Recent Progress on the UV Lifetime Demonstrator Program

Earth Science Technology Forum 2018

June 13, 20158

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Outline

- **UV Lifetime Demonstrator (UVLD) laser**
  - Design
  - Performance characterization
  - Lifetime testing

UVLD Team

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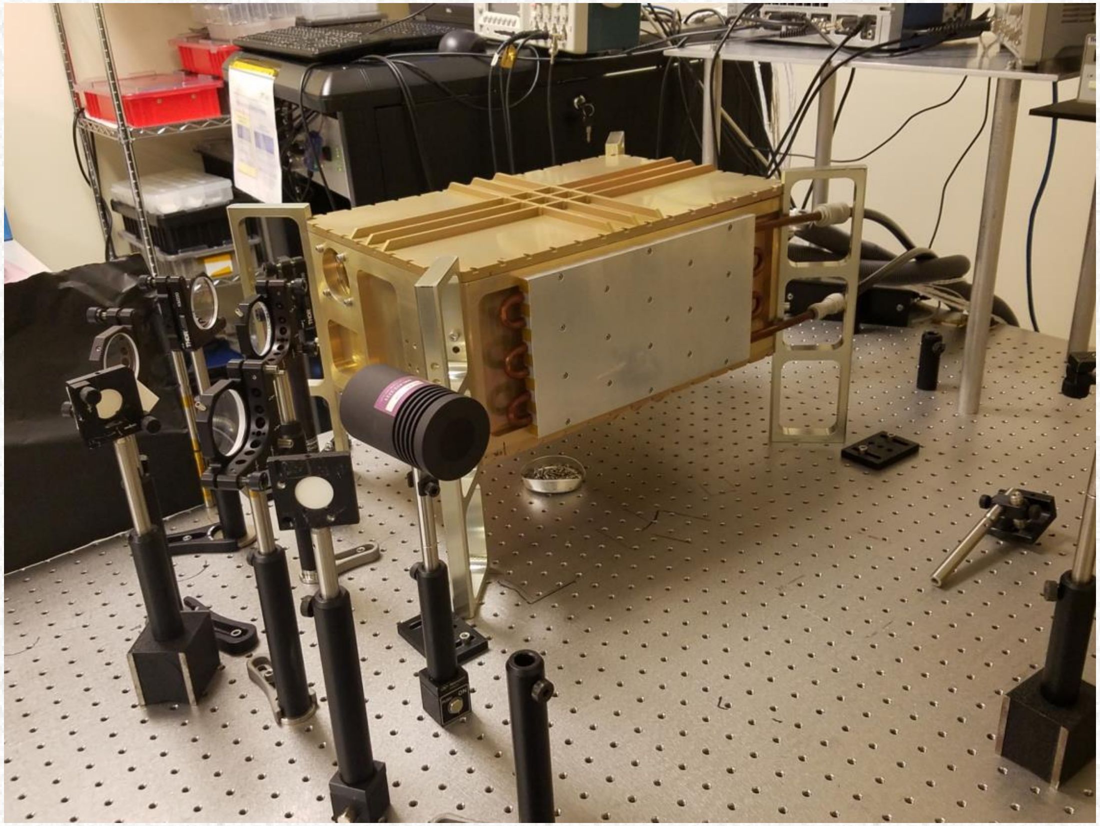

UVLD Program Objectives & Approach

- **Develop a 100 mJ, 150 Hz UV laser transmitter with a lifetime of >10^{10} shots**
  - Design architecture & critical componentry based on proven laser technology
  - Develop a purely conductively cooled Laser Optics Module (LOM) design
  - Develop a UV module design that converts the 250 mJ pump to 100 mJ at 355 nm
- **Conduct initial high repetition rate (20 kHz) UV testing of candidate LBO triplers**
- **Conduct 532 nm life testing**
- **Conduct half power UV life testing**
- **Conduct full power UV life testing**
- **Conduct environmental testing to advance design from TRL 4 to TRL 6**
  - Thermal-vacuum & vibration

