48th CGSIC Meeting - Timing Subcommittee

Savannah, Georgia, 16 September 2008

Chair: **Włodzimierz Lewandowski, BIPM,**
Co-Chair: **Victor Zhang, NIST**

14:00 Introduction – *Włodzimierz Lewandowski, BIPM*
14:20 Report from NIST – *Victor Zhang, NIST*
14:40 USNO Time Service – *Demetrios Matsakis,USNO*
15:00 Timing operations – *Wendy Kelley, USNO*
15:10 Progress on time transfer calibration – *Ed Powers, USNO*
15:20 Break
15:40 Update on the ITU-R WP7A work on the Future of UTC
– *Tom Bartholomew* (invited talk)
16:00 Time and Navigation Exhibition at the Smithsonian: An Update
– *Andrew Johnston, National Museum of American History*
16:20 Discussion
17:20 Session End

AREAS BEING SERVED

- International Atomic Time (TAI) and UTC
- International Timing Centers
- Global Navigation Satellite Systems
- Telecommunications Industries
- NASA/JPL Deep Space Network
- NIST Global Time Service
- Power Grids and other Industries
- As Research and Comparison Tool
- Other

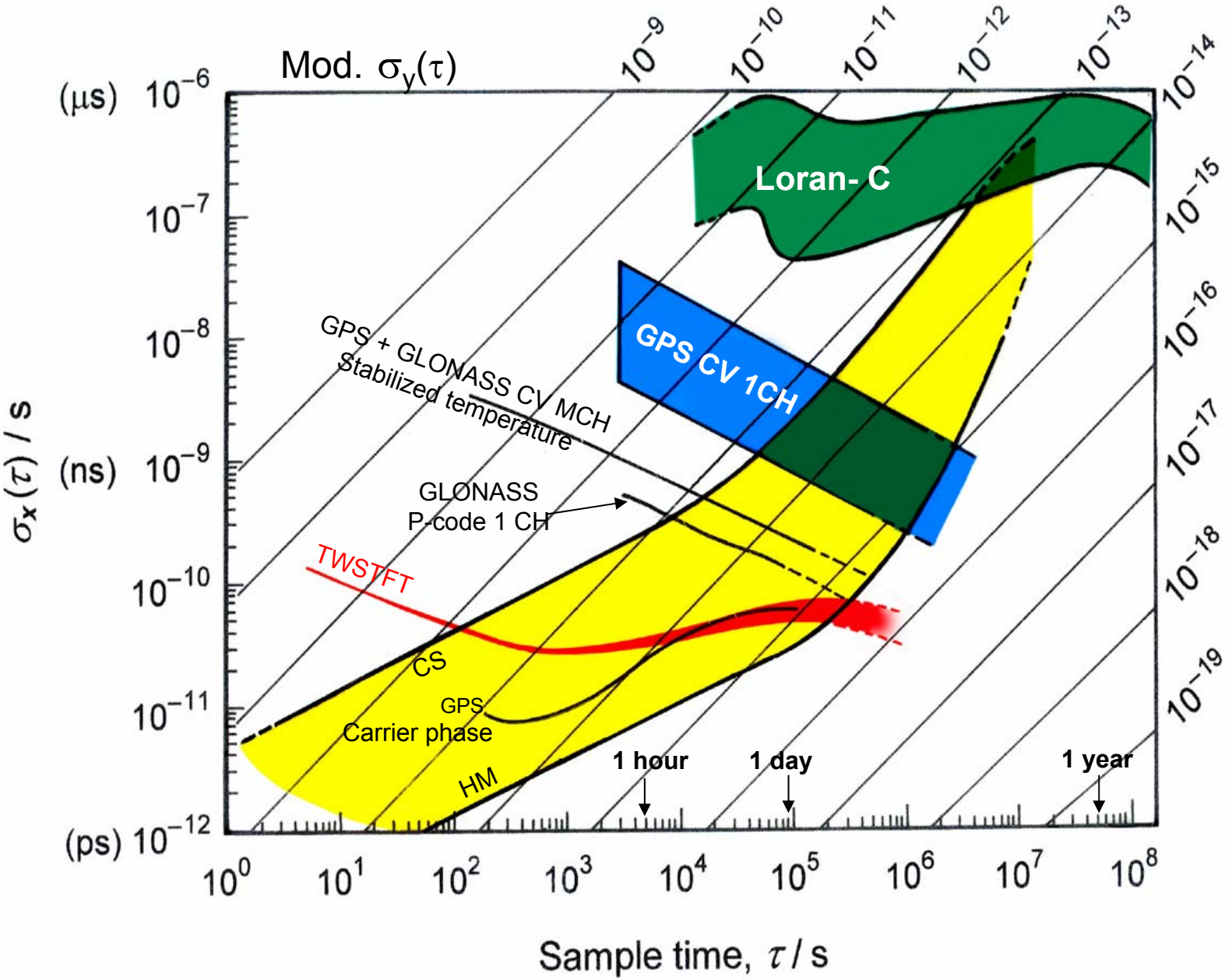
Outline of presentation

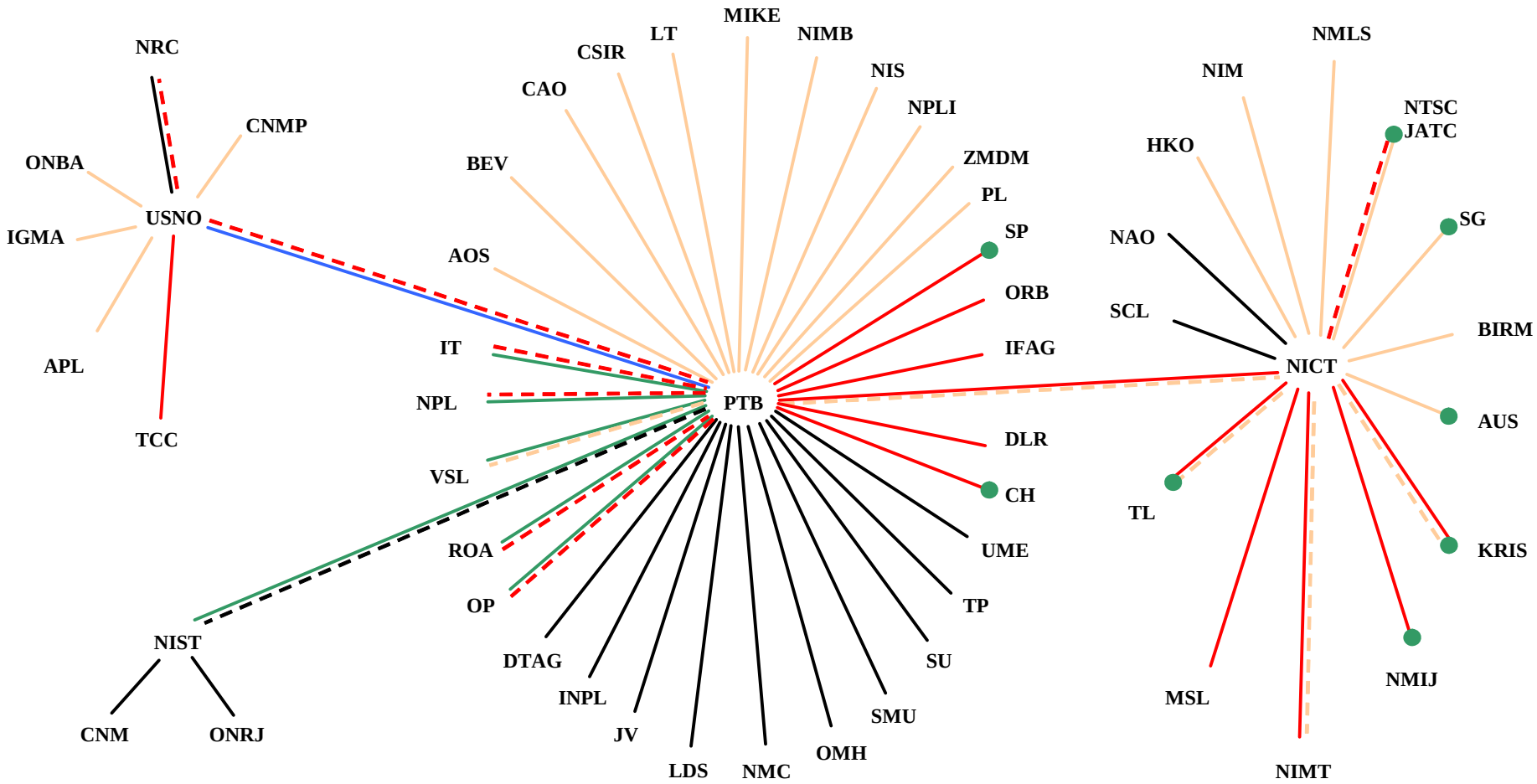
- **International time comparisons**
  - Uncertainties
  - Upcoming techniques
  - Glonass and Galileo
- **Time scales for satellite navigation systems**
  - Leap second
  - ICG Recommendation

Methods now in use

	uA/ns	uB/ns
• **GPS C/A-code SCH**	**3.0**	**5.0**
• **GPS C/A-code MCH**	**1.5**	**5.0**
• **GPS P3 (geod. receiv.)**	**0.7**	**5.0**
• **TWSTFT**	**0.5**	**1.0**

