Frequency standards in TAI and realization of TT(BIPM)

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TT(BIPMxx)

- As TAI is computed in real time and never corrected in retrospect, it is not optimal. Therefore the BIPM computes a post-processed time scale TT(BIPM).
- Each new version TT(BIPMxx) updates and replaces the previous one.

- TT(BIPMxx) calculation
  - Post-processed using all available PFS data, as of year 20xx.
  - Complete re-processing starting 1993 (possibly with change of algorithm).
  - f(EAL) is estimated each month using available PFS. Monthly estimates are smoothed and integrated to obtain TT(BIPMxx).

- Last realization: TT(BIPM14), released in January 2015.

ftp://tai.bipm.org/TFG/TT(BIPM)/TTBIPM.14

TT(BIPMxx)

- No significant change in the computation of TT(BIPM) since CCTF'2012.

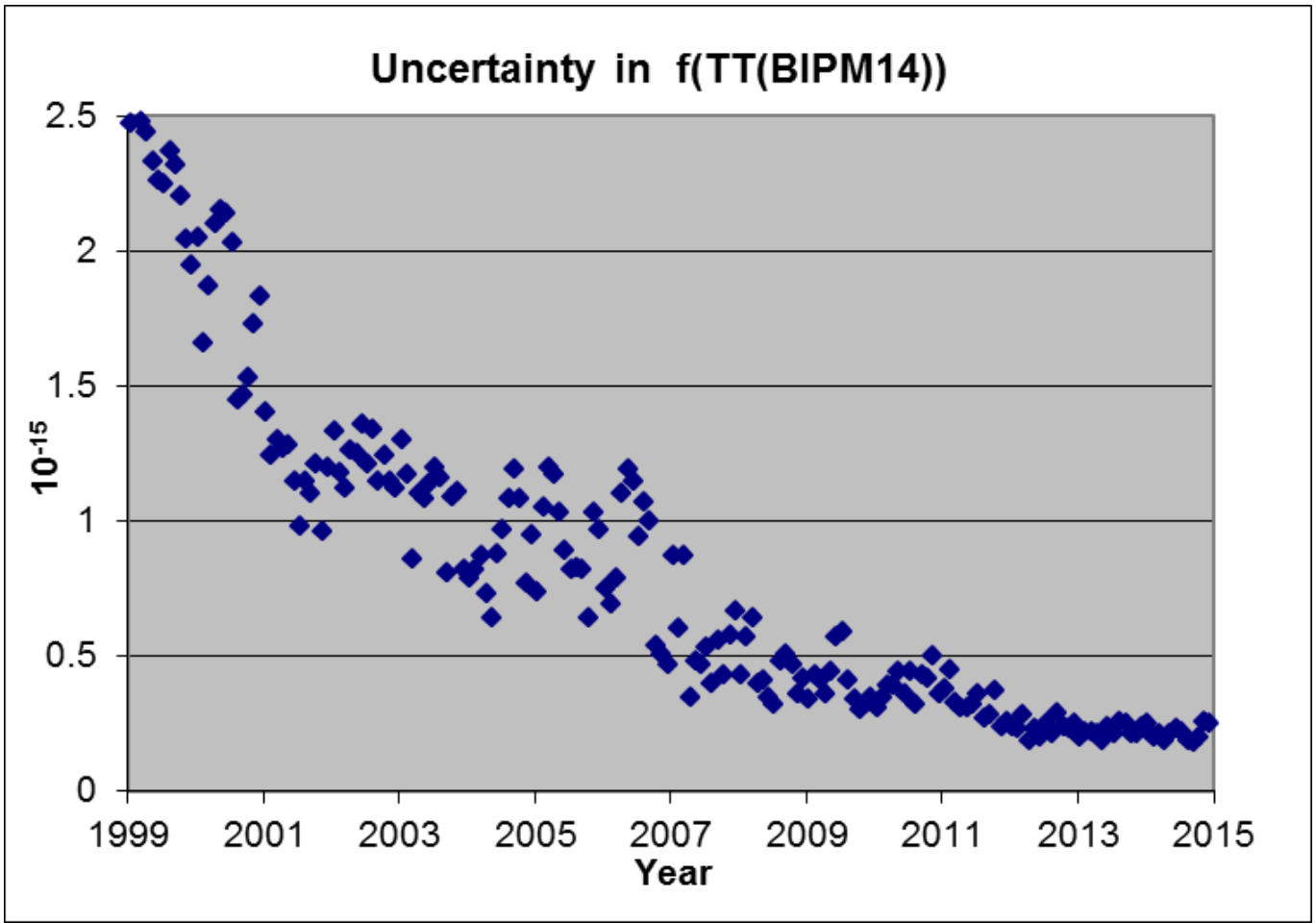
- Since 2010, a prediction of TT(BIPM) has been published .
  - First as monthly extensions
  - Since TT(BIPM13), as a function of TAI valid for the whole year

