CGPM

Towards a Moon reference timescale

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Chair of the CCTF Task Group on Moon time

Time on the Moon?

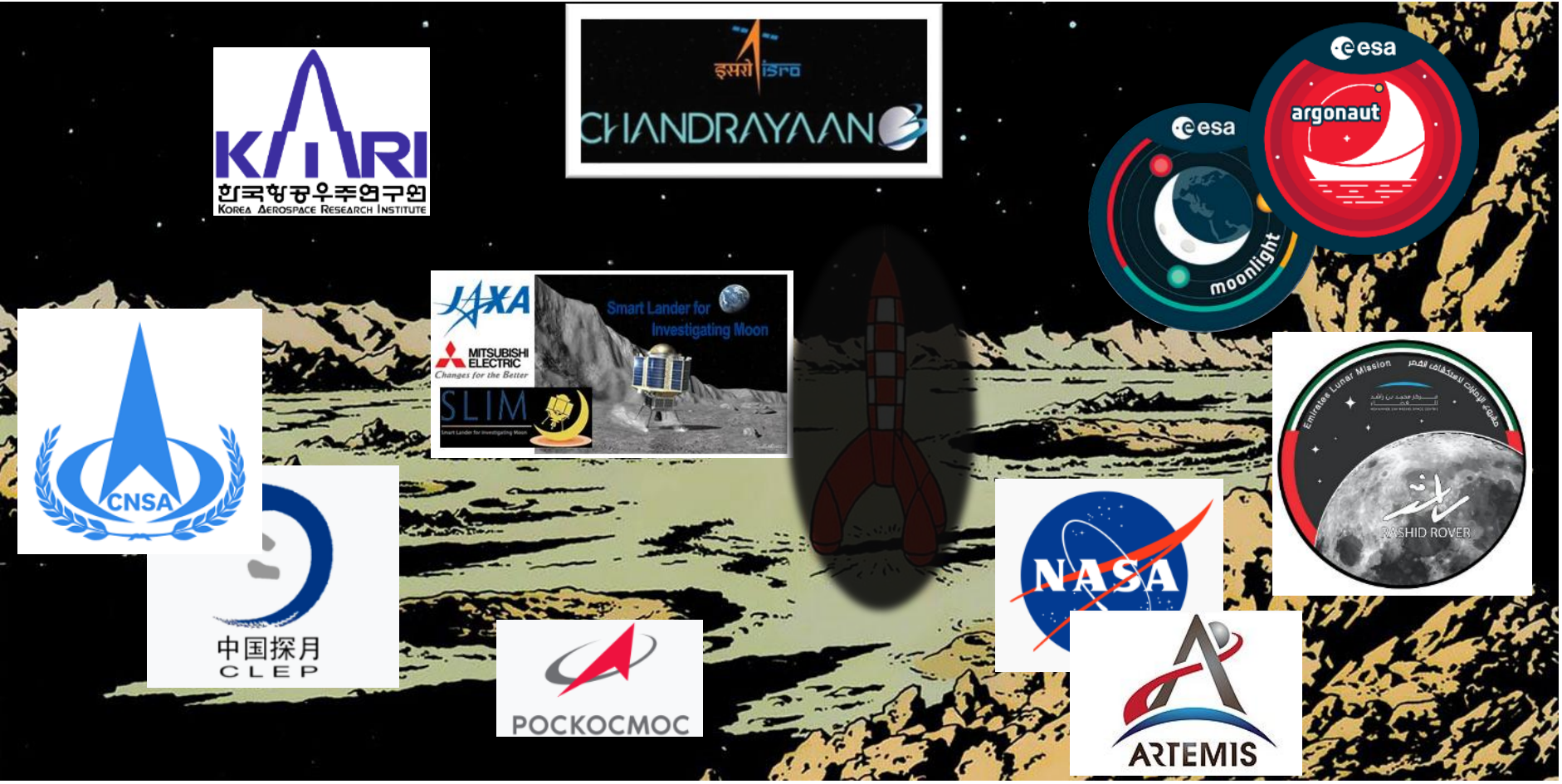


Apollo missions :
no need for high accuracy timing

Some missions required precise timing, but working on their own
→ no need for coordination



