The High Altitude Lidar Observatory (HALO): A multi-function lidar and technology test-bed for airborne and space-based measurements of water vapor and methane

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[4]Welch Mechanical Designs

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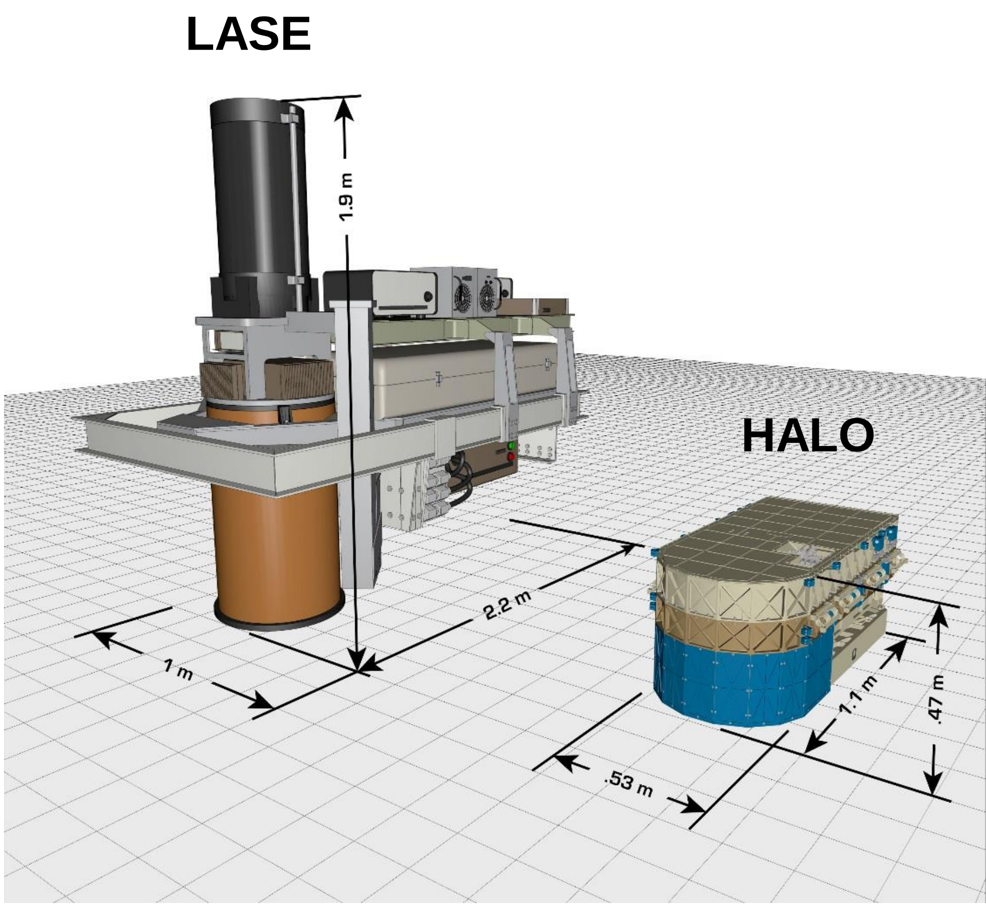
Motivation

- New capability to measure H_2O profiles from <u>smaller</u> and <u>high altitude</u> airborne platforms
  - Currently: LASE is only capable of going on large aircraft (DC-8, and possibly P3, C130)
  - Development of more compact H_2O DIAL system with additional (CH_4) DIAL and HSRL measurement capabilities
- DIAL measurements along with measurements of aerosol/cloud properties combines many of the measurement requirements for airborne campaigns and satellite calibration and validation
- Flight demonstration of advanced lidar technologies on various airborne platforms



Science Objectives

Use combined lidar profiles of water vapor, aerosols, and clouds to better understand…

1. Boundary layer processes (2017 Decadal Survey)
   - Shallow clouds, shallow and deep convection, convective aggregation, arctic mixed phase clouds, aerosol cloud interactions…
2. Weather and dynamics (2017 Decadal Survey)
   - Genesis and intensification of hurricanes, land-atmosphere feedbacks
3. Upper atmospheric transport and chemistry
   - Moistening of the stratosphere in a warming climate
4. Assessment and improvement of GCM and CRM and comparison of satellite data products

Science Objectives….continued

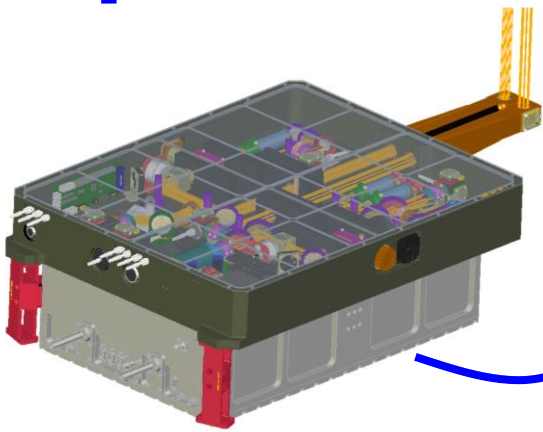
Combine lidar measurements of XCH_4, aerosols/clouds to better understand…

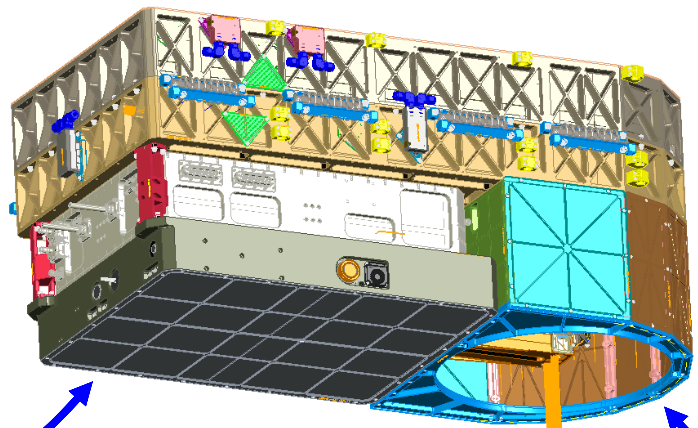
1. Quantify XCH_4 surface fluxes (2017 Decadal Survey)
   - Survey carbon stocks in warming Arctic (ABOVE) and tropics, survey oil and gas production….
2. Assessment and improvement of chemical transport models and comparison of satellite data products
   - Mixed layer vs free tropospheric mixing and transport
   - Validation of MERLIN CH_4 Lidar, TROPOMI

System Architecture

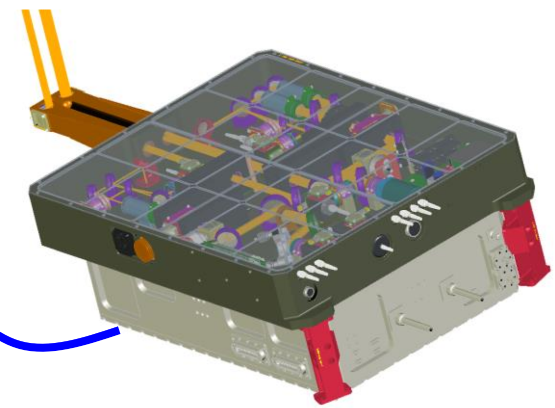
Interchange two common architecture lasers and single receiver to enable **H_2O DIAL+HSRL** or **CH_4 DIAL+HSRL** measurements

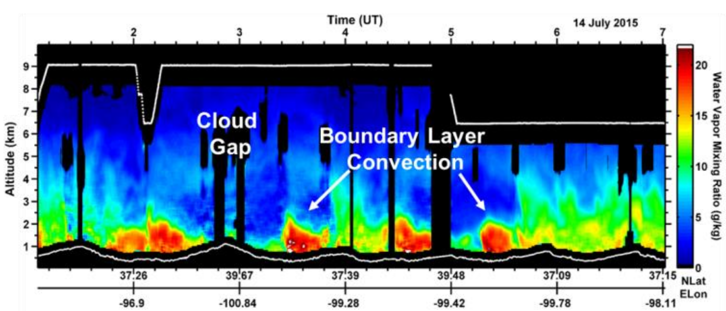
H_2O Transmitter





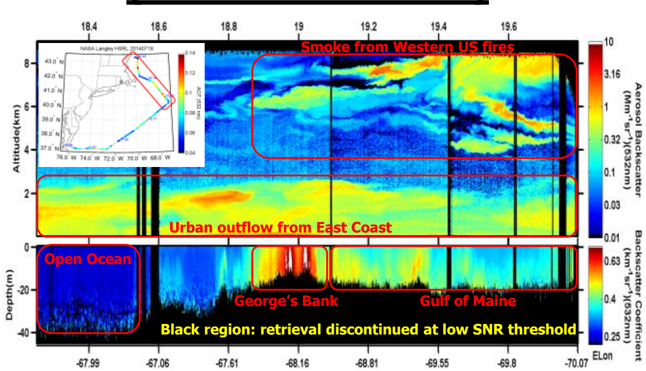
CH_4 Transmitter



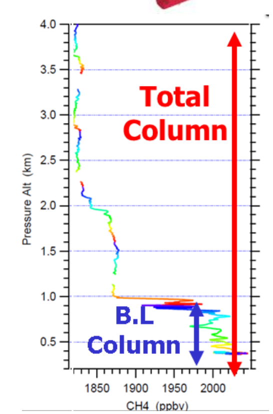


- **Water vapor profiles**
- **Total perceptible water**

HSRL Measurements (common to both)

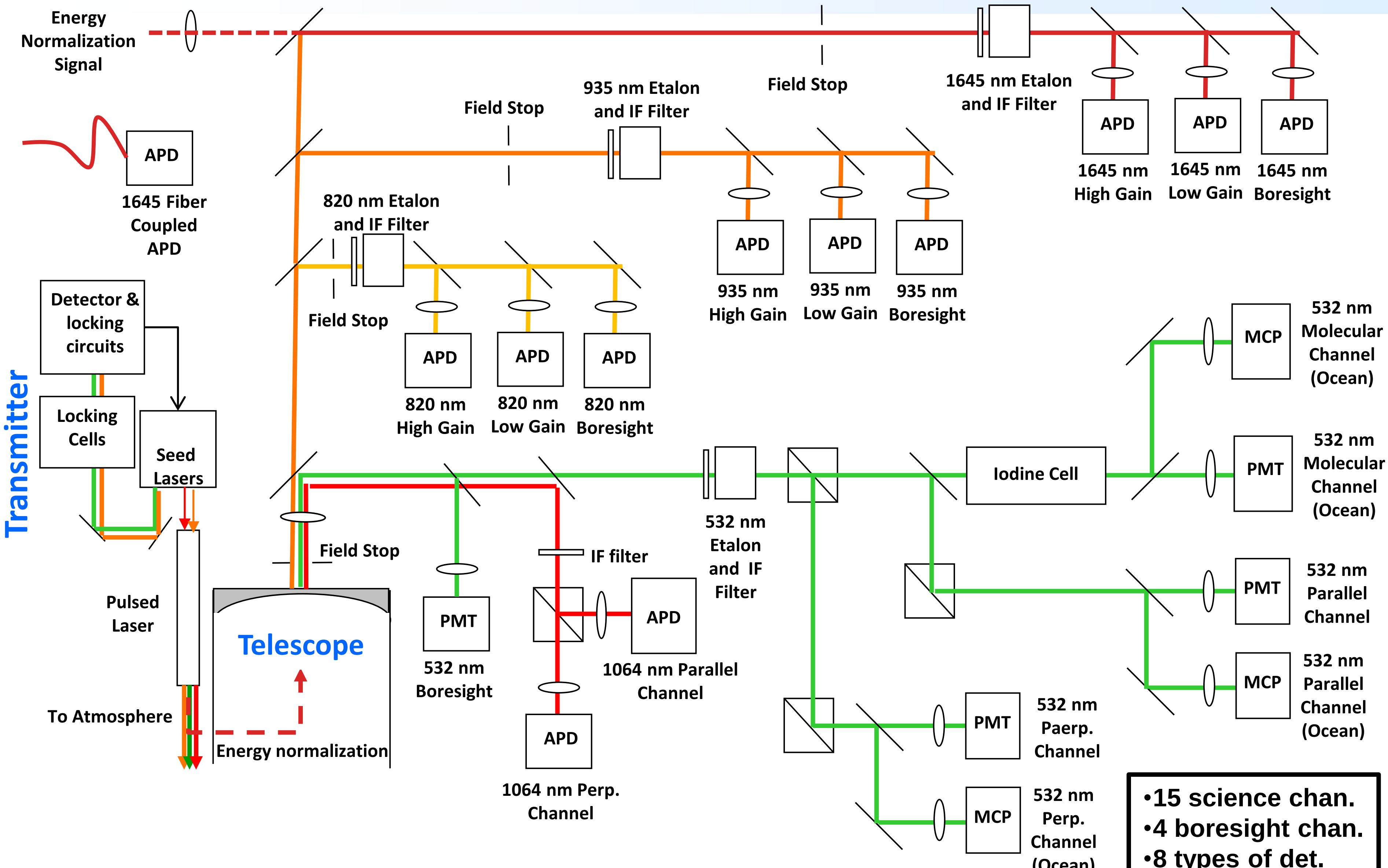


- **Aerosol, cloud, and ocean profiling**



- **Column weighted XCH_4**
- **Clear air mixed layer XCH_4**

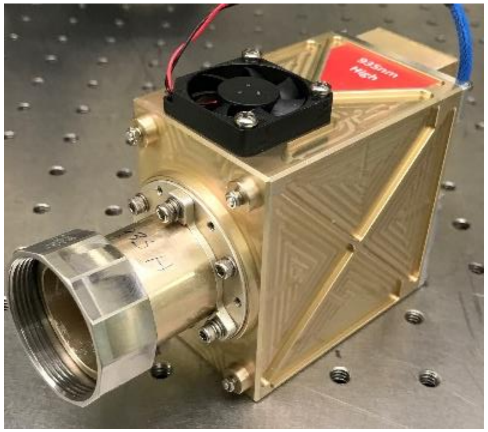
System Block Diagram

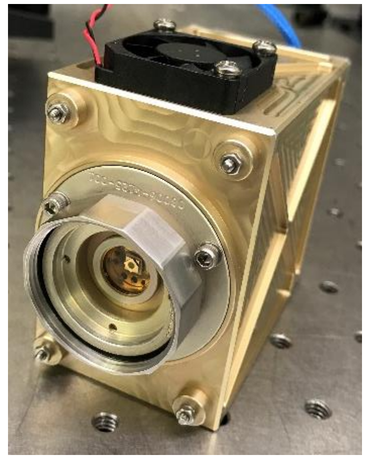


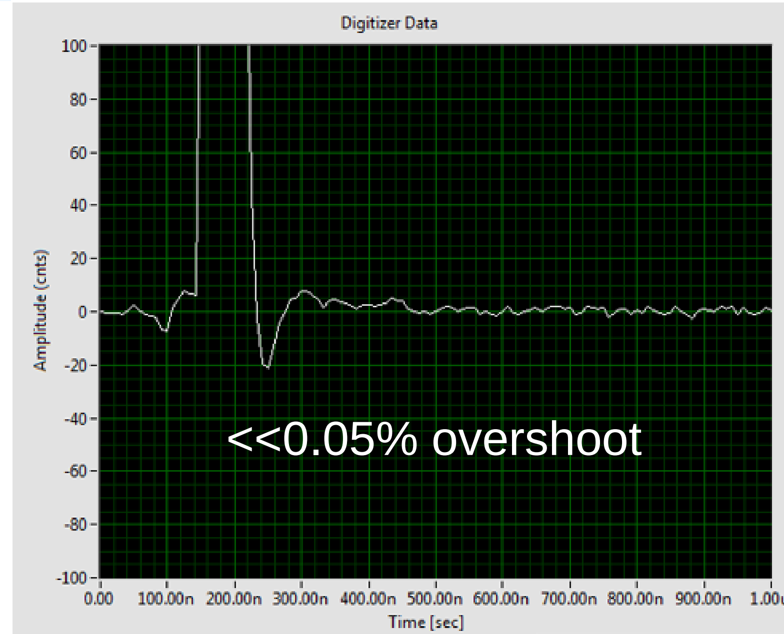
- 15 science chan.
- 4 boresight chan.
- 8 types of det.

