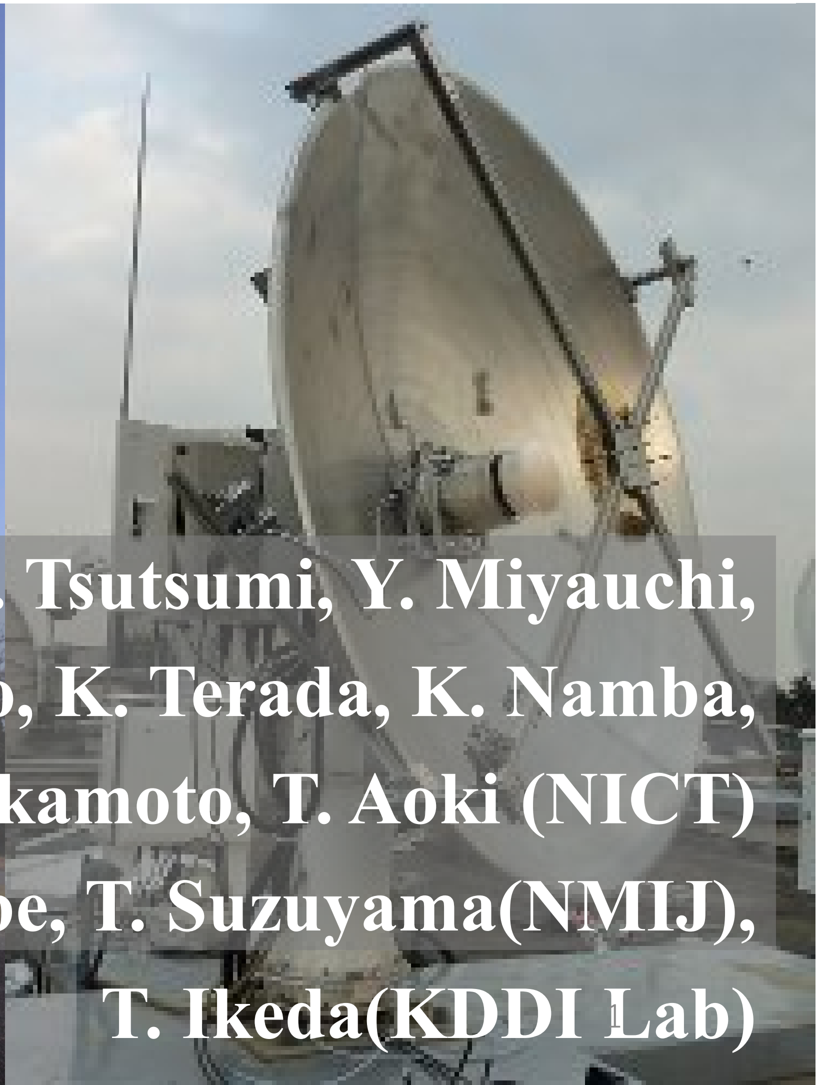
Frequency Transfer with New Broadband VLBI.
–NMIJ-NICT Test Experiment –

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E. Kawai, S. Hasegawa, Y. Koyama, J. Komuro, K. Terada, K. Namba,
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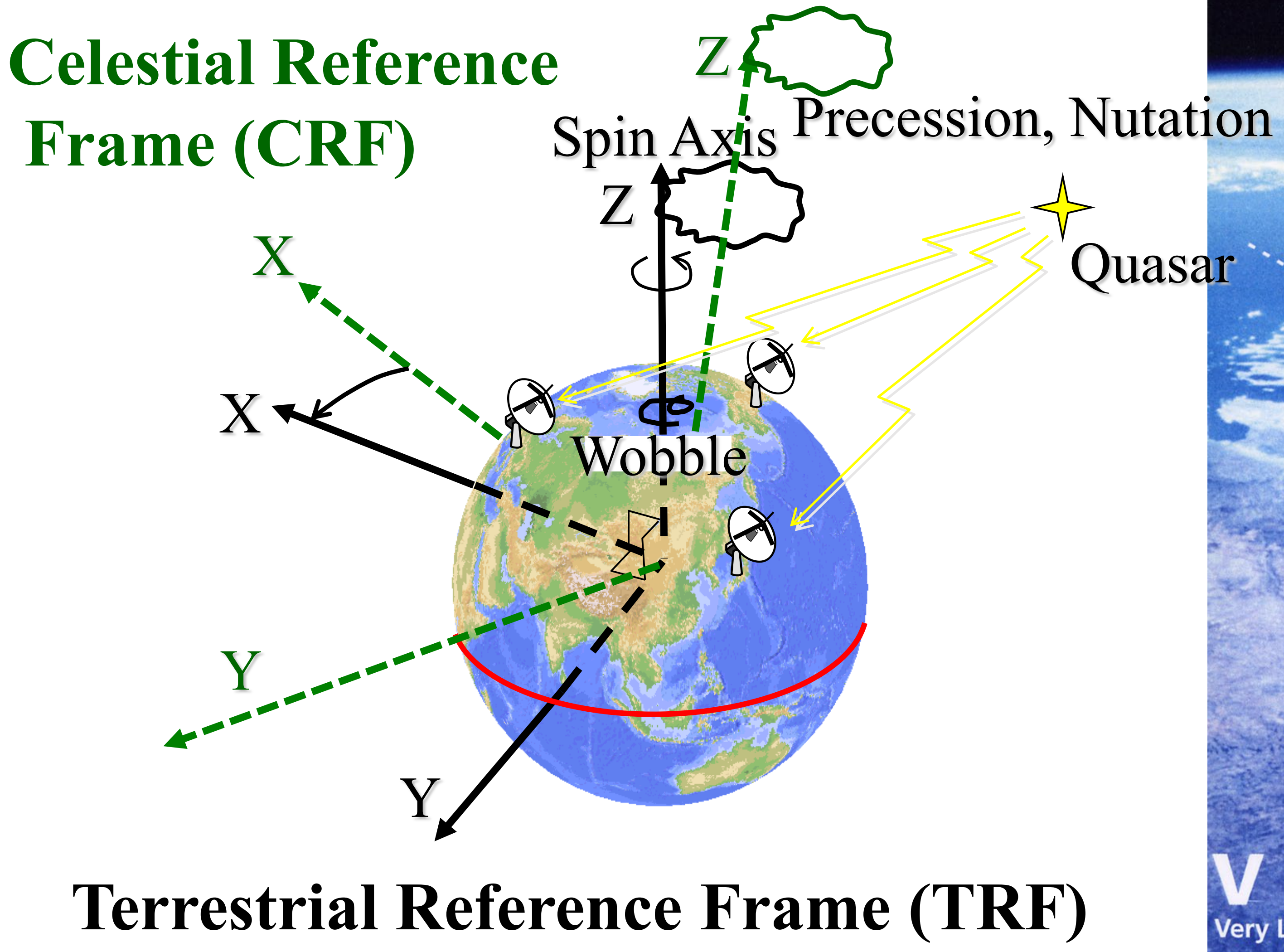
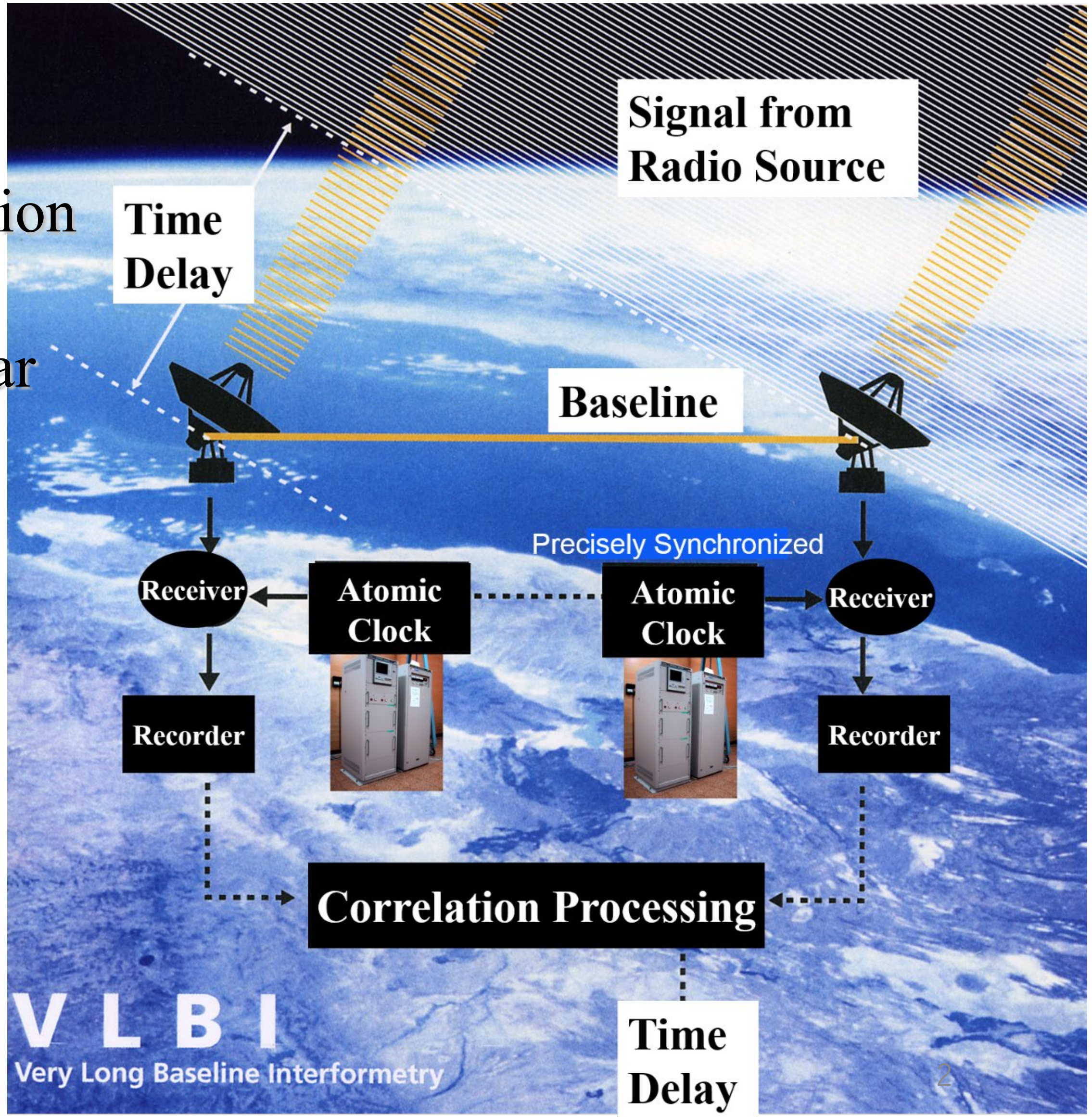
T. Ikeda(KDDI Lab)

