Development of a Space-qualifiable, Conductively-cooled 2-micron Coherent Lidar Transmitter for Global Wind Measurements

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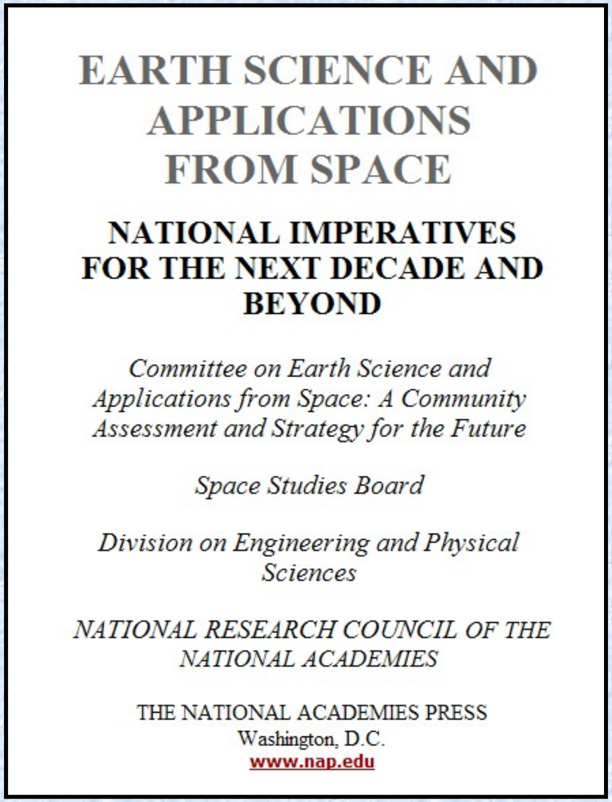
Working Group on Space-based Lidar Winds
Boulder, Colorado
April 28-29, 2015,

Outline

- **Background and motivation**
- **Technology Development**
  - Compact 2μm wind lidar transceiver
  - Conductive cooled 2μm Oscillator/Amplifier development
- **Ground and Airborne campaigns**
- **Fully Conductively-cooled Risk Reduction Laser**
- **Conclusions**

Motivation for 2µm Laser/Lidar Development
NRC Recommended "3-D Winds" Mission

"Knowledge derived from global tropospheric wind measurement is an important constituent of our overall understanding of climate behavior .[1]"



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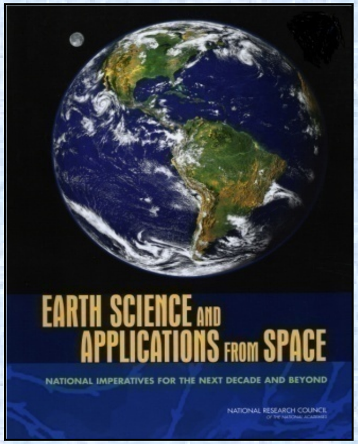
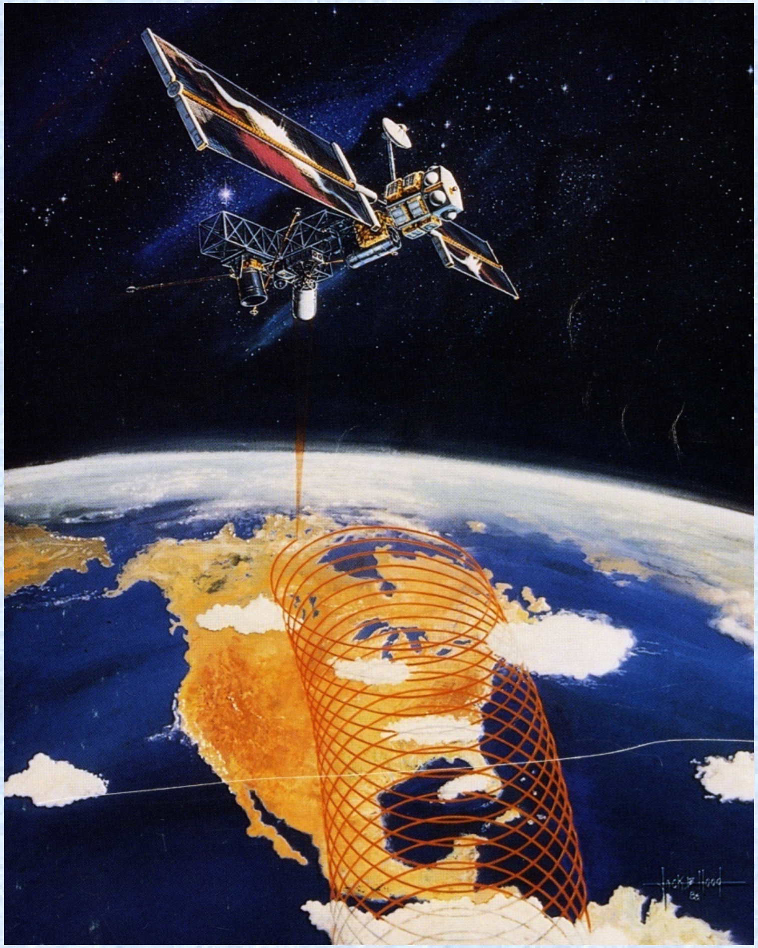


Global Winds 9 Societal Benefits	
Extreme Weather Warnings	✓
Human Health	✓
Earthquake Early Warning	
Improved Weather Prediction	**✓#1**
Sea-Level Rise	
Climate Prediction	
Freshwater Availability	
Ecosystem Services	
Air Quality	✓

[1] Baker et al., *Lidar measured Wind Profiles – The Missing Link in the Global Observing System*, Bulletin American Meteorological Society. 95 (4), 515-519 (April 2014)

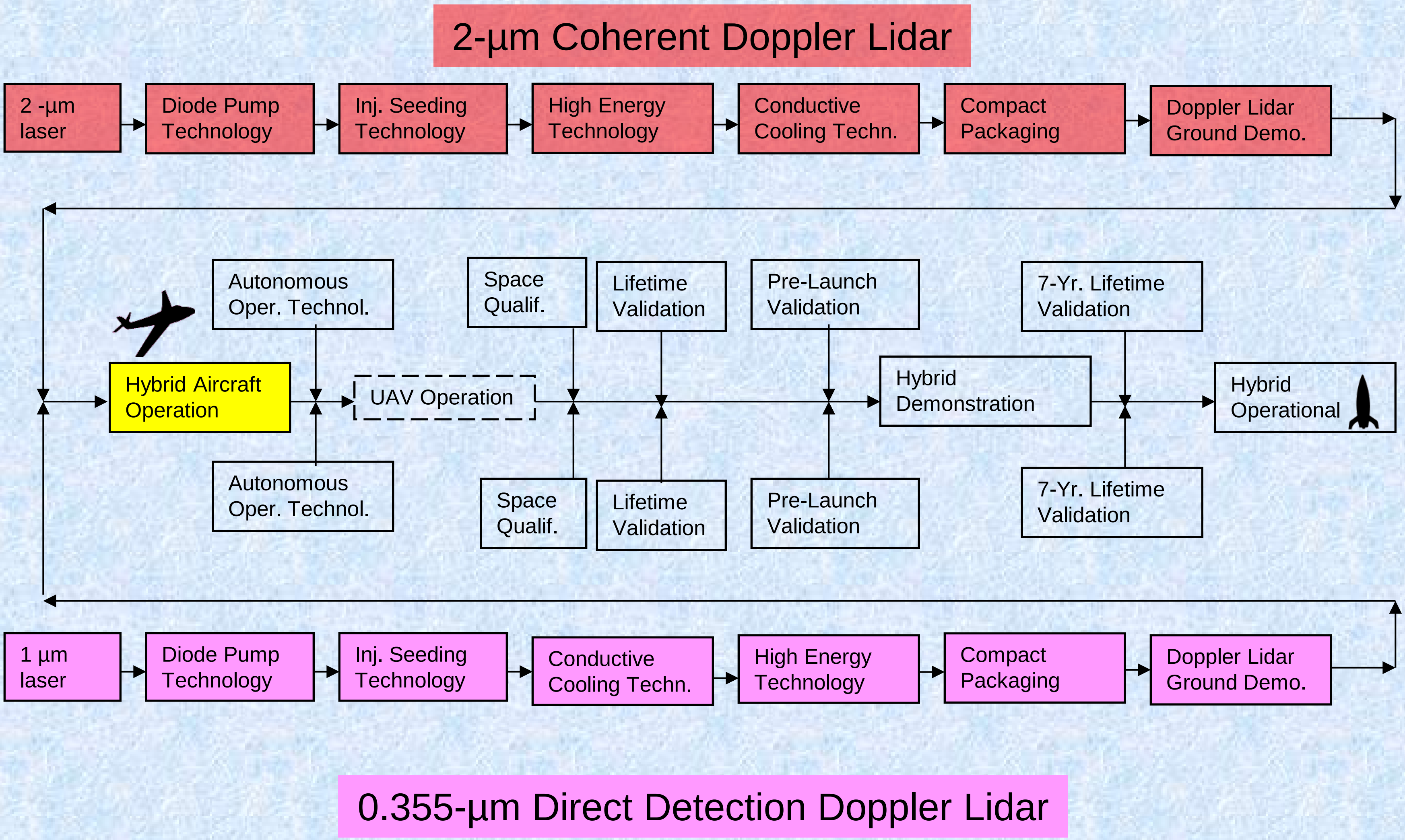
Early Mission Concept for Earth Winds
Laser Atmospheric Wind Sounder (LAWS)



