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Development of a Lightweight UAV-Mountable Open-Cell Methane Sensor Using Mid-Infrared Tunable Diode Laser Interfaced with a Low-Cost Embedded Platform

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Canada

Motivation

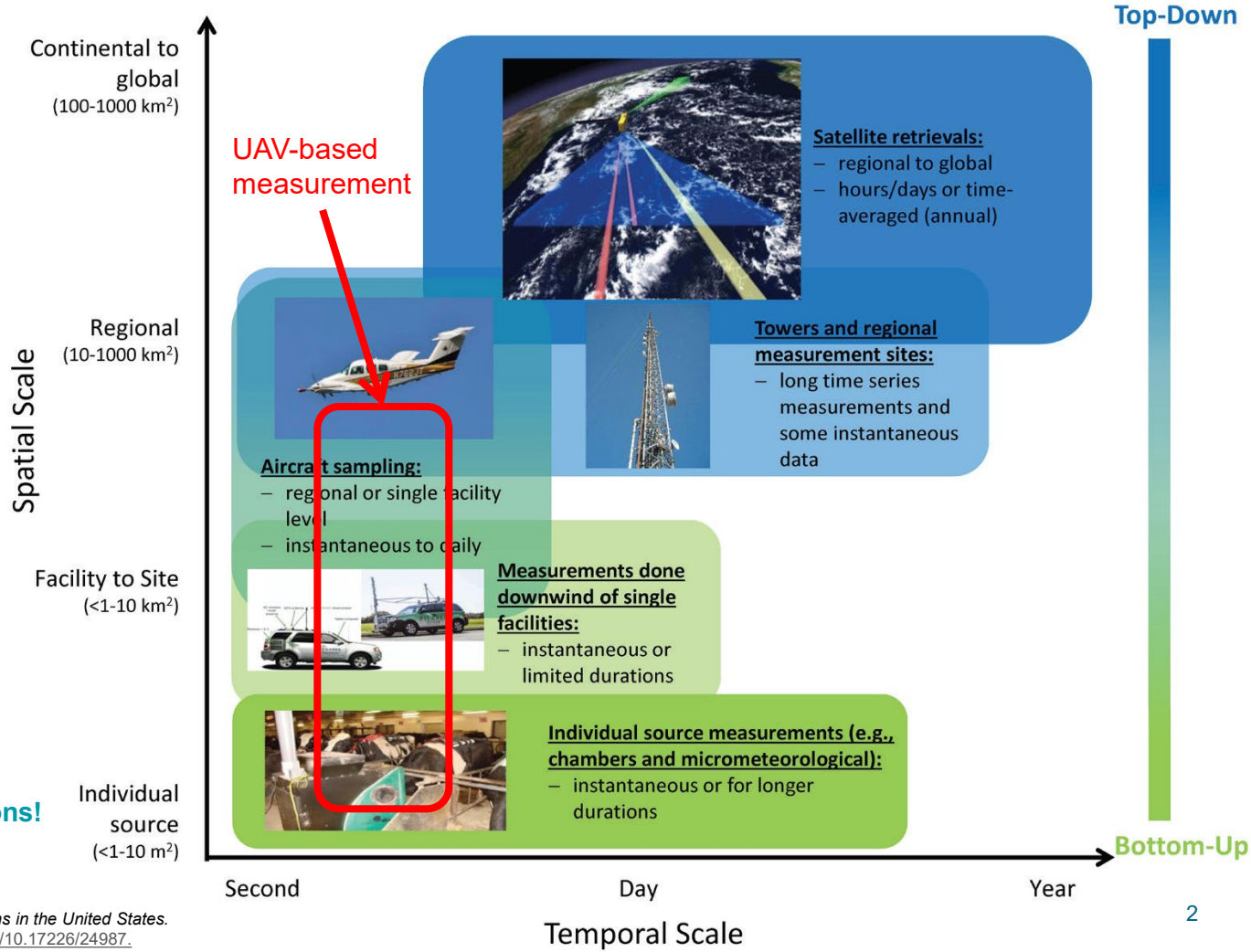
UAV-based GHG measurements

- Near-surface operation
- Autonomous
- Flexible flight patterns
- Low operation cost (vs. manned aircrafts)
- Mobile-lab and ground surveys are time consuming

Challenges

Payload constraints: weight, size, power consumption

Reminder:
No single method fits all applications!



Improving Characterization of Anthropogenic Methane Emissions in the United States. Washington, DC: The National Academies Press. https://doi.org/10.17226/24987.

