# Laser Sounder for the ASCENDS Mission: Initial Space Instrument Study


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Poster presentation at:
NASA Carbon and Ecosystems Workshop

April 28, 2008



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# Abstract



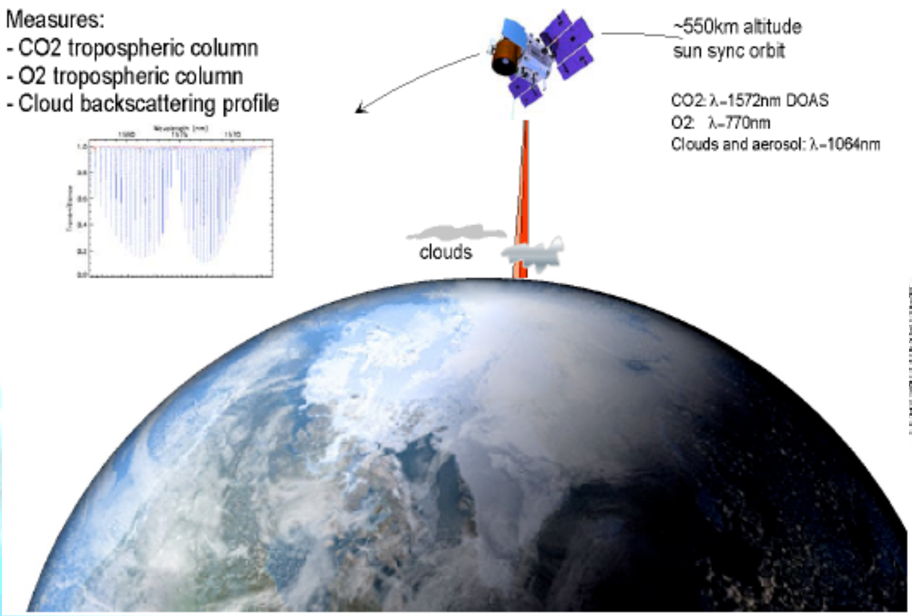
Our group is developing the laser sounder approach to measure tropospheric CO2 concentrations from space for the ASCENDS Mission. This work is ongoing and has been supported by the NASA ESTO ACT and IIP programs.

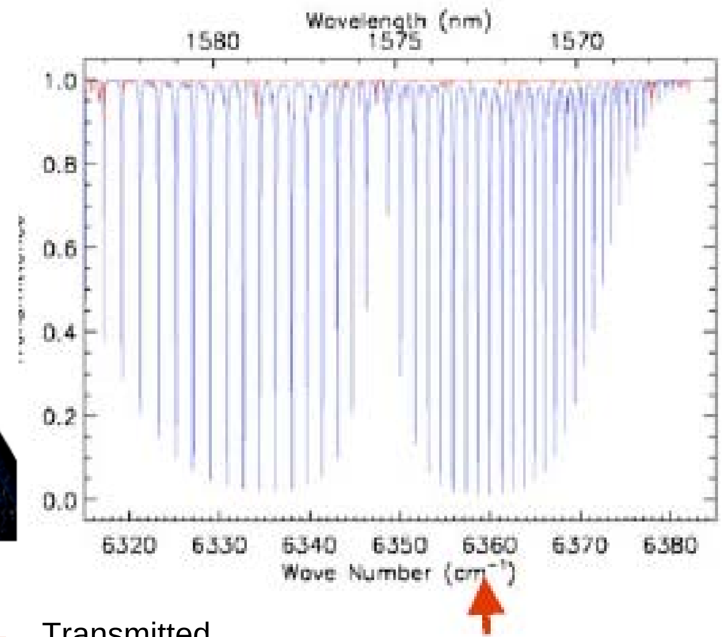
The laser sounder approach uses the 1570-nm CO2 band and a pulsed dual channel laser absorption spectrometer. This uses differential lidar absorption measurement in an altimeter mode, and continuously measures at nadir from a near-polar circular orbit. It uses several tunable fiber laser transmitters allowing simultaneous measurement of the absorption from a CO2 absorption line in the 1570 nm band, O2 extinction in the oxygen A-band, as well as surface height and aerosol backscatter in the same measurement path. It directs the narrow co-aligned laser beams toward nadir, and measures the energy of the pulsed laser echoes reflected from land and water surfaces. During the measurement, the lasers are tuned across a selected CO2 line and a region between two O2 lines near 765 nm. The lasers have spectral widths much narrower than the gas absorption lines and are wavelength tuned at kHz rates. The receiver uses a telescope and photon counting detectors, and measures the background light and energies of the laser echoes from the surface, along with scattering from any clouds and aerosols in the path. The gas extinction and column densities for the CO2 and O2 gases are estimated from the ratios of the on and off line signals. We use pulsed laser signals and time gating to isolate the laser echo signals from the surface, and to reject photons scattered from thin clouds and aerosols in the path, which can otherwise bias retrievals.

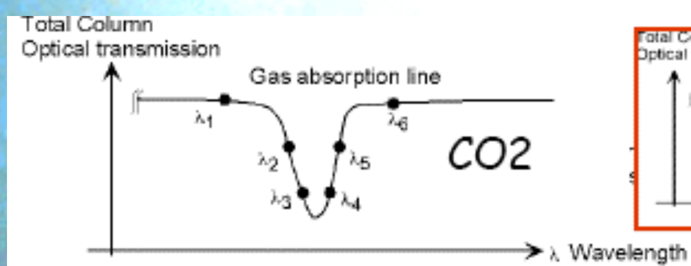
We have recently completed an initial design study for the space instrument. For the study, we selected a nominal sun-synchronous orbit with an altitude of 500 km and equator crossing time of 1:30 pm, and a receiver telescope with 1.5 m diameter. Some highlights are shown.

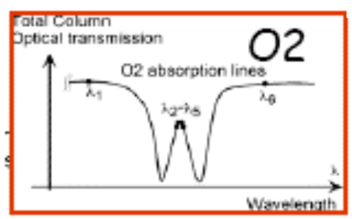
# Measurement Approach





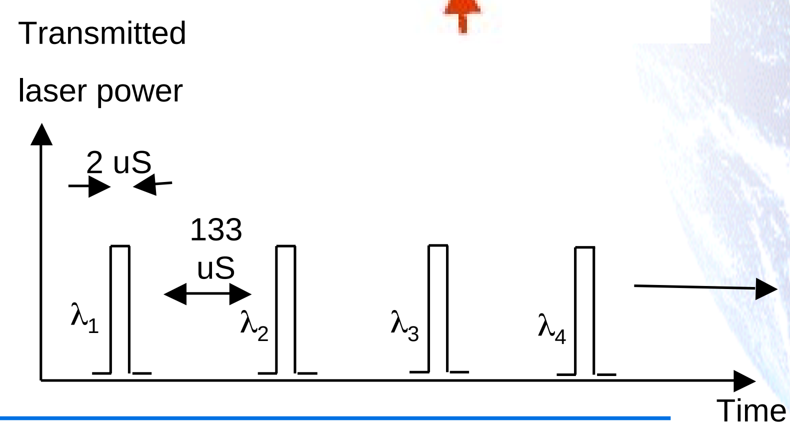




1572 nm for CO2

765 nm for CO2

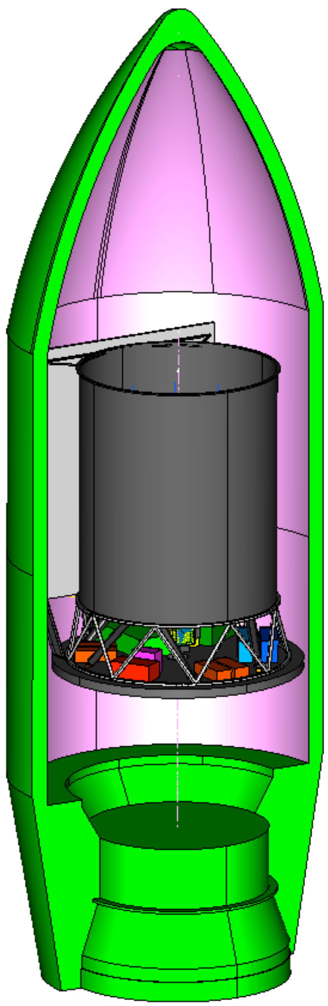
Frequency doubled from 1530



# Assumed Mission Parameters & a Concept Layout



- Sun synchronous orbit
  - Altitude 500 km
  - 97 degree inclination
- Mission Risk Class B
  - 5 year mission life
  - 85% mission reliability
  - Mitigate all non-mechanical single point failures with either 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)