Existing Lunar Programs



Need for a common reference

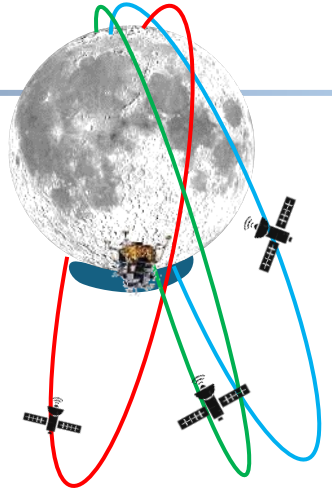
Increasing need for safe navigation

→To land accurately

→To find your way

→To communicate with Earth stations

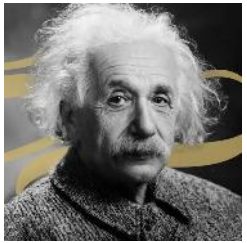
→To make funny science



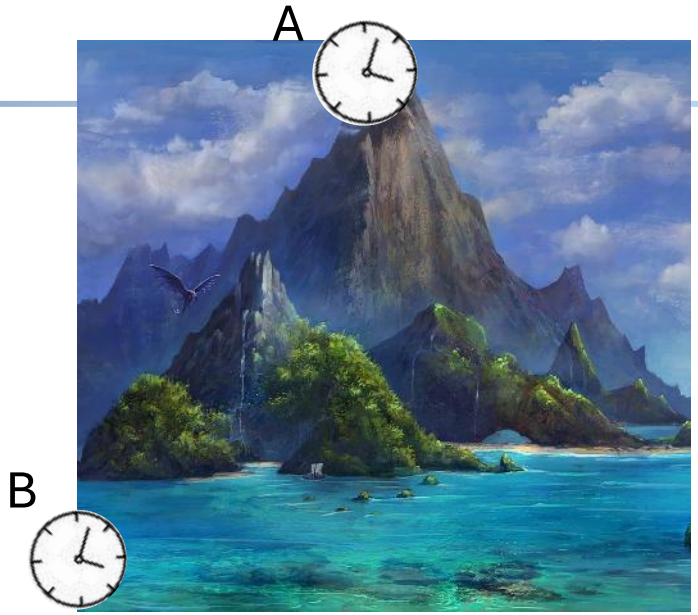
Several systems from different space agencies → need for coordination:
define a common reference system
define a common reference time → ask BIPM → CCTF Task Group

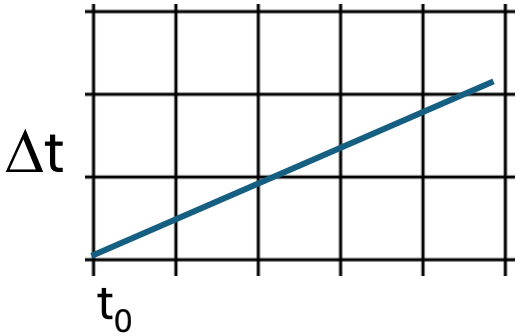
First interested bodies: space agencies
But
Possible impact for all countries in the future
→ International collaboration for Lunar Time as for UTC

Relativity of time



Time contraction with gravity
Time dilation with velocity

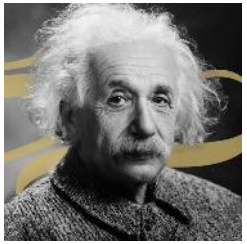




~ few ns /day

Starting the clocks at same time t_0
clock A will show an increasing advance with respect to B

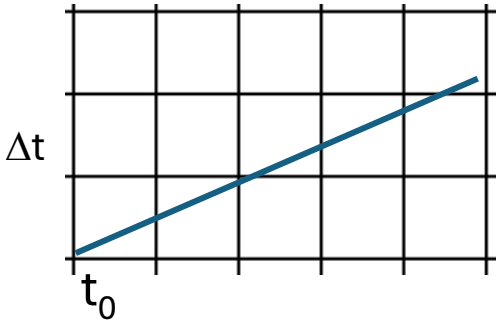
Relativity of time between Earth and Moon