- 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

- Required: eye-safe laser

Space-Based Doppler Wind Lidar



Global Winds Approach Using Hybrid Doppler Lidar

Basic Performance Goals for 2µm Doppler Lidar

Wavelength	2.053 -µm
Laser Pulse Energy	250 mJ
Repetition Rate	10 Hz
Pulse Width	>150 ns
Beam Quality	M^2< 1.2
Pulse Spectrum	Single frequency (seeded)
Cooling	Conductively cooled via heat pipes
Laser Size	23.9” x 14” x 7.7” (L x W x H) Including heat pipes and condenser

Laser Risk Reduction Program (LaRC-GSFC)

(NASA HQ Funded Directed Program 2001-2010)

2 Lasers, 4 Techniques, 6 Priority Measurements

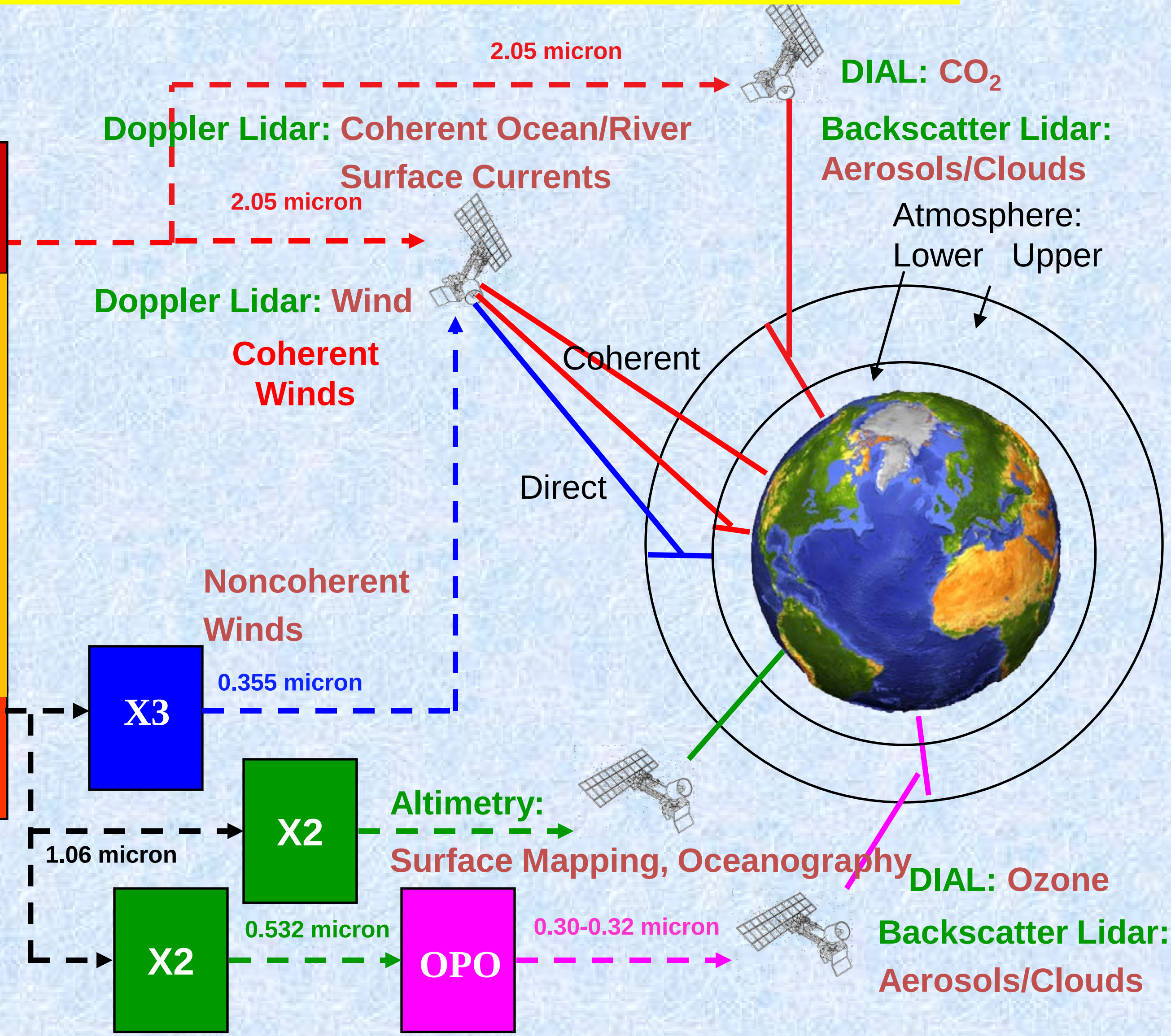
Pulsed Laser Development

2 MICRON

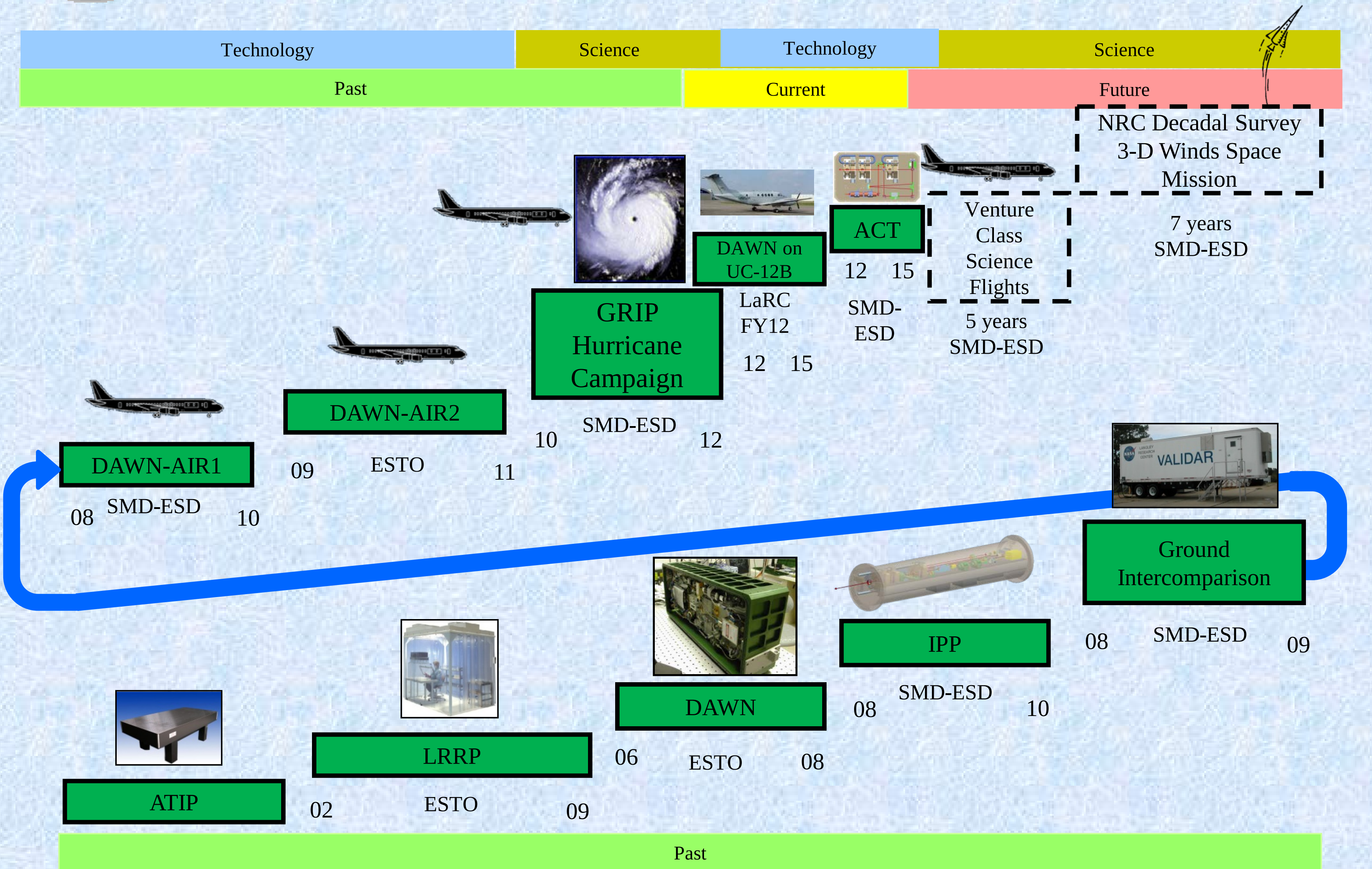
Key Technologies in Common

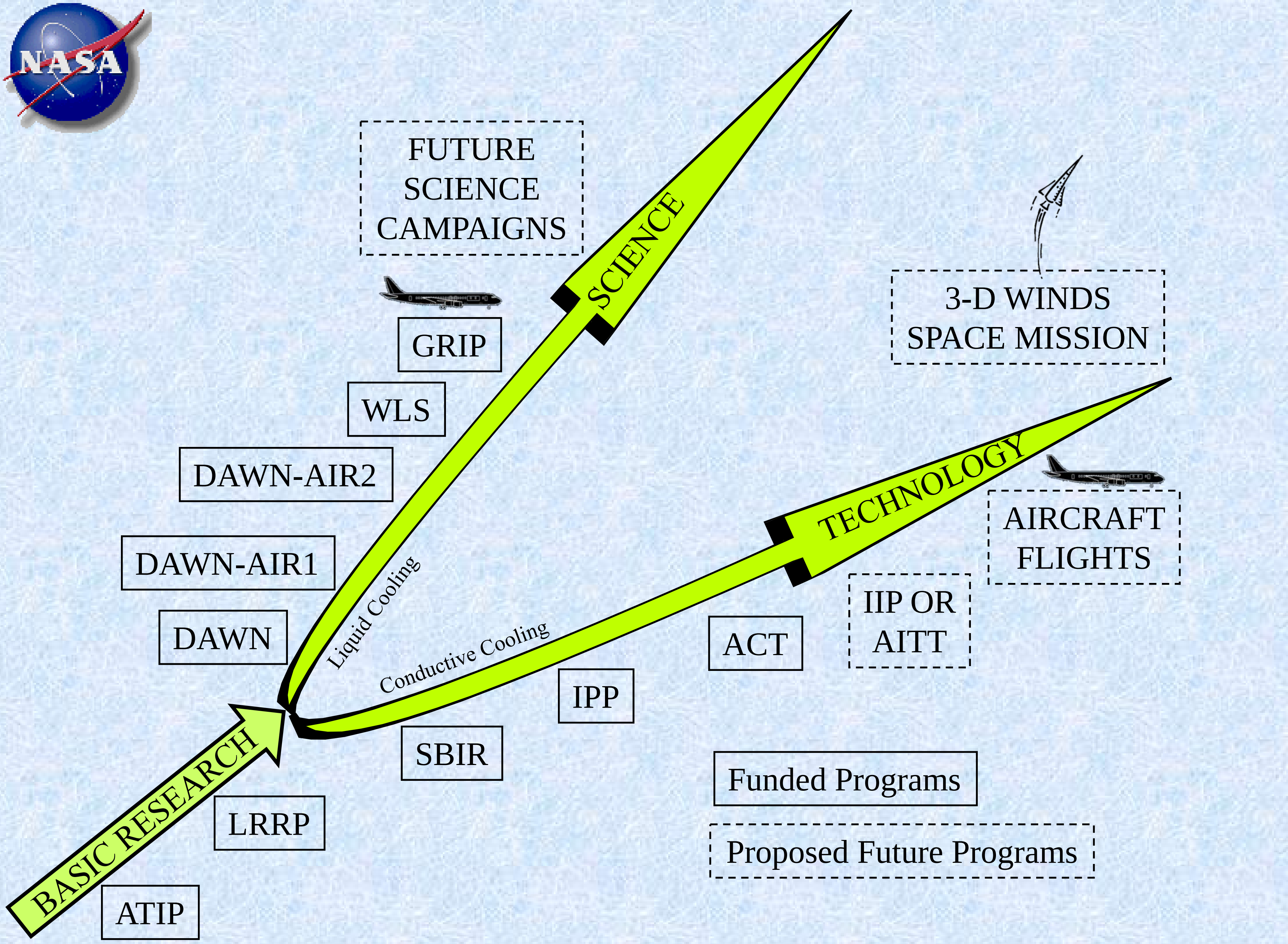
- Laser Diodes
- Laser Induced Damage
- Frequency Control
- Electrical Efficiency
- Heat Removal
- Ruggedness
- Lifetime
- Contamination Tolerance

