Using Infrared Laser Heterodyne Radiometry to Search for Methane on Mars

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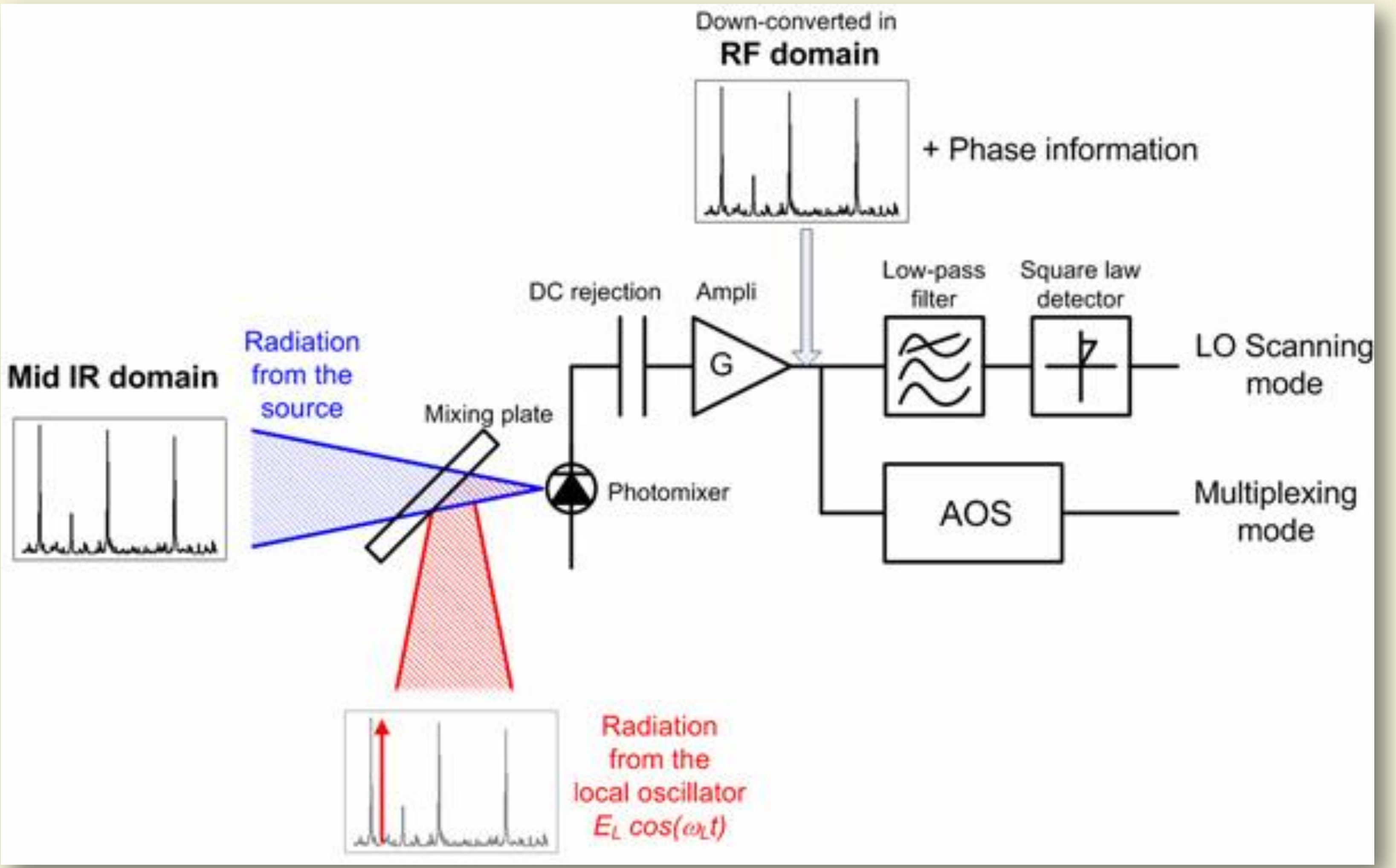
Introduction

Methane has been detected in the atmosphere of Mars by several research teams in the last few years. Ground-based observations[1][2] and space-based instruments (e.g. the Planetary Fourier Transform spectrometer on Mars Express[3]) have reported low levels of methane gas (approximately 10 ppb) in the Martian atmosphere. Methane detection is important as its presence could imply a biological origin, and Martian methane sources are still unknown. However, current methane concentration measurements are at instruments' lower limits of detection. The viability of remote sensing using passive mid-infrared laser heterodyne radiometry to detect methane in the Martian atmosphere is investigated.