Delta II Fairing

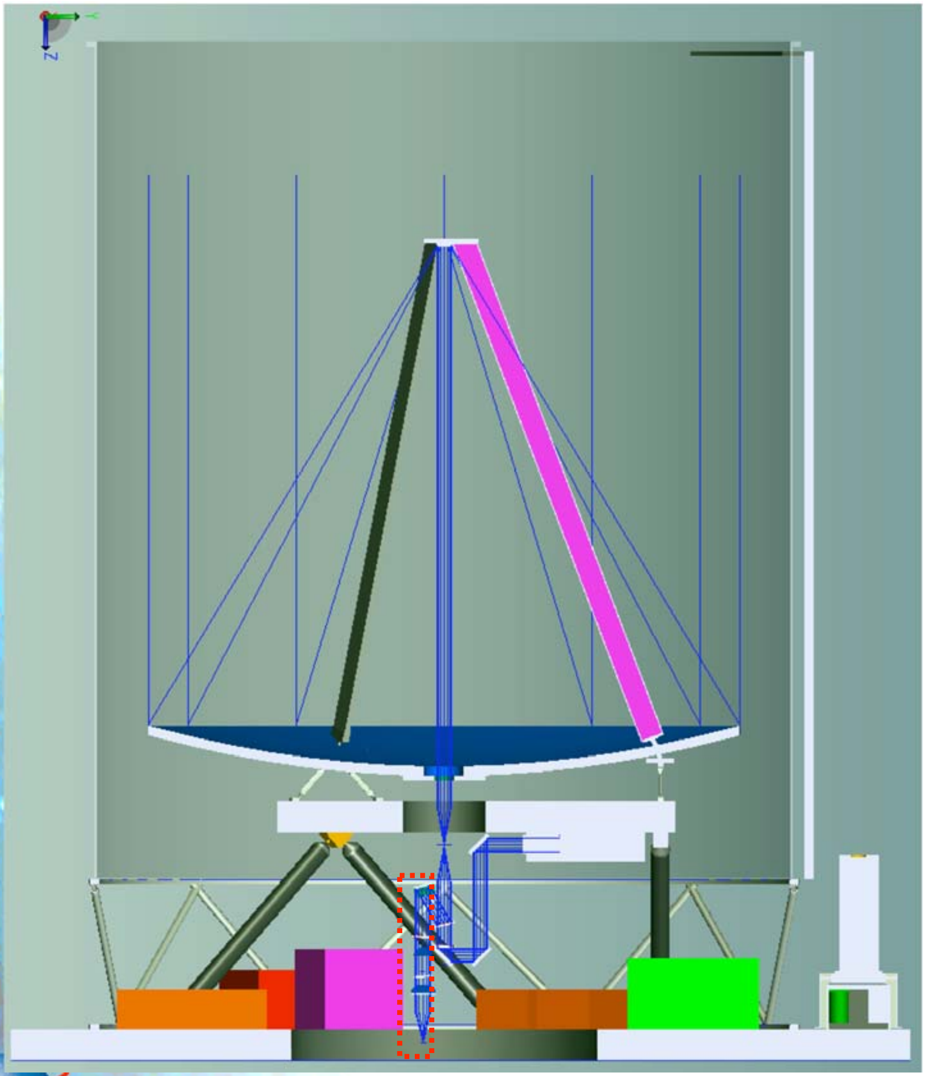
# Study Assumptions

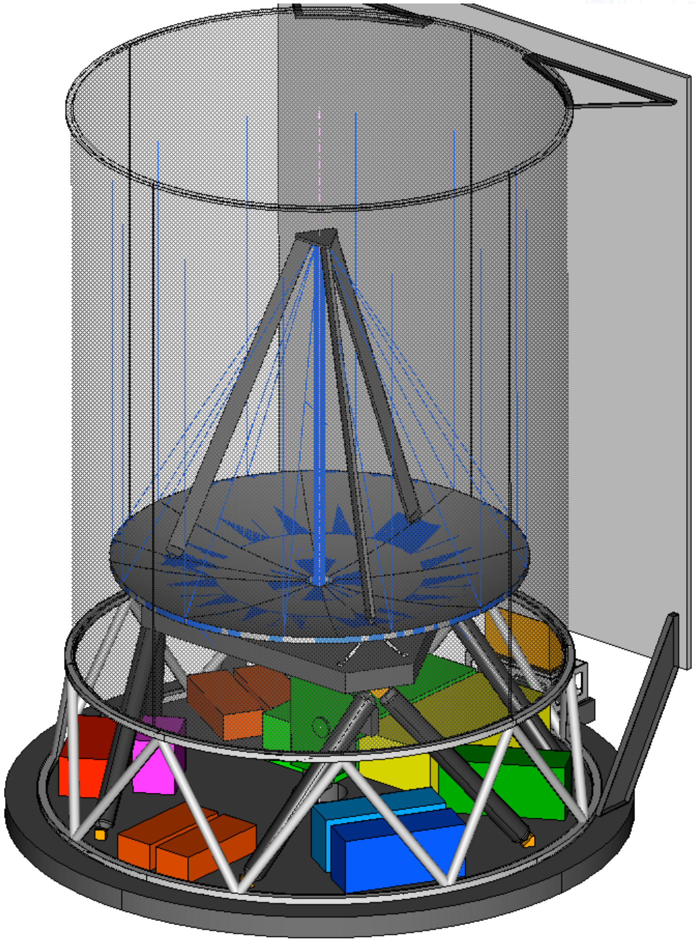


- Two channel ($CO_2$ and $O_2$) LIDAR system
  - $CO_2$ lower tropospheric column measured near 1572 nm
  - 02 total column measured across two lines near 765 nm
  - Altimetry and atmospheric profiling via off-line 765 nm pulses
- Pulsed EDFA seed lasers
  - 2 us wide pulses with 133 usec pulse periods (7.5 KHz pulse rate)
  - 6 sequential wavelengths per channel
  - Total $CO_2$ channel pulse energy of ~2 mJ at BOL (from 4 or more laser amplifiers)
  - Total $O_2$ channel pulse energy ~ 2 mJ at BOL (from 8 laser transmitters)
  - On-orbit transmitter-receiver bore-sighting required
  - Sample & monitor total transmitter energy for each channel
- Zero path and Gas Reference Cells ($O_2$ and $CO_2$) calibration
- Energy measurement resolution ~1000:1 SNR for online energies
- Both receiver channels use photon counting detectors
  - $CO_2$ uses a Photo Multiplier Tube (PMT) (or equiv) passively cooled to 200K
  - $O_2$ uses 8 Single Photon Counting Modules (SPCM) operating at room temperature
- Maintain temps of all optics except telescope to <1 C over mission lifetime

