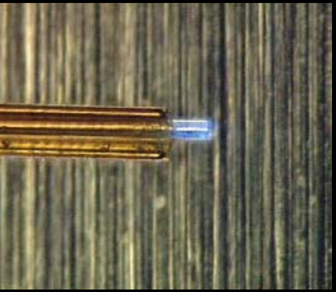
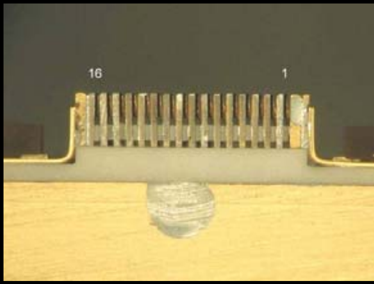
Optical Fiber Array Assemblies for Space Flight from the NASA Electronics Parts and Packaging Program

**Melanie N. Ott, Rob Switzer, William Joe Thomas,
Richard Chuska, Frank LaRocca, Shawn Macmurphy**

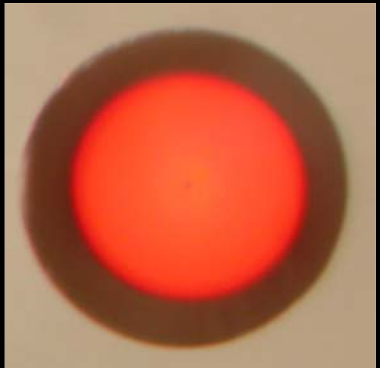


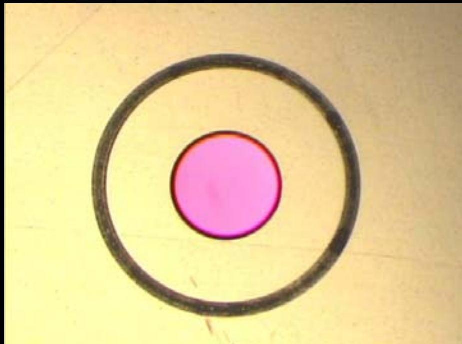


CODE 562 PHOTONICS Group @ GSFC

Melanie N. Ott
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
NEPP.nasa.gov
Photonics.gsfc.nasa.gov



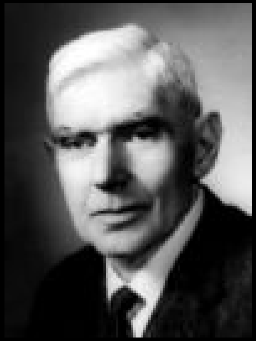


Outline

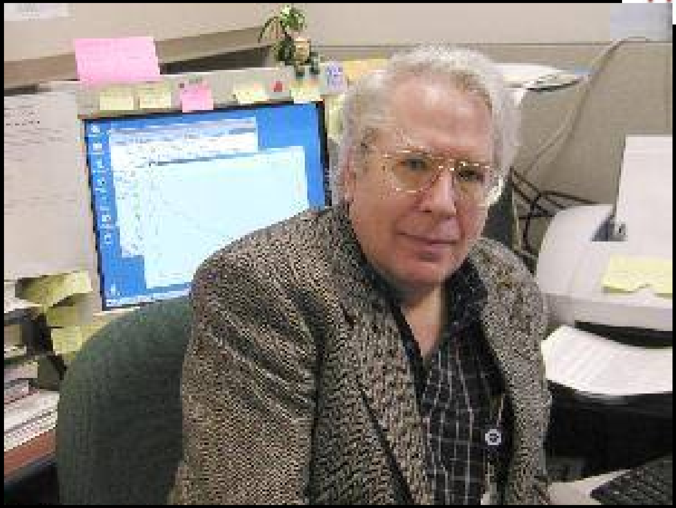
- Introductions
- LRO (LOLA & LR) Introduction & Requirements
- LRO Solutions
- Design to Integration
  - –Lessons Learned
  - –Integration
- Conclusions

Mentorship Mapping

Arnold Sommerfeld
Russia, 1868 - 1951
German Physicst
Quantum Theory



Karl F. Herzfeld
Vienna, 1892 – 1978
John's Hopkins University Professor, 1926
Catholic University Professor, 1936



Henning Leidecker, USA,
Catholic University Professor, 1967
NASA Goddard Space Flight Center, 1985
NASA GSFC Chief Parts Engineer, Currently

Students/Nobel Laureates

1) Werner Karl Heisenberg, 1901-1976, Quantum Mechanics
2) Wolfgang Ernst Pauli, 1900 – 1958, Theoretical Physics, uncertainty principal
3) Peter Joseph William Debye, 1884 - 1966 Physics, Physical Chemistry
4) Hans Albrecht Bethe 1906 – 2005, Physics
5) Herbert Kroemer, 1928 -
6) Linus Carl Pauling, 1901 - 1994

Melanie N. Ott

CODE 562 PHOTONICS Group @ GSFC

Melanie N. Ott, Group Leader, 1994-2008
Applied Engineering Technologies Directorate, Electrical Engineering Division

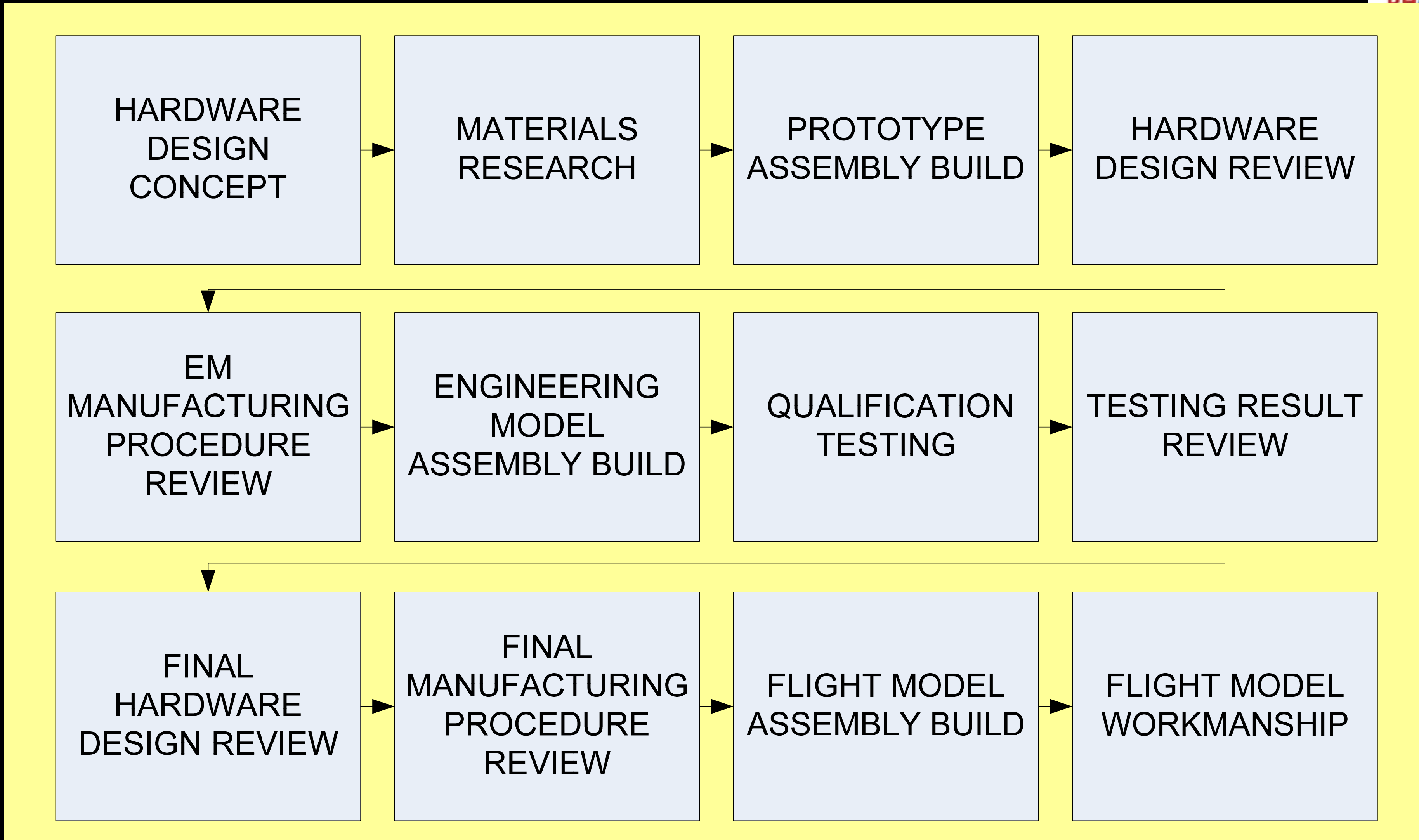
Rob Switzer, Frank LaRocca, W. Joe Thomes, Melanie Ott, Richard Chuska

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

Project	Dates	Design	Qualification Performance over Harsh Environment	Manufacturing	Integration	Failure Analysis
ICESAT, GLAS,	1997 - 2005	X	X	GSE		Prototype
ISS	1998 - 2008					Vendor/ Flight
ISS - HDTV	2003	X	X	FLIGHT		
Fiber Optic Data Bus	1997 -2000	X	X			
Messenger – MLA,	2001 - 2004	X	X	FLIGHT	X	
Sandia National Labs (DOE)	1998 -2008		FLIGHT			Vendor/ Flight
ISS-Express Logistics Career	2006 -2009	X	X	FLIGHT	X	
Air Force Research Lab	2003, 2008		X			
Shuttle Return To Flight	2004 -2005			FLIGHT		
Lunar Orbiter Laser Altimeter	2003 -2008	X	X	FLIGHT	X	Prototype
Mars Science Lab ChemCam	2005 -2008	X	X	FLIGHT	X	Vendor
Laser Ranging, LRO	2005 - 2008	X	X	FLIGHT	X	Prototype
Fiber Laser IIP/IRAD	2003 - 2006	X	X	QUAL		
ESA/NASA SpaceFibre	2008 (TBD)		X	QUAL		

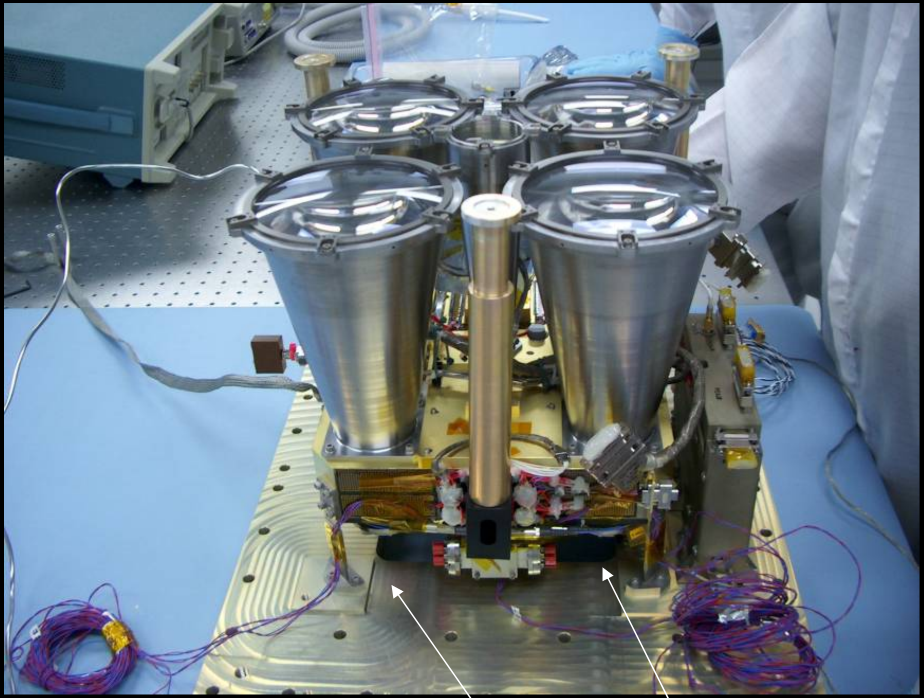
Upcoming is the 3rd Event in coordination with ESA/CNES/JAXA/NASA on optics for space
Publications from work noted above can be found @ **misspiggy.gsfc.nasa.gov/photonics**

How Does the Photonics Group Go from Ideas to Flight?

