AU-JP Radio Astrometry School in Kagoshima
March 29, 2016

# Geodetic VLBI and its Perspectives

National Institute of Information and Communications Technology

Tetsuro KONDO

## Contents

- What is geodetic VLBI?
- How to get residual delay and delay rate from correlation data
- Measurements of plate motion and crustal deformation
- Evolution of VLBI system
  - direct sampling
  - Wideband bandwidth synthesis, etc.
  - VGOS (VLBI Global Observing System)

# Space Geodetic Techniques

- **VLBI**
  (Very Long Baseline Interferometry)

- GNSS (Global Navigation Satellite System)
  - GPS (USA), GALILEO (EU), GLONASS (Russia), BeiDou (China), QZS (Japan), IRNSS (India)

- SLR (Satellite Laser Ranging)

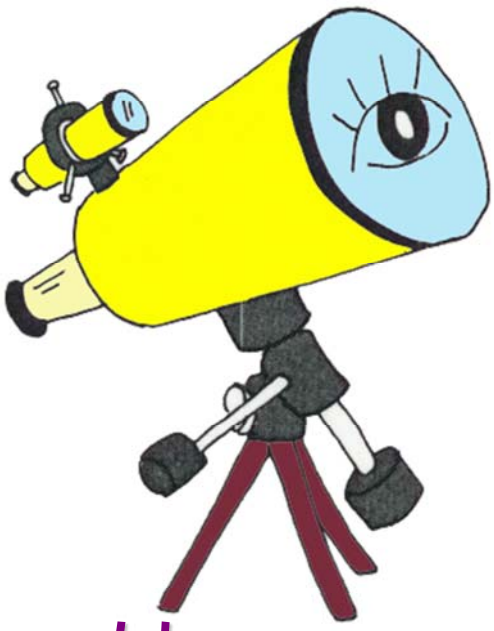
NICT

# VLBI can measure what?

## two functions as a tool

**Geodetic VLBI**

microscope
to investigate Earth

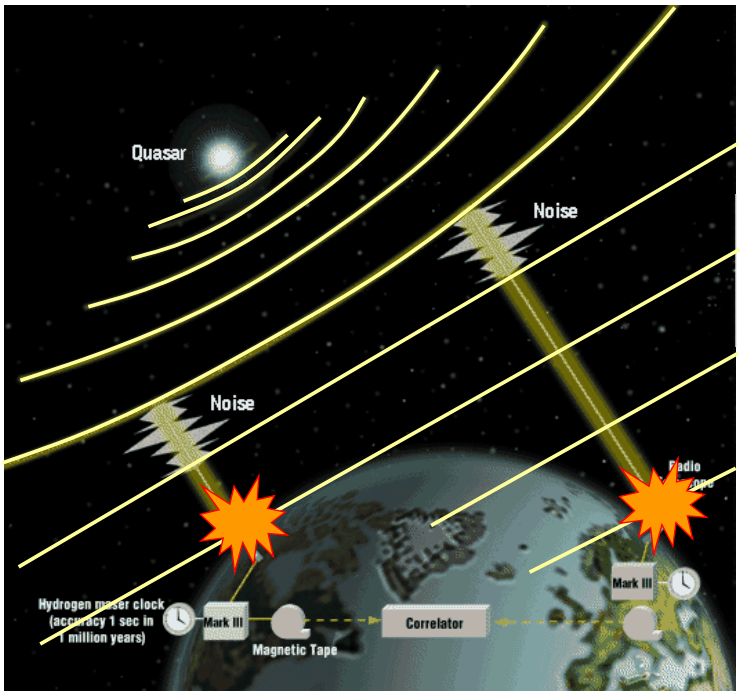


telescope
to investigate space

NICT

# Measure Time Delay

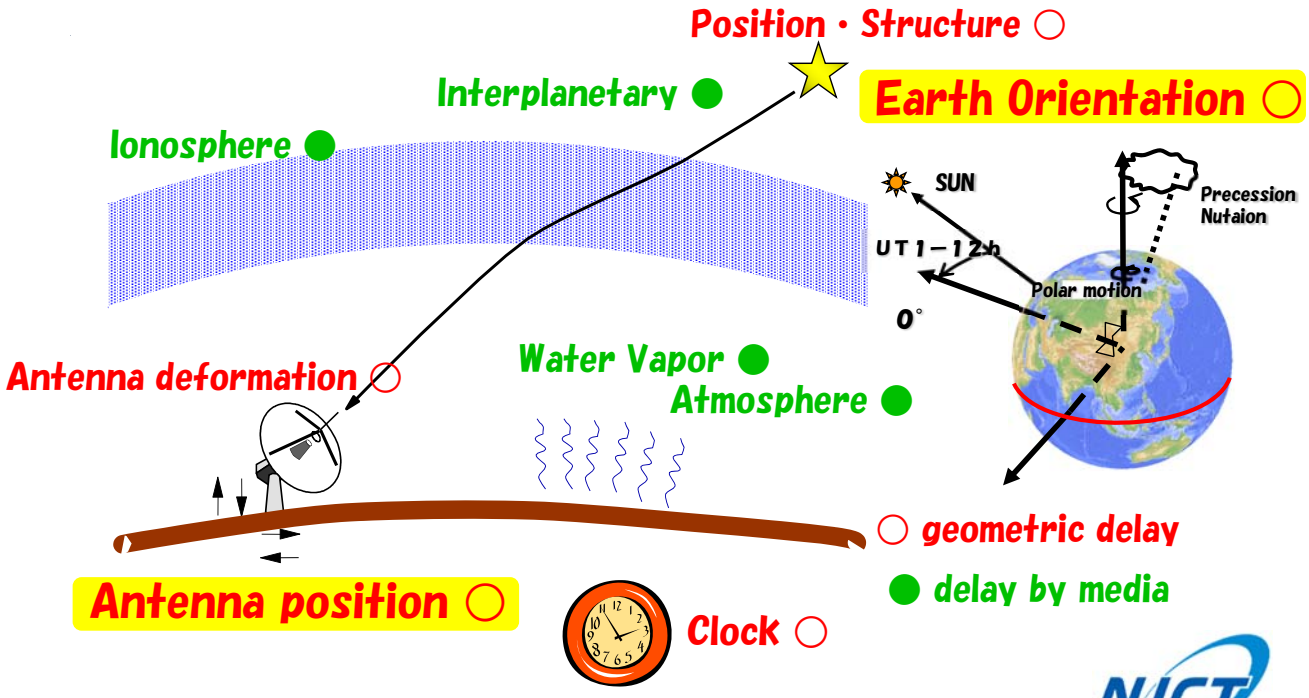
receive radio star signals at 2 stations




measure time delay

NICT

# Measured delay is affected by

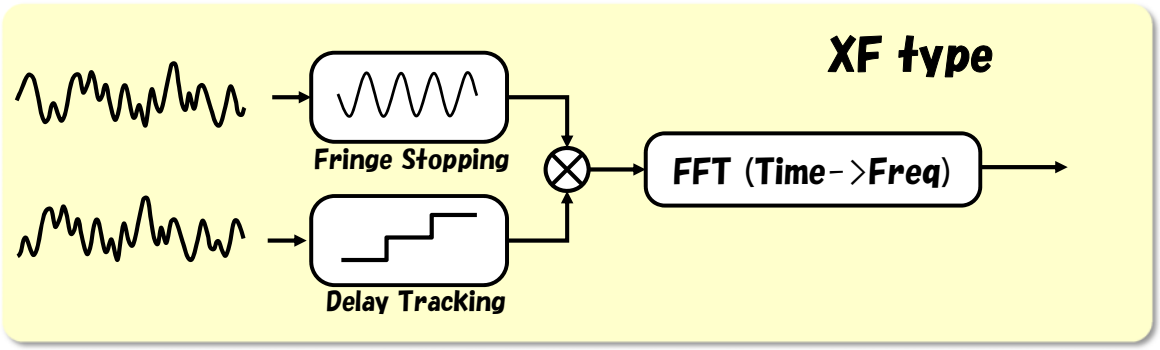


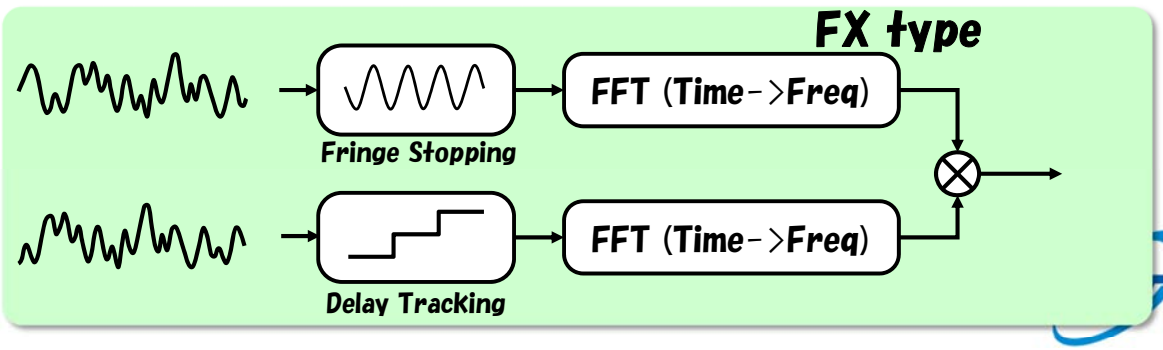

NICT

# How to get residual delay and delay rate

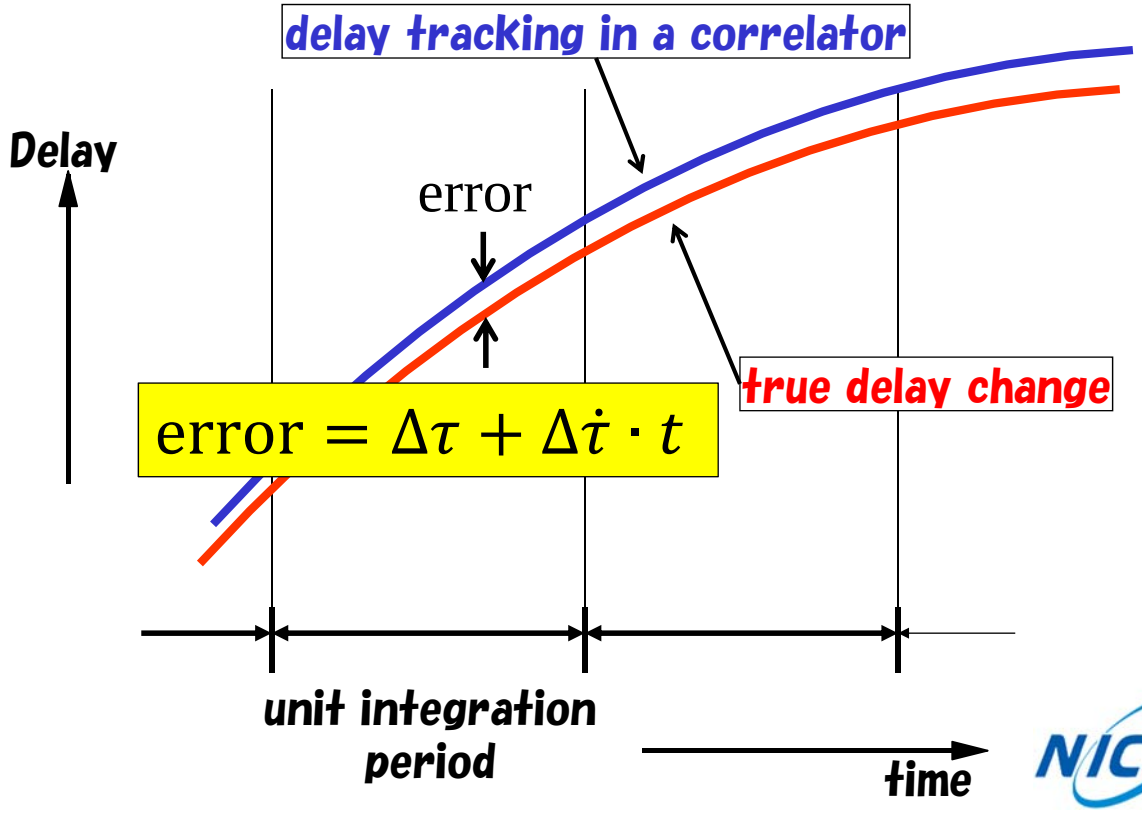
## Correlation Processing

### Two types of correlators

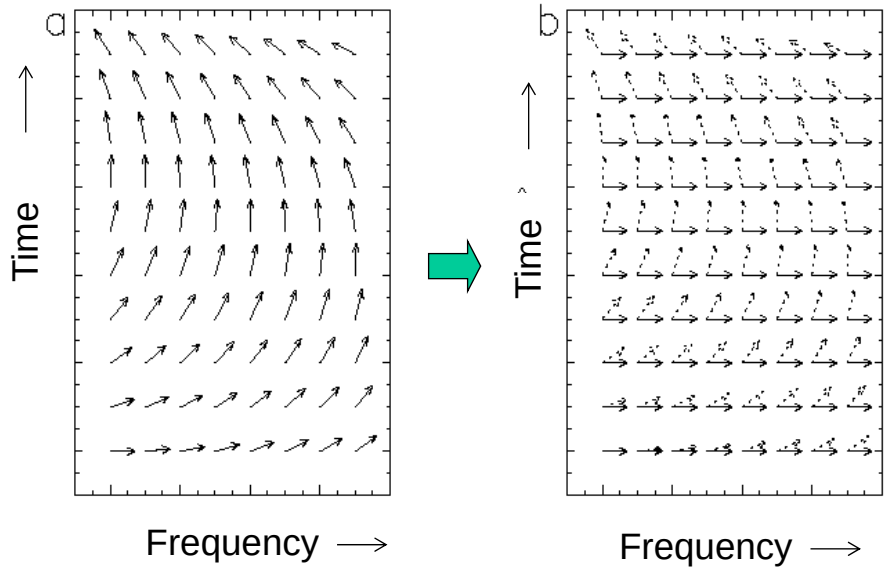


# residual delay $\Delta\tau$ and delay rate $\Delta\dot{\tau}$




# How to obtain residual delay $\Delta\tau$ and delay rate $\Delta\dot{\tau}$ from cross-spectra



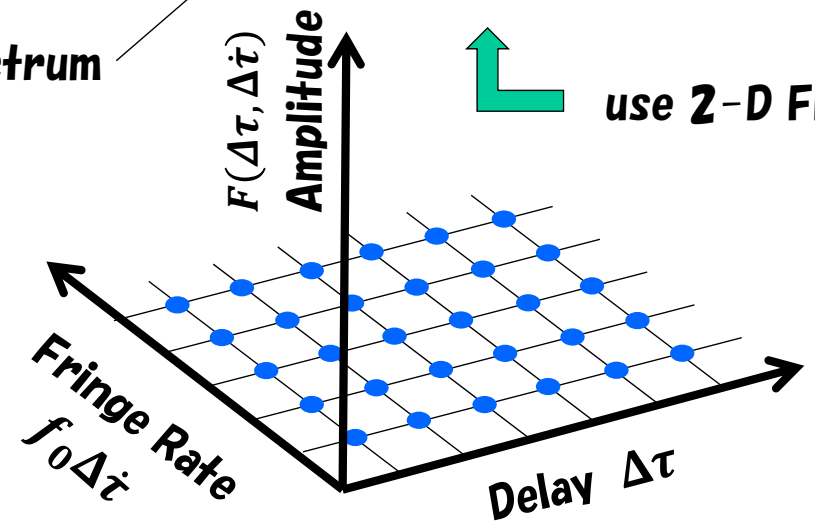

$\Delta\tau$ yields phase rotation on frequency domain

$\Delta\dot{\tau}$ yields phase rotation on time domain

# Search Function

$$F(\Delta\tau,\Delta\dot{\tau}) = \left| \int_0^B \left\{ \int_0^T S(f,t) e_0^{-i2\pi f_0 \Delta\dot{\tau} t} dt \right\} e^{-i2\pi\Delta\tau f} df \right|$$

