# Recent Progress on Lasers for Space-Based Wind, Aerosol, and Altimetry Lidar Systems

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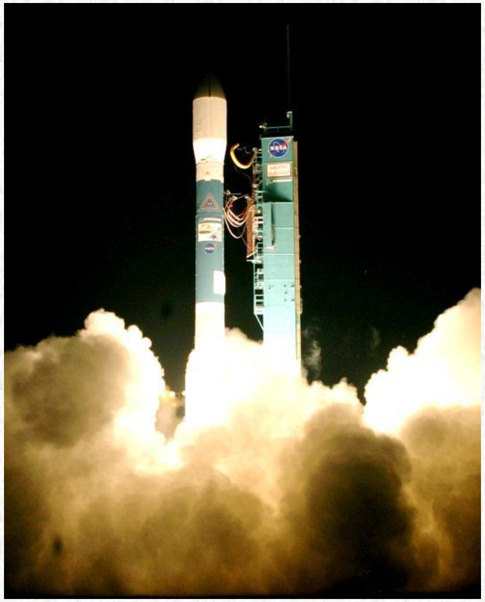
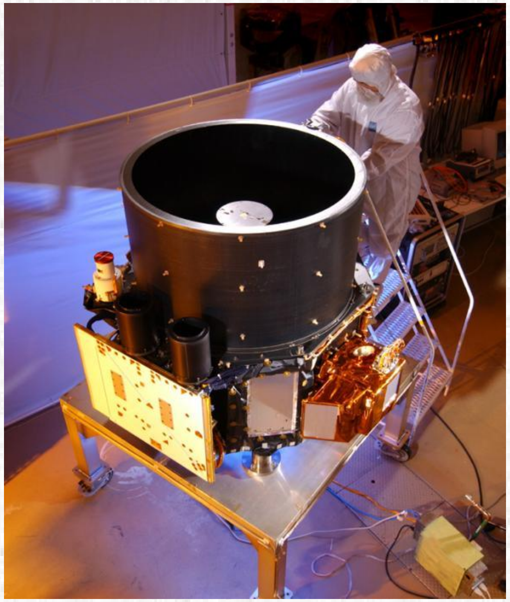
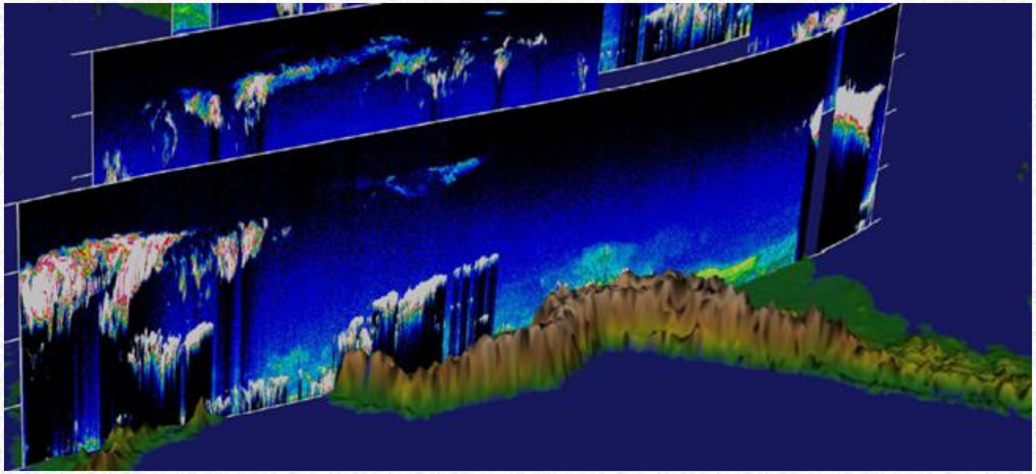
# Outline

- CALIPSO on orbit performance summary
- Cloud Aerosol Transport System for ISS (CATS/ISS) Status
- ICESat-2 Status
- Overview of the High Efficiency UV Demonstrator (HEUVD) Program
- Laser Design for ATHENA/OAWL

# CALIPSO Flight Lasers







| CALIPSO Flight Lasers |
|---|
| Launched 2006 |
| Space-based aerosol measurements |
| Nd:YAG<br>20 Hz<br>110 mJ @1064 and 532 nm |
| 3 yr mission completed with laser SN #2<br>Laser SN #1 operational for additional 5 years, projected to operate > 7 yr<br>4.7x$10^9$ shots on orbit |
| Two fully space-qualified laser transmitters and electronics units delivered |

# CALIPSO Laser On-Orbit Performance

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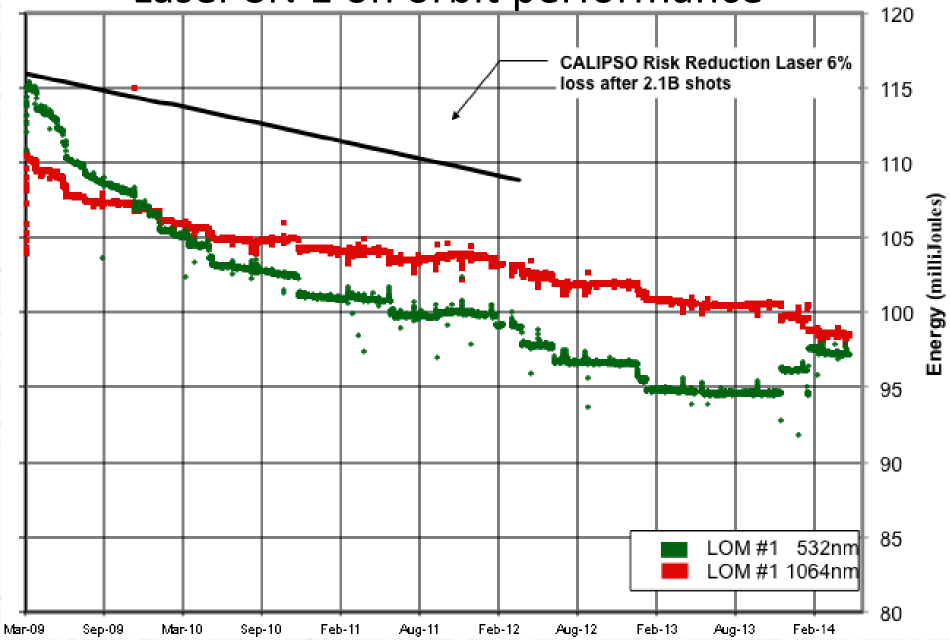
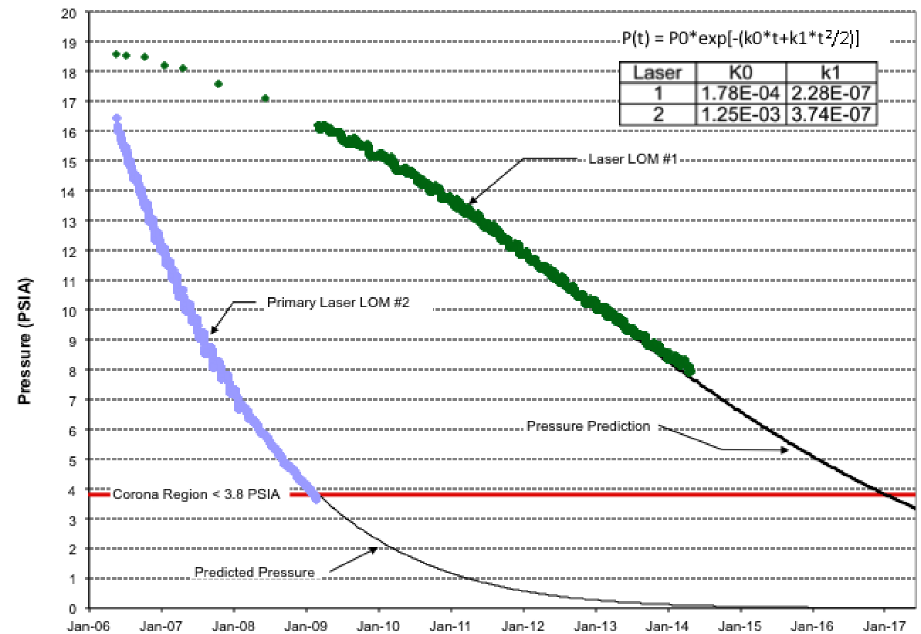
Laser SN 1 on orbit performance



