TEST RESULTS for the BROADBAND CARBON DIOXIDE LIDAR

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OUTLINE OF TALK

1. INTRODUCTION –MOSTLY ABOUT ASCENDS
2. BROADBAND LIDAR-THEORY
3. BROADBAND LIDAR-OUR IMPLEMENTATION
4. SOME EARLY RESULTS
5. PLANS AND CONCLUSIONS

THE ASCENDS MISSION

- The goal of Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission is to significantly enhance the understanding of the role of CO_2 in the global carbon cycle.

  Science themes addressed by ASCENDS include:
  - Shifts in terrestrial carbon sources and sinks
  - Identifying processes controlling biospheric carbon fluxes
  - Understanding the evolving nature of oceanic carbon fluxes
- Planned to be launched in the 2013-2016 time frame - http://cce.nasa.gov/ascends/index.htm
- The National Academy of Sciences recommended in its decadal survey that NASA put in orbit a CO_2 lidar to satisfy this long standing need.

- Existing passive sensors suffer from two shortcomings.
  - Their measurement precision can be compromised by the path length uncertainties arising from scattering within the atmosphere.
  - Also passive sensors using sunlight cannot observe the column at night.

- Both of these difficulties can be ameliorated by lidar techniques.

LIDAR SYSTEMS

- Lidar systems will present global measurement of carbon dioxide column with the aim of discovering and quantifying unknown sources and sinks - a high priority for the last decade.

- Spectroscopy data is a major challenge to CO_2 remote sensing. Uncertainties in line intensity and line pressure broadened width parameters, inadequate line position knowledge, incomplete knowledge or measurement of spectrum for isotopes, and pressure shift are large CO_2 retrieval error sources.

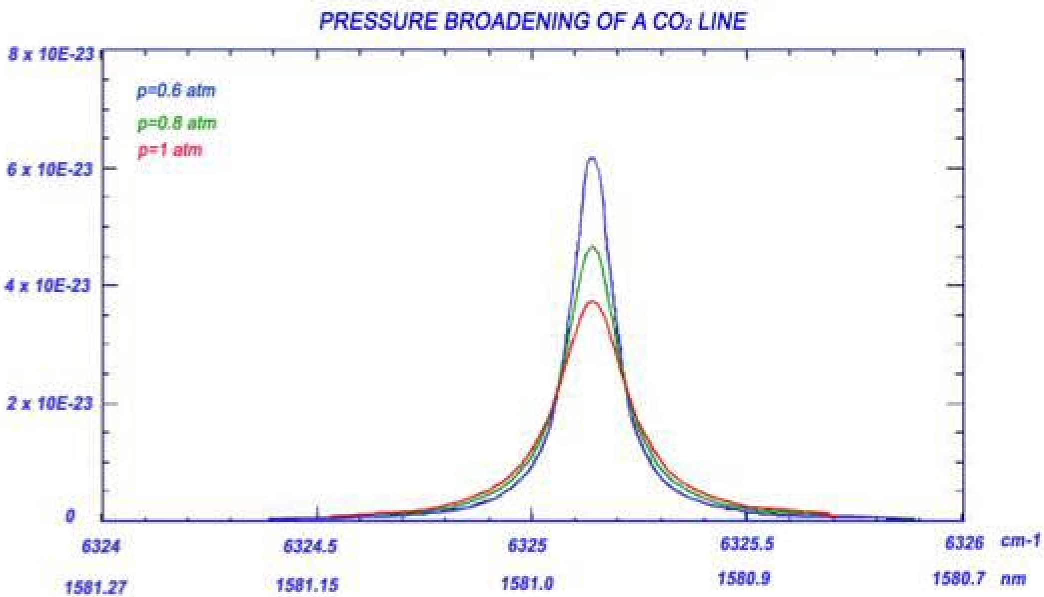
    - Temperature changes in the atmosphere alter the cross section for individual CO_2 absorption features.

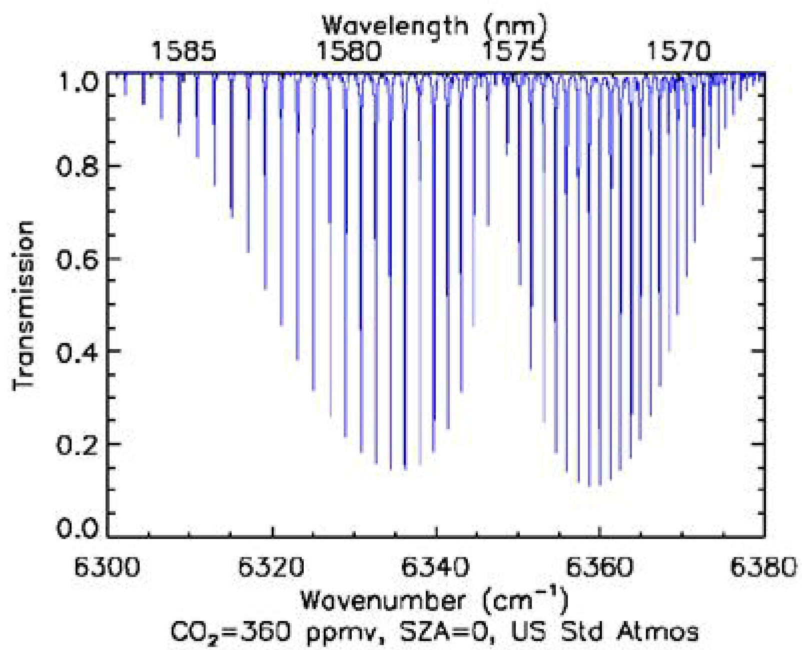
    - Different atmospheric pressures encountered passing through the atmosphere broaden the absorption lines.

- Currently proposed lidars require multiple lasers operating at multiple wavelengths simultaneously in order to untangle these effects.

