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Pulsed Lidar for the ASCENDS Mission: Space Instrument Studies

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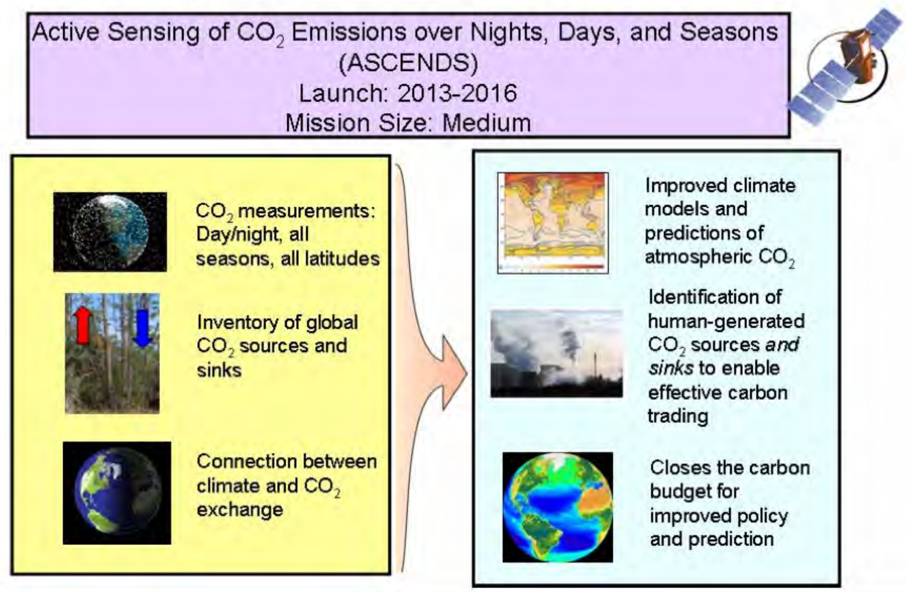
ASCENDS Mission

Why lasers ?

- Measures at night & all times of day
- Constant nadir/zenith path
  - Illumination = observation path
  - Continuous "glint" measurements over oceans
- Measurements at high latitudes
- Small measurement footprint
- Measure through broken clouds
- Measure to cloud tops
- Very high spectral resolution and accuracy

Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS)



Lidar approaches for CO2 column:

Broadband laser - 1570 nm band - λ tuned receiver

1 line - 2 um band - pulsed - direct detection

1 line - 2 um band - CW heterodyne detection

1 line - 1570 nm band - synchronous direct detection

Our approach → 1 line - 1570 nm band - pulsed direct detection

Laser Sounder Approach for ASCENDS Mission

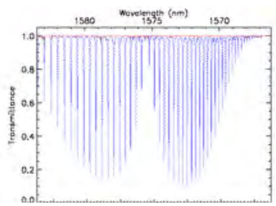
3 simultaneous laser measurements

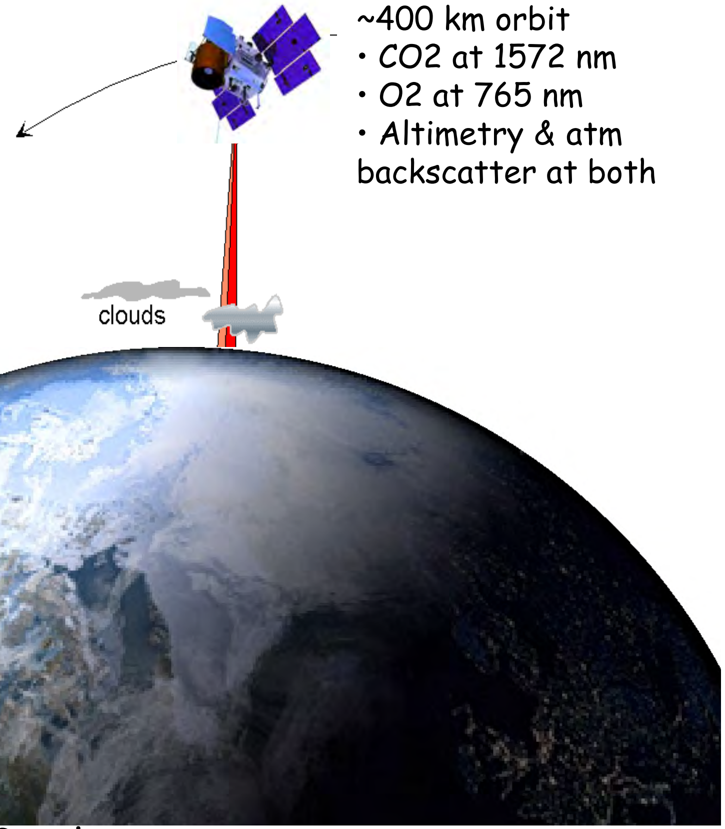
1. CO2 lower tropospheric column
   One line near 1572 nm
2. O2 total column (pressure)
   Measured between 2 lines near 765 nm
3. Altimetry & atmospheric backscatter profile from CO2 signal
   Surface height and atmospheric scattering profile at 1572 nm

Measurements use:

- Pulsed EDFA lasers
- 8 KHZ pulse rates
- ~ 8 laser wavelengths/ gas line
- Time gated Photon counting receiver

Measures:
- CO2 tropospheric column
- O2 tropospheric column
- Cloud backscattering profile

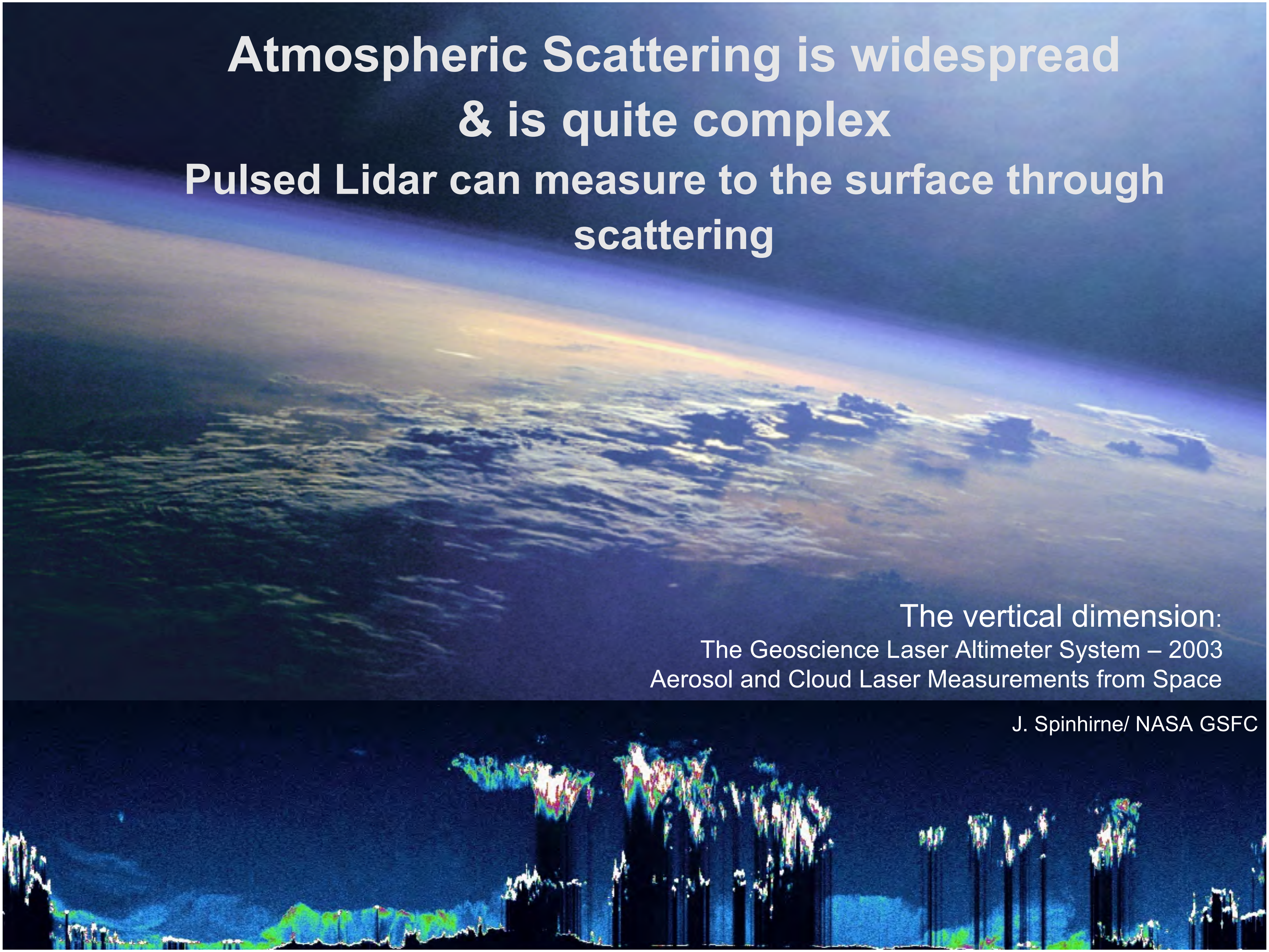




~400 km orbit
- CO2 at 1572 nm
- O2 at 765 nm
- Altimetry & atm backscatter at both

