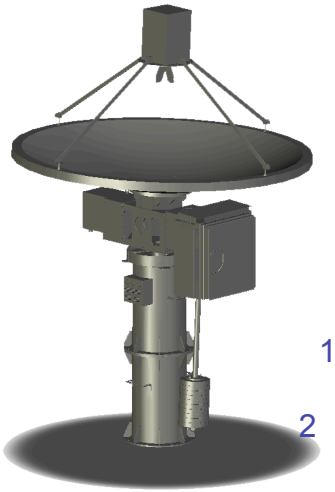
October 31, 2008
Asia-Pacific Workshop on
Time and Frequency (2008)

VLBI MEASUREMENTS FOR FREQUENCY TRANSFER



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Introduction Background

✓ Development of frequency standard

- **Atomic fountain**

NICT-CsF1
..... developing

2×10^{-15}
@a few days

- **Optical clocks**

NICT
optical clocks
..... developing

$10^{-16}\sim10^{-17}$
@a few hours

✓ Time and frequency transfer technique

» **GPS Carrier Phase**
2×10^{-15} @1day

» **TWSTFT**
$2\text{-}4\times10^{-15}$ @1day

» ***long averaging period***

» ***insufficient accuracy***

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

VLBI

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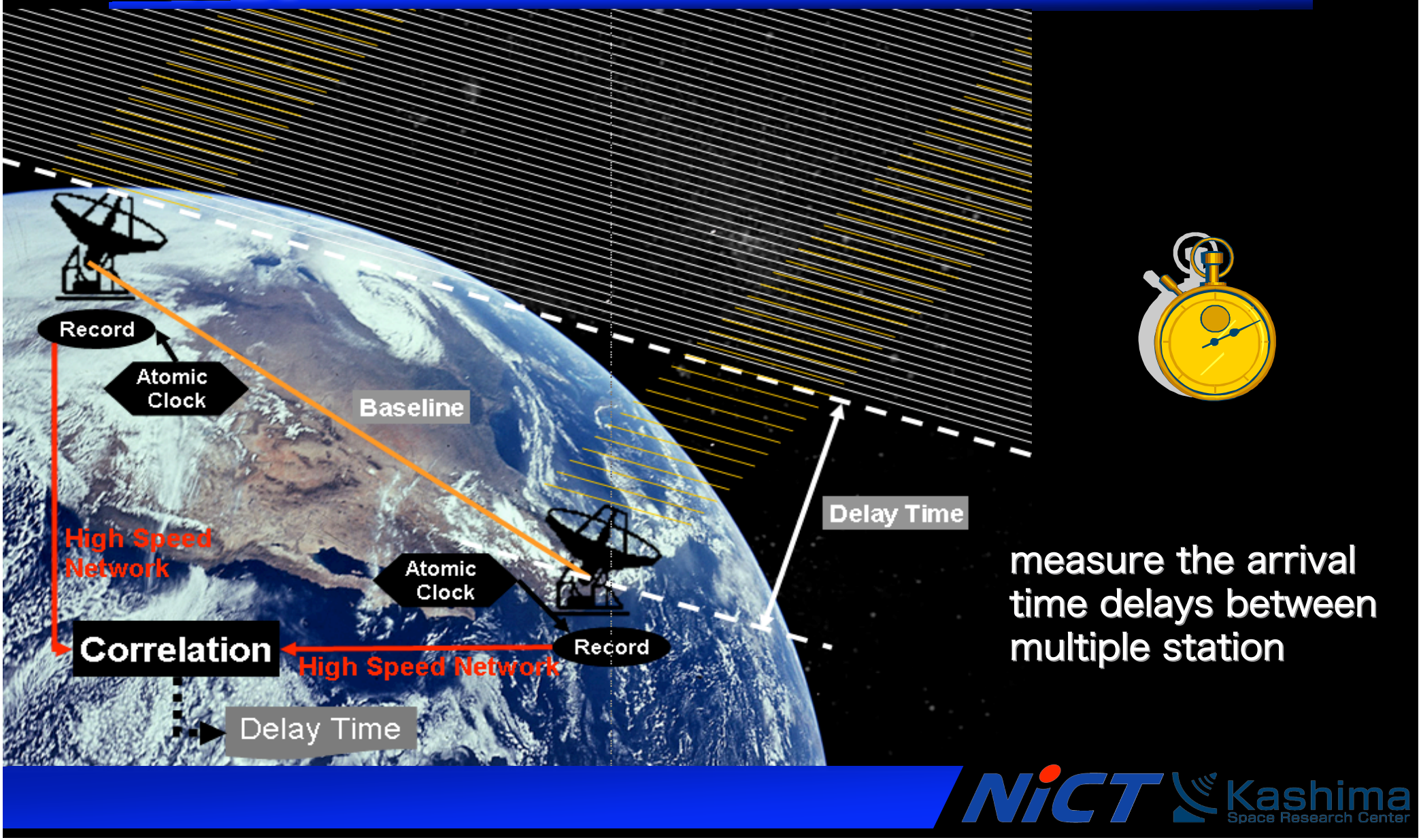
VLBI

