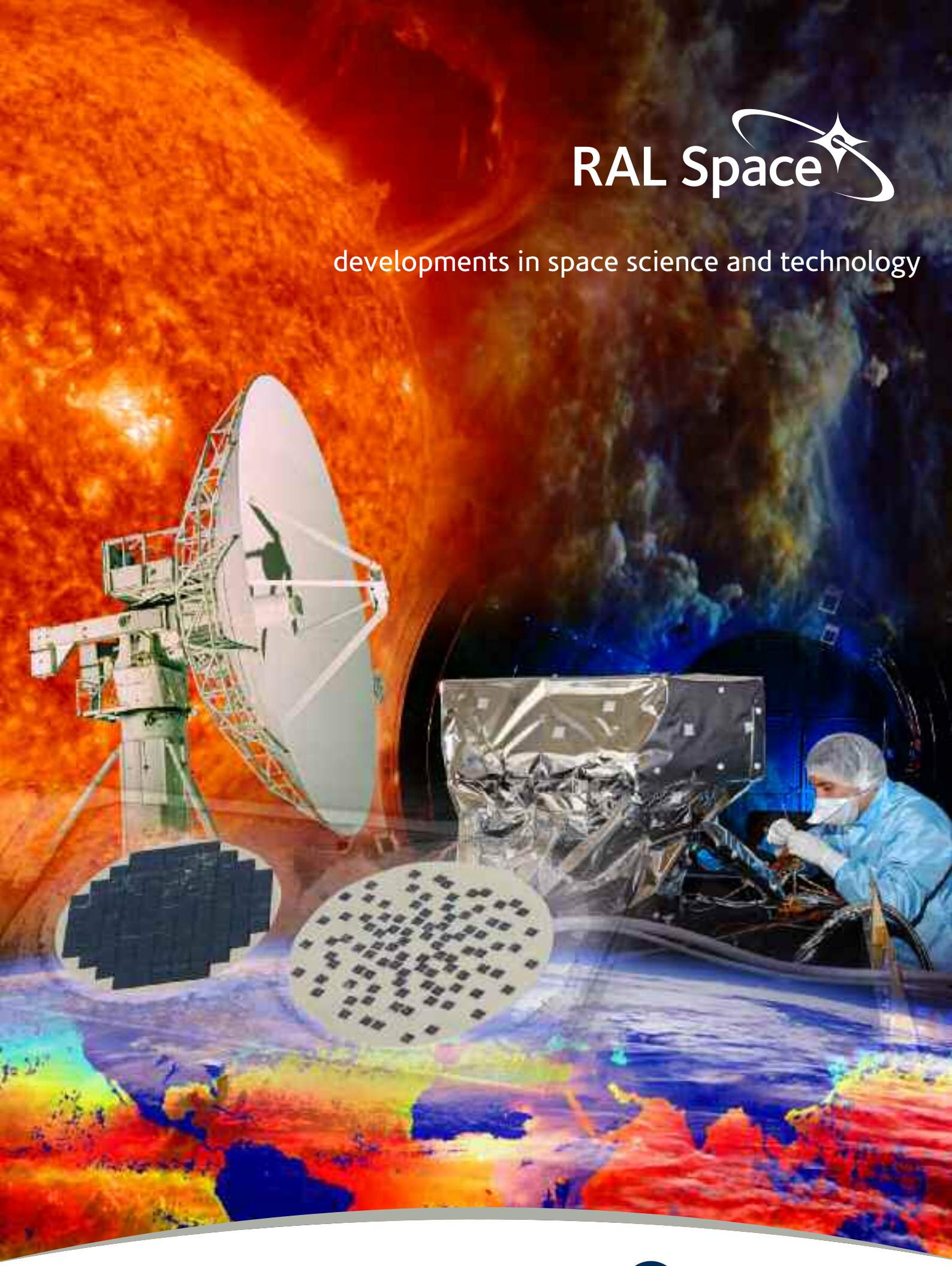
RAL Space

developments in space science and technology



Science & Technology Facilities Council

WELCOME TO RAL SPACE

RAL Space is an integral part of STFC's Rutherford Appleton Laboratory. It is a national resource for the benefit of the whole of the UK Space Community, and operates in a similar way to a National Space Laboratory, being science-led, technology-enabled and with many (over 150) collaborations with academia and industry.

RAL Space has 50 years of experience and expertise in space programmes, and is unique in the UK in its positioning between industry and academia. Its strength lies in the broad mix of its highly trained staff, and activities from research, development and facilities, to data curation and analysis, programme management, and the provision of strategic advice to external partners. It has always worked very closely with UK industry and academia, and leads on a number of new initiatives such as Space Weather on behalf of the community.

Our priorities include:

Carrying out research programmes in areas of space science and technology where we have an international standing, including:

Solar physics; space environmental physics; infra-red /sub-mm-wave astrophysics; atmospheric science, atmospheric composition, climate change and Earth observation; radio communications and radio propagation; CCD detector and ASIC microelectronics technology; millimetre-wave technology; laser heterodyne radiometry and Fourier-transform spectroscopy for Earth Observation; and highly innovative robotics;

Developing new technologies and space facilities to improve access to space, exploiting the new technologies with industry and applying these technologies and skills to areas outside the space sector where appropriate;

Lead and aid industry and universities in the use of space techniques and scientific investigations, with active participation in the 'Grand Challenges' of Climate Change, Security, Ageing Population (primarily Health) and Energy by bringing forward ideas and technologies from our space technology to aid these programmes;

Providing project management support and other specialist skills to national and international programmes, and continue to promote and undertake studies in our new Concurrent Design Facility;

Continuing to pioneer research programmes into impacts of solar ejecta on the Earth, e.g. exploiting the UK instruments aboard the STEREO spacecraft. The application of this research is being developed for exploitation in space weather applications on the international arena;

Developing our collaborative and strategic teaming arrangement with UK industry in space science, Earth observation, ground-based astronomy and other non-space sectors;

Working with NERC, and in particular the National Centre for Earth Observation (NCEO) and the National Centre for Atmospheric Science (NCAS) to develop and support future programmes, and help the UK formulate its position on Space Weather and Space Situational Awareness (SSA);

Provision of top-class space and ground-based facilities available to the whole community including two ground stations, atmospheric research radar and supporting infrastructure, environmental test facilities, robotics test facility, molecular spectroscopy facility and a concurrent design facility as well as the operation of national data archives including the NERC EO Data Centre (NEODC), the British Atmospheric Data Centre (BADC), and the UK Solar System Data Centre (UKSSDC).

Prof Richard Holdaway
Director RAL Space

CONTENTS

The Sun	3
Near-Earth observation	5
Earth observation	7
Planetary science	13
Astronomy	15
Research	17
Facilities	19
Design	21
Technology	23
Operations	27
Data management	29
RAL Space missions	33

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THE SUN

RAL has a long heritage of solar space mission involvement, mainly through the development and operation of spectroscopic instrumentation in the extreme-UV and X-ray wavelengths. We use observations of the solar atmosphere to determine its plasma characteristics.

SOLAR ORBITER

Solar Orbiter was selected in October 2011 as ESA's M class mission scheduled for launch in 2017. The mission is highly challenging, using repeated flybys of Venus to enable the spacecraft to climb out of the ecliptic, allowing it to make the first high latitude observations of the solar atmosphere. This will: determine in-situ the properties and dynamics of plasma, magnetic fields and particles in the near-Sun heliosphere; survey the fine detail of the Sun's magnetised atmosphere; and identify the links between activity on the Sun's surface and the resulting evolution of the corona and inner heliosphere. RAL Space are leading the SPICE (Spectral Imaging of the Coronal Environment) instrument on behalf of ESA, with a consortium of teams from six countries. As well as managing the instrument development, build, integration and test, RAL Space are also providing the APS detectors and front-end electronics (funded by the UKSA).

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SOLAR DYNAMICS OBSERVATORY

SDO is NASA's high resolution space-based solar observatory providing detailed imaging of the Sun in ultraviolet and extreme-ultraviolet light, and mapping the Sun's magnetic fields. The ultraviolet images allow us to study the complex solar atmosphere in excellent detail and this, combined with the magnetic maps that are produced exploiting the so-called Zeeman effect, and with our associated instruments on the SOHO, Hinode and STEREO spacecraft, are providing the most comprehensive, thorough view of a star's atmosphere ever produced. RAL has provided the CCD camera electronics systems for two of the three scientific instruments on SDO to the Lockheed Martin Solar and Astrophysics Laboratory, and participates in the scientific exploitation of the mission as a Co-Investigator group.

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GOES-R

The Geostationary Operational Environmental Satellite (GOES) program is a key element of the National Oceanic and Atmospheric Administration's (NOAA) operations. The GOES-R series of spacecraft are intended to provide more timely and accurate weather forecasts, and improve support for the detection and observations of meteorological phenomena that directly affect public safety, protection of property, and ultimately, economic health and development. RAL are providing the camera electronics for the solar ultraviolet imaging instrument (SUVI) on GOES-R, the first of which is due for launch in 2015.

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HINODE

The Solar-B mission, now known as Hinode, was launched in September 2006, carrying instruments developed by Japan, the USA and the UK. Building on the highly successful SOHO and Yohkoh solar missions, Hinode has imagers that can map the magnetic fields at the solar surface, and resolve the structure and evolution of the different layers of the solar atmosphere with unprecedented high-resolution.

The Extreme-ultraviolet Imaging Spectrometer (EIS) was built by an international consortium led by the Mullard Space Science Laboratory (UK). EIS measures spectral emission lines in order to accurately diagnose the conditions in the solar plasma at a pixel size of 750 km on the solar surface, and RAL scientists are using the data to better understand the Sun's atmosphere and its effect on Earth. RAL was a key player in the development of EIS, providing assembly, integration and test facilities, with particular responsibility for cleanliness and contamination control.

RAL is also responsible for the vital radiometric calibration of EIS and for software for operations planning and support.

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STEREO

The Sun occasionally ejects vast gas clouds into space. Known as coronal mass ejections (CMEs), each cloud may carry 1,000,000,000 tonnes of gas into space at several hundred km/s. When these clouds engulf Earth they can disrupt power, navigation, communication and satellite control systems.

The NASA STEREO mission was launched in October 2006. Two identical probes are now in solar orbit, one flying ahead of the Earth and one behind the Earth, from where they look back at the Sun and the space between the Sun and the Earth. This two-platform view allows 3D images of the Sun to be produced, as well as unprecedented views of the entire Sun. However, it is the RAL-led Heliospheric Imagers on STEREO that look at the space between the Sun and the Earth, using wide-angle telescopes. They have provided unprecedented views of Earth-impacting clouds, allowing us to explore new ways of predicting impacts at the Earth and other locations in the Solar System, and enabling methods to track CMEs from Sun to Earth. In addition to leading the HI instruments, all of the imaging instruments aboard the two STEREO spacecraft use a novel CCD-based camera system developed by RAL.

