Development of specialist space 'radio' set to establish UK as global leader in high-frequency technology

A novel terahertz (THz) receiver, which can measure gases in the highly dynamic and poorly understood boundary region between the Earth's outer atmosphere and space, will further our understanding of interactions between space weather and the atmosphere, and the long-term effects of climate change. It will also improve our knowledge of how the variability of the outer atmosphere affects the orbits of low flying satellites and space debris. This crucially contributes to protecting our low Earth orbit (LEO) assets through collision avoidance, and helps with targeted re-entries, a rapidly increasing concern in the ever more congested LEO region of space.

Altitudes between 50 km to 250 km, the Mesosphere – Lower Thermosphere System (MTS), cannot be visited by in-situ observation platforms, so we rely on remote sensing techniques. Historically, a lack of high-frequency instrumentation and an opaque lower atmosphere means that little is known about the gases in the MTS upper atmosphere, yet this is an area that affects the orbits of near-Earth satellites.

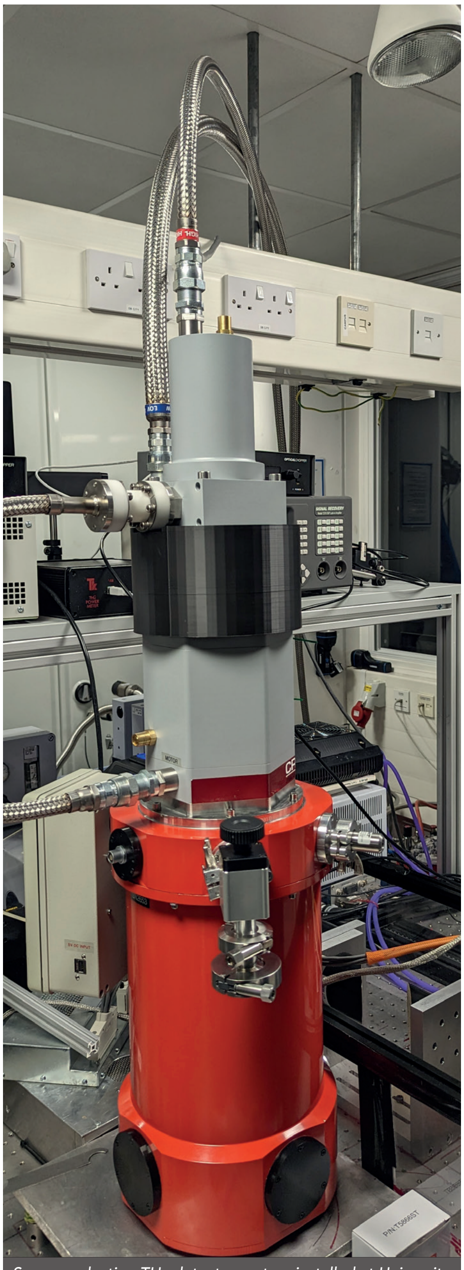
The most urgent measurement gap is an almost complete lack of knowledge of the abundance and variability of atomic oxygen, the most abundant species at that altitude, yet that has never been measured globally. Atomic oxygen can be detected at characteristic frequencies of 2 THz or 4.7 THz.

Existing technology, such as infrared or microwave sensors, don't cover this frequency range with sufficient sensitivity and accuracy, so a new receiver technology to unlock it is urgently needed.

Setting out to address this is Keystone, one of the European Space Agency's (ESA) Earth Explorer 12's candidate missions, which would provide the first direct observations of the temperature and density of the MTS, its winds, the crucial missing species that is atomic oxygen, as well as a comprehensive set of secondary trace gas observations.

Keystone will be enabled by a new generation of receivers that work at frequencies close to and above 1 THz, and which will collect critical data about the poorly characterised upper atmosphere. Not only will this give us a unique, complete picture of the chemical and thermal composition and variability of the MTS, it will also allow us to understand better how the atmosphere is affected by space weather events, long term climate trends, and significantly improve our models of residual orbital drag on satellites.

One element of Keystone is the development of a 2 THz receiver, a type of 'radio' designed to pick up signals given off naturally from low concentrations of gases such as atomic oxygen and ozone in the upper atmosphere.