Very Long Baseline Interferometry



measure the arrival time delays between multiple station

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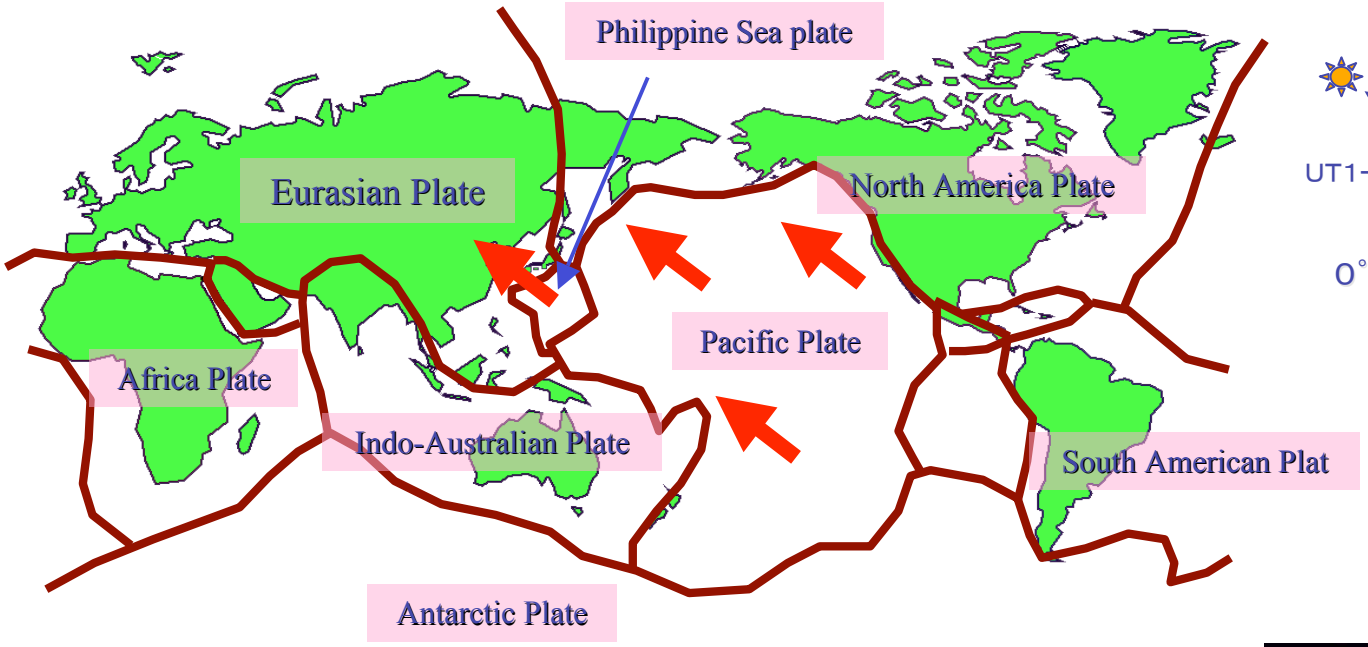
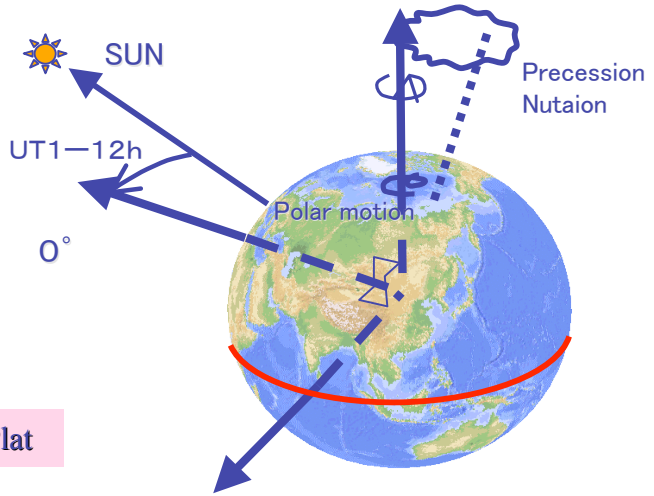
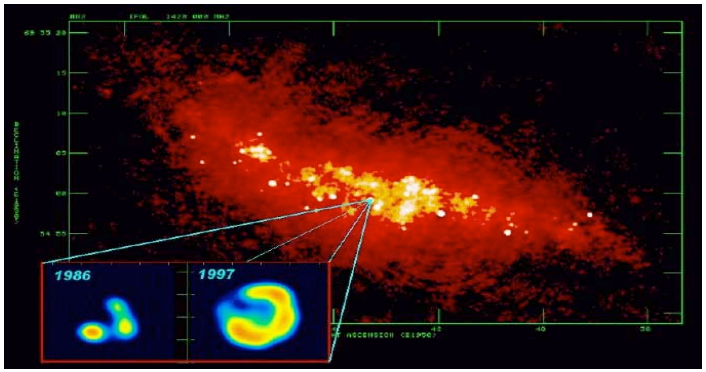
The applications of VLBI





