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2-micron Triple-pulse Integrated Path Differential Absorption Lidar Development (IPDA) for Simultaneous Airborne Column Measurements of Carbon Dioxide and Water Vapor in the Atmosphere

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Outline

- Objective
- Introduction
- Methodology
- Instrument specifications
  - Transmitter
  - Receiver
  - Data Acquisition & Control
- Summary

Objective

To demonstrate and validate simultaneous and independent measurements of the weighted-average, column dry-air mixing ratios of carbon dioxide (XCO_2) and water vapor (XH_2O) using a single instrument from an airborne platform

Introduction

Active remote sensing of CO_2 have been recommended by the National Research Council (NRC) to increase our understanding of the gas worldwide sources, sinks, and fluxes to enhance carbon-cycle and climate studies[1]

Based on the above recommendation and the success of ESTO funded Double-Pulse Integrated Path Differential Absorption (IPDA) Lidar, this effort funded by ESTO Instrument Incubator Program -2013, we present the current status of developing a next generation of the lidar: **An Airborne triple-pulse 2-?m IPDA Lidar for CO_2 and H_2O Column Measurement**

- Why Pulsed?
  Pulsed operation allows range determination

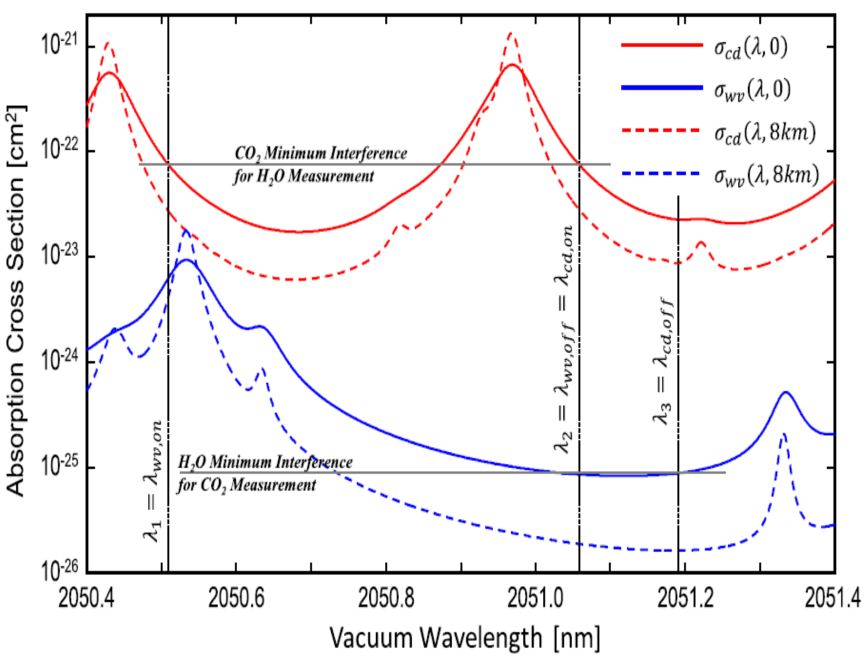
- Why Triple-Pulse?
  Triple-pulse operation enables measurement of two species with a single instrument

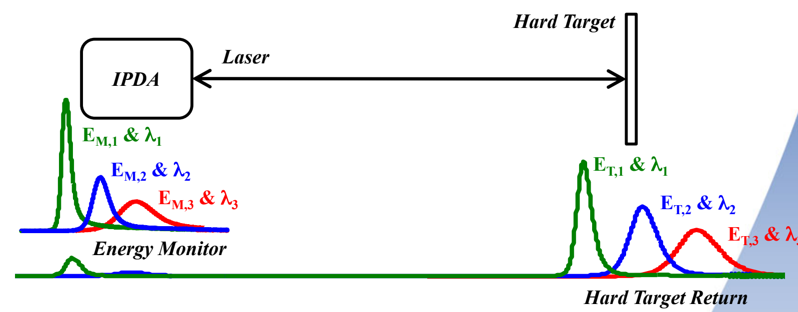
- Why 2-?m wavelength?
  This wavelength provides the required measurement sensitivity with mature and reliable technology

[1] National Research Council (NRC), "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond," The National Academies Press, Wash DC, "known as Decadal Survey (DS)" (2007)

Methodology

- $\boxed{?}_1$ and $\boxed{?}_2$ for H_2O sensing, with the same amount of CO_2 absorption.
- $\boxed{?}_2$ and $\boxed{?}_3$ for CO_2 sensing, with the same amount of H_2O absorption.
- Simultaneous measurement of the CO_2 and H_2O while avoiding interference.

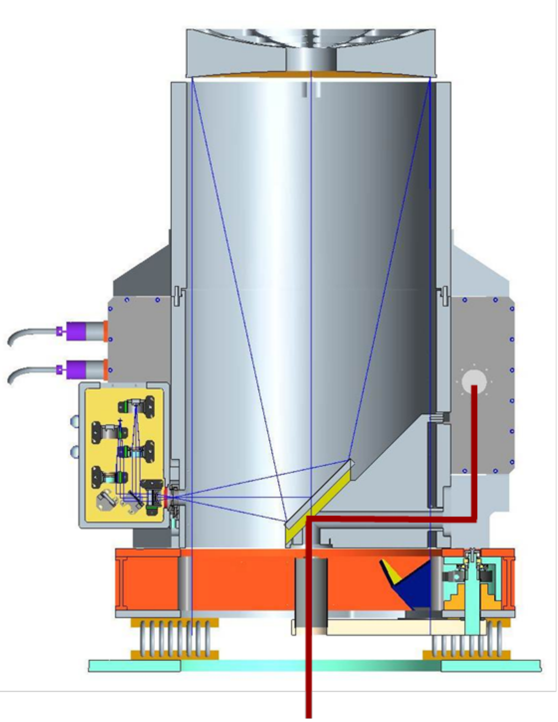




$$dOD_{1,2} = \int_0^R 2 \cdot \left(\Delta\sigma_{wv}^{1,2} \cdot N_{wv} + \Delta\sigma_{cd}^{1,2} \cdot N_{cd}\right) \cdot dr = ln\left(\frac{E_{T,2} \cdot E_{M,1}}{E_{M,2} \cdot E_{T,1}}\right)$$

$$dOD_{2,3} = \int_0^R 2 \cdot \left(\Delta\sigma_{wv}^{2,3} \cdot N_{wv} + \Delta\sigma_{cd}^{2,3} \cdot N_{cd}\right) \cdot dr = ln\left(\frac{E_{T,3} \cdot E_{M,2}}{E_{M,3} \cdot E_{T,2}}\right)$$

