Impact of multi-GNSS on international timekeeping

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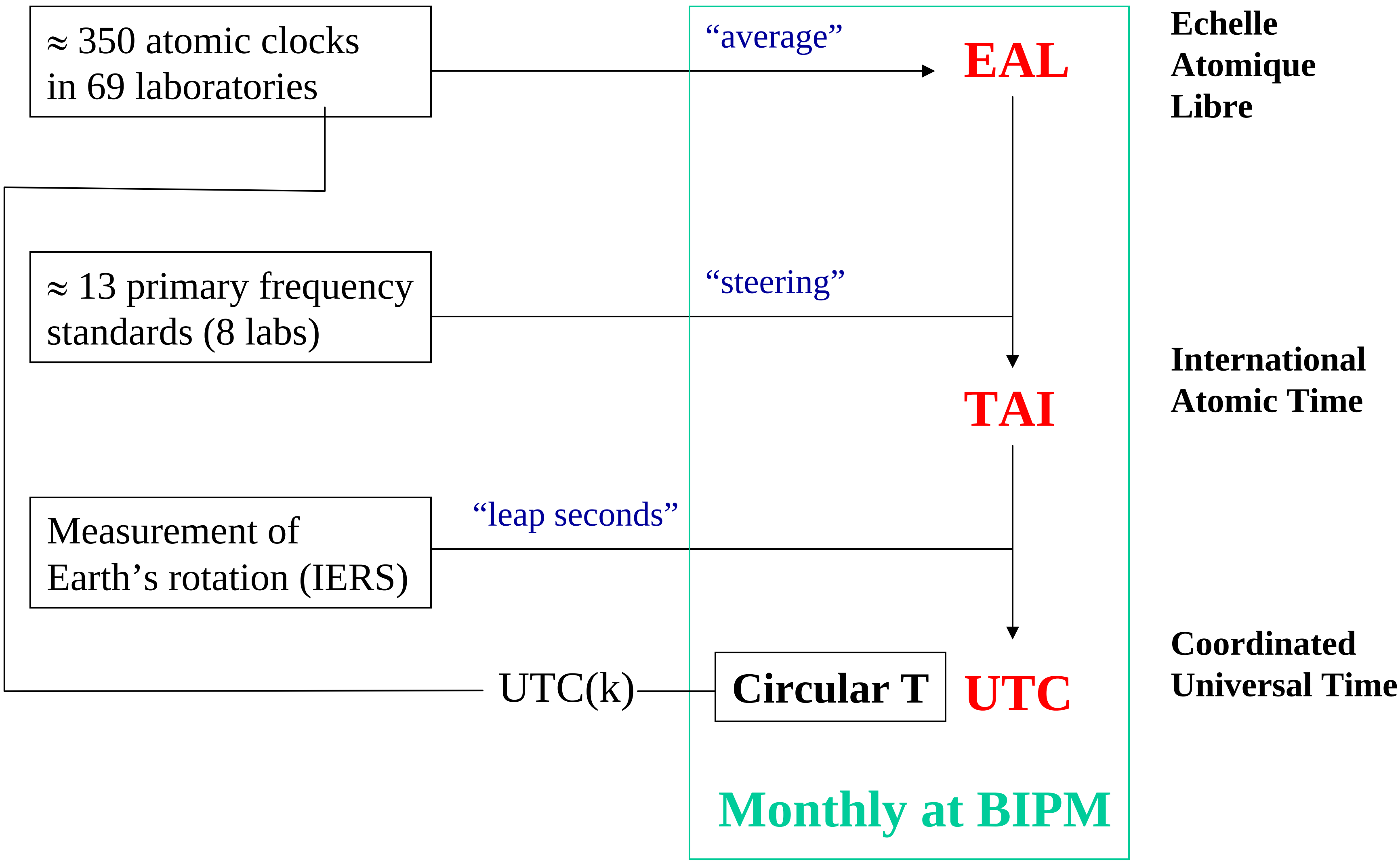
Outline

