High Accuracy Frequency Standards in TAI

Peter Wolf, Gérard Petit

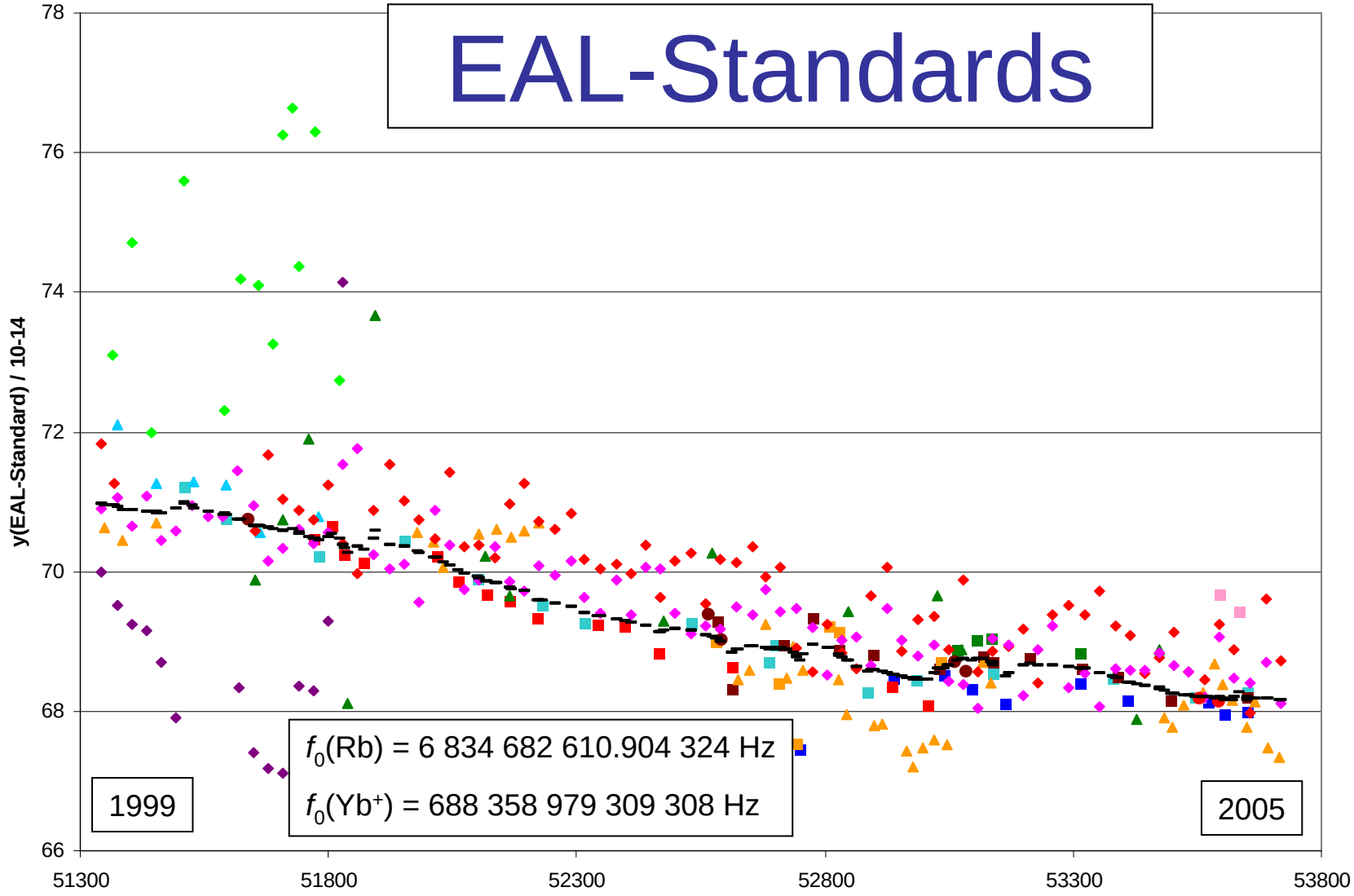
CCTF 2006

Introduction

- Over the period 1999 – 2005 BIPM received 69 measurements of EAL frequency with respect to high accuracy primary frequency standards (PFS), i.e. Cs fountains (FO).
- Secondary representations of the SI second (SR), frequency standards using other atomic transitions, are showing uncertainties comparable to the best PFS.
- Seven measurements of EAL frequency by SR were contributed for this study (5 from BNM-SYRTE Rb microwave fountain, 2 from PTB Yb^+ optical ion trap).

