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Demonstrating Multi-View Spectroscopy for Greenhouse Gas Remote Sensing

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Science & Technology Facilities Council
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Science & Technology Facilities Council
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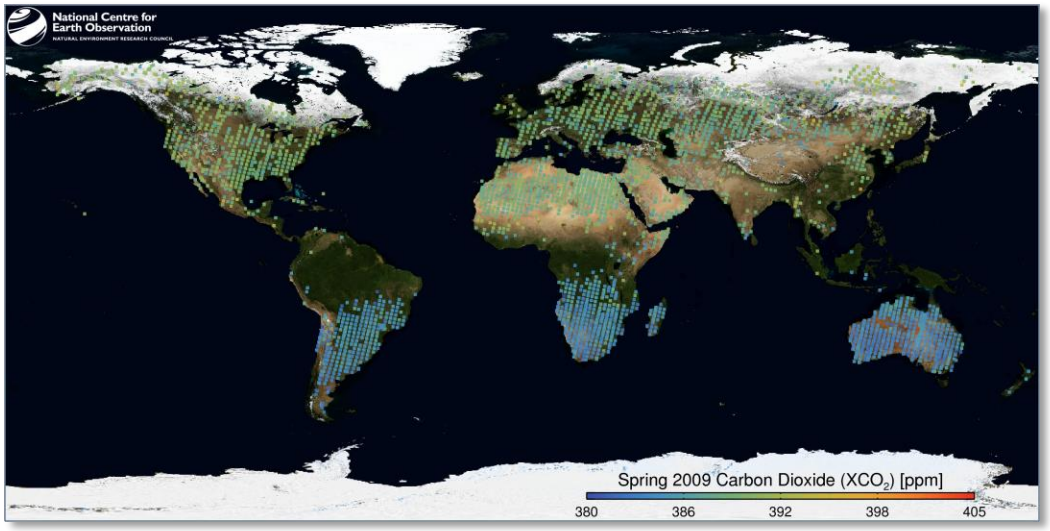
Space-Based Greenhouse Gases Measurements

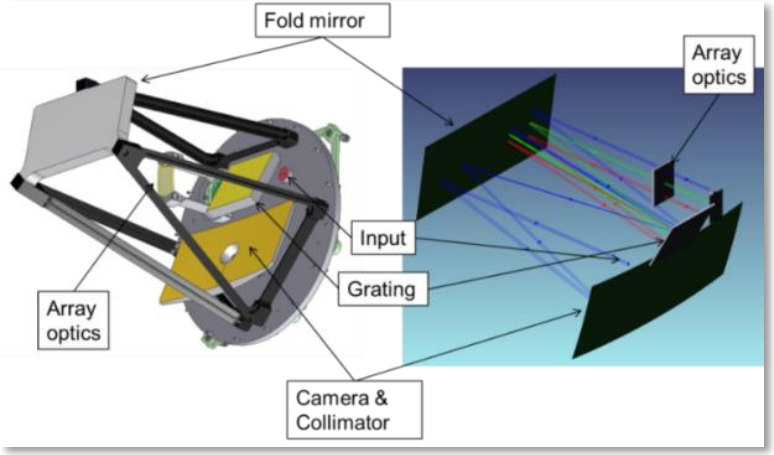
- Shortwave-infrared spectroscopy is key technology for space-based CO_2 and CH_4 measurements
- Series of pioneering LEO missions (GOSAT, OCO-2, TanSat)
- But, poor coverage and potential biases in Tropics due to clouds & aerosols leaves critical knowledge gaps



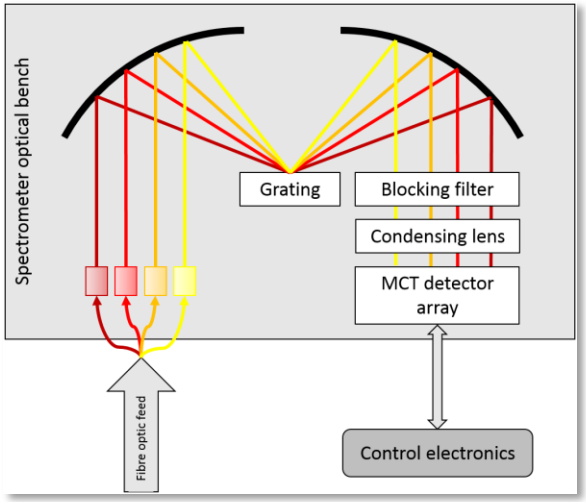
GHG-CCI esa Climate Change Service UNIVERSITY OF LEICESTER

