Working Group on Primary Frequency Standards

T. E. Parker

National Institute of Standards and Technology

Time and Frequency Division

TAI Meeting

September 12-13, 2006

Working Group on Primary Frequency Standards

- New working group organized in 2005.
- Membership includes 20 individual from 13 metrology organizations, including the Time Section of the BIPM.
- Six laboratories now regularly reporting, or have reported, the results of formal evaluations to the BIPM from seven different Cs fountain primary frequency standards (PFS). More to come?
- This large number of new primary standards reflects a very healthy community, but also increases the need for coordination and communication among the labs in order to maintain accuracy in the stated uncertainties.

Working Group on Primary Frequency Standards

Objectives (from Terms of Reference)

(1) Develop and propose standards for the documentation of frequency biases and uncertainties, operational details, and frequency transfer uncertainties for a PFS. Develop and propose standards for the reporting of the results of a PFS evaluation to the BIPM.

(2) Provide a forum to evaluate and discuss the consistency among primary frequency standards.

(3) Provide a forum to discuss and assess the overall knowledge of the accuracy of the SI second for use in establishing the frequencies of secondary standards (microwave and optical) and possibly an eventual redefinition of the second.

(4) Interact with the BIPM on issues related to PFS contributions to the accuracy of TAI, particularly in the process of integration of the first reports of a standard.

(5) Encourage and facilitate direct comparisons between primary frequency standards.

(6) Encourage and support laboratories with new standards under construction.

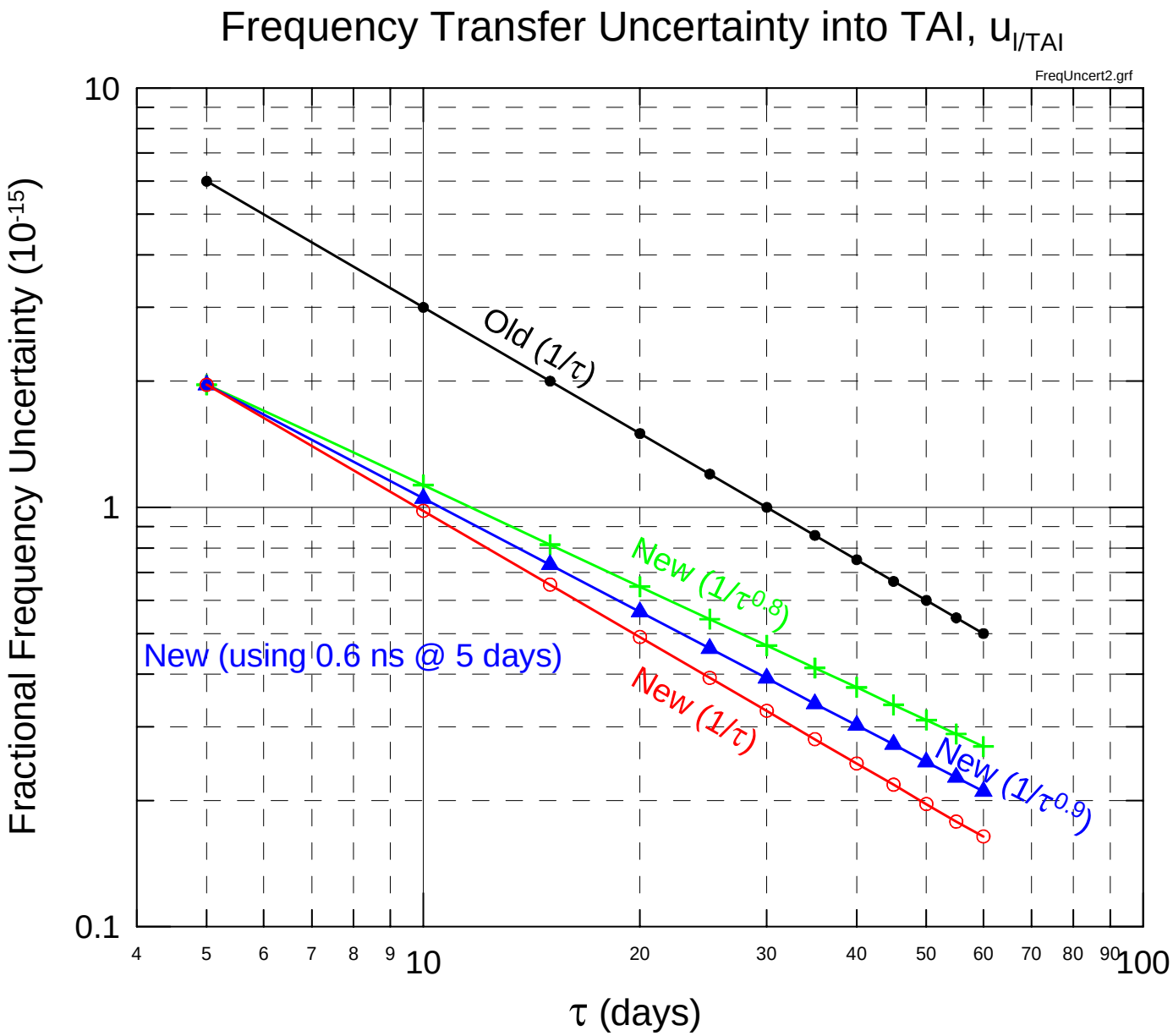
Frequency Transfer Uncertainty into TAI

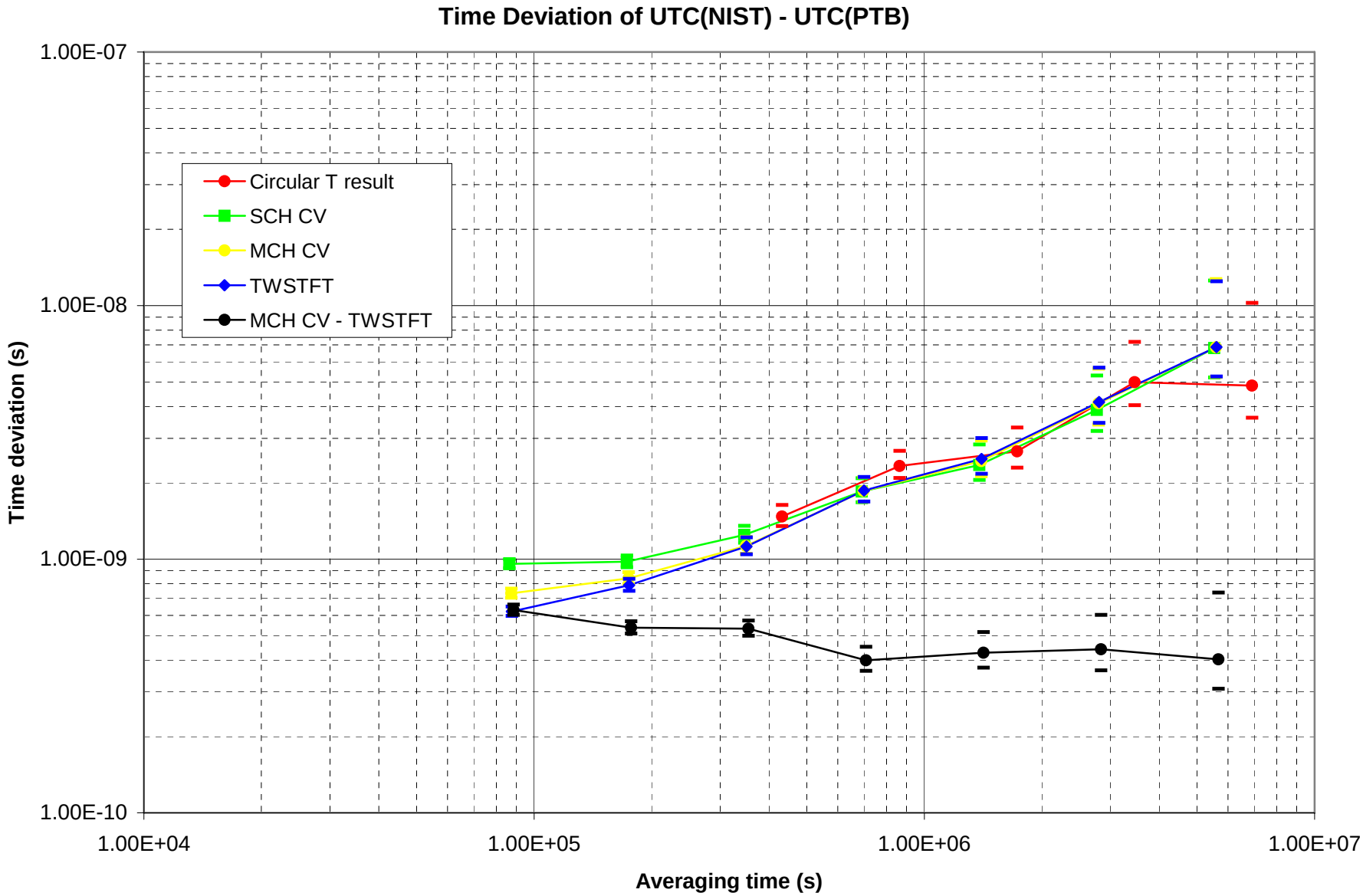
Old Equation $$u_{l/TAI} = 3x10^{-14} / \tau$$