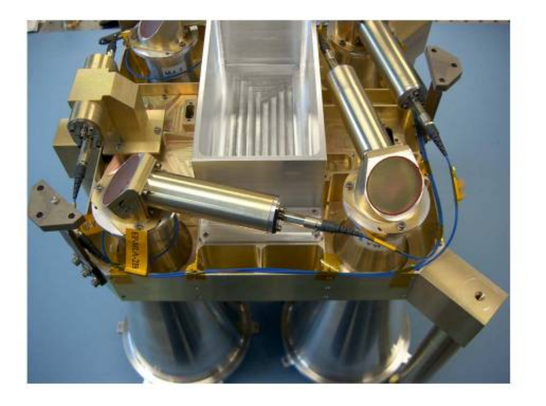


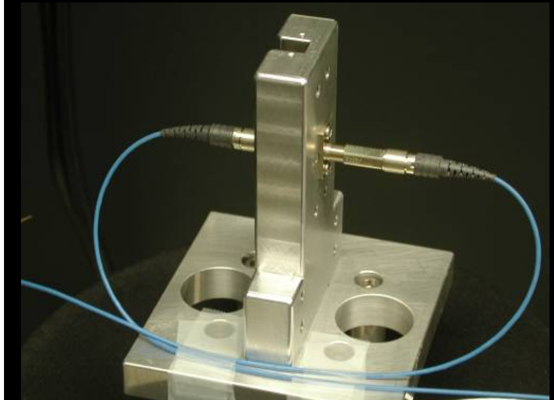
BASIC PRODUCT LIFE CYCLE

Mercury Laser Altimeter 2001-2003



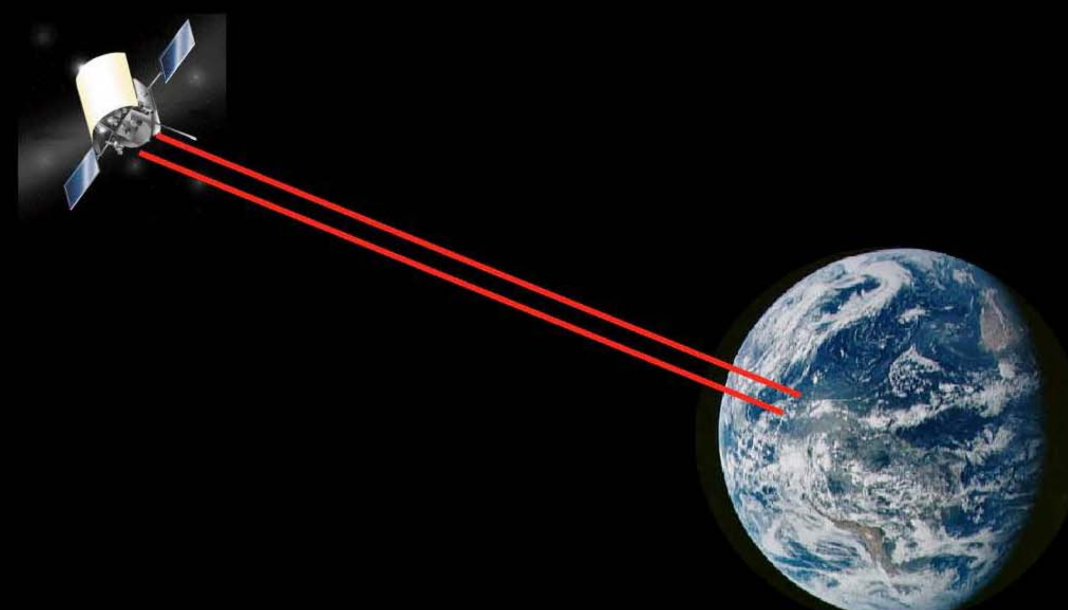
Receiver telescopes focused into optical fiber assemblies that route to different detectors.
The MLA is aboard MESSENGER currently sending data from Mercury!





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

REPORT

Laser Altimeter Observations from MESSENGER's First Mercury Flyby

Maria T. Zuber,[1]* David E. Smith,[2] Sean C. Solomon,[3] Roger J. Phillips,[4] Stanton J. Peale,[5] James W. Head III,[6] Steven A. Hauck II,[7] Ralph L. McNutt Jr.,[8] Jürgen Oberst,[9] Gregory A. Neumann,[2] Frank G. Lemoine,[2] Xiaoli Sun,[2] Olivier Barnouin-Jha,[8] John K. Harmon[10]

A 3200-kilometers-long profile of Mercury by the Mercury Laser Altimeter on the MESSENGER spacecraft spans ~20% of the near-equatorial region of the planet. Topography along the profile is characterized by a 5.2-kilometer dynamic range and 930-meter root-mean-square roughness. At long wavelengths, topography slopes eastward by 0.02°, implying a variation of equatorial shape that is at least partially compensated. Sampled craters on Mercury are shallower than their counterparts on the Moon, at least in part the result of Mercury's higher gravity. Crater floors vary in roughness and slope, implying complex modification over a range of length scales.

Topography is a fundamental measurement to characterize quantitatively the surfaces of solid planetary bodies at length scales ranging from the long-wavelength shape to such local and regional processes as impact cratering, volcanism, and faulting. During the first flyby of Mercury by the MESSENGER spacecraft on 14 January 2008 (*1*), the Mercury Laser Altimeter (MLA) (*2*, *3*) successfully ranged to the planet's surface, providing the first altimetric observations of the planet from a spacecraft.

Previous measurements of the shape and topography of Mercury had been derived from Earth-based radar ranging (*4*, *5*) constrained by range observations from Mariner 10 (*6*). Because of the low inclination (7°) of Mercury's orbital plane to the ecliptic, Earth-based altimetric profiles are limited to ±12° latitude and have a spatial resolution of ~6 × 100 km^2 and a vertical precision of 100 m (*5*). These observations indicated a planetary reference radius of 2440 ± 1 km, an equatorial ellipticity of 540 ± 54 ×10^{-6}, and an equatorial center of figure (COF) offset from the planet's center of mass (COM) of 640 ± 78 m in the direction 319.5° ± 6.9° W (*6*, *7*).

The MLA profile (Fig. 1) was acquired approximately along Mercury's equator, in a region that was in darkness during the flyby, and within the hemisphere not imaged by Mariner 10. Consequently, there are no optical images of the region in which altimetry was collected, so we used an Arecibo radar image (*8*) to correlate the profile with surface features. The MLA began ranging ~1 min before the spacecraft's closest approach and continued for ~10 min. Usable returns were received up to an altitude of 1500 km, which was larger than the expected maximum of 1200 km (*2*). As the spacecraft velocity and range from Mercury changed during the flyby, the size of laser spots on the surface varied from 23 to 134 m and the shot spacing varied from 888 to 725 m (*9*). The vertical precision varied with the received signal strength and is <15 cm at the closest range, limited by the resolution of the timing electronics. The radial accuracy of ~100 m is limited by uncertainties in the trajectory associated with errors in the ephemerides of MESSENGER and Mercury.

The profile spans ~20% of the circumference of the planet and shows a 5.2-km dynamic range of topography and 930-m root-mean-square (RMS) roughness (Fig. 1). The radius of Mercury apparently decreases by 1.4 km along the equator from ~10° to 90° E, corresponding to a 0.02° downward slope to the east. This long-wavelength surface tilt begins 30° west of the previously estimated COF/COM offset (*6*) and was not sampled in Earth-based radar altimetry (*4*). Such a long-wavelength slope, if a fundamental feature of the equatorial shape of the planet, might arise from crustal thickness or crustal density variations, global-scale mantle density variations, or topography along the planet's core-mantle boundary, which for Mercury is ~600 km beneath the surface.

The slope can be interpreted in the context of an ellipsoidal planetary shape (*10*). If we suppose that the difference in principal moments of inertia, $B - A$, is entirely a result of an ellipsoidal distribution of surface mass with density ρ_s and with semi-axes $a > b > c$, then

$$B - A = \frac{4\pi\rho_s abc}{15}(a^2 - b^2) \approx \frac{8\pi\rho_s R^4}{15}(a - b) \quad (1)$$

from which we may write

$$a - b = \frac{5}{2}R\left(\frac{B-A}{C_m}\right)\left(\frac{C_m}{C}\right)\left(\frac{C}{MR^2}\right)\frac{\langle\rho\rangle}{\rho_s} \quad (2)$$

where $A < B < C$ are the principal moments of inertia of Mercury, C_m is the moment of inertia of the mantle and crust alone, and M,

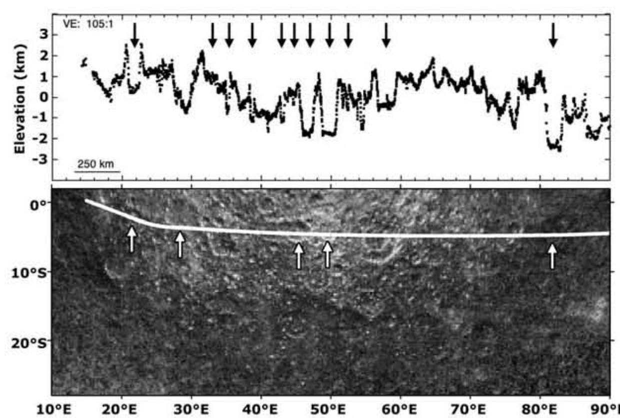


Fig. 1. (**Top**) MLA profile (vertical exaggeration 105:1). (**Bottom**) Arecibo radar image [adapted from (*8*)] with MLA profile location (white line) superposed. Arrows at top indicate locations of craters in Table 1 interpreted from detailed analysis of MLA profile points. The locations of several of the major craters are indicated by arrows on the radar image. The two-ringed circular structure in the Arecibo image at ~55 to 60°E is represented in part by a deep depression in the altimetry, but north-south radar ambiguities may be contributing to the structure in the image.