GHOST – GreenHouse gas Observations of the Stratosphere and Troposphere

- GHOST is joint development by U. Leicester and Edinburgh and UK ATC (funded by NERC and STFC)
- GHOST is a unique shortwave infrared spectrometer for airborne platforms with 4 (5) spectral bands with CO_2, CH_4 and CO absorption
  - Reductions in size and weight by using technology originally developed for astronomy instruments
  - Main innovation: use of optical fibre feed system in combination with blocking filters and multiple grating orders to provide several bands with different wavelengths onto single detector (Virgo 2K MCT)



Humpage et al, SPIE, 2014



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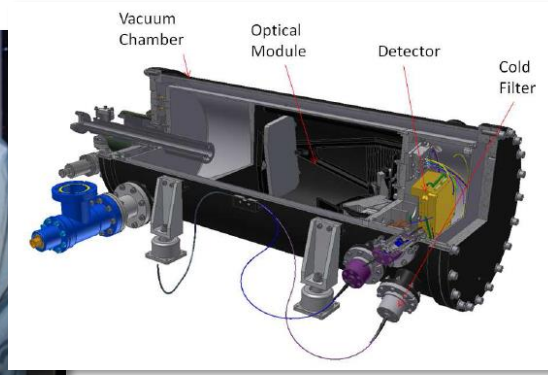
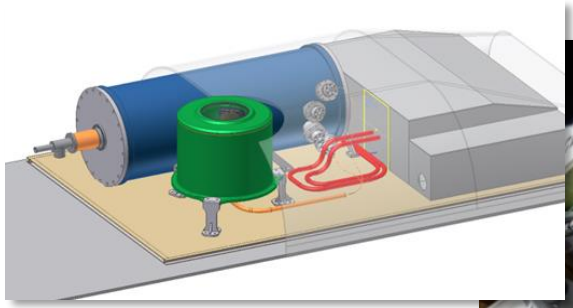
GHOST Concept

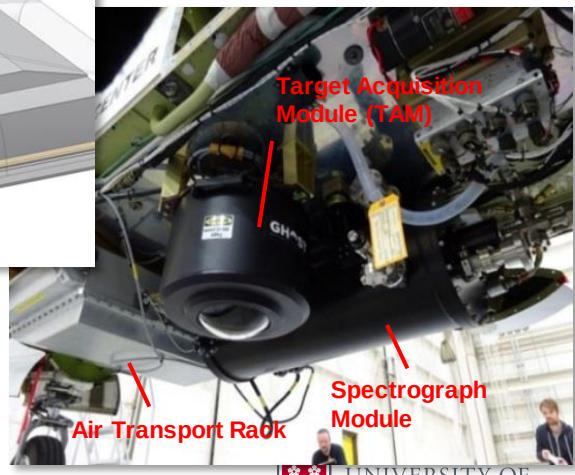
- Designed to meet engineering requirements for installation on NASA Global Hawk
  - Challenge: stable operation for ~20h flight for pressures and temperatures @20km

GHOST components:

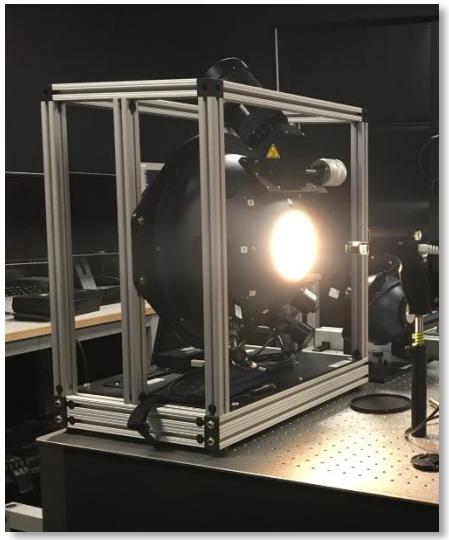
- Target Acquisition Module (TAM): active mirror-based pointing system to feed light into optical fibre bundle
- Spectrometer Module housed in LN2 cryostat to maintain detector temperature (98K) and reduce thermal background
- Air Transport Rack (ATR): pressurised enclosure that houses the electronics





