Status of Wind-SP: Developing 2-Micron Pulsed Coherent Wind Lidar Technology for Space

Presenter: Michael J. Kavaya

PI: Michael J. Kavaya

Team Members: J. Yu, J. Marketon, L. Petway, J. Lee, T. Wong, S. Henderson. P. Kratovil, D. Bruns, and D. Emmitt

Program: IIP-16

Thank you ESTO for your support!

Problem to Solve
Enable High-Accuracy Global Wind Lidar Measurement from Space

Complete

1990 – 2 micron coherent wind lidar (CWL) 22 mJ

1993 – 2 micron airborne CWL 0.75 mJ

1994 – LaRC advances laser to 100 mJ;

then 1997 – 600 mJ; then 2005 – 1200 mJ

2010 – LaRC DAWN airborne CWL 100 mJ

through 2019 (Aeolus Cal/Val Campaign)

To Do For Space

- Fiber laser pumped
- End pumping for less laser heat removal
- Rugged, compact CWL transceiver
- Space-unique technologies development
- Switching dual line-of-sight (LOS) for space
- Conductive-cooling architecture
- Compact beam expanding telescope
- Aircraft accommodation structure
- Aircraft demonstration of system
- Space qualification
- Laser life test

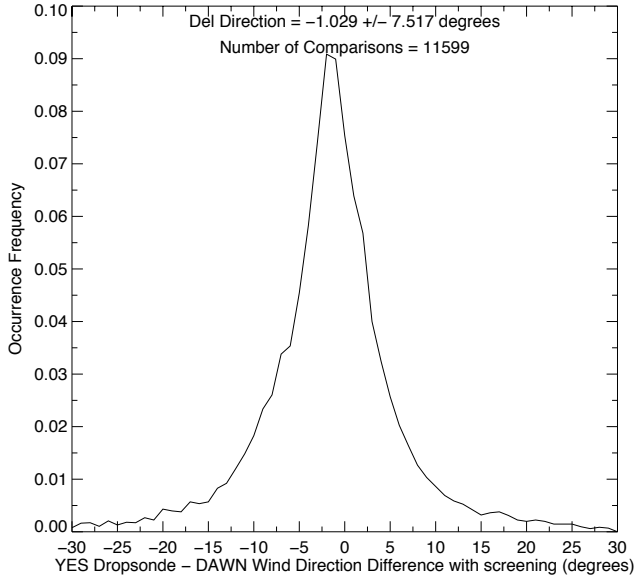
Solution

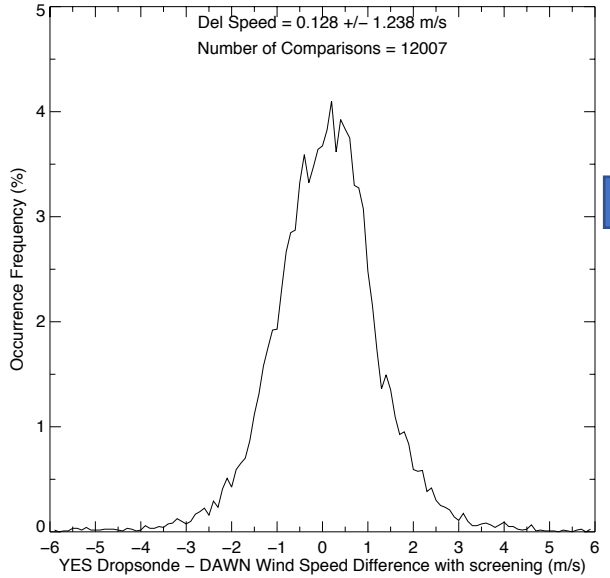
DAWN-Dropsonde Differences

12,000 speeds: 0.13 ± 1.2 m/s
11,600 directions: -1.0 ± 7.5°

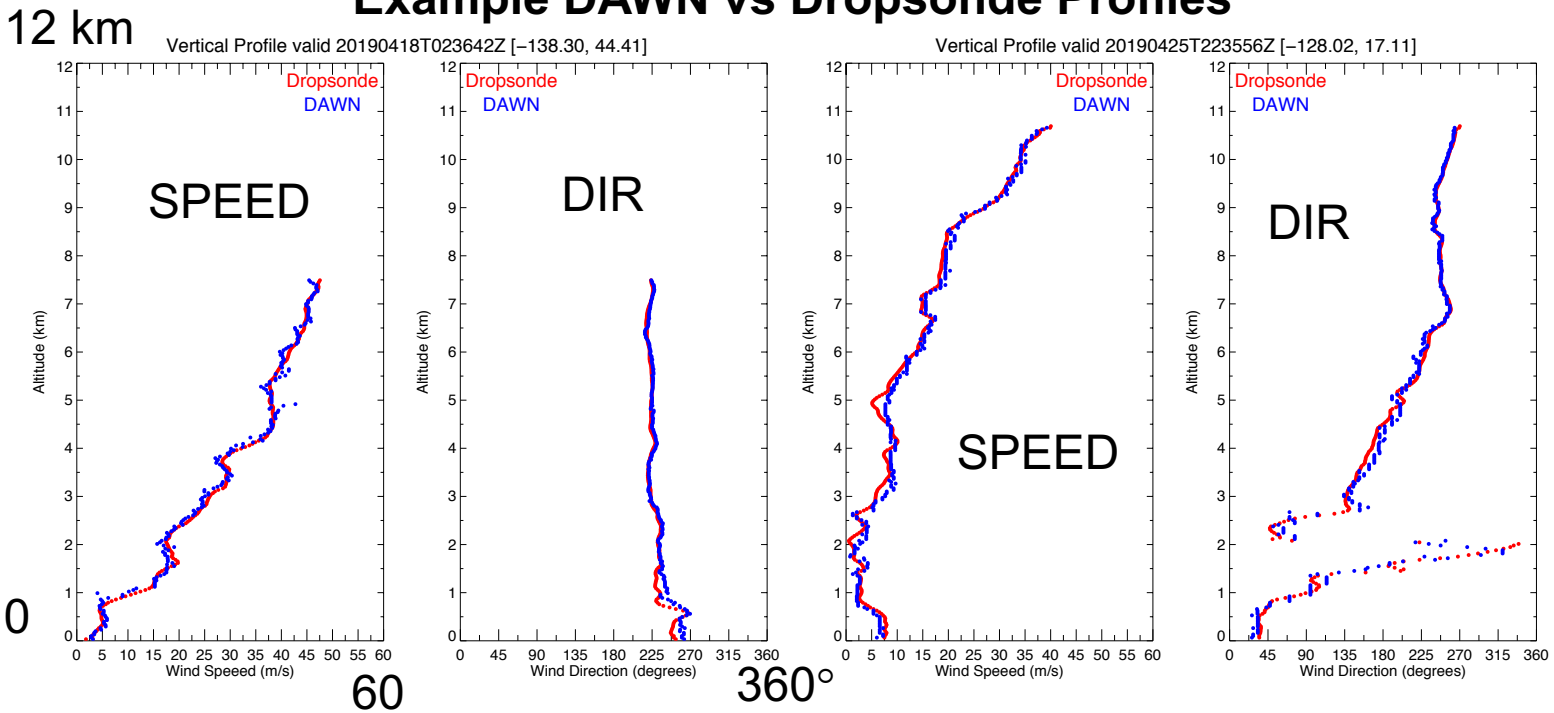
- Doppler wind lidar routinely provides high accuracy & precision winds with high vertical and spatial resolution
- This exceeds the capabilities of other airborne or space-borne measurement systems [GOES cloud tracked wind precision is ~5 m/s, compared to 1.2 m/s from wind lidar]
- Not an "only PBL" instrument, but **ideal** for **PBL science**