- Time scale contruction, case of UTC
  - Role of GNSS for time transfer
- Use of GNSS today
  - GPS and GLONASS
  - Quality of time transfer
- Future use of GNSS for time transfer
  - Is the present situation adapted to multi-system time transfer?
  - Cases and solutions

Construction of UTC - Algorithm ALGOS



Statistical generation of a time scale

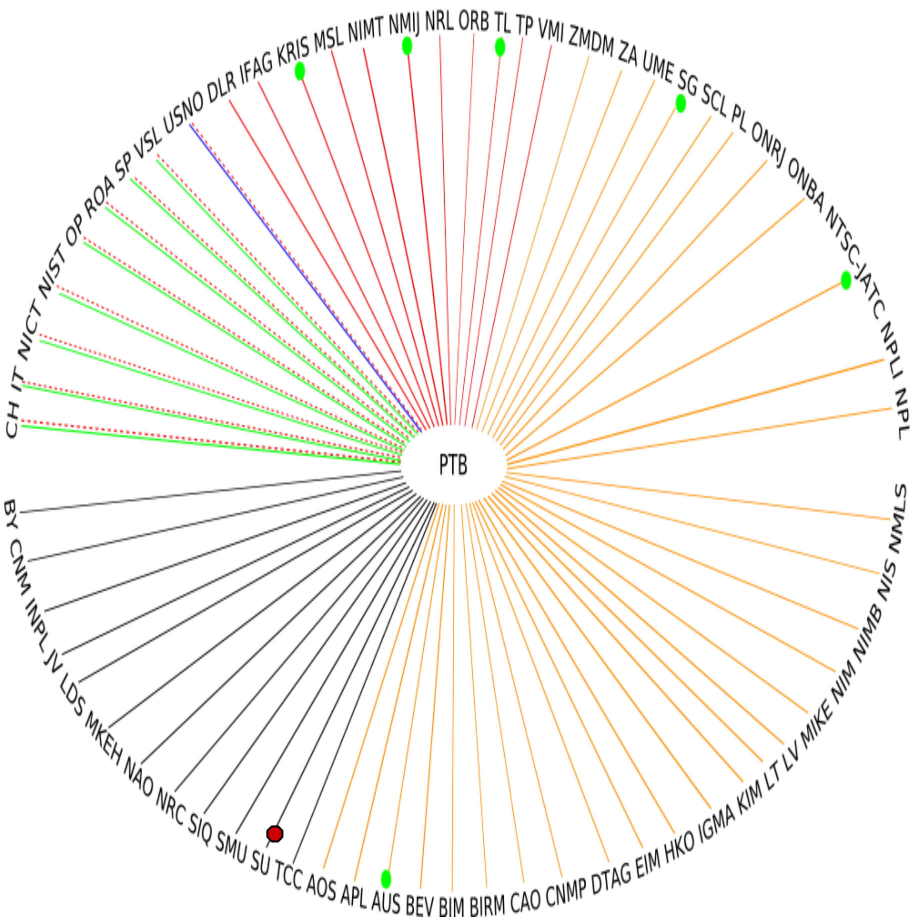
- Algorithm for raising the stability, accuracy and reliability above the level of performance that can be realized by any individual clock in the ensemble.

- Basic data in time scale algorithm:
  - Clock differences

- ALGOS strongly depends on the quality of the time transfer
  - Time transfer is a constraint to the long-term frequency stability of the UTC scale (4 x 10^{-16} at one month)