SPECTROSCOPY-PRESSURE EFFECTS

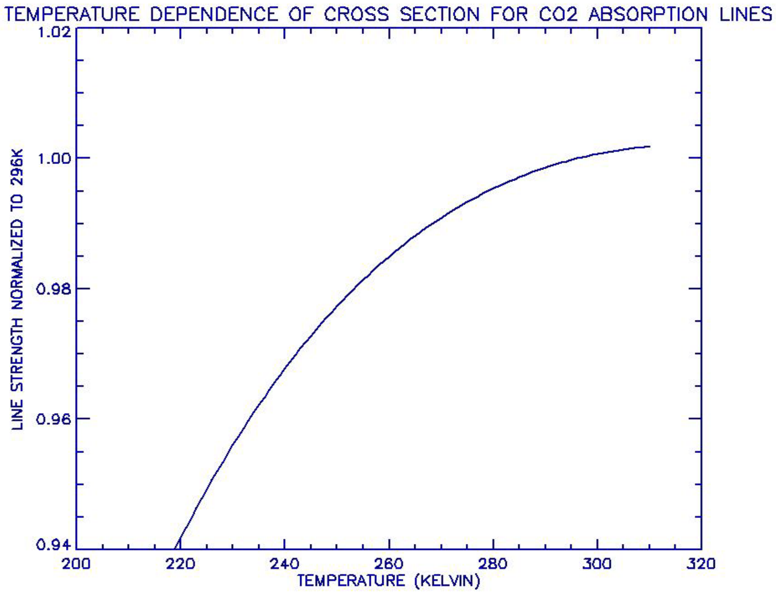
At the top of the atmosphere the width of a spectral line is dominated by the Doppler effect. Proceeding lower into the atmosphere collisional (pressure) broadening begins to manifest itself to a greater and greater extent. A shift in the center frequency also occurs as the result of collisions. There is only a minimal contribution to the absorption in the wing from the upper atmospheric CO_2 the effect of a surface source or sink will be a larger perturbation on the overall column absorption at these wavelengths.

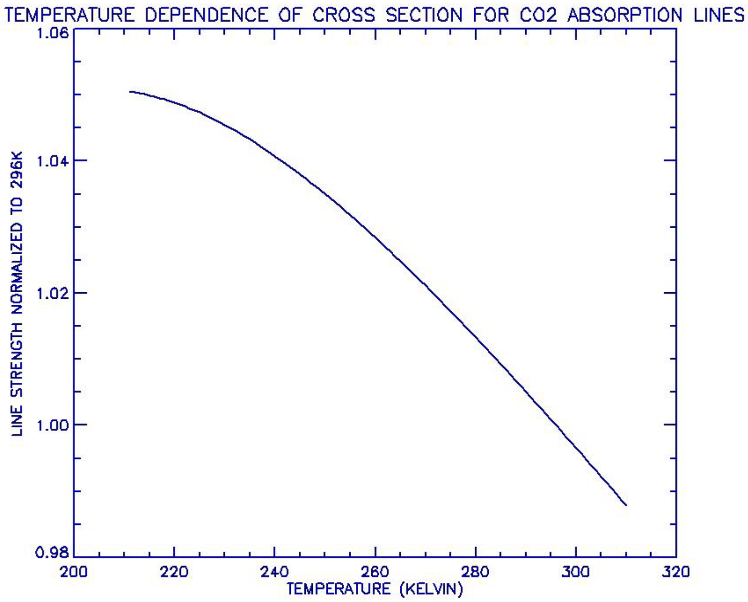




SPECTROSCOPY-TEMPERATURE EFFECTS

The line strengths change with the temperature of the atmosphere This can introduce errors in the column as large as 1ppm for a 2 degree K change in temperature. This means that using a single absorption line and relying on meteorological measurements or models to provide the temperature correction may not suffice for the CO_2 column measurement. Small changes in strengths and widths affect CO_2 retrievals at high airmass.





Major LIDAR Contenders for ASCENDS Mission

1. LaRC-ITT Team—"Lock-In" LIDAR --simultaneous, continuous transmission of 3 wavelengths at different positions on CO_2 absorption line
2. JPL—2.0 micron Heterodyne LIDAR --continuous transmission detected using local oscillator mixer. Operates in wings of very strong absorption features
3. NASA (Abshire Team)—Conventional pulsed LIDAR cycles rapidly through 3 or more wavelengths
4. NASA (Heaps Team)—Broadband LIDAR-simultaneous pulsed transmission of "ON" and "OFF" wavelengths.

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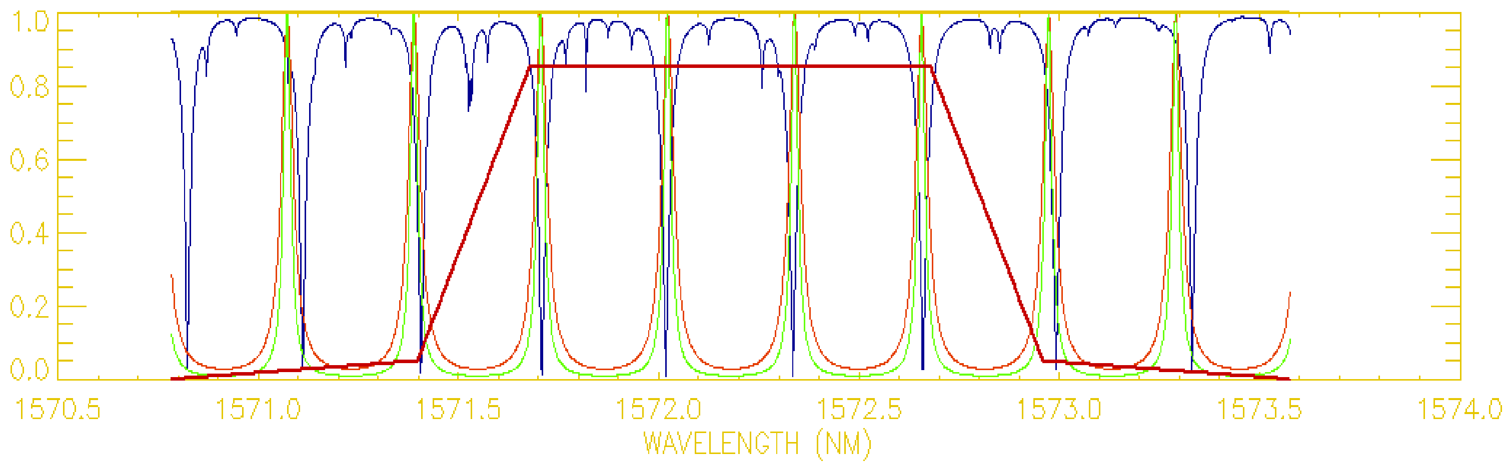
BROADBAND LIDAR APPROACH FOR ASCENDS MISSION

- Our current goal is to develop an ultra precise, inexpensive new lidar system for precise column measurements of CO_2 changes in the lower atmosphere that uses a Fabry-Perot interferometer based system as the detector portion of the instrument.
- We replace the narrow band laser commonly used in lidars with a laser like source that emits over a wider spectrum--a number of ways to do this
- This approach reduces the number of individual lasers used in the system from three or more to one—considerably reducing the risk of failure.
- It also tremendously reduces the requirement for wavelength stability in the source putting this responsibility instead on the Fabry-Perot subsystem.



