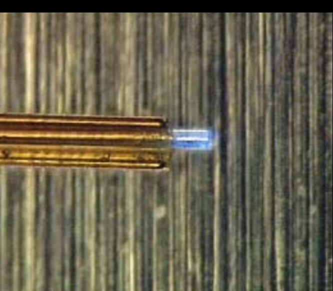
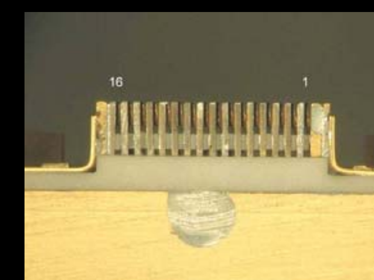
Space Flight Optical Fiber Activities & Capabilities

CODE 562 PHOTONICS Group @ GSFC

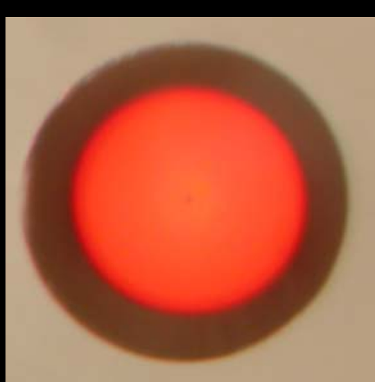


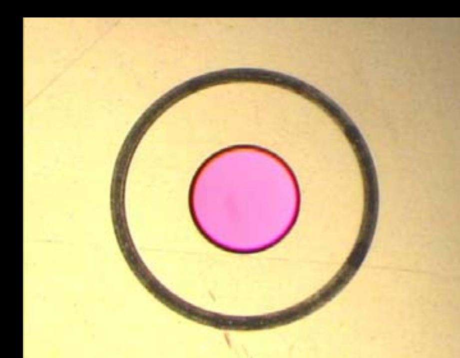


Melanie N. Ott
W. "Joe" Thomes
Rick Chuska
Frank LaRocca
Rob Switzer

NASA Goddard Space Flight Center
Applied Engineering & Technology Directorate, Electrical Engineering Division,

301-286-0127, melanie.n.ott@nasa.gov
301-286-8813, william.j.thomes@nasa.gov
misspiggy.gsfc.nasa.gov/photonics





IMAPS 2008

CODE 562

PHOTONICS

Group @ GSFC

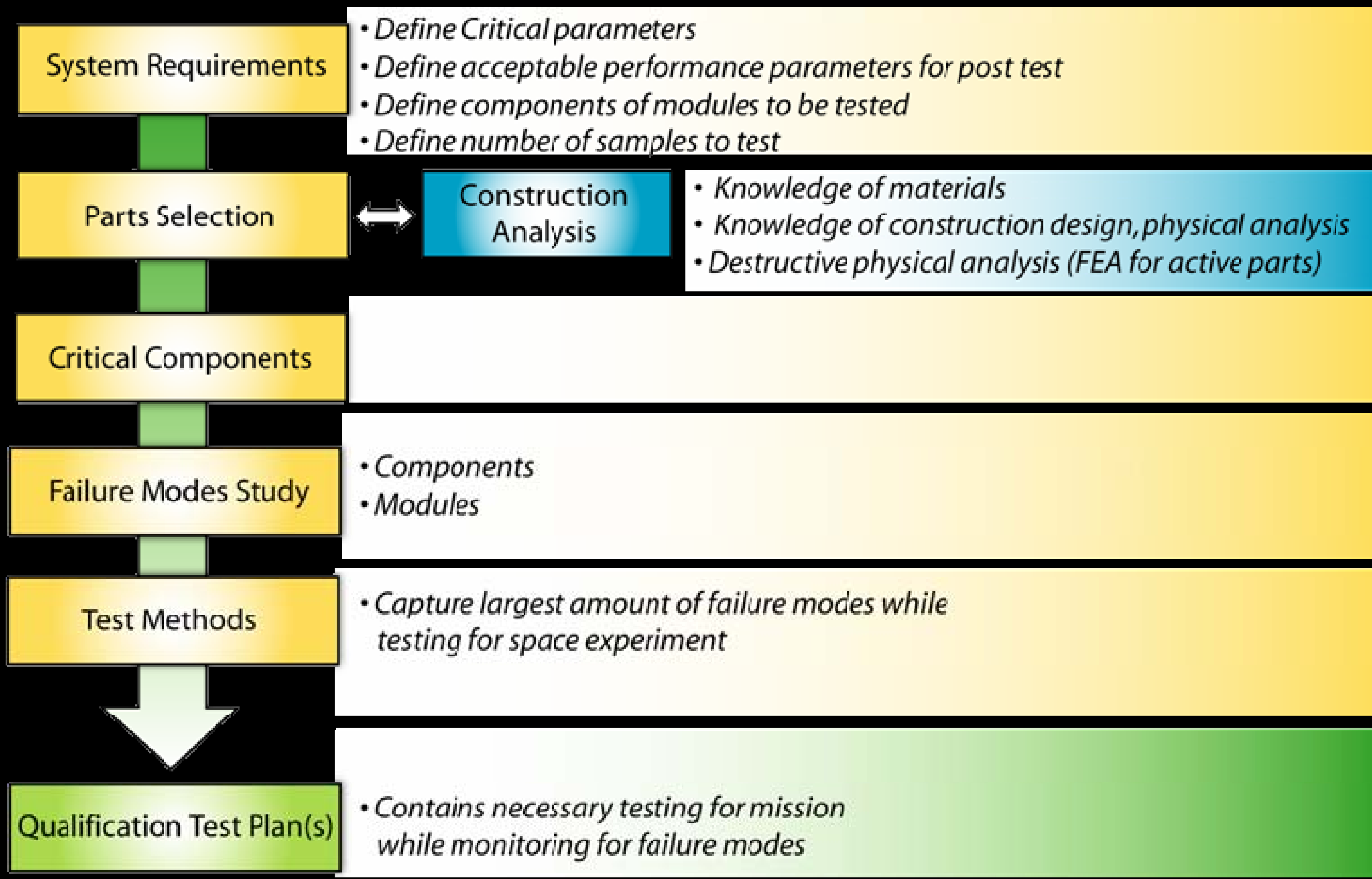
GSFC
CODE 562 PHOTONICS Group @ GSFC

Melanie N. Ott, Group Leader

Applied Engineering Technologies Directorate, Electrical Engineering Division

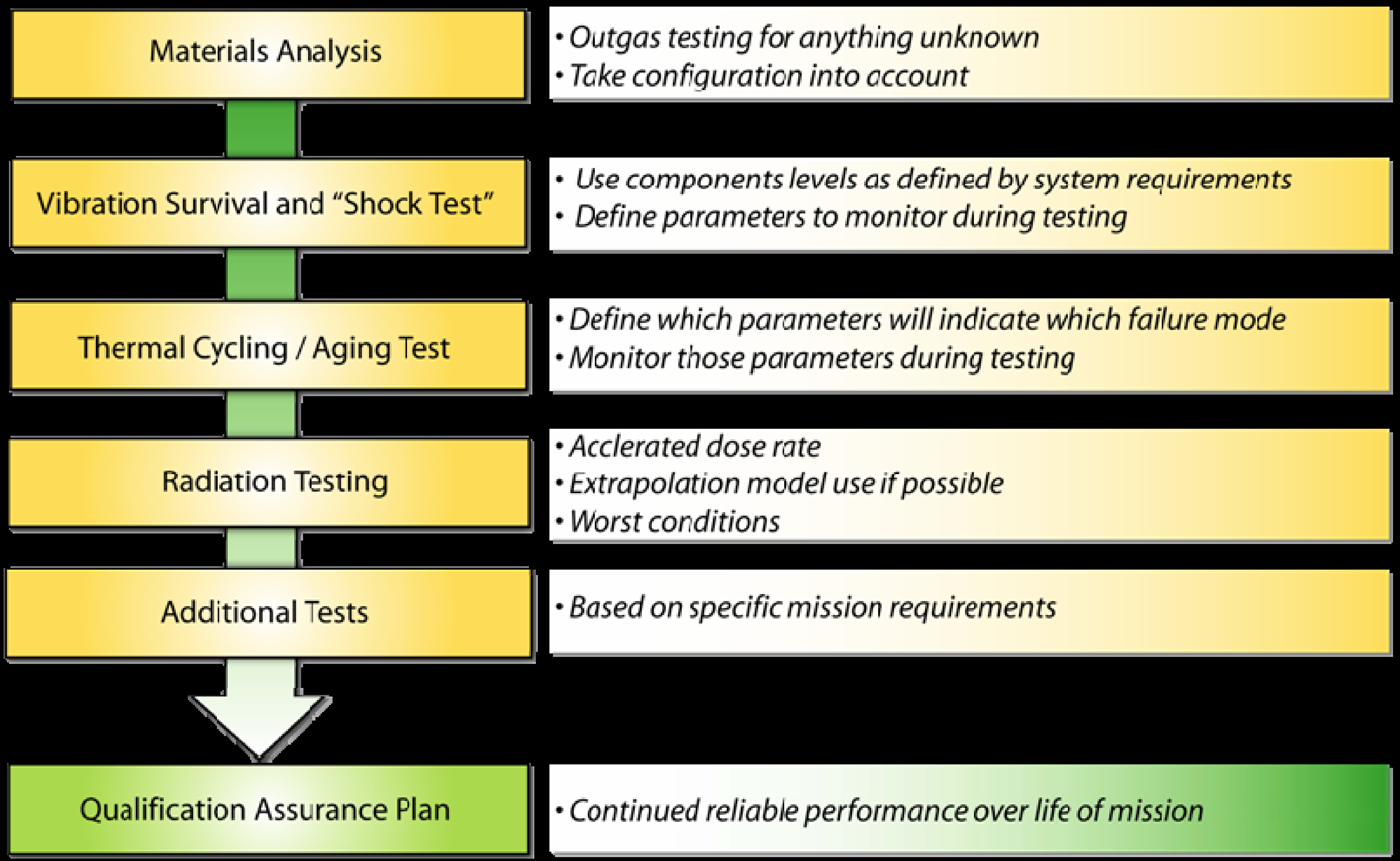
Rob Switzer, Frank LaRocca, W. Joe Thomes, Melanie Ott, Richard Chuska