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SOHO

Launched in 1995, the ESA/NASA Solar and Heliospheric Observatory (SOHO) is the world's largest solar physics space mission and it has revolutionised our understanding of the Sun. RAL's Coronal Diagnostic Spectrometer (CDS) is a unique instrument, designed to detect solar extreme ultraviolet radiation which allows us to probe conditions in the solar corona. The spectra recorded by CDS provide information on temperature, density, elemental composition and flows of very hot plasma trapped in the Sun's magnetic field. The CDS operation is run from RAL, where the requests for observations from a user community of 15 UK institutes and over 60 worldwide groups are coordinated, planned and run. CDS has enabled the discovery of a number of phenomena, including rotating columns of plasma that resemble tornadoes and the fact that the Sun's atmosphere is riddled with Earth-sized explosions known as blinkers.

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NEAR-EARTH OBSERVATION

CLUSTER

Cluster is an ESA mission, revolutionising our understanding of the interaction between electrically charged particles from the Sun and the Earth's magnetic field. The four Cluster spacecraft were launched in pairs on 16 July and 9 August 2000 and now orbit the Earth in formation. This unique set of multi-point measurements allows us to study, for the first time, the three-dimensional structure of the fundamental physical processes occurring in the near-Earth environment as they vary with time. Originally planned to last two years, the mission has been through several extensions making use of new multi-scale formations and visiting scientific regions not covered earlier in the mission. Cluster is expected to continue returning exciting new science measurements until at least 2014.

RAL Space has a major hardware involvement in two of the instruments: RAPID measures the energetic ions and electrons, while PEACE measures the lower energy electrons. RAL also provides ESA's Cluster Joint Satellite Operations Centre which has responsibility for planning and commanding the international science operations. The UK Cluster Data Centre (page 31) is also located at RAL and provides science data processing and dissemination facilities for the national Cluster community and is also responsible for the technical development of ESA's Cluster Active Archive. RAL Space scientists play a leading role in the science exploitation from the mission and in coordinating activities with ground-based instrumentation such as EISCAT (page 8).

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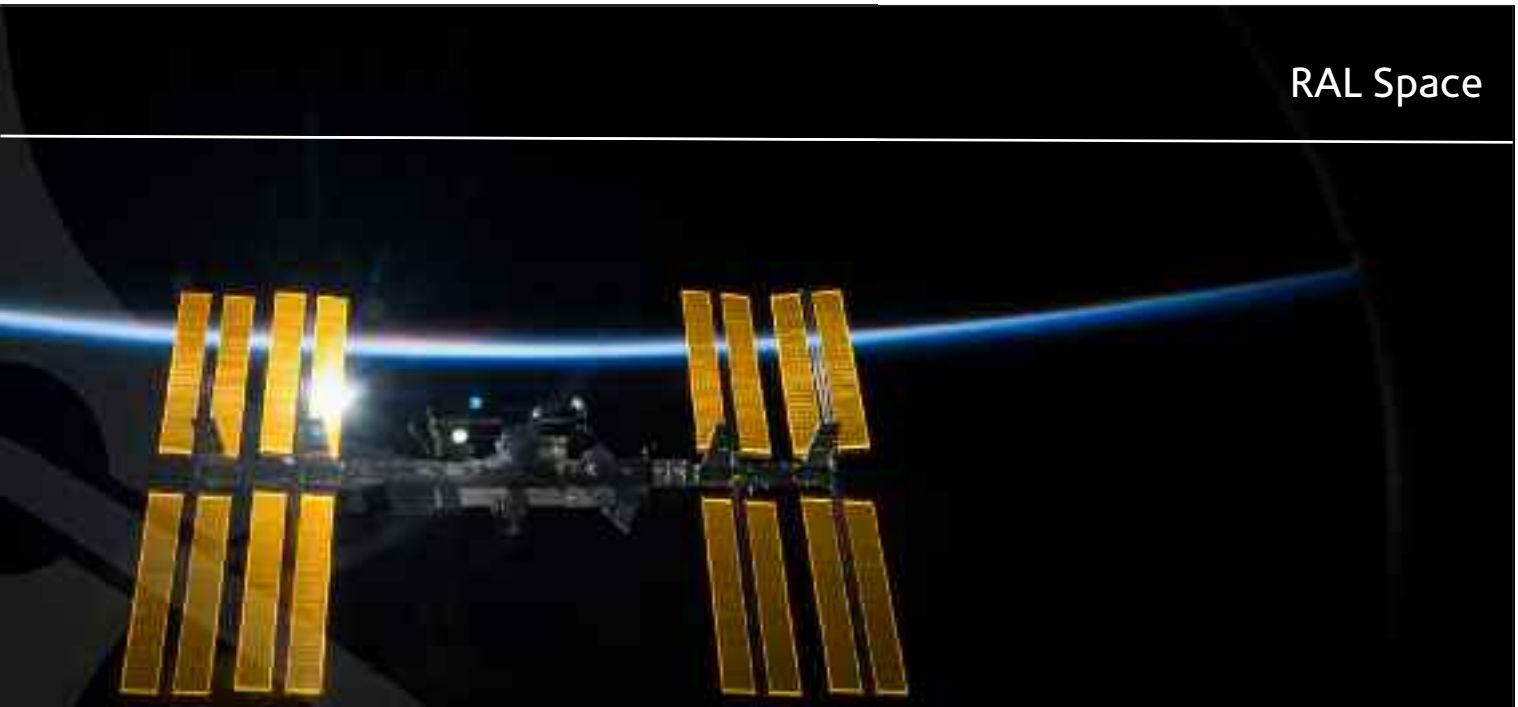

THE MicroFTS INSTRUMENT

A novel Fourier Transform Spectrometer (FTS) design, based on a static optical configuration, has been developed in RAL Space. The microFTS is an ultra compact instrument that employs a technique known as Static Imaging Fourier Transform Spectroscopy (SIFTS) to perform the same function as a Michelson interferometer.

The development of the microFTS is funded by STFC Innovations Ltd and NERC through a proof of concept grant. During this project a breadboard prototype instrument operating in the near infrared and visible spectral regions has been developed. The prototype measures 50 × 50 × 30 mm and has a mass of 0.4 kg.

The compact and rugged nature of the SIFTS instrument means that it could be used in environments where current FTIR spectrometers would be unsuitable. This technology has a wide range of applications, but would useful in specific areas such as:

- Atmospheric composition and air-quality monitoring through in-situ sampling, e.g. ground-based urban air-quality monitoring or from Unmanned Arial Vehicles (UAV's) and radiosondes.
- On-line sensors to improve the efficiency of large scale industrial chemical processes.
- Atmospheric monitoring through remote sensing techniques, either through ground-based observations or from microsatellite platforms.
- Environmental testing by enforcement and operating agencies, e.g. hazardous waste, roadside vehicle emissions spot checks, gas leak detection and monitoring, etc.

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EARTH OBSERVATION

Making observations of the land, sea and air from space allows scientists to develop and improve their models of our environment. Space instruments provide continuous, global measurements for many years at a time, allowing events like El Niño to be studied.

CFARR

The Chilbolton Facility for Atmospheric and Radio Research is equipped with a wide range of advanced meteorological radars, lidars and radiometers; they are being used to study atmospheric processes that lead to storms and flooding, and to more accurately predict climate change. Activities include measurements of: (i) Clear air turbulence and refractivity, (ii) Cloud characteristics, (iii) Precipitation, (iv) Water Vapour, and (v) Aerosol. The Facility makes a major contribution to reducing current uncertainties in numerical weather and climate models by making detailed measurements of key parameters. The data collected is archived and distributed by the BADC. CFARR is operated with support from the Natural Environment Research Council.

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GLOBAL NAVIGATION SATELLITE SYSTEMS (GNNSS)

Since early 2006, the 25 m antenna at Chilbolton Observatory has been used to conduct regular in-orbit testing (IOT) on the Giove-A and Giove-B 'Galileo' satellites for SSTL and the European Space Agency. Detailed measurements have also been made on Chinese 'Compass-Beidou', Russian GLONASS, and American GPS satellites. Various geostationary satellites transmitting the EGNOS navigational overlay signals have also been characterized.

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RADAR FOR SPACE SITUATIONAL AWARENESS (SSA)

As part of ESA's Space Situational Awareness Preparatory Programme, the Chilbolton radar has recently been used to track, and to characterise, over 40 satellites in low-earth orbit out to 2500 km range. Targets with radar cross sections below 1 square metre have been successfully observed with the current system, and modifications are planned to increase the radar's sensitivity by 100 fold – greatly extending its capability to track micro-satellites and space-debris.

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EISCAT

The European Incoherent SCATter facility consists of three radar systems in Northern Scandinavia. RAL Space manages the UK participation in EISCAT, under contract from NERC and in close collaboration with NERC research centres. Current EISCAT research focuses on the influences of the Sun on the Earth's environment, including topics relevant to space weather, universal plasma processes, space debris and potential upper atmosphere influences on climate. Much of the research is carried out in conjunction with spacecraft, including ESA's Cluster quartet, and future support is planned for the Swarm and KuaFu missions, as well as other ground-based instruments. EISCAT is currently engaged in the design of a next-generation phased array radar system (EISCAT_3D) to replace the present facilities in mainland Scandinavia. RAL Space is involved in the design and planning of the new system, which will greatly extend the range and sensitivity of EISCAT. In addition, a collaboration with the Chinese Research Institute of Radio Propagation is set to provide a new 50 m dish for the EISCAT Svalbard Radar, greatly enhancing the capabilities of that system.

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ENVISAT

ESA's ENVIronmental monitoring SATellite was successfully launched on 1 March 2002. It carries the AATSR instrument – the third in the AlongTrack Scanning Radiometer (ATSR) series – which has now produced a 15–year data set. AATSR monitors global sea surface temperatures (SST) to an accuracy of 0.3°C for climate study purposes. RAL provided subsystems and laboratory calibration, and also the reference data processing system. MIPAS, an infrared spectrometer, measures pressure, temperature and trace gases such as ozone from 6 km to 70 km in the atmosphere. RAL provided the low vibration cooler electronics. RAL is also involved with the development of new atmospheric data products from AATSR, SCHIAMACHY and MIPAS for the wider benefit of the research community.

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MSG (GERB)

The Geostationary Earth Radiation Budget series of instruments monitor the reflected sunlight and thermal emissions from Earth, to study daily variations and long-term climate changes. There are four instruments in the series: these have been designed and built by a European consortium led by RAL.

