Phase-Modulator Laser Dispersion Sensor for measuring atmospheric methane

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Introduction

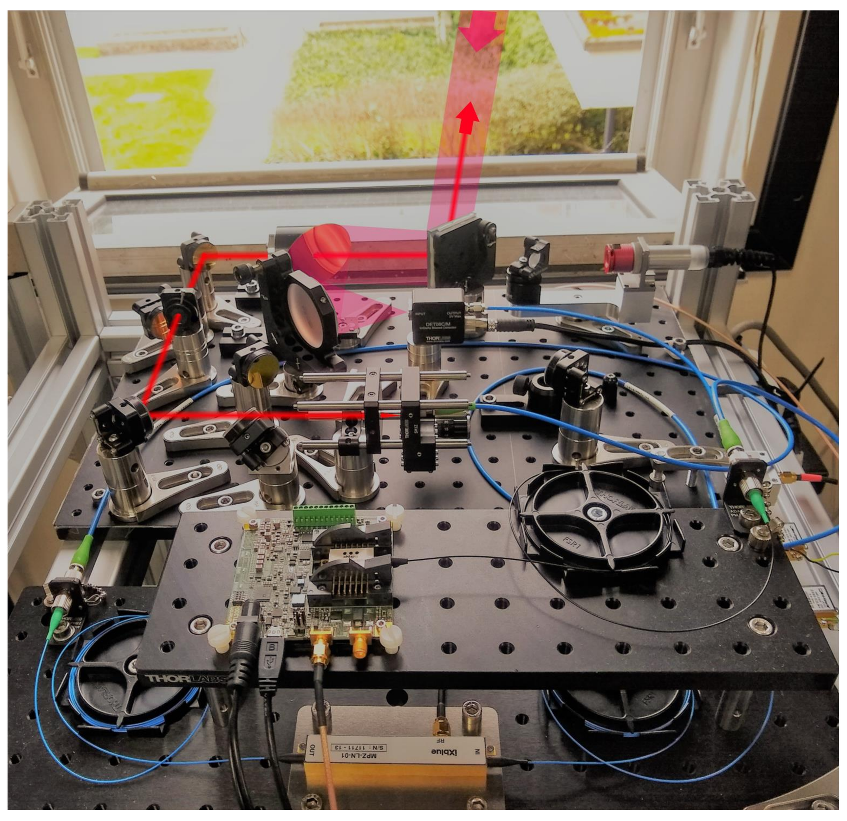
Methane has a damaging effect on air quality. It is the primary contributor to the formation of ozone at ground level, which is toxic for humans and reduces crop yields.

There are many anthropogenic sources of methane, including agriculture, landfill sites, and oil and gas extraction. There is currently no robust, drift-free, autonomous sensor that can be deployed to remote locations for methane monitoring.

The RAL Space Spectroscopy Group has developed a laboratory-based instrument for making open-path measurements of atmospheric methane, using the drift-free, zero-baseline technique of laser dispersion spectroscopy.

Operating in the near-infrared (NIR), the instrument takes advantage of mature telecoms technology to allow a low-power, compact optical design.

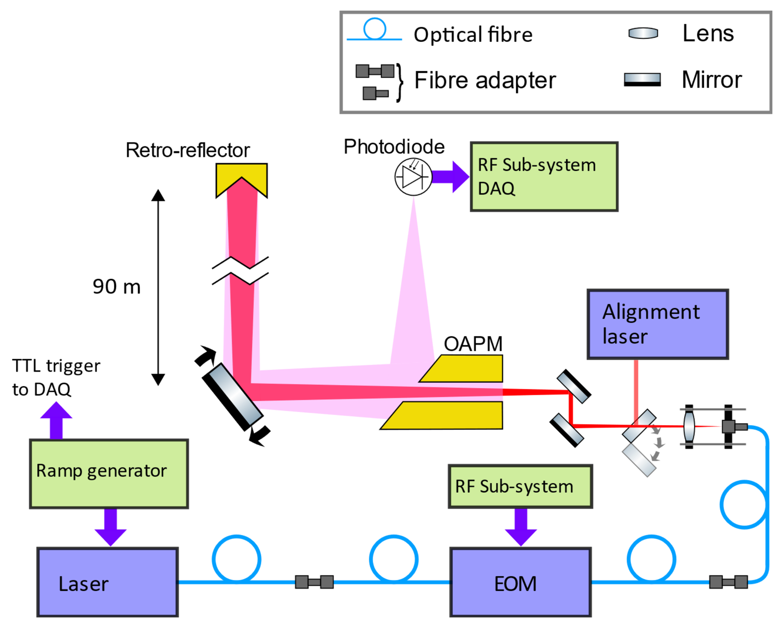
The instrument has been tested in laboratory trials, and demonstrated through measurements of atmospheric methane concentration on the Harwell Campus.



