

Primary Frequency Standards in TAI

Gérard Petit

Bureau International des Poids et Mesures
92312 Sèvres Cedex, France



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Résumé

- Primary Frequency Standards reported to the BIPM
- PFS measurements referenced to TT(BIPM)
- Variability in PFS measurements
- Accuracy of TAI and steering policy



Performance of primary standards and time scales

- Primary Cs standards (thermal beam): **Accuracy:** $\leq 1 \times 10^{-14}$
- Primary Cs fountains: **Accuracy:** \leq order 1×10^{-15}
 - SYRTE-FO1 (in 1995-1997), FO2 and FOM (since 2002)
 - NIST-F1 (since end 1999)
 - PTB-CSF1 (since mid 2000)
 - IEN-CSF1 (since 2003)
- Time scales and time links
 - EAL/TAI: **Stability** $\sigma_y(\tau) \leq 1 \times 10^{-15}$ (τ from 20 to 60 days)
 - Time links: Typical **uncertainty in frequency** comparison is 1×10^{-15} after (a few) several days of measurements.



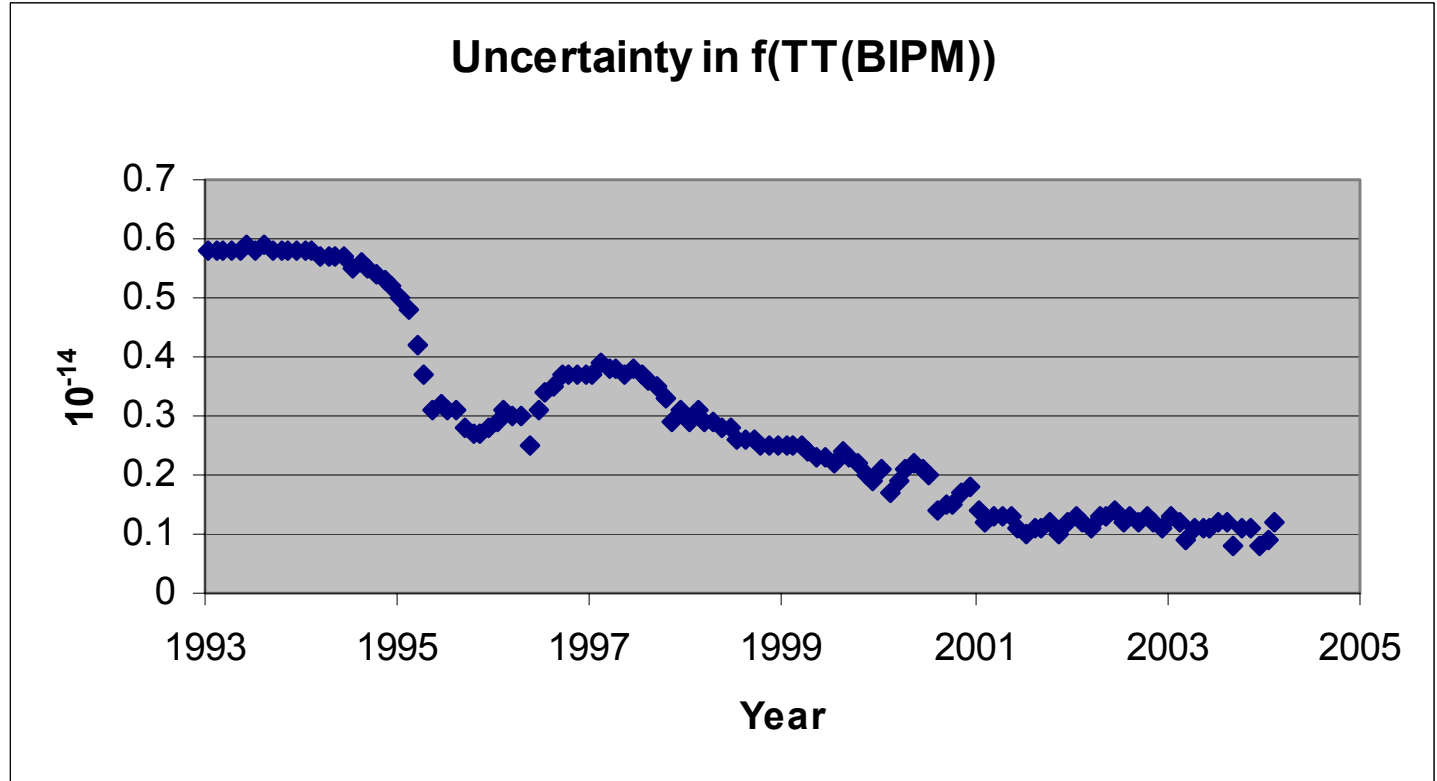
Primary frequency standards reported in 2002-2004