CO2 & O2 column measurements:

- Pulsed (time gated) signals :
  - Isolates full column signal from surface
  - Reduces noise from detector & solar background
- Target: ~ 1ppmV in ~100 km along track sample


Atmospheric Scattering is widespread
& is quite complex
Pulsed Lidar can measure to the surface through scattering
The vertical dimension:
The Geoscience Laser Altimeter System – 2003
Aerosol and Cloud Laser Measurements from Space
J. Spinhirne/ NASA GSFC

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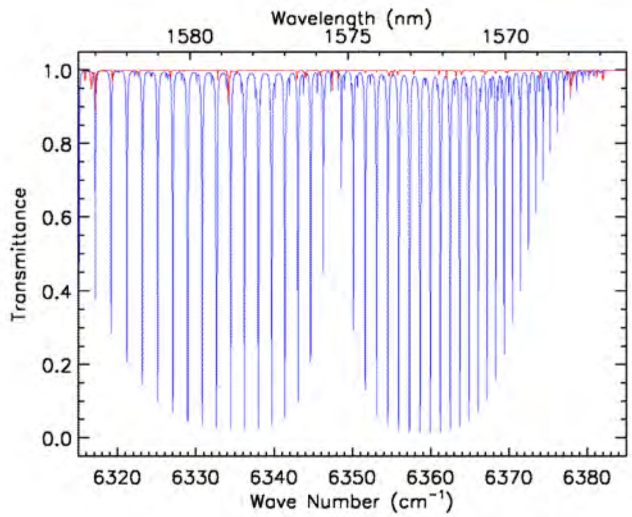
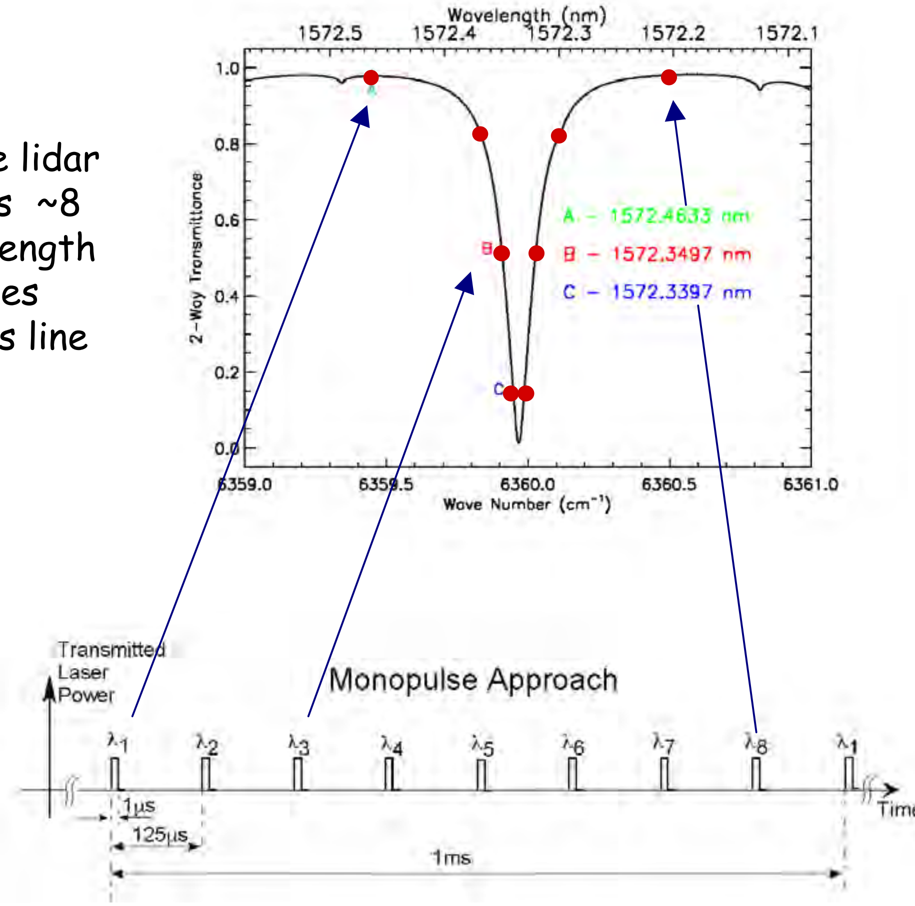
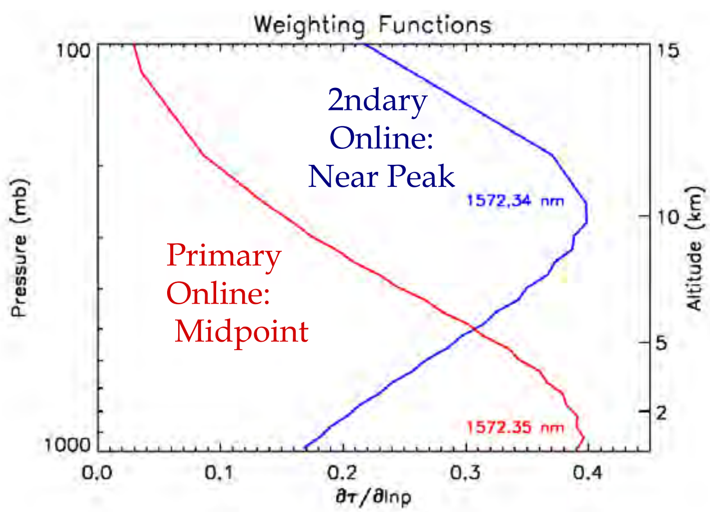
Candidate CO_2 Line, Sampling & Vertical Weighting Functions



