2009年度VLBI懇談会シンポジウム
「将来を見据えた研究協力を目指して」
12月5日（土）@奥州宇宙遊学館

測地VLBI技術による高精度周波数比較

VLBI MEASUREMENTS FOR FREQUENCY TRANSFER

瀧口 博士[1], 小山 泰弘[1] , 市川 隆一[1] , 後藤 忠広[1] ,
石井 敦利[1,2,3] , Thomas Hobiger[1] , 細川 瑞彦[1]

[1]情報通信研究機構,
[2]国土地理院, [3] (株) エイ・イー・エス

NiCT Kashima Space Research Center

Content

- ✓ Introduction
  - » *Previous study*
    - *Intercomparison : VLBI (IVS) vs. GPS (IGS)*
      - Wettzell - Onsala
    - *How stable are current VLBI systems?*
      - Kashima34m – Kashima11m
      - Kashima11m – Koganei11m
- ✓ Intercomparison between VLBI and other techniques
  - » *Can the VLBI measure the right time difference?*
    - Kashima34m - Kashima11m
      - Artificial change by Line Stretcher & Trombone
- ✓ Conclusions

Introduction Background

✓ Development of frequency standard

- Atomic fountains

NICT-CsF1
..... *developing*

2×10^{-15}
@a few days

- Optical clocks

NICT
optical clocks
..... *developing*

10^{-17}～
@a few hours

✓ Time and frequency transfer technique

» GPS Carrier Phase
2×10^{-15} @1day

» TWSTFT
$2\text{-}4 \times 10^{-15}$ @1day

» *long averaging period*

» *insufficient accuracy*

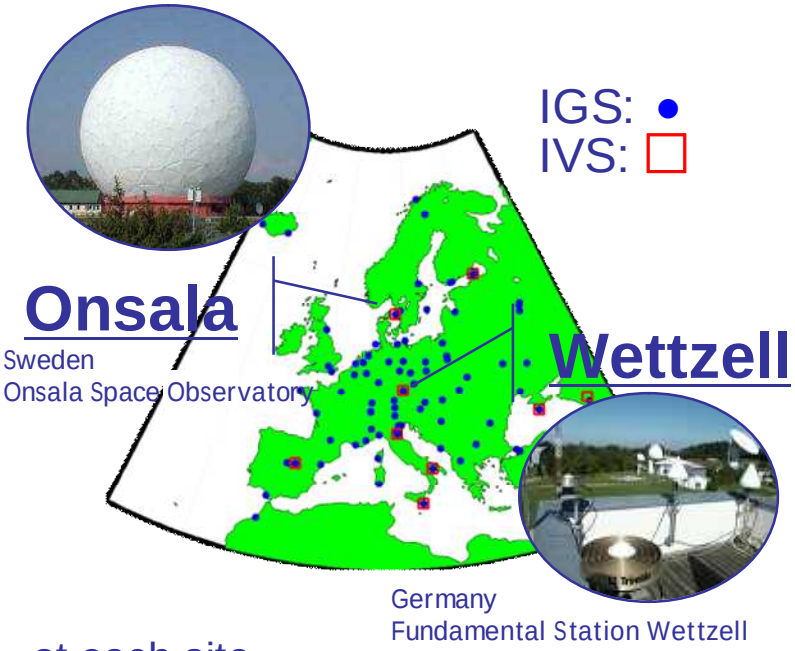
➢ **improvements of highly precise time and frequency transfer techniques are strongly desired**

