Implementation of Commercial Components in Space Flight Optical Science Instruments

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Electrical Engineering Division

The Optical Society of America: Workshop on Optics in Space
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https://photonics.gsfc.nasa.gov

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Meet the Photonics Group of NASA Goddard

Over 20 years of space flight hardware development, testing, & integration

Back row L-R: Erich Frese, Joe Thomes, Marc Matyseck
Middle row L-R: Rick Chuska, Eleanya Onuma, Cameron Parvini, Rob Switzer
Front row L-R: Hali Jakeman, Melanie Ott, Diana Blair

Trevon Parker

Alexandros Bontzos

Clairy Reiher

Alejandro Rodriguez

All great things require a great team!

https://photonics.gsfc.nasa.gov

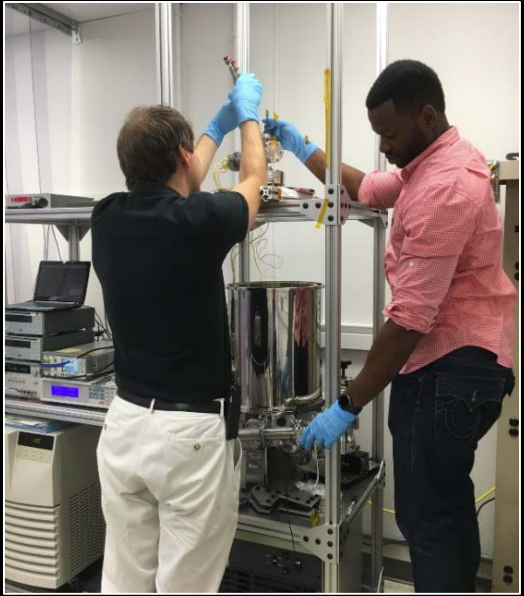
Outline

- Introduction
- Space Flight Missions: 20 Year Overview
- Approaching Qualification for Commercial Products
- Environmental Parameters: materials, vibration, radiation
- Optoelectronics: 10 year screening and qualification overview
- Summary
- Conclusions

Custom Spaceflight Optical & Optoelectronic Subsystems using Commercial Components

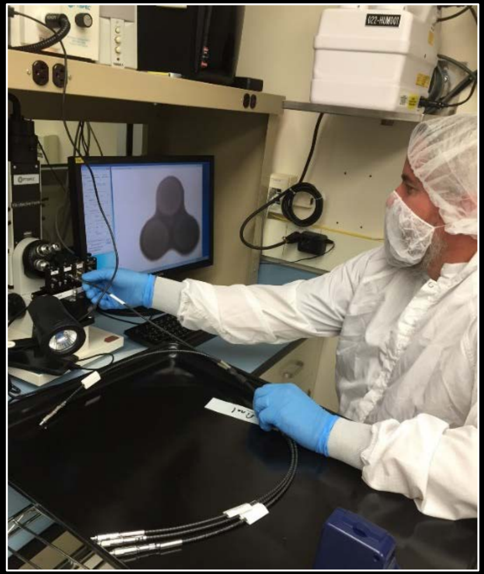
Integration

Materials Selection and Inspections



Environmental Testing

Manufacturing



One Stop Shopping for Concept through Delivery

How Do You Develop and Fabricate Hardware?

Characterization Testing

Qualification Testing

Failure Analysis

Development / Design
(Failure Modes Mitigation / Cost Reduction)

Quality
(For Compliance, highest reliability possible)

Fabrication/Manufacturing
(For High Reliability with Rigorous Quality)

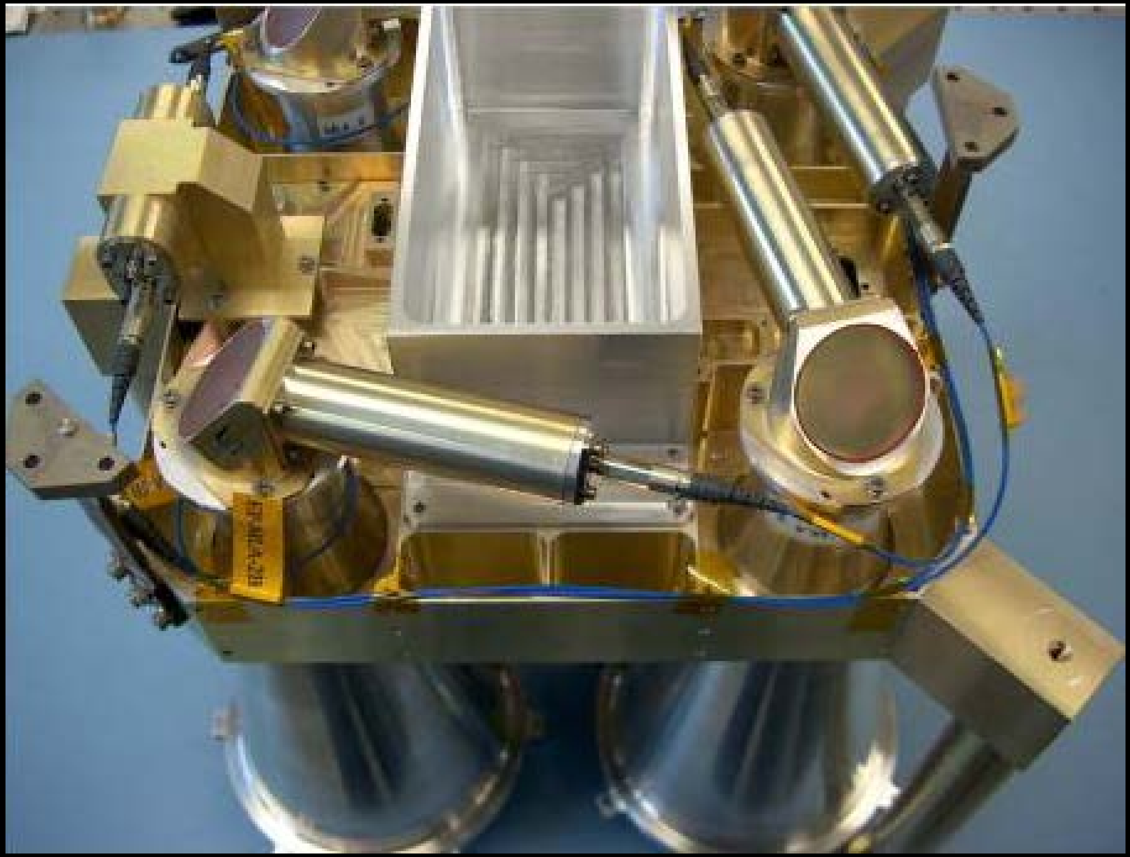
Risk mitigation to reduce cost - use space flight component failure mode knowledge;
Design out what you can –through configuration; packaging, materials, processes, screening.

Planetary and Earth Orbiting LIDARS

Mercury

Mercury Laser Altimeter on Mercury Surface, Space Environment, Geochemistry and Ranging (MESSENGER); development 1999-2003, built by NASA Goddard Space Flight Center

Launch 2004, Operation 2011-2015 (travel time 7 years, 4 years usage, decommissioned in 2015)



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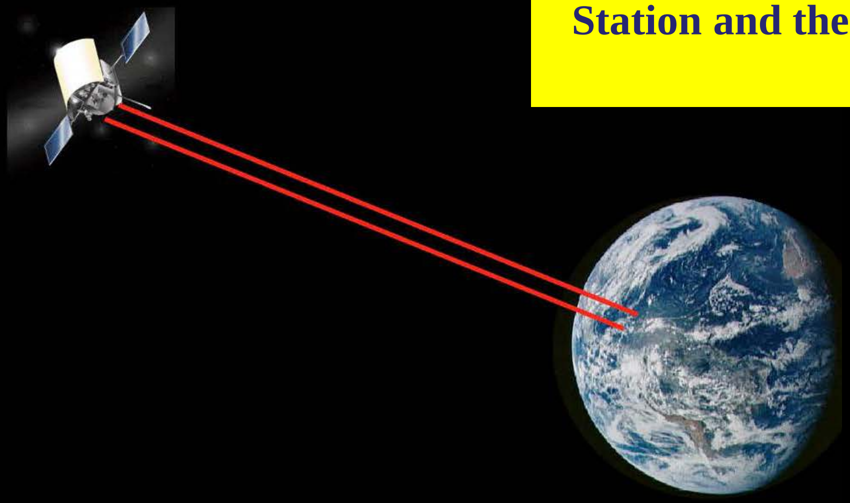
Planetary and Earth Orbiting LIDARS
Mercury

Smith, D. E., *et al.*, Two-way laser link over interplanetary distance, *Science*, 311, 5757, 53, Jan. 2006.

The 24 Million Km Link with the Mercury Laser Altimeter

Jay Steigelman
Dave Skillman
Barry Coyle
John F. Cavanaugh
Jan F. McGarry
Gregory A. Neumann
Xiaoli Sun
Thomas W. Zagwodzki
Dave Smith
Maria Zuber

MOLA Science Team Meeting
Bishop’s Lodge, Santa Fe, NM
August 24-25, 2005



On the way to Mercury a link between NASA GSFC Greenbelt Station and the MLA was established - Longest Laser Link in Space Flight @ 24 Million Km.

The success of this experiment led the way for the Laser Ranging investigation on the Lunar Reconnaissance Orbiter.

Planetary and Earth Orbiting LIDARS
The Moon

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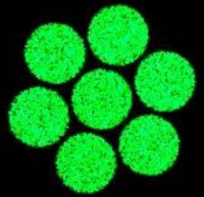
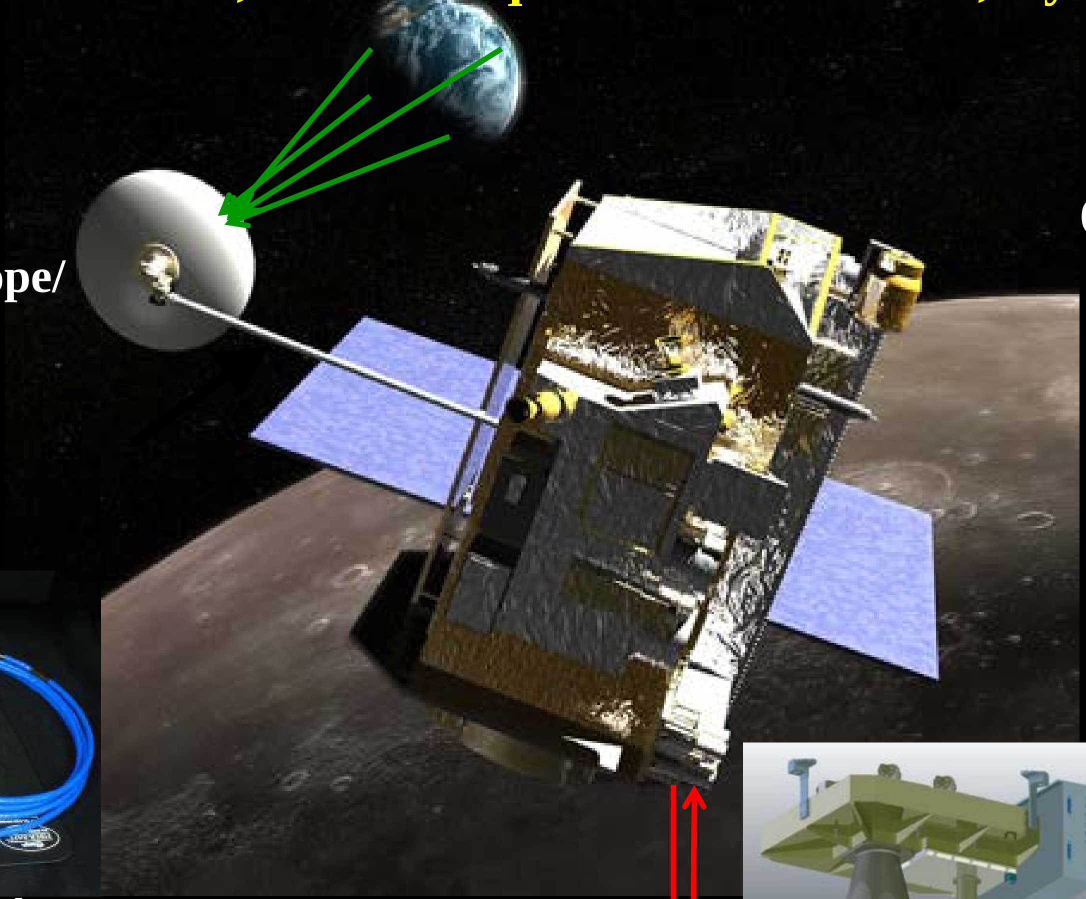
Laser Ranging Experiment & Lunar Orbiter Laser Altimeter (LOLA) –Lunar Reconnaissance Orbiter (LRO) Developed 2005-2008; Launch 2009, lifetime requirement 14 months, 3 years desired, actual 10 years and counting…..

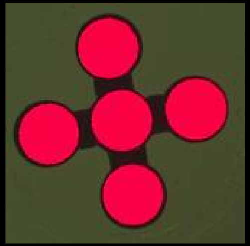
LASER RANGING @ 532 nm - Stations Around the World Transmitting to the receiver telescope/ 7 optical fiber array

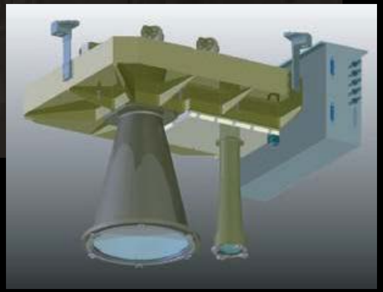


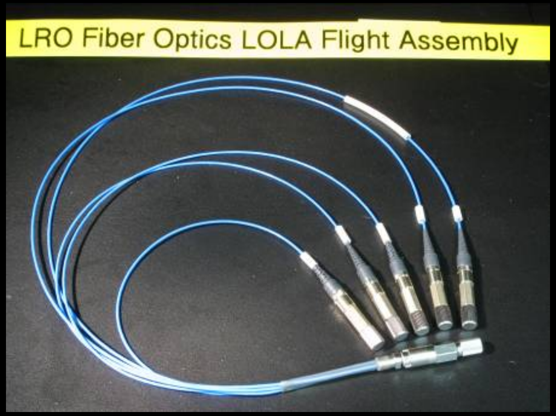
The assemblies traverse two moving gimbals, and a deployable mandrel 10 meters away to LOLA.



