
# Frequently Asked Questions

## CCTF

CCTF Task Group on Moon Timing

IOAG / ICG Joint Workshop on Cislunar PNT, Vienna, Austria, 10-13 Feb 2026

# List of FAQs

- Definition of concepts and symbols
- What are the considered options for Lunar Timescale ?
- Why is TCG not used as reference time on the Earth ?
- Are the UTC(k) (and clocks on Earth) corrected for local gravity ?
- Which option of Lunar Time is easier to be realized with a clock on the lunar surface ?
- Where is the SI second defined (SI second = 9192631770 oscillations observed from Cs emission) ?
- What is the relation between the TAI (or UTC) scale unit and the SI second ?
- If TL or TCL becomes a standard lunar time, does one second measured with a clock indicating the standard time deviate from SI second?
- SI meter and its measure
- is TL easier in case of Loss of connection with Earth / Lunar PNT satellites ?
- Equations and models to convert from TCL to TCB/TCG/TT
- How is the Moon Reference Time realized ?
- How should interoperability between different lunar PNT systems be ensured ?
- Traceability of the Moon Reference Time to UTC
- describe the operational step to set up a time scale with a clock on Earth and similarly on Moon (steering a DO, free running…)
- When available, should (Moon time – UTC) be published by the BIPM?
- The different space agencies will realize their own lunar time. Shall a single organization evaluate a “coordinated” realization of Moon time (like UTC and UTC(k))?

# **FAQ:** Key time concepts

## on the Earth

**TT:** coordinate time scale, defined by IAU

**UTC(k):** local real-time realizations of UTC, maintained by timing laboratory k (typically not independently realized, but steered on UTC)

**UTC:** centrally coordinated realization of TT, primary realization of coordinate time, maintained by the BIPM

## on the Moon

**TCL:** coordinate time scale, defined by IAU

(if needed TL=TCL + scaling $\Delta\mathbf{f}$, defined by IAU/IAG)

**TCL(k) or TL(k) :** local real-time realizations of TCL or TL, maintained by the entity k

**?** International Lunar Time: centrally coordinated realization of TCL or TL (to be decided), maintained by? (to be decided) and how? (to be decided), needed in the long term?

# **FAQ:** Are the UTC(k) (and clocks on Earth) corrected for local gravity ?

1 ns /day = $10^{-14}$, 1 microsec/day = $10^{-11}$

**TT** (realized by TAI/UTC)

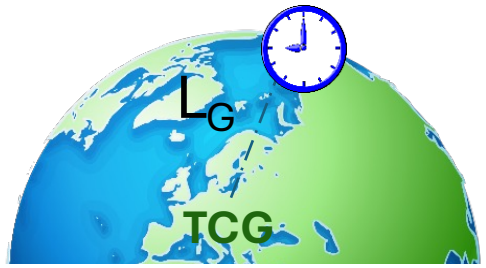
When we switch ON a clock on Earth, its frequency is realizing TT or UTC frequency?

- No, the clock is realizing a "proper time", to realize a coordinate time as TT the gravitational potential is to be measured, and the clock frequency corrected to be reported to the conventional gravitation potential of the 4D coordinate systems. A frequency adjustment due to gravitation ($10^{-16}$/m) is to be applied

Do we do that on Earth?

- No! only for Primary Frequency Standard (accurate at $10^{-16}$) to get the best accuracy when they contribute to UTC (or some UTC(k))

Usually the clocks are steered to UTC, or they are GNSS disciplined oscillators




This gravitational correction can be masked by larger clock instabilities and inaccuracies

- the clock has a "retrace" capacity = actual frequency may have an offset versus the nominal value (eg $10^{-13}$ for Cs clock, $10^{-12}$ for H maser...). For better accuracy a calibration and frequency adjustment versus a better standard or UTC is necessary
- Even if perfectly calibrated the frequency of the clock has a liner drift (about $10^{-15}$/day for AHM, $10^{-14}$/day for S-PHM, $10^{-13}$/day for S-RAFS). A time-varying frequency adjustment is necessary
- Moreover there are other source of instability for which the clock frequency is not constant, it can be white or a random walk, a periodical recalibration and frequency adjustment may be necessary (depending on the requested accuracy)

- Only primary frequency standards ensure the frequency is accurate without any calibration at $10^{-16}$ and only with those standards we are interested in realizing TT though TAI and UTC for a primary realization of a coordinate time used as reference by all other clocks

# **FAQ**: Where is the SI second defined ?

## The SI is always realized *locally and it is a proper realization:*

**extract from the "Mise en Pratique" for the definition of the second,**
**https://www.bipm.org/documents/20126/41489667/SI-App2-second.pdf**

SI Brochure – 9th edition (2019) – Appendix 2 20 May 2019

A future re-definition of the second will be justified if these idealized conditions can be achieved much easier than with the current definition.

