

Advances on 2-micron Coherent Doppler Wind Lidar

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**Meeting of the US Working Group on Space-based Lidar Winds
May 13-14, 2014, Boulder, CO**

Outline

- **Background**
- **Roadmap**
- **Technology Development**
 - 1.2 Joule/pulse energy demonstration
 - Compact 2-micron wind lidar transceiver
 - Conductive cooled 2-micron osc/amp development
- **Ground and Airborne campaigns**
- **Fully Conductively-cooled Risk Reduction Laser**
- **Conclusions**

Motivation for 2-Micron Laser/Lidar Development

NRC Recommended “3-D Winds” Mission

NRC Decadal Survey

EARTH SCIENCE AND APPLICATIONS FROM SPACE

NATIONAL IMPERATIVES FOR THE NEXT DECADE AND BEYOND

Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future

Space Studies Board

Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS

2007

Washington, D.C.
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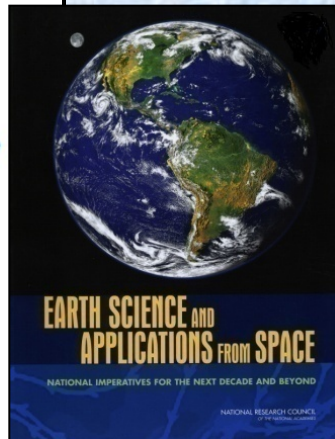
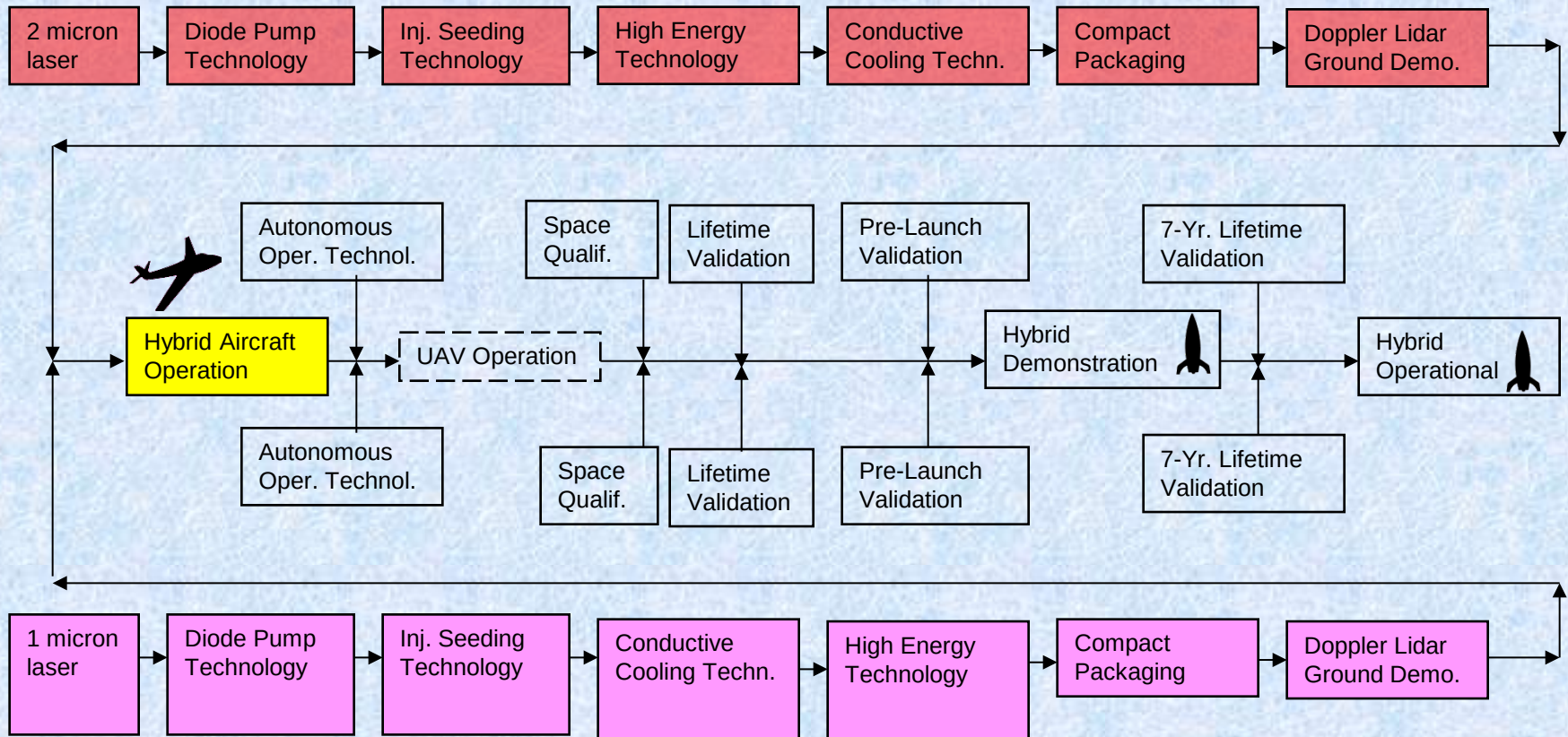


TABLE ES.2 Launch, Orbit, and Instrument Specifications for Missions Recommended to NASA

Decadal Survey Mission	Mission Description	Orbit ^a	Instruments	Rough Cost Estimate (FY 06 \$million)
2010-2013				
CLARREO (NASA portion)	Solar and Earth radiation; spectrally resolved forcing and response of the climate system	LEO, Precession	Absolute, spectrally resolved interferometer	200
SMAP	Global Winds 9 Societal Benefits			
ICESat-II				
DESDynI				Extreme Weather Warnings
2013-2016				
HyspIRI	Human Health			✓
ASCENDS	Earthquake Early Warning			
SWOT	Improved Weather Prediction			✓#1
GEO-CAPE	Sea-Level Rise			
ACE	Climate Prediction			
2016-2020				
LIST	Freshwater Availability			
PATH	Ecosystem Services			
GRACE-II	Air Quality			✓
SCLP	Snow accumulation for freshwater availability	LEO, SSO	Ku- and X-band radars K- and Ka-band radiometers	500
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	600
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	650

Space-Based Doppler Wind Lidar Roadmap

2-Micron Coherent Doppler Lidar



0.355-Micron Direct Doppler Lidar

Global Winds Roadmap Via Hybrid Doppler Lidar

Early Mission Concept for Earth Winds Laser Atmospheric Wind Sounder (LAWS)



- 525 km orbit height
- Single pulsed coherent Doppler lidar system covers troposphere
- Continuously rotating telescope/scanner
- Line of sight (LOS) wind profiles from each laser shot
- ~ 20 J pulse energy
- ~ 1.5 m rotating telescope
- Requirement: eyesafe solid state pulsed laser
- 2-micron technology for coherent detection
- 20 mJ/5 Hz demonstrated vs. 20 J/10 Hz req.
- **Energy deficiency of x1000 (30 dB) !**

Laser Risk Reduction Program (LaRC-GSFC)

(NASA HQ Funded Directed Program 2001-2010)