Primary Standard	Type /selection	Typical type B std. uncertainty	Operation	Comparison with	Operation period	Typical duration of comparison
CRL-01	Beam /Opt.	$4-6 \times 10^{-15}$	Discontinuous	UTC(CRL)	1998->....	10-15 d
IEN CSF1	Fountain	$<2 \times 10^{-15}$	Discontinuous	H maser	2003->....	10 d
NIST7	Beam /Opt.	$X \times 10^{-15}$	Discontinuous	H-maser	1995->2000	30 d
NIST-F1	Fountain	$<1 \times 10^{-15}$	Discontinuous	H maser	1999->....	30 d
PTB CS1	Beam /Mag.	8×10^{-15}	Continuous	TAI	1998->....	30 d
PTB CS2	Beam /Mag.	12×10^{-15}	Continuous	TAI	1993->....	30 d
PTB CSF1	Fountain	$<1 \times 10^{-15}$	Discontinuous	H maser	2000->....	15 to 30 d
SYRTE-JPO	Beam /Opt.	$6-8 \times 10^{-15}$	Discontinuous	H maser	1999->....	30 d
SYRTE-F02	Fountain	$<1 \times 10^{-15}$	Discontinuous	H maser	2002->....	5 to 30 d
SYRTE-FOM	Fountain	$<1 \times 10^{-15}$	Discontinuous	H maser	2002->....	30 d

