Qualification and Integration of the Laser Transmitter for the CALIPSO Aerosol Lidar Mission

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Presentation Overview

- **Programmatics**
- **Flow down of system level lidar requirements**
- **Laser transmitter performance**
- **Laser transmitter qualification**
- **Lidar integration & test**

Program Overview

- **Fibertek responsibilities**
  - Design, build, and qualification of the laser transmitter
  - Support of post ship testing at Ball
  - Fibertek was supported by Ball in design and test issues unique to space-qualification
    - > Radiation hardness
    - > Electrical parts selection
    - > Contamination control
    - > Software qualification
    - > Environmental testing
- **Ball responsibilities**
  - Payload design, production, and integration
    - > Rayleigh/ Mie Lidar for clouds and aerosols (CALIOP)
    - > Wide Field Camera (modified startracker)
    - > Imaging Infrared Radiometer (Sodern/CNES)
  - Joint development activities with NASA LaRC
  - Management and support of the laser transmitter contract to Fibertek
  - Payload Flight Software
  - Science Data Delivery System
    - > X-band Transmitter and antenna
    - > Ground Support Network (United Space Network)
  - Satellite integration and test support (at Alcatel in Cannes and Vandenberg Air Force Base)
  - On-Orbit Commissioning support

System Level Lidar Requirements

- **The lidar requirements were part of NASA's SOW to Ball**
- **Prior to starting the Flight Build, the Risk Reduction Laser (RRL) was completed**
  - **Demonstrated design approach for the laser and basic laser performance**
- **RRL performance provided basis for lidar/ laser trades**
  - **An iterative approach to the lidar design produced the final requirements for the flight lasers.**

Laser Transmitter Subsystem Performance Requirements

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Laser performance requirements are not particularly stressing from a laser design viewpoint

• 1064 nm energy	100-125 mJ
• 532 nm energy	100-125 mJ
• Pulse width	15 ns < Δt < 50 ns
• Repetition rate	20 Hz
• Beam quality	< 10 mm-mrad, both λ
• 1064 nm line width	< 150 pm
• 532 nm line width	< 35 pm
• 532 nm polarization	> 100:1 linear
• Beam co-linearity	< 10 % of output divergence
• Beam jitter	< 10 % of output divergence

System level requirements are more challenging

- Lifetime of 2 billion shots
- Pure conduction cooling
- Fully redundant lasers and electronics
- Modest thermal requirements
  - Operate within specification in a +/- 5°C band around optimum (~20°C)
  - Operate without damage from -5°C to 30°C
  - No impact from non-operational -30°C to +60°C thermal cycling
- Power requirements are somewhat challenging
  - No more than 20 W required in standby
  - No more than 102 W required operationally
- Severe vibrational requirements (>10.5 g_{rms})
- Dual wavelength energy monitors with +/-2% precision over full orbit
  - Based on integrating sphere technology
- 100 urad +/- 10 urad final divergence required matched shimming of Beam Expander Optics to each laser
- Electro-Magnetic Interference specification

System Level Lidar Requirements

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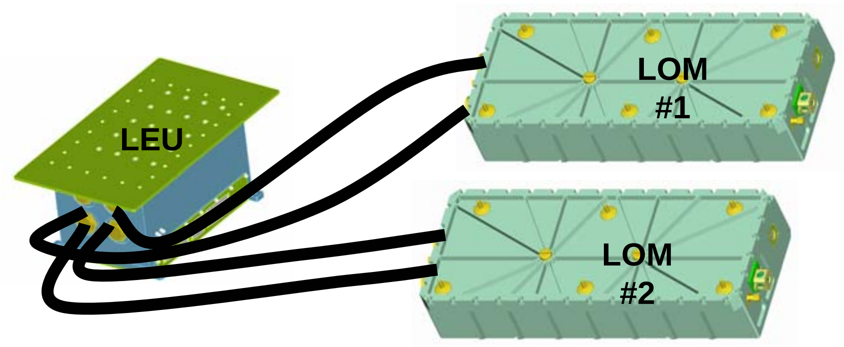
Lidar requirements determined the Flight Laser specifications

Lidar Requirement	Impacted Laser Specification
Reliability	Pump diode lifetime
	Canister leak rate
	Laser & electronics redundancy
	Contamination Control Plan/materials used
	Parts use for radiation (KTP, laser FETs)
Lidar Stability (<4.7%)/orbit	Energy Monitor Stability –Orbit/Orbit
	Pointing stability
	Wavelength stability
	Linewidth
Efficiency	Electrical power conversion efficiency
	Diode efficiency & spectral distribution
	Resonator efficiency
Polarization	532 nm polarization purity & alignment

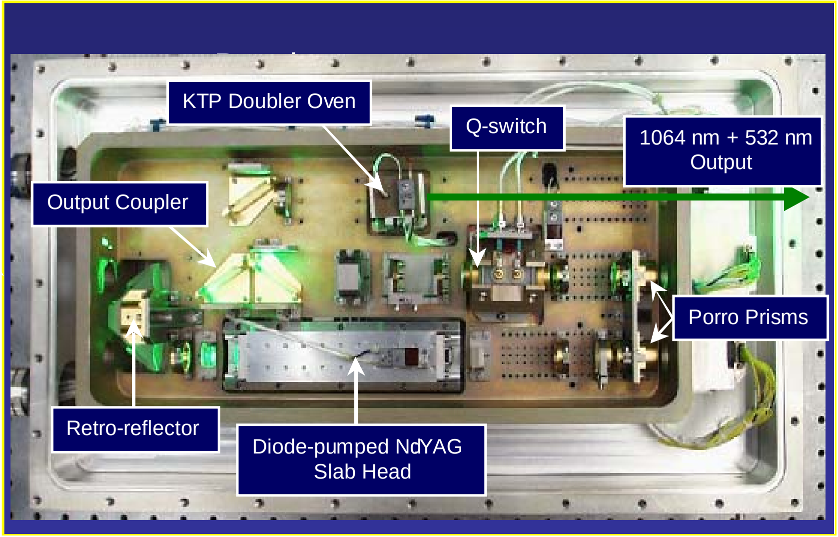
An iterative process was used to develop a final set of laser specifications that allowed the lidar system requirements to be met

