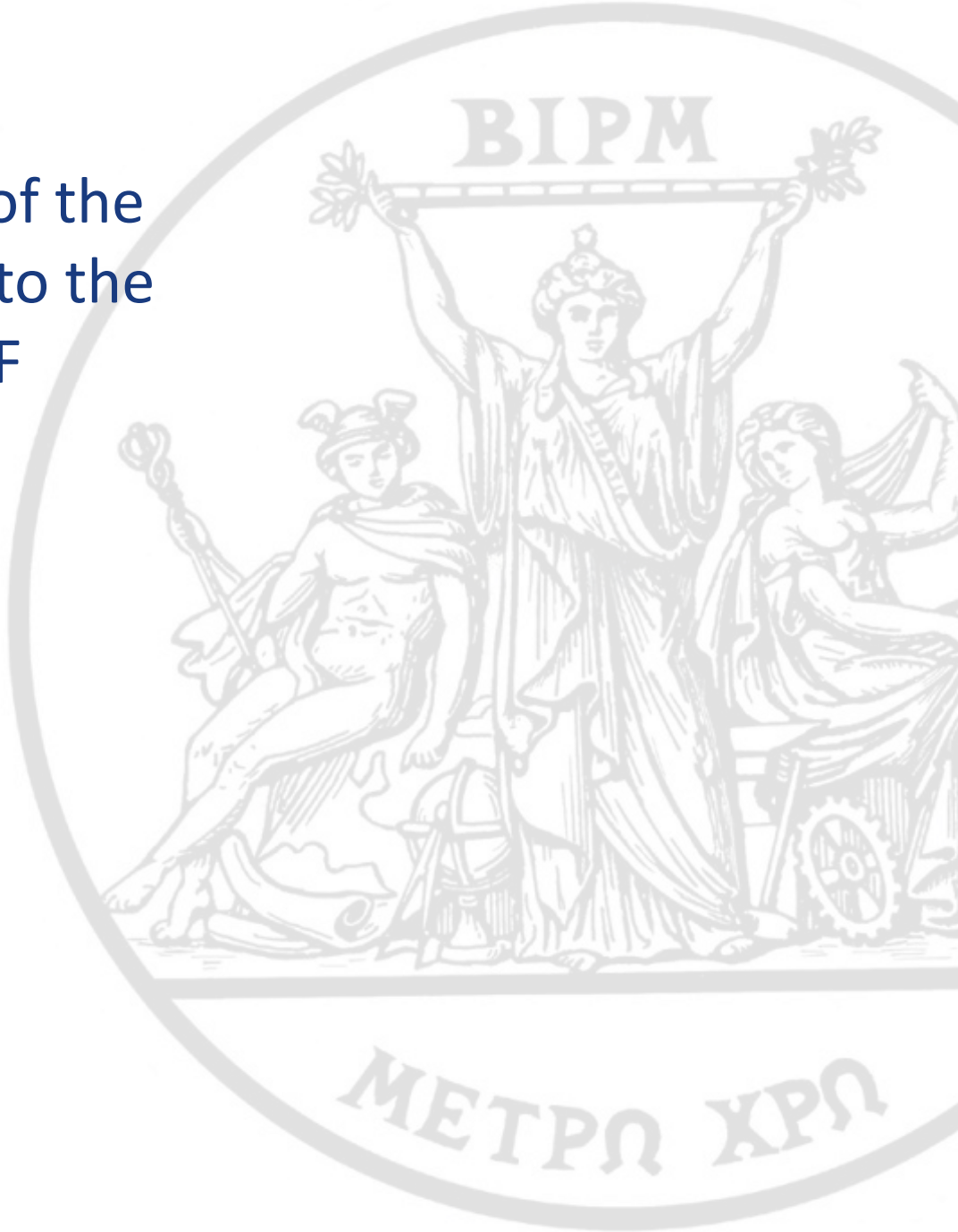
Report on the activities of the BIPM Time Department to the 21st Meeting of the CCTF

Elisa Felicitas Arias

21st Meeting of the CCTF
Sèvres, 8-9 June 2017



Bureau International des Poids et Mesures

Programme of Work 2016-2019

PROJECTS	DELIVERABLES	
Computation and dissemination of time scales	✓ UTCr ✓ UTC ✓ TT(BIPM)	Broader disemination of products and services
Calibration of time transfer equipment	to decrease the uncertainty of [UTC-UTC(k)]	to improve the accuracy of time dissemination
Very accurate standards and appropriate transfer techniques	To include SRS (optical) in TAI	To better characterize their uncertainties
International liaison and coordination	To take collective actions on timescale definition, dissemination and applications	
	To support the activities of laboratories in the frame of the CIPM MRA	

Staff of the Time Department (2015-2017)

Permanent

Felicitas Arias	director (retiring 30/11/17)
Johanna Gonçalves	calculation, software development (started 1/03/17)
Aurélie Harmegnies	calculation, software development, t. transfer
Zhiheng Jiang	time transfer, calibration
Hawaï Konaté *	calculation, data management, publications (retired 31/10/16)
Gianna Panfilo	algorithms, pfs, MRA
Gérard Petit	time transfer, PFS/SFS, calibration, international liaison
Lennart Robertsson	optical frequencies, internal services
Laurent Tisserand	laboratory management, software development, t transfer

