The Compact Infrared Imager and Radiometer (CIIR)

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CIIR Consortium

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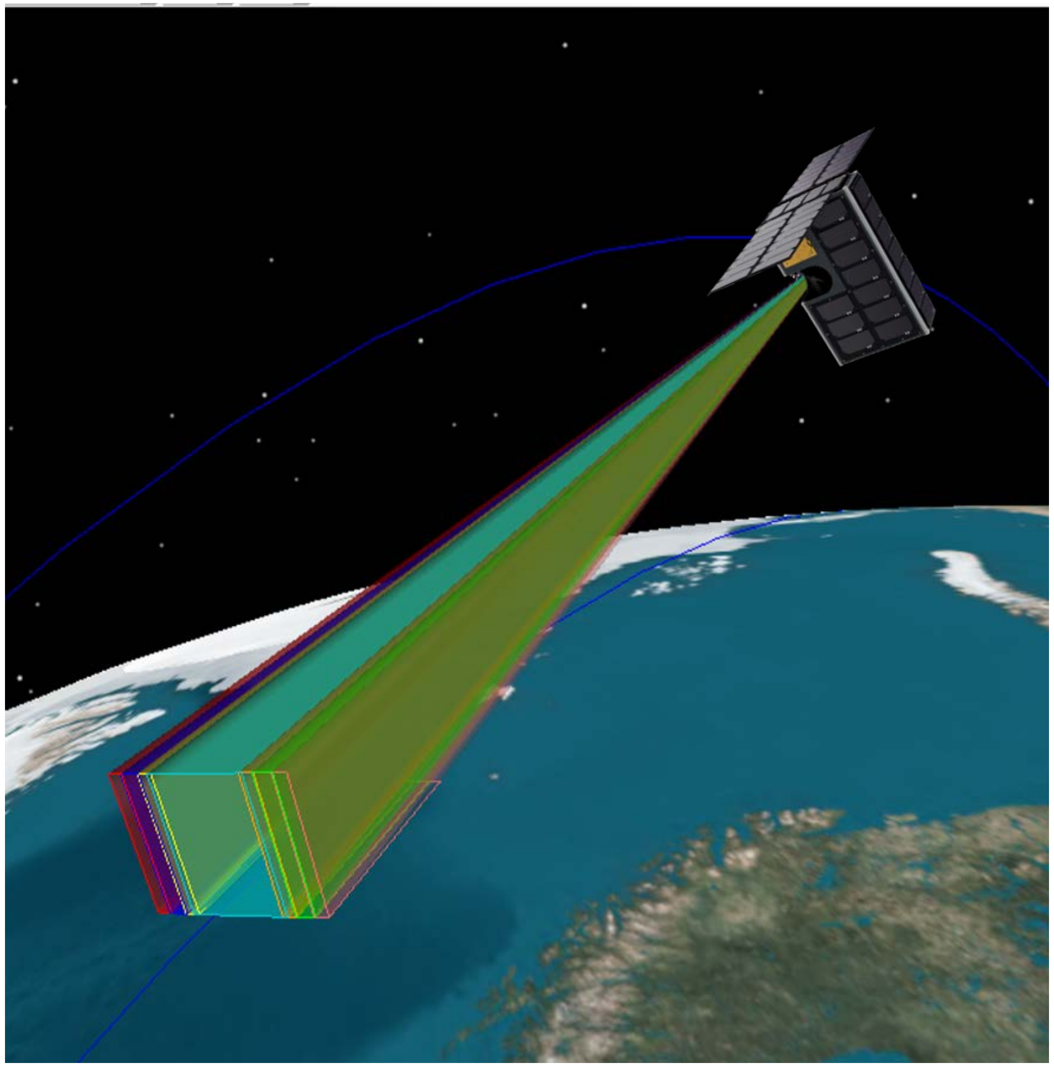
CubeSat concept

- Development of the previously flown Compact Modular Sounder (CMS)
- Nadir and limb viewing infrared filter radiometer
- Tightly integrated into a 6U CubeSat spacecraft
- Earth observation from Sun synchronous orbit
- Small constellations enable frequent global observation
- Aim to provide calibrated data on hour to year timescales

- CIIR is designed to fit niches in EO where:
  - High temporal resolution is required
  - There are gaps in data between major missions (e.g. limb sounding)
  - Fast development turn around is required



Science goals

Baseline goals: "To study the effects of aerosols, clouds, and the behaviour of stratospheric water vapour on the Earth's radiation budget."