Lunar Orbiter Laser Altimeter (LOLA) Measuring moon topography @ 1064 nm with a 5 fiber array







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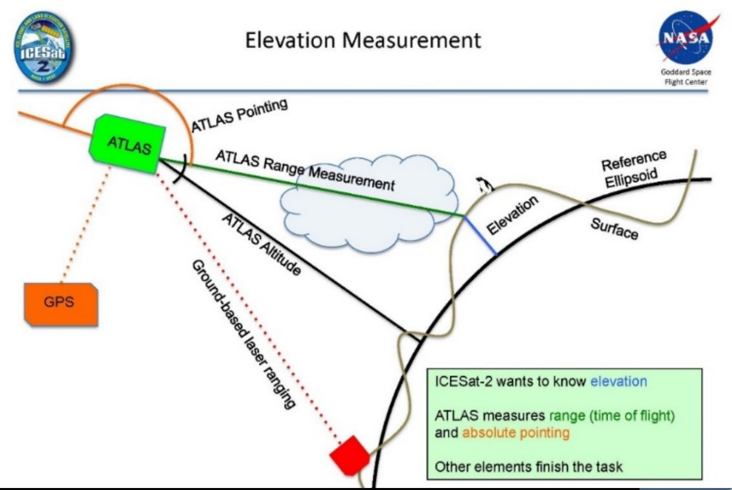
https://lunar.gsfc.nasa.gov

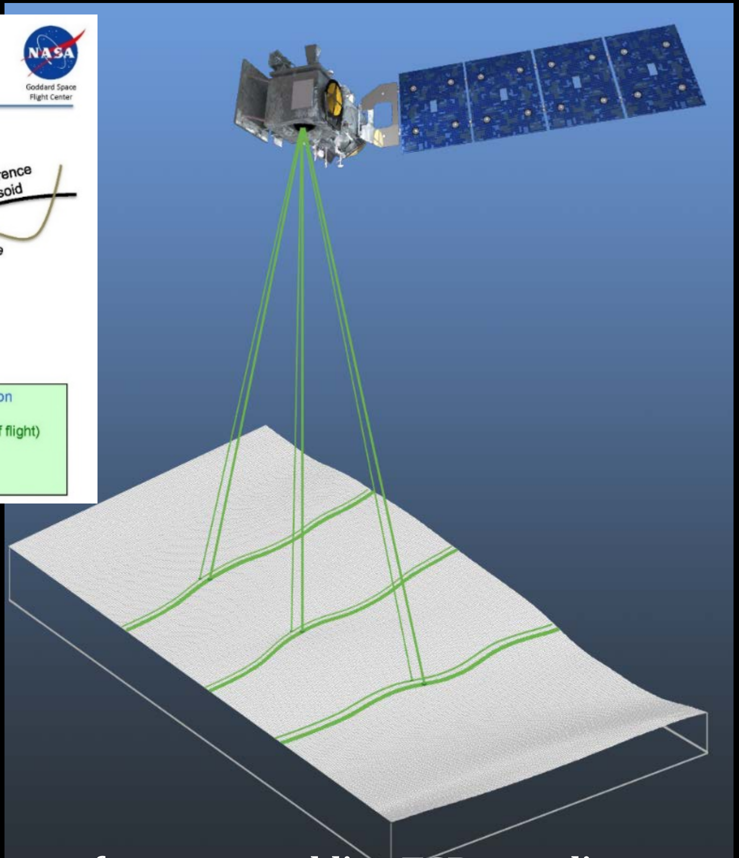
Planetary and Earth Orbiting LIDARS
Earth

https://icesat.gsfc.nasa.gov

Ice, Cloud and Land Elevation Satellite **(ICESat-2) – (ATLAS)** Advanced Topographic Laser Altimeter System (2012 – 2018)
Launched 2018, currently in operation. Expected lifetime > 3 years – measuring the height of sea ice to within an inch.



ATLAS uses ranging measurements with 532 nm and has a sophisticated real time, calibration system.



25 simplex, 4 bundle/array to fan out assemblies, ESD compliant—
5 different types of fiber; dual and quad fiber arrays; 52 interconnections.
Commercial LED - on board calibration system
Fibertek lasers

Melanie Ott (fiber system lead) inspecting the final flight configuration for fiber optic system. Transmission requirement of >98% for optical fiber receiver system.

Reference: http://icesat.gsfc.nasa.gov

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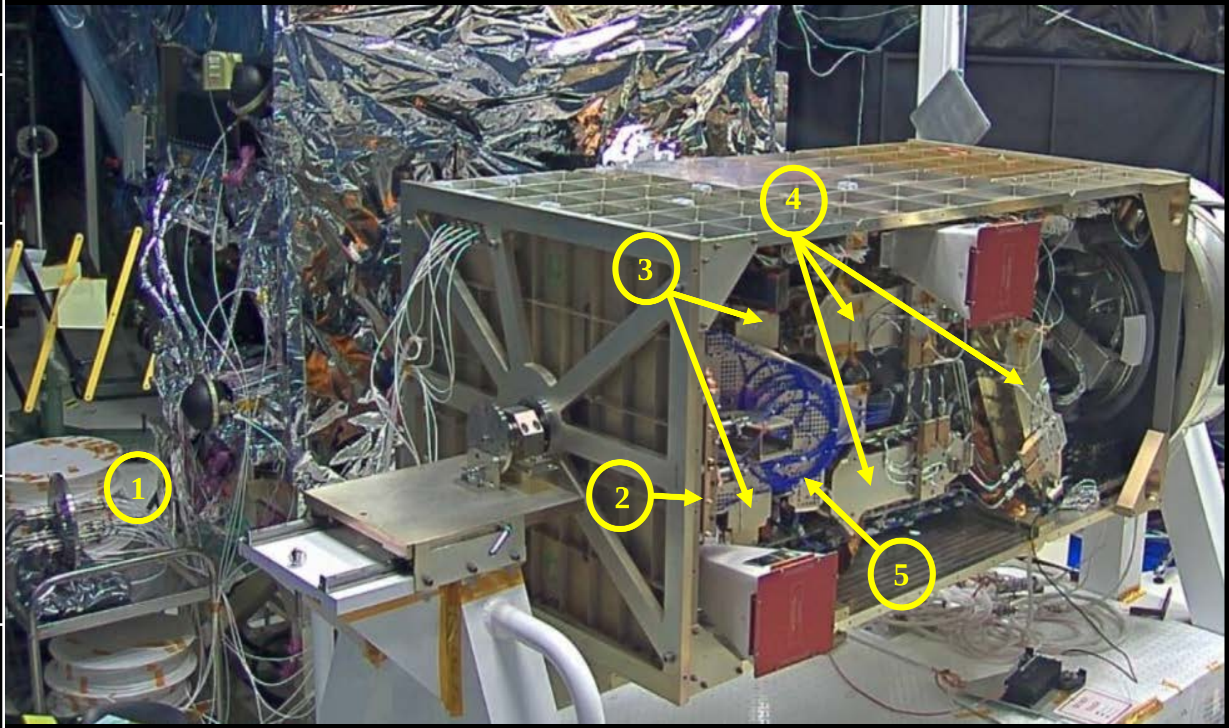
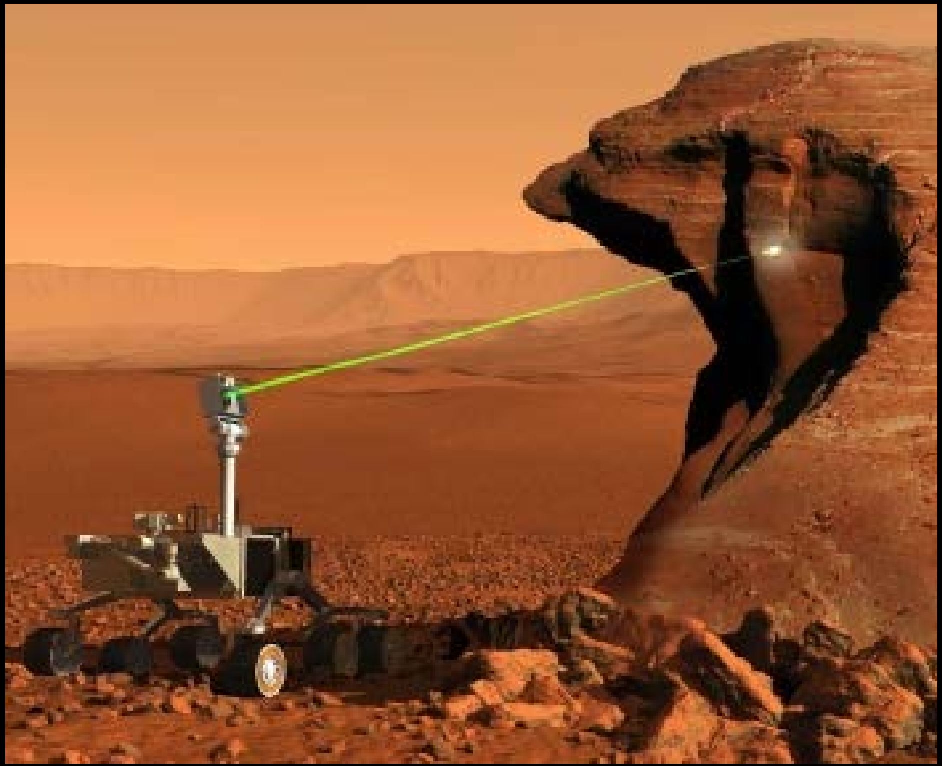
Planetary and Earth Orbiting LIDARS
Earth

GEDI: Global Ecosystem Dynamics Investigation LIDAR (2016-2018)
Launched Dec 2018, operating currently on International Space Station

#	GEDI Subsystem	Hardware Deliveries
1	Checkout Equipment	Development, fabrication & integration: laser & detector test rack used for qualification of flight instrument, TVAC fiber assemblies down to -120°C.
2	Detector Qualification	Qualification of engineering & flight unit detectors
3	Laser Beam Dithering Unit	Development, fabrication, qualification & integration of engineering and flight units
4	Optical Laser Components	Development, qualification & fabrication of flight laser fiber optic feedthrough. Incoming inspection of laser components.
5	Flight Fiber Optic System	Development, qualification & integration of flight 600/600µm fiber optics transmission >97%; 200/220µm triple fiber arrays for start pulse. Adapter inspections and screening.

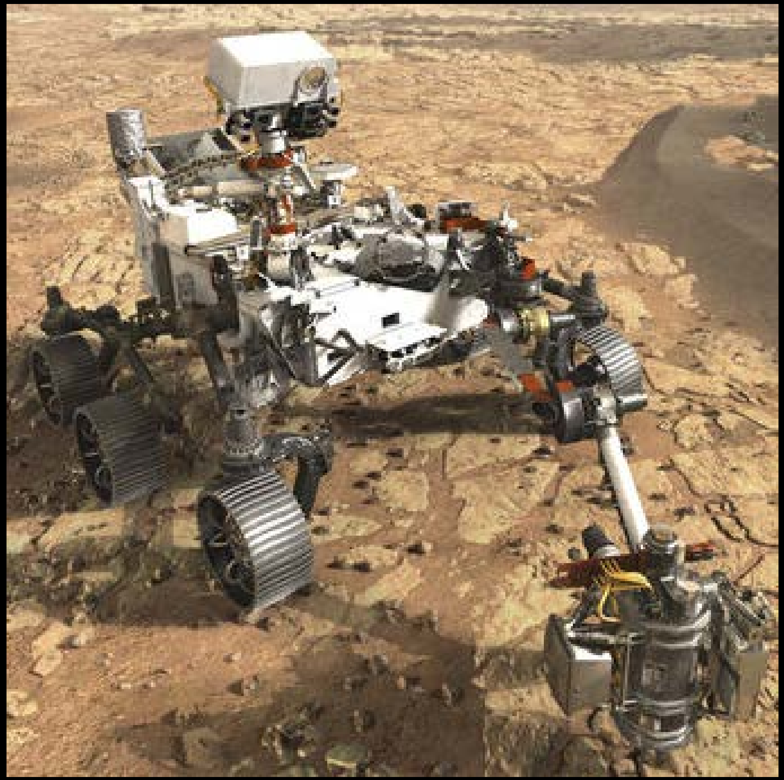


Science, Rovers and Communications
Mars

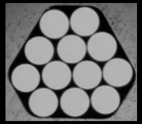


Mars Curiosity Rover; ChemCam Instrument
Launch Nov. 2011,
currently in operation.

Hali Jakeman inspects the flight Mars2020 assemblies



Mars 2020 Rover, SuperCam Instrument
Currently in integration and test.



Development, fabrication, qualification of flight hardware delivery for JPL

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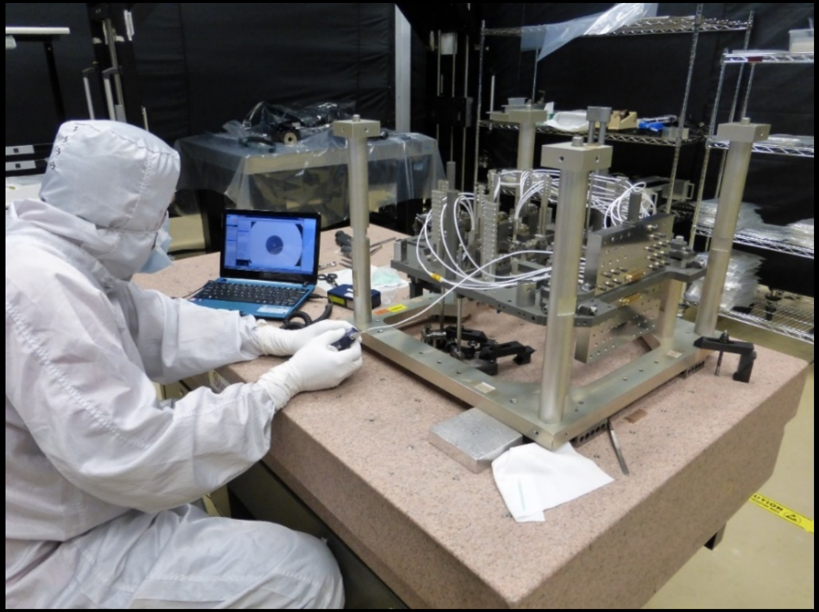
Science, Rovers and Communications

Communications: Multimode and Singlemode;

- Express Logistics Carrier on International Space Station. – Qualification of transceivers, fiber optic assemblies (2006 – 2010)
- Lunar Laser Communications Demonstration cryogenic hardware for MIT LL (2010)
- Communications for Cloud Aerosol Transport System; cats.gsfc.nasa.gov (2014) w/ FiberTek, Micropac
- Laser Communications Relay Demonstration; Screening and qualification (laser diodes & photonic components) (2014)

Science: Infrared, and/or polarization maintaining, single and multimode, thermal vacuum and cryogenic applications:

- James Webb Space Telescope; Ball Aerospace, Johnson Space Center & GSFC. (2008-2018)

