Science & Technology Facilities Council
Rutherford Appleton Laboratory

RAL Space
Laser Spectroscopy

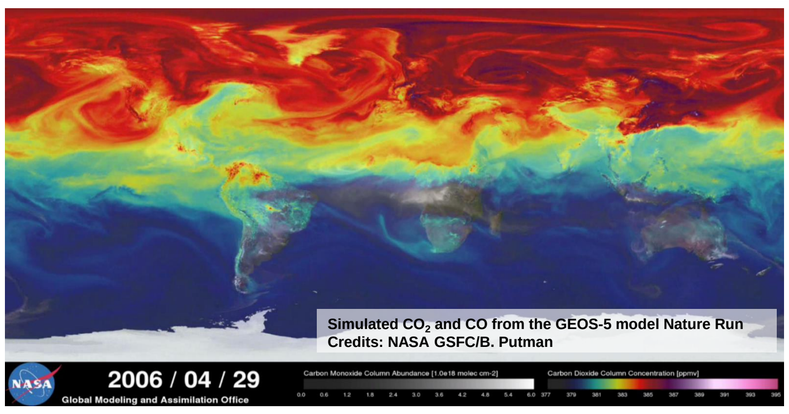
Arctic field deployment of the RAL CO_2 Laser Heterodyne Radiometer (LHR) within the FRM4GHG instrument inter-comparison campaign

Alex Hoffmann(*), Marko Huebner, Neil Macleod, Damien Weidmann, and the FRM4GHG team

RAL Space, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, OX11 0QX, UK

www.stfc.ac.uk/ralspace/LaserSpectroscopy - (*) alex.hoffmann@stfc.ac.uk

Context and objectives



Scientific rationale and technology development objectives

- CO_2 major atmospheric component of terrestrial C-cycle and climate system, and best-known GHG. Strong PBL and seasonal variations and slow rising trend due to anthropogenic emissions. Large spatio-temporal differences, but (diurnal) variations in the total column amount typically <1 ppm on ~400 ppm background

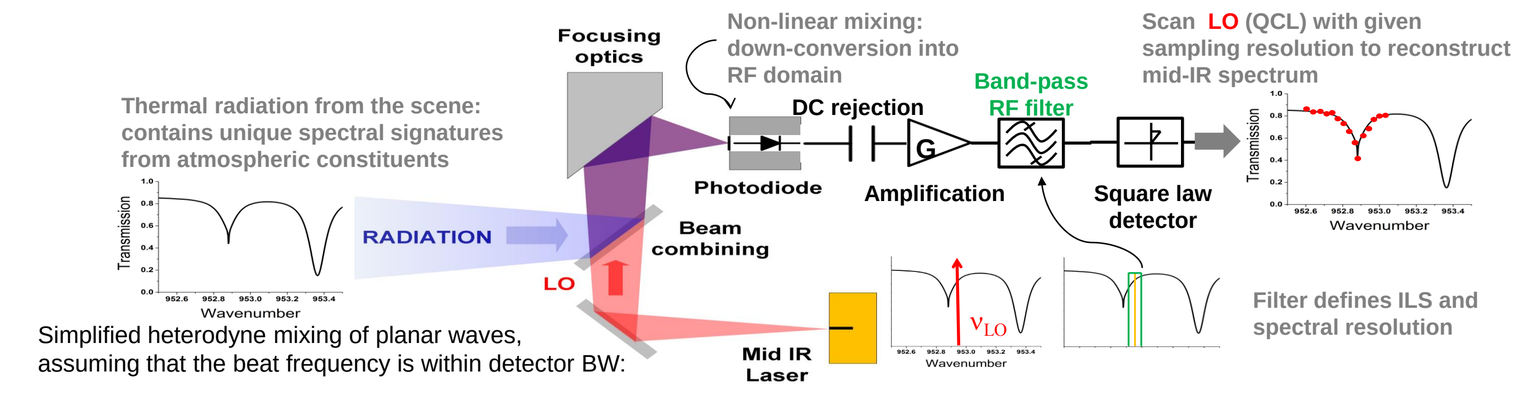
⇒ **need for accurate, high-precision instrumentation, suitable for network deployment for source, sink & transport studies**

FRM4GHG campaign aims (March – November 2017)

