Centre for EO Instrumentation & Space Technology

Projects Funded in the CEOI-ST 7th Call for EO Technologies

The following projects have been approved for funding following the CEOI-ST 7th Call for EO technologies.

Fast Track Projects (up to 12 months duration)

Project Description	Lead Organisation	Team members
'LOCUS Critical Payload Development for Future In Orbit Demonstration'	U Leeds	STFC RAL, Star Dundee
TRUTHS: a benchmark mission for decadal climate – Facilitating its urgent implementation	NPL Management Ltd	SSTL
Exploring SAR interferometer calibration solutions for ocean surface current errors for the Wavemill space mission	NOC	Starlab Ltd Airbus DS
Global Satellite observations of winds, rain and clouds	U Reading	U. Leicester
Mechanised Precision Bonding of Composite Assemblies	U Glasgow	Gooch & Housego
MISRlite - Multi-angle IR Stereo radiometer using uncooled microbolometer arrays for global winds	MSSL-UCL	Thales
Radiation Testing of Selex ES CMOS ROICs for Earth Observation IR Sensors	Selex ES, UK	
Contactless Power & Data Transfer for Conical Scanning Instruments	SEA Ltd/Thales Alenia Space UK Ltd	ESR Technology Ltd

Pathfinder Projects (typically 6 months duration)

Project Description	Lead Organisation	Team members
183 GHz Frequency Selective Surface (FSS)	Queens U Belfast	None
Hyperspectral Imaging for Air Quality: Application of a hyperspectral imaging suite for 3D retrievals	U Leicester	None
UK Support for the ALiSS Mission Study	STFC RAL	None
HIgh frequency Doppler Radars #2 (HIDRA 2)	STFC RAL	U.Leicester
Demonstration of CO2 LHR	STFC RAL	
ICEMuSIC – Instrument optimisation study and mission definition	U Cardiff	Met Office U.Hamburg
Characterisation of Ferrite Material in Remanent State for use in New High Peak Power Applications	COM DEV International Systems Ltd	
COnformal Retro Reflectors for Earth Observation (CORREO)	Cranfield University	University of Nottingham

LOCUS Critical Payload Development For Future In Orbit Demonstration Project

(University of Leeds with STFC Rutherford Appleton Laboratory and StarDundee Ltd)

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 have shown such measurements to be 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, UK scientists and technologists have developed the concept of a novel and breakthrough limb sounding, multi-channel radiometer operating in the terahertz (THz) spectral range (0.8 – 5 THz) and deployed in low Earth orbit. The radiometer payload will be carried aboard a small UK developed satellite and will allow global high spectral resolution measurements of important MLT atmospheric species, particularly atomic oxygen and the hydroxyl radical.

As a direct outcome of previous CEOI-ST support, the UK team has proposed a Low Cost Upper atmosphere Sounder (LOCUS) mission to the European Space Agency (ESA) for study as a candidate in-orbit demonstrator. The mission concept has key objectives of demonstrating breakthrough THz science and technology, and has been accepted for further study by ESA.

With the possibility of a space flight demonstration before the end of the current decade, the CEOI-ST is supporting the UK technical team with the advancement of the LOCUS mission concept by addressing key aspects of the payload detector and infrastructure technology. This will raise the instrumentation technical maturity to a level compliant with the in-orbit-demonstration opportunity, 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 advance and demonstrate UK THz radiometer and high-speed signal processing technology used in conjunction with a UK developed miniature spaceborne cryogenic system. Our proposed programme is extremely well matched to CEOI-ST strategy. Moreover, it will deliver additional return through future application in a wider range of diverse disciplines including planetary science, astronomy, spectroscopy, security and telecommunications.