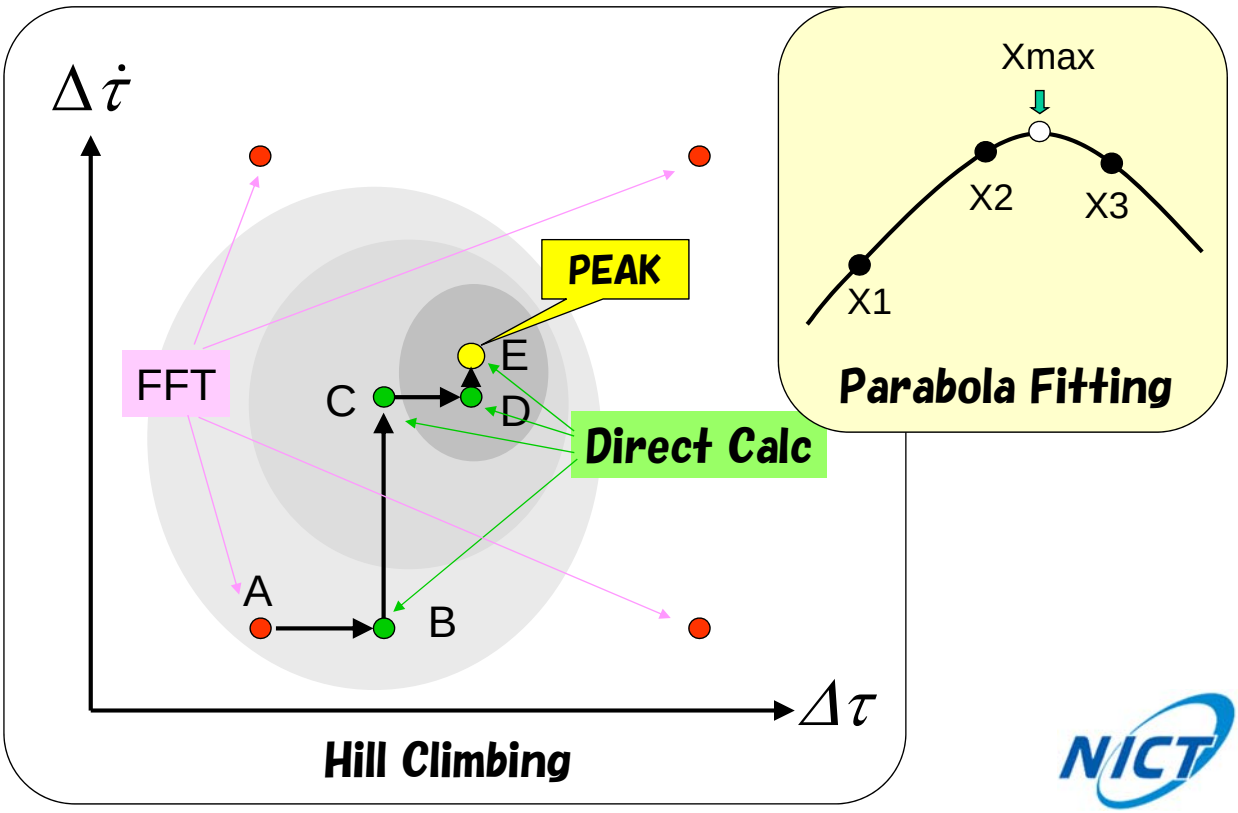
cross spectrum



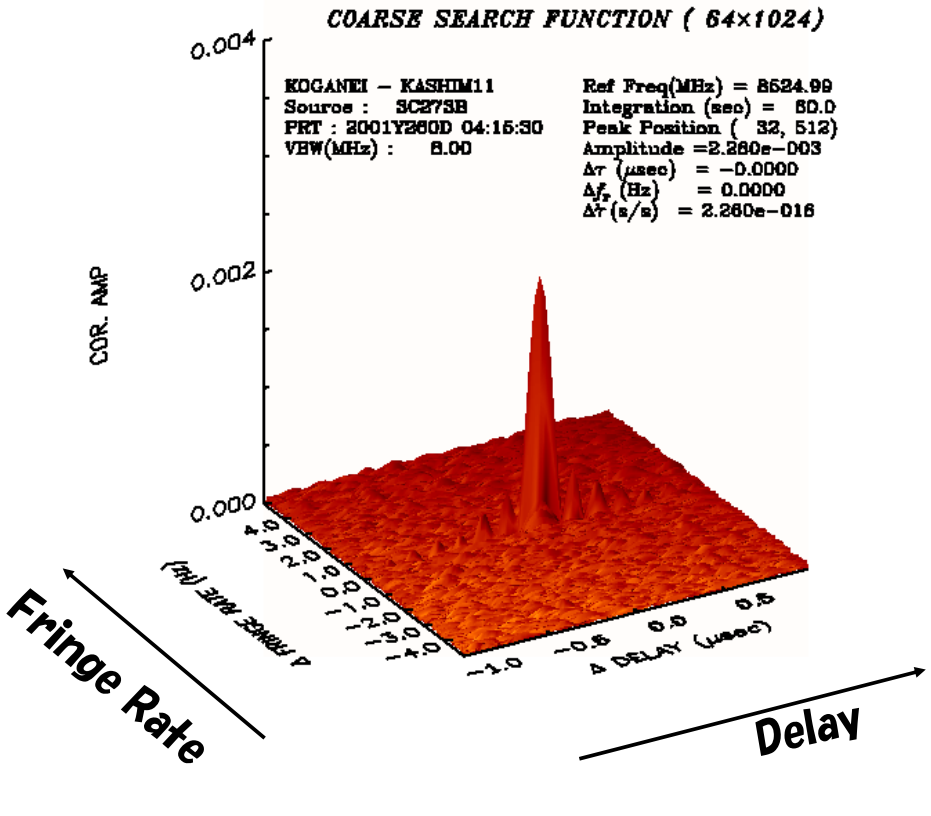

use 2-D FFT

$f_0$ : reference RF frequency

# Hill climbing method and parabola fitting

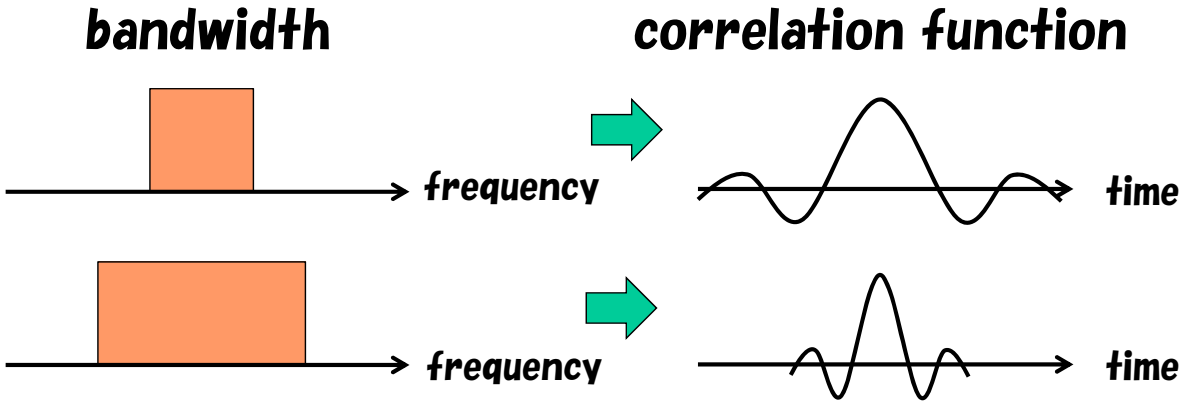


# Example of actual search function

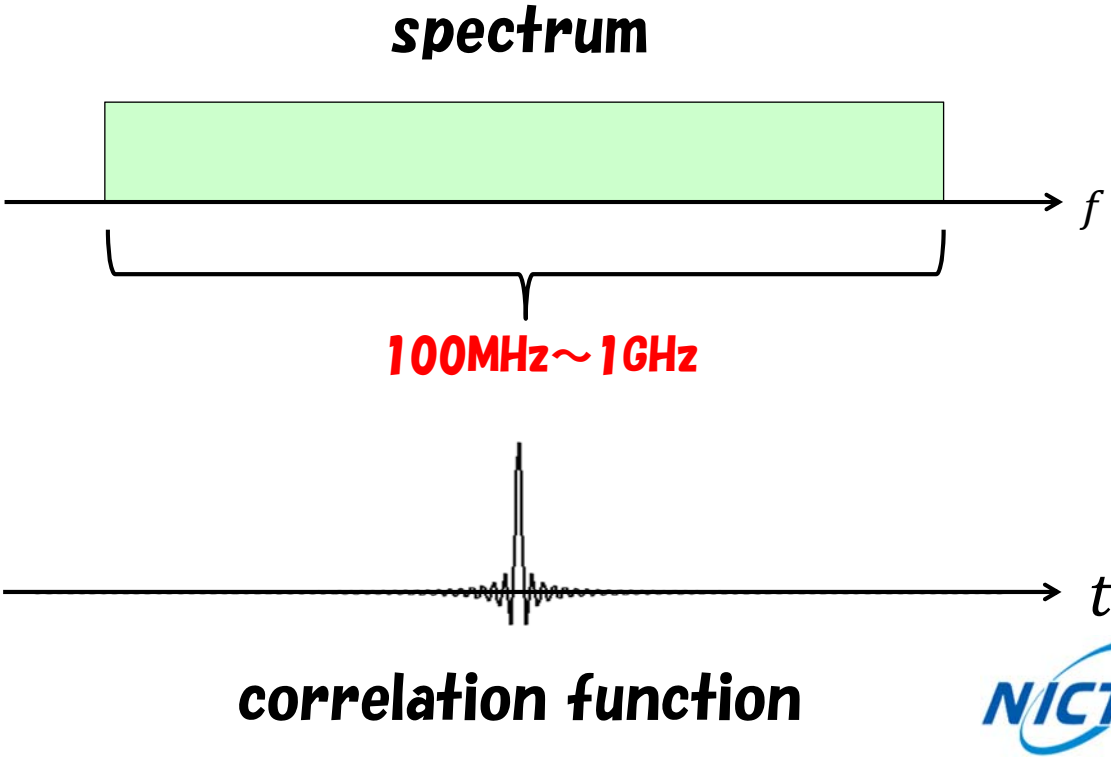



# Bandwidth Synthesis (BWS)

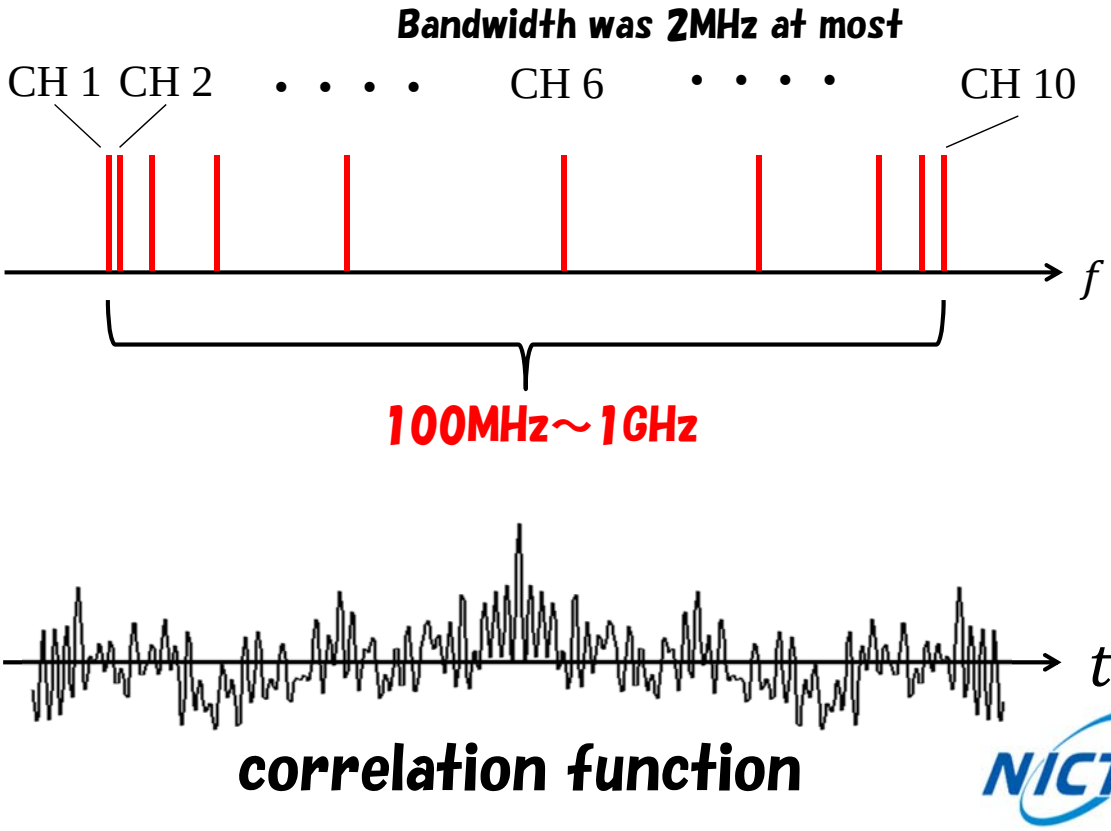
# delay resolution ∝ 1/bandwidth




# Conventional Bandwidth Synthesis



# Conventional Bandwidth Synthesis




# Search Function for BWS

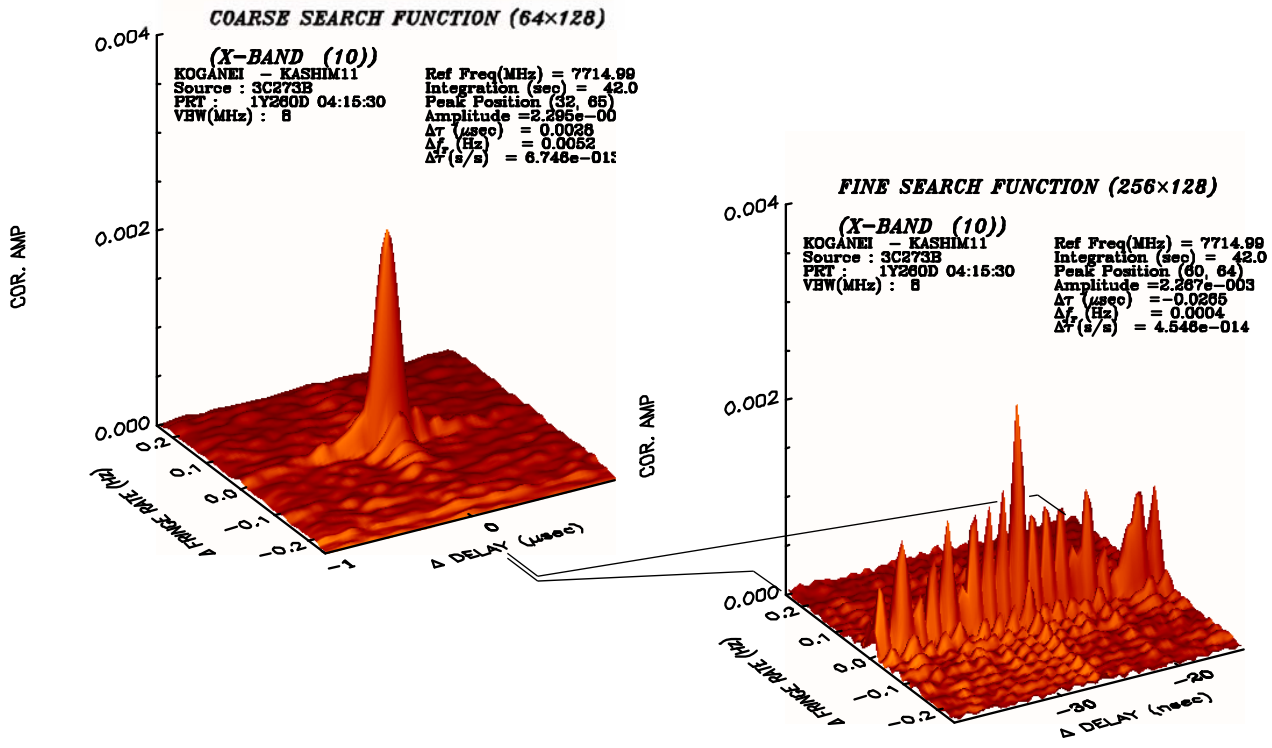
$$F(\Delta\tau, \Delta\dot{\tau}) = \left| \int_0^B \left\{ \int_0^T S(f,t) e_0^{-i2\pi f_0 \Delta\dot{\tau} t} dt \right\} e^{-i2\pi\Delta\tau f} df \right|$$