Detection and Acquisition Subsystems

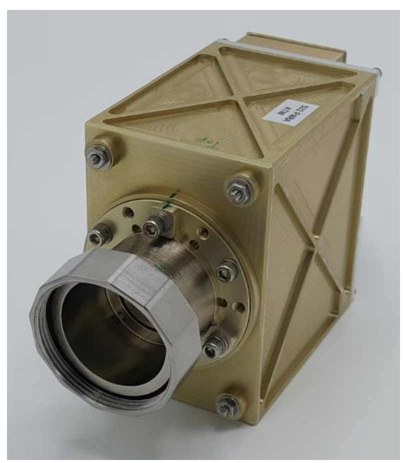
Packaged APD detector modules





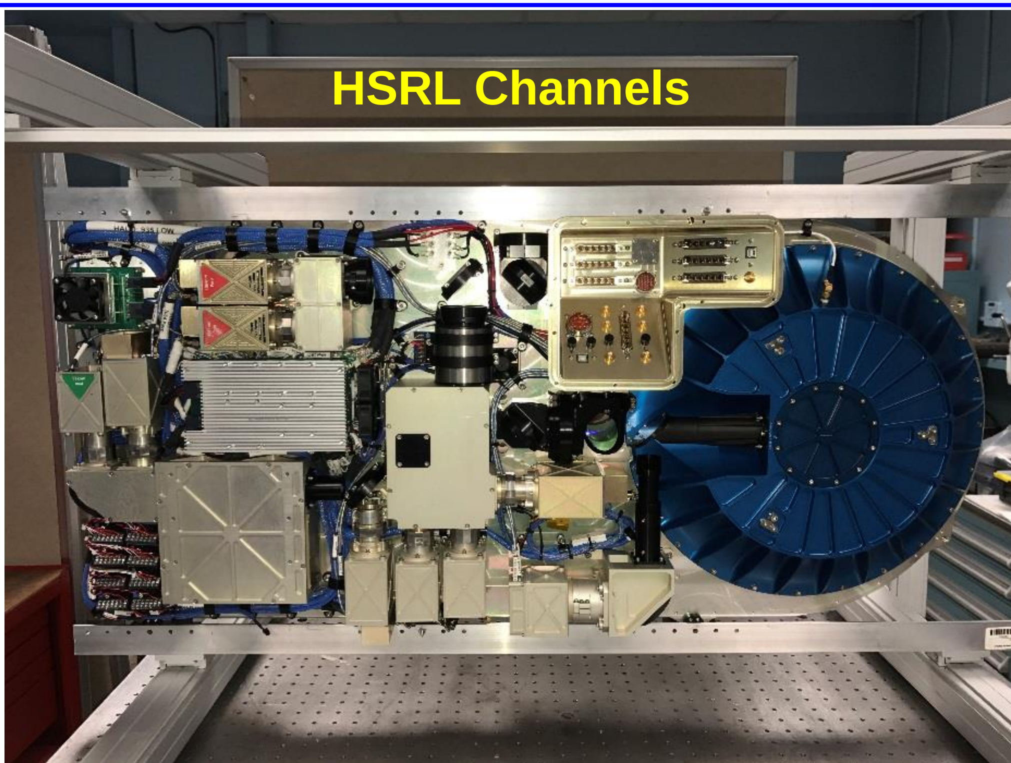


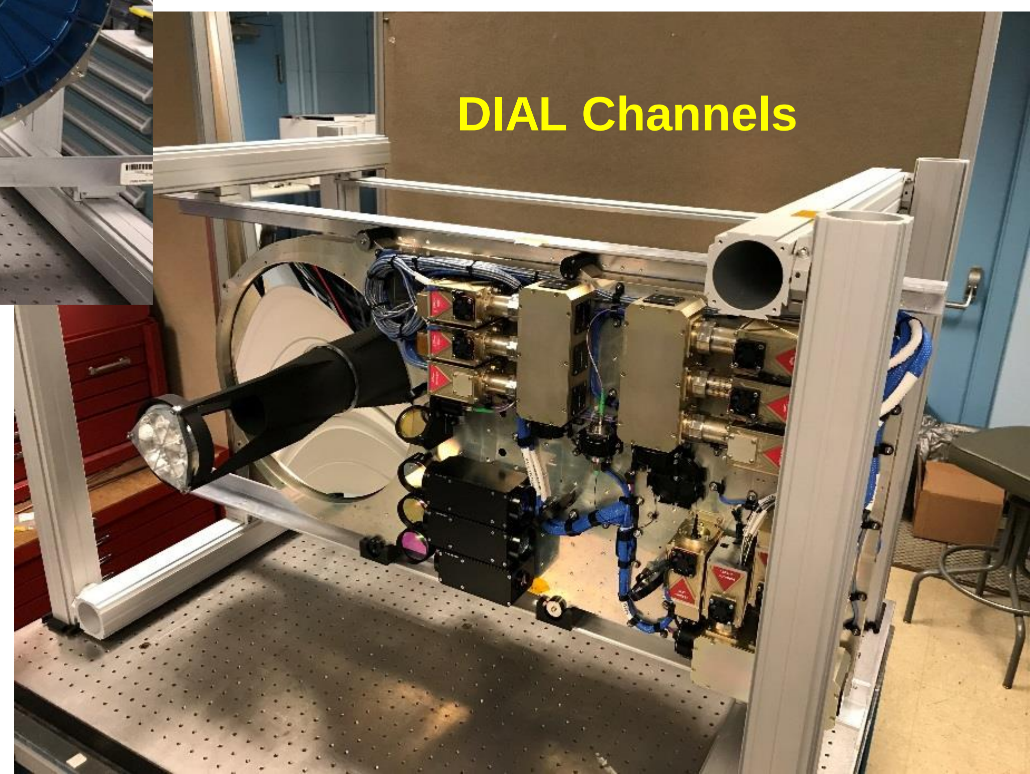
Packaged PMT/MCP detector modules



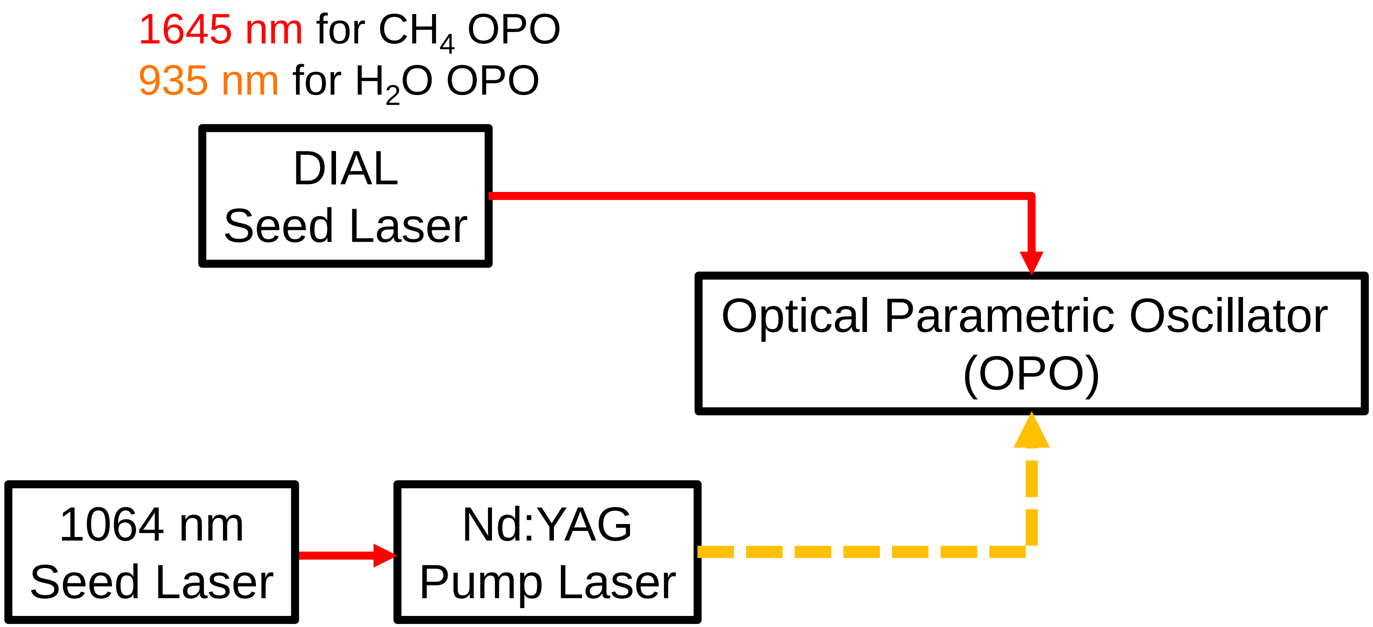
Power Acquisition and Control

Completed Receiver





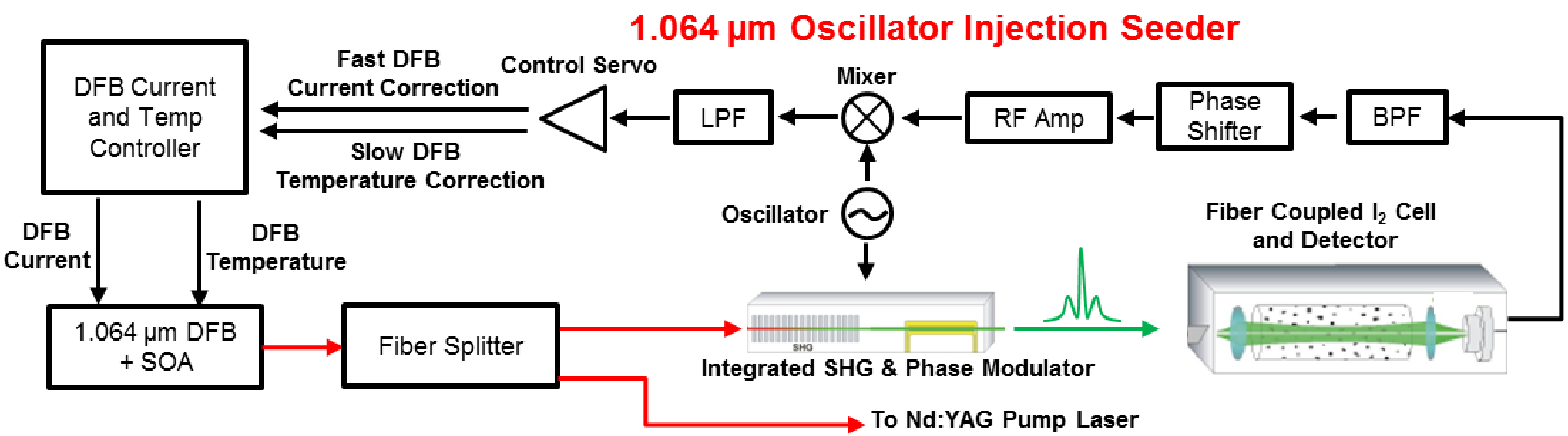
Laser Architecture



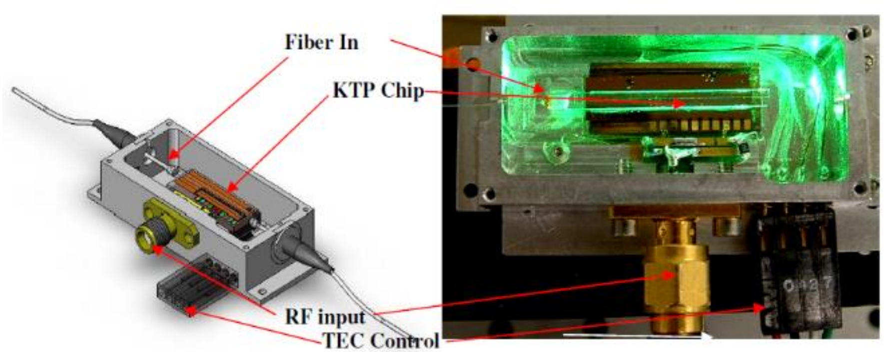
- **Three seed laser: 1064, 1645, 935 nm**
  - **Frequency stability, robust and compact packaging**
- **Two pulsed lasers: 1645, 935 nm**
  - **Transmit power, spectral purity, and robust packaging**

Seed Laser: 1064 nm Architecture

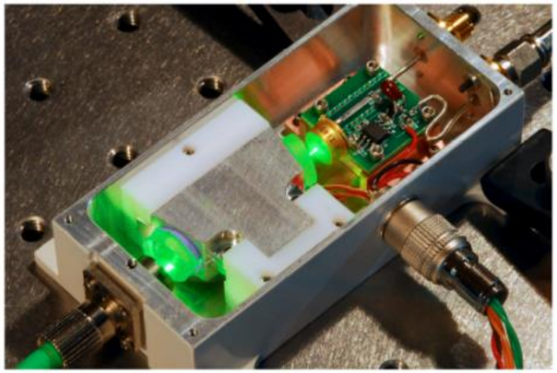
- 1 U 1064 nm laser for injection seeding both Fibertek OPO pump sources
- Frequency stabilized to I_2 absorption line at 532 nm using PDH approach
- 3 channel optical heterodyne between pulsed and seed lasers