AP-RASC2019@New Delhi.

What is VLBI? : Measure of spatial coordinates





Why Freq. Transfer with VLBI?

Technique	By means of	Orbit info Dependency	Radio Signal Transmission	Accuracy	Running Cost
TWSTFT	Communication Satellite	Slightly	Need License	< 1.e-15 (Code) < 1.e-16 (Carrier Phase)	>10k USD/yr.
GNSS	GPS /GNSS satellite	Highly	Free	< 1.e-15 (IPPP)	Low
VLBI	Celestial Radio Sources (CRF)	Free	Free	< 1.e-15 (Broadband)	Low (*)

* Running cost of small VLBI station is low, although large dimeter antenna may not be.

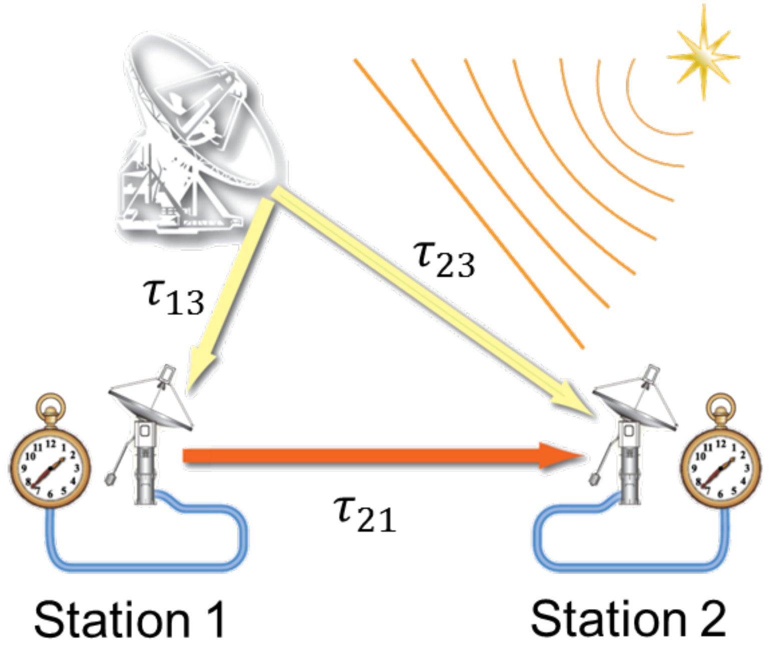
- VLBI is one of space geodetic techniques maintaining spatial reference frames (ICRF, ITRF, and EOP). Time scale can be constructed consistently with these special reference frames.
- VLBI can be operated without using communication satellites. Japan-Europe time link is suffered from lack of communication satellites these years.
- VLBI uses fiducial radio sources in the sky. That leads to long time stability of VLBI measurements.
- VLBI does not need radio transmission license, thus can be used any time anywhere on the earth.

- Higher implementation cost (large antennas) was disadvantage.

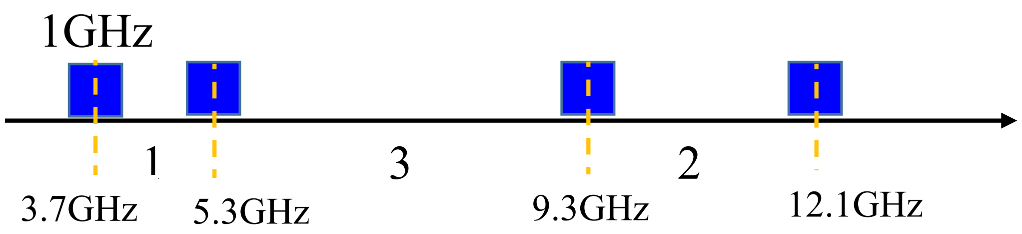
This could be overcome by using small diameter transportable stations with Broadband VLBI.

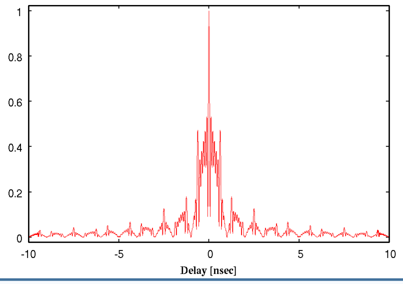
GALA-V Project Overview

Frequency comparison by using transportable broadband telescopes.



- Radio Frequency : 3.2-12.6 GHz
- Data Acquisition : 4 band (1024MHz width/band)
  - Nominal Freq. Array : Fc=3.7GHz, 5.3GHz, 9.3GHz, 12.1GHz
  - Effective Bandwidth : 3.3GHz (10 times wider than conventional system)



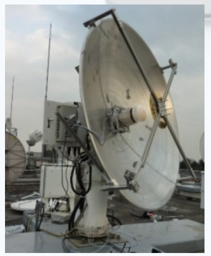


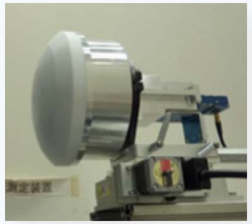
$$\tau_{21} = \tau_{13} - \tau_{23}$$

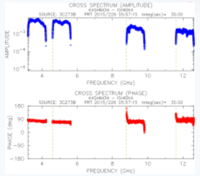
Closure delay is computed for small antenna pairs.

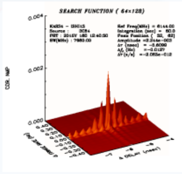
Broadband Feed for Cassegrain → RF-Direct Sampler → (VDIF Stream) → Recording → Correlation GICO3 → Broadband Synthesis → Mk3DB → Calc/Solve

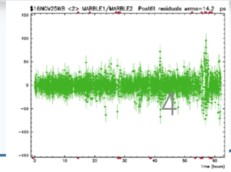
Compatible with Mk6, Flexbuf (jive5ab)