[1]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139–4307, USA. [2]Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA. [3]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA. [4]Southwest Research Institute, Boulder, CO 80302, USA. [5]Department of Physics, University of California, Santa Barbara, CA 93106, USA. [6]Department of Geological Sciences, Brown University, Providence, RI 02912, USA. [7]Department of Geological Sciences, Case Western Reserve University, Cleveland, OH 44106, USA. [8]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA. [9]Institute of Planetary Research, German Aerospace Center (DLR), Berlin, D-12489 Germany. [10]National Astronomy and Ionosphere Center, Arecibo Observatory, Arecibo 00612, Puerto Rico.

*To whom correspondence should be addressed. E-mail: zuber@mit.edu

Lunar Reconnaissance Orbiter
NASA Goddard Space Flight Center

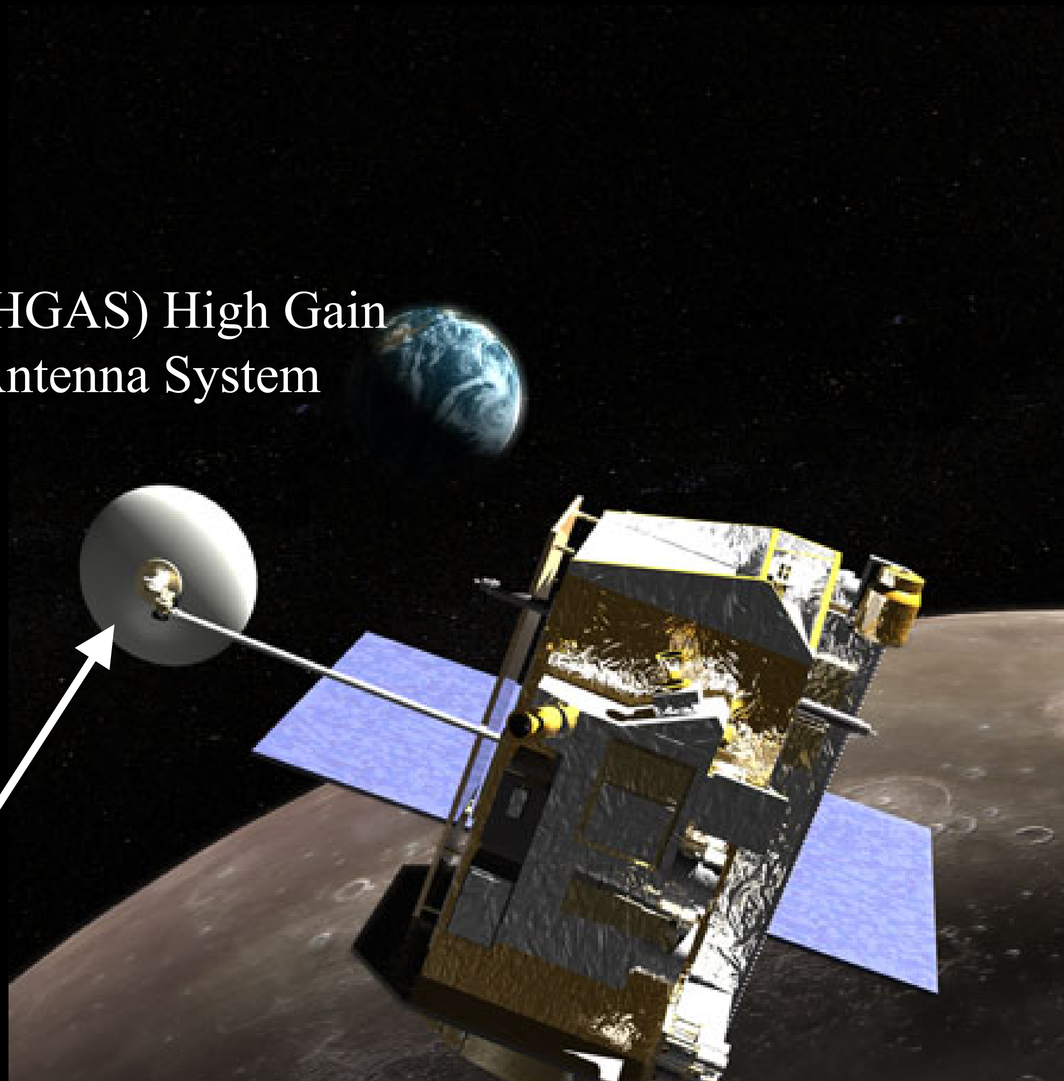
The Concept Challenges:

1) LOLA; For the Lunar Orbiter Laser Altimeter (LOLA) Reduce size and weight of previous MLA hardware design from four telescopes into one telescope with fiber based array in a precise compressed pattern.

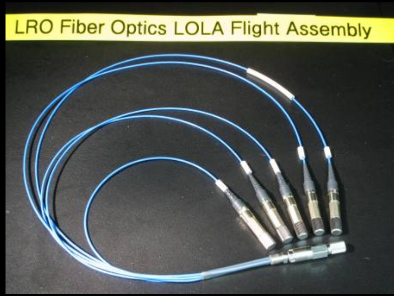
2) LASER RANGING; F or the Laser Ranging Application from Earth,
- **carry the signal from the telescope located on the High Gain Antenna system (HGAS)**
- **Traverse three subsystems, to given detector on LOLA, with high reliability and compactness**
- **Several interconnections would have to be accommodated for integration subsystem ease.**

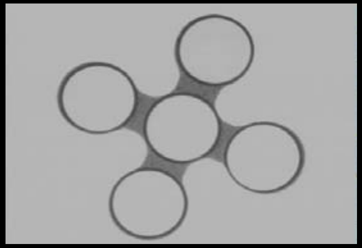
The Lunar Reconnaissance Orbiter; The Laser Ranging Mission and the Lunar Orbiter Laser Altimeter

(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)

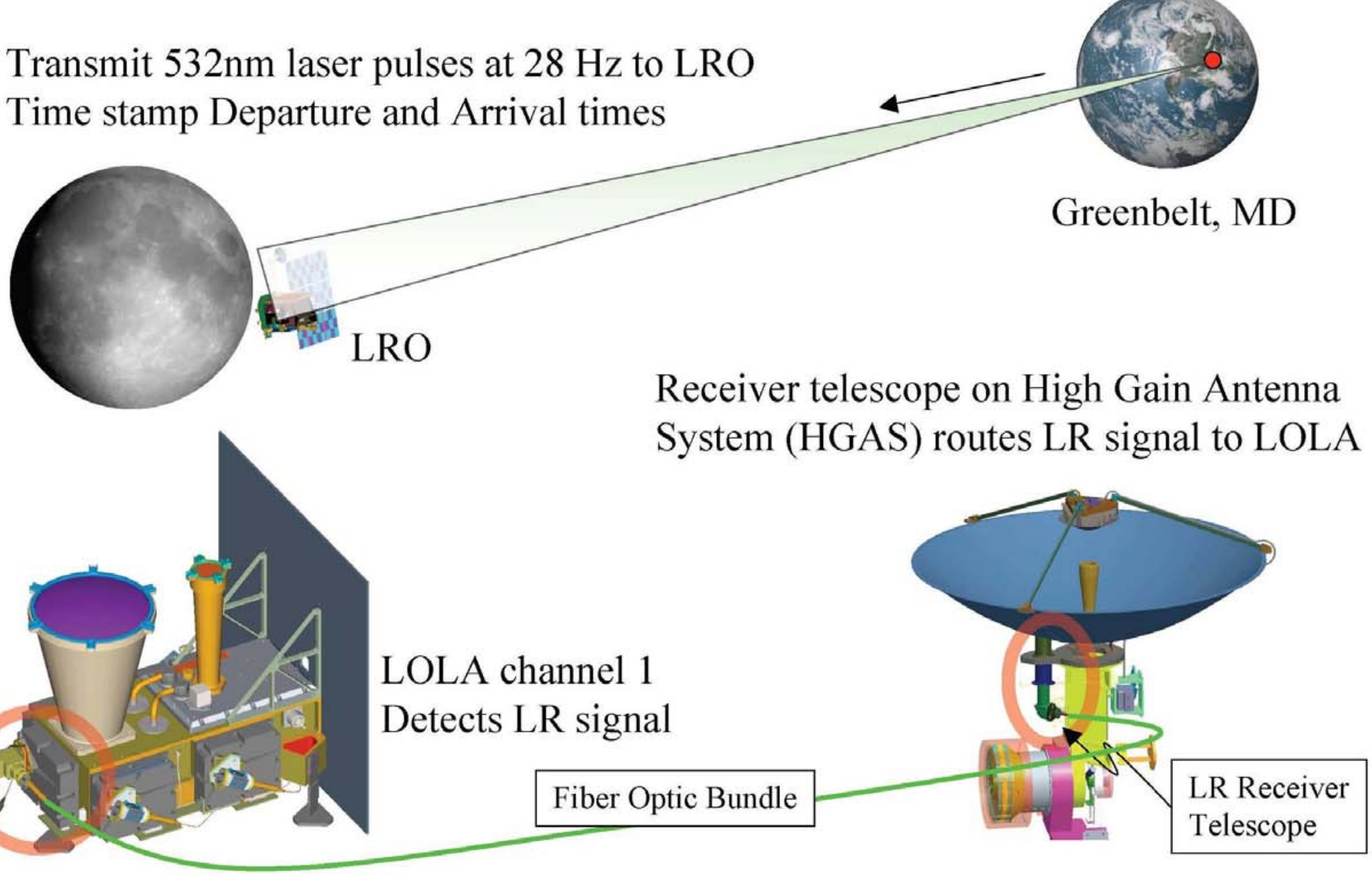
Resulting Products Overview

1. Relative range measurements to LRO spacecraft at <10cm precision at 1 Hz

2. Gravity model with sufficient accuracy to calculate knowledge of spacecraft position to within 50 m along track, 50 m cross track, and 1 m radial
    - Requires LR Ranges, S-band tracking data and LOLA Science data

