GNSS and Time Metrology: Report from the CCTF Working Group on GNSS

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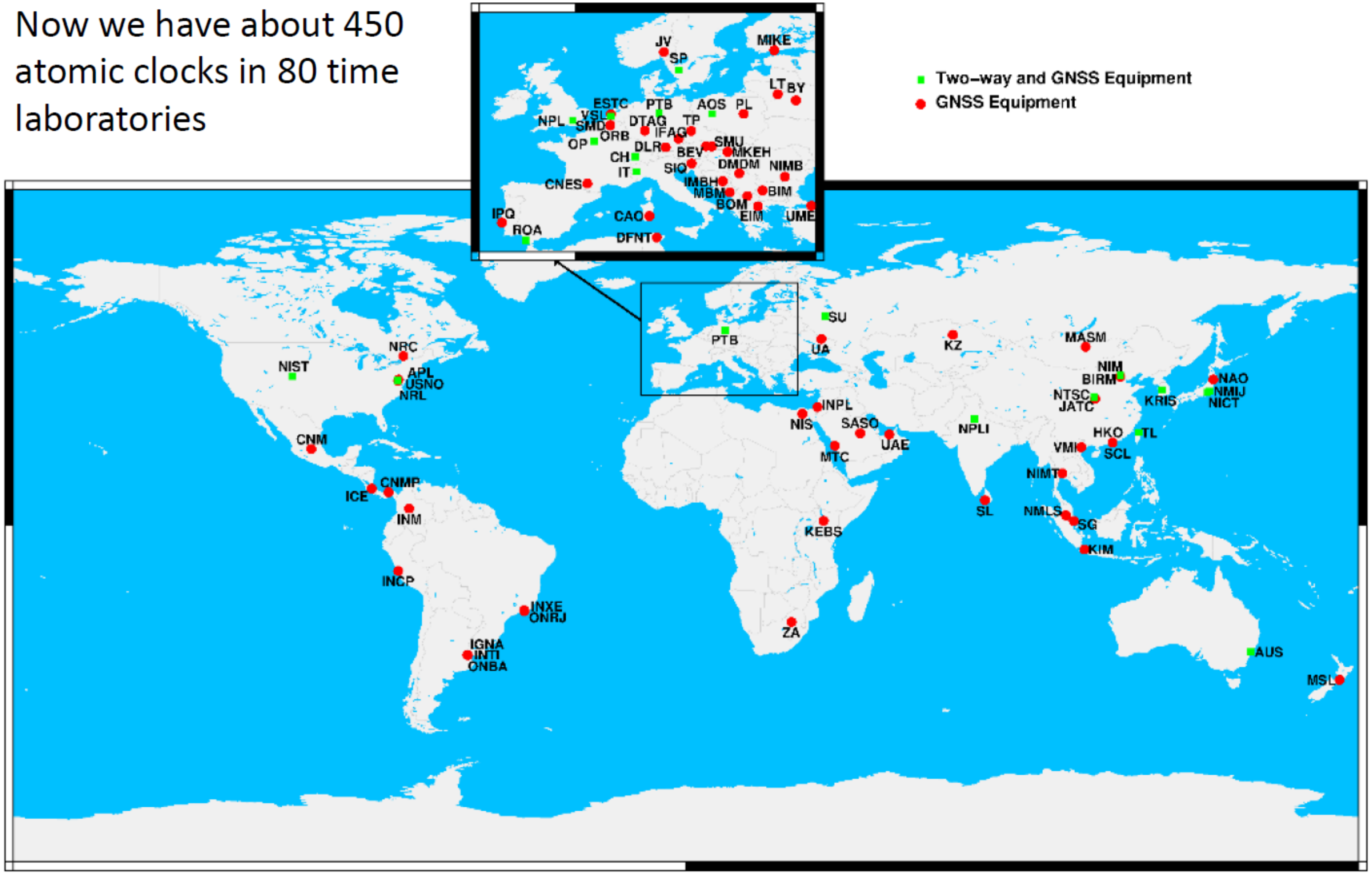
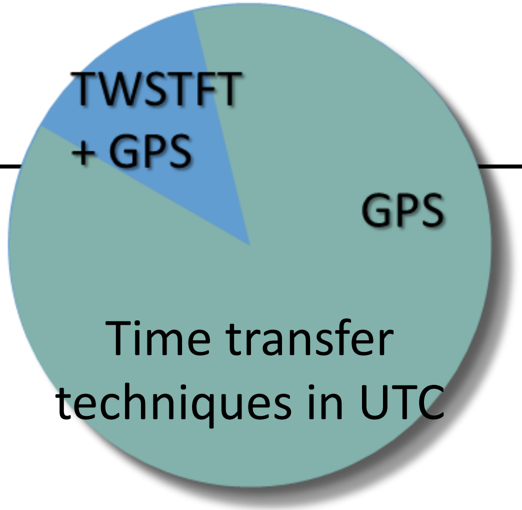
Current use of GNSS for UTC

Now we have about 450 atomic clocks in 80 time laboratories



Current use of GNSS for UTC



To date: all UTC(k) labs are connected via **GPS**,
and 87% of the links are entirely based on GPS

GLONASS was used for some links during more than ten years

The accurate receiver calibration for GLONASS signals is still an issue.