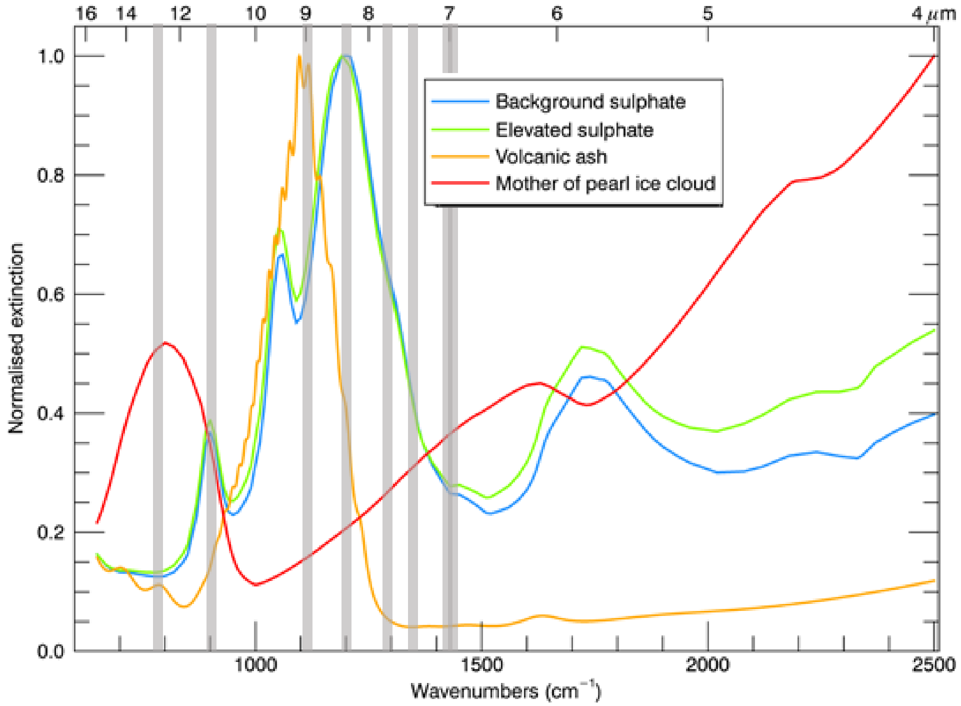
Two example atmospheric science targets

i. Volcanic Debris

- Injection of volcanic ash into the stratosphere and troposphere influences the Earth's radiation balance by interacting with both solar and thermal radiation
- Identification of volcanic ash for hazard avoidance
- Full and detailed characterization of volcanic ash properties to help understand volcanic processes