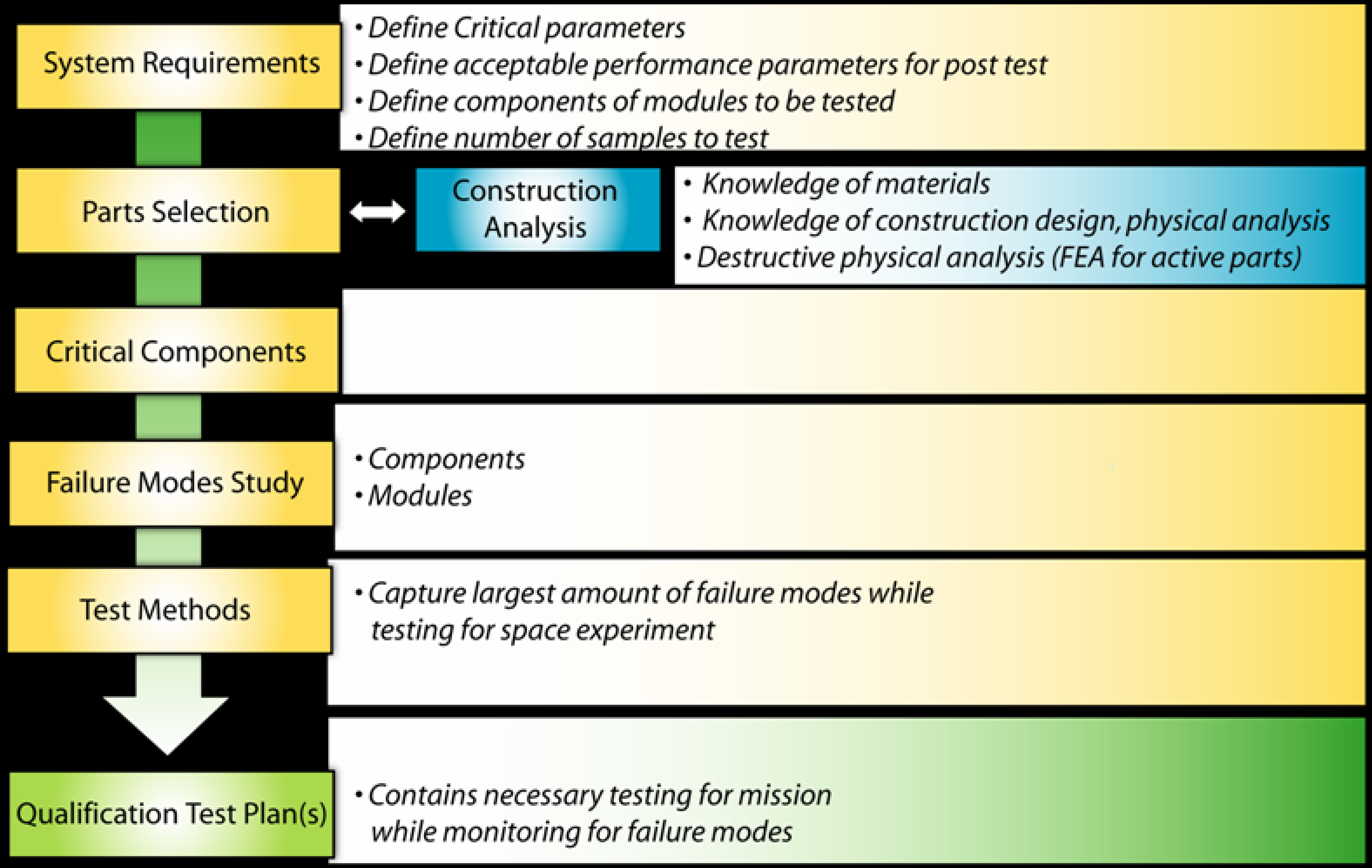


Rob S. @ Ball installs cryo assemblies

Eleanya Onuma installs vacuum feedthroughs

**Rob Switzer and Melanie Ott,
ELC integration @ Kennedy Space Center**

COTS Technology Assurance Approach



COTS Space Flight "Qualification"

Step	Notes
Materials Analysis	• *Outgas testing for anything unknown* • *Take configuration into account*
Vibration Survival and "Shock Test"	• *Use components levels as defined by system requirements* • *Define parameters to monitor during testing*
Thermal Cycling / Aging Test	• *Define which parameters will indicate which failure mode* • *Monitor those parameters during testing*
Radiation Testing	• *Acclerated dose rate* • *Extrapolation model use if possible* • *Worst conditions*
Additional Tests	• *Based on specific mission requirements*
Qualification Assurance Plan	• *Continued reliable performance over life of mission*

Selection, screening & qualification of laser components similar to the process of EEE parts but modified for optical components. EEE parts qualification is not applicable as a recipe for optoelectronics.

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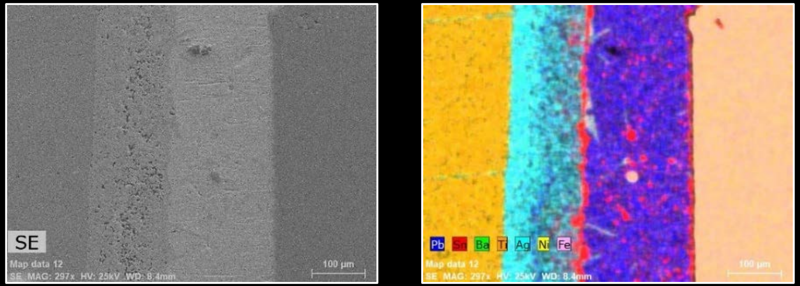
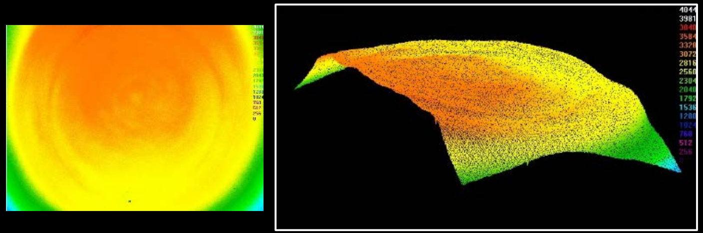
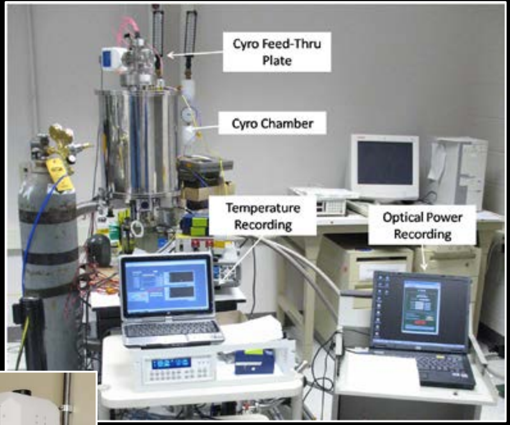


10 k X Mag SEM & Material Identification



LED Beam Profile

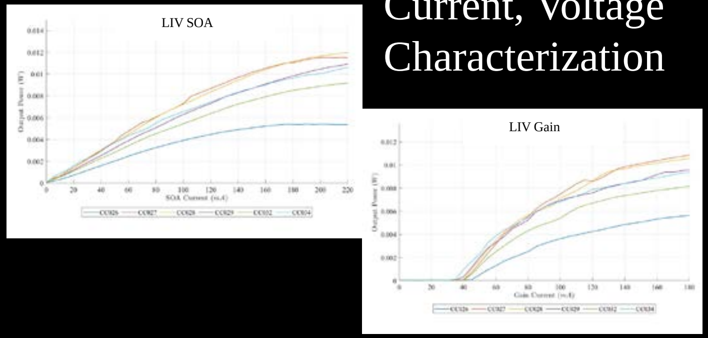


Cryogenic Test Facility

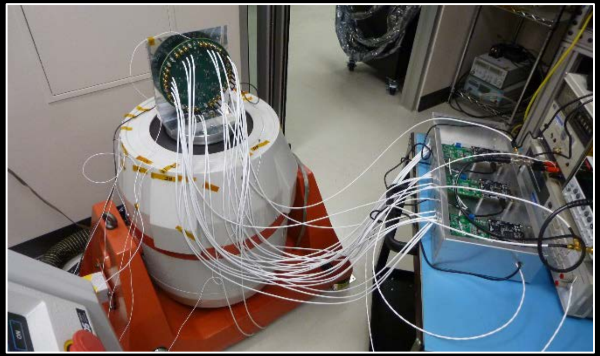
Radiation Test Equipment

Materials Screening / Construction Analysis → **Optical Inspection & Screening** → **Performance Characterization** → **Vibration / "Shock" Testing** → **Thermal Cycling / Vacuum** → **Radiation Testing** → **Additional Testing?**

Optical Power, Current, Voltage Characterization



White Light LED Testing in Environmental Chamber



Random Vibration Test & Shock Equipment

Issues to Consider

- Schedule, shorter term
- Funds available,
- Identify sensitive or high risk components.
- System design choices for risk reduction.
- Packaging choices for risk reduction.
- Quality by similarity means no changes to part or process.
- Qualify a “lot” by protoflight method—you fly the parts from the lot qualified, not the tested parts.
- Telcordia certification less likely now for non communication type applications.
- Process changes at the component level happen often.

Reference: ***Optical Society of America Frontiers in Optics, Session on Space Qualification of Materials and Devices for Laser Remote Sensing Instruments I, Invited Tutorial,*** **M. Ott, September 2007.**

Define "Qualification"

Are you rich or are you poor?

- $$$$= MIL-STD's + Telecordia + NASA or Space Requirements
  - Lifetime Lot buys for COTS parts or anything that will go obsolete.
- $$$ = Telecordia + NASA or Space Requirements
  - Buy critical parts , qualify by Lot.
- $$ = COTS Approach for Space Flight (NASA Requirements)
  - Requires careful planning especially with materials selection
  - Lot specific testing
  - Destructive physical analysis/ packaging or construction analysis necessary early on
  - Radiation testing performed early in selection phase – saves schedule later.

Reference: ***Implementation and Qualification Lessons Learned for Space Flight Photonic Components, Invited Tutorial*** **M. Ott, International Conference on Space Optics, Rhodes Greece, October 2010.**

Environmental Parameters

- Vacuum requirements
  - (Materials Analysis, Vacuum Test, Contamination)
- Vibration requirements
- Thermal requirements
- Radiation requirements
- Other Validation Tests

Reference: ***Optical Society of America Frontiers in Optics, Session on Space Qualification of Materials and Devices for Laser Remote Sensing Instruments I, Invited Tutorial*, M. Ott, September 2007.**

Environmental Parameters: Vacuum

Vacuum outgassing requirements:

- ASTM-E595: 100 to 300 milligrams of material
  125°C at 10^{-6} Torr for 24 hours
  Criteria: 1) Total Mass Loss < 1%
  2) Collected Volatile Condensable Materials < 0.1%
- Configuration test or are Optics or laser nearby, contamination?

1) Use approved materials, outgassing.nasa.gov
2) Preprocess materials, vacuum, thermal
3) Decontaminate units: simple oven bake out, or vacuum?
4) Vacuum test when materials analysis is not conducted and depending on packaging and device.

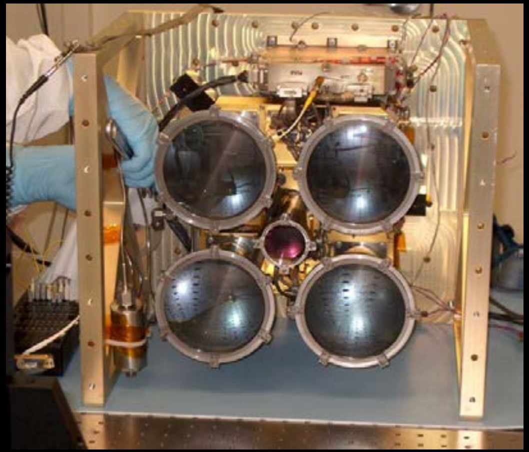
Space environment; vacuum is actually 10^{-9} torr, best to test as close as possible for laser systems. TVAC chambers no $<10^{-7}$ torr.

Knowing your materials & how to use process them properly.

Vibration Validation Testing
Goddard Environmental Spec (GEVs)

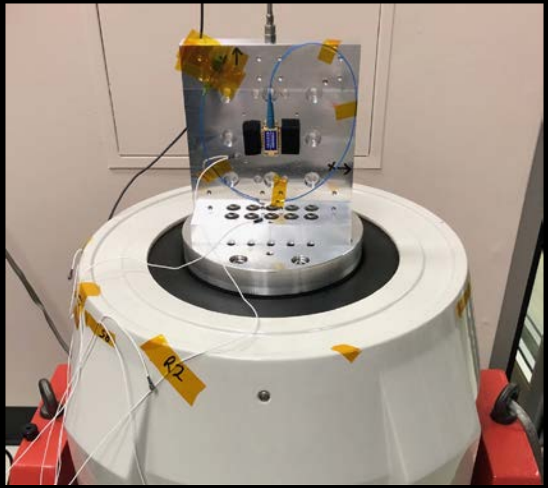
3 min/axis for Random Vibration

Frequency (Hz)	Level
20	0.013 g^2/Hz
20-50	+6 dB/octave
50-800	0.08 g^2/Hz
800-2000	-6 dB/octave
2000	0.013 g^2/Hz
Overall	**9.8 grms**



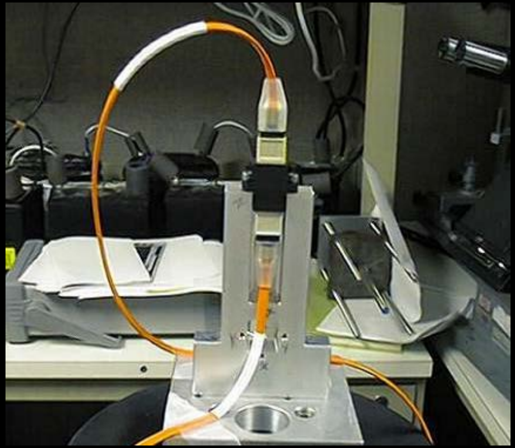
Instrument Random Vibration: Mercury Laser Altimeter

Frequency (Hz)	Level
20	0.026 g^2/Hz
20-50	+6 dB/octave
50-800	0.16 g^2/Hz
800-2000	-6 dB/octave
2000	0.026 g^2/Hz
Overall	**14.1 grms**



Component Random Vibration: Photonic Integrated Circuit

Frequency (Hz)	Level
20	0.052 g^2/Hz
20-50	+6 dB/octave
50-800	0.32 g^2/Hz
800-2000	-6 dB/octave
2000	0.052 g^2/Hz
Overall	**20.0 grms**



Small Part Random Vibration: Array connector

Environmental Parameters: Thermal

- There is no standard, typical and benign –25°C to +85°C.
  - -45°C to +80 °C : Telcordia.
  - -55°C to +125 °C : Military – Has it changed?
  - -165°C (108K) for Europa extravehicular, or -223°C (50K) or less for IR instruments.
- Depending on the part for testing;
  - In situ testing is important,
  - Add 10°C to each extreme for box level qualification or 20°C for survival
- Thermal cycles determined by part type, schedule vs. risk
  - 30 cycles minimum for assemblies, high risk
  - 60 cycles for assemblies for higher reliability
  - 100 or more, optoelectronics and longer term missions

Knowledge of packaging and failure modes really helps with cycles determination.

