Centre for EO Instrumentation

EO Technology and Instrument Developments

Funded in the CEOI 10th Call

September 2017

Part 1 - Airborne Demonstrators

CEOI10-HigherTRLFS-001

Project Title SPIDER Proof-of-Concept Campaign

Project Lead Airbus Defence and Space Limited

Project Partners Airbus DS Ltd

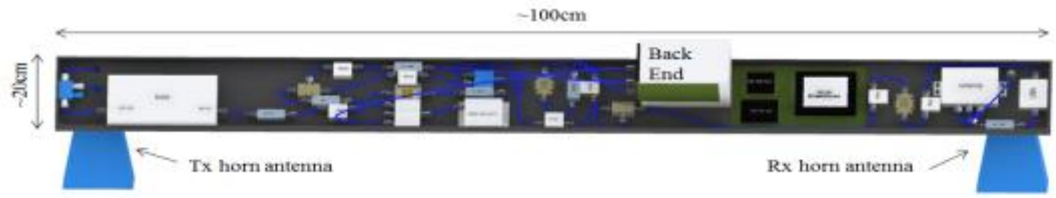
Maritime surveillance has historically been a top priority for security and defence agencies all around the world. The problems of global maritime surveillance are the immensity of the area to cover: more than 3.6 x 108 km2; the necessary low data latency: typically less than 1h; and the required revisit time: typically less than 2h. Although different users might have slightly different needs, these numbers illustrate the problem and present the challenge of ocean monitoring.

Currently, global maritime surveillance is addressed by combining information from several systems including optical, Synthetic Aperture Radar (SAR), and AIS spaceborne sensors. Of these, SAR is the most reliable payload for ship detection, offering all-weather day and night capabilities. However, SAR instruments require large antennas, and are bulky and power hungry. These features result in significant costs that are then multiplied by the required number of satellites needed for global timeliness and coverage. Although SAR instruments are excellent for detecting ships, many of the features of a traditional SAR are not needed in a system for pure maritime surveillance ship detection.

With this in mind, Airbus Defence and Space has recently proposed a new kind of radar, specifically designed for ship detection and referred to as SPIDER (Ship Position and Detection Radar). This innovative concept provides ship position, detection, and tracking capabilities. Being a designed-for-purpose payload, SPIDER significantly reduces the DC power consumption, the required downlink data-rates, and the antenna size with respect to SAR systems, resulting in a lightweight highly efficient instrument.

The work to be undertaken covers the implementation, validation, and verification of a SPIDER airborne proof-of-concept demonstrator from an existing preliminary design based on COTS components. The technology proposed for the demonstration enables a compact lightweight design that can be adapted to an existing aircraft pod making the approach cost-efficient.

The airborne campaign will demonstrate the proposed ship detection concept and will evaluate the results for relevant maritime scenarios.



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CEOI10-HigherTRLFS-005

Project Title Demonstrating Multi-View Spectroscopy for Greenhouse Gas Remote Sensing”

Project Lead University of Leicester

Project Partners Uni of Leicester, UK ATC, STFC RAL Space, Uni of Edinburgh

The Tropical Carbon Mission (TCM) addresses key science challenges of current carbon cycle research by collecting targeted data that will reduce the uncertainties in the tropical carbon budgets, and thus will allow us to determine with confidence if the tropics are a net source or sink of CO_2. TCM data, if launched around 2025, will also complement global survey CO_2 measurements from near-polar missions that are planned for the next 5-10 years such as the planned European CO_2 mission for carbon emission monitoring. By virtue of the multi-angle approach, TCM will provide reference CO_2 measurements compared to the planned nadir-only missions. The TCM concept is also attractive because the UK has the engineering and scientific expertise to contribute to all levels of design and application.

TCM was originally developed as a bilateral mission with NASA JPL, and further developed in a recent CEOI-funded EE-9 study. The budgetary constraints of the ESA EE-9 call would not allow us to submit TCM to that competition, unless we significantly compromised our primary science objectives. The TCM concept has matured significantly by virtue of recent CEOI funding, cumulative experience with the GreenHouse gas Observations of the Stratosphere and Troposphere (GHOST) spectrometer, and recent key science innovations associated with aerosol characterization using a multi-view approach.

In this project, we will use airborne demonstrations to firmly establish the GHOST instrument technology as TRL 6 and raise the SRL of the multi-view spectroscopy of CO_2 to SRL 5, in preparation for a future ESA EE-10 competition. We will achieve the multi-view measurements for the airborne demonstration by using an existing pointing system combined with a RAL-calibrated, optically upgraded version of GHOST. Using the results from the airborne demonstration and previous projects, we develop a roadmap for the TCM mission concept towards EE-10.

Part 2 - Fast Track Projects

CEOI10-EOTechDevFT-001

Project Title A New Generation of Deployable Optical Systems to Increase Small Satellite Capability

Project Lead Surrey Space Centre, University of Surrey

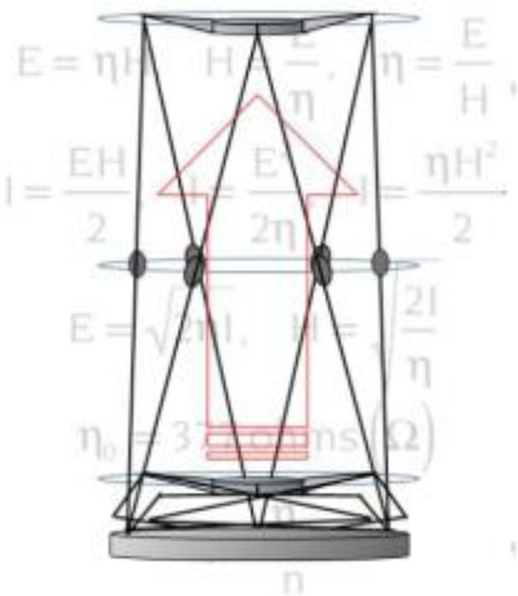
Project Partners Surrey Space Centre, SSTL

The ever-increasing demand for high resolution imagery for the Earth Observation market, with latency of minutes rather than days, requires satellite constellations, and due to the limited capabilities of current launch vehicles there is a need to reduce significantly the size and cost of the payload/camera and satellites.

However, to maintain the required resolution, the size of the optics and distance between elements cannot be significantly reduced. Therefore there is a need for deployable systems where the structure that supports the optical elements can be folded to allow a tightly packed configuration during launch and then deployed once in space, to position the optical elements at the required distances.