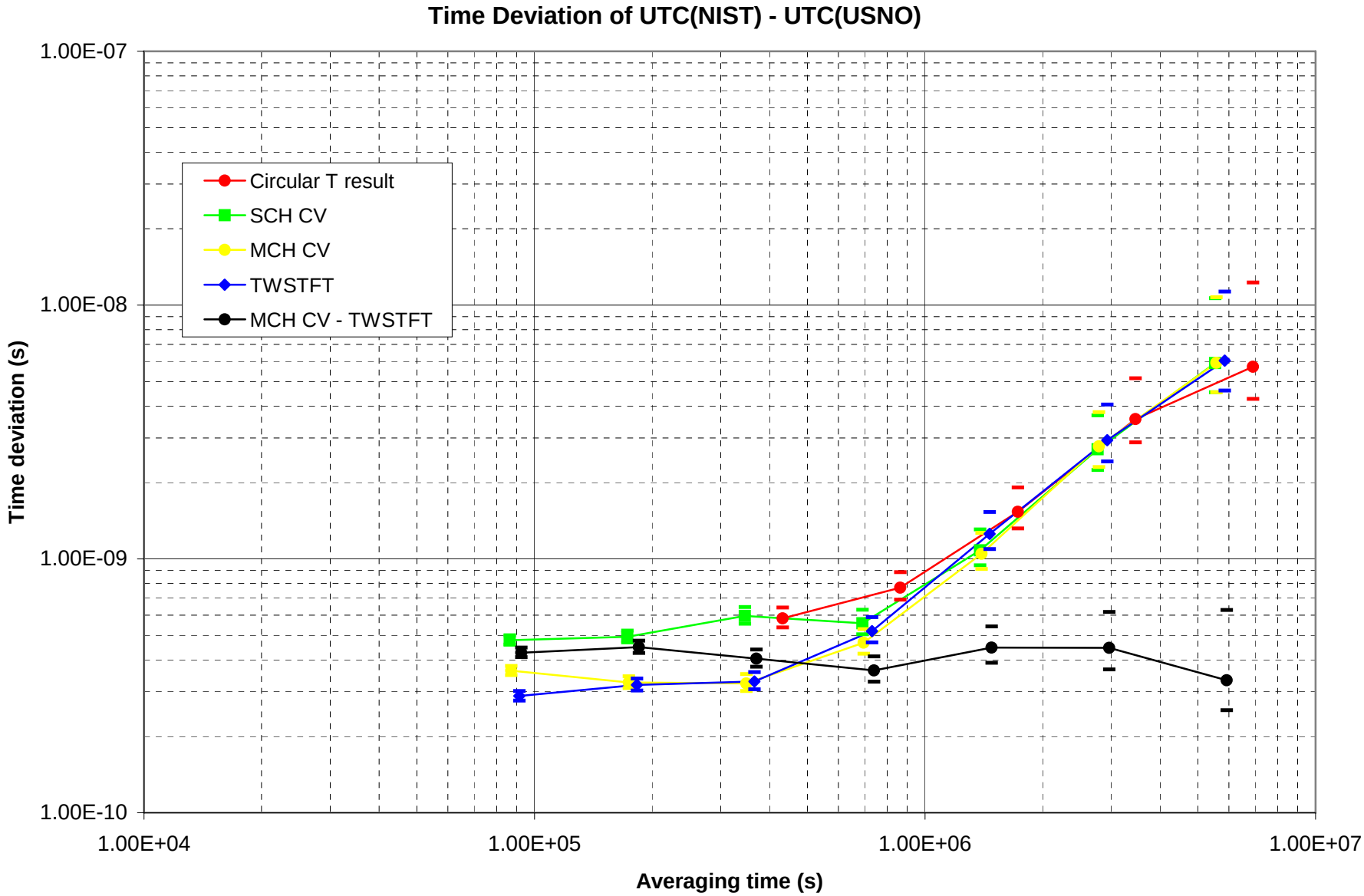
New Equation $$u_{l/TAI} = \left(\frac{\sqrt{u_A(k)_1^2 + u_A(k)_2^2}}{86400 \cdot \tau_0} \right) \frac{1}{(\tau / \tau_0)^{0.9}}$$

$u_A(k)_1$ and $u_A(k)_2$ are the uncertainties, in seconds, from Circular T at the beginning and end of the PFS report interval respectively, for laboratory k,. Within a Circular T report $u_A(k)_1 = u_A(k)_2$.

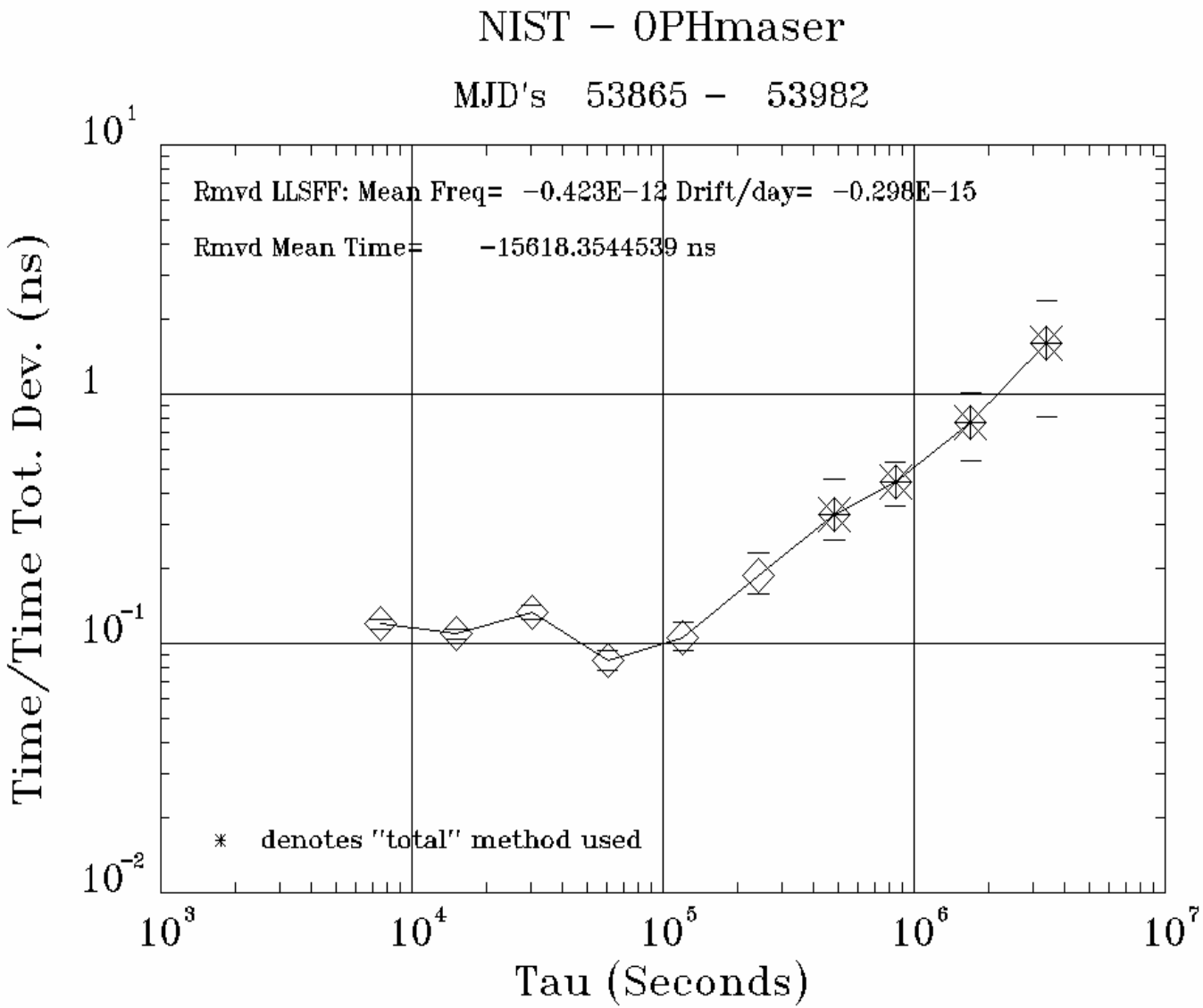
$\tau_0 = 5$ days. τ is the PFS report interval in days.