Laser Transmitter Reliability

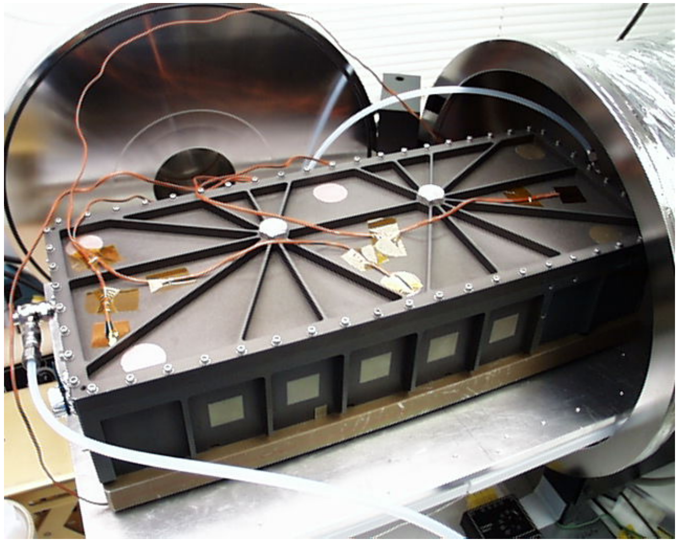
- RRL demonstrated required 3 year, 2 billion shot lifetime
- Each flight Laser Optics Module (LOM) had a dedicated set of electronics for full redundancy
- A flight-like canister pressurized to 28 psia passed He leaks tests after qualification level vibration and during three –30°C to 70°C thermal/vacuum cycles
- Both flight units passed helium leak testing during four –30°C to 60°C thermal/vacuum cycles before the beginning and at the end of qualification testing



Fully redundant lasers and electronics



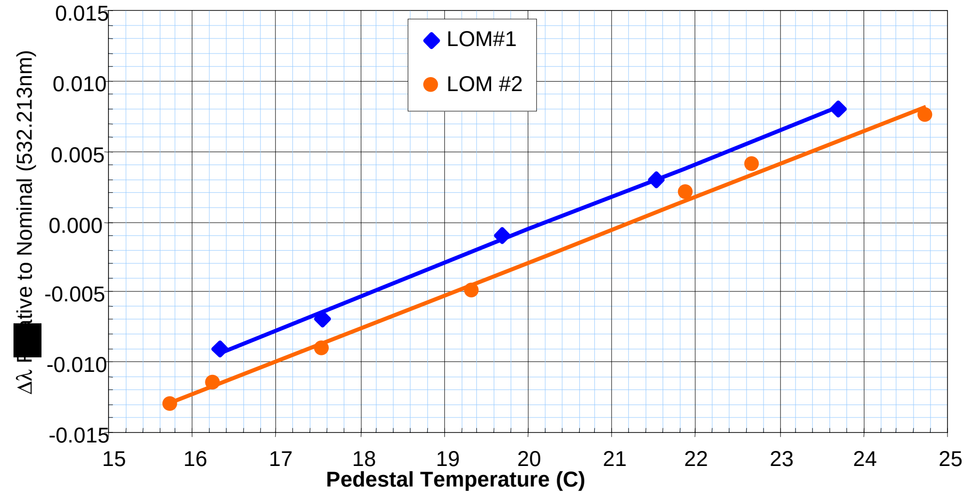
Risk Reduction Laser



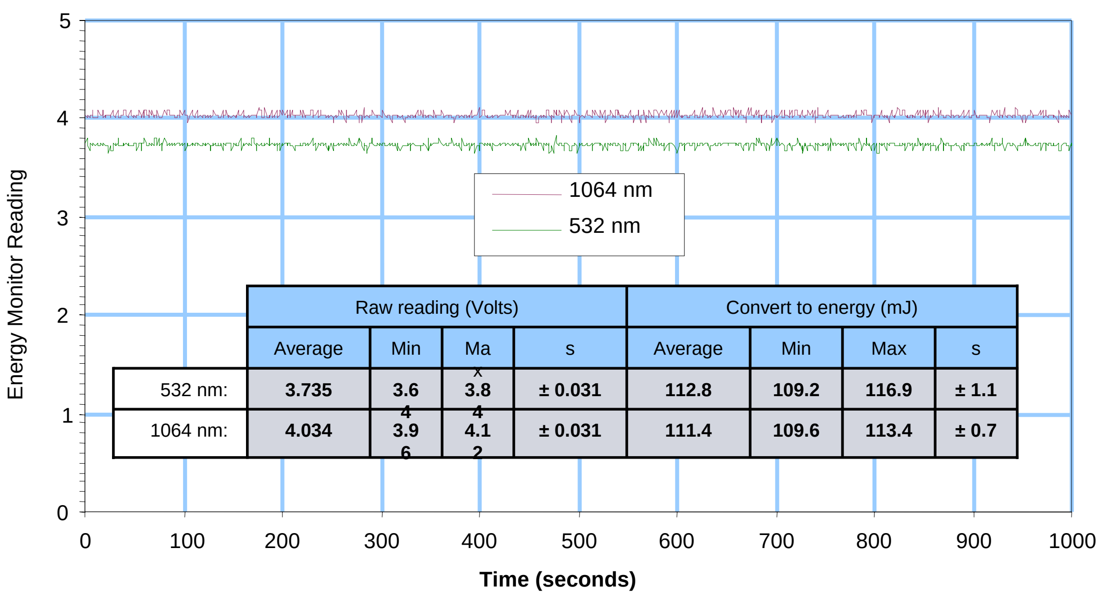
Thermal vacuum helium leak testing of laser canister

Laser Stability

- Energy monitor precision over full orbit ≤ 2%
- Shot-to-shot energy jitter is ≤ 1.1%
- 532 nm wavelength varies ~ 20 pm over a 10°C change
  - Value is consistent with the temperature shift of the Nd:YAG emission profile
- Laser output energy unchanged since delivery in 2002
- > 99.5% of the of the pulses had pointing jitter that was <10% of the full beam divergence



532 nm wavelength vs. laser head temperature



	Raw reading (Volts)				Convert to energy (mJ)			
	Average	Min	Max	s	Average	Min	Max	s
532 nm:	**3.735**	**3.64**	**3.84**	**± 0.031**	**112.8**	**109.2**	**116.9**	**± 1.1**
1064 nm:	**4.034**	**3.96**	**4.12**	**± 0.031**	**111.4**	**109.6**	**113.4**	**± 0.7**

