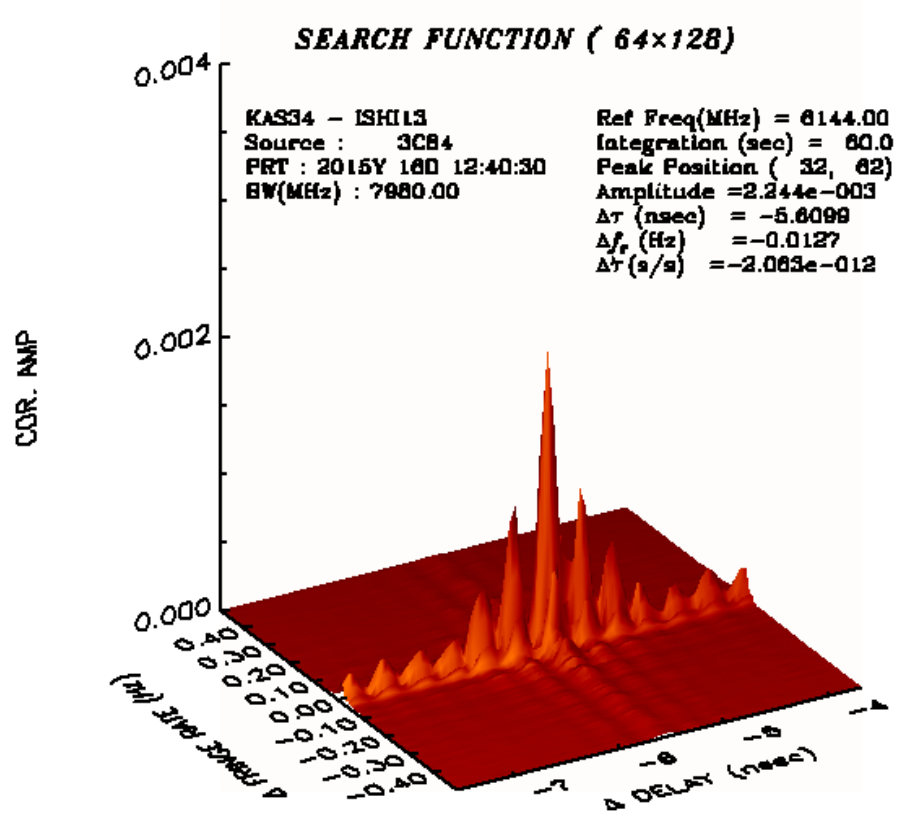
New Technology 3

Broadband bandwidth Synthesis has been developed by Calibration with radio source

Cross correlation spectrum



Delay Resolution Function



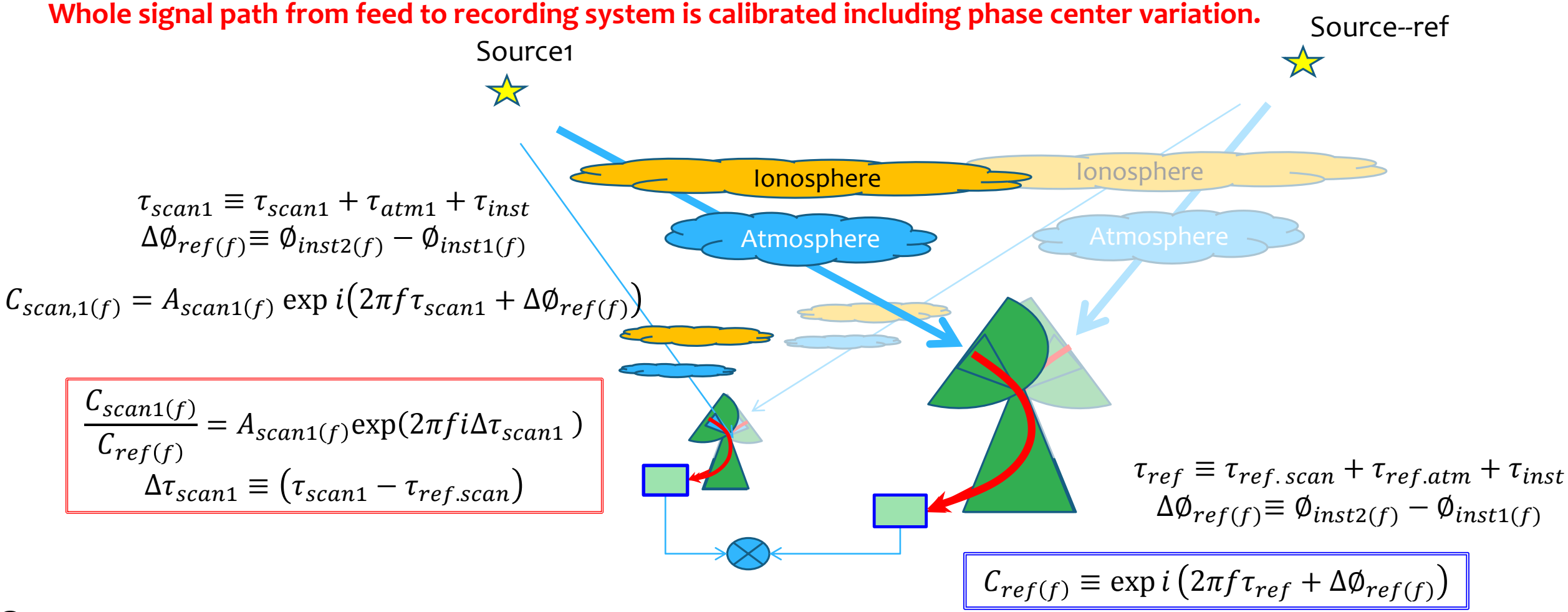
Observation data between Kashima 34m – Ishioa 13m

New Technology 3

Calibration with Radio Source to recover Linear Phase

1. Observing strong radio source as a reference
2. Frequency dependent correlation phase response is used as reference to calibrate the other correlation data.