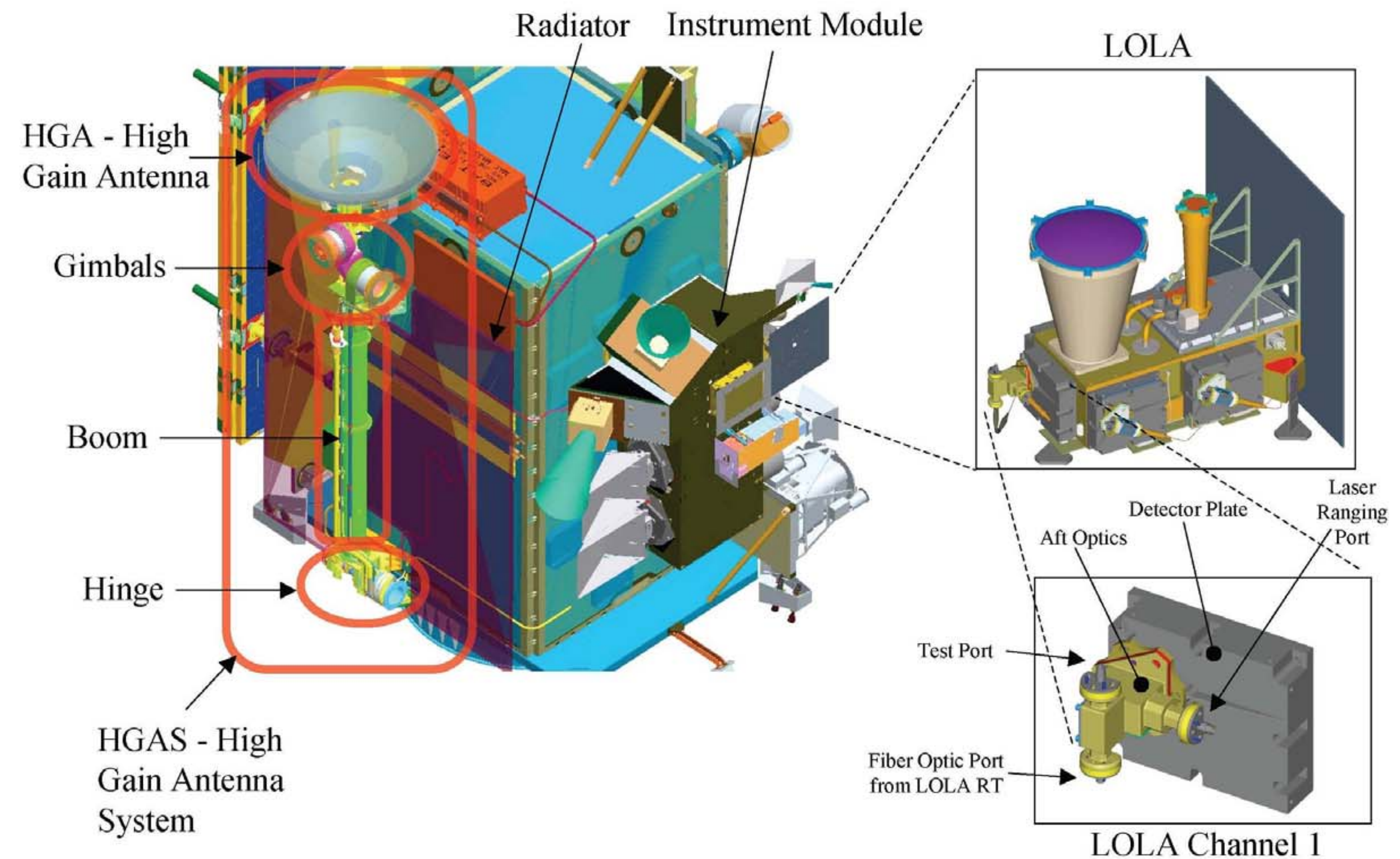
LR Operations Overview

- Transmit 532nm laser pulses at 28 Hz to LRO
- Time stamp Departure and Arrival times



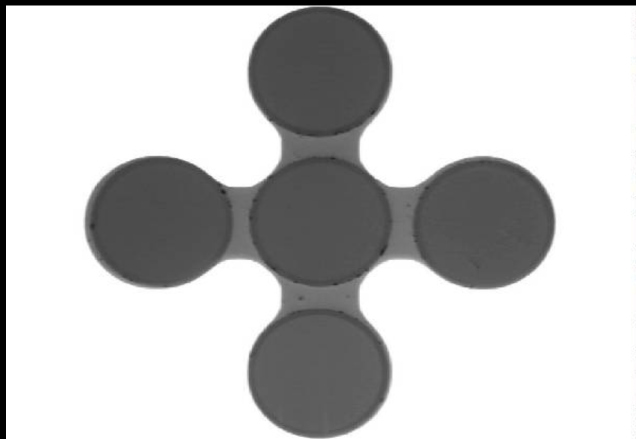
R.Zellar/Sep2006

LR Flight System Components



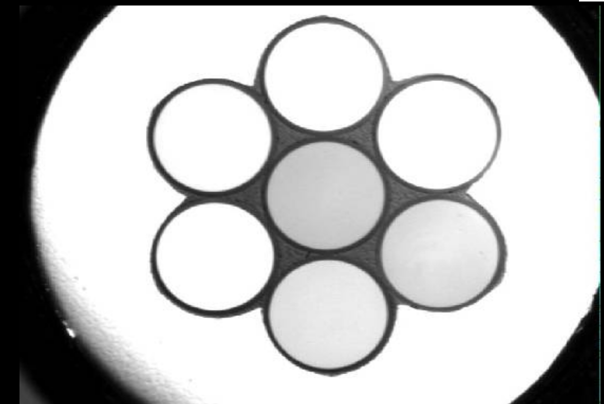
R.Zellar/Sep2006

The Solution; NASA GSFC Fiber Optic Array Assemblies for the Lunar Reconnaissance Orbiter



Array Side End Face Picture at 200X magnification

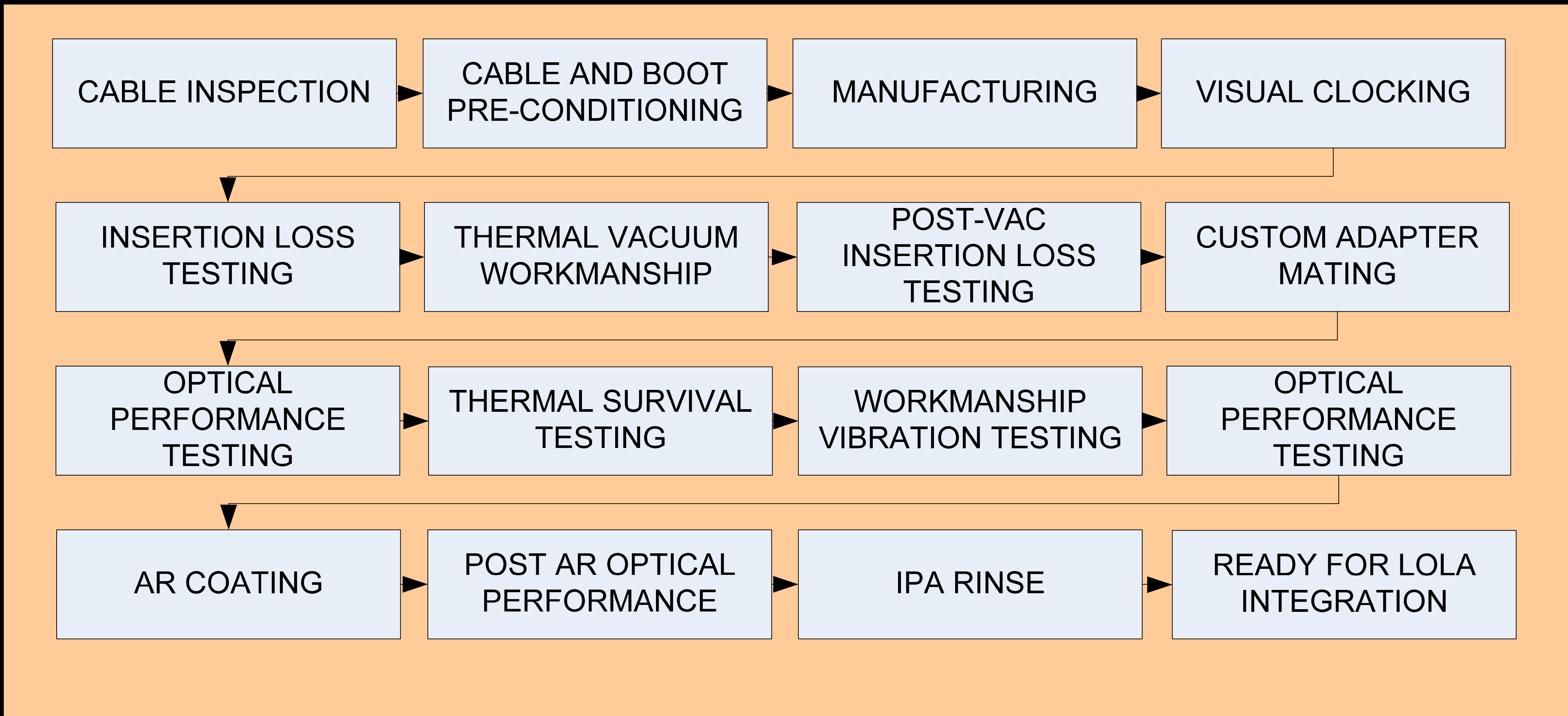
Lunar Orbiter Laser Altimeter (LOLA) Assemblies
Description: 5 Fiber Array in AVIM PM on Side A, Fan out to 5 individual AVIM connectors Side B
Wavelength: 1064 nm
Quantity ~ 3 Assemblies Max ~ 0.5 m long



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

LOLA Assembly Flight Flow



LOLA Documentation for Configuration Management

Document Name	CM Documentation Number
LOLA Fiber Optic Flight Assemblies	LOLA-OPTICS-WOA-0338
Thermal pre-conditioning on Flexlite 200/220 μm fibers for flight application	562-PHOT-WI-LOLA-TP-001
Preconditioning Procedure for AVIM Hytrel Boots for LOLA fiber optic assemblies	562-PHOT-WI-LOLA-VAC-001
Procedure for Diamond AVIMS PM Kit Pre-Assemble Inspection	LOLA-PROC-0104
Assembly and Termination Procedure for the Lunar Orbiter Laser Altimeter Five Fiber Custom PM Diamond® AVIM Array Connector for the Lunar Reconnaissance Orbiter	LOLA-PROC-0098
Insertion Loss Measurement Procedure For LOLA 5-Fiber Assembly (Open Beam Configuration)	562-PHOT-WI-LOLA-IL-001
Integration of the LOLA Fiber Optic Bundle to the Telescope Adapter	LOLA-PROC-0140
LOLA Fiber Bundle Inspection and Test Procedure	LOLA-PROC-0099

Laser Ranging on Lunar Recon Orbiter 2006-2008

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 assemblies	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

Qualification Testing on Engineering Models

- **Array Compression Testing.**
- **Thermal Vacuum Workmanship Testing, 8 cycles**
- **Vibration Launch Conditions.**
- **Thermal Cycling with Active Monitoring (accelerated life)**
- **Cold Gimbal Motion Testing,**
  20,000 Mechanical Cycles with Active Monitoring
- **Gimbal Life Testing, 20,000 Motion Cycles.**
- **Gamma Radiation Testing with Active Monitoring.**

Qualification Testing on Flight Models

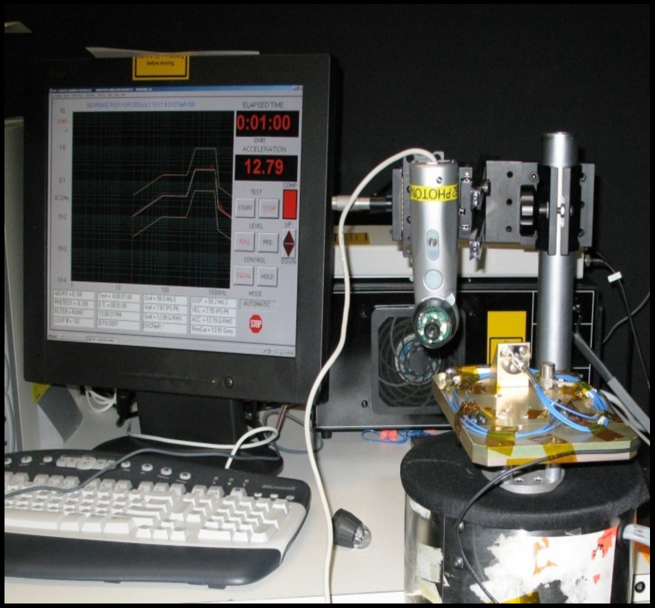
Array Compression Testing.
Thermal Vacuum Workmanship Testing, 8 cycles.
Vibration Launch Conditions, Instrument Levels.

