The Tropical Carbon Mission (TCM)

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

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The State of the Global Carbon Budget

34.1 $GtCO_2$/yr

91%

9%

3.5 $GtCO_2$/yr

Sources = Sinks

16.4 $GtCO_2$/yr

44%

31%

11.6 $GtCO_2$/yr

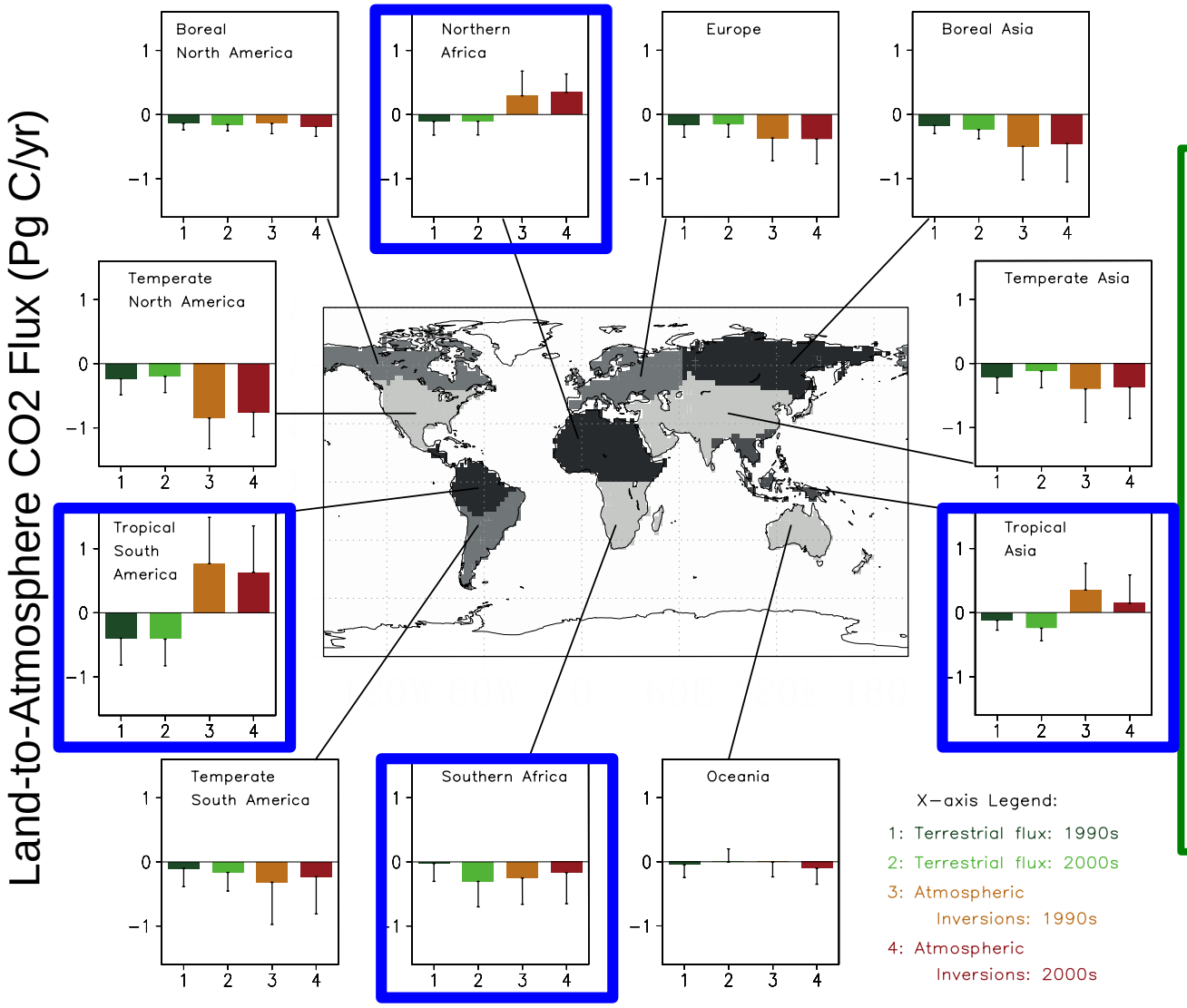
26%

9.7 $GtCO_2$/yr

Calculated as the residual of all other flux components

Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2016; Global Carbon Budget 2016

