Lunar Reference Frame & Time Session
Lunar Reference Frame Standards

ICG-IOAG Lunar PNT WG
11 February 2026

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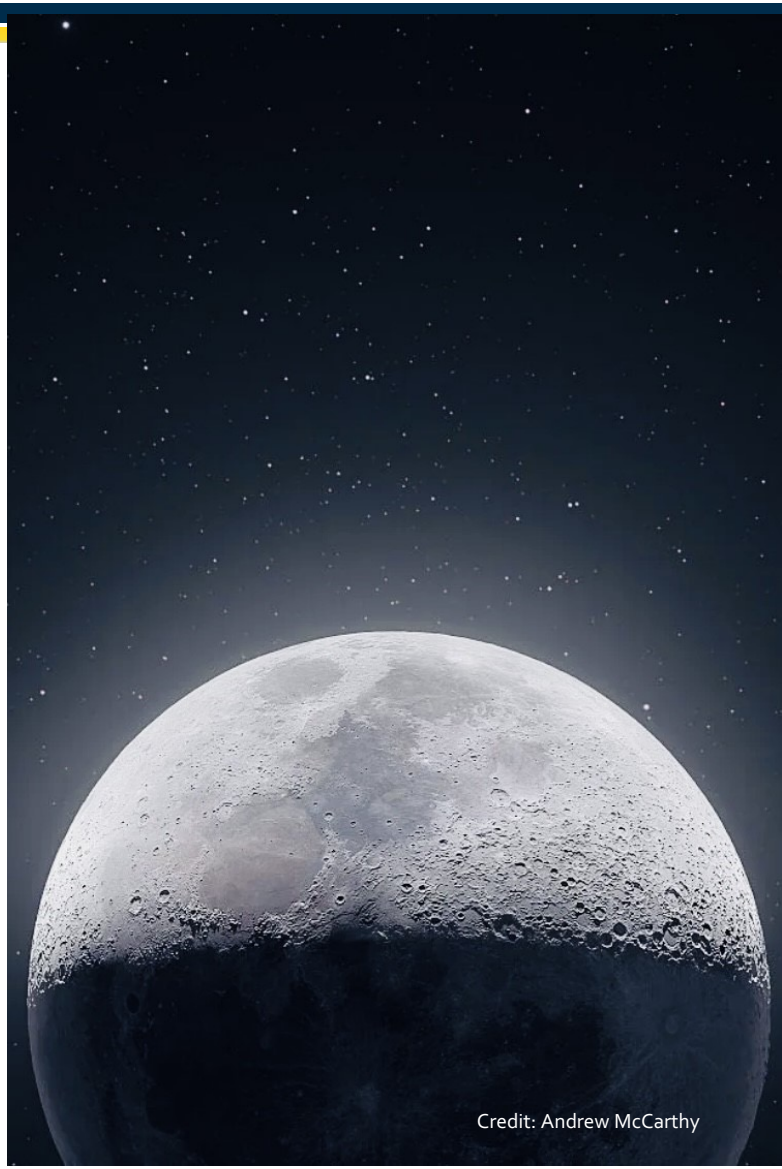
Commission A3 Fundamental Standards
International Astronomical Union


Credit: Andrew McCarthy

Lunar Reference Frame and Time Session

Path to Standardization

- Realization of conventions
- Adoption and implementation
- Interoperability

Lunar Reference Frame

- International Association of Geodesy (IAG) Working Group 3.1.1 proposal for the Lunar Reference Frame
- International Combined lunar ephemerides
- Implementation plans & lessons learned