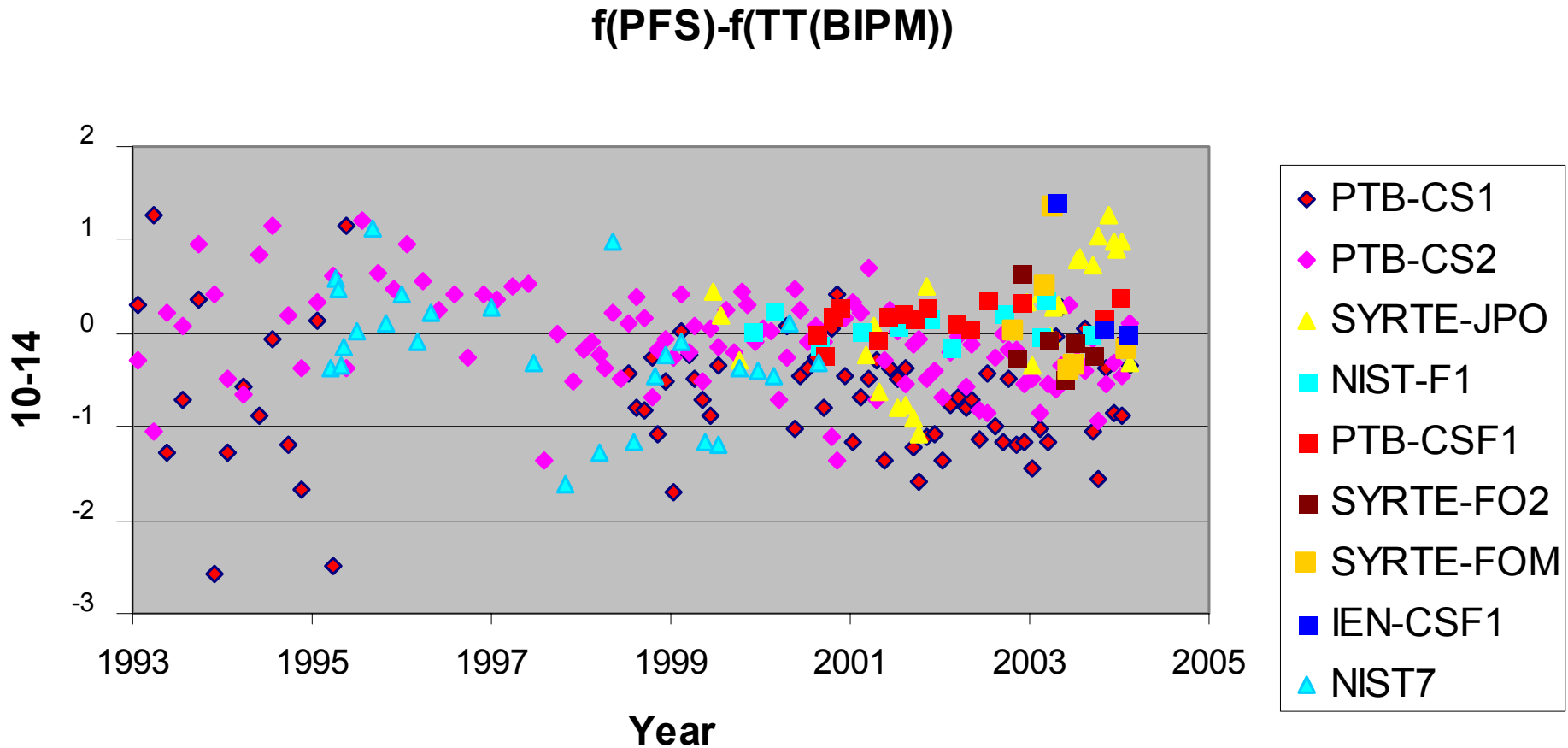


Use of TT(BIPM) as a reference for PFS measurements

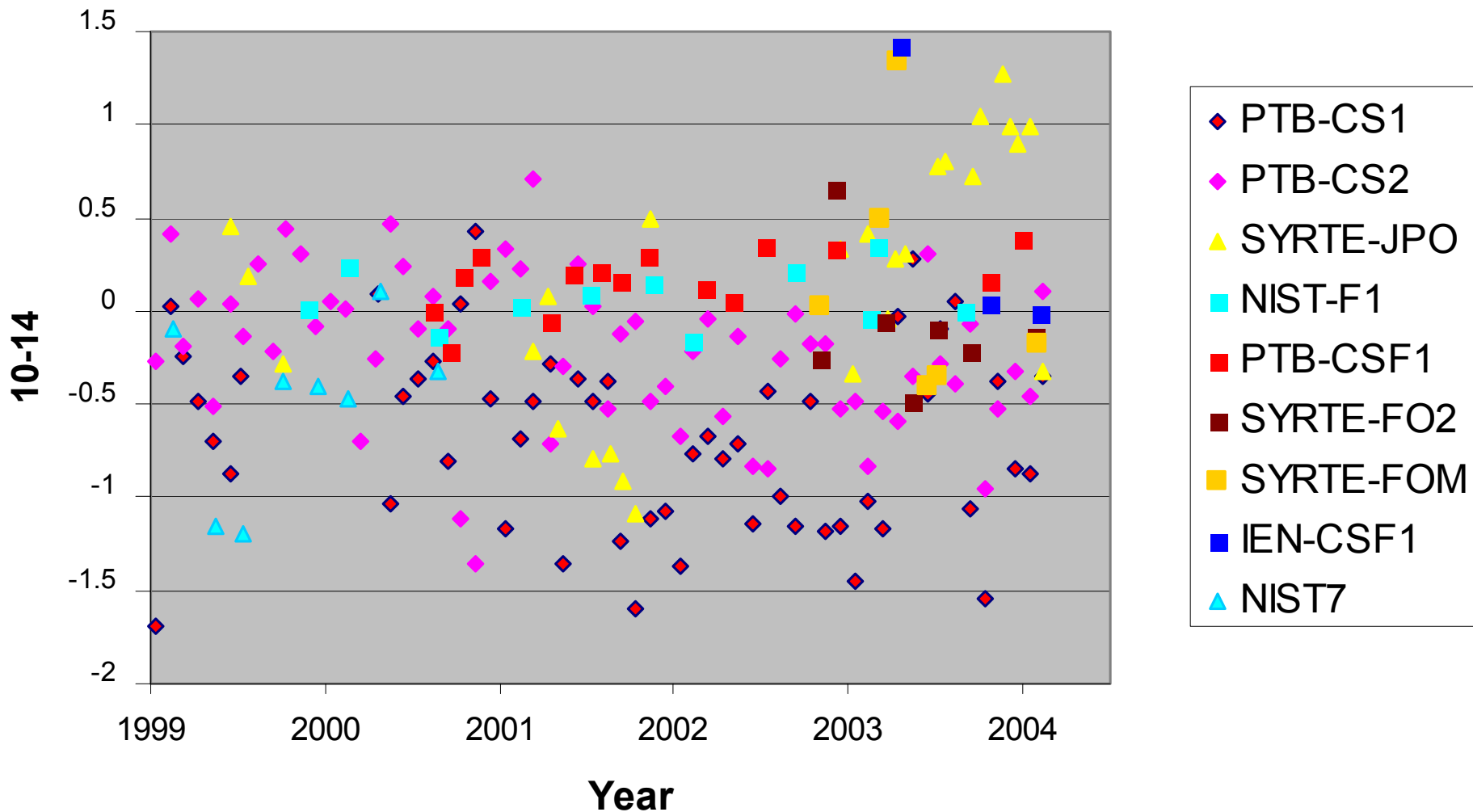
- TT(BIPM) is a post-processed time scale, with the 1-2 month stability of EAL and accuracy from PFS, better than “real time” TAI.
- TT(BIPM) is used as a reference to compare all PFS evaluations.
- Standard uncertainty of monthly estimates of $f(\text{TT}(\text{BIPM}))$: from 6×10^{-15} in 1993-1994 to $< 2 \times 10^{-15}$ since 2001.



