Uncertainty of NIST-F1 and Its Stability Over Time Relative to the Frequency of Various Time Scales

Thomas E. Parker

National Institute of Standards and Technology

Time and Frequency Division

Boulder, CO USA

Sixth Meeting of Representatives of Laboratories Contributing to TAI
March 31, 2004, BIPM, France

Are the Uncertainties on the Frequency Standard and Frequency Transfer Correct?

- Uncertainties are based on "known" biases and instabilities.
- Is the standard's long-term stability consistent with its accuracy? (This is a function of the stable reference that is used.)
- Are different standards in agreement?

- Affirmative answers are necessary, but not sufficient conditions for the verification of uncertainties.
- We may not know for sure the true accuracy of a standard until the next generation comes along.

NIST-F1 Current Results into Circular T

• Systematic Uncertainty (Type B)	0.44×10^{-15}
• Statistical Uncertainty (Type A)	0.50×10^{-15}
• Dead Time Uncertainty (Type A)	0.20×10^{-15}
• Combined Uncertainty (in House)	0.70×10^{-15}
• Time Transfer Uncertainty (30 Days)	1.00×10^{-15}
• Total Uncertainty into TAI	1.22×10^{-15}

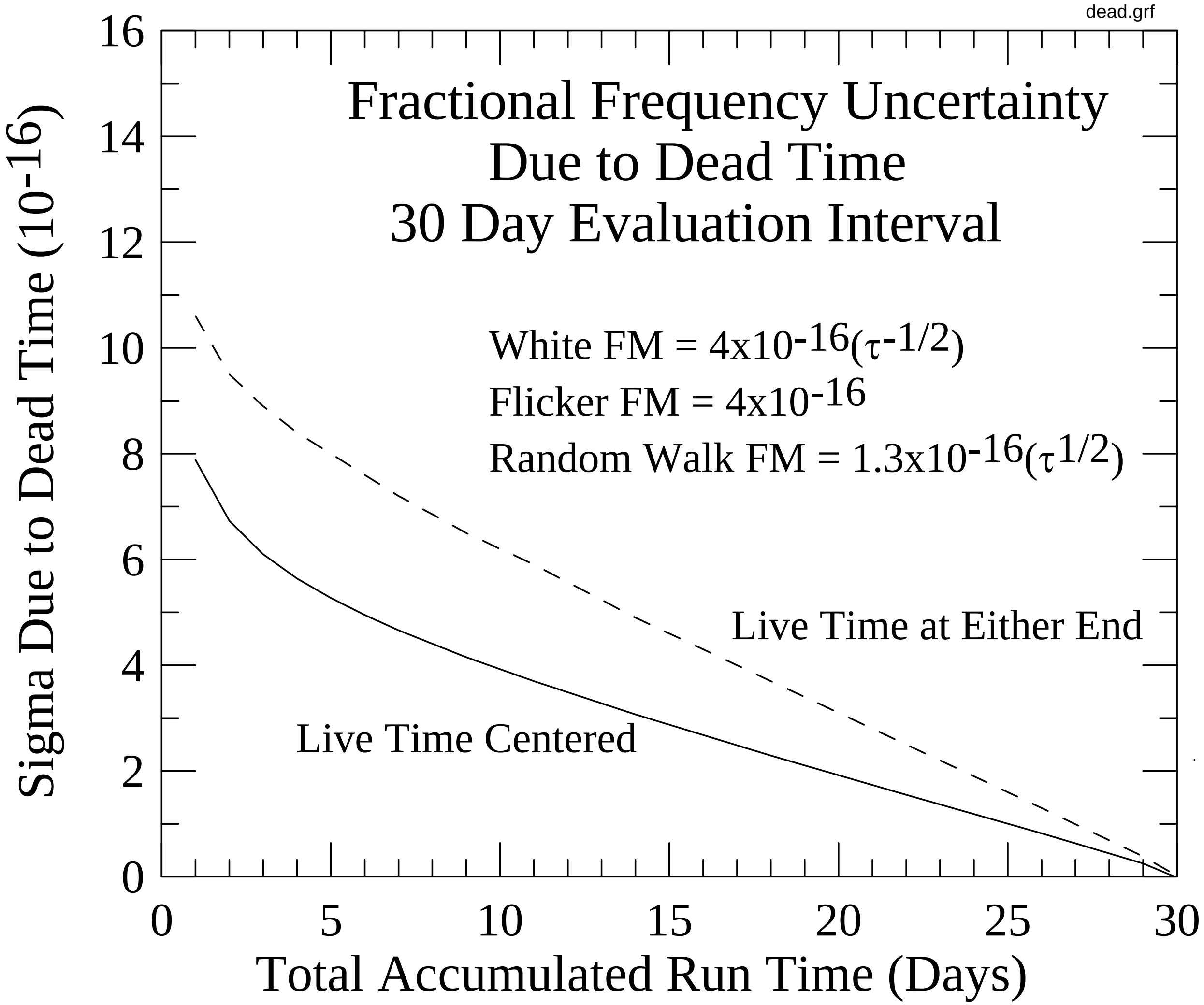
Current Systematic Uncertainties of NIST-F1

