Precise Frequency Transfer Experiments using VLBI and Other Techniques

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Outline

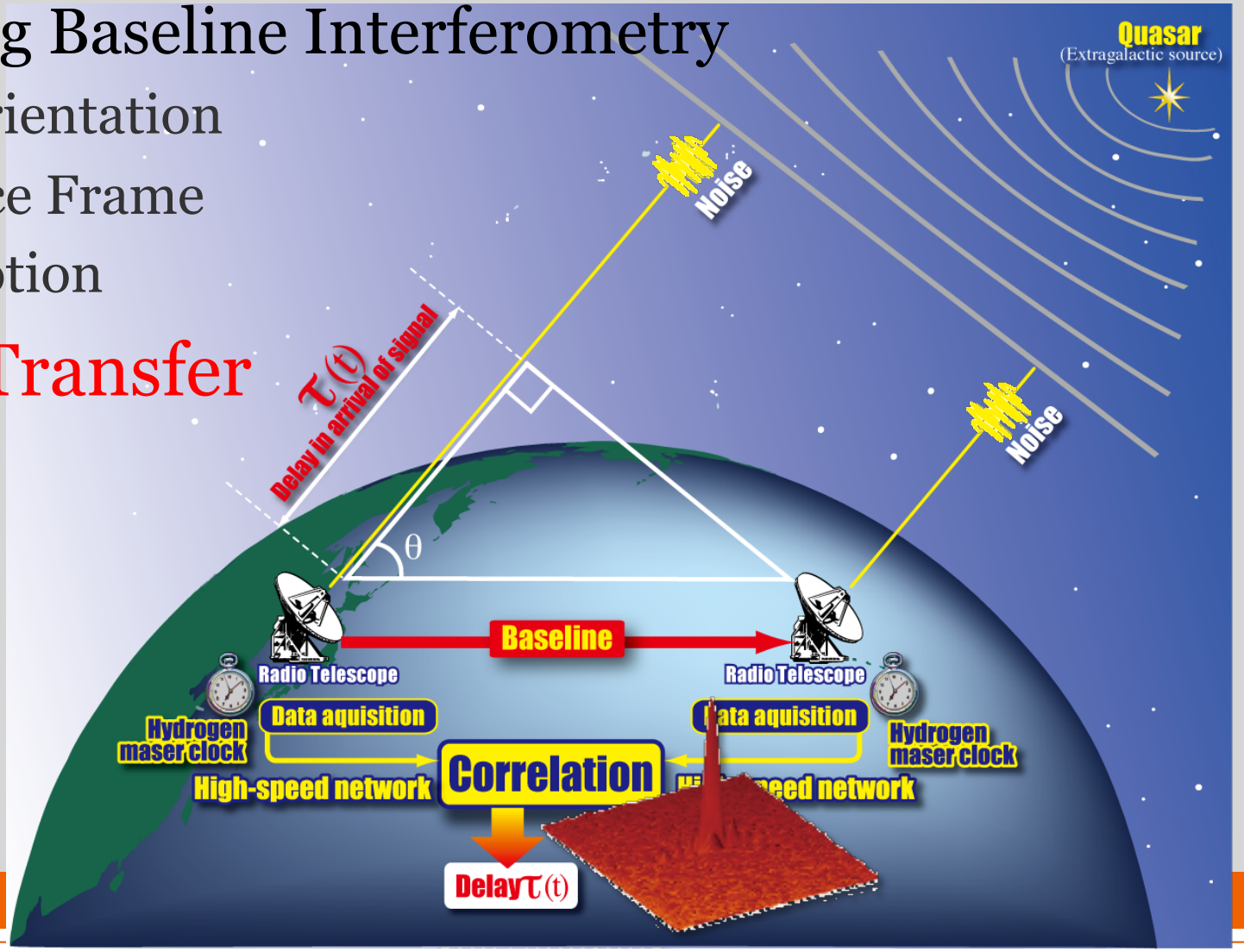
- Introduction
- T&F Transfer using Space Geodetic and Other Techniques
  - VLBI, GNSS, TWSTFT, TCE/ETS-VIII
- Result of Comparison Experiment
- Simulation of VLBI T&F Transfer
- Summary
- Outlook

Space-geodetic techniques for T&F transfer

Technique	Status	T&F methods
GNSS (GPS, GLONASS, GALILEO, QZSS, …)	In use	Common view, All-in view, PPP
SLR	Under testing	T2L2
Very Long Baseline Interferometry (**VLBI**)	Proposed by NICT (this talk)	Baseline analysis

What is VLBI?

- Very Long Baseline Interferometry
  - Earth Orientation
  - Reference Frame
  - Plate Motion
  - Time Transfer