Visitors/secondees

J. Feng (NIM) , July 2016: Training for the ICAG 2017 at NIM (financed by NIM)

D. Matsakis (USNO), 10 October-10 November 2016: uncertainties in key comparison (financed BIPM)

Liang Kun (NIM), year 2017: time transfer, new satellite systems (co-financed NIM/BIPM)

J. Leute (post-doc), August 2017-August 2019: very accurate time/frequency transfer (co-financed CNRS-BIPM)

Regular provision of the high quality time scales covering multiple applications

Weekly « Real-time » UTC through Rapid UTC solution

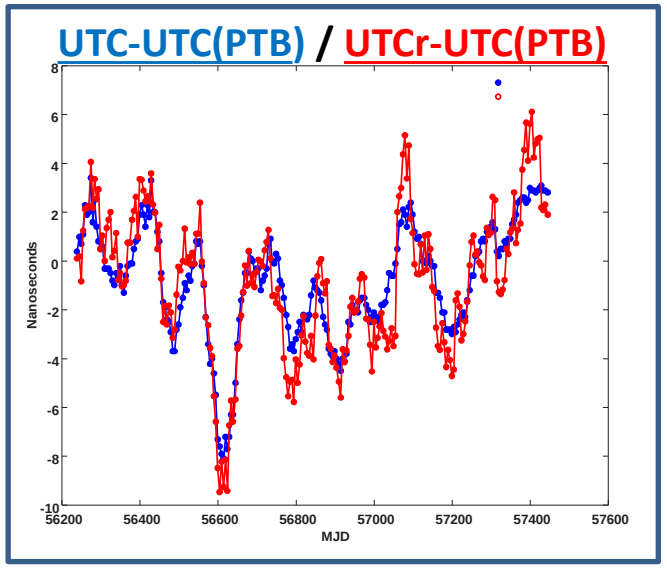
Rapid reference for better synchronization to UTC of local UTC(k)
Stability 5×10^{-16} @ 30 d
Offset wrt UTC < |3 ns|

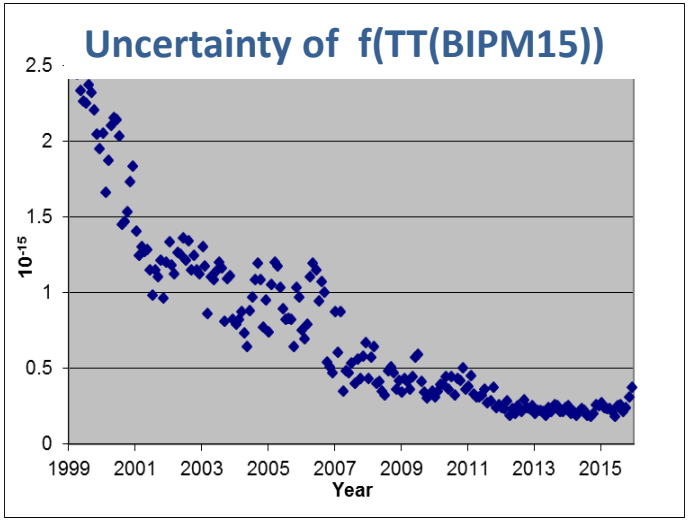
Monthly UTC through BIPM *Circular T* and CCTF K-001.UTC

Ultimate traceability to the SI second to NMIs
Stability 2×10^{-16} @ 30 d
Accuracy 4×10^{-16}

Yearly long-term stable TT(BIPM)

Reference for astronomy and deep space navigation
Accuracy < 3×10^{-16}
Based on PFS - SRS