Shot-to-shot energies

Laser Efficiency

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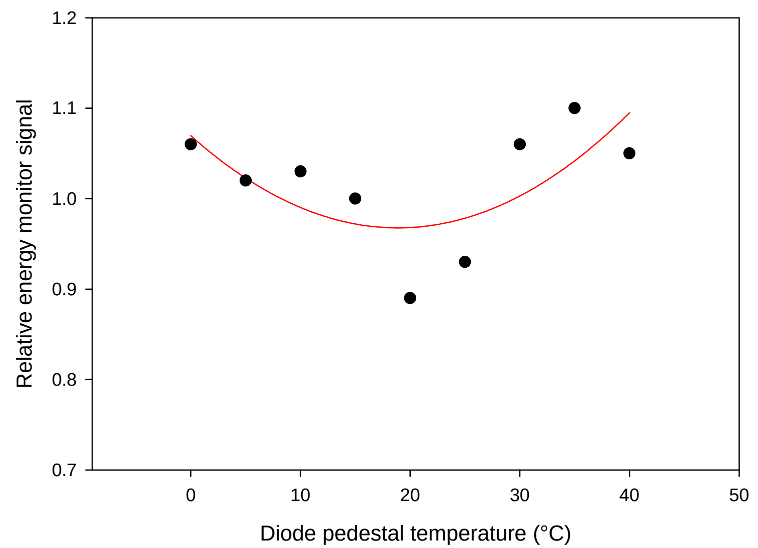
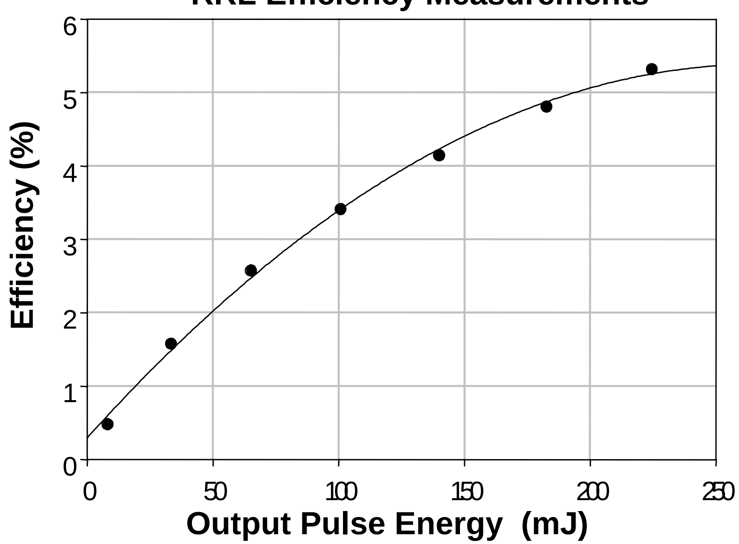
- RRL measurements with the RRL show that higher efficiencies are achieved with higher pulse energies
- Two key efficiency drivers: 1) electrical power conversion efficiency & 2) spectral overlap of diodes with Nd:YAG absorption bands
  - Electrical power conversion efficiency of 83%
  - Spectral overlap somewhat off peak due to requirement to match peak 532 nm etalon transmission
- LOM 1 wall plug efficiency was 4.2% (4.4 W output for 104 W total electrical input)
- LOM 2 wall plug efficiency was 4.4% (4.4 W output for 100 W total electrical input)

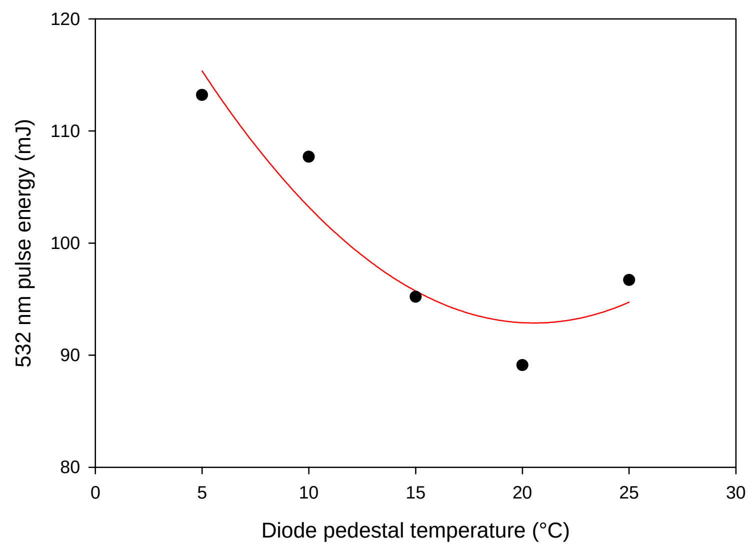
LOM 1 532 nm Energy Monitor Singals During Thermal/Vac Testing



RRL Efficiency Measurements



Temperature Dependence of LOM 1 532 nm Output Energy



Integrated Laser Polarization Measurements

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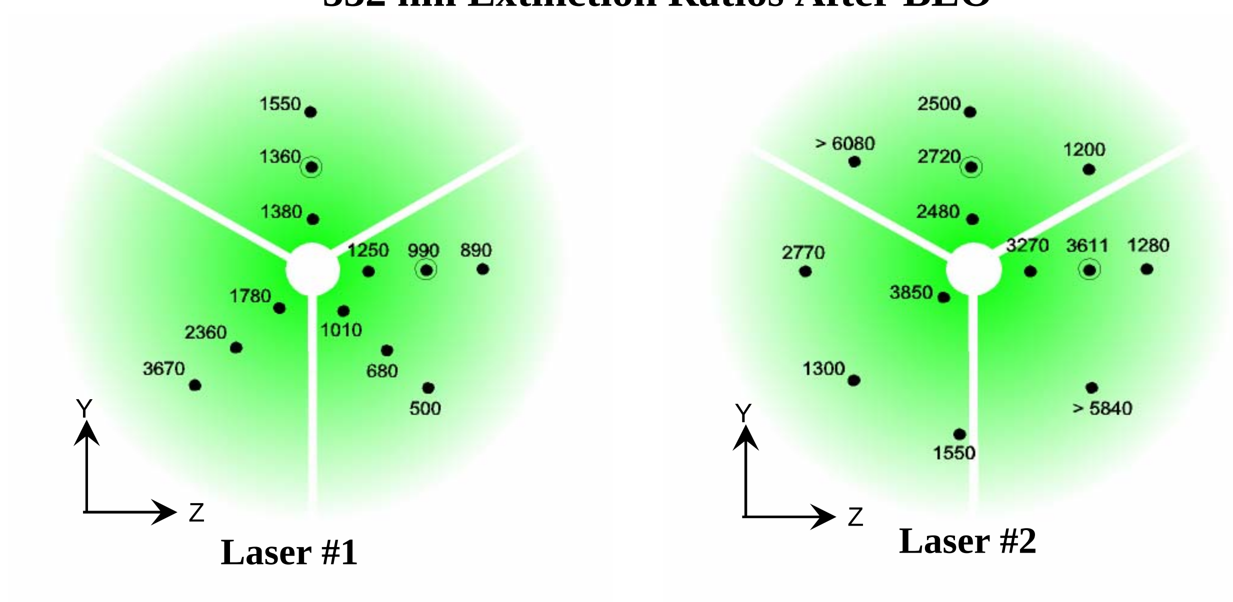
- The 532 nm polarization ratios after the Beam Expander Optics meet the 1000:1 lidar requirement
- Aligning the axis of the 532 nm polarizations to within a few mrad of the axis of the alignment cube was a significant technical challenge
- Thermal equilibrated polarization stability was < 4%

Summary of Extinction Ratios and Polarization Alignment

	Laser #1	Laser #2	Laser #2 previous measurement (without BEO)
Vector Orientation	-2.1 mrad	-16.8 mrad	-16.6 mrad
Extinction Ratio	1450:1	2860:1	~3400:1
Extinction Stability	Stable to < 4% once laser is at thermal equilibrium		