COTS Technology Assurance Approach



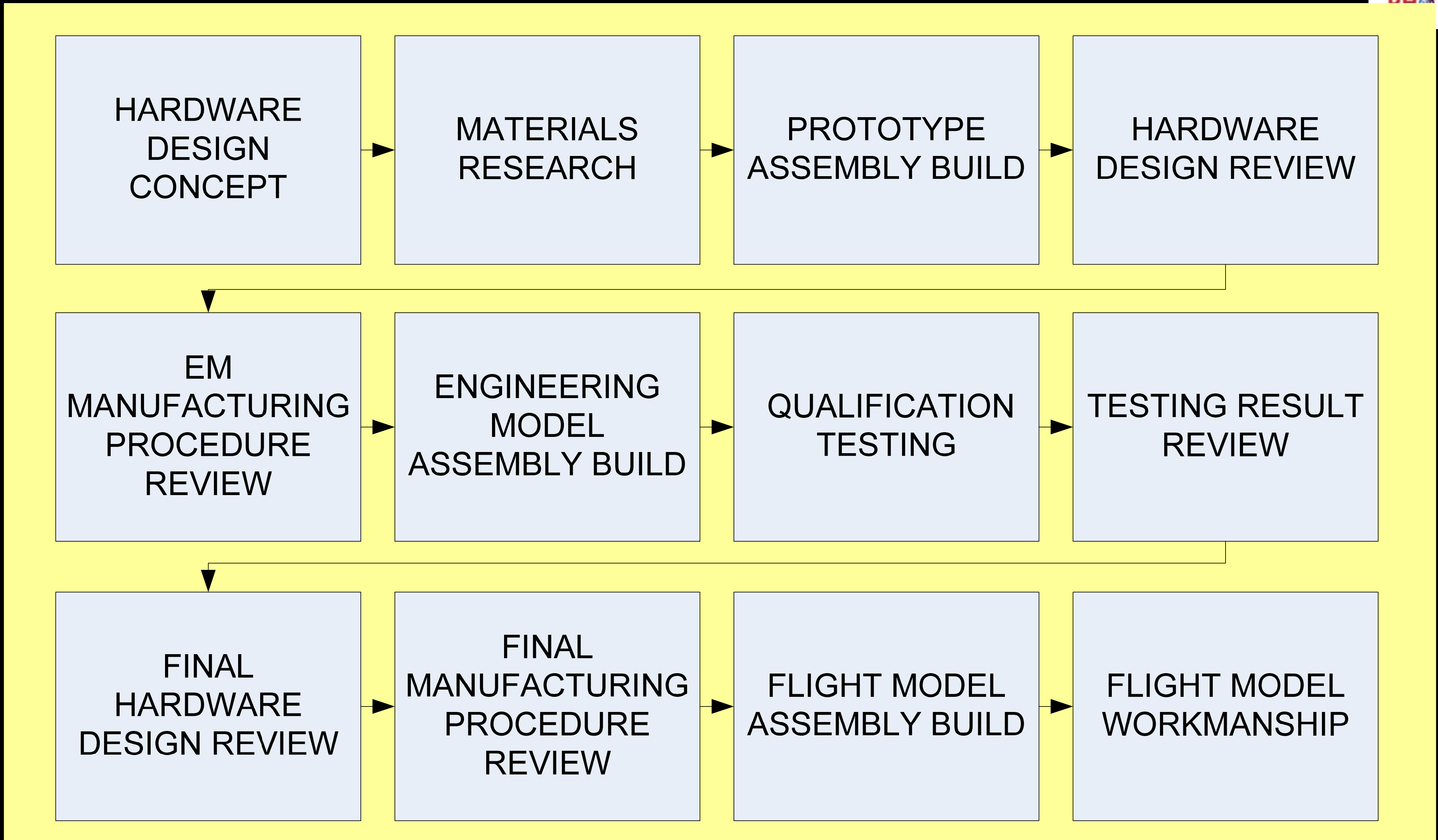
* *Photonic Components for Space Systems*, M. Ott, Presentation for Advanced Microelectronics and Photonics for Satellites Conference, 23 June 2004.

COTS Space Flight “Qualification”



* *Photonic Components for Space Systems*, M. Ott, Presentation for Advanced Microelectronics and Photonics for Satellites Conference, 23 June 2004.

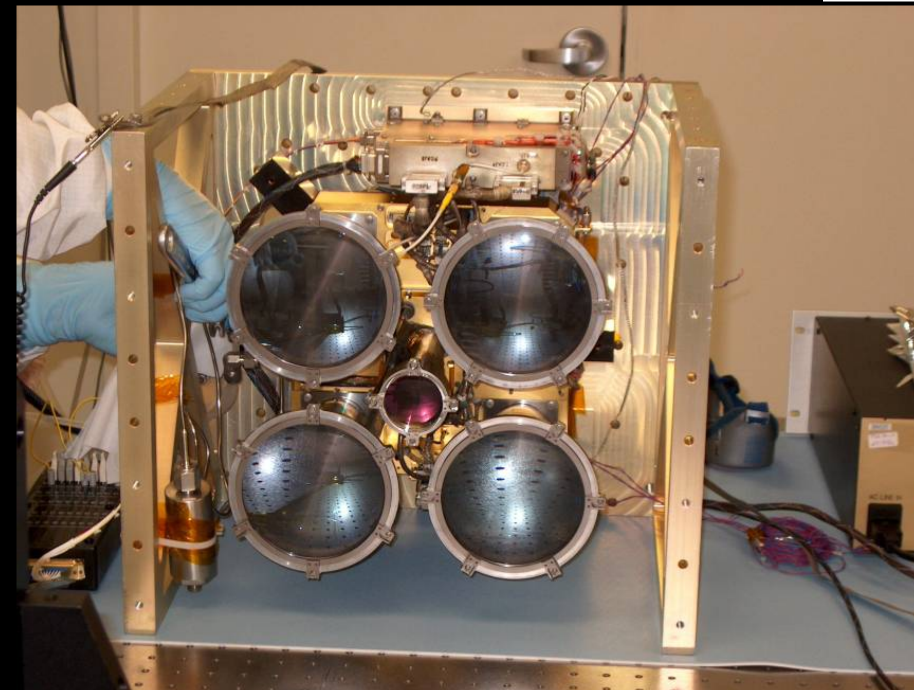
How Does the Photonics Group Go from Ideas to Flight?



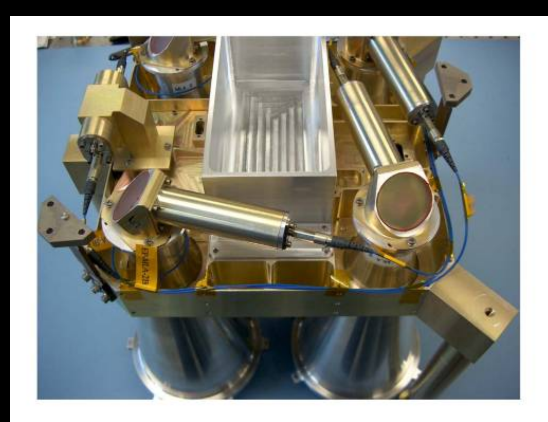
BASIC PRODUCT LIFE CYCLE

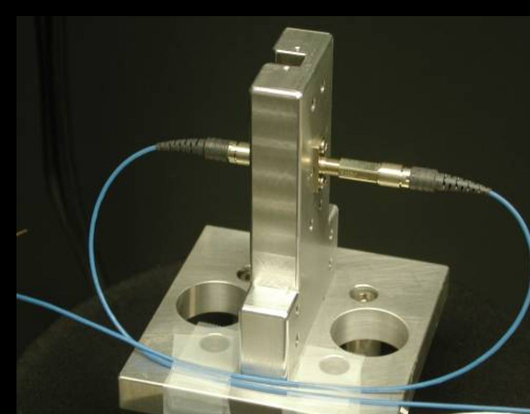
Lesson: Thermal Workmanship Testing is a must for COTS flight hardware

Mercury Laser Altimeter 2001-2003



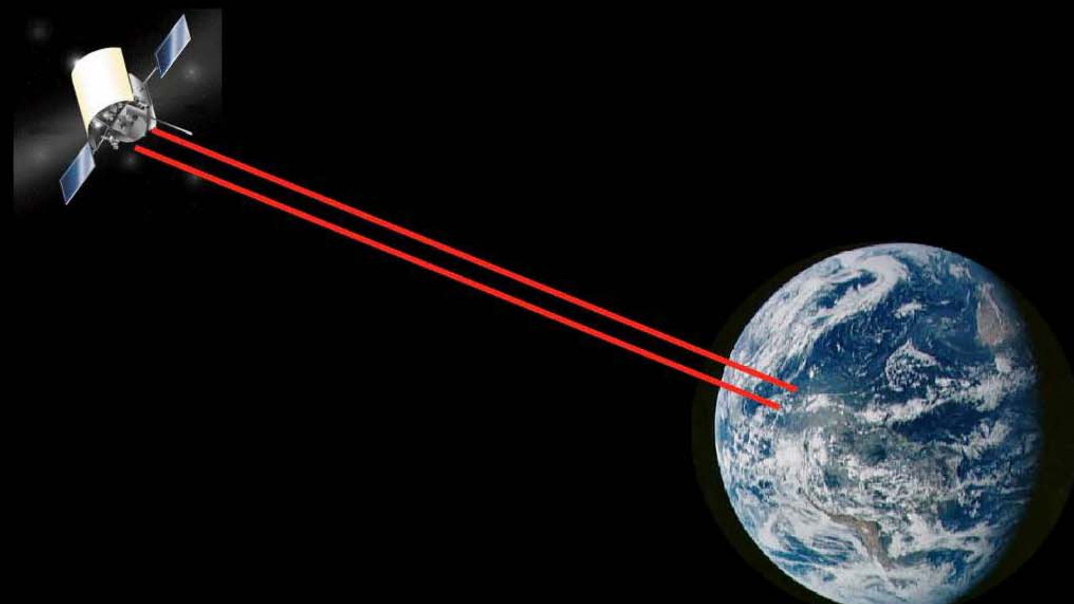
Receiver telescopes focused into optical fiber assemblies that route to different detectors.
The MLA is aboard MESSENGER on its way to Mercury!





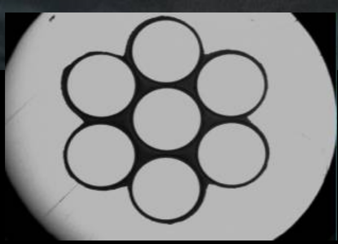
The 24 Million Km Link with the Mercury Laser Altimeter

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

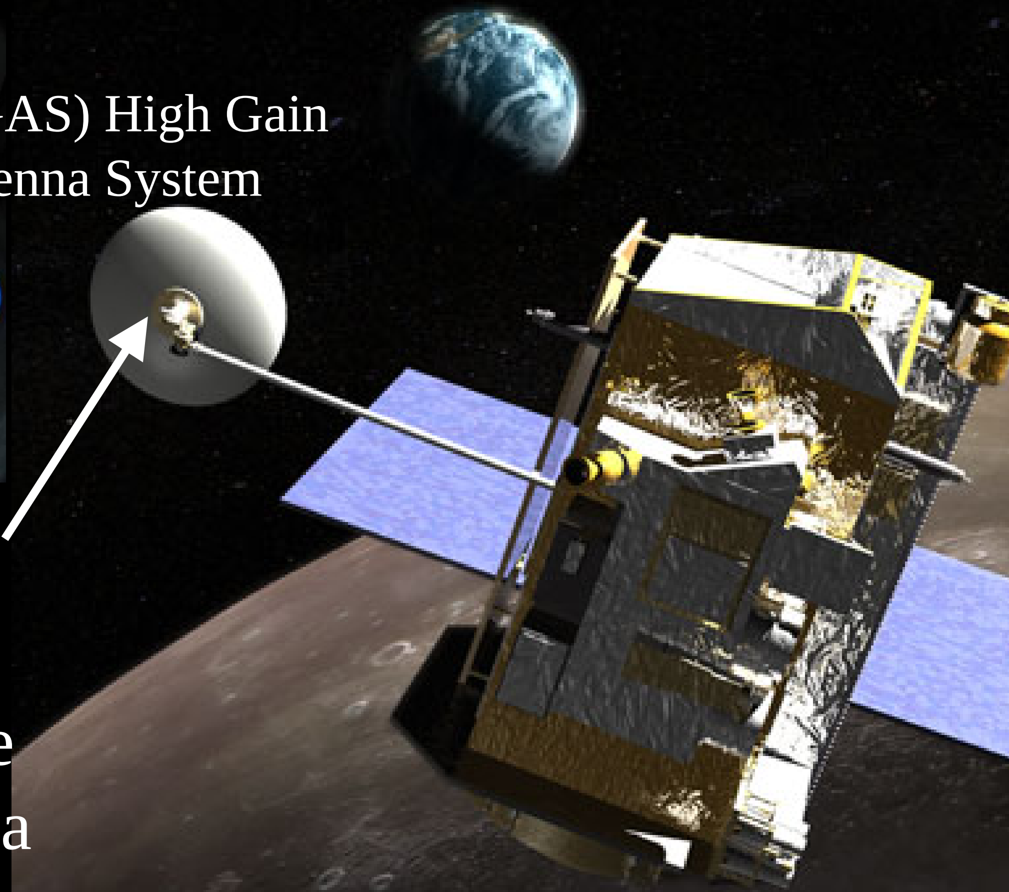


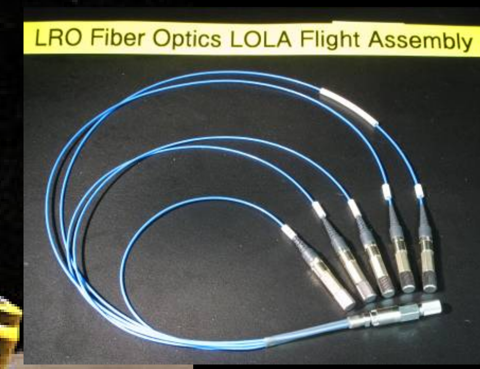
MOLA Science Team Meeting
Bishop's Lodge, Santa Fe, NM
August 24-25, 2005

