Development of a Coherent Differential Absorption Lidar for Range Resolved Atmospheric CO$_2$ Measurements

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Outline

• 2-micron Pulsed Lidar Approach for CO$_2$ Measurement
• 2-micron Pulsed Lidar DIAL/IPDA Roadmap
• High Energy 2-micron Pulsed Lidar- for Mobile Ground and Airborne CO$_2$ Profiling
  – Double Pulse Laser Transmitter for DIAL
  – High Accuracy Wavelength Control and Switching
  – Ground Based High Energy Coherent CO$_2$ DIAL Demonstration
• Summary
A CO$_2$ profiler from ground or airborne platform is an indispensible validation tool for ASCENDS mission.

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.

The weighting function in the 2-µm region is most favorable for making CO$_2$ measurements near the surface and PBL, where the sources and sinks of CO$_2$ are located.
CO$_2$ Absorption Line at 2-micron
Requirement on high sensitivity of the WF to the lowest atmosphere

Selection of the R30 CO$_2$ absorption line at 2050.967 nm in the (2001) $\leftrightarrow$ (0000) band of CO$_2$ as one of the most suitable line for DIAL measurement from space.

Weighting function peaking in the lowest part of the atmosphere

Courtesy: Fabien Marnas, LMD/IPSL
Approach Rationale

- High energy ground based mobile system/Airborne DIAL system for ASCENDS instruments validation
  - Unique range-resolved profiling – critically needed
  - Unique up looking profiling system up to 4 Km
  - Matured, compact, highest energy coherent DIAL System

- High Repetition Rate 2-micron DIAL System
  - High Efficiency
  - High accuracy and precision
  - Higher temporal and spatial coverage
  - Airborne system capable of providing profiling in planetary boundary layer and free troposphere, as well column content – unique capability
Through LRRP funding, NASA LaRC has developed two unique technological approach and associated hardware to provide CO$_2$ profiling from ground, as well as airborne.

- **High Energy – Low Repetition Rate**
  - Demonstrated high precision ground based CO$_2$ profile measurement
  - Plan to fly a LRRP developed compact packaged 2-micron lidar (Step -1)

- **Moderate Energy – High Repetition Rate**
  - Develop a compact airborne high repetition rate DIAL System (Step – 2)
Coherent Pulsed CO$_2$ IPDA/DIAL Roadmap

Up Looking, Ground based Profiling System

**Past**
- High Energy Ho:Tm LuLiF
- 90mJ, 5Hz .45W
- Wisconsin - 2007
- Intercomparison Vertical In situ Sensors
- Completed

**Present**
- High Energy Ho:Tm YLF
- 250mJ, 10Hz 2.5W
- March, 2010
- Intercomparison Horizontal Lidar, In situ Sensors
- Completed

VerNatcal In situ Sensors Completed
Coherent Pulsed CO\(_2\) IPDA/DIAL Roadmap

**Down Looking, Airborne Profiling/Column System**

**Step - 1**
- High Energy Double-Pulsed Ho:Tm:YLF
  - 250mJ, 10Hz
  - 2.5W
  - 2010-2012

Intercomparison Vertical Lidar, In situ Sensors

**Step - 2**
- High Rep Rate, Tm fiber:Ho YLF
  - 6mJ, 1KHz
  - 6.0W
  - 2011-2013

System Ready for Lidar Intercomparison
- Higher Accuracy
- Higher Spatial Resolution Flux Measurement

**Airborne Campaign**
- High Rep Rate, Tm fiber:Ho YLF
  - 6mJ, 1KHz
  - 6.0W
  - FY 2013-14

Validation + Inter comparison Campaign with Existing Capabilities in US

**FY 2013-14**
- Validation of ASCENDS Instruments

**2010-2012**
- AIIT Proposal Submitted

**2011-2013**
- IIP Proposal - Planned
CO₂ profiling from space is currently not feasible due to lack of mature technology. The energy and receiver technology needs to advance by more than an order of magnitude. Laser does not exist and development of an appropriate laser will require at least 5-7 years of sustained efforts with lot of funding.

