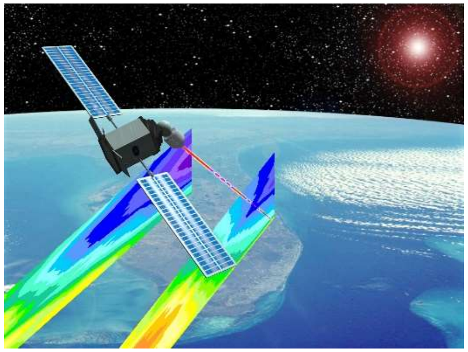
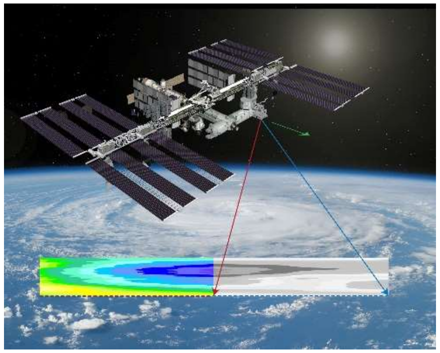


Advancement of Pulsed 2-Micron Coherent Wind Lidar Technology Towards Space Readiness

Michael Kavaya

Jirong Yu, **John Marketon,** Songsheng Chen, Larry Petway, Upendra Singh

NASA Langley Research Center, Hampton, Virginia 23681



Working Group on Space-Based Lidar Winds

Boulder, CO

7-8 Feb 2018

Wind-SP Project

- Funded by NASA HQ Earth Science Division

- Project Goals:
  - ✓ 1. Determine feasibility of a coherent space wind lidar
  - ☐ 2. Advance coherent space wind lidar components
  - ☐ 3. Ground demonstration

- Collaborative effort between:

NASA LaRC

Beyond Photonics

Simpson Weather Associates

Wind-SP Key Team Members

Langley
Michael Kavaya
John Marketon
Jirong Yu
Zhaoyan Liu

Larry Petway
Songsheng Chen
Diego Pierrottet
Connor Huffine

Beyond Photonics
Sammy Henderson
Charley Hale

Simpson Weather Associates
Dave Emmitt

FEASIBILITY OF COHERENT SPACE WIND LIDAR

3D Wind Space Pathfinder Conceptual Design Study

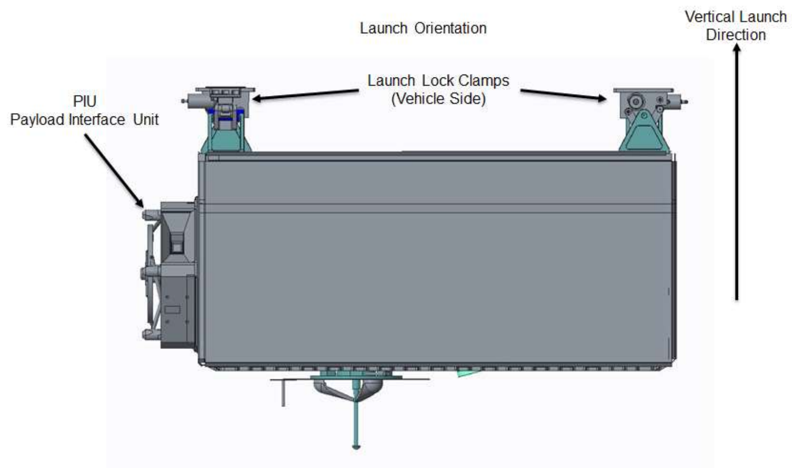
- LaRC Engineering Design Studio (EDS) session to determine feasibility of operating a Wind Space Pathfinder (Wind-SP) instrument on ISS

- ISS JEM-EF selected as the study "bounding box"

