Frequently asked questions

CCTF Task Group on Moon Timing

2026-07-10

This document has been written collegially by members of the CCTF TGMT to clarify the discussions that have taken place within the group and when its members interacted with the various communities involved.

Contents

1 Definition of concepts and symbols **1**

2 What are the considered options for Lunar Timescale? **3**

3 Why is TCG not used as reference time on the Earth? **3**

4 What are the possible problems associated with the use of a scaled coordinate time like TL? **4**

5 How is the Moon Reference Time realized? **4**

6 Which option of Lunar Time is easier to realize with a clock on the lunar surface? **4**

7 Are the UTC(k) (and clocks on Earth) corrected for the local gravity? **5**

8 Which is the difference between TCL and TL concerning the steering of the clocks? **5**

9 Where is the SI second defined (SI second = 9192631770 oscillations observed from Cs emission)? **6**

10 What is the relation between the TAI (or UTC) scale unit and the SI second ? **6**

11 If TL or TCL becomes a standard lunar time, does one second measured with a clock indicating the standard time deviate from the SI second? **6**

12 SI meter and its measure **6**

13 Is TL easier in case of loss of connection between Earth and Lunar PNT satellites ? **7**

14 Equations and models to convert from TCL to TCB/TCG/TT by IAU and IAG **7**

15 How should interoperability between different lunar PNT systems be ensured? **7**

16 Traceability of the Moon Reference Time to UTC **8**

17 When available, should Moon time (ILT) - UTC be published by the BIPM? **8**

18 The different space agencies will realize their own lunar time. Shall a single organization (Space agencies propose the BIPM) evaluate a "coordinated" realization of Moon time (like UTC and UTC(k))? **9**

1 Definition of concepts and symbols

In the framework of special and general relativity, "proper time" and "coordinate time" are two separate concepts, that both play a role in the present discussion. "Proper time" can be viewed as the reading of a perfect clock. "Coordinate time" is the coordinate along the time axis in the chosen reference frame, and in general it does not bear any physical meaning. The relationship between the two depends on the local metric and the motion of the clock with respect to the chosen reference frame. Proper times are often denoted with the Greek letter τ, with coordinate times being denoted with latin letter t, with varying styles and/or indices that can be used to visualize its binding to one or another reference frame. "Coordinate*d* time", on the other hand, is not a relativistic concept: it designates the fact that its realization is the result of the coordination of several time sources.

In most practical applications we can choose a "locally inertial reference frame" that allows us to apply simple laws of dynamics, close to Newton's laws + small corrections of increasing order. For example, for motion around the Earth, the geocentric reference system (GCRS) and its associated frame provide a natural way to describe orbits. In the Solar System, the IAU has defined a method to build such reference systems as associated with any body, and this defines both a spatial reference frame and its associated time scale.

Choosing what reference frame is adequate is of course highly application-dependant, because it comes with associated assumptions on what accelerations can be neglected, for example.

Some coordinate times have already been defined by the IAU and, in some case, the BIPM:

- TCB: "barycentric coordinate time", coordinate time associated with the Barycentric Coordinate System (BCRS). It is the coordinate time that allows us to write the equations of motions of the Solar System bodies in the simplest way.
- TDB: "barycentric dynamical time", a *scaled* version of TCB so that the differences with respect to UTC are only periodic terms, with no linear drift.
- TCG: "geocentric coordinate time", coordinate time associated with the Geocentric Coordinate System (GCRS), i.e. centered on the Earth's barycentre. Its frequency difference with respect to TCB is calculated by imagining a clock that follows exactly the same path as the Earth's barycentre (i.e. it is subject to the same accelerations, due to the presence of all other bodies of the Solar System), but without taking into account the influence of the mass of Earth itself. This is general to all barycentric times defined by the IAU.
- TT: "terrestrial time", a *scaled* version of TCG, which takes into account the effect of the mass of Earth at 1 Earth radius distance. This is useful because, historically, timekeeping started on Earth's surface long before the relativistic effects were discovered (or mattered, from a human point of view). It is important to note that the scaling factor, $1 - L_G$, is now a conventional value, close to what was implied by previous concepts of "mean sea level", but which is nothing more than a fixed number. Physically speaking it corresponds to an equipotential surface W_0 that is taken as the reference geoid. TAI is a realization of TT, obtained by running a large set of (imperfect) clocks and correcting their mean frequency towards the geoid by using Primary and Secondary Frequency Standards, which have known (or rather : evaluated) frequency offsets induced by their altitude with respect to the geoid.
- TCL: "Lunar Coordinate Time", coordinate time associated with the Moon's barycentric Coordinate System (LCRS), defined by the IAU in 2024. The name itself has been established by 2024 GA but the concept is exactly the one defined in the 1991 and 2006 resolutions.
- TL: to-be-defined (if needed) "Lunar Time", which could be a scaled version of TCL, with a frequency offset to be defined so that the rate of TL is equal to the rate of proper time of a clock on a given lunar geoid (see Option 2 in the FAQ explaining the different options for a Lunar Time, sec. 2)

On Earth, coordinated times can designate:

- UTC: "Coordinated Universal Time" is the international reference time scale, with leap second adjustment with respect to TAI so that $|\mathrm{UTC} - \mathrm{UT1}| < 0.9|$ seconds. It is maintained by the BIPM.
- UTC(k): local real-time realizations of UTC, maintained by timing laboratory k.

If we decide to define such coordinated times on the Moon (these acronyms are all proposals at this stage):

- ILT: "International Lunar Time", centrally coordinated realization of TCL or TL (to be decided), maintained by (to be decided), and realized through (to be decided). This may be needed in the long term.
- TCL(x) or TL(x): local real-time realizations of TCL or TL, maintained by entity x.

Another important concept to have in mind while defining a reference timescale is to recognize that all we can do with real clocks is compare one to another, and therefore perform a time and frequency transfer experiment between the two. When the two clocks are distant, then we have to carefully assess how our "locally inertial" hypothesis stands, what correction we have to apply, and what simultaneity conventions are implied by our protocol. Our goal here is to find the most convenient frame to perform the calculations we need, as simply as possible, but not more.

2 What are the considered options for Lunar Timescale?

Due to the Moon's significantly smaller mass compared to Earth, general relativistic effects cause time on the Moon to advance faster than on Earth. Calculations estimate this divergence to be approximately 56 microseconds per day, corresponding to a fractional frequency offset of about 6.5×10^{-10}. Consequently, directly implementing UTC on the Moon would necessitate compensating for this frequency offset. Applying a frequency correction might appear to be a sufficient solution for low precision applications, but would not be sufficient for high precision applications like satellite navigation. Indeed, besides the rate difference, additional periodic variations must be accounted for, arising from the gravitational potential differences at the Earth and Moon centers, as well as from differences between the Earth rotation and the Moon rotation. Being dependent on the clock position, these corrections would require complex algorithms. This can be mitigated if a local coordinate time is defined to be used for high precision applications in the lunar region.

Options for Lunar timescale (A Bourgoin et al 2026 Metrologia **63** 015003, `https://doi.org/10.1088/1681-7575/ae2c03`):

- Option 1: Lunocentric coordinate time associated with LCRS IAU (2024). This time scale is called TCL.
- Option 2: A scaled version of TCL, so that the rate of this coordinate time scale is equal to the rate of proper time of a clock on a given lunar geoid. This would be the lunar-equivalent to TT on the Earth, and would be called TL.
- Option 3: A scaled version of TCL, so that the difference between this coordinate time scale and UTC has only periodic terms, with no secular variation.

Option 3 has been ruled out for several reasons: first, a scaling in general should be avoided as it implies the introduction of new scaled values for physical parameters like mass and distances, and adds complexity in the transformations between the different coordinate systems of the solar systems. Furthermore, in case of Option 3, the scaling value is quite large which increases the risk of significant error in case of misuse. Another issue is that, considering that the approach selected for the Moon should later be applied to the planet Mars, the scaling factor would be extremely large in that case, and quite impossible to determine accurately due to the interaction of all the planets of the solar system.