- inter-compare collocated novel and established ground-based IR sounding spectrometers and associated retrievals for GHGs
- validate retrieved dry total column amounts against TCCON reference data and balloon-borne AirCore in-situ profiles
- collect reference datasets for validating (mostly C-based) global GHG satellite observations, in particular S5P, giving TC amounts

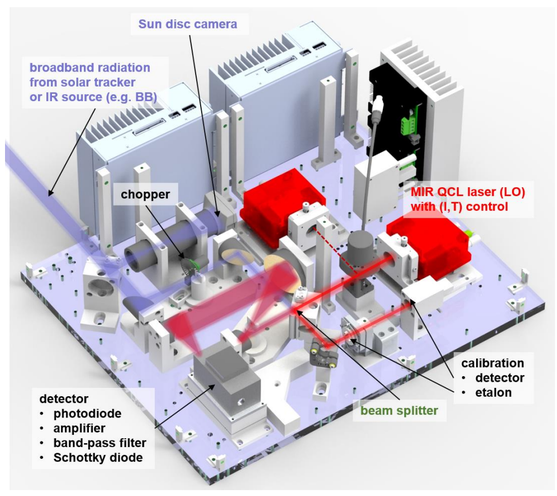
⇒ **evaluate potential of low-cost portable spectrometers for new GHG observing systems, complementing TCCON and NDACC** (also for regional to global flux inversion using models)

Principles, prototype and performance of the LHR

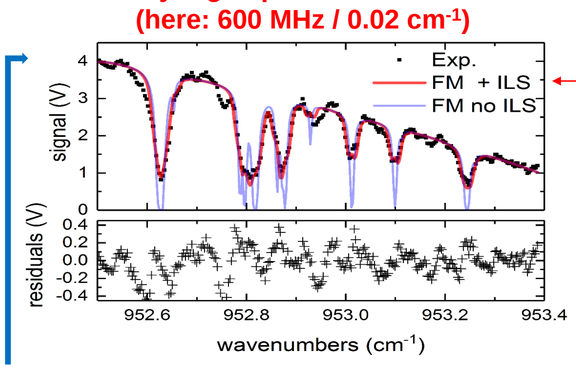


Simplified heterodyne mixing of planar waves, assuming that the beat frequency is within detector BW:

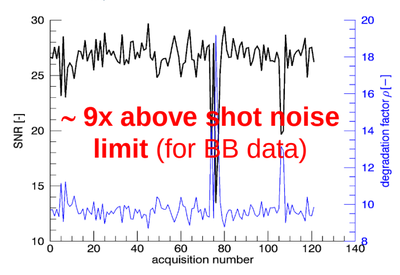
$$i_{ph}(t) = k \cdot \iint_D (E_S + E_{LO}) \cdot (E_S + E_{LO})^* \, ds = k \cdot \langle [E_S \cdot \cos(\omega_s \cdot t + \varphi) + E_{LO} \cdot \cos(\omega_{LO} \cdot t)]^2 \rangle_{\tau_d} = k \cdot \left[\frac{P_S + P_{LO}}{2} + \sqrt{P_S \cdot P_{LO}} \cos[(\omega_{LO} - \omega_S)t - \varphi] \right]$$



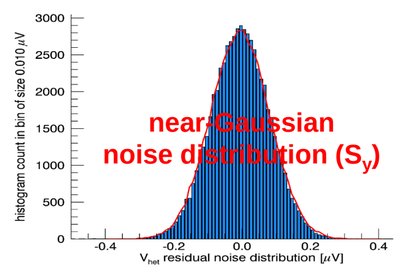
very high spectral resolution (here: 600 MHz / 0.02 cm^{-1})



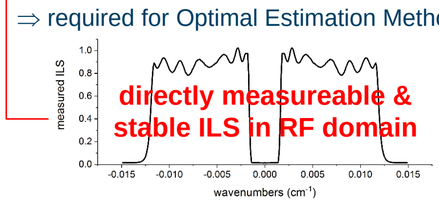
Initial characterization measurements with an IR source at $T_b \cong 1190$ K
(τ = 30 ms, t_{acq} = 30 s, 500 samples, DSBW = 600 MHz)