Superconducting THz detector system installed at University of Leeds in phase one of the facility upgrade programme

The background to the 2 THz receiver

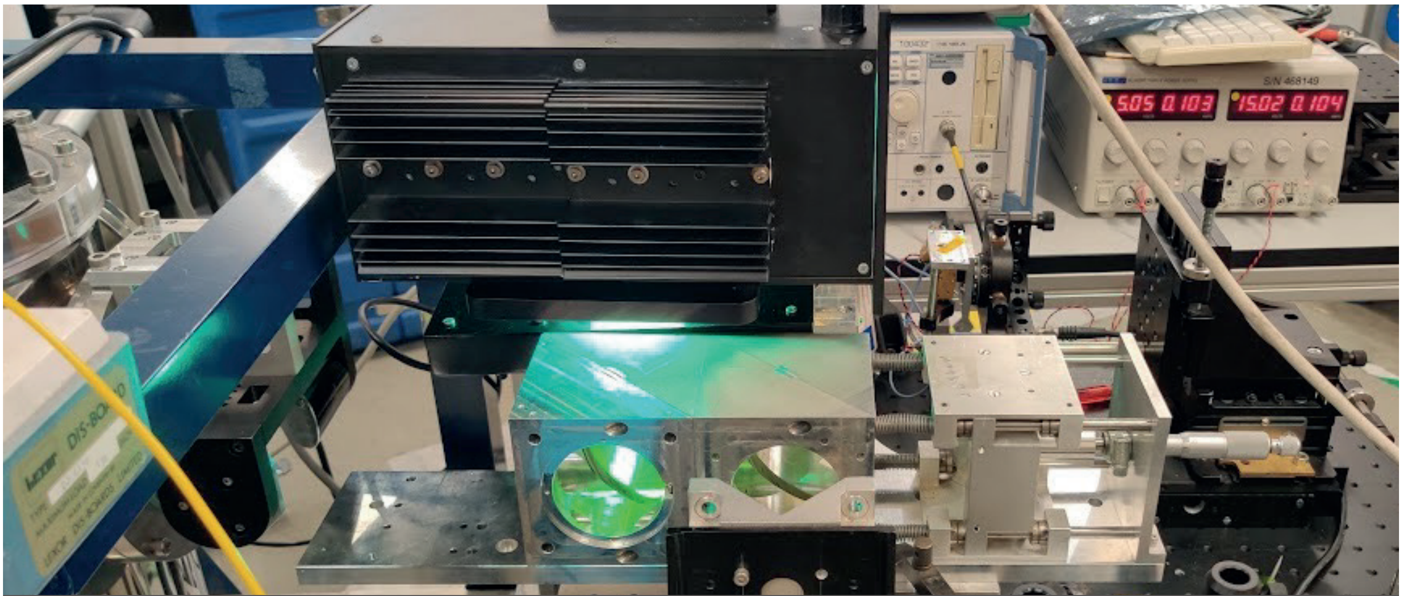
A precursor to this ground-breaking technology began with the enhancement of the THz-frequency characterisation facilities at the University of Leeds. While the UK is a frontrunner in THz technology, test-capability was urgently needed to further strengthen the development of THz instruments for satellite-borne or terrestrial systems, and to support UK roles in the Earth Explorer 12 candidate missions.

Funding of £320,000 from the UKSA's Centre for Earth Observation Instrumentation (CEOI) boosted the facilities at the University of Leeds, with the upgrade including a world-leading superconducting detector system and increasing testing throughput by reducing reliance on unsustainable liquid helium usage.

A key element was improving capability for THz spectral measurements with a new state-of-the-art THz spectrometer, and beam quality measurements with a custom-built automated 3D THz beam profiling system, as there is an increasing need for devices with precise emission characteristics.

At RAL Space, prior CEOI funding for Schottky diode-based receiver development has supported the development of high performance, space flight qualified, mm-wave to THz devices. Detectors produced at the RAL Space are operating in space on the first of the Met-Op Second Generations series of satellites, providing essential remote sensing data on atmospheric temperature and humidity for numerical weather prediction. Very recently, on January 11th, 2026, the first in-orbit demonstrator of the Hyper Spectral Microwave Sounder (HYMS) was launched by Spire Global Ltd. This radiometer instrument resulted from a collaboration between RAL Space staff and Spire, with HYMS technology developed and demonstrated by RAL Space with CEOI funding, and then licenced to Spire Global for their commercial weather forecasting purposes.

In parallel, again with CEOI support, RAL Space staff have been developing the sub 1 μm diameter gallium arsenide Schottky diodes needed for operation at the Keystone frequencies. Existing devices, as used in Met-Op Second Generation instruments, are simply too large to work efficiently at 2 THz and higher. The team has been applying advanced optical and electron beam fabrication techniques to make the much smaller Keystone diodes.