532 nm Extinction Ratios After BEO



Laser Environmental Qualification

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A systematic approach to laser qualification, beginning at the optical subassembly level and proceeding incrementally to the full module level, has resulted in the successful qualification of both Laser Optic Modules as well as the Laser Electronics Unit

Optical component and subassembly testing

- Nd:YAG slab
- Corner cube
- Steering prism
- Telescope
- Porro prism
- Q-switch
- Second harmonic generator
- Diode arrays

→

Module vibration and seal testing

- Diode-pumped laser head burn in
- Canister seal testing
- Canister/optical bench vibration testing

→

LOM & LEU qualification testing

- Burn-in
- Thermal/vac seal test
- Vibration testing
- Operational vacuum testing

Laser Optics Module System Level Qualification

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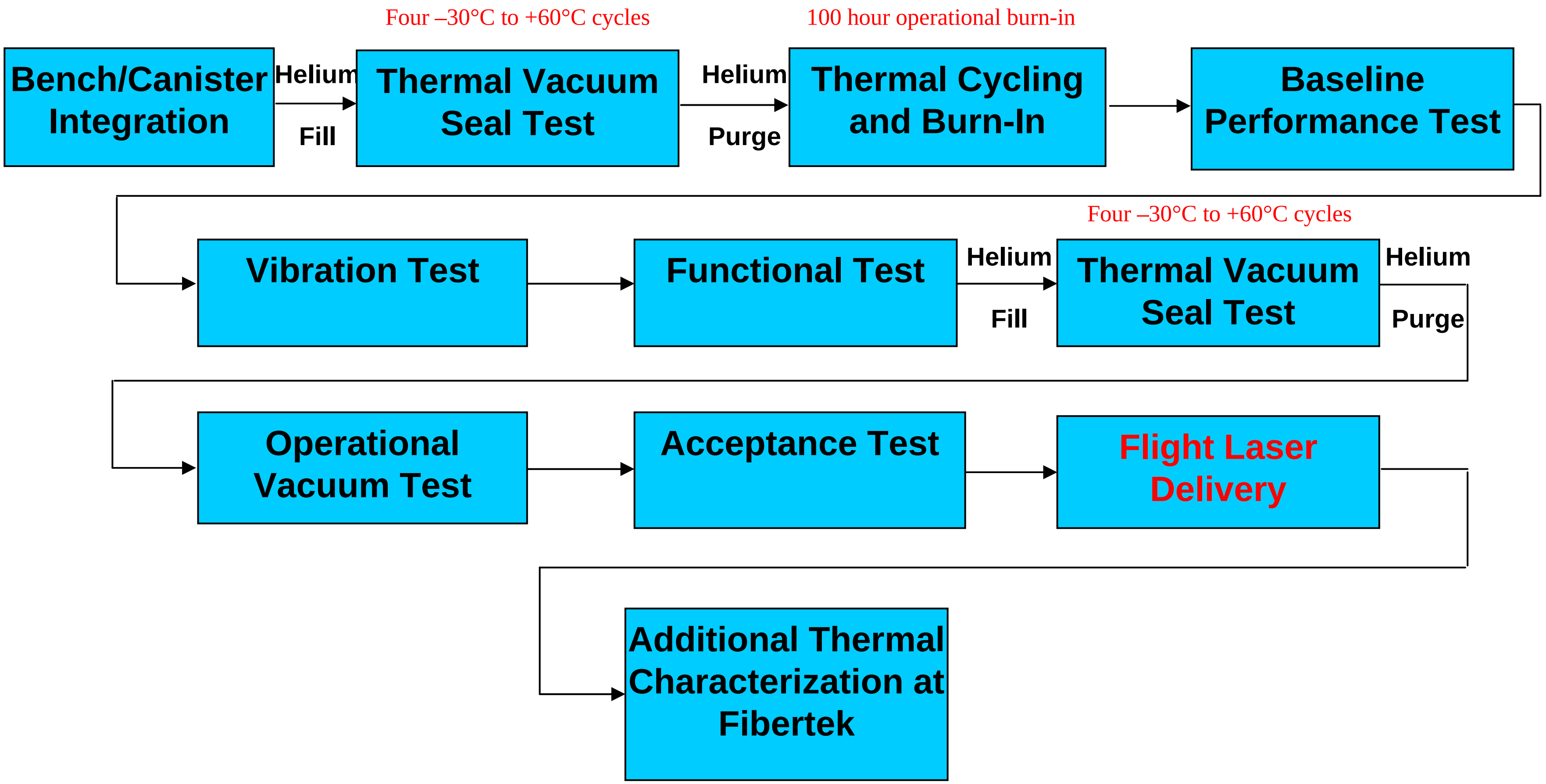
Qualification Flow Plan



Both laser's outputs were unchanged at the end of full space-qualification testing

Laser Build & Qualification Issues

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- **Space-qualified electronics were more expensive to build and test than anticipated**
  - **Use of radiation hard parts required complete redesigns of previously used electronics**
  - **Laser Electronics Unit test plan required almost 2 man years of effort to develop**
    - **Software Flight Qualification Test was more extensive than originally planned to meet NASA requirements**
    - **Software test procedure alone was >70 pages and was executed 5 times**
- **Conducted EMI due to pulsed power draw required addition of large EMI filter by Ball**
- **Subtle power supply changes surfaced intermittent start up glitches after space craft integration and required modification to the Laser Control Board**

Integrated Laser Transmitter (ILT)