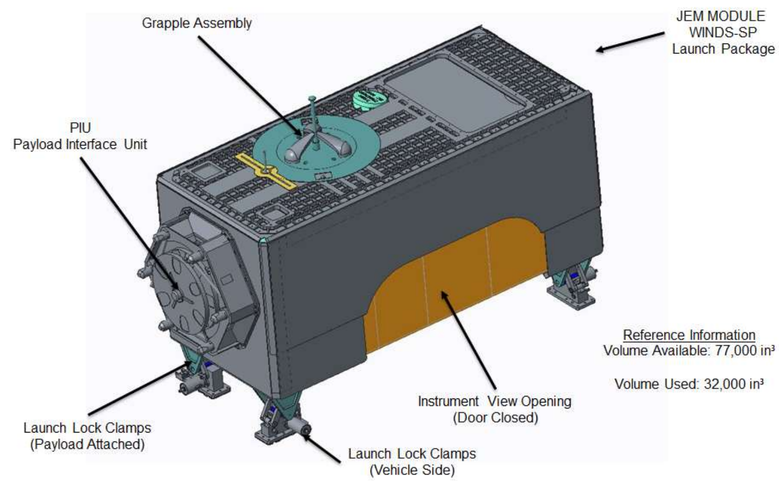
  All results apply equally to a freeflyer

- Session Objectives:
  - Develop a Wind-SP conceptual point design for ISS JEM-EF
  - Define system and subsystem designs and interfaces that meet JEM-EF constraints (mass, power, volume, look angles, and data rates)
  - Define technical risks for this concept
  - Develop parametric mission cost estimate
  - Assess achievable science based on closed point design for ISS

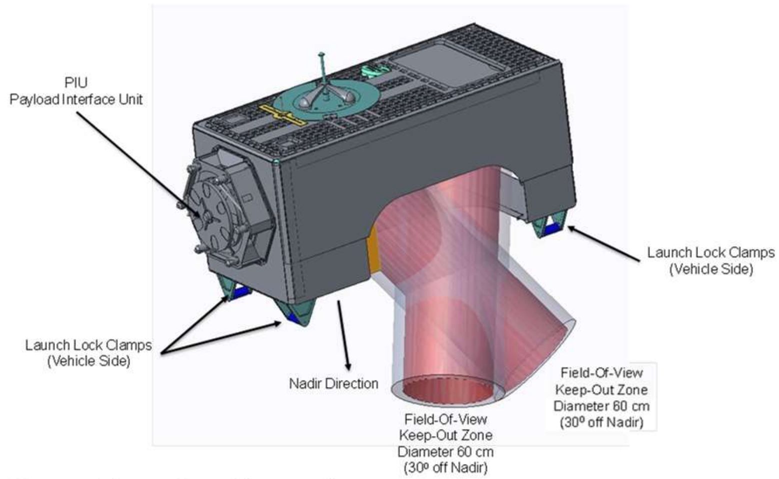
Wind-SP Payload Overview



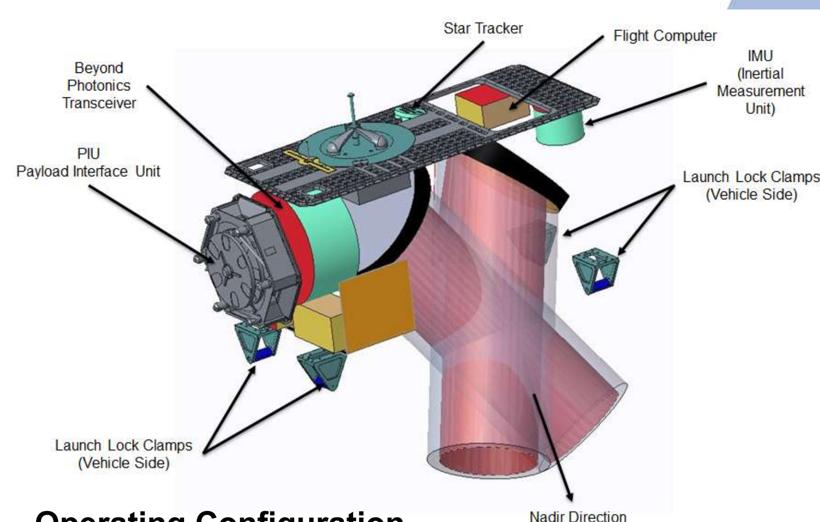
Launch Configuration
for installation in SpaceX Dragon Trunk