# Conceptual Layout (not optimized)

Integrated Design Capability / Instrument Design Laboratory

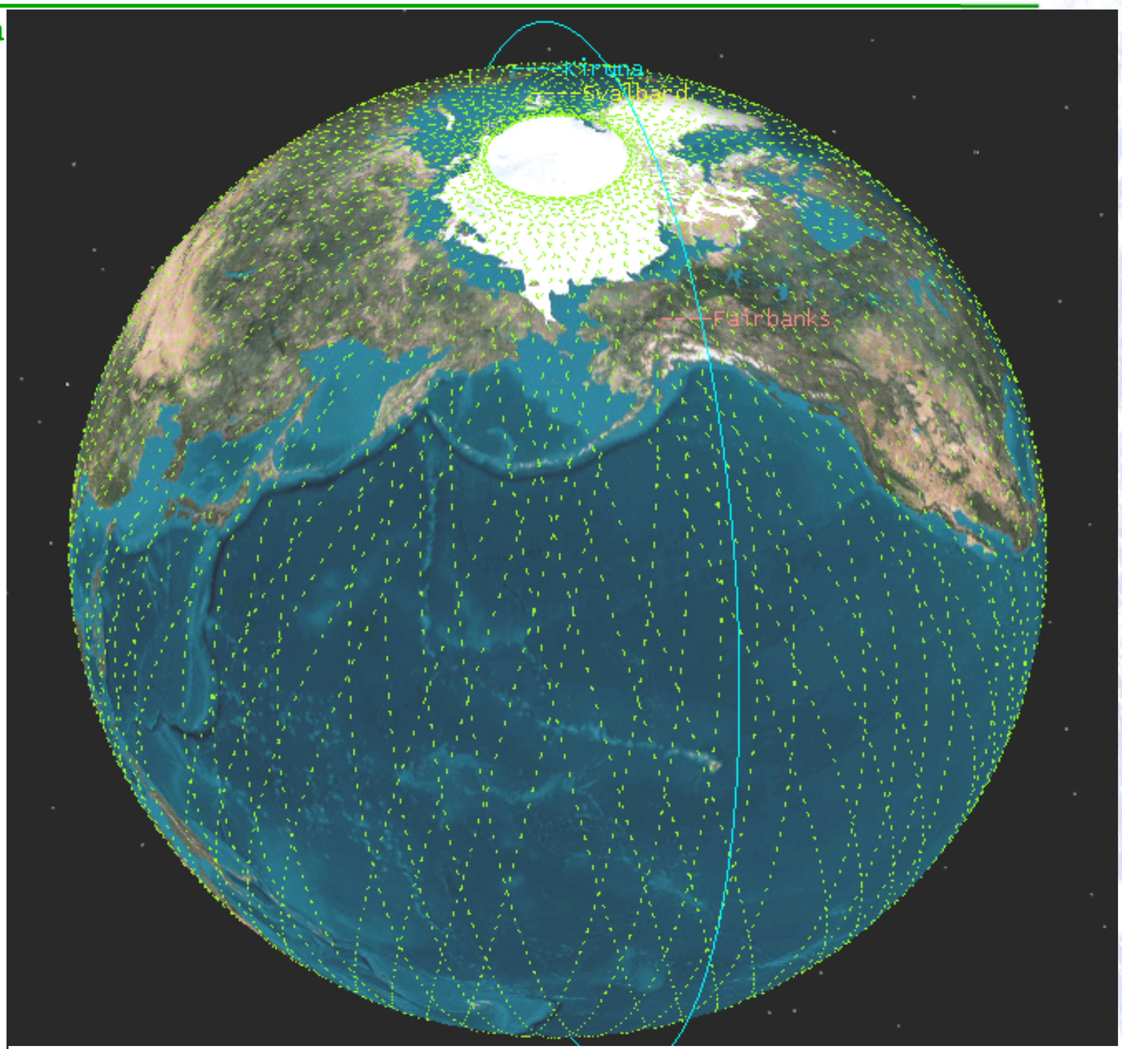




# Assumed Orbit and Example -Eight Days of ASCENDS Gnd. Tracks (cell size 1.5 km x 15 km)



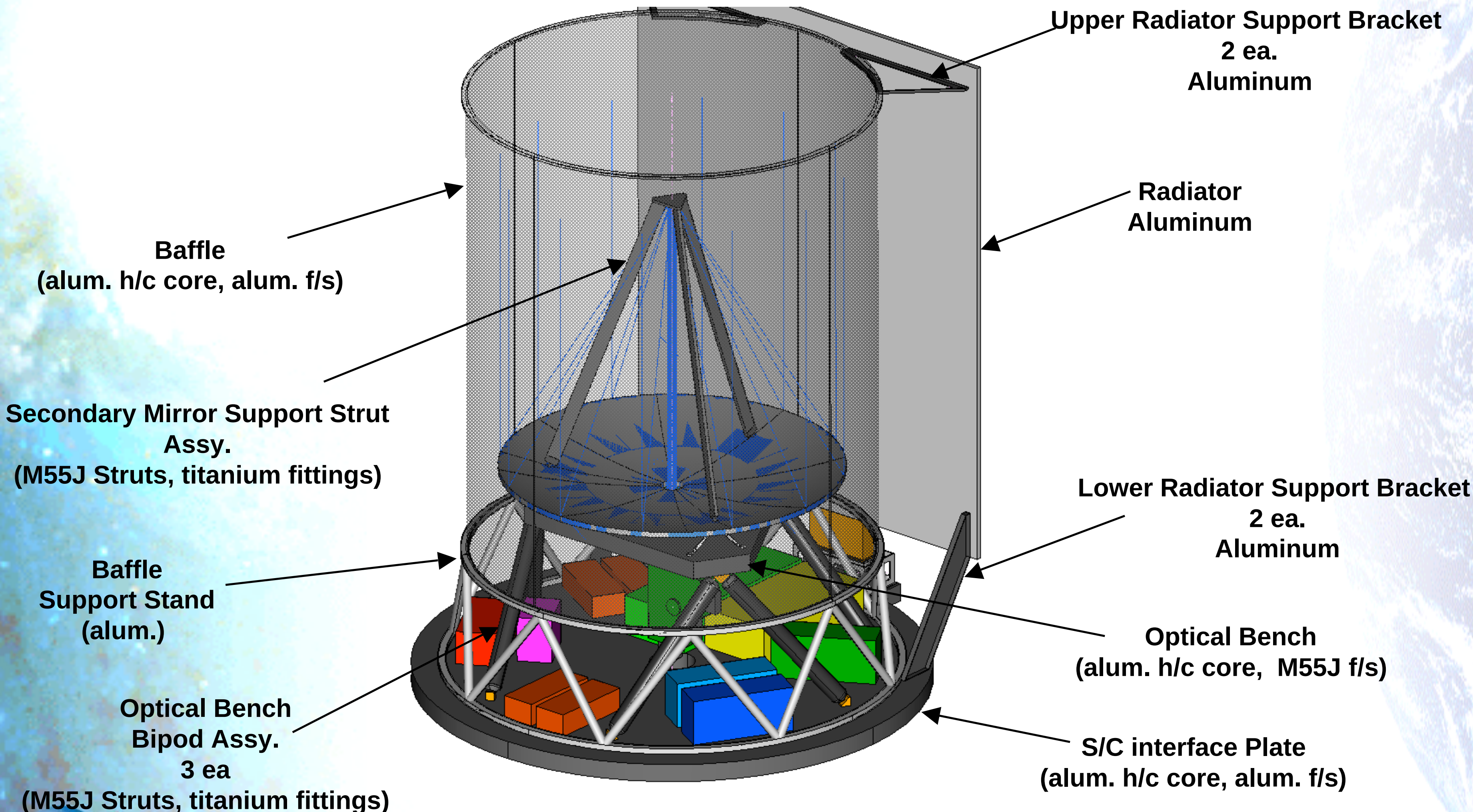
- **Near-polar, near-circular orbit**
- **500 km altitude**
- **97.4º inclination**
- **Argument of perigee: 0º**
- **Right ascension of ascending node: 272º**
- **Equator crossing local time (ascending): 13:30**




High latitude gnd. Stations shown; Svalbard has best access, data in Final Report

