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Multi-Wavelength Laser Transmitter for the Two-Step Laser Time-of-Flight Mass Spectrometer

Anthony W. Yu, Steven X. Li, Molly E. Fahey, Andrej Grubisic,
Benjamin J. Farcy, Kyle Uckert, Xiang Li and Stephanie Getty
NASA Goddard Space Flight Center
Greenbelt, MD

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Agenda

- Motivation
- L2MS Instrument Overview
- L2MS Laser Architecture
- Preliminary Performance
- Future Work & Conclusions

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Science Motivation

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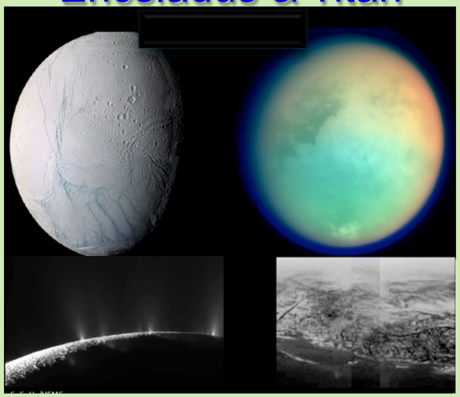
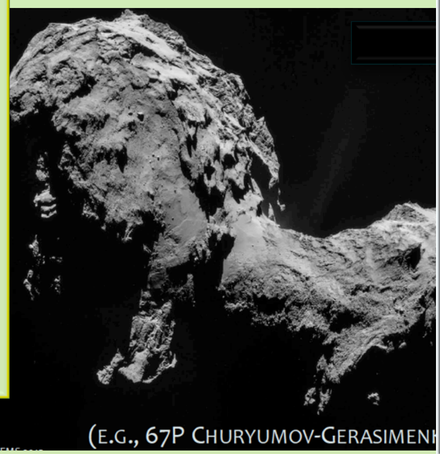
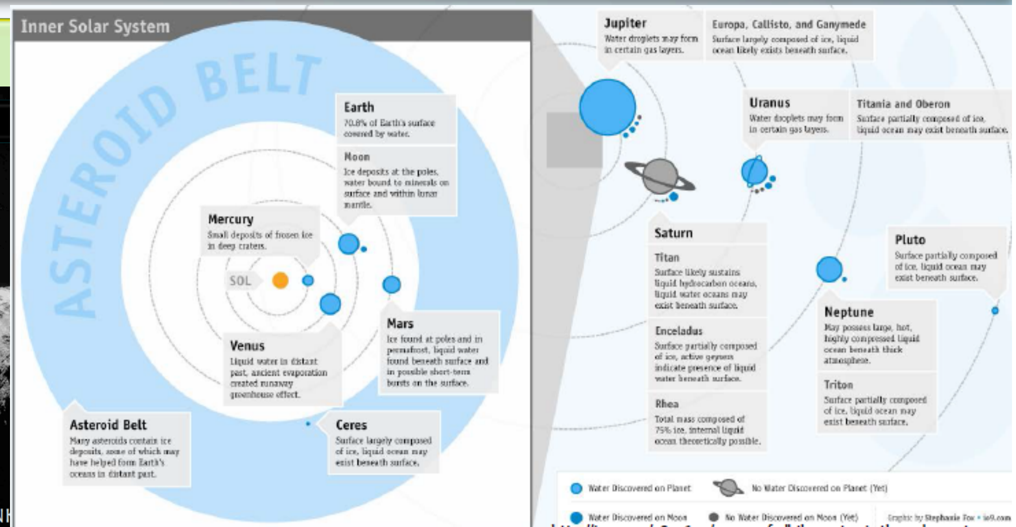
Enceladus & Titan



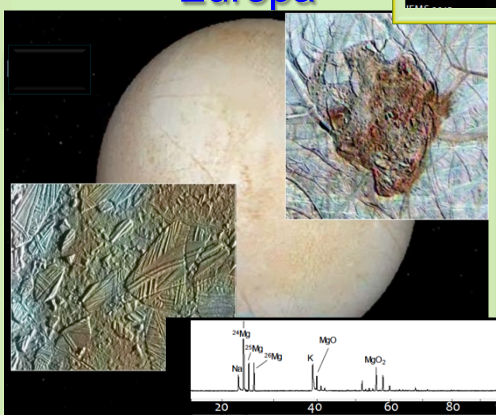
Comets



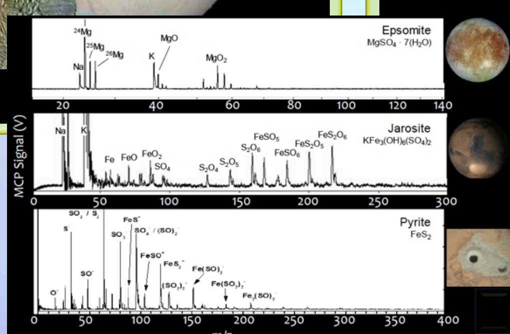


http://io9.com/5827649/a-map-of-all-the-water-in-the-solar-system

Europa



Ceres



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

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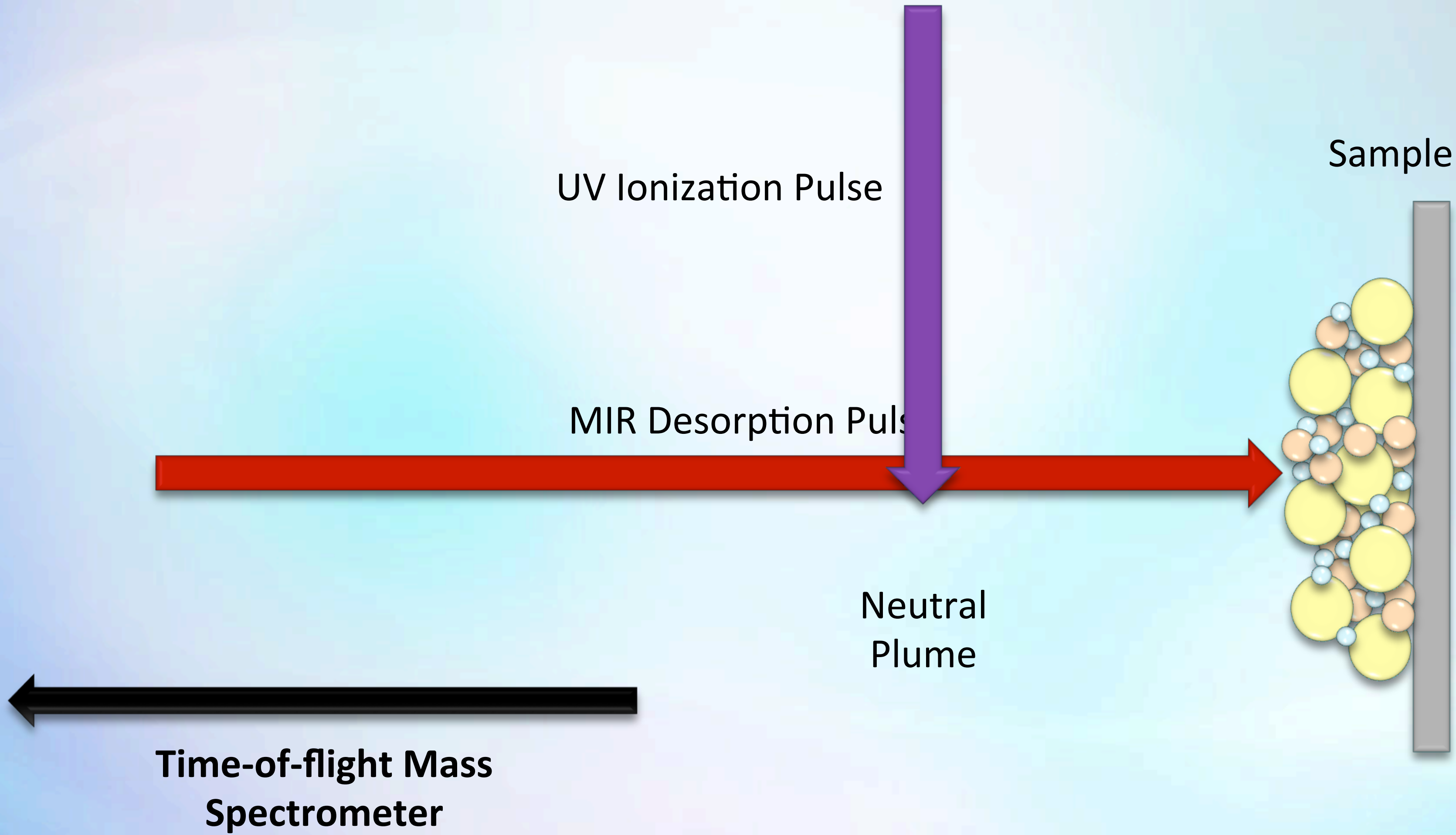
Laser Desorption/Ionization Mass Spectrometry