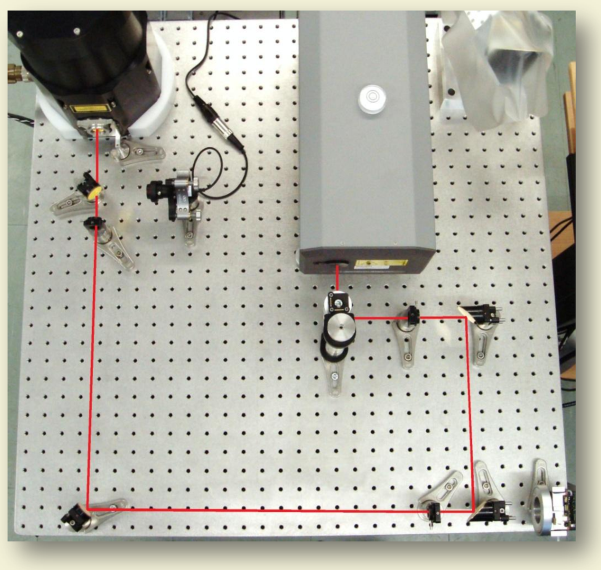


Schematic of the prototype LHR instrument

Quantum Cascade Laser as Local Oscillator

At the heart of the LHR is the use of a Quantum Cascade Laser (QCL) as the local oscillator. The majority of previous spectroscopy studies using the IR heterodyne technique have been carried out with a CO_2 gas laser as the LO source. However, the invention of mid-infrared quantum cascade lasers (QCLs)[6] have offered a new alternative. QCLs offer the prospect of room temperature operation coupled with a wide spectral tuning range. They also have the advantage of being extremely compact, robust and reliable devices which make them ideal candidates for flight and satellite deployment.

The major feature of QCLs, which has been exploited for absorption spectroscopy, is their ability to be continuously tuned in frequency. The spectral coverage of a heterodyne receiver is determined by the LO frequency, the bandwidth of the photomixer and the related electronics[5].



Setup of the optical bench during testing of the 7.7 µm QCL at the Rutherford Appleton Laboratory

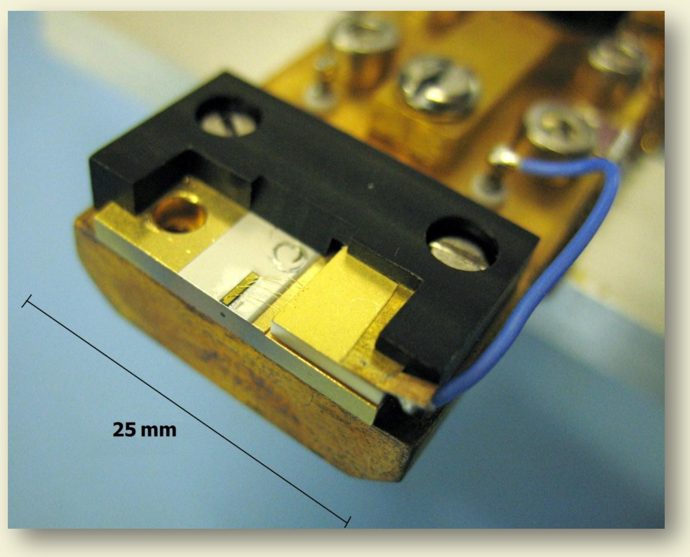
The design of the LHR allows for a compact and lightweight (approx. 5 - 10 kg) instrument. The current Quantum Cascade Laser based LHR at the Rutherford Appleton Laboratory has a dimension of 0.75 m x 0.75 m and there is potential for significant miniaturization through optical integration. It has also been shown that a carefully selected specific high resolution microwindow provides as much information as a medium resolution radiometer covering a broad spectral range[5].

The Laser Heterodyne Radiometer

Laser heterodyne radiometers (LHRs) have been used extensively, and with much success, for atmospheric studies, such as work on stratospheric ozone[4], mainly because of their ability to make measurements with an ultrahigh spectral resolution (greater than 0.001 cm^{-1}) over a narrow spectral range (~10 cm^{-1}) when a quantum cascade laser is used as local oscillator.

Heterodyne Detection

The heterodyne method down-converts the received signal to a lower, intermediated frequency (IF) signal, in order to process it more easily. This is done by mixing the incident radiation with that from the local oscillator (LO) at the detector with a nonlinear response. The IF signal is divided and amplified without degradation of the signal-to-noise ratio (SNR), which allows efficient spectral multiplexing[5].



