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Development of a Pulsed 2-micron Laser Transmitter for CO_2 Sensing from Space

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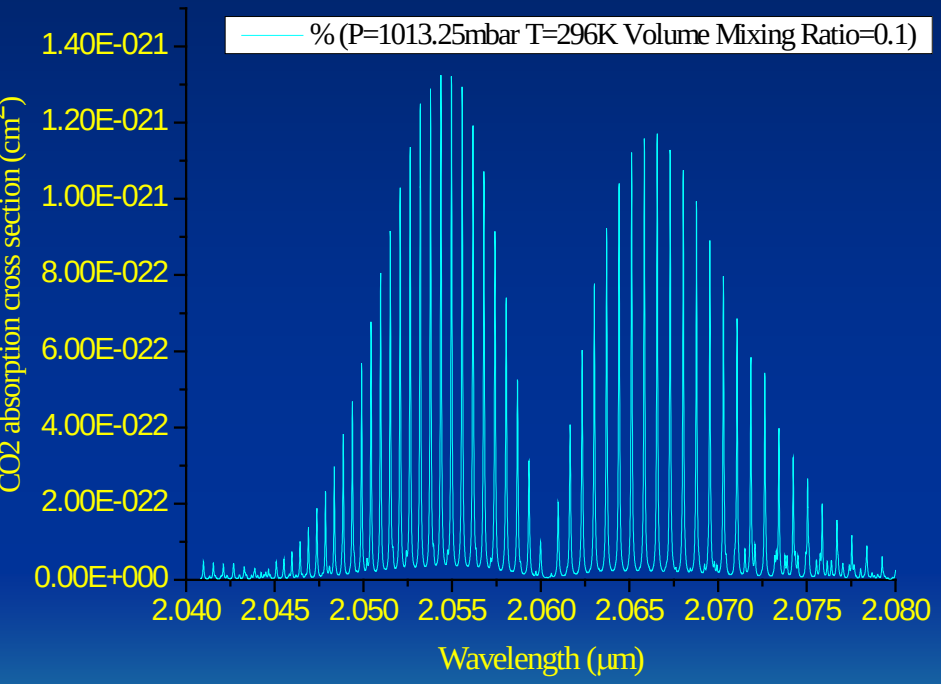
Outline

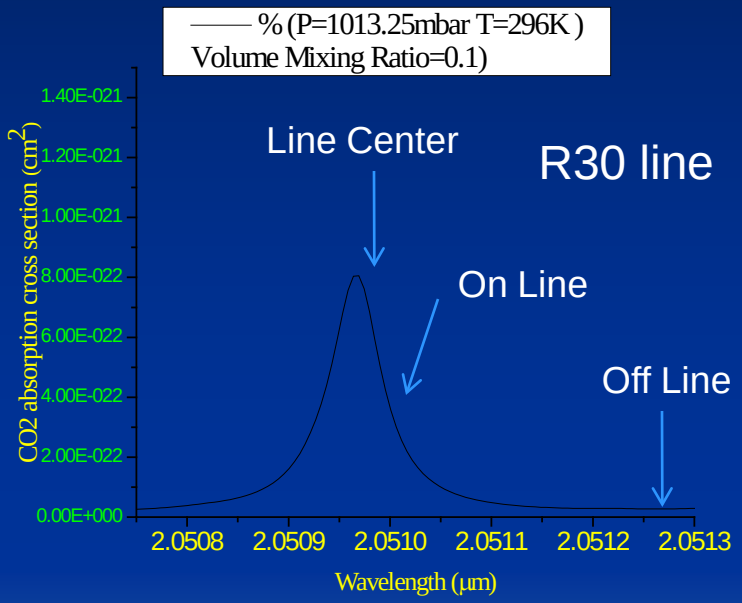
- Background
- CO_2 DIAL/IPDA Research Activities
- 2-micron Pulsed Lidar Approach for CO_2 Measurement
- 2-micron Pulsed Coherent Detection Lidar- for Mobile Ground-based CO_2 Profiling
- 2-micron Pulsed Direct Detection IPDA Lidar for CO_2 Column Measurement from Airborne Platform
- Summary

Pulsed Lidar Approach

- The National Academies has identified CO_2 measurement from space as a critical mission for study of climate change and global warming
- NASA has planned Active Sensing Of CO_2 Emissions Over Nights, Days, And Seasons (ASCENDS) mission for CO_2 column measurements from space
- For column measurements, the pulsed lidar approach can eliminate contamination from aerosols and clouds to yield high accuracy measurements
- The pulse approach can determine CO_2 concentrations as a function of distance with high spatial and temporal resolution, a valuable data product that is not currently available

CO_2 Absorption Line at 2-micron





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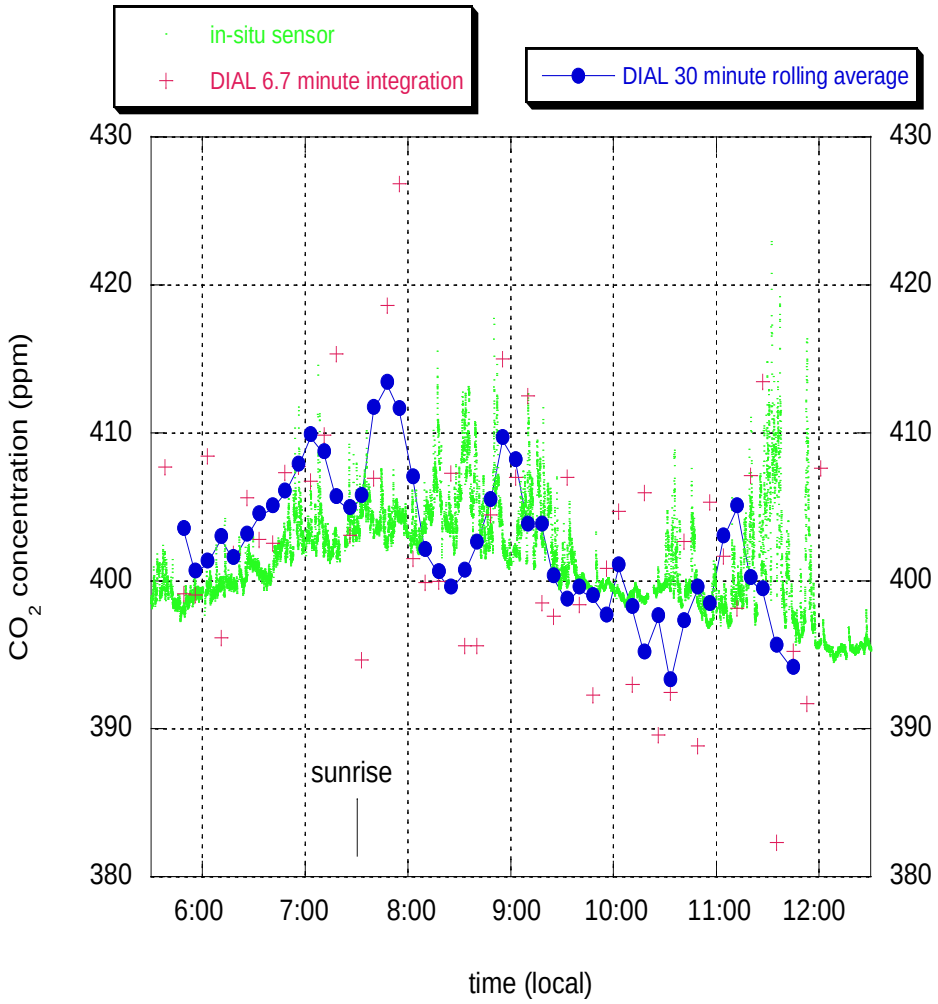
Atmospheric Testing—2007 Results