*IGS precise orbits and iono maps applied for GPS

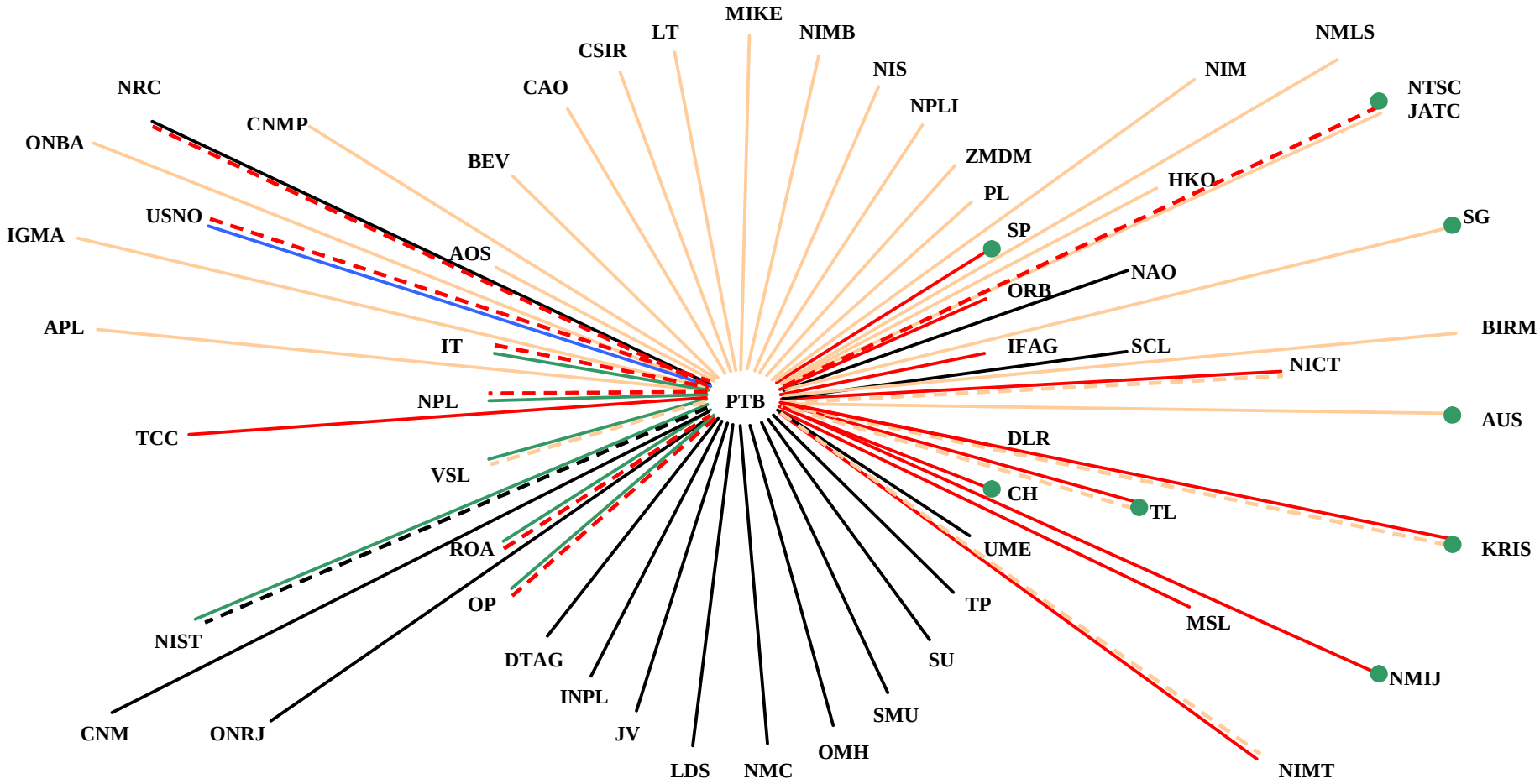

Mod. $\sigma_y(\tau)$
$\sigma_x(\tau)$ / s
Sample time, τ / s
(μs)
(ns)
(ps)
Loran- C
GPS CV 1CH
GPS + GLONASS CV MCH
Stabilized temperature
GLONASS
P-code 1 CH
TWSTFT
CS
GPS
Carrier phase
HM
1 hour
1 day
1 year



ORGANIZATION OF THE COMMON-VIEW INTERNATIONAL TIME

August 2006

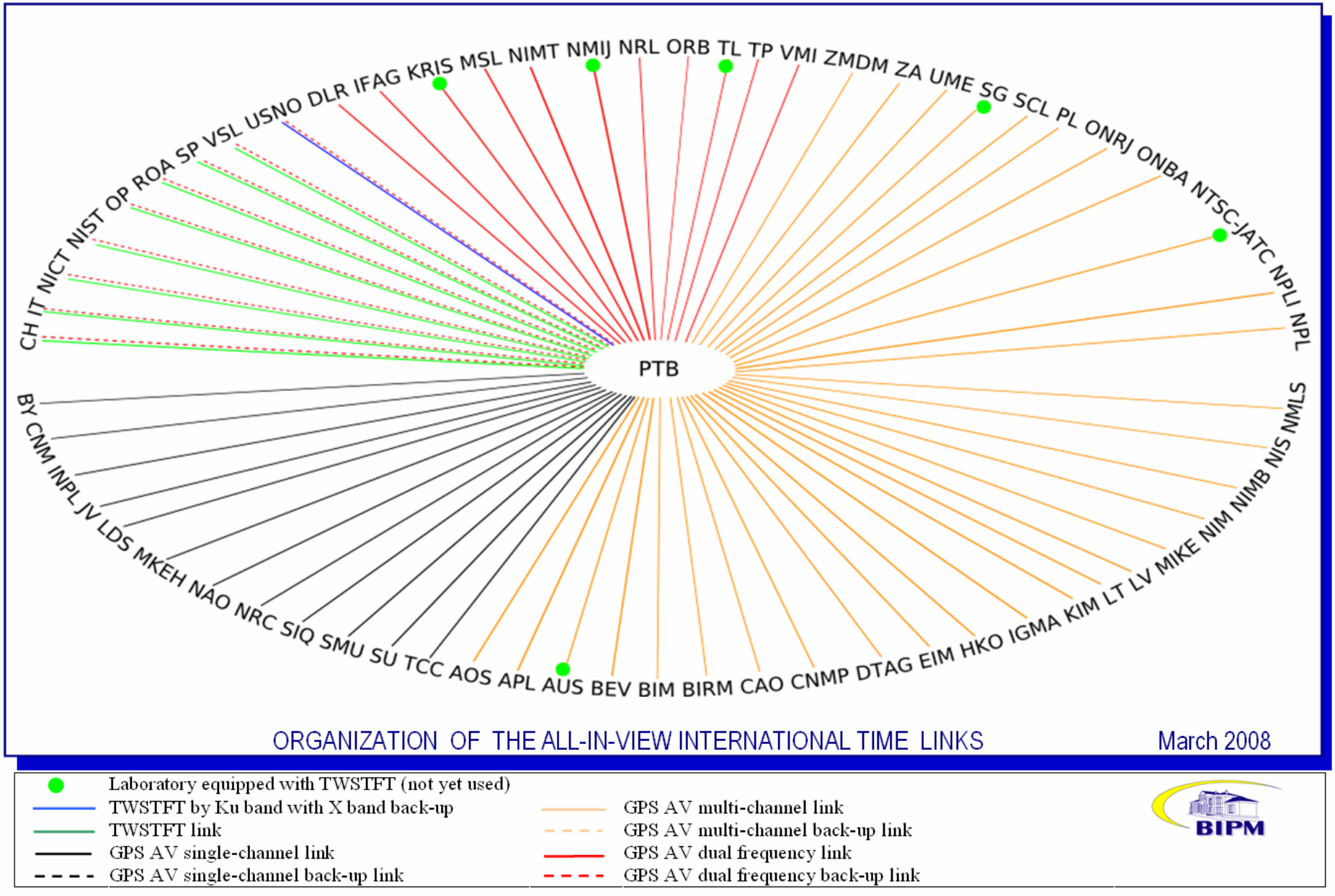
- Laboratory equipped with TWSTFT (not yet used)
- TWSTFT by Ku band with X band back-up
- TWSTFT link
- GPS single-channel link
- GPS single-channel back-up link
- GPS multi-channel link
- GPS multi-channel back-up link
- GPS dual frequency link
- GPS dual frequency back-up link