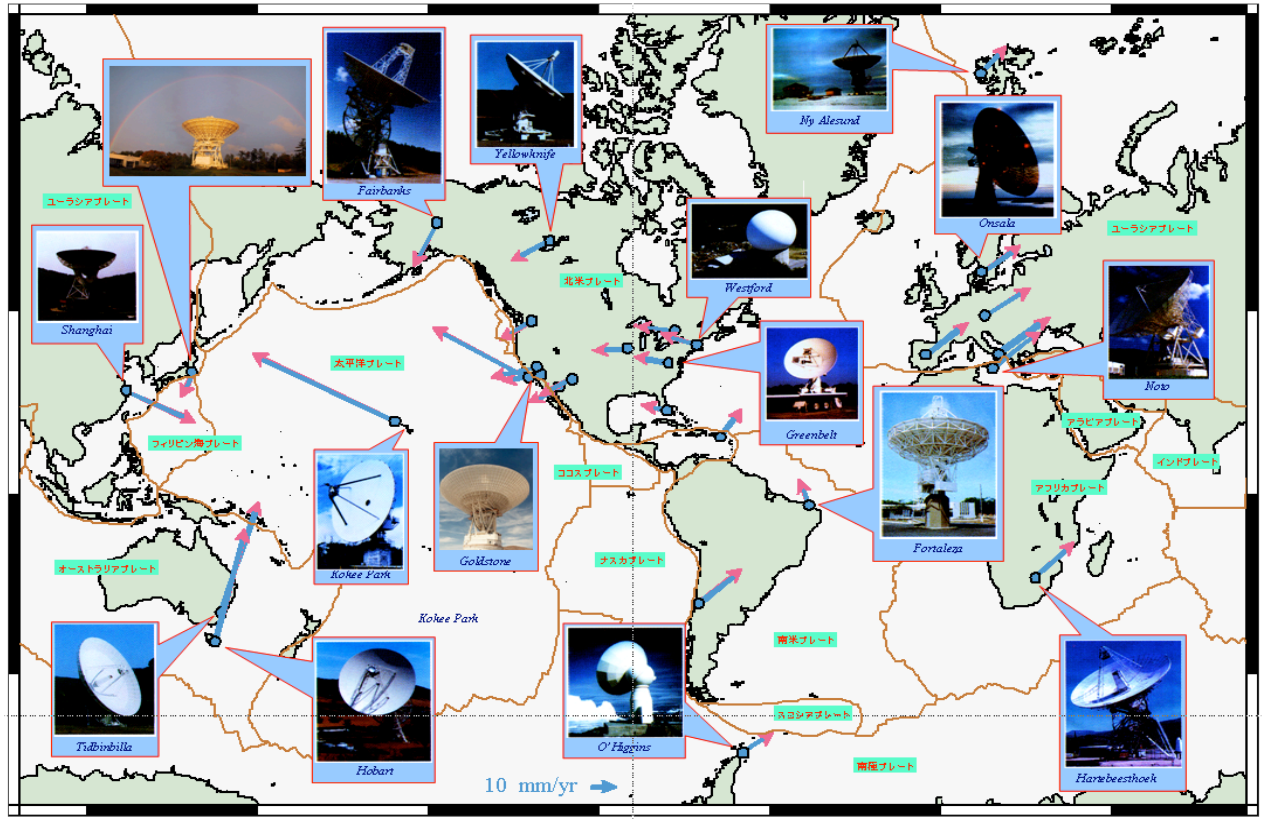
- ✓ **Geophysics : Tectonic plate motion**
- ✓ **Radio Astronomy : High resolution imaging, astro-dynamics**
- ✓ **Reference Frame : Celestial / Terrestrial Reference Frame**
- ✓ **Earth Orientation Parameters**



Why VLBI ?

✓ Geodetic VLBI experiment by IVS

» The averaging formal error of the clock offset : 20 ps
← better than other current techniques



In usual geodetic VLBI analysis, clock offsets and their rates of change at each station are estimated with respect to a selected reference station.

IVS
(International VLBI Service for Geodesy and Astrometry)

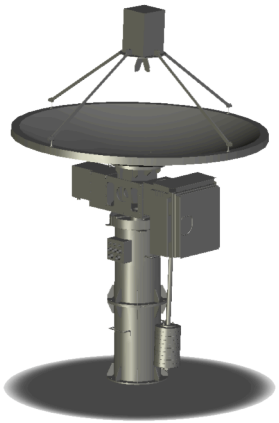
VLBI frequency transfer

Activities at NICT

1. Developing a compact VLBI system

» **MARBLE SYSTEM**

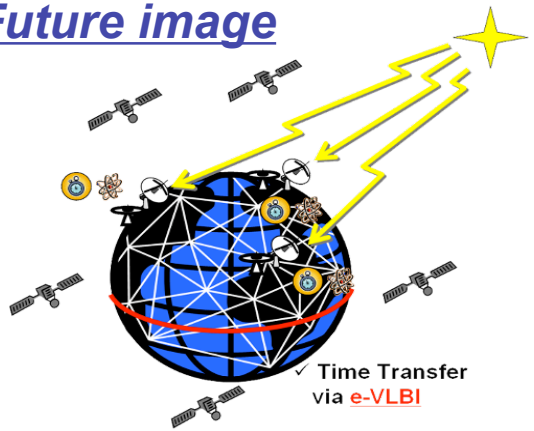
Multiple Antenna Radio-interferometry of Baseline Length Evaluation



- Diameter **1.65m**
- **S/X-band**
- Front-fed paraboloidal reflector
- Az-El mounting
  - Max speed AzEl **5** deg/sec
- **Transportable**
  by few person