Time contraction with gravity
Time dilation with velocity

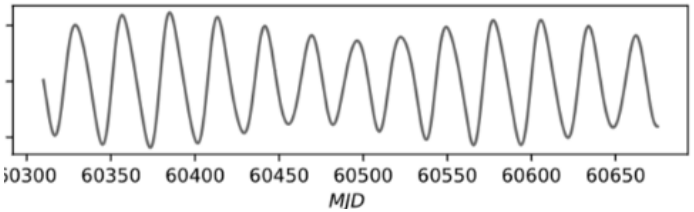


Moon clock – Earth clock



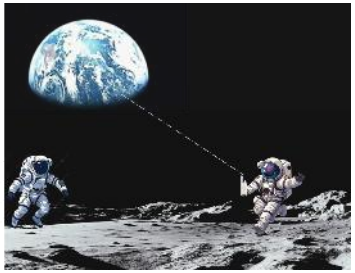
~ 56 μs/day
(1 s in 50 yr)

After drift removed



Monthly Periodicities, ~μs
position-dependent

UTC cannot be the reference on the Moon

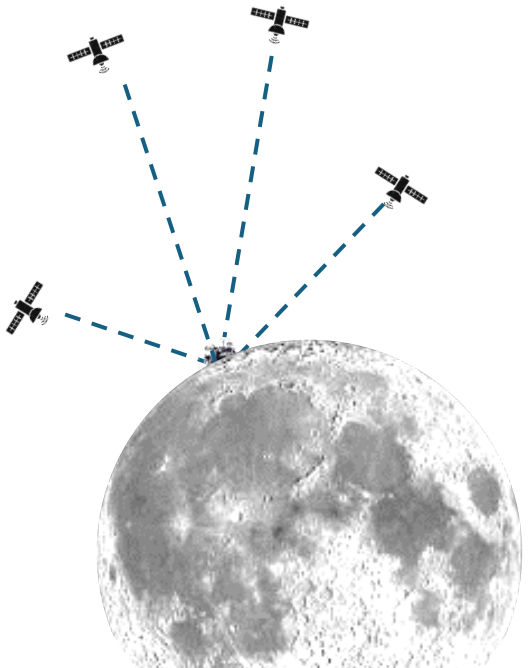


Use UTC ??

OK → ~milliseconds

Navigation signals : 300.000 km/h

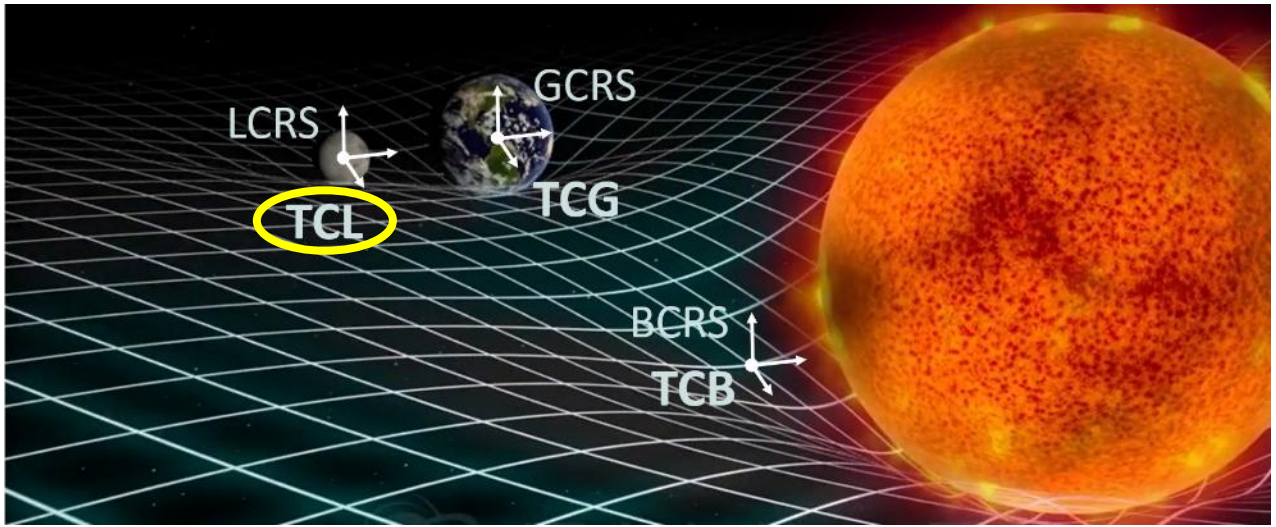
Synchronization needed between satellites
A few ns errors ~ a few meters in position
→ UTC cannot be directly used



