TC Time and Frequency:

Highlights, Challenges and Visions

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EURAMET 6th General Assembly

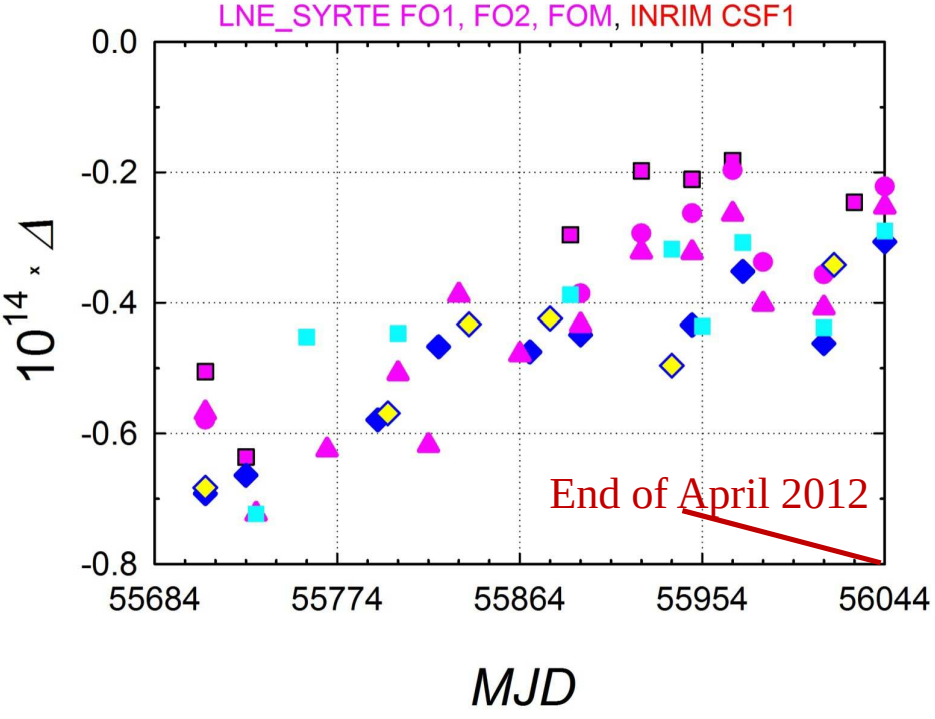
HIGHLIGHT(1)

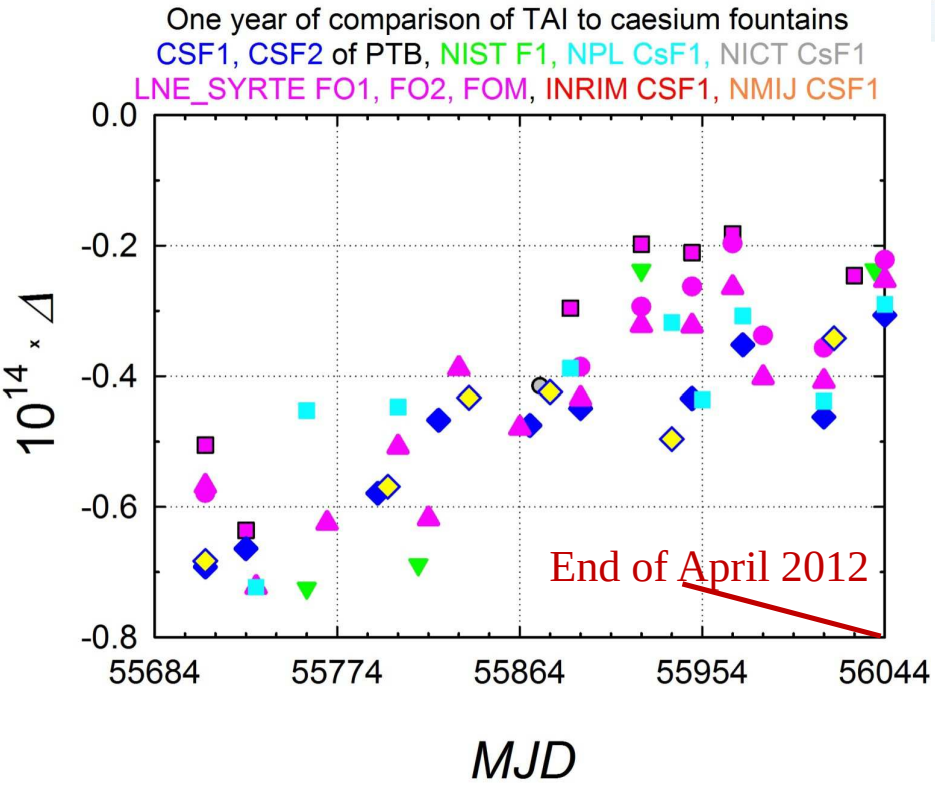
The European measurement infrastructure in the T+F domain is internationally competitive and recognized, and it is based on high-quality research.

30 institutes residing in 24 EURAMET member states collaborate with BIPM to realize Coordinated Universal Time.