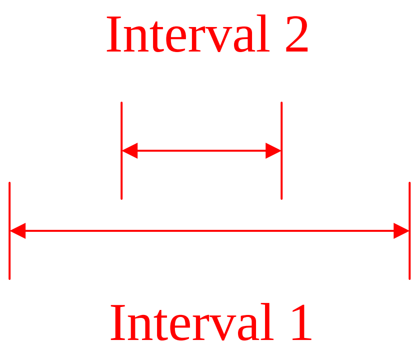
Physical Effect	Bias (10^{-15})	Type B Uncertainty (10^{-15})
Second-order Zeeman	+36.10	0.10
Second-order Doppler	< 0.1	< 0.1
Cavity pulling	< 0.1	< 0.1
Rabi pulling	< 0.01	< 0.1
Dynamic end to end	-0.2	<0.1
Cavity phase (distributed)	< 0.1	< 0.1
Fluorescence light shift	< 0.1	<0.1
Adjacent atomic transitions	< 0.1	< 0.1
Spin exchange	0.5	0.27
Blackbody	-19.31	0.26
Gravitation	+180.54	0.10
Electronics		
RF spectral purity	0	< 0.1
Integrator offset	0	< 0.1
AM on microwaves	0	< 0.1
Microwave leakage	0	0.18
Total Type B Standard Uncertainty 0.44		

NIST-F1 Current Results into Circular T

- Systematic Uncertainty (Type B) 0.44×10^{-15}
- Statistical Uncertainty (Type A) 0.50×10^{-15}
- Dead Time Uncertainty (Type A) 0.20×10^{-15}
- Combined Uncertainty (in House) 0.70×10^{-15}
- Time Transfer Uncertainty (30 Days) 1.00×10^{-15}
- Total Uncertainty into TAI 1.22×10^{-15}

