Towards an International Lunar Time Reference – LunaNet Reference Time

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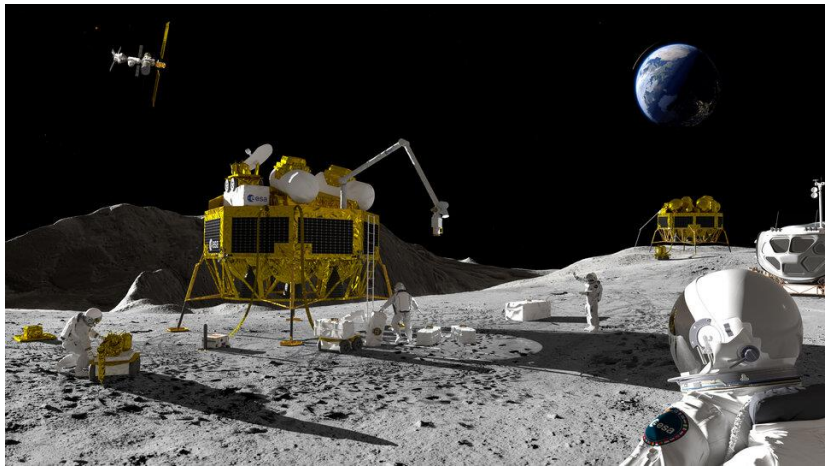
Workshop on Cislunar PNT, Vienna International Centre, from 11 to 13 February 2025

Introduction

- Accurate reference frames and Time are required to support Lunar PNT, and official resolutions/recommendations of the scientific international bodies are not yet covering all operational needs.
- Given the short timeline for Lunar activities – NASA/ESA/JAXA PNT systems are under development - **LunaNet timing aspects** are critical.
- NASA/ESA/JAXA aim for a short-term solution coordinated with partner agencies, allowing the later transition to an international lunar reference frame **(including Time).**