The GLONASS common view is used as back up for some links.

Galileo : data analysis shows a better performances than GPS in terms of code noise.

- Calibration available since June 2020
- Use in UTC – in test phase

BeiDou : transition from BDS-2 to BDS-3 (different signals and frequencies)

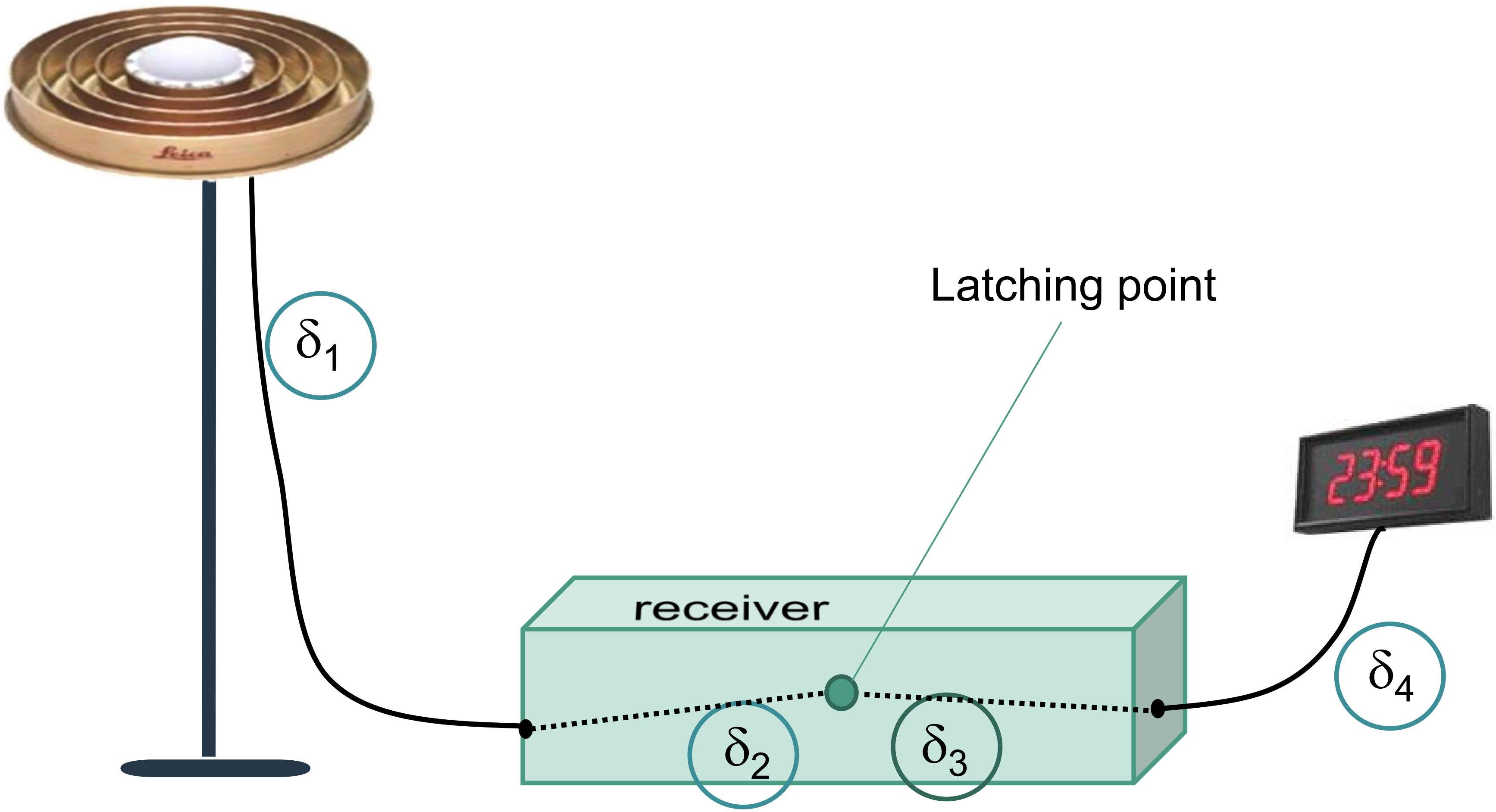
- only a few receivers get the BeiDou 3 signals
- Absolute calibration for BDS-3 just started

