Seven new CEOI cutting-edge Earth observation technology projects to be funded

The CEOI is pleased to announce grant funding to UK businesses and organisations, matched with their own investments, to develop new EO technologies for future operational or commercial missions. Particular emphasis is on technology developments that could create export opportunities for the UK and the match to the ambitions of the newly released EO Technology Strategy.

The seven winning projects are:

1. **GRaCE: G-band Radar for Cloud Evaluation**

A consortium led by STFC RAL Space and including Thomas Keating Ltd, the University of Leicester, and the University of St Andrews has been awarded £609K to build and demonstrate a 200GHz, 1.5mm wavelength cloud profiling radar, able to provide enhanced scientific data that can improve the accuracy of societally important numerical weather prediction models.

2. **Development of a high-resolution multispectral camera system for EO applications using a new TDI CMOS image sensor**

A consortium led by Teledyne e2v and including Surrey Satellite Technology Ltd (SSTL) and the Open University has been awarded £968K to develop and demonstrate a novel very high resolution imaging system incorporating Time Delay and Integration (TDI) CMOS image sensor technology. The new design will provide a new entry level for customers looking to take advantage of sub-metre ground sampling grid using a smaller, lower-cost imager system than would normally be required, positioning UK industry to take advantage of the rapidly growing international market.

3. **OVERPaSS: On-board VidEo Rapid ProceSSing**

Optimising data processing on-board a satellite can substantially reduce the amount of data the satellite needs to store and downlink, increasing the satellite's overall utility. A consortium led by Earth-i Ltd and including SSTL, Cortexica Vision Systems, and University College London has been awarded £820K to implement, test and demonstrate ultra-high-resolution optical image analysis techniques (including super-resolution enhancement of images; retrieval of sub-pixel 3D point clouds; cloud detection and image quality assessment; change detection and moving object extraction; video compression), involving both innovative software techniques and dedicated hardware such as Graphical Processing Units (GPUs).

4. **Compact Multispectral Imager for Nanosatellites II**

A consortium led by the University of Strathclyde and including Wideblue Ltd has been awarded £719K to demonstrate the application of an innovative single-pixel sensing technique to multispectral imaging instruments. The resulting payload is very compact and suitable for nanosatellite deployment, providing high capability at low cost.

5. **Fast Slew Gimbaled Optics for Real-time Earth Observation Applications**

A consortium led by the Surrey Space Centre at the University of Surrey, and including In-Space Missions Ltd has been awarded £867K to develop the mechanisms, optics and interfaces to deliver a protoflight model of a zoomable, fast slew, gimbaled video and still camera system. This will address an upcoming flight opportunity in 2020, and form the basis for a low-cost family of commercial products.

6. **Characterisation of Leonardo MCT APD arrays in the ANU hyperspectral instrument**

Leonardo MW Ltd will develop and characterise large format Mercury Cadmium Telluride (MCT) Avalanche PhotoDiode (APD) arrays for use in future infra-red instruments for export and operational space missions. The project is a collaboration with the Australian National University, who will develop a system to test and characterise the devices.

