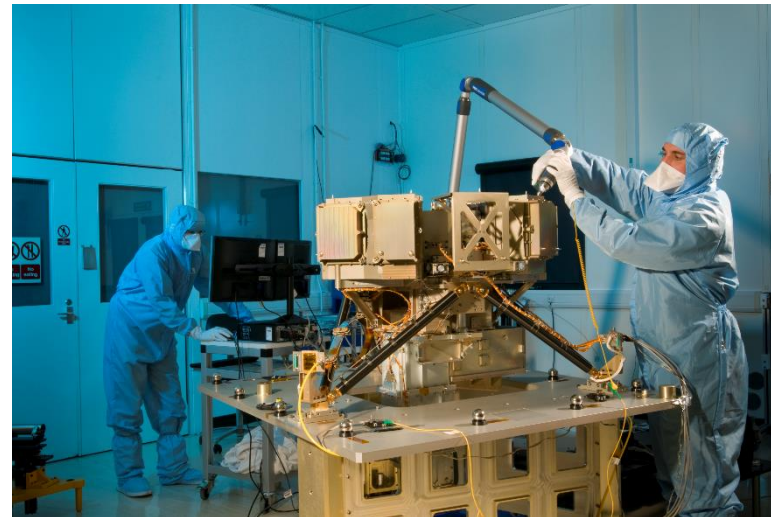
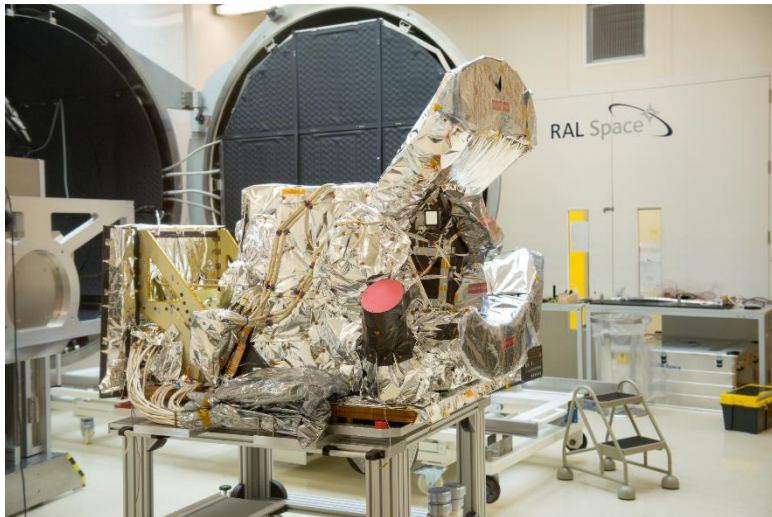


EO and Space Science R&D Programmes at RAL Space

Professor Chris Mutlow

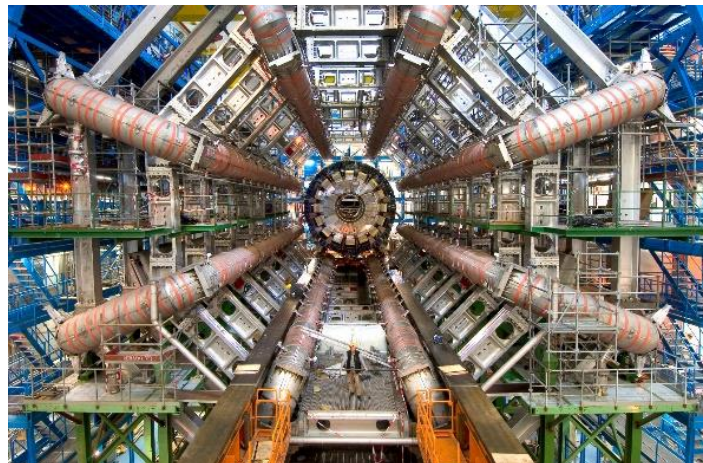
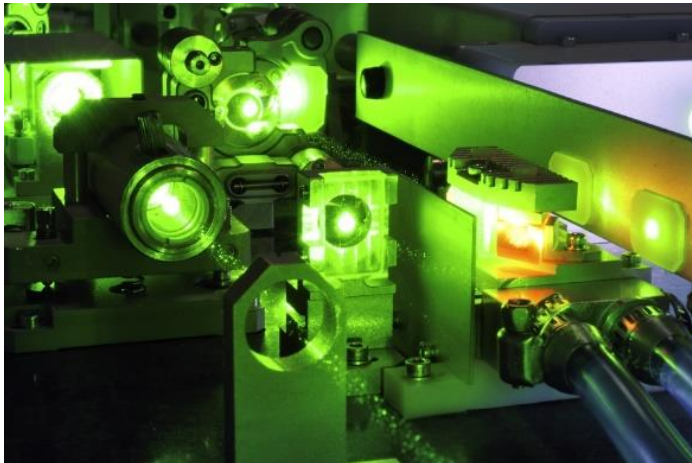
Director, STFC-RAL Space



Science and Technology Facilities Council (STFC)

The Science and Technology Facilities Council (STFC) provides:

- ✦ Particle Physics, Nuclear Physics, Space Science and Astronomy Funding
- ✦ World-leading facilities and expertise
 - ✦ World-class science
 - ✦ Enabled by world-class technologies
- ✦ Major input to UK economic growth

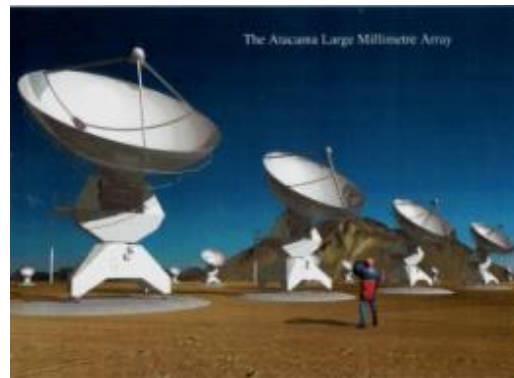
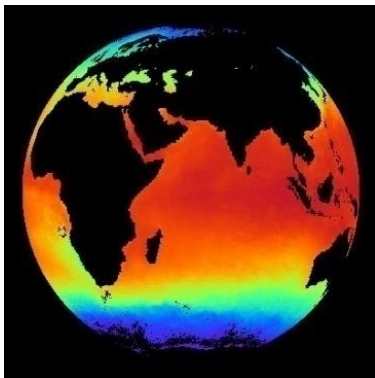