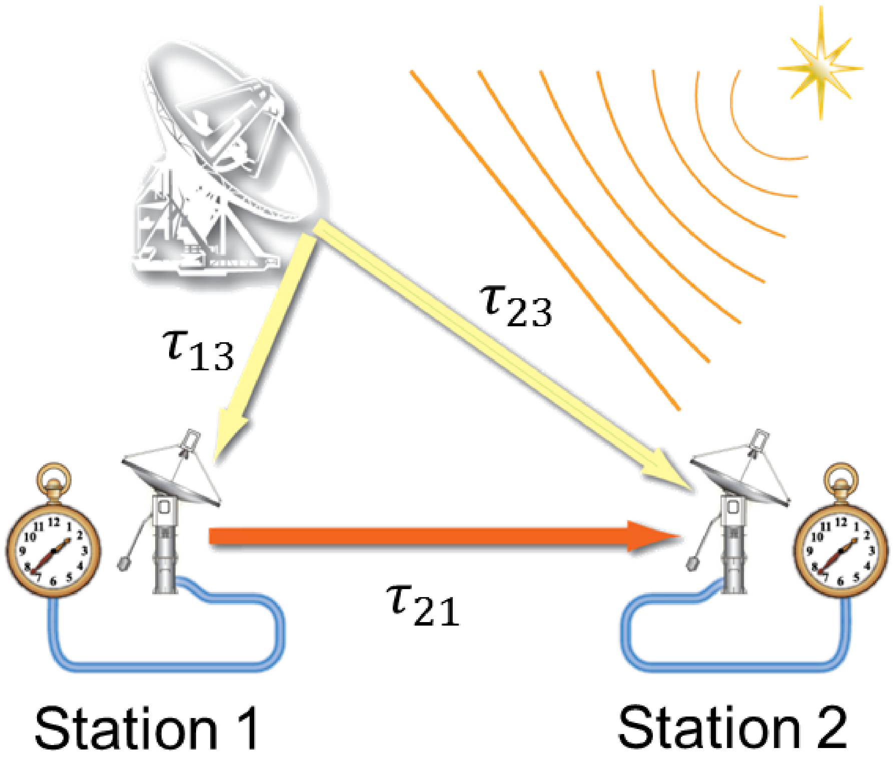
Broadband VLBI Experiments

‘Small – Small’ Baseline

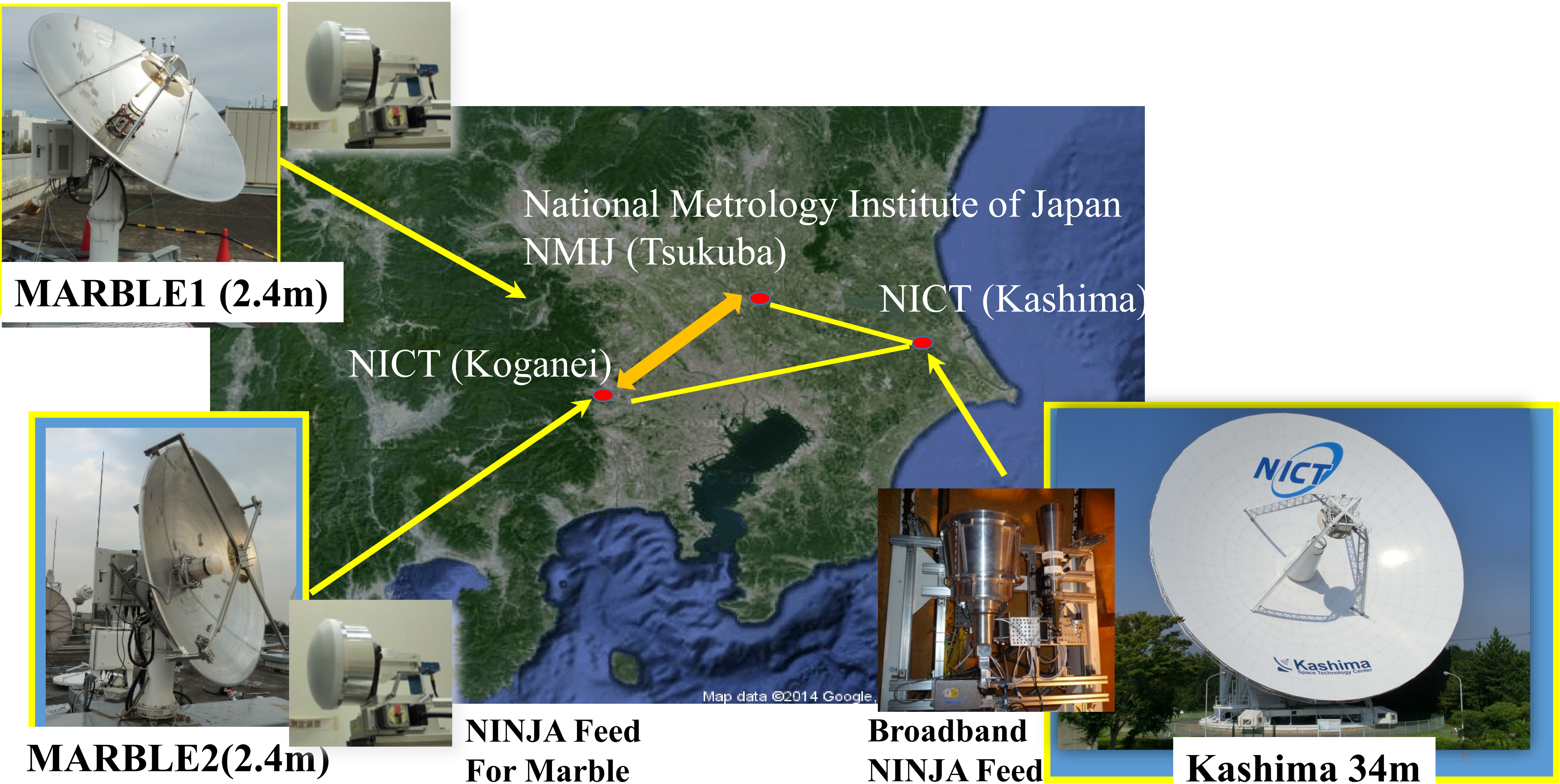
- <u>Closure delay</u> relation used for ‘small-small’ baseline.

$$\tau_{21}(t_1) = \tau_{23}(t_1) - \tau_{13}(t_1) + \tau_{13}(t_1)\dot{\tau}_{21}(t_1)$$

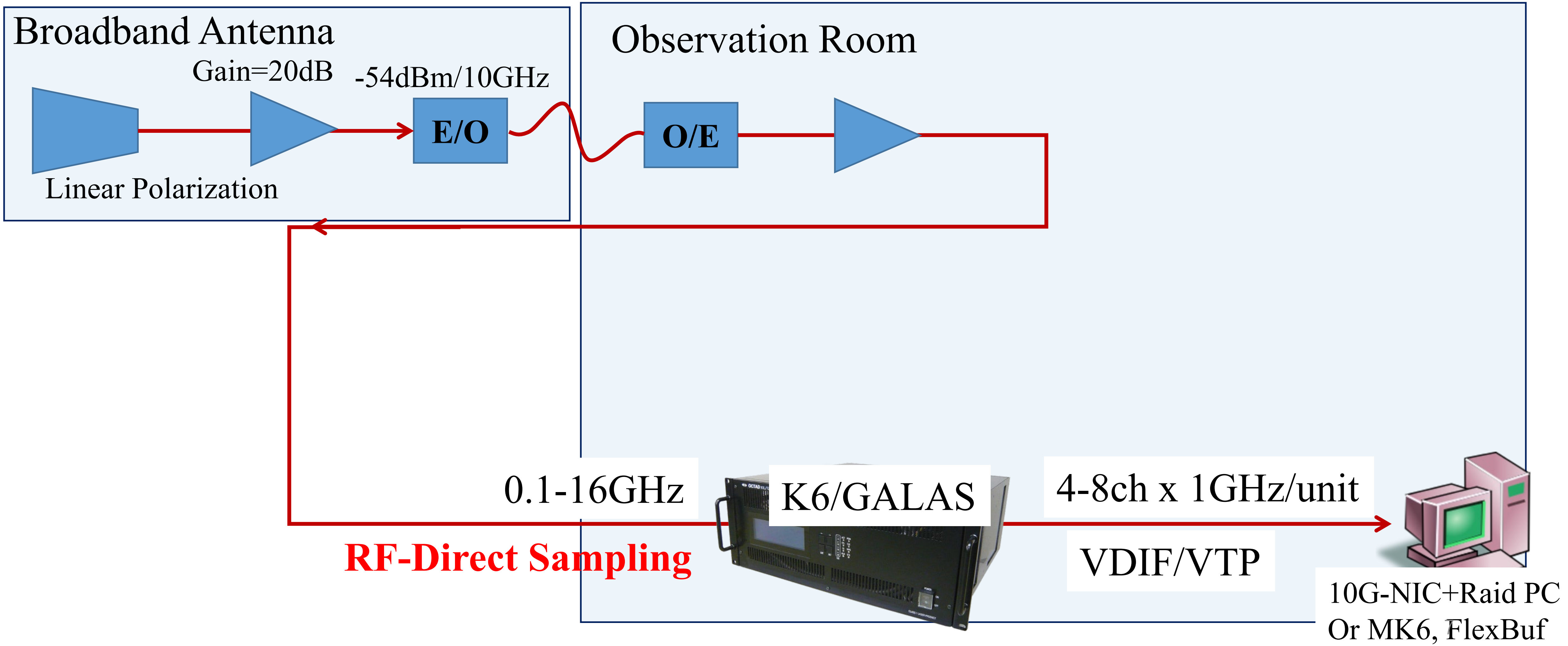
- Advantages of using small antennas :
  - <u>Quick slew and small distortion.</u>
  - <u>Large antenna’s effects are canceled out.</u>
  - Lower cost.
- Disadvantage:
  - Lower sensitivity,
  - Source structure effects to closure delay.