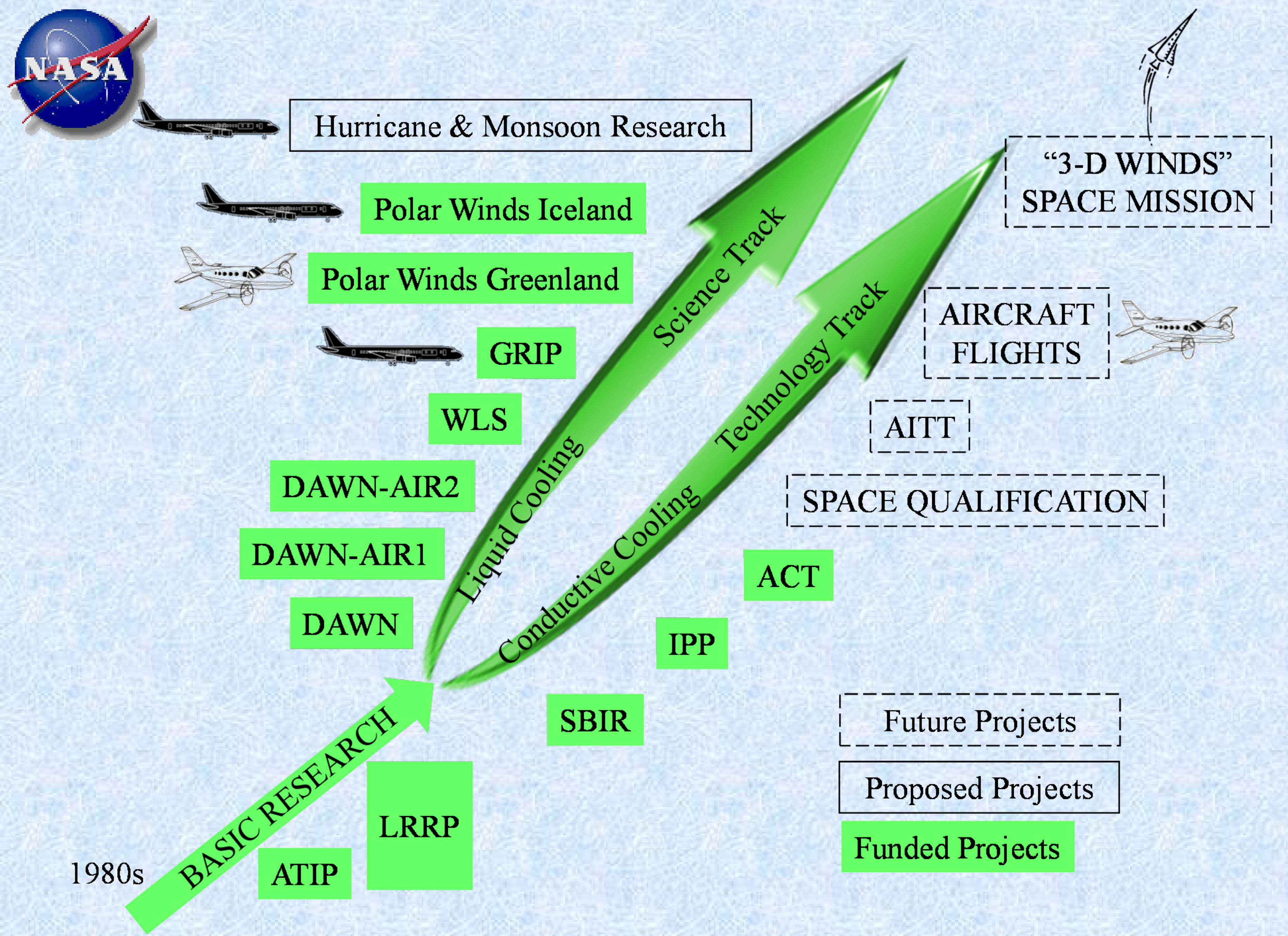
1 MICRON



Process to 3-D Winds Space Mission at NASA Langley



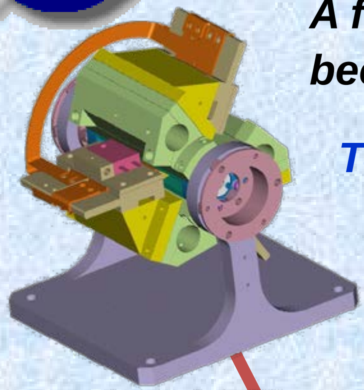

FUTURE SCIENCE CAMPAIGNS
SCIENCE
GRIP
WLS
DAWN-AIR2
DAWN-AIR1
DAWN
Liquid Cooling
3-D WINDS SPACE MISSION
TECHNOLOGY
AIRCRAFT FLIGHTS
IIP OR AITT
ACT
Conductive Cooling
IPP
SBIR
BASIC RESEARCH
LRRP
ATIP
Funded Programs
Proposed Future Programs


Hurricane & Monsoon Research
Polar Winds Iceland
Polar Winds Greenland
GRIP
WLS
DAWN-AIR2
DAWN-AIR1
DAWN
LRRP
ATIP
1980s
BASIC RESEARCH
Science Track
Liquid Cooling
Technology Track
Conductive Cooling
"3-D WINDS" SPACE MISSION
AIRCRAFT FLIGHTS
AITT
SPACE QUALIFICATION
ACT
IPP
SBIR
Future Projects
Proposed Projects
Funded Projects

Wind Lidar Technology Maturation

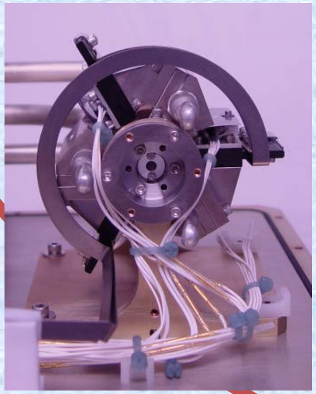
A fully conductively cooled 2-micron solid-state pulsed laser has been demonstrated for the first time.