DIFFERENTIAL ABSORPTION LIDAR

BEER'S LAW

$$I = I_0 \exp(-n\,s\,z)$$

$$\underline{I} = \underline{I}_0 \exp(-n\,\underline{s}\,z)$$

$$\log(I/I_0) = -n\,s\,z$$

$$\log(I/I_0) - \log(\underline{I}/\underline{I}_0) = -n(s-\underline{s})z.$$

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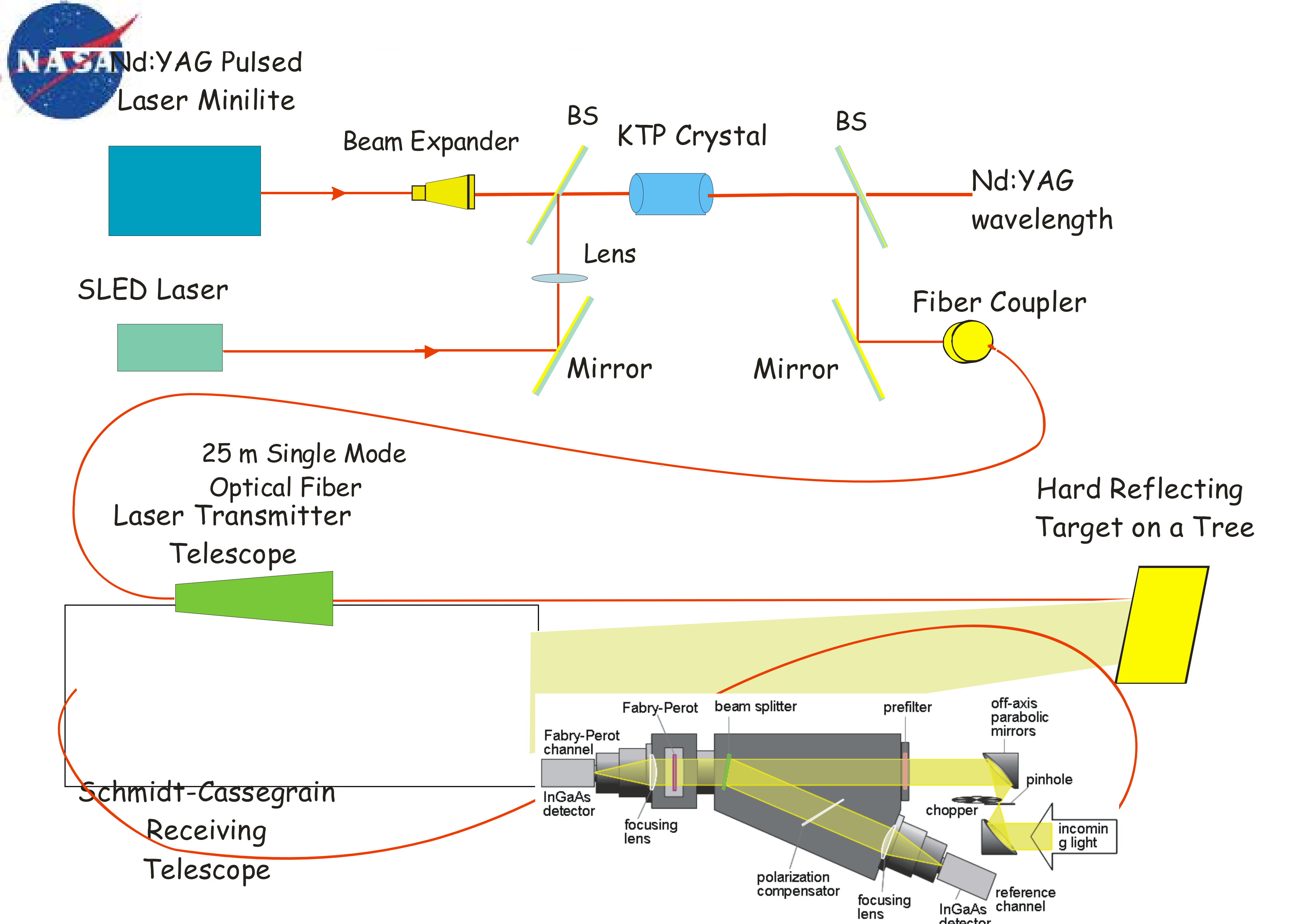
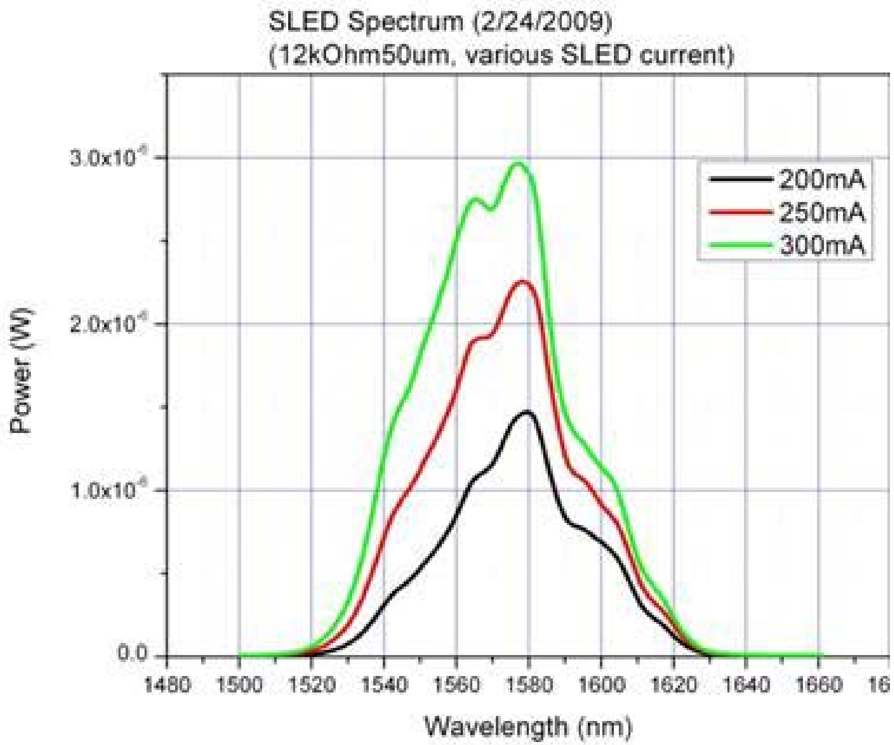
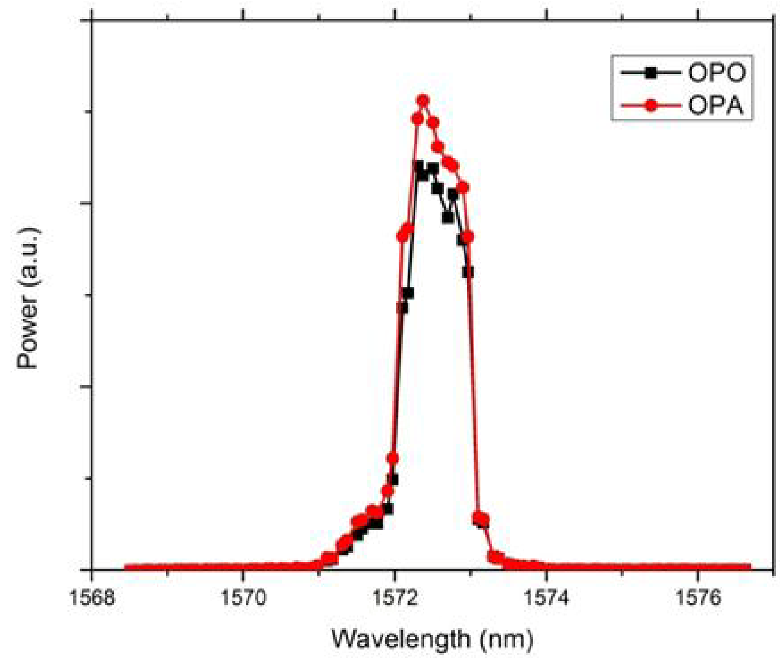