ii. Water vapour abundance

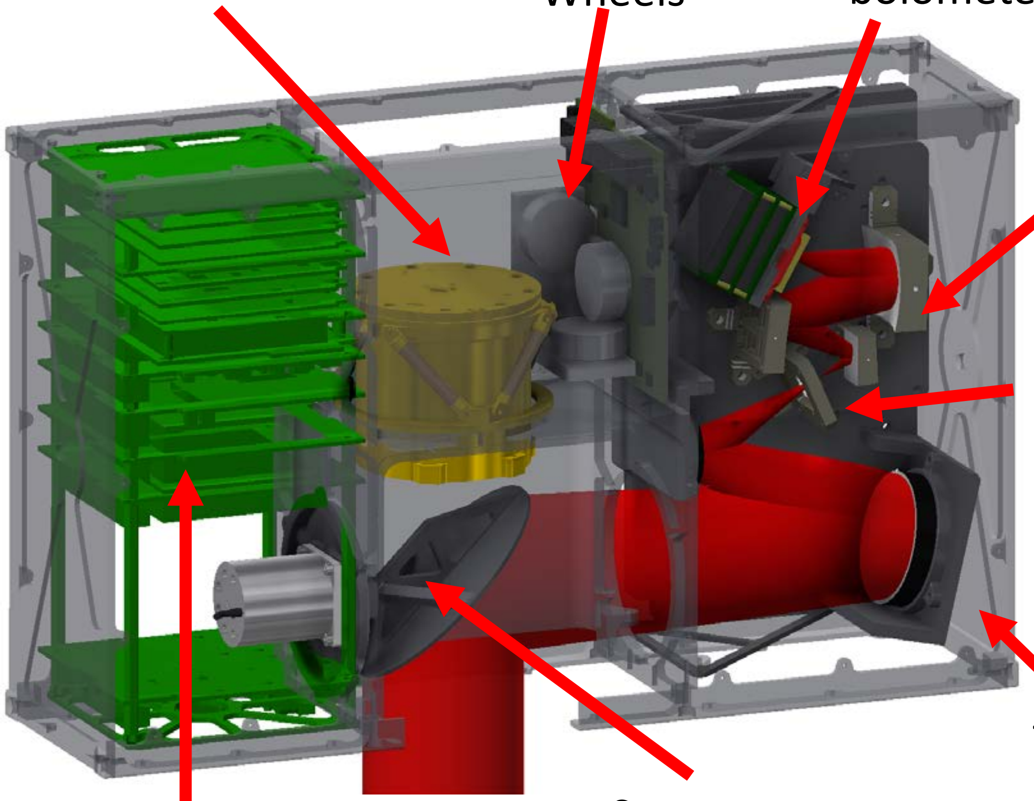
- Stratospheric vapour acts as a greenhouse gas
- Global calibrated measurements are needed to reduce uncertainty in climate models



Targeted bands on CIIR will distinguish different atmospheric aerosol species

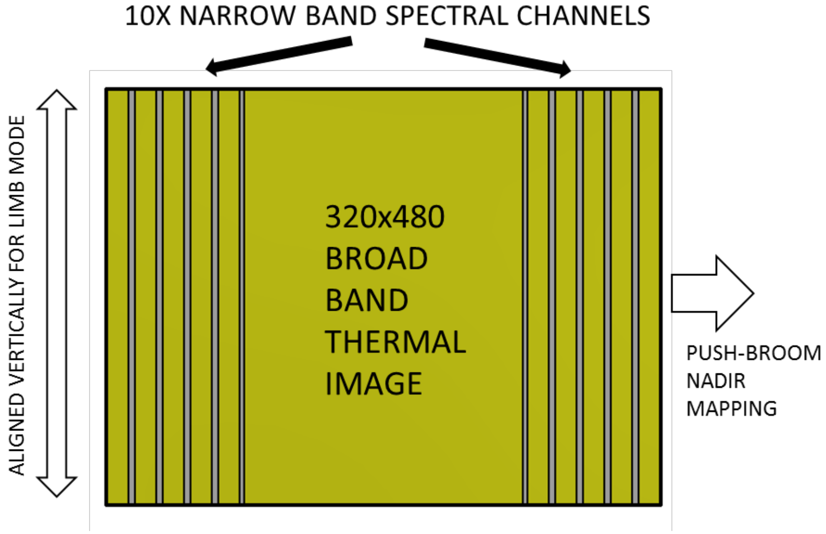
Instrument concept

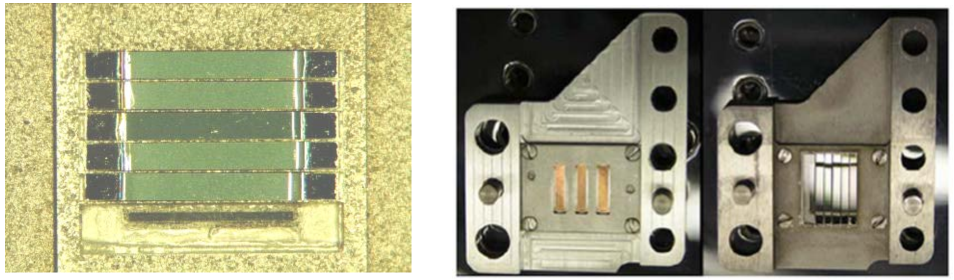
- Miniature multi-channel filter radiometer supported by standard CubeSat avionics
- Design driven by need for accurate radiometric calibration prompting integrated black body
- Novel intermediate focal plane separates filter array from the detector, reducing instrument noise and frequency of calibration
- All reflective design allows wide wavelength coverage, increasing instrument versatility
- Detector is uncooled, avoiding larger and power hungry cooling technology required by other IR technology



