Compact, Engineered, 2-Micron Coherent Doppler Wind Lidar Prototype for Field and Airborne Validation

IIP-04-0072

“Doppler Aerosol WiNd lidar (DAWN)”

Interim Review #1 (6 months)

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michael.j.kavaya@nasa.gov

23 June 2006
# IIP Key Personnel

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
<th>Position/Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Michael J. Kavaya</td>
<td>NASA LaRC</td>
<td>PI</td>
</tr>
<tr>
<td>Dr. Farzin Amzajerdian</td>
<td>NASA LaRC</td>
<td>Co-I, coherent lidar receiver lead</td>
</tr>
<tr>
<td>Dr. Grady J. Koch</td>
<td>NASA LaRC</td>
<td>Co-I, overall lidar system lead &amp; field demonstration lead</td>
</tr>
<tr>
<td>Mr. Ed A. Modlin</td>
<td>NASA LaRC</td>
<td>Technician</td>
</tr>
<tr>
<td>Dr. Upendra N. Singh</td>
<td>NASA LaRC</td>
<td>Co-I, LRRP PI</td>
</tr>
<tr>
<td>Mr. Bo. C. Trieu</td>
<td>NASA LaRC</td>
<td>Mechanical and system engineering</td>
</tr>
<tr>
<td>Dr. Jirong Yu</td>
<td>NASA LaRC</td>
<td>Co-I, pulsed transmitter laser lead</td>
</tr>
<tr>
<td>Dr. Yingxin Bai</td>
<td>SAIC</td>
<td>Laser design</td>
</tr>
<tr>
<td>Mr. Mulugeta Petros</td>
<td>STC</td>
<td>Laser design</td>
</tr>
<tr>
<td>Mr. Paul Petzar</td>
<td>SAIC</td>
<td>Electronic Design</td>
</tr>
<tr>
<td>Mr. Karl Reithmaier</td>
<td>SAIC</td>
<td>Opto-mechanical design</td>
</tr>
</tbody>
</table>

Also many thanks to Brian Killough, Keith Murray, Garnett Hutchinson, and Ken Anderson.
## IIP Motivation

<table>
<thead>
<tr>
<th>Mission</th>
<th>Measurement</th>
<th>Technique</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Science: Weather, Climate</td>
<td>Earth Vertical Wind Profiles</td>
<td>Scanning Doppler Lidar</td>
</tr>
<tr>
<td></td>
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<tr>
<td>Secondary</td>
<td>Science: Climate</td>
<td>Earth Vertical CO$_2$ Concentration Profiles</td>
<td>Scanning DIAL Lidar</td>
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<tr>
<td></td>
<td>Science &amp; Exploration: Atmos. Char., EDL</td>
<td>Mars Vertical Density Profiles</td>
<td>DIAL Lidar (CO$_2$)</td>
</tr>
<tr>
<td></td>
<td>Science &amp; Exploration: Atmos. Char., EDL</td>
<td>Mars Vertical Wind Profiles</td>
<td>Scanning Doppler Lidar</td>
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<tr>
<td></td>
<td>Science: Climate</td>
<td>Earth Vertical Aerosol Concentration Profiles</td>
<td>Backscatter Lidar</td>
</tr>
<tr>
<td></td>
<td>Science &amp; Exploration: Atmos. Char., EDL</td>
<td>Mars Vertical Dust Profiles</td>
<td>Backscatter Lidar</td>
</tr>
</tbody>
</table>
IIP Abstract

The state-of-the-art 2-micron coherent Doppler wind lidar breadboard at NASA/LaRC will be engineered and compactly packaged consistent with future aircraft flights. The packaged transceiver will be integrated into a coherent Doppler wind lidar system test bed at LaRC. Atmospheric wind measurements will be made to validate the packaged technology.