DAWN vs Dropsonde Across 60 Dropsonde Profiles (2019)





Example DAWN vs Dropsonde Profiles



Courtesy K. Bedka, Z. Liu, J. Cooney

Solution

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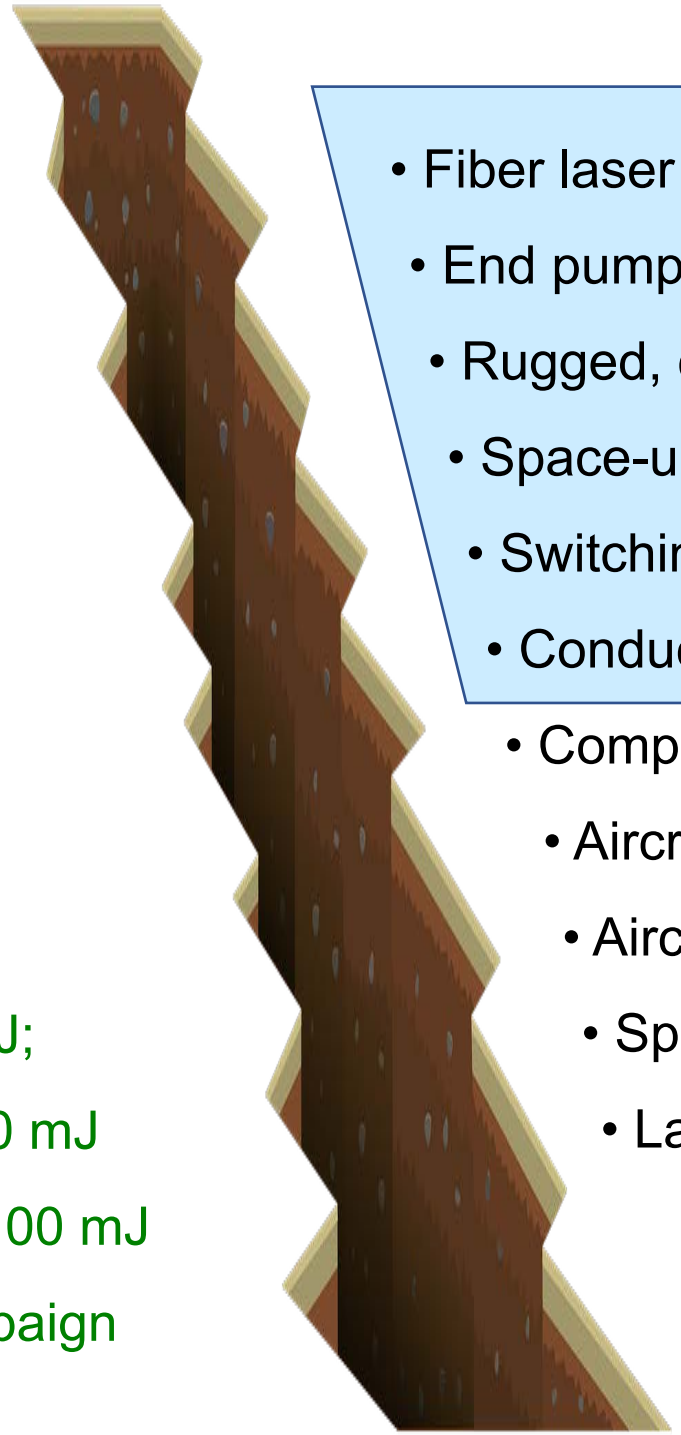

To Do For Space

Wind-SP Project

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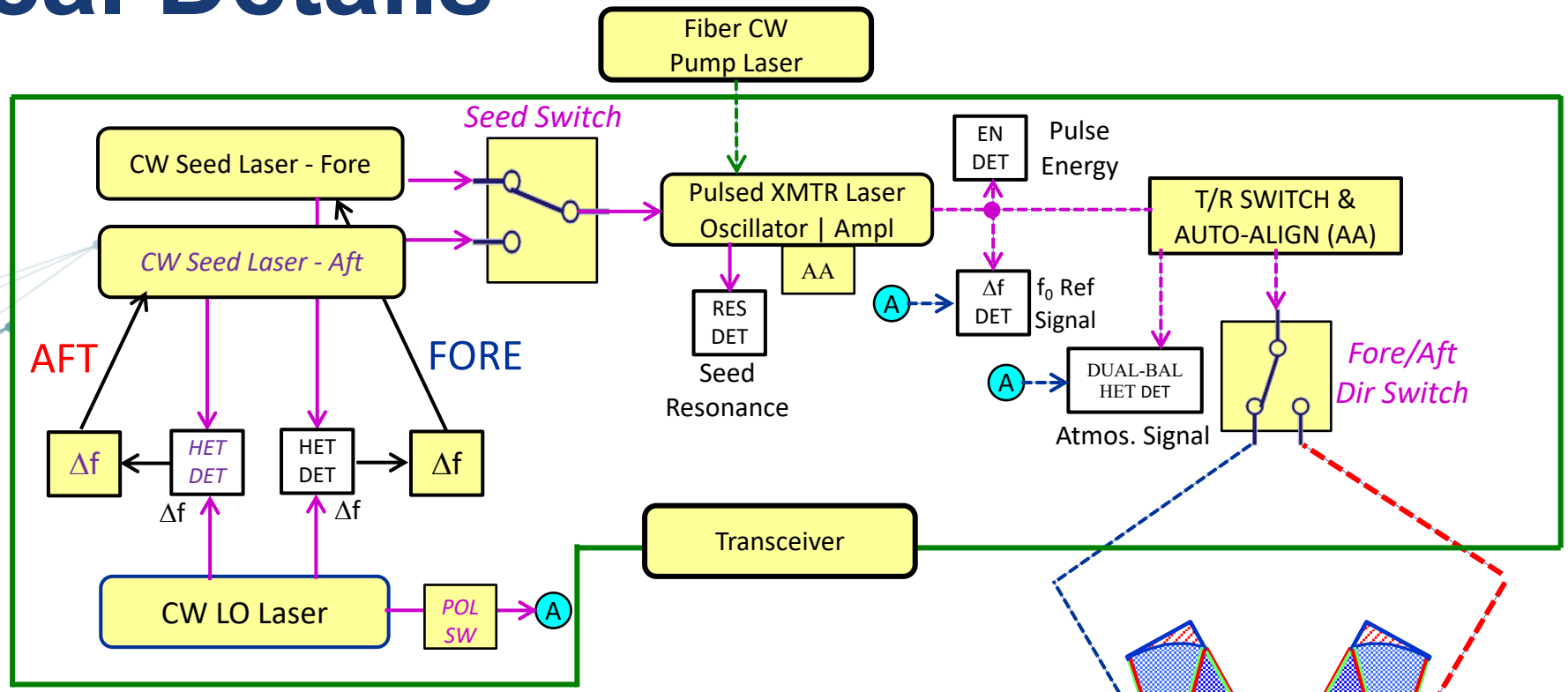
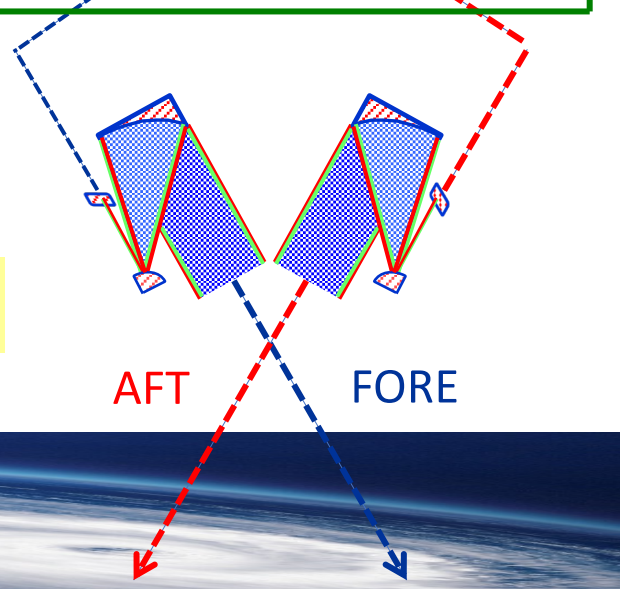
Technical Details