Whole signal path from feed to recording system is calibrated including phase center variation.



$$\tau_{scan1} \equiv \tau_{scan1} + \tau_{atm1} + \tau_{inst}$$
$$\Delta\emptyset_{ref(f)} \equiv \emptyset_{inst2(f)} - \emptyset_{inst1(f)}$$

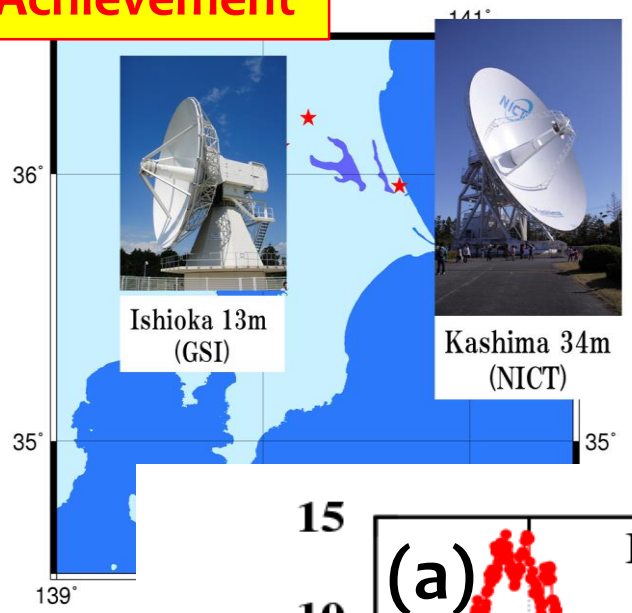
$$C_{scan,1(f)} = A_{scan1(f)} \exp i\left(2\pi f \tau_{scan1} + \Delta\emptyset_{ref(f)}\right)$$

$$\frac{C_{scan1(f)}}{C_{ref(f)}} = A_{scan1(f)} \exp(2\pi f i \Delta\tau_{scan1})$$
$$\Delta\tau_{scan1} \equiv \left(\tau_{scan1} - \tau_{ref.scan}\right)$$

$$\tau_{ref} \equiv \tau_{ref.scan} + \tau_{ref.atm} + \tau_{inst}$$
$$\Delta\emptyset_{ref(f)} \equiv \emptyset_{inst2(f)} - \emptyset_{inst1(f)}$$

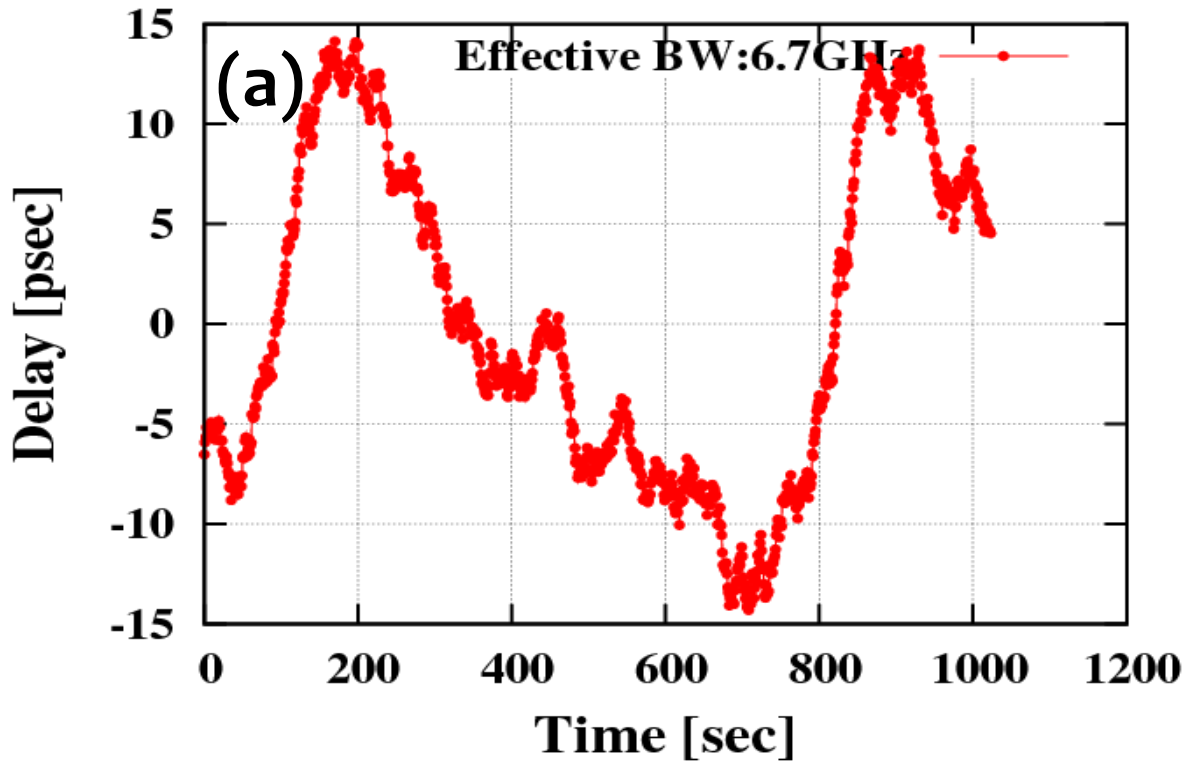
$$C_{ref(f)} \equiv \exp i\left(2\pi f \tau_{ref} + \Delta\emptyset_{ref(f)}\right)$$

