Development of Broadband VLBI System

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East Asia VLBI Netwrok Workshop 2015@Sapporo

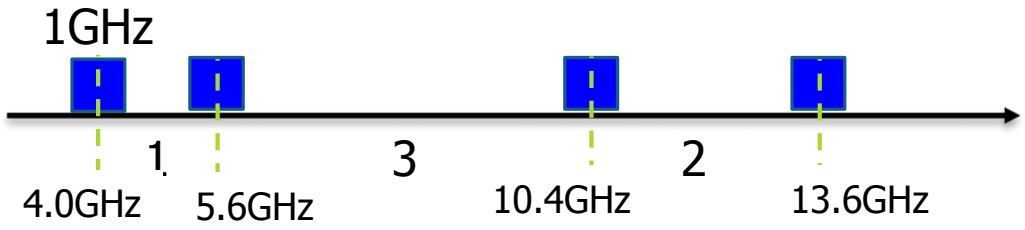
Gala－V Project Overview

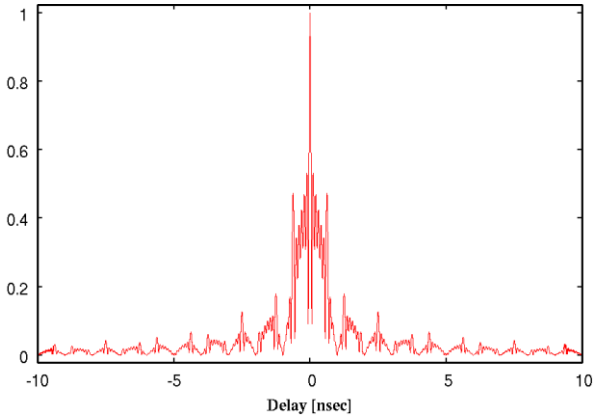
Distant Frequency Comparison with Transportable Broadband telescopes

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

  B: 16MHz → 1024MHz (64 times)

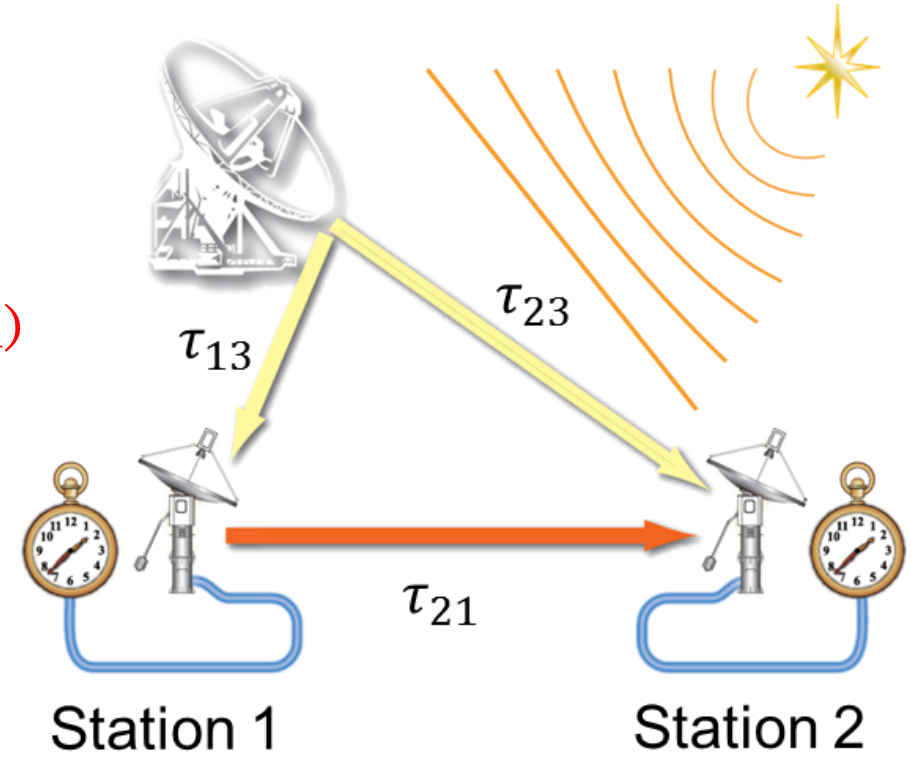
- Radio Frequency： 3－14GHz
- Data Acquisition： 4 band（1024MHz width）
  - Fc＝4. 0GHz、5. 6GHz、10. 4GHz、13. 6GHz
  - Effective Bandwidth：3. 8GHz（10 times of Conventional）





Delay Resolution Function

10 time higher resolution will be gained by broader bandwidth



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

VGOS(Next Generation Geodetic VLBI System) Promoted by IVS

* What is VGOS?
  * System：Broadband(2-14GHz), Fast Slew antenna
  * Targeting precision：1 mm
  * Progress of Stations ：USA, Germany, Spain, Japan, Russia, Australia, Sweden, Norway, China, …
* Japanese VGOS station at Ishioka GSI.
  * Completed First fringe in 2014
* Original Broadband VLBI Development by NICT

OUTLINE

1. VGOS Compatible broadband VLBI System Development
   1. Original Broadband Feed for Cassegrain Antenna(IGUANA-H: 6.5-15GHz, NINJA:3.2-14.4GHz)
   2. Direct Sampling technique with high speed sampler K6/GALAS

2. Broadband Experiments in 2015
   1. Westford, GGAO -- Kashima34
      * International exp. with broadband feed on 20 Jan. 2015
   2. Kashima34 – Ishioka 13
      * 6-14GHz Broadband observation 8GHz bandwidth, 16 Jan. 2015