Qualification of Engineering Models

Random Vibration Testing for EMs

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

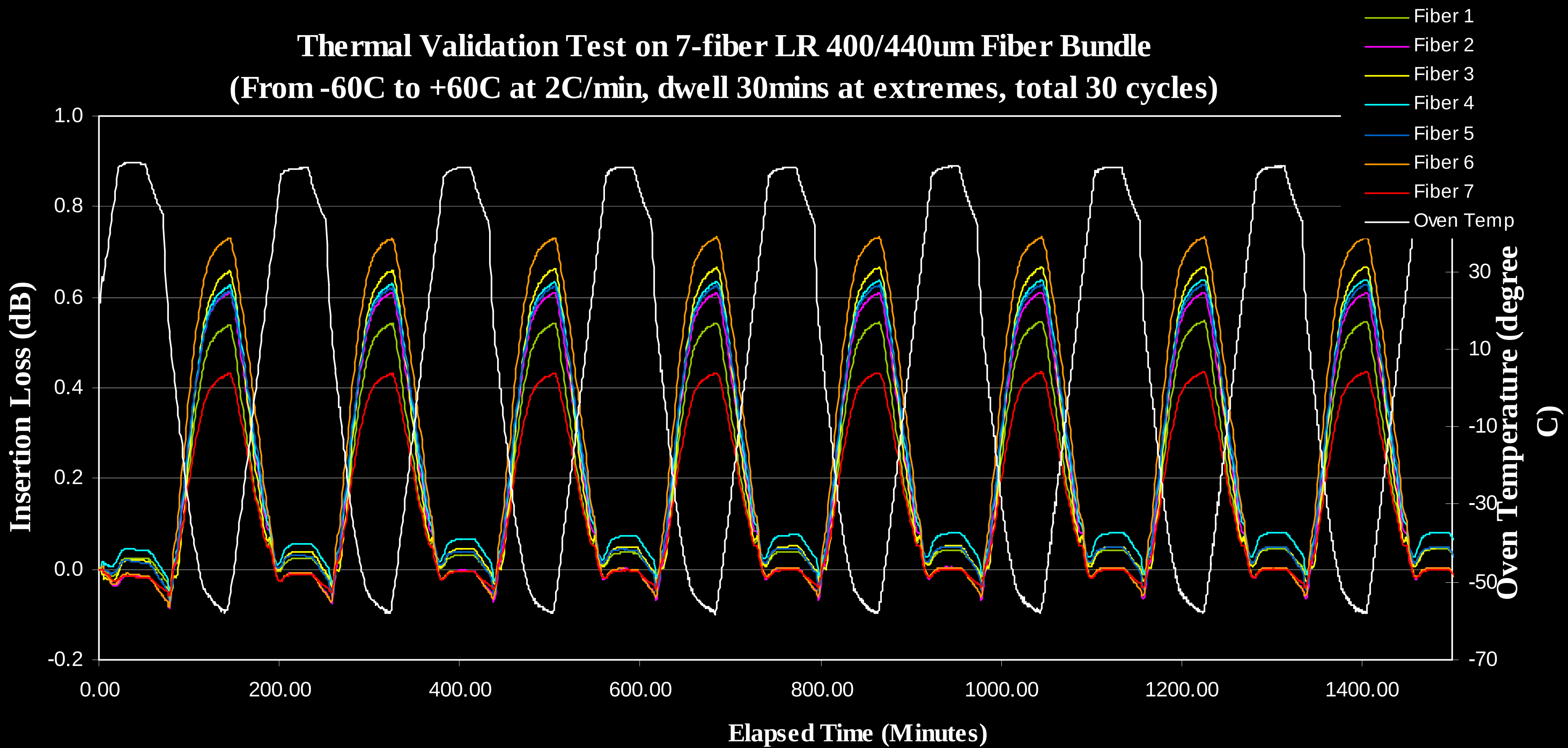
Frequency (Hz)	Protoflight Level
20	0.052 g^2/Hz
20-50	+6 dB/octave
50-800	0.32 g^2/Hz
800-2000	-6 dB/octave
2000	0.052 g^2/Hz
Overall	20.0 grms



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

Both LR and LOLA Assemblies

Thermal Qualification Data on Laser Ranging Optical Assemblies



LRO Laser Ranging Cold Gimbal Motion Life Testing

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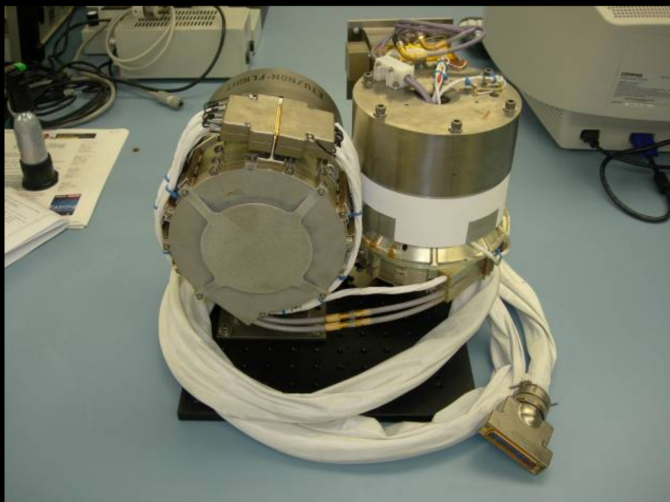
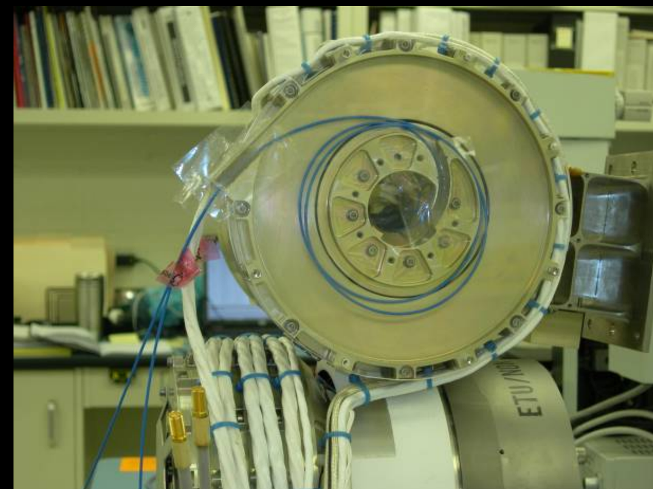
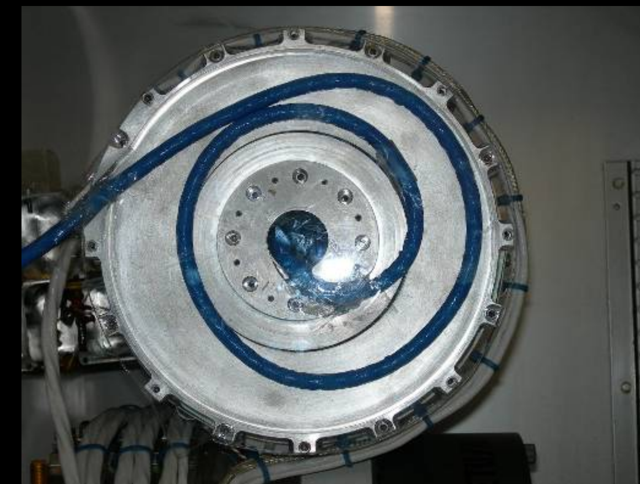


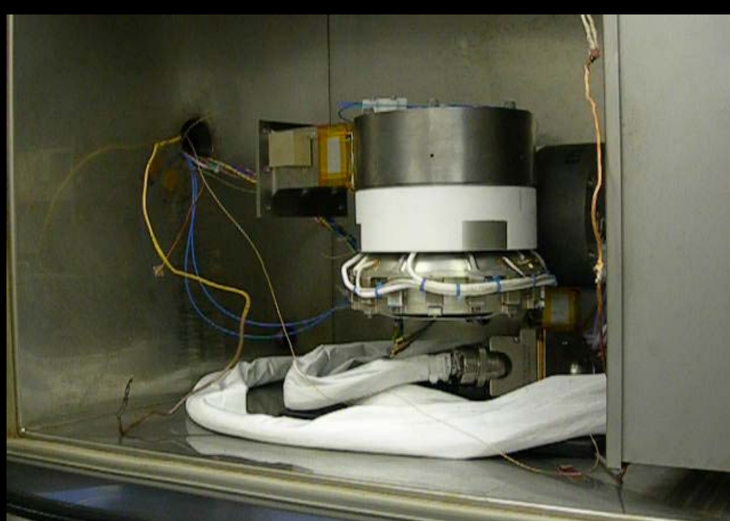
Gimbals



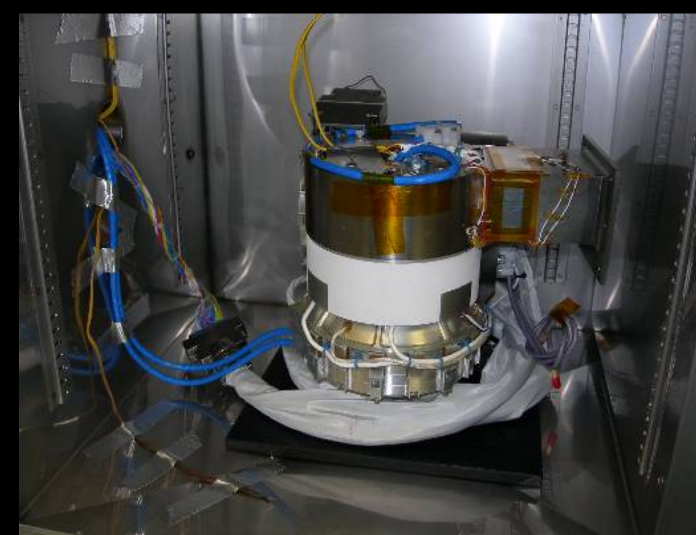
Window inside gimbal;
Flexlite cable inside



Window inside gimbal;
Bundle cable inside.