Space lidar plan is ~8 wavelength samples across line



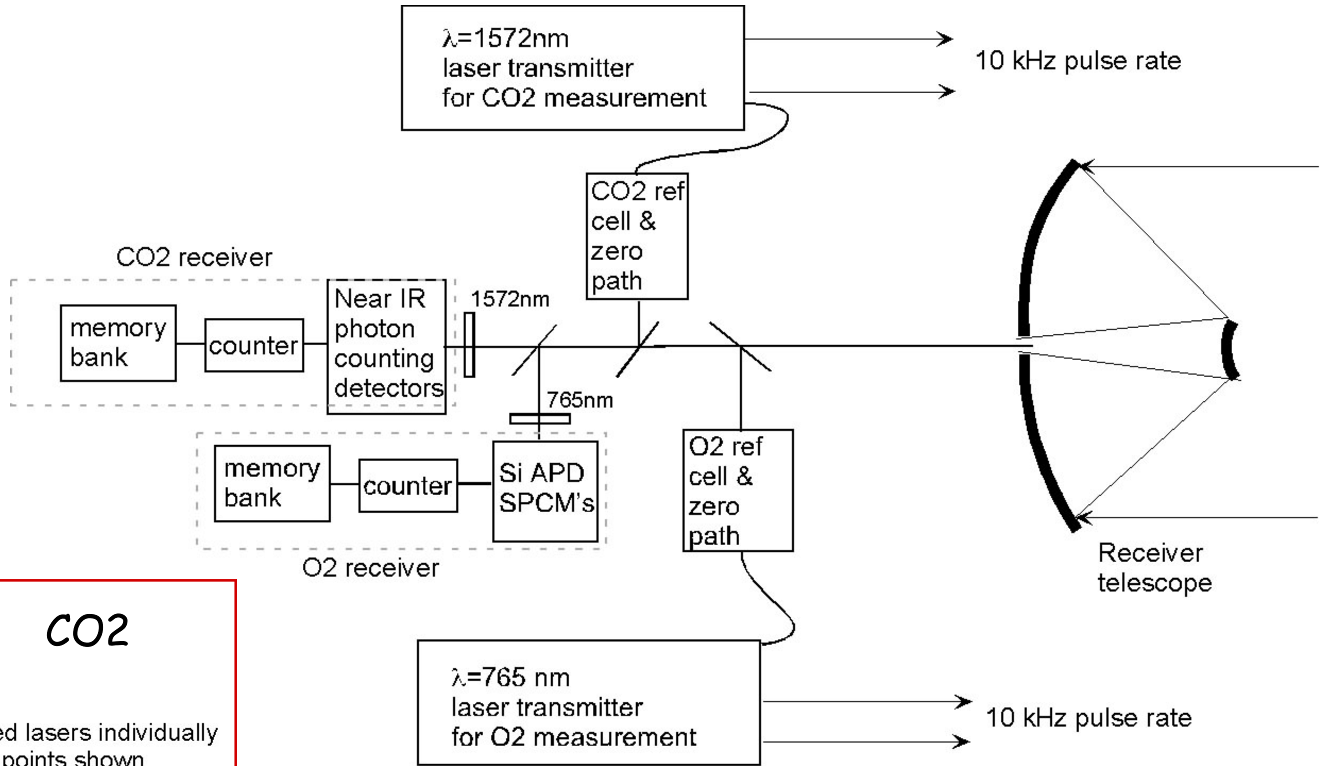


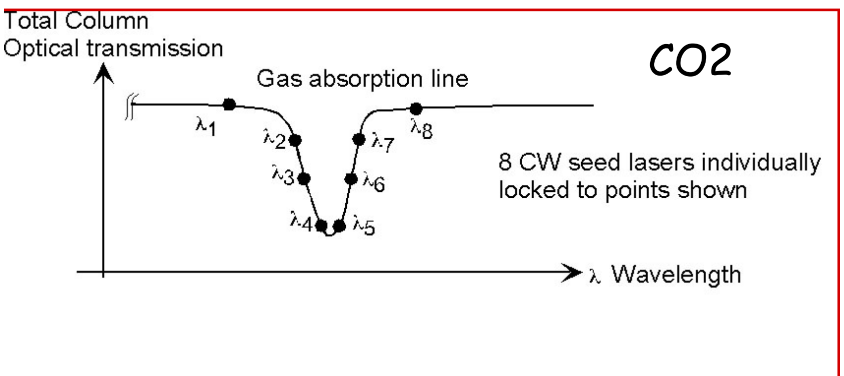
Total Column from line area

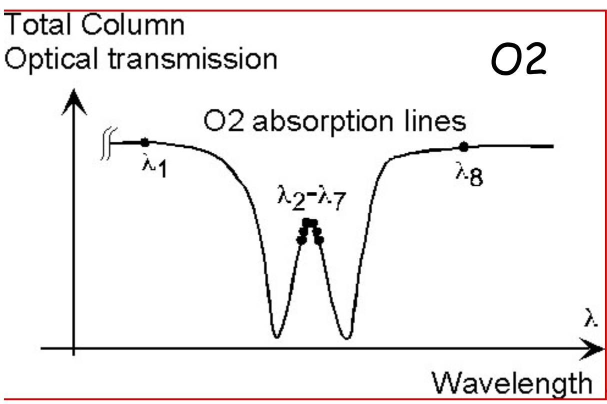
Multi-wavelength Line Sampling allows:

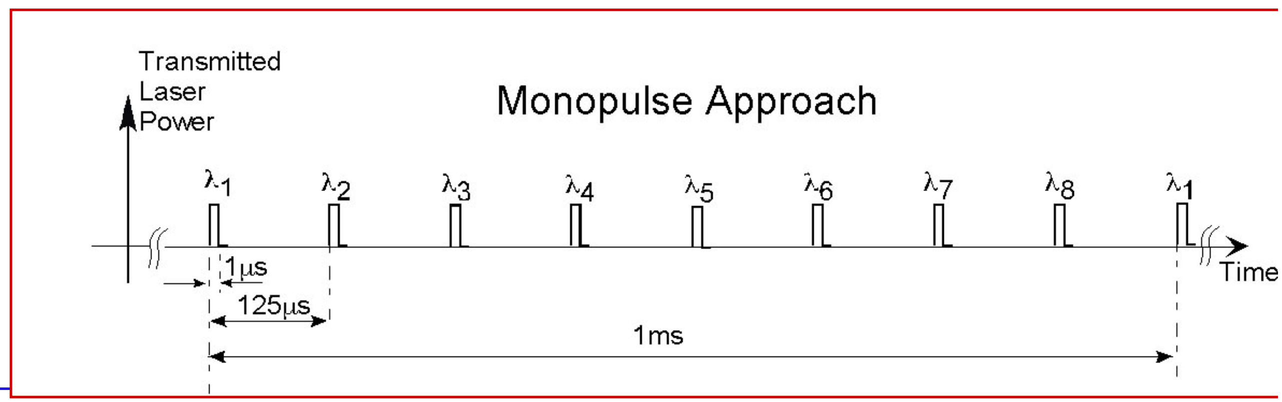
- Detection & correction of Doppler & λ errors
- Modeling -> reducing errors from varying λ response
- CO_2 retrievals for: Lower troposphere
- Total column; Line shape information

Measurement approach for Space









Space: SNR & Relative Measurement Errors

(10 seconds observing time, 500* km orbit, 1.5m telescope)

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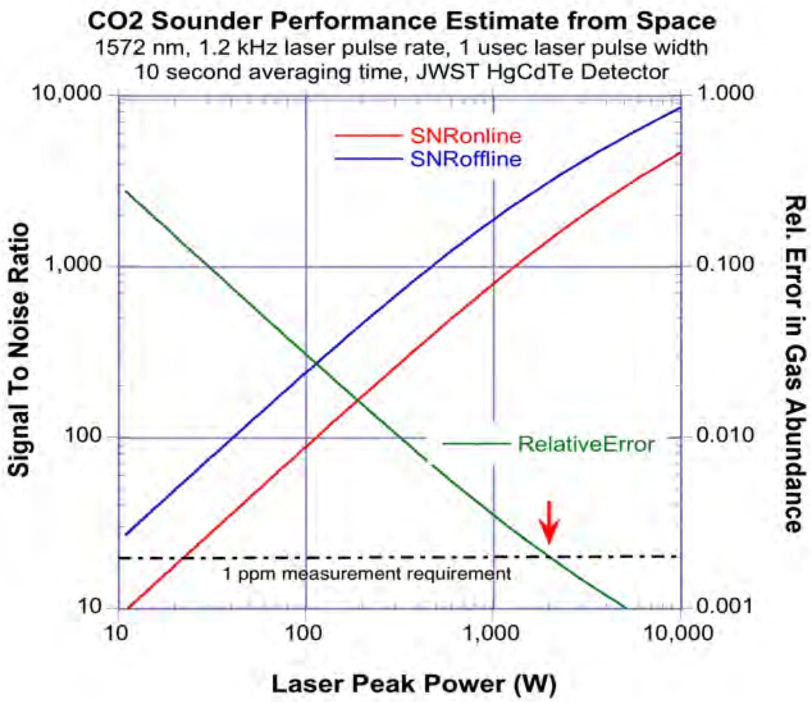
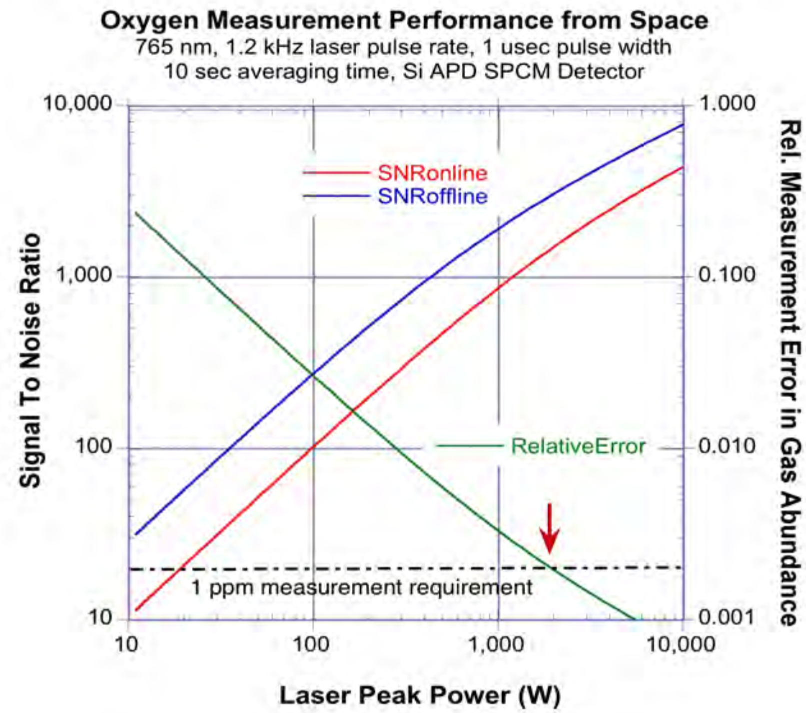
CO_2 column measurement



~ 3 mJ/pulse energy (PMT detector)

Ave optical power ~25-30W

O_2 column measurement



~ 3 mJ/pulse energy (PMT detector)