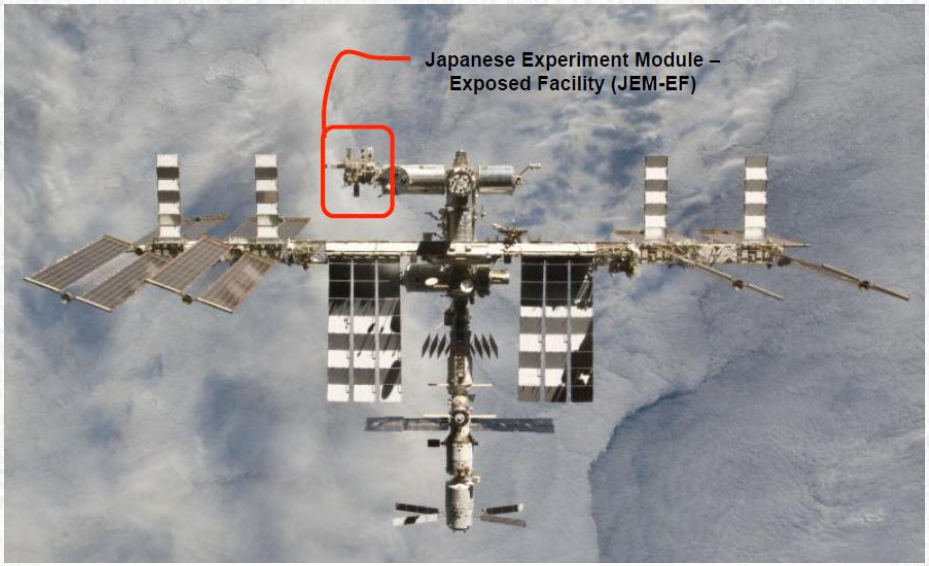



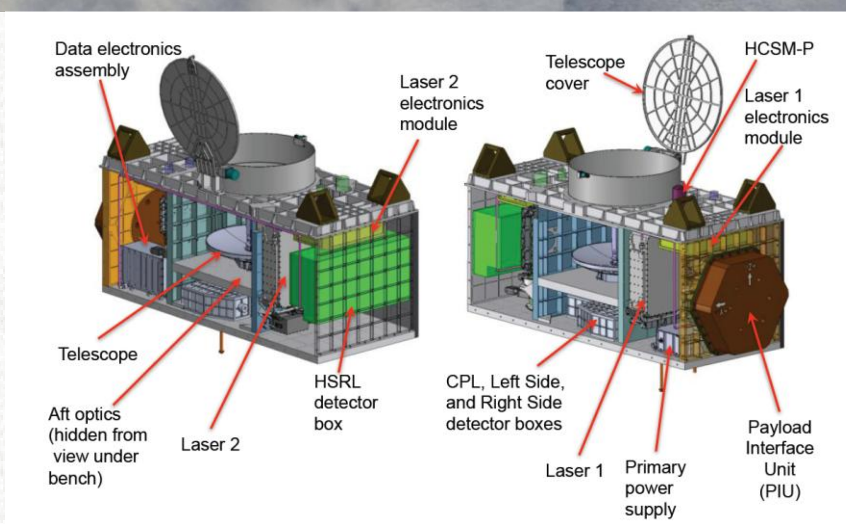

On orbit pressure profiles

- **Laser SN 2 met 3 year mission life**
  - Power decay rate was 2.2% per year
  - Lifetime limited by slow pressure leak observed before launch
- **Laser SN 1 still in operation**
  - Power decay rate has been 2.7% per year
  - Current pressure and power decay rates supports operation into 2017
- **Restart of SN 2 being evaluated**
  - Will be out of low pressure corona region by 2017

