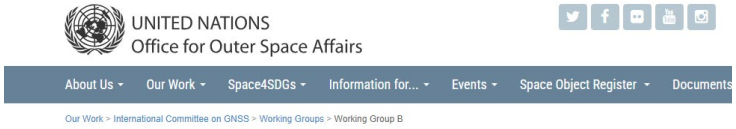


Session 3: Lunar Reference Systems and Timing

BIPM perspective

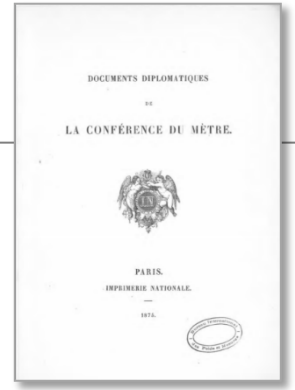
Patrizia Tavella

Head of Time Dept

Exec secretary of the Consultative Committee of Time and Frequency - CCTF

Bureau International des Poids et Mesures

The Bureau International des Poids et Mesures - BIPM an international organization


DOCUMENTS DIPLOMATIQUES

DE

LA CONFÉRENCE DU MÈTRE.

PARIS.

IMPRIMERIE NATIONALE.

1875.

Established in 1875 when 17 States signed the Metre Convention, now with 64 Member States and 37 Associate States and Economies **working together to promote and advance the global comparability of measurements**

CGPM – Conférence générale des poids et mesures

Official representatives of Member States.

CIPM – Comité international des poids et mesures

Eighteen individuals of different nationalities elected by the CGPM.

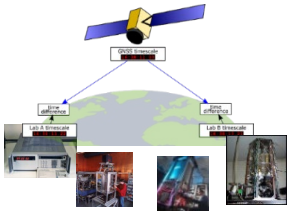
Scientific and technical headquarter (in Sèvres)

- *International coordination and liaison*
- *Technical coordination – laboratories*
- *Capacity building*
- *Home of the* **Coordinated Universal Time (UTC)**

Consultative Committees (CCs)

CCAUV – Acoustics, US & Vibration
CCEM – Electricity & Magnetism
CCL – Length
CCM – Mass and related quantities
CCPR – Photometry & Radiometry
CCQM – Amount of substance
CCRI – Ionizing Radiation
CCT – Thermometry
CCTF – Time & Frequency
CCU - Units

Construction of the Coordinated Universal Time



National time laboratories realize real-time approximations **UTC(k)**

≈ 450 atomic clocks
≈ 15 primary frequency standards

in ~ 85 laboratories

TAI

International Atomic Time

Measurement of Earth's rotation UT1 (by IERS International Earth Rotation and Reference Systems Service)

leap seconds

UTC

Coordinated Universal Time

|UT1 – UTC| < 1 s

The offset [***UTC*** - ***UTC(k)***] is published in **BIPM *Circular T***

UTC definitive results each month
UTC Rapid solution each week
UTC(k) are national realizations in real time

The BIPM works together with other International Organizations

- **ITU:** collaboration with Working Party 7A (WP 7A) - Time signals and frequency standard emissions- on the dissemination of time and frequency signals
- **IGS**: the BIPM is member of IGS Governing Board, and of IGS WG on *Clocks* and *AR*
- **IAU**: collaboration with *Commission A3 Fundamental Standards*, chair of IAU WG on *Time Metrology Standards*
- **IAG**: member of the IAG QuGe WG3 *chronometric geodesy*, and the WG 1.1.3 *Lunar Reference Frames.*
- **ICG** - International Committee on GNSS- concerning timing aspects (WG-D), calibration of receivers, measurements of UTC prediction broadcast by GNSS
- **IERS** – International Earth Rotation and Reference Systems Service – on the coordination between UTC and the rotational angle of the Earth UT1
- **URSI -** International Union of Radio Science- with Commission A: *Electromagnetic metrology*