Methodology

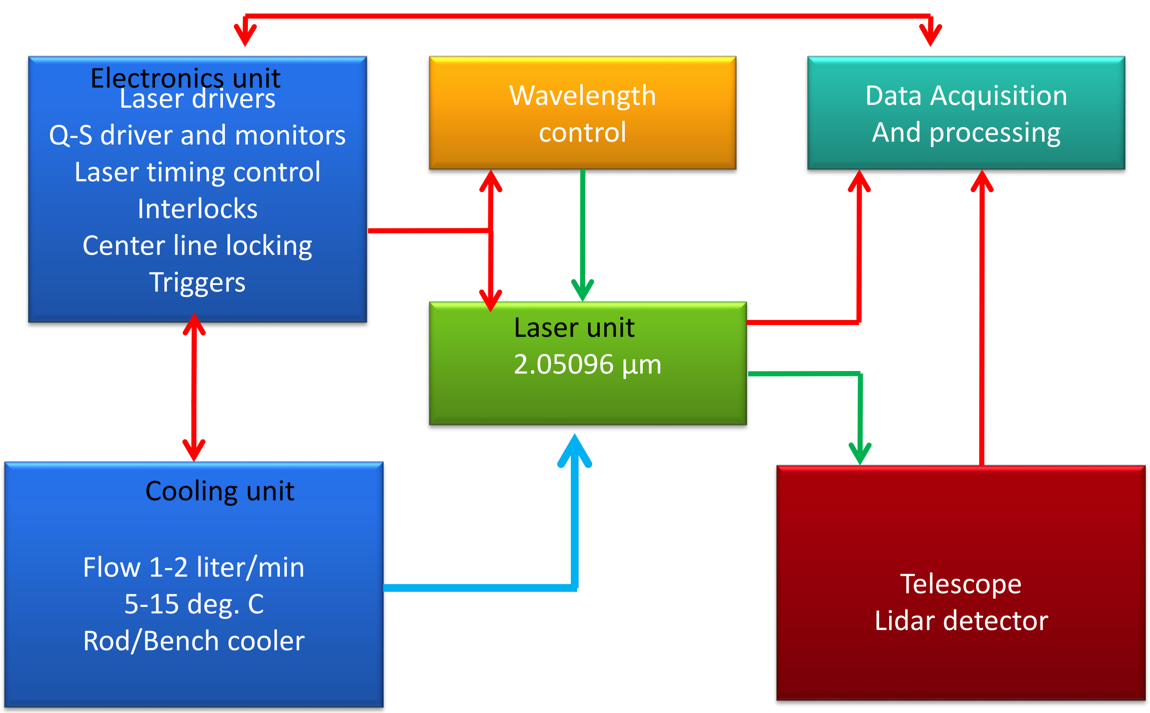


Targets

- Design and fabricate a conductively-cooled, triple-pulsed, 2-μm laser transmitter
- Design and develop wavelength control system for rapid and fine tuning of the three sensing lines of the CO_2 and H_2O IPDA lidar
- Integrate receiver optics and direct detection electronics
- Integrate laser transmitter with receiver to develop the 2-μm triple-pulsed IPDA lidar instrument
- Conduct ground-based and airborne CO_2 and H_2O measurements and validate with *in-situ* sensors

Instrument Specifications

Instrument Block Diagram



Instrument Specifications

Laser Transmitter

Parameter	Specifications			Unit
Wavelength ($\boxed{?}_1$ / $\boxed{?}_2$ / $\boxed{?}_3$)	2050.5094 /	2051.0590 /	2051.1915	(nm)
Output Energy	50	15	5	(mJ)
Pulse length	30	60	100	(ns)
Repetition Rate		50		(Hz)
Pulse separation		200		(μs)
Beam Divergence		150		(μrad)
Beam Quality		< 2		(M^2)
Laser Line Width		Transform limit		
Frequency Control Accuracy		1		(MHz)
Wall-plug Efficiency		2		(%)

