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Greenbelt, MD

CLEO 2017
15 MAY 2017
• Motivation
• L2MS Instrument Overview
• L2MS Laser Architecture
• Preliminary Performance
• Future Work & Conclusions
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All these bodies contain volatiles, including water just waiting to be analyzed

Our science motivation is to seek a solution with “Universal” detector for
- Comprehensive sample analysis
- Flexibility to adapt for different mission architectures including flybys, orbiters, landers, and/or rovers!
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L2MS Instrument Overview

Laser Desorption/Ionization Mass Spectrometry

UV Ionization Pulse

MIR Desorption Pulse

Neutral Plume

Sample

Time-of-flight Mass Spectrometer
• Wavelengths are selected based on key vibrational and electronic resonances in the targeted species aligned with the organic diversity and mineralogy expected for future planetary missions of high priority to NASA
  • 2.75 µm - IR vibrational resonances of hydrated minerals
  • 3.4 µm - C-H vibration resonance of organic species
  • 266 nm - coincides with a short-lived metastable state in many aromatic molecules
• Matching MIR laser wavelength allows for selective desorption
• Typical delay between Laser 1 and Laser 2 (Δt) range between 0.3-2 μs
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## L2MS Laser Requirements

<table>
<thead>
<tr>
<th>Lasers Requirement</th>
<th>MIR Laser</th>
<th>UV Laser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse Repetition Frequency (PRF)</td>
<td>1 – 20 Hz</td>
<td>1 – 20 Hz</td>
</tr>
<tr>
<td>Wavelength</td>
<td>2.8X µm and 3.40±0.05 µm</td>
<td>266 nm</td>
</tr>
<tr>
<td>Energy</td>
<td>~ 100 µJ</td>
<td>~ 18 µJ</td>
</tr>
<tr>
<td>Pulse Width</td>
<td>&lt; 7 ns</td>
<td>&lt; 7 ns</td>
</tr>
<tr>
<td>Peak Power</td>
<td>~14 kW</td>
<td>~2.5 kW</td>
</tr>
<tr>
<td>Peak Intensity (assuming 100 µm beam diameter)</td>
<td>180 MW/cm²</td>
<td>~30 MW/cm²</td>
</tr>
<tr>
<td>Spectral Width</td>
<td>Few GHz</td>
<td>Few GHz</td>
</tr>
<tr>
<td>Timing</td>
<td>$t_0$</td>
<td>$t_0 + \Delta t; \sim 100$ ns $&lt; \Delta t &lt;$ few µs</td>
</tr>
<tr>
<td>Laser Lifetime</td>
<td>3 year mission at 10% duty cycle $\sim 64$ Mshots @ 20 Hz</td>
<td></td>
</tr>
</tbody>
</table>
• Laser design for both Laser 1 (MIR) and Laser 2 (UV) is based on the previously flown Lunar Orbiter Laser Altimeter (LOLA) laser transmitter

<table>
<thead>
<tr>
<th>Instrument</th>
<th>LOLA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mission</strong></td>
<td>LRO</td>
</tr>
<tr>
<td><strong>Launched</strong></td>
<td>6/18/2009</td>
</tr>
<tr>
<td><strong>Laser type</strong></td>
<td>Cr:Nd:YAG, 5 way beam split</td>
</tr>
<tr>
<td><strong>Laser Architecture</strong></td>
<td>Cross-Porro resonator passively Q-switched</td>
</tr>
<tr>
<td><strong># of lasers</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Laser Wavelength</strong></td>
<td>1064.3 ± 0.1 nm</td>
</tr>
<tr>
<td><strong>Laser pulse energy</strong></td>
<td>2.7 ± 0.3 mJ</td>
</tr>
<tr>
<td><strong>Laser Pulse Repetition Rate</strong></td>
<td>28.0 ± 0.1 Hz</td>
</tr>
<tr>
<td><strong>Laser Pulsewidth</strong></td>
<td>6.0 ± 2.0 ns</td>
</tr>
<tr>
<td><strong>Laser Beam quality</strong></td>
<td>TEM00</td>
</tr>
<tr>
<td><strong>Laser Divergence</strong></td>
<td>100 μrad (= 5 m footprint)</td>
</tr>
</tbody>
</table>

As of 3/2016, the number of shots fired by each lasers are:
• Laser 1 ~ 2.1B
• Laser 2 ~ 2B
L2MS Laser Architecture

Laser 1

Porro RW WP Slab Pol EOQS WP RW KTA

3.47 µm

Laser 2

Porro RW WP Slab Pol EOQS WP RW OC

266 nm

PP – Porro Prism; RW – Risley Wedge; WP – Wave plate; Pol – Polarizer; EOQS – Pockels Cell; M – Mirror; OC – Output Coupler
Input pump, $\frac{hc}{l_1}$, spontaneously generates pairs of photons, $\frac{hc}{l_2}$, $\frac{hc}{l_3}$ (parametric noise) which are then amplified.