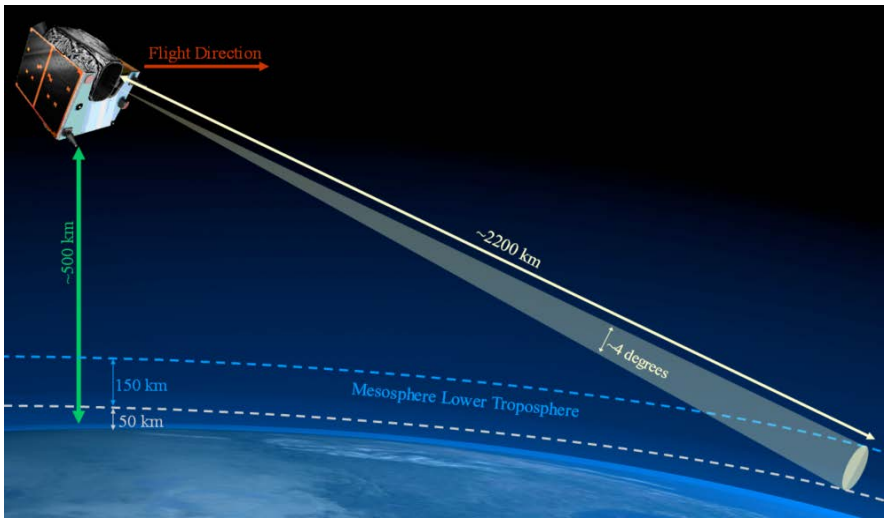
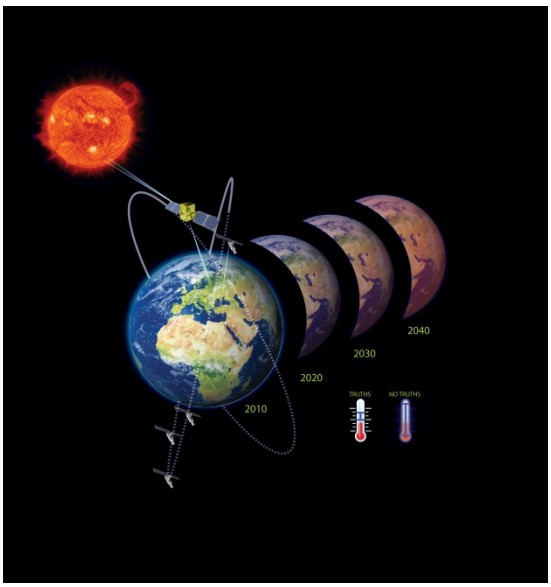


Illustration of the LOCUS limb-sounding radiometer in operation.



TRUTHS: A climate benchmark mission

National Physical Laboratory with Surrey Satellite Technologies Ltd (SSTL)

The establishment of an observational climate benchmark data set of sufficient accuracy to enable the unequivocal detection of climate change with the ability to constrain and test climate forecast models on a decadal time scale is one of the key challenges laid down by the international climate science community. The UK led TRUTHS (Traceable Radiometry Underpinning Terrestrial- and Helio- Studies) and its US sister, CLARREO (Climate Absolute Reflectance and Refractivity Observatory) are mission concepts proposed to address this exacting issue. TRUTHS' primary goal is to provide benchmark measurements of both incoming (solar) and outgoing (reflected solar) radiation with sufficient spectral resolution and accuracy to detect the subtle changes in as short a timescale as possible (~12 yrs) - limited by natural variability of the climate system. In summary, measuring global spectrally resolved (10 nm) Earth radiances, continuously sampled (spectrally and spatially) with GIFOV of ~<100 m from 340 to 2340 nm and the corresponding solar spectral irradiances both with uncertainties to SI units of <0.3%.

Although not selected in the ESA EE8 call, TRUTHS received a strong recommendation of support and encouragement that an early implementation should be explored as part of a wider international collaborative effort. In support of that goal this project will look towards developing optimised baseline designs for the missions core elements: Imaging spectrometer (Earth and Sun view) and the on-board calibration system together with key aspects of the satellite bus impacting the observational requirements, with the aim to establish a set of baseline building blocks with outline designs to facilitate the establishment of international partnerships for early implementation of TRUTHS

The design study will trade-off complexity/risk/cost against science drivers ensuring that the core objectives, climate benchmark are achieved whilst maximising the opportunity for secondary objectives. The study will also evaluate the performance advantages achievable from using TRUTHS as a reference calibration satellite for sensors with Sentinel 2 & 3 like characteristics and also as a 'calibration mother ship' for low cost constellations.

Exploring SAR interferometer calibration solutions for ocean surface current errors for the Wavemill space mission

National Oceanographic Centre with Starlab Ltd and Airbus D&S Ltd

The Wavemill concept for measuring ocean surface currents globally, at unprecedented spatial resolution using a novel SAR approach, makes it a potential Earth Explorer 9 Call candidate mission. It is also a CEOI indicative mission. The potential of this approach has been shown using the Wavemill airborne demonstrator, but that work pointed up the need for accurate calibration of the interferometic phase from which the ocean surface current measurements are obtained. Here we propose to investigate the calibration problem theoretically and suggest a solution that can be implemented technologically both for a future Wavemill space mission and for the existing airborne demonstrator. As part of the study new antenna hardware will be developed that can be used with the Wavemill airborne demonstrator to enable dual-sided viewing and therefore emulate the calibration approach of the flight instrument. This study on the calibration aspects of the Wavemill instrument represents a new and ground-breaking area of work: namely, the calibration of squinted interferometric SAR systems.