The definition of the second should be understood as the definition of the unit of proper time: it applies in a small spatial domain which shares the motion of the caesium atom used to realize the definition.

In a laboratory sufficiently small to allow the effects of the non-uniformity of the gravitational field to be neglected when compared to the uncertainties of the realization of the second, the proper second is obtained after application of the special relativistic correction for the velocity of the atom in the laboratory. It is wrong to correct for the local gravitational field.

**The transformation from proper time to coordinate time (TCL or TL) needs the knowledge of the gravitational potential. Coordinate time unit is the SI second TCL (or TL)- compatible**

**The choice of a reference timescale does not change the definition of the SI second.**

# **FAQ**: What is the relationship between TAI (or UTC, TT, TCG, TCB, TL…) and the SI second ?

- In each case the unit of the scale is the **SI second** (compatible with the related reference system)
- A coordinate time (as TAI or UTC, TT, TCG, TCB, TL) is attached to a particular **reference system** (e.g., geocentric, barycentric, lunar-centric…)
- In the case of TT/UTC/TAI, a fixed frequency offset is introduced with respect to TCG to account for the Earth's gravity potential and connect to the "historical" timekeeping practices on the Earth surface.
- Clocks measure proper time, in principle **all of them** need corrections to be compared to a coordinate time scale.

# **FAQ:** Which option of Lunar Time (TL or TCL) is easier to be realized with a clock on the lunar surface?

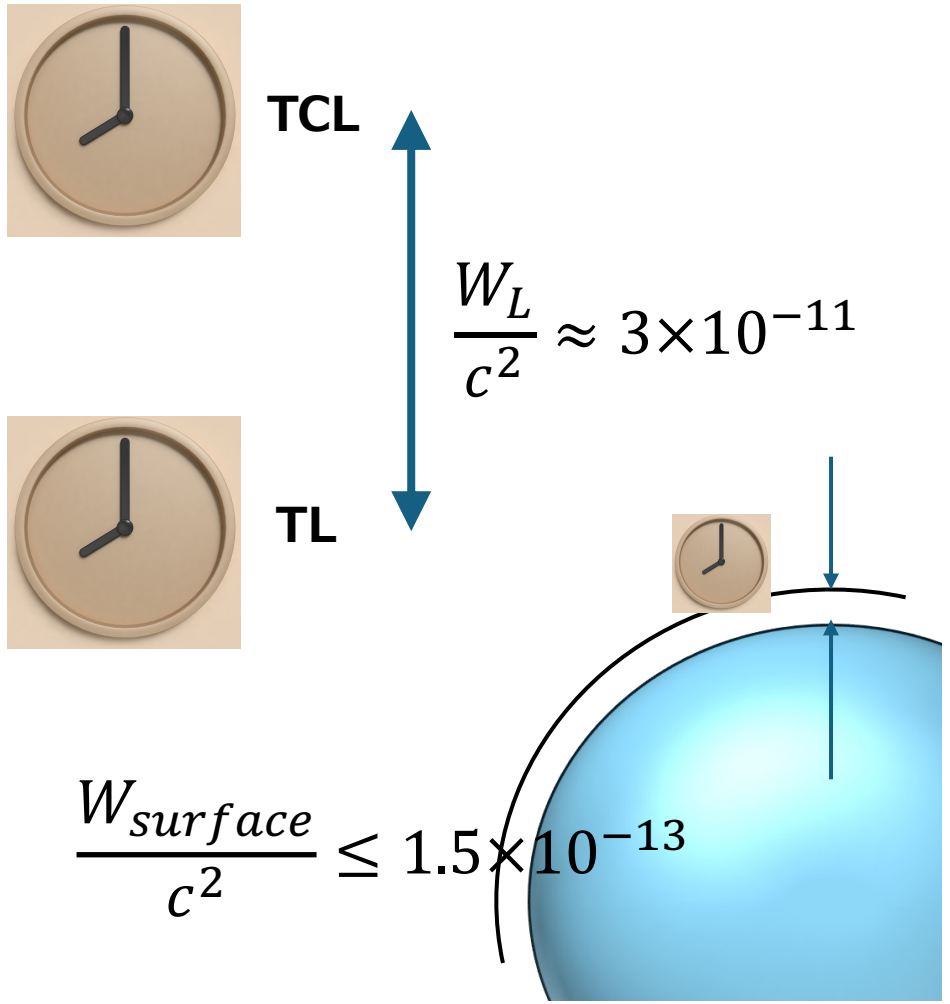
## Ans: There is no significant difference between them.

A clock on the lunar surface will realize its "**proper time**". To transform this to a "coordinate time", the effect of the gravitational potential has to be considered, and the frequency of the clock has to be corrected.