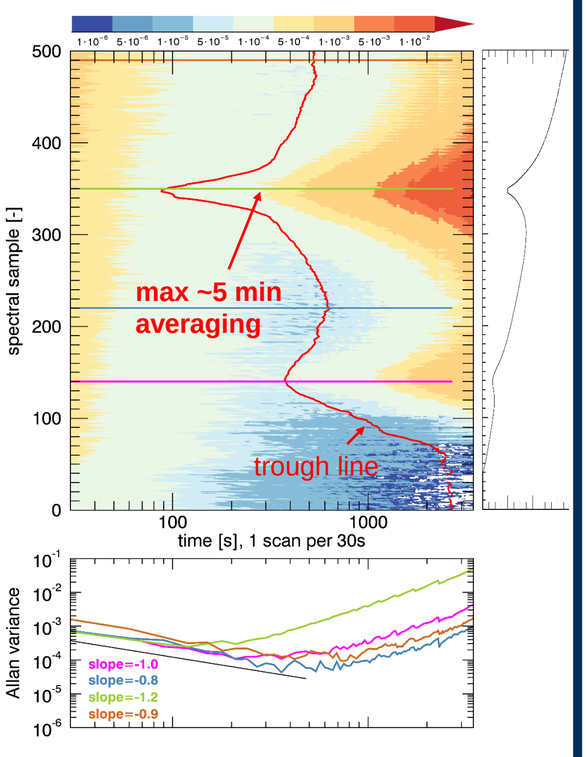
⇒ SNR_{pred} for Sun ~230, **SNR_{med} > 100**



⇒ required for Optimal Estimation Method

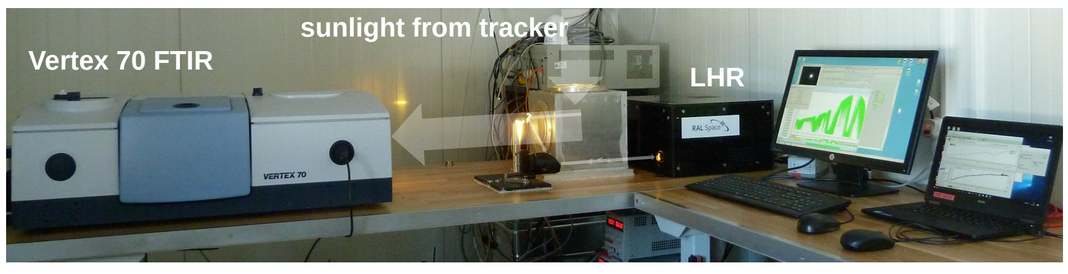


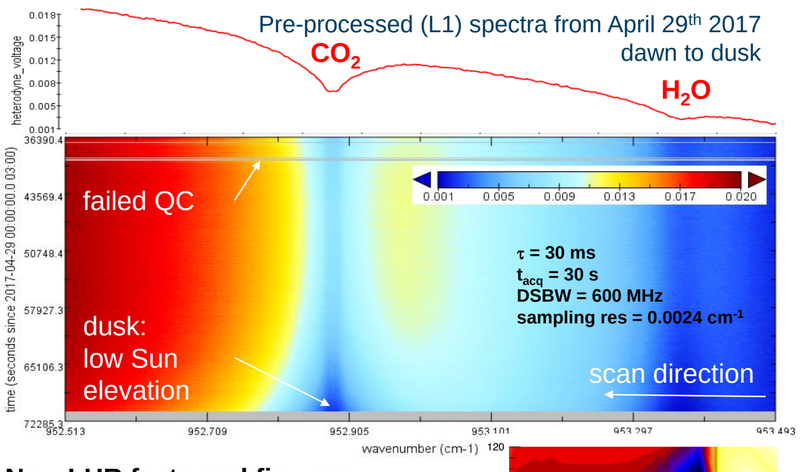
Allan variance computed over successive real atmospheric spectra
16:00-18:00 LT on 29th April 2017