Topics

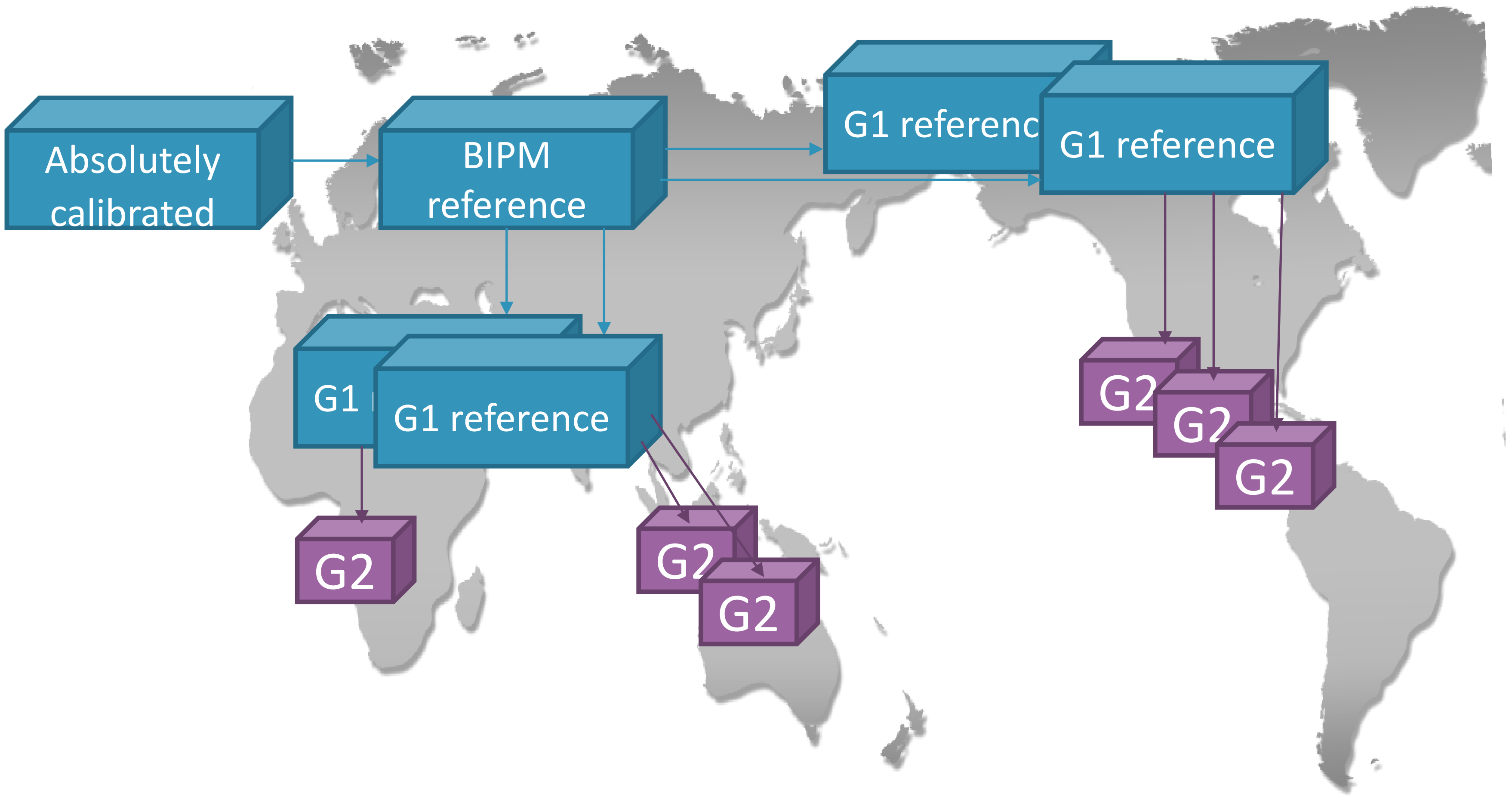
- Calibration of GNSS equipment
- Time transfer with new GNSS
- Update on Circular T, Section 4

  (UTC-Broadcast_UTC_{GNSS}), to include all GNSS, with uncertainties
- Task Group on traceability to UTC from GNSS Measurements