This will greatly advance the coherent part of the hybrid Doppler wind lidar solution to the need for global tropospheric wind measurements.
IIP TRL Advancement

“4 → 5”

Space Qualification Tests

Lifetime Demonstration

Aircraft Validation

Compact, Engineered Packaging

<table>
<thead>
<tr>
<th>TRL 9</th>
<th>Actual system “flight proven” through successful mission operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRL 8</td>
<td>Actual system completed and “flight qualified” through test and demonstration (Ground or Flight)</td>
</tr>
<tr>
<td>TRL 7</td>
<td>System prototype demonstration in a space environment</td>
</tr>
<tr>
<td>TRL 6</td>
<td>System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)</td>
</tr>
<tr>
<td>TRL 5</td>
<td>Component and/or breadboard validation in relevant environment</td>
</tr>
<tr>
<td>TRL 4</td>
<td>Component and/or breadboard validation in laboratory environment</td>
</tr>
<tr>
<td>TRL 3</td>
<td>Analytical and experimental critical function and/or characteristic proof-of-concept</td>
</tr>
<tr>
<td>TRL 2</td>
<td>Technology concept and/or application formulated</td>
</tr>
<tr>
<td>TRL 1</td>
<td>Basic principles observed and reported</td>
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# IIP and the LaRC Development of Pulsed, 2-Micron Laser Technology For Space

## Category Sub-Category/Date

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-Category/Date</th>
<th>6/02</th>
<th>9/02</th>
<th>2/03</th>
<th>4/03</th>
<th>11/03</th>
<th>2/05</th>
<th>12/05</th>
<th>LRRP</th>
<th>IIP</th>
<th>SPACE DEMO</th>
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<tbody>
<tr>
<td><strong>Demonstrated</strong></td>
<td>(Side-Pumped, LuLiF)</td>
<td>0.135</td>
<td>0.355</td>
<td>0.095</td>
<td>0.626/1.05</td>
<td>0.1/0.073</td>
<td>1/1.5</td>
<td>1.2</td>
<td>0.25</td>
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<tr>
<td><strong>Pulse Energy (J)</strong></td>
<td>(in double pulse)</td>
<td>0.095</td>
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<td>1.2</td>
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<td>2</td>
<td>10</td>
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</tbody>
</table>

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**Notes:**
- ✓ indicates availability.
- All other entries are placeholders for future data.

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**Additional Information:**
- IIP = Initial Incremental Performance
- SPACE DEMO = Space Demonstration
## IIP Re-Plan, Fall 2005

<table>
<thead>
<tr>
<th></th>
<th>Original Plan</th>
<th>Proposed Replan</th>
<th>Citation/Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contracts</strong></td>
<td>$1850K to Raytheon over 3 years (450/650/750) for packaging the lidar transceiver</td>
<td>$1800K to in-house effort with small contracts as needed for packaging the lidar transceiver</td>
<td>IIP proposal, page 16</td>
</tr>
<tr>
<td><strong>Starting Point</strong></td>
<td>Some Raytheon IRAD spending during past few months</td>
<td>Completed compact design from $600K LRRP task in FY05</td>
<td>ESTO e-books report LRRP-05-0011-A-OCT-2005 plus CDR at LaRC on 11/28/05</td>
</tr>
<tr>
<td><strong>Lidar Transceiver Pulse Energy</strong></td>
<td>Packaging 100 mJ design</td>
<td>Packaging 250 mJ design</td>
<td>Closer to space &amp; more validation options with higher energy</td>
</tr>
<tr>
<td><strong>Packaged Transceiver Specifications Guaranteed</strong></td>
<td>No (contractor will not include IRAD in SOW per 12/2/05 comments on SOW)</td>
<td>Yes</td>
<td>See 12/2/05 comments on SOW from Raytheon</td>
</tr>
<tr>
<td><strong>Hardened for Future Post-IIP Aircraft Flight</strong></td>
<td>Not included in NASA funding; promised IRAD effort may do some hardening</td>
<td>Flight-designed; ready for passenger compartment flights; ready for 60 Kft pressure</td>
<td>Necessary for aircraft flight</td>
</tr>
<tr>
<td><strong>Electronics Advancement</strong></td>
<td>No planned effort</td>
<td>Yes, compact laser control electronics included; heading towards high altitude &amp; autonomous operation electronics</td>
<td>Necessary for future high-altitude aircraft flight in external pod for space perspective validation</td>
</tr>
<tr>
<td><strong>External-to-Transceiver Thermal Management</strong></td>
<td>No work planned outside of packaged transceiver</td>
<td>Custom-designed chiller/pump in addition to packaged transceiver</td>
<td>Necessary for future aircraft flights</td>
</tr>
<tr>
<td><strong>Autonomous Operation Sensors And Electronics</strong></td>
<td>No planned effort</td>
<td>Novel quad detector in laser cavity to monitor alignment</td>
<td>Milestone towards auto-alignment maintenance of laser; required for high-altitude aircraft and space</td>
</tr>
<tr>
<td><strong>Delivery Schedule</strong></td>
<td>32 months after start</td>
<td>30 months after start</td>
<td>Earlier delivery allows more ground testing &amp; validation</td>
</tr>
</tbody>
</table>