Frequency Transfer Uncertainty into TAI, u_l/TAI
FreqUncert2.grf
Fractional Frequency Uncertainty (10^-15)
10
1
0.1
Old (1/τ)
New (1/τ^0.8)
New (using 0.6 ns @ 5 days)
New (1/τ)
New (1/τ^0.9)
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
τ (days)

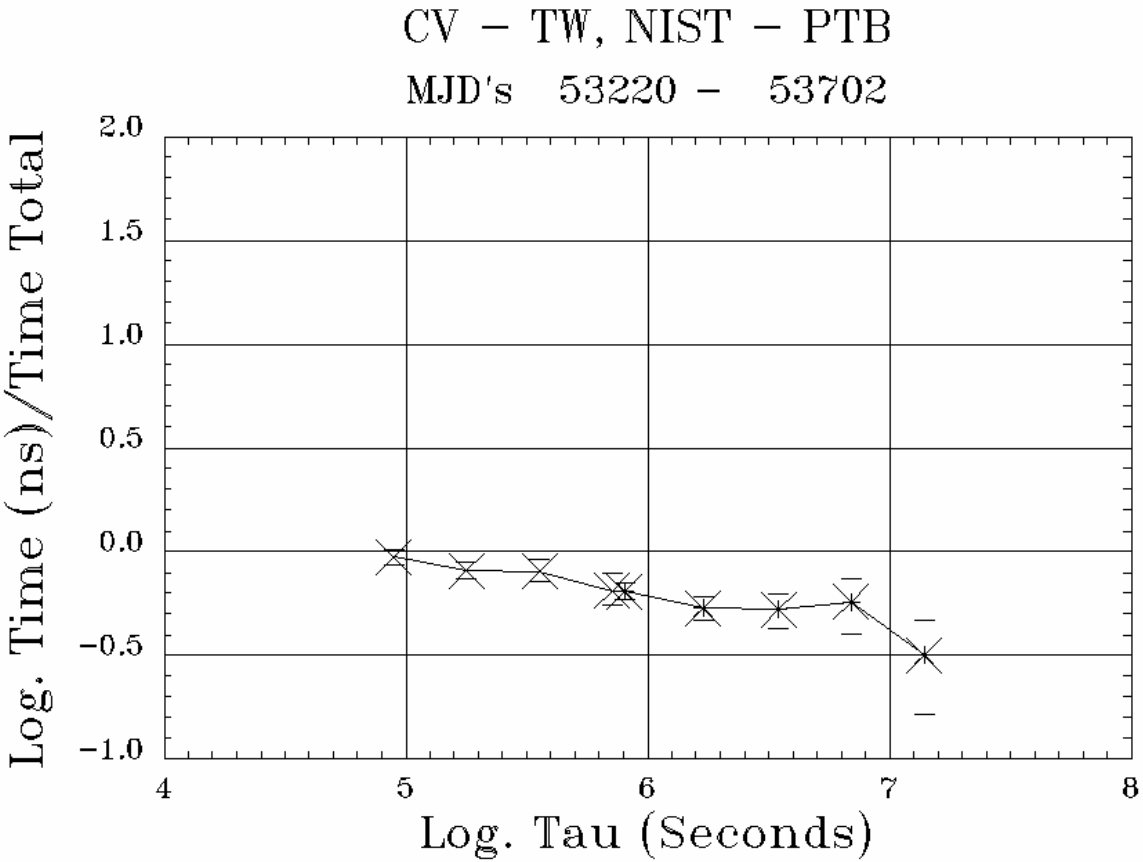

Time Deviation of UTC(NIST) - UTC(PTB)
1.00E-07
1.00E-08
1.00E-09
1.00E-10
Time deviation (s)
1.00E+04
1.00E+05
1.00E+06
1.00E+07
Averaging time (s)
Circular T result
SCH CV
MCH CV
TWSTFT
MCH CV - TWSTFT


Time Deviation of UTC(NIST) - UTC(USNO)
1.00E-07
1.00E-08
1.00E-09
1.00E-10
Time deviation (s)
1.00E+04
1.00E+05
1.00E+06
1.00E+07
Averaging time (s)
Circular T result
SCH CV
MCH CV
TWSTFT
MCH CV - TWSTFT