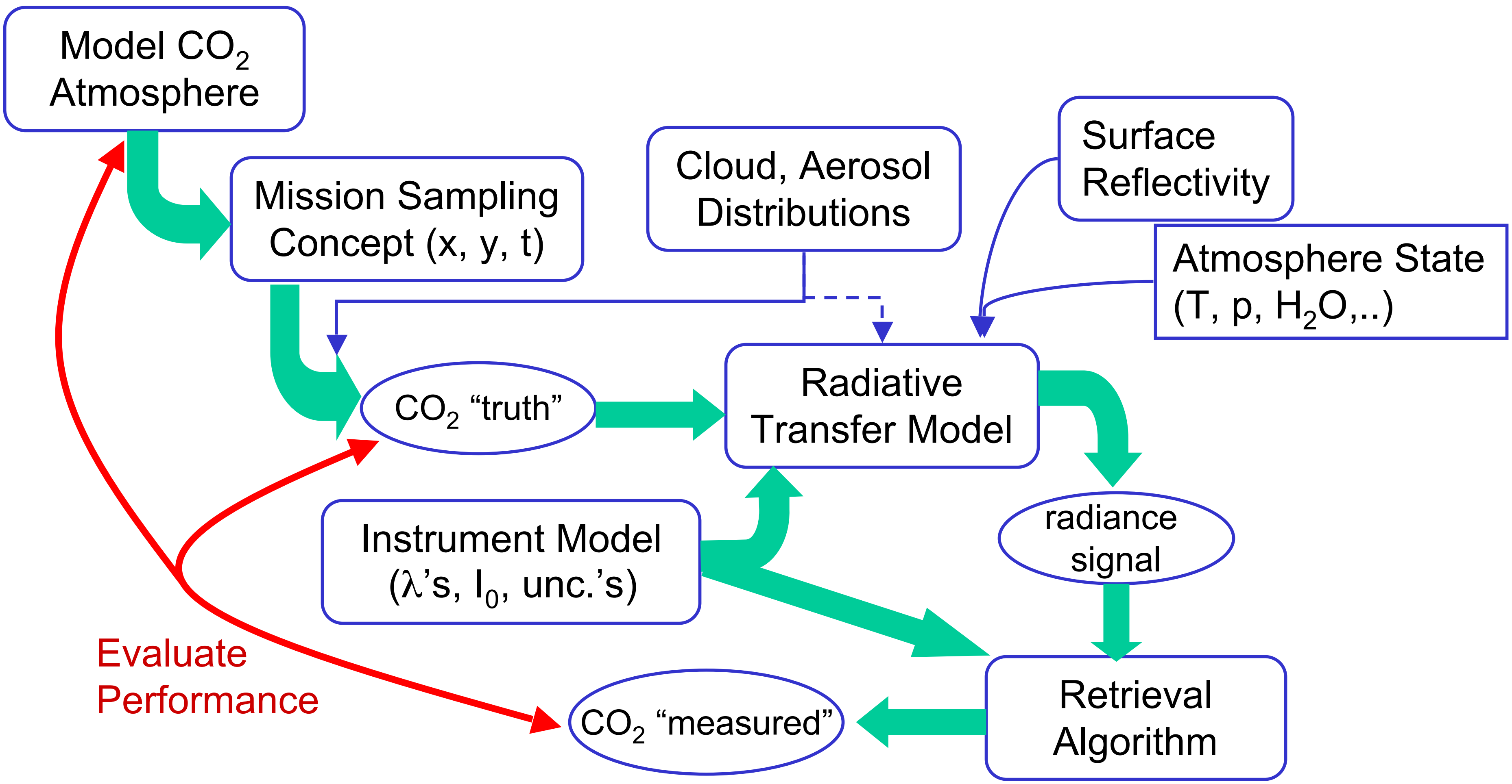
6 mJ energy from 1530 nm amp, 50% doubling

Ave optical power ~25-30 W

* - Same performance at 3 mJ/pulse with PMTs at 400 km orbit

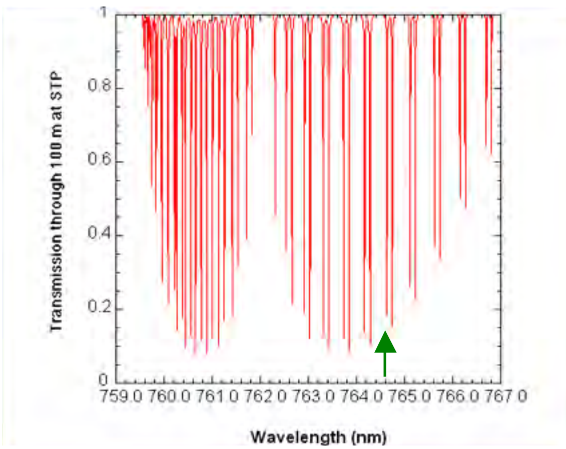
Rel Measurement Errors scale as (laser pulse energy)$^{-1}$*(T)$^{-1/2}$

Measurement Model used in Mission Performance Simulation (Randy Kawa)



➔ **Test sensitivity of inferred CO_2 distributions to varying mission and instrument design parameters.**

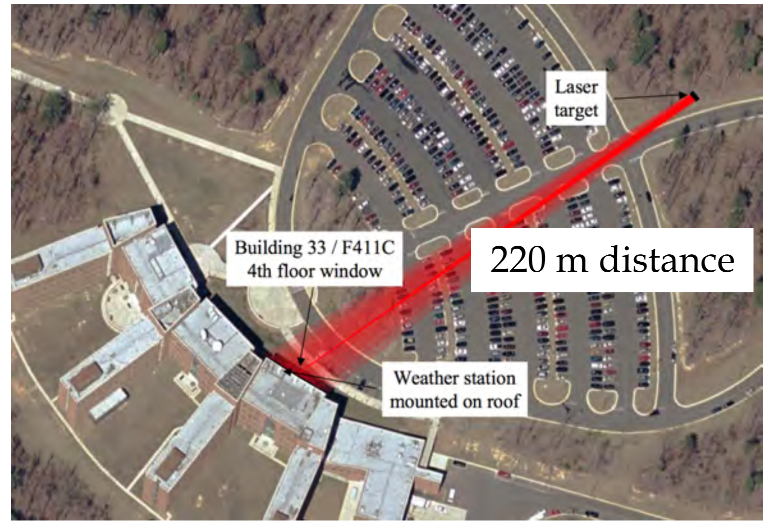
Oxygen - Open path measurement of absorption lines near 765 nm (M. Stephen)

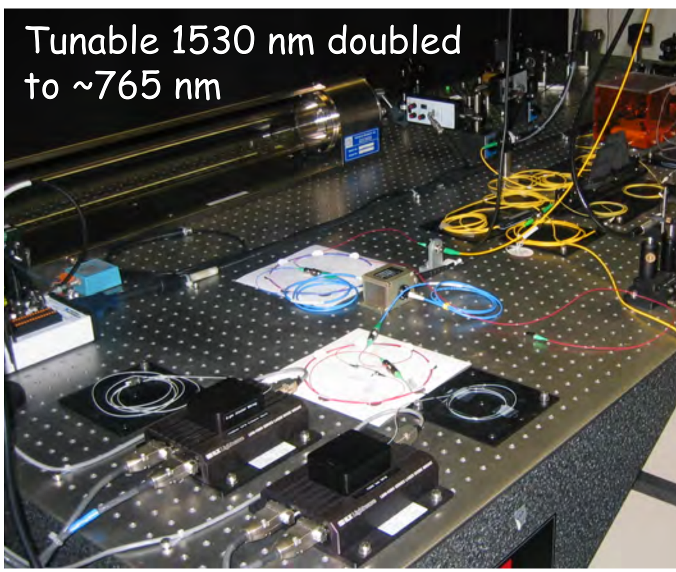


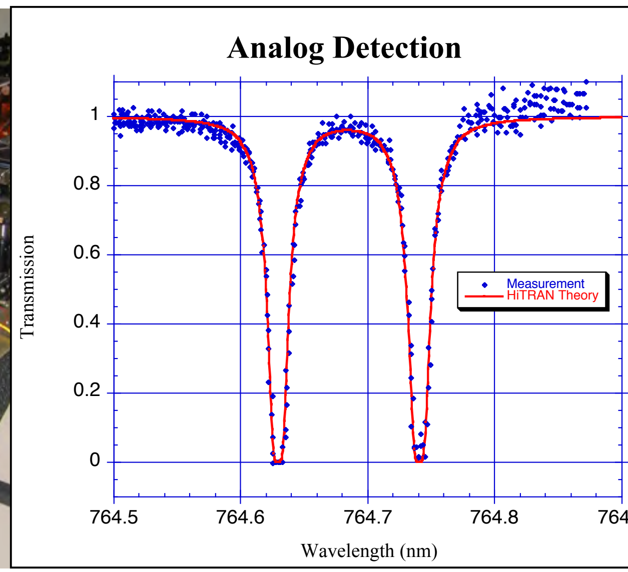
Oxygen A band: Calculated atmospheric transmission for 100 m path at STP