3 Why is TCG not used as reference time on the Earth?

The definition of the second was originally based on the Earth rotation and subsequent apparent motion of the Sun in the sky, measured from astronomical observations on the surface of the Earth. The reference time scale on the Earth (called Universal Time, following the terms used at the Washington Conference in 1884) was a succession of these seconds so that 86400 seconds corresponds to a mean solar day. When the definition of the second became based on the Caesium atom in 1967, the General Relativity effects were well established and known to impact significantly high precision astronomy and time keeping. But for continuity, the atomic definition had to inherit the mean value of the second as defined by Universal Time. It would have been highly disruptive to change that, with no obvious benefits. What is now called TCG, the coordinate time associated with the GCRS, was formalized only in 1991, for the needs of high precision astronomy. Its rate was determined as "de-scaling" the coordinate time TAI realized by clocks on the surface. On the Moon, whatever the duration of the reference time scale unit, it will have no link with the Moon rotation, and no link with any previous time scale already in place there. So, TCL could be used as reference with no need to change anything already existing.

4 What are the possible problems associated with the use of a scaled coordinate time like TL?

Scaling a coordinate time scale corresponds to defining a linear function of the fundamental time scale of the 4D relativistic coordinate system. In the present case, it would be $\mathrm{TL} = \mathrm{TCL} - \mathrm{L_L}(\mathrm{TCL} - t_0)$. To date, two scaled coordinate times have been defined by the IAU: $\mathrm{TT} = \mathrm{TCG} - \mathrm{L_G}(\mathrm{TCG} - t_0)$ and $\mathrm{TDB} = \mathrm{TCB} - \mathrm{L_B}(\mathrm{TCB} - t_0)$. The consequences of scaling a coordinate time are that, in order to keep the speed of light unchanged, it is also necessary to scale the distances, and in order to keep unchanged the equations of motion where the acceleration is given by the Newton's Second Law ($F = ma$), it is also necessary to scale the masses. As a consequence, the masses of the bodies, their radii as well as all distances, and also all quantities depending on the time, distance or mass, like e.g. gravity, keep their fundamental physical values when using TCL, TCG or TCB, while they get different values when they are used in a scaled system, with different values for TL-compatible, TT-compatible, or TDB-compatible systems. Adding yet another scaling for the Moon, and extending the same principle of scaling to Mars later, and maybe other planets or satellites, will bring a lot of possible confusion in the numerical values depending on the coordinate system in which the measurements are determined. It will furthermore add significant complexity in all transformations between the different coordinate systems inherent to the communications between different bodies, increasing the risk of error.

Moreover, all ephemerides of the solar system are currently expressed in TDB-compatible or TCB-compatible units. Defining a new scaling for the Moon, and hence for other planets later, will therefore require ephemerides users (and/or providers) to plan for an additional conversion method to the new scaled coordinate times, also increasing the risk of confusion.

5 How is the Moon Reference Time realized?

Initially, there will be no accurate clock on the Moon to realize the Lunar Time. The Moon reference time can however be determined from the measured difference between a Moon clock and an Earth clock realizing UTC, after removing the modeled light time and applying all the relativistic transformations between TT and either TCL or TL. $\mathrm{TCL_{UTC(k)}}$ or $\mathrm{TL_{UTC(k)}}$ will then be known through the difference with the Moon clock:

$$\text{clock} - \mathrm{TCL_{UTC(k)}} \text{ or clock} - \mathrm{TL_{UTC(k)}} = [\text{clock} - \mathrm{UTC(k)}]_{\text{measured}} - \text{relativistic transformation} - \text{light time}$$

Then the Moon clock could be steered in order to minimize this difference, however this will not be considered as a primary realization of the reference time, as it is based on UTC realizations.