Recent TWSTFT Data



Time deviation



Allan deviation

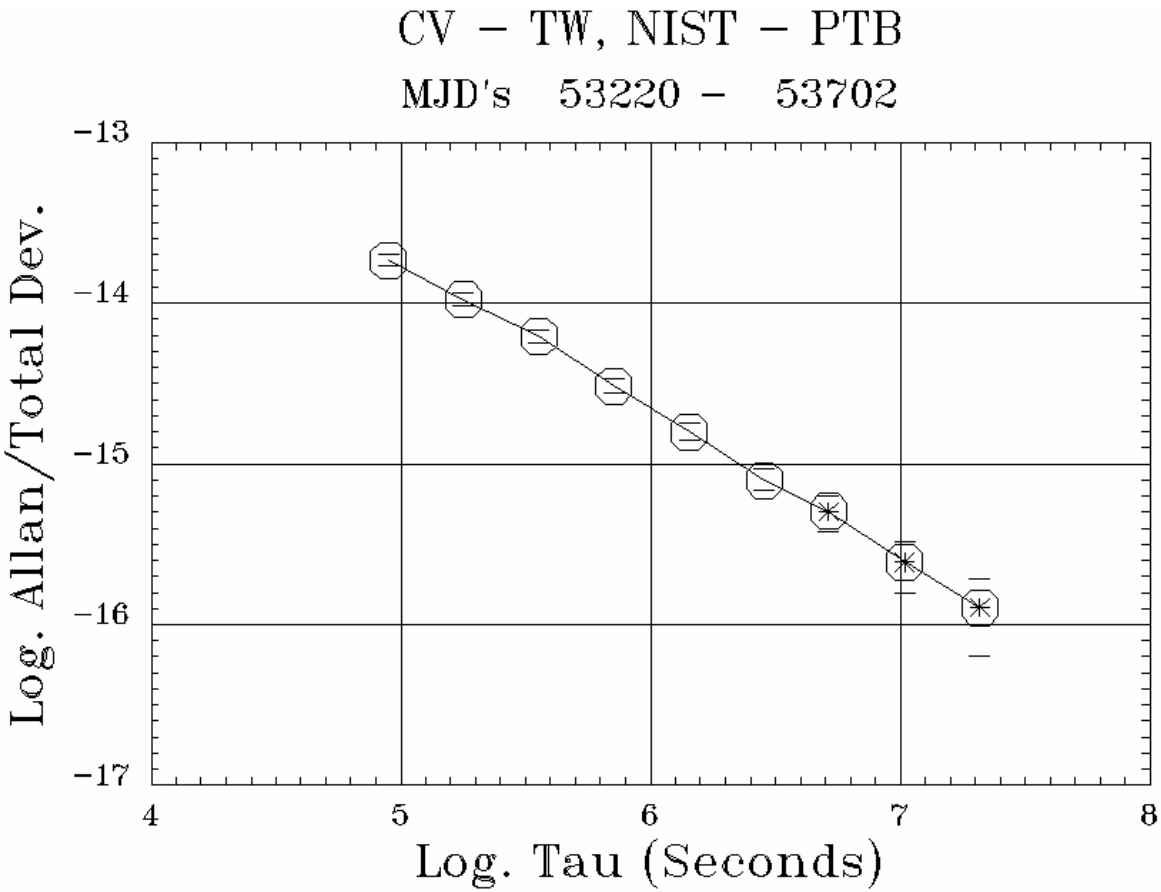
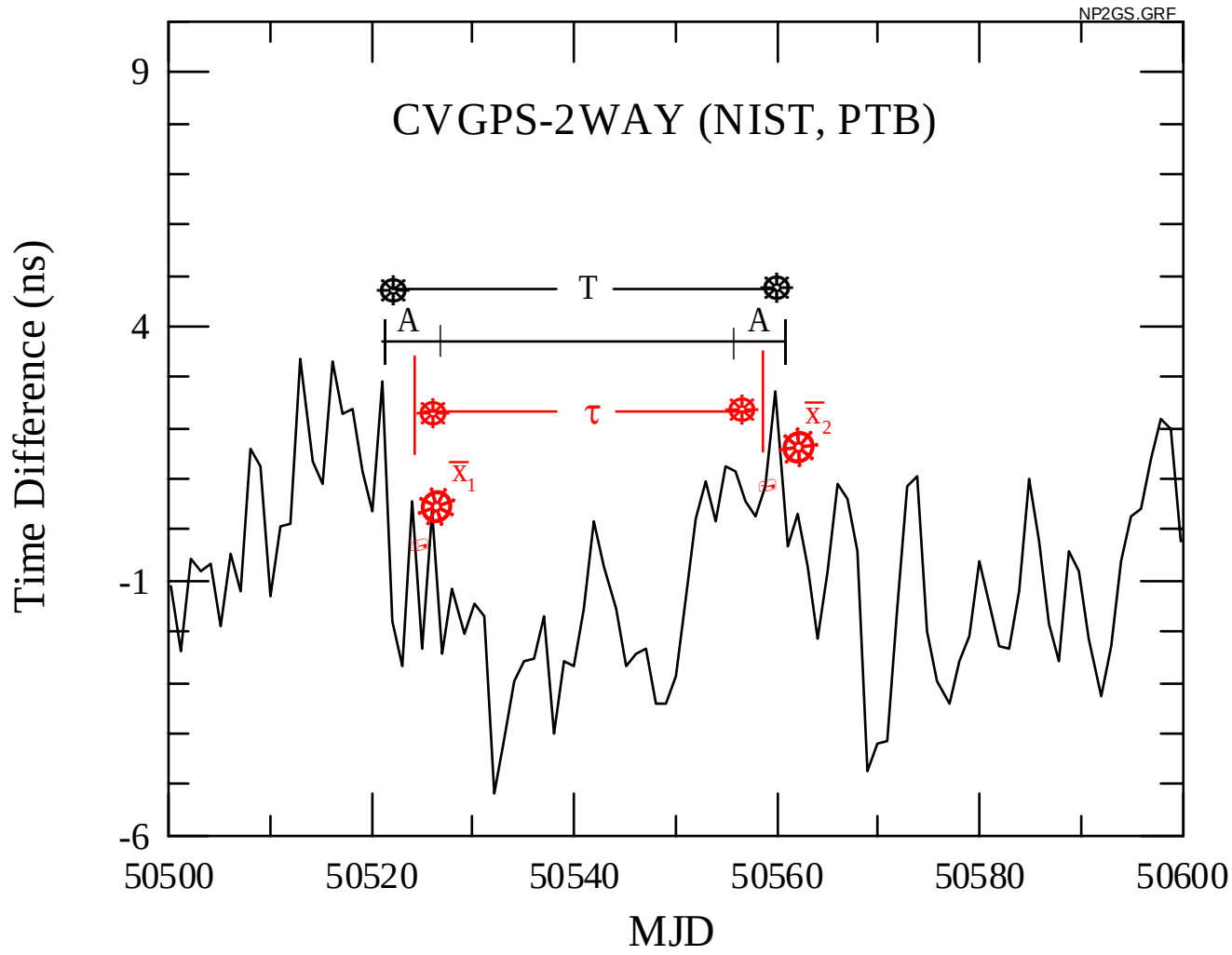


Illustration of how $\sigma_{ft}(A,\tau)$ is calculated for a sample data set.



