Development and deployment of a compact eye-safe scanning differential absorption lidar (DIAL) for spatial mapping of carbon dioxide for monitoring/verification/accounting at geologic carbon sequestration sites

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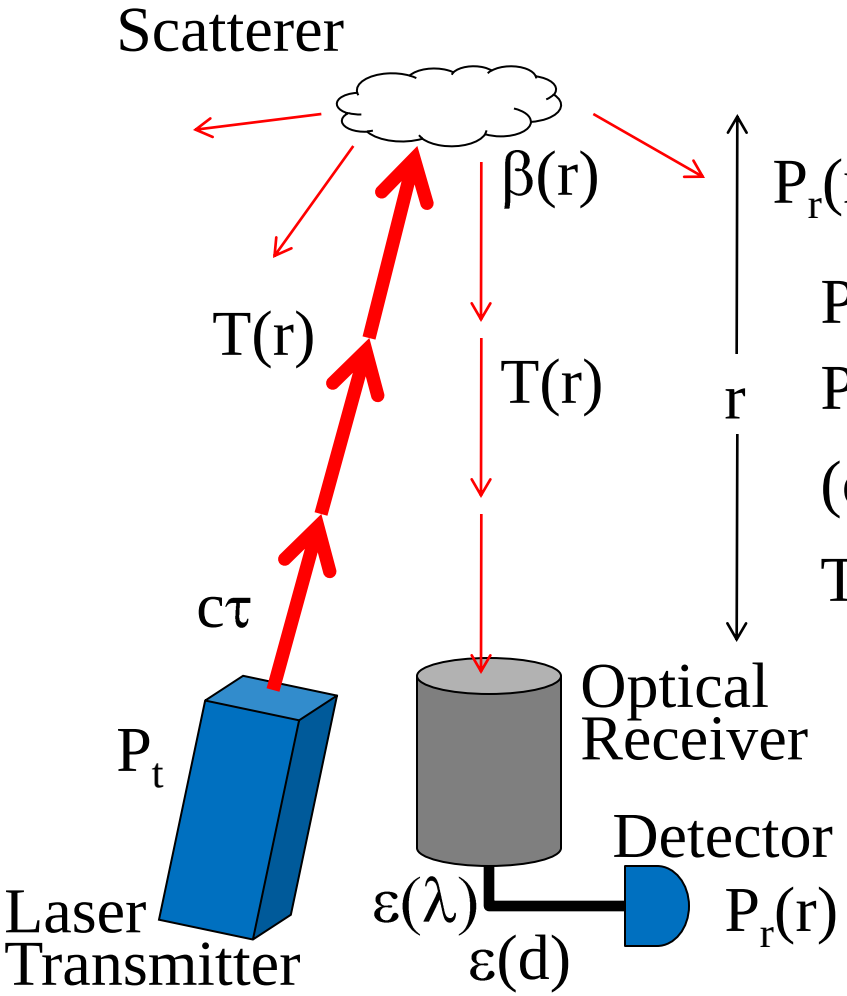
Goals of the Project

- Develop a field deployable scanning DIAL instrument for mapping carbon dioxide number densities at carbon sequestration sites.
  - 1.573 μm wavelength (Telecommunications components available)
  - Eye-safe
  - 150 m range resolution, 2 km maximum range
  - 1 minute averaging times
  - 3- dimensional scanning capabilities
- Demonstrate the DIAL instrument at the Zero Emissions Research Technology (ZERT) controlled release site.
- Deploy the instrument at a Carbon Sequestration Partnership field site.

Lidar Fundamentals



Lidar Equation

$$P_r(r) = P_t(c\tau/2)\,T(r)\,\beta(r)\,(A/r^2)\,T(r)\,\varepsilon(\lambda)\,\varepsilon(d)$$