SATELLITE OBSERVATION OF WIND, RAIN AND CLOUDS

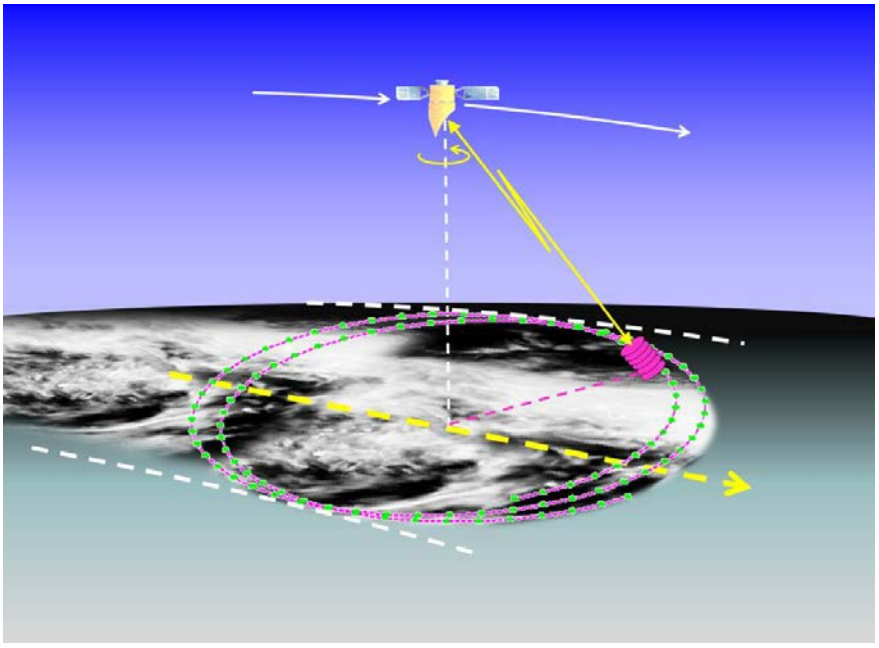
University of Reading with University of Leicester

Building on recent ESA and CEOI studies, we propose a conically scanning spaceborne broad-swath Dopplerised 94GHz radar to provide global measurements of winds, rainfall and cloud ice water content using the radar returns from cloud and precipitation particles. The observations will have 50km horizontal and 1km vertical resolution with several visits every day at European latitudes.

Windstorms in Europe caused £18.5B of damage in Europe in 1999, £1.5B in 2009 and £1.3B in 2010. High losses also result from flooding. The loss of life in tropical cyclones is decreasing due to improved forecasts and better warnings: compare the 138,000 deaths in Myanmar due to cyclone Nargis in 2008 with the 43 deaths from the more powerful Indian super-cyclone, Phailin, in October 2013. Better observations would lead to more accurate forecasts with improved timing and location so that mitigation activities can be better focussed. The in-cloud winds from this project would complement the clear air winds from the ESA explorer ADM/AEOLUS when it is launched in late 2014.

The 94GHz (3mm) radar has a very narrow beam and so even with a slant path can achieve the 1km vertical resolution. The satellite will have the same 94GHz transmitter that has operated flawlessly for Cloudsat since its launch in 2006. The 2.9 by 1.8m elliptical antenna rotates once every seven seconds sweeping out a broad swath on the ground. The Doppler shift and rainfall rates will be derived using the returns from twin pulse pairs alternately polarised in the horizontal and vertical. We propose validation of this polarisation diversity technique with observations from with the recently upgraded 94GHz radar at Chilbolton, Hampshire.

Following a successful ground based demonstration of the technique we will propose the concept to ESA when they have their next Earth Explorer call which is expected in early 2015. If this is successful, the next stage would be to test the technique using an airborne 94GHZ radar



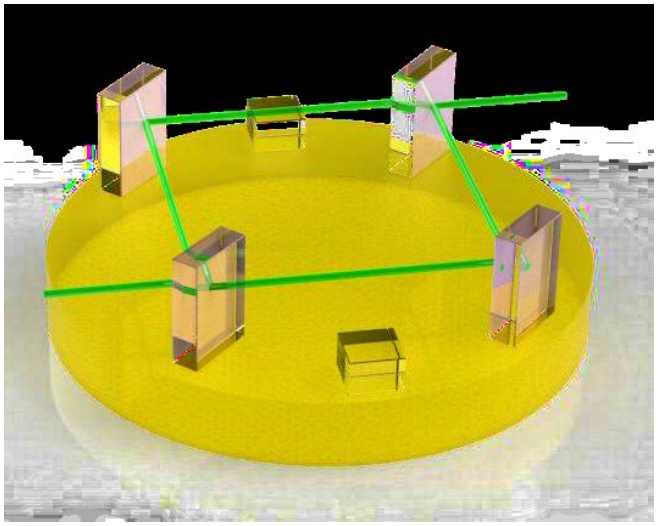
The 'WIVERN'- WInd VElocity Radar Nephoscope - concept from a recent ESA study by Astrium, Starlab and the U of Reading.

