Planned LLR station in Russia and its impact on the Lunar Ephemeris Accuracy

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• Precise modern Lunar Ephemerides (DE/LE, INPOP, EPM-ERA) are based on only LLR observations obtained at several LLR ground stations during 1969 – 2013 years:

<table>
<thead>
<tr>
<th>LLR station</th>
<th>Time interval</th>
<th>Obs.number</th>
</tr>
</thead>
<tbody>
<tr>
<td>McDonald</td>
<td>1970 March-1985 June</td>
<td>3440</td>
</tr>
<tr>
<td>MLRS1</td>
<td>1985 Jan-1988 January</td>
<td>275</td>
</tr>
<tr>
<td>MLRS2</td>
<td>1988 August-2012 April</td>
<td>3114</td>
</tr>
<tr>
<td>HALEAKALA</td>
<td>1988 August-1990 August</td>
<td>694</td>
</tr>
<tr>
<td>CERGA</td>
<td>1985 Jan-2013 February</td>
<td>9599</td>
</tr>
<tr>
<td>APACHE</td>
<td>2006 July-2012 August</td>
<td>1576</td>
</tr>
<tr>
<td>Total</td>
<td>1970 March-2013 February</td>
<td>18700</td>
</tr>
</tbody>
</table>

• There are two projects of new LLR stations: Altay(Russia) and La Silla(Europe) stations.

Expected impact of new Russian LLR station on the Lunar ephemeris accuracy is the main topic of the presentation.
1. Location: Siberia, Altay Optical-Laser Center, approximate coordinates are (51°N, 82°E, 385 m).

2. **3.12 meter** telescope (Altay Optical-Laser Center) as probable base telescope for the LLR station.

3. Target accuracy of LLR observations (normal point) is about **3mm**.

4. Meteorological conditions: **1400 clear night hours, 240 nights** suitable for LLR observation per year.

5. Major project participants: OJC «Research-and-Production Corporation «Precision Systems and Instruments», VNIIFTRI and IAA RAS.

Motivation and methods are presented below:

- To check the urgency of the project it should be shown in particular that the accuracy of the lunar ephemeris will visibly increase.

- The only way to prove that fact now is the numerical simulation.
Numerical simulation

1. Distribution of real LLR observations (18700) at interval 1970-2013 have been analyzed depending on LLR station:
   • Target reflectors distribution
   • Elevation distribution
   • Observations per day distribution
   • Etc

   ![Reflectors distribution](image1)
   ![Elevation distribution](image2)
   ![Observations number per day](image3)

2. Due to complexity and irregularity of the distributions above it was decided that observation programs of real LLR stations will be used for numerical simulations

3. Observation programs of Apache and Cerga stations have been chosen as the basis to create simulated LLR measurements

4. Special SW was developed for simulation:
   • LLR observations simulation for Altay station
   • Adjusted parameters estimation using both real and simulated LLR measurements
Numerical simulation: scenarios

I.1. 18700 real observations (1970-2013 years) + simulated observations from 2006 till 2013 at Altay station like it was observed at Apache (Apollo) or Cerga station. (in simulation-”Apache 2006”, “Cerga2006”).

I.2. 18700 real observations (1970-2013 years) + simulated observations from 2006 (-1 month shift) till 2013 at Altay station like it was observed at Apache (Apollo) or Cerga station. (in simulation-”Apache 2006shift”, “Cerga2006shift”).

II. 18700 real observations (1970-2013 years) + simulated observations from 2008 till 2013 at Altay station like it was observed at Apache (Apollo) or Cerga station. (in simulation-”Apache 2008”, “Cerga2008”).

III. 18700 real observations (1970-2013 years) + simulated observations from 2012 till 2013 at Altay station like it was observed at Apache (Apollo) or Cerga station. (in simulation-”Apache 2012”, “Cerga2012”).
Simulation results