$P_r(r)$ detected optical power from range r

P_t emitted laser optical power

$(c\tau/2)$ range bin size

$T(r)$ atmospheric transmission to range r

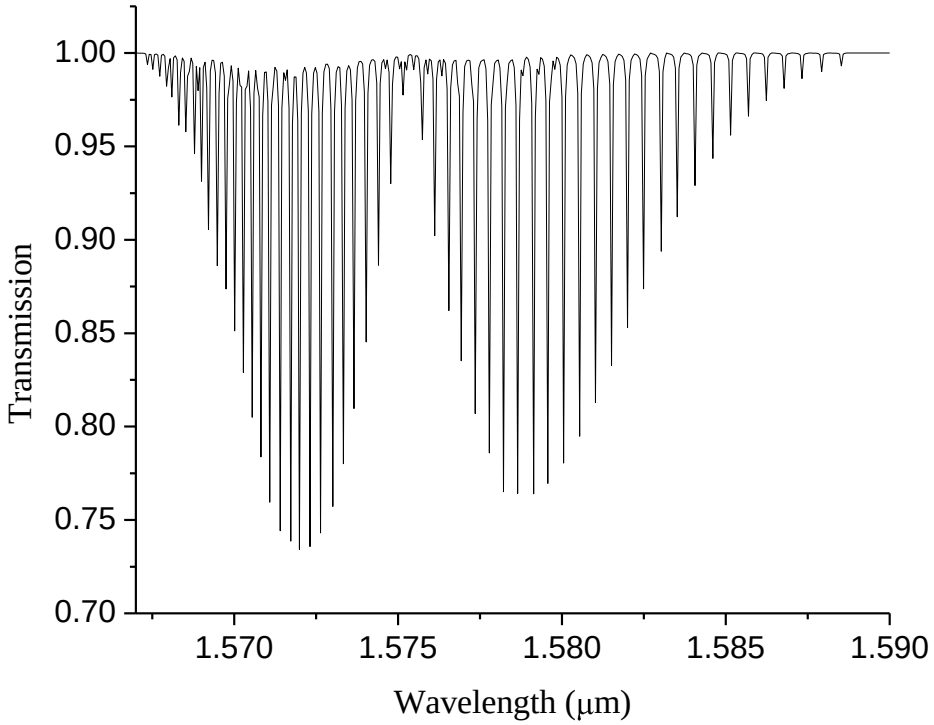
$\beta(r)$ backscatter coefficient

(A/r^2) receiver solid angle

$\varepsilon(\lambda)$ receiver optics transmission

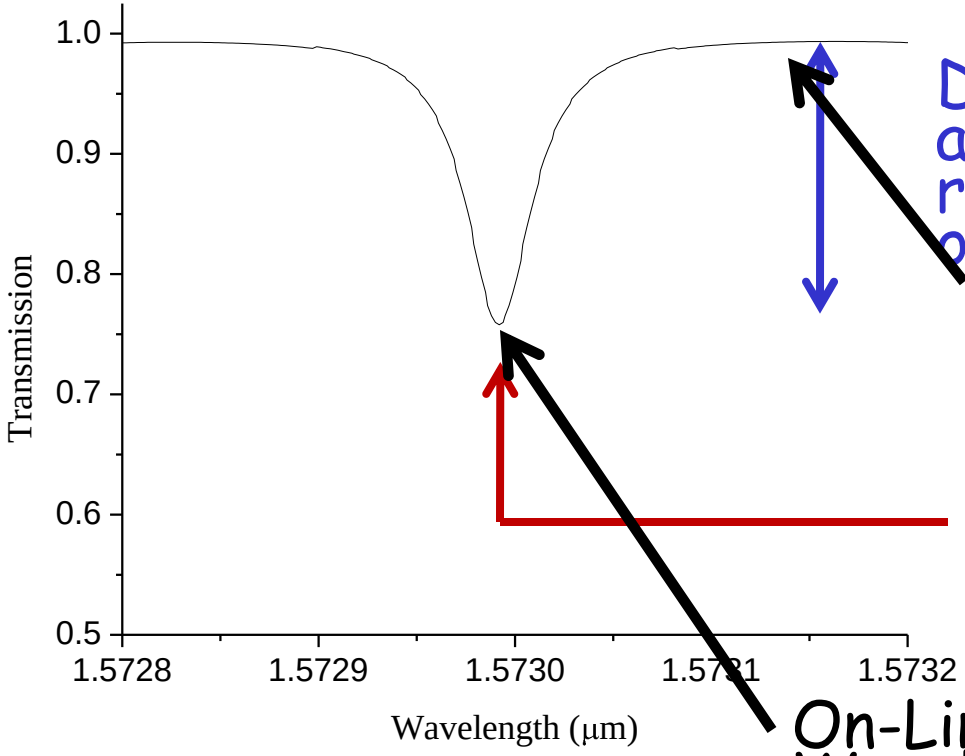
$\varepsilon(d)$ detector efficiency

Atmospheric Transmission



- Absorption spectrum of CO_2 near 1.57
- 387 ppm CO_2 concentration
- 4 km pathlength

Atmospheric Transmission



Depth of the absorption feature is related to the number of molecules.

Off-Line Wavelength

Wavelength of the absorption feature can be used to identify the molecule.

On-Line Wavelength

DIAL Fundamentals

- Using closed spaced on-line and off-line wavelengths, the only difference in the lidar returns results from the change in transmission due to molecular absorption for the on-line wavelength.
- The atmospheric transmission as a function of wavelength and range can be written:

$$T_A^2(\lambda, r) = e^{-2\int_0^r \kappa(\lambda, r')dr'} e^{-2\int_0^r \sigma(\lambda, r')N(r')dr'}$$

DIAL Equation

Using the lidar equation for closely space on-line and off-line wavelengths and the wavelength dependent atmospheric transmission, the DIAL equation can be written:

$$N(r) = \frac{1}{2\Delta r(\sigma(\lambda_{on},r) - \sigma(\lambda_{off},r))}\left[ln\left(\frac{P(\lambda_{on},r)P(\lambda_{off},r+\Delta r)}{P(\lambda_{on},r+\Delta r)P(\lambda_{off},r)}\right)\right]$$