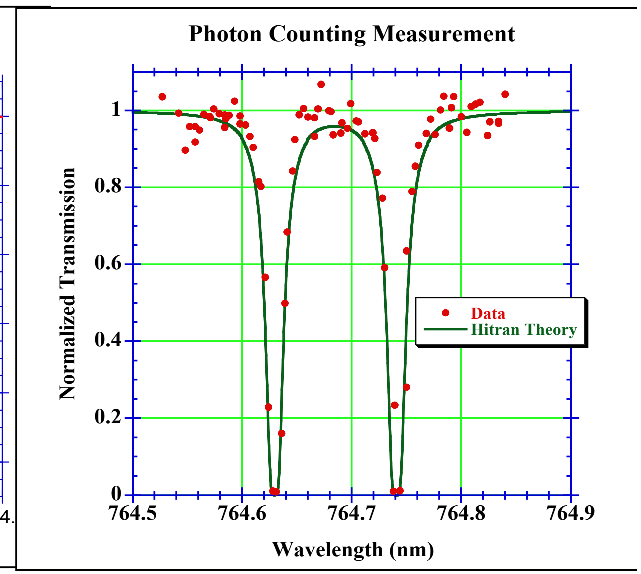
Telescope viewing target

Peak optical power ~ 50 mW
Attenuation for round trip was ~10^6



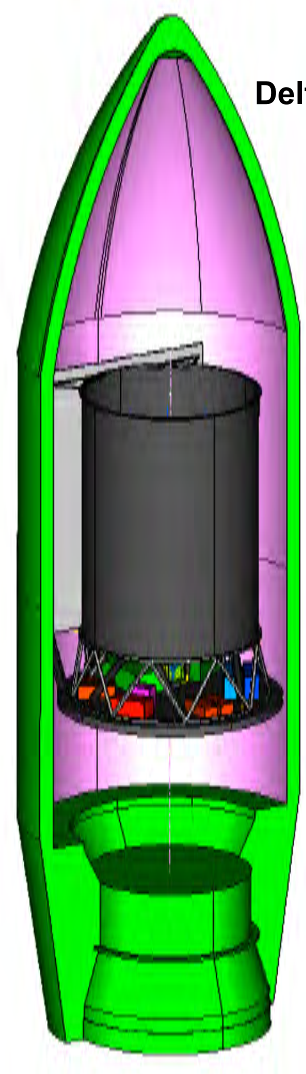




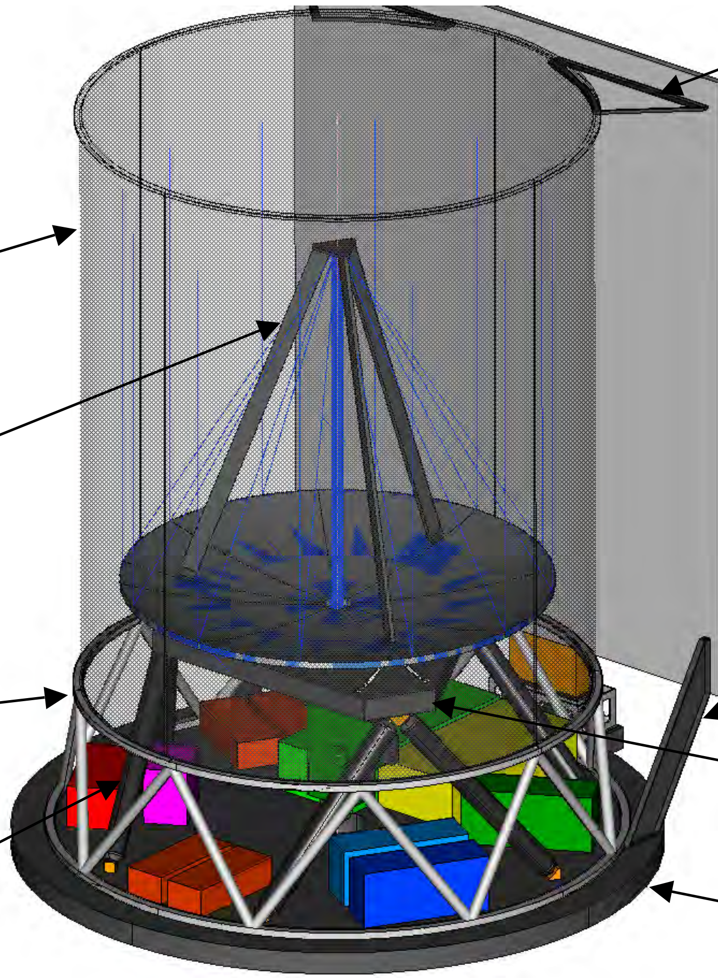


Initial Space Instrument Study

- Sun synchronous orbit
  - Altitude 500 km
  - Sun-sync inclination, 1:30 pm crossing time
- Mission Risk Class B
  - 5 year mission life
  - 85% mission reliability
  - Mitigate single point failures with redundancy or high reliability parts
- Traditional S/C bus orbit and attitude knowledge sufficient for mission requirements (i.e., no on-instrument attitude processing required)

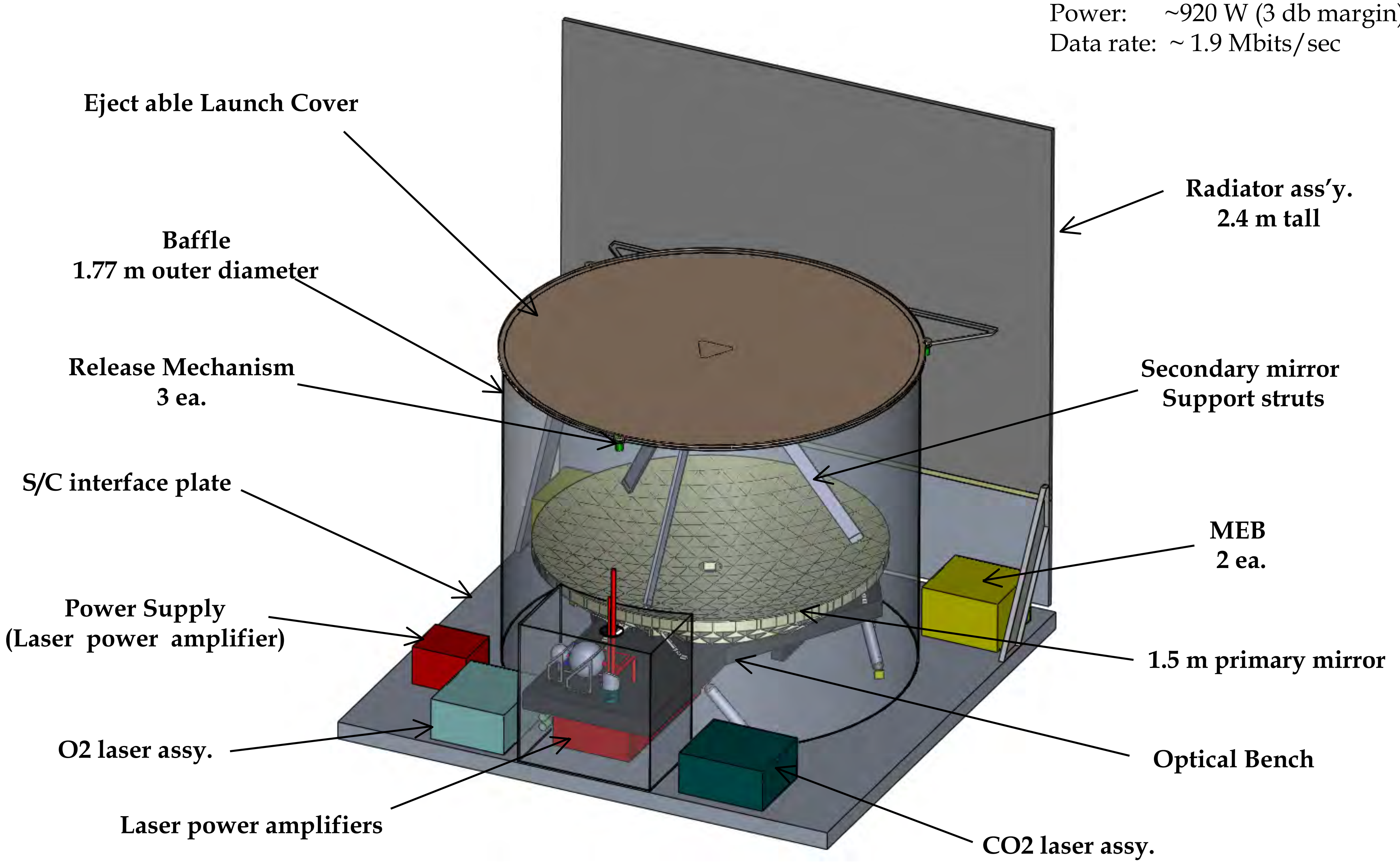


Initial Concept Layout for Lidar (telescope diameter = 1.5 m)