Freq. Link Experiment by Broadband VLBI

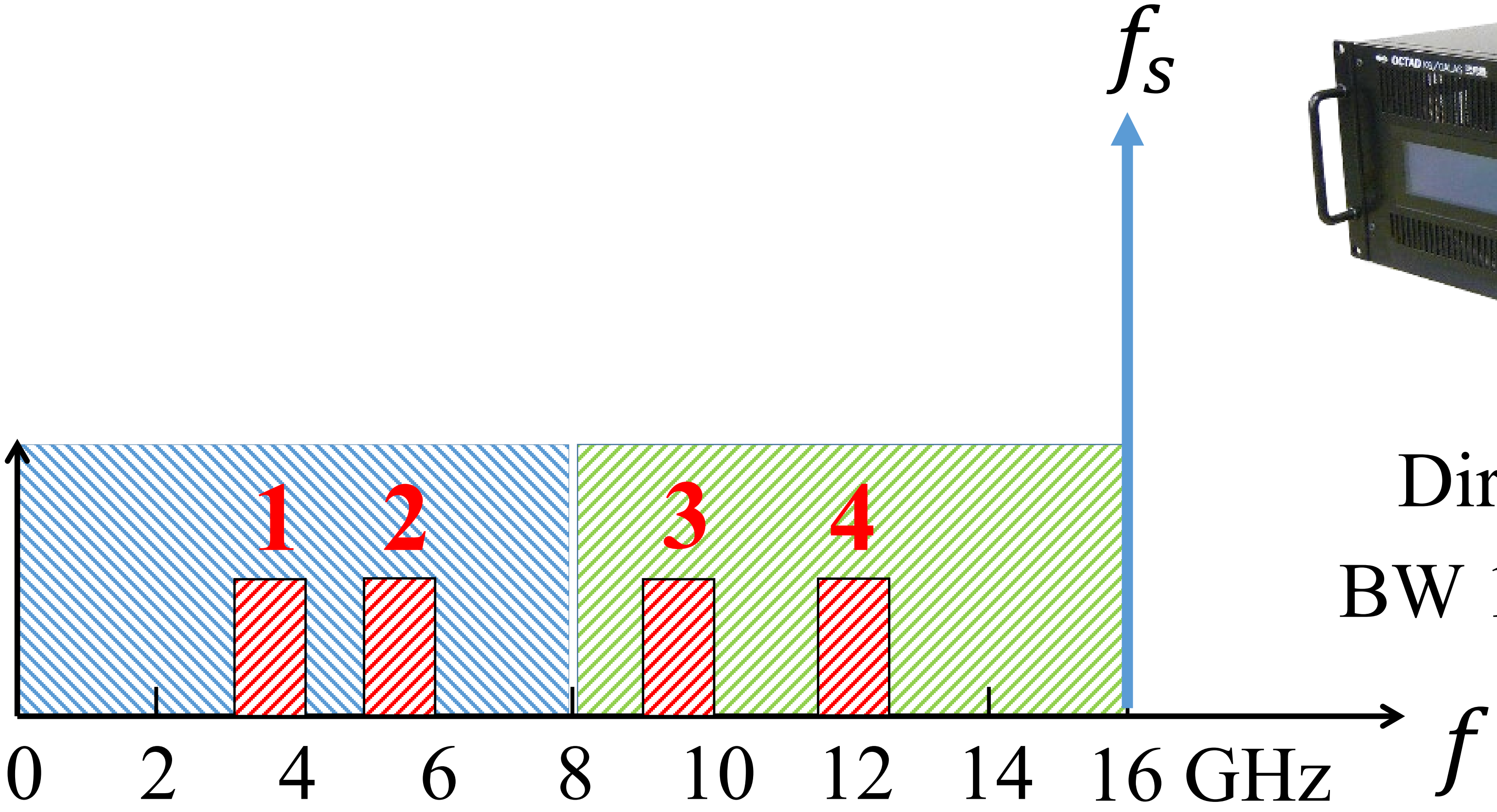


Simple Data Acquisition System



Zero redundant frequency allocation ➡ Fine delay resolution

Broadband ➡ No delay ambiguities



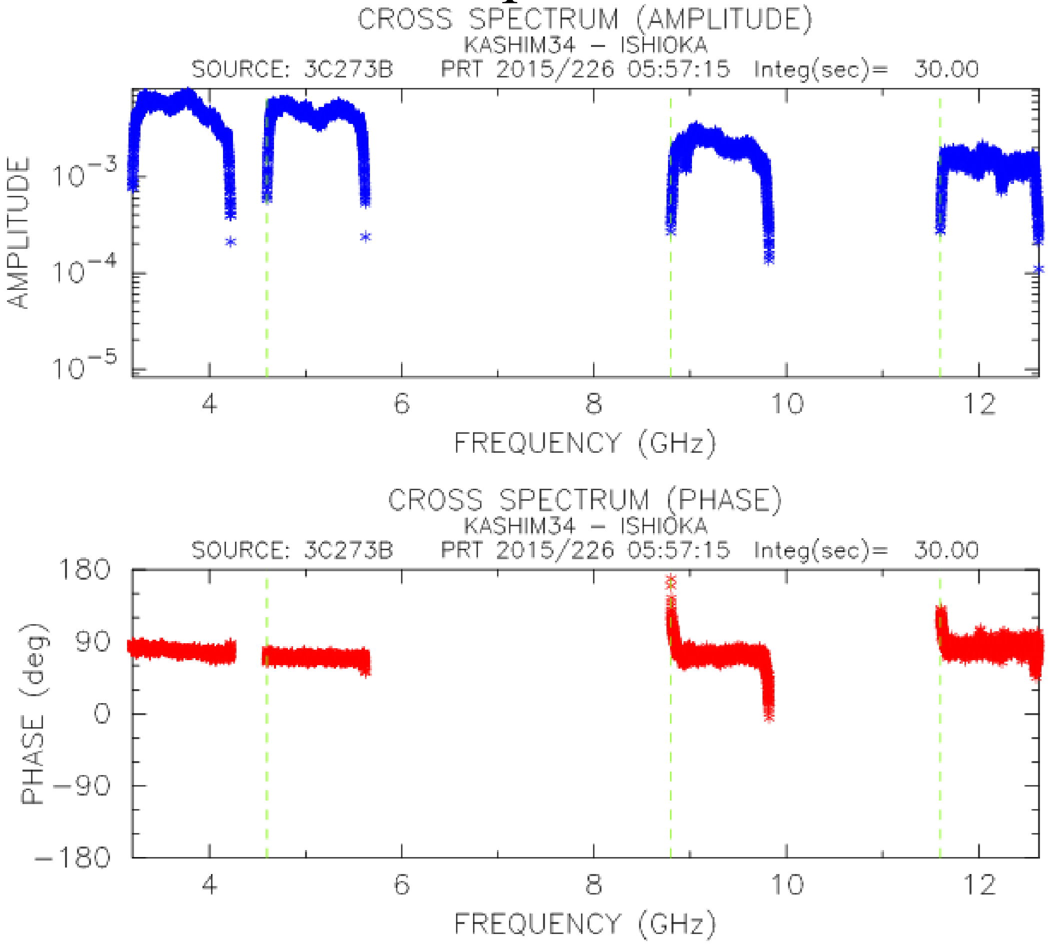
Direct Sampling

BW 1024MHz each

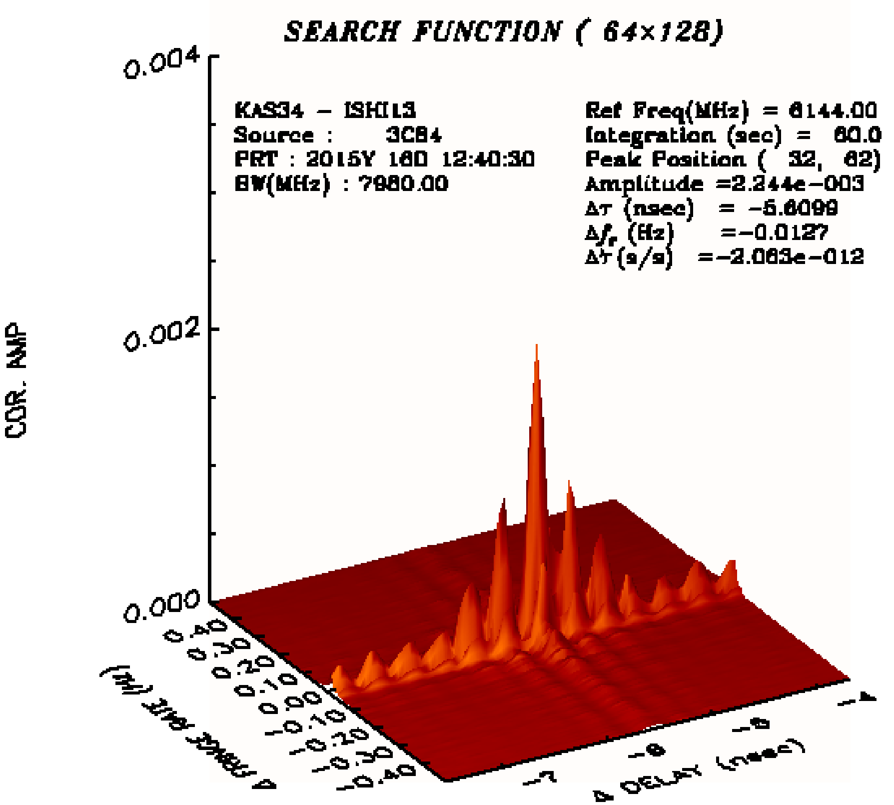
Lower Edge= 3.2, 4.8, 8.8, 11.6GHz

Full Bandwidth Synthesis (3.2-12.6GHz)

