Airborne measurements of atmospheric methane using pulsed laser transmitters

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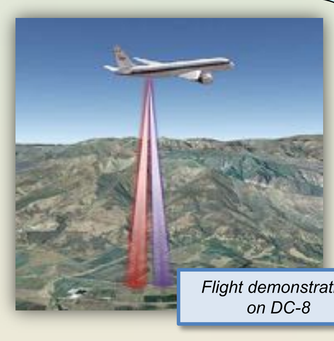
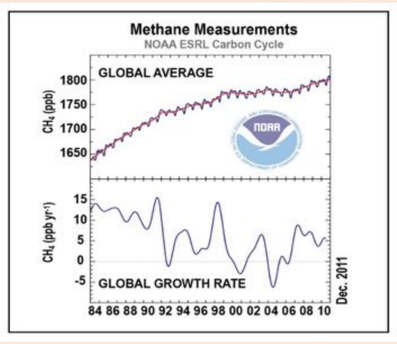
At NASA Goddard Space Flight Center, we have been developing a laser-based technology needed to remotely measure methane (CH_4) from orbit. Our lidar transmitter is based on an optical parametric process to generate near infrared laser radiation at 1651 nm, coincident with a CH_4 absorption. In an airborne flight campaign in the fall of 2015, we tested two kinds of laser transmitters --- an optical parametric amplifier (OPA) and an optical parametric oscillator (OPO). The two laser transmitters were successfully operated in the NASA's DC-8 aircraft, measuring methane from 3 to 13 km with high precision.

Background

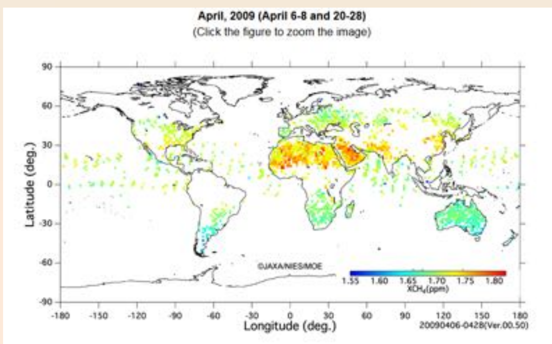
- Methane measurements for earth science
  - Strong greenhouse gas (>x20 radiative forcing than CO_2)
  - Closing the carbon budget, global coverage
  - Methane hydrate in the Arctic (where passive spectrometer won't work)
- Requirements for space instrument
  - Wavelength: ~1.65µm (outside fiber amplifier band)
  - Energy: >~250µJ (for 1% error, 10kHz rep. rate)



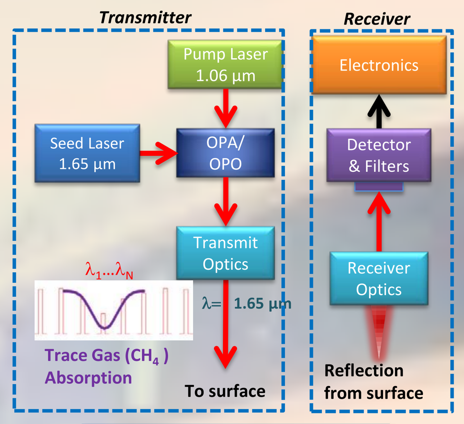
Flight demonstration on DC-8



Global average methane concentration in Earth's atmosphere



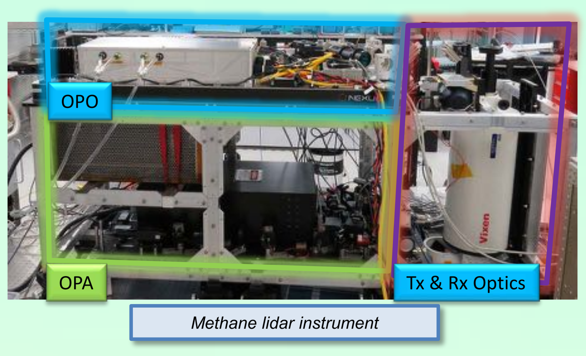
Monthly Global Map of the CH4 column-averaged volume mixing ratios from GOSAT



Measurement concept

2015 CH_4 airborne campaign

- Aircraft: NASA DC-8 (NA817)
  - 1 engineering & 2 science flights, total ~12 hours
  - From Armstrong Flight Research Center, CA
- Telescope: 20cm, 300µrad field of view
  - Transmitter divergence: ~150µrad
- Detector: DRS eAPD, 90% QE, ~10^9V/W
- Compare OPA-OPO performance