2 Lasers, 4 Techniques, 6 Priority Measurements

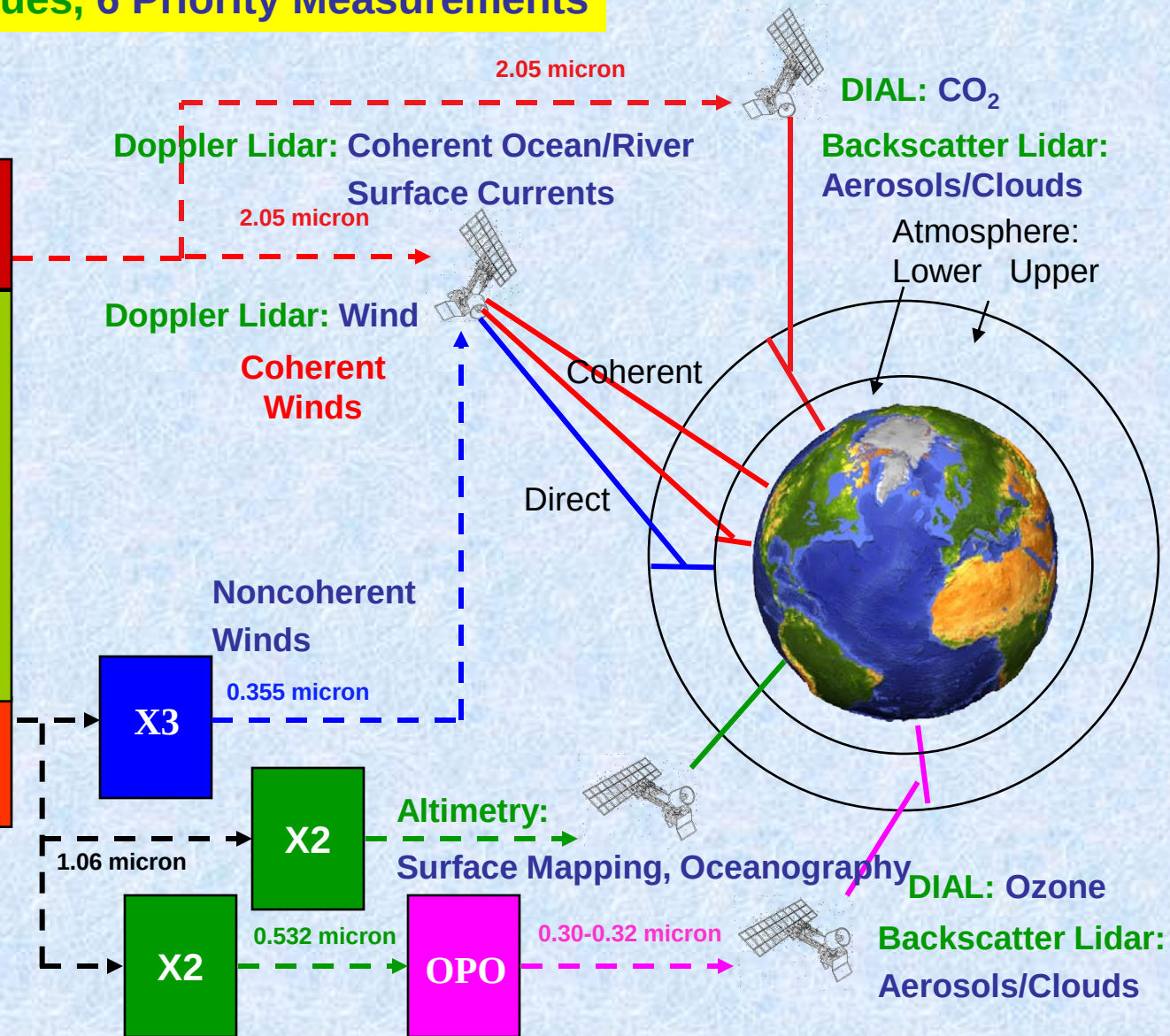
**Pulsed
Laser Development**

2 MICRON

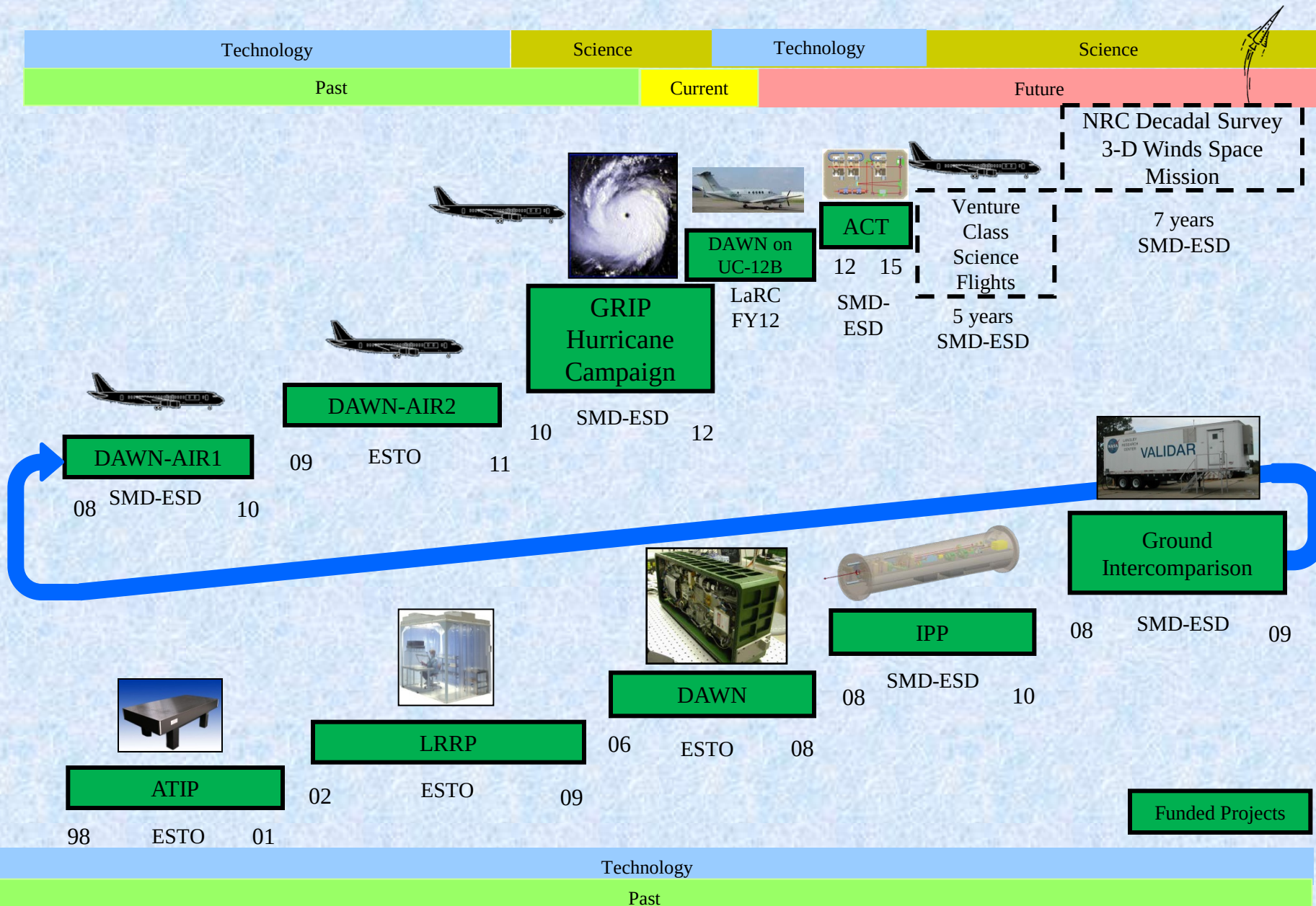
Key Technologies in Common

Laser Diodes
Laser Induced Damage
Frequency Control
Electrical Efficiency
Heat Removal
Ruggedness
Lifetime
Contamination Tolerance

1 MICRON



Roadmap to 3-D Winds Space Mission at NASA Langley



Objectives & Technical Approach

Objectives

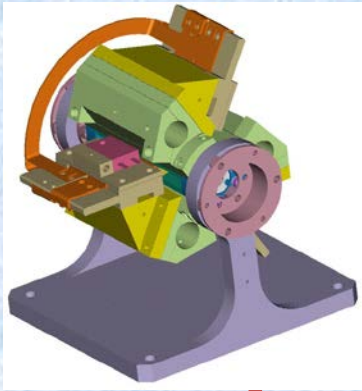
Develop related laser technologies leading to a **conductively cooled, diode-pumped high-energy and high-efficiency 2-micron pulsed laser** suitable for space-based remote sensing Lidar applications to support science and exploration missions.

Technical Approach

“Systematically conduct theoretical and experimental research to develop related laser technologies included but not limited to **new laser materials, innovative cavity designs, pump module designs, diode configurations, advanced thermal management systems, creative mechanical design and fabrication technologies.**”

Technology Maturation Example

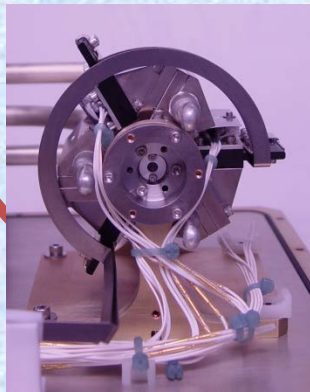
A fully conductively cooled 2-micron solid-state pulsed laser has been demonstrated to enable 3-D Winds from a space platform



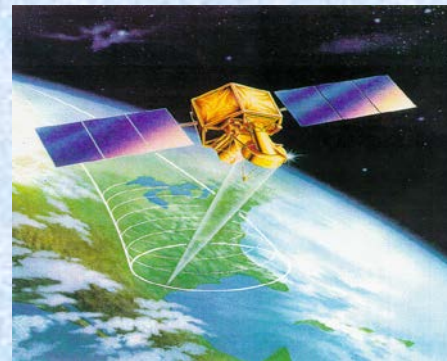
Analysis &
Design



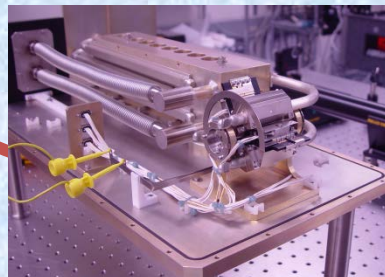
Quantum Mechanical
Modeling



Fabrication



Space Qualifiable
Design



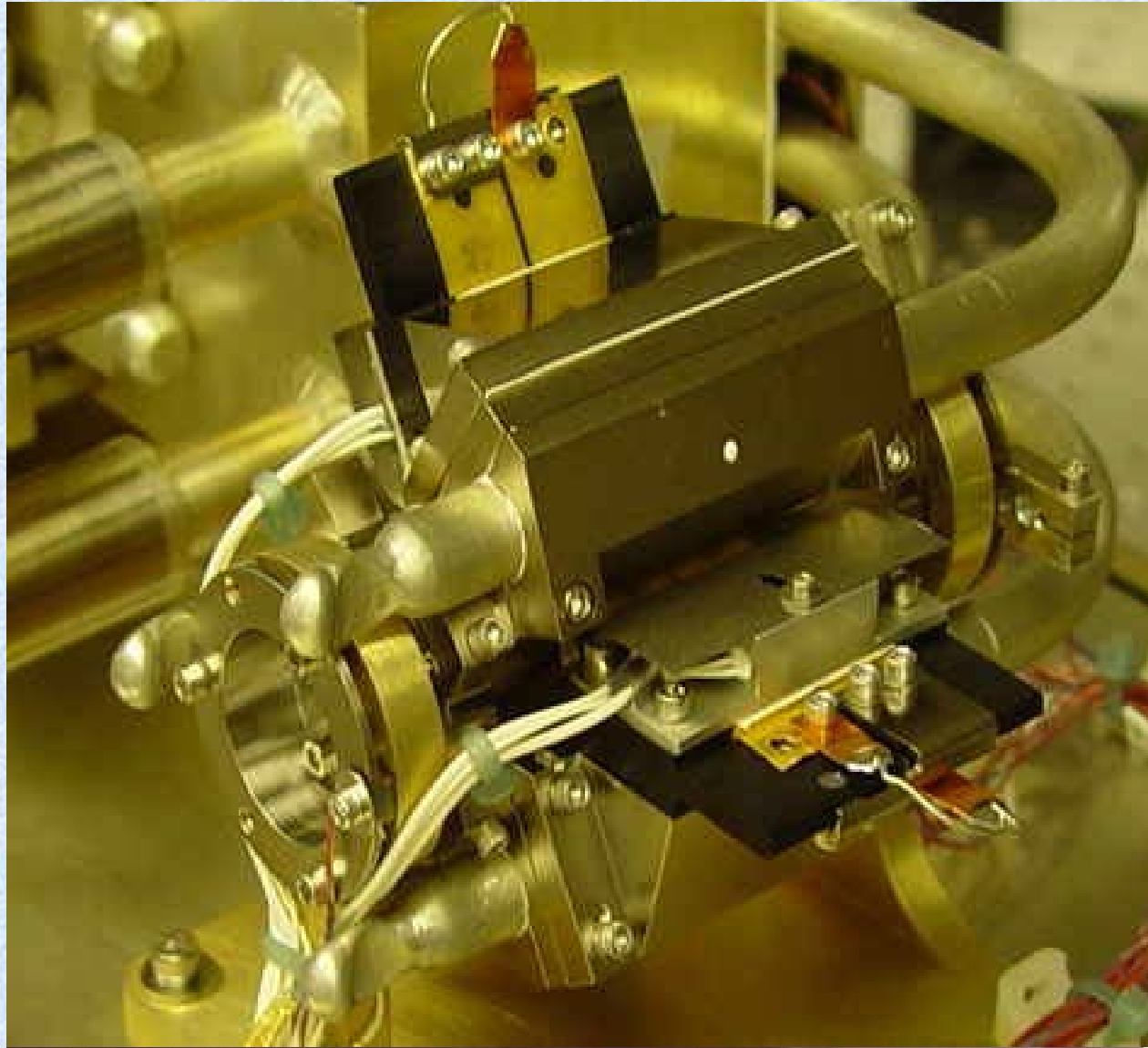
System Integration



Testing and
Model Verification

Development of a Pulsed 2-Micron Laser for Coherent Wind Profiling Lidar -Airborne and Space Applications