Cross Spectrum

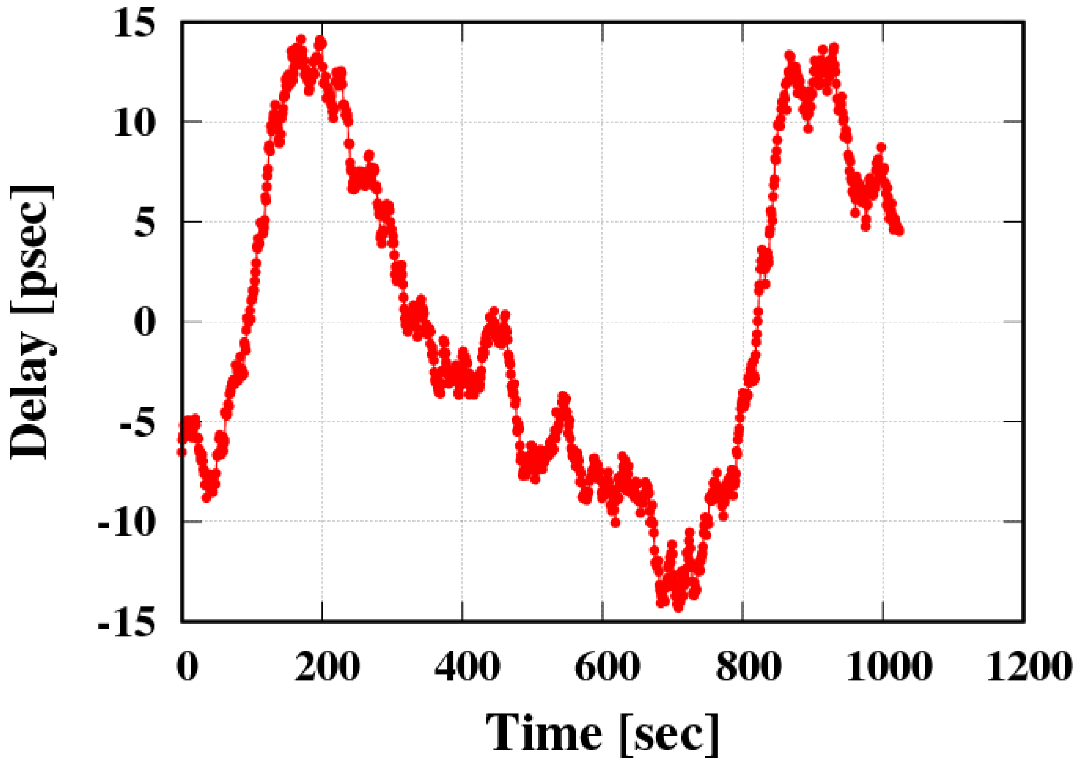


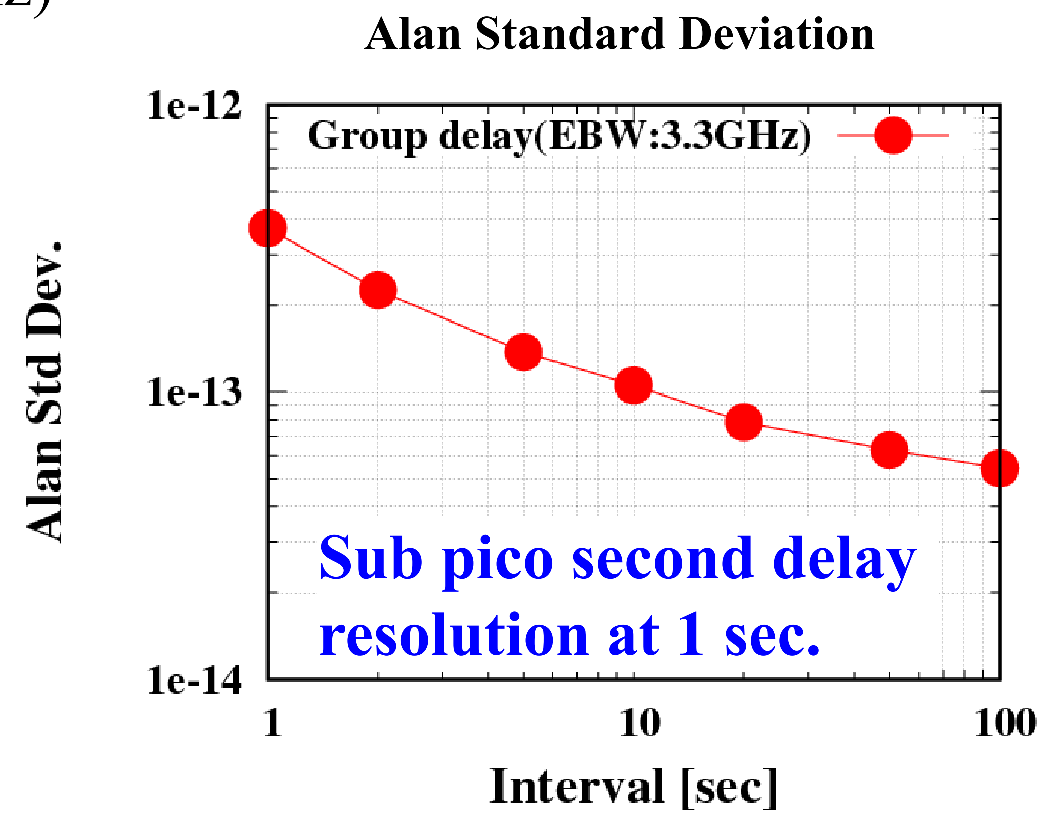
Delay Resolution Function



Delay Precision Test
Broadband Group Delay (3.2-12.6GHz)
Kashima34 – Ishioka 13m

Exp. on 14 Aug.2015,
Freq. array=(Lower Edge=3.2, 4.8, 8.8, 11.6GHz)





Delay Precision

Broadband (6.7GHz Eff. BW)
v.s.
Conventional (500MHz BW)