→ Need to fix Reference Time for the Moon

Choosing a reference time

4D Reference systems
defined by the International Astronomical Union (IAU)



Natural systems

Governed by known relativistic transformations

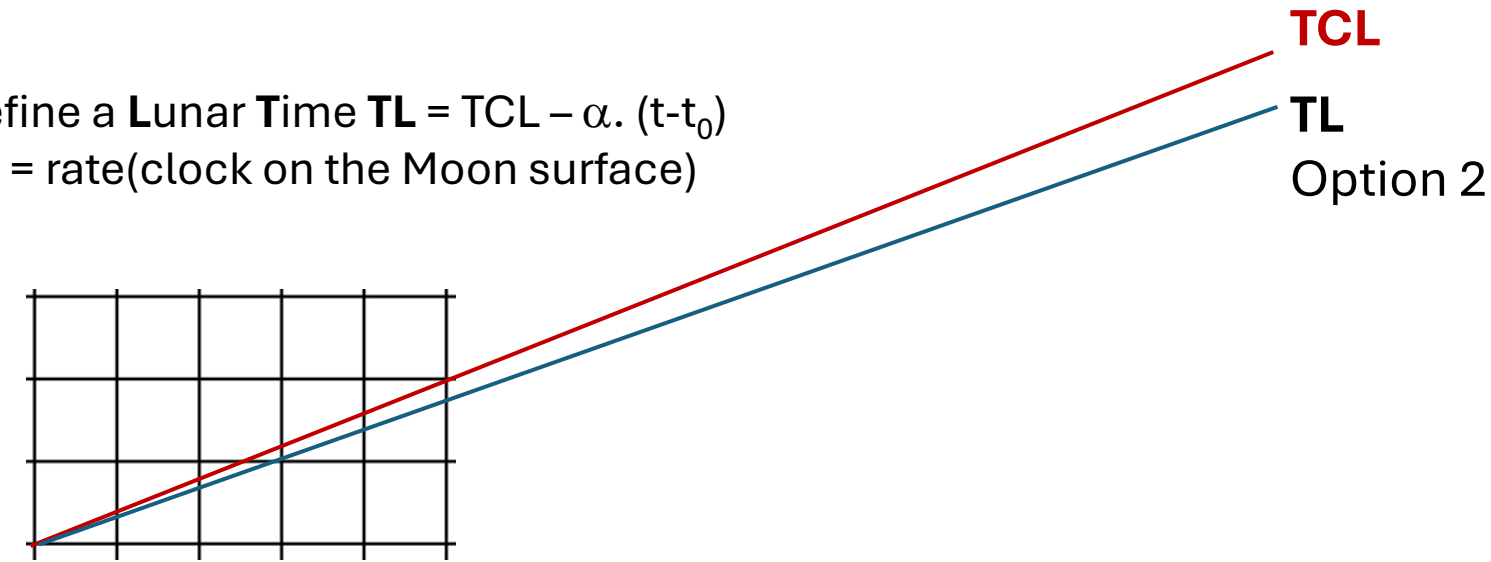
TCL = **L**unar **C**oordinate **T**ime of 4D relativistic system (x,y,z,t)

Reference Lunar Time: Should be either **TCL** or a linear function of TCL

2 options were considered

Option 1: Use **TCL** (**L**unar **C**oordinate **T**ime)
= the coordinate time scale of the LCRS (Lunar Celestial Reference System)

Option 2: define a **L**unar **T**ime **TL** = TCL – α. (t-t_0)
→ rate(TL) = rate(clock on the Moon surface)



Impacts of the choice of the reference

	Option 1 TCL	Option 2 TL
Independent of geoid definition	✓	☒
Avoid scaling	✓	✗
Realization, Steering correction	✓	✓
Traceability to UTC	✓	✓
Access to the SI second	✓	✓
….		

