# Status report on TAI

**Elisa Felicitas Arias**

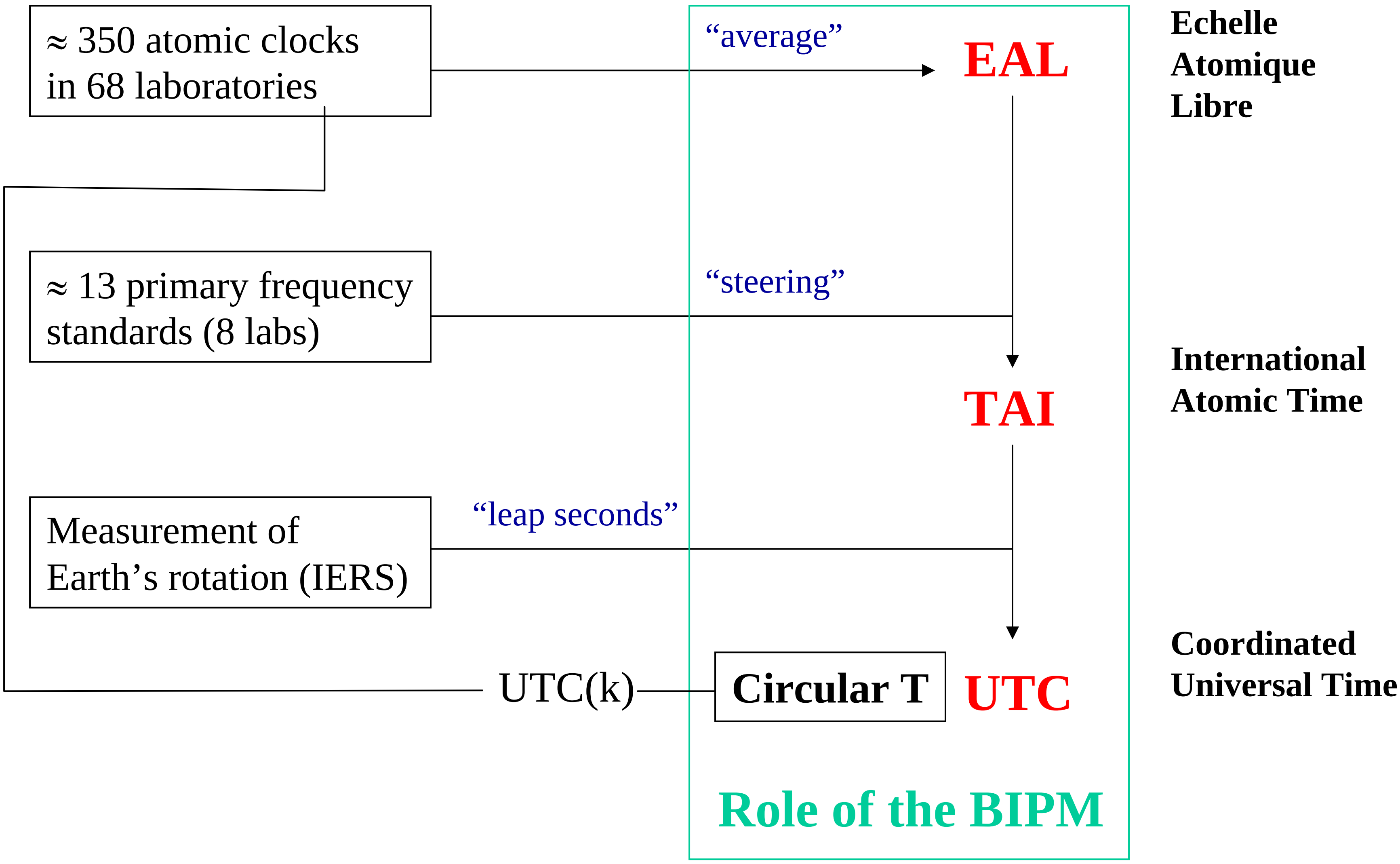

8th Meeting of representatives of laboratories contributing to TAI

BIPM, Sèvres, 3 June 2009

# General organization
# Time, frequency and gravimetry section

- Staff
  - E. Felicitas Arias (Head)
  - Wlodzdimierz Lewandowski
  - Raymond Felder
  - Zhiehng Jiang
  - Aurélie Harmegnies (since November 2008)
  - Hawaï Konaté
  - Jacques Labot
  - G. Panfilo (since August 2007)
  - Gérard Petit
  - Lennart Robertsson
  - Laurent Tisserand
  - Leonid Vitushkin

# Elaboration of TAI and UTC - ALGOS



# Clocks in TAI

- Participating clocks
  - ~ 350
  - 87% HP/Agilent/Symmetricom 5071A and H-masers
  - 15% of clocks at $w_{max}$ (in average)