Collaborating with GSI

Future image



2. Verifying the ability of VLBI frequency transfer

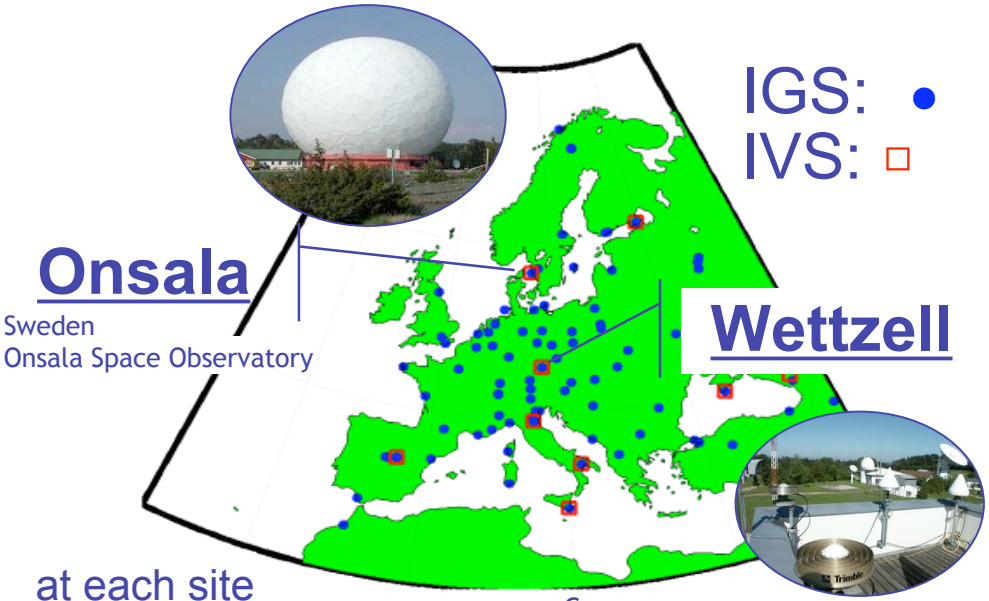
» **to show the capability of the current VLBI system**