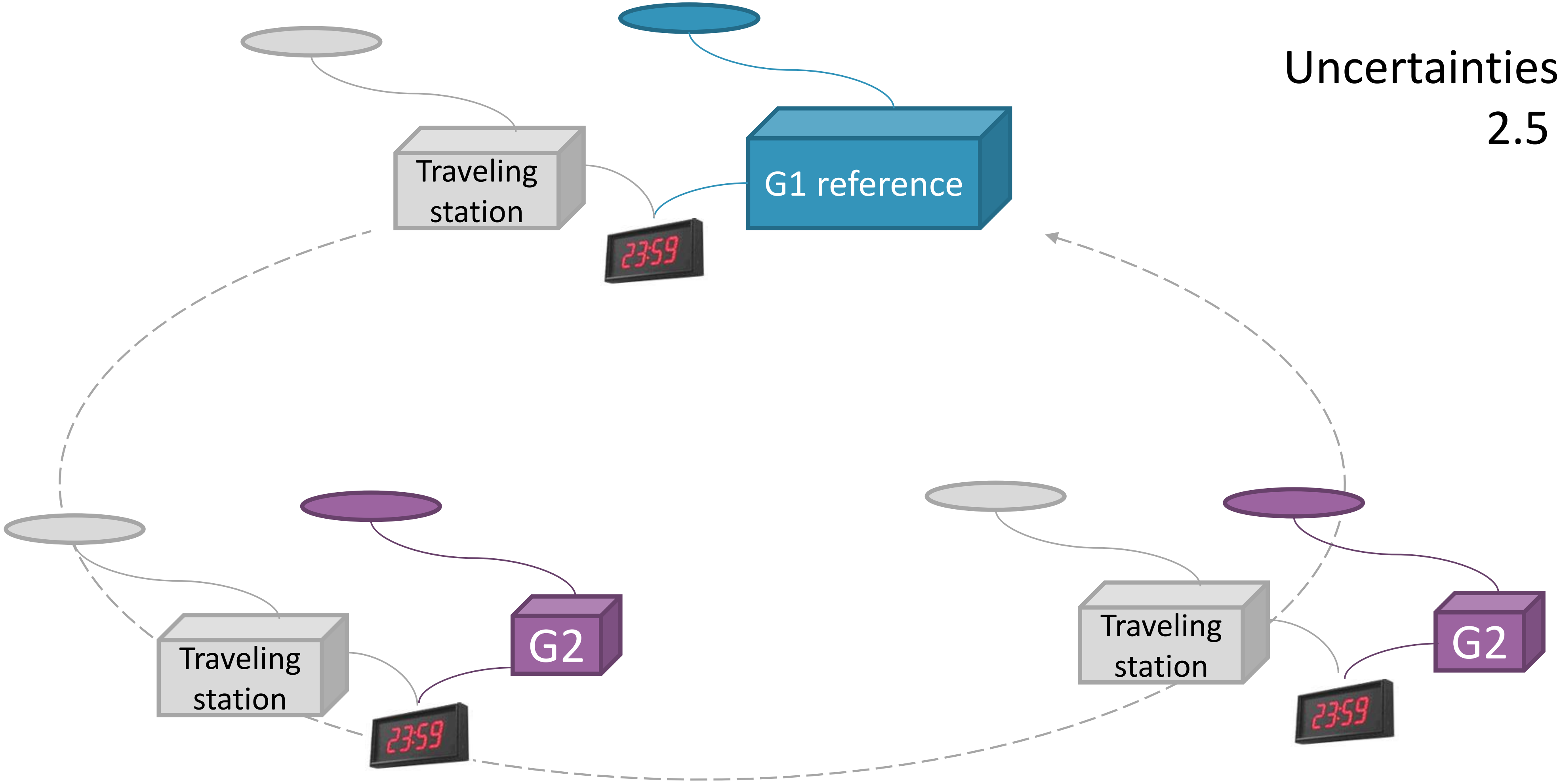
Hardware delay calibration



Calibration scheme



Calibration trip



Uncertainties:

2.5 ns (or better)