Design Overview

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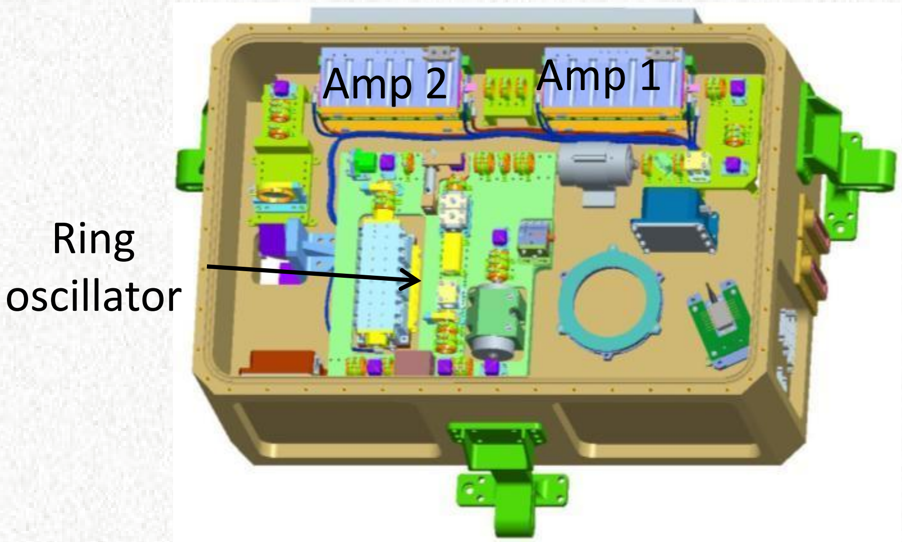
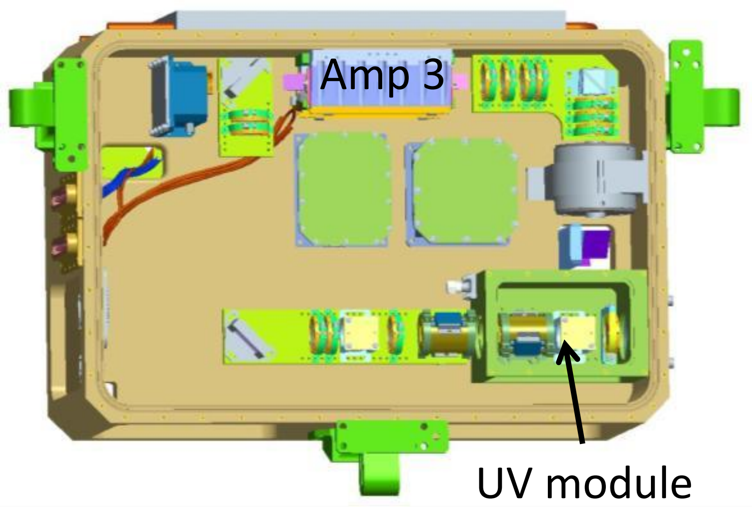
- **Sealed, dual compartment design**
  - Reduced sensitivity to contamination
  - Vacuum alignment stability
- **All UV components in a hermetic, near polymer free environment**
  - Improved lifetime
- **Internal telescope in UV box**
  - Reduces fluence on down stream optics
- **Pure conductive cooling to a single external thermal interface**
  - Simplifies thermal design
  - Required for a space-based system
  - Amplifiers mounted on laser module wall
- **Flexure mounted for high launch vibration levels**





Final Optics Module

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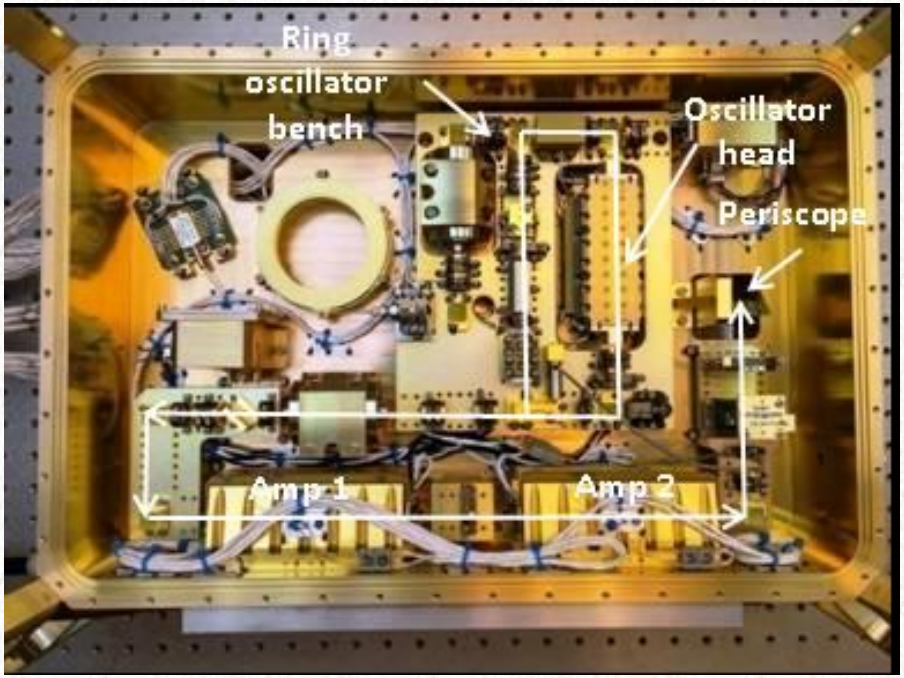
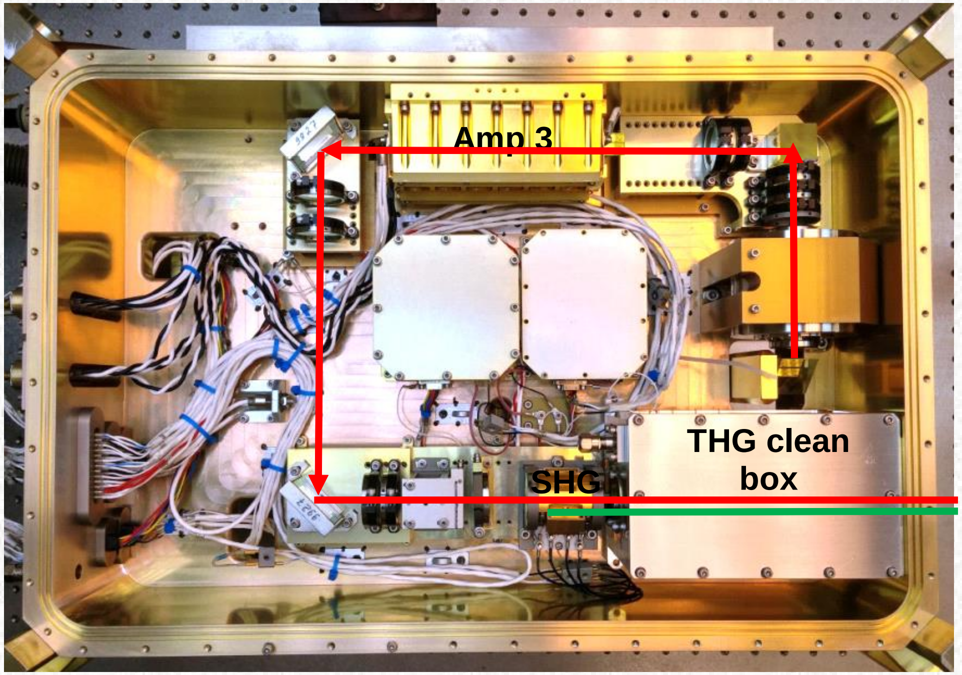


