DIFFERENTIAL ABSORPTION LIDAR FOR GREENHOUSE GAS MEASUREMENTS

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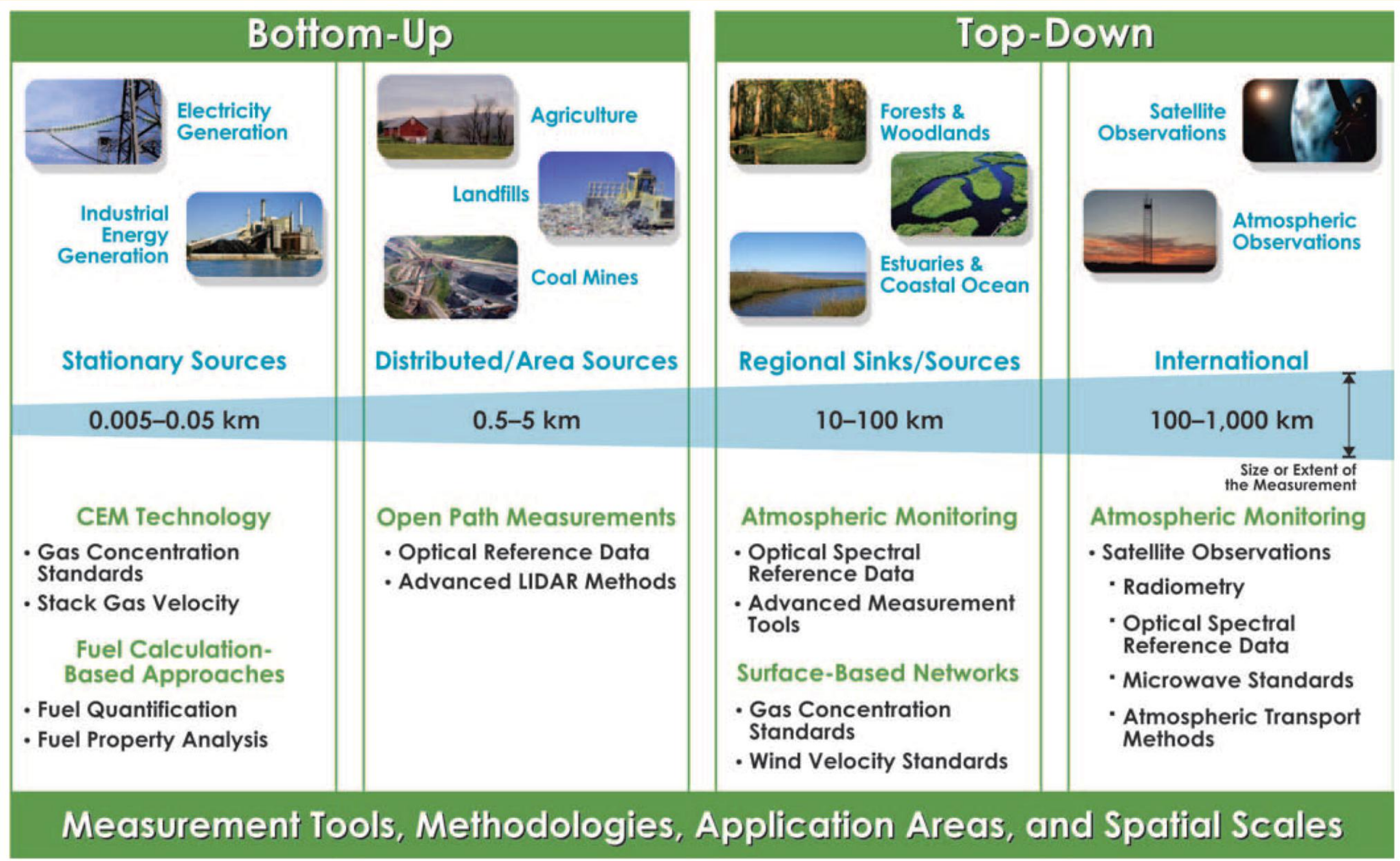
- Program & Project Objectives
- What is measured
- Background about LIDAR and Differential Absorption LIDAR
- Our Approaches
- Results and Current Status

CHALLENGES FOR GHG EMISSION MEASUREMENTS



NIST PROGRAM OBJECTIVES

- Develop and validate advanced measurement tools that improve the quantitative determination of GHG sources and sinks and the accuracy of climate science measurements
- Deliverable: Transfer new, validated diagnostic and measurement technologies to the private sector and embody their methods in documentary standards.

Project Objectives – Diff. Absorption LIDAR

- Develop methods for accurately quantifying greenhouse gas emissions from natural and anthropogenic distributed sources and sinks.
- Develop an indoor testing facility to rigorously test hardware components and software algorithms in well quantified conditions.

GHG Flowrate (Flux)

$$\dot{m}_{\mathrm{ghg}} = \sum \dot{m}_t x_{gi}$$

Where: $\dot{m}_t$ is total mass flow rate

x_{gi} is relative abundance of i^{th} gas

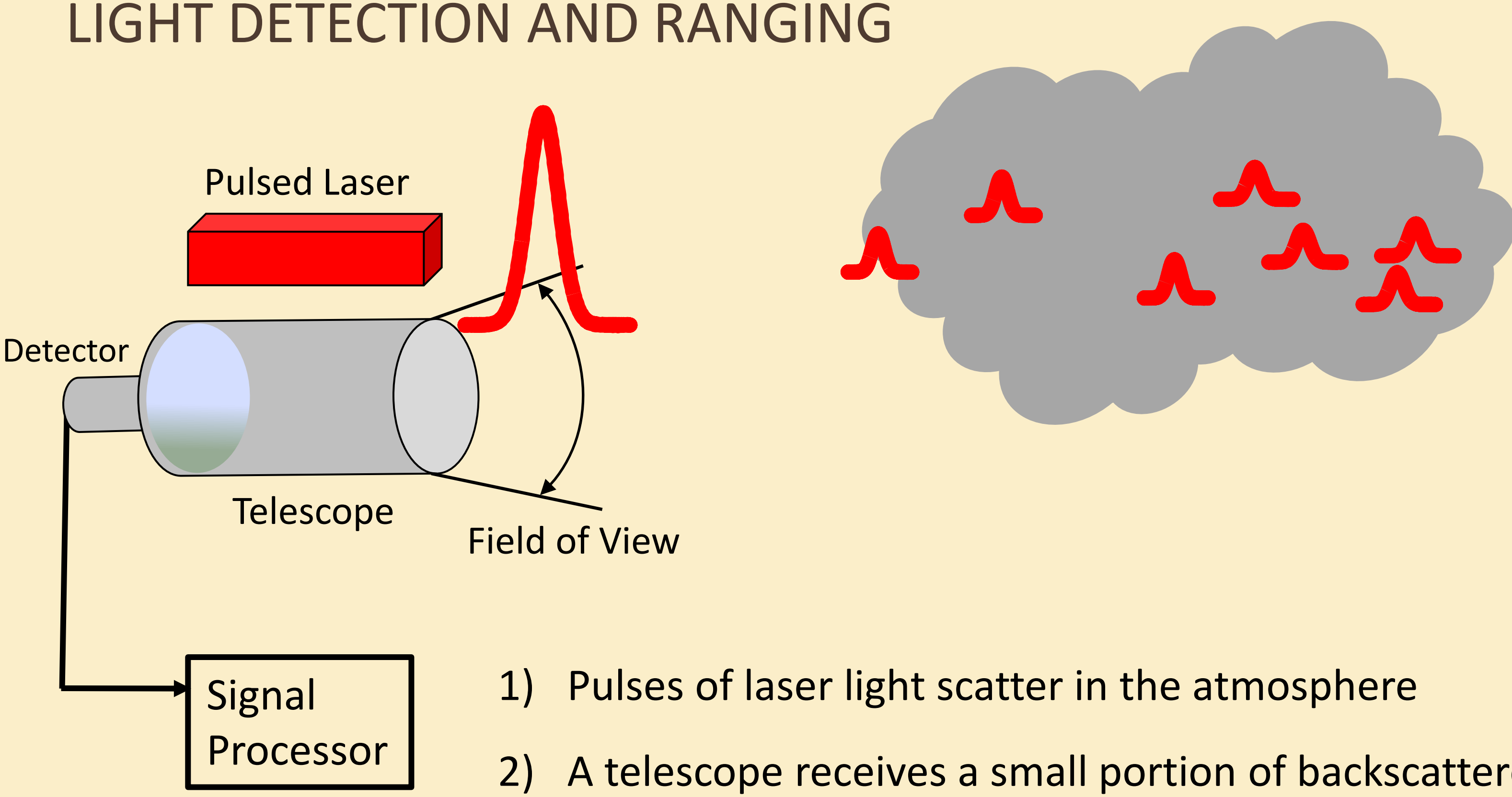
Inventory: Sum of continuous flux over a year

(either emissions to or capture from the atmosphere)

For a flux measurement, both the density of GHG and its velocity are required, along with error contributions from both quantities.