Expert support laboratory for UK space activities

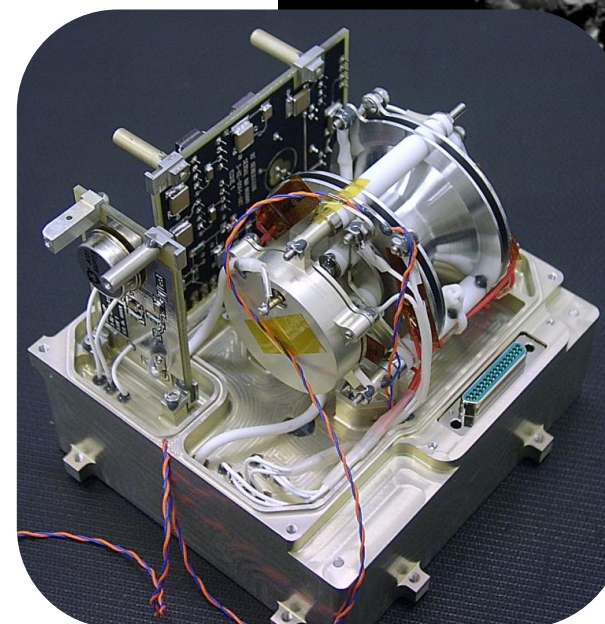
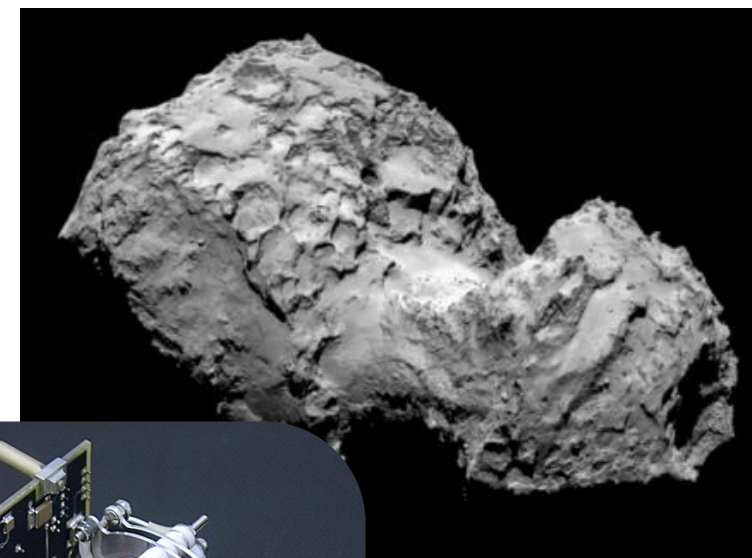
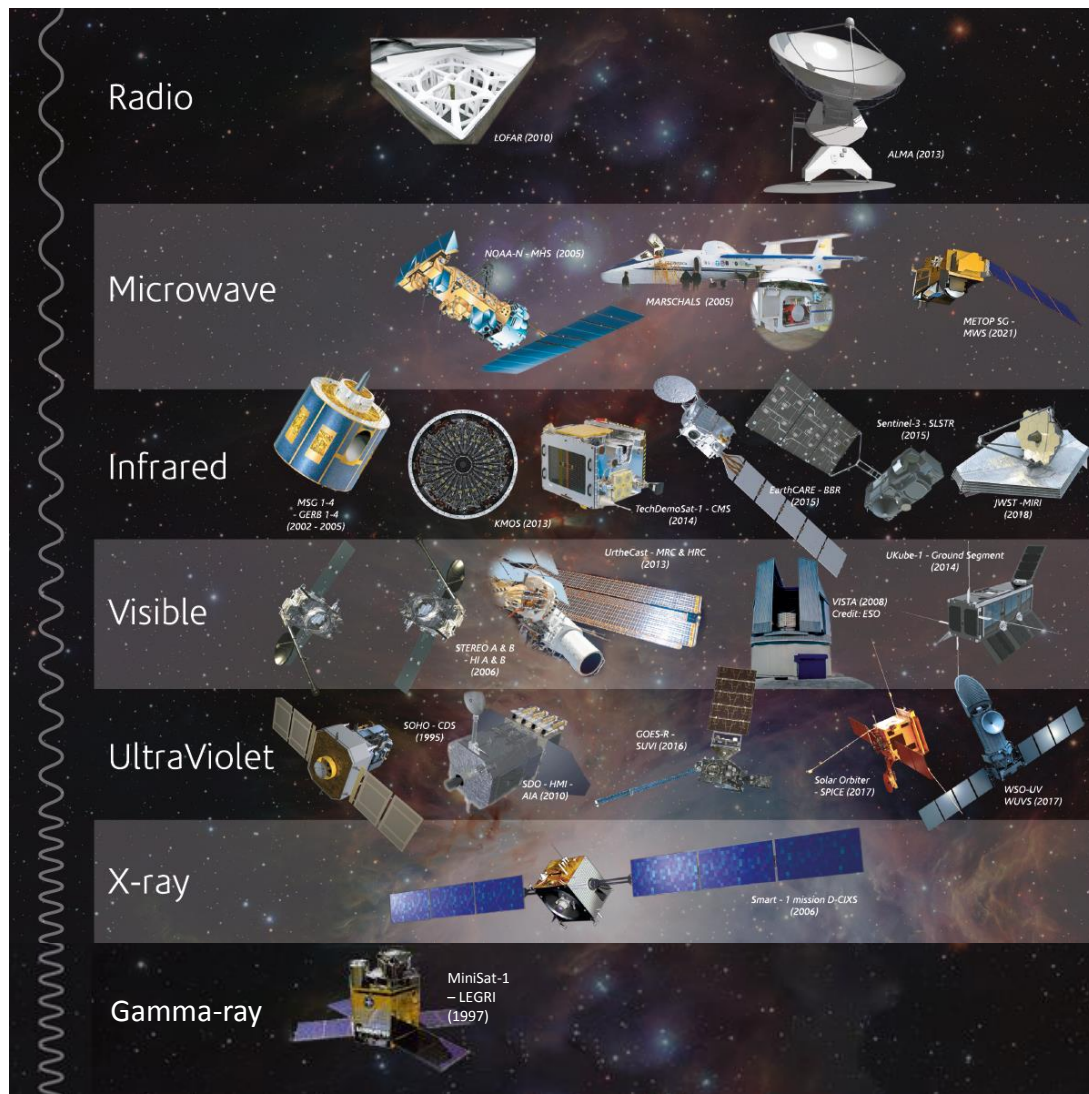
- ✦ Targeting growth and impact from the science base
 - ✦ Partnering with academia, industry and government
- ✦ £27M annual turnover (over £12M from outside UK)
 - ✦ Primary customer: Government, other members of UK Research and Innovation. ESA
- ✦ Gateway to more than 170 organisations in 34 countries
 - ✦ Space agencies (inc. NASA, ESA, UKSA, JAXA, ROSCOSMOS, CNSA, ISRO)
 - ✦ Research institutes (inc. JPL, GSFC, Sandia, NRL, USAFRL, Met Office, ECMWF, NCAR)
 - ✦ Companies (inc. Airbus, TAS, Lockheed, SciSys, Telespazio, SSTL)
 - ✦ Universities (inc. MIT, Cal-Tech, Oxford, Cambridge, Imperial, UCL/MSSL, Surrey, Leicester, Leeds, Reading)
- ✦ Supporting growth of the Harwell Space Cluster
 - ✦ Satellite Applications Catapult, ESA Harwell (ECSAT), ESA BIC

What do we do?

- ✦ Research (10%)
 - ✦ Solar physics, Infrared astronomy, space weather, climate, atmospheric composition, radio propagation
- ✦ Design and build space instruments (50%)
 - ✦ Over 211 instruments in space plus ground-based telescopes
- ✦ Develop key technologies (15%)
 - ✦ Electronics/detectors, optics/thermal, MMT, robotics
- ✦ Data, algorithms and information centres (25%)
 - ✦ Acquisition, analysis, dissemination, curation



Instrument Heritage



Solar Science

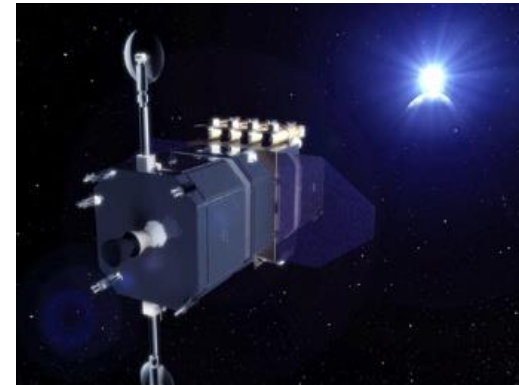
- ✦ Drive the research agenda in the UK and internationally
- ✦ Design and build instruments
- ✦ 10 solar missions over the last 30 years
- ✦ Range of study
 - ✦ Physics and chemistry of the Sun and solar activity, Earth climate and space weather



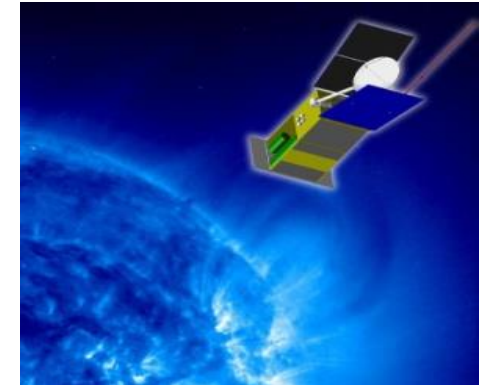
HINODE



STEREO



SDO

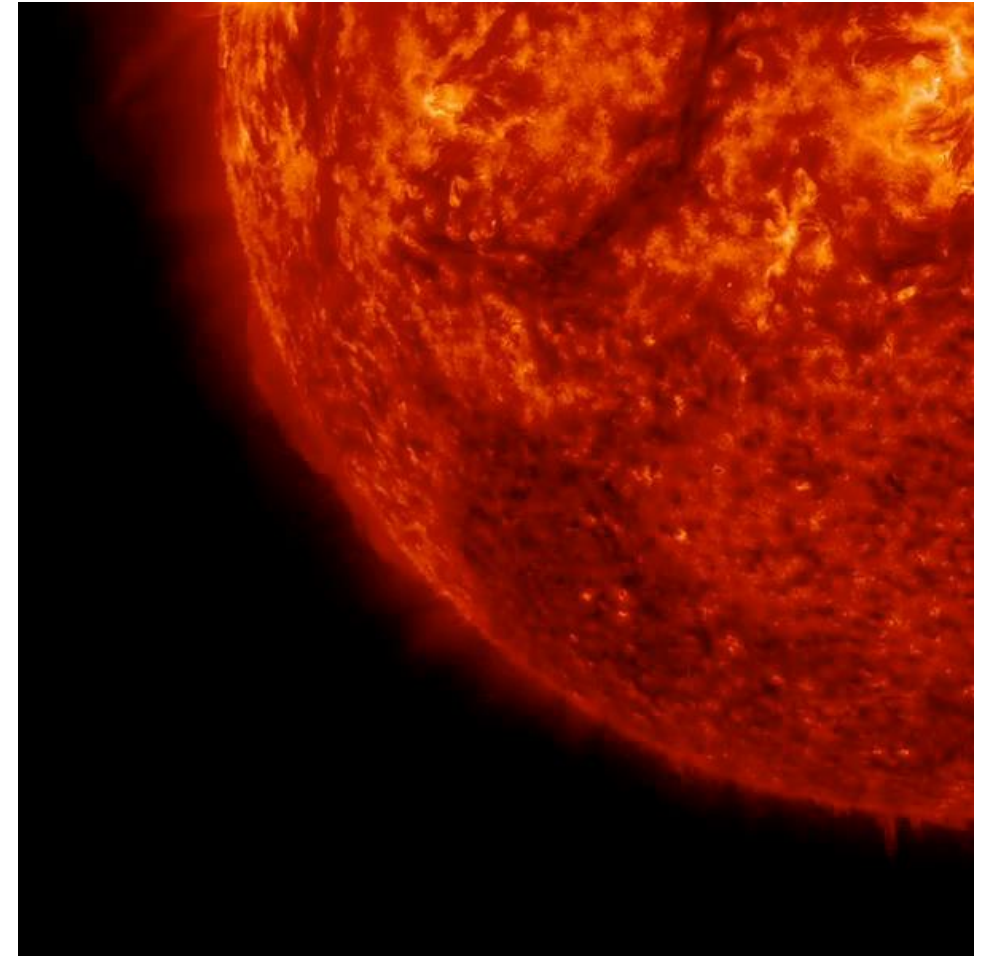


Solar Orbiter

Videos of the Sun



NASA SDO movie of the Sun: extreme UV light at 171 \AA , emitted from highly ionized iron – effectively a million degree movie of the corona. Taken in Feb 2015. **Our cameras, of course!**