FAQ https://www.bipm.org/documents/d/guest/faq-moon-time

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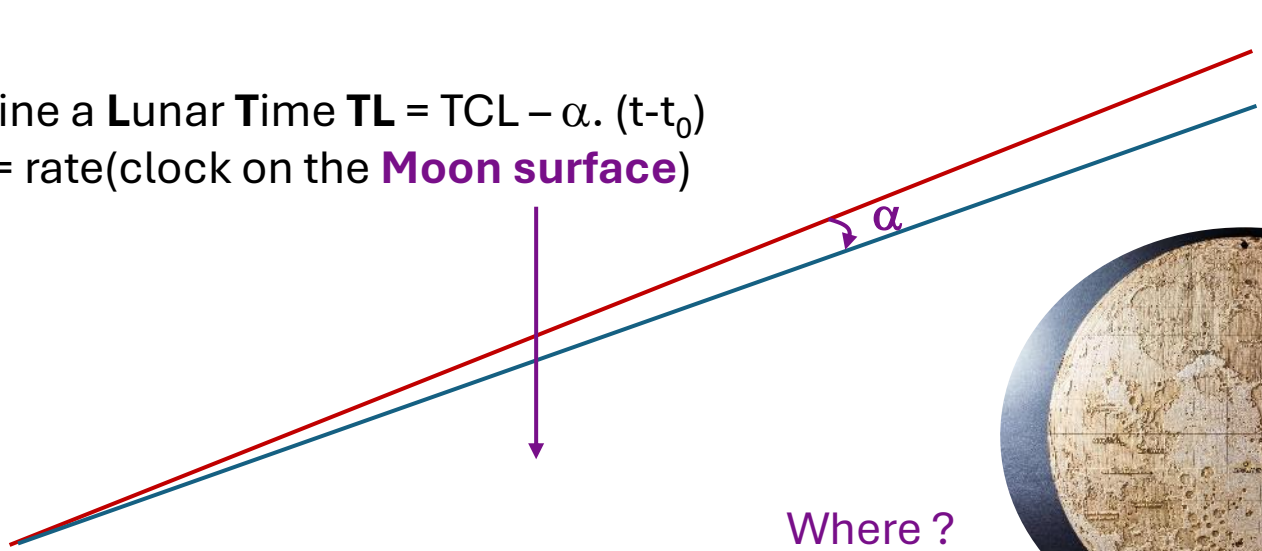
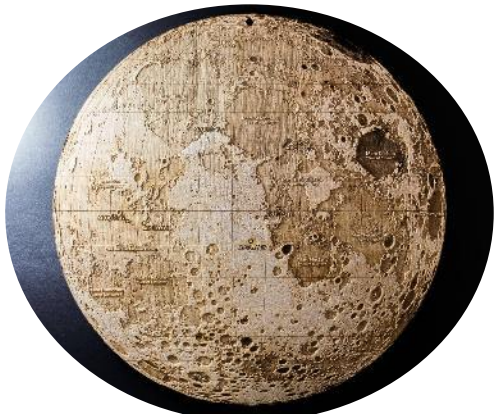


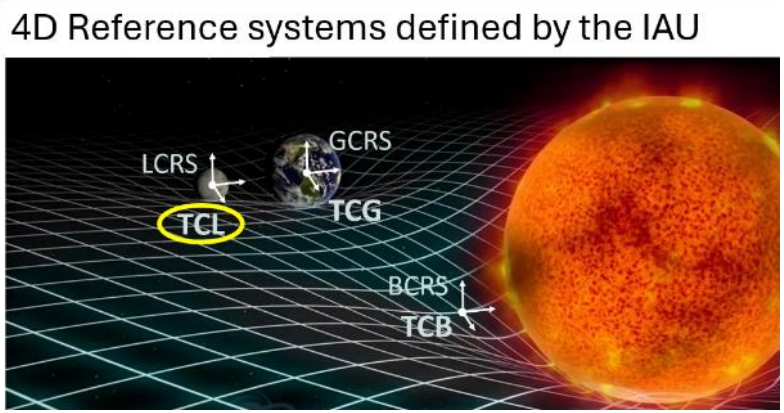
Option 2



[-10,+10] km

Where ?
Geoid like for the Earth ?
To be defined by **International Association of Geodesy**

Impact of a scaling



Natural systems:

1 s of TCL associated with 1 m of LCRS
associated with 1 kg (Plank Constant)

Lunar **T**ime **TL** = **TCL** – α. **(t-t$_0$)**

Change of reference time

→ change of reference second : 1 second (TL) > 1 second (TCL)