L2MS Instrument Overview

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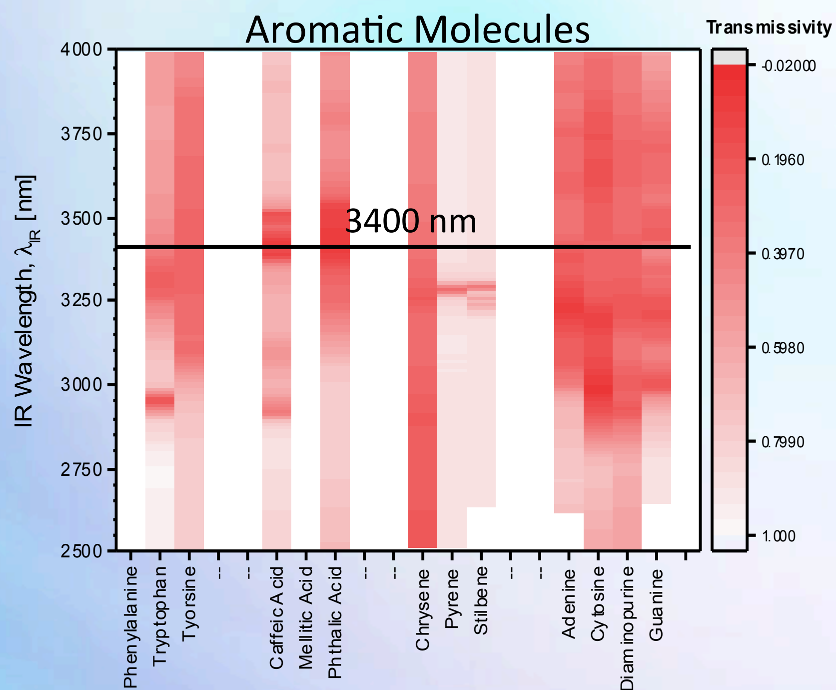
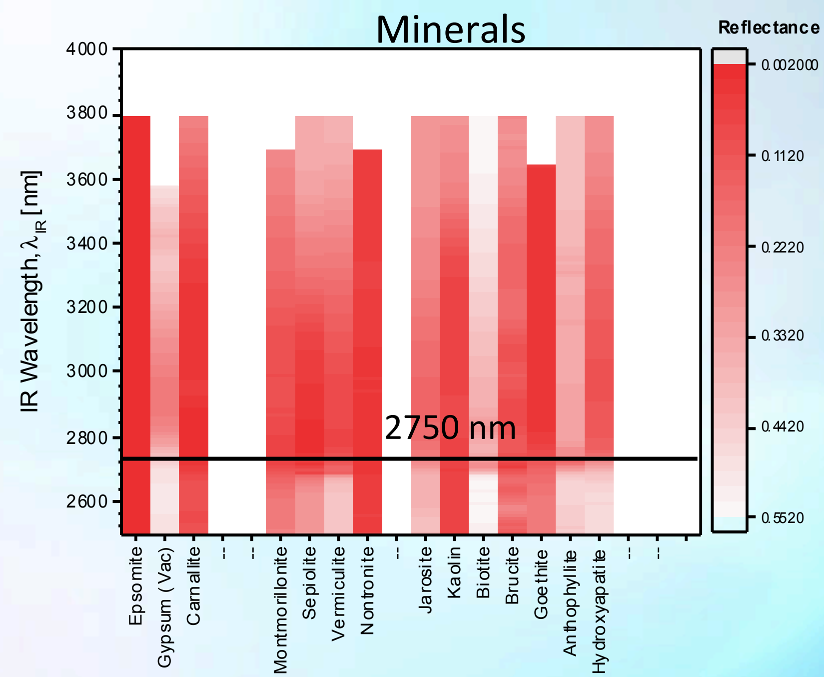
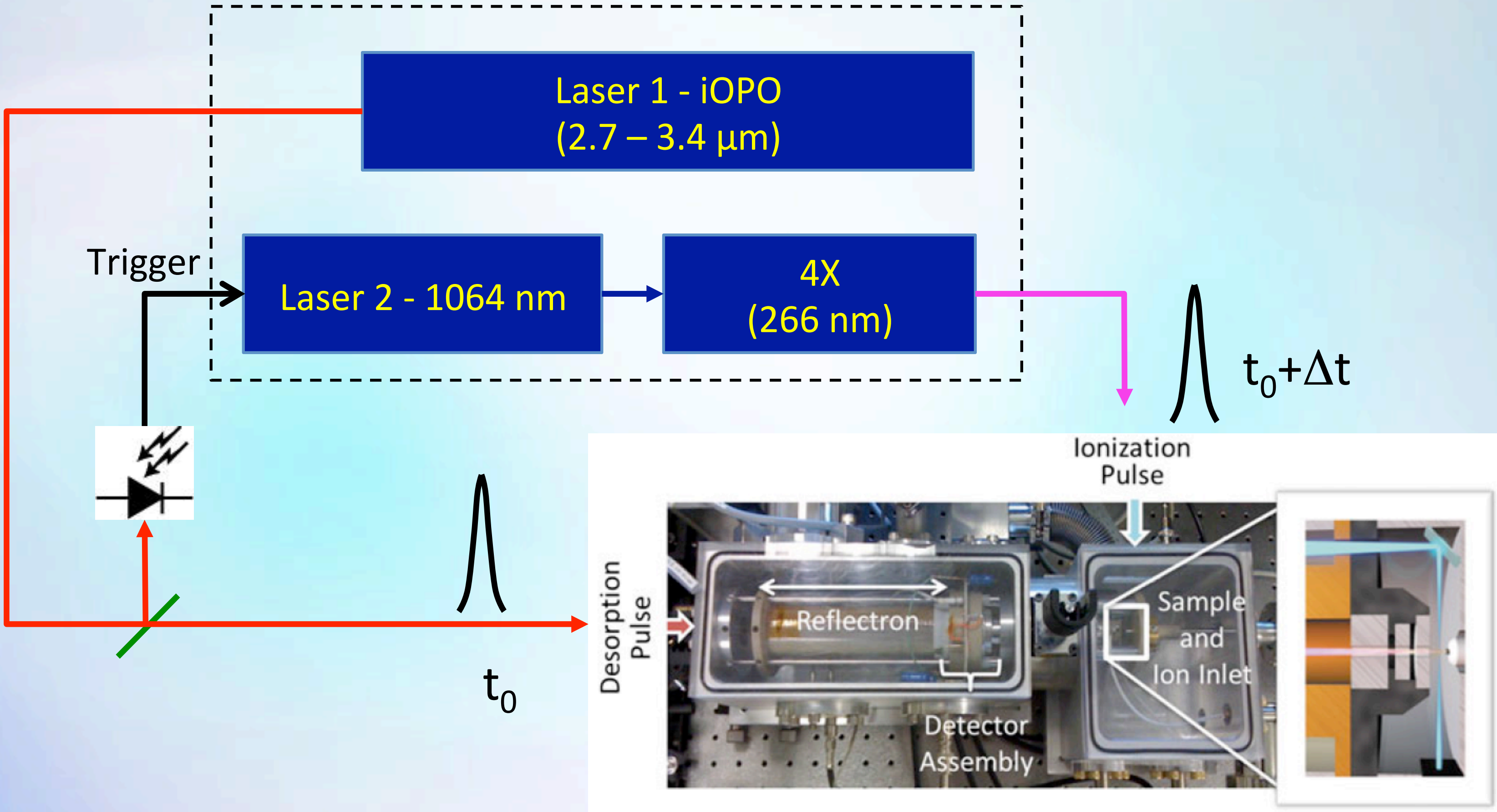
- Wavelengths are selected based on key vibrational and electronic resonances in the targeted species aligned with the organic diversity and mineralogy expected for future planetary missions of high priority to NASA
  - 2.75 µm - IR vibrational resonances of hydrated minerals
  - 3.4 µm - C-H vibration 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





L2MS Instrument Overview



- Typical delay between Laser 1 and Laser 2 (Δt) range between 0.3-2 µs

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L2MS Laser Requirements

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Lasers Requirement	MIR Laser	UV Laser
Pulse Repetition Frequency (PRF)	1 – 20 Hz	1 – 20 Hz
Wavelength	2.8X μm and 3.40±0.05 μm	266 nm
Energy	~ 100 μJ	~ 18 μJ
Pulse Width	< 7 ns	< 7 ns
Peak Power	~14 kW	~2.5 kW
Peak Intensity (assuming 100 μm beam diameter)	180 MW/cm^2	~30 MW/cm^2
Spectral Width	Few GHz	Few GHz
Timing	t_0	$t_o + \Delta t$; ~100 ns < Δt < few μs
Laser Lifetime	3 year mission at 10% duty cycle ~ 64 Mshots @ 20 Hz	

