Functional Organization of GSFC Tasks

- **One Micron Laser Architecture**
  - Oscillator Theory
  - Oscillator Development
  - Amplifier Development
  - Thermal Management
  - Mechanical Tolerances and Packaging
  - Electronics
  - Laser Seeder
- **High Power Laser Diode Arrays**
  - Laser Diode Testing
- **Environmental Effects**
  - Gas Phase Contamination
  - Contamination Mechanisms
  - Radiation Testing
- **Frequency Conversion & Nonlinear Materials**
  - OPO Development for Ozone LIDAR
  - OPO Development for CO₂ LIDAR
  - Nonlinear Materials Life Test
- **Detectors**
  - Low Noise APD development
- **Knowledge Capture and Management**
  - Mechanical Mounts Database
  - Knowledge Database Development
Earth Sciences Application Foci

2 Lasers, 4 Techniques, 6 Priority Measurements

Pulsed Laser Development

2.05 micron

Doppler Lidar: Coherent Ocean/River Surface Currents

2.05 micron

Doppler Lidar: Wind Coherent Winds

0.355 micron

Altimetry: Surface Mapping, Oceanography

DIAL: CO₂ Backscatter Lidar: Aerosols/Clouds

Backscatter Lidar: Aerosols/Clouds

Risk Factors addressed by GSFC Tasks

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Overview of Tasks
Thermal Management

Conductively Cooled Amp

Spray Cooling

Objective

Develop robust techniques for management of 100W space-based laser systems, with 2500 W of thermal heat load.

Approach

Develop/scale-up innovative technologies and demonstrate compatibility with space mission

- CPLs and LHPs
- Spray Cooling
- Electrohydrodynamics
- Vapor Compression Systems

Schedule and Deliverables

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<tr>
<th>FY03</th>
<th>FY04</th>
<th>FY05</th>
<th>FY06</th>
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<tbody>
<tr>
<td>Develop requirements</td>
<td>Select approaches &amp; begin dev.</td>
<td>Complete scale-up to 1J</td>
<td>Demonstrate Performance</td>
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</table>

Applicability

Broad applicability to high-power laser systems intended for deployment in space.

Co-Is/Partners

- Lou Fantana, Jeff Dodson, Eric Silk, GSFC
- JPL, University of MD, Office of Naval Research (ONR),
- Illinois Institute of Technology, Wright-Patterson Air Force Base, Swales

Instruments

Active Optical

Diode Laser-Based Injection Seeder

Objective

High power, Q-switched lasers must be injection seeded to guarantee single mode operation, thereby eliminating optical damage due to multi-longitudinal mode beating. A compact, efficient, single frequency, stabilized diode laser is being developed as a seed laser that can be readily configured for altimetry, wind and molecular lidar applications.

Accomplishments

Prototype seeder units have demonstrated 400-kHz linewidth operation.

1st prototype in use to identify seeding variables.

2nd prototype is currently being assembled, mechanical design for flight qualification in progress.

Schedule and Deliverables

- 1st prototype for preliminary injection seeding of HOMER received (3/03)
- 2nd prototype with PM fiber-coupled, ultra-stable design delivered (10/03)
- Mechanical design for flight qualified use complete (9/03)

Projected Infusion

Incorporation into 1-micron testbed.

Instruments

Active Optical
Determination of Gas-phase Compounds Responsible for Lowering Damage Threshold of Optics in Sealed Lasers

**Objective**

Determine remediation procedure for "must use" compounds that present concerns.
Determine mechanism of damage.
Provide input for computational effort.

**Approach**

Compile database of compounds of concern which reduce optical damage threshold. Include parameters of concentration/film thickness, wavelength, atmosphere. Perform tests to validate computational results.

**Schedule and Deliverables**

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<tr>
<th>OEF</th>
<th>FY03</th>
<th>FY04</th>
<th>FY05</th>
<th>FY06</th>
<th>FY07</th>
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<tr>
<td>SOF</td>
<td>1064 nm Measurements</td>
<td>532 nm Measurements</td>
<td>355 nm Measurements</td>
<td>Computational Effort</td>
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</table>

**Applicability**

Broad applicability to optical materials intended for deployment in space.

