Laser Heterodyne Radiometer Potential for use in NWP

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- The Laser Heterodyne Radiometer (LHR) is an instrument developed at the Rutherford Appleton Laboratory in the UK. It is a passive infrared radiometer based on the use of quantum cascade lasers (QCL) that can make measurements at extremely high spectral resolution (down to 10MHz or 0.00033cm^{-1}) and very high spatial resolution (50m from LEO, 400m from GEO).
- Current ground-based instruments have been used in solar occultation mode to measure ozone profiles, to perform CO_2 and H_2O retrievals, and to detect species such as CH_4, N_2O and CCl_2F_2.
- The instruments are very small and getting smaller all the time and are thus ideal for a piggyback mission or constellation.
- The aim of this study is to see if a nadir-viewing LHR could provide useful information on atmospheric temperature for NWP.
- The LHR proves to be extremely promising for upper-atmosphere sounding, giving complementary information to existing IR sounders (IASI).

1. The LHR Instrument

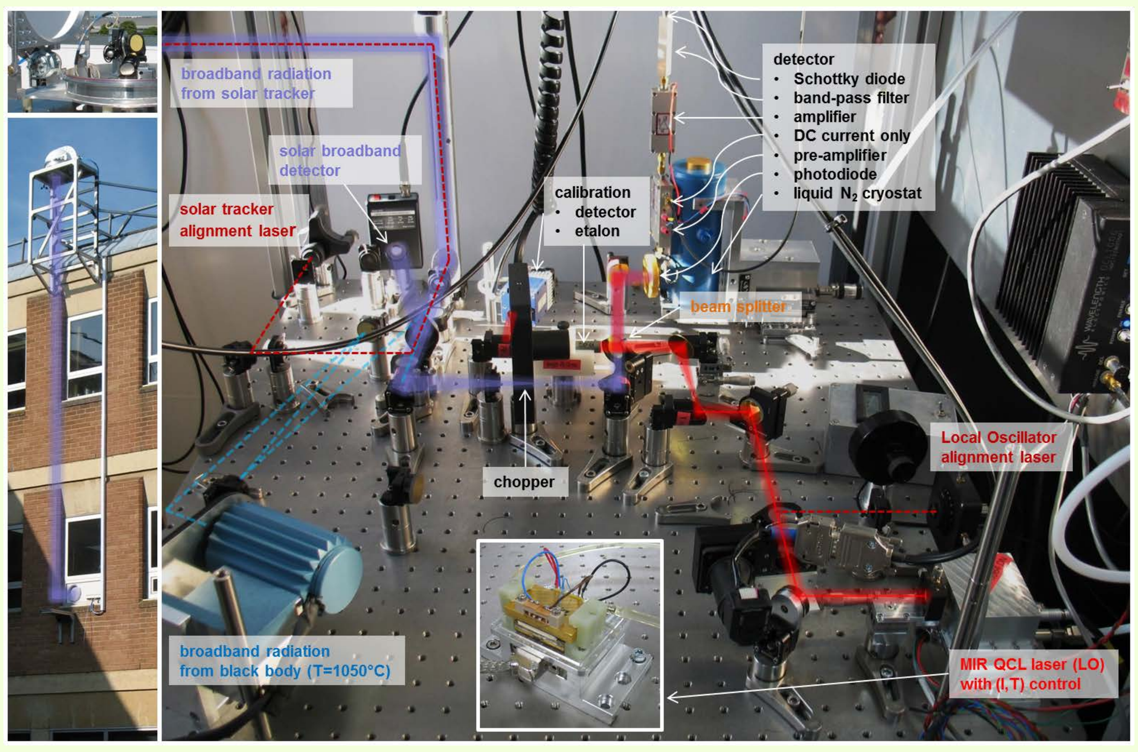

Fig 1: Benchtop LHR instrument in solar occultation mode at RAL

Heterodyne detection mixes the incident radiation with that of a local oscillator (LO), in this case a QCL, to create a difference frequency signal proportional to the power of the LO. Thus, a strong LO gives a strong heterodyne signal from a weak input, allowing detection of even weakly absorbing gases.

