

Development Status of Broadband VLBI System (Gala-V) -(II)



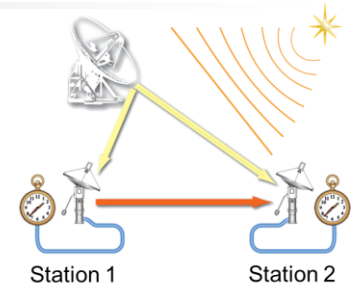
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S.Hasegawa⁽¹⁾, T.Kondo⁽¹⁾, E.Kawai⁽¹⁾, R.Ichikawa⁽¹⁾, H.Takiguchi⁽¹⁾,
T.Goto⁽¹⁾, K.Watabe⁽²⁾, T.Suzuyama⁽²⁾, Y.Koyama⁽¹⁾

1) National Institute of Information and Communications Technology

2) National Metrology Institute of Japan

Contents of presentation

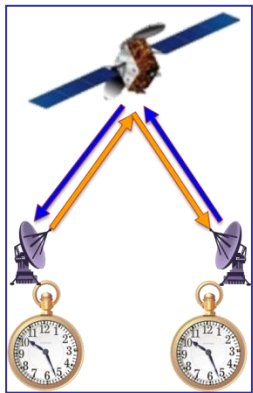
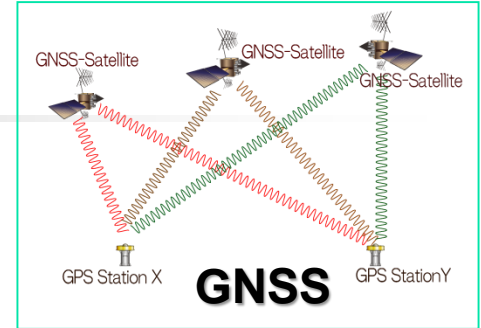
- Frequency transfer via VLBI
- Gala-V system Development
 - Broadband observation
 - Marble1,2 (1.5m,1.6m) : 3-15GHz
 - Kashima34m : 6-14GHz
 - Compliant with VGOS (Next generation Global VLBI system)
- Installation to NMIJ(Tsukuba) and NICT(Koganei)
 - First Geodetic observation after installation
 - Principle proving



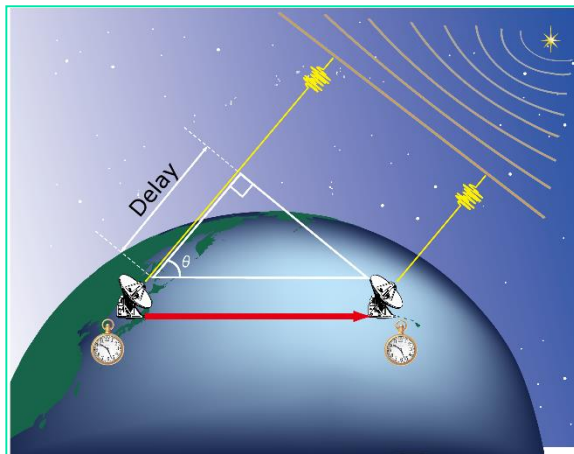
Precise Frequency Transfer over intercontinental distances

Space Technologies for Distant Frequency Comparison

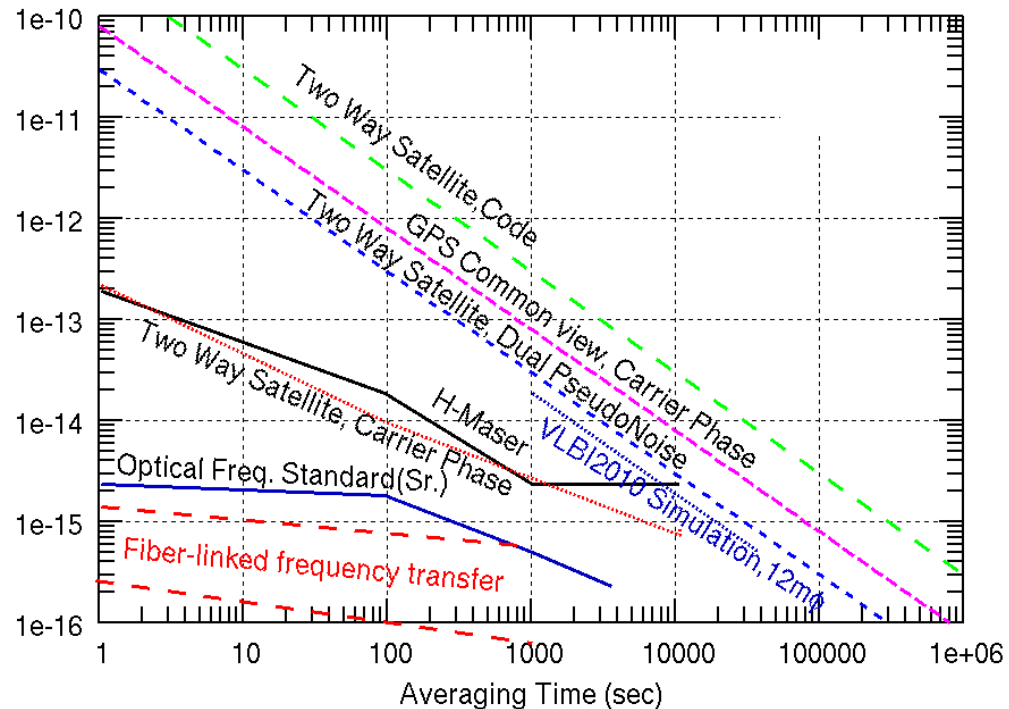
- GNSS(Common view, PPP)
- Two way Satellite Time and Frequency Transfer(TWSTFT)
- **VLBI**



TWSTFT



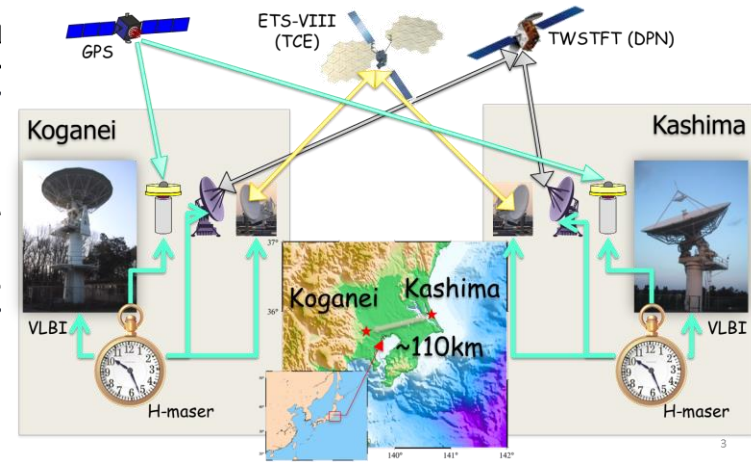
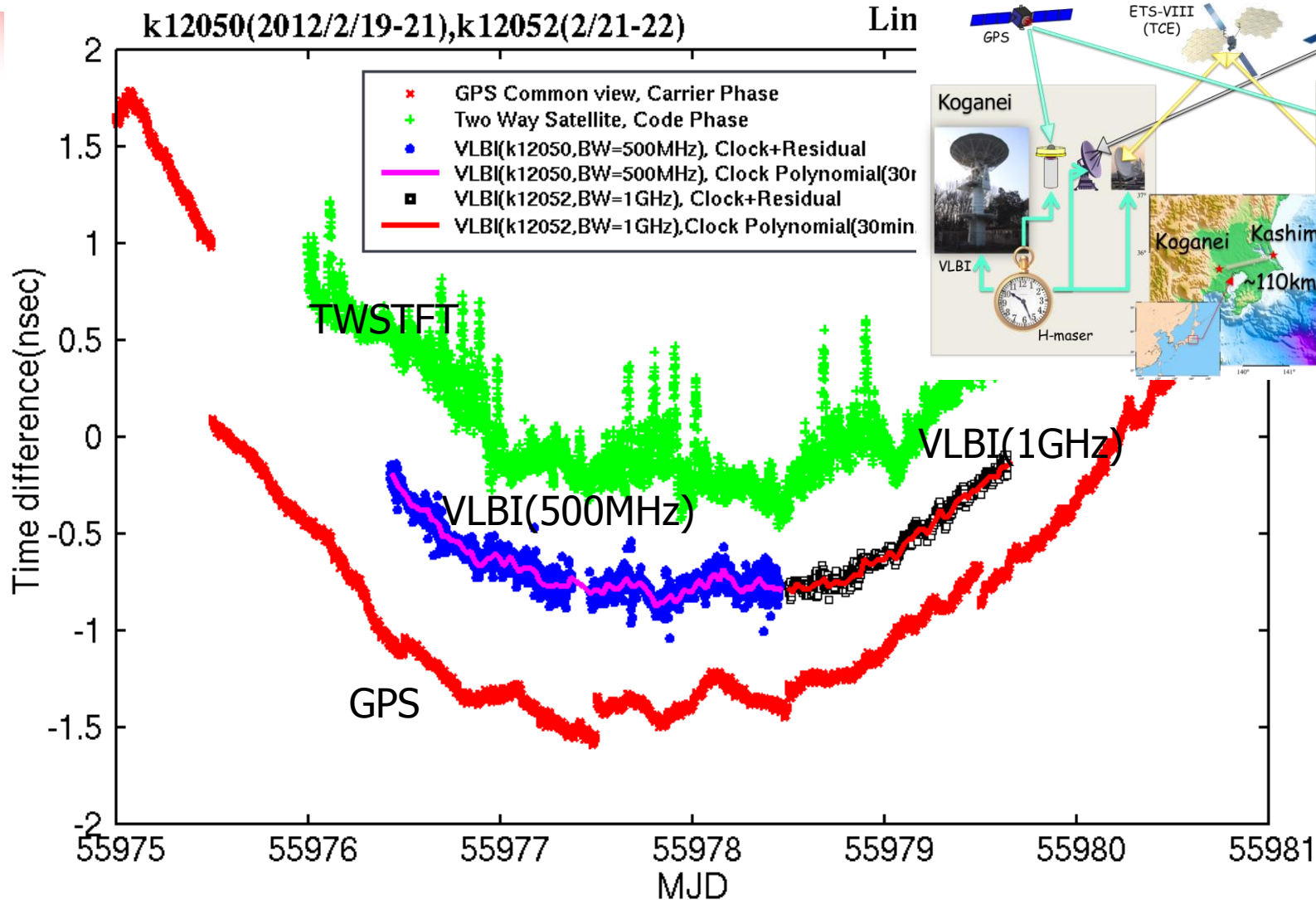
VLBI