Resonator & preamplifier compartment



Power amplifier & nonlinear conversion compartment

150 Hz, 1064/532 nm Performance

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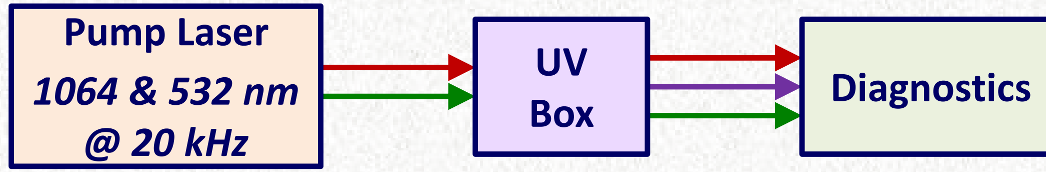
- 1 µm optical performance has met or exceeded all design objectives
- 532 nm results met or exceeded all design objectives
- Full conductive cooling was successfully demonstrated

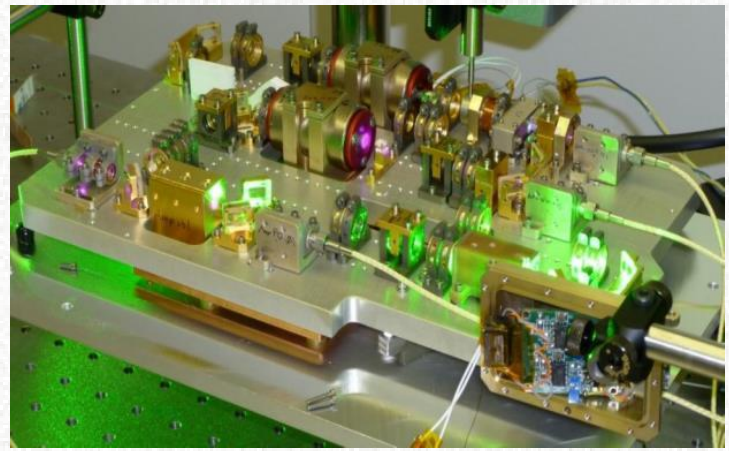
Parameter	Objective	Demonstrated
Pulse Repetition Rate	150 Hz	150 Hz
1064 nm Pulse Energy	250 mJ	275 mJ
532 nm Pulse Energy	135 mJ	165 mJ
1064 nm Pulse Width	10 – 20 ns	14 ns
532 nm Pulse Width	10 – 20 ns	11 ns
1064 nm Beam Quality	2.0 M^2	1.9 M^2
532 nm Beam Quality	3.0 M^2	2.2 M^2

20 kHz UV Life Test Approach & Objectives

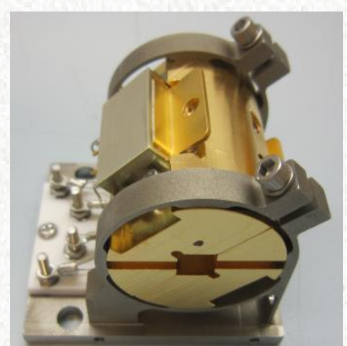
- **Perform pre-screening of the UV approach & key components**
  - Third harmonic mixing crystal & UV Box assembly
- **Surface potential failure mechanisms early to allow for corrective actions**
  - 20 kHz PRF over 1 month test duration = 50 x10^9 shots
- **Test at intensities needed for efficient UV conversion to further accelerate the damage processes**
  - 100 MW/cm^2 input intensity to generate ≥ 50 % conversion to the UV