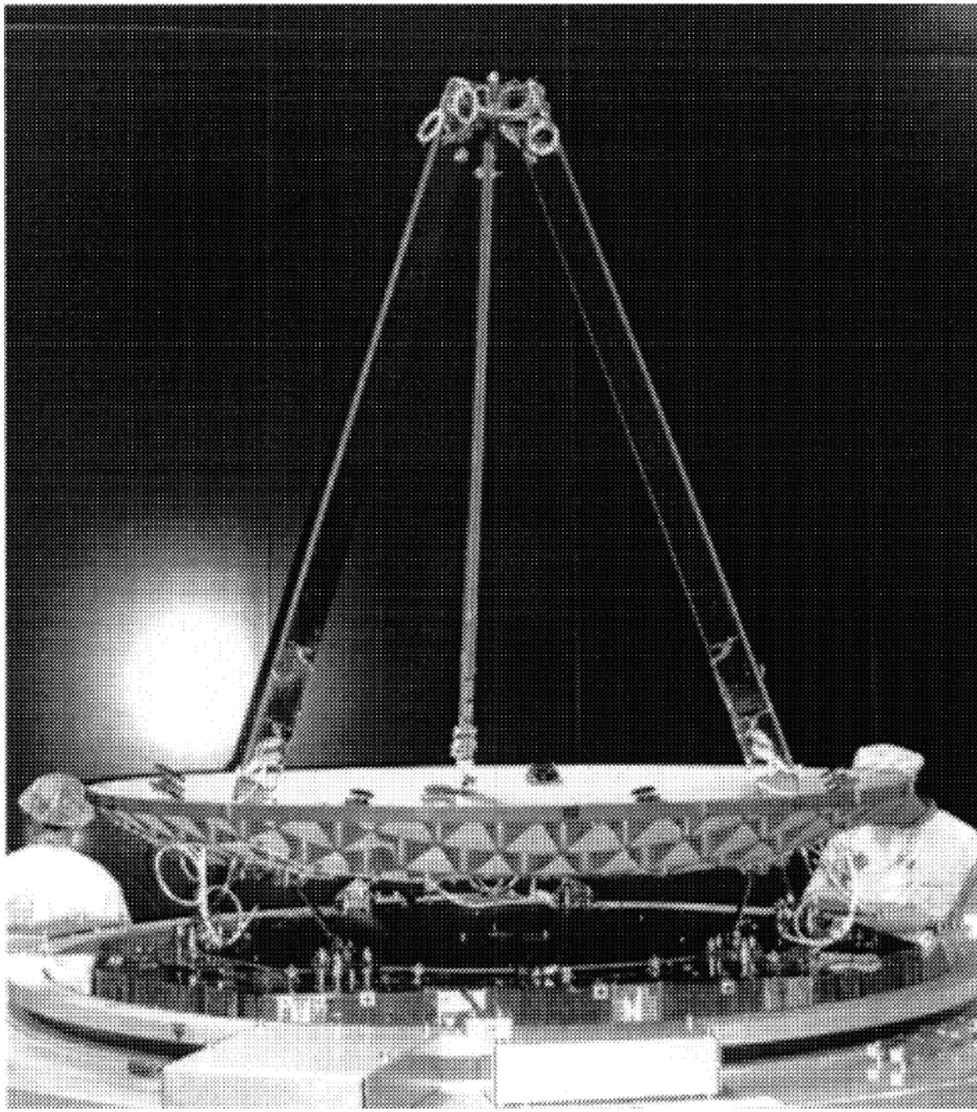


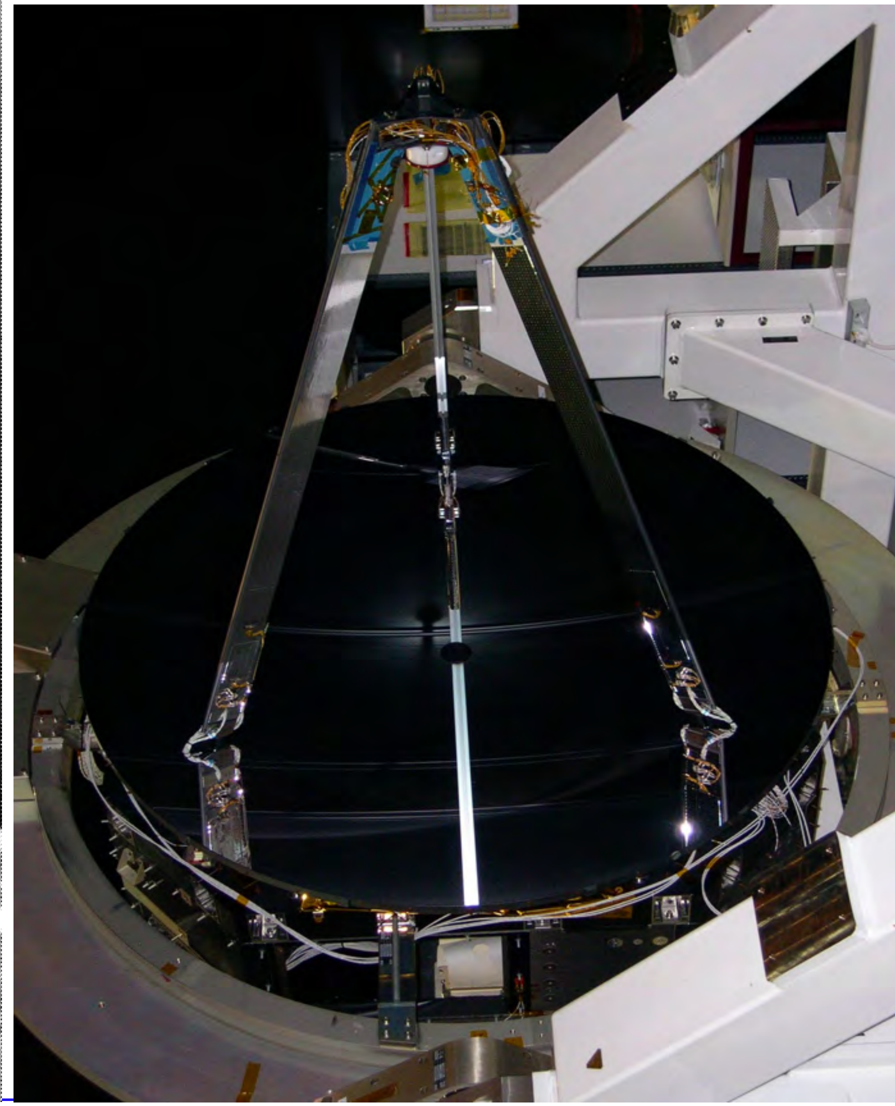
Second Study: ASCENDS LidarConfiguration (layout not optimized)

Mass: ~420 kg
Power: ~920 W (3 db margin)
Data rate: ~ 1.9 Mbits/sec



ESA ALADIN 1.5 m Receiver Telescope





CO_2 Receiver - Photon Counting Detectors

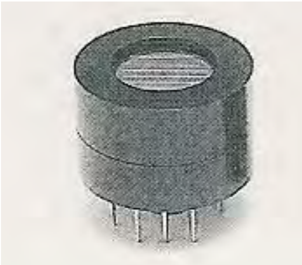
HV supply and PMT housing

Now:

Hamamatsu H9170-75 PMT

-Detector used in airborne receiver

- Turn-key operation
- QE = 2-16% at 1570nm
- InP/InGaAs photocathode
- Photocathode: ~5 mm diameter
- Dark count rate ~200 KHz at -80 C (TEC cooled)
- PMT power consumption ~150mW



TO-8 PMT package with transmissive photocathode

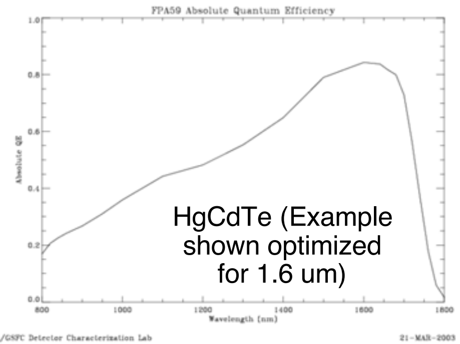
Under Development:

Adapting HgCdTe Photon Counting Detectors

The Infrared Detectors for the Wide Field Camera 3 on HST

ABSTRACT

We present the performance of the IR detectors developed for the WFC3 project. These are HgCdTe 1K×1K devices with cutoff wavelength at 1.7μm and 150K operating temperature. The two selected flight parts, FPA#64 (prime) and FPA#59 (spare) show quantum efficiency higher than 80% at λ=1.6μm and greater than 40% at λ>1.1μm, readout noise of ~25 e⁻ rms with double correlated sampling, and mean dark current of ~0.04 e/s/pix at 150K. We also report the results obtained at NASA GSFC/DCL on these and other similar devices in what concerns the QE long-term stability, intra-pixel response, and dark current variation following illumination or reset.