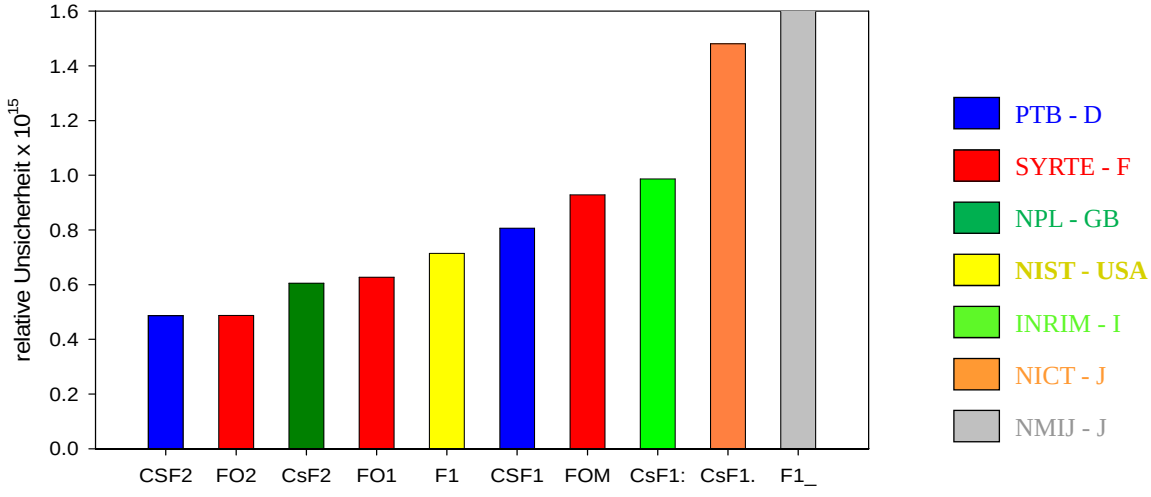
They provided data from more than 100 commercial atomic clocks and 9 primary clocks during the last 12 months.

One year of comparison of TAI to caesium fountains
CSF1, CSF2 of PTB, NPL CsF1,
LNE_SYRTE FO1, FO2, FOM, INRIM CSF1



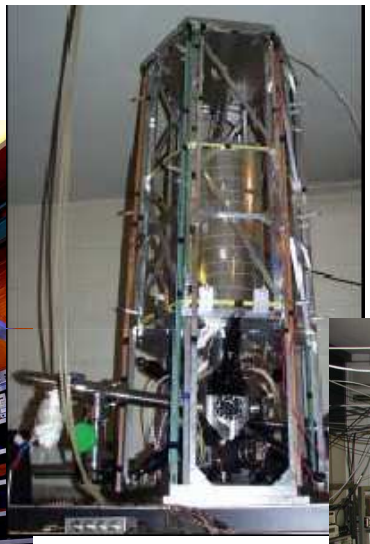


Comparison of fountain realizations of the Second vs. TAI
Relative measurement uncertainty (systematic + link)



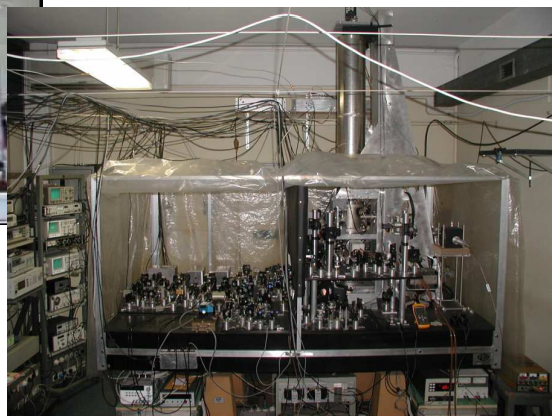
Provided by Stefan Weyers, PTB

PTB



LNE-SYRTE
FO-2

INRIM



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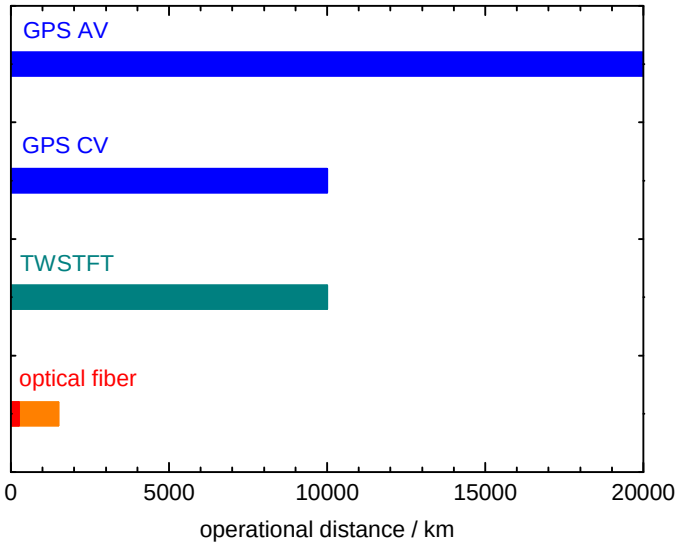
The improvement in clock performance (stability and accuracy) has been overwhelming during recent years.

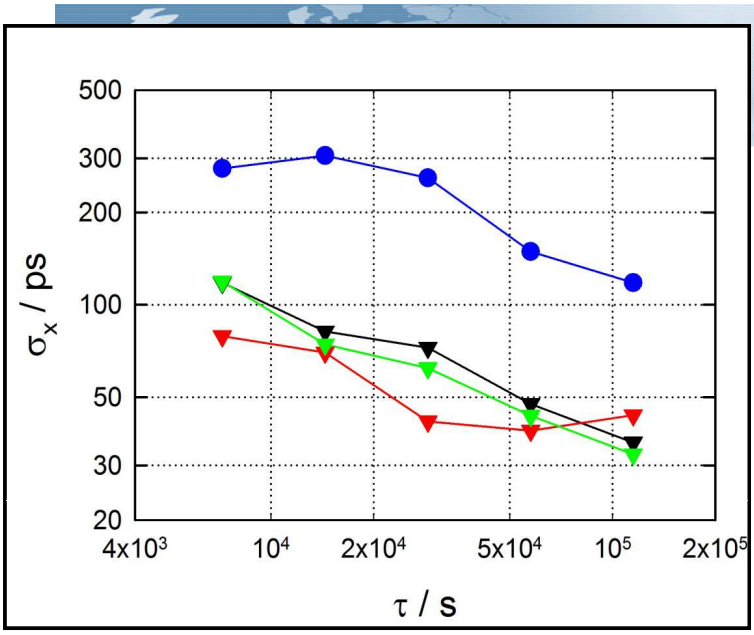
But it can only be exploited if the means for comparisons are improved at the same pace.