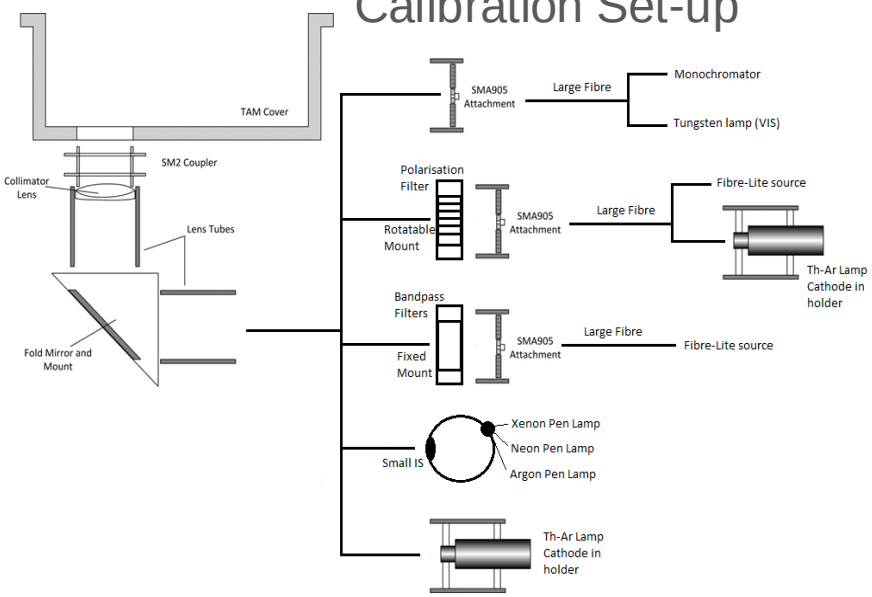


Calibration & Performance



NERC FSF Integrating Sphere

Calibration Set-up



Flats, Radiometric

Polarisation

Straylight

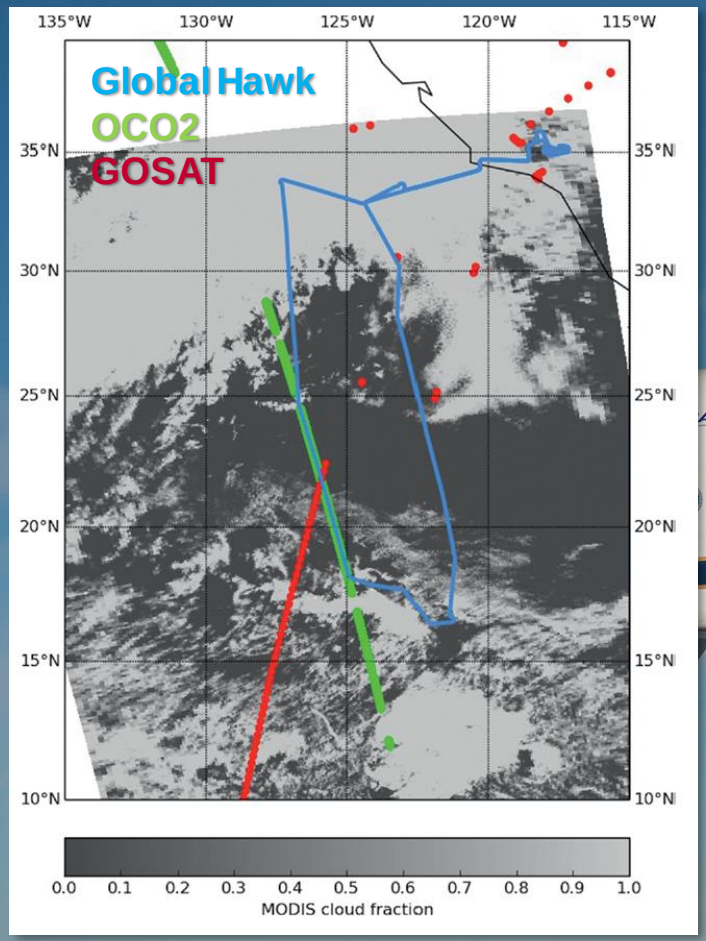
Spectral

Spectral

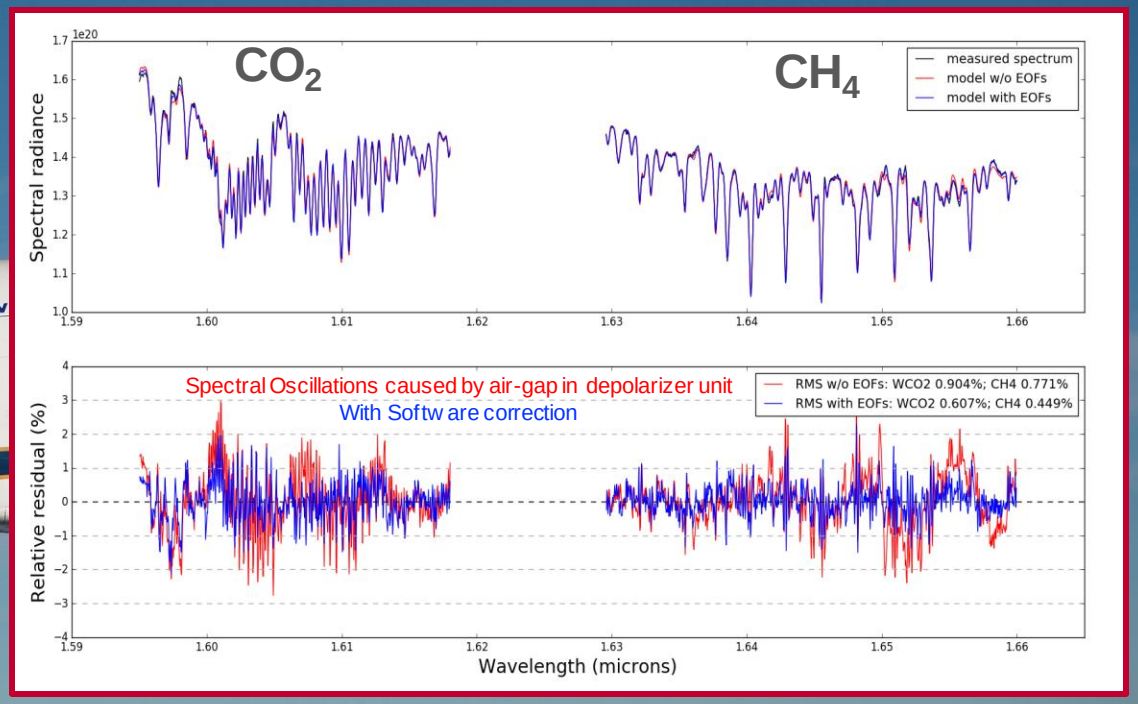
Band	Gases	Range (μm)	Resolution (nm)	Sampling	SNR (@Lref)
1	O_2	1.24 – 1.30	0.10 – 0.11	3.3 – 3.8	187
		1.25 - 1.29	0.1	3	150
2A	CO_2, CH_4, H_2O	1.59 – 1.67	0.23 – 0.24	6.0 – 6.5	428
		1.59 - 1.68	0.3	3	80
2B	CO_2, CH_4, H_2O	1.59 – 1.67	0.17 – 0.20	4.4 – 5.1	303
		1.59 - 1.68	0.3	3	80
3	CO_2, H_2O	1.99 - 2.09	0.25 – 0.26	5.2 – 5.4	286
		2.04 - 2.09	0.3	3	100
4	CH_4, CO, H_2O	2.27 - 2.38	0.26 – 0.28	4.8 – 5.1	203
		2.31 - 2.39	0.3	3	80