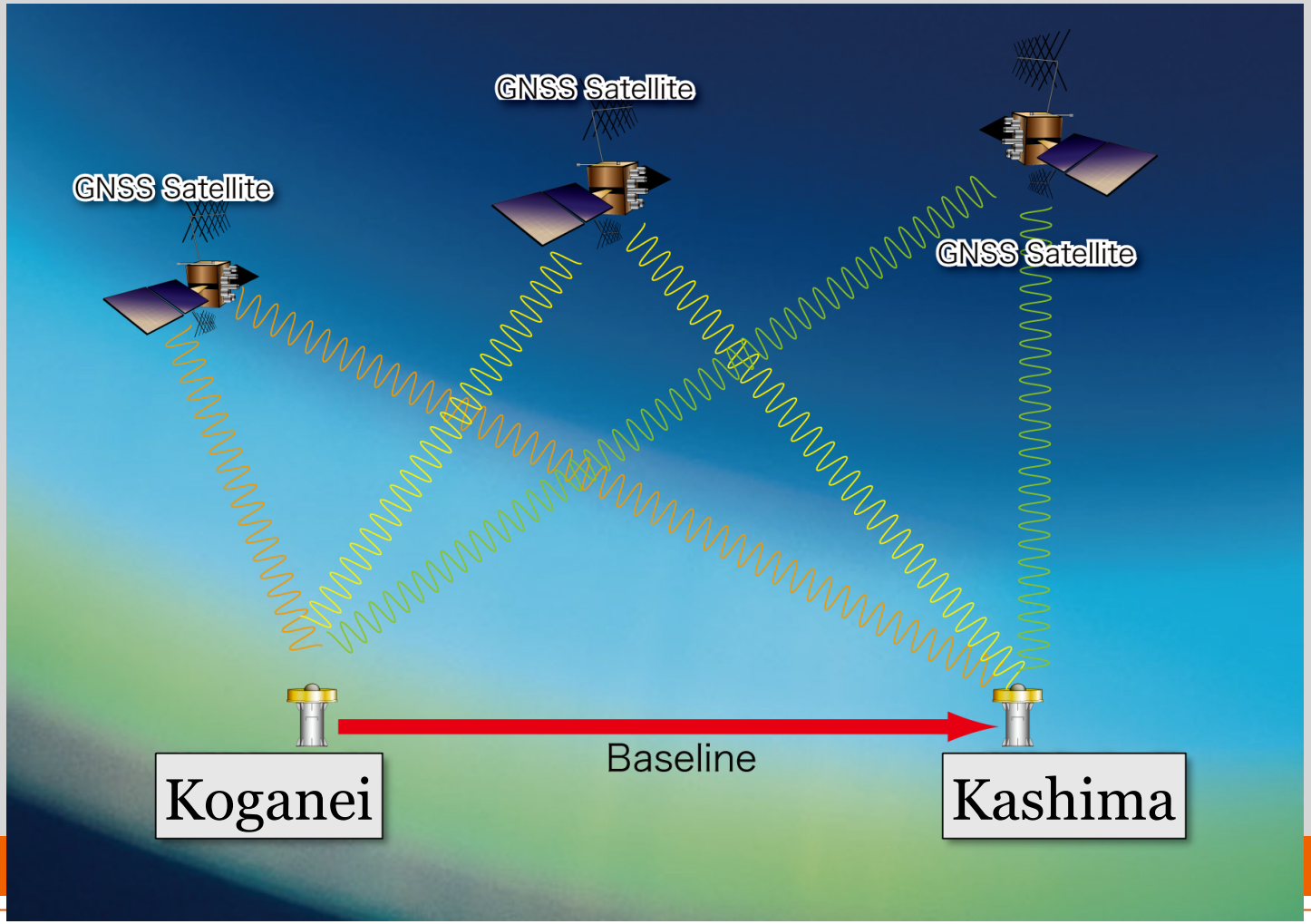


Measurement principle of VLBI

- Correlator provides 4 quantities
  - group delay (only this is currently used)
  - phase delay (future use)
  - amplitude
  - doppler shift
- Measuring different quasars allows computation of baseline length
- Clock and troposphere delay can be separated from station coordinates within space-geodetic analysis

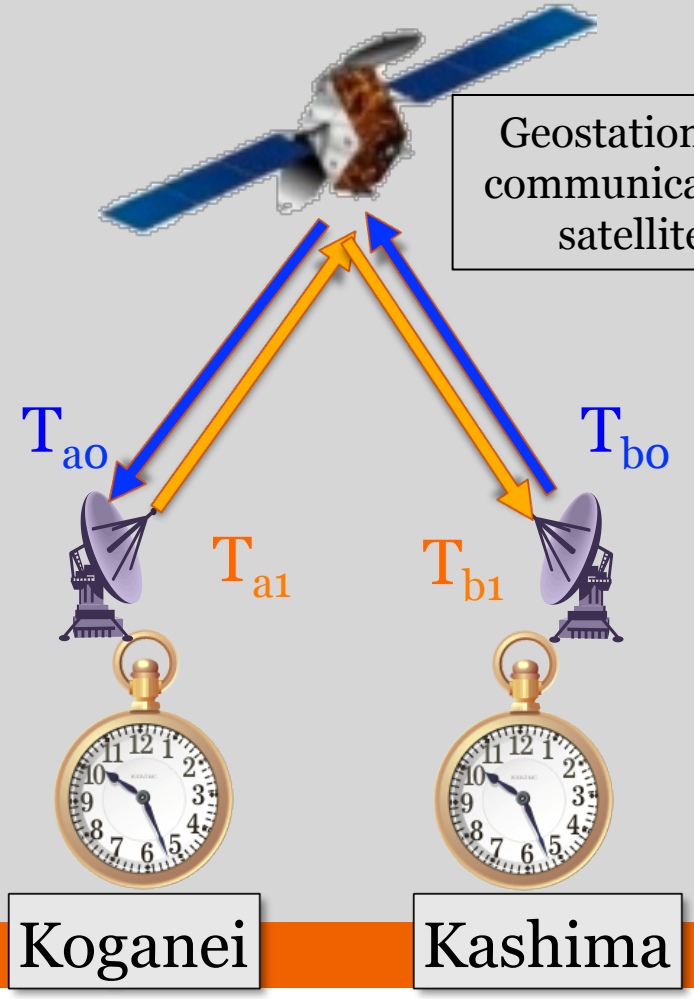
GNSS

- Global Navigation Satellite System



TWSTFT

- Two Way Satellite Time and Frequency Transfer



Dual Pseudo Random Noises (DPN)