A primary (or autonomous) realization of the reference time scale should be done with one or more accurate clocks ticking their proper time on the Moon. The Lunar reference time rate then corresponds to the frequency of those clocks corrected for either W/c^2 if the reference time is TCL, or the gravitational difference $(W - W_0)/c^2$ where W is the gravity potential at the clock location and W_0 is the reference potential used in the definition of TL.

Then, all the secondary realizations of the reference time scale would be steered on the primary realization, whatever the definition.

Some primary realizations of the reference coordinate lunar time could be called TCL(x) or TL(x). International Lunar Time (ILT) —a centrally coordinated realization of the lunar coordinate time (TCL or TL)— analogous to UTC on Earth, is not yet defined. And the need has not yet been identified. On Earth, UTC is computed by the BIPM as a weighted average of clock data provided by national laboratories, but extending a similar role to the Moon would probably require new mandates, infrastructure, and arrangements. The question of who should generate, maintain, and disseminate an official ILT realization, and under which institutional framework, is therefore an open issue. Such a need is expected to arise only in a longer-term perspective, as lunar timekeeping capabilities evolve, and is proposed to be addressed within the Task Group.

6 Which option of Lunar Time is easier to realize with a clock on the lunar surface?

There is no significant difference between them.

The primary realization of the reference time scale should be done with one or more accurate clocks ticking their proper time on the Moon. The Lunar Time frequency then corresponds to the frequency of those clocks corrected for either the gravitational difference $(W - W_0)/c^2$, where W is the gravity potential at the clock location and W_0 is the reference potential used in the definition of TL, or W/c^2 if the reference time is TCL. Then, all the secondary realizations of the reference time scale would be steered on the primary realization, whatever the definition.

In the first years or decades, on the Moon there will be no primary realization of the reference time scale. The reference time scale will be obtained from measurements of lunar clocks with respect to Earth clocks realizing UTC, and applying the relativistic transformations between the Earth and the Moon. This complexity of the procedure will therefore be exactly the same for both options of lunar time scale.

The secondary realizations of the Lunar reference Time will then be obtained, as on the Earth, by a steering of the clock on the reference, or on another realization.

7 Are the UTC(k) (and clocks on Earth) corrected for the local gravity?

Yes, in theory, but not in practice. UTC(k) is a realization of the coordinate time UTC. It corresponds to the frequency signal generated in real time from the signal generated by an atomic clock. The frequency signal generated by the clock corresponds to a proper time, it is then converted into the coordinate time UTC(k) by applying a frequency correction which contains both the clock inaccuracy and the gravitational redshift. For time laboratories equipped with very accurate Primary Frequency Standards (PFS), the UTC(k) can be realized thanks to the signal generated by these PFS and corrected for the gravitational redshift. But for the majority of UTC(k) laboratories, the time difference UTC(k)-UTC is evaluated via Circular T published monthly by the BIPM. Each institute then steers its UTC(k) signal to minimize this time difference, thereby realizing a practical signal that is close to UTC. The local gravity in that case is not considered at all in the realization of UTC(k).

8 Which is the difference between TCL and TL concerning the steering of the clocks?

Steering a clock means adjusting the output frequency to align it on a reference. It can be done just once at the clock start, or more regularly, depending on the clock stability. On the Moon, the need for steering will depend mainly on the user need and on the user clock accuracy, and to a lesser extent, on the definition of the reference.

Let us consider different cases.

- If the clock accuracy is better than 1×10^{-11} (i.e. Cs clock or better), and the reference is TL, then the magnitude of the difference between the clock rate and the rate of TL will be at the level of the clock accuracy or the altitude-dependent gravitational effect $(W - W_0)/c^2$, which can be as large as 1.5×10^{-13}, whichever is worse. If the user requires greater accuracy than this difference, then the user will have to apply a steering to its clock output to compensate this difference.
- If the clock accuracy is better than 1×10^{-11} (i.e. Cs clock or better), and the reference Lunar Time is TCL, then the magnitude of the difference between the clock rate and the rate of TCL will be at the level of 3×10^{-11}. If the user requires greater accuracy than this difference, the user will have to apply a steering to its clock to compensate this difference.
- If the clock accuracy is worse than 1×10^{-11} (which will be the case for most of the clocks, being quartz or Rb clocks), the steering correction will depend only on the clock accuracy and on the user needs, not on the choice of the reference Lunar Time.