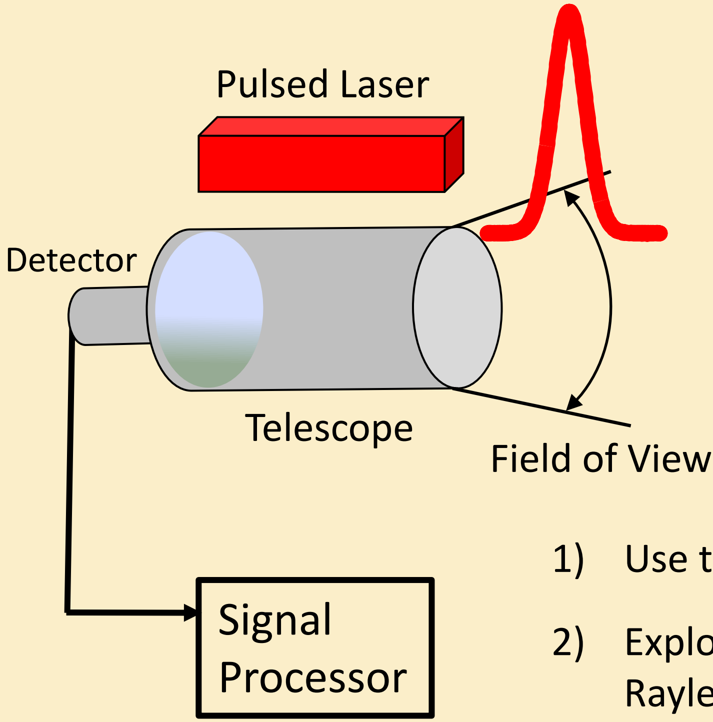
- **Construct prototype DIAL systems for the detection of GHGs from distributed area sources**
  - **3 - 5 km range**
  - **~10 meter spatial resolution**
- **Integrate DIAL concentration measurements with measurements of wind speed (Doppler LIDAR)**
- **Develop and assess GHG flux retrieval algorithms and understand measurement uncertainties**

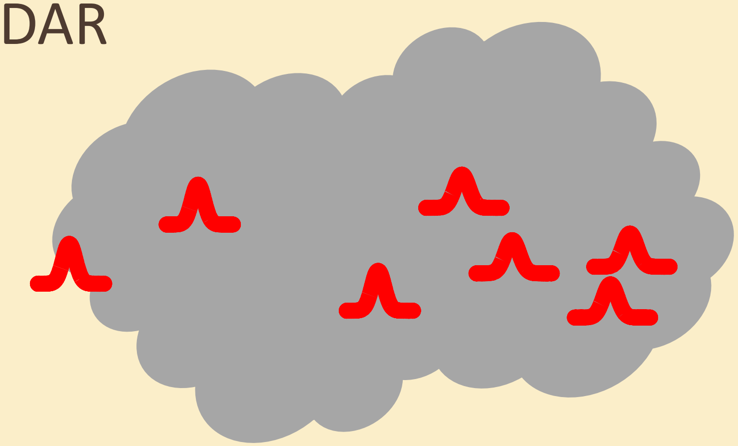
LIGHT DETECTION AND RANGING



1) Pulses of laser light scatter in the atmosphere
2) A telescope receives a small portion of backscattered light
3) A detector converts received light to electronic signals
4) A data system digitizes and stores the signals
5) Range is found from pulse time-of-flight (150 m/µs)