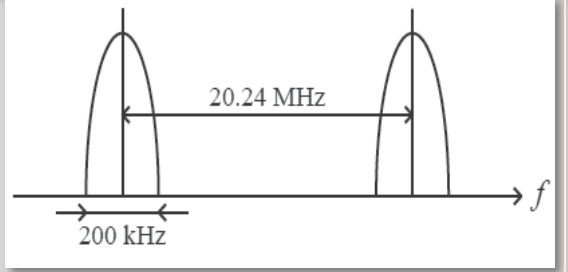
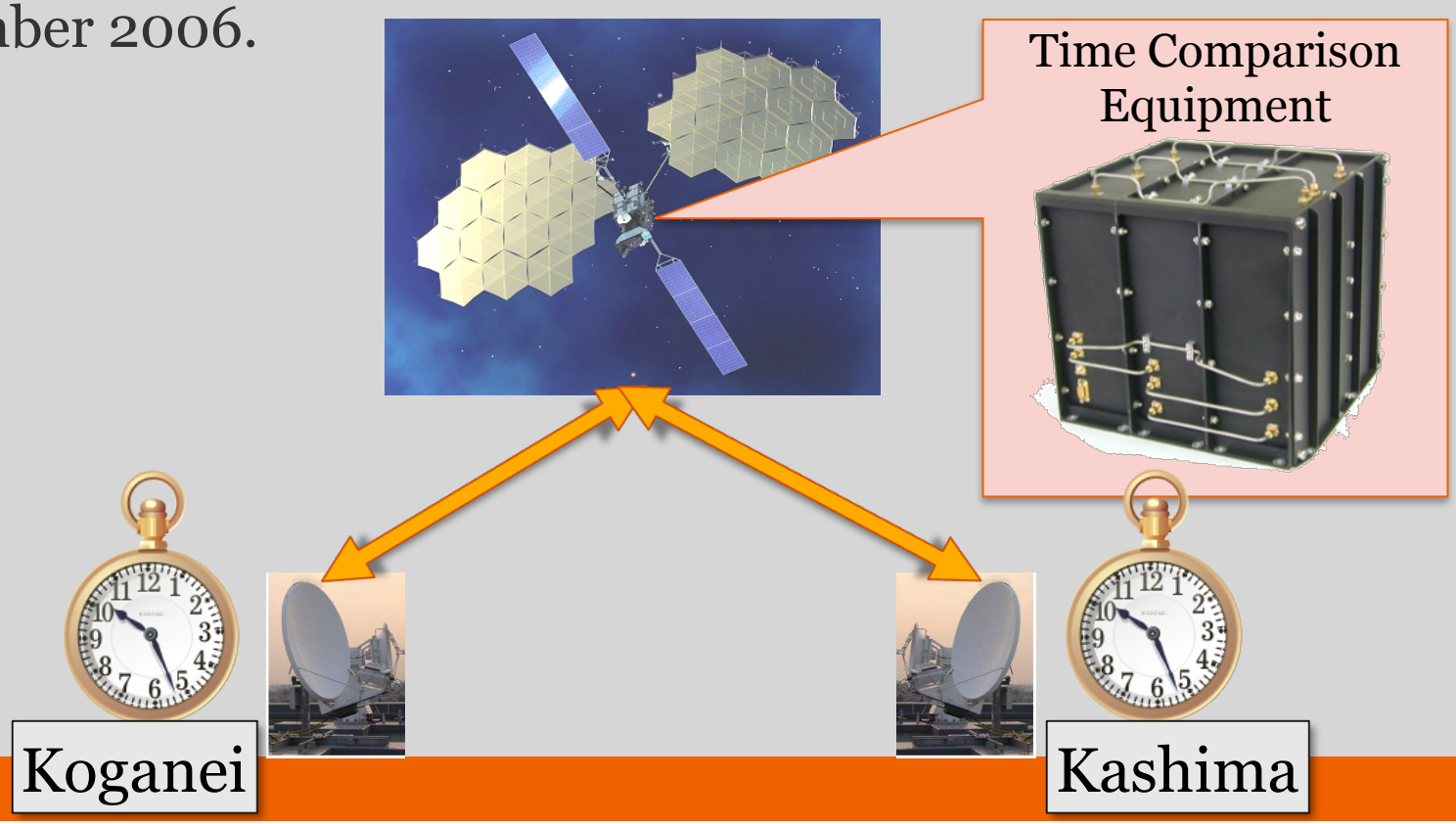


Figure 1 Dual pseudo-random noise code.

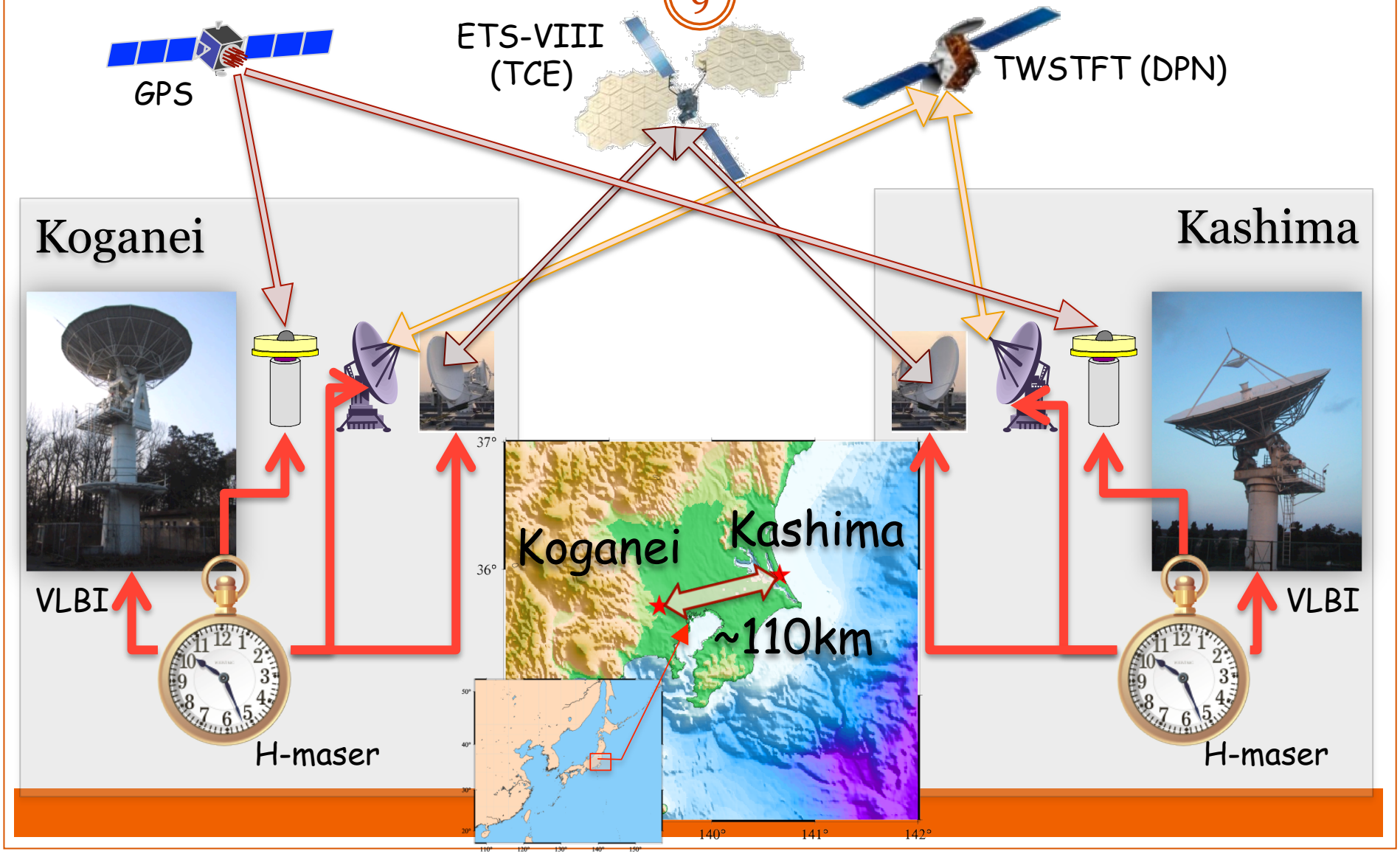
after Gotoh et al.[2010]