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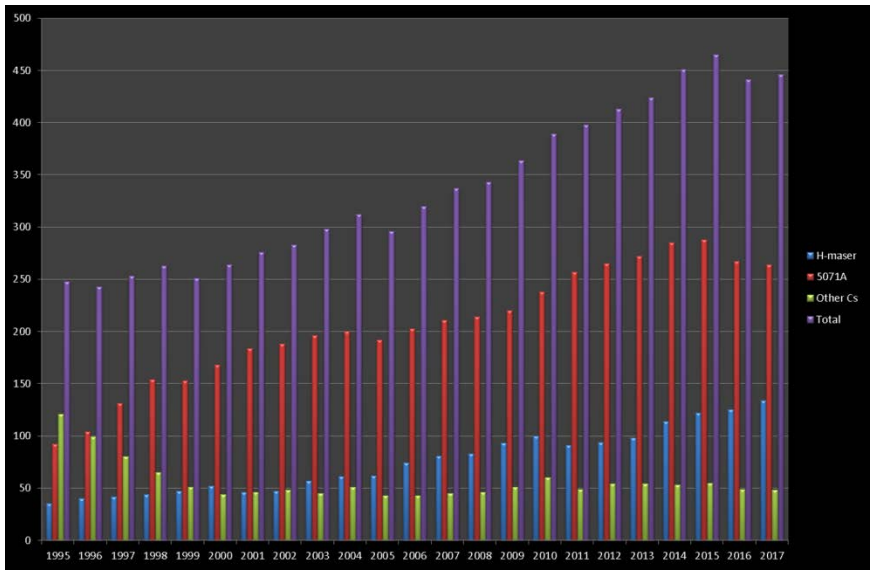
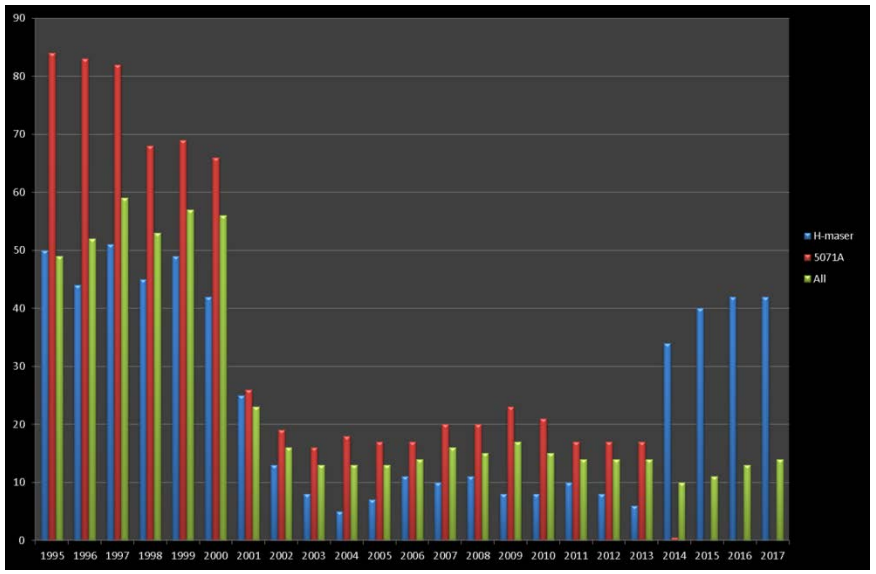
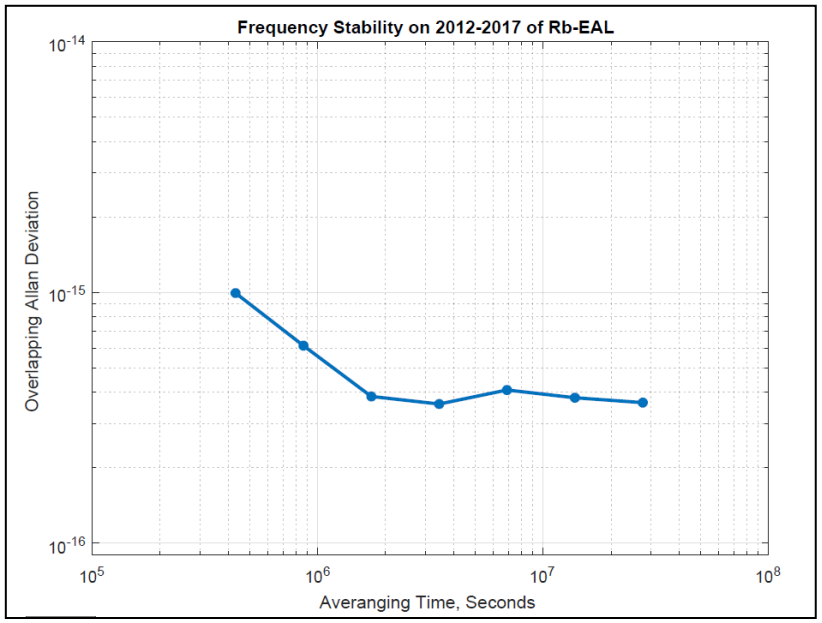
Highlights (Sept. 2015 – June 2017)

- **Algorithm for TAI**
  - Studies for implementing a new algorithm of computation of the uncertainties of [UTC-UTC(k)].
- **Rapid UTC**
  - Uniterrupted weekly publication. Actions for improvement.
- **Improvement of time transfer uncertainty by:**
  - Regular GPS equipment calibrations in cooperation with RMOs and NMIs;
  - Studies to decrease the noise of TW links (with CCTF WG TWSTFT)
- Secondary representations of the second
  - Procedure for evaluation of frequencies, rations and uncertainties supporting CCL-CCTF WGFS
- **Dissemination of information**
  - New presentation of Circular T
  - Re-organized ftp/web
  - Time Department Data Base
- **Time scales definition, work with ITU**
  - Study Group on Time Scales Definition

Coordinated Universal Time UTC / Algorithm







- ✓ Clock frequency prediction by a quadratic model
- ✓ Weight reflects the clock predictibility
- ✓ Interval for clock drift evaluation reduced from 6 to 3 months (Circular T 350, Feb. 2017) (presentation G. Panfilo)