Laser SN 2

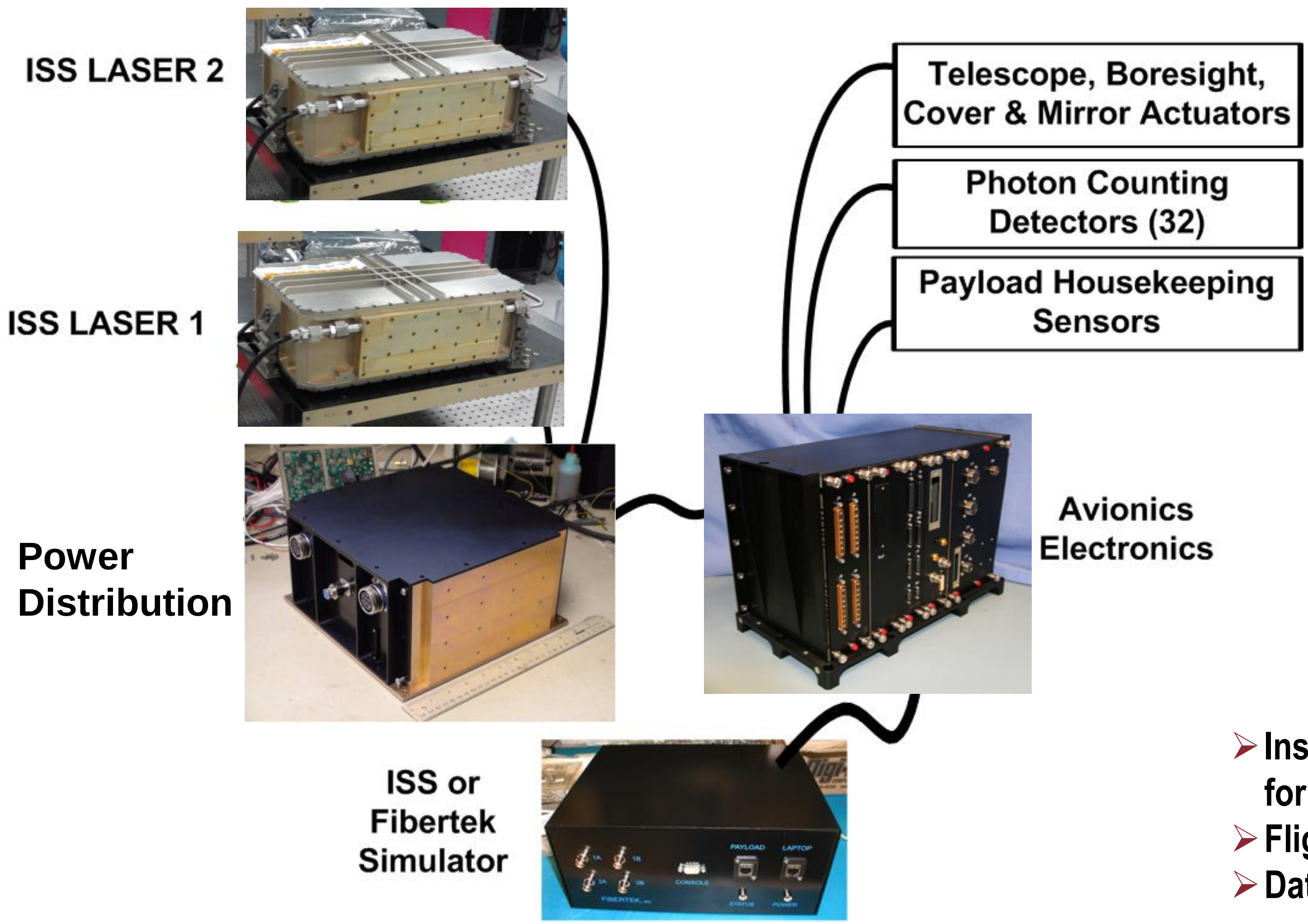
# Cloud-Aerosol Transport System for ISS




- **The Cloud-Aerosol Transport System (CATS) is a LIDAR remote sensing instrument designed to provide range-resolved profile measurements of atmospheric aerosols and clouds.**
- **The CATS instrument uses high repetition rate lasers operating at three wavelengths (1064, 532, and 355 nm) to derive properties of cloud and aerosol layers including: layer height, layer thickness, optical depth, extinction, and depolarization-based discrimination of particle type.**

# Fibertek CATS-ISS Deliverables

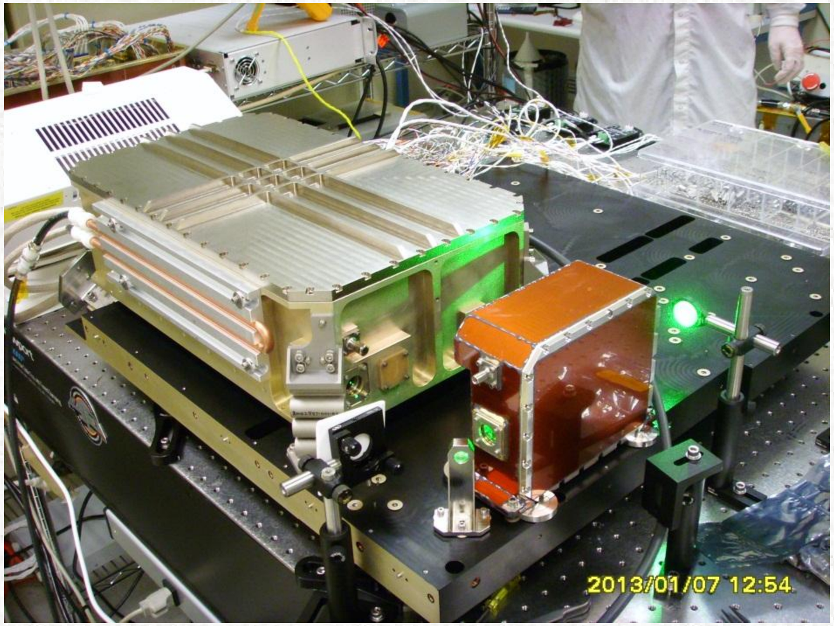



- Instrument Flight Controller for GSFC, PI
- Flight Firmware, Data System
- Data transport to GSFC

# CATS-ISS Laser Systems

FIBERTEK, INC.