L2MS Laser Overview

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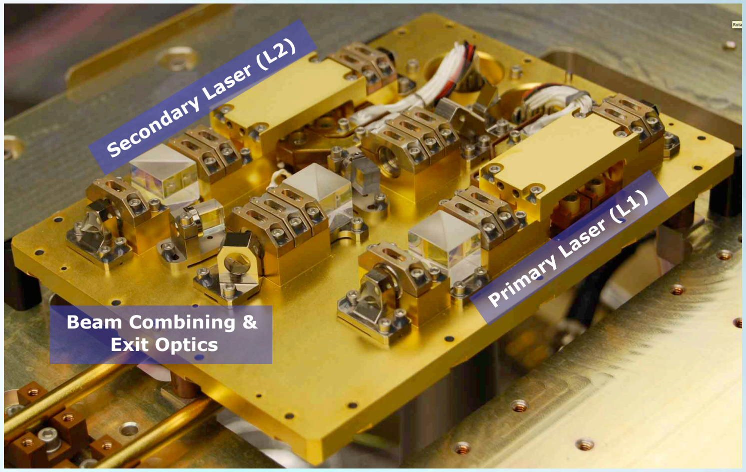
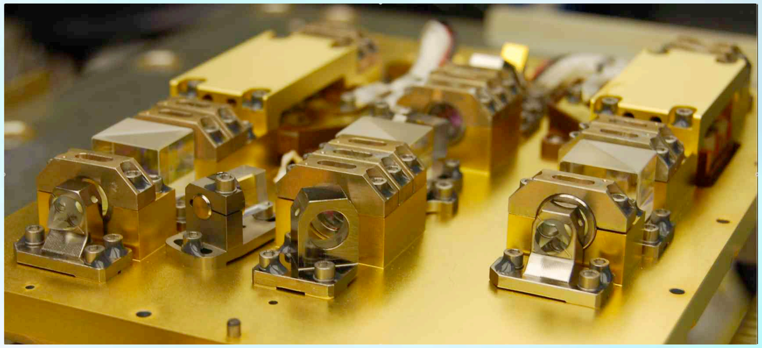
- Laser design for both Laser 1 (MIR) and Laser 2 (UV) is based on the previously flown Lunar Orbiter Laser Altimeter (LOLA) laser transmitter

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

LOLA laser transmitter





As of 3/2016, the number of shots fired by each lasers are:

- Laser 1 ~ 2.1B
- Laser 2 ~ 2B

L2MS Laser Architecture

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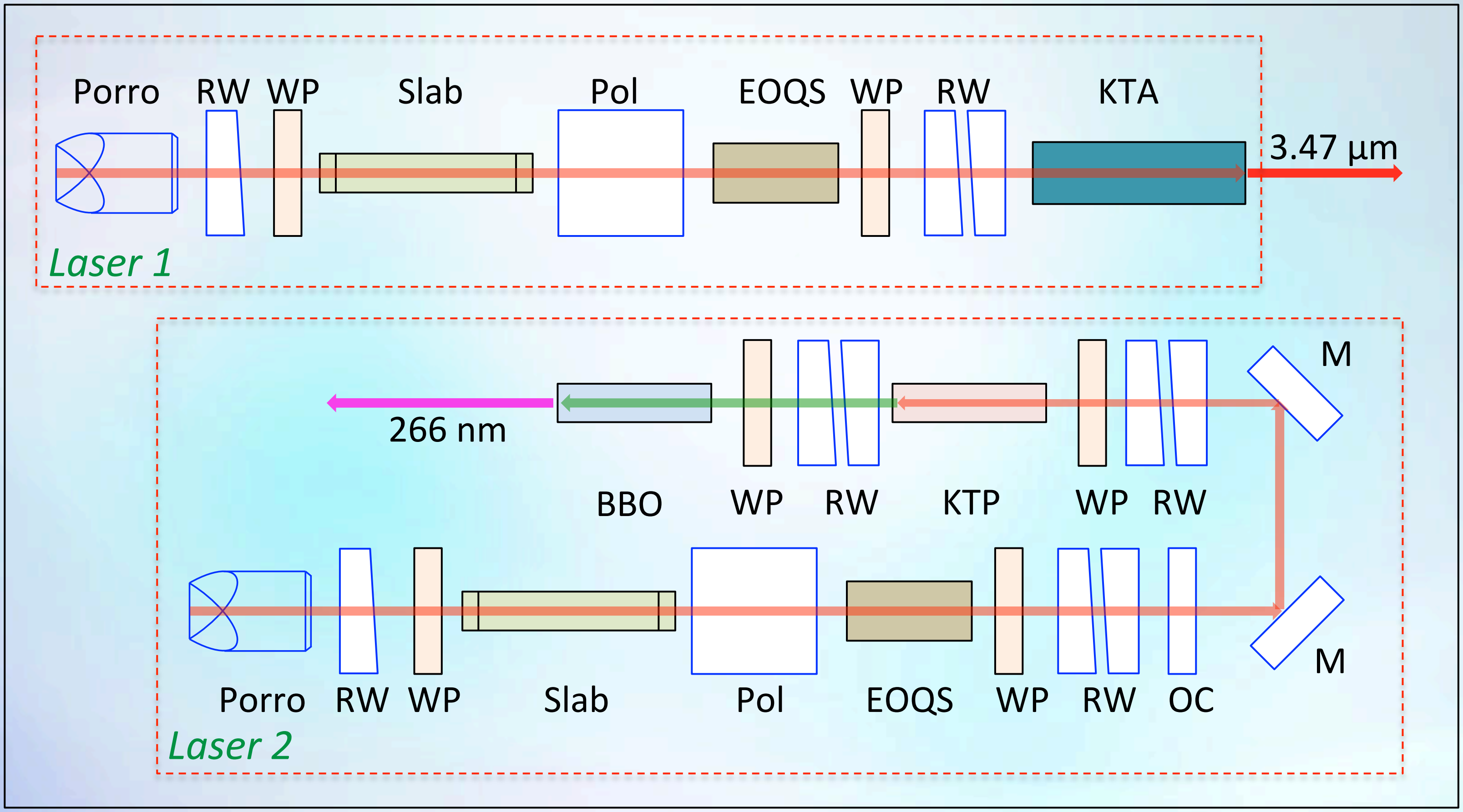

PP – Porro Prism; RW – Risley Wedge; WP – Wave plate; Pol – Polarizer; EOQS – Pockels Cell; M – Mirror; OC – Output Coupler

Parametric generation

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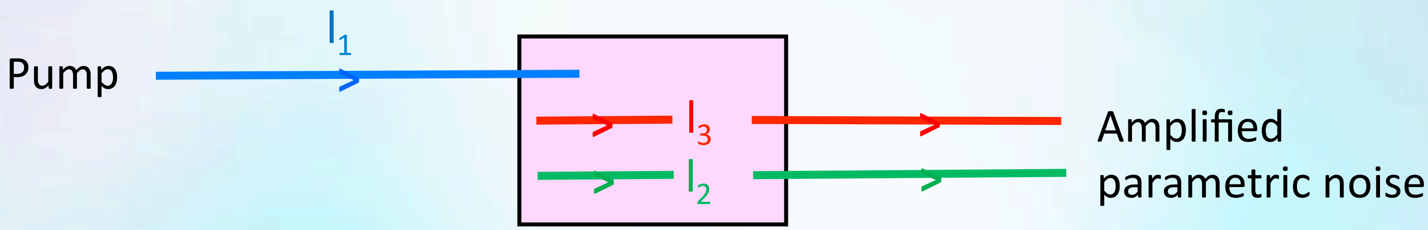


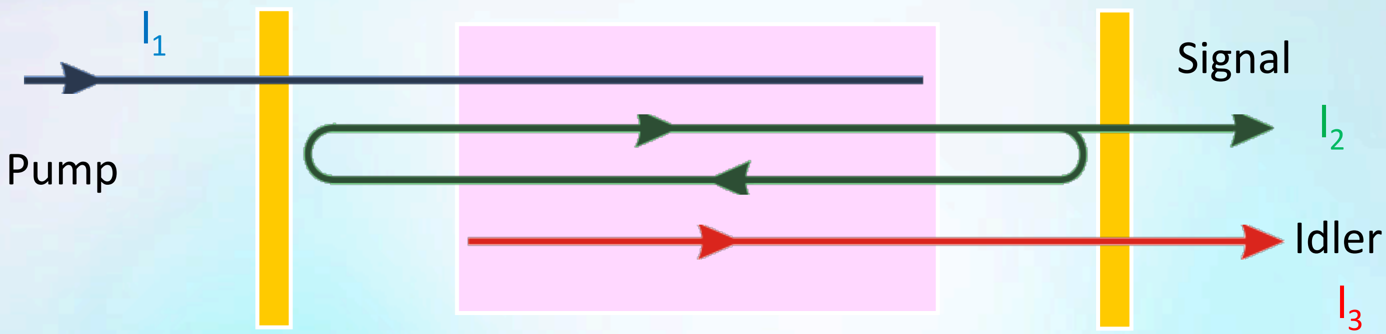
Input pump, hc/l_1, spontaneously generates pairs of photons, hc/l_2, hc/l_3 (parametric noise) which are then amplified.