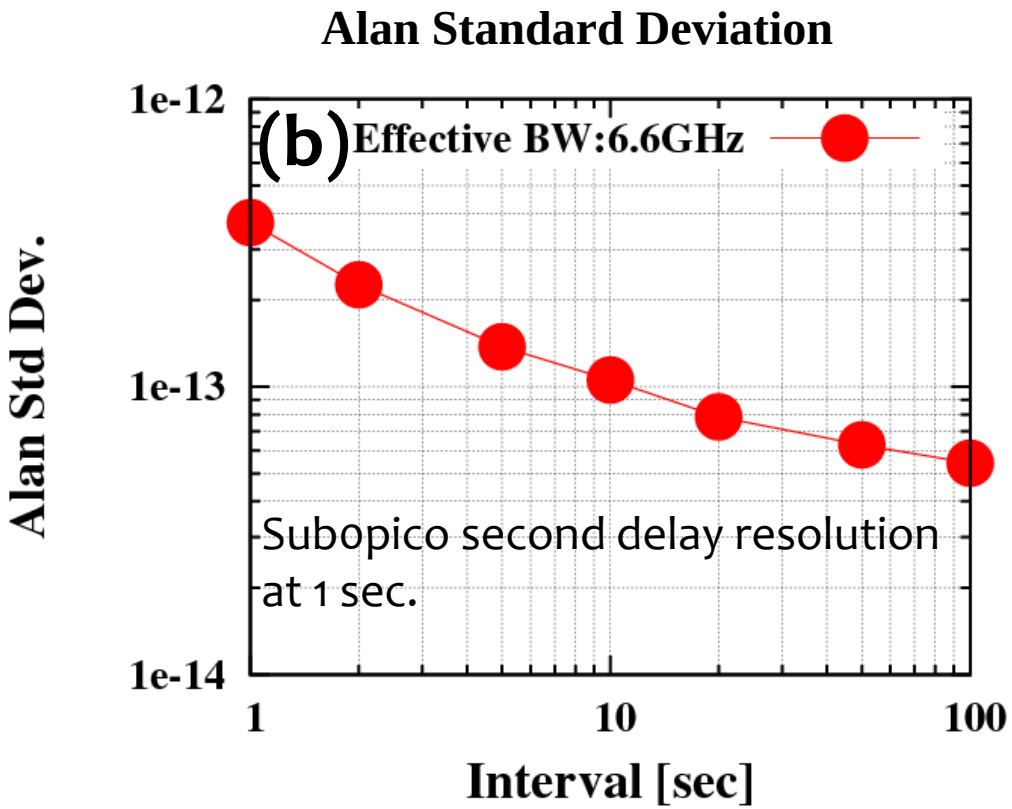
Achievement



Broadband Delay (3.2--12.6GHz) derived on Kashima34 – Ishioka 13m

1. Delay measurement reaches to sub--pico second with 1 sec. of observation.
2. Delay fluctuate of 10 pico--sec scale in hundreds of time scale is supposed to be caused from atmospheric delay change.

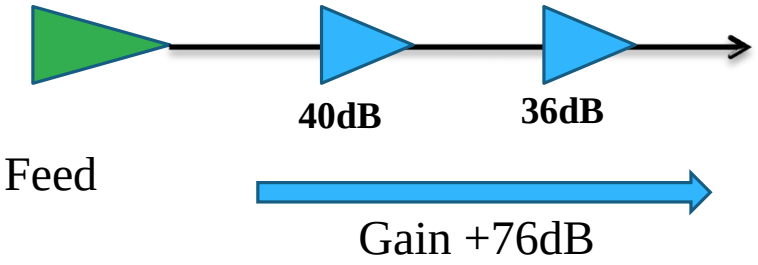




Interesting fact

Broadband System is Tolerant to RFI ?!

Input signal power level is
200K=**--176dBm/Hz== --116dBm/MHz = --76dBm/10GHz**



0dBm with BW=10GHz
At Input level to Sampler

=> **--40dBm/MHz**

In case of RFI contamination with power of +20dB above the noise floor at RBW=1MHz(= --96dBm).

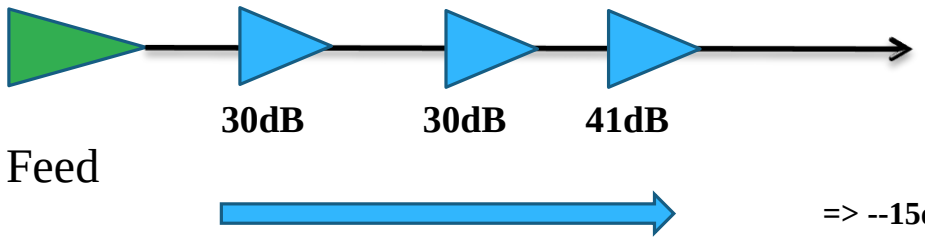
Power of **RFI** **vs** Total power of signal (noise)

--20dBm < **0dBm**

Broadband – BW = 10GHz

Narrowband – BW= 32MHz case

200K=**--176dBm/Hz== --116dBm/MHz = --101dBm/32MHz**

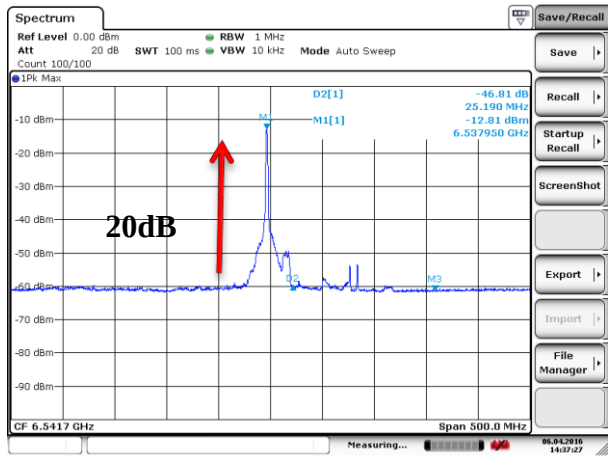


+0dBm
32MHz

=> **--15dBm/MHz**

Power of **RFI** **vs** Total power of signal (noise)

