

Efficient, High Energy 2-micron Solid-State Laser Transmitter for NASA's Space-based CO₂ Measurements

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Outline

- Background
- 2-micron Pulsed Lidar Approach for CO₂ Measurement
- 2-micron Pulsed Coherent Detection Lidar- for Mobile Ground-based CO₂ Profiling
- 2-micron Pulsed Direct Detection IPDA Lidar for CO₂ Column Measurement from Airborne Platform
- Summary

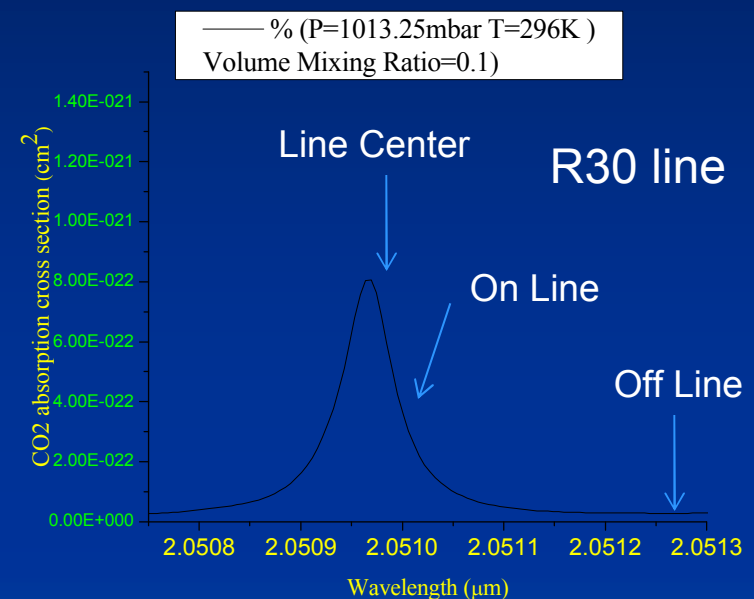
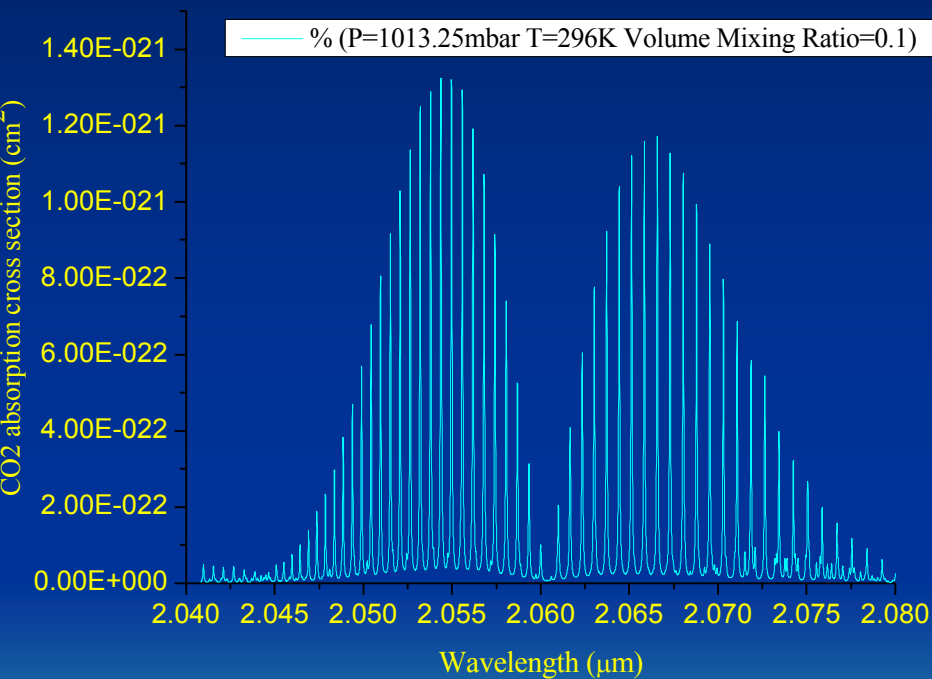


Pulsed Lidar Approach

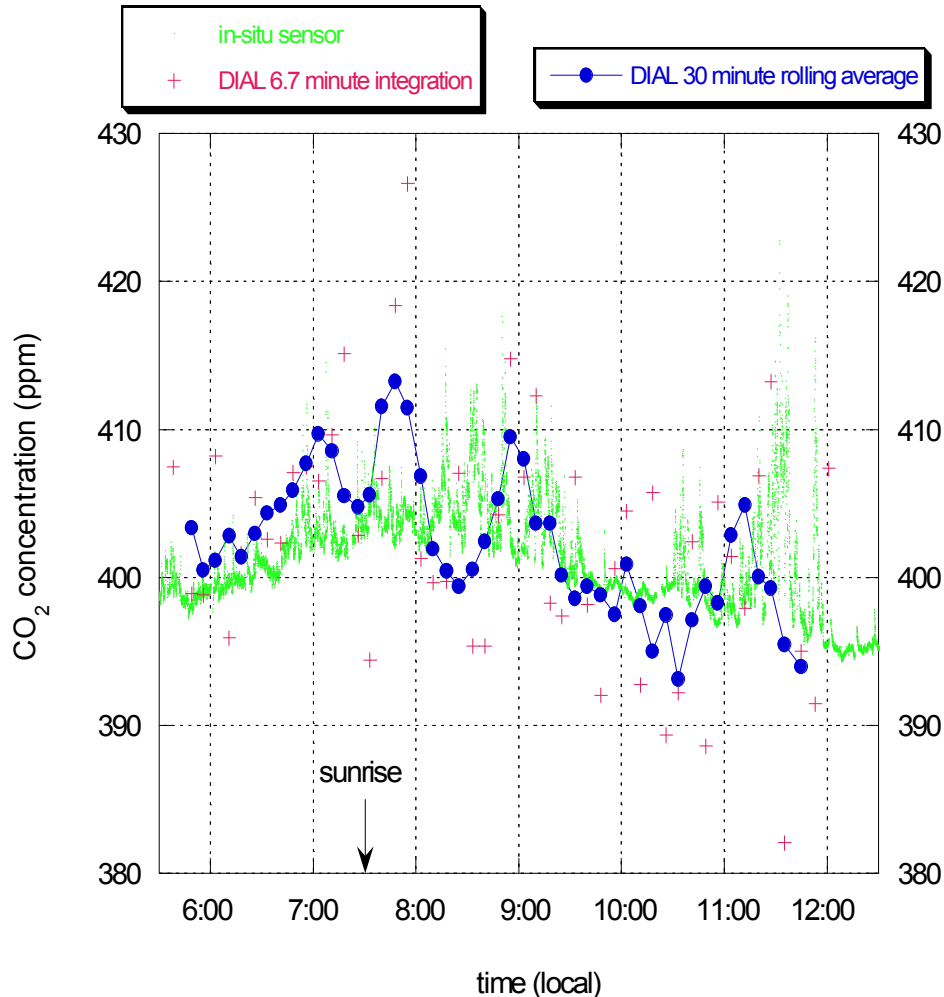
- The National Academies has identified CO₂ measurement from space as a critical mission for study of climate change and global warming
- NASA has planned Active Sensing Of CO₂ Emissions Over Nights, Days, And Seasons (ASCENDS) mission for CO₂ column measurements from space
- For column measurements, the pulsed lidar approach can eliminate contamination from aerosols and clouds to yield high accuracy measurements
- The pulse approach can determine CO₂ concentrations as a function of distance with high spatial and temporal resolution, a valuable data product that is not currently available