Energy conservation: $E = \mathbf{hc} \,/\, \mathbf{l_1} = \mathbf{hc} \,/\, \mathbf{l_2} + \mathbf{hc} \,/\, \mathbf{l_3}$

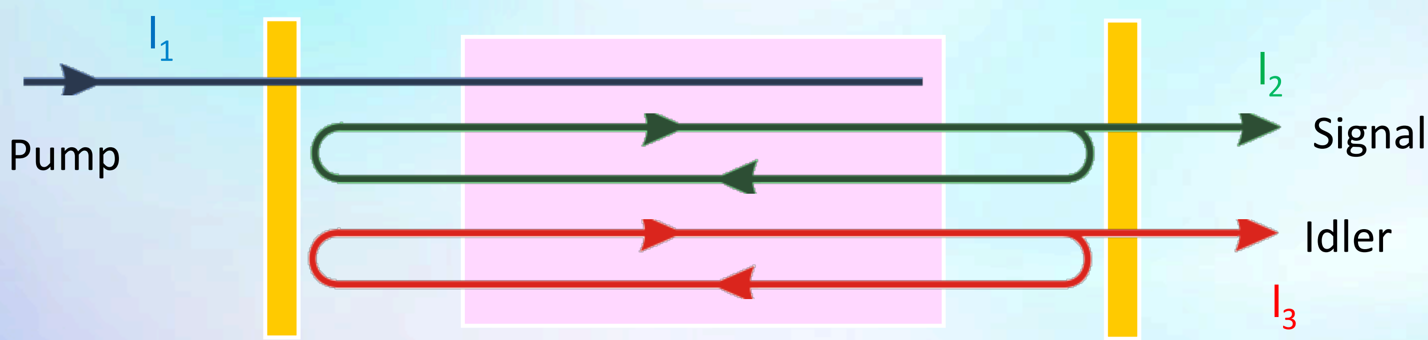
1 / 1064 nm = 1 / 1651 nm + 1 / 2993 nm

1 / 1064 nm = 1 / 1573 nm + 1 / 3288 nm

Optical parametric oscillation



Singly-resonant oscillator (SRO)



Doubly-resonant oscillator (DRO)

Intra-cavity OPO (iOPO)

Monolithic OPO crystal design

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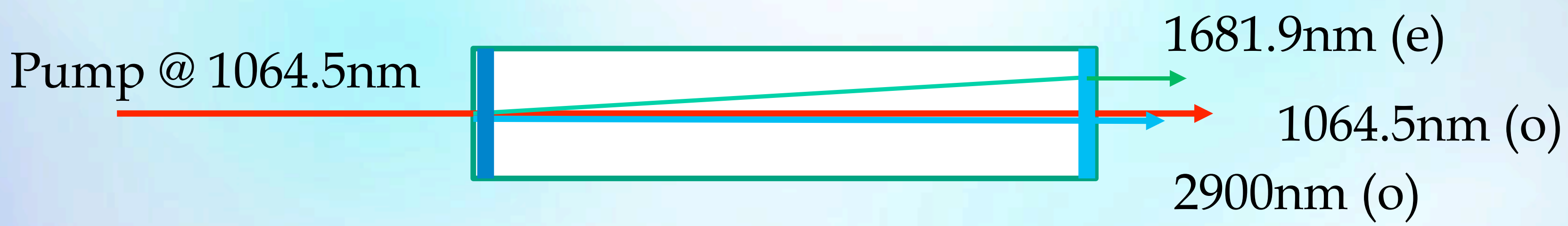
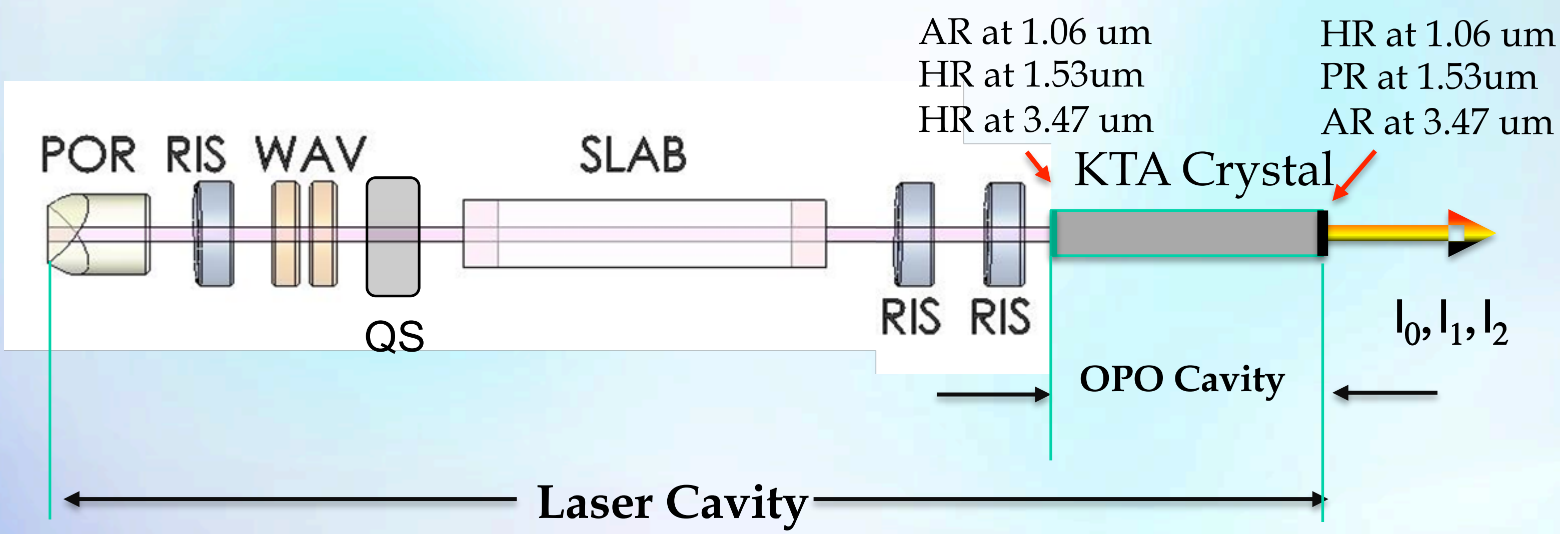
Nonritical phase matching (NCPM)