DIFFERENTIAL ABSORPTION LIDAR

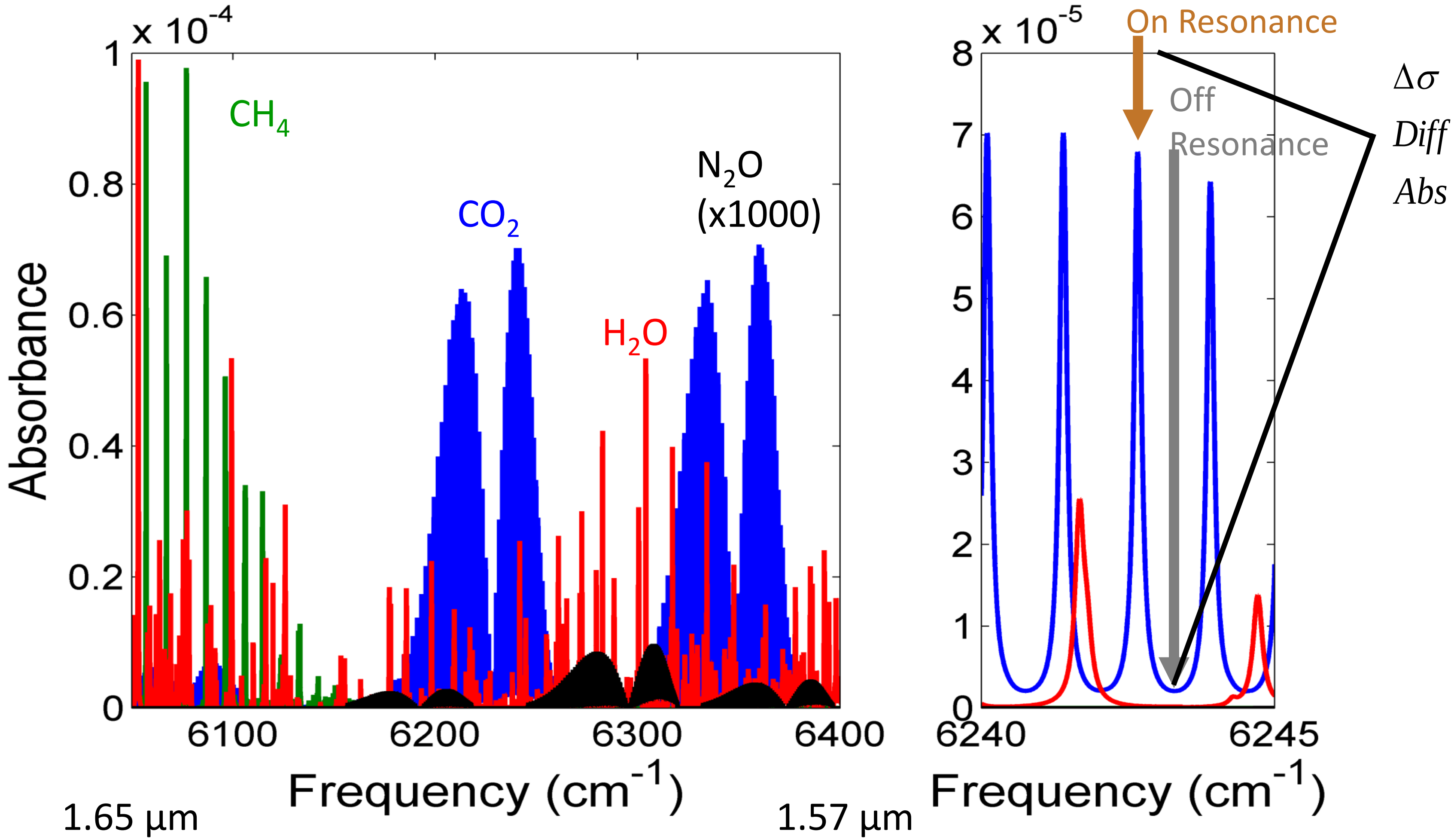




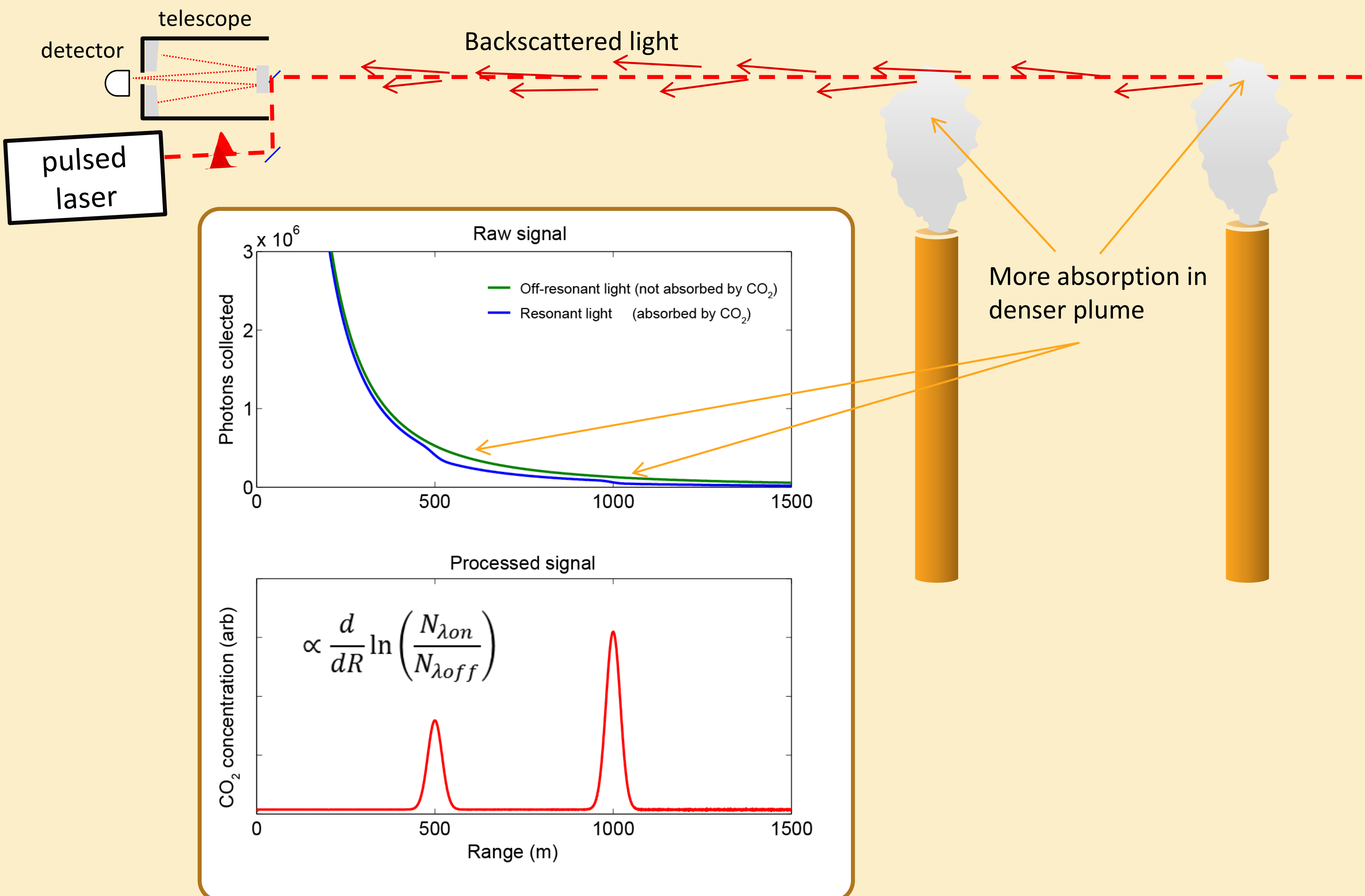
1) Use two or more wavelengths of light
2) Exploit the fact that the REFLECTANCE of atmospheric aerosols and Rayleigh backscattering are WEAKLY dependent on wavelength
3) Exploit the fact that the ABSORPTION of trace gases (CO_2, CH_4, H_2O, etc) STRONGLY depends on wavelength

- Ratio of captured reflected light at two different wavelengths as a function of time reveals the density of the measured gas as a function of distance
- Ratio removes common effects – geometry, collection efficiencies, etc.

ABSORPTION FEATURES RELEVANT FOR GHG DIAL

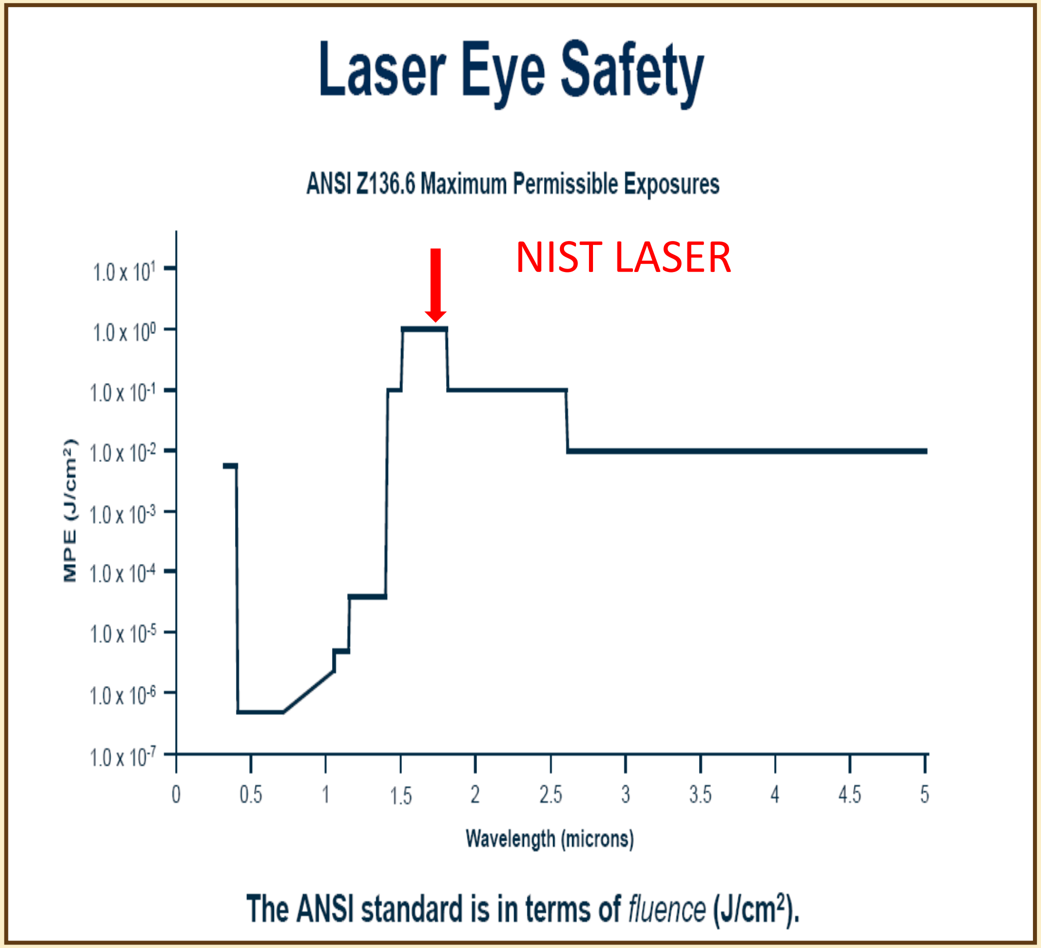


DIFFERENTIAL ABSORPTION LIDAR (DIAL) CARTOON



ADVANTAGES OF OPERATION IN THE NEAR IR

- Eye safety
- Wide availability of laser sources
- High sensitivity detectors (PMT)
- COTS technology from telecom industry
- Relatively weak absorption strength means DIAL can probe longer distances
- Minimal water absorption