InGaAs-on-Si APD

**Photon Counting Detectors for the 1-2 Micron Wavelength Range**

**Objective**

Optical detectors with photon counting sensitivity over the 1.0 - 2.0 micron wavelength range:
- Quantum efficiency: 10 - 70%
- Detector size: 200 mm diameter
- Dark counts: < 100 kcps

Solid State APD: InGaAs photocathode, silicon or InAlAs avalanche region.

**Approach**

Most commercial InGaAs APDs are grown on indium phosphide (InP) substrates. To access improved noise performance it will be necessary to investigate alternative substrate materials. This task will procure InGaAs-Si APDs from Nova Crystals and InGaAs-InAlAs APDs from Spectrolab and conduct photon counting experiments at low temperature.

**Schedule and Deliverables**

- Nov. 2003 - 1st gen InGaAs-InAlAs APD mfg. & t.e.
- Mar. 2004 - 1st gen InGaAs-Si APD mfg. & t.e.
- Jul. 2004 - 2nd gen InGaAs-InAlAs APD mfg. & t.e.
- Sep. 2004 - 2nd gen InGaAs-Si APD mfg. & t.e.

**Applicability**

Optical instruments operating in the 1-2 micron wavelength range.

InGaAs-on-Si APD
Optomechanical Mounts

Objective
Provide the LRRP with an informative collection of laser mount designs. Provide engineers with multiple options/solutions to choose from for different laser configurations.

Approach
Conduct a study of several flight laser instruments to develop a database of different optomechanical mounts that have been used for mounting the various components of the lasers. Document any issues/problems found with previous laser optomechanical mounts. Develop new concepts and/or suggest improvements on previous laser mount designs.

Co-I's/Partners
Armando Morell, James Marsh, William Mamakos, GSFC
LaRC, Industry

Schedule and Deliverables

Applicability
Optomechanical mounting systems are a critical part of all laser instruments.

High Power, Narrowband, Infrared OPO

Objective
Develop and demonstrate efficient non-linear optics technologies for the conversion of 1-micron pump laser light into tunable IR wavelengths suitable for profiling CO$_2$ at very high precision (0.3%) from ground and space. Develop and demonstrate narrow time averaged linewidth for IR optical parametric oscillator.

Approach
Apply optical parametric conversion techniques to downshift 1-micron radiation into the 1.57-micron CO$_2$ sounding band.

Co-I's/Partners
Dale Richter, ITT

Schedule and Deliverables

Applicability
High precision measurement of CO$_2$ from ground and space.
Environmental Effects on Optical Mat'l's (FY07 220K$)

PI: Brad Boone JHU-APL

Objective

- Identify and test compounds used in the assembly of space-based lasers that may result in or cause laser induced optical damage.
- Evaluate radiation effects of laser diode arrays and nonlinear crystals to determine their reliability and suitability in the space environment for extended missions.

Approach

- Measure the effect of beta (Cobalt 60) and proton exposure on nonlinear optical materials.
- Measure intrinsic differences in performance of non-linear optical materials.

Co-Is/Partners

- Matthew Bevan, JHU-APL
- Galina Malivichko, Mont St

Key Accomplishments/Milestones

- FY06 Conduct proton testing on "G" style laser diode package.
- FY06 Complete laser damage testing of original series of sample compounds.
- FY06 GC-MS measurements of space materials.
- FY07 evaluate non-linear material performance and correlate with differences in ENDOR spectra

TRL = 3/4

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Lifetime and Efficiency Studies of Nonlinear Optics Materials

Edward Dowdye, NASA GSFC

Objective

Many lidar applications require coherent light at a wavelength other than 1.0 micron, requiring the use of nonlinear frequency conversion materials. The longevity and durability of these materials is not well understood. Our objective is to measure the operational lifetime and efficiency of various nonlinear crystals to determine their suitability for use in space.

Approach

Materials will be exposed to 1-micron laser radiation and used for frequency doubling, tripling, etc. Changes in performance as well as physical changes in the materials will be monitored.