Dead Time

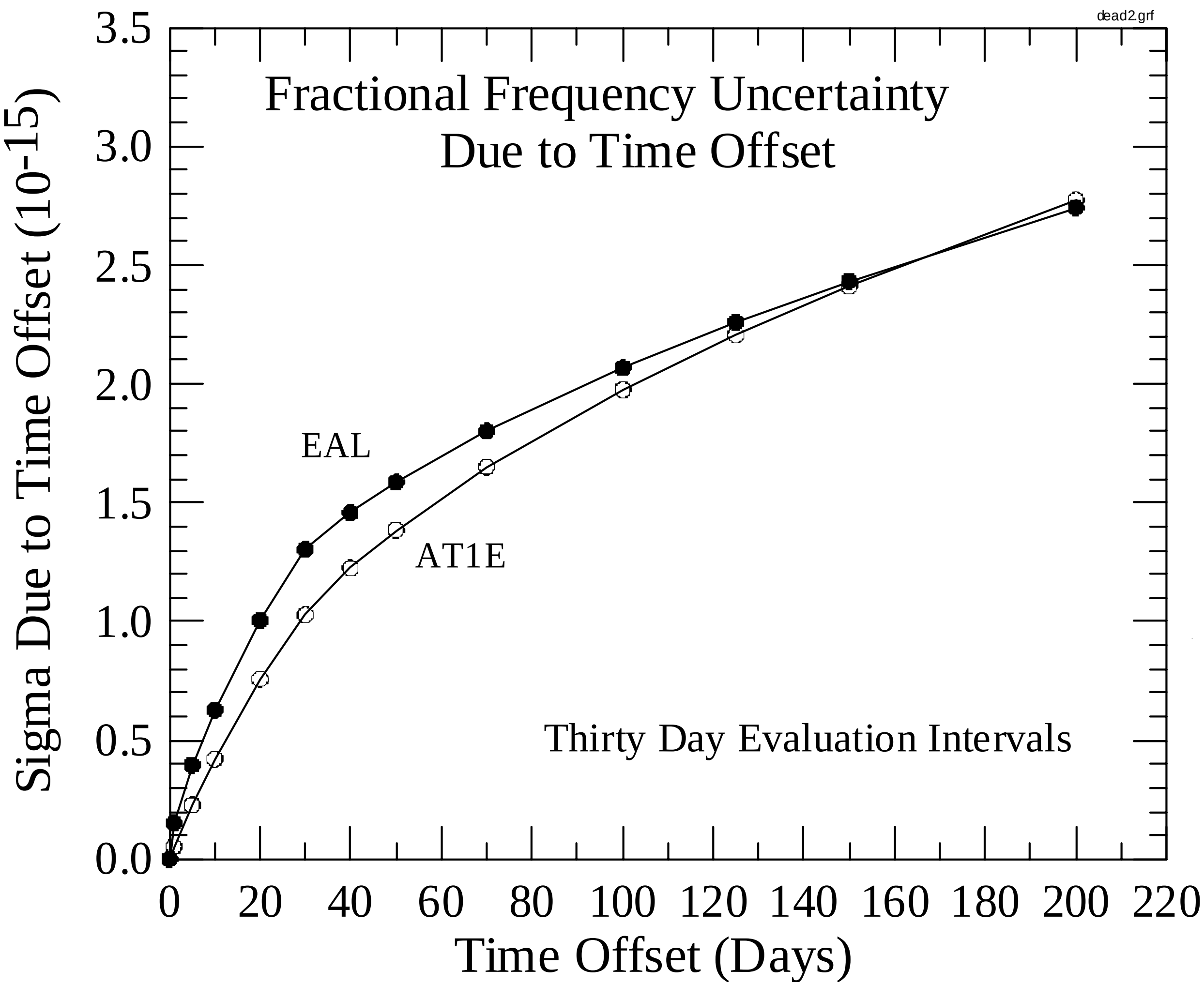

dead.grf
Fractional Frequency Uncertainty
Due to Dead Time
30 Day Evaluation Interval
White FM = $4x10^{-16}(\tau^{-1/2})$
Flicker FM = $4x10^{-16}$
Random Walk FM = $1.3x10^{-16}(\tau^{1/2})$
Live Time at Either End
Live Time Centered
Sigma Due to Dead Time (10-16)
Total Accumulated Run Time (Days)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30


Interval 2
Interval 1

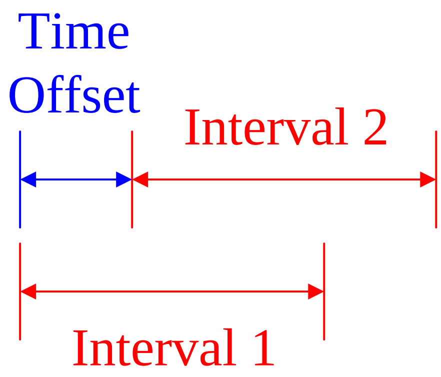
Stable Frequency Reference at NIST

- Five cavity tuned hydrogen masers
- Four high performance cesium standards
- Post-processed time scale
  - TP171, generic name (as calculated)
  - AT1E = y(TP171) with 483x10^{-15} frequency offset removed

