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CPF calculation in circumlunar satellite laser ranging observations

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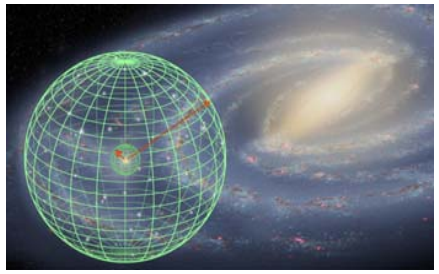
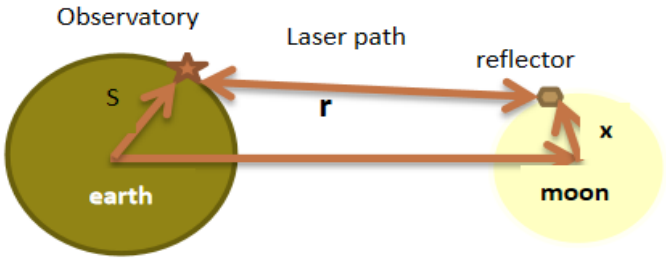
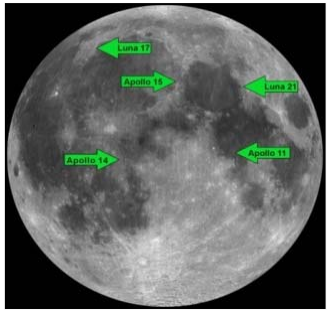
Context



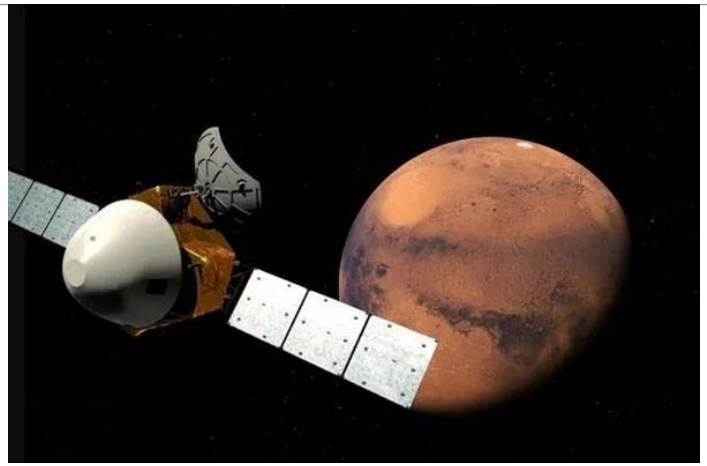


The mode of Lunar Laser Ranging

LLR at YNAO



The distribution of lunar retroreflectors



Launching artificial satellites to the vicinity of celestial bodies is a primary means for humans to explore target celestial bodies.