Test set up

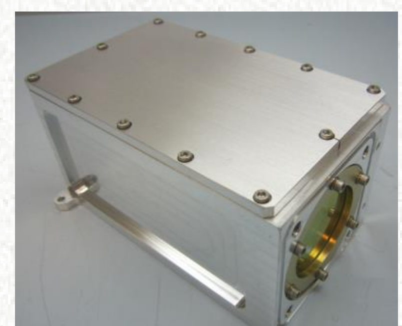




10 kHz pump laser from ICESat-2



THG Assembly



UV Box Assembly

355 nm, 20 kHz Life Test Results

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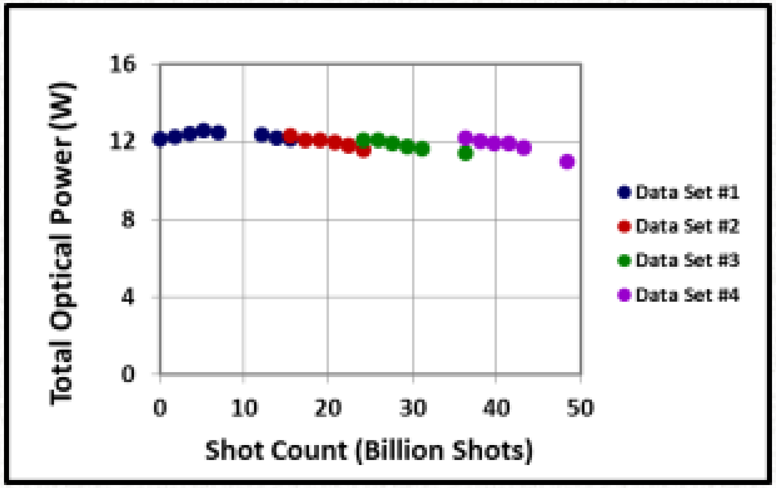
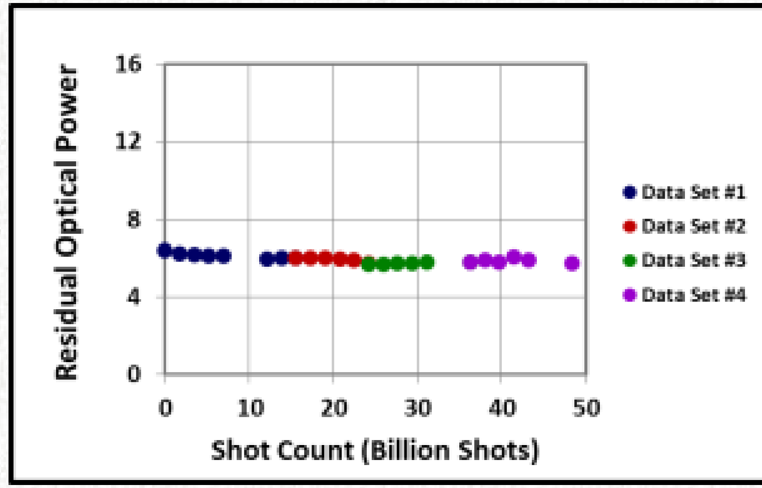
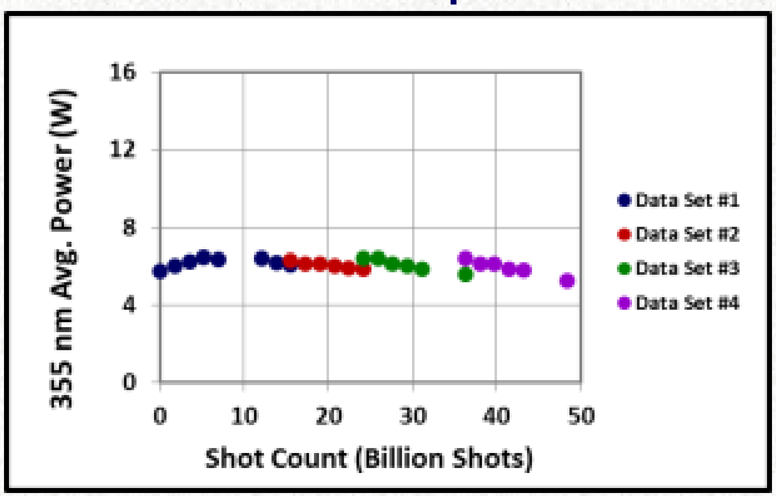
Total Optical Output Power



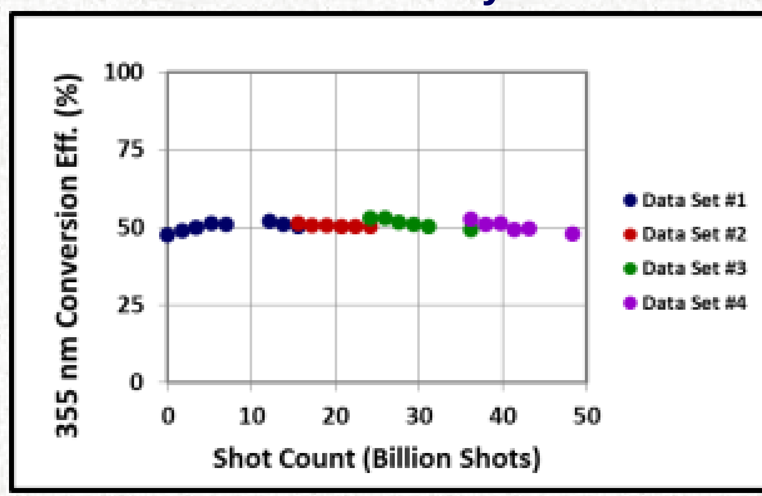
Residual 1064 & 532 nm Power



355 nm Output Power



Conversion Efficiency to 355 nm



Periodic fall off in output was due only to degradation of external diagnostic optic