- DIAL at better than 0.7% precision for column over ½ hour (9000 pulses).
- Range-resolved at better than 2.4% on 500-m bins and 6.7 minutes (2000 pulses)

Improvements for 2010 Tests

- Higher pulse energy (90mJ to 250mJ) for higher SNR.
- Higher pulse repetition rate (5Hz to 10 Hz) for more pulse averaging.
- Double pulsing format for more pulse averaging and better atmospheric sampling.
- More favorable line (R30) for less water vapor bias.

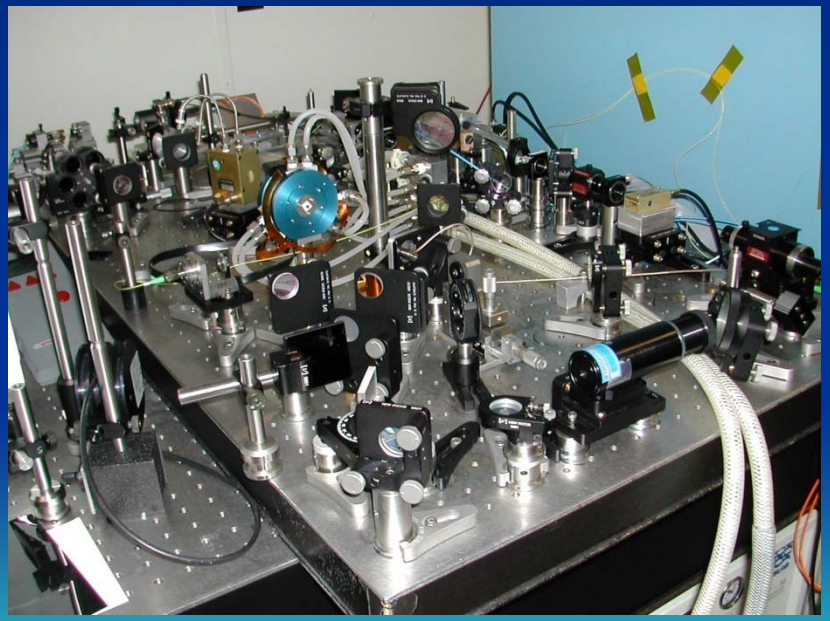
G.J. Koch et. al., Applied Optics 47, (7), 944-956 (Mar. 2008)

Mobile Ground based High Energy CO_2 DIAL Profiling Lidar – LRRP Funded

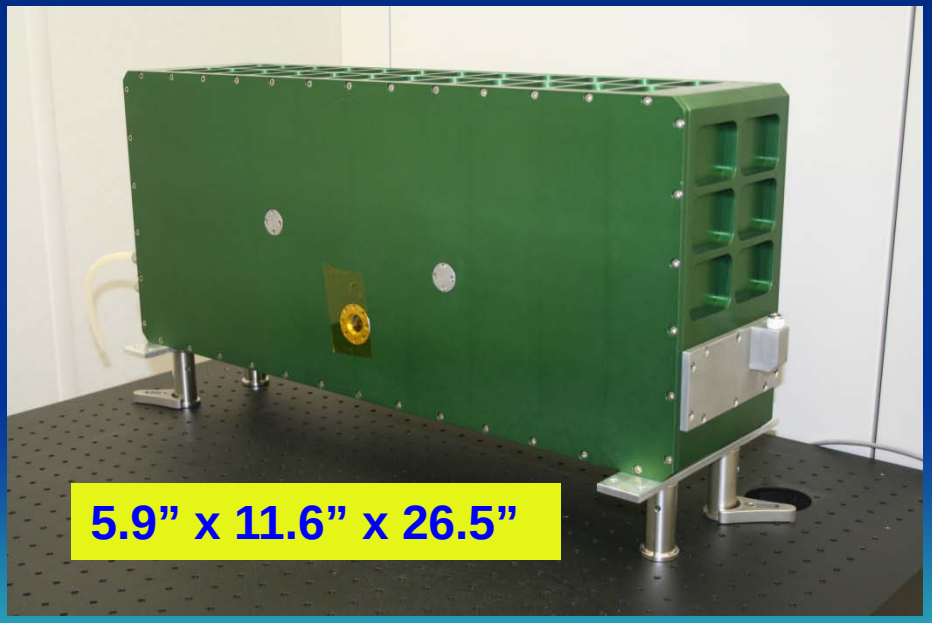
Table Top Transceiver
(Transmitter + Receiver)
90 mJ/pulse, 5 pulses/sec.
3'x4' Optical Table
(no telescope or scanner)

- **Smaller**
- **More energy**
- **More robust**

Transceiver (Transmitter + Receiver)
250 mJ/pulse, 10 pulses/sec.
5.9" x 11.6" x 26.5", 75 lbs.; 15 x 29 x 67 cm, 34 kg
(no telescope or scanner)