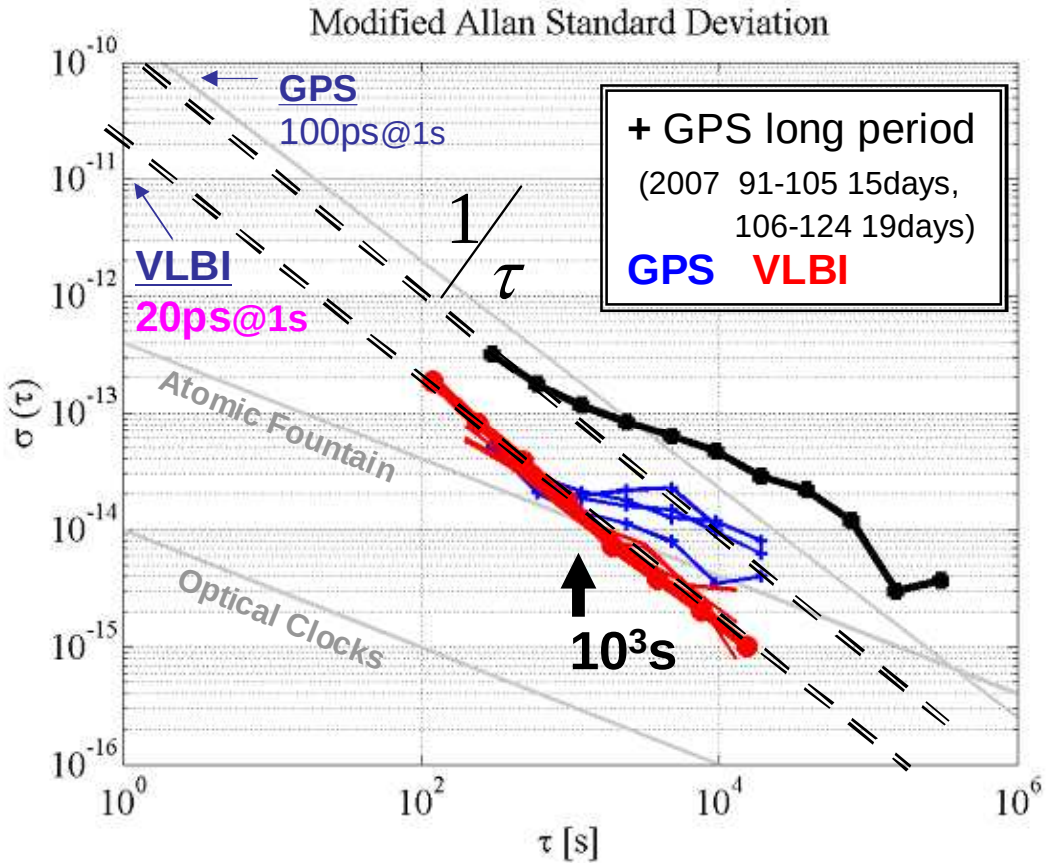
VLBI

Previous study

Intercomparison : VLBI vs. GPS

1. Wettzell-Onsala
   - VLBI vs. GPS CP
   - IVS and IGS data





- ✓ VLBI is more stable than GPS
- ✓ surpassing the stability of atomic fountain at 10^3s
- ✓ VLBI stability : follows a $1/\tau$ law very closely
- ✓ 2×10^{-11} (20ps) @1s

at each site
VLBI a
are *sh*

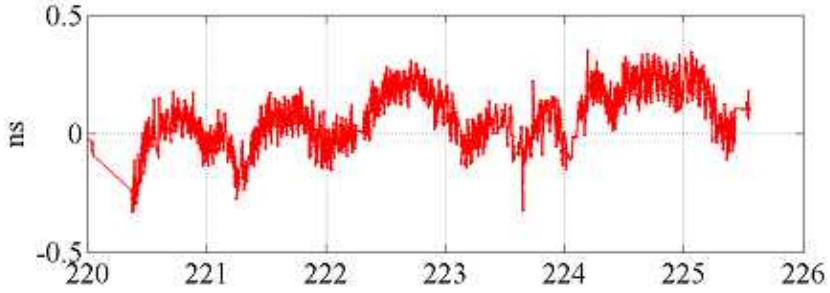
The geodetic VLBI technique has the potential for precise frequency transfer

NiCT Kashima Space Research Center

Previous study

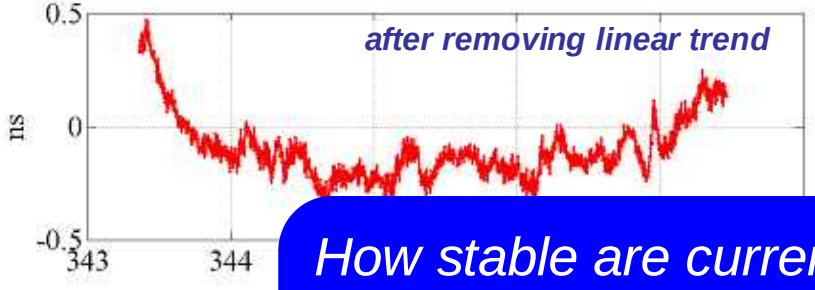
How stable are current VLBI systems?