GERB2 was launched into geo-synchronous orbit on the first of EUMETSAT's METEOSAT Second Generation Satellites (MSG-1) on 28 August 2002, and GERB1 on MSG-2 on 21 December 2005. This meets EUMETSAT's requirement to have two of the MSG satellites in orbit at any time, one providing the operational service and the other acting as a reserve. Each instrument can scan the Earth roughly every three minutes and both are designed to provide a service for more than 15 years. RAL has also developed and operates a major part of the GERB ground segment, receiving data from the instrument in near real-time, then processing and archiving it.

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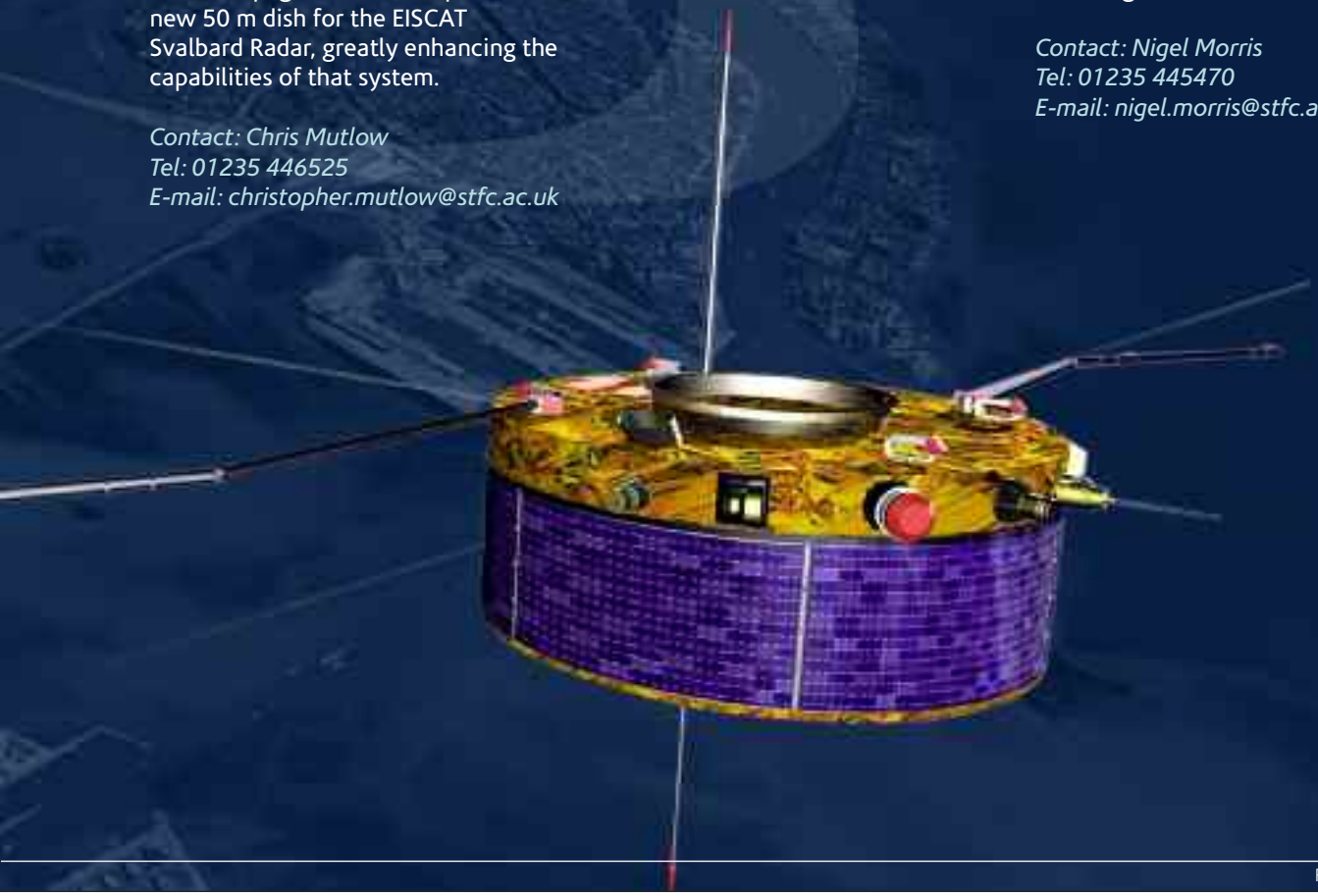

EARTH OBSERVATION
CONTINUED

MST RADAR

The NERC Mesosphere-Stratosphere-Troposphere Radar at Aberystwyth is the UK's most powerful and versatile wind-profiling instrument. In the ST mode it provides continuous measurements of the three-dimensional wind vector over the altitude range 2 km to 20 km at high resolution (300 m in altitude and a few minutes in time). The data are operationally assimilated by the Met Office for the purposes of numerical weather prediction. In the M mode it provides continuous observations of the altitude range 58 - 94 km. The unusually strong and persistent Mesosphere Summer Echoes, which occur during June and July of each year, are known to be related to the occurrence of Noctilucent Clouds, which form at altitudes of around 85 km. The radar underwent a major refurbishment in early 2011 which has significantly improved its performance.

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ATMOSPHERIC COMPOSITION DATA FOR CLIMATE RESEARCH

As a partner in the National Centre for Earth Observation, RAL Space has developed schemes to retrieve atmospheric constituents of major importance to climate research from satellite observations. The cloud and aerosol schemes devised in co-operation with Oxford University for the ATSR-2 and AATSR sensors are now being employed to produce global data sets from 1995 onwards in ESA's Climate Change Initiative. The ozone profile scheme is similarly being employed to produce height-resolved data sets spanning the troposphere and stratosphere from nadir-viewing uv/visible spectrometers (GOME-1, SCIAMACHY and GOME-2) from 1995 onwards in the CCI. A scheme to retrieve height-resolved methane from the ir spectrometer (IASI) on MetOp has also now been demonstrated in NCEO, and will be used to produce global data from 2007 onwards, to augment height-averaged data available from shortwave ir spectrometers.

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PREMIER

PREMIER is a candidate mission for ESA's Earth Explorer-7. It aims to quantify processes controlling atmospheric composition in the height region of most importance to surface climate by observing the mid/upper troposphere and lower stratosphere in 3D and on much finer scales than previously accessible from space. This will be achieved by limb-emission sounding with fixed arrays at ir and millimetre wavelengths. By viewing rearwards and flying in formation with the Eumetsat's MetOp-Second Generation satellite to collocate with observations by its suite of advanced nadir sounders, PREMIER aims to also quantify links with surface emissions, pollution and air quality. RAL Space has a leading scientific role in the mission and also in the airborne demonstration of new millimetre-wave observing techniques and development of critical technology.

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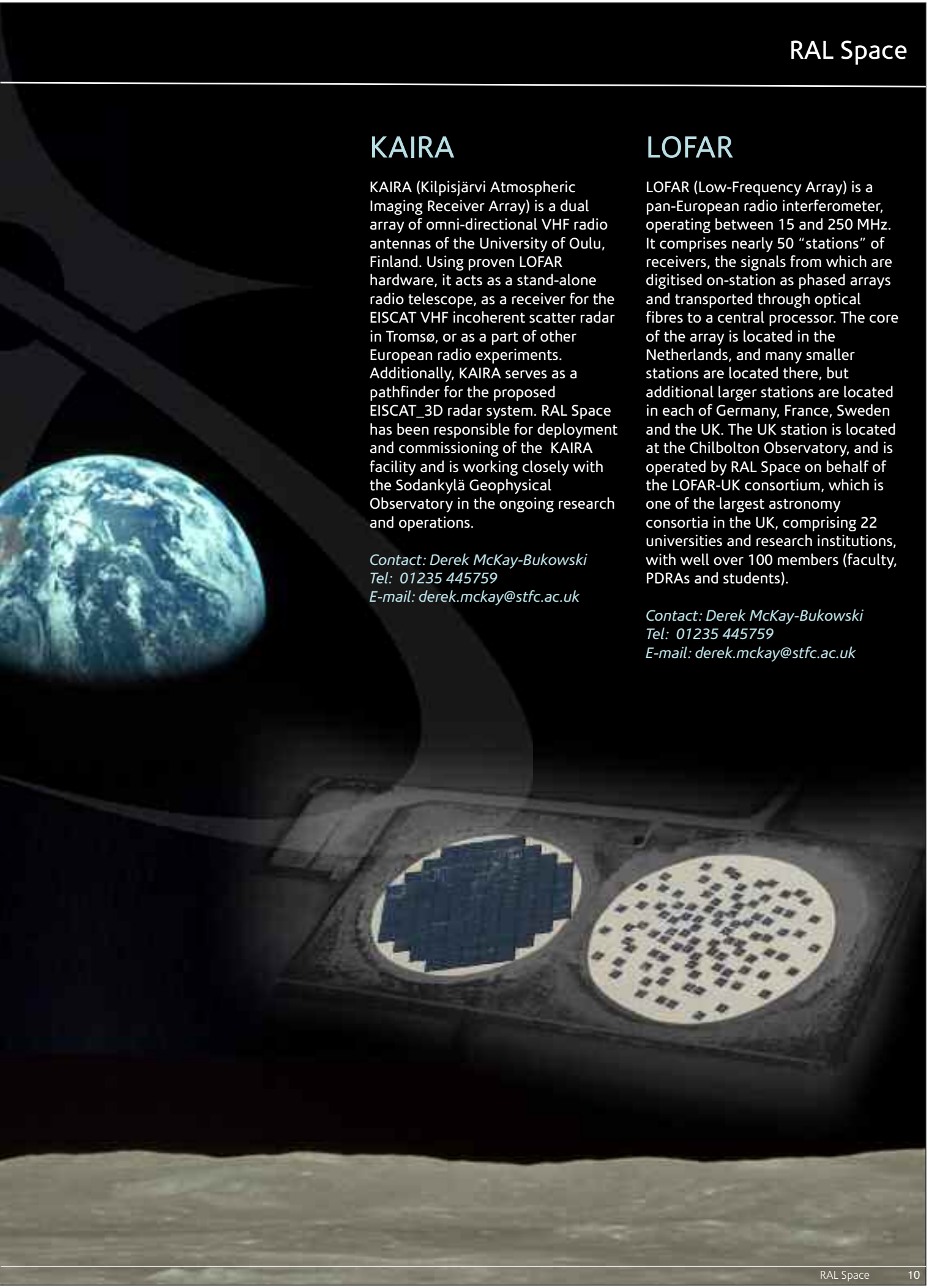

KAIRA

KAIRA (Kilpisjärvi Atmospheric Imaging Receiver Array) is a dual array of omni-directional VHF radio antennas of the University of Oulu, Finland. Using proven LOFAR hardware, it acts as a stand-alone radio telescope, as a receiver for the EISCAT VHF incoherent scatter radar in Tromsø, or as a part of other European radio experiments. Additionally, KAIRA serves as a pathfinder for the proposed EISCAT_3D radar system. RAL Space has been responsible for deployment and commissioning of the KAIRA facility and is working closely with the Sodankylä Geophysical Observatory in the ongoing research and operations.