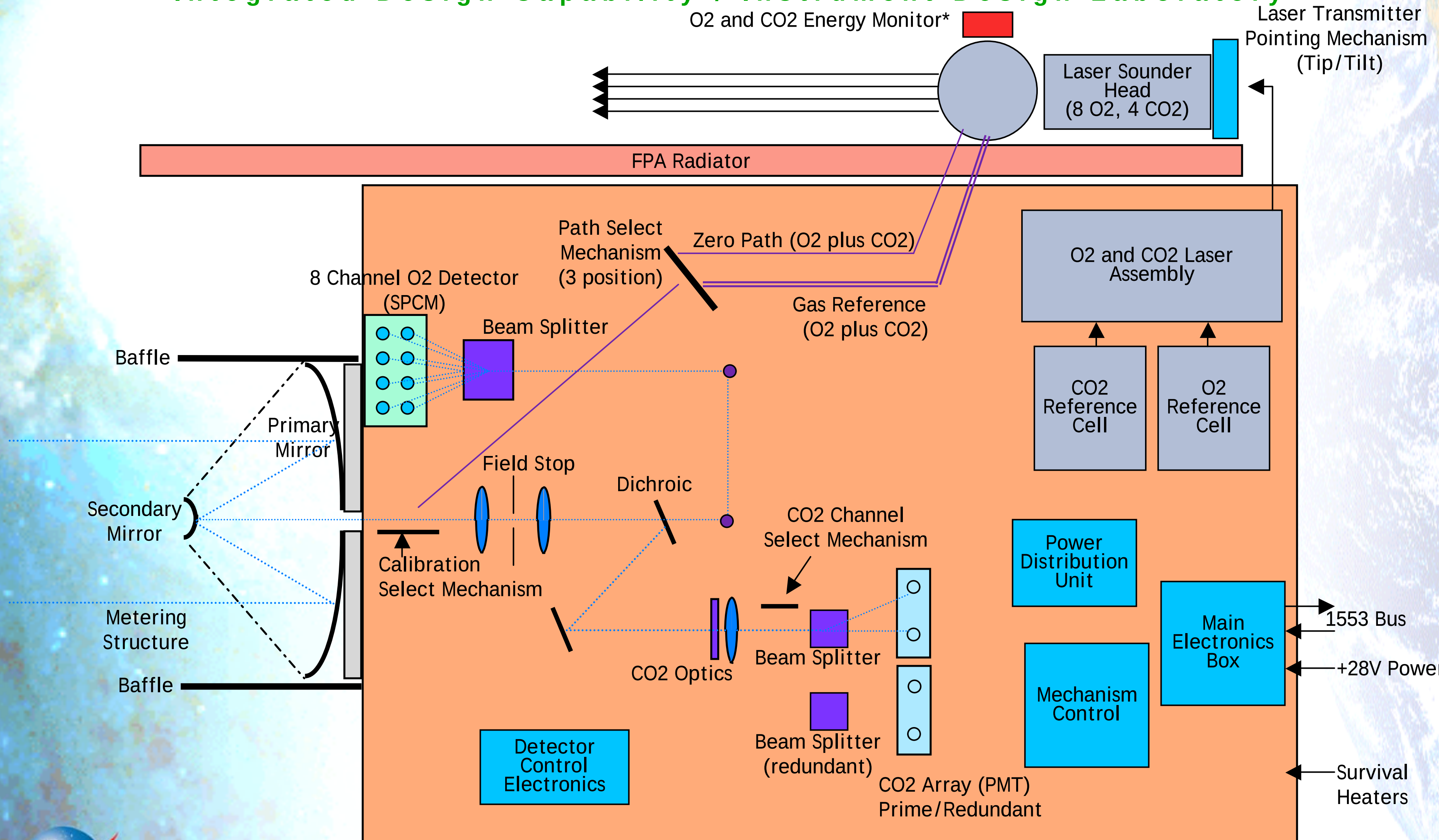
# Concept Layout - Overview

**Integrated Design Capability / Instrument Design Laboratory**



# Instrument Components & Diagram

Integrated Design Capability / Instrument Design Laboratory



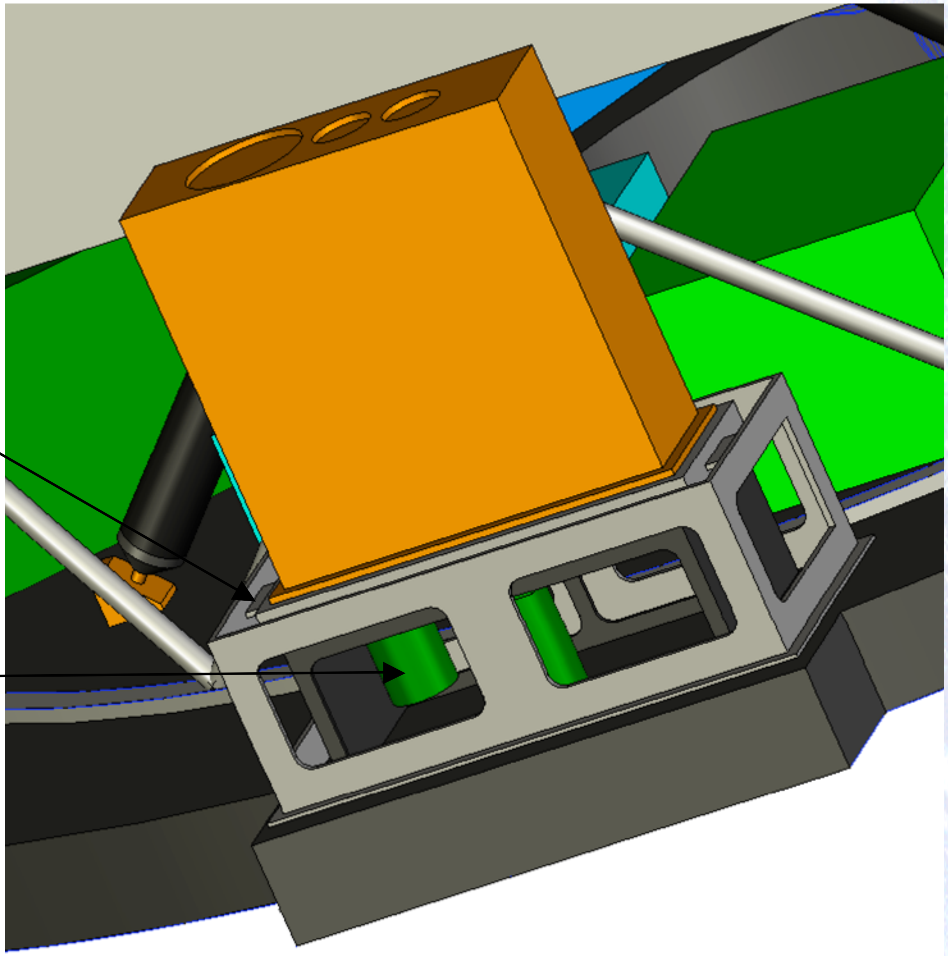
# Laser Transmitter Pointing

Integrated Design Capability / Instrument Design Laboratory

Flexure System secures assembly but allows small rotations

One possible actuator

- 3X PI NEXLINE N-214.00 Piezo inchworm strut with integral optical encoder.

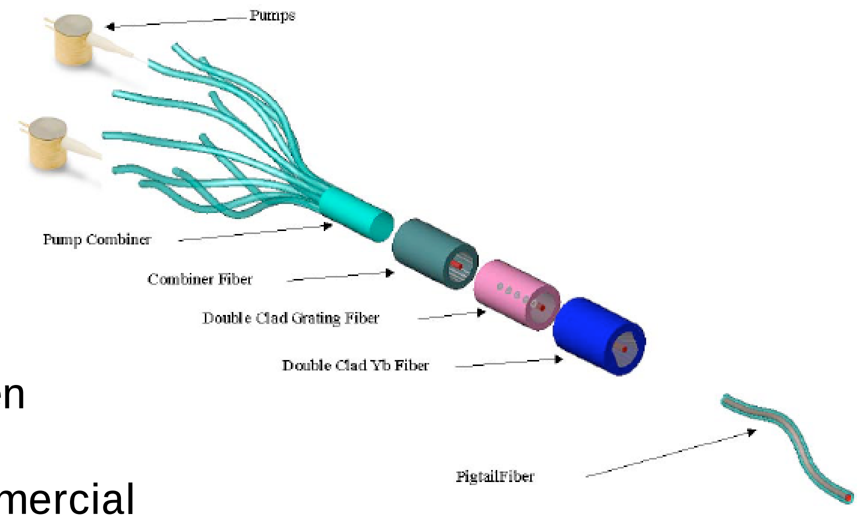


# Pulsed Fiber laser amplifiers



**Pros:**

- Low optical misalignment.
- Low contamination risk.
- Strong leverage from telecommunication industry (reliable laser diodes).
- Waveguide guided, good beam quality.