Calibration for GNSS hardware delays

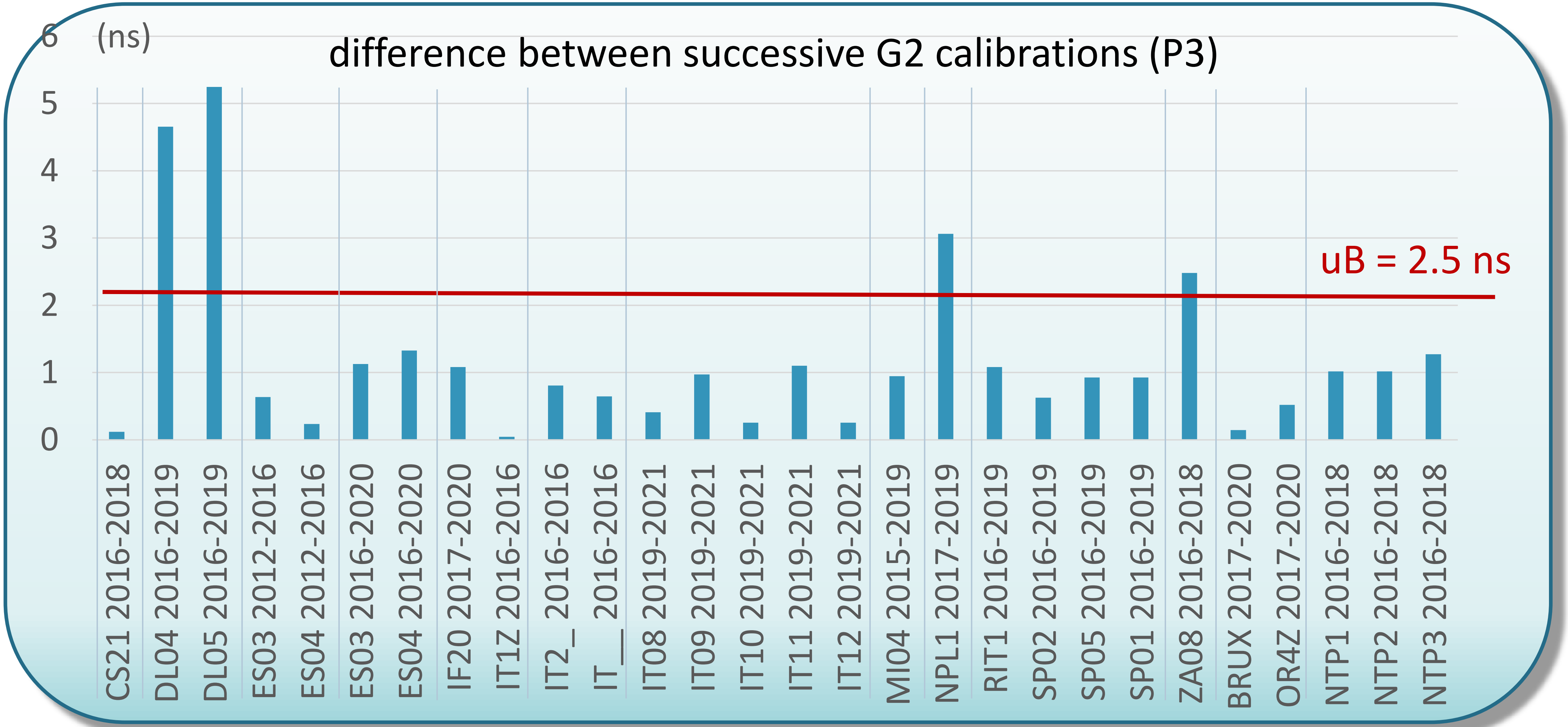
G1 calibration trips:

Since 1001-2018 all of them include Galileo

Excellent stability on GPS:

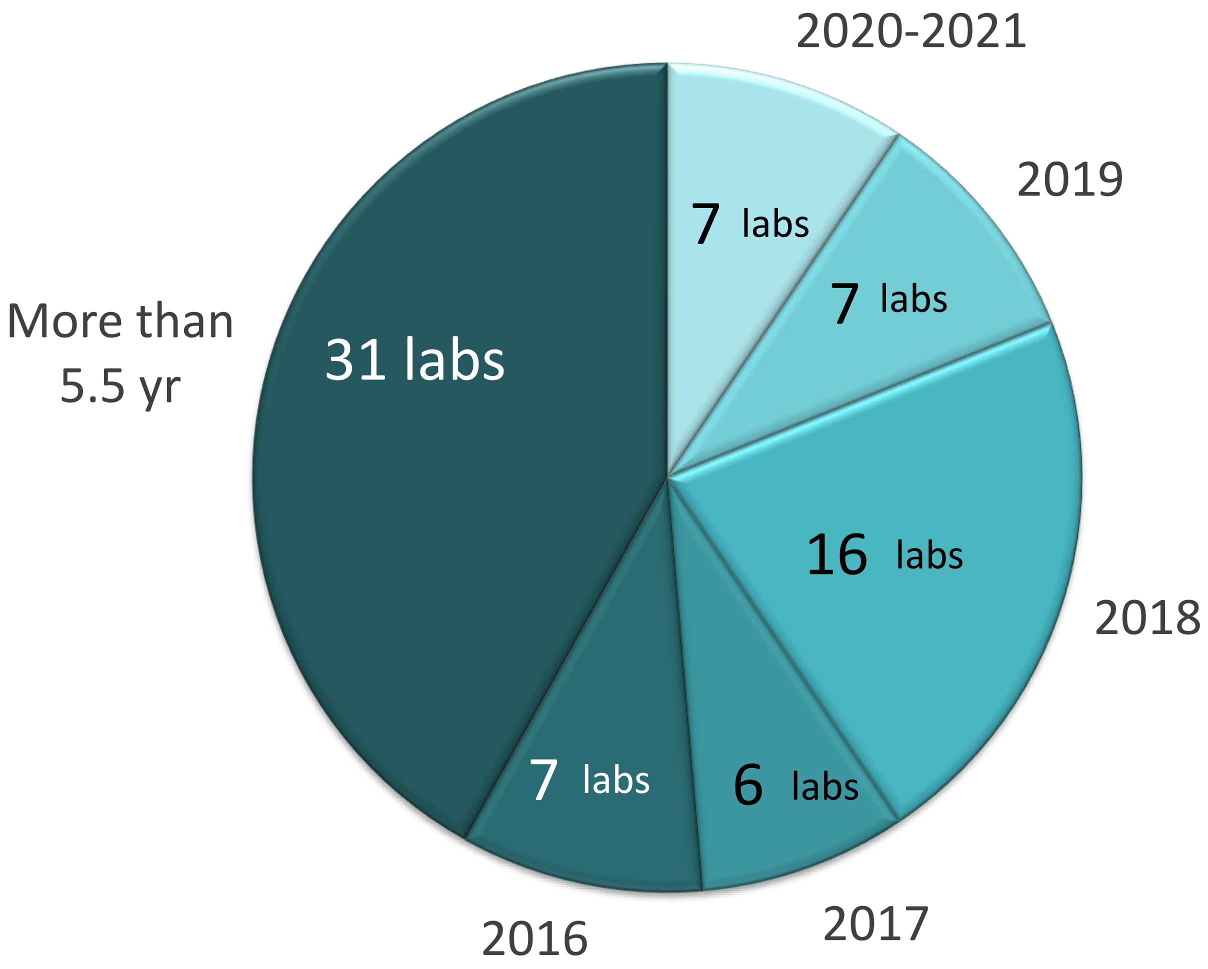
Ensemble	Nr	DIDP1	DIDP2	DIDC1	DIDP3
APMP (2018 – 2016) Ave	9	-0.1	-0.1	-0.2	-0.1
EURAMET (2018 – 2016) Ave	9	0.1	0.0	0.1	0.2
SIM (2018 – 2016) Ave	5	0.0	0.2	0.2	-0.2