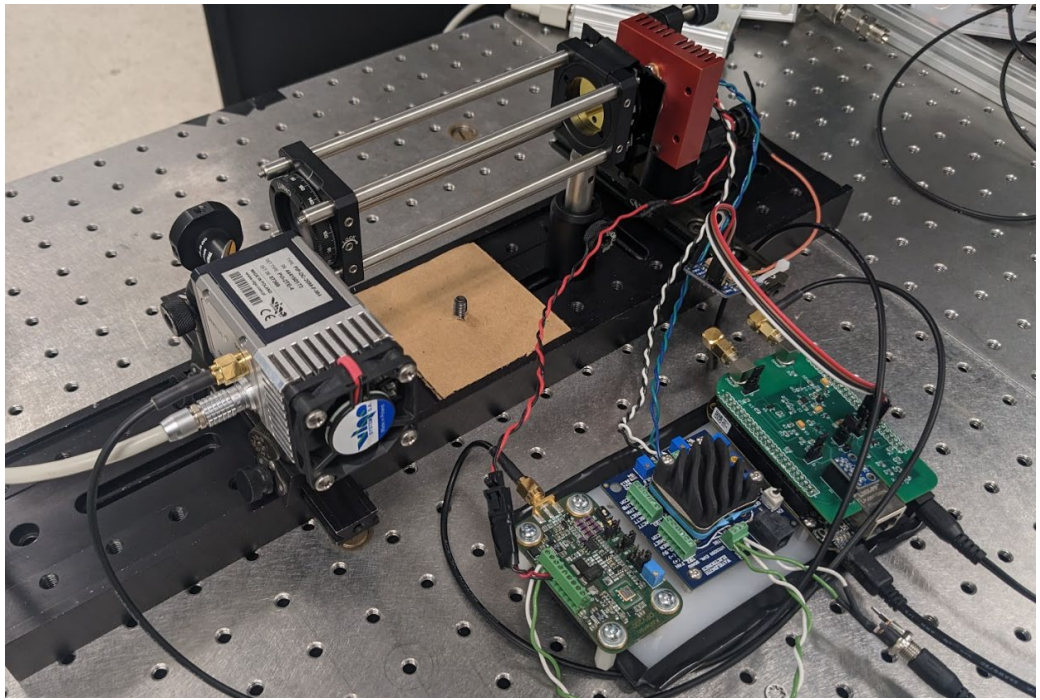
Project overview

Sensor requirements

- Cost effective
- Compact and light weight
- High resolution
- fast response rate

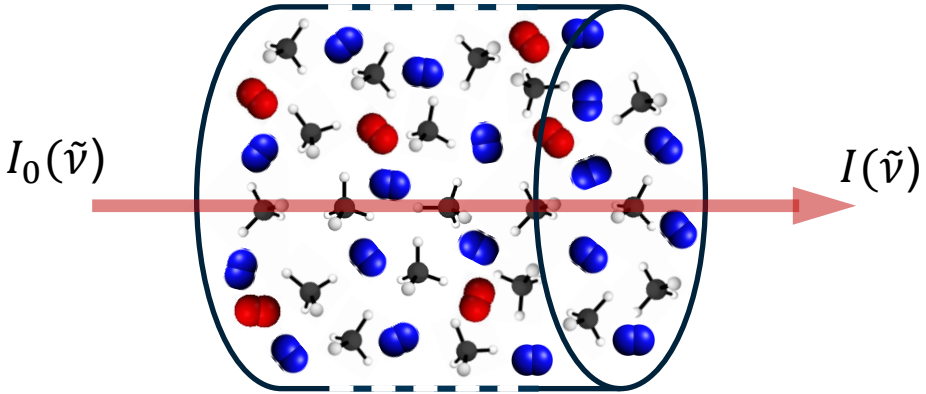
Design

- Near-surface operation
- Tunable diode laser spectroscopy (TDLAS)
- Thermoelectrically cooled (TEC) mid IR laser & photodetector
- Embedded single board computer (SBC) for signal generation, data processing & storage
- Peripheral temperature, pressure, RH sensor, GPS



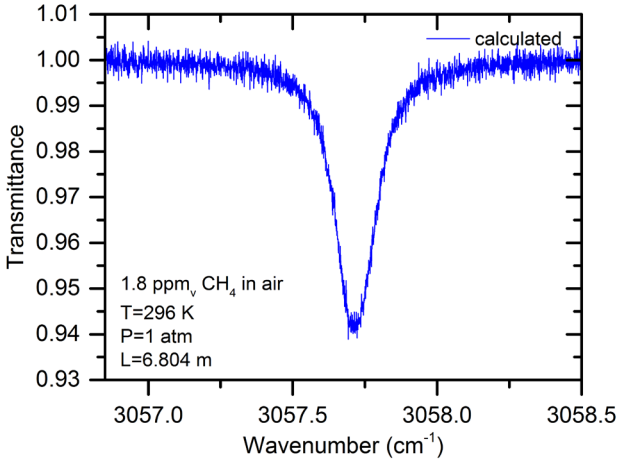
Experimental setup

Principle: tunable diode laser absorption spectroscopy (TDLAS)