Now combined cross spectrum

**Each channel phase is compensated by using the phase of PCAL signal**

$f_0$ : reference RF frequency

# Improvement of Delay Resolution by Bandwidth Synthesis



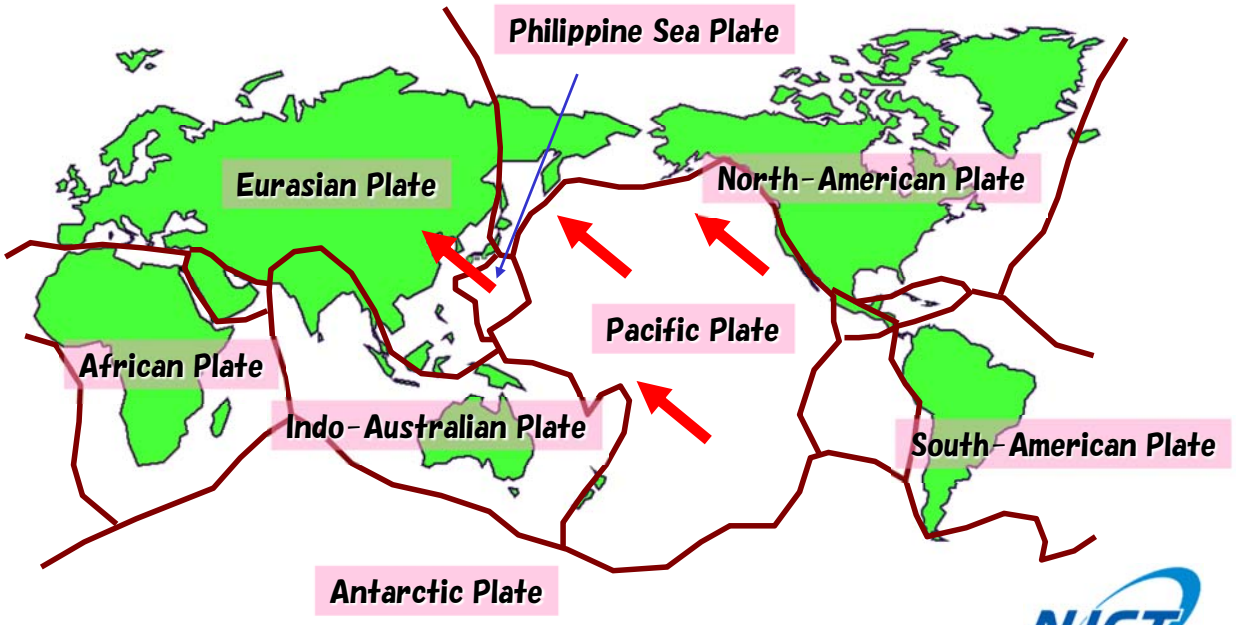

# Antenna Motion during Geodetic VLBI


10sec -> 1hrs

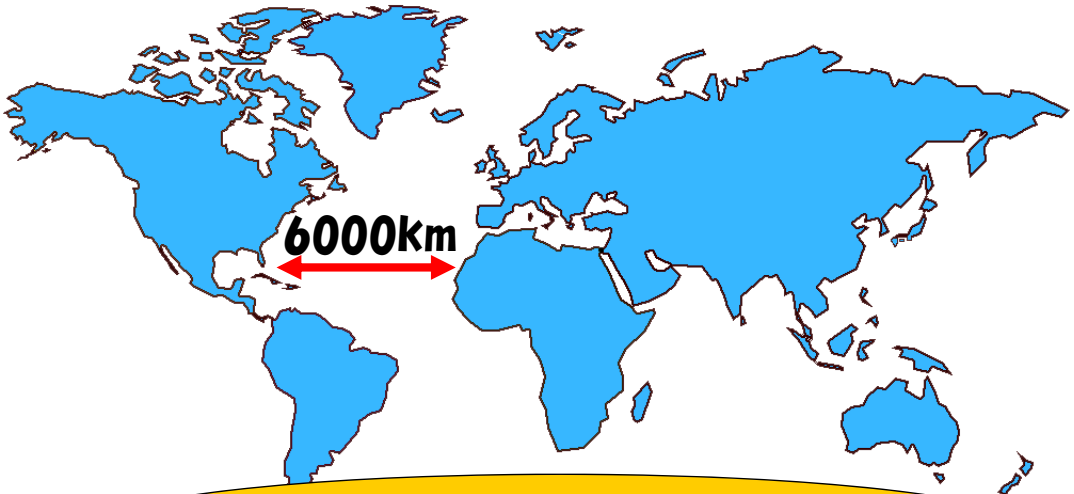
100~300 scans/24 hours

# First Target was Measurements of Plate Motion

## Tectonic Plates



# Estimation of Plate Motion

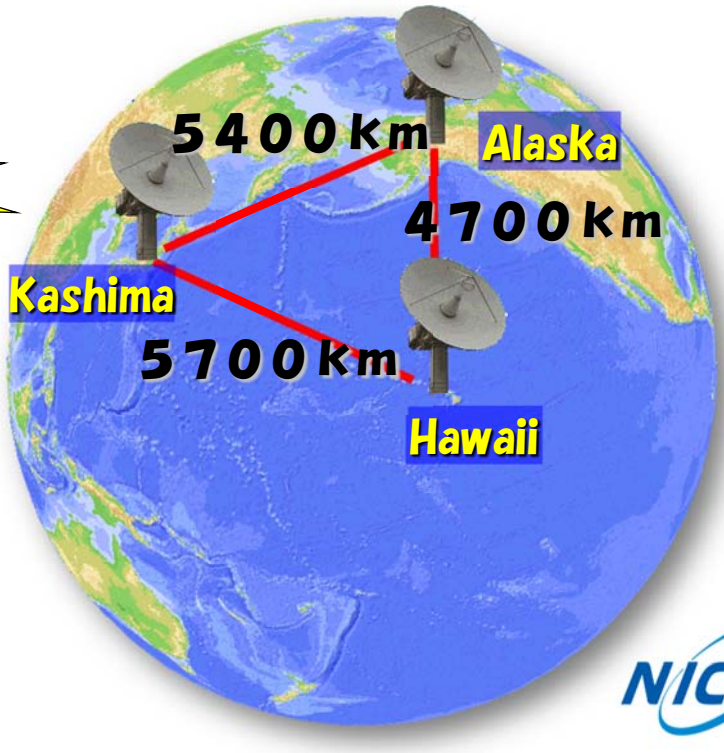



Atlantic Ocean began to spread 50 Ma ago

6000km/50Ma = 12cm/year

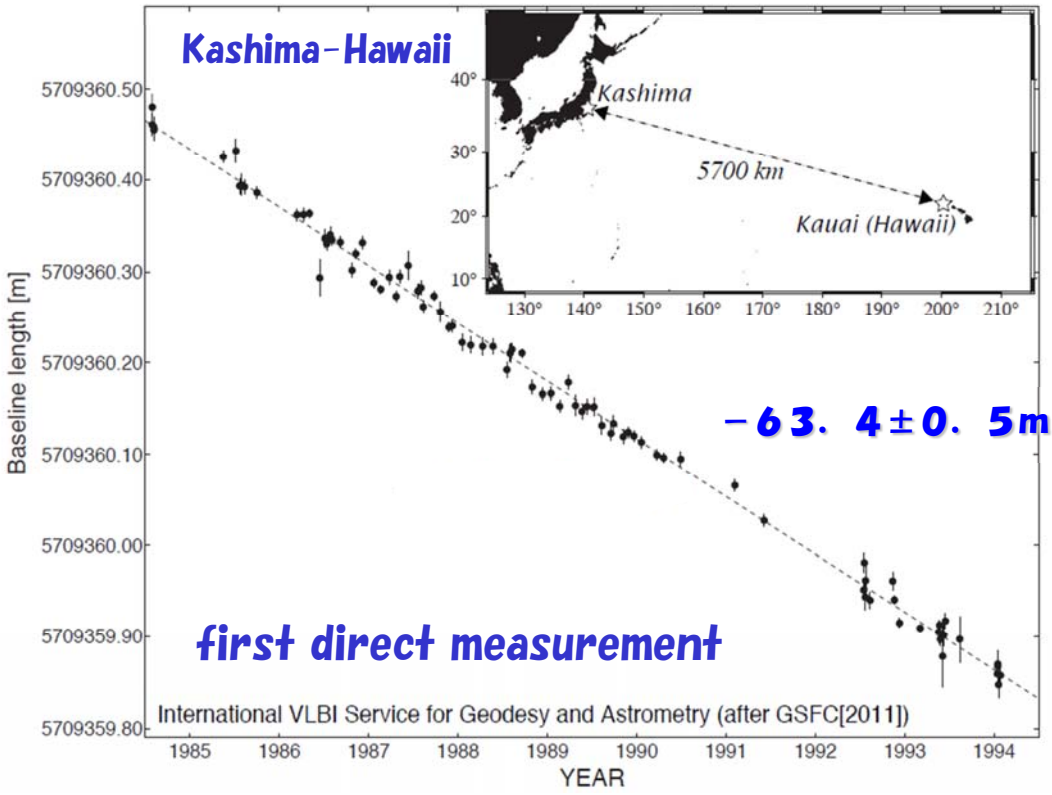
# Crustal Dynamics Project
## (direct measurements of plate motion)