Critical phase matching



Monolithic iOPO Design

- Replace LOLA laser output coupling section with a monolithic OPO



Reconfigure LOLA to iOPO

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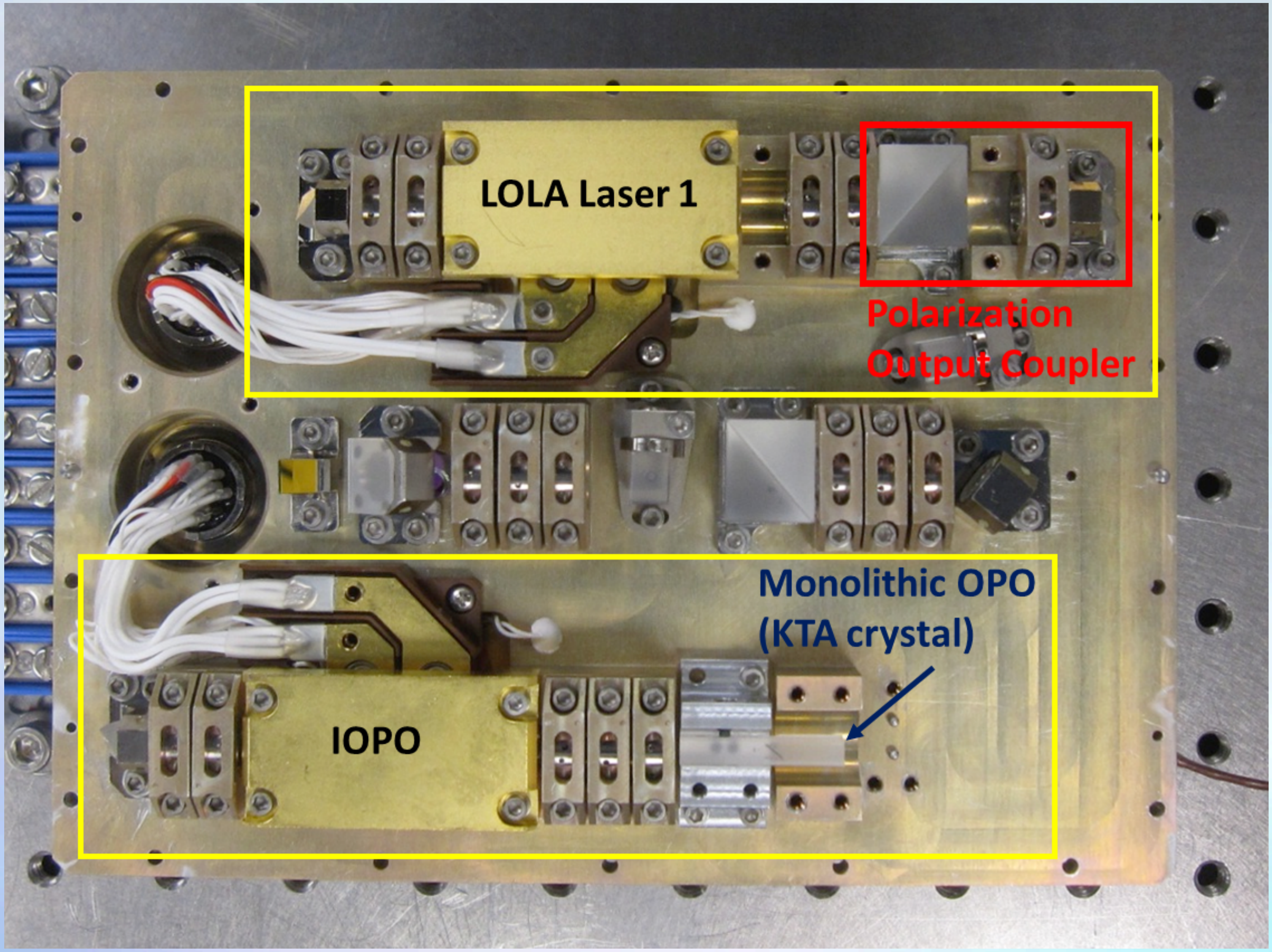

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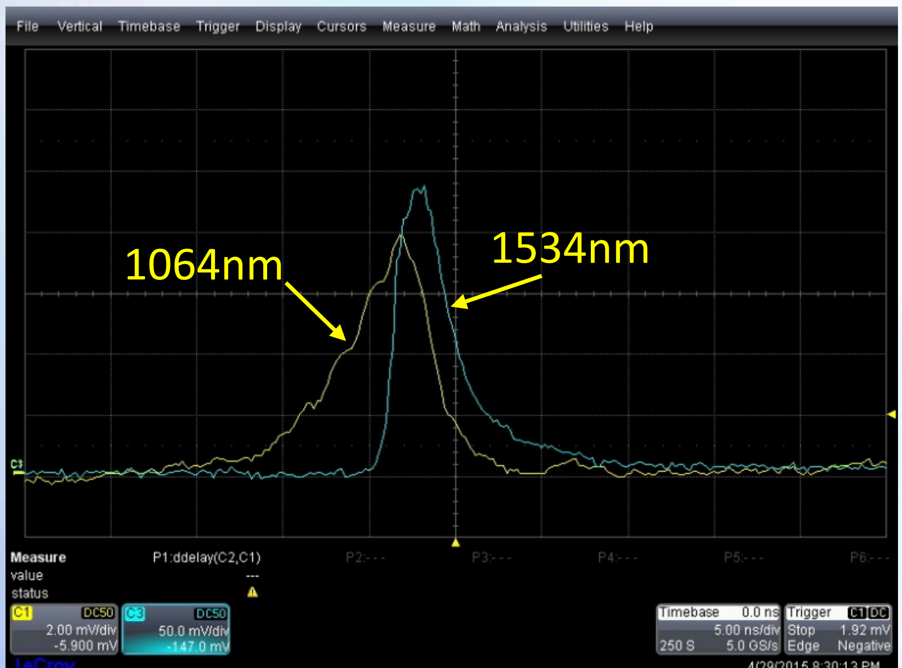
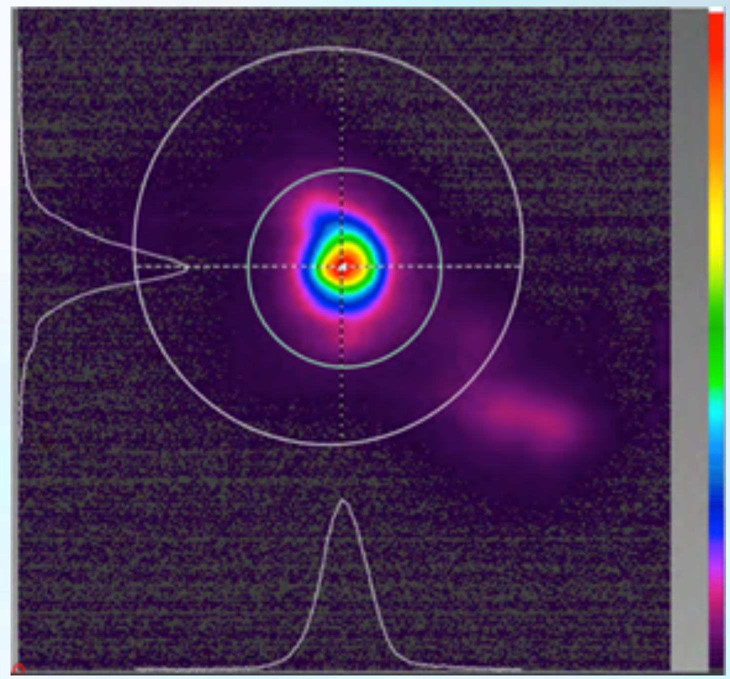
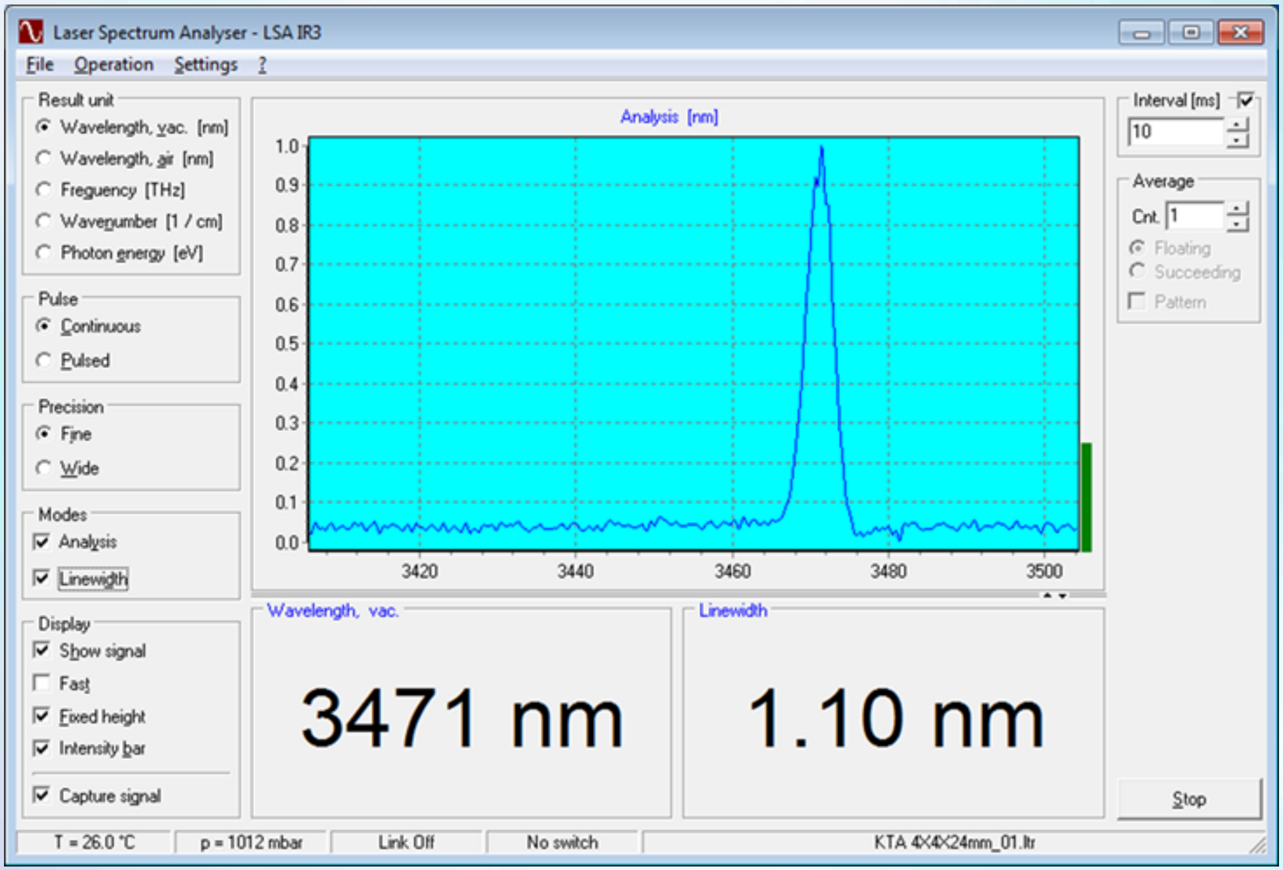
iOPO Experimental results, 3.4 µm