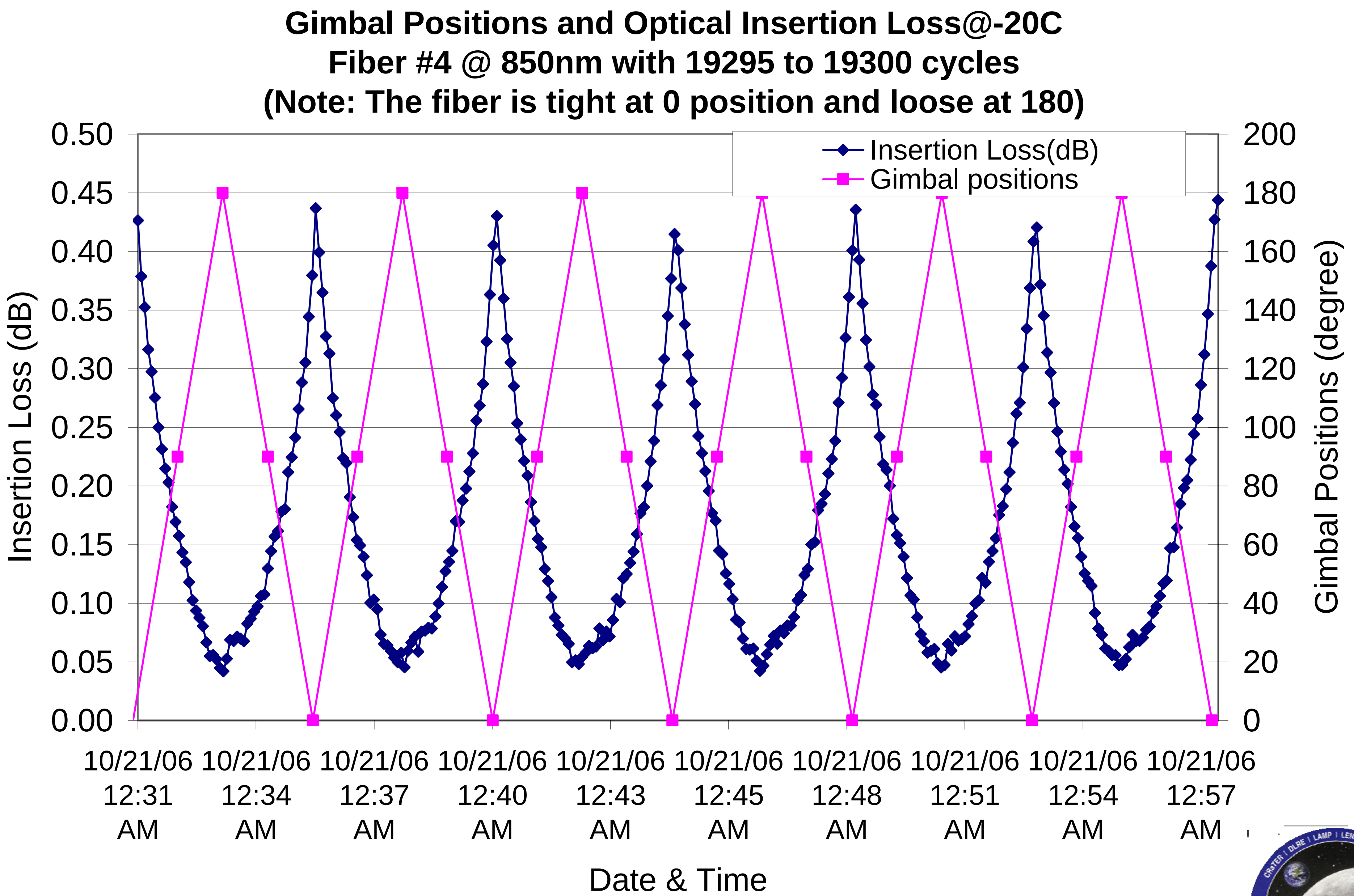
Gimbals w/ single flexlite in thermal chamber