Filters and detector array

- Magnification using relay optics allows larger numbers of filters to be used (10-20)
- Filters are arranged for pushbroom spectral mapping and broadband imaging modes
- Interference filters custom made by Reading University, heritage from HIRDLS, MCS, Diviner
- An uncooled microbolometer provides moderate resolution, wavelength coverage and detectivity whilst meeting CubeSat requirements
  - ULIS 640x480 array, 17µm pitch, 7.5 to 15 µm response (also has response > 15µm if un-windowed)
- Baseline optical design provides 0.18 mrad pixel field of view. At 800km altitude, resolutions of 0.6km at the limb and 0.15km on the surface
- On board averaging is used to reduce data volume and increase signal to noise performance, at the expense of resolution





Reading supplied filters, MCS filter frames

Phase-A study

The Centre for Earth Observation Instrumentation (CEOI) funded a mission design report to assess the capability of the CubeSat to perform remote sensing measurements normally made from larger conventional platforms. Principal results were:

- Nadir viewing at moderate spatial resolution (~150 m) is achievable in the thermal-IR.
- Aerosol measurements meet the target accuracy with existing CubeSat hardware.
- A 0.5K temperature accuracy is achievable. Spacecraft pointing jitter over 10 second integration time dominatesthe error.
- Water vapour measurements with resolution of < 900km are not possible due to the jitter noise introduced by CubeSat pointing stability.

Target accuracies were taken from the "ESA, PREMIER - Report for Mission Selection" (2012) and, for aerosols, from the 2013 IPCC report.

Instrument test bench

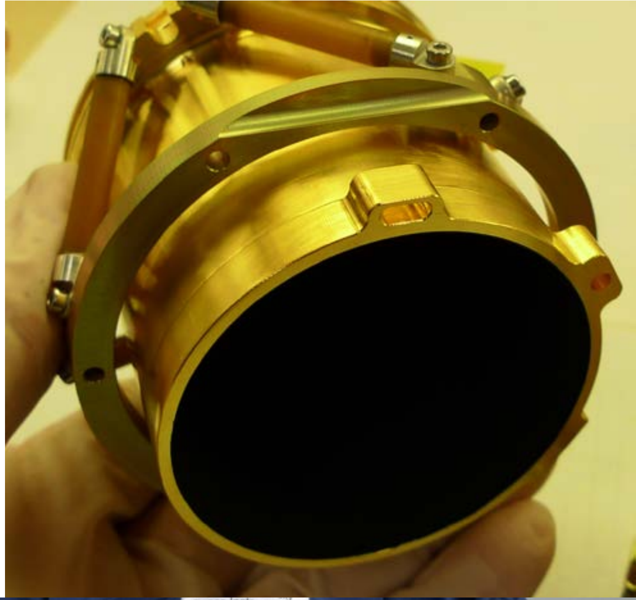
Currently being built and tested under a CEOI grant to investigate the instrument calibration and pointing performance following the mission design report.