Time Offset

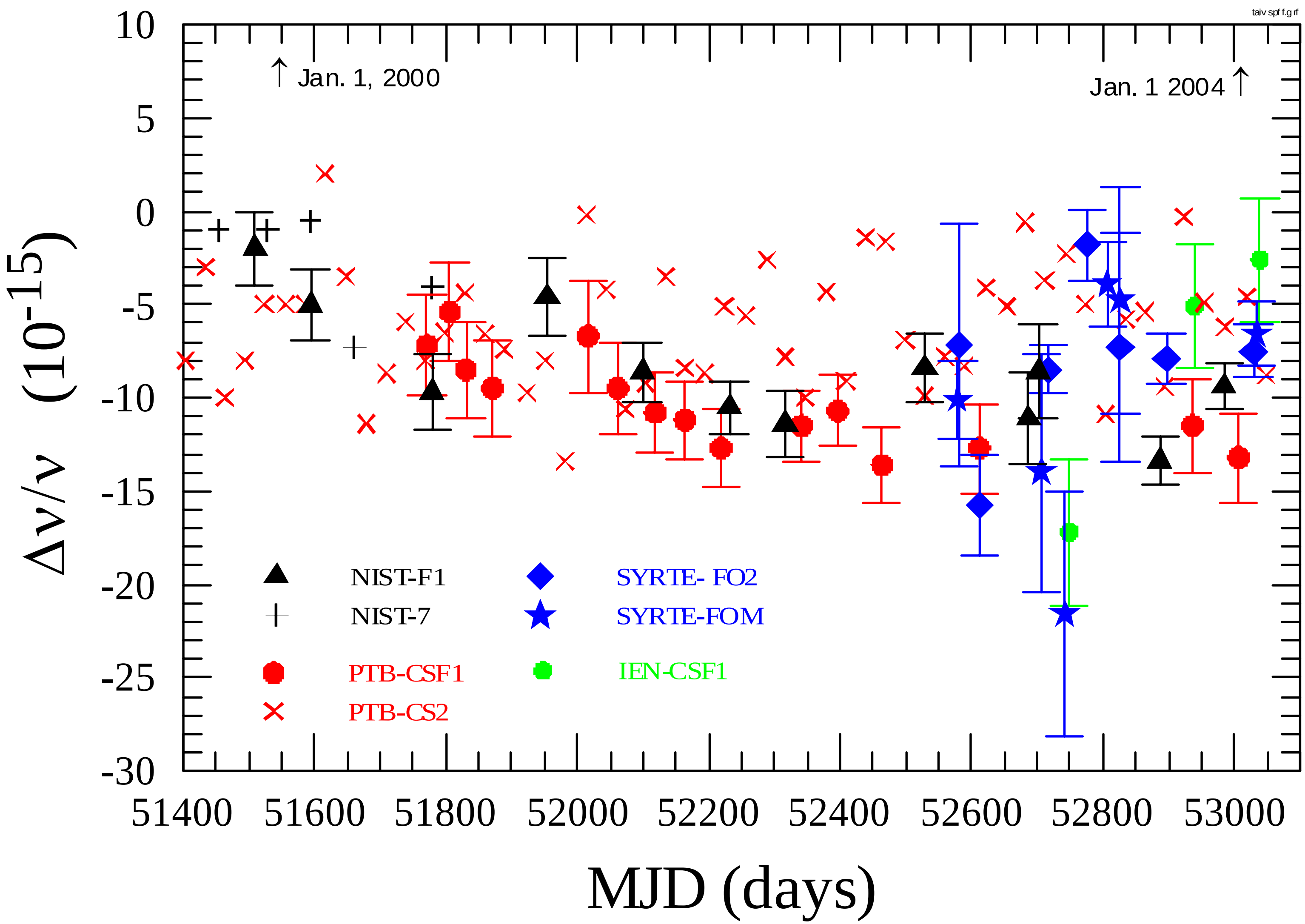


dead2.grf
Fractional Frequency Uncertainty
Due to Time Offset
EAL
AT1E
Thirty Day Evaluation Intervals
Sigma Due to Time Offset (10^{-15})
Time Offset (Days)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
20
40
60
80
100
120
140
160
180
200
220

