Broadband VLBI System GALA-V and Its Application for Geodesy and Frequency Transfer

Mamoru Sekido, K.Takefuji, H.Ujihara, T.Kondo, M.Tsutsumi, Y.Miyauchi, E.Kawai, S.Hasegawa, R.Ichikawa, Y.Koyama, Y.Hanado, J.Komuro, K.Terada, K.Namba, R.Takahashi, K.Okamoto, T.Aoki, T.Ikeda (NICT)

K.Watabe, T.Suzuyama (AIST/NMIJ)

R.Kawabata, M.Ishimoto, T. Wakasugi (GSI)

EVGA2017@Chalmers Univ. Tech.

Remarks from our Broadband VLBI Experiences

1. **Broadband VLBI is tolerant to RFI**

   It may sound strange, but true. (No enouch time to explain today.)

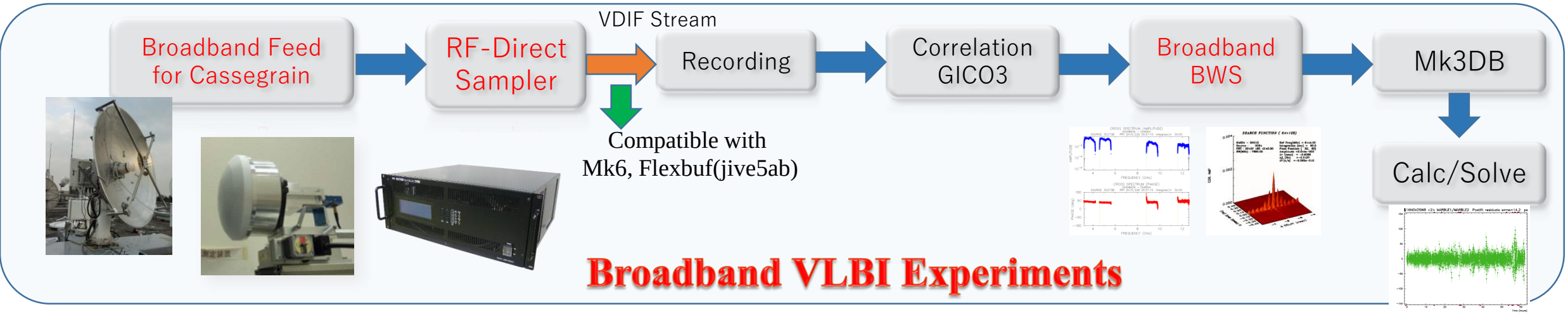
2. **Sub-picosecond delay precision is enabled by Broadband even with small (1.6-2.4m) antenna pair.**

   It is promising the great delay precision of VGOS.

3. **RF Direct Sampling enables stable Broadband group delay measurement (Pcal free).**

Contents of this Presentation

- **Components of the GALA-V System**
  - Broadband Feed and Antenna performance
  - RF-Direct Sampling
  - Broadband Bandwidth Synthesis and Phase Calibration with radio source
- **Broadband VLBI Experiments**
  - Delay measurement precision (Conventional S/X v.s. Broadband)
  - Geodetic Solution and our Clock comparison



GALA-V Project Overview

Frequency comparison by using Transportable Broadband telescopes

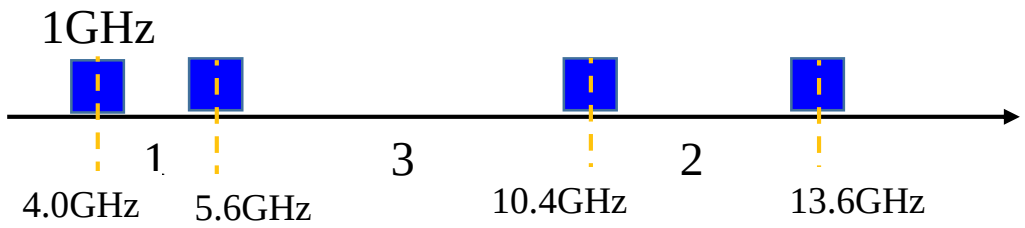
- VLBI Sensitivity :VLBI Sensitivity$=\propto D_1 D_2 \sqrt{BT}$

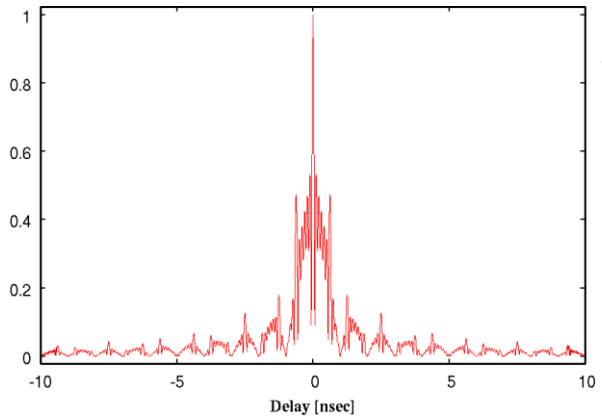
  B: 32MHz → 1024MHz (32 times)

■Radio Frequency： 3-14 GHz

■Data Acquisition： 4 band (1024 MHz width)

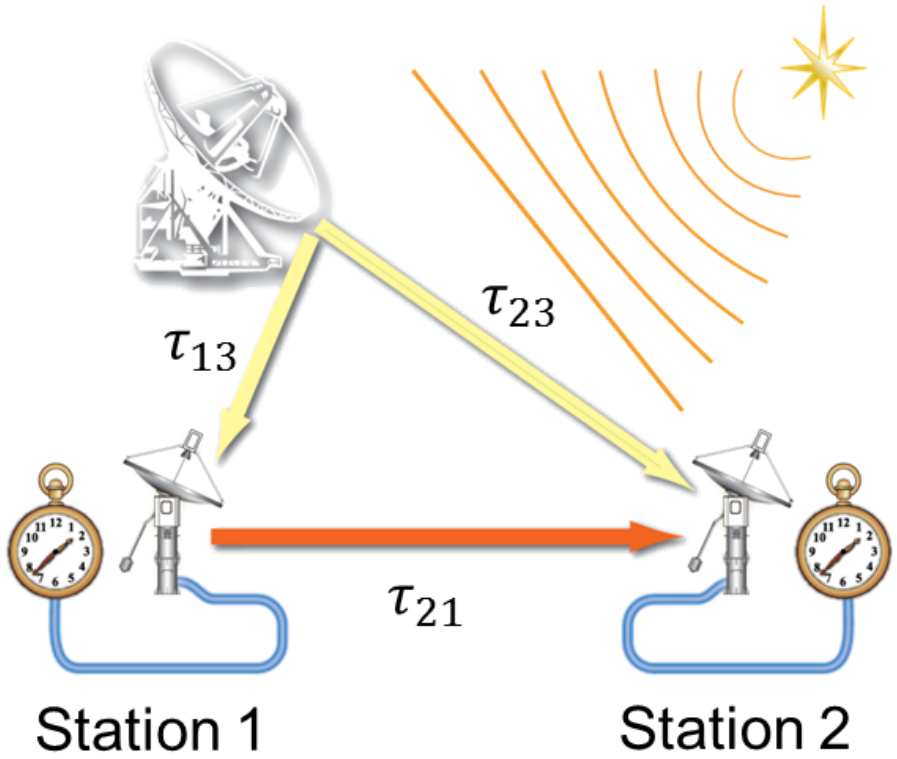
- ■ Nominal Freq. Array: Fc=4.0GHz, 5.6GHz, 10.4GHz, 13.6GHz
- ■ Effective Bandwidth：3.8GHz (10 times more than Conventional）





Delay Resolution Function

10 time higher resolution will be gained by broader bandwidth



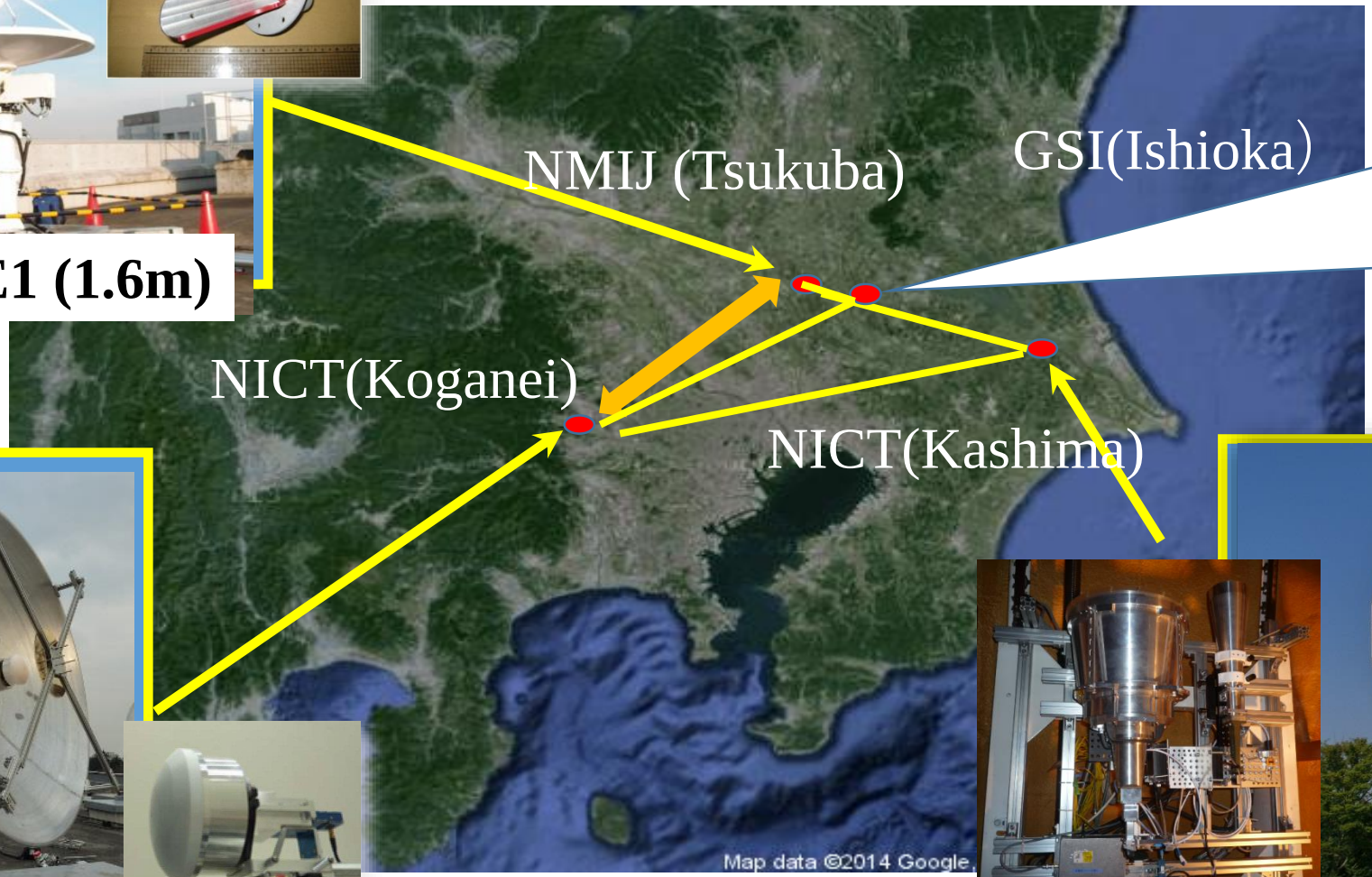
$$\tau_{21} = \tau_{13} - \tau_{23}$$

By using closure delay relation.