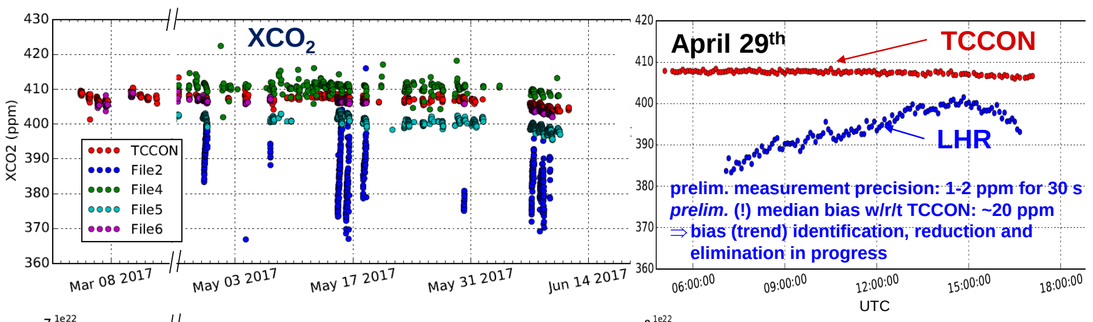
Gas pressure retrievals from pure C_2H_4 10-cm cell measurements with an IR source background yield 20.0 ± 0.22 mbar (20.08 ± 0.81 mbar over 81 1-min measurements), comparable to the expected pressure gauge reading of 20 mbar.

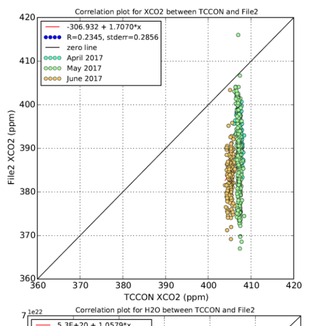
Deployment and initial results (solar absorption configuration)

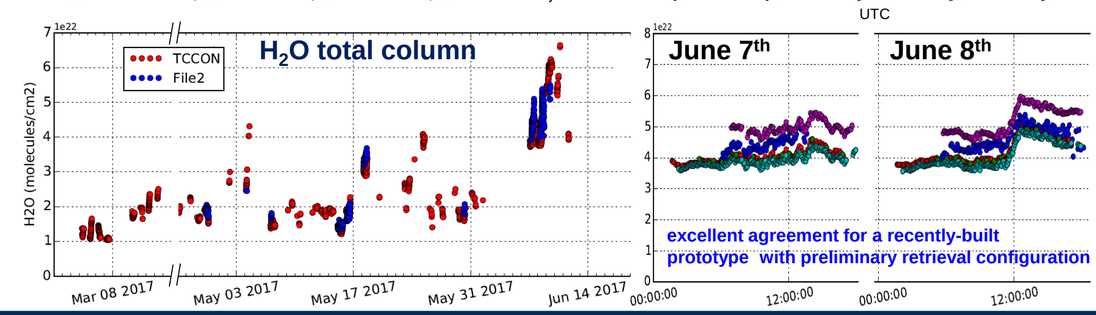


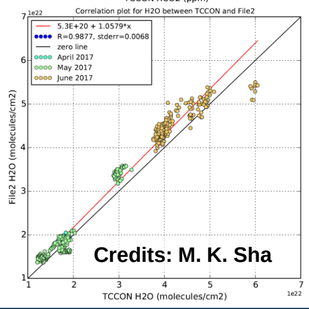


- LHR data retrieval (total column amounts and profiles) based on Optimal Estimation Method (Rodgers), using RFM (Dudhia, 1997) as a forward model, the HITRAN 2017 spectroscopic database, WACCM-based priors and NCEP data for p and T profiles
- Retrieval grid (6 levels for CO_2, 5 levels for H_2O) optimized following the cumulative trace method (using high-res averaging kernels)
- Preliminary results suggest ~5.3 total DFS for 3 baseline coefficients, CO_2 and H_2O combined



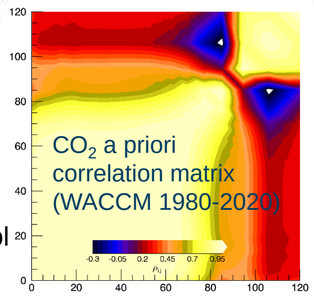






New LHR facts and figures:

- LHR h/w and s/w developed from scratch for FRM4GHG project
- user-friendly operator interface
- raw data output in netCDF
- full processing chain L0 → L1 → L2
- Sun camera for QC and tracker control
- 16k+ (10k+ valid) spectra since 29/04



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References:
FRM4GHG web site, and LHR for CO_2 prototype
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