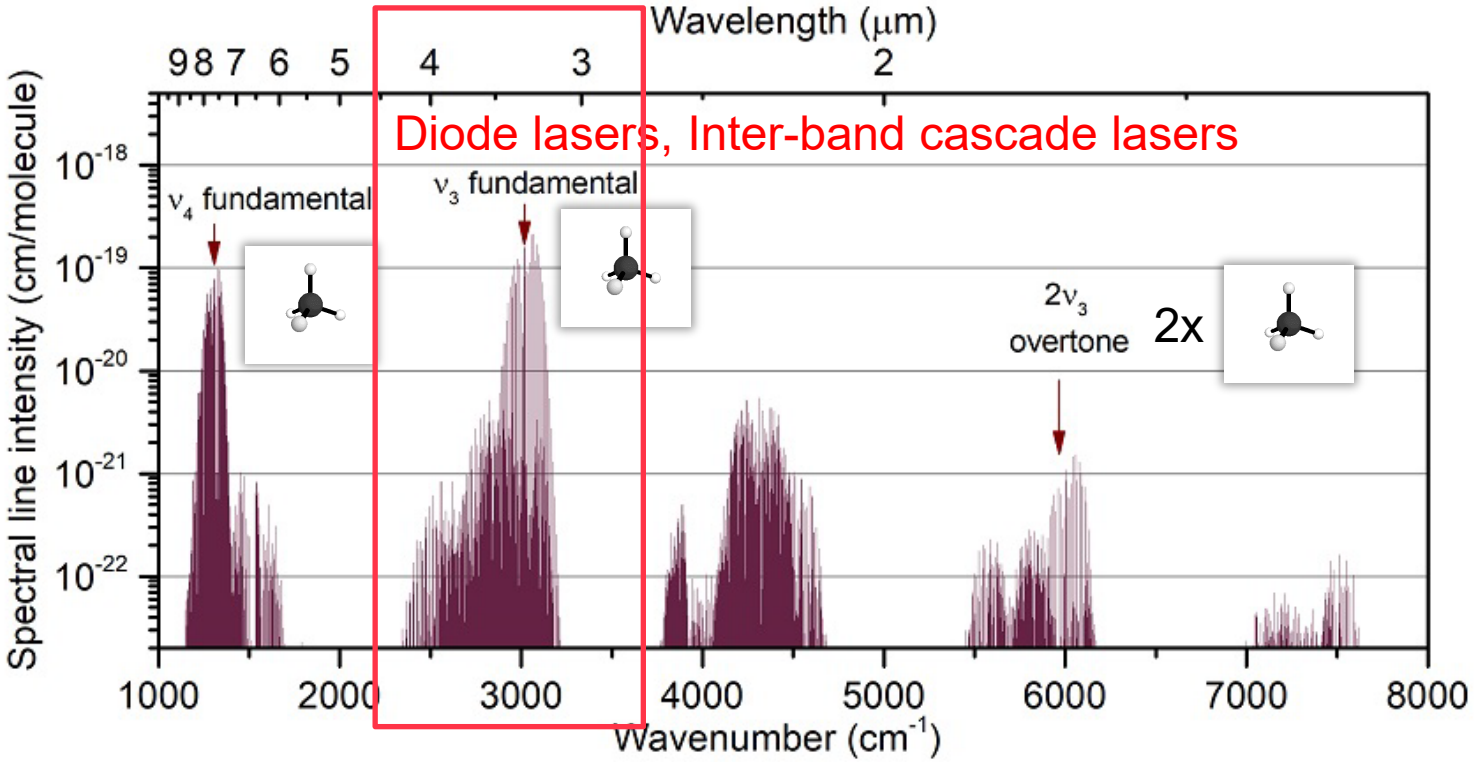


$$I(\upsilon) = I_0(\upsilon)\, e^{-\tau_{ij}(\upsilon,T,p)}$$

$$\tau_{ij}(\upsilon,T,p) = [\mathrm{CH_4}]\, l\, S_{ij}(T) f(\upsilon;\, \upsilon_{ij},T,p)$$

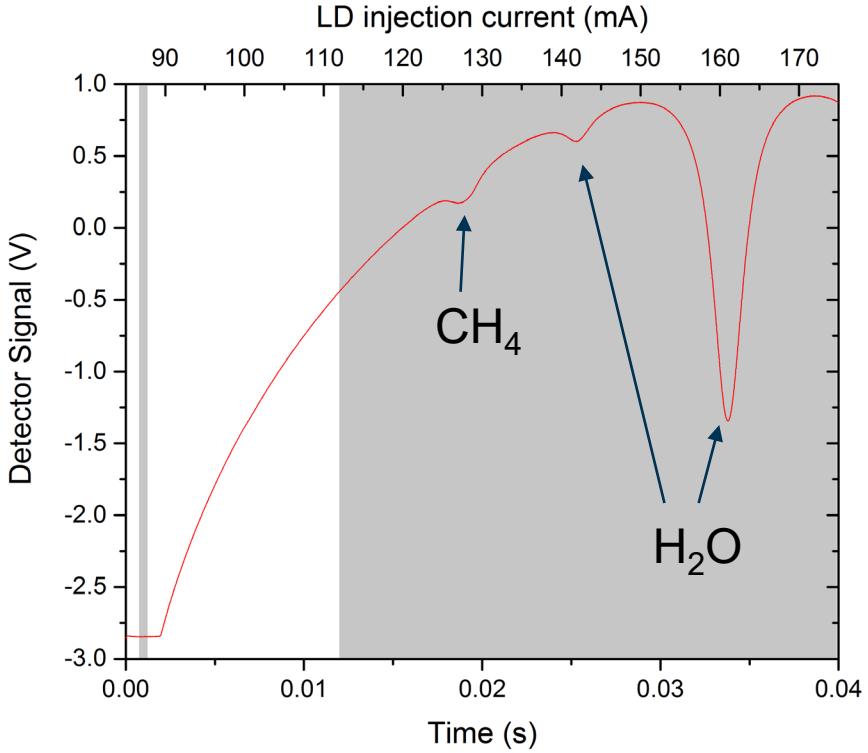


Absorption bands of Methane



Based on HITRAN 2016 database

Principle: tunable diode laser absorption spectroscopy (TDLAS)