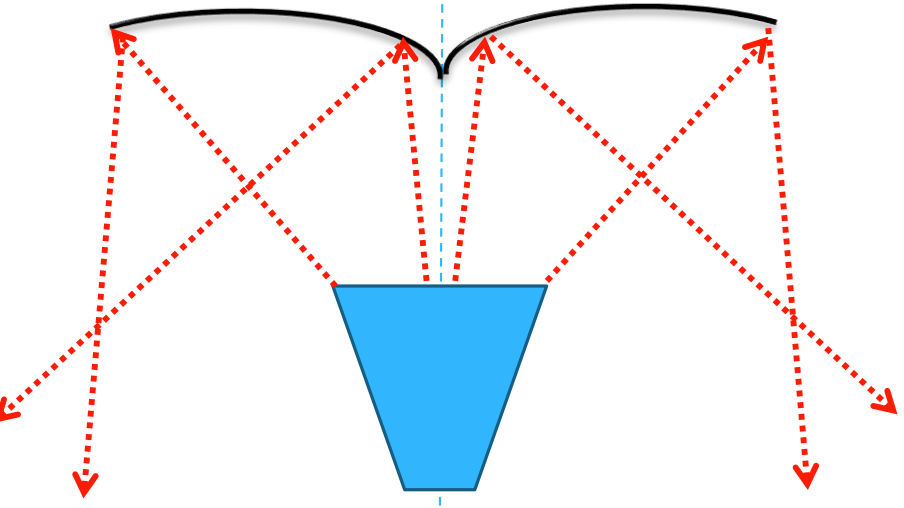
World First

3. Advantage of Direct Sampling

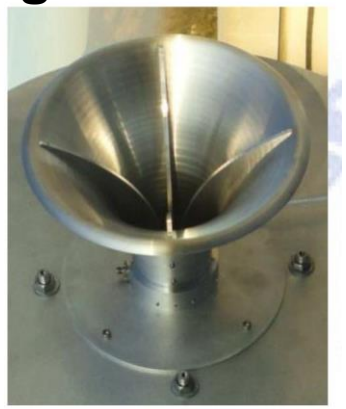
Developments

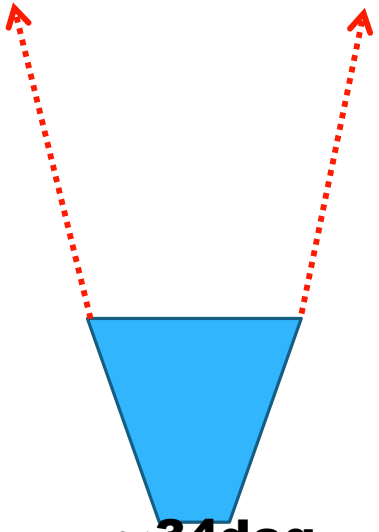
NICT Development of Broadband Feed

Requirement of
Broadband Frequency and
Narrow beam width

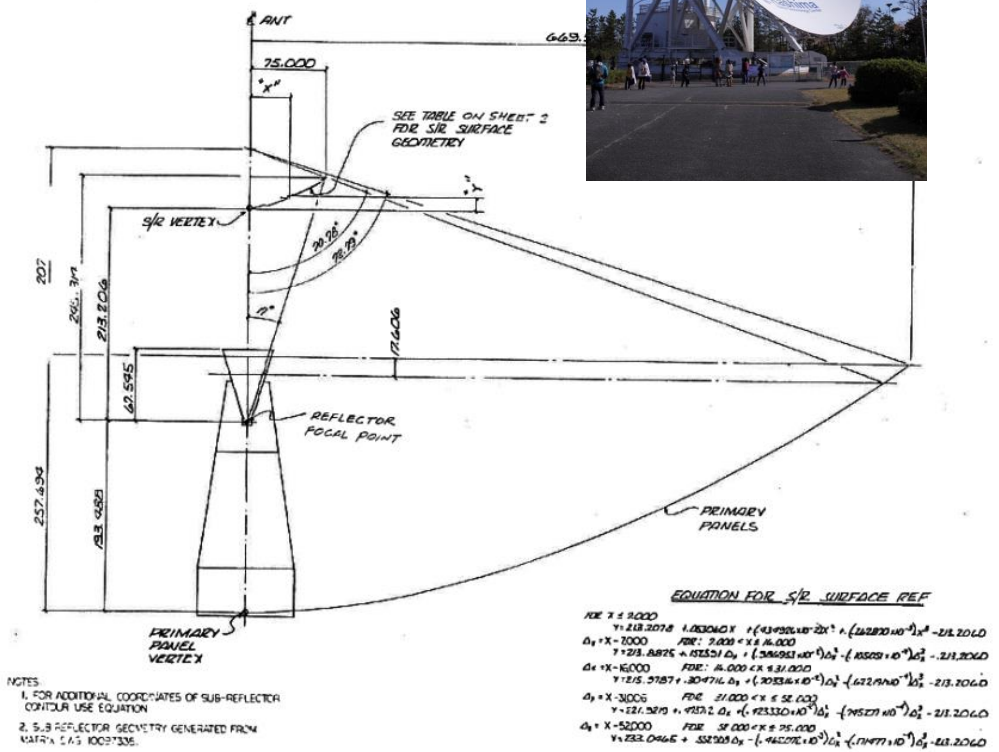


~120deg.

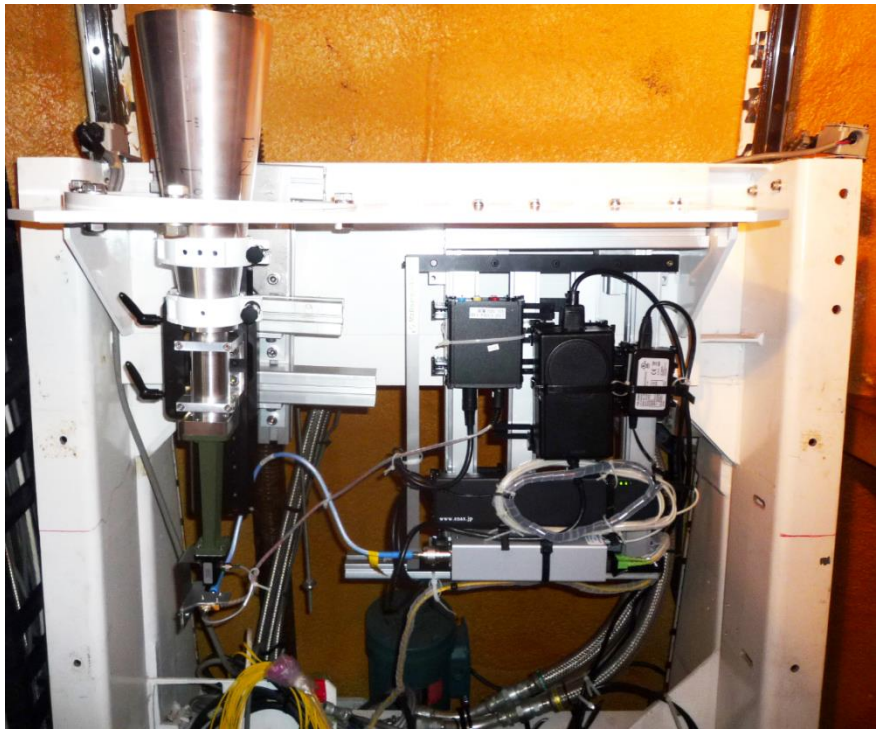




~34deg.



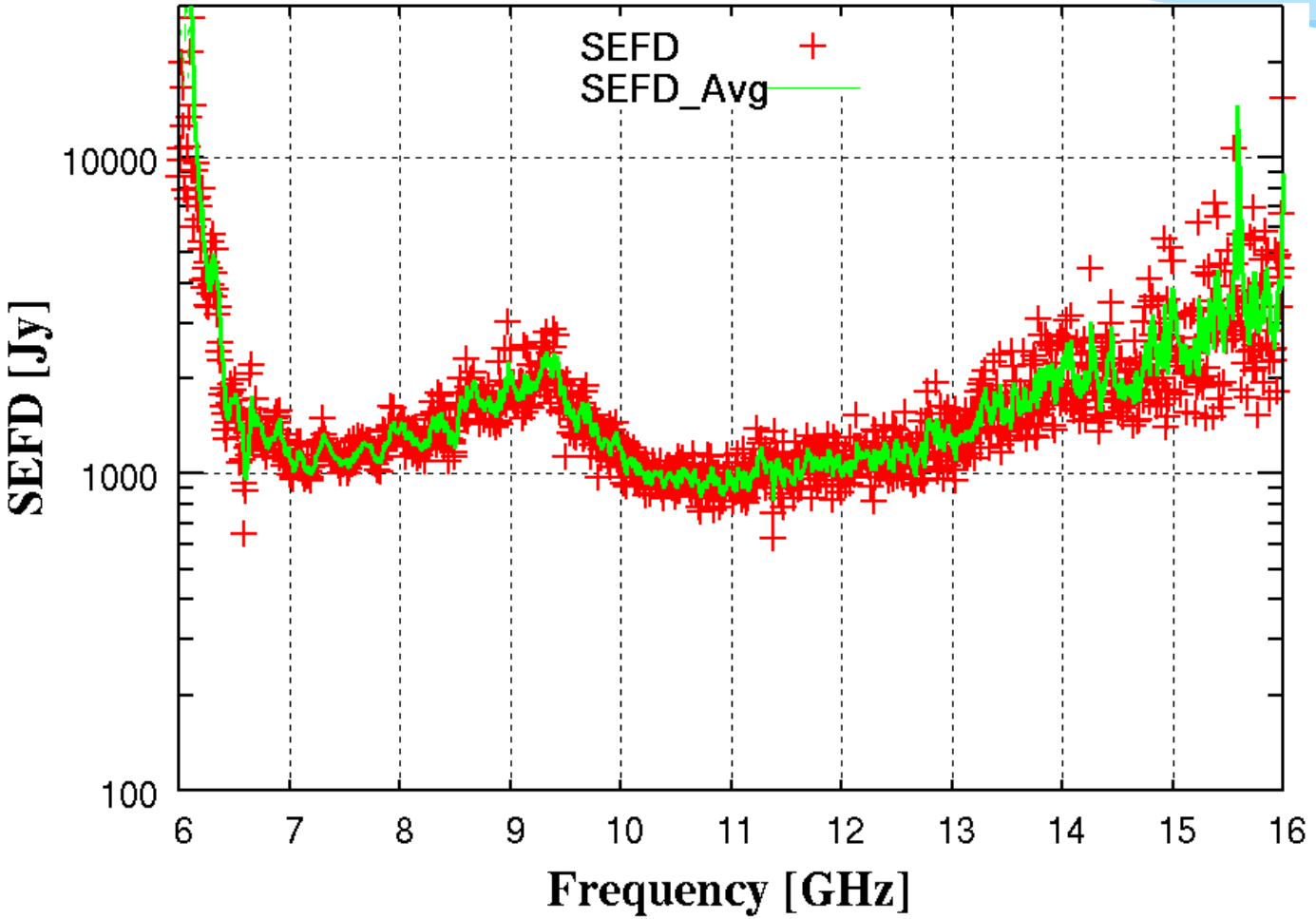
Broadband Feed for Cassegrain optics Kashima 34m antenna