The objective of this project is to develop a physical proof of concept of a deployable optical system to pave the way to its implementation in a real SSTL demonstration mission. This will mainly utilize as building blocks technologies that are known, with the main innovation at system level, bringing together all the elements, with the necessary modifications to realize a system that meets the end-2-end requirements, thus de-risking its use in real missions to a level compatible with SSTL business model. Note that to date, the types of deployable system envisaged in this project have haven't yet reached a level of maturity to allow them to fly.

The focus will be on deployable frameworks as SSTL & SSC preliminary investigations have shown that this is the most promising structural typology for medium term application in space. The work will proceed as follows: Initially elicit requirements, conduct trade-off study on several deployment technologies (e.g. from conventional torsion spring driven knuckle joints, to tape springs hinge systems, to shape-memory composites etc.) and select a feasible technology for design. The middle phase of the project revolves around designing a truss structure with the chosen technology and performing numerical simulations. In the final phase of the project, the full truss structure will be constructed based on the most viable deployment technology chosen. The prototype will undergo fully functional testing including both a truss stability and a truss synchronisation and then will undergo detailed environmental testing (EVT).



The project will be led by the Surrey Space Centre and will be executed in partnership with SSTL to ensure industrial viability and a seamless route to market exploitation.

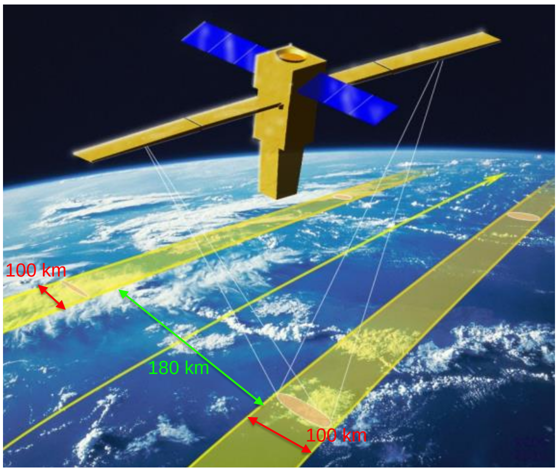
CEOI10-EOTechDevFT-002

Project Title SEASTAR+: enhancing the mission concept

Project Lead National Oceanography Centre

Project Partners NOC, Airbus DS Ltd, Satellite Oceanographic

The SEASTAR (previously Wavemill) satellite mission concept aims to measure the Ocean Surface Current (OSC) globally at unprecedented spatial resolution and is a candidate for a future core ESA Earth Explorer. SEASTAR seeks to deliver high-resolution wide-swath synoptic maps of total ocean surface currents from space to improve the parameterisations of oceanic mesoscale and sub-mesoscale dynamics. The primary products consist of total ocean surface current vectors, ocean wind vectors and directional ocean swell spectra over 2 x 100 km swaths with challenging requirements on spatial resolution (1 km or finer) and accuracy (5 cm/s). In a previous study this strong requirement on accuracy has been shown to be achievable except when the wind is aligned in some directions (specifically, the look directions of the two squint antennas). This non-optimal retrieval capability is due to weak wind direction sensitivity in these look directions, leading to poor estimates of wind direction and hence of the retrieved current vector. The addition of a third antenna with a broadside look direction, as on ASCAT, is thought to be the optimal geometry to retrieve an unbiased wind direction estimate, which is necessary to recover the current accurately.



The proposed work is aimed at enhancing the mission concept through studying the impact on the performance and the instrument definition of including this third look in the broadside direction and the need for dual polarisation in the two squinted beams. In addition, technical consideration will also be given to two other aspects of the payload design: i) assessing adding frequency scanning capabilities in elevation to increase the swath; ii) assessing the Hammerhead option for the original design. These variants have the potential to increase the available swath width and the performance over that swath of SEASTAR. Therefore, this study will increase both the Science Readiness Level and the Technical Readiness Level of the mission by enhancing the maturity of the technical solution. The output of this study will have a major impact on the credibility of the mission concept’s ability to achieve the defined measurement requirements and enable it to become a successful Earth Explorer candidate.

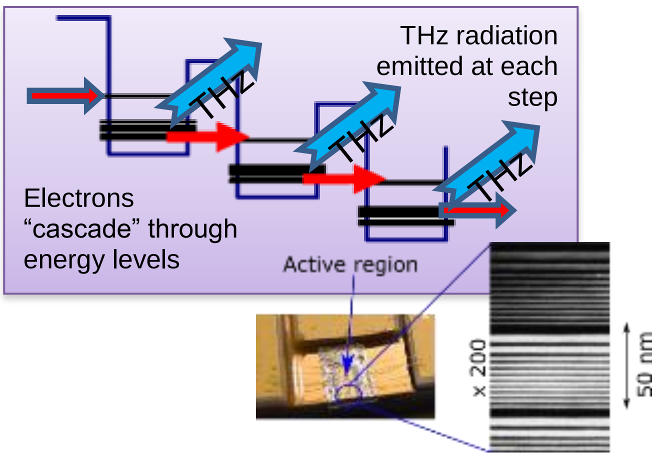
CEOI10-EOTechDevFT-003

Project Title	Stabilisation of 3.5 THz quantum-cascade laser local oscillators using Schottky diode technology
Project Lead	University of Leeds
Project Partners	Uni of Leeds, STFC RAL

Advances in satellite remote-sensing measurements of the constituents of the atmosphere have substantially increased our knowledge of atmospheric composition over the last decade. For instance, relatively localized studies of the mesosphere and lower thermosphere (MLT) region of the Earth's atmosphere provide an important indicator of global climate change. Nonetheless, global measurements of key atmospheric species have not been made directly by previous satellite missions.

To address this limitation, a proposed UK satellite mission, LOCUS (Linking Observations of Climate, the Upper atmosphere and Space weather) will deploy a multi-channel radiometer operating in the terahertz (THz) spectral range (0.8–4.7 THz) in low Earth orbit and will allow global high spectral-resolution measurements of important MLT atmospheric species, particularly atomic oxygen and the hydroxyl radical. Following the proposal of LOCUS for the 9th call of the ESA Earth Explorer programme, and the successful acceleration of its key payload technology through CEOI-ST support, the UK technical team now proposes to significantly enhance the stability and spectral-resolution of the THz radiometers. This will raise the instrumentation technical maturity to a level compliant with future in-orbit-demonstration opportunities, and will place the UK in a position of scientific and technical leadership with respect to MLT climate studies.