Broadband VLBI Stations in Japan

Rindgren
QRHA

MARBLE1 (1.6m)



Ishioka 13m

MARBLE2(2.4m)

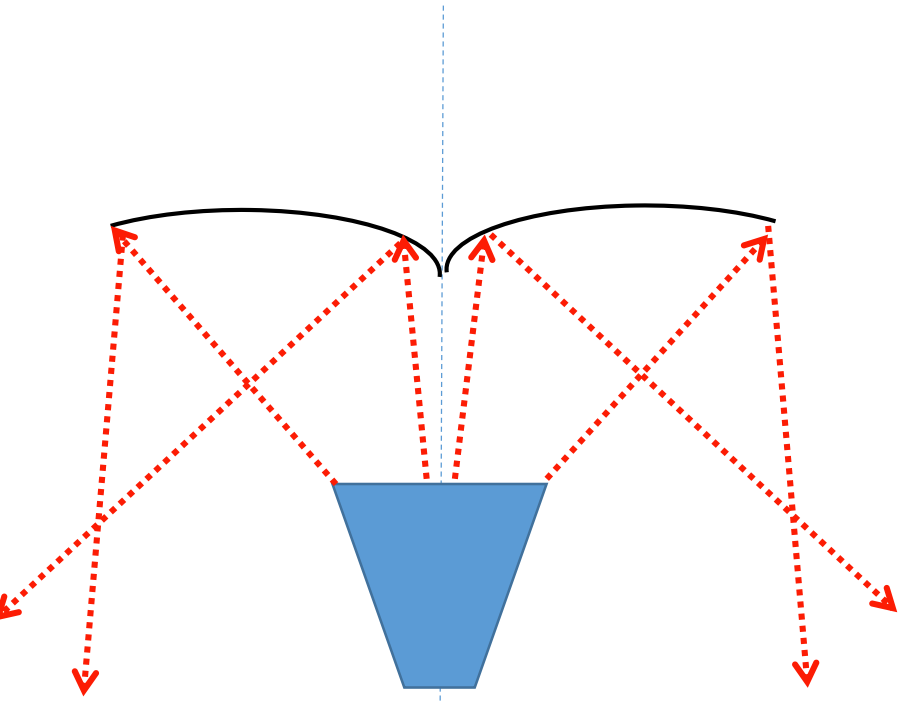
NINJA Feed
For Marble

Broadband
NINJA Feed

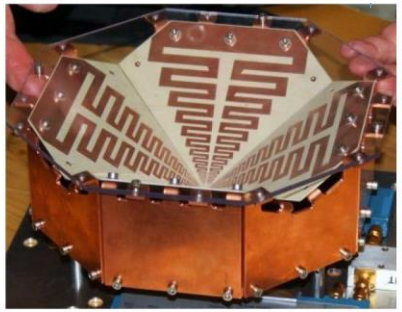
Kashima 34m

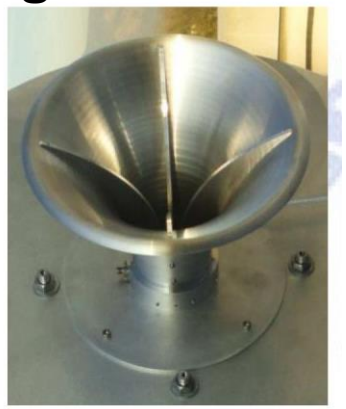
Reason why NICT Developed own Broadband Feeds

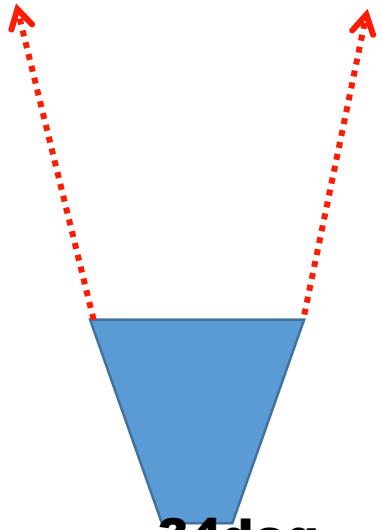
Requirement of
Broadband Frequency
and **Narrow beam width**



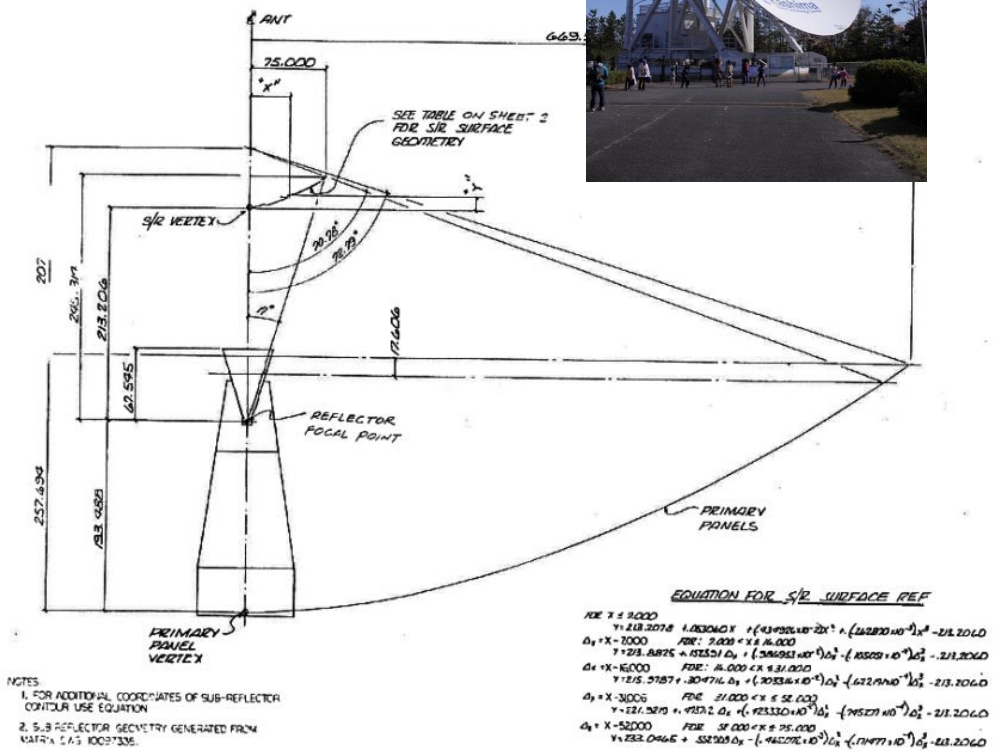
~120deg.



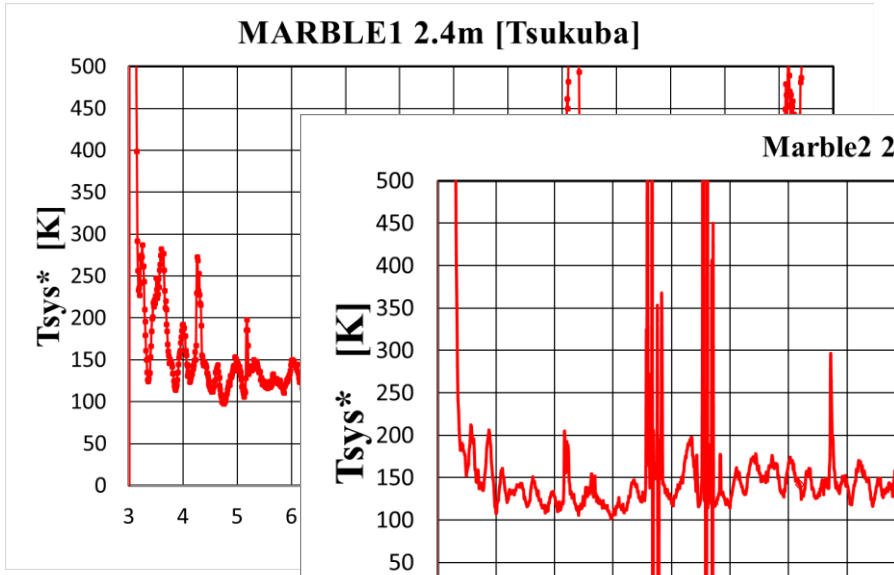




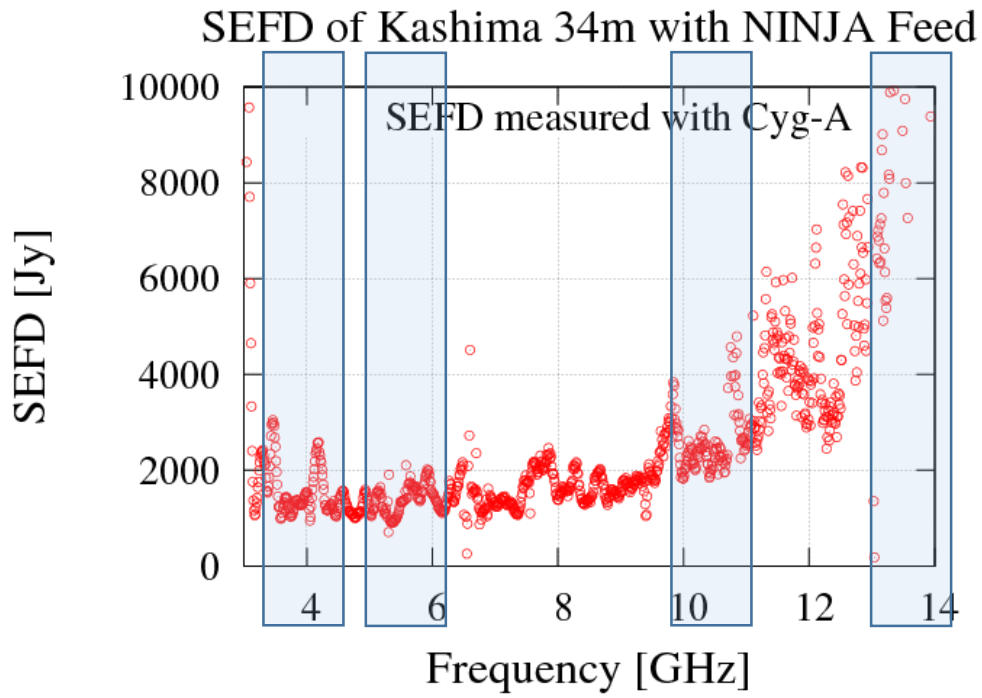
~34deg.