    For 2015: $TT(BIPM14)_{ext}$ = TAI + 32.184 s + 27697.0 ns

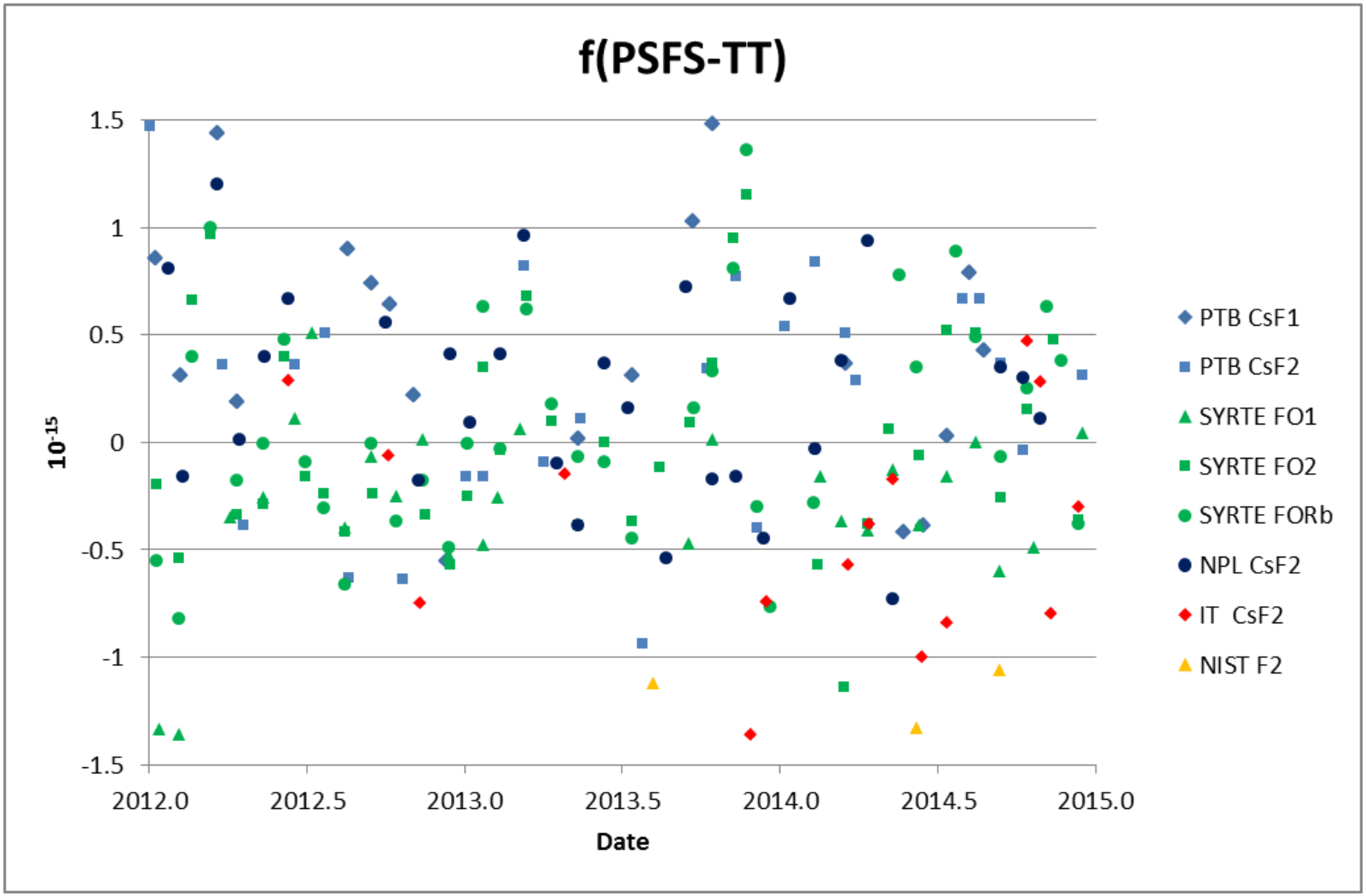
- Since August 2011, a monthly computation of TT(BIPM) is performed to compute the clock drift to be used for TAI, but is not published.