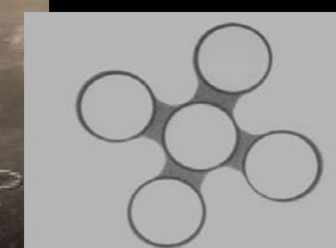
The Lunar Reconnaissance Orbiter; The Laser Ranging Mission and the Lunar Orbiter Laser Altimeter



(HGAS) High Gain Antenna System



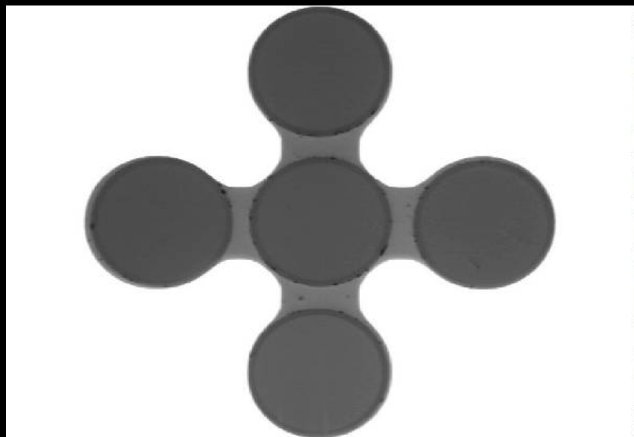




Receiver Telescope mounted on antenna and a fiber array to route signal from HGAS to LOLA

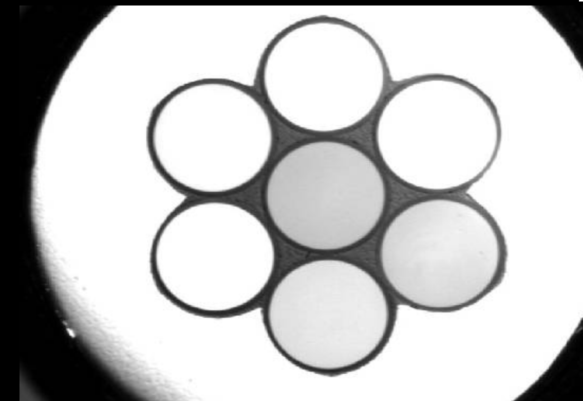
Lunar Orbiter Laser Altimeter (LOLA)

NASA GSFC Fiber Optic Array Assemblies for the Lunar Reconnaissance Orbiter



Array Side End Face Picture at
200X magnification

Lunar Orbiter Laser Altimeter (LOLA) Assemblies
Description: 5 Fiber Array in AVIM PM on Side A,
Fan out to 5 individual AVIM connectors Side B
Wavelength: 1064 nm
Quantity ~ 3 Assemblies Max ~ 0.5 m long



End Face Picture of both assembly ends at
200X magnification

Laser Ranging (LR) for LRO Assemblies
Description: 7 Fiber Array on both Sides in AVIM
PM Connector
Wavelength: 532 nm
Quantity ~ 9 Assemblies ~ 1 to 4 m long each

Laser Ranging on Lunar Recon Orbiter 2006-2008
GSFC Photonics Group Quality Documentation

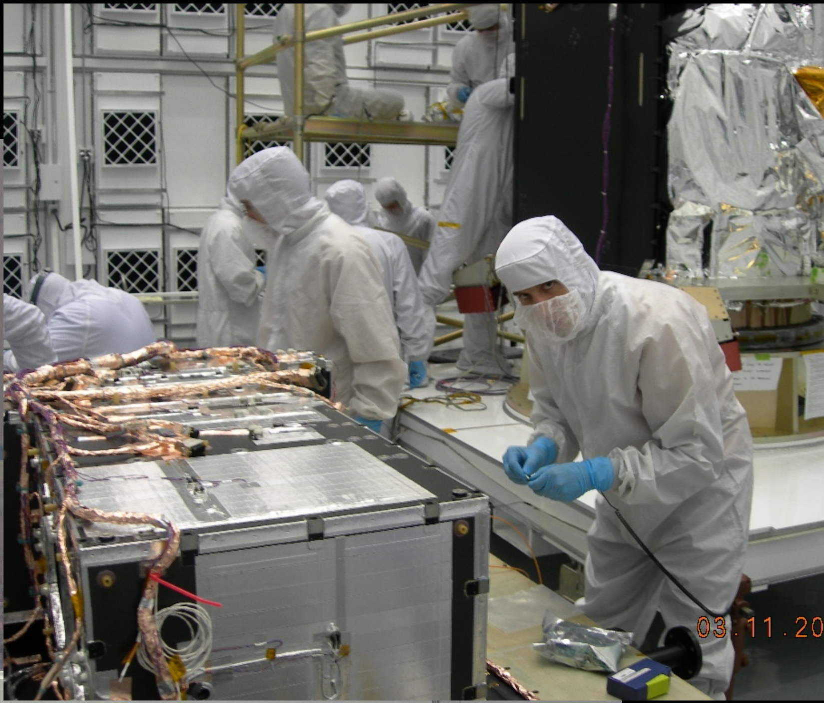
Document Name	CM Documentation Number
Thermal Pre-conditioning on Flexlite 200/220 μm fibers for flight application	LOLA-PROC-0137
Preconditioning Procedure for AVIM Hytrel Boots for LOLA fiber optic	LOLA-PROC-0138
Diamond AVIM PM Kit Pre-Assembly Inspection	LOLA-PROC-0104
Ferrule Polishing & Ferrule/Adapter Matching Procedure	LOLA-PROC-0139
Assembly and Termination Procedure for the Laser Ranging Seven Fiber Custom PM Diamond AVIM Array Connector for the Lunar Reconnaissance Orbiter	LOLA-PROC-0112
Compression Test Procedure for Fiber Optic Connector	LOLA-PROC-0141
Active Optical Power Optimization Procedure for The Laser Ranging Optical Fiber Array Assemblies	LOLA-PROC-0110
Laser Ranging Fiber-Optic Bundle Optical Test Procedure	LOLA-PROC-0107
Insertion Loss Measurement Procedure for The Laser Ranging Optical Fiber Array Bundle Assemblies	LOLA-PROC-0111
Mating of Two LR 7-Fiber Optical Fibers Using Cleanable Adapter	LOLA-PROC-0142
Cutting Back The Kynar Strain Relief For Integration	LOLA-PROC-0143
Fiber Optic Bundle Inspection and Insertion Loss Measurement	LOLA-PROC-0148

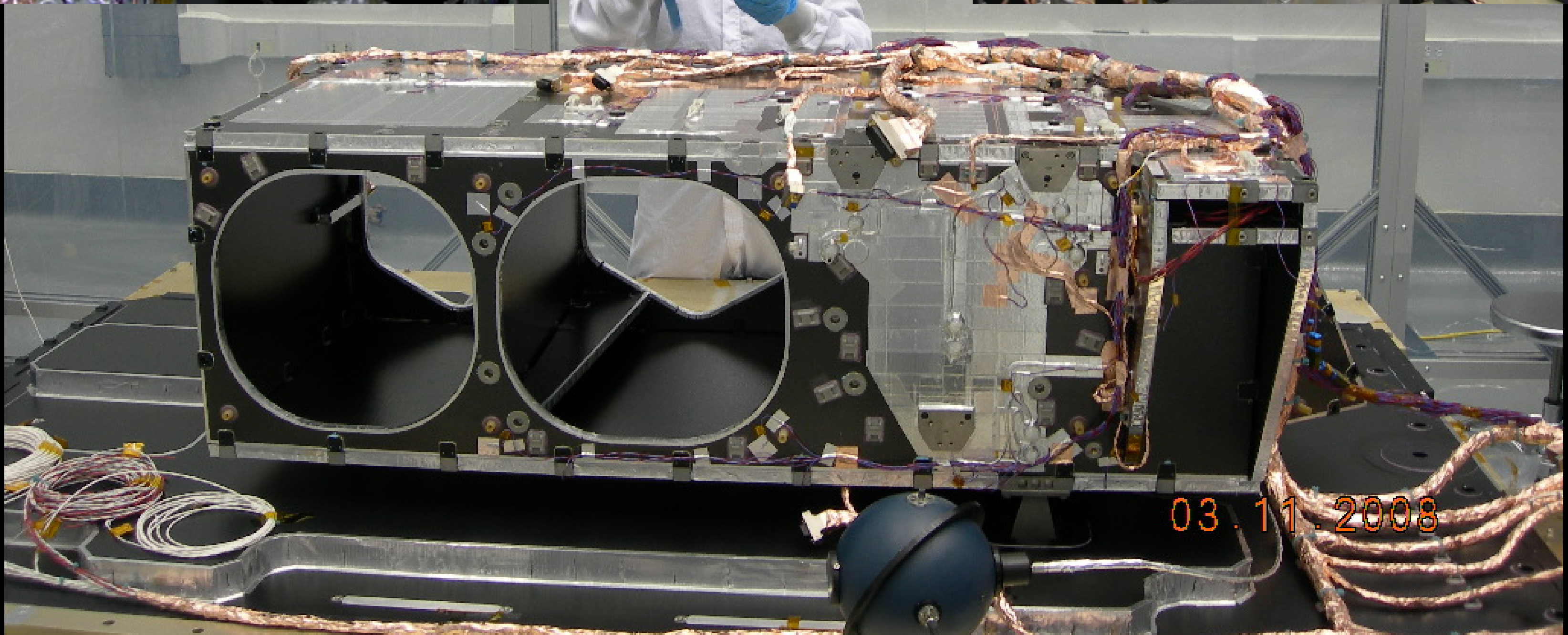
All manufacturers need in-depth quality documentation