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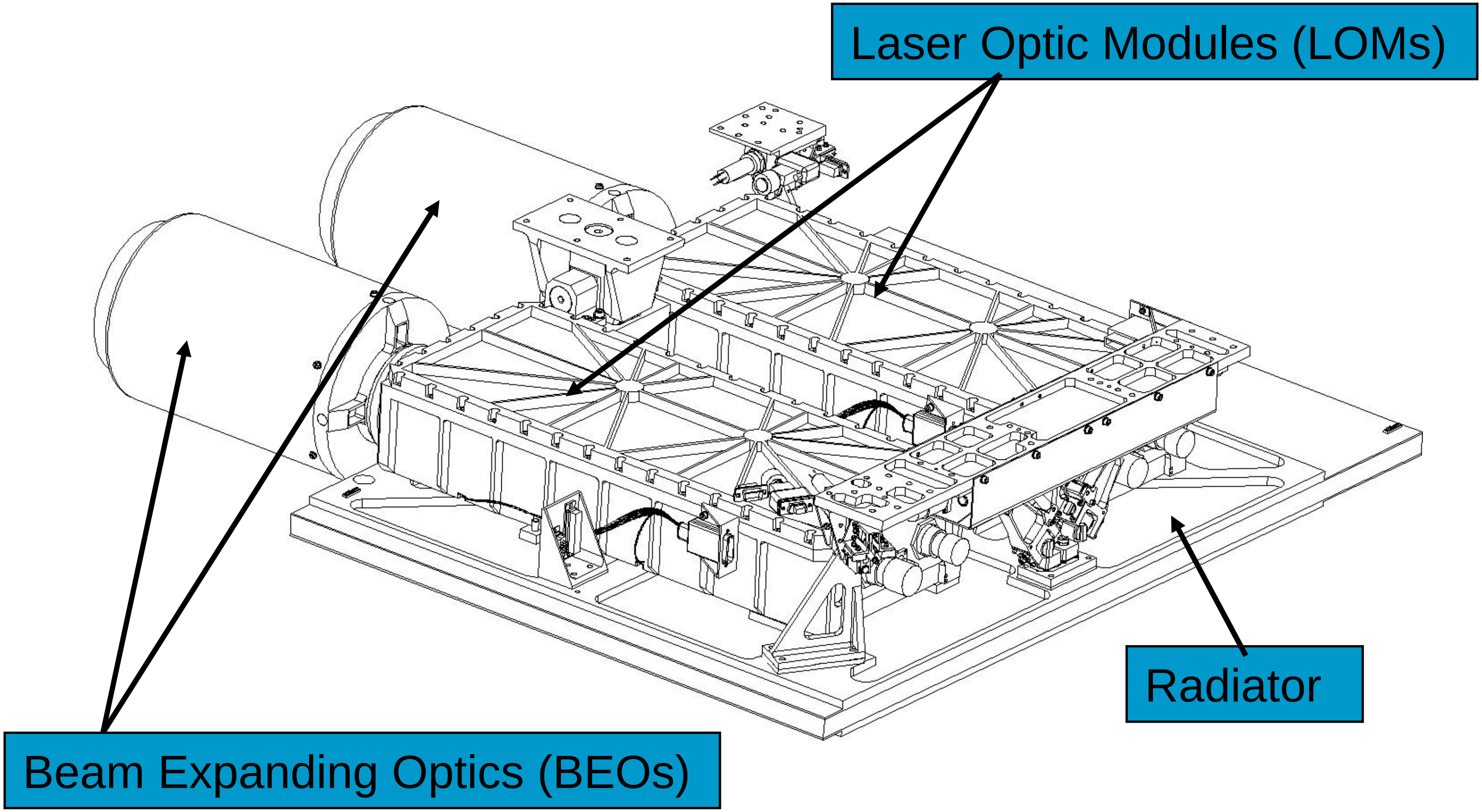
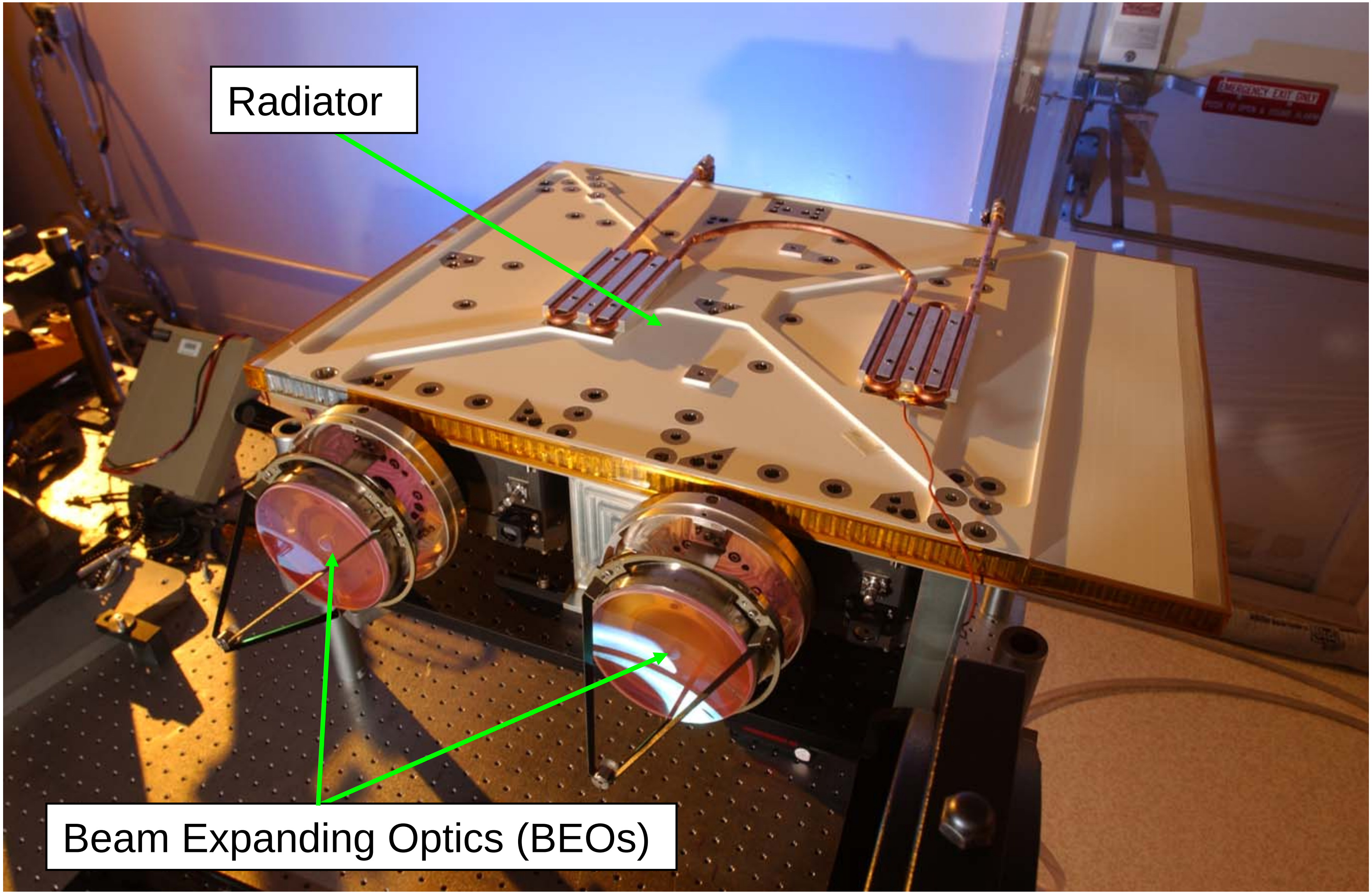
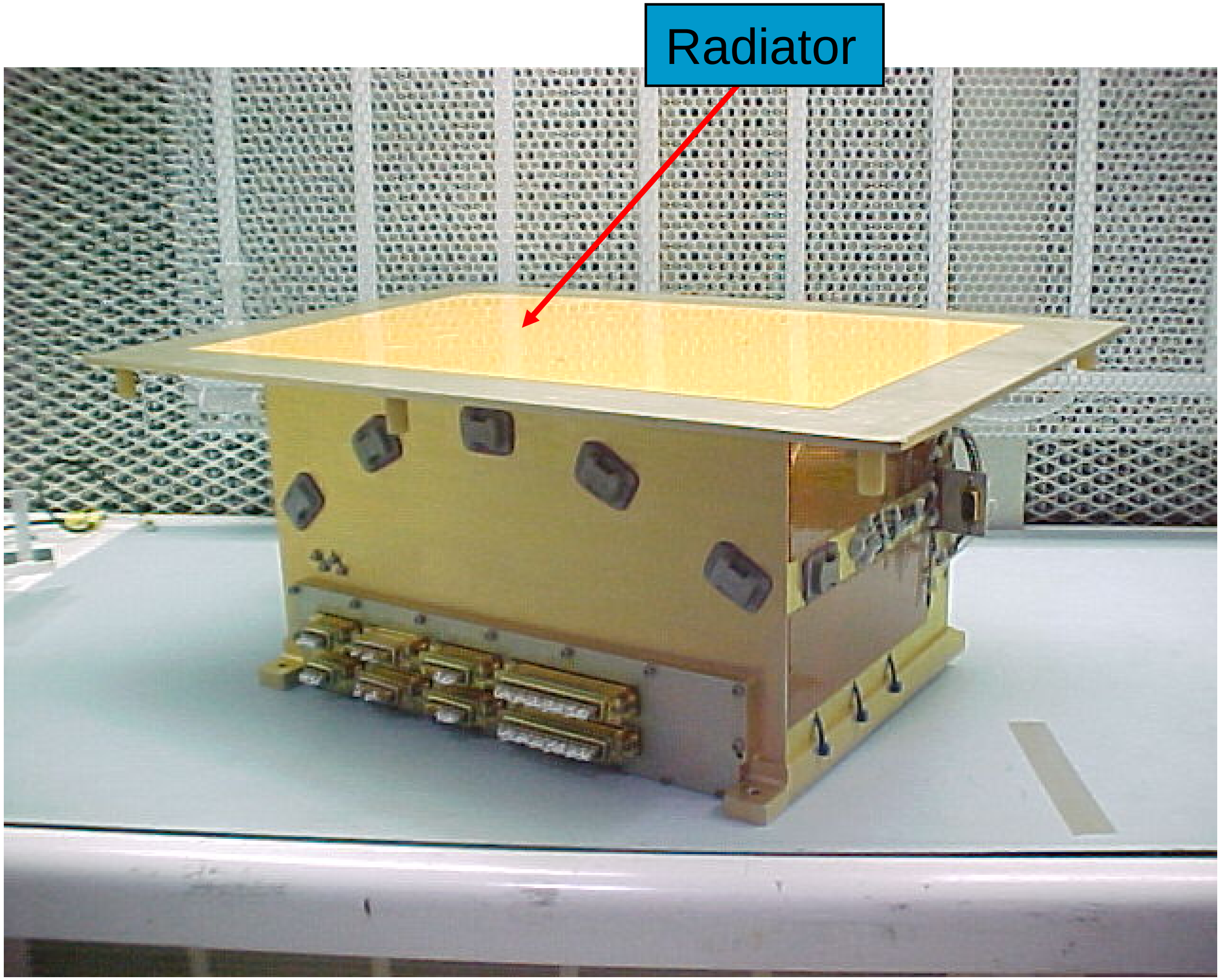