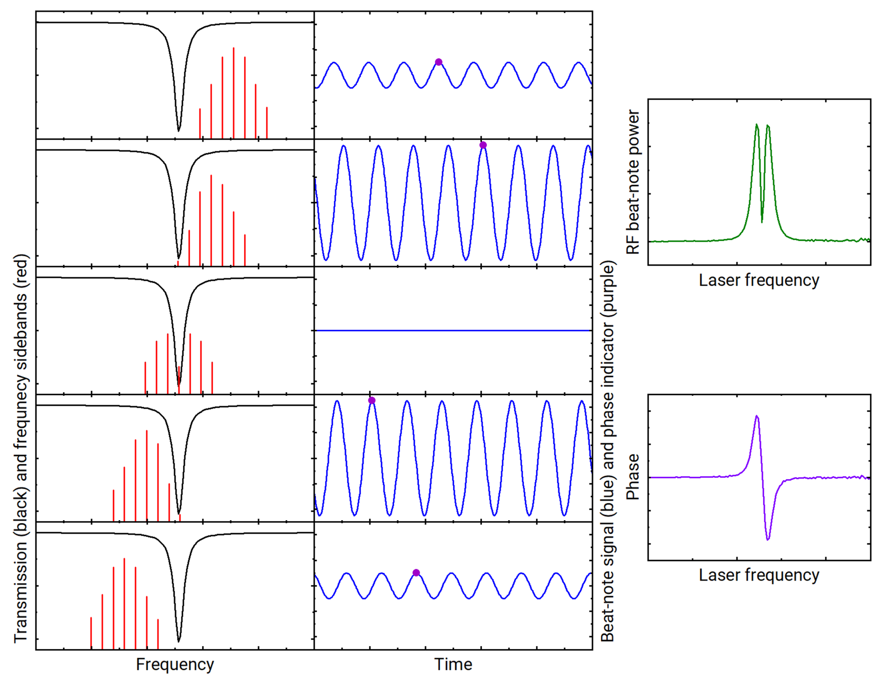
Detection method

NIR radiation (1651 nm) from a fibre-coupled diode laser is propagated through a waveguide electro-optic phase modulator (EOM) which adds frequency sidebands with interval 1.5 GHz.

When the laser frequency is close to that of a molecular resonance, the phase and amplitude of the sidebands are perturbed.



When the radiation is detected by a square-law detector the sidebands cause a radio-frequency beat-note signal at 1.5 GHz. As the laser scans over the molecular resonance, the perturbation to the various sidebands causes a frequency-dependent variation in the phase of the RF beat-note. The molecular concentration can be calculated from the phase shift.