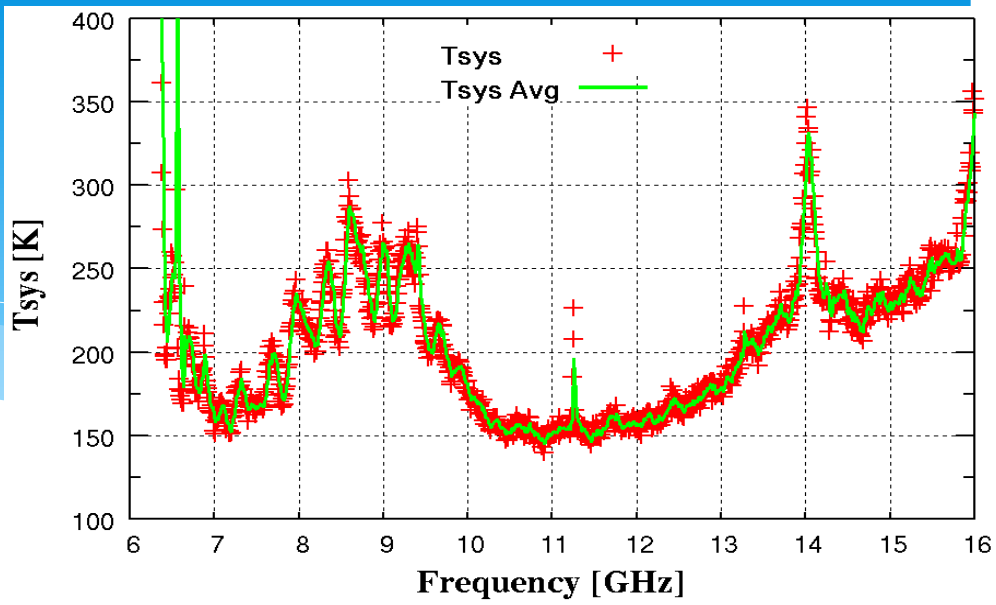


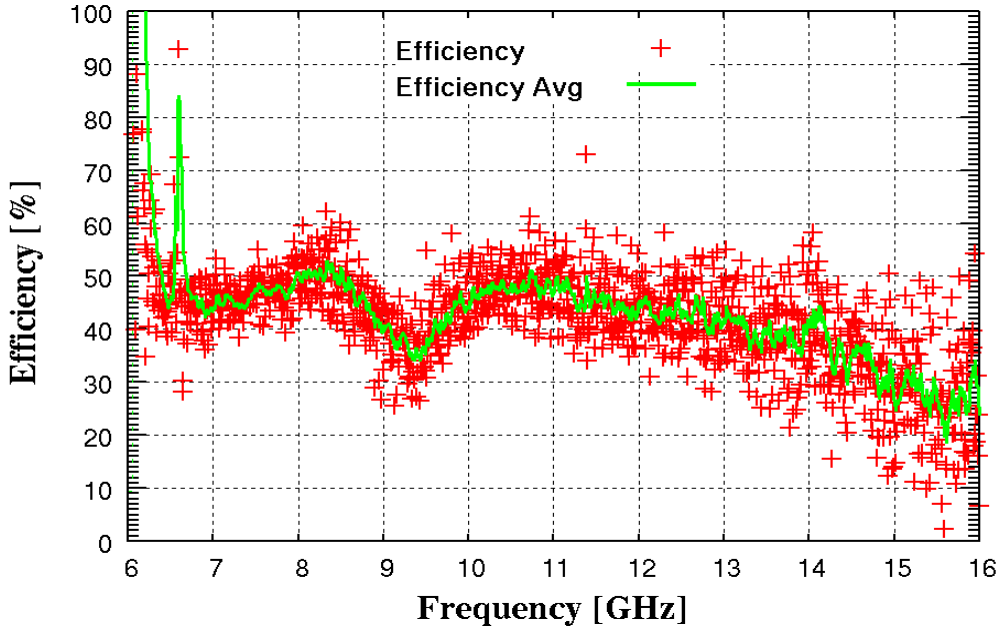
IGUANA-H Feed (6.5-15GHz)

NINJA Feed (3.2-14.4GHz, nominal)

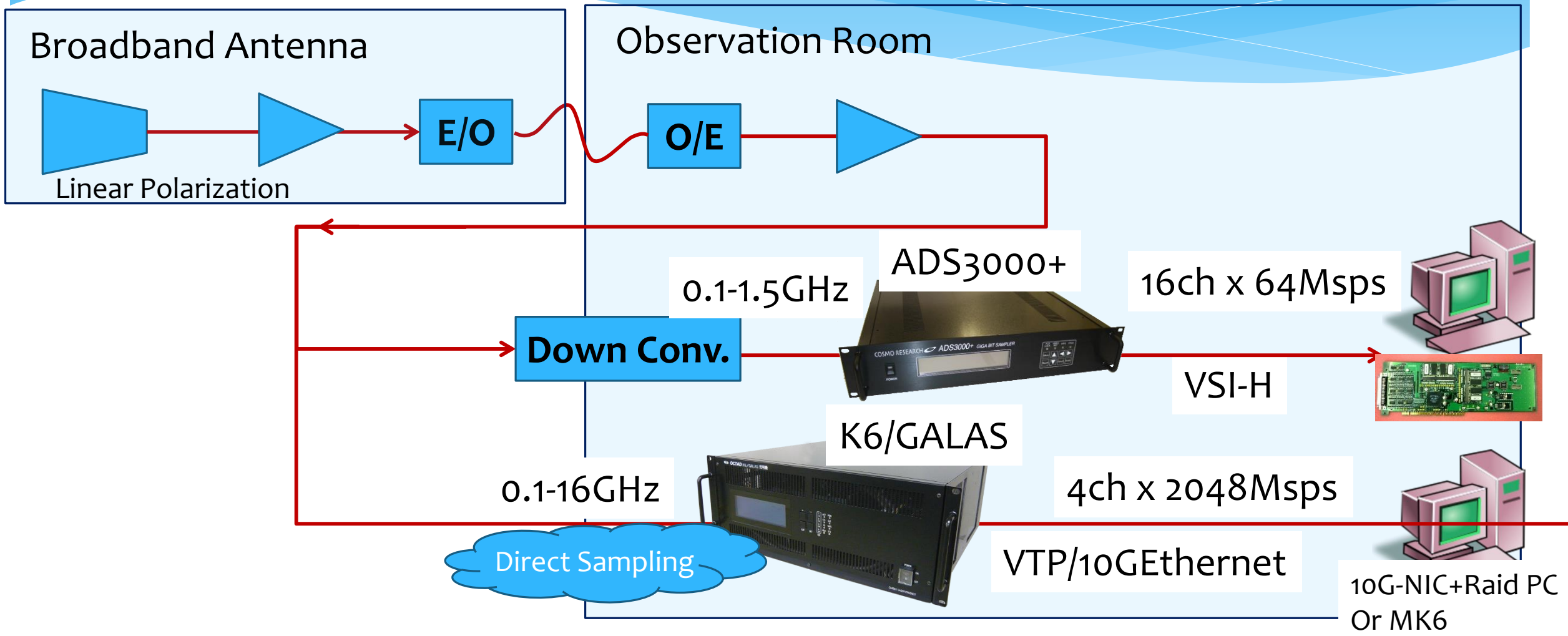
IGUANA-H Broadband Feed on 34m antenna







Signal Chain and DAS



Direct Sampling of RF signal, Digital Filter and Freq. Conv.