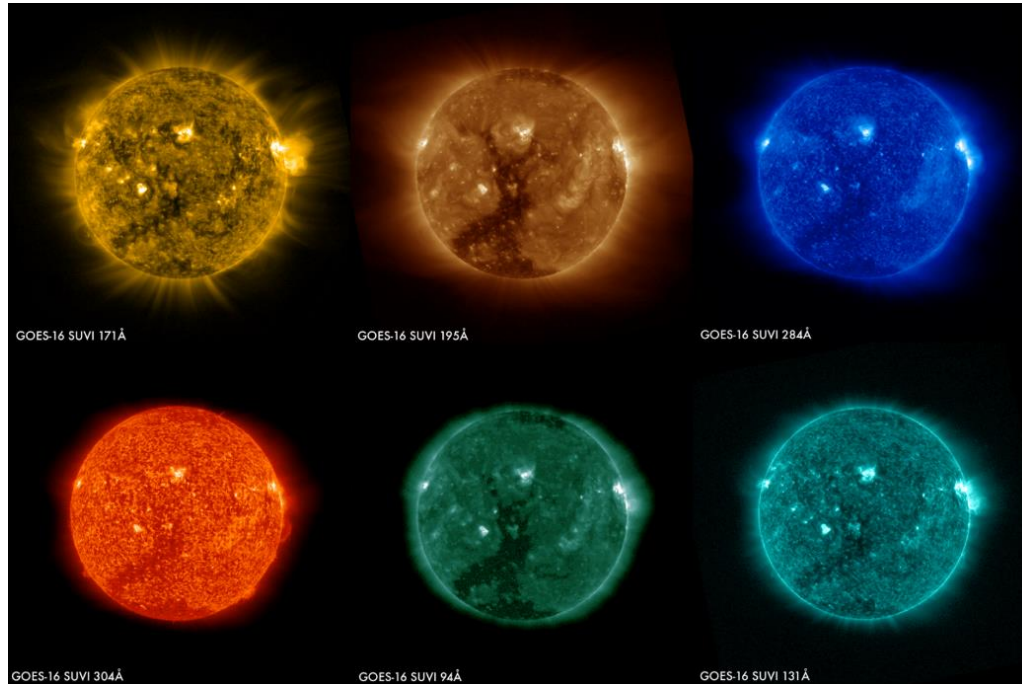
Same mission, same month: emission at 304 \AA from helium – effectively an image at a few tens of thousands of degrees, showing the low solar atmosphere. You can't miss the prominence eruption! **Again, RAL cameras!**

GOES-R / GOES-S – Space Weather Sensor

GOES-16 / 17

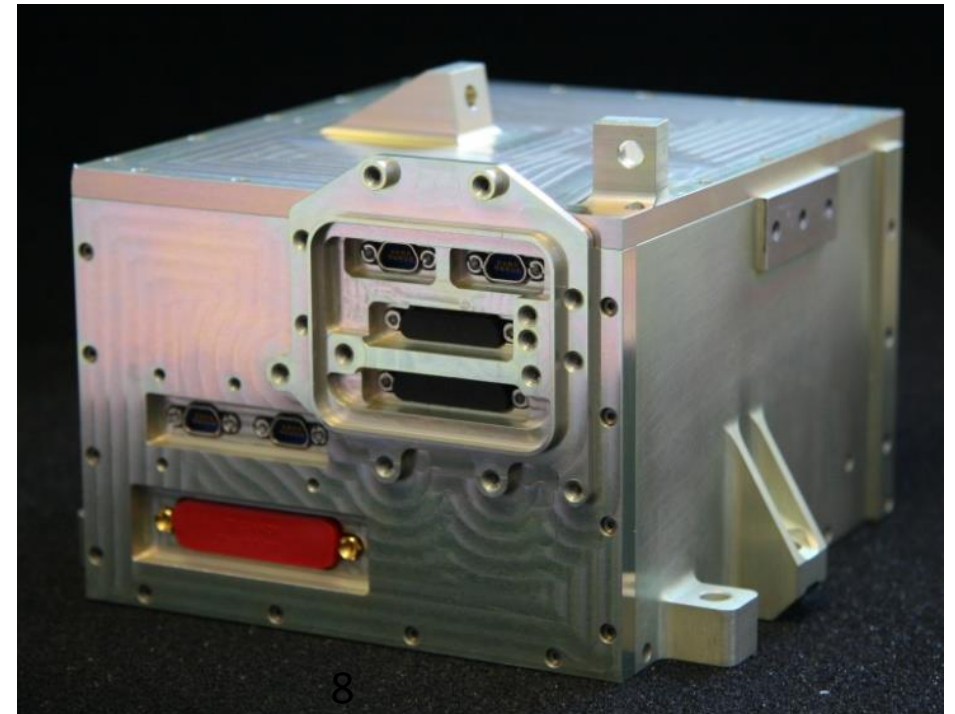
Launched 19 Nov 2016 / 1 March 2018

<https://www.goes-r.gov/featureStories/firstGOES17SUVIimagery.html>



Camera electronics for Solar Ultraviolet Imager (SUVI)

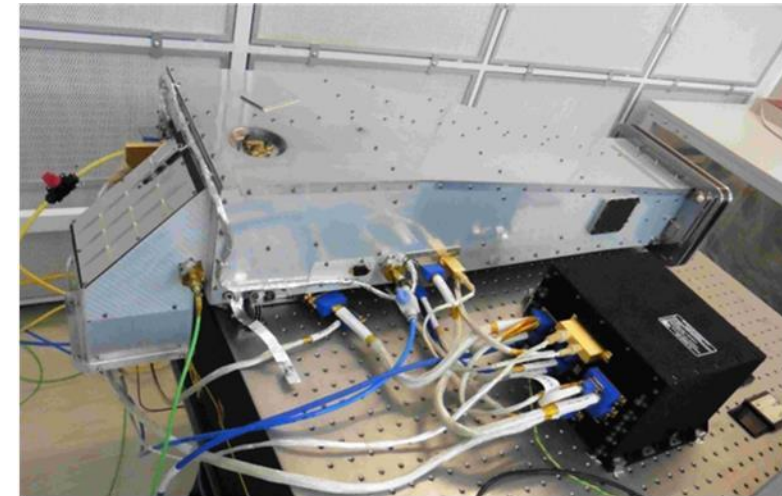
- Four flight cameras using Teledyne e2v CCDs
- Fifth CEB to be completed in 2019



Launch early 2020

Camera electronics for SPICE

- **SPICE:** Spectral Imaging of the Coronal Environment is a UV spectrograph
- Short- and long-wave UV intensified CMOS detectors
- HAS2: 1k x 1k pixel CMOS detectors
- Control and readout electronics and analogue ADCs



Flight Model: Optics Unit connected to Electronics Box during bench testing

PUNCH - NASA SMEX - Phase A

PUNCH: Polarimeter to Unify the Corona and Heliosphere

Led by SwRI

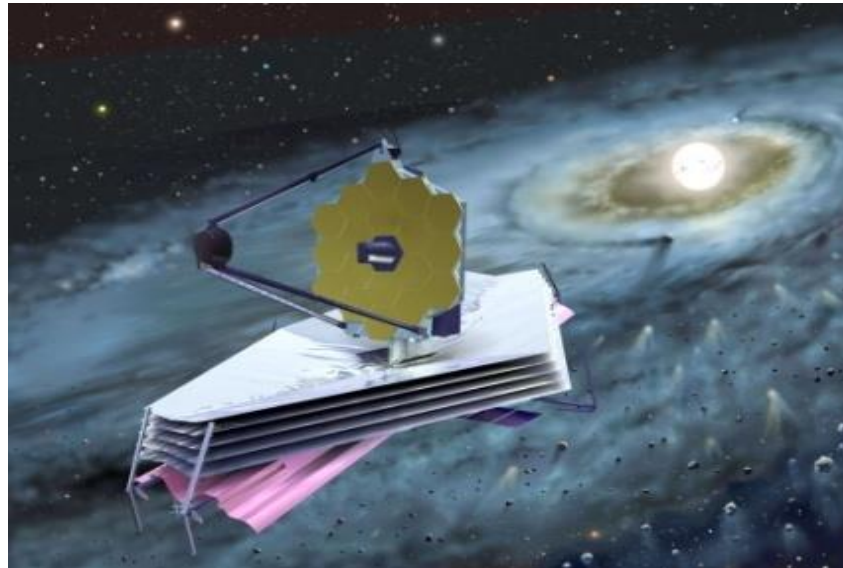
Camera electronics for the four PUNCH Spacecraft

- RAL to design and provide the CCD camera electronics
- RAL to specify the 4k x 2k pixel CCD detectors
- Launch 2022
- Prototype CCD electronics below:



Astronomy

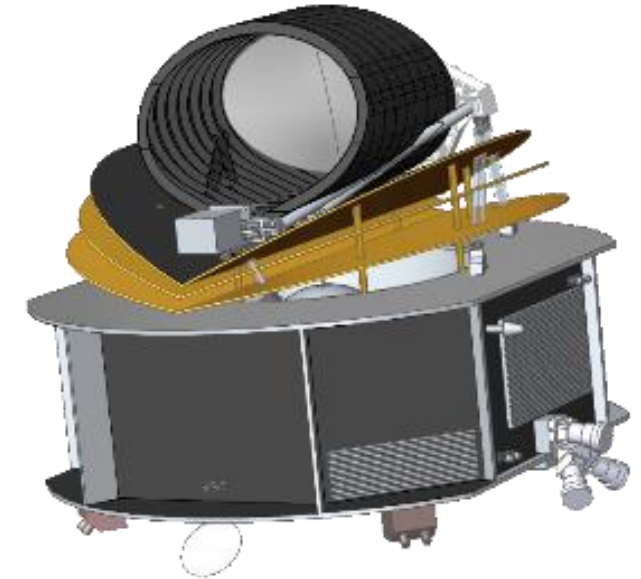
- ✦ Design and build instruments
- ✦ New Star formations, exoplanets
- ✦ Dust clouds and decaying stars
- ✦ Search for exoplanets
 - ✦ working with UCL PI to deliver Ariel new ESA M4 mission



ARIEL Selected by ESA

Mission to study planet formation and evolution through survey of the chemical composition and conditions in the atmospheres of ~1000 exoplanets in the galactic neighbourhood

- ✦ Selected at March 2018 ESA SPC selected ARIEL as the next Cosmic Vision Medium-class mission (M4)
- ✦ UK-led consortium of 15 countries provides the payload under the leadership of the PI (Prof Giovanna Tinetti, UCL) with management and technical coordination provided by RAL Space
- ✦ UK team includes teams at UCL MSSL, Cardiff and Oxford Universities, RAL Space, STFC Technology Department and the UK Astronomy Technology Centre



Payload is a 1-m class telescope, cooled to cryogenic temperatures, with 3 photometric channels and 3 low resolution spectrometers giving continuous wavelength coverage from 0.5 – 7.8 μ m

Now in a 2-year “Definition Phase” (phase B1) before formal Adoption, with plan for launch in 2028.

World Space Observatory

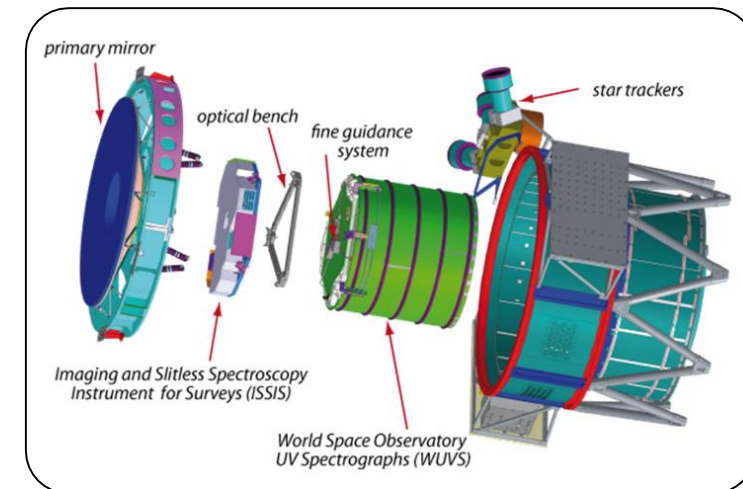
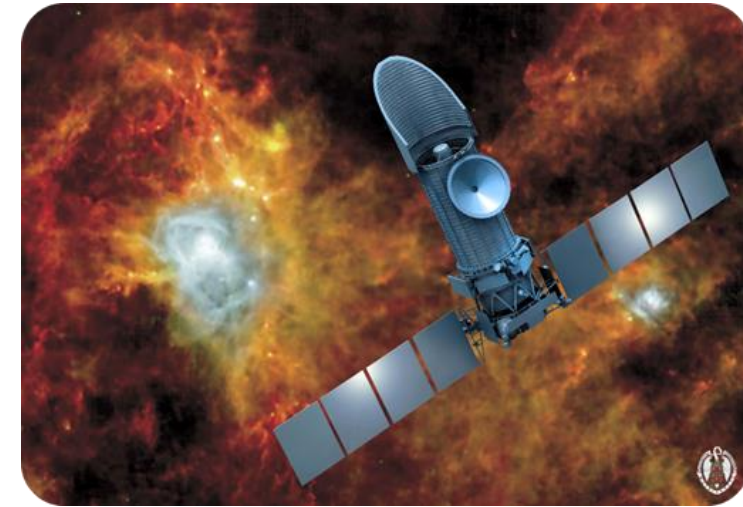
World Space Observatory Ultra-Violet (WSO-UV)

Major international collaboration led by Russia

Aims to study Universe at 115 nm to 320 nm.

- 1.7m aperture ultra-violet telescope
- Two science instruments:
 - FCU – led by Spain
 - WUVS – led by consortium of Russian institutes

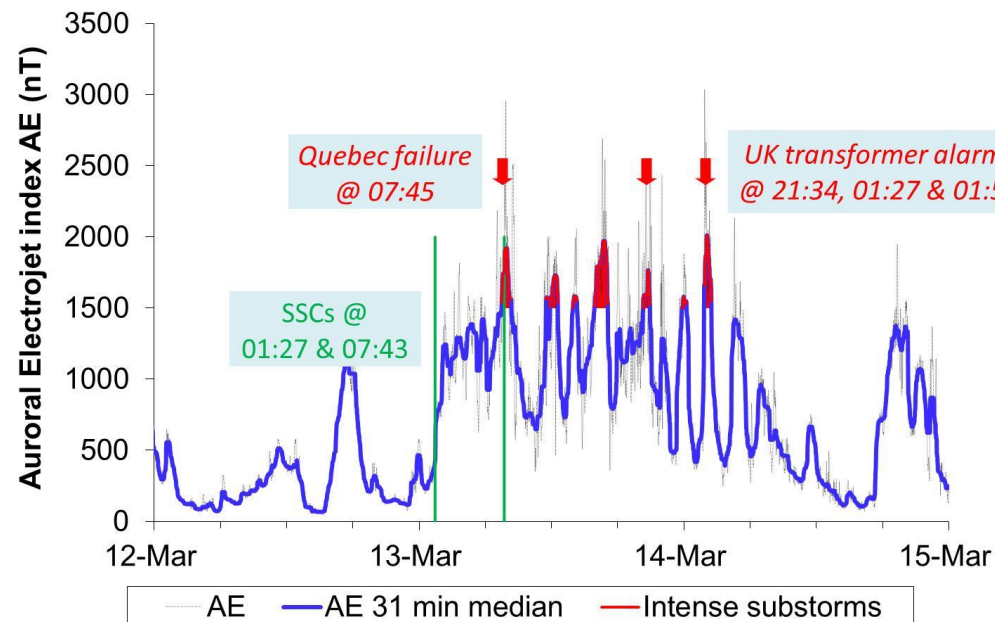
Launch expected 2024



Space Weather Impact

RAL Space working with Met Office & other partners to quantify:

- Economic impact of space weather, esp. on UK, using historical data such as 1989 magstorm that caused damage to Nat. Grid (figure below)
- Can this reduced by better forecasts? – and justify investment in operational missions?
- Complements our technical work on missions (Lagrange)
- All vital preparation for 2019 ESA Ministerial, esp Space Safety element