Installation Configuration
Aperture door closed

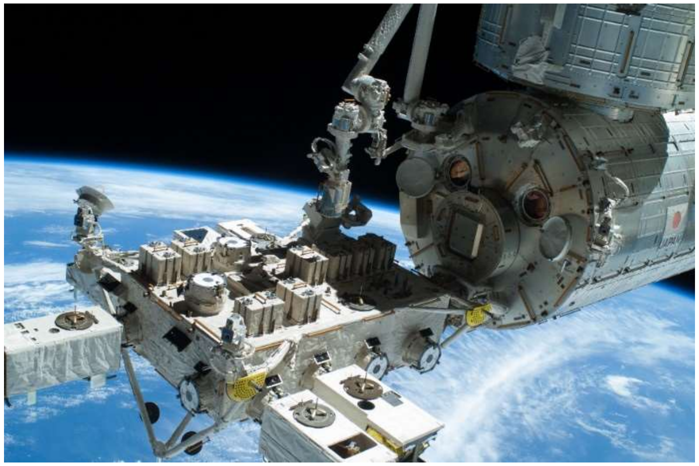


Operating Configuration
Aperture door open
Telescope field of view shown for illustrative purposes



Operating Configuration
JEM-EF enclosure removed for illustrative purposes

EDS Session Summary



Resource	Allocation*	EDS Conceptual Design
Mass*	1,150 lb (550 kg)	1010 lb (458.3 kg) (w/30% margin)
Volume	~73 x 32 x 41 in	Standard JEM-EF enclosure with ISS interface hardware. No envelope violations.
Power*	500-700 W, 120 V	720 W, 120 V (w/25% margin)
Thermal	Active cooling via fluid loop. Active heating (120 V heaters)	Active cooling via fluid loop during operation. Active survival heaters.
Data	1 Mbps 1553B ~50 Mbps Ethernet	< 1 Mbps system data ~30 MBS science data rate (>40% margin on science data)

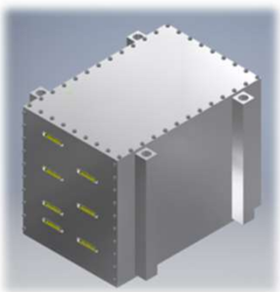
- **Most JEM-EF resources are shared and actual allocations are negotiated with services varying at different sites.*

- **Conceptual design developed for Wind-SP instrument installed on the ISS JEM-EF platform.**
- **Design complies with all major ISS and JEM-EF design constraints**
  - Mass, power, volume, instrument beam path, and data rates
- **Design complies with all major instrument design constraints**
  - Power, look angles, pointing knowledge and stability
  - Instrument support subsystems: power; data processing, storage, and transmission; instrument control; thermal control
- **Technical risks and a parametric mission cost estimate were defined**

Transceiver Elements & Power

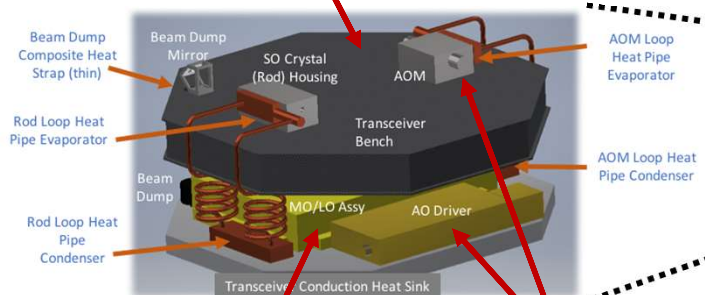
- **Main power consumers:**
  - Pump laser (Fibertek SBIR): ~20% efficiency, 470W max, run at 200W
  - Q-Switch: AOM 252W (current), moving to EOM 20W

Transceiver Control Electronics
9.6x7.4x7.8 in, 28 lbs,
~150 W Power, ~130 W Heat



LO, MOs Control
Offset Lock Electronics
Xcvr Health Monitoring Electronics
Injection Seed Servo Electronic
Transmitter Crystal TEC Control

Transceiver and MO/LO Benches
Transmitter + Bulk Optic
T/R Small Beam Assy.
20”. dia x 6”, 32 lbs
Laser Crystal /TEC Heat Load ~50W