- We use this data to study four questions:
    1. What are the effects of the high accuracy PFS on the uncertainty of TAI ?
    2. How self coherent are the measurements from individual PFS ?
    3. How do the measurements from individual PFS compare to those from the “rest of the world” (all other PFS) ?
    4. How do SR perform and compare to PFS ?

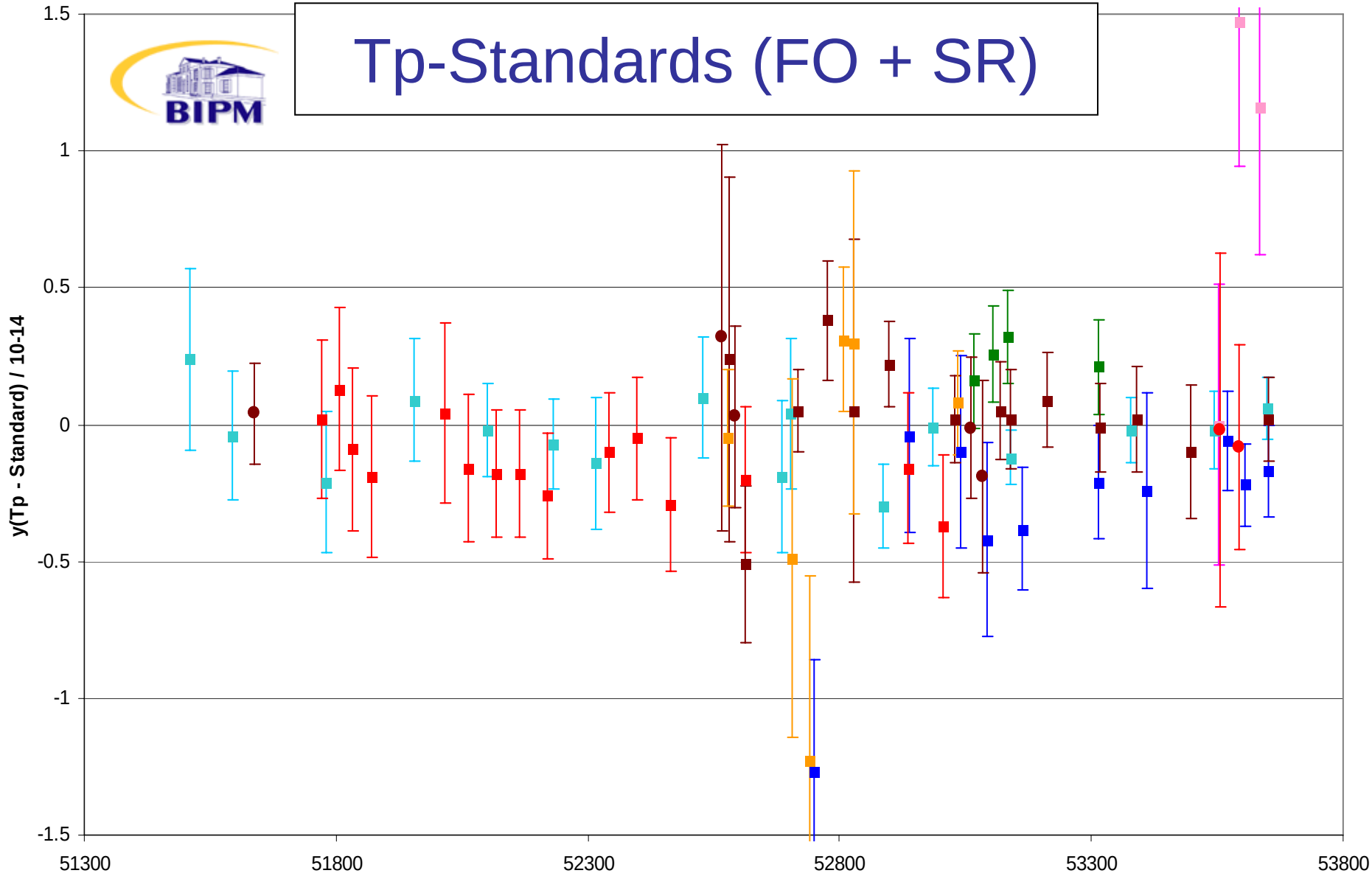
EAL-Standards



Tp: "Best estimate" of y(EAL – SI second) for a given interval.