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LOFAR

LOFAR (Low-Frequency Array) is a pan-European radio interferometer, operating between 15 and 250 MHz. It comprises nearly 50 "stations" of receivers, the signals from which are digitised on-station as phased arrays and transported through optical fibres to a central processor. The core of the array is located in the Netherlands, and many smaller stations are located there, but additional larger stations are located in each of Germany, France, Sweden and the UK. The UK station is located at the Chilbolton Observatory, and is operated by RAL Space on behalf of the LOFAR-UK consortium, which is one of the largest astronomy consortia in the UK, comprising 22 universities and research institutions, with well over 100 members (faculty, PDRAs and students).

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EARTH OBSERVATION CONTINUED

BROAD-BAND RADIOMETER (BBR)

The Broad-Band Radiometer (BBR) instrument will be one of four instruments on ESA's EarthCARE (Earth Clouds, Aerosols and Radiation Explorer) satellite. The mission's aim is to study the role that clouds and aerosols play in reflecting incident solar radiation back into space and in trapping infrared radiation emitted from the Earth's surface. These are currently the largest uncertainties in weather prediction models.

BBR's role is to study the radiance at the top of the atmosphere, using three telescopes to look in three directions simultaneously. The instrument is being designed, assembled and tested at RAL, in collaboration with SEA in Bristol.

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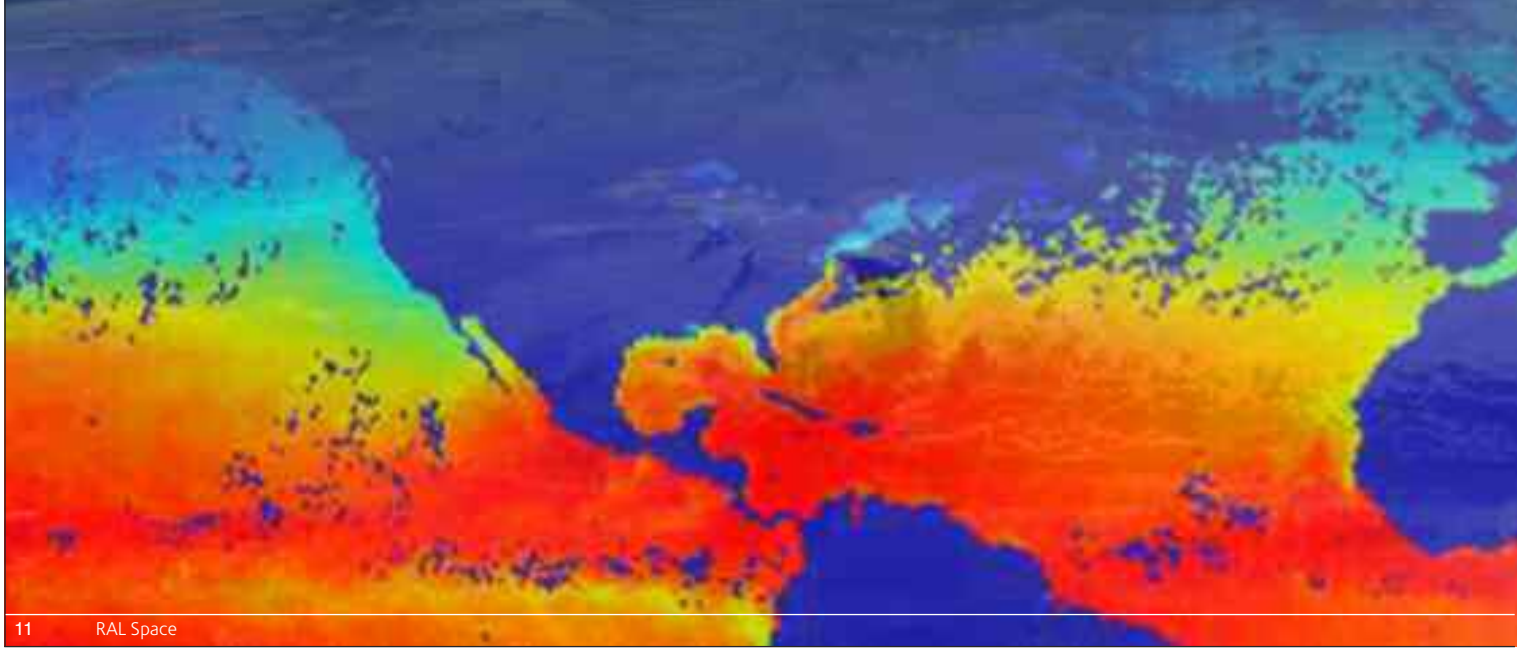

SEA AND LAND SURFACE TEMPERATURE RADIOMETER (SLSTR)

The Sea and Land Surface Temperature Radiometer (SLSTR) on the ESA/EU GMES Sentinel-3 mission will provide highly accurate measurements of global Earth surface temperatures. Data from SLSTR will continue the sea surface temperature (SST) records provided by the successful Along Track Scanning Radiometer (ATSR) series. As with ATSR, the principle design feature is a conical scanning geometry that provides two views of the earth at different view angles to enable accurate atmospheric correction. SLSTR builds on the concept by incorporating a wider swath to improve the global coverage and incorporates additional spectral channels to improve cloud detection and forest fire detection.

The design concept for SLSTR, that was originally proposed in studies undertaken by RAL Space and Thales, is currently being developed for flight by the instrument prime contractor Selex Galileo (Italy). RAL Space scientists and engineers are playing a key role in the development of the instrument design, its calibration and the definition of the data products and processing algorithms. A dedicated facility is being built at RAL Space for the pre-flight calibration activities that are essential for SLSTR providing accurate and traceable measurements.

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SISTeR

SISTeR Instrument for Satellite In-orbit Validation.

In-orbit validation of satellite measurements is a critical process which ensures the accuracy of the scientific data returned from Earth Observation (EO) satellites. Through the use of the ship borne Sea Surface Temperature (SST) monitoring instrument, SISTeR (Scanning Infrared Sea Surface Temperature Radiometer), satellite data is validated when the satellite and SISTeR measurements coincide and the SST is recorded at the same location by both instruments.
The SISTeR instrument, developed at RAL, is a compact, self-calibrating infrared filter radiometer that uses two internal reference blackbodies to maintain its own calibration. This provides highly accurate measurements (noise <30mK) that are traceable to the ITS-90 temperature scale.

Through a partnership between the STFC and the Carnival Group UK (Cunard's parent company), SISTeR has been installed on the largest ocean going liner in the world, the Queen Mary 2. SISTeR is positioned at the prominent vantage point, high on the starboard bridge wing, giving a perfect view of unbroken water. The mixture of transatlantic crossing, (from Southampton to New York) and tropical round the world cruises give an ideal combination of hot and cold water measurements which can be used to validate EO satellites.

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PLANETARY SCIENCE

RAL has a very strong instrument programme, including missions to all the inner solar system planets, as well as comets and the Saturnian system. These missions continue to yield a wealth of science and help us to understand the Earth and the solar system, and the planetary systems of other stars.

CHANDRAYAAN-1 and SMART-1

RAL Space provided a sophisticated miniature X-ray spectrometer (D-CIXS), which employs new technology to reduce the mass and volume of the instrument, for the ESA SMART-1 mission (2003 to 2006) and an enhanced version (C1XS) for the Indian Space Research Organisation (ISRO) Chandrayaan-1 mission (2008 to 2009).

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MARS EXPRESS

RAL supplied the micro-channel plates for ASPERA-3 (Analyzer of Space Plasma and EneRgetic Atoms), one of the instruments on Mars Express. RAL is part of the team, led by IRF Sweden, studying the erosion of the atmosphere by the solar wind. RAL provided the Payload Operations Service for Mars Express supporting science operations planning and commanding under contract to ESA (see page 28).

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VENUS EXPRESS

2005 saw the launch of Venus Express, a small ESA mission intended to build on the success of Mars Express. Venus presents many mysteries, not least the evolution of its comet-like atmosphere and its interactions with the solar wind which will be probed by the ASPERA-4 instrument in which RAL is involved.

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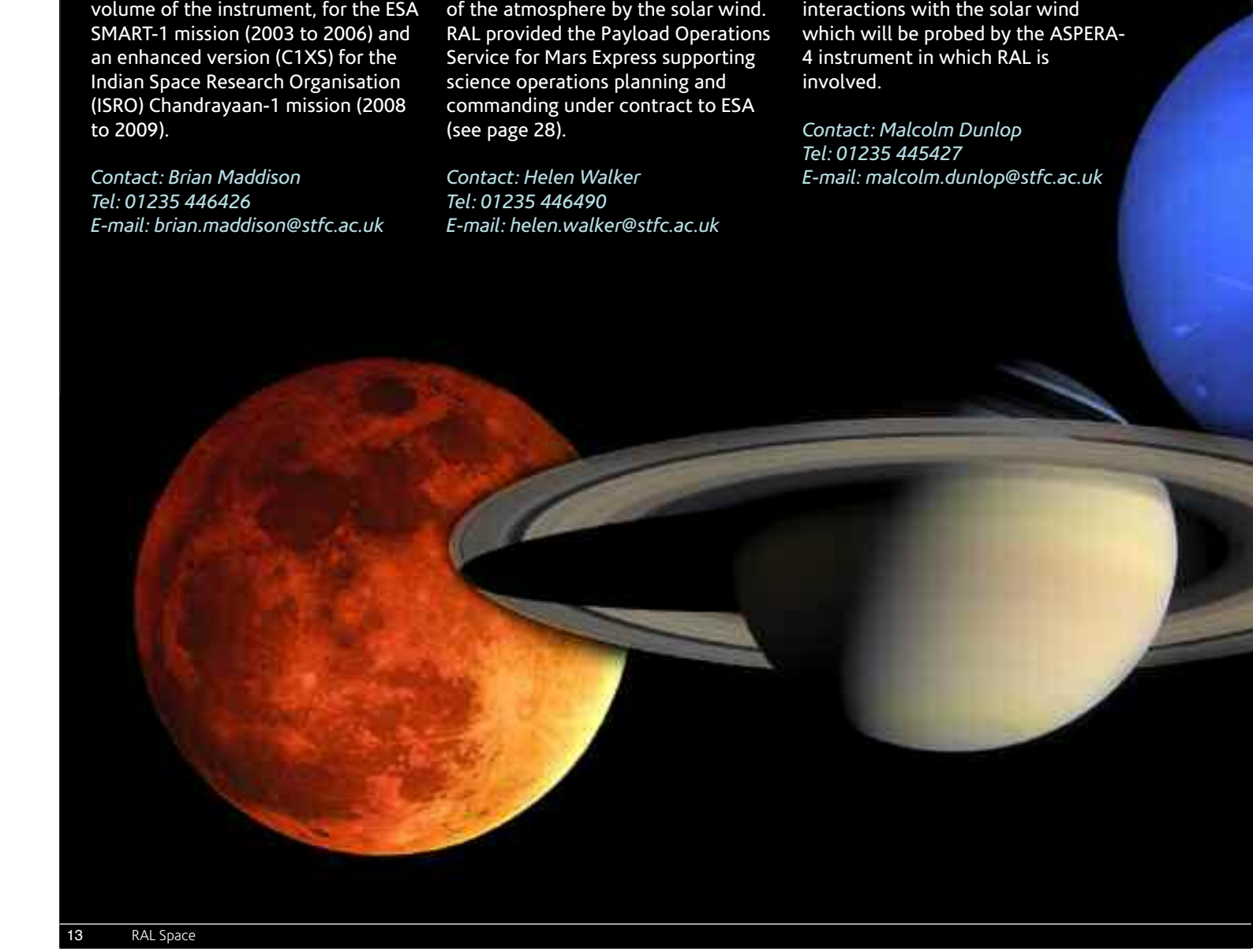