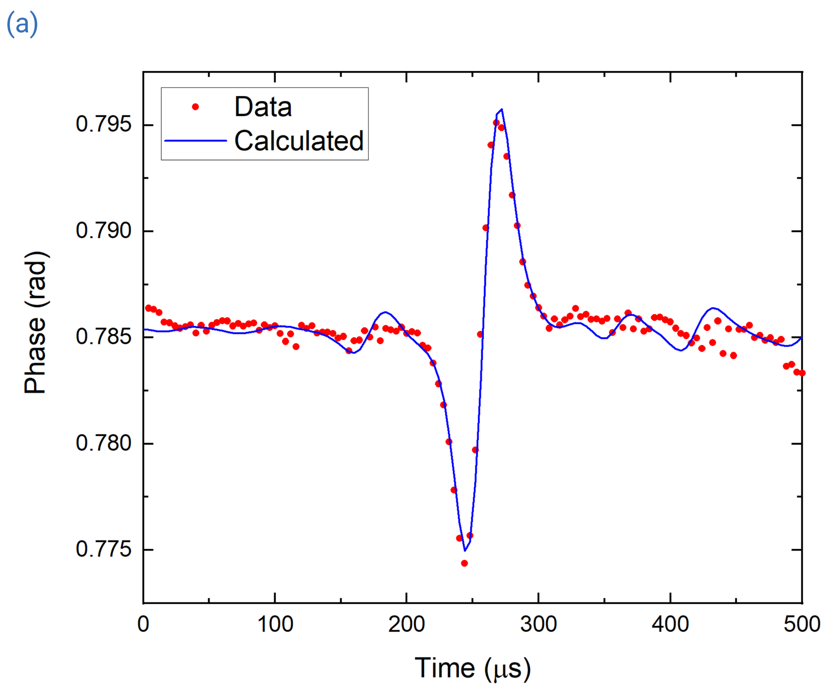


Phase data and sensitivity

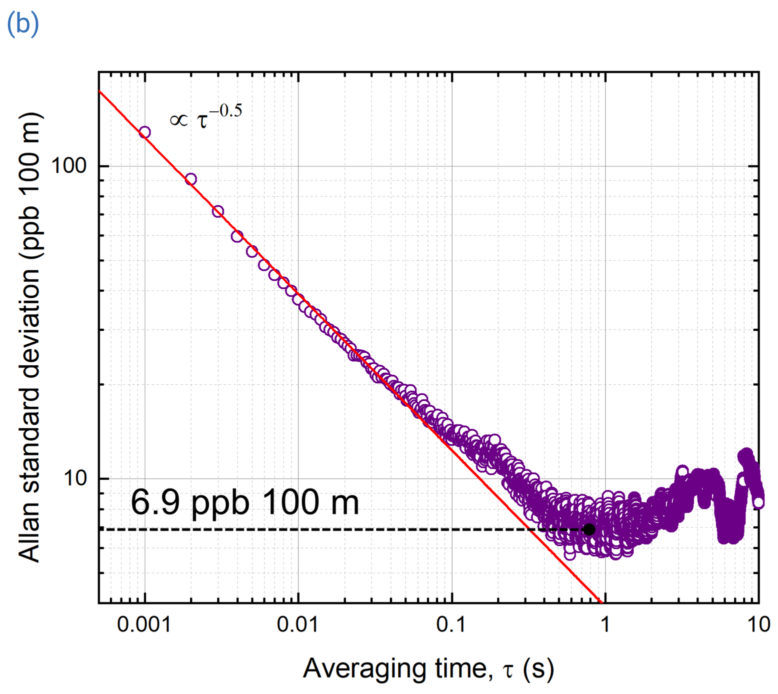
(a) shows the an example of the measured phase signal as a function of time (red points) as the laser is scanned over a methane molecular resonance. The data were recorded using a path length of 86 m across the Harwell Campus, with an averaging time of 1.5 sec. The blue line shows the output of the model.

(b) shows measurements of the Allan standard deviation made in the laboratory with a gas cell sample of methane in air (30 torr partial pressure methane in 730 torr air, 190 mm path length). The instrument sensitivity limit is shown to be **6.9 ppb · 100 m with an averaging time of 0.9 sec**.

(a)



(b)



Atmospheric measurements

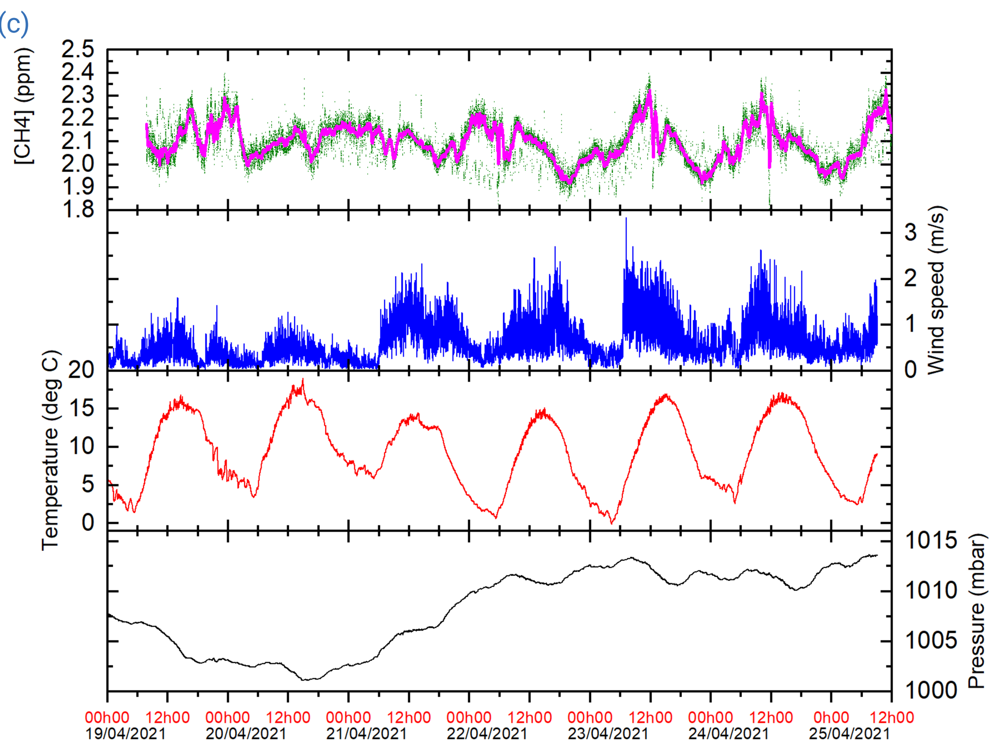
Open-path atmospheric data were recorded over a six-day period in April 2021. Methane concentration measurements were made with an instrument-to-retro-reflector path length of 86 m.