Technology Enables: Measurement of global 3-D Winds



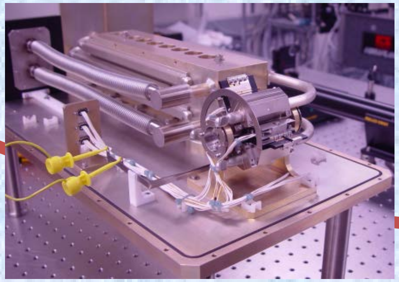
Analysis & Design

Quantum Mechanical Modeling



Fabrication

Space Qualifiable Design

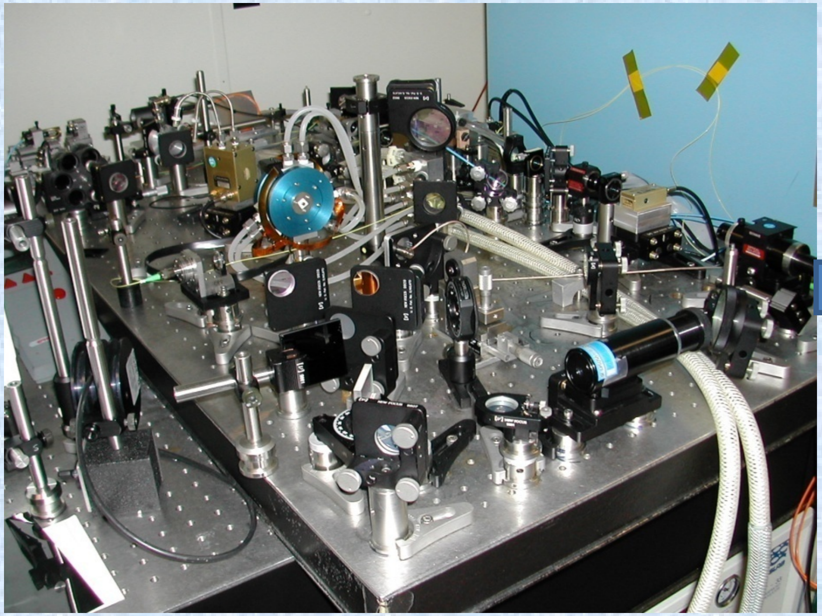


System Integration

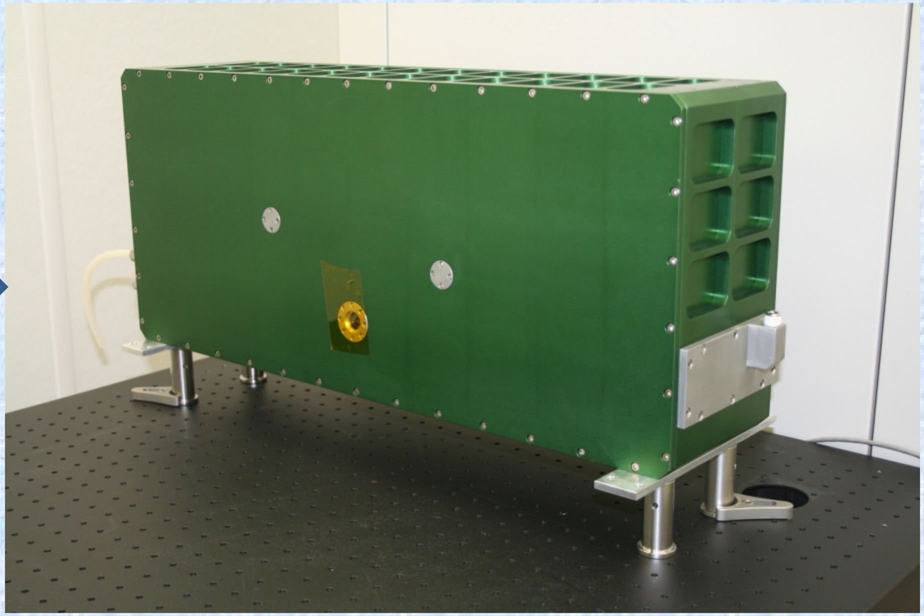
Testing and Model Verification

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

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



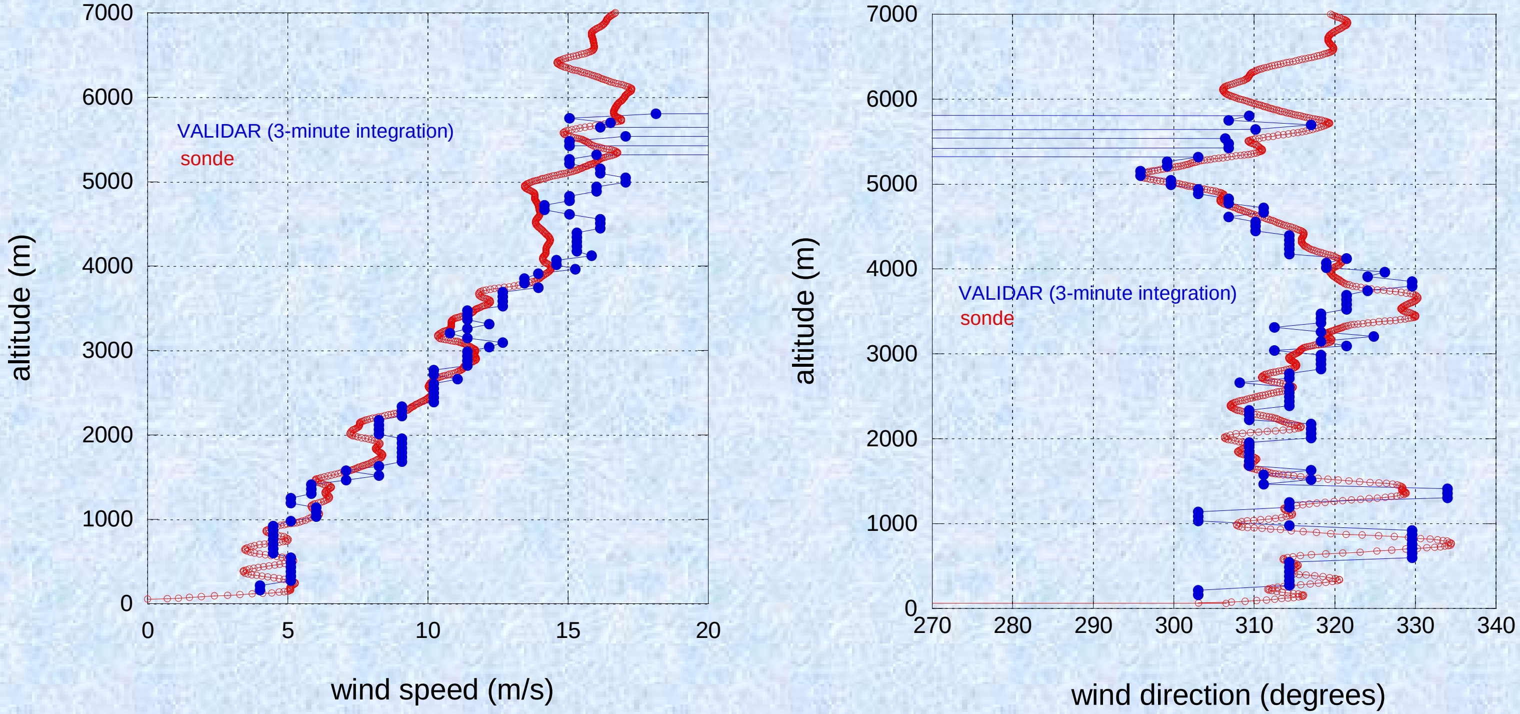
Engineered Transceiver
250 mJ/pulse, 10 pulses/sec.
5.9" x 11.6" x 26.5", 75 lbs.;
15 x 29 x 67 cm, 34 kg
(no telescope or scanner)



Ground-Based Hybrid Wind Lidar Demo

- The LaRC mobile lidar is deployed as part of NASA HQ funded Program
- Utilized NASA LaRC Compact DAWN Lidar Transceiver for 2-μm lidar
- Site at Howard University Research Campus in Beltsville, Maryland