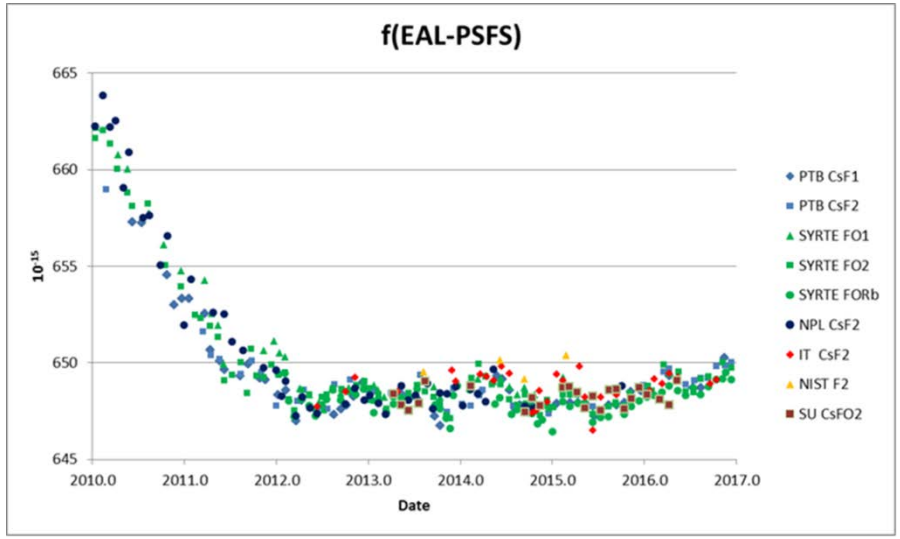
Coordinated Universal Time UTC / frequency accuracy

Primary Standard	Type /selection	Type B std. uncertainty/ 10^{-15}	u_B(Ref)/10^{-15}	Ref(u_B)	Comparison with	Number/typical duration of comp.
IT-CsF2	Fountain	(0.17 to 0.48)	0.18	[1]	H maser	7 / 10 d to 35 d
NIM5	Fountain	1.4	1.4	[2]	H maser	4 / 20 d to 20 d
NIST-F1	Fountain	0.31	0.35	[3]	H maser	1 / 20 d
PTB-CS1	Beam /Mag.	8	8.	[4]	TAI	12 / 30 d to 35 d
PTB-CS2	Beam /Mag.	12	12.	[5]	TAI	12 / 30 d to 35 d
PTB-CSF1	Fountain	0.7 then (0.35-0.37)	1.4	[6]	H maser	6 / 15 d to 35 d
PTB-CSF2	Fountain	(0.20 to 0.22)	0.41	[7]	H maser	10 / 10 d to 30 d
SU-CsFO2	Fountain	0.25	0.50	[8]	H maser	4 / 15 d to 30 d
SYRTE-FO2	Fountain	(0.25 to 0.35)	0.23	[9]	H maser	12 / 10 d to 30 d

Secondary Standard	Type	Type B std. uncertainty/ 10^{-15}	u_B(Ref)/10^{-15}	Ref(u_B)	Comparison with	Number/typical duration of comp.
SYRTE-FORb	Fountain	(0.28 to 0.35)	0.32	[10]	H maser	13 / 10 d to 35 d

Contribution of PFS and SRS in 2016 (from AR 2016)

- ✓ Steering correction changes deemed necessary by the end of 2016, when d ~ 7u
- ✓ After the change in the length of the clock drift evaluation interval d ~ 2u



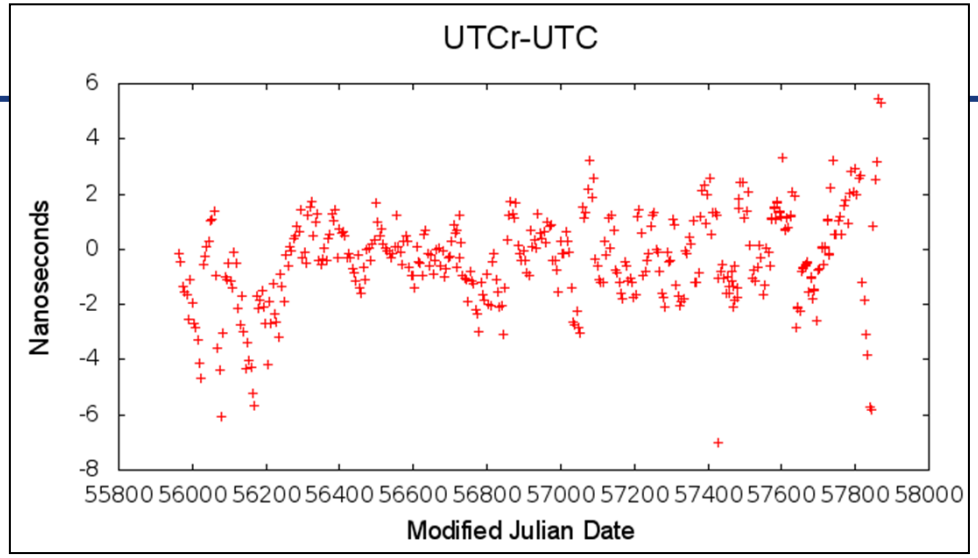
Improving the uncertanty of UTC-UTC(k)