Performance Requirements

Soaring High with the Global Hawk: Flying New GHG Technology



Deployment over Pacific



Harris et al., BAMS, 2017; Humpage et al., AMT, 2017

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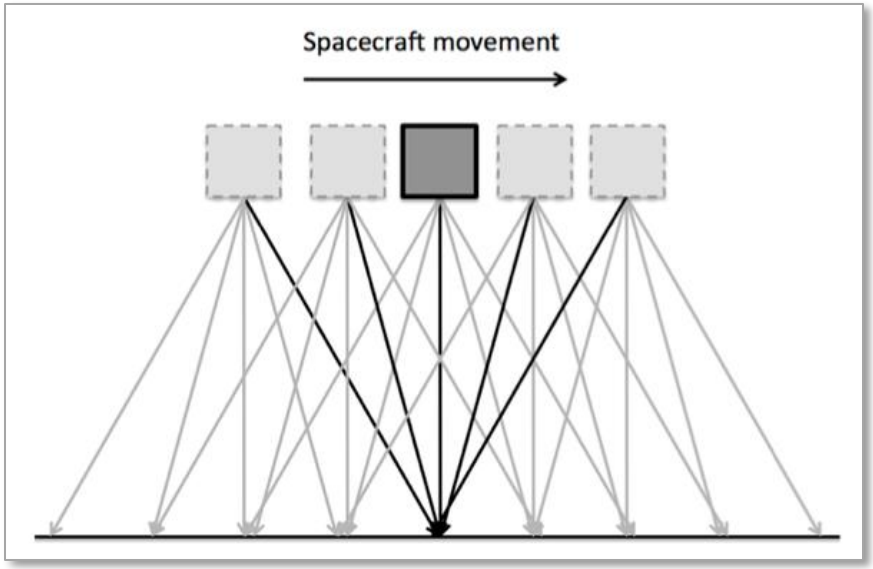
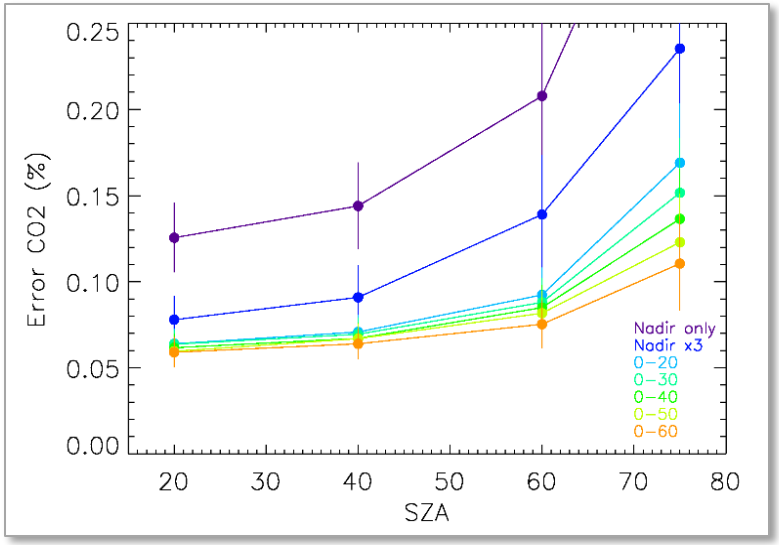
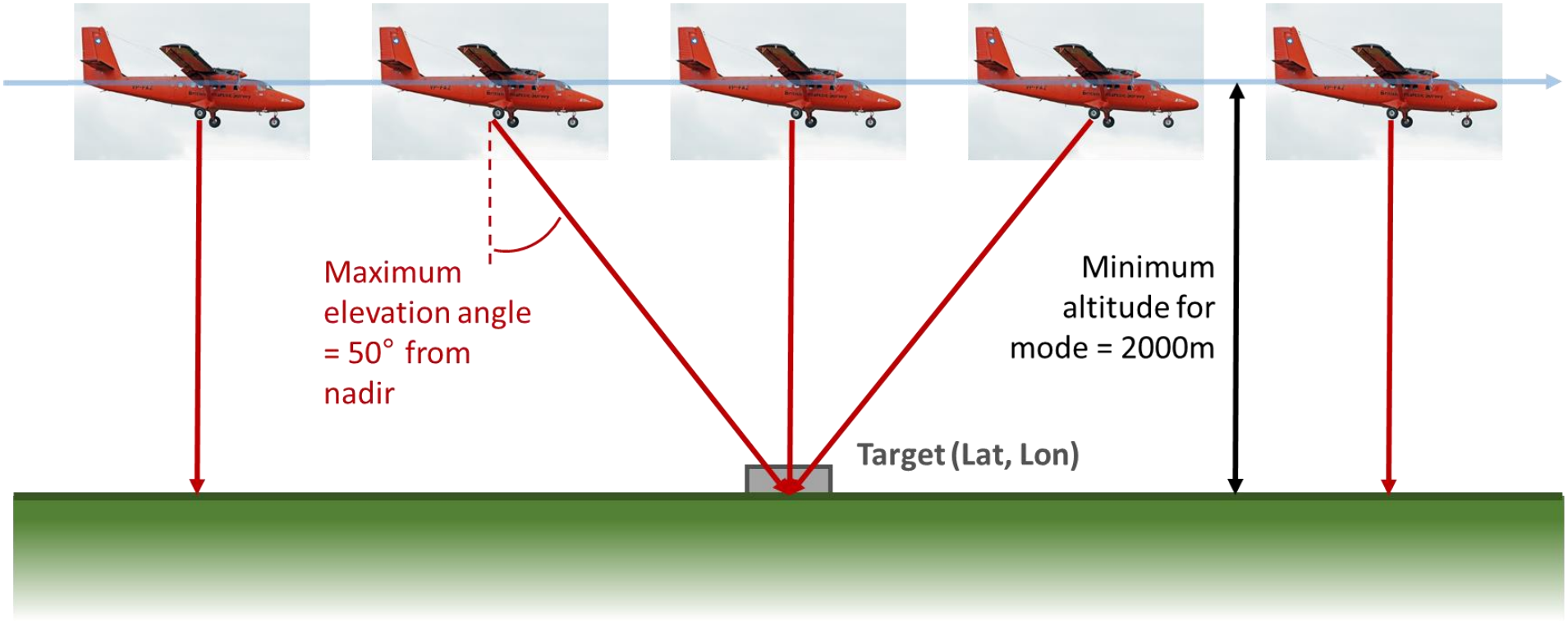
Motivation for Multi-view Spectroscopy