Satellite based comparison techniques are barely capable of providing the required measurement uncertainty.

Useable baseline lengths of time and frequency transfer links

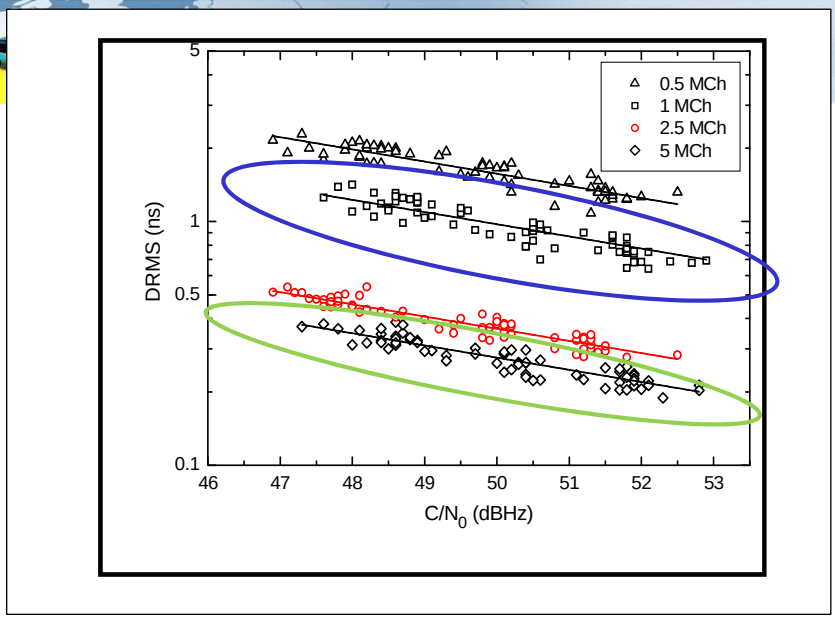


CHALLENGE (1)



Time instability $\sigma_x(\tau)$ of TWSTFT OP and PTB, (12/2011) analysis by OP;
blue: standard operation of the network of 10 stations simultaneously

other plots: operation when only the two stations OP and PTB were transmitting,



Measurement noise in TWSTFT as a function of occupied bandwidth

Red: in use until 2011, Blue: economically affordable in 2012

Green: technically feasible without change of equipment

•Work on the fiber transfer in an advanced state
in France, Germany, Sweden, UK, Italy, CZ, Austria

• JRP-11 “SI Broader Scope” from this field

• One EURAMET project regarding time transfer through optical fibers

• Two EURAMET projects regarding GNSS-based time transfer

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From routine TC work

to HIGHLIGHT (2)

CCTF-2009 Recommendation regarding GNSS receiver calibration

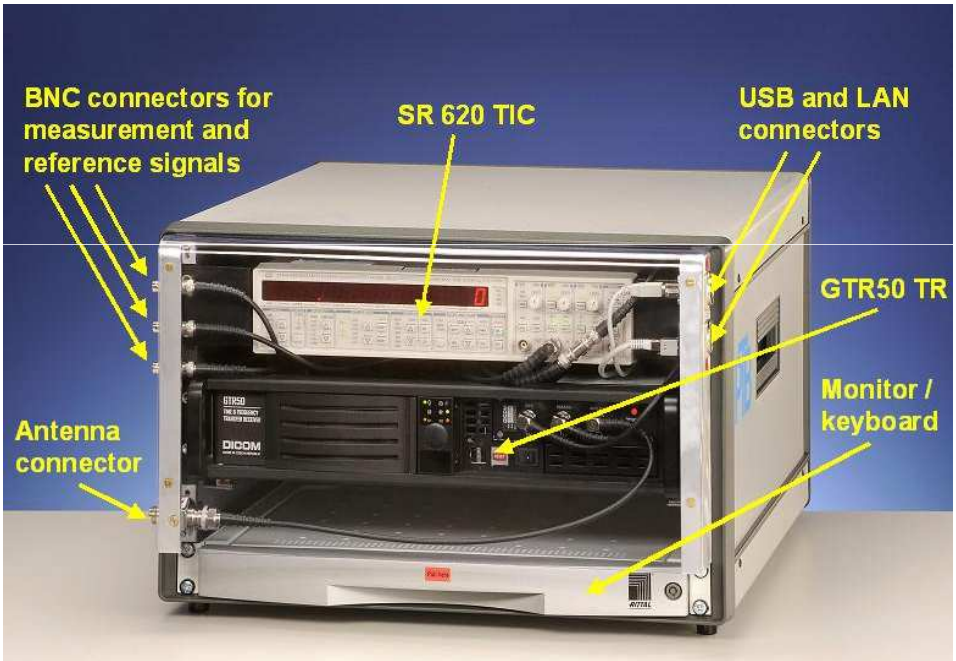
- encourages BIPM to continue GNSS receiver characterization for a subset of the laboratories
  - Imposes supplementary work to be done by RMOs
  - Issues:
    - Which institutes see an urgent need? 2012: MIKES, VSL, SIQ
    - Which receiver type is best suitable as travelling receiver?
    - How do we document the results and make use of them?