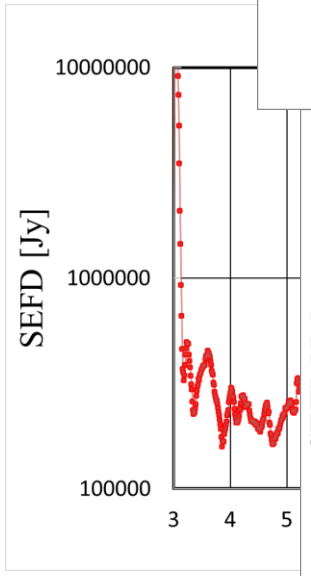


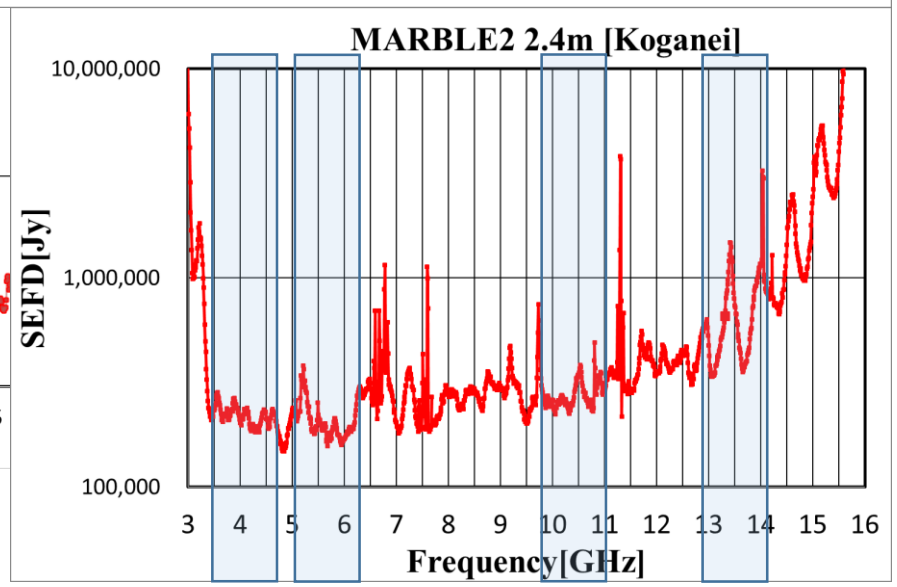
Kashima 34m
Tsys* [K]
Frequency [GHz]


MARBLE1 2.4m [Tsukuba]
Tsys* [K]

Marble2 2.4m [Kog
Tsys* [K]
Frequency[GHz]


SEFD of Kashima 34m with NINJA Feed
SEFD measured with Cyg-A
SEFD [Jy]
Frequency [GHz]

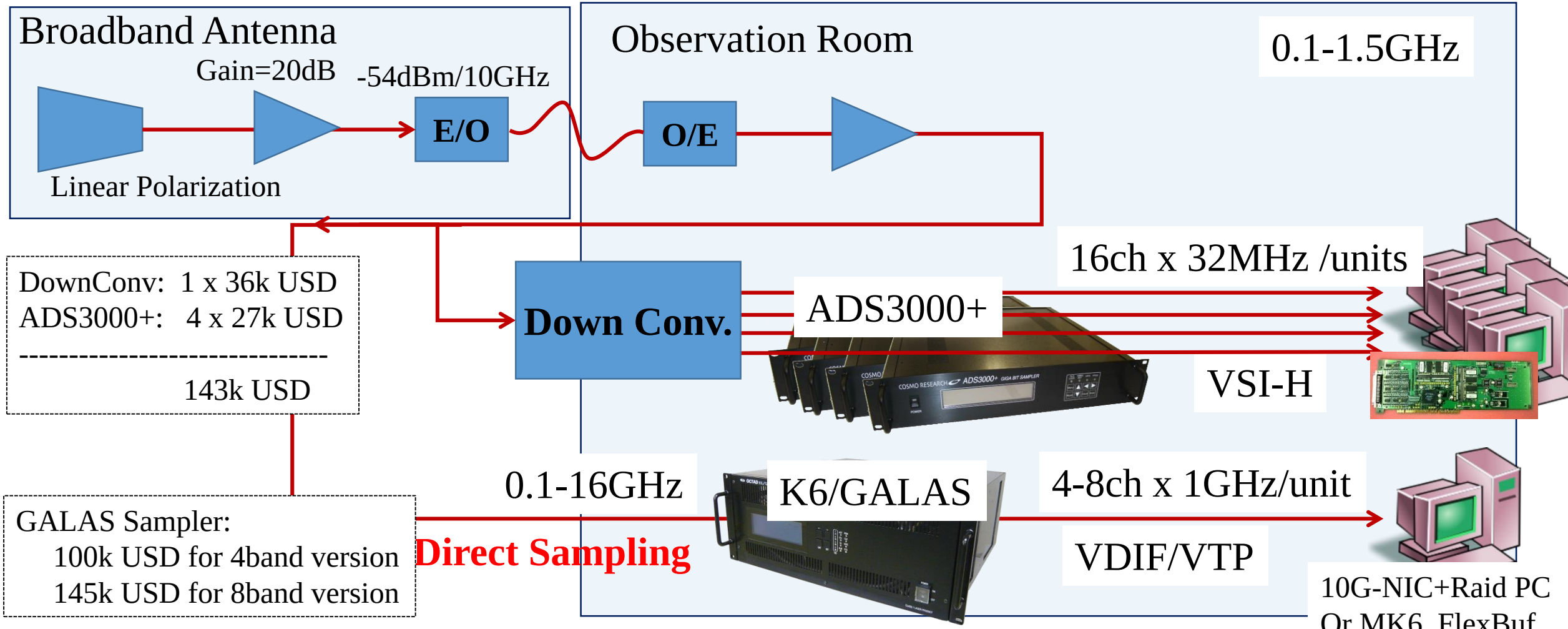

SEFD [Jy]


MARBLE2 2.4m [Koganei]
SEFD[Jy]
Frequency[GHz]

Data Acquisition System

300k=-174 dBm/Hz
-74dBm/10GHz

We have to be careful to compromise (1)avoiding saturation of system and (2) increase of noise figure, as discussed by Chris(2012) .