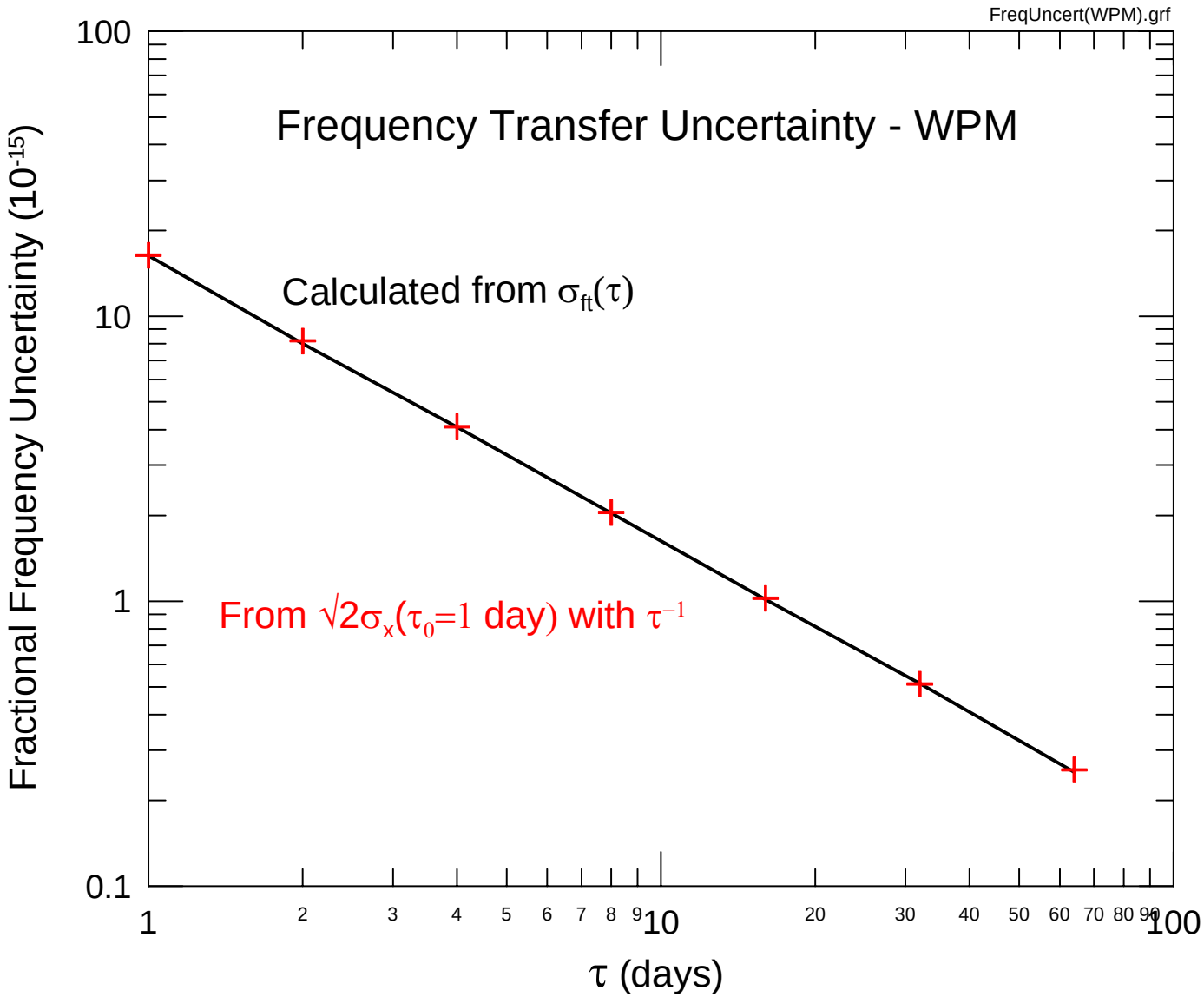
Frequency Transfer Uncertainty

$$\sigma_{ft}^2(A,\tau) = \frac{\left\langle \left(\bar{x}_{t+\tau} - \bar{x}_t\right)^2 \right\rangle}{\tau^2} = \frac{1}{\tau^2 n}\sum_{i=1}^{n}\left(\bar{x}_{i+\tau} - \bar{x}_i\right)^2$$

Can only be used on data which has no clock offset or clock noise.

An example is two-way minus common view between the same clocks.

White PM Noise



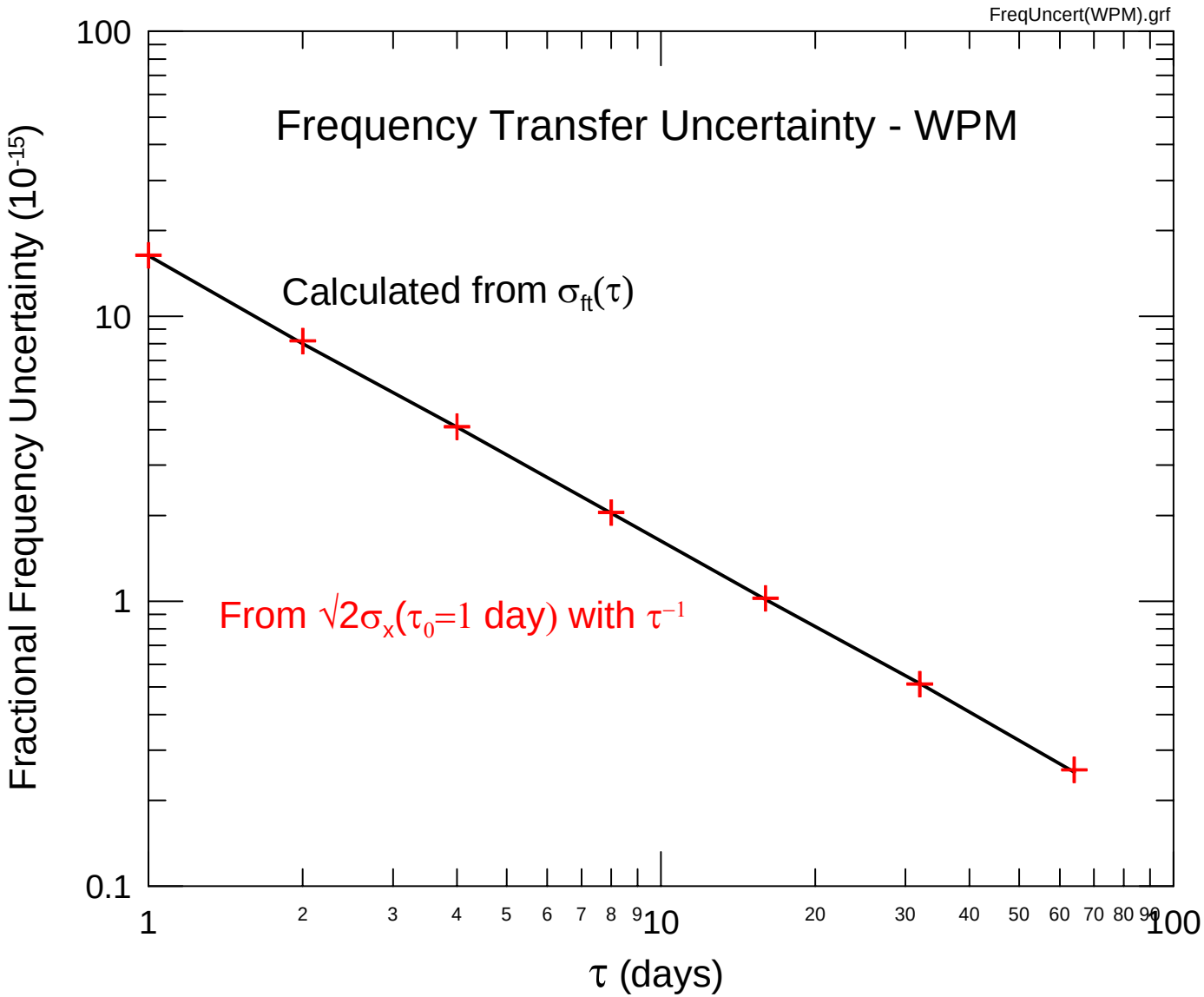
Frequency Transfer Uncertainty

$$u_{l/TAI} = \left(\frac{\sqrt{u_A(k)_1^2 + u_A(k)_2^2}}{86400 \cdot \tau_0} \right) \frac{1}{(\tau / \tau_0)^{0.9}}$$