: **geodetic specification** ← ***This study***

Comparison study

1. Wettzell-Onsala

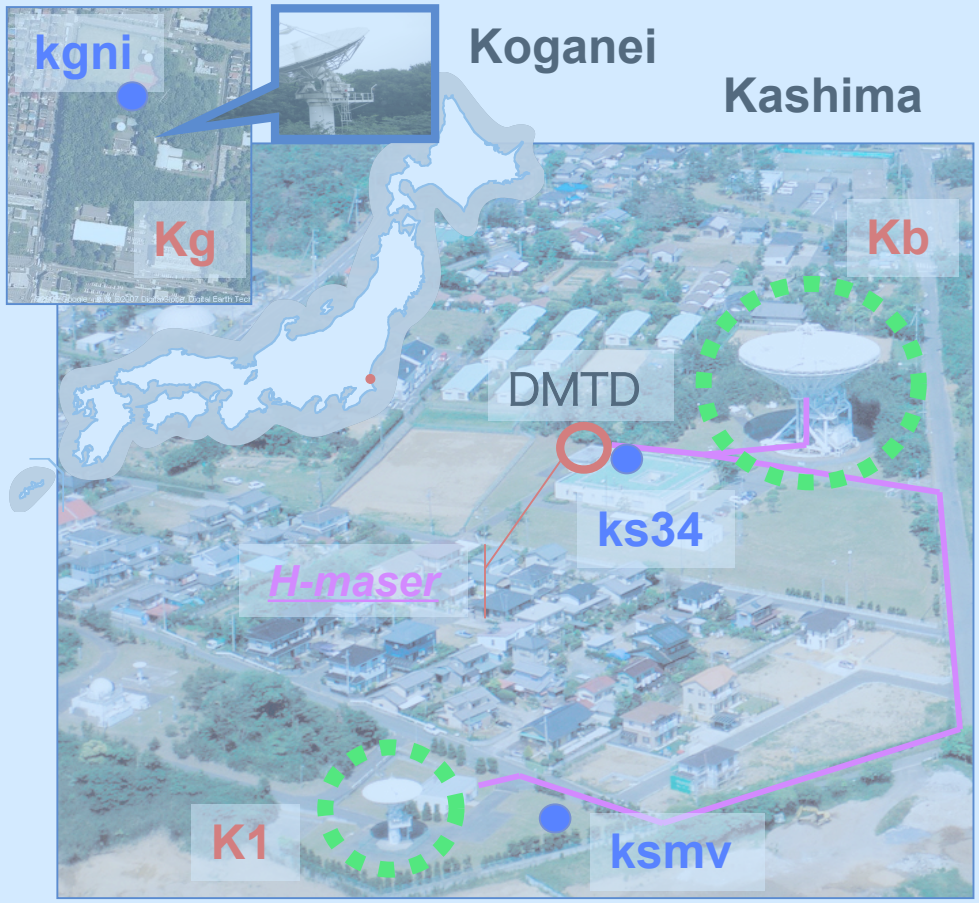
- VLBI vs. GPS CP
- IVS and IGS data



at each site
VLBI and GPS
are *sharing* the H-maser

2. Kashima-Koganei

- VLBI vs. GPS CP vs. DMTD



Comparison study Wz-On

VLBI					On:Onsala, Wz:Wettzell	GPS				
Session	Date	DOY	Time	Duration	Stations	Date	DOY	Time	Duration	Stations
R1258	07JAN09	9	17:00	24	HhKkNyOnTsWfWz	07JAN09	9	–	–	–
R1260	07JAN22	22	17:00	24	KkNyOnTcTsWfWzZc	07JAN22	22	0:00	48	onsa, wtzr
R1262	07FEB05	36	17:00	24	HhKkNyOnShTsWfWz	07FEB05	36	0:00	48	onsa, wtzr
R1263	07FEB12	43	17:00	24	HhKkNyOnShTcWfWz	07FEB12	43	0:00	48	onsa, wtzr
R1265	07FEB26	57	17:00	24	KkMcNyOnTcWfWzZc	07FEB26	57	0:00	48	onsa, wtzr
R1270	07APR02	92	17:00	24	HhKkNyOnShTsWfWz	07APR02	92	0:00	48	onsa, wtzr
R1271	07APR10	100	17:00	24	KkNyOnTcTsWfWzZc	07APR10	100	0:00	48	onsa, wtzr
R1273	07APR23	113	17:00	24	KkMcNyOnTcTsWfWz	07APR23	113	0:00	48	onsa, wtzr
R1274	07MAY02	122	17:00	24	FtHhNyOnTcWzZc	07MAY02	122	0:00	48	onsa, wtzr
R1285	07JUL16	197	17:00	24	HhKkOnWfWz	07JUL16	197	0:00	48	onsa, wtzr
R1291	07AUG27	239	17:00	24	KkNyOnTcTsWfWz-Zc	07AUG27	239	0:00	48	onsa, wtzr
R1292	07SEP04	247	17:00	24	HoKkNyOnTcTsWfWz	07SEP04	247	0:00	48	onsa, wtzr
R1293	07SEP10	253	17:00	24	KkNyOnTcTsWfWz	07SEP10	253	0:00	48	onsa, wtzr
R1294	07SEP17	260	17:00	24	HhKkNyOnWfWz	07SEP17	260	0:00	48	onsa, wtzr
R1295	07SEP24	267	17:00	24	HhKkNyOnTcWfWz-Ho	07SEP24	267	0:00	48	onsa, wtzr
R1311	08JAN14	14	17:00	24	BdFtHhNyOnTcWfWz	08JAN14	14	–	–	–
R1312	08JAN22	22	17:00	24	FtHhNyOnTcWfWz	08JAN22	22	–	–	–
R1315	08FEB11	42	17:00	24	FtHhOnTcWfWz-Ny	08FEB11	42	–	–	–
R1316	08FEB19	50	17:00	24	FtHhNyOnTcWfWz	08FEB19	50	–	–	–
R1325	08APR22	113	17:00	24	BdFtHhOnTcWz-NyWf	08APR22	113	–	–	–
R1327	08MAY05	126	17:00	24	BdFtHhNyOnTcWfWz	08MAY05	126	–	–	–
R1334	08JUN23	175	17:00	24	FtHhMaNyOnTcWfWz	08JUN23	175	–	–	–
R1336	08JUL07	189	17:00	24	FtHhNyOnTcWfWz-Bd	08JUL07	189	–	–	–

2007

2008

wtzr : not stable

R1: Monday session, to provide twice weekly EOP results

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Data analysis

✓VLBI

- » CALC/SOLVE
- » multi baseline
- » S/X ionosphere-free linear combination
- » reference to WETTZELL
  - station coordinates
  - atmospheric delay / 60min
  - clock offset / 60min