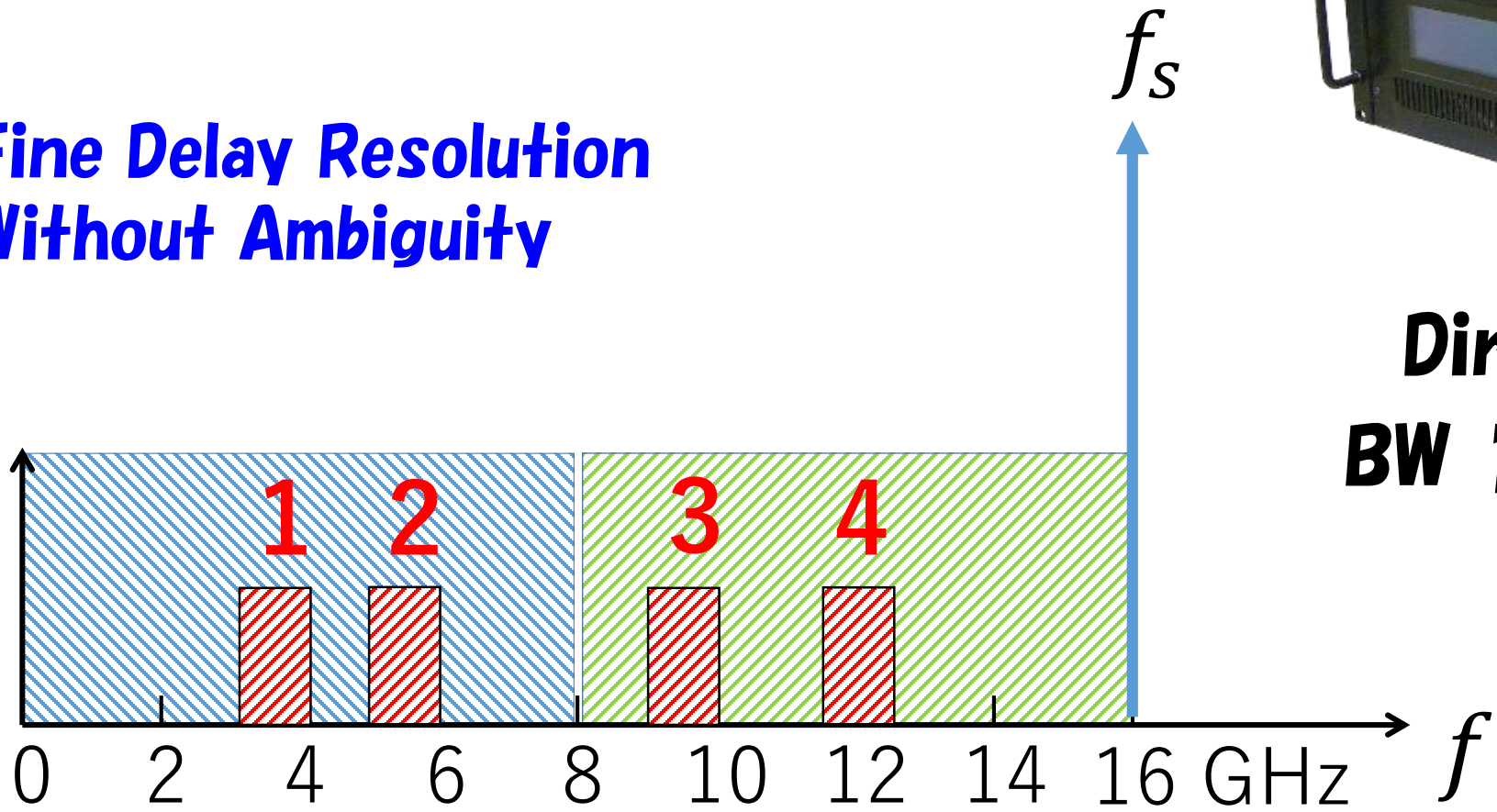
As close as Zero Redundancy

Frequency allocation

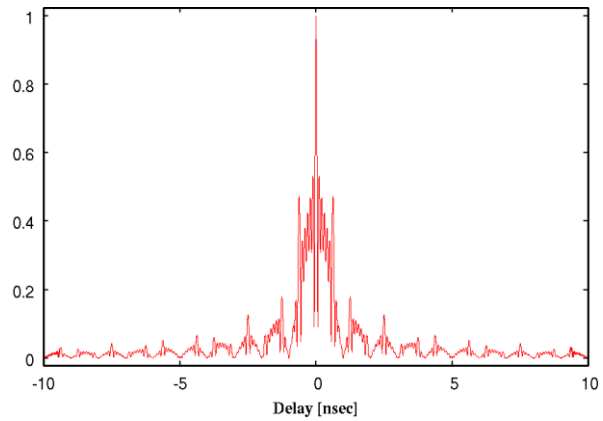
Direct Sampling

BW 1024MHz each

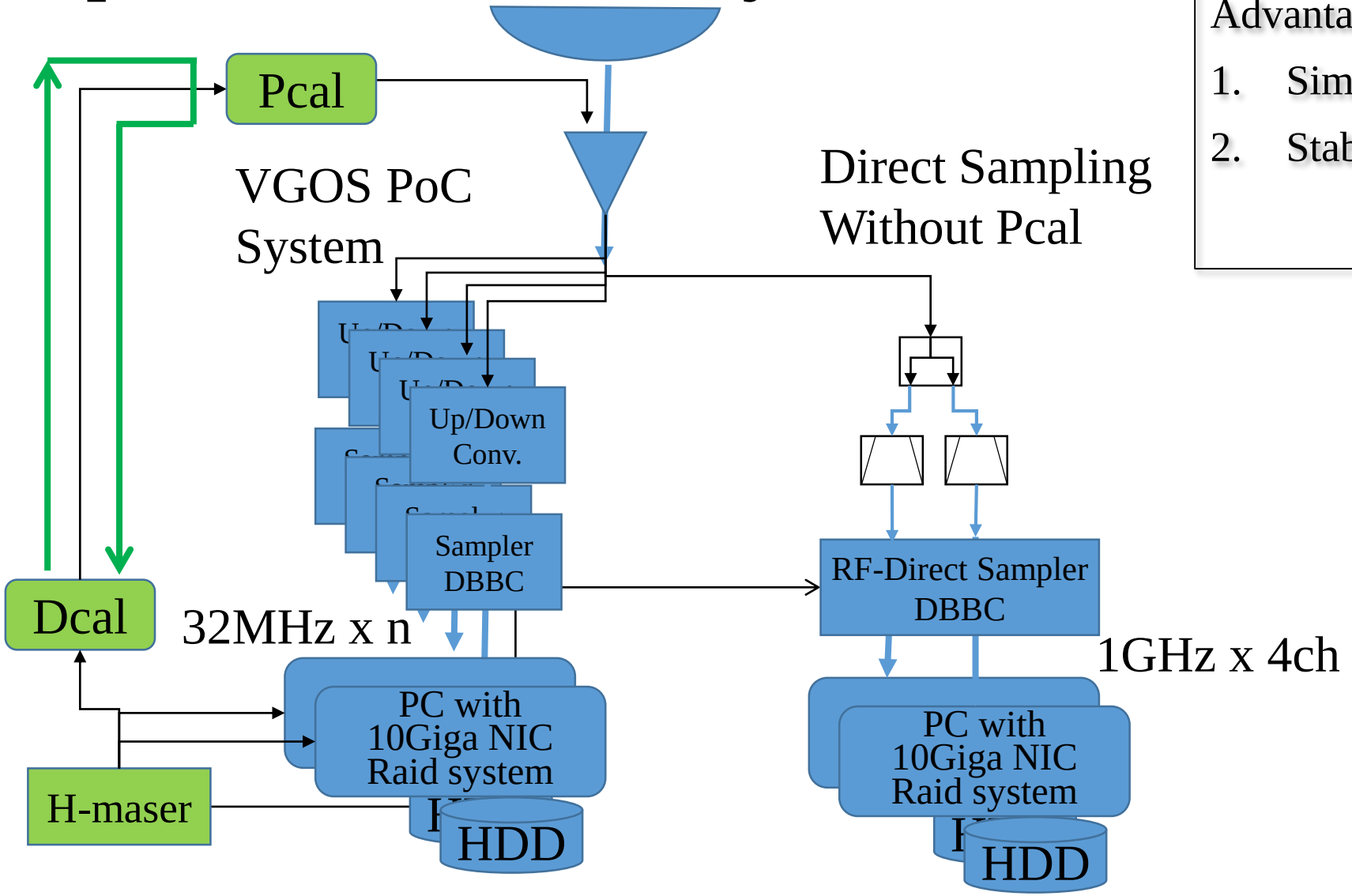
Fine Delay Resolution
Without Ambiguity



Lower Edge= 3.2, 4.8, 8.8, 11.6GHz



Advantages of RF-Direct Sampling Technique possible Pcal-free system

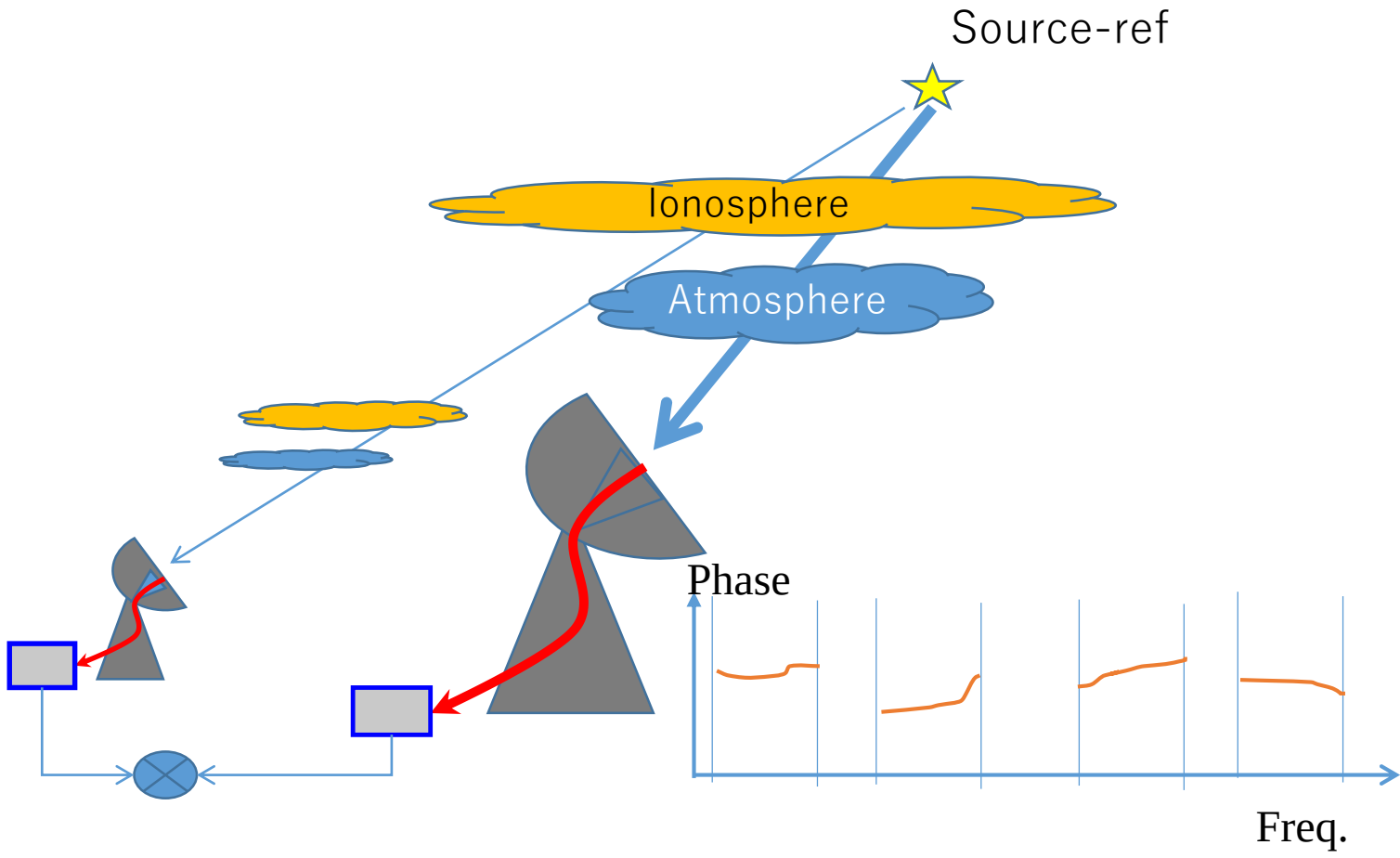


Advantages of Direct sampling

1. Simple and less system components.
2. Stable inter-band phase relation

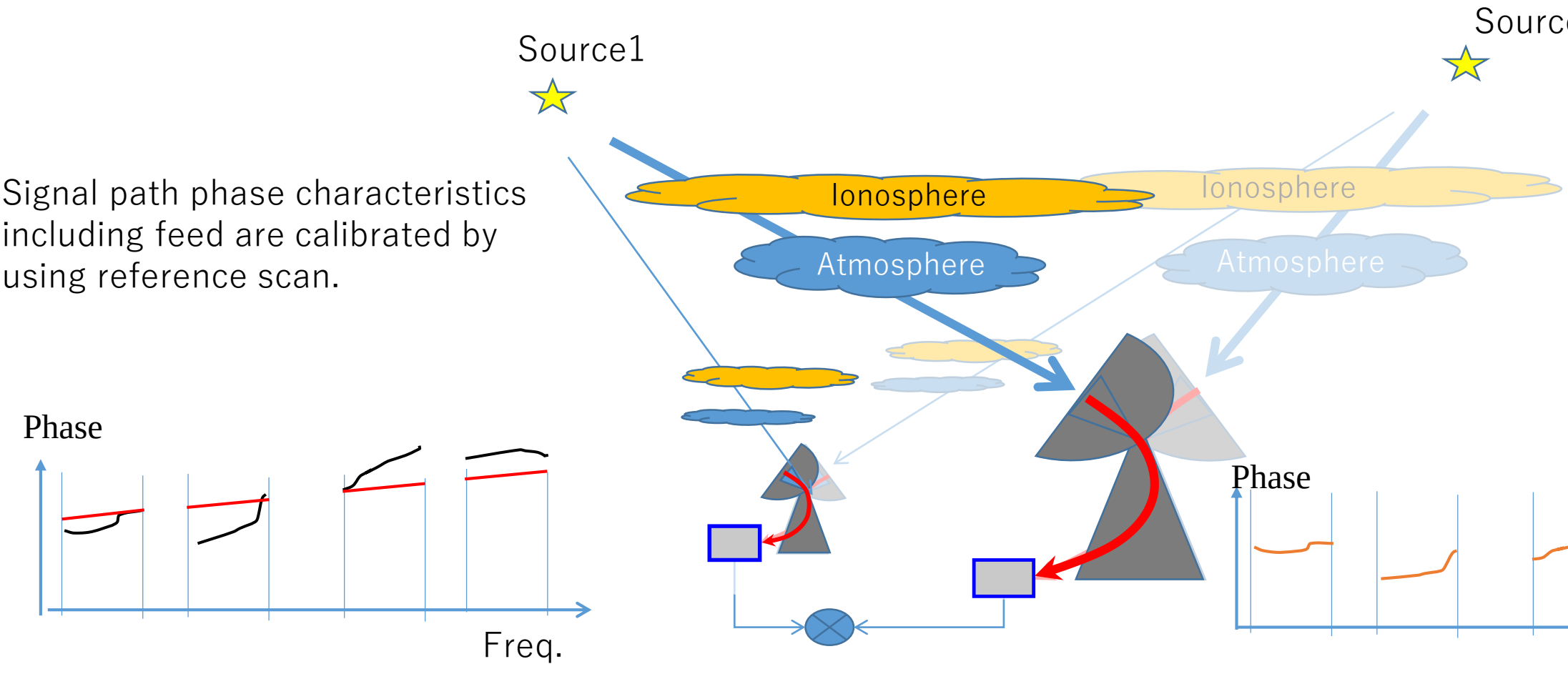
=> (Pcal,Dcal free)

Procedure of Broadband Phase Calibration with radio source



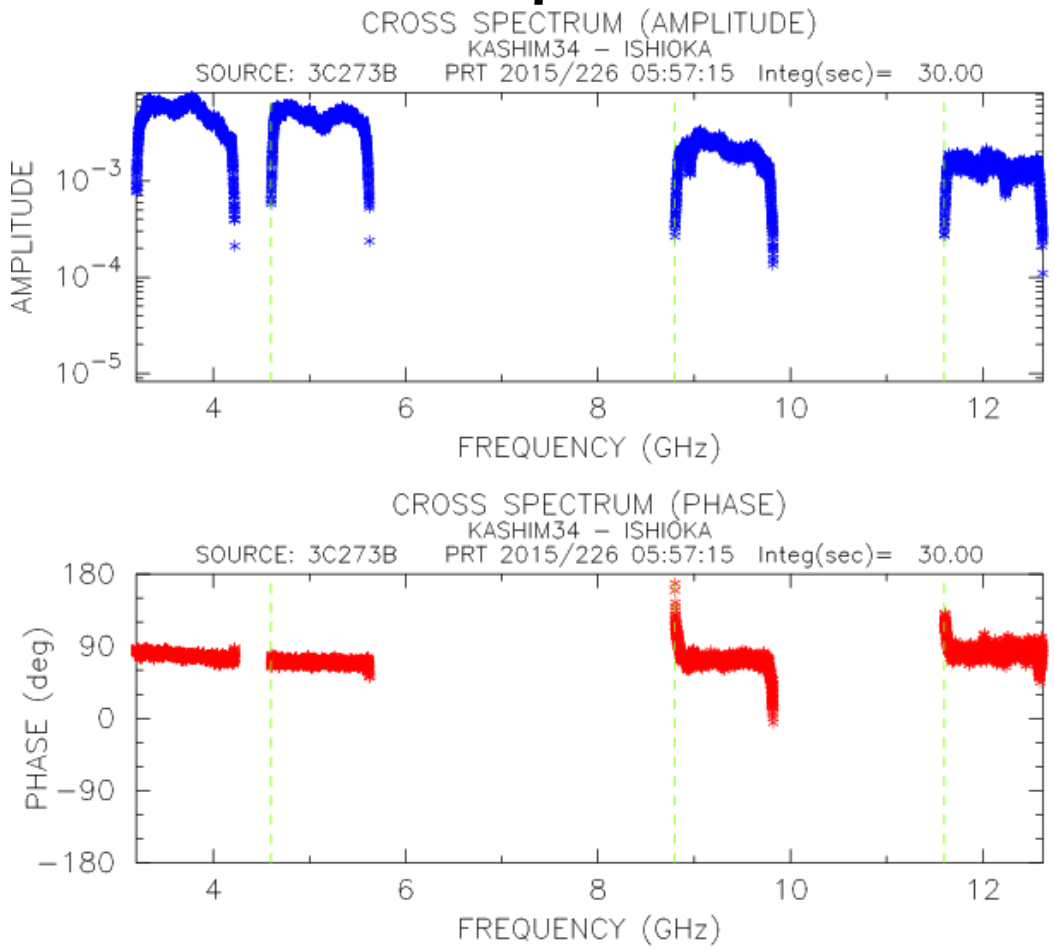
Procedure of Broadband Phase Calibration with radio source

Signal path phase characteristics including feed are calibrated by using reference scan.