Stability of G2 calibration results



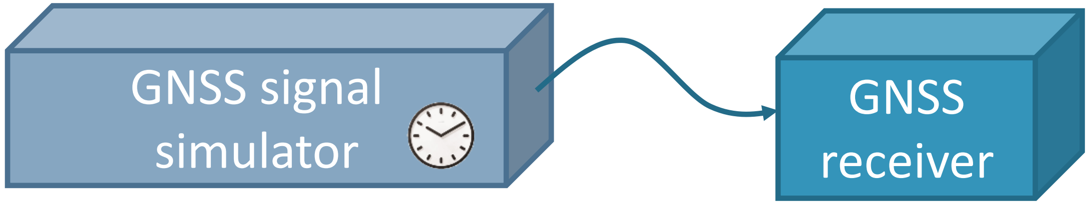
G2 calibration status – June 2021

Age of last calibration



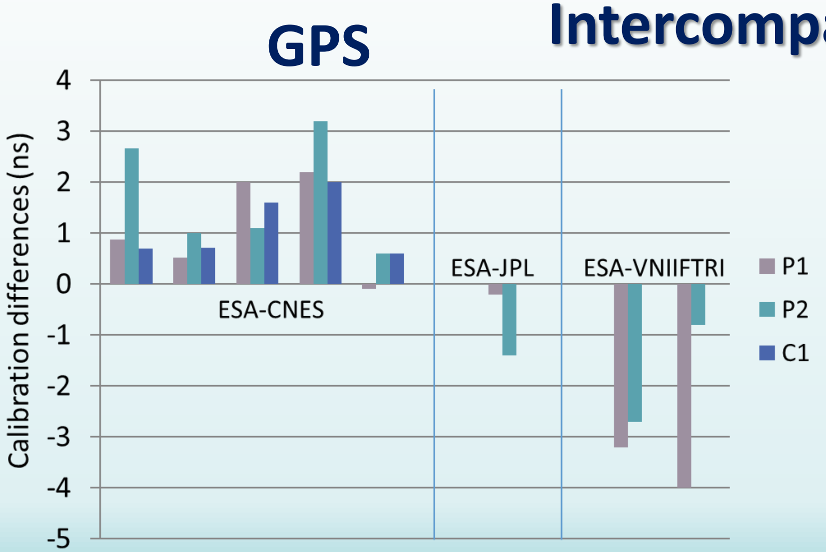
Improved information distributed to time laboratories. (July 2021)