Testing RAL Space's THz Schottky mixer with a University of Leeds quantum cascade laser

Enter the 2 THz receiver for upper atmosphere science

Existing THz sensor systems are too large, fragile and complex for most applications outside the laboratory and lack the sensitivity needed for studying reactive gases, limiting the prospects for THz systems being deployed in space.

Described as "vital" for the success of the Keystone mission, the 2 THz Schottky diode-based heterodyne receiver is a highly advanced, sensitive system that combines two groundbreaking semiconductor technologies:

- **THz Quantum Cascade Lasers (QCLs)** which generate precise high-frequency signals with high output powers
- **THz Schottky diode mixers** which convert very weak signals at THz frequencies into lower frequency signals that can be processed using conventional electronic methods.

These new technologies are important, firstly because they are microscopic, portable devices, and secondly, because the UK is investing more widely in semiconductor technology as part of its National Semiconductor Strategy.

The 2 THz technology continues to be developed through a collaboration between the University of Leeds and RAL Space, thanks to £760,000 in funding received from the CEOI.

Current status of the project

The project has made significant progress, with high-purity 2 THz beams being generated from QCLs, and radiometric testing confirming the receiver's capability and feasibility as a key component in a functional THz radiometer for future satellite-borne use.

Further work is needed to develop the space flight readiness of the core technology that underpins this project. Circuit designs will need to be optimised and qualified for space flight, and systems engineering aspects require development.

The project is a cornerstone in the development of the technology that will be crucial for the Keystone mission.

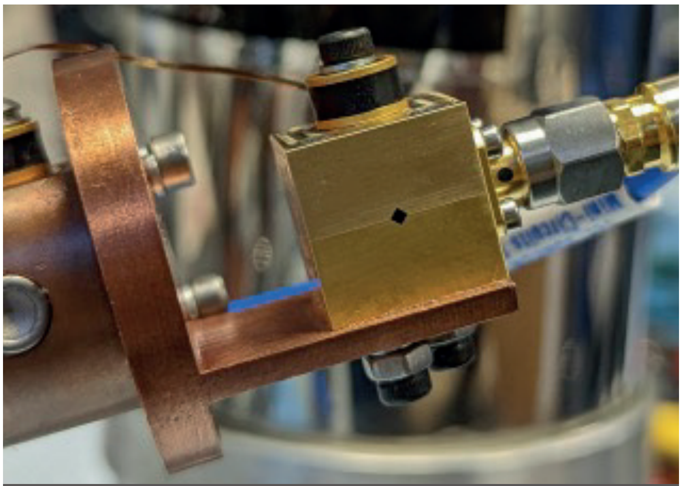
Furthering this work will not only cement the UK's position as a global leader in high-frequency technology, but data from the mission will also allow the UK to be at the forefront of improved weather prediction and climate models.

What's next?

The strides made in developing a 2 THz receiver establishes a benchmark for the 2 THz atomic oxygen channel of Keystone, and they pave the way towards the higher frequency Keystone channels at 3.5 and 4.7 THz.
Every molecule has a distinct 'fingerprint' frequency at which it emits (and absorbs) radiation. Another strong signature of atomic oxygen is at 4.7 THz, while many other important atmospheric gases can be observed at 3.5 THz. As such, increasing the receiver frequency could allow for better data on the concentration of molecules and the speed at which they are moving, providing valuable information on winds and the energy balance in the atmosphere. This next development will add to the value of the Keystone mission by offering a different receiver for each different frequency.
Outside of the space industry, the same QCL and receiver technology can be used on Earth for ultra-fast "beyond 6G" wireless communications, agricultural pollution monitoring, industrial process control, and for the clean-energy transition.

The impact of funding from CEOI

Funding from CEOI has allowed for the development of more powerful and more accurate tools for studying the upper atmosphere.
Advancing UK technology development and investing in innovative solutions like QCLs and Schottky diodes strengthens the UK's position as a leader in high-frequency technology research and development. It demonstrates that the UK is a key player in European and global aerospace innovation, while also supporting the development of next-generation scientific knowledge and training.



RAL Space's quantum-cascade laser module mounted in the University of Leeds' characterisation system for testing

In the words of Peter Huggard

Terahertz Researchers Lead, RAL Space

"If the Keystone mission goes ahead, it will be a world double first, both in terms of the region of the atmosphere it is probing and the observing frequencies. Characterising