1 s (TL) = (1 – α) s (TCL)

Impact of a scaling

Scaling the time TL = TCL – α. (t-t_0)

→ scaling distances : x' = (1-α). x and scaling mass parameters (GM)'= $(1-\alpha)$. GM

Doing the same for Mars with a parameter α_{Mars}

→ scaling distances : x'' = (1-α_M). x and scaling mass parameters (GM)''= $(1-\alpha_M)$.GM

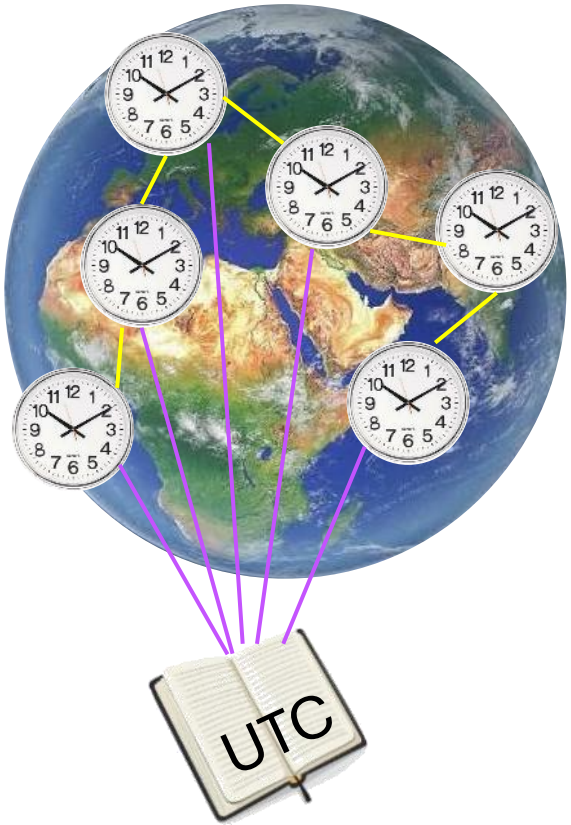
Additional complexity:

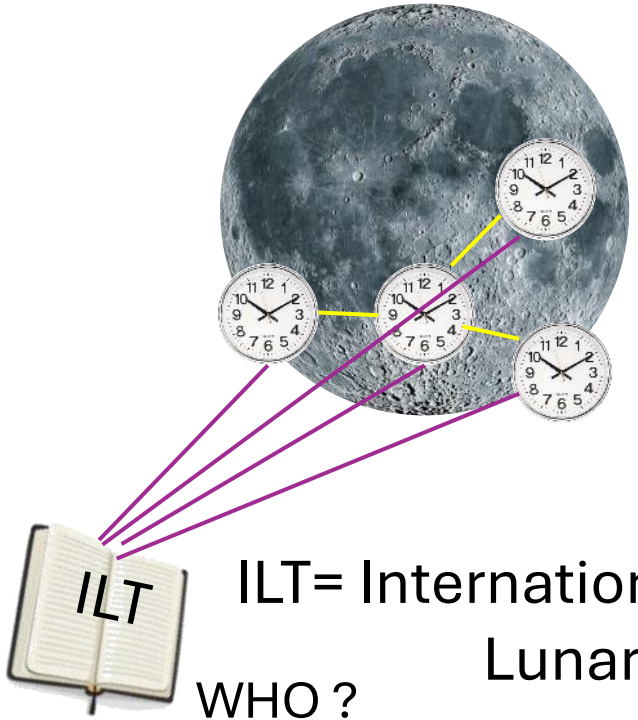
coefficients in all transformation equations between Barcycentric, Moon, Earth, Mars, … coordinate systems

→ Risk of confusion, risk of error

→ Preferable to avoid scaling

A coordinated time on the Moon?