Methane lidar instrument

GSFC methane sounder team

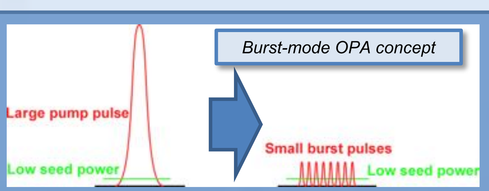
Lidar instrument in DC-8's cabin

Flight paths

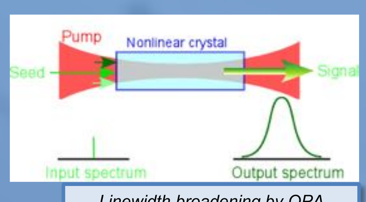
Burst-mode OPA

Overview

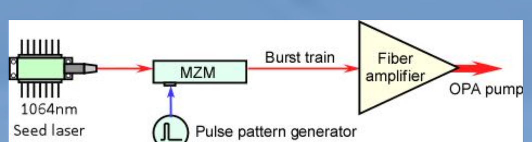
- Pump laser (1064nm)
  - Yb-fiber amplifier, LMA fiber, built by Fibertek
  - Burst mode, 20 micro pulses, 3ns micro pulse width
  - Works with low power (~20mW) seed
  - Minimizes output linewidth broadening
- Nonlinear crystal
  - 50mm MgO:PPLN
- Scanning seed laser
  - Beat against master laser for wavelength monitor



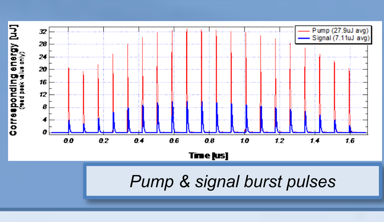
Burst-mode OPA concept



Linewidth broadening by OPA



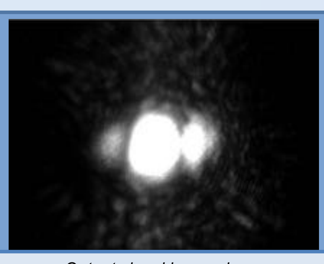
Burst pump generation



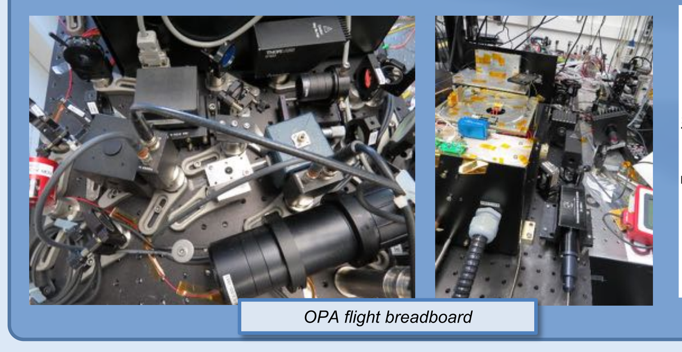
Pump & signal burst pulses

Laser source

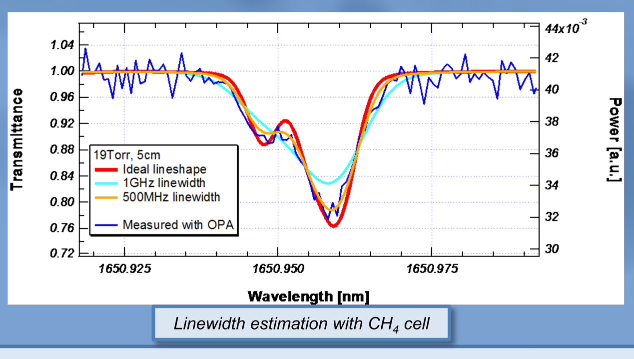
- Output energy
  - Reduced to ~40µJ per burst (not enough for space)
  - Due to several simplifications for the airborne demonstration
- Linewidth: ~500MHz Estimated from CH4 reference cell
- Number of wavelength: 20 Step scanned across the line @ 10kHz