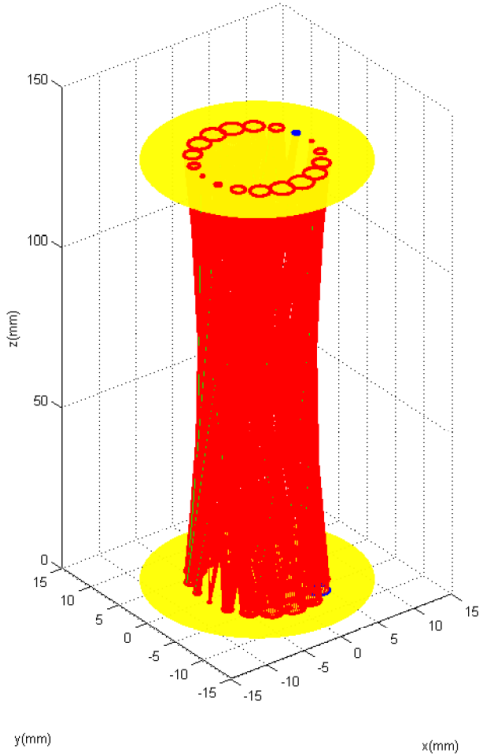


Multi-pass cell design

Herriott-type cell

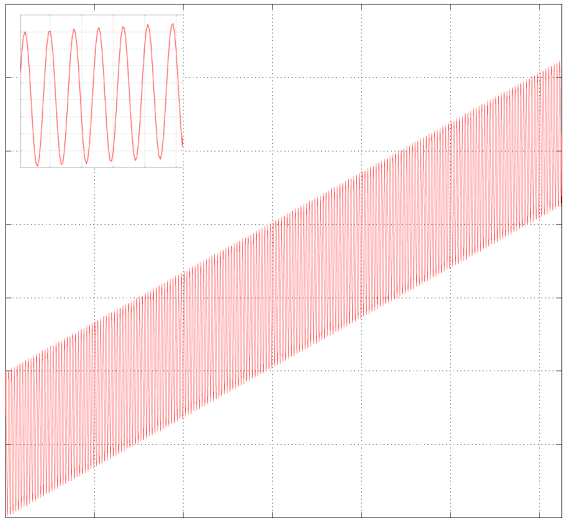
- 1-inch gold-coated (R>98.5%) spherical mirrors
- ~125mm overall length
- 35 passes, 4.663 meters of pathlength
- Open-path
- Not invoking the paraxial ray approximation

Pattern traced with red visible laser



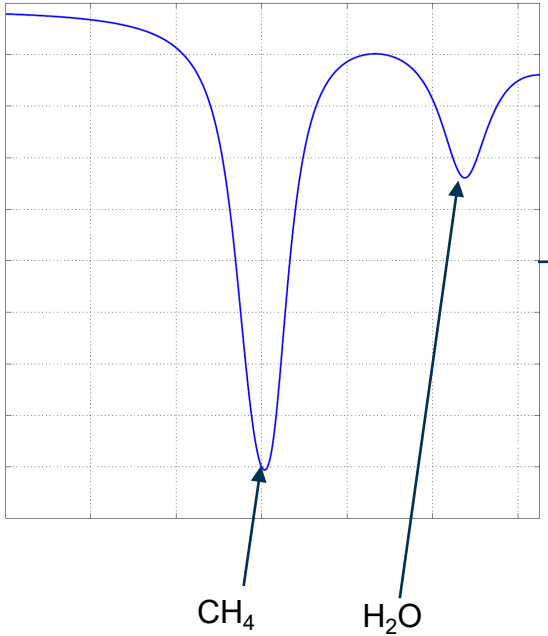
Optical system operation

Laser input:
Current sweep + sine wave modulation

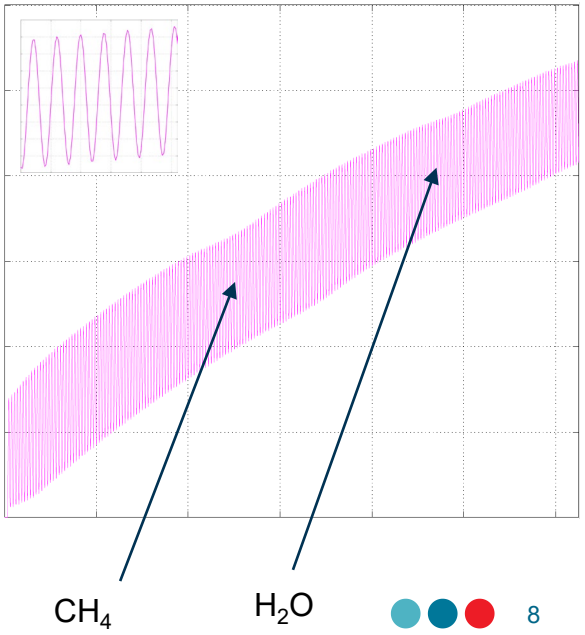


x

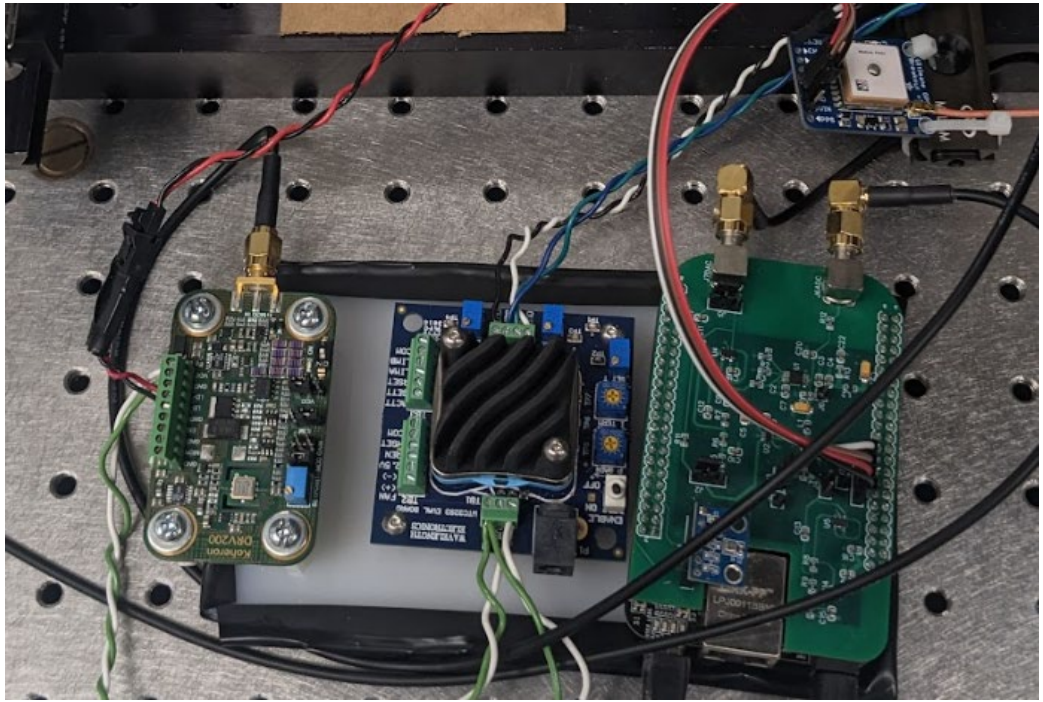
Sample in multi-pass cell:
Signal attenuation due to CH_4 & H_2O