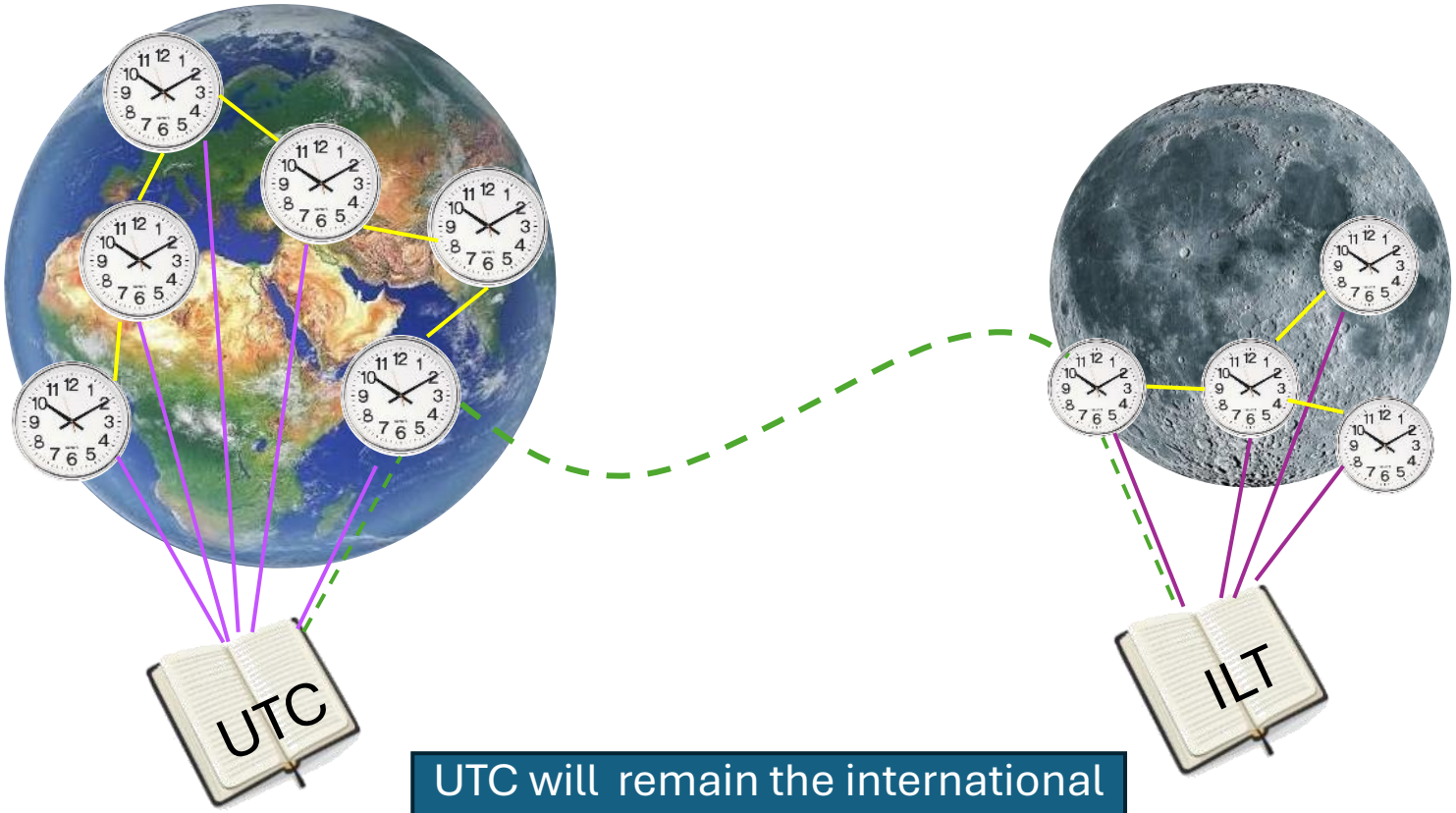


ILT= International Lunar Time

WHO ?

WHERE ?

Traceability of Lunar time to UTC



UTC will remain the international reference

Conclusion / Way forward

- Up to now, the works of the CCTF Task Group on Moon Time show that

  - both options TL and TCL fulfill the metrological requirements
  - Primary realization of both options is equivalent
  - Scaling like TL = TCL – α.(t-t_0) induces risk of complexity and error
  - TL should not be defined as long as a lunar geoid is not defined by the IAG

- A FAQ is available on https://www.bipm.org/documents/d/guest/faq-moon-time

Future work of the Task Group

- Continue the interaction with space agencies to answer their questions, and consider their operational needs,
- Ensure the traceability to UTC of Lunar time scale realizations
- Coordination with the IAG / IAU about the Lunar space/time reference systems

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Thank you
for your attention