start 1983



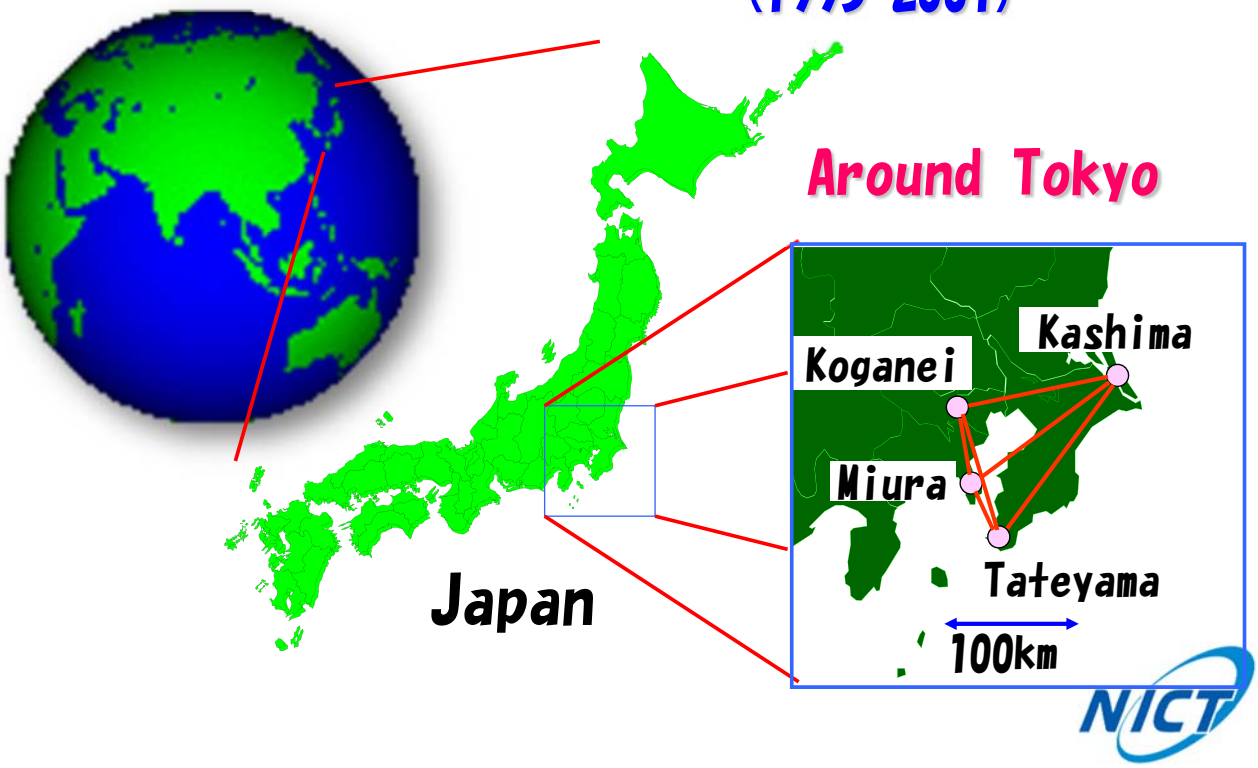

CDP was promoted by NASA

# Baseline length change measured on Kashima-Hawaii Baseline



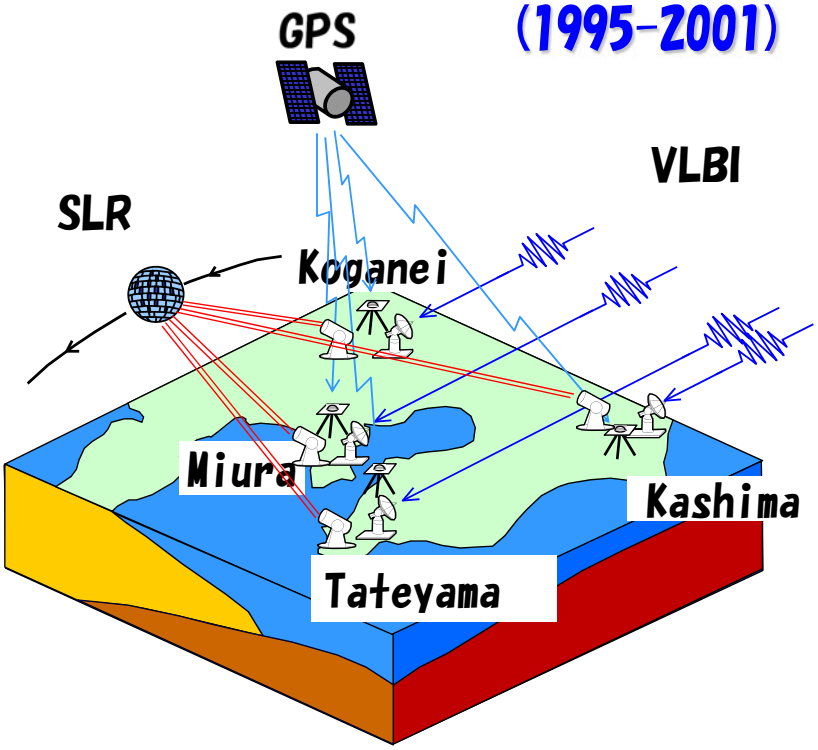

# Continuous Measurements of Crustal Deformation Around Tokyo (KSP Project)

# KSP (Key Stone Project)
(1995-2001)



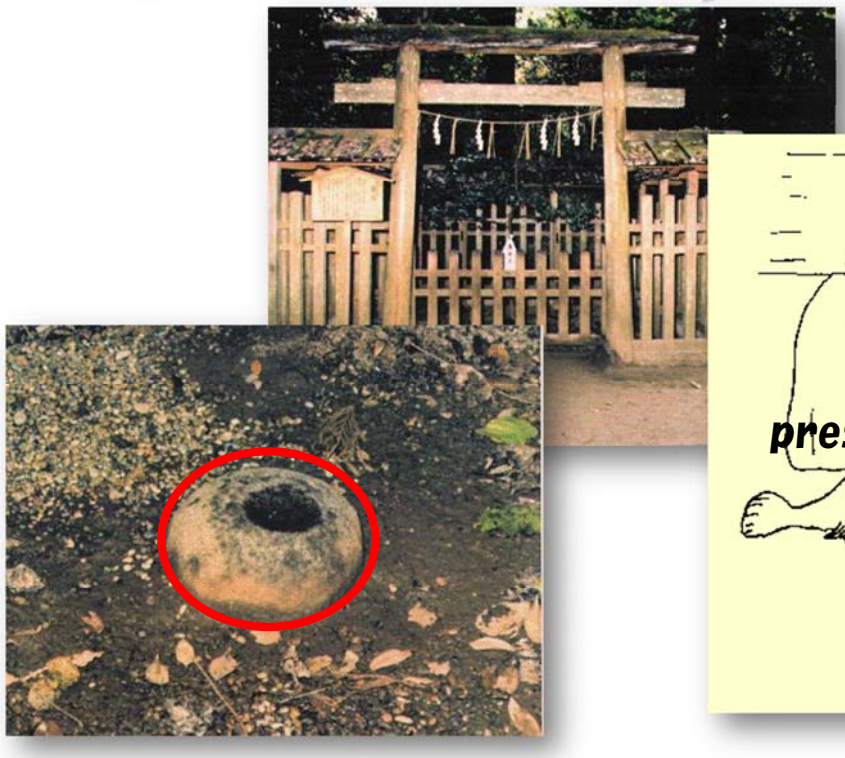

NICT

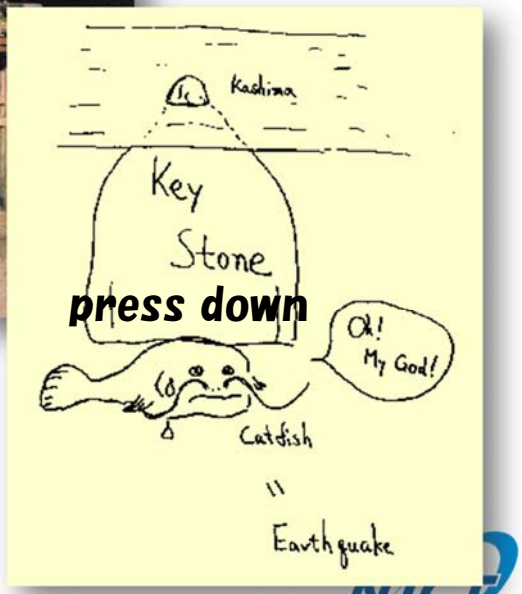
# KSP (Key Stone Project)
(1995-2001)