**Laser #2 Integrated onto the Flight Optical Bench**

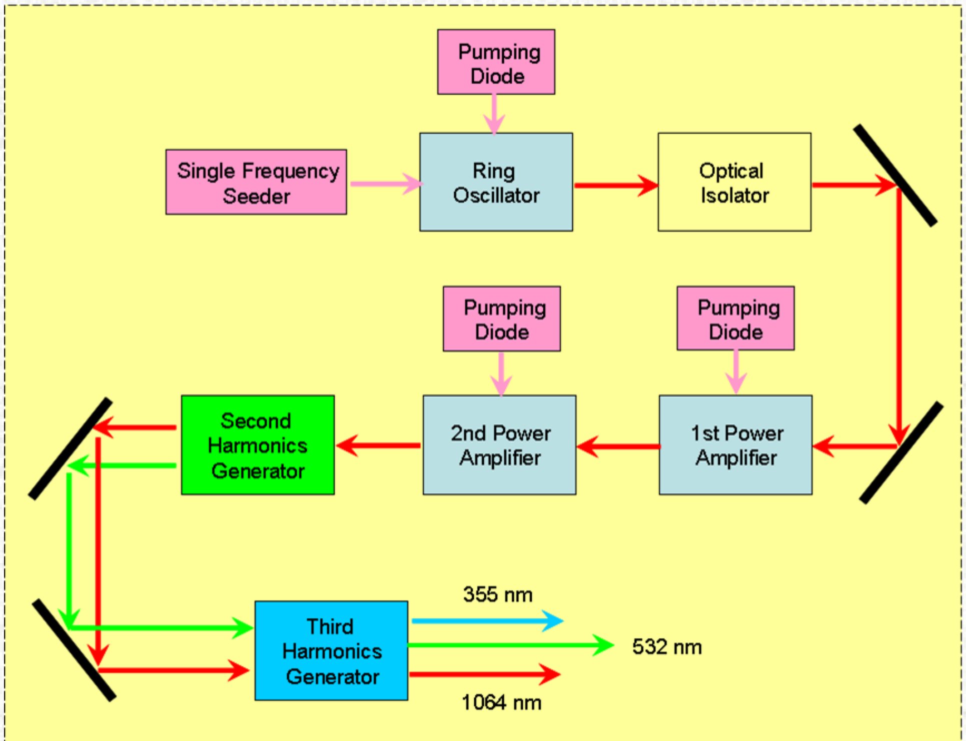


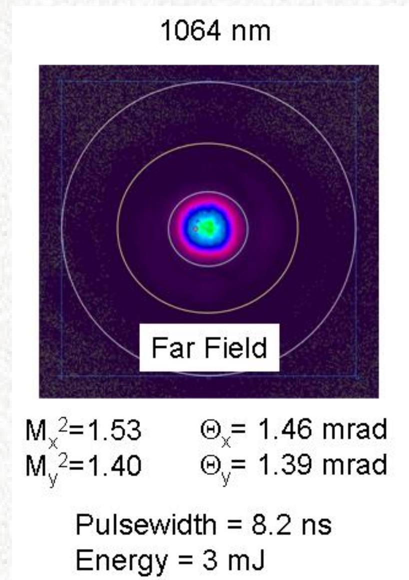

**Key Performance Parameters**

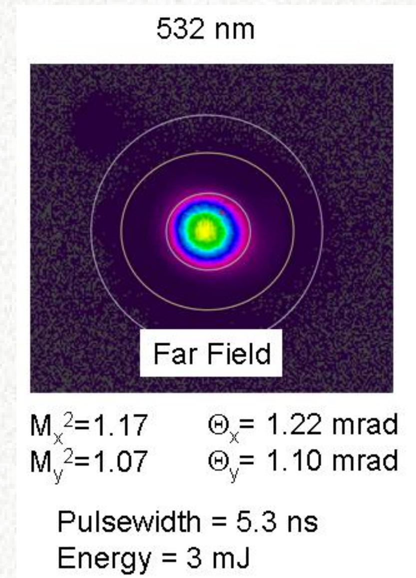
| Parameter | Laser #1 | Laser #2 |
|---|---|---|
| Total Power (W) | 27 | 23.3 |
| Rep Rate (Hz) | 5,000 | 4,000 |
| 1064 nm (W) | 13 | 9.4 |
| 532 nm (W) | 14 | 4.6 |
| 355 nm (W) | NA | 9.3 |
| Linewidth (pm) | 0.1-0.3 | Single-frequency |

**The combination of average power (~25 W), beam qualities ($M^2 < 1.5$), and linewidth are a significant improvement over previous flight missions**

# CATS-ISS Laser #2 Performance




- **CATS laser systems, 2 flight systems, were designed, built, qualified and delivered in a 2 year period.**

# CATS-ISS Mission Status

FIBERTEK, INC.

- **Launch vehicle changed from HTV to SpaceX Dragon capsule**
  - Resulted in an increase in predicted random vibration axial loads from 4 $g_{rms}$ to 6.5 $g_{rms}$
- **Full CATS-ISS payload successfully retested at 6.5 $g_{rms}$ in May 2014**
- **CATS-ISS mission on track for a fall 2014 launch**

# ICESat-2 Mission Overview

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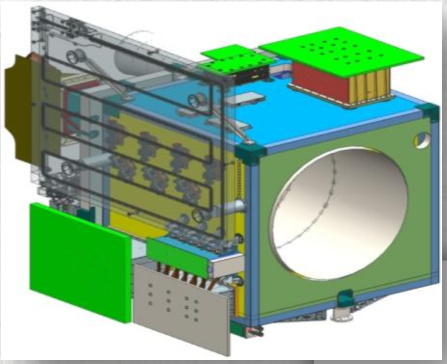
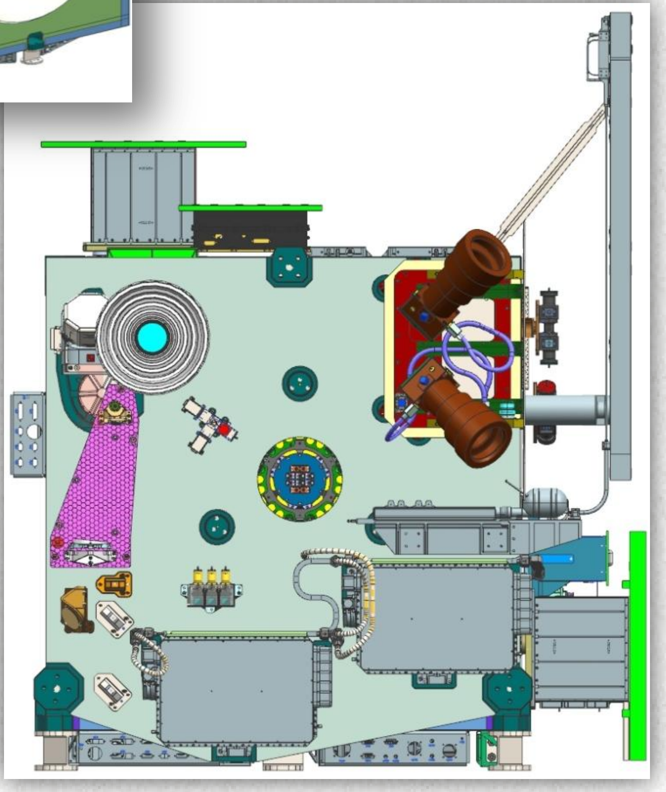
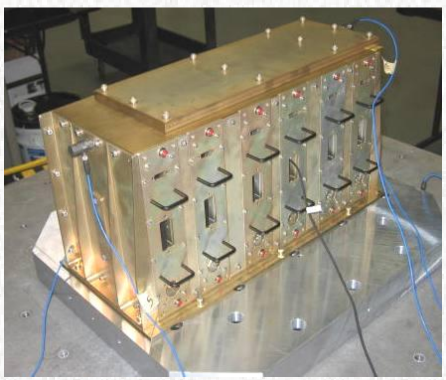




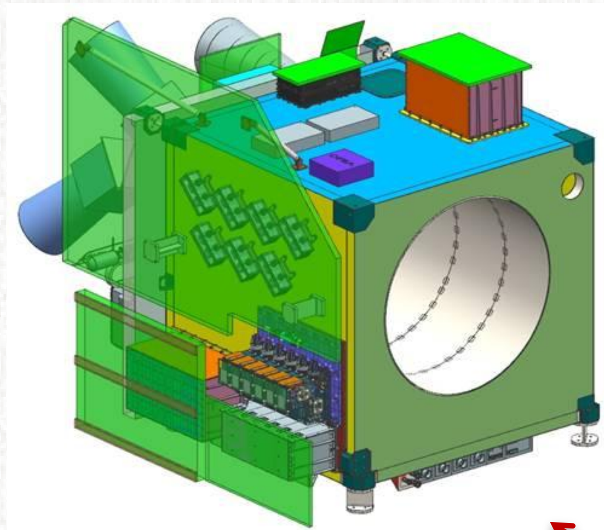
- **The ATLAS instrument is a multi-beam, micropulse, cm class laser altimeter with a dense along-track sampling of 70 cm**
- **Science Objectives:**
  - Quantifying polar ice-sheet contributions to current and recent sea-level change and the linkages to climate conditions.
  - Quantifying regional signatures of ice-sheet changes to assess mechanisms driving those changes and improve predictive ice sheet models.
  - Estimating sea-ice thickness to examine ice/ocean/atmosphere exchanges of energy, mass and moisture.
  - Measuring vegetation canopy height as a basis for estimating large-scale biomass and biomass change.
  - Enhancing the utility of other Earth observation systems through supporting measurements.