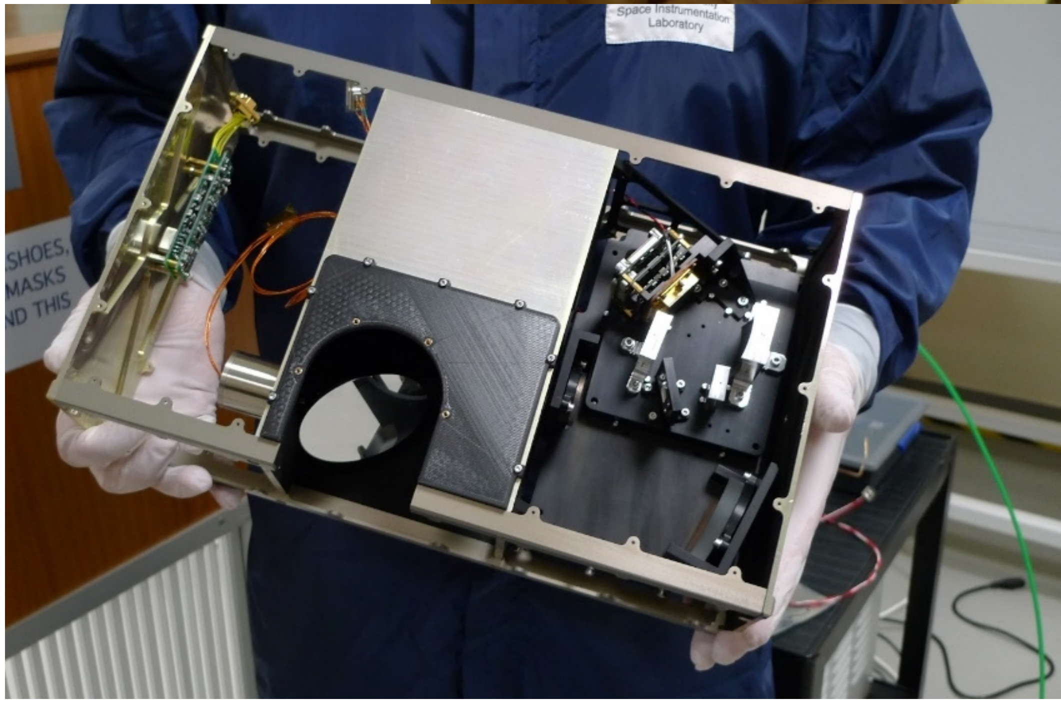
Goals:

- Determine the limits of the onboard calibration
- Determine the limitation of the pointing performance of an off the shelf CubeSat platform

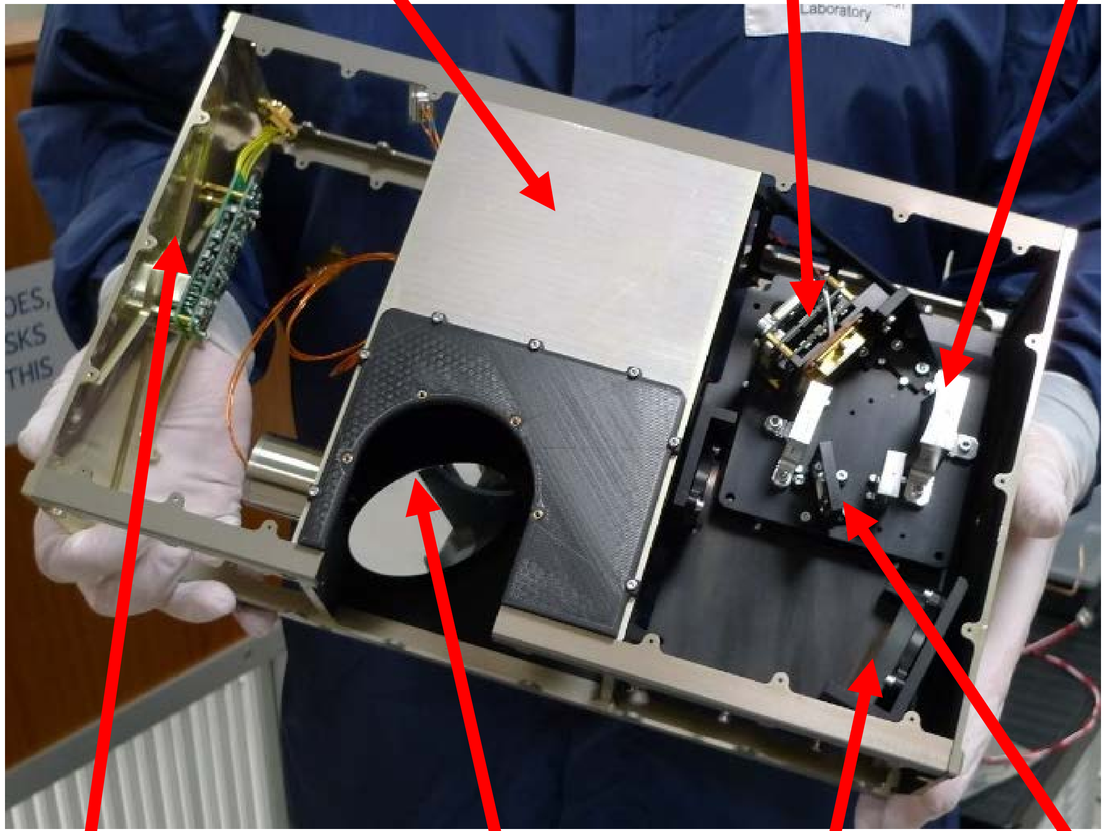
Consists of CubeSat structure, flight-like blackbody, and representative optics reused from CMS flight spares, to be tested within the University of Oxford Space Instrumentation Laboratory facilities.