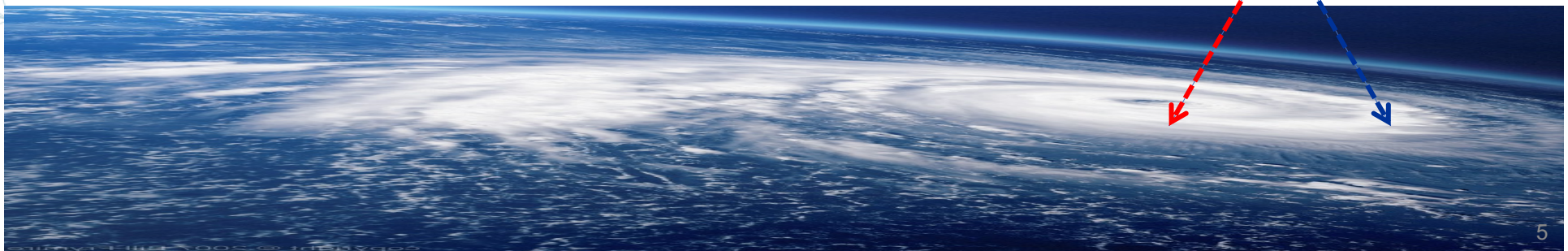


Space Concept Geometry

$\theta_N = 30°$

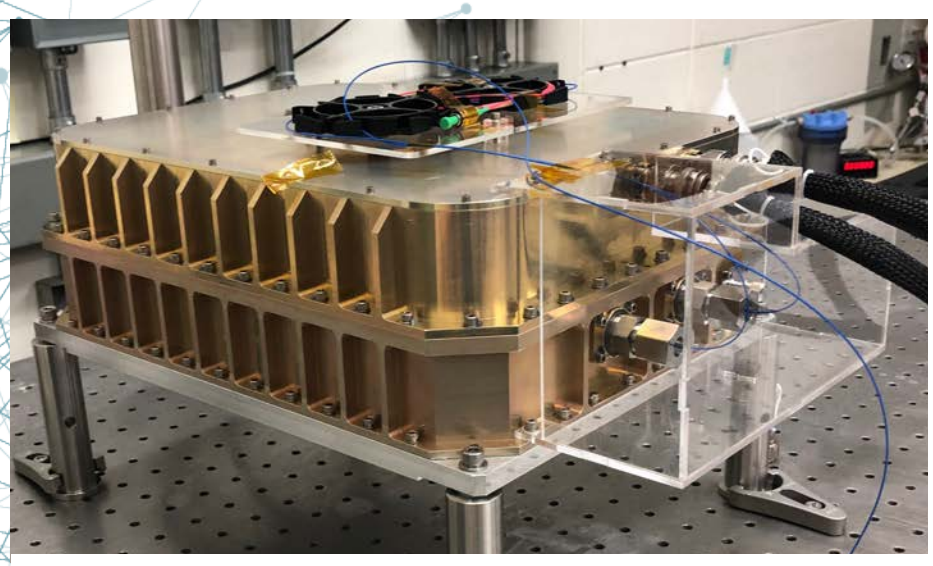
$\phi_A = \pm 45°$

- "must have" new technologies needed for space coherent wind lidar

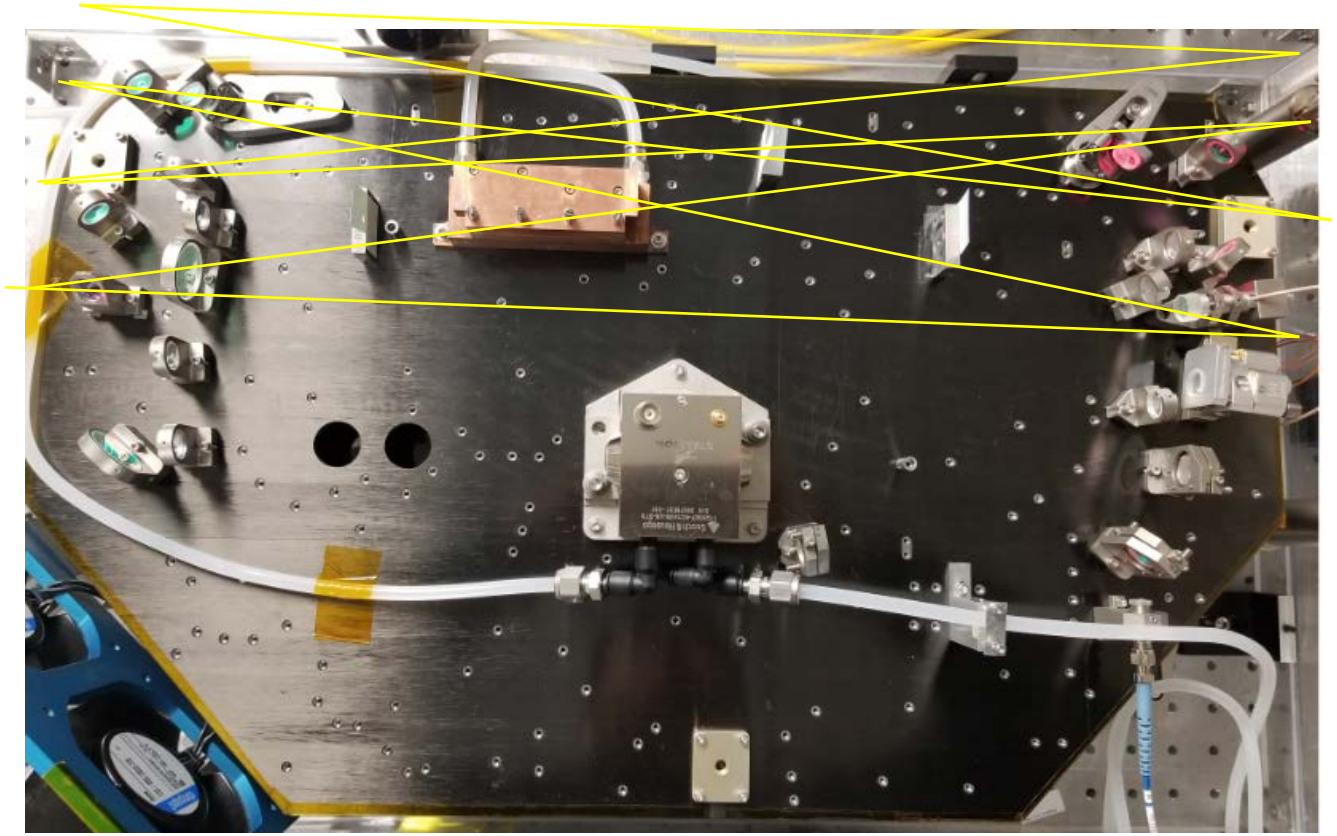


Technical Details

Fibertek Pump Laser & LaRC Oscillator on BP CFC Optical Bench



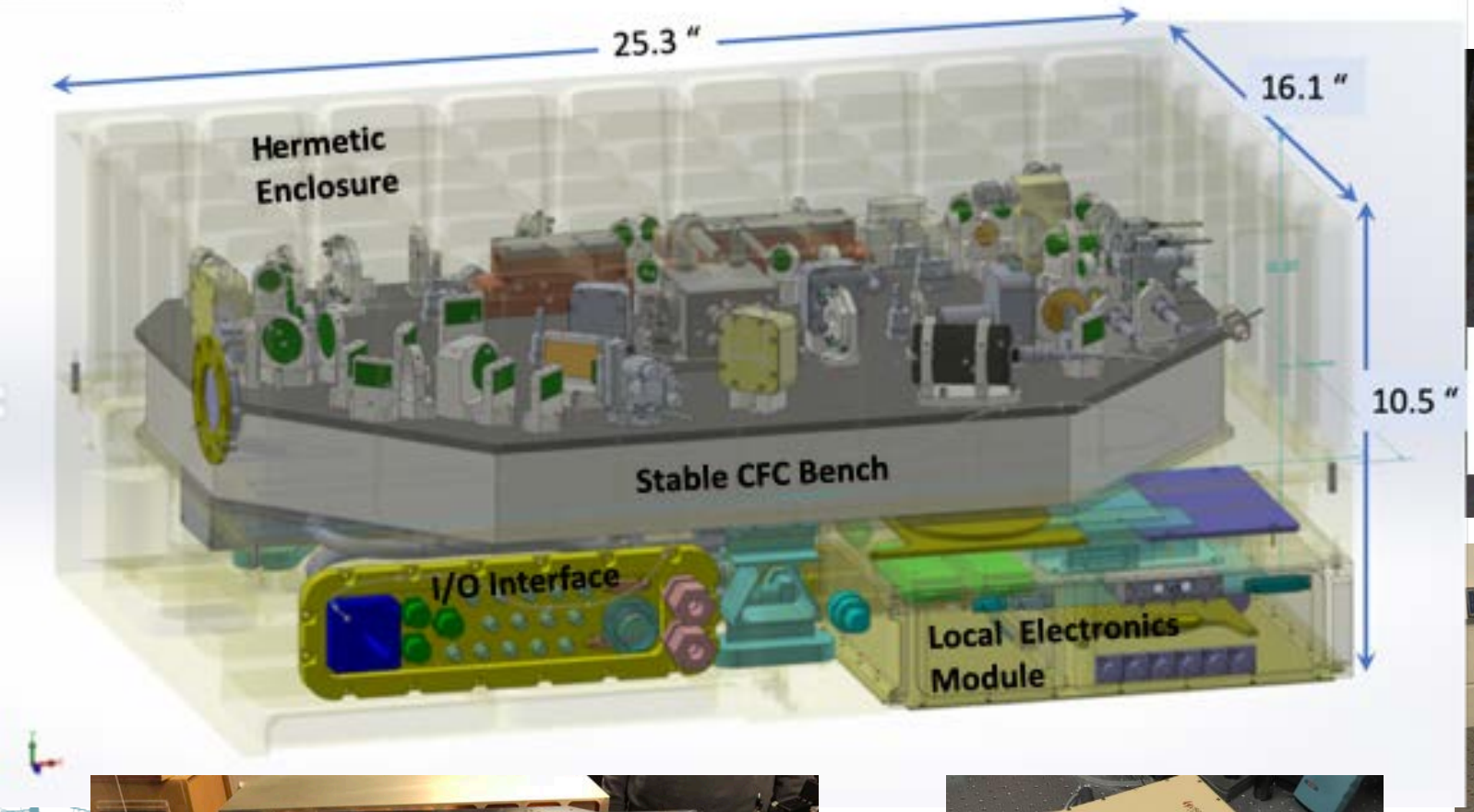
Fibertek space-prototype, high-reliability, 1940 nm, 100 W Tm fiber pump laser. High > 50% optical-to-optical efficiency; > 22% WPE. 30 lbs. Heritage: ICESat-2, Space Laser Communications, and CO_2 space lidar technology

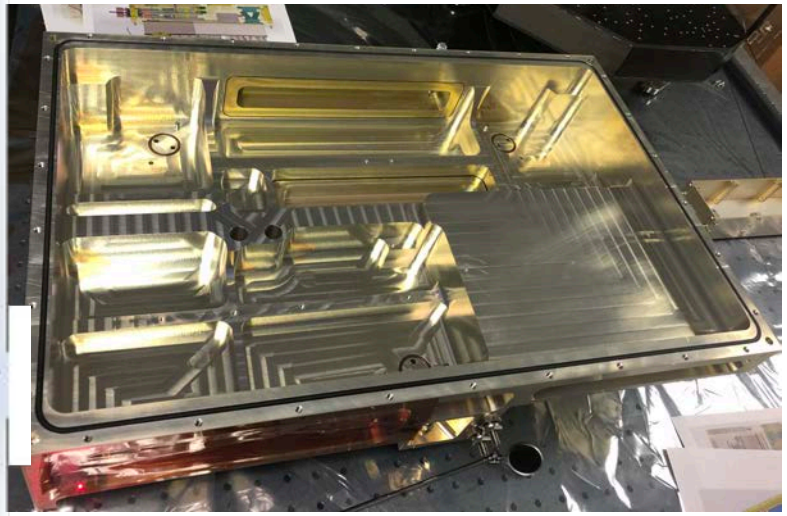


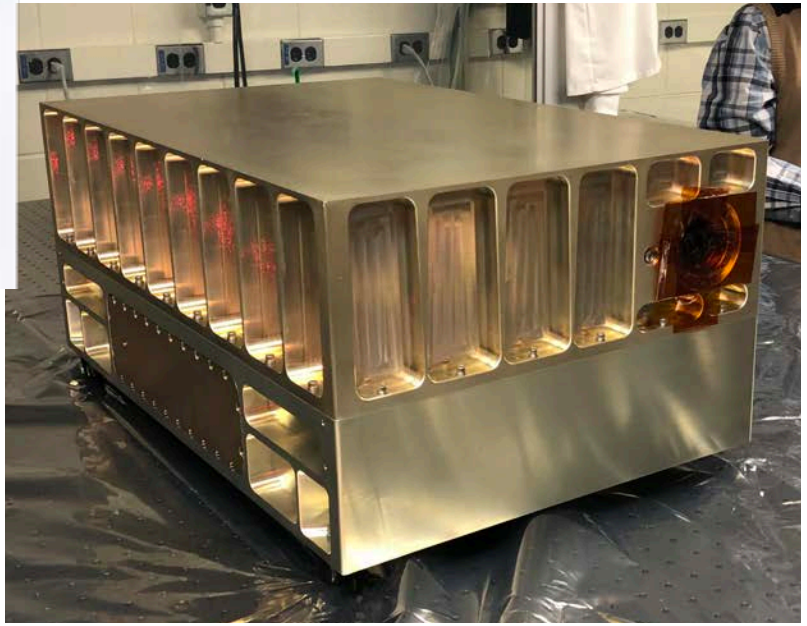
LaRC Laser oscillator (yellow) on stable athermal CFC Bench and optical mounts. Thermal tested. Overcame challenge to lengthen the pulse and prevent power loss. 8-mirror folded resonator. 37.5 mJ at 200 Hz on track to meet requirements