What happens when you want data beyond the specification?
COTS vendors typically don't test way outside of the specification

Cryogenic Polarization Maintaining Fiber In-Situ Testing: Polarization Extinction Ratio

Coated bare fiber in the cryogenic shroud/chamber

Cryogenic chamber with custom design/fabricated (in-house) feedthrough and equipment to monitor polarization extinction ratio during exposure to temperatures </= -165°C

Test Conducted in the GSFC 562-Photonics Labs.

Alejandro Rodriguez integrating the test system

Cryogenic Stress Test – Optical Fiber Polarization Extinction Ratio Validation Test

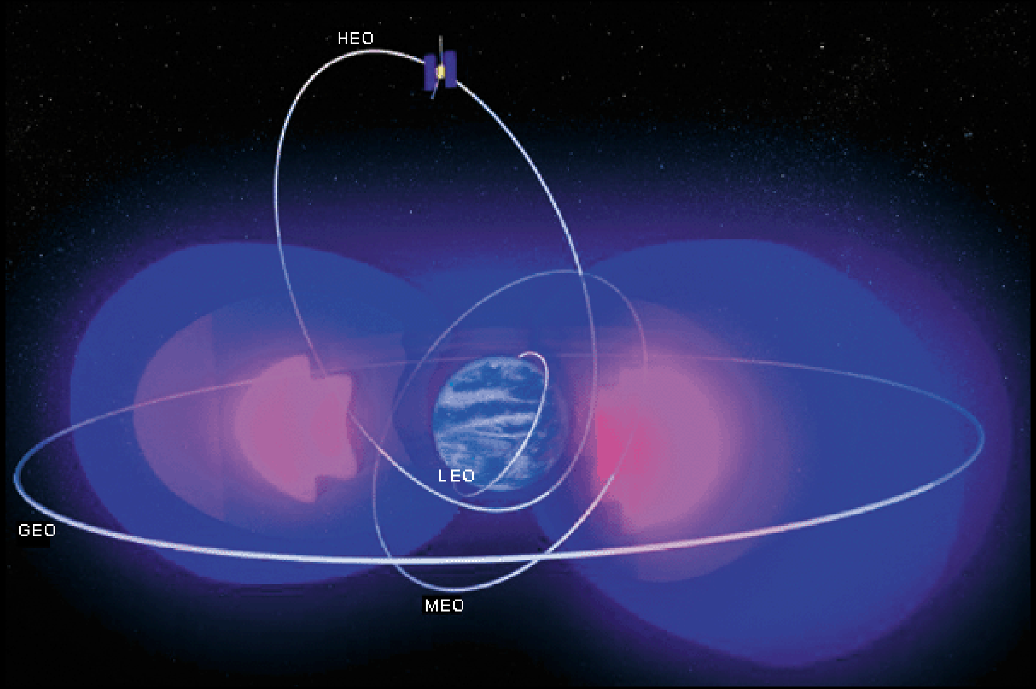
Cryogenic exposure for extravehicular implementation: polarization fiber test results (PER vs. Temperature)

Candidate (10 m)	**Room Temperature PER (dB)**	**Cold Temperature (dwell)**	**Change in PER (dB), as compared to 25°C**
Coherent Nufern PM980-XP	27.3	-205°C	0.40
Coherent Nufern PM980B-XP	23.8	-165°C	0.20

Change in Polarization Extinction Ratio @ -165ºC (108K) is negligible

Engineer Consultants and Scientists told the project that polarization maintaining fiber didn't work below -55ºC. Within months we debunked this "myth"

Environmental Parameters: Radiation



Assuming 7 year mission, Shielding from space craft:

- LEO, 5 – 10 Krads, SAA
- MEO, 10 –100 Krads, Van Allen belts
- GEO, 50 Krads, Cosmic Rays

Proton conversion to Total Ionizing Dose (TID)
At 60 MeV, 10^{10} protons/Krad for silicon devices
For systems susceptible to displacement damage

- Testing for displacement damage: 3 energies in the range ~ 10 to 200 MeV.
- If you have to pick one or two energies stay in the mid range of 65 MeV and lower. Less probability of interaction at high energies like 200 MeV (too high as a qualification level, alone).
- Ballpark levels: 10^{12} p/cm^2 LEO, 10^{13} p/cm^2 GEO, 10^{14} p/cm^2 Europa

Reference: ***Optical Society of America Frontiers in Optics, Session on Space Qualification of Materials and Devices for Laser Remote Sensing Instruments I, Invited Tutorial,*** **M. Ott, September 2007.**

Environmental Parameters: Radiation

Typical space flight background radiation total dose = 30 Krads – 100 Krads over 5 to 10 year mission.

Dose rates for fiber components:

- ICESat-1 was GLAS: 100 Krads, 5 yr, .04 rads/min
- Mercury Laser Altimeter: 30 Krads, 8 yr, .011 rads/min (five year ave)
- Earth Orbiter-1: 15Krads, 10 yr, .04 rads/min
- ISS Extra vehicular: 1 Mrad/year, 2 rads/min – Not really that bad!
- Europa: 12Mrads, 210 Krads/min @ -165C – risk mitigation with test as you would fly.

Other environments to consider?

For example,

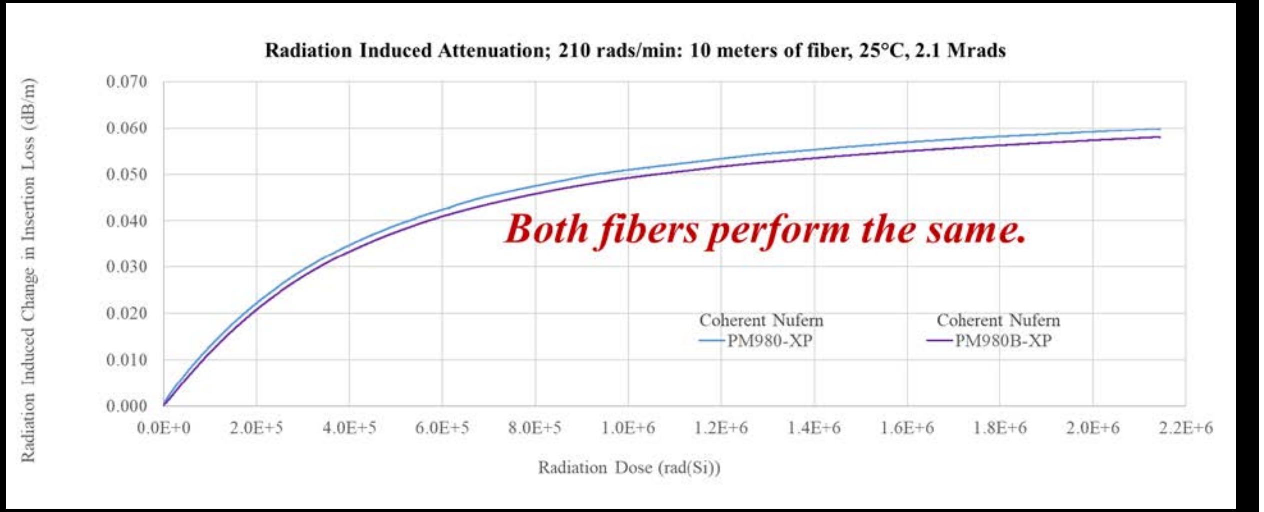
1) Radiation exposure at very cold temp, or prolonged extreme temperature exposure based on mission demands – there are risk mitigation strategies.

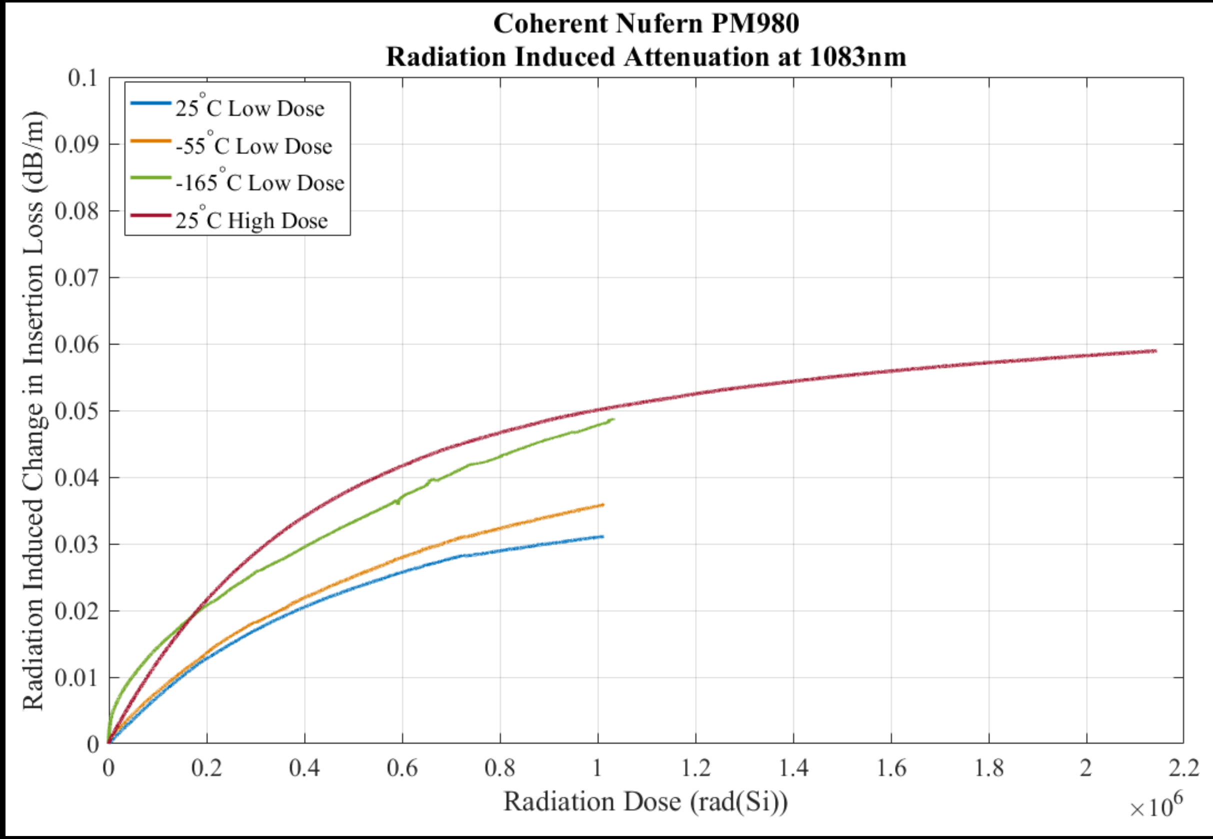
2) Motion during cold exposure for a long time? LRO is now been in cold motion for 10 years!

Reference: ***Optical Society of America Frontiers in Optics, Session on Space Qualification of Materials and Devices for Laser Remote Sensing Instruments I, Invited Tutorial,*** **M. Ott, September 2007.**

Extravehicular @ Europa
Cold, High Total Dose & Dose Rate Radiation Exposure

- Why should you buy down the high risks early in instrument development?
  - Example Europa –a radiation study that proved the extravehicular fiber would work even under conditions of radiation dose rate 2 orders of magnitude higher than a LEO (1 Mrad/yr).





1) Which fiber works better?
2) Formulate a "predictive" model at any temp, dose rate & total dose?
3) Can use the model to predict end of life losses for the system?