Output Energy = 450 µJ at 3471nm
= 1.2 mJ at 1534nm

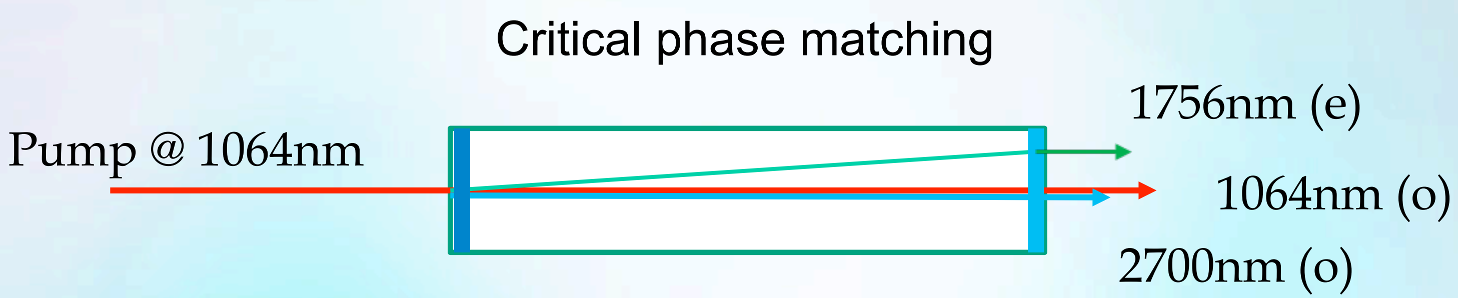


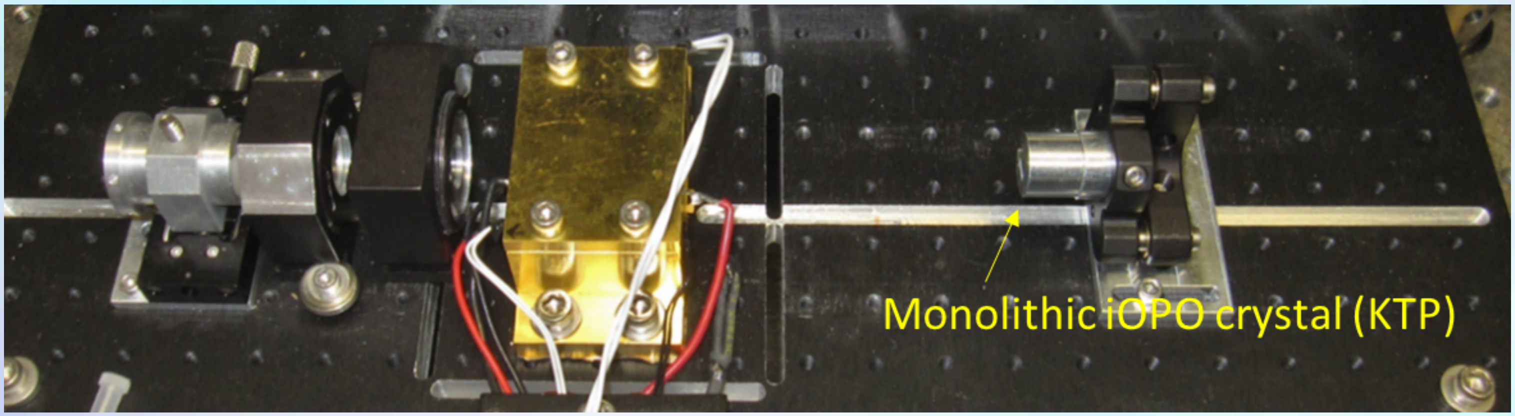


iOPO Experimental result, 3.4 μm



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





Coating damage near 2.85um

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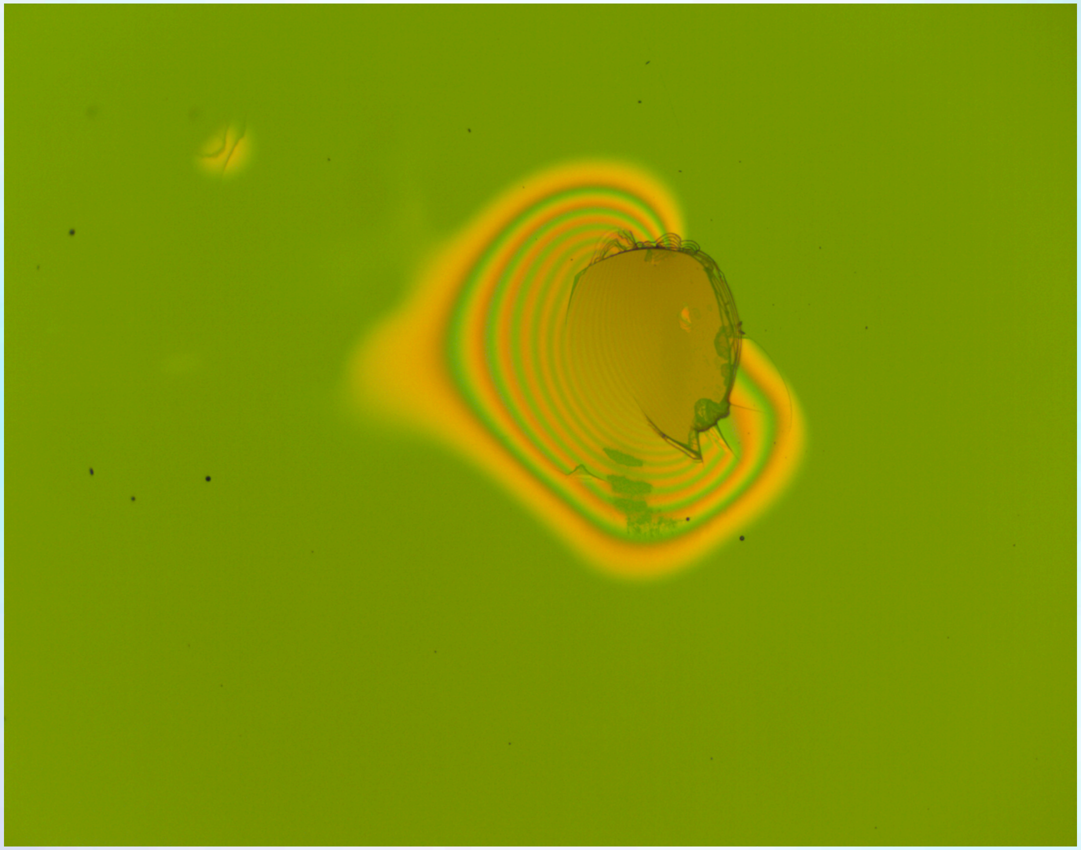