- Obtained using all PFS measurements at ±360 days.
- Weighted by their uncertainty and distance from interval.
- Dependent on model for EAL stability: ($3\ 10^{-15}\ \tau^{-1/2}$, $0.5\ 10^{-15}$, $0.1\ 10^{-15}\ \tau^{1/2}$), τ in days.
- For this graph, Tp is calculated for each interval of measurement of a standard.

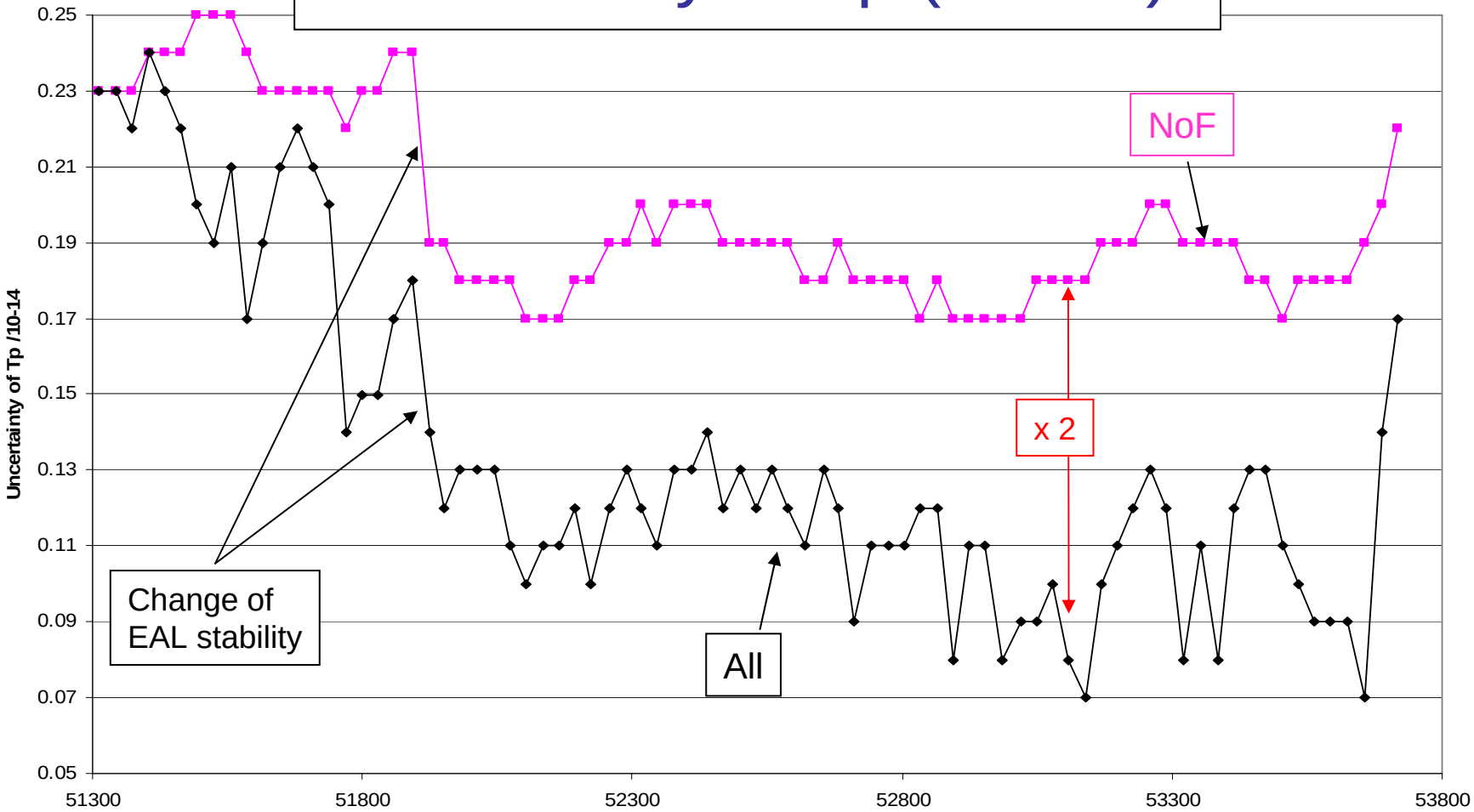
Tp-Standards (FO + SR)



- Generally good agreement within uncertainties.
- Some outliers.
- Systematic behaviour “per standard” ?