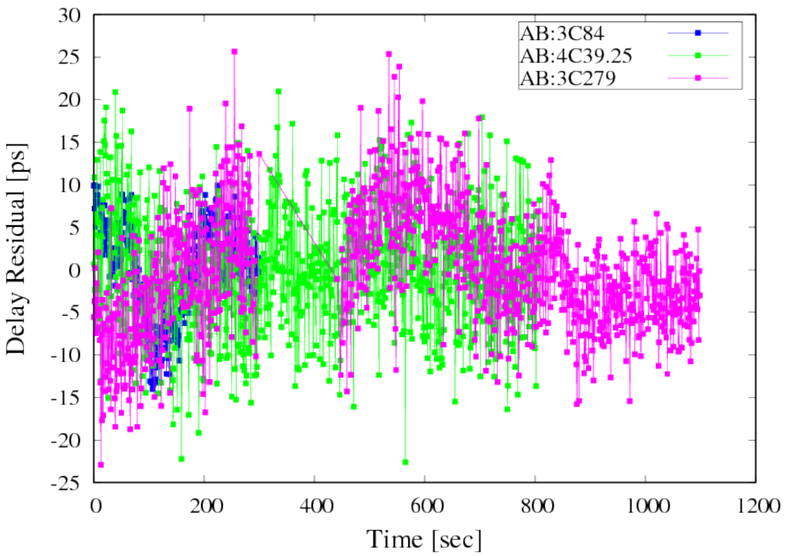
2.4m Diameter
at Koganei

1.6m Diameter
at Tsukuba

11m Diameter
at Koganei

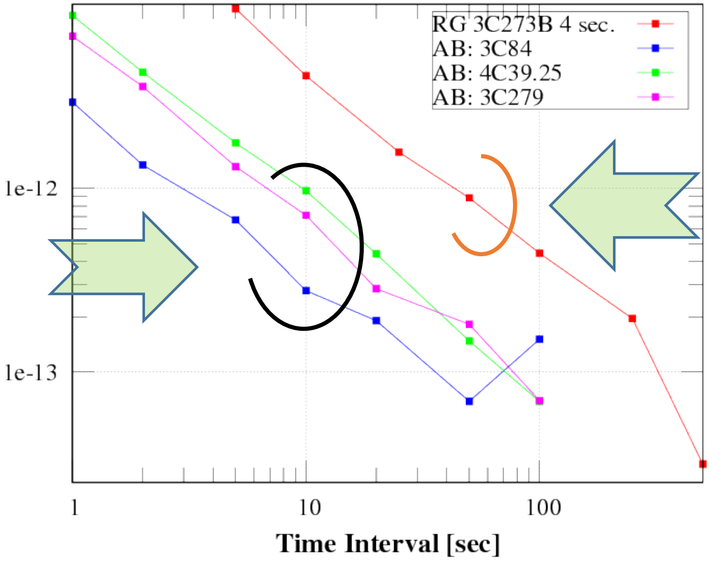
11m Diameter
at Kashima

Broadband



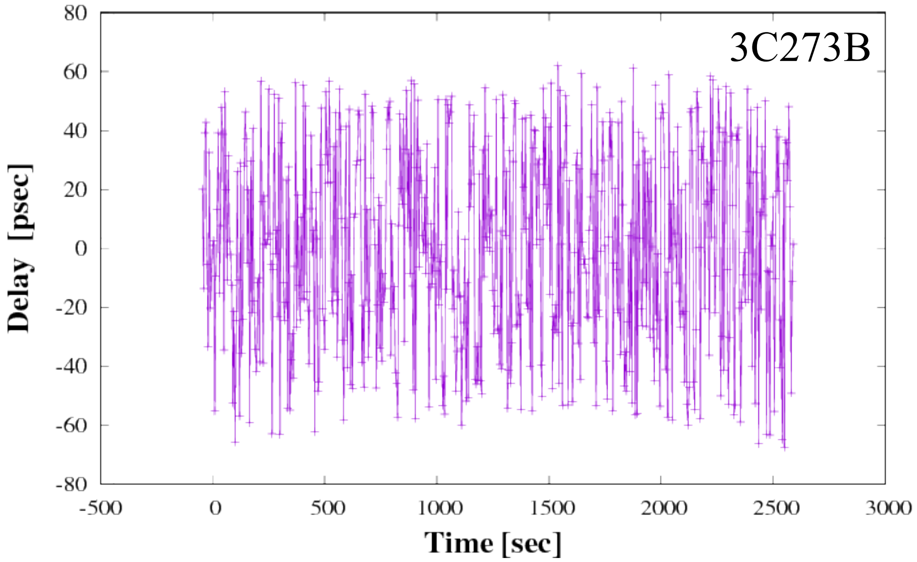
1point/1sec

Allan Standard Deviation



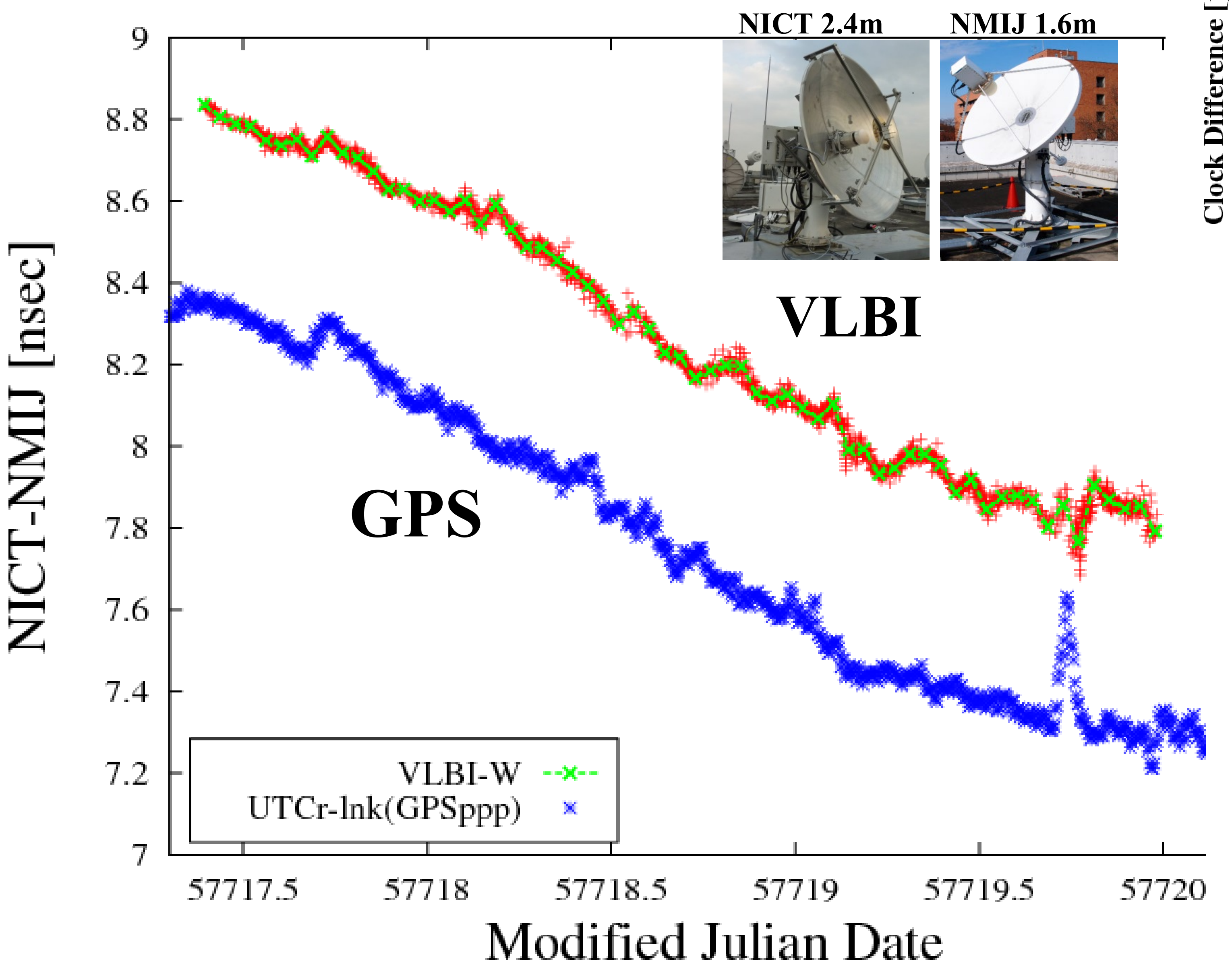
Conventional

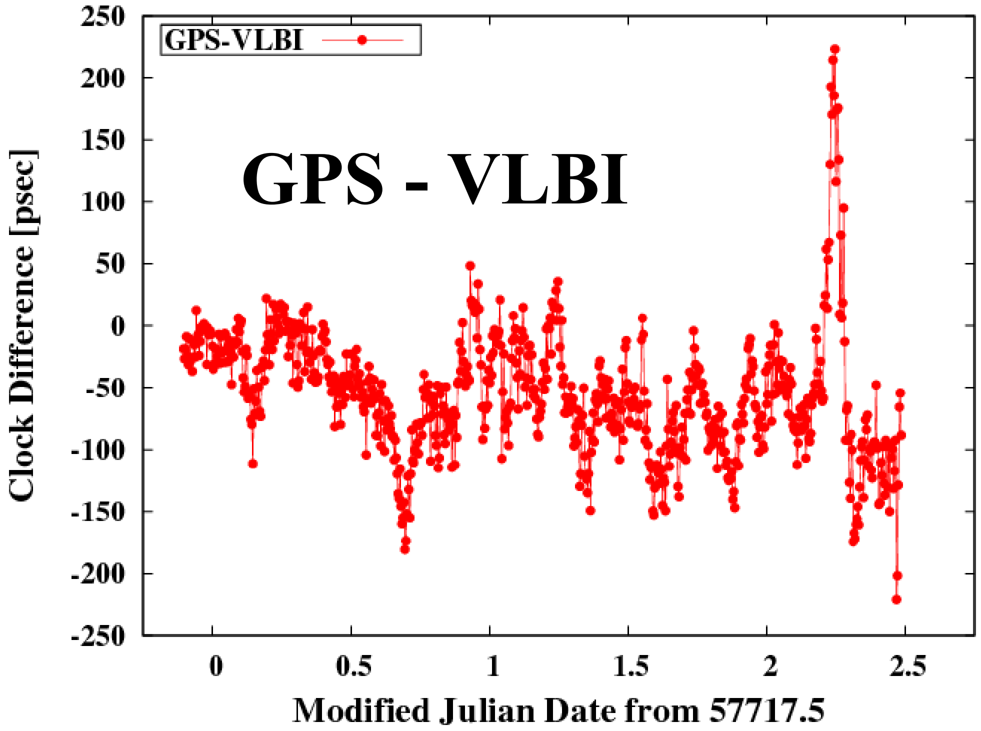
Residual delay after 4th order poly-fit.