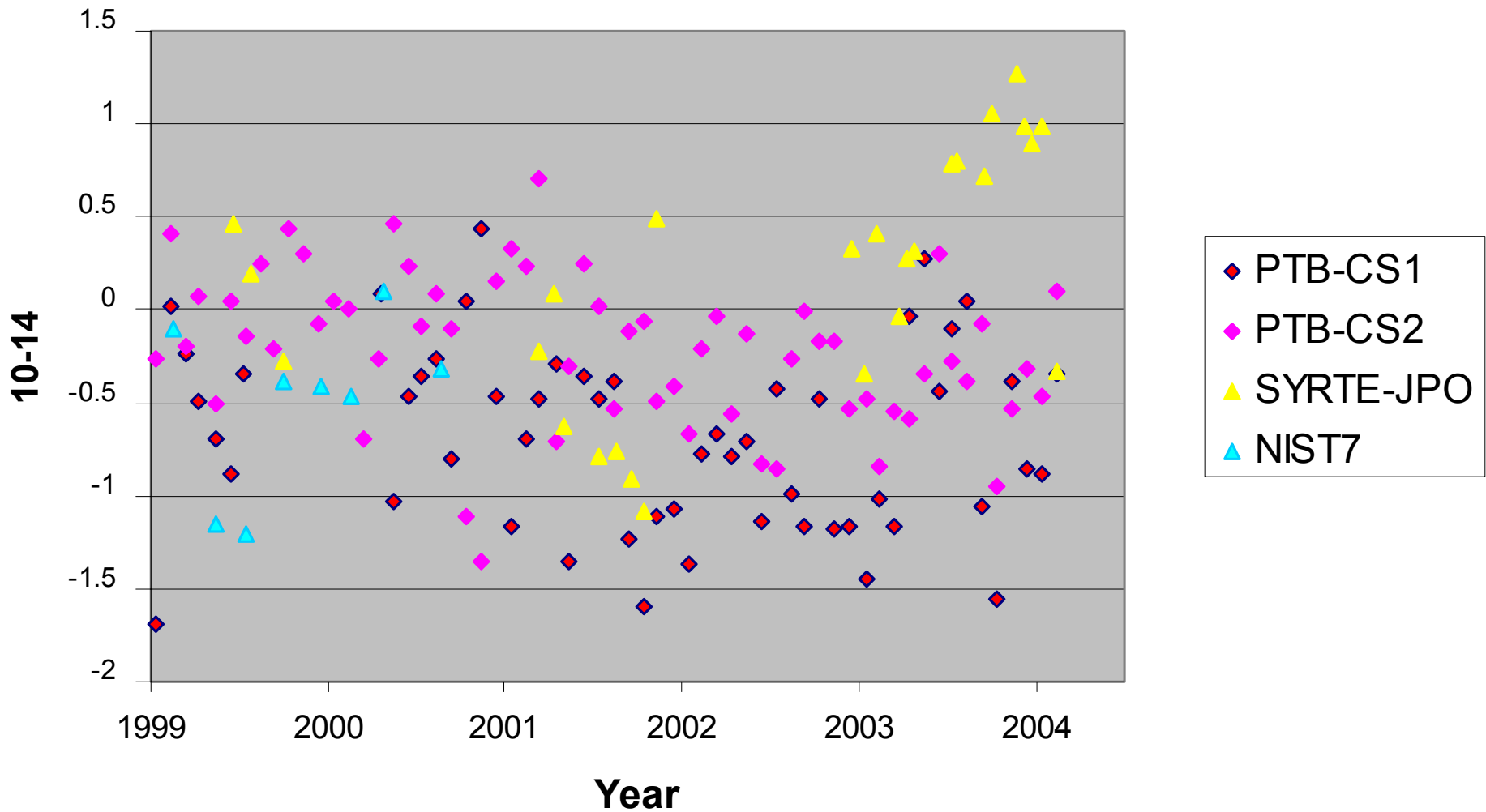
- Introduction of new PFS greatly improves the density of measurements starting 1999.
- Scatter of measurements not vastly improved until very recently.