LRO Integration HGAS

Lunar Recon. Orbiter - LRT & HGAS

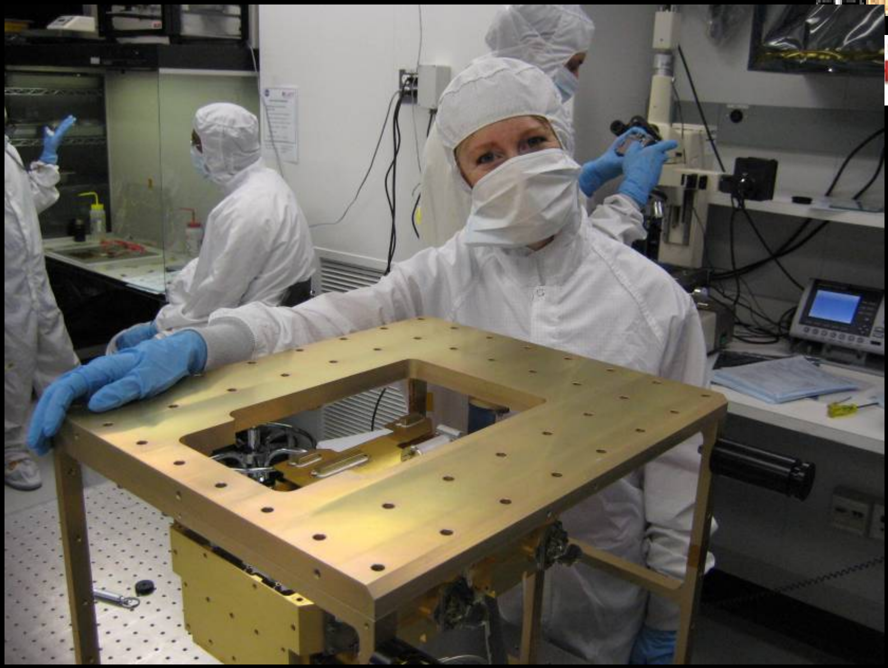
LRO Integration @ IM Deck



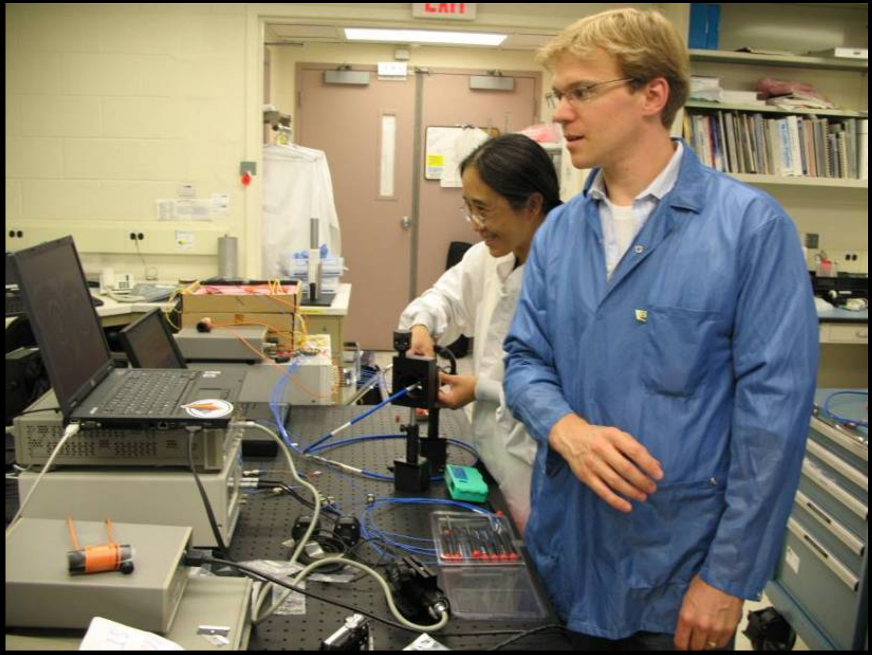


LOLA Integration & Laser Ranging Testing

GSFC



Mel Integrating the flight hardware to LOLA during Oct. and Nov 2007



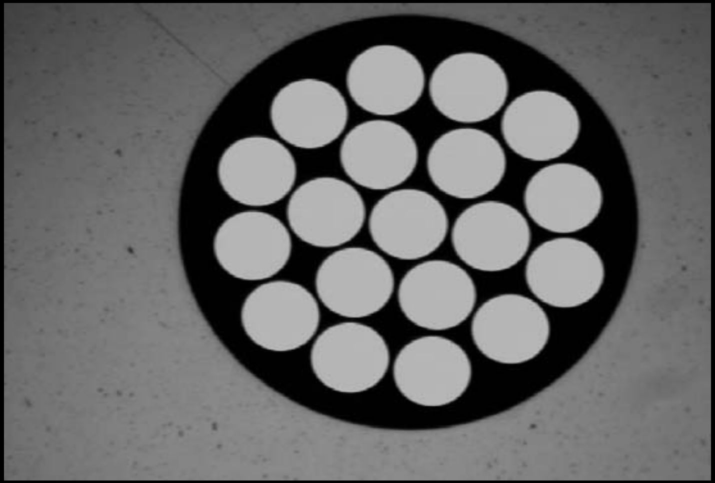
Team testing the flight Laser Ranging Assemblies in the Photonics Lab

Mars Science Lab, Chem Cam
AVIM connectors – Flexlite Cable

MSL CM Documentation

Document Name	CM Document Number
Optical Cable Inspection	562-PHOT-QAD-MSL-FON1482-INSP
Cable Thermal Pre-Cond	562-PHOT-QAD-MSL-THERM-PC
Polymers Degas	562-PHOT-WOA-MSL-BOOTS (Hytrel degas @ Materials)
Mission Survival Radiation Total Dose Testing	562-PHOT-QAD-MSL-RAD (12-day worst-case cobalt60 radiation testing)
Mission Survival Vibration Qualification	562-PHOT-QAD-MSL-VIBE (7.9grms to 14.4grms step-up vibration on selected samples)
Mission Survival Thermal Cycling Testing	562-PHOT-QAD-MSL-THERM-CYCLE (100+ cycles including planetary bake-out)
FC Cable Manufacturing (non-flight)	562-PHOT-QAD-MSL-MAN-92 (Patch Cables)
AVIM Cable Manufacturing (non-flight)	562-PHOT-QAD-MSL-MAN-92-332 (Prototype Development)
AVIM Cable Manufacturing (flight-like)	562-PHOT-QAD-MSL-MAN-332-EM (Eng Models)
AVIM Cable Manufacturing (FLIGHT)	562-PHOT-QAD-MSL-MAN-332-FM (FLIGHT and FLIGHT Spares)
Insertion Loss Testing (All-Cables)	562-PHOT-QAD-MSL-INS-92-332 (Insertion Loss testing Pre and Post all tests)
Non-flight Cable Workmanship Testing	562-PHOT-QAD-MSL-WKM-92-NONFL (Non-flight workmanship)
FLIGHT Workmanship Testing	562-PHOT-QAD-MSL-WKM-332-FLIGHT (FLIGHT workmanship)
MSL CABLE TRAVELER	GSFC-PHOTONICS CABLE TRAVELER REV 080101
Engineering Documents Review	GSFC-PHOTONICS ENGINEERING DOCUMENT REVIEW (Lead Manufacturing, Project Lead)
Pre-Shipment Inspection Checklist	GSFC-PHOTONICS PRE-SHIPMENT PROCEDURE CHECKLIST
Cable Packing Procedure Checklist	GSFC-PHOTONICS PACKING PROCEDURE CHECKLIST

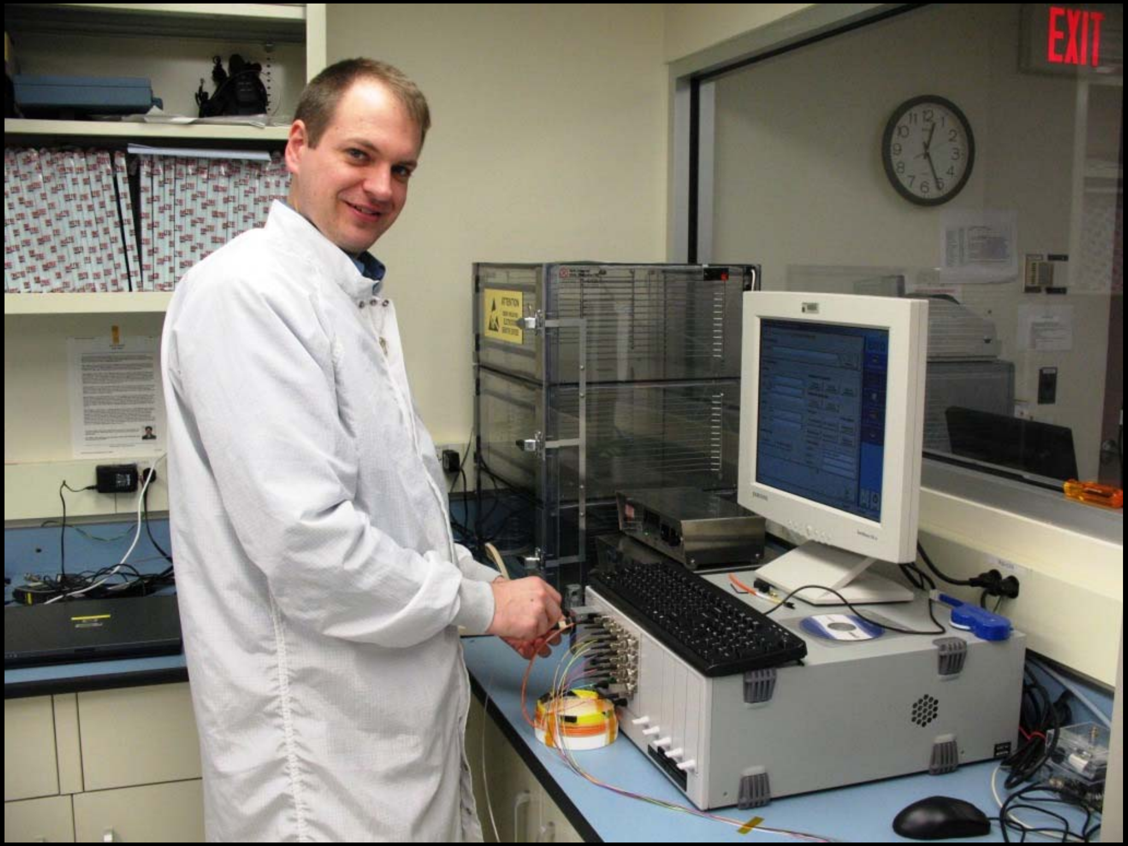
2008 New Capability
19 Fiber Arrays with Linear to Bundle Mapping

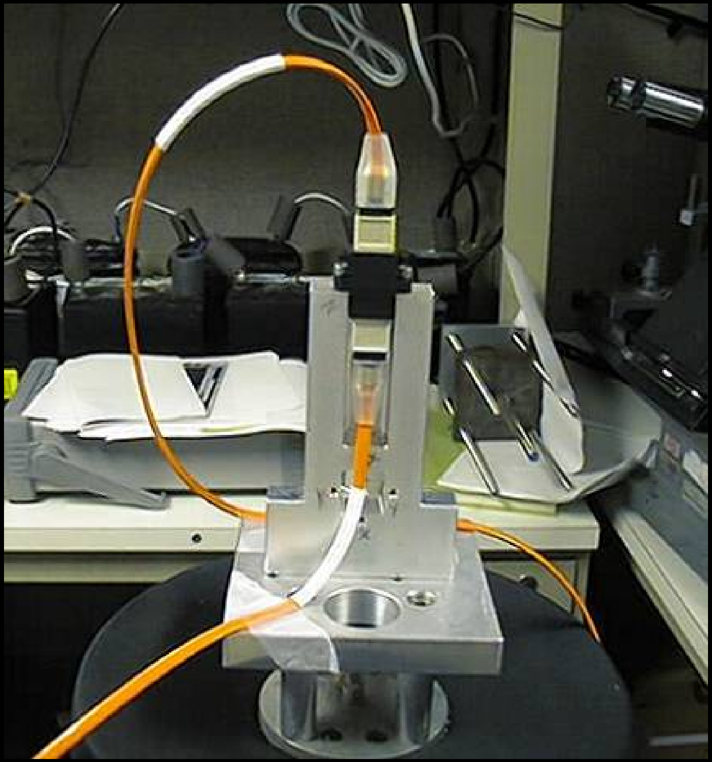


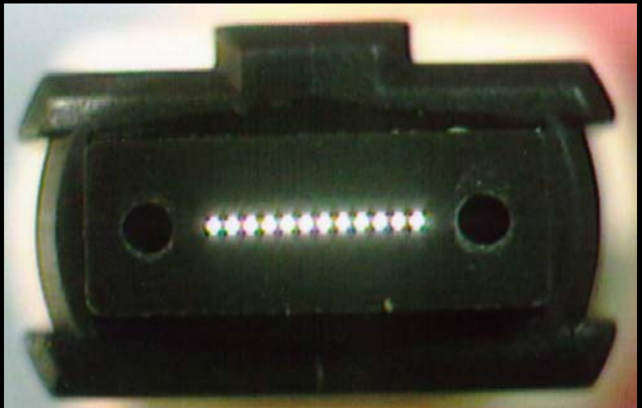
Express Logistics Carrier, Connection to ISS AVIM connectors – Flexlite Cable

Fiber Optic Flight Assemblies for Space Photonics Transceiver Inspection, Preconditioning, Manufacturing, Testing and Workmanship Procedure, (As Run Format)
ELC PROC 000400

Qualification Testing of the MTP for Sandia National Labs
1998 - 2008







Materials Issues
Shuttle Return to Flight: Construction Analysis

Optical Fiber Pigtailed Collimator Assemblies

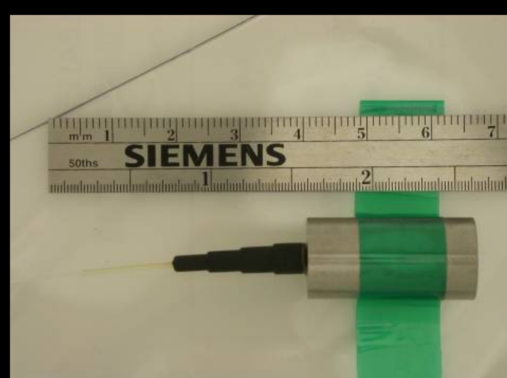
Lightpath: pigtailed fiber to collimator lens and shell