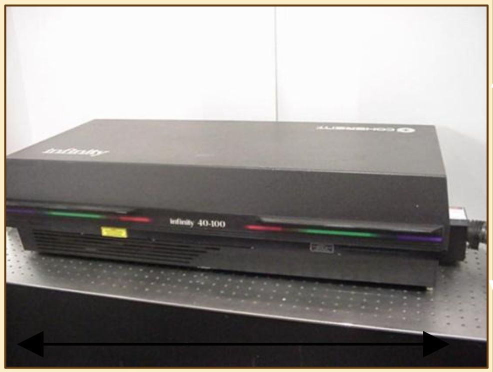
NIST ROAD MAP TO GHG REMOTE SENSING

DIAL System Designs

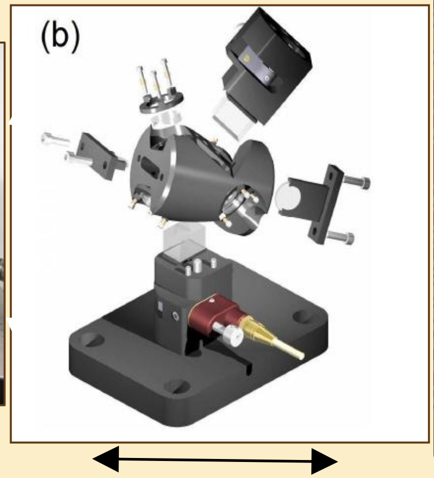
Direct Detection (PMT)	Heterodyne Detection (InGaAs APD)
↓	↓
Light source (OPO | Fiber Amp)	Light Source (OPO | Fiber Amp)
↓	↓
Sequential multi - λ rapid λ switching	Simultaneous multi - λ
↓	↓
Etalon based wind measurement	Wind speed from Doppler shifted aerosol return

GOAL → Simultaneous concentration & wind speed

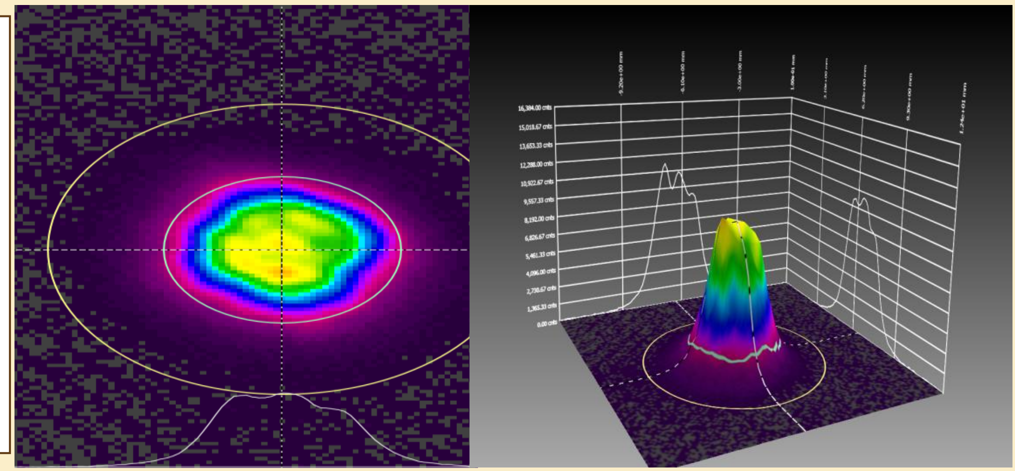
Rotated Image Singly-Resonant Twisted RectAngle



80 cm



10 cm



Demonstrated: 50 mJ/pulse at 1.6 mm

200 MHz spectral linewidth

<u>RISTRA Optical Parametric Oscillator Features</u>

- New technology

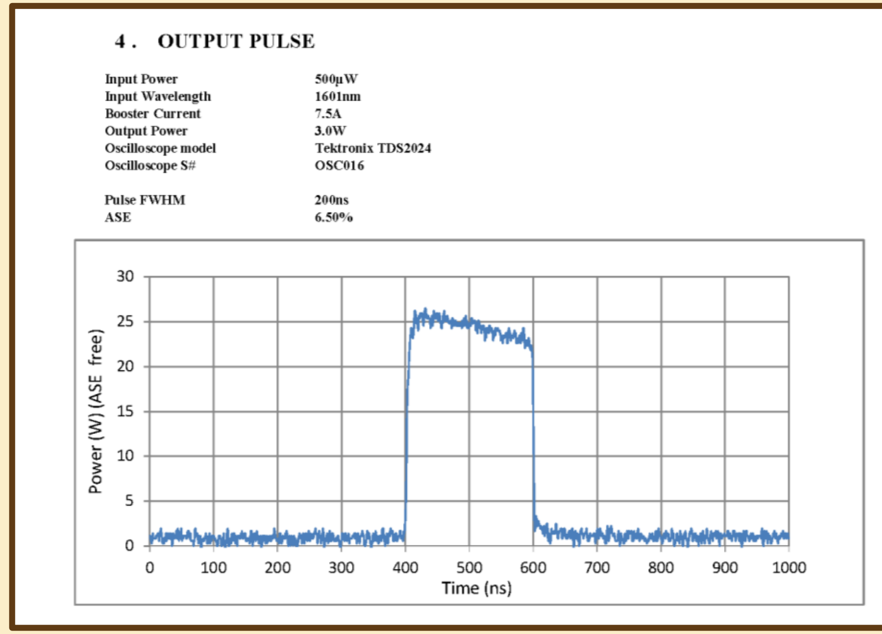
  A tunable high energy laser source with good beam quality needed for long range remote sensing