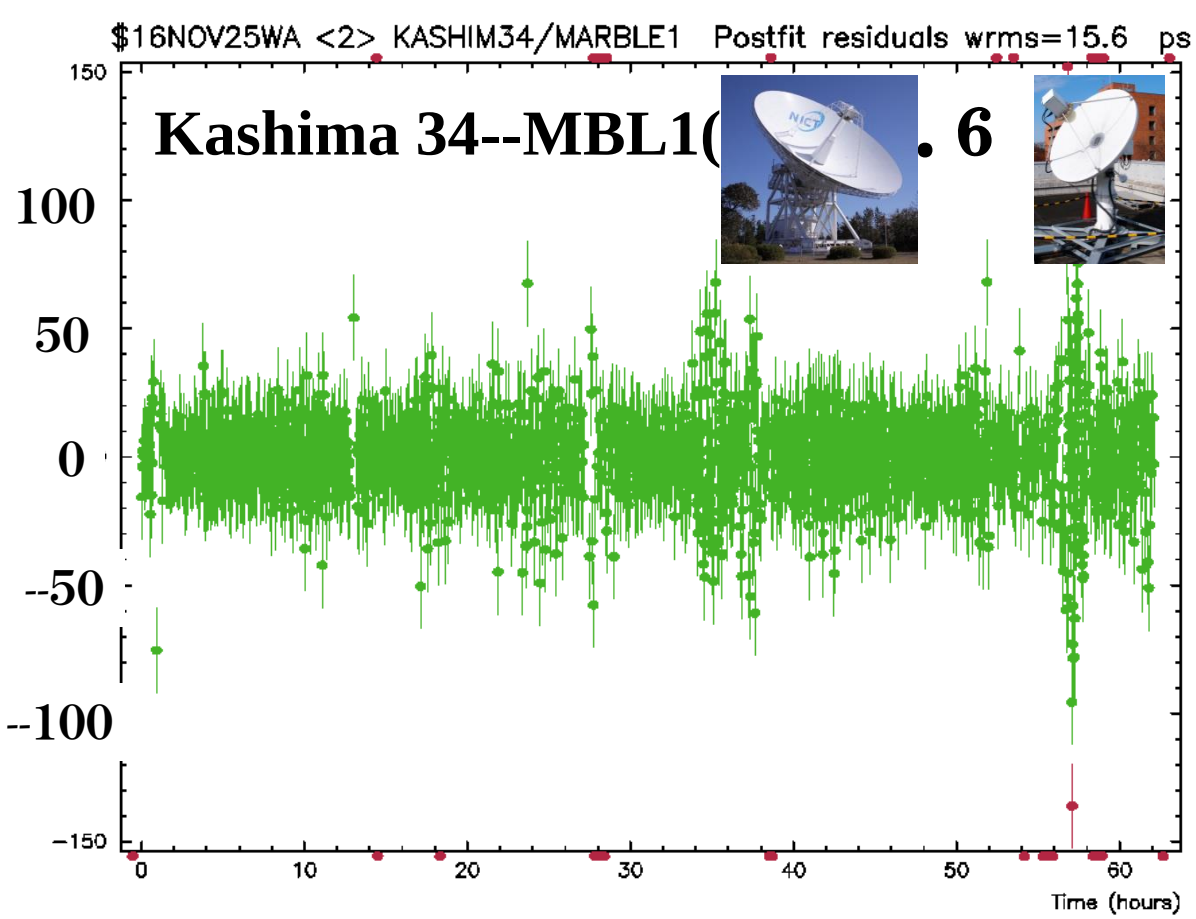
+5dBm > **0dBm**

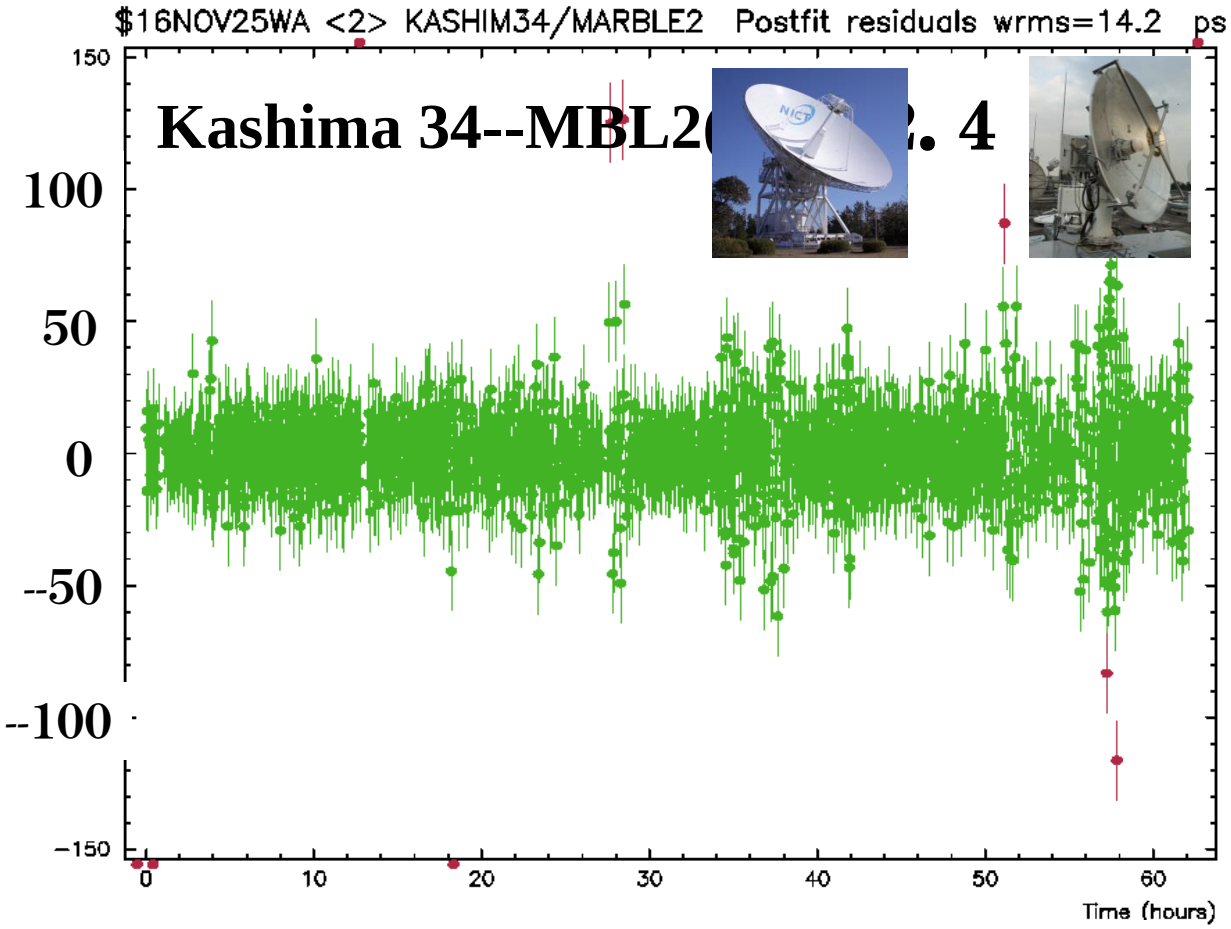


Results

Broadband delay: Post fit residual by CALC/SOLVE

WRMS of Large dimeter antenna – Small diameter antenna baseline was around **15 psec.**