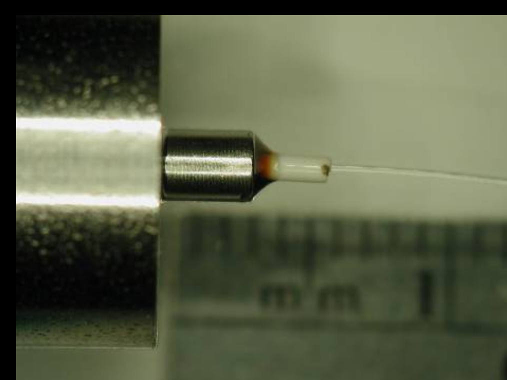
GSFC: upjacket (cable), strain relief and termination, AVIMS, PC, SM

Materials & Construction Analysis

- Non compliant UV curable adhesive for mounting lenses to case
  - Solution 1: replace with epoxy, caused cracking during thermal cycling
  - Solution 2: replace with Arathane, low glass transition temp. adhesive

  Lesson: coordinate with adhesives expert, care with adhesive changes.
- Hytrel, non compliant as an off the shelf product (outgassing, thermal shrinkage)
  - Thermal vacuum preconditioning (145°C, <1 Torr, 24 hours)
  - ASTM-E595 outgas test to verify post preconditioning.
  - Thermal cycling preconditioning (30 cycles, -20 to +85°C, 60 min at +85°C)





Materials Issues: Shuttle Return to Flight

GSFC

CODE 562 PHOTONICS Group @ GSFC

Laser Diode Assemblies

Fitel: laser diode pigtails

GSFC: Upjacket (cable), strain relief, termination, AVIMS APC SM

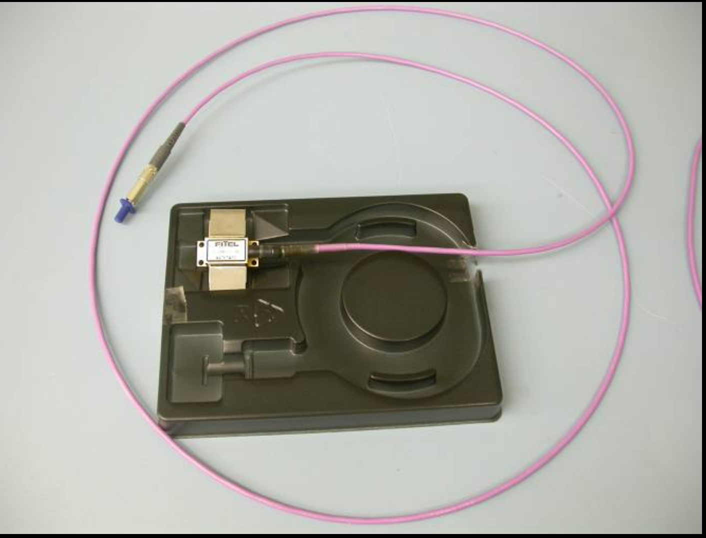
Fitel uses silicone boot, non-compliant!

Too late in fabrication process, schedule considerations to preprocess.

Cable: Thermal preconditioning, 30 cycles

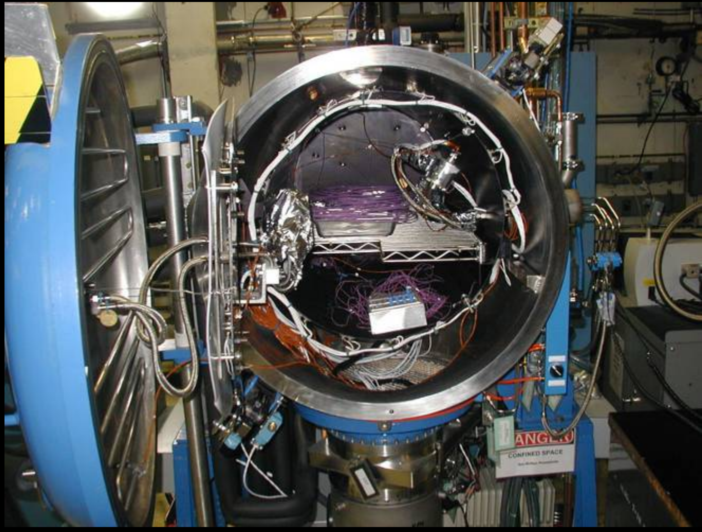
Hytrel boots: Vacuum preconditioning, 24 hours

Kynar heat shrink tubing, epoxy: approved for space use.



Post manufacturing decontamination of entire assembly required

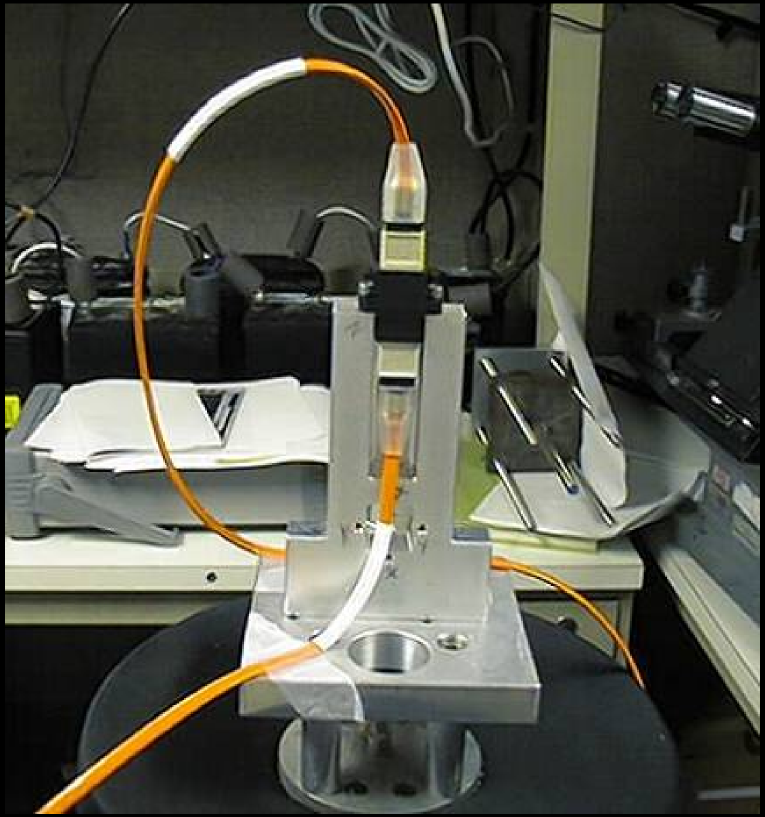
Laser diode rated for 85°C processing performed at 70°C



Environmental Parameters: Vibration

Launch vehicle vibration levels for small components (GEVS) (based on box level established for EO-1) on the "high" side.

Frequency (Hz)	Protoflight 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



3 minutes per axis, tested in x, y and z

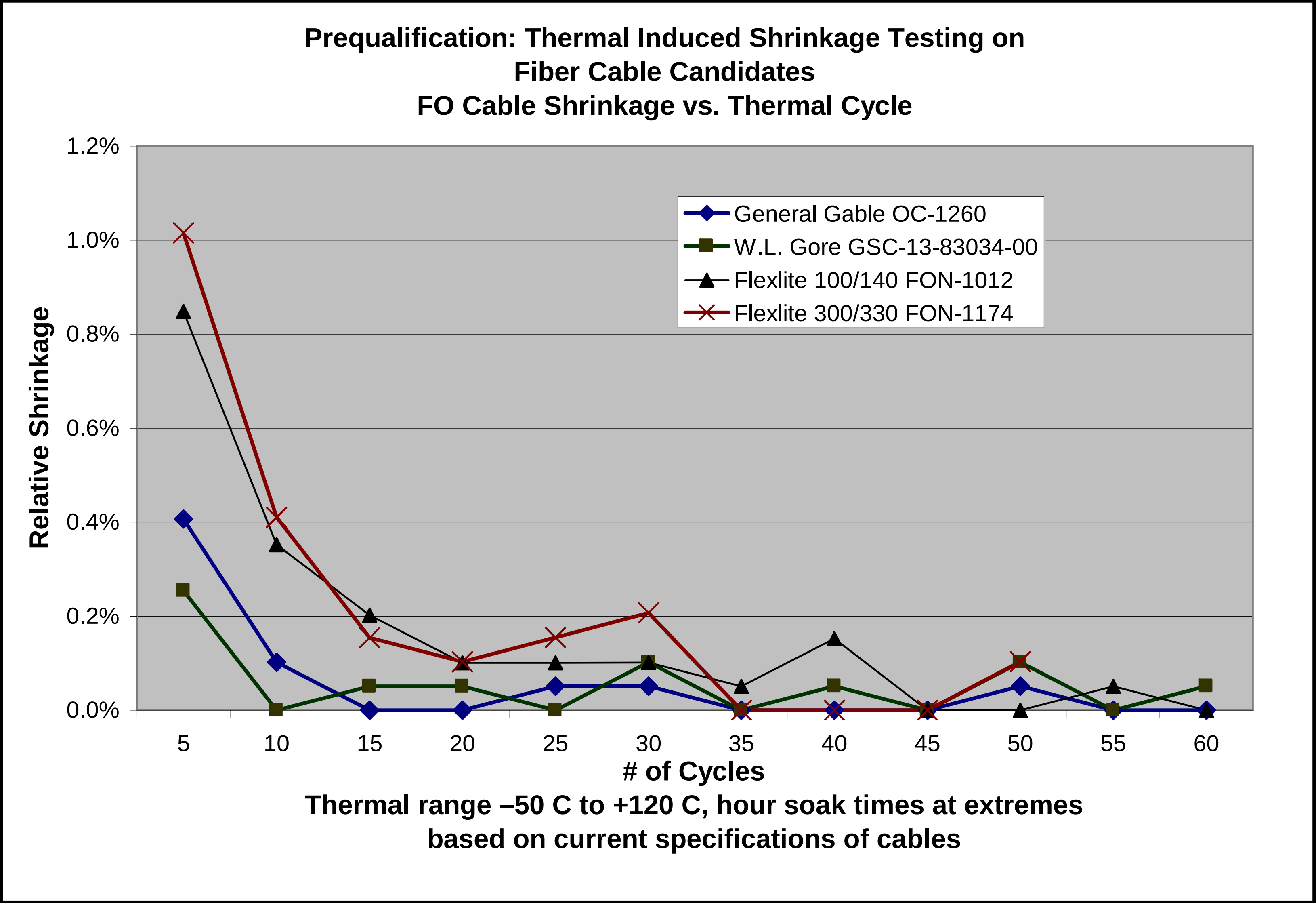
Lesson: Better to test higher than find out at the last minute your profile is too low

Thermal Effects

Thermal stability is dependent on;

- Cable construction
  - Outer diameter (smaller=more stable).
  - Inner buffer material (expanded PTFE excellent).
  - Extrusion methods (polymer internal stresses).
- Preconditioning
  - 60 cycles usually keep shrinkage less than 0.1%
  - Survival limits (hot case) is used for cycling.
  - Cut to approximate length prior.
- Termination
  - Ferrule – Jacket isolation necessary.
  - Polishing methods (especially at high power).

ISS Cable Candidates; Thermal Screening for Shrinkage



Because fluoropolymers have thermal shrinkage issues.