7. Next Generation Infrared calibration Sources (NGENIRS)

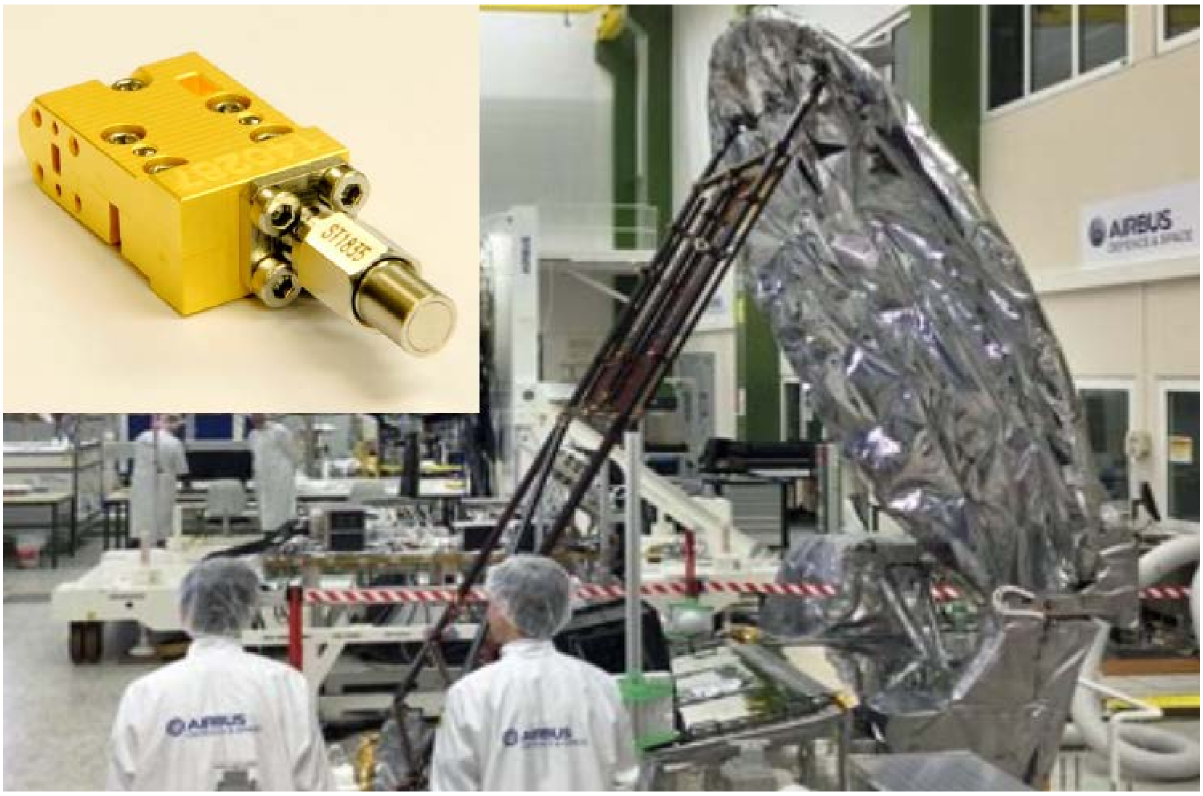
A consortium led by STFC RAL Space and including Surrey Nano Systems Ltd and the National Physical Laboratory has been awarded £594K to combine a range of technologies funded through previous CEOI and NSTP programmes in order to build and characterise a fully functional prototype flight black body demonstrator, which is a key enabling technology for delivering high-performance and accurate data from infrared sensing missions.

These projects are described in more detail on the following pages.

GRaCE: G-band Radar for Cloud Evaluation

(STFC RAL Space with University of Leicester, University of St. Andrews and Thomas Keating Ltd)

In response to the CEOI’s 11th call, a highly experienced national team proposes to build and demonstrate a 200 GHz, 1.5 mm wavelength, cloud profiling radar, establishing the basis for the future operation of a similar Earth observing radar in space. The radar is called GRaCE: G-band Radar for Cloud Evaluation. The small wavelength of a 200 GHz space radar will provide enhanced global information on the distribution of small droplets in the atmosphere. When operated in tandem with existing lower frequency space radars, the dual wavelength observations will enable atmospheric scientists to better characterize the microphysical properties of hydrometeors in water and ice clouds. Such information is needed to improve the accuracy of societally important numerical weather prediction models.



Examples of the team members’ current capability for development in the course of the project.

JAXA’s EarthCARE 94 GHz Pulsed Cloud Radar, incorporating Thomas Keating Ltd.’s quasi-optical multiplexer and antenna feed network and, inset, a 183 GHz Schottky diode mixer produced by RAL Space for MetOp-SG millimetre wave meteorology instruments

Over the next 18 months, team members Thomas Keating Ltd., and the Universities of Leicester and St Andrews, under the leadership of STFC RAL Space, will design, build and field test the GRaCE ground-based demonstrator radar. The programme exploits the complementary strengths of the partners so that the radar delivers the most useful scientific information: Thomas Keating Ltd. will develop their existing space radar antenna networks for higher frequencies, RAL Space will adapt space Schottky technology to provide the necessary high transmitted powers and sensitive receivers, the University of St Andrews will bring their millimetre wave radar system development expertise to the system design, test and calibration, and the University of Leicester will contribute expertise in analysing radar data and atmospheric modelling. Previous CEOI funding of the Leicester and RAL Space partners, under the POLYDOROS and HIDRA4PPM grants, has contributed to the technical and scientific foundations for the 200 GHz radar.