Comparison of TWSTFT, GPS, VLBI

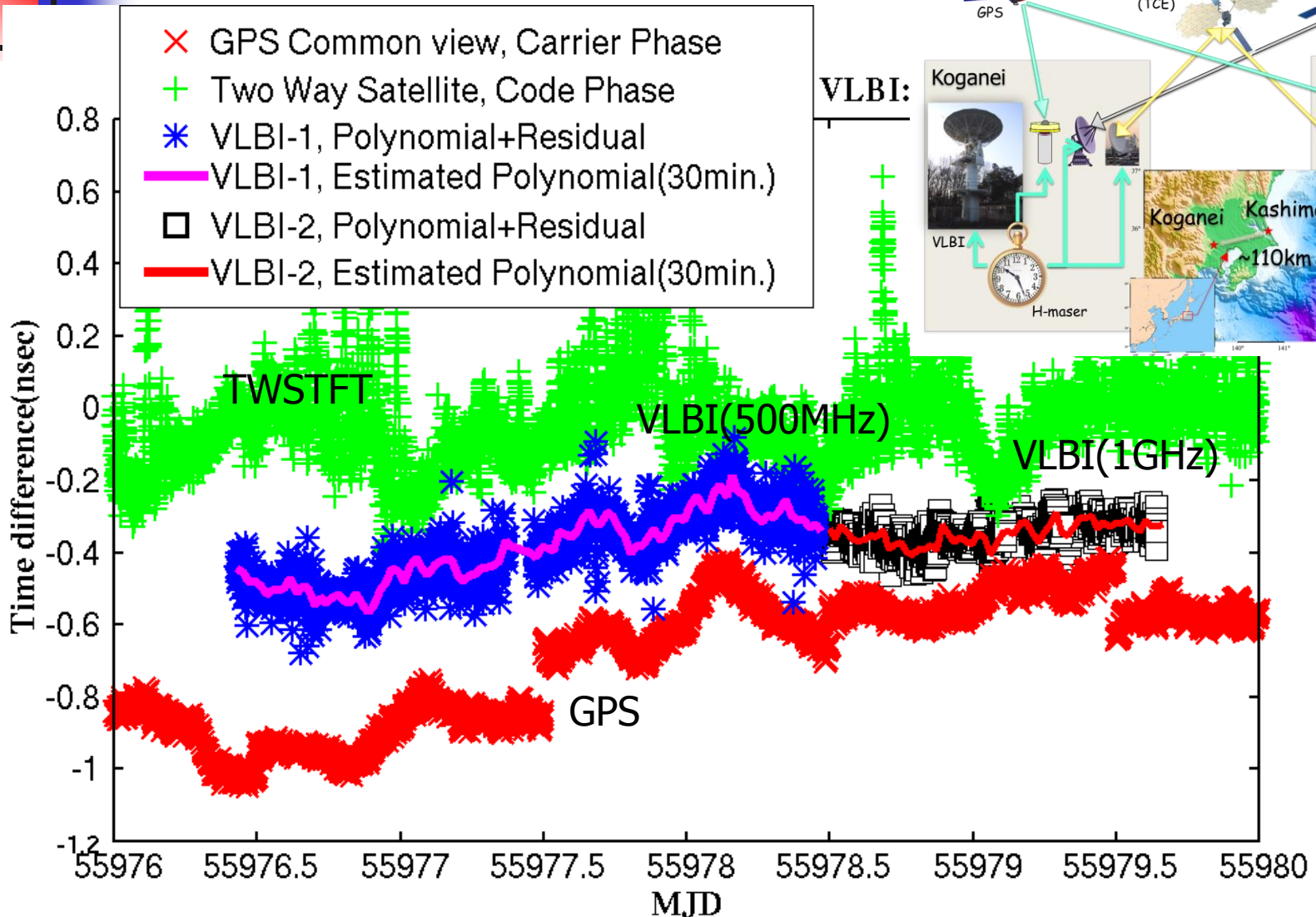
Exp. on 19-22 Feb. 2012

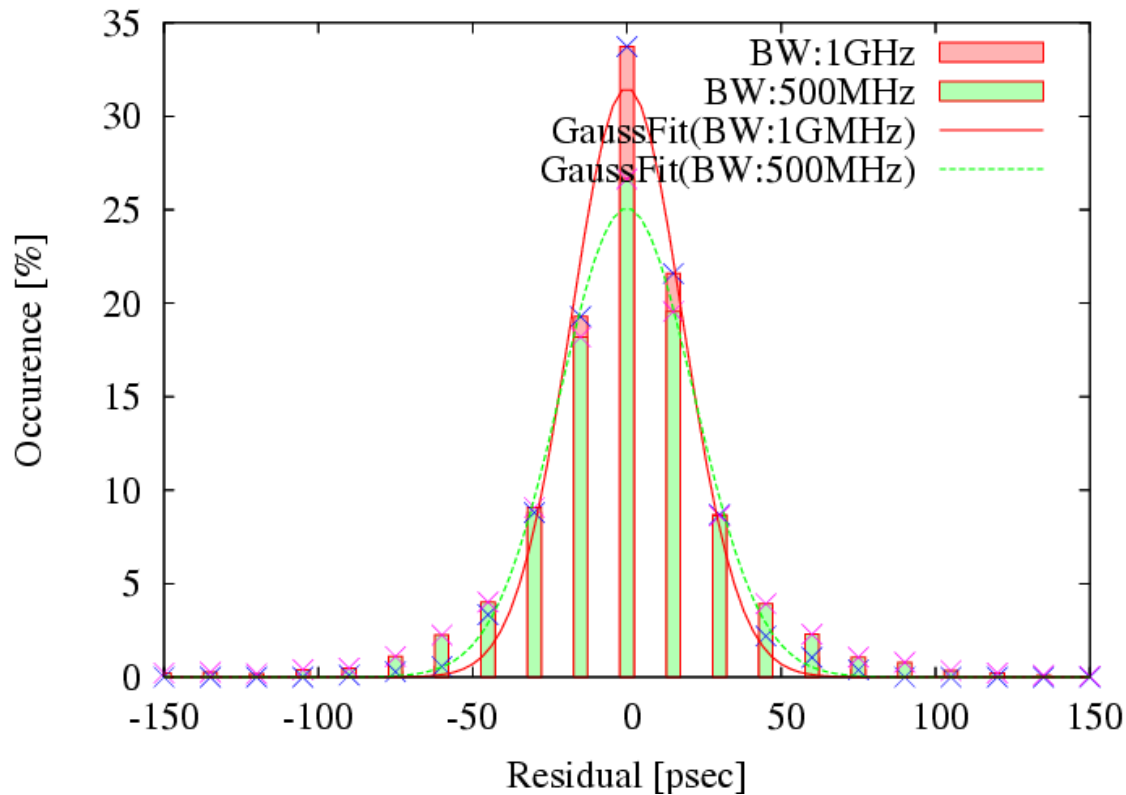
Comparison of Frequency Transfer Techniques
Experiment on 100 km baseline



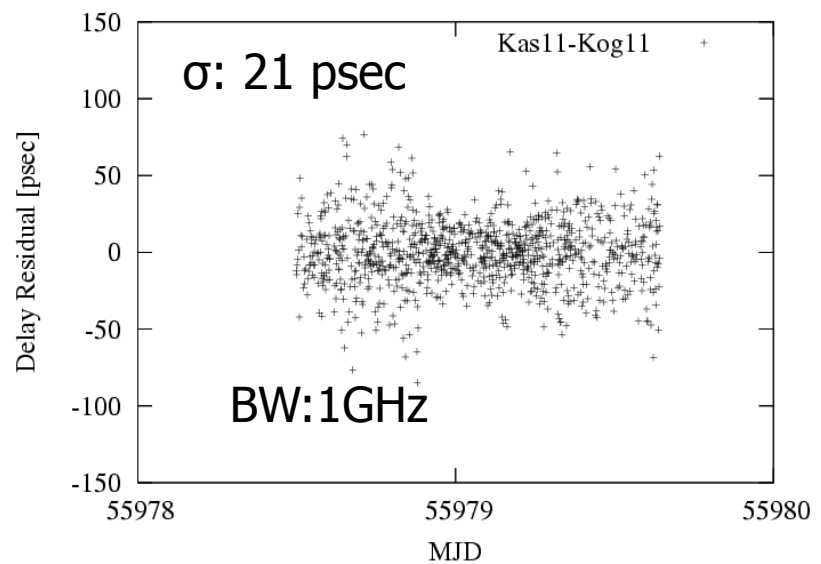
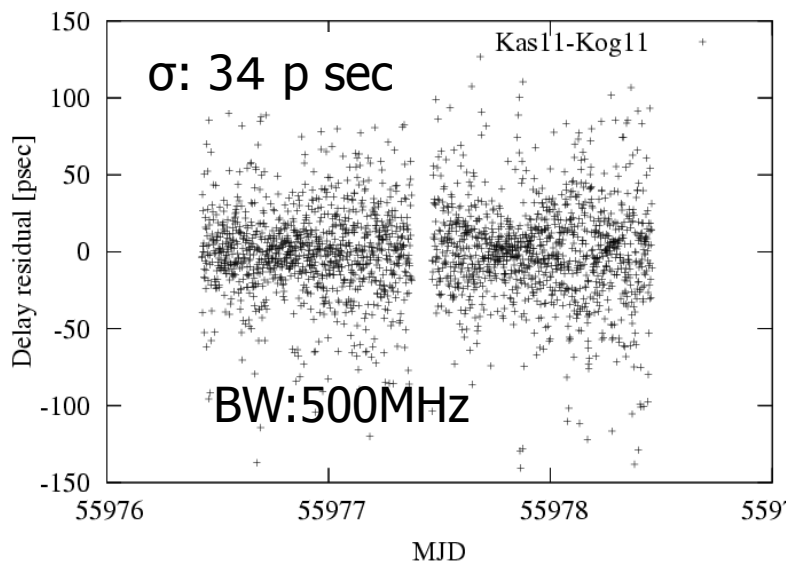
Comparison of TWSTFT, GPS, VLBI Exp. on 19-22 Feb. 2012

Comparison of Frequency Transfer Technique
Experiment on 100 km baseline





VLBI Delay residual is improved by expanding observation frequency band.



Precision of VLBI



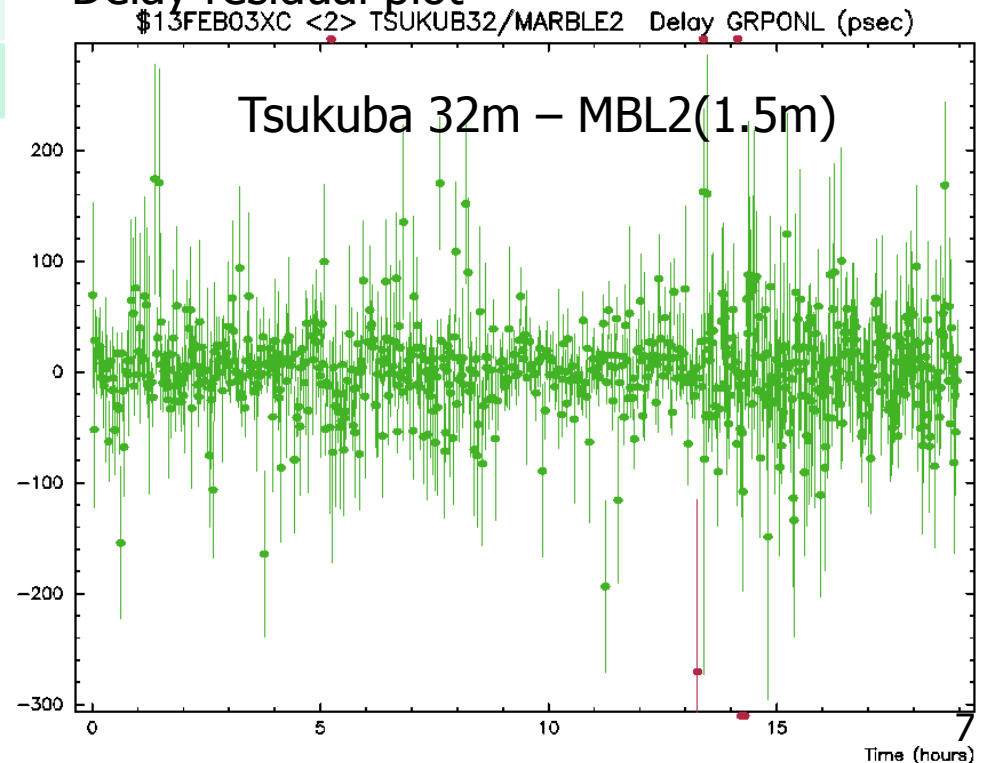
Tsukuba 32m



MBL2(1.5m)
Koganei

Antenna Diameter	RMS residual
11m-11m	~ 30 psec.
32m-11m	~ 20 psec.
32m-1.5m	~ 30 psec.