NASA Langley Research Center, 2000 – 2011



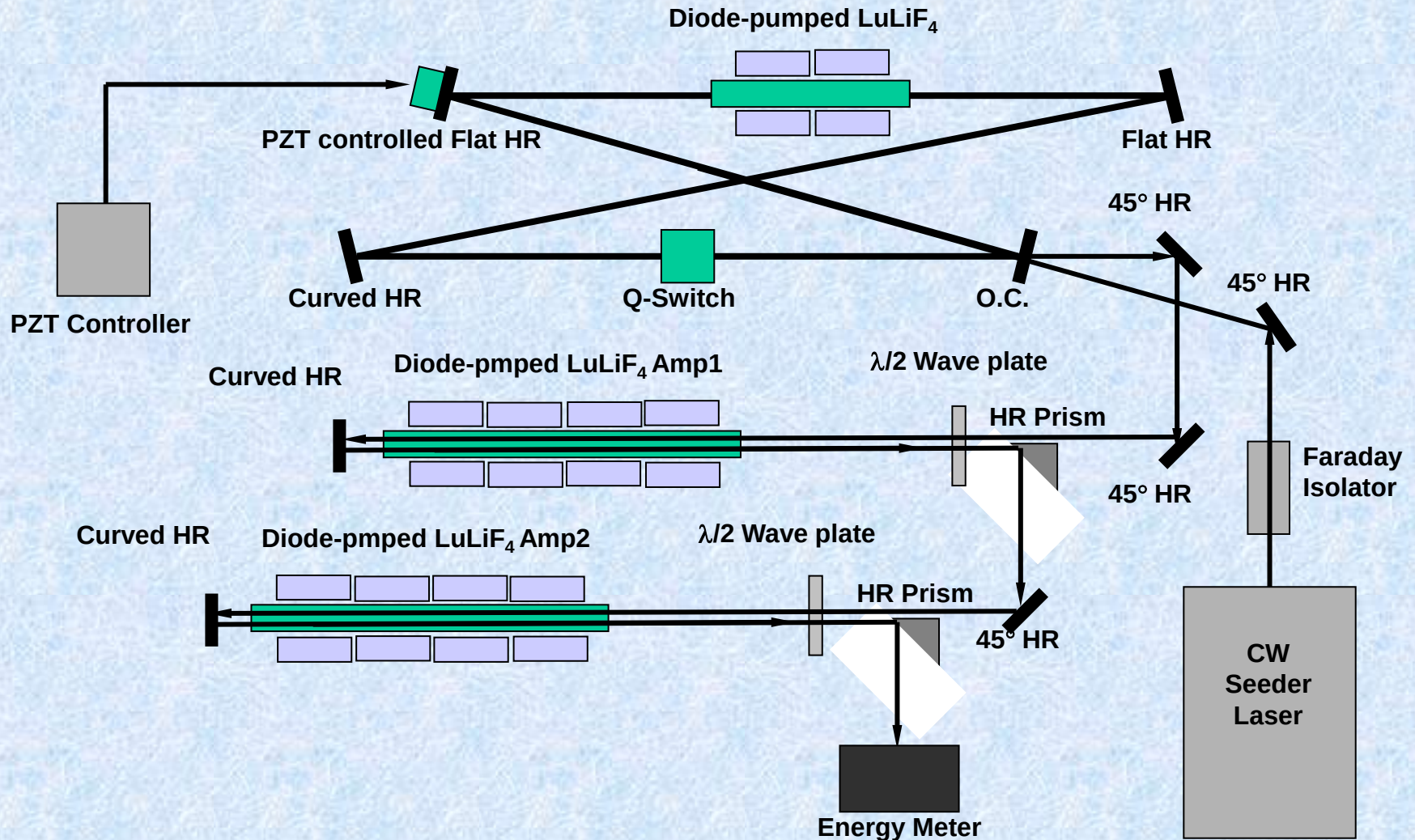
100 Diode
10 Diode
Arrays

Arrays
Conductively
4 Water

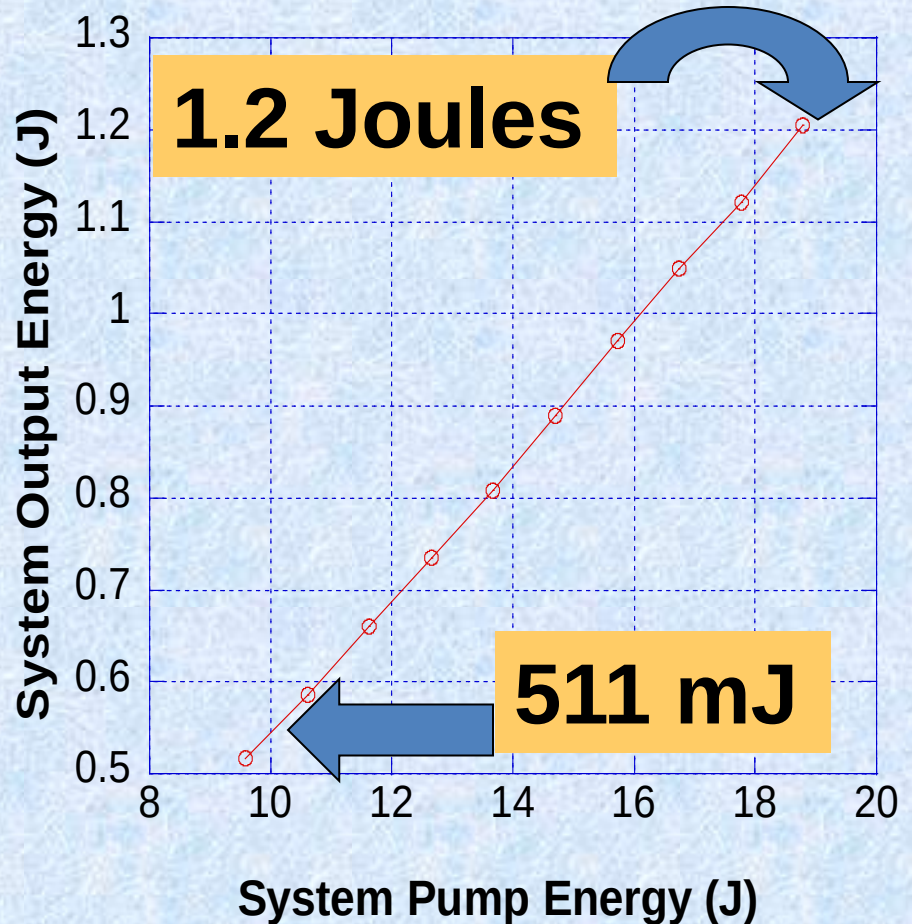
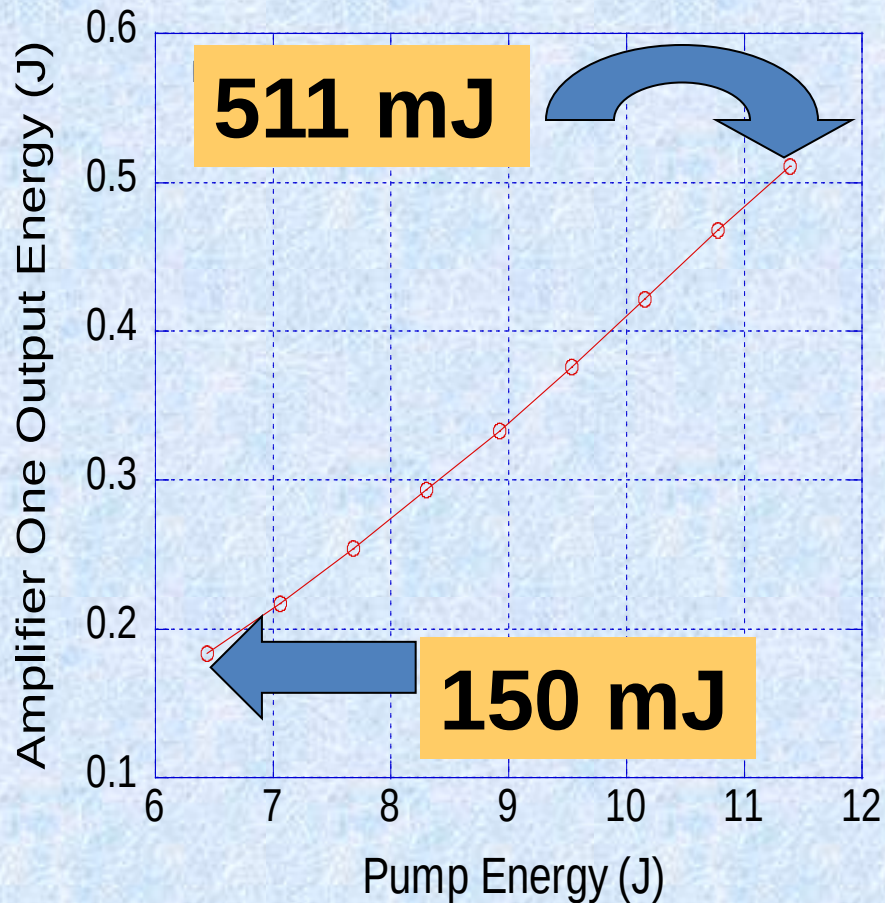
28 Water
Cooled
Channels
Channels

2004-2006
2002-2003
2001-2002

MOPA Schematic



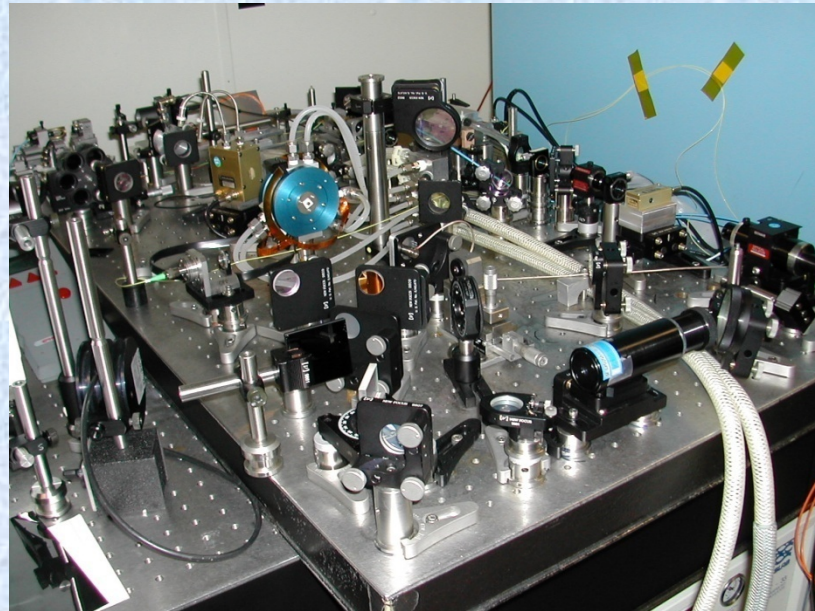
Amplifier Performance (First and Second)