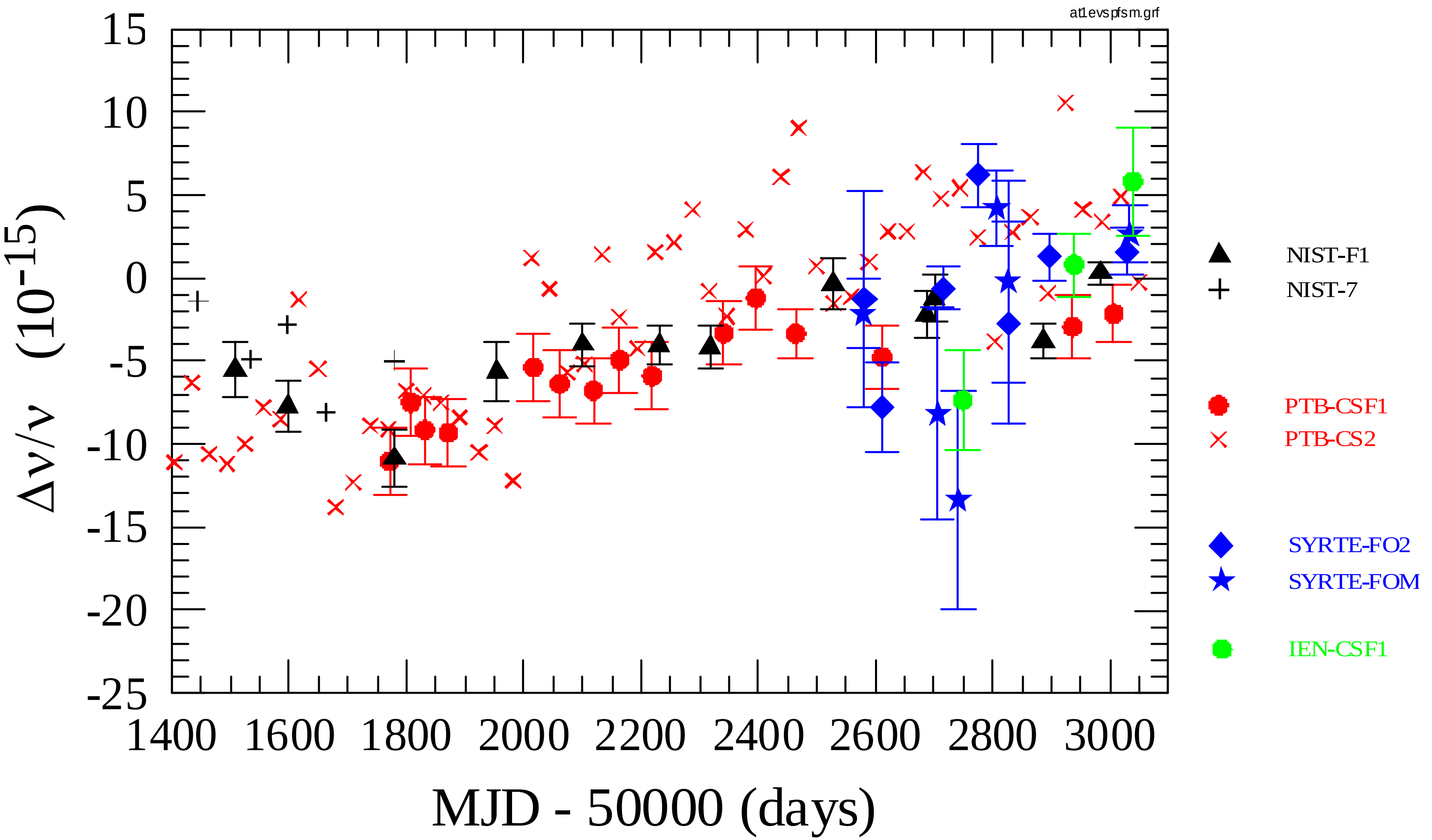


Time
Offset
Interval 2
Interval 1

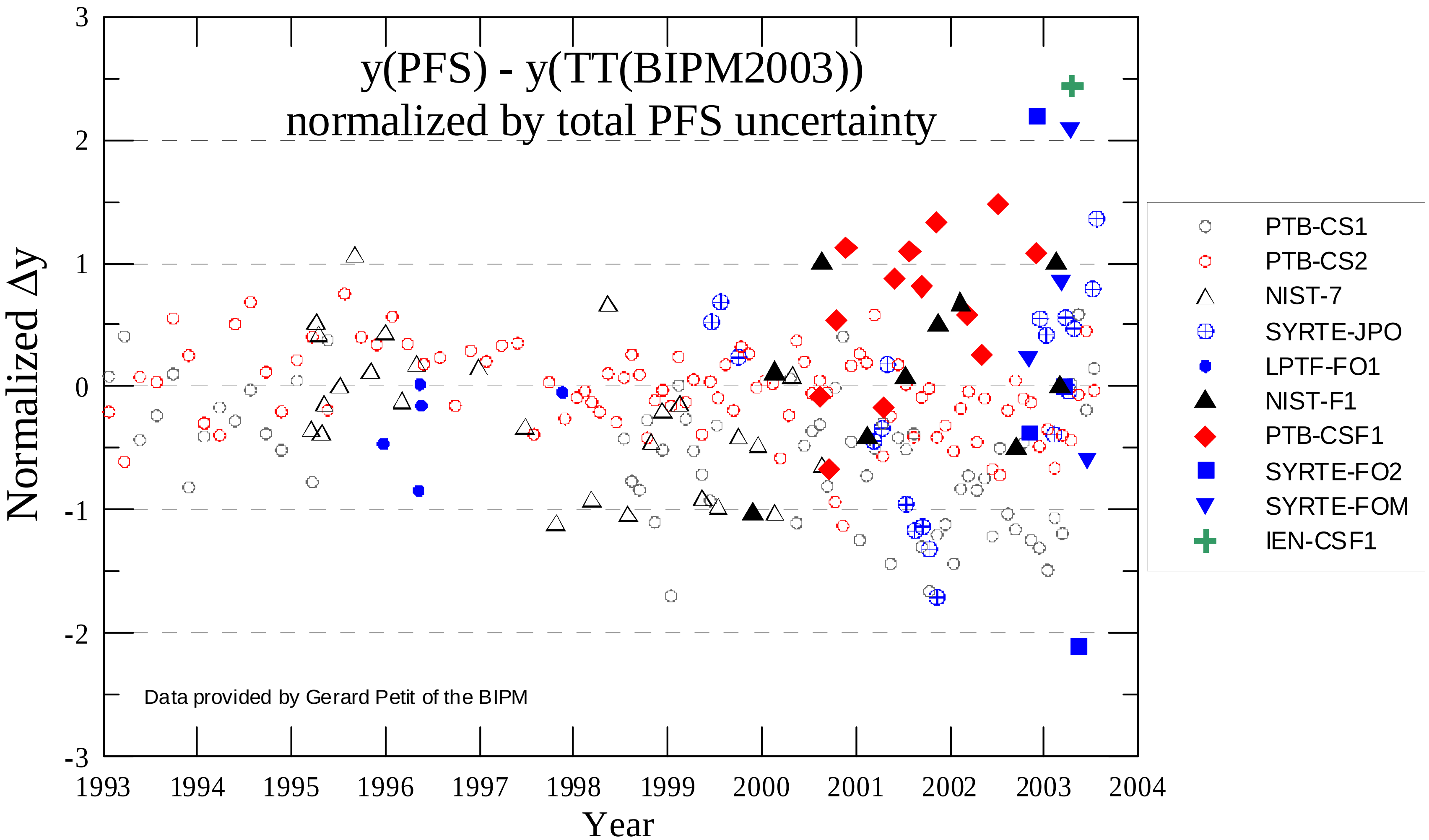
TAI vs Primary Standards



AT1E vs Primary Standards



Primary Standards vs TT(BIPM2003)



Conclusions

- Over 4 years (12 official reports to the BIPM) the point to point stability of NIST-F1 as compared to TAI (or TT(BIPM2003)) and AT1E has been statistically consistent with total uncertainties (this is not a very precise process).
- For 5 overlapping or contiguous runs between NIST and PTB:

  $y(F1\text{-}CSF1) = -1.43\text{x}10^{-15}$ $u(total) = 1.6\text{x}10^{-15}$

  $\{ub(total) = 1.4\text{x}10^{-15}, ua(total) = 0.9\text{x}10^{-15}\}$
- The evaluation of the performance of primary frequency standards is an on going process.