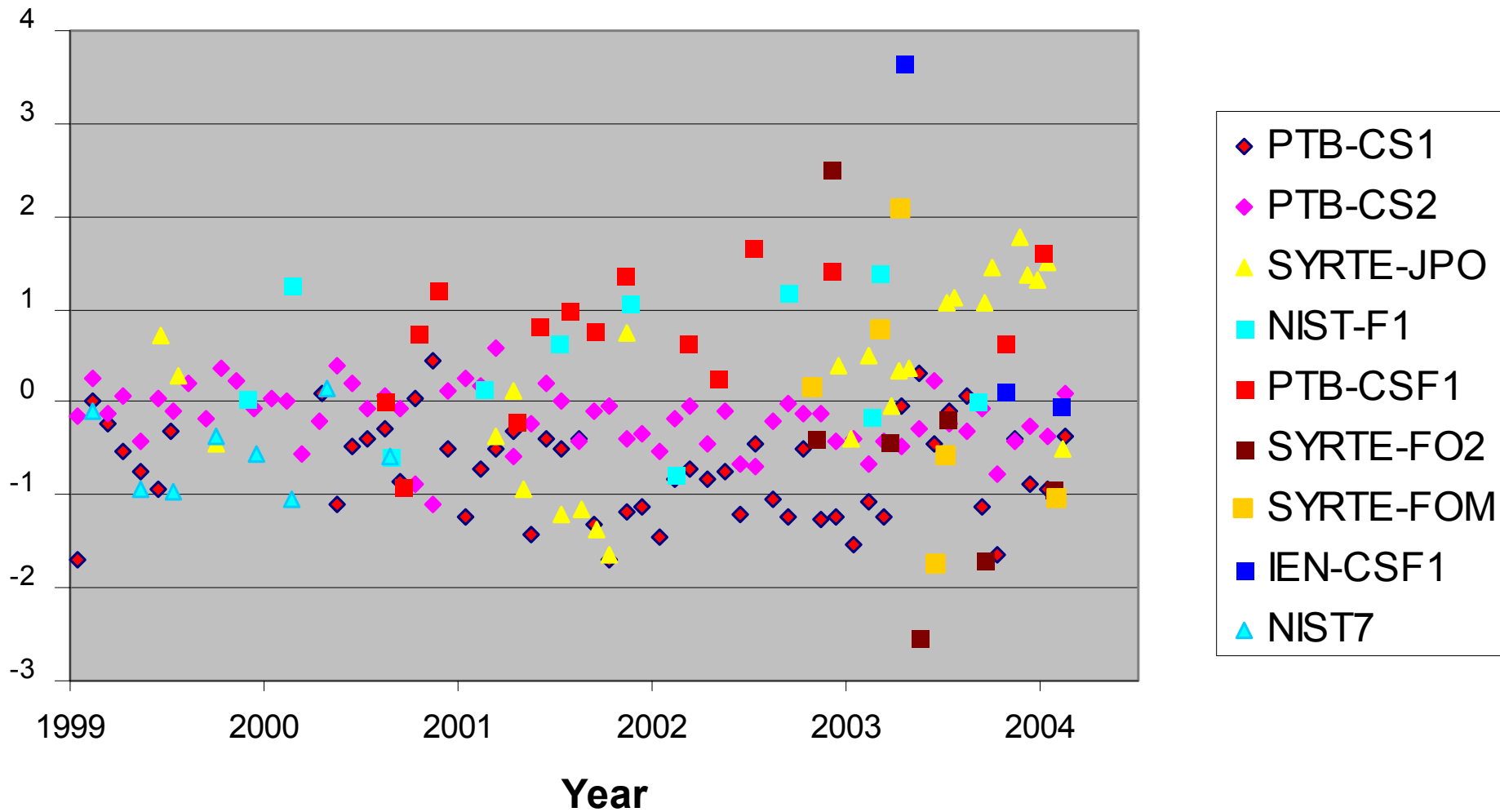
f(PFS)-f(TT(BIPM))



