

Laser Production for NASA's Global Ecosystem Dynamics Investigation (GEDI) Lidar

SPIE DSS April 19, 2016

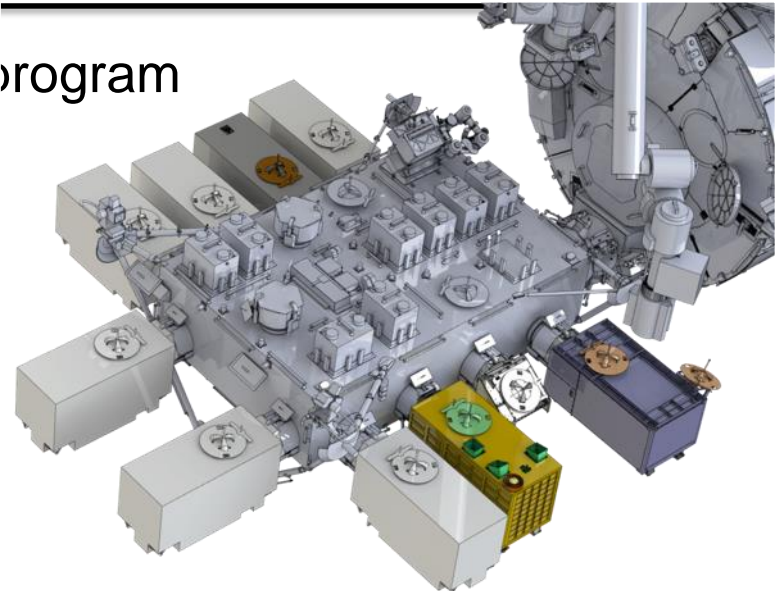
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Frese, Gordon Blalock, Peter Morey, Richard B. Kay,
Demetrios Poullos, Michael Hersh







NASA-Goddard Space Flight Center



GEDI Mission Overview

- NASA Earth Ventures Instrument (EVI) program
- \$90 M , cost capped, “PI-Led” mission
- Class C, 1-2 year mission
- Multi-beam waveform lidar instrument with 10 ground tracks
- Launch Vehicle:
Space-X Falcon 9/Dragon or equivalent
- Platform: International Space Station,
- Japanese Experiment Module Exposed Facility, Site: EFU#6
- Orbit: 415 km average; 51.6 degrees
- Payload Allocations (TBR): 600 Kg., 887 W, 5.4 Mbps
- Science and Mission Operations Ground System, B.32 GSFC

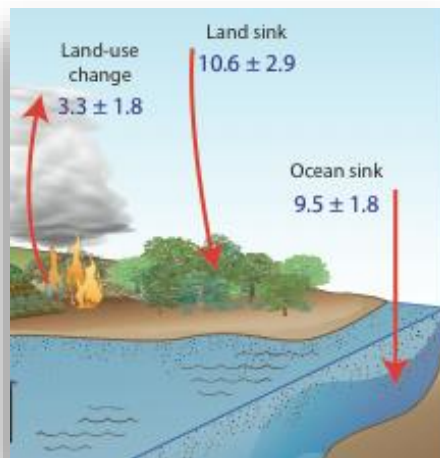


2015	2016	2017	2018	2019	2020
 SRR 6-15	 PDR 4-16	 CDR 1-17	 PER 8-17	 PSR 5-18	 LRD 8-18
				Primary Mission: 365 Days of Science Collection	Extended Mission to Account for ISS Induced Downtime



Science Goal

Characterize the effects of changing climate and land use on ecosystem structure and dynamics



CARBON CYCLE



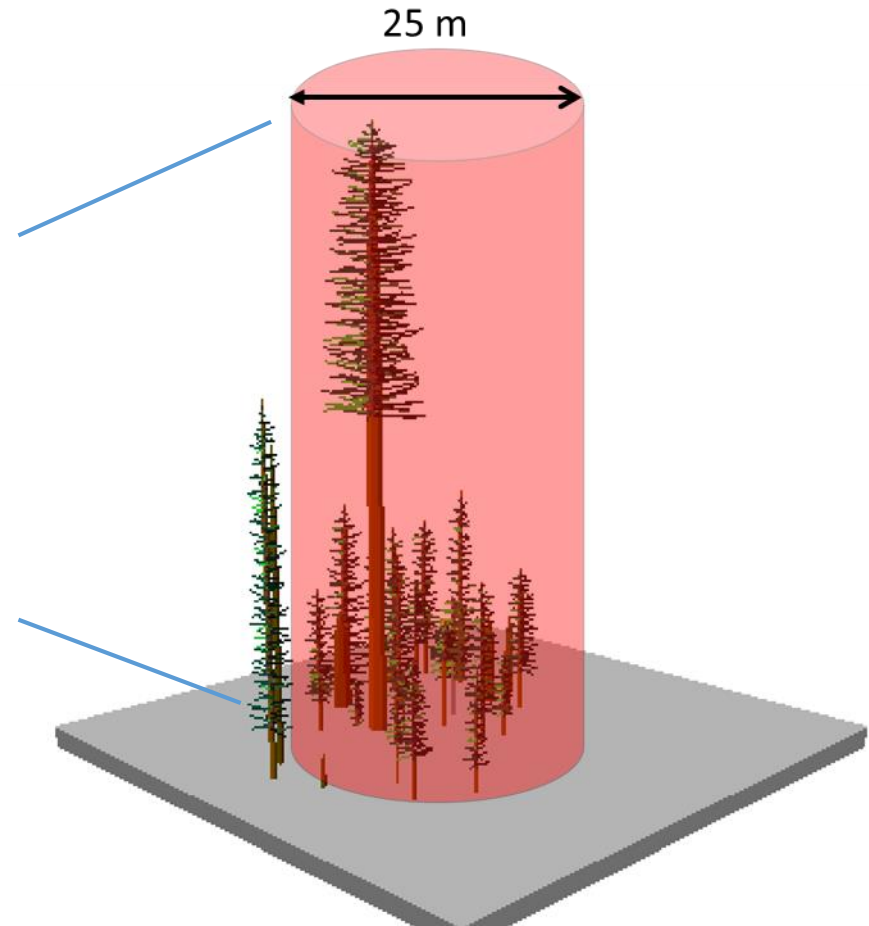
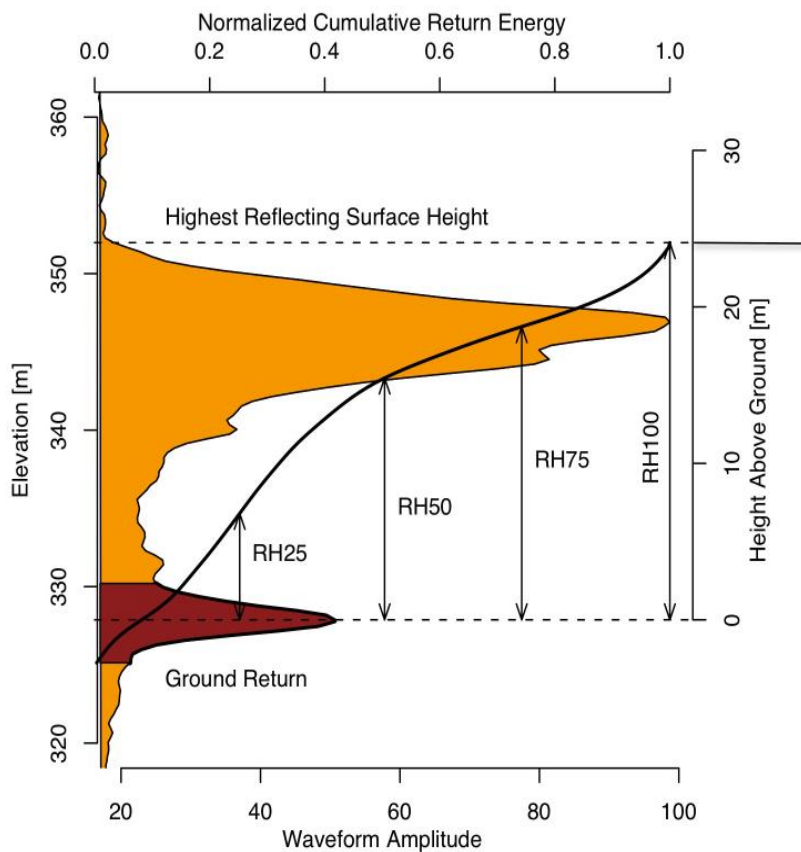
BIODIVERSITY

GEDI provides the Earth's first comprehensive and high-resolution data set of ecosystem structure



Lidar Measurement

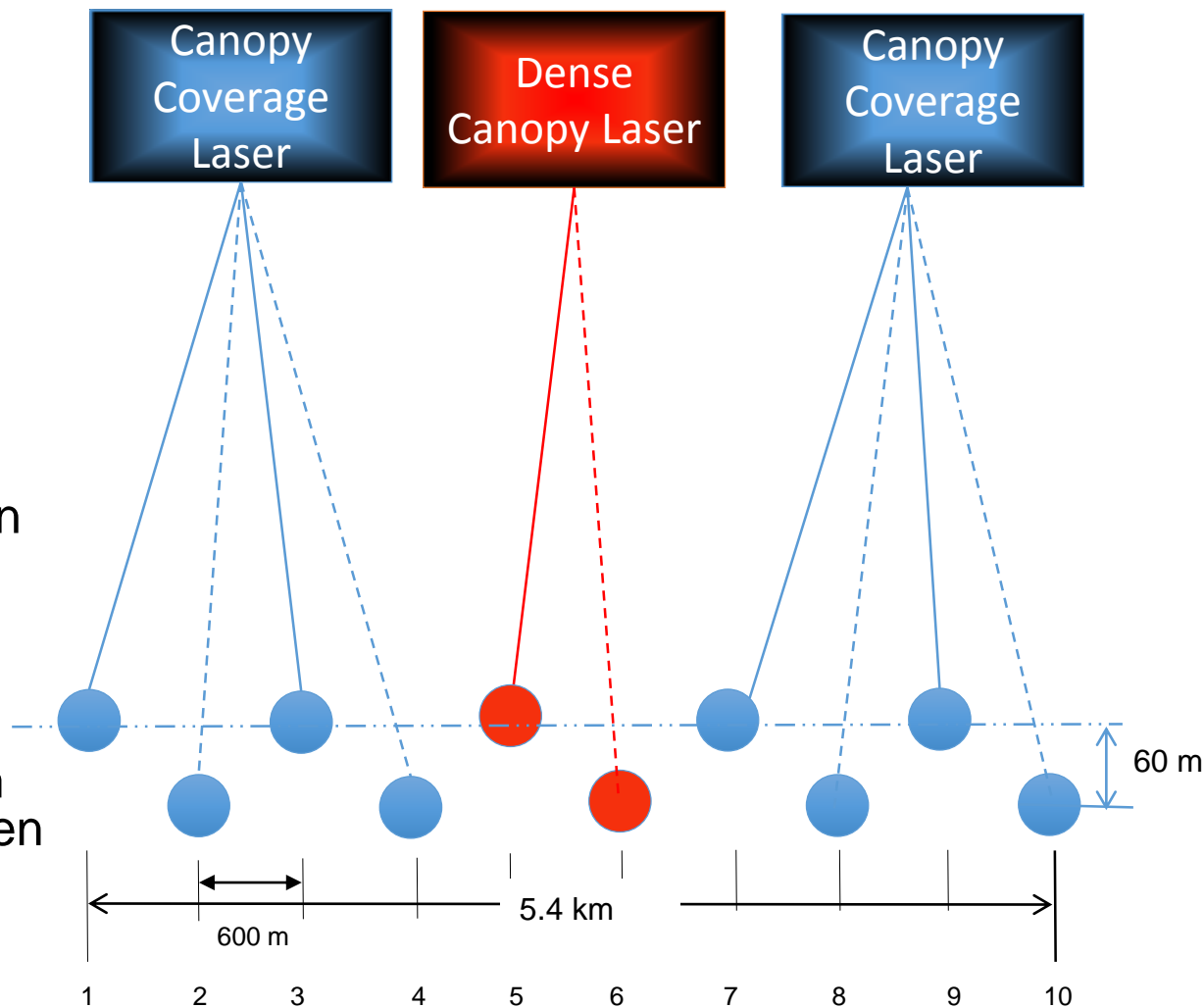
- Sole GEDI observable is the lidar waveform
 - Provide ground elevation, canopy height, canopy cover and various vertical profiles and metrics