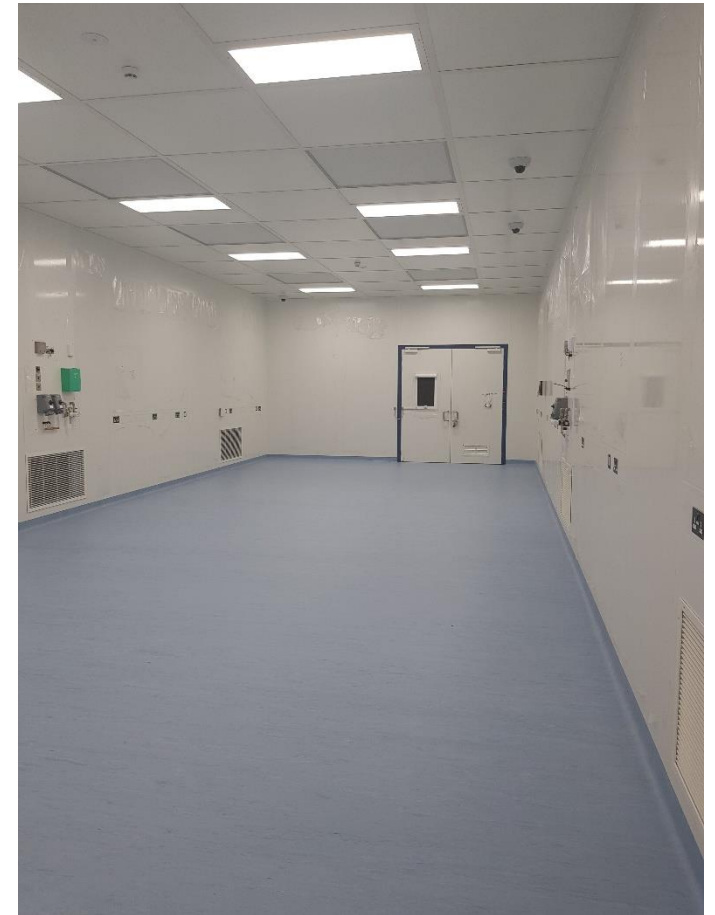
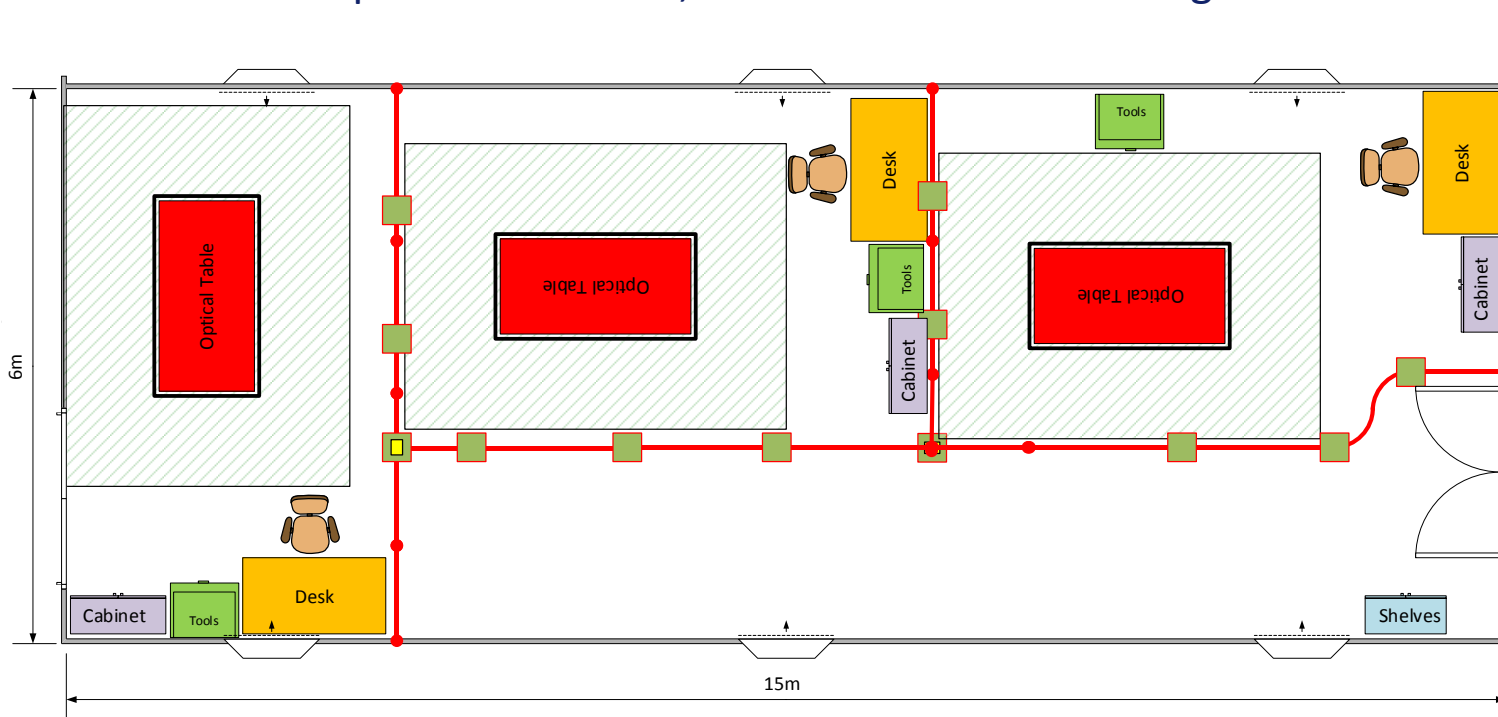
Field Trials Unit

- ✦ The Autonomous Systems at RAL Space has a network of contacts across Europe to contribute to all aspects of field testing
- ✦ Includes access to a wide variety of platforms, personnel, software capability, test sites and equipment internally and from partners
- ✦ The unit builds up required additional resources for each field trial based on requirements, but experience and procedures are re-used.
- ✦ RAL Space has its own support equipment for communication (including satellite broadband), ground truth, data logging, calibration, aerial imagery, on-board computing, DEM software and differential GPS.
- ✦ Can also provide support for requirements, test definition and benchmarking.
- ✦ We can store trials data and STFC can support data archiving.
- ✦ Previous work includes trials for SEEKER and SAFER in the UK and Chile, and Newton field trials in China.



Quantum Space Lab

- 90sqm lab surface[†]
- Reconfigurable lab partitions
- Access to:
 - Space Test Facilities (vib, tvac, +NSTF)
 - AIV/AIT
 - RALSpace Mechanical, Thermal & Electronics Eng's



RAL Space Gravity Gradiometer

Key Features:

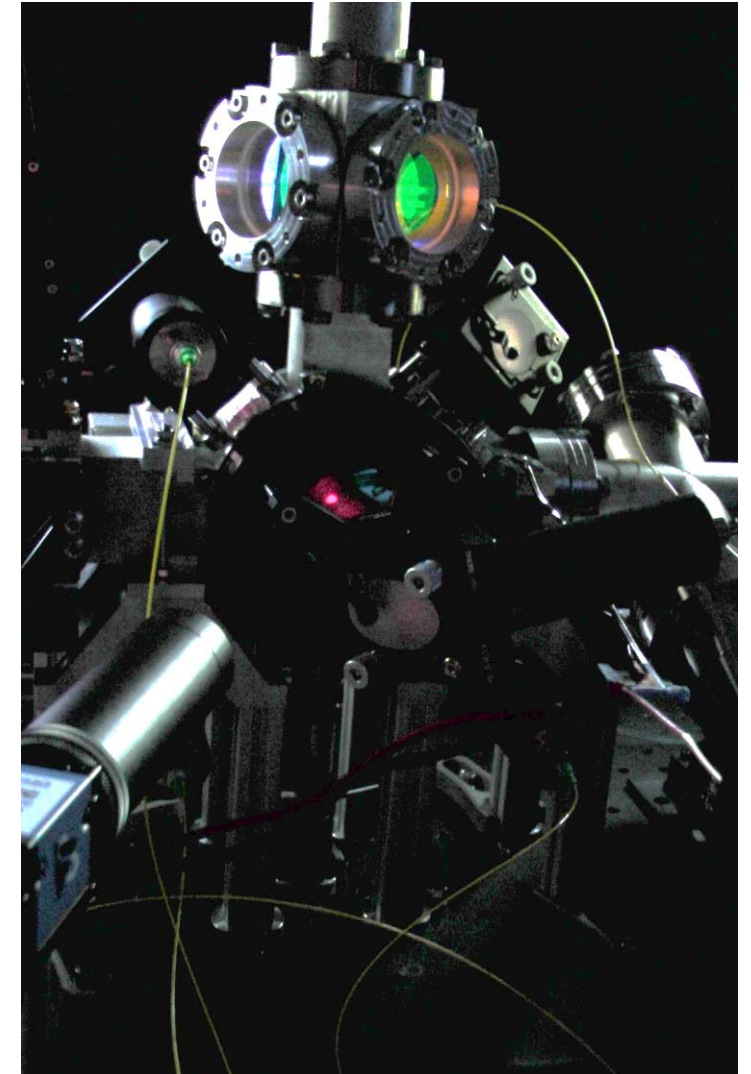
- ✧ Rb: 2D-3DMOT System
- ✧ 70cm tall fountain

Status:

- ✧ Vacuum chamber assembled
- ✧ Optics assembled
- ✧ 3D MOT being optimised and characterised
- ✧ μ -shield being procured