LO / Mos Head + Fiber Route/Mix & Det Module
9x13x2 in, 11 lbs, 13 W

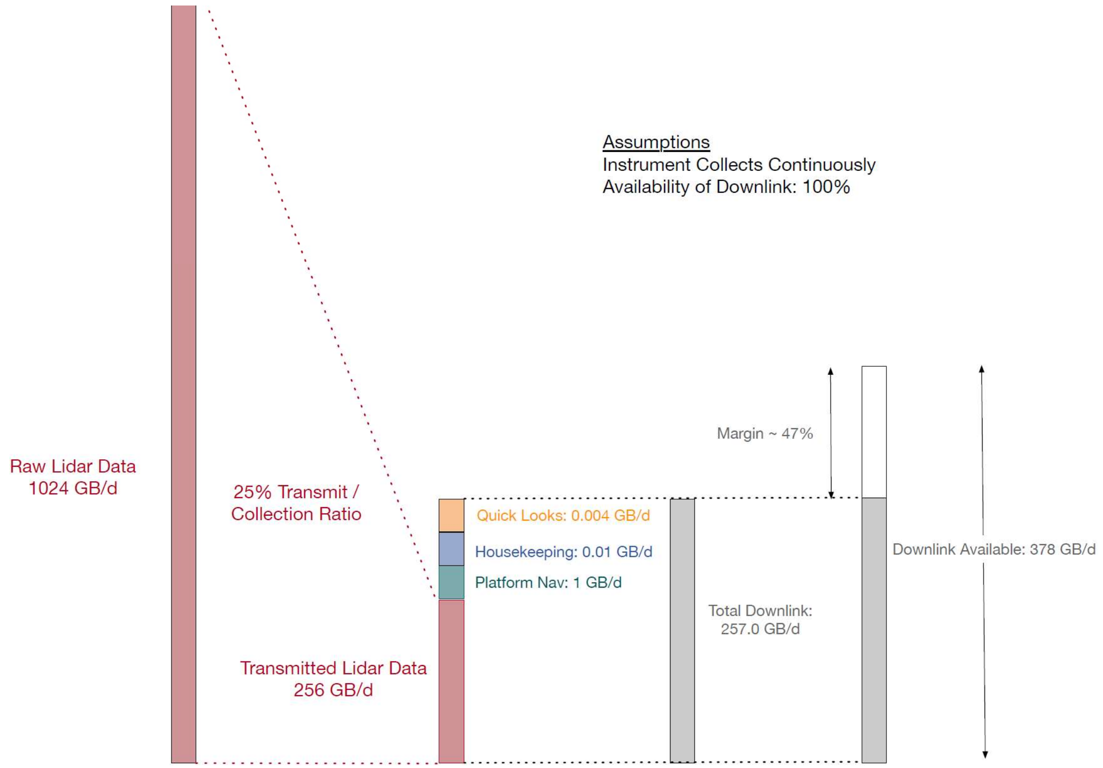
AO Shown – 252 W
EO Planned - <20 W

Transceiver Pressurized Enclosure
23" dia. x,10.5”high,
30 lbs empty, 87 lbs fully loaded