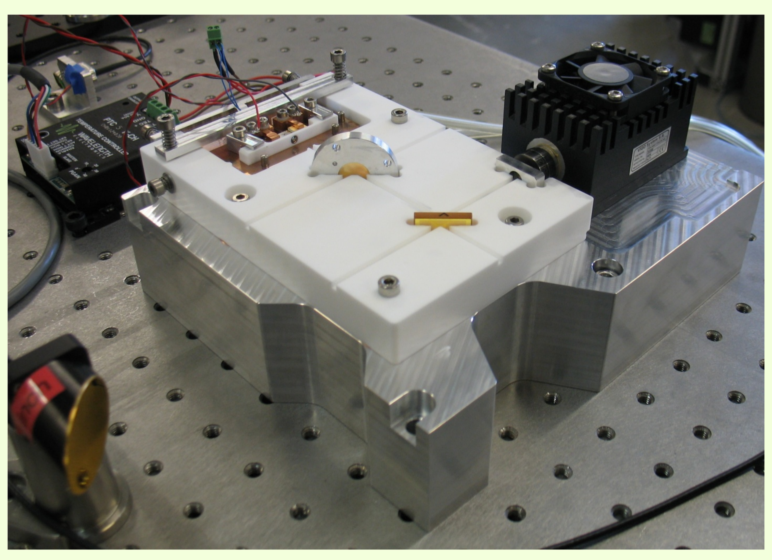

Fig 2: This new generation LHR: is just 10 x 12 cm. You can see the HWG cutting across the white ceramic substrate.

The breakthrough of the LHR is the QCL: a strong, stable laser in a tiny device that can be operated at room temperature with low power. They can have a wide spectral tuning range and are extremely robust, reliable devices: ideal candidates for flight and satellite deployment.

Another major development is the use of hollow waveguide (HWG) technology. The HWG can purify the mode structure of the QCL radiation and is able to virtually eliminate optical feedback to the laser. It also results in superior stability and prevents alignment problems.

2. Investigating the potential of the LHR for NWP

The principle behind the use of the LHR for NWP is similar to microwave sounding. Measurements are made at high spectral resolution across the wings of just one or two absorption lines. As the central frequency of the measurement drifts from the centre of the absorption line, the channel sensitivity moves lower in the atmosphere.

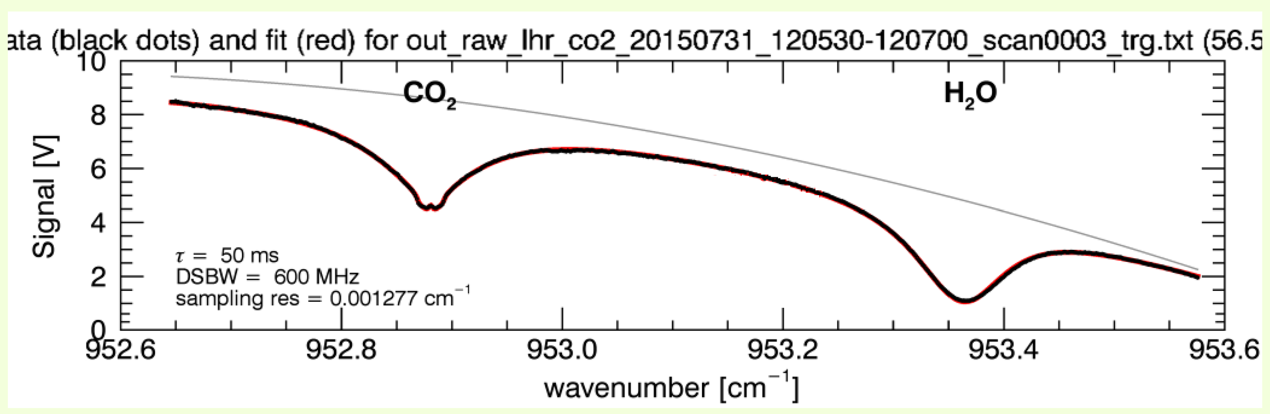

Fig 3: A an actual measured spectrum from the benchtop LHR in Fig 1. The current achievable spectral resolution is capable of resolving the individual absorption lines

For temperature sounding, clean CO_2 absorption lines in the 650-720cm^{-1} region are sought, with minimal contamination from trace gases and water vapour. Information content (Degrees of Freedom for Information; DFS) calculations are used to choose the best microwindows for improving the NWP background forecast, using the Infrared Atmospheric Sounding Interferometer (IASI) as a benchmark.