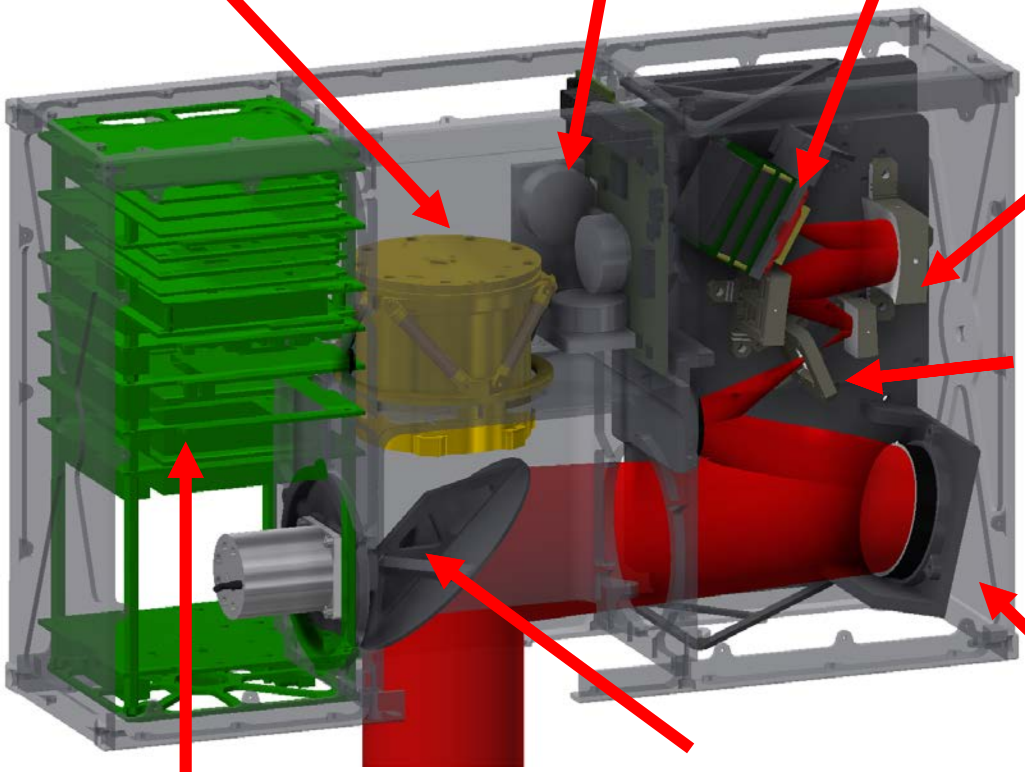
Right: Black body
Below: CIIR test bench





