### **CCTF Task Group representing UTC/NMI laboratories**

on Moon timing

April 29, 2025

Bureau International des Poids et Mesures





## Agenda

- Summary of the Vienna workshop (PT, FM)
- Update on the 3 different possibilities to define a Lunar reference time (PD, FM, AB)
- Concerning the topic: "Define a gradual approach for the implementation and realization, ensuring traceability to UTC, based on the collaboration of the UTC laboratories",
  - Which time scale will be generated by your space agency in the Moon projects?
  - How this will be measured versus an Earth Clock? Is a UTC lab involved?
    - IS: info from ESA projects
    - TI, MS: info from Jaxa projects
    - o BP, JL, NASA expert: info from NASA projects
    - Others...

We welcome 3 new members:

- Myoung-Sun Heo from KRISS, working with KASA Korea Aerospace Administration
- Warren Walls, USNO, working with NASA and NIST
- Yin Dongshan, NTSC working with China Academy of Space Technology (CAST) and NIM

## Time reference and TF metrology for the Moon



Based on our timekeeping expertise and history we can

- help in identifying the key issues in time dissemination, synchronization, traceability to UTC and uncertainty evaluation
- stimulate contacts between metrology institutes and (inter)national space agencies to to work together and define common and agreed reference standards ensuring interoperability and comparability of measurements, since the beginning

To fulfill these aims, we need the support of experts, and we need a good liaison with national, regional, international organizations to understand their needs and, if possible, recommend common metrological standards.

### Aim of the CCTF task group

## Time reference and TF metrology for the Moon



Any time scale on the Moon (or anywhere) should be connected to UTC:

- the theoretical behavior versus TT/UTC is known (mathematical equations in the frame of General Relativity)
- when feasible, their difference is measured and the contributions to uncertainty evaluated (issue in the theoretical expectations, retrace of the clock frequency, steering...)

### Summary of the Vienna workshop

# International Committee on GNSS (ICG)

# Cislunar PNT workshop

The International Committee on Global Navigation Satellite Systems (ICG) and the Interagency Operations Advisory Group (IOAG) Organize a workshop

Session 3: Lunar Reference Systems and Timing Co-Chairs: Susan STEWART (IAU), Patrizia TAVELLA (BIPM)

Thanks for your participation. In person or online, most of the CCTF Task Group was there

https://ioag.org/meetings/cislunar/





### Workshop on Cislunar Positioning, Navigation, and Timing (PNT)

11 - 13 FEBRUARY 2025 VIENNA INTERNATIONAL CENTRE, AUSTRIA

Jointly organized by the International Committee on Global Navigation Satellite Systems (ICG) and the Interagency Operations Advisory Group (IOAG)

### **Session 3: Lunar Reference Systems and Timing**

Summary of the Vienna workshop

Session 3 (1): Time & Reference Systems/Frames – Definition & Standards 13:30 - 13:40IAU Status Update: Lunar Standards, Susan STEWART (IAU) Activities of the IAG Working Group 1.1.3 on Lunar Reference 13:40 - 13:50Systems and Frames, Krzysztof SOSNICA (representing IAG WG on Lunar Reference Frame) 13:50 - 14:00**BIPM Perspective**, Patrizia TAVELLA (BIPM) Relativistic Aspects Impacts on Operations, Biju PATLA (USA, 14:00 - 14:20NIST) 14:20 - 14:30Discussion 14:30 - 14:50Break Session 3 (2a): Time & Reference Systems Application 14:50 - 15:00Conceptual Framework for Lunar Time, Dongshan YIN (NTSC) 15:00 - 15:10India & Partner(s) Perspectives, T Subramanya GANESH (ISRO) 15:10 - 15:20LunaNet Perspectives, Suzuna OKAMOTO (JAXA) (online) Towards an International Lunar Time Reference – LunaNet 15:20 - 15:30Reference Time, Cosimo STALLO (ESA) LunaNet Perspectives – How the International Standards 15:30 - 15:50Community Can Help, Cheryl GRAMLING (NASA) 15:50 - 16:20Break Session 3 (2b): Time & Reference Systems Application – Time System Operational Aspects BIPM Time Metrology Contribution – How can we realize time on or around the Moon and measure its offset versus UTC?, Frédéric 16:20 - 16:40MEYNADIER + CCTF WG