355 nm, 20 kHz Life Test Summary

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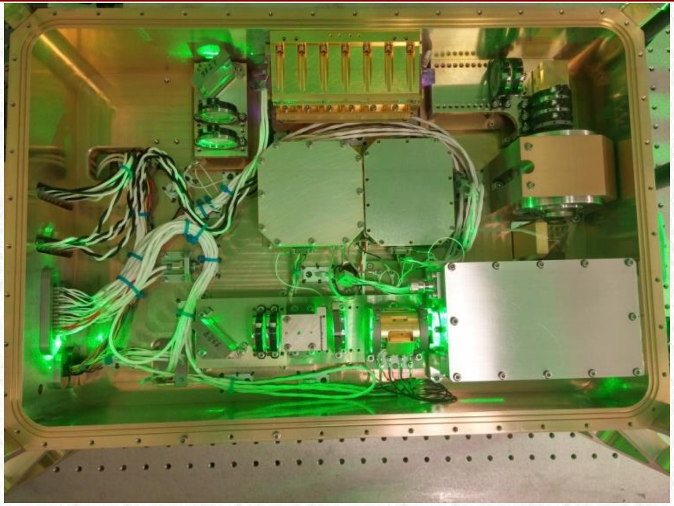
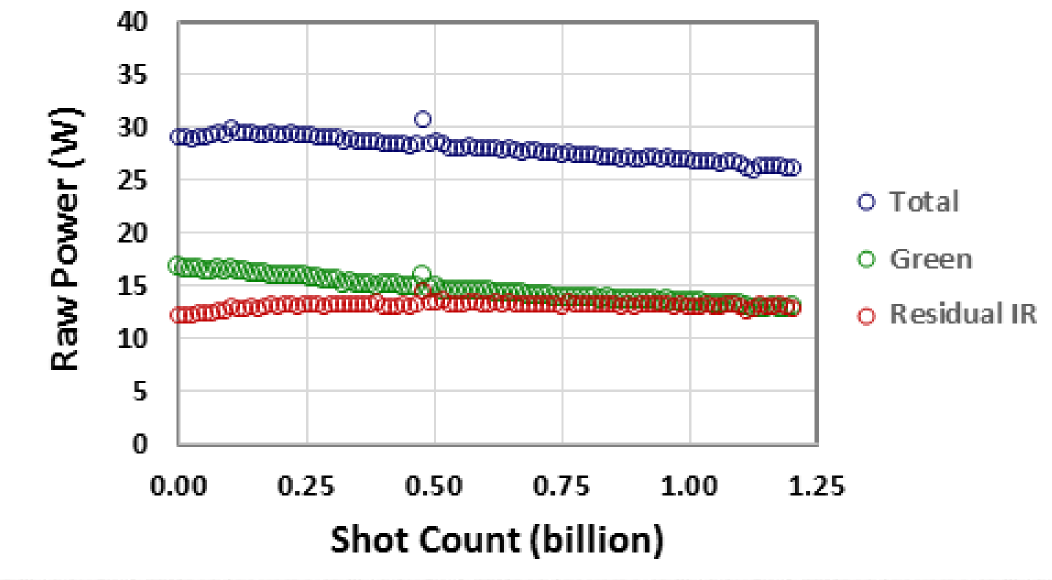
- **UV conversion module was a duplicate of the UVLD box except for a smaller cross section LBO tripler**
  - Same LBO vendor and AR coatings
  - Near polymer free
  - Contamination control processes derived from ICESat-2
- **50 x10^9 shot, high intensity life test at 355 nm**
  - 6 W of third harmonic UV at was generated at 20 kHz
  - 50% conversion from the IR with 150 MW/cm^2 pump intensities
  - Average life test UV intensity of 3 kW/cm^2
- **Post test inspections validated design and contamination control approach**
  - No damage on components interior to the conversion module
  - Significant contamination damage on exterior diagnostic optics

532 nm Life Test Summary

- Set up UVLD for 50% conversion to 532 nm (125 mJ, 150 Hz)
- 1.2 billion shots at completion
- Total power down 9%
- 532 nm power down 19% due to 1064 nm pump decay
- No evidence of any optical damage
- Power fall-off traced to pump diode decay
  - Turned down diode currents and increased pulse width before UV life tests





355 nm, 50 mJ, 150 Hz Life Test Results

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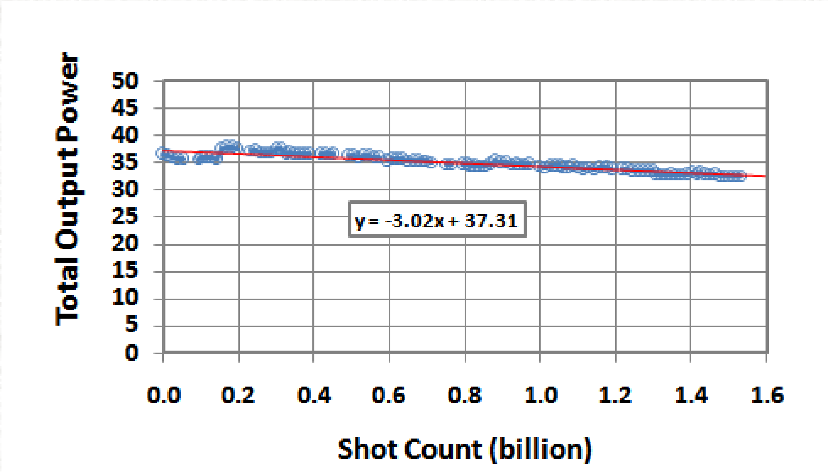
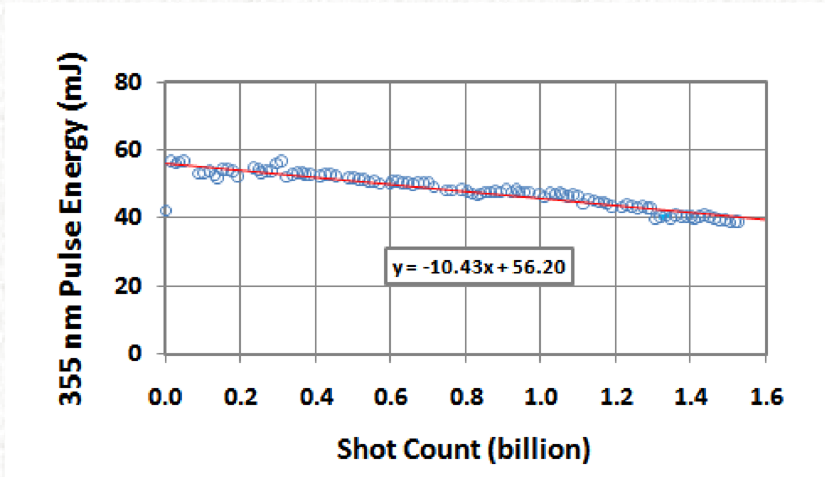
Life Test Data – Total Output Power