Nd:YAG Pulsed
Laser Minilite
Beam Expander
BS
KTP Crystal
BS
Nd:YAG
wavelength
Lens
SLED Laser
Fiber Coupler
Mirror
Mirror
25 m Single Mode
Optical Fiber
Laser Transmitter
Telescope
Hard Reflecting
Target on a Tree
Fabry-Perot
beam splitter
prefilter
off-axis
parabolic
mirrors
Fabry-Perot
channel
pinhole
InGaAs
detector
chopper
focusing
lens
incomin
g light
Schmidt-Cassegrain
Receiving
Telescope
polarization
compensator
focusing
lens
reference
channel
InGaAs
detector

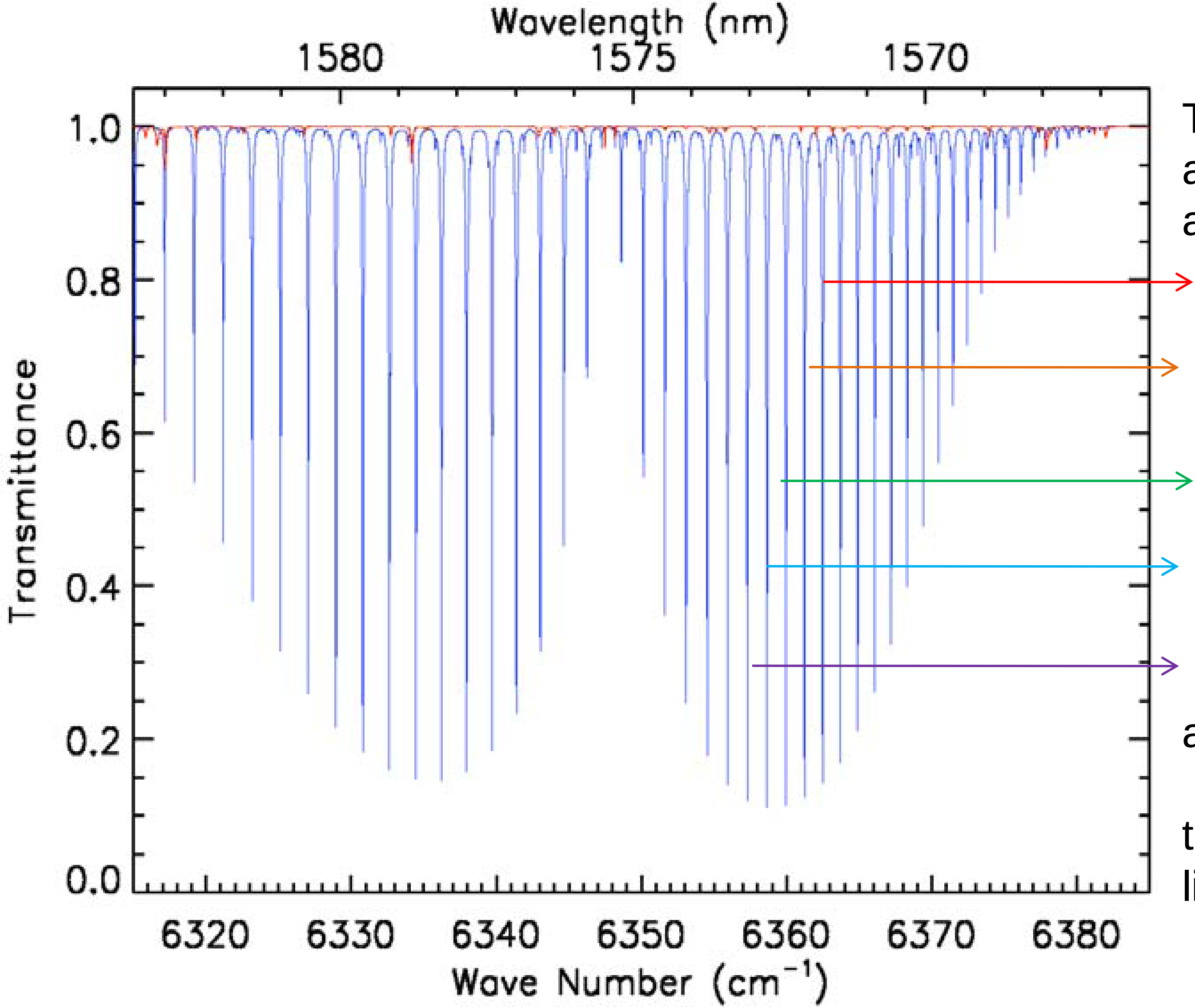
Figures show the unamplified spectral output of the SLED and the narrower amplified output of the OPA





The output of the SLED increases with increasing drive current. The spectral output is quite broad covering almost 100 nm. We only use a narrow region 2-3 nm wide centered around 1571 nm. The OPA is designed to amplify this region in particular.

This figure shows a scan of the output of the OPA made using the same monochromator. The spectral width has been reduced to about 2 nm. All of the photons coming out of the OPA are within the bandpass of our lidar receiver.