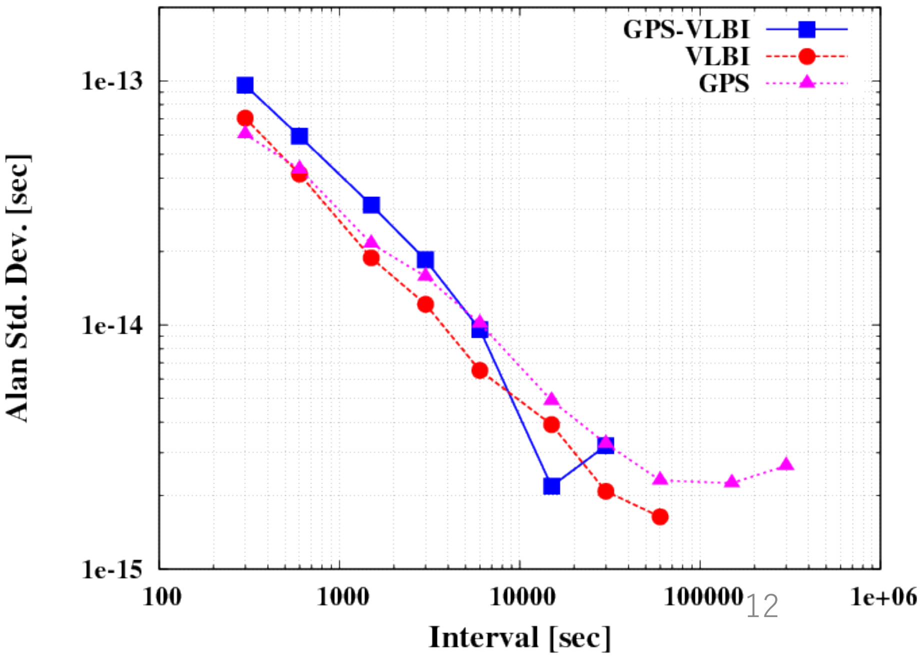


1point/9sec

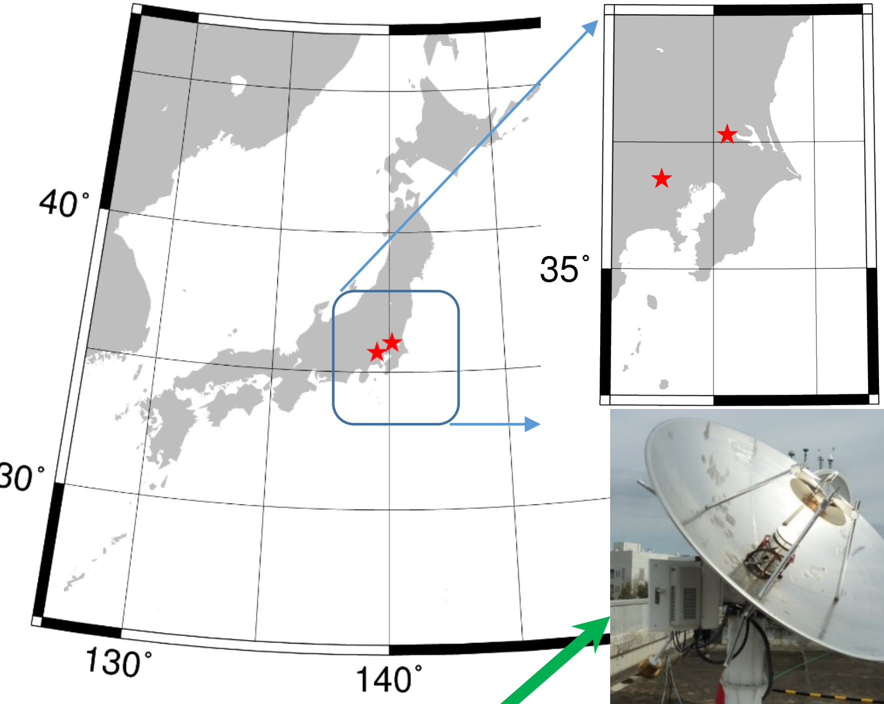
Clock Comparison via VLBI and GPS-ppp
2016Nov25 UTC(NICT) – UTC(NMIJ)