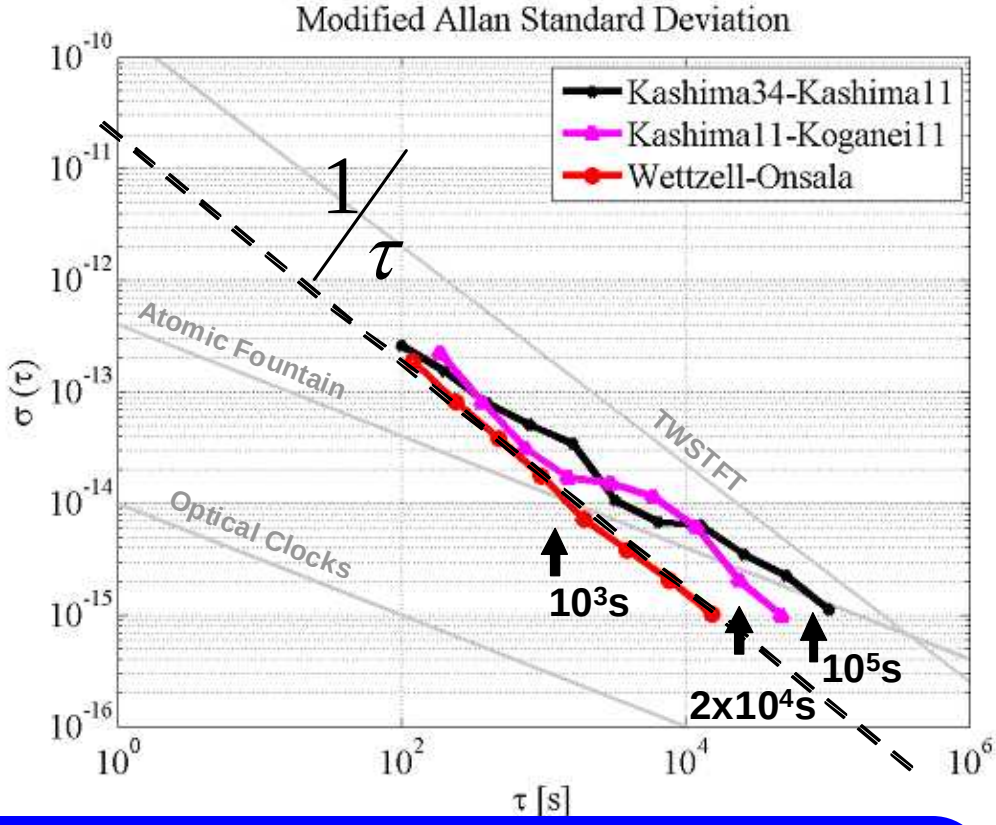
Kashima34m-Kashima11m



in summer

Kashima11m – Koganei11m





How stable are current VLBI systems?

→ surpassing the stability of atomic fountain at 2×10^4 , 10^5 s

⇒ unstable than international baseline (Wettzell-Onsala)

⇒ influence of temperature change

Measures to reduce the influence of the temperature change are necessary.

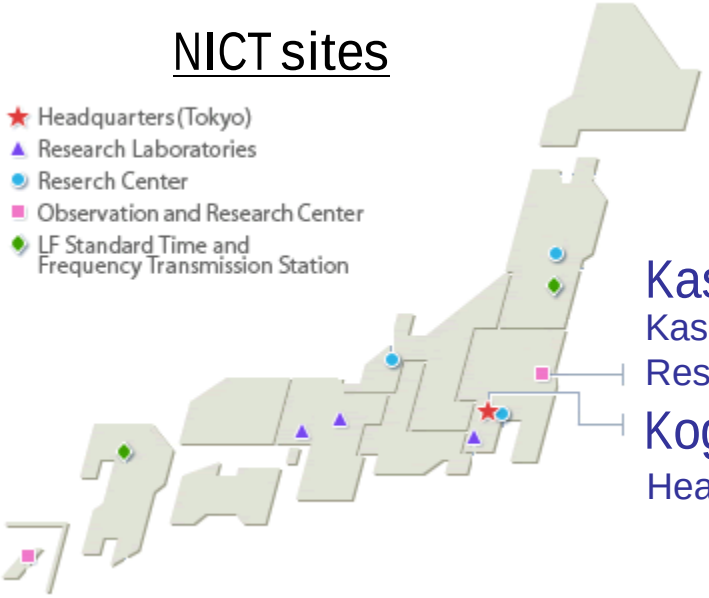
What's Next ?

- ✓ The geodetic VLBI technique has the potential for precise frequency transfer
  - » VLBI is more stable than GPS
  - » surpassing the stability of atomic fountain at 10^3s (Wettzell-Onsala)
  - » $2x10^4$, 10^5 s (Kashima11-Koganei, Kashima34-Kashima11)

- ✓ *Improve the station environment*
  - » *for Geodesy → for T&F transfer*
- ✓ *Intercomparison*
  - » *MARBLE*
  - » *International*
  - » *other techniques : GPS, DMTD, TWSTFT, TEC(ETS-8)*
- ✓ *Calibrate instrumental delay*

Intercomparison : VLBI vs. other techniques

NICT sites



Kashima
Kashima Space Research Center

Koganei/Tokyo
Headquarters

- ✓ Kashima34m – Kashima11m 239m
- ✓ Kashima11m – Koganei11m 109km

Kashima

- VLBI
- MARBLE
- GPS

H-maser, DMTD

Koganei

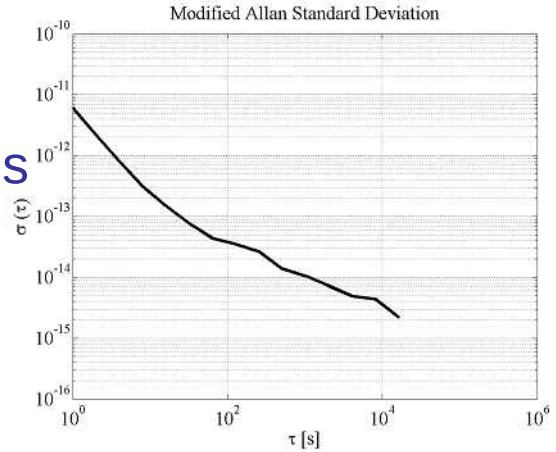
- VLBI
- GPS
- TWSTFT
- TEC (ETS-8)