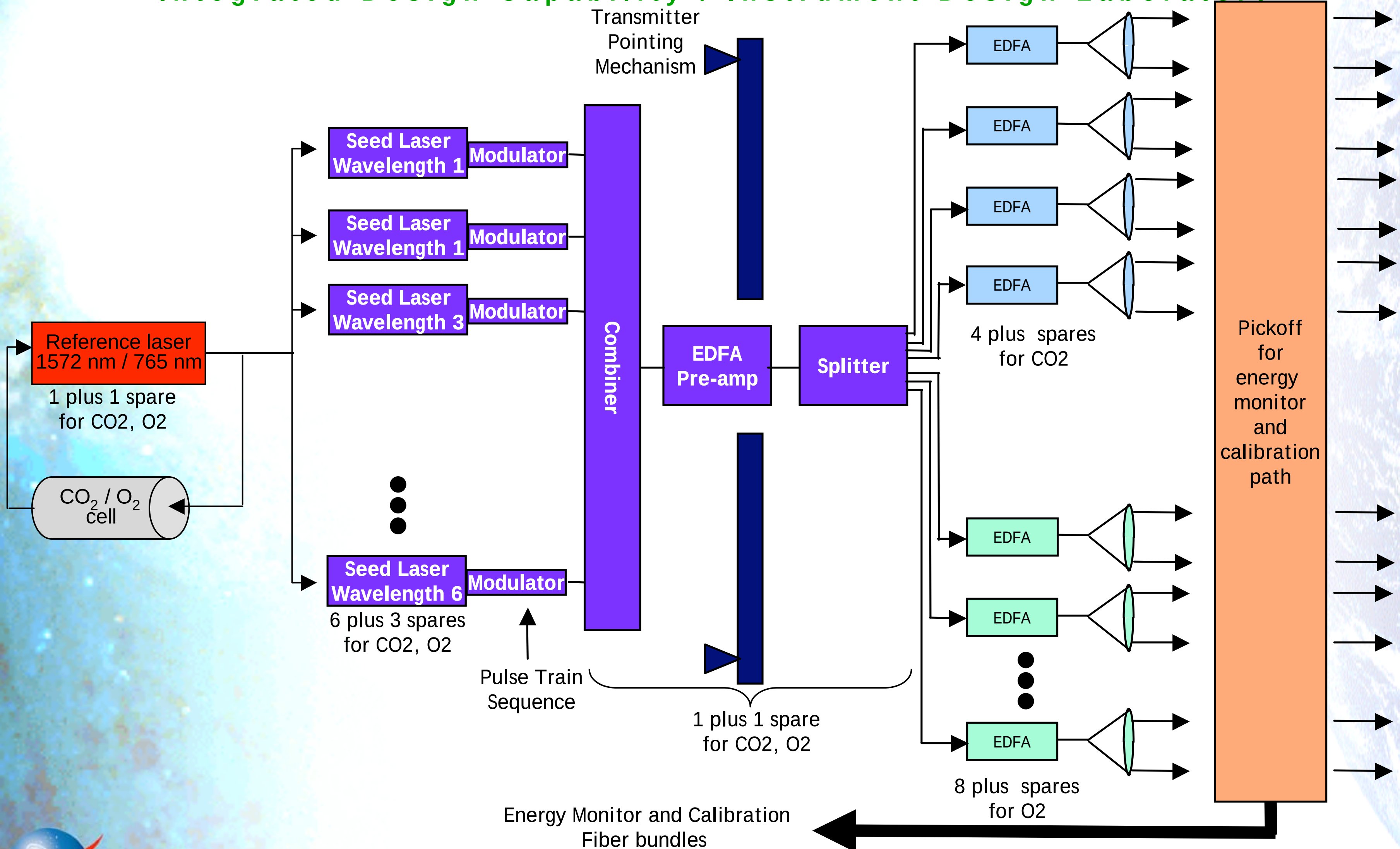

- Space-qualified high power EDFAs have been developed
- Significant progress has been made on commercial and other R&D for high peak power SF EDFAs
- Can leverage the high peak power SF EDFAs from commercial vendors, DoD and other R&D programs

**Factors to be considered for design:**

- Peak power limited by nonlinear effect, SBS (for small core size fibers)
- Energy storage limits of fiber amplifiers
- Newer technology.