EXOMARS

The Raman spectrometer has been selected as one of the instruments to fly on ESA's Exomars mission to Mars and will play a key role in the elemental and molecular analysis of the Martian surface. In particular, it will look for the geological and biogeological spectral signatures that could herald the presence of extinct or extant life on Mars. RAL is providing the CCD focal plane and readout electronics for the instrument, including custom-designed ASICs.

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CASSINI/HUYGENS

The Huygens probe (built by ESA) has landed on Titan, Saturn's largest moon. It carried the surface science package, which contained RAL electronics and packaging to support the sensors from various institutes. RAL also contributed to the Cassini Plasma Sensor and the Cosmic Dust Analyser which are on board Cassini for its four-year campaign in orbit around Saturn.

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ROSETTA

ESA's Rosetta satellite was launched successfully in 2004 and will rendezvous with comet Churyumov-Gerasimenko in May 2014. Once it has arrived, it will carry out very precise isotopic ratio measurements as the comet evolves during its journey towards the Sun. RAL supported the Open University by building an advanced gas chromatography instrument, Ptolemy, which is part of the lander. It includes a compact, low-power, mass spectrometer, controlled by integrated circuits (ASICs) designed at RAL and making use of nanotechnology developed at RAL for the ionisation device. The challenge for the team was not only to build the instrument in an ultra-compact, low power and lightweight form, but also to ensure that it would function perfectly after several years of inactivity on the way to the comet.

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ASTRONOMY

RAL supports astronomers using instruments in space and on the ground, with a wide range of expertise in design, building, testing and calibration. RAL scientists also participate in astronomical research using data from these and other instruments to further our understanding of galaxies and the formation of stars and planets.

ALMA

RAL is participating in the construction of the Atacama Large Millimetre Array (ALMA), located in the Atacama Desert of Northern Chile at an altitude of over 5000 m. The facility will combine fifty-four 12 m diameter and twelve 7 m diameter telescopes to form an interferometric imaging array. When completed in 2012, the instrument will provide an unprecedented sensitivity and spatial resolution at millimetre and sub-millimetre wavelengths. It will be used to detect and study the earliest and most distant galaxies, and probe dust-obscured regions which are the birthplace of stars and planets. The project is an international collaboration between Europe, North America and Japan. RAL is contributing to key areas of ALMA construction technology – cryogenics, photonics, calibration, and receiver integration – and hosts the ALMA UK Project Office.

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JWST MIRI

The James Webb Space Telescope (JWST) is planned to succeed the Hubble Space Telescope. The Mid-Infrared Instrument (MIRI) on JWST will provide unique capabilities to study the dust-enshrouded regions of the universe. RAL is responsible for several key areas, including assembly, verification, calibration, thermal systems engineering and contamination control.

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HERSCHEL (SPIRE)

The Spectral and Photometric Imaging REceiver (SPIRE) is one of three instruments on ESA's Herschel mission which was launched in May 2009. The instrument operates between 200 and 700 microns to observe the coolest parts of the Universe. In three years of highly successful operations the instrument has provided astronomers with a unique view of the formation of stars and galaxies with over three hundred scientific papers using SPIRE data published so far. The instrument was built and operated by a consortium of European and American groups, led by Cardiff University. RAL Space was responsible for the instrument conceptual design, project management and ground testing. We are currently leading the in-flight operations and instrument calibration.

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PLANCK

Planck is an ESA mission to map the structure of the Cosmic Microwave Background radiation. The detail and sensitivity of the measurements will help determine fundamental parameters relating to the origin and evolution of the universe. For frequencies higher than 100 GHz, a bolometer receiver system is used, operating at very low cryogenic temperatures. RAL Space has provided thermal analysis for the design of the system and RAL Technology Department provided the design, parts of the hardware and testing of the cooling stage that reduces the temperature from 20 K to 4 K using a Joule-Thomson system.

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VISTA

The Visible and Infrared Survey Telescope for Astronomy is a 4 m diameter wide-field survey telescope, dedicated to conducting detailed imaging surveys of the sky. The project is nearing completion at the European Southern Observatory's Cerro Paranal Observatory in Chile, with the UKATC having provided the telescope and enclosure, and RAL having led the team that built the 3 tonne, 3 m long IR Camera. The Camera comprises a large vacuum vessel with sixteen 2k x 2k pixel infrared detectors cooled to liquid nitrogen temperatures, making up the largest IR focal plane in the world.

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KAIRA

KAIRA (Kilpisjärvi Atmospheric Imaging Receiver Array) is a dual array of omni-directional VHF radio antennas of the University of Oulu, Finland. Using proven LOFAR hardware, it acts as a stand-alone radio telescope, as a receiver for the EISCAT VHF incoherent scatter radar in Tromsø, or as a part of other European radio experiments. Additionally, KAIRA serves as a pathfinder for the proposed EISCAT_3D radar system. RAL Space has been responsible for deployment and commissioning of the KAIRA facility and is working closely with the Sodankylä Geophysical Observatory in the ongoing research and operations.

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LOFAR

LOFAR (Low-Frequency Array) is a pan-European radio interferometer, operating between 15 and 250 MHz. It comprises nearly 50 "stations" of receivers, the signals from which are digitised on-station as phased arrays and transported through optical fibres to a central processor. The core of the array is located in the Netherlands, and many smaller stations are located there, but additional larger stations are located in each of Germany, France, Sweden and the UK. The UK station is located at the Chilbolton Observatory, and is operated by RAL Space on behalf of the LOFAR-UK consortium, which is one of the largest astronomy consortia in the UK, comprising 22 universities and research institutions, with well over 100 members (faculty, PDRAs and students).

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RESEARCH

RAL Space undertakes pure research in solar physics, solar-terrestrial physics atmospheric physics, planetary and magnetospheric physics, astronomy and fundamental physics. The research encompasses a wide range of interests, running in close harmony with the space hardware projects, and involves collaboration with many university groups in the UK and abroad.

SOLAR PHYSICS

RAL's Solar Physics Group is a cornerstone of UK solar physics research, providing an established, world-leading research programme with observational and scientific leadership over a wide range of key areas. The basic underpinning experimental expertise of the group is solar atomic spectroscopy, for the derivation of solar plasma diagnostics. The group has a long heritage, including the NASA Solar Maximum Mission (1980-89), the CHASE Spacelab 2 experiment (1985), the Japanese Yohkoh mission (1991-2001), and SOHO (page 4). The group has major hardware roles in the NASA STEREO (page 4) and the Japanese Hinode (page 4) missions, and studies are underway for an RAL-led instrument for the ESA Solar Orbiter (page 3). The Group is involved in SDO (page 3) and also in some smaller projects such as the RESIK instrument aboard the Russian Coronas spacecraft, and the NASA SERTS and EUNIS rocket experiments. The bulk of the research effort over the last few years has been underpinned by observational work using the SOHO spacecraft and, in particular, the RAL-led Coronal Diagnostic Spectrometer (CDS) and, more recently, the STEREO and Hinode observations. Specific research areas include studies of fundamental processes in the solar atmosphere, research into solar mass ejection processes and flares, and plasma diagnostic techniques.

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SPACE ENVIRONMENT PHYSICS AND SPACE WEATHER

Space environment studies within RAL Space covers a broad range of pure and strategic research. We are particularly concerned with how the space environment affects human activities through space weather impacts on advanced technologies and through the effect of solar activity on Earth's climate. We have leading roles in a wide range of UK, European and international activities including studies of extreme space weather events, studies of long-term trends in space weather and climate, the development, operation and exploitation of space-based and ground-based instruments for space weather studies – and work with our solar physics colleagues on the effects of heliospheric transients such as coronal mass ejections and co-rotating interaction regions. This research is underpinned by strong involvement in studies of key physical processes in the space environment including reconnection and particle energisation. The research is centred around RAL Space's involvement in projects such as Cluster, SWARM, STEREO, UKSSDC, ESPAS, the Chilton and Port Stanley ionosondes, and the EISCAT and EISCAT-3D radars. We work closely with several university groups including Lancaster, Reading and Warwick and with partners in the rest of Europe, China and the US.

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ATMOSPHERIC PROCESS RESEARCH

The research activities supported by the Chilbolton Group are directed to studying atmospheric physical processes; in particular those involving cloud, rain, water vapour and aerosol. Using measurements made with ground-based radars, lidars and radiometers, we are: (i) establishing spatial-temporal models of convective storms, (ii) characterising water vapour density profile variations, and (iii) studying aerosol profile variations. In addition, boundary layer processes are being studied using measurements of sensible heat flux, water vapour profiles, and vertical wind profiles. The ability to undertake these process studies at the Observatory has been enhanced by the recent deployment of a Met Office wind profiling radar.

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FACILITIES

We are able to provide a range of services to customers, which can enhance a project's technical and management programme. We can provide assistance through experts and managers from various related disciplines.

ENVIRONMENTAL TEST

The environmental test facilities at RAL have been developed to meet the exacting needs of people involved in the design, manufacture and qualification of space hardware.

The facilities consist of a vibration test facility, with the capability of cryogenic vibration, numerous thermal vacuum facilities, vacuum bakeout facilities and large clean rooms for assembly and integration of sensitive flight hardware. They are all equipped with the latest instrumentation, and have modern computer-based control and monitoring/data acquisition systems. Our largest facility is a 3 m diameter by 5.5 m long thermal vacuum chamber (currently the largest in the UK), which is currently being configured to perform the thermal calibration of the MIRI Instrument, one of three instruments on the James Webb Space Telescope. The test facilities also include an extreme ultraviolet radiometric calibration facility for solar instruments, capable of taking instruments up to 3 m long. These facilities are available for use by industry and universities.