- Wavelength ranges

  Signal 1595 nm – 1650 nm

  Idler 2995 nm – 3082 nm

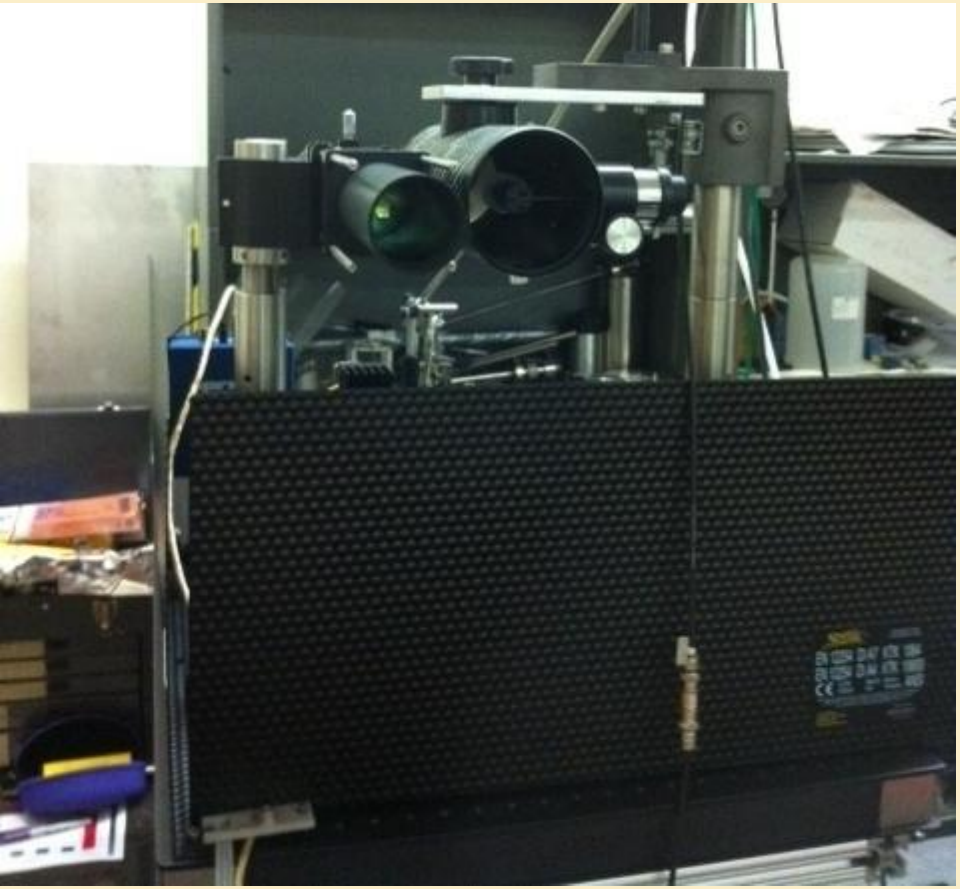
LIGHT SOURCE: PULSED FIBER AMPLIFIER

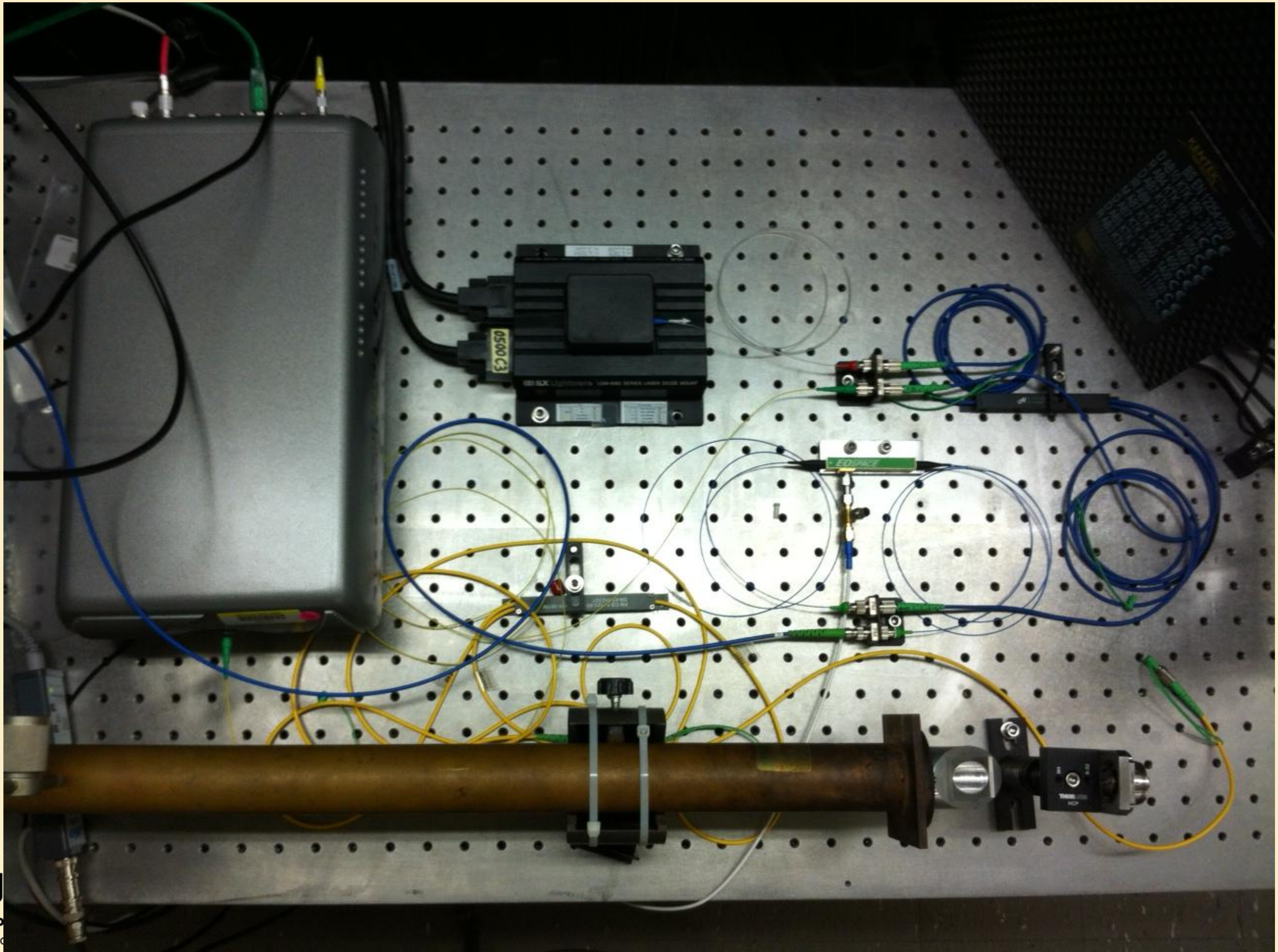


Repetition rate: 500 kHz (designed for short range)
Mean power : 3W
Peak power : 25-30W
Energy/pulse : 6μJ

Provides a tunable high energy laser source with good beam quality needed for long range remote sensing AND ultra-portable, no alignment needed