There are CO_2 absorption lines located at

1571.7,

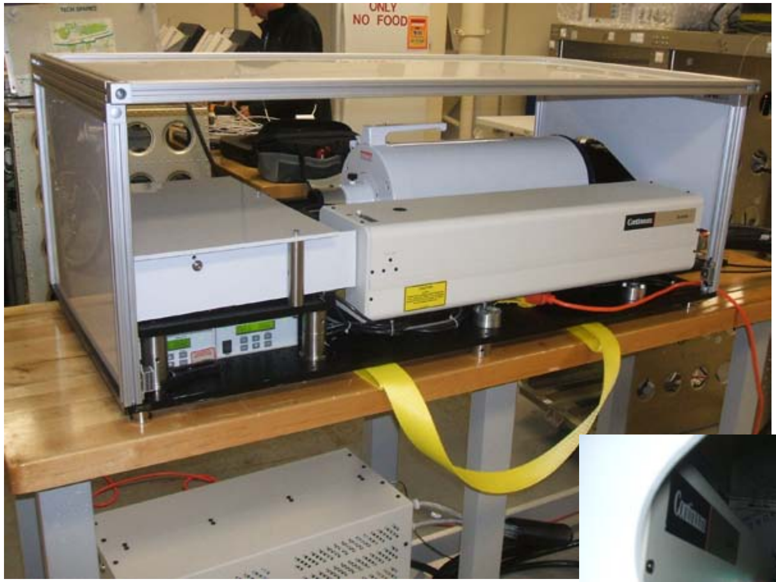
1572.0,

1572.3,

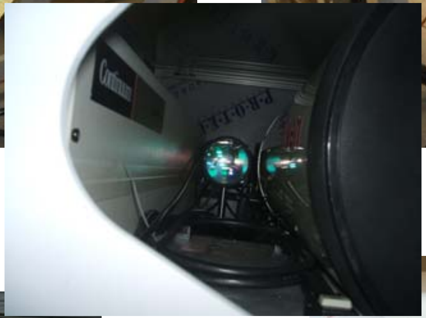
1572.65,

and 1573.0 nm

that will absorb light from this transmitter.