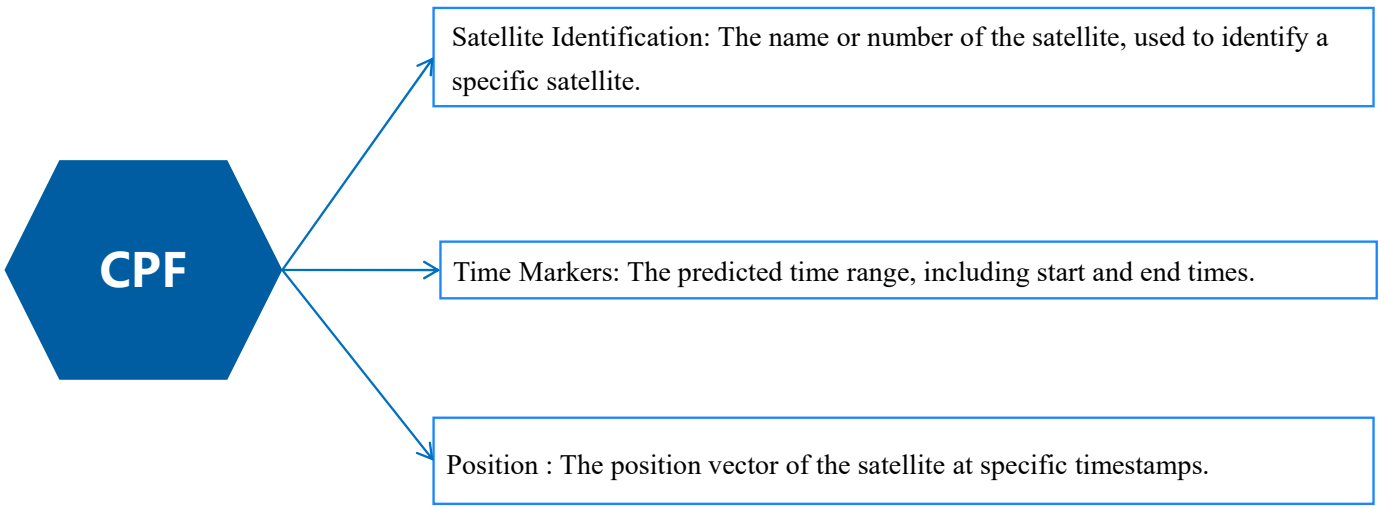
During the flight process, the artificial satellite needs to perform multiple orbital controls and maneuver to its predetermined orbit.

In this process, the determination of the satellite's orbit is crucial, and satellite laser ranging is the most effective technical means for precisely measuring the distance to the satellite.

Context

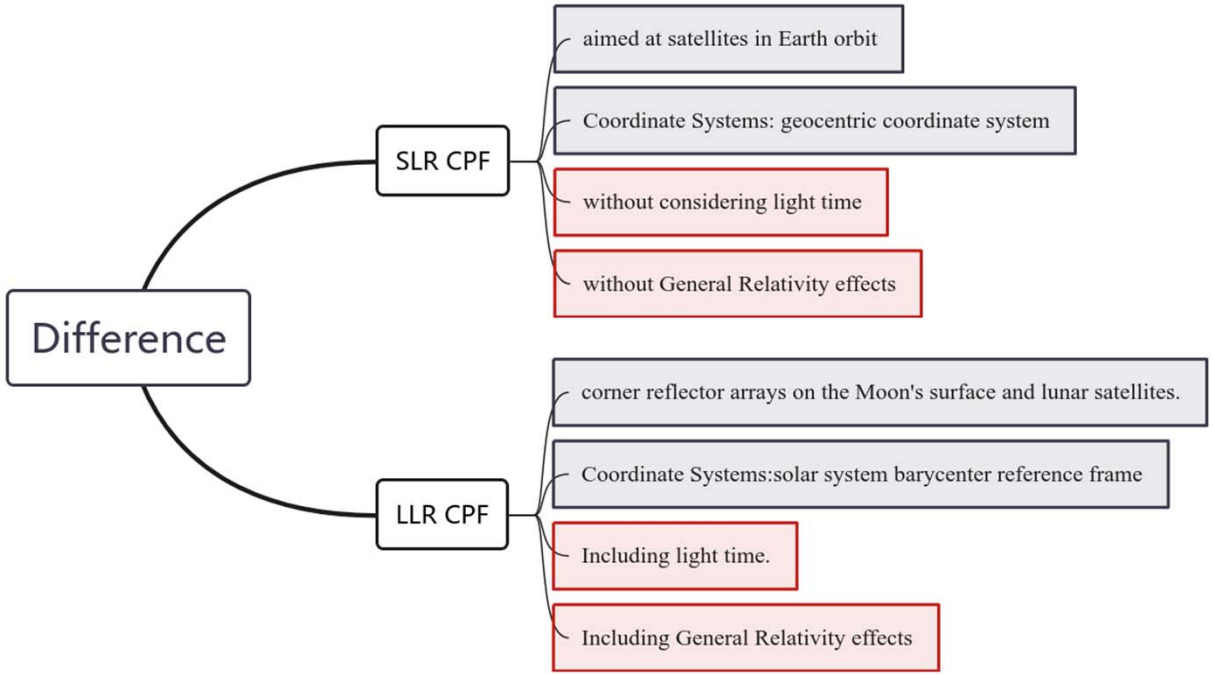
CPF（Consolidated Prediction Format）:

- CPF is a standardized file format used for storing and exchanging satellite orbit prediction data. The CPF file contains key information required for satellite laser ranging
- The CPF file is a key component in satellite laser ranging activities, ensuring that ground stations can accurately point to the satellite and emit laser pulses at the right time for precise distance measurements.



Context

The differences between Lunar Laser Ranging (LLR) and Satellite Laser Ranging (SLR) in Consolidated Prediction Format (CPF) files.



For circumlunar satellites, the generation format of the LLR CPF files should be utilized.

Methods

Coordinate system transformation (ITRS to ICRS)

The coordinates of the station are in the ITRS , while the coordinates of the circumlunar satellite are described in the ICRS. Therefore, we need to uniform it to the same coordinate system.

Time conversion :(UTC to TDB)

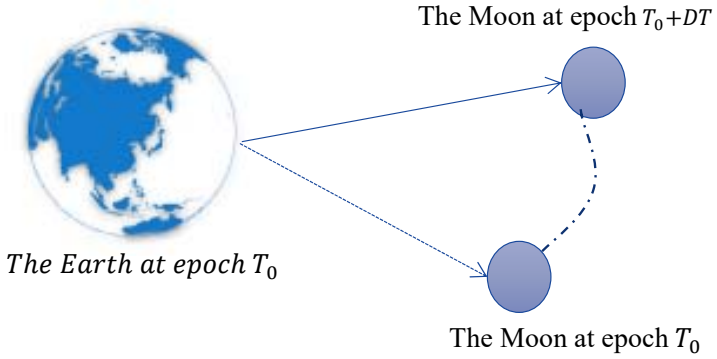
The observation station uses UTC , while the ephemeris is TDB time. It is necessary to unify the time to TDB.