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MOLECULAR SPECTROSCOPY FACILITY

The Molecular Spectroscopy Facility (MSF) offers use of world-class instruments and unique equipment, combined with scientific and technical support.

It is home to two of the highest resolution Fourier-transform spectrometers in the UK and these, as well as a number of lower resolution spectrometers, may be coupled with a variety of sample-containment cells. These have optical path lengths ranging from less than a millimetre up to one kilometre and may be operated at temperatures between 77 and 473 K, and pressures up to five atmospheres. The facility has gas and aerosol handling equipment and time-resolved, aerosol, and reflectance spectroscopy accessories.

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PRODUCT ASSURANCE

RAL Space has managed and contributed to many projects involving universities, UK research councils, government departments, industry, ESA, NASA, EUMETSAT, ESO and the EU. All our work on space and ground-based instruments is covered by our Quality Management System which is certified to the ISO 9001:2008 and TickIT (Software) standards, and the RAL Space Product Assurance Group ensures compliance with any applicable customer or agency standards such as ECSS.

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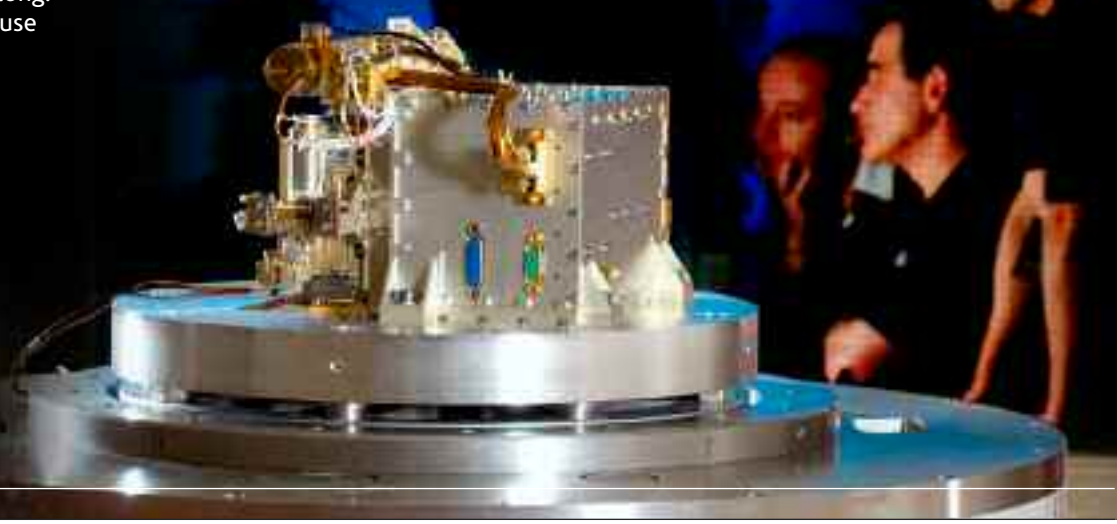

CHILBOLTON OBSERVATORY

The Chilbolton Observatory is a research station in Hampshire, where experimental studies into weather, climate and radio science are conducted. The site is dominated by the fully steerable 25m antenna (dish) which can host advanced radars and sophisticated, sensitive receivers. Radar systems on the dish are used for weather observations and for tracking satellites and detecting space debris in support of Space Situational Awareness (page 7). The receivers on the dish are used for in-orbit testing of global navigation satellites (page 7).

A significant part of the Observatory's work is performed by the Chilbolton Facility for Atmospheric and Radio Research – CFARR (page 7), a ground-based atmospheric remote sensing facility serving both the atmospheric science and the radio science communities. It is one of the largest ground-based atmospheric profiling facilities in the world. Data collected by the Facility instruments are archived and distributed through the BADC (page 29).

Major experimental campaigns are frequently based at the Observatory; visiting scientists from the UK and overseas are able to operate their instruments alongside those of the Facility while research aircraft collect data overhead. The site hosts numerous observing instruments on a long term basis for different organisations that can benefit from the co-located observations, and support capabilities of the staff. The Met Office has established their own compound which is instrumented to make upper air observations.

In 2010, the first UK site for a LOFAR station was established on a field site at the Observatory. LOFAR (page 10) is an advanced radio astronomy telescope which uses arrays of stationary antennas. It can be used on its own to conduct observations, or linked to a growing network of LOFAR stations in

Europe to enhance overall capability. The Observatory also supports the RAL Ground Station (page 28) by hosting three antennas which are remotely controlled: a UHF/VHF satellite system to support cubesats, and 4.5m and 6.1m S/X-band systems used to receive the high rate data from earth observation satellites.

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DESIGN

Our experienced engineers use the latest tools to design and build space and ground-based instruments. We adopt an integrated approach and support projects throughout the full life cycle, from requirements analysis and conceptual design through to flight or commissioning.

MECHANICAL DESIGN AND STRUCTURAL ANALYSIS

RAL has a team of highly-skilled mechanical engineers with considerable experience in the design of lightweight subsystems for scientific instruments. We use the latest 3-D computer-aided design tools, with links to computer-aided manufacture and in-house rapid prototyping technologies. We also have finite element software tools for detailed structural analysis of parts and complete systems.

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ELECTRONICS DESIGN

The Space Electronics Group has provided electronics packages for many of the instruments described in this brochure. Specialities include camera electronics systems, on-board processors and their software, and image processing using advanced electronics.

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THERMAL SYSTEMS ENGINEERING

The Thermal Engineering Group has many years experience in the design, development and verification of spacecraft scientific payloads and ground-based space instruments. We provide a range of services from conceptual studies and detailed analysis, through to the definition and management of thermal tests. We also design and manufacture multilayer insulation blankets.

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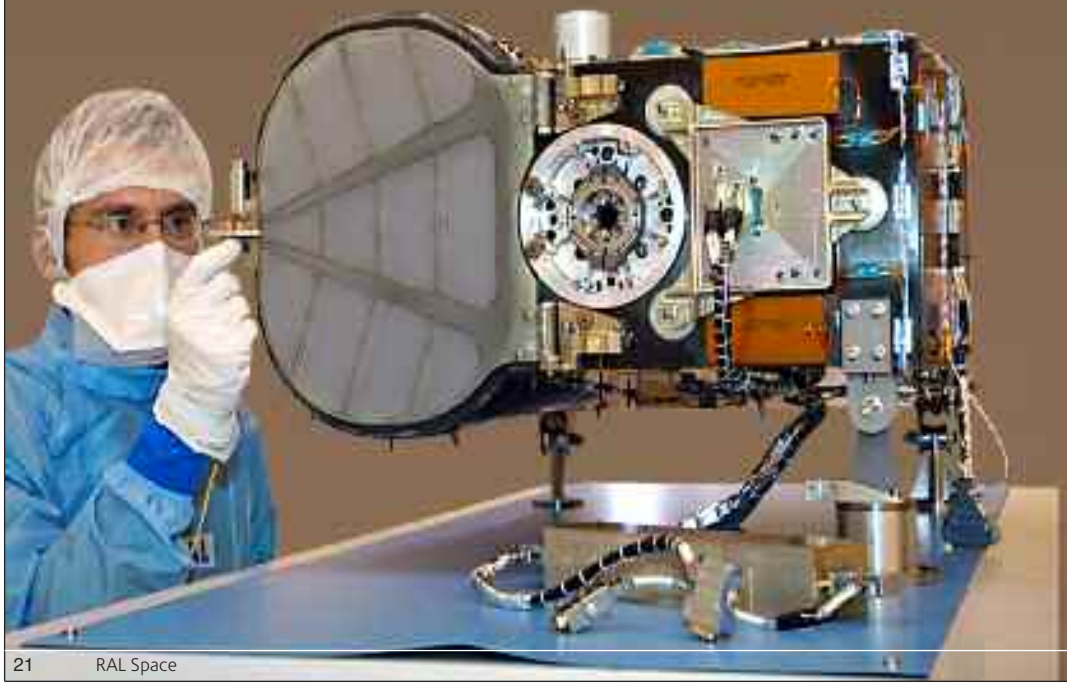

OPTICAL SYSTEMS

RAL designs and builds novel optical systems for a wide variety of space-borne instruments and ground-based astronomy projects. The range of applications includes high-resolution cameras for remote sensing, fibre-fed spectrographs for IR astronomy, and non-imaging systems (illumination and stray light analysis etc).

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RF DESIGN

We are expert in the design of advanced radars, radiometers, satellite and terrestrial propagation measurement links, and their associated data acquisition systems. Our experience spans the RF range from HF to millimetre-wave, with customers in the government, academic and commercial sectors. We specialise in custom designs and prototypes, and have a proven track record of delivery encompassing concept studies, system engineering and detailed, component-level, design- and-build.

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TECHNOLOGY

RAL has a number of internationally-important technology groups, each specialising in a specific critical technology associated with cutting-edge space instrumentation. This expertise, backed by RAL's extensive engineering capability, allows us to play a leading role in defining novel scientific instruments.

RADAR SYSTEMS

We are expert in all aspects of radar design, with extensive practical experience in polarimetric, Doppler, phase-coherent, and pulse-compression techniques at UHF, microwave and millimetre wavelengths. Our operational systems span the range 1 to 94 GHz, employing advanced RF and signal processing technology to characterize meteorological processes (such as precipitation, clouds and clear-air atmospheric effects), and objects in low-earth orbit (such as satellites and space-debris).

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HIGH RESOLUTION VIDEO FROM THE ISS

RAL Space have been awarded a contract to build two cameras to fly on the International Space Station for the UrtheCast project. Building on the heritage of other RAL Space Earth observation programmes, one camera will be capable of imaging to a resolution of 5m per pixel over a swath of 40km. The second will be a new high-resolution video camera capable of 1m per pixel imagery mounted on a steerable platform that will allow near real-time video footage of events across the globe.

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CCD TECHNOLOGY

The group has a strategic programme in the development of CCD detectors, and readout electronics technology. It provides a UK lead through the development of radiation-tolerant ASICs designed specifically for science-grade CCD camera systems. A new CCD video processing ASIC provides a preamplifier, correlated double sampler and 16-bit ADC all in one low-power chip.

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LASER HETERODYNE RADIOMETER

Mid-infrared Laser Heterodyne Radiometers (LHR) offer chemical remote sounding with high detection sensitivity, high spectral, and spatial resolutions. We are developing both passive and active optical heterodyne systems based on quantum cascade lasers, as well as optical integration for miniaturization of LHR systems. Applications cover Earth and planetary observations, environmental monitoring, and security and defence.