**Notes:**
- **LRRP:** Low Risk Research and Development
- **LaRC:** Langley Research Center
- **SOW:** Statement of Work
- **Milestones:** Key points in the project's timeline that need to be reached.
IIP – Scope of the Effort
Pulsed Doppler Wind Lidar Measurement Scenario

Lidar System

Propagation Path (Atmosphere)

Target (Atmospheric Aerosols)
Pulsed Doppler Wind Lidar System

Lasers and Optics

- Electronics
- Computer, Data Acquisition, and Signal Processing (including software)
Lasers and Optics Portion

Lidar Transceiver (to be engineered under IIP)

- Transmitter Laser
- Receiver

Large Optics
(telescope, scanner)

- Pol. BS
- λ/4 Plate
- T/R Switch
Transmitter Laser

Pulsed Laser Diode Array → Pulsed Laser Oscillator → Pulsed Laser Amplifier

Seed Oscillator

AOM

CW Laser Diode

To T/R Switch
Receiver

From T/R Switch

Photodetector

Seed Oscillator or Local Oscillator
IIP- Milestones & Schedule

**Year 1**
- 12/20/05: Complete packaged transceiver requirements document
- 12/20/06: Conceptual DR CoDR
- 12/20/06: NOW

**Year 2**
- 12/20/06: Demo prototype breadboard transmitter
- 12/20/07: Demo performance of engineered oscillator

**Year 3**
- 12/20/07: Complete lab testing of engineered transceiver
- 12/20/08: Integrate engineered transceiver Into testbed
- 12/20/08: Complete test of engineered transceiver In lidar testbed
Coherent Doppler Wind Lidar Technique
What Is “Coherent” Lidar?

LO Laser

Laser

Telescope

Detector
Benefits Of The LO Laser

• Heterodyne gain effectively eliminates signal shot noise, thermal or Johnson noise, dark-current noise, and amplifier noise. LO spatial filtering eliminates background light noise
• Translation of optical frequency to radio frequency allows signal processing with mature and flexible electronics and software, and reduces 1/f noise
• Extremely narrow bandpass filter using electronics or software rejects even more noise
• Frequency of beat signal is proportional to the target velocity - truly a direct measurement of velocity
Benefits Of The LO Laser

- High accuracy
- High photon efficiency
- No intensity measurements needed

“heterodyne detection can allow measurement of the phase of a single-frequency wave to a precision limited only by the uncertainty principle”

Michael A. Johnson and Charles H. Townes
Optics Communications 179, 183 (2000)
Range and Height Resolution
1 μs (150m) Of Lidar Data And Its Spectrum

True wind, frequency = 10 m/s, 10 MHz
Effect Of SNR On Velocity Estimation

Rod Frehlich, Stephen Hannon, Sammy Henderson

Actual lidar data
6000 shots at 4.9 Hz

Top = Figure 4, R = 1 km, high SNR

Unsuccessful or “bad” wind estimates; uniformly distributed over “allowed” velocity range

Bottom = Figure 5, R = 5 km, low SNR
Example of coherent lidar velocity estimator performance

Example plots are for a maximum likelihood estimator.

These curves ‘slide’ up and down the x-axis as a function of lidar design.

Maximum and minimum values and shape of each will vary with lidar parameters. However ‘S’ shape and the relationship between the two curves are characteristic of all advanced coherent lidar velocity estimators.

Theory and experiment agree to within 5%.