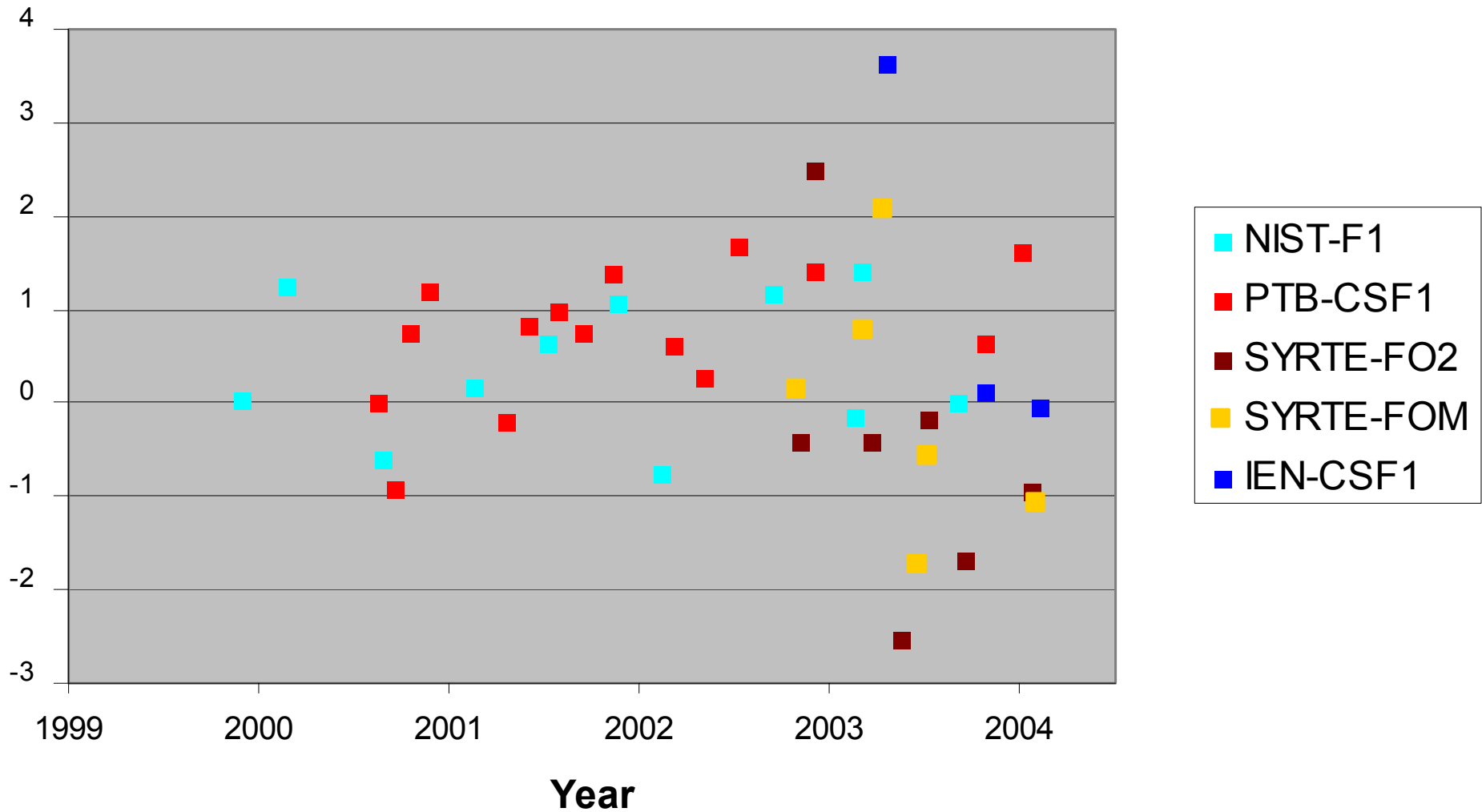
f(PFS)-f(TT(BIPM)) (no fountains)