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### Summary of the Vienna workshop 3 options for a reference time on the Moon

(1) Using TCL



## Questions for the discussion

- 1. What do you think on the 3 possibilities to **DEFINE** a lunar reference time scale?
- 2. How will you **REALIZE** the definition and have a physical signal realizing lunar time:
  - a) On the Moon?
  - b) On a station orbiting around the Moon?
  - c) On a GNSS-like navigation satellite around the Moon?
  - d) From Earth?
  - e) And during travel to the Moon?
- 3. For the interoperability of GNSS-like navigation systems around the Moon should a common lunar time **realization** be used as common pivot? Could each navigation system broadcast the offset of its system time versus this common lunar time realization? Can BIPM publish coordinated Moon time UTC?
- 4. Work together with IAU, IAG (WG1.1.3 on Lunar Reference Systems and Frame), and other organizations to agree on common internationally adopted standards

### Summary of the Vienna workshop International Committee on GNSS (ICG) Cislunar PNT workshop

### **Future Recommendations and Considerations Needed**

### IAU

- 1. Update standard terminology to include cislunar terms
- 2. Define a convenient analytical approximation between TCB and TCL allowing the implementation of IAU resolution 2024
- 3. Support IAG to establish a unified standard lunar body-fixed (surface) reference system (LRS) with coordinate system, reference frame, reference ellipsoid, topography model, gravity model, etc. specified.
- 4. Collaborate and endorse the work of the CCTF/BIPM on a lunar time as an international standard, related to UTC
- 5. Extend to other solar system bodies

### **CCTF/BIPM** task group

- 1. Detail the 3 different possibilities to define a Lunar reference time
- 2. Define a gradual approach for the implementation and realization, ensuring traceability to UTC, based on the collaboration of the UTC laboratories
- 3. Each member of the task force to exchange with his/her national and international space agency to get feedback on the preferred reference for Lunar PNT
- 4. Exchange with the colleagues of IOs, and space agencies, involved in this discussion with the aim to have a consensus on the Lunar reference time
- 5. If a Lunar Time (LT) on the surface has to be defined, collaborate with the IAG and IAU in order to define an equipotential surface on the Moon, and an associated conventional L<sub>L</sub> as scaling factor between TCL and LT.
- 6. collaborate with IAU to update terminology (especially, confirm if TL is an appropriate designation for Lunar Time, knowing that LT is already meaning "Local Time" in other contexts).

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# Conclusion and way forward

#### Concepts:

#### -> by end of May?

- Finalize the paper by Pascale, Adrien, Frederic and distribute
- Discussion on the coordinate time scale not depending on position (MS to send email)
- Other papers?
- Propose starting epoch of the Lunar time scale (in agreement with UTC, with NO future adjustments)
- Evaluate examples of "user cases" with time differences between different points on Moon- Earth and draft procedure for its computation

#### Discussion with space agencies:-> feedback by end of June ? We can share this presentation to write on the same doc

- 3 different possibilities to define a Lunar reference time, pros/cons, also from operational point of view
  - Dependence of the positions on Moon Earth
  - Scaling in the def of TL and consequences on mass and distance measurements
- Accuracy of the offset TL UTC? In the GNSS like broadcast prediction? What can be neglected ? Microseconds?
- starting epoch in agreement with UTC, with NO adjustments and Operational use of Julian day (86400 "Lunar Time" seconds)
  - Divergence of Lunar and Terrestrial days
- Naming convention TL, TL(k), ...
- Define a gradual approach for the implementation and realization of Lunar time
  - on the Earth, on Moon space station/satellites, on Moon surface ensuring traceability to UTC, based on the collaboration of the UTC laboratories, type of measurements Will realizations of Lunar Time be coordinated?

Can BIPM publish a "Coordinated" Lunar Time – UTC offset? Or TL(k) – UTC? Based on measurements at UTC laboratories

Collaborate with IAG WG1.1.3 on Lunar Reference Systems and Frame (Pascale and Patrizia): the WG is working towards the definitor of a reference solenoid and gravity equipotential surface. Reference ephemerids? Feedback from IAG

Collaborate with IAU on the implementation of TCL – TCB (Pascale, Frederic, Noel at the IAU symposium), feedback from IAU



Thanks for your collaboration