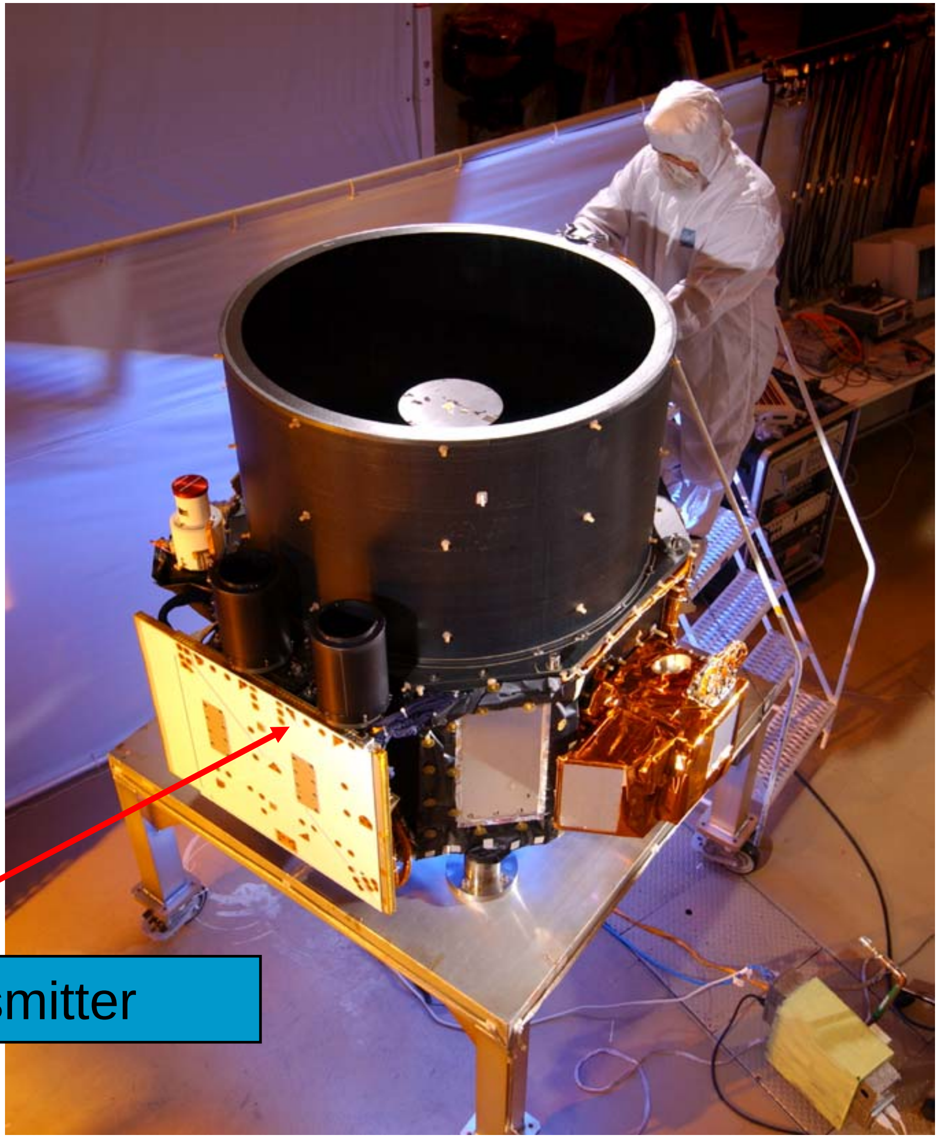
Integrated Laser Transmitter (ILT)