NICT

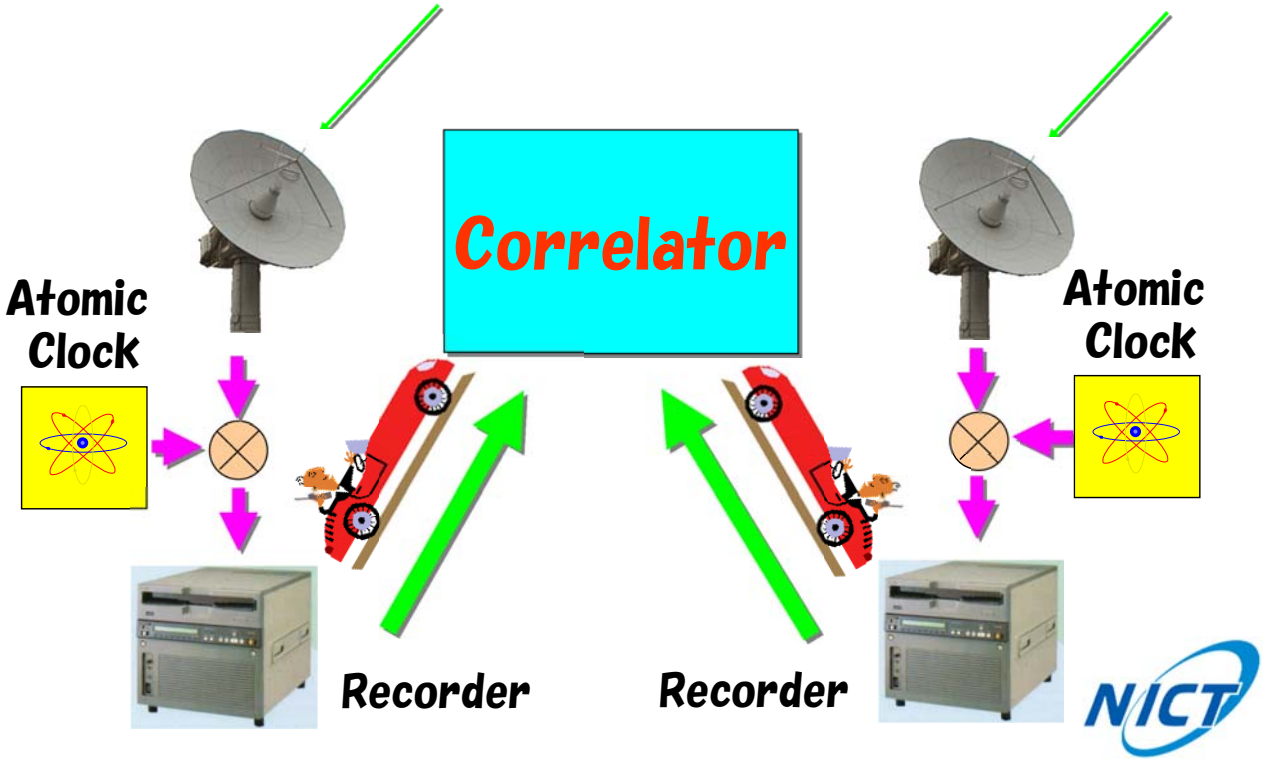
# Keystone at Kashima Jingu Shrine



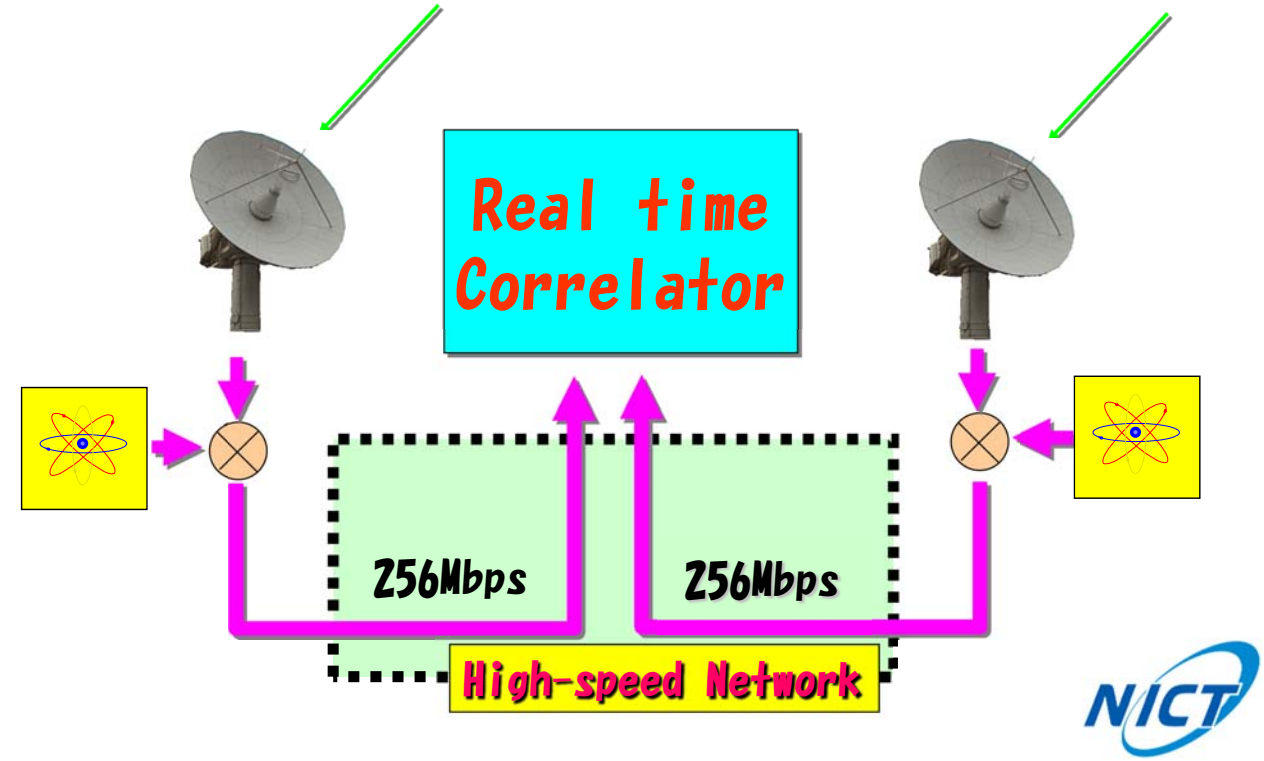



# Keystone Legend

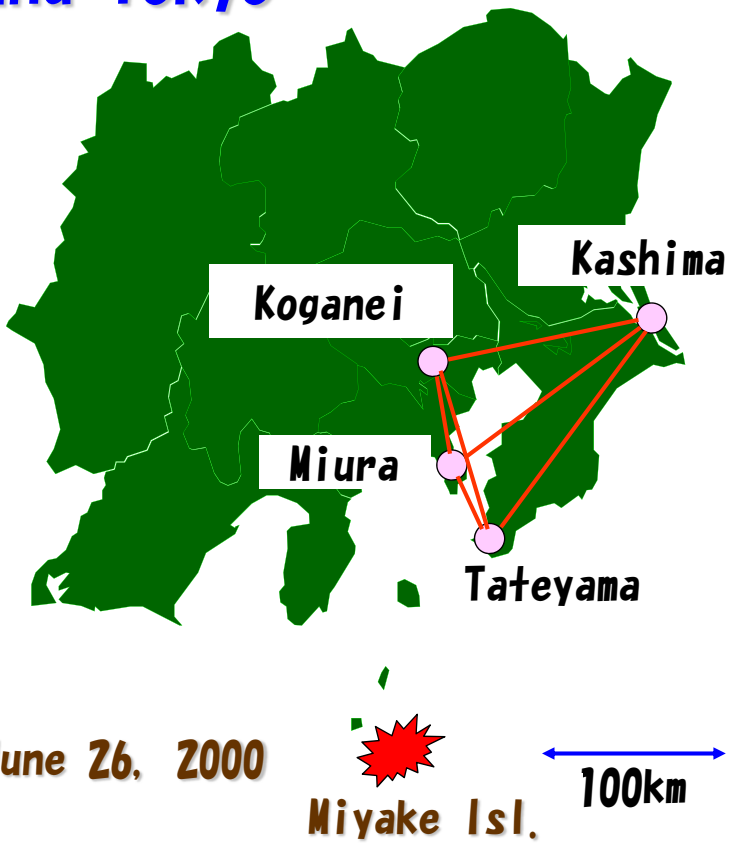
# Conventional VLBI at that time



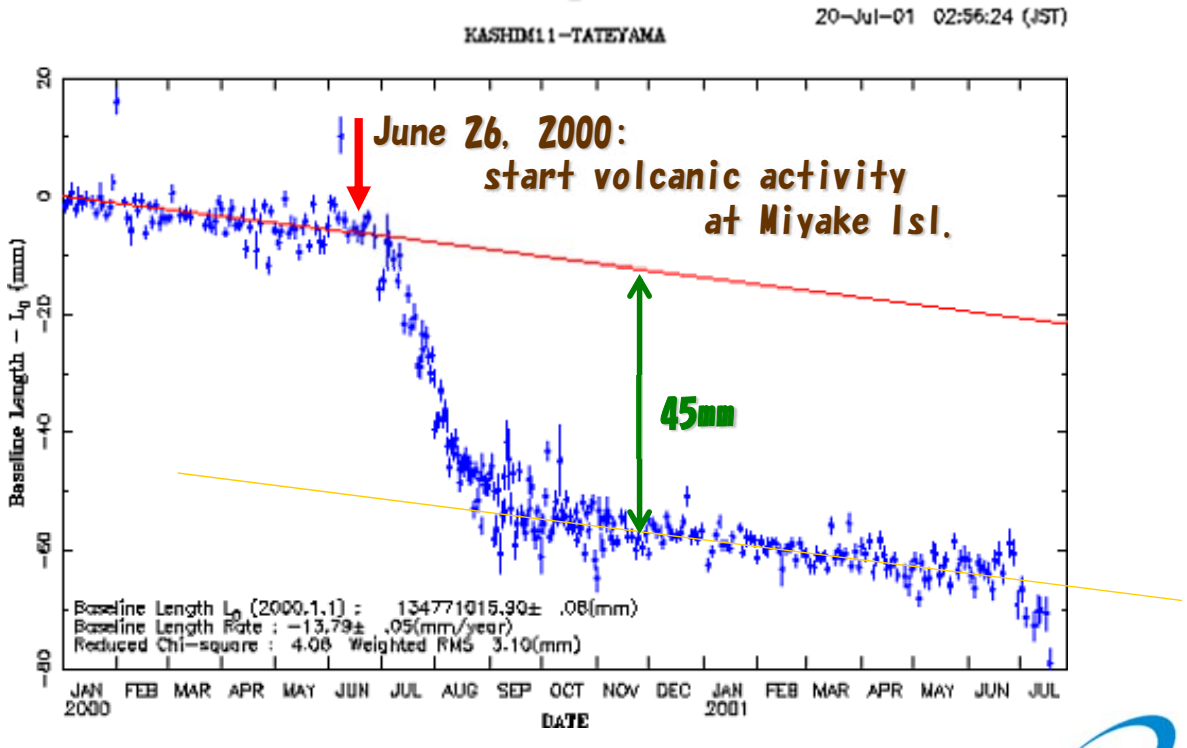

# Real Time VLBI (e-VLBI)



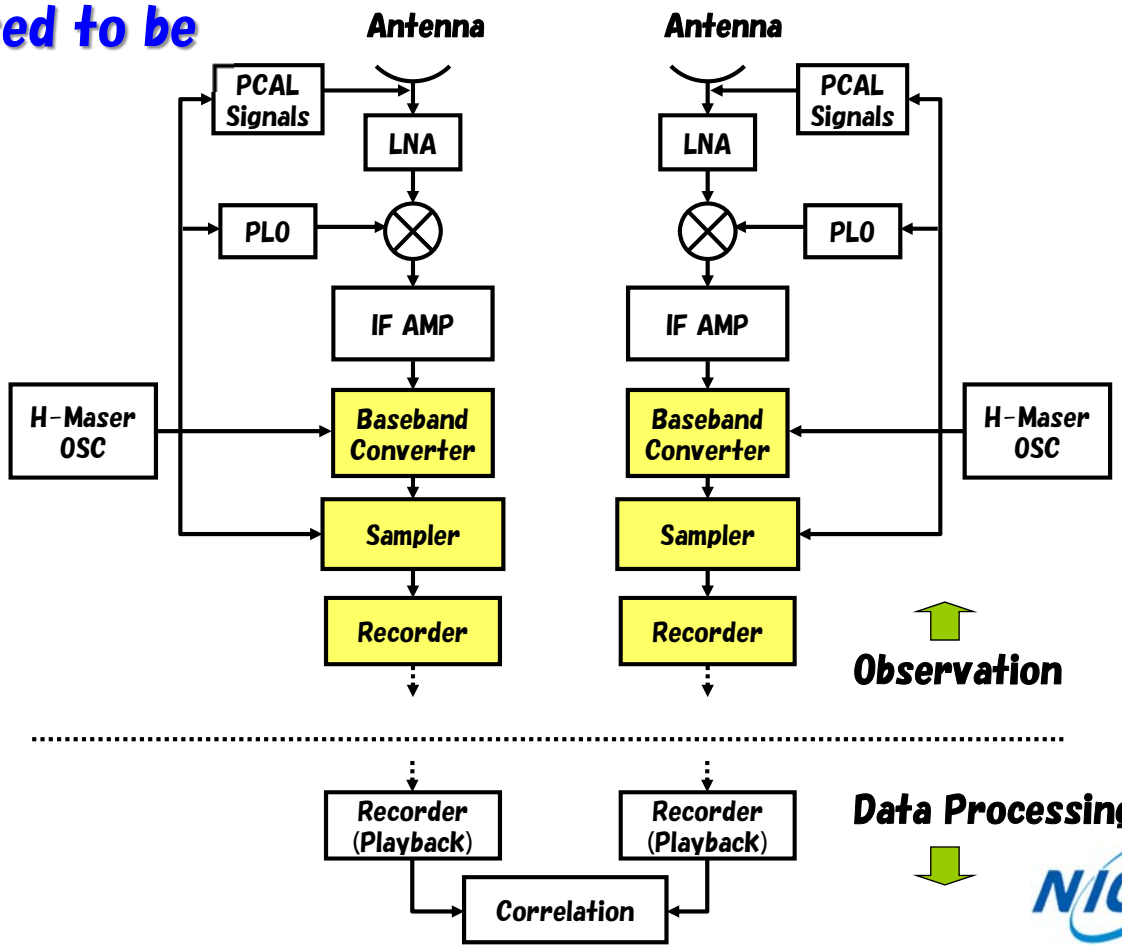
# Around Tokyo

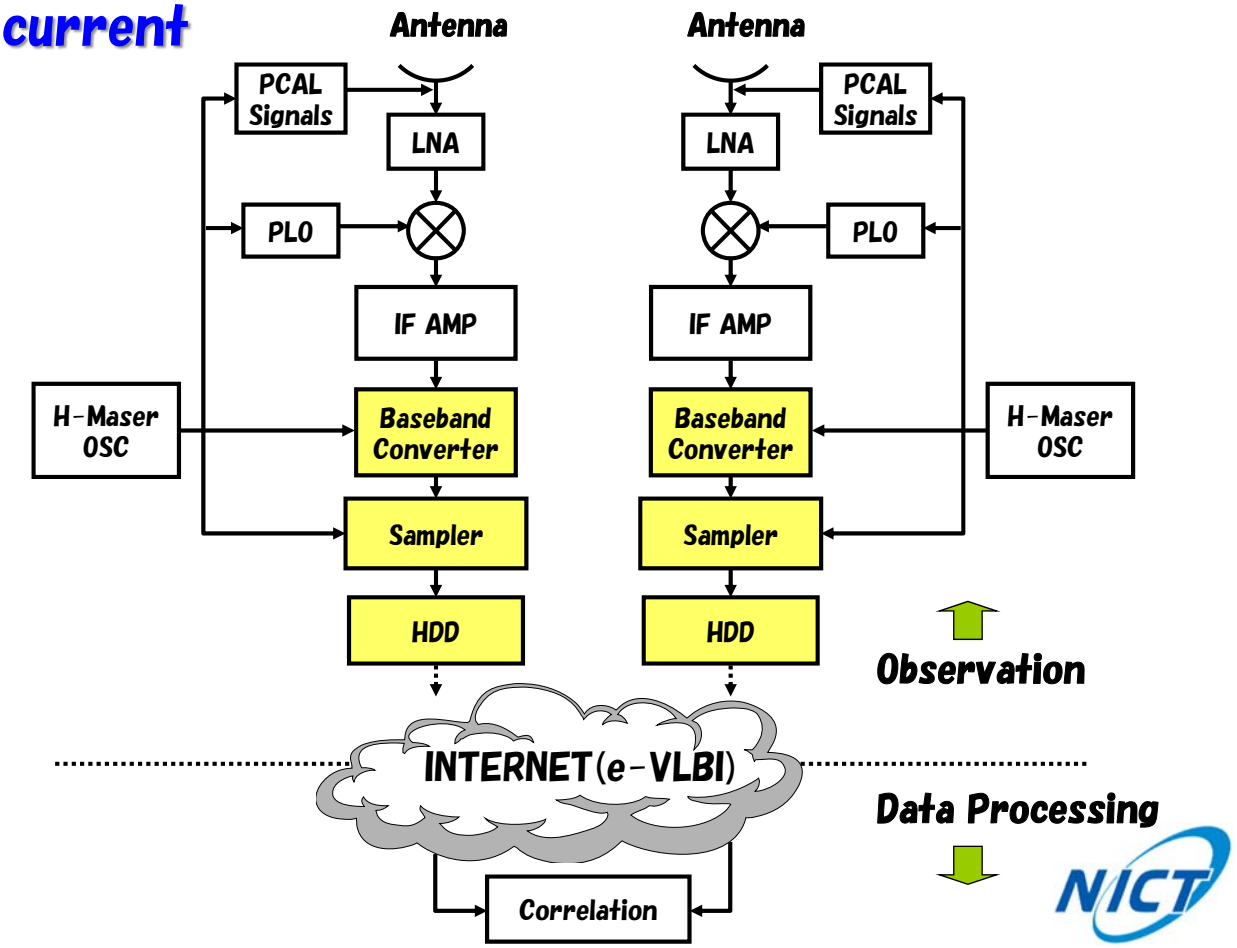


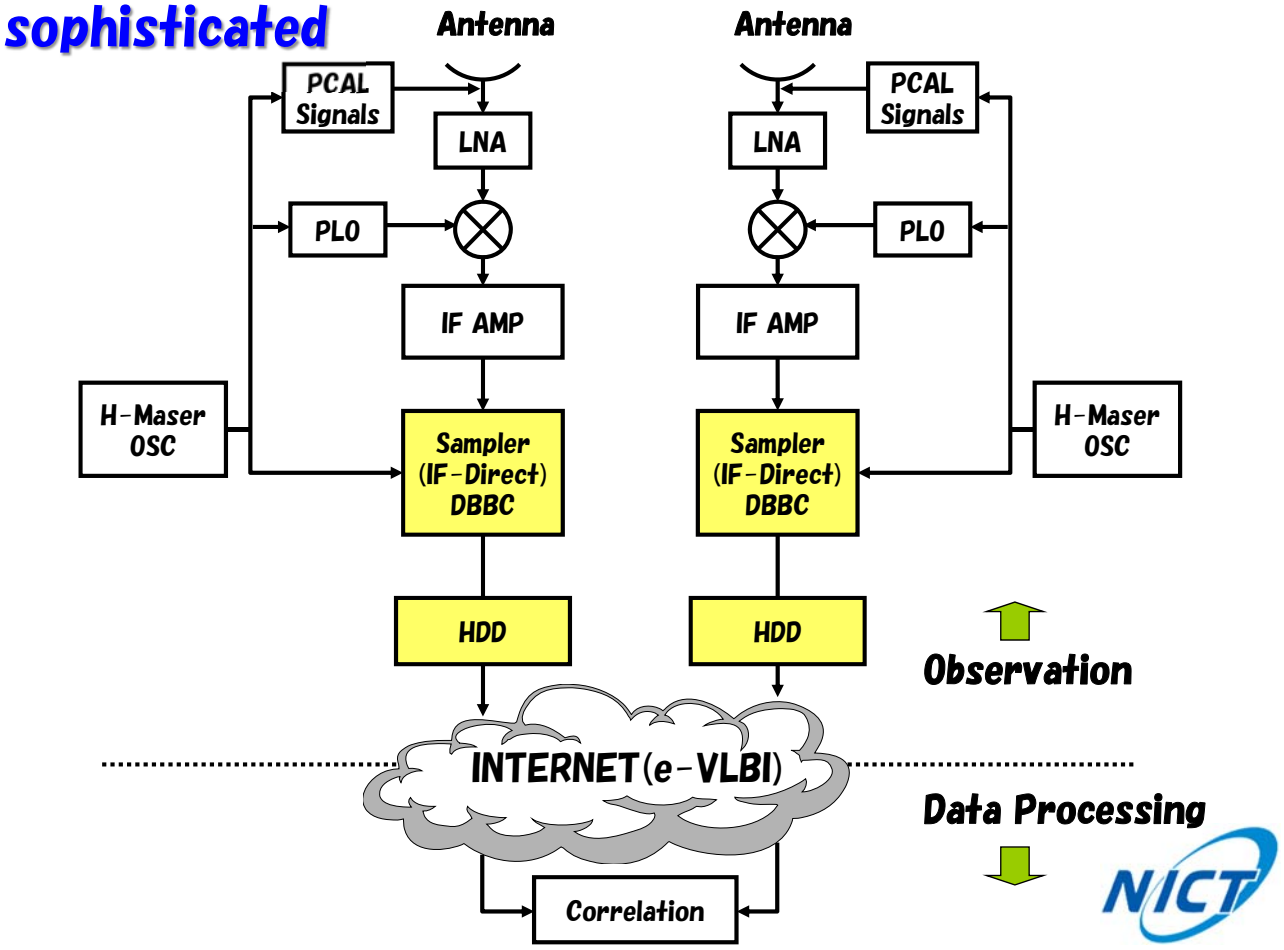

# Kashima – Tateyama baseline



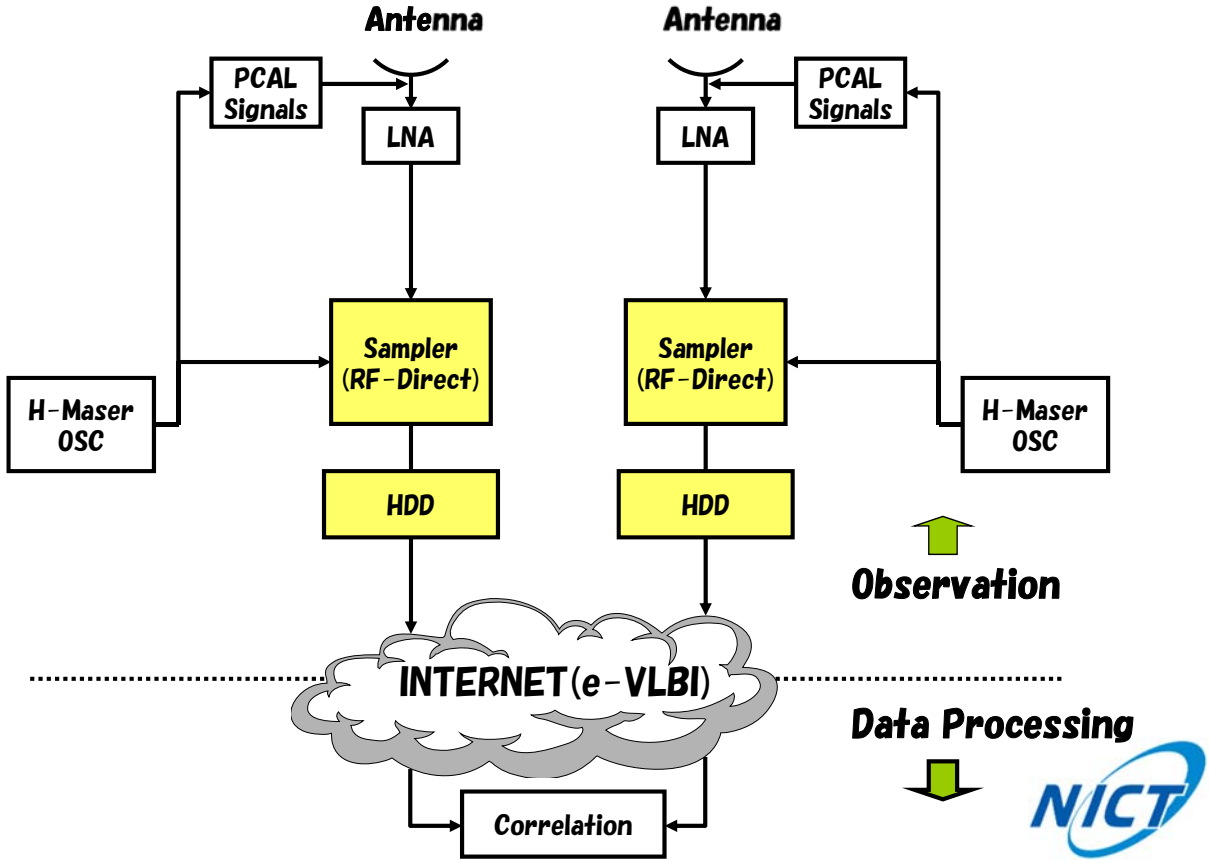
# Evolution of VLBI System




current
Antenna
Antenna
PCAL Signals
LNA
PLO
IF AMP
H-Maser OSC
Baseband Converter
Sampler
HDD
Observation
INTERNET(e-VLBI)
Data Processing
Correlation
NICT


sophisticated
Antenna
Antenna
PCAL Signals
LNA
PLO
IF AMP
H-Maser OSC
Sampler (IF-Direct) DBBC
HDD
Observation
INTERNET(e-VLBI)
Data Processing
Correlation
NICT