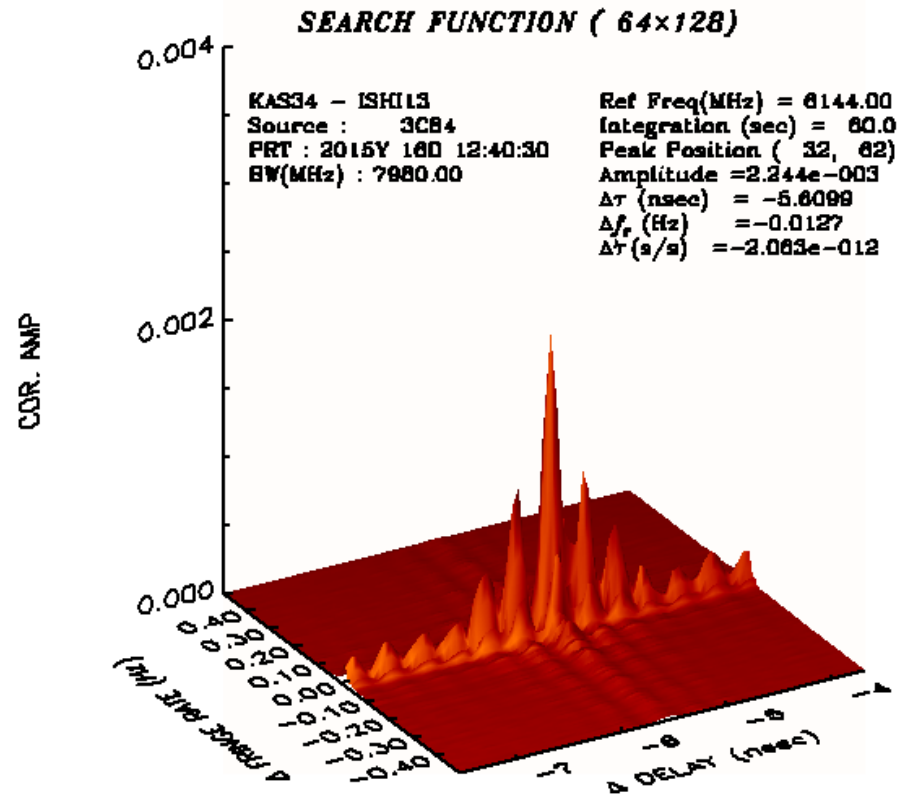


Full Bandwidth Synthesis #1-#(6-14GHz)

Cross Spectrum



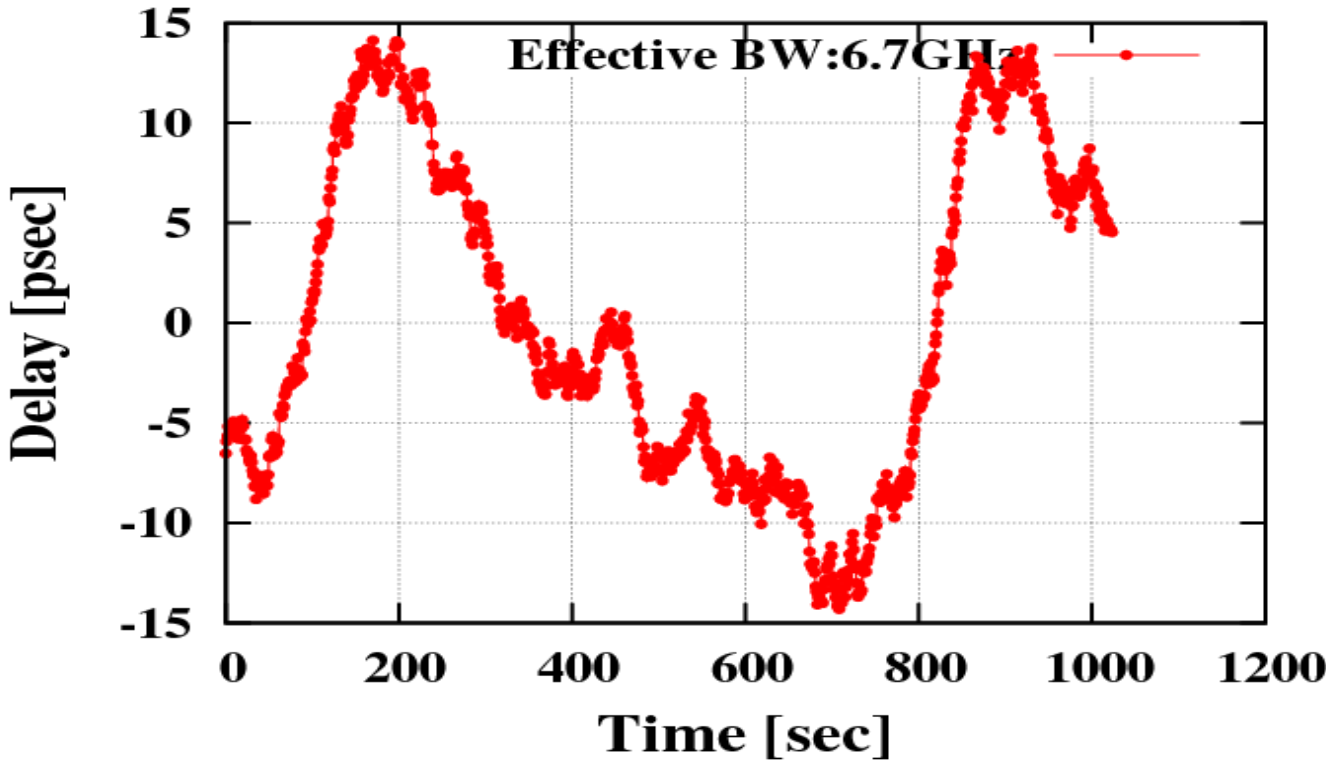
Delay Resolution Function

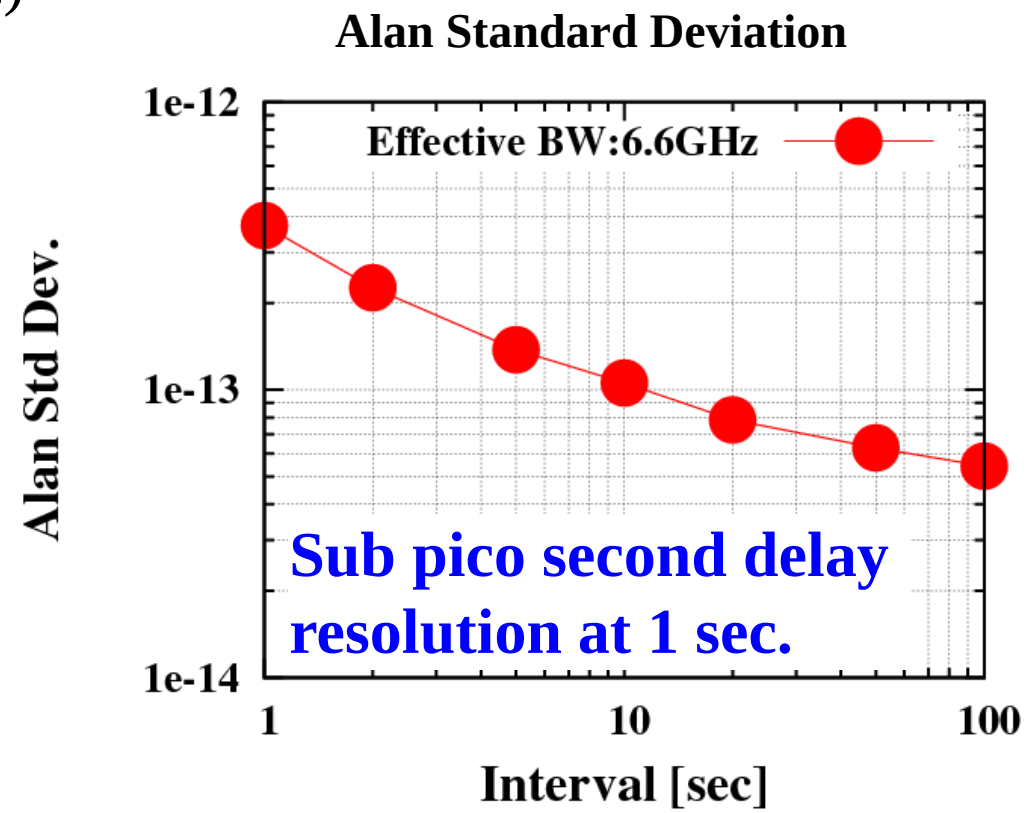


Broadband VLBI Experiments

Delay Behavior 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)



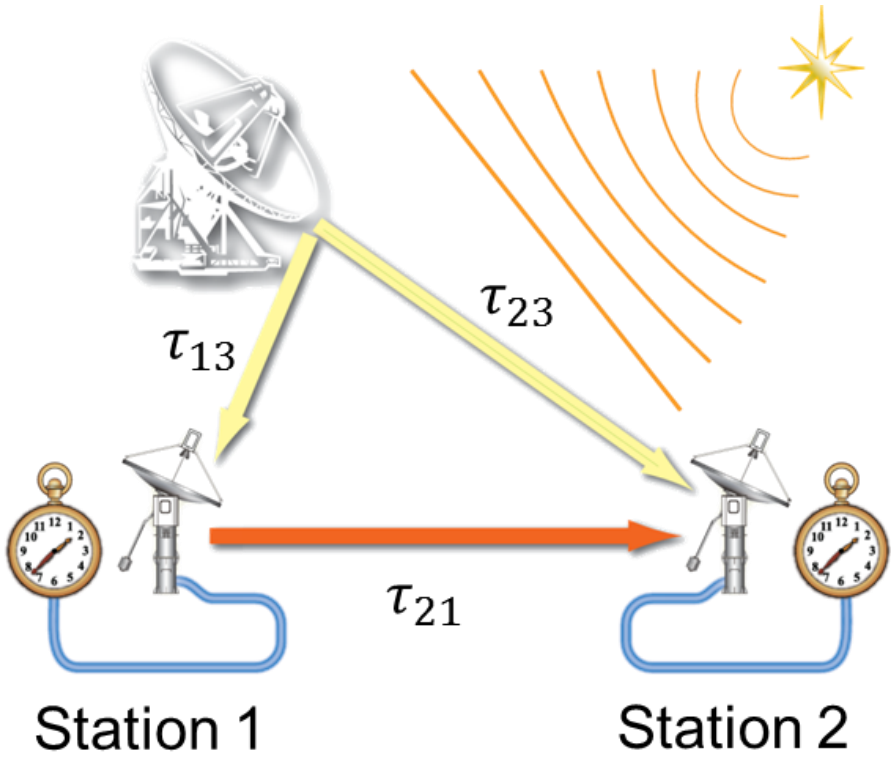


‘Small – Small’ Baseline

- Small diameter antenna pair is used for Atomic Clock comparison.
- Closure delay relation used for ‘small-small’ baseline.

$$\tau_{21}(t_1) = \tau_{23}(t_1) - \tau_{13}(t_1) - \tau_{13}(t_1)\dot{\tau}_{12}$$

- Advantage:
  - Quick Slew and small distortion
  - Large Diameter’s effects are canceled out.
  - Lower Cost
- Disadvantage:
  - Lower Sensitivity,
  - source structure effect in closure delay.