Link calibrations made during 2011

ROA – INRiM – PTB

PTB – NPL

PTB – USNO



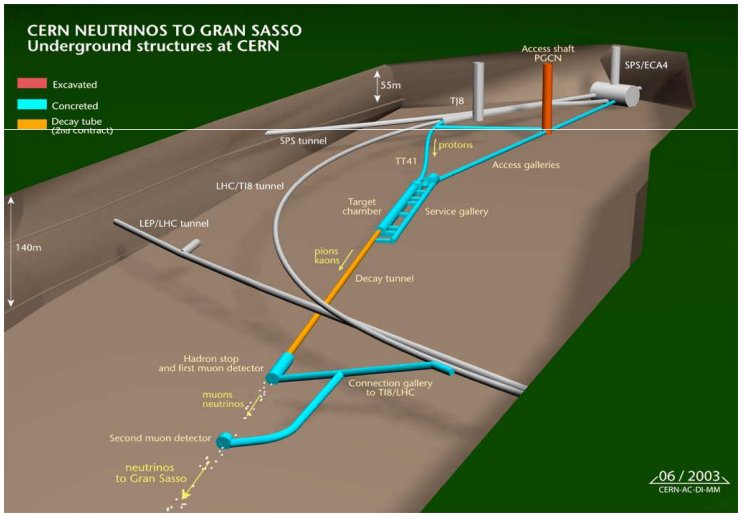
CERN, autumn 2011

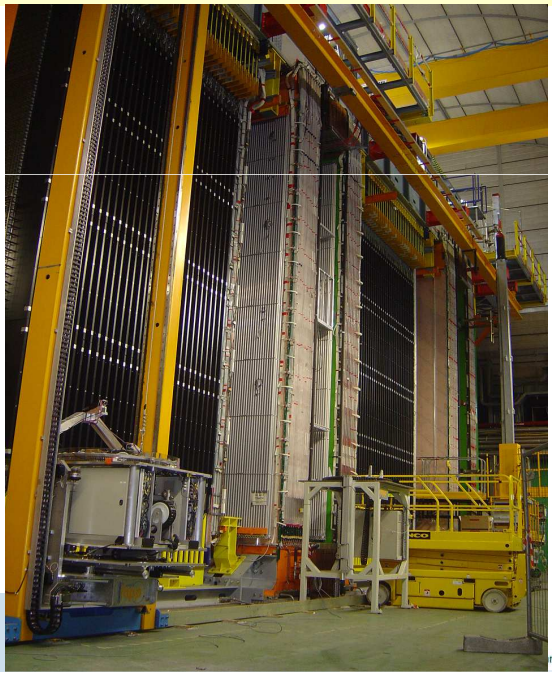
Calibration set-up in special mission

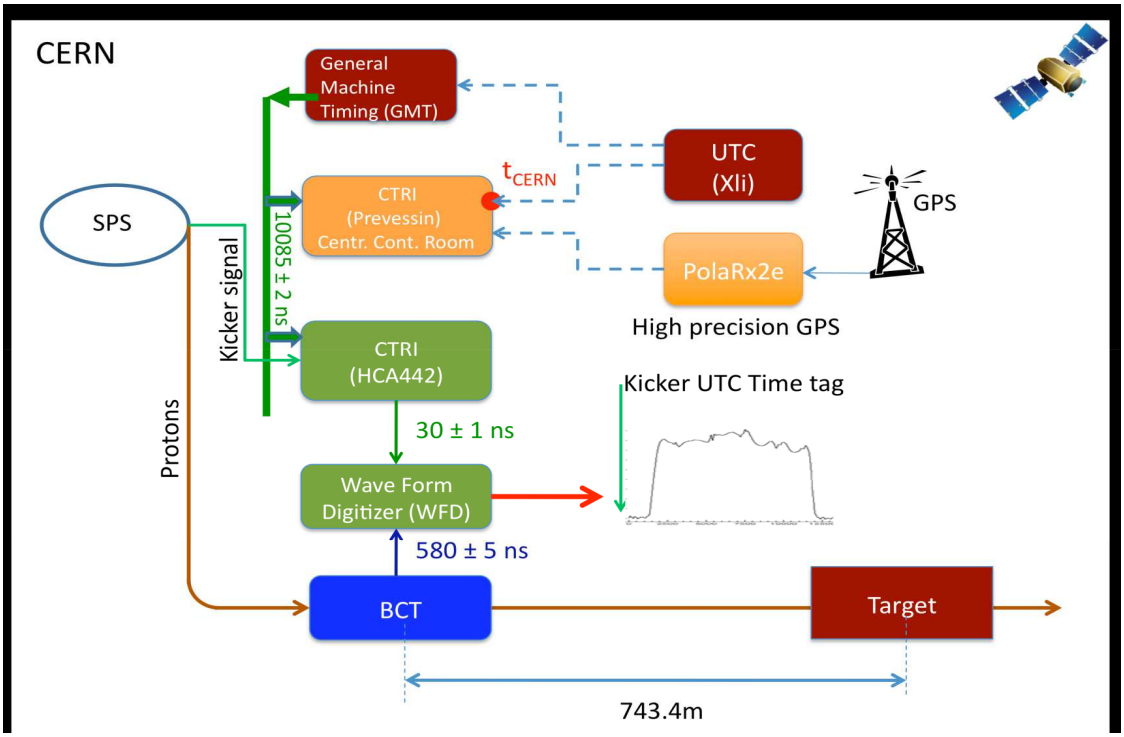
Source: Javier Serrano, CERN, Dario Autiero, LNGS