Example of VLBI analysis Delay residual plot



Major error sources

1. Error of atmospheric delay estimat
2. Thermal noise $\propto 1/(\text{SNR} \times \text{BW})$

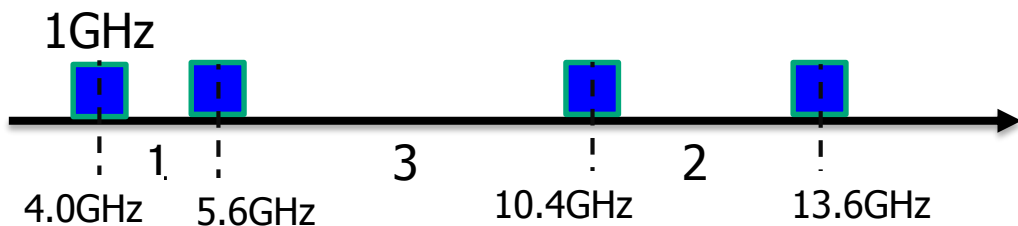
ity :

Gala-V project Overview

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

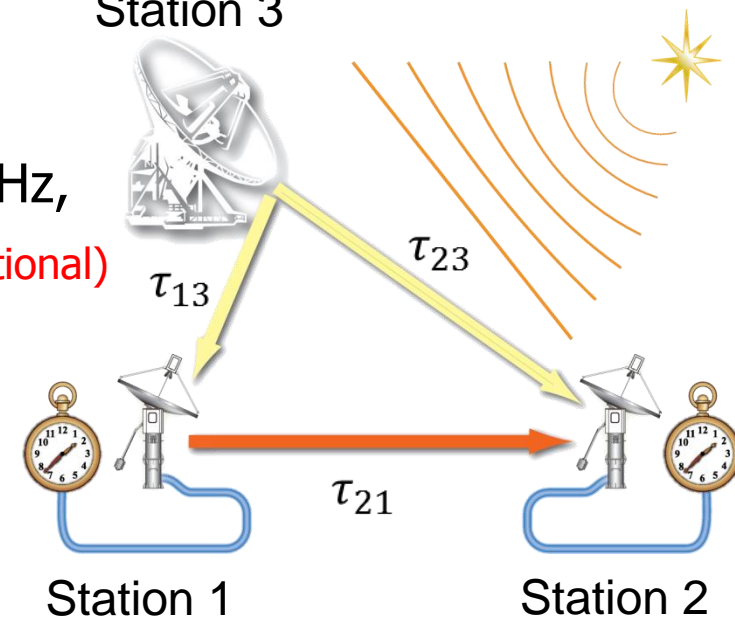
B: 16MHz \rightarrow 1024MHz (64 times)

- Obs. Freq. : **3-14GHz** Freq. Range
- Observation: **4 band (1024MHz)**
 - Fc = 4.0GHz, 5.6GHz, 10.4GHz, 13.6GHz,
 - **Effective BW: 3.8GHz (10 times of conventional)**



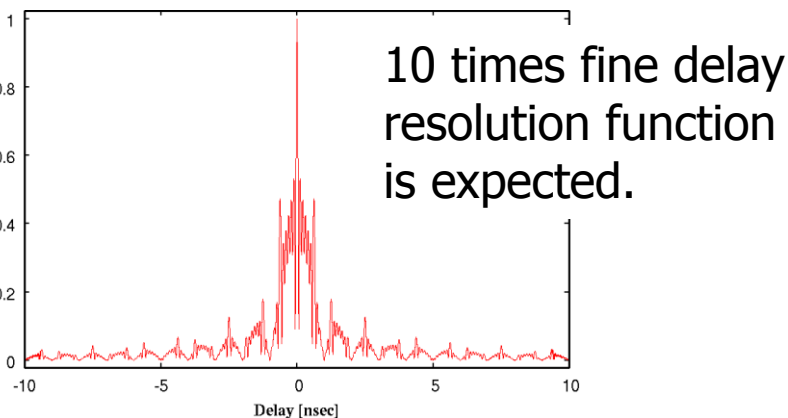
Combination of Small and Large Diameter antennas

Station 3



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

Delay observable of Baseline 1-2 is obtained from 1-3 and 2-3 baseline data.



Developments of New Technologies for the Gala-V system

Target Precision: 30 ps -> 7 ps

Broadband observation

Broadband Feed Design

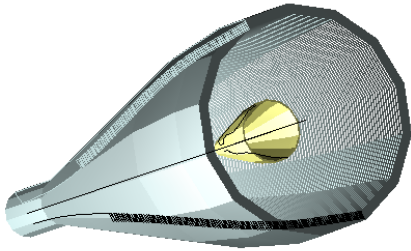


Image of 'Iguana' feed

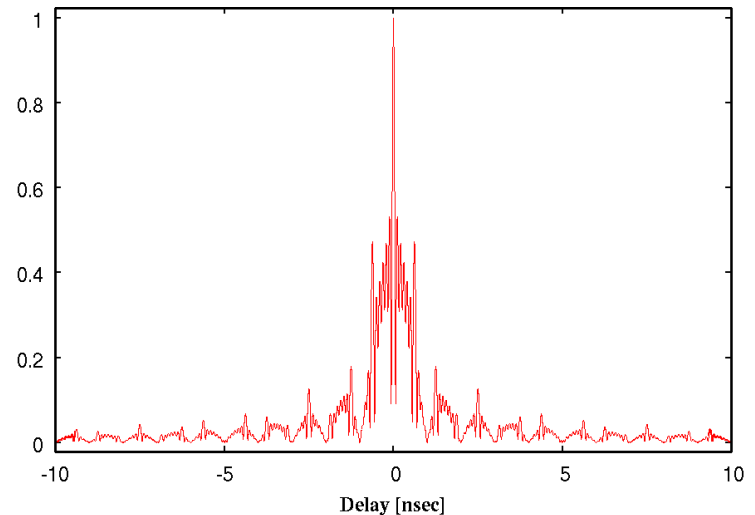
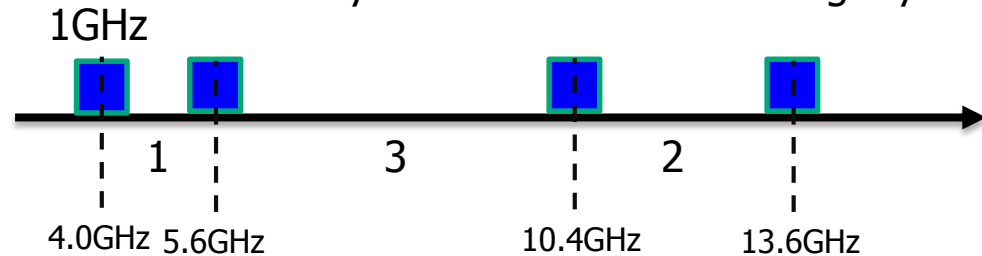
Direct RF Sampling



High speed sampler (16GHz) GALAS

**Bandwidth Synthesis for
10 times wider frequency range**

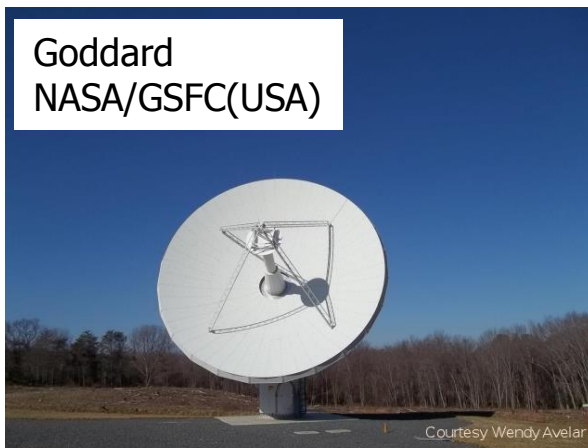
- Zero redundancy Array for 4 channels.
- Fine Delay resolution without ambiguity.



VLBI2010 Global Observing System VGOS(Next generation Geodetic VLBI)



- Radio Frequency: 2-14GHz
- Antenna Slew Speed: (>3 deg/sec)
- Target Accuracy: 1 mm

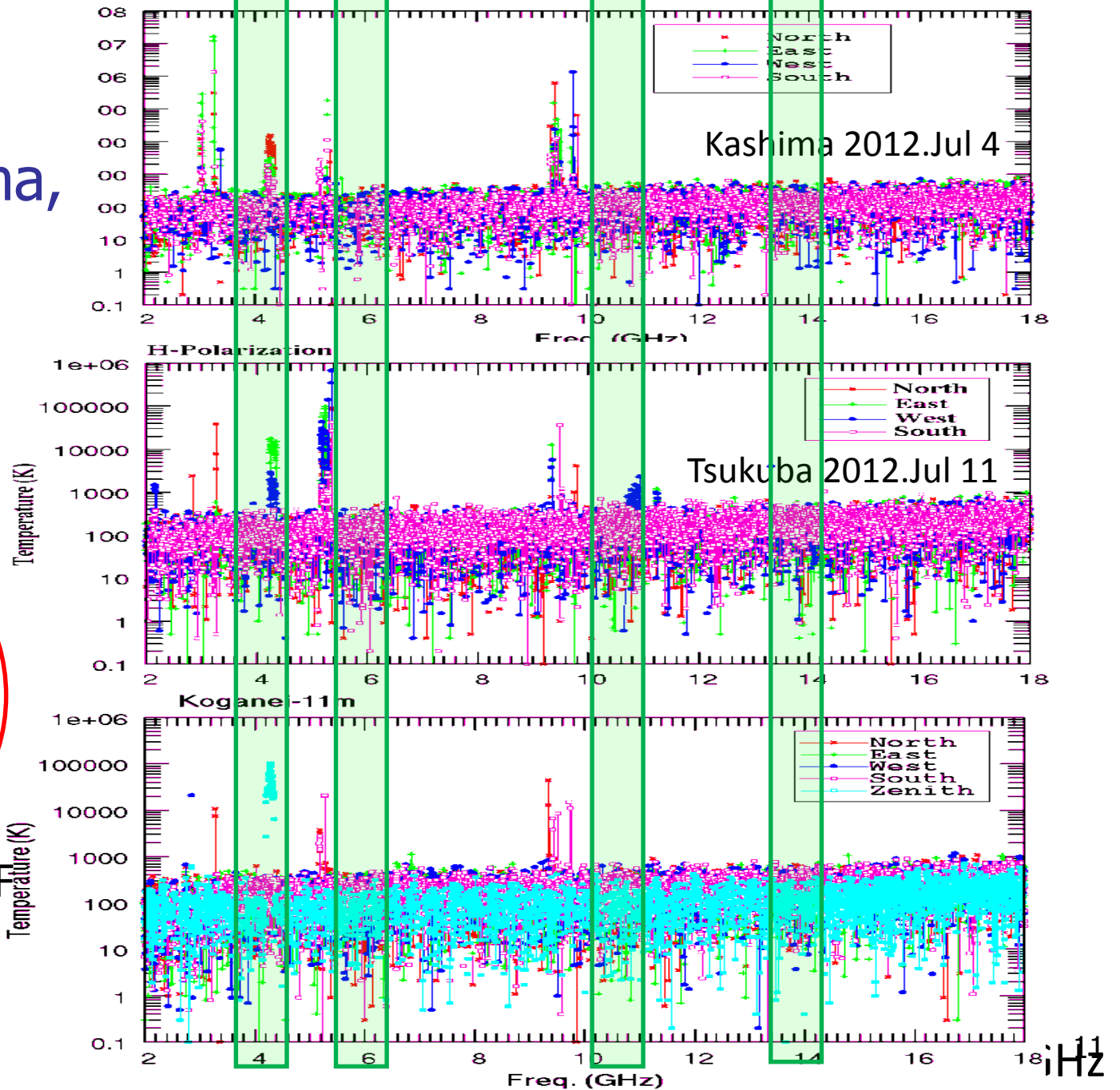


RFI 調査

2-18GHz at Tokyo, Kashima, and Tsukuba



With 3.5GHz HPF
before LNA



1.6/1.5m and 34m VLBI antenna



1.5m compact antenna



Kashima 34m antenna

- VLBI2010 仕様に 部分準拠
 - 1 GHz x 4 band 3-15GHz Frequency Range

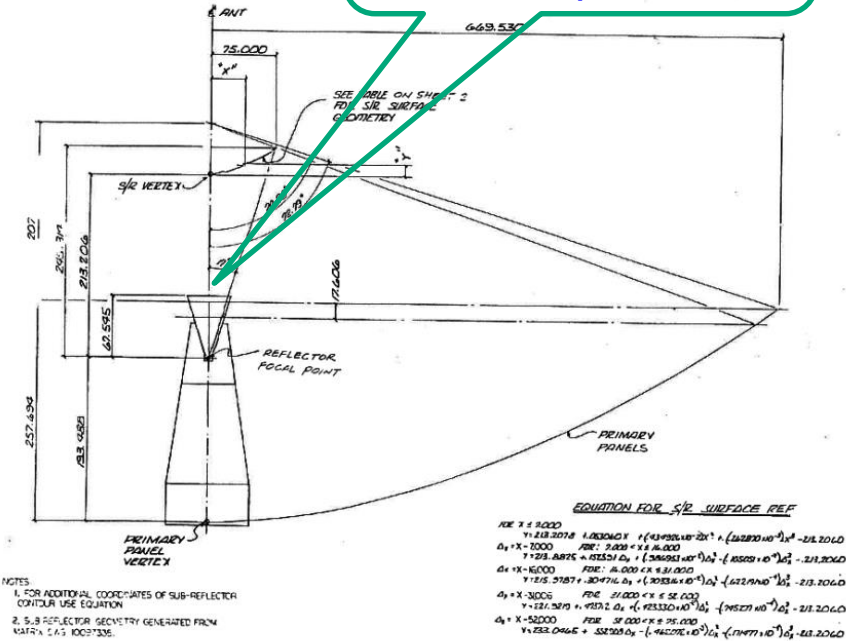


“Iguana” Feed

Requirement:

- 35 deg. Beam width over the wide frequency range.