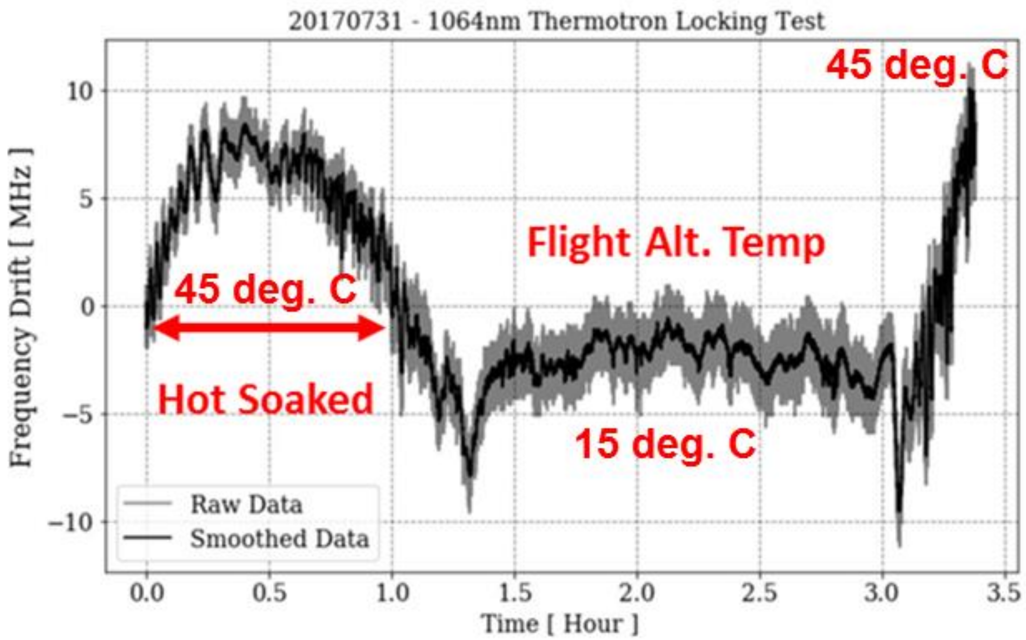
Planar Lightwave Circuit

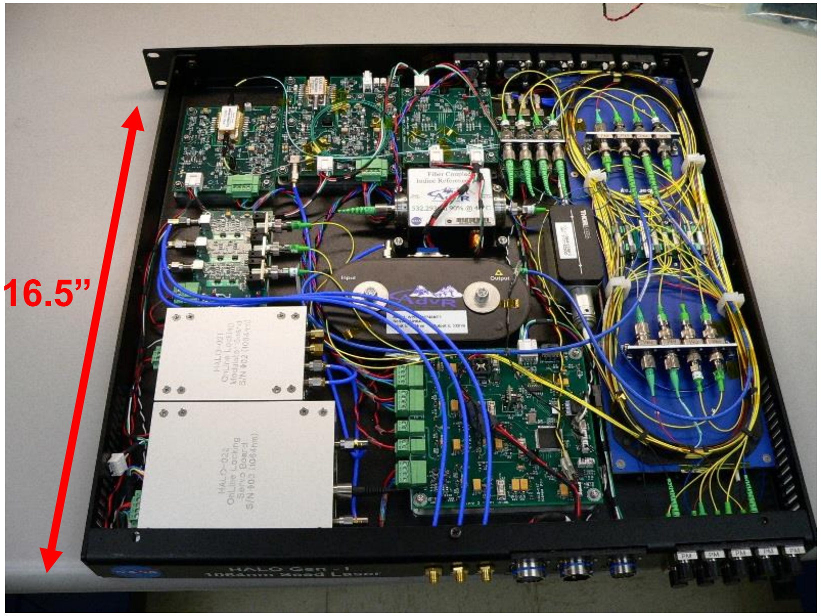


Integrated I_2 Cell



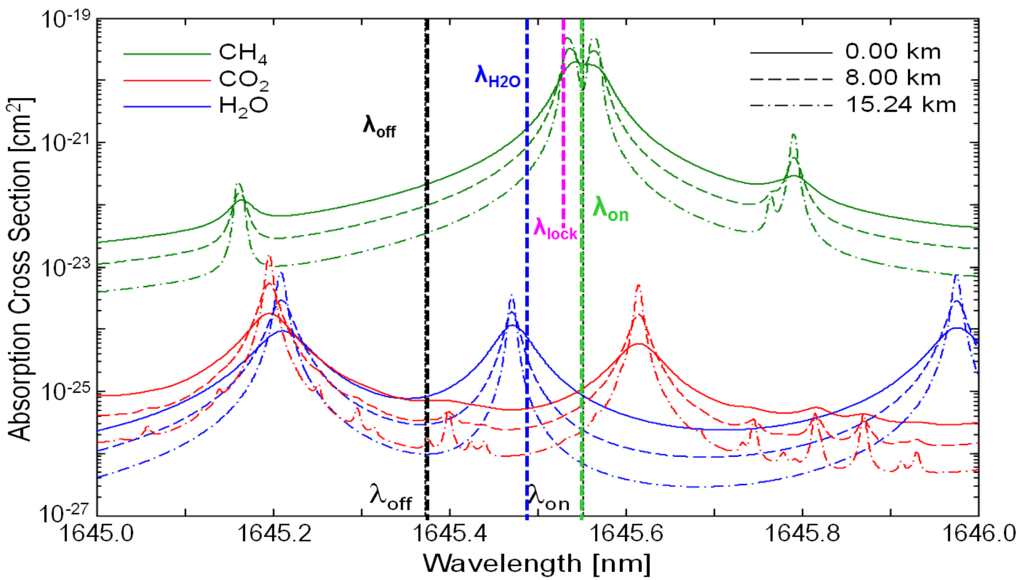
Seed Laser: 1064 nm Performance

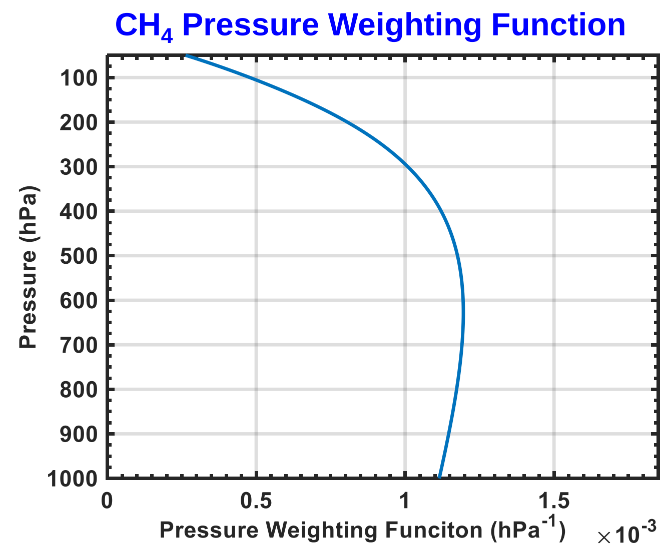


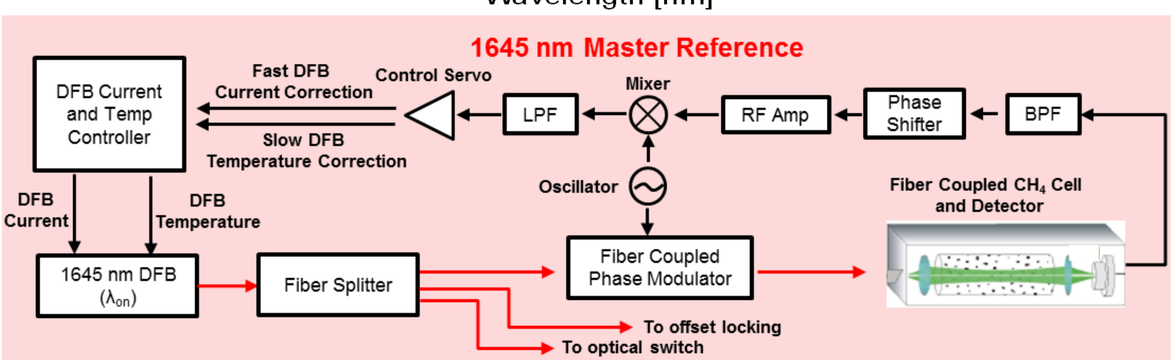


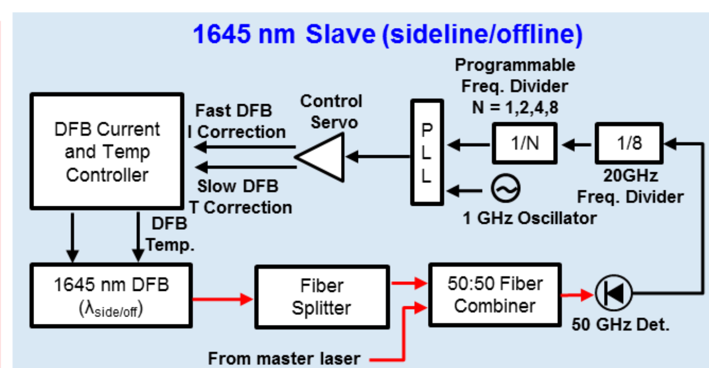
Seed Laser: 1645 nm Architecture

- 4 λ1645 nm seed laser for injection seeding Fibertek CH_4 OPO
- Online wavelength locked to trough of CH_4 R6 doublet
- Master reference locked to R6 peak. Weighted to upper troposphere
- Sideline/offline offset locked with respect to master laser
- Fast electro-optic 4x1 optical switch used to sequentially injection seed OPO



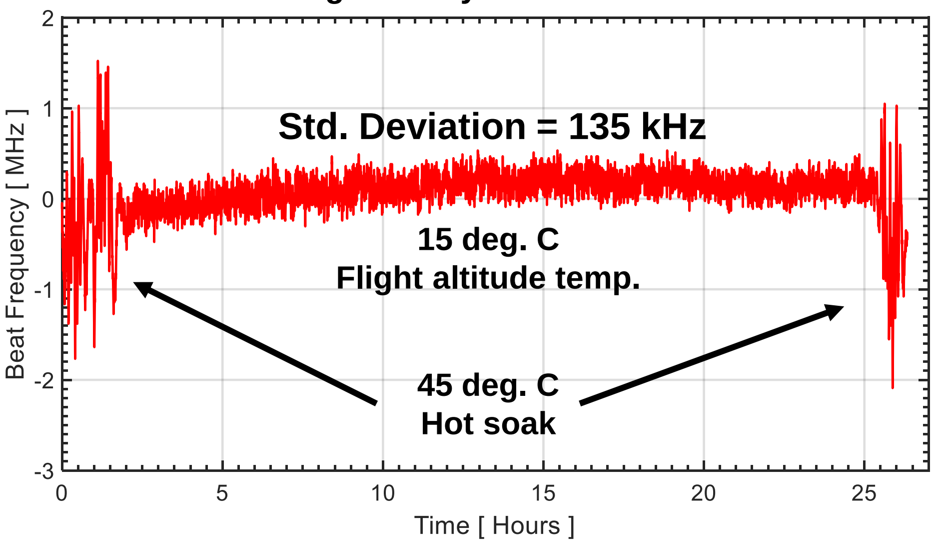




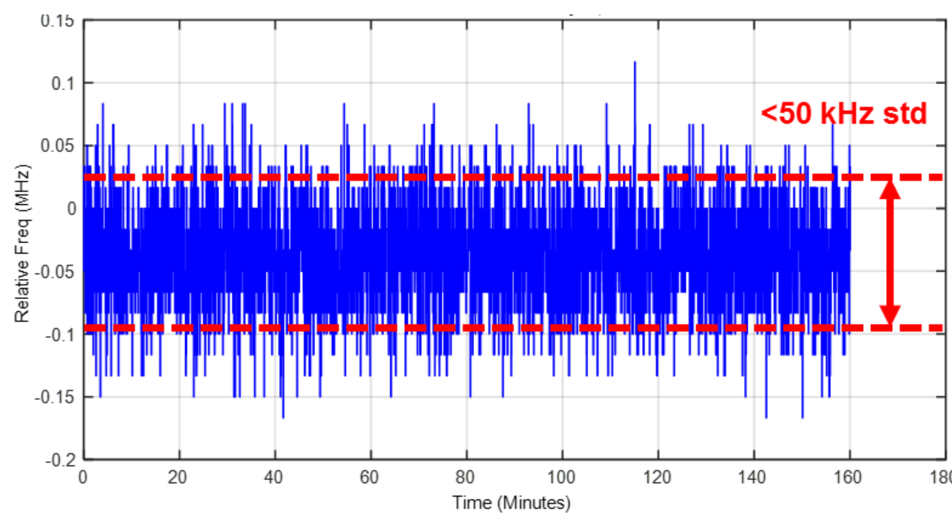


Seed Laser: 1645 nm Performance

Online Locking Stability: Online/Master Beat note

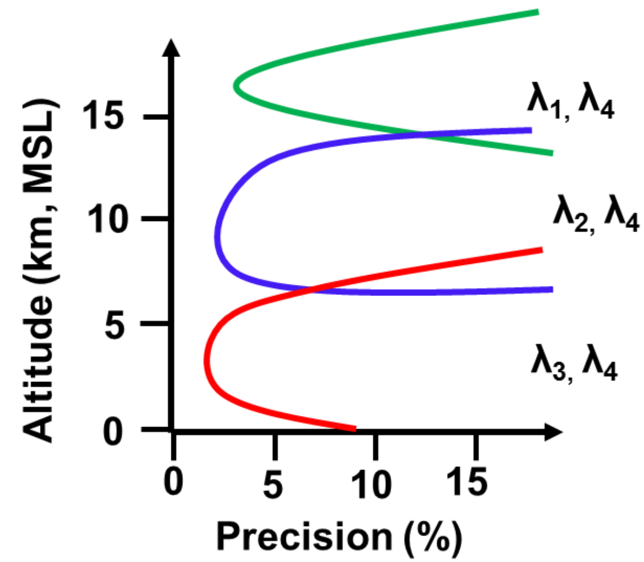


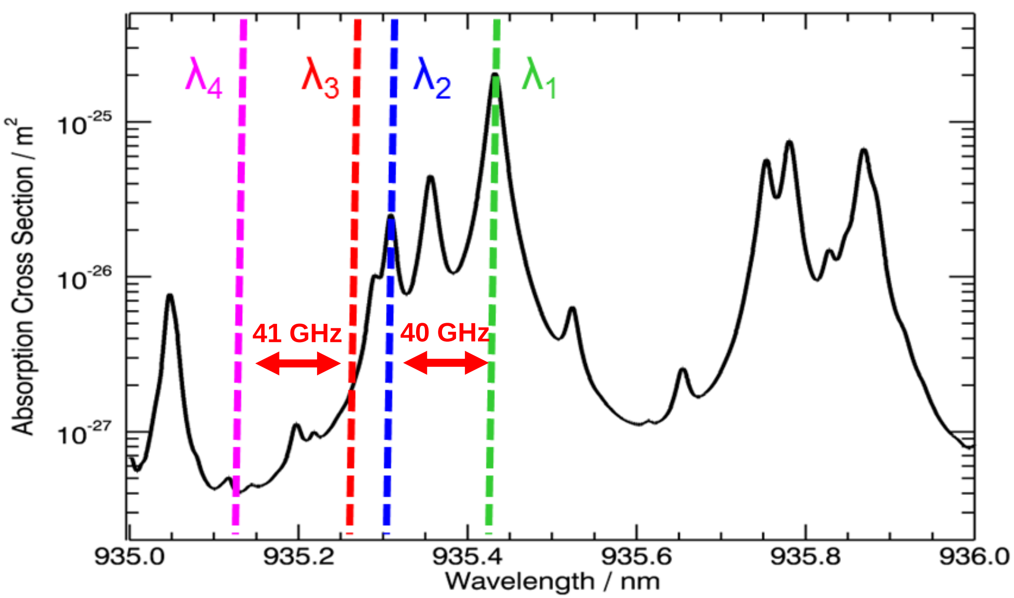
Offline Locking Stability: Master/Offline Beat note