CERN Neutrino production

OPERA detector, Laboratorio Nazionale Gran Sasso







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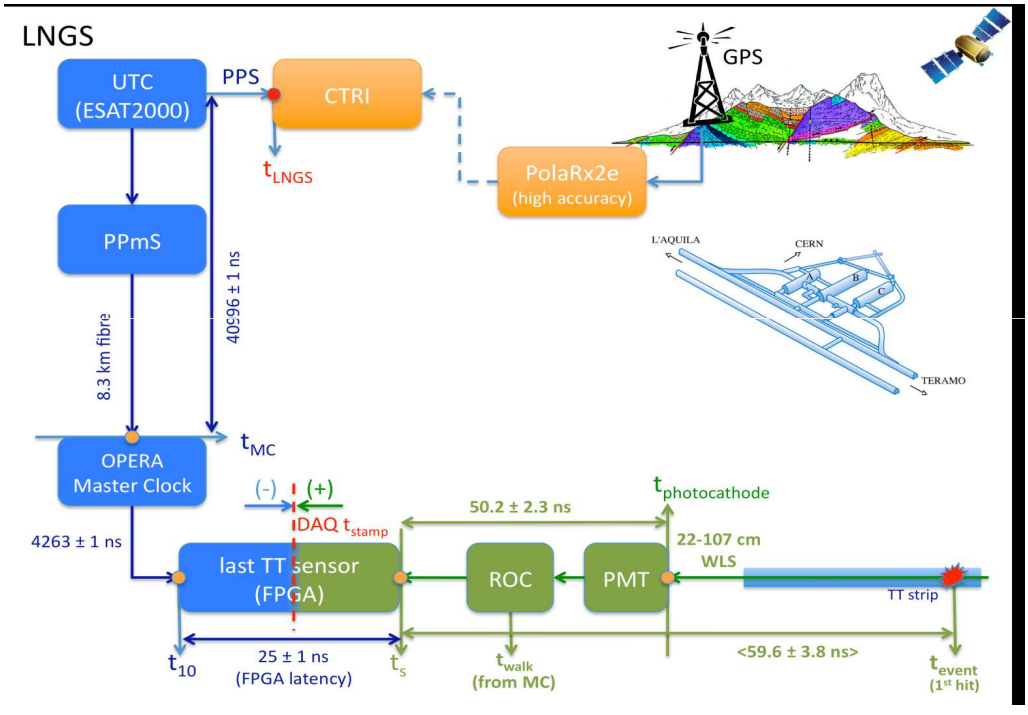
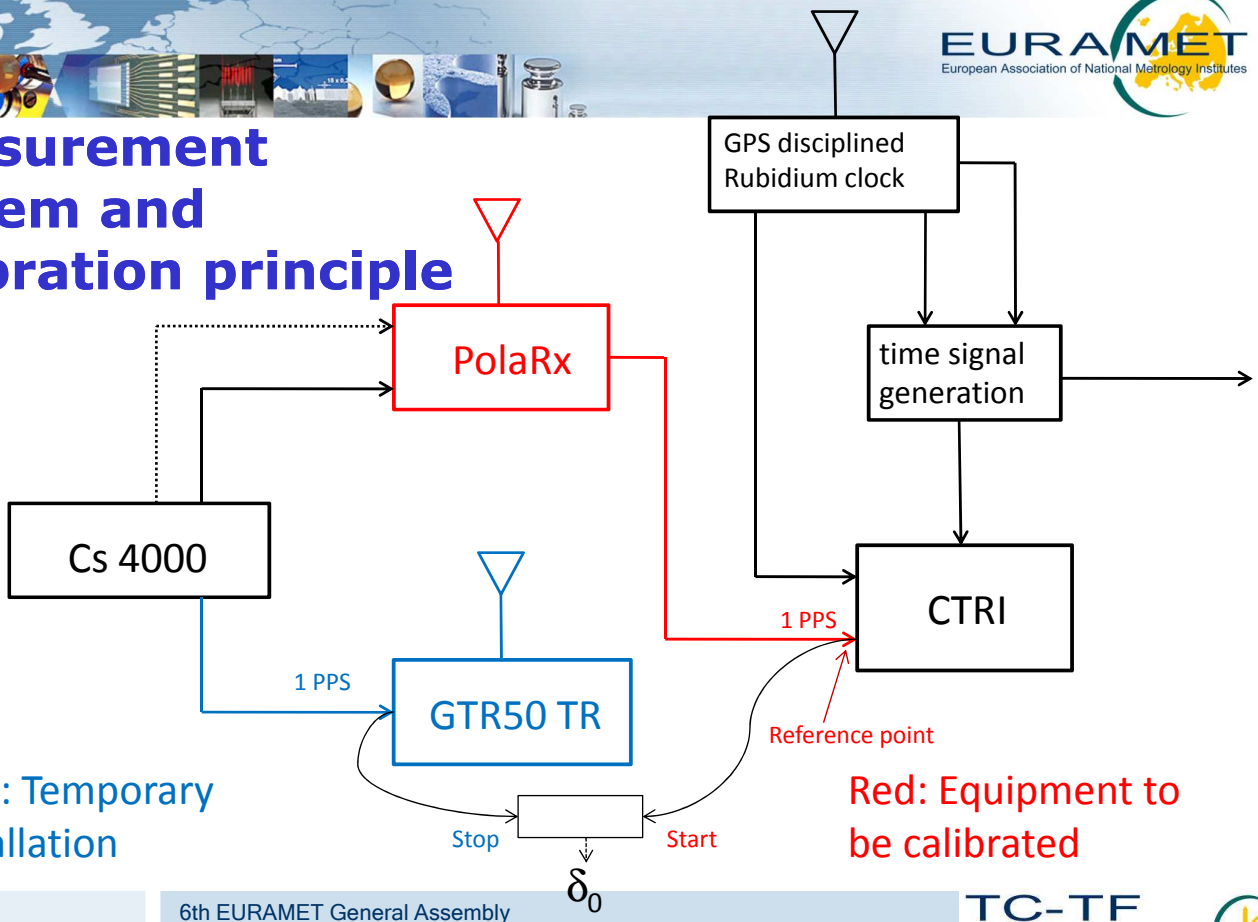