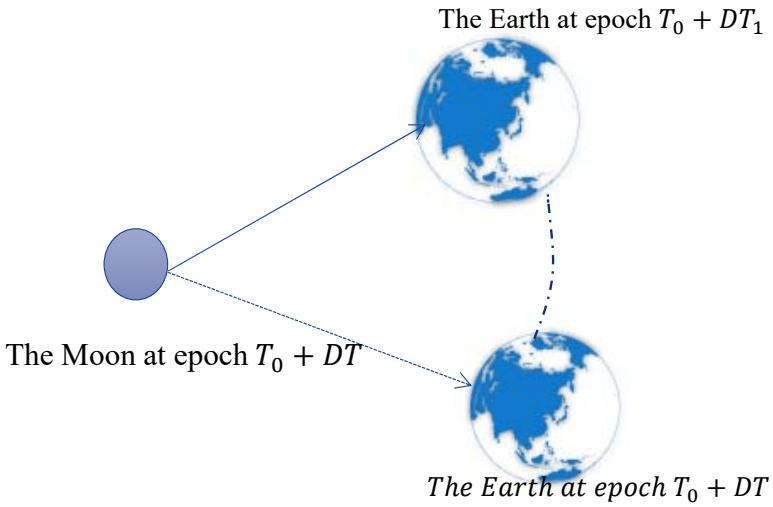
General Relativity effects：

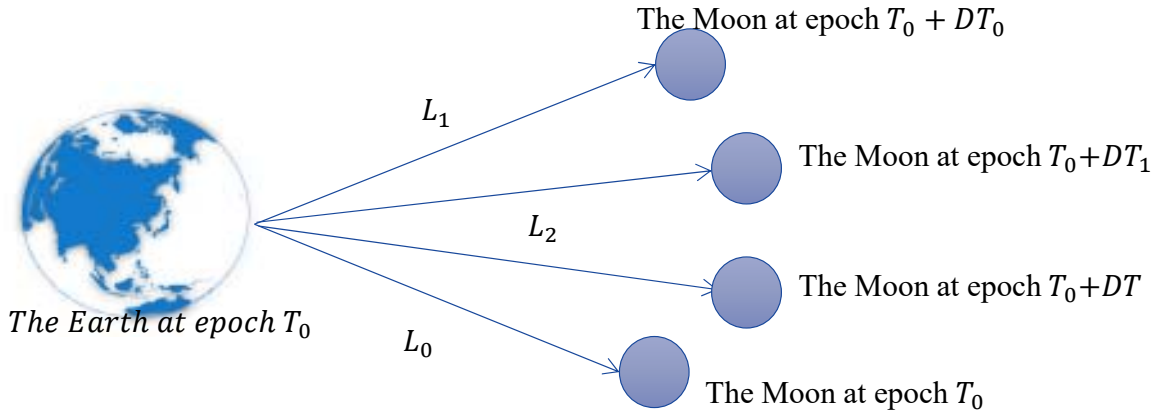
Due to the gravitational effects of celestial bodies such as the Sun, Earth, and Moon, lasers will experience varying degrees of bending as they propagate through gravitational fields. Thereby increasing the light time. This experiment uses the gravitational bending equation from the IERS2010 Conventions to calculate this correction value. The formula is as follows:

$$\Delta t = \frac{\rho}{c} + \sum_{J} \frac{2GM_J}{c^3} \ln\left(\frac{r_{J1} + r_{J2} + \rho}{r_{J1} + r_{J2} - \rho}\right)$$

Methods







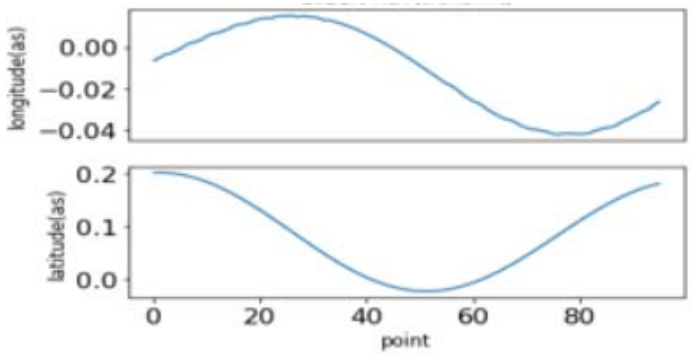
(1) Starting from the geometric position at the given T_0 (initial) epoch, calculate the estimated light time DT_0 from the observer to the celestial body to obtain the initial distance L_0.

(2) Based on the motion velocity of the celestial body, compute the new position at $T_0 + DT_0$ (Initial time plus light time)and recalculate the distance L_1, estimating the light time DT_1.

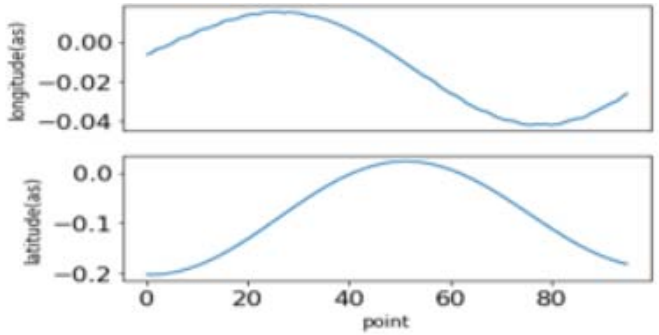
(3) Based on the motion velocity of the celestial body, compute the new position at $T_0 + DT_1$ and recalculate the distance L_2, estimating the light time DT_2.