TT(BIPM14)

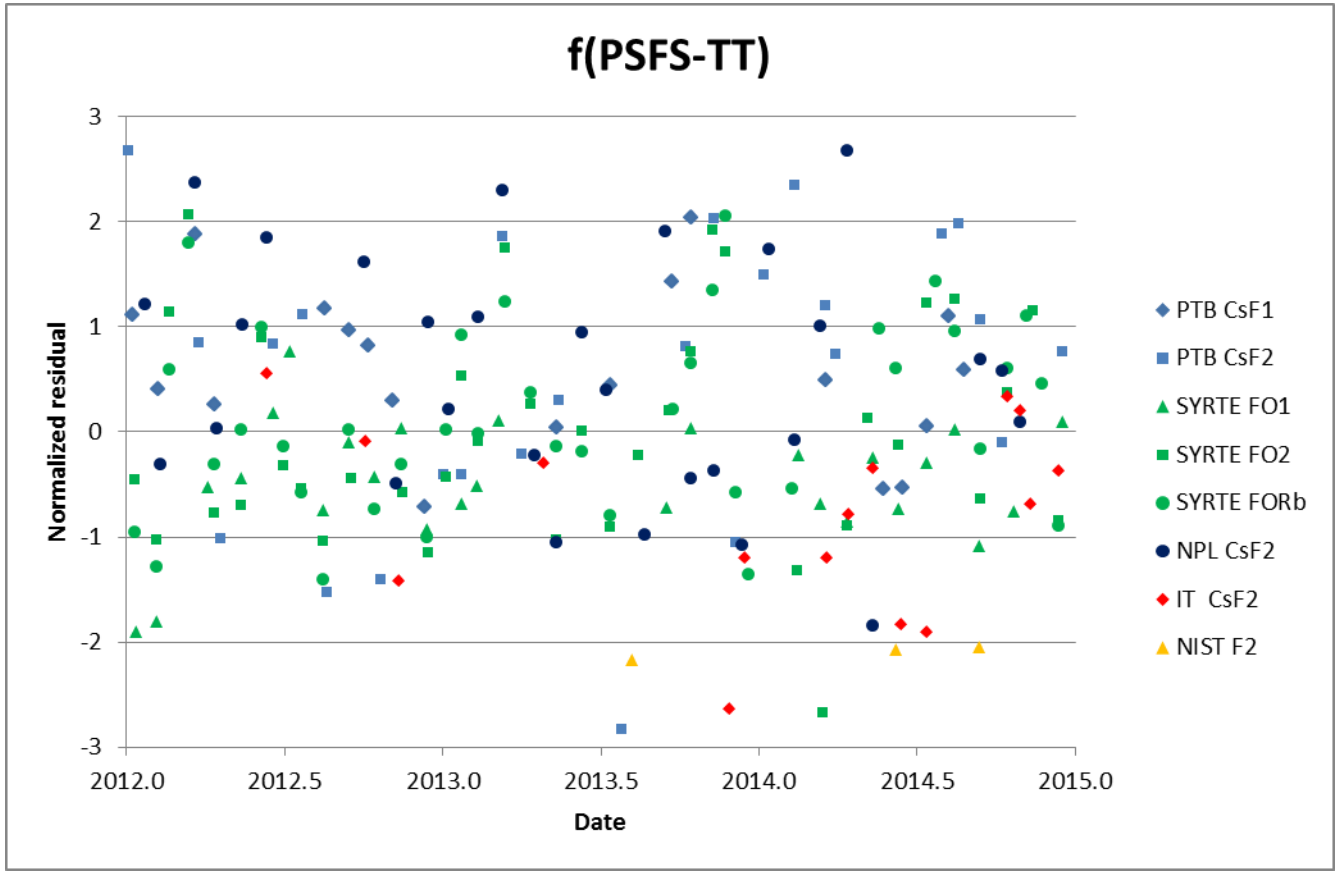
- Frequency accuracy of TT(BIPM) has regularly decreased since the introduction of Cs fountains from
  2.5×10^{-15} in 1999 to $< 1 \times 10^{-15}$ since 2004, $< 5 \times 10^{-16}$ since 2008
  $\sim 2 \times 10^{-16}$ since 2012.
- It directly depends on the uncertainty budget of the PFS