Measurement system and calibration principle



Blue: Temporary installation

Red: Equipment to be calibrated

Relative time link calibration:

Measurements at each site:

$$\langle \mathrm{PolaRx(LNGS)} - \mathrm{TR@LNGS} \rangle = C_1$$

$$\langle \mathrm{PolaRx(CERN)} - \mathrm{TR@CERN} \rangle = C_2$$

Calibration value:

$$C_{GPS} = C_{LNGS} - C_{CERN}$$

$$\mathrm{PolaRx(CERN)} - \mathrm{PolaRx(LNGS)} + C_{GPS} = \mathrm{RP(CERN)} - \mathrm{RP(LNGS)}$$

Results

$$C_{GPS,P3} = -2.31 \text{ ns} \pm 0.90 \text{ ns}$$

A simple calibration could rule out an error in the comparison of the time references in CERN and LNGS.

In the meantime, two causes for errors in determining the delay between OPERA Master Clock and the event trigger point were detected (Javier Serrano, May 2012).

Likely the books of physics need not be re-written.

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VISIONS

Preparation for the next phase – „EMPIR“

- proposal for EMRP successor programme expected by EURAMET members, RC, Commission, Parliament, partners; option mentioned in Horizon 2020
- agreement to metrology research programme similar to EMRP structured along
  - exploiting and serving Basic Science related to metrology
  - advanced Metrology meeting the Grand Challenges Energy, Environment and Health
  - Innovation: Industrial implementation of advanced metrology for increased competitiveness
- including capacity building
- agreement to go for Art185, roughly same size as EMRP, implementation by EURAMET making use of established structures and processes
- awareness of the need to open funded participation to non-NMIs/DIs

BoD
Tres Cantos, 7 February 2012[2]

TC-TF
Time and Frequency
EURAMET Technical Committee

TC-TF inherited three Roadmaps from the iMera period:

A coordinator was nominated for the final roadmap editing,

•Ground Clocks – Joseph Achkar (F);

•Space Applications– Laurent-Guy Bernier (CH);

•Time and Frequency Transfer – Andreas Bauch (DE).

Great Challenges:

Atomic Frequency Standards (AFS)
and Time and Frequency Transfer (TFT)

play an instrumental role in applications like network synchronization and monitoring (e. g. the smart grid), and in environmental monitoring from ground and from space.

Research and development involves European industry and many university institutes, maybe more than the NMIs directly.

Innovation:

A strong need for advanced AFS, preferentially from European production, will exist in view of continuously operating and upgrading the European satellite navigation system Galileo
and the augmentation system EGNOS.

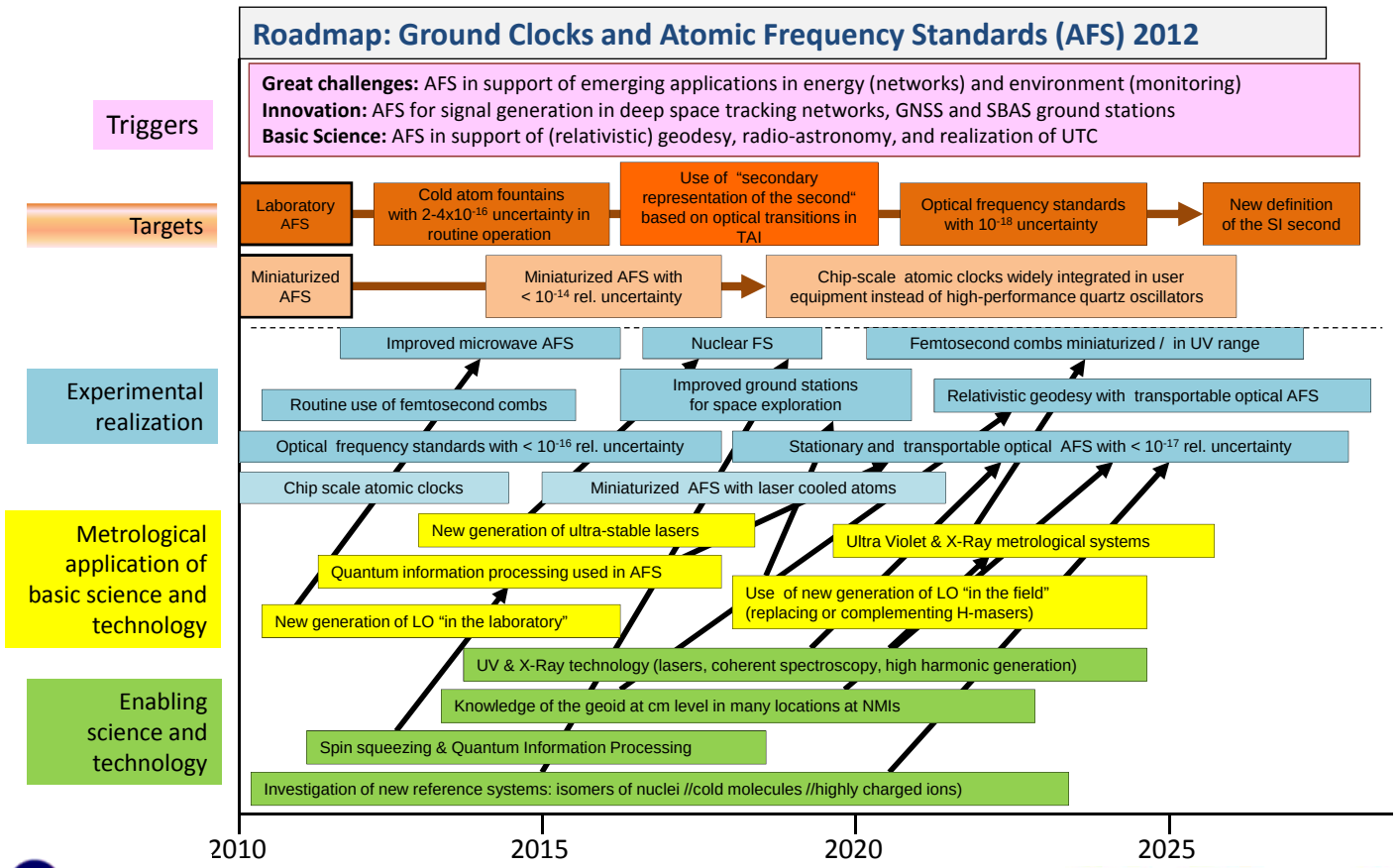
Earth exploration and location based services have aside of their scientific involvement (climate monitoring, geodesy) also found commercial interest, and this trend is going to continue.