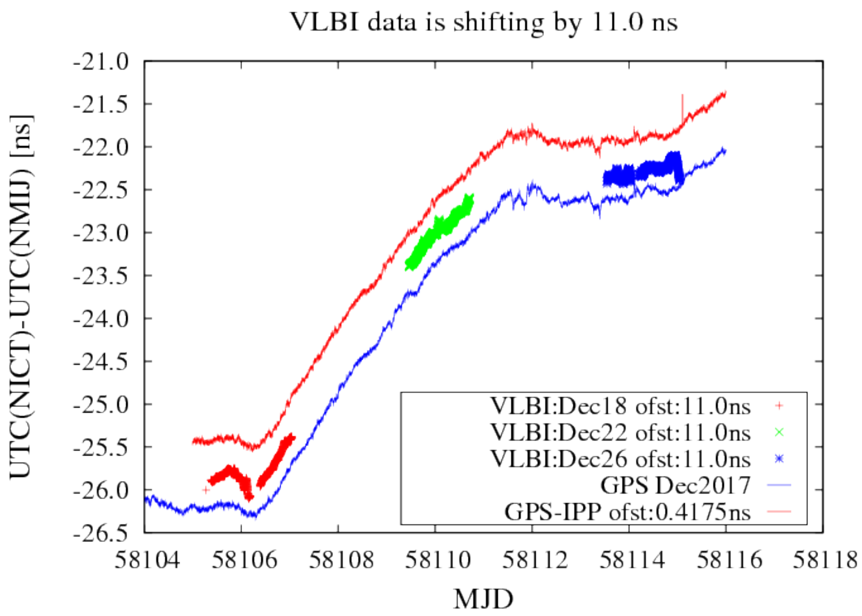


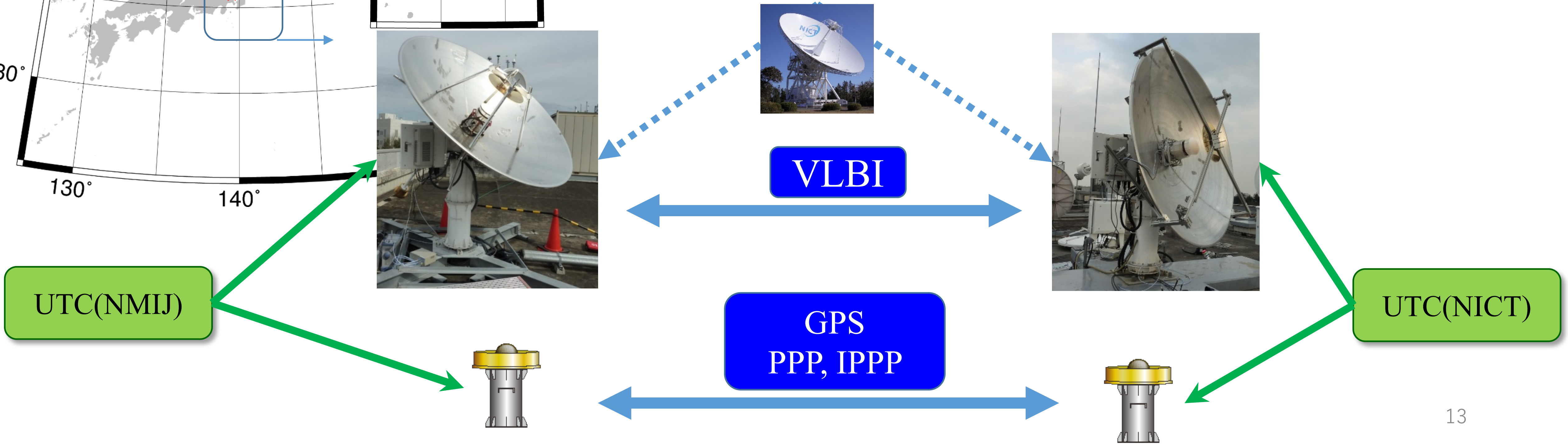




VLBI-GPS Freq. Transfer Comparison

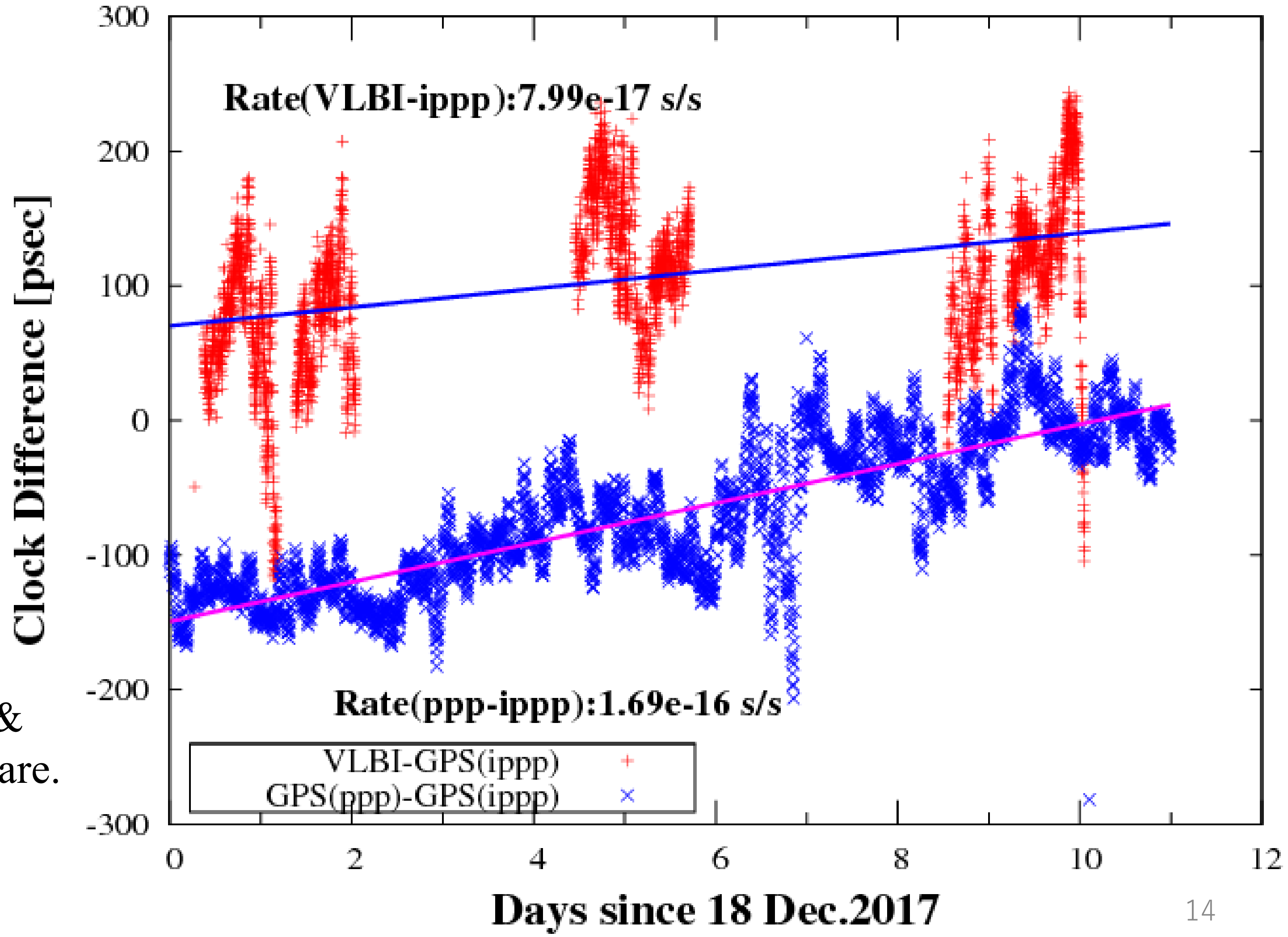






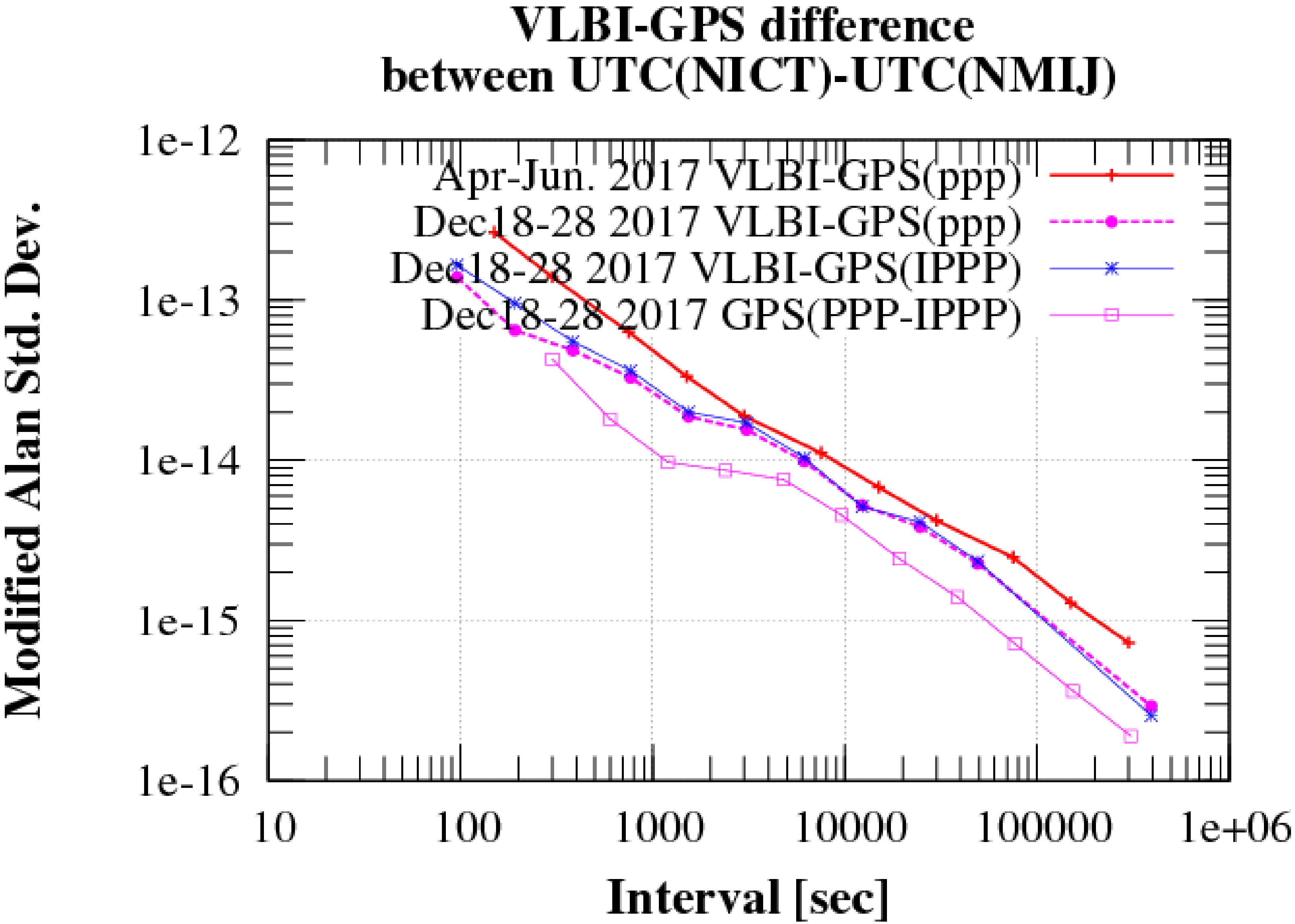
Evaluation of VLBI-link, GPS(PPP)-link with GPS(IPPP) as reference

VLBI-link –GPS(IPPP) is closer to zero than GPS(PPP)-GPS(IPPP).



IPPP results computed by curtesy of J. Leute & G. Petit of BIPM using the CNES GINS software.

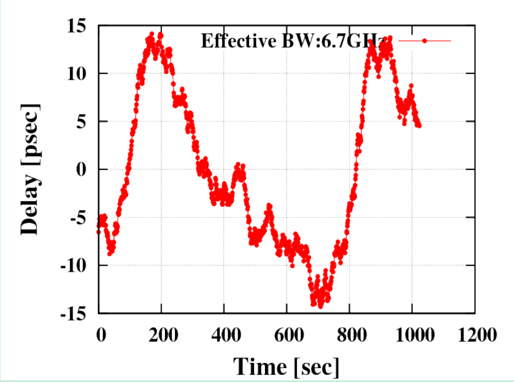
Comparison between VLBI and GPS(PPP,IPPP)

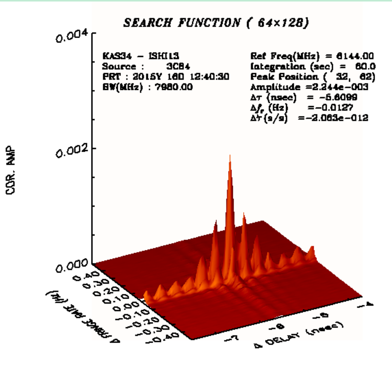


Note: “Modified Allan STD” here is computed by using linear interpolation of data, since VLBI data is not constant interval. Thus this is underestimating than true Modified Allan STD.

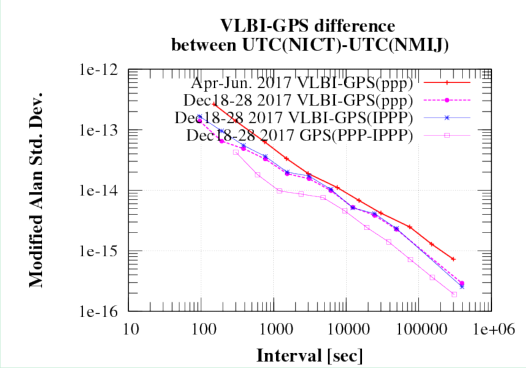
Summary

Broadband 2.4mAntenna and RF-Direct Sampling





Broadband bandwidth Synthesis



VLBI-Link < 1.e-15

1. **Broadband (3-14GHz) VLBI** system with small diameter antennas (2.4m and 1.6m) have been developed for frequency transfer and for geodesy.
2. Broadband VLBI System demonstrated **sub-pico second** delay precision.
3. VLBI, GPS(PPP), GPS(IPPP) were compared. Long time stability of VLBI results is anticipated.
4. VLBI frequency transfer performance was evaluated as better than 1.e-15 for a few days of interval.

Thank you for your Attention

Acknowledgements

- Development of Broadband Feed was supported by a grant (2013-2014) of Joint Development Research from National Astronomical Observatory of Japan.
- IPPP results computed by curtesy of J. Leute and G. Petit of BIPM using the CNES GINS software.
- Highs speed research network environment is supported by JGN.