N(r) is the molecular number density at range r

$\Delta r = c\tau/2$ is the range bin size

λ_{on} (λ_{off}) is the on-line (off-line) wavelength

$P(\lambda,r)$ is the lidar received optical power

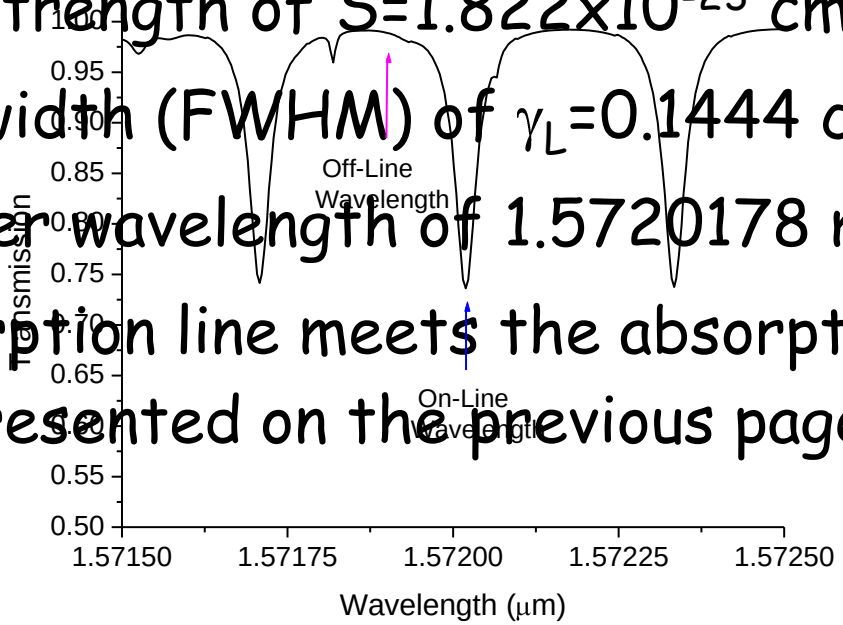
$\sigma(\lambda,r)$ is the scatter cross section

Absorption Line Selection

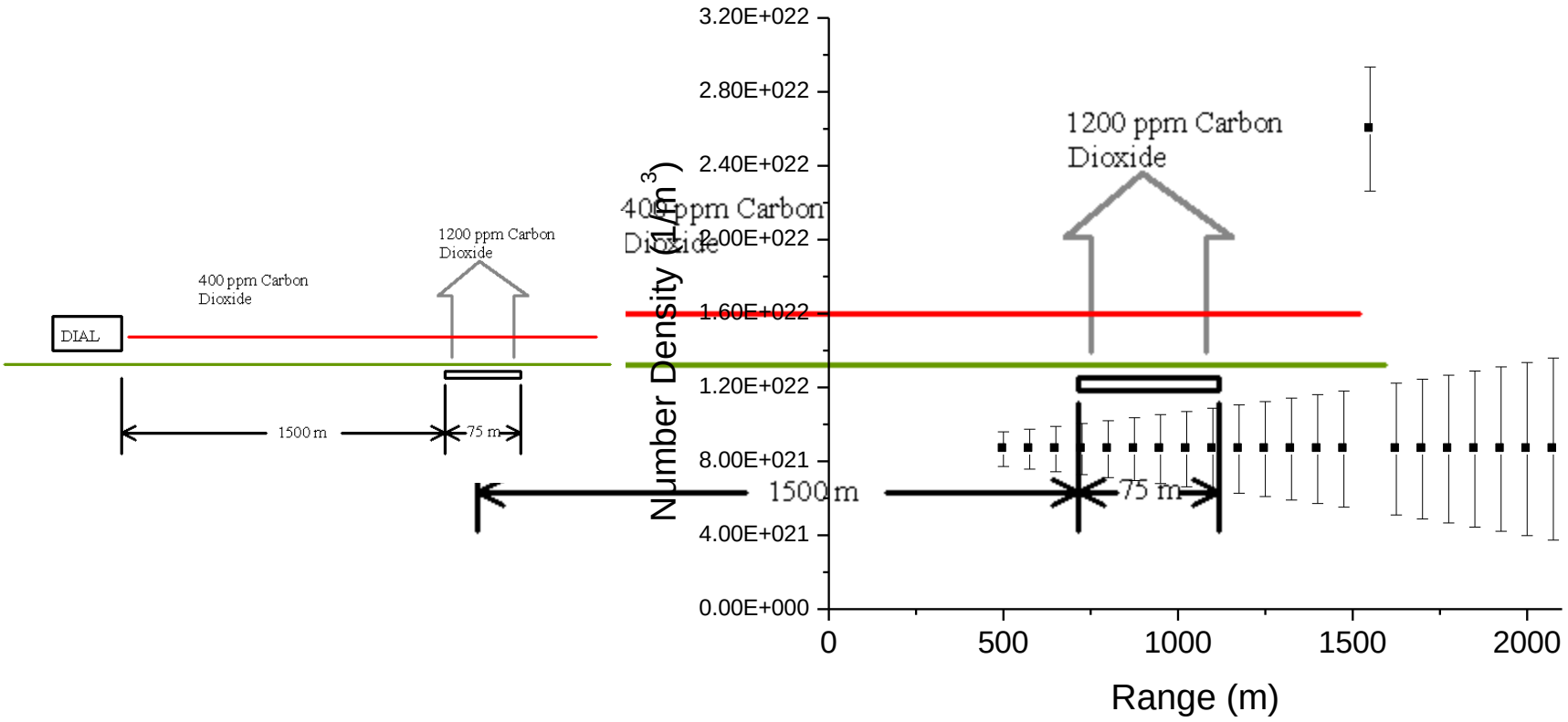
- The absorption line selection requires
  - a line with the appropriate line strength. (approximately 50% transmission over the maximum range associated with the DIAL instrument)
  - No nearby absorption features from other atmospheric molecules.
  - Temperature insensitivity of the absorption feature.