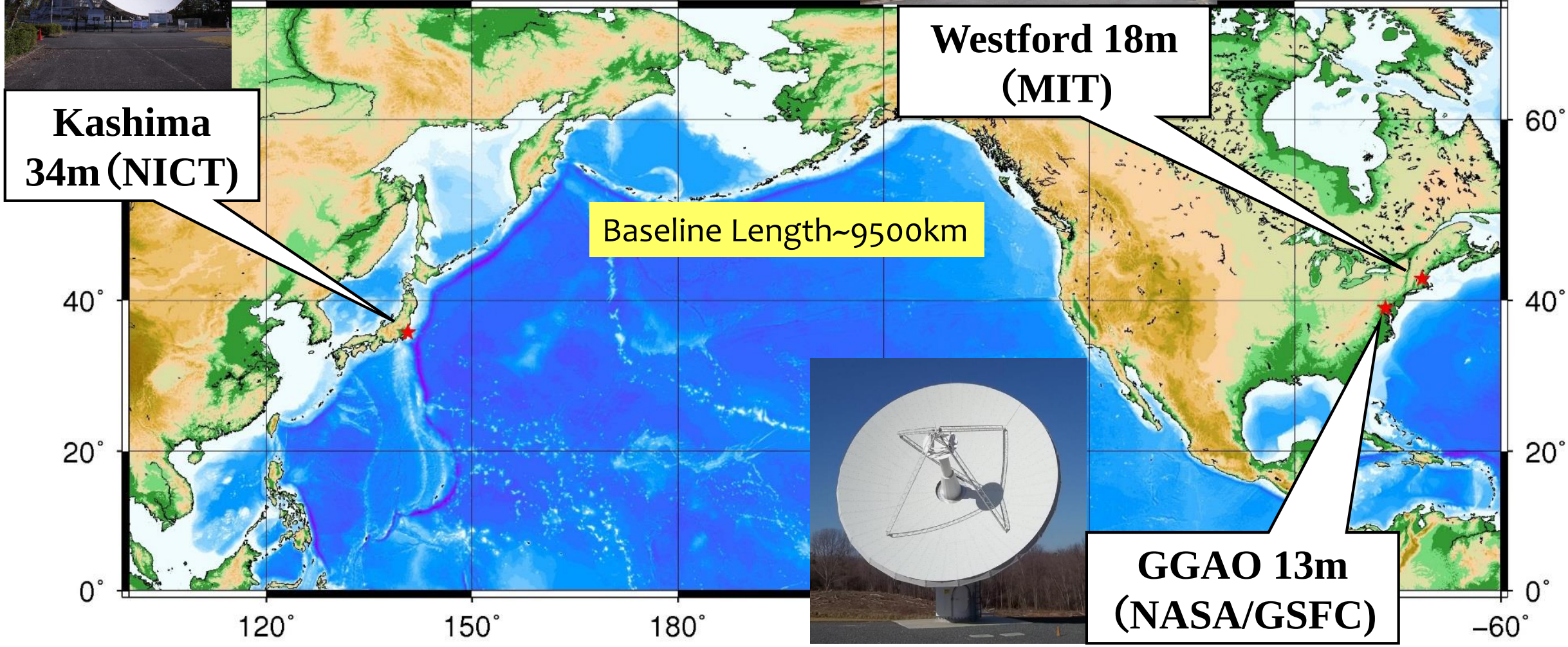
K6/GALAS Sampler

IF Input Port	2
Input Freq. Range	0.1-16.4 GHz
Sampling mode	**DBBC Mode** **Nch/unit=1,2,3, or 4** 2048 Msps/ch Qbit=1, or 2 bit
Output Port	10GBASE-SR, 4port
Max Data rate	16384 Mbps/port

Experiments

The first Intercontinental VLBI with Broadband Feed 20 Jan. 2015

Collaboration with MIT Haystack and NASA/GAFC

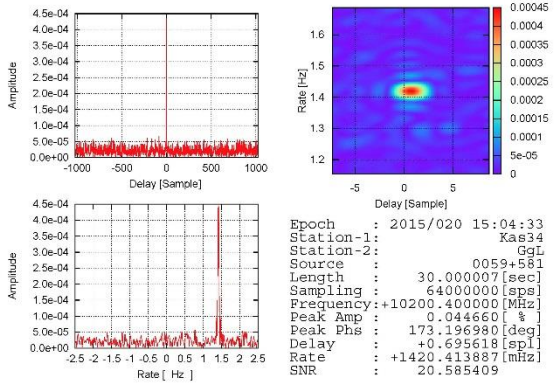
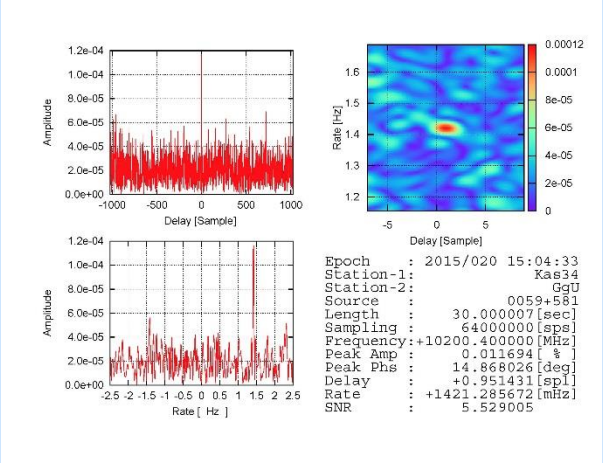
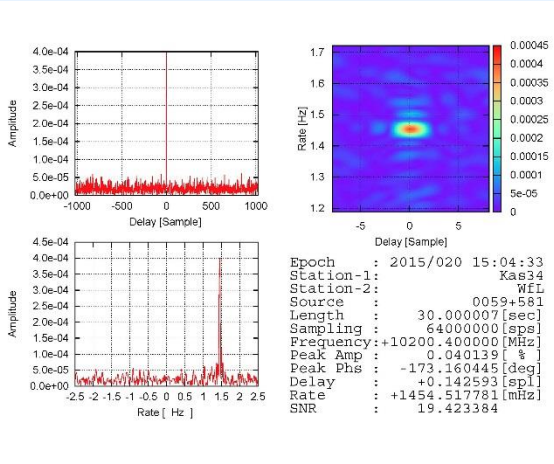
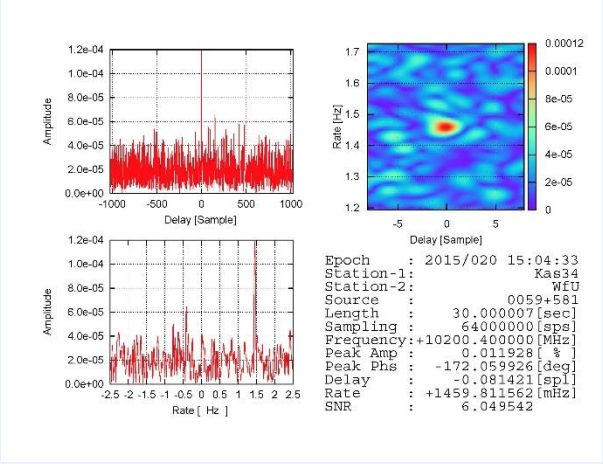


Target of the Experiment

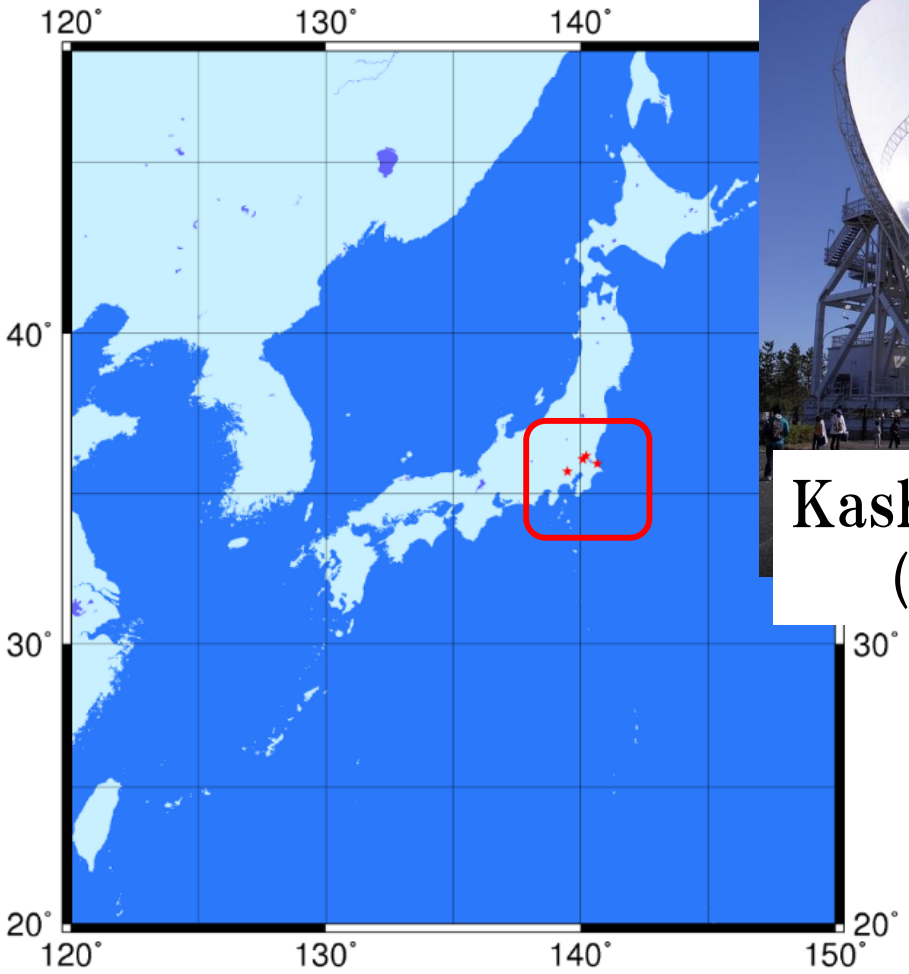
* Fringe detection with Broadband feed on intercontinental Baseline.
  * Linear Polarization, Hour angle difference
* Compatibility test with each DAS systems.
  * DAS of USA(RDBE+MK6) and Japanese DAS(ADS3000+, PC−VSI)
* Radio Frequency: 10. 2−10. 7GHz

	Westford, GGAO	Kashima34
Sampling Recording	RDBE and Mark6 →VDIF 	K5/ADS3000+ And PC-VSI →VDIF  
Correlation	DiFX Sfotware Correlator Fourfit: Bandwidth Synthesis	GICO3 Software Correlator − 32MHz single channel