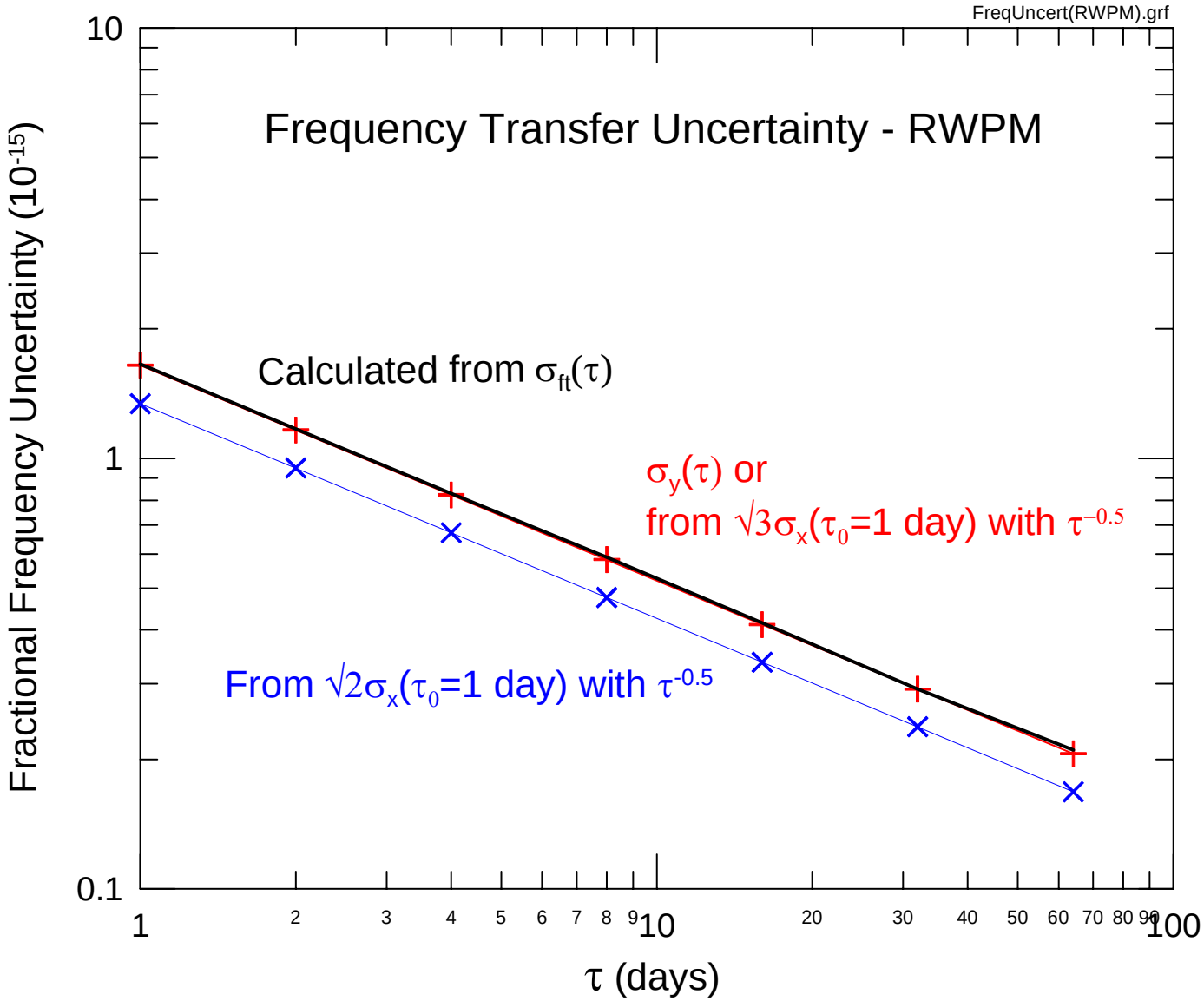
For WPM

- Substitute $\sigma_x(\tau_0)$, or std. dev., for $u_A(k)_1$ and $u_A(k)_2$
- Exponent is 1.0

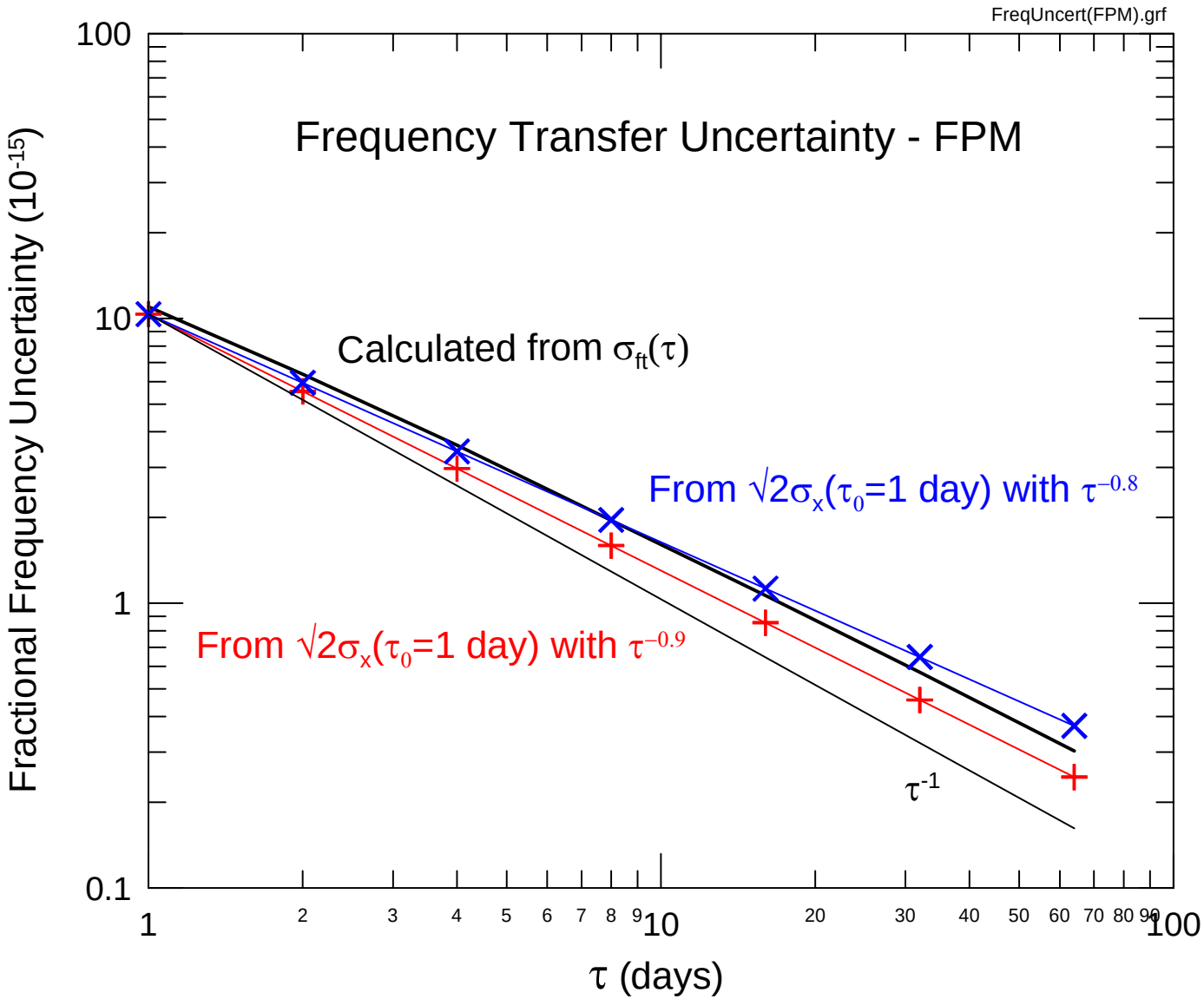
White PM Noise



Random Walk PM Noise (WFM)



Flicker PM Noise



Other Activities Related to Primary Frequency Standards

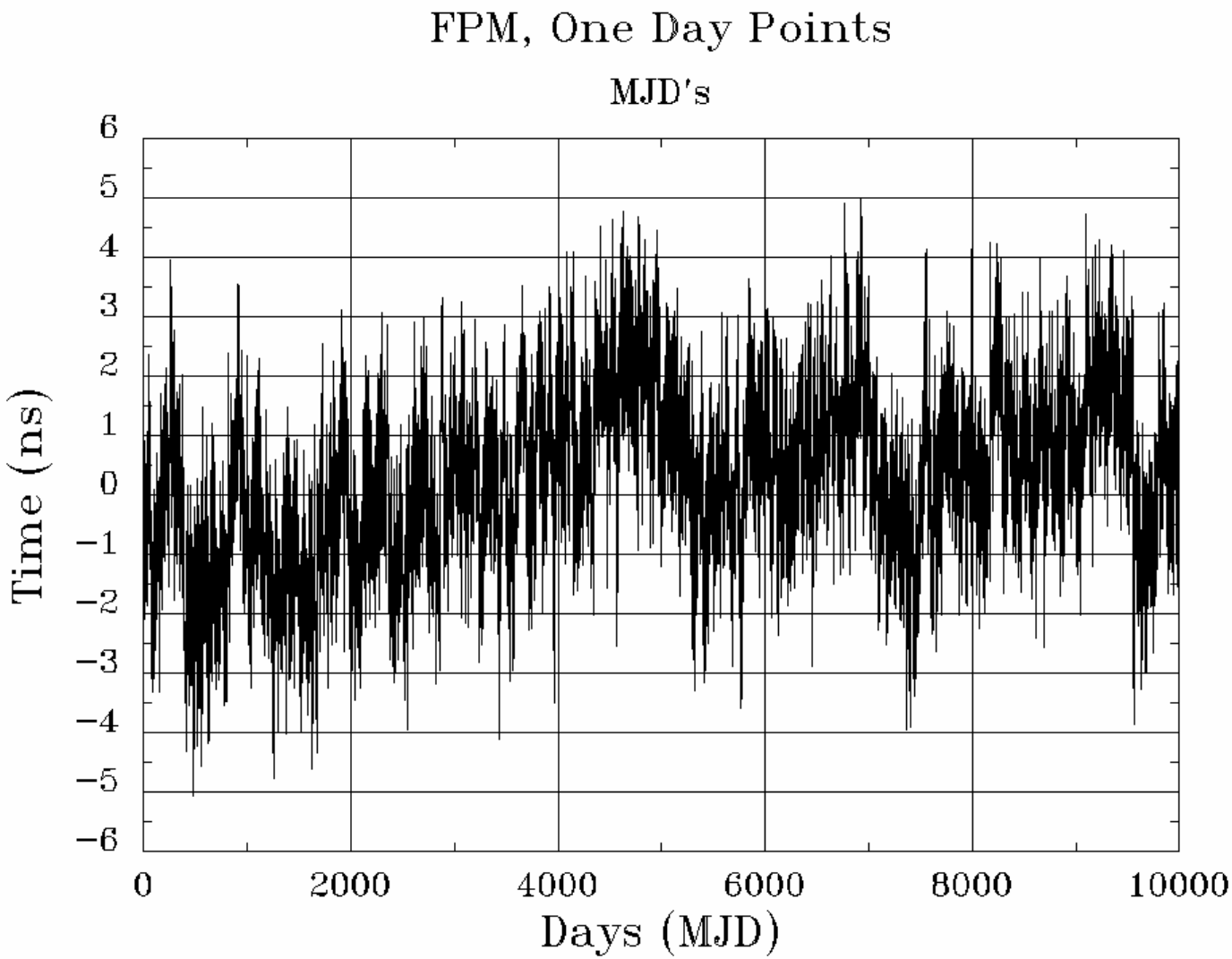
- Working group also addressing issues related to stated uncertainties of PFS.
- Planning a one day workshop for May 2007.