Absorption Line Selection

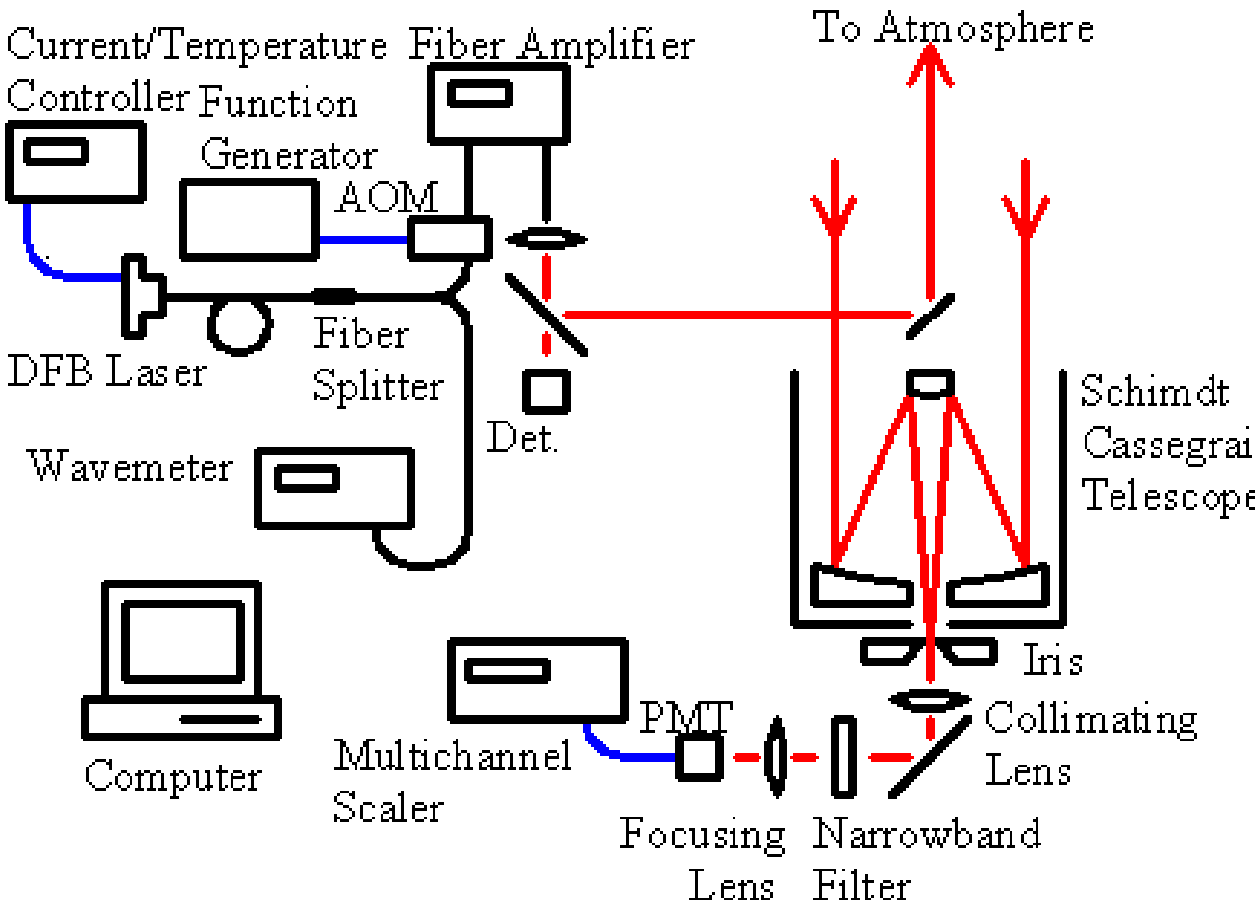
- The parameters for the chosen line are found from the HITRAN database to be:
  - Linestrength of $S=1.822 \times 10^{-23}$ cm/molecule
  - Linewidth (FWHM) of $\gamma_L=0.1444$ cm^{-1}
  - Center wavelength of 1.5720178 mm
- This absorption line meets the absorption line selection criteria presented on the previous page.