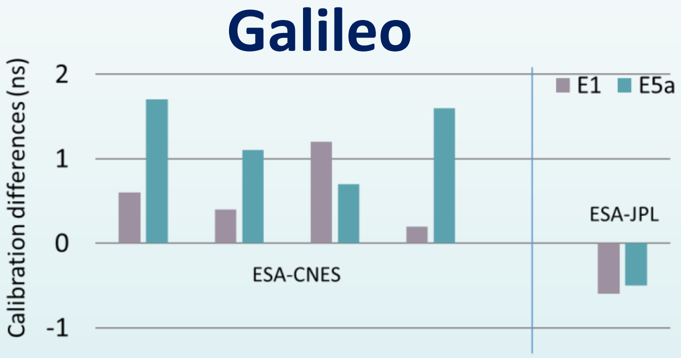
Progress in absolute calibration



To date :
absolute calibration by
ESA – CNES – JPL - VNIIFTRI

Intercomparisons



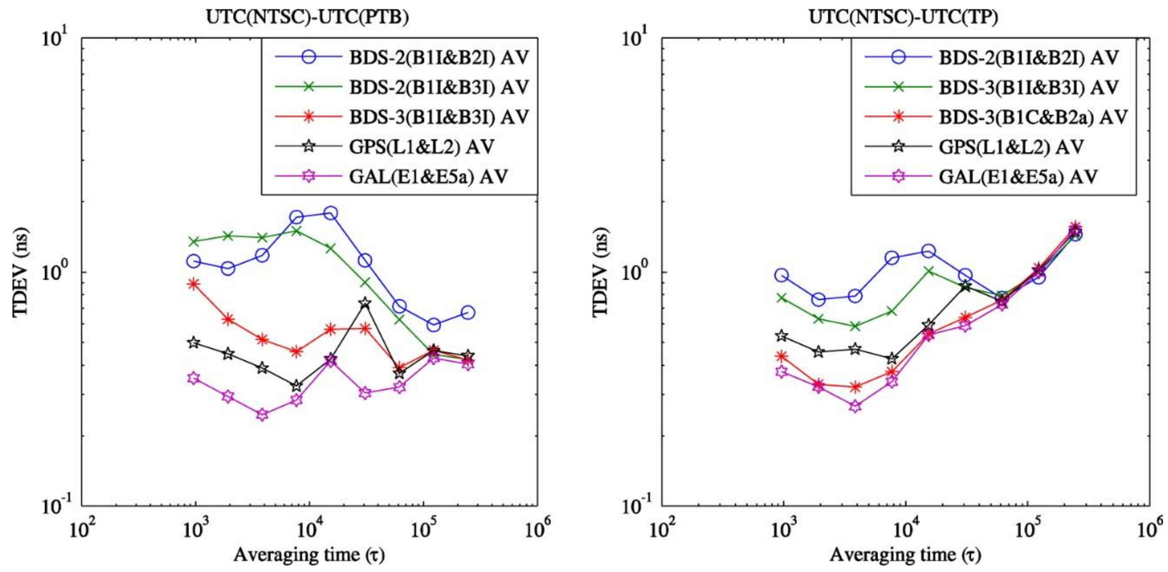


Recent absolute calibrations agree within (peak-to-peak)
4 ns for GPS
2.5 ns for Galileo

Time transfer with new GNSS

Several studies carried out.
The conclusions converge:

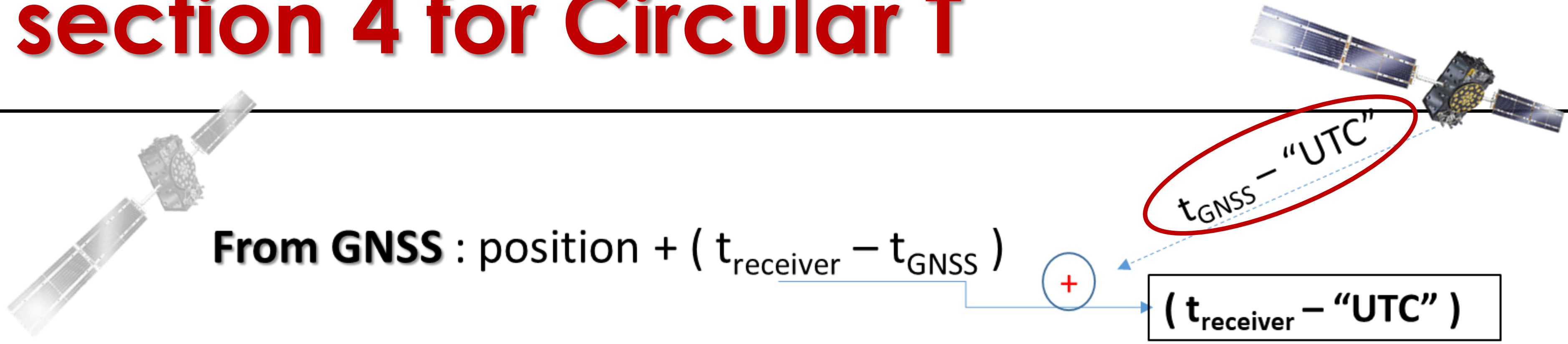
- BeiDou-3 (B1C&B2a) provides similar performances as GPS
- Galileo code measurements are less noisy, and provide short-term stability typically better than GPS P3, but not always at $\tau \sim 0.25$ day



Guang et al 2020 *Metrologia* **57** 065023

→ Introduction of Galileo links in the computation of UTC, as backup to GPSPPP (~20 links in 12/2020)

Revised section 4 for Circular T



GOAL :

Provide a validation of t_{GNSS} – "UTC" → quantify UTC – "UTC"

Current situation :

- Only GPS and GLONASS

  [UTC-UTC(USNO)_GPS] = C0', [TAI-UTC(USNO)_GPS] = 37 s + C0'