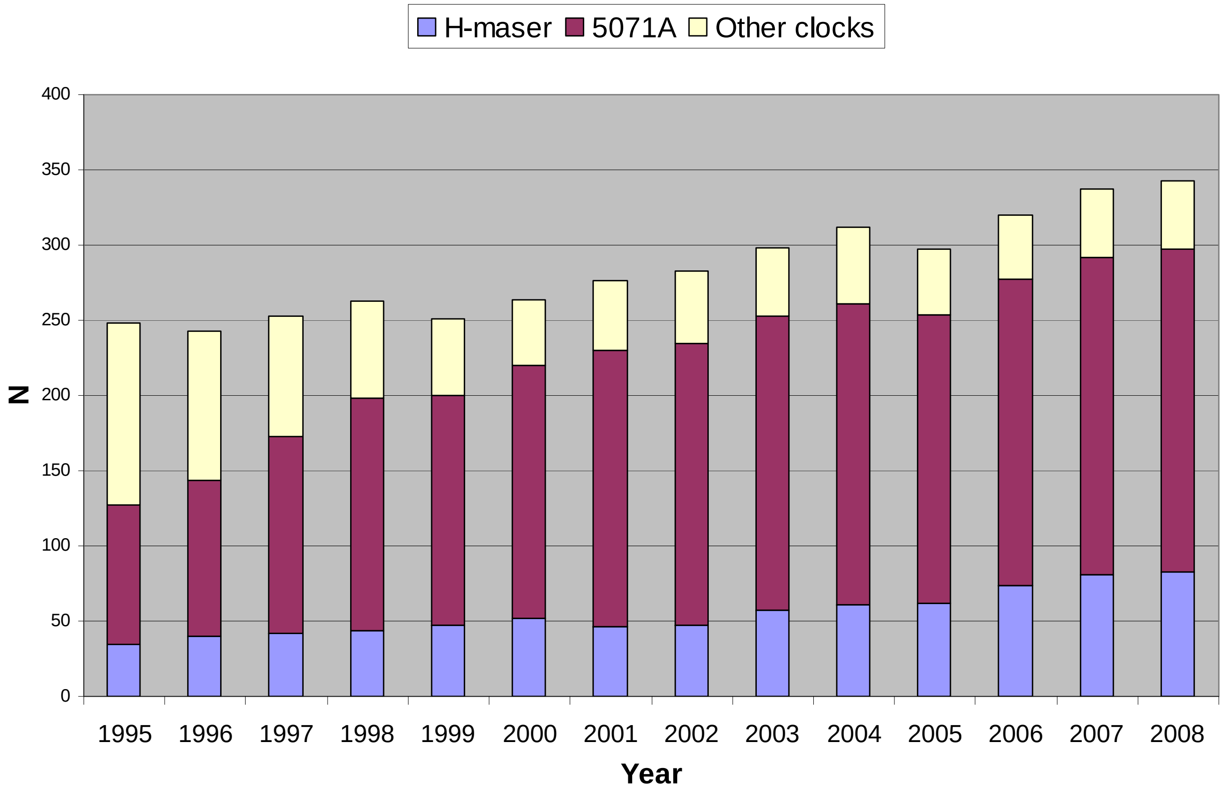

**Relative weights**

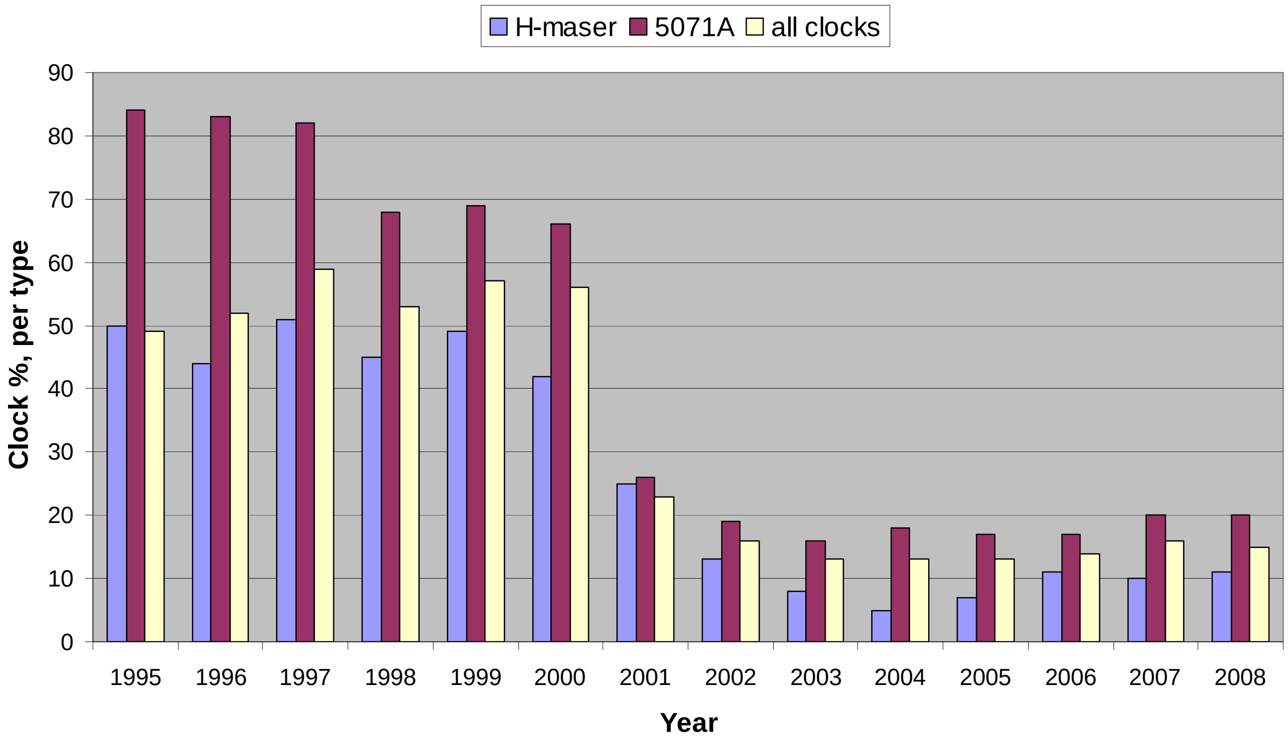
$$\omega_{max} = 2.5 / N$$

**15% of clocks**

**20% of HP5071A**

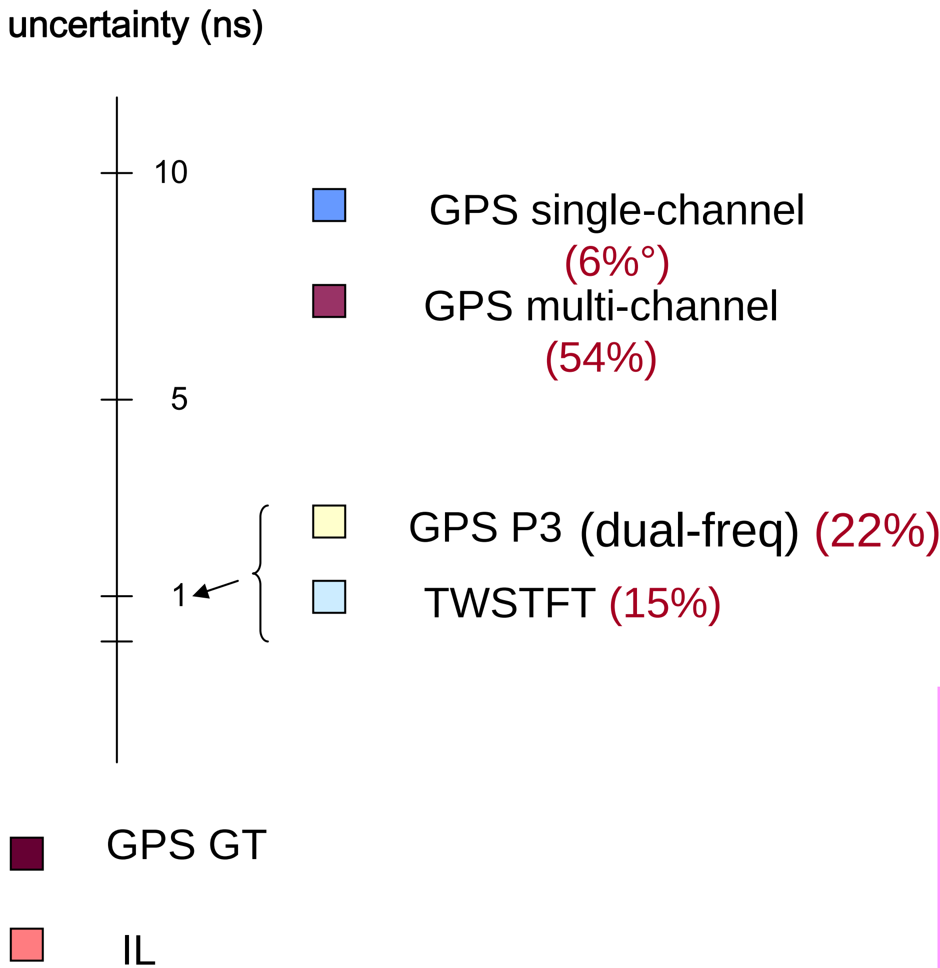
**11% of H-masers**


H-maser
5071A
Other clocks
400
350
300
250
200
150
100
50
0
N
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Year



H-maser
5071A
all clocks
Clock %, per type
90
80
70
60
50
40
30
20
10
0
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Year