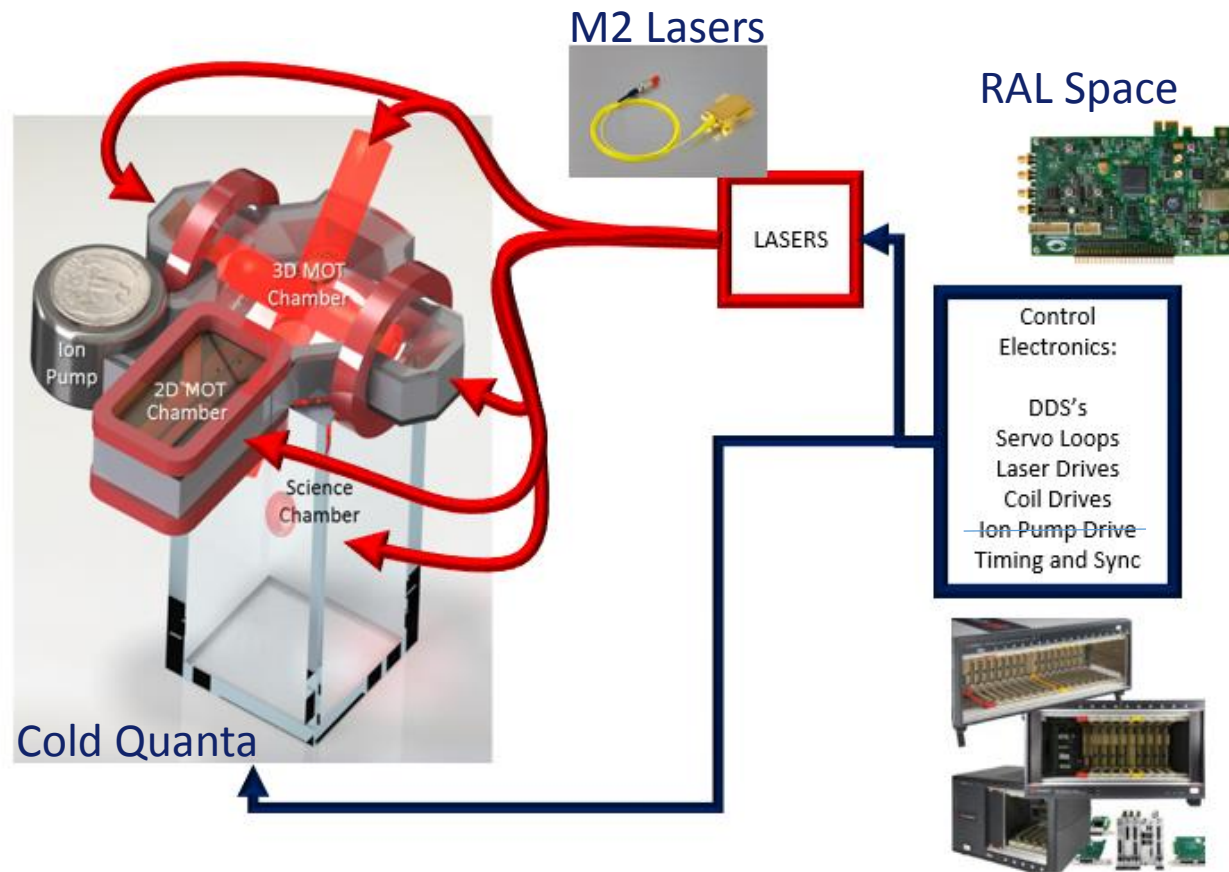
Next Steps:

- ✧ Atomic fountain implementation and optimization
- ✧ Rabi oscillations and Ramsey Spectroscopy
- ✧ Gravity measurement (Atom Interferometry in atomic fountain, single cloud)
- ✧ Atom Cloud “Juggling”
- ✧ Gravity Gradient measurement (Atom Interferometry in atomic fountain, two clouds)



McLaren: Space CA Electronics

McLaren: Miniaturised CoLd Atom GRavimeter for SpacE ApplicationS



QubeSat: UK/Singapore QKD

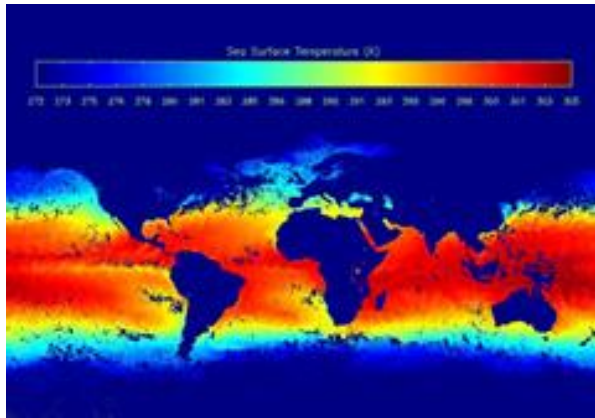


- 6U CubeSat, 3U space for QKD payload
 - Steering camera, wide angle & low noise
 - Downlink/uplink optics: pellicle beam splitters and MEMs steering mirror to host multiple quantum optics payloads
 - Optical ground-station using COTS telescope system with customised drive
 - £5M BEIS and £5M Singapore
-
- Support current generation (down conversion) QKD systems and help demonstrate first of the new breed single photon emission systems.
 - Help to develop operational model for industry

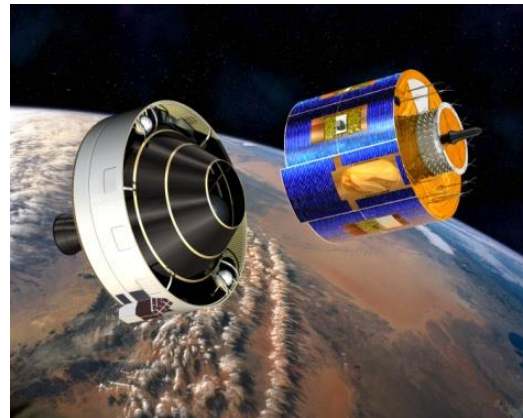
EO and Atmospheric Science

Expert support laboratory for the community

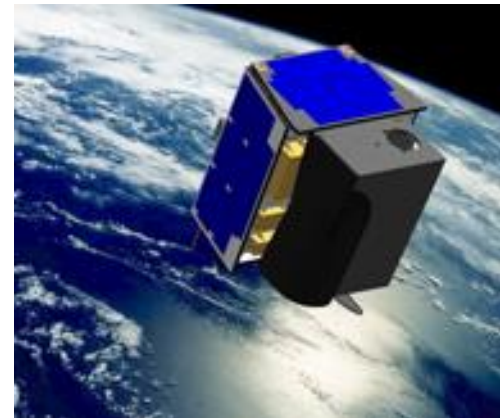
- ✦ Design and build instruments
- ✦ Make observations: atmospheric, land/ocean surface and climate
- ✦ Develop algorithms and produce new geophysical data sets
- ✦ Operate data centres and archives – JASMIN for NCAS, NCEO, DEFRA, UKSA
- ✦ Major projects: next generation ATSR – SLSTR, METOP SG, EarthCare BBR



Along Track Scanning Radiometer - ATSR



MSG - GERB



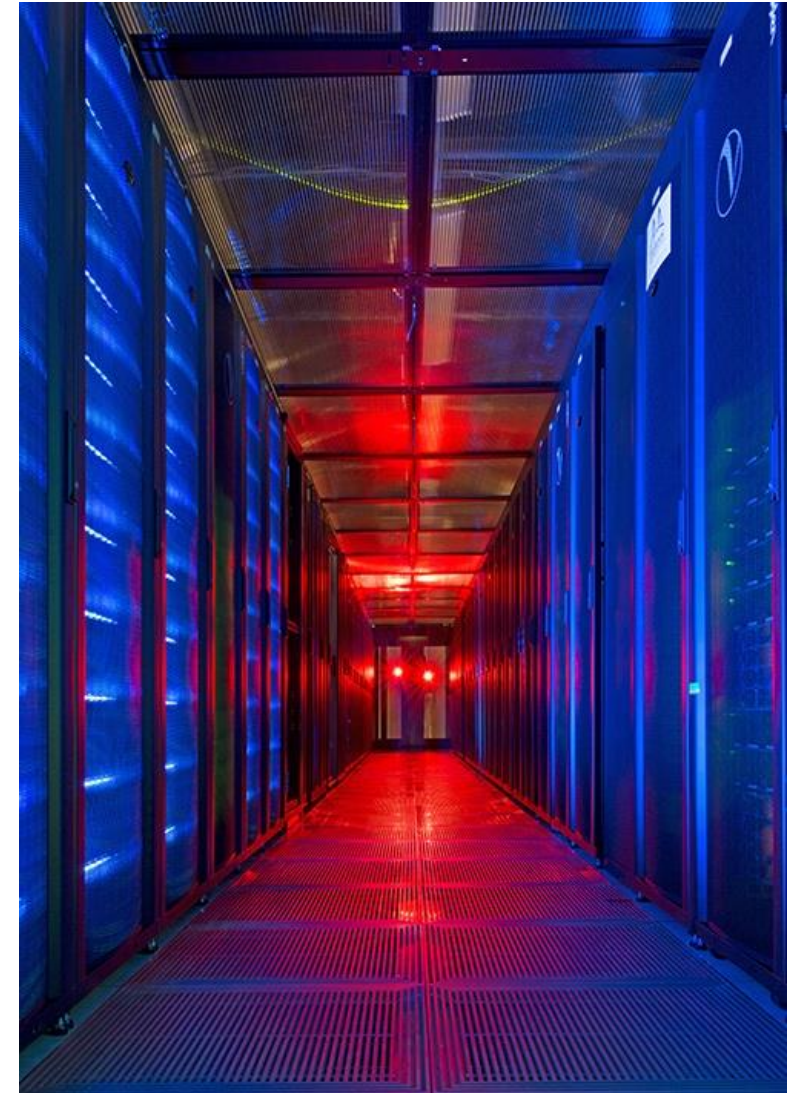
TopSat – low cost cameras



Sentinel-3 / Sea and Land Surface
Temperature Radiometer - SLSTR

JASMIN

- ✦ JASMIN provides a data commons for the environmental sciences community
- ✦ Hosted and operated by STFC for the Natural Environment Research Council (NERC)
- ✦ An STFC cross-department collaboration
 - ✦ STFC Scientific Computing Department
 - ✦ Hardware architecture, cloud software and operation
 - ✦ CEDA (RAL Space)
 - ✦ User services and applications development, cloud software and architecture



What is JASMIN?