Trade-off studies were performed, to investigate the effects of changing the spectral resolution, microwindow width and sensing time. These parameters affect the instrument noise – a critical aspect in deciding whether the instrument will be useful for NWP and whether it should target a LEO or GEO platform.

3. Optimal microwindow study

Jacobians from the Havemann-Taylor Fast Radiative Transfer Model (HT-FRTC) were used to calculate DFS for spectral resolutions of 0.001cm^{-1} to 0.02cm^{-1} across the region 645-720cm^{-1}, assuming background errors consistent with the Met Office Global model and no RT error.

Trade-off studies were performed for regions with the highest DFS and lowest contamination (Fig 4). Long integration time, high resolution and wide microwindows all give a higher information content. The LHR seems most promising for upper atmosphere sounding (Fig 5); in this case, high spectral resolution is probably the highest priority.

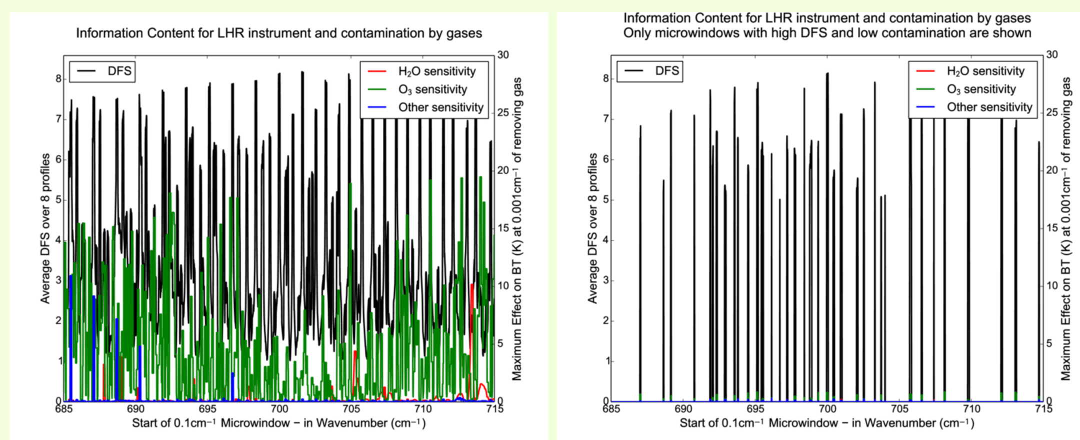

Fig 4: Microwindows were assessed for contamination by H_2O, O_3, and other species.
Left: DFS of all 0.1cm^{-1} microwindows between 685 and 715 cm^{-1}, and level of contamination
Right: Only those microwindows with the highest DFS and low contamination.