Valid Approach if Ultra-low noise Detector for Direct Detection is not Available

Preferred Approach if low NEP Detector is Available - EXCALIBUR prefers this approach
ESA is developing detector
Pulsed 2-micron Transmitter for Direct and Coherent Detection of CO₂

EXCALIBUR
Direct Detection
65mJ, 50Hz, Ho:YLF

IIP
Coherent Detection
6mJ, 1000Hz, Ho:YLF

Tm:FIBER LASER

CW LINE CENTER LASER

EOM

CO₂ gas cell

OFFSET LOCKING ELECTRONICS

CW 'ON' LINE LASER

AMP.

QS

OSC.

'CWX LINE LASER

BEAM EXPANDER

20W

25W

15W

20W

65mJ, 50Hz, Ho:YLF

6mJ, 1000Hz, Ho:YLF

65mJ, 50Hz, Ho:YLF

6mJ, 1000Hz, Ho:YLF

'TWX LINE LASER

激光器能量

激光器线宽

激光器脉冲宽度
Pulsed Coherent CO\textsubscript{2} DIAL

- Pulsed 2-micron laser transmitter
  - 250 mJ/10Hz
- Coherent DIAL
- Provide CO\textsubscript{2} profiling/column density measurement

Seeding & Wave-length Locking Control

Transceiver
(2 micron laser and Receiver electronics)

6” Telescope & Steering Mirrors

19” Electronic Rack:
1. Laser Control Electronics 5U (8.75”)
2. DAS Analog Processing 3U (5.25”)
3. PXI Controller 3U (5.25”)
4. User Interface Computer 3U (5.25”)

Cooling System

Transmit
Return
Signals & Feedback
Control

Wavelength Locking and switching
Laser transmitter and receiver
Data acquisition and processing electronics
Telescope

Thermal management

Compact and ruggedized package
Prototype has been demonstrated with optimization and packaging remaining
Prototype has been demonstrated with modification and optimization remaining
Coherent CO$_2$ DIAL Transceiver

Transmitter Side

Receiver Side
10 Hz Oscillator Performance

Performance of 3m resonator

Pulse length as a function of pump energy

Output (mJ)

Input pump (J)

Pulse length (ns)

Input pump (J)
Double Pass Amplifier Performance

Amplifier gain: double pass ~3
Laser Beam Profile
FRERQUENCY LOCKING AT CO₂
ABSORPTION LINE CENTER

---- ABSORPTION & LOCKING CURVES

8M Cell 1.5Torr

8M Cell 3.0Torr

8M Cell 7.0Torr

Scanning
Normalization
Absorption
Locking
FRFREQUENCY LOCKING AT CO\textsubscript{2} ABSORPTION LINE WING
---- PRINCIPLE & DIAGRAM

Reference Laser

Online Laser

PZT Control

DC AMP

RF Spectrum Analyzer

F-V Converter

High Pass

RF AMP
FRQUENCY LOCKING AT CO2 ABSORPTION LINE WING

---- BEATING SIGNALS ON ESA

3 GHz BEAT SIGNAL

4 GHz BEAT SIGNAL
FREQUENCY LOCKING AT CO₂ ABSORPTION LINE WING ---- SHORT TERM STABILITY

FREQUENCY LOCKING AT 3 GHz FROM THE CENTER

FREQUENCY LOCKING AT 4 GHz FROM THE CENTER
CO$_2$ Coherent DIAL in Trailer
Telescope and Scanner
Double Pulsed 2-µm Laser Operation
Double Pulse
Single Frequency
Summary

• 2-micron team has successfully developed a pulsed coherent DIAL, and demonstrated ground based measurement

• For the first time, a unique double pulse laser technique has been used in DIAL, which increase the laser efficiency and improves measurement accuracy

• Accurate laser wavelength control and switching has been demonstrated, which meets the frequency stability and accuracy requirement for the CO₂ DIAL.

• Team is developing a high repetition 2-micron transmitter for airborne CO₂ DIAL measurement
BACKUP SLIDES
FRQUENCY LOCKING AT CO$_2$ ABSORPTION LINE CENTER

---- OPTIMIZATION OF FREQUENCY LOCKING

![Graph showing normalized slope vs. CO$_2$ pressure for different cell lengths: 6, 8, and 10 meters.](image-url)
Atmospheric Return Signal