Basic Science:

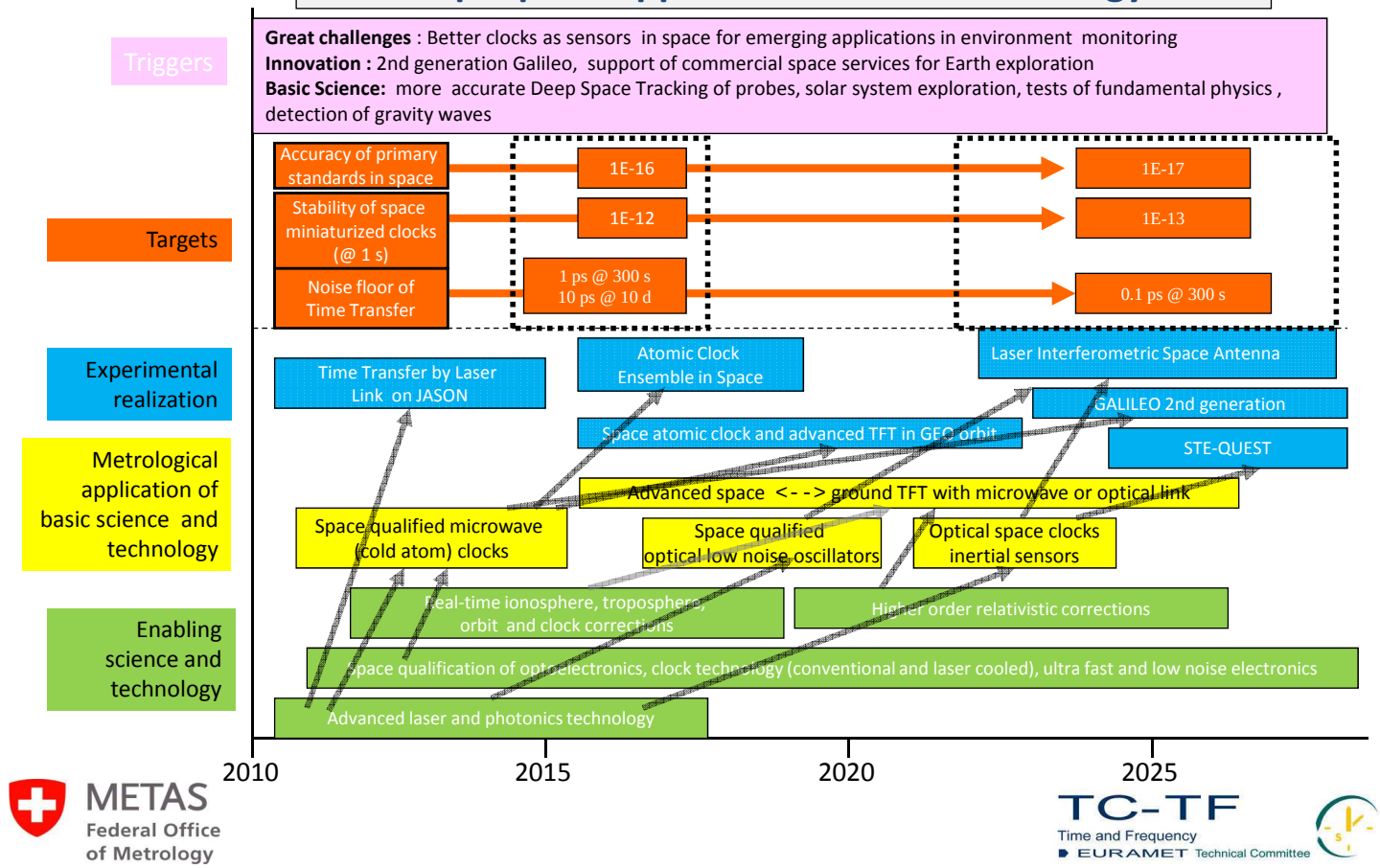
Time is one of the basic physical dimensions and also the physical quantity that can be measured to the highest precision.

It is therefore granted that clocks and frequency standards will also in the future play an important role in quantitative tests of the fundamental principles of physics.

Other fields of science that require continuous improvement in AFS and TFT are geodesy, radio-astronomy, space exploration, and gravity wave detection.