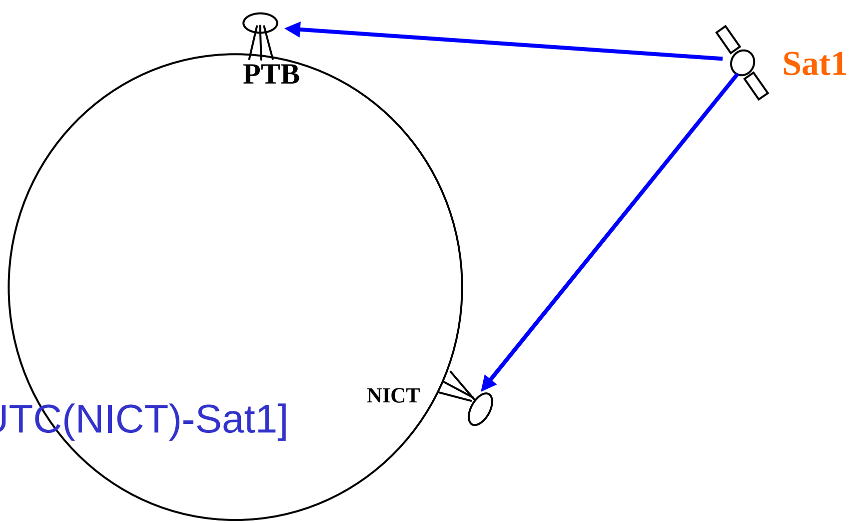
Time transfer for UTC

Present UTC network of 69 contributing laboratories



- All 69 labs are equipped for GPS reception
- 58 official comparisons (85%) are by GPS
- 1official comparison is by GLONASS
- UTC clock comparison by GPS started ~20 years ago
- UTC clock comparison by GLONASS (•) started in Nov 2009
- 19 labs are equipped for GLONASS reception

Measure with each clock a common external signal: GNSS



Each station measures

- (Local clock – Satellite clock)

Then two solutions

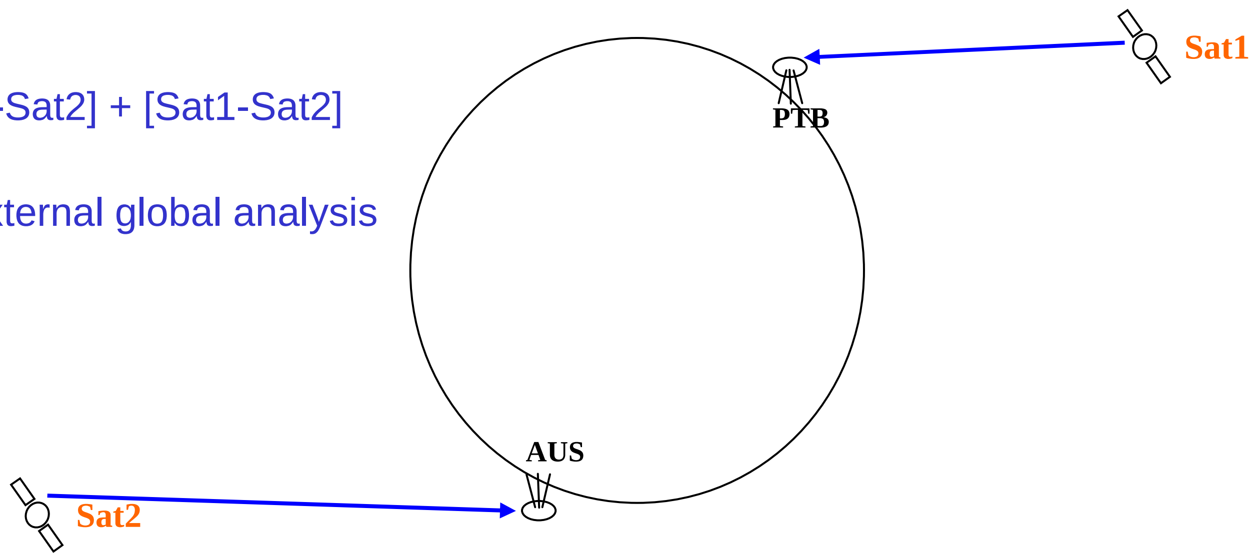
- Common-view

UTC(PTB)-UTC(NICT) = [UTC(PTB)-Sat1] - [UTC(NICT)-Sat1]