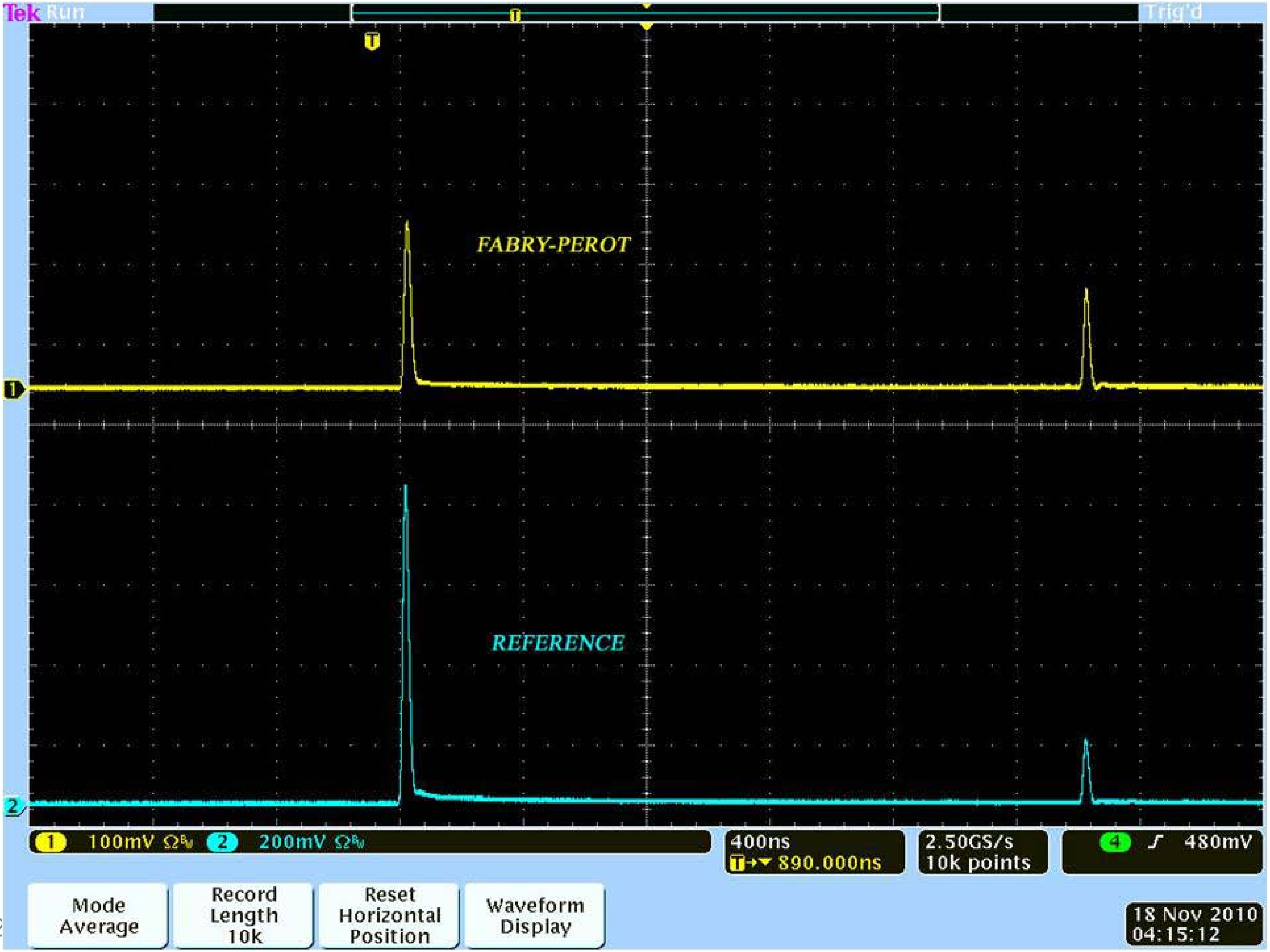

ONLY
NO FOOD


Vixen




CALIBRATE BEFORE USE

TYPICAL LIDAR RETURNS



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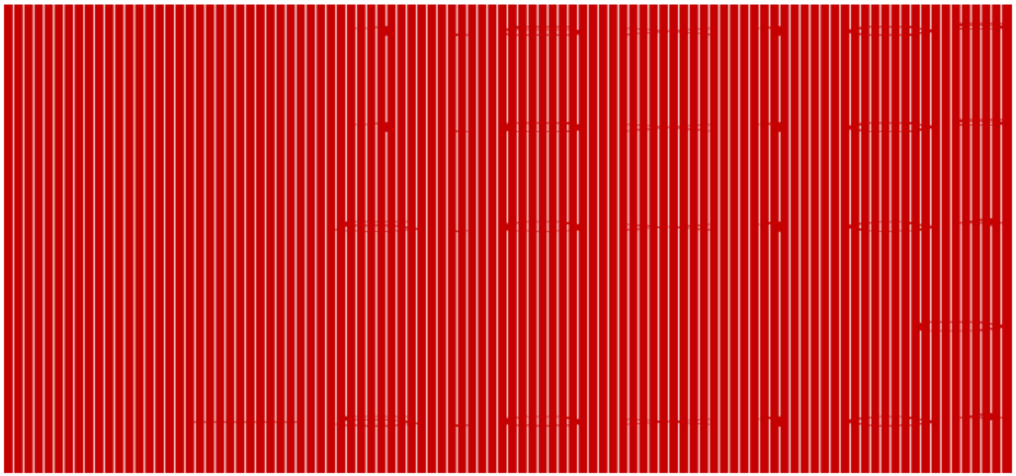
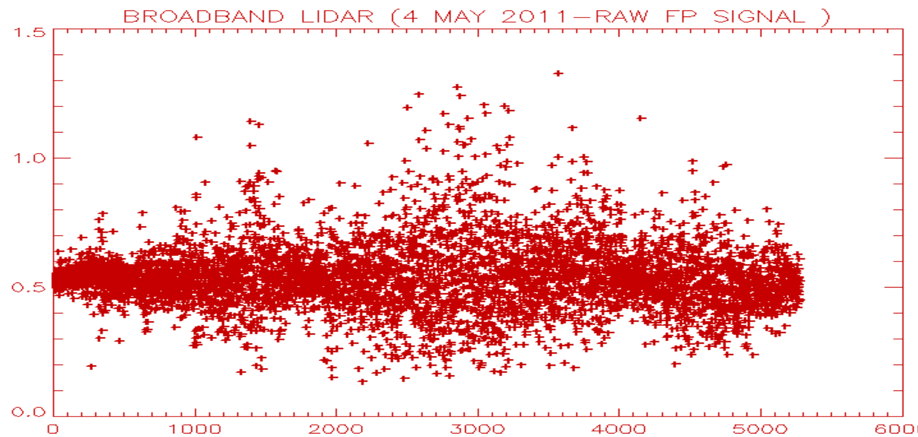
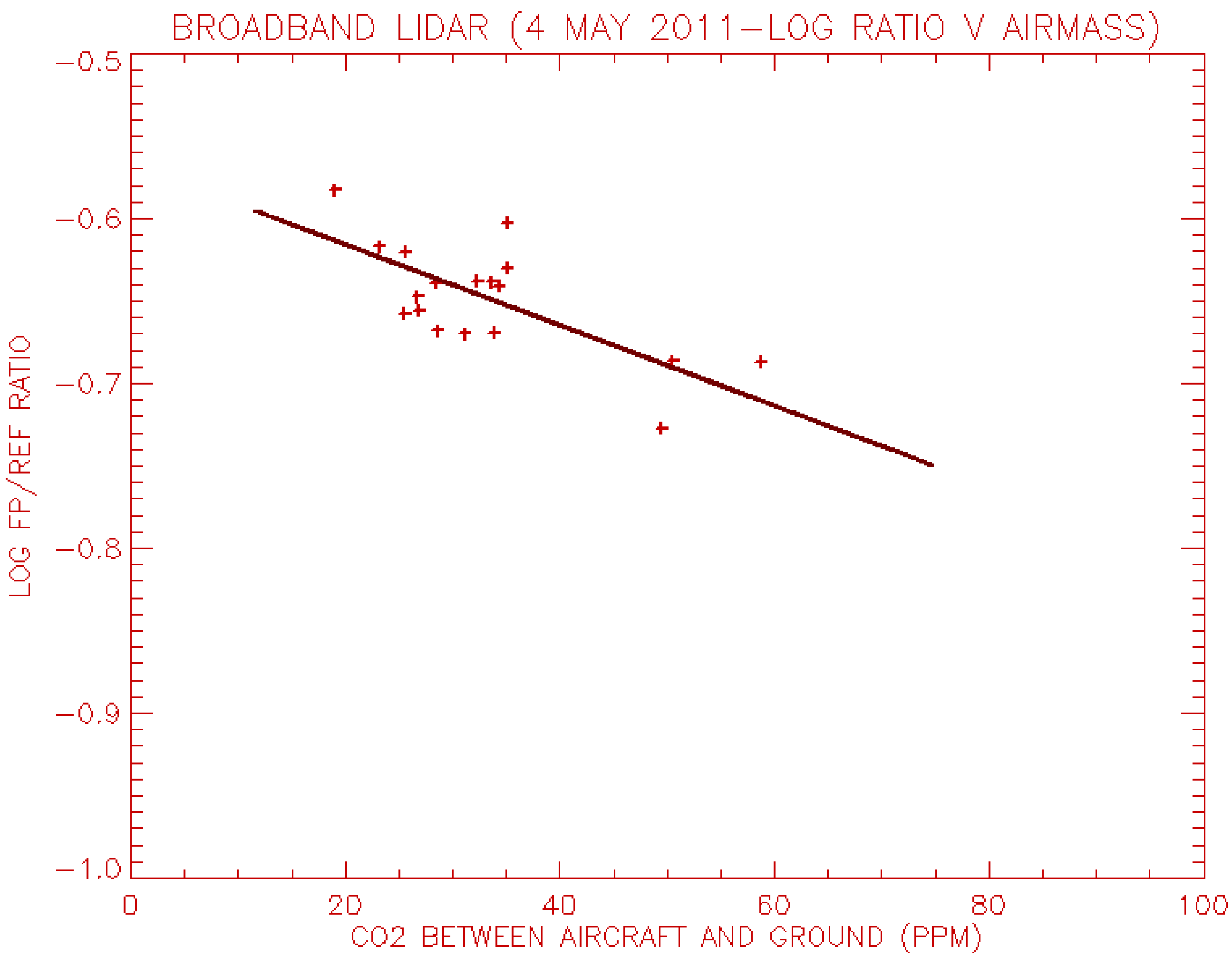
Test Flight May 4, 2011