Baseline Length

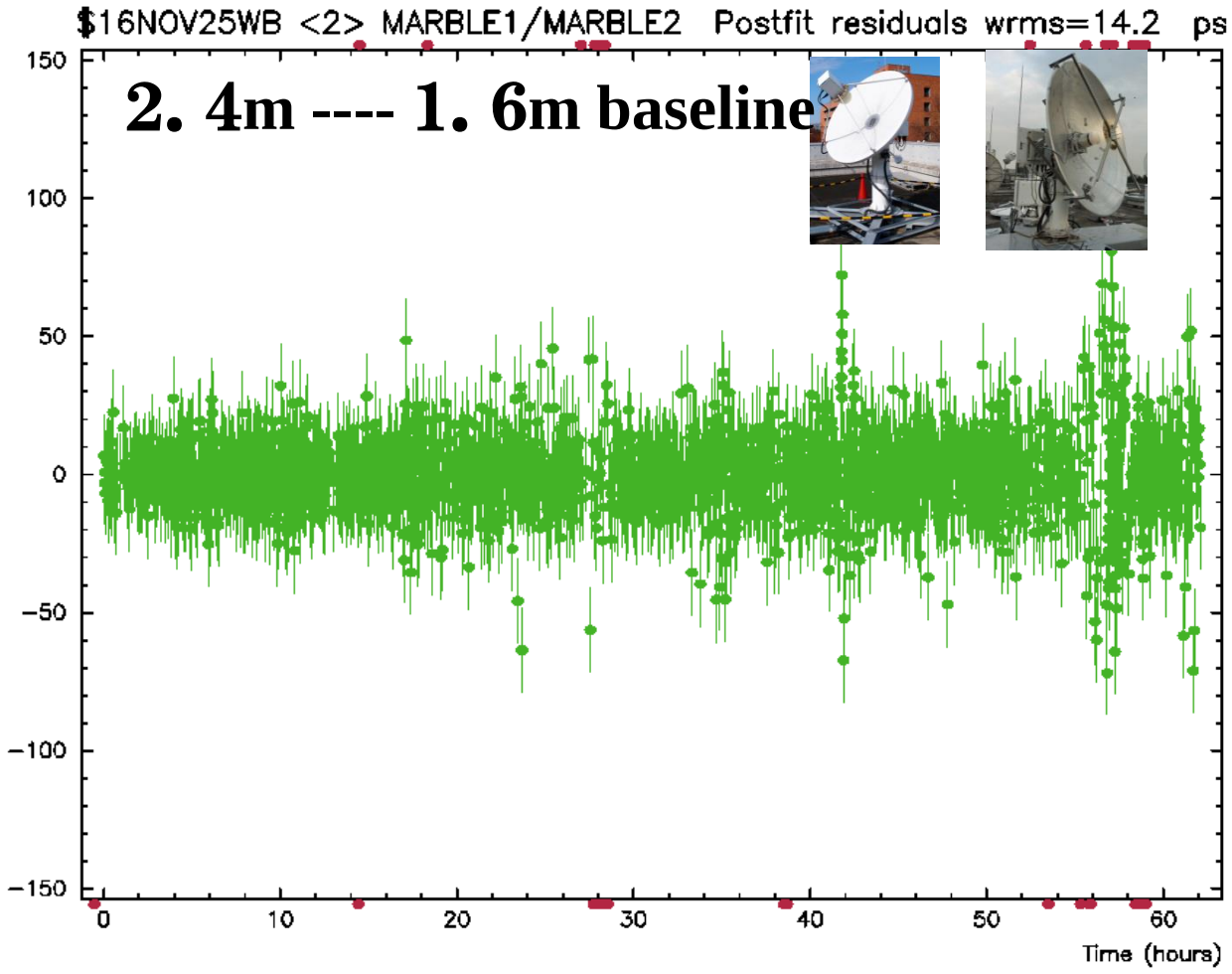
Kashima 34	– MARBLE1 1. 6:	48718193.8 mm 0.6 mm
Kashima 34	-- MARBLE2 2. 4:	109427397.8 mm 0.7 mm
MARBLE2 2. 4	-- MARBLE1 1. 6:	70218038.2 mm 0.8 mm