Petascale storage and cloud computing for big data challenges in environmental science

- ✦ 44 PB high performance storage
- ✦ > 11,000 computing cores
- ✦ High-performance network design
- ✦ Dedicated high memory and data transfer machines
- ✦ Enables academic-commercial partnership



Sentinel Data at CEDA



CEDA is collecting, storing and archiving the entire Copernicus dataset

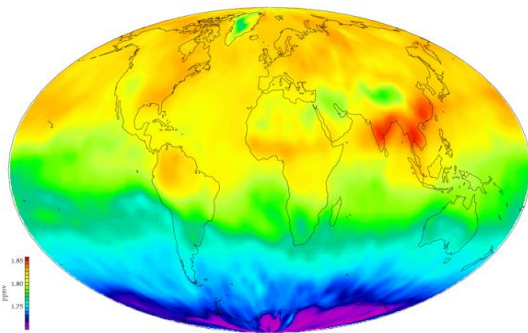
- ✦ Receives and stores >10 TB incoming data each day
- ✦ Operates a Sentinel mirror archive for registered users
 - ✦ Self-service access for data download to user site
 - ✦ Local processing on JASMIN in your choice of virtual environment
- ✦ Part of the UK Collaborative Ground Segment
 - ✦ CEDA/JASMIN: Data hub and processing environment for research community
 - ✦ Catapult/CEMS: Data and services for commercial users
- ✦ CEDA also holds model data, and ECMWF



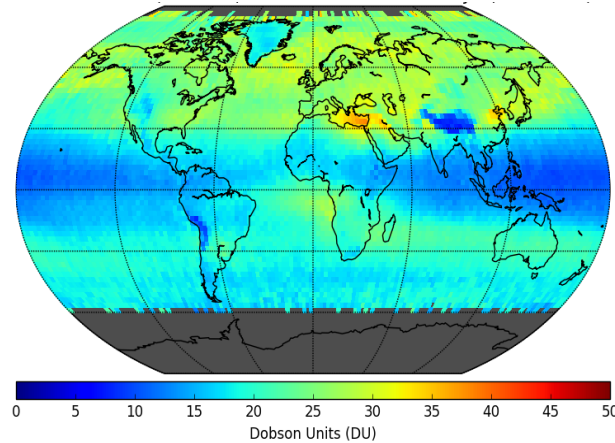
Remote Sensing at RAL Space

- World-class standing in atmospheric composition sounding
 - Global climate data on ozone, methane, water vapour, aerosol & cloud

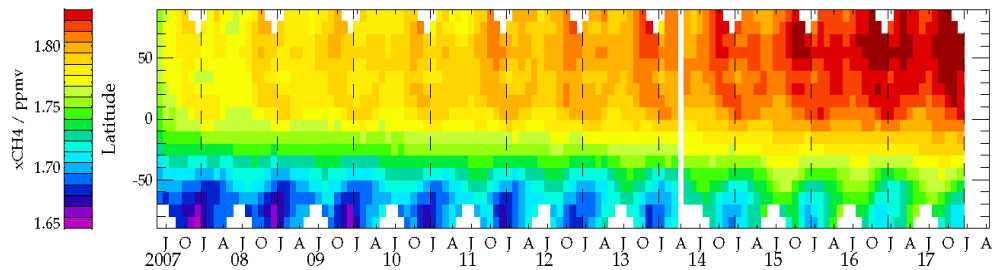
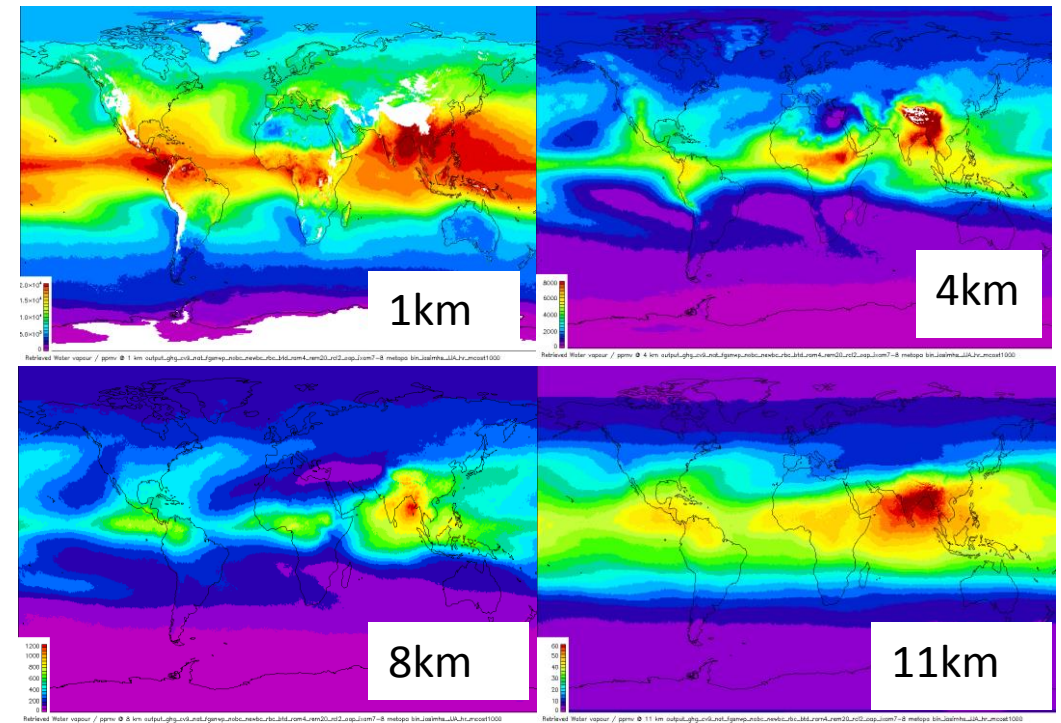
Methane