Version 2 18th June 2014

Mechanised Precision Bonding of Composite Assemblies

University of Glasgow and Gooch and Housego (UK) Ltd

The ability to design and construct complex optical assemblies is crucial to many experiments that use light to carry information. As requirements on missions become more demanding, so the precision of the sensing apparatus must improve. An advanced technology – hydroxide catalysis bonding – used to join parts together at the molecular level has been adapted at the University of Glasgow to make space flight hardware for the LISA Pathfinder mission. The bonding technology has many advantages over traditional methods like epoxy and optical contacting, and components have been aligned with submicron accuracy. The aim of the proposed project is to secure the UK lead on this enabling technology by demonstrating alternate methods to realise bonded optical assemblies using novel procedures such as mechanised component alignment and bonding, and ground surface active alignment prior to bonding. These advances will result in the technology becoming more mature and at the same time requiring less infrastructure to perform, opening the technology up to become a simpler and therefore more widely used method of making precision sensing hardware, and one that is more suitable to the operating methods of industrial manufacturers of precision optics such as Gooch and Housego.



MISRlite - Multi-angle IR Stereo radiometer using uncooled microbolometer arrays for global winds from the ESA-EUMETSAT tandem EPS platforms:

Mullard Space Science Laboratory (MSSL), UCL with Thales

Atmospheric winds are a vital input parameter to Numerical Weather Predictions (NWP). Most of these wind measurements come from tracking passive cloud tracers (known as Cloud Motion vectors or CMVs) in geostationary (15 minute interval) thermal IR images up to ±55º of latitude and overlapping (90 minute separation) thermal IR features from polar orbiting satellites (above ±70º of latitude). The NASA MISR (Multi-angle Imaging Spectro-Radiometer) instrument is a 9-look push-broom sensor, which has been producing CMVs along the track since March 2000 at resolutions down to 1.2km but only up to 380km in swath-width and only during daylight. These winds have much more accurate 3D heights compared with the aforementioned CMWs and are about to be processed in near real-time (<<5 hours).

The Multi-angle IR Stereo Radiometer (MISRlite) is a thermal IR satellite concept for a 1500km swath-width capable of day/night operation to produce CMVs at 900m resolution. MISRlite is based on proven microbolometer technology exploiting Time Delay Integration and fast electronics to generate high quality thermal IR images. MISRlite will address the proposed geometric gCMV concept selected by ESA to meet the needs of a tandem mission with the EPS 2nd Generation MetOp operational satellite due for launch in the early 2020s. In this Fast-Track proposal, we plan to design, develop and demonstrate a prototype on a gimbal mount and demonstrate this on a series of flights in Australia where a coincident lidar altimeter will record the cloud-top heights.

Our industrial partner, SEA Ltd, will study the flight implementation of the MISRlite concept and derive system design and baseline resource budgets. They will also investigate the data processing required to handle the data from multi-element focal plane required for the flight implementation.

Radiation Testing of Selex ES CMOS ROICs for Earth Observation IR Sensors

Selex ES Ltd

In response to the latest funding call from the Centre for Earth Observation Instrumentation and Space Technology (CEOI-ST), Selex ES is proposing a fast track programme of work under theme 2 of the Technology call. This programme of work is aimed at positioning the UK for imminent international flight programmes and future bi-lateral opportunities and so will provide a return on the investment made in these programmes by the UK, through exploitation of our leading edge infrared detector technological capability.

Building upon earlier work carried out successfully with NSTP funding to demonstrate the environmental performance of MCT avalanche photodiode arrays, we now propose to undertake heavy ion testing of the latest large format ROIC technology for MCT infrared detectors. This will support detector proposals for earth observation missions including those where low flux conditions would take advantage of the in-pixel avalanche gain already exploited in other high performance applications such as wave-front sensors supplied for ground based astronomy. This work will advance existing EO technology developments towards a higher TRL, which will de-risk the flight programmes indicated.

Contactless Power & Data Transfer for Conical Scanning Instruments

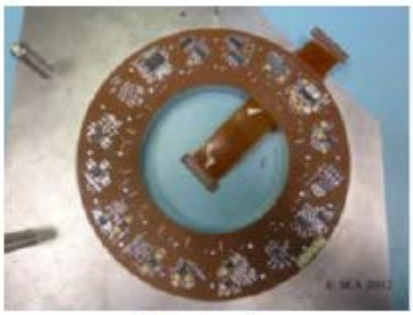
SEA Ltd/Thales Alenia Space UK Ltd

SEA, in partnership with ESR, have developed a contactless power and data transfer device to TRL3 under ESA TRP funding, with an end objective to be available at TRL5 for the Metop Second Generation (M2G) programme. This has proven that 95% power transfer efficiency & high reliability data transfer at rates in excess of 5Mbps can be achieved and gives confidence that development to TRL5 can proceed with minimum schedule risk.