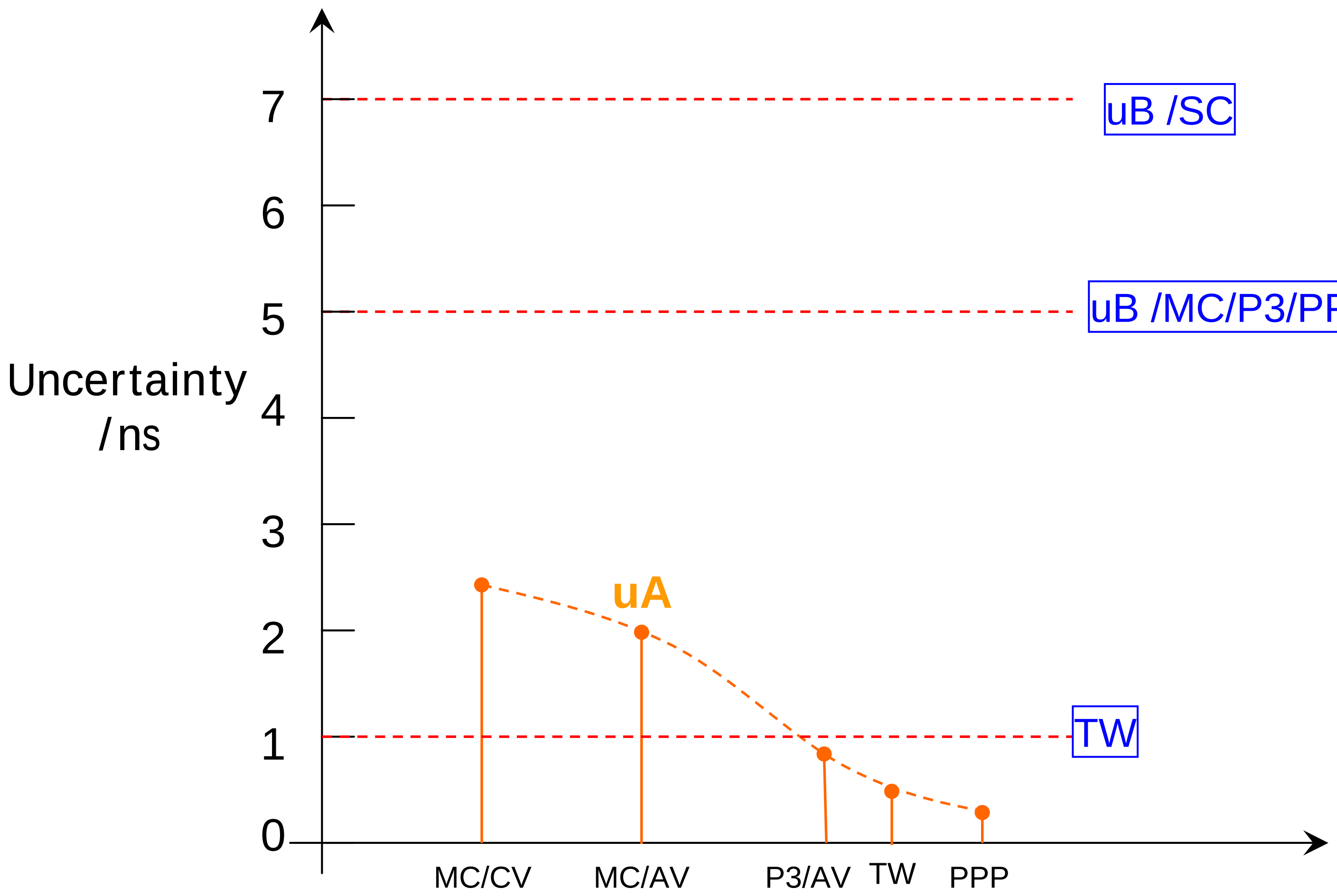
# Clock comparison

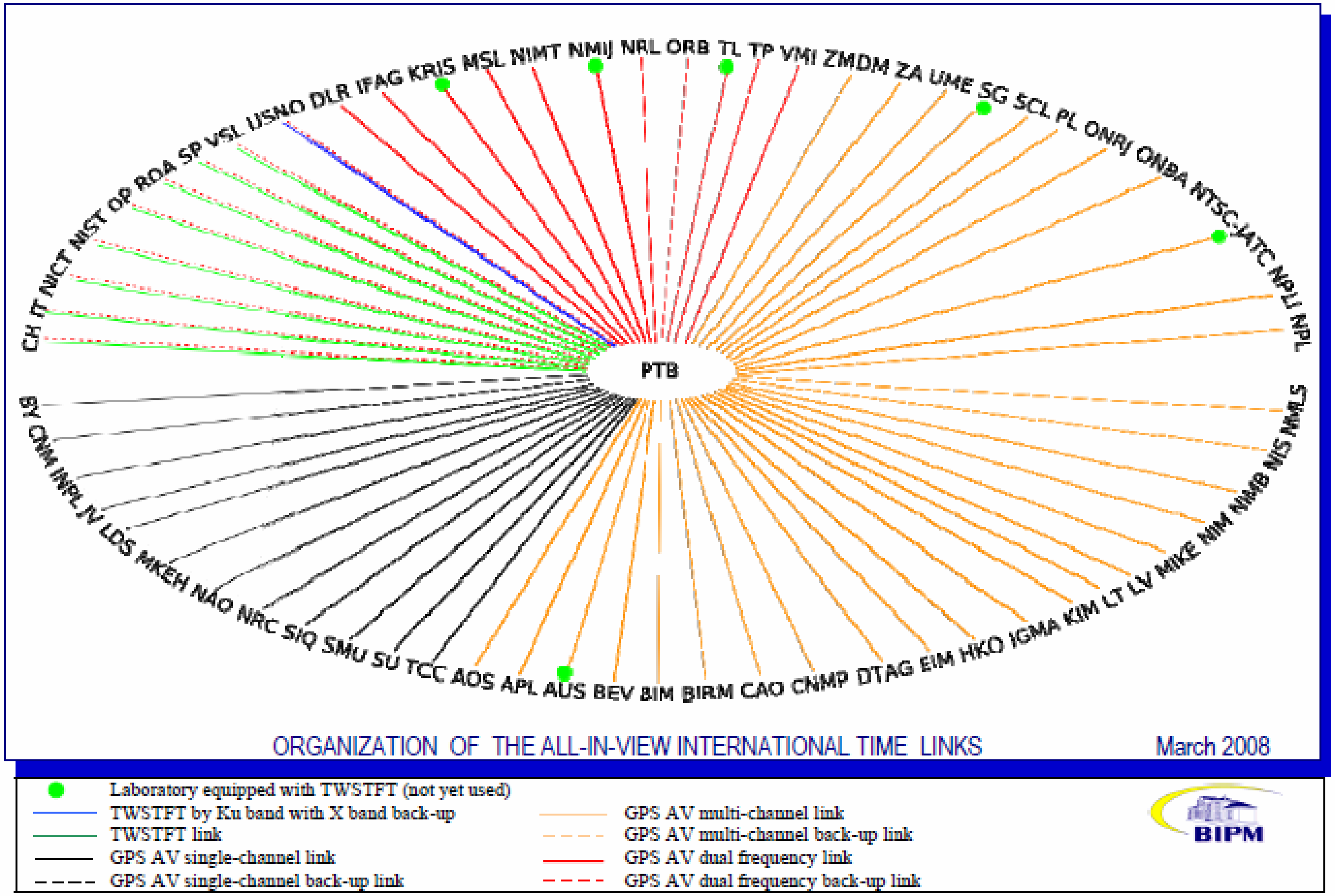


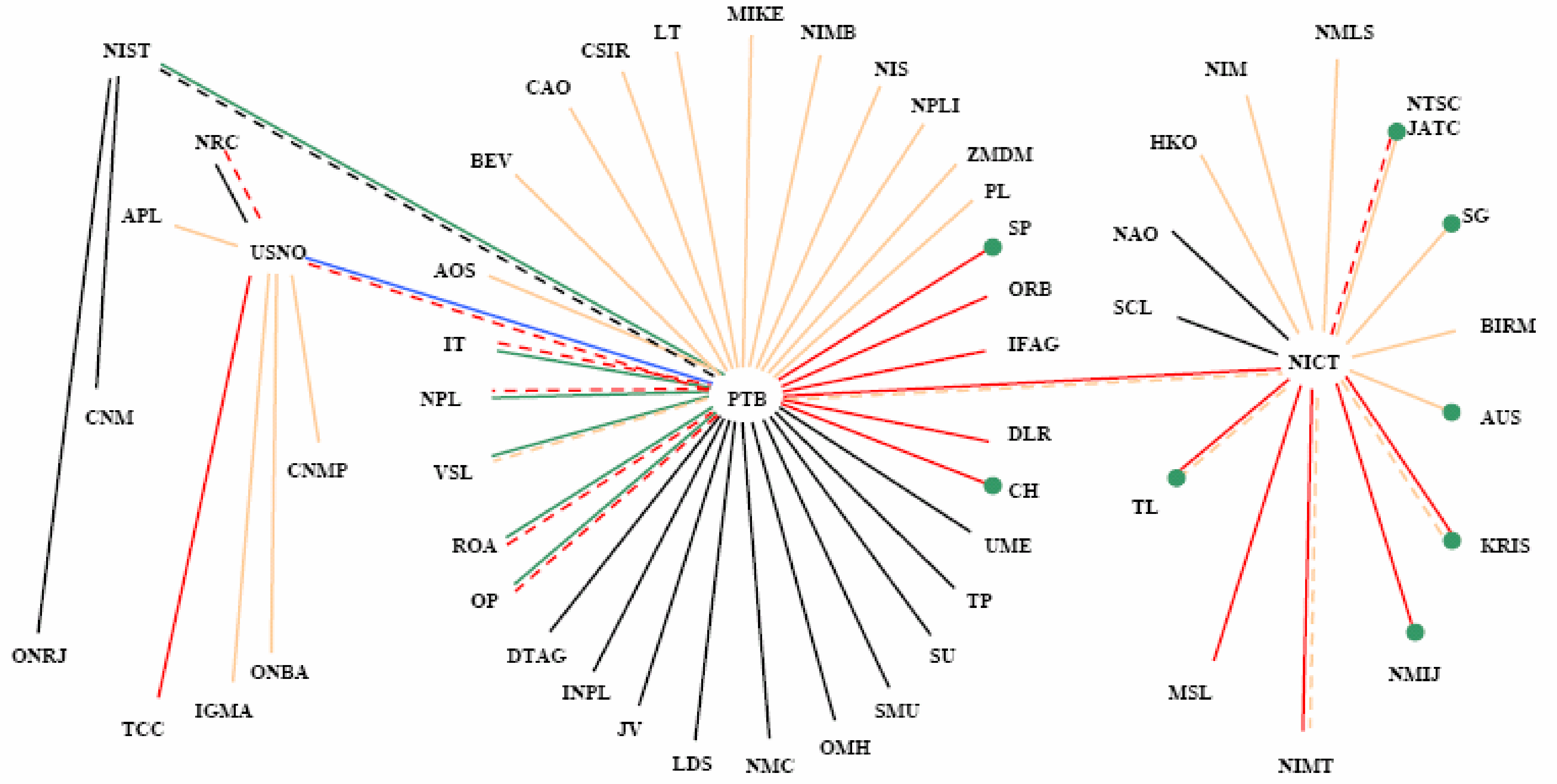

IGS products

- orbits
- ionosphere
- clocks

# Uncertainty of UTC time transfer (calibrated equipment only)




PTB
CH IT NICT NIST OP ROA SP VSL USNO DLR IFAG KRIS MSL NIMT NMIJ NRL ORB TL TP VMI ZMDM ZA UME SG SCL PL ONRJ ONBA NTSC JATC NPLI NPL
NMLS NIS NMB NIM MIKE LV LT KIM IGMA HKO EIM DTAG CNMP CAO BIRM BIM BEV AUS APL AOS TCC SU SMU SIQ NRC NAO MKEH LDS JV INPL CNM BY
ORGANIZATION OF THE ALL-IN-VIEW INTERNATIONAL TIME LINKS
March 2008
Laboratory equipped with TWSTFT (not yet used)
TWSTFT by Ku band with X band back-up
TWSTFT link
GPS AV single-channel link
GPS AV single-channel back-up link
GPS AV multi-channel link
GPS AV multi-channel back-up link
GPS AV dual frequency link
GPS AV dual frequency back-up link
BIPM




ORGANIZATION OF THE INTERNATIONAL TIME LINKS April 2006

- ● Laboratory equipped with TWSTFT (not yet used)
- TWSTFT by Ku band with X band back-up
- TWSTFT link
- GPS CV single-channel link
- GPS CV single-channel back-up link
- GPS CV multi-channel link
- GPS CV multi-channel back-up link
- GPS CV dual frequency link
- GPS CV dual frequency back-up link

# Progress in the period 2006-2009

- Techniques and methods of time transfer
  - GPS single-frequency
  - GPS dual-frequency
  - TWSTFT
  - GPS all-in-view
  - TAIPPP (pilot experiment)
  - Baselines with multiple techniques
  - Comparison of techniques / methods
  - Characterization of
    - relative delays in GNSS equipment (single and dual-frequency) – 65% of labs
    - absolute started (CNES, OP, BIPM)
    - Page on ftp ftp server
  - Publication of link comparison results on ftp server

# Progress 2006-2009

- Key comparisons

    - Key comparison in Time CCTF-K001.UTC (published in the BIPM Key Comparison Data Base, KCDB) ftp server

    - Key comparison in Frequency CCTF-K002.FREQ (proposal to be adopted by the CCTF this week)