Shot Accumulation Improves Velocity Estimation Trade Sensitivity For Time/Range/Resolution

- 1 pulse no accumulation
- Actual lidar data
- \( R = 5 \text{ km} \) “low SNR”
- 6000 shots at 4.9 Hz
Doppler Wind Lidar Measurement Geometry: 833 km

- Return light: t+6.6 ms, 49 m, 6.8 μrad
- Second shot: t+100 ms, 744 m, 103 μrad
- First Aft Shot: t + 106 s

- 90° fore/aft angle in horiz. plane

- 30° fore/aft angle in horiz. plane

- 45° fore/aft angle in horiz. plane

- 180 ns (27 m) FWHM (76%)
- 17 m (86%)

- 2 lines LOS wind profiles
- 1 line “horiz” wind profiles

- 120 shots = 12 s = 78 km
- 1/10 s = 658 m

- 1/10 s = 658 m
Space-Based Coherent Lidar Wind Measurement

**LO Laser**
- Frequency Stability

**Pulsed Laser**
- Wavelength
- Spectrum
- Temporal Profile
- PRF

**Atmosphere**
- Wind Turbulence
- Wind Shear
- Backscatter Gradients
- Wind Uniformity
- Vertical Wind
- Clouds

**SNR**

**Velocity Estimation Algorithm**

**Radial Wind Velocity Estimates**

**Orbit**
- Period
- Velocity
- Height
- Nadir Angle

**Azimuth Angle Scanning**

**Shot Management**

**Spatial Coverage, Angle Diversity**

**Horizontal Wind Velocity Estimates**

**Data Product**
Doppler Lidar Firsts Relevant to this IIP

2005 – selection of IIP winds proposals
2002 – begin NASA Laser Risk Reduction Program
1999 – airborne CO₂ pulsed laser winds with conical scan
1997 – 2-micron pulsed laser reaches 600 mJ
1994 – airborne 2 micron pulsed laser wind measurement
1994 – 2-micron pulsed laser reaches 100 mJ
1998 – ESA begin ADM
1997-9 – SPARCLE (canceled)
1991 – pulsed Tm,Ho:YAG laser wind measurement
1988 – pulsed Nd:YAG laser wind measurement
1984 – airborne pulsed CO₂ laser wind measurement
1977 – pulsed CO₂ laser wind measurement
1971 – airborne CW CO₂ laser wind measurement
1967 – CW CO₂ laser wind measurement
1964 – CO₂ laser demonstrated
1960 – laser demonstrated
1978 – winds from space feasibility study (scheduled shuttle flight in 1983)
## IIP Packaged Transceiver Requirements

<table>
<thead>
<tr>
<th>Category</th>
<th>Requirement</th>
<th>Goal (if different) and/or Space Requirement</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Architecture</td>
<td>Master Oscillator Power Amplifier (MOPA)</td>
<td></td>
<td>High energy, beam quality, optical damage</td>
</tr>
<tr>
<td>Laser Material</td>
<td>Ho:Tm:LuLiF</td>
<td></td>
<td>High energy, high efficiency, atmospheric transmission</td>
</tr>
<tr>
<td>Nominal Wavelength</td>
<td>2.053472 microns</td>
<td></td>
<td>Atmospheric transmission</td>
</tr>
<tr>
<td>Pulse Energy</td>
<td>150 mJ</td>
<td>250 (space)</td>
<td>Computer modeling of measurement performance</td>
</tr>
<tr>
<td>Pulse Repetition Frequency</td>
<td>10 Hz</td>
<td>10-20 (space)</td>
<td>Shot accumulation, optimum laser diode array lifetime</td>
</tr>
<tr>
<td>Pulse Beam Quality</td>
<td>&lt; 1.4 x diffraction limit</td>
<td></td>
<td>Heterodyne detection efficiency influence</td>
</tr>
<tr>
<td>Pulse Spectrum</td>
<td>Single Frequency</td>
<td>Few MHz (space)</td>
<td>Frequency estimation process</td>
</tr>
<tr>
<td>Injection seeding success</td>
<td>95%</td>
<td>99%</td>
<td>Shot accumulation</td>
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<tr>
<td>Laser Heat Removal</td>
<td>Partial Conductively Cooled</td>
<td>FCC (space)</td>
<td>No liquid lines in space</td>
</tr>
<tr>
<td>Packaging</td>
<td>Compact, engineered</td>
<td>Aircraft ready Space qual. (space)</td>
<td>As ready as possible for aircraft follow on</td>
</tr>
</tbody>
</table>
Laser Design Considerations