TT(BIPM) allows to estimate the performance of PSFS

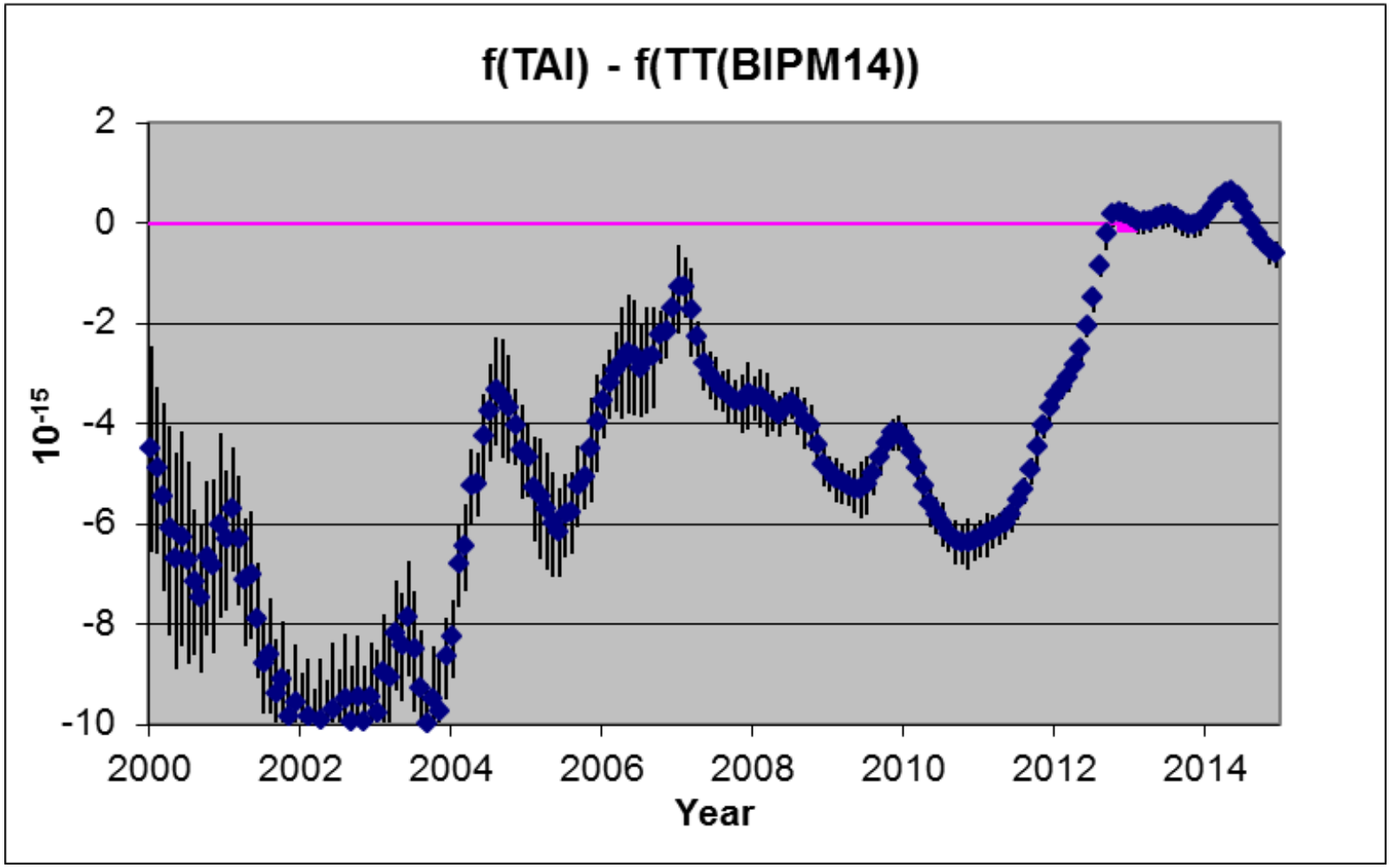


- Overall (1228 evaluations over 22 years) normalized residuals have a standard deviation of 1.0
- Still OK in recent years (461 evaluations over 5 years) Stdev = 1.1