Instrument Specifications

Receiver

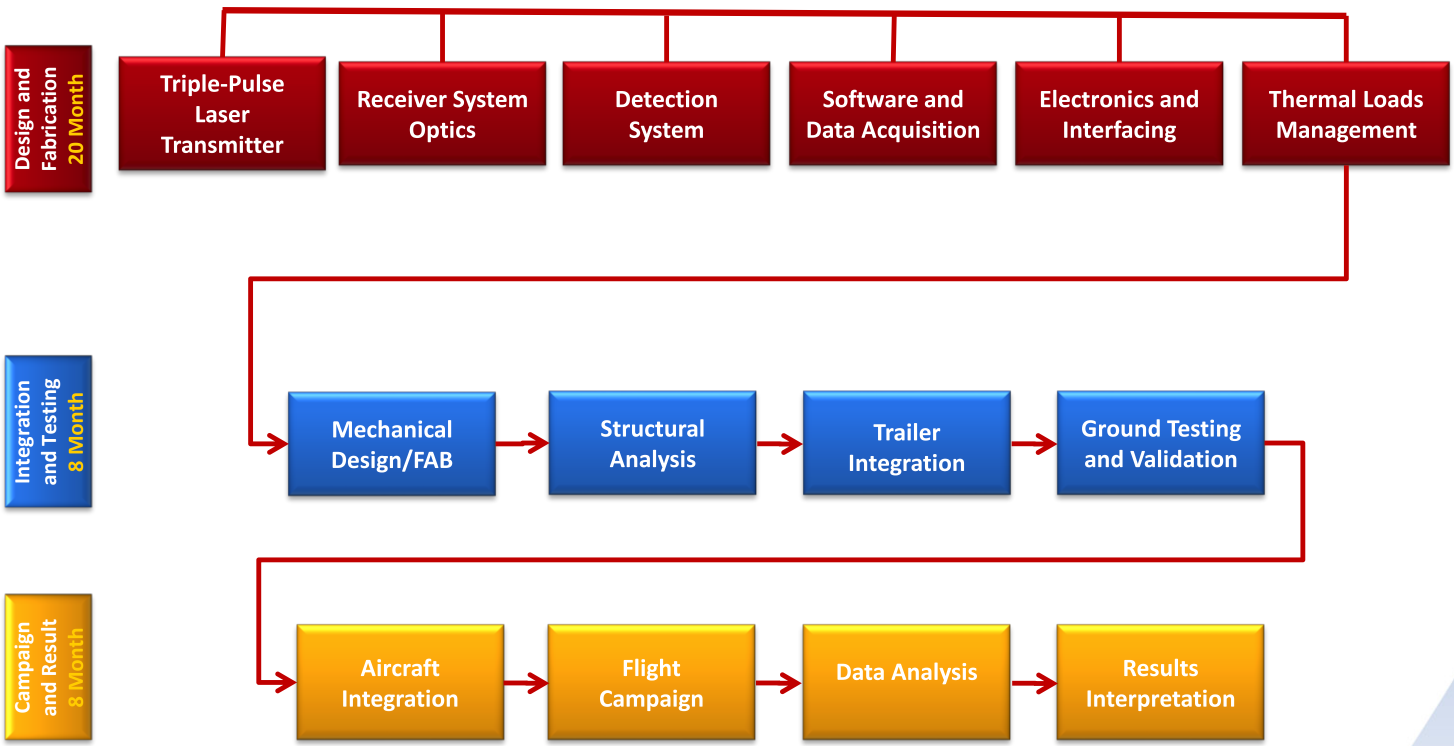
Parameter	Specifications	Unit
Telescope Dia.	40	(cm)
Telescope Field of View	300	(µrad)
Telescope F#	2.3	
Optical Efficiency	65	(%)

Detector

Parameter	Specifications	Unit
Quantum Efficiency	67.75	(%)
Bias voltage	300	(mV)
Dark current	3.7	(nA)
Capacitance	29.3	(pF)

Instrument Specifications

Instrument Integration Task Flow



Transmitter

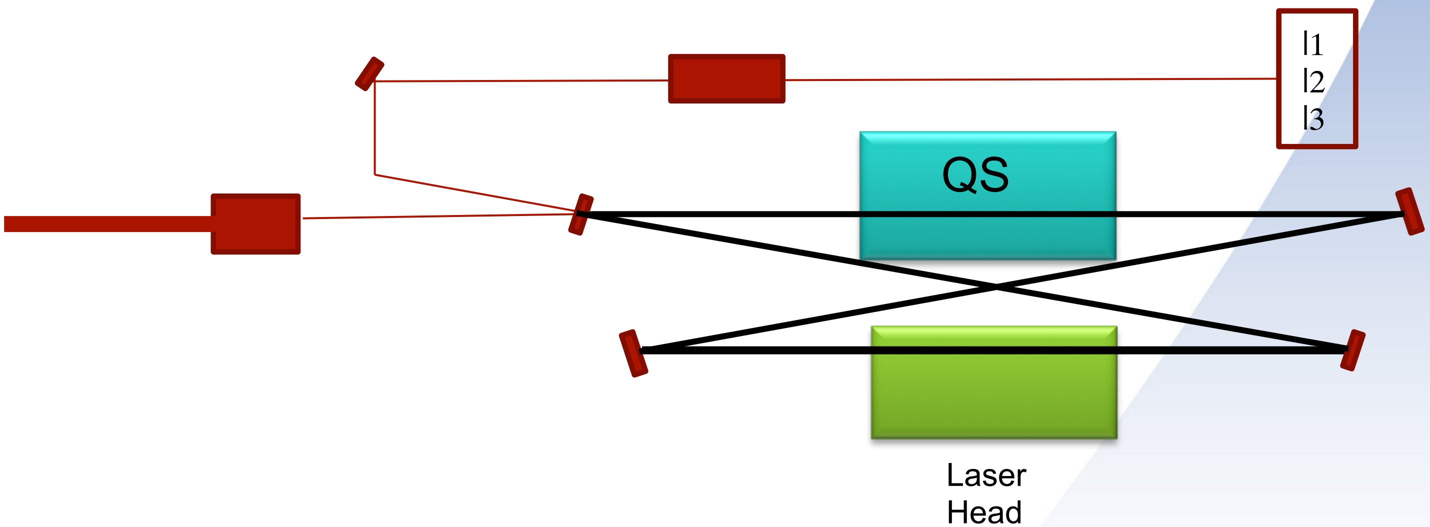
Transmitter Design Parameters

Item	Parameter	Rationale
Laser crystal	Ho:Tm:YLF	Triple pulse, R30, long lifetime
Tm concentration	2%, 3%, 4%	Heat load reduction
Ho concentration	>.8%	Better Q-S performance
Laser crystal size	2x2x15	Heat extraction
Operation temperature	5-15° C	Ground state depletion (GSD)
Crystal configuration	Diffusion bonded	pump face cooling
Cooling method	conductive	
Pump power	200W max 2.5ms	25 watt heat
Pump wavelength	792nm	
Pump beam radius	500µm	
Resonator configuration	Ring <1m	