TCE (Time Comparison Equipment)

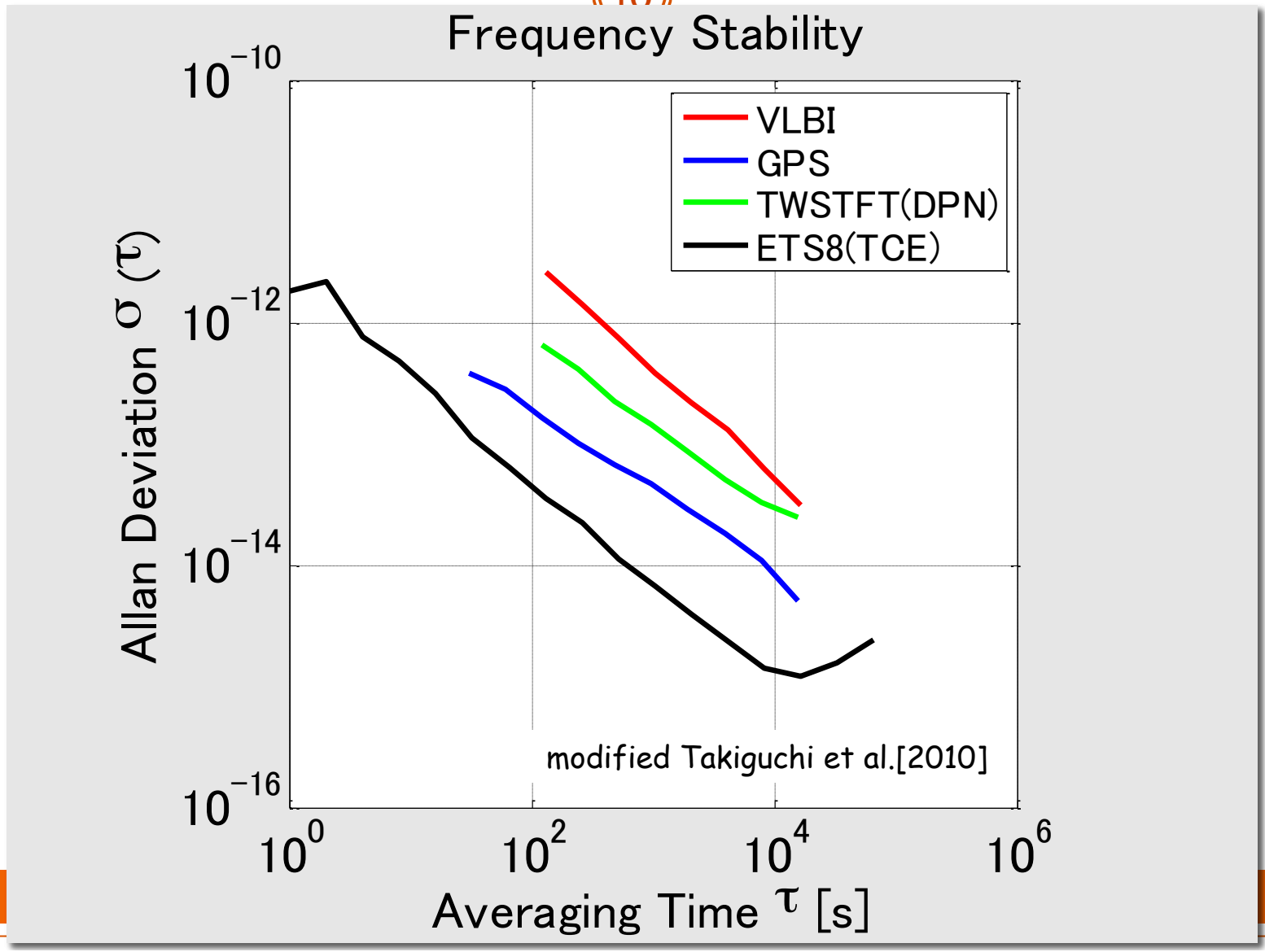
- TCE (Time Comparison Equipment) for ETS-VIII
  - ETS-VIII (Engineering Test Satellite VIII) is the JAXA's eighth technology test satellite. It was launched with the H2A on December 2006.