- Multi-view spectroscopy brings together approaches used for trace gas and aerosol retrievals
- Viewing same target from multiple angles allows for better characterisation of scattering effects e.g. from aerosols and cirrus
  - Improved CO_2 retrievals in presence of aerosols/clouds





Demonstrate Multi-view Observations from an Aircraft

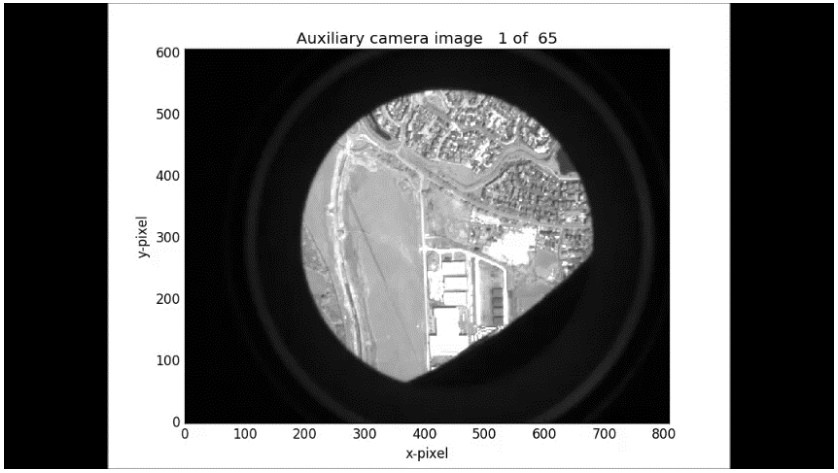


- When target co-ordinates are within the gimbal viewing geometry, gimbal continuously tracks the target
- Otherwise, gimbal reverts to nadir pointing

Instrument Installation

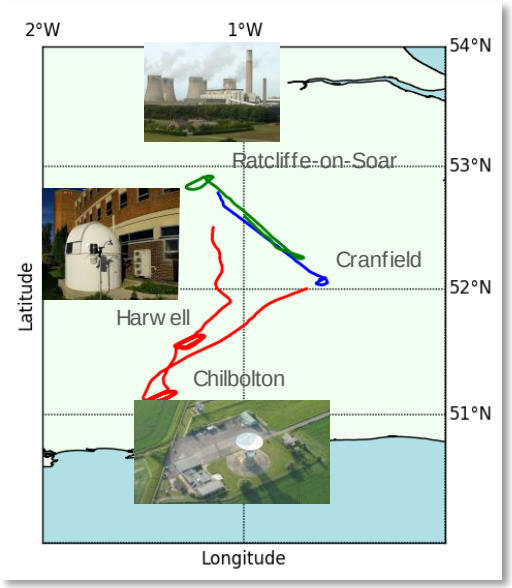
GHOST Installation on the BAS Twin Otter Aircraft in 17 May 2018