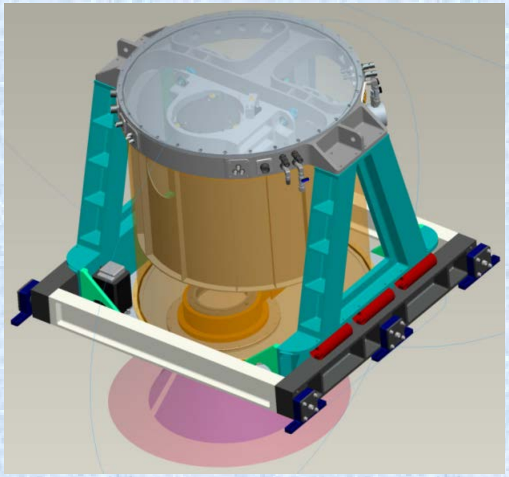
Comparison of Coherent Lidar and Sonde

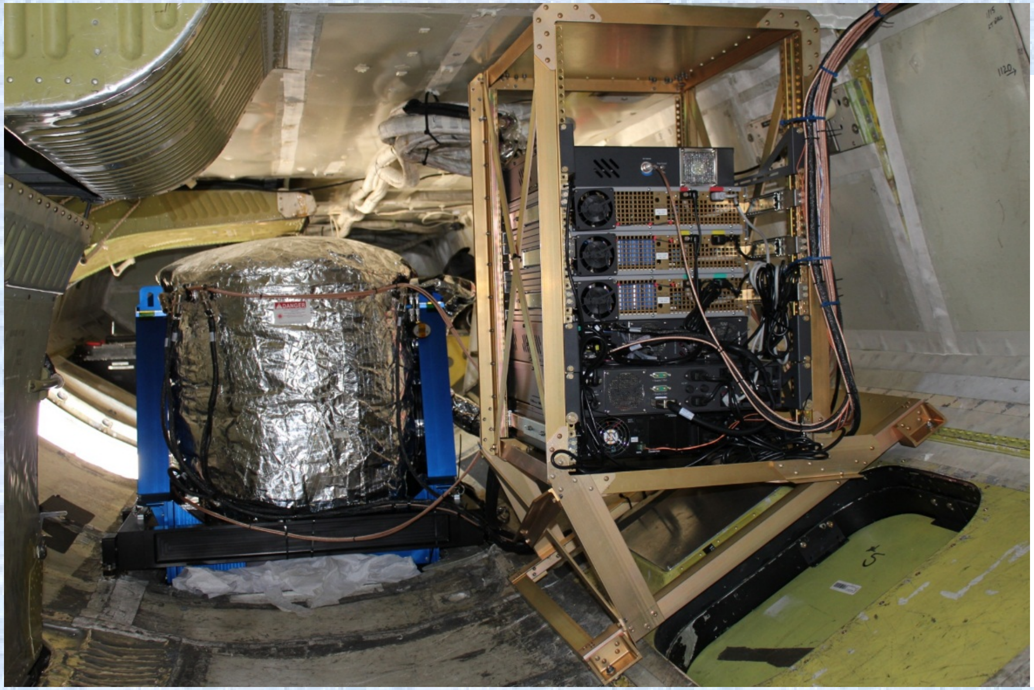


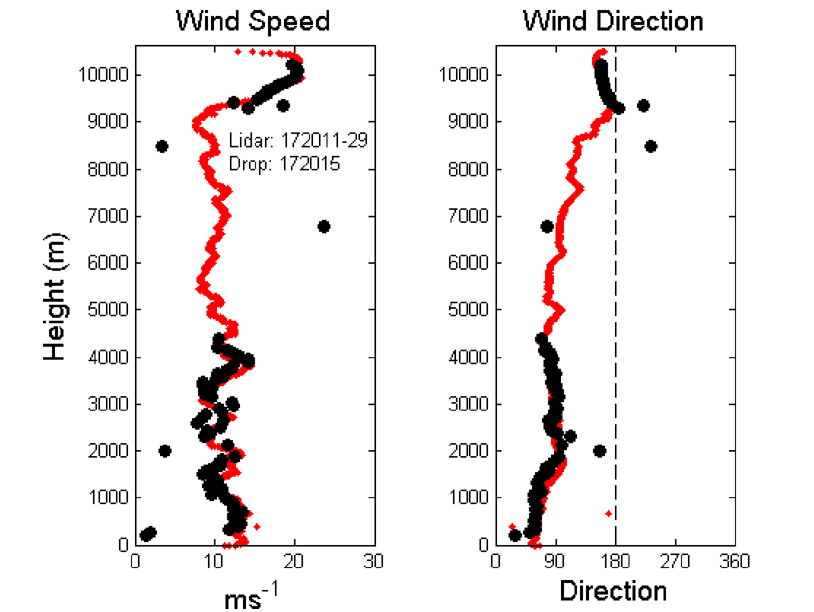
- Root-mean-square of difference between two sensors for all points shown is **1.06 m/s** for wind speed and **5.78 deg.** for wind direction

DC-8 Wind Lidar During GRIP (2010)

- Harden the transmitter for airborne application
- Add telescope and scanner within the enclosure
- Airborne wind measurement during GRIP campaign







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)

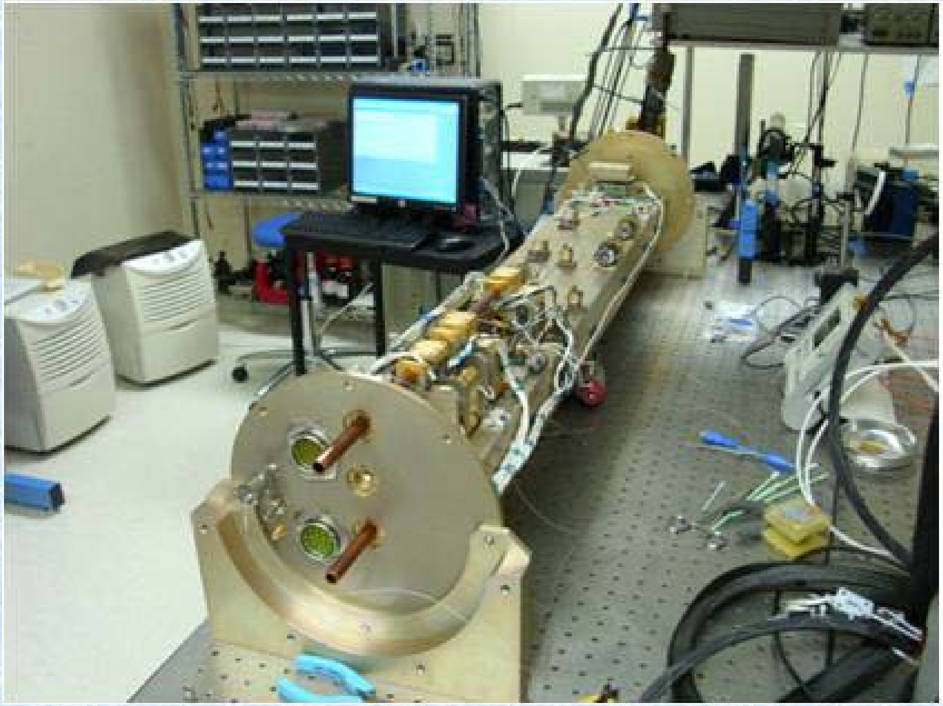
Partnership with Fibertek:

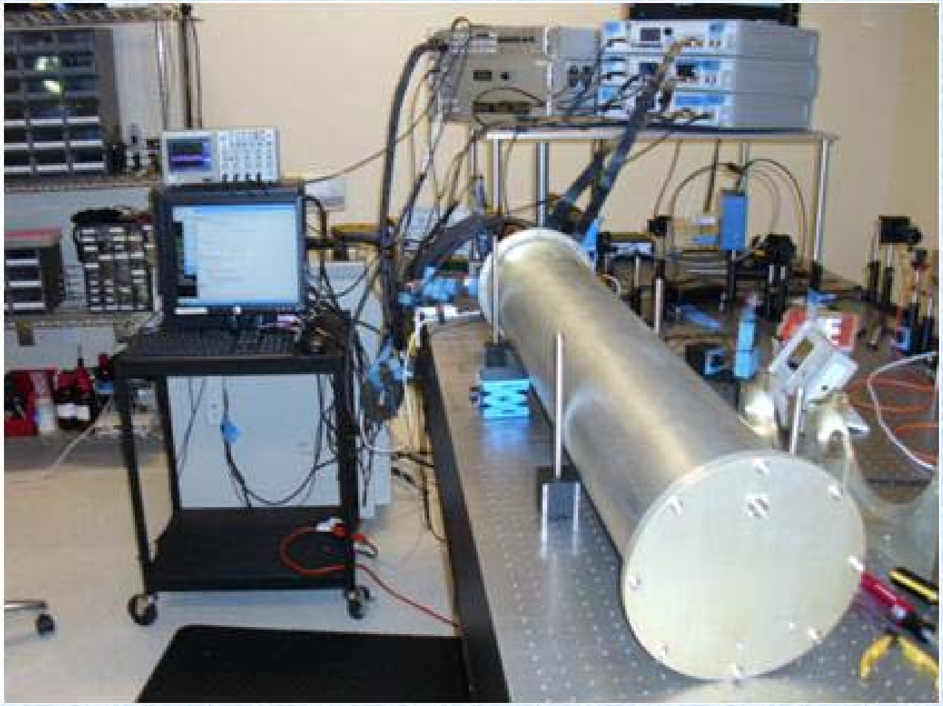
- **Innovative Partnership Program (LRRP/ESD/Fibertek)**
  - 3-m cavity, 792 nm pumped, conductively cooled 200 mJ, single frequency output at 5 Hz – first generation
- **Advanced Component Technology (LaRC/ESTO/Fibertek)**
  - Compact, 1.5 meter cavity, 808 nm pumped, fully conductively cooled laser 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