Our specific technical goal is to develop the first satellite-compatible (compact, integrated, robust and low-power) subsystem for stabilising the frequency of a compact 3.5-THz laser source. To this end, we will construct a harmonic mixer based on Schottky diode technology, and couple this to a local oscillator (LO). We will develop a precisely tunable 3.5-THz quantum-cascade laser (QCL) and use our LO/mixer system to stabilise and control its emission frequency. Our proposed programme is extremely well matched to CEOI/UKSA/NSTP strategy. Moreover, it will deliver additional return through future application in a wider range of diverse disciplines including planetary science, astronomy, spectroscopy, security and communications.



CEOI10-EOTechDevFT-005

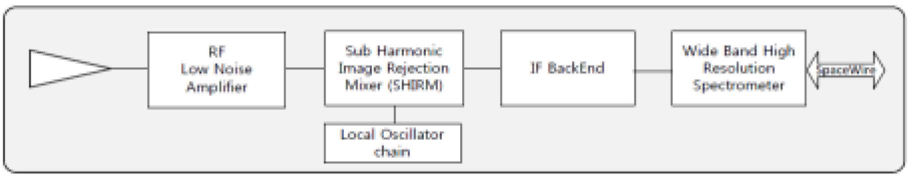
Project Title	HYMS (HYper-spectral Microwave Sounder): Novel and Critical Component Development and System Bread-boarding
Project Lead	Science and Technology Facilities Council (STFC)
Project Partners	STFC RALSpace, STAR-Dundee Ltd, JCR Systems Ltd

ESA has recently concluded a study contract that demonstrates the importance of hyperspectral microwave sounding as a future observational tool relevant to weather prediction. In this context, “hyperspectral” means “many channels” and at microwave frequencies it requires the use of hundreds of detection channels spread across a wide signal range that sample key molecular absorption bands, e.g. O2 and H2O. The information gained via this observation technique considerably enhances the accuracy of atmospheric profile retrievals and leads, in turn, to superior climate modelling and weather prediction.

With the above in mind, it is highly likely that new opportunities will be generated via ESA that involve the development and application of microwave hyperspectral sounding. This will be followed by airborne scientific measurement campaigns that will demonstrate the technique and the corresponding improvement anticipated in Numerical Weather Prediction (NWP). In order for the UK to be well positioned to engage with ESA in this respect, it is essential that related technical pre-development work is carried out in advance.

Developing and deploying a hyper-spectral imager poses many technical challenges. The most notable is the need to sample the spectral intensity within a narrow bandwidth and which, in turn, demands a reduction in system noise if the same radiometric precision is to be maintained. This implies a requirement for highly sensitive heterodyne radiometers with corresponding receiver channels containing state-of-the-art low noise front-end components.

We propose to develop via the CEOI a novel HYper-spectral Microwave Sounder (HYMS) laboratory demonstration system that possesses ultra-high radiometric sensitivity (<0.4 K) and exquisite spectral resolution (3 MHz). The system will target the most important line, O2 spectral signature with a centre frequency around 60GHz. This exciting development task will require the creation of an innovative receiver system architecture, critical component selection, especially in the areas of low noise amplifier technology, and the use of new ultra-high-speed digital backend data processing. The result will be a novel and highly advanced UK generated spectroscopy system that will be the precursor to a new wave of microwave remote sounders.



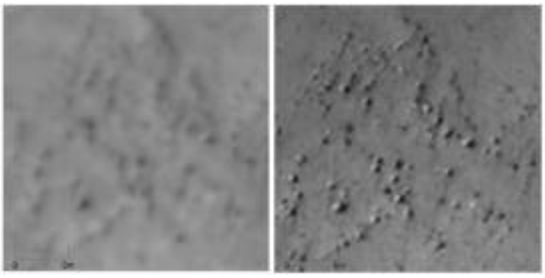
The technical advancement made will place the UK in a superior position with respect to likely international competitors and substantially enhance prospects of gaining involvement in and leadership of large-scale related development programmes which are expected to be announced by ESA in the near future.

The proposed activity is highly relevant to CEOI 10th Call Fast Track theme of new and innovative ideas and through this will advance corresponding TRL. The bidding team will comprise RAL (lead), STAR-Dundee and JCR Systems with scientific consultancy support provided via the UK Met Office.

CEOI10-EOTechDevFT-010

Project Title	SuperRes-EO: Super-resolution for high resolution EO imaging for targeted and global applications
Project Lead	University College London – Mullard Space Science Laboratory
Project Partners	UCL, SSTL

Very high spatial resolution imaging data is playing an increasing role in many commercial and scientific applications of Earth observation. However, given the physical constraints of the imaging instruments themselves, one needs to be able to trade-off spatial resolution against launch mass as well as trade off resolution against telecommunications bandwidth for transmitting data back to the Earth. This suggests that even with future optical communications, satellite images are unlikely to be able to resolve features smaller than 25cm in the near future for any usable swath-width. Many innovative remote-sensing applications are hampered by the size of the smallest object we can resolve from an orbital probe. These applications include precision agriculture and forestry mapping, intra-urban intelligence, maritime tracking and detection, and monitoring of key sites in very high levels of details for defence and security. A breakthrough technology is the use of super-resolution restoration. Although there have been demonstrations of super resolution restoration (SRR) techniques which have been successfully applied to video restoration and microscopic imagerys, they have never been able to achieve a resolution enhancement beyond the theoretical 1.75x limit. For EO satellite remote-sensing applications, these problems are exacerbated due to camera angle differences and the perturbing effects of isoplanatic patches of turbulence in the Earth's atmosphere.



Recent breakthrough research started within the EU FP-7 Planetary Robotics Vision Data Exploitation (PRoViDE) project (http://provide-space.eu). The MSSL Imaging group developed a novel super-resolution algorithm, (Gotcha-PDE-TV Super-resolution Restoration GPT-SRR), to restore distorted features from multi-angle observations using advanced feature matching and regularization approaches, achieving a breakthrough factor of up to 5x enhancement in resolution. The technique was originally demonstrated to resolve new surface information on individual rocks (diameter<150cm), rover tracks, and new evidence for the Beagle-2 lander using multi-angle repeat-pass Mars Reconnaissance Orbiter (MRO) HiRSIE 25cm images.