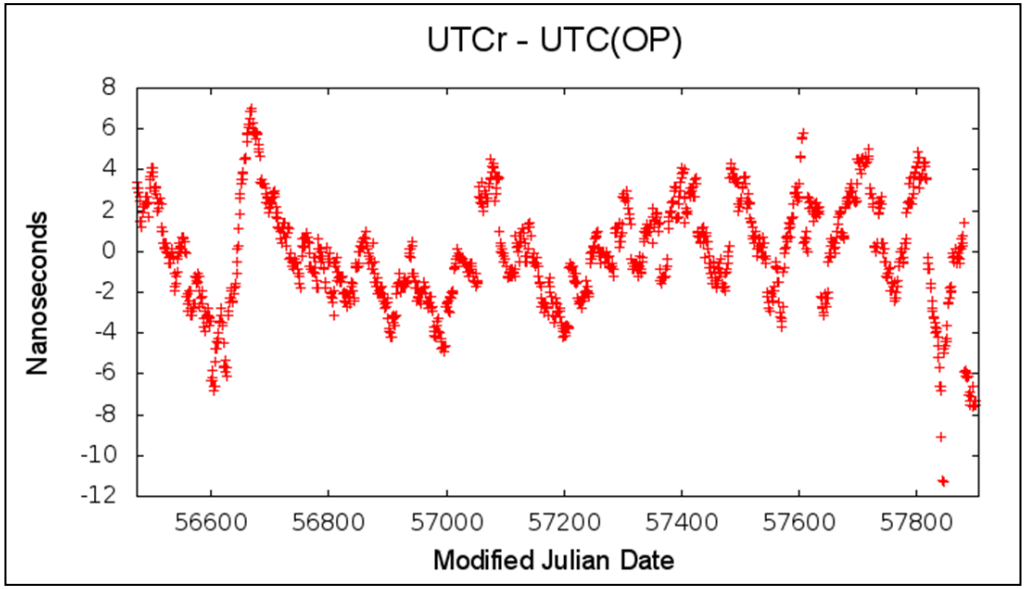
- Changes in the algorithm will be proposed for:
  - Making use of the best available time transfer measurements (redundant links);
  - Avoiding a time link structure based on a unique pivot laboratory;
  - Dealing with correlations;
  - The process will be introduced by steps.

(presentation G. Panfilo)

Rapid UTC

- Uninterrupted publication since July 2013 (weekly)
- 52 participants (+ 10 since 2015)
- ~ 70% of the clocks in UTC





Problems detected

✓ big steps UTC-UTCr and UTCr-UTC(k)

Possible reasons

✓ differences between the algorithms of UTC and UTCr (weight)

✓ Start of the computation interval

✓ Some input data differences

Studies for finding solutions ongoing (presentation G. Petit)

Time transfer equipment calibrations

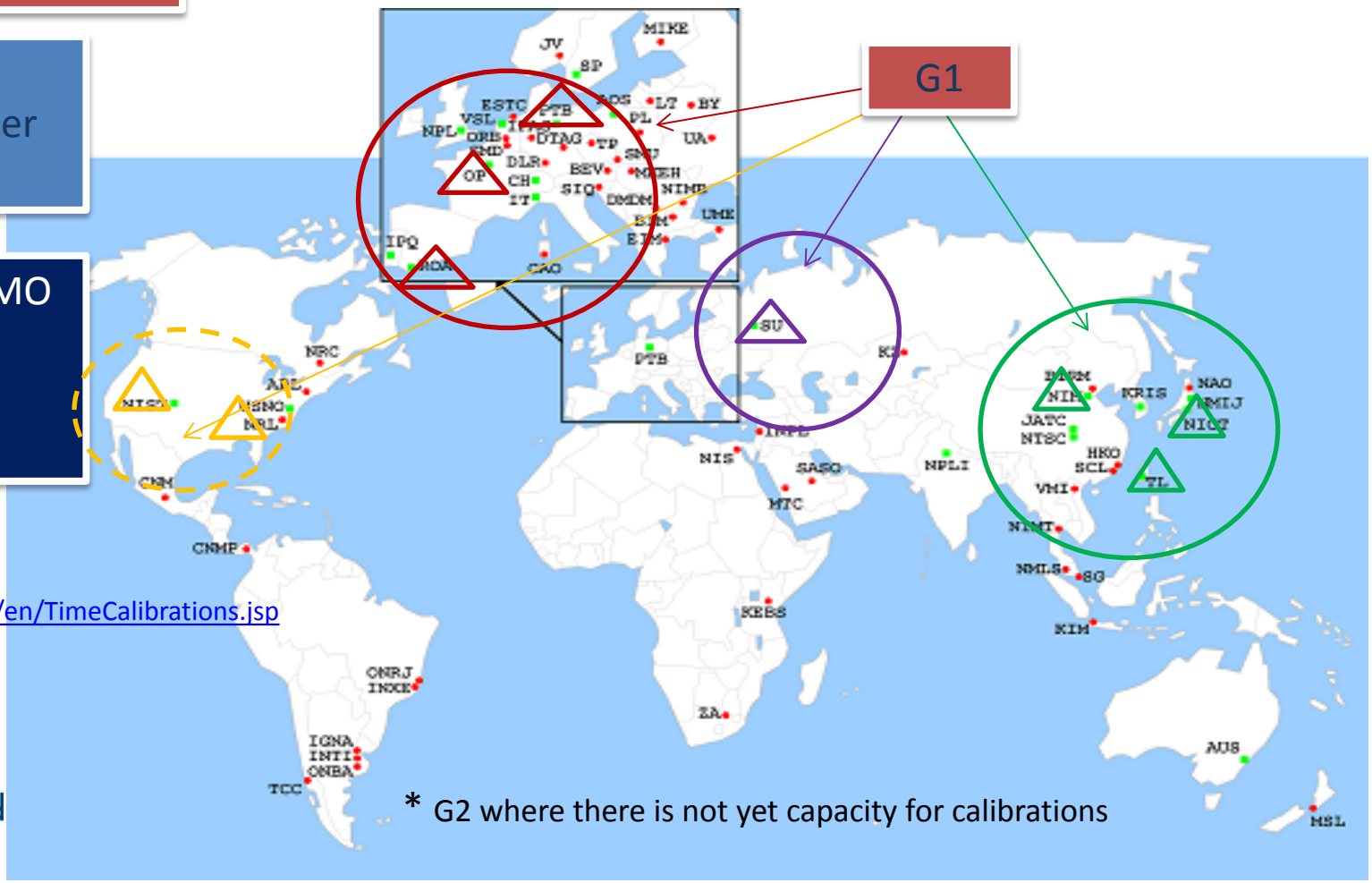
improving the accuracy of UTC-UTC(k) by implementing continuous calibration campaigns for reducing time link uB from 5 ns to < 2.5 ns