Delay Precision

Broadband(small-small)

v.s.

Conventional 8180-8680MHz

S/X **500MHz(T2 session)**

2.4m Diameter

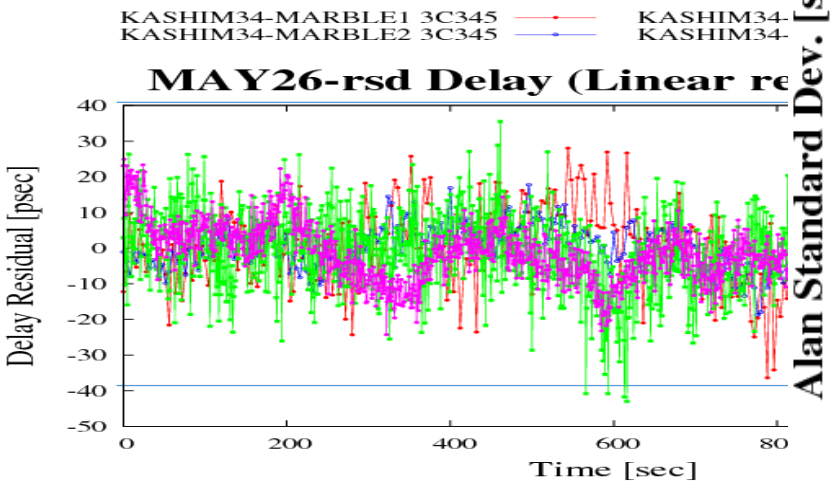
1.6m Diameter

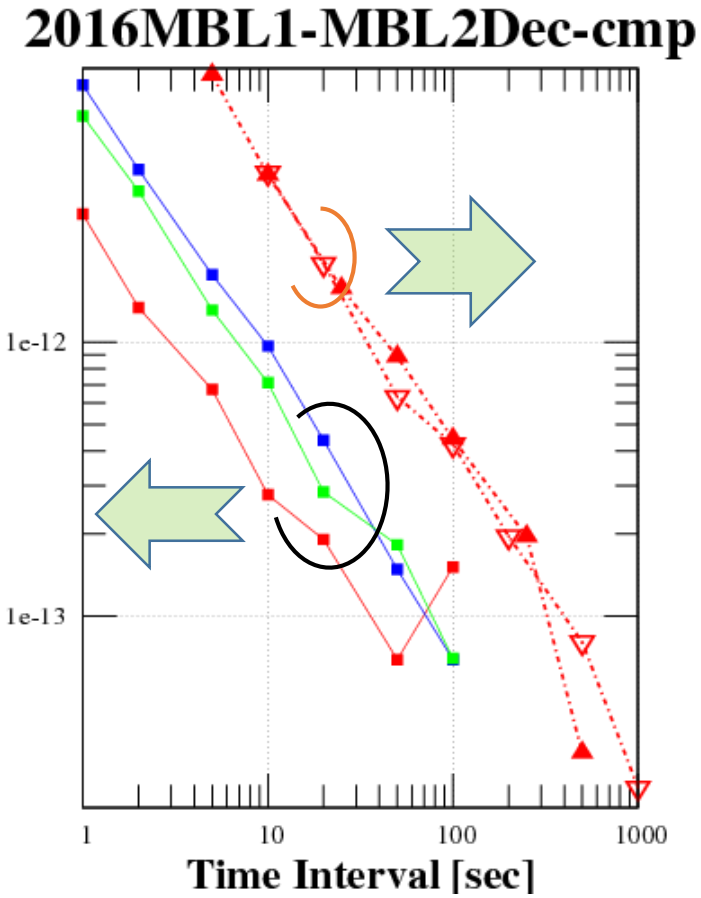
3C273B

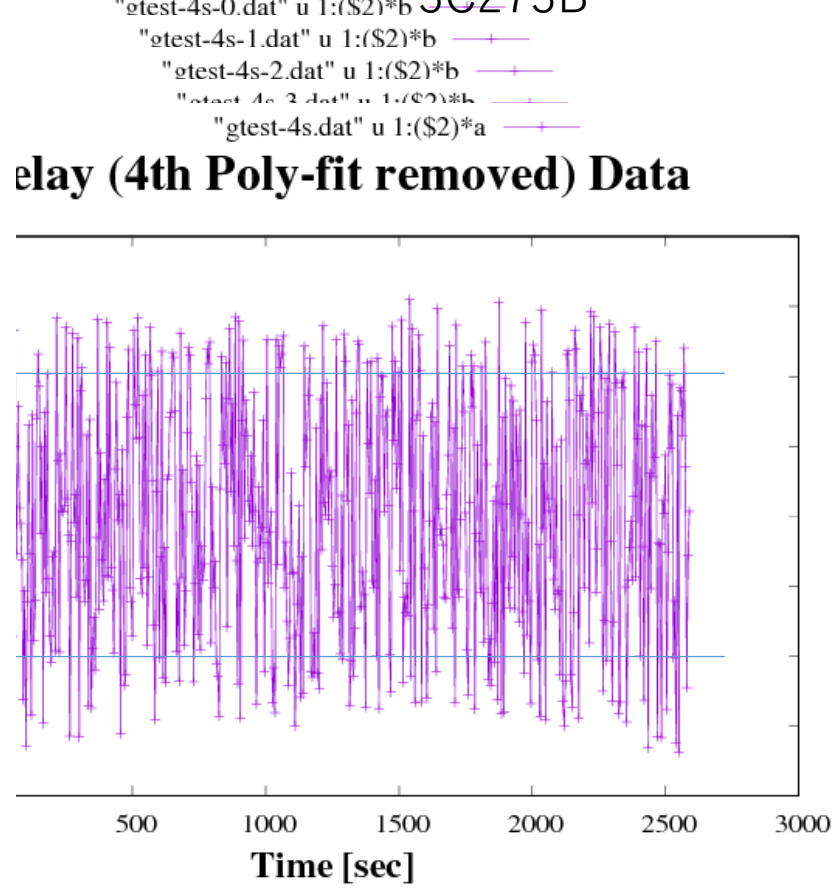
4C39.25

Broadband

'small-small' ba
by closure delay





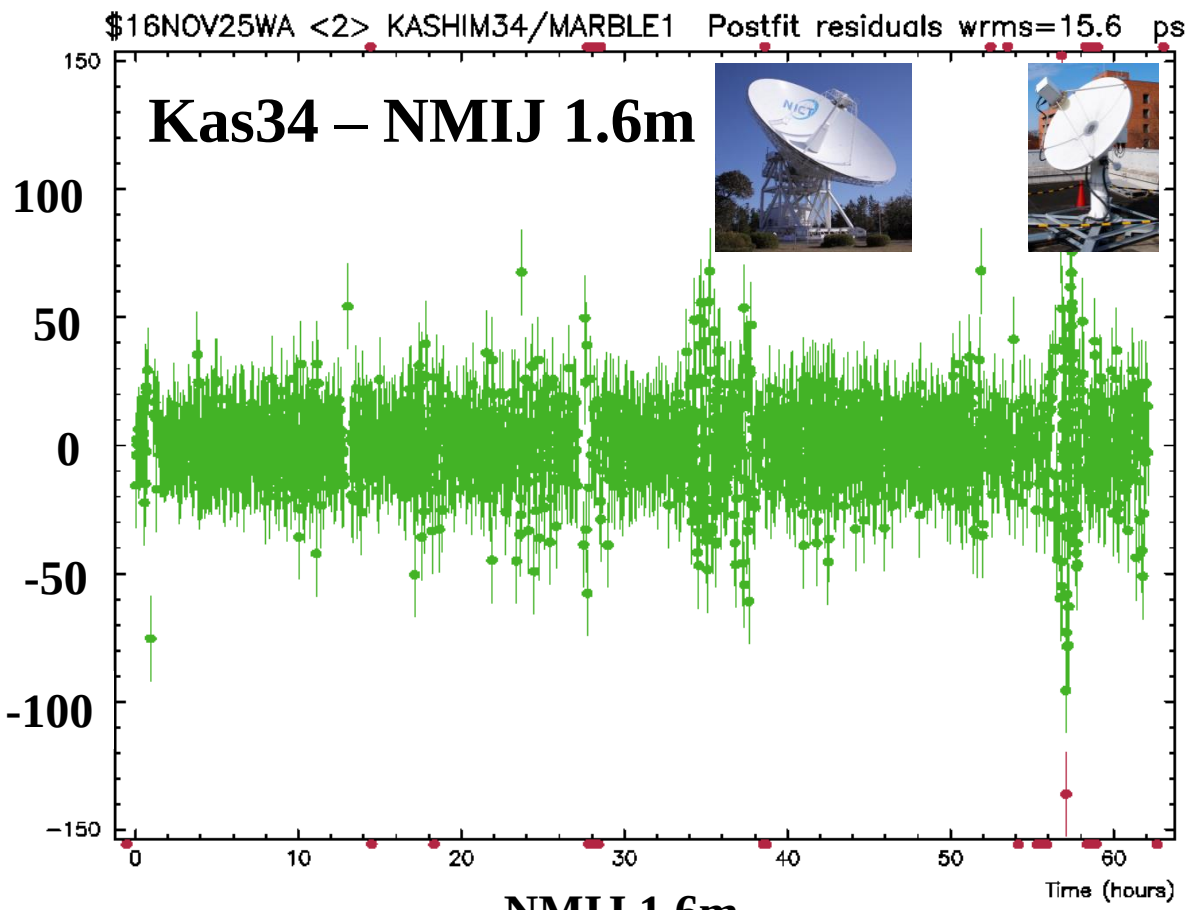


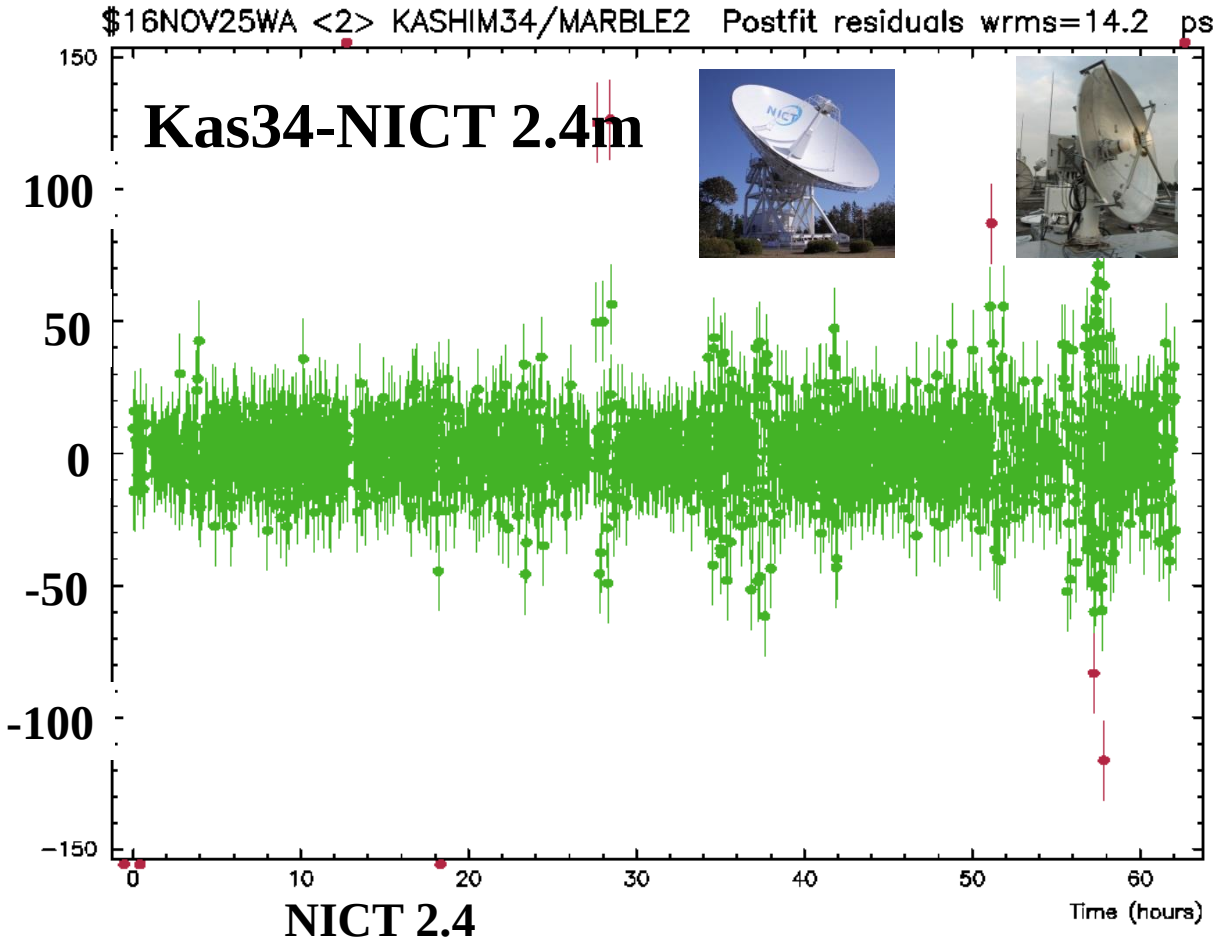
CALC/SOLVE Residual

Baseline Length

Kashim34 -NMIJ 1.6m : 48718193.8 mm 0.6 mm