# Fibertek ICESat-2  Deliverables

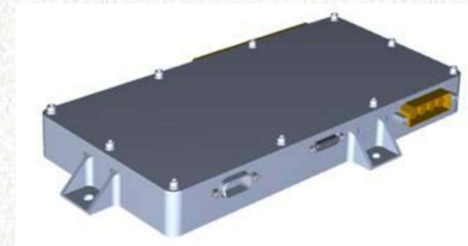
**Photon Counting  CFD circuits (120 PMT Channels)**



**Delivery: June 2014**



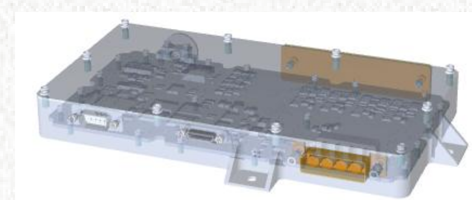
**Start Pulse Detector Altimeter $T_o$ Signal (Integrate and Test)**



**Delivery: June 2014**

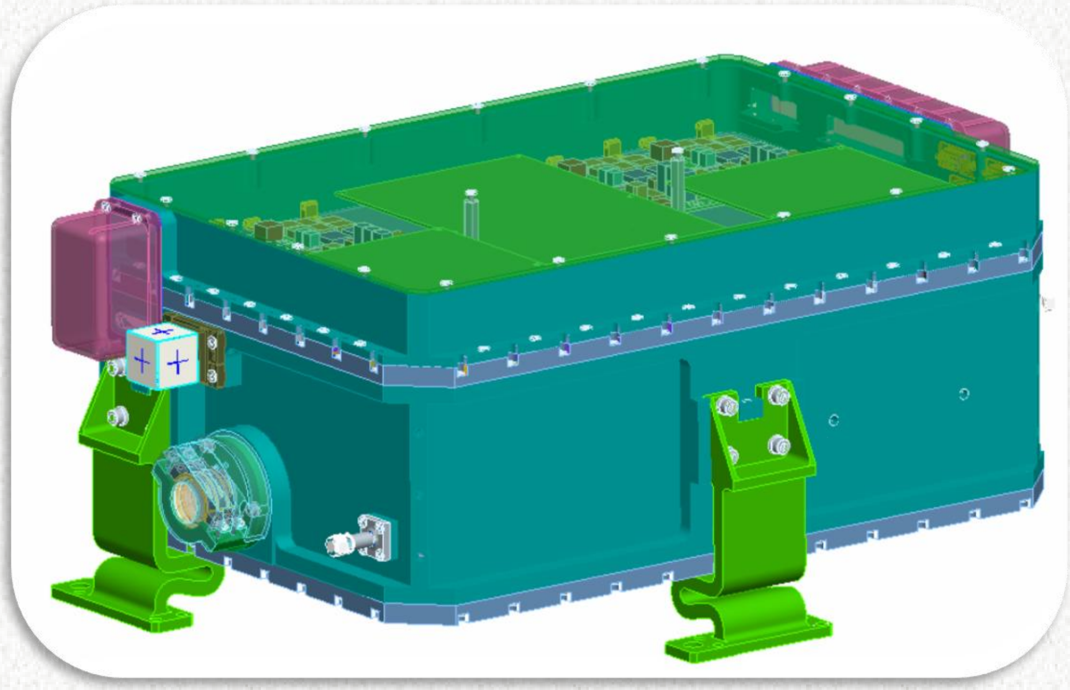
**Lasers**

**Laser Wavelength Control Electronics (Integrate and Test)**



**Delivery: May 2014**

# ICESat-2 Laser Driving Requirements



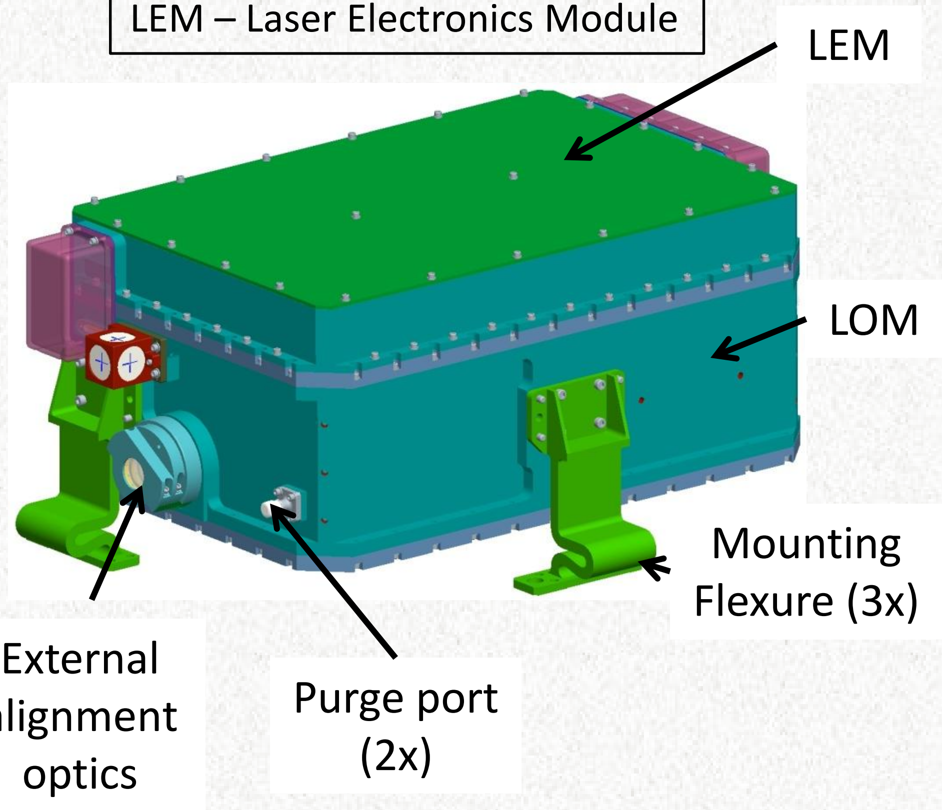
| Driving Requirements |
| --- |
| Wall-Plug Efficiency >5 % |
| Tunable Pulse Energy 250 - 900 µJ |
| Center Wavelength 532.xxx nm ±15 pm, in vacuum |
| Wavelength Stability & Linewidth < 30 pm |
| Mean output wavelength tuning |
| Mean Pulse Width < 1.5 ns |
| Repetition Rate 10 ± 0.3 kHz |
| Polarization Linear 100:1 |
| Spatial Mode 1.6 x diffraction limit [M2 < 1.6] |
| Shot-to-shot Pointing Stability < 10.8 µrad drift |
| Boresight shift during vibe testing < 200 µrad |
| Lifetime 3 years + 60 days |
| Environmental Survival GEVS (14.1 grms qual vibe) |

# Flight Laser System Packaging Overview

FIBERTEK, INC.