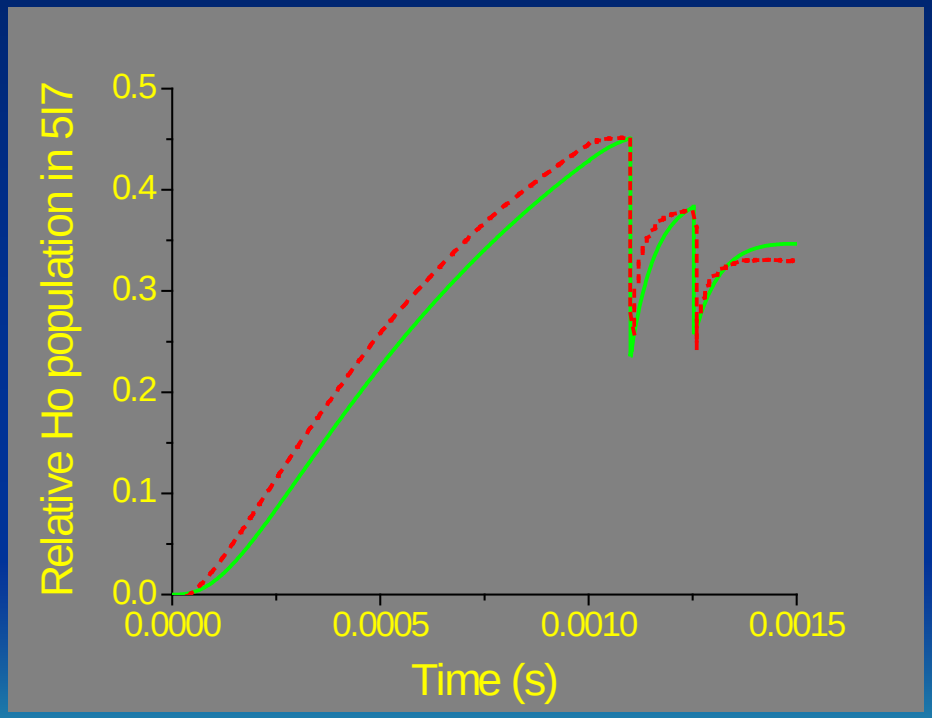


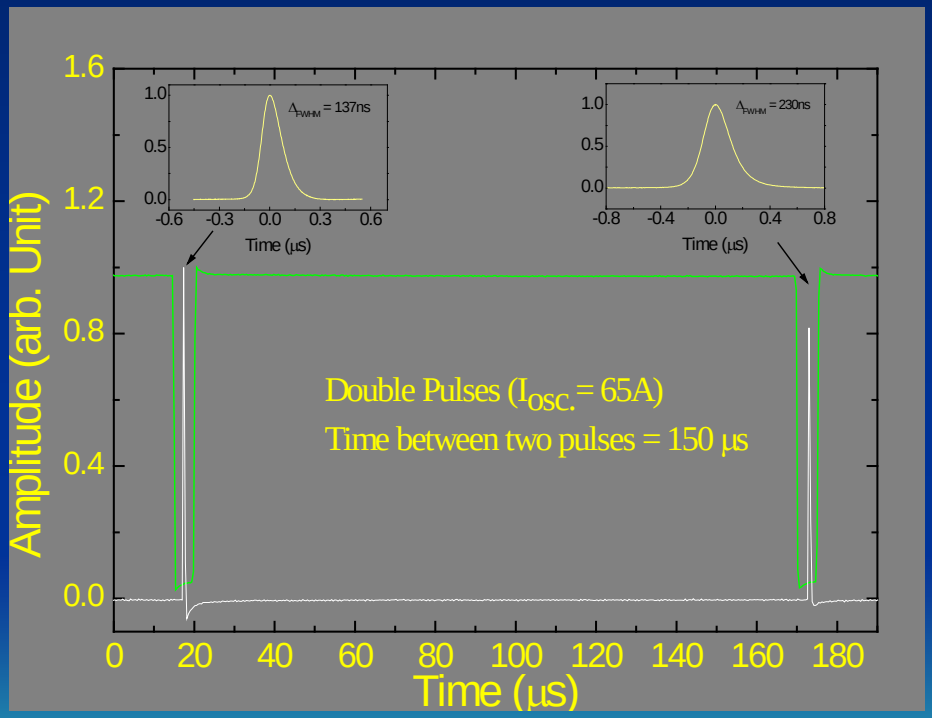
Previous implementation
90 mJ per pulse



Small, Robust, 250 mJ per pulse

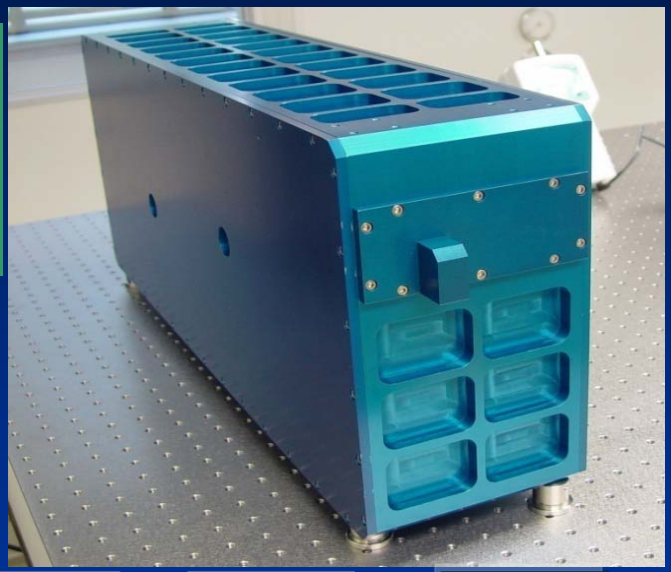
Double Pulsed 2-μm Laser Operation

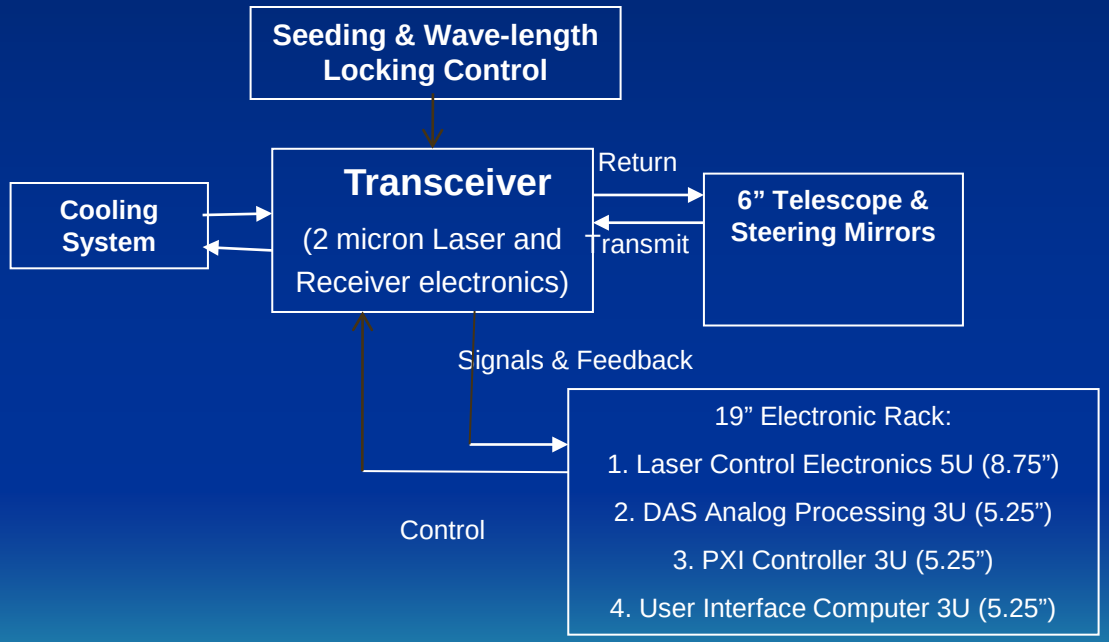