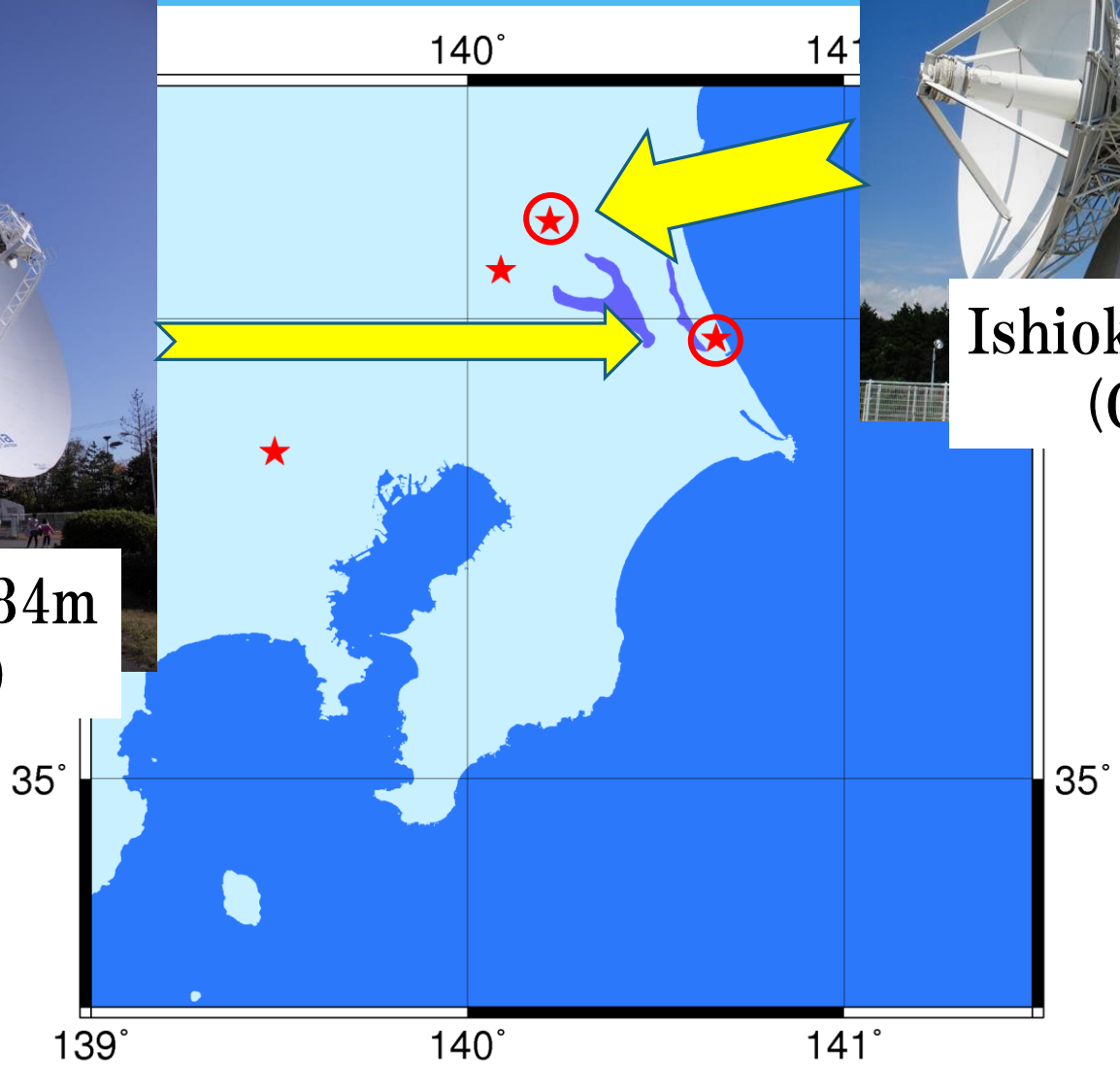
NICT side: Software Correlator GICO3
Single channel processing

	Polarization V－V	Polarization V－H
Kashima34m — NASA／GGAO		
Kashima34m — MIT／Westford		

Domestic Broadband Experiments
30 Jan. 2015



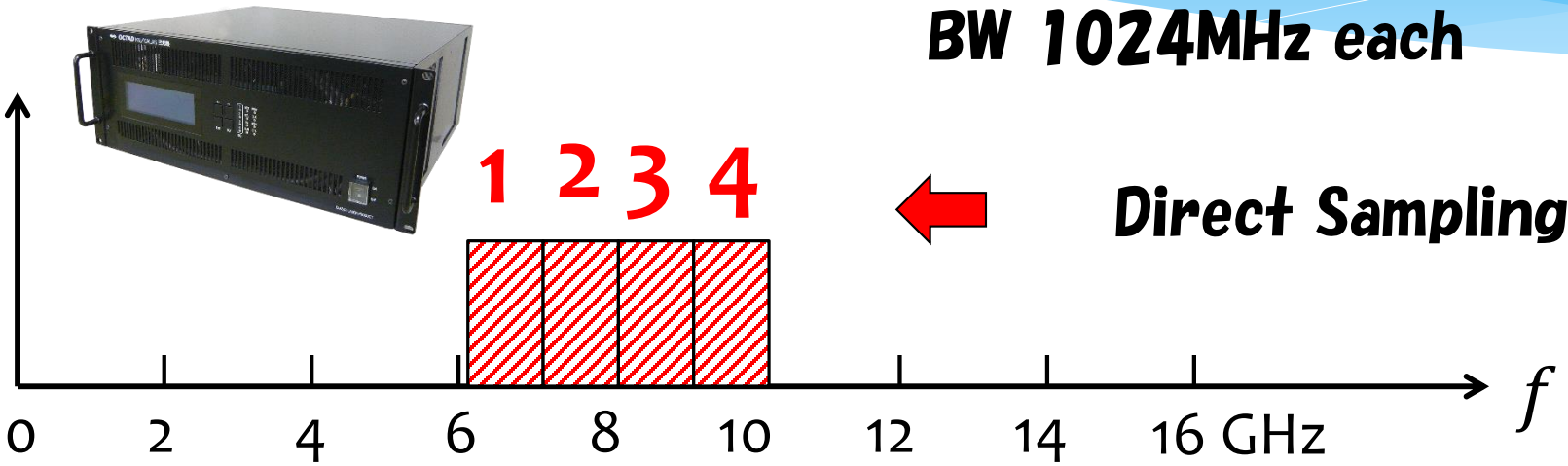
Kashima 34m
(NICT)



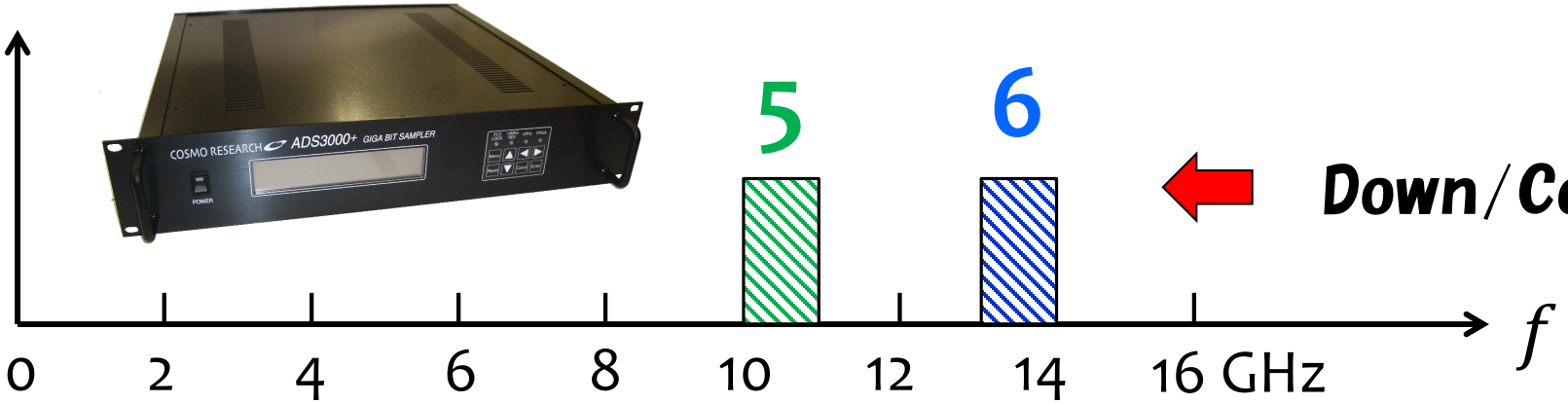
Ishioka 13m
(GSI)