Parameter	Value	Units
Shot Count	1.53	10^9 shots
Start Test Power	37.3	W
End Test Power	32.7	W
Power Degradation	12.4	%
Power Degradation	8.1	%/10^9 shots

Life Test Data – 355 nm Output Energy



Parameter	Value	Units
Shot Count	1.53	10^9 shots
Start Test Energy	56.2	mJ
End Test Power	40.3	mJ
Power Degradation	28	%
Power Degradation	18.6	%/10^9 shots

Fall off in output primarily due to continued pump diode degradation

355 nm, 50 mJ, 150 Hz Life Test Summary

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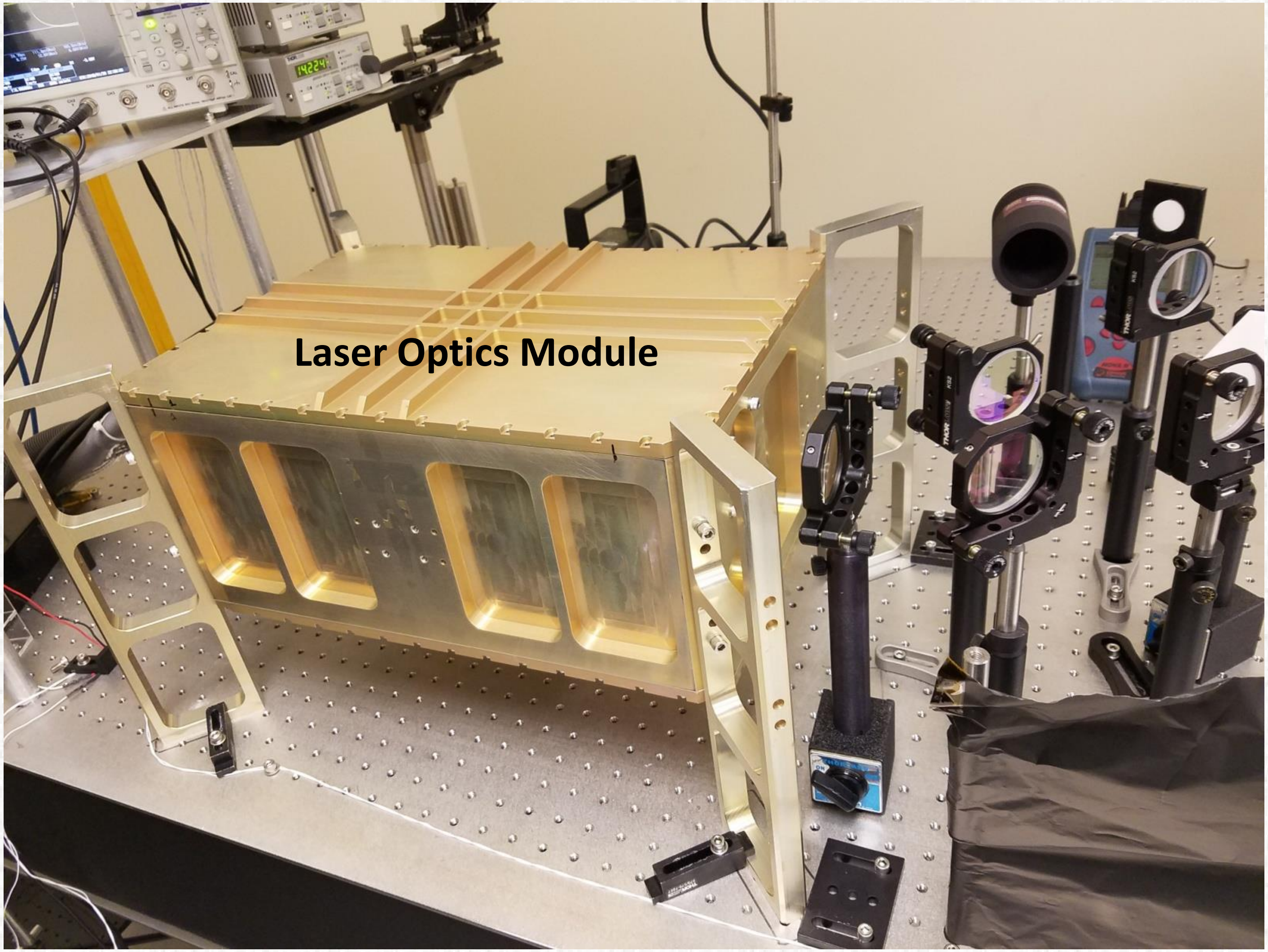
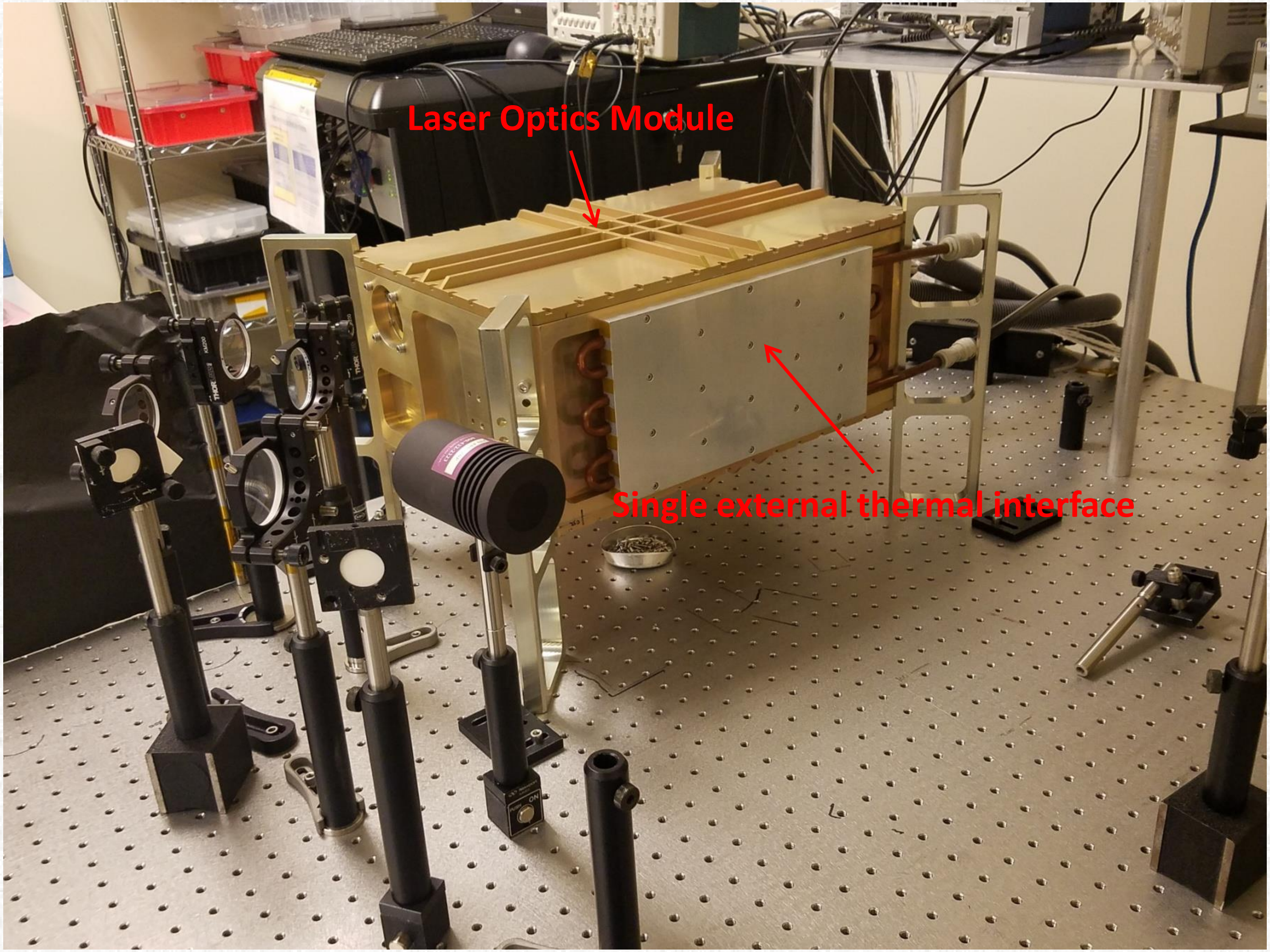
- **1.53 billion shots**
- **Total power is down ~12%**
  - Driven by drop in 1064 nm power due to continued diode degradation
  - Diode derating did not have anticipated effect and needs further investigation
- **UV power is down ~28%**
  - Primarily due to drop in 1064 nm pump power
  - No visible degradation of LBO tripler coatings
  - Faint damage on clean box telescope lenses but no contribution to UV power drop
- **Identified areas for improving optical robustness**
  - Air gap waveplates
    - Switch to ICESat-2 style optically contacted waveplates
  - Triple AR fused silica lenses in clean box expansion telescope
  - More diode derating to achieve decay rate compatible with 10×10^9 shot missions