ORGANIZATION OF THE ALL-IN-VIEW INTERNATIONAL TIME LINKS

September 2006

- Laboratory equipped with TWSTFT (not yet used)
- TWSTFT by Ku band with X band back-up
- TWSTFT link
- GPS single-channel link
- GPS single-channel back-up link
- GPS multi-channel link
- GPS multi-channel back-up link
- GPS dual frequency link
- GPS dual frequency back-up link


PTB
BY CNM INPL JV LDS MKEH NAO NRC SIQ SMU SU TCC AOS APL AUS BEV BIM BIRM CAO CNMP DTAG EIM HKO IGMA KIM LT LV MIKE NIM NIMB NIS NMLS
CH IT NICT NIST OP ROA SP VSL USNO DLR IFAG KRIS MSL NIMT NMIJ NRL ORB TL TP VMI ZMDM ZA UME SG SCL PL ONRJ ONBA NTSC-JATC NPLI NPL
ORGANIZATION OF THE ALL-IN-VIEW INTERNATIONAL TIME LINKS
March 2008
Laboratory equipped with TWSTFT (not yet used)
TWSTFT by Ku band with X band back-up
TWSTFT link
GPS AV single-channel link
GPS AV single-channel back-up link
GPS AV multi-channel link
GPS AV multi-channel back-up link
GPS AV dual frequency link
GPS AV dual frequency back-up link
BIPM

BIPM CALIBRATIONS OF GPS/GLONASS C/A-code and P-code TIME EQUIPMENT

BIPM differential calibrations of GPS/GLONASS

C/A-code and P-code time equipment

Uncertainty for GPS C/A-code 3 ns (1 σ)

- In 2004/2006 six campaigns were carried out
  - 2004: OP, PTB, NPL,VSL
  - 2005: OP, NTSC, HKO, TL, SG, AUS, KRIS, NMIJ, NICT
  - 2005: OP, TCC, ONBA, IGMA, CNMP
  - 2006: OP, CNM, NIST, USNO, NRC
  - 2006: BIPM, OP, PTB, AOS, USNO, NRL, CSIR (ongoing)
  - 2006: OP, AOS, GUM, LT, TP, BEV, OMH, NIMB, NMC, ZMDM
- In total 20 laboratories out of the 50 that contributes to TAI have been calibrated, and additional 10 will be this autumn.

PTB

Date	UTC(i)–UTC(j)	Differential correction /ns	Estimated uncertainty /ns
Oct 86	UTC(PTB) –UTC(OP)	+9	2
Oct 94	UTC(PTB) –UTC(OP)	+4	2
July 97	UTC(PTB) –UTC(OP)	+2	3
Nov 97	UTC(PTB) –UTC(OP)	+4	2
Mar 98	UTC(PTB) –UTC(OP)	–6	2
June 98	UTC(PTB) –UTC(OP)	+5	3
June 03	UTC(PTB) –UTC(OP)	–5	4
August 03	UTC(PTB) –UTC(OP)	0	3
July 04	UTC(PTB) –UTC(OP)	0	3

BIPM calibrations

- BIPM will continue its GPS/GLONASS C/A-code/P-code calibration campaigns; a new TTS-3 receiver is now dedicated for this purpose.
- Two new BIPM calibrations campaigns are now ongoing.
- BIPM will continue to help the regional metrology organizations to organize GPS/GLONASS calibration campaigns.