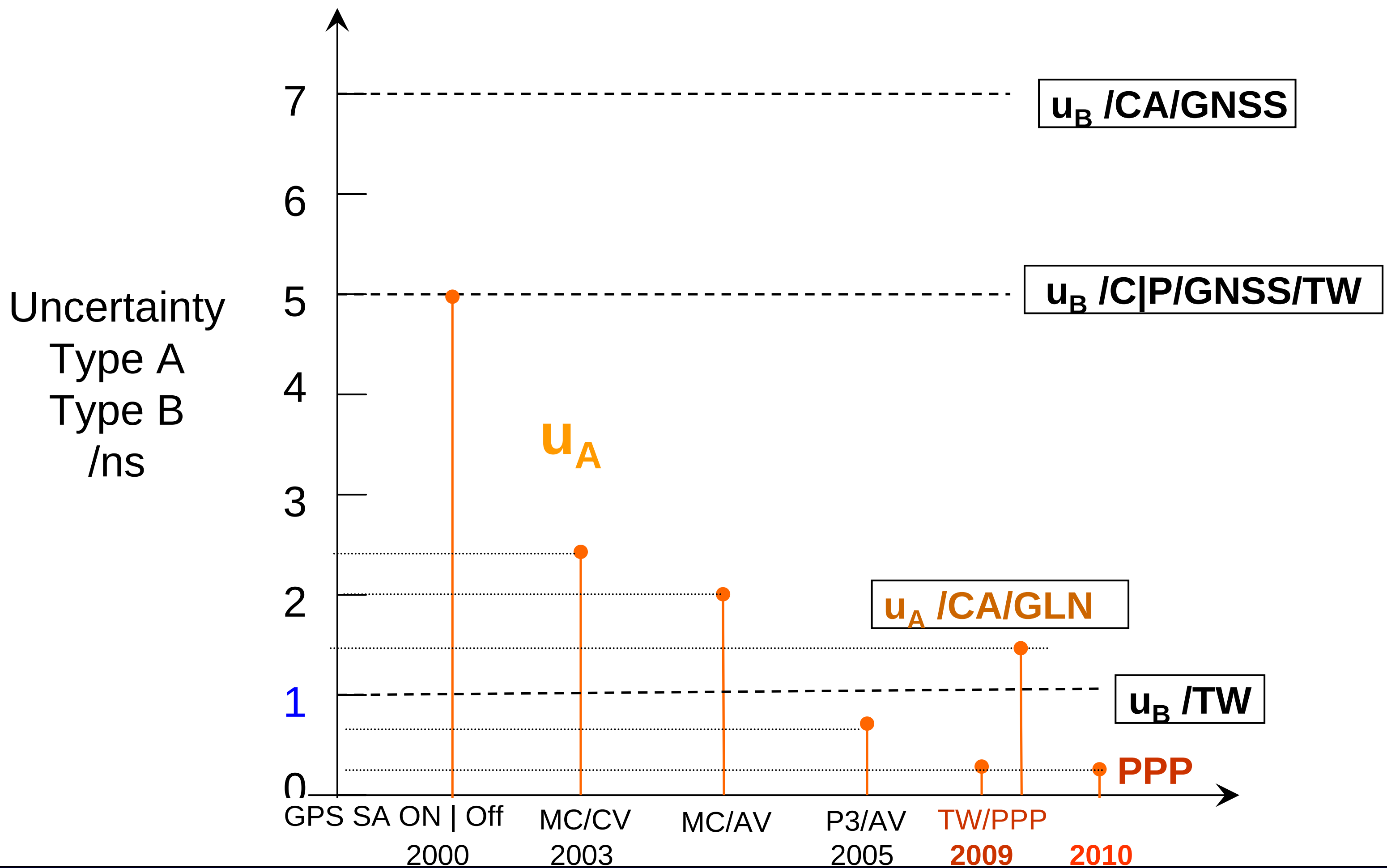
- All-in-view

UTC(PTB)-UTC(AUS) =
[UTC(PTB)-Sat1] - [UTC(AUS)-Sat2] + [Sat1-Sat2]

with [Sat1-Sat2] provided by external global analysis



Time transfer for UTC
Uncertainty of the time links



- Observable is the difference
  [UTC(k) – GNSS time]