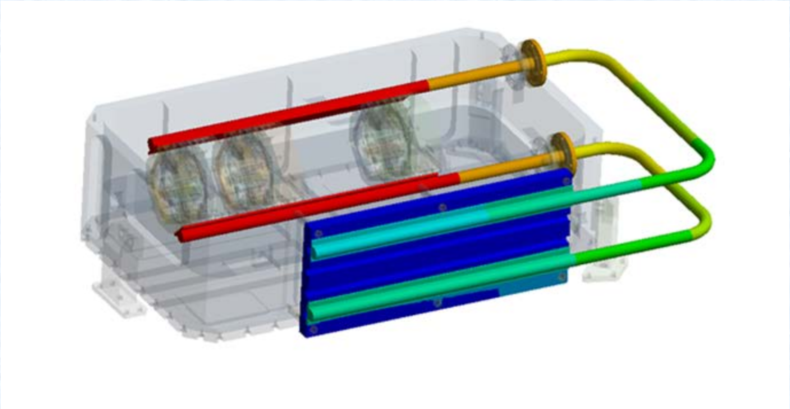


2-micron Risk Reduction Laser Transmitter

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

- 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

- 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 test while operating at the output requirements of the 3-D Winds mission

• 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 acceptance testing	07/15
• Complete analysis and performance testing	12/15