Frequency allocation

BW 1024MHz each



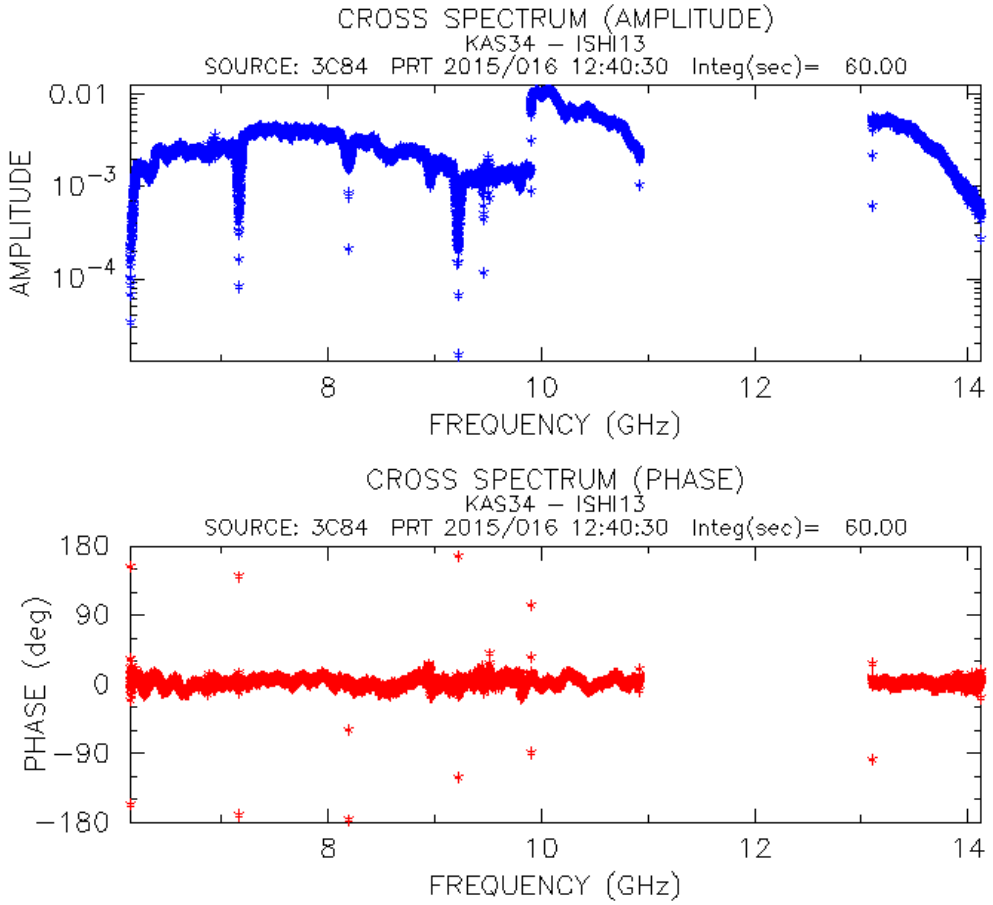
Direct Sampling (K6/GALAS)



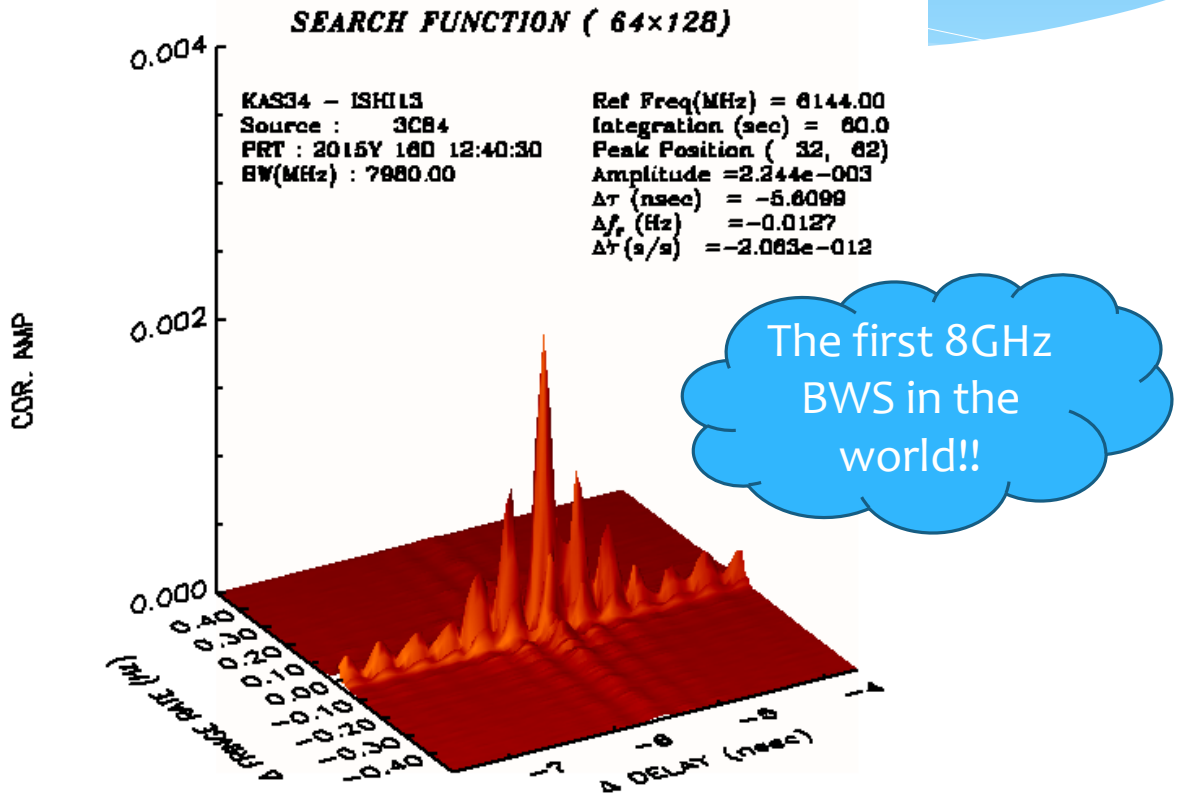
Down/Conv. +ADS3000+

Full Bandwidth Synthesis #1-#6 (6-14GHz) after Intra, Interband Phase correction

Cross Spectrum

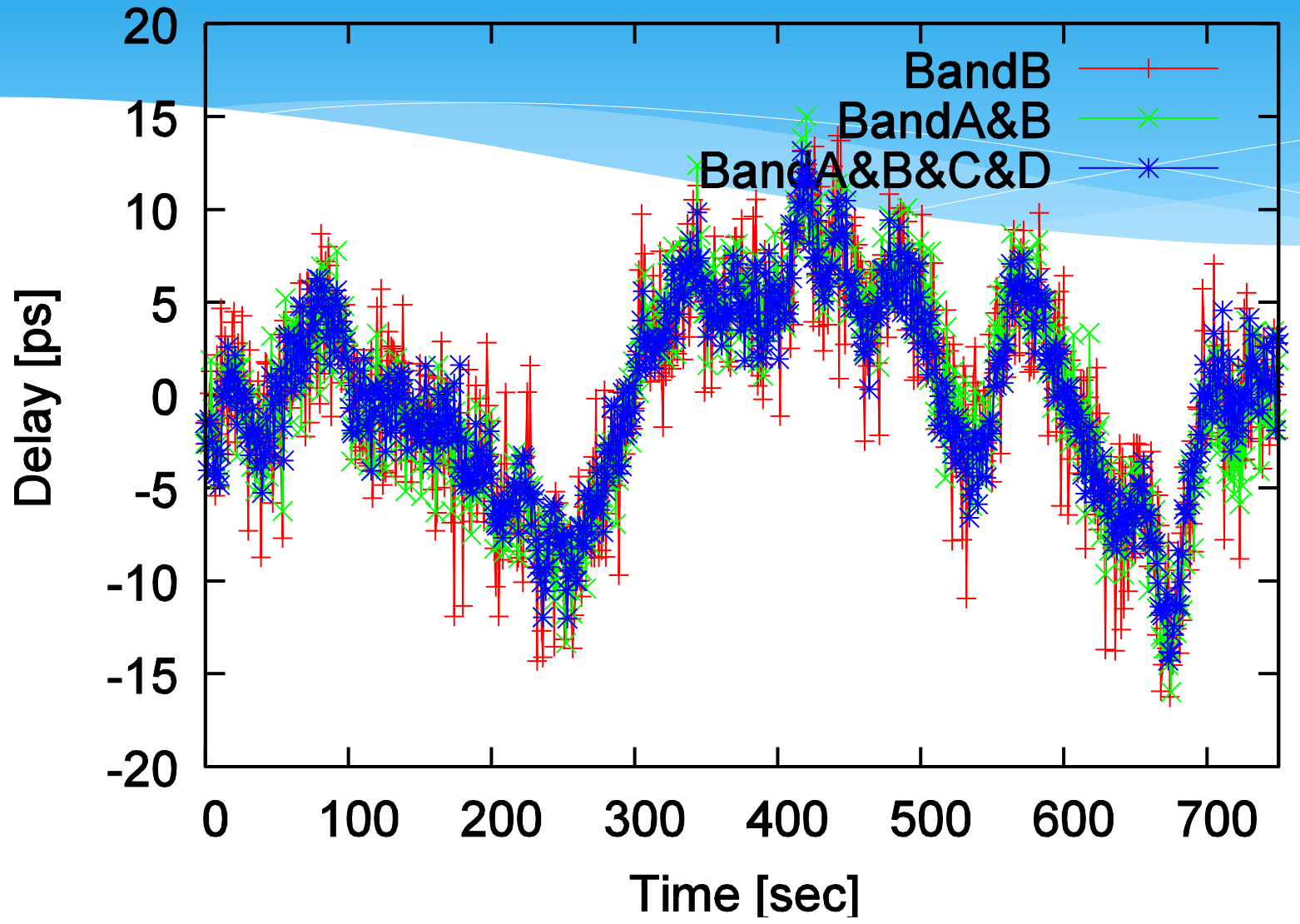


Delay Resolution Function



Theoretical delay precision is 27 femto sec.