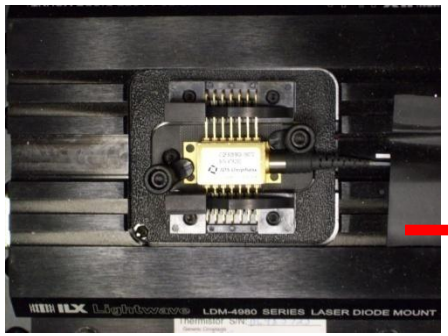
Modeled CO_2 DIAL Performance

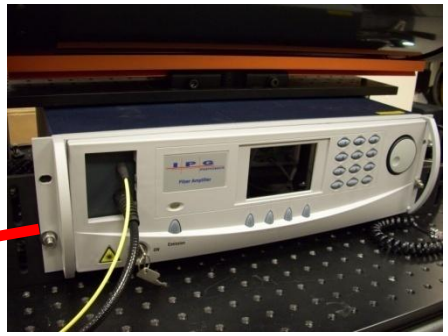


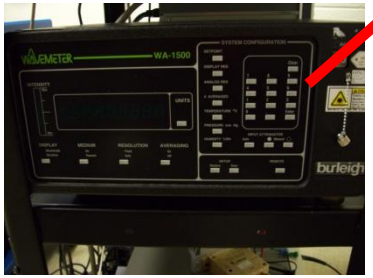
Schematic of the CO_2 DIAL

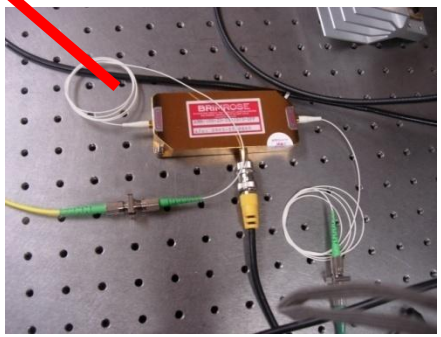


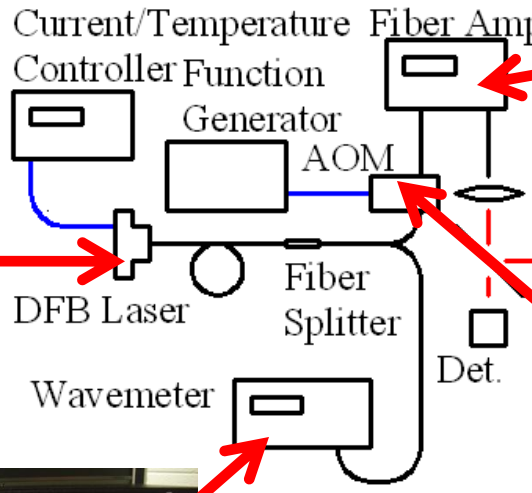
Laser Transmitter



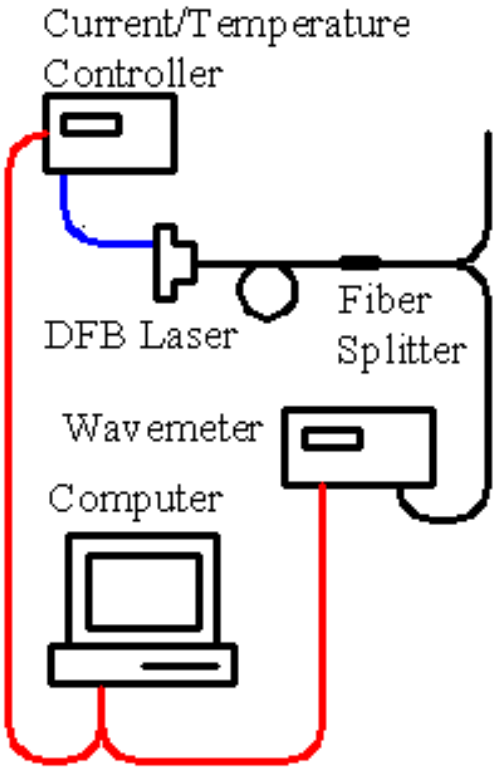


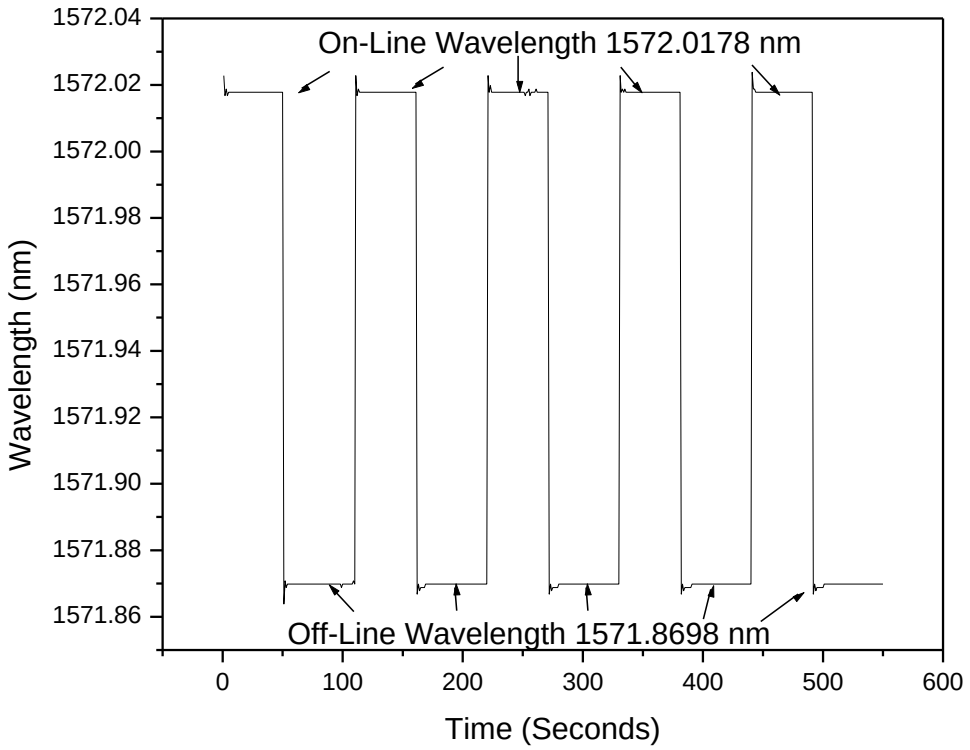