- **Integrated LOM/LEM with single thermal interface**
  - Mass < 21.6 kg
  - <50 cm x 30 cm x 15 cm
  - Robust to GEVS random vibe
- **Wavy flexure mounts**
  - Filters high-frequency content of GEVS 14.1 $g_{rms}$ random vibe inputs
  - Provides short-term & long term pointing stability
- **Dual compartment LOM with pressure insensitive center plane**
  - Allows air pressurization for long optical reliability
  - Short term & long term pointing stability

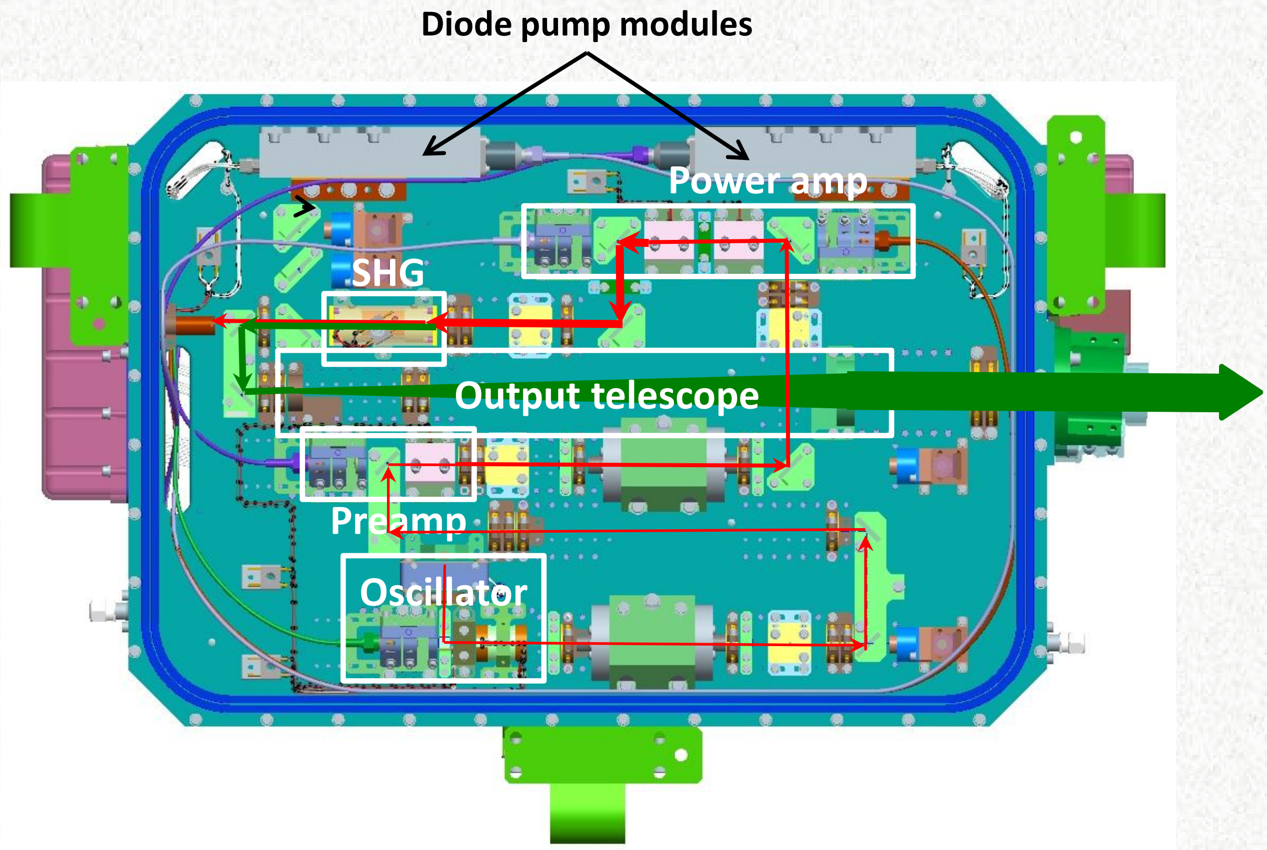
LOM – Laser Optical Module
LEM – Laser Electronics Module




**Packaging approach meets key mechanical driving requirements**

# Flight Optical Configuration

- **Fiber-coupled diode pump modules**
- **Short, electro-optic (E-O) Q-switched oscillator**
  - 1.3 ns pulse width
  - 100:1 linear polarization
- **End-pumped gain medium**
  - $M^2 \sim 1.3$
  - Supports 7% wall plug efficiency @ 532 nm
- **MOPA configuration**
  - 250-900 µJ/pulse
- **LBO doubled Nd:YVO4**
  - 532 nm
- **Internal telescope**
  - 10 mm output beam

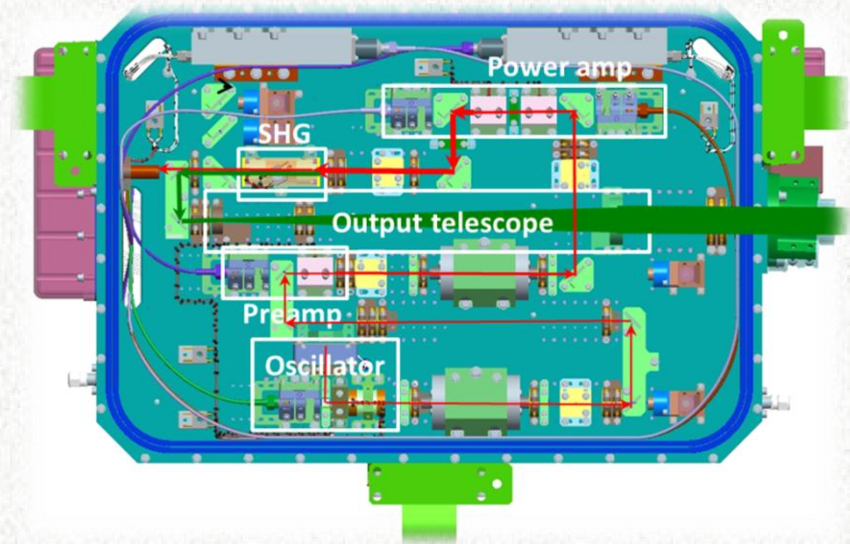


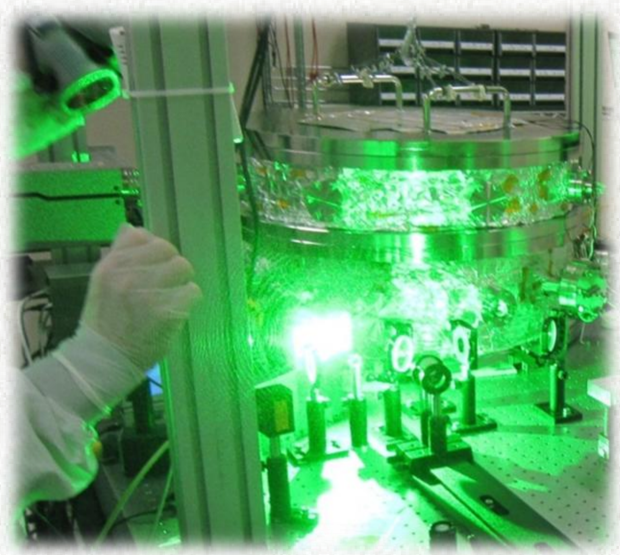

Frequency doubled Nd:$YVO_4$ MOPA achieves key optical driving requirements

# ICESat-2 Laser Design Performance Overview

FIBERTEK, INC.