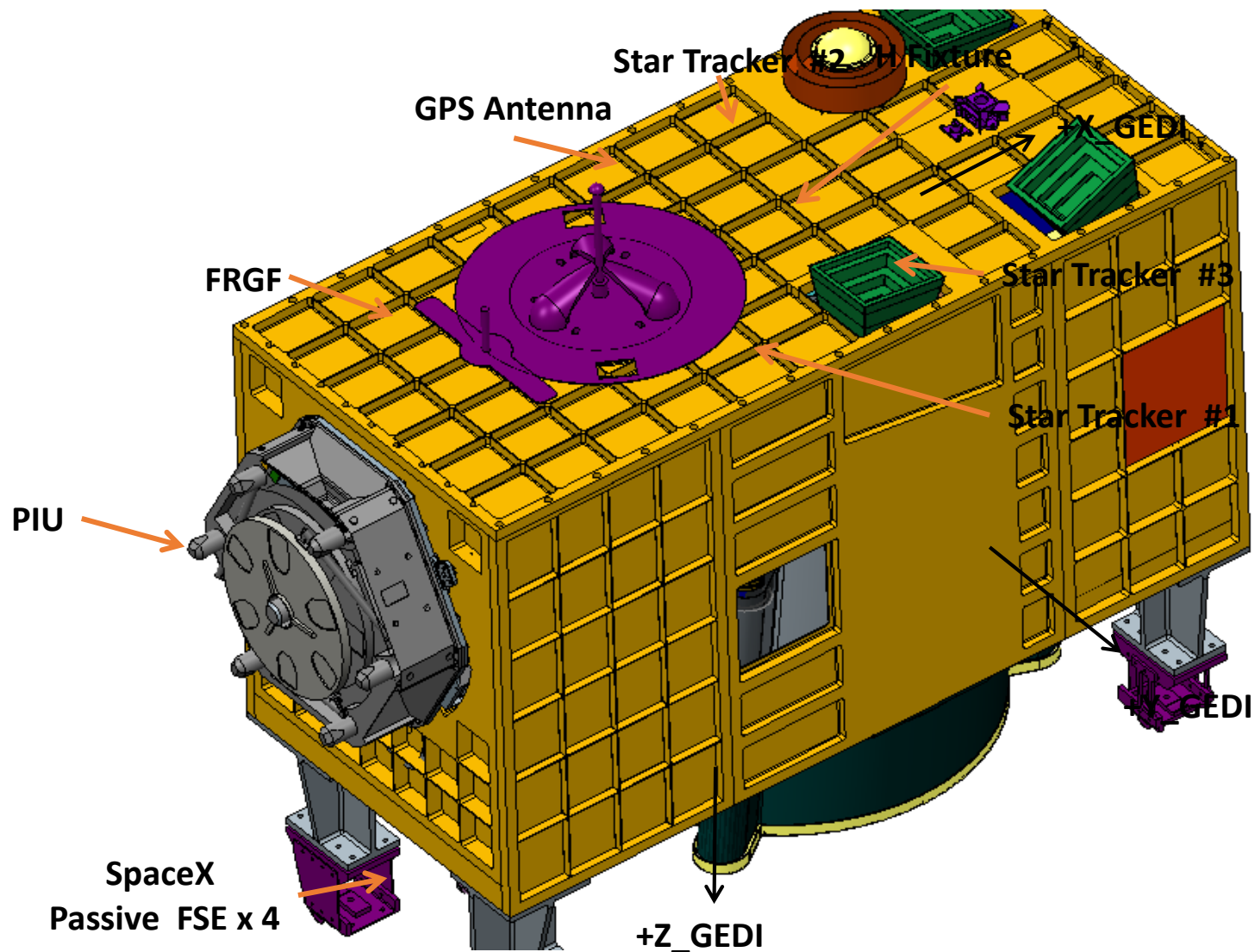
GEDI Laser Ground Track Coverage

- GEDI is self-contained laser altimeter
- 3 lasers produce a total of 10 ground tracks
- Precise ranging, attitude & position sensors enable precise geo-location of each laser footprint (10-m knowledge)
- Active Pointing Control Mechanism (PCM) provides even distribution and complete coverage of ground tracks (225-m control)