Mobile Ground based High Energy Wind Lidar Transceiver – LRRP/DAWN Funded

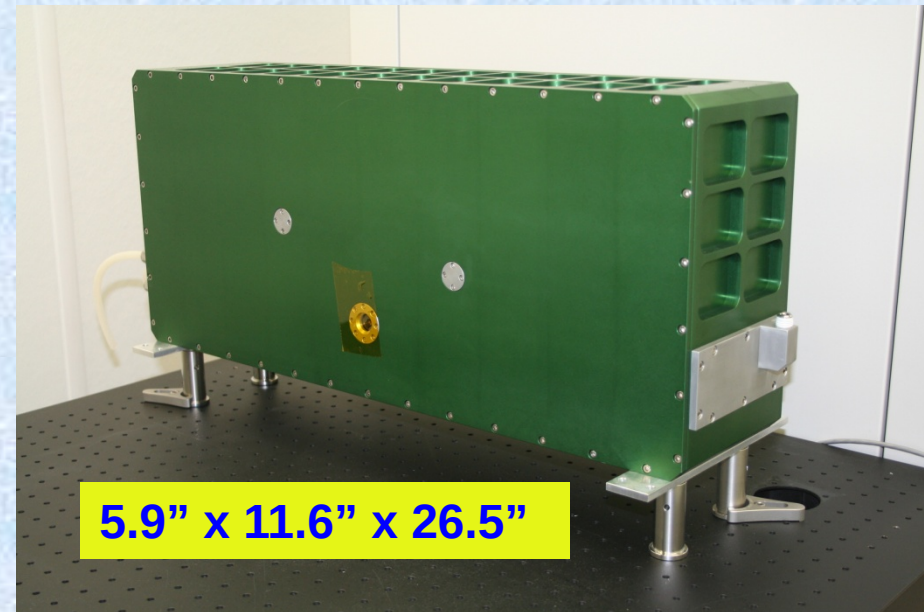
- Smaller
- More energy
- More robust

**Table Top Transceiver
(Transmitter + Receiver)**
90 mJ/pulse, 5 pulses/sec.
3'x4' Optical Table
(no telescope or scanner)



**Previous implementation
90 mJ per pulse**

**Transceiver (Transmitter +
Receiver)**
250 mJ/pulse, 10 pulses/sec.
5.9" x 11.6" x 26.5", 75 lbs.; 15 x
29 x 67 cm, 34 kg
(no telescope or scanner)



5.9" x 11.6" x 26.5"

Small, Robust, 250 mJ per pulse

2- μm Lidar Parameters

- Pulse energy = 250 mJ
- Pulse repetition rate = 5 Hz (currently at 10 Hz)
- Pulsewidth = 200 ns
- Telescope aperture = 15 cm
- Wavelength = 2053 nm (Ho:Tm:LuLiF)
- Data acquisition : 500 Ms/s, 8 bits, real-time processing
- Scan pattern: zenith view interleaved with 45-degree elevation cone
- Operations: run continuously up to 84 hours, unattended for long periods

Ground-Based Hybrid Wind Lidar Demo Winter 2009

**GSFC 355-nm
Doppler lidar**

**LaRC 2- μ m
Doppler lidar**

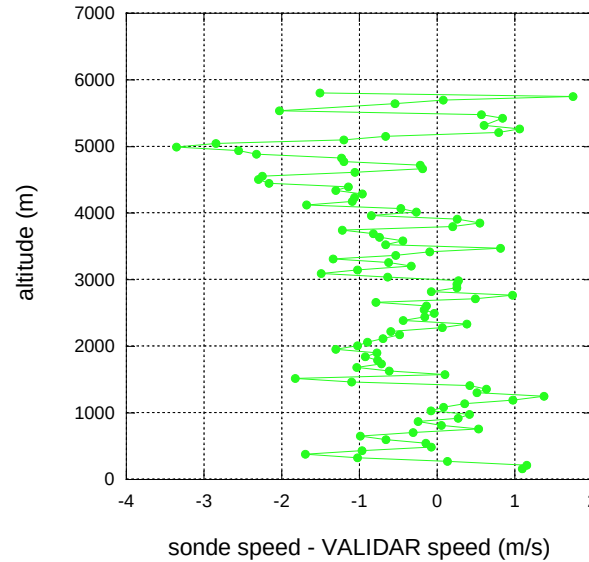
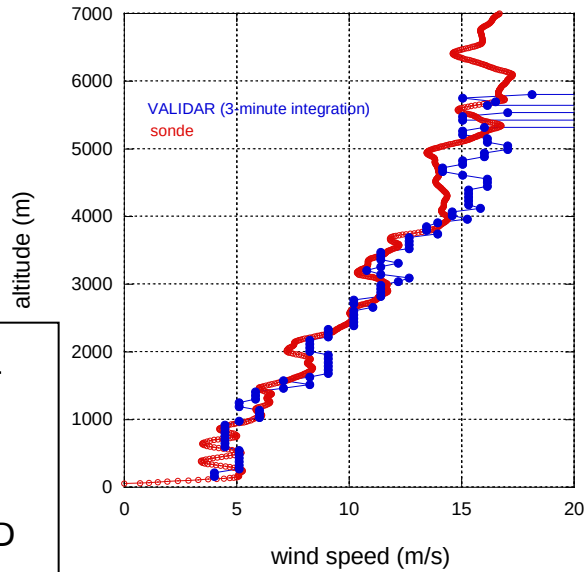


- The LaRC mobile lidar is deployed as part of NASA HQ funded (ROSES-2007, Wind Lidar Science Proposal entitled “Intercomparison of Multiple Lidars for Wind Measurements (PI: Upendra Singh)
- Utilized NASA LaRC Compact DAWN Lidar Transceiver for 2-micron lidar
- Site at Howard University Research Campus in Beltsville, Maryland

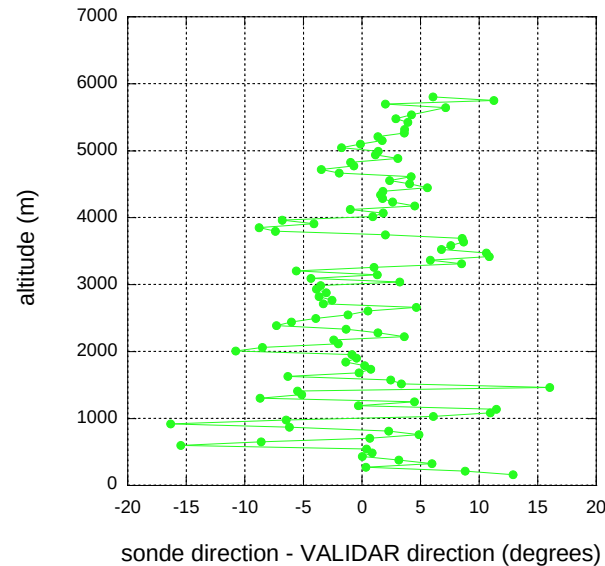
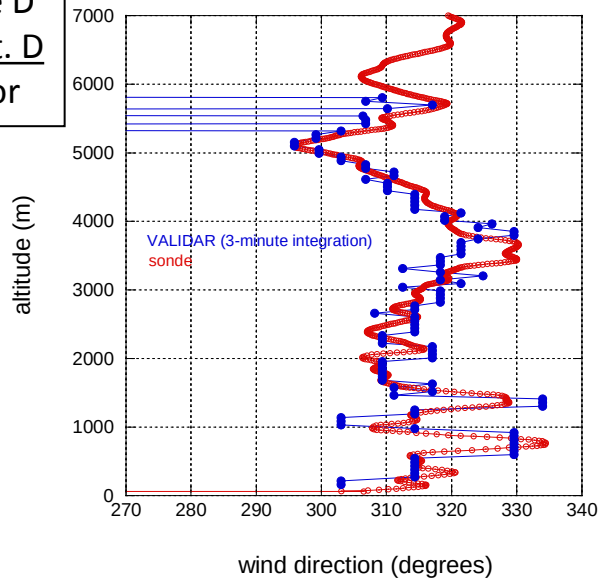
Comparison of Coherent Lidar and Sonde

Error Tree

Lidar
+Sonde
+Location D
+Time D
+M Volume D
+M Time Int. D
=Total Error



- Root-mean-square of difference between two sensors for all points shown = **1.06 m/s**

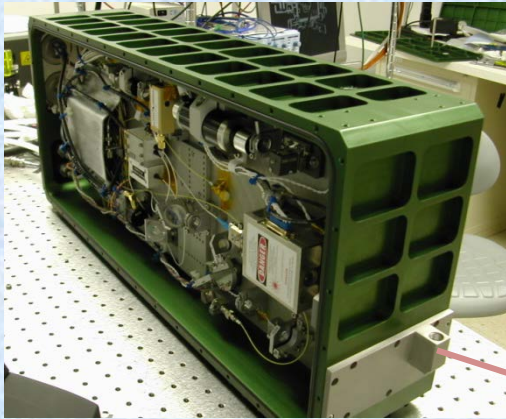


- Root-mean-square of difference between two sensors for all points shown = **5.78 deg**

Genesis and Rapid Intensification Process (GRIP) Campaign

Coherent Pulsed Doppler Wind Profiling Lidar System

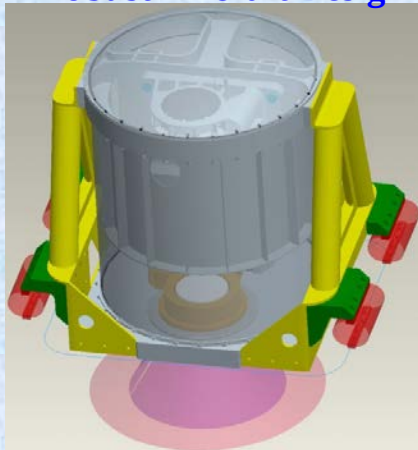
1. World's Most Capable Transceiver Packaged, Compact, Robust