• Laser wavelength
• Laser material
• Laser pumping geometry
• Laser cavity design
• Laser architecture
Why Ho:Tm:LuLiF

• Why Ho laser?
  – Tm lasers in 2-μm region have such a low gain cross-section ($\sigma_{em} \sim 10^{-20}$ cm$^2$) that efficient, high-energy laser amplification is impossible without the risk of laser crystal or associated optics damage.
  – Ho lasers have large enough stimulated emission cross-section ($\sigma_{em} \sim 10^{-19}$ cm$^2$) for effective amplification to obtain high-energy.

• Why co-doped?
  – Takes advantage of diode pumping for Tm lasers
  – Takes advantage of the efficient Tm 1:2 relaxation energy transfer process
  – Takes advantage of the high emission cross-section of Ho laser
Why Ho:Tm:LuLiF — Cont.

• Why fluoride?
  – Fluoride
    • Long upper laser level lifetime ~ 15 ms, store more energy
    • Low up-conversion loss
    • Higher emission cross-section
    • Naturally birefringent material, no depolarization loss
    • Negative $dn/dT \rightarrow$ weak thermal lensing
  – Garnet
    • Isotropic
    • Excellent thermo-mechanical properties

• Why Lutetium?
  – Lanthanide series ions
    • Lutetium, Yttrium, Gadolinium
  – Lutetium
    • Lutetium – larger crystal field
      – larger manifold stark splitting -> Small thermal population of ground state
Laser Architecture
Master Oscillator Power Amplifier (MOPA)

• Energy requirement
  – Single oscillator can’t produce required energy

• Beam quality
  – MOPA preserves the good beam quality

• Lifetime
  – Permits more derating of pump diodes

• Efficiency
  – Multiple pass amplifier improving the efficiency

• Optics Damage
  – Reducing intra-cavity fluence
Cavity Configuration

• Linear Cavity
  – Standing waves
  – Simple
  – Round trip - pass gain medium twice

• Ring Cavity
  – Traveling waves
  – No spatial hole burning in the gain-> single mode
  – Long cavity needed to obtain narrow linewidth
  – Beneficial for injection seeding through output coupler
Pumping configuration

• Pumping geometry
  – Side Pumping
    » Power scaling
    » Uniform pumping
  – End Pumping
    » Easy thermal management
    » Easy to mode match
    » Higher pump density

• Single Longitudinal Mode
  – Interferometric mode selection
  – Monolithic design, short cavity
  – Injection seeding
Optical Bench

- Two options:
  - 26.5 x 23.0 x 7 inch single side
  - 26.5 x 11.5 x 7 inch double sided
- The split can be done such that the receiver optics and the seed laser on one side, and the power Oscillator amplifier on the other.
- Optical bench is water cooled, enclosed and dry purged.
LRRP Pulsed, 2-Micron Laser Transmitter Opto-Mechanical Design

- 3-m, bow-tie, unidirectional master oscillator power amplifier
- Seeding and receiver optics on reverse side
- Expect this hardware in about 8 weeks for LRRP
Seed Laser

CW seed laser

Seed laser driver
Oscillator features

- Injection seeded
- Cavity length >3m Ring
- Output coupler Reflectivity ~70%
- Diode pump lasers: 36 bars 100W/b conductive cooled
- Crystal doped material length 21mm
- Undoped LuLF length 15 mm
- Laser crystal cooling: H₂O, Methanol
- Tube size: 6mm OD 5mm ID AR coated for 792nm
- Laser rod ends wedged 0.5° along c-axis AR coated for 2.053µm
- Laser rod cylinder AR coated for 792nm
Oscillator Head
Oscillator cavity length

• Long cavity length is needed to obtain narrow linewidth
  • Pulse length is one of the critical parameters of a coherent Lidar.
  • A short pulse compromises frequency resolution while a long pulse compromises range resolution.
• To meet the pulse length requirement, the oscillator length was changed from 2m to 3m. It prolongs the pulse width to near 200ns
• The resonator has six mirrors and 8 bounces.
Amplifier features