Transmitter

Transmitter Design Parameters

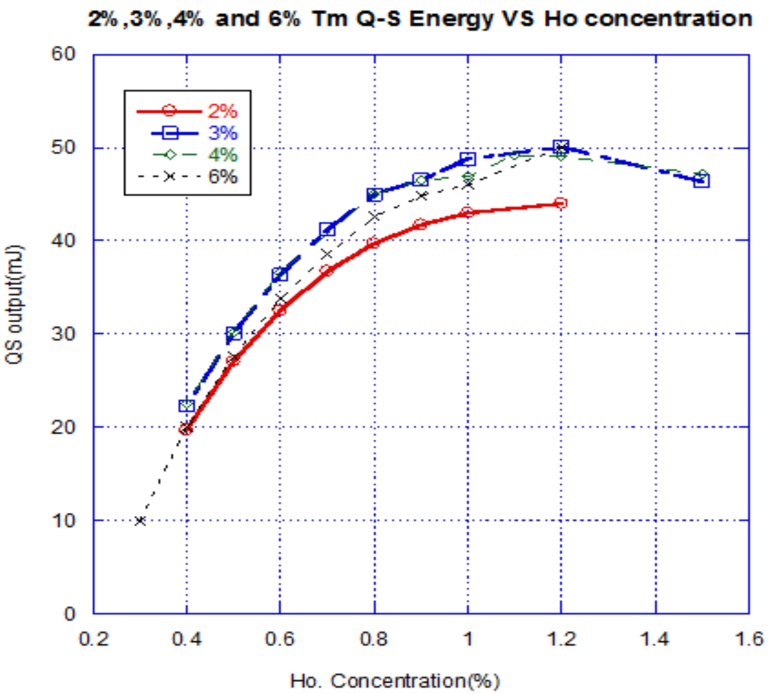
Item	Parameter	Rationale
Laser Enclosure	6”x26”x11”	compatibility
Laser Configuration	Oscillator	
Output Reflectivity	75%	
Pump configuration	End pump	Higher efficiency



Transmitter

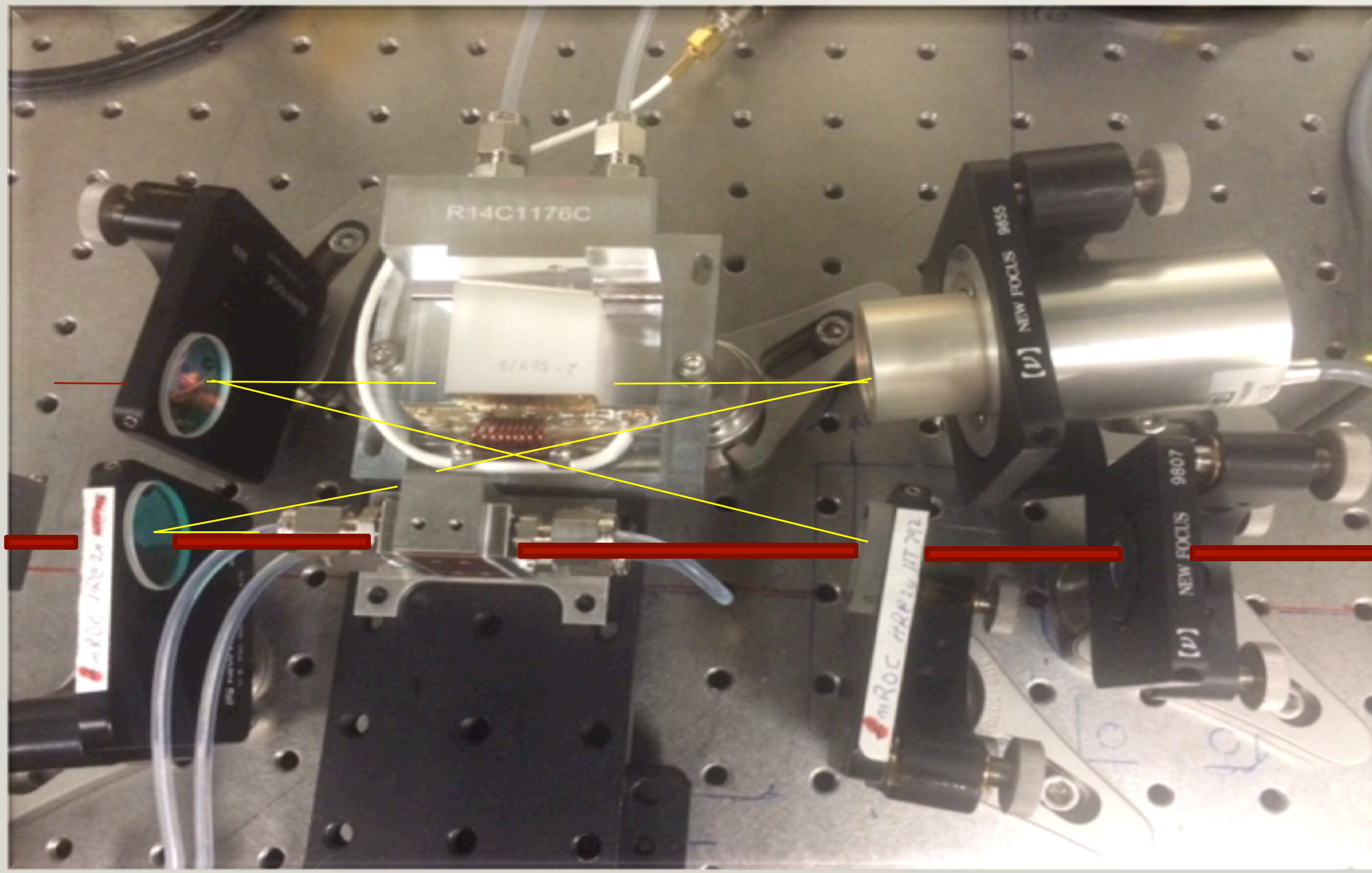
Crystal Concentration Study

- Thulium (Tm) and Holmium (Ho) concentrations are modified in the crystal
- Reduced Tm concentration from 6% to 2-4% to accommodate thermal loading
- Raised Ho concentration to enhance the Q-S performance