More recently, in collaboration with UrtheCast®, we have performed a series of successful experiments using repeat 4m Deimos-2 imagery over several test sites to produce SRR results with up to 4x resolution enhancement. Independent evaluation from UrtheCast® has shown that the GPT-SRR system outperforms any existing SRR algorithms tested to date. In particular, the test images taken from the Deimos constellation have every conceivable atmospheric interference including, smoke, haze, clouds. The final SRR results are crisp and show none of these obscurations because they do not occur in the same place.

In this proposed work, we plan to take the technology to the next stage by developing a GPU enabled SRR system to process very rapidly SRR imagery with up to 2 orders of magnitude increase in computation speed and up to 4 times resolution enhancement. This will open up a wide range of new commercial possibilities for Earth observation applications. UCL-MSSL will work closely with the satellite operating companies SSTL and UrtheCast® on specifying requirements, development, evaluation, and demonstration of SRR performance using Deimos-2 data and Carbonite high resolution (<1m) multi-angle video system. The resultant GPU-based solution will then be tested on a cloud computing service by UrtheCast® with a view to developing a fast operational system for the future UrtheDaily™ constellation being built by SSTL under contract to UrtheCast®.

CEOI10-EOTechDevFT-019

Project Title Proton radiation testing of Leonardo large format MCT arrays

Project Lead Leonardo MW Ltd

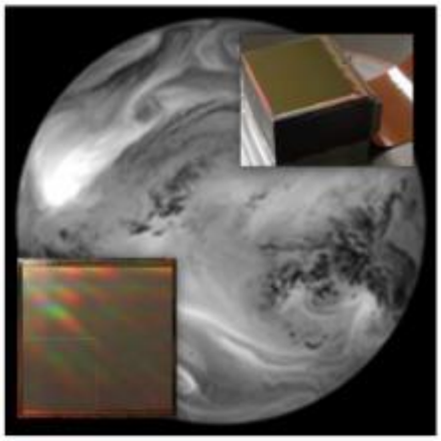
Project Partners Leornado MW Ltd

In response to the CEOI 10th Call for Earth Observation Technology and Instrument Development Proposals Leonardo are submitting a fast track programme of work under the theme of 'New and innovative ideas for EO technology projects'.

The proposed work is aimed at raising the Technology Readiness Level (TRL) of the NIR and SWIR large format arrays developed for ESA, using a radiation hard cell library in 0.35 micron CMOS silicon and enabled for avalanche photodiode operation. This will provide valuable evidence for de-risking the use of these devices and others yet to be developed in the same CMOS technology, for future earth observation missions such as those proposed for ESA Earth Explorer 9 and 10. It would therefore provide a return on the investment made in the ESA Earth Observation programme by the UK, through exploitation of our leading edge infrared detector technological capability.

Previous work carried out successfully with NSTP and CEOI funding has demonstrated the performance of MCT avalanche photodiode arrays under a range of operating conditions and characterized the immunity to heavy ion radiation of arrays using the near infrared large format silicon readout IC. We now propose to undertake proton testing on the NIR large format arrays which will provide valuable information on their operability under radiation and specifically the nature of the effects to determine whether they are permanent or can be managed through appropriate operating procedures controlled from the host system.

The silicon readout ICs (ROICs) are enabled for use with MCT diode arrays operating at unity gain as conventional diodes and in avalanche gain mode by adjustment of the operating voltage. When this virtually noiseless gain is combined with low noise ROIC technology and MCT diode array formats up to 2000 x 2000 pixels, it offers a disruptive technology to provide improvements in the quality of data available to scientists without compromising the payload size, weight or power. This combination of features has already been exploited in other high performance applications such as wavefront sensors for ground based astronomy and will be brought closer to deployment for space applications through the work proposed.



The result of successful completion of this work would be high performance large format MCT array designs which could be rapidly deployed for space applications using existing space qualified manufacturing techniques most recently exploited during the detector development for the IASI NG programme.

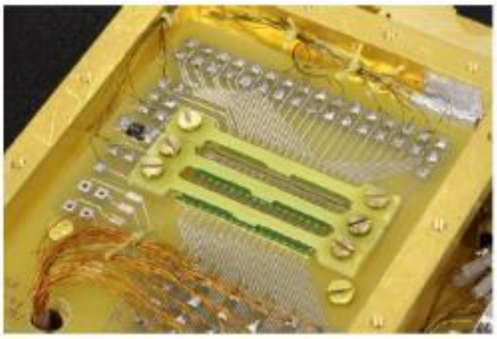
CEOI10-EOTechDevFT-021

Project Title	HYMAS – Filterbank spectrometers for HYperspectral Microwave Atmospheric Sounding
Project Lead	Cardiff University
Project Partners	Cardiff Uni, Uni of Cambridge

We propose to develop and demonstrate the key enabling technologies for a future satellite-based hyperspectral microwave and submillimetre instrument. Such an instrument will have unprecedented sensitivity for meteorology and climatology applications. It will enable atmospheric temperature and humidity profiles to be retrieved with very high accuracy and resolution. And it will enable essential climate variables to be constrained to high accuracy for climatology applications.

Over the last two decades, there have been quite significant improvements in the efficacy of numerical weather prediction (NWP) models, thanks to the increased usage of satellite observations in data assimilation systems. Major contributors to the reduction of forecast errors from temperature soundings are the Advanced Microwave Sounding Unit-A (AMSU-A - on board several platforms) and the Infrared Atmospheric Sounding Interferometer (IASI) hyperspectral instrument on board Meteorological Operational (MetOp) satellites. For water vapour retrieval, currently one of the most informative satellite radiometers for humidity soundings is the Advanced Microwave Sounding Unit-B/Microwave Humidity Sounder (AMSUB/ MHS).

However, all of these instruments have drawbacks. Retrievals from infrared hyperspectral instruments such as IASI are considered to be of high quality. But these observations are restricted to clear sky conditions only. The microwave instruments can see down into clouds, and therefore provide important information. But the vertical resolution is very poor, due to the very limited (<10) number of sounding channels. The radiometric noise in these channels is also a limitation on performance.