CO₂ Absorption Line at 2-micron



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

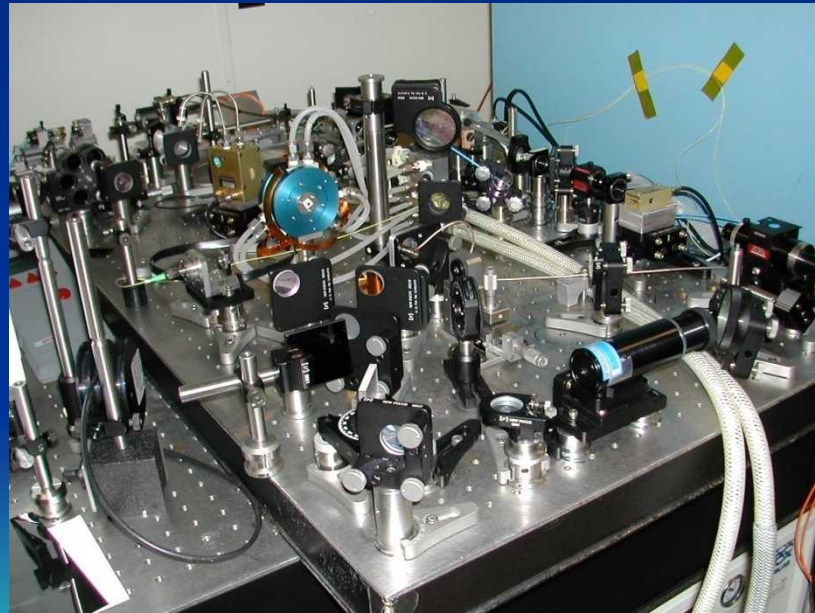
- Higher pulse energy (90mJ to 250mJ) for higher SNR.
- Higher pulse repetition rate (5Hz to 10 Hz) for more pulse averaging.
- Double pulsing format for more pulse averaging and better atmospheric sampling.
- More favorable line (R30) for less water vapor bias.

Mobile Ground based High Energy CO₂ DIAL Profiling Lidar – LRRP Funded

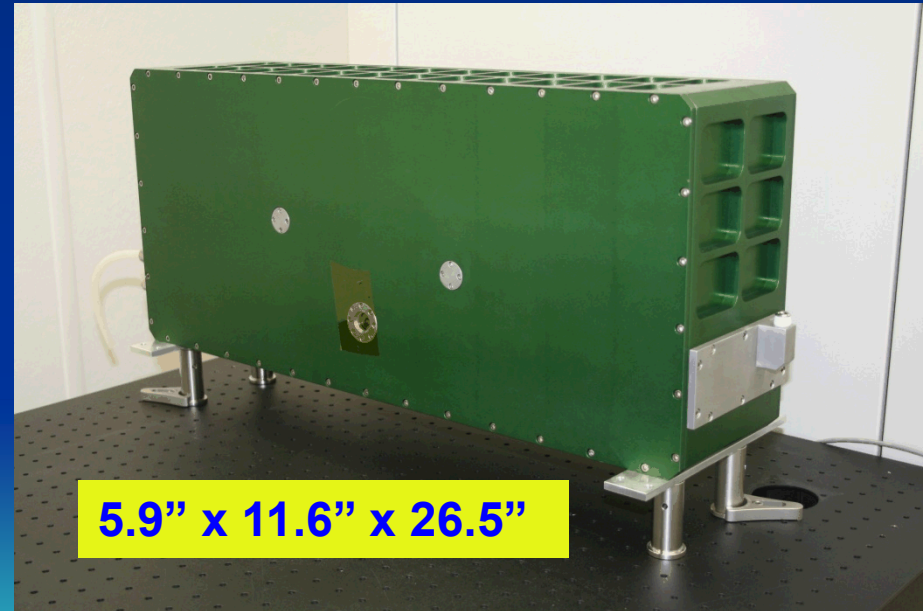
**Table Top Transceiver
(Transmitter + Receiver)**
90 mJ/pulse, 5 pulses/sec.
3'x4' Optical Table
(no telescope or scanner)

- **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)



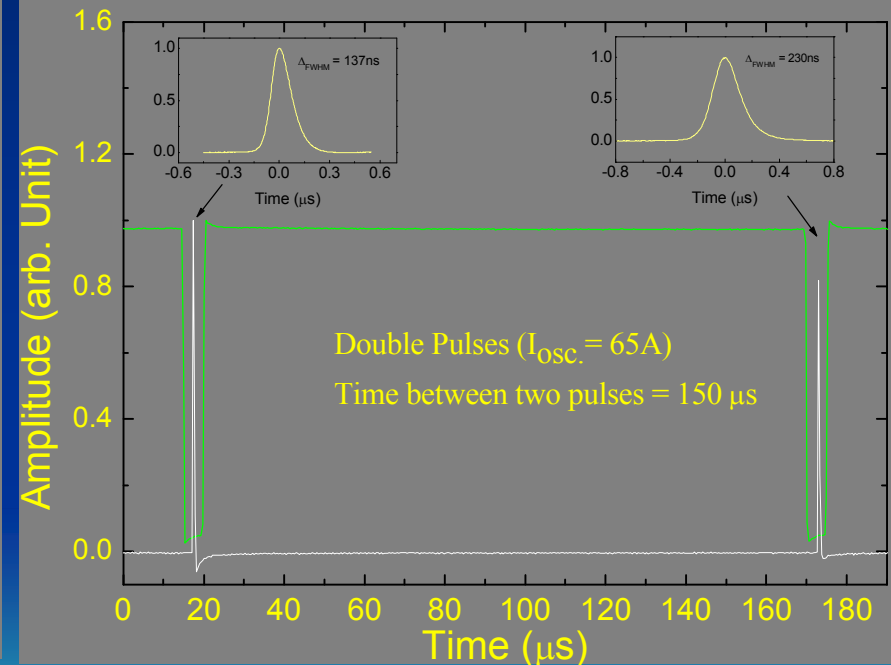
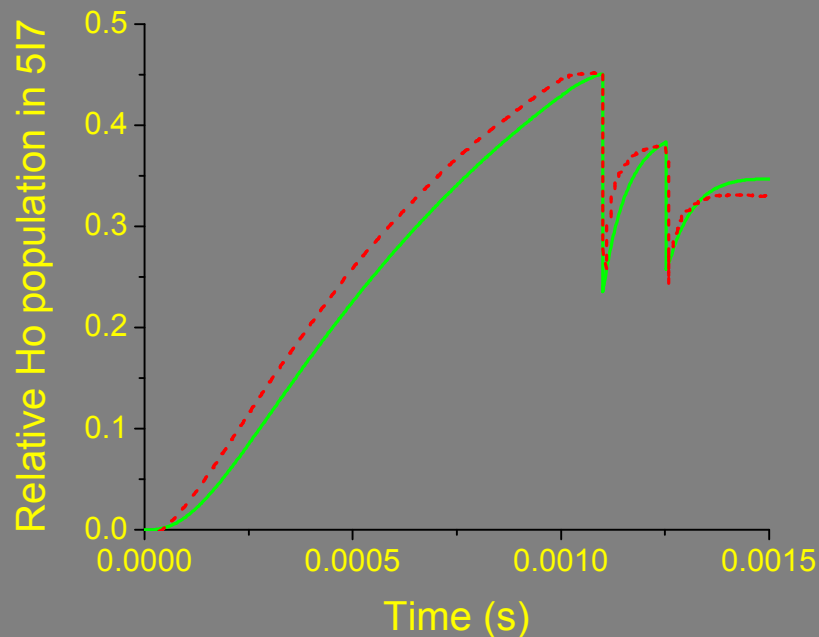
**Previous implementation
90 mJ per pulse**