This project takes the existing prototype, designed for integration within a particular scan mechanism breadboard device and looks into adapting it for wider use as module on M2G and other missions by:

- Adjustment to maximise efficiency and adaptability for use on a range of instrument opportunities;
- Addition of new channels and interfaces into the data transfer system to ensure
- compatibility with a range of instrument data interface requirements;
- Adaptation to be accommodated as a module within the anticipated envelope available for Conical Scanners;

As such it offers a unique, high reliability solution to overcome the constraints.



Data transfer

Transformer Cores

Power Converter

Power Rectifier

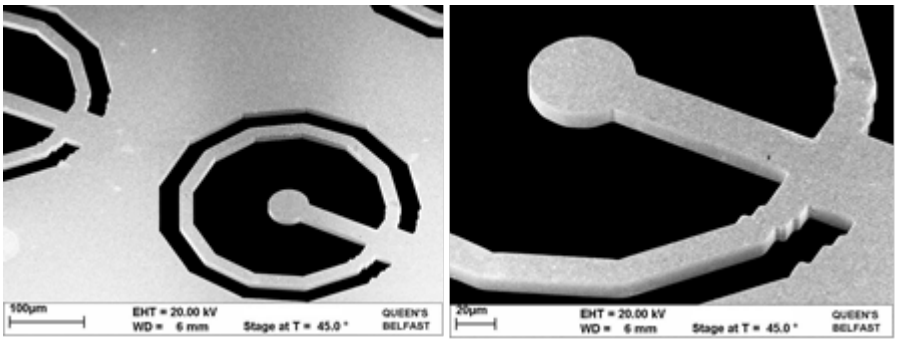
Power and Data transfer Annular Circuit Elements

Pathfinder Projects

183 GHz Frequency Selective Surface (FSS)

Queens University Belfast

The purpose of this project is to develop an FSS to separate the 183 GHz channel from the 166 GHz channel in the MetOp-SG Microwave Sounder. At these frequencies the instrument provides global temperature and water vapour profiles for numerical weather predictions. They are closely spaced with an edge-of-band ratio of only 1.05, requiring state-of-the-art filter performance to separate. Current MWS instrument technology shows higher NEDT than required, and this project aims to demonstrate improved performance from ultra-low loss FSS.

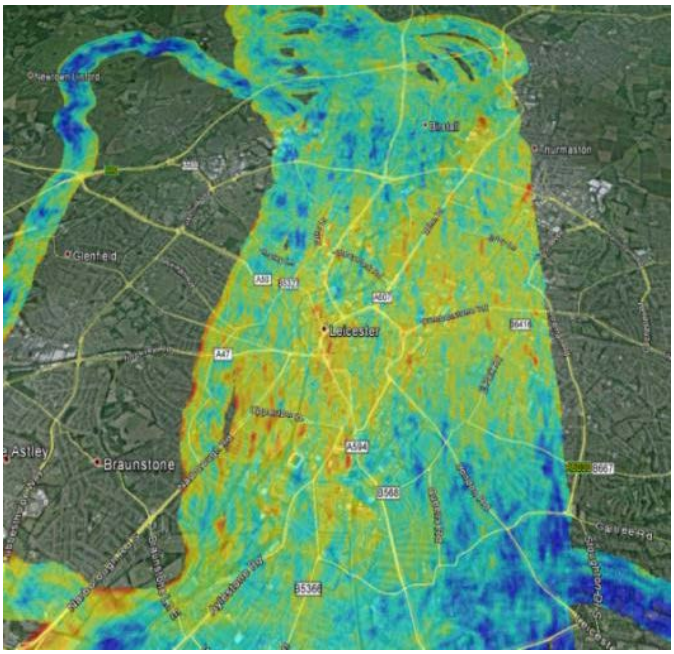


Hyperspectral Imaging for Air Quality: Application of a hyperspectral imaging suite for 3D retrievals

University of Leicester

This project will enhance the future flight potential of UK hyperspectral imagers such as CompAQS, through instrument optimisation and demonstration of key application areas for data. The University of Leicester project will extend and enhance the successful CEOI funded project which enabled the demonstration of an airborne hyperspectral instrument, CompAQS. The TRL of CompAQS will be improved through an intense six-month programme of work. The work will include instrument optimisation, an additional flight with ground-based CompAQS instruments in operation and improved retrieval algorithms.

Improvements in retrieval algorithms will lead to the development and demonstration of a 3D retrieval of NO2 concentrations over a city scale using two ground-based CompAQS instruments and one airborne CompAQS instrument. The combined understanding of air quality will demonstrate the value of enhanced hyperspectral imaging, and the applications which could be delivered as a result. These findings will feed into both future payload proposals, and future application developments.