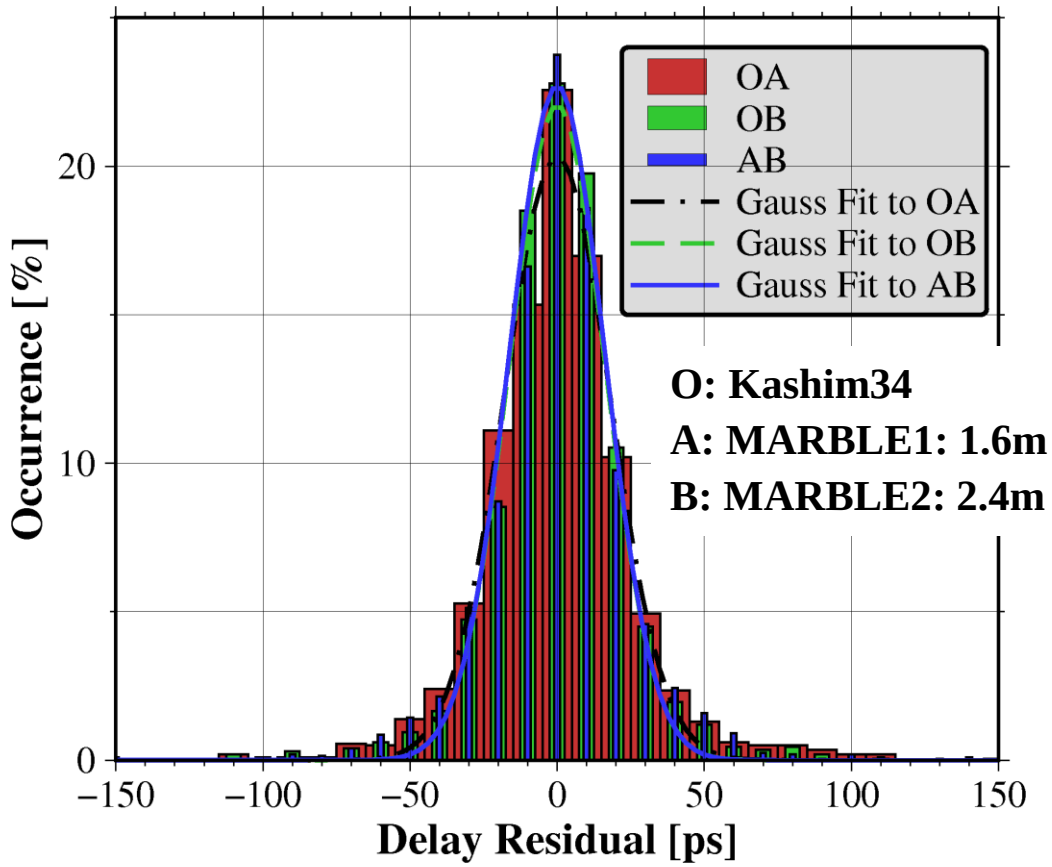
Results

Post fit residual by CALC/SOLVE

Baseline Length :70218041.2 mm ±0.7 mm
MABRL1:1. 6 -- MARBLE2:2. 4：

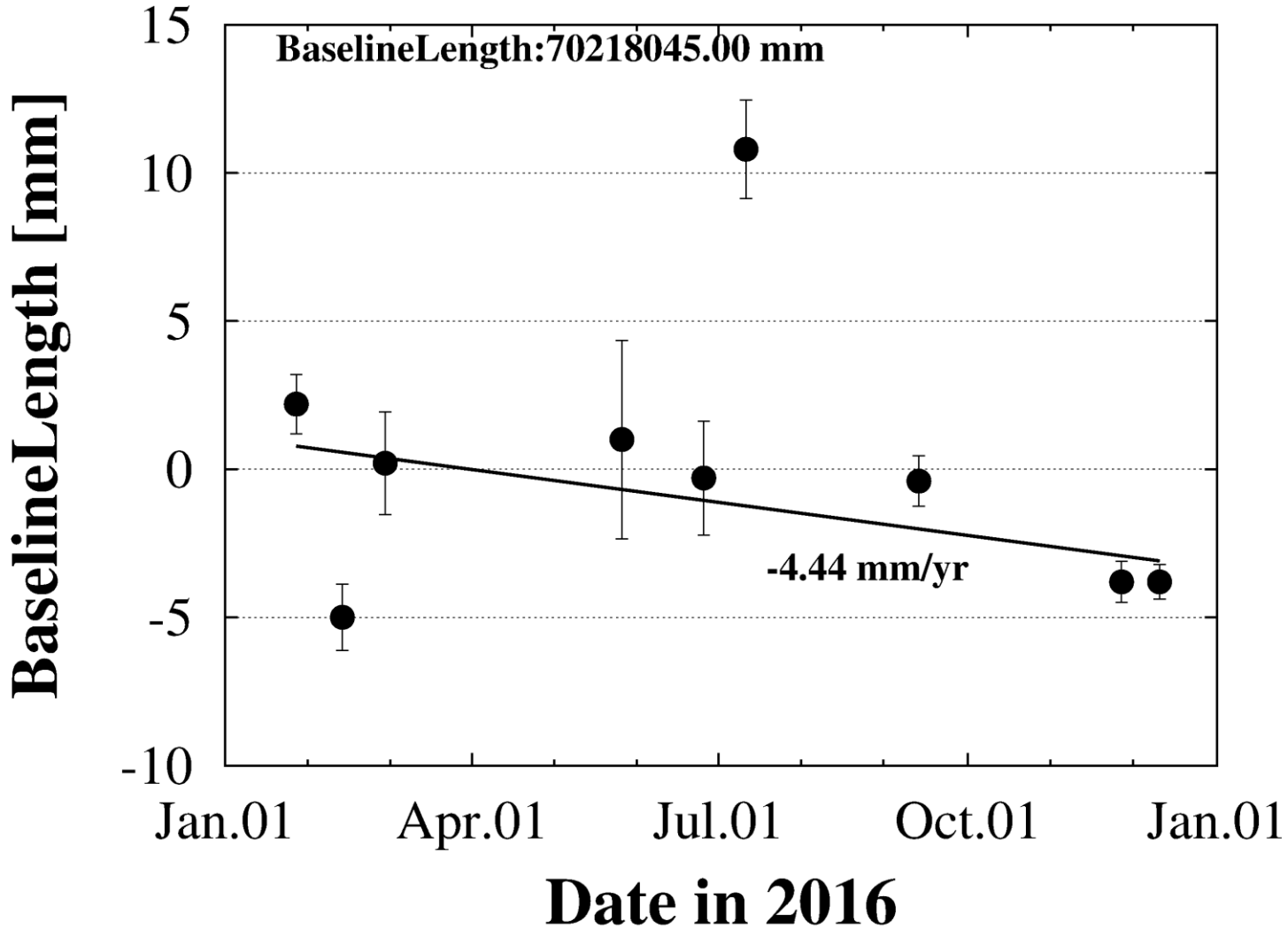
Delay observable between small diameter antenna pair was **computed by closure delay relation**
WRMS of small diameter antenna pair was around **15 psec, too. This indicating that error source other than delay data precision (atmospheric delay uncertainty) is dominating the analysis.**

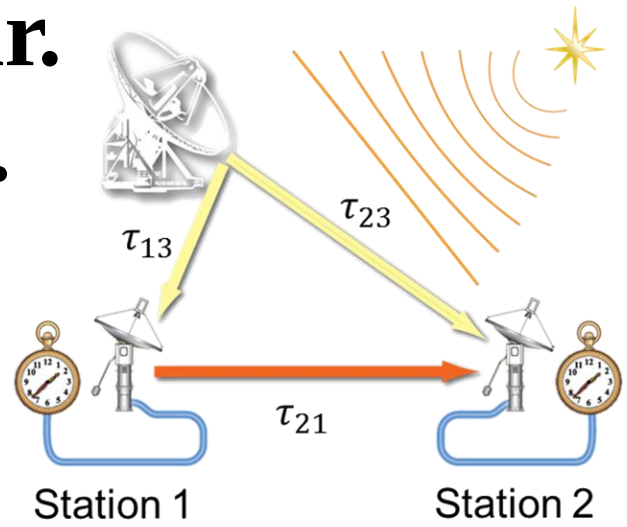




Results

Baseline Length between small antenna pair. Composed delay by closure delay relation.