$f(\text{PFS}) - f(\text{TT}(\text{BIPM})) / \text{total PFS uncertainty}$



$f(\text{PFS}) - f(\text{TT}(\text{BIPM})) / \text{total PFS uncertainty (fountains)}$



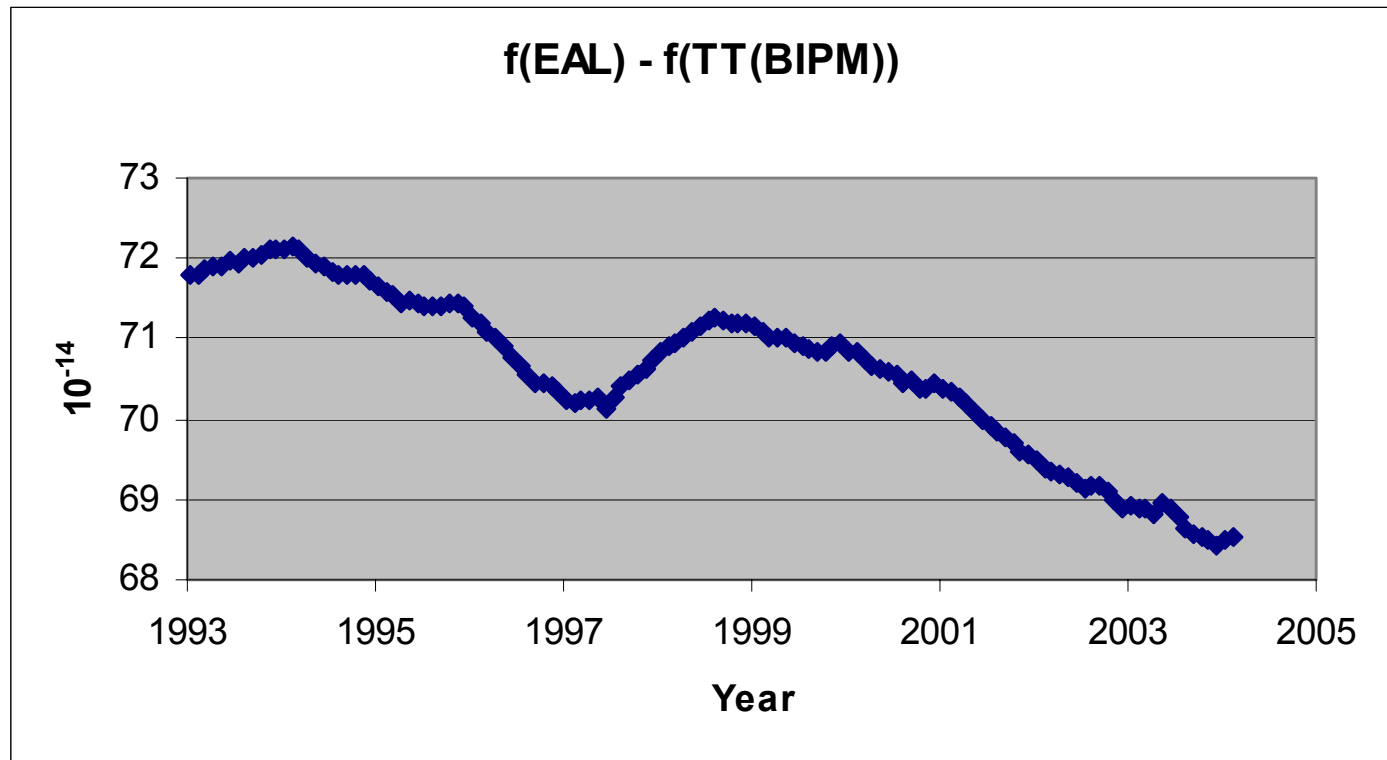
Variability of PFS measurements

- Standard uncertainty of PFS measurements is based on
 - u_A , u_B and u_{linklab} from laboratory report
 - u_{linkTAI} from a rather conservative estimate ($30/T \times 10^{-15}$ with T duration of measurement in days)
- The global dispersion of all measurements indicates that uncertainties are nearly correctly estimated (slightly under-estimated?).
 - Agreement between Cs fountains is sometimes slightly beyond expected level.
 - May be partly due to instability of local “flywheel” and to time transfer.
- More data necessary?
- Guidelines for PFS measurements?