7.7 µm QCL mounted on a substrate and installed in a custom made laser head

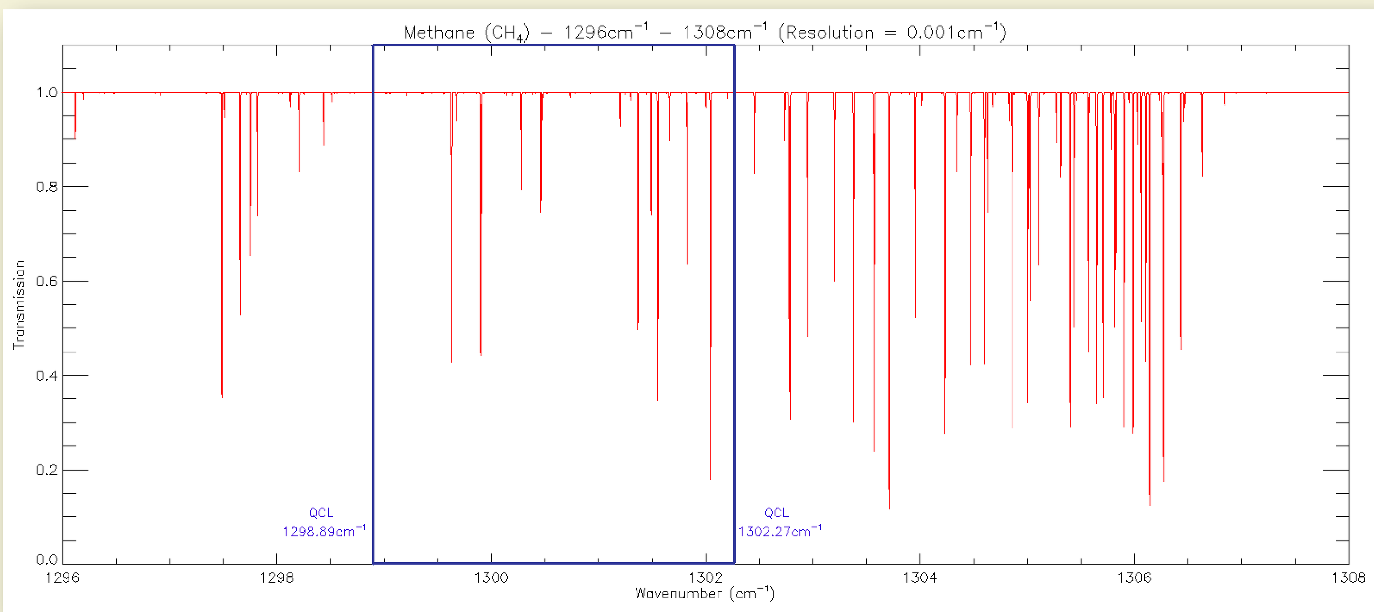
QCL Advantages:

- Extremely **compact**
- **Robust** and **reliable**
- Feature a **wide spectral tuning range**
- Can operate at **room temperature**
- QCLs provide milliwatts of power and are ideal for high-resolution spectroscopy where **high sensitivity** is required

Laboratory and Future Work

Tests have been performed on a 7.7 µm QCL to determine the spectral tuning range of the LHR. The instrument is currently being assessed to determine its ability to measure methane gas transmission through small gas cells. A Martian atmosphere will then be replicated which will include aerosols that represent typical dust concentrations. Data from the LHR will be processed and wavelength calibrated transmission spectra will be produced. The instruments sensitivity and discrimination of overlapping spectral features will be analysed.

Also, a side-by-side spectroscopic comparison will be made between the LHR and a high resolution Fourier transform spectrometer (a Bruker IFS 125HR). A conclusion will be made whether methane can be detected using the LHR as well, or better, than the FTS. If successful, consideration will then be made for developing the instrument further in order to make remote sensing measurements of the Martian atmosphere. The instruments potential for a future Martian orbiter will also be considered.



High resolution (0.001 cm^{-1}) simulated CH_4 spectrum from 1296 - 1308 cm^{-1} with the 7.7 µm QCL tuning range shown in blue

References: [1] Krasnopolsky et al. (2004) *Icarus*, 172, 537-547. [2] Mumma et al. (2009) *Science*, 323, 1041. [3] Formisano et al. (2004) *Science*, 306, 1758-1761. [4] Weidmann et al. (2007c) *Applied Optics*, 46, 7162-7171. [5] Weidmann et al. (2007b) *Review of Scientific Instruments*, 78, 73107. [6] Faist et al. (1994) Science, 264, 553-556.