# more sophisticated RF direct sampling




# Merits

No use of analog frequency converter

⇩

Simple receiving system
(minimum use of analog circuits)

⇩

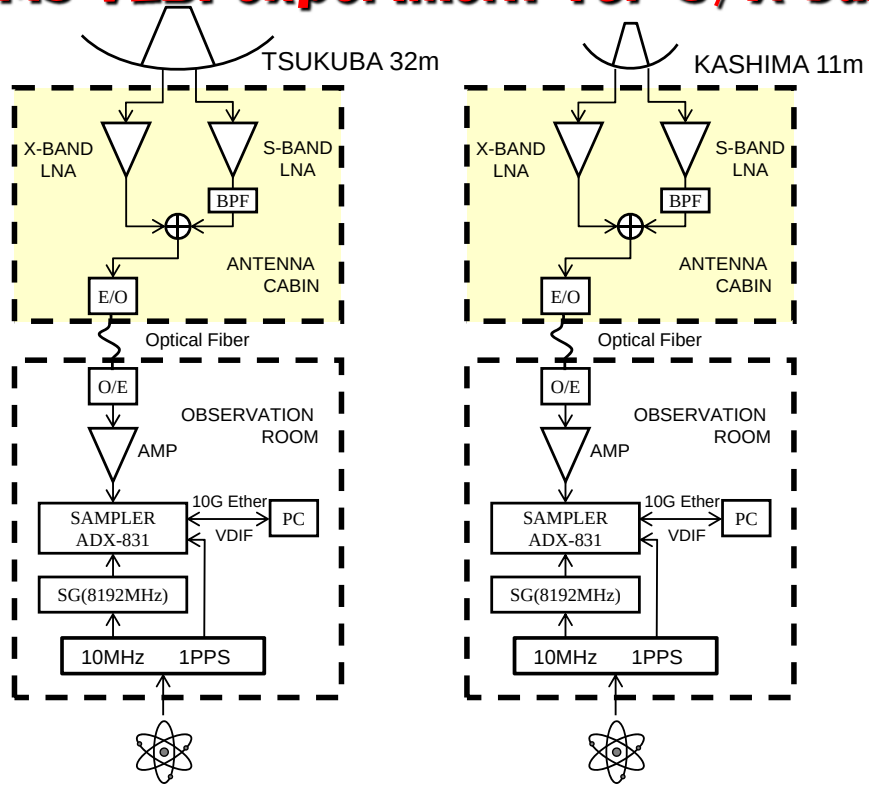
◎more stable and reliable
=> accuracy improvement
◎low cost system

# Proof-of-Concept Experiment

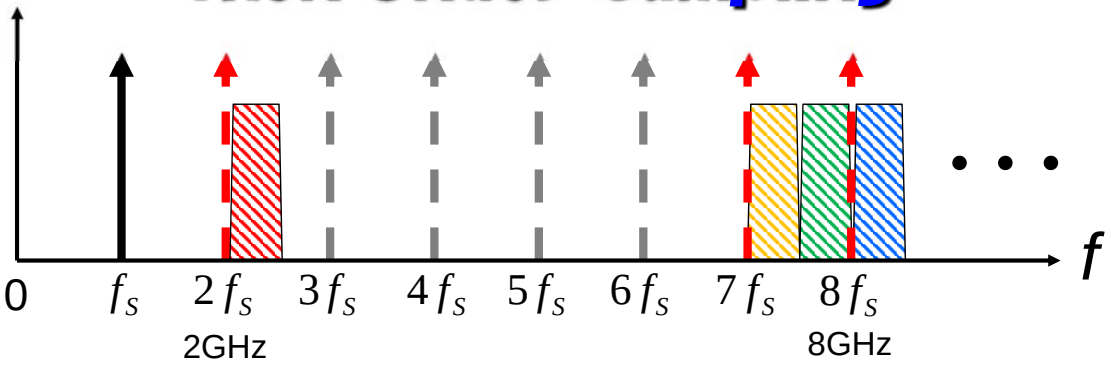
## DSAMS: Direct Sampling Applied to Mixed Signals

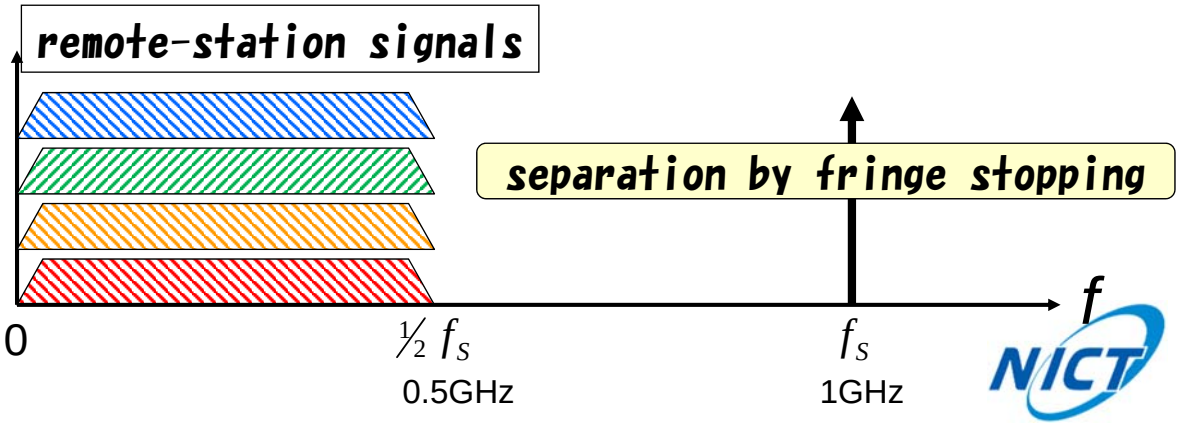
## Proof-of-Concept Experiment

## DSAMS VLBI experiment for S/X bands

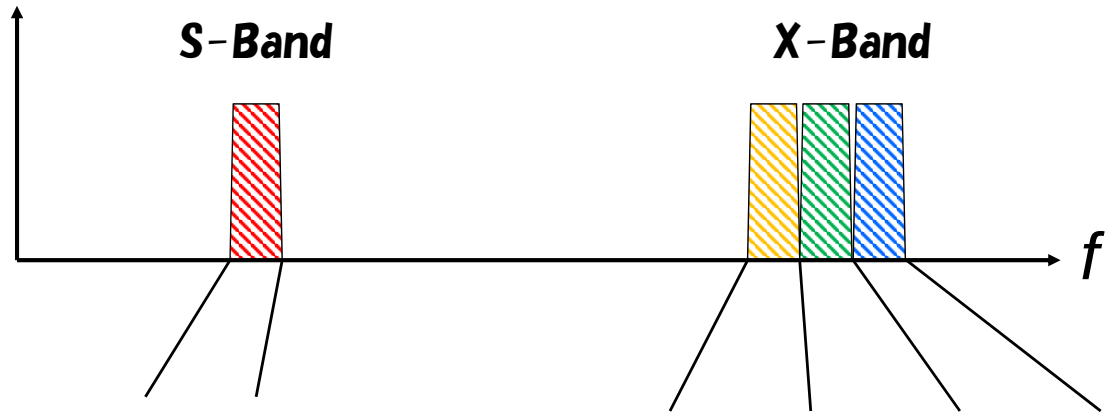


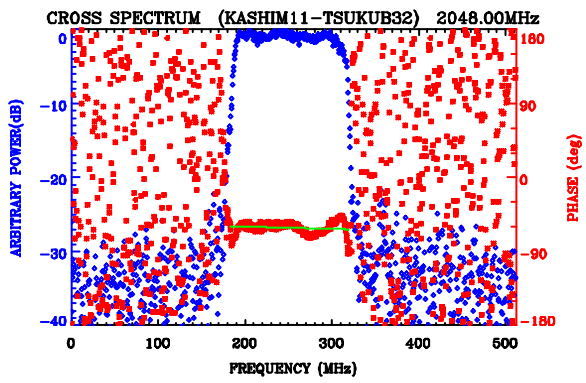
# Merging S and X bands at RF then Under Sampling

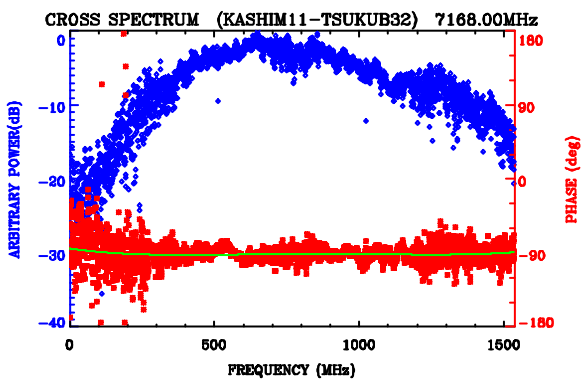


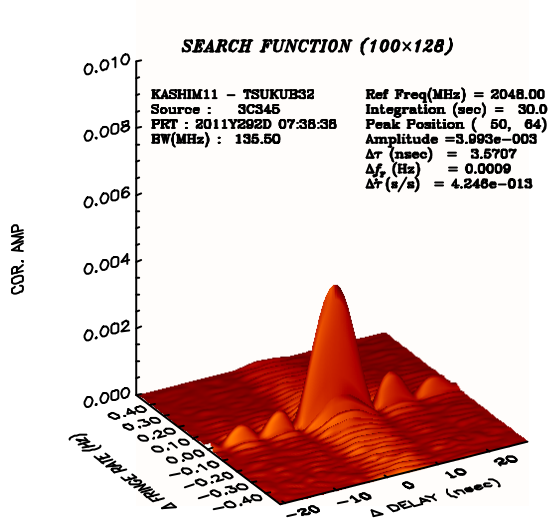

# Results of DSAMS VLBI Experiment



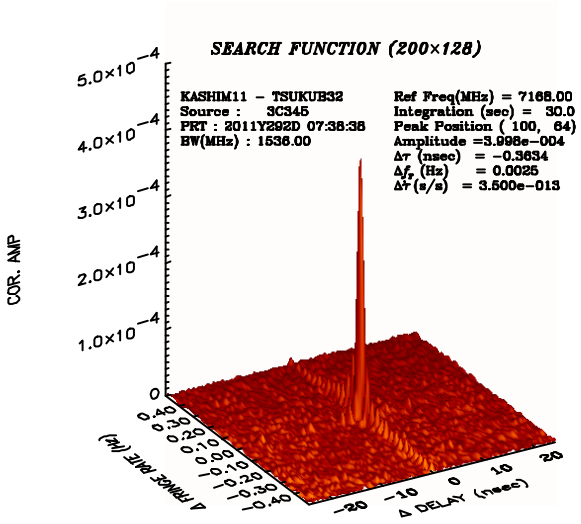



# DSAMS VLBI Experiment



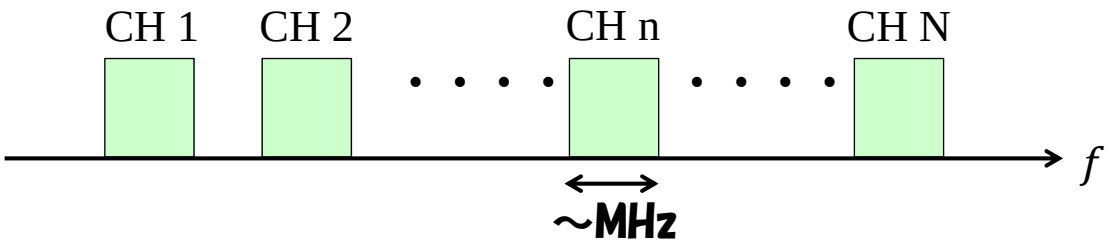

S-Band

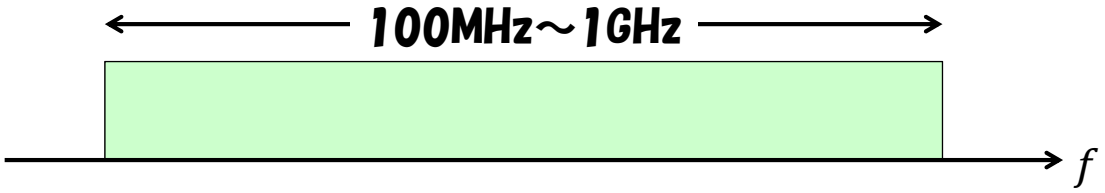



X-Band

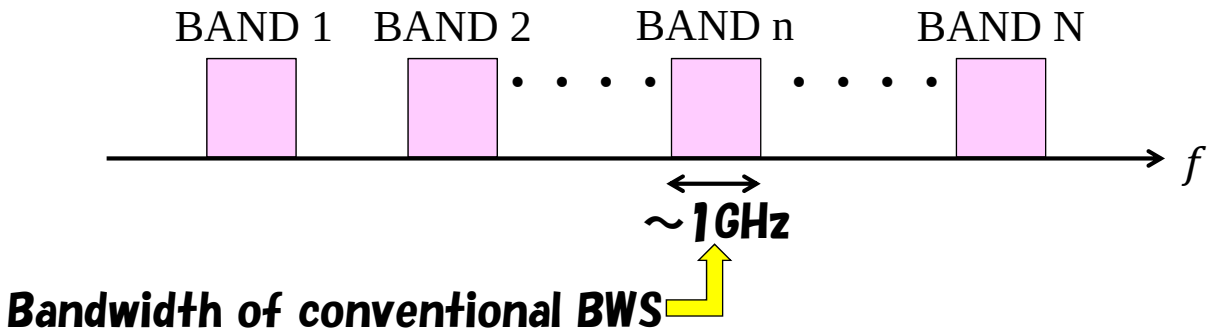
# Wideband Bandwidth Synthesis (WBWS)

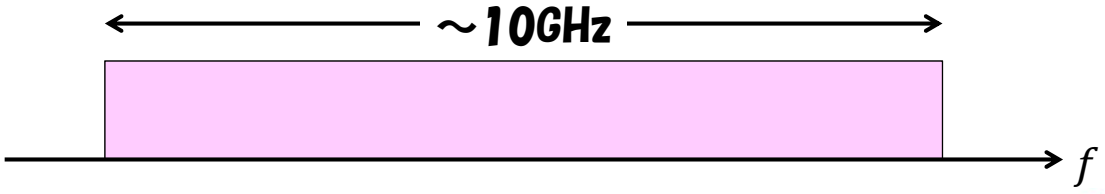
# Conventional Bandwidth Synthesis




# Wideband Bandwidth Synthesis (WBWS)



# Search Function

## Conventional Bandwidth Synthesis

$$F(\Delta\tau,\Delta\dot{\tau}) = \left| \int_0^B \left\{ \int_0^T S(f,t) e_0^{-i2\pi f_0 \Delta\dot{\tau} t} dt \right\} e^{-i2\pi\Delta\tau f} df \right|$$