SMALL-SCALE HARD-TARGET SYSTEM




0500C3
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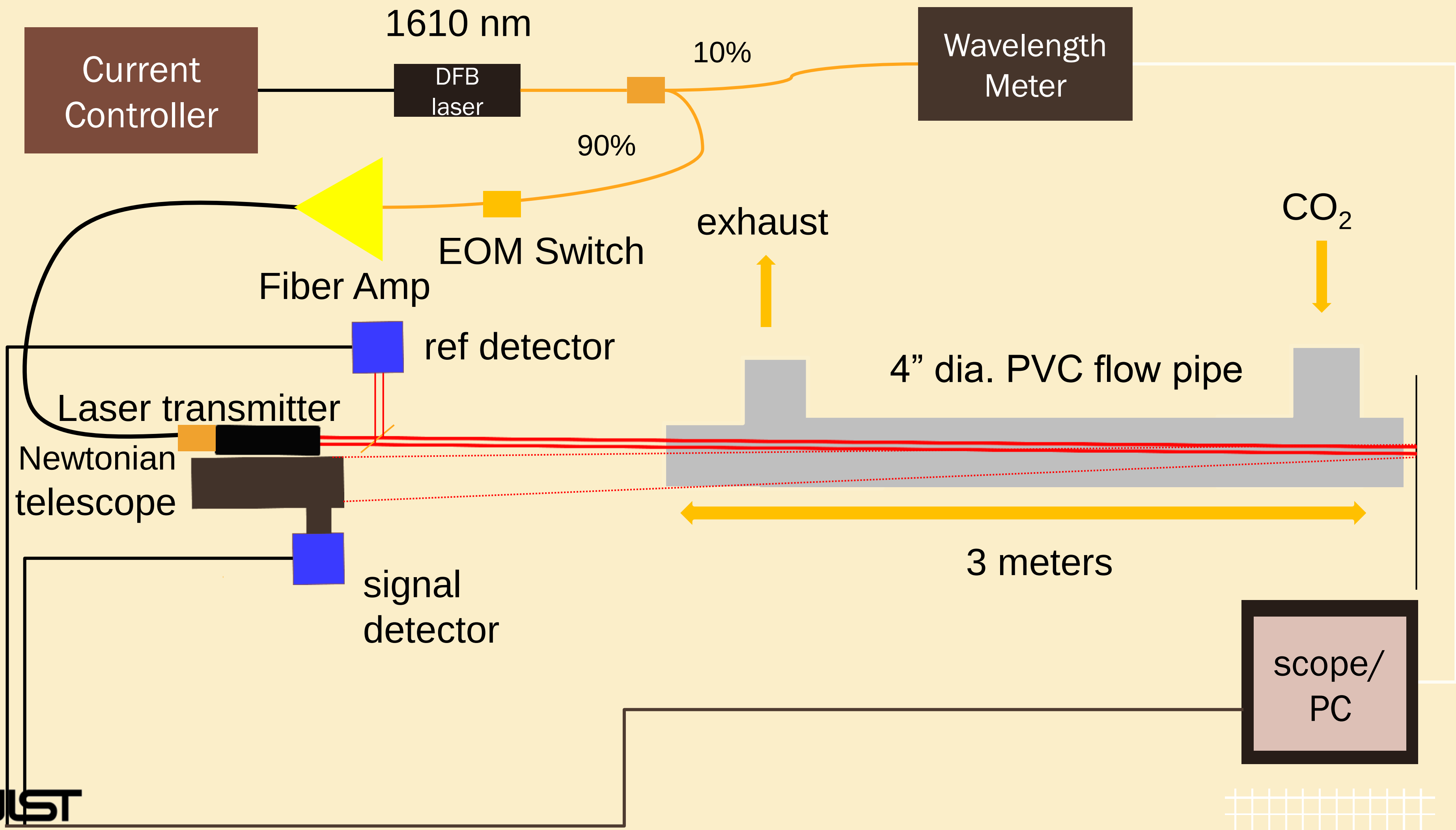
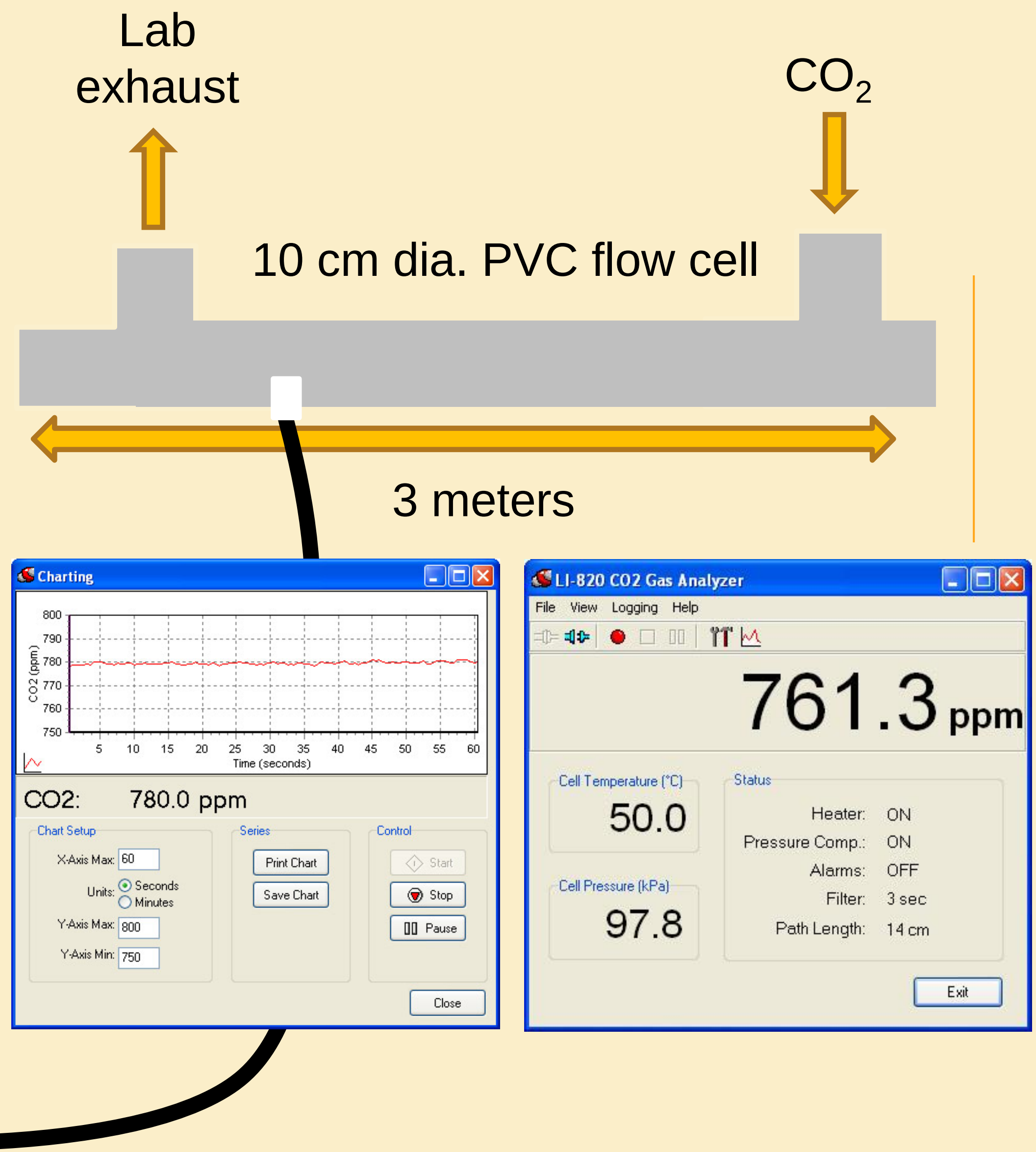
OPTICAL LAYOUT: HARD-TARGET DIAL