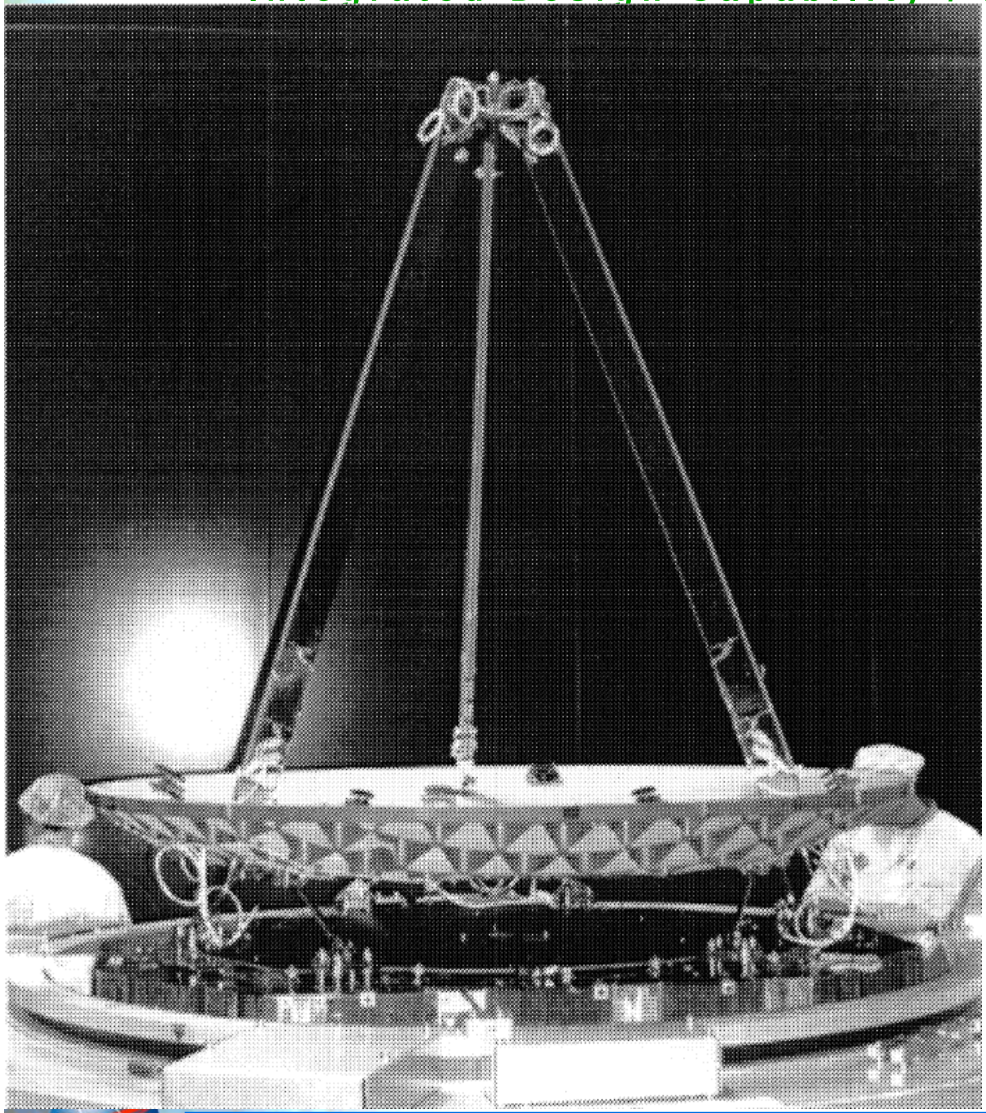
# Laser Transmitter Block Diagram

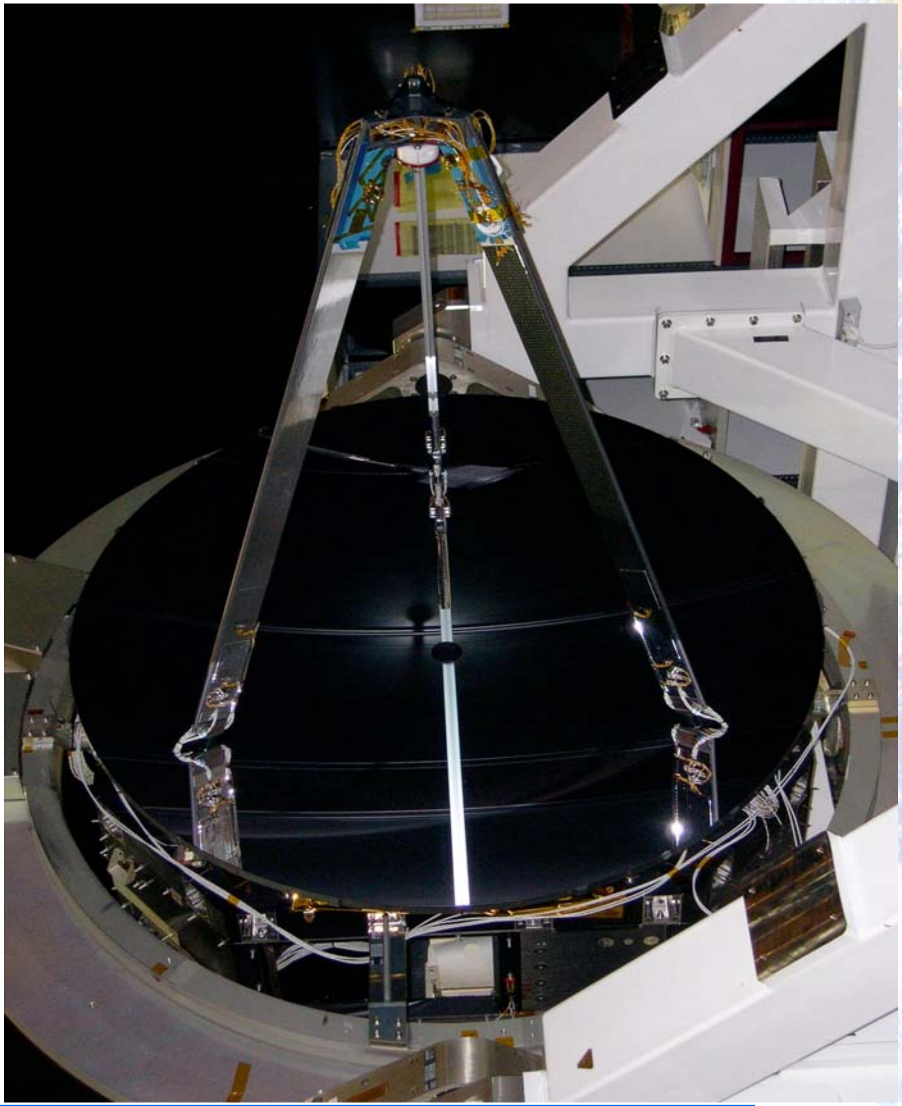




# ESA ALADIN 1.5 m Receiver Telescope

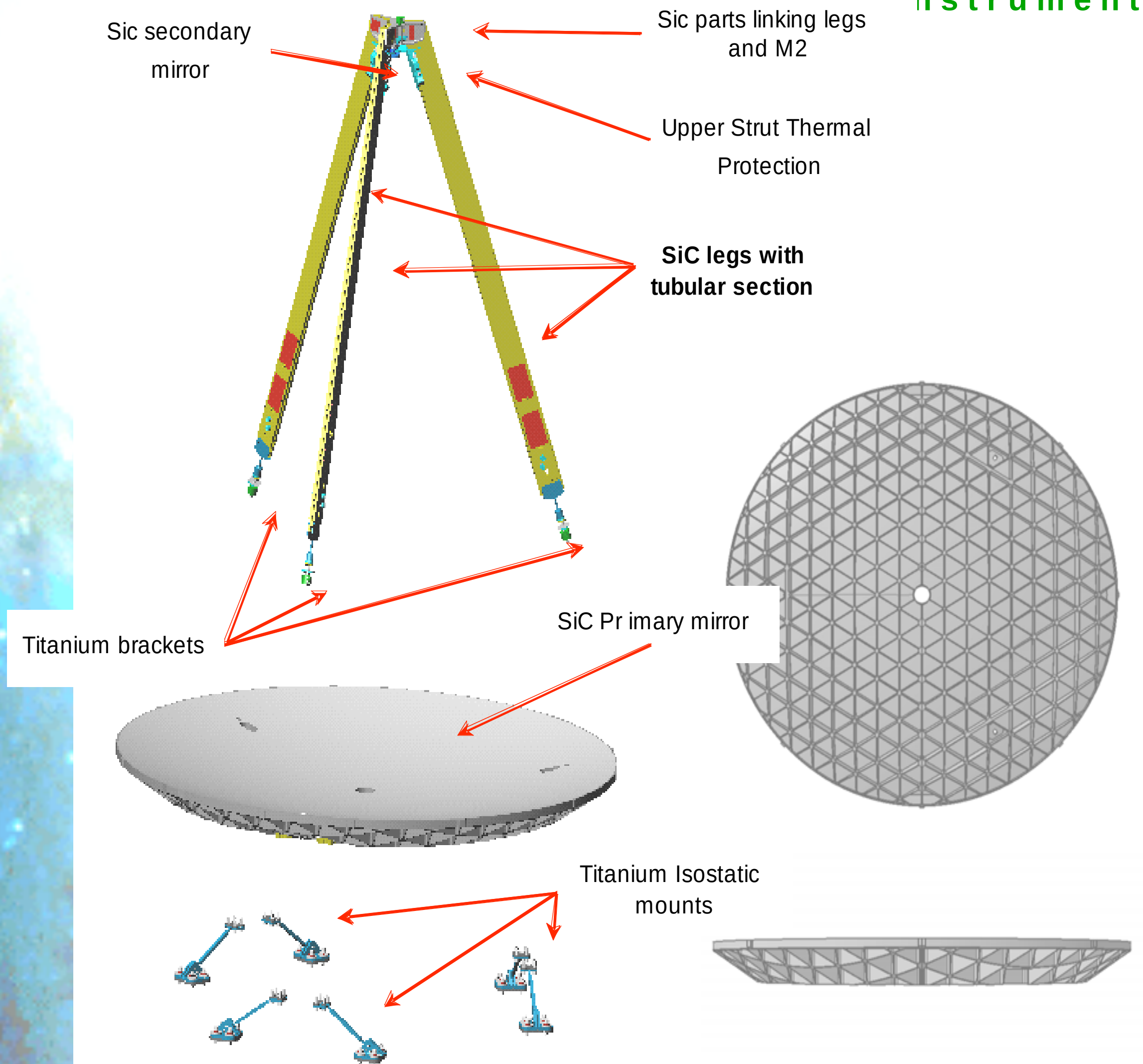






# ESA ALADIN transmit/receive telescope






- Ultra-lightweighted Telescope all in silicon carbide (SiC)
- Diameter: 1.5 m
- Afocal optics
- Mass complete: 75 Kg
- First frequency > 60 Hz
- Thermal re-focusing capability
- Wavefront error: 350 nm (complete telescope)