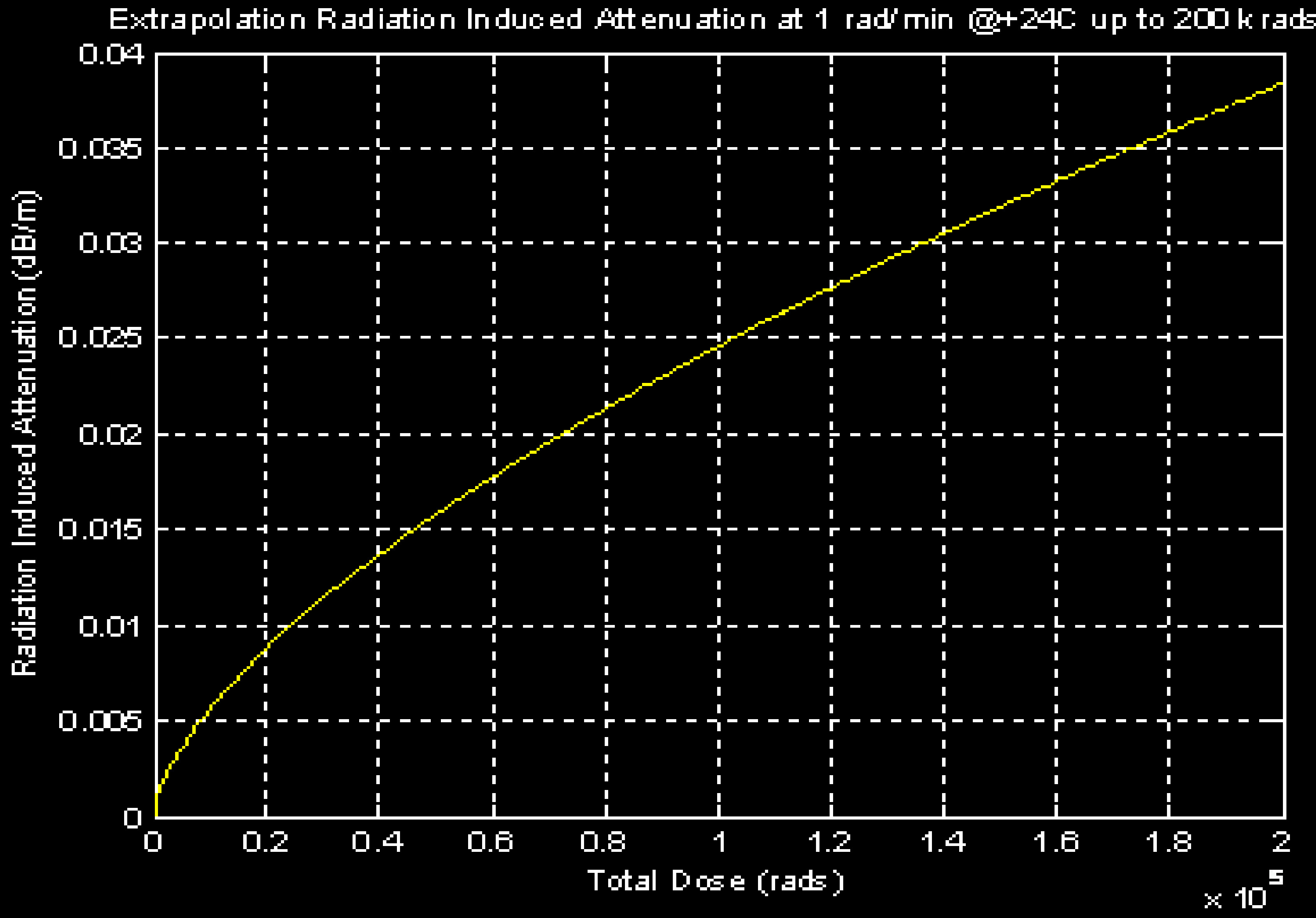
Gimbals w/ bundle in thermal chamber

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

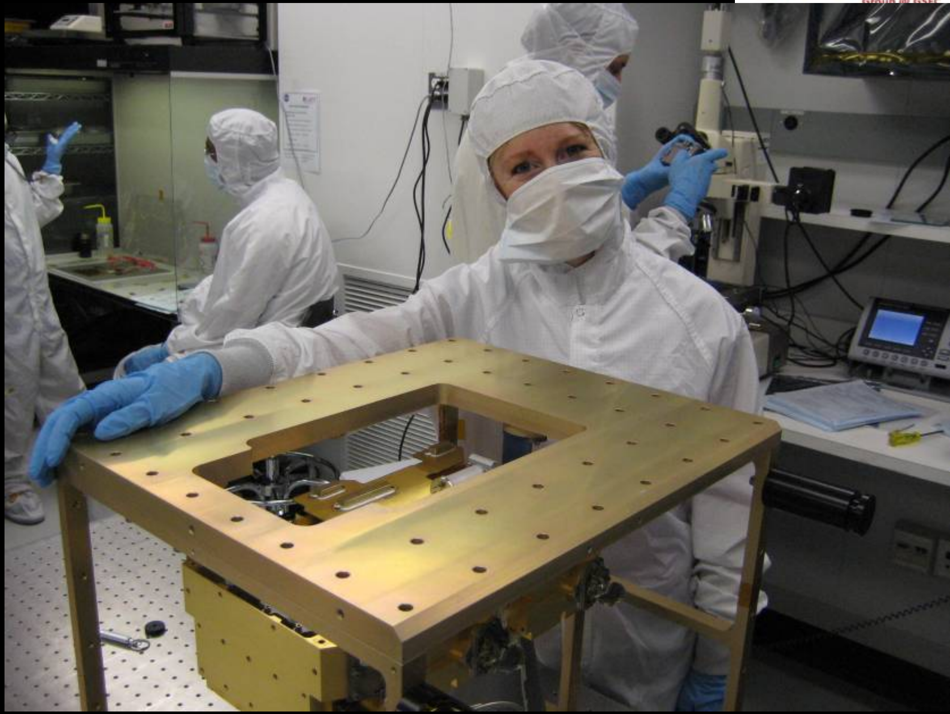


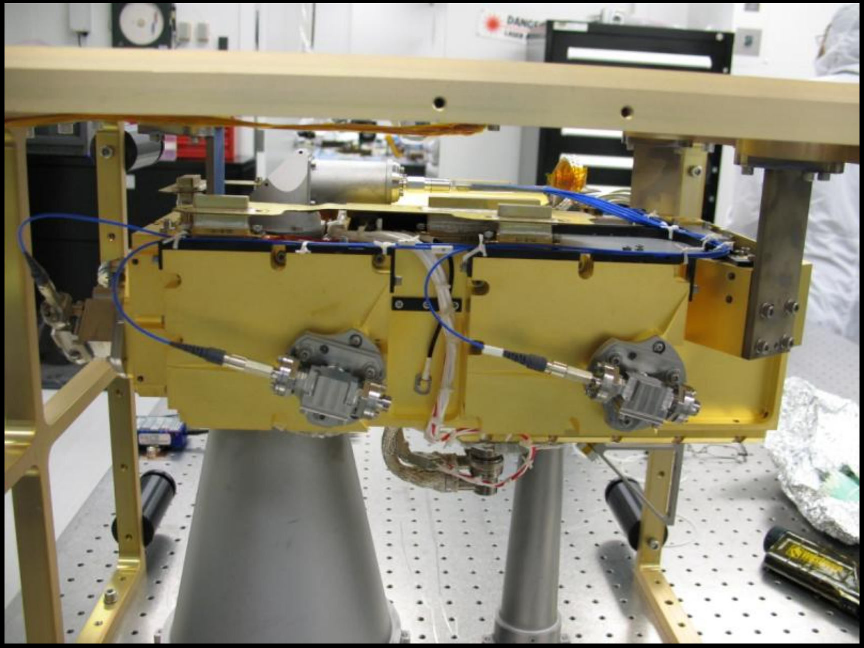
Radiation Testing and Modeling

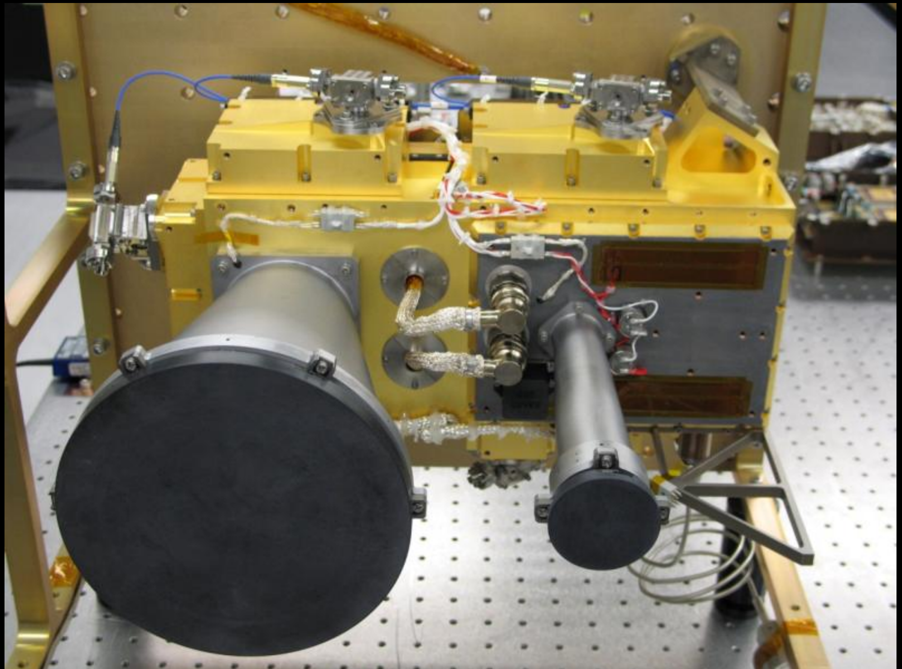


$$A(D) = 1.4516 * 10^{-4} \phi^{1-0.6412} D^{0.6412}$$

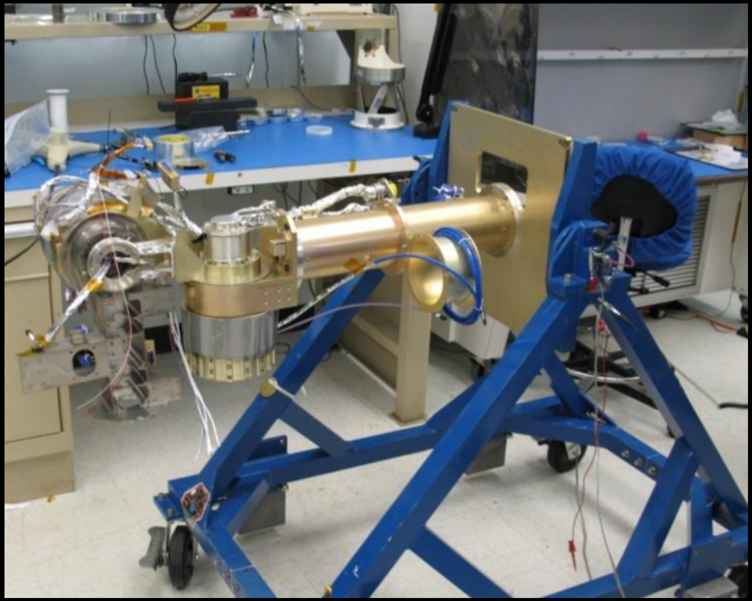
LOLA Integration, October 2007

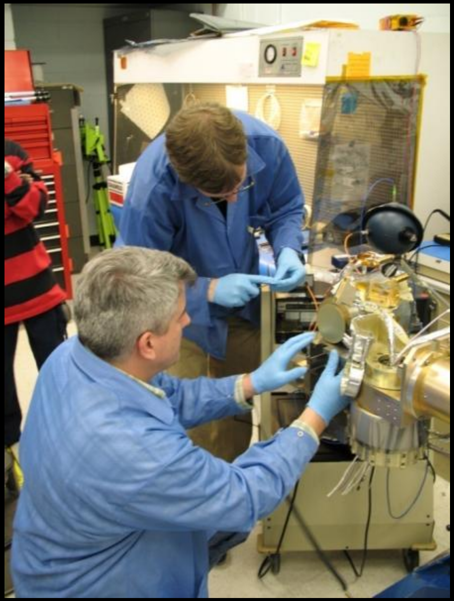






Gimbal Integration, December 2007

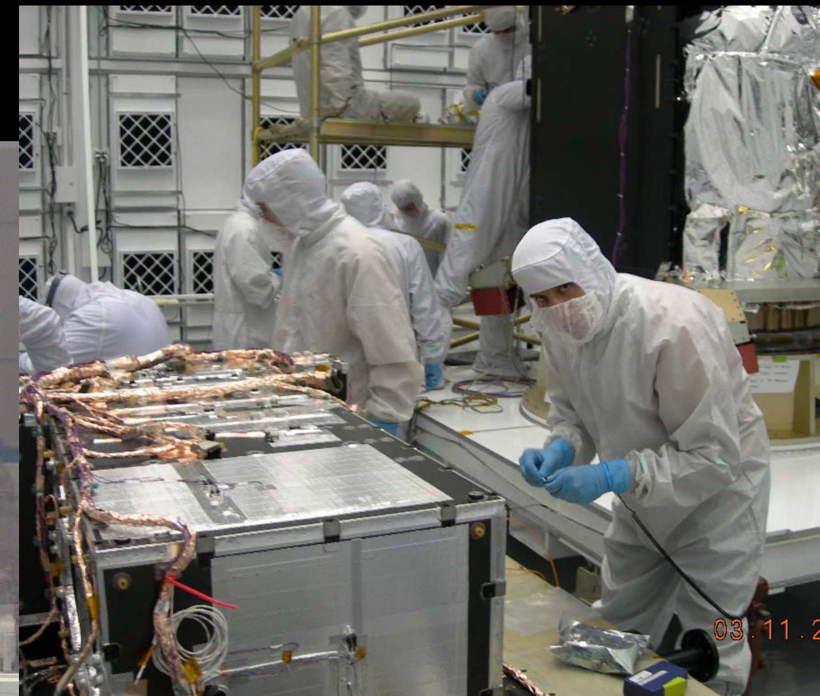


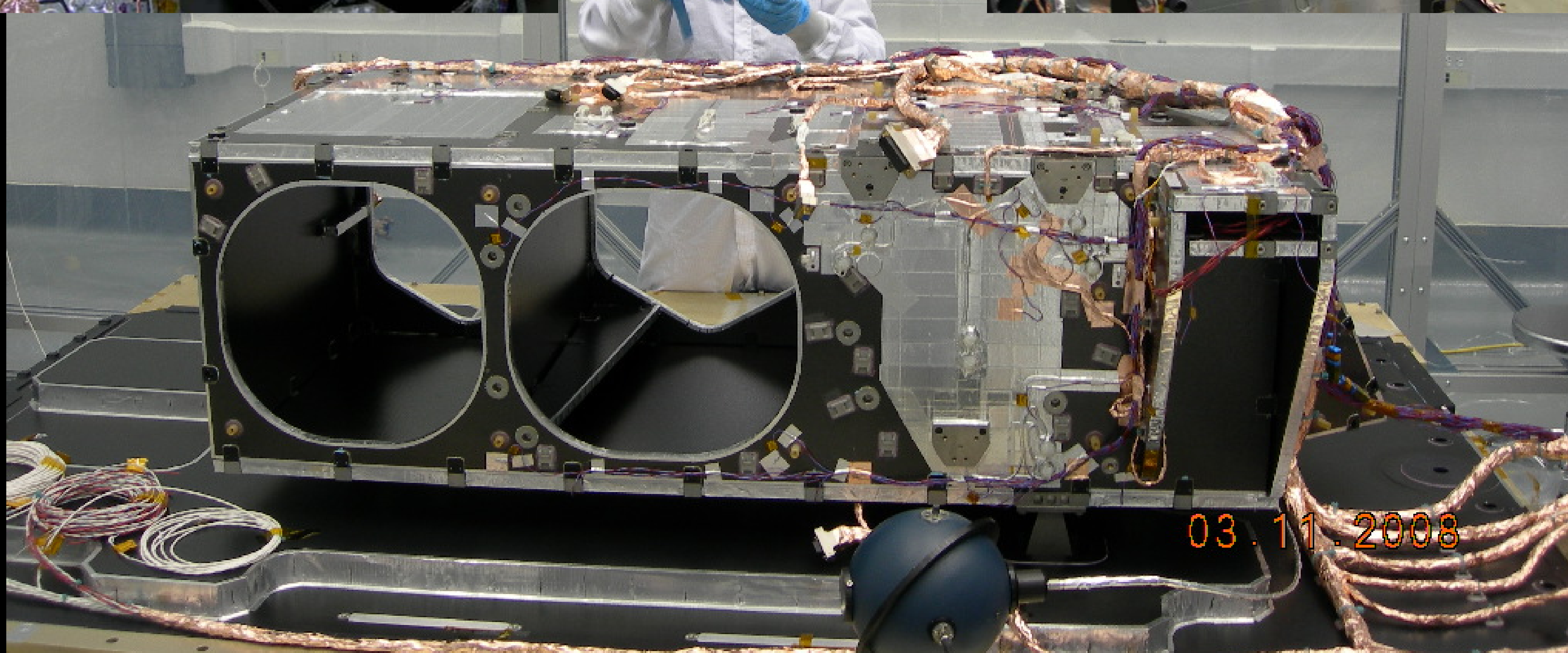


LRO Integration HGAS, 02-2008

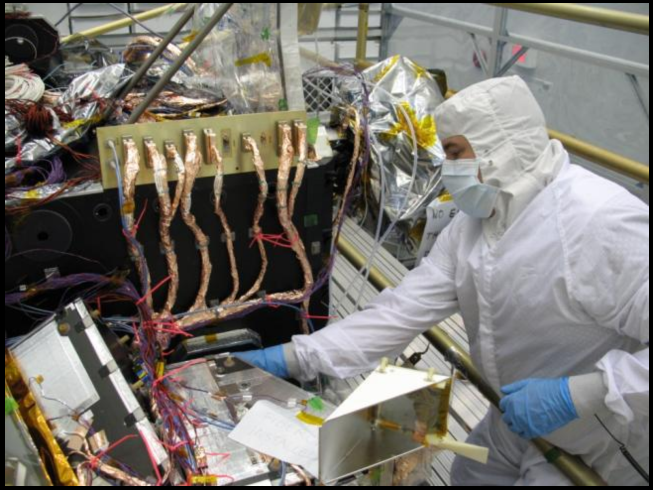
Lunar Recon. Orbiter - LRT & HGAS, 02-2008