TCM will address fundamental gaps in our scientific understanding of the tropical C cycle



Decadal average CO_2 fluxes for 11 land regions as estimated by:

- 10 different atmospheric CO_2 inversions for the 1990s (yellow) and 2000s (red) and
- 10 dynamic vegetation models (DGVMs) for the 1990s (green) and 2000s (light green)

IPCC, 2013

TCM Mission Objectives

The primary mission objective of TCM is to **reduce the overall uncertainties in the magnitude and distribution of tropical CO_2 fluxes** such that we can determine with certainty in any particular four-week period the sign and magnitude of the net carbon balance of the tropics.

The secondary science objectives of TCM are to: i) **reduce the uncertainties in the magnitude and distribution of CO and CH_4 fluxes**; and ii) **improve source attribution of observed variations in atmospheric CO_2** by using concurrent measurements of CO and CH_4.

TCM will complement future global survey CO_2 measurements from low-Earth orbiting instruments by improving their ability to infer extra-tropical fluxes.

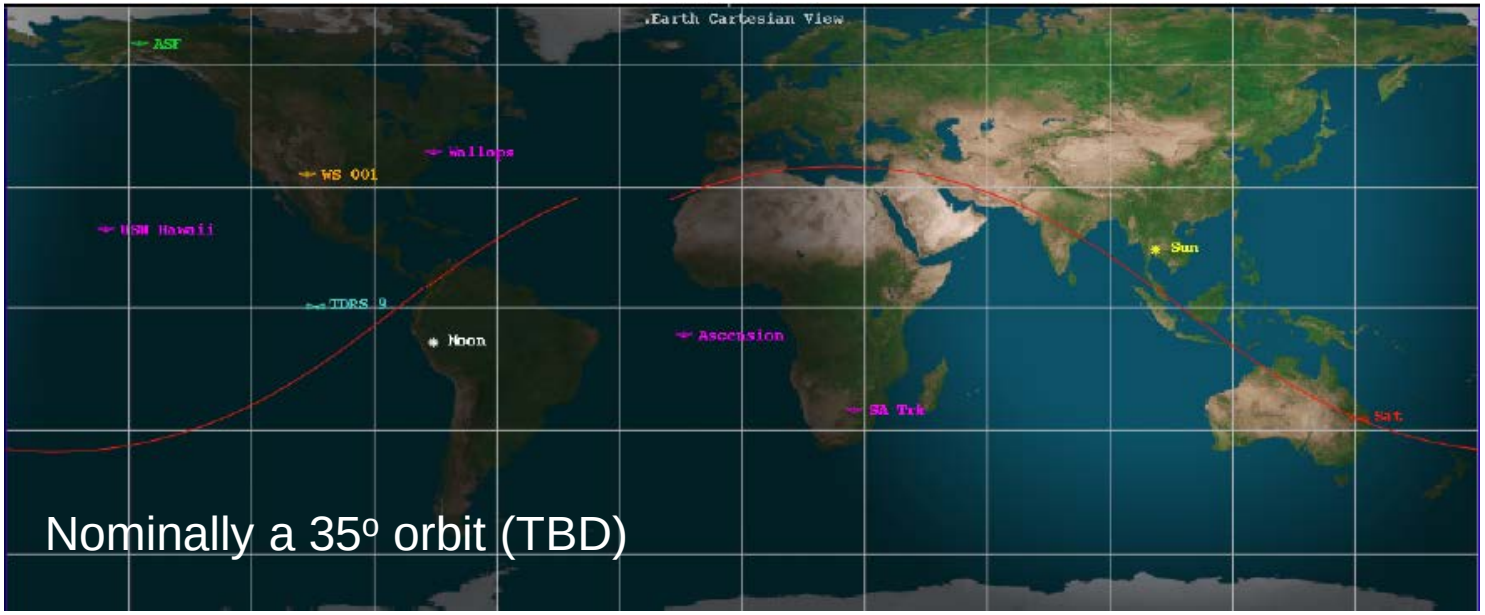
TCM Instruments: high TRL through Heritage