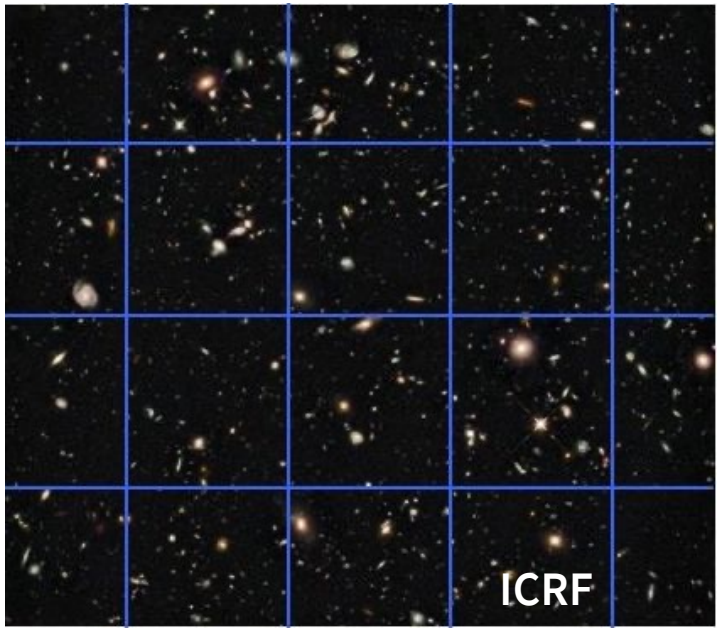
Lunar Reference Time

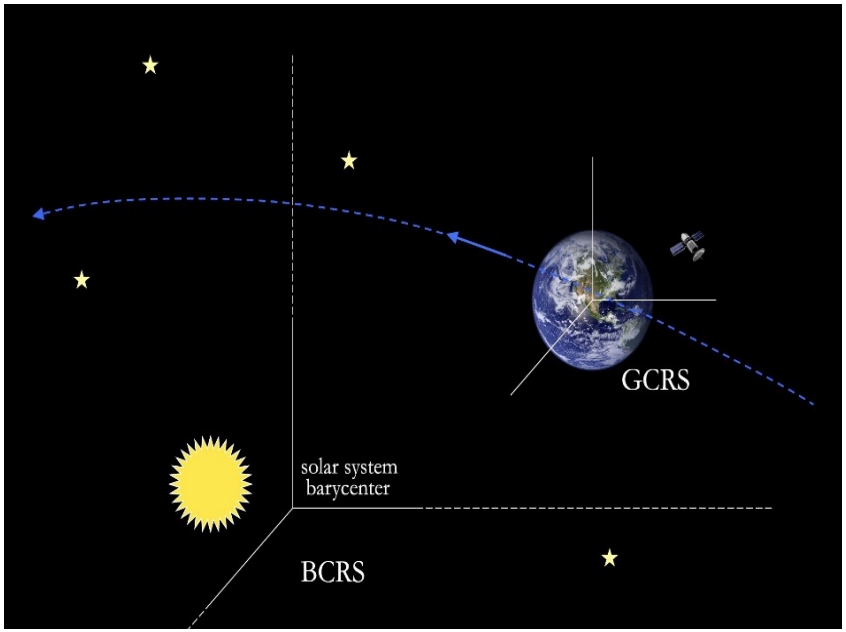
- BIPM's proposals for the Lunar Reference Time
- Implementation constraints

Discussion

Standards provide interoperability for safety and integrity of operations.

Lunar Reference Frames





Reference System: conventions, algorithms and numerical constants, and models
Reference Frame: attaches system to the real world; establishment of real positions; "realizes" a coordinate system

Lunar Reference Time

Proper time:
time kept by a perfect clock

Coordinate time:
time dimension of a reference system
Idealized mathematical construct
not physically measurable

$$d = v_o t + \tfrac{1}{2} a t^2$$

TCL (LCRS) ***4D*** ***TCB (BCRS)*** ***4D*** ***TCG (GCRS)***

Lunar Coordinate Time Adopted 2024

Barycentric Coordinate Time

Geocentric Coordinate Time

Lunar Reference Frame

The XXXIInd International Astronomical Union (IAU) General Assembly,
August 2024, Cape Town SA
"*to establish a standard Lunar Celestial Reference System (LCRS) and Lunar Coordinate Time (TCL)*"

- The same techniques used to construct the Geocentric Celestial Reference System (GCRS) analogous Lunar Celestial Reference System (LCRS); locally inertial