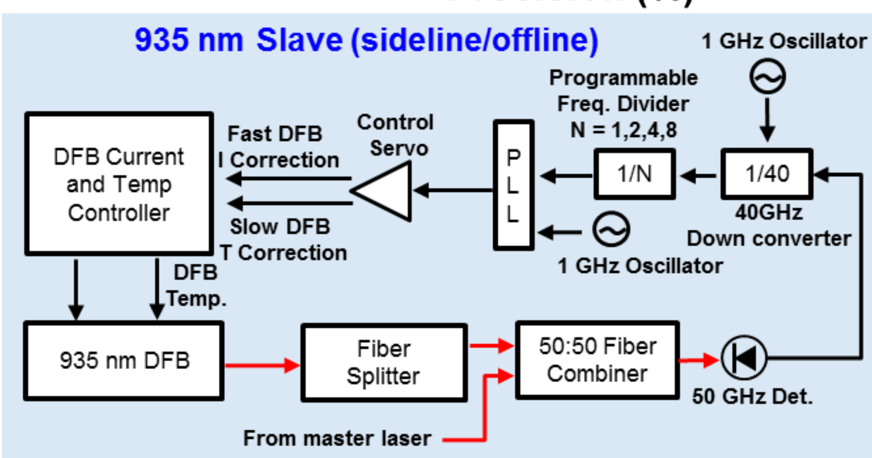


Seed Laser: 935 nm Architecture

- 4 λ 935 nm seed laser for injection seeding Fibertek H_2O OPO
- Stratospheric line (λ_1) locked to strong H_2O line using PDH method
- Mid-troposphere line (λ_2) offset locked ~ 40 GHz with respect to λ_1
- Boundary layer line (λ_3) offset lock with respect to (λ_2). 1-19 GHz tuning range
- Offline (λ_4)offset locked ~ 41 GHz with respect to λ_3.
- Fast electro-optic 4x1 optical switch used to sequentially injection seed OPO



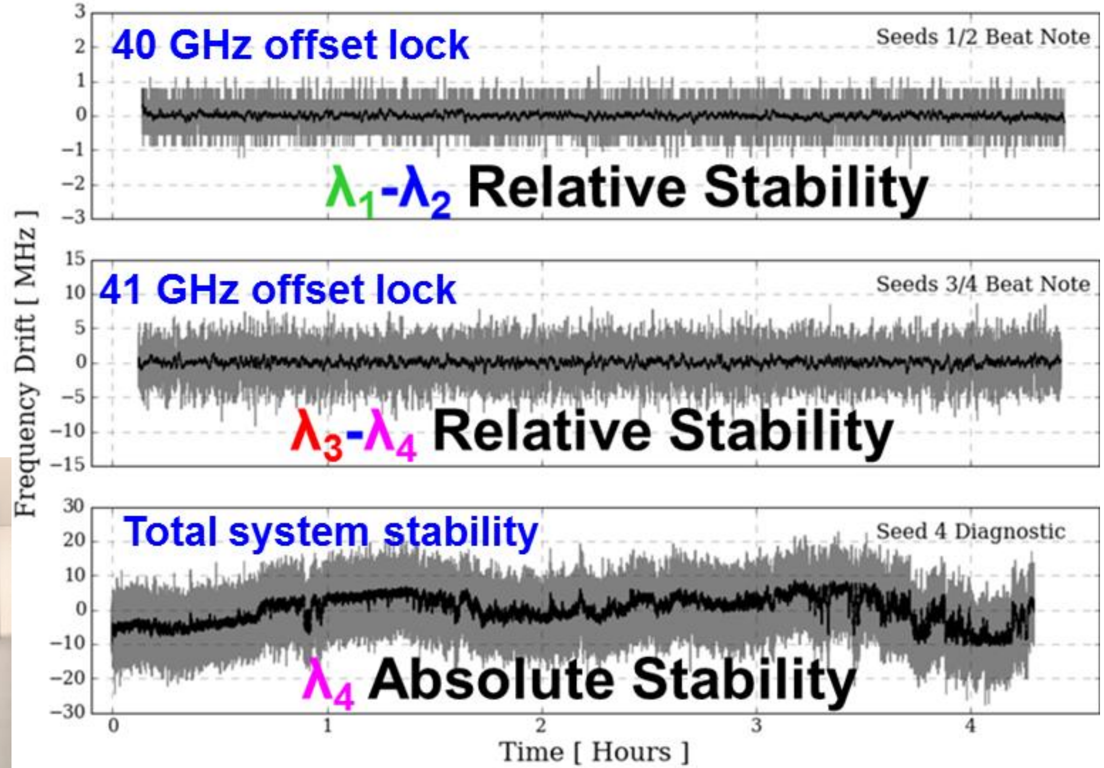




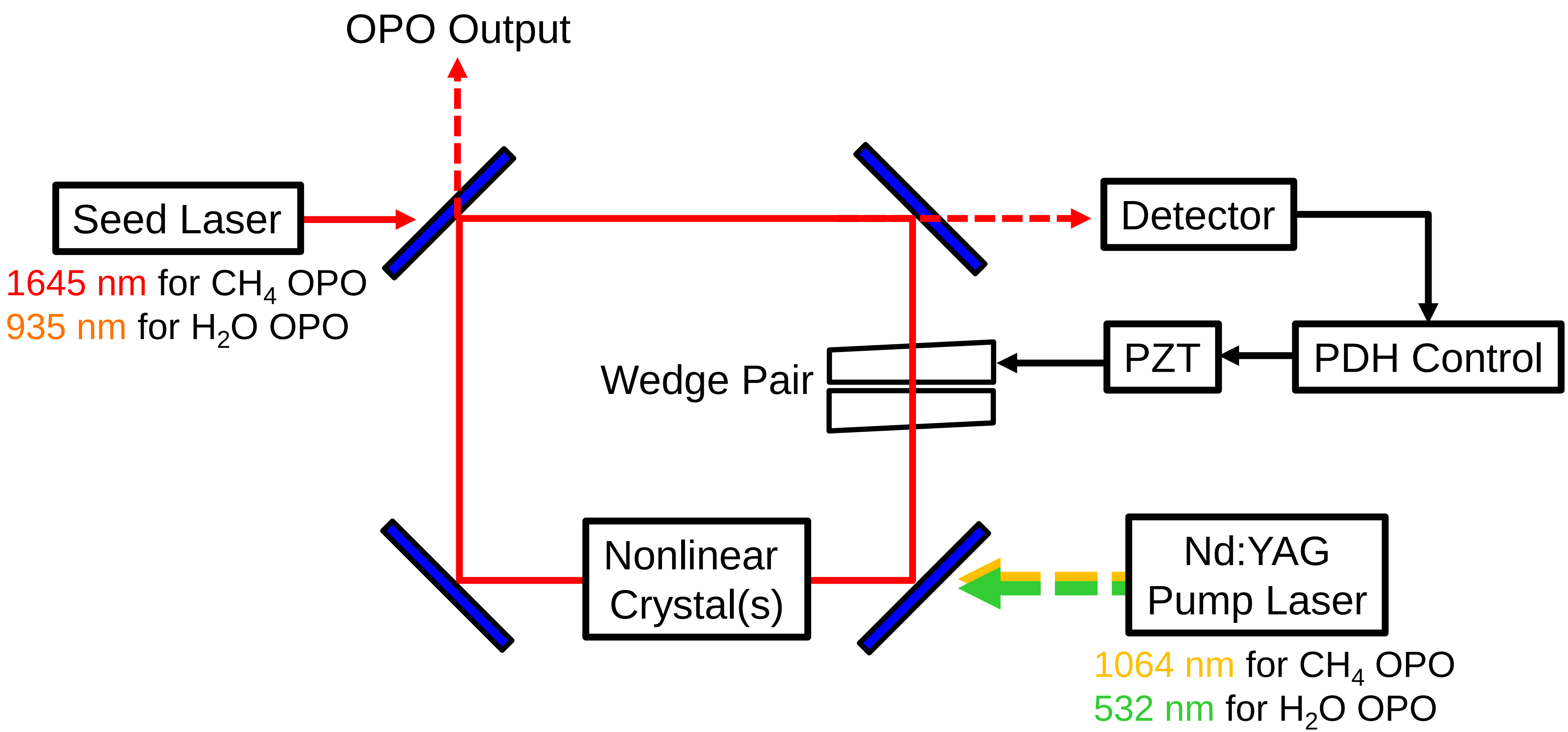
Seed Laser: 935 nm Performance

2U Fiber Engine

3U DFB Module

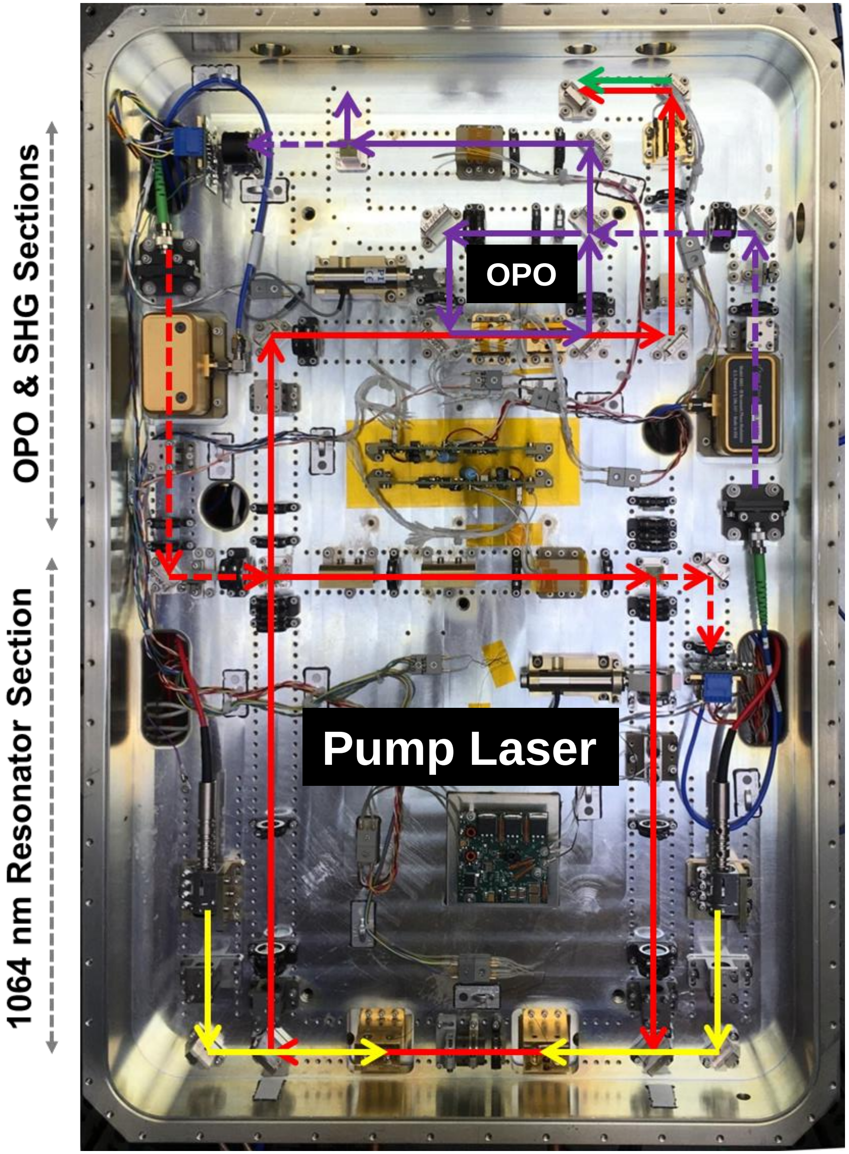


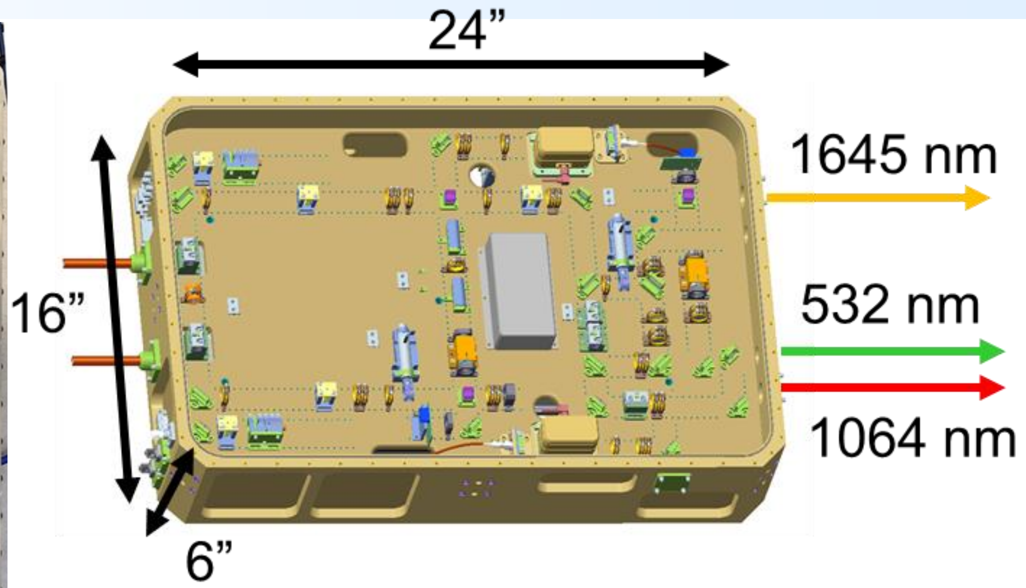
Fibertek Common Architecture Pulsed Lasers

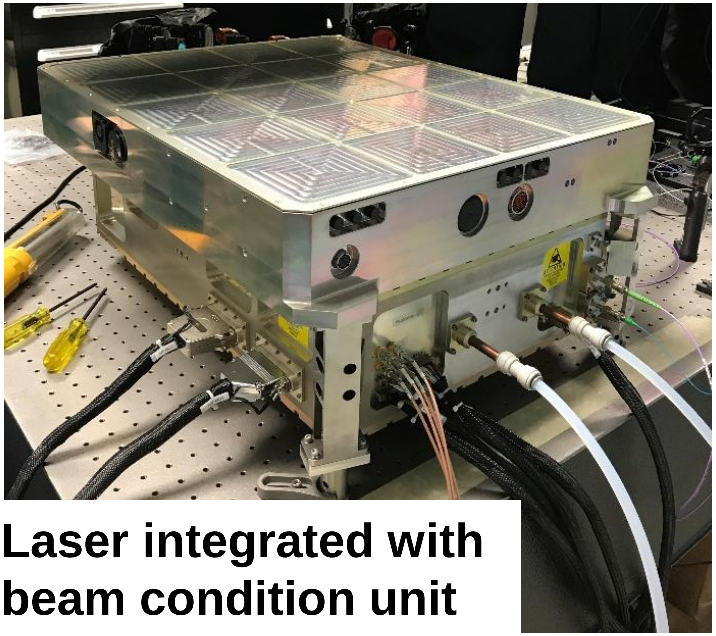


935 and 1645 nm lasers maintain common optical, mechanical, and electrical interfaces

Integrated 1645 nm Pulsed Laser





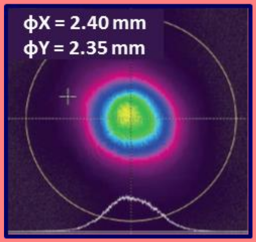


Laser integrated with beam condition unit

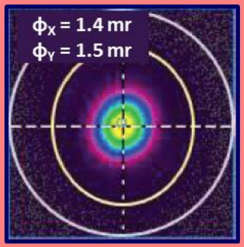
Fibertek CH_4 Laser Performance

- 1064 nm pump: 11 mJ, 1 kHz (11 W)
- 1645 nm OPO: 2.5 mJ (2.5W)
- Environmental testing (vibration and thermal)
- OPO and 1064 nm lasers both exhibit spectral purity > 3000:1 (validated in flight)
- CH_4 laser is integrated into system and flown on two separate campaigns