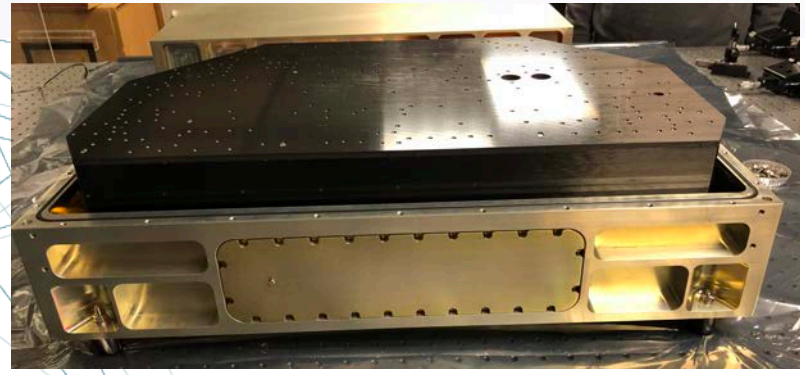
Technical Details

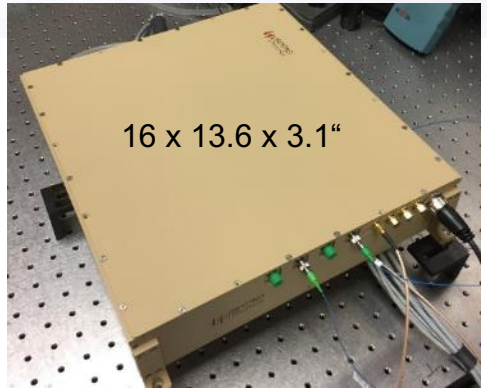
Transceiver Hermetic Bench Enclosure



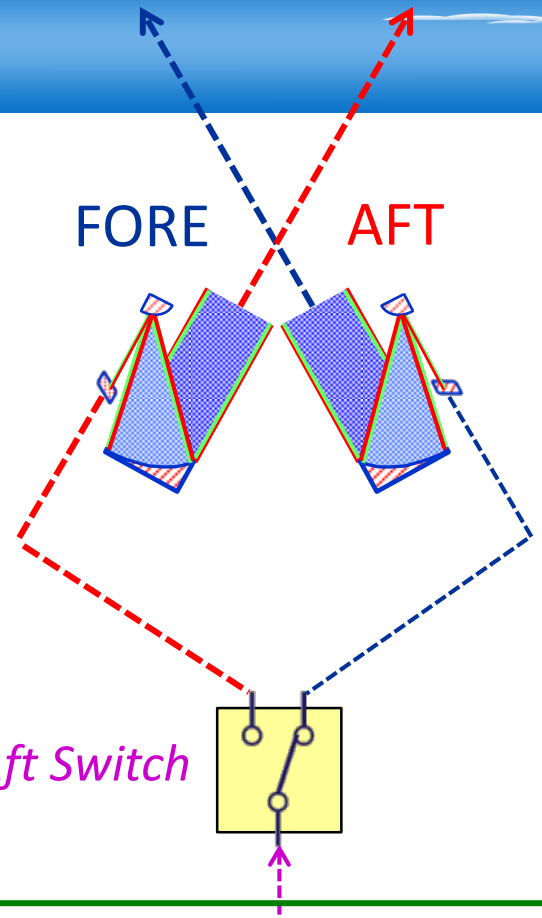






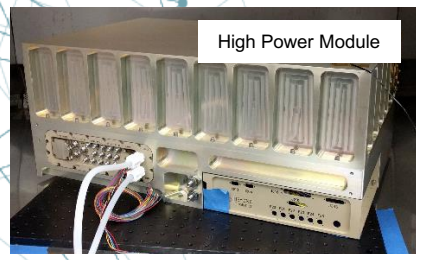


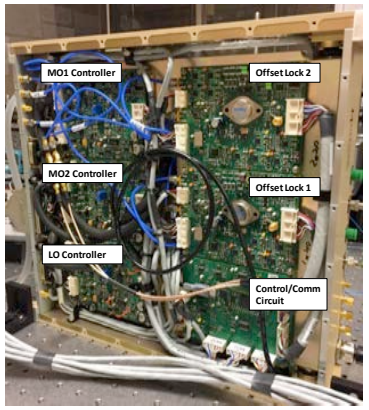
Technical Details

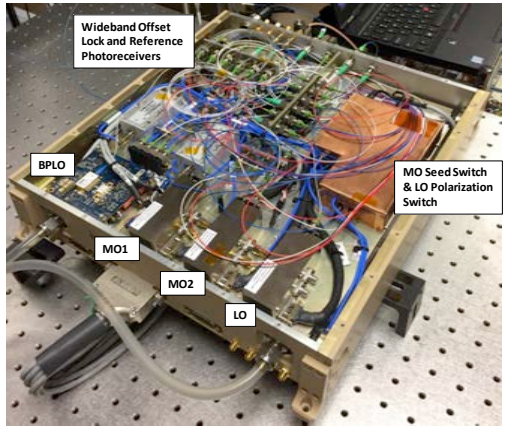


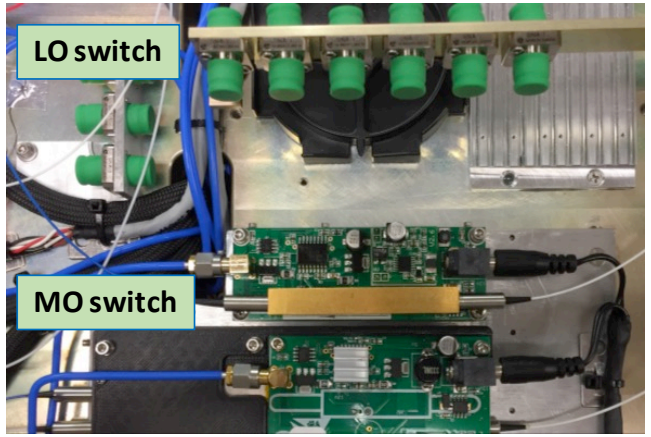
Ground-based demonstration of vertical profile of horizontal wind using inverted space concept geometry

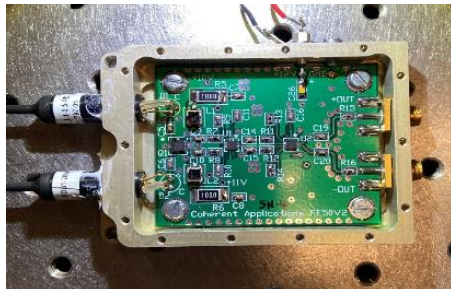
Transceiver, Electronics, Data Acquisition
(several completed components shown)