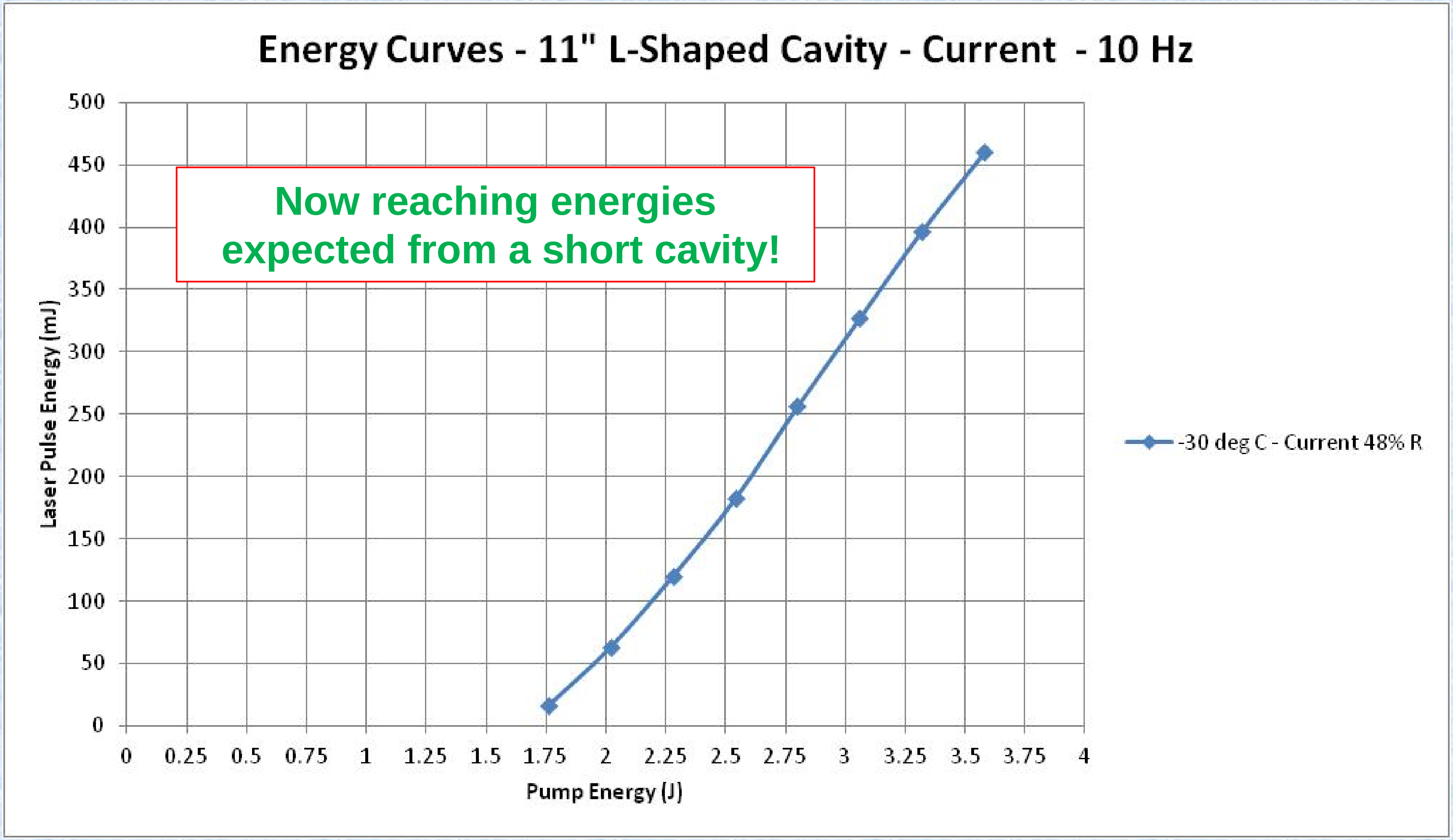
TRL_{in} = 3 TRL_{out} = 5

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

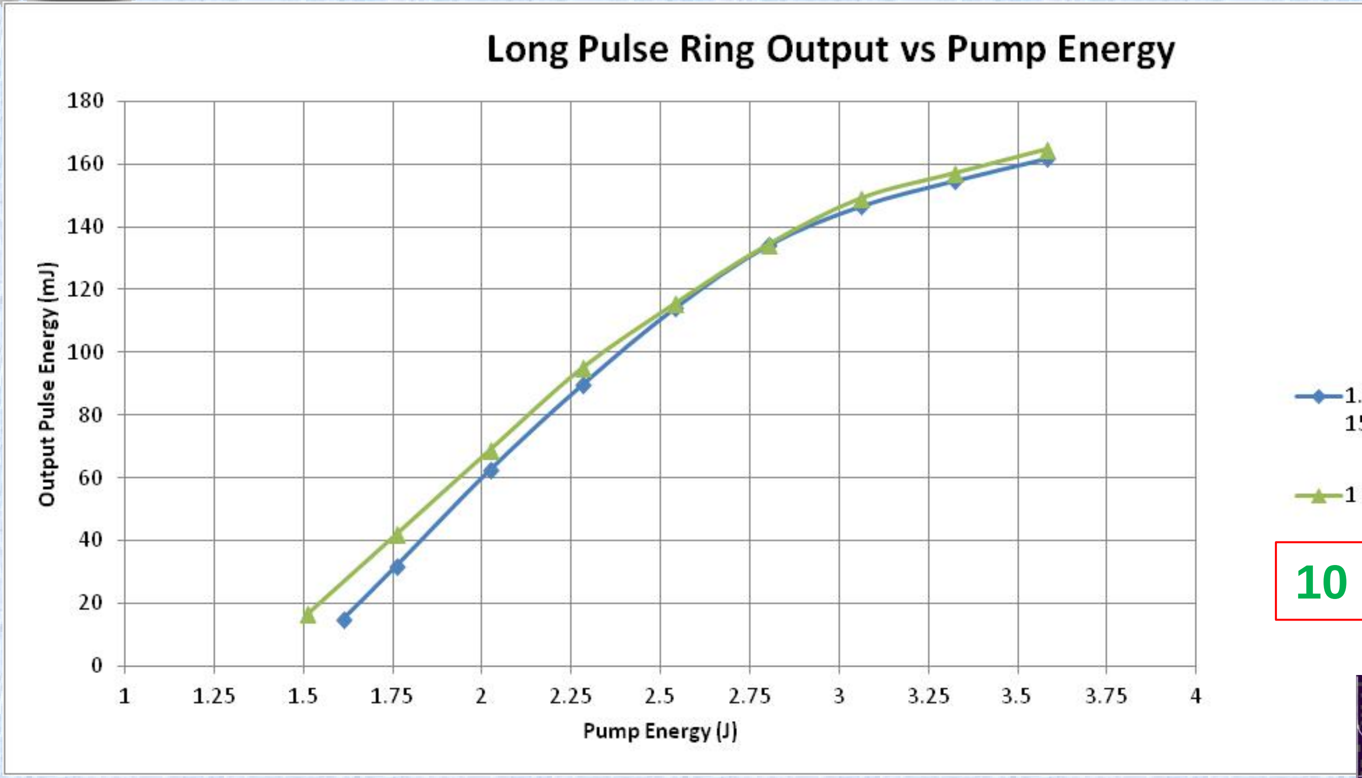
ACT Program Summary

- **Technical Objective(s)–**
  - *Deliver a ruggedized 2.053 µm MOPA laser with the following parameters:*
    - *250 mJ pulse energy*
    - *10 Hz repetition rate*
    - *Beam quality (M^2) < 1.2*
    - *>100 ns pulse width*
    - *Conductively cooled via heat pipes*
  - *Reach Technical Readiness Level (TRL) 5 by surviving a thermal-vac test.*
- **Period of Performance** – *38 months*
- **Deliverable Items -** *2 µm laser meeting the performance requirements after surviving a thermal vac test, monthly technical and financial reports, quarterly and yearly financial reports, thermal vac test definition and results report, oscillator test procedure and results report, final technical report*
  - *2 µm laser transmitter meeting the performance requirements and surviving a thermal-vac test*
