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Photonics for Space Flight Instruments

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https://photonics.gsfc.nasa.gov

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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 = General Environmental Verification Standard
- 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
- NEPP = NASA Electronic Parts & Packaging
- OSAM = On-Orbit Servicing, Assembly and Manufacturing
- OTES = OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer) Thermal Emission Spectrometer
- PER = Polarization Extinction Ratio
- RCS = Relative Calibration System
- RST = Roman Space Telescope
- SAA = Space Act Agreement
- SM APC= Single Mode Angled Physical Contact
- SEM = Scanning Electron Microscope
- SPLICE = Safe and Precise Landing – Integrated Capabilities Evolution
- 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

Meet the Photonics Group of NASA Goddard

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

Trevon Parker

Alejandro Rodriguez

Not Pictured: Duncan Turner

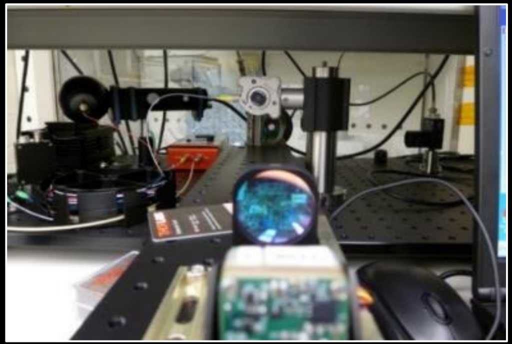
Back row L-R: Erich Frese, Joe Thomes, Marc Matyseck
Middle row L-R: Rick Chuska, Eleanya Onuma, Cameron Parvini, Rob Switzer
Front row L-R: Hali Jakeman-Flores (Group Lead), Melanie Ott (Founder & Retired Group Lead), Diana Blair

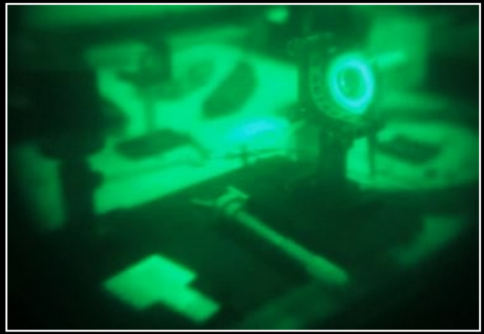
All great things require a great team!

https://photonics.gsfc.nasa.gov

Outline

- Introduction
- Optoelectronics: 12-year screening and qualification overview
- Tunable Laser Evaluation
- NEPP Mini LiDAR Evaluations
- Summary
- Conclusions



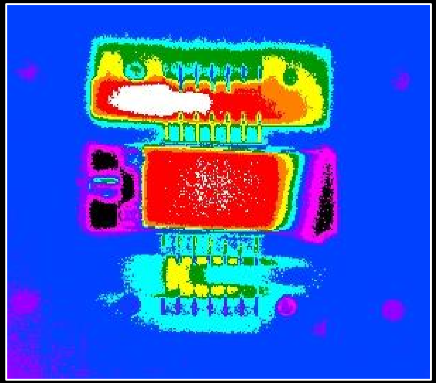


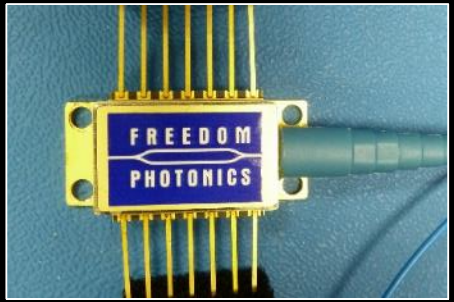
COTS LiDARs for Lander – & Autonomous Rendezvous

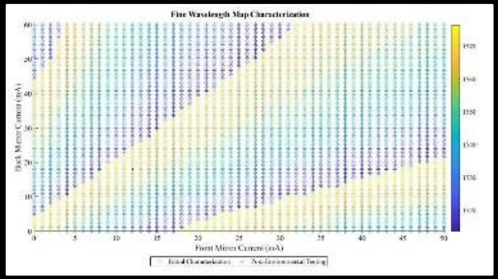
Tunable Lasers for Orbiter Communications

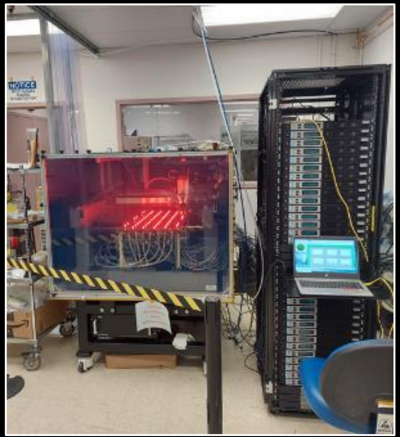
Detectors for Rover Spectroscopy

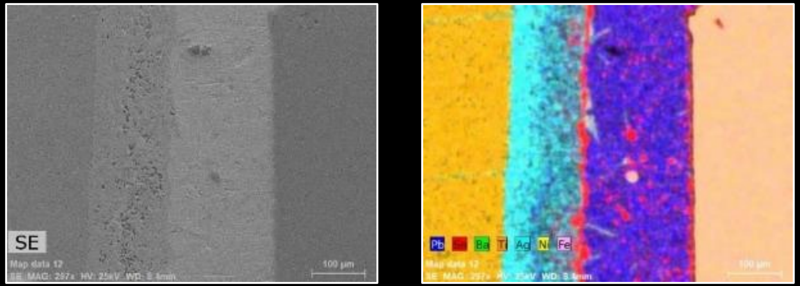
Screening and Qualification of Optoelectronics & Photonics for Space Flight