- Pump energy 7.2 Joules
- Diode laser 12x6 bar arrays with 100 watts/bar
- Laser crystal conductive cooled ‘AA’ Pkg
- Doped Crystal length Ho:Tm:LuLF 0.5% Ho 6% Tm 41 mm
- Ends diffusion bonded 15 mm undoped LuLF crystals
- Laser crystal cooling H2O 792nm
- Flow tube size 6 mm OD 5 mm ID AR coated 792 nm
- Rod end surfaces AR coated for 2.053 µm
- Laser cylinder AR coated for 792 nm
- Path configuration double pass
Amplifier Module
Proposed Transceiver “Box”

- Modular approach with injection seed & local oscillator separate from transceiver.
- Separate seed/LO allows flexibility to adapt to 3 measurements scenarios:
  - simple, fixed frequency LO for ground or low platform speed.
  - higher intermediate frequency for high platform speed.
  - swept LO for very high platform speed.
- DIAL of CO₂

Note: only optical paths are represented; electrical and water paths are not shown.
Seed/LO Option 1

- baseline design for ground-based implementation.
- recommended for IIP demonstration.
- fiber-to-free space through AOM then back to fiber is disadvantageous—looking into fiber optic pigtailed AOM.
- could be packaged in rack-mount breadboard with fan for cooling (need thermal analysis).
Test Bed: Putting it all Together
VALIDAR Scanner

• scanner is mounted on roof of laboratory trailer.
• 8-inch clear aperture.
• can be pointed or scanned in elevation/azimuth for hemispherical coverage.
• linked to data acquisition computer for automated profiling of wind.
VALIDAR Telescope

- off axis Dall-Kirkham design.
- 6-inch aperture
- 20X expansion
Data Acquisition and Processing System

CompactPCI Chassis

Scanner Control Computer

Lidar Transceiver

Outgoing Pulse

Lidar Return

Analog Front End

Digitizer

Digital Signal Processor--2 cards of 4 chips

Control Program

Host CPU

Storage Devices

Real-Time Display & User Interface

RS-232

CompactPCI Bus
Atmospheric Measurements

(will be better than this VALIDAR sample)

jets

virga

rain enhancing backscatter

passage of frontal system
Installation of Laser Timing Device

• The Laser Timing Device was installed in the VALIDAR system and tested in complete lidar.

• Significance of this new hardware:
  – Reduces size, weight, and complexity of control electronics associated with laser transmitter.
  – Improves performance of injection seeding and offers simpler adjustment of parameters.
  – Allows implementation of double-pulsing with injection seeding.
  – Graphical user interface.
Simplification of Hardware

BEFORE

8 separate electronic boxes

AFTER

19” rack-mount enclosure, 1.75 inches high
## IIP Year 1 Financials

As of 6/8/06

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*1.45 FTE plan
0.57 FTE actual
Summary

• IIP project 6 months into 36 month effort
• On schedule and budget to date
• Leveraging LRRP work on compact laser in 05 and 06
• Plan on significant steps of compact, engineered packaging of state-of-the-art laser/lidar technology. TRL definitions do not reveal significant progress.
• Companion IIP at GSFC for noncoherent Doppler wind lidar will complement this project to permit hybrid DWL on aircraft and then in space
• Project very consistent with findings of NASA/ESTO Laser/Lidar Technology Requirements Working Group results (FY06). To be issued in final report
• Anticipate strong endorsement of global winds by NAS decadal study on earth sciences
• Same technology promises additional applications for earth and Mars
BACK UP
Seed/LO Option 2

- used for aircraft.
- same as Option 1, except AOM offset is higher.
- system may require replacement of heterodyne photodetectors.
- aircraft speed and scanner angle are used to select a frequency to beat down heterodyne signal to bandwidth of data acquisition system.
Seed/LO Option 3

- used with space mission with very high Doppler shifts from satellite motion. While IIP hardware would not be used for a space mission, useful system testing could be accomplished if this seed/LO option could be incorporated into system.
Solid State 2-micron Lasers