- Corrections
  - Atmospheric delays (iono, tropo)
  - Satellite motion (orbits)
  - Satellite clocks

- System time scale or other
  - GNSS time, IGS time

- Terrestrial reference frame
  - ITRF

Necessary for all-in-view

GNSS time transfer

What techniques do we use now?

("We" means the T/F community participating to the computation of UTC at the BIPM)

GNSS, mostly GPS

- Code measurements

  C/A (1.575 GHz, 1 Mchip/s)

  P1/2 (1.575/1.227 GHz, 10Mchip/s)

Achievable uncertainty: < ~ 1/few ns

Limited by

Multi-path reflections

Transmission delay in troposphere

- Phase + code measurements

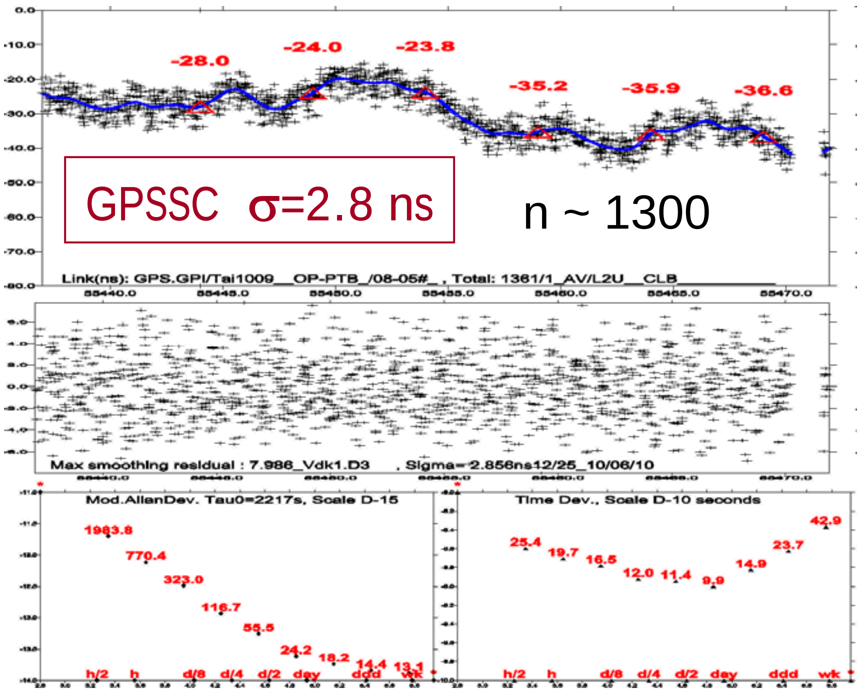
  L1/2, P1/2 (1.575/1.227 GHz)