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CRYOGENIC ENGINEERING

RAL has a specialist capability in cryogenic engineering for space projects. We are involved throughout the full project life cycle, and have the expertise to cover all areas of instrument design and testing.

A number of project-dedicated cryostats are currently being used to verify flight hardware designed and built at RAL.

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MILLIMETRE WAVE TECHNOLOGY

The Group is expert in technology for heterodyne radiometry between 100 GHz and 3.5 THz. Our devices, components and systems are used from ground, air and space borne platforms for astronomy and remote sensing of the Earth's atmosphere. Examples of the Group's capabilities range from mixers and frequency multipliers, through photomixer sources and wire grid polarisers, to autonomous cryogenic radiometer systems. World class design, assembly and test skills are complemented by a Precision Development Facility and a dedicated semiconductor processing laboratory.

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INTEGRATED FOCAL PLANES

Our CCD partnership with e2v technologies extends to the development of new technology enabling the integration of large arrays of CCDs within a focal plane together with the front-end electronics needed to operate them. New digital signal processing techniques are being developed for handling the video signals from multiple CCD outputs. In addition, new high-voltage ASICs are being developed to replace previously required boards of electronic components.

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TECHNOLOGY CONTINUED

ROBOTICS GROUP

The Robotics Group at RAL Space is developing autonomous robotic platforms that can be used both for space and terrestrial applications. The Group was formed to exploit existing in-house expertise in electro-mechanical systems, sensors and autonomous systems. Research and development is currently underway as to how such devices may be used, not just in the space arena for the exploration of the Moon and Mars, but also importantly, for the large number of potential applications here on Earth.

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CONCURRENT DESIGN FACILITY

The RAL Space Concurrent Design Facility (CDF) is a newly commissioned facility for the quick and efficient conceptual design of complex space programmes. The CDF has been developed by RAL Space Engineers, but incorporates the experience and best practice of other CDFs located overseas (for example ESA-ESTEC, NASA, ASI, CNES, JAXA and DLR).

The RAL Space CDF consists of three elements:

- The facility infrastructure: The room itself, the IT and communications hardware and the specialist space mission design software which enable Engineers to design individual elements of a complex mission.
- The CDF design database: The software which automatically links the design of the individual elements of a mission into a coherent system
- The methodology: The process for efficiently coordinating the design activities of Engineers and Scientists in a concurrent design environment.

These three elements of the CDF enable novel space concepts to be quickly and efficiently assessed from technical, financial and programmatic points-of-view.

The key benefits of utilising the RAL Space CDF for Mission studies are:

- Study Quality: The rigorous and systematic approach to the design process helps ensure that the results are of a consistently high standard.
- Efficiency: ESA and other CDF operators report a reduction in assessment study costs by a factor of two and elapsed time by a factor of four.
- Fostering Collaboration: Teams of Scientists and Engineers from different organisations and countries are able to start work together on real projects quickly, build collaborations and profit from each other's strengths.
- Stimulation of new scientific and business initiatives: New ideas and concepts can be refined, elaborated and assessed from scientific, technical and business points-of-view and take them to the next level of maturity.

The RAL Space CDF is currently working on three separate studies designing:

- A mission for monitoring atmospheric Carbon from Space.
- A mission to provide an early warning system for Space Weather events which threaten critical infrastructure on Earth.
- A concept to provide Mars Landers with long range autonomy thanks to a novel propulsion system.

The CDF is currently available to be used by ISIC members as well as the wider UK space community to help ensure that we remain internationally competitive.

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OPERATIONS

RAL has a proven track record, recognised internationally, in the areas of satellite mission planning and payload science operations, providing ground-station services and software for the precision control of a wide variety of telescope systems.

TELESCOPE CONTROL

RAL played a major role in developing the control system for the two 8 m Gemini astronomy telescopes operating in Hawaii and Chile and the VISTA 4 m infrared survey telescope at ESO's Cerro Paranal observatory (page 16). Current projects include the 2 x 8 m Large Binocular Telescope in Arizona and the Pan-STARRS observatory in Hawaii. RAL software will be used for the 8 m Large Synoptic Survey Telescope to be built in Chile and for the refurbished control systems for the 8m Keck telescopes. RAL also played a leading role in the evaluation of the pointing performance of the prototype 12 m ALMA mm telescopes (page 15).

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MISSION PLANNING AND OPERATIONS

RAL has been carrying out satellite mission planning and payload science operations dating back to the late 1970s with missions such as Ariel 5, IRAS, AMPTE-UKS and ISO. More recent work included the design, implementation and execution of science operations services for three of ESA's missions. The first of these is the Joint Science Operations Centre for the four-satellite Cluster mission (page 5), launched in 2000 and the first of ESA's Cornerstone missions. The second is the Payload Operations Service for ESA's Mars Express (page 13) mission, operating since early 2004 and Europe's first mission to Mars. The third is the European Payload Operation Service for the two satellite Double Star Programme mission, launched in late 2003 and mid 2004, the first joint mission between ESA and the China National Space Administration. The Cluster mission is still operational, the Double Star Satellites have re-entered Earth's atmosphere and ESA has taken over full operation of Mars Express.

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SATELLITE GROUND STATION FACILITY

The RAL Satellite Ground Station Facility operates a number of antenna systems. It can provide tracking, telemetry and control (TTC), as well as data reception for earth orbiting satellites, and near earth spacecraft. The 12 m antenna supports S-band uplink and downlink using standard modulation schemes and data protocols. It is linked to the International Space and Innovation Centre Flight Operations Centre – ISIC and will provide the ground station for ISIC missions.

The 4.5 m antenna and the newly installed 6.1m antenna support S and X-band high rate data reception. A recently established UHF/VHF ground station and a 2.4 m S-band antenna will be used to support amateur satellites within the international community. RAL is providing the primary ground station services for the UKube-1 and TechDemoSat-1 satellites which are to be launched in 2013.

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DATA MANAGEMENT

RAL Space has very wide experience in the processing, analysis and archiving of science data. This expertise covers the fields of ground and space-based astronomy, solar terrestrial physics, and ionospheric, atmospheric and Earth observation. Allied to this, it has set up and maintains many web sites providing the science community with access to archived data.

CEDA (CENTRE FOR ENVIRONMENTAL DATA ARCHIVAL)

CEDA is a partner in the development and operation of the CEMS (Climate and Environmental Monitoring from Space) in ISIC, the International Space Innovation Centre.

The CEMS facility aims to provide Earth Observation data, processing capability and services to support both science and commercial users. This includes storage and access to datasets, and tools for quality control (assessment and dissemination of information on data/product quality), production capacity for new products, hosted service capabilities and links to the data visualisation centre at ISIC. The physical infrastructure includes around 1.7PB storage and 20 processing nodes with commercial and academic components hosted at ISIC and STFC's e-science data centre respectively. The facility is a joint academic commercial partnership between CEDA/NCEO and Logica and Astrium-GEO.

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BADC

The British Atmospheric Data Centre supplies meteorological and other atmospheric data to the scientific community. It also provides a long-term archive for data collected by NERC-funded research. Data suppliers include the UK Meteorological Office, the European Centre for Medium-range Weather Forecasts and NASA. The BADC is involved in setting European standards for data exchange and developing data infrastructure for the global exchange on climate data.The BADC is a NERC Environmental Data Centre.

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UKSSDC

The UK Solar System Data Centre, incorporating the World Data Centre for STP, archives and distributes data, encompassing a diverse set of satellite and ground-based observations concerning the Sun, the planets, interplanetary space and the Earth's magnetosphere and ionosphere (spanning many solar cycles).

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CDHF

The Cluster Data Handling Facility is a national facility for the collection and distribution of data from the ESA Cluster and related Solar Terrestrial Physics missions. The CDHF is part of a European network of data centres for the Cluster and Double Star missions (page 5), and also provides a mirror site of survey data from all of NASA's related missions. The CDHF is actively involved in heliophysics virtual observatory activities and standards development, and is one of the founding members of the international Space Physics Archive Search and Extract (SPASE) consortium, which aims to improve access to space physics data.

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UK CDC

The UK Cluster Data Centre is the national facility responsible for providing the centralised collection, processing, formatting and distribution to the scientific community of quicklook and survey level data from the ESA Cluster cornerstone mission. The UKCDC provides online facilities in support of instrument performance monitoring, multi-instrument inter calibration and science investigations. The data centre provides formal support for more than 120 registered Cluster Principal Investigators, Co-Investigators and science affiliates as well as hundreds of additional UK and international users of the publicly accessible services and data products. The UKCDC has also played a defining role in the development of the ESA Cluster Archive which is providing long-term, standards based repository for the Cluster data that will provide an important scientific legacy from this major mission. The four Cluster spacecraft were launched in the summer of 2000 and are currently expected to operate until about 2014.

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DATA MANAGEMENT
CONTINUED

CCSDS

The Consultative Committee for Space Data Systems is the body that develops standards for space data and information transfer systems. The member agencies of CCSDS include NASA, ESA, JAXA and UKSA. These standards are essential to ensure that cooperating space agencies can communicate with each other's spacecraft and control centres. An example of this is the use of CCSDS standard protocols in the flight operation control centre at the International Space Innovation Centre on the Harwell campus, enabling it to control a wide range of spacecraft. As well as enabling interoperability between agencies, the standards also drive cost reduction since having clear standards for communication and control means that each agency does not need to develop separate protocols for their own missions. RAL represents UKSA on the management council and contributes to work on data archiving standards.

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HELIOPHYSICS VIRTUAL OBSERVATORIES

Exploitation of data from solar system missions has traditionally been hampered by the heterogeneous nature of the data combined with the need to combine many different measurements in order to fully understand physical processes and the context within which they operate. In recent years improvements in computers, networks, standards and techniques have started to come together to address these issues. RAL Space has a significant role in a number of projects including the NASA led SPASE initiative and the EU FP7 funded HELIO virtual observatory that are making significant progress in helping scientists to better exploit the measurements both from historical and future missions.

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NEODC

The NERC Earth Observation Data Centre (NEODC) is the NERC dedicated data centre for earth observation science. As one of seven NERC Environmental Data Centres it is responsible for active curation and dissemination of NERC's environmental data holdings, and provides dedicated support to the NERC National Centre for Earth Observation (NCEO). NEODC provides the NERC and wider environmental science communities with access to a growing collection of EO data from a variety of satellite and airborne sensors. Recent highlights include the provision of access to hundreds of Terabytes of data from remote sensing instruments on board ESA's ENVISAT and EUMETSAT's MetOp satellites. The data are available to download to registered users, and more recently, the CEMS facility provides access to a cloud computing infrastructure for users to efficiently process the data next to the archives.