Wideband prototype feed designed by Dr. Ujihara has been installed to Kashima 34m with room temp. LNA at the end of 2013.



This feed has sensitivity at 6.4-14GHz range at present. Upgraded feed with 2.2-18GHz Freq. range is intended.

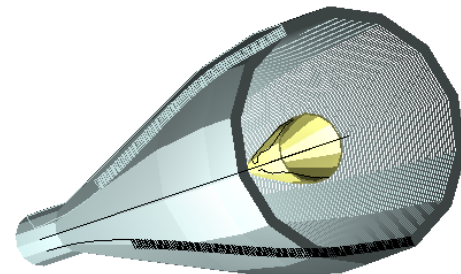
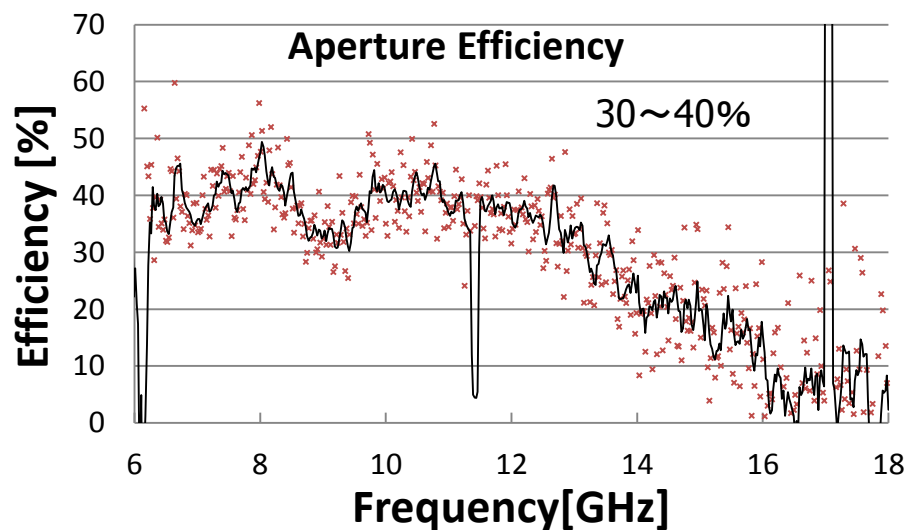
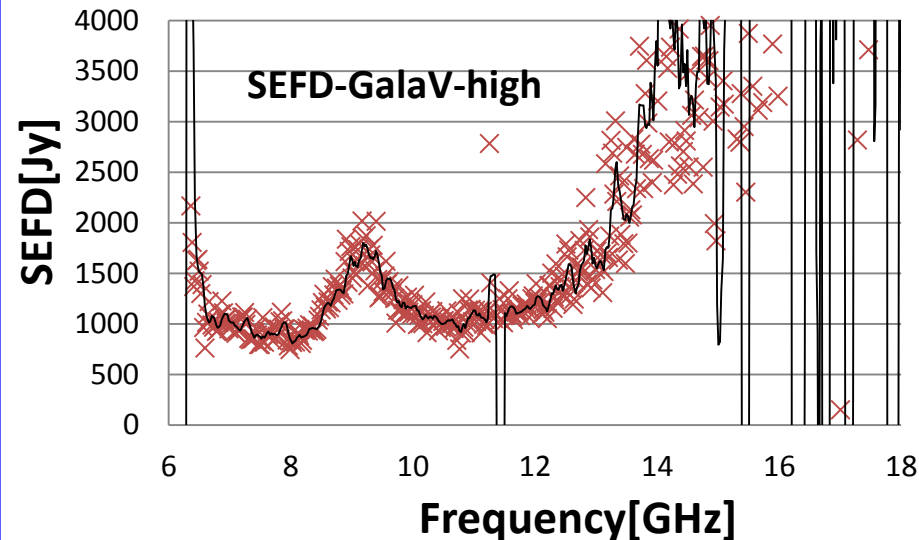
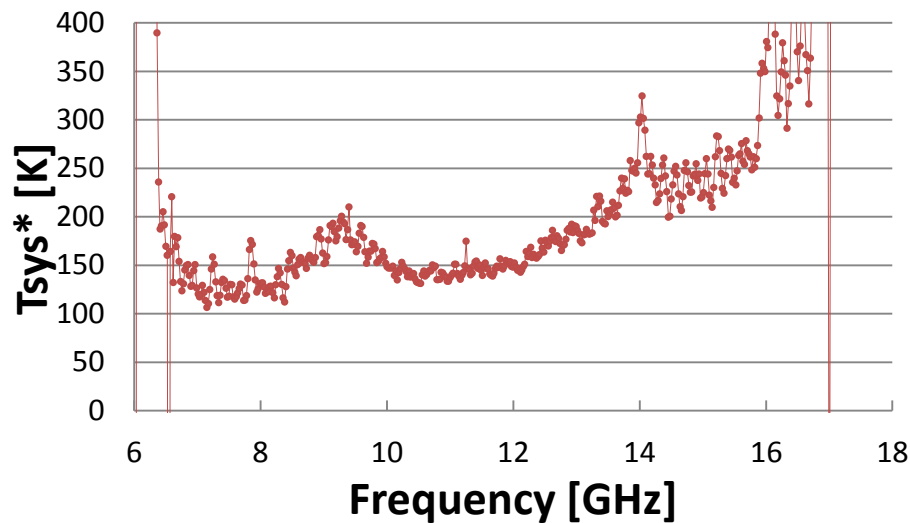


Image of 'Iguana' wideband feed

Performance of the Prototype broadband Feed

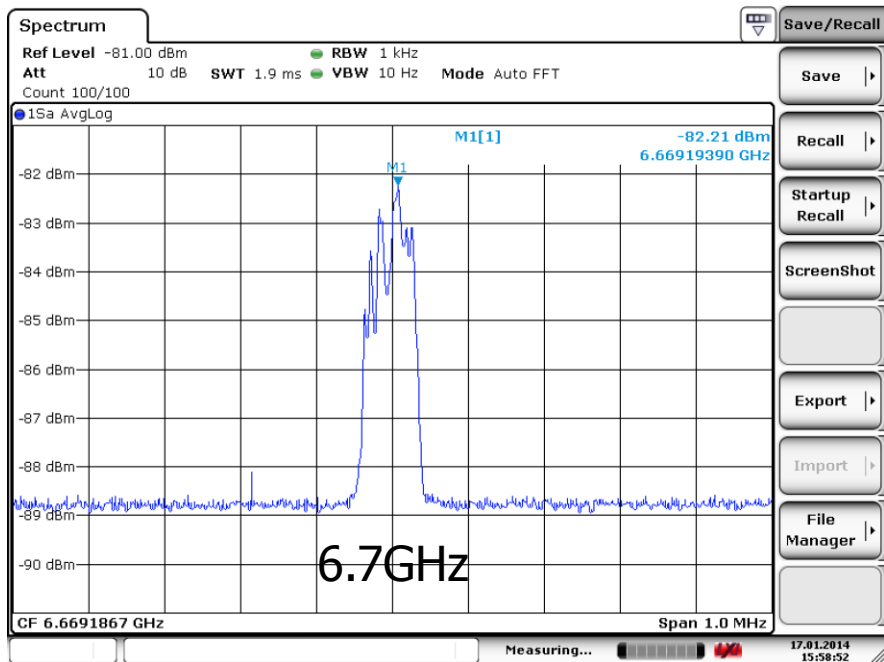




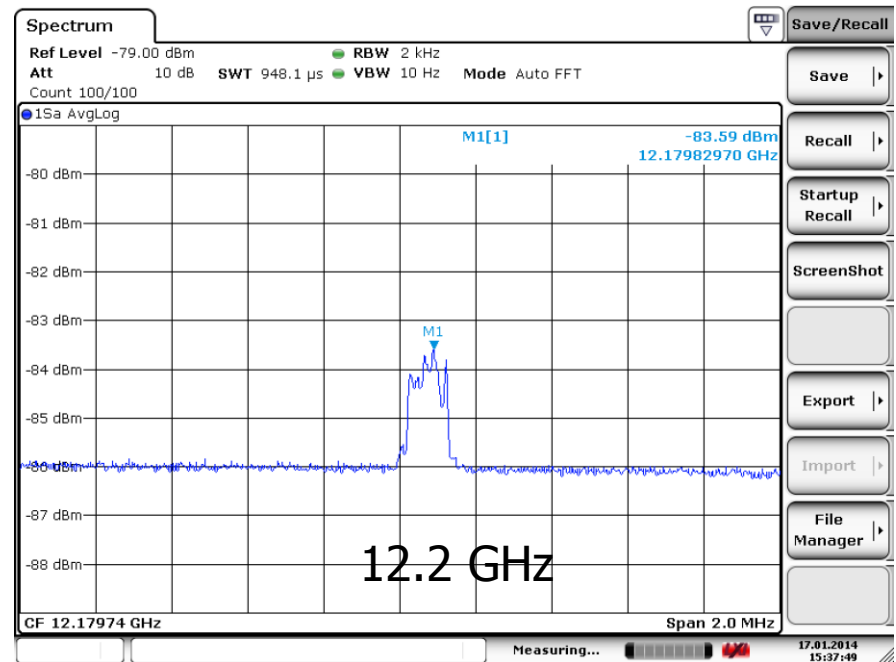
Methanol Maser



- Simultaneous Observation of Methanol Maser line at 6.7GHz and 12.2GHz on W3OH for test observation (first light) on 16 Jan.2014.

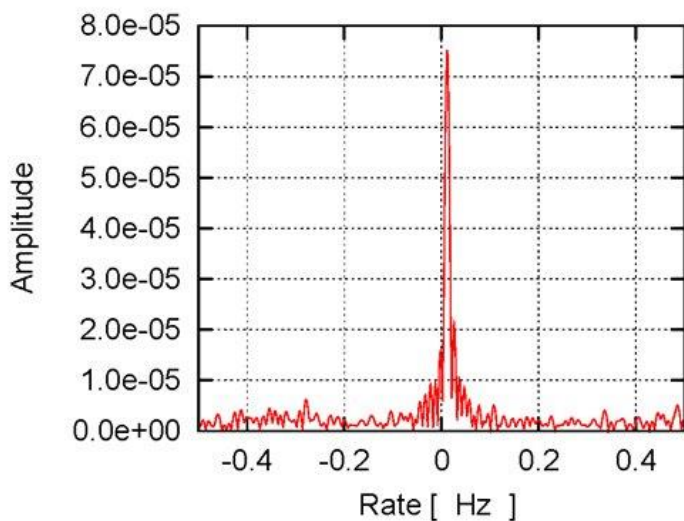
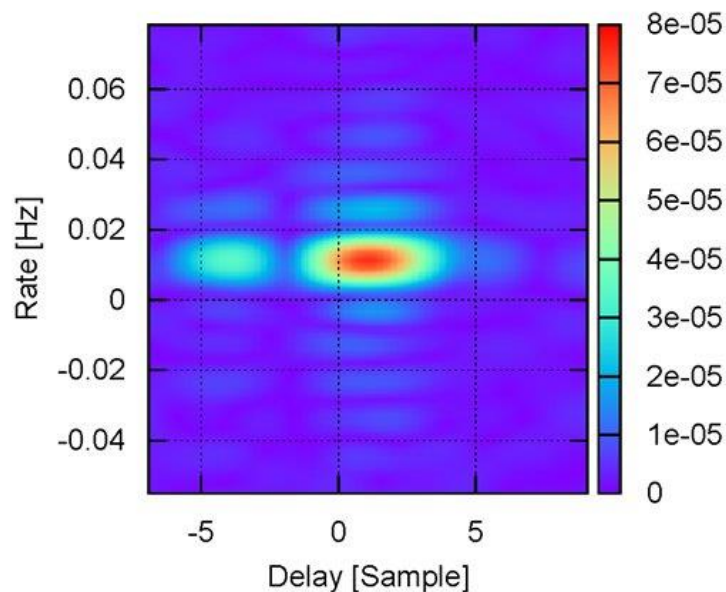
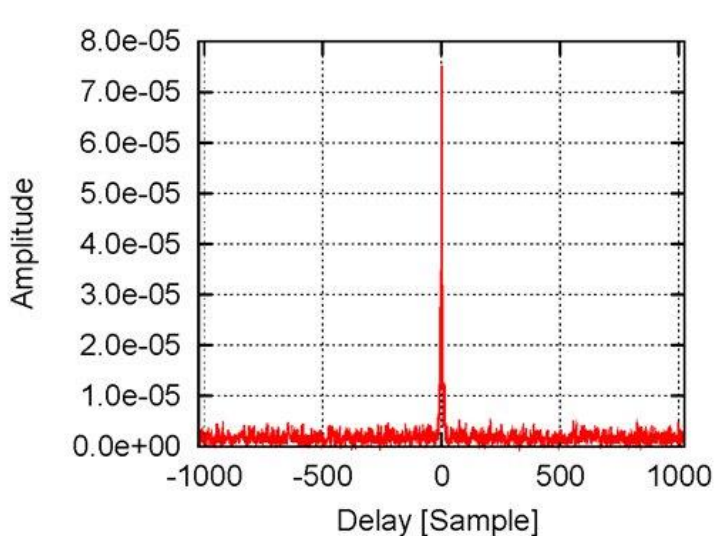