Energy conservation: \[ E = \frac{hc}{l_1} = \frac{hc}{l_2} + \frac{hc}{l_3} \]

\[ \frac{1}{1064 \text{ nm}} = \frac{1}{1651 \text{ nm}} + \frac{1}{2993 \text{ nm}} \]

\[ \frac{1}{1064 \text{ nm}} = \frac{1}{1573 \text{ nm}} + \frac{1}{3288 \text{ nm}} \]
Optical parametric oscillation

Singly-resonant oscillator (SRO)

Doubly-resonant oscillator (DRO)
Intra-cavity OPO (iOPO)

M_1 \quad M_2 \quad M_3

Pump \quad \text{Signal} \quad \text{Idler}

I_p \quad I_s \quad I_i
Monolithic OPO crystal design

Noncritical phase matching (NCPM)

Pump @ 1064.5nm

Critical phase matching

Pump @ 1064.5nm

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Replace LOLA laser output coupling section with a monolithic OPO.
Reconfigure LOLA to iOPO

- LOLA Laser 1
- Polarization Output Coupler
- Monolithic OPO (KTA crystal)

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Output Energy = 450 µJ at 3471nm
= 1.2 mJ at 1534nm
iOPO Experimental result, 3.4 μm

![Graph showing wavelength and linewidth analysis with values 3471 nm and 1.10 nm.]

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iOPO breadboard using CPM monolithic OPO crystal, 2.7 & 2.9 μm

Critical phase matching

Pump @ 1064nm

1756nm (e)
1064nm (o)
2700nm (o)

Monolithic iOPO crystal (KTP)
Coating damage near 2.85um
\[ \lambda_p = 1064 \text{ nm} \]
\[ \lambda_s = 1534 \text{ nm} \]
\[ \lambda_i = 3480 \text{ nm} \]
### MIR Laser Breadboard Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measurement</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>3471 nm</td>
<td>3400 nm ± 50 nm</td>
</tr>
<tr>
<td>Pulse Repetition Frequency (PRF)</td>
<td>20 Hz</td>
<td>1-20 Hz</td>
</tr>
<tr>
<td>Average Power</td>
<td>4.2 mW</td>
<td>NA</td>
</tr>
<tr>
<td>Energy</td>
<td>210 µJ</td>
<td>100 µJ</td>
</tr>
<tr>
<td>Pulse Duration</td>
<td>1.9 ns</td>
<td>&lt; 7 ns</td>
</tr>
<tr>
<td>Conversion Efficiency</td>
<td>10.5 %</td>
<td>NA</td>
</tr>
</tbody>
</table>

**Graphs:**
- 1064 nm
- 1535 nm
- 3471 nm
- 1.35 nm

**Power Measurements:**
- 210 µJ @ 3480 nm
- Rep rate = 10 Hz
## 266 nm Laser Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measurement</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>266.2 nm</td>
<td>266 nm</td>
</tr>
<tr>
<td>Pulse Repetition Frequency (PRF)</td>
<td>20 Hz</td>
<td>1-20 Hz</td>
</tr>
<tr>
<td>Energy</td>
<td>220 μJ</td>
<td>18 μJ</td>
</tr>
<tr>
<td>Pulse Duration</td>
<td>6.6 ns</td>
<td>&lt; 7 ns</td>
</tr>
<tr>
<td>Peak Power</td>
<td>32.5 kW</td>
<td>2.5 kW</td>
</tr>
<tr>
<td>Peak Intensity (assuming 100 μm beam diameter)</td>
<td>415 MW/cm²</td>
<td>30 MW/cm²</td>
</tr>
<tr>
<td>Divergence (full angle)</td>
<td>$\theta_x = 0.66$ mrad $\theta_y = 1.12$ mrad</td>
<td>NA</td>
</tr>
<tr>
<td>Overall 4th Harmonic Conversion Efficiency</td>
<td>10%</td>
<td>NA</td>
</tr>
</tbody>
</table>
Successful coupling of the laser breadboards to the L2MS instrument enabled detection of caffeic acid encapsulated by a thin layer of water ice, for the first time.

A mass spectrum of caffeic acid coated with water ice, measured at cryogenic temperatures is shown above.
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Future Work

Laser 1 – MIR Laser
• Test 3.4 μm breadboard with L2MS laboratory instrument and compare with commercial OPO
• Complete 2.75 μm breadboard laser
• Finalize design for dual wavelength (2.75 μm and 3.4 μm) concept

Laser 2 – UV Laser
• Investigate other non-linear optical crystals for SHG and FHG – leverage ICESat-2/ATLAS LBO aging study
• Optimize overall 4th harmonic conversion efficiency
• Test breadboard with L2MS laboratory instrument and compare with commercial UV laser
• Develop epoxy-free opto-mechanical design for mounting optics to minimize UV induced contamination on optical surfaces

Laser Transmitter
• Improve packaging of the laser transmitter for space flight
• Build brass board laser transmitter that will generate both MIR and UV wavelengths on a single laser bench
• We are developing a multi-wavelength laser transmitter for the L2MS Instrument

• A new laser architecture based on the LOLA laser transmitter that generates a single discrete MIR and UV wavelengths has been demonstrated

• The approach provides a straightforward path toward space laser design and deployment

• Preliminary laser breadboard results show compliance with the L2MS instrument requirements