A Methane Lidar for Greenhouse Gas Measurements

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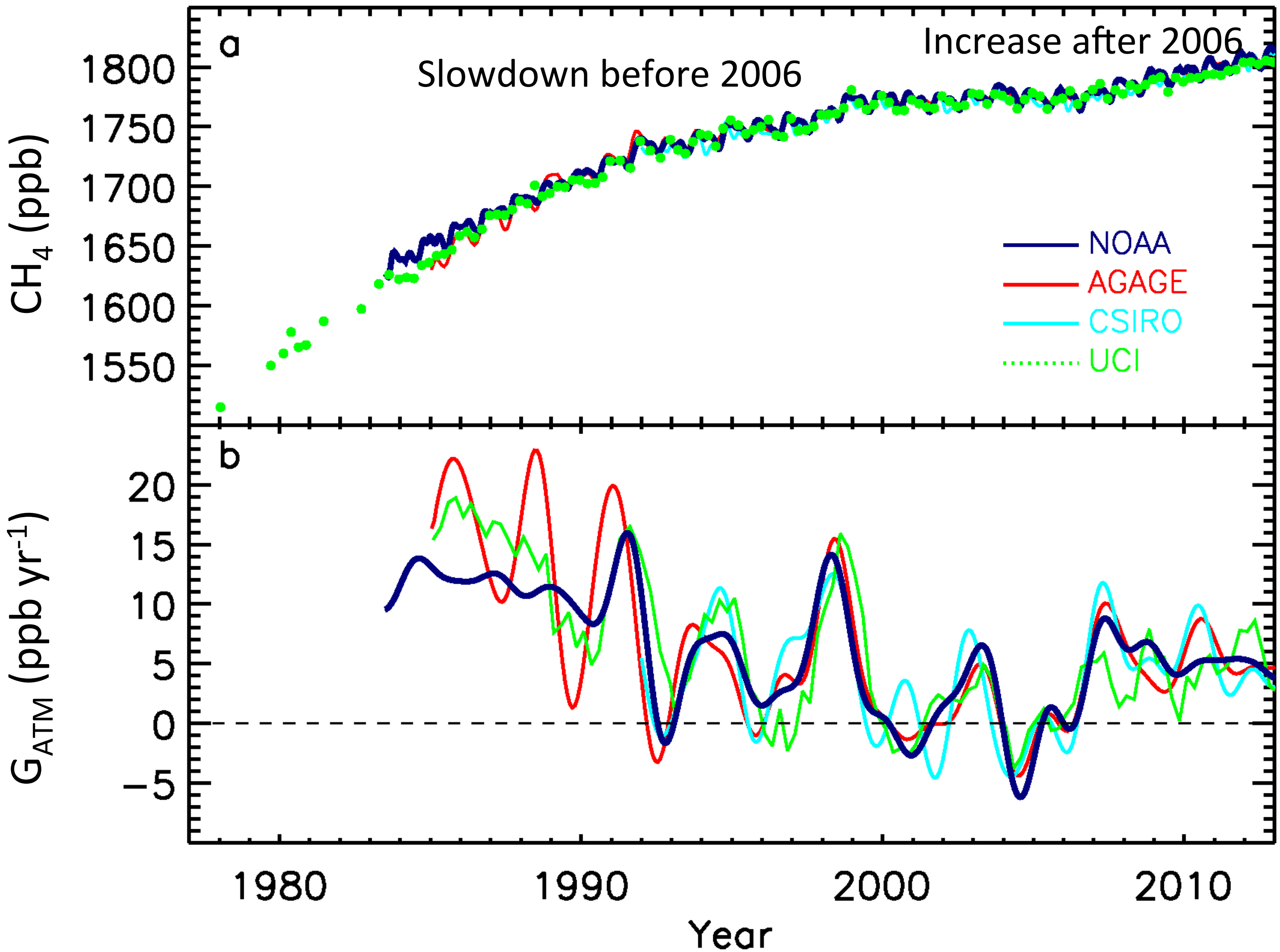
Outline

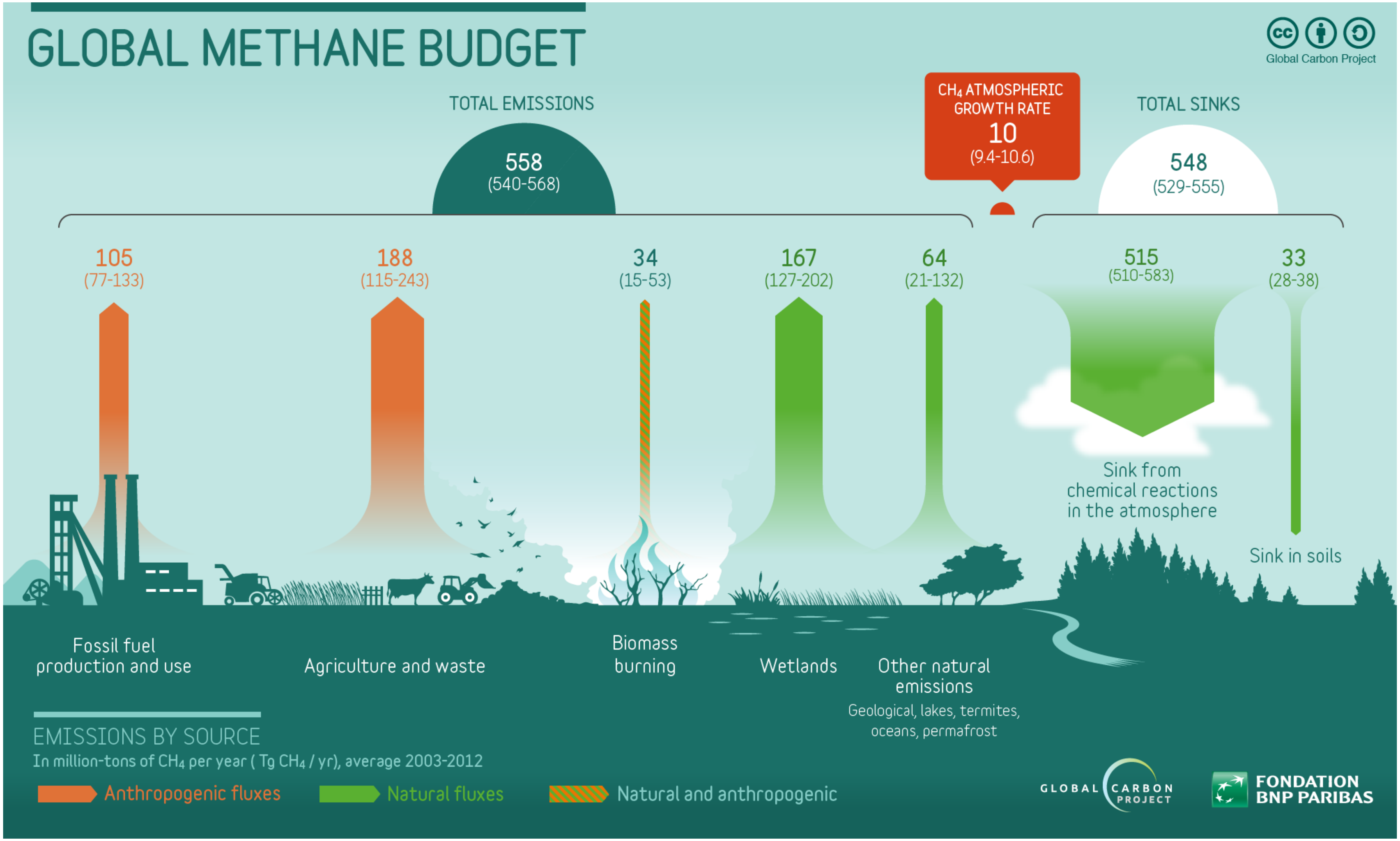
- Motivation - Why measure Methane?
- GSFC Measurement Approach
- Airborne Campaign Results
- Current Status
- Summary

Why measure Methane?