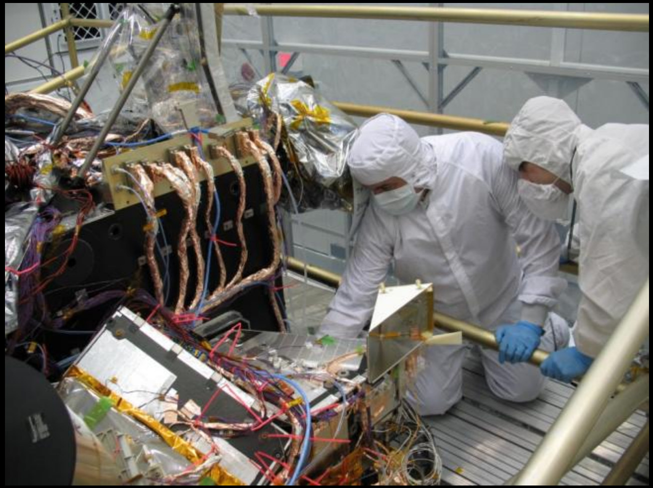
LRO Integration @ IM Deck, 03-2008



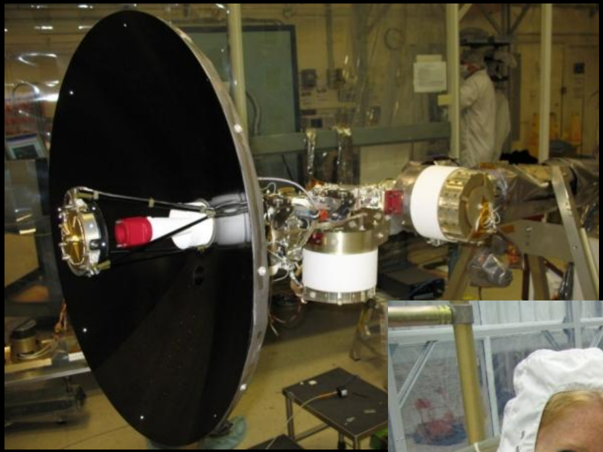


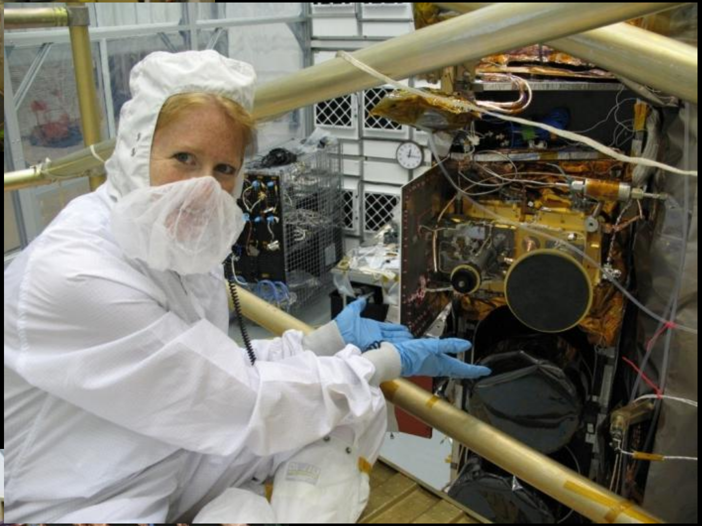
LR Segment 3 Flight Routing, April 2008

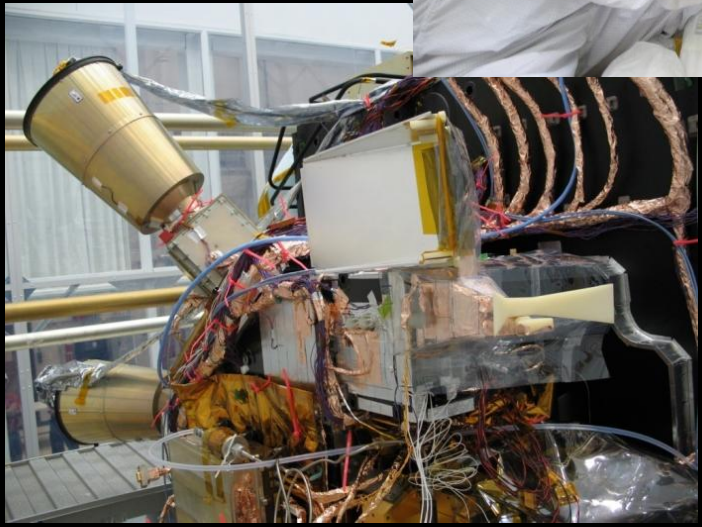


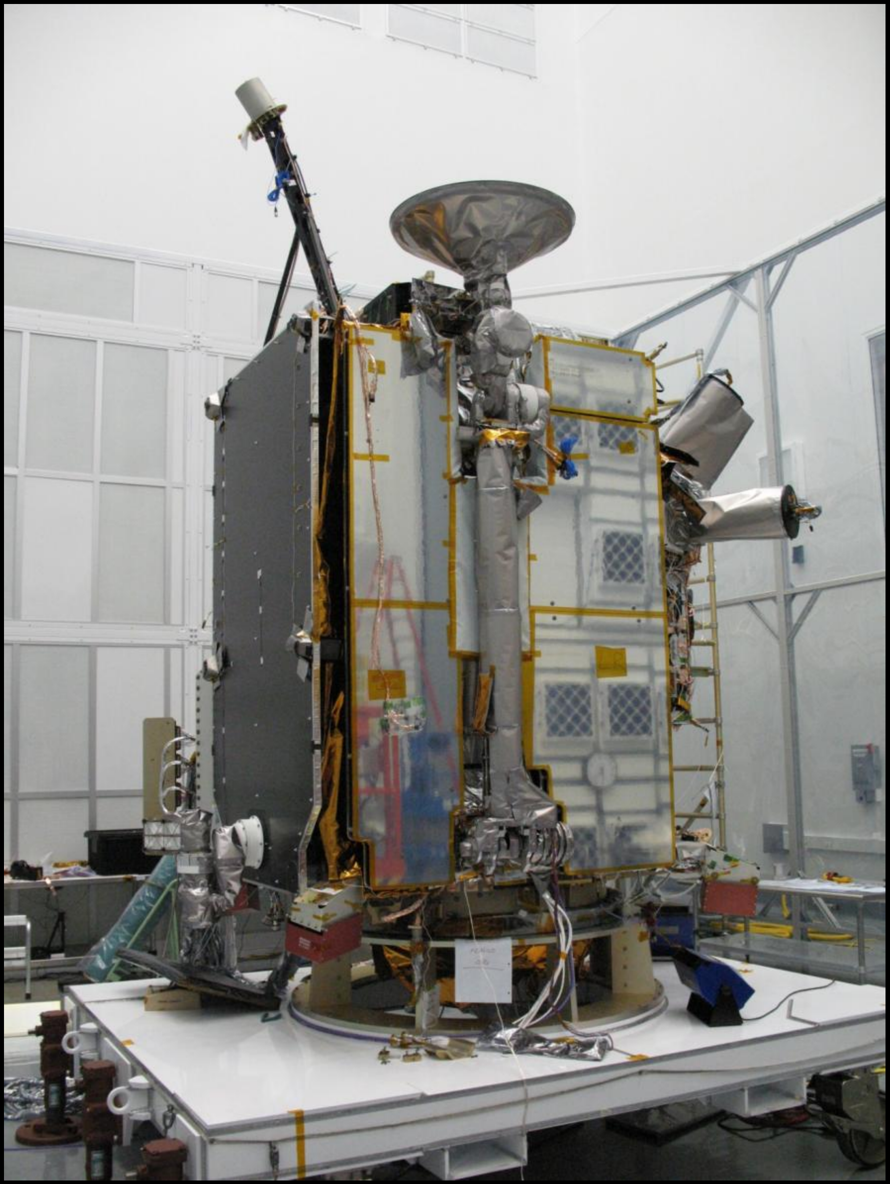


Additional Pictures of LRO, June 2008
Integration Complete



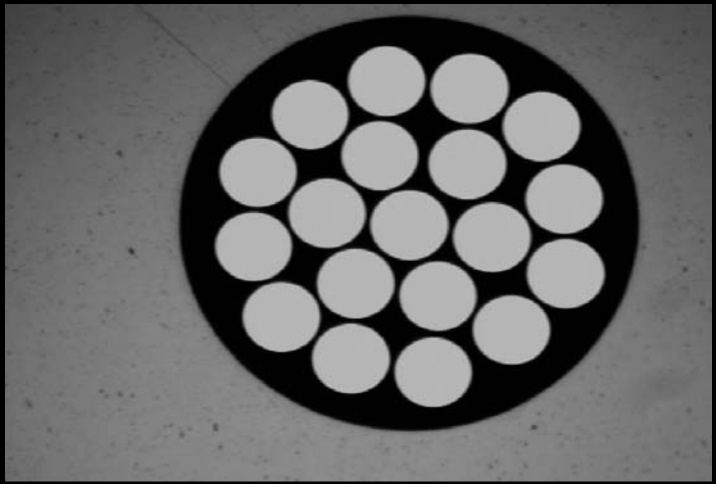






LOLA Instrument Team
“It Takes a Village”

2008 New Capability
19 Fiber Arrays with Linear to Bundle Mapping



Conclusion

Do Not Go Where the Path May Lead,
Go Instead Where There Is No Path
and Leave a Trail….

- Ralph Waldo Emerson

Thank you
for the invitation!

For more information please visit the website:

misspiggy.gsfc.nasa.gov/photonics
NEPP.nasa.gov