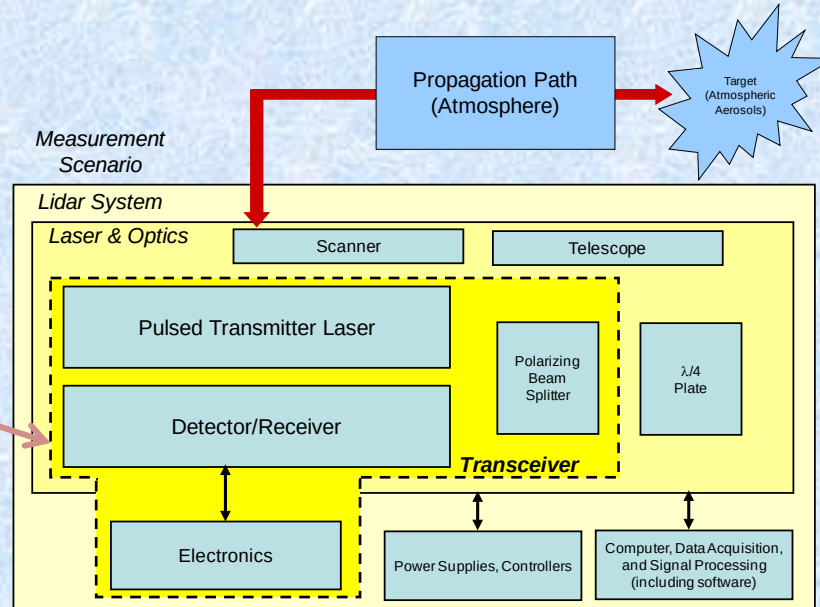
- 0.25 J pulse energy, 10 Hz pulse repetition frequency (PRF)
- 15 cm receiver optical diameter, 34 kg (75 lbs.)
- 15.2 x 29.5 x 67.3 cm (6 x 11.6 x 26.5 inches)

4. Enclosure for All Lidar Optics

Robust Aircraft Design



2. Complete System Utilizing Transceiver



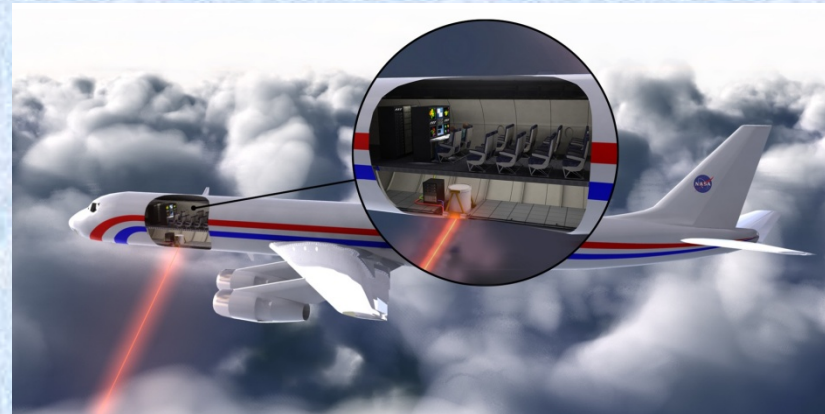
3. Ground-based Wind Measurement Performance

- RMS wind difference from balloon sonde, 0 – 6 km altitude, = 1.1 m/s and 5.8°
- No alignment needed after interstate travel in trailer
- Overnight unattended operation
- Vertical winds to 11 km altitude
- Horizontal vector winds to 7 km altitude
- Data processing choice of multiple values of vertical and horizontal resolution
- Same technology as anticipated space mission

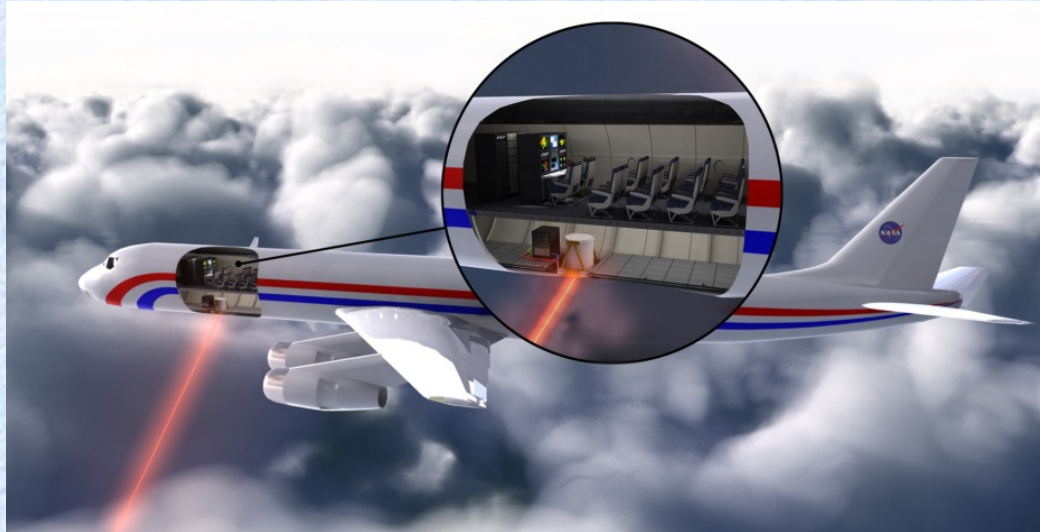
5. Optics in DC-8



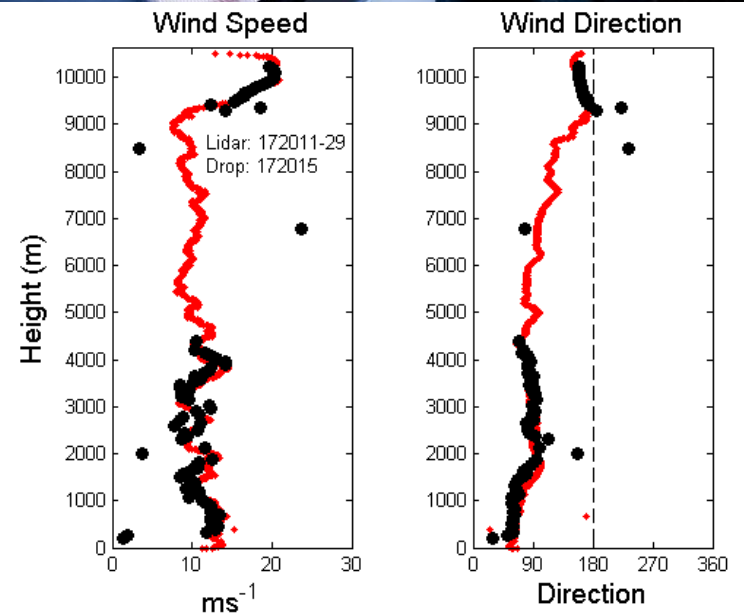
6. Lidar System in DC-8



NASA Langley DC-8 Wind Lidar During GRIP (2010)



Ho:Tm:LuLiF, 2.05 micron, 250 mJ, 10 Hz, 15 cm, coherent-detection





Toward 3D-Winds

(NASA ESTO investments)

Tropospheric Wind Lidar Technology Experiment (TWiLiTE)



UV Direct Detection
Molecular Winds
(Gentry, NASA GSFC)

Doppler Aerosol Wind Lidar (DAWN)



2.0 μ m Coherent Doppler
Aerosol Winds
(Kavaya, NASA LaRC)

Optical Autocovariance Wind Lidar (OAWL)



UV Direct Detection
Aerosol & Molecular Winds
(Grund/Tucker, Ball Aerospace)



2008 Ground
Comparison

(Singh, NASA LaRC)



2011 Ground
Comparison with
NOAA mini-MOPA



Flew on the ER-2 in 2009 &
2011 and is being configured
to fly on the Global Hawk for
the Hurricane and Severe
Storm Sentinel (HS3) EV-1
Mission in 2012.



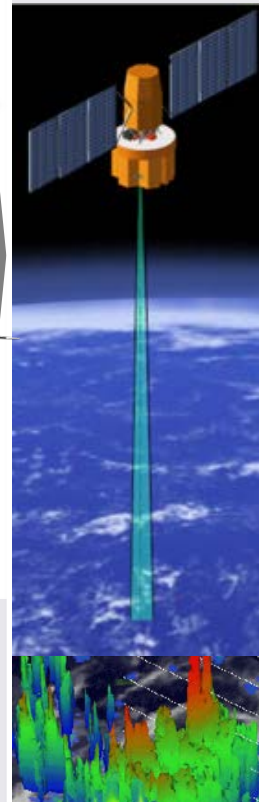
Flew 112 hours over 15 flights
on the DC-8 in 2010 in support of
the NASA GRIP campaign.
Additional flights are planned
on the B200.