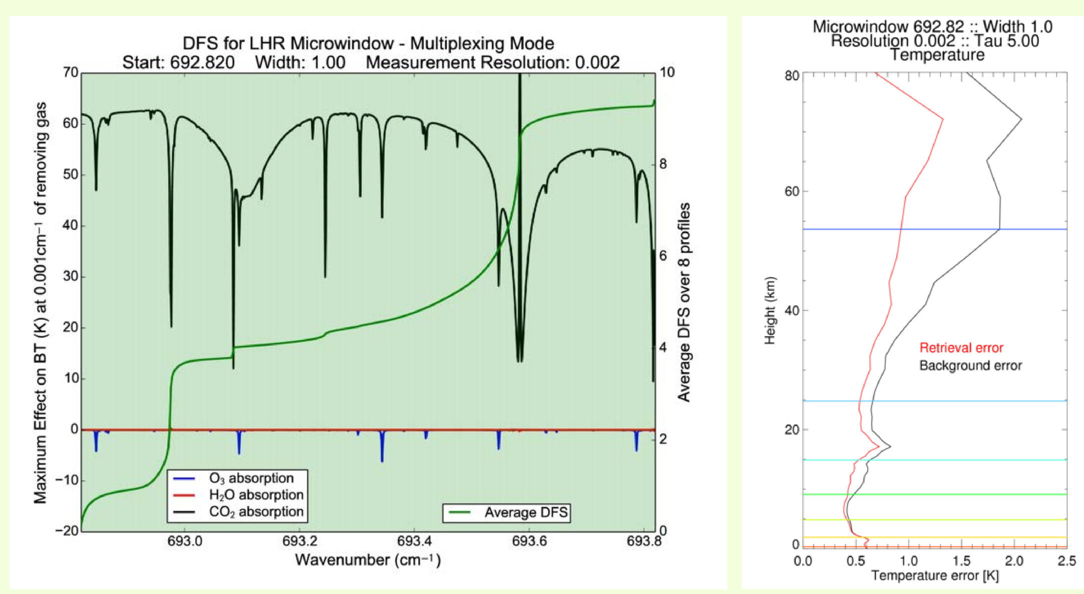

Fig 5: A heavily multiplexed instrument could span up to 1.0cm^{-1} during the same acquisition time as a simpler instrument can span 0.1cm^{-1}.
Left: The change in DFS with each sample (green vertical line) across a 1.0 cm^{-1} microwindow starting at 692.82 cm^{-1}. The DFS increases when CO_2 lines are measured.
Right: This instrument could provide benefit for temperature sounding in the upper atmosphere.

4. Complementarity with IASI

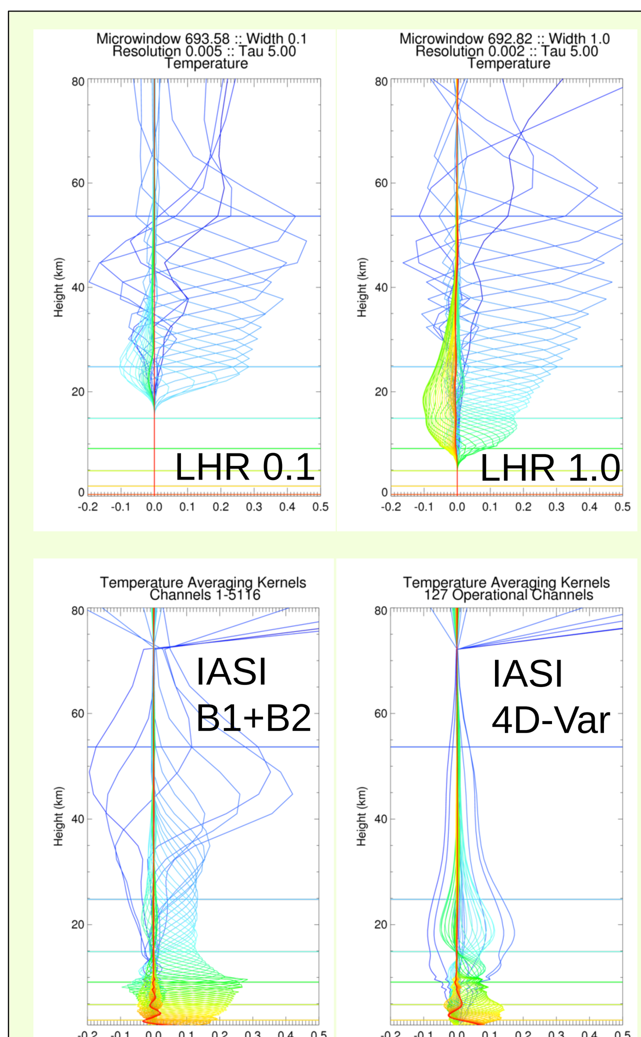

Fig 6: Ideal Averaging Kernels (no RT error) for
(Top Left) LHR at 693.58cm^{-1} with 0.1 cm^{-1} microwindow and 0.005 cm^{-1} spectral resolution
(Top Right) LHR at 692.82cm^{-1} with 1.0 cm^{-1} microwindow and 0.002 cm^{-1} spectral resolution (see Fig 5)
(Bottom Left) Full IASI spectrum for Bands 1 and 2
(Bottom Right) 127 IASI channels from B1&2 assimilated operationally in the Met Office 4D-Var

The averaging kernels show that the LHR has the potential to provide information high in the atmosphere. A wide microwindow gives higher DFS, but a narrow one prevents contamination from the troposphere. This information is complementary to that provided by IASI, which primarily sounds the troposphere.

The averaging kernels plotted are for an integration time of 5 s, suitable for GEO orbit or a stop-and-stare LEO mission. However, 1 s is viable for some configurations, which would give contiguous sampling of the stratosphere from LEO orbit.

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