The steering of the user clock could be avoided:

- If the reference Lunar Time is TCL: only if the user need is lower than 1×10^{-11} and lower than the clock accuracy
- If the reference Lunar Time is TL: only if the user need is lower than 1×10^{-13} and lower than the clock accuracy

9 Where is the SI second defined (SI second = 9192631770 oscillations observed from Cs emission)?

The SI second is unambiguously defined in the "*Mise en pratique* for the definition of the second in the SI" (`https://www.bipm.org/documents/20126/41489667/SI-App2-second.pdf/3c76fec8-04d9-f484-5c3c-a2e280a0f248`) 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." The same document later states "It is wrong to correct for the local gravitational field.".

This means that the SI second is defined **locally**. And all clocks, everywhere in the solar system, realize the SI second, with a given accuracy associated with the clock performance.

10 What is the relation between the TAI (or UTC) scale unit and the SI second ?

The scale unit of TAI is, by definition, the SI second at a reference gravity potential W_0, also called geoid. The scale of TAI is determined with Primary and Secondary Frequency Standards which are usually not on the geoid. Their measured frequency, corresponding to the local SI second, is then corrected analytically for the gravitational redshift $(W - W_0)/c^2$, where W, is the gravity potential at the clock site, to get the scale unit of TAI. Unsteered clocks at a given location will tick the local SI second. But all clocks steered on UTC, except if they are located exactly on the geoid, will not tick the local SI second.

11 If TL or TCL becomes a standard lunar time, does one second measured with a clock indicating the standard time deviate from the SI second?

Yes in both cases, but with different magnitudes.

If a clock on the Moon surface is steered on TCL, the seconds generated by this clock are about 3×10^{-11} s shorter than the local SI second. If a clock on the Moon surface is steered on TL, the seconds generated by this clock can have up to 1.5×10^{-13} s differences with the local SI second, depending on their altitude on the surface, and depending on the definition of the W_0.

But the SI second is defined as unit of proper time, it must always be measured with primary frequency standards which are ***not steered***.

12 SI meter and its measure

Since 1983, the SI meter is defined directly from the second, by fixing the value of c. It ensures that, like the second, the SI meter is defined **locally** and can be realized everywhere. A major source of misunderstanding is that this unit is then used to measure distances much bigger than the laboratory where this realization applies. For contexts where relativistic corrections cannot be neglected, it should be understood that we then make an implicit choice of reference frame, and define a simultaneity convention (the two "ends" of the length we measure are supposed to be events that share the same coordinate time).

Although manufacturing physical length standards to the level where relativistic differences would matter is well beyond present capabilities, it can be argued that 2 meter standards manufactured at different values of geopotential would seem different if compared remotely (e.g. at the level of 1×10^{-12} m if one is at sea level, and the other on top of the Everest), but would have exactly the same size if brought next to each other.

The reasoning behind this last affirmation is as follows : if for simplicity sake we assume that the meter standard is made of a crystalline structure of platinum, the size of the crystal cell is solely determined by the quantum properties of the platinum and the thermodynamic temperature, just like the frequency of its transitions. Then, manufacturing a meter standard translates to counting the right number of crystal cells to reach the 1m length as closely as possible. When transported, this number does not change. And when brought beside a meter standard manufactured elsewhere, atoms from both standards should be identical and produce crystal cells of the same size. Thus the two standards should match perfectly in length.

However, note that as there is a coordinate time, there will be also a coordinate system for the positions. The meter in this coordinate system is a coordinate meter, not the proper meter at a given location. In case of the definition of TL as lunar time, the coordinate system should be adapted to get a TL-compatible meter, i.e. the coordinate distances on the Moon should be scaled similarly as the coordinate time. On the Moon, this would correspond to a relative difference of 3.14×10^{-11} on the meter, i.e. a sub-mm effect on the Lunar radius. On the Earth, the difference between the TT-compatible and TCG-compatible Earth radius is about 5 mm.