- **Fully redundant lasers and electronics**
- **Sealed, dual compartment laser canisters**
- **Air operation better understood & reduces sensitivity to trace contamination**
- **Master oscillator/power amplifier**
  - End-pumped for high beam quality and efficiency
  - Compact EO Q-switched resonator for < 1.5 ns pulse width
  - VBG output coupler provides wavelength tuning
- **End pumping achieves wall plug efficiency to 532 nm of 7%**
  - 1064 nm Optical-to-Optical efficiency  35%

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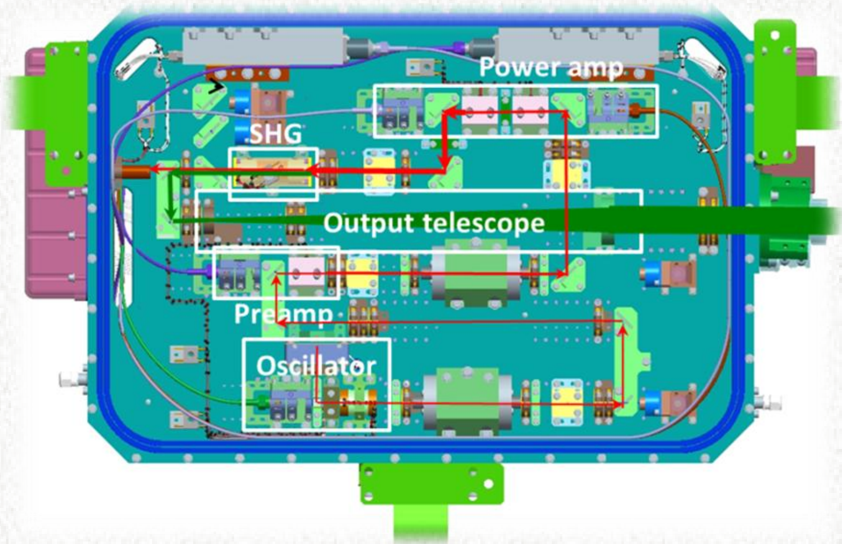
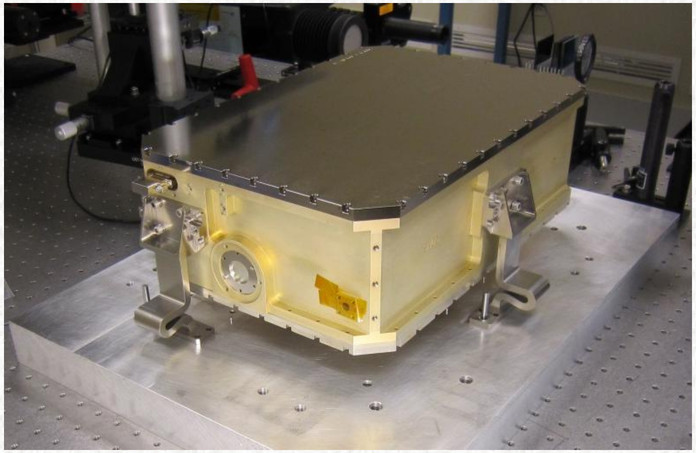
# ICESat-2 Laser Build Status

- **Integration and Test Laser (qual unit)**
  - Laser Optics Module (LOM) fully assembled and tested
    - Meets all performance specs with margin
  - Laser Electronics Module (LEM) assembled and tested
  - Integrated testing of LOM and LEM is ongoing in preparation for qual testing
- **Flight SN1**
  - LOM is built and tested through the output telescope
    - Meets all performance specs with margin
  - All LEM boards are built and tested
- **Flight SN2**
  - LOM is built and tested through the SHG
    - Meets all performance specs with margin
  - All LEM boards are built and tested
- **On track for Q4 2014 deliver of flight units**



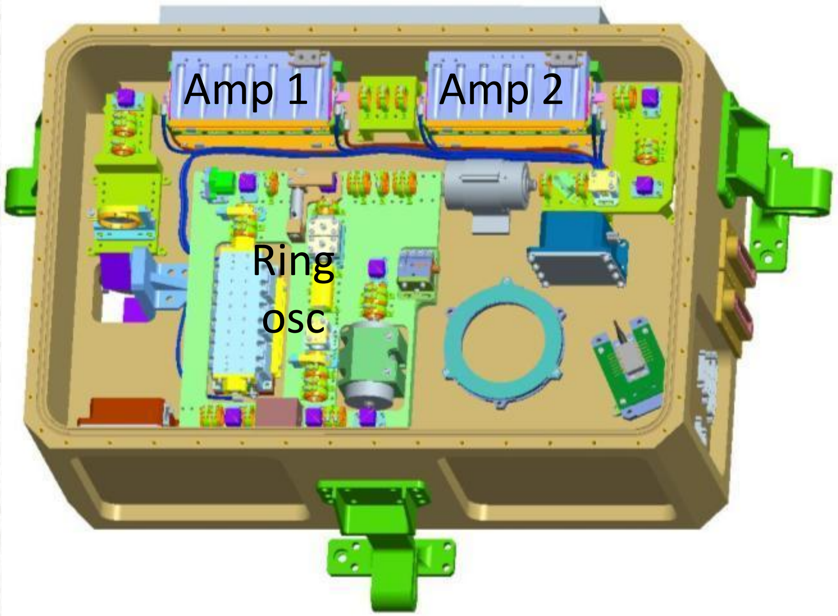
Flight Laser SN1 after flexure installation

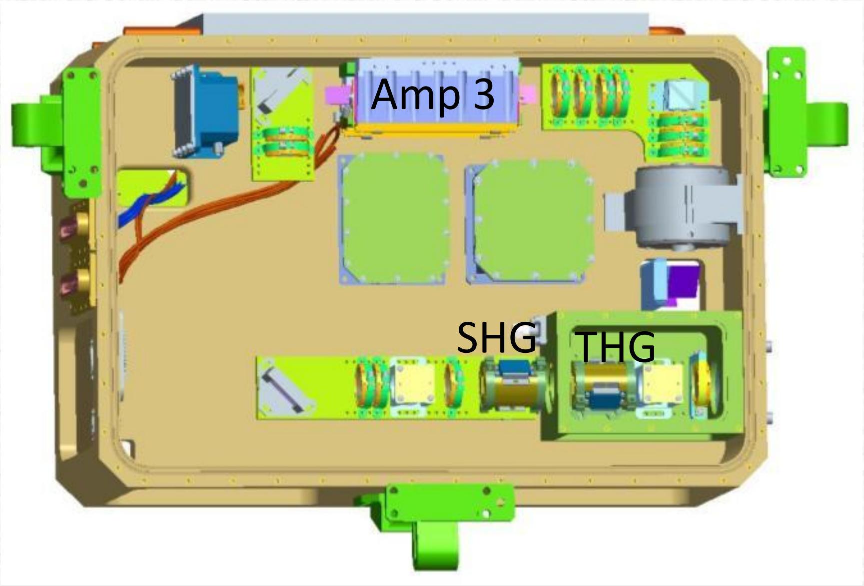
# High Efficiency UV Demonstrator (HEUVD) Objectives

FIBERTEK, INC.

