Relativistic Lunar Time, Lunar Dynamics and A Proposal for an Adjusted Lunar Time

Thomas Marshall Eubanks*[1]

[1]Space Initiatives Inc – United States

Abstract

The proper time on the Moon runs at a different rate from terrestrial proper time (and thus TAI) due to a combination of kinematic and gravitational red-shifts. This includes both a long-term quasi static blue shift, and a large set of periodic time-rate shifts, mostly due to the elliptical lunar orbit and its perturbations. The long term mean lunar surface proper time runs faster than the terrestrial surface proper time by 6.48154x 10ˆ-10 s/s or 56.0005 micro seconds / day. The largest periodic term, due to the lunar equation of the center (its orbital ellipticity) has the period of the mean anomaly (27.5545 days) and an amplitude of 1.27847 x 10ˆ-12 s/s, giving a monthly amplitude of _˜479.667 nanoseconds between the terrestrial and lunar surface proper time. The largest indirect variable solar time-shift, from the solar evection, will cause a clock rate shift with an amplitude of 1.0784 x 10ˆ-13 s/s or 47.174 nanoseconds, while the direct solar tidal time-shift (the differential solar redshift over the lunar orbit) amounts to 6.517 x 10ˆ-14 s/s at 1 AU. The largest differential planetary clock rate-shift is that due to Venus, _˜7.5 x 10ˆ-18 at closest approach, and the lunar solid body tides cause even smaller clock rate changes, amounting to order 2 x 10ˆ-18 s/s at mid-latitudes.

Modern space flight qualified clocks will be able to observe at least some of these lunar clock rate-shifts, and the Moon may be the first place in the solar system where chronometric geodesy becomes an important scientific tool. Lunar fiducial sites combining Lunar Laser Ranging retroreflectors, Very Long Baseline Interferometric beacons and other geodetic and astrometric tools, would certainly benefit from the collocation of accurate clocks and (when possible) two-way time transfer with the Earth. Once the absolute position of a surface fiducial point is determined to within a fraction of a meter, it should be possible to predict its future position to the meter level for months into the future, making such fiducial points important reference points for autonomous lunar navigation in systems such as the proposed LunaNet.

The expanding amount of lunar exploration and resource utilization will in the relatively near future require a definition of a lunar time standard. Given the close connection between lunar activities and the Earth at present, and the success of adjusting many GNSS satellite clocks to run at the TAI rate, it seems reasonable, and almost inevitable, that this time will be a Lunar Adjusted Time (LAT), where the clock rates are slowed by 6.48154 x 10ˆ-10 s/s to make the mean clock rate agree with TAI. LAT would at all times match TAI to within _˜ 1 microsecond, which would be sufficient for many uses, but clocks on the Moon would stay in synchronization to better than 10ˆ-17 without further adjustment. Of course, the detailed sub-microsecond changes between LAT and and TAI could be accurately predicted

*Speaker

and applied from the dynamical ephemeris, if necessary for years into the future. Clearly, timing and lunar clocks will play an important part in the future of lunar exploration, and the time is now ripe to develop a temporal standard for the future.