    - 46 participants

# Progress 2006-2009

The effect of the linear prediction algorithm has been studied

- on the Caesium clock → it works well
- on the H-masers → it does not work well

The impact of the H-masers on EAL frequency drift has been analyzed

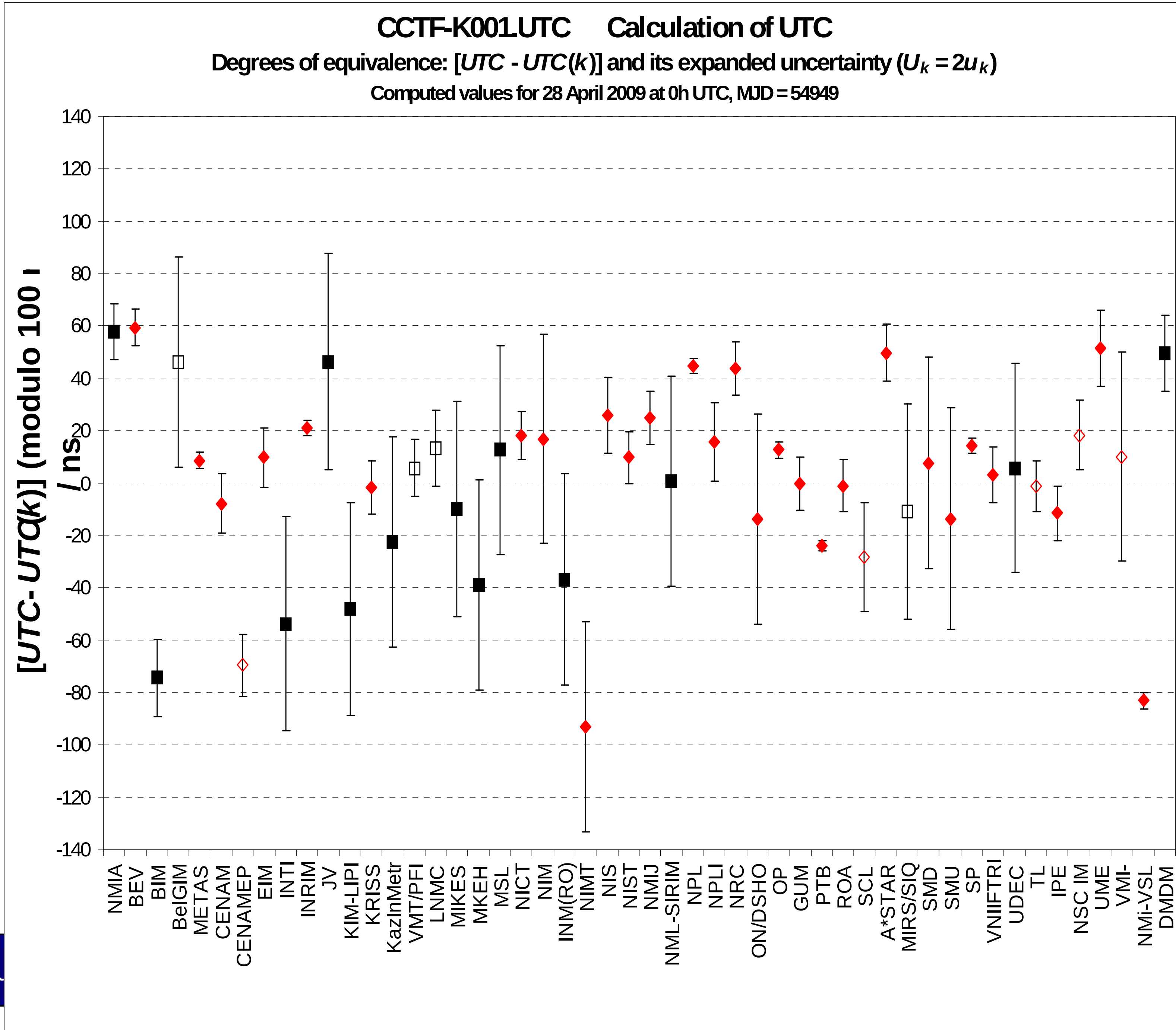
A new mathematical expression for the prediction has been found. It includes the treatment of H-maser frequency drift

# Progress 2006-2009

A test for the 3-year period was done applying the linear prediction to the caesium clocks and the quadratic prediction to the H-masers

One month of past data was used to evaluate the frequency drift, a longer period could be tested

EAL still shows a significant drift, further work needs to be done on EAL weighting algorithm


CCTF-K001.UTC Calculation of UTC
Degrees of equivalence: [UTC - UTC(k)] and its expanded uncertainty (Uk = 2uk)
Computed values for 28 April 2009 at 0h UTC, MJD = 54949
[UTC- UTC(k)] (modulo 100 ns) / ns
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
NMIA
BEV
BIM
BelGIM
METAS
CENAM
CENAMEP
EIM
INTI
INRIM
JV
KIM-LIPI
KRISS
KazInMetr
VMT/PFI
LNMC
MIKES
MKEH
MSL
NICT
NIM
INM(RO)
NIMT
NIS
NIST
NMIJ
NML-SIRIM
NPL
NPLI
NRC
ON/DSHO
OP
GUM
PTB
ROA
SCL
A*STAR
MIRS/SIQ
SMD
SMU
SP
VNIIFTRI
UDEC
TL
IPE
NSC IM
UME
VMI-
NMi-VSL
DMDM

- **Frequency steering**

  Apply a frequency correction to assure the accuracy of the scale

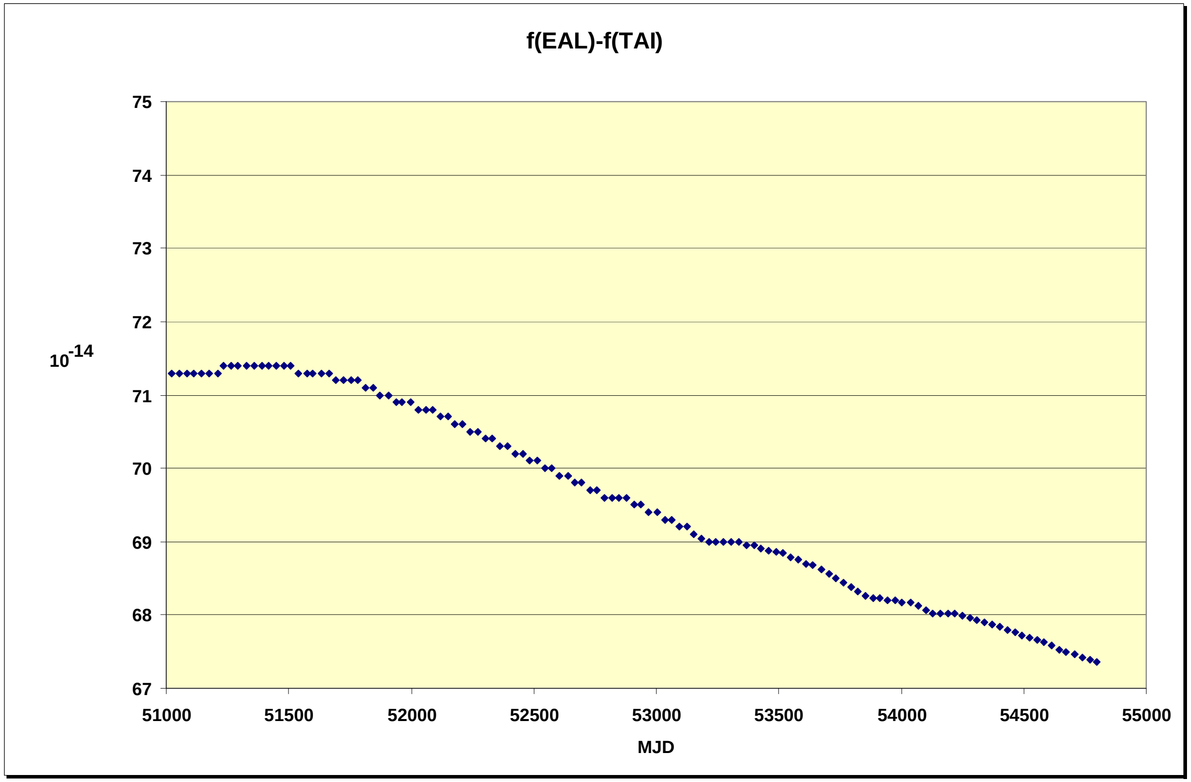
  f(TAI) = f(EAL) + corr (steering, pilotage)

