Observations from LEO orbit up to the moon

J. J. Eckl, K. U. Schreiber¹, T. Schüler

Geodetic Observatory Wettzell

Federal Agency for Cartography and Geodesy

¹Technical University of Munich
Two operating modes (from/to GEO):
1. High repetition rate
2. “eye-safe”
3. High energy mode
4. (LLR, Debris)
**“eye-safe” - requirements -**

- **IEC 60825-1:2014 → Class 1 („eye-safe“):**
  - 1064 nm: 7,7e-8 J @ 5 cm, 10 ps → \(~170 \, \mu J\) (WLRS)
  - 532 nm: 7,7e-7 J @ 5 cm, 10 ps → \(~17 \, \mu J\) (WLRS)

- Min. req. NIR Power: \(~0,1\, W\) (link budget)
- Limited in max. rep.-rate: 400 Hz (rt-cal & regen. Amp.)

→ Single Pulse Energy of 170 \, \mu J @ 400 Hz optimum
Alternatively: rotating mirror or polarizer & beam block
- Polarizer & Beam Block
  - 1064 nm „eye-safe“

- Etalon passage < 25 degree in elevation
- 1000 returns in 180 seconds
- Polarizer & Beam Block
  - 532 nm „eye-safe“ -

- Lares passage

- Permanent operation in high repetition rate mode planned with upcoming system automation
### LLR Signal / Noise

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection Efficiency (SPAD)</td>
<td>~50% @ 1064</td>
</tr>
<tr>
<td>PGA-080u-1064TOT (now ARGO)</td>
<td></td>
</tr>
<tr>
<td>Aperture</td>
<td>0.75 m</td>
</tr>
<tr>
<td>Pulse Energy (dual pulse)</td>
<td>75 mJ &amp; 60 mJ</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1.064 nm</td>
</tr>
<tr>
<td>Transmit &amp; Receive Efficiency</td>
<td>???</td>
</tr>
<tr>
<td>Transmit Gain</td>
<td>???</td>
</tr>
<tr>
<td>Field of View</td>
<td>10 arcsec</td>
</tr>
<tr>
<td>Spectral Filter Width</td>
<td>0.35 nm</td>
</tr>
<tr>
<td>Range Gate</td>
<td>~100 ns before</td>
</tr>
<tr>
<td>Optical Alignment</td>
<td>???</td>
</tr>
<tr>
<td>Target Signature</td>
<td>???</td>
</tr>
</tbody>
</table>

→ optimum condition: Expected $N_{pe} \sim 0.2 \%$
Optical Alignment

- Prior to each Lunar observation → adjust the optical axis to ~ 1 arcsec
- Piezo actuator for laser beam steering installed, FoV adjustment pending
- Remote control of telescope retros
Transmit & Receive Efficiency

- Take samples @ different positions of the beam path
- Averaging @ positions with large beam diameter

<table>
<thead>
<tr>
<th>Position</th>
<th>Loss in Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before T/R</td>
<td>10,8</td>
</tr>
<tr>
<td>After T/R</td>
<td>22,8</td>
</tr>
<tr>
<td>After 5 x Expander</td>
<td>36,4</td>
</tr>
<tr>
<td>@ Telescope Output</td>
<td>76,7</td>
</tr>
</tbody>
</table>
Transmit Gain
- seeing -

Night of 2018_09_29

Night of 2018_09_28
- After renewing the telescope drives
  → Telescope tracking error detected (LLR showstopper)

Workaround needed
1. Crater referencing (many Thanks to OCA team!!!)
2. Reflector tracking & definition of reference
3. Interactive telescope positioning
- first light after many years -

- Apollo 15, March/2018
- Usually signal is visible after post-processing only
- Calculate Return Rate per Normal Point
- Optimum: \( \sim 0.2 \text{ Percent} \)
- phase & time of day -

**Lunokhod 17 daytime ranging**

<table>
<thead>
<tr>
<th>Date</th>
<th>Moon Illumination</th>
<th>Max. Sun Elevation</th>
<th>Avg. Moon Elevation</th>
<th>Distance Sun-Moon</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018_08_05</td>
<td>45%</td>
<td>18 degree</td>
<td>53 degree</td>
<td>~112 degree</td>
</tr>
<tr>
<td>2018_08_06</td>
<td>34%</td>
<td>33 degree</td>
<td>55 degree</td>
<td>~55 degree</td>
</tr>
<tr>
<td>2018_09_06</td>
<td>16%</td>
<td>17 degree</td>
<td>57 degree</td>
<td>~53 degree</td>
</tr>
</tbody>
</table>
\[ Precision = \frac{\text{Single Shot RMS}}{\sqrt{\text{Number of Echos}}} \]
- target signature -

- Simulated MoonLIGHT echos
- WLRS single shot RMS ~ 3 mm (10 ps Laser)
  $\rightarrow$ S/N also improves by about factor 2 (narrow Filter)
Conclusion

- SLR-Systems with 1 m class telescopes allow for eyesafe SLR with capability of ranging all ILRS satellites @ a wavelength of 1064 nm

- LLR with laser pulse width of only 10 ps shown
- With improved target signature single shot RMS < 5 mm feasible
- Further optimization planned (T/R efficiency, Beam Profile, Adaptive Optics, ...)

8/11/2018