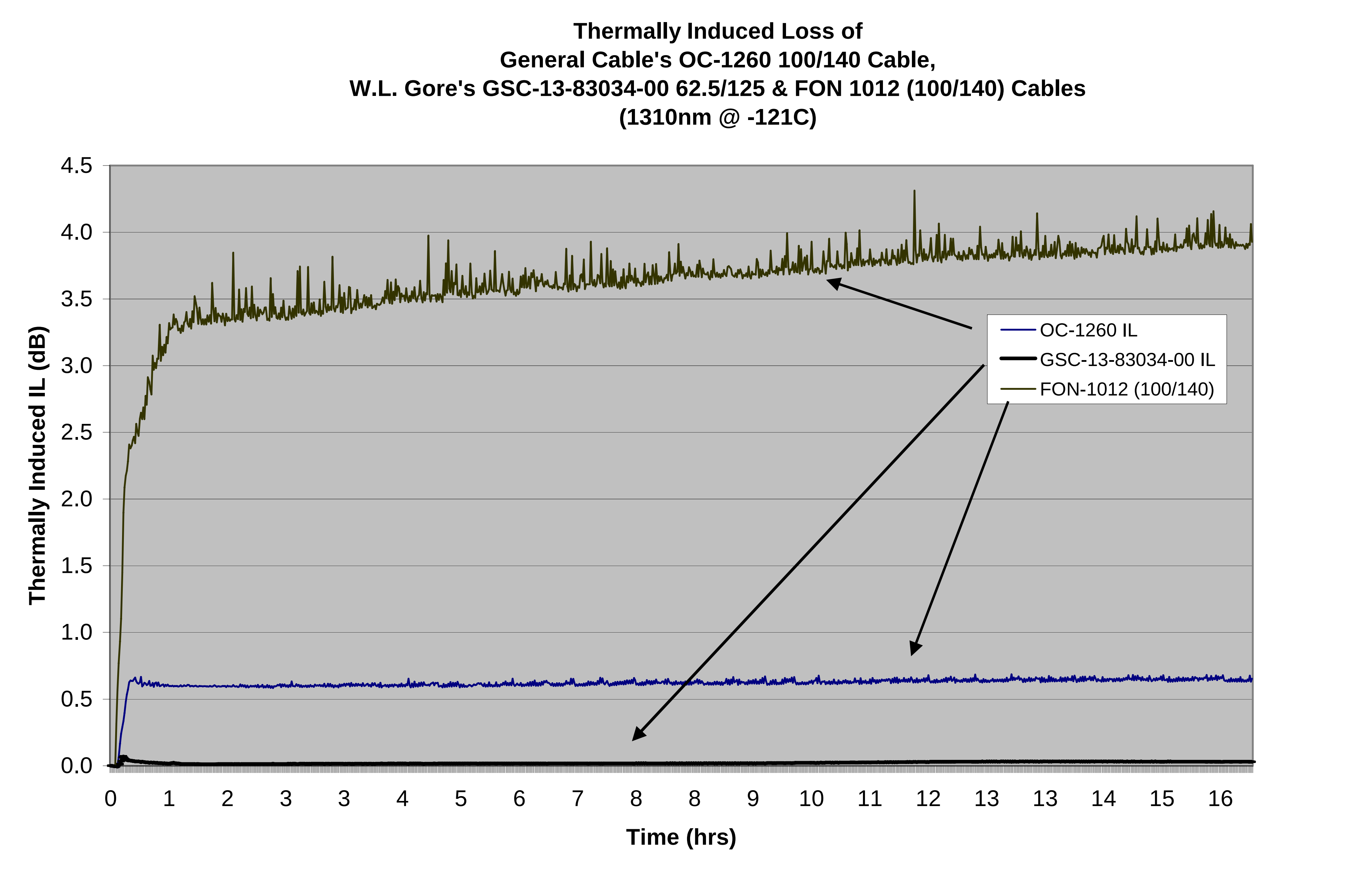
ISS Cable Candidates; Thermal Pre Qual, -121°C

Manufacturer	Part Number	Fiber Type	Thermal Range
W.L Gore	FON1012, FLEX-LITE™	OFS BF05202 100/140/172	-55 to +150°C
General Cable	OC-1260	Nufern (FUD-2940) 100/140/172	-65 to + 200°C
W.L Gore	GSC-13-83034-00 1.8 mm	Nufern (FUD-3142) 62.5/125/245	-55 to +125°C

The above cable candidates were tested for 16 hours at -121°C

ISS Cable Candidates; Thermal Pre Qual, -121°C

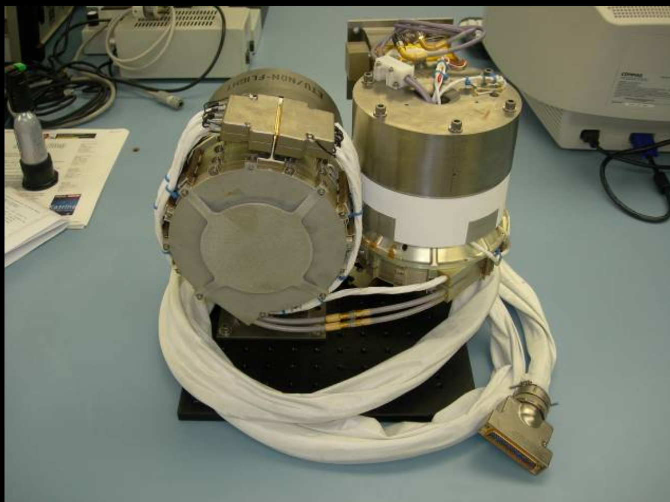
9 meters



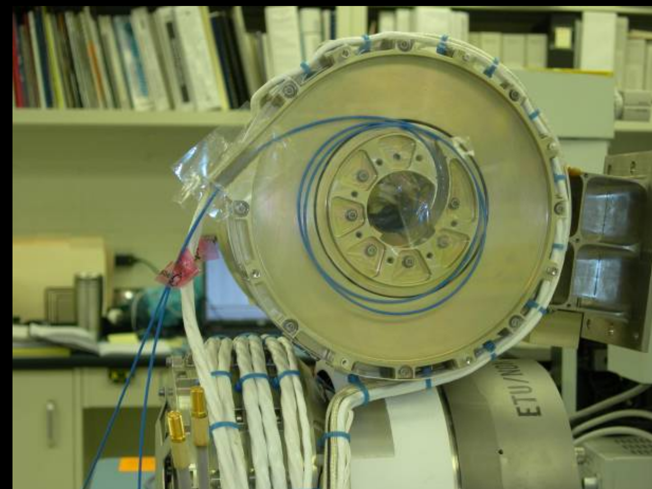
LRO Laser Ranging Cold Gimbal Motion Life Testing

GSFC

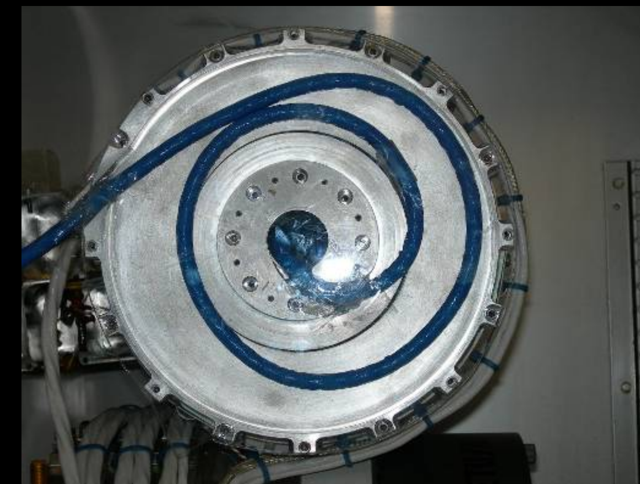
CODE 562 PHOTONICS Group @ GSFC



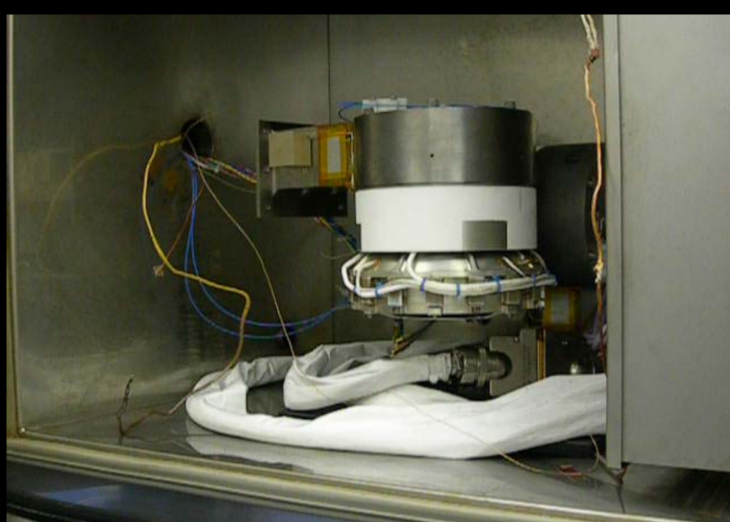
Gimbals



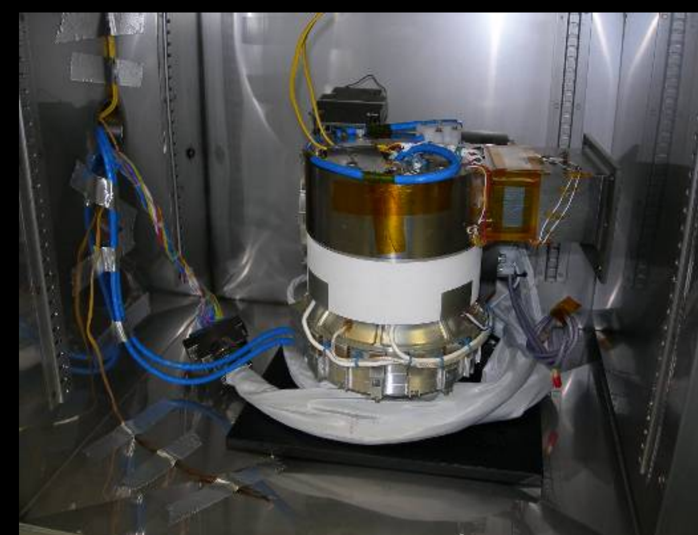
Window inside gimbal;
Flexlite cable inside



Window inside gimbal;
Bundle cable inside.



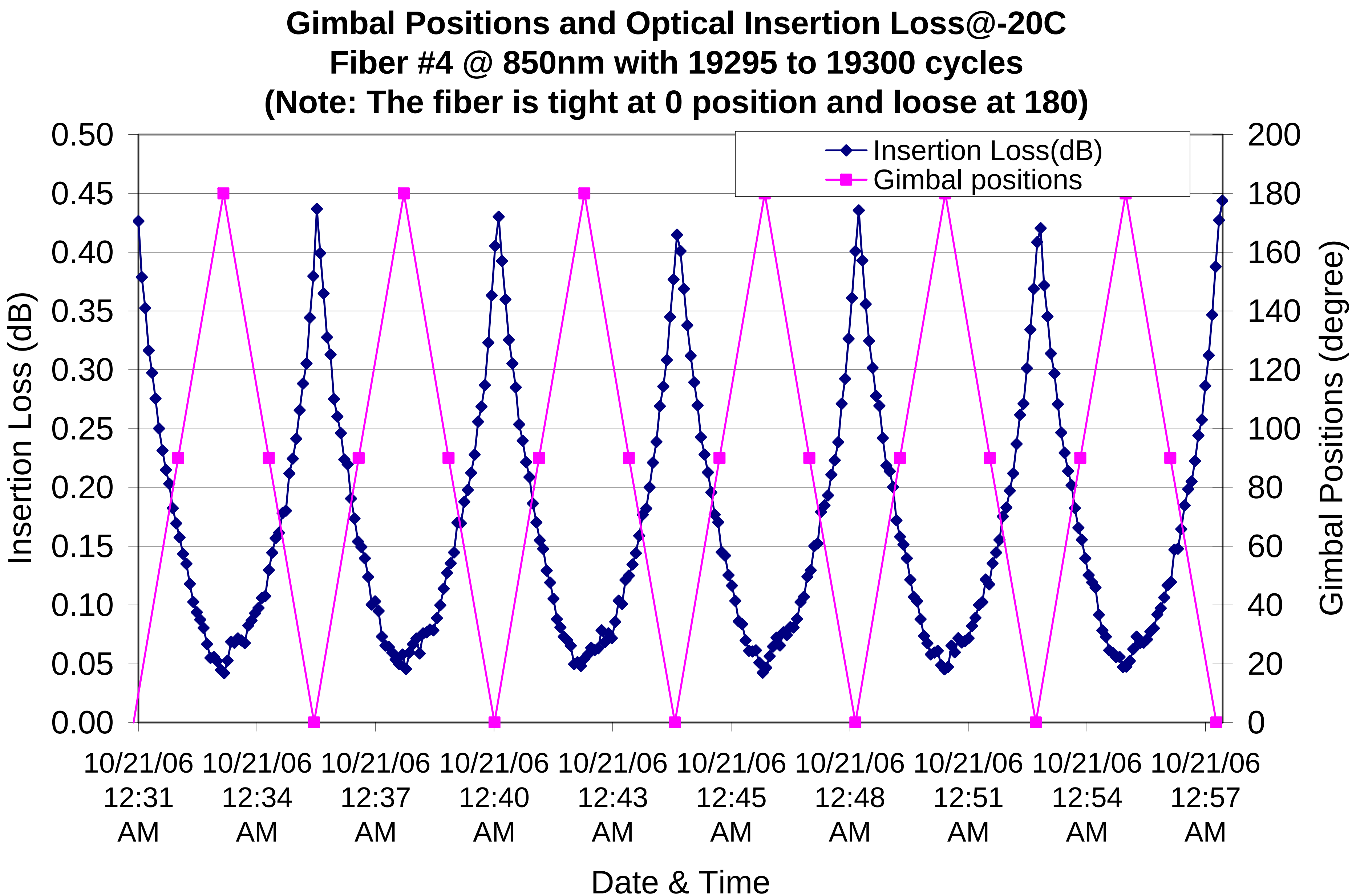
Gimbals w/ single flexlite in thermal chamber