- ESTO funded development/risk reduction program
- Improved 1064 nm final power amplifier - 750 mJ/pulse @ 50 Hz with an $M^2 < 2$
- Purely conductively cooled Laser Optics Module (LOM) design for packaging the 50 Hz, 750 mJ 1064 nm pump laser
- UV conversion module design with a lifetime of $>10^9$ shots that achieves 350 mJ at 355nm
- Advance the design TRL from 4 to 6
- Execute an 8 month life test of the pump laser and UV conversion module

# HEUVD Design Overview




- **Flexure-mounted, dual compartment design**
- **All amplifiers conductively cooled to a single wall**
- **Ring oscillator and first two amps lifted from HSRL-2**
- **New final power amplifier design**
  - Higher power and beam quality pump on bounce design
- **Near polymer free UV conversion module**
  - Only polymers are seal o-rings
  - Includes an internal beam expander
- **Electronics are a mix of COTS and custom designs**

# HEUVD Final Power Amplifier Status

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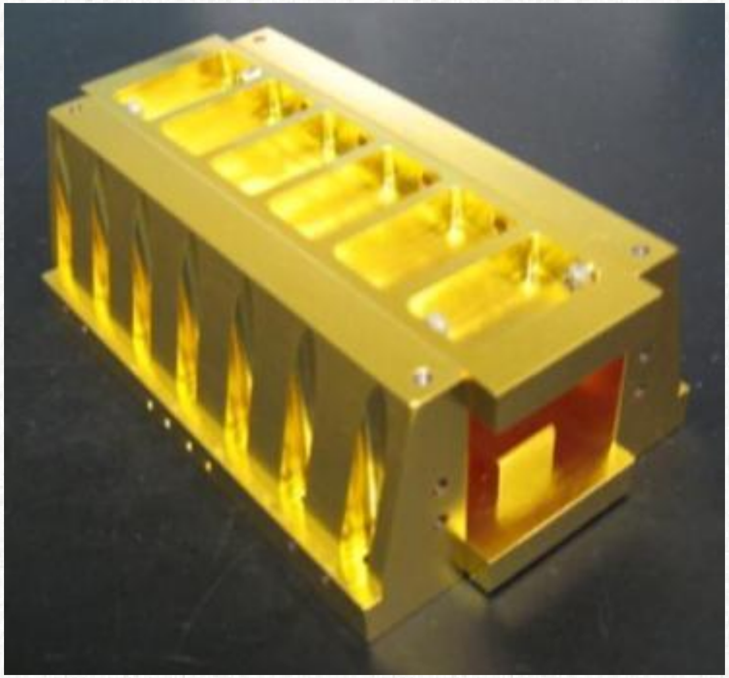


- **Amplifier is assembled and testing is underway**
  - Probed under full pump load
  - Measured small signal gain met expectations
  - Currently quantifying focusing and impact on beam quality

# Key HEUVD Milestones

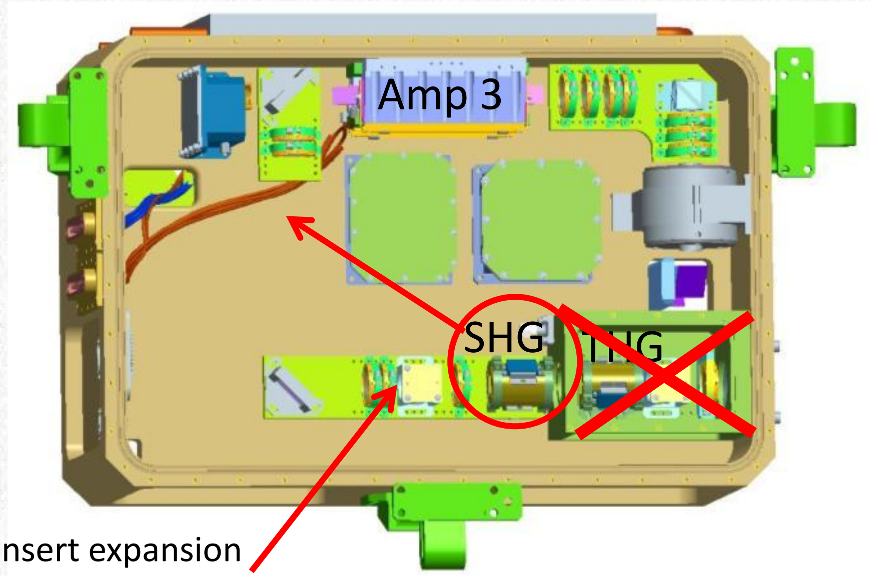
FIBERTEK, INC.

- Final boresight over pressure and thermal analyses completed in May 2014
- All parts ordered by late June 2014
- Laser assembly August-November 2014
- Environmental testing (vibe and TVAC) December 2014 through January 2015
- Lifetime testing February-September 2015

# ATHENA-OAWL Laser Design

FIBERTEK, INC.

- **Essentially HEUVD without the tripler**
  - Optimization for 150 Hz operation accomplished with modest changes to the beam conditioning optics
- **Final amp will probably change to a second HSRL-2 final amp**
  - HEUVD final amp is overkill for required pulse energies
- **Doubler will be moved closer to the final power amp**
- **Pressure insensitive expansion telescope will go into output leg**
  - Derived from ICESat-2 design
  - Pressure insensitive




Insert expansion scope here

| Predicted ATHENA-OAWL laser performance | |
|---|---|
| Repetition rate (Hz) | 150 |
| Osc. 1064 nm energy (mJ) | 7 |
| Amp #1 1064 nm energy (mJ) | 60 |
| Amp #2 1064 nm energy (mJ) | 150 |
| Amp #3 1064 nm energy (mJ) | 280 |
| 532 nm energy (mJ) | 180 |
| Residual 1064 nm (mJ) | 100 |
| 532 nm $M^2$ | < 2 |
| 532 nm beam diameter before expansion (mm) | 3 |
| 532 nm beam diameter after expansion (mm) | 22 |
| Final beam divergence (μrad) | <150 |
| 532 nm pulse width (ns) | >25 ns |