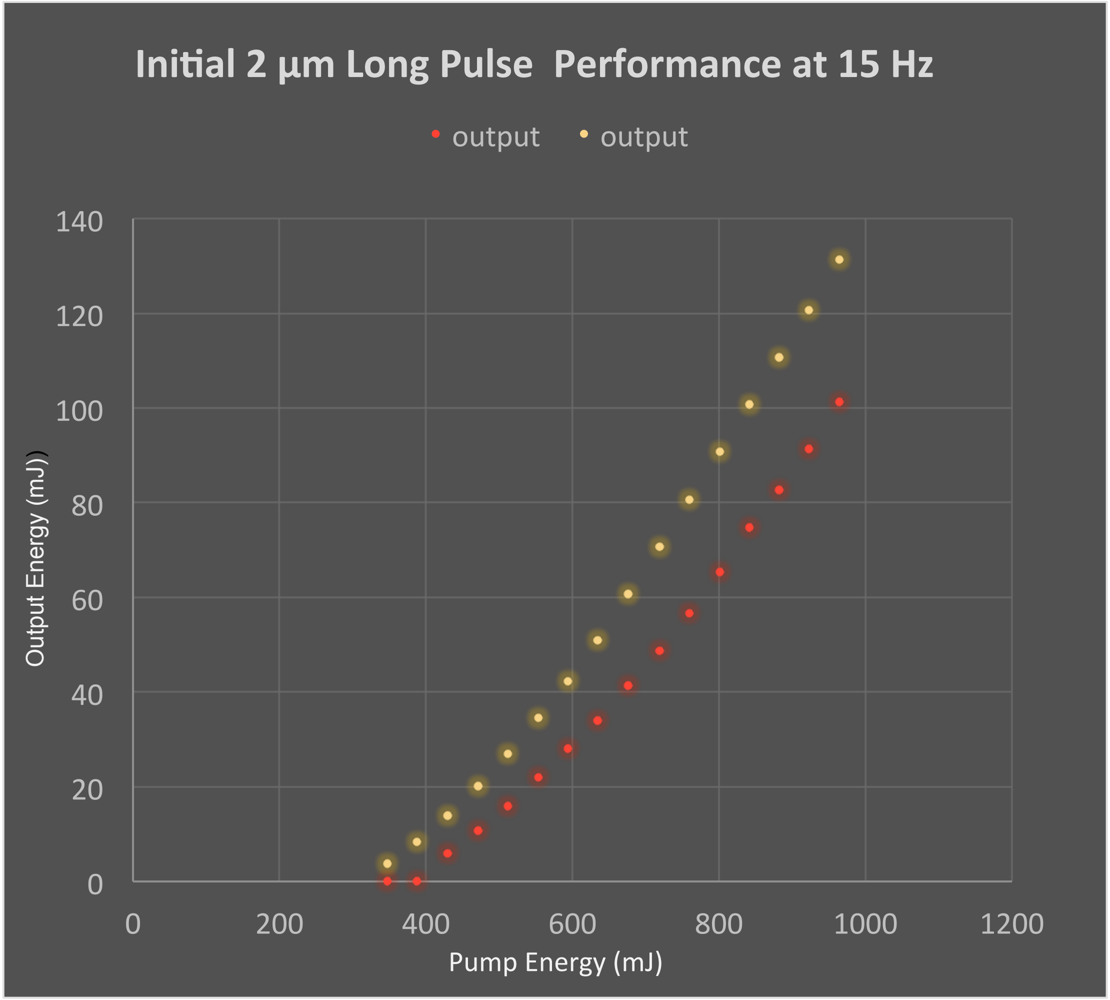


Transmitter

Experimental Setup for a Prototype Ring Laser



Transmitter



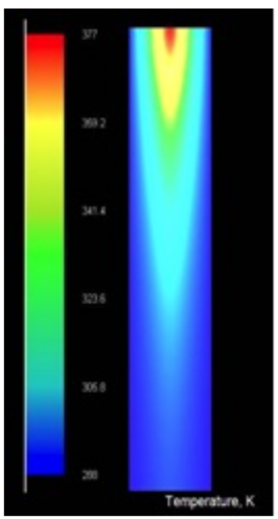
Initial Laser Demonstration at 15 Hz & 15°C

- The initial laser output indicates sufficient energy storage in the crystal
- 81% reflective mirror produces higher energy but the potential for damage is high in QS operation mode
- The energy dropped when the repetition rate was raised to 25 Hz

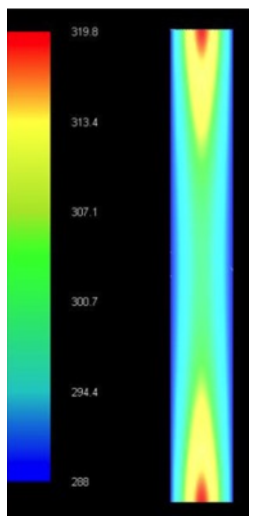
Transmitter

Laser Technical Challenges

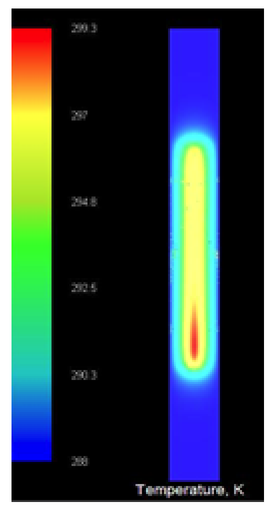
- Thermal loading on the crystal at 50 Hz operation reduced output energy
- Thermal fracture resulted from single-end pumping of the crystal
- The crystal non-uniform thermal expansion induced excessive mechanical stress
- Single-end pumping created uneven absorption along the length of the crystal and resulted in reabsorption loss