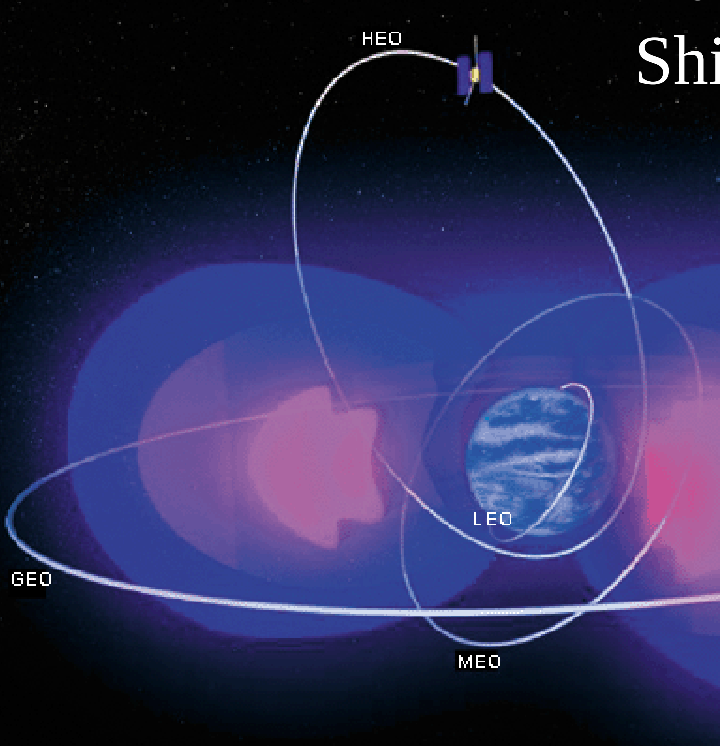
Gimbals w/ bundle in thermal chamber

LRO Laser Ranging Bundle Cold Gimbal Motion Testing Results

End of Test, relative IL ~ 0.50 dB, @ 850 nm, -20°C, 400/440 FV flexlite in Bundle



Environmental Parameters: Radiation



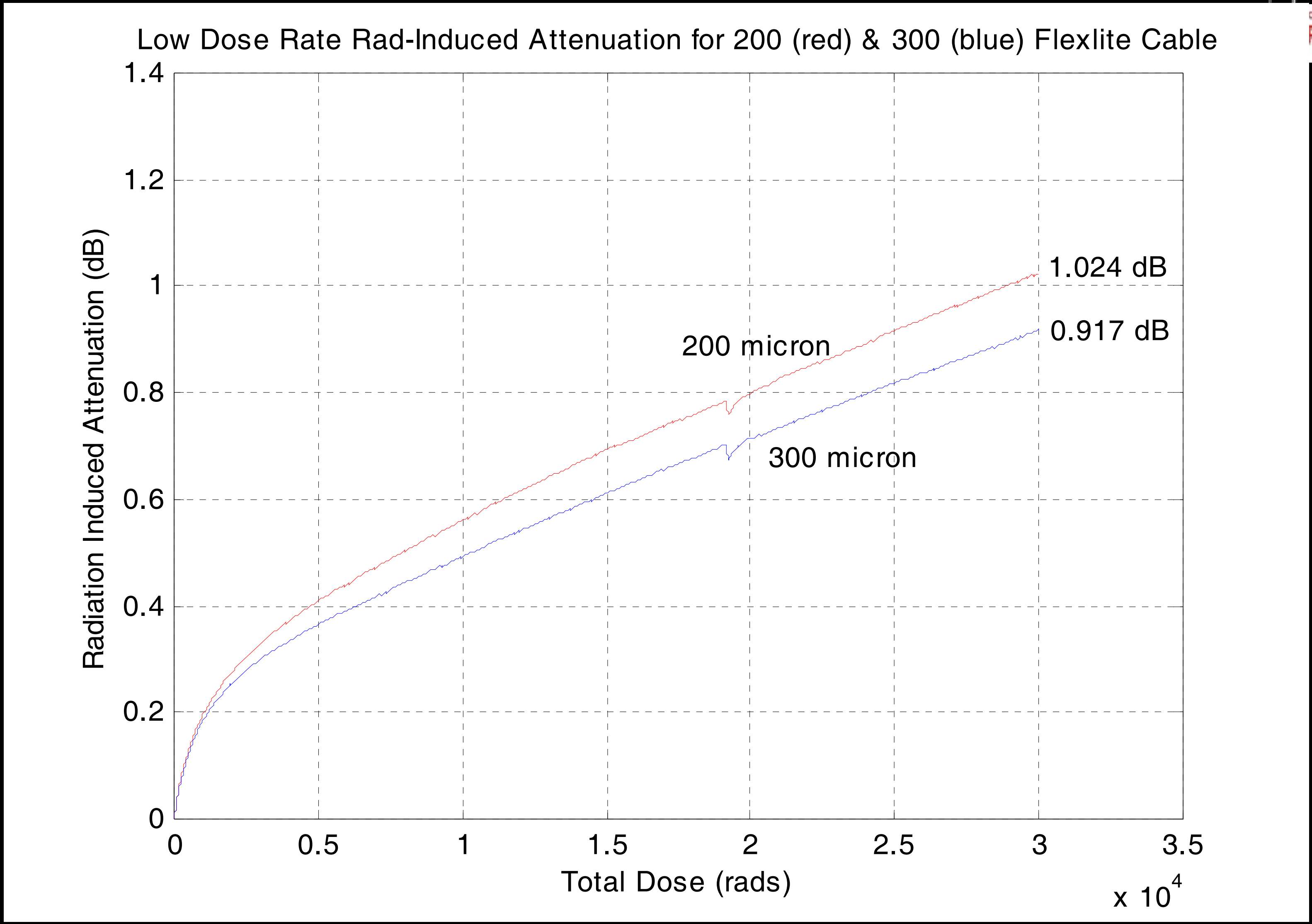
Assuming 7 year mission,
Shielding from space craft

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

Lesson: You will over-estimate the radiation induced losses without a comprehensive thermal/dose/dose-rate model based on lower dose rate data.

Radiation Effects Mercury Laser Altimeter



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

MSL Radiation Requirements using the LRO Radiation Model @ 532 nm, for the Polymicro FV400/440 (.22 NA)

Duration	Dose Rate Rads/min	Total Dose	Temperature	Attenuation
36 months	0.0064	10 Krad	-80 C	0.0015 dB/m
36 months	0.0126	20 Krad	-80 C	0.0030 dB/m
8 months	0.0289	10 Krad	-80 C	0.0025 dB/m
8 months	0.0578	20 Krad	-80 C	0.0049 dB/m

- **Good extrapolation models will serve in analysis for other environments and missions, saving time and $ in the end.**
- **There is a lot to lot variability so radiation testing should still be conducted.**
- **Radiation testing also serves as a screening for the COTS product. Defective products will show poor radiation performance.**

A Decade of Service from the Photonics Group for Optical Fiber Components and Assemblies Code 562, Electrical Engineering Division of AETD, NASA GSFC

Project	Design	Qualification Performance over Harsh Environment	Manufacturing	Integration	Failure Analysis
GLAS	X	X	GSE		
ISS					2000-2008
ISS-2003	X		X		
Fiber Optic Data Bus	X	X			
Messenger - MLA	X	X	X	X	
Sandia National Labs (DOE)		X			X
ISS-Express Logistics Career	X	X	X	X	
Air Force Research Lab		X			
Shuttle Return To Flight			X		
Lunar Orbiter Laser Altimeter	X	X	X	X	X
Mars Science Lab ChemCam	X	X	X	X	X
Laser Ranging, LRO	X	X	X	X	
Fiber Laser IIP/IRAD	X	X	X		
ESA/NASA SpaceFibre	X	X	X		

Upcoming is the 3rd Event in coordination with ESA/CNES/JAXA/NASA on optics for space

What's Coming?

- Diamond AVIM international standard for space.
- Multi Fiber Arrays
  - Linear, Bundled, Custom Patterns
- High Power Terminations
  - Fiber Lasers – Intersatellite Communications
- Ruggedized Fiber Optic Cables
  - Wide thermal range, rugged cable
  - For future missions or replacement on exising systems

Conclusion

All components are not appropriate for all applications.

Knowledge of failure modes and materials is crucial to making feasibility decisions as well as design, manufacturing procedures and test plans.

Acknowledgements

NASA Electronic Parts and Packaging Program for funding this talk.

For more information, please see the website:

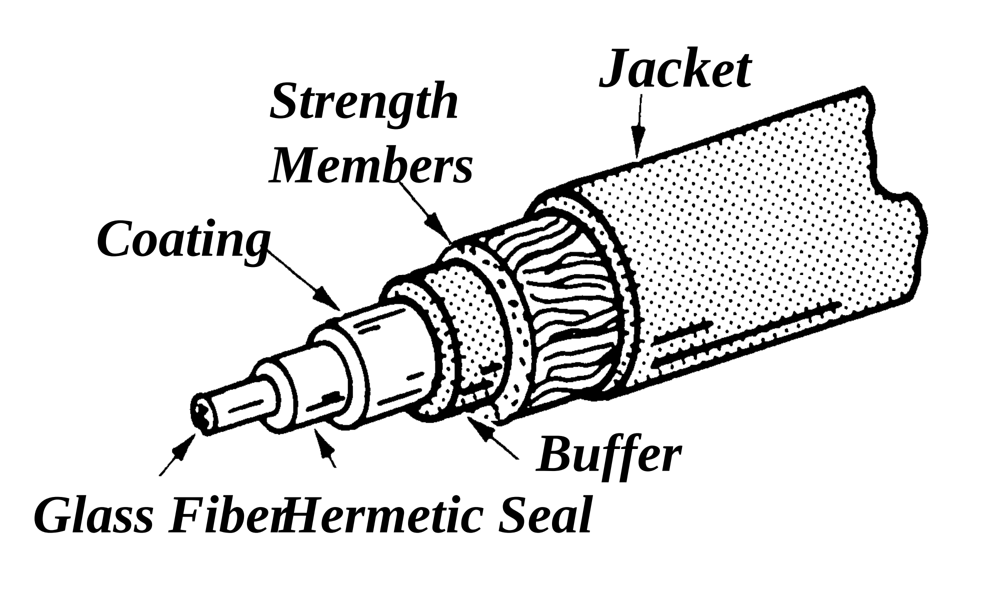
http://misspiggy.gsfc.nasa.gov/photonics
http://nepp.nasa.gov