Kashim34 - NICT 2.4m : 109427397.8 mm 0.7 mm
NICT 2.4m - NMIJ 1.6m : 70218038.2 mm 0.8 mm

WRMS Delay Residual ~ 16ps





NMIJ 1,6m

X ：-3962279099.2 mm 1.9 mm
Y ： 3308886482.2 mm 1.5 mm
Z ： 3733538092.1 mm 1.8 mm

NICT 2.4

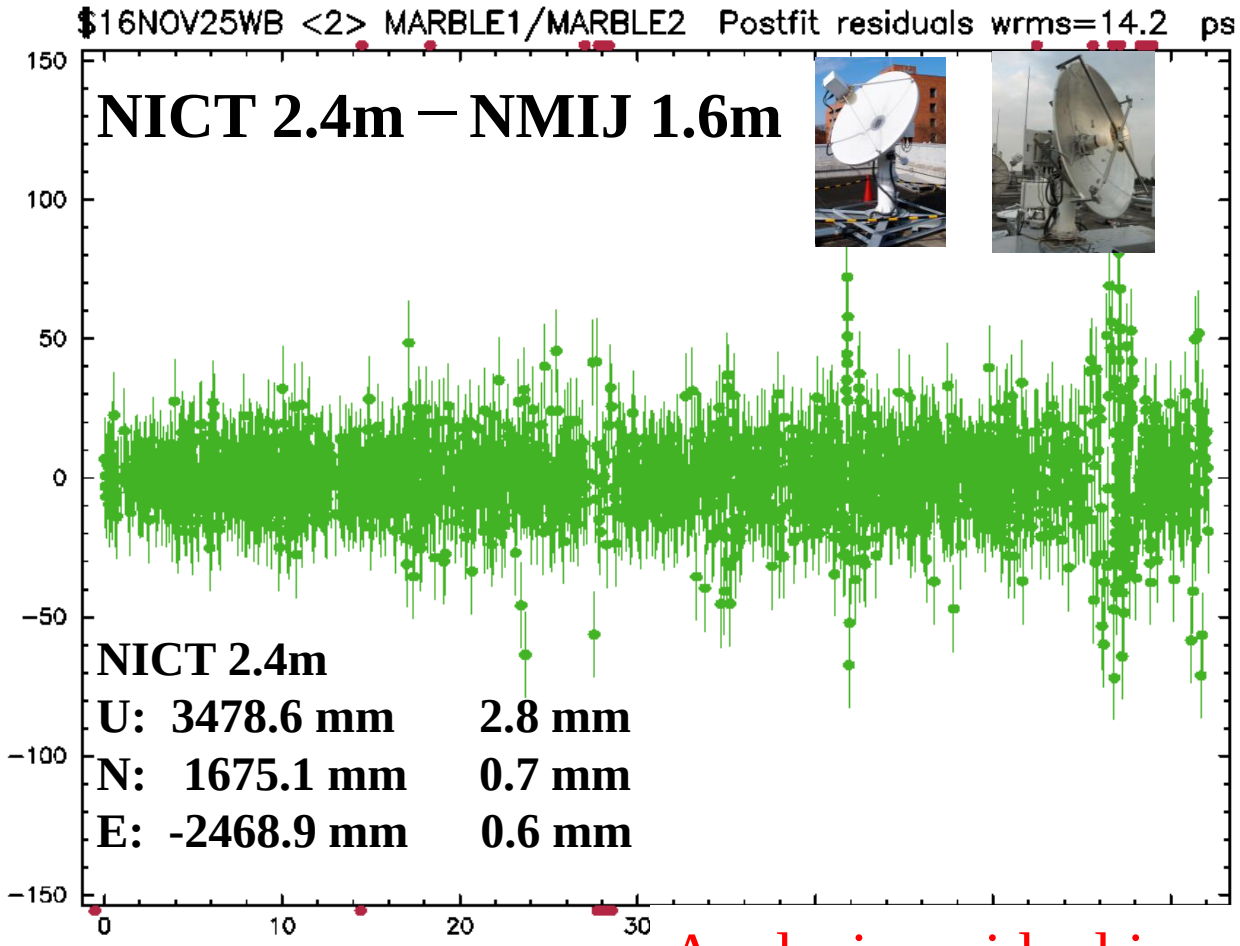
X: -3942068754.6 mm 1.8 mm
Y: 3368281011.8 mm 1.5 mm
Z: 3702003908.5 mm 1.7 mm

CALC/SOLVE Residual

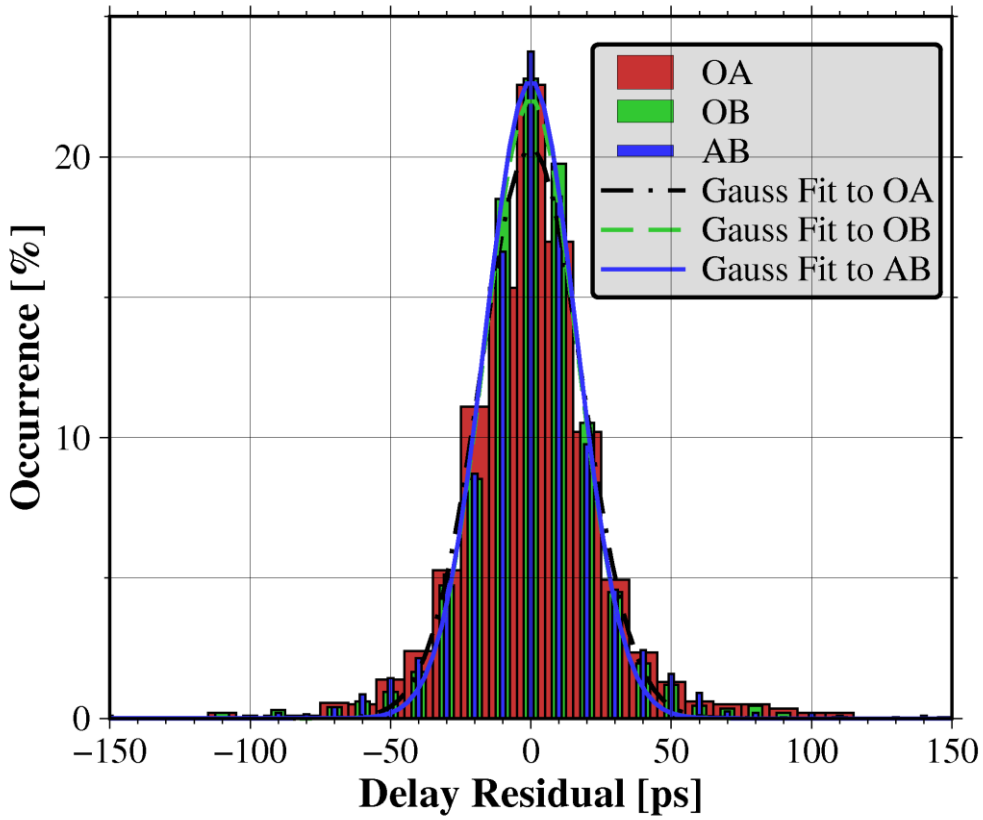
Baseline Length
MBL1(1.6m) – MBL2(2.4m): 70218041.2 mm 0.7 mm