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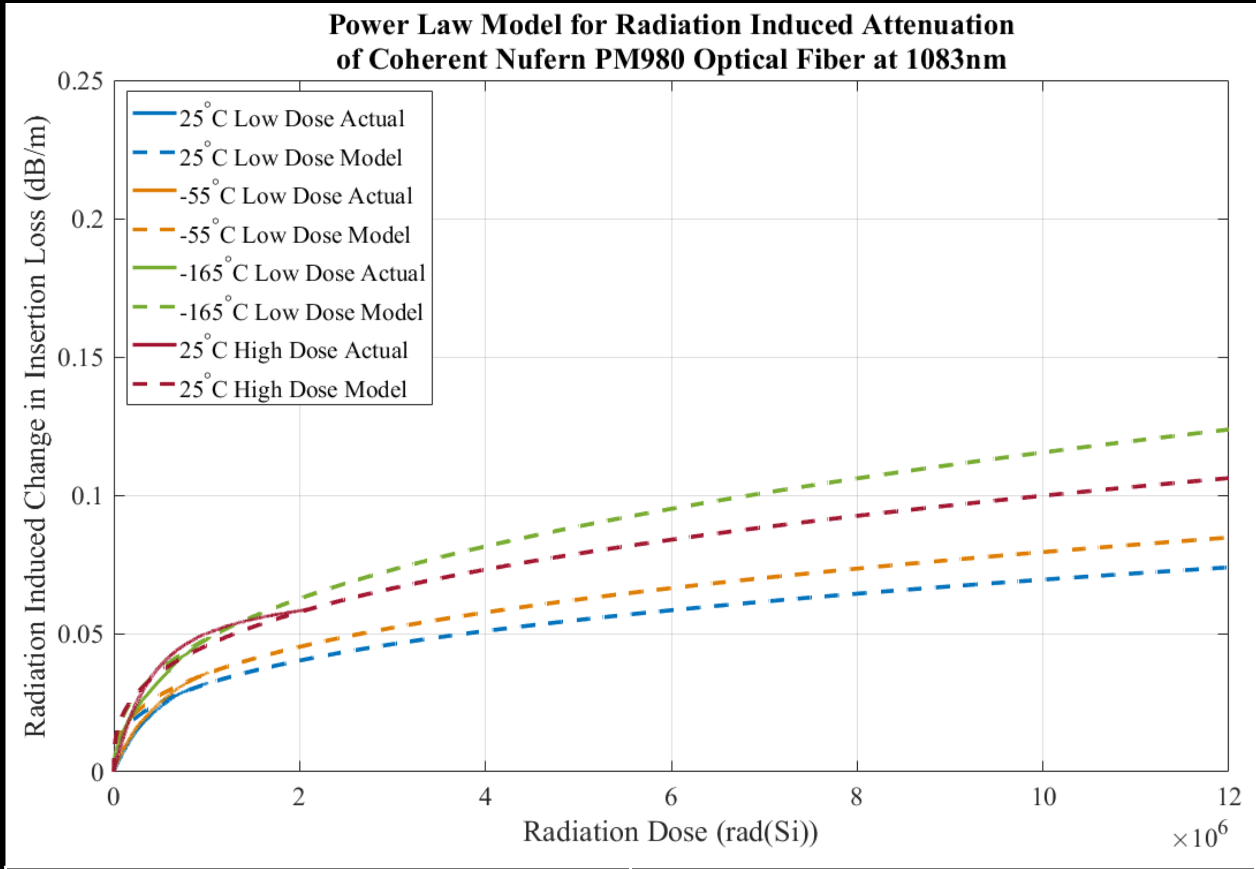
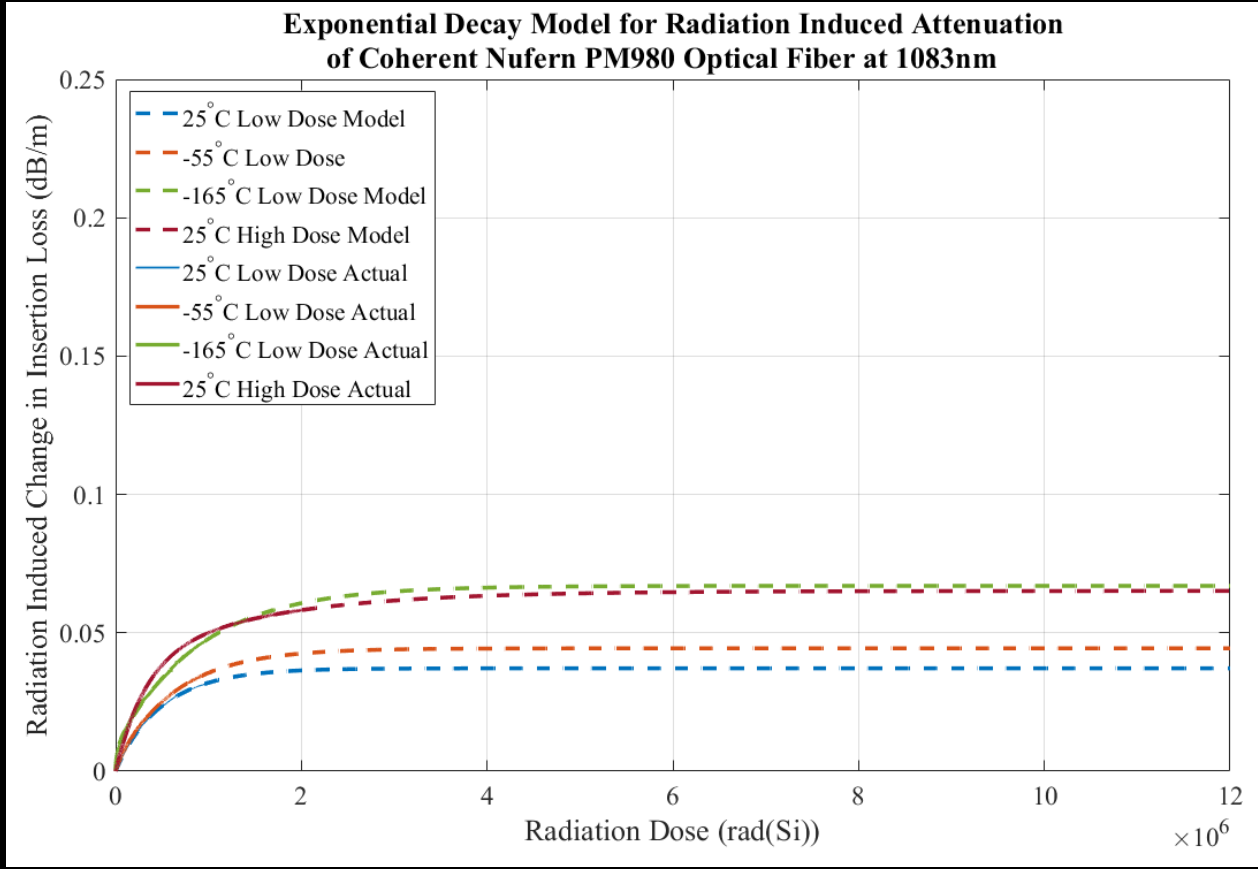
Debunk the "myths" regarding radiation performance of optical fiber

Power Law Model (Overestimation) – 12 Mrads



Total Extrapolated Radiation Induced Attenuation	1.4 dB @ EOL

Exponential Decay Model (Realistic) – 12 Mrads



Total Extrapolated Radiation Induced Attenuation	0.8 dB @ EOL

Yes, study proved that the fiber system could handle cold temperatures and high radiation: significant weight and power reduction as a result

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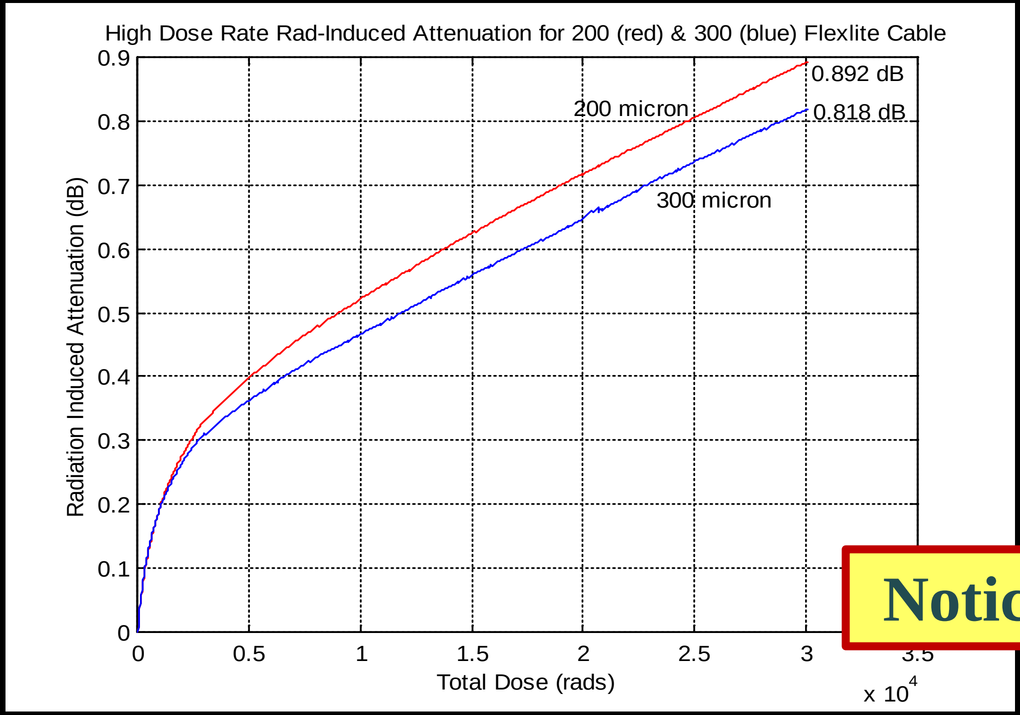
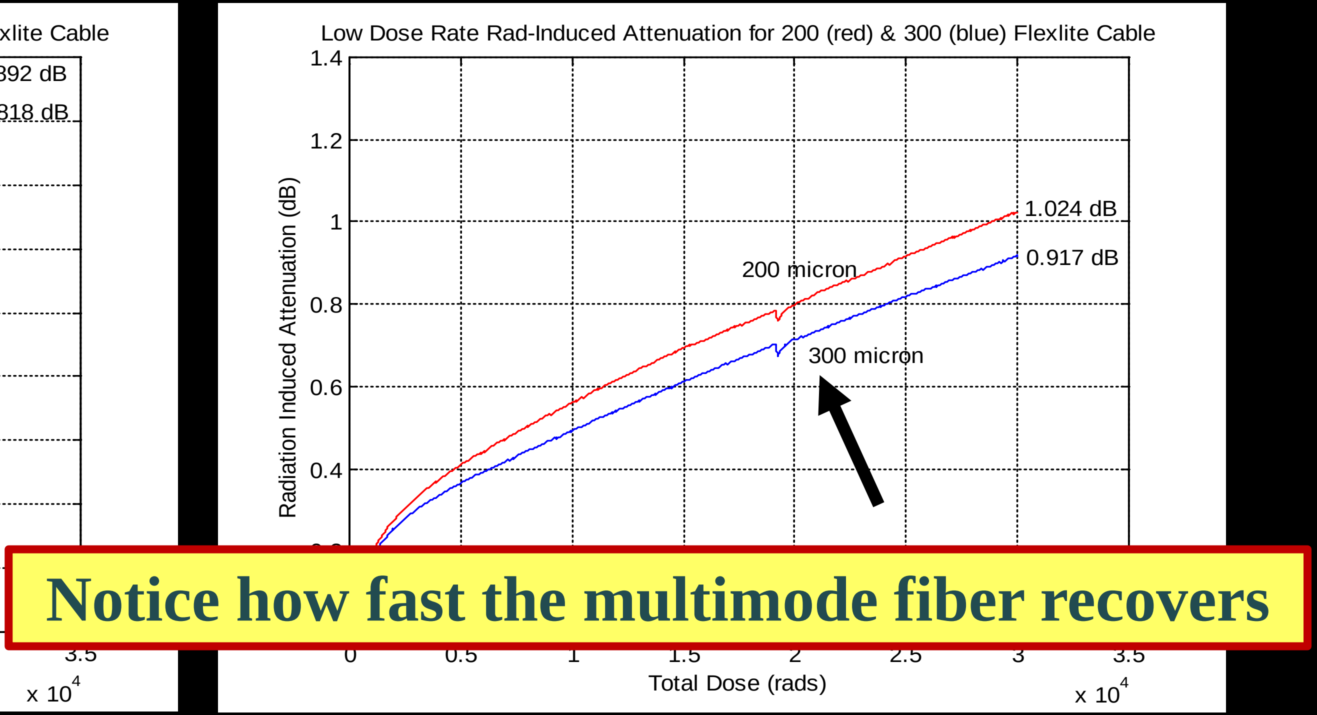
Radiation Performance

Not usually a detriment - for calibration and risk reduction is always necessary



Flexlite Radiation Test, 22.7 rads/min at –18.3°C



Flexlite Radiation Test, 11.2 rads/min at –24.1°C

Radiation Conclusion: < .07 dB, using 11.2 rads/min, -24.1°C, 26.1 in, "dark"

Results for 10 m, at 30 Krads, -20°C, 850 nm, 23 rads/min ~ 1 dB or 0.10 dB/m

Radiation Induced Attenuation: Optical Fiber Summary of Remote Sensing (20 years overview)

Location & Instrument	Dose Rate (rad(Si)/min)	Total Dose (rad(Si))	Temp (°C)	Wavelength (nm)	RIA for 10m (dB)
MERCURY Laser Altimeter (20 years ago)	11.2*	30 Krad	-24	850	1.0
MOON: LOLA on LRO (10 years)	1	5 Mrad	24	850	0.19
EARTH: ICESAT-2 Laser Altimeter	5.5	8 Krad	24	532	0.21
EUROPA Clipper	210	12 Mrad	-165	1083	1.0 **

*Dose rate from actual radiation test. No prediction model. Actual mission dose rate ~0.011 rads/min.

**System analysis result based on worst case, lowest power level located just before sensor

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Optoelectronics Mission Highlights: last 10 years
(communications transceivers not included in table)