5.9" x 11.6" x 26.5"

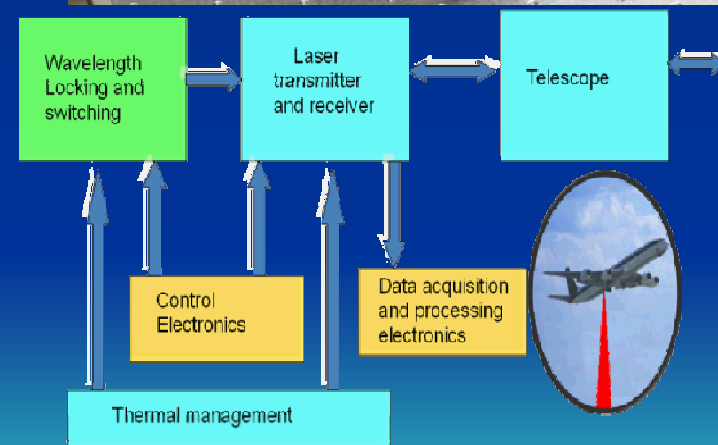
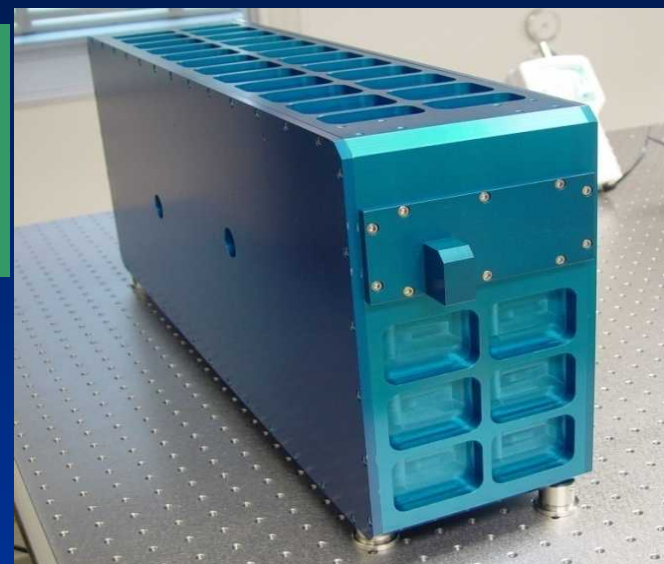
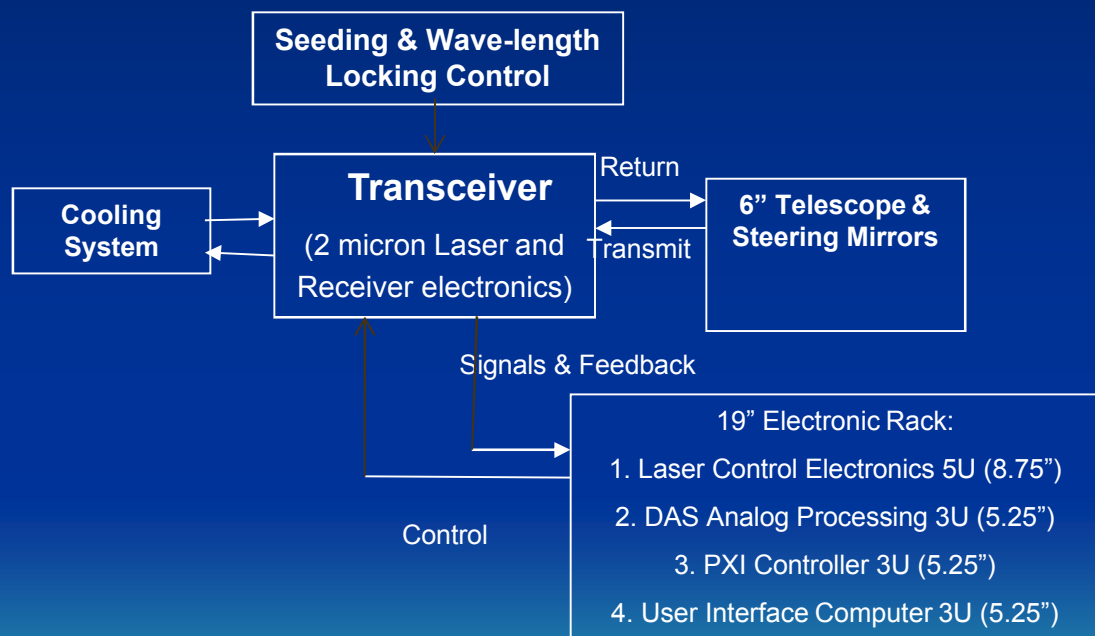
Small, Robust, 250 mJ per pulse