**TCL** is realized by correction of fixed frequency offset ($3\times10^{-11}$) and topological effect ($\leq 1.5\times10^{-13}$)

**TL** is realized by correction of topological effect ($\leq 1.5\times10^{-13}$) .

In both cases, the accuracy is limited by the knowledge of the local gravitational potential, and accuracy of the clock itself including its frequency offset and drift (which can be the most important component) .



# **FAQ**: How is the Moon Reference Time realized

A Moon Reference Time realization requires:

- at least one clock on the Moon
- with a local gravity potential estimate

This will provide a realization with uncertainty associated with the clock accuracy and the gravity potential measure uncertainty.

This could provide a TCL(k) or TL(k), local time realizations of the coordinate time (TCL or TL)

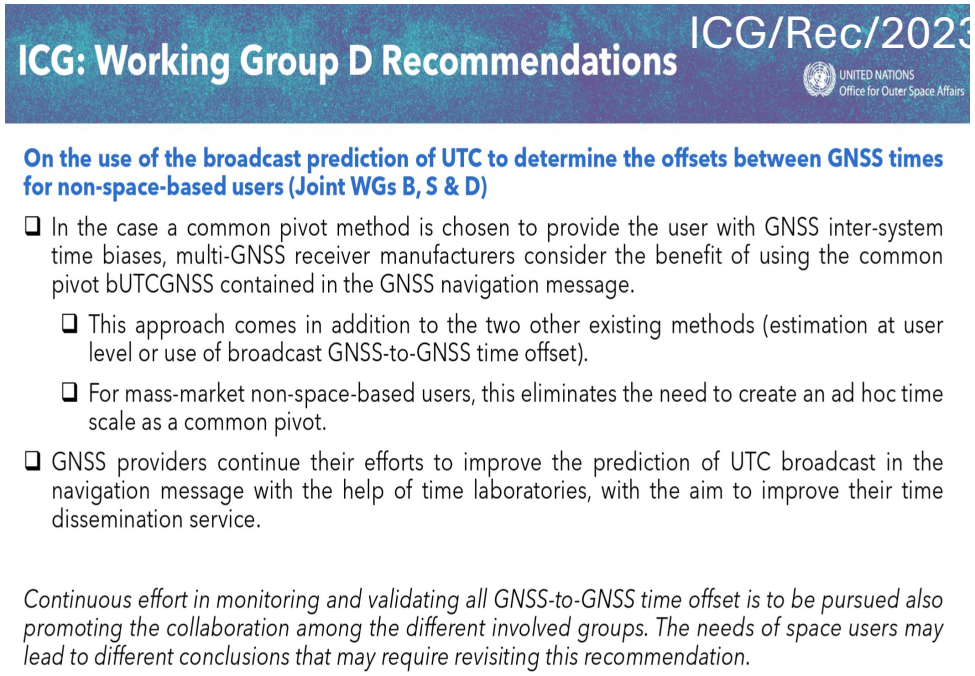
They should all be validated through a time transfer with some UTC(k) to ensure their traceability to UTC.

Is there a need for a centrally coordinated time scale for the Moon (International lunar time)? This depends on the future needs of the space agencies.

# **FAQ:** How should interoperability between different lunar PNT systems be ensured?

## on the Earth

**UTC** has been recommended as common reference to be used to ensure **GNSS interoperability**



**ICG: Working Group D Recommendations** ICG/Rec/2023

UNITED NATIONS Office for Outer Space Affairs

**On the use of the broadcast prediction of UTC to determine the offsets between GNSS times for non-space-based users (Joint WGs B, S & D)**

- In the case a common pivot method is chosen to provide the user with GNSS inter-system time biases, multi-GNSS receiver manufacturers consider the benefit of using the common pivot bUTCGNSS contained in the GNSS navigation message.
  - This approach comes in addition to the two other existing methods (estimation at user level or use of broadcast GNSS-to-GNSS time offset).
  - For mass-market non-space-based users, this eliminates the need to create an ad hoc time scale as a common pivot.
- GNSS providers continue their efforts to improve the prediction of UTC broadcast in the navigation message with the help of time laboratories, with the aim to improve their time dissemination service.

*Continuous effort in monitoring and validating all GNSS-to-GNSS time offset is to be pursued also promoting the collaboration among the different involved groups. The needs of space users may lead to different conclusions that may require revisiting this recommendation.*

## on the Moon (having chosen TCL or TL)

Same approach is recommended: each lunar PNT system shall disseminate the difference bw its system time and a **common reference**, to avoid XYTO-like complexity

### Early phase: No lunar clocks

Common reference: UTC
as transitional reference for interoperability

### Intermediate phase: First lunar clock

Common reference: TCL(k) or TL(k)
Single physical realization of the lunar coordinate time (TCL or TL) on the Moon, independent from but compared vs UTC

### Long-term: Multiple lunar clocks

Common reference: International Lunar Time realization
Centrally coordinated realization of the lunar coordinate time (TCL or TL), as UTC on Earth. Is it needed? Generated by who?how?