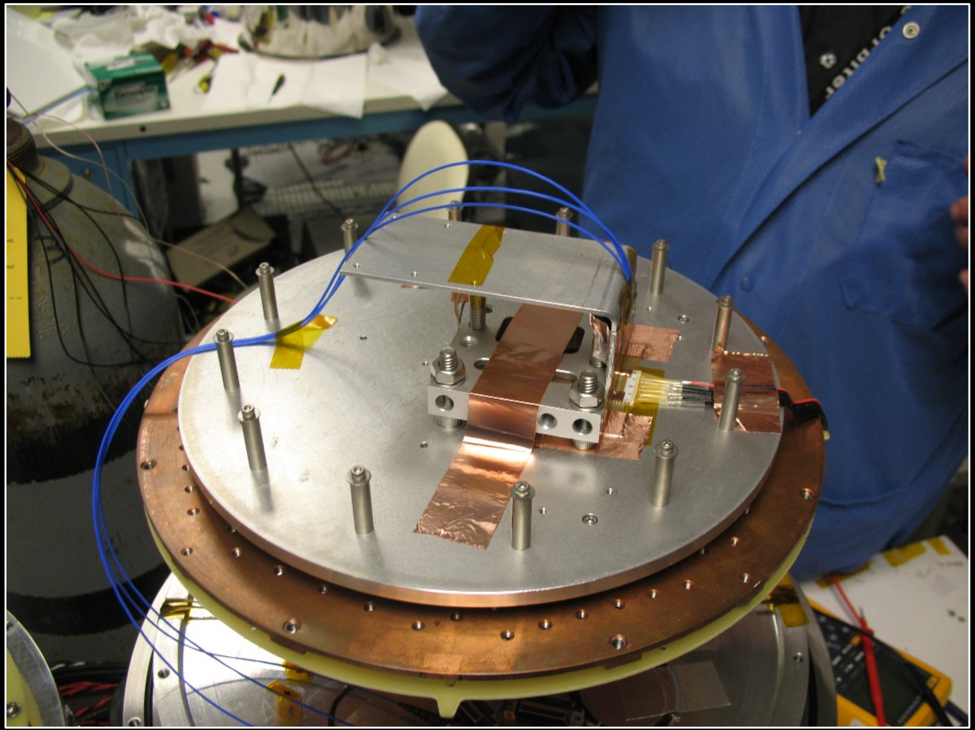
NASA

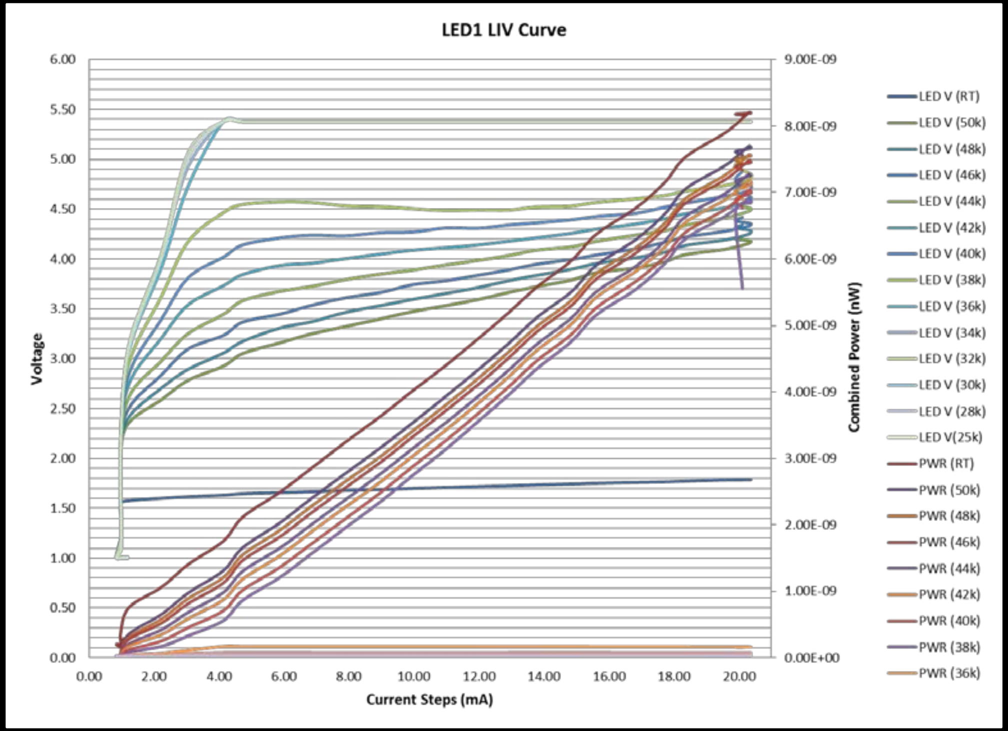
Project	Part Type	Wavelength (nm)	Quantity	Dates	Screening	Qualification	Radiation	Packaging Analysis
SAA Harris	Laser Diode	635, 660	30	2009	x	x		x
JWST	LED	633	6	2009		x		
TSIS/GLORY	Photodiode	140 – 1100	25	2010	x			x
LADEE/MAVEN	LED	450 – 650	50	2010	x	x		
SSCP	LED	450 – 650	290	2012	x	x		x
GOES-R	LED	315	4	2012				x
ATLAS	Photodiode	400 – 1100	10	2013	x		x	
OTES	Photodiode	450 – 1050	60	2014	x	x		x
OTES	Pyroelectric Detector	4000 – 50000	8	2014	x	x		x
SSCP	LED	635	842	2010-2013	x	x	x	x
ATLAS	LED	520	300	2012 - 2013	x	x	x	x
Solar Orbiter	Laser Diode	850	70	2013 - 2014	x	x		x
Solar Orbiter	Photodiode	450 – 1050	70	2013 - 2014	x	x		x
OTES	Laser Diode	850	50	2014 - 2015	x	x		x
MOMA	Micropirani	N/A	25	2014 - 2015	x	x		x
SSCO	LED	450 – 650	1000	2016-2019	x	x	x	x
SAA ASU	Laser Diode	850	45	2017 - 2018	x	x		x
SAA ASU	Pyroelectric Detector	4000 – 50000	43	2017 - 2019	x	x		x
NASA GCD Program	Photonic Integrated Circuit	1550	8	2018 - Present	x	x	x	x

James Webb Space Telescope (JWST)

- LEDs were evaluated for use in a cryogenic environment.

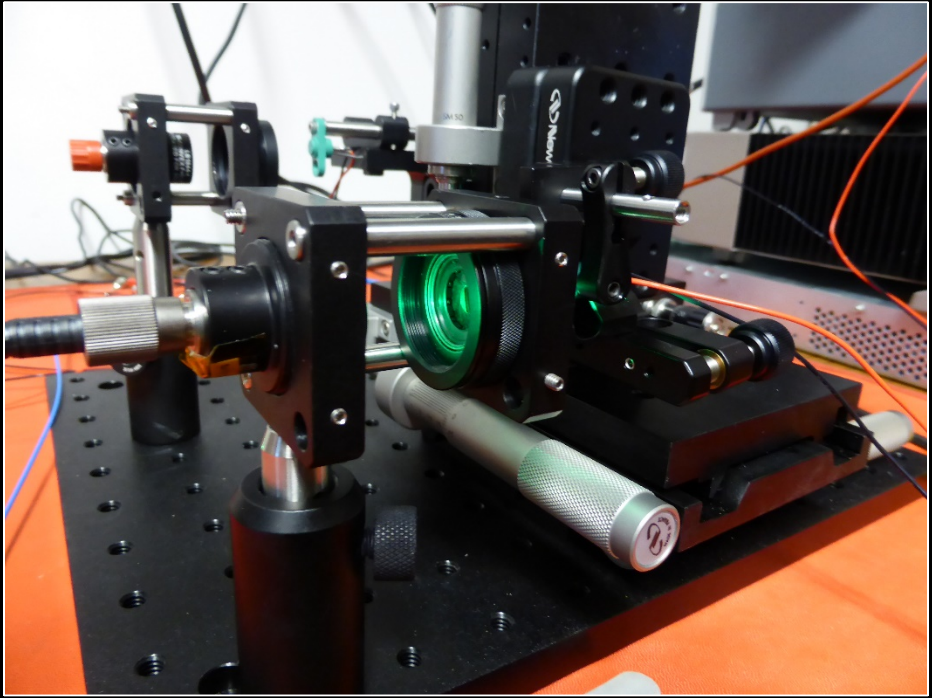
- In-situ electro-optical measurements were acquired to assess the component’s performance characteristics.

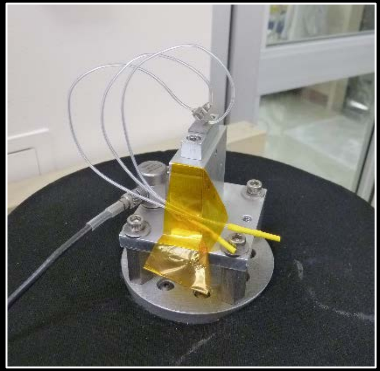


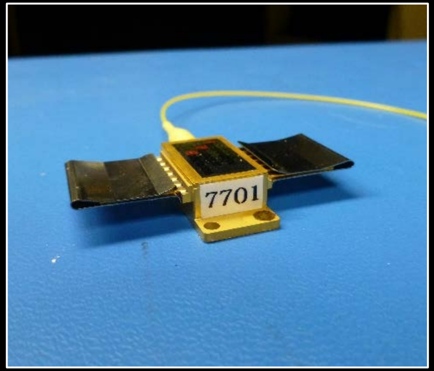


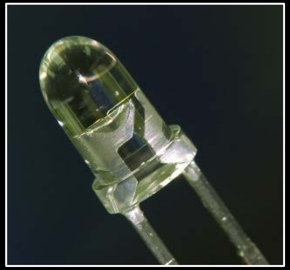
Ice, Cloud and Land Elevation Satellite (ICESat-2) – (ATLAS) Advanced Topographic Laser Altimeter System

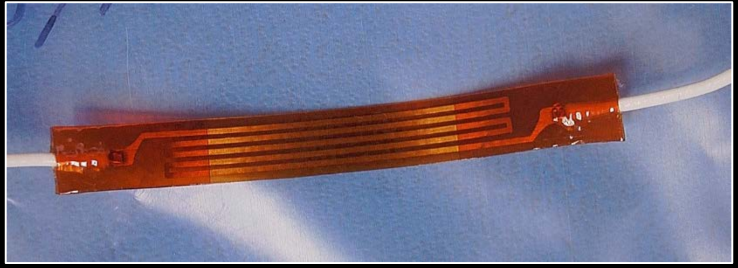
- The Code 562 Photonics Group was involved in the testing or evaluation of seven components used on the ATLAS instrument, currently operating on ICESAT-2.
- Testing included: visual inspections; thermal, electrical, and optical characterization; random vibration; radiation testing; and destructive physical analysis.







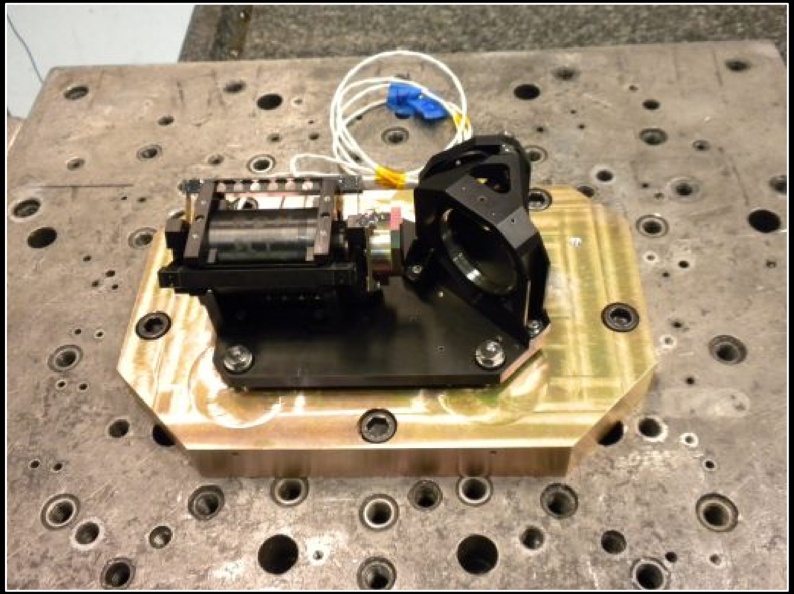


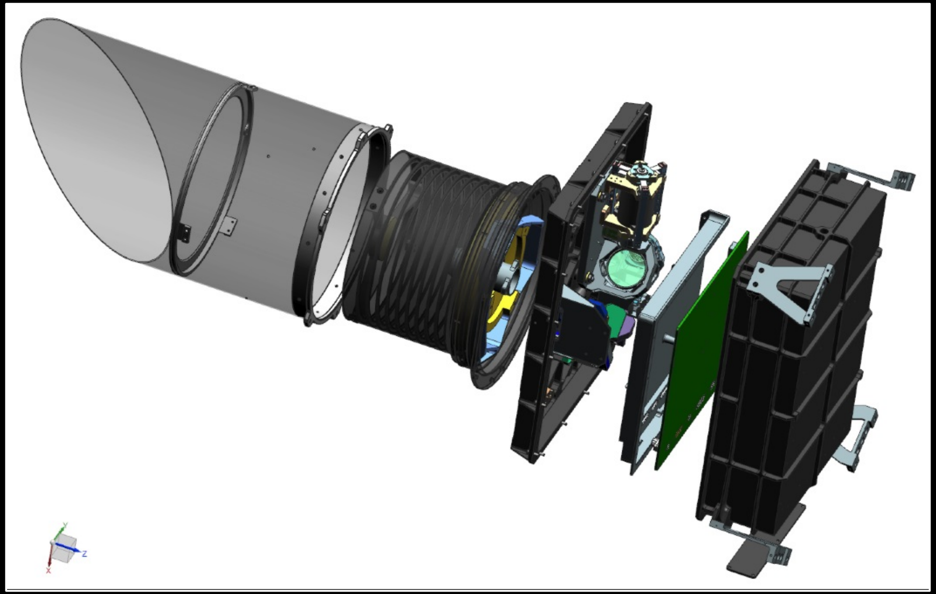


The Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) Mission to Bennu

The Thermal Emission Spectrometer OTES instrument is a point spectrometer on board (OSIRIS-REx) spacecraft.

- It is capable of mapping the asteroid Bennu’s material composition, with a 4-50 um wavelength range.
- OTES; developed at the School of Earth and Space Exploration at Arizona State University.



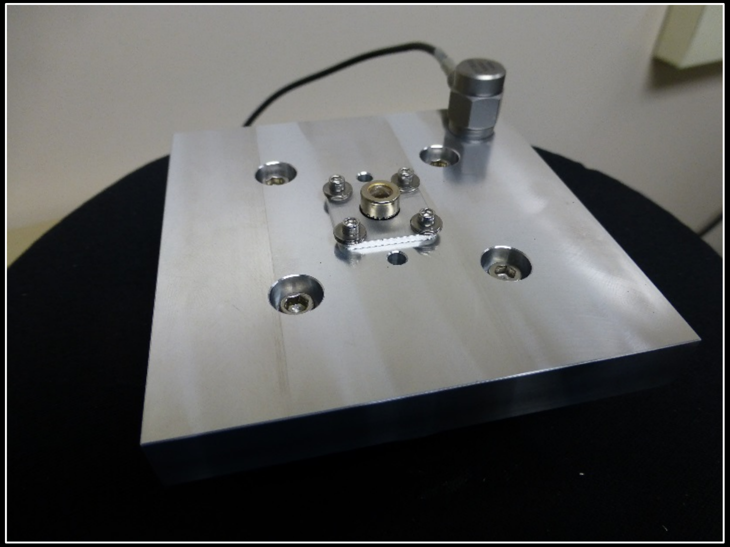


Reference: http://spaceflight101.com/osiris-rex/osiris-rex-instruments/

Partnership with Arizona State University Screening and Qualification

ASU partnered with the Code 562 Photonics Group to perform the screening and qualification of laser diodes, pyroelectric detectors, and photodiodes for;

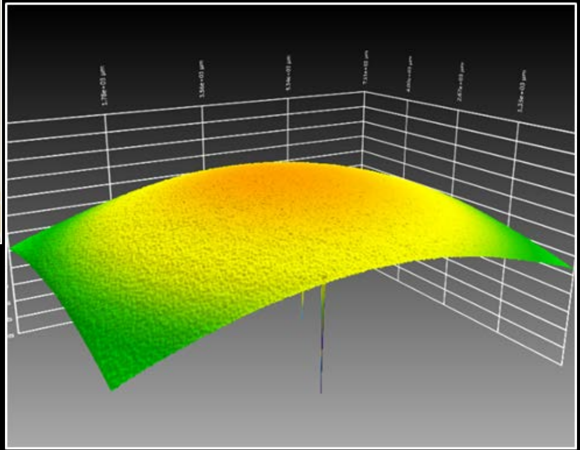
- Thermal Emission Spectrometer,
- Space Act Agreement (Mars environment)
- Currently on LUCY (mission to Jupiter Trojans).