Double Pulsed 2- μm Laser Operation



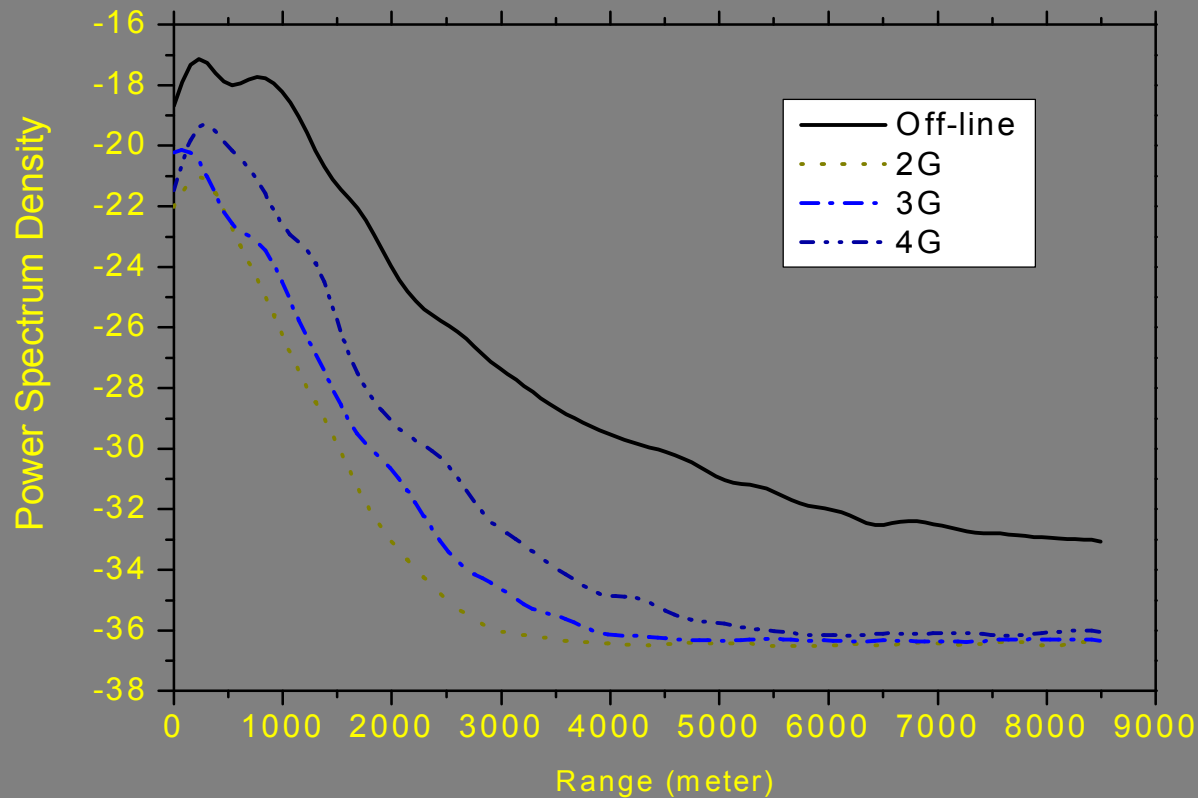
Pulsed Coherent CO₂ DIAL

- Pulsed 2-micron laser transmitter
 - 250 mJ/10Hz
 - Coherent DIAL
- Provide CO₂ profiling/column density measurement



- Compact and ruggedized package
- Prototype has been demonstrated with optimization and packaging remaining
- Prototype has been demonstrated with modification and optimization remaining

On-Off Return Signal



Pulsed 2 μm Direct Detection IPDA Lidar System for CO₂ Column Measurement

- Pulsed 2 μm lidar, with ranging capabilities, provides a direct measurement of the atmospheric CO₂ 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 XCO₂ with a precision and accuracy sufficient to constrain CO₂ fluxes within 0.02 Pg C yr⁻¹ on a scale of 1000 x 1000 km².
- A-SCOPE: IPDA: Instrument Parameters for two wavelengths (1.57 and 2.05 micron)

<i>Transmitter</i>		
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
<i>Receiver</i>		
Telescope diameter	1 m	1.2 m
<i>Detector</i>		
Quantum efficiency	0.74	0.75
Noise Equivalent Power	46 fW/Hz^{0.5}	100 fW/Hz^{0.5}

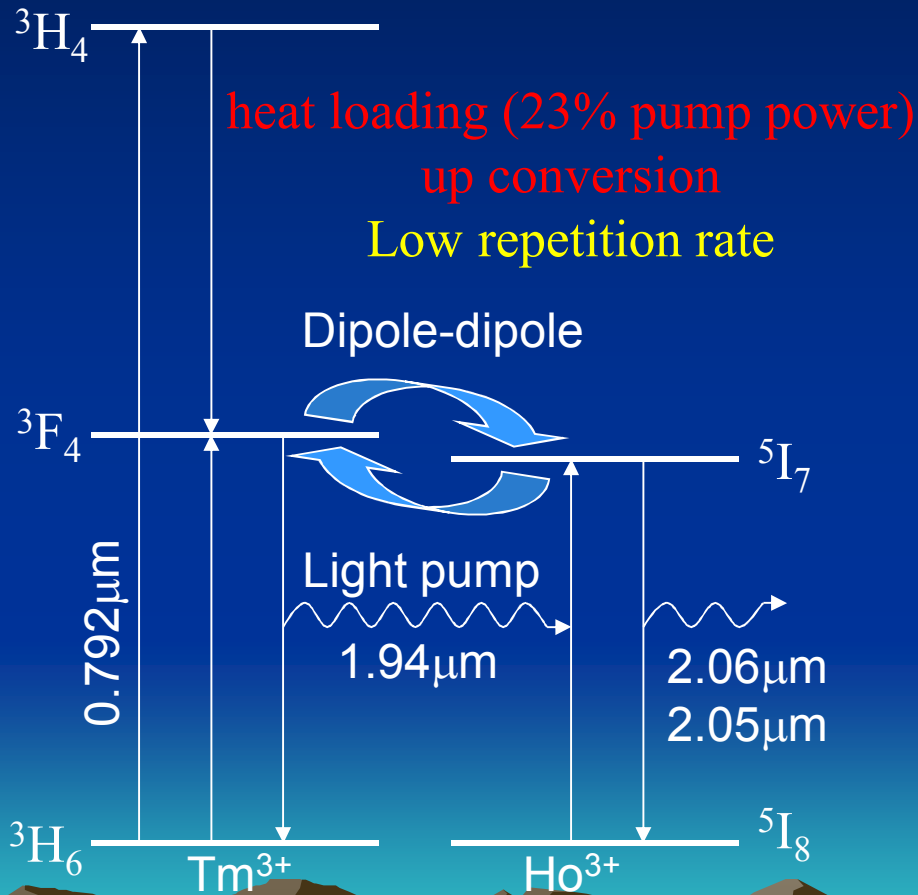
European Space Agency (ESA), "A-SCOPE – Advanced Space Carbon and Climate Observation of Planet Earth, Report For Assessment", ESA-SP1313/1 (2008), available at http://esamultimedia.esa.int/docs/SP1313-1_ASCOPE.pdf.