TCM comprises 3 instruments developed from current technology:

1) a short-wave IR (**SWIR**) **multi-view** spectrometer that will measure **CO_2**, **CH_4**, **CO**, and **O_2**;
2) a co-boresighted aerosol imager; and
3) a wide-view cloud imager [optional]

- The SWIR spectrometer is based on the UK GHOST instrument
- The aerosol imager will improve the characterization of atmospheric aerosols and cirrus clouds prevalent over tropical latitudes. It builds on technology and techniques developed for MISR, POLDER and (A)ATSR.
- A cloud imager may be used to help intelligent pointing and post-processing of data

A low-inclination orbit achieves necessary sampling

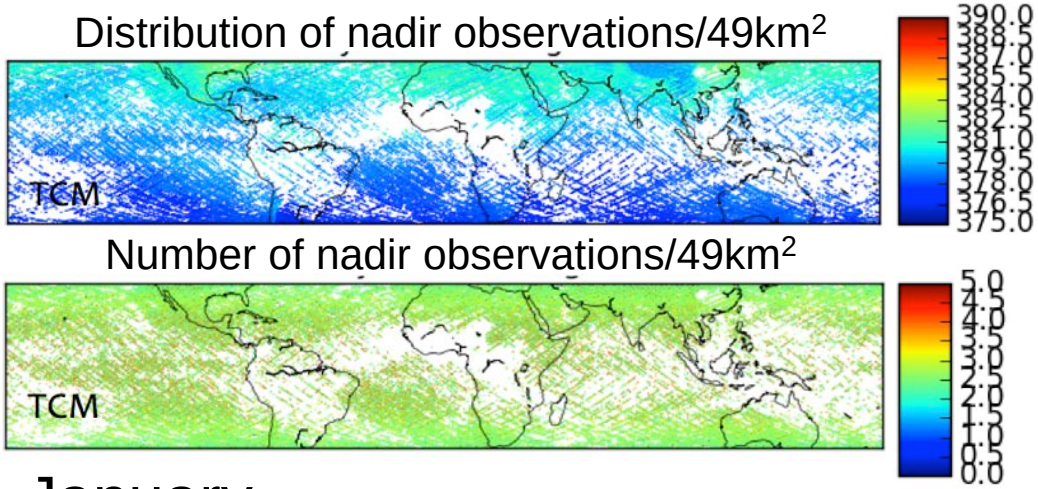


Nominally a 35º orbit (TBD)

JPL TeamX and STFC CDF studies

In one month TCM will provide ~7 million clear-sky measurements w/out temporal sampling bias

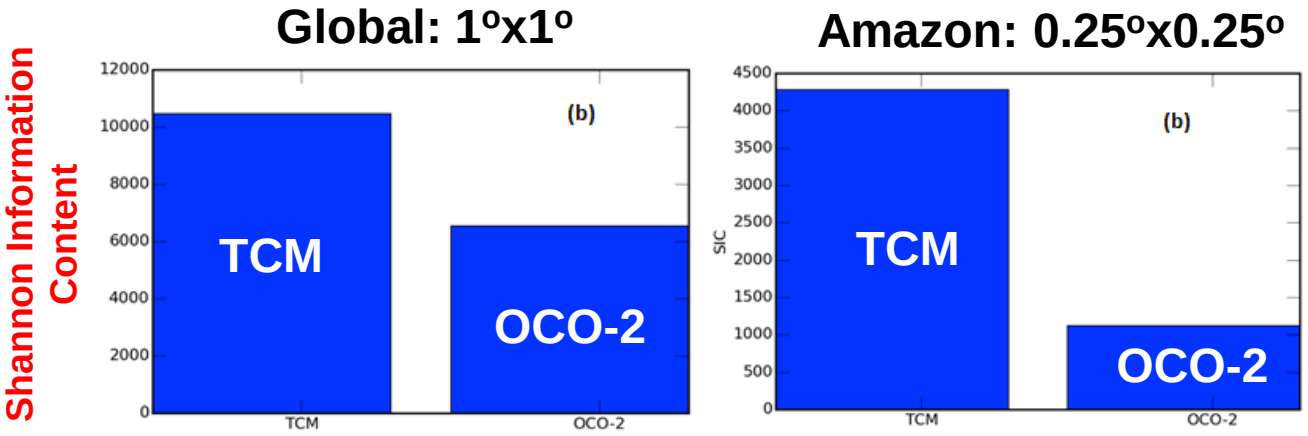
Result: flux estimates on spatial scales close to regional aircraft