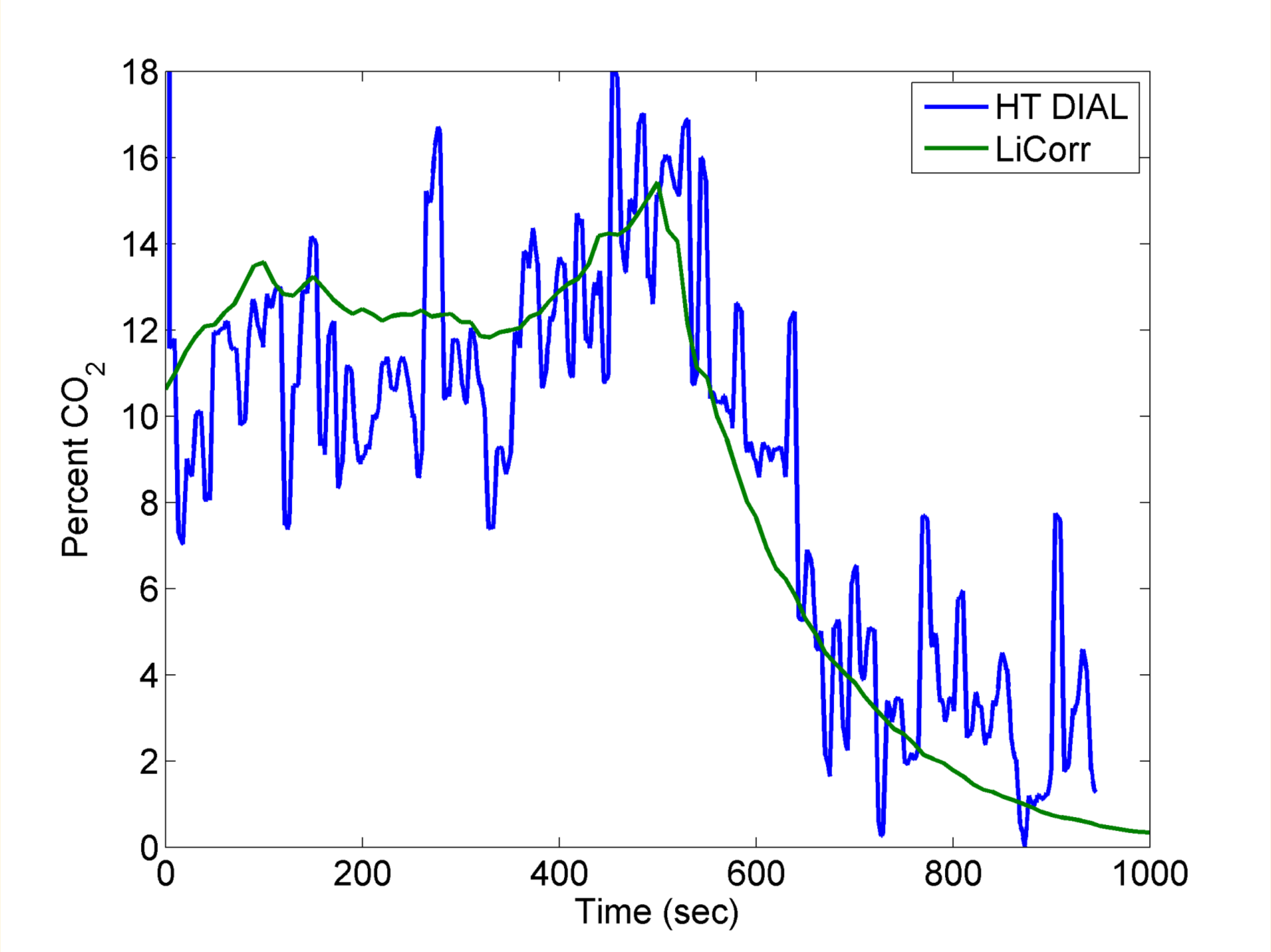


FLOW CELL

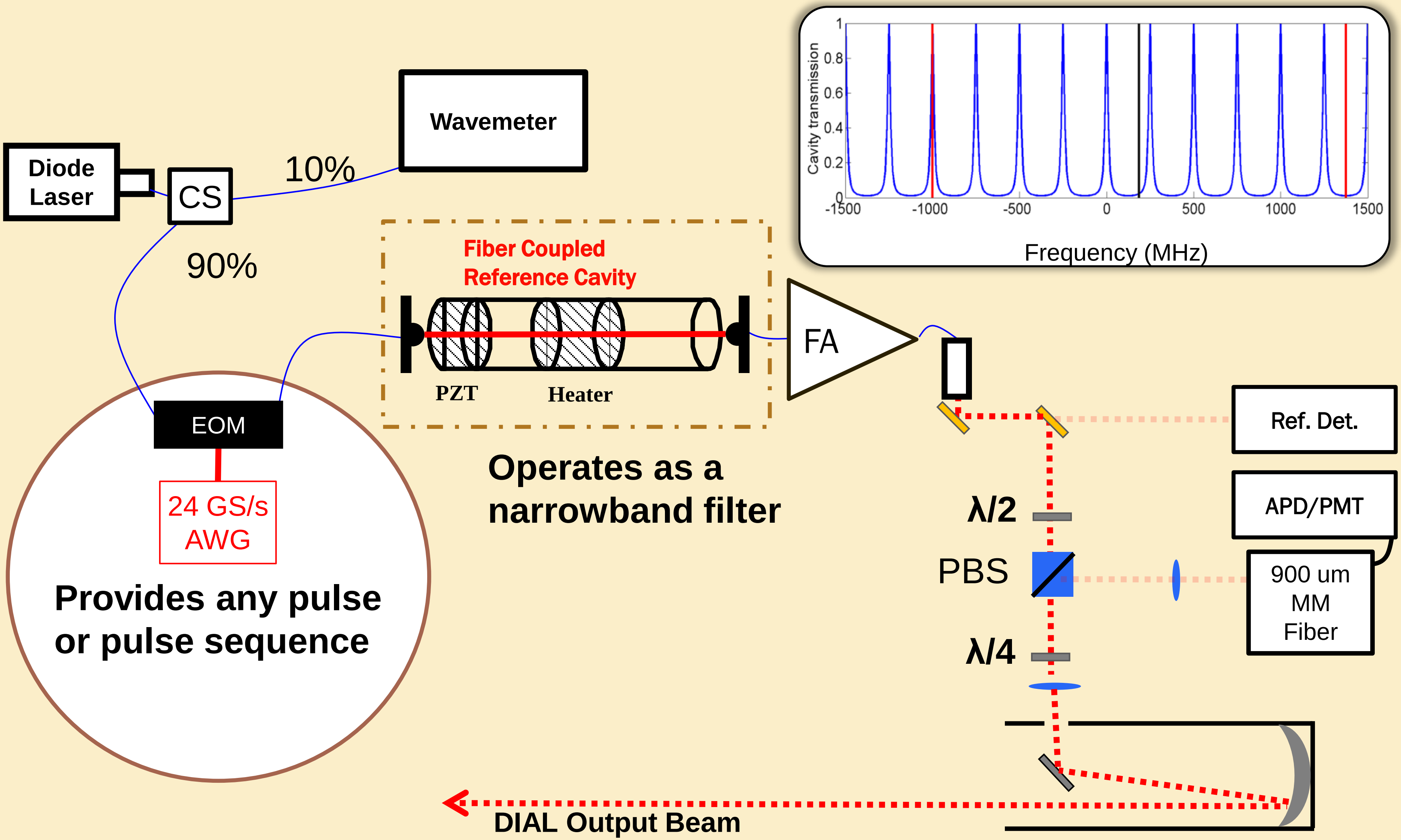
- NDIR sensor calibrated with 5500 ppm CO_2 (10% uncertainty) and zeroed with high purity N_2