# ASCENDS Aft optics concept

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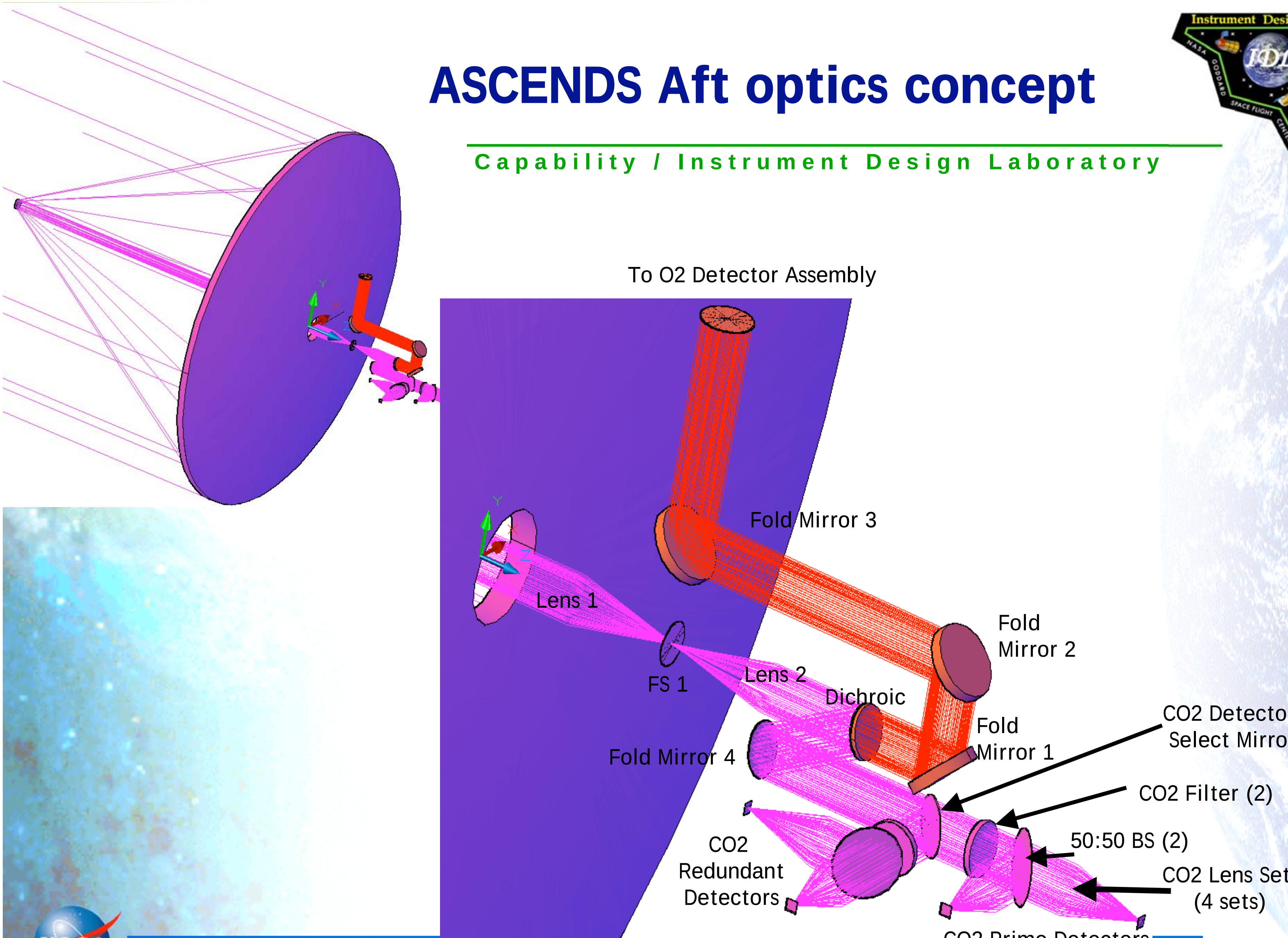

# Co2 & O2 Detector Assumptions for Study



CO2 Channel Detectors

- NIR PMTs (4 each)
- 9% QE now avail commercially (Hamamatsu)
- Higher QE units in R&D stage
- Passive cooling to ~200K
- Need to up-screen & repackage commercial units
- Advantages: Small, PMT Flight heritage, ease of use.

O2 Channel Detectors

- SCPM Detectors (8 each)
- > 65% QE from Perkin Elmer
- Now operating on GLAS/ICESat
- TRL=9
- Need to upscreen commercial units
- Advantages: High Sensitivity & High TRL

# Electrical System Concept

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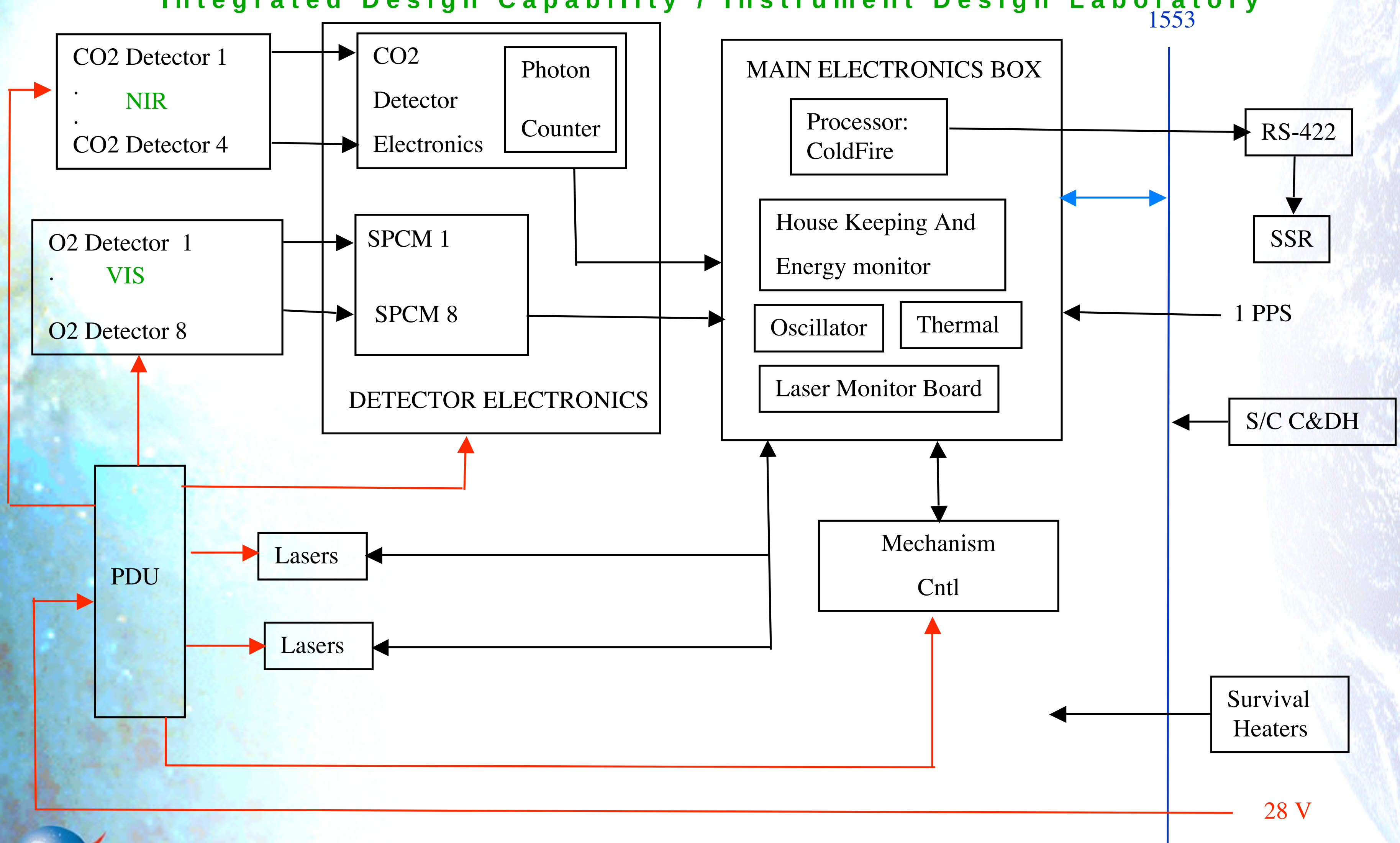