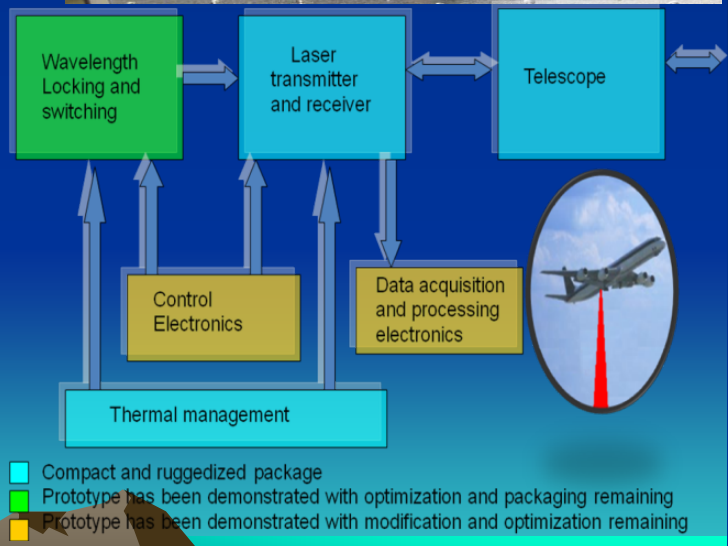


Pulsed Coherent CO_2 DIAL

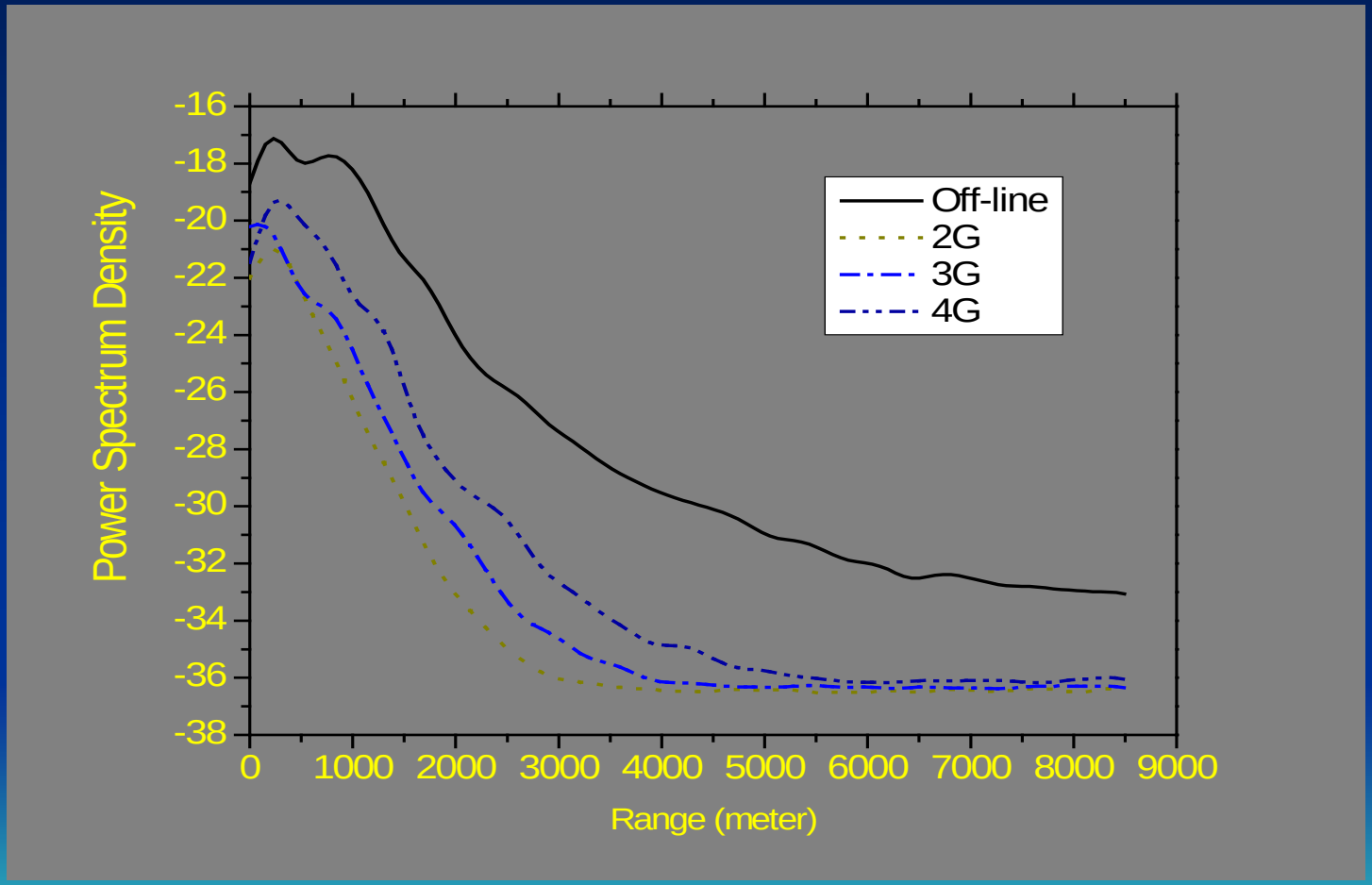
- **Pulsed 2-micron laser transmitter**
- **250 mJ/10Hz**
- **Coherent DIAL**
- **Provide CO_2 profiling/column density measurement**