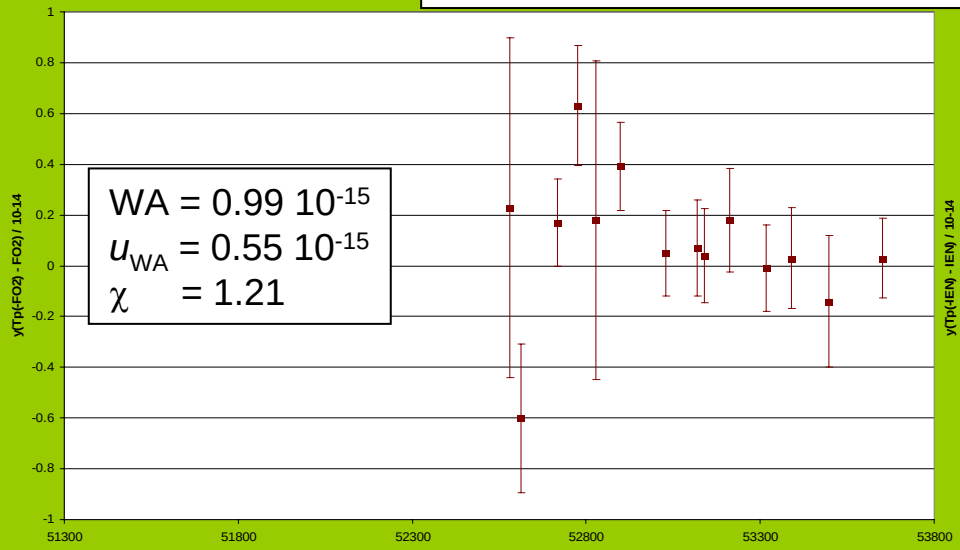
$$u^2 = u_A^2 + u_B^2 + u_{l/lab}^2 + u_{l/TAI}^2 + u_{Tp}^2$$

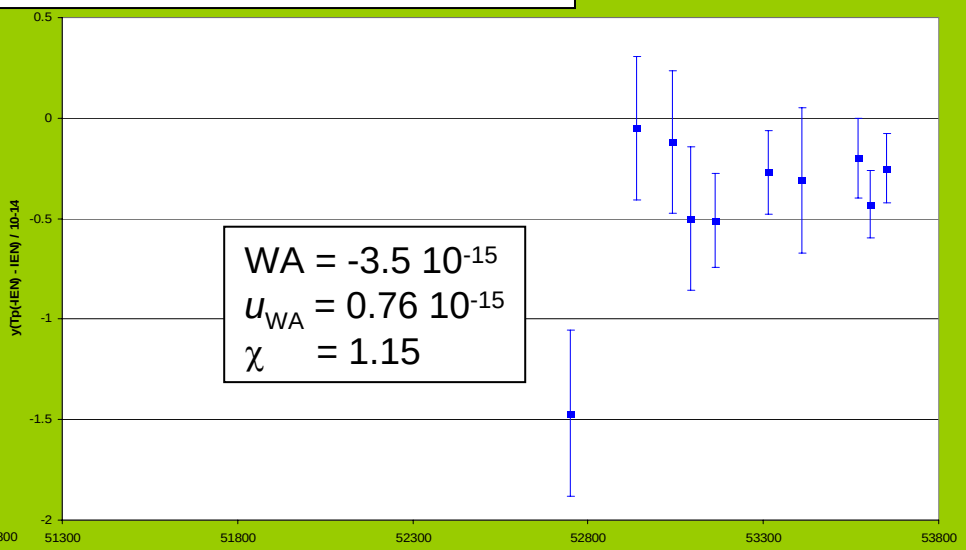
Uncertainty of Tp (⇒ TAI)