Accuracy of TAI and steering policy (1)

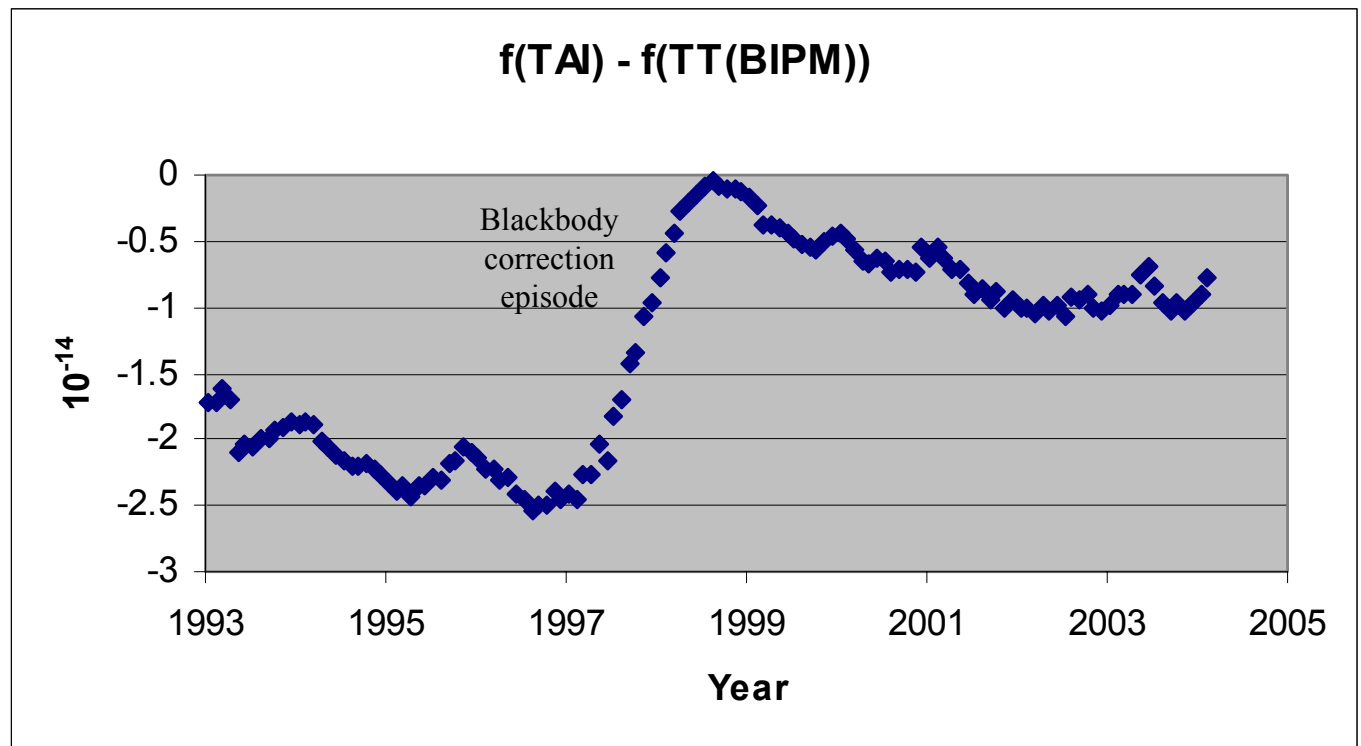
- TAI is expected to be stable (from EAL) and accurate (from PFS).
- $f(\text{TAI}) = f(\text{EAL}) + \text{steering frequency}$
- Steering frequency presently changed by at most 1×10^{-15} every **two months** to preserve TAI stability.
- But $f(\text{EAL})$ is affected by systematic variations



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Accuracy of TAI and steering policy (2)

- Therefore TAI accuracy has been far from optimal for several years.
- Present steering policy just prevents $f(\text{TAI})$ to drift, but does not ensure accuracy
- Steering frequency could be changed **every month** by slightly smaller steps e.g. 0.75×10^{-15} (or 0.5×10^{-15} when back on track) to preserve TAI stability and ensure better accuracy.
- Goal is to better conform TAI to its definition.



Conclusions

- Re-assess PFS measurements for TAI.
 - uncertainty budget, including time transfer
 - Guidelines for PFS measurements
- More regular evaluations of PFS for TAI use.
 - e.g. goal of at least 2 fountains each month
- Steering policy should be modified to improve TAI accuracy.