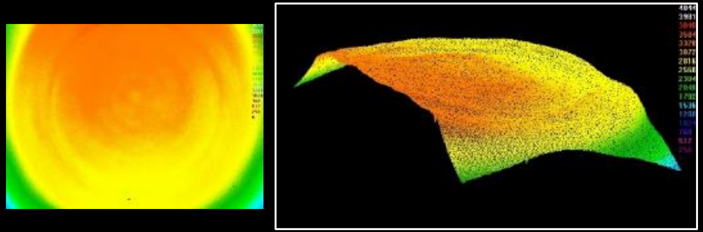


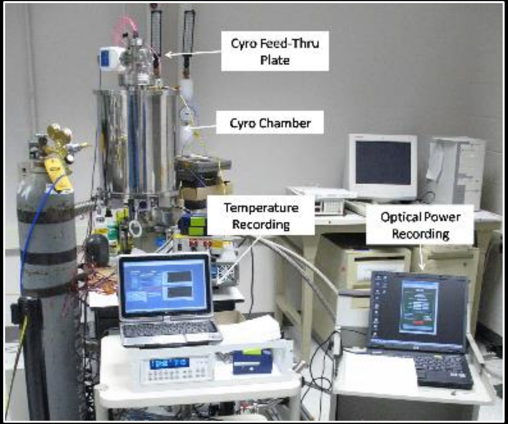






10 k X Mag SEM & Material Identification


LED Beam Profile



Cryogenic Test Facility

Materials Screening / Construction Analysis

→ **Optical Inspection & Screening**

→ **Performance Characterization**

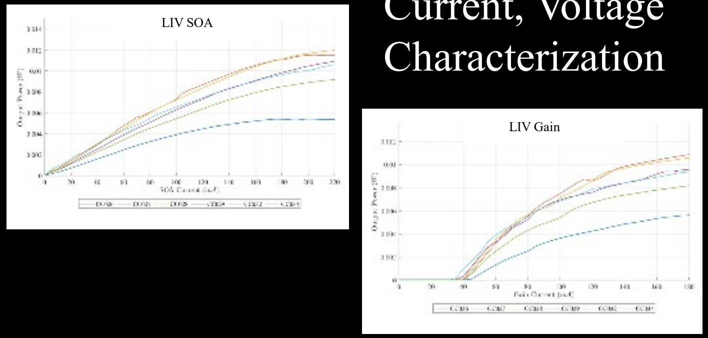
→ **Vibration / "Shock" Testing**

→ **Thermal Cycling / Vacuum**

→ **Radiation Testing**

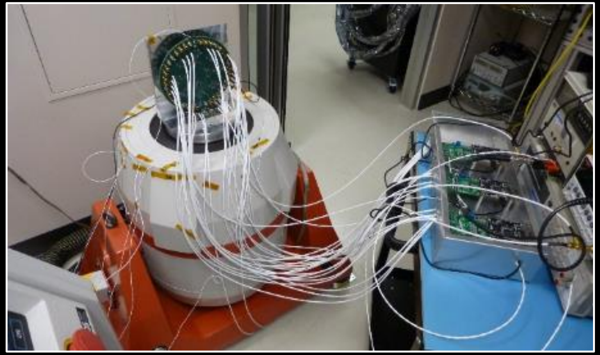
→ **Additional Testing?**

Optical Power, Current, Voltage Characterization




Radiation Test Equipment


White Light LED Testing in Environmental Chamber


Random Vibration Test & Shock Equipment

Issues to Consider

- Schedule (shorter term)
- Funds available
- Identifying sensitive or high-risk components
- System design choices for risk reduction
- Packaging choices for risk reduction
- Quality by similarity → requires 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 is less likely now for non communication type applications
- Process changes at the component level happen <u>often</u>

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.**

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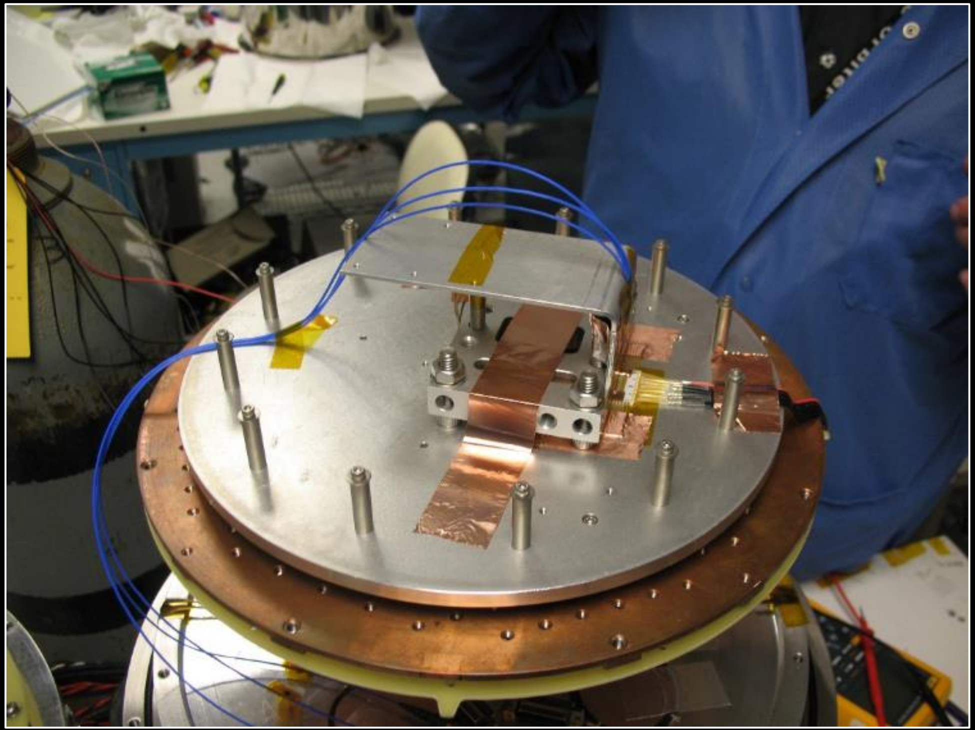
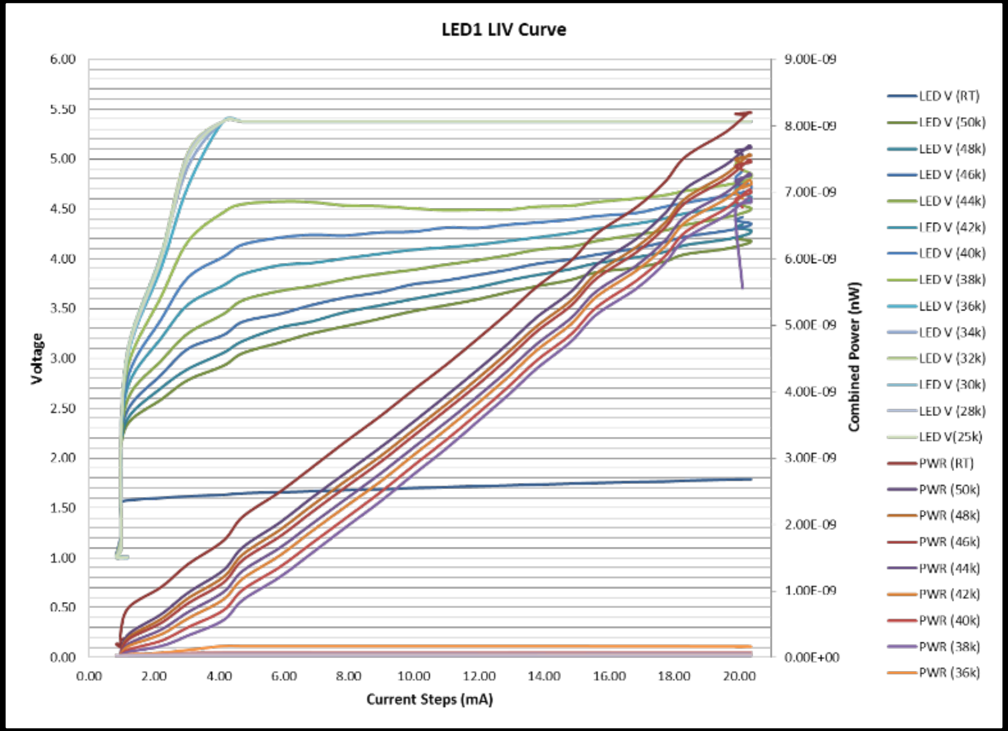
Optoelectronics Mission Highlights: last 12 years
(communications transceivers not included in table)

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
OSAM-1	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 - 2020	x	x	x	x
LUCY/LTES	Pyroelectric Detector	6000-75000	25	2019-2021	x	x		x
SPLICE/HDL	Laser Diode	976, 1030	40	2020-Present	x	x		x
RST RCS	LED (Custom)	635, 880, 1070, 1300, 1550, 1750	1200+	2019-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.
- Testing was performed circa 2009.