Source: Saunois et al. 2016

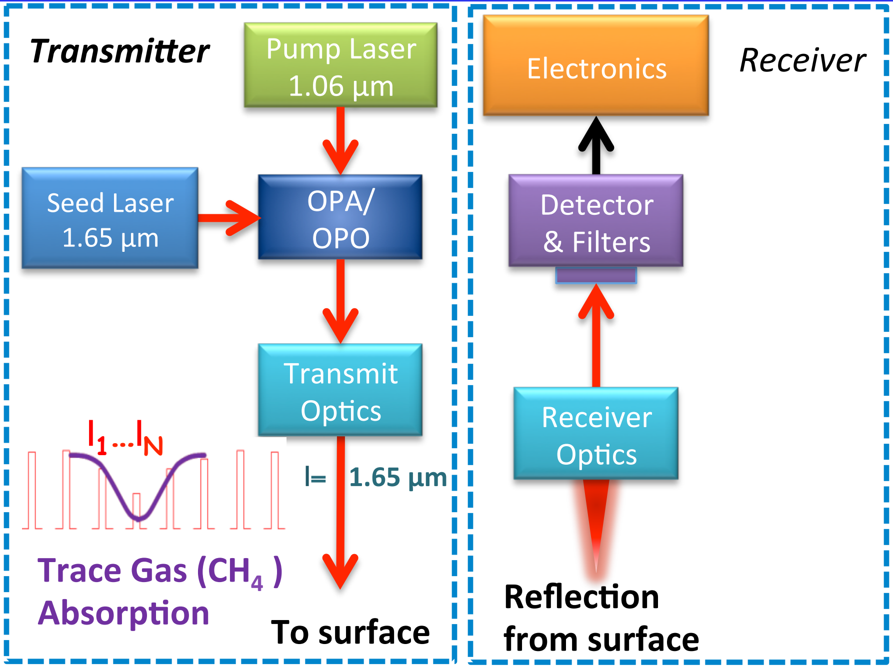
Global Methane Budget

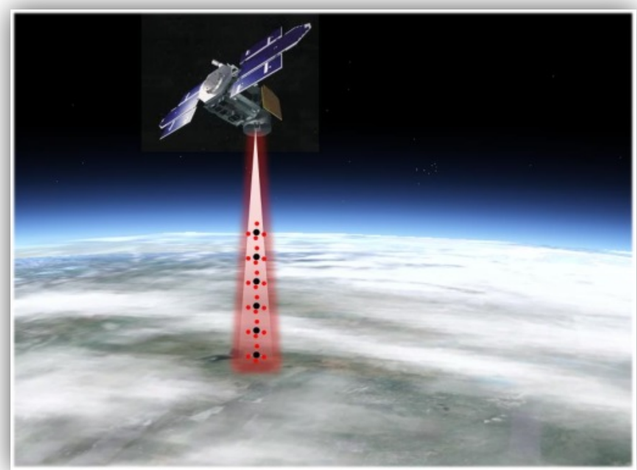


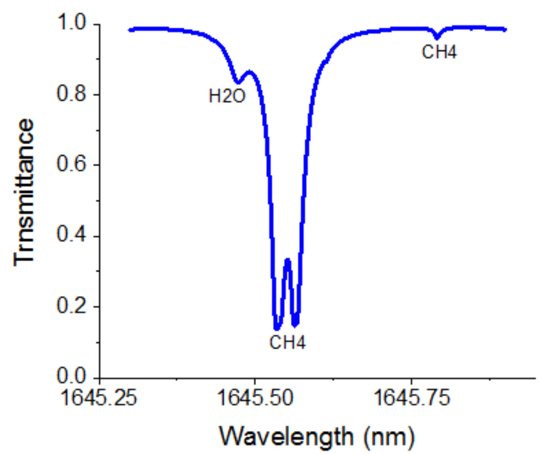
Source: http://www.globalcarbonatlas.org

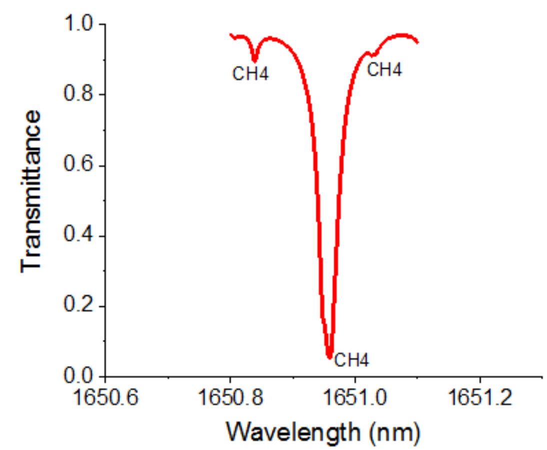
GSFC CH_4 IPDA Lidar

- ***Transmitter (Laser) technology***
  - Current (optimum) Wavelength for CH_4 Earth Detection: ~1.64-1.66 µm
  - Optical Parametric Oscillators (OPO) and Optical Parametric Amplifiers (OPA) are the “baseline” solutions for the transmitter.
  - Other options (Er:YAG and Er:YGG) now possible.
- ***Receiver (Detector) Technology***
  - DRS e-APD

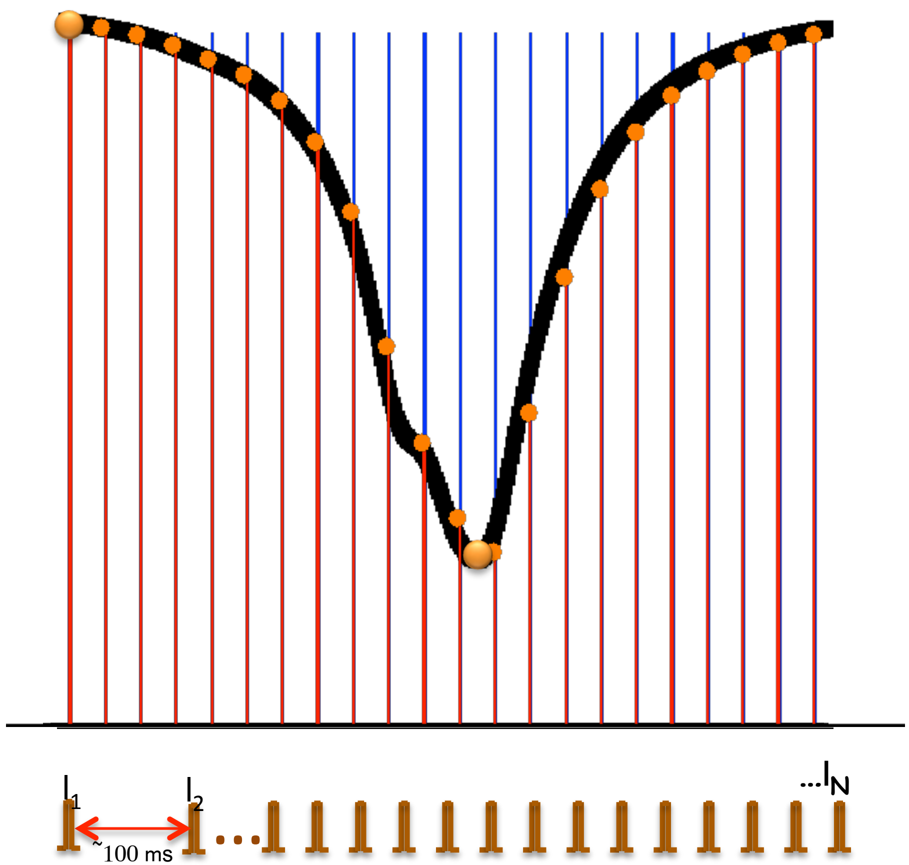






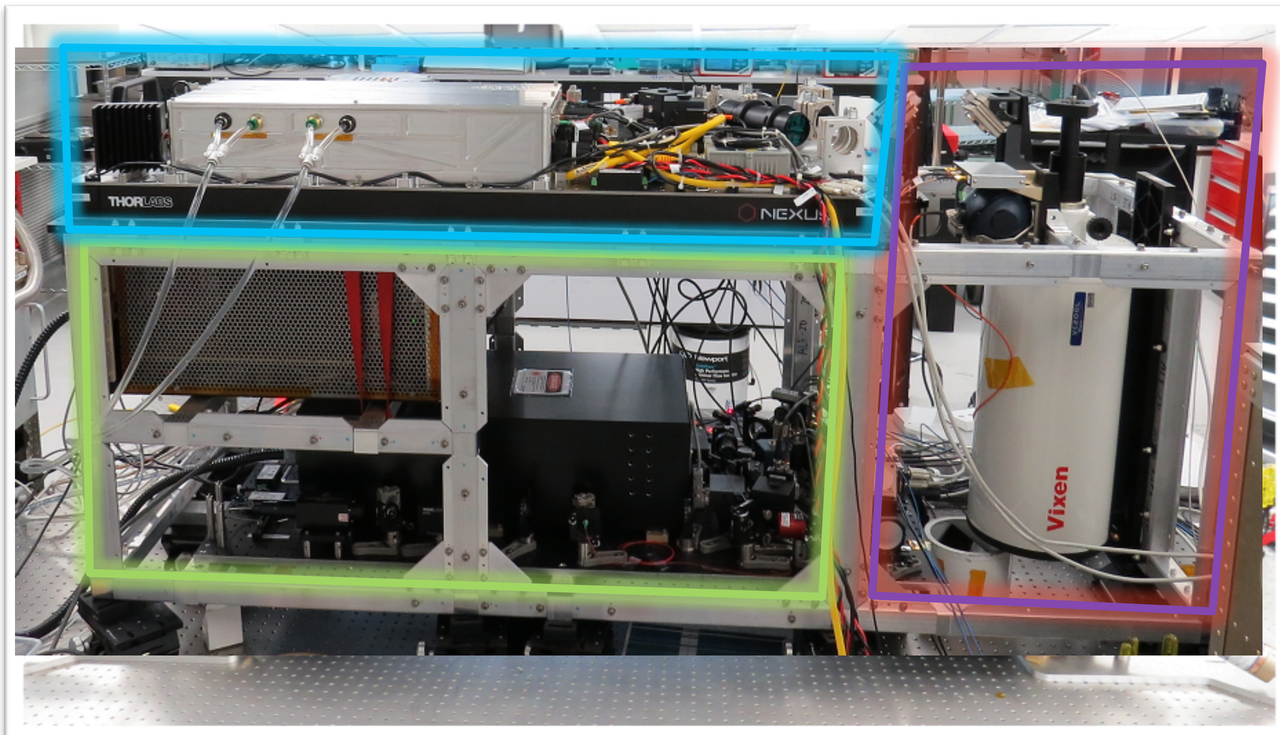


Why use multiple wavelengths?



"Ideal" Instrument – has only random noise which can be averaged indefinitely.
Two wavelengths can adequately sample the lineshape. Averaging always helps.
Real Instrument – has random and non-random noise which can NOT always be averaged.
Two wavelengths can NOT adequately sample the lineshape or reduce biases.