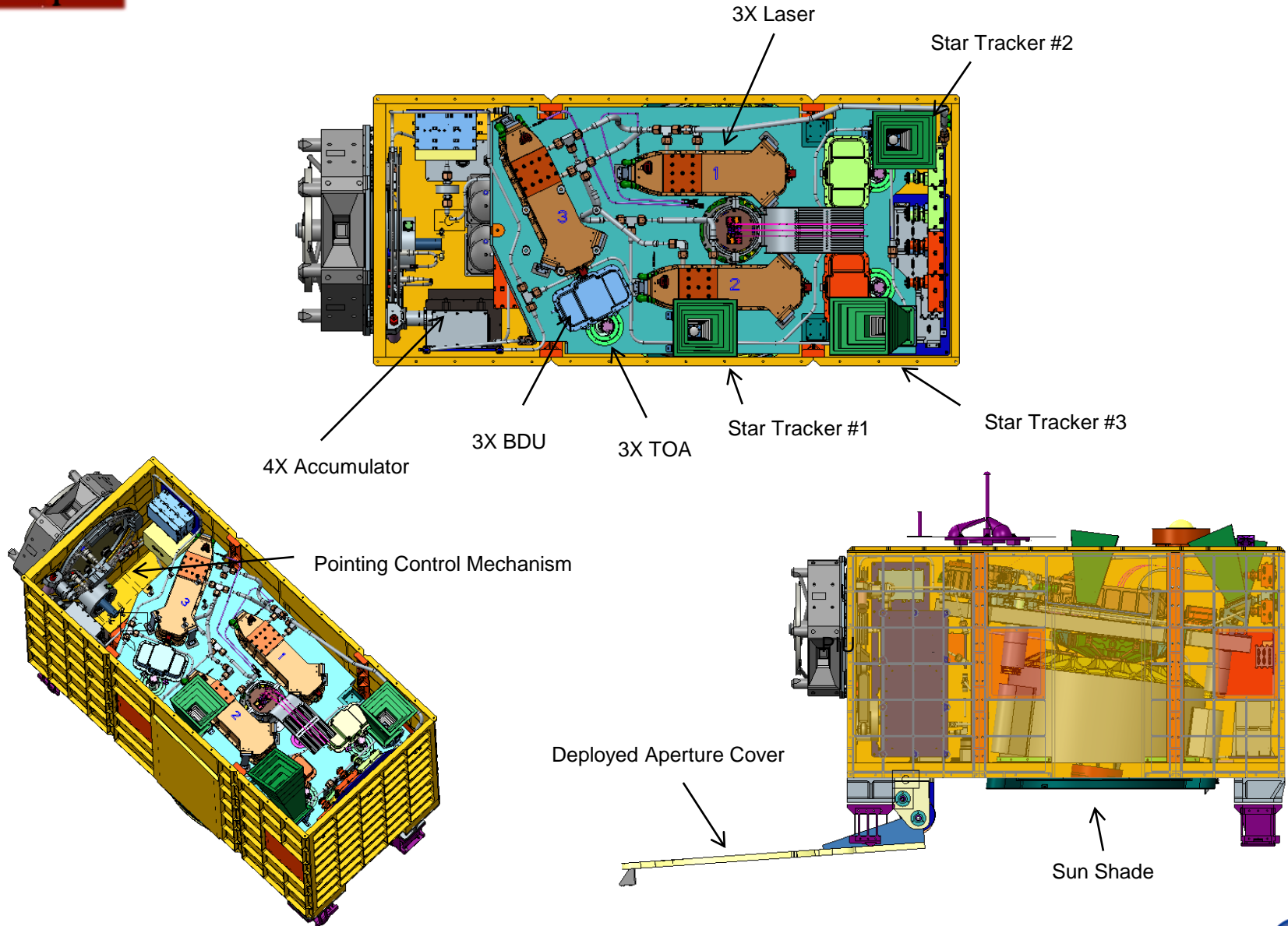


GEDI Instrument



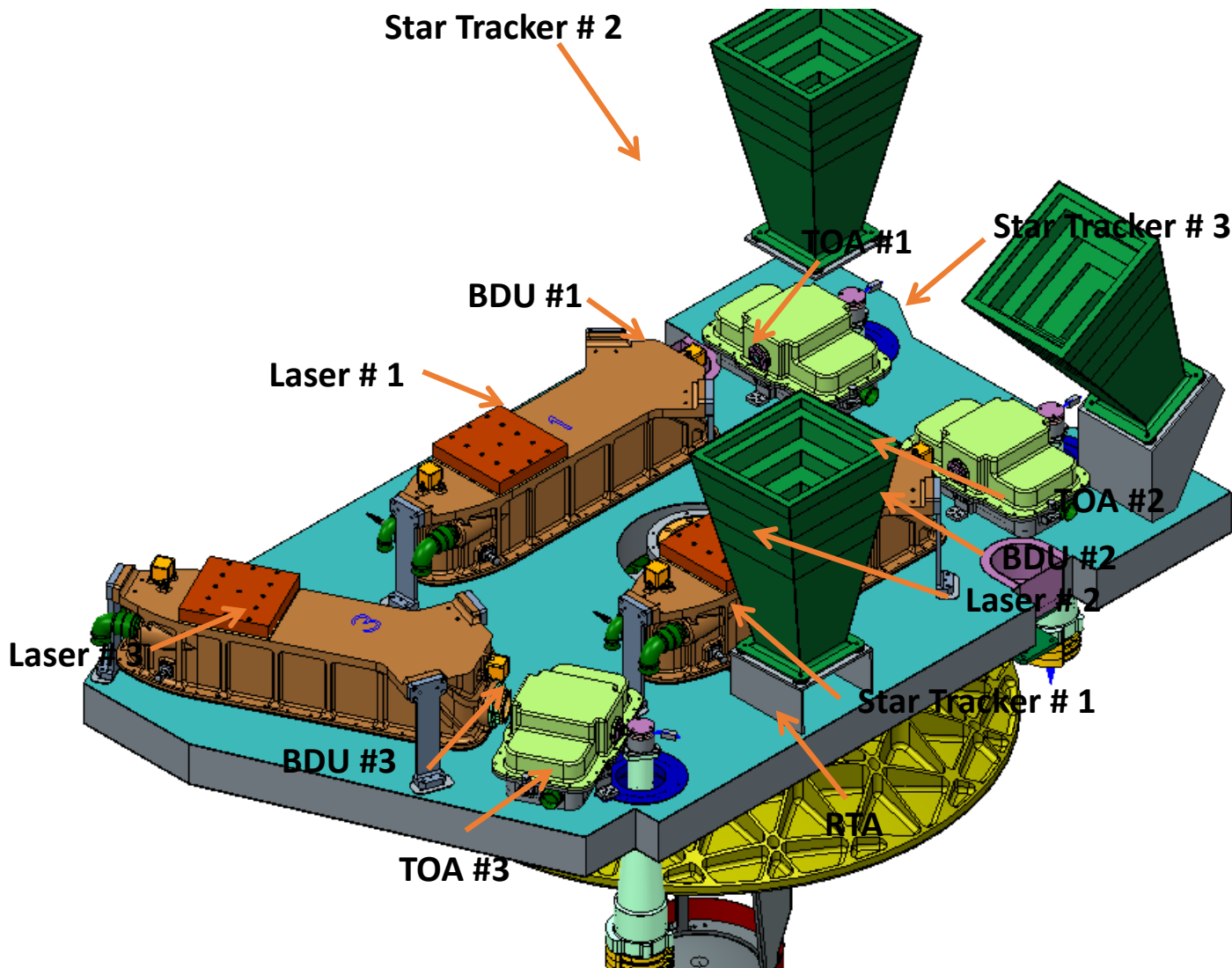


GEDI – Internal Views





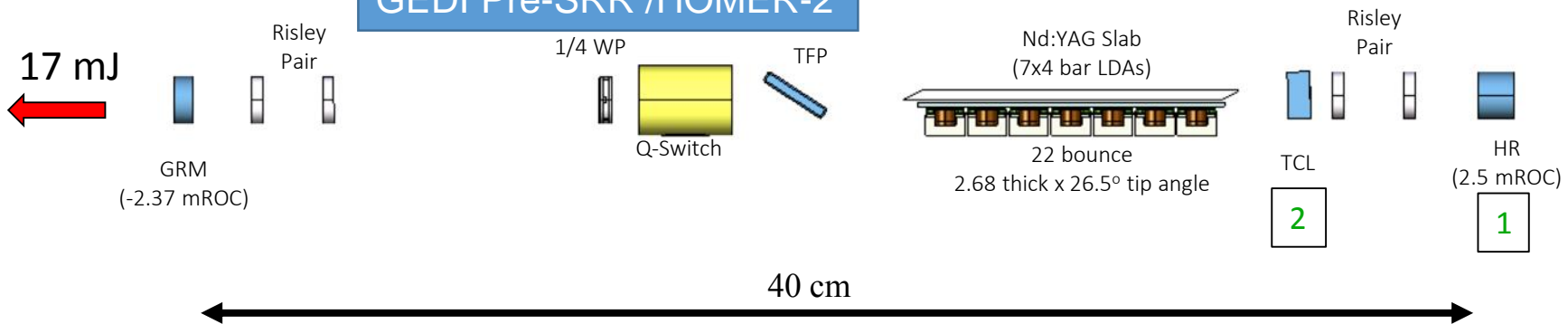
GEDI Optical Bench



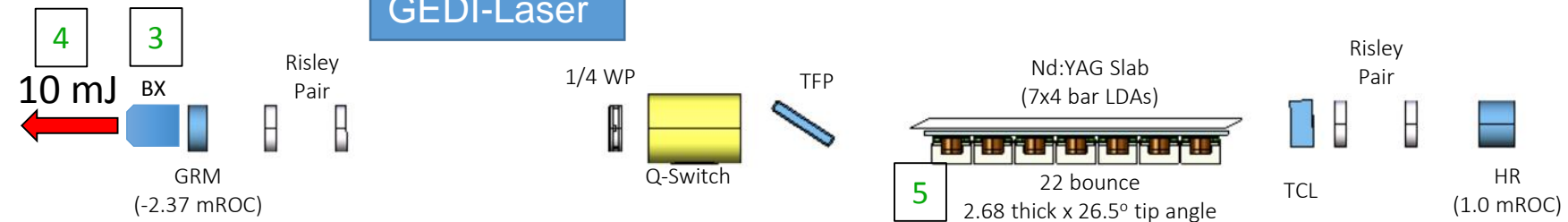


Laser Optical Design Overview

GEDI Pre-SRR /HOMER-2



GEDI-Laser



HR = high reflective mirror
TCL = thermal compensation lens
TFP = thin film polarizer
QS = Q-Switch
1/4 WP = 1/4 wave plate
GRM = gradient (Gaussian) reflective mirror

1. HR mirror prescription change 2.5 mCC to 1.0 mCC
2. The TCL focal length is “adjusted” for each cavity or slab installed, to best match thermal lensing. (TCLs ordered at a range anyway)
3. Mini-BX added to adjust for change in divergence
4. Reduction in output power from 17 mJ to 10 mJ to maintain same damage margins
5. Reduction of power allocation from 50 W to 40 W

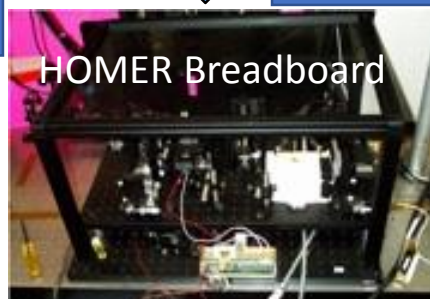


HOMER Class Heritage and Philosophy

Design:
-Model
-Best practices
-Margins

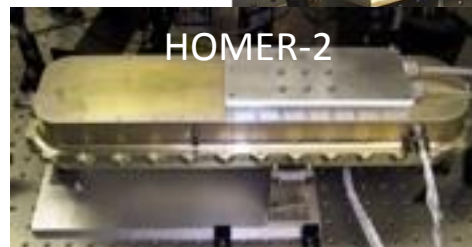
Bread Board:

- Confirm basic performance
- Confirm “laser physics” margins
- COTS parts



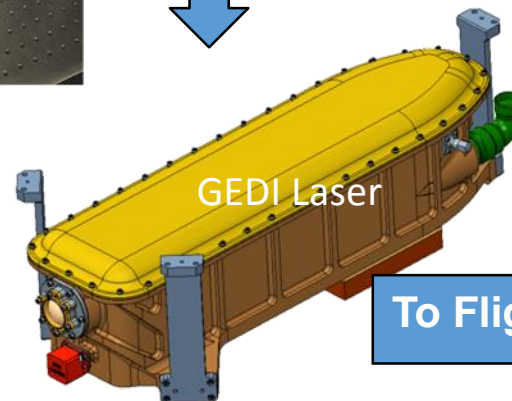
Hardened bread boards/EDUs:

- Confirm mechanical margins
- Environmental/Life Testing



ETUs:

- Flight-like procedures
- Test to flight levels
- Life testing



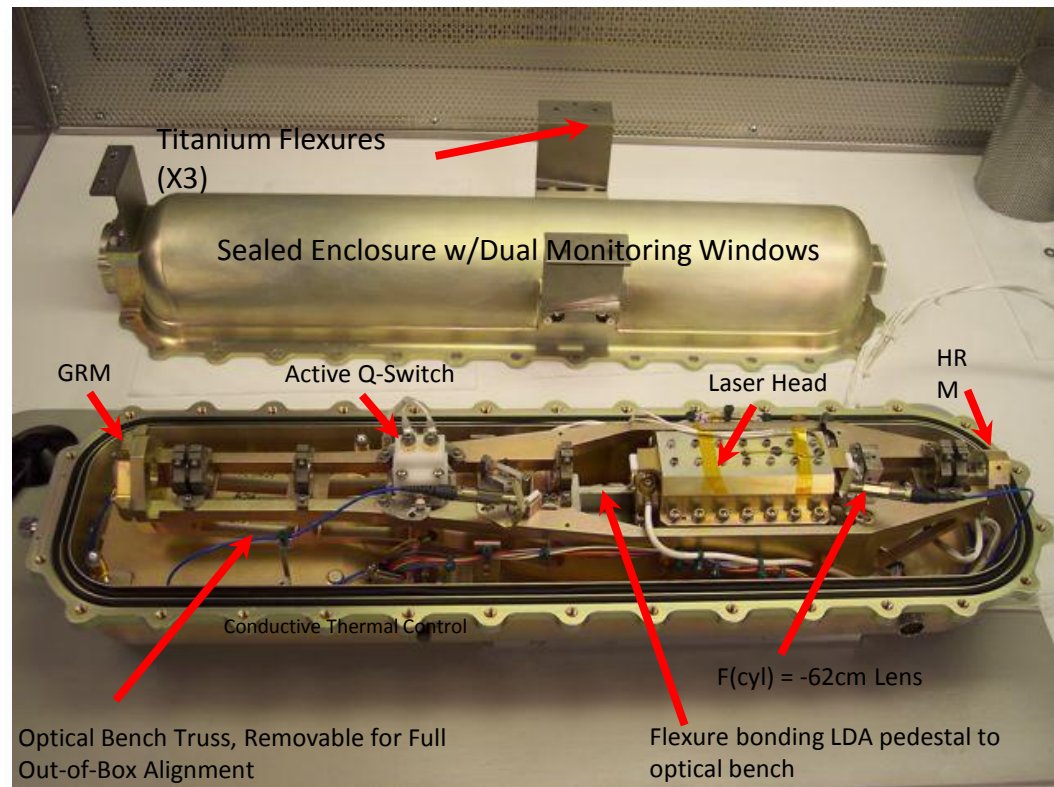
To Flight

Any change to laser is checked for impact to performance and margins



HOMER TRL-6 Performance Summary

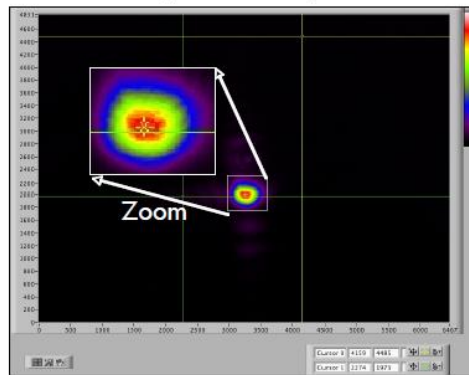
Parameter	HOMER Output
Energy	20 - 15 mJ
Pulse Width	12 +/- 1 ns
Rep Rate	250 -100 Hz
LDA Current	48-80 A
LDA Derating	50%
TRL 6 Mass	6 kg
Total QS Shots HOMER Design	15+ Billion