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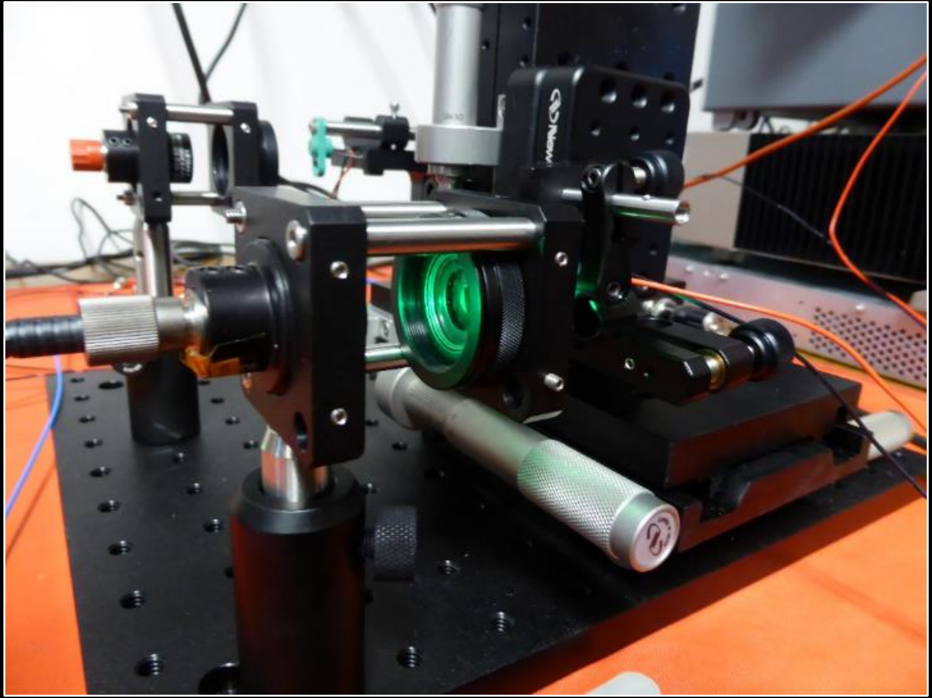
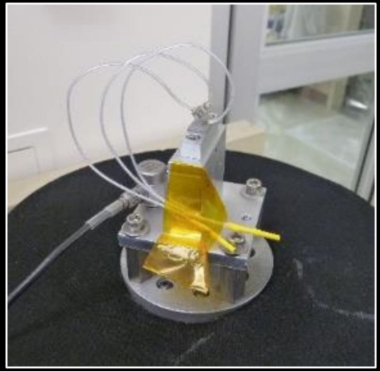
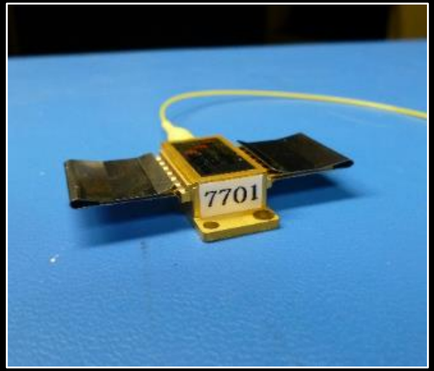
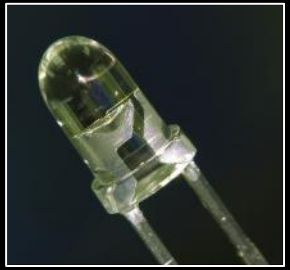
Ice, Cloud and Land Elevation Satellite (ICESat-2) – (ATLAS) Advanced Topographic Laser Altimeter System

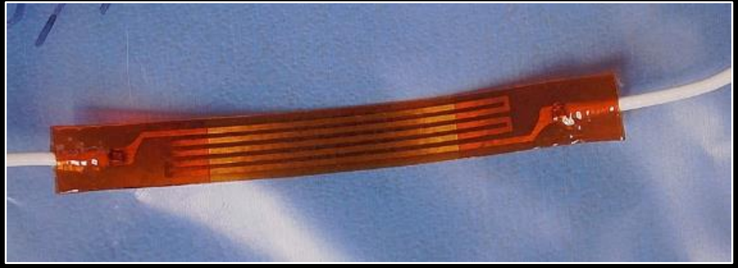
- The Code 562 Photonics Group performed testing/evaluation of seven components used on the ATLAS instrument, currently operating on ICESAT-2.
- Testing included: visual inspections; thermal, electrical, and optical characterization; random vibration; radiation testing; and destructive physical analysis.





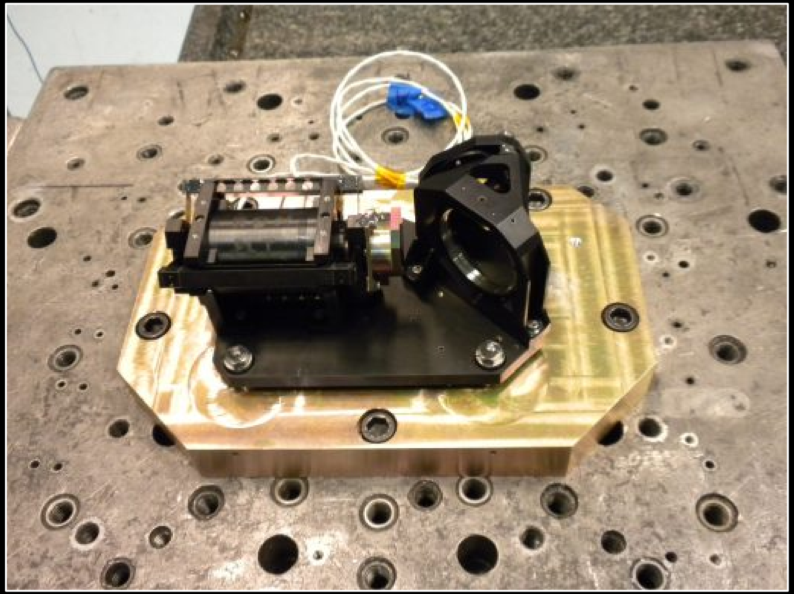


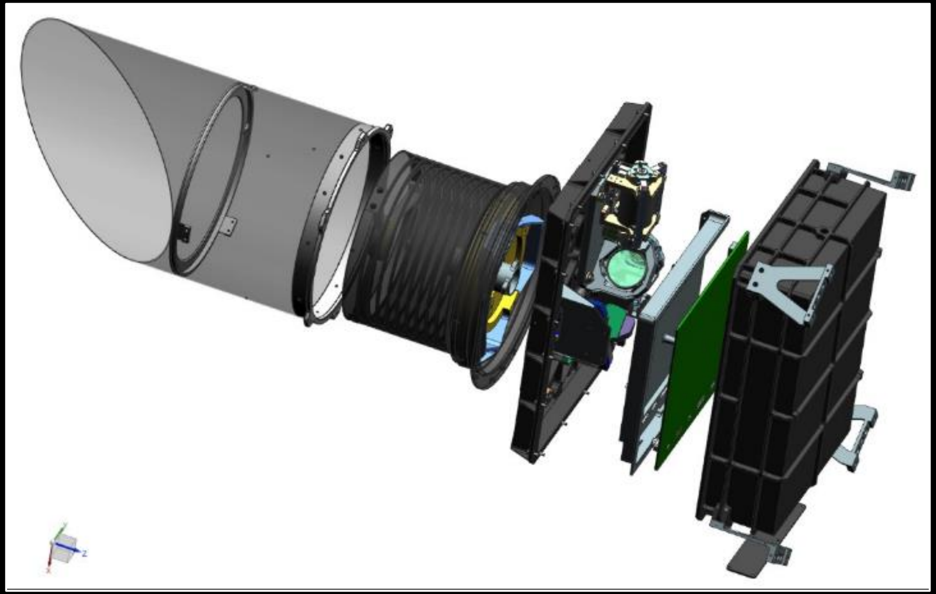




The Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) Mission to Bennu

- The Thermal Emission Spectrometer (OTES) instrument is a point spectrometer on board (OSIRIS-REx) spacecraft.
  - OTES successfully mapped the asteroid Bennu's material composition, within a 4-50 um wavelength range. Upon arriving in 2018, evidence of water was discovered.
  - The instrument was developed at the School of Earth and Space Exploration at Arizona State University.