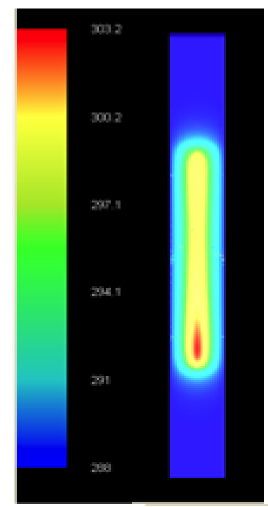
3%Tm
Max. temp.=377K



3%Tm
Max. temp.=320K



3%Tm
Max. temp.=303K



2%Tm
Max. temp.=299K

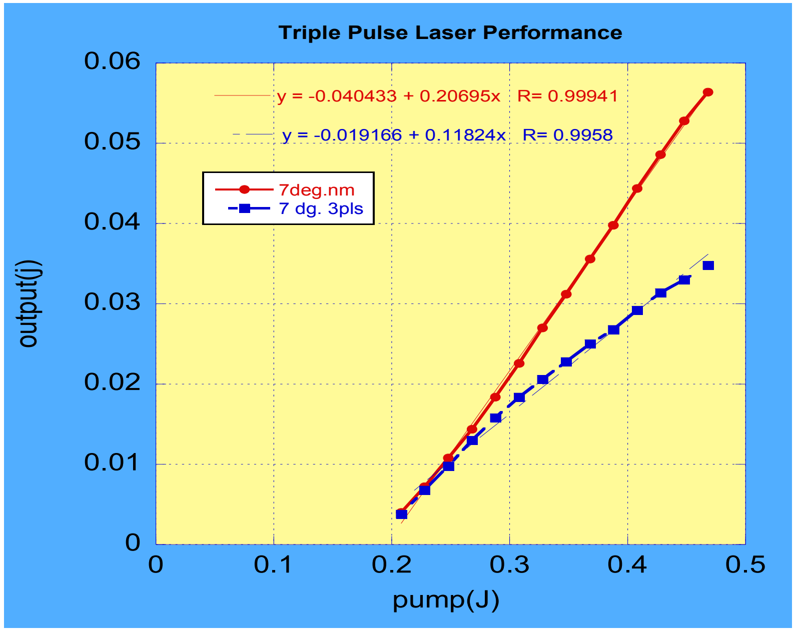
Transmitter

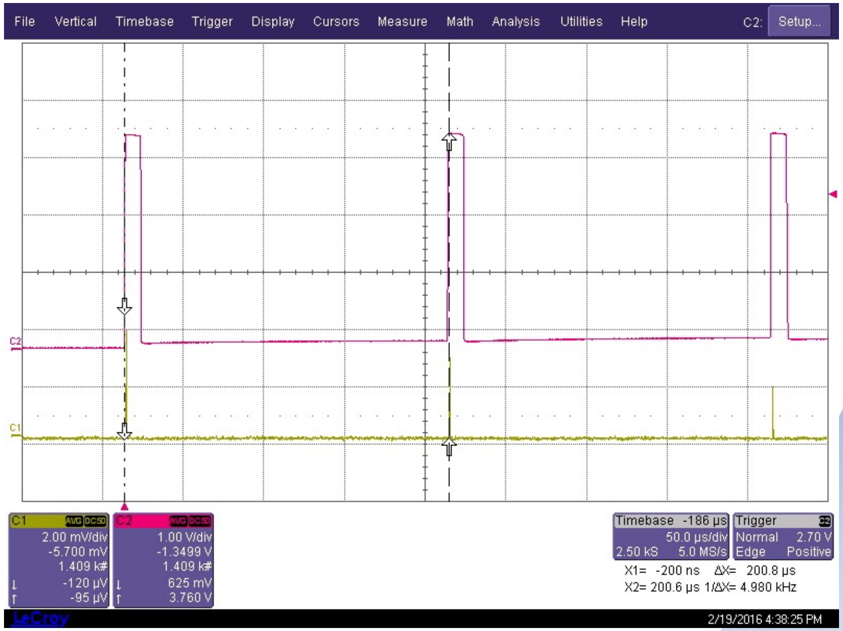
Solutions Sought

- Optimized pump length from 5 ms down to 3 ms
- Crystal double-end pumping
- Custom-designed, spring loaded crystal mount to accommodate non-uniform thermal expansion
- Crystal length optimization with respect to Tm concentration to homogenize pump absorption distribution
- Diffusion bonding of pump-ends of the crystal with un-doped YLF to cool the pump spot and provide six surface cooling