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2006 AUGUST 10, 14h UTC

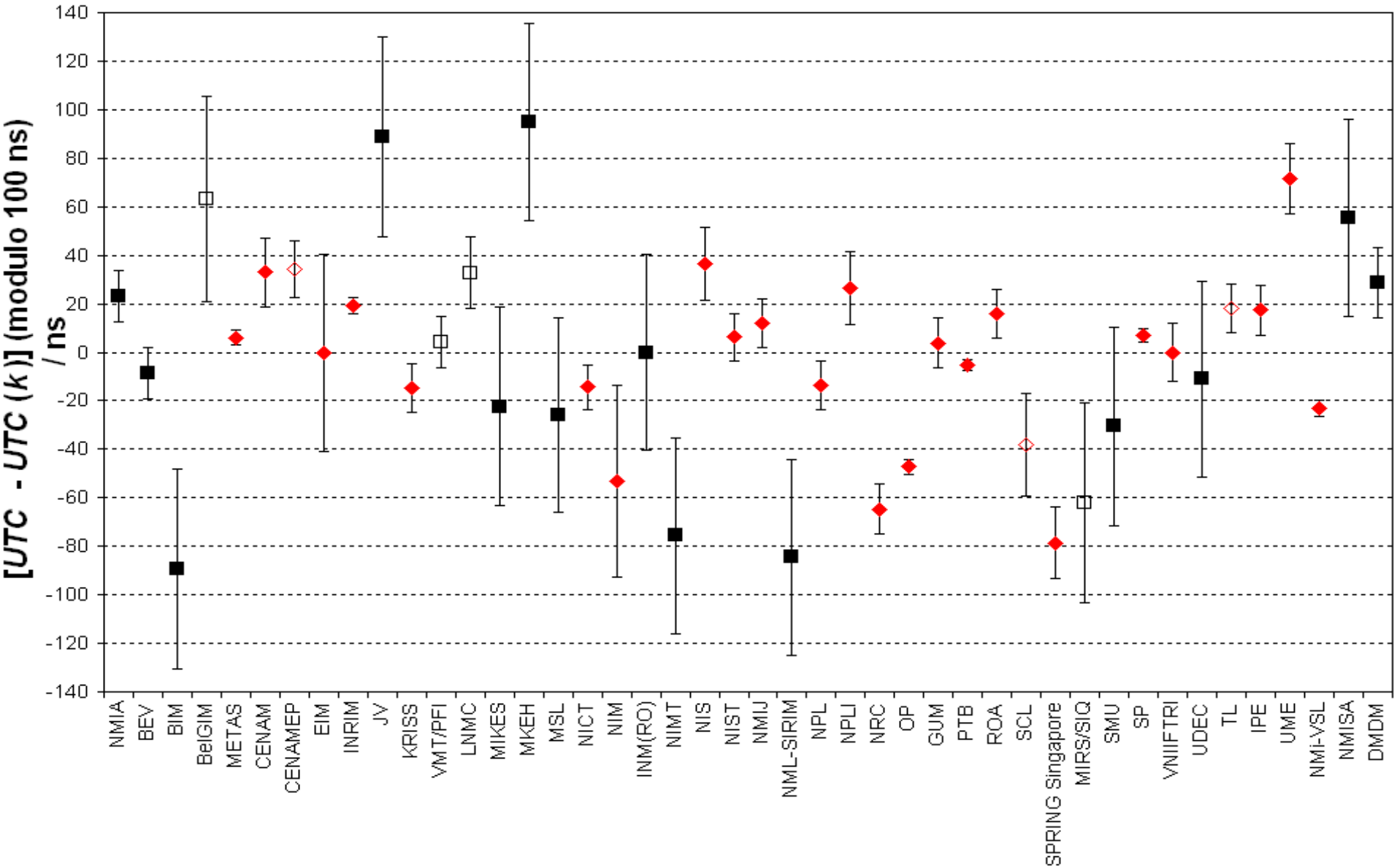
BUREAU INTERNATIONAL DES POIDS ET MESURES

Date 2006 0h UTC	JUN 28	JUL 3	JUL 8	JUL 13	JUL 18	JUL 23	JUL 28	Uncertainty/ns		
MJD	53914	53919	53924	53929	53934	53939	53944	uA	uB	u
Laboratory k	[UTC-UTC(k)]/ns									
AOS (Borowiec)	5.2	9.3	3.3	6.2	10.6	7.1	9.9	1.6	5.3	5.5
APL (Laurel)	0.8	4.6	-0.7	-3.4	-4.3	3.7	15.4	1.6	5.2	5.4
AUS (Sydney)	-529.0	-498.6	-490.1	-489.2	-475.2	-445.1	-437.4	3.2	6.3	7.1
BIRM (Beijing)	-1874.4	-1893.8	-1898.2	-1913.1	-1930.8	-1946.6	-1964.5	2.8	20.4	20.6
CH (Bern)	30.9	31.3	36.1	32.2	29.9	25.1	21.5	0.8	5.2	5.3
IT (Torino)	-5.0	-5.2	-3.4	-4.6	-3.6	-2.8	-1.1	0.7	2.2	2.3
KRIS (Daejeon)	-14.6	-5.4	-4.0	-8.2	-1.6	2.2	-0.3	1.4	6.3	6.5
LT (Vilnius)	147.0	153.3	145.7	138.2	149.2	161.1	143.2	1.6	5.3	5.5
NIS (Cairo)	-2.4	-3.9	-2.7	-6.4	-7.7	-8.7	-12.4	1.6	7.2	7.4
NIST (Boulder)	9.2	8.3	9.2	8.6	8.1	6.7	6.5	0.7	4.9	5.0
NMIJ (Tsukuba)	-10.3	-11.3	-8.1	-8.3	-7.1	-3.0	0.4	1.4	6.3	6.5
NPL (Teddington)	7.9	4.9	5.2	3.4	1.1	0.6	0.5	0.7	2.2	2.3
NPLI (New-Delhi)	119.6	138.9	154.2	169.9	-119.2	-108.5	-94.9	2.5	7.2	7.6
NRC (Ottawa)	-27.1	-21.3	-26.3	-32.7	-33.7	-28.9	-30.3	3.0	15.1	15.4
NTSC (Lintong)	10.4	7.1	5.1	1.7	-0.8	1.5	7.3	2.6	6.1	6.6
ONRJ (Rio de Janeiro)	7524.1	7568.6	7624.1	7672.2	7726.0	7770.0	7821.6	5.0	20.5	21.1
OP (Paris)	-2.9	-2.8	-2.6	3.8	3.2	5.8	2.4	0.7	2.2	2.3
ORB (Bruxelles)	3.8	2.0	0.1	-3.9	-8.0	-10.0	-7.0	0.8	5.2	5.3
PL (Warszawa)	13.1	11.0	9.0	2.8	12.5	25.5	22.1	1.5	5.0	5.3
PTB (Braunschweig)	25.8	20.8	18.7	17.2	18.2	17.4	13.9	0.5	1.6	1.7
ROA (San Fernando)	63.5	63.4	67.0	61.3	74.6	79.1	69.7	0.8	5.2	5.3
SP (Boras)	25.4	20.1	24.1	25.5	25.6	28.2	25.1	0.8	2.2	2.3
SU (Moskva)	48.1	45.3	45.7	43.6	42.6	43.2	41.1	3.0	5.2	6.0
TL (Chung-Li)	3.1	-0.7	-3.1	-3.8	-7.0	-10.2	-12.1	1.3	6.1	6.3
USNO (Washington DC)	-2.9	-0.3	2.9	3.9	5.3	4.8	5.7	0.5	1.7	1.8
VSL (Delft)	5.6	10.8	5.1	4.3	-3.9	-7.8	-11.6	0.7	3.4	3.4