On-Off Return Signal



Pulsed 2 μm Direct Detection IPDA Lidar System for CO_2 Column Measurement

- Pulsed 2 μm lidar, with ranging capabilities, provides a direct measurement of the atmospheric CO_2 path
- Provides high sensitivity in the boundary layer with no bias from aerosol layers and clouds on the measurement accuracy
- Higher per-pulse SNR (signal-to-noise ratio) obtainable with high energy 2 μm pulsed backscatter means less reliance on multi-pulse averaging, providing potential for higher along-track spatial resolution and better measurement capability in regions of partial cloud coverage, benefiting high precision measurements.
- Operating at 2 μm results in a weighting function that peaks near the surface
- Technical Challenges for IPDA Lidar Transmitter:
  - High efficiency
  - High average power
  - Good beam quality
  - Single frequency
  - Wavelength switching and controlling

Advanced-Space Carbon and Climate Observation of Planet Earth Mission Studies

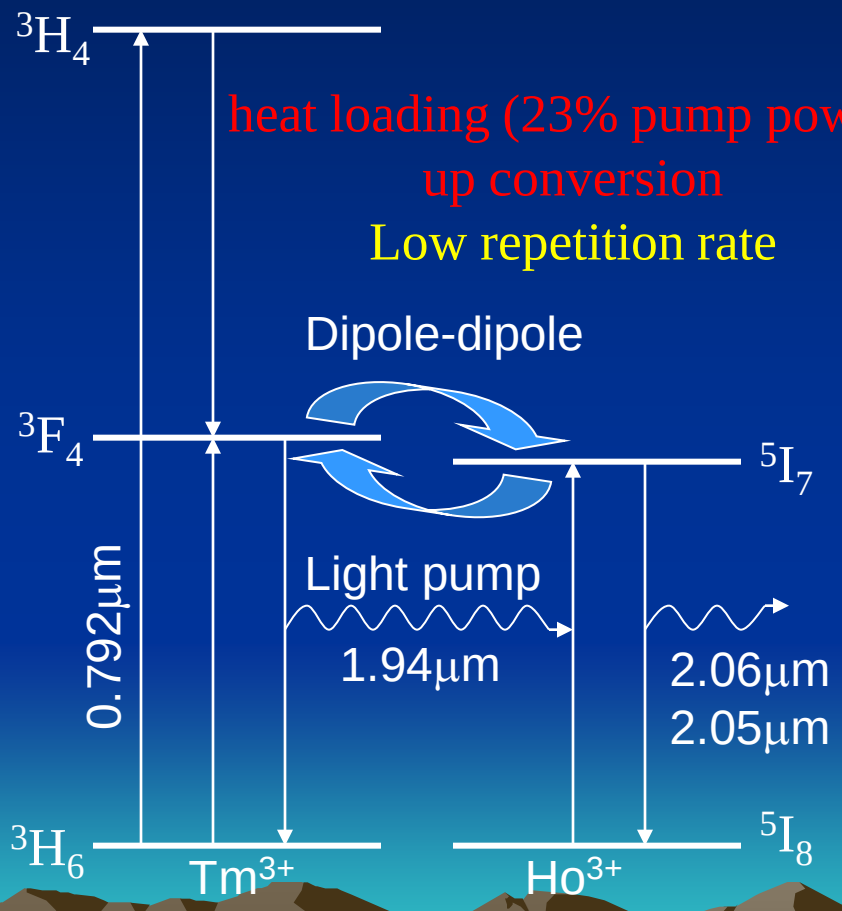
- A-SCOPE: Scientific objective: The observation of the spatial and temporal gradients of atmospheric XCO_2 with a precision and accuracy sufficient to constrain CO_2 fluxes within 0.02 Pg C yr^{-1} on a scale of 1000 x 1000 km^2.
- A-SCOPE: IPDA: Instrument Parameters

Transmitter		
Wavelength	**1.57 μm**	**2.05 μm**
Pulse Energy	**50 mJ**	**55 mJ**
Pulse Repetition Frequency	**50 Hz**	**50 Hz**
Spectral line width	**50 MHz**	**50 MHz**
Receiver		
Telescope diameter	**1 m**	**1.2 m**
Detector		
Quantum efficiency	**0.74**	**0.75**
Noise Equivalent Power	**46 fW/$Hz^{0.5}$**	**100 fW/$Hz^{0.5}$**

European Space Agency (ESA), "A-SCOPE – Advanced Space Carbon and Climate Observation of Planet Earth, Report For Assessment", ESA-SP1313/1 (2008), available at http://esamultimedia.esa.int/docs/SP1313-1_ASCOPE.pdf.
Ehret G., Kiemle C., Wirth M., Amediek A., Fix A., Houweling S., "Space-borne remote sensing of CO2, CH4, and N2O by integrated path differential absorption lidar: a sensitivity analysis", Applied Physics B 90, 593-608 (2008), an comprehensive study funded by European Space Agency under contract No.10880/03/NL/FF