$$\tau_{21} = \tau_{13} - \tau_{23}$$

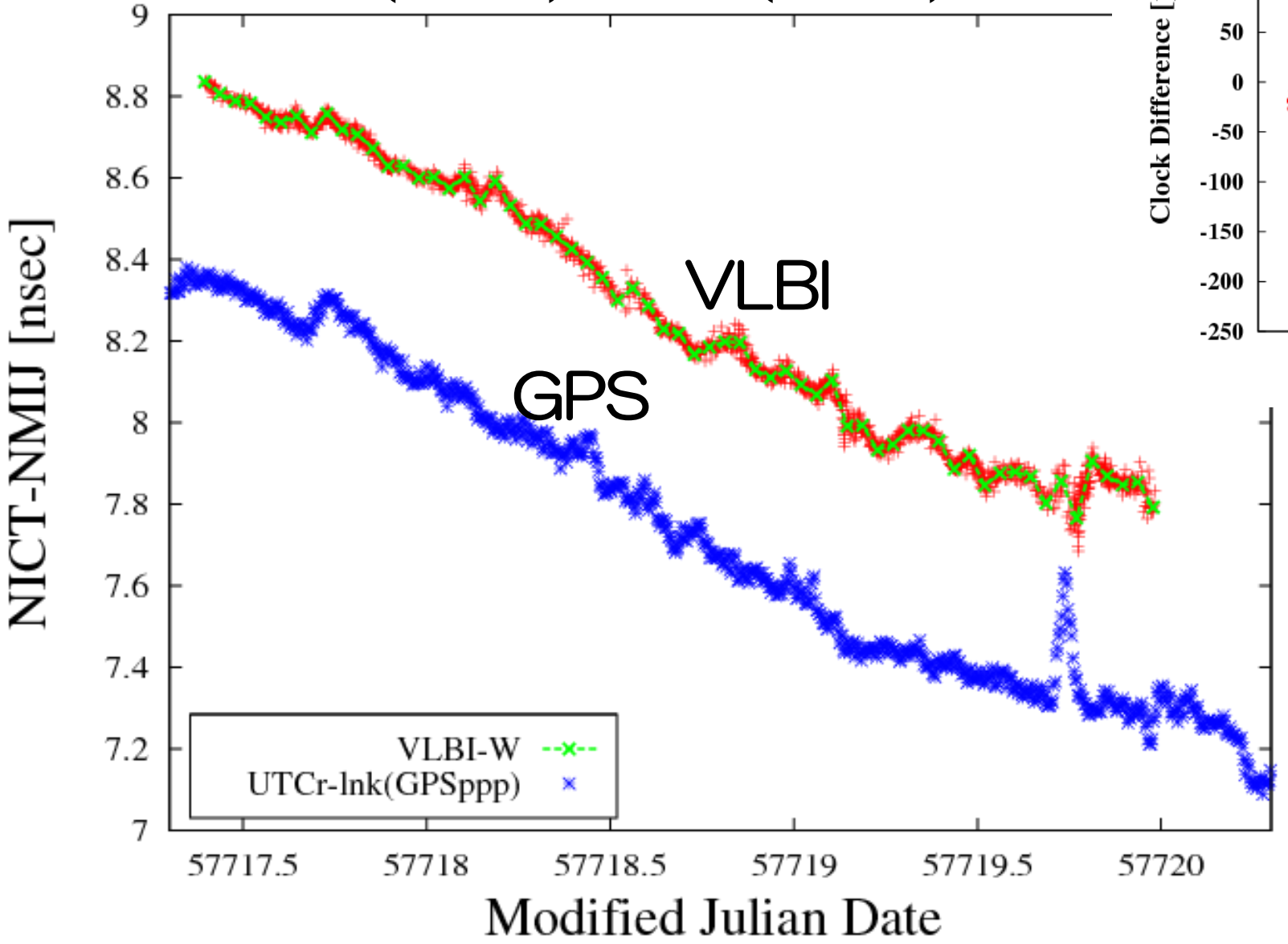
MARBLE1 1.6m

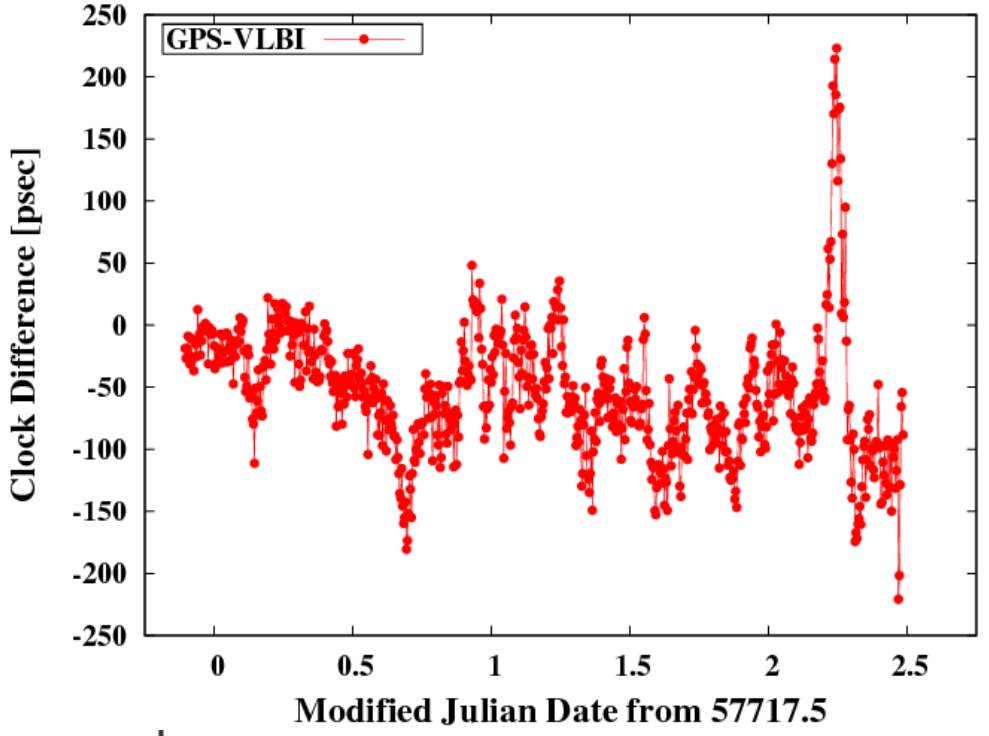
MARBLE2 2.4m

Results

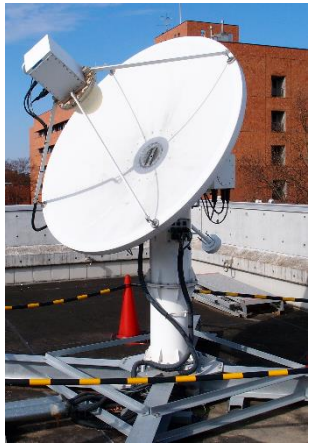
Clock Difference between VLBI and GPS--ppp

2016Nov25 UTC(NICT) – UTC(NMIJ)