Single Mode Far Field Image
 $D_x/D_y = 0.99/0.96$ mRad

Laser Settings:

- Diode Pulse = 65us
- I = 48 A (~55% derated)
- F = 241 Hz

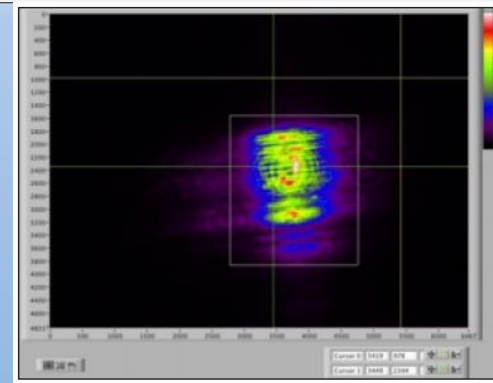


Reported 01/06/2010

HR mirror Near Field Image
 $W_x/W_y = 1.8/2.12$ mm

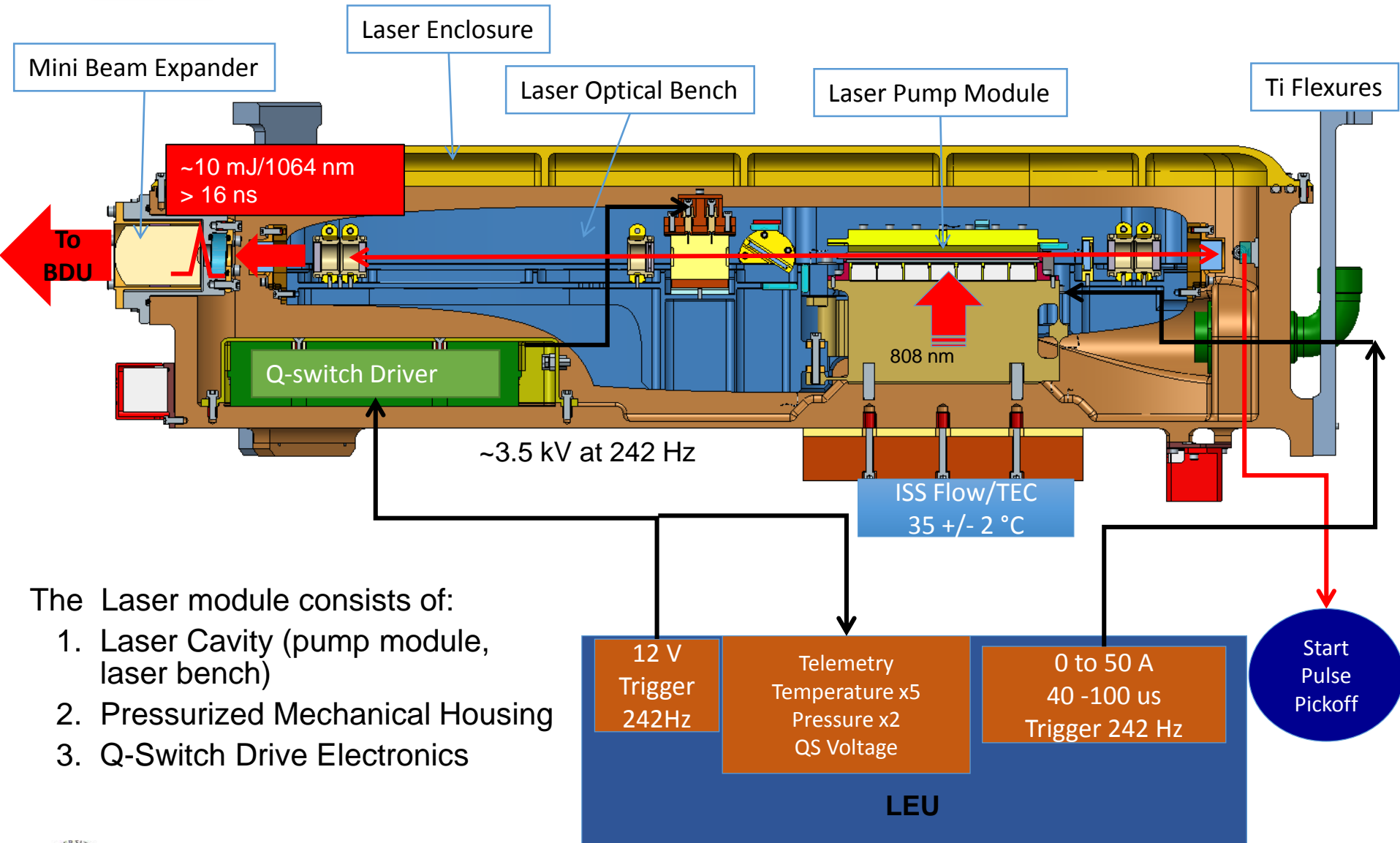
Laser Output:

- E = 16 mJ
- Q-switch pulse ~11ns
- Fluence < 2.5 J/cm²



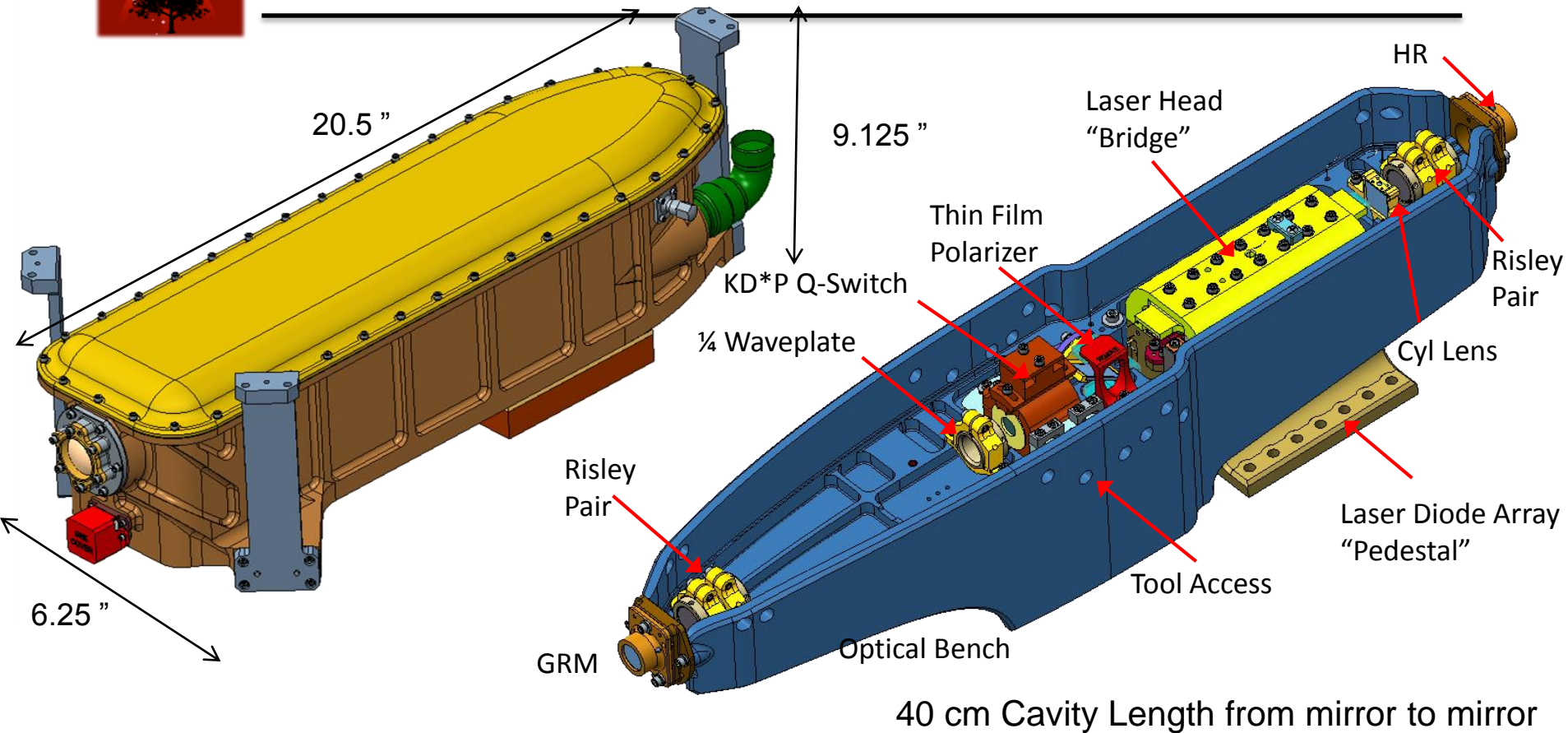


GEDI Laser Interface and Functional Overview





GEDI Laser Mechanical Overview

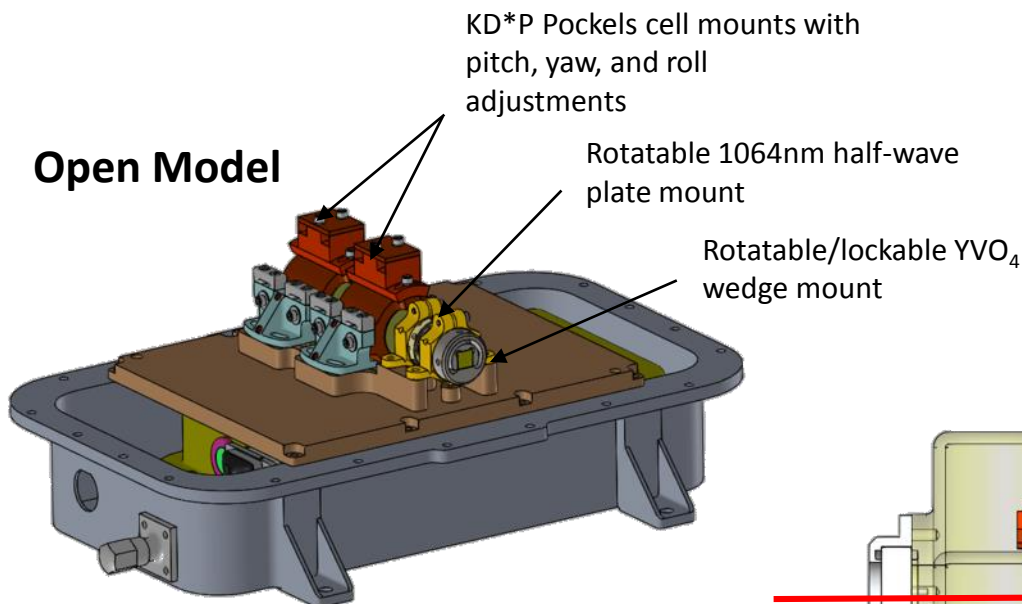


- Incorporating all opto-mechanical lessons learned from HOMER-2, LOLA, MLA, CALIPSO, DESDYNI, & ESA's ALADIN
- Modular design allows complete laser assembly, alignment, and substantial performance without the enclosure if necessary
- Preliminary leak rate, structural, and thermal analysis performed and will be tested