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

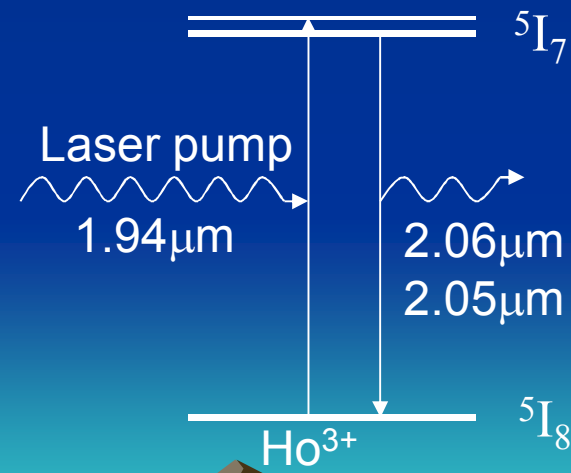
Ho Laser Energy Level Diagram

0.78/0.792 μm Diode Pumping

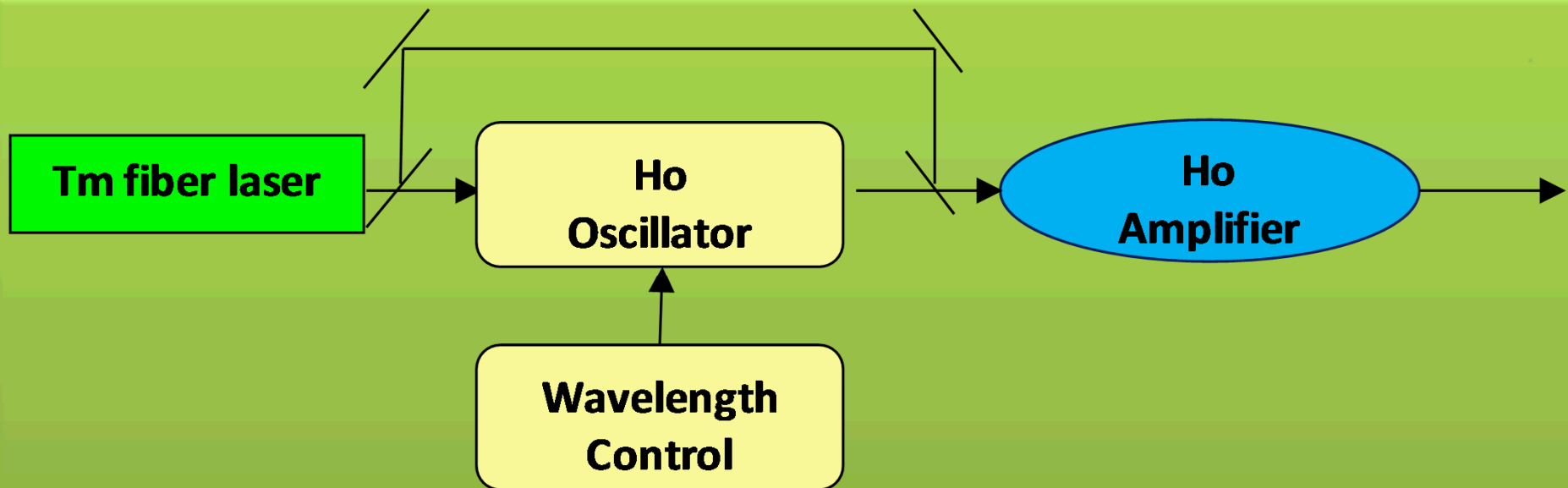
Tm:fiber Laser Pumping



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



Schematics of Lidar Transmitter



Commercially available



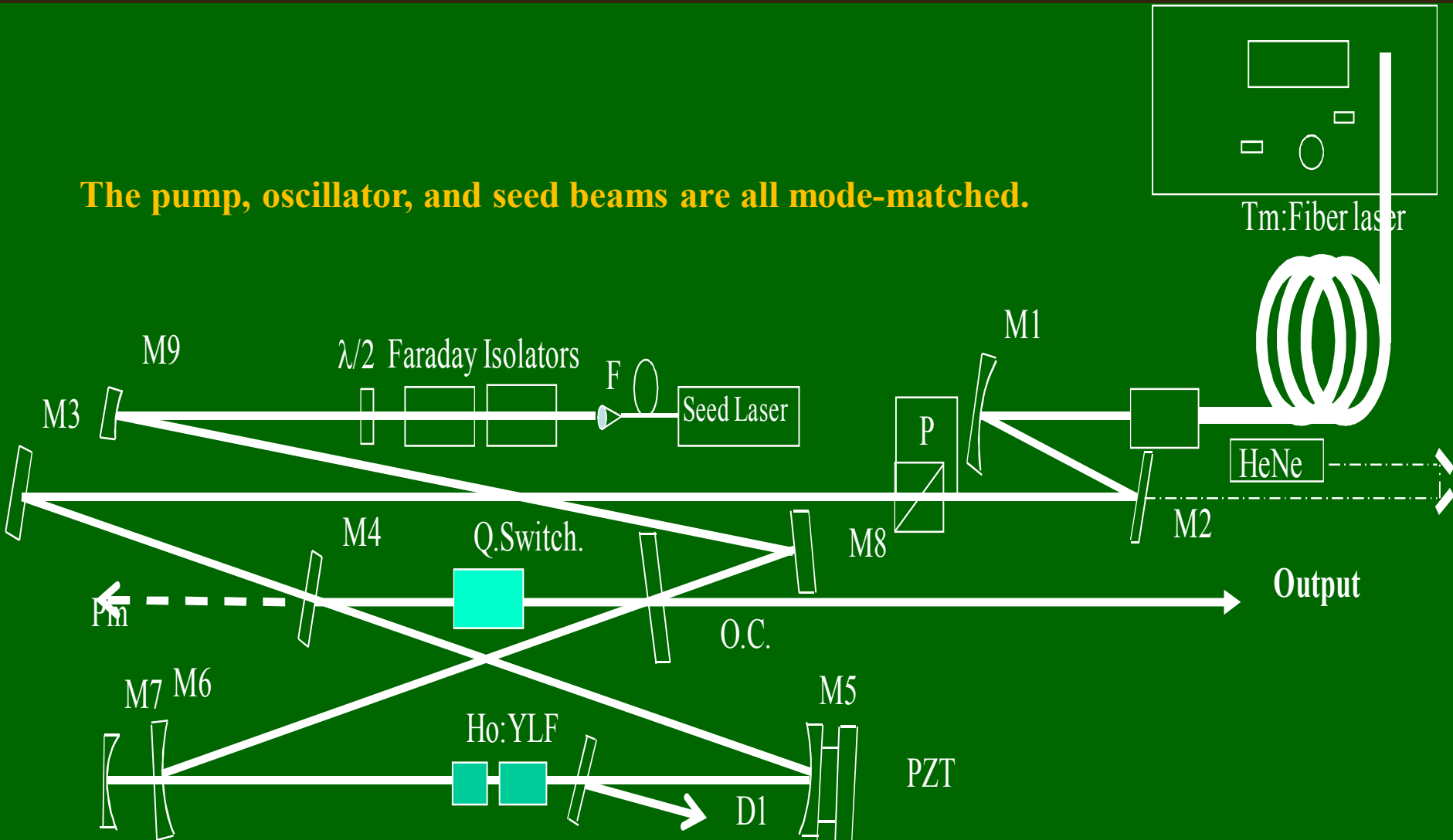
Technology demonstrated and bread boarded; compacting and packaging is planned