Next Steps / Contributions

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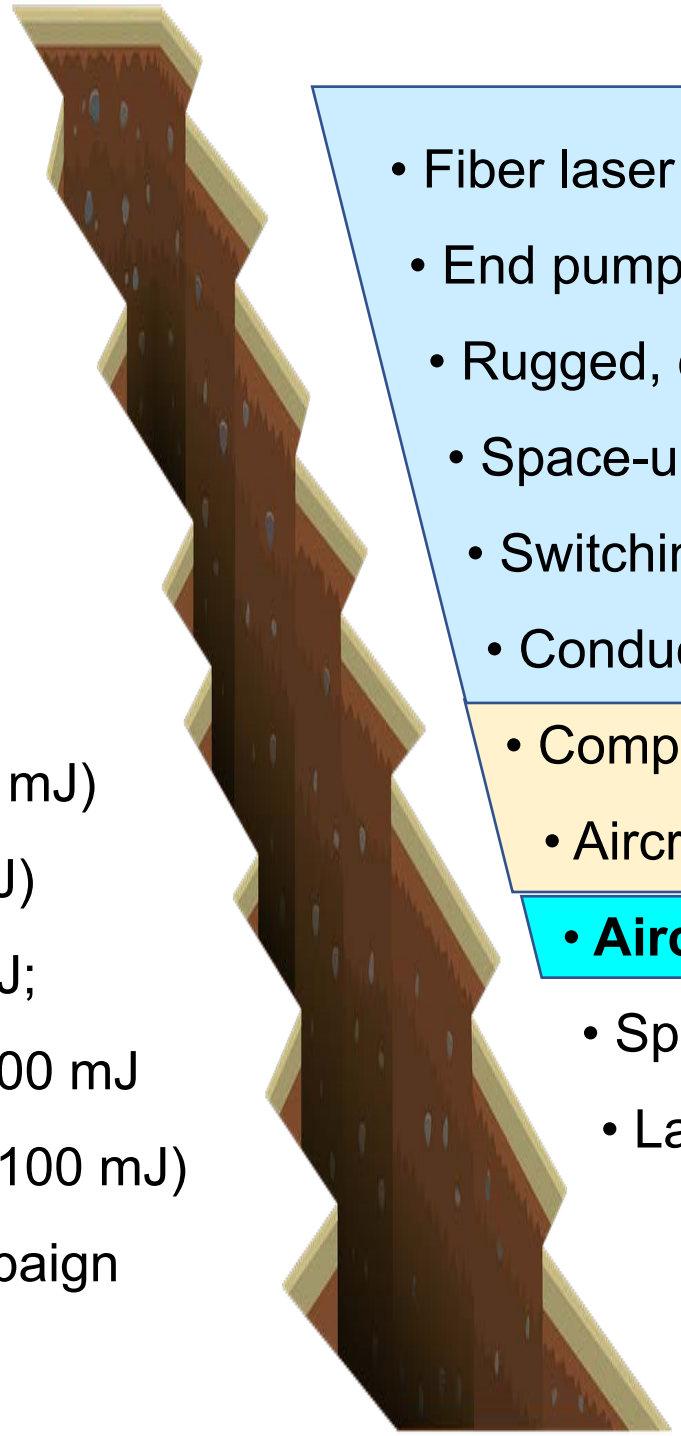

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IRAD
SBIR

- **Aircraft demonstration of system**

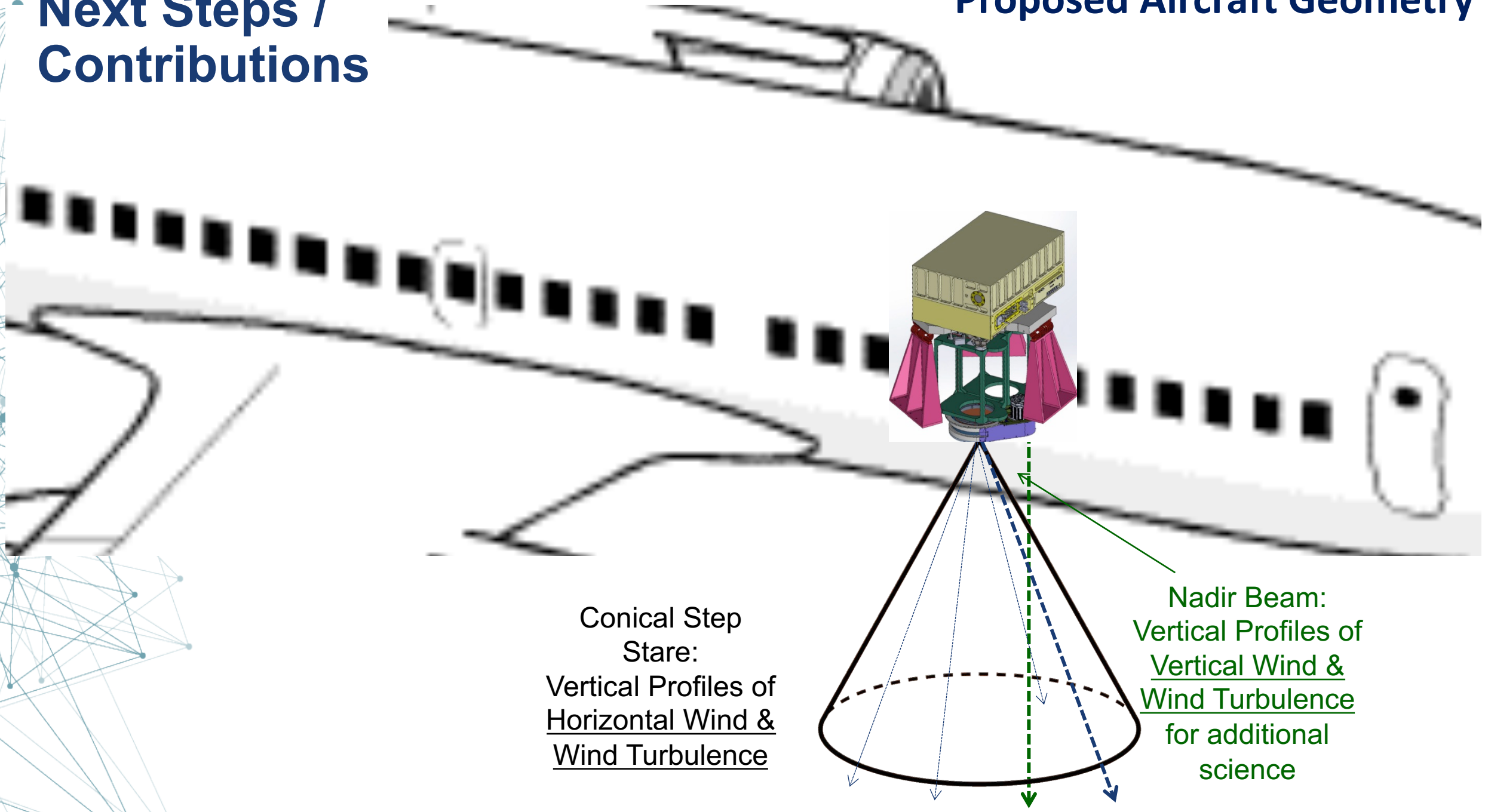
- Space qualification
- Laser life test

Tasks Started

Key Technology Validation

Next Steps / Contributions

Proposed Aircraft Geometry



Summary

- Wind-SP has developed several critical technologies needed for space operation of pulsed coherent wind lidar
- A rugged, athermal CFC optical bench and mounts hold the pulsed transmit laser and other electro-optic components comprising the lidar transceiver, the most complex subsystem of a coherent lidar system
- After integration & testing of all components, we will demonstrate from the ground vertical profiling of horizontal winds
- Added nadir view for aircraft provides collocated 3-D horizontal and vertical vector winds
- Work has begun with internal & SBIR funds to accommodate Wind-SP on aircraft
- A key future step will be flight validation of the system

Wind-SP Team: Langley, Beyond Photonics, Simpson Weather, Fibertek

ESTO – Ghuman/Murray

PI – Kavaya

Science – Bedka, Trepte, Winker (SD), Emmitt (SWA)

Instrument Lead – Marketon

1. Space Mission Feasibility/Guidance ✓ (9/2017)

Space Mission Concept: Chrone, Deacon (SACD)

Space Instrument Concept (EDS): Goggin, Hutchinson, ED branches

2. Coherent Wind Lidar Demonstrator

Transmit Laser: **Yu**, Lee, Wong, Petway, Chen

Transceiver/Technologies/Bench: **Henderson**, Hale, Kratovil, Bruns, Cotie, Depagnier, Diamond, Vanasse (BP)

Het. Detector, Preamp, Analog Circuit: **Pierrottet**

Structure: **Marketon**

Algorithms **Liu** Emmitt

Computer, Software: **Liu,** Huffine, Marketon, Begay

Integration, Test, and Demo: **Yu**, Lee, Wong, BP, SWA

Pump Laser: **Storm, Engin** (Fibertek)