CCTF-K001.UTC Calculation of UTC

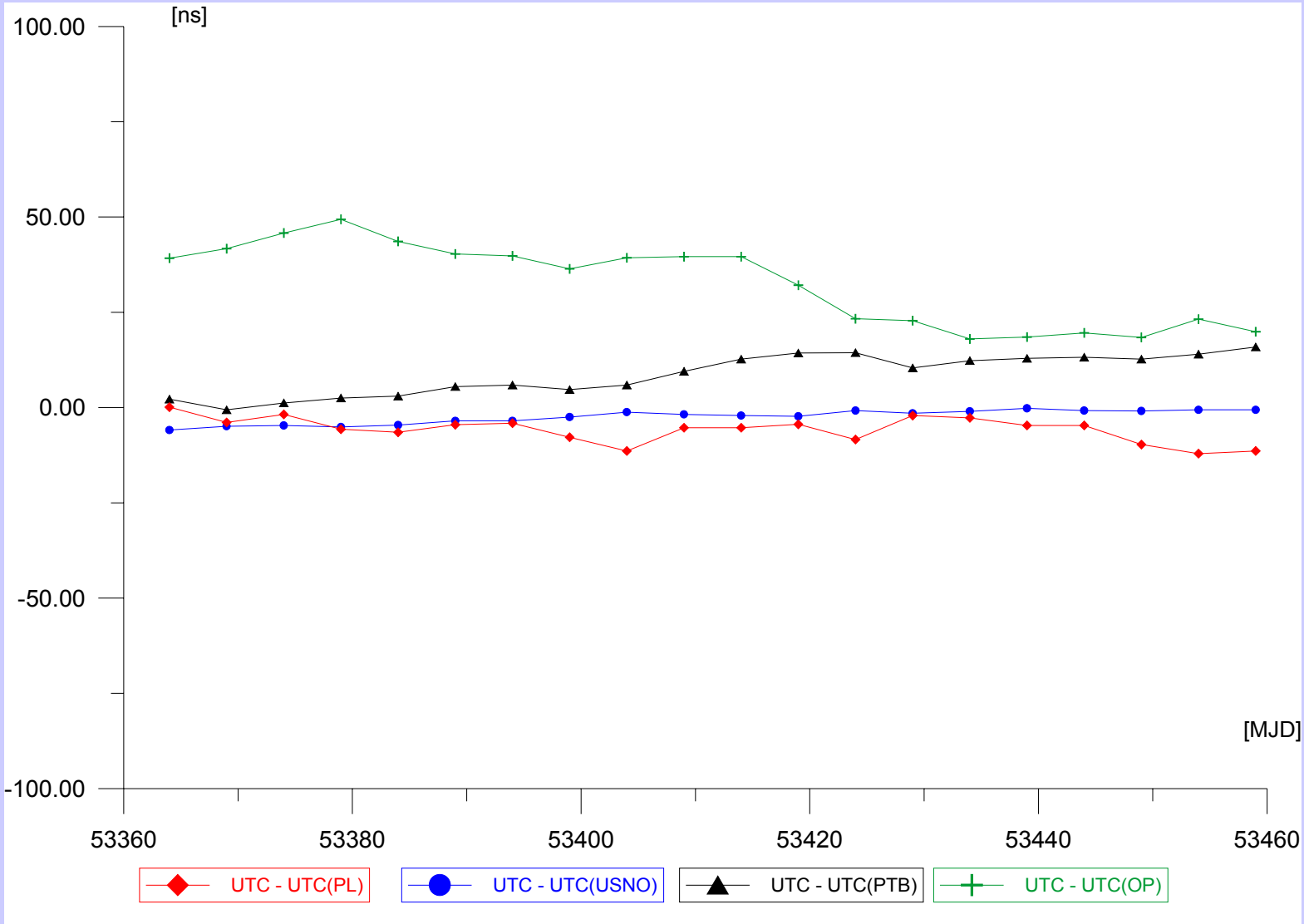
Degrees of equivalence: [*UTC* - *UTC*(*k*)] and its expanded uncertainty ($U_k = 2u_k$)