Transmitter

Performance Characterization

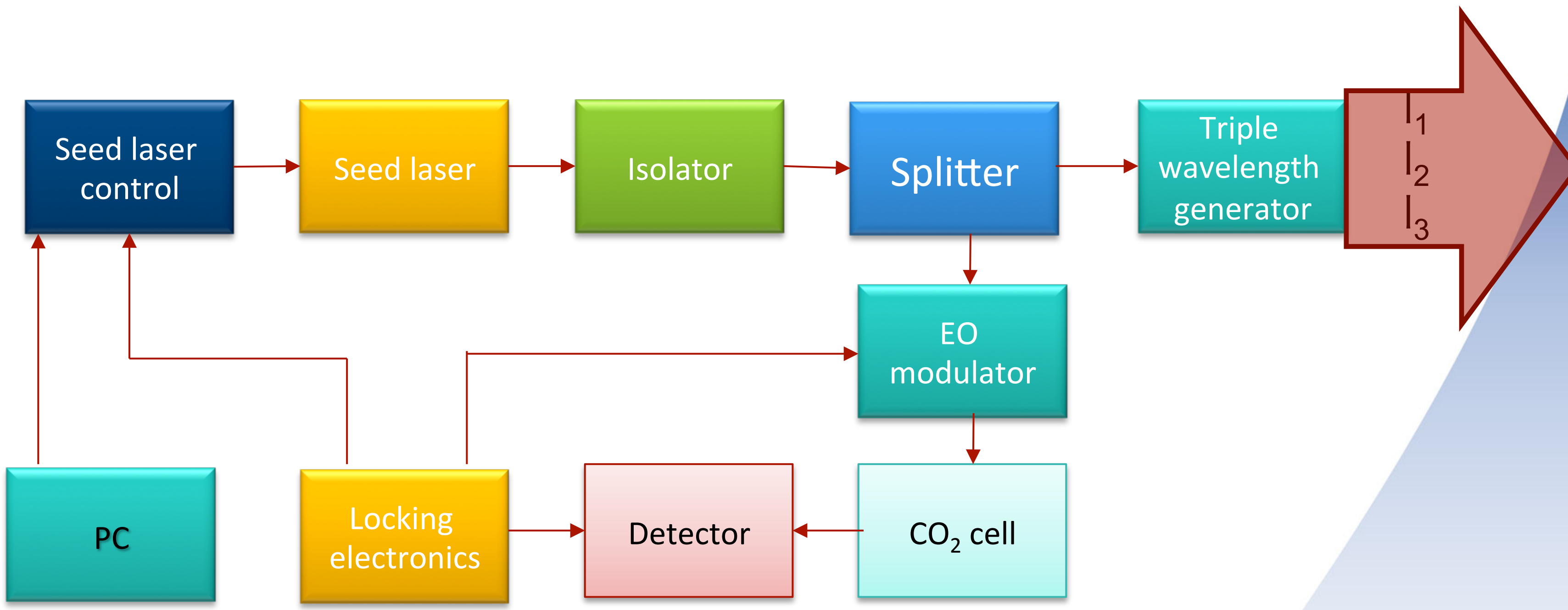




Transmitter

Wavelength Control

GOAL: Generate three distinct wavelengths, with respect to a CO_2 absorption locked center-line wavelength.

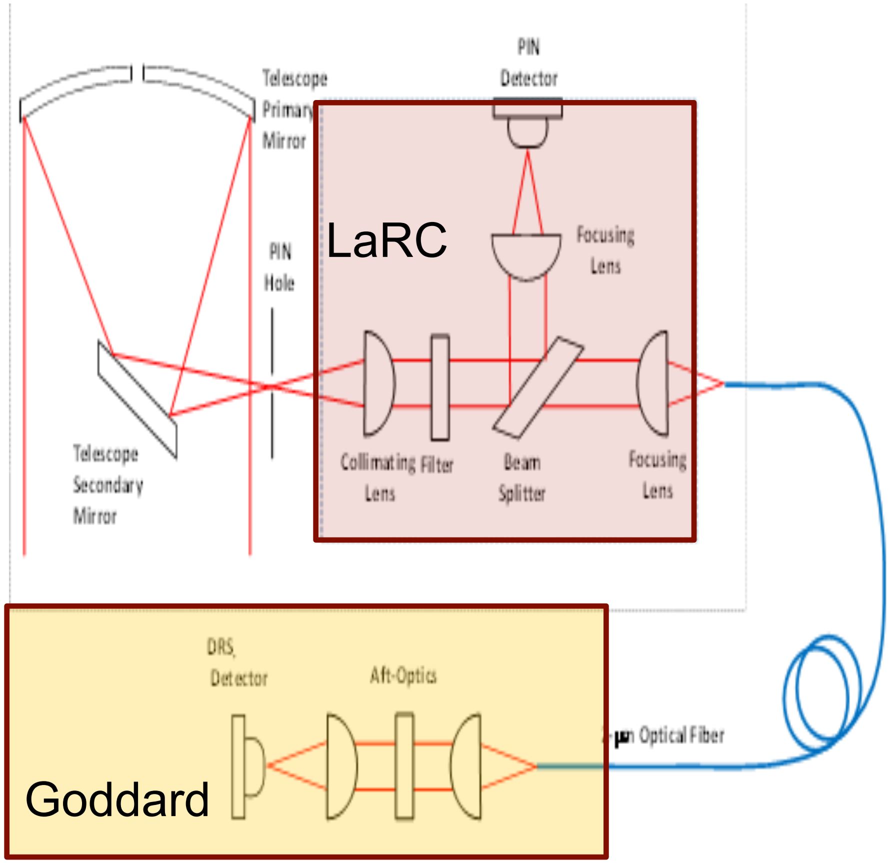


Transmitter

Wavelength Control Electronics

- Center line locking successfully completed
- A second center line locking hardware built. It will be used to further characterize the spectral line width and the jitter of the locked line system

Receiver

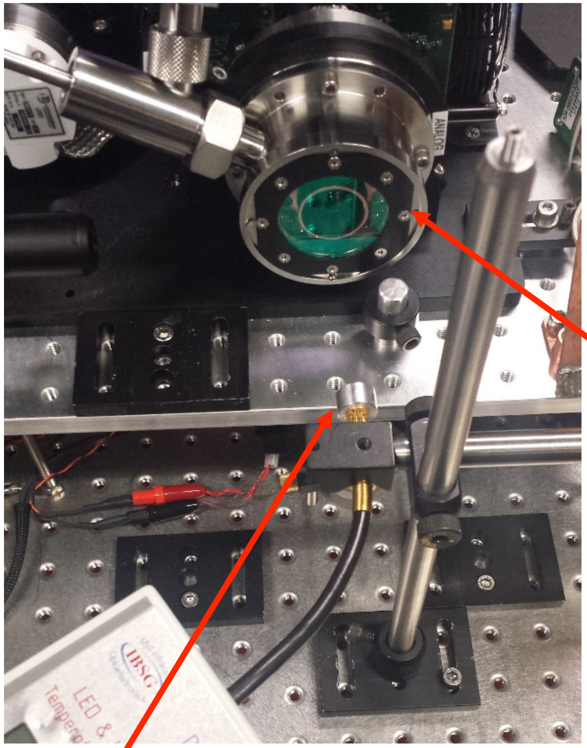


- The receiver system consists of two Aft-optics configurations
- A room temperature pin InGaAS detector (double pulsed system) and a high sensitivity cryogenic cooled MCT e-APD detector
- LaRC modifies the double pulsed system aft-optics to accommodate a fiber port to Godard's detector
- Work with Godard provides MCT e-APD detection system complete with the aft-optics and control electronics