NiCT Kashima Space Research Center

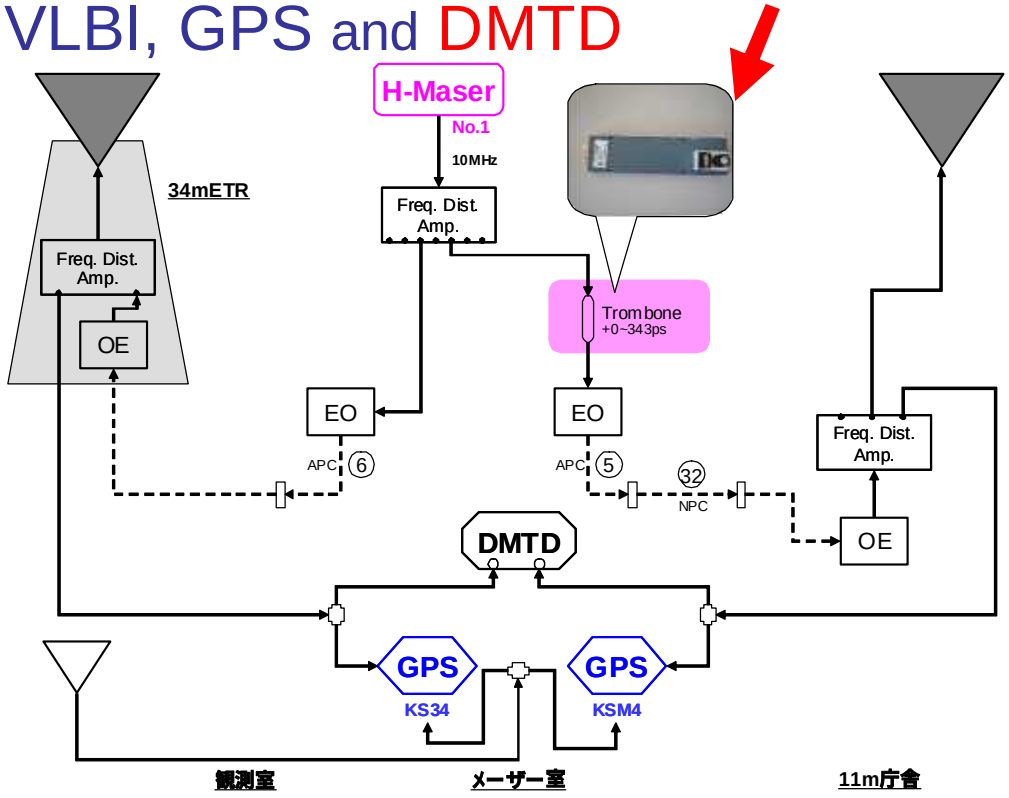
Can the VLBI measure the right time difference?

- ✓ Kashima34m – Kashima11m
  - » Artificial time difference change
    - using Line Stretcher & Trombone
  - » Intercomparison between VLBI, GPS and DMTD

DMTD
6×10^{-12}@1s
(6ps)



Trombone



Differences with the normal observation

- ✓ Normal Geodetic VLBI
  - » Observation
    - multiple sources
    - antenna slew time
    - different scan time
    - 24 hours
  - » Data Analysis
    - estimate
      clock parameter
      atmosperic delay
      station coordinates

- ✓ This study
  - » Observation
    - **one source** : 3C84
    - no antenna slew time
    - same scan time
    - a few hours
  - » Data Analysis
    - estimate only
      clock parameter
    - atmospheric delay :
      short baseline, one source
    - station coordinates :
      fixed to a-priori coordinates

Data analysis

✓VLBI

- » CALC/SOLVE
- » single baseline
- » S/X ionosphere-free linear combination
  - clock offset / 30sec

- » Time Defference
  clock offset / 30sec

✓GPS

- » NR Canada's PPP
  - **IGS Final** Orbit & Clock(30s)
- » Precise Point Positioning
  - satellite clock interpolation
  - clock offset / 30sec

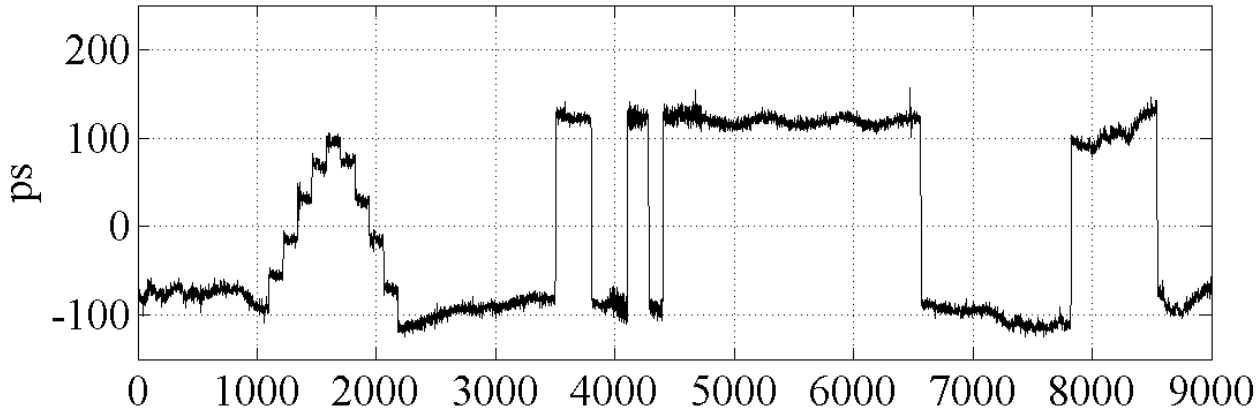
- » Time Defference
  clock offset A – clock offset B
  / 30sec