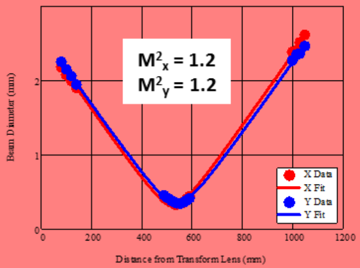
1064 nm resonator (pump) 11W, 7 W residual pump



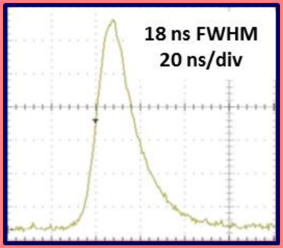
Near Field Spatial Distribution



Far Field Spatial Distribution

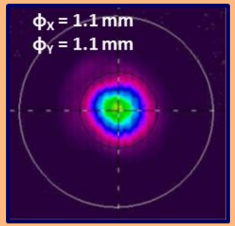


Beam Quality

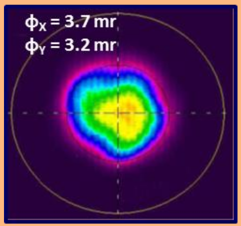


Temporal Distribution

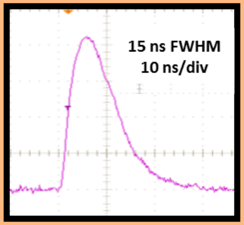
1645 nm OPO, 2.5W



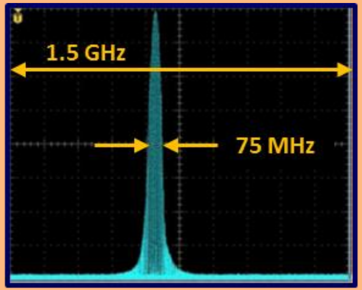
Near Field Spatial Distribution



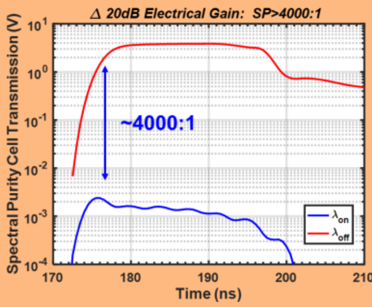
Far Field Spatial Distribution



On-Line Temporal Distribution

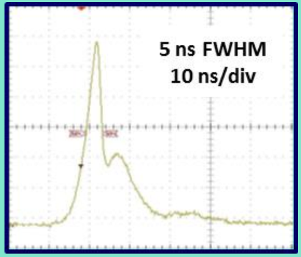


On-Line Spectral Distribution Scanning Fabry-Perot

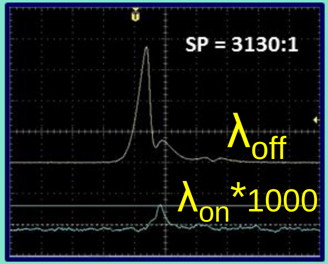


In Flight Spectral Purity

532 nm (HSRL) 1 W

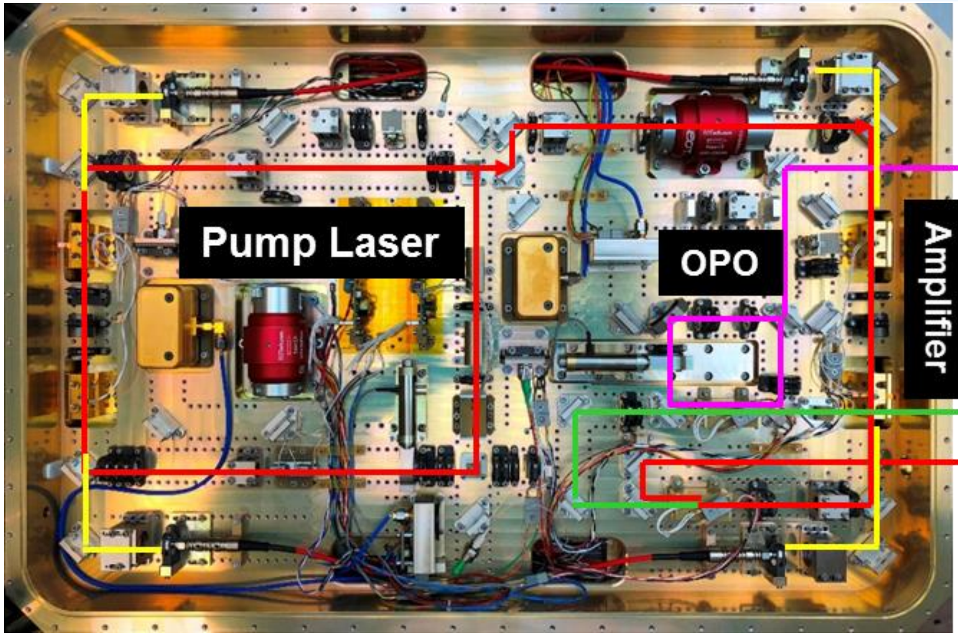


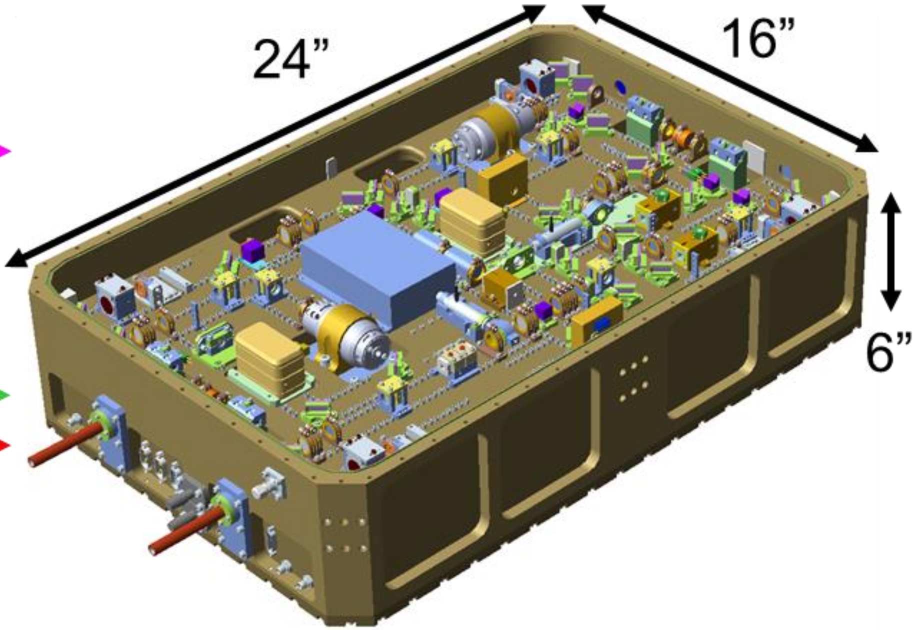
Temporal Distribution



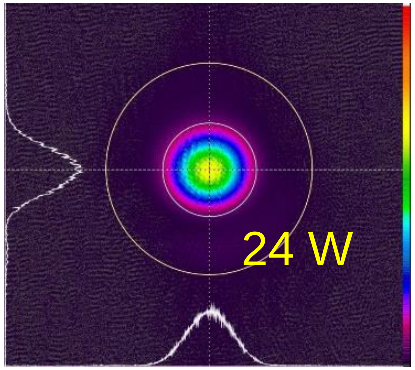
Spectral Purity w/ I_2 Cell – 1104 Line w/ OPO locked On-Line

Fibertek 935 nm H_2O Laser Architecture

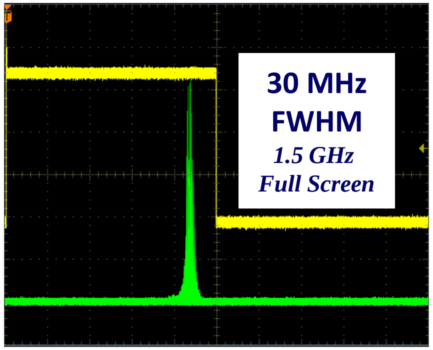


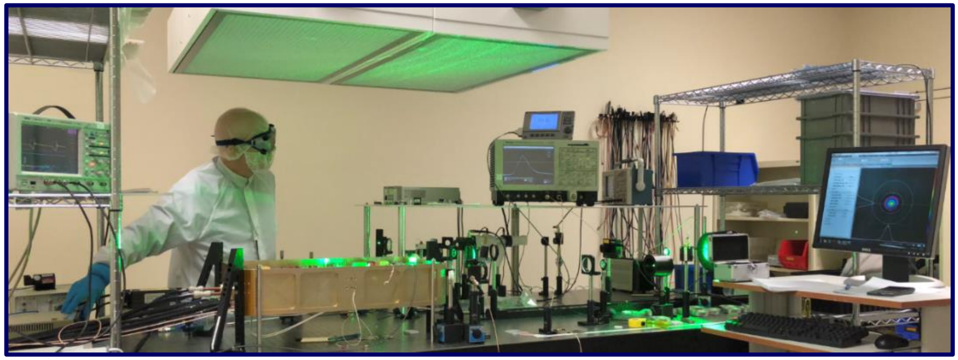


1064 nm Far Field Image



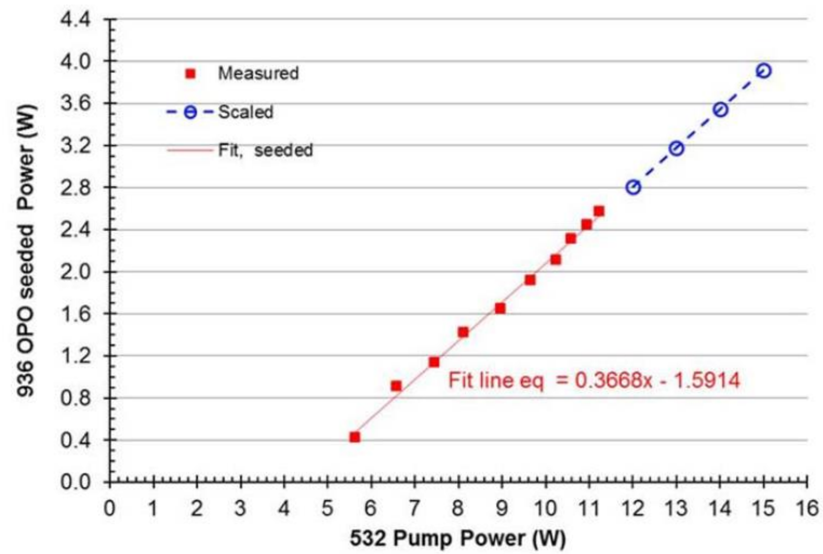
Oscillator
Spectral Width





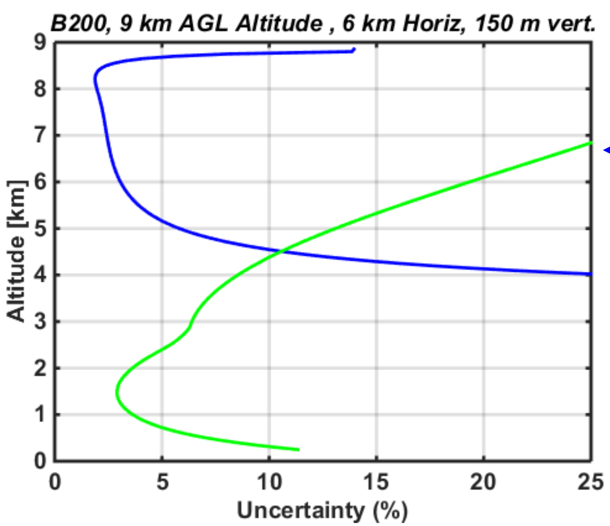
Fibertek 935 nm H_2O Laser Performance

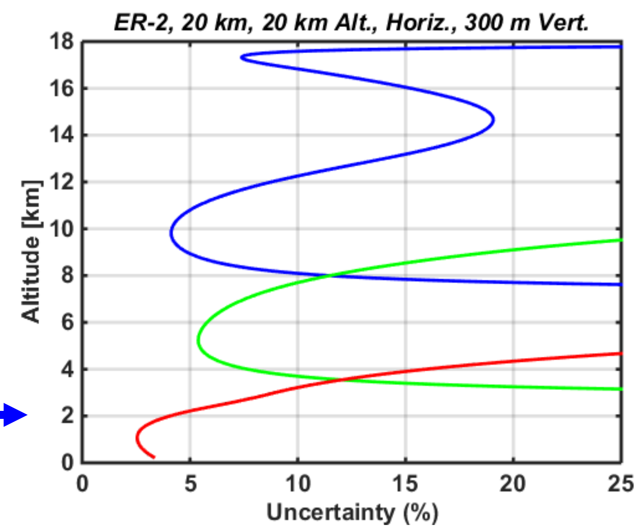
- 1064 nm osc.+amplifier: 24 mJ, 1 kHz (24 W)
- 532 nm pump: 14 mJ, 60 % conversion efficiency
- 935 nm OPO: currently being built
  Target ≥ 3mJ



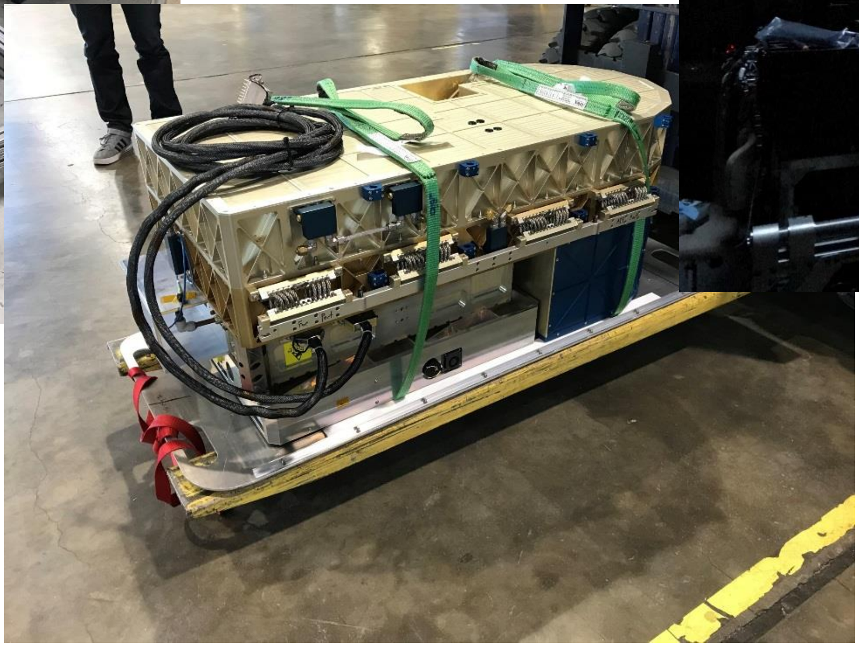
Simulated Performance (B200)