Receiver

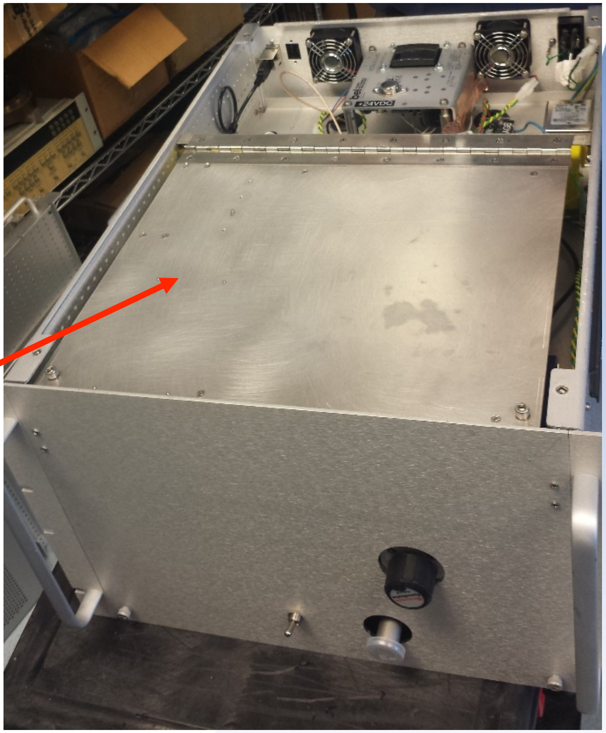
Receiver

MCT e-APD Hardware



- System packaging is in progress
- Performance testing of the detector using blackbody radiation and 2-μm fast LED.

MCT e-APD detector Array



2-μm fast LED

Detection system enclosure 19” rack, 7U
It includes electronics access to each of the pixel in the array

Data Acquisition

Waveform Digitizers

IPDA State-of-the-art Digitizers Manufactured by Agilent

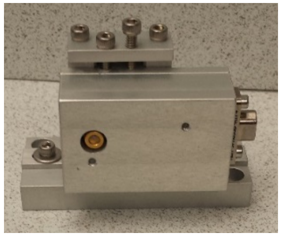
	Double-Pulse IPDA		*Triple-Pulse IPDA*
	Energy Monitor	**Hard Target Return**	**Both**
Part Number	**U1065A**	**U1066A**	**U5303A**
Number of Bits	**10 Bits**	**12 Bits**	**12 Bits**
Maximum Sampling Rate	**4 GS/s**	**420 MS/s**	**1.0 GS/s**
Number of Channels	**2-Channels**	**2-Channels**	**2-Channels**
Bandwidth	**DC up to 3 GHz**	**DC up to 300 MHz**	**DC up to 400MHz**
Input Impedance	**50 ?**	**50 ?**	**50 ?**
Coupling	**DC Coupling**	**DC Coupling**	**DC Coupling**
Support	**Supported**	**Obsolete**	**New Product**

Data Acquisition & Control

Control Electronics

- **Laser Transmitter Control (LTC) Electronics**
  - Controls the laser pump of the transmitter
  - Injection locking and Q-switching functions
  - Sends synchronizing signal to data acquisition and wavelength control

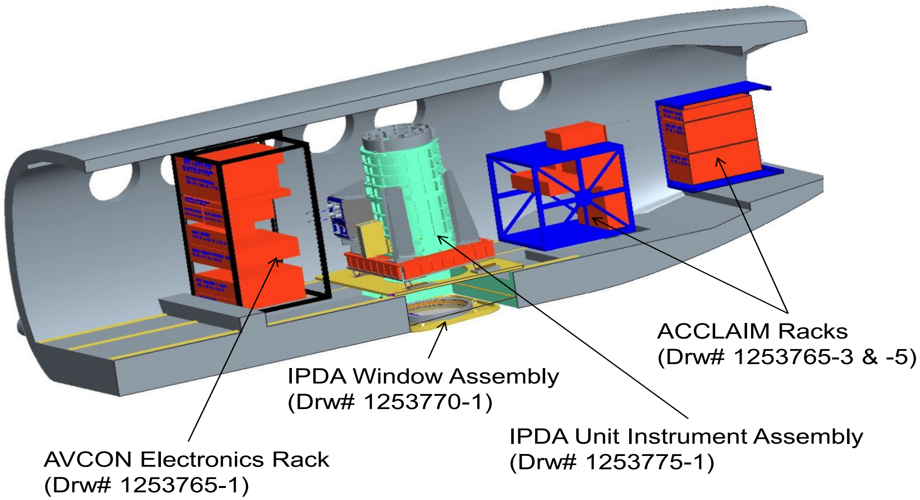
Resonance detector package



Laser timing control unit

- **Wavelength Control Electronics**
  - Seed laser driver
  - Provides CO_2 Online Locking
  - Generates three frequencies offset from the center line

Summary



- Triple-pulse 2-μm IPDA lidar instrument is under development for measuring atmospheric CO_2 and H_2O simultaneously
- IPDA transmitter is under development
- IPDA receiver and data acquisition systems have progressed well
- Instrument compact design fits NASA B-200 payload requirement
- Projected full system integration and ground testing by the end of this year
- Airborne testing is planned for next year

NASA