DSCD Measurements of NO2 from CompAQS over Leicester city. Red shows relatively high areas of NO2 and blue shows areas with relatively low levels of NO2

UK Support for the ALISS Bilateral Mission Study

STFC Rutherford Appleton Laboratory

This project will provide a UK contribution to the feasibility study for the Atmospheric Limb Sounding Satellite (ALiSS), a future potential bi-lateral mission for the UK. ALiSS is a bilateral (Canada and Sweden) mission comprising three instruments including a modified version of the STEAMR instrument previously included as a Swedish national contribution to the PREMIER ESA Earth Explorer 7 (EE7) candidate mission. This study leverages previous UK technology developments targeting the STEAMR instrument and funded by CEOI, including novel sideband-separating mixer (SHIRM) and Wideband Spectrometer (WBS) developments at RAL and Star Dundee respectively. CEOI has also supported development of a combined breadboard radiometer incorporating both technologies (to be deployed in an atmospheric field measurement campaign on Jungfraujoch in February 2014) while UK Space Agency have co-funded (with STFC) forthcoming integration of both technologies into ESA's MARSCHALS airborne limb sounder, to be deployed in the StratoClim scientific flight campaign in the Asian Monsoon region in 2015. These activities have been predicated on the knowledge that, uniquely, STEAMR offered two flight opportunities: EE7 PREMIER being one, and a Swedish national mission being the other. Following the EE7 de-selection, the Swedish national mission remains, and has evolved into the bilateral Canada-Sweden ALiSS. It therefore remains an excellent flight opportunity. Involvement in this mission would provide an early flight opportunity for UK technology (mm-wave receivers, calibration loads etc.) of relevance to future operational programmes including MetOp SG. The UK has been formally invited to participate in the (ongoing) Part 1 of the Feasibility Study, and to support Part 2 of the study which will conclude in March 2015.

HIgh-frequency Doppler Radars #2: HIDRA-2

STFC Rutherford Appleton Laboratory with University of Leicester Despite the well-recognized role played by clouds and precipitation in affecting our climate, gaps in the remote sensing capabilities of their vertically resolved microphysics significantly hamper progress in understanding the physical processes within them, whose parameterizations underpin numerical weather and climate models. A previous CEOI-funded seedcorn study (HIDRA4PPM) has established the potential of G-band Doppler radars (i.e. frequency between 110 and 300 GHz), in combination with Ka and W-band millimetre wave radars, to improve current profiling capabilities in precipitating snow (see Figure 1). This is achieved by partially overcoming the snow microphysical deadlock, i.e. the dependence of the snow rate on the snow microphysical characteristics: particle habit, fall velocity and size distribution.

The present work aims at further developing a mission concept based on a dual frequency, 35 and 240 GHz, Doppler radar with radiometric mode for the detection and quantification of mid and high latitude precipitation. STFC-RAL will focus at developing a prototype of 240 GHz frequency multiplier with the challenging high output power level required to drive the radar transmitter's output stage. The University of Leicester will analyse the potential of the system to improve further the retrievals of microphysical properties in precipitating snow and also in stratocumulus, cirrus and mid-level ice clouds.

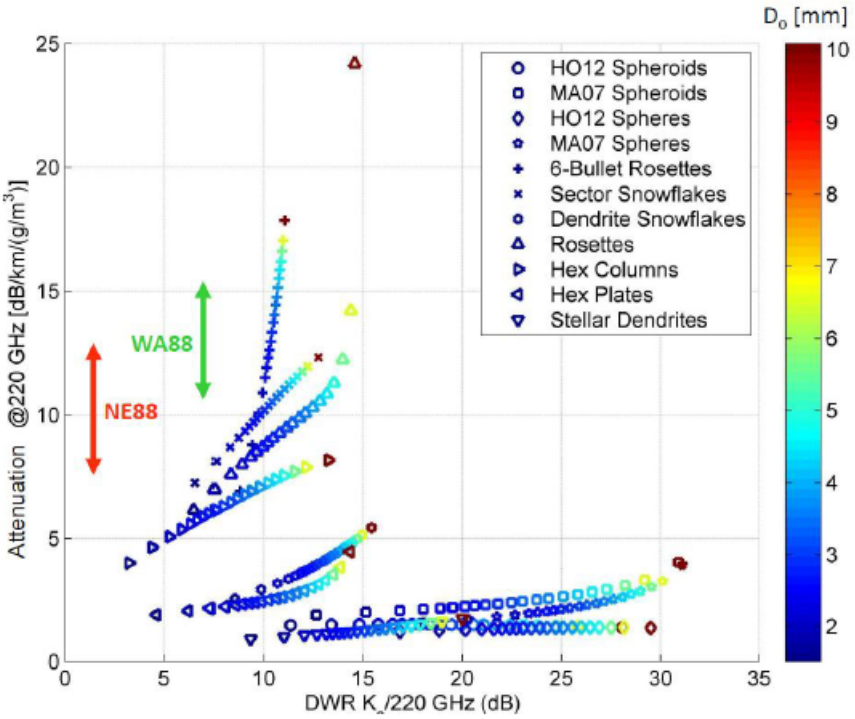


Figure 1: Snow attenuation per unit mass at 220 GHz for different snow particle habits and particle size distribution (the colour indicates the mean volume diameter of the particle size distribution), plotted against Ka–220 GHz dual wavelength ratio (DWR). A 35-220 GHz radar measurement has great potential for identifying the dominant particle habit and the mean particle size. See Battaglia et al., 2014 for details.