IAU General Assembly 2024 resolutions

- **Resolution II**: Defines a standard Lunar Celestial Reference System and associated coordinate time (*Built on previous 1991 and 2000 IAU resolutions concerning all bodies of the Solar System)*

  https://iau.org/static/resolutions/IAU2024_Resol2_English.pdf

- **Resolution III**: Encourages the establishment of a lunar reference time scale by international agreement

  Considers *that Coordinated Universal Time (UTC), as established by the Bureau International des Poids et Mesures (BIPM) based on international collaboration and coordination, has been a successful worldwide reference time scale for operational systems in the near-Earth environment,*

  Recommends *the relationships between the possible versions of a lunar reference time scale and other time scales, in particular a lunar coordinate time and UTC, are pursued in collaborative agreement among the relevant international organizations.*

  https://iau.org/static/resolutions/IAU2024_Resol3_English.pdf

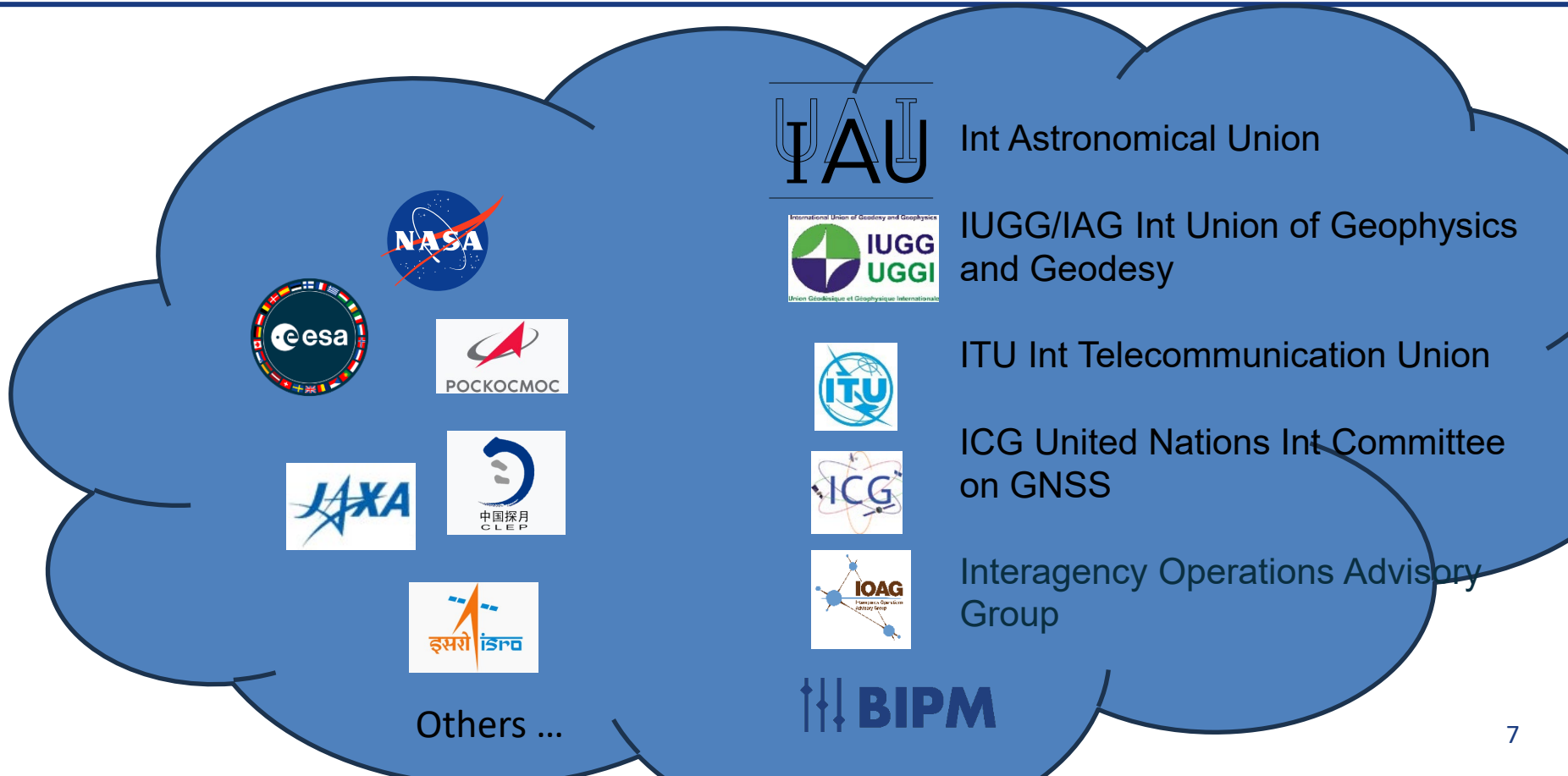
A Working Group-L on Lunar PNT is created (Oct. 2024)