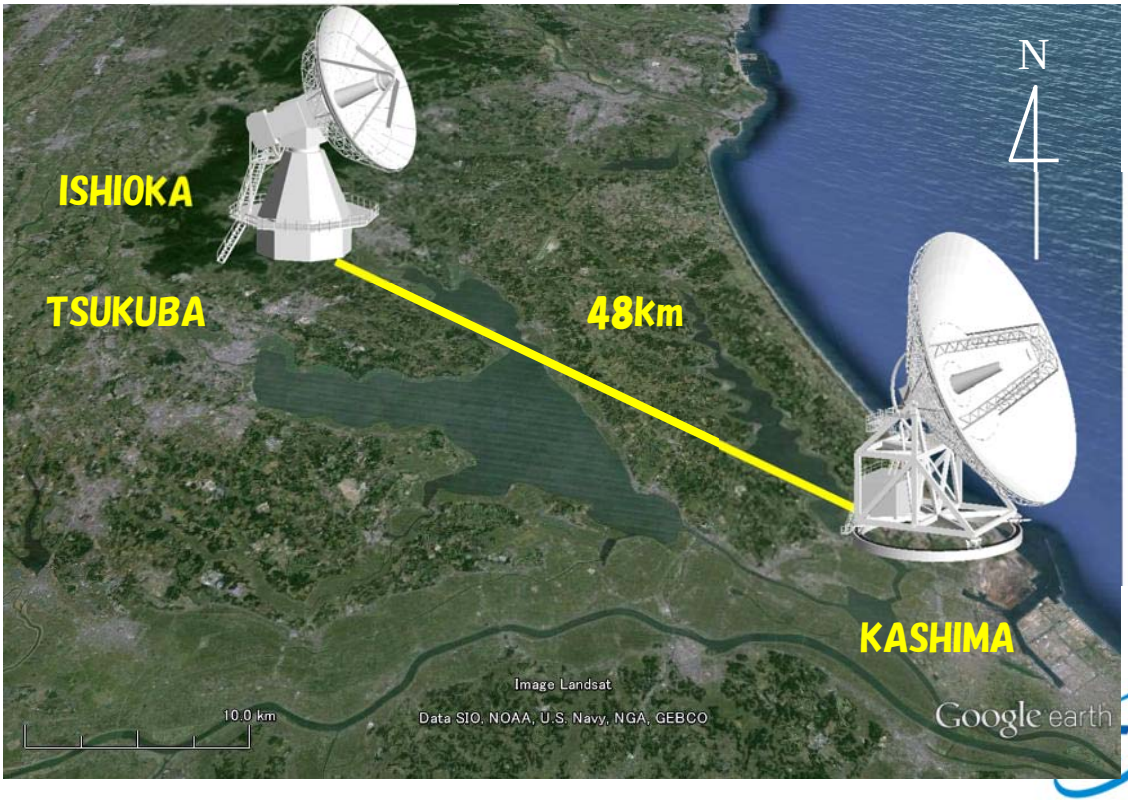
## Wideband Bandwidth Synthesis

$$F(\Delta\tau,\Delta\dot{\tau}) = \left| \int_0^B \left\{ \int_0^T S(f,t) e_0^{-i2\pi (f_0+f)\Delta\dot{\tau} t} dt \right\} e^{-i2\pi\Delta\tau f} df \right|$$