Test flight on 31 May: Functional test of target tracking



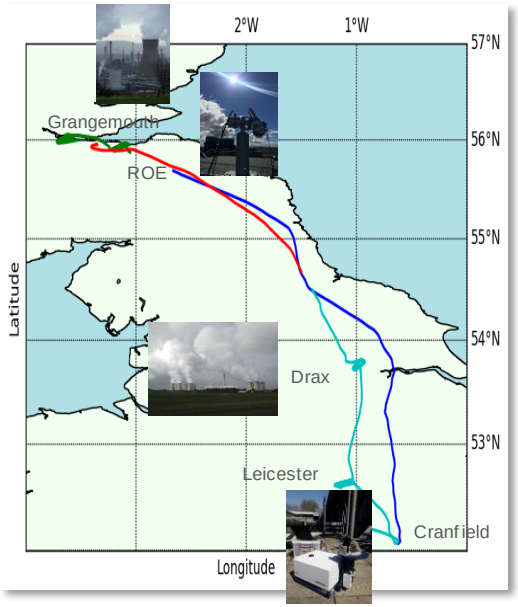
Cardington Hangars

Flight Campaigns



21st June 2018: Chilbolton, Harwell, Ratcliffe-on-Soar

- Chilbolton
  - Ceilometer, lidars for aerosol
  - Cimel sunphotometer for AOD
- Harwell/RAL
  - Bruker 125 FTS
- Ratcliffe-on-Soar
  - Power station
  - GPS failure



22nd June 2018: Edinburgh, Drax, Leicester

- Royal Observatory, Edinburgh
  - Laser heterodyne radiometers
- Grangemouth
  - Crude oil refinery
- Drax
  - Power station
- Leicester:
  - Portable FTS

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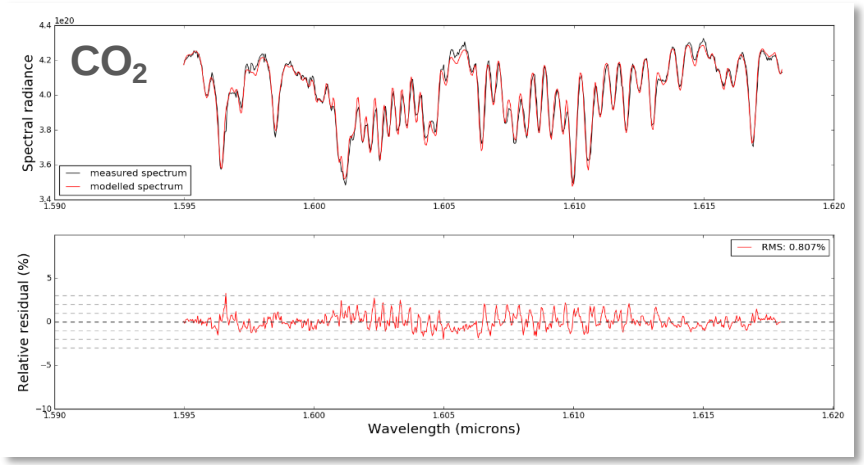
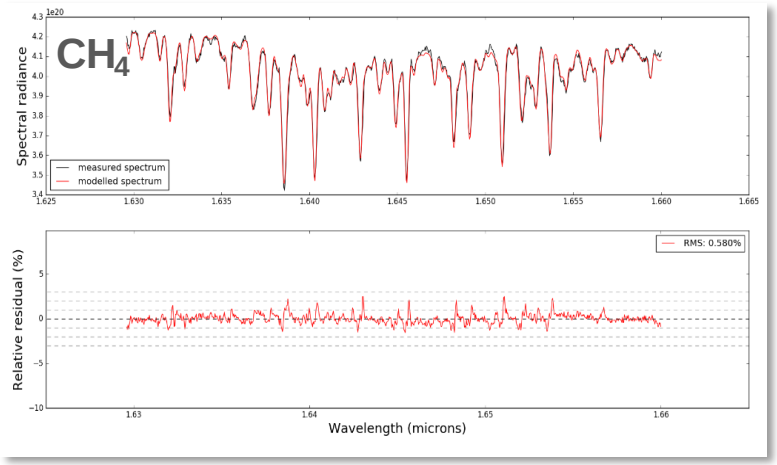
Flight Data Analysis

- **Flight 1:**
  - 6,500 spectra during 4.5 h flight
  - Target tracking over Harwell and Chilbolton covering +/- 45 degrees
- **Flight 2:**
  - 15,000 spectra during 7h flight
  - Target tracking over Royal Observatory, Grangemouth Refinery, Leicester covering +/- 45 degrees
- **Spectral Analysis looks good but is still ongoing**