BIPM calibrates equipment in selected labs per region (G1) + G2*

RMOs calibrate equipment in other labs (G2)

BIPM validates RMO calibrations and computes final results

- ✓ 1st campaign to all G1 concluded/results implemented
- ✓ 2nd campaign ongoing in EURAMET and SIM G1
- ✓ ZA (NMISA) G2 equipment calibrated



* G2 where there is not yet capacity for calibrations

http://www.bipm.org/jsp/en/TimeCalibrations.jsp

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Time link uncertainty

Link stability

Calibration

Calib. aging

Alignement

u_{Stb} accounts for measurement noise and random effects @ 1 to 30 days

uStb/ns	uCal/ns	uAg/ns	Al/ns	YYMM
0.3	11.2	10	24.3	1511
0.3	5.8	3		
0.3	2.5	0		
1.5	9.2	6		
0.4	20.0			
1.5	7.6	3		
1.5	9.2	6		
8.0	20.0			
0.3	4.0	0		
2.5	11.2	10	-27.3	0804
0.5	7.1	1	41.7	1607
0.7	20.0		10.3	1507
0.7	2.5	0		
0.3	7.3	2		
0.3	7.6	3		
2.5	7.8	6		
0.3	5.4	2		
0.3	7.3	2	+15.9	1304
0.3	5.8	3		

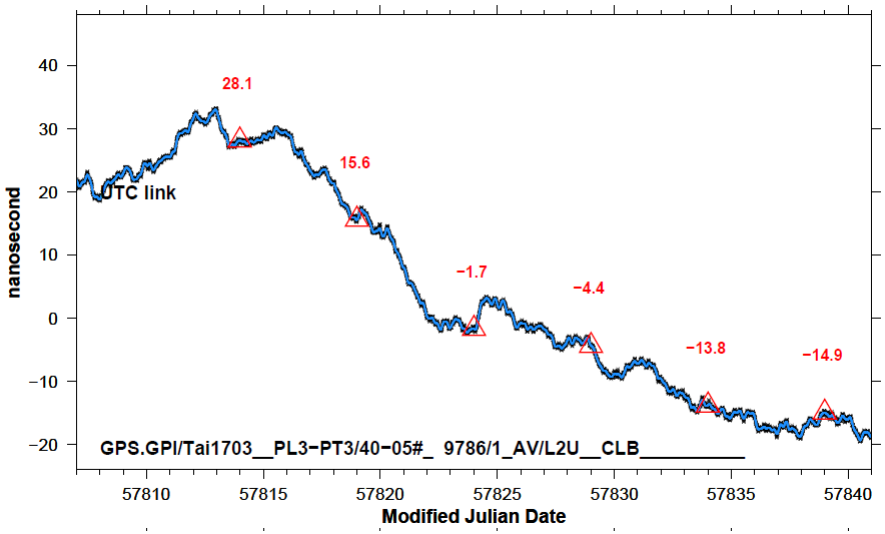


TABLE II. EVOLUTION OF u_B INCREASING WITH TIME AS A RANDOM WALK PROCESS

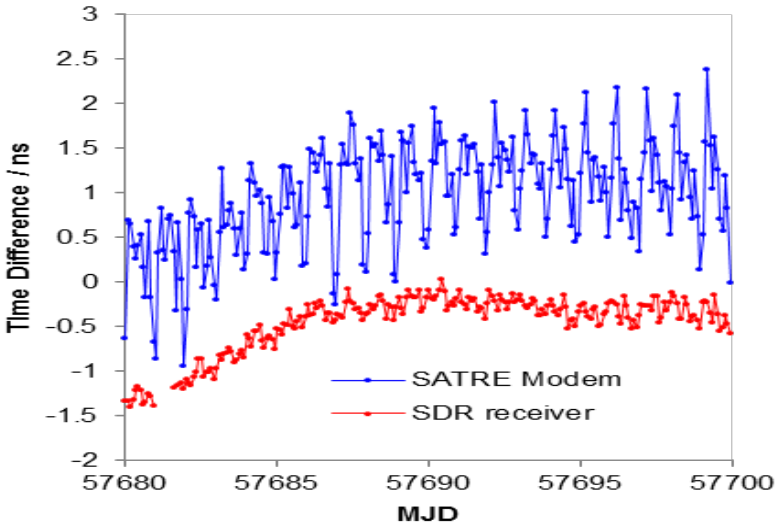
Link	$u_B(T_0)$ /ns	u_A /ns	u_B(1yr) /ns	u_B(3yr) /ns	u_B(5yr) /ns	u_B(10yr) /ns	u_B(>10yr) /ns
TW	1.0	0.3	1.4	2.1	2.5	3.4	10
GNSS P	2.0	0.5	2.6	3.6	4.4	5.8	10
GNSS C/A	3.0	0.7	3.9	5.2	6.2	8.2	10