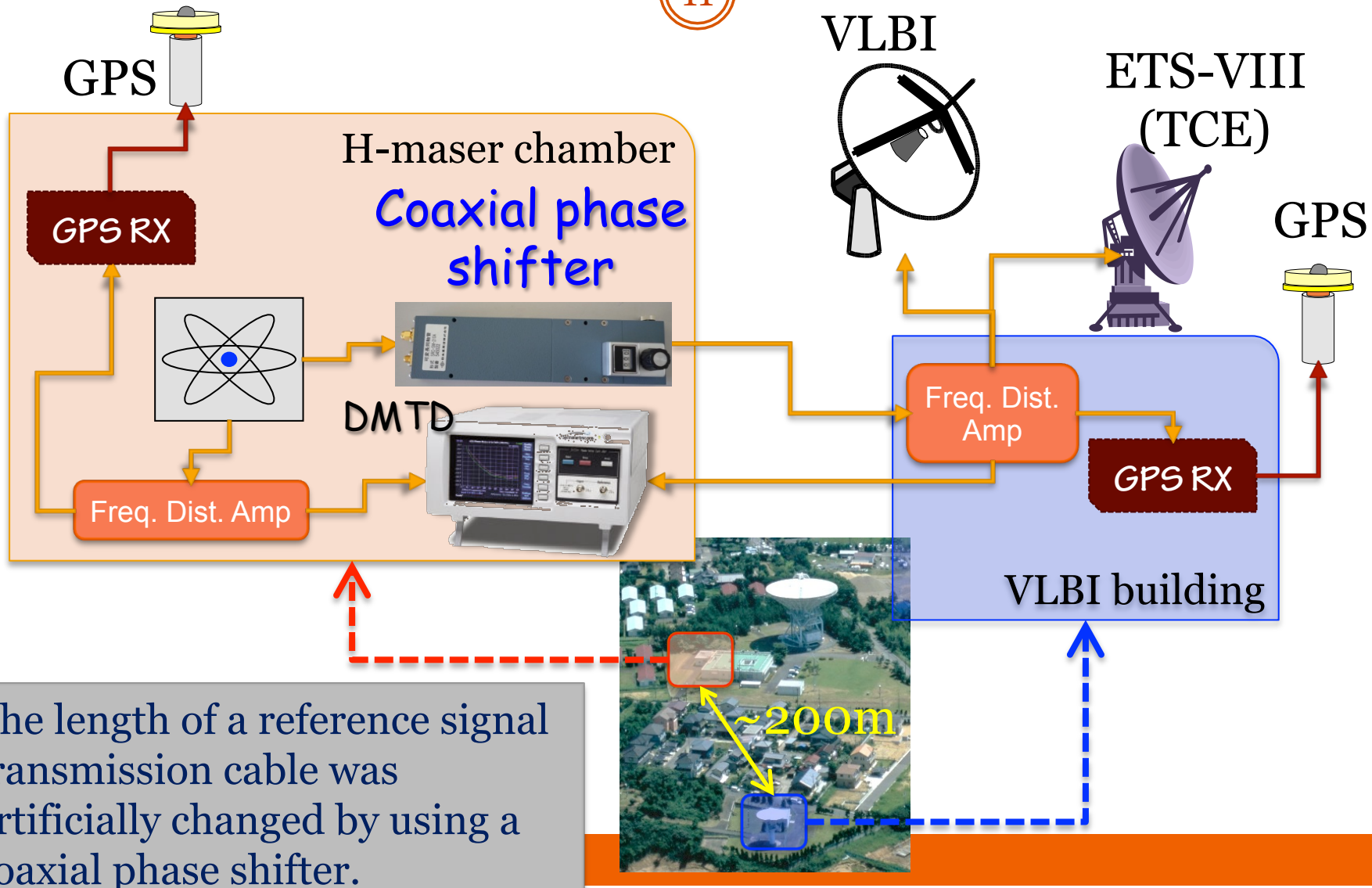
Comparison of Precise Frequency Transfer