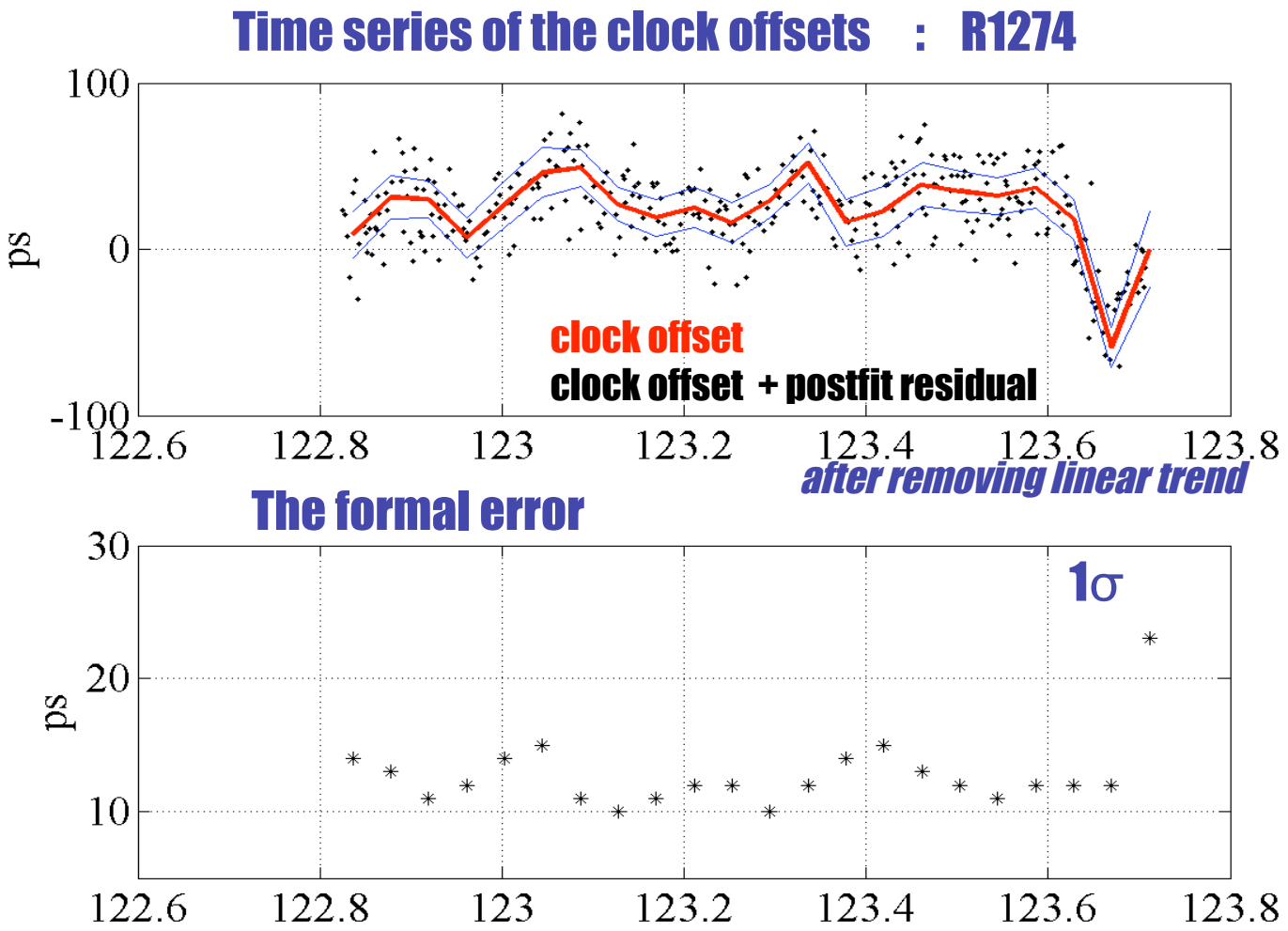
- » clock offset / scan

✓GPS

- » GIPSY-OASIS II
- » Precise Point Positioning
  - station coordinates
  - atmospheric delay / 5min
  - clock offset / 5min