Full Power Life Test Set Up



Full Power Life Test Set Up



355 nm, 50 mJ, 150 Hz Life Test Results

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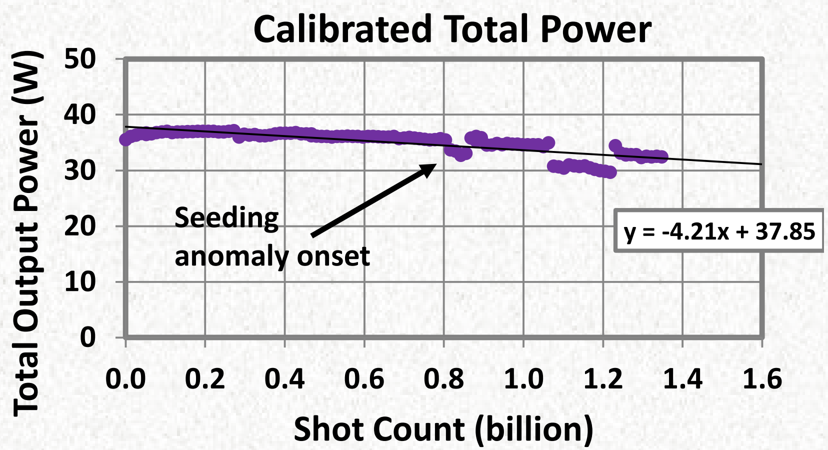
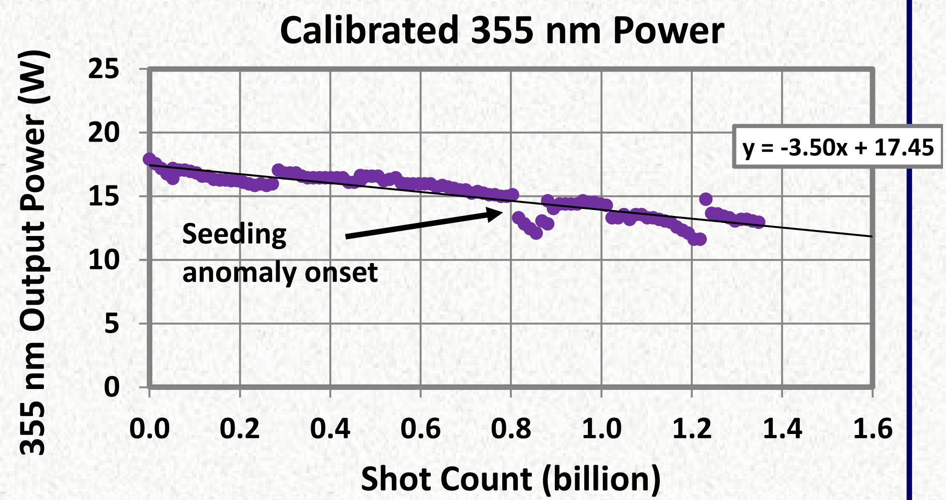
Life Test Data – Total Output Power



Parameter	Value	Units
Shot Count	1.35	10^9 shots
Start Test Power	37.9	W
End Test Power	32.2	W
Power Degradation	13.2	%
Power Degradation	9.8	%/10^9 shots

Life Test Data – 355 nm Output Energy



Parameter	Value	Units
Shot Count	1.35	10^9 shots
Start Test Power	17.5	W
End Test Power	12.8	mJ
Power Degradation	27	%
Power Degradation	19.9	%/10^9 shots

Fall off in output primarily due to continued pump diode degradation

355 nm, 100 mJ, 150 Hz Life Test Summary

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- **1.35 billion shots**
- **Total power is down ~13%**
  - Driven by drop in 1064 nm power due to continued diode degradation
  - Diode derating did not have anticipated effect and needs further investigation
- **UV power is down ~27%**
  - Primarily due to drop in 1064 nm pump power
  - No visible degradation of LBO tripler coatings
  - Faint damage on clean box telescope negative lens, no contribution to UV power drop
  - Faint damage on clean box external windows, no contribution to UV power drop
  - Final beam profile degraded near end of test
    - Root cause is under investigation, did not seem to result in any power drop
- **Identified areas for improving optical robustness**
  - Anomaly at 800 million shots leading to unstable seeding needs root cause determination
  - Late degradation of beam profile needs root cause determination
  - Further work on contamination effects external to clean box is needed
  - More diode derating to achieve decay rate compatible with 10×10^9 shot missions

UV Lifetime Demonstrator Summary

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- **Assembly complete, met all performance goals**
- **The 20 kHz UV lifetest has been successfully completed**
- **4 month 532 nm lifetime successfully completed**
  - Pump diode decay was faster than anticipated
  - Additional derating did not achieve expected ≥ 2.3X improvement
- **4 month half power UV lifetest completed with encouraging results**
  - Proved value of contamination control to reduce UV optical damage
  - Larger than expected diode decay rate continued
- **4 month full power UV lifetest (100 mJ/150 Hz) has been completed**
  - UV and total power trends similar to half power test
    - Further validated approach to contamination control
    - Larger than expected diode decay rate continued
  - External optic coatings need further work
  - Seeding and beam profile anomaly need root cause determination
- **Environmental testing still to be done**

Conclusions

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- **A fully conductively cooled, single-frequency UV demonstrator laser has been built and tested**
  - 100 mJ/pulse, 150 Hz @ 355 nm
  - Successfully completed life testing
    - 1.3 billion shot, full power 532 nm
    - 1.5 billion shot, 50 mJ 355 nm
    - 1.35 billion shot, 100 mJ 355 nm
      - Still needs root cause determination for seeding anomaly and late in test beam profile anomaly
  - Environmental testing to follow final Preparing for full power UV lifetest followed by TVAC and vibe

Acknowledgements

This work was supported by funding from the NASA Earth Science Technology Office.