MIR Laser Breadboard

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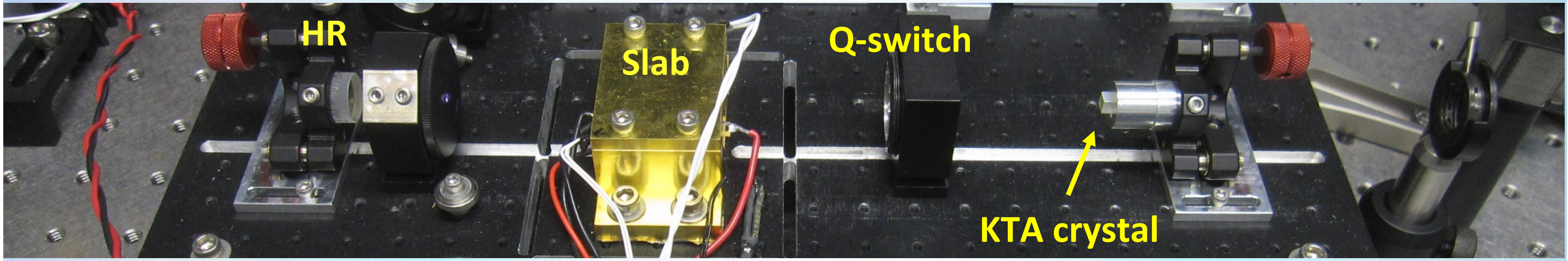
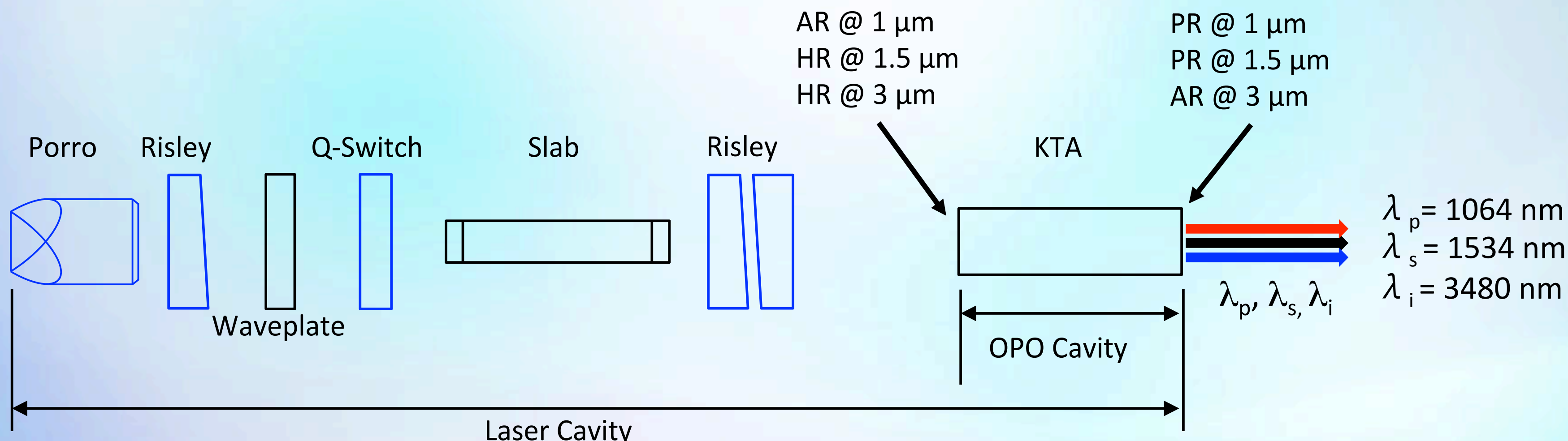
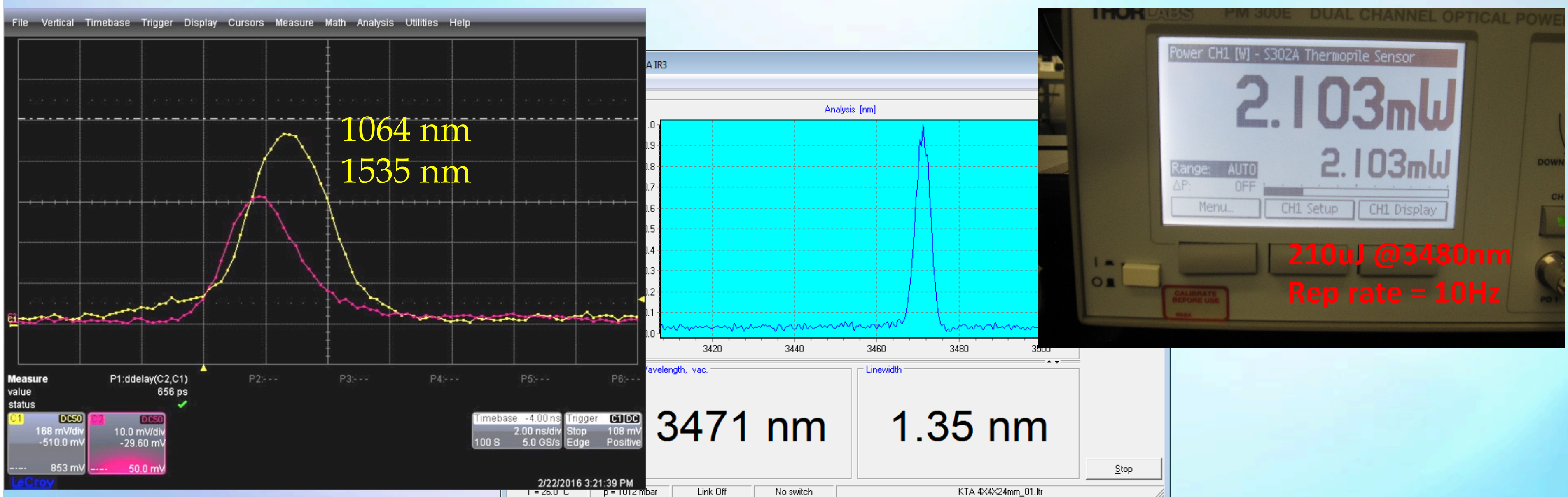


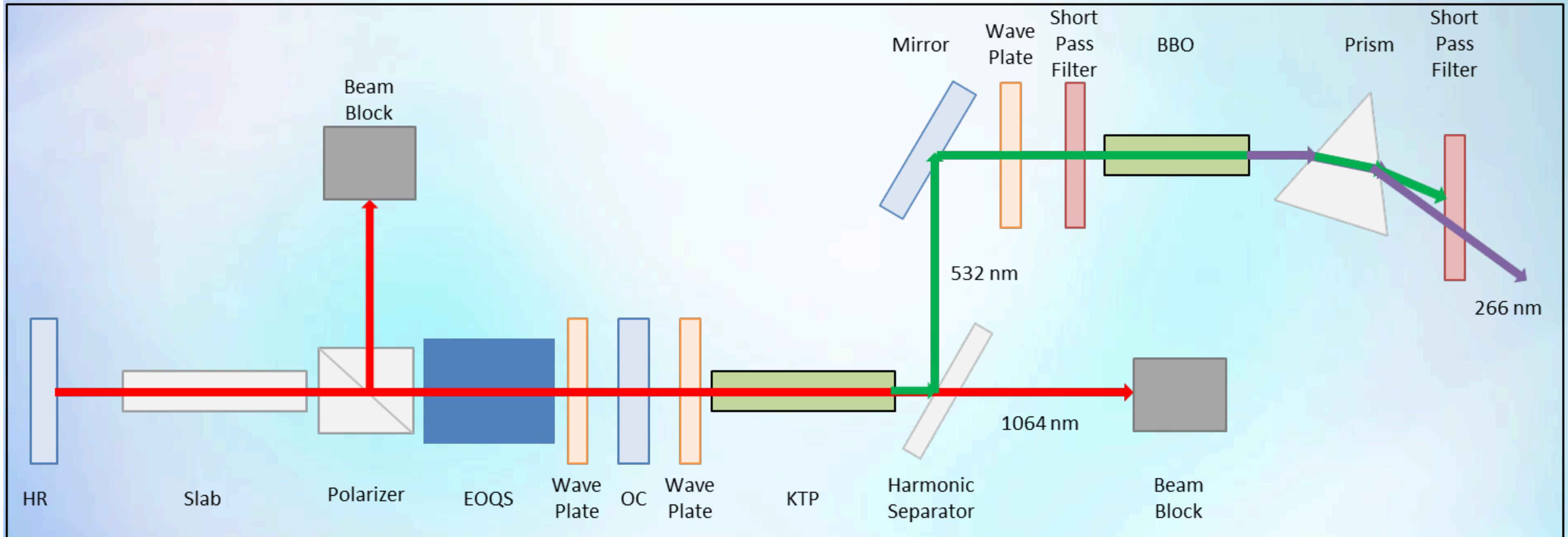


MIR Laser Breadboard Performance

Parameter	Measurement	Requirement
Wavelength	3471 nm	3400 nm ± 50 nm
Pulse Repetition Frequency (PRF)	20 Hz	1-20 Hz
Average Power	4.2 mW	NA
Energy	210 µJ	100 µJ
Pulse Duration	1.9 ns	< 7 ns
Conversion Efficiency	10.5 %	NA