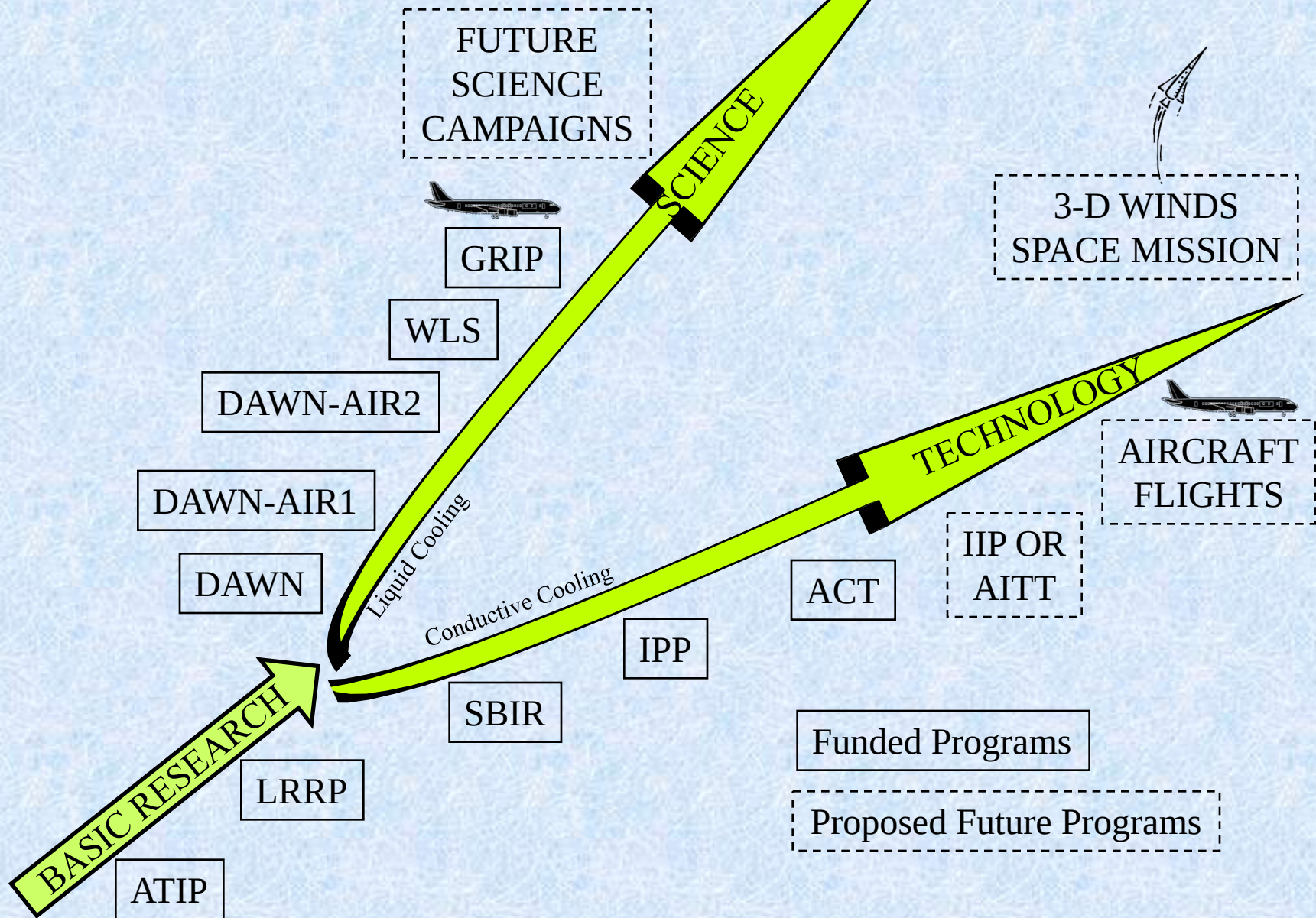
Test flights conducted on
the WB-57 in 2011.

IDL / MDL testing, and an Observing System
Simulation Experiment (OSSE) are planned
for 2012.

3D-Winds Decadal Survey Mission



3-D Winds Mission Science and Technology Roadmap



LaRC Partnership with Fibertek for Space Qualifiable 2-micron Laser Development for NASA 3-D Wind Mission

➤ **Laser Risk Reduction Program (ESTO) - 2001-'10**

- LaRC has demonstrated fully conductively cooled oscillator/amplifier to 400 mJ, 5 Hz (08/07)

Partnership with Fibertek:

➤ **Innovative Partnership Program (LRRP/ESD/Fibertek)**

- 3-m cavity, 792 nm pumped, conductively cooled 200 mJ, single frequency output at 5 Hz – first generation

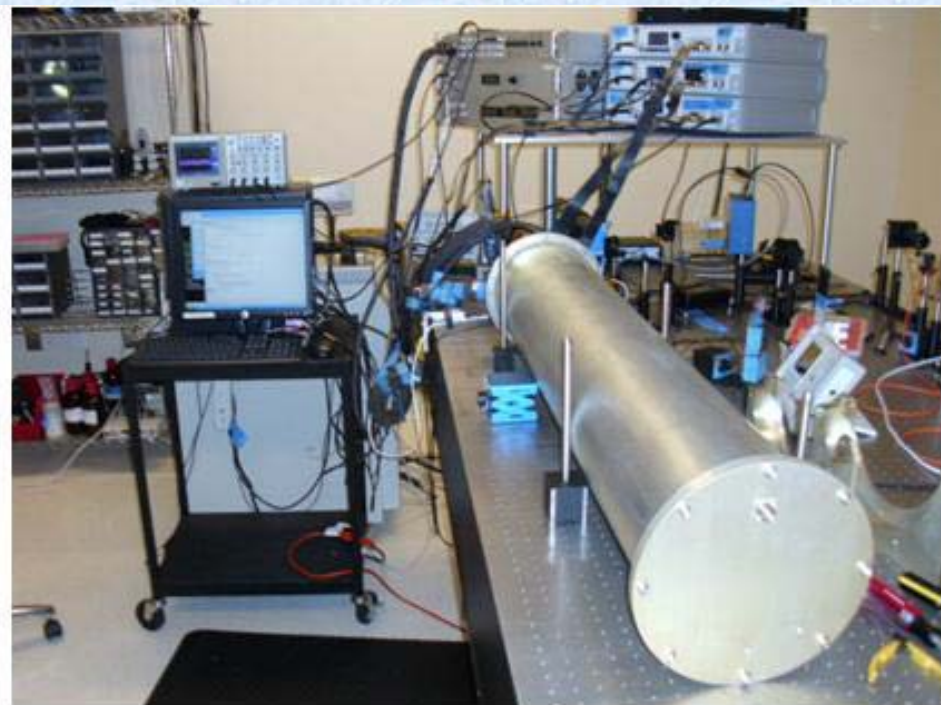
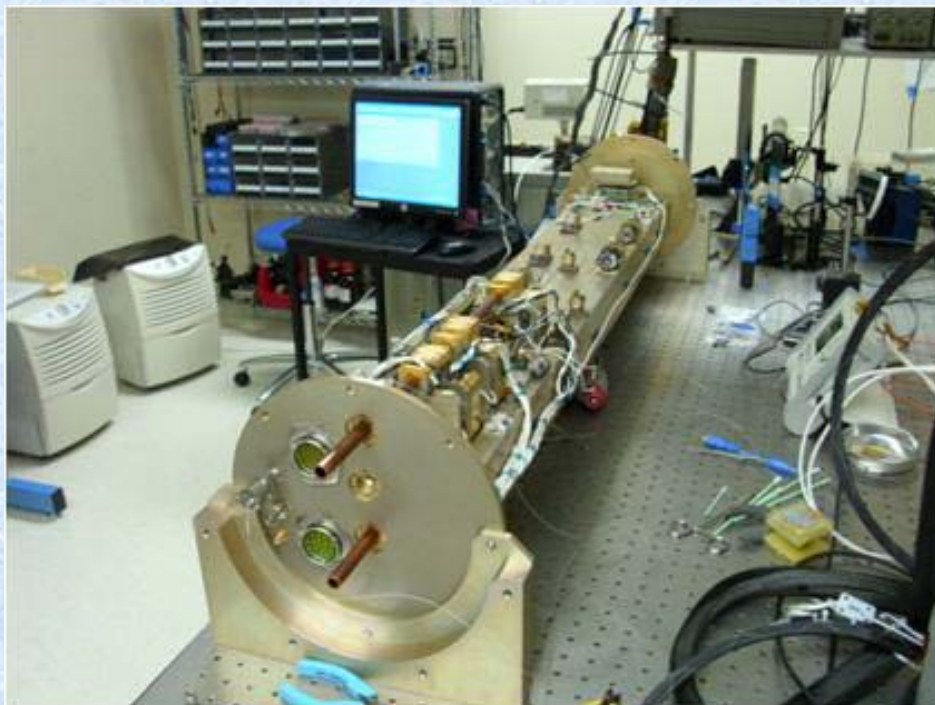
➤ **Advanced Component Technology (LaRC/ESTO/Fibertek)**

- Compact, 1-meter cavity, 808 nm pumped, fully conductively cooled laser transmitter delivering wind quality 250 mJ 10 Hz output for 3-D Wind mission

Innovative Partnership Program (LRRP/ESD/Fibertek) 2007-2010

(PI: Singh, Co-I: Yu, Kavaya LaRC; Co-I: Hovis, Fibertek)

**Single frequency 2-micron Laser (200 mJ/5Hz) built and
delivered by Fibertek to NASA LaRC**



2-micron Risk Reduction Laser Transmitter

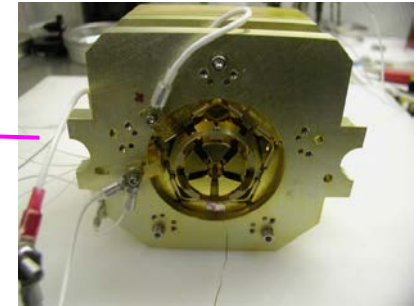
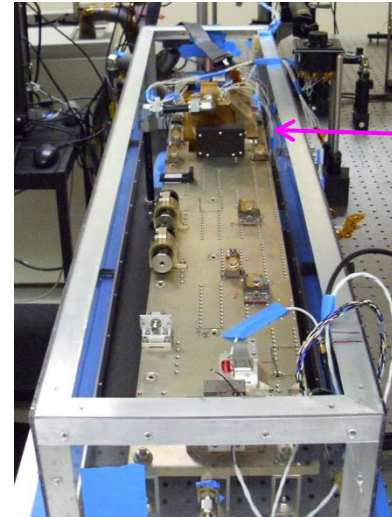


Design and Fabrication of a Breadboard, Fully Conductively Cooled, 2-Micron, Pulsed Laser for the 3-D Winds Decadal Survey Mission

PI: Upendra Singh, NASA LaRC

Objective

- Design and fabricate a space-qualifiable, fully conductively-cooled, 2-micron pulsed laser breadboard meeting the projected 3-D Winds mission requirements
 - Utilize improvements in key technologies including high-power, long-life space-proven 804 nm pump diodes; derated diode operation, and heat pipe conductive cooling
- Perform a long-duration life test on the laser system to evaluate mission readiness.



2-Micron Space Qualifiable Pulsed Laser for 3-D Winds
Left: early breadboard,
Above: ruggedized laser head

Approach

- Leverage LaRC 2-micron laser development from earlier efforts
- Utilize Fibertek CALIPSO mission flight laser design and development knowledge
- Upgrade previous Fibertek two-micron laser design for flight-like laser based on space heritage
- Utilize space-ready, sealed cylindrical package
- Perform vacuum and lifetime tests while operating at the output requirements of the 3-D Winds mission

Key Milestones

- | | |
|---|-------|
| • Complete laser mechanical design update and improved laser thermal modeling | 01/13 |
| • Assemble and test heat pipe cooled module | 04/13 |
| • Fabricate and test ring laser with heat pipe cooled module | 12/13 |
| • Install and test amplifiers | 03/14 |
| • Integrate with canister and test | 04/14 |
| • Vacuum-test laser | 10/14 |
| • Complete 8 months of life testing | 03/15 |
| • Complete analysis and performance testing | 04/15 |

Co-Is/Partners: Jirong Yu, Michael Kavaya, LaRC;
Floyd Hovis, Tim Shuman, Fibertek, Inc.