January

The Role of Orbital Precession on Reconstructing Distribution of Atmospheric CO_2

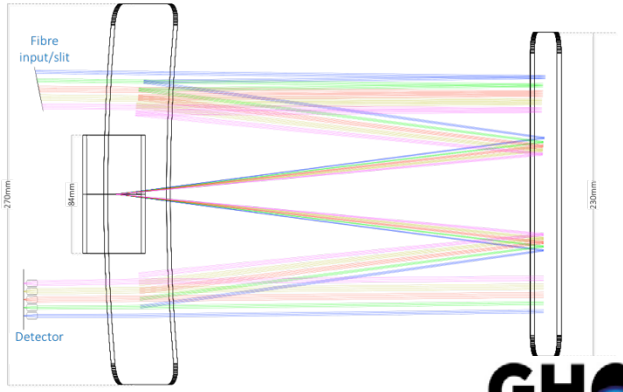
- To assess the observational constraint from TCM, we calculate the Shannon information content of simulated observations
- TCM observations:
  - On a 1° grid: TCM has 60% more information than polar orbiters like OCO-2
  - On a 0.25° grid: TCM has >x3 information than OCO-2 over South America
- Dense coverage of TCM will largely increase our ability to observe CO_2 variations in Tropics and hence provide much improved constraint on tropical fluxes



TCM innovates on established mission concepts

Innovative instrument design

Minimize moving parts, size, mass while maximizing S/N: one grating and two detectors, Merging astronomy and EO designs.



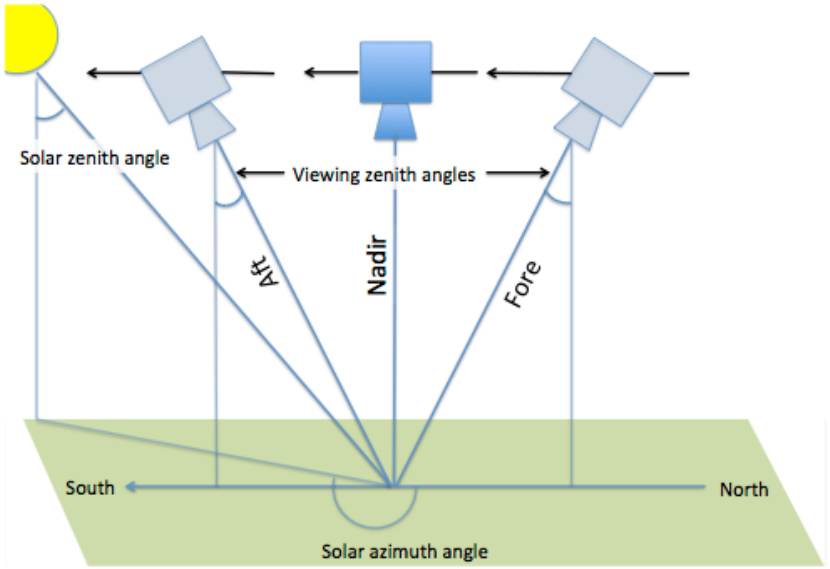
GHOST

Orbital configuration

low-inclination orbit focused on tropical latitudes.