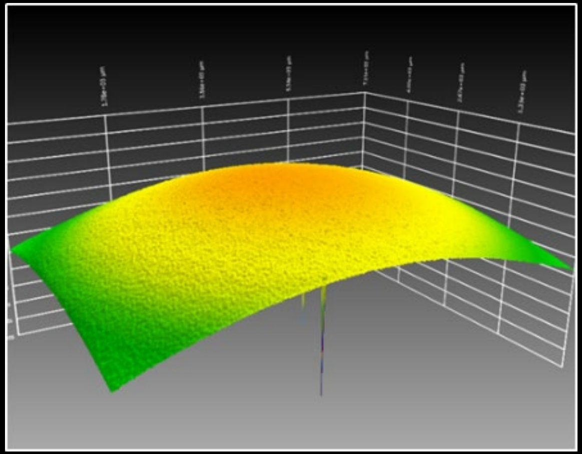




Reference: http://spaceflight101.com/osiris-rex/osiris-rex-instruments/

On-Orbit Servicing, Assembly and Manufacturing 1 (OSAM-1) Mission

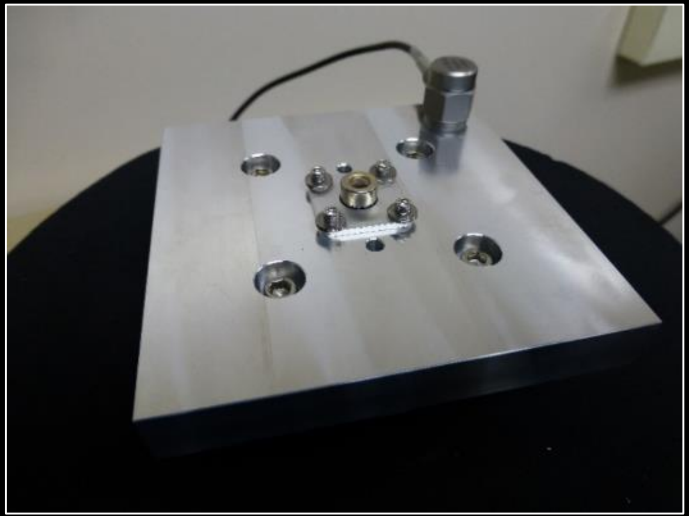
- The OSAM-1 spacecraft is a satellite servicing platform that can rendezvous, redirect, refuel, and thus enable missions to operate beyond their designed lifetimes (will refuel Landsat-7).
- We provided screening & qualification of white LEDs for the Vision Sensor Subsystem (VSS), used to illuminate targets for docking, arm maneuvering, and other servicing tasks.
- We are currently working on the LiDAR "Kodiak" to enable autonomous robotic docking.



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

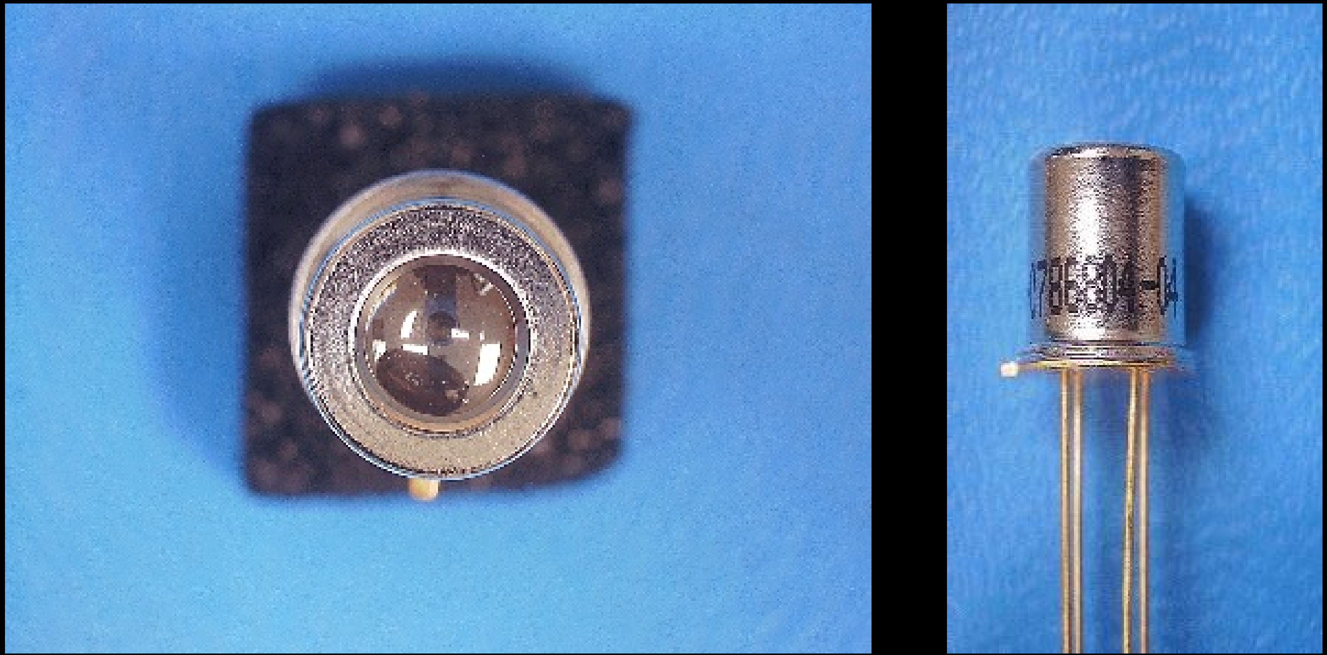
Partnership with Arizona State University Screening and Qualification

- ASU partnered with the Code 562 Photonics Group to perform the screening and qualification of laser diodes, pyroelectric detectors, and photodiodes for:
  - OSIRIS-REx Thermal Emission Spectrometer (circa 2015);
  - Space Act Agreement (Mars environment, circa 2018);



Partnership with Arizona State University Screening and Qualification: LUCY

- ASU partnership with the Code 562 Photonics Group was extended (circa 2020) to perform the screening and qualification of pyroelectric detectors for LUCY (mission to Jupiter Trojans)
  - Testing campaign was successful, despite COVID-19 impacts.



Top and side view images of LUCY detector sample

Detector samples shown in thermal chamber for burn-in testing

Indium-Phosphide, Photonic Integrated Circuit (PIC) Evaluation

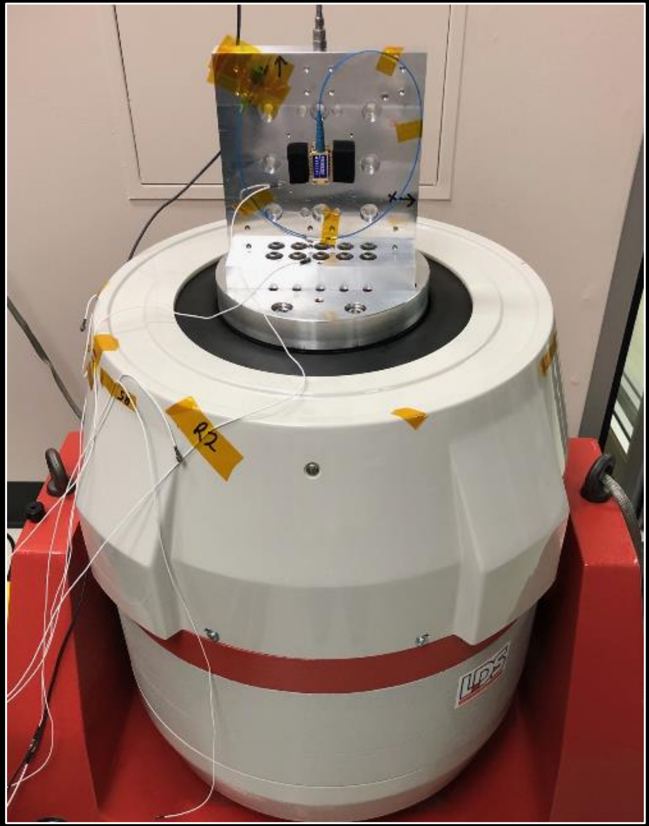
Funded by Space Technology Mission Directorate Game Changing Program