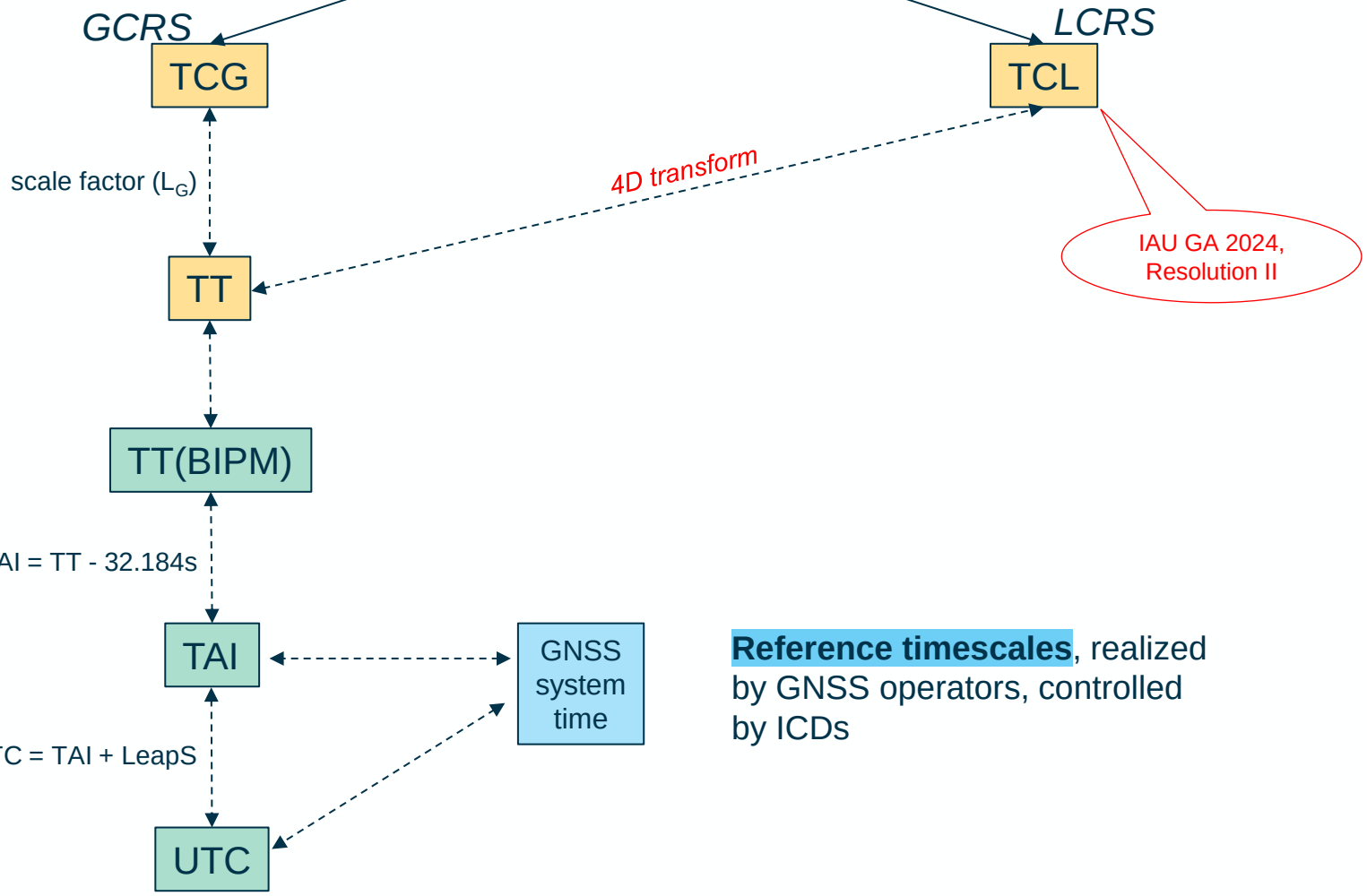


- Key elements:
    1. Interoperability of reference frames and reference time realizations for different Lunar PNT solutions.
    2. International coordination among all involved organisations for their definition and agreement by the international community.

1. LunaNet will define the interoperable parameters for reference systems and time that LunaNet-compliant services must meet.
2. LunaNet PNT plan is to rely on the international standards organization to identify definitions of these critical underpinnings through international recognition and consensus.

LunaNet Starting Point

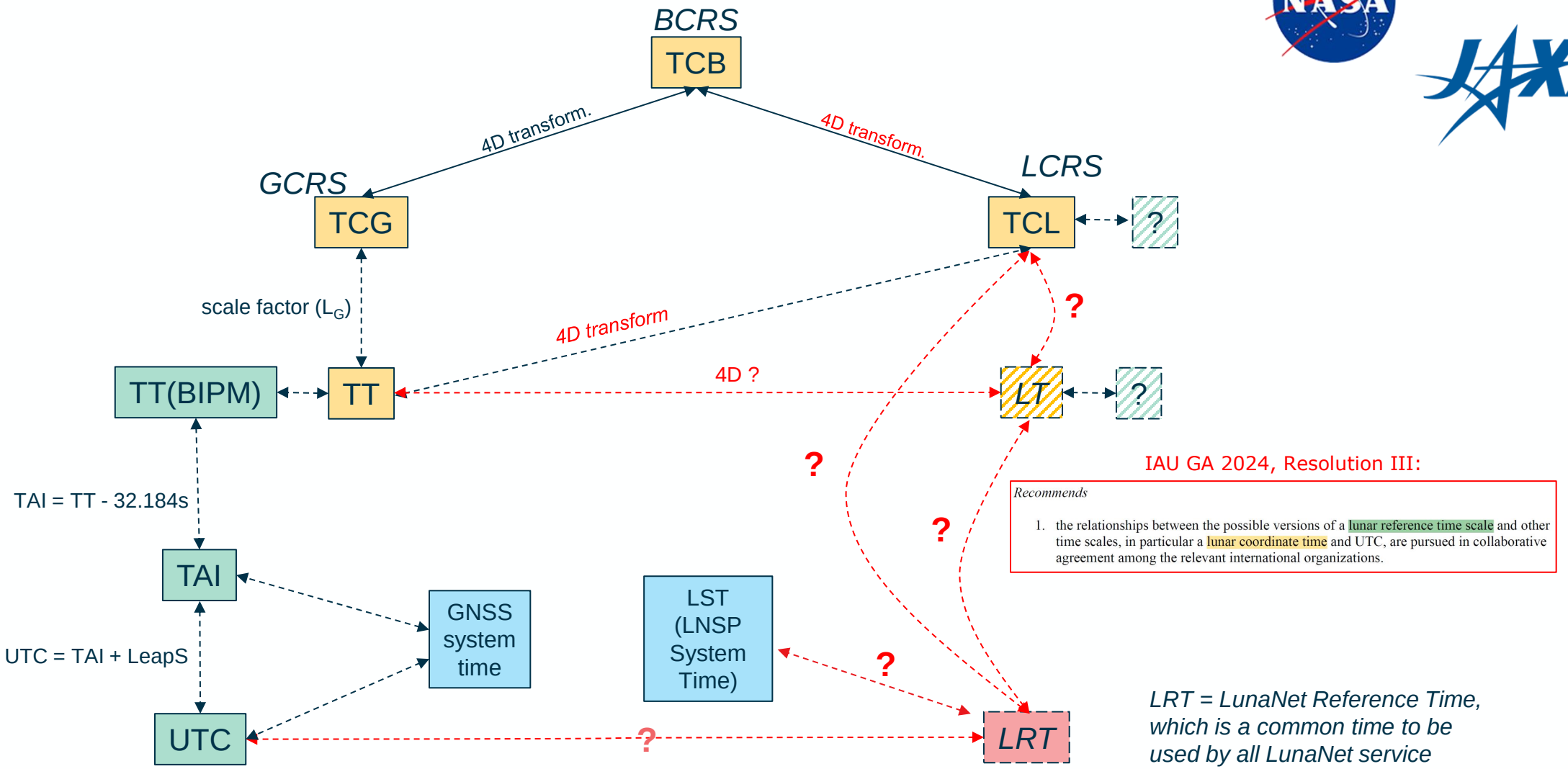
Coordinate time, governed by IAU resolutions