- Most presently operating fountains have no systematic bias
  - IT-CsF2 marginally below TT; PTB CsF1 marginally above TT; NIST F2 has 3 values only



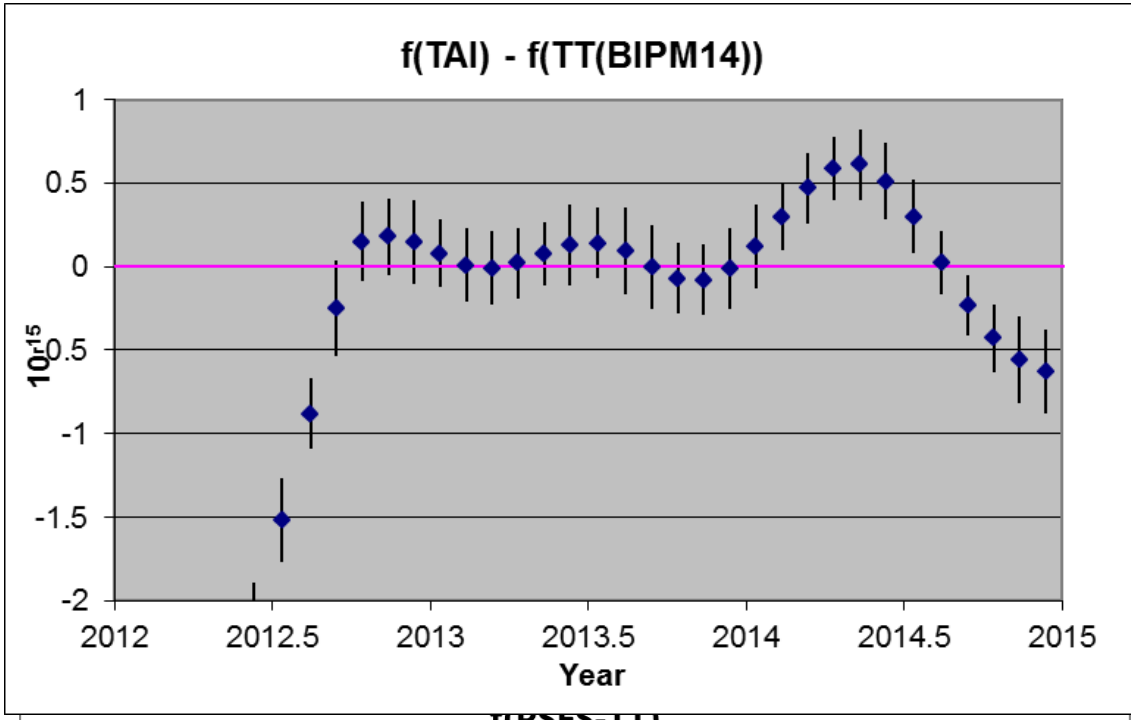
TT(BIPM) allows to estimate the accuracy of TAI