Computed values for 30 November 2007 at 0h UTC, MJD = 54434



Red diamonds: direct values [*UTC* – *UTC*(*k*)]
Black squares: [*UTC* – *UTC*(*k*)] values taken modulo 100 ns
Open symbols represent values for laboratories in Associate States and Economies of the CGPM

UTC – UTC(i)


[ns]
100.00
50.00
0.00
-50.00
-100.00
[MJD]
53360
53380
53400
53420
53440
53460
UTC - UTC(PL)
UTC - UTC(USNO)
UTC - UTC(PTB)
UTC - UTC(OP)

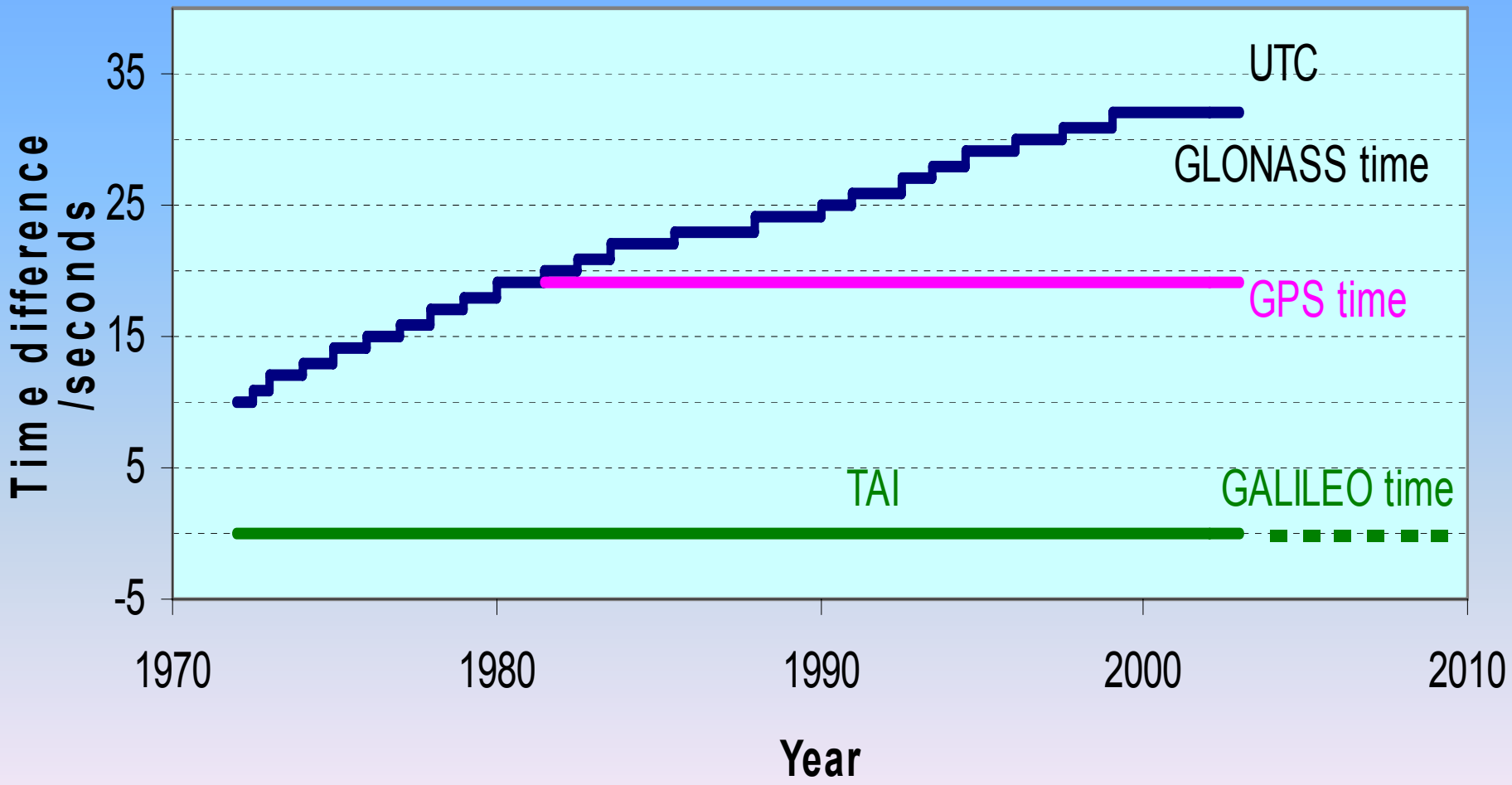
New Developments

- Melting pot / all-in-view with IGS time
- Use of Glonass P-code
- Use of SBAS (WAAS, EGNOS, …)
- New generations of TWSTFT
- Improvements in use of geodetic receivers
- GPS carrier-phase
- Use of geodetic techniques (PPP)
- Real-time (challenge for Galileo and in future for BIPM)