Instrument test bench





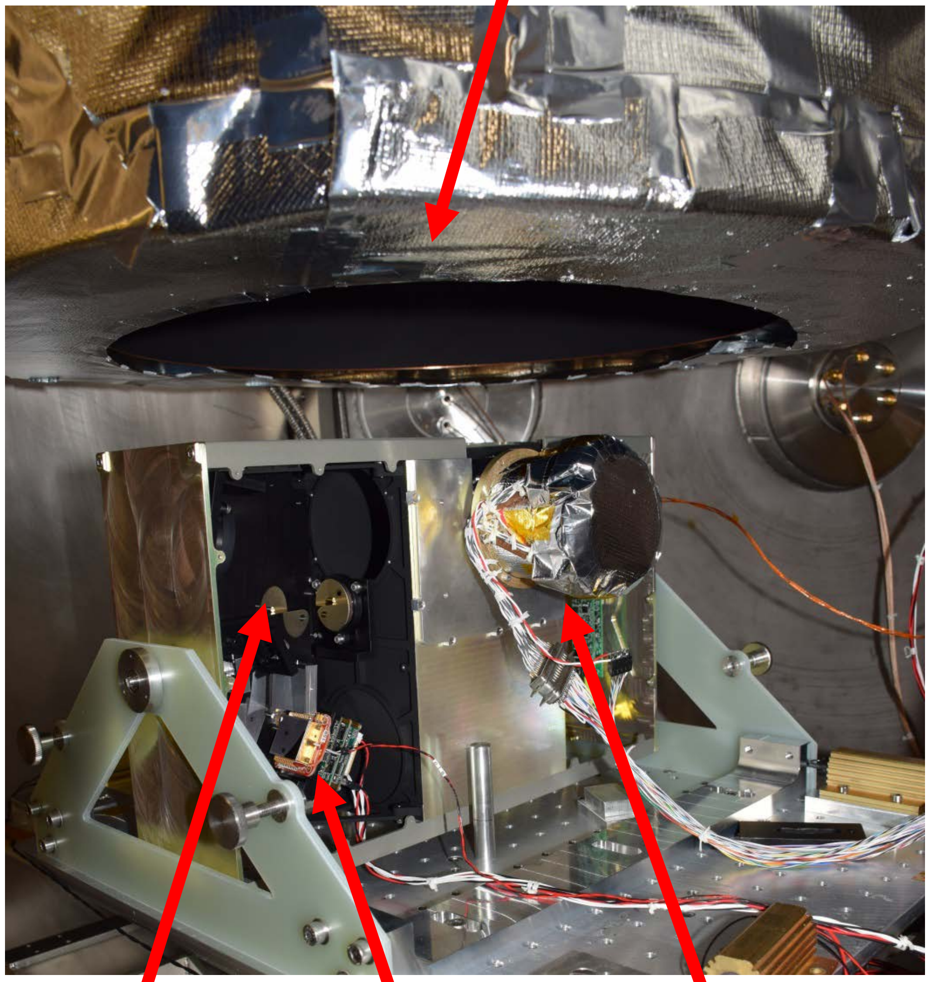
Radiometric testing

Calibration consists of viewing two targets of known radiance, hotter and colder than the target scene. Absolute calibration accuracy is crucial to interpretation of remote observations, particularly when comparing different platforms.

- This is tested in a simulated space environment vacuum chamber with a cryogenically cooled shroud (77K) simulating space views
- The onboard black body, a second reference black body, and external target are used in various calibration tests

This setup allows determination of:

- The absolute accuracy of the system
- The response to different calibration intervals
- Stability to changes of temperature of the detector and platform with change of scene viewed
- Long term calibration stability through thermal cycling