The Working Group must coordinate, as needed, with other ICG Working Groups and with external international organizations, such as the Bureau International des Poids et Mesures (BIPM), …

Coordinate with appropriate international organizations and ICG Working Group D to support standardization of lunar time with traceability to UTC.

https://www.unoosa.org/documents/pdf/icg/2024/ICG-18/ICG-18_WG-B_Recommendation_1.pdf

Moon (and beyond…) decisions can involve multiple actors



Time and Frequency metrology for the Moon

Based on our timekeeping expertise and history we can

- help in identifying the key issues in time realization, dissemination, synchronization, traceability to UTC and uncertainty evaluation
- stimulate contacts between metrology institutes and (inter)national space agencies 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.

CCTF Consultative Committee of Time and Frequency

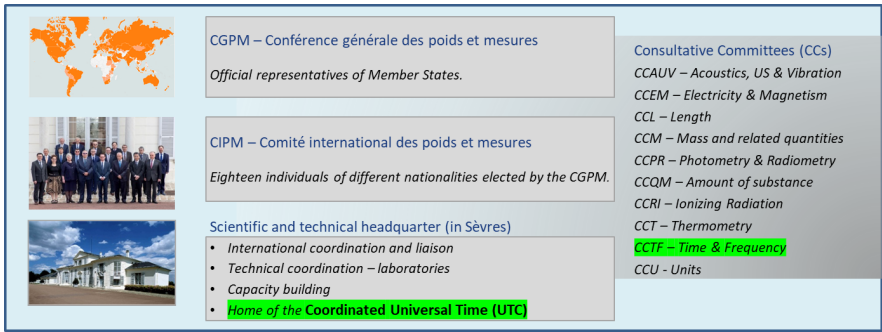
In Nov 2024 adopted a

RECOMMENDATION CCTF-2024-1

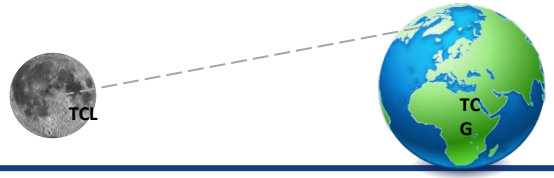
On the development of a common Lunar reference time scale and its traceability to UTC

We have formed a CCTF Task Group on Moon timing
with National Metrology Institutes/Laboratories of countries connected to Moon projects

China:	**NIM**
EU:	**ORB, INRIM, OP**
India:	**NPLI**
Japan:	**NICT**
Russia:	**VNIIFTRI**
USA:	**NIST**
BIPM	**Time Dept**