Co-Is/Partners

Dr. Hossin A. Abdeldayem, William L. Maynard, Dr. Chris Scurlock (GSFC), Industry, Academia

Schedule and Deliverables

<table>
<thead>
<tr>
<th>FY08</th>
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<tr>
<td>Optical Bench &amp; Nd:YAG Laser Setup System Validation</td>
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Applicability

Broad applicability to optical materials and devices intended for deployment in space.
High Output Maximum Efficiency Resonator (HOMER) Development

**Objective**

Final goal is to significantly advance the state of the art for present and future laser mapping altimeters for vegetation, ice sheets and topography (earth and planetary) as well as atmospheric and wind lidars.

**Approach**

- Develop flight qualified one micron laser transmitter (LT).
- Target output energy = 100 mJ. Plan is to use this design for the oscillator stage of the 1.0 J LT.
- Final LT is to be fully environmentally tested, flight qualified and characterized.
- Parallel oscillator breadboards being built for margin, stability, and component studies.

**Schedule and Deliverables**

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<th>FY05</th>
<th>FY06</th>
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<tr>
<td>Investigate new techniques for efficiently removing contamination</td>
<td>Develop controlled test program</td>
<td>Complete test program</td>
<td>Complete final guidelines/protocols</td>
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<td>Publish guidelines/protocols</td>
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**Applicability**

Altimetry, winds, ozone.

| **TRL = 3** |

**Instruments**

Active Optical

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Oscillator Architecture Evaluation

**Objective**

Determine the state of the art of current laser oscillator architecture as it applies to space based applications.

Improve our current modeling techniques for laser oscillator design.

**Approach**

- Review current oscillator designs: GLAS, VG, MLA, MOLA, others
- Improve Modeling Techniques, add software GLAD, LasCad, OptiCad:
- Create new oscillator designs
- Breadboard and evaluate the new designs
- Incorporate results in new designs

**Schedule and Deliverables**

- Existing designs modeled & evaluated
- New models made for 5-7 mJ lasers & breadboard side pumped 6-mJ zig-zag laser constructed & being evaluated
- Breadboard end pumped laser under construction
- 100-mJ oscillator design undertaken

**Applicability**

Broad applicability to laser system architectures intended for deployment in space.

| **TRL = 3** |

**Instruments**

Active Optical
Objective

- Develop and demonstrate technologies leading to a diode-pumped 1-micron, 800 miliJoule, 50 Hz laser for space-based lidar applications.
- 100 mJ oscillator
- 40 Watt optical amplifier unit.
- Demonstrate frequency stabilization on a 1064 nm oscillator.
- Construct a 10-20 mJ laser based on the space laser heritage existing within NASA. Demonstrate the capability of that laser to perform continuously, in vacuum environment over 3 billion shots.

Approach

- Develop 1-micron, 800mJ Joule, 50 Hz "Testbed Laser". Use testbed to identify challenges to development of high average power space flight lasers. Test the design modifications which address those challenges.
- Develop 10-20 mJ "Heritage Laser" based on MOLA/GLAS/MLA flight programs. Place Heritage Laser in extended vacuum life test.

Co-Is/Partners

- Barry Coyle, GSFC 920
- Dan Krebs, GSFC 554
- Dr. R. Kay, American U.
- Alan Lukemire, SPE
- A. Rosanov/S. Chen, SSAI
- A. Nove-Gradac, GSFC 554

Key Accomplishments/Milestones

- 10/05 Amplifier integrated with 100mJ oscillator
- 1/06  350 mJ output achieved from testbed.
- 2/06 Vacuum Test Laser (Heritage Laser) operational.
- 3/06 Vacuum test started.
- 8/06 All testbed pieceparts inspected & tested.
- 8/06 Vacuum test laser reaches 0.5B shots.
- FY07 Diagnose heritage laser degradation
- FY07 Initiate further Heritage design tests
- FY07 Complete build of laser amplifier