Date: 17.JAN.2014 15:58:51



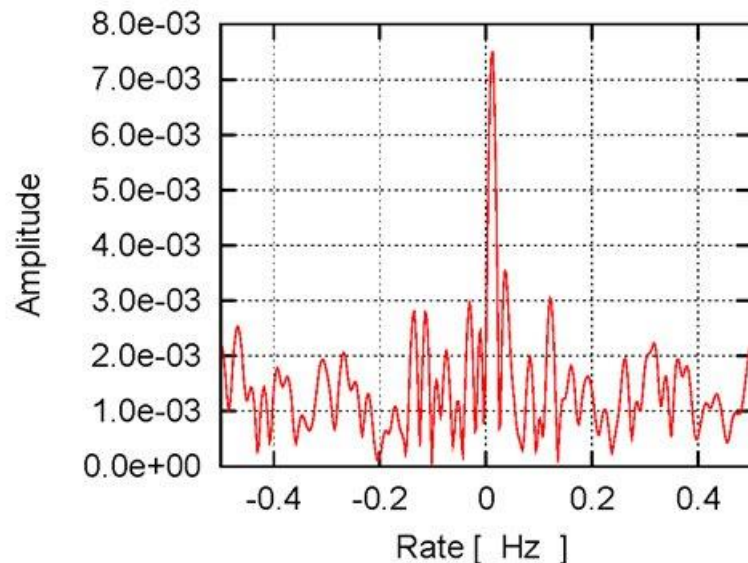
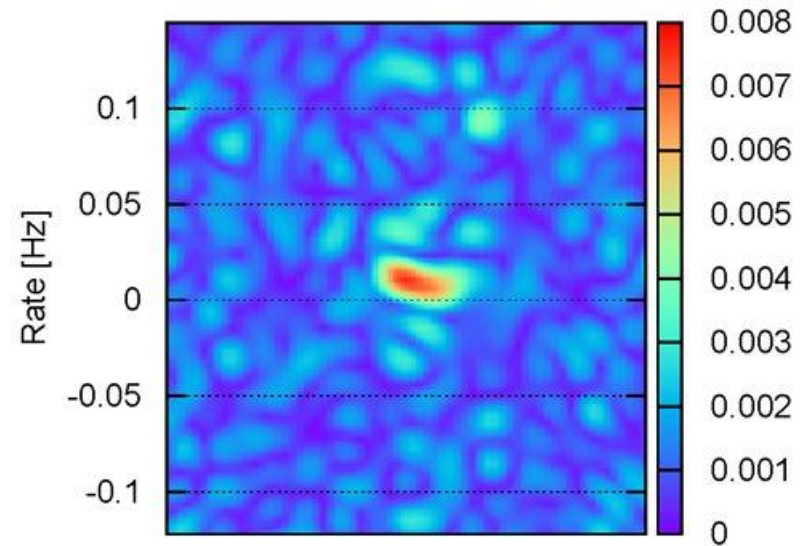
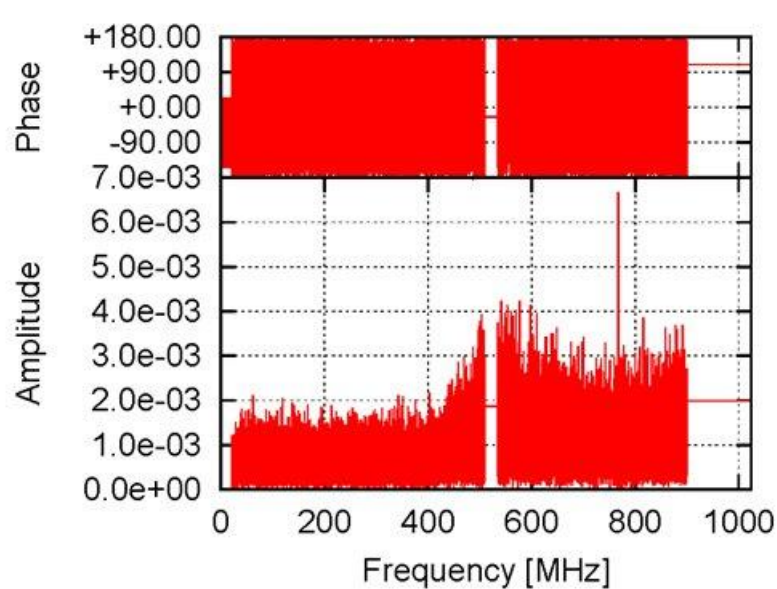
Date: 17.JAN.2014 15:37:49

Kas34-Mbl1 (12GHz:512MHz) 3C273B



```
Epoch      : 2014/281 06:10:00
Station-1  : kas34
Station-2  : mbl1
Source     : 3C273B
Length     : 120.000000 [sec]
Sampling   : 2048000000 [sps]
Frequency  : +11414.000000 [MHz]
Peak Amp   : 0.007527 [%]
Peak Phs   : 47.832690 [deg]
Delay      : +1.085587 [spl]
Rate       : +11.651866 [mHz]
SNR        : 42.662682
```

Kas34-Mbl1 W3OH (12.181GHz)

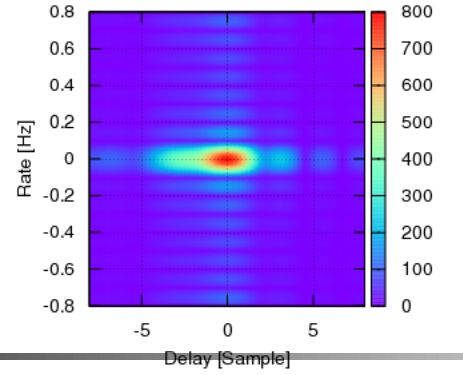
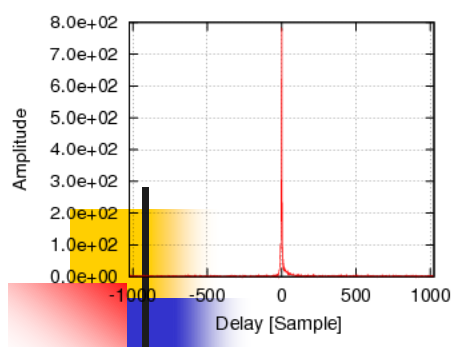


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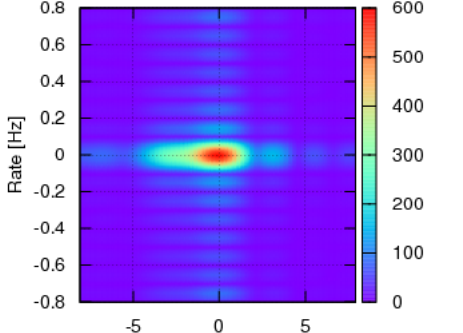
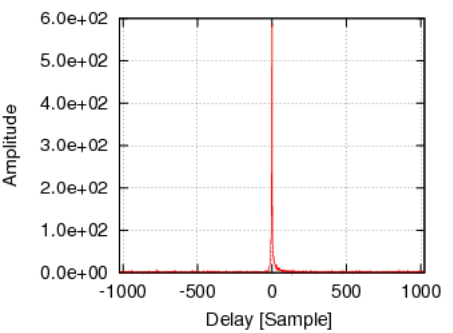
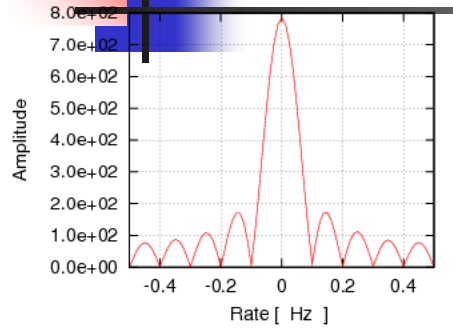
Epoch      : 2014/281 06:23:00
Station-1  : kas34
Station-2  : mbl1
Source     : w3oh
Length     : 60.000000 [sec]
Sampling   : 2048000000 [sps]
Frequency  : +11414.000000 [MHz]
Peak Amp   : 0.755263 [%]
Peak Phs   : 96.430956 [deg]
Peak Freq  : +767.138633 [MHz]
Rate       : +11.454010 [mHz]
SNR        : 16.599317
    
```

First Fringes with VERA (6.7GHz)

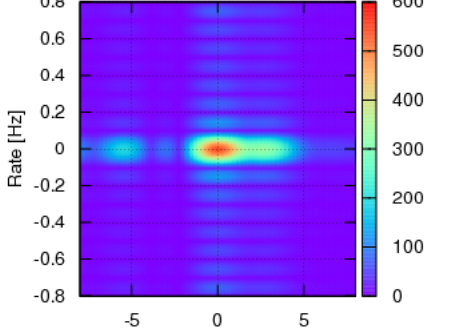
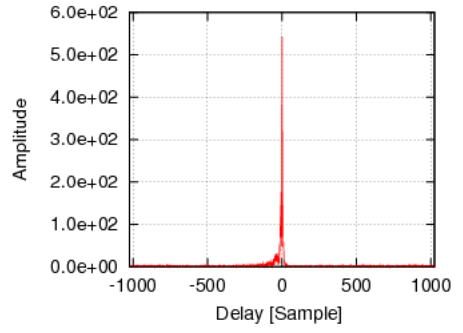
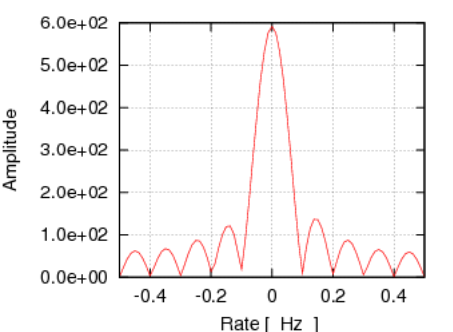
Observation on 1st-2nd Oct. 2014



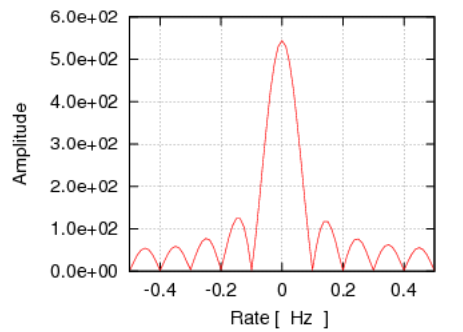
```
Epoch      : 2014/274 12:50:00
Station-1  : KASHIM34
Station-2  : ISHIGAKI
Source     : 3C84
Length    : 10.000000 [sec]
Sampling  : 1024000000 [sps]
Frequency : +6408.000000 [MHz]
Peak Amp  : 78367.191596 [%]
Peak Phs  : 61.470817 [deg]
Delay     : -0.025192 [spl]
Rate      : +0.160217 [mHz]
SNR       : 429.267698
```



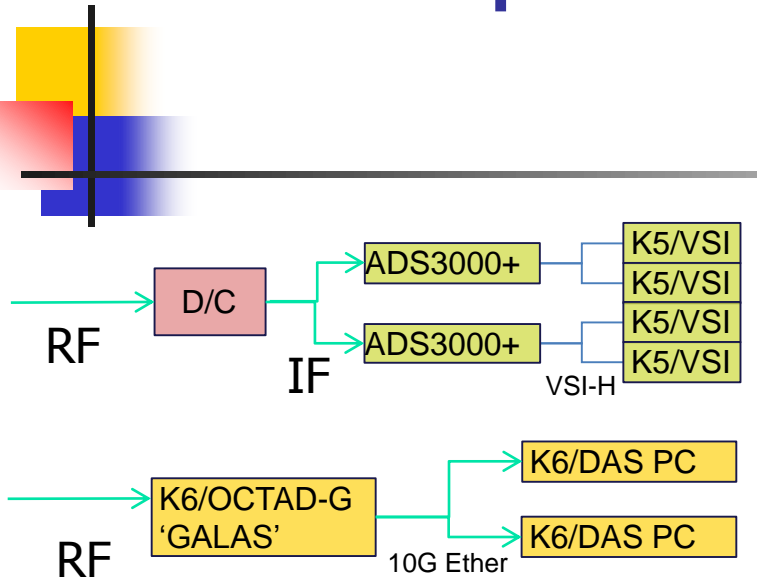
```
Epoch      : 2014/274 12:50:00
Station-1  : KASHIM34
Station-2  : OGASA20
Source     : 3C84
Length    : 10.000000 [sec]
Sampling  : 1024000000 [sps]
Frequency : +6408.000000 [MHz]
Peak Amp  : 59136.762216 [%]
Peak Phs  : 48.150952 [deg]
Delay     : -0.084427 [spl]
Rate      : -0.064087 [mHz]
SNR       : 344.224222
```