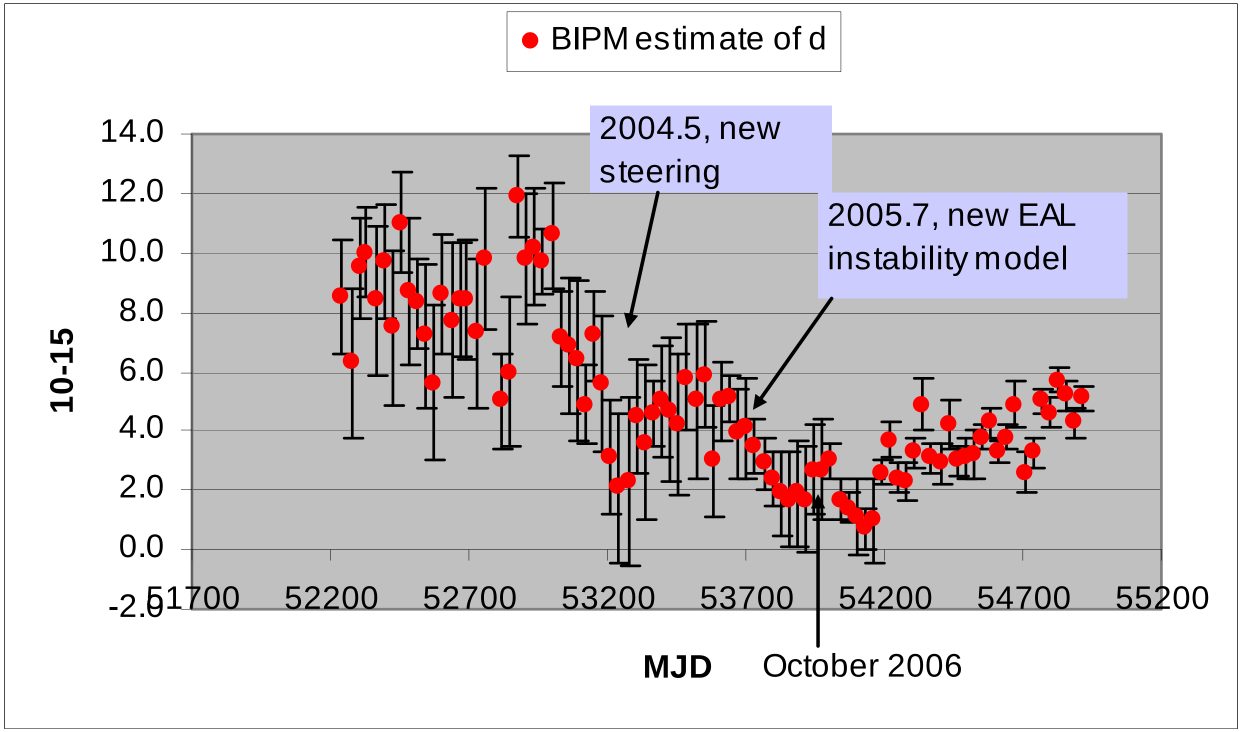
- since july 2004 $corr_{max} = -0.7 \times 10^{-15}$ monthly

- October 2006-April 2009
  - Total correction $-10.1 \times 10^{-15}$
  - Max correction $-0.6 \times 10^{-15}$

# EAL and TAI

Present steering policy (since CCTF'2004): Steering frequency can be changed every month by steps (typically < 0.6x10-15) small enough to preserve TAI stability, but sufficient to ensure better accuracy.




BIPM estimate of d
2004.5, new steering
2005.7, new EAL instability model
October 2006
10-15
MJD
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
51700
52200
52700
53200
53700
54200
54700
55200

# TT(BIPM)

The BIPM computes in deferred time TT(BIPM), which is based on a weighted average of the evaluations of TAI frequency by the PFS.

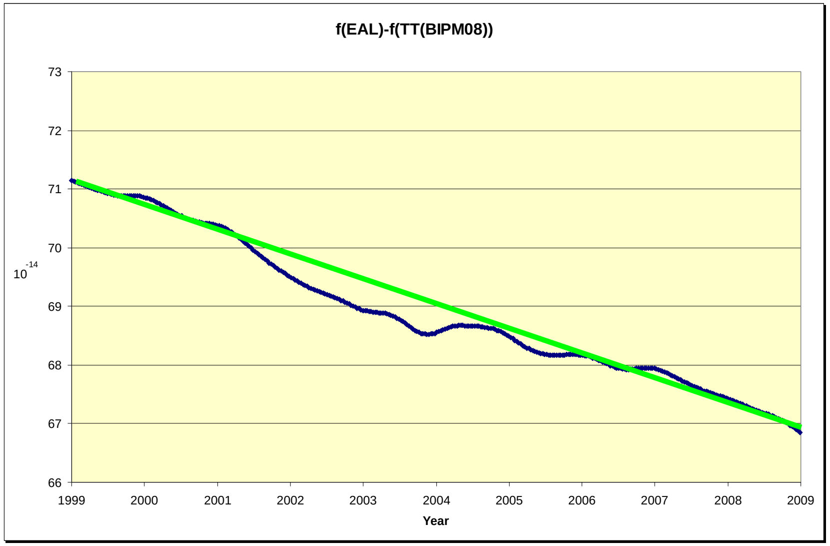
TT(BIPM) is computed in deferred time and updated every year.

It is the same algorithm used to evaluate f(EAL) but in post processing.

TT(BIPM) is used as frequency reference to evaluate:

1. f(EAL) performance
2. f(TAI) performance
3. PFS performance

# f(EAL)-f(TT)



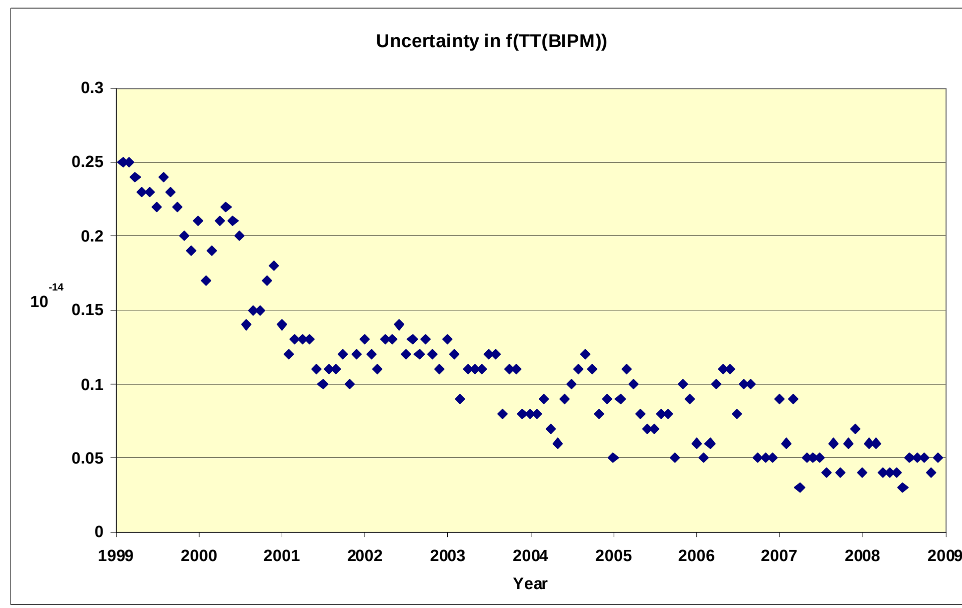

EAL shows a frequency drift

$$4\times10^{-16}\ /\ month$$

Uncertainty in TT(BIPM) estimates accuracy in TT(BIPM)