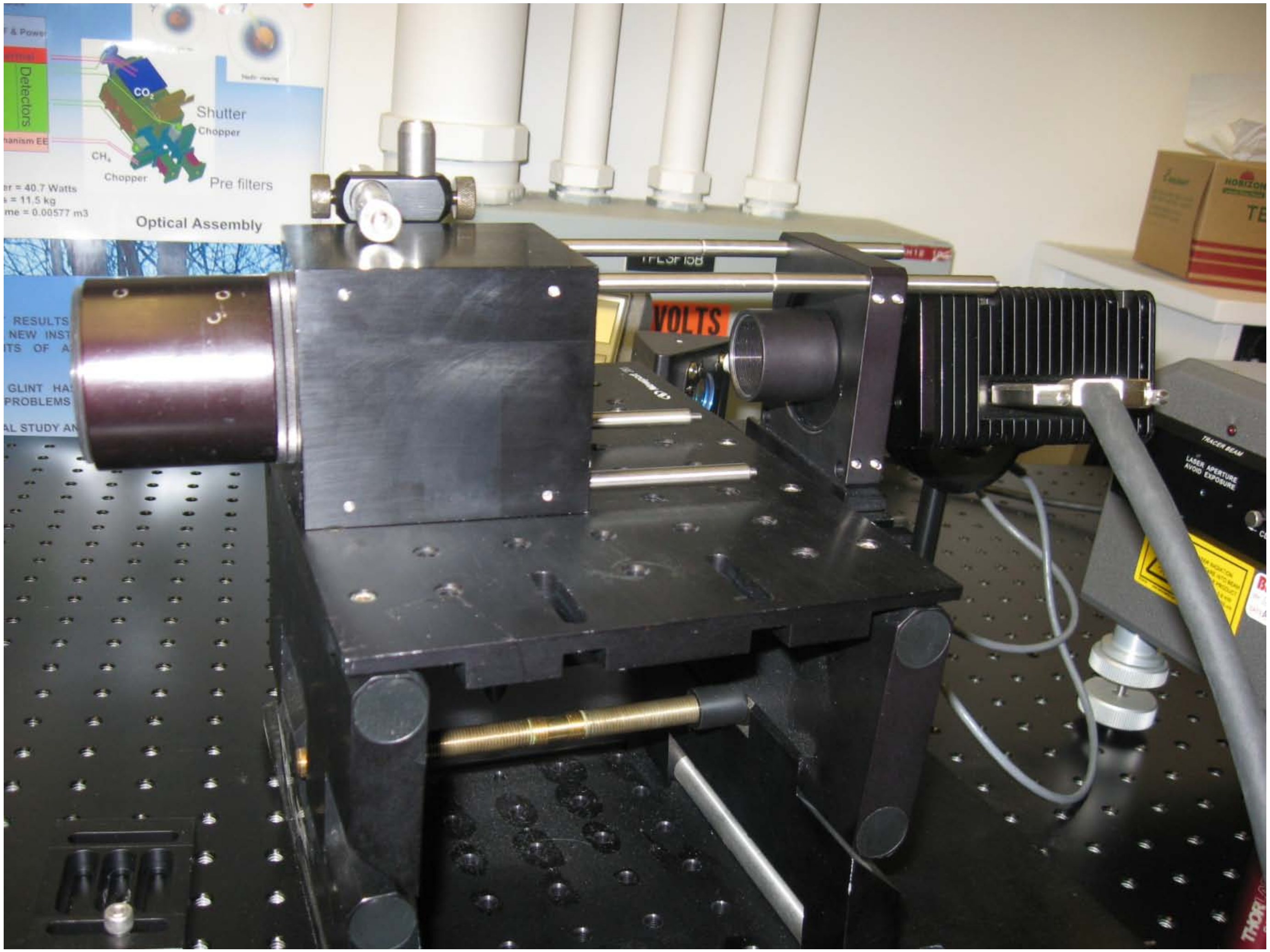


ENGINEERING TEST FLIGHT
MAY 4, 2011

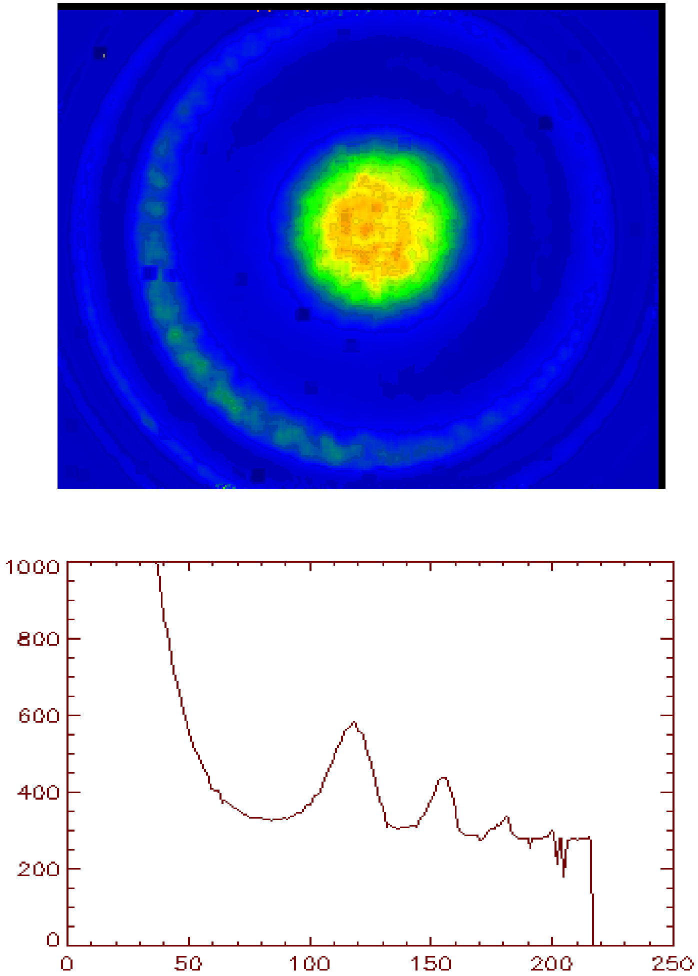


THE REAL UNKNOWN IN THE DEVELOPMENT PATH OF THE BROAD BAND LIDAR IS THE DEGREE TO WHICH FLUCTUATIONS IN THE LASER OUTPUT SPECTRUM CAN GENERATE NOISE THAT LIMITS THE PRECISION

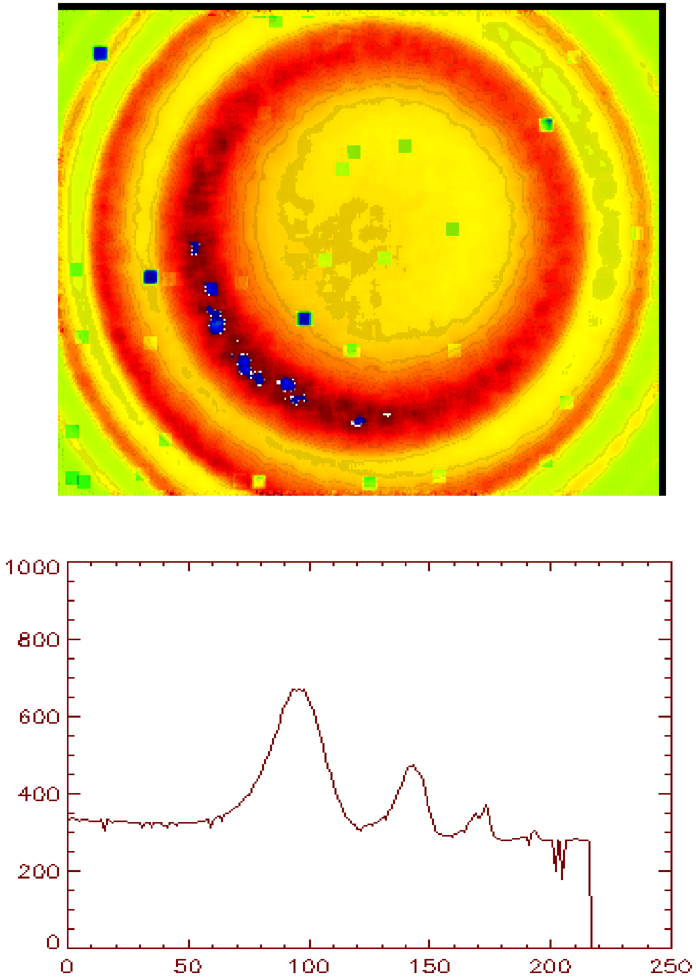
FABRY-PEROT WITH CAMERA SERVES A LASER DIAGNOSTIC TOOL