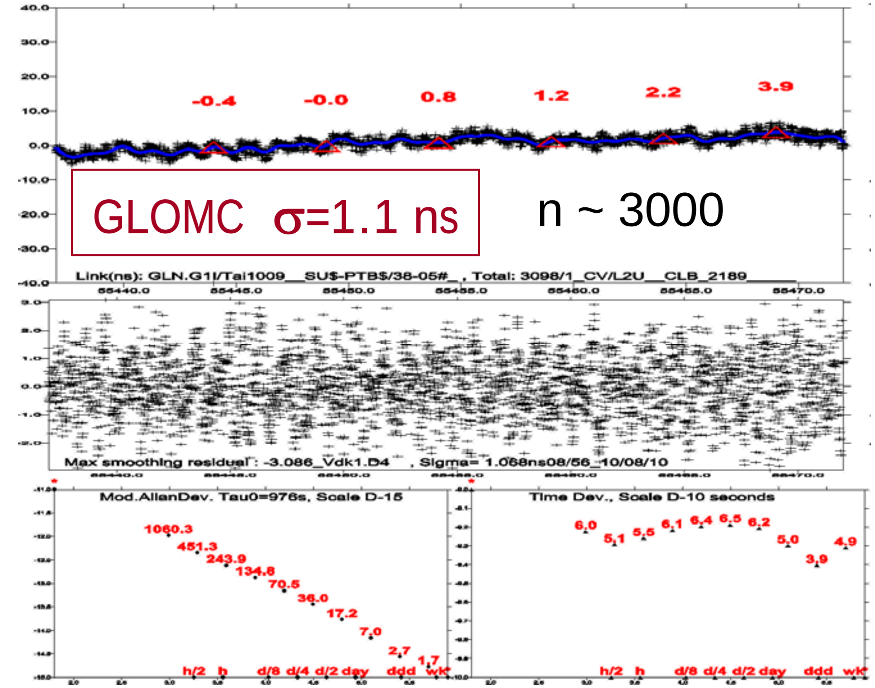
Achievable uncertainty: (few) 0.1 ns

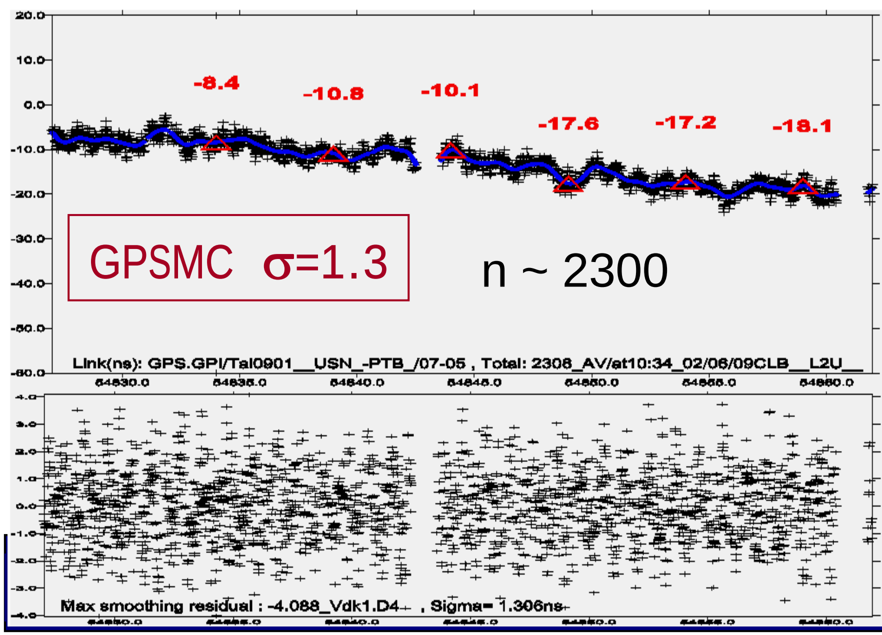
Limited by

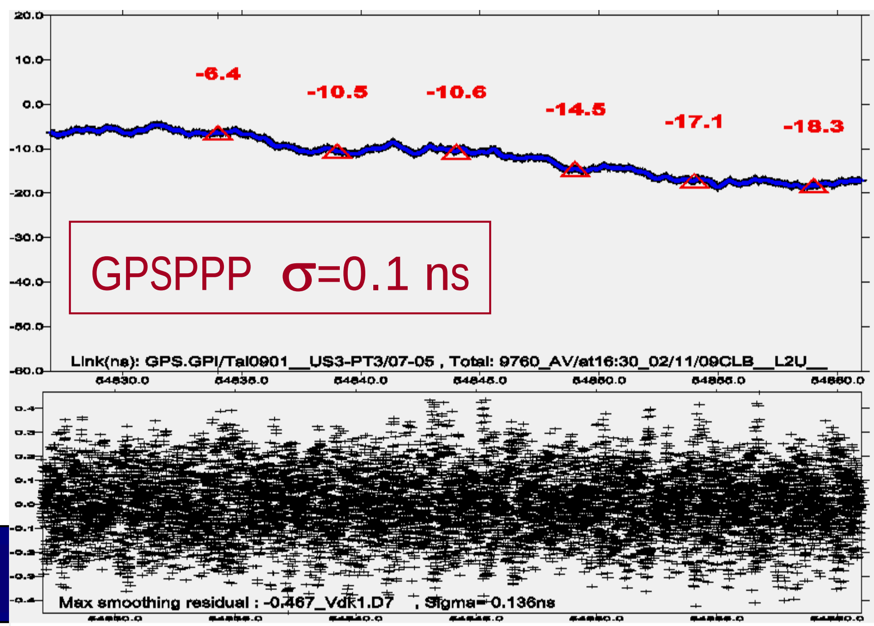
Phase ambiguity resolution

Various effects @ < 0.1 ns level


-28.0
-24.0
-23.8
-35.2
-35.9
-36.6
GPSSC σ=2.8 ns
n ~ 1300
Link(ns): GPS.GPI/Tai1009__OP-PTB_/08-05#_ , Total: 1361/1_AV/L2U__CLB
Max smoothing residual : 7.986_Vdk1.D3 , Sigma= 2.856ns12/25_10/06/10
Mod.AllanDev. Tau0=2217s, Scale D-15
Time Dev., Scale D-10 seconds


-0.4
-0.0
0.8
1.2
2.2
3.9
GLOMC σ=1.1 ns
n ~ 3000
Link(ns): GLN.G1I/Tai1009__SU$-PTB$/38-05#_ , Total: 3098/1_CV/L2U__CLB_2189
Max smoothing residual : -3.086_Vdk1.D4 , Sigma= 1.068ns08/56_10/08/10
Mod.AllanDev. Tau0=976s, Scale D-15
Time Dev., Scale D-10 seconds


-8.4
-10.8
-10.1
-17.6
-17.2
-18.1
GPSMC σ=1.3
n ~ 2300
Link(ns): GPS.GPI/Tai0901__USN_-PTB_/07-05 , Total: 2308_AV/at10:34_02/06/09CLB__L2U__
Max smoothing residual : -4.088_Vdk1.D4 , Sigma= 1.306ns


-6.4
-10.5
-10.6
-14.5
-17.1
-18.3
GPSPPP σ=0.1 ns
Link(ns): GPS.GPI/Tai0901__US3-PT3/07-05 , Total: 9760_AV/at16:30_02/11/09CLB__L2U__
Max smoothing residual : -0.467_Vdk1.D7 , Sigma= 0.136ns

What would multi-GNSS time transfer could bring?

GPS+GLONASS+Galileo+COMPASS

- Phase + code measurements
- New frequencies, new codes
- More satellites
- Error source mitigation
- Redundancy
- Reliability
- Choice of best solution

Which solution?

- GNSS all-in-view satellites, if
  - IGS provides clock corrections for all GNSS