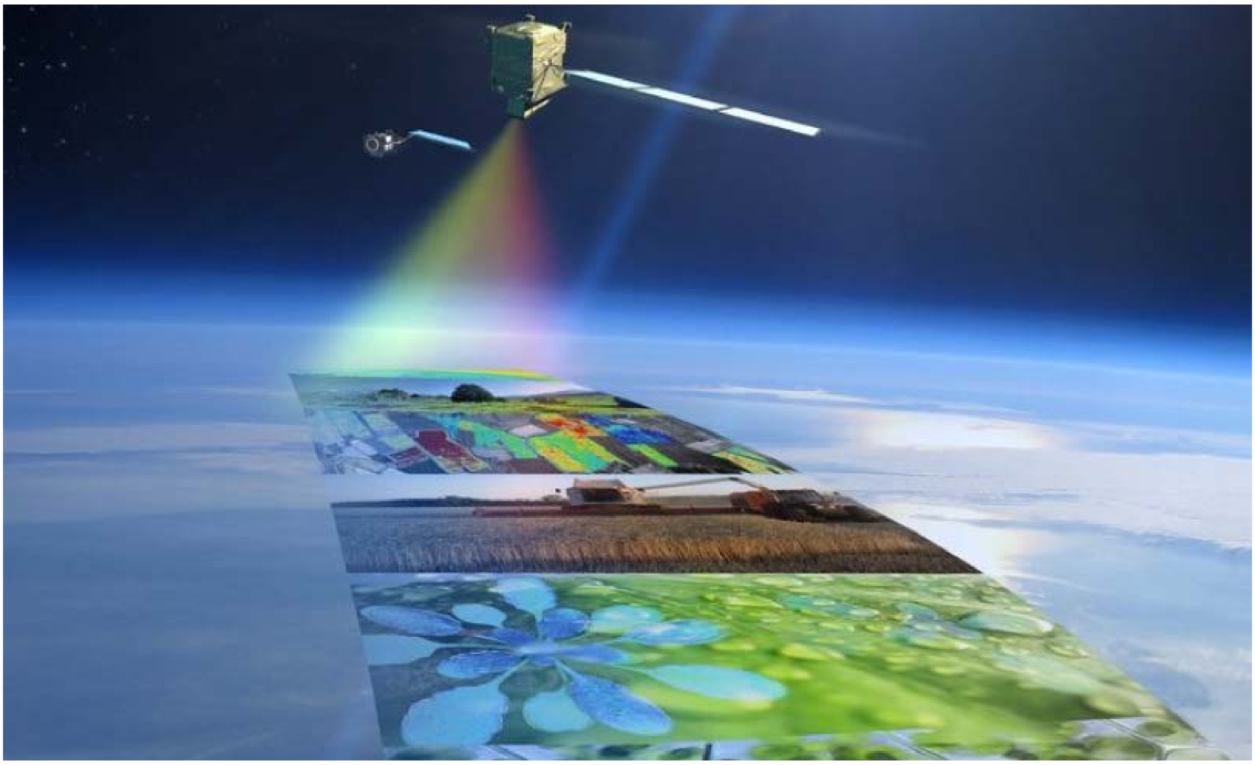
Development of a high-resolution multispectral camera system for EO applications using a new TDI CMOS image sensor

(Teledyne e2v with SSTL and the Open University)

Earth observation (EO) is a rapidly expanding area of space science and technology, fuelled by the demands for timely, comprehensive and informative data for an increasing number of applications. With the increased affordability of satellites EO is becoming accessible to a larger pool of commercial developers and users.