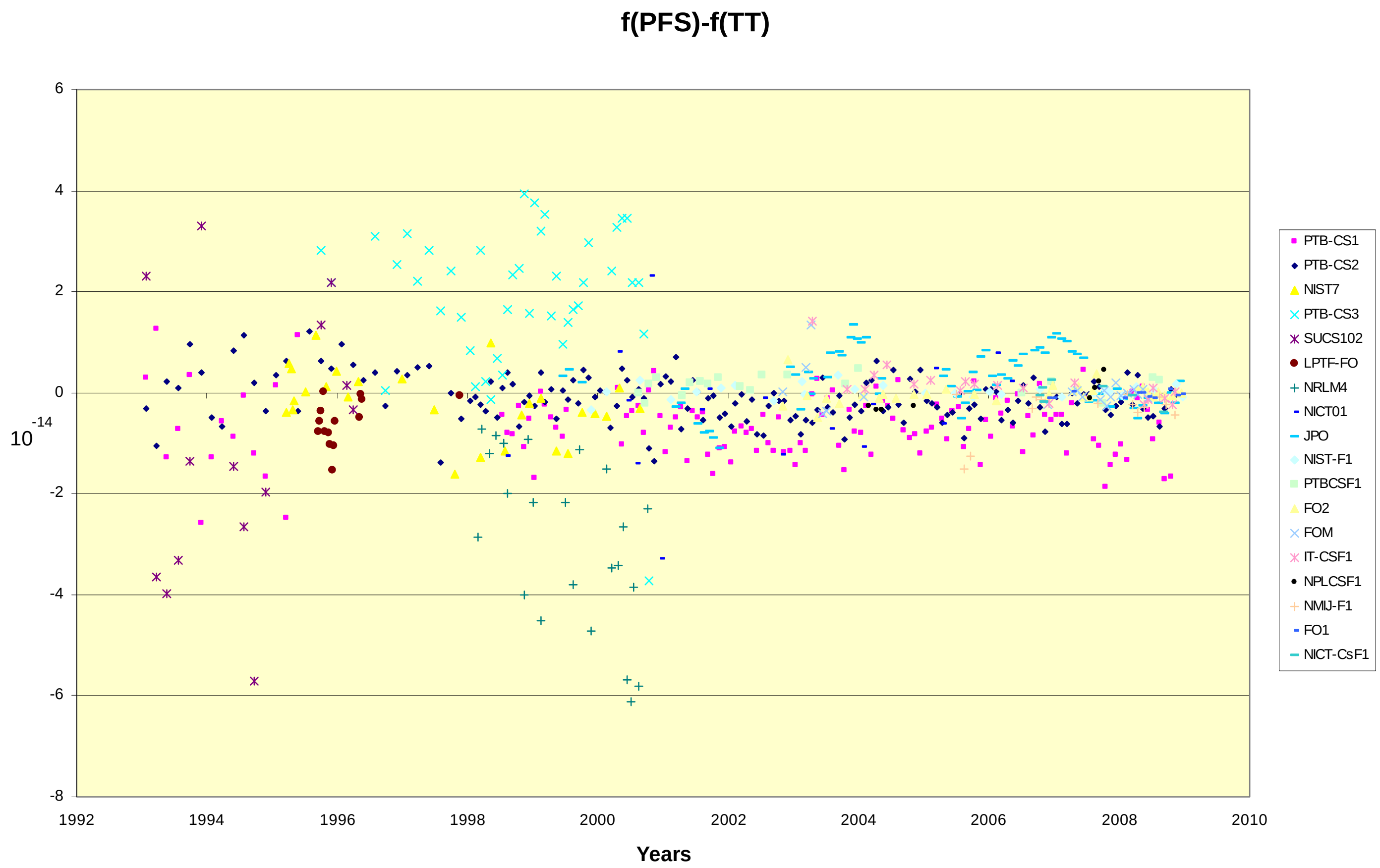
Over 2008, on average:

$$5\times10^{-16}$$

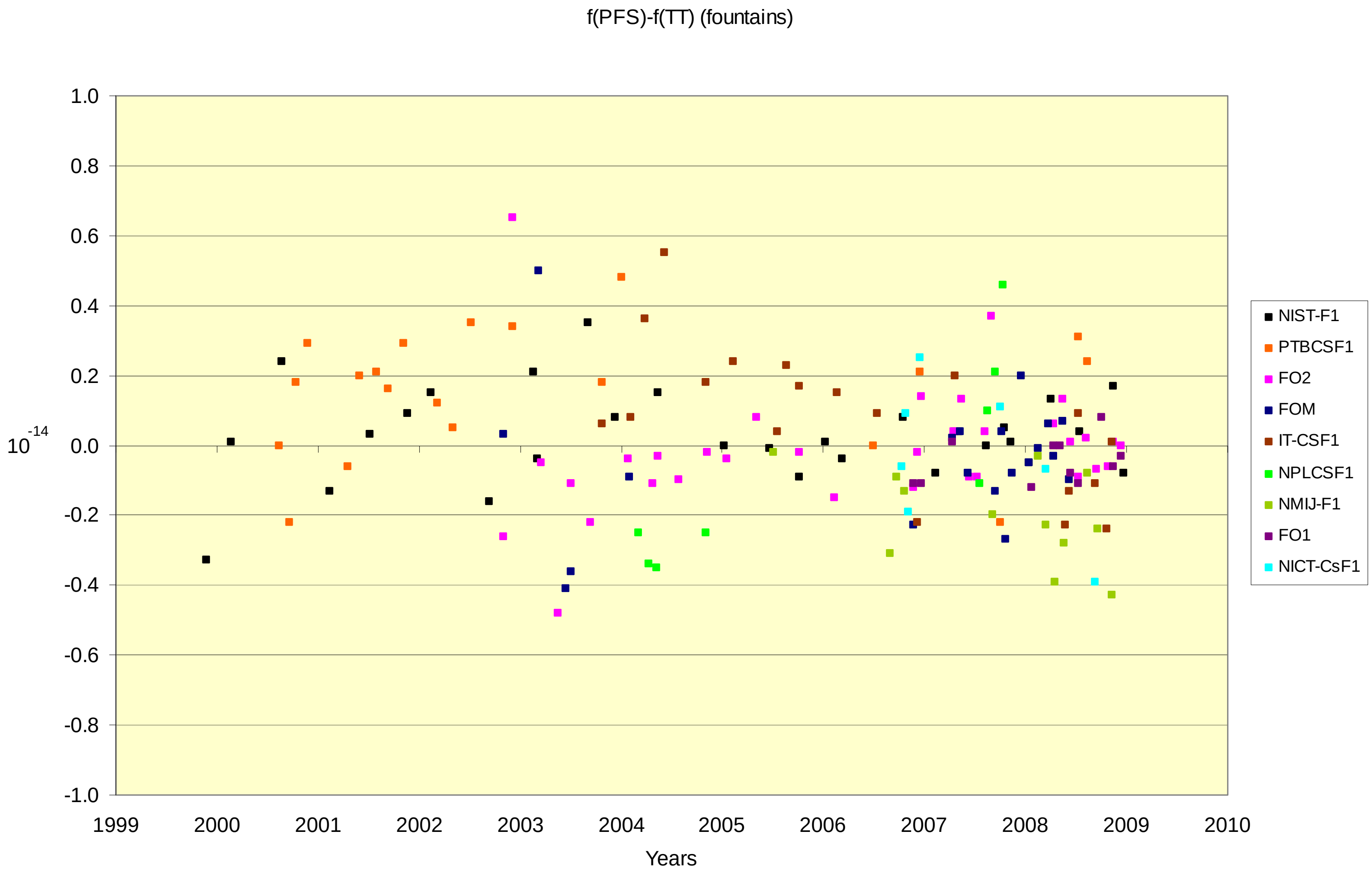


# PFS evaluations

By TT the performance of PFS measurement can be estimated:

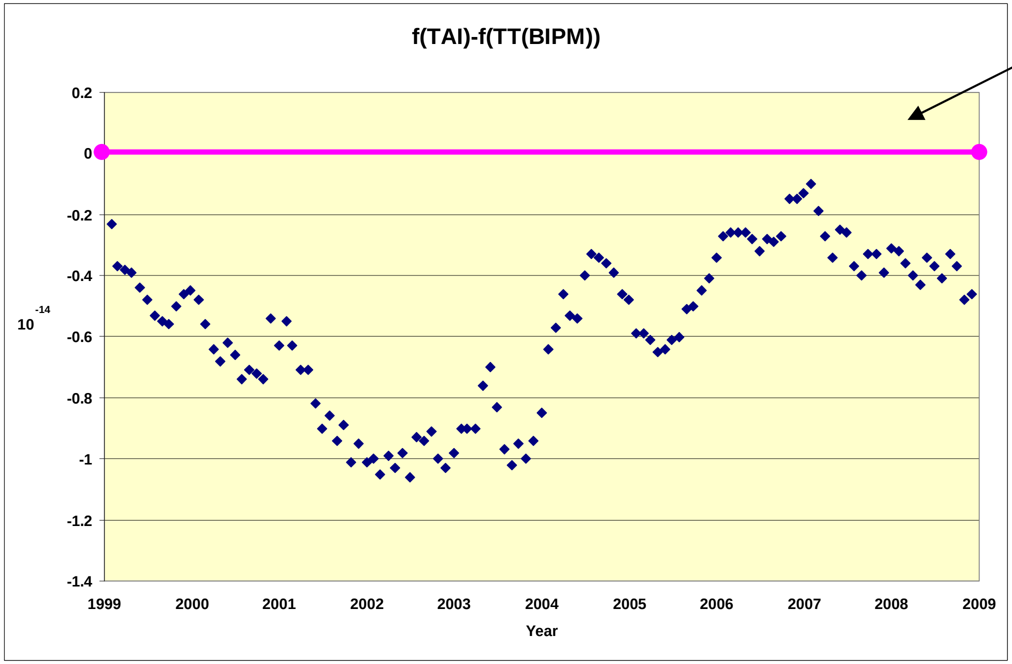


# Cs Fountains respect to TT(BIPM)



# f(TAI) - f(TT(BIPM))

The goal!




TAI is close to its definition (< $5 \times 10^{-15}$ over last 2 years), but still off

# Conclusions about EAL and TT

By the comparison between f(TT) and f(EAL) we can observe that:

-EAL is affected by a frequency drift of about $4 \times 10^{-16}$/month

The accuracy of TT(BIPM) improved in 2007 and 2008.

This is due to the ever increasing number of PFS evaluations and to the improved accuracy of each fountain evaluation.

# Conclusion about TAI and UTC

TAI and UTC have the same metrological qualities.

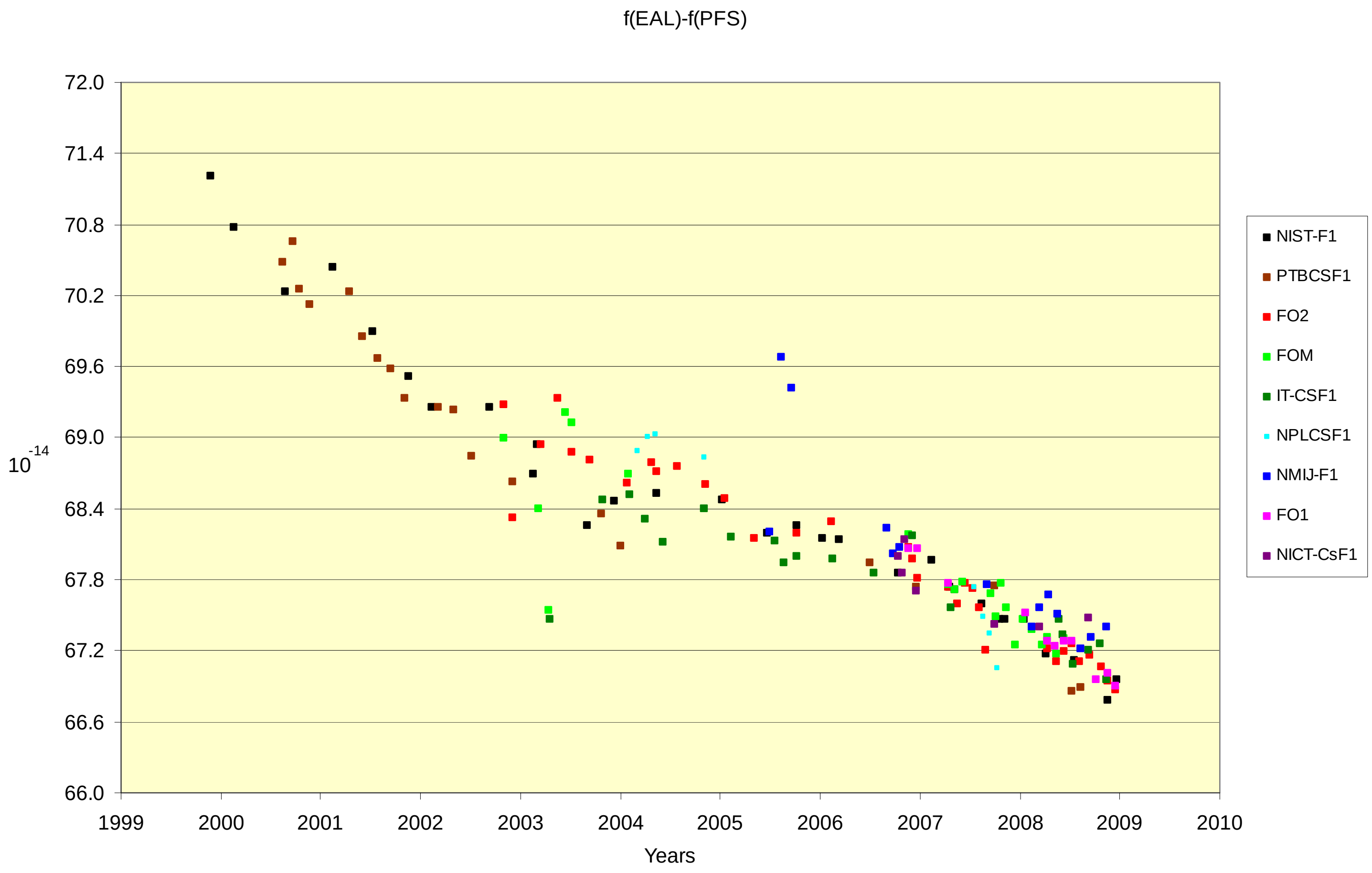
The long-term instability of TAI is between $1 \times 10^{-15}$ and $2 \times 10^{-15}$, a factor two or three worse than the value for TT(BIPM).

The TAI accuracy is limited from EAL frequency drift.

Now TAI has a frequency accuracy at the level of one part in $10^{15}$.


Thank You!

# f(EAL) respect to PFS




By using the PFS we evaluate the systematic variation of EAL

# Stability of TAI respect to TT(BIPM)