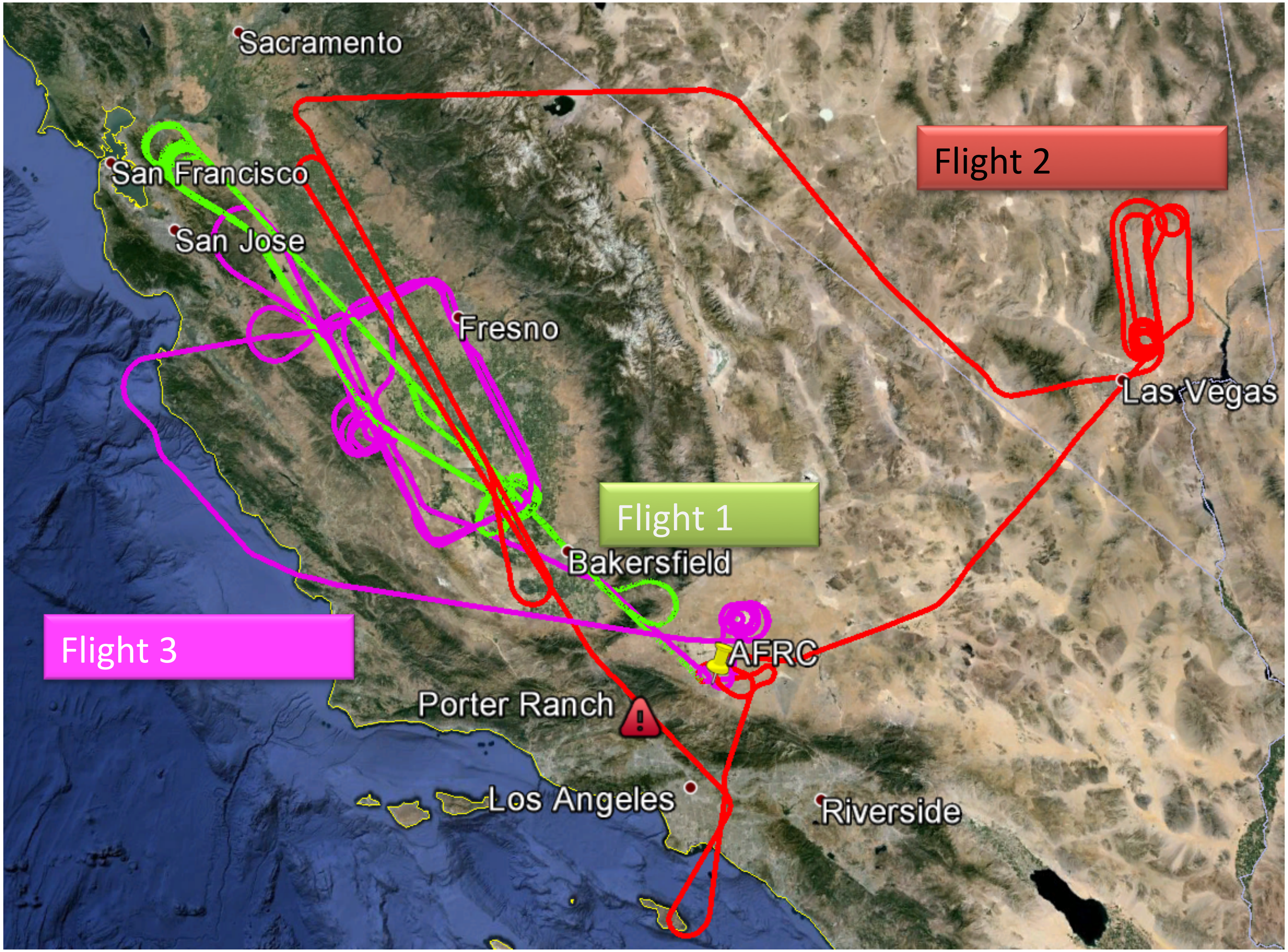
CH_4 Airborne Instrument



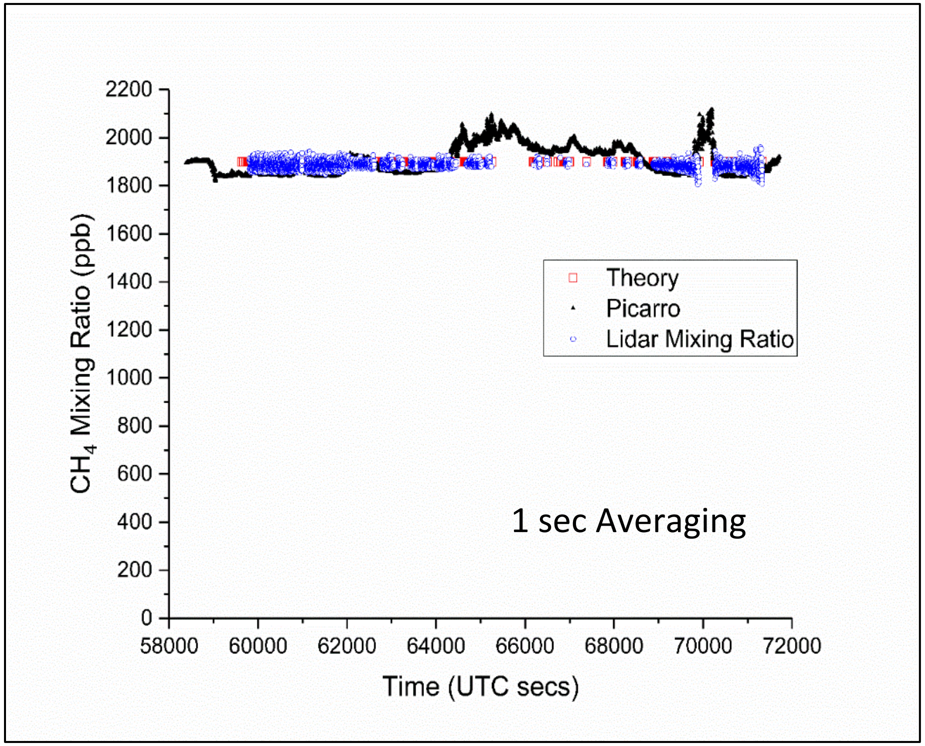
Parameter	Value (OPA/OPO)
Center l	1650.9 nm
Number of l	20/5
Pulse Width	~700/80 ns
Energy/pulse	~25/250 µJ
Bin width	4 ns
Divergence	~150 µrad
Receiver diam.	20 cm
Field of view	300 µrad
Receiver BP	0.8 nm (FWHM)
Averaging time	1/16 s *
Detector Resp.	~1-1.5 x 10^9 V/W

