Advanced Laser Architecture for the Two-Step Laser Tandem Mass Spectrometer

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• Motivation
• L2MS Instrument Overview
• L2MS Laser Architecture
• Preliminary Laser Performance
• Future Work
• Conclusions
• Motivation
  • L2MS Instrument Overview
  • L2MS Laser Concept
  • Preliminary Laser Performance
  • Future Work
  • Conclusions
• Contribute to and compliment our understanding of the processes governing the formation, distribution and evolution of primitive materials throughout the solar system

• Future astrobiology missions will focus on small, primitive bodies and the icy moons of the outer planets that may host diverse organic compounds

• These missions require advanced instrument techniques to fully and unambiguously characterize the composition of surface and dust materials

• Targeted missions include flybys, orbiters, landers and rovers to Europa, Trojan, a main belt asteroid, comet, Jupiter belt object (KBO), Titan, Enceladus or Mars
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Combines TOF-MS (time-of-flight mass spectrometry) and LDMS (laser desorption/ionization mass spectrometry)

In situ measurements of non-volatile samples to determine both mass assignments and clues to structural information

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

Uses mid-infrared (MIR) and ultra-violet (UV) wavelengths

- 2.8 – 2.9 μm (TBD) - 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
Molecular desorption is enhanced when the IR laser wavelength matches the molecular vibrational resonance.

NIST IR transmission measurements:
- Red color indicates regions of decreased transmittance (increased absorption), thus this is the ideal IR wavelength to be used for that compound
- Four different classes of aromatic molecules are plotted
• Desorption is enhanced when the IR wavelength matches the mineral absorption resonances.

• IR reflectance spectra from USGS (U.S. Geological Survey) or laboratory measurements:
  - Red color indicates regions of decreased reflectance (increased absorption), thus an ideal IR wavelength to be used for that mineral.
  - Three different classes of minerals are shown.
• Two discrete MIR wavelengths (~2.8 μm and 3.4 μm) and UV wavelength (266 nm) on the same bench
• Laser design is based on the previously flown Lunar Orbiter Laser Altimeter (LOLA) laser transmitter
• Monolithic intracavity optical parametric oscillators (iOPO) generate the MIR wavelengths
• Frequency quadrupled Nd:YAG generates the UV wavelength
• Typical delays range between 0.3-2 μs
**Fluence Estimation**

- Assumptions – Pulse energy = 1 mJ
- Solid lines are from the fitted equation from previous three charts
- Markers are calculated values using the measured/fit beam size from the PV320 camera

We can obtain the same max fluence of ~0.3J/cm², using a 100 µJ pulse and 100 µm beam waist (radius)
## 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>2.8(\mu)m and 3.40±0.05 (\mu)m</td>
<td>266 nm</td>
</tr>
<tr>
<td>Energy</td>
<td>(~100 \mu J)</td>
<td>(~18 \mu J)</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 (\mu)m beam diameter)</td>
<td>180 MW/cm(^2)</td>
<td>(~30) MW/cm(^2)</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); (~100 \text{ ns} &lt; \Delta t &lt; \text{ few } \mu \text{s})</td>
</tr>
<tr>
<td>Laser Lifetime</td>
<td>3 year mission at 10% duty cycle (~64) Mshots @ 20 Hz</td>
<td></td>
</tr>
</tbody>
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PP – Porro Prism; RW – Risley Wedge; WP – Waveplate; Pol – Polarizer; EOQS – Pockels Cell; M – Mirror; OC – Output Coupler

266 nm

3.47 µm
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$\lambda_p = 1064$ nm  
$\lambda_s = 1534$ nm  
$\lambda_i = 3480$ nm

Laser Cavity

Porro  Risley  Q-Switch  Slab  Risley

Waveplate

OPO Cavity

AR @ 1 µm  
HR @ 1.5 µm  
HR @ 3 µm

PR @ 1 µm  
PR @ 1.5 µm  
AR @ 3 µm
### Parameter Measurement

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>3471 nm</td>
</tr>
<tr>
<td>Pulse Repetition Frequency (PRF)</td>
<td>20 Hz</td>
</tr>
<tr>
<td>Average Power</td>
<td>4.2 mW</td>
</tr>
<tr>
<td>Energy</td>
<td>0.21 mJ</td>
</tr>
<tr>
<td>Pulse Duration</td>
<td>1.9 ns</td>
</tr>
<tr>
<td>Conversion Efficiency</td>
<td>10.5 %</td>
</tr>
</tbody>
</table>

#### Additional Information

- **Parameter Measurement**
  - Wavelength: 3471 nm
  - Pulse Repetition Frequency (PRF): 20 Hz
  - Average Power: 4.2 mW
  - Energy: 0.21 mJ
  - Pulse Duration: 1.9 ns
  - Conversion Efficiency: 10.5 %

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

- **Images**
  - 210uJ @ 3480nm Rep rate = 10Hz
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>1064 nm</td>
</tr>
<tr>
<td>Pulse Repetition Frequency (PRF)</td>
<td>20 Hz</td>
</tr>
<tr>
<td>Average Power</td>
<td>41 mW</td>
</tr>
<tr>
<td>Energy</td>
<td>2.1 mJ</td>
</tr>
<tr>
<td>Pulse Duration</td>
<td>9.8 ns</td>
</tr>
<tr>
<td>Peak Power</td>
<td>210 kW</td>
</tr>
<tr>
<td>Divergence (full angle)</td>
<td>θ_x = 1.53 mrad</td>
</tr>
<tr>
<td></td>
<td>θ_y = 1.83 mrad</td>
</tr>
</tbody>
</table>

**Far Field Beam**
## 532 nm Laser Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>532 nm</td>
</tr>
<tr>
<td>Pulse Repetition Frequency (PRF)</td>
<td>20 Hz</td>
</tr>
<tr>
<td>Average Power</td>
<td>26 mW</td>
</tr>
<tr>
<td>Energy</td>
<td>1.3 mJ</td>
</tr>
<tr>
<td>Pulse Duration</td>
<td>8.7 ns</td>
</tr>
<tr>
<td>Peak Power</td>
<td>150 kW</td>
</tr>
<tr>
<td>Divergence (full angle)</td>
<td>$\theta_x = 1.53$ mrad $\theta_y = 1.76$ mrad</td>
</tr>
<tr>
<td>2nd Harmonic Conversion Efficiency</td>
<td>64%</td>
</tr>
</tbody>
</table>

![Far Field Beam](image-url)
## 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 \text{ mrad} ) ( \theta_y = 1.12 \text{ mrad} )</td>
<td>NA</td>
</tr>
<tr>
<td>Overall 4th Harmonic Conversion Efficiency</td>
<td>10%</td>
<td>NA</td>
</tr>
</tbody>
</table>
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Future Work

Laser 1 – MIR Laser
- Measure and quantify 3.4 μm MIR iOPO breadboard beam quality
- Test 3.4 μm breadboard with L2MS laboratory instrument and compare with commercial OPO
- Finalize design for dual wavelength concept
- Continue to work on 2.8 μm iOPO breadboard and resolve coating damage issue

Laser 2 – UV Laser
- Replace KTP crystal with critically phase matched LBO crystal for SHG of 532 nm
- Improve mechanical design of LBO crystal housing for better conversion efficiency
- Optimize overall 4th harmonic conversion efficiency
- Test breadboard with L2MS laboratory instrument and compare with commercial UV laser
- Develop mechanical design for mounting optics without using epoxies to avoid contamination issues

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
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Conclusions

- 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