BDU Design Overview

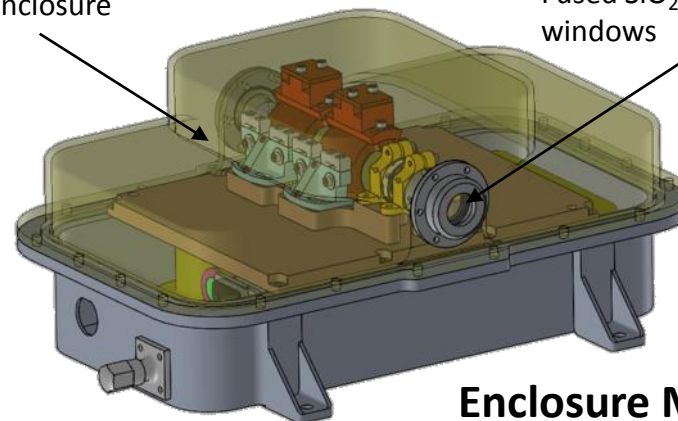
Open Model



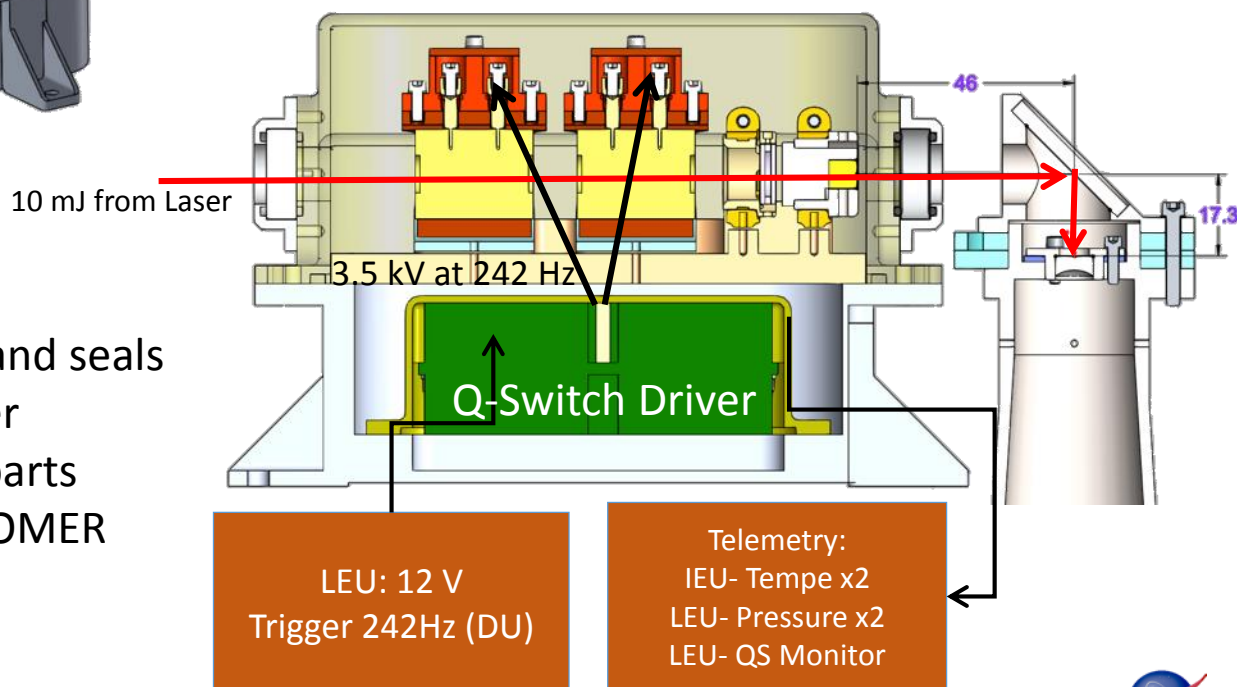
CBE Total Mass: ~1.81 kg
All optics, mounts, sensors, and seals (except the wedge) are either directly using or leveraging parts already being using in the HOMER laser

BDU enclosure

Fused SiO₂ AR-coated windows



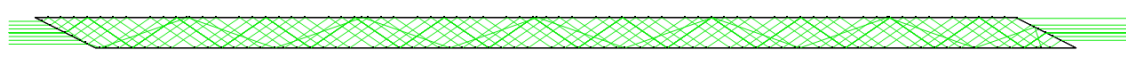
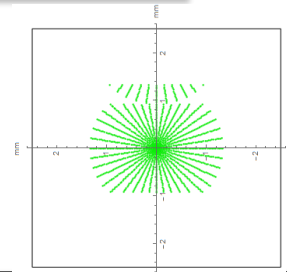
Enclosure Model





Side Lobe Description Summary

Beam Image of Slab Exit:



A few rays at “top” of Y-axis travel a different path. This produces a clipping effect, or “lobe” at the slab output end.

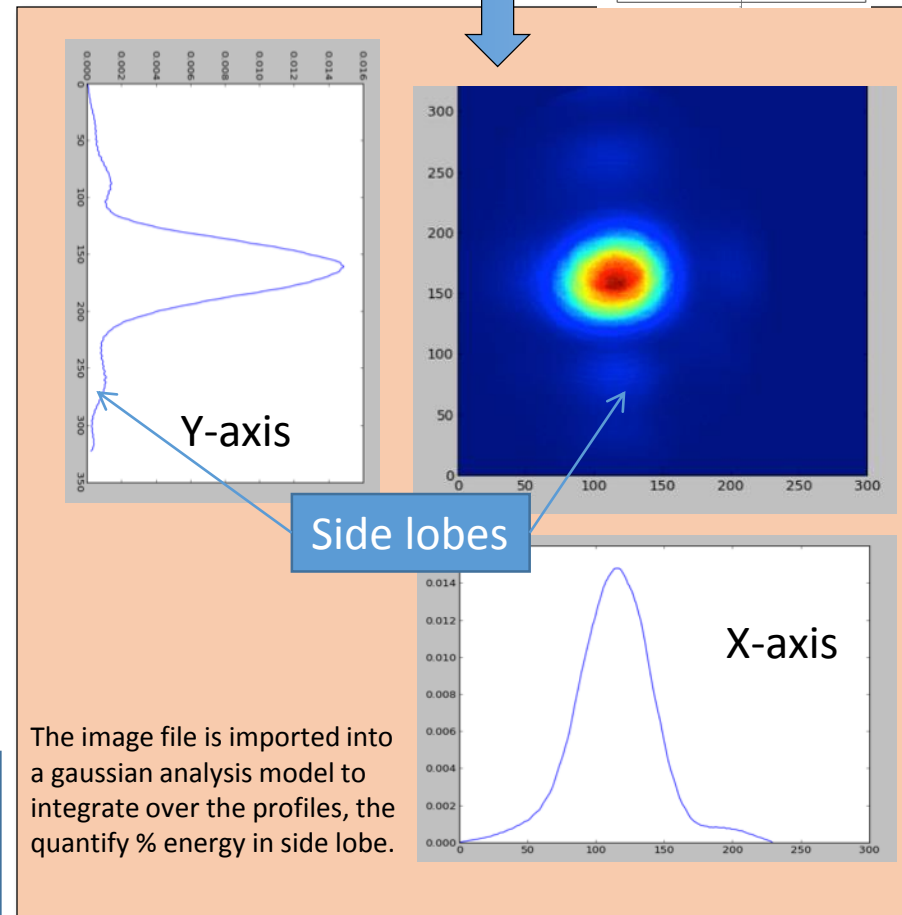
This creates problems for science differentiating between sloped ground and tree height.

To remove this you can either:

- 1) Clip off the side lobes outside the cavity
- 2) Make the beam smaller
- 3) Make the slab bigger

All options were explored and GEDI selected option 2 by changing HR Mirror curvature.

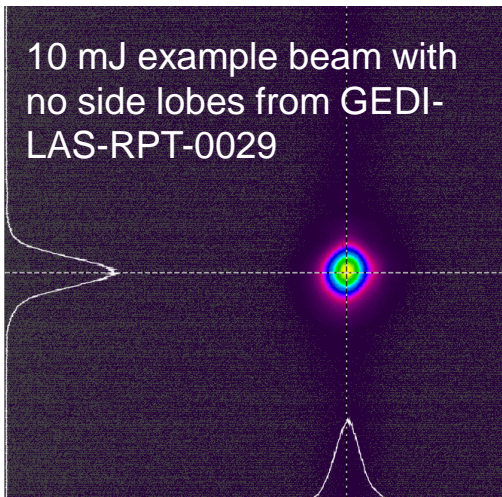
Options were reviewed externally by NESC supervised laser team from 554, 562, and expert from NGS. See GEDI-LAS-REVW-0004





Laser Testing Performance Summary

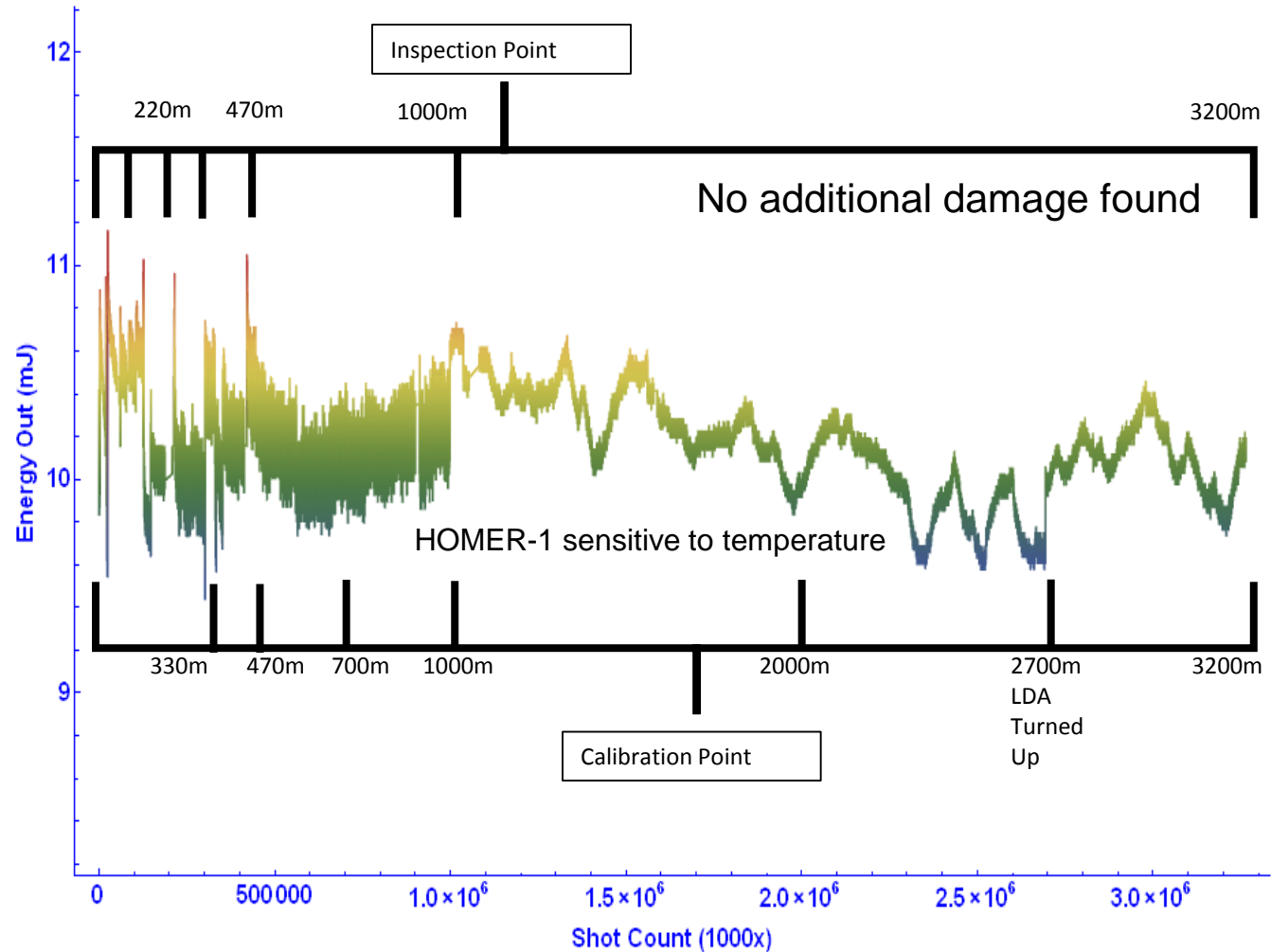
Parameter	Value	Unit
Average Energy	10.2	mJ
Frequency	242	Hz
Pump Width	71-77	μ s
Current	55	A