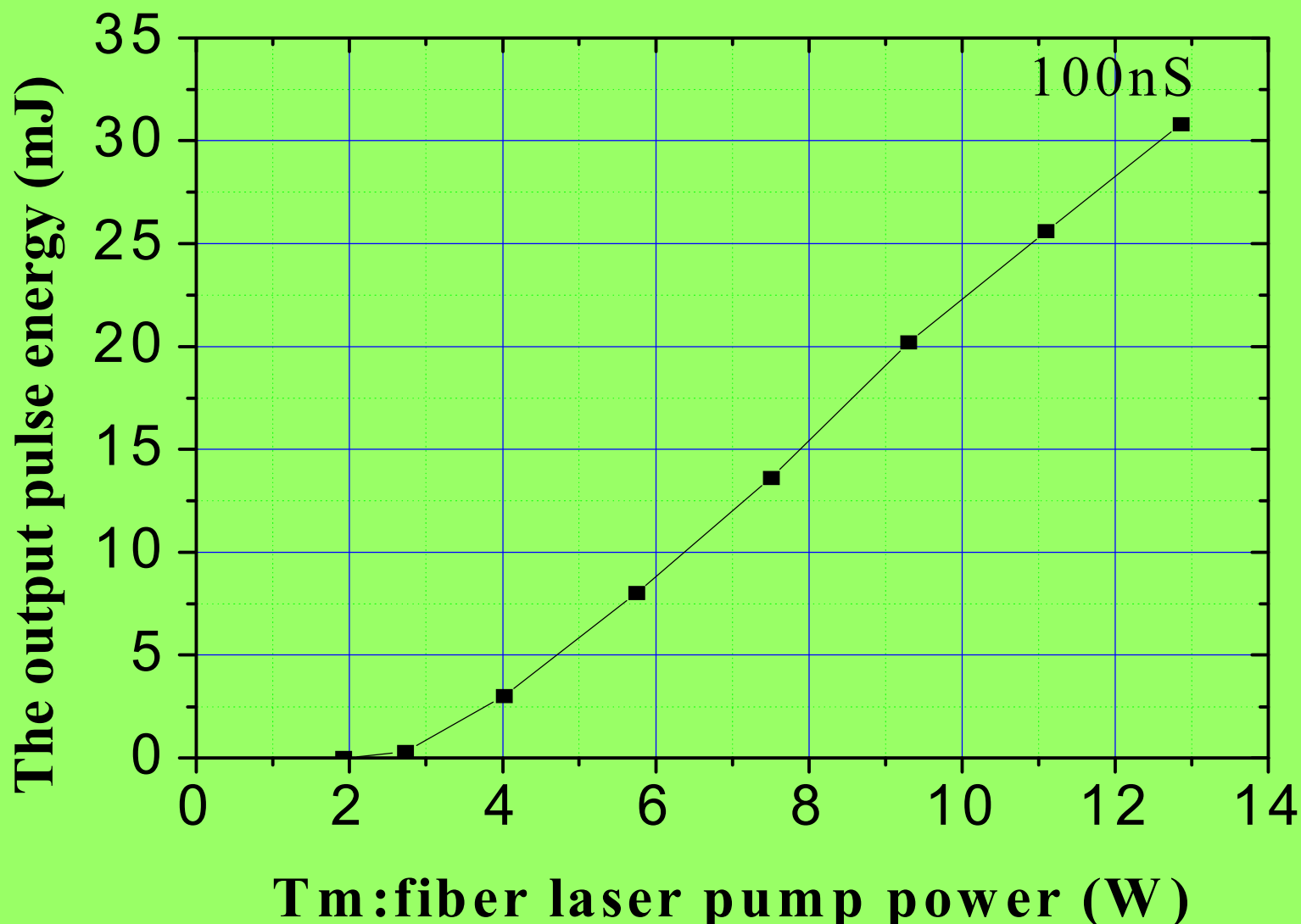
Technology need to be developed/improved/demonstrated; system engineering and packaging is planned

Master Slave Laser System

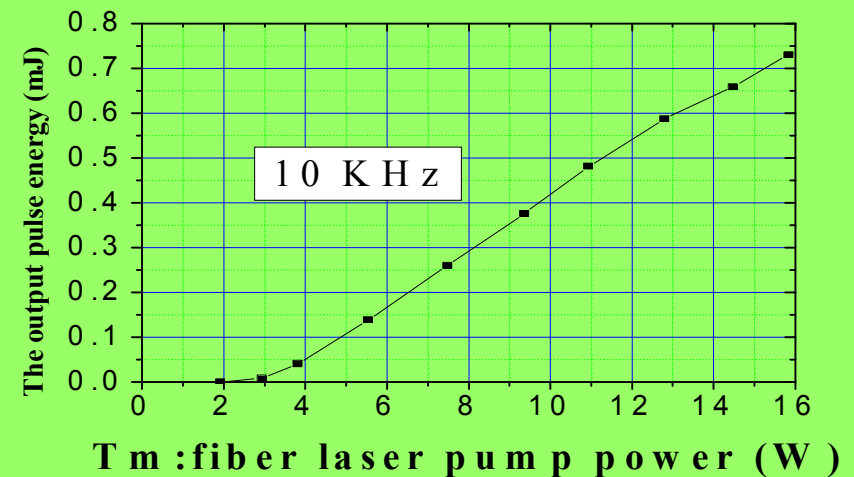
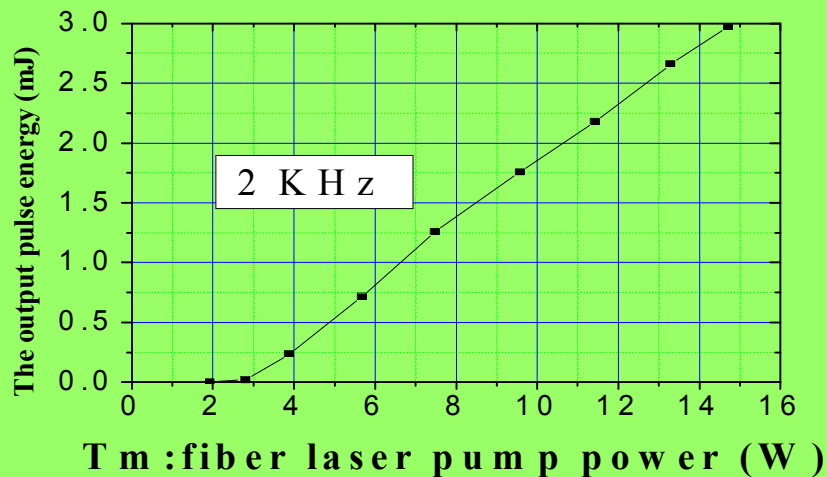
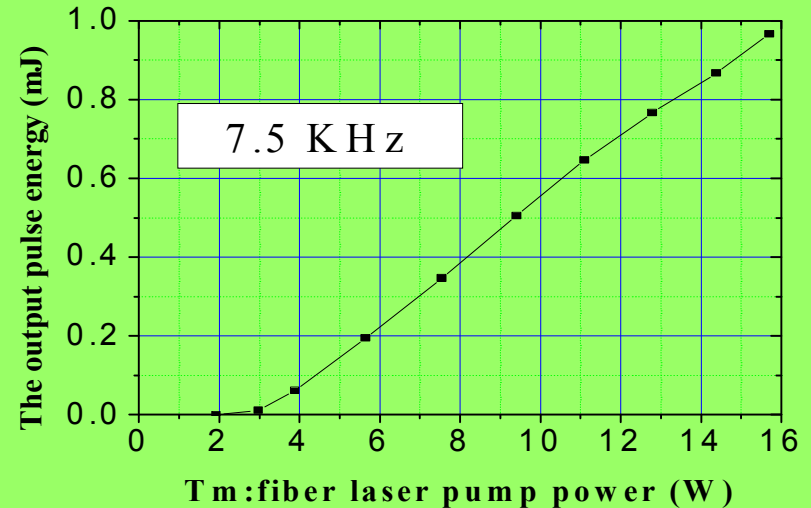
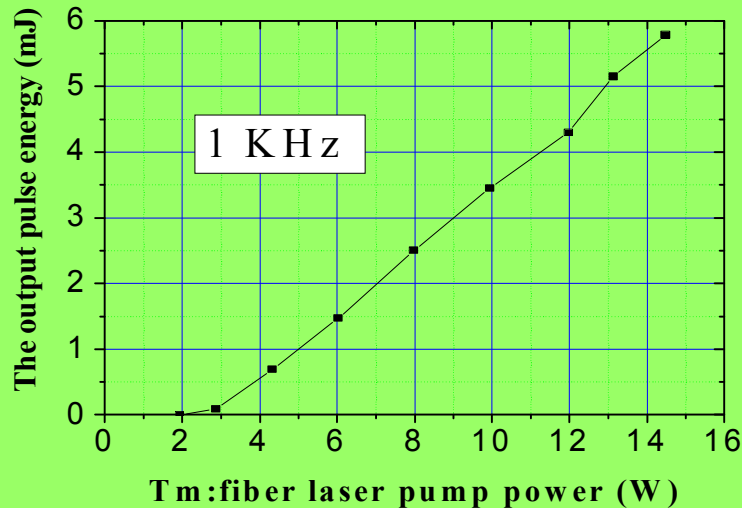
The pump, oscillator, and seed beams are all mode-matched.