Photodetector output:
Modulated signal with CH_4 & H_2O features



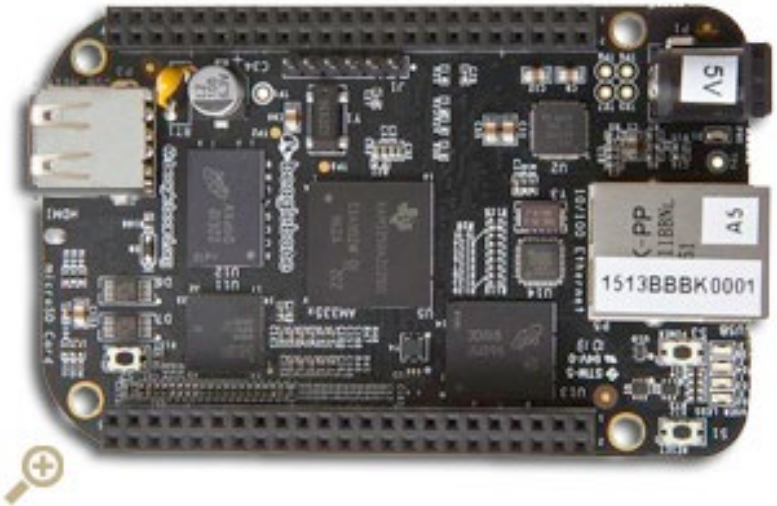
Electronics



Tasks:

- Generate output signal and drive TDL
- Maintain laser & detector temperature
- Capture photodetector output
- Analyze spectrum, extract & store concentration information
- Capture T, P, GPS information

Single board computer - overview



BeagleBone Black (BBB)

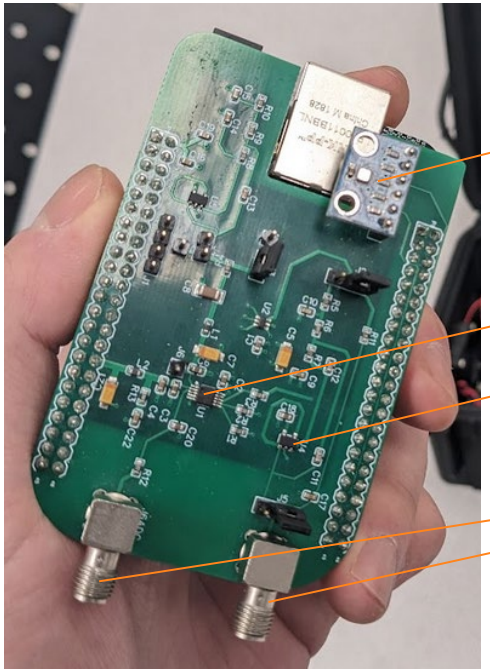
Features:

- Low cost (70$)
- Light weight (90g)
- Debian Linux, programmed in C

2x programmable real time units

- 200MHz clock speed to achieve rapid digital input / output
- Bit-banged serial peripheral interface (SPI) in assembly for precise interfacing with subordinate chips

Single board computer – custom cape board

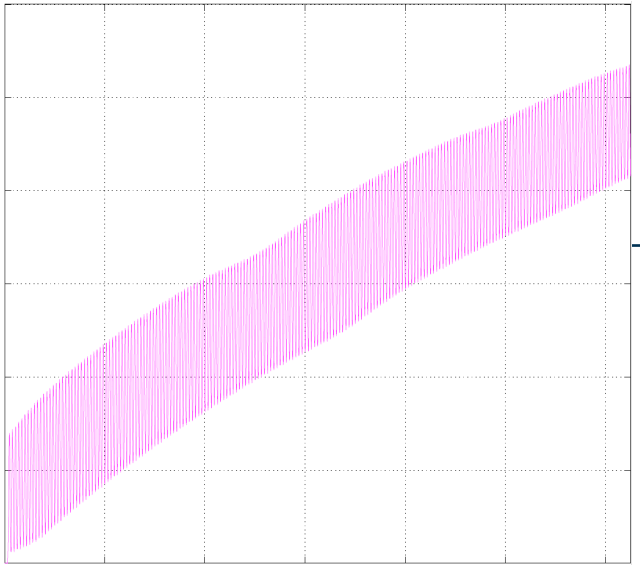


Added capabilities:

- High frequency, high resolution digital to analog / analog to digital conversions
- 400,000 samples per second input / output with conversion chips
- Analog filters on input / output to eliminate high frequency electronic noise
- T, P, RH sensor to record ambient condition during deployment