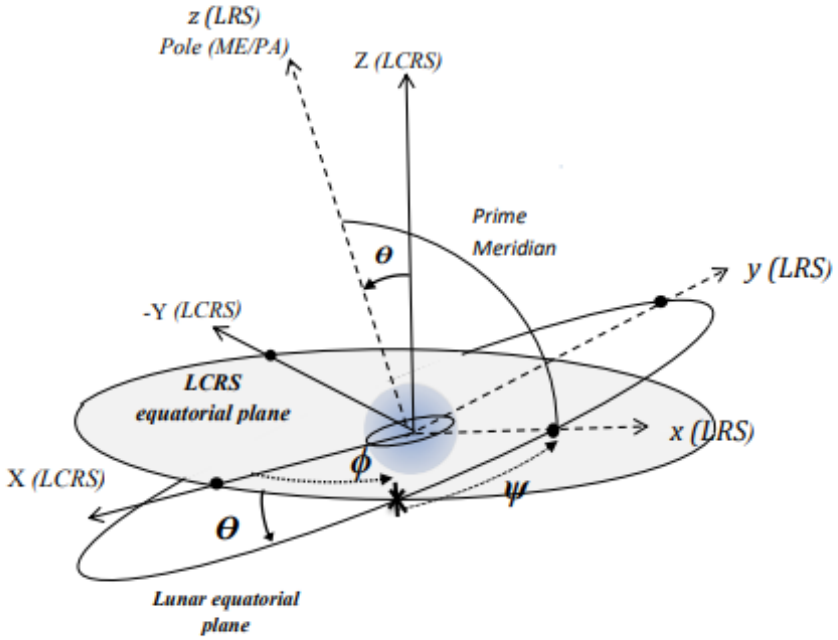
- Time coordinate designated Lunar Coordinate Time (TCL), zero point defined exactly when the reading of TCB be 1977 January 1, 0h 0 m 32.184s at the center of the Moon

- The unit of measurement of TCL be consistent with the SI second

- LCRS origin at Moon center of mass used for Moon-based astrometry; LLO orbit calculations

- A well-defined method that can be used for any celestial body in the solar system.

Lunar Reference Frames



- ✓ **LCRS** : Lunar Celestial Reference System : GCRS
- ✓ **TCL**: Lunar Coordinate Time : TCG

LRS : Lunar (surface-fixed) Reference System/Frame (ILuRS/ILuRF) : ITRF

TL : Lunar Reference Time (to be determined) : TT

Lunar Reference Frame

Conclusions from Last ICG-IOAG Meeting – Feb 2025

- **Implement the Lunar Celestial Reference System (LCRS).**
- **Define an analytical transformation between TCB and TCL** to enable the implementation of IAU Resolution 2024.
- **Support the International Association of Geodesy (IAG)** in establishing a unified standard lunar body-fixed reference system.
- **Collaborate with and endorse the work of the CCTF/BIPM** on a lunar time standard traceable to Coordinated Universal Time (UTC).
- **Strive to extend these standards** to other celestial bodies in the solar system.
- **Update standard terminology** to include cislunar terms.

Lunar Reference Frame

Conclusions from IAU Symposium, LaPlata, Argentia – August 2025

- **Clarify Roles & Responsibilities:** Define the specific roles of international bodies (IAU, IAG, IERS, BIPM) for creating and managing all lunar standards, from reference frames to time.

- **Establish Leadership for Lunar Time:** The BIPM (International Bureau of Weights and Measures) is taking the lead role in coordinating the definition and realization of a practical lunar time scale.

- **Improve Coordination:** Emphasize the vital need for collaboration between scientific bodies and operational users, such as international space programs.

- **Centralize Lunar Standards (Key Proposal):** A proposal to form a joint IAU/IAG working group received strong support.
  - **Goal:** To draft integrated lunar conventions and manage all models in a single, centralized location.
  - **Look to the Future**: Discussed the feasibility of establishing "IERS-like" services for other celestial bodies and the need for best practices in validating ephemerides.

Lunar Reference Frame

ICG-IOAG Meeting Sub-Session on Lunar Reference Frame – Feb 2026

- **Introduction & Strategic Roadmap**
  - Introduction to Lunar Reference Frames: Goals, history, and session outline.
  - Roadmap for International Conventions: The path to consensus and adoption.

- **Implementation & Mission Application**
  - NASA Implementation Plans for Artemis: Requirements and interagency coordination.
  - Mission Case Study: KPLO: Implementation and lessons learned.

- **Technical Foundations & Realization**
  - Realizing the Frame with Lunar Laser Ranging (LLR): Accuracy and standardization.
  - Ephemerides & Dynamical Models: Realizing lunar orientation (INPOP, DE, EPM).
  - The IAG/IERS Perspective: Technical aspects and combined solutions.
  - Defining the Lunar Geoid: Status and impacts.

- **Future Work & Wrap-Up**
  - Next Steps & Future Outlook: VLBI, in-situ frames, and combined solutions.
  - Wrap-Up, Key Issues, and Questions

Thank you for your attention

Lunar Reference Frames

Sub-Session Lunar Reference Frames Summary (TBD)

Lunar Reference Frames & Time

Session Wrap UP & Summary (at Conclusion of Meeting, TBD)

Day 4 Discussion

Suggested Discussion Questions (TBD)