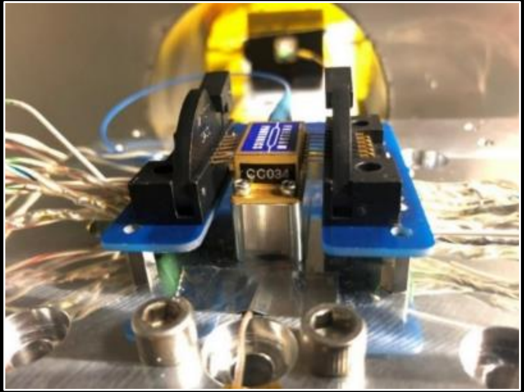
Motivation

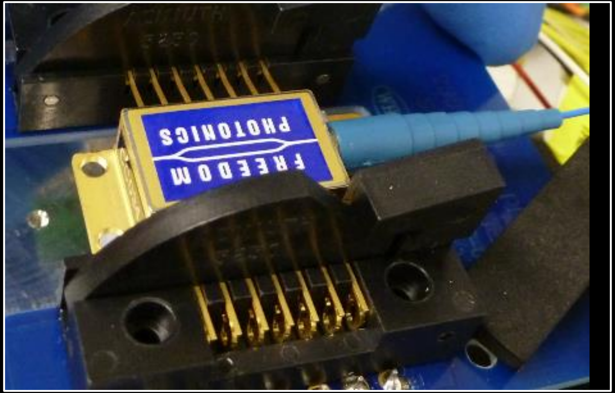
- There is a demand for high-reliability, low size, weight and power (SWaP) for RF/Photonics (an emerging technology).
- This effort geared toward technology maturation, to enhance the "Technology Readiness Level" (TRL) of this technology.

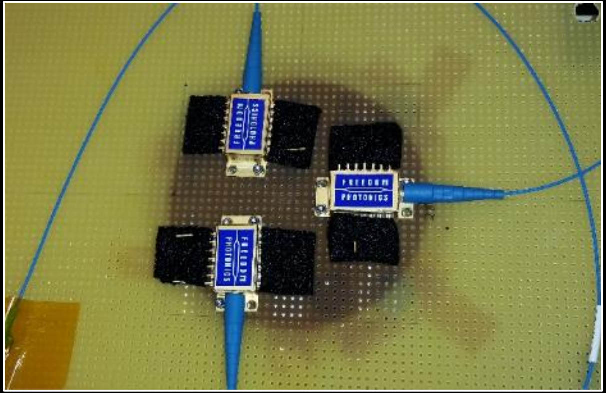
@ GSFC Evaluation of the Freedom Photonics Tunable Laser

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









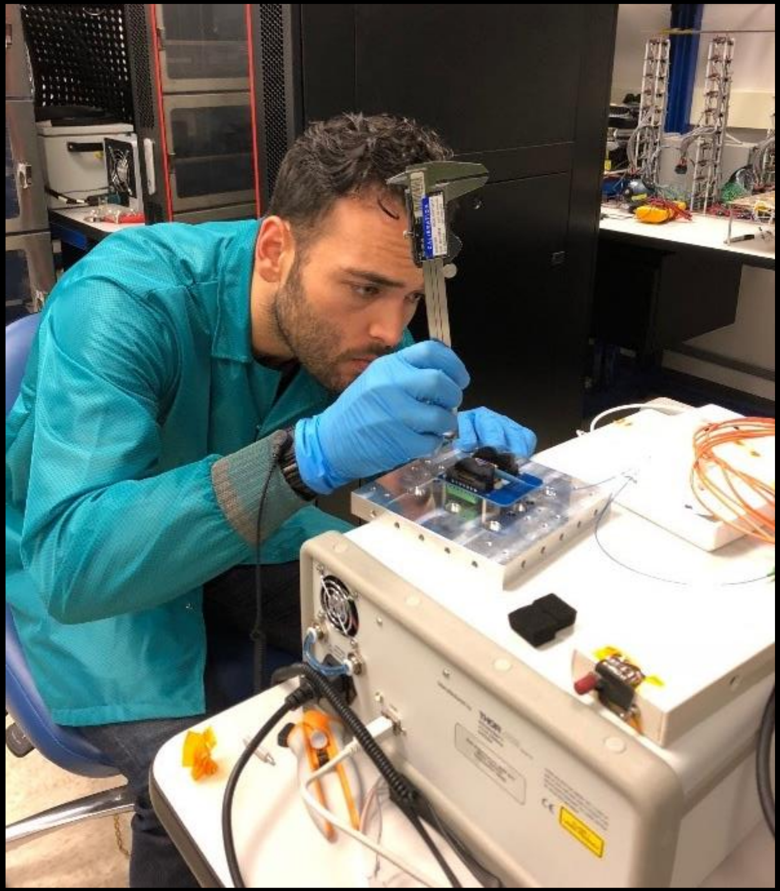
Indium-Phosphide Photonic Integrated Circuit Evaluation – Game Changing Program

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

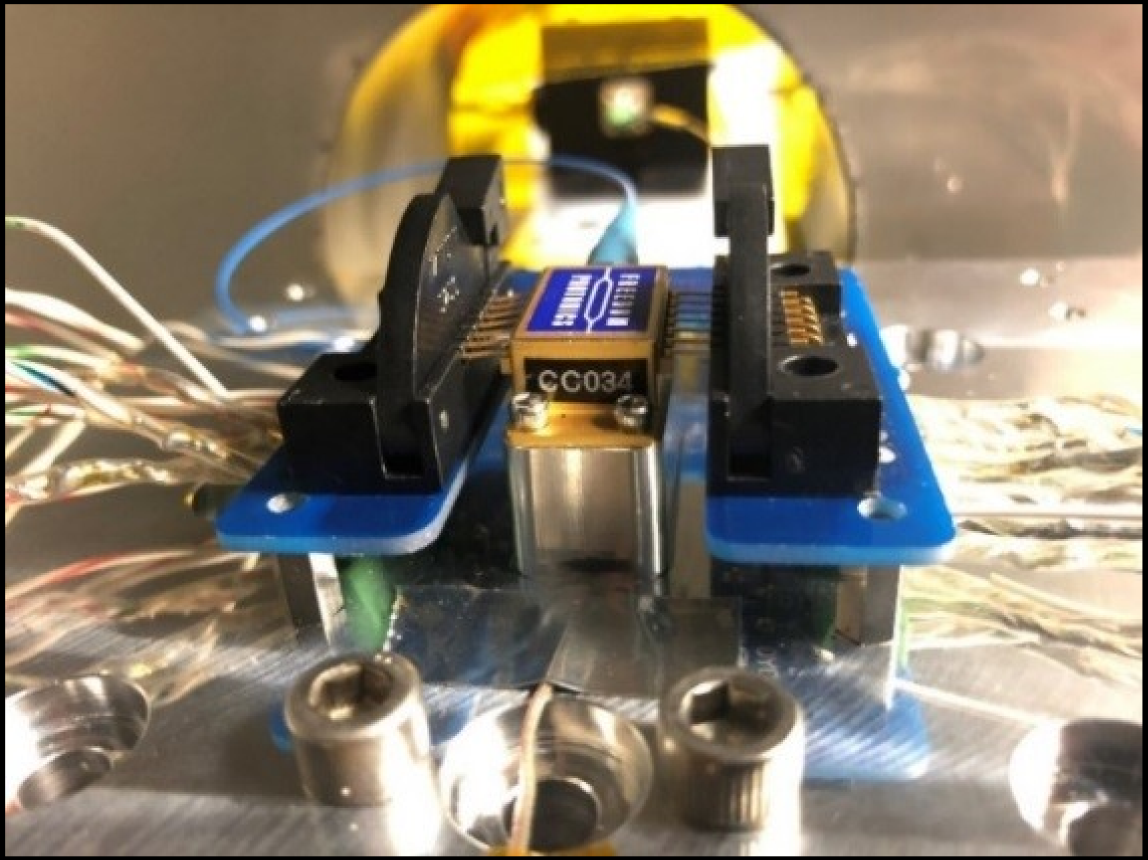
TEC = Thermoelectric Cooler; * Anomaly on TEC Behavior ; X = Completed

This is very typical performance for a COTS device subjected to flight qualification.