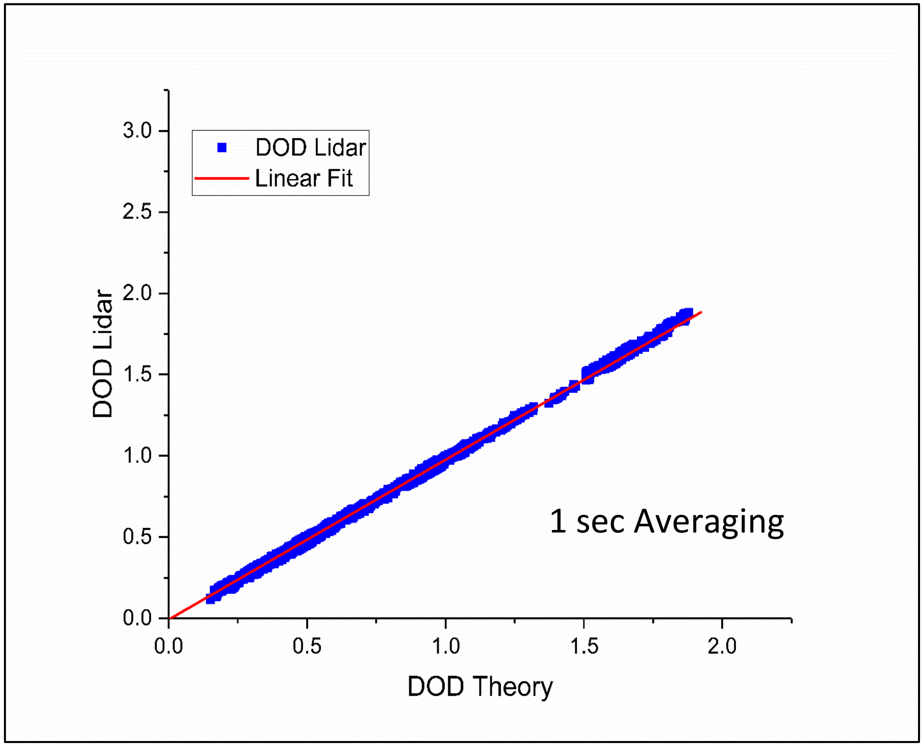
*Data analysis uses 1s averages

2015 Airborne Demonstration Flight Tracks



Flight 1-OPA

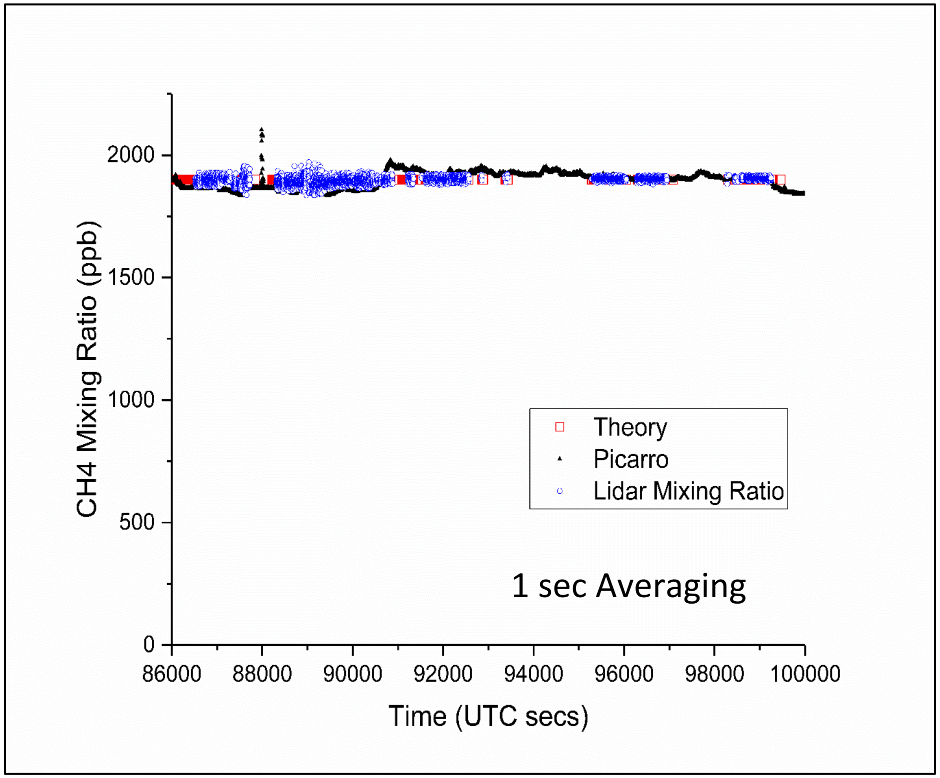


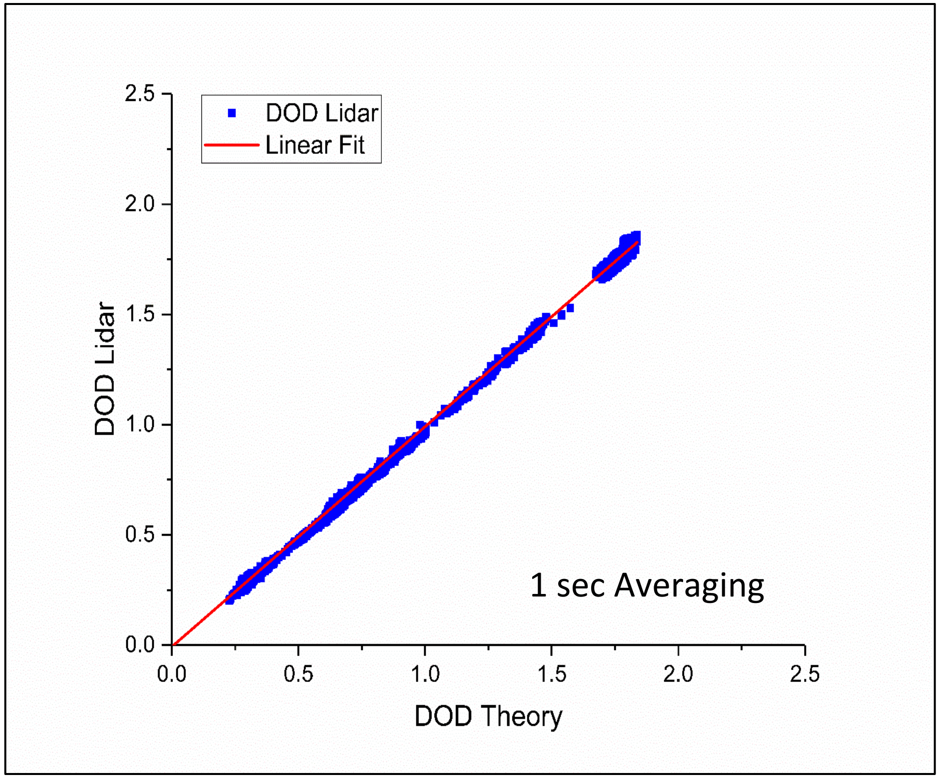


Precision: 14.9 ppb or ~0.8%

Slope= 0.98; offset=-0.007; R^2=0.994.

Flight 2-OPA

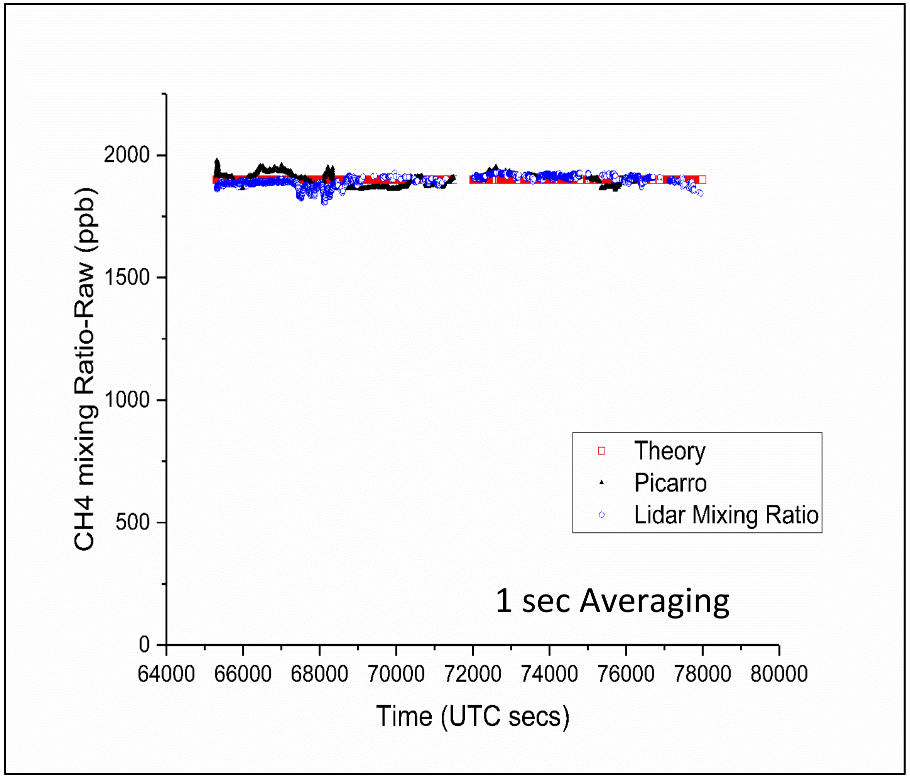


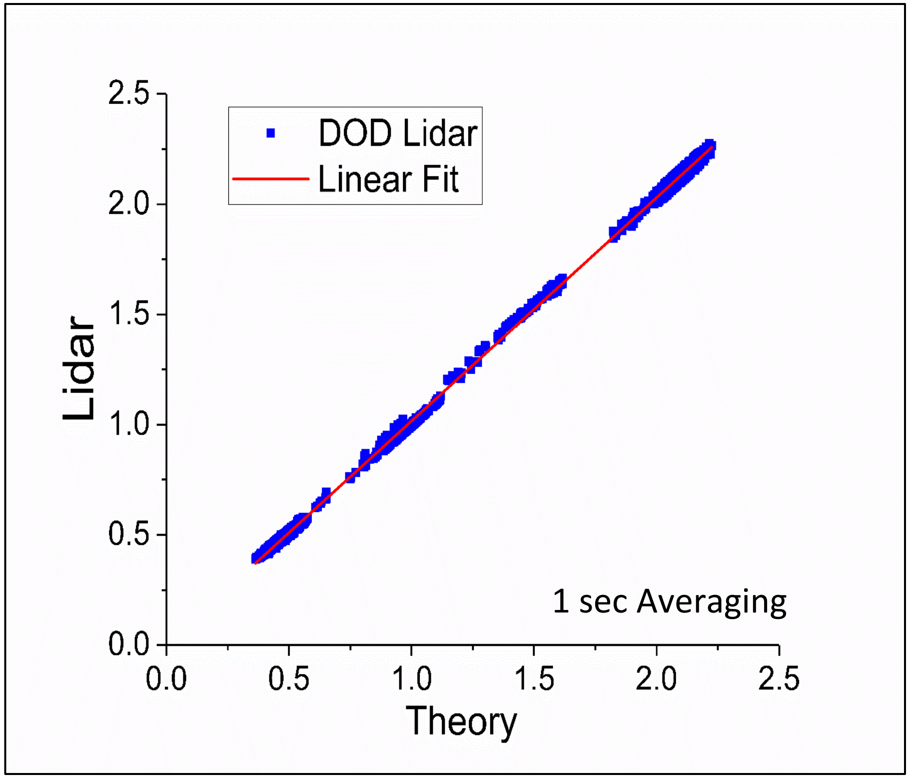


Precision: 13.4 ppb or ~0.7%

Slope= 0.998; offset=-0.007; R^2=0.990.

Flight 3-OPO





Precision: 21.4 ppb or ~1.1%

Slope= 1.01; offset=-0.003; R^2=0.999.

Airborne Demonstration Summary

- ✓ *Best* precision for:
  - ✓ OPA ~ 6-9 ppb; overall 12-15 ppb
  - ✓ OPO ~ 10-12 ppb; overall: 21 ppb
- ✓ 20 wavelengths (OPA) produced better fits than 5 (OPO).
- ✓ OPO correction needed for cross talk.
- ✓ DRS e-ADP works very well at 1651 nm and is linear over a remarkable range of signals and gain settings.
- ✓ New airborne instrument designed.

Current summary of laser efforts

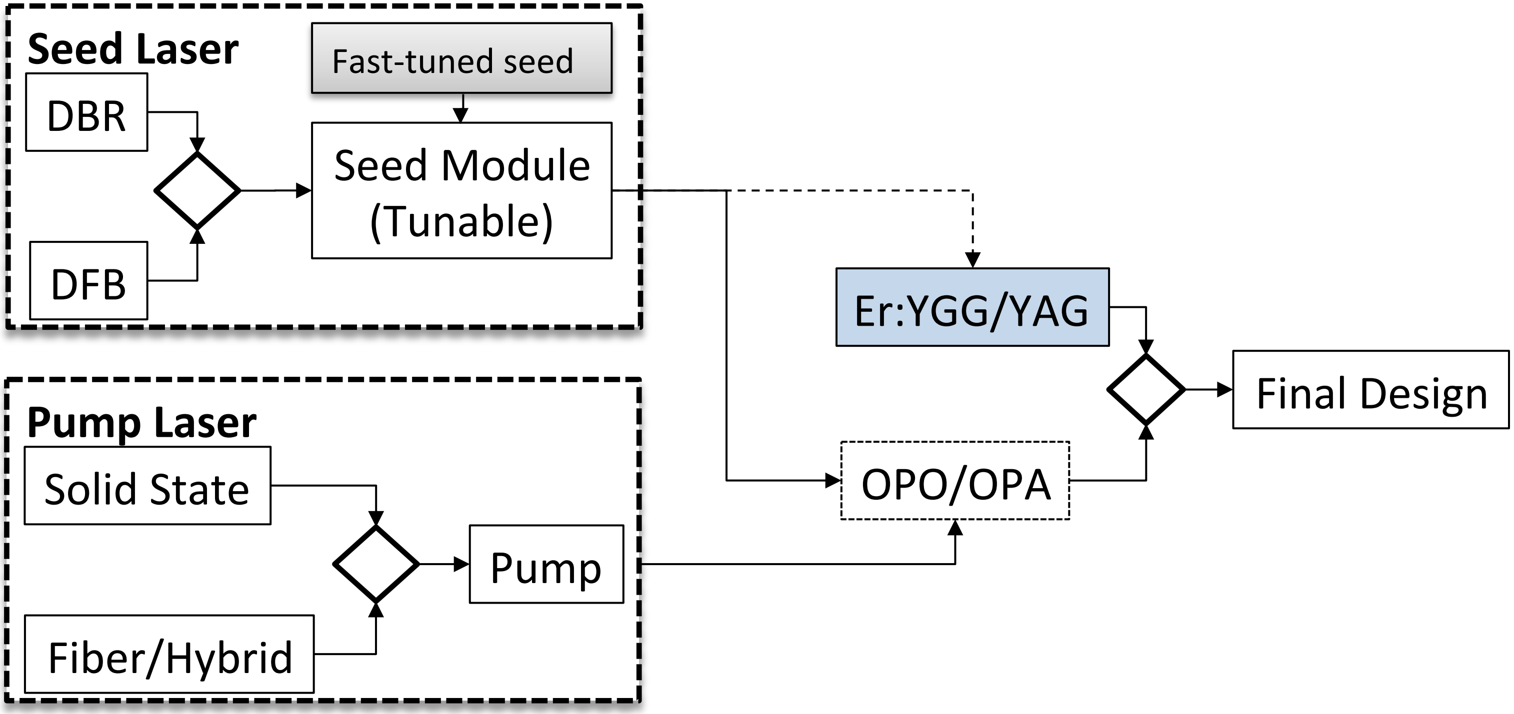
Transmitter Requirements:

High Energy (~600 µJ)

Narrow linewidth

***Tunable** (10-20 wavelengths)*

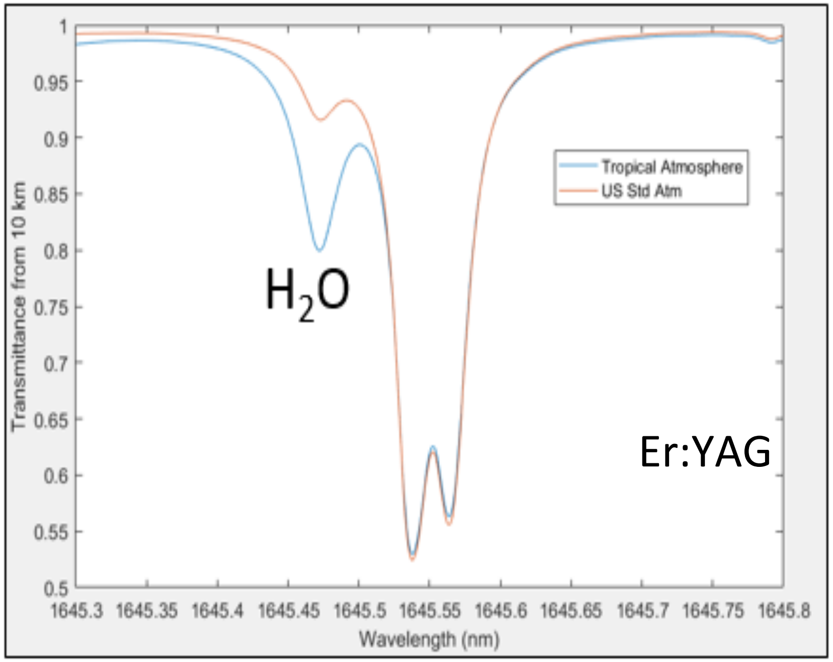
Robust

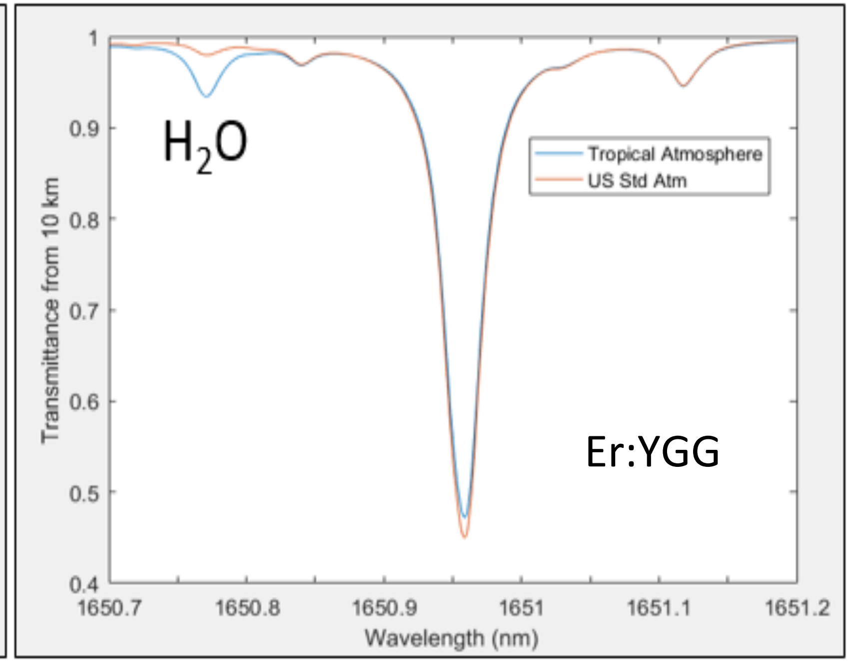


Other transmitter options: Er:YAG and Er:YGG

- Why consider other transmitter options?
  - OPAs and OPOs are parametric conversion techniques. They are complex and difficult to implement are sensitive to vibration.
  - Size/mass/cost of airborne/space instrument needs to reduced.
- Potential for "simpler" and more efficient solid-state" laser transmitter technology.
- ***Tuning and lasing at the right wavelength remain an issue.***

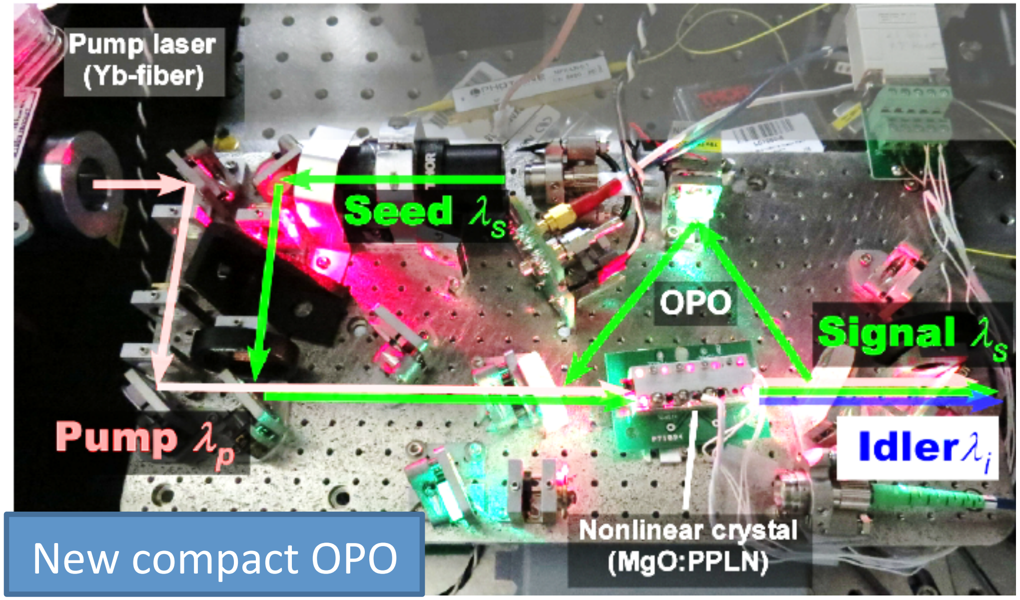
Er:YAG or Er:YGG ?



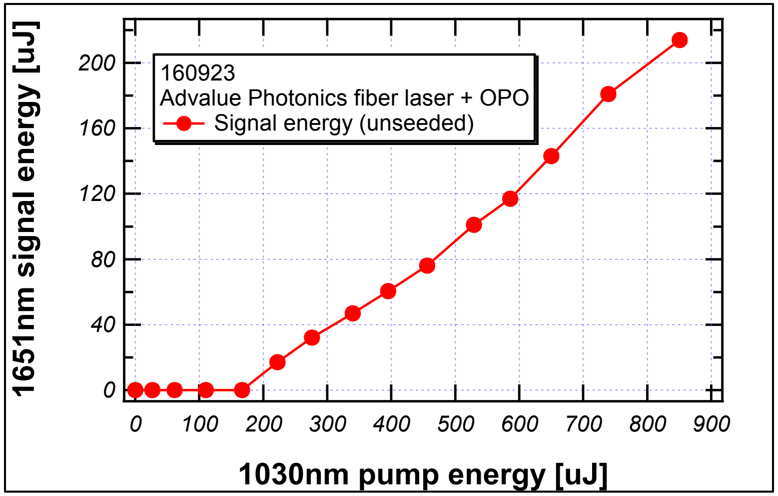


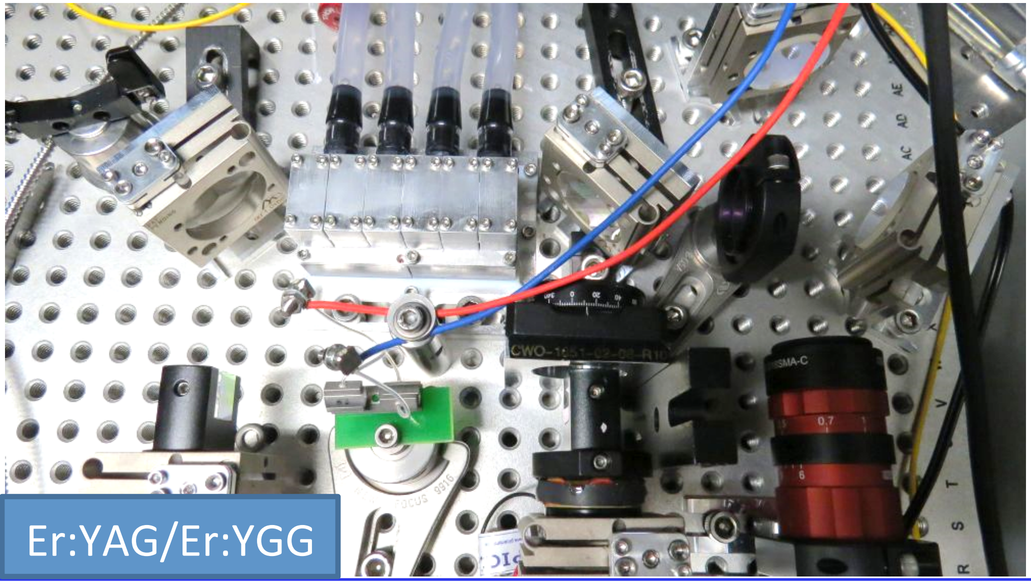
- Spectroscopy (temperature dependence, line mixing, etc.)
- Interferences from H_2O vapor.
- Power and Tunability requirements for the laser.