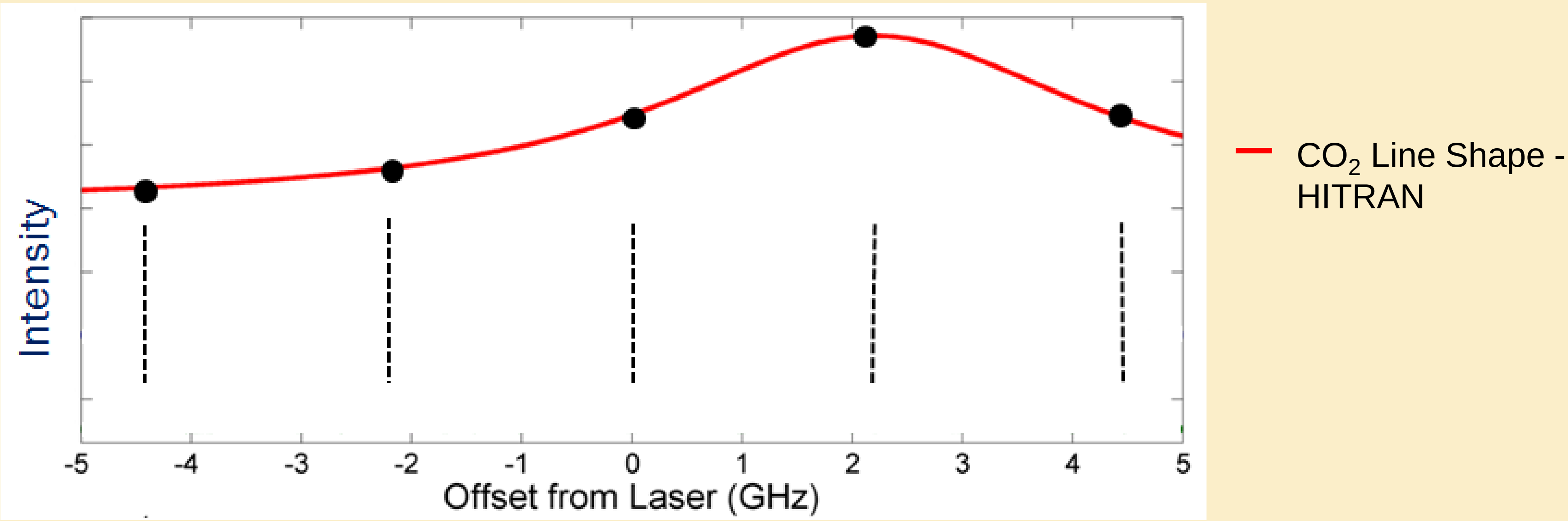
COMPARISON OF HT DIAL TO NDIR MONITOR



ETALON-BASED HIGH-SPEED WAVELENGTH SWITCHING

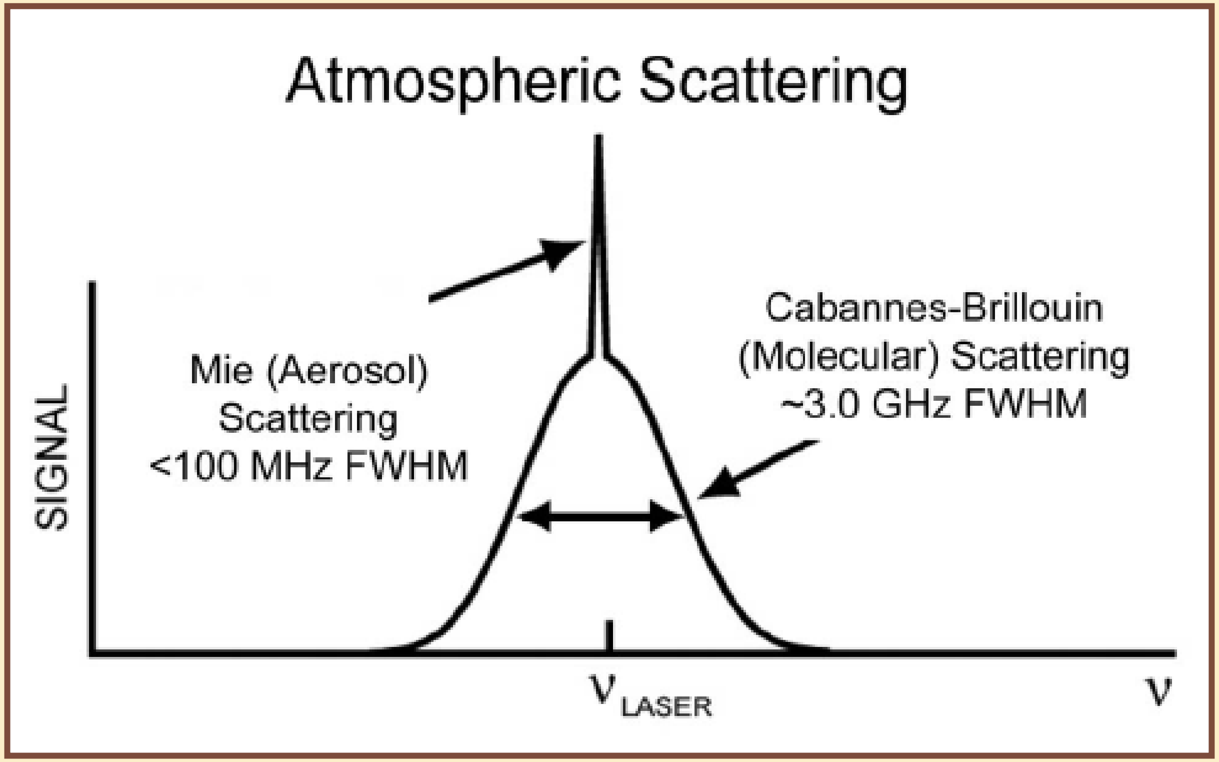


MULTI-WAVELENGTH HETERODYNE DIAL CONCEPT



- Produce multiple wavelengths simultaneously across the absorption line of
- Heterodyne detection puts each frequency point (black dot) on the absorption curve into a separate detection channel.

THE 2ND PARAMETER – WIND SPEED MEASUREMENT



- A 2 mph (1 m/s) wind velocity yields a 1 MHz Doppler shift at 1.6 mm
- Doppler shift can be measured using heterodyne techniques or by exploiting filter properties of Fabry-Perot cavities.

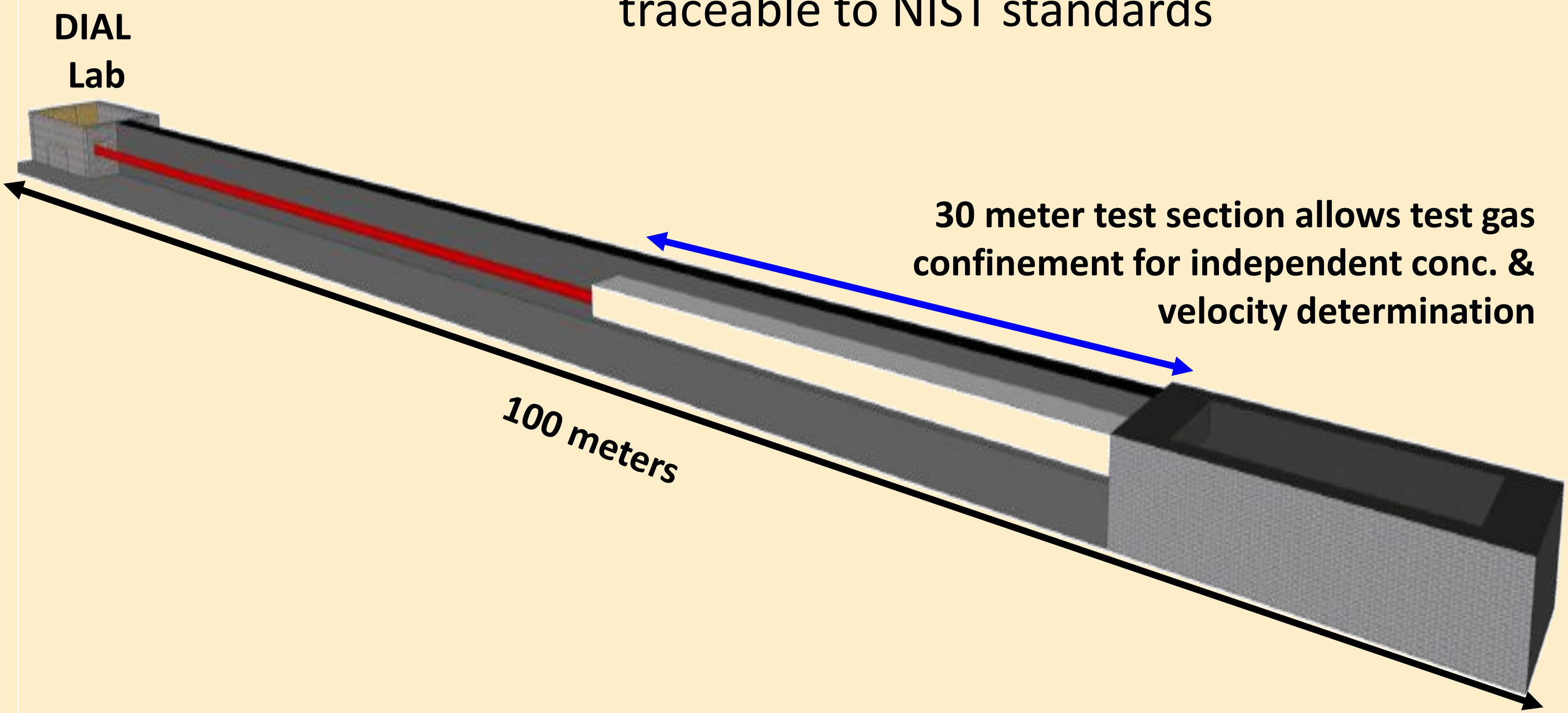
Several approaches are being pursued:

1. OPO laser system → We estimate 5 – 10 mph resolution limit
2. Fiber amplifier system → 2 mph resolution limit
3. Commercially available systems → 2 mph resolution

NIST DIAL TEST FACILITY CONFIGURATION

Flux Parameters

velocity and GHG concentration
traceable to NIST standards



RESULTS AND SUMMARY

- Designed and constructed two prototype DIAL systems for the detection of GHGs from distributed area sources
    - OPO operating at 100 Hz
    - Fiber based amplifier operating at 500 kHz

- Developed new methods to perform rapid sequential scans for direct detection and single pulse multi-l scans for heterodyne detection.

- Developing an indoor test facility for characterization of the DIAL system in a controlled environment.

- Goal is to move system outside to characterization of GHG densities and fluxes at the few km scale