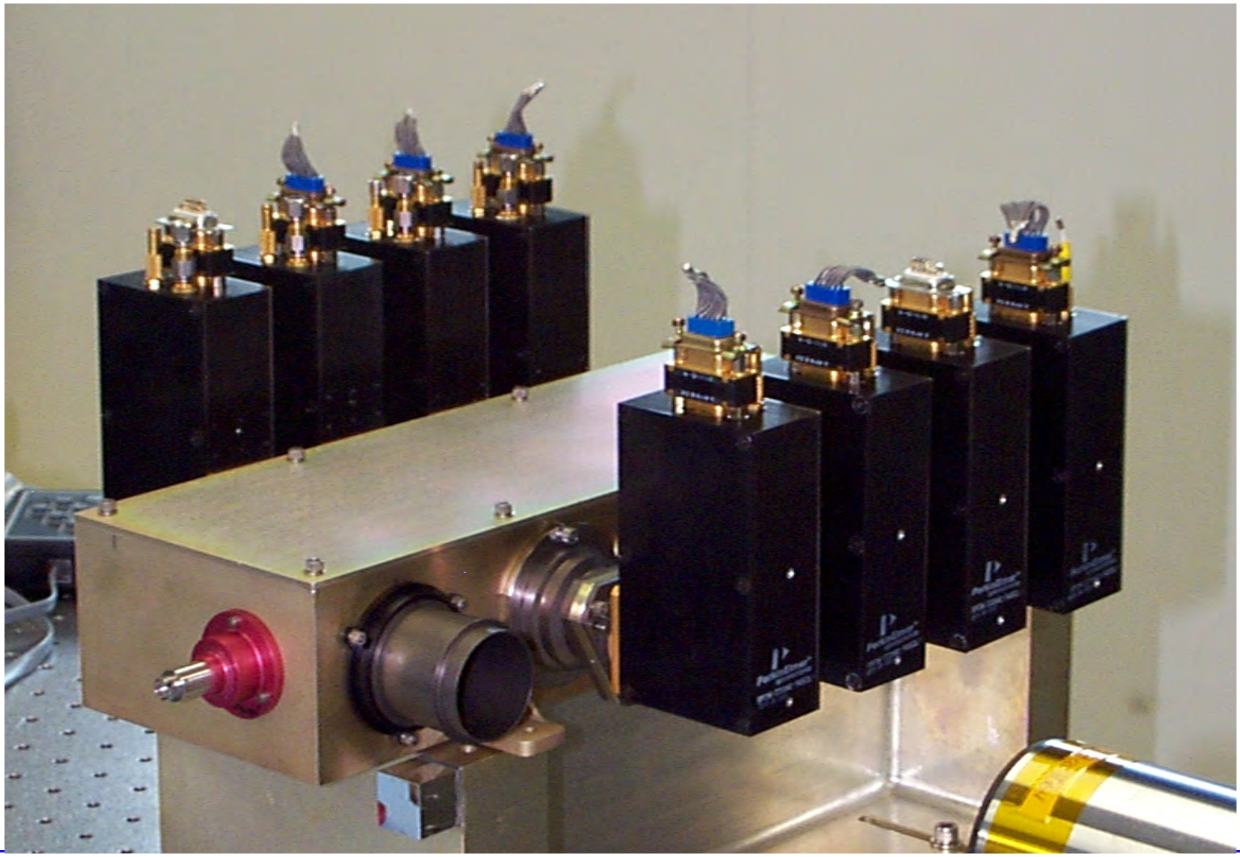
80% photon detection/accumulation efficiency at 1550 nm with ~0.04 dark counts/sec at 150K

Present read-out configured for photon accumulation

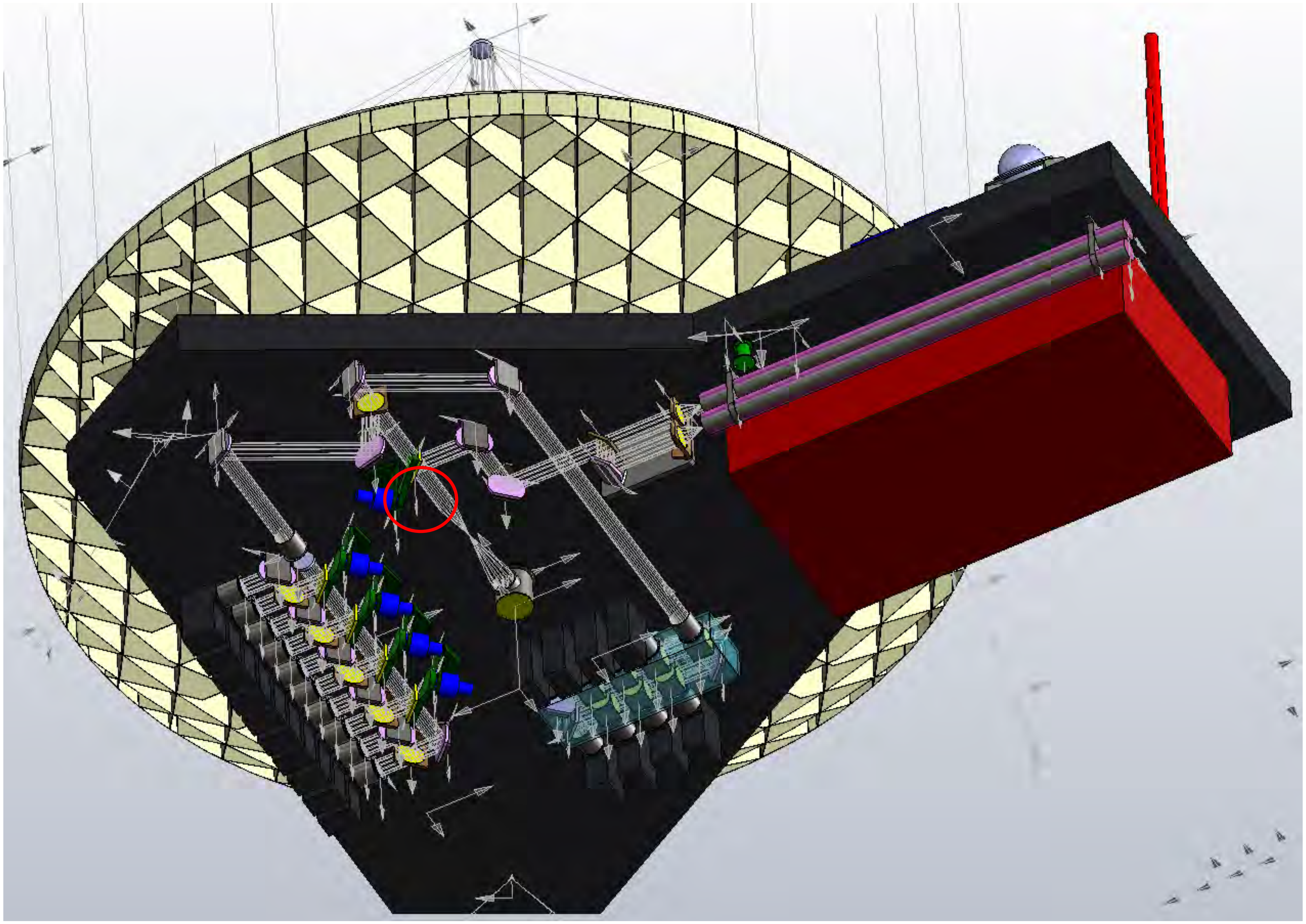
O2 Channel Detectors:
Ones used for 532 nm channel of ICESat/GLAS Lidar

O2 Channel Detectors

- SCPM Detectors (8 each) From Perkin Elmer
- ~70% QE (765 nm) Now TRL=9
- Successfully improved & up-screened commercial units for GLAS/ICESat
- Advantages: High Sensitivity High TRL



2nd study - Aft view of optical bench



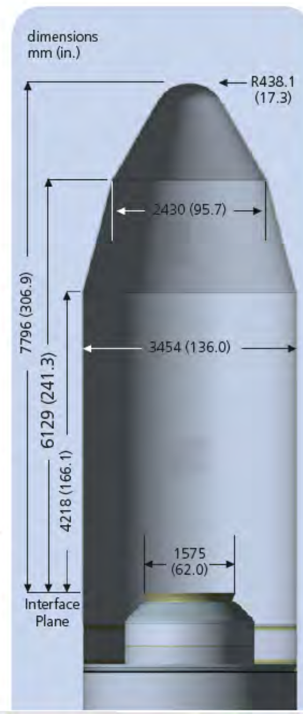
2nd ASCENDS Lidar Study: Two candidate rockets
(both have considerable excess lift capacity)

Space-X Falcon 9

Quarter section of the 5.2 m Falcon 9 fairing at SpaceX's Hawthorne, CA headquarters.