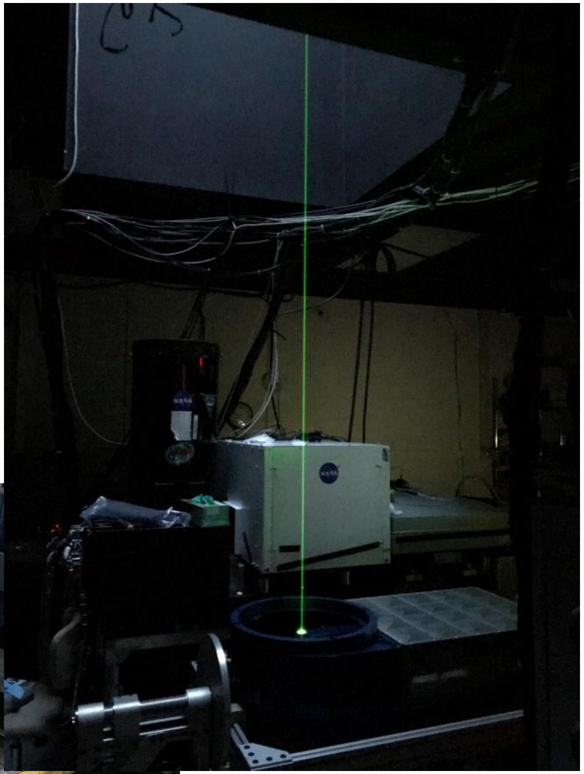
Simulated Performance (ER-2)