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

WRMS Delay Residual ~ 15 psec

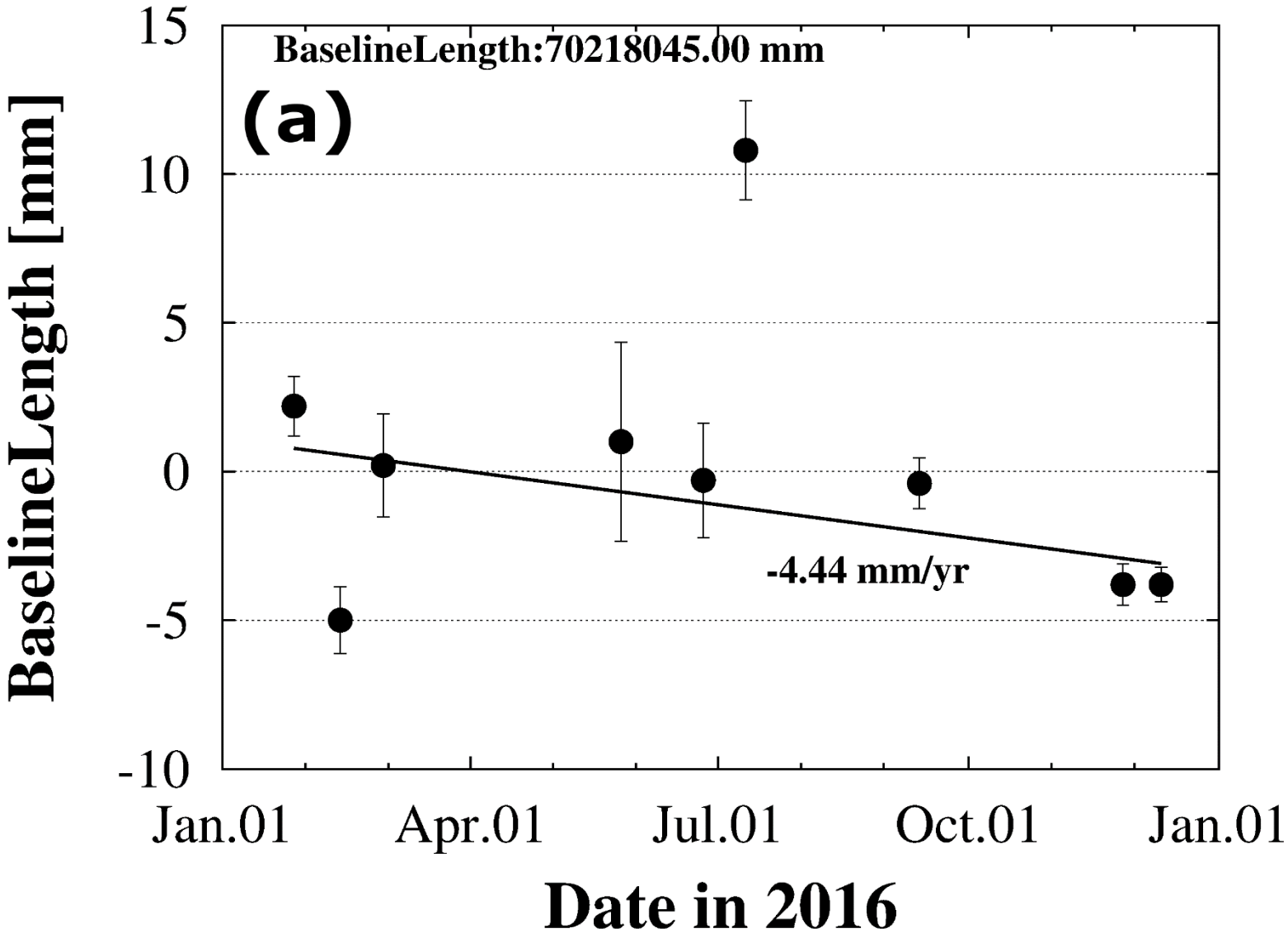


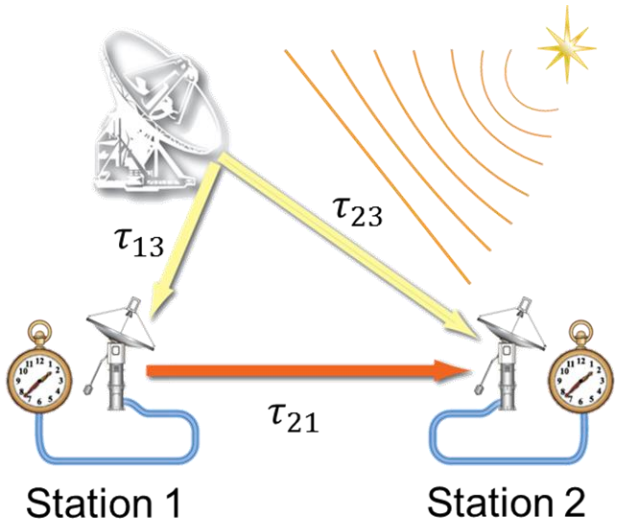
O:Kashim34
A:MARBLE1 NMIJ 1.6m
B:MARBLE2 NICT 2.4m



Analysis residual is no more dominated by measurement precision, but unknown excess delay, it may be troposphere.

Position Solution of MBL1-MBL2

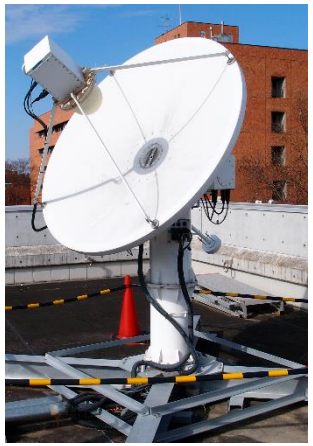




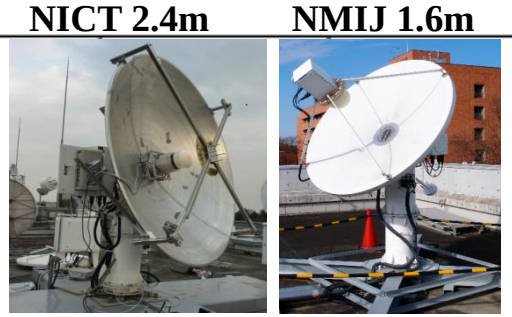
$$\tau_{21} = \tau_{13} - \tau_{23}$$

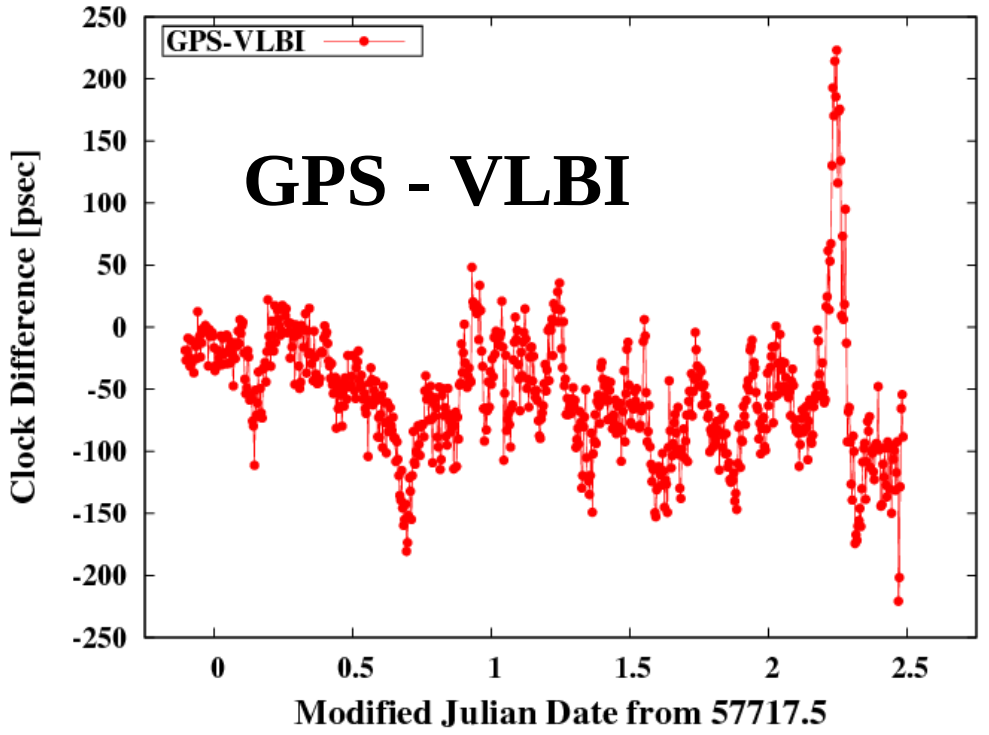
NICT 2.4m

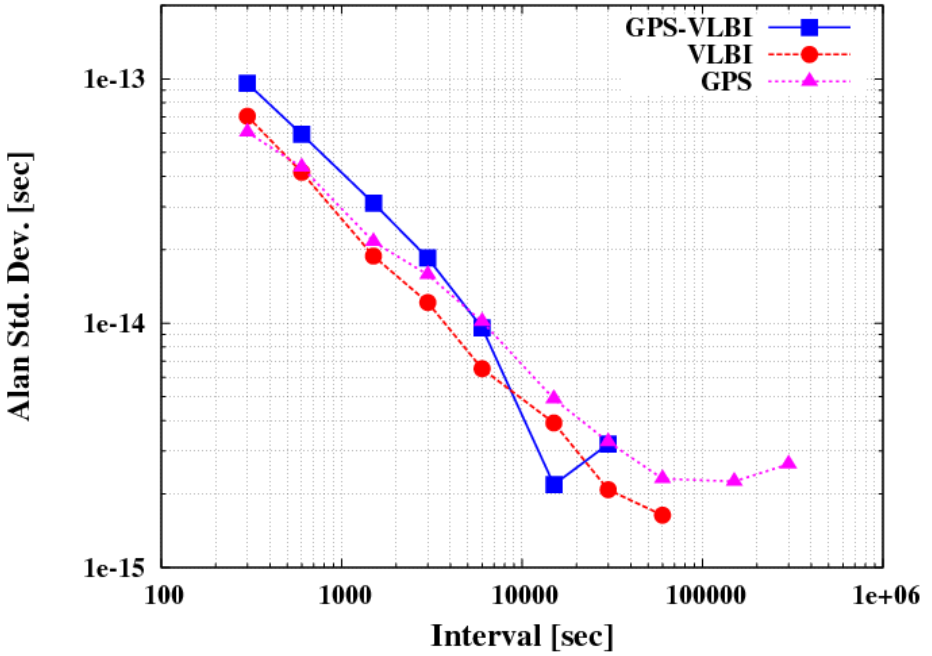
NMIJ 1.6m



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



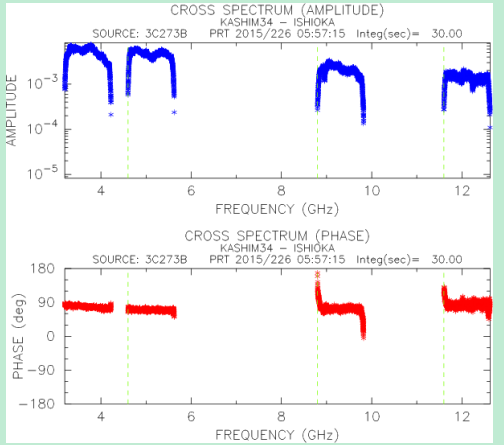


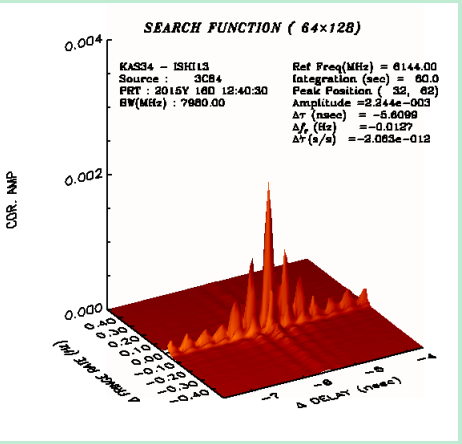


Summary

Broadband Feed: NINJA

RF-Direct Sampling K6/GALAS





Broadband bandwidth Synthesis

1. We developed Broadband VLBI Observation/Processing System
2. Broadband Observation is relatively robust to RFI.
3. Broadband (3-12GHz) observation gives higher precision delay measurement even with 1.6 m – 2.4m baseline.

Thank you for Attention

Acknowledgements

- Development of Broadband Feed was supported by a grant (2013-2014) of Joint Development Research from National Astronomical Observatory of Japan(NAOJ).
- Broadband experiments with Ishioka Station was kindly supported by GSI.
- Highs speed research network environment is supported by JGN.