ICEMuSIC – Instrument optimisation study and mission definition

Cardiff University with Met Office and University of Hamburg

Cirrus (ice) clouds play a crucial role in the global climate system and energy budget of the atmosphere, in that they reflect near-infrared radiation back to space (cooling effect), whilst reflecting thermal emission from the Earth's surface back to Earth (warming effect). The net effect on the atmosphere is very important to understand. It depends on the cloud's horizontal extent, vertical position, ice water content, and ice microphysical properties, all of which influence the cloud's optical thickness. These parameters are currently poorly constrained in global circulation models, and represent large uncertainties in predictions of future climate.

We have developed a novel instrument concept to observe ice clouds and humidity that will allow us to retrieve these critical parameters. This instrument uses large arrays of detectors to make observations in the millimetre and submillimetre wavelength regions. It completely avoids the need for mechanical scanning, and has large advantages over the "traditional" heterodyne instruments proposed for this type of observation. Particularly, we benefit from high sensitivity, high spatial and spectral resolution, and we have access to frequency ranges not currently available with heterodyne technology.

This project will develop the existing outline instrument concept into a full instrument proposal, ready for application to follow-on funding opportunities. We will look at the science areas, over and above ice cloud studies, where we can achieve maximal impact, and trade-off instrument concepts to arrive at the optimal solution.

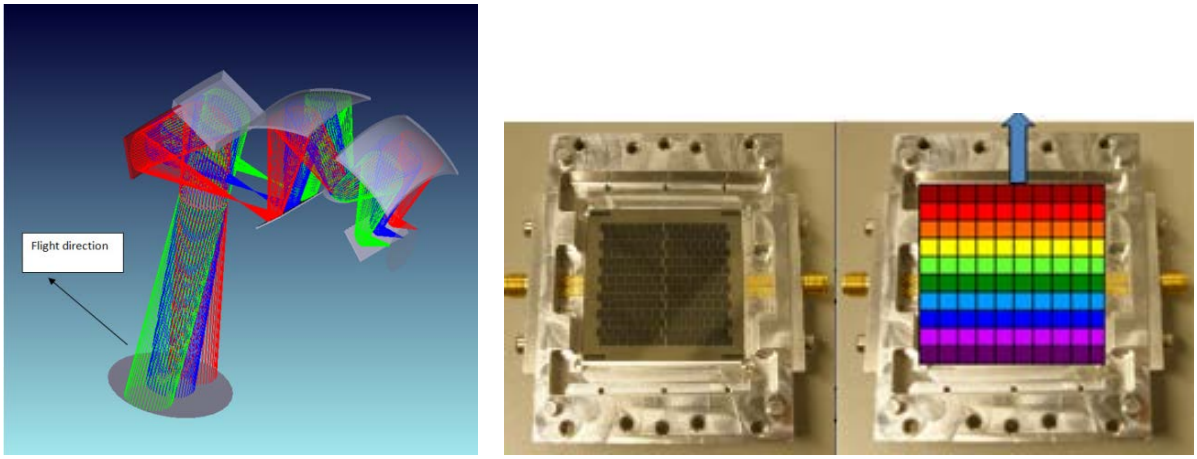


Figure 1. Left: Wide FOV fore-optics coupled to detector array via re-imaging optic and reflective cold stop. Right: Indication of multispectral/hyperspectral imaging configuration. Flight direction is indicated by the arrow. Across-track direction is spatial domain, along-track direction is spectral domain.

Demonstration and assessment of laser heterodyne radiometry for CO2 sounding

STFC Rutherford Appleton Laboratory

This project focuses on the demonstration and assessment of thermal infrared laser heterodyne spectro-radiometry for the remote sensing of carbon dioxide. Theoretical concept studies based on modelling have indicated Laser Heterodyne Radiometers (LHRs) can contribute to improving remote sensing of carbon dioxide in the thermal infrared, on-board a variety of platform from ground-based to space-based. During the project, ground-based measurements will be carried out and compare against theoretical modelling in order to fully assess the instrument technology and devise forward steps toward low cost, miniature autonomous carbon dioxide remote sensors. As one of the most important greenhouse gas, improved carbon dioxide measurements are needed to address both science questions related to the carbon cycle and to develop emission measurements services.