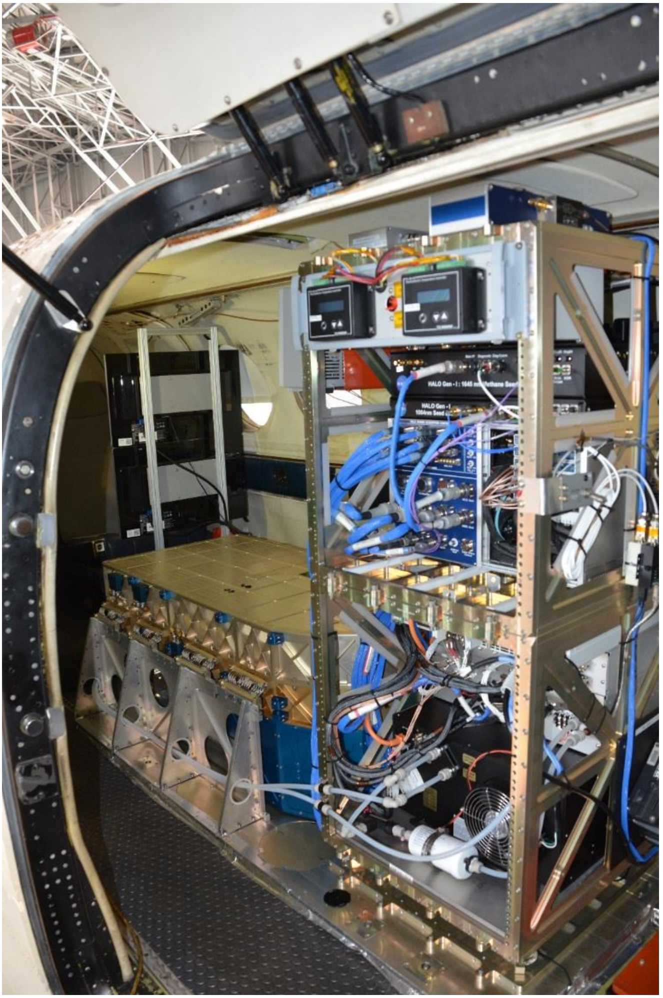


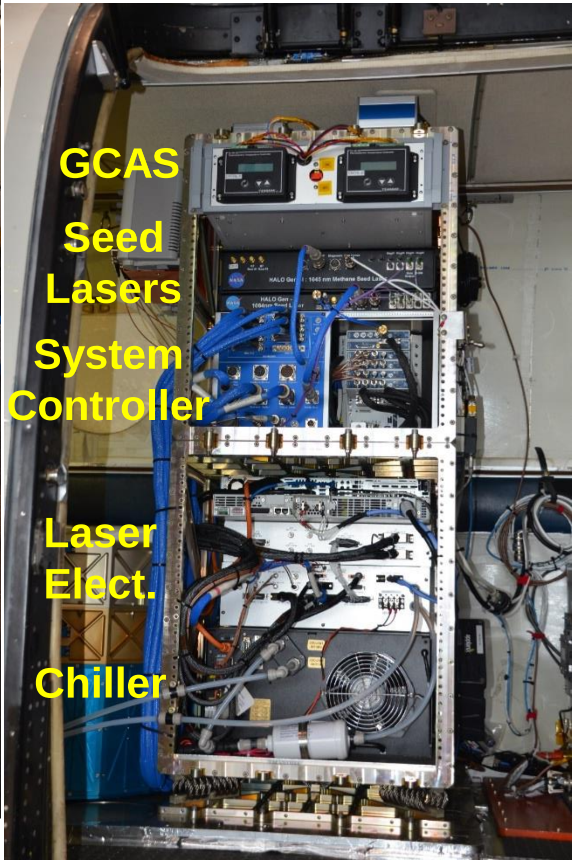
Integrated System: CH_4 Configuration



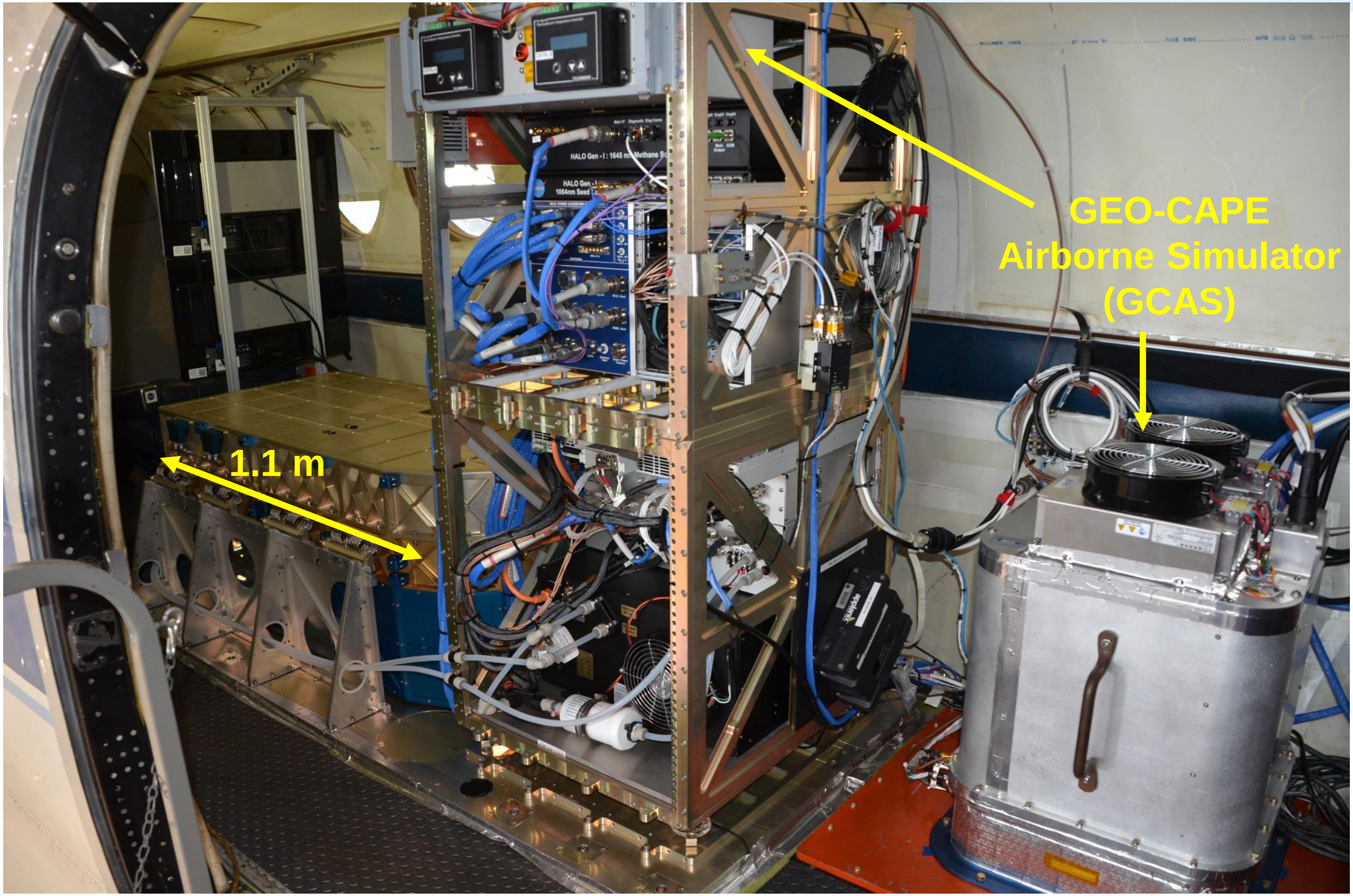


HALO CH_4 Config. Integrated on UC-12

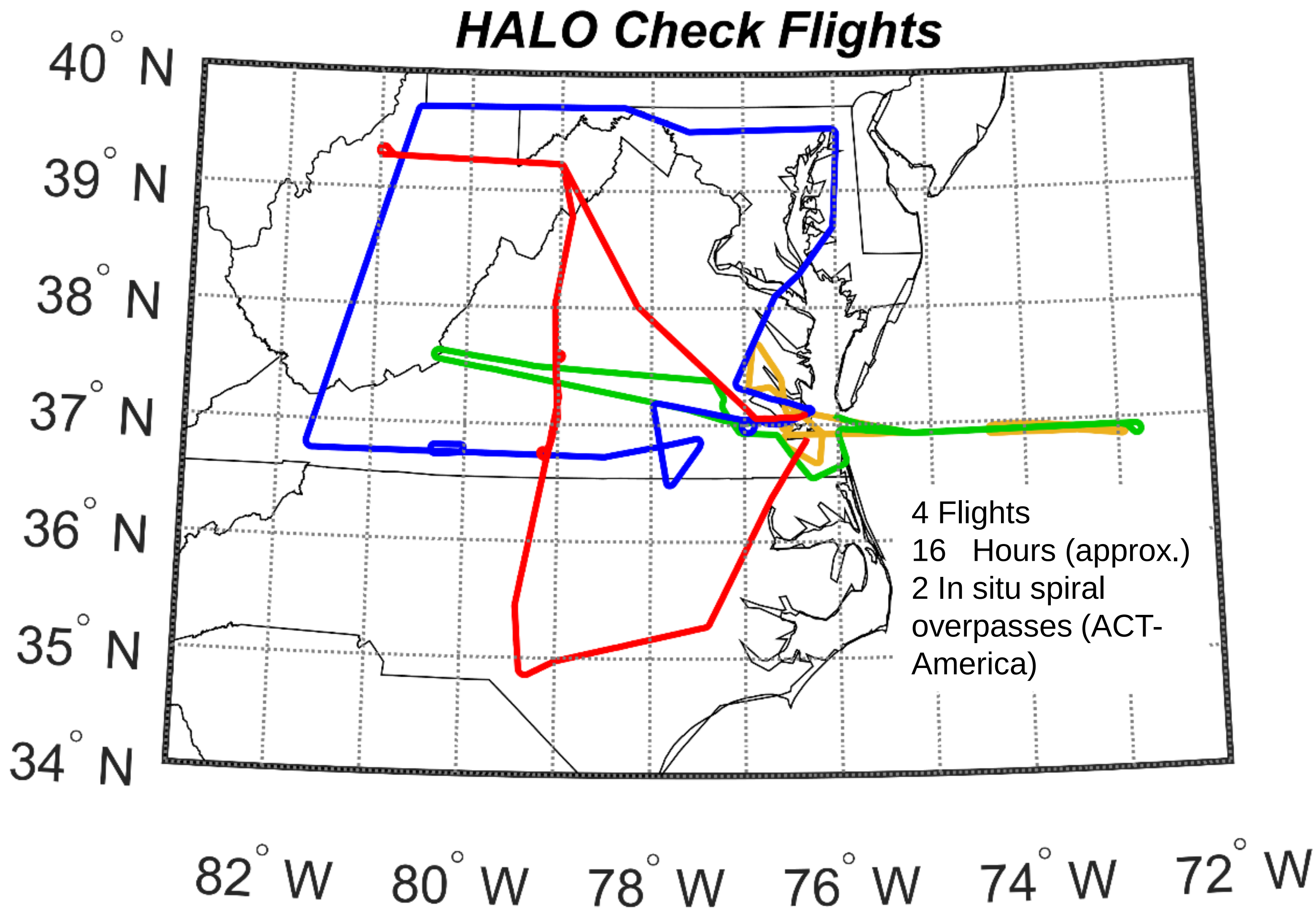




Co-Hosted Payload

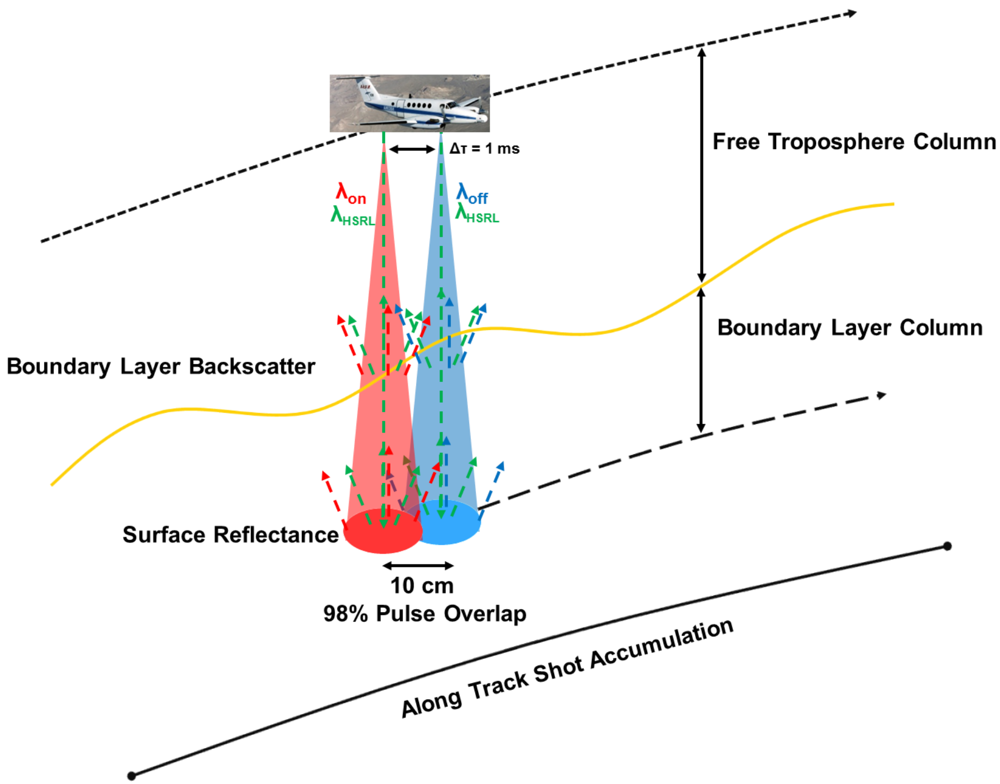


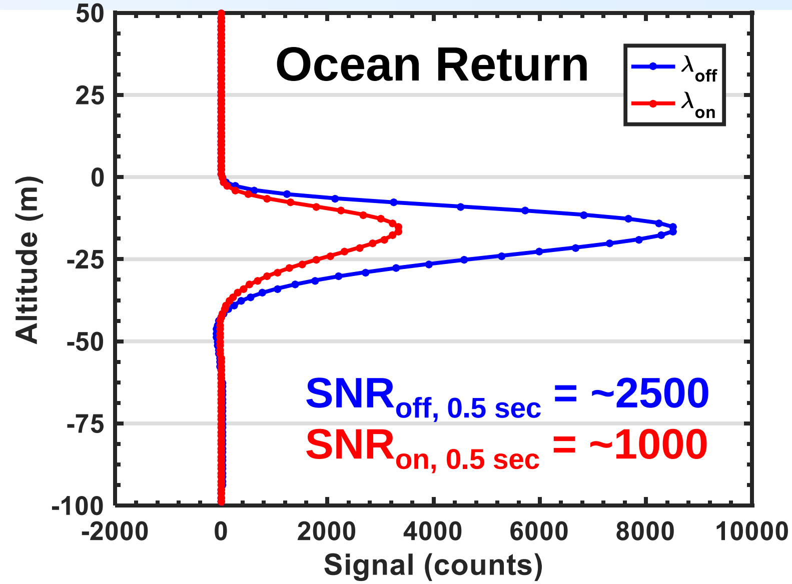
Spring 2018 CH_4 Check Flights

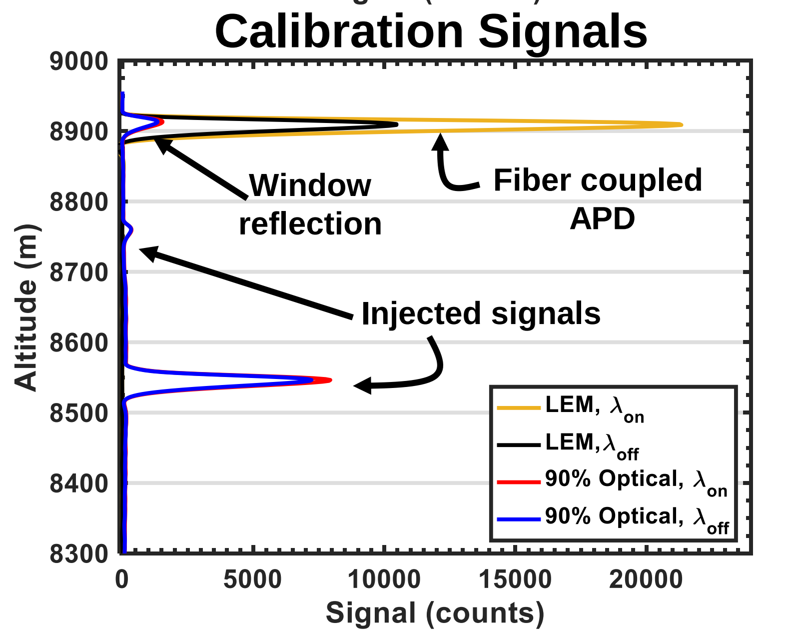


First Light: Integrated Path DIAL (IPDA) Channels

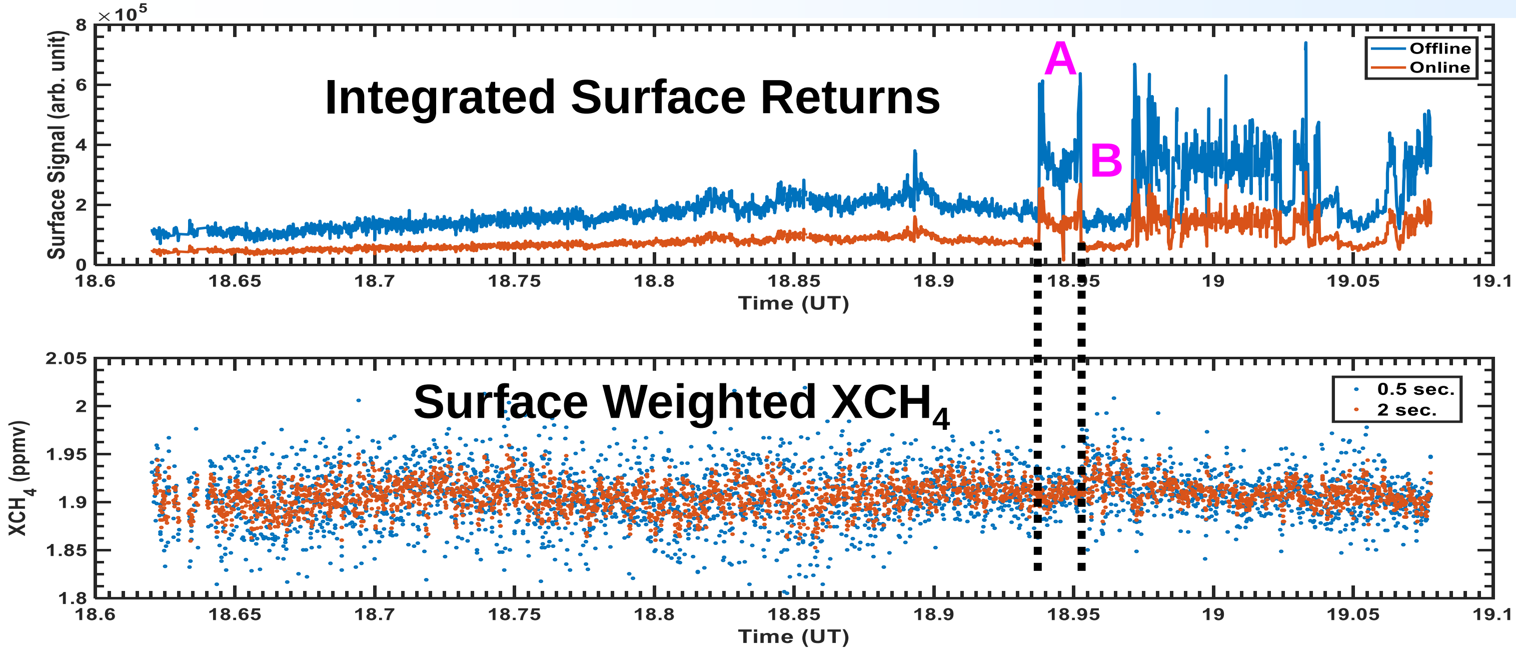
- Integrated path differential absorption (IPDA) measurement between transmitted energy signal and surface return
- High SNR over low albedo targets
- Integrating spheres used to sample transmitted energy
- Five independent calibration methods