Data Downlink Bottleneck

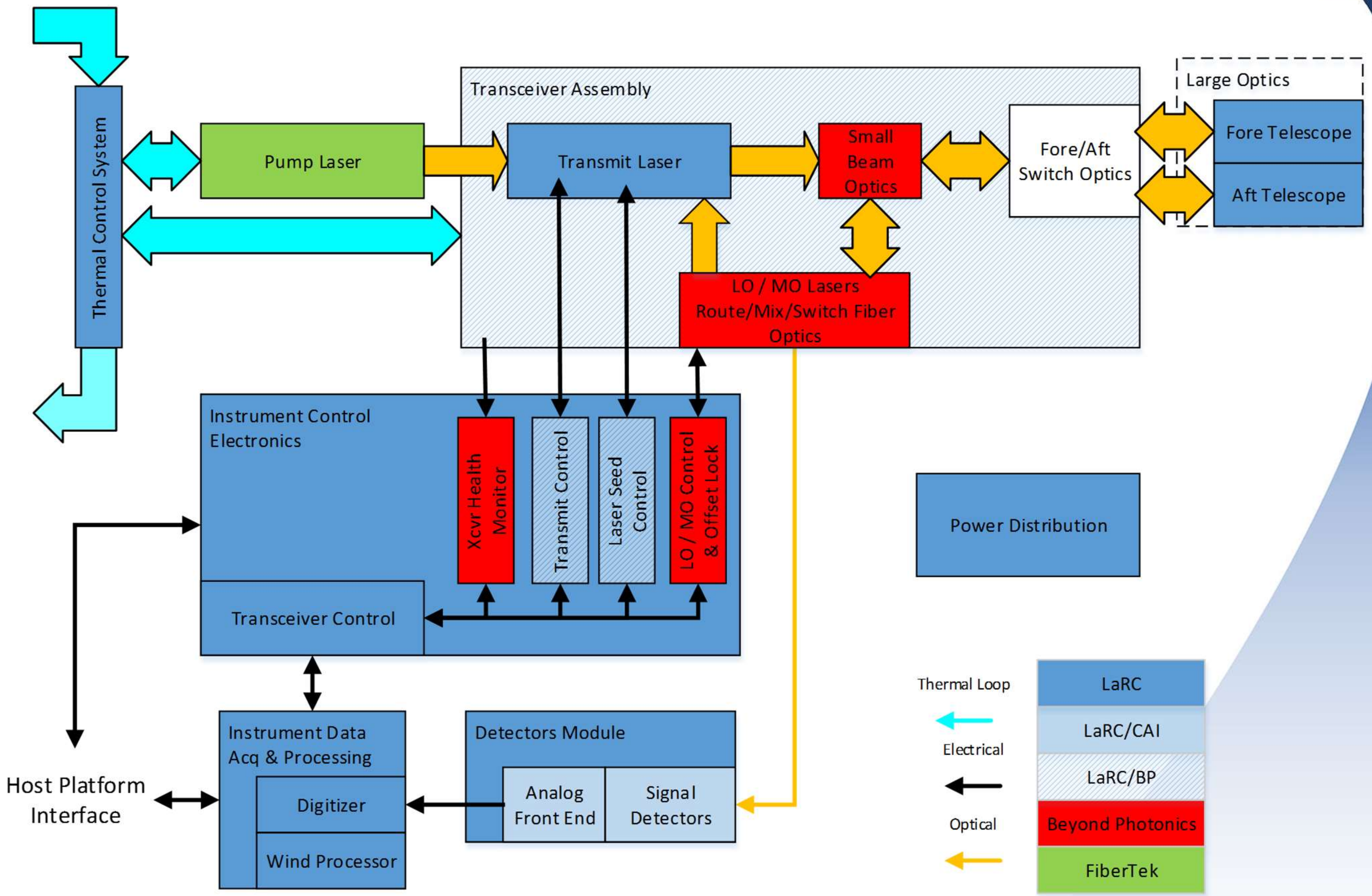
➤ **ConOps to reduce data volume:**

- Data collected and processed continuously: **~1TB/day**, 2 looks, 50% duty cycle
- On-orbit processing of QuickLook wind product required
- Downlink raw data only for regions of interest
- Algorithms to be developed/tested/demonstrated