CCTF Task Group activity

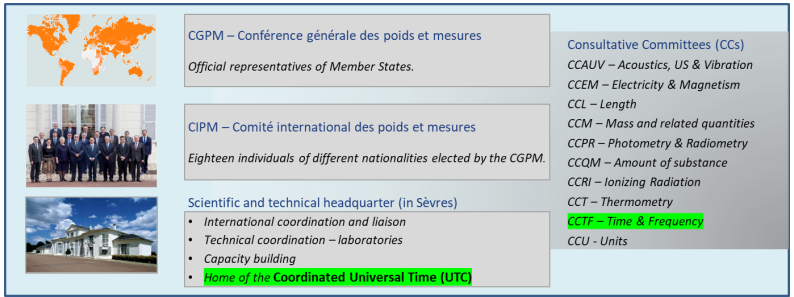


1. **Any time scale on the Moon (or anywhere) should be connected to UTC:**
   - the theoretical behavior versus TT/UTC is known (mathematical equations in the frame of General Relativity)
   - Its practical realization and, when feasible, measurement versus UTC, should assess uncertainty evaluation, steering, traceability, retrace, …

Last part of this session

2. **Metrology Institutes collaborate with (inter)national organizations**
   - Organize a workshop with space organizations, together with the ICG Cislunar PNT workshop
   - Contact our national/international space agency to share our projects

3. **Aiming to submit a recommendation to the CCTF meeting in Sept 2025 and a draft resolution to the General Conference on Weights and Measures in Oct 2026**



Thanks for your attention

RECOMMENDATION CCTF-24-1

On the development of a common Lunar reference time scale and its traceability to UTC

The Consultative Committee for Time and Frequency (CCTF), at its 24th - Session 1 meeting in 2024,

Considering

- that national and international space agencies are launching projects aimed at establishing communication and navigation systems on or around the Moon, and the necessity for interoperability among them;
- the requirement for these communication and navigation systems to rely on a reference coordinate system and a reference time scale;
- that Resolution III "on the establishment of a coordinated lunar time standard by international agreement," adopted in 2024, by the International Astronomical Union (IAU) XXXIInd General Assembly, states that
    - "considering that UTC has been a successful worldwide reference time scale for operational systems in the near-Earth environment;
    - recommends the establishment of a lunar reference time scale by international agreement and that the relationships between the possible versions of a lunar reference time scale and other time scales, in particular a lunar coordinate time and UTC, are pursued in collaborative agreement among the relevant international organizations".

Noting

- the creation in 2024 of a Working Group-L on Lunar PNT by the International Committee on GNSS (ICG) "to be coordinated, as needed, with other ICG Working Groups and with external international organizations, such as the BIPM, to support standardization of lunar time with traceability to UTC";
- the work of the International Association of Geodesy (IAG) WG1.1.3 on Lunar Reference Frames;
- the studies at International Telecommunication Union – Radiocommunication (ITU-R) carried out by WP 7B, with contribution of WP 7A, on the allocation of frequency bands for future communication systems on the lunar surface and between lunar orbit and the lunar surface.

And further noting

- that the above International Organization have requested collaboration and support from the BIPM concerning the definition and realization of reference time scales.

Considering that the expertise of BIPM and CCTF in precision timekeeping can:

- help identify key issues in time scale realization, dissemination, synchronization, traceability to UTC and uncertainty evaluation;
- foster collaboration between metrology institutes and space agencies to develop shared reference standards that ensure interoperability and comparability of measurements.

Recalling

- that, in agreement with the CCTF WG on Strategic Planning, the BIPM has started the call for a task group involving NMI colleagues with relationship with space agencies involved in Moon projects.

Recommends that

- the CCTF Task Group on Lunar timing is confirmed with the goal of:
    - pursuing an efficient coordination between UTC laboratories and NMIs of countries connected to Moon projects, and with the concerned International Organizations and space agencies;
    - addressing metrological questions related to a Lunar time scale definition, its practical realization, its retrace and traceability to UTC;
    - preparing for the 24th - Session 2 meeting of the CCTF in 2025, a draft resolution to be submitted to the 28th CGPM for approval.