Observing strategy

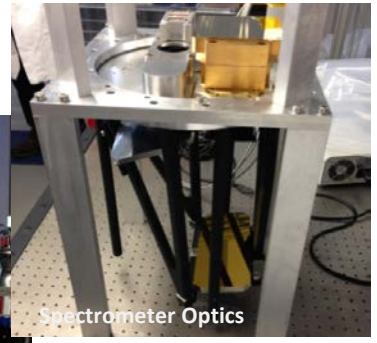
using (SWIR and aerosol) multi-view angles to better characterize aerosol that currently represent the #1 uncertainty in XCO2 retrievals. viewing angles offsets from nadir.

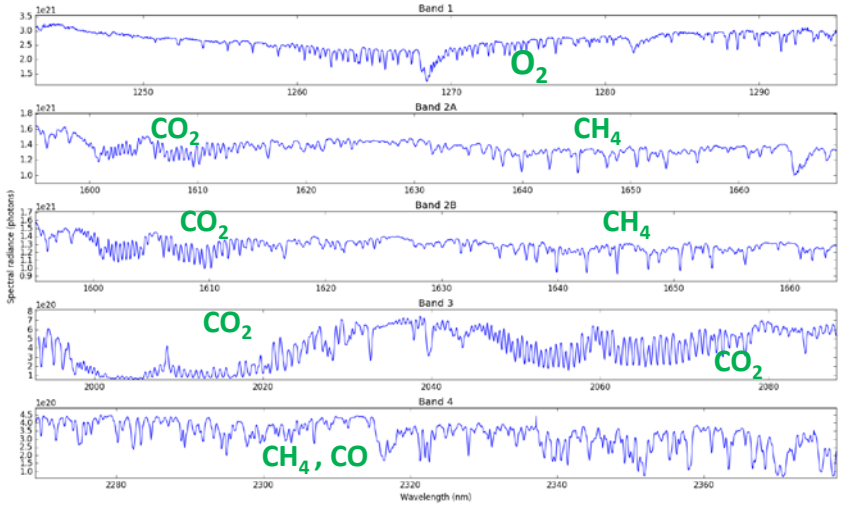


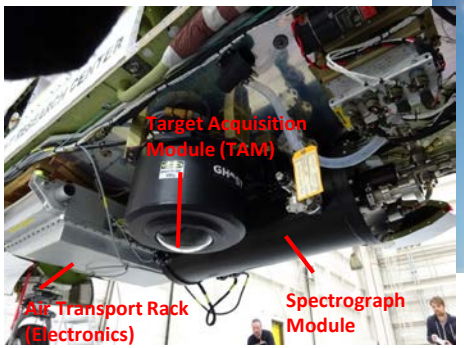
Frankenberg et al, 2012

Innovative Instrument Design - GHOST

- GHOST is a novel SWIR spectrometer designed to simultaneously measure columns of carbon gases CO_2, CH_4 and CO from the high-altitude platform Global Hawk
- GHOST uses a innovate optical design to acquire 4 spectral bands with a single detector and grating
- GHOST has been successfully operated on Global Hawk over the Pacific Ocean (March 2015) and deployed on NERC ARSF Dornier 228 aircraft over UK targets (CEOI BCM project)