In this proposal, we will develop novel on-chip filterbank spectrometers, based on superconducting resonators, coupled to Transition Edge Superconducting (TES) detectors. These devices will enable a gamechanging instrument; one that has potentially better performance (in terms of retrieval accuracy) than the IR instruments, and not restricted to only clear sky conditions. The best of both worlds. The proposed device will couple the incoming signal through a broad-band antenna, which feeds into a co-planar waveguide or microstrip. The signal is then passed through a filterbank in the form of an array of superconducting resonators. The signal coupled into each resonator is read out with a very sensitive transition edge superconducting (TES) detector. This technology should allow the incoming signal to be split into up to 1,000 narrow-band spectral channels. This new solution will allow full access to the 50-60 GHz atmospheric oxygen lines, which are critical for high-quality atmospheric temperature retrievals, with the potential for continuous spectral coverage up to ~1THz.

In summary, this technology will enable a new generation of high-accuracy temperature and humidity sounding instruments, to enable improved weather forecasting ability. At the same time, the ability to cover much higher frequencies with the same instrument will provide critical data for climate modellers to better constrain global climate models.

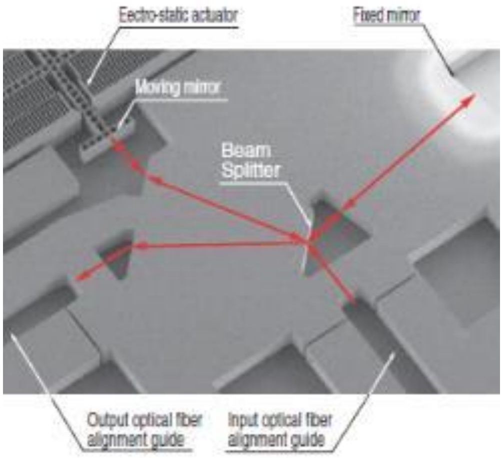
Part 3 – PATHFINDER PROJECTS

CEOI10-EOTechDevPF-003

Project Title	MEMS-based spectrometers for ultra-miniature space-borne hyperspectral remote sounders
Project Lead	STFC RAL Space
Project Partners	STFC RAL Space

Lightweight, power-efficient, low-cost, yet efficient, sensors are highly sought after for space applications. Hyperspectral remote sensors are of particular interest since they are the prime tool to carry out global observation of planet's atmospheres, including the Earth, and the requirements on remote sensors keep becoming even more stringent. Novel disruptive technologies are therefore needed. Over the recent years, the concept of highly miniaturized micro-electro-mechanical systems (MEMS) monolithically embedded into silicon wafers has been developed to a stage at which "chip" based spectrometers have been demonstrated and become available.

In this project we aim to evaluate the relevance of such a novel device for low-cost nanosatellite based Earth observation, and more particularly the remote sounding of greenhouse gases using solar scattered radiation in the short wave infrared. A MEMS-based Fourier transform spectrometer will be evaluated for this application in the laboratory using gas cell analogues and will undergo space environment testing to study the impact of space qualification on the MEMS spectrometer. At the same time, the laboratory test data on the MEMS sensor will inform a modelling activity aiming to provide a first evaluation of the prospect of this ultra-miniaturized technology for greenhouse gas observation from nanosatellite platforms.



CEOI10-EOTechDevPF-006

Project Title Freeform Gratings for Ultracompact Spectrograph Designs

Project Lead Durham University

Project Partners Durham Uni

The project submitted in this Pathfinder proposal is to investigate the potential of ultra-precision diamond machining techniques to produce efficient diffraction gratings on aspheric or freeform metal surfaces with full control of the blaze micro-structure. This work is intended to supplement an ESA technology development programme for optical gratings which has focussed on diffraction gratings manufactured by ion beam etching on holographic masks (IBEHM). With the recent development of new space-qualified ultrafine aluminium alloys, and progress in the field of directly machined freeform surfaces, diamond machined freeform gratings could play an important part in future spaceborne hyperspectral missions, particularly at SWIR and LWIR wavelengths where the improved thermal performance of metal optics at cryogenic temperatures is well established. Freeform diamond machined gratings can either offer a cost-effective, more compact, and more flexible alternative to IBEHM or complement that technology in areas where IBEHM is currently not demonstrated (e.g multi-blaze gratings and heavily curved surfaces).

Imaging spectrometers equipped with diamond machined freeform gratings will also be a competitive technology where there is a requirement for compactness combined with fine spectral resolution over multiple spectral bands. An extended spectral band at optimal efficiency can be achieved via multiblaze groove patterns, and very compact designs can be realised by combining the grating with one of the spectrograph re-imaging optical surfaces.

We will investigate a specific approach where the freeform blazed grating is added in place of the pupil mirror array in an image slicer based spectrograph. This single surface then achieves three optical functions at the same time: (i) reformatting, (ii) re-imaging and (iii) dispersion. This highly modular concept opens a new window on the design of future compact and modular spectral imagers. The ultra-compactness of the design, combined with the financially competitive manufacturing process, will make multi-channel imaging spectrographs ideal candidates for deployment on small Earth Observation satellites similar to Proba-V and possibly in future CubeSat missions. Similar designs can also be considered for use on airborne platforms and at ground level

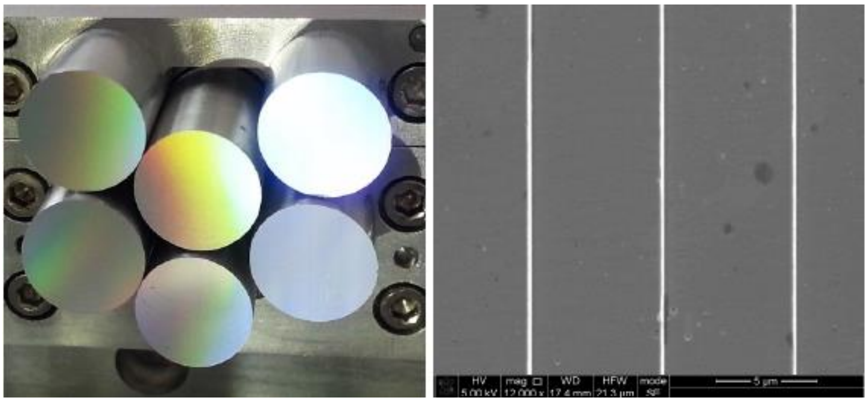


Figure 1: (Left) array of aluminium freeform gratings; (Right) SEM image of a diamond machined grating.