New Transmitters: Compact OPO and Er:YAG/Er:YGG



New compact OPO

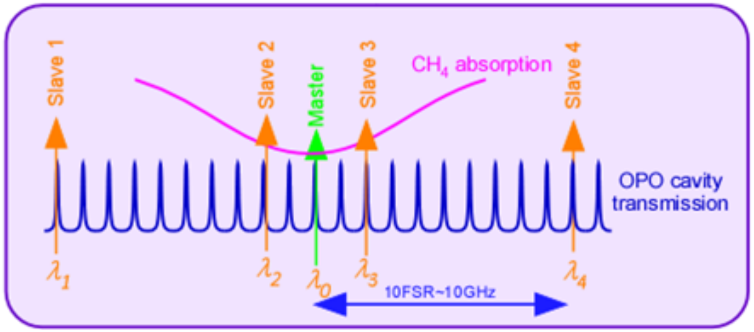


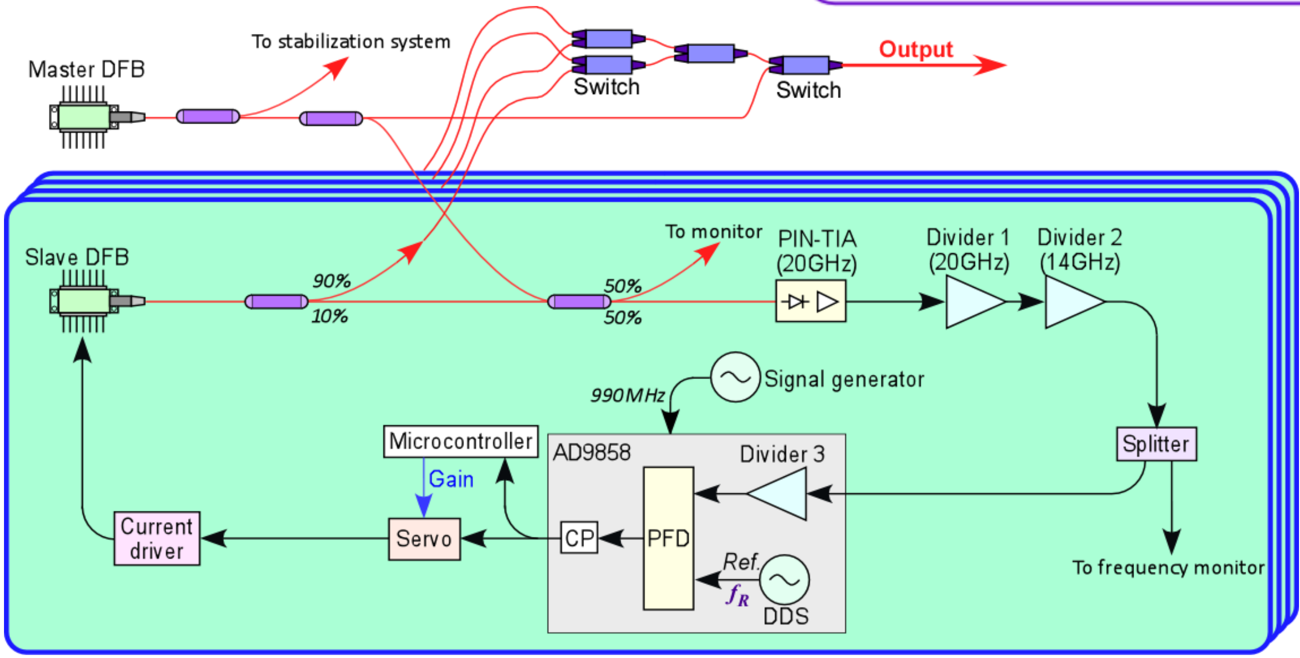


Er:YAG/Er:YGG

Existing OPO (Er:YAG/YGG) Tuning

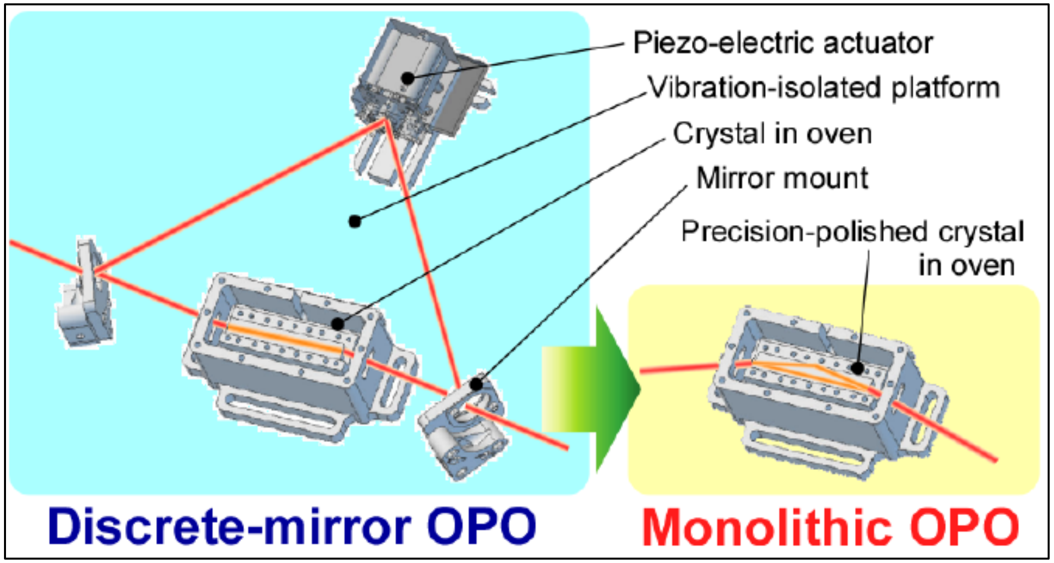
- 5 wavelength system for injection seeding
  - 5 lasers
  - 4 OPLLs
  - 4 optical switches
  - 4 fast detectors