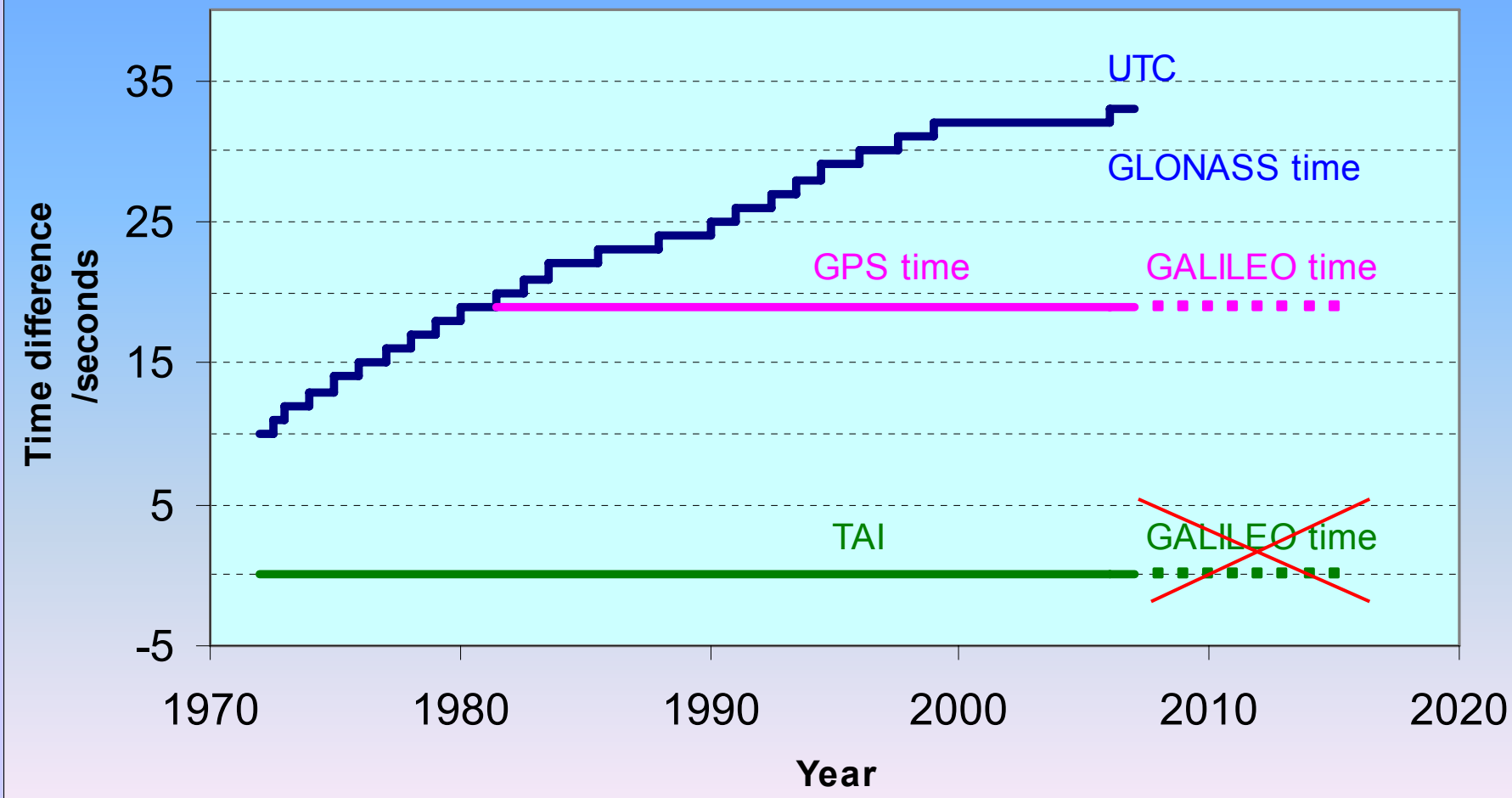
TIME SCALES
FOR SATELLITE NAVIGATION SYSTEMS

- Change in the definition of international time scales
  - UTC
  - TAI
  - Leap second
- Relation between satellite time scales
  - GPS time
  - Glonass time
  - Galileo system time

[*TAI - Time scale (i)*]



[*TAI - Time scale (i)*]



International Committee on Global Navigation Satellite Systems (ICG)
Pasadena, California
8 - 12 December 2008

ICG Draft Recommendation

International Committee on Global Navigation Satellite Systems (ICG)

considering

- **the international value of having many GNSS operational with a composite contribution of several tens of satellites,**
- **the desirability of using all systems interchangeably,**
- **the use by GPS of references very close to UTC and ITRF,**
- **the GLONASS efforts to approach UTC and ITRF,**
- **the Galileo design referring to UTC and ITRF,**
- **that other important satellite navigation systems are now being designed and developed*),**

recommends

- **that the reference times (modulo 1 s) of satellite navigation systems be synchronized as closely as possible to UTC,**
- **that the reference frames for these systems be in conformity with the ITRF,**
- **that these systems broadcast, in addition to their own System Time (ST):**
  1. **the time difference between ST and a real-time realization of UTC,**
  2. **a prediction of the time differences between ST and UTC.**

***) Compass, IRNSS, QZSS, various SBAS, …**

ITU meeting on redefinition of UTC
Geneva, 6 -10 October 2008

To avoid proliferation of time scales ITU plans to stop application of leap seconds to UTC

- October 2008: ITU Working Party 7A will submit to ITU Study Group 7 project recommendation on stopping leap second
- During 2009 Study Group 7 will conduct a vote through mail among member states
- 2011: if 70 % member states agree World Radio Conference will approve recommendation
- 2013: application of leap second will stop and UTC will become a continuous time scale

BIPM

Louis Essen :

“…… In 1960s there was a suggestion that astronomical time should be used for sea navigation and domestic purposes, and atomic time for air navigation and scientific work. My experiences with time signals and standard frequency transmissions convinced me that this would cause endless confusion as well as involving duplication of equipment and I argued strongly that a method of combining all the information in one set of transmission must be found…..”

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