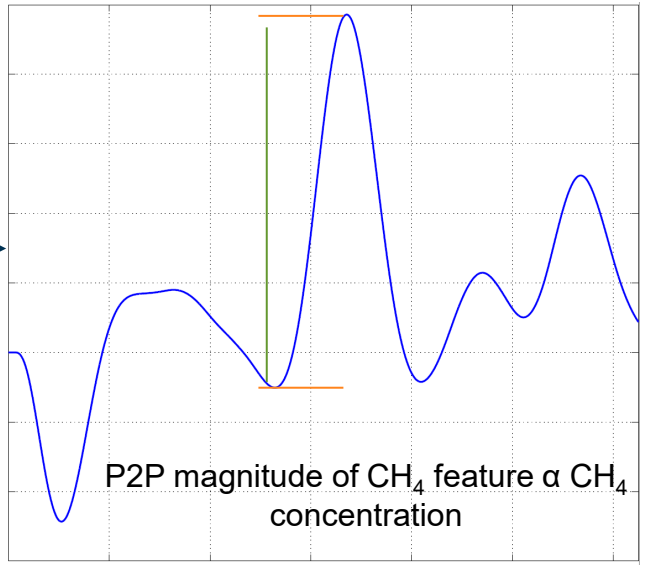
Single board computer – data processing

ADC measured signal:
Modulated response with CH_4 & H_2O features



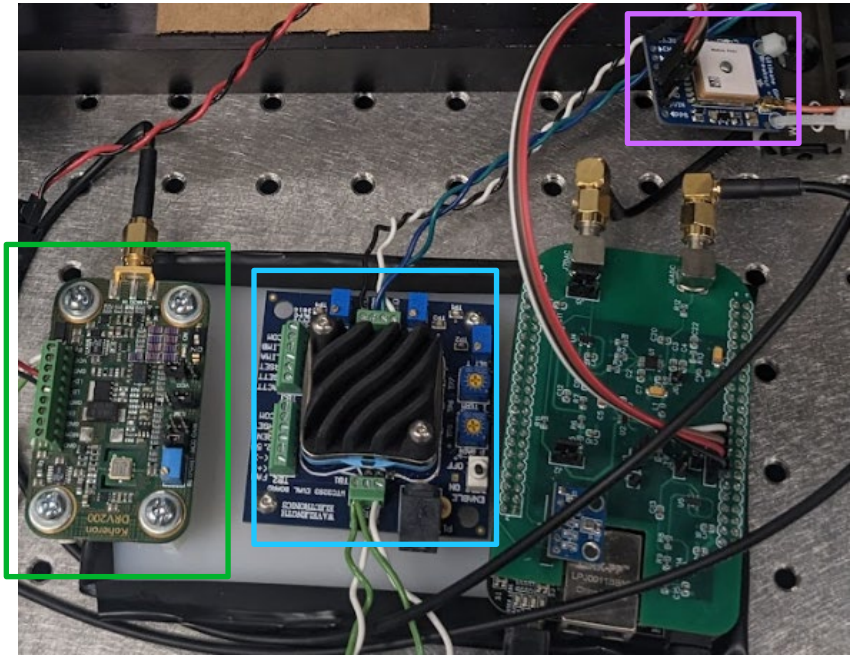
Digital lock in amplifier
COS ⓧ LPF

2nd harmonic spectrum of response



100 cycles per second – 100 Hz concentration capture rate

Laser driver, TEC controller, GPS



Laser driver:

- Converts voltage output to drive current for laser

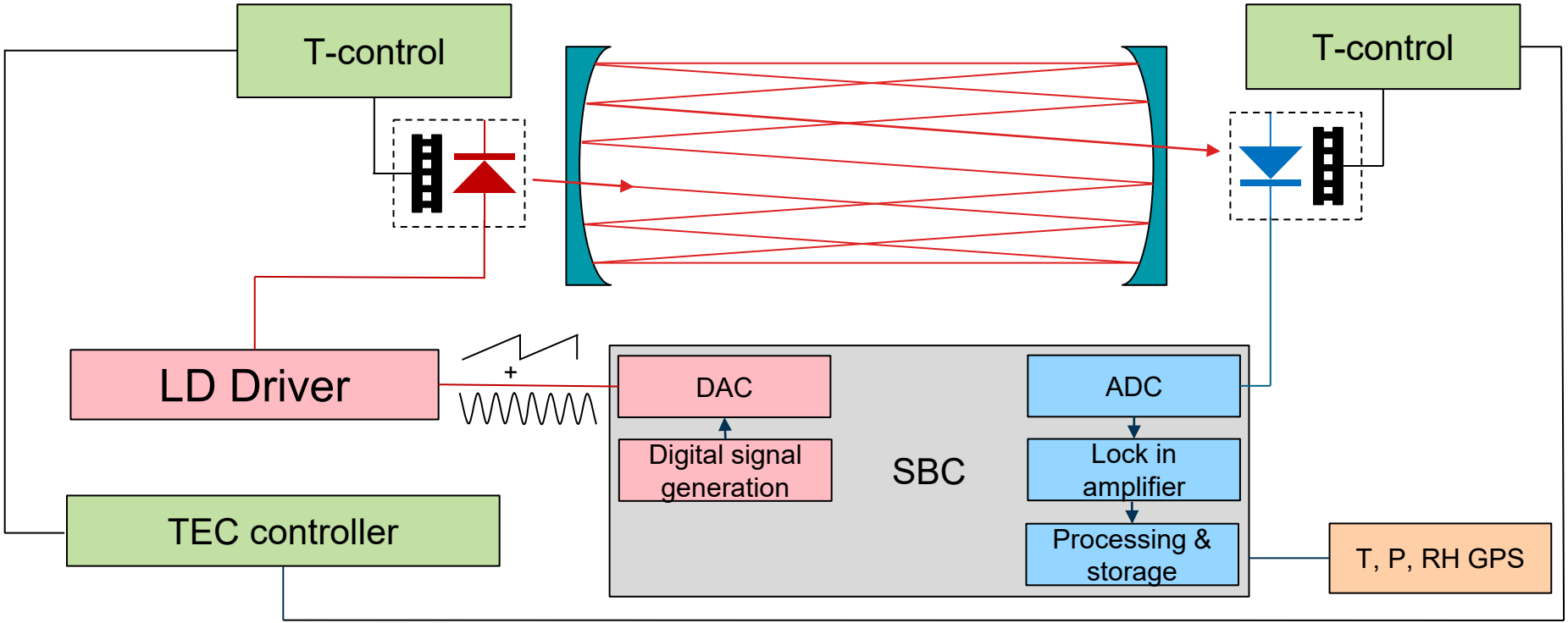
TEC controller:

- Cools laser to 8°C
- Cools photodetector to -60°C

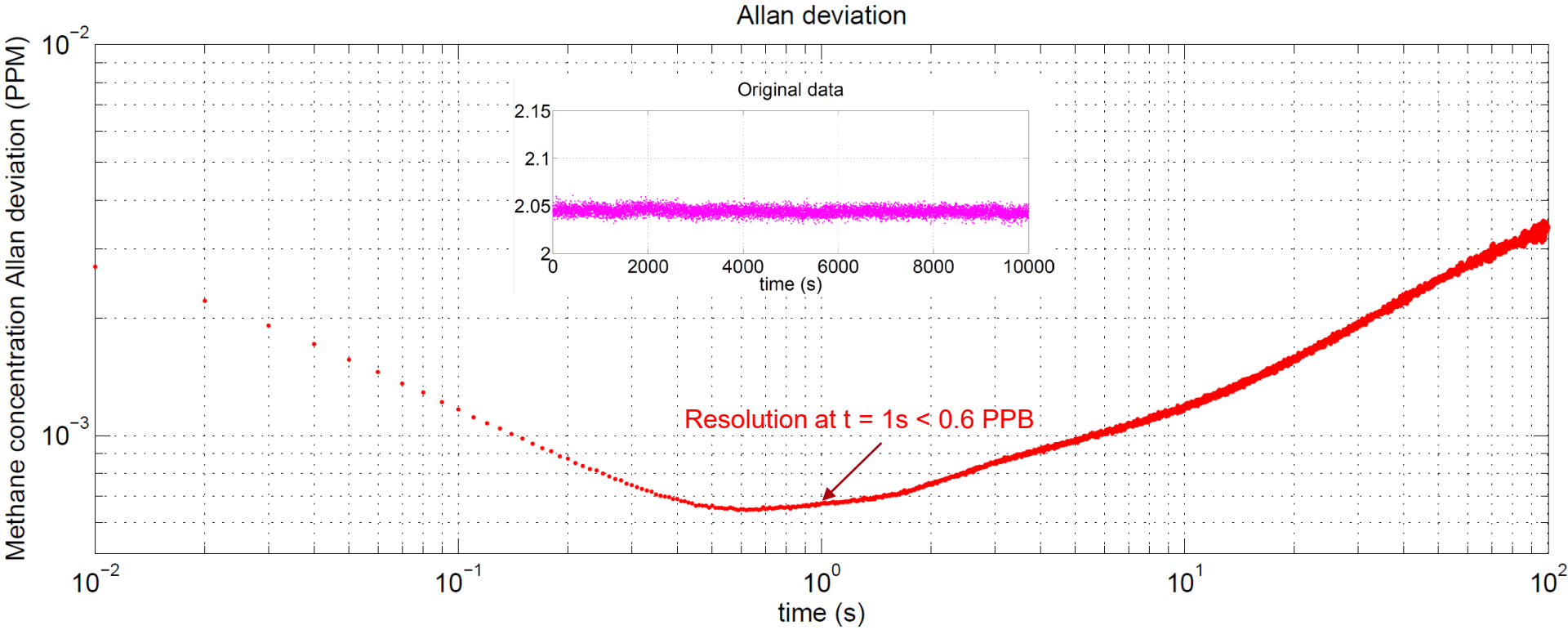
GPS

- Communicates to SBC through UART
- 5 Hz capture rate, geo-stamp concentration measurements