Freedom Photonics InP PIC Thermal Cycling Preparations & Characterization



Cameron Parvini prepares the thermal cycling test fixture for the InP Photonic Integrated Circuit



The InP device in oven configuration just prior to thermal cycling. The custom device test mounting shown was fabricated by Photonics Group staff.

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**

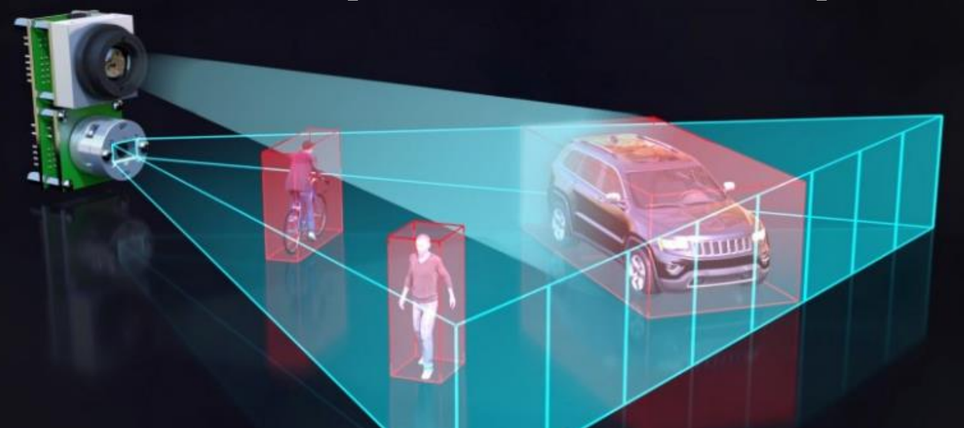
2 samples were exposed to this level, TEC anomaly.

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

Qualifying and Producing LiDARs for Lander Autonomous Rendezvous Applications

Our Sponsors:

1) Space Technology Mission Directorate, Safe and Precise Landing – Integrated Capabilities Evolution (SPLICE) Program:
   a. GSFC Hazard Detection LiDAR
   b. LaRC's Navigational Doppler LiDAR
2) NEPP: Evaluation of Compact Industrial LiDAR components



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

- 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

- 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

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

COTS Mini LiDAR Candidate Selection Summary

Introduction: Qty (9) LiDAR candidates were evaluated for flight feasibility and down-selected.
Criteria: 1) ease of operation, 2) baseline performance, 3) operability or testability, 4) consistency
Drone application one dimensional time of flight LiDAR

	LiDAR Candidate	Range	Op. Temp Range	Accuracy
1	Carlson	0.5 -150 m	-20 to 60°C	10 cm
2	Garmin LiDAR-Lite	5 cm – 40 m	-20 to 60°C	+/- 2 cm @ > 2 m
3	Benewake	0.4 – 22 m	-10 to 60°C	5 cm
4	Terabee TeraRanger	0.2 -14 m	to 40°C	+/- 2 cm in precision mode

NEPP Commercial Mini LiDAR Performance Evaluation Experimental Setup

Target surface simulations

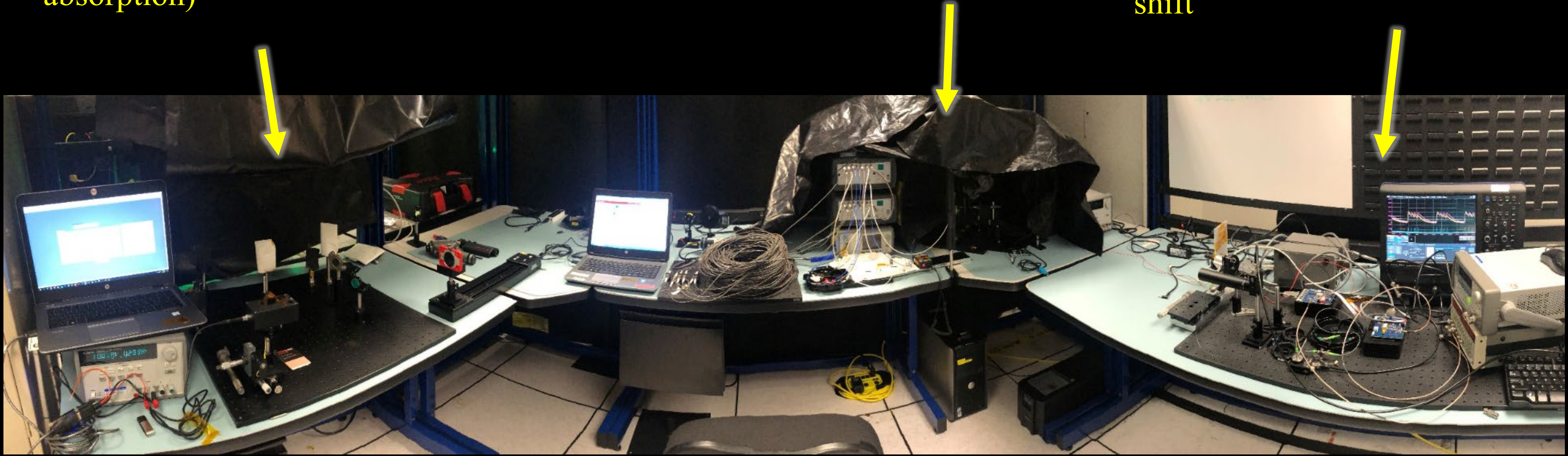
- Utilizes mirrors and targets of different optical properties (reflectivity/ transmissivity/ absorption)

Longer distance simulation: optical fiber delay line

- Couples light through optical fibers of various lengths

Short distance simulation, electrically generated delay

- Distance simulated using trigger delays, attenuation, and phase shift



NEPP Commercial Mini LiDAR Test & Environmental Evaluation Summary

Evaluation Test	LiDAR Candidate			
	1	2	3	4
Initial Characterization – "baseline"	X	X	X	X
Acceptance Level Vibration (GEVS 9.8 Grms)	X	X	X	
Performance Characterization	X	X	X (Anomaly)	
Thermal Cycling & Characterization	X	X		
Performance Characterization	X			

Mini LiDAR Candidate 3, which exhibited a clear performance anomaly post-vibration.