$S(f,t)$: **combined cross spectrum over all bands**

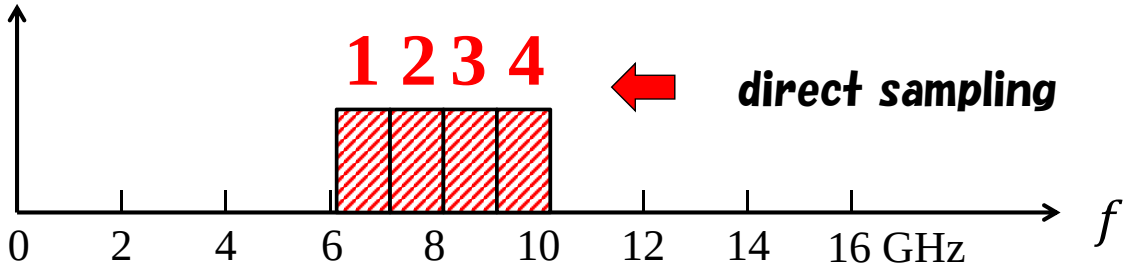
$f_0$ : **reference RF frequency**

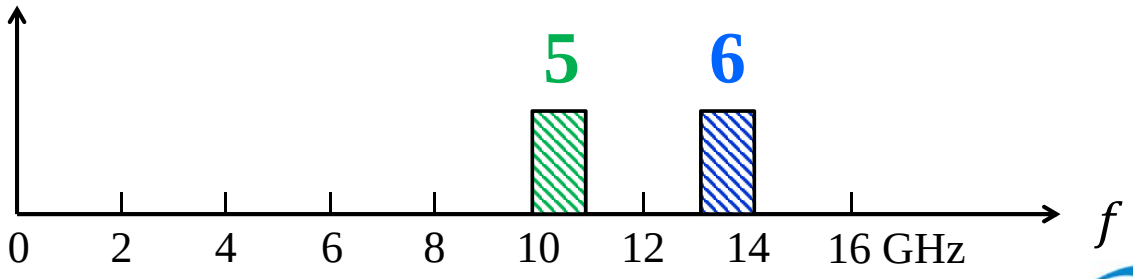
# Kashima – Ishioka baseline



# Frequency Allocation

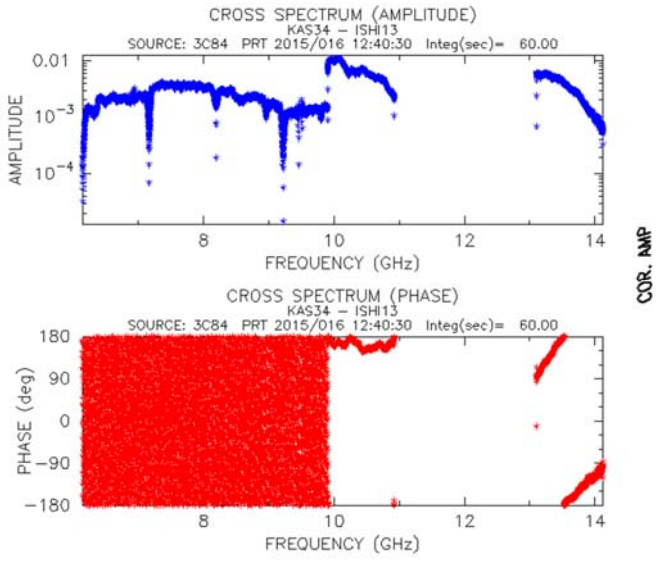
**Bandwidth : 1024MHz**



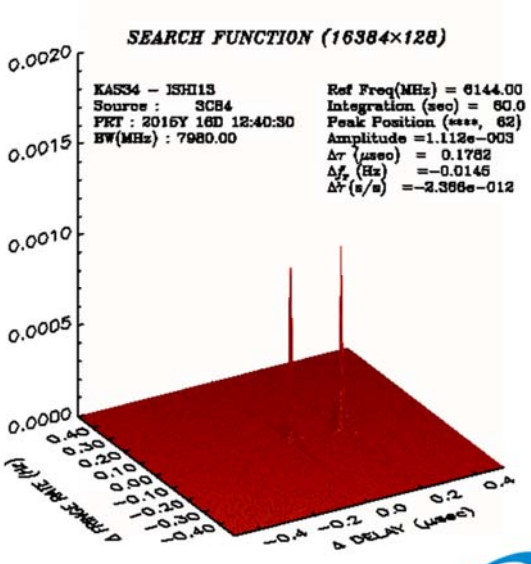




# combine all bands without any correction

## cross spectrum

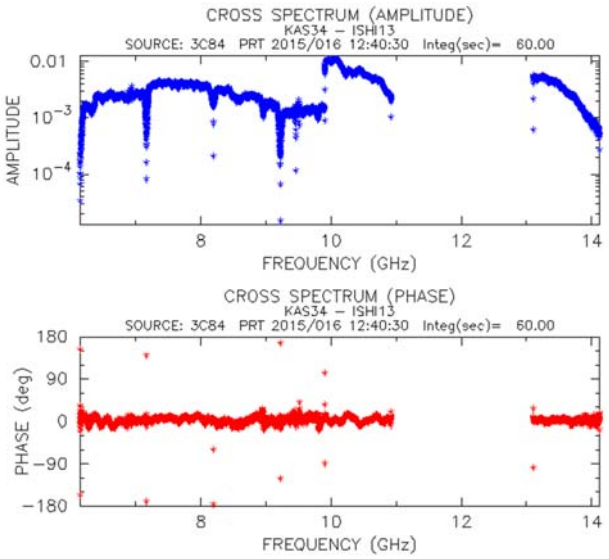



## search function

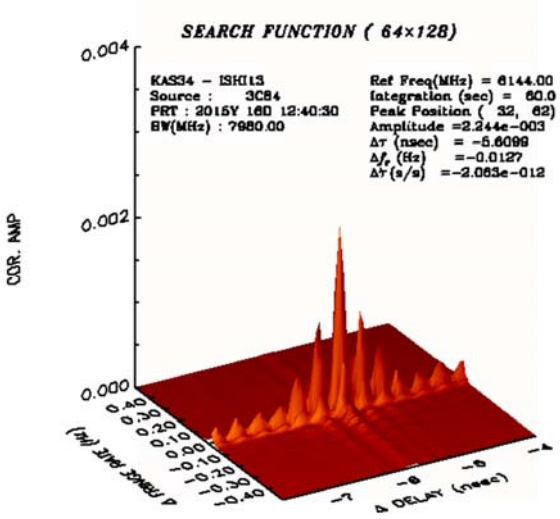


**combine after band delay and phase corrections using reference scan data**

cross spectrum




search function



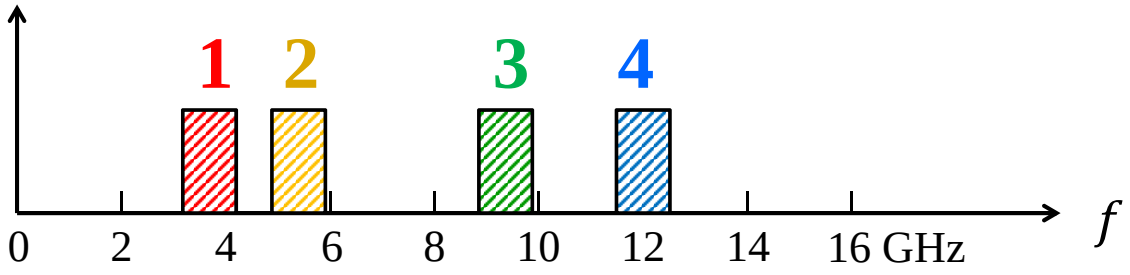

theoretical error = 27fs

integration period = 60 sec

# another example

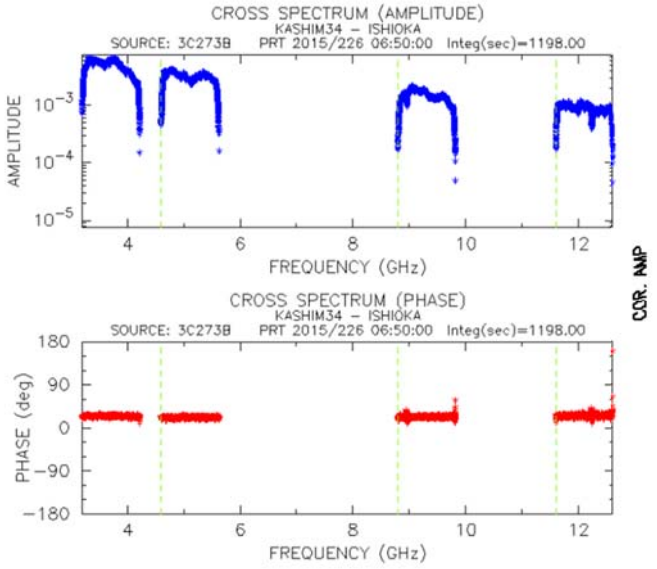
## Frequency Allocation

Bandwidth : 1024MHz

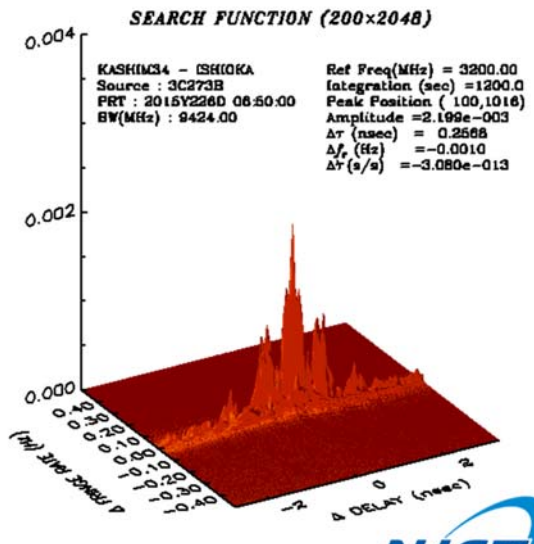


# after Wideband Bandwidth Synthesis

## cross spectrum

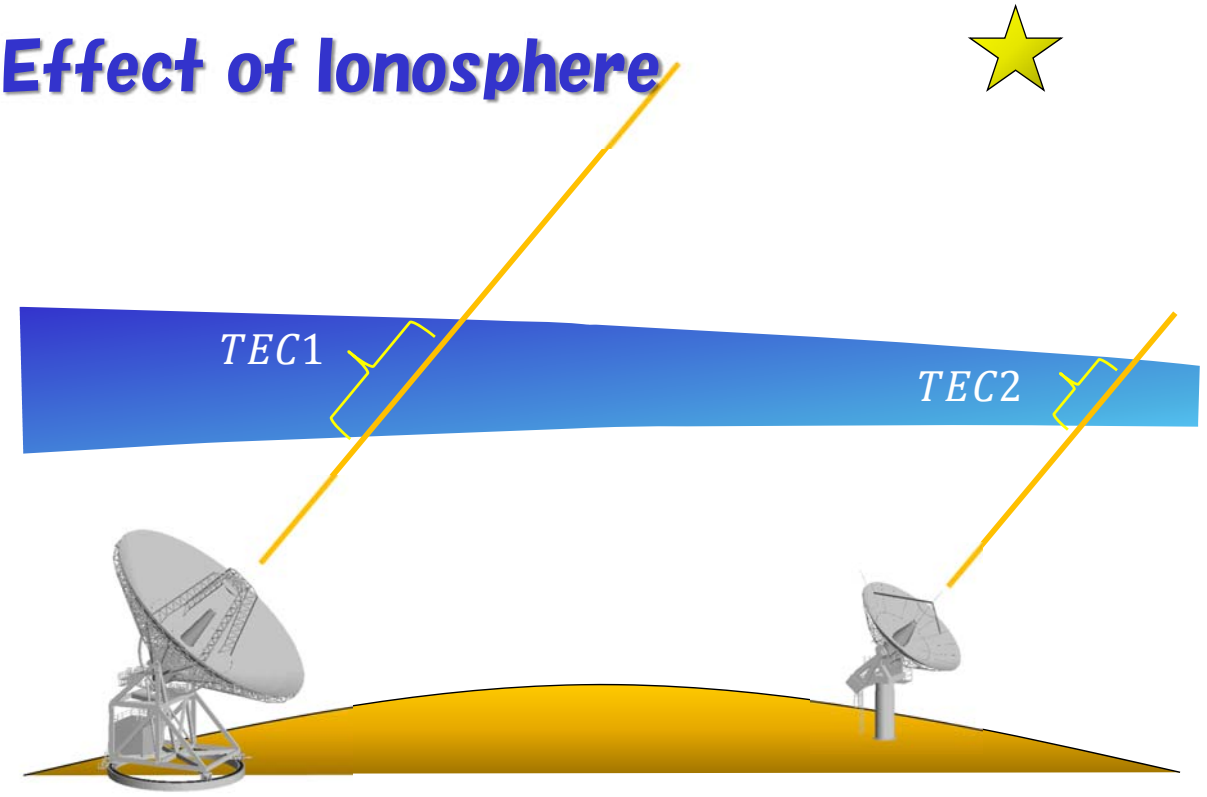



## search function



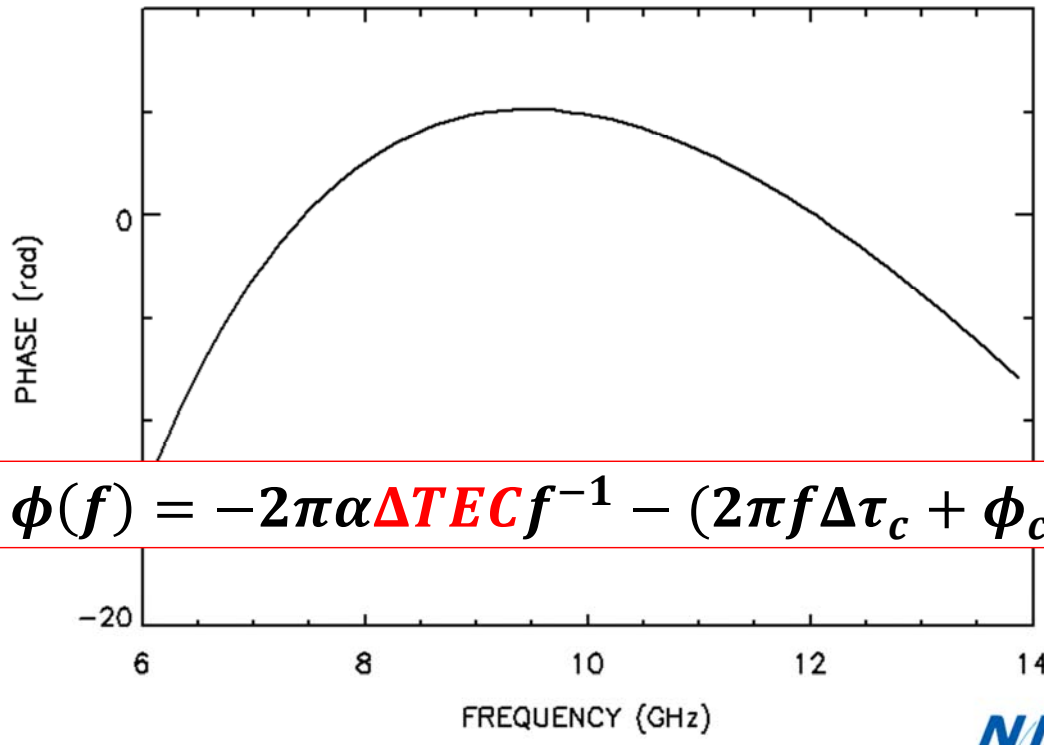

integration period = 1200 sec

# Effect of Ionosphere



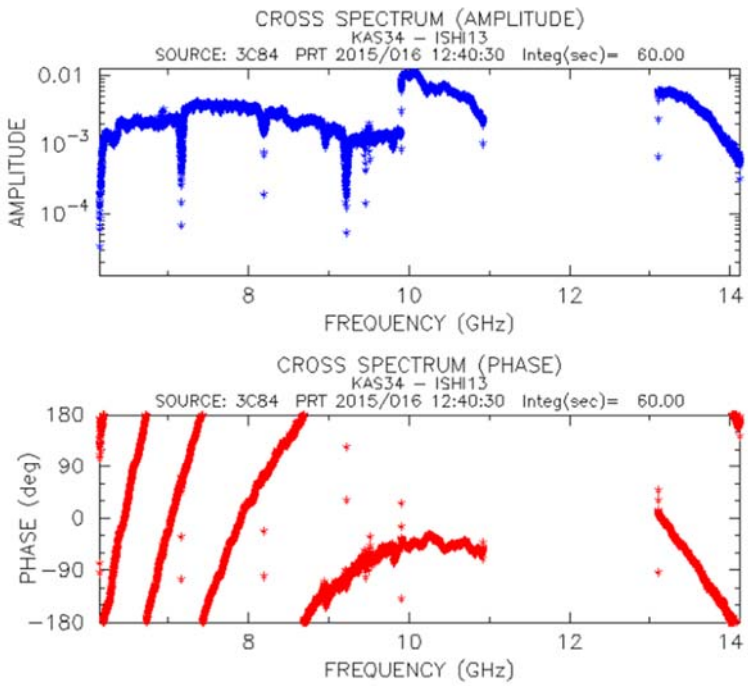

$$\Delta TEC = TEC1 - TEC2$$

# Example of Phase Spectrum after WBWS




$$\phi(f) = -2\pi\alpha\Delta TEC f^{-1} - (2\pi f \Delta\tau_c + \phi_c)$$

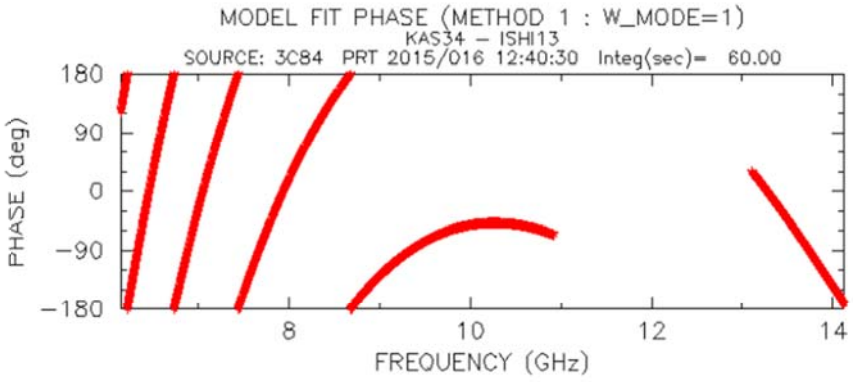
# Simulated Cross Spectrum (after WBWS)



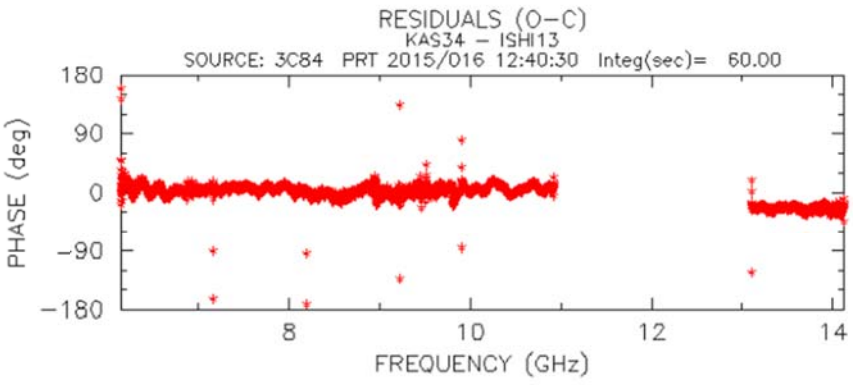

$\Delta TEC = +100\ TECU$

# Model phase after TEC estimation and residual phase

model phase

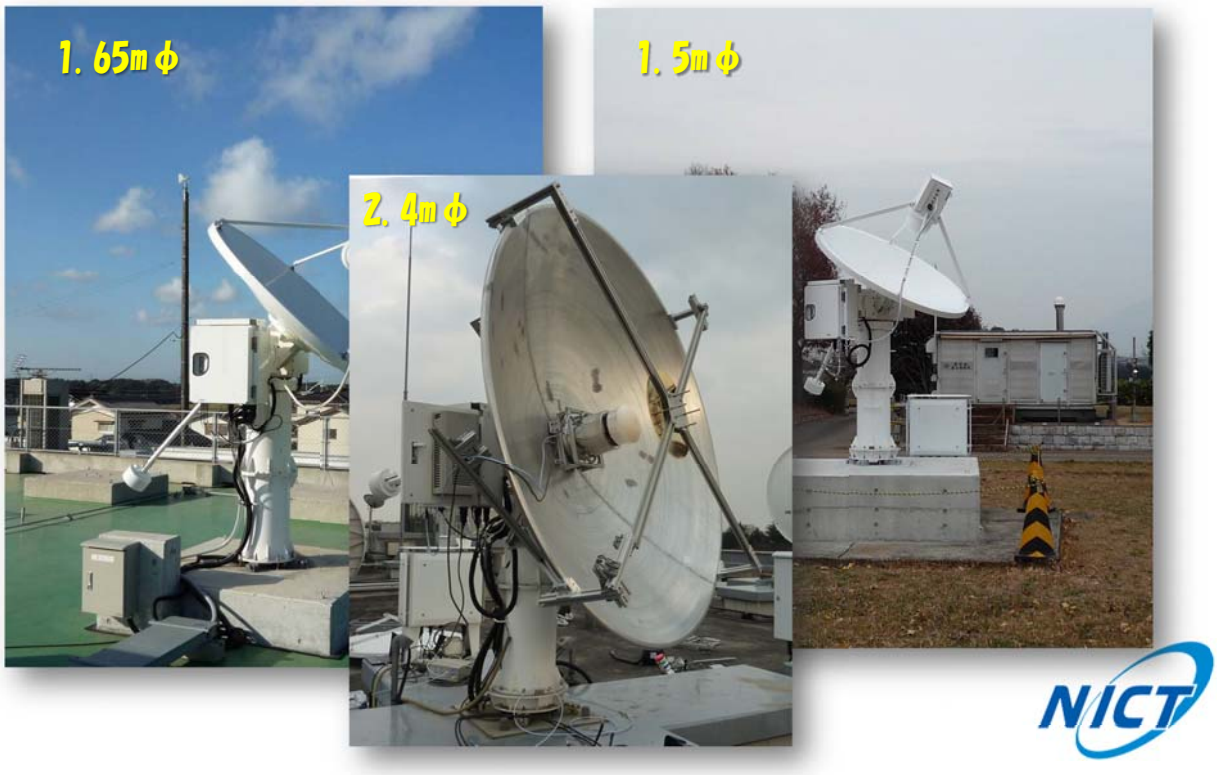



residual phase




# VLBI With a Small Antenna System

# MARBLE System




# Easy Installation (only by human power)

# VGOS (<=VLBI2010)

## defined by IVS

**V**LBI
**G**lobal
**O**bserving
**S**ystem

IVS: International VLBI Service
for Geodesy & Astrometry

NICT

# VGOS GOAL

- 1-mm position accuracy on global scales
- continuous measurements for time series of station positions and Earth orientation parameters
- turnaround time to initial geodetic results of less than 24 hours

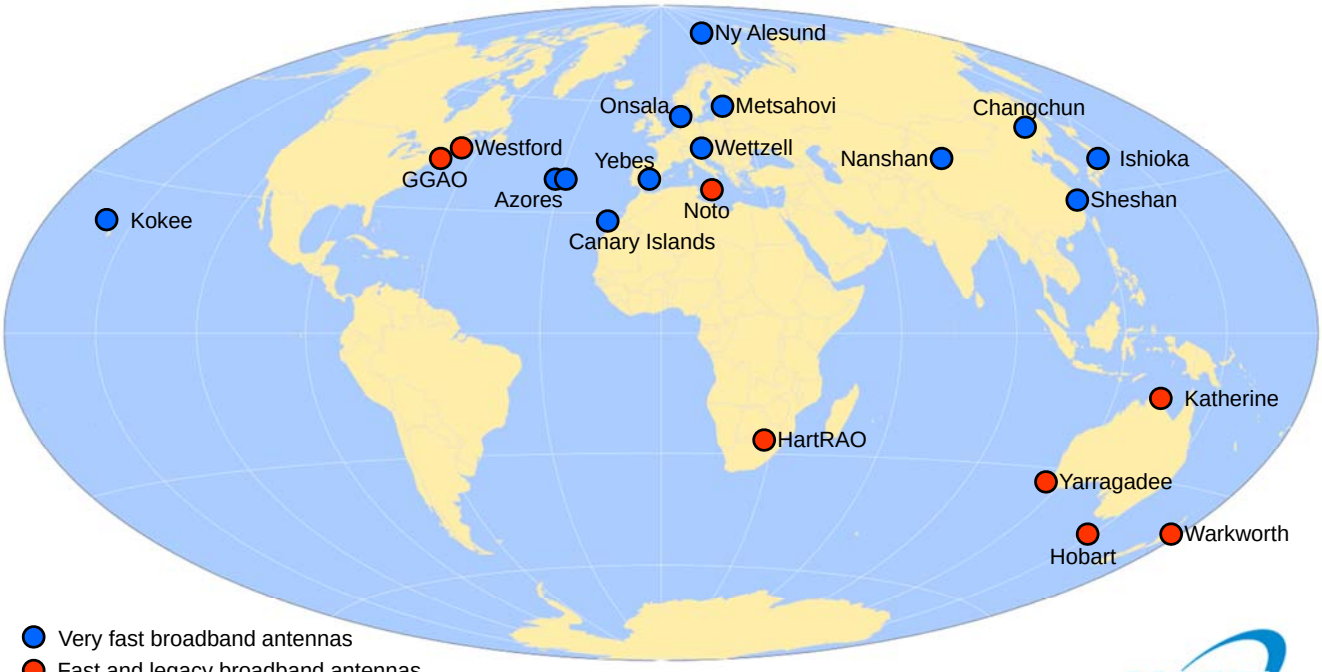
NICT

# Summary of VGOS Specifications

| | Current | VGOS |
|---|---|---|
| Antenna Size | 5 – 100 m dish | ~ 12 m dish |
| Slew Speed | ~0.3 – 3.3 deg/sec | ≥ 12 deg/sec (single ant)<br>≥ 5 deg/sec (pair ant) |
| Sensitivity | 200–15,000 SEFD | ≤ 2,500 SEFD |
| Frequency Range | 2/8 | 2 – 14 GHz |
| Polarization | RHCP | Dual Linear Polarization |
| Data Rate | 128, 256 Mbps | 8 – 16 Gbps future 32 Gbps |
| Data Transfer | Ship disks, some e-transfer | e-transfer, e-VLBI, some ships |

## VGOS Network anticipated for 2017

Strong in the North Polar Region
Weaker in the Americas and Pacific Region




(after Petrachenko, EGU, Vienna, 2013)

# First VGOS Antenna in Japan

Ishioka 13 m
GSI

# Outlook for the future

- Wideband Bandwidth Synthesis (WBWS) on the inter-continental baseline to proof ionospheric correction
- Evaluate broadband system proposed in VGOS
- Continuous technology development for e-VLBI