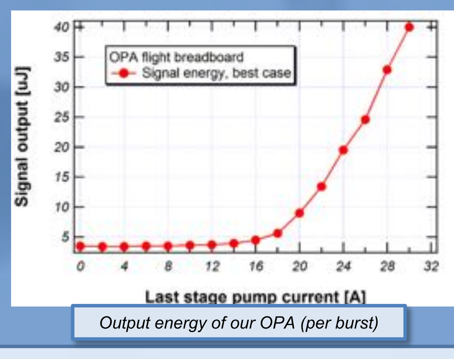
Output signal beam shape



OPA flight breadboard



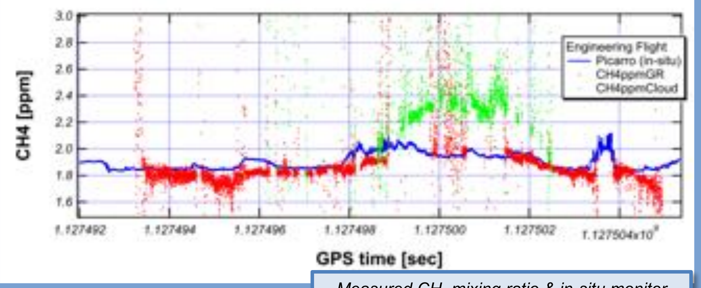
Linewidth estimation with CH_4 cell



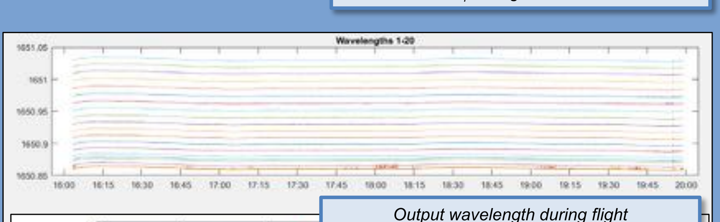
Output energy of our OPA (per burst)

Airborne results

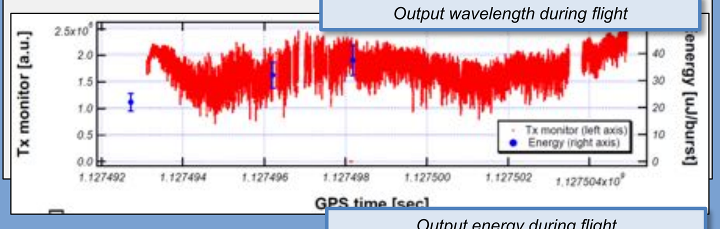
- Analysis overview
  - 1s averaging, uniform 1900ppb model
  - ~0.4% error for the best ~20min section
  - Stable signal up to the highest altitude (~13km)
- Problems identified
  - Power stability (unstable LMA fiber mode)
  - Low output energy, wide linewidth
  - Retrieval with cloud return



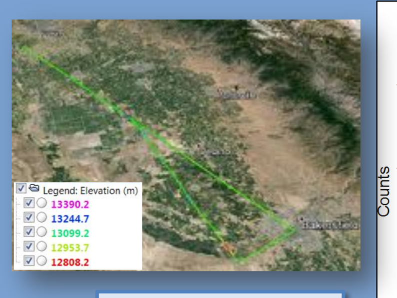
Measured CH_4 mixing ratio & in-situ monitor



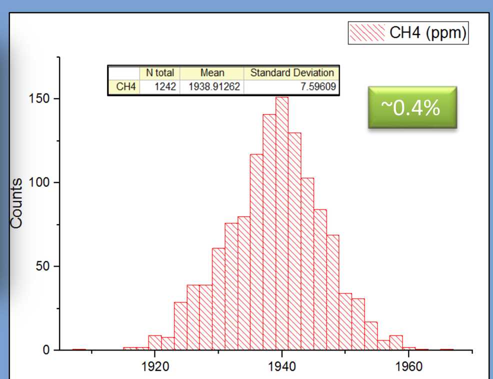
Output wavelength during flight

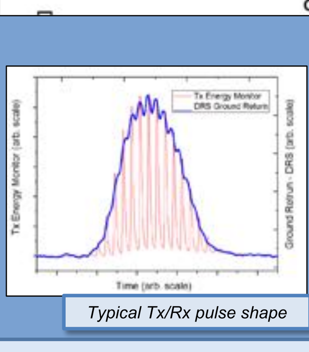


Output energy during flight

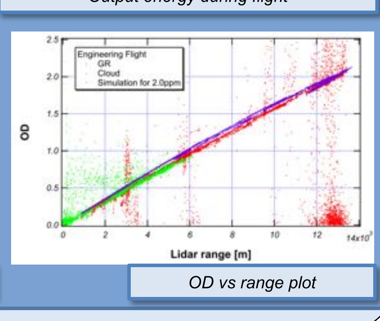


Best OPA flight section (~13km altitude)