Frequency Stability

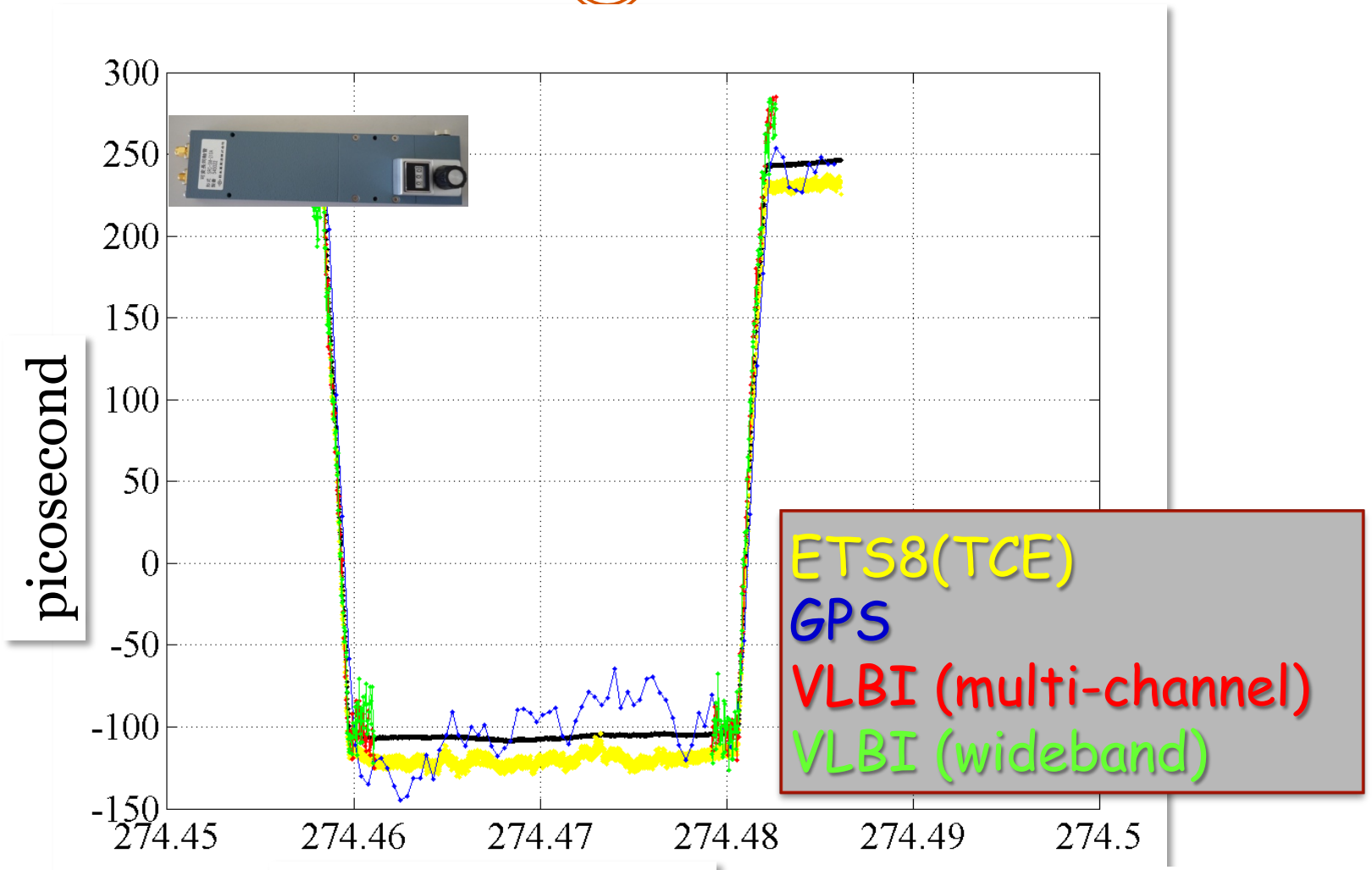


Detection of Path-Length Change -Kashima-



The length of a reference signal transmission cable was artificially changed by using a coaxial phase shifter.

Detection of Path Length Change (cont'd)



After Takiguchi et al.[2010]

Simulation of T&F Transfer using future VLBI

The upcoming new geodetic VLBI concept "VLBI2010"

Based on simulation data, we are going to evaluate the frequency transfer performance of the future VLBI2010 network.

- long-term frequency stability on intercontinental links
- short-term frequency transfer capability

VLBI systems

	Current systems
Frequencies	2 (X, S)
Bandwidth	256 MHz (16 sub-bands)
Antenna diameter	> 20m
Antenna slew speed	< 1 deg / sec
Scan length	> 2 min (on average)
Main observable	Group delay
Measurement uncertainty	A few 100 ps
Observing time	2-3 24h sessions / week
Operation	Station staff
Processing	Semi-automated

After Hobiger et al.[2011]

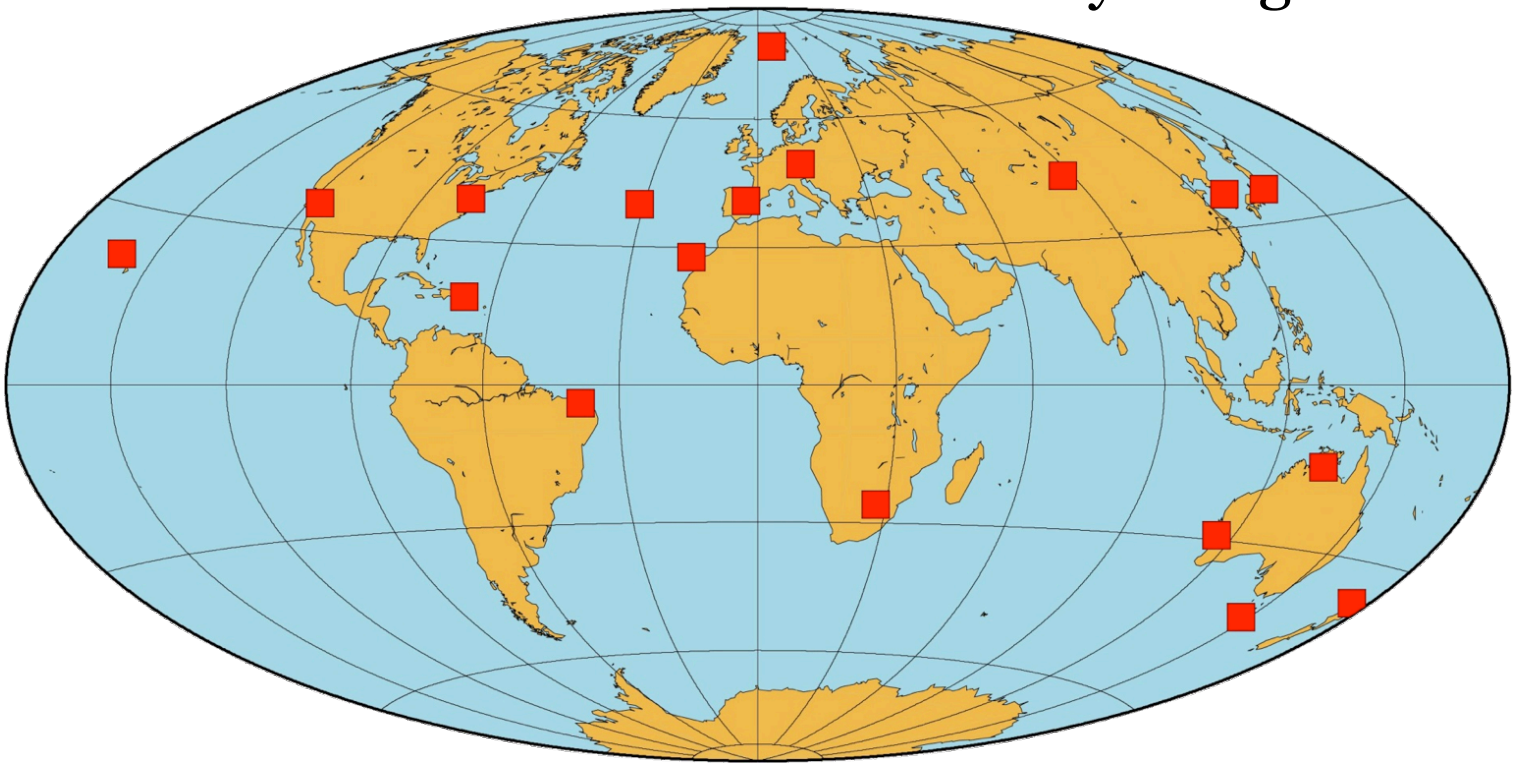
Potential for T&F Transfer using VLBI?