Roadmap: Space Applications of T&F Metrology 2012



METAS
Federal Office of Metrology

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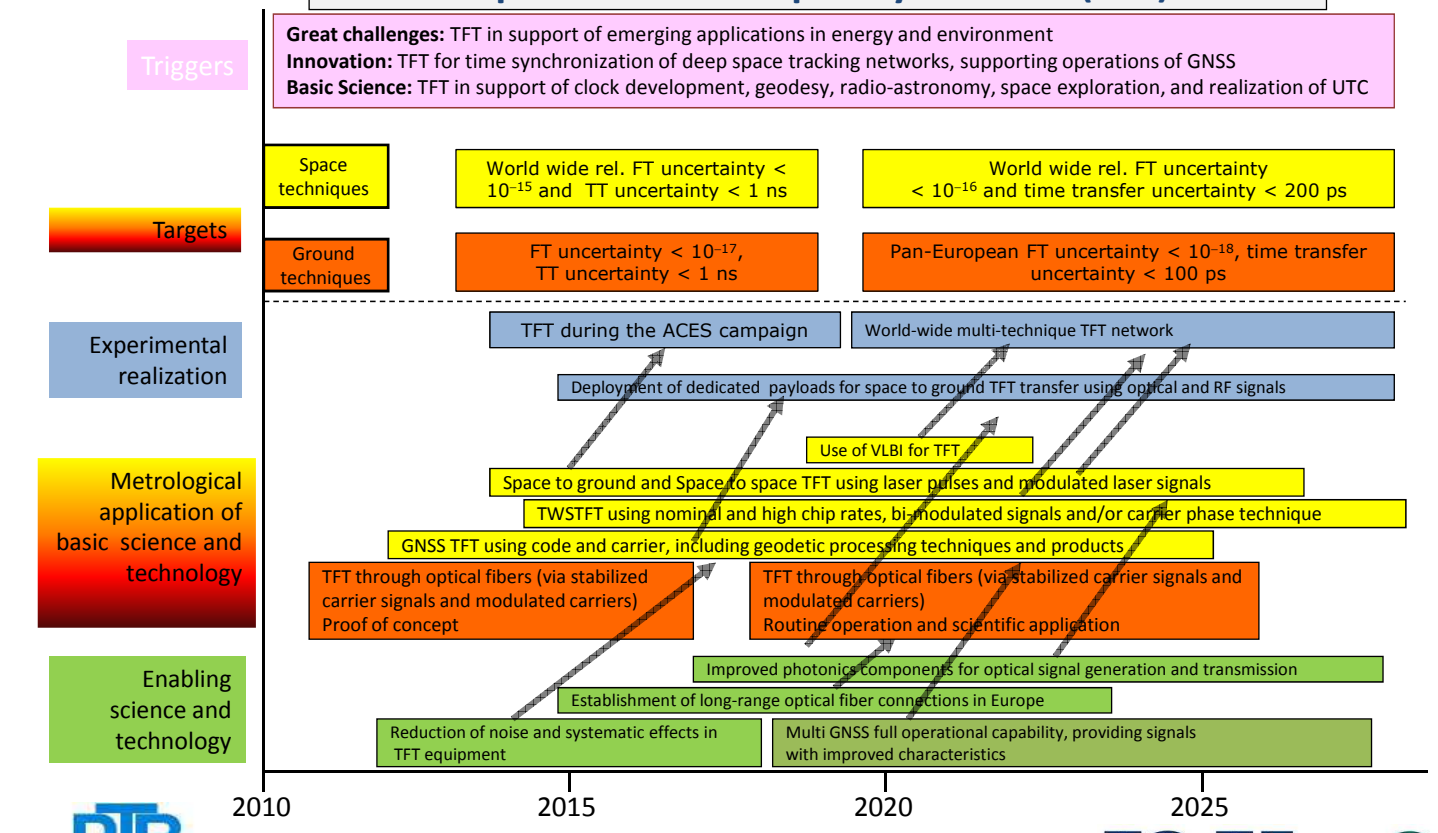
Roadmap: Time and Frequency Transfer (TFT) 2012



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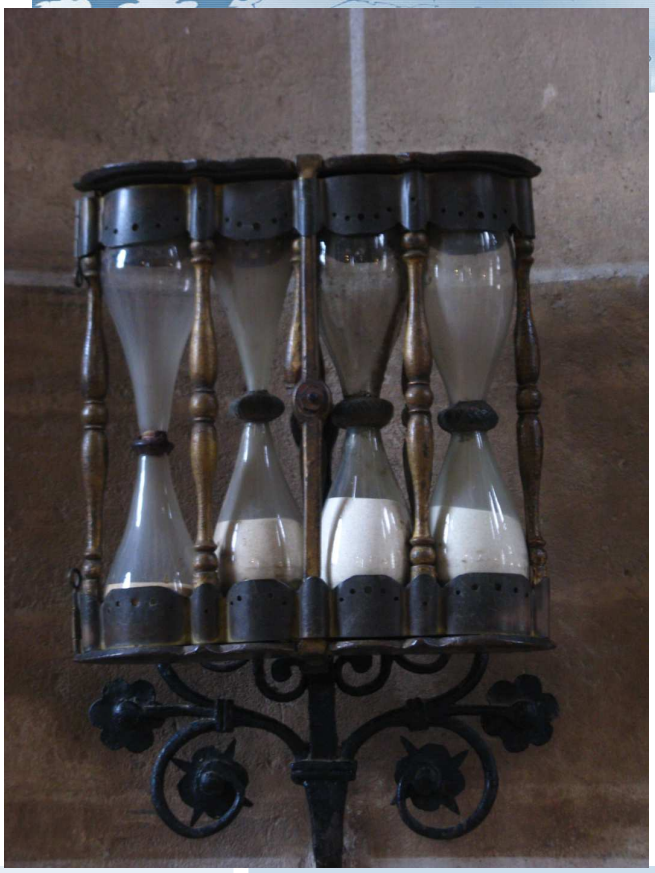

Thank you for your attention