```
Epoch      : 2014/274 12:50:00
Station-1  : MIZNAO20
Station-2  : KASHIM34
Source     : 3C84
Length    : 10.000000 [sec]
Sampling  : 1024000000 [sps]
Frequency : +6408.000000 [MHz]
Peak Amp  : 54394.542049 [%]
Peak Phs  : -170.898469 [deg]
Delay     : +0.000397 [spl]
Rate      : +0.001526 [mHz]
SNR       : 313.880318
```



Data Acquisition: 1GHz x 4 Ch

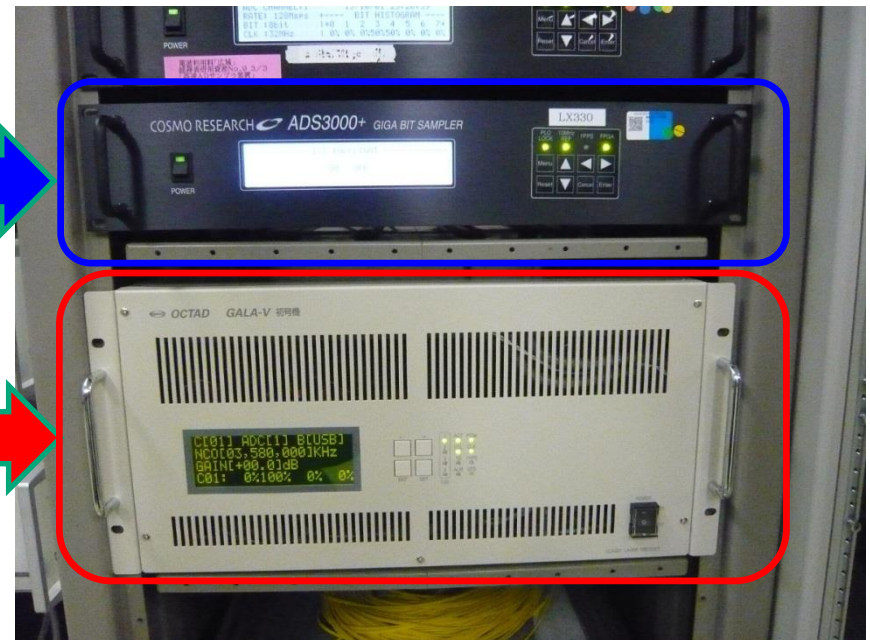
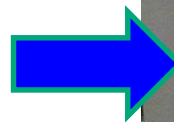


Two Approaches

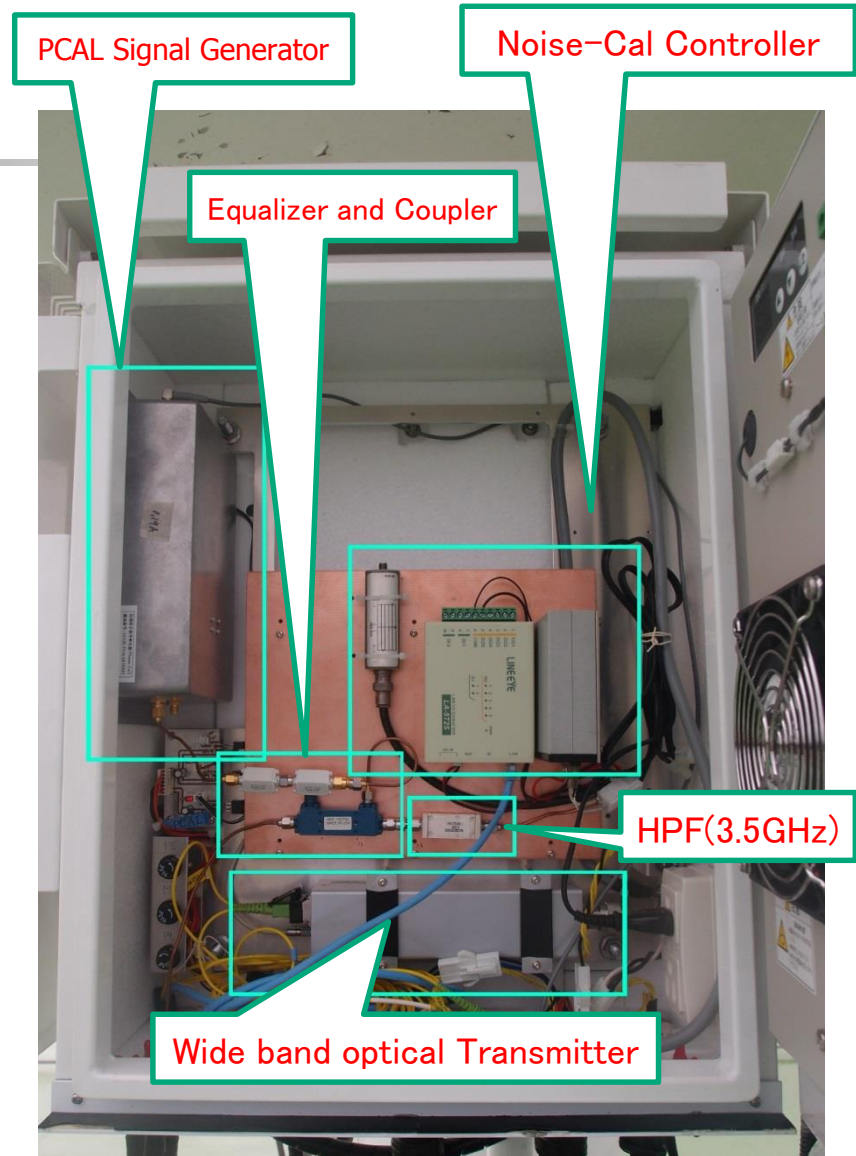
1. Analog Down Converter + “ADS3000+”
 - Digital BBC function for legacy mode observation.
2. Direct Sampler “GALAS”
 - Digital Down Conversion function for any frequency by 1MHz step.

ADS3000+ Sampler
DBBC or 1-2 Gbps

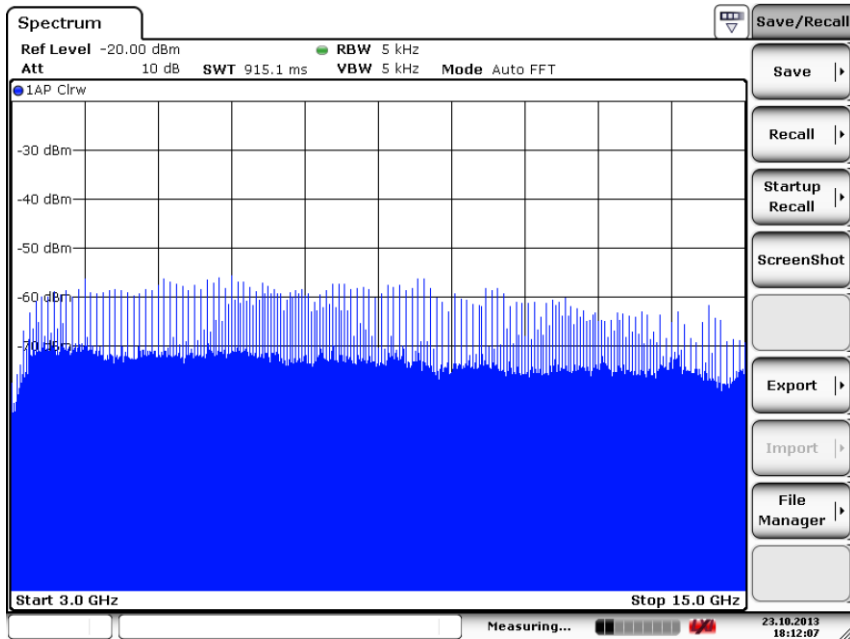
Direct Sampler
K6/OCTAD-G
code name=“GALAS”
DBBC(BW=1024MHz)



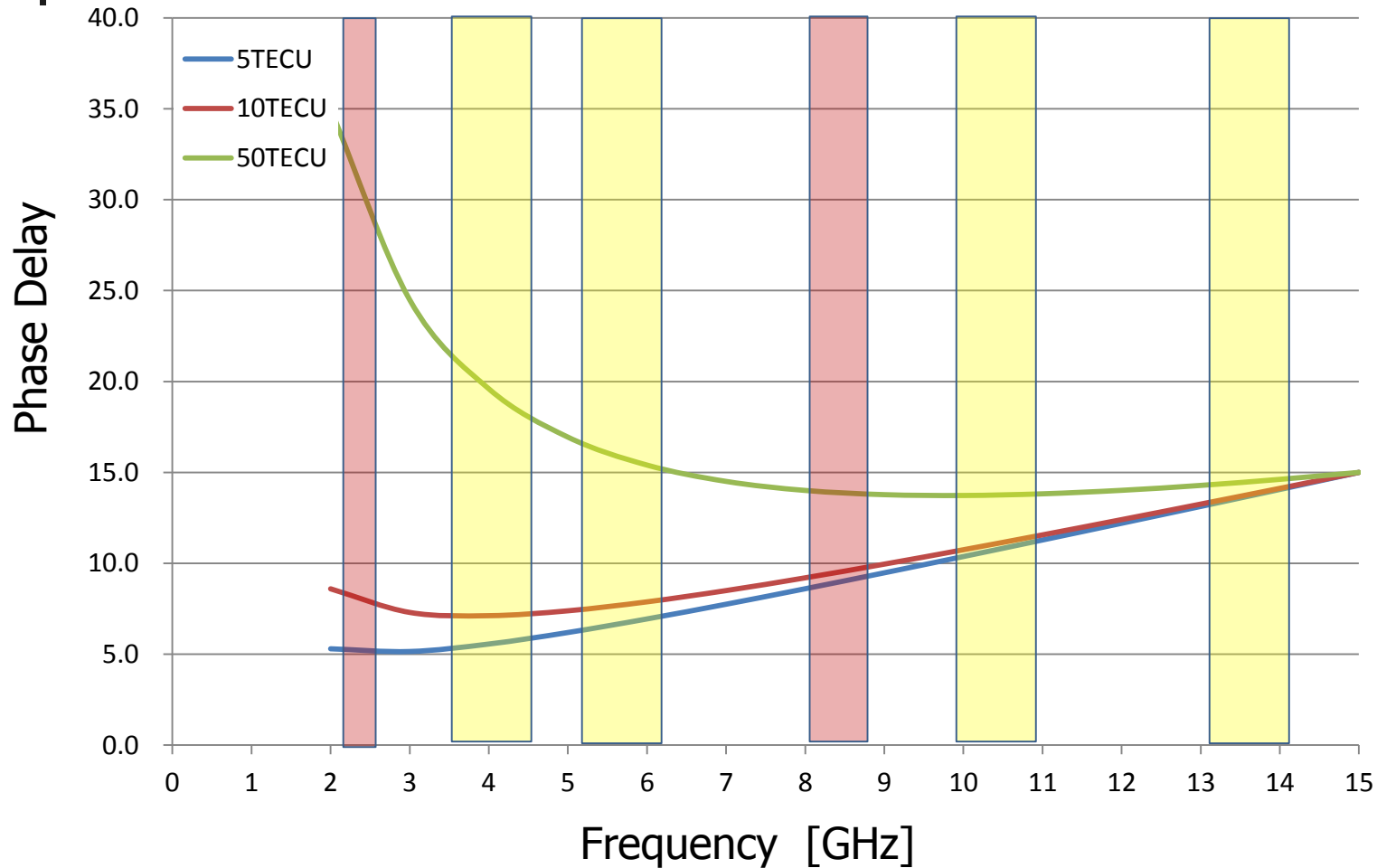
RF-Box of MARBLE small antenna



Monitoring at Observation Room
(3-15GHz). RBW=5kHz



Observation Frequency Band & Ionosphere Delay Contribution



Ready for Observation

KASHIMA 34m



34m Antenna NICT Kashima

MARBLE2



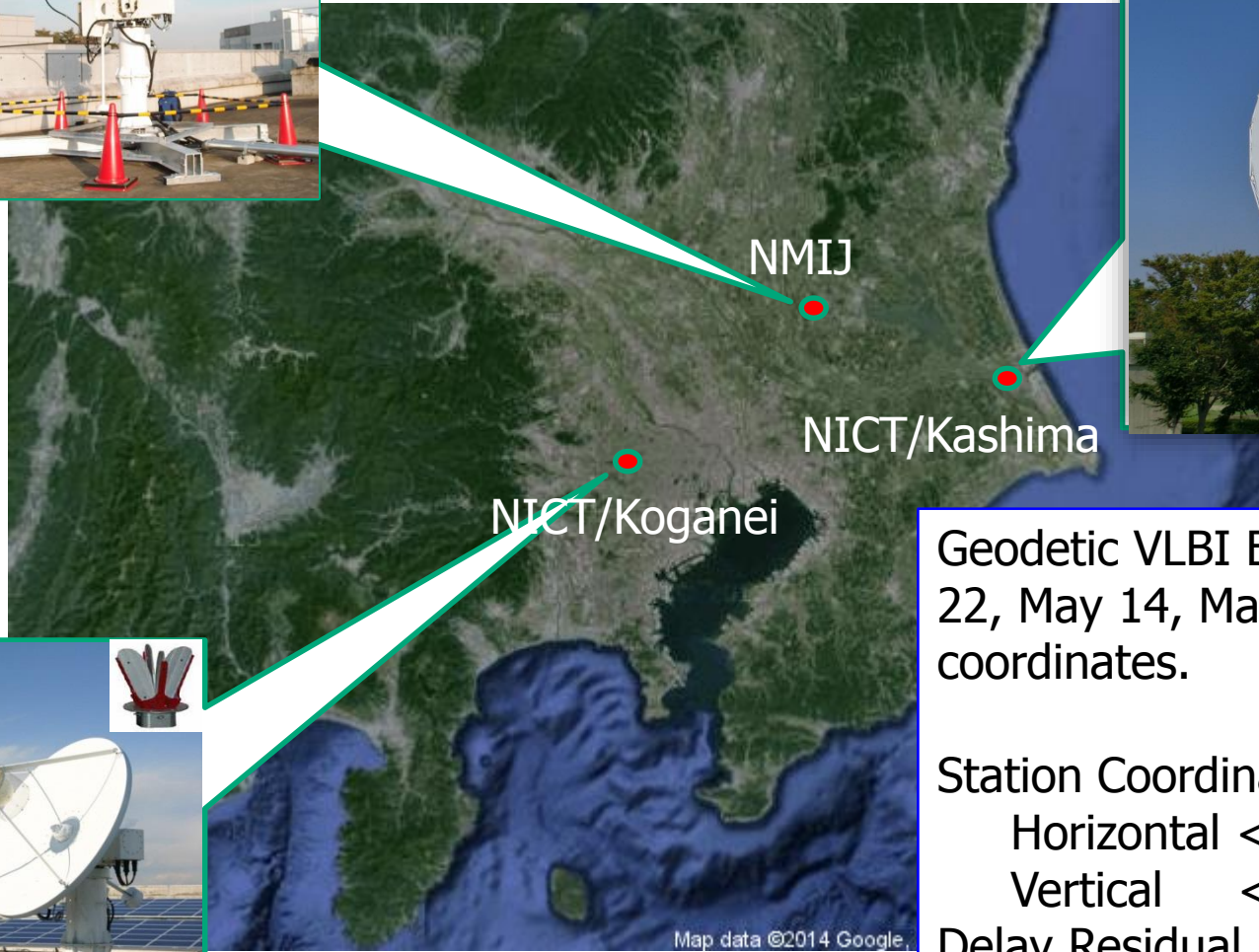