Reference timescales, governed by CGPM/CCTF resolutions, realized and coordinated by BIPM

Reference timescales, realized by GNSS operators, controlled by ICDs

Defining Time on the Moon…



IAU GA 2024, Resolution III:

Recommends

1. 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.

LRT = LunaNet Reference Time, which is a common time to be used by all LunaNet service providers for interoperability purposes

Terminology and Definitions

Given that from IAU GA Res II:

TCL is the Lunar Coordinate Time at the centre of the moon, in analogy with TCG at earth centre

And In line with IAU GA 2024 Resolution III terminology, the following options are being considered by Timing Community:

- Option 1: LRT is a lunar reference time scale that is on the lunar “geoid”, in analogy with UTC
- Option 2: LRT is a lunar reference time scale that is at the moon centre, with no analogy with Earth case

Noting that IAU GA Res III is titled:

Resolution on the establishment of a coordinated lunar time standard by international agreement

Recommends

1. 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.

We are asking the international timing community to define terminology and standards for lunar reference time!!

Realizing Reference Time for LunaNet

- **Key elements for the realization**

  The realization of the LunaNet reference time shall:

  - Be Interoperable by definition.
  - Be traceable to Coordinated Universal Time (UTC)
  - Consider the possibility of physical realization with infrastructure deployed on the Moon (long term)

- **Different approaches are under discussion**

  - a phased approach needs to start from an agreed upon mathematical model
  - Lunar time aligned to UTC (proportional to UTC + PL)

    Where PL is the periodic component of the frequency shift caused by the difference of gravity potential and velocity between Earth and Moon.

  - Proper time from clocks in the cislunar environment

- **Different options can be explored to support short and longer term needs**

Way-forward

- We recommend to start from existing internationally agreed standards, resolutions and recommendations (IAU, IAG, BIPM etc), and clear terminology and associated definition shall be agreed at international level.
- There are different options for the lunar reference time scale (e.g. Moon centred or on lunar geoid or scaling towards UTC).
- The level of validation possible for the Earth-Moon transformation model via in-situ clocks will be affected by various error contributions that need to be properly identified, analysed and quantified.
- LunaNet is identifying a set of open points and questions that need to be addressed by relevant international bodies.
- Timeline of phased approach needs to be elaborated to ensure provider implementation can be in line.