Parametric Testing :

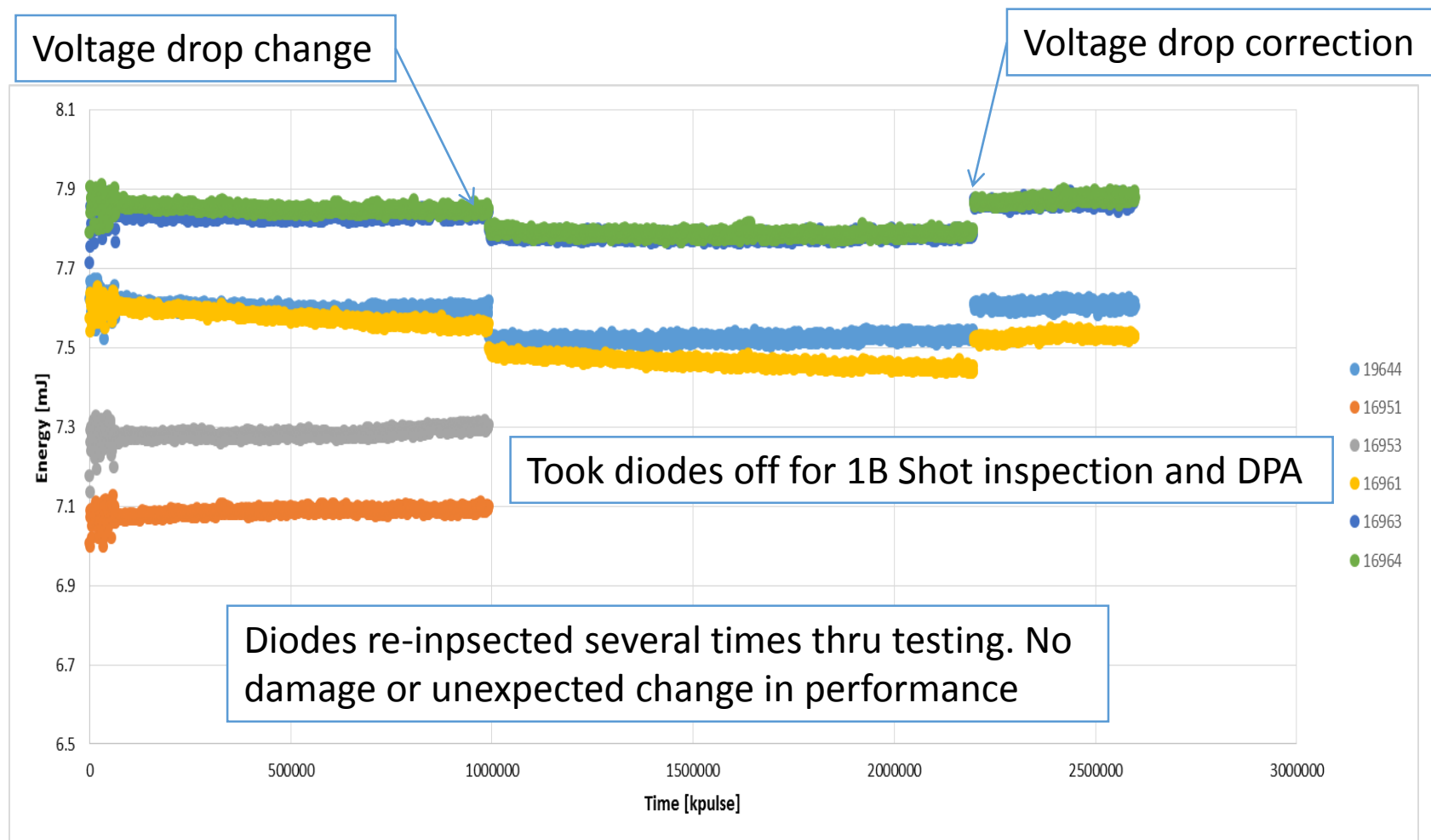
- Thermal lensing
- Diode distance
- End mirror tolerance

HOMER-1 1 mCC HRM Life Assessment Testing





ETU Diode Life Test Results





Cavity Fluence Estimates

Energy (avg) Inside laser cavity with output coupler reflectivity $R_{OC} = R_{GRM}$:

$$E_{in} = E_{out} \times \frac{(1 + R_{GRM})}{(1 - R_{GRM})}$$

But our reflectivity changes with beam size on the GRM, so we have to estimate:

$$R_{GRM} = \frac{1}{\rho a^2} \cdot \int_0^{2\rho} \int_0^a R_0 \cdot \exp\left[\frac{-2r^2}{W^2}\right] \cdot r \cdot dr \cdot dq$$

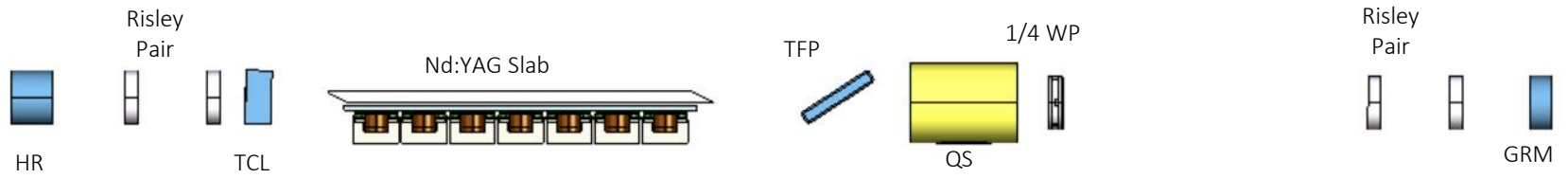
... To get the operational damage margin for each optic:

$$M_D = j_{LIDT} / j_{calc}$$

So we can calculate the fluence on each optic:

$$j_{calc} = E_{in} \times \frac{2}{\rho \times W_{calc}^2}$$

*worst case:
round beam
at GRM-end
of slab



	HR	Risley Pair	TCL	Slab Face	Slab TIR	Slab Face		TFP	QS	¼ WP		Risley Pair	GRM
Meas LIDT (J/cm²) j_{LIDT}	11.5	44	25	>10	12*	>10		20	>10	>10		44	4
Calc Fluence (J/cm²) j_{calc}	1.75	1.95	2.08	2.37 (1/2.23)	2.37* (1/1.56)	2.37 (1/2.23)		2.22	2.69	2.85		3.06	3.24
Margin M_D	4.2	22.6	15.3	>9.4	6.1*	>9.4		9.0	>3.7	>3.5		14.4	1.23
Sigma	0.32	0.36	0.37	<0.43	0.43*	<0.43		0.4	0.48	0.51		0.55	0.58



GED I Laser Requirements Verification

O = Occasional
C = Continuous
X = One Time
Measurement

ID	Requirement	Values	FT	CPT	Life test	Technique Used
1	Laser Wavelength	1064.5 nm \pm 0.2 nm in vacuum		x	O	Pickoff beam. Use built in software to calibrate measurement for vac. Take vacuum and air values
2*	Laser Output Energy	10 mJ +5% fully captured beam at the output	x	x	C	Measuring Total Output Energy using energy meter with 10ms integration time. CPT - energy meter put at the end of the snout to get full output. Used to calibrate pickoff measurement as well FT/Lifetest - calibrated pickoff
3*	Far-Field Divergence of the Central Lobe	0.6 mrad \pm 0.08mrad 1/e ² div.	x	x	C	Spiricon camera (raw beam data) 5-10 captures Computer Analysis and post processing for side lobes FT-50 cm lens CPT - Rayleigh Range
6	Laser Output Polarization Ratio	\geq 200:1		x	O	Measure by hand using wave-plate/hi ratio polarizer configuration
9	Pulse Repetition Rate	242 \pm 2 Hz	x	x	C	Confirm pulse with Tektonix 2024C and use e-drive output reading for continuous measurement
10	Pulse Width	<16ns ns Full-width and half-max	x	x	C	FT- 200 MHz Oscilloscope Average of 16 captures of laser pulses CPT -2 GHz scope. High speed Oscilloscope compiling 10,000 shots with histogram through computer analysis and post processing. LMB will be measured as well.
12	Laser Pulse Energy Concentration in Far-Field Outside of Central Lobe	\leq 0.5% of 1/e ² Central Lobe per energy concentration		x	O	Spiricon camera (raw beam data) 5-10 captures Computer Analysis and post processing
13*	Number of Laser Shots for Life Testing	3.2 billion shots	x	x	C	GSE shot counter will monitor shots for every test. ETU life time shot count will be monitored continuously
24	LDA Operating Temperature	35 +/- 2 °C		x	C	.Internal 10k thermistors read by EGSE