**1.5m Antenna
NICT Koganei**

MARBLE1



**1.6m Antenna
NMIJ Tsukuba**

1.6m/1.5m and 34m VLBI antennas have been installed for T&F.



Geodetic VLBI Experiments on Apr. 22, May 14, May 30 to fix station coordinates.

Station Coordinates Repeatability:
Horizontal < 6mm
Vertical < 15mm

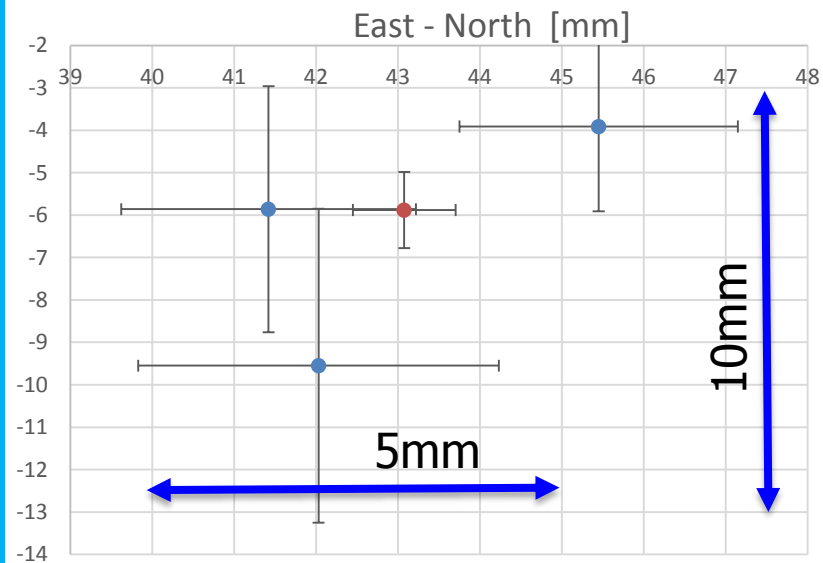
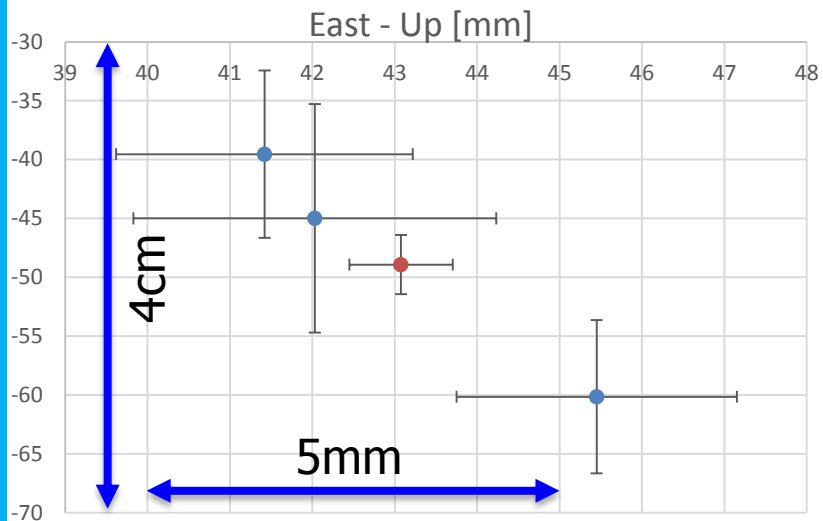
Delay Residual
WRMS is about 35 psec@30sec.

Geodetic VLBI Observation

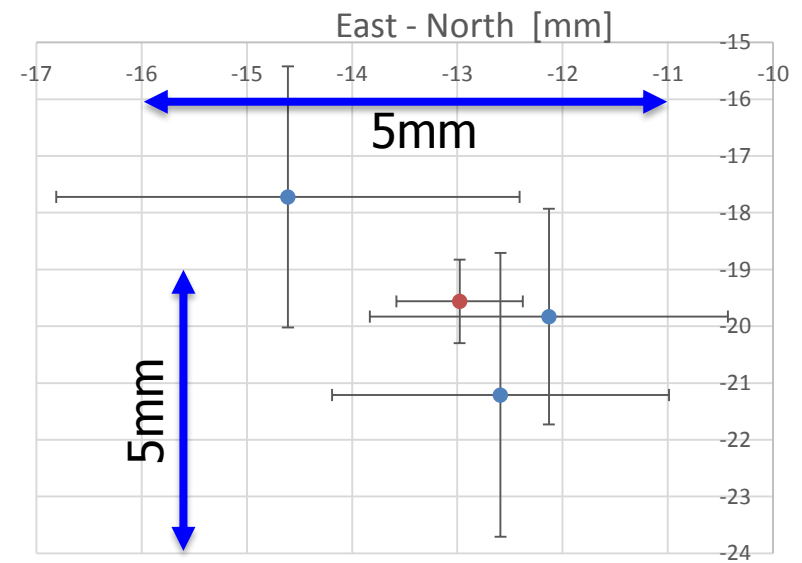
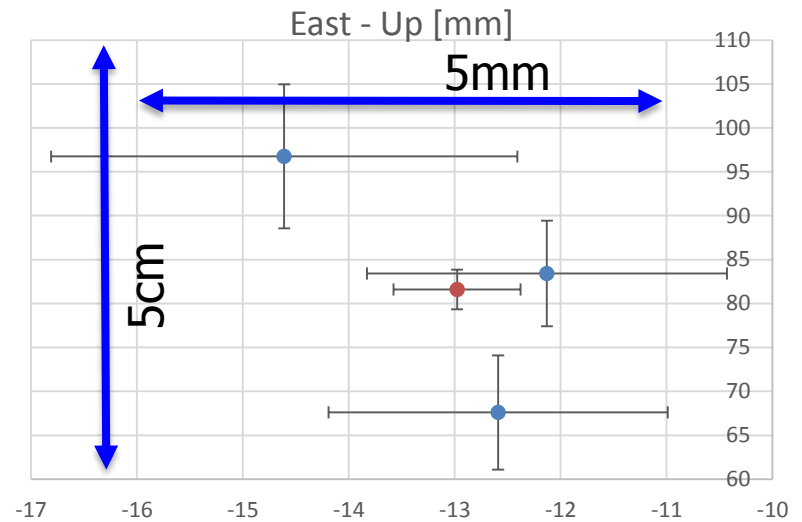
- Stations:
 - Kashima(34m),Tsukuba(1.6m),Koganei(1.5m)
- Radio Frequency:
 - X-band: 8080-9080MHz, Bandwidth: 1GHz
- Experiments:
 - Gx14112: 2014. Apr. 22-23 24 hours.
 - Gx14134: 2014. May 14-15 24 hours.
 - GX14150: 2014. May 30-31 24 hours.

Geodetic Observation in April-May

MARBLE1(NMIJ,Tsukuba)



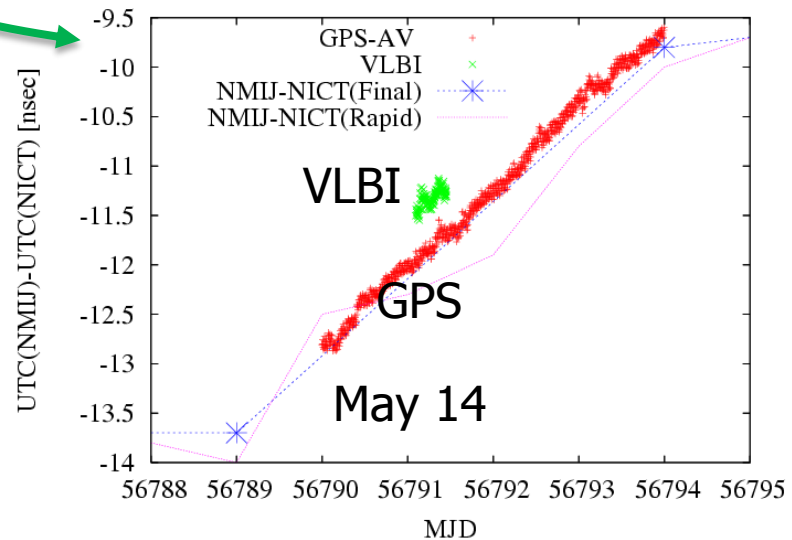
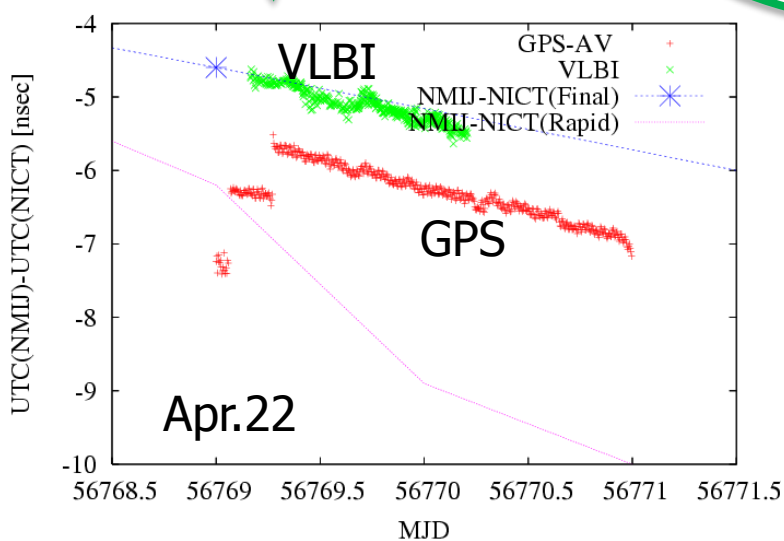
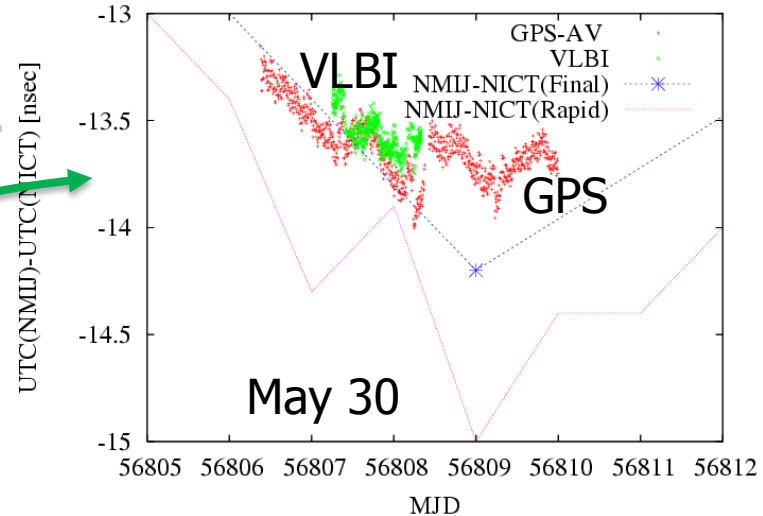
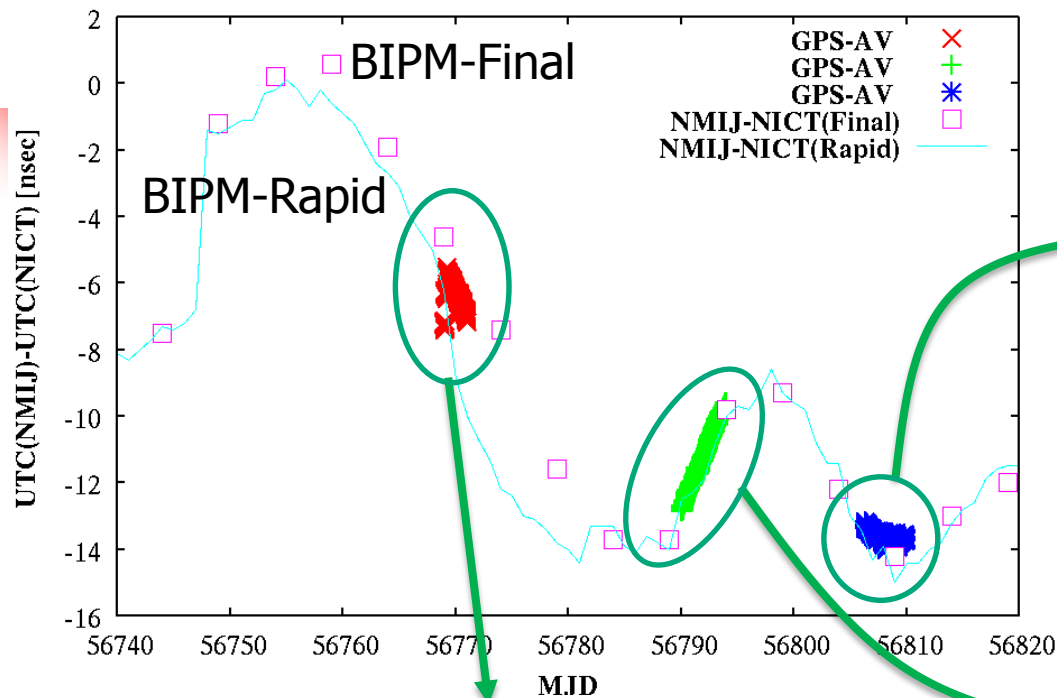
MARBLE2(NICT,Koganei)



Clock Estimation

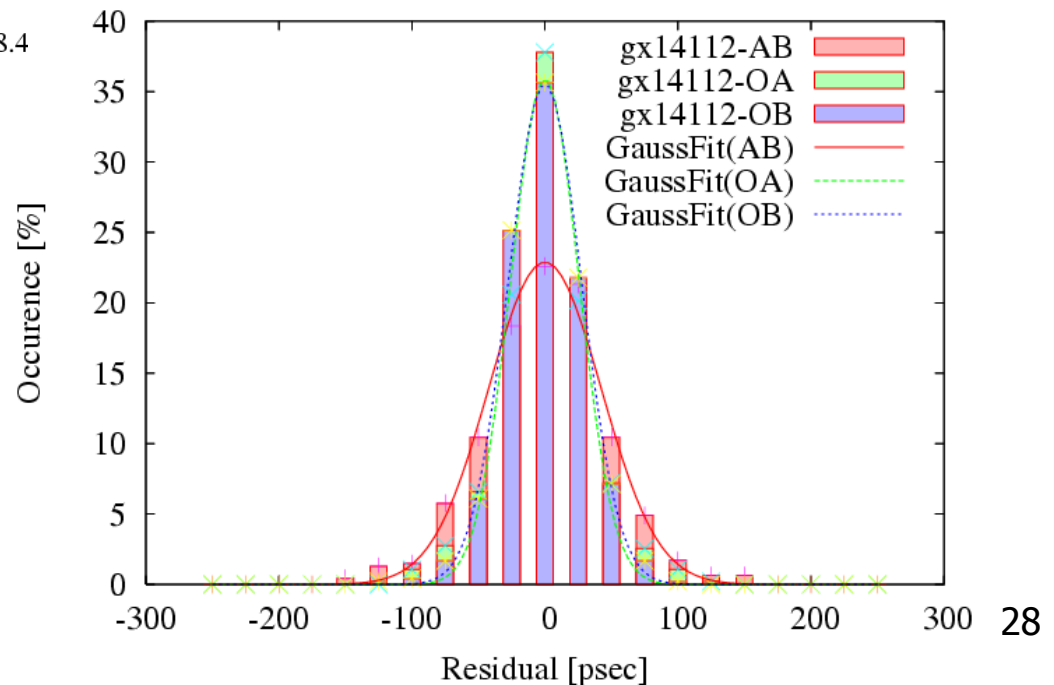
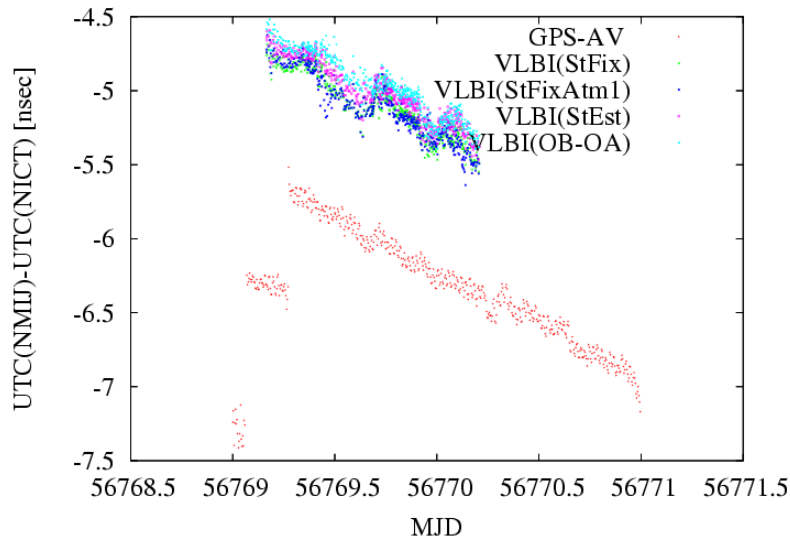