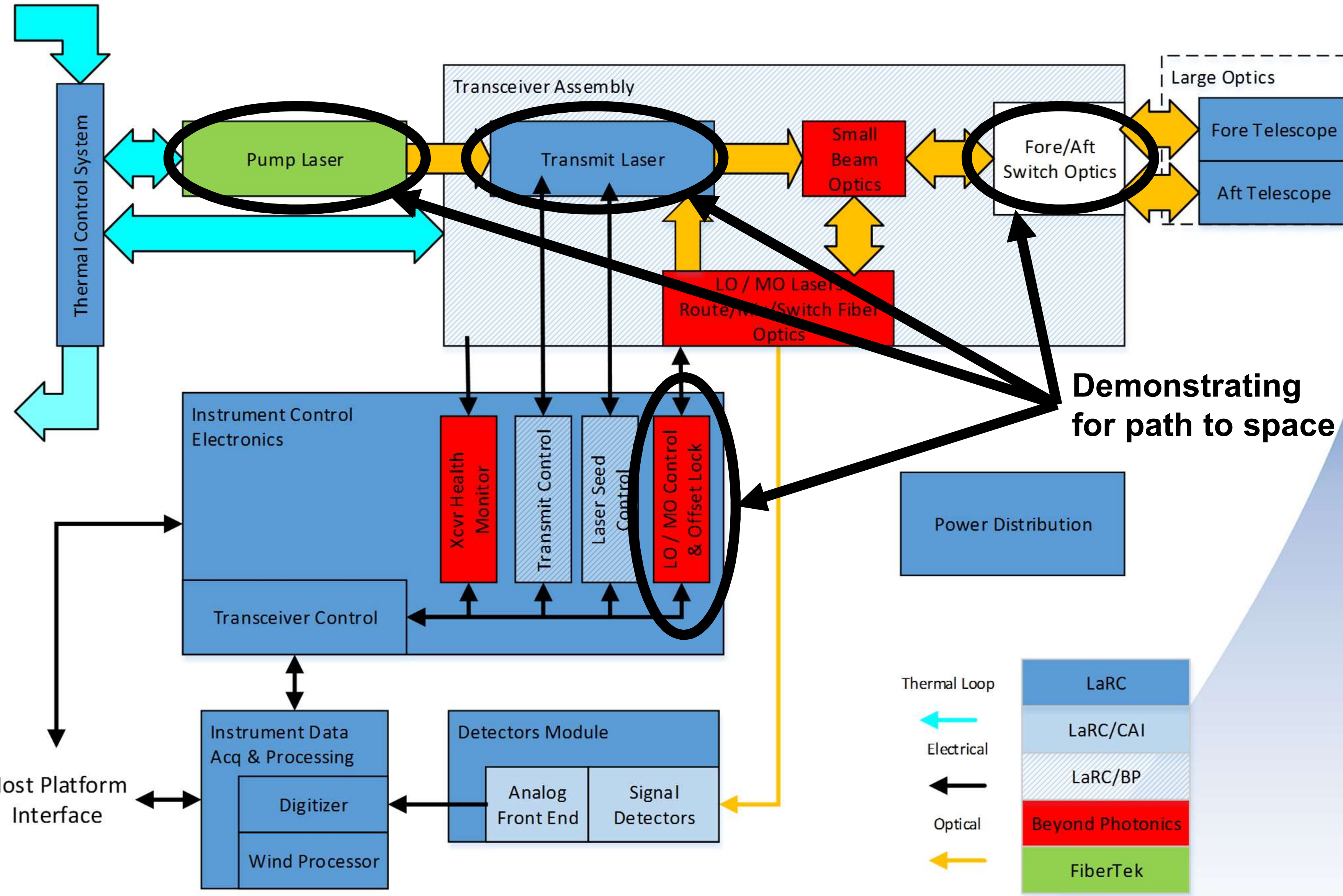


ADVANCE COHERENT SPACE WIND LIDAR COMPONENTS

Wind-SP Simplified Block Diagram



Wind-SP Simplified Block Diagram

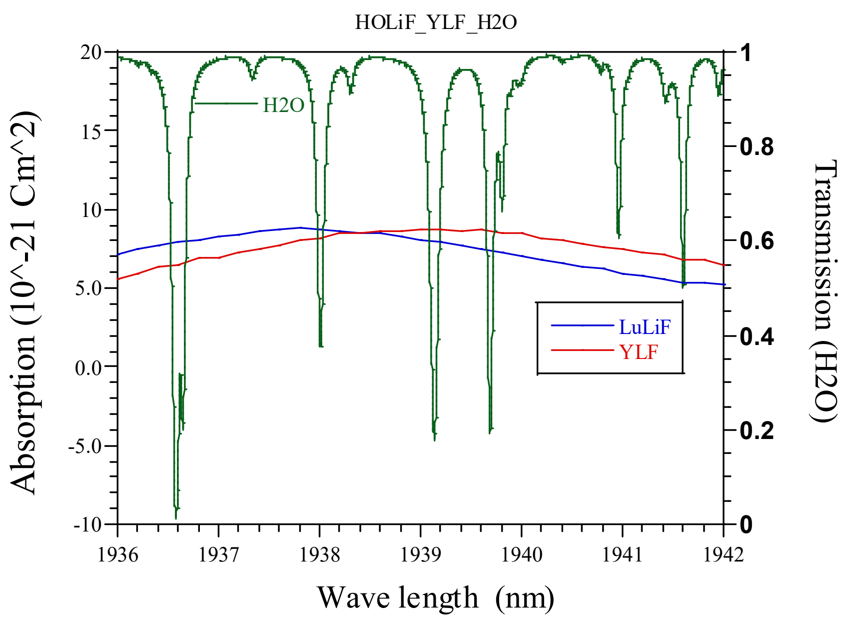


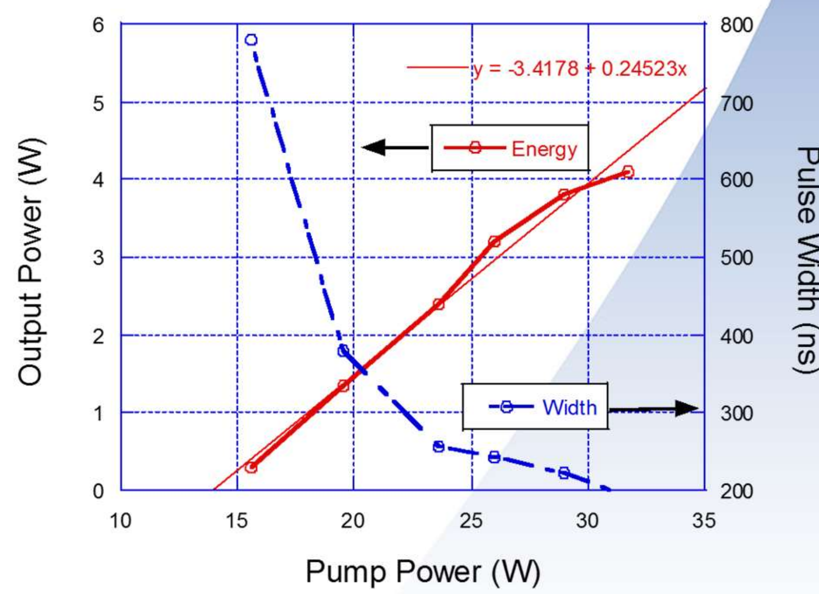
Main Component Advancement Effort

1. Medium pulse rate, end-pumped 2-micron transmit laser
   - Tm pumped Ho:LuLiF laser (low quantum defect, low thermal loading)
   - Oscillator only design (amplifier design backup)

Laser Figure of Merit:

Goal	200 Hz	56 mJ	180 ns	$M^2 = 1.04$
Threshold	200 Hz	40 mJ	150 ns	$M^2 < 1.2$



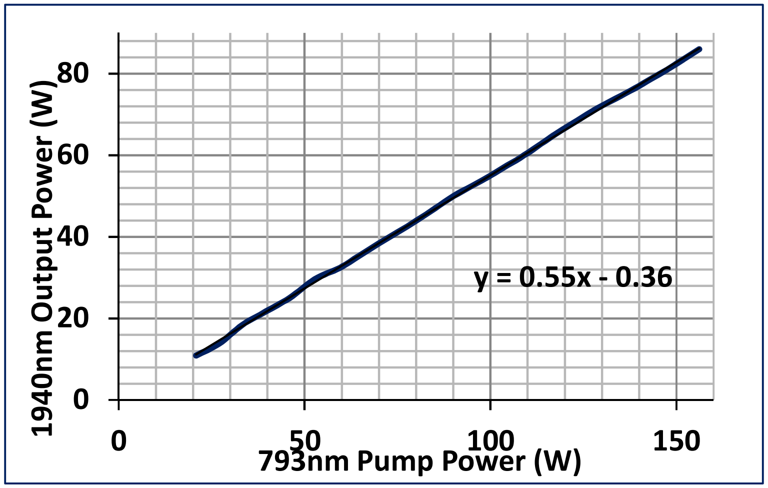


Main Component Advancement Effort