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Tropical Carbon Mission (TCM)

Quantifying tropical carbon fluxes from space using high-resolution, multi-view SWIR spectroscopy and aerosol retrievals

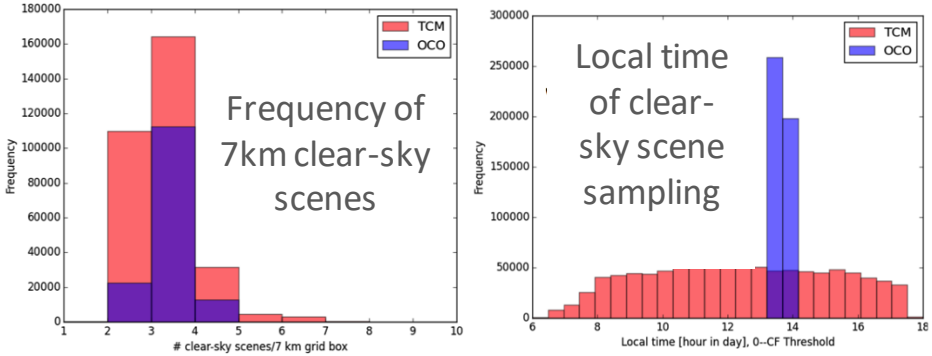
Primary mission objective: reduce uncertainties in the magnitude and distribution of tropical CO_2 fluxes to determine the sign and magnitude of the net carbon balance of the tropics every four weeks.

Secondary science objectives: a) reduce the uncertainties CO and CH_4 fluxes, and b) improve source attribution of observed variations in atmospheric CO_2.

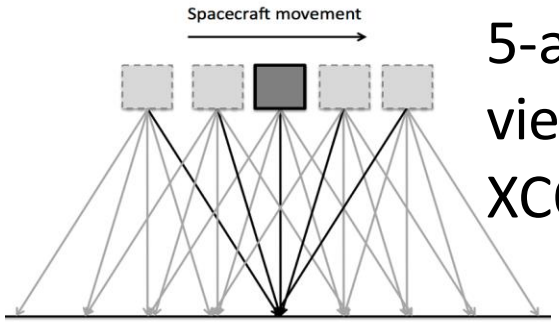
Complements CO_2 measurements from LEO instruments by improving their ability to infer extra-tropical fluxes.

A 35° inclination orbit achieves necessary sampling

Using unique NASA global 7km CO_2 simulation (self-consistent analysis of cloud, aerosol, CO_2) :



TCM: more clear-sky data with less gaps than OCO-2 and no temporal bias: more robust CO_2 fluxes

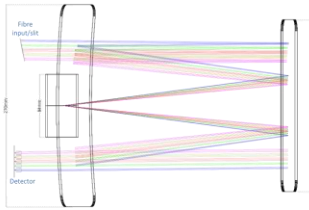


5-angle multi-view improve XCO2 retrieval

Increases # clear-sky observations (super-obs) and reduces measurement gaps. Optimize XCO2 information content.

Innovative instrument design

Merging astronomy and EO designs.



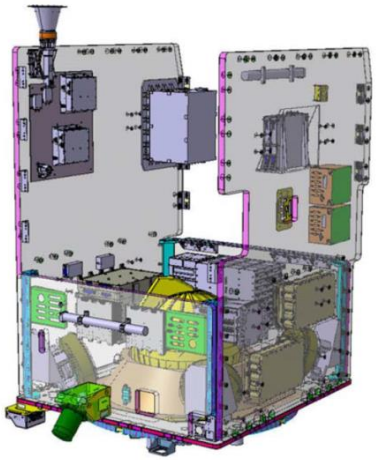
GHOST

High TRL through heritage

SWIR spectrometer (GHOST), aerosol imager (MISR, POLDER, (A)ATSR), cloud imager.

Design fits available bus platforms

Power, size, mass fit within available launch vehicles.



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Summary

- GHOST is a novel GHG spectrometer developed in the UK using innovative shortwave-infrared technology
- GHOST has been designed and deployed on NASA Global Hawk
- Successful conducted two aircraft deployments of GHOST in the UK to with target tracking to demonstrate multi-view spectroscopy
- GHOST serves as airborne technology demonstrator for the Tropical Carbon Mission TCM concept