Delay variations in 15min tracking



A few ps variation can be seen even in 15 min

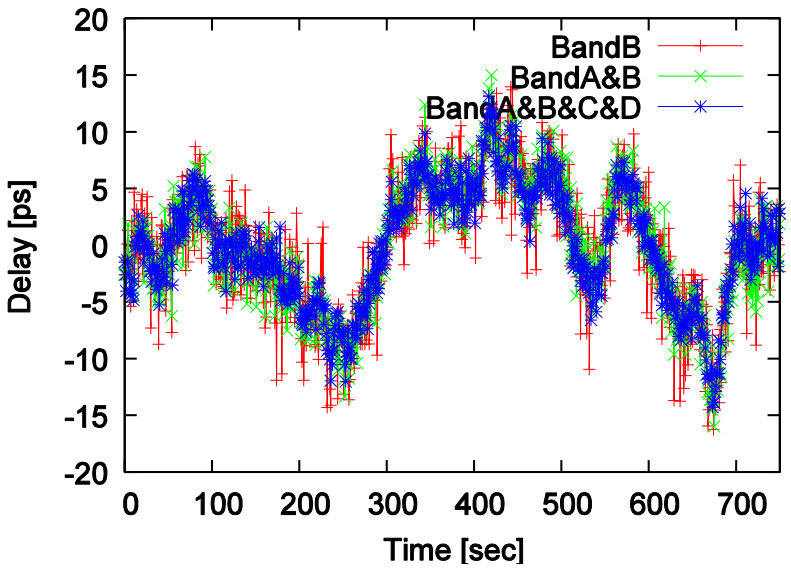
Delay Measurement Precision

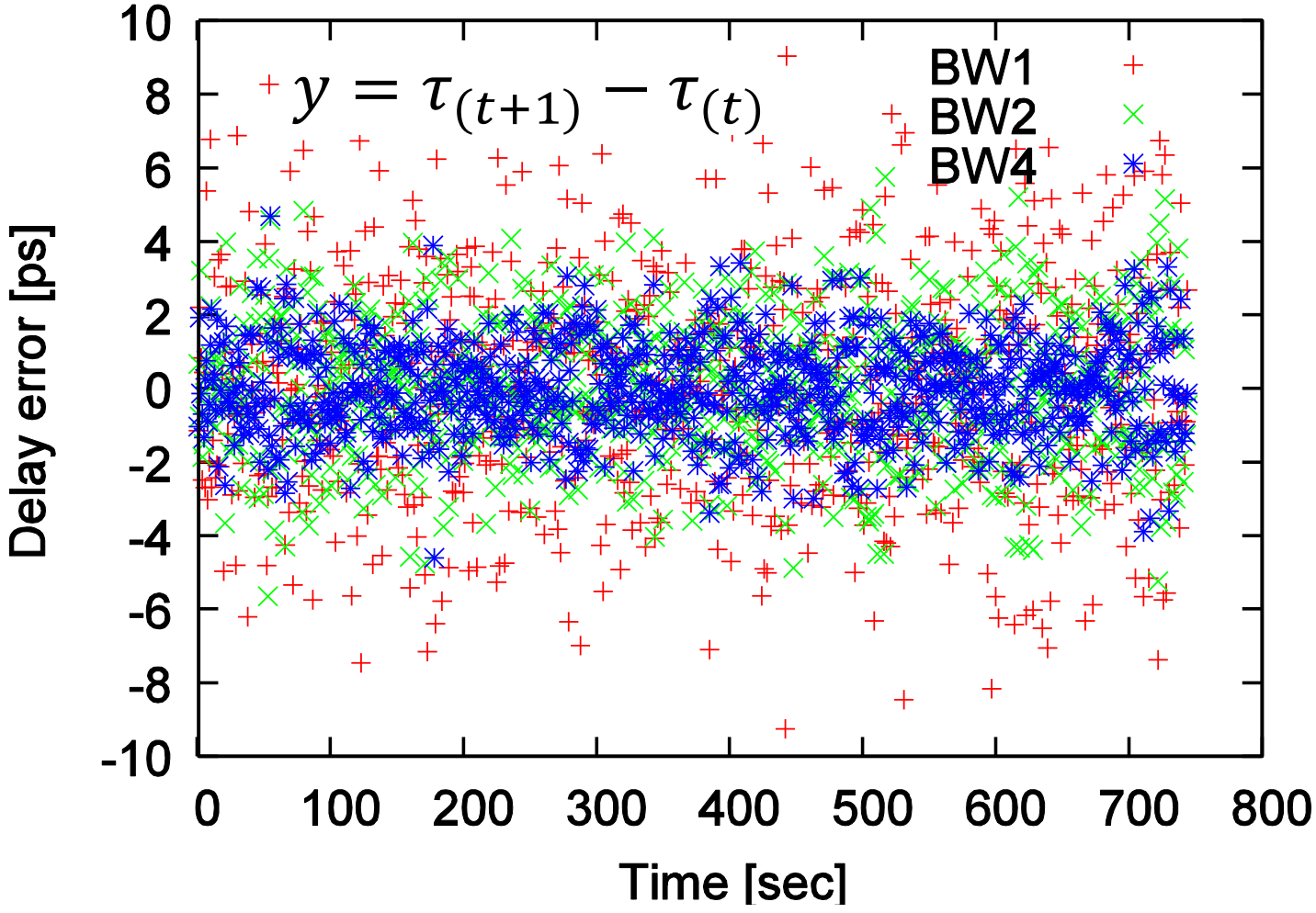
Difference of delay observable at 1 sec. interval is plotted for each of bandwidth synthesized data set.

$$\tau = s + n_t$$

$$\sigma_y^2 = \left\langle \left(\tau_{(t+1)} - \tau_{(t)}\right)^2 \right\rangle$$

$$\approx \left\langle \left(n_{(t+1)} - n_{(t)}\right)^2 \right\rangle \approx 2\sigma_n^2$$