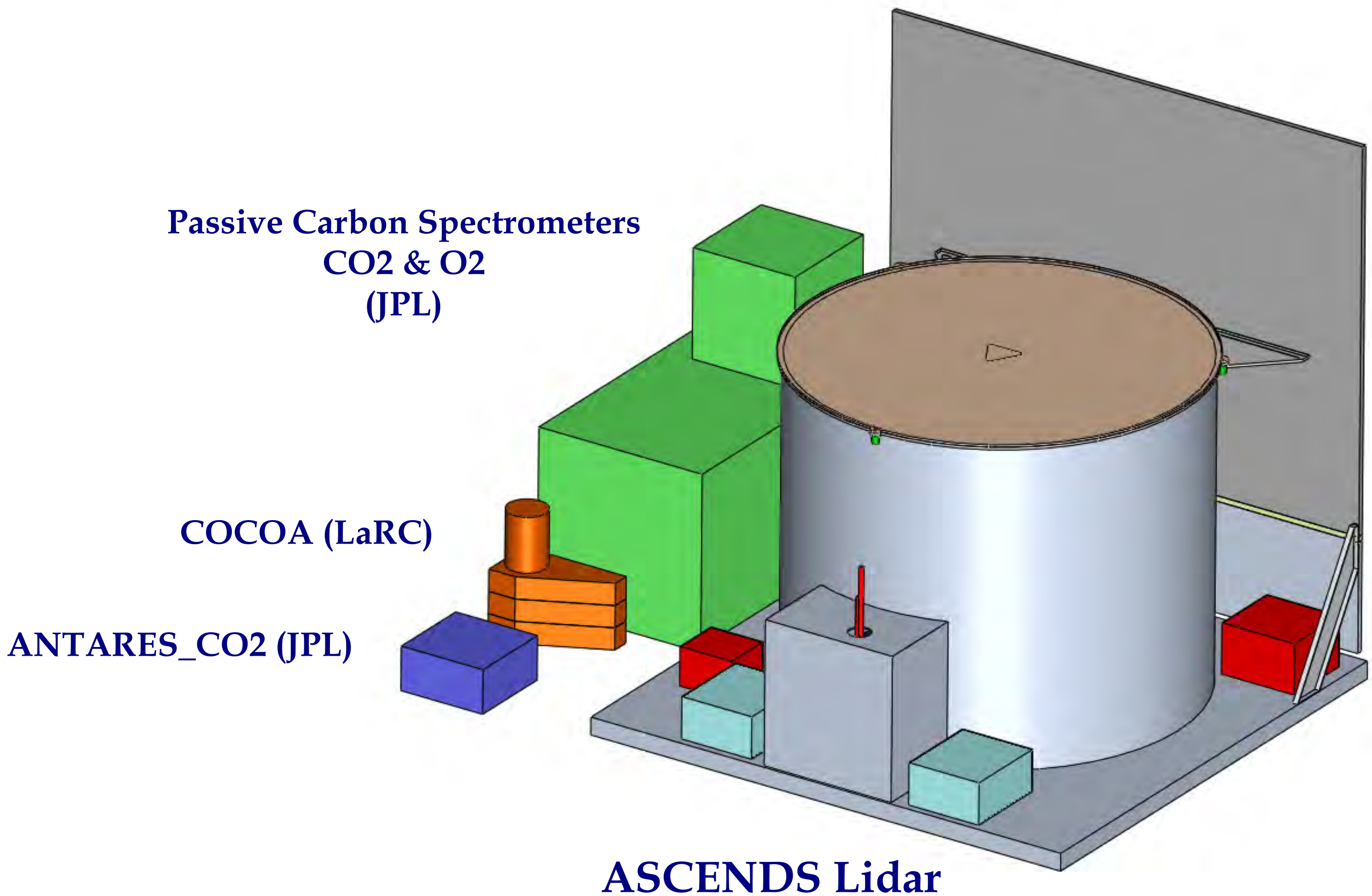
Ascends Observatory (lidar + spacecraft + fuel) needs only ~1/4 lift capacity

Falcon 9 Engines Close Up

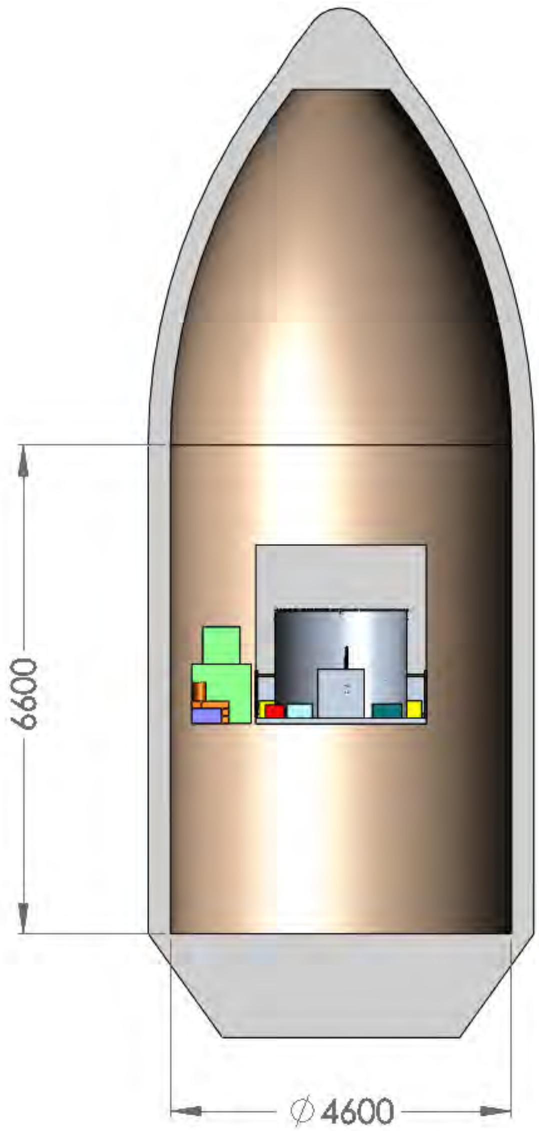


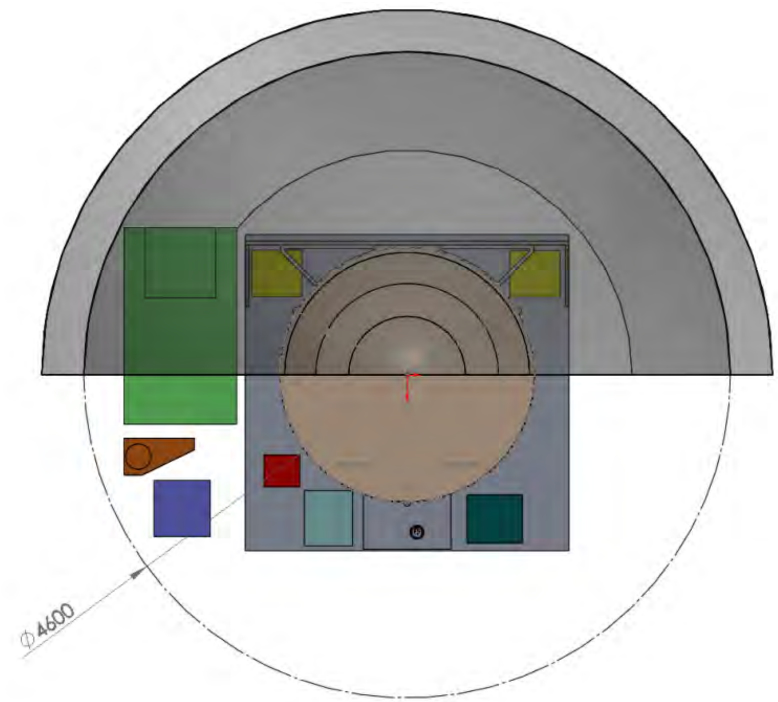
Ascends Observatory needs ~1/2 capacity

2nd Study: ASCENDS lidar and some candidate passive spectrometers



ASCENDS Lidar & 3 Spectrometers in a Falcon 9 Faring





ASCENDS Space Lidar Studies - Summary

- Conducted two studies of this approach for ASCENDS space lidar in 4/08 and 9/09
- Measures CO_2 & O_2 via pulsed direct detection from ~ 400 km, sun-sync 1:30 pm orbit
- Straightforward space lidar design:
  - Mass: ~ 420 Kg (can be reduced via more efficient layout)
  - Power: ~ 800 - 920W (3dB margin); driven by SNR needs, detector choice
  - Data rate: ~1.9 Mbit/sec - Ok for use of high latitude comm. ground site
  - Size - driven by receiver telescope diameter and radiators needed for lasers
- Low risk: use of space qualified telescope, O_2 detectors, thermal system
- Primary power draw & thermal source: laser subassemblies
- Laser architecture -> high efficiency & reliability, switchable cold spares
- Detectors -> reliability via use of multiple detectors & switchable spares.
- Several aspects can be optimized in follow on studies