COnformal Retro Reflectors for Earth Observation (CORREO)

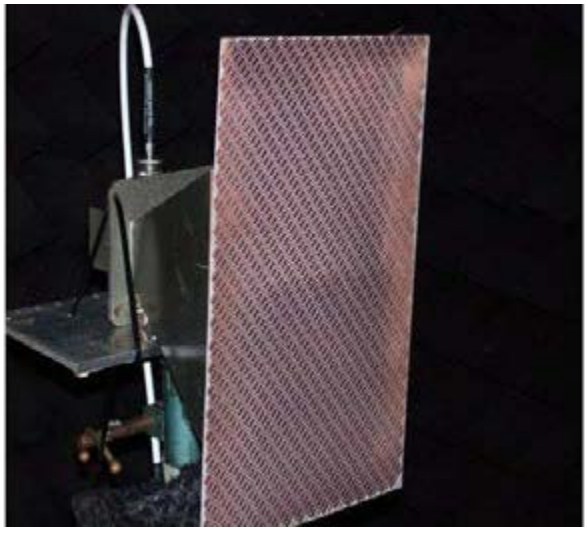
University of Cranfield with University of Nottingham

Ground-segment calibration and validation activities in support of a satellite mission are a vital and continuous component of the mission, and ultimately upon which successful exploitation of the data depends. Time has seen increasing sophistication in SAR functionality and the emergence of new application areas with a clear trend towards higher resolution and increased radiometric and geometric performance. In addition, future systems, featuring digital beam forming techniques based on multi-channel architectures, will require further sophistication of calibration techniques and procedures. In contrast to these advances, the use of trihedral retro reflectors in calibration strategies has remained largely static. Trihedrals are an effective but blunt tool;- they have fixed, broad beam patterns and operate across wide bandwidths.

The dimensions of a corner reflectors are chosen to give a large signal-to-noise (SNR) to allow them be seen and located precisely amongst background clutter in a radar image. Unfortunately, this usually results in the corner reflector being large and cumbersome which can;

- make it difficult transporting the reflector to and around the site
- make the reflector difficult to secure to a structure such as a bridge or side of a building
- cause problems with stability in the presence of high winds and extreme weather conditions
- become an eyesore in an urban environment, meaning planning applications may be resisted
- require regular maintenance as reflectors often fill with flotsam and jetsam borne by the wind, in addition to water and snow
- make them likely to be the subject of theft and vandalism.

To address these issues, the team is developing a new form of passive retro-reflector. A meta-reflector (M-R) is conformal, thin, lightweight, easily attached, and possesses a highly stable reflection phase property.



Electromagnetic Band Gap (EBG) polarisation transformer

Characterisation of Ferrite Material in Remanent State for use in New High Peak Power Applications

ComDev International Systems Ltd

The next generation of radar missions cover a wide range of frequencies from C-band to Ka-band. A common feature of all these missions is the dramatic increase in the peak power requirement of the system. Whereas previous instruments operated at typical peak powers of 100W, the newer requirement is for peak powers in excess of 3kW, thus presenting new challenges to power amplifier, radar feeds, antenna, and switching element providers. Ferrite switches are the technology of choice for radar switching elements since they provide a very high number of switching actions over the instrument lifetime, low insertion loss, high reliability, fast switching time, and high peak and average power handling. A key issue for the design of ferrite switches capable of handling high peak power is the selection of the ferrite material, and being able to predict the power threshold at which the switch will start to behave in a non-linear manner.

In a ferrite switch (latching circulator) the ferrite material is used in its remanent state. This is significantly different from the majority of other ferrite-based RF applications. Consequently, the materials' properties appropriate for operation in the remanent state are not generally available from ferrite vendors. This means that it is difficult to model and predict any ferrite switch performance, in particular identifying the peak power maximum threshold, above which the switch becomes non-linear (absorbs RF energy).

The goal of the proposed activity is to develop a low cost generic measurement system which will be used to characterise any ferrite material in its remanent state. Data will be gathered from a number of different ferrite materials at a selection of RF frequencies. This data will be used to generate and refine models for predicting peak power thresholds and magnetic (and hence insertion) losses.

If successful, this activity will result in a measurement and analysis process which will enable designers to confidently select the appropriate ferrite material for high peak power switch designs, thus removing the potential costly and lengthy re-iterative bread boarding and testing phase.

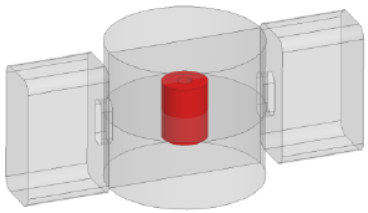


Figure 1 - Dielectric ring resonator

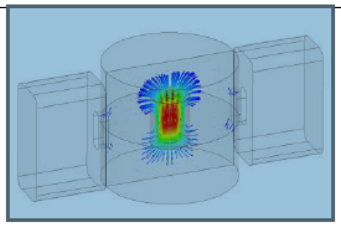


Figure 2 - Magnetic field distribution in the dielectric resonator