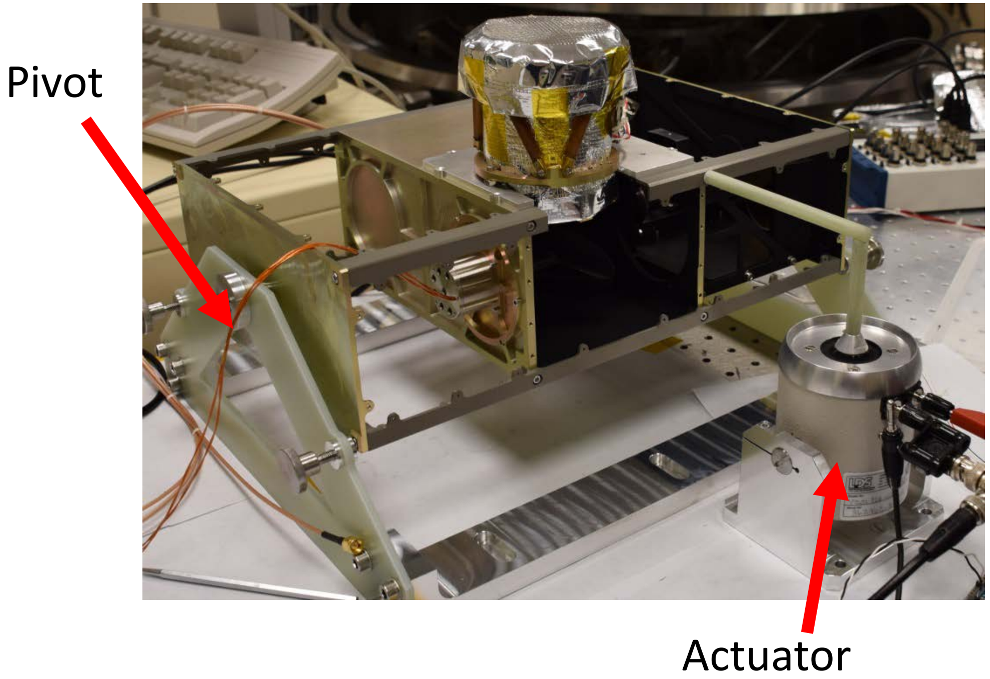


Pointing testing

Pointing performance limits the capability for accurate limb measurements with long integration times.

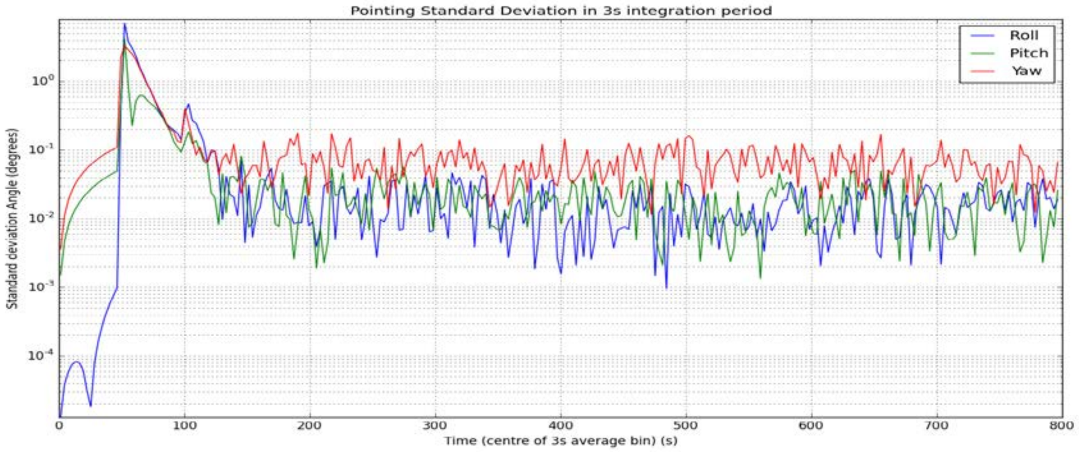
To measure the affects the on orbit platform stability is simulated.

- Mounted to a pivot an actuator drives a known jitter profile into the testbench whilst viewing a distant hot target
- Different jitter profiles can be compared



A possible solution to the limit on long integration times is to combine multiple faster integration time frames with a pixel dependent offset to account for the platform jitter.

- An accurate onboard gyroscope will allow for the pixel offset to be calculated and simulated, where it would be accommodated on the CubeSat with an FPGA in realtime.



Clyde Space pointing data from Phase A study

Ongoing testing

Currently under vacuum and testing, some early calculations

- Initial noise calculations indicate uniform detector specific responsivity (D*) that matches specification, and exceeds baseline of $5 \times 10^8\ cm\,\sqrt{hz}\,W^{-1}$ giving <0.5K NETD
- Black body heating and cooling matches model results, indicating that the stability over calibration remains <0.1K

Project concluding by the end of October, other remaining tasks include qualification testing (vibration and thermal) of the flight like black body, to verify the lifetime on the complete assembly, and creation of an algorithm to apply pixel corrections for pointing.

Future developments include updating the testbench closer to a flight unit, with optimised optics and the latest generation detector, and performing selection and qualification on multiple detector units.