Presently, there does not exist in the market a low cost payload with the performance required to meet the growing demands of the commercial 'New Space' EO market (very high resolution, good quality image, low mass and low recurrent cost).

Teledyne e2v, SSTL and the OU have developed considerable expertise in imaging design, manufacturing and testing for space applications. This consortium is collaborating to establish the UK as a truly integrated technical lead for image sensors, focal planes, instruments and satellites in the highly competitive and rapidly growing application of high and medium resolution EO. The team will produce a prototype instrument to demonstrate the operation of a novel imaging system incorporating Time Delay and Integration (TDI) CMOS image sensor technology.



The main activities that will be carried out by the consortium will be:

- Teledyne e2v will be responsible for developing the prototype TDI CMOS sensor technology platform, including associated packaging, back-thinning and AR coating.
- The OU will be responsible for the characterisation of the sensor performance including radiation testing and will work with SSTL on the design and build of a set of drive electronics suitable for mounting in the telescope focal plane.
- SSTL will then evaluate the performance of the focal plane in a prototype telescope.

This new imaging sensor technology, in addition to SSTL's experience in building very high resolutions imagers, will provide a new entry level for customers looking to take advantage of a sub-metre ground sampling grid using a smaller imager system than would normally be required. The smaller system will also lend itself well for constellation building as it will be easier to build batches simultaneously in comparison to the traditional systems.

The existing CCD solutions will not work for new platforms especially with the demand for ever higher resolution, so the market will definitely change. TDI CMOS will give a much lower cost system with dramatically reduced power consumption and weight enabling new space applications that are still being created.

The UK is currently in a good position and this development will enable the UK to maintain its market lead in a key enabling technology within a rapidly growing market sector. It is estimated that it will enable the capture of market share with a significant ROI and contribute to helping the UK achieve its ambition of growing its share of the global space market to 10% by 2030. Around 90% of this business will be generated by exports thus helping the UK to achieve the goal of reaching £25bn a year in exports in the same period.

Next Generation Infrared calibration Sources (NGENIRS)

(STFC RAL Space with National Physical Laboratory and Surrey Nano Systems)

A number of new earth observation missions operating in the thermal infrared wavelength range are on the horizon. These include the Land Surface Temperature Mission (LSTM) for the Copernicus Sentinel extension programme for which studies are in progress, the ESA Earth Explorer-9 FORUM which plans to measure the Earth's entire emission spectrum from 100 cm^{-1} to 2760 cm^{-1} (3.62 µm – 100 µm), Sentinel-3 next generation which would replace the current Sentinels 3A – D. These missions are dependent on blackbody (BB) calibration sources to ensure the traceability of the radiometric calibration to international standards. As well as these 'high-end' missions, airborne and field sensors for atmospheric and surface measurements and the growing range of commercially available infrared cameras require readily available and low-cost blackbody calibration sources.

The basic design and performance of flight infrared calibration black bodies that were originally developed for the Along Track Scanning Radiometer and adapted for other missions including the Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR), the Geostationary Earth Radiation Budget (GERB) experiment and the Infrared Atmospheric Sounding Interferometer (IASI) has changed very little in the last twenty-five years. Mission requirements for radiometric accuracy, stability and traceability have become far more demanding and there is downward pressure on the mass, power and volume as the focus is for smaller and cheaper satellite missions. To fulfil these demands requires a step change in the key technologies that are employed in IR calibration sources.

Breadboard blackbody cavity with carbon nano-black coating developed in a previous UKSA project

Our consortium has already developed a number of component technologies through previous CEOI and NSTP studies specifically to address the quality of black body thermometry, temperature traceability and the radiometric performance of the black body cavity advancing the TRL to 2/3. The project will bring these technologies together to build and characterise a fully functional prototype flight black body demonstrator in a format compatible with a flight opportunity.

Our target technology readiness level is TRL 5/6. These advances will put UK in a strong position to bid for future flight and terrestrial missions.