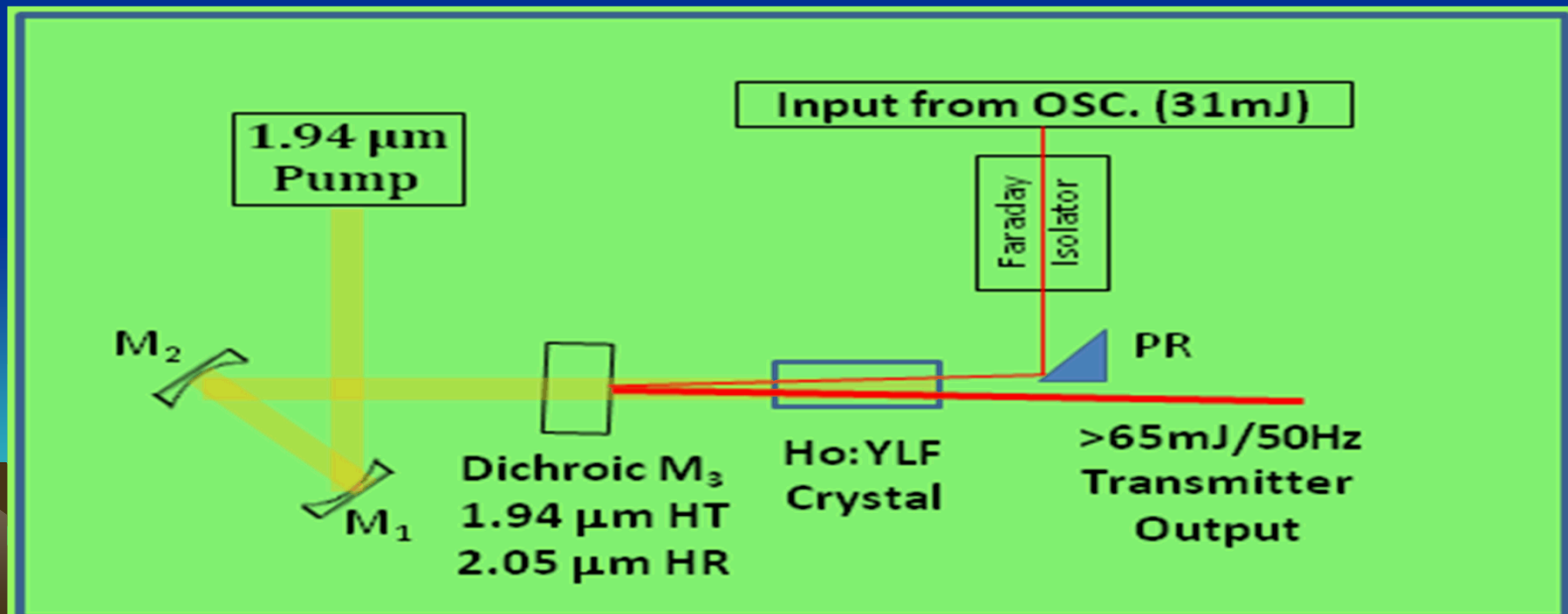
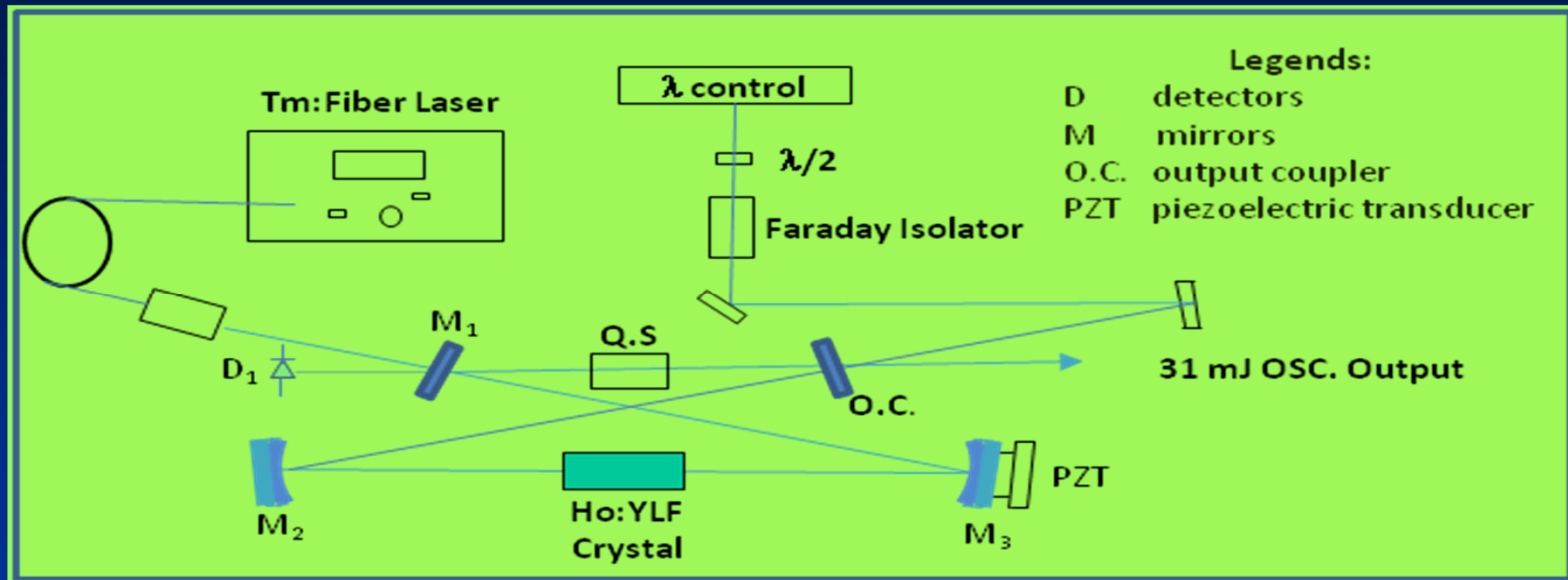
Ho:YLF Oscillator Performance (100 Hz)