Summary

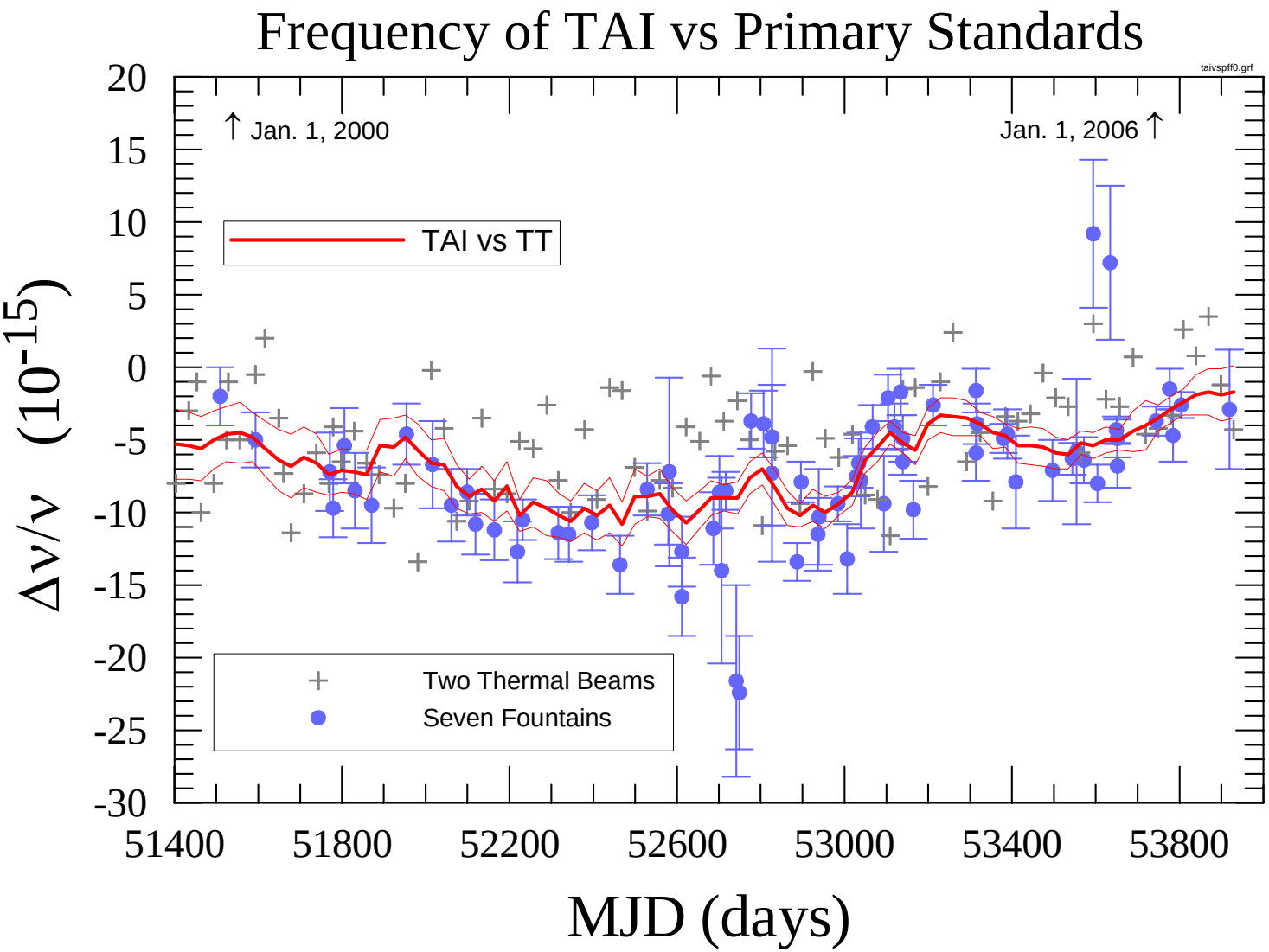
- New working group to help facilitate the use of PFS.
- Recommended new frequency transfer uncertainty.
- Examining aspects of stated accuracies of PFS .
- Planning a one day workshop for May, 2007.