This project will exploit the unique diamond machining facilities at Durham University, which have been used to deliver successful image slicing integral field instruments for JWST (NIRSpec IFU) and ESO VLT (KMOS), in addition to the diamond machined optics for the NOMAD instrument on the ExoMars Trace Gas Orbiter.

CEOI10-EOTechDevPF-008

Project Title Calibration and pointing capabilities of a CubeSat based radiometer

Project Lead The Chancellor, Masters and Scholars of the University of Oxford

Project Partners Uni of Oxford

This proposed study is intended to bring the design of the Compact Infrared Imager and Radiometer (CIIR) to a level of maturity from which it can be implemented as a flight CubeSat payload with high confidence that ambitious scientific goals in remote sensing of the terrestrial atmosphere and surface can be achieved. This work follows on from a CEOI funded design study in 2015 and addresses specific limitations highlighted by the study and by the final review.

The CIIR was designed for both nadir viewing and scanning of the Earth's limb, preferably from a Sun synchronous orbit. The infrared filter bandpasses analysed in the study were targeted to support investigations of the properties of clouds and aerosols and also monitor concentrations of stratospheric water vapour.

The CIIR/CubeSat combination will provide a proof of concept for future missions based on low cost, constellations of spacecraft to allow multiple local times to be sampled. The CIIR concept (Figure 1) builds on the design heritage of the Compact Modular Sounder (CMS) instrument currently flying on TechDemoSat-1 and adapts it to work on a CubeSat. CIIR includes two components to ensure it returns data that can reliably complement and enhance existing Earth observation data sets. Firstly, it includes a traceable radiometric calibration target. Secondly it incorporates an intermediate focus between the input telescope and detector array; this allows a large (>10) number of discrete spectral channels to be used. Finally, the instrument uses an uncooled microbolometer array to combine medium resolution imaging with atmospheric sounding.

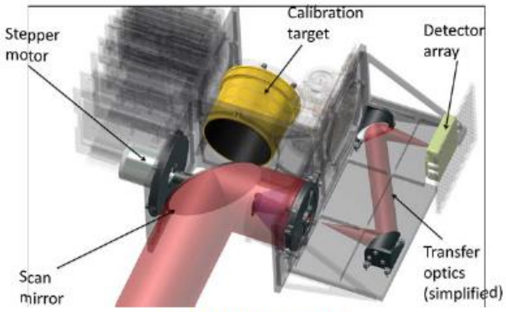


Figure 1. CIIR Concept.

The principle results from the study were:

- The integrated CubeSat/instrument concept is viable for low cost Earth system science where global coverage is a requirement.
- Scientifically useful data on stratospheric aerosol are achievable with the baseline design.
- Nadir viewing at moderate spatial resolution (~150 m) is achievable in the thermal-IR.
- Trace gas abundances such as water vapour and ozone are more challenging but further optimisation is possible.
- A significant source of error in limb sounding is the pointing performance.

The extent to which the CIIR can be used for limb sounding of trace gases and for inter-comparison with existing datasets depends critically on two areas:

- the absolute accuracy of the on-board calibration and
- the pointing stability during an observation.

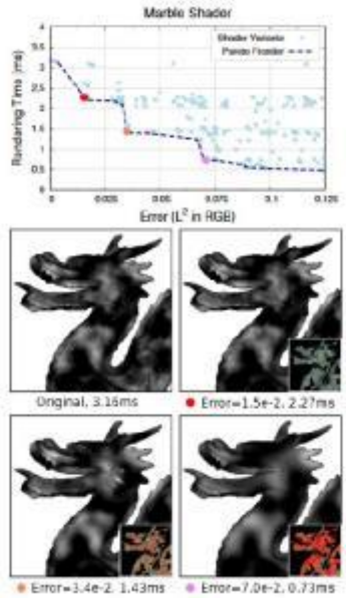
The tasks proposed in this study will allow us to determine accurately the currently achievable limits for these two parameters and put us in a position to bid to manufacture a flight model radiometer for an in-orbit demonstration.

CEOI10-EOTechDevPF-010

Project Title	Onboard Data Autonomy for Next Generation of EO Nanosatellites
Project Lead	Craft Prospect Ltd
Project Partners	UCL; Uni of Manchester; Craft Prospect Ltd; Bright Ascension Ltd

Progress within nanosatellite systems development makes niche EO missions feasible; however these systems will remain downlink limited, i.e. able to capture more data than can be returned to the ground in traditional raw or near-raw forms. The embedding of existing ground-based image processing algorithms into on-board systems is non-trivial especially in limited resource nanosatellites, necessitating new approaches.

This project will deliver a framework for, and improved understanding of, the implementation of key algorithms for autonomous data processing on-board constellations of EO nanosatellites, covering data selection, reduction, prioritisation, and distribution. The focus will be exploitation of low-resource algorithms developed in other sectors, including autonomous vehicles and commercial machine learning.



Throughout, the trade of on-board process against downlink power will be considered to ensure a systems solution, together with a constraint on total system power based on a typical nanosatellite mission. The project will deliver a prototype data flow to TRL4/5 using selected algorithms based on a typical FPGA-based nanosatellite on-board computer, together with a systems engineering view as to the overall framework for later growth and expansion. Flight opportunities in support of the CubeSat IOD mission as value adding to existing payloads or as demonstration on drones will be presented for next steps.

Given the growth of EO nanosatellite class missions, an existing route to market will be utilised that offers value adding services and products to current ongoing and planned missions.

CEOI10-EOTechDevPF-012

Project Title	New Electronic Switching Arrangement for mm-wave Radiometer Calibration
Project Lead	Queen’s University Belfast
Project Partners	Queens Uni Belfast

This activity aims to develop a new electronic quasi-optical switching method for more efficient calibration on millimetre and submillimetre wave EO radiometers. All radiometers must be calibrated regularly to ensure high measurement accuracy and most current techniques operate by switching between hot and cold sources using large power hungry motor driven mechanical systems. A schematic of the concept is shown in Figure 1. This electronic system permits rapid sampling of the scene radiation and the two on board calibration (OBCT) targets. Several different promising enabling technologies will be investigated to provide electronic tunability of the Frequency Selective Surface (FSS) switches, including; liquid crystal material and MEMS piezoelectric actuators. The most suitable candidate shall be selected for prototyping and a range of key parameters, including; insertion and reflection loss, channel isolation, switching speed and manufacturing repeatability will be determined. Numerical predictions and experimental results will be used to demonstrate compatibility with typical requirements for future missions.