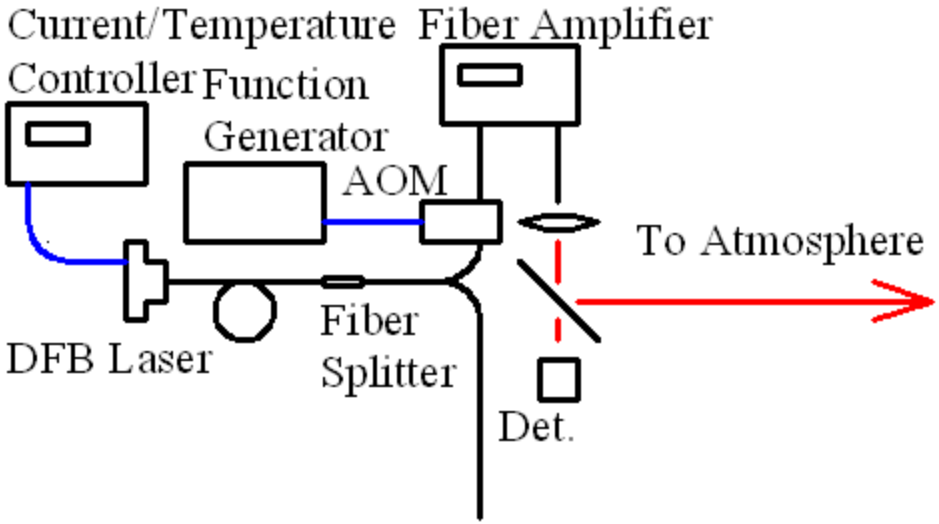


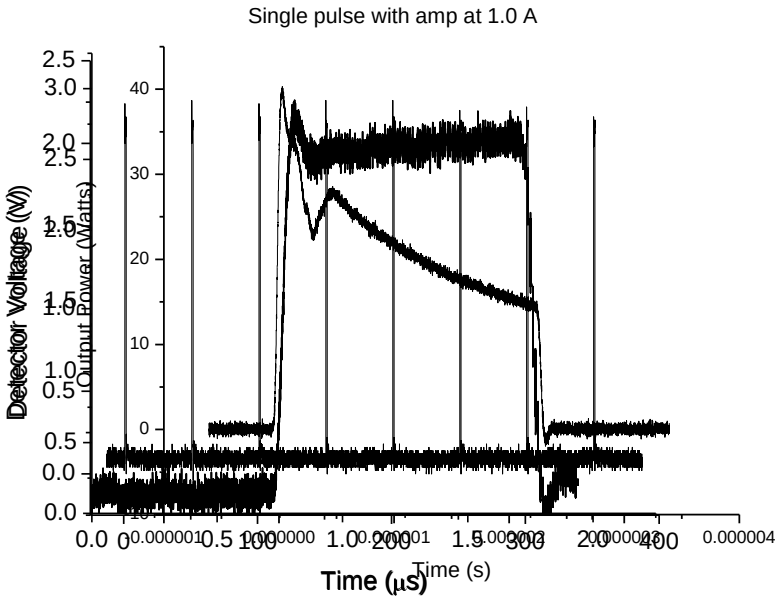
Wavelength Control



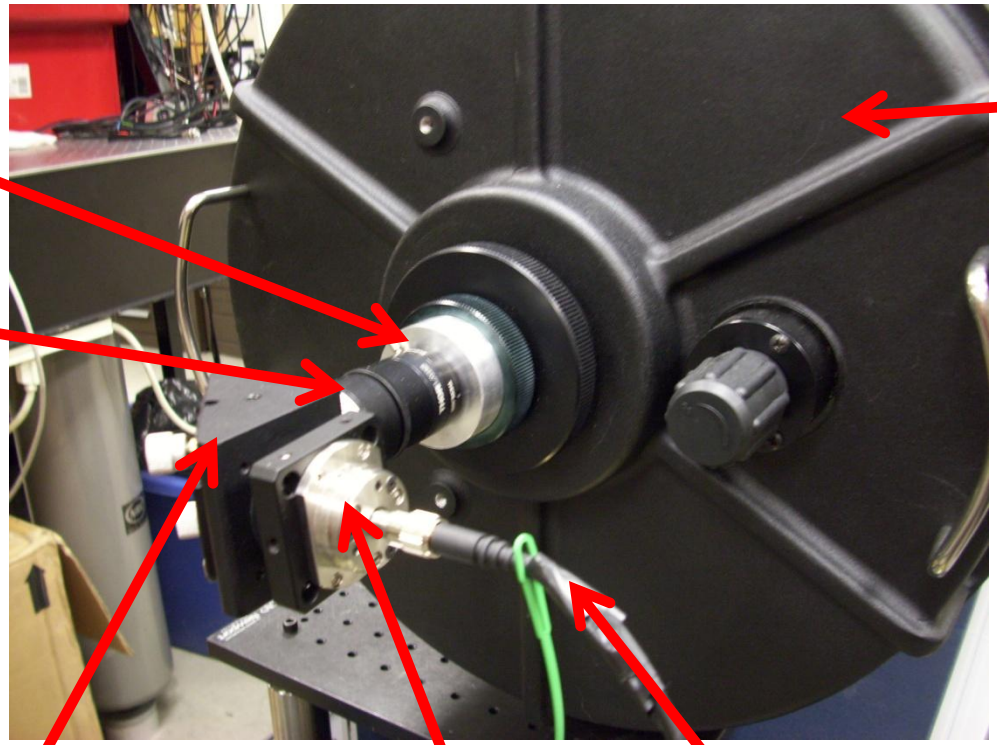


Pulse Generation



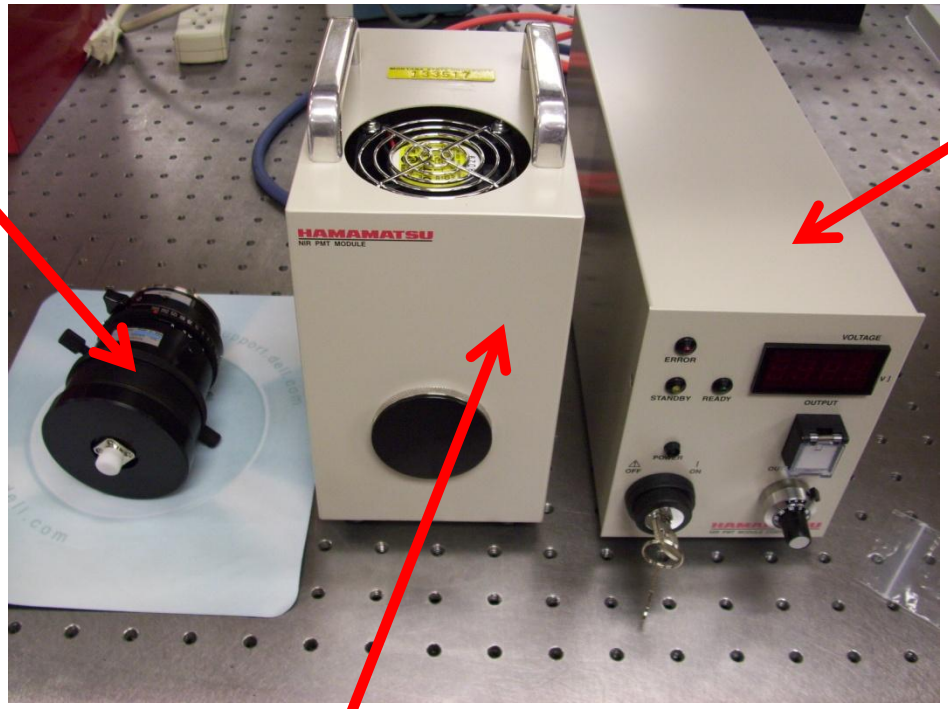


DIAL Receiver Optics



Photomultiplier Tube

Fiber Coupler



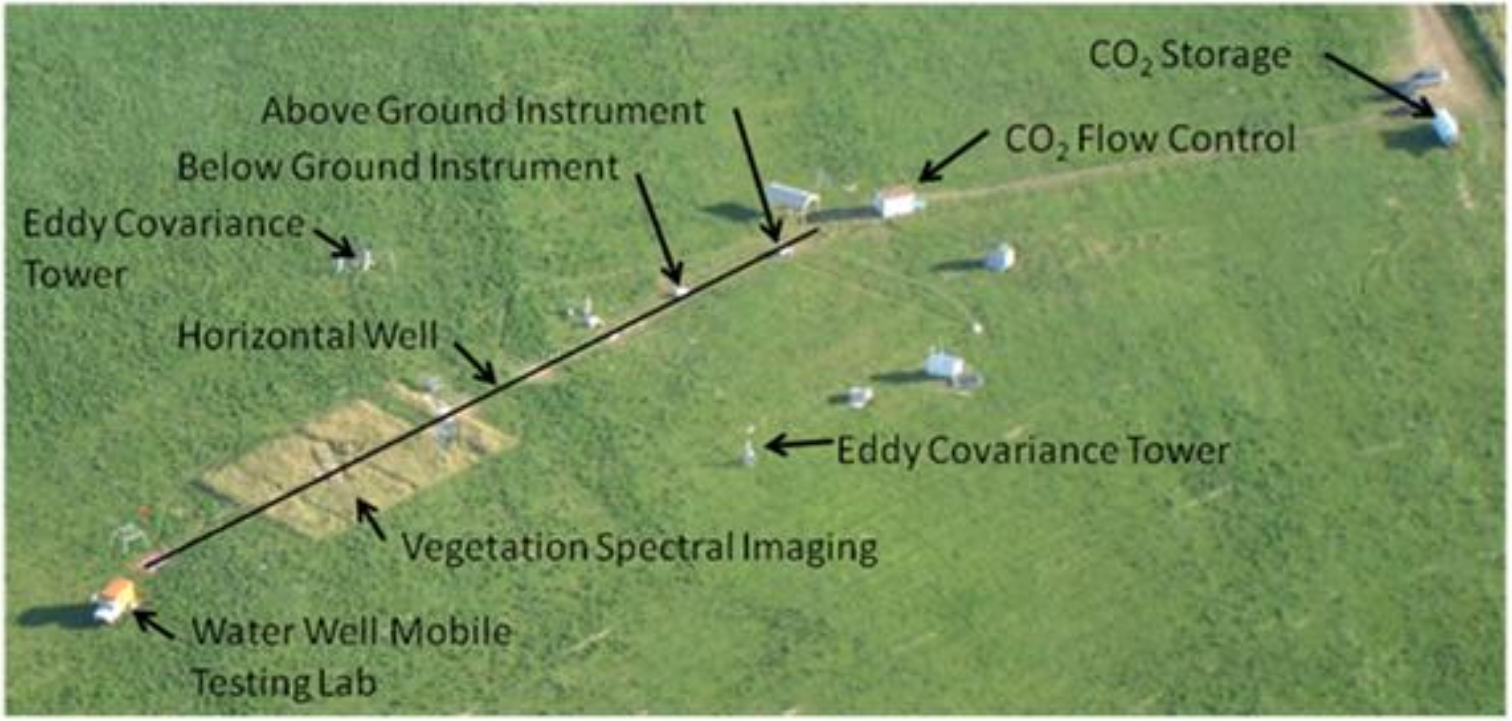
High Voltage Supply and Temperature Controller

TEC Cooled PMT

Projected Instrument Parameters

Parameters	Values
λon,, λoff (nm, Vacuum)	1572.0178/1571.8698
Pulse Repitition Frequency (kHz)	20.0
Pulse Width (μs)	0.5-2
Pulse Energy (μJ)	80
Transmitter Linewidth (FWHM; MHz)	< 0.5
Frequency Stability (MHz)	88
Spectral Purity	0.99
Telescope Diameter (cm)	33
Far-field Full Field of View (μrads)	~200
Filter Bandwidth (FWHM; pm)	~ 250

Zert Controlled Release Site



ZERT Controlled sub-surface release facility at the western edge of the Montana State University campus developed for testing carbon sequestration site monitoring instrumentation.

Conclusions

- Laser transmitter is completed.
- Optical train for the DIAL receiver is completed and aligned.
- Characterization of the PMT is currently underway.

Thanks Kindly For Your Time