vs. DMTD Time Difference / 1sec

DMTD

Time Difference

DMTD



5 6 12 14 16 18

4 7 11 13 15 17

3 8

2 9

1 10

0 ⇒ Max

50メモリ

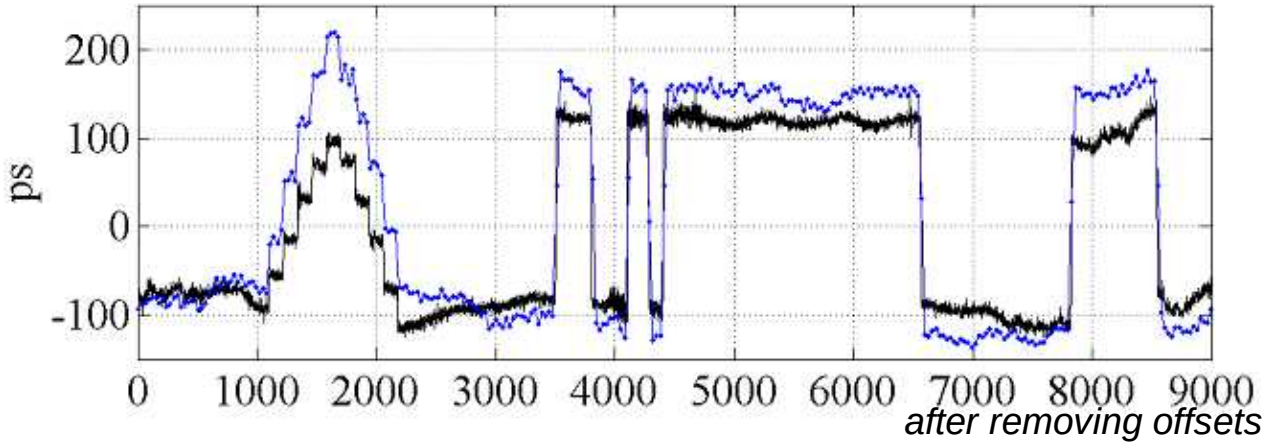
	DMTD	
1	37.9	
2	39.7	
3	46.9	
4	38.8	
5	26.7	
6	-22.5	
7	-45.0	
8	-43.3	***42 ps***
9	-55.1	
10	-43.7	
11	207.9	
12	-210.1	
13	214.2	
14	-215.3	
15	216.8	***211 ps***
16	-210.6	
17	203.8	
18	-212.3	

GPS vs. DMTD

rms : GPS-DMTD

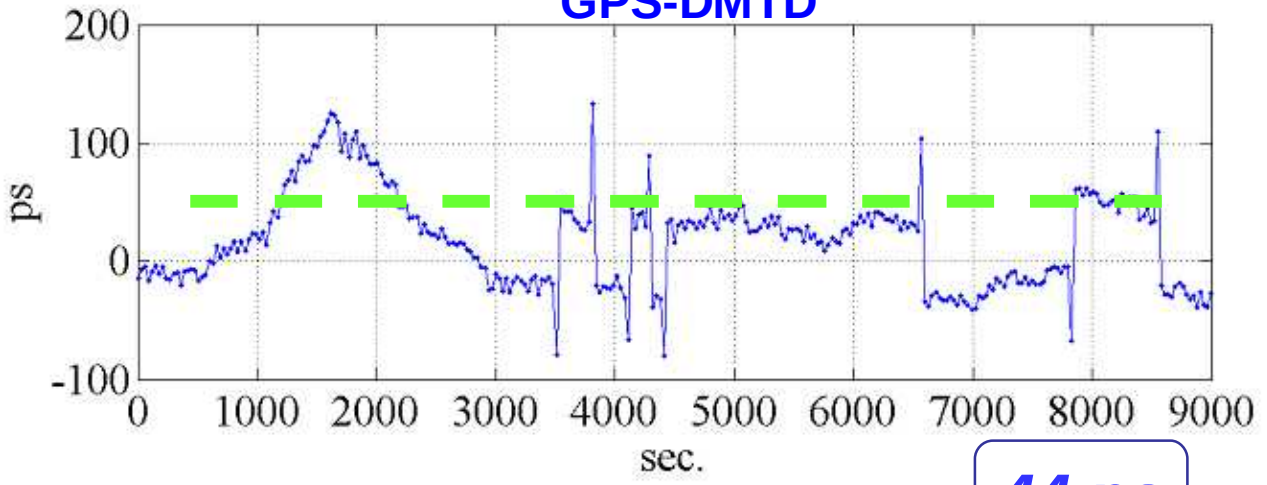
Time Difference

DMTD **GPS**



after removing offsets

GPS-DMTD



44 ps

	DMTD	GPS	GPS-DMTD
1	37.9	61.7	23.8
2	39.7	66.3	26.7
3	46.9	62.1	15.2
4	38.8	54.6	15.8
5	26.7	44.3	17.7
6	-22.5	-43.7	21.2
7	-45		8.0
8	-43.5		10.7
9	-55.1	-72.0	16.9
10	-43.7	-65.3	21.6
11	207.9	268.0	60.1
12	-210.1	-263.0	52.9
13	214.2	273.0	58.8
14	-215		67.7
15	216.		60.6
16	-210.6	-274.3	63.7
17	203.8	269.3	65.6
18	-212.3	-279.0	66.7