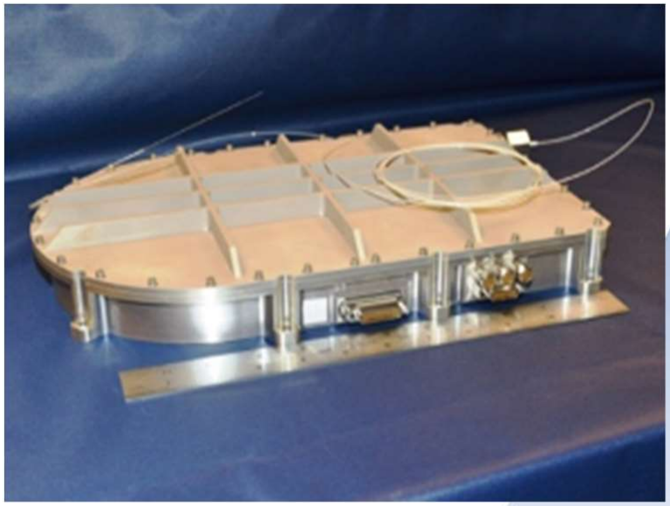
2. MO/LO controllable offset frequency
   - Revised approach: AOM (MHz offsets) vs Offset-Locked MO (GHz offsets)
3. Optical Switching
   1. RTA material characteristics and suitability at 2µm
   2. Optical switches
      1. Q-Switch to reduce heat/power
         - Currently using AO (power est ~252 W)
         - Replace AO with EO Q-Switch (power est ~20W)
      2. Fore/Aft optical switch
4. Additional components/subsystems
   1. Stable, efficient LO/MO CW lasers (BP SBIR)
   2. Auto-Alignment for transmit laser and lag angle compensation (BP SBIR)
   3. High efficiency pump laser at 1.9µm (Fibertek SBIR)