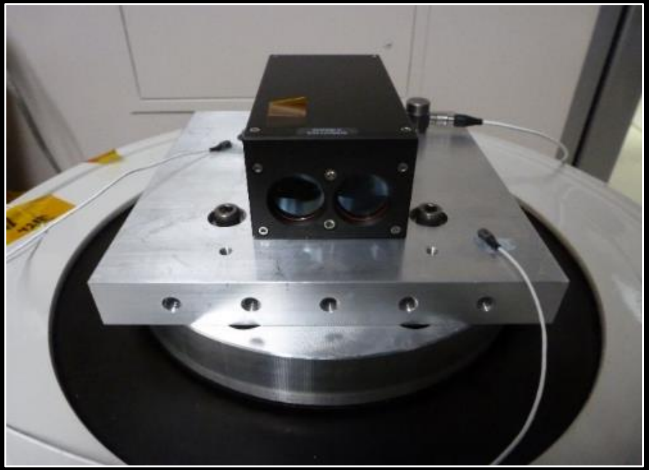
X Completed
X Anomaly

Random Vibration Test & Evaluation

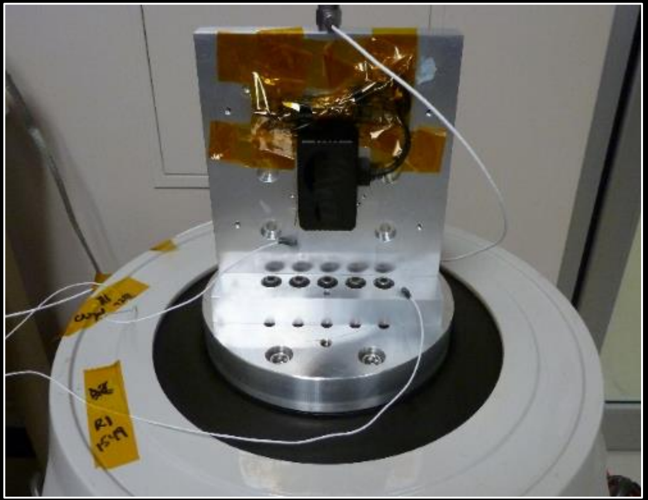
Acceptance level
GEVS

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	0.08 g^2/Hz
800-2000	-6 dB/octave
2000	0.013 g^2/Hz
Overall	**9.8 grms**



Carlson (candidate 1) on vibration shaker

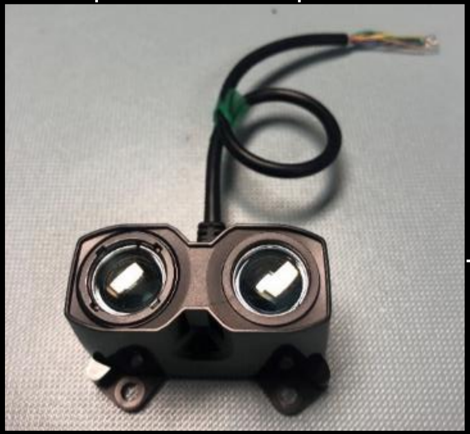


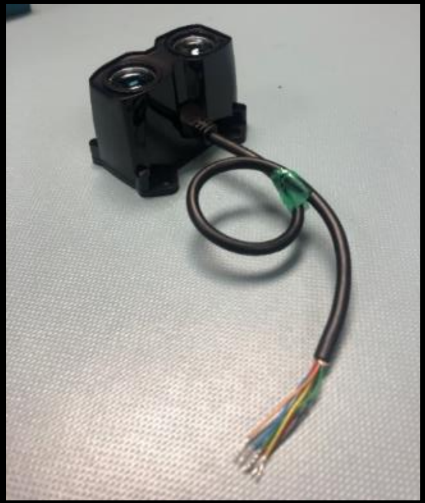
Benewake (candidate 3) on vibration shaker

Garmin (candidate 2) on vibration shaker

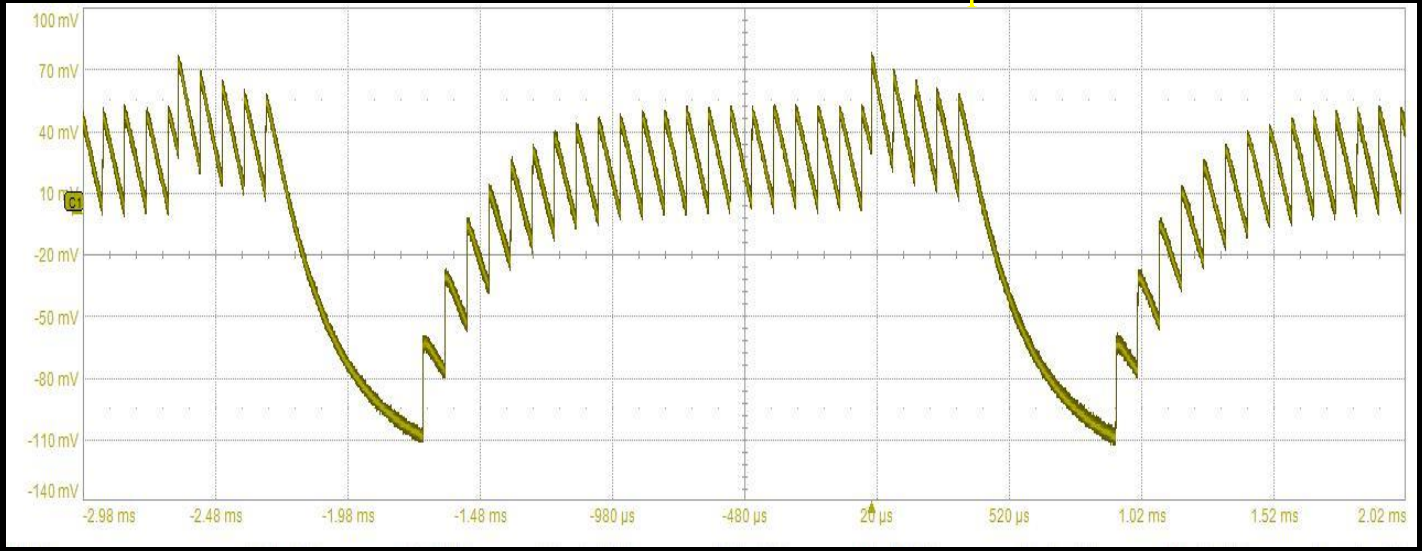
Garmin LIDAR-Lite v3HP
Candidate Rank - 1

Price	Range	Op. Temp Range	Positives	Negatives	Specifications	Performance
$149.00	40m	-20 to 60C	• Customizable triggering advantageous for test setup. • Nominal beam dimensions & collimated source. • I2C communications allow for fast data rate. • Exceptional performance over temperature.	• Complex modulated pulse characteristics (see below; can be a pro for noise reduction & con for customizable testing) • Precision ~ 2cm at room ambient temperatures. (Worse precision & more noise than candidate 2). • Requires triggering, cannot operate with only a power supply.	• Supply Voltage: 4.75-5VDC; 6V Max • Current consumption: 65ma idle; 85ma during acquisition • Weight: 34g (1.2oz) • UART Communications	• Wavelength: 905 nm • Peak power: 1.3 W • Accuracy: +/- 2 cm at distances >2 m • Resolution: 1 cm • Divergence: 8 mRadian • Sampling rate: Greater than 1 kHz