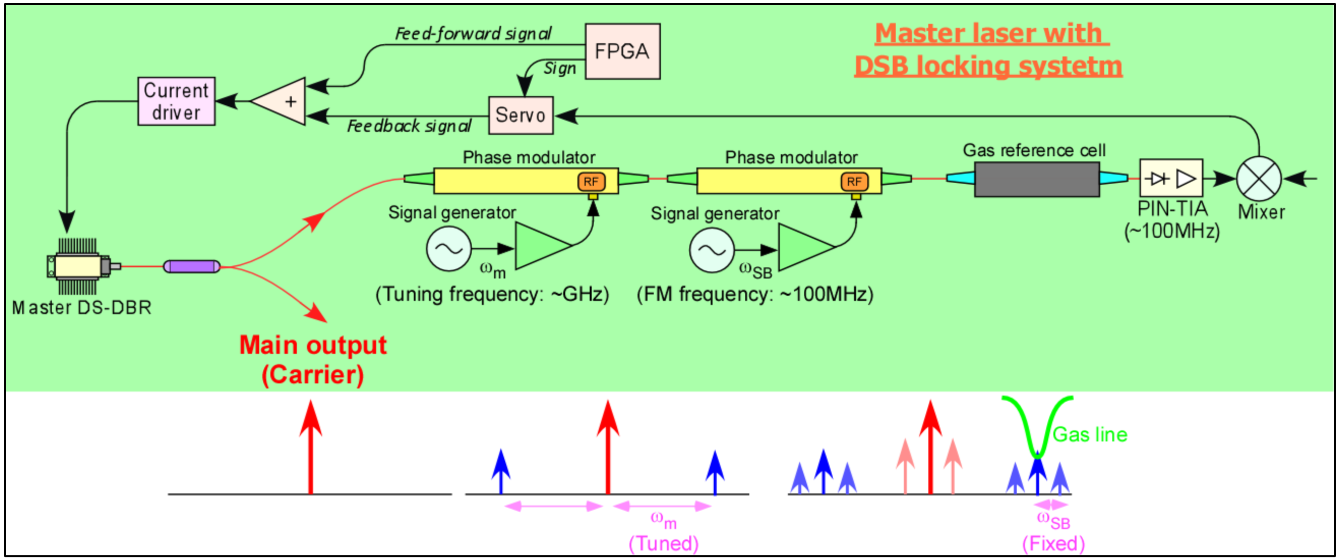




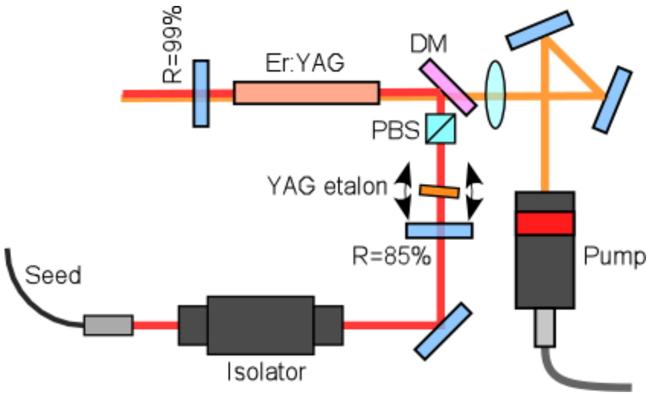
New tuning concepts and monolithic OPO

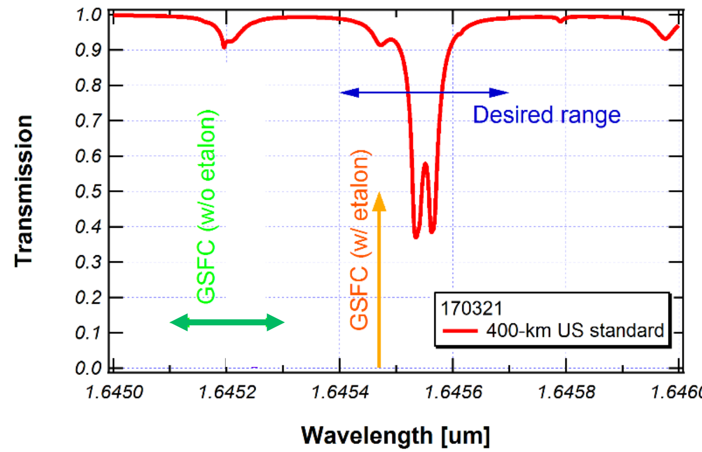
- Simplify the existing multi-laser (wavelength) system
- Two proposed schemes:
  - Dual Sideband (DSB): requires Game Changing DBR deliverable
  - Single Sideband (SSB)
  - Both showing promising results





Er:YAG and Er:YGG

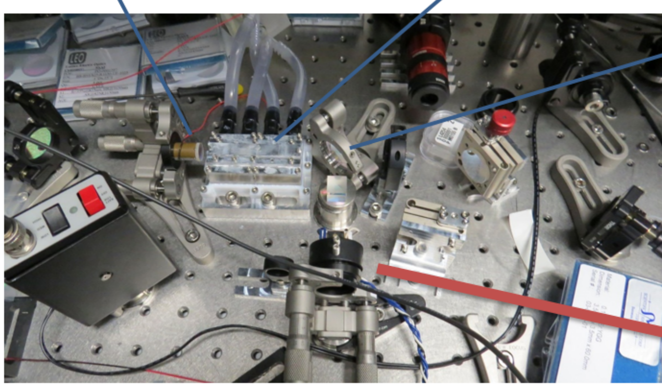




End mirror on PZT

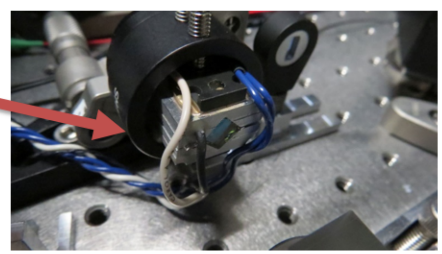
Er:YGG

Dichroic mirror



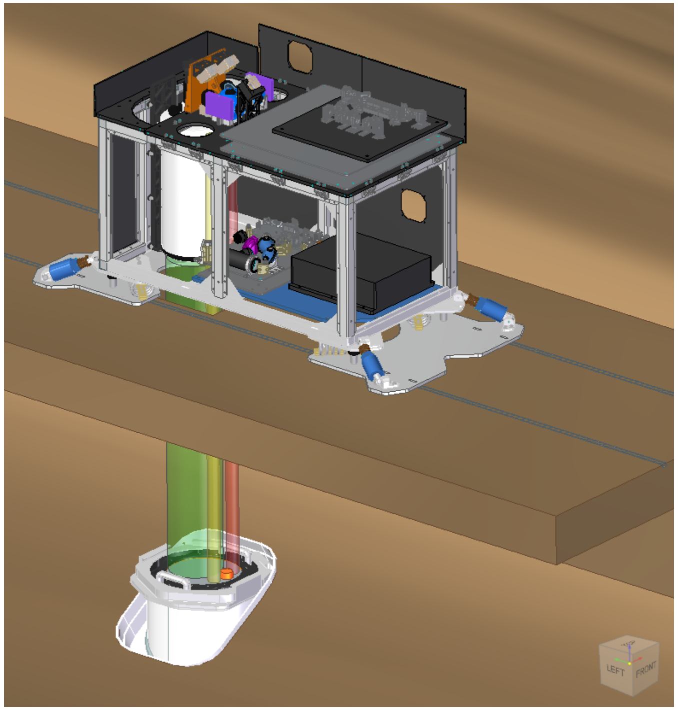
Er:YGG setup as of Jun. 2017

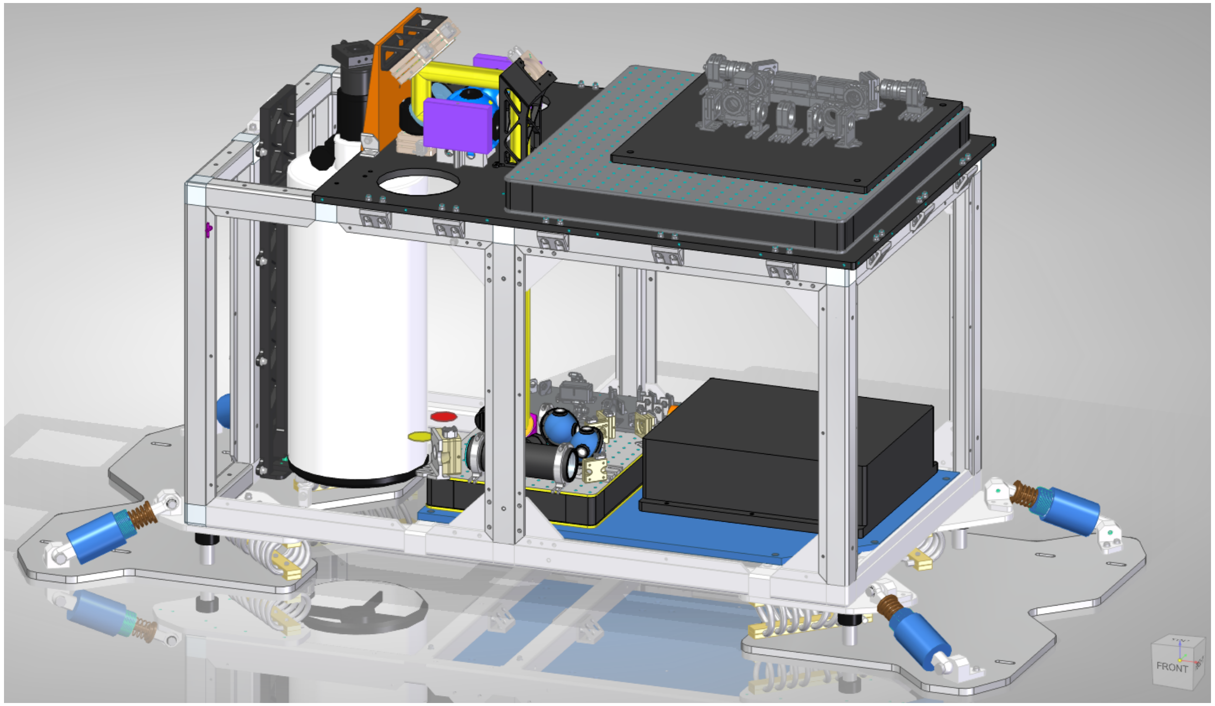
New VBG installed



Both Er:YAG and Er:YGG require a wavelength-selecting element to lase at the right wavelength.
Tuning becomes exceedingly complicated if we need to tune both the seed/cavity and the wavelength-selecting element

New (improved) airborne sensor





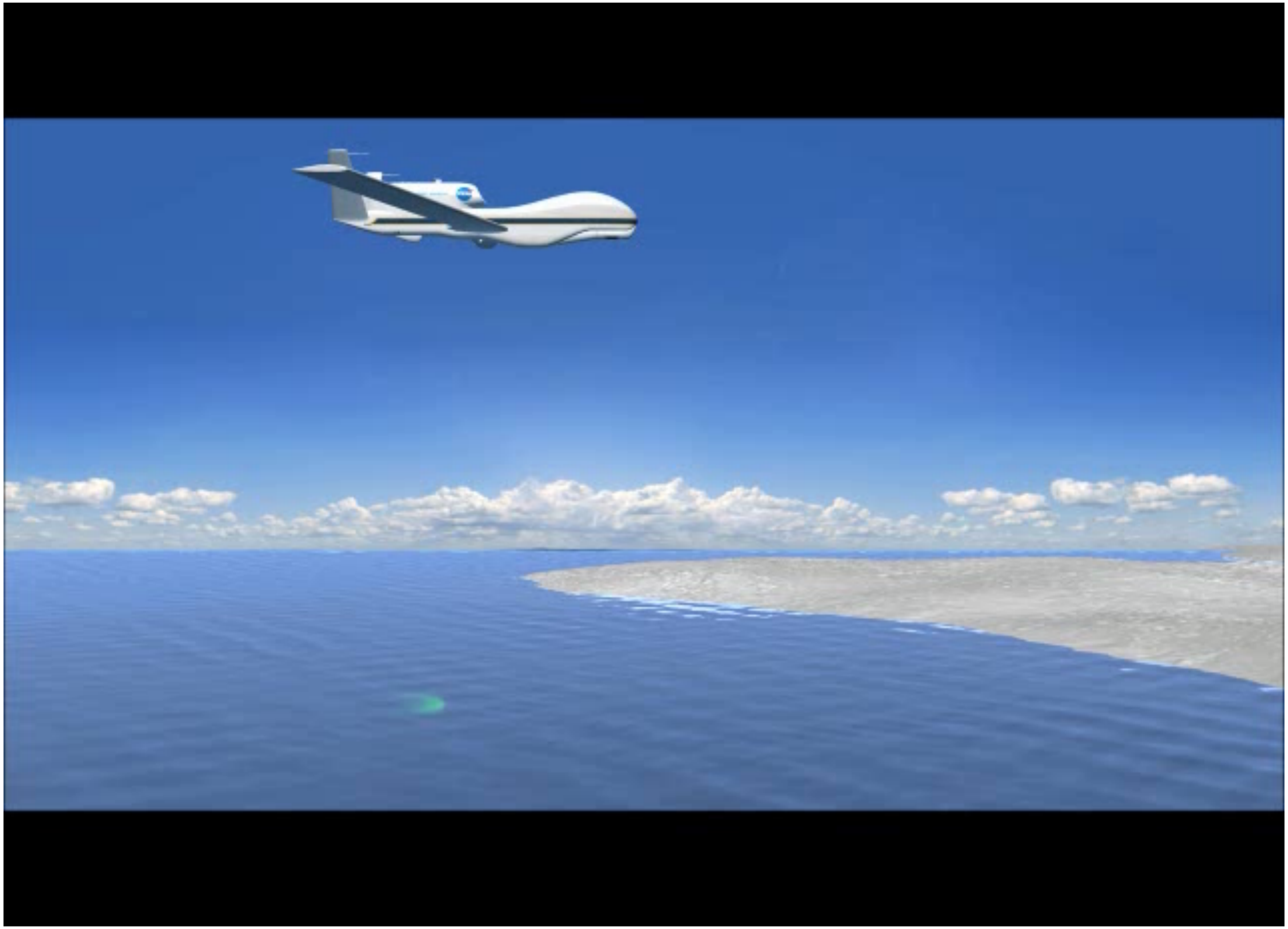
- New transceiver uses Er:YAG/Er:YGG and new, compact OPO (AdValue pump laser)
- Two beams can be fired simultaneously (unlike the earlier version)
- Smaller than the earlier version but still too big to fly on small aircraft
- Vibration isolation maintained