1 Micron Testbed (FY07 670 K$)
PI: Steve Li, NASA Goddard Space Flight Center, Code 554

1 micron, 1 Joule Laser Design

Oscillator: output power = 60-100 mJ
Rep rate = 100 Hz

Injection Seeder

Isolator

Relay Imaging optics

Porro Prism

0.57 Waveplate

8 mm x 8 mm slab

18 bars array

-350 mJ

8 mm x 8 mm slab

-675 mJ

8 mm x 8 mm slab

Output

- 1 J
Heritage Laser Vacuum Test Unit: Oscillator Only

- Highly stable TEMoo operation.
- 2.7 mJ, 80Hz, 170 microsecond switchout.
- Diode current 60A (MLA = 100A)
- Stable over wide thermal range.
- Pump diodes = CEO

Switch Out Time Behavior

6-7 µs decrease in switch out time per 1A increase of diode laser current
**High-Power Laser Diode Arrays (FY07 430 K$)**

**PI:** Mark Stephen, NASA Goddard Space Flight Center, Code 554

### Objective
- Quantify effect of operational and environmental parameters on Laser Diode Array (LDA) performance.
- Develop procedures for purchasing, handling, storage and operation.
- Develop prediction/screening capability.
- Enable improved reliability and performance of future laser missions.

### Approach
- Develop complete characterization capability of LDAs to establish a baseline for individual array performance and status.
- Test LDAs under various operational and environmental conditions and measure effects.

### Key Accomplishments/Milestones
- New measurement capabilities - time-resolved thermal imaging, polarized near-field analysis, Microphotoluminescence spectroscopy.
- 1 billion pulses on LDA test measuring effects of power and temperature cycling.
- Results of proton radiation and vibration testing.
- Second generation, extended operation performance test.
- FY07 Testing of newer diode designs.

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**4-LDA Accelerated Performance Test**


This is accelerated performance test of 4 LDAs (G2 packages) to qualify two vendors (Nuvonyx (1) & Coherent (2)), observe potential problems and compare performance to assist choosing the flight vendor for LOLA mission.

Test was stopped after 4.86 billion pulses.
Space Qualifiable Fiber Lasers/Amplifiers (FY07 430 KS)
PI: Michael Krainak, NASA Goddard Space Flight Center, Code 554

Objective
To develop low-risk space-qualifiable fiber laser/amplifier technology for NASA Earth science, lunar and planetary active-remote-sensing exploration and scientific instruments.

Approach
- Leverage present capability from US DoD and telecom industry (high power fiber amps for comm) to develop space-qualifiable fiber laser and amps for NASA science & exploration applications.
- Emphasize 2 near term NASA applications:
  - Atmospheric Spectroscopy (e.g. Mars/Earth H2O, CO2 and CH4) and 3-D mapping (e.g. Moon/Mars landing sites & topography)

Co-I's/Partners
- US Commercial and Aerospace Industry:
  - Northrop-Grumman, Hughes, Lucent, IPG Photonics, Keopsys, Nufern, Aculight, Fianium

Key Accomplishments/Milestones
- 8/06 SBS model validated with experimental data and including temp and e
- 10/06 Demonstrate optimized narrow A high peak pwr Nd, Er, and Yb fiber amps.
- Evaluate units under procurement
- FY 07 Increase output power with narrow Bandpass
- FY 07 Complete model of SBS

TRL=3 (for this NASA application specific to

High Pulsed Laser for Altimetry (FY07 100K$)
PI: George B. Shaw, NASA Goddard Space Flight Center, Code 554

Objective
- Develop breadboard, high pulse rate (1-10 kHz) lasers with pulse energies greater than 750pJ for altimetry applications.
- Perform design trades of passive versus active q-switching and monolithic versus non-monolithic laser designs.
- Evaluate the new, high power fiber-coupled pump arrays that are becoming commercially available.

Approach
- Model and construct end-pumped lasers using the new fiber coupled pump arrays.
- Evaluate design limits and q-switching methods for this class of laser.
- Evaluate various design schemes to meet the desired specifications.

