

Lunar Reference Frame – Status and Possible Updates

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Introduction: The IAU Working Group on Cartographic Coordinates and Rotational Elements (WG) has made past recommendations regarding the lunar reference frame [1]. Over the last 2 years both the Artemis III SDT report [2] and the LEAG-MAPSIT LCDP SAT report [3] has included recommendations for an updated lunar reference frame. In addition Ryan et al. [4] have published new Solar System ephemeris results that include a new lunar laser ranging (LLR) solution and lunar orientation ephemerides. The latter includes the DE440 ephemeris in the ME frame (defined below), which is compatible with their earlier DE421 ME frame recommended for use by the WG. Besides NASA's interest in improving the lunar frame, the USA National Geospatial-Intelligence Agency is considering the creation of a Lunar Reference System, which would incorporate a lunar frame definition [5].

Given the recent activities and interest on the lunar reference frame, and the expected increase in lunar missions by the USA and other nations, both robotic and human, it is appropriate for the WG to consider updating the recommendations on a lunar reference frame in its next main report or a separate report. The purpose of this abstract is to solicit input for such a recommendation.

Background: Two different coordinate systems have long been in use for the Moon. These are the Mean Earth/polar axis (ME, sometimes MER for Mean Earth/Rotation) and the Principal Axis (PA) systems. In brief, ME is defined by having 0° longitude in the mean direction of the Earth and an equator defined by the mean direction of the lunar pole, whereas PA is defined by the axes of the principal moments of inertia of the Moon (e.g., see [1]). The WG previously has recommended the use of the JPL DE421 ephemeris, rotated to an ME frame for defining lunar coordinates.

Issues to Consider: The Moon is one of few bodies in the Solar System without a specific longitude defining feature. After many years of discussion, it may be timely to finally use an LLR solution to define the lunar reference frame, following long-standing IAU and WG recommendations [1, p. 7]. Currently a particular such LLR solution is already the underlying basis for the DE421 ME frame. So such a solution and similar future improved solutions could instead serve to directly define the frame in the ME system, and in practice would match in a no-net rotation sense the existing recommended DE421 ME frame.

Separately, the lunar orientation model could now be specified by using the JPL DE440 ephemeris in the ME frame. The new JPL solutions use substantially more available data, and improved modeling compared to the previous (2008) DE421 solution. Differences from the previous model are on the order of 1 meter at the most during the early part of this century. Differences in the underlying LLR solutions are < 1.5 meters. Such differences are not so significant as to be noticeable in the positioning of data products except at the highest current levels of accuracy. This update would nevertheless help to prepare for the best future accuracy, by removing one minor source of error.

The current JPL products are the most likely data sources for updating the lunar frame in the near term, as they appear to be the most recent LLR solution and ephemeris results. Eventually, updates would need to consider LLR solutions and ephemerides from other sources, possibly in some sort of combined solutions.

Arguments for and against updating the lunar reference frame definition will be covered in the meeting presentation.

Request for input: The WGCCRE is requesting feedback from the lunar community on these issues. Is using (the current new JPL) LLR solution to define the lunar reference frame appropriate? Is using the DE440 ephemeris in the DE421 ME frame appropriate as a new lunar orientation model? Are there other LLR and lunar ephemeris solutions that could be considered for use in this process? Feedback to the lead author is welcome, preferably by the time of or at the PSIDA meeting. We hope to complete the next version of our main WG report by the end of this year and possibly include an update for a recommended lunar frame definition.

References:[1] Archinal et al. (2018) *Report of IAU WGCCRE...*, *CMDA 130:22*. [2] NASA (2020) *Artemis III Science Definition Team report*. NASA/SP-20205009602. [3] LEAG-MAPSIT Special Action Team (2021) *Final Report of the Lunar Critical Data Products SAT*; see MAPSIT website. [4] Ryan et al. (2021) *The JPL Planetary and Lunar Ephemerides DE440 and DE441*, *Astron. J.* 161(3), 105. [5] Garner, T. (2022), *Developing a Lunar Reference System for Navigation Safety*, ION International Technical Mtg.

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