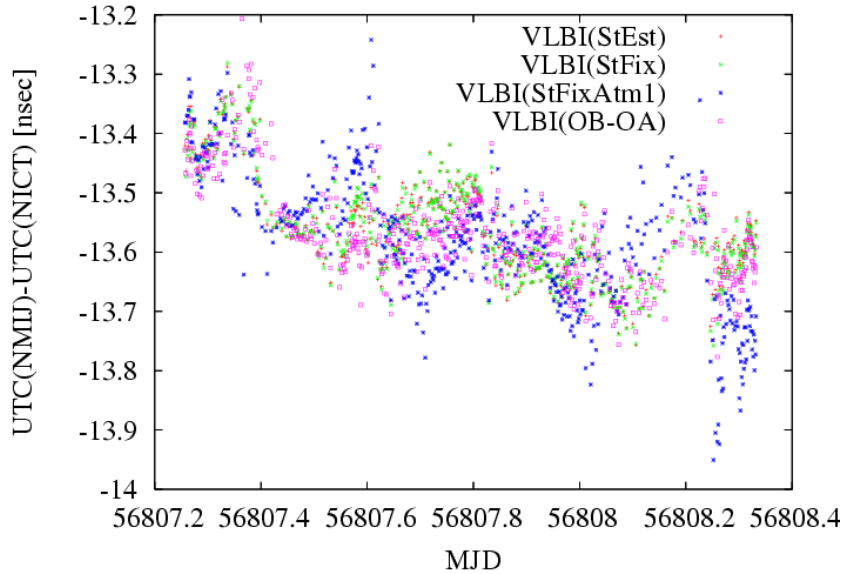
- Stations:
 - Kashima(34m),Tsukuba(1.6m),Koganei(1.5m)
- Experiments:
 - Gx14112: 2014. Apr. 22-23 24 hours.
 - Gx14134: 2014. May 14-15 24 hours.
 - GX14150: 2014. May 30-31 24 hours.
- Analysis:
 - OA,OB->AB baseline data conversion
 - $\tau_{21} = \tau_{31} - \tau_{32} - \dot{\tau}_{21} \times \tau_{32}$

Time comparison Analysis



Clock Estimation from VLBI data

- Clock parameters seems is stable against changes of analysis conditions.
- Error of AB baseline data composed from OA,OB data increased by $\sqrt{2}$ as expected.





Nest steps to be done

- Long span VLBI observations for frequency comparison
- Broadband Observations
 - Domestic: Kashima34, Marble1, Marble2
 - Geodetic, Time transfer experiments
 - International: We are planning to perform intercontinental broadband observation with MIT/Haystack.
- Target precision:



Acknowledgements

- Broadband Feed Development is supported by NAOJ-fund(Prof. Fujisawa et al.)
- Gala-V Experiments is supported by
 - NMIJ:(Dr.Watabe, Dr.Amemiya, Dr.Suzuyama)



Thank you for Attention!

AB Baseline Data