(4) When DT_n-DT_{n-1} difference of light time is approximately equal to zero, the precise light time $DT_n$is determined, from which the accurate apparent position of the celestial body can be determined

Conclusion



The forecasted launch position is differenced with the CPF file (with each time point spaced 15 minutes apart).

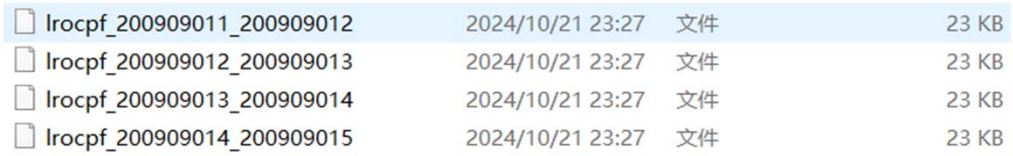


The forecasted reception position is differenced with the CPF file (with each time point spaced 15 minutes apart).

Conclusion: The difference between the laser transmission and reception positions and the CPF file published by the ILRS shows that the difference in the longitude direction in the geocentric coordinate system is 0.2 arcseconds, and the latitude difference is less than 0.1 arcseconds. Further experiments indicate that this difference does not increase when transformed into the observation station's coordinate system. Therefore, the differences in the longitude and latitude directions of the generated file are both better than the pointing accuracy of 1 arcsecond of the 1.2-meter telescope at the Yunnan Observatories, indicating the feasibility of the CPF file.

Conclusion

Generate CPF file of LRO(Lunar Reconnaissance Orbiter)



lrocpf_200909011_200909012 - 记事本

文件(F) 编辑(E) 格式(O) 查看(V) 帮助(H)

```
H1 CPF 2 YNO 2024 10 21 15  90 7 LRO    imcce_inpop21
H2 103 103 0 2009 9 11 0 0 0 2009 9 12 0 0 0 900 0 1 0 0 0 3
H9
10 1 54708      0.0 0     -175172928.486     -323458590.004      96737370.326
10 2 54708      0.0 0      175234190.366      323497396.448     -96765008.388
30 1       -704.    -35619.     13821.    25.6
10 1 54708    900.0 0     -195281050.717     -311694617.959      97112714.961
10 2 54708    900.0 0      195344800.880      311729463.931     -97140360.013
30 1       -3033.    -35502.     13824.    25.6
10 1 54708   1800.0 0     -214602275.127     -298682305.078      97487490.199
10 2 54708   1800.0 0      214668257.240      298713030.956     -97515142.237
30 1       -5348.    -35233.     13828.    25.6
10 1 54708   2700.0 0     -233059214.156     -284474102.415      97861694.073
10 2 54708   2700.0 0      233127161.650      284500565.189     -97889353.098
30 1       -7642.    -34814.     13831.    25.6
10 1 54708   3600.0 0     -250577965.421     -269127251.167      98235324.618
10 2 54708   3600.0 0      250647602.556      269149325.090     -98262990.627
30 1       -9904.    -34245.     13835.    25.7
10 1 54708   4500.0 0     -267088407.751     -252703551.720      98608379.864
10 2 54708   4500.0 0      267159450.749      252721128.903     -98636052.856
30 1      -12124.    -33529.     13838.    25.7
10 1 54708   5400.0 0     -282524481.904     -235269114.511      98980857.839
10 2 54708   5400.0 0      282596640.098      235282105.431     -99008537.814
30 1      -14293.    -32670.     13842.    25.7
10 1 54708   6300.0 0     -296824454.983     -216894093.546      99352756.573
10 2 54708   6300.0 0      296897431.995      216902427.485     -99380443.526
30 1      -16401.    -31670.     13845.    25.7
10 1 54708   7200.0 0     -309931167.329     -197652403.794      99724074.092
10 2 54708   7200.0 0      310004662.319      197656029.209     -99751768.025
30 1      -18440.    -30535.     13849.    25.7
```

The generated file complies with the format for lunar laser ranging and can meet the needs for ranging of circumlunar satellites.


Thank you teachers and professors for listening