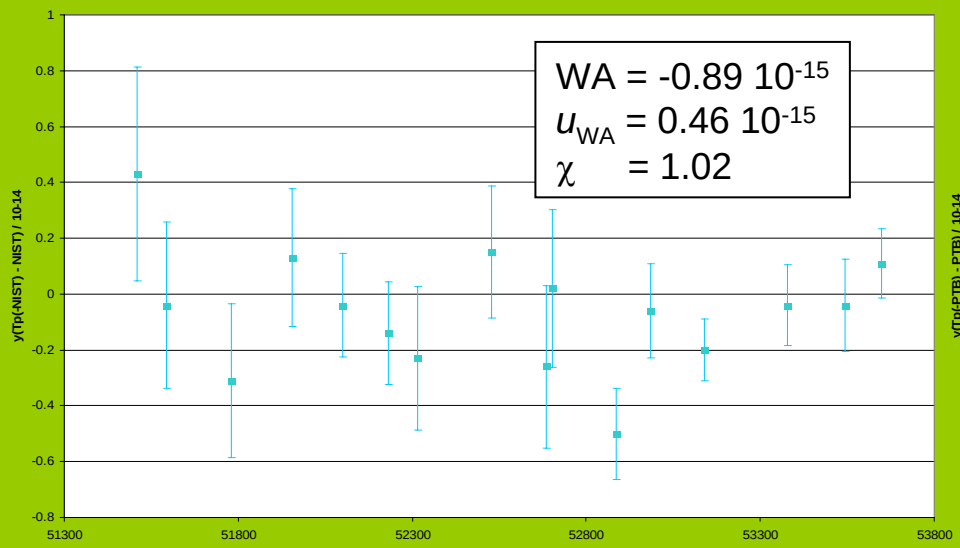


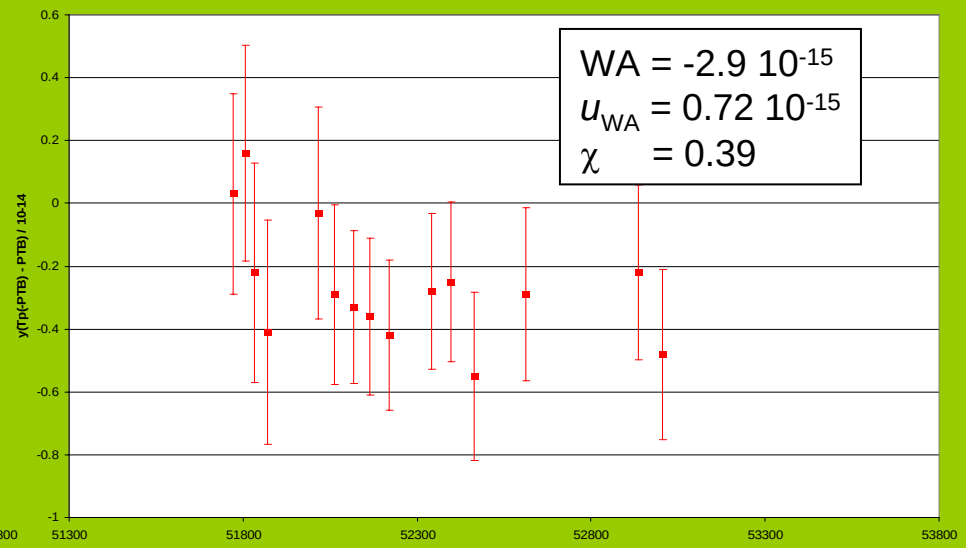
Tp: - For this graph, Tp is calculated for each calendar month.
- using all PFS or all except fountains (NoF).
- significant improvement with fountains.

Individual Standards









- Compare each PFS (> 10 points) to the best estimate of the SI second from all <u>other</u> PFS.
-Calculate weighted average (WA), its uncertainty (u_{WA}), sum of χ^2 around WA / N-1 (χ).

Conclusion

1. - High accuracy PFS (fountains) have improved the uncertainty of Tp ($\Rightarrow$ TAI) by about a factor 2.

- Less than expected from improvement in PFS uncertainty (factor 5 – 10), likely due to duration (time transfer) and density of FO evaluations, and to EAL instability.

2. - The calculated χ^2 sums indicate good self coherence of the four studied PFS, particularly for recent data.

3. - None of the four studied PFS agree with the "rest of the world" within the uncertainties (1.8 to 4.6 σ discrepancies).

4. - SR agree well with the PFS (within the uncertainties).

- Limited by uncertainties from link to TAI ($\Rightarrow$ longer measurements required).
- The limited number of points does not allow meaningful statistics ($\Rightarrow$ more measurements required).

- Our results depend on the uncertainties of the standards as reported by the labs, but also on our estimates of $u_{l/TAI}$ and of the EAL model (entering u_{TP}). We consider our estimates "conservative". More "realistic" estimates are likely to lead to larger improvements in 1. but also larger discrepancies in 3. and possibly less coherence in 2.