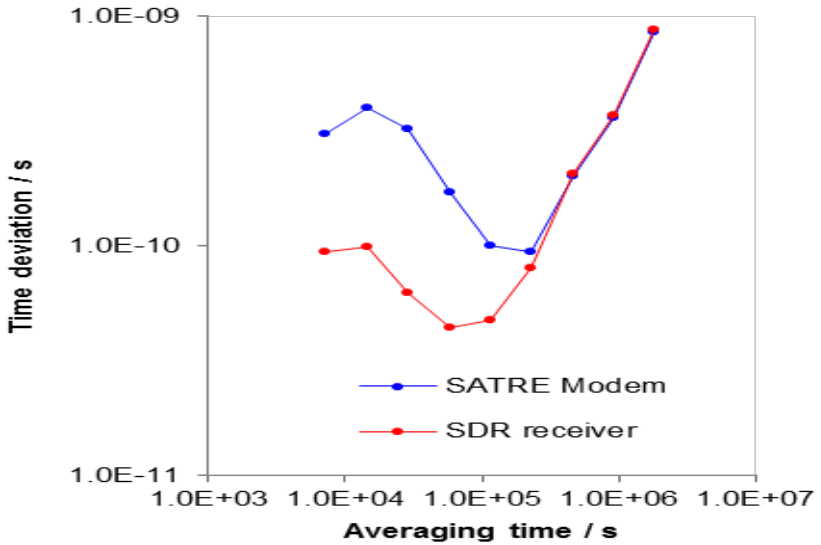
Reducing diurnal measurement noise in TWSTFT

- ✓ Degradation of TWSTFT stability due to ~ 2 ns peak-to-peak diurnal noise;
- ✓ Noise reduction with the operation of a software-defined-radio receiver (SDR);
- ✓ Pilot study BIPM/WG TW shows significant noise reduction on short baselines.

(presentations Z. Jiang, V. Zhang)

link: OP-PTB





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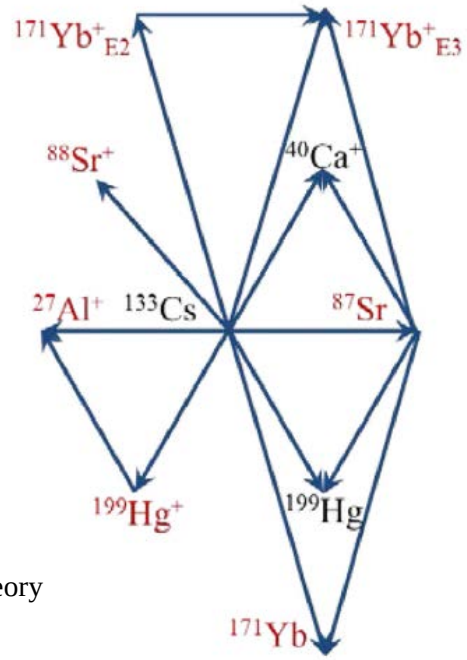
Uncertainty evaluation of optical frequencies to be recommended for secondary definition of the second

- ✓ Optical transitions recommended by the CIPM as SRS are potential candidates to redefine the SI second; they are selected by the CCTF from measurements of frequencies and frequency rations reported by NMIs;
- ✓ The number of reported transitions and rations is increasing, as well as the number of NMIs developing the same atomic species, making the system more complex.

It became necessary to develop independent mathematical methods to evaluate the recommended values of the transitions and ratios and to estimate their uncertainties.

Based on the graph theory a second method* for solving measurement and ratio loops with deviations to zero closure due to noise or systematic errors has been implemented and validated by comparison to Margolis and Gill (*Metrologia* 52 628-634, 2015)



* On the evaluation of ultra-high-precision frequency ratio measurements: examining closed-loops in a graph theory framework, L Robertsson. *Metrologia* 53, 1272–1280, December 2016

Enhanced distribution of data and results through interactive *Circular T* and *Time Department Data Base*

CIRCULAR T 345

2016 OCTOBER 10, 14h UTC

BUREAU INTERNATIONAL DES POIDS ET MESURES

ORGANISATION INTERGOUVERNEMENTALE DE LA CONVENTION DU MI

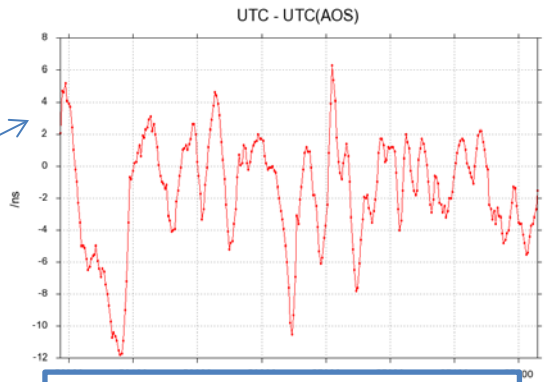
PAVILLON DE BRETEUIL F-92312 SEVRES CEDEX TEL. +33 1 45 07 70 70 FAX. +33 1 45 34