19 ps

62 ps

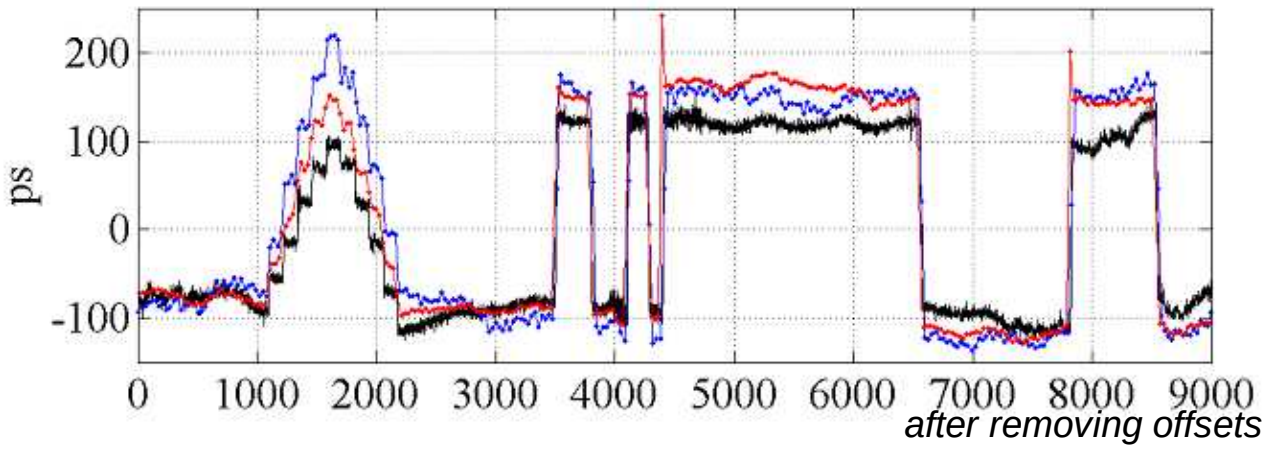
NiCT Kashima Space Research Center

VLBI vs. GPS and DMTD

rms : VLBI-DMTD

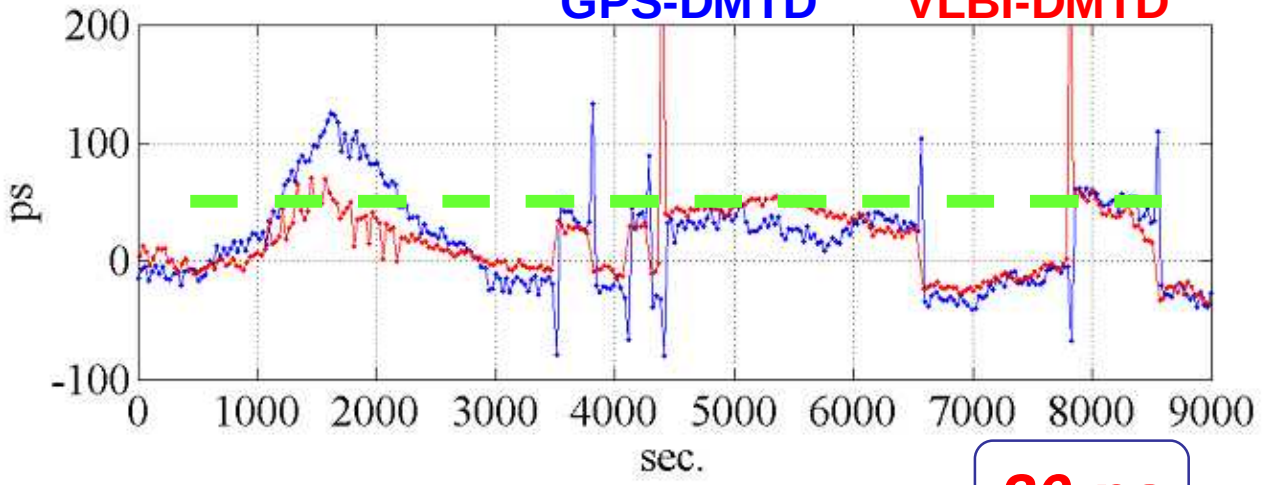
Time Difference

DMTD GPS VLBI



after removing offsets

GPS-DMTD VLBI-DMTD



	DMTD	VLBI	VLBI-DMTD
1	37.9	48.3	10.4
2	39.7	48.2	8.5
3	46.9	60.8	13.9
4	38.8	48.5	9.7
5	26.7	27.3	0.6
6	-22.5	-30.2	7.7
7	-45.		8.2
8	-43.		0.3
9	-55.1	-62.6	7.5
10	-43.7	-54.5	10.7
11	207.9	243.8	35.8
12	-210.1	-244.0	33.9
13	214.2	256.6	42.4
14	-215		36.0
15	216.		45.9
16	-210.6	-258.5	47.9
17	203.8	259.0	55.3
18	-212.3	-254.6	42.3