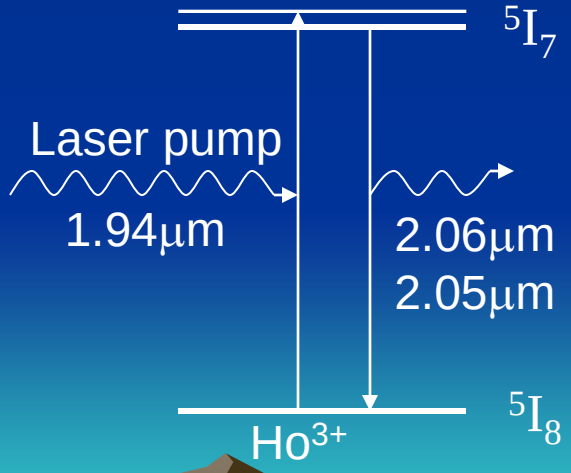
Ho Laser Energy Level Diagram

0.78/0.792μm Diode Pumping

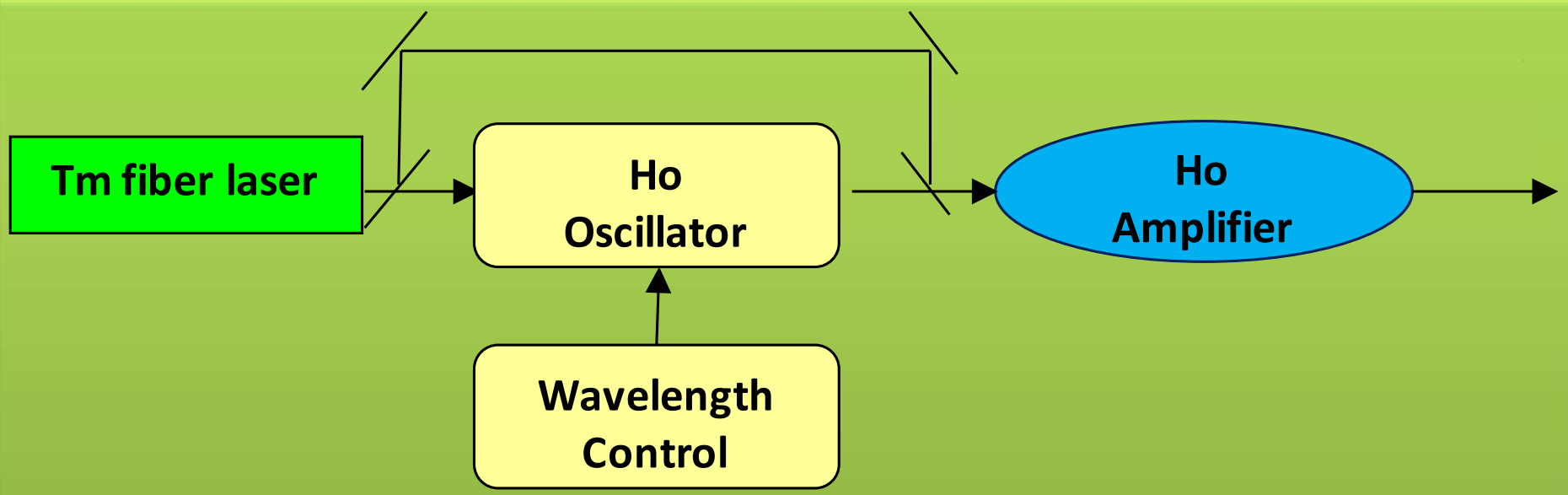


Tm:fiber Laser Pumping

low heat loading (5% pump power)
less up-conversion
high efficiency
CW/high repetition operation



Schematics of Lidar Transmitter



Commercially available

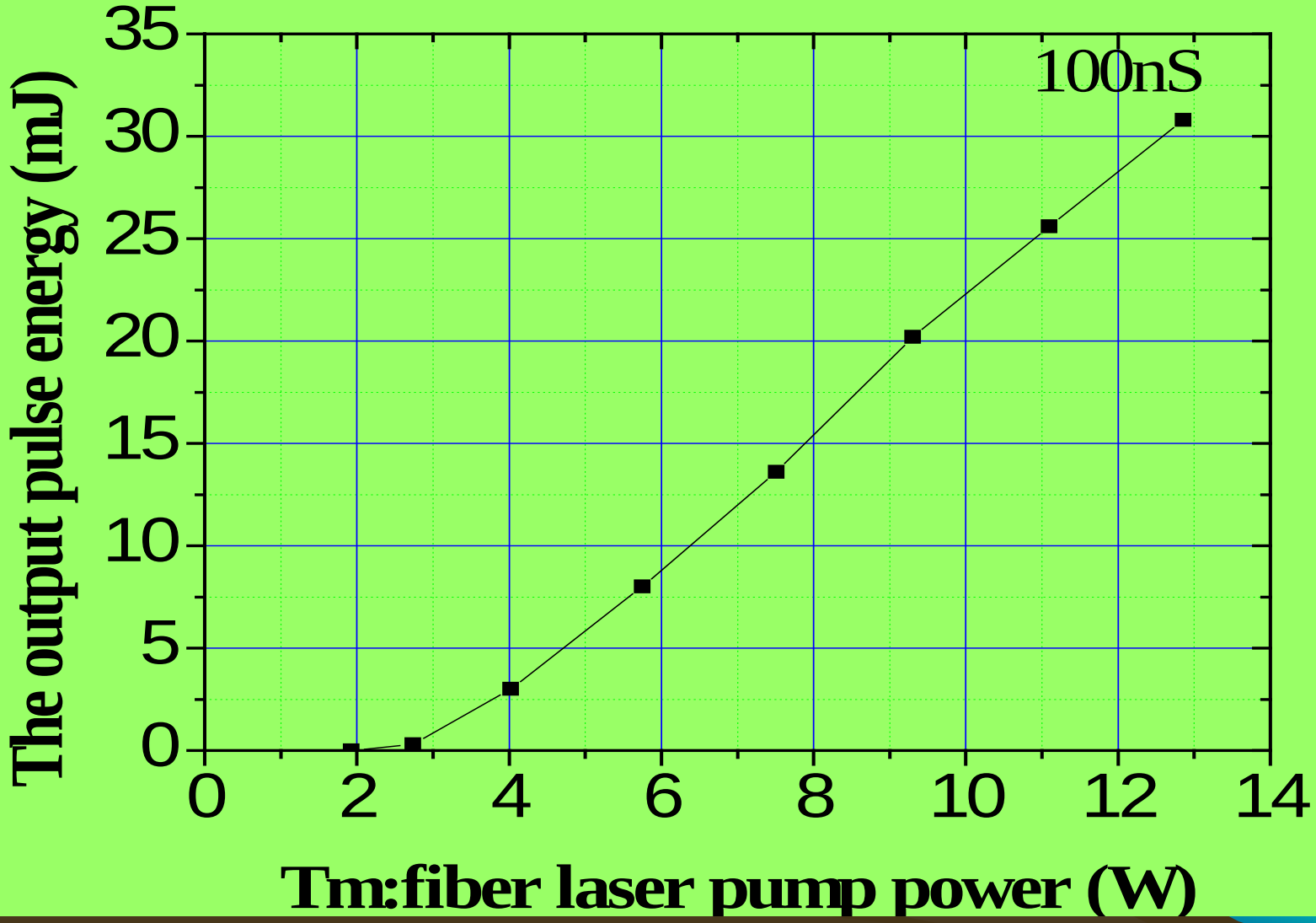
Technology demonstrated and bread boarded; compacting and packaging is planned

Technology need to be developed/improved/demonstrated; system engineering and packaging is planned