- Current systems provide a frequency link stability of about 2×10^{-15} @ 1d (ADEV) (Rieck et al. [2010])
- VLBI2010 is expected to perform much better than current systems
- VLBI2010 will be a continuously operating space geodetic technique
- Only initial cost
- No transponder cost
- prototype VLBI2010 system currently under development → no data for verifying TFT potential

simulations based on VLBI2010 specifications

Simulation network

18 stations, planned for VLBI2010,
more than half of them are currently being built



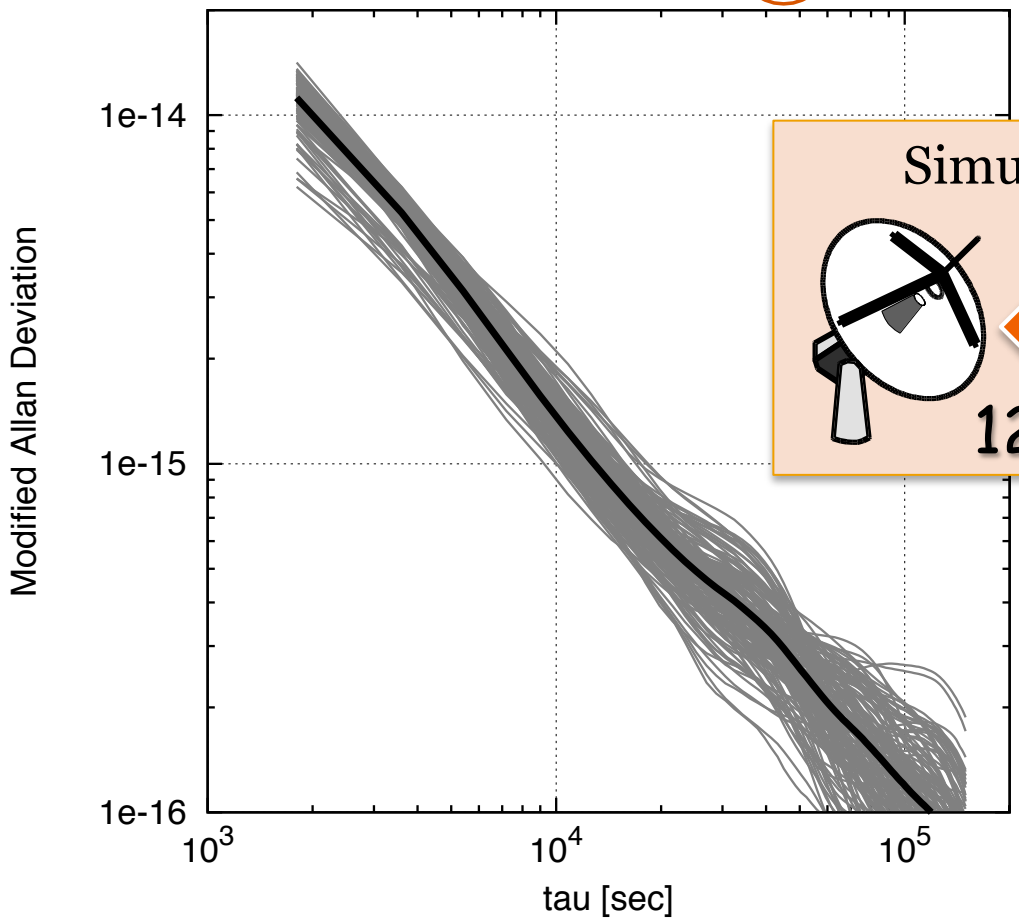
18 stations → 18 x (18-1) / 2 = 153 baselines for TFT

After Hobiger et al.[2011]

Simulation parameters

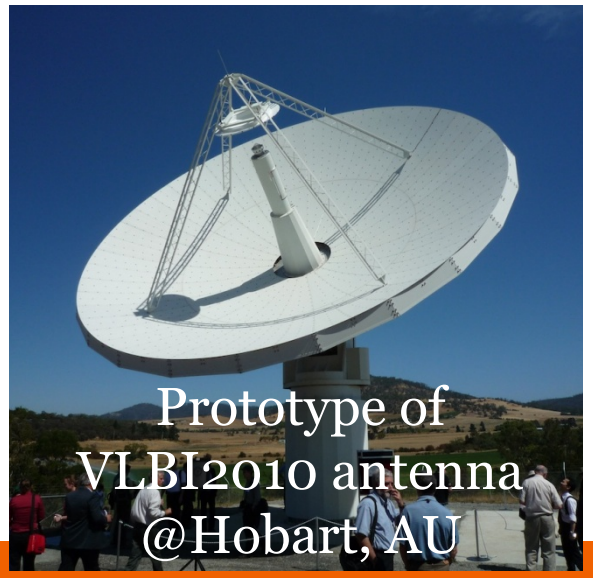
- Measurement uncertainty 10 ps (white noise), i.e. 3x the specified accuracy of the fully operational VLBI2010 system
- Troposphere turbulence with $C_n = 10^{-7}$, H=2000 m (Nilsson and Haas [2008])
- Station clocks: 10^{-16}@1d (Next-generation freq. standards)
- Analysis (least squares adjustment):
  - Station coordinates fixed
  - Estimate: troposphere and station clocks
  - Compute difference estimated – simulated clock (i.e. access the true TFT capability)
  - Derive freq. stability over all possible baselines