Impact on parameter's accuracy: "Apache 2006" and “Cerga2006” scenarios

<table>
<thead>
<tr>
<th>N</th>
<th>Parameter</th>
<th>N</th>
<th>Parameter</th>
<th>N</th>
<th>Parameter</th>
<th>N</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X Moon</td>
<td>15</td>
<td>A11 PY</td>
<td>29</td>
<td>CERGA PX</td>
<td>42</td>
<td>C20</td>
</tr>
<tr>
<td>2</td>
<td>Y Moon</td>
<td>16</td>
<td>A14 long</td>
<td>30</td>
<td>CERGA long</td>
<td>43</td>
<td>C21</td>
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<tr>
<td>3</td>
<td>Z Moon</td>
<td>17</td>
<td>A14 PX</td>
<td>31</td>
<td>CERGA PY</td>
<td>44</td>
<td>S21</td>
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<tr>
<td>4</td>
<td>Vx Moon</td>
<td>18</td>
<td>A14 PY</td>
<td>32</td>
<td>Halaek PX</td>
<td>45</td>
<td>C22</td>
</tr>
<tr>
<td>5</td>
<td>Vy Moon</td>
<td>19</td>
<td>L2 long</td>
<td>33</td>
<td>Halaek long</td>
<td>46</td>
<td>S22</td>
</tr>
<tr>
<td>6</td>
<td>Vz Moon</td>
<td>20</td>
<td>L2 PX</td>
<td>34</td>
<td>Halaek PY</td>
<td>47</td>
<td>C30</td>
</tr>
<tr>
<td>7</td>
<td>Libration Θ</td>
<td>21</td>
<td>L2 PX</td>
<td>35</td>
<td>MLRS1 PX</td>
<td>48</td>
<td>C31</td>
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<tr>
<td>8</td>
<td>Libration φ</td>
<td>22</td>
<td>A15 PX</td>
<td>36</td>
<td>MLRS1 long</td>
<td>49</td>
<td>S31</td>
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<tr>
<td>9</td>
<td>Libration ψ</td>
<td>23</td>
<td>MCD PX</td>
<td>37</td>
<td>MLRS1 PY</td>
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<td>C32</td>
</tr>
<tr>
<td>10</td>
<td>Libration dΘ/dt</td>
<td>24</td>
<td>MCD long</td>
<td>38</td>
<td>Apache px</td>
<td>51</td>
<td>S32</td>
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<tr>
<td>11</td>
<td>Libration dψ/dt</td>
<td>25</td>
<td>MCD PY</td>
<td>39</td>
<td>Apache long</td>
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<td>C33</td>
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<tr>
<td>12</td>
<td>Libration dψ/dt</td>
<td>26</td>
<td>MLRS PX</td>
<td>40</td>
<td>Apache py</td>
<td>53</td>
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<tr>
<td>13</td>
<td>A11 long</td>
<td>27</td>
<td>MLRS long</td>
<td>41</td>
<td>Lag Earth</td>
<td>54</td>
<td>T*sidt Moon</td>
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<tr>
<td>14</td>
<td>A11 PX</td>
<td>28</td>
<td>MLRS PY</td>
<td>42</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Adjusted parameters

Impact on parameter's accuracy: "Apache 2006" and “Cerga2006” scenarios

Impact on the Lunar ephemeris accuracy

"Apache 2006" and “Cerga2006” scenarios

Adjusted parameters: initial Lunar state vector and libration angles

- Apache
- Cerga
1. SHELLI (Southern Hemisphere Lunar Laser Instrument) project, location: ESO, La Silla, Chile (29°S, 70°W, 2400m)
2. NTT telescope (3.6 meter) as proposed base telescope for the LLR station
3. As a twin of Apache Point in terms of quality and regularity of the produced data
4. Meteorological conditions: ESO, bordering the southern extremity of the Atacama desert in Chile
5. Probable project participants: ESO, Geoazur (OCA), INSU
Altay vs La Silla station

Altay station: "Apache 2006" and “Cerga2006” scenarios

La Silla station: "Apache 2006" and “Cerga2006” scenarios
Altay vs La Silla station

Altay station: "Apache 2006" and “Cerga2006” scenarios

La Silla station: "Apache 2006" and “Cerga2006” scenarios
Observation conditions: latitude dependence

Elevation of the Moon: Apache, Cerga, Altay

Every 30 min during 0.5 year (2014)
Conclusions

• According our simulations new Russian LLR observations will provide visible accuracy improvement of the Lunar ephemeris and corresponding physical models: about 2-16% depending on the adjusted parameter.

• Simulation SW was developed estimating the impact of new LLR stations on the accuracy of Lunar ephemeris.

• Russian LLR station (Altay) has observational limitation due to geographical position. So, its observation program should be very intensive to provide the impact comparable with other modern LLR stations.

• The received result are in good agreement with analogous works (for example, the paper French colleagues about proposal of installation LLR device at 3.6 m telescope in Southern Hemisphere, La Silla).

• Russian LLR station can give contribution into the common world database of LLR observations.
Thank you for attention