  [UTC-UTC(SU)_GLONASS]= C1', [TAI-UTC(SU)_GLONASS]= 37 s + C1'

- No specified uncertainty

Revise section 4 for Circular T

Naming Convention : “UTC” → Broadcast_UTC_{XXX} (xxx= BDS GAL GLO GPS)

Pivot UTC(k)

UTC – Broadcast_UTC_{XXX}

= $[UTC(k) – Broadcast\_UTC_{XXX}]_{GNSS} – [UTC(k) – UTC]_{circular\ T}$

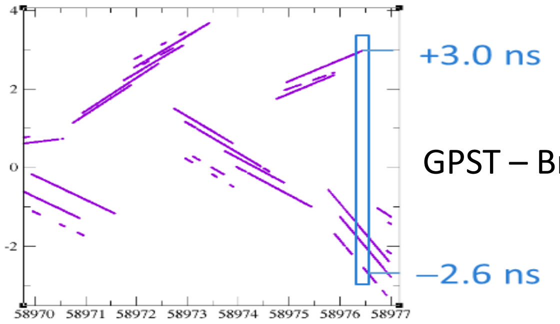
G1 laboratories

- laboratories regularly calibrated and monitored by the BIPM,
- directly calibrated differentially against an absolutely calibrated station
- Geographically distributed over the world

Uncertainties

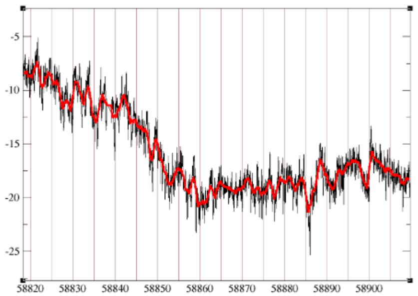
Uncertainties on UTC-Broadcast_UTC$_{GNSS}$

1. GNSSTIME – Broadcast_UTC$_{GNSS}$ from different satellites



GPST – Broadcast_UTC$_{GPS}$

2. The uncertainties in the solution UTC(k)-GNSST due to multipath, and satellite clocks and orbits in the navigation messages.



3. Receiver calibration

4. Uncertainty on UTC-UTC(k) for the pivot UTC(k)

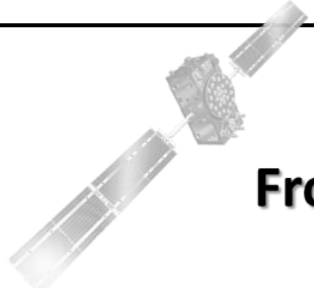
5. Differences between single-frequency and dual-frequency solutions.

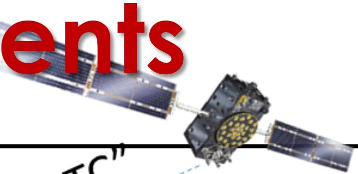
Uncertainties on UTC-Broadcast_UTC$_{GNSS}$

Final uncertainty Budget:

	BeiDou	Galileo	GLONASS	GPS
Calibration	2.6	2.4	3.8	2.6
Broadcast value dispersion	3.0	0.5	1.7	1.3
Code noise and multipath	1.5	0.7	3.5	0.9
UTC-UTC(k) pivot	2.2	2.2	2.2	2.2
Total	**4.8 ns**	**3.4 ns**	**5.9 ns**	**3.7 ns**

Traceability to UTC using GNSS measurements





From GNSS : position + ($t_{receiver} - t_{GNSS}$)

t_{GNSS} – "UTC"

($t_{receiver}$ – "UTC")

Increasing use of GNSS for synchronization
& increasing demand for traceability

Need for guidelines on
- how the user can get UTC from GNSS (including equipment and calibration)
- and how traceability can be obtained when using GNSS for synchronization to UTC (UTC from Signal in Space or UTC from UTC(k))

Task force of the GNSS WG, with the help of the WG on MRA.

Task Force on Traceability to UTC using GNSS measurements

CCTF survey → some questions on the traceability to UTC using GNSS

Answers : from the UTC(k) laboratories + stakeholders (telecom, IT, Science, TF equipment manufacturers, standardization bodies, …)

Observations from the answers received

- The term „traceability“ is used with different connotation in the various user groups. often ignoring the definition of (metrological) traceability in the Vocabulaire International de Metrologie (VIM).
- Traceability and accuracy are sometimes not clearly distinguished.
- GNSS signals are employed for getting a reference for frequency, for epoch, for time-of-day, with quite different accuracy requirements.

Task Force on Traceability to UTC using GNSS measurements

Final Goals :

- Produce unified guidelines on how to get traceability to a realization of UTC through GNSS measurements

    - Different options are on the table,
    - Work in progress

- Disseminate the information to the end user, via e. g. RMOs, ICG, GNSS providers, GNSS stakeholders

Thank You

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- Wenjun Wu (NTSC)