- » Time Defference
  clock offset A – clock offset B
  / 5min

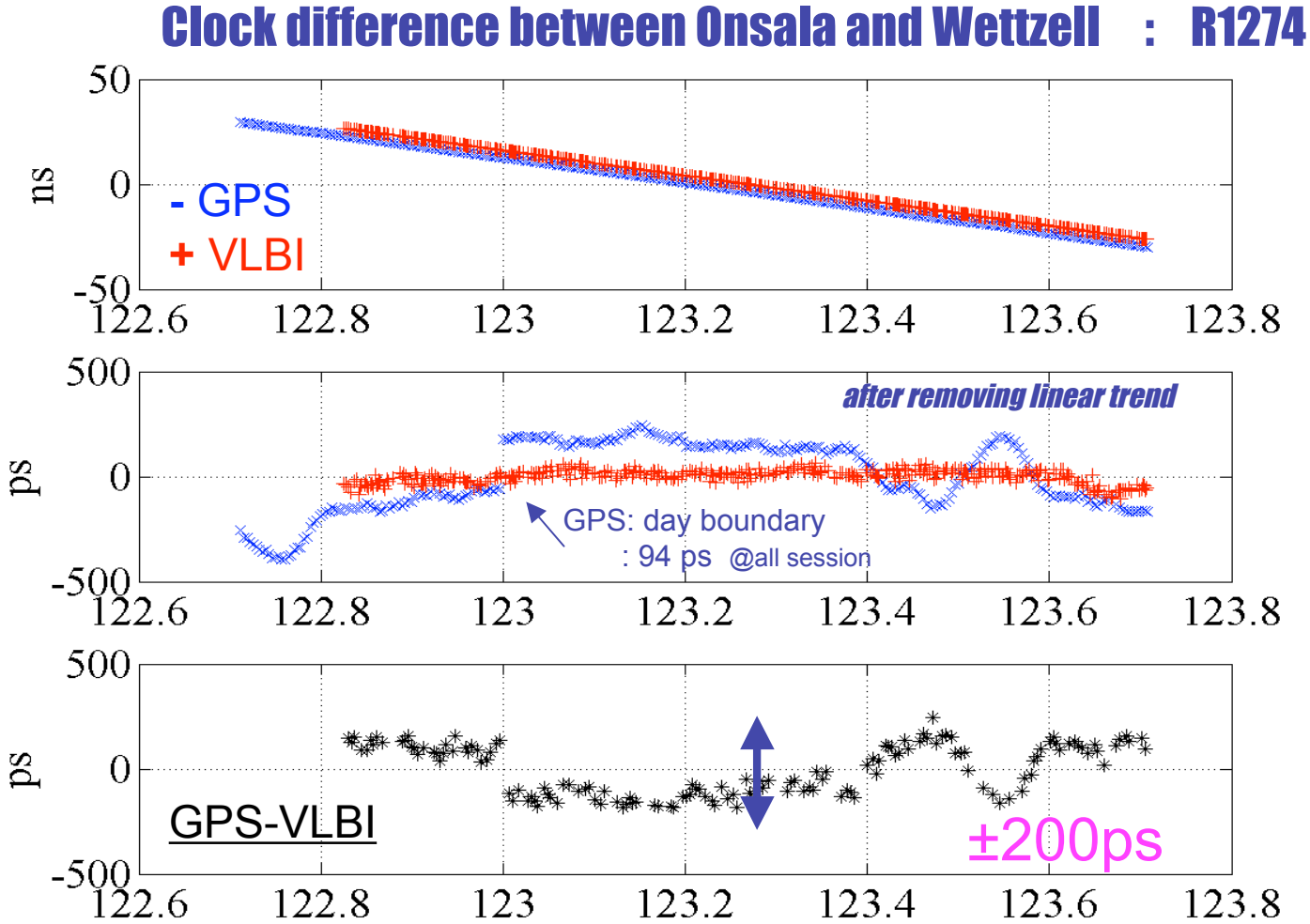
VLBI: Clock offset



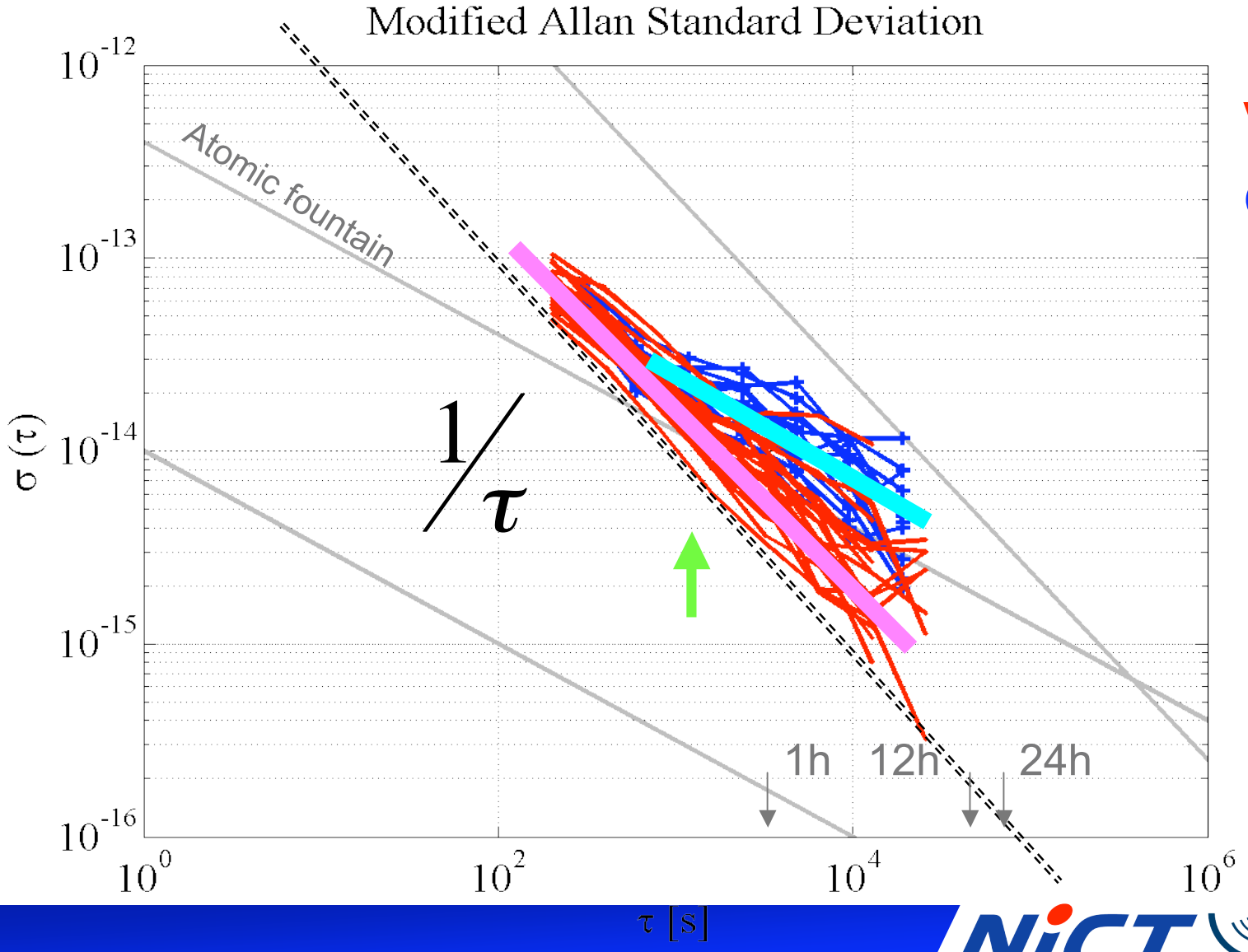
Session	1 sigma
R1258	12
R1260	11
R1262	9
R1263	16
R1265	12
R1270	13
R1271	13
R1273	14
R1274	12
R1285	17
R1291	15
R1292	12
R1293	14
R1294	14
R1295	21
R1311	18
R1312	13
R1315	13
R1316	14
R1325	18
R1327	19
R1334	31
R1336	19