OVERPaSS: On-board VidEo Rapid ProceSSing

OVERPaSS: On-board VidEo Rapid ProceSSing

(Earth-i Limited with University College London, Cortexica Visions Systems Ltd and SSTL)

The objective of the project is to implement, test and demonstrate ultra-high-resolution optical image analysis techniques, involving both software and dedicated hardware such as Graphical Processing Units (GPUs). The project will also determine the extent to which these capabilities could be deployed on-board British optical imaging satellites in future, with a roadmap for inclusion in a forthcoming constellation.

The specific processing capabilities to be explored are: Super-resolution enhancement of images; Retrieval of sub-pixel 3D point clouds; Cloud detection and image quality assessment; Change detection and moving object extraction; Video compression.

The team has identified several highly marketable opportunities resulting from incorporating such capabilities on-board the satellites in future:

• Processing on-board the satellite can substantially reduce the amount of data the satellite needs to store and downlink, increasing the satellite's overall capacity;

o Compression can offer a reduction in data volumes, and works well with satellite video data where redundancy is high

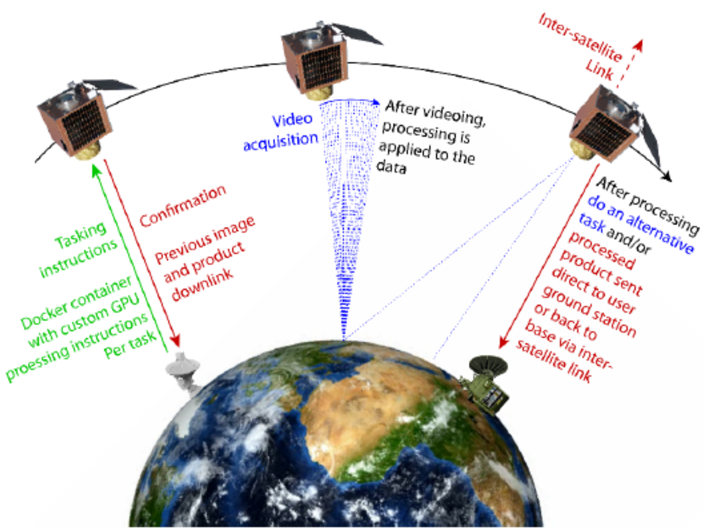
o Cloud detection can be used to only downlink imagery if the target is visible

o Quality assessment on-board means that otherwise unusable imagery need not be downlinked, for example if the signal to noise ratio is too low.

o Extracting alternative information products can mean that the entire video or image set need not be downlinked

• Processing the video data into data products can provide directly to the ground recipient a product that has already been processed prior to use, reducing the need for ground infrastructure for interpretation and reducing latency;

• In any case, where a visibility, quality or other assessment is made this could be fed back into the mission plan for automatic re-tasking with different specifications, such as to attempt acquisition from an alternative angle or with a different frame integration time



Since it may not be possible to do all the necessary processing on board the satellite, the project will trial different onboard processing approaches and determine the optimum combination of onboard and on-ground processing considering various hardware and software implementations and end user needs. The team has engaged with potential end-users of the resulting products and services and all have expressed a keen interest in exploiting such technology in future.

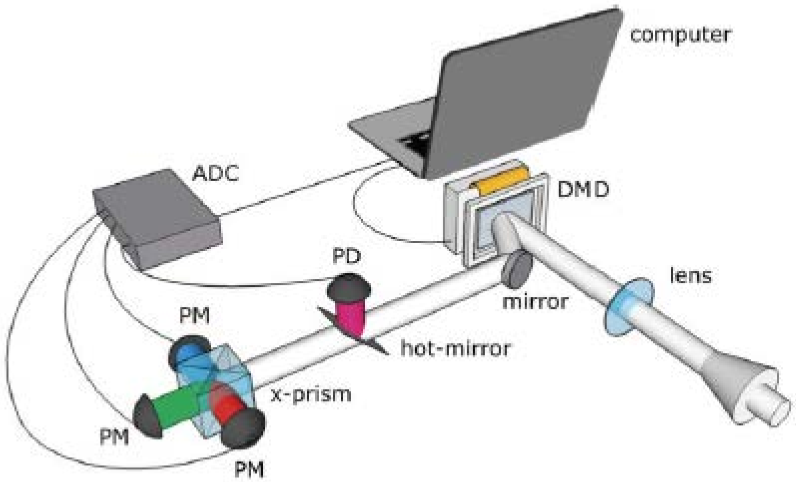
This is a time critical opportunity to achieve deployment within commercially meaningful timescales as international competition is growing. It uses existing low-cost technologies for rapid deployment.