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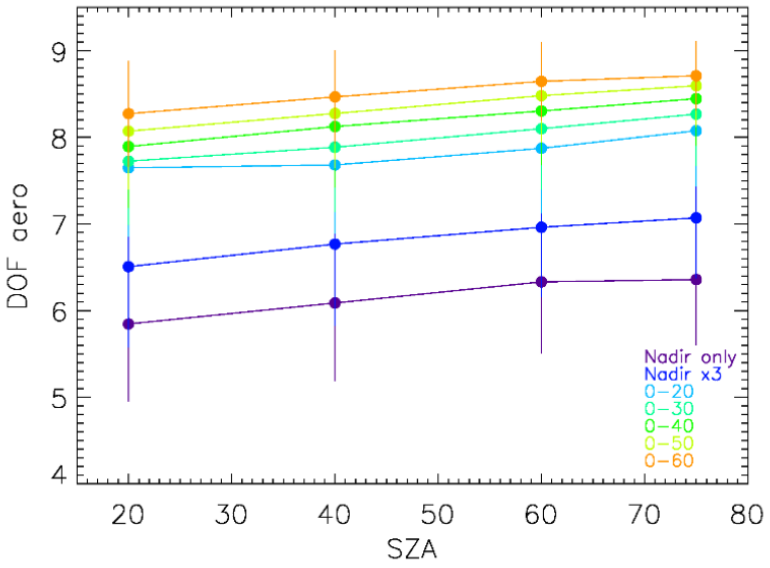
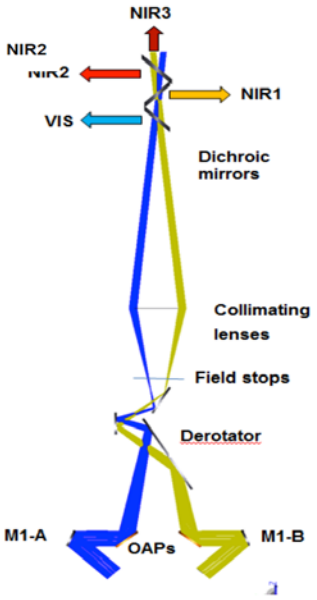
GHOST

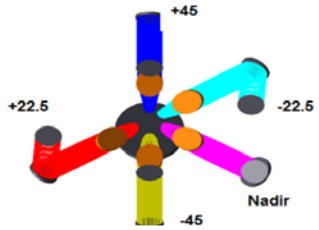
Multi-View Observations

- Multi-view spectroscopy combines the approach for aerosol retrieval with SWIR CO_2 retrievals
  - Increased aerosol information for more accurate CO_2 retrievals
- New design for a front-end optics providing multi-views along and across track by front wheel rotating plus de-rotator both rotating about nadir
- Along track: multiple observing angles of same ground pixel for removal of aerosol affects
- Across track: spatial coverage/swath

Degrees of Freedom for aerosols for system with 3 viewing angle





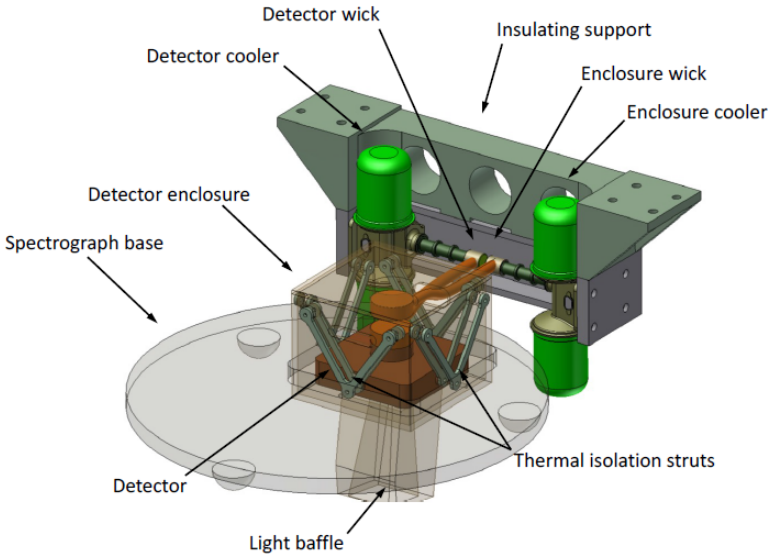


Optical layout overview of front-end optics

Detector Assembly and Cooling

- To meet the required signal-to-noise and dark current, the detector needs cooling to 110 K
- Two-stage cooling system, with an independently-cooled detector enclosure and light baffle that reduces the radiative heat transfer to the array
- Baseline is a state-of-the-art small scale Stirling cycle developed by RAL Technology Department

