Technical Concept for a European Laser Altimeter for Planetary Exploration


June 8, 2003

LAPE: Laser Altimeter for Planetary Exploration
14th International Workshop on Laser Ranging
Mercury Exploration

Messenger (NASA)  BepiColombo (ESA)

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<table>
<thead>
<tr>
<th></th>
<th>Messenger</th>
<th>BepiColombo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission</td>
<td>1 Earth year</td>
<td></td>
</tr>
<tr>
<td>Launch vehicle</td>
<td>Delta 7925H</td>
<td>Soyuz-Fregat</td>
</tr>
<tr>
<td>Launch mass</td>
<td>988 kg</td>
<td>1500 kg</td>
</tr>
<tr>
<td>Orbit details</td>
<td>200 - 15200 km</td>
<td>400 - 1500 km</td>
</tr>
<tr>
<td></td>
<td></td>
<td>400 - 12000 km</td>
</tr>
<tr>
<td>Experiment</td>
<td>MLA</td>
<td>LAPE</td>
</tr>
<tr>
<td></td>
<td>Dual Imaging System</td>
<td>Vis. + near IR camera (stereo)</td>
</tr>
<tr>
<td></td>
<td>Magnetometer</td>
<td>Magnetometer</td>
</tr>
<tr>
<td></td>
<td>Spectrometers (various)</td>
<td>Spectrometers (various)</td>
</tr>
</tbody>
</table>

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Mission Requirements

- Total mass < 8.5 kg (goal 7 kg)
- Total el. Power < 30 W (goal 25 W)
- Range 300 km < R < 1000 km (1200 km)
- Range resol. 1 m
- Heat influx < 20 W

- Small telescope
- „DC-pumped“ Laser (no capacitor banks)
Laser Link Equation

\[ n_{pe} = \eta_q \left( \frac{E_t \lambda}{hc} \right) \eta_t G_t \sigma \left( \frac{1}{4 \pi R^2} \right) A_r \eta_r \]
Alternative Concept

• some parameters of the link equation have penalties:
  - weight (telescope...)
  - power consumption (laser...)
  - heat influx (telescope...)

• some parameters are trade-offs
  - system transmission
  - detector quantum efficiency

--> Find the combination for the best solution
Alternative Concept

- reduction of $n_{pe}$ to small values ($n_{pe} < 1$)
- high quantum efficiency by avalanche photo diodes
- high repetition rate and statistical pre-processing
- aperture size 15 cm to avoid heat influx over 20 watts
Mercury Surface: 400 - 1600 km

$v \approx 2.4 \text{ km/s}$
Altimeter Block Diagram

- Spatial / spectral filtering
- Temporal filtering
- Event timer
- Data reduction
- Orbit reference
- Microlaser
- Telescope

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I. Micro-Laser
<table>
<thead>
<tr>
<th>Model</th>
<th>NG-00121-100</th>
<th>NP-00321-100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength [nm]</td>
<td>532</td>
<td>1064</td>
</tr>
<tr>
<td>Energy / Pulse [µJ]</td>
<td>&gt; 1</td>
<td>&gt; 6*</td>
</tr>
<tr>
<td>Pulse Width [ns]</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Repetition Rate [kHz]</td>
<td>10 – 20</td>
<td>10 - 20</td>
</tr>
<tr>
<td>Beamprofile</td>
<td>TEM\textsubscript{00}</td>
<td>TEM\textsubscript{00}</td>
</tr>
</tbody>
</table>

* 100 µJ if fibre amplifier applied
II. Semiconductor Detector
Geigermode Operation

Geiger- Pulse

HV
Noise Reduction

- spatial filtering
- spectral filtering
- temporal filtering
- pattern recognition
Altimeter Operation

Clock

Laser fire

Epoch determination

Evaluation Telemetry

Rangegate generator

Orbit prediction

Echo
III. Statistical Data Reduction
Data Simulation

h = 800 km, P = 2 \mu J, d = 15 cm, Rep.Rate = 16 kHz, Sampling = 0.1 s
Worst Case scenario

\[ h = 1600 \text{ km}, \ P = 2 \ \mu\text{J}, \ d = 15 \text{ cm}, \ \text{Rep.Rate} = 16 \text{ kHz}, \ \text{Sampling} = 0.6 \text{ s} \]
Expansion: Det. Prob. 20%

Range Residuals [ns]

Time [s]

h = 1600 km, P = 2 µJ, d = 15 cm, Rep. Rate = 16 kHz, Sampling = 0.6 s
## Altimeter at Apogee

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case 1</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture Size [cm]</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Energy / Pulse [µJ]</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Receiver Transmission</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Repetition Rate [kHz]</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Detector Efficiency</td>
<td>0.6</td>
<td>0.7</td>
</tr>
</tbody>
</table>
(1) Simple noise reduction model, (2) Case-1 settings, (3) Case-2 settings
# Performance depending on Range

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case A</th>
<th>Case B</th>
<th>Case C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse Energy [$\mu$J]</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Telescope Diameter [cm]</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Repetition Rate [kHz]</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Detector Efficiency</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Averaging Time [s]</td>
<td>0.5</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Mercury Albedo</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Detection Probability

Height [km]

A
B
C

0.0
0.2
0.4
0.6
0.8
1.0
1.2

200 400 600 800 1000 1200 1400 1600 1800

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IV. General Considerations
Telemetry

- Limited Bandwidth (500 bps)
- Data reduction
- Single return transfer on demand
Signal Processing...

Histogram of Raw Observations

-60 -40 -20 0 20 40 60

Range Residuals [s]

0 1 2 3 4 5 6 7 8 9 10

# of Events

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Residual Histogram after Cross-Correlation

-60 -40 -20 0 20 40 60

Range Residuals [ns]

0 100 200 300

Probability [a. u.]

... by Correlation Techniques

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moderately rough surface: $\sigma = 1\ m$
Deadtime Correction

same dataset as before
Summary

• the laser link equation leaves room for adjustments

• single photon counting helps against the weight, heat influx and power consumption penalty

• high repetition rate and statistical pre-processing is then required