Result

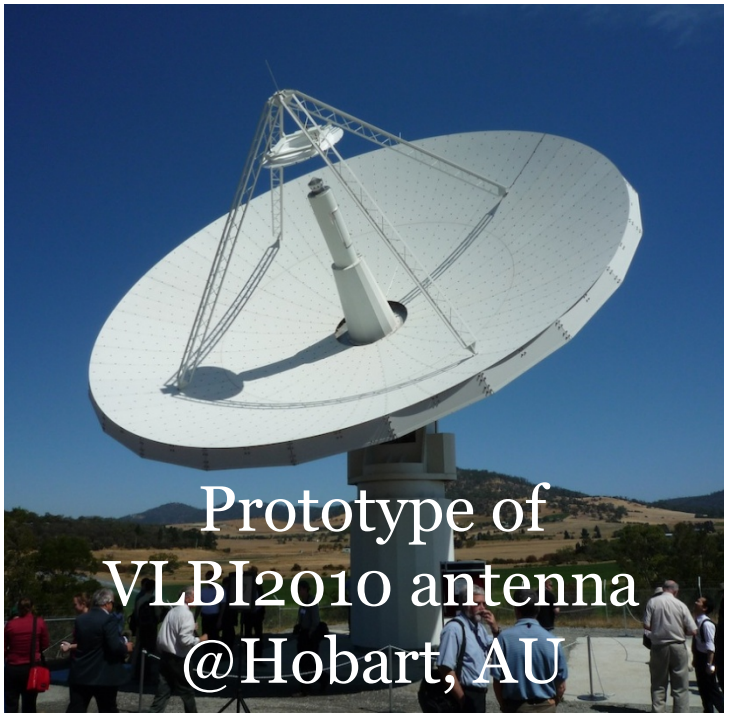


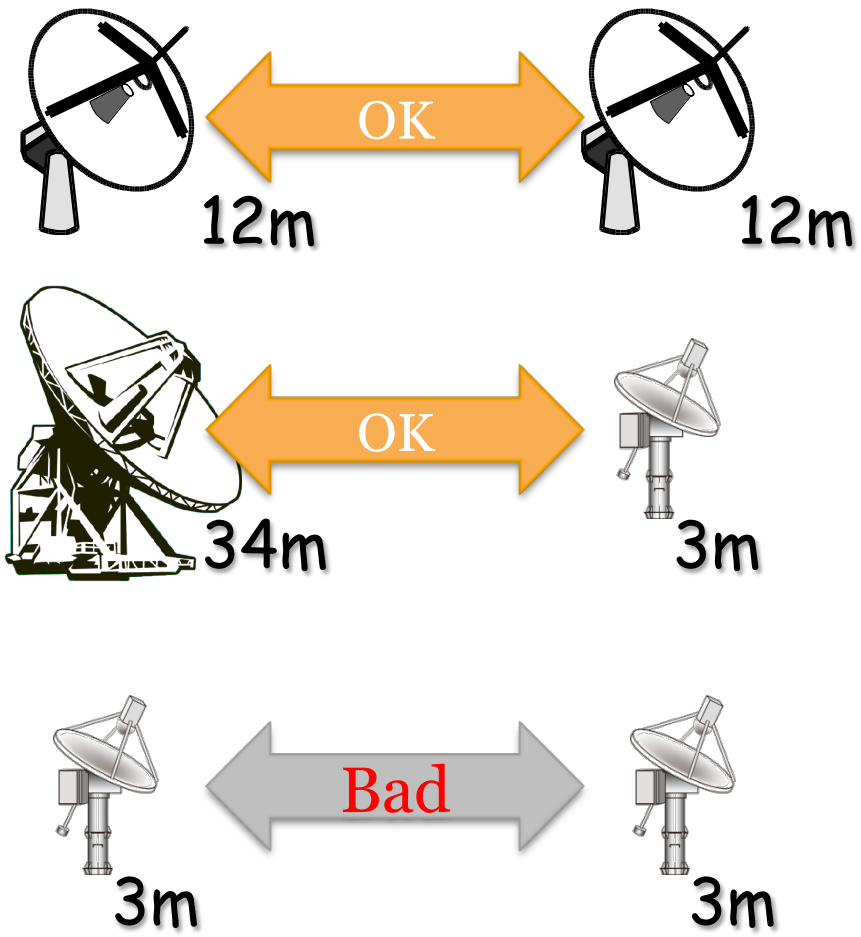
After Hobiger et al.[2011]

Simulation for antenna size



Available Antenna Size for T&F Transfer



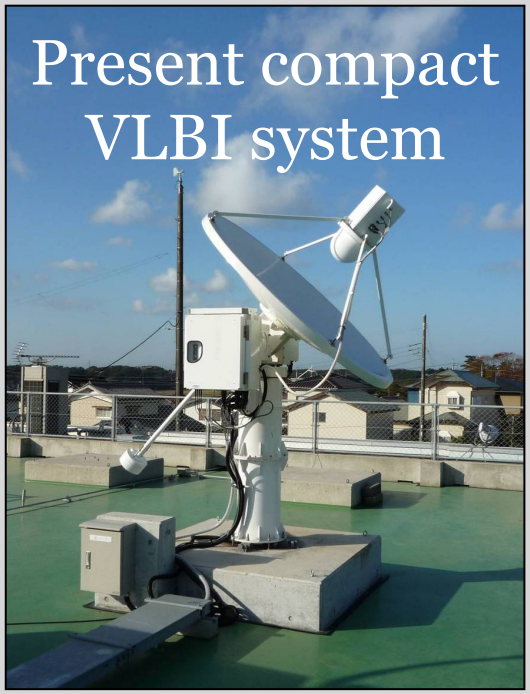


Summary

- Present frequency stability obtained by VLBI
  - Normal geodetic analysis strategy: 1 X 10^{-13}@1hr
  - Analysis strategy for one source tracking: 2 X 10^{-14}@1hr
- Detection of path length change of reference signal cable
  - VLBI and other techniques can detect length change with several picoseconds accuracy.
- VLBI2010 looks like another promising candidate for next generation T&F transfer based on the simulations

Outlook

- NICT will develop a compact VLBI system that includes the VLBI2010 specification for the purpose of T&F transfer.



Thank you very much for your attention.