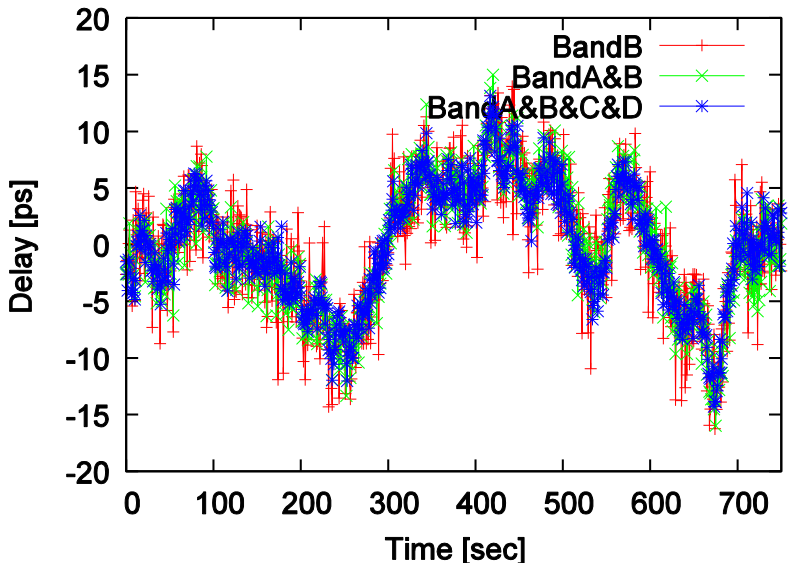
RMS of the noise in 1sec

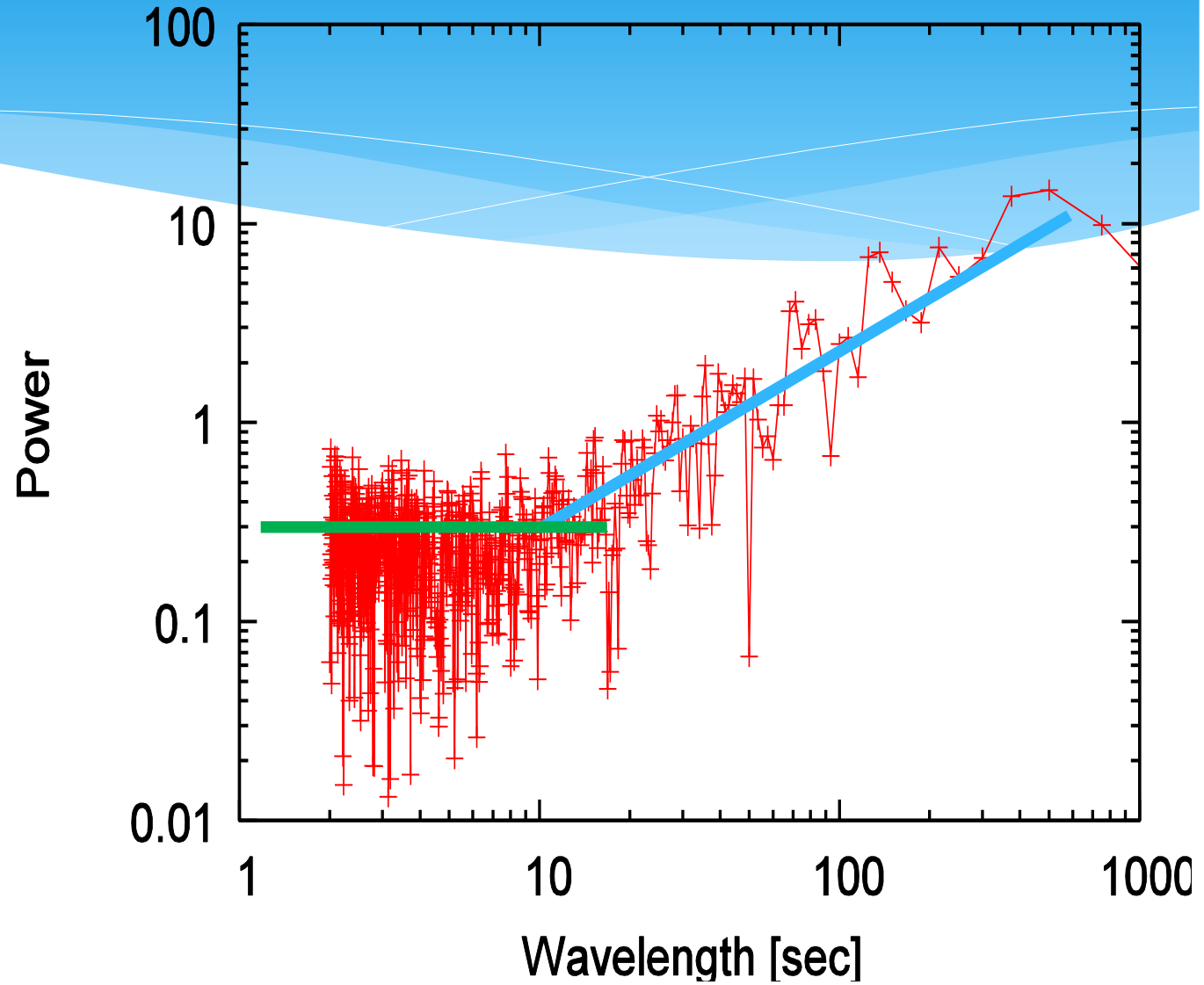
Band width	RMS/sec [ps]	Remark
1GHz	3.08	Band #2
2GHz	2.01	Band #1 and #2
4GHz	1.29	Band #1 to #4
4GHz	0.96	After intra-band correction
8GHz	0.60	All 6 Bands

If we operate 7.5sec integration like VGOS,
RMS will be 200 femto second !

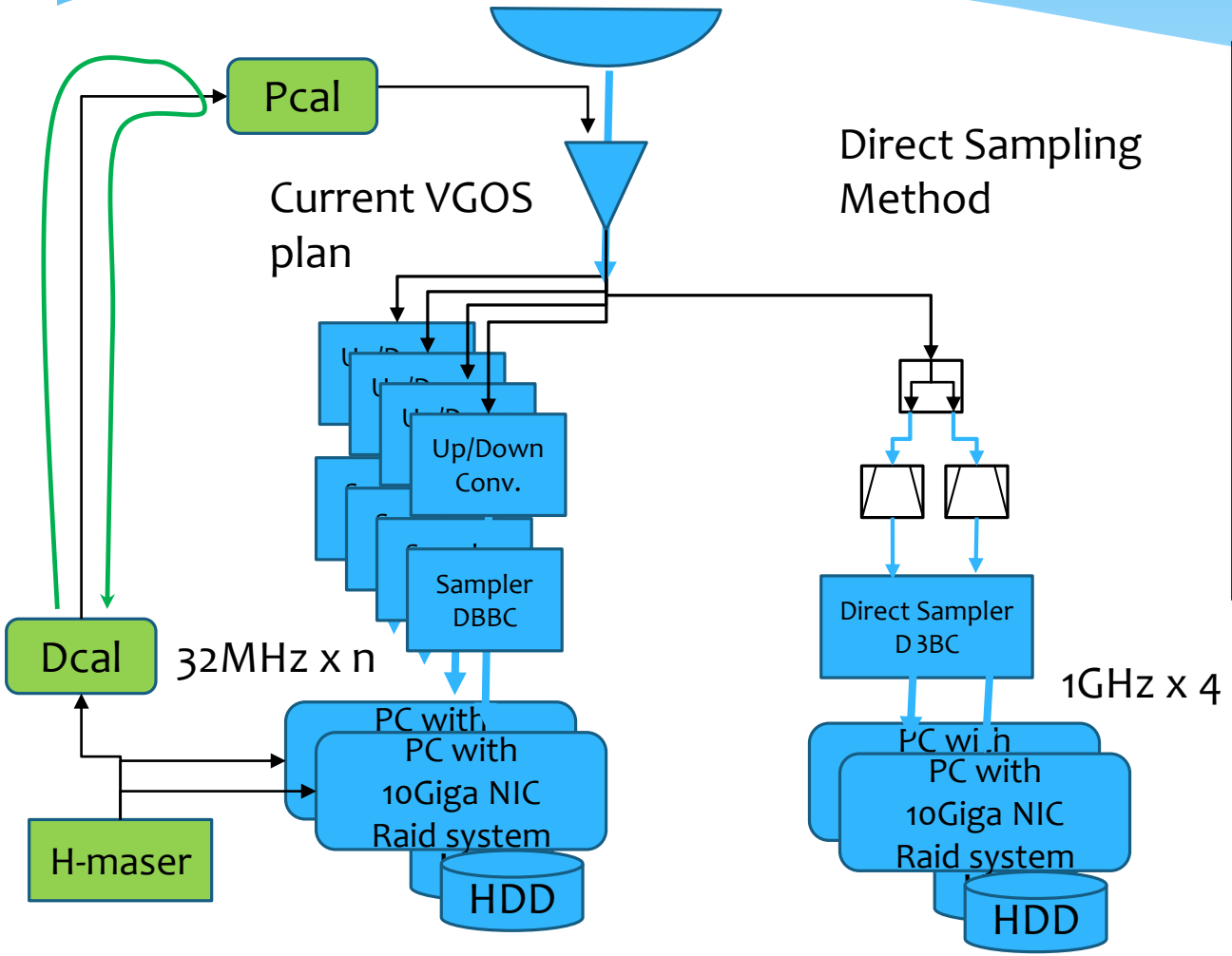
Noise spectrum

Behavior of white noise component is observed until about 15sec
One source has a duration of 7.5 sec integration In VGOS specification





Great Advantages of Direct Sampling Technique



Advantages of Direct sampling

1. Simple and Smart
2. Small Delay variation between band

   Easy data processing and BWS

   Possibility to avoid P-cal device

   → Delay-Cal device is not necessary

Summary

1. Original developed Broadband feed for Cassegrain focus telescope is in progress.
   * Please contact us if you upgrade your antenna to Broadband!
2. The Super Broadband BWS (8GHz width) was achieved.
   * Delay precision reaches to sub-pico second.
3. We are proving the direct sampling technique is quite effective for broadband observation.
   * Interband delay/phase variations are small and stable because A/D conversion is made at once.
   * Pcal and D-cal device might be avoidable. To be investigated.

Acknowledgements

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