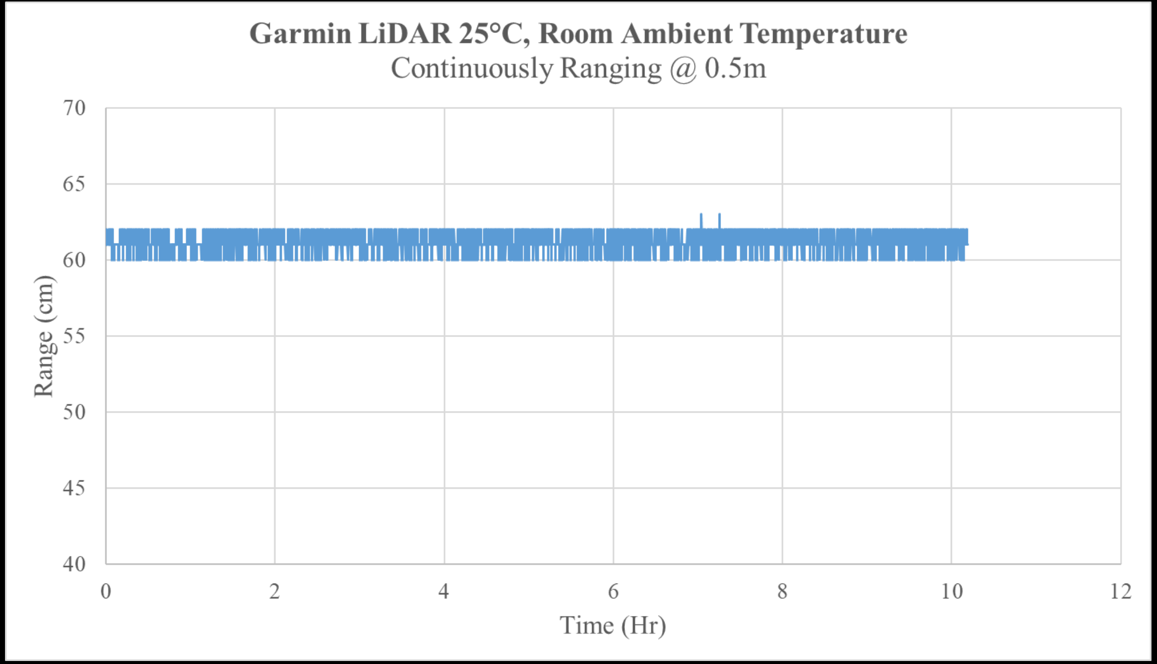
Measured LiDAR Source Output



Thermal Cycling

Garmin V3HP: Candidate Rank 1

- Five operation thermal cycles: 10°C to +60°C, 1°C/min, 30-minute dwell at extremes
  - Powered, system functional, in-situ measurements
- Two survival cycles: -20°C to +70°C, powered off



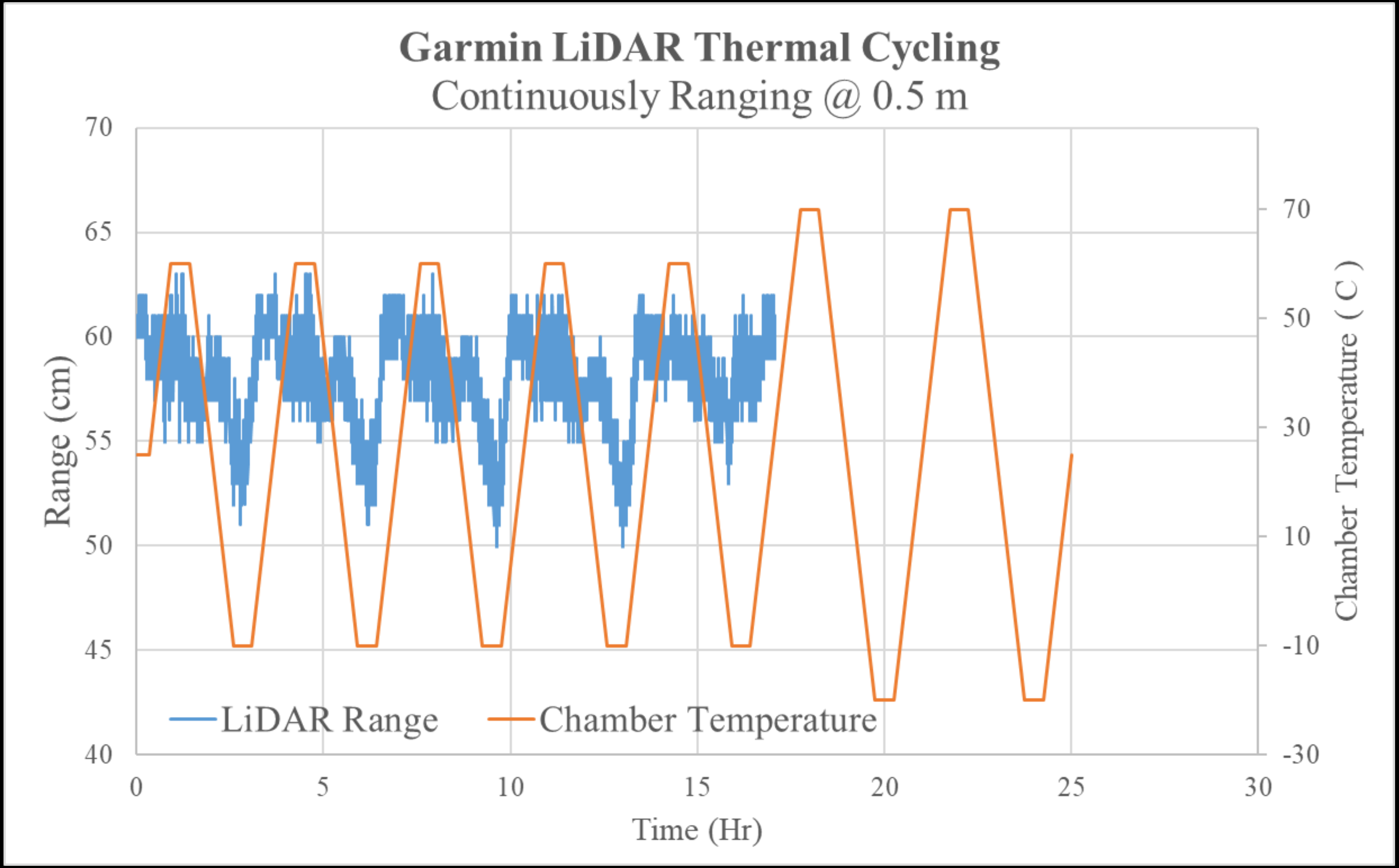
Mini LiDAR stability monitoring: data matches specified noise jitter:

- Range max = 63 cm; Range min = 60 cm
- Accuracy = 11.5 cm; Precision = 3 cm

Mini LiDAR in thermal chamber pointed to the target at the end of the chamber feedthrough hole

Thermal Cycling

Garmin V3HP: Candidate Rank 1



Mini LiDAR In-situ (post vibration) thermal cycling data

<u>Thermal Shifts:</u>

Range max = 63.0 cm

Range min= 50.0 cm

<u>Implying:</u>

Accuracy = 6.5 cm

Precision = 13.0 cm

Photonics For Spaceflight Standards Documents

- Drafted Optoelectronics commodity section for NASA-STD-8739.11, which lists screening and qualification requirements for photodiodes, laser diodes, and LEDs for all mission risk classification levels.
- Developed a Spaceflight applications requirements appendix with IPC.
- Working with IPC to implement and update IPC-A-640 and IPC-D-640 documents to possibly replace NASA-STD-8739.5.

Summary

- NASA GSFC has been screening and qualifying photonic/optoelectronic components for 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.
  - ***Most photonic parts are COTS!***
- 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 please have a comprehensive understanding of requirements such that negotiations for cost savings on test plans and risk mitigation is possible and expedient.
  - Parts engineers may try and levy EEE parts test plans – those need to be modified for optoelectronics.
  - Vendors please communicate regarding procedural changes on "heritage" parts to continue "preferred" supplier standing.
- 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 (industry using NASA resources) with us allow communication without giving away proprietary information.

Thank You to our NEPP Sponsors and Partners!
(not all are listed here)

And thank you for your time!

https://photonics.gsfc.nasa.gov

BACK UP SLIDES

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