Compact Multispectral Imager for Nanosatellites II

(University of Strathclyde with Wideblue Ltd)

Multispectral imaging (MSI) from space has important applications for Earth Observation but conventional MSI instruments are necessarily more complex, bulky and costly than single band or RGB-VIS imagers, restricting their deployment to larger satellites. A novel imaging paradigm, Single-Pixel (SP) imaging, offers the possibility of performing shared aperture MSI with a more compact payload together with greater operational flexibility and vastly reduced data handling requirements compared with conventional instruments.

The key goals of the project are to demonstrate the application of SP techniques to MSI instruments suitable for nanosatellite deployment and provide high capability at lower cost. The team will continue translation of terrestrial SP technology (begun under UKSA NSTP-3 funding) to design and build a prototype and characterise its performance. This form of scanning-type single-pixel imaging is suited to multi-spectral operation in bands where conventional MSI is difficult or expensive for nanosatellite platforms. The team will continue engaging end users and upstream providers to inform and update developmental pathways, and perform downstream application scanning and development. The initial aim is to build and operate a prototype that would be the basis for a space-qualified instrument for in-orbit-demonstration on a nanosatellite.



Snapshot SP MSI. From M.P. Edgar, et al.,Sci Rep 5, 10669 (2015)

The outputs from the work will progress the roadmap for rapid realisation of cost-effective MSI from nanosatellites and provide a concrete realisation of new enabling technologies. The primary objectives for this work are:

- To provide experimental proof-of-principle of Single-Pixel multi-spectral imaging with characteristics suitable for nanosatellite deployment.
- To analyse signal processing techniques that further enhance the method
- To design, build, and test a protoype MSI instrument
- Develop downstream applications and engage users as well as upstream providers The properties of SP imaging, specifically that an image can be formed from a very small amount of intensity data, provide the key advantage that will allow significant multispectral imaging on nanosatellites.

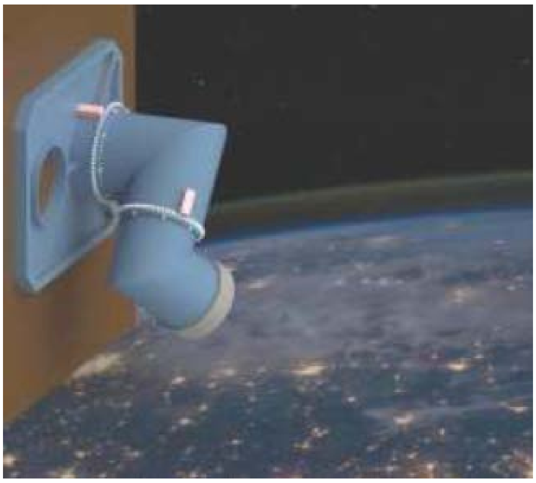
Moreover, application of an optical processor allows for reprogrammable case-specific information filtering, changes the imaging paradigm and paves the way for a different category of imaging data consumers who can actively decide the specifications of the imaging device on the fly. By applying algorithms from image analysis and machine learning, the imaging device can also play the role of a fast alerting system that is able to quickly inform users about events of given characteristics.

Fast Slew Gimbaled Optics for Real-time Earth Observation Applications

(Surrey Space Centre, University of Surrey with In-Space Missions Ltd)

The proposing team – Surrey Space Centre (SSC) and In-Space Missions Limited (ISML) – has identified both an urgent specific need and large market for a zoomable, fast slew, gimbaled video and still camera system. This product is designated 'Nimble'.