The contents of the sections of BIPM *Circular T* are fully described in the document " Explanatory supplement to BIPM Circular T " avail /explanatory_supplement_v0.1.pdf

1 - Difference between UTC and its local realizations UTC(k) and corresponding uncertainties. From 2015 July 1, 0h UTC, *TAI-UTC*

Date 2016 0h UTC		AUG 29	SEP 3	SEP 8	SEP 13
	MJD	57629	57634	57639	57644
Laboratory *k*					[*UTC-UTC(k)*]/ns
AOS	(Borowiec)	-5.4	-4.4	-3.7	-3.6
APL	(Laurel)	0.1	1.1	1.4	1.1
AUS	(Sydney)	739.2	757.2	779.6	796.8
BEV	(Wien)	22.2	24.1	25.8	25.0
BIM	(Sofiya)	4507.0	4525.1	4543.9	4571.9
BIRM	(Beijing)	-	1.0	0.0	-2.0
BY	(Minsk)	-3.2	-3.6	-3.8	-3.6
CAO	(Cagliari)				
CH	(Bern-Wabern)				
CNES	(Toulouse)				
CNM	(Queretaro)				
CNMP	(Panama)				
DFNT	(Tunis)				

57604	-3.6	+/-	0.4	2.9	2.9
57609	-3.6	+/-	0.4	2.9	2.9
57614	-4.3	+/-	0.4	2.9	2.9
57619	-4.8	+/-	0.4	2.9	2.9
57624	-5.5	+/-	0.4	2.9	2.9
57629	-5.4	+/-	0.4	2.9	2.9
57634	-4.4	+/-	0.4	2.7	2.7
57639	-3.7	+/-	0.4	2.7	2.7
57644	-3.6	+/-	0.4	2.7	2.7
57649	-3.2	+/-	0.4	2.7	2.7
57654	-2.7	+/-	0.4	2.7	2.7
57659	-1.5	+/-	0.4	2.7	2.7



Circular T HTML

no. 345 [September 2016] View

Circular T (nos. 125 to date)

no. 345 [September 2016] View

Circular T ARCHIVE (nos. 1-124)

no. 124 [May 1998] View

BIPM Time Department Data Base

General | Participation guidelines | Interactive plots | GNSS equipment | Calibration | Clocks

In this web site, information can be found on equipment in UTC contributing laboratories
To obtain these information, go to tabs :

General

Laboratories info = laboratories' location and RMO
Laboratories codes = full list of participating labs and their BIPM codes
UTC/UTCr Contributors = contributing laboratories to UTC and UTCr

Participation guidelines = full documentation and guidelines for UTC and UTCr participation

Interactive plots

UTC(k) and GNSS times = Interactive plot of UTC(k) and GNSS system times wrt UTC/UTCr

GNSS equipments

all = list of all GNSS equipment whose data are submitted to BIPM
by laboratory = list of GNSS equipment from a given lab

Calibration

all = list of all calibrated GNSS equipment
by laboratory = GNSS equipment calibration in a lab

18/07/16 : BIPM Internal
14/09/16 : Web availabil

BIPM Annual Report on Time Activities

BIPM 2015 View

BIH Annual Report (extract)

BIH 1987 View

http://webtai.bipm.org/database/html/

www.bipm.org/en/bipm/tai/

International liaison and cooperation - ITU / Time scale definitions and dissemination

- WRC-15
  - Recognized the roles of the BIPM and ITU concerning time scales definition and maintenance, and their dissemination;
  - Invited the various organizations to cooperate for developing studies on the present and potential future reference time scales and submit contributions to WRC-23;
  - Decided than until WRC-23 Rec. 460-6 will continue to apply.

- BIPM Time Department
  - Organized and participated to the Task Group on Time Scales Definition of the CCTF WG TAI ;
  - Developed a strategy in view of the CGPM (2018) and WRC-23.

  (discussion at CCTF WG TAI meeting 7/06/2017)

Publications

- BIPM Publications and services (http://www.bipm.org/en/bipm-services/timescales/time-ftp.html)
  - *BIPM Annual Report on Time Activities* 2015, 2016
    - Electronic http://www.bipm.org/en/bipm-services/timescales/time-ftp/annual-reports.html
  - *BIPM Circular T*, monthly http://www.bipm.org/en/bipm-services/timescales/time-ftp/Circular-T.html
  - *UTCr*, weekly http://www.bipm.org/en/bipm-services/timescales/time-ftp/Rapid-UTC.html ftp://ftp2.bipm.org/pub/tai/Rapid-UTC/
  - TT(BIPMXY) for 2015, 2016, 2017 http://www.bipm.org/en/bipm-services/timescales/time-ftp/ttbipm.html
  - Scientific publications (staff)
- Web/ftp server of the Time Department

THANKS FOR YOUR ATTENTION

Bureau International des Poids et Mesures