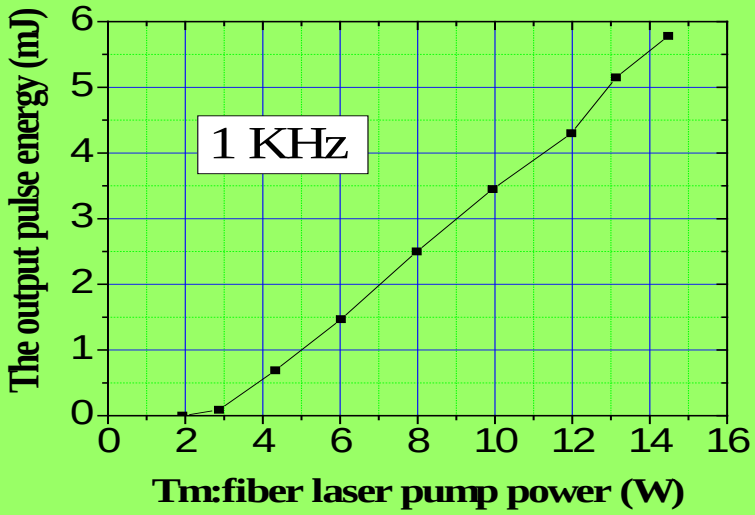
Master Slave Laser System

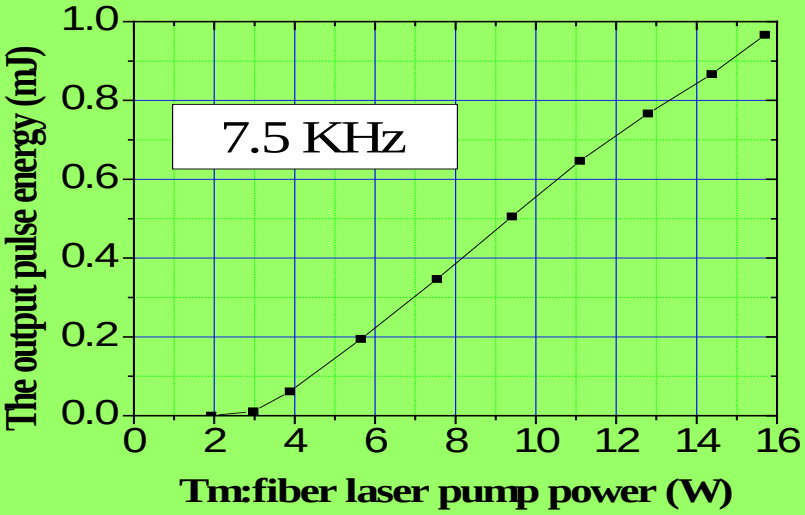
The pump, oscillator, and seed beams are all mode-matched.

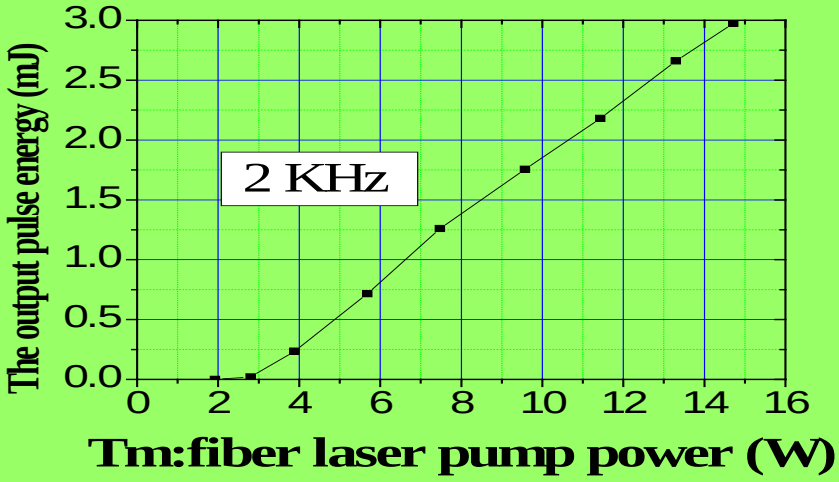
Ho:YLF Oscillator Performance (100 Hz)

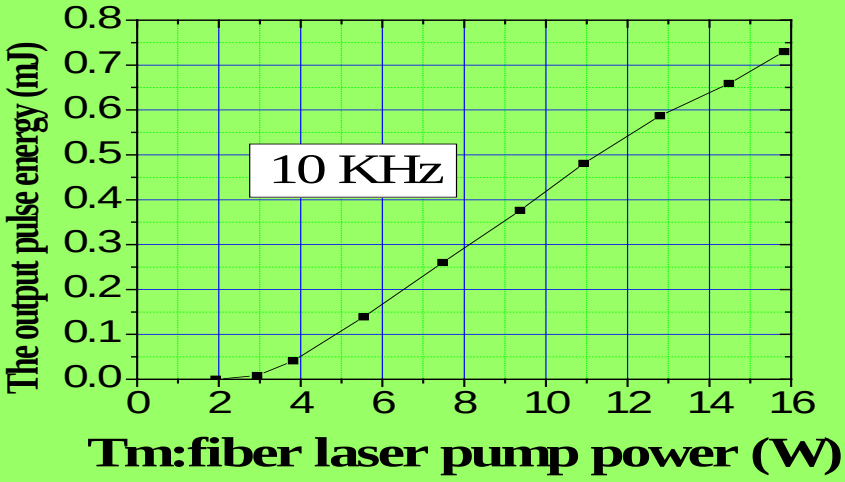


Oscillator Performance (High RR)