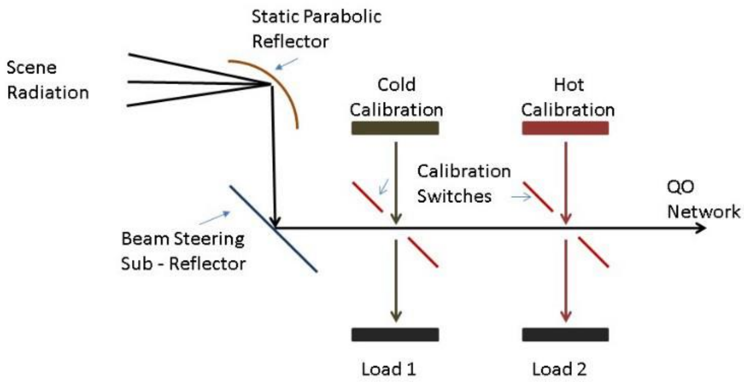


Figure 1: On board electronic calibration concept based on two FSS switches

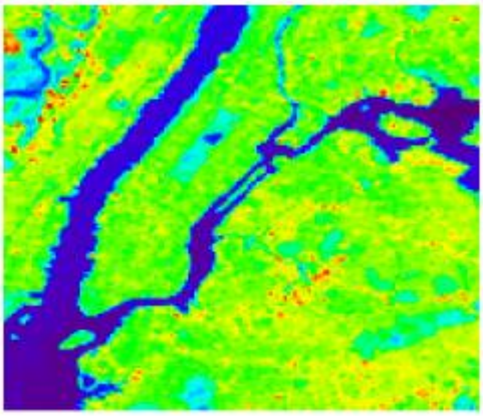
CEOI10-EOTechDevPF-013

Project Title HYPERSPECTRAL HIGH RESOLUTION THERMAL IMAGER

Project Lead STFC RAL SPACE

Project Partners STFC RAL Space; Uni of Leicester

Infrared satellite sensors such as SLSTR on Sentinel-3 and VIIRS on JPSS Suomi typically offer spatial resolutions of order 1 km. While this is sufficient for many applications of global surface temperatures, there is a strong user application and science requirements for higher spatial resolution (~100 m) higher spectral (hyper-spectral or multi-spectral) resolution IR (HHRTII) imagers. This has been recognised in several ESA studies and in the preparatory work for the Copernicus Space Component Evolution Plan (CSCEP). Furthermore, although some thermal imaging capability for Land Surface Temperature (LST) measurement is available through Landsat and ASTER, ESA is now developing a thermal imager (TIRI) to complement Sentinel-2. The user community agrees that science and applications are currently restricted by the limited number of spectral bands (typically two bands at 11um and 12um) and the limited temporal sampling. By further extending the spectral coverage and resolution the range of applications can be widened to include, LST, Sea Surface Temperatures (SST) in coastal waters, emissivity, land classification, volcanology, fire radiative power, cloud masking, aerosols, and trace gases.



Overall, there is a high probability that a sophisticated thermal instrument, most likely hyperspectral, will fly as either an ESA Earth Explorer or a next generation Copernicus instrument. Increasing definition of UK expertise in this area will ensure it is well-positioned to respond effectively to future opportunities when they arise.

There are several technical challenges that need to be overcome to provide an instrument concept to meet these requirements, and the aim of this project is carry out a comparative assessment of available options. Typically, the focus tends towards detectors as the limiting factor (cooled or uncooled), but there are other considerations including how to achieve the required spectral dispersion and the radiometric calibration (conventional grating-based spectrometer or innovative Fourier-transform system) that must not be overlooked.

Any technical solution shall of course be driven by the science requirements. Thus, this study will consolidate, review and refine the requirements, particularly the spectral range, spectral resolution, radiometric noise and accuracy, and spatial coverage. The main technical challenges and the key potential technologies that require further development will then be identified and a plan developed that would inform future TRL raising activities.

CEOI10-EOTechDevPF-014

Project Title High Performance Pyroelectric Detectors for Space-Based Instruments

Project Lead Leonardo MW Ltd

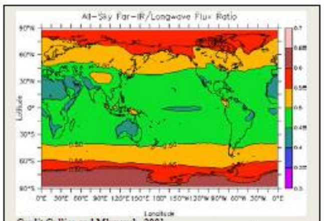
Project Partners Leonardo MW Ltd

In response to the 10th Call for Earth Observation Technology and Instrument Development Proposals issued by the Centre for Earth Observation Instrumentation (CEOI), Leonardo MW Ltd. is proposing a technology development activity for enhanced performance uncooled pyroelectric detectors to be used in space-based EO instruments. The objective of this programme of work is to demonstrate a significant improvement in the detectivity of pyroelectric detectors through the use of an alternative material composition.

Leonardo holds a world-leading position in the development and manufacture of single element pyroelectric detectors using DLATGS for use in scientific instruments such as laboratory and hand held FTIR spectrometers for chemical analysis. The company's pyroelectric detectors are also used in space, principally for thermal emission spectrometers on science and exploratory missions, including NASA's Mars rovers and the recently launched OSIRIS Rex.

The DLATGS (deuterated L-alanine doped triglycine sulphate) material used by Leonardo has an inherently broad spectral response from 0.3µm to beyond 100µm which can be tailored through the choice of a suitable window material. Of particular interest to earth scientists is the far infrared region (15µm and greater) because it includes 50% of the Earth's infrared energy emitted to space and contains most of the Earth's water vapour greenhouse effect. However, it has never been measured spectrally in its entirety from space, due primarily to the technical difficulties associated with achieving the necessary instrument signal to noise across the region.

Two earth observation missions being considered at present intend to make measurements in this region using the unique characteristics of DLATGS pyroelectric detectors. These are NASA's CLARREO (Climate Absolute Radiance and Refractivity Observatory) mission and the ESA EE9 candidate mission, FORUM (Far-infrared-Outgoing-Radiation Understanding and Monitoring).



Credit Collins and Mlynczak, 2001

Enhanced pyroelectric detector performance will enable more accurate measurements across a wide infrared spectral range

The baseline design for the FFTS (FORUM Fourier Transform Spectrometer) instrument uses optical concentrators to maximise the incident light coupled to the sensitive area of the detector element. Enhanced detector performance would enable greater degrees of freedom in the equipment design in terms of improved system detection sensitivity. This would allow more accurate scientific measurements, simplification of the optics, and help reduce payload size and mass as well as mitigate risks associated with optics design. This aligns with the stated theme of 'New and innovative ideas for EO technology development'.