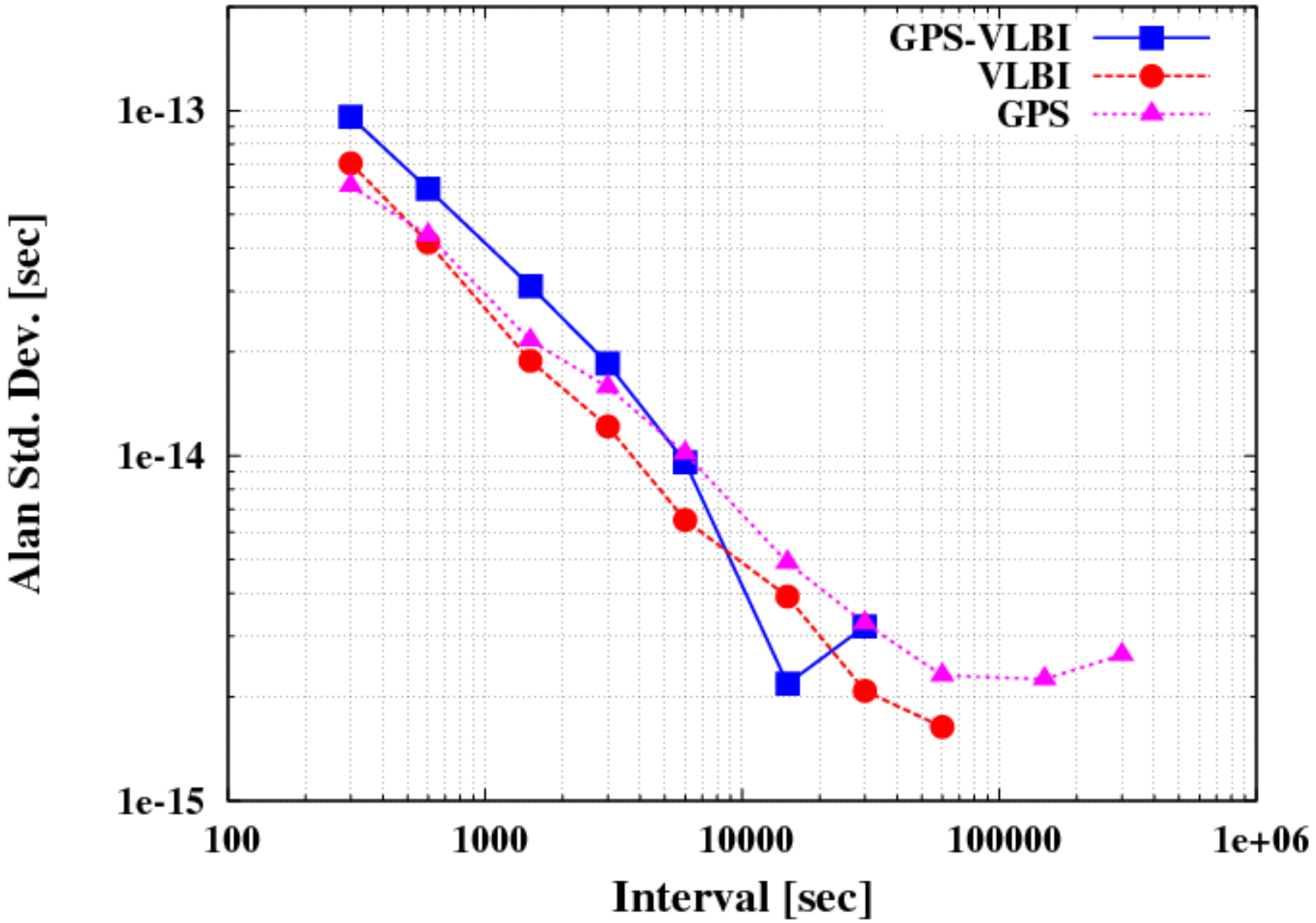
MARBLE1 1.6m

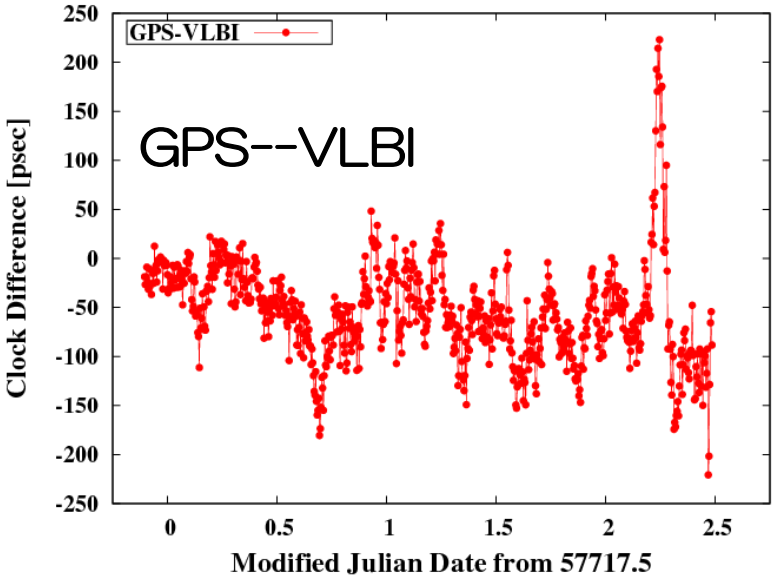


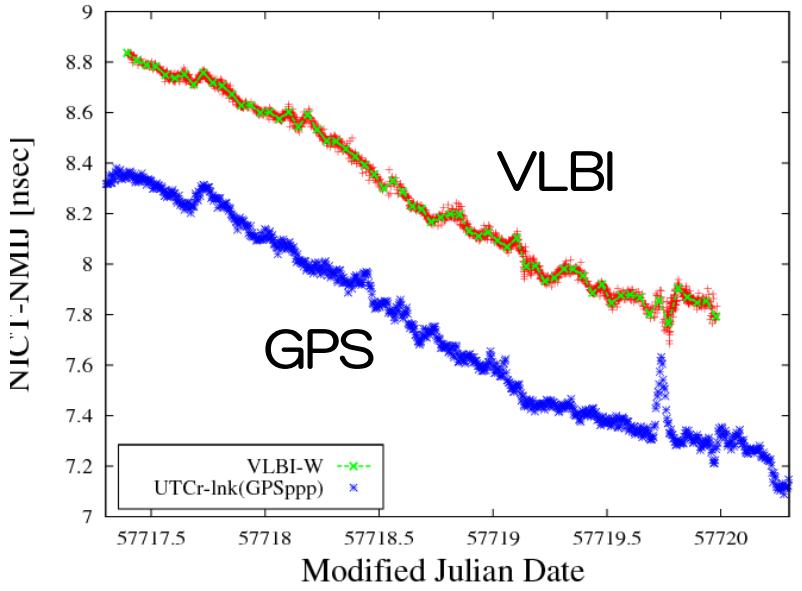
MARBLE2 2.4m

Results

Clock comparison performance VLBI and GPS







Summary

1. New Broadband System has been developed
    1. Broadband Feed for Cassegrainian optics 34m antenna and small diameter antenna.
    2. RF Direct--Sampling technique, which enabled precise and stable measurement.
    3. Broadband Bandwidth Synthesis and Phase Calibration with Radio sources
    4. Broadband delay precision reaches to sub--pico sec. in one sec. of observation
2. A series of VLBI sessions have been conducted in 2016.
    1. A few mm baseline length repeatability on small diameter antenna pair.
    2. Clock comparison on small antenna baseline become available.
3. Next step
    1. Experiments of Intercontinental baseline is necessary.