Laser Electronics Unit

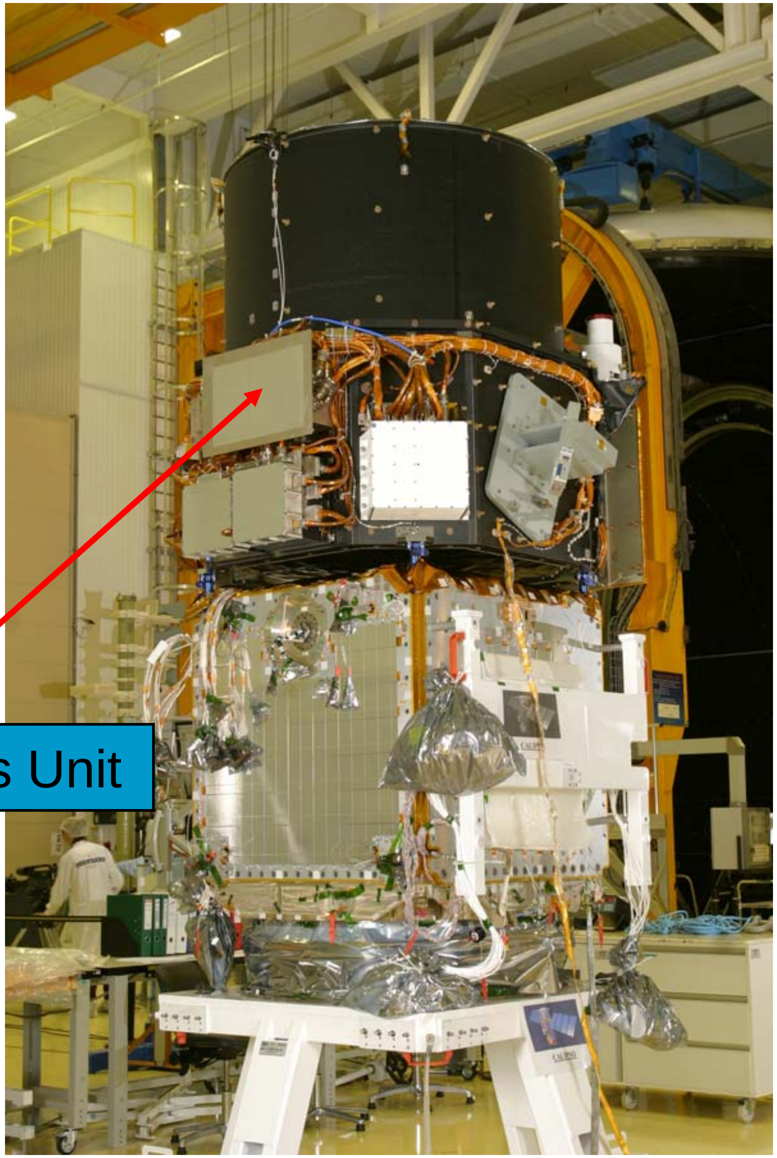


Payload Integration



Integrated Laser Transmitter

Spacecraft Integration

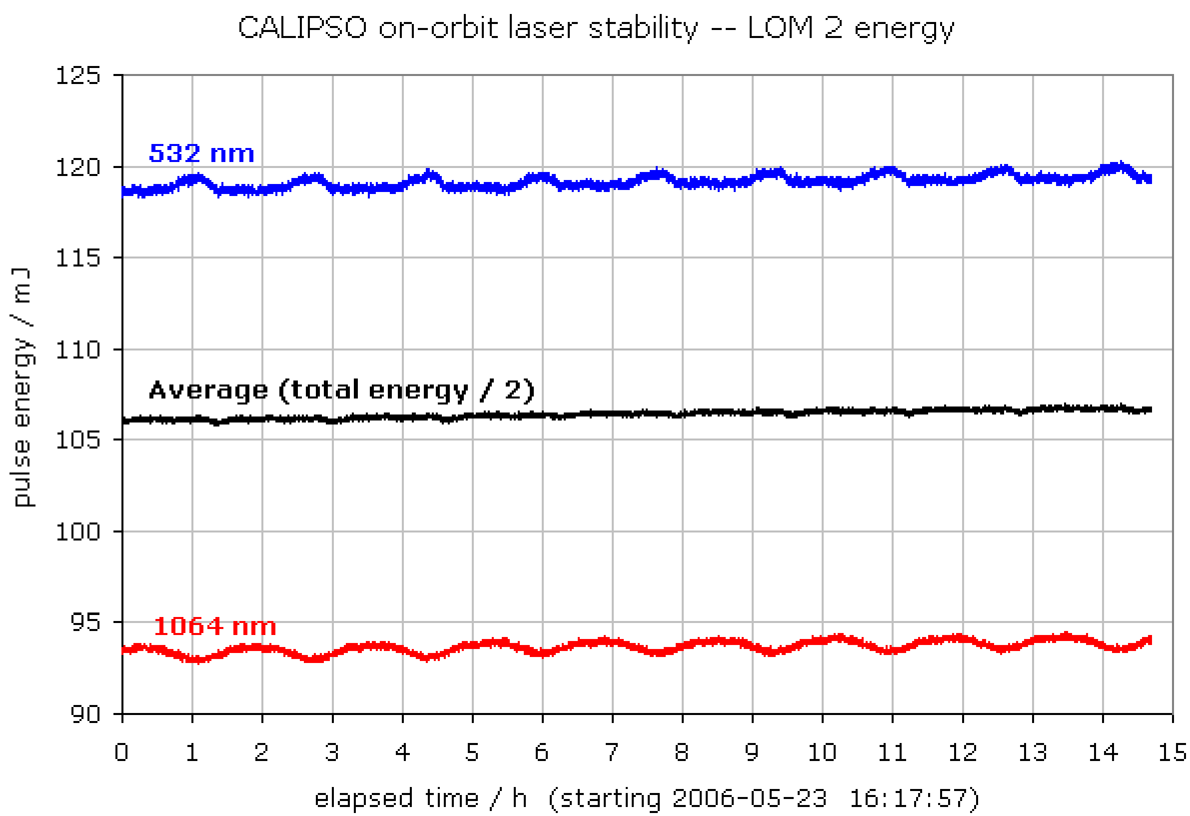


Laser Electronics Unit

Orbital Laser Performance

- CALIPSO launched on April 28, 2006
- Health of the electronics and internal pressure verified for both lasers ~ 2 weeks later
- Laser #2 was successfully operated at full power on May 23
  - Total power unchanged, small balancing of 1064 nm/532 nm needed
  - A lidar ground return was observed even though the laser transmitter assembly pointing had not been aligned, yet.
- The laser was shutdown to allow final orbit correction maneuvers and was restarted June 6 after the satellite had entered the A-Train
  - Final laser and lidar alignments performed week of June 5
- First lidar data released June 9

Orbital Laser Energy Trend – First Day



Laser firing at 20 Hz, energy data sampled at 0.2 Hz (one sample per 100 shots)