CAMERA WAVELENGTH CALIBRATION

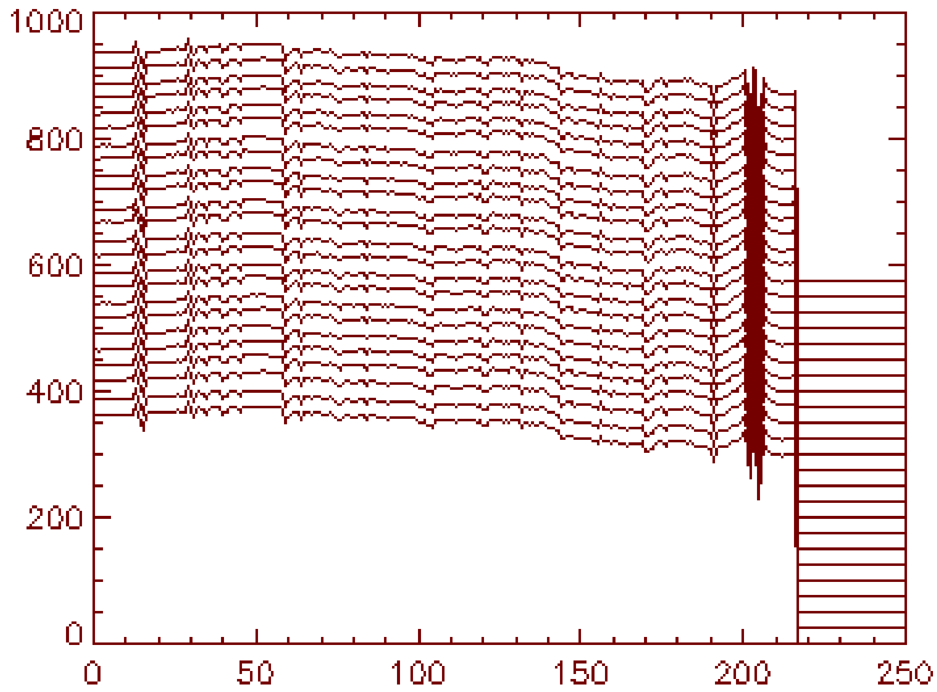


1574.0 nm



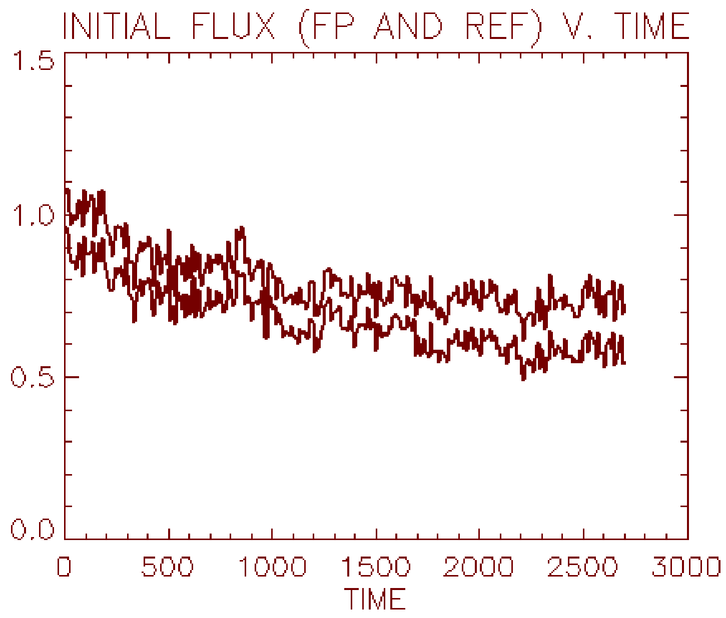
1572.5 nm

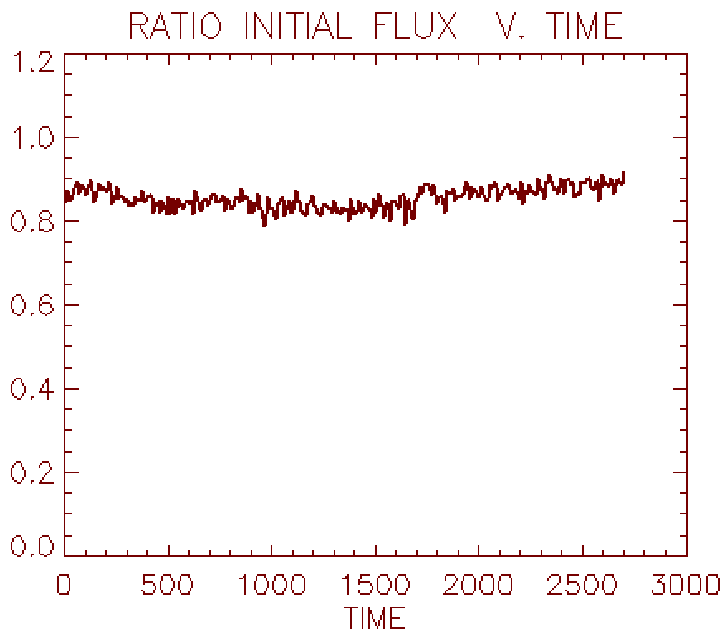
2 HOUR TEST OF LASER SPECTRUM STABILITY



VERTICAL SEPARATION OF TRACES IS ~6 MINUTES

I_0 THROUGHOUT MAY4 FLIGHT





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Conclusions

•Innovative active system using advanced source technology development– will enable daytime or nighttime measurements of column CO_2

• Directly responds to NRC DS ASCENDS mission

• Number of lasers is reduced compared to competing technologies which reduces the complexity of sensor and thus the cost and risk of failure,

• Knowledge gained from previously developed passive sensor decreases the risk and cost of the present lidar system development

•Plan to participate in lidar intercomparison flights on DC-8 next month.

• Laser power poor during first engineering test flights—at present power is ~ 30-60 times greater

• Shot to shot ratio stability 3.5% needs to be improved. Can be improved by better broadband laser source and ameliorted by improved receiver that discriminates wavelength. Funds requested from ESTO to build this receiver.

Great thanks to ESTO for their continued support in our efforts to develop a high precision sensor for the carbon dioxide column