Typical Tx/Rx pulse shape

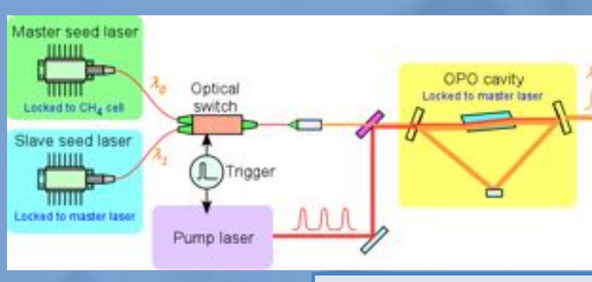


OD vs range plot

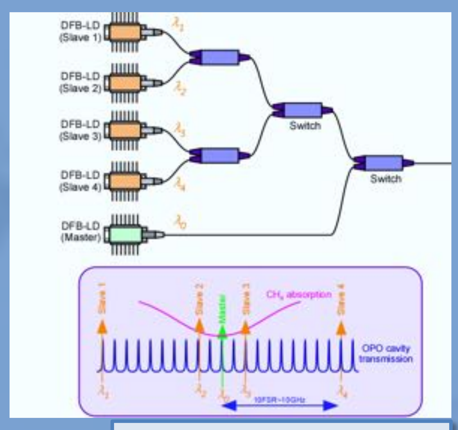
Seeded OPO

Overview

- Pump laser (1064nm)
  - Seeded, active Q-switch, Nd:YAG laser built by NASA/GSFC
  - Single pulse, ~1.5mJ, ~60ns pulse width
  - Works with low power (~20mW) seed
- Nonlinear crystal
  - 35mm MgO:PPLN
- 4 slave seed lasers
  - Optical PLL
  - Fast optical switch



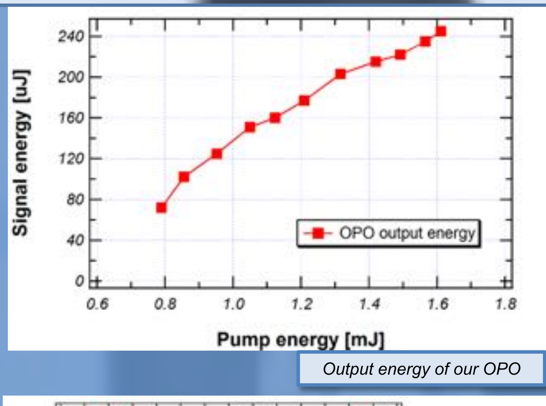
Conceptual design of our seeded OPO



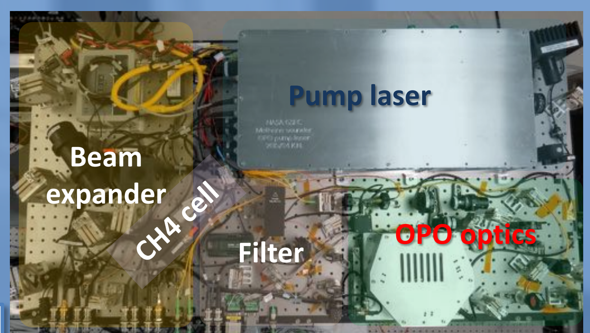
5 phase-locked seed lasers

Laser source

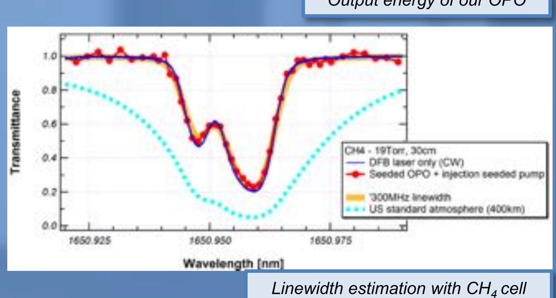
- Output energy
  - ~240µJ (satisfying requirement for space) @ 10kHz
  - Too much energy for the airborne demonstration
- Linewidth: <~100MHz
- Number of wavelength: 5
- OPO cavity control
  - Phase modulation
  - Mirror on PZT
  - Temperature control