Advisory Panel: Macdonnell (SD) Edwards/Little (ED)

Mechanical/Structure/Thermal/ Electrical Support: Boyer, Jackson, Saulman, Scola, Turczynski

3. Roadmap to Space

- Thanks to the Langley team, partners BP/SWA/Fibertek, and ESTO

Back Up Slides

Solution

Pulsed Coherent Wind Lidar

Heavy aerosols as target (much less Brownian motion vs. molecules, narrow signal spectrum)

+ Narrow laser pulse spectral width (long pulse ~ 200 ns)

+ Heterodyne detection (THz signal mixed down to MHz for electronics, diffraction limited FOV)

+ Capture of full signal spectrum into a computer

+ Very narrow detection bandwidth via software (vs. optical filters)

+ Frequency estimation (less error sources vs. multiple intensity estimations)

=

- Very **accurate** & low bias horizontal wind profile
- Excellent horizontal & vertical **resolution**
- **Immunity** to background light; equal day & night performance
- Highly photon (electrical) **efficiency**; effective elimination of all noise except quantum noise
- Second moment available (wind **turbulence**)
- **Flexible**, multi-parameter-combination data processing
  - With same data, trade resolutions, backscatter sensitivity, Pr{outliers}, & velocity search bandwidth
- Ideal features for **planetary boundary layer science**

Technical Details

Wind-SP vs. DAWN Laser Transmitter

	DAWN	Wind-SP	
Objective	Wind	Wind	
Laser Material	Ho:TM:LLF(LuLiF)	Ho:LLF(LuLiF)	E
Laser Wavelength nm	2053.495	2052.92	
Pumping Method	Side pumping	End Pumping	E
Pump source	Diode laser	Tm fiber laser	E
Beam Quality M^2	1.1	1.1	
Cavity length m	3	3	
Energy mJ	250	**56**	
Pulse Width ns FWHM	180	**180**	
PRF Hz	10	**200**	
Average Power W	2.5	11.2	
Laser FOM	**3.14**	**3.14**	
Electrical-Optical Efficiency %	1.51	3.80	
Electrical Power W	166	295	

← E – Raises Efficiency

← Fibertek space prototype, heat separated from LLF

← Better cloud deck penetration, less representativeness error

← Equal aerosol sensitivity

Technical Details

Science Parameters Trade-Off

Multiple science parameter combinations possible with same data for various priorities

Science $\propto$ Atmospheric Coverage $\propto$

$$\frac{1}{\beta_{MIN}} \propto \frac{\sqrt{z_{RESOL} h_{RESOL}}}{V_{SEARCH}^{"0.2"} \left[\Pr\{good\} \right]^{"1.3"}} D^2 \eta_H \eta_Q T_{ATM}^2 \frac{U_L \sqrt{f_L} \tau_L^{"0.285"}}{1 + \left(M^2 \right)^2} \frac{1}{R^2}$$

Science Lidar

Atmosphere Laser Geometry

"value depends on conditions"

Technical Details

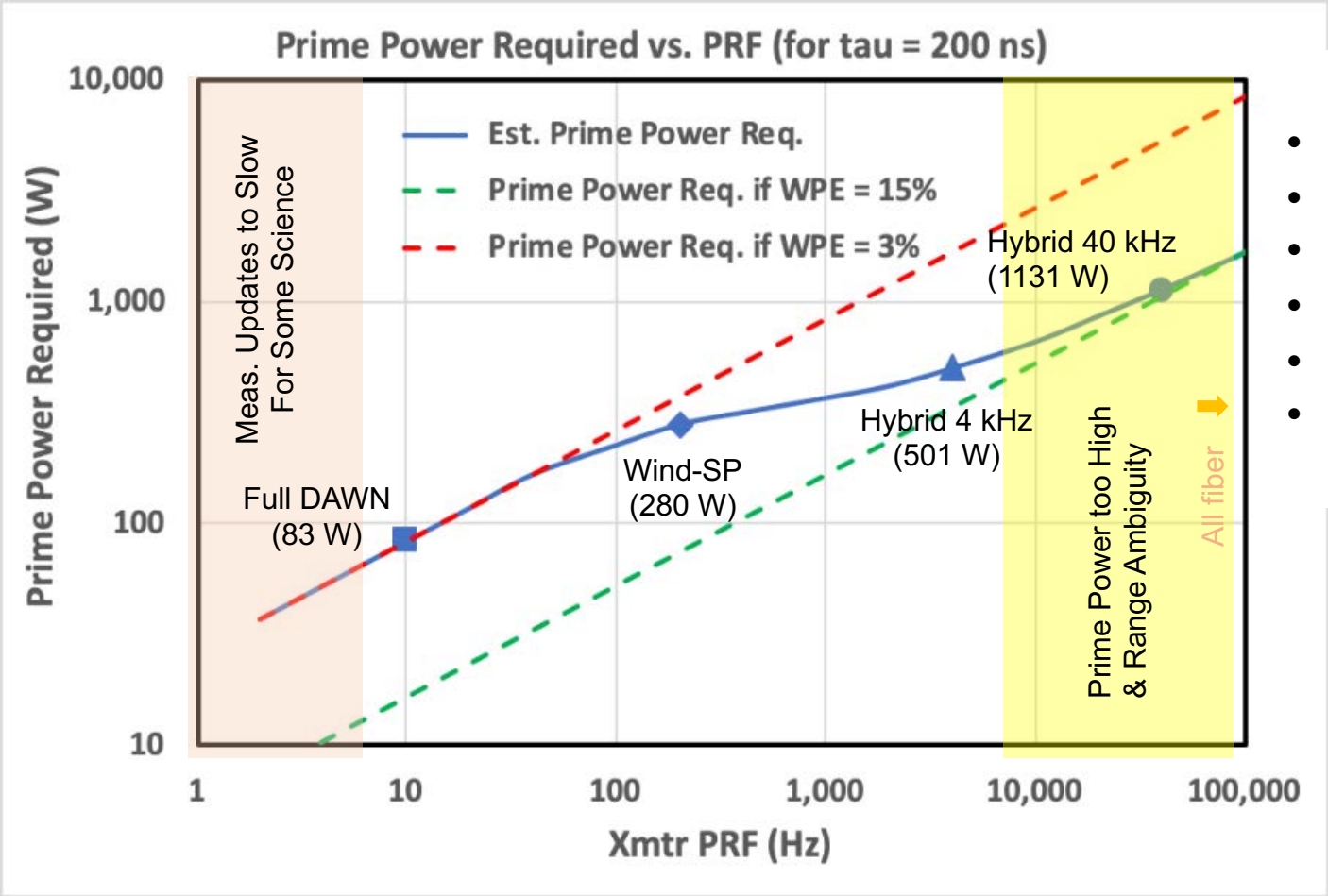
Laser PRF Trade-Off

$$\frac{1}{\beta_{MIN}} \propto FOM_{LA} = \frac{2}{1+\left(M^2\right)^2}\tau_L^{0.285} E_L \sqrt{f_L}$$