Co-I's/Partners
- Steven Li, GSFC 554
- Antonio Seas, GSFC 554

Key Milestones
- Beginning with 0.5 mJ 1 kHz laser:
  - Increase rep rate to 5-10 kHz
  - Increase Energy to 1.0 mJ
  - Improved beam quality
- All tasks completed by end of FY07

TRL=3
LRRP supports NASA mission opportunities

Highlights

• Over 25 publications and conference presentations. One national award, and several patents in application process.

• Many Tasks in LRRP directly or indirectly support missions recommended in the NRC Decadal Survey
  - Ice Sheet Laser Altimeter
  - Column CO2 Laser Sounder
  - Wind Lidar
Partnering with Industry and Academia

- **Industrial Partners**
  - AdvR Corporation
  - Genesis Engineering
  - ITT Advanced Engineering Systems
  - Science Systems and Applications Inc. (SSAI)
  - Space Power Electronics
  - Mantech

- **Academic Partners**
  - American University
  - Johns Hopkins University
  - Montana State University
  - University of Maryland

**Publications (1/3)**

- J. S. Canham. "Surface Analytical evaluation of contamination related laser induced damage to a TIR slab." SPIE Code 599147
Publications (2/3)


Publications (3/3)

The 1 micron legacy

Several successful missions and missions in planning have benefited from advances by the LRRP:

- Messenger Laser Altimeter
- Lunar Orbiter Laser Altimeter
- ICESAT II
- DESDYNI
- ASCENDS
- WIND LIDAR

Messenger Laser Altimeter

MLA used laser diodes whose performance was verified by LRRP protocols.

Two-Way Laser Link over Interplanetary Distance

David E. Smith,1 Maria T. Zuber,1,2 Xiaoli Sun,1 Gregory A. Neumann,1,2 John F. Cavanaugh,1 Jan F. McGarry,1 Thomas W. Zagwodzki1

Here we report timed observations with subnanosecond precision of short laser pulses at a distance of nearly 24 million kilometers between the Mercury Laser Altimeter (MLA) aboard the MESSENGER (MErcury Surface, Space ENvironment, GEOchemistry, and Ranging) spacecraft and the NASA Goddard Geophysical and Astronomical Observatory (GGAO). Forty MLA downlink observations and 90 uplink observations were obtained during observing sessions on 27 and 31 May 2005. Precise standard ground timing allowed a solution for spacecraft range, range rate, and acceleration, as well as clock bias. This experiment established a new distance record for laser detection and accomplished a two-way laser link at an interplanetary distance.
LOLA was designed, built, and flown in record time because of knowledge gained in LRRP.

We Have Learned a Lot about Diodes

- >6 years diode life testing
- Diode design improvements
- Established working group with vendors
- Diagnostic tests for acceptance
- Radiation tolerance is excellent
- Knowledge base for other NASA programs
We Have Learned a Lot about non-Linear Materials

Developed new robust OPO's and OPA's
Examined radiation damage and observed self healing
Consulted with other NASA programs on crystal degradation
Uncovered new diagnostics for material quality

We Have Learned a Lot about Contamination

Some commonly used cleaning solvents enhance laser damage
Some commonly use adhesives enhance laser damage
Presence of oxygen in laser container can reduce risk
Developed comprehensive diagnostics to evaluate damage when it occurs
Consultant to other NASA programs
We Have Learned a Lot about Wavelength Control

- Supported development of new low cost solid state seeder
- Developmental work on seeding techniques for space
- Seeding reduces risk of laser damage

We Have Learned a Lot about Laser Design

- Developed several new oscillator types
- Developing "BIG" Amplifier
- Lifetime testing of HOMER Laser
- Vacuum Lifetime testing of "Heritage" laser
- Developmental work on Fiber Lasers
We Have Learned a Lot More......But

New applications for lasers in space proposed every day
We have not tested some types of diodes that we will need in the future
We have not tested diodes for as long as some missions propose to operate
We have techniques to differentiate between materials and components but we have not determined which are good and which are bad

FOR MOST MISSIONS EMPLOYING LASER TECHNOLOGY THE LASER REMAINS THE HIGHEST RISK ELEMENT FOR THE MISSION

All good things must end but...

We wish to thank NASA's Earth Science Technology Office for its continued support and encouragement.