Sensor design: block diagram



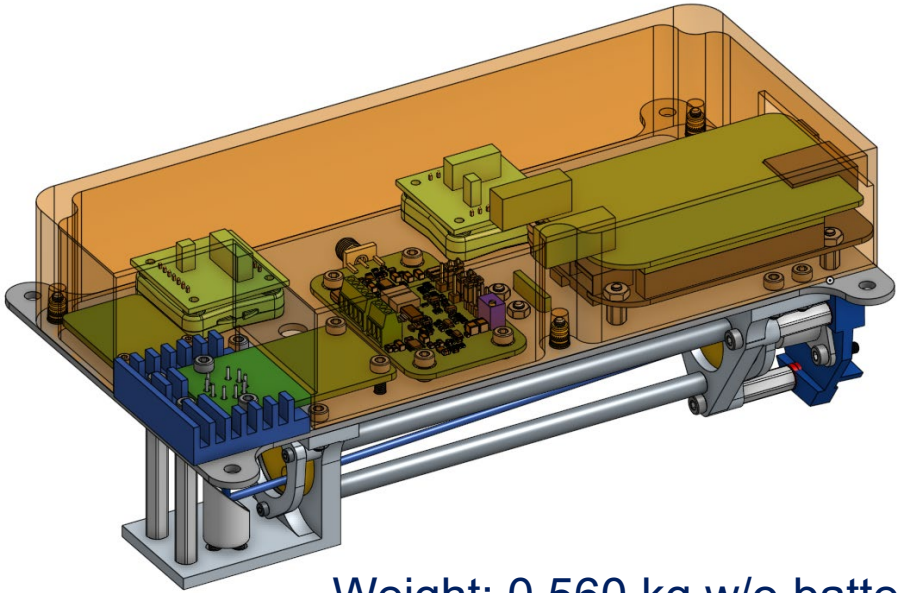
Sensor resolution

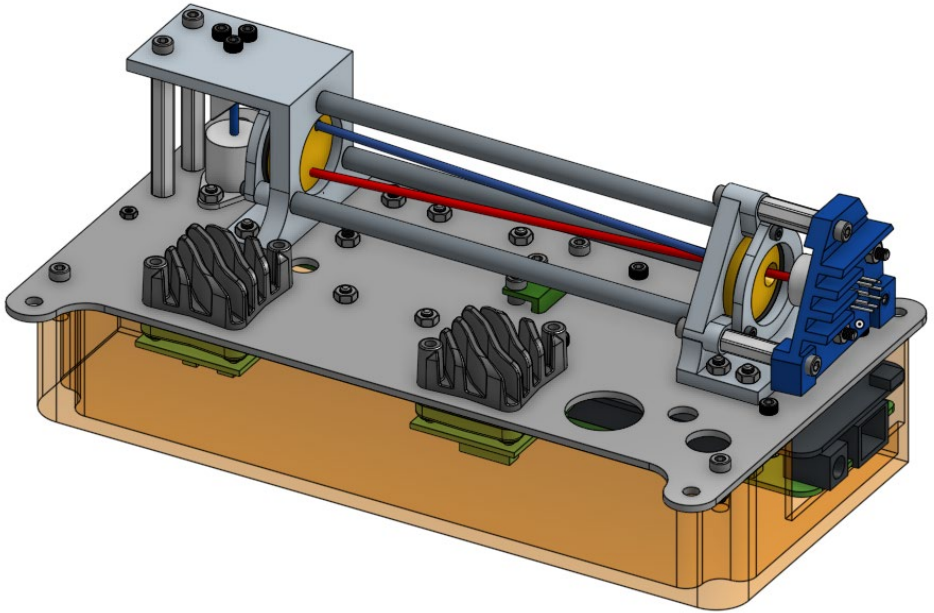


Mobile testing

Experimental setup mounted on top of electric vehicle and driven around waste water processing plant

UAV mounting package





Weight: 0.560 kg w/o battery Power consumption: ~11 W
Dimensions: 23 cm x 9.5 cm x 8.5 cm (LxWxH)

Outlook

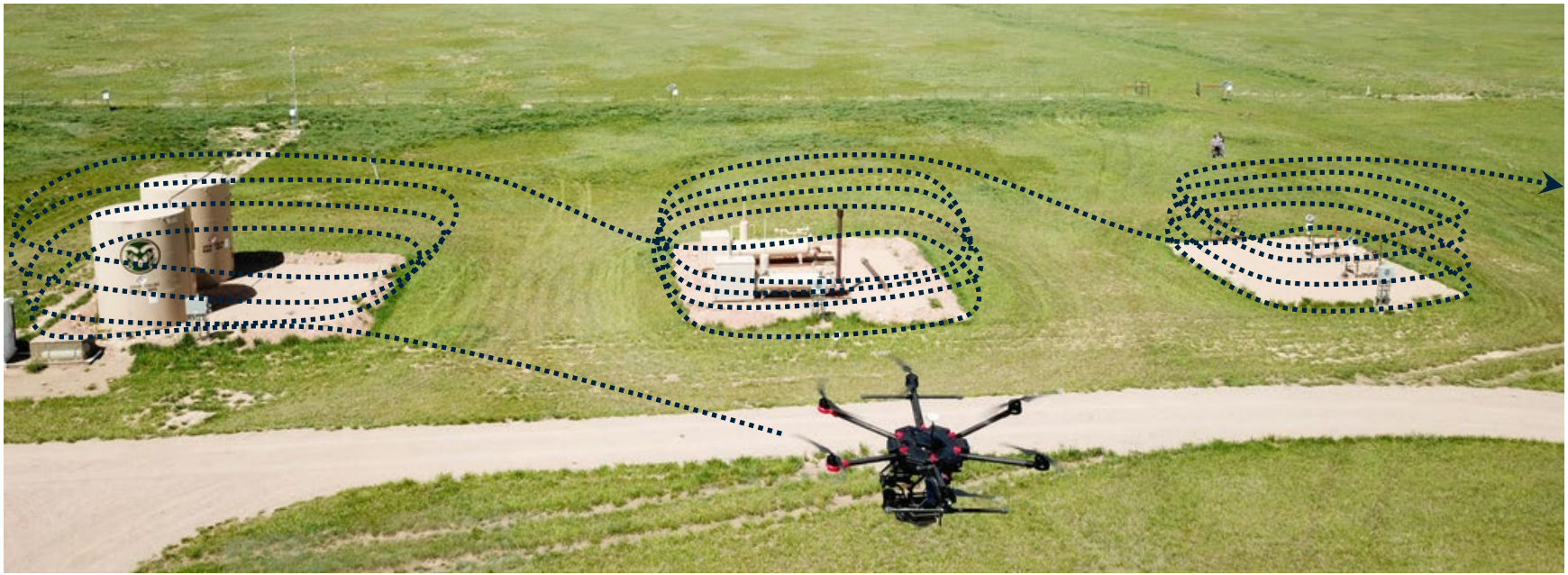


Image: EDF blog

THANK YOU

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