Coherent Lidar Favors Energy over PRF

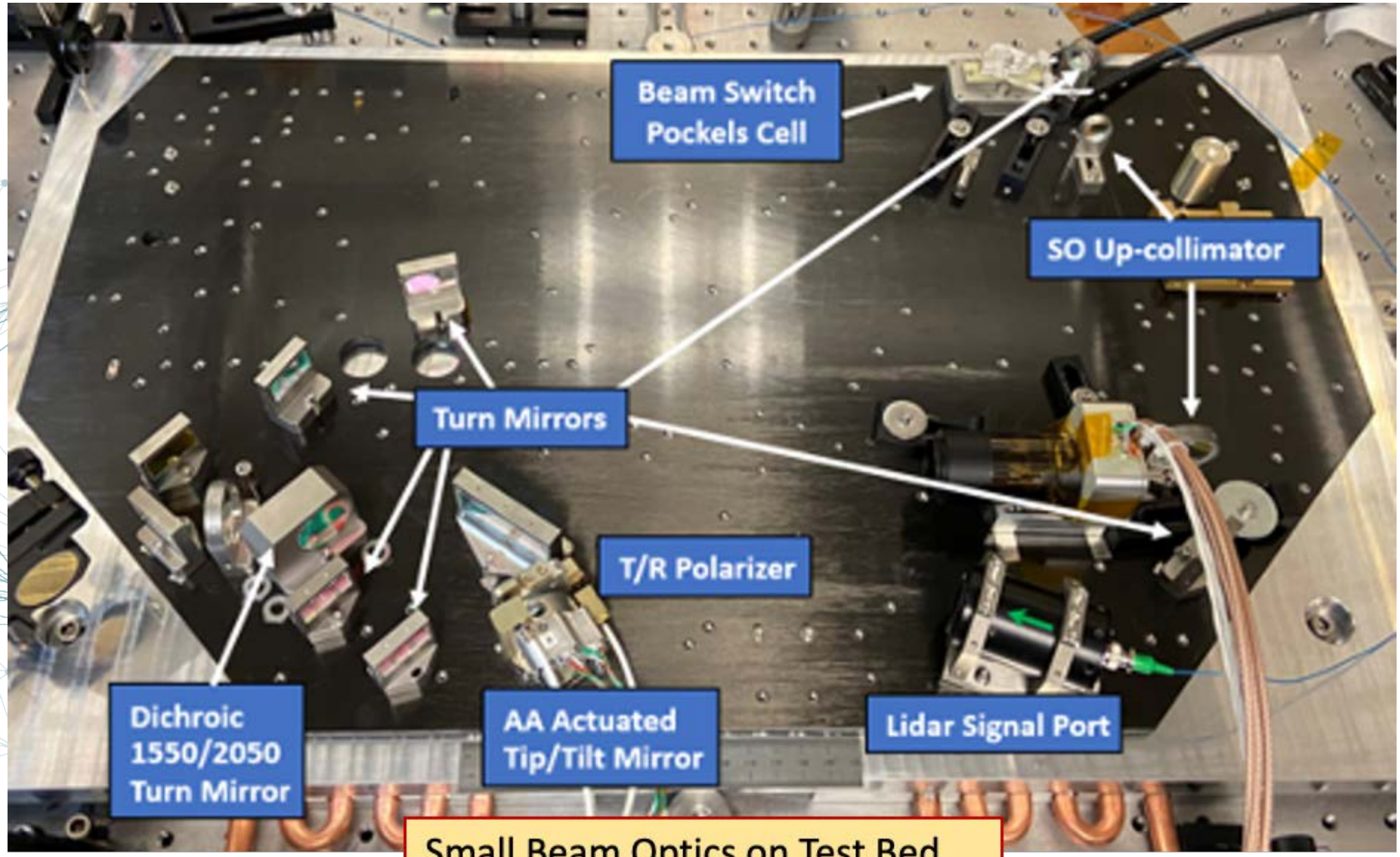
Low PRF

- High pulse energy
- Lower average power
- Crystal lasers less efficient & larger



High PRF

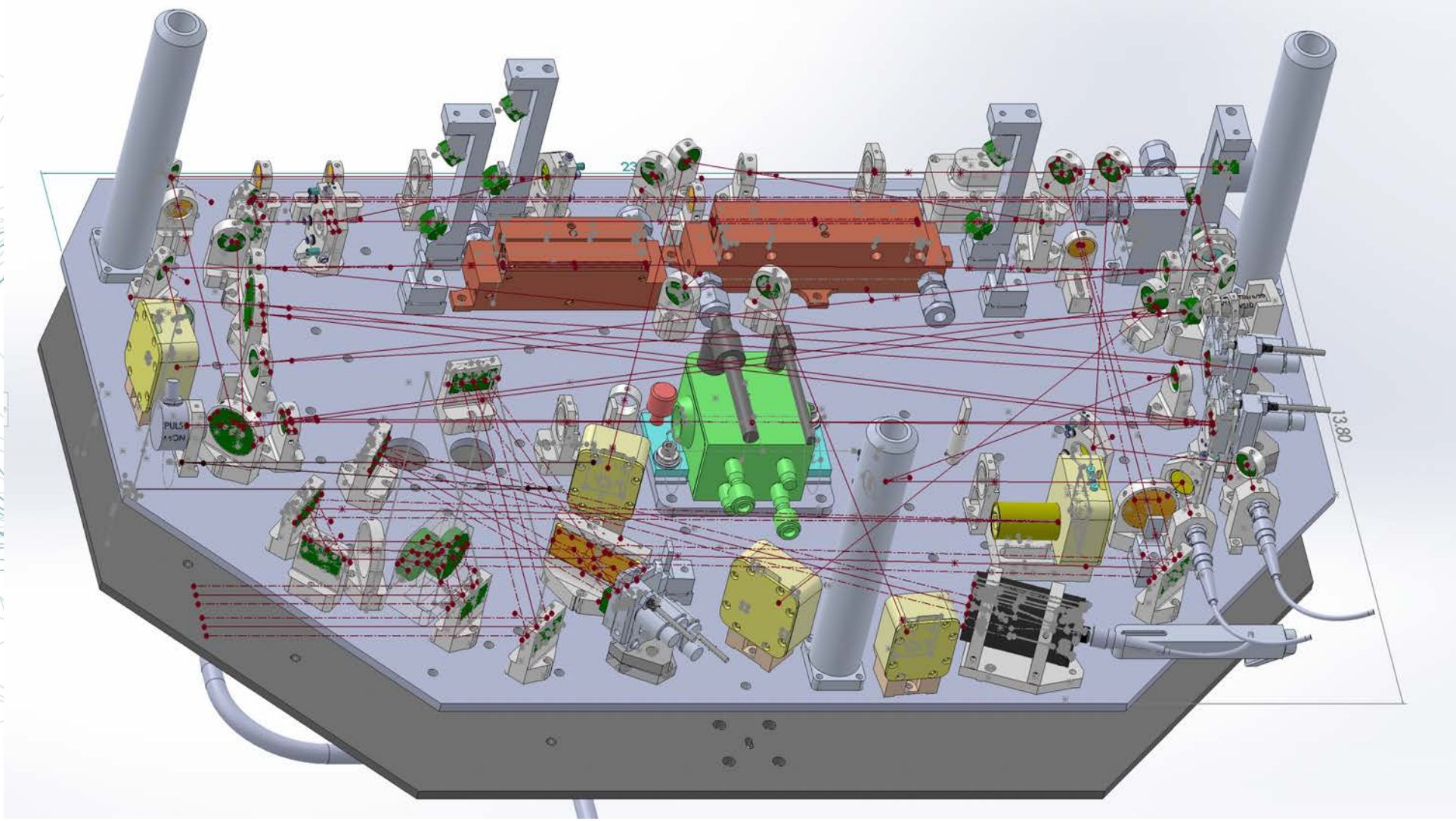
- Efficient fiber lasers
- High average power
- FOM drives up power
- More computation
- Higher data rate
- Atmospheric pulse confusion above 3.1 kHz



Small Beam Optics on Test Bed

Technical Details

Folded Transmitter & Transceiver Bench Layout



23.3 x 13.8”