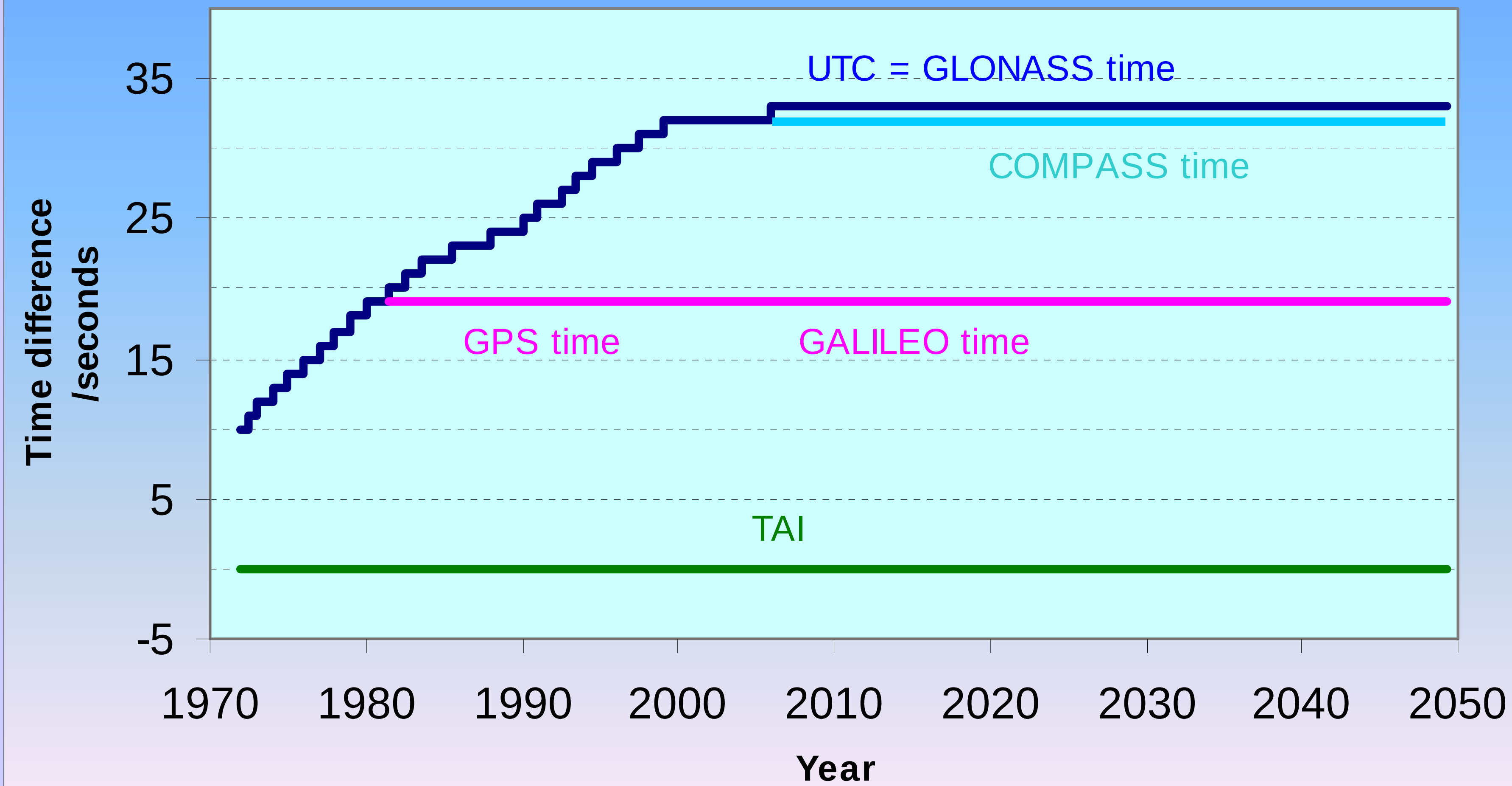
- Multi-system time transfer network with
- Single-system individual links
  - Choice of the best GNSS-solution for each link

- Multi-system time transfer network
- Multi-system individual links
  - Combination (weighted) of all GNSS-solutions for each link

Under which conditions the multi-GNSS time transfer would be possible

- Consistent geodetic references
  - Today, GLONASS PZ-90 terrestrial frame is transformed into ITRF,
- If a multi-system individual solution is chosen
  - The IGS should provide clock corrections for all GNSS satellite clocks,
- Multi-system GNSS receivers should be available on the market at affordable cost for operations in national time laboratories
- And a final comment on GNSS times, their steering to the (non-continuous) reference UTC, and the possible future situation in case of the adoption of a new definition of UTC, without leap seconds.

[*TAI - Time scale* (*i*)]



Thanks for your attention