High Efficiency, Space Qualified, Tm Fiber Pump Laser

- Tm Fiber laser, 793nm pumped
- 86W, Diffraction limited, 55% Optical to Optical efficiency.
- Estimated 20% Electrical to Optical Efficiency (from power into the diode pump laser)
- Polarization Maintaining.
- Will be packaged inside TRL 6, GEVS Tested, Space EDFA Package (25W at 1.57um)
- Thermal Analysis and Structure show good performance and meets margin of safety.
- High Reliability, redundant pump diodes.
- Expect radiation testing will confirm acceptable performance for 3 Year ISS mission



Laser Efficiency 55% Optical to Optical.
Estimate 20% Electrical to Optical
3X better than COTS Tm lasers

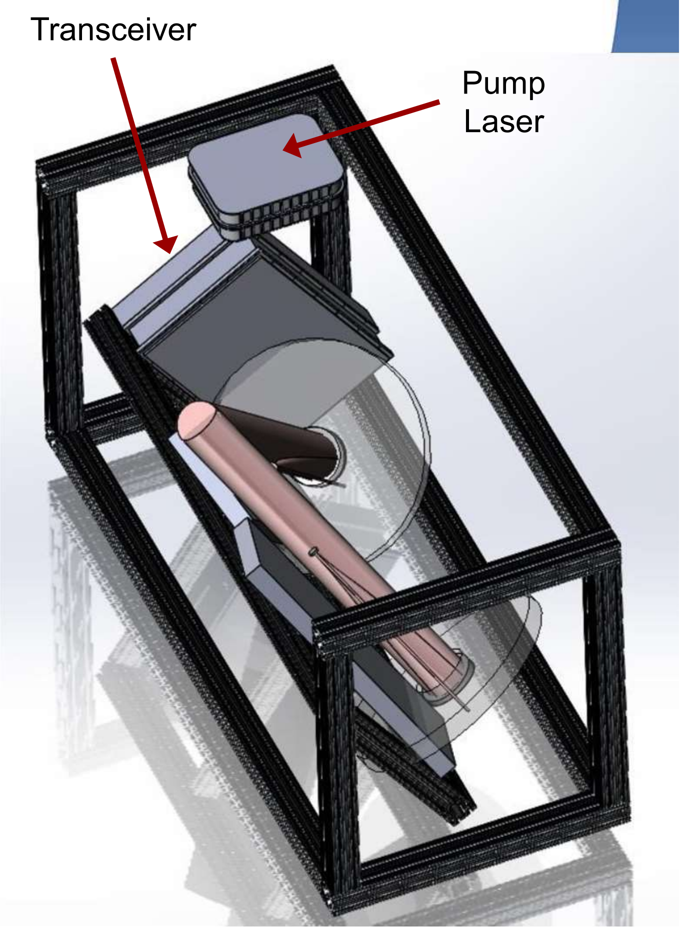


Tm Laser will fit inside Fibertek 25W
EDFA TRL6 Tested Space Laser Package
Size: 14" x 8.5" x 2.1". Mass is <8.5 lbs.

GROUND TECHNOLOGY DEMONSTRATOR

Ground Demonstrator

- Geometry matches JEM-EF concept – but *upside down*
- Enclosure ~73 x 32 x 41 inches
- Two looks (Fore/Aft), 30° off nadir
  - Space: 60cm off axis beam expander telescopes
    Cost prohibitive for project
  - Ground/Air: 15cm off axis beam expander
    Use DAWN prototype beam expanders
- Liquid coolant loop to enclosure
  - Simulated JEM-EF coolant loop
- All electronics "COTS Behind the curtain"



Summary

- No obvious showstoppers for coherent lidar space form/fit/function

- Focused component advancement:
  - Transmit Laser
  - LO/MO Offset Lock
  - Fore/Aft Switch
  - LO/MO Lasers
  - Auto-alignment
  - Pump Laser

LaRC Roadmap to 3-D Coherent Doppler Lidar Global Wind Measurement