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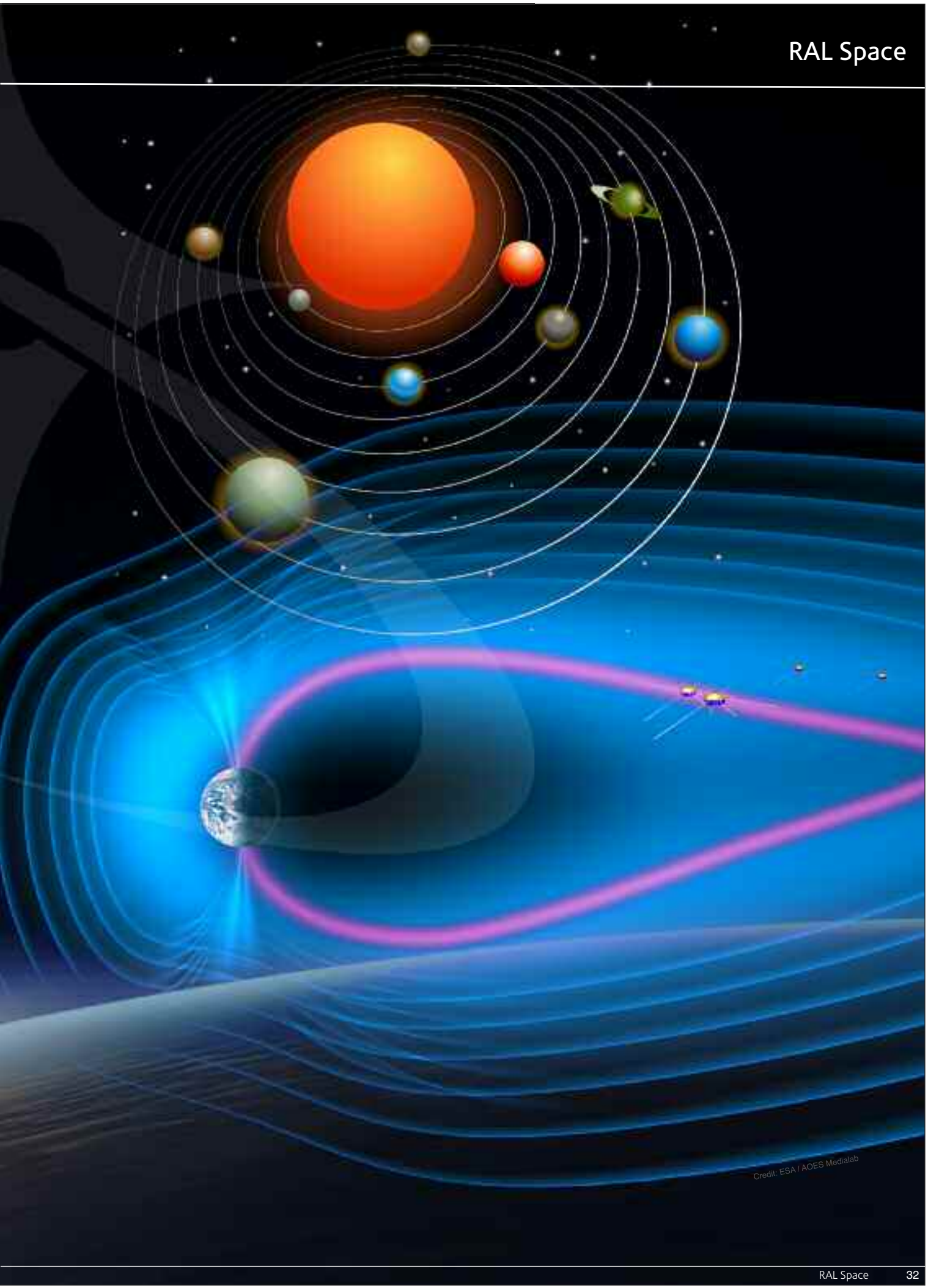
Credit: ESA / AOES Medialab

RAL SPACE MISSIONS

RAL Space has been involved in more than 200 space missions and instrument (as of October 2012).

Launch year	Mission	Main RAL involvement	Objectives
1974	Ariel-5	Services, operations	Astronomy
1978	IUE	Design, technology, data management	Astronomy
1979	Ariel-6	Services, operations	Astronomy
1980	SMM (XRP)	Technology, operations, data management	Sun
1983	IRAS	Operations	Astronomy
1984	AMPTE-UKS	Design, technology, operations, data management	Near-Earth
1985	Giotto (DIDSY, JPA)	Services, technology, data management	Near-Earth
1985	Spacelab 2 (CHASE)	Services, design, technology	Sun
1987	Ginga (Astro C, LAC)	Services, technology	Astronomy
1989	ZEBRA (balloon-borne)	Services, technology, operations	Astronomy
1990	HST	Data management	Astronomy
1990	ROSAT (WFC)	Technology, data management	Astronomy
1990	CRRES (MICS)	Technology	Near-Earth
1991	ERS-1 (ATSR-1)	Services, technology, operations, data management	Earth
1991	UARS (ISAMS, MLS)	Technology	Earth
1991	Yohkoh (BCS)	Technology	Sun
1995	ERS-2 (ATSR-2)	Services, technology, operations, data management	Earth
1995	ISO (LWS, PHT, CAM)	Services, technology, operations, data management	Astronomy
1995	SOHO (CDS)	Services, design, technology, data management	Sun
1996	Polar (CEPPAD,CAMMICE)	Technology	Near-Earth
1997	Minisat-1 (LEGRI)	Technology	Astronomy
1997	ACE	Operations	Sun
1997	Cassini/Huygens (CAPS, CDA, SSP)	Technology	Planetary
1998	TRACE	Data management	Sun
1999	UOSAT 12	Services	Earth
2000	Cluster II (RAPID, PEACE)	Services, technology, operations, data management	Near-Earth
2000	STRV-1c/d	Operations	Earth
2001	CORONAS-F (RESIK)	Services, technology	Sun
2001	BADR-B	Technology	Earth
2001	MoroccoSat	Technology	Earth
2002	ENVISAT-1 (AATSR, MIPAS)	Services, technology	Earth
2002	EOS-AQUA (HSB)	Technology	Earth
2002	NOAA-M (AMSU-B)	Technology	Earth
2002	MSG-1 (GERB2)	Services, design, technology	Earth
2002	Coriolis (SMEI)	Electronics	Sun

Launch year	Mission	Main RAL involvement	objectives
2003	Mars Express (ASPERA)	Design, technology, operations	Planetary
2003	SMART-1	Technology	Planetary
2003	NIGERIASAT-1	Services	Earth
2003	BILSAT-1	Services	Earth
2003	UK-DMC	Services	Earth
2004	Double Star (Equatorial)	Operations	Near-Earth
2004	Rosetta (MODULUS)	Services, design, technology	Planetary
2004	EOS-AURA(HIRDLS)	Services, design	Earth
2004	Swift	Services	Astronomy
2004	Double Star (Polar)	Operations, technology	Near-Earth
2005	TopSat	Technology	Earth
2005	Venus Express	Technology	Planetary
2005	MSG-2 (GERB1)	Services, design, technology	Earth
2005	GIOVE-A	Services	Earth
2006	Solar-B (EIS, HINODE)	Services, technology, data management	Sun
2006	Metop 3	Services	Earth
2006	STEREO (SECCHI)	Services, design, technology	Sun
2007	CFESAT	Services	Earth
2007	RAPIDEYE	Services	Earth
2008	Chandrayaan-1	Design, technology	Planetary
2008	GIOVE-B	Services	Earth
2009	Herschel (SPIRE)	Services, design, technology, operations	Astronomy
2009	Planck (HFI, LFI)	Services, design, technology	Astronomy
2010	Solar Dynamics Observatory	Services, design, technology	Sun
2012	MSG-3 (GERB3)	Services, design, technology	Earth
2013	UrtheCast	Technology	Earth
2014	LISA Pathfinder	Design, technology	Astronomy
2014	MSG-4 (GERB4)	Services, design, technology	Earth
2015	BepiColombo	Services, design, technology	Planetary
2015	SUVI or GOES-R	Design, technology	Sun
2015	ACECHEM	Technology	Earth
2017	Solar Orbiter	Services, design, technology	Sun
2017	LISA	Services, design, technology	Astronomy
2018	JWST (MIRI)	Services, design, technology	Astronomy

Further information
The Rutherford Appleton Laboratory is part of the Science and Technology Facilities Council and is a partner member of the UK Space Agency (UKSA).

RAL Space conducts the bulk of its programmes in collaboration with other UK scientific institutes and universities. These include the following:

Aberystwyth
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ATC
Bath
Birmingham
Bristol
Cambridge
Cardiff
Central Lancashire
Cranfield
DECC
DEFRA
De Montfort
DSTL
DTI
Durham
East Anglia
Edinburgh
EPSRC
Essex
FCO
Glamorgan
Glasgow
Herriot Watt
Hertfordshire
Hull
Imperial College, London
Keele
Kent
Kings College London
Leeds
Leicester
Liverpool John Moores
Manchester
Met Office
MOD
MRC
Mullard Space Science Laboratory
NERC
Nottingham
Ofcom
Open University
Oxford
Plymouth
Portsmouth
Queen's Belfast
Queen Mary London
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St. Andrews
Strathclyde
Surrey
Sussex
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UKSA
University College, London
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CNES (France)
CNR (Italy)
CNSA (China)
CONAE (Argentina)
COSPAR (International)
CRCSS (Australia)
CRERS (Morocco)
CSA (Canada)
CSIRO (Australia)
DLR (Germany)
DoD (USA)
DSRI (Denmark)
EUMETSAT (Europe)
ESA (Europe)
ESO (Europe)
EU (Europe)
IAA (International)
IAF (International)
IFSI (Italy)
IKI (Russia)
INPE (Brazil)
INTA (Spain)
IRF (Sweden)
ISIC (UK)
ISRO (India)
ITU (International)
JAXA (Japan)
KARI (Korea)
NASA (USA)
NPL (UK)
NRL (USA)
NCAR (USA)
NDRE (Norway)
NIVR (Netherlands)
NOAA (USA)
NSPO (Taiwan)
OECD (International)
PSI (Switzerland)
Roskosmos (Russia)
SACC
SRON (Netherlands)
SSA (Sweden)
SSTC (Belgium)
SUPARCO (Pakistan)
SWPC (USA)
UN (International)
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RAL Space also works with over 120 industry partners.

The Department provides opportunities for hosting senior scientist and engineers on sabbatical leave, visiting scientists on short-term visits, and university sandwich course students on one-year placements. RAL Space also provides graduate engineer training and CASE studentships. For more information see the Council's website.

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Science & Technology Facilities Council