  - *Thermal vac test procedure and results report*
  - *Oscillator and amplifier performance report*

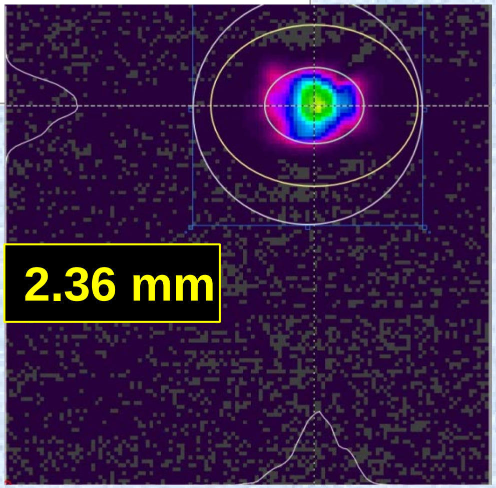
Linear Cavity Data



Current Ring Laser Results – Long Pulse



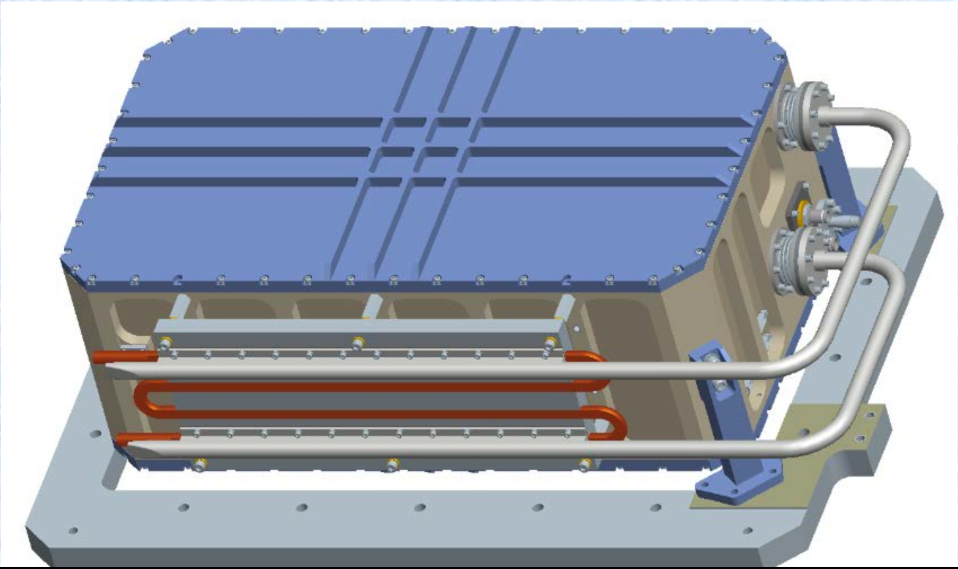
10 Hz, 150 A



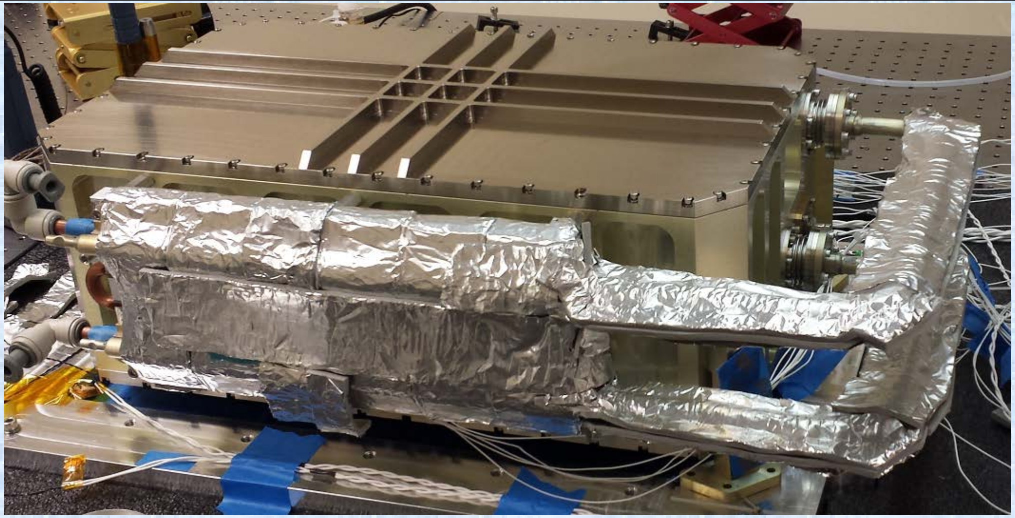
Expect 80 mJ of Q-switched output for 3.6 J of pump energy

Phase II achieved 3X amplification – on track for 240 mJ after amplifier pair

Conductively Cooled Laser Design

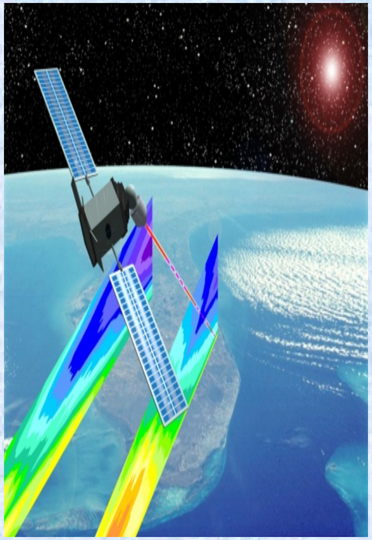


Box dims: 19”x11”x7.1” (LxWxH) **ICESat-2**: 16”x11”x4.4” (LxWxH) Mounting feet for illustration only	**Housing itself: 19”L x 11”W x 6.1”H** **Complete assembly : 23.9”L x 14”W x 7.7”H**



Summary and Conclusion

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 2µm solid state energy	1200 mJ 2-µm solid state energy
Space required energy = 20 J	Space required energy = 0.25 J
Energy deficit = 1,000	Energy surplus = 5
2µm lidar not aircraft validated	2µm lidar is aircraft validated



Questions?