13 Is TL easier in case of loss of connection between Earth and Lunar PNT satellites ?

Although it is clear that, in a first stage, the best clocks and frequency standards will be on Earth, and that their signal will have to be transferred to Moon clocks, it is also expected that this link will not be continuous. Thinking of Mars makes this even more blatant, with long periods of time when Earth, Sun and Mars are aligned enough to block any direct electromagnetic transmission. Clocks on the lunar surface could also receive time signals from the orbiting satellites, and work as GNSS do on Earth. The question then arrives on the clock accuracy if losing the satellite signal.

A frequent argument in favor of choosing a reference time corresponding to the proper time of a clock on the moon surface is that, when losing the link with the Earth or with the lunar satellites, the clock will simply follow its free-running tendency, and that choosing TCL would cause the clock to deviate by about 2 μs/d from the reference. Note that the free-running tendency, if using TL, will be aligned with the reference time only if the clock accuracy and stability is better than 1×10^{-11}, i.e. a Cesium clock or better, and if the user need is not higher than the clock accuracy and not higher than 1×10^{-13}.

Furthermore, this argument relies on the idea that the frequency received from Earth or lunar satellite is directly used to drive the local oscillator. However it is also possible to simply let the local oscillator run freely and only apply the correction on the measurement, software-side. In that case, when connection is lost, the correction would simply stay at its last value, and the accuracy of the clock would then evolve according to its own stability specifications.

In the case of driving an oscillator from the signals received from the Earth or from lunar satellite, the steering can be based on either a frequency synthesizer (or micro-phase steppers), or a PLL. In the first case, the last frequency corrections can be maintained during the holdover, maintaining the reference time with a quality depending on the clock stability. In the PLL case, i.e. the oscillator is adjusted by phase jumps periodically, the loss of Earth or satellite signals would cause no correction. However, the oscillators associated with PLL are usually quartz or Rb clocks, with a limited frequency accuracy and stability, so that when they will lose the contact with the satellites or with the Earth, they will deviate from the reference due to their clock inaccuracy (1×10^{-10} at best) and not due the reference time definition ($\sim 3 \times 10^{-11}$).

Similarly, a recurring question is "does the choice of TL or TCL as a reference modify how often a clock should be steered ?". Following the above explanation, the answer is "no", the choice of the definition will only determine the value of the initial clock steering. After that, the need for additional steering corrections will depend only on the clock stability, and these additional steering corrections will be the same whatever reference time scale is chosen.

14 Equations and models to convert from TCL to TCB/TCG/TT by IAU and IAG

Providing the equations to convert TL or TCL to TCB (and, from there, to TT/TAI/UTC) is responsibility of the International Astronomical Union (IAU), for example through the SOFA library, or any other agreed ephemeride or combination of ephemerides. As this relies on ephemerides, there is no "simple and universal" relation. BIPM will not provide this, we will use whatever is consensually agreed between celestial mechanics experts from the IAU. Furthermore, the relation between TCL (or TL) and TT depends on the coordinate time used to express the difference, and also depends on the positions of the clocks for which the transformation is required, at least when high precision is needed. It is therefore impossible to provide a unique difference between TCL (or TL) and TT at better than the 0.1 millisecond level.

15 How should interoperability between different lunar PNT systems be ensured?

For Earth GNSS, the use of UTC as a common reference time has been recommended to ensure interoperability, rather than relying on direct estimation of time offsets between different System Times (e.g. GGTO). The same approach is recommended for the Moon - the lunar time standard should be used as a common reference. In a first phase, when there is no realization of TCL/TL on the Moon, we recommend to use a transformation of UTC into a Moon time realization, using adequate coordinate time transformations. In a second phase, a provisional lunar time realization based on one clock deployed on the Moon could be used, if all navigation satellite systems can regularly compare their System time to that clock. Finally, in a further future, an International Lunar Time (ILT) — defined as a centrally coordinated realization of the lunar coordinate time (TCL or TL) — can be used, similarly as UTC on Earth as explained before. Each lunar PNT system should disseminate, in its navigation message, the offset between its own System Time and the selected common reference time. Users can then derive the time offsets between different systems through this common reference, thus ensuring interoperability. In such a scenario, there is no need to disseminate the differences between different system times.