$TRL_{in} = 3$ $TRL_{current} = 3$

Objectives of ACT

- Advance the technical maturity of a solid state 2 μm laser to TRL-5
- Fabricate a ruggedized, conductively-cooled, high energy solid state 2 μm laser transmitter meeting the performance requirements of an airborne or space-borne coherent detection or hybrid wind LIDAR system
- A thermal vacuum test will be used to demonstrate achievement of TRL-5

Basic Performance Goals

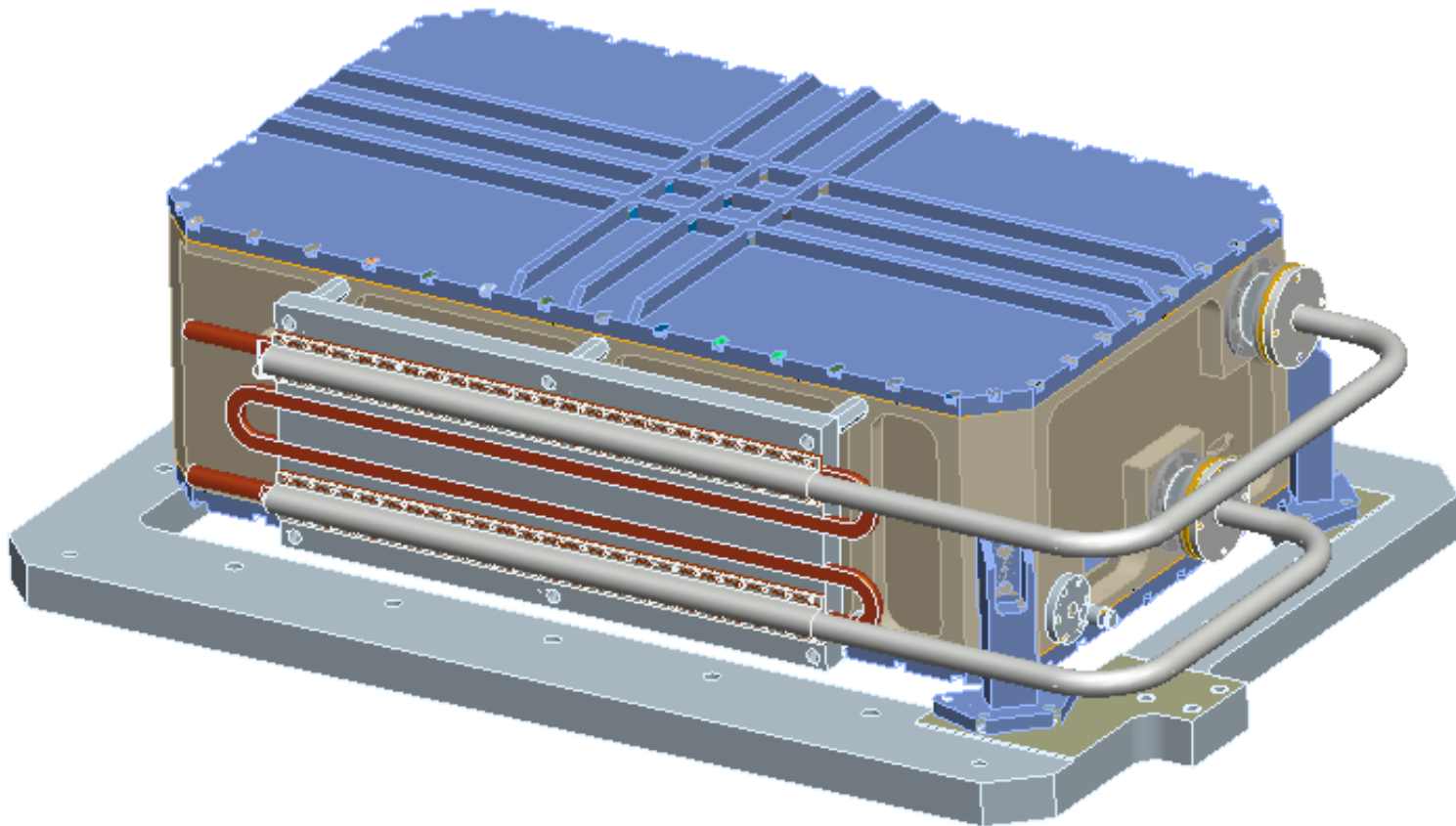
Wavelength	2.053 microns
Laser Pulse Energy	250 mJ
Repetition Rate	10 Hz
Pulse Width	>100 ns
Beam Quality	$M^2 < 1.2$
Pulse Spectrum	Single frequency (seeded)
Cooling	Conductively cooled via heat pipes
Laser Head Size	23.9" x 14" x 7.7" (L x W x H) Including heat pipes and condenser



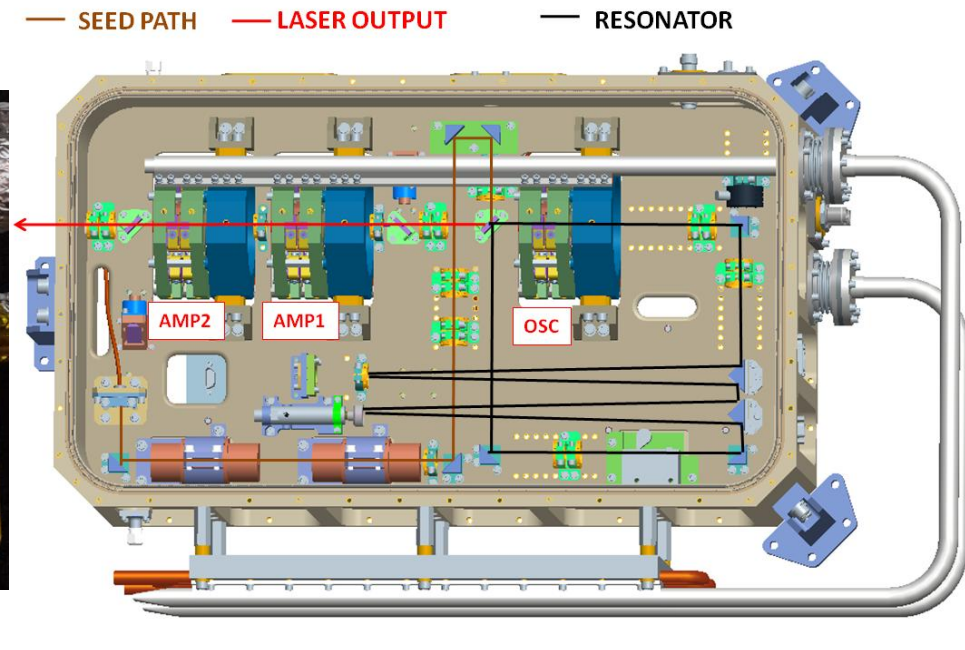
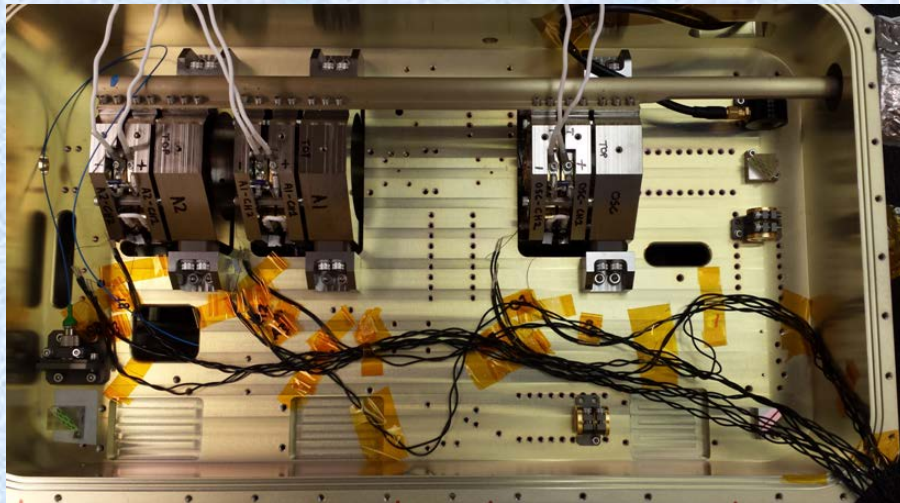
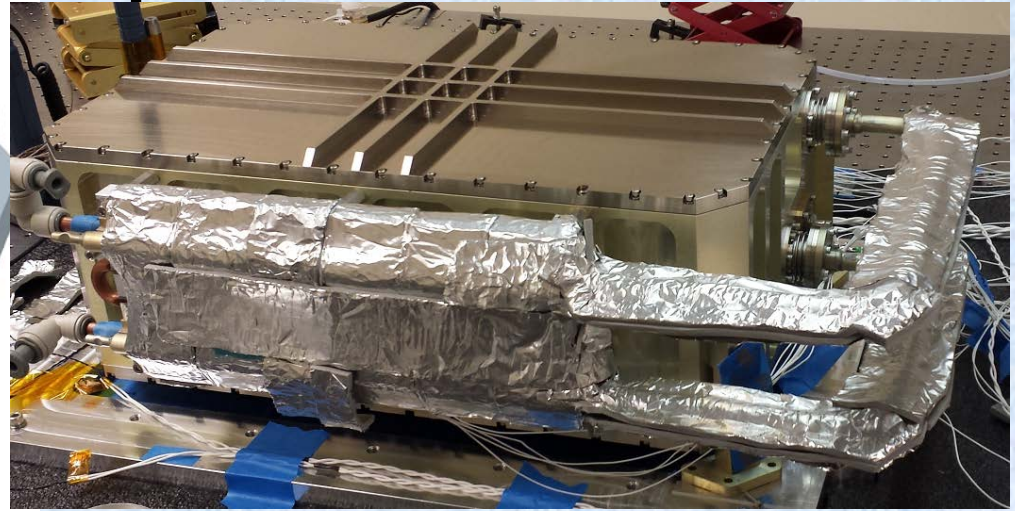
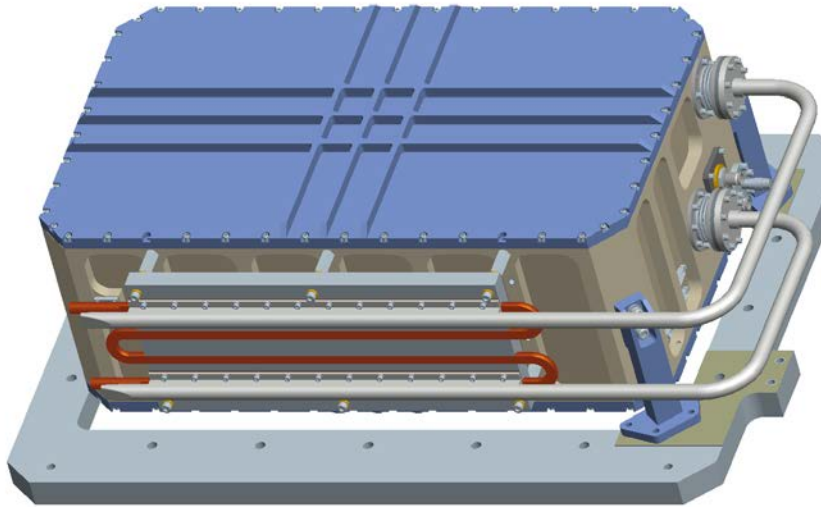
Conductively Cooled 2 μm Laser in Expanded ICESat-2 Housing