Summary

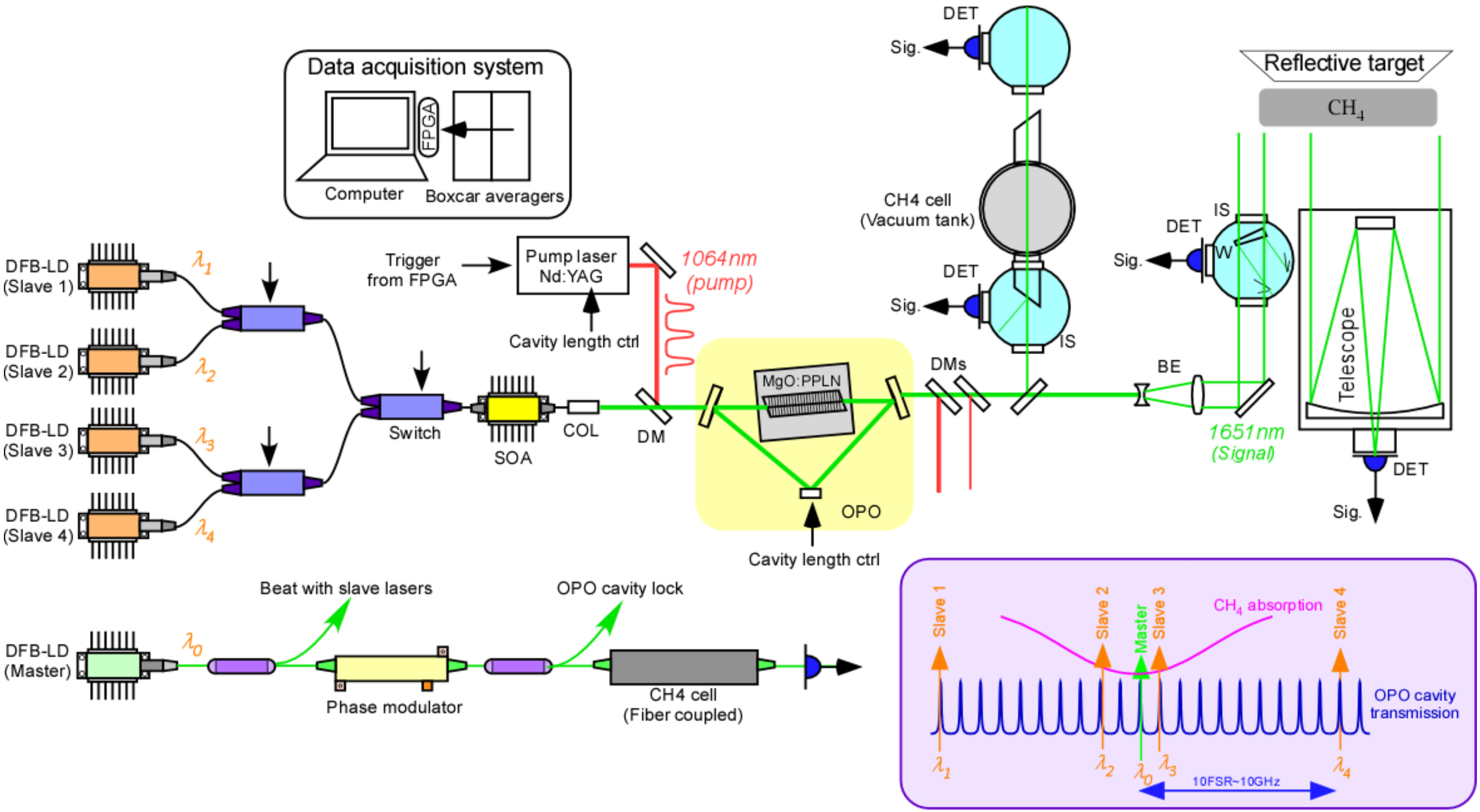
- ✓ Demonstrated CH_4 airborne measurements using two lidar transmitters (OPA and OPO).
- ✓ Many different approaches and options for the laser transmitter are being investigated.
- ✓ Demonstrated power scaling with several options.
- ✓ Will incorporate Freedom Photonics seed laser deliverable and decide on final configuration.
- ✓ Looking for opportunities to fly!
- **We would like to thank ESTO and GSFC IRAD for their support.**

BACKUP

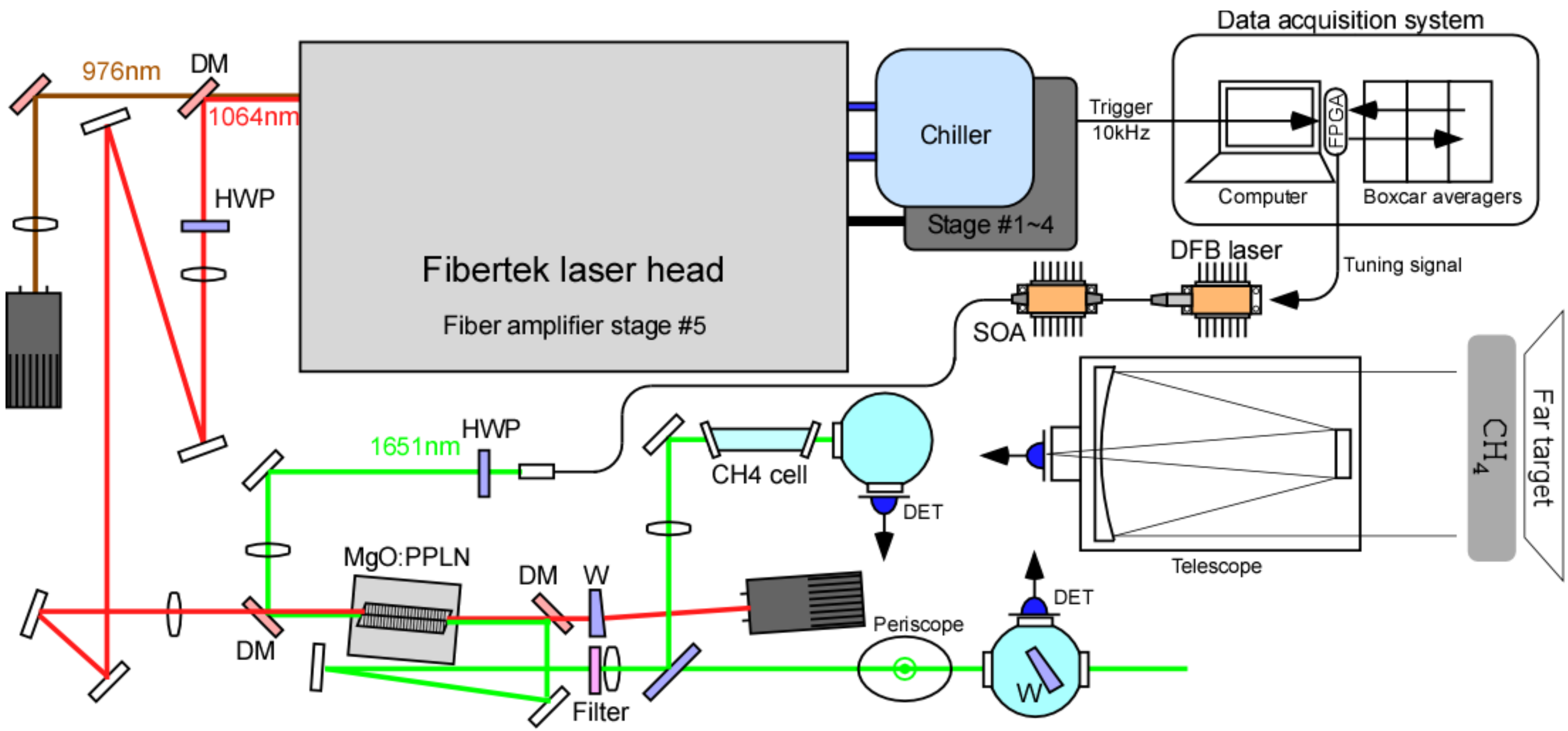
GSFC CH_4 Lidar with Integrated Path Differential Absorption Lidar (IPDA)



Setup for 5-wavelength OPO



OPA Open-path measurement setup



CH_4 Laser Transmitter: OPO-OPA