15 ps

VLBI vs. GPS


Clock difference between Onsala and Wettzell : R1274
50
0
-50
ns
- GPS
+ VLBI
122.6
122.8
123
123.2
123.4
123.6
123.8
500
0
-500
ps
after removing linear trend
GPS: day boundary
: 94 ps @all session
GPS-VLBI
±200ps

Frequency stability



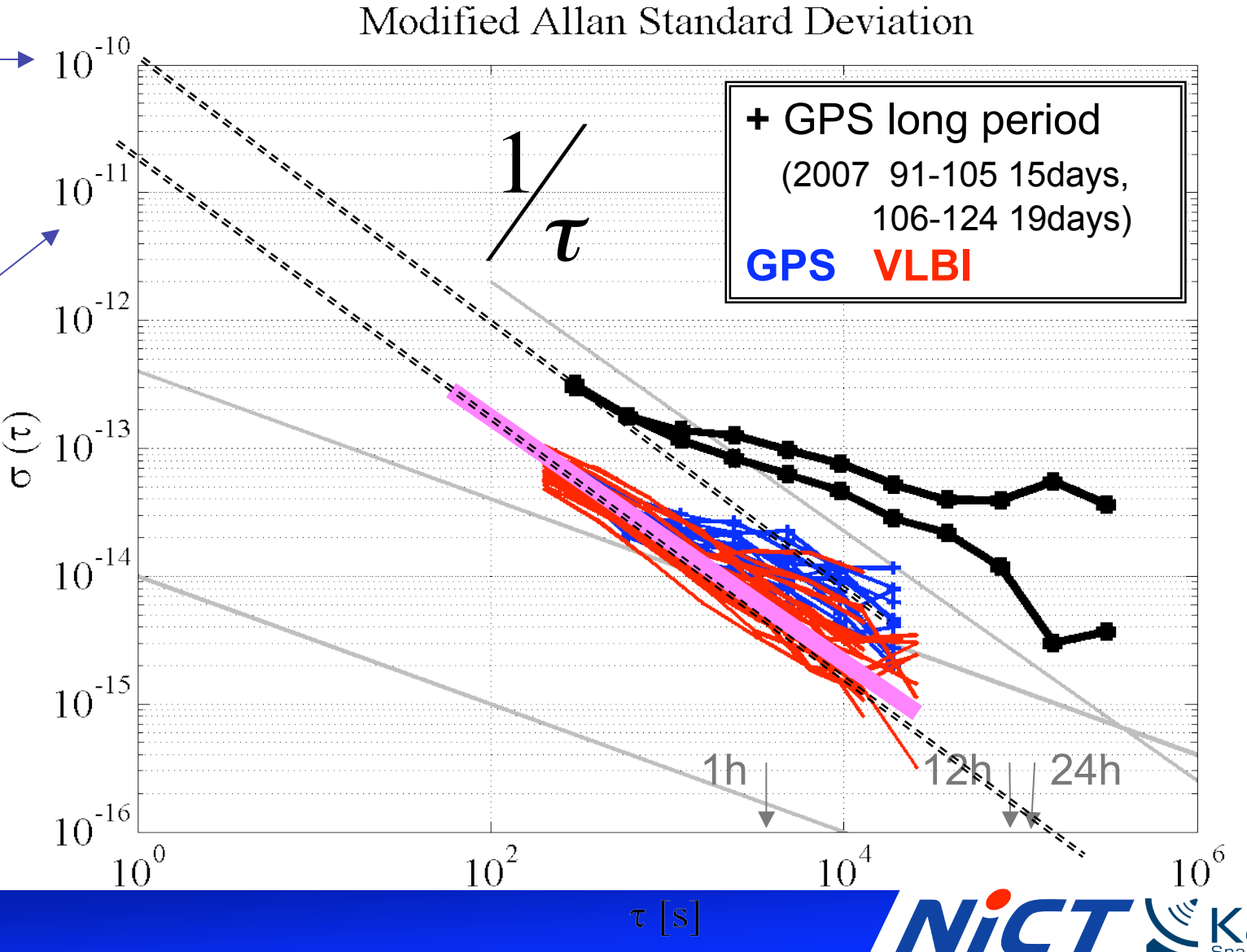
VLBI

GPS

Frequency stability

GPS
100ps
@1s

VLBI
20ps
@1s



Conclusions

- ✓ VLBI vs. GPS CP　　IVS and IGS data
  - » Clock offset
    - The formal error of VLBI : 15 ps@60min.
    - Good agreement : ±200ps
  - » Frequency stability
    - VLBI is more stable than GPS
      - same baseline and same period
      - over 10^3 averaging time
    - VLBI stability : follows a $1/\tau$ law very closely
    - 2×10^{-11} （20ps） @1s

The geodetic VLBI technique has
the potential for precise frequency transfer

Future plans

- ✓ Improve the station environment
  - » for Geodesy → for T&F transfer
- ✓ Stability at long averaging period
- ✓ Experiment
  - » MARBLE
  - » International
- ✓ Calibrate instrumental delay
  - » Zero baseline interferometry

Acknowledgements

IVS and IGS
for the high quality products

Thank you very much for your attention.