The project will develop the mechanisms, optics and interfaces to deliver a protoflight model of the Nimble system. This project will develop the first generation of the Nimble camera system to be ready for launch in 2020. Profits from sales of the NimbleX5 will be leveraged, alongside some additional private investment, to develop a family of cameras to address a wide market.



In order to be ready for launch in early 2020, the project must conclude by end of Q3 2019 with the build and qualification of a protoflight NimbusX5 unit. The development will exploit terrestrial COTS and processes alongside industrial and academic know-how to build a product that is low cost and allows a rapid schedule by design.

Surrey Space Centre brings many years of experience in satellite technology and payload development and have world class capability in nanosatellite and mechanism development.

In-Space Missions Limited bring over 50 years of combined experience in designing, building, testing, launching and operating low cost satellites and satellite payloads. In addition, ISML has the ability to industrialise and commercialise the technology and has access to a number of low cost flight opportunities via the Faraday IOD programme.

Characterisation of Leonardo MCT APD arrays in the ANU hyperspectral instrument

(Leonardo MW Ltd in collaboration with the Australian National University (ANU))

Leonardo MW Ltd will work in collaboration with the Australian National University (ANU) to develop world-leading UK infrared EO technologies for future operational and commercial missions. This is aligned to the UKSA EO Technology Strategy through technological and economic benefits.

The existing Leonardo SAPHIRA array has revolutionised adaptive optics principles for ground based systems through the combination of virtually noiseless avalanche gain and high quality mercury cadmium telluride (MCT) material with a low noise, high speed silicon readout circuit. The prospect of larger format MCT Linear avalanche photodiode (L-APD) arrays offers a technology capable of delivering a disruptive improvement in the quality of imaging data available to scientists without compromising the payload size, weight or power.

In order to exploit this world leading technology in remote sensing applications two key developments need to be undertaken. One is a larger format MCT avalanche photodiode array required to deliver the necessary simultaneous spectral and spatial mapping speeds for efficient application to these fields. The other is the flight-ready control hardware for operation of the detector in a space qualified instrument.

The project will develop the next generation large format 1Mpixel SAPHIRA device, advancing from the current conceptual design status TRL3 to TRL7 through characterisation in a simulated space environment through the partnership with the ANU. The key contributions to this programme by the ANU are the development of the necessary control system, together with the resources required to complete the characterisation work and reach TRL7.

Image credit: Space Simulation Facility – Australia National University

The proposed work at Leonardo will take advantage of data gathered from a number of previous activities which together de-risk the major technology elements required for the development of large format, smaller pitch MCT APD arrays.

Leonardo has developed large format arrays for ESA including a low noise silicon readout IC (ROIC) which uses a radiation hard cell library in 0.35 micron CMOS silicon. CEOI funding has allowed us to characterize this ROIC for immunity to heavy ion radiation. This has been followed up by a successful programme of proton radiation testing on the same device type, through further CEOI funding. To date this ROIC has been used with conventional MCT diode arrays, but it has been selected for the proposed work because it is also designed for use with MCT APD arrays operating as conventional diodes at unity gain as well as in avalanche mode by adjustment of the operating voltage.

NSTP funding has allowed Leonardo to complete characterisation of existing smaller format MCT APD products under a range of operating voltages and temperatures and ESA funding has recently been used to conduct gamma and proton radiation testing of the current SAPHIRA APD array.

The proposed work will therefore involve the development of an MCT APD structure based on the design used in the SAPHIRA device, optimised for use with the larger format, smaller pitch ROIC. This will be characterized with the controller to be developed by the ANU in a demonstration of smaller pitch larger format MCT APD arrays for earth observation missions.

The high performance MCT array designs resulting from this work would be produced for space applications using existing Leonardo space qualified manufacturing facilities and techniques currently being employed for the IASI NG programme. The ANU plan for an in-orbit demonstrator to be deployed on the ISS in a subsequent stage, would provide flight heritage to support selection for future missions such as follow-on programmes for ANU hyperspectral imagers and the EC Copernicus expansion programme. This would 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.