Backup Slides

Simulated FPM Data



Primary Standard Data

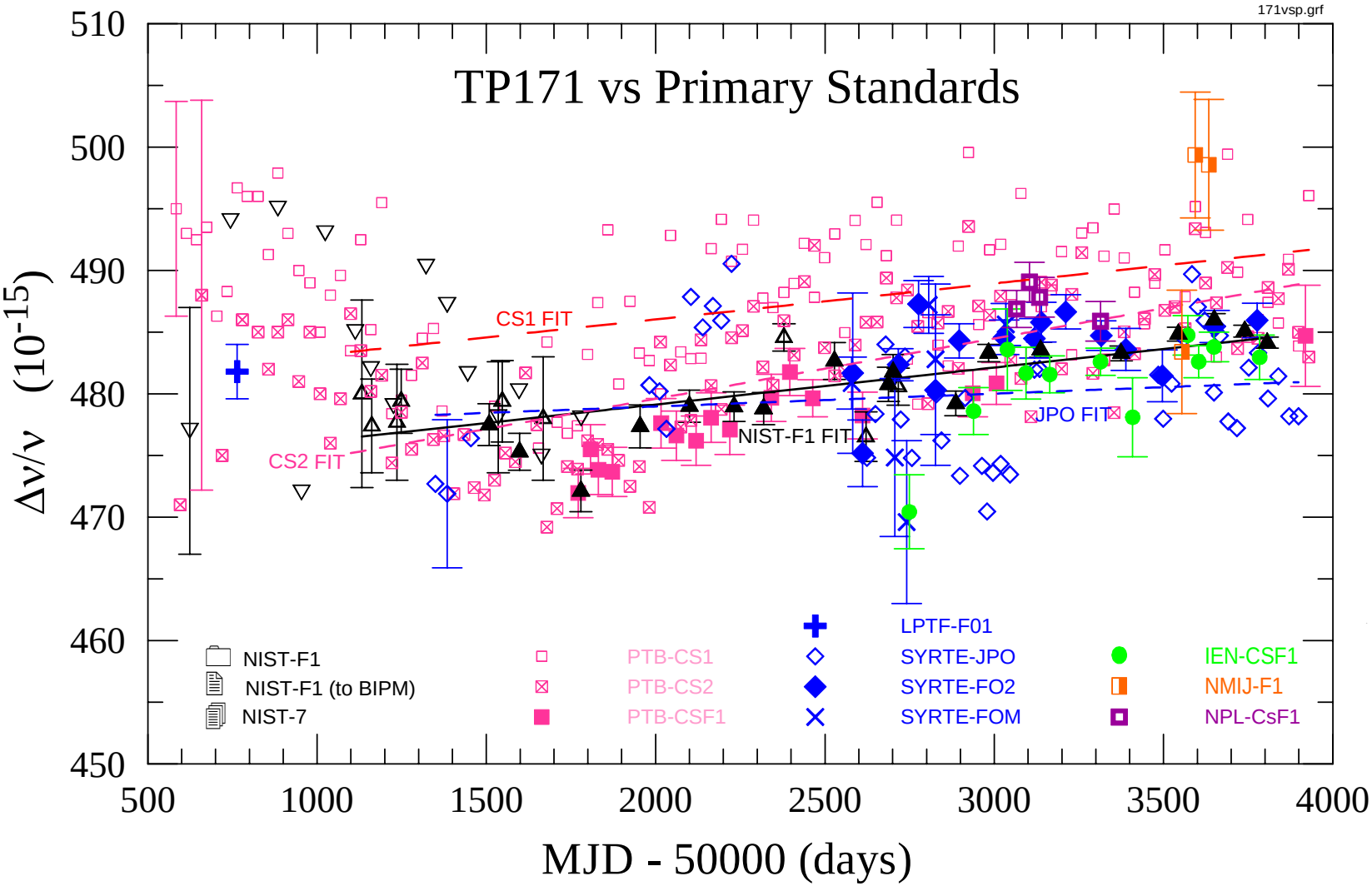


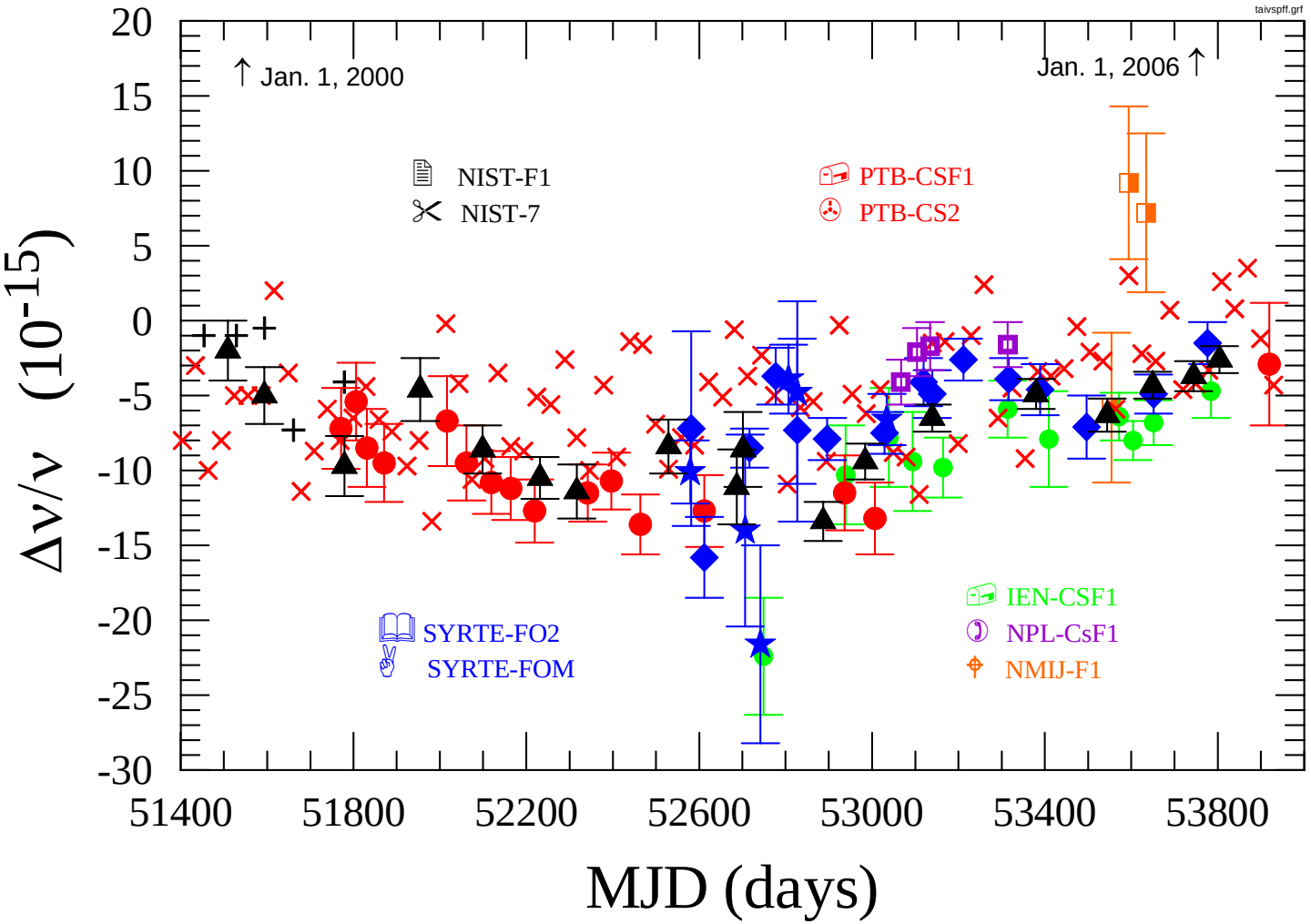
Points to be made

- Long-term drift is TAI. Red line is TT, except for points in 2006.
- Thermal beams are PTB-Cs2 and NIST-7
- As expected TT follows closely the fountain data
- For all 73 fountain points versus TT - reduced χ^2 is ~ 1.3 (about 4% probability)
  - A. Factors that cause reduced χ^2 to be too low.
    - (1) Some correlation between TT and individual fountains
    - (2) Frequency transfer uncertainty too large for more recent data points
  - B. Factor that causes reduced χ^2 to be increased
    - (1) Weight of beam standards is too high for u_B.
      - a. Some thermal beams are always present
      - b. Weight of beam standards is in the range of 25 to 30%
      - c. Systematic bias due to beam standards is only about 3×10^{-16}
- Self-inconsistencies occur more frequently in the first few reports of a new PFS
- There are some systematic biases between fountains larger than the stated uncertainties.

Primary Frequency Standards

- A relatively large number of primary standards reporting to the BIPM. Reduced χ^2 close to 1 for entire data set of 73 fountain measurements relative to TT.
- Self-consistency problems occur more frequently early in the operation of new standards.
- Evidence of systematic inconsistencies between some standards.
- Are the stated uncertainties correct? Are they consistent with the statistics and with direct comparisons?
- How should the uncertainty of the rate of TAI and TT be reported in Circular T and the Annual Report? Currently based only on supplied uncertainties.
- Paper by Wolf, et. al. at the 2006 EFTF


171vsp.grf
TP171 vs Primary Standards
Δν/ν (10-15)
MJD - 50000 (days)
510
500
490
480
470
460
450
500
1000
1500
2000
2500
3000
3500
4000
CS1 FIT
CS2 FIT
NIST-F1 FIT
JPO FIT
NIST-F1
NIST-F1 (to BIPM)
NIST-7
PTB-CS1
PTB-CS2
PTB-CSF1
LPTF-F01
SYRTE-JPO
SYRTE-FO2
SYRTE-FOM
IEN-CSF1
NMIJ-F1
NPL-CsF1


TAI vs Primary Standards
taivspff.grf
Jan. 1, 2000
Jan. 1, 2006
NIST-F1
NIST-7
PTB-CSF1
PTB-CS2
SYRTE-FO2
SYRTE-FOM
IEN-CSF1
NPL-CsF1
NMIJ-F1
Δν/ν (10-15)
MJD (days)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
51400
51800
52200
52600
53000
53400
53800