9 ps

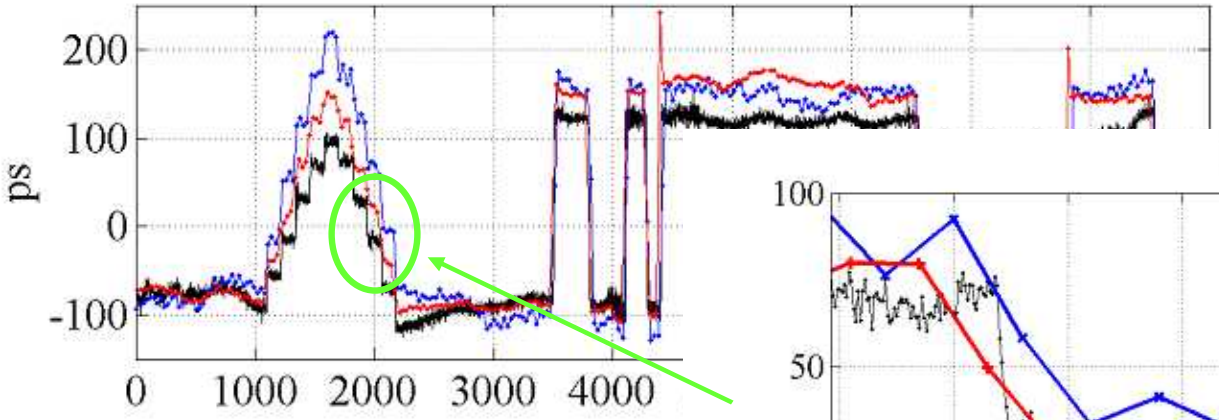
43 ps

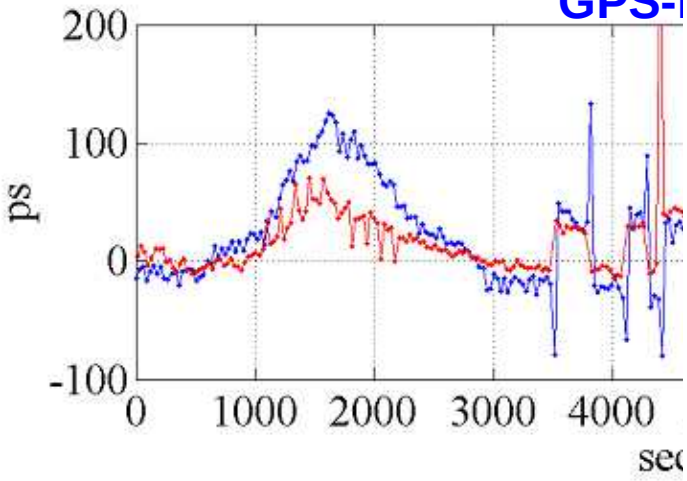
30 ps

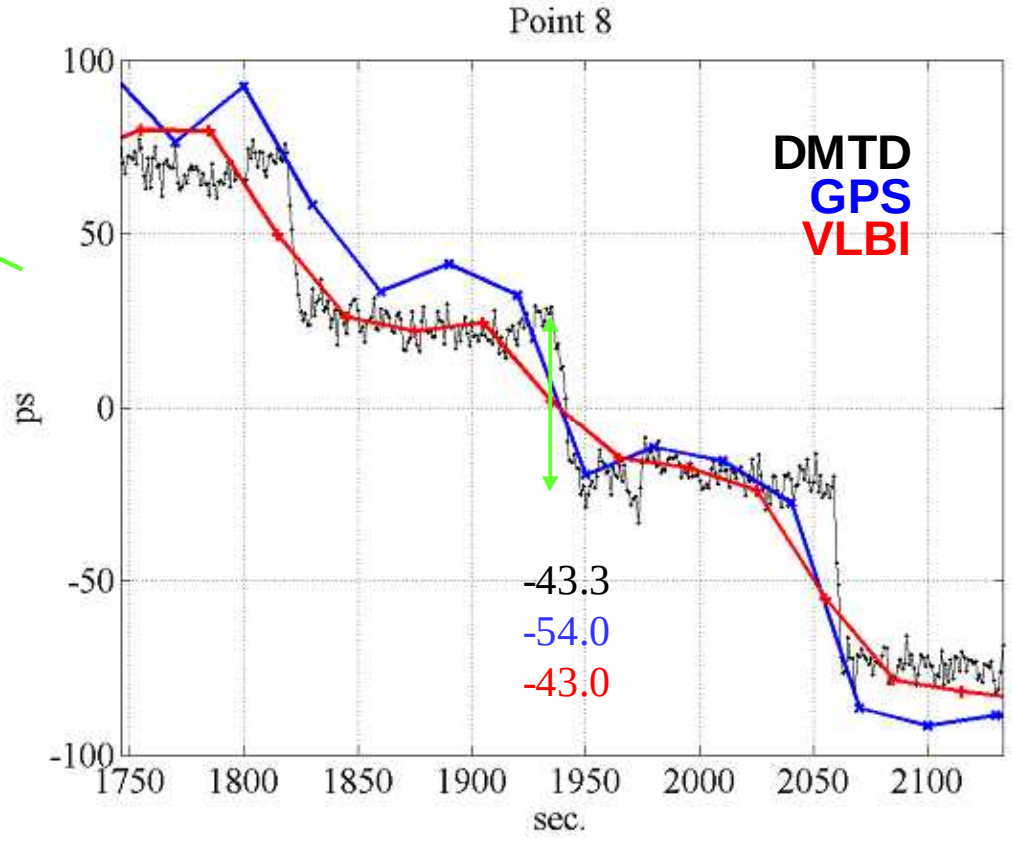
NiCT Kashima Space Research Center

VLBI vs. GPS and DMTD

Time Difference DMTD GPS VLBI







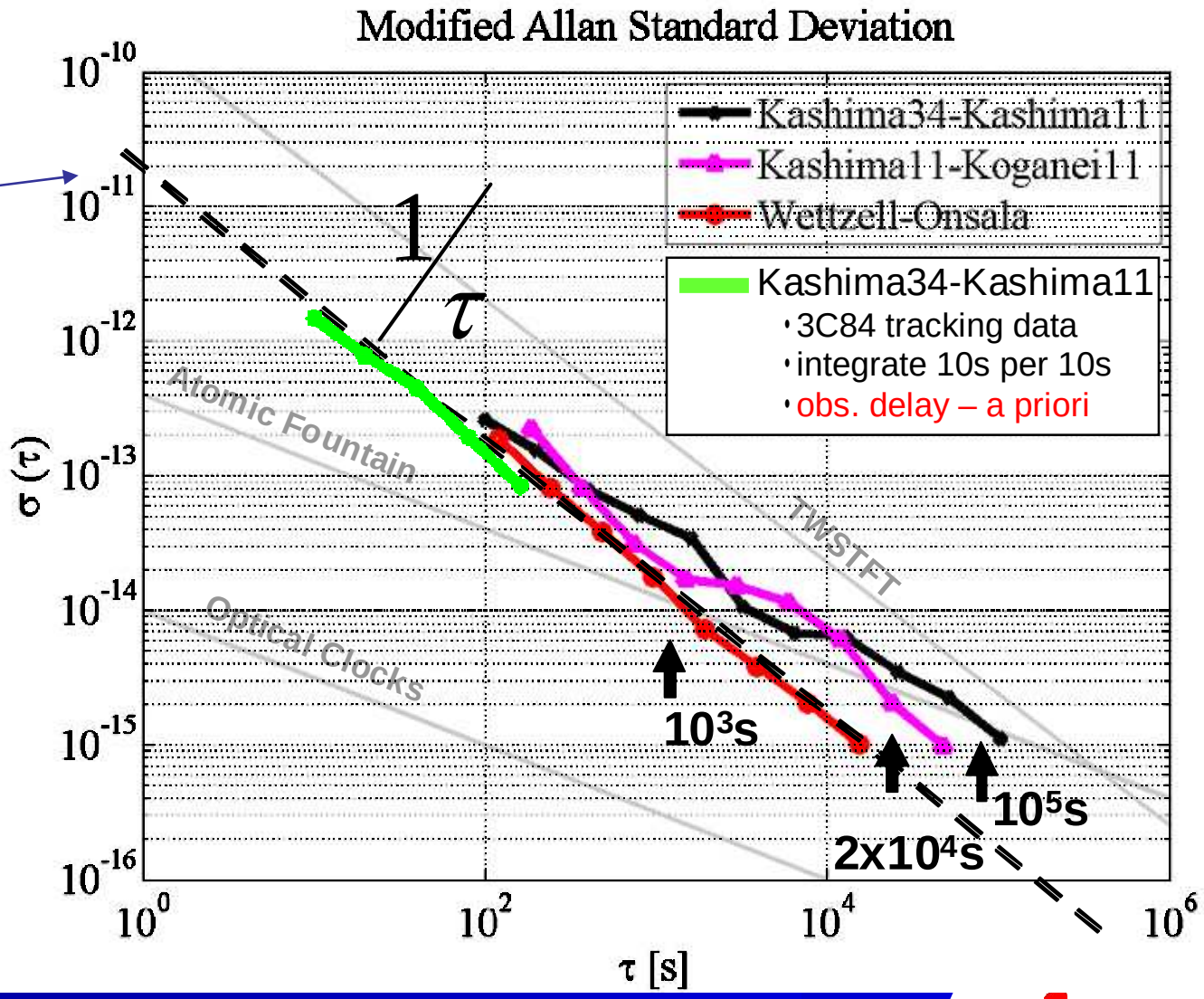
Conclusions

- ✓ Can the VLBI measure right time difference?
  - » VLBI vs. GPS CP and DMTD
  - » Artificial change
    - VLBI vs. DMTD: rms **9**ps@40ps, 43ps@200ps
      ↑ **good agreement**
    - GPS vs. DMTD: rms19ps@40ps, 62ps@200ps

» The geodetic VLBI technique can measure the right time difference**.**

How stable are current VLBI systems?

VLBI
20ps@1s



Acknowledgements

IVS and IGS
for the high quality products

GSFC, JPL, NRC Canada
for VLBI and GPS analysis software

Thank you very much for your attention.