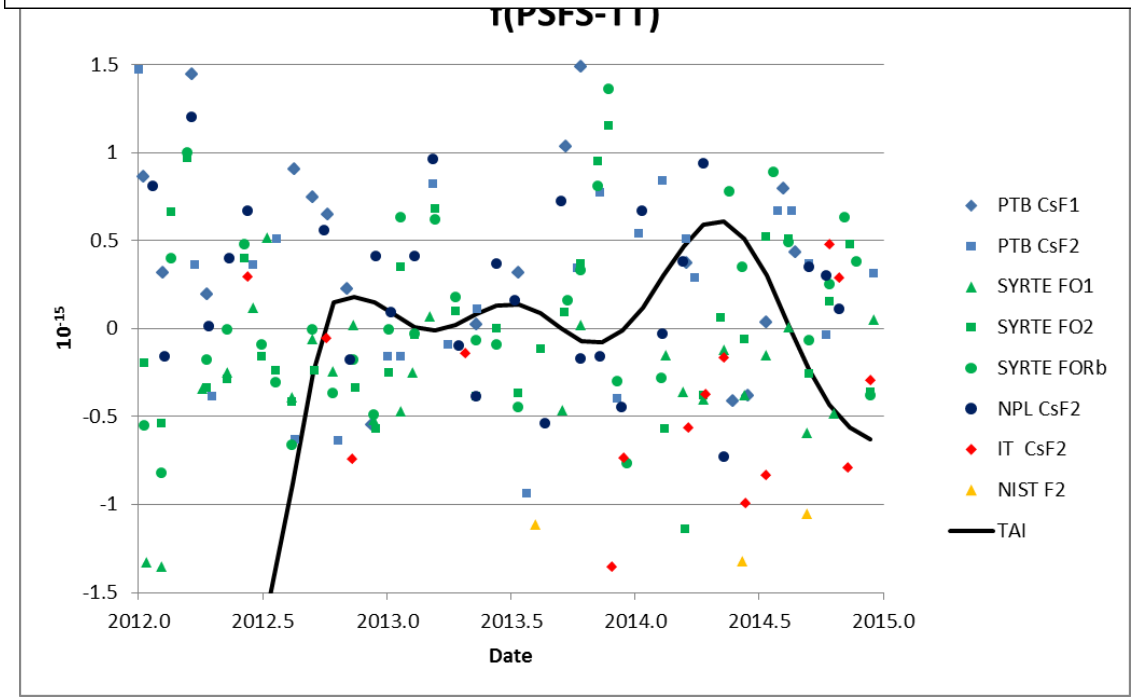
- Since end 2012, the drift of clocks is determined vs. TT
- f(TAI –EAL) remains constant (no steering).



TAI frequency was back to TT in the end of 2012

Since then, it seems to have some « slow variations » with respect to TT / PSFS





Contributions of frequency standards to TAI

No significant change in Circular T for the publication of PFS evaluations between July 2012 (top) and July 2015 (bottom)

Secondary Standards contribute to the steering of TAI since July 2013.