16 Traceability of the Moon Reference Time to UTC

As explained in the FAQ on realization (sec 5), TL(x) or TCL(x) are based on the frequency of a physical clock on the Moon operated by an entity x, possibly corrected for the local gravitational redshift. Traceability to UTC can be established by combining time-transfer measurements between TL(x)/TCL(x) and a terrestrial UTC(k) with the official UTC(k) − UTC comparisons published by the BIPM. However note that as TL(x)/TCL(x) and UTC(k) are in different four-dimensional systems, their comparison depends on the position of the clocks in latitude, longitude and altitude on the Earth and on the Moon, with differences up to the microsecond level depending on the clock locations. Declaring the traceability to UTC with a certain level of accuracy could therefore only be considered if the relativistic transformations have been applied.

Furthermore, reporting the difference TCL(x) or TL(x) to UTC would not make sense, as it is clock position-dependent. Only the difference between TCL(x) and TCL as obtained when transforming UTC to the Moon, called $\mathrm{TCL_{UTC}}$ or $\mathrm{TL_{UTC}}$, should be reported.

This should be determined from time transfer between TCL(x) and some UTC(k) on Earth:

$$\mathrm{TCL}(x) - \mathrm{TCL_{UTC}} = [\mathrm{TCL}(x) - \mathrm{UTC(k)}]_{\mathrm{measured}} - \text{relativistic transformation} - \text{light time} - [\mathrm{UTC} - \mathrm{UTC(k)}]$$

or the same relation when replacing TCL(x) by TL(x) and $\mathrm{TCL_{UTC}}$ by $\mathrm{TL_{UTC}}$. The relativistic transformations involved in the physical comparison TL(x)/TCL(x) − UTC(k) must be modeled and corrected for using appropriate models and lunar ephemerides. The associated modeling uncertainty must be included when establishing traceability to UTC.

In the future, if an International Lunar Time ILT is realized on the Moon, then its traceability to UTC should be demonstrated though realizations TCL(x) compared to some UTC(k) as explained here above, and the reported quantity should be:

$$\mathrm{ILT} - \mathrm{TCL_{UTC}} = [\mathrm{ILT} - \mathrm{TCL}(x)] + \left[\mathrm{TCL}(x) - \mathrm{TCL_{UTC(k)}}\right] - [\mathrm{UTC} - \mathrm{UTC(k)}]$$

or the same relation when replacing TCL(x) by TL(x) and $\mathrm{TCL_{UTC(k)}}$ by $\mathrm{TL_{UTC(k)}}$. The value of this difference will depend on the TCL(x) and UTC(k) used as pivots, but should remain within the combined uncertainty budget of the different quantities.

17 When available, should Moon time (ILT) - UTC be published by the BIPM?

As explained in the previous FAQ, the BIPM should only report on the accuracy of the time scale realization, using UTC as reference, which means that the offset to be provided by the BIPM would be either $\mathrm{TCL}(x) - \mathrm{TCL_{UTC}}$ or $\mathrm{ILT} - \mathrm{TCL_{UTC}}$.

The differences between TCL(x)/TL(x) and ILT should be determined locally on the Moon. However it is too early to determine how it will be maintained, and which international body will be responsible for its generation.

18 The different space agencies will realize their own lunar time. Shall a single organization (Space agencies propose the BIPM) evaluate a “coordinated” realization of Moon time (like UTC and UTC(k))?

The coordinated realization is not mandatory as each of the space agencies can maintain its own realization aligned on $\mathrm{TCL}_{\mathrm{UTC}}$ or $\mathrm{TL}_{\mathrm{UTC}}$. The question about which international organization would be responsible for the coordinated realization is probably premature.