Orbital Energy Distribution- First Day

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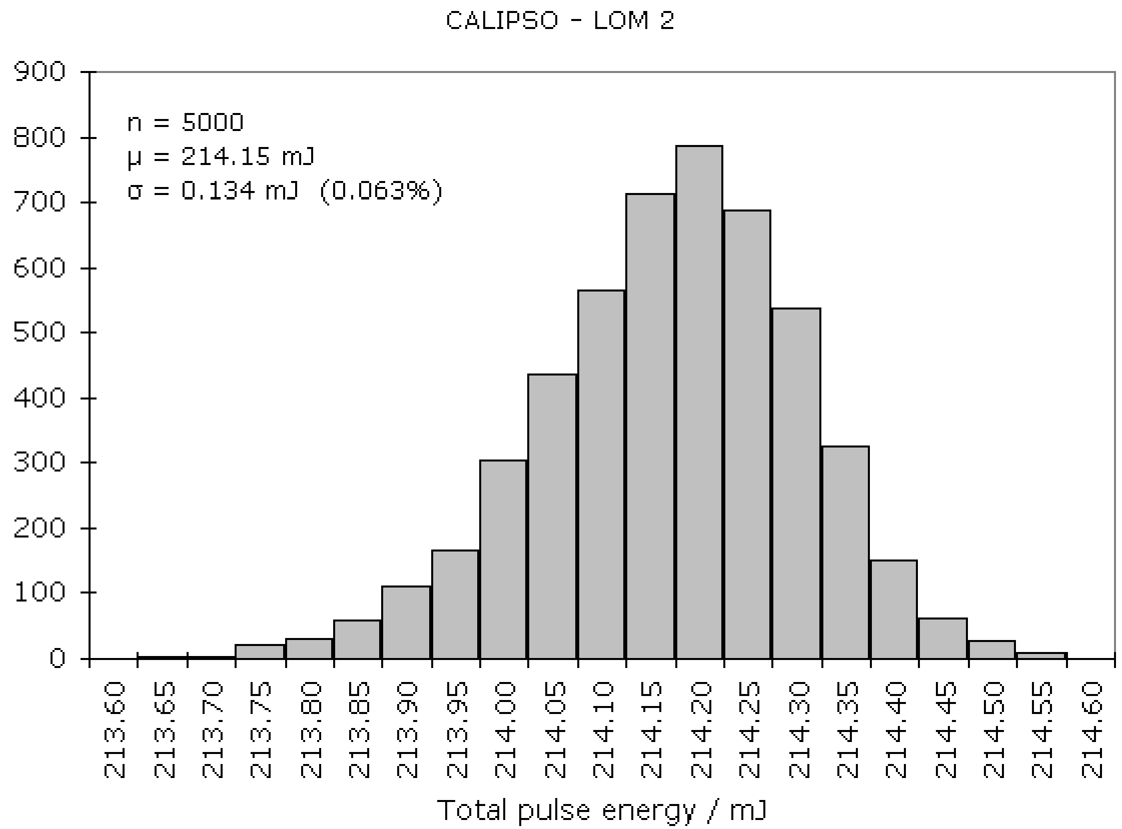
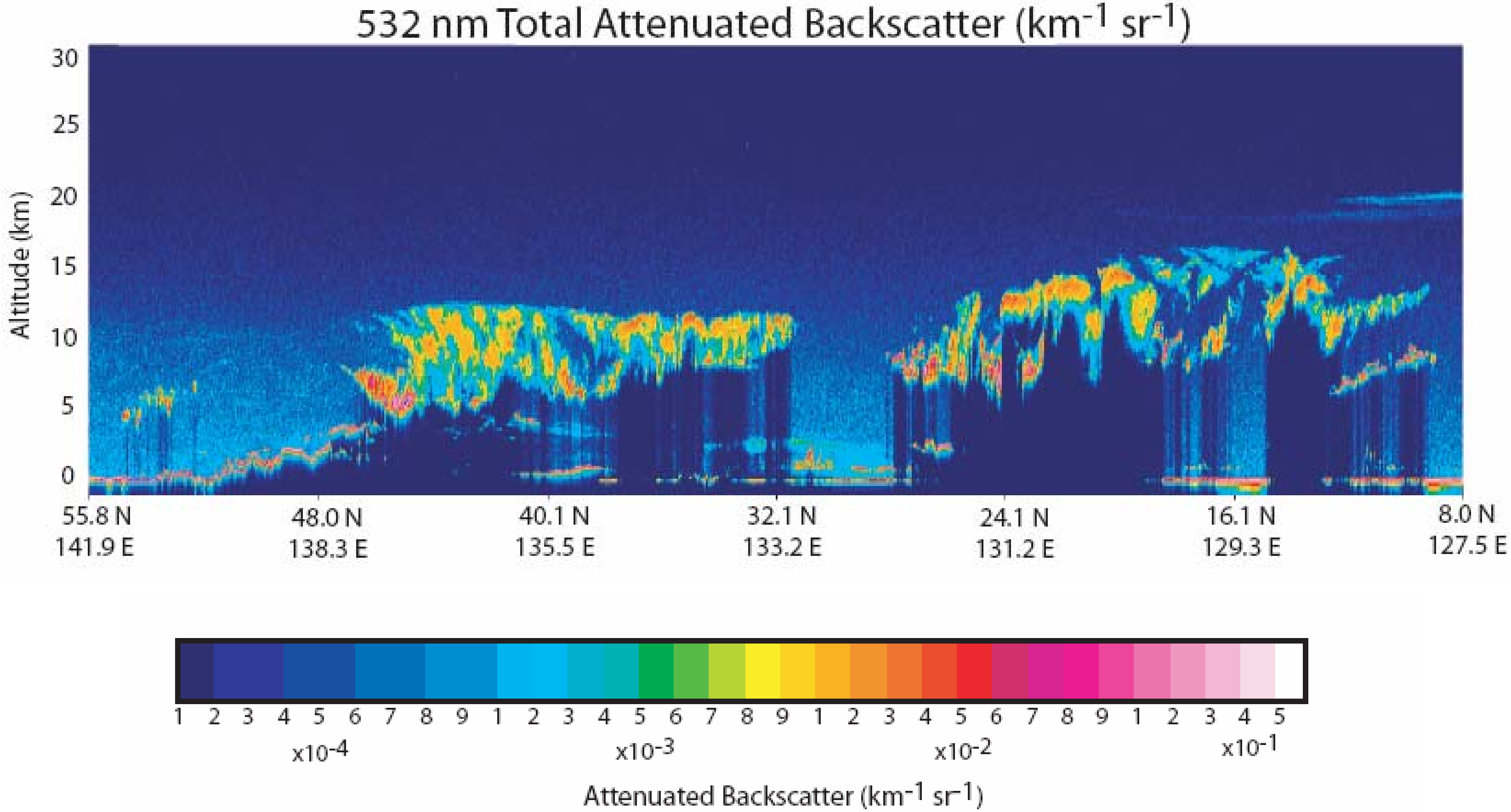


Histogram and statistics computed after removing linear trend from chart above

CALIPSO 'First-Light' Lidar Measurements
7 June 2006



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