And SFS are now reported together with PFS => new column introduced.

Standard	Period of Estimation	d	u_A	u_B	$u_{1/Lab}$	$u_{1/Tai}$	u	Ref(u_B)	u_B(Ref)	Note
PTB-CS1	56104 56139	-14.58	6.00	8.00	0.00	0.06	10.00	T148	8.	(1)
PTB-CS2	56104 56139	-0.98	3.00	12.00	0.00	0.06	12.37	T148	12.	(1)
NIST-F1	56089 56114	2.07	0.34	0.31	0.25	0.23	0.57	T214	0.35	(2)
SYRTE-FO1	56104 56129	2.05	0.30	0.55	0.12	0.23	0.68	T227	0.72	(3)
SYRTE-FO2	56099 56119	1.52	0.25	0.24	0.23	0.28	0.50	T227	0.65	(3)
SYRTE-FO2	56119 56139	1.25	0.20	0.24	0.14	0.28	0.44	T227	0.65	(3)
PTB-CSF2	56124 56139	1.99	0.21	0.39	0.02	0.12	0.46	T287	0.41	(4)

July 2012

Notes:

(1) Continuously operating as a clock participating to TAI
(2) Report 31 JUL. 2012 by NIST
(3) Report 02 AUG. 2012 by LNE-SYRTE
(4) Report 01 AUG. 2012 by PTB

The second table gives the BIPM estimate of d, based on all available PFS measurements over the period MJD 55744-56139, taking into account their individual uncertainties and characterizing the instability of EAL as noted above. u is the computed standard uncertainty of d

Period of estimation	d	u	
56104-56139	1.6×10^{-15}	0.3×10^{-15}	(2012 JUN 26 - 2012 JUL 31)

BIPM Circular T 295 - 4

Standard	Period of Estimation	d	u_A	u_B	$u_{1/Lab}$	$u_{1/Tai}$	u	$u_z$rep	Ref(u_z)	Ref(u_B)	u_B(Ref)	Note
PTB-CS1	57199 57234	-9.80	6.00	8.00	0.00	0.06	10.00	PFS/NA		T148	8.	(1)
PTB-CS2	57199 57234	-1.60	3.00	12.00	0.00	0.06	12.37	PFS/NA		T148	12.	(1)
IT-CsF2	57199 57229	0.09	0.29	0.30	0.12	0.20	0.48	PFS/NA		T315	0.18	(2)
SYRTE-FO2	57199 57234	0.86	0.35	0.27	0.11	0.17	0.49	PFS/NA		T301	0.23	(3)
SYRTE-FORb	57204 57224	0.87	0.20	0.31	0.11	0.28	0.48	1.3	[1]	T301	0.32	(3)
SU-CsFO2	57199 57234	0.78	0.19	0.25	0.13	0.51	0.61	PFS/NA		T315	0.50	(4)

July 2015

Notes:
(1) Continuously operating as a clock participating to TAI
(2) Report 29 JUL. 2015 by INRIM
(3) Report 03 AUG. 2015 by LNE-SYRTE
(4) Report 03 JUL. 2015 by SU
[1] CIPM Recommendation 1 (CI-2013) : Updates to the list of standard frequencies in Proces-Verbaux des Seances du Comite International des Poids et Mesures, 102nd meeting (2013), 2014, 188 p.