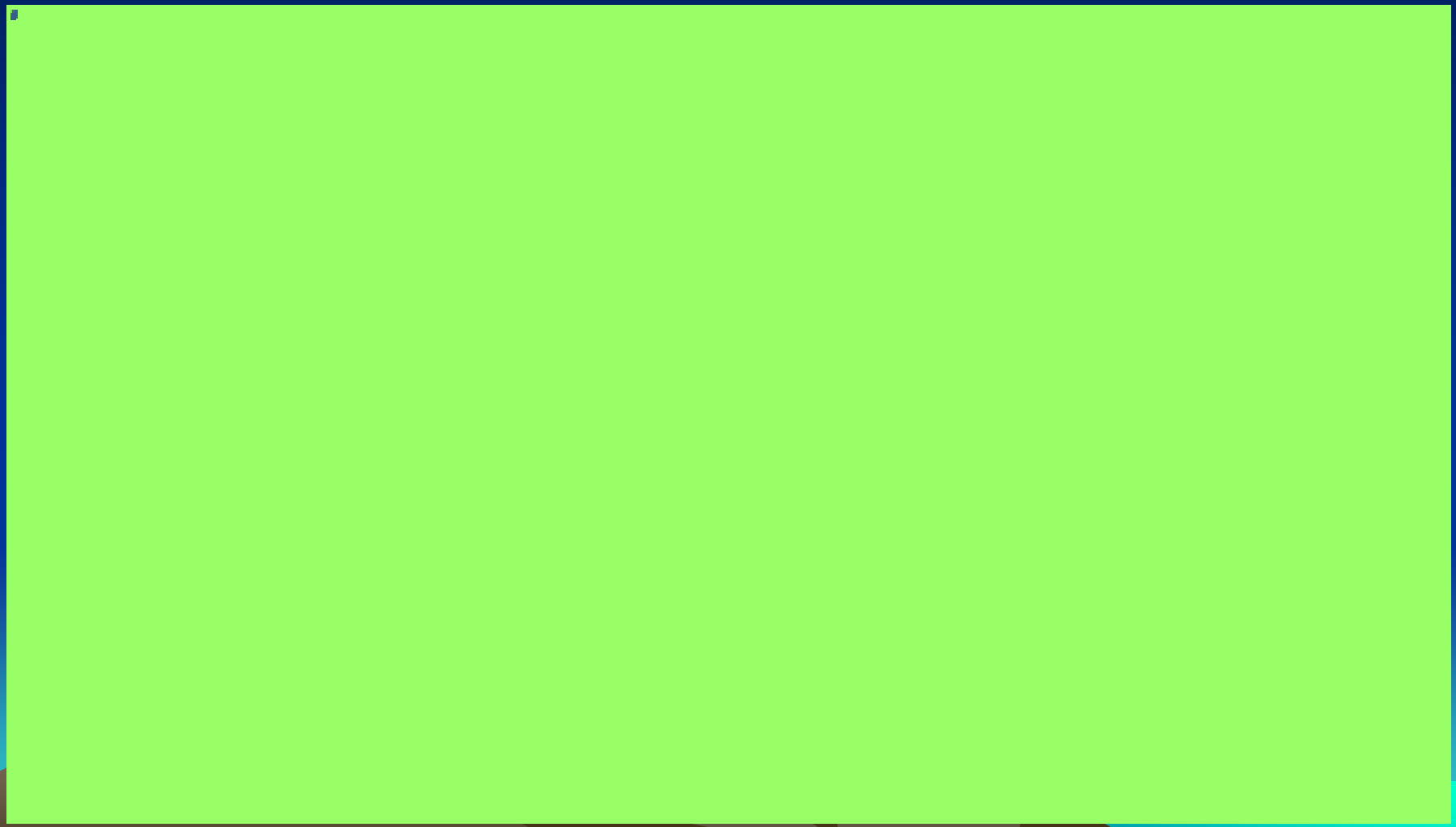




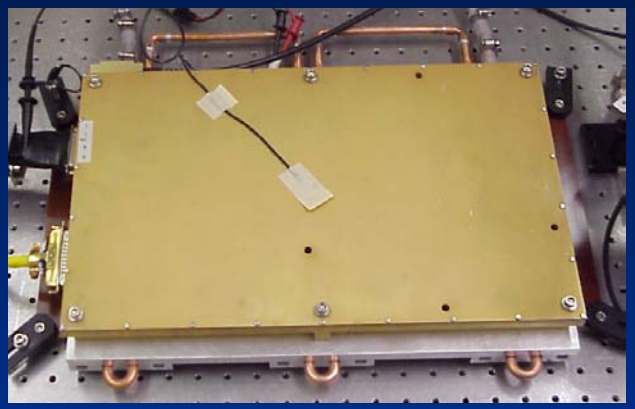


Master Oscillator-Amplifier Configuration

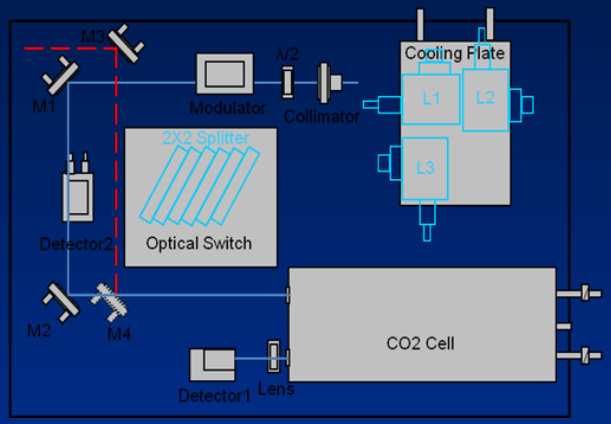
Breadboard Seed Lasers Schematic



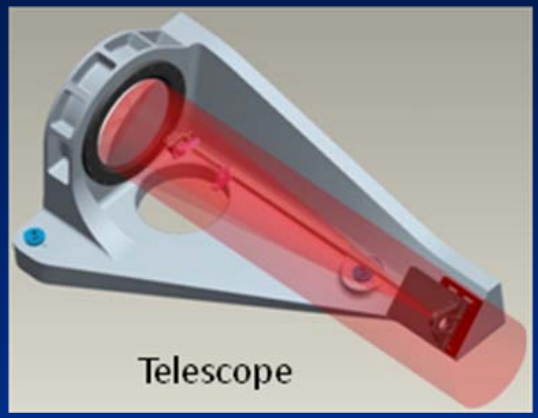
Lidar Components



Thulium-Fiber Pump Laser
Ruggedly Packaged 80 W laser



CO_2 DIAL/IPDA Wavelength Control
Prototype wavelength and control layout



CO_2 DIAL/IPDA Telescope

CO_2 DIAL/IPDA Electronics

CO_2 DIAL/IPDA Data Acquisition System

2-micron Laser Transmitter Specifications

Parameter	Development Objectives for Current System	Target Objectives for Space-based System
Wavelength (μm)	2.051	2.051
Energy(mJ)/ Rep. Rate (Hz)	>65mJ / 50Hz	65mJ / 50Hz
Pulse width (ns)	<= 50ns	<= 50ns
Transverse Mode	TEMoo	TEMoo
Longitudinal mode	Single frequency	Single frequency
Frequency Control accuracy	<2MHz	2MHz

Summary

- ESTO funded 2-micron Doppler lidar technology under LRRP was heavily leveraged in developing high energy, pulsed 2-micron coherent lidar system for ground-based CO_2 profiling. The system was field tested in Wisconsin during 2007
- 2-micron team has successfully developed a double-pulsed, high energy coherent DIAL system and demonstrated ground based measurement
- Accurate laser wavelength control and switching has been demonstrated, which meets the frequency stability and accuracy requirement for the CO_2 DIAL
- The NASA LaRC developed Ho pulse laser meets or exceeds the generally accepted requirements of a direct detection 2μm IPDA system, which can provide adequate CO_2 column density measurements from space
- The pulsed lidar transmitter architecture, energy, repetition rate, line width, frequency control are all suitable for space application without major scale up requirements.