If the FORUM mission is selected by ESA it would be the first use of Leonardo pyroelectric detectors in a space based FTIR instrument for an ESA earth observation mission. This would open the way to use this detector type for future ESA missions as well as for enhanced versions of the existing thermal emission spectrometers.

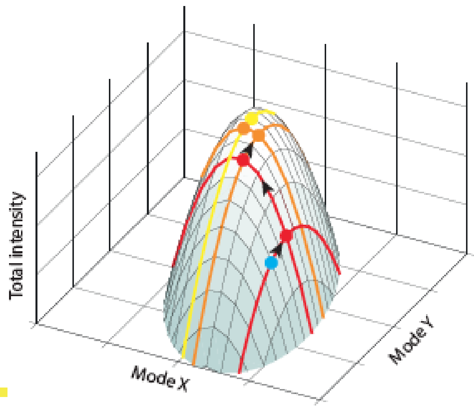
Like FORUM, the CLARREO science team includes UK institutions such as Imperial College, London. Therefore the return on this investment would be realised not only by Leonardo but also the UK science community through its access to state of the art technology applicable to these missions.

CEOI10-EOTechDevPF-019

Project Title	Smart optics for Satellite Applications
Project Lead	University of Oxford
Project Partners	Uni of Oxford; SSTL

A significant challenge for optical earth observation systems is the alignment of the telescope components. Systems are frequently out of alignment, at least in part, leading to unfocussed or incomplete images, a major cause of failure of satellite missions. The long-term aim of our work is to develop adaptive optic techniques for application to telescopes, building upon world-leading expertise at the University of Oxford on adaptive systems for microscopes and related applications and world-leading satellite development and deployment expertise at Surrey Satellite Technology Ltd. This feasibility project will focus upon the alignment of the optics within a factory build context, as the first step towards the longer term goal, which includes the ability to robotically adjust telescopes in orbit and develop self-correction systems using appropriate actuators.

The current approach to aligning satellite optics is manual, with adjustments informed by measurements from camera images of alignment laser beams and from live interferometry; heuristic and time-consuming techniques.



We will bring automation into the alignment process by adopting methods for adaptive optics using indirect measurements to infer the aberrations in the system such as, in this case, the misalignment of mirrors and other components. This modified procedure has demonstrated a substantial improvement in comparison to traditional wavefront sensors in microscope devices.

One methodology that will be applied is image based sensing in which a number of different aberrations are intentionally applied to the system and the interpretation of their effects is able to infer the aberration itself. With an appropriate range of applied aberrations, based upon a mathematical model of the system, it is possible to determine the corrections that are required for the system to align the system. These aberrations could be applied through small misalignments of mirrors along the x, y and z axes and rotation about these axes; an optimisation of five variables, similar to, but simpler than, the 20 or more aberration modes needed in microscopy.

Existing methods are inefficient and inexact and therefore require a very large number of iterative steps. The new methods will dramatically reduce these from about nine person-months to potentially one person-month. Combining the approach with other techniques such as interferometry, greater sensitivities may be achieved by using interferograms for finer tuning.

This feasibility study will involve the design and supply of an optical bench by Surrey Satellites, together with an assessment of their current procedures for telescope alignment and a definition of the requirements for an improved system. This will enable the Oxford team to test a set of methodologies against these requirements and establish a protocol for alignment in order to conduct an accuracy, time and cost assessment of the system so that its feasibility is demonstrated as well as the cost-benefit analysis for scale-up and implementation within a factory context.

A successful feasibility study will lead on to full scale demonstration associated with a real satellite mission undertaken by SSTL and further development phases towards automated in-orbit demonstration with associated IPR and business model development.

CEOI10-EOTechDevPF-021

Project Title Feasibility of Passive Bistatic Geosynchronous Radar using Comsats
Project Lead Cranfield University
Project Partners Cranfield Uni; Uni of Birmingham

Radar imaging from geosynchronous orbits (GEO) promises new services which add to our ability to monitor Earth from space. GEO satellites use high orbits and appear stationary in the sky since their orbits rotate at the same speed as Earth itself; these satellites view large areas of Earth continuously. Cameras and radars on these satellites would allow us to observe many processes which conventional satellites in low orbits have difficulty in seeing – low orbit satellites only pass over the same place infrequently. However, a conventional approach to radar imaging from GEO requires expensive spacecraft which are unlikely to be built unless the benefits can be shown to justify the cost. This project proposes an alternative approach which should be both low-cost and capable; it also takes advantage of recent trends in technology, such as software-defined payloads and radar reusing transmissions designed for other purposes.

The mission concept is to detect the reflections of communication satellite transmissions and use these for radar imaging. The payload required for this could be added to new communication satellites as a small "hosted" payload. This hardly affects the communication satellites but has the potential to add new imaging services at low cost. The applications could be in areas such as weather forecasting, rapid disaster response, farming and water supplies. The concept has been discussed before and even partially demonstrated using ground-based equipment. The aim of this study though is to test the ideas of the whole mission concept, (a) to understand how good the performance could be with modern satellites, (b) to find out what practical problems there might be and how these can be solved, and (c) to decide which are the most useful applications. As well as answering these questions, the study will identify the next steps towards developing an operational system – which could be in orbit by 2025.

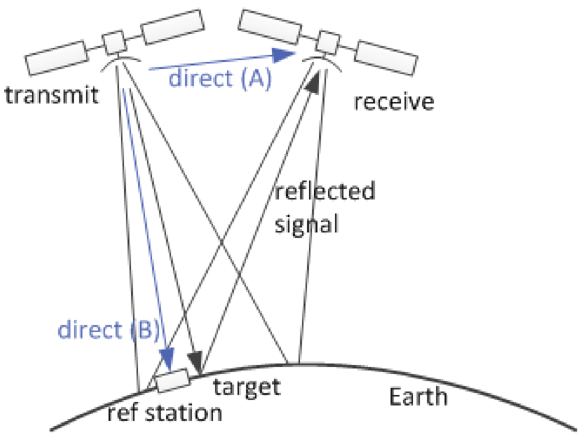


Figure 1 Example system architectures for PBR