UV Laser Breadboard



266 nm Laser Performance

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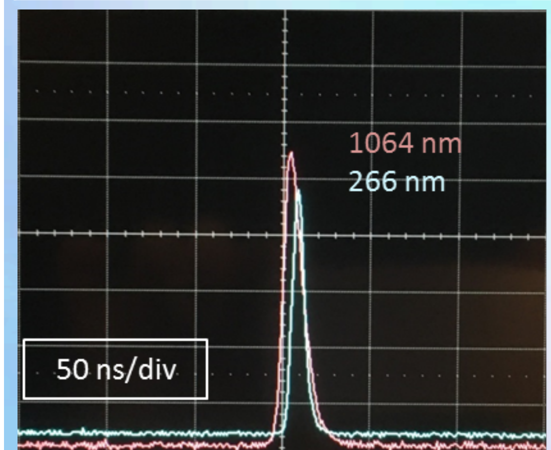
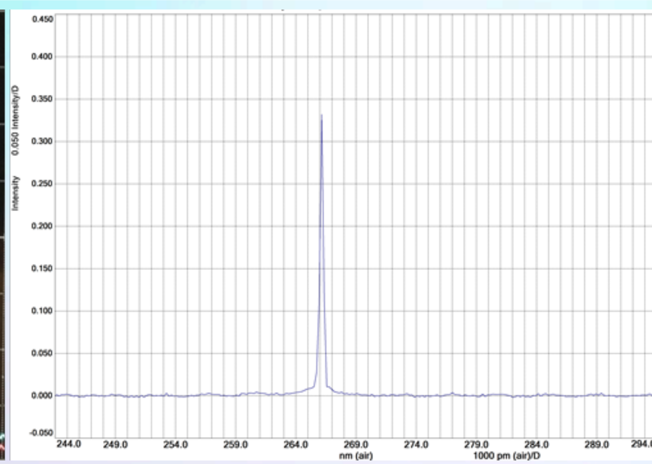
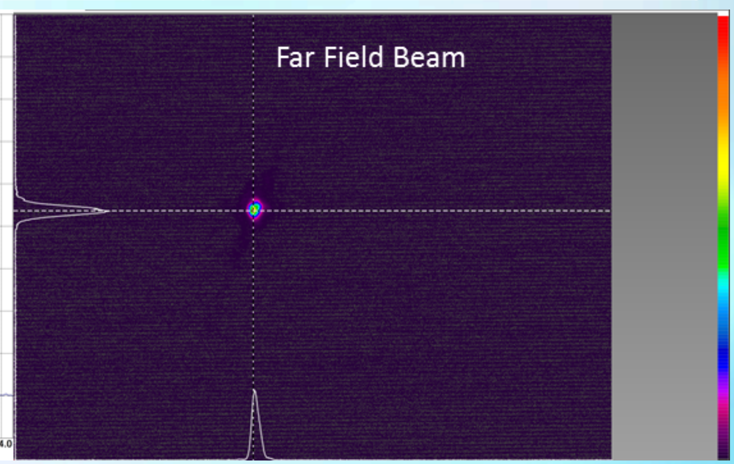
Parameter	Measurement	Requirement
Wavelength	266.2 nm	266 nm
Pulse Repetition Frequency (PRF)	20 Hz	1-20 Hz
Energy	220 μJ	18 μJ
Pulse Duration	6.6 ns	< 7 ns
Peak Power	32.5 kW	2.5 kW
Peak Intensity (assuming 100 μm beam diameter)	415 MW/cm^2	30 MW/cm^2
Divergence (full angle)	θ_x = 0.66 mrad θ_y = 1.12 mrad	NA
Overall 4th Harmonic Conversion Efficiency (1064 nm – 266 nm)	10%	NA







Integration of Laser to L2MS Instrument

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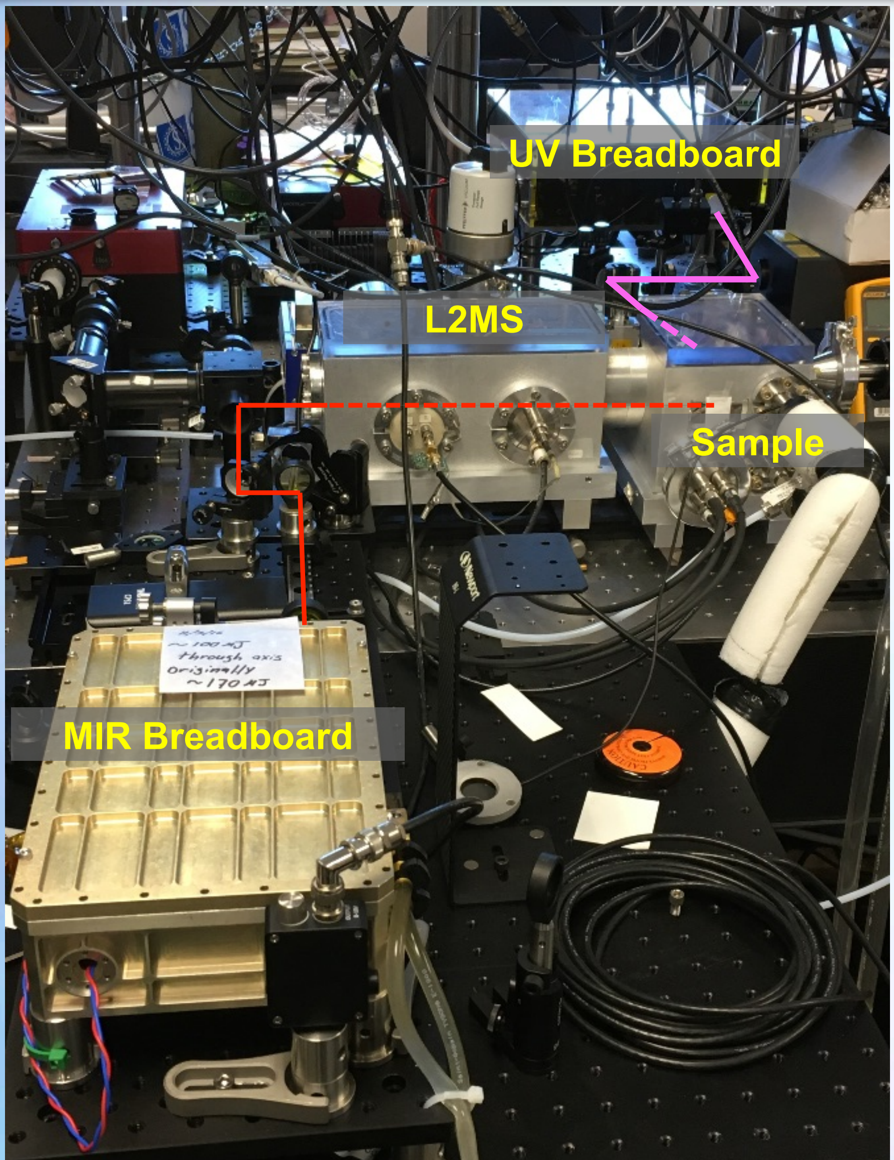

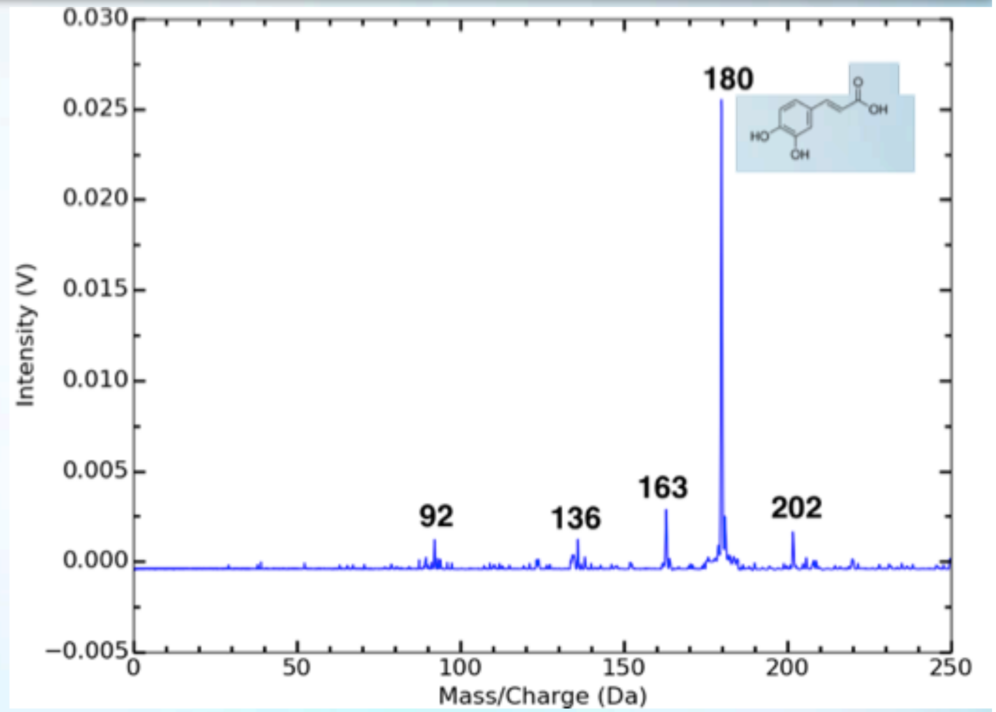

- Successful coupling of the laser breadboards to the L2MS instrument enabled detection of caffeic acid encapsulated by a thin layer of water ice, for the first time
- A mass spectrum of caffeic acid coated with water ice, measured at cryogenic temperatures is shown above

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Future Work

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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 4^{th} 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

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