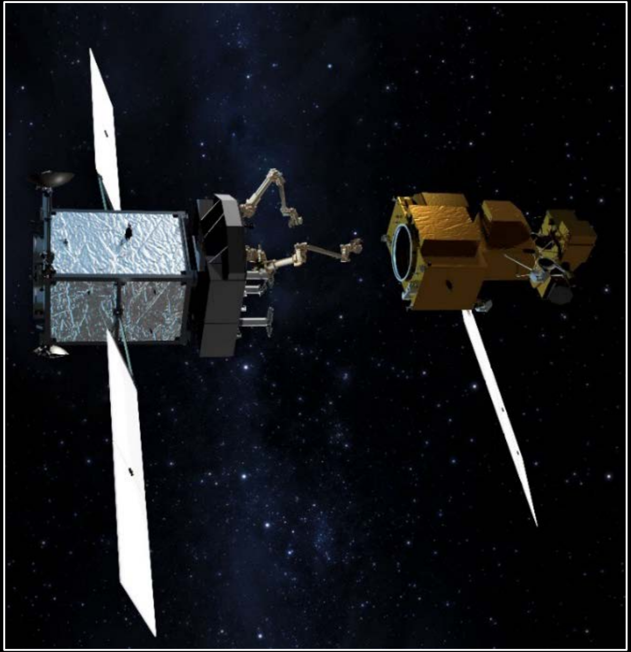


Vision Sensor Subsystem (Restore-L)

The Restore-L spacecraft is a satellite servicing platform that can rendezvous, redirect, refuel, and thus enable missions to operate beyond their designed lifetimes.

We provided: screening & qualification- white LEDs for Vision Sensor Subsystem (VSS), used to illuminate targets for docking, arm maneuvering, and other servicing tasks.





Reference: https://www.nasa.gov/feature/nasa-s-restore-l-mission-to-refuel-landsat-7-demonstrate-crosscutting-technologies

Indium-Phosphide (InP) Photonic Integrated Circuit (PIC) Evaluation

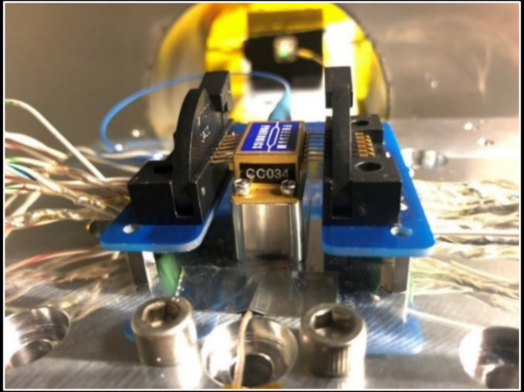
CODE 562 PHOTONICS Goddard Space Flight Center

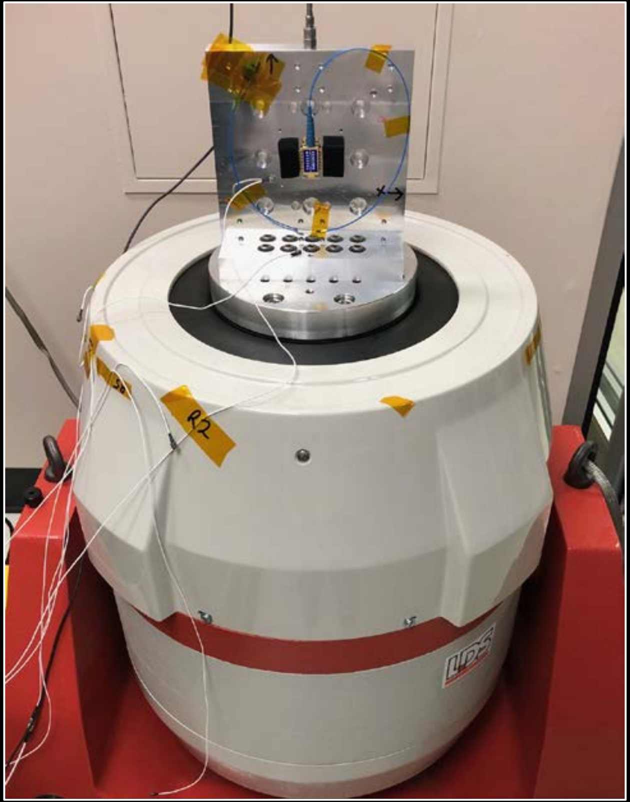
Motivation

- Demand for high-reliability, low size, weight and power (SWaP) for RF/Photonics.
- This is for the purpose of technology maturation to enhance the "Technology Readiness Level" TRL.

@ GSFC Evaluation of the Freedom Photonics Tunable Laser

- Vibration, thermal cycling, and radiation testing (planned).
- Repeatable, low system noise characterization.
- Expertise in risk assessment and quick anomaly resolution.





CODE 562 PHOTONICS
Goddard Space Flight Center

Indium-Phosphide Photonic Integrated Circuit Evaluation – Game Changing Program

Test Name	Sample Number				
	CC026	CC027	CC028	CC029	CC032
Initial Characterization	X	X	X	X	X
Acceptance Level Vibration (GEVS 9.8 Grms)	X	X	X	X	X
Performance Characterization	X	X	X	X	X
Qualification Level Vibration (non-NASA) 14.9 Grms)	X				X
Performance Characterization	X				X
Thermal Cycling & Characterization	X*	X	X	X	X*
Performance Characterization	X	X	X	X	X
Thermal Electric Cooler Functional Verification	X	X	X	X	X
Qualification Level Vibration (GEVS 14.1 Grms)		X	X	X	
Thermal Characterization for TEC bond check		X	X	X	
Packaging Construction Analysis on TEC bond	X				X

See next slide for vibration profile details * Anomaly on TEC Behavior, ***X = In Process***; X = Completed

This is very typical performance of a COTS device when enduring flight qualification.
Device GEVs qualification compliant.

Random Vibration Qualification Profile Levels

Acceptance level
GEVS
Random Vibration,
3 minutes per axis (X,Y,Z)

Frequency (Hz)	Level
20	0.013 G^2/Hz
20-50	+6 dB/octave
50-800	0.080 G^2/Hz
800-2000	-6 dB/octave
2000	0.013 G^2/Hz
Overall	**9.8 Grms**

All 5 samples were exposed to this level.

Qualification level
GEVS
Random Vibration,
3 minutes per axis (X,Y,Z)

Frequency (Hz)	Level
20	0.026 G^2/Hz
20-50	+6 dB/octave
50-800	0.16 G^2/Hz
800-2000	-6 dB/octave
2000	0.026 G^2/Hz
Overall	**14.1 Grms**

All 5 samples were exposed to this level.

Qualification level
Commercial Satellite Specification
Random Vibration,
3 minutes per Axis (X,Y,Z)

Frequency (Hz)	Level
20	0.032 G^2/Hz
20-50	+8 dB/octave
50-600	0.200 G^2/Hz
600-2000	-8 dB/octave
2000	0.033 G^2/Hz
Overall	**14.9 Grms**

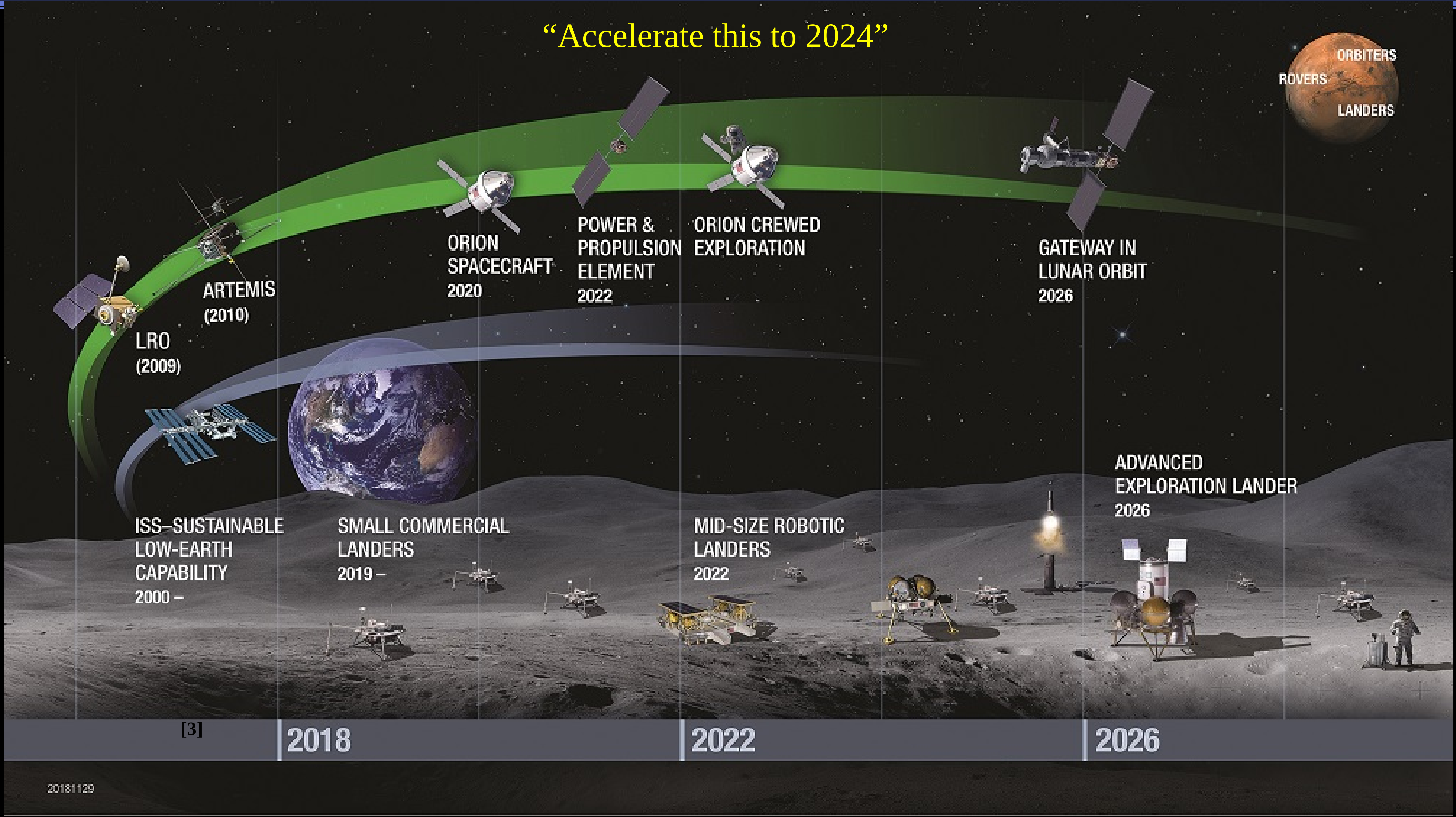
2 samples were exposed to this level, TEC anomaly.

Reference: General Environmental Verification Standard, for GSFC Flight Programs and Projects, GSFC-STD-7000, http://msc-docsrv.gsfc.nasa.gov/cmdata/170/STD/GEVS-STD-7000.pdf

Gateway Roadmap

https://spacenews.com/is-the-gateway-the-right-way-to-the-moon/

“Accelerate this to 2024”



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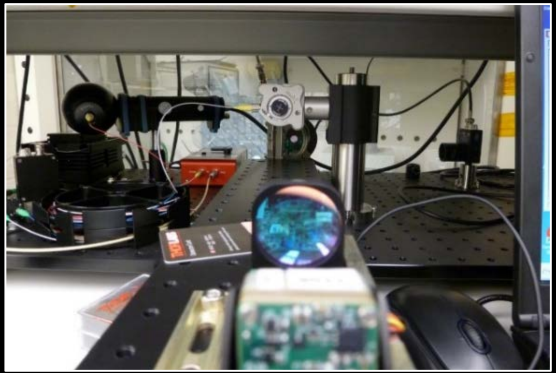
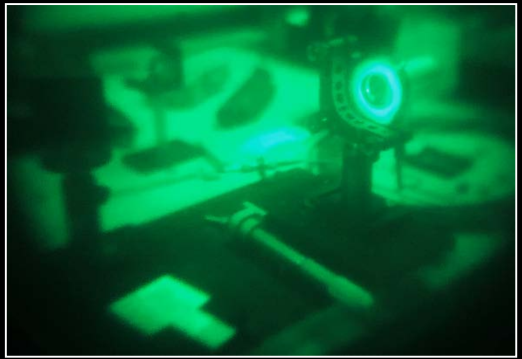
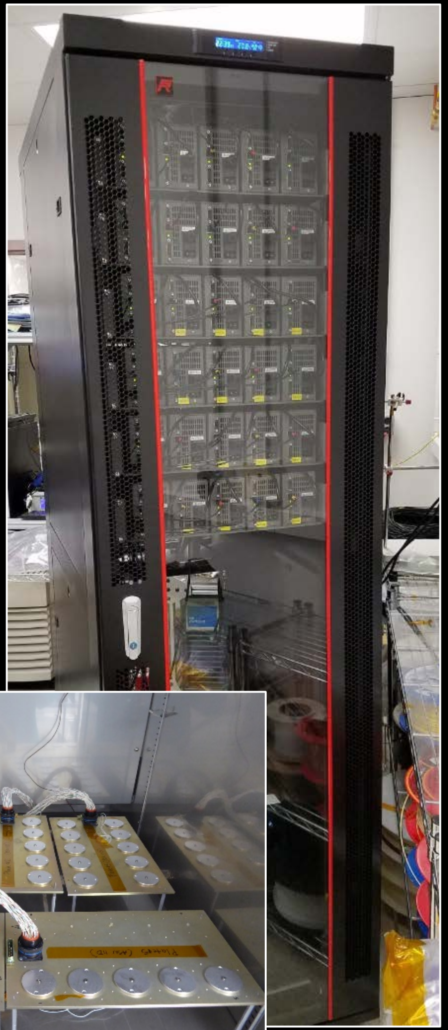
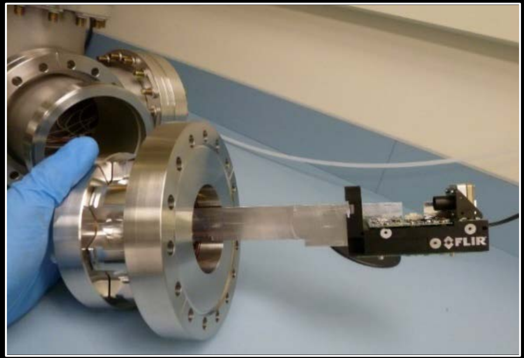