Box dims: 19"x11"x7.1" (LxWxH)
ICESat-2: 16"x11"x4.4" (LxWxH)
Mounting feet for illustration only

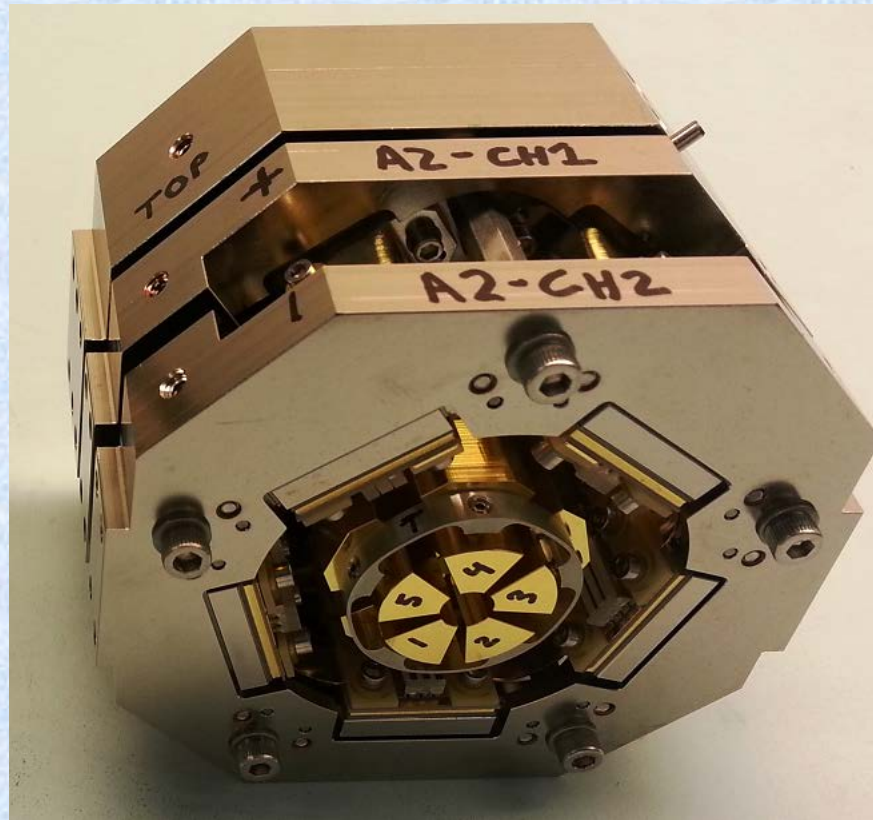
Housing itself: 19"L x 11"W x 6.1"H
Complete assembly : 23.9"L x 14"W x 7.7"H



Conductively Cooled Laser



Pump Module Design & Hardware

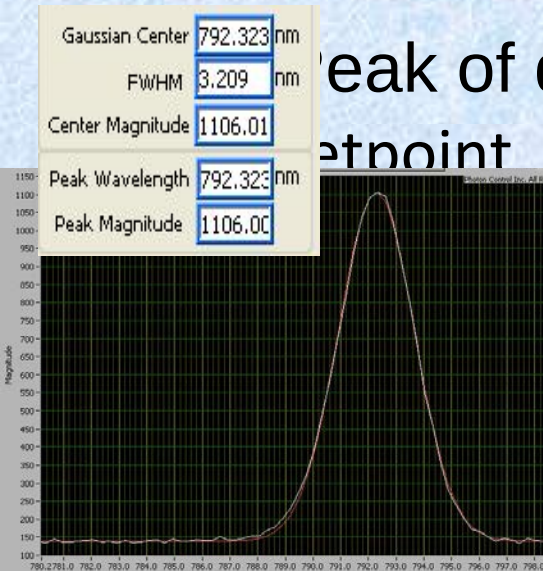


Thermal Management Performance

- Heat pipes are able to cool the laser with a total input load of 199.5 W

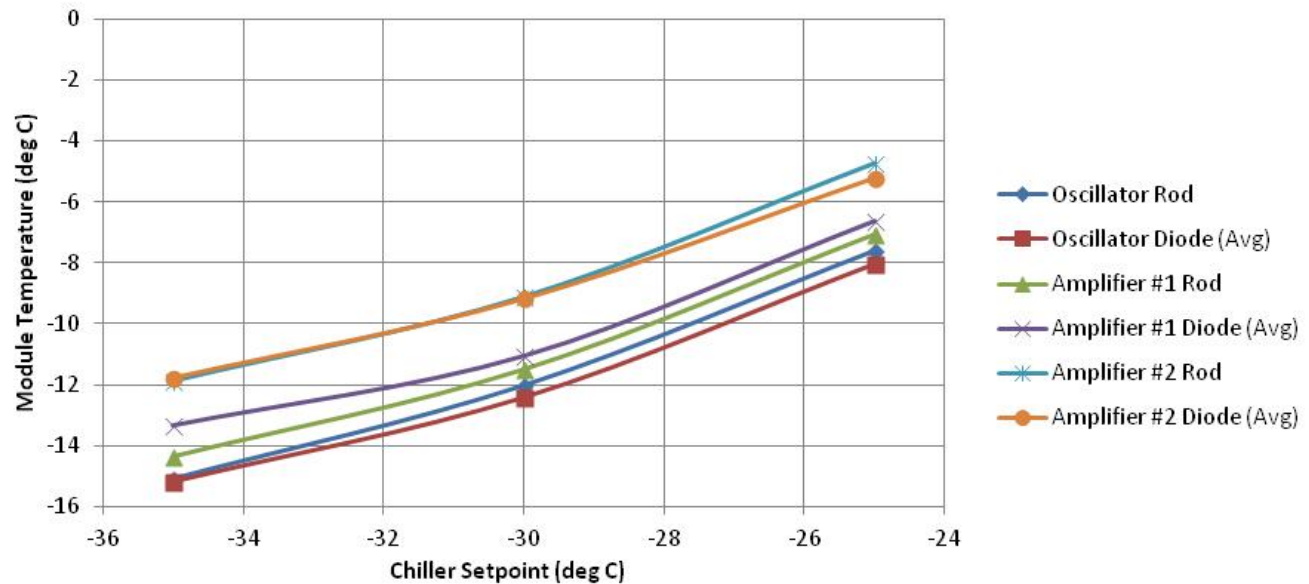
– 3.6 J design energy per pulse at 100 W

Peak of c
etpoint

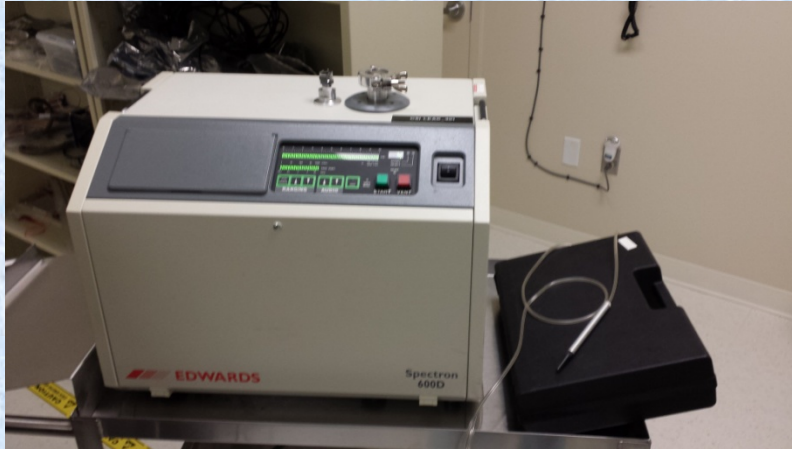


750 μ s, 150 A, -30 deg C
Emission Spectrum

Modules Temperatures vs. Chiller Setpoint at 3.6 J
Operating Point



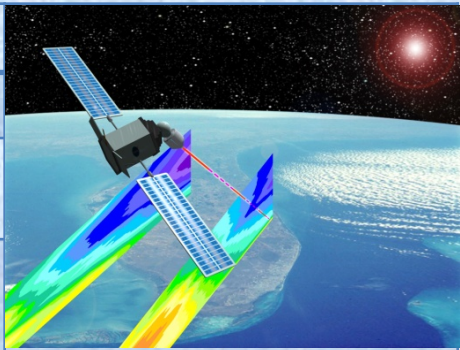
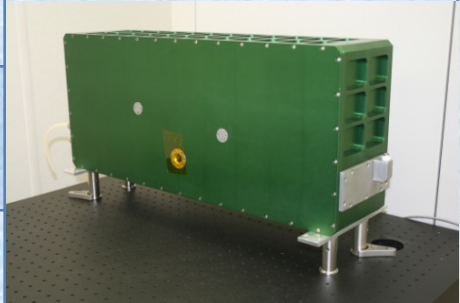
Initial Pressure Test



- Filled sealed housing with ~5 psi of helium
- Used helium sniffer around all joints and screws to look for leaks
- None found meaning structure seals are sufficient for the thermalvac test



Advancements Dramatically Lower Risk of Winds Space Mission

Past		Today	
525 km		400 km	
12 cross-track positions		2 cross-track positions	
1 shot measurement		Multiple shot accumulation	
Continuously rotating 1.5 m telescope		4 stationary 0.5 m telescopes	
Single coherent Doppler lidar		Dual coherent & direct hybrid Doppler lidar	
Gas laser		Solid-state eyesafe laser	
20 mJ 2-micron solid state energy		1200 mJ 2-micron solid state energy	
Space required energy = 20 J		Space required energy = 0.25 J	
Energy deficit = 1,000		Energy surplus = 5	
			Conductively Cooled Laser

➤ From a 20-J, 10-Hz gas laser with 1.5-m diameter rotating telescope, to a 0.25-J, 10-Hz solid-state eyesafe laser with non-moving 0.5-m telescopes!



Questions?