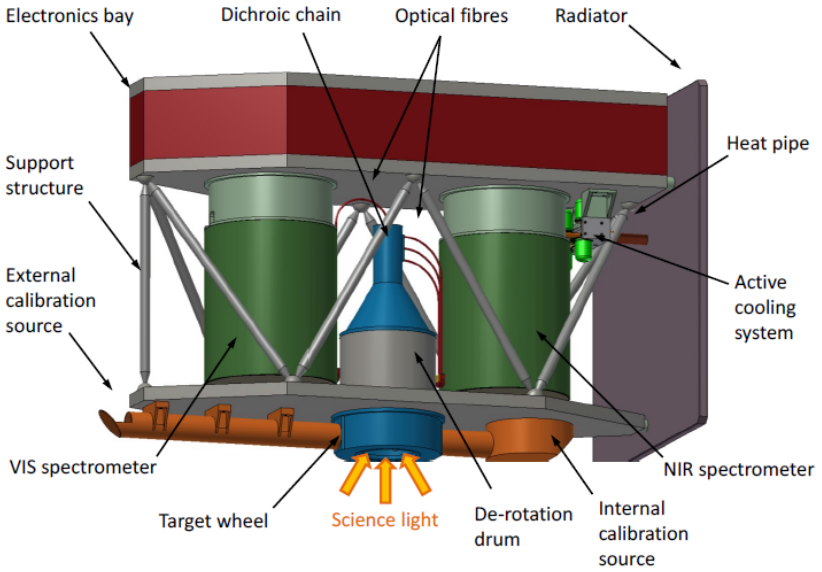
Detector enclosure assembly with active cooling

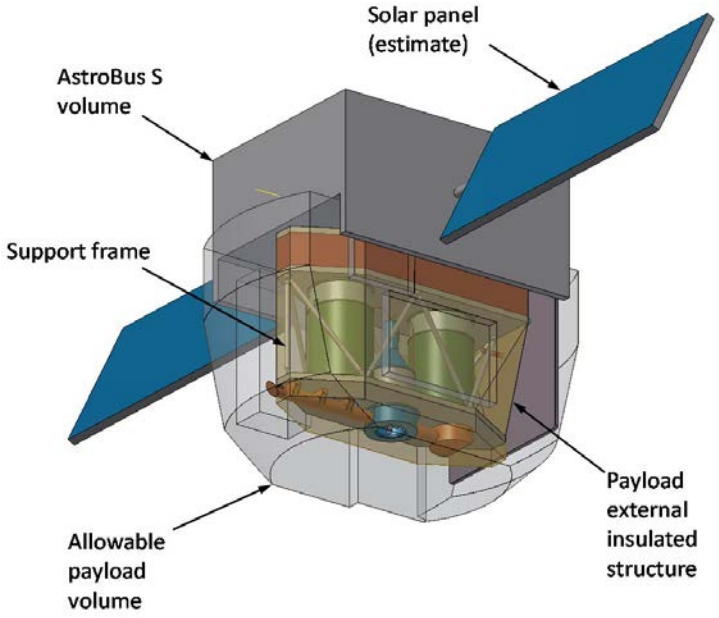


RAL small scale cooler

Mission design

- Instrument design is consistent with small off-the-shelf platform Astrobus S
- Mass and volume consistent with VEGA C launcher
- Inclined orbit leads to variable illumination conditions on fixed solar panel with only 40% of capability in average. SADM is recommended to increase science imaging time
- Larger power conditioning and distribution unit (PCDU) also recommended to achieve maximum imaging time
- Two ground stations over the tropics: data transfer 1.6-2.0 Tbit/day assuming single pole medium-gain antenna (MGA)





Summary

Centre for EO Instrumentation

- The Tropical Carbon Mission TCM is a new science-driven mission concept aimed reducing the uncertainties of the magnitude and distribution of tropical CO_2 fluxes
- The development of the TCM mission concept has been supported by a CEOI EE9 preparation study
- A CEOI project of the 10th call will allow us to demonstration of the multi-view concept (a key selling point of TCM) with airborne demonstration using GHOST
- The main opportunities for TCM will be ESA EE10 and/or bilateral opportunities with countries in tropics