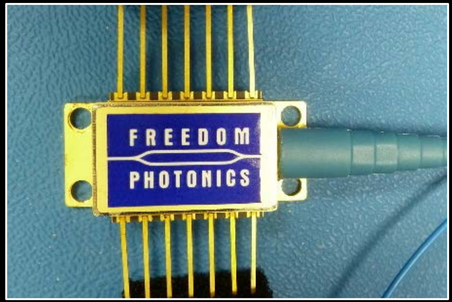


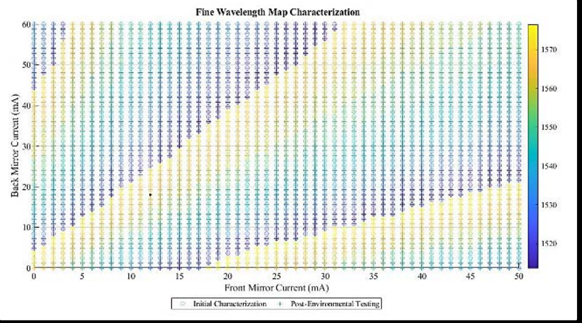
COTS LiDARs for Lander Autonomy

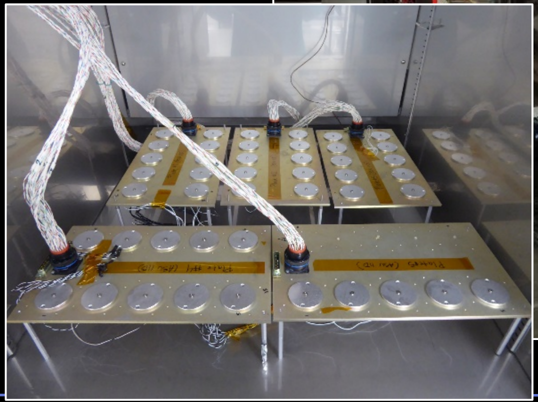
Tunable Lasers for Orbiter Communications

Detectors for Rover Spectroscopy

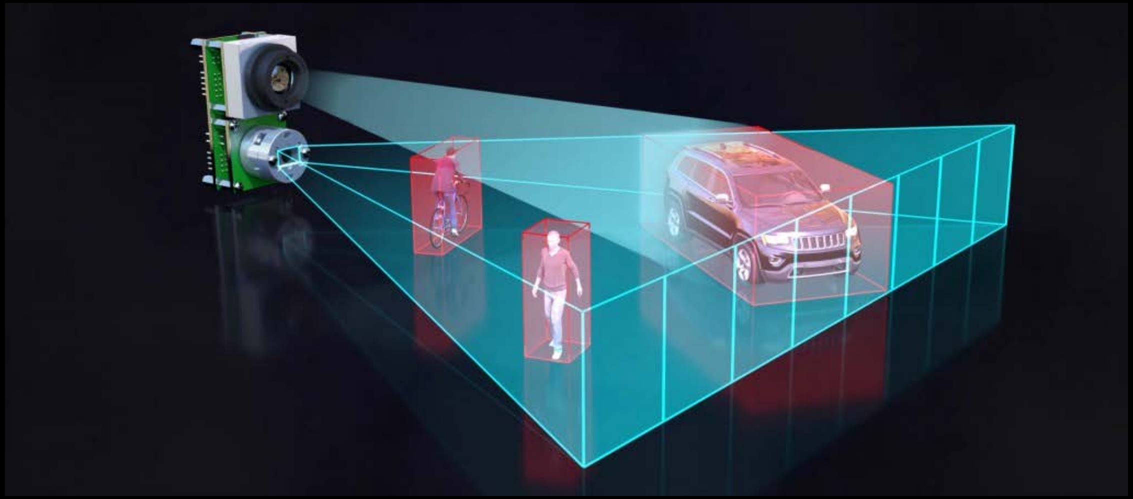
Qualifying Optoelectronics & Photonics for Space







Qualifying COTS LiDARs for Lander Applications



https://www.allaboutcircuits.com/news/solid-state-LiDAR-is-coming-to-an-autonomous-vehicle-near-you/

COTS LiDAR instruments have generated interest for use in space applications including:

- Docking
- Real-time hazard avoidance
- Remote sensing
- Improved lander and rover autonomy
- Rendezvous with asteroids and other spacecraft

COTS LiDAR technologies are commonly used today in the following terrestrial applications:

- Autonomous vehicle systems
- Small-footprint, light weight drone development
- Land surveying/Civil Engineering
- DIY and industrial robotics

https://www.nasa.gov/content/morpheus-prototype-uses-hazard-detection-system-to-land-safely-in-dark

Summary

- NASA GSFC has been screening and qualifying photonic/optoelectronic components for more the past 30 years.
  - Trends indicate decreasing component size, weight, and power (SWaP).
  - Screening and qualification **does not** have to be expensive and time-consuming.
  - Parts that we have qualified ahead of flight exhibit higher reliability and lifetime.
- When dealing with components that have flown in **some configuration** it's up to the project **and** vendor to qualify, be honest with flight heritage, and **re-qualify when necessary**.
  - Systems engineers, have a full understanding of why and what the requirements are such that they can negotiate for cost savings on test plans and risk mitigation.
  - Parts engineers may try and levy EEE parts test plans – those needs to be modified for optoelectronics.
  - Vendors should communicate regarding procedural changes on "heritage" parts to continue to be considered "preferred" suppliers.
- Contracting non-profit independent test houses (NASA, institutions are examples) creates naturally secure collection points for failure modes, mechanisms, and test data.
  - Agreements similar to Space Acts with us allow communication without giving away proprietary information.

Conclusion

- Teaming with knowledgeable partners with a proven track record saves time and money.
  - Don't believe the "myth"
  - Know the difference between a sales pitch and work backed by heritage and data.
- Photonic components in subsystems (optoelectronics, transceivers, fiber optic components)
  - When correctly implemented over high reliability and outstanding performance:
    1. MERCURY: 24 Mkm laser link in space from a LIDAR instrument.
    2. MOON: Laser Altimeter and Ranging (visible) – a decade of success
    3. MARS: Curosity ChemCam operation – 3 times the projected lifetime.
    4. EARTH LEO: Transceivers flight heritage for over 30 years – recently a new transceiver currently on ISS.
    5. REMOTE Planets: Lasers and LIDARs successfully implemented for the more than 20 years.
- Systems and System Scientists – be wary of over-engineering.
  - Don't over engineer! Cost over-runs and cancellation risks,
  - Subcomponents and component vendors exist with a proven track record - Don't put a good component in the wrong application.

Be sure decisions are made by data.

CODE 562 PHOTONICS
Goddard Space Flight Center

Thank You to Our Partners!
(not all are listed here)

NASA — JSC, GSFC, KSC, MSFC
DIAMOND the fiber meeting
GORE Creative Technologies Worldwide
Polymicro TECHNOLOGIES A Subsidiary of molex
ULTRA COMMUNICATIONS
MIT Lincoln Laboratory
Honeywell
NUFERN
Lightpath
esa
MIT
Fermilab
ZEPHYR PHOTONICS
Gooch & Housego ENABLING PHOTONIC TECHNOLOGIES
cnes CENTRE NATIONAL D'ÉTUDES SPATIALES
APL The Johns Hopkins University APPLIED PHYSICS LABORATORY
Los Alamos NATIONAL LABORATORY EST. 1943
OZ Optics
ofs A Furukawa Company
asi agenzia spaziale italiana
DARPA
ITT
SSL
Ceram Optec
KAYSER-THREDE
Ball
CARLISLE INTERCONNECT TECHNOLOGIES
Sandia National Laboratories
FIBERTEK
HARRIS TECHNOLOGY TO CONNECT, INFORM AND PROTECT
OSI Optoelectronics An OSI Systems Company
AIR FORCE RESEARCH LABORATORY
Mii MICROPAC
JPL
FREEDOM PHOTONICS
NIST National Institute of Standards and Technology U.S. Department of Commerce

And thank you for your time!

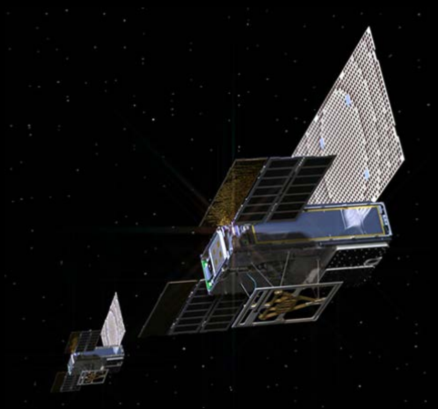
https://photonics.gsfc.nasa.gov

BACK UP SLIDES

Failure Modes & Failure Mechanisms

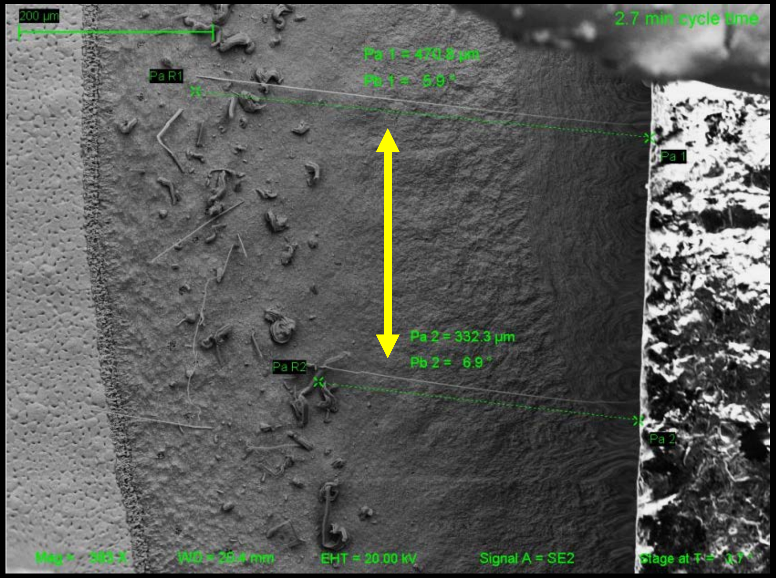
"… 22 percent of cubesats were never heard from after launch. That figure is significantly higher in special cases, such as some classes of university-built cubesats."

https://spacenews.com/smallsat-developers-focus-on-improving-reliability/



"NASA's first interplanetary CubeSats fall silent beyond Mars"

https://www.theverge.com/2019/2/6/18213594/nasa-marco-cubesats-deep-space-insight-mars-mission-communications-silent



SEM image of Tin Whiskers shorting a bond pad to packaging. (example)

NASA reliability studies on technologies new to spaceflight typically begin by establishing:

- <u>Known Failure modes</u>
- <u>Known Failure mechanisms</u>
- <u>How to find these modes and mechanisms.</u>
- General research on existing screening/qualification test data.

Fiber optic connectors: AVIM Flight Heritage

Project	Dev	Launch	Connectors	Description	Details
Geoscience Laser Altimeter System (GLAS) on ICESAT	1998	2001	AVIM Standard Single Mode / Multi Mode / Flat Polish	Gore Flexlite SM & MM 2 Km of SM	Custom drill in ferrule, tungsten carbide shell ferrules
Mercury Laser Altimeter (MLA) MESSENGER	2001	2004	AVIM Standard, Flat Polish	330 um MM Flexlite	Custom drill in ferrule, tungsten carbide shell ferrules
Shuttle Return to Flight NEPTEC Laser Heat Tile Sensor	2003	2005	AVIM standard SM APC & SM	BICC OC1008, one sided terminations.	Standard pilz ferrule, ceramic shell
Lunar Orbiter Laser Altimeter on Lunar Recon Orbiter	2007	2009	AVIM array connector, 303 SS ferrule drill @ GSFC	PM AVIM for 5 220 um fibers side one, fan out with flexlite side two	Custom drill 220 um on fan out side, with standard AVIM tungsten carbide shell ferrules
Laser Ranging on Lunar Recon Orbiter	2007	2009	AVIM Array connector, 416 SS ferrule flower drill @ Diamond	SS larger PM AVIM for 7 440 um fibers, large custom cable	Both sides array flower pattern. Gimbal, cold, to -55 C.
Mars Science Lab, ChemCam	2008	2011	AVIM standard custom drill ferrule for 330 um	Flexlite	Gimbal, cold, hot to 110 C
Express Logistics Carrier on ISS	2008	Nov-2009	AVIM standard custom drill for 140 um	Space Station cable & Flexlite	Pilz ceramic shell ferrules
NASA GSFC evaluation of Mini AVIM & DMI	2008	none	Mini AVIM & DMI	Bare fiber for thermal and vibration testing.	Vibration and thermal qualification
James Webb Space Telescope	2008	GSE	FC & AVIM titanium ferrules.	Cryogenic PTFE configuration.	Multiple sizes, multiple materials
Cloud-Aerosol Transport System (CATS)	2014	2015	MINI AVIM	Flexlite, 100/140 um fiber for communications	Custom Drill for 140 um
ICESat-2 Advanced Tropographic Laser Altimeter System (ATLAS)	2012	2018	AVIM & Array AVIM	Multiple fiber sizes of the Polymicro FV series with Flexlite + other materials	Dual and Quad arrays, simplex in 120, 220, 330, & 440

Acronyms

- ASTM = American Society for Testing and Materials
- ASU = Arizona State University
- ATLAS = Advanced Topographic Laser Altimeter System
- CATS = Cloud-Aerosol Transport System
- COTS = Commercial Off the Shelf
- DIY = Do It Yourself
- EEE = Electrical, Electronic, and Electromechanical
- FC = Field Connector
- GCD = Game Changing Development
- GEDI = Global Ecosystem Dynamics Investigation
- GEVs = Goddard Environmental Specification
- GEO = Geosynchronous Orbit
- GOES-R = Geostationary Operational Environmental Satellite-R Series
- GLAS = Geoscience Laser Altimeter System
- GSFC = Goddard Space Flight Center
- ICESat = Ice, Cloud, and land Elevation Satellite
- InP PIC = Indium-Phosphide Photonic Integrated Circuits
- ISS = International Space Station
- JWST = James Webb Space Telescope
- LADEE = Lunar Atmosphere Dust Environment Explorer
- LED = Light Emitting Diode
- LEO = Lower Earth Orbit
- LiDAR = Light Detection and Ranging
- LIV=Light-Current-Voltage
- LOLA = Lunar Orbiter Laser Altimeter
- LRO = Lunar Reconnaissance Orbiter
- MAVEN = Mars Atmosphere and Volatile Evolution Mission
- MESSENGER = Mercury Laser Altimeter on Mercury Surface, Space Environment, Geochemistry and Ranging
- MEO = Medium Earth Orbit
- MIL-STD = Military Standards
- MLA = Mercury Laser Altimeter
- MOLA = Mars Orbiter Laser Altimeter
- MOMA = Mars Organic Molecule Analyzer
- OTES = OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer) Thermal Emission Spectrometer
- PER = Polarization Extinction Ratio
- SAA = Space Act Agreement
- SM APC= Single Mode Angled Physical Contact
- SEM = Scanning Electron Microscope
- SSCO = Space Servicing Capabilities Office
- SSCP = Space Servicing Capabilities Project
- SWaP = Size, Weight and Power
- TEC = Thermoelectric Cooler
- TID = Total Ionizing Dose
- TSIS = Total and Spectral Solar Irradiance Sensor
- TRL = Technical Readiness Level
- VSS = Vision Sensor Subsytem

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