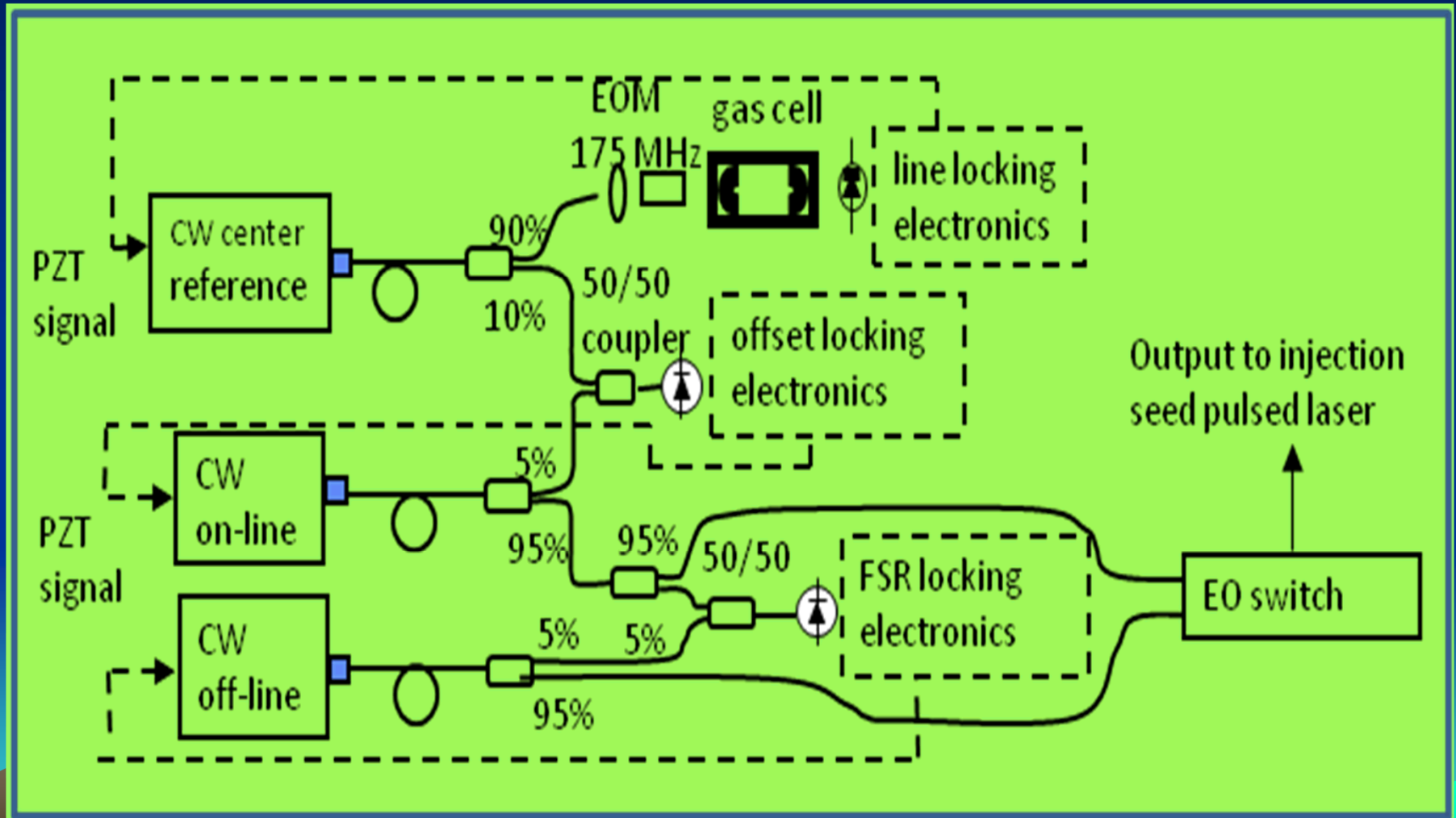
Oscillator Performance (High RR)



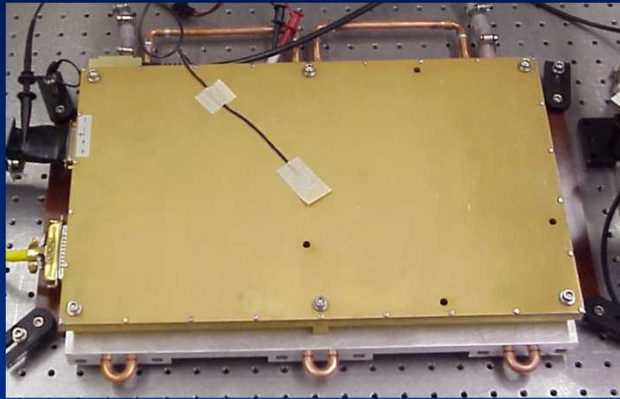
Master Oscillator-Amplifier Configuration



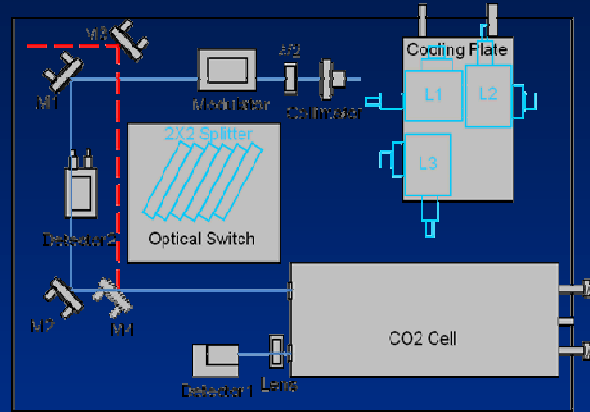
Breadboard Seed Lasers Schematic



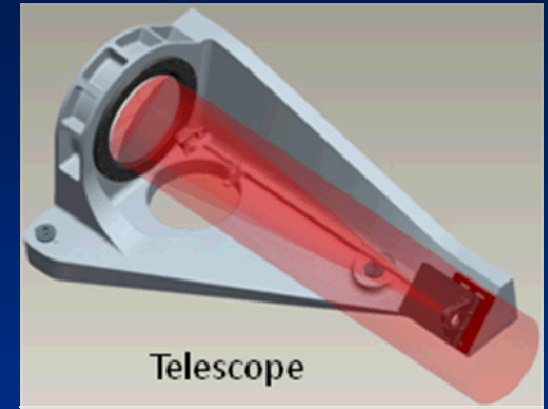
Lidar Components



Thulium-Fiber Pump Laser
Ruggedly Packaged 80 W laser



CO₂ DIAL/IPDA Wavelength Control
Prototype wavelength and control layout



CO₂ DIAL/IPDA Telescope



CO₂ DIAL/IPDA Electronics



CO₂ 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)	$\leq 50\text{ns}$	$\leq 50\text{ns}$
Transverse Mode	TEM ₀₀	TEM ₀₀
Longitudinal mode	Single frequency	Single frequency
Frequency Control accuracy	<2MHz	2MHz

Summary

- NASA Earth Science Technology Office (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 CO₂ 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 CO₂ 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 CO₂ 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.