# Thermal Control Concept

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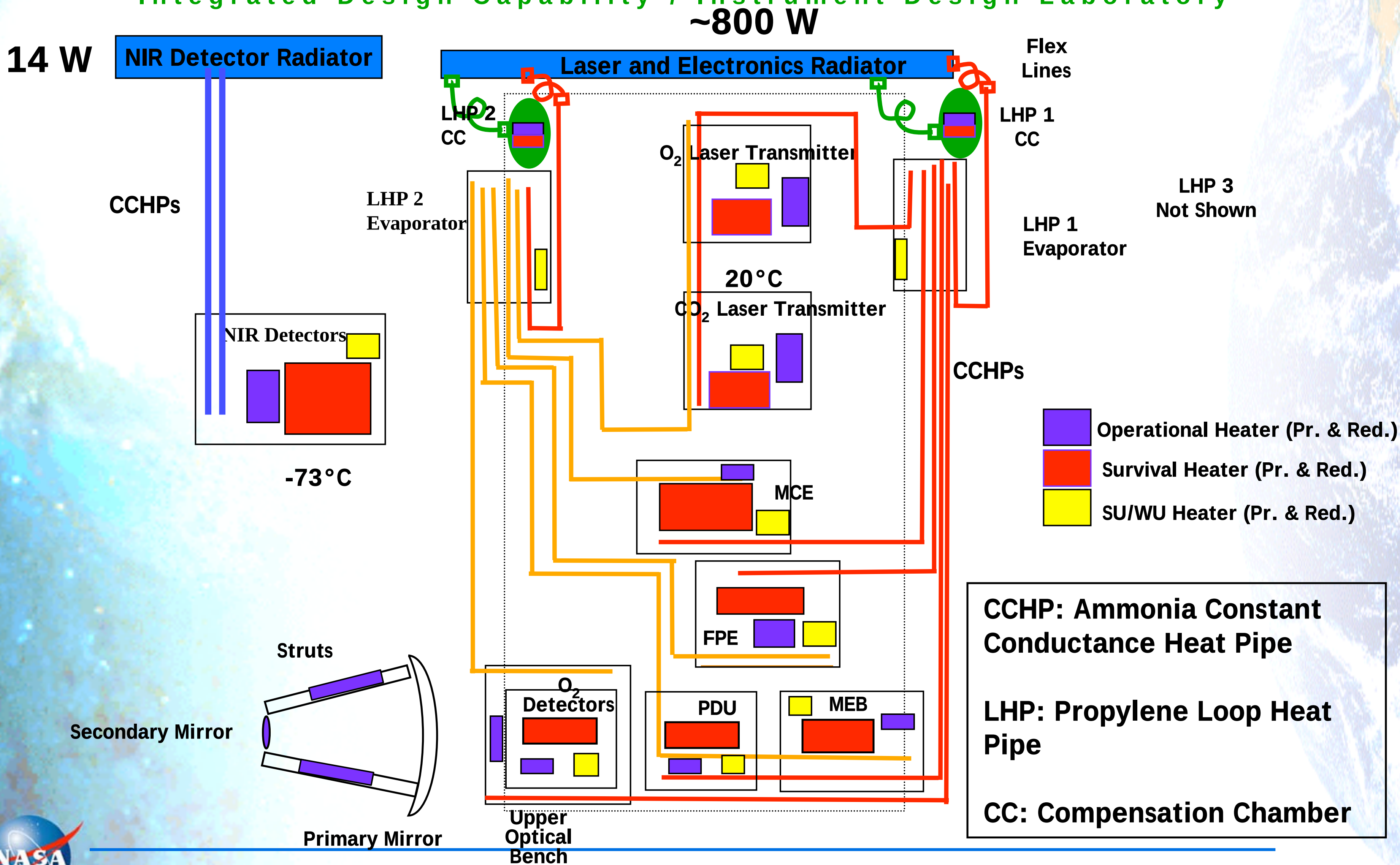
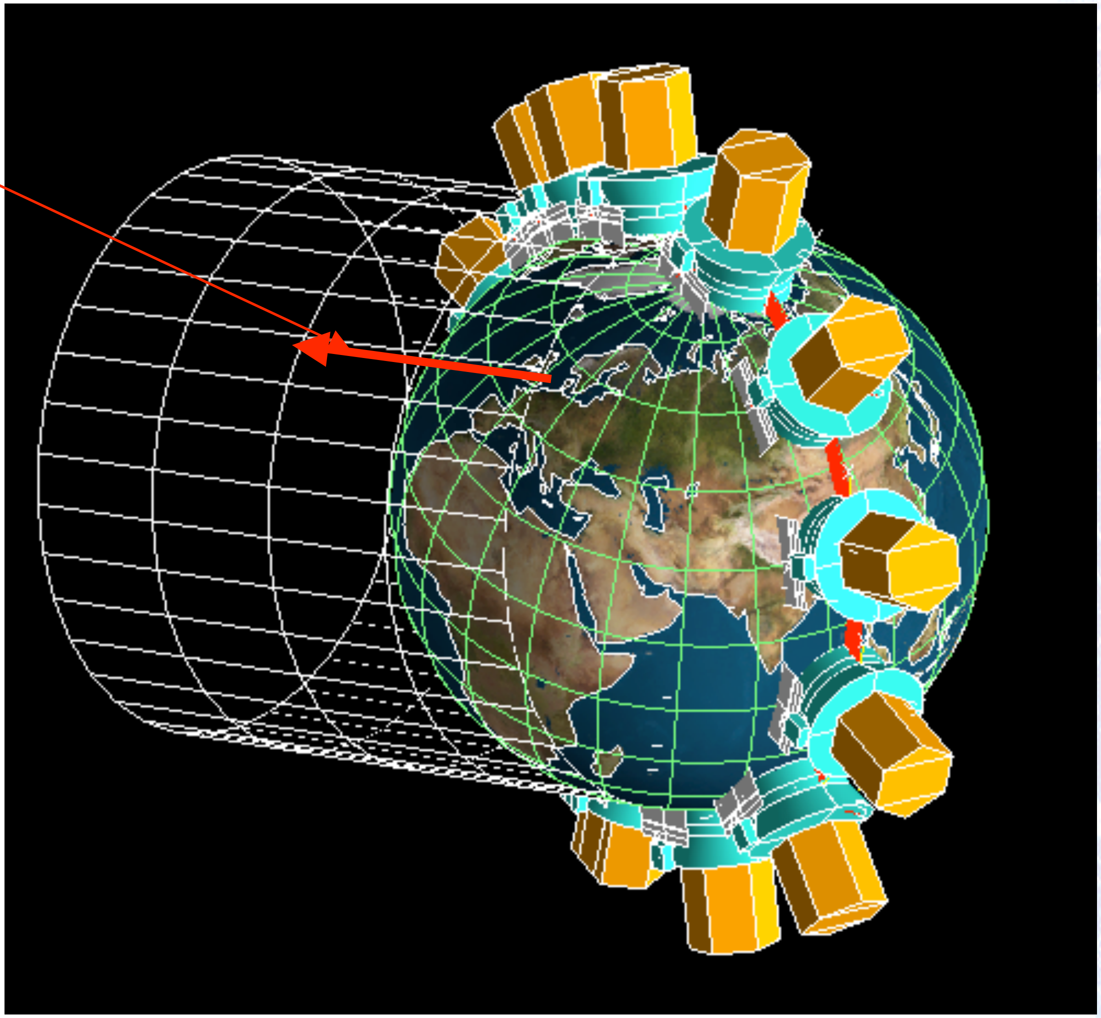


# Thermal Model (Worst Cold case shown)

Integrated Design Capability / Instrument Design Laboratory

**Sun's Rays**



**Worst Cold Case for Radiators:**

21º Beta

94.5 Minute Orbit

34.8 Minute Eclipse

**Worst Hot Case for Radiators:**

40º Beta

94.5 Minute Orbit

31.8 Minute Eclipse

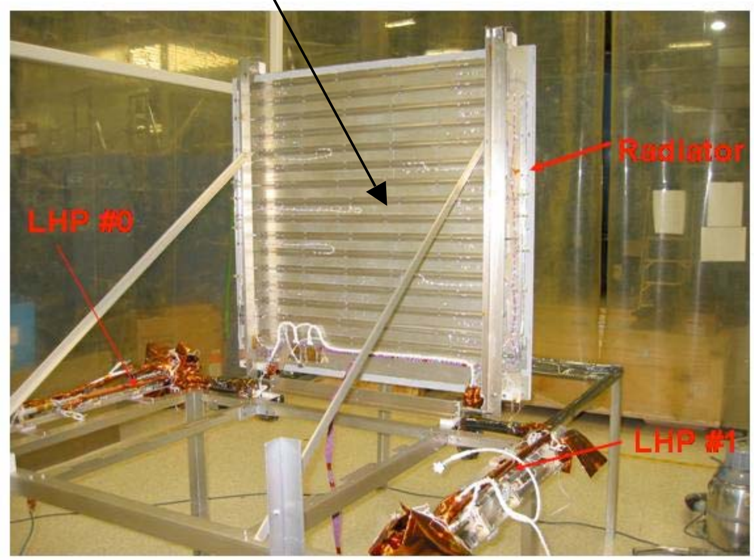
**Spacecraft enlarged to show its orientation**

# Example of a suitable thermal Radiator



Swift BAT Radiator


Swift BAT LHP Condensers



# Initial Concept Study - Summary



- Straightforward space lidar design
- Low risk - use of space qualified telescope, O2 detectors, thermal system
- Instrument Mass: 350-400 Kg (can be reduced via more efficient layout)
- Instrument Power: ~800W (driven by SNR assumptions)
- Data rate: ~1 Mbit/sec - Ok for use of high latitude comm. ground site
- Primary power draw - laser subassemblies
- Primary thermal source - laser subassemblies
- Mechanisms - all functions already demonstrated in prior space missions
- Laser architecture -> high reliability via switchable cold spares
- Detector approach -> reliability via use of multiple detectors & spares.
- Several aspects can be optimized in follow on studies
- No show stoppers