GEDI Laser Test Matrix GEDI-SYS-PLAN-0019

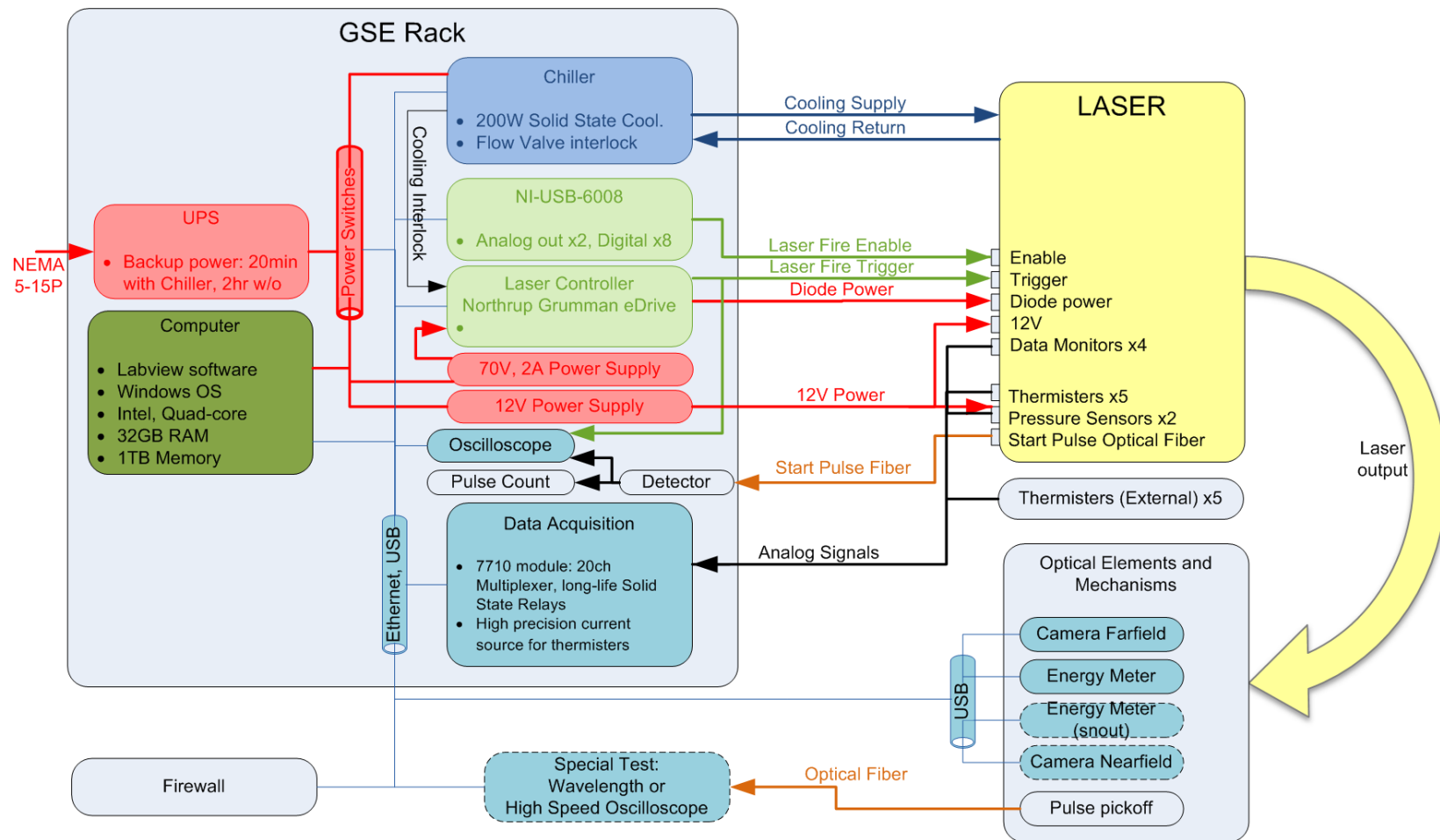
Level of Assembly	Item	Supplier	Quantity	Hardware Type
C	Laser	GSFC	3	PF

Structural Mechanical													EMI/EMC & Magnetics (1,2)					Thermal / Vacuum (3)																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
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- Environmental Testing performed on ETU and Flight units
 - ETU: Vibration, TVAC, EMC, and life test
 - Flight: Vibration, TVAC, EMI/C (at instrument level)
 - CPTs before and after each test (or specific cycles)
- Interface testing: BDU, LEU, DOE

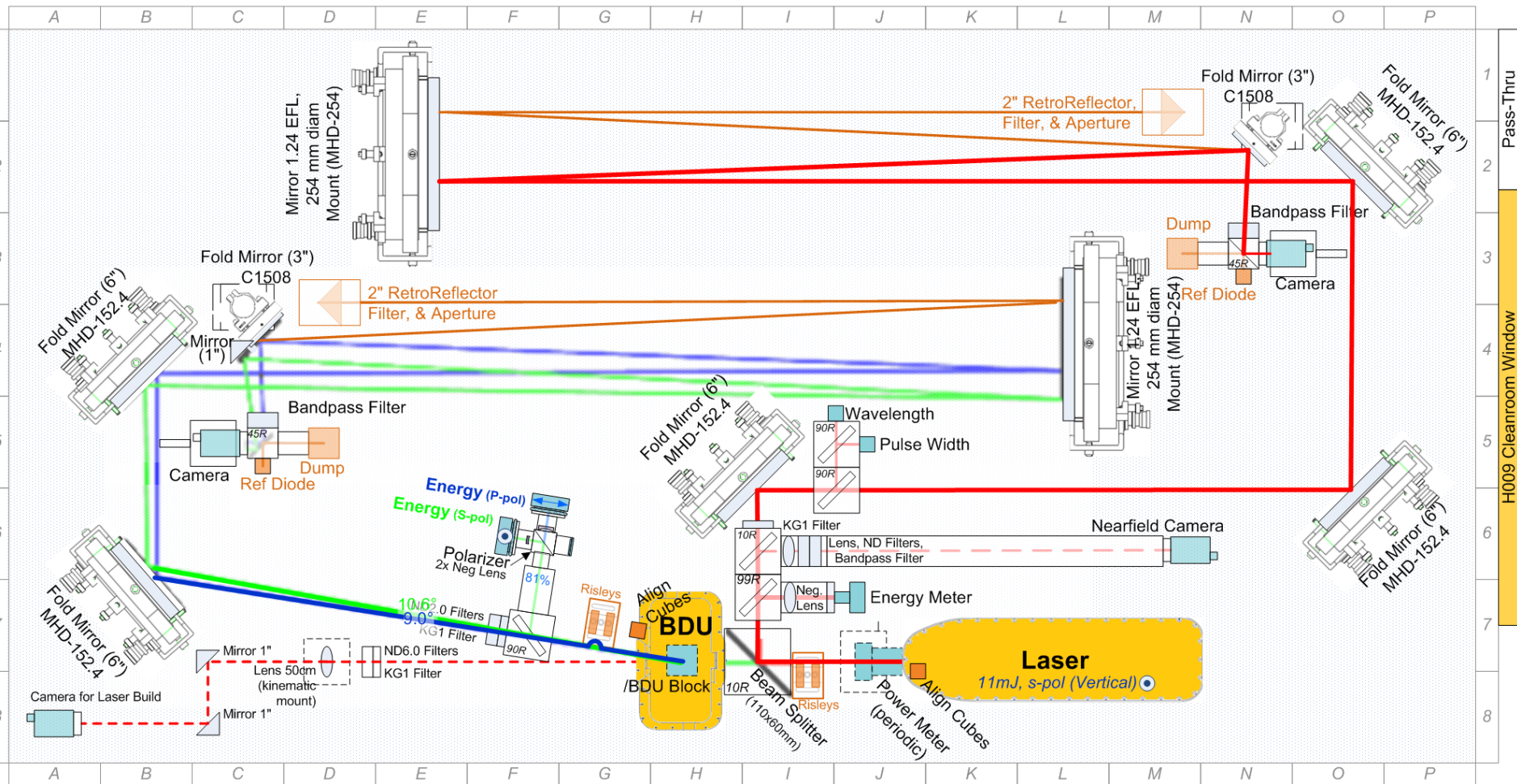


Laser GSE Functional Diagram





Optical Setup – Laser Lifetest w/BDU



Laser & BDU Lifetest Optical Table (8' x 4')



ETU Laser Development Flow

LEGEND

Parts Ordered Paperwork Release	Parts Delivered Complete Task
------------------------------------	----------------------------------

- Complete
- Monitor - no tech/cost/schd impact
- Monitor - tech/cost/schd impact
- On Plan

Start
Build

GSE

Optical Parts
Procurement

Mechanical
Fabrication

Electrical

SLAC
Repair

Preparation 1/16

Acceptance
Testing

Harnessing

Bonding

Kitting &
Inspection

Pre-Qual 1/16

Q-switch

Spare
Enclosure
Seal Test

Sub-Assembly 3/16

Pump
Module

Optical
Bench

Enclosure

Q-switch
Driver

Laser Module
Assembly 4/16

Integrate Pump
Module and
Optical Bench

Integrate
Electronics

Test Cavity
Performance

Integrate
Enclosure

CPT

Special
Testing*

TRR

Environmental
Testing 5/16

Vibration/CP
T

EMC

TVAC/CPT

Interface
Test

Start Life
Testing 5/16

*Special testing includes pressure and temperature cycling



Laser Assembly Flow

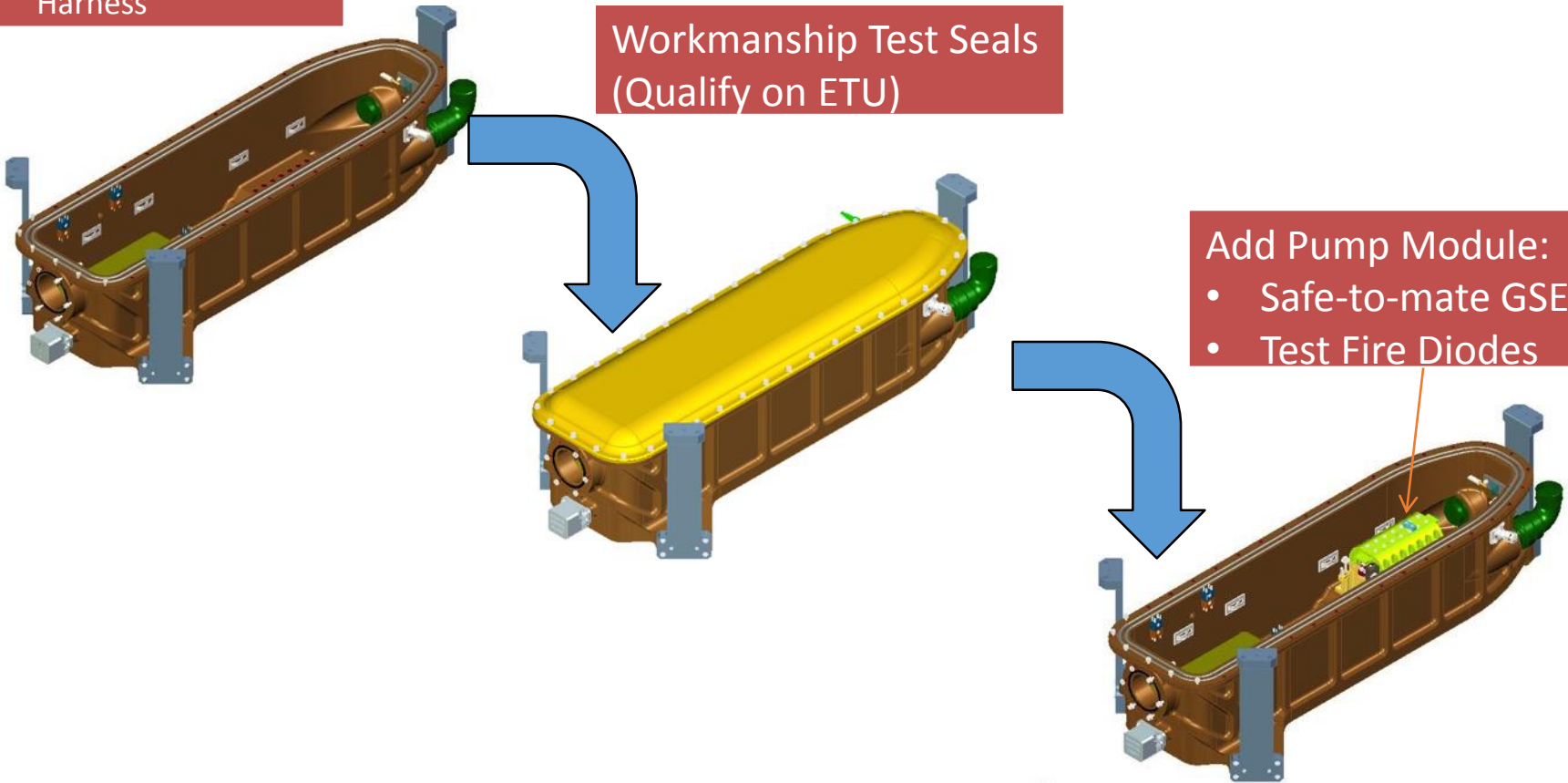
Assemble bucket:

- Flexures
- QSD
- Harness

Workmanship Test Seals (Qualify on ETU)

Add Pump Module:

- Safe-to-mate GSE
- Test Fire Diodes





Laser Assembly Flow

Add Laser Optical Bench &
Bench Optics

Seal Enclosure

Environmental
& Interface
Testing

Functional Test:
LASER-2,3,9,10,11

Special Test:

- Lab Temp Cycle
- FT every 0.5 C

Comprehensive Performance
Test:
LASER-
1,2,3,4,5,6,7,8,9,10,11,12,15,1

Special Test:

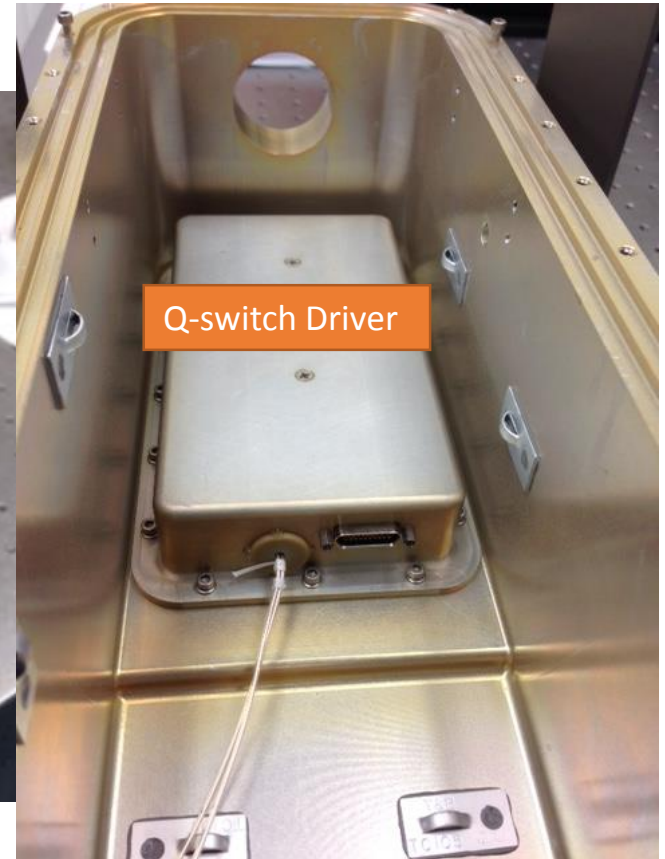
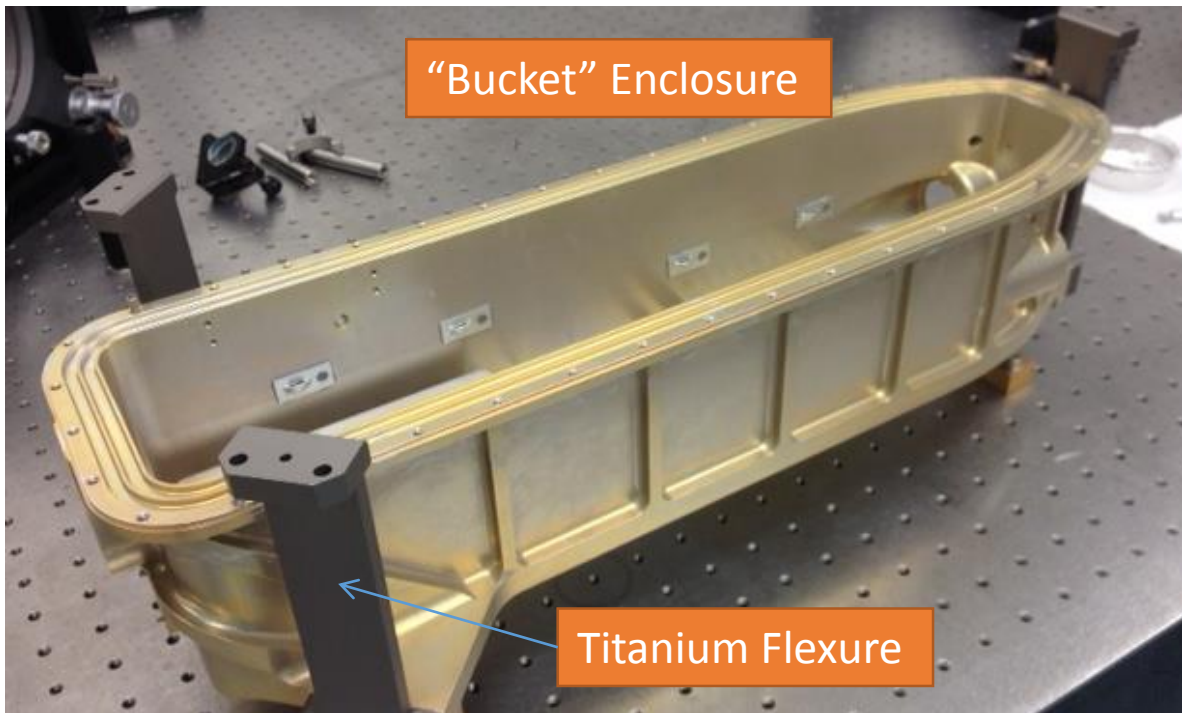
- Lab Pressure Test
- FT min/nom/max pressure

Special Test:

- Lab Temp Cycle
- FT every 0.5 C

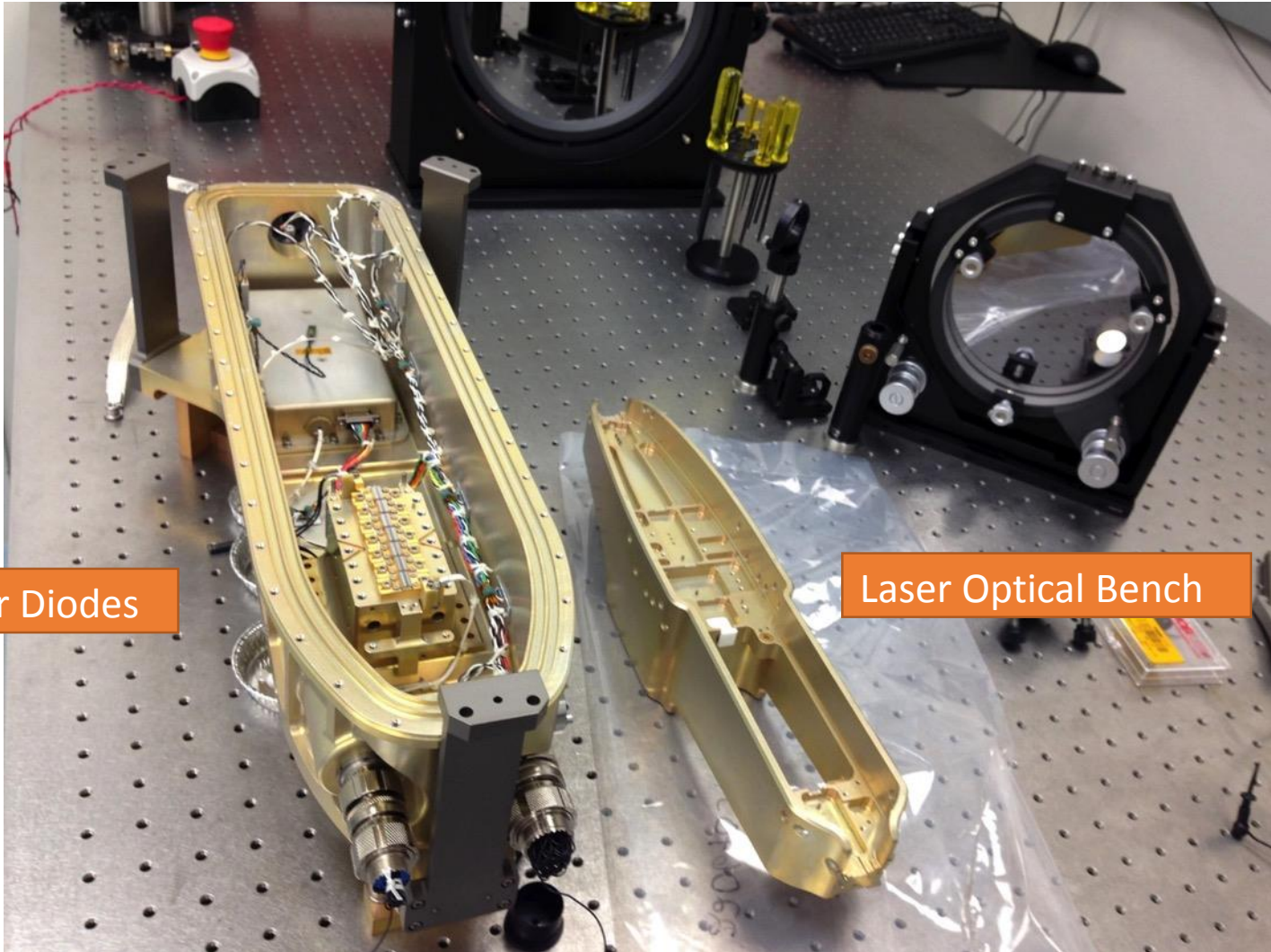


Laser ETU Bucket and Driver Assembly





Laser ETU Diode and Bench Assembly



Laser Diodes

Laser Optical Bench



BDU ETU Assembly Test Configuration