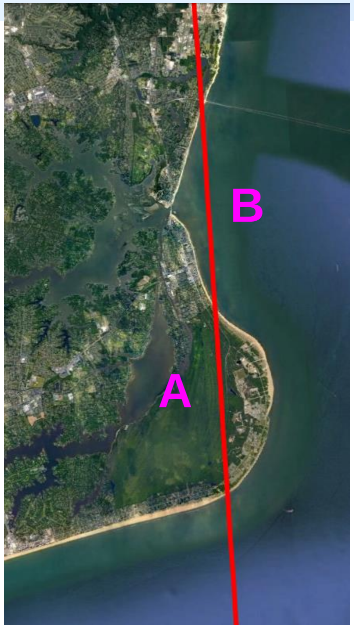


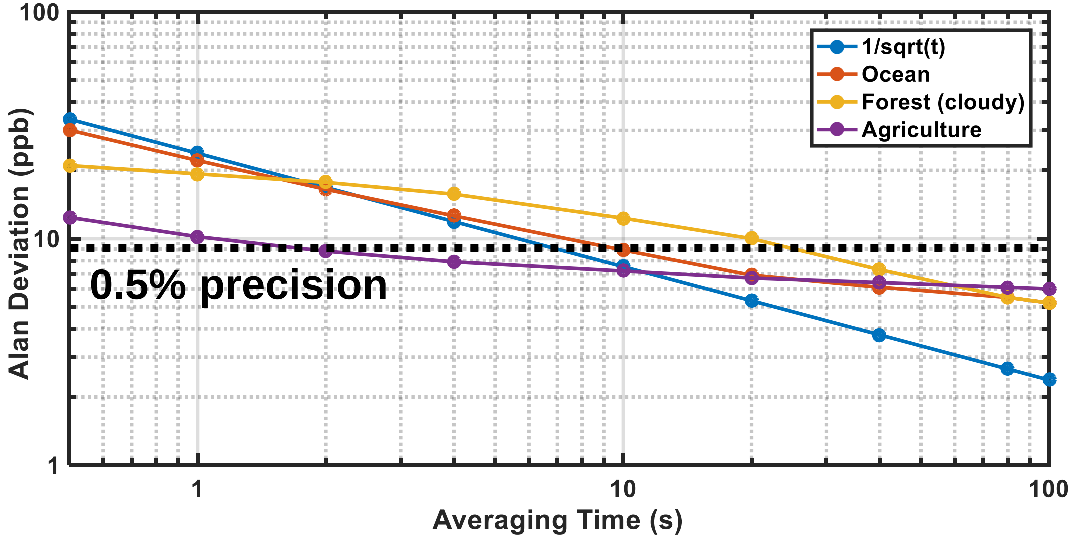




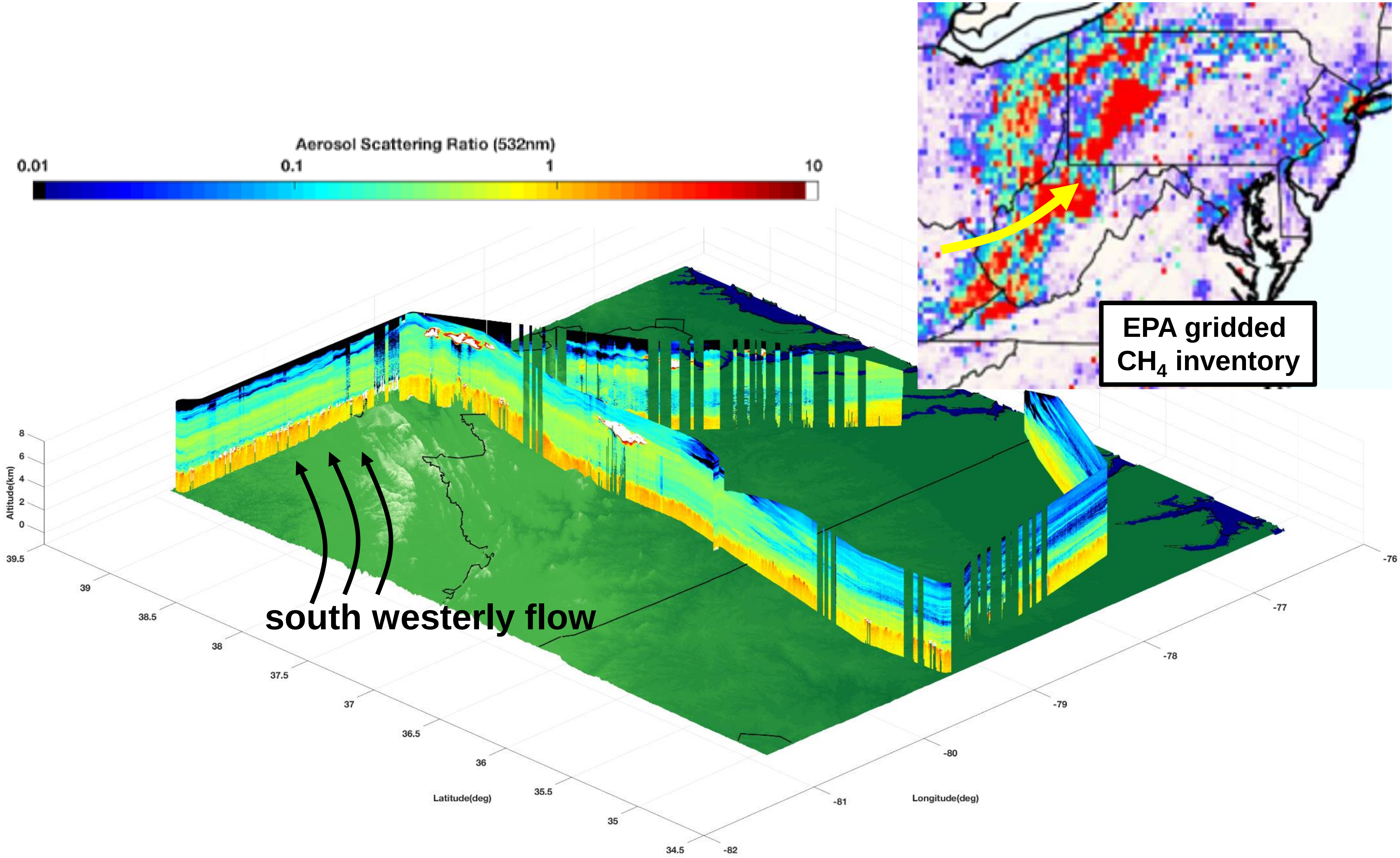
Preliminary CH_4 IPDA Results



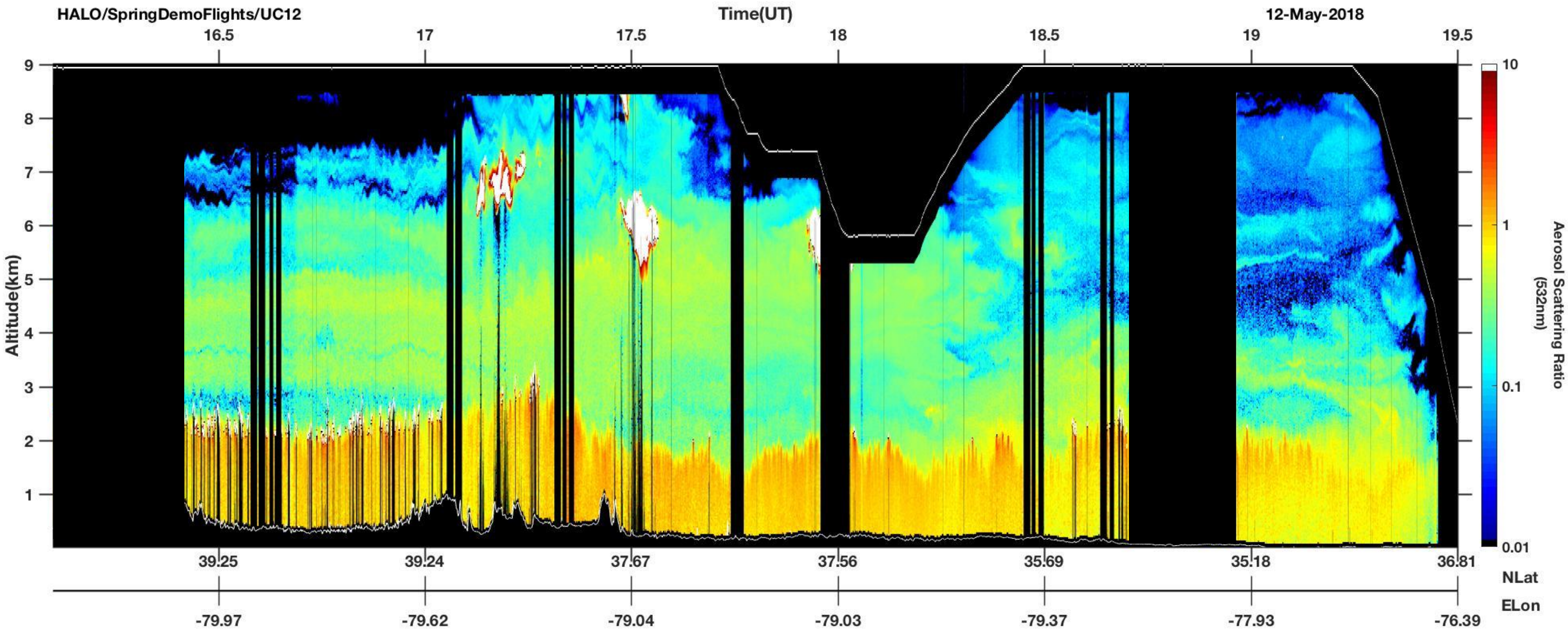




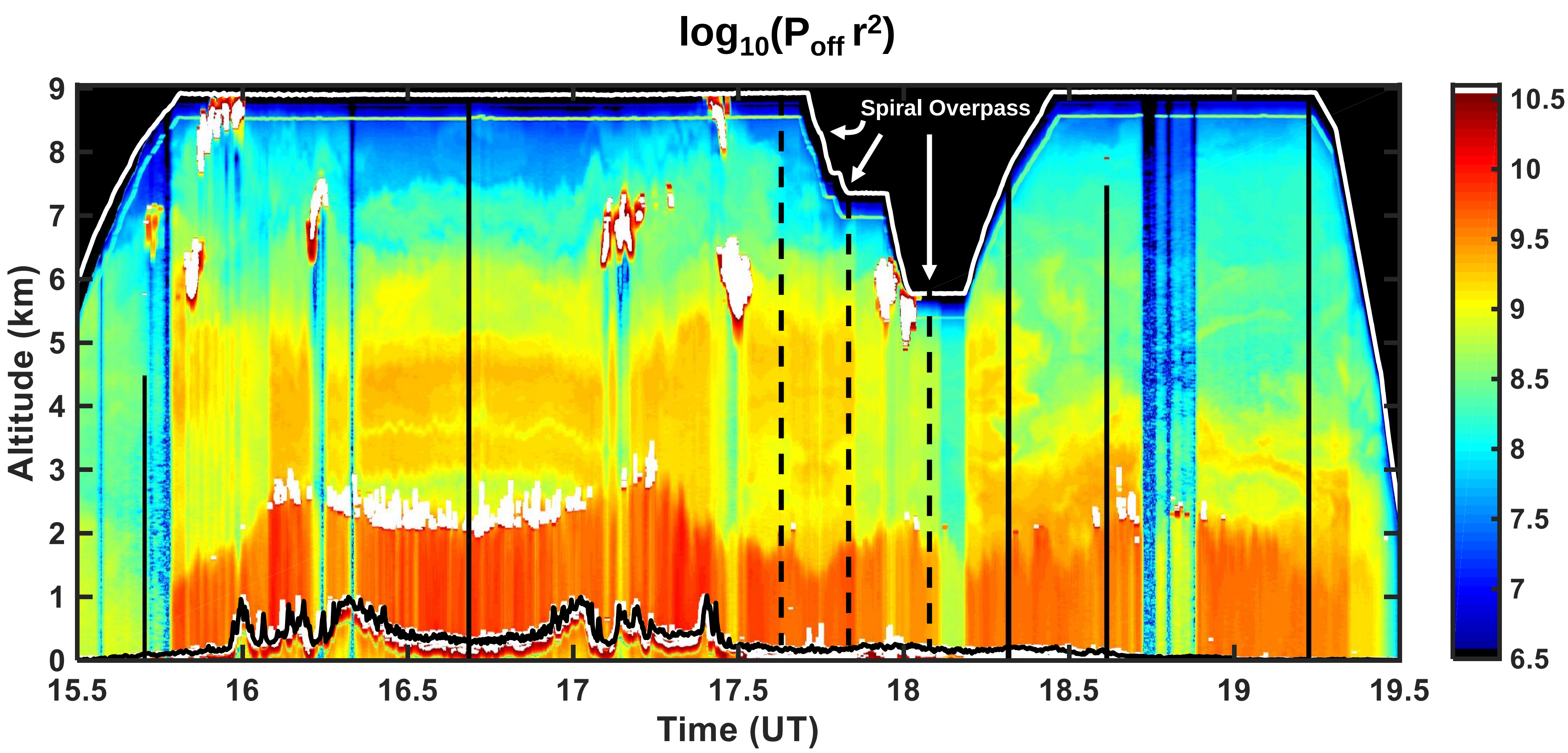
Atmospheric Products: May 12 2018



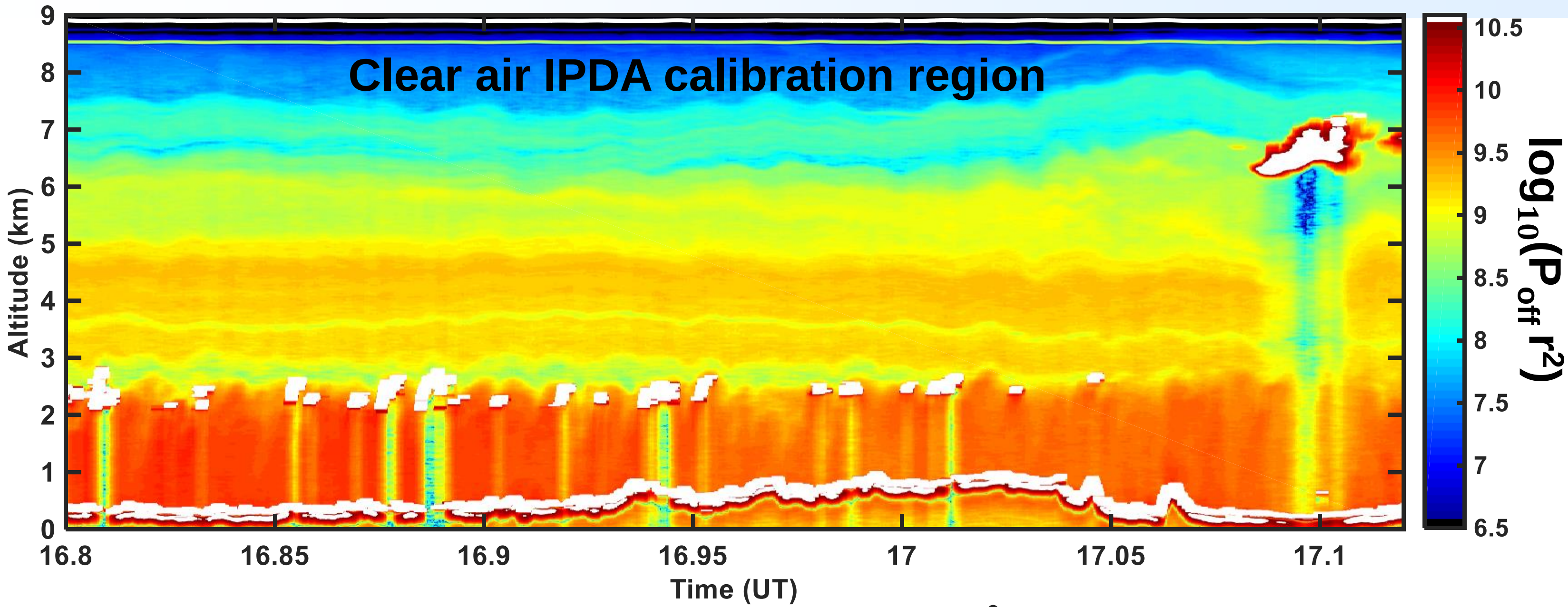
Preliminary Aerosol Products

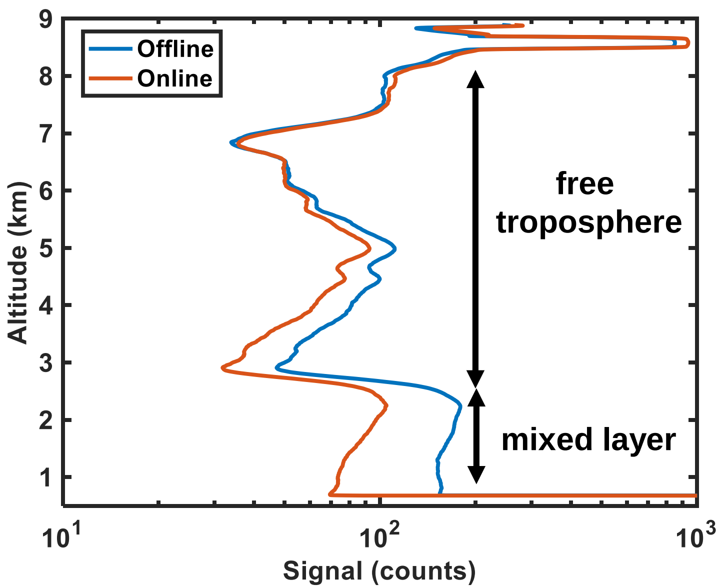


1645 nm Backscatter Profiles

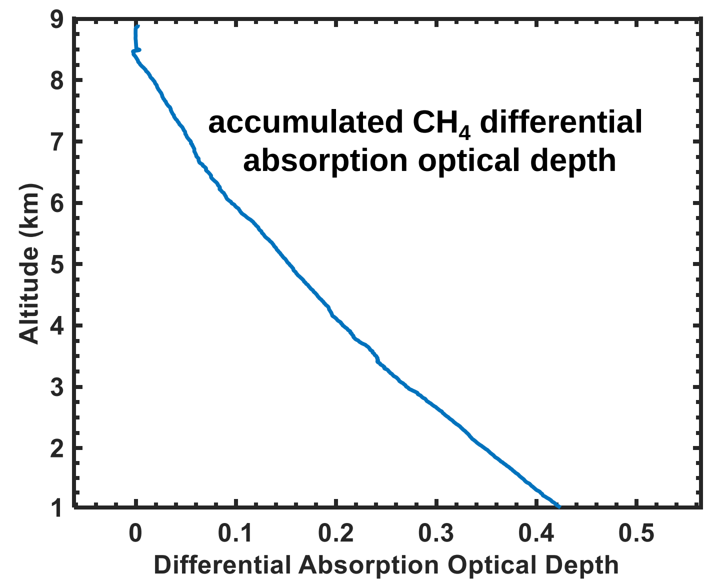


Preliminary CH_4 DIAL Products





$$OD_{CH_4}(r) \propto \frac{P_{on}(r)}{P_{off}(r)}$$



Summary and Future Plans

Summary

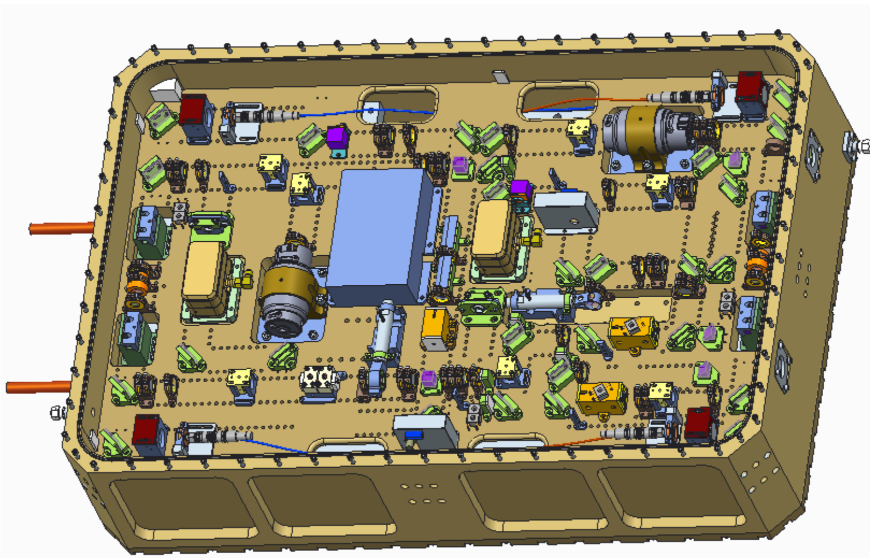
- Developed and environmental tested three flight hardened seed lasers
- Developed high power and high spectral purity CH_4 pulsed laser
- Demonstrated spectral purity requirements in relevant aircraft environment
- Integrated and test multi-channel receiver
- Demonstrated first airborne CH_4 measurements using OPO laser on turbo prop aircraft

Future plans

- Deploy CH_4 configuration in Long Island Sound Ozone Study campaign
- Continue development of CH_4 retrievals and improvements to CH_4meas.
- Assess feasibility of integrating HgCdTe detector for clear air CH_4 meas.
- Complete development of H_2O pulsed laser in 2018
- Demonstrate water vapor measurements from B200 in 2019
- AITT to transition instrument to ER-2 and other platforms
    - Water vapor focused upper atmospheric/boundary layer process studies
    - Co-hosted payload with Differential Radar, wind lidar, and spectrometers
    - Serve as the U.S. MERLIN validation instrument

Path to Space-Based Observations

Water Vapor OPO: H_2O Profiles+HSRL
(this program)



Er:YAG: CH_4+H_2O Profiles
(ongoing tech development)

Reduction in Size Weight and Power

Airborne Science → **EVI/DS Explorer mission**

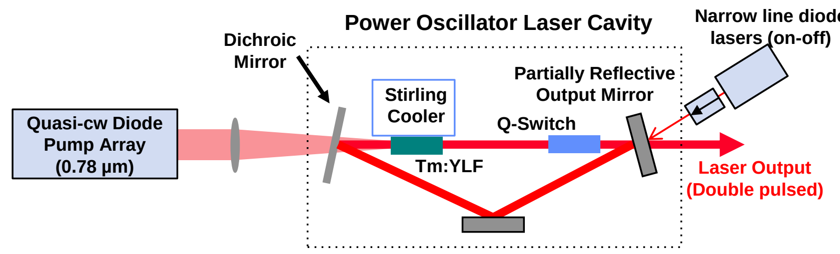
Technology Maturation

Laser Transmitter for space-based water vapor lidar

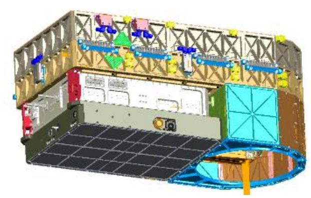
PI: Tso Yee Fan / MIT Lincoln Laboratory

Objective

- Develop a space-based water vapor differential absorption lidar (DIAL) transmitter based on a Tm:YLF pulsed laser at 816 nm
  - Laser pulse energy ≥ 100 mJ
  - Double pulse repetition rate ≥ 50 Hz
  - Spectral purity >99.9%
  - Wall plug efficiency ≥ 5%
- Reduce the risk, cost, and development time of a future water vapor DIAL satellite instrument
- Revolutionize atmospheric remote sensing by developing laser technologies that will enable high resolution and accurate 3-D observations of water vapor profiles from space



HALO Instrument Head



AITT

Space

Approach:

- Develop an efficient high power laser transmitter at 816 nm based on newly emerging Tm:YLF laser crystals
- Implement double pump-pulse operation and validate laser theoretical performance with varying pulse periods
- Implement laser injection seeding and cavity stabilization control system and validate that closed-cycle cooled Tm:YLF can meet all key functionalities required for space-based DIAL systems
- Develop a hardened brassboard laser for future integration into the HALO lidar instrument as an airborne prototype for a future satellite instrument

CoIs: Amin Nehrir, NASA LaRC; Steven Augst, MIT Lincoln Lab

Key Milestones

• First light, breadboard laser	4/18
• 100 mJ/pulse from breadboard laser	9/18
• Unidirectional operation from breadboard laser	2/19
• Double pulse operation from breadboard laser	5/19
• Injection seeded, double pulse operation	9/19
• Brassboard laser transmitter design complete	1/20
• Demonstrate fully functional brassboard	9/20

TRL_{in} = 2

Acknowledgments

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