Output energy of our OPO



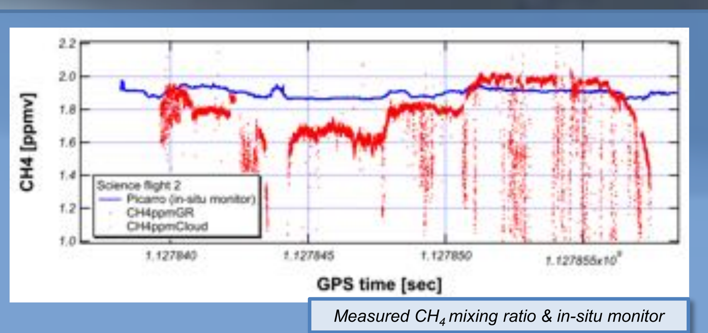
OPO flight breadboard



Linewidth estimation with CH_4 cell

Airborne results

- Analysis overview
  - 1s averaging, uniform 1900ppb model
  - No DRS non-linearity correction yet
  - ~0.5% error for the best ~9 min section
  - Stable output energy
  - Detector gain minimized at low altitude
- Problems identified
  - Detector saturation (too high energy)
  - Cavity unlock (to be improved)



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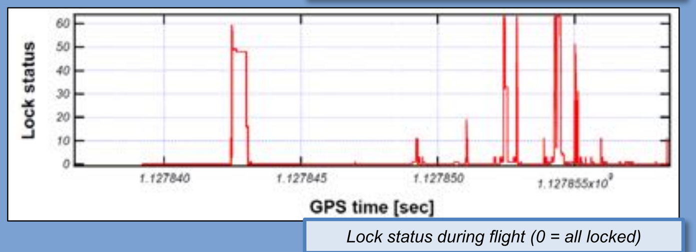
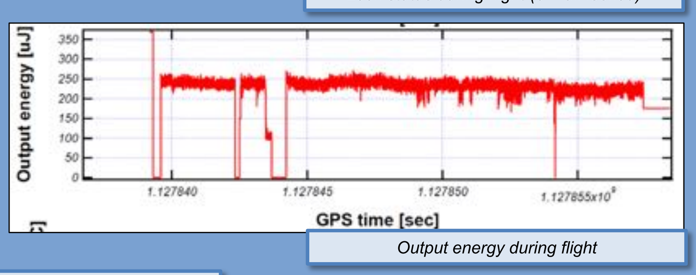
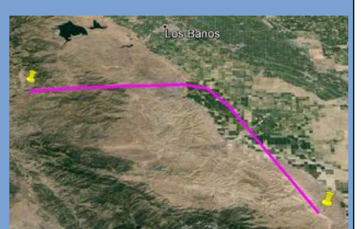


Lock status during flight (0 = all locked)



Output energy during flight



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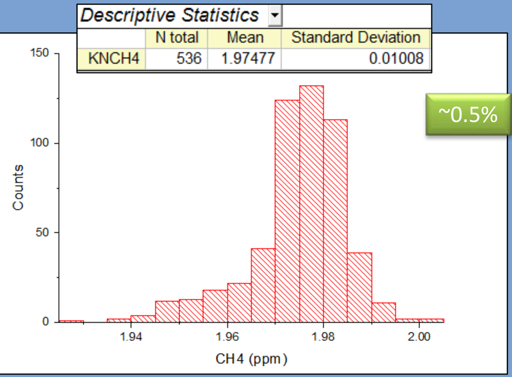

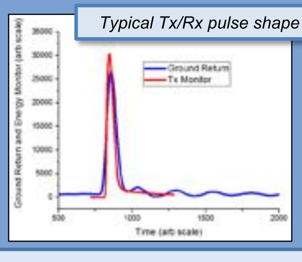

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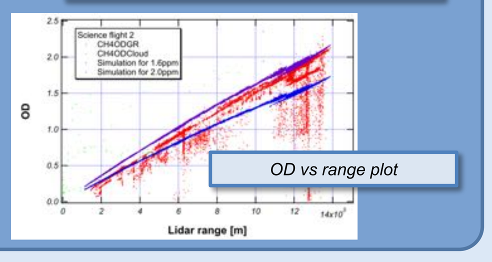

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