The second table gives the BIPM estimate of d, based on all available PFS and SFS measurements over the period MJD 56839-57234, taking into account their individual uncertainties and characterizing the instability of EAL as noted above. u is the computed standard uncertainty of d

Period of estimation	d	u	
57199-57234	0.55×10^{-15}	0.27×10^{-15}	(2015 JUN 26 - 2015 JUL 31)

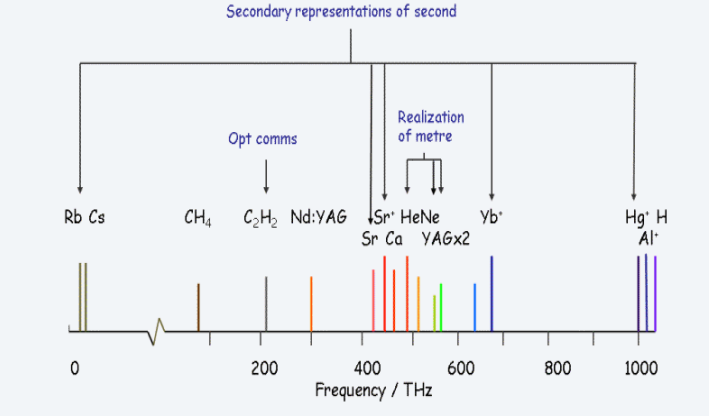
Primary and secondary frequency standards in 2014

Primary Standard	Type /selection	Type B std. Uncertainty / 10^{-15}	Operation	Comparison with	Number/typical duration of comp.
IT-CsF2	Fountain	(0.17 to 0.25)	Nearly continuous	H maser	9 / 10 d to 30 d
NIM5	Fountain	1.4	Discontinuous	H maser	6 / 15 d to 30 d
NIST-F2	Fountain	0.15	Discontinuous	H maser	3 / 25 d to 45 d
NPL-CSF2	Fountain	(0.20 to 0.27)	Discontinuous	H maser	8 / 10 d to 30 d
NPLI-CsF1	Fountain	(2.36 to 3.01)	Discontinuous	H maser	2 / 10 d to 20 d
PTB-CS1	Beam /Mag.	8	Continuous	TAI	12 / 30 d
PTB-CS2	Beam /Mag.	12	Continuous	TAI	12 / 30 d
PTB-CSF1	Fountain	(0.70 to 0.73)	Discontinuous	H maser	6 / 10 d to 35 d
PTB-CSF2	Fountain	(0.28 to 0.35)	Nearly continuous	H maser	9 / 10 d to 35 d
SU-CsFO2	Fountain	0.50 then 0.25	Discontinuous	H maser	4 / 20 d to 30 d
SYRTE-FO1	Fountain	(0.36 to 0.41)	Nearly continuous	H maser	10 / 15 d to 35 d
SYRTE-FO2	Fountain	(0.25 to 0.29)	Nearly continuous	H maser	11 / 20 d to 35 d
SYRTE-FORb	Fountain	(0.29 to 0.36)	Nearly continuous	H maser	10 / 10 d to 30 d

- Frequency standards reported and evaluated in 2014 (see annual report)
  - 68 from 10 PFS fountains
  - 10 from 1 SFS
- Four of the fountains are nearly continuously operating

Secondary frequency standards

- CCL-CCTF working group (merged in 2005): producing and maintaining a single list of *Recommended frequency standard values for applications including the practical realization of the metre and* ***secondary representations of the second***.



- Since 2012 SYRTE has reported 43 evaluations of the Rb fountain FO2(Rb)
- For some SFS, all systematic effects can be estimated with an uncertainty much lower than for the best PFS
- The BIPM Time department expects to receive new SFS evaluations in order to provide visibility and to get experience with their possible use in TAI steering.

Conclusions

- Primary frequency standards still continue to gain in accuracy ("typically" by one order of magnitude every 10-12 years). We are at 2×10^{-16}.

- The full accuracy of PFS is not completely passed to TAI and TT(BIPM) because of
  - the noise of frequency transfer
  - (possibly) some slightly inconsistent PFS evaluations
- Nevertheless the PFS reported uncertainties are globally consistent with the data.
  - this implies that TT(BIPM) accuracy is $\sim 2.5 \times 10^{-16}$ since 2012 and the TAI frequency is known with the same uncertainty.
- We need evaluations of secondary standards
  - to gain experience and promote their use
  - to determine their reference frequency
  - to prepare for future changes