Figure (c) [top panel] shows methane measurements, with each green point representing a 1.5 sec average, and the purple trace representing a 15 minute moving average.

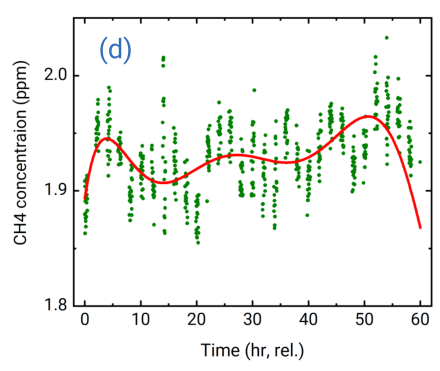
The figure also shows data recorded by a weather station located close to the measurement area.

Analysis of the atmospheric data gives a short-term sensitivity of **9.7 ppb · 100 m with 1.5 sec** averaging time

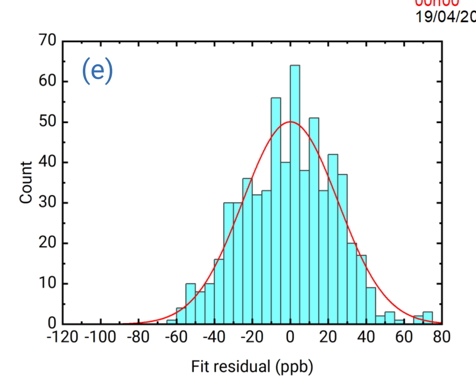
(c)



(d)



(e)



(d) shows concentration data (green points) recorded over one hour during a still night, as well as a high order polynomial fit to the data (red line).

(e) shows a histogram of the residuals from the polynomial fit, from which we measure a longer-term stability of **21.6 ppb · 100 m over a one-hour period**.

PRIAM – Portable Reference Instrument for Atmospheric Measurements

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From laboratory instrument to field-deployable reference sensor

- There is a need for portable gas sensors that can be used as a robust reference for calibrating low-cost sensors (LCSs).
- Low-resource regions often suffer from poor air quality, but lack reliable AQ data. Often networks of LCSs are used to measure AQ.
- LCSs suffer from long-term biases, reducing the usefulness of the data.
- Open-path laser dispersion spectrometers can be used to make drift-free, calibration-free gas sensing measurements, and can operate in a range of weather conditions [see the ORION poster].
- An open-path sensor can perform AQ measurements over a wide area (~1 km^2), allowing calibration of many LCS from a single location.
- We will develop the laboratory-based instrument described above into a field-deployable instrument, and demonstrate the following improvements:
  - Proof-of-concept of **dual-species detection** (methane and CO_2)
  - **Demonstration of an optical head** that allows open-path detection over a wide range of directions
  - **Device miniaturization**
  - Robust **sensor enclosure**
- In parallel with this, we will reach out to a **range of stakeholders around the globe**, especially in **sub-Saharan Africa**, where the collaboration has pre-existing links.
- Lagos is the largest city in Nigeria, and is set to become one of the world's largest megacities in the 21st century. Lagos suffers from poor (and poorly measured AQ). We will focus on building links with researchers and agencies in Lagos.
- Information from the stakeholders will be fed back into the sensor design
- We will work with the stakeholders to arrange future field trials in Lagos, and will seek funding with them for further sensor development.

A new partnership for AQ measurements

ETA ENJOY THE AIR
- Advise on data analysis needs for AQ measurements,
- Engage stakeholders around the globe and feed back measurement needs

UNIVERSITY OF CAMBRIDGE
- Stakeholder engagement in low-resource regions
- Build ties with Lagos Metropolitan Area Transport Authority (LAMATA)

Coventry University
- Stakeholder engagement in low-resource regions
- Strengthen existing ties with Lagos State Environmental Protection Agency (LASEPA)

MIRICO Transformational Gas Measurement
- Consult on the design of the instrument miniaturization and rugged enclosure
- Manufacture parts for the sensor's mechanical structure and enclosure

UKRI Science and Technology Facilities Council RAL Space
- Develop the NIR phase dispersion instrument for dual-species detection and miniaturise
- Demonstrate the new sensor through laboratory measurements and a field trial