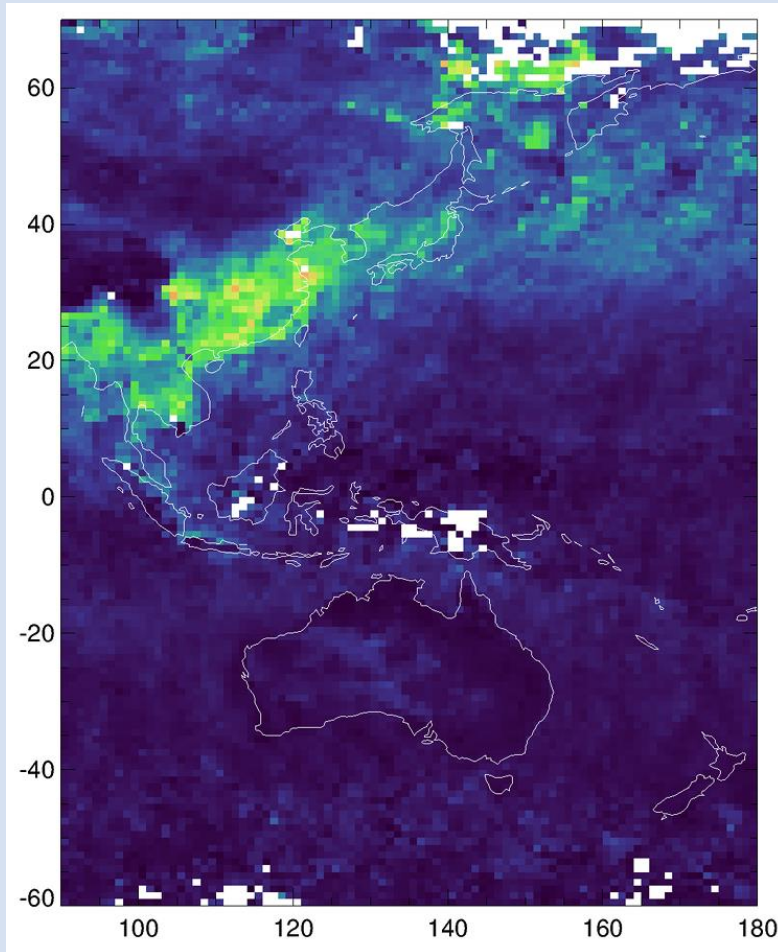
Tropospheric Ozone



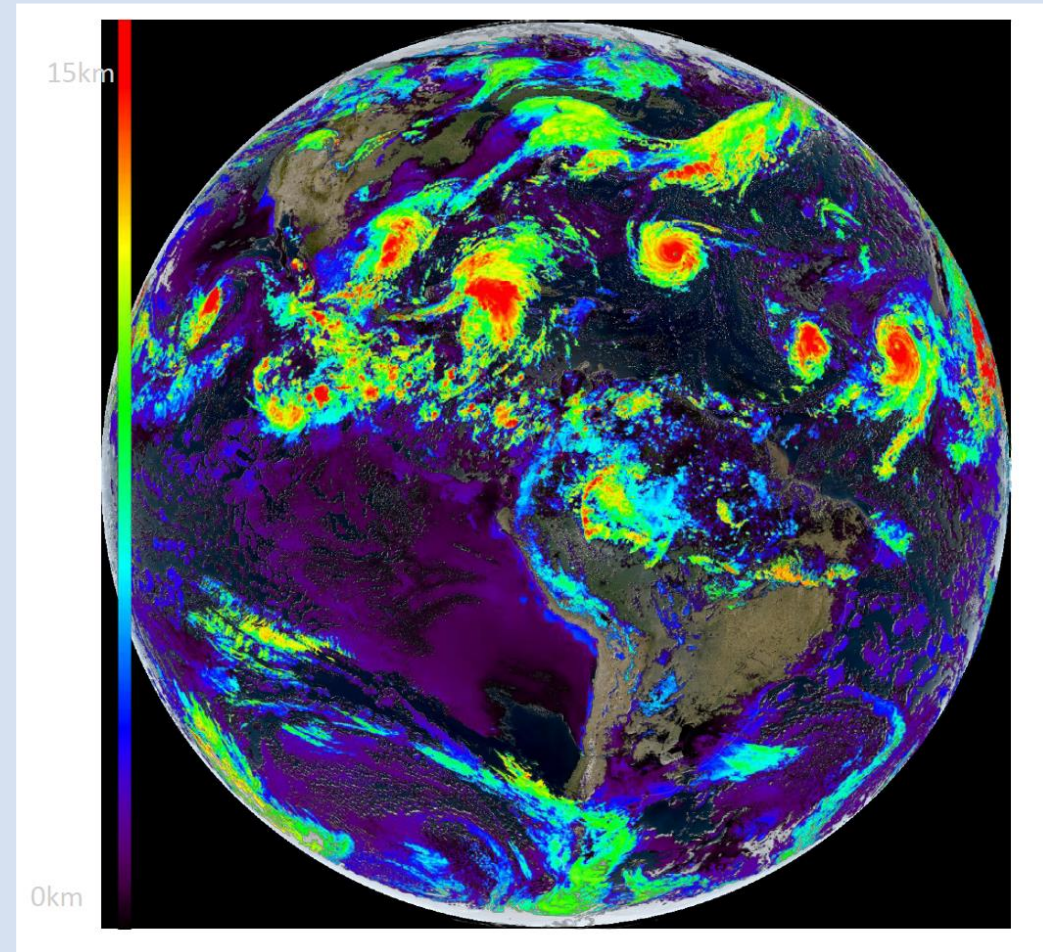
Water Vapour



Remote Sensing Impacts



Aerosol plume from Indonesian fires 2011



Cloud-top height September 2018 Florence and other hurricanes

Chilbolton Observatory

- ❖ 25m steerable Doppler radar
 - ❖ atmospheric studies – cloud particles, phase and motion
 - ❖ space surveillance and tracking
- ❖ Meteorological instrumentation: active (radar, lidar) and passive sounding to 100GHz
- ❖ Sole UK site for the LOFAR radio astronomy telescope
- ❖ Supporting satellite communications and data downlinks for UK businesses
- ❖ Support guest observation facilities, e.g. UK Met Office, NCAS



LOFAR Telescope Site

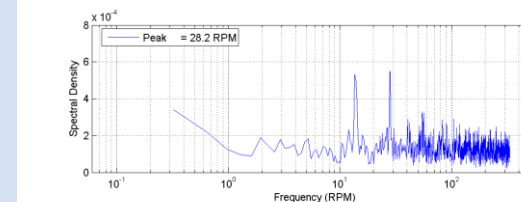
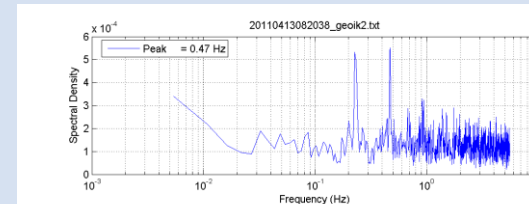
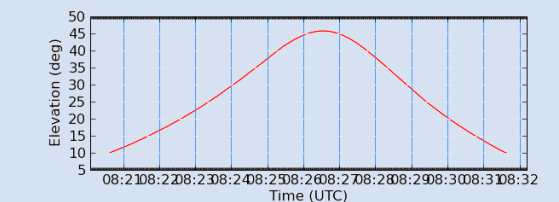
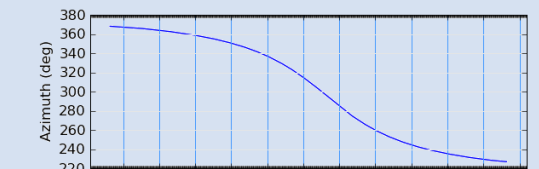
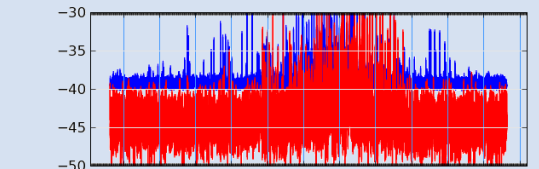
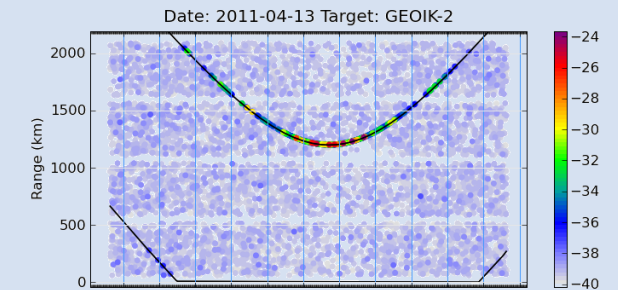


Host to Met Office Observation Facilities

Chilbolton 25m Radar

Measuring the rotation rate of the tumbling satellite, GEO-IK-2

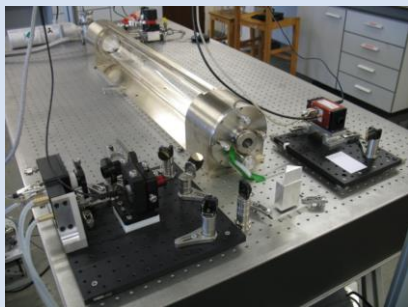
- Following a launch anomaly, there were reports that the GEO-IK-2 geodesy satellite might be tumbling
- Chilbolton radar observations produced the quick-look plot shown on the right
- This data was transformed into the frequency domain:
- The resulting spectrogram shows a peak at 0.47 Hz (28.2 rpm)
- However, the line at 14.1 rpm is only slightly weaker
- We conclude that the satellite was tumbling at the time of the radar observation:
- The tumbling rate is likely to be 14.1rpm or possibly a sub-multiple of this figure
- The Spectral lines are probably due to radar glints off the solar-panels and other panel-like features on the satellite bus (see picture)



Laser Spectroscopy Sensing

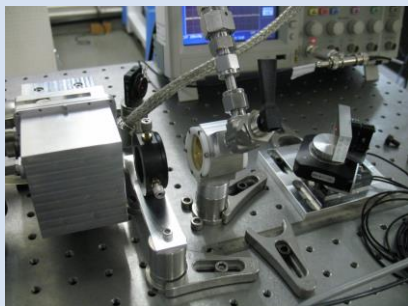
In-situ laser sensors

From concept to elegant breadboard



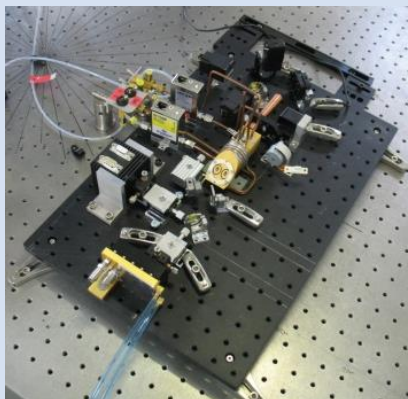
Mesospheric
diagnostic sensing

Study of quantum
molecular effects



Environmental
sensing

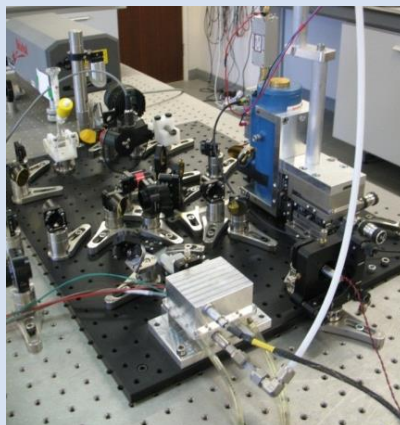
Quantum cascade
laser widely tuneable
systems



Atmospheric and
planetary sciences

Miniaturised laser
isotope analysers

Laser remote sensing systems



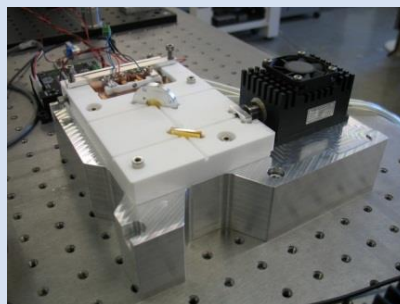
Atmospheric profiling
Planetary sciences
Satellite validation
Air quality

Laser heterodyne
spectrometers



Threat analysis
Emission analysis

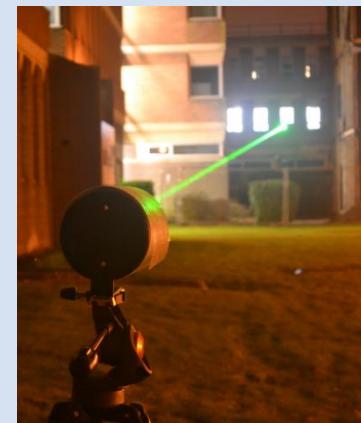
Spectroscopic lidar



Nano and microSat
technologies

Miniaturised laser
systems

Long open-path sensing systems



Geosciences
Industrial emissions
Air quality
Climate

Molecular dispersion
spectrometers

Mapping gas
emissions

And more ...

- ✦ Instrument field deployment
- ✦ Instrument data analysis software
- ✦ Spectral processor
- ✦ Instrument simulator
- ✦ Ad hoc technology development

National Satellite Test Facility (NSTF)

**A new facility to support the growth of the UK space industry and inward investment.
Building on the success of RAL Space R100**





R100

Science & Technology
Facilities Council

RAL Space