Extra Slides

International Space Station 2000

Failure Analysis: Optical Fiber Cable 1999-2000

Failure Analysis: Optical Fiber Termini 2005-2006



Bad Combination

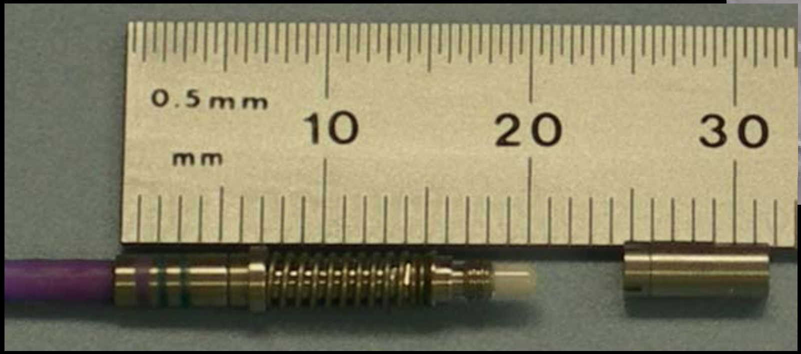
Fiber Optic Cable "Rocket Engine" Defects

- Hermetic coating holes,
- Polyimide coating holds water
- Fluorine generated during extrusion of buffer
- Hollow tube construction
  - water and fluorine interaction results in HF acid
- HF etches pits into fiber getting through holes in coating
- Etch pits deep into the core caused losses and cracks

International Space Station Study on Termini 2006

Vendor provided termini that somehow passed integration QA During integration by the contractor. Node 2 welded into place. Cost of changing termini on Node 2 more than $1 M. Node 3 fixed.

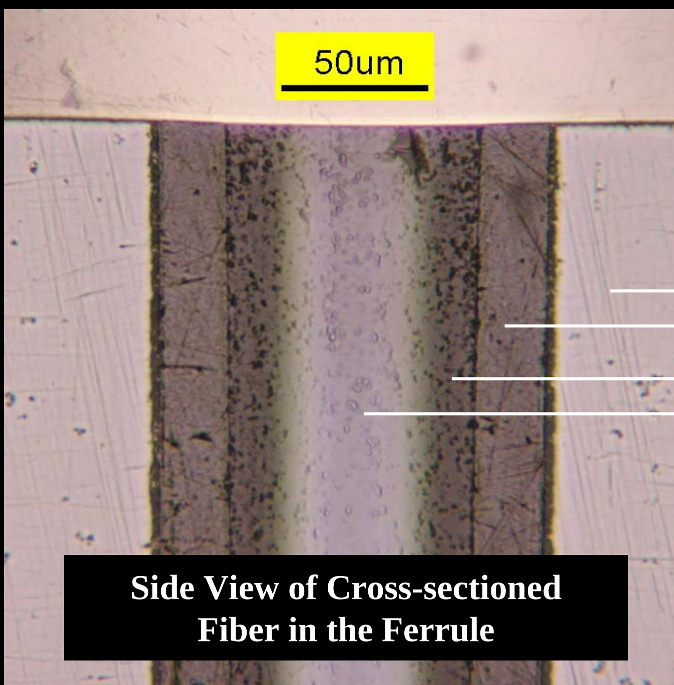
32 termini are installed into one "MIL-C-38999" type connector.



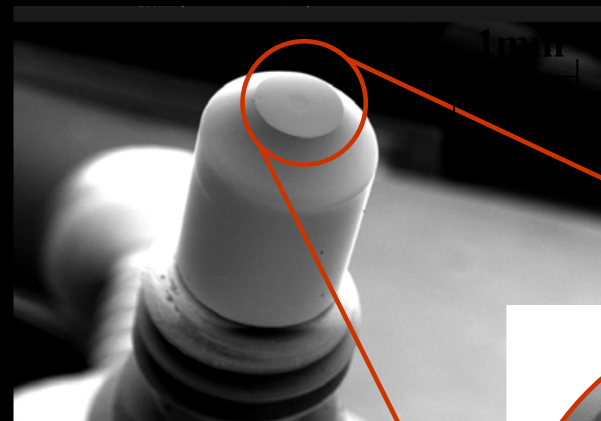
Termini end faces were found to be cracked after failing insertion loss testing during integration.

ISS Termini Failure Analysis

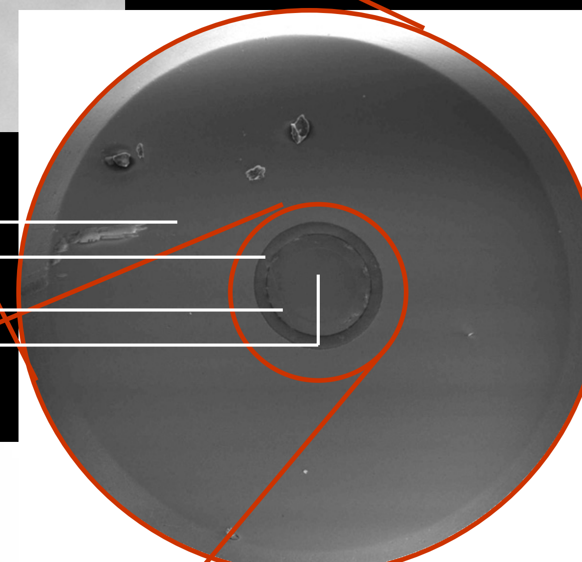
The below cross section of the terminus shows a concave end-face. This is per specification. If the end-face were convex, the glass would likely experience an impact when connected, causing a fracture.



Side View of Cross-sectioned Fiber in the Ferrule



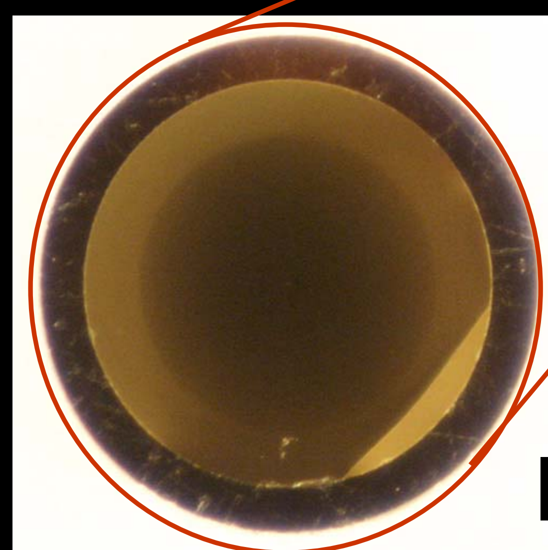
The fiber must be free of cracks in order to prevent a degraded or blocked optical signal. If a glass fiber has a crack after the polishing process, the crack will grow over time.



Ferrule & Fiber End View

<u>The termination is made up of:</u>

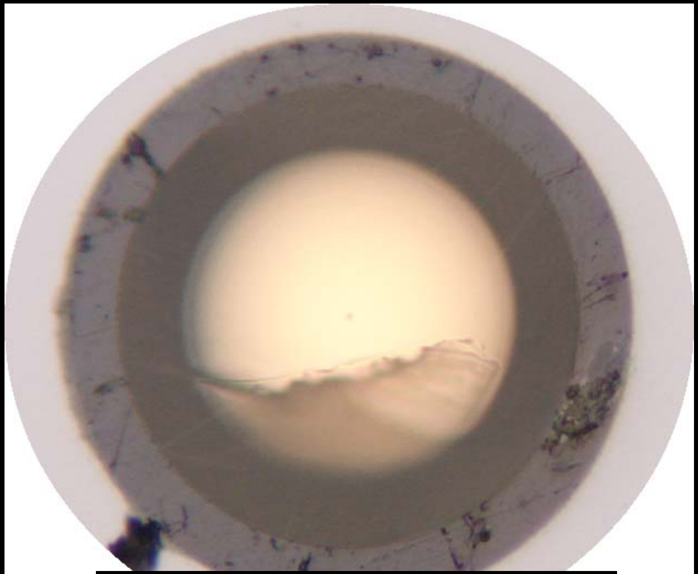
- A zirconia ferrule
- Polyimide coating
- Pure silica cladding
- Germanium doped core



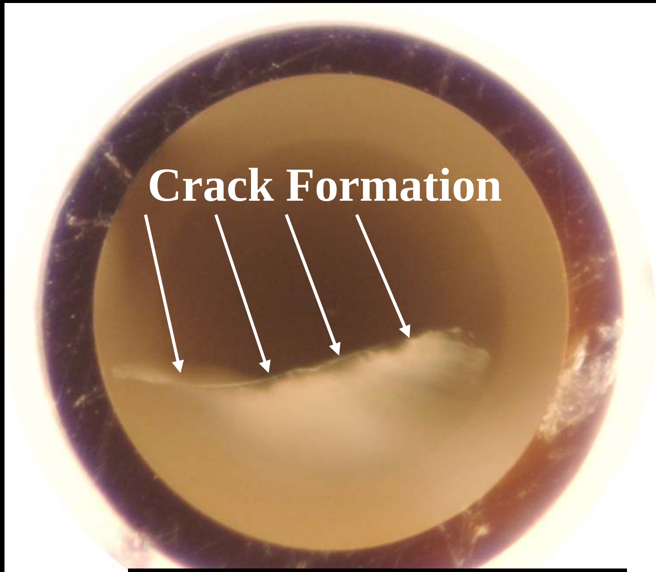
Core, Cladding, & Coating End View

The end-face of this optical fiber is 140µm. If dirt is present, the optical signal would be degraded or blocked.

ISS FA Optical Microscopy



Bright Field Image at 200X



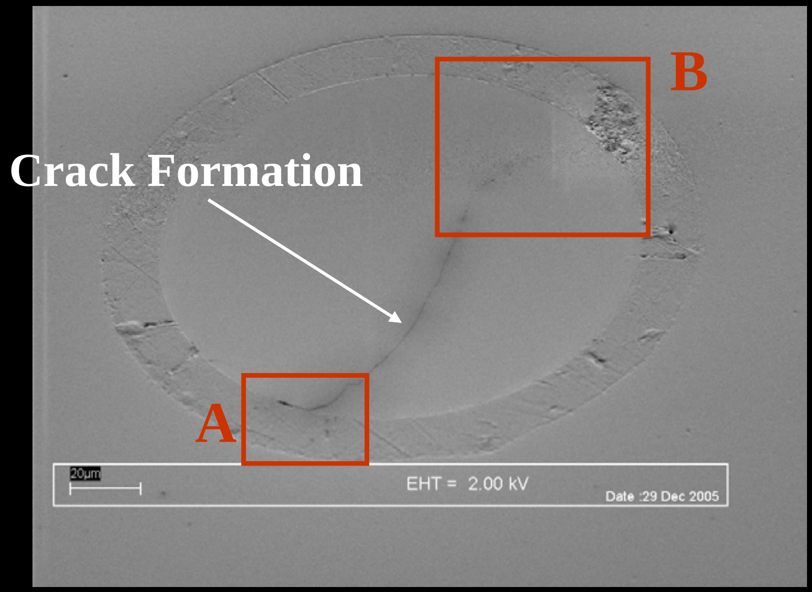
Dark Field Image at 200X

Optical Microscopy:

- Bright field (Top) & dark field (Bottom) illumination (taken at 200X) can be used to enhance certain features of the terminus.
- At 200X, a crack formation can be seen, and the “smudge” appears to be sub-surface cracking.
- More information is required to characterize the crack.
- Optical microscopy is not enough to identify an origin of the crack, so SEM will need to be performed.

ISS FA Scanning Electron Microscopy

Fiber Most Likely to Fail Because of Crack



Scanning Electron Microscopy (SEM):

- SEM gives a clear image of the crack, and could be observed at over 50000X magnification.
- At 500X, the ends of the crack can be observed and analyzed.
- A concave or convex profile of the end-face cannot be determined using the SEM, so the terminus must be evaluated using confocal microscopy.