- Tm Lasers (pump diodes 780-805nm)
  - YAG, YLF, YAIO$_3$, YVO$_4$
- Ho:Tm Lasers (pump diodes 780-805nm)
  - LuLF, YLF, GdLF, YAG, YVO$_4$
- Tm pumped Ho lasers (pump diodes 780nm)
  - Tm solid state laser pumped Ho Laser
  - Tm fiber laser pumped Ho Laser
- Ho Lasers (pump diodes 1900nm)
  - YAG
Transceiver Environment Requirements

- **Platform:** ground-based (Airborne qualify-able)
- **Operational Temperature:** 0°C -30°C
- **Non-Operational Temperature:** -25°C; +50°C
- **Operating Altitude Range:** Sea level to 30,000 ft
- **Humidity:** <50% RH@25°C
- **Vibration:** 2.0 g-rms
- **Optical bench:** temperature controlled
- **Coolant Temperature:** 5°C
- **Coolant Flow**
  - Laser rod: 0.4 GPM
  - Diode Laser: 1.5 GPM
  - Bench: 1.5 GPM
- **Coolant Pressure:** 50 psi at 6 GPM

3/26/2008
Wind Lidar Block Diagram

- Telescope
- Transceiver unit
- Cooler Unit
- Electronics Unit
Oscillator and Amplifier layout
Receiver Optics layout

1. Seed laser input
2. Fiber beam splitter
3. Collimator
4. Faraday isolator
5. ½ wave plate
6. Polarizer
7. Beamsteering optics
8. Receiver signal optics
9. Heterodyne monitor
10. Receiver detectors
11. AOM output
Transceiver integration with lidar

- CW master oscillator
- Isolator
- AOM 105 MHz
- Oscillator fiber optic port
- Turning mirror (deflects beam up toward scanner)
- Beam expander
- λ/4
- Transceiver

Diagram:
- CW master oscillator
- Isolator
- AOM 105 MHz
- Oscillator fiber optic port
- Turning mirror (deflects beam up toward scanner)
- Beam expander
- λ/4
- Transceiver
Sensors

• Optical detectors:
  - Energy monitor (InGaAs or Pyroelectric)
  - Temporal pulse and energy monitor (Photo electro-magnetic detector)
  - Resonance detector (InGaAs)
  - Seeding quality (InGaAs)
  - Return signal (dual input InGaAs fiber coupled)

• Humidity sensors
• Temperature monitors
Seed Laser

- **Spatial mode**: $\text{TEM}_{00}$ Gaussian
- **Output**: $>35\text{ mw}$
- **Output isolation**: $60\text{ dB fiber coupled}$
- **Additional protection**: $>50 \text{ dB between the oscillator and the AO modulator}$
- **Fiber type**: single mode polarization preserving
- **Fiber core diameter**: $6\mu\text{m}$
- **Operating conditions**: $20^\circ \text{ to } 25^\circ \text{C heat sink temperature}$
Seed Laser Linewidth Measurement

Seed Laser 1

Seed Laser 2

Coupler

Detector

Spectrum Analyzer
Seed laser line width

Emission Bandwidth
13.11 kHz
10Hz Oscillator performance

Performance of 3m resonator

\[ y = -0.1464 + 0.073887x \quad R = 0.98893 \]

\[ y = -0.45074 + 0.20352x \quad R = 0.99948 \]

Pulse length as a function of pump energy

Pulse length (ns)

output(J)

pump energy (J)

Pulse length as a function of pump energy

Pulse length

pump energy (J)
Amplifier Architecture

Half wave Plate  Faraday Isolator  Half wave Plate  Amplifier

Osc.
Double pass amplifier performance

10Hz Amplifier Double-pass Performance

- Output with 5°C rod temperature
- Probe = 95 mJ
- Rod temperature = 8°C

Output with 5°C rod temperature
- Probe = 101 mJ

Current (A) vs. Output (mJ) graphs for 10Hz Amplifier Double-pass Performance and output with 5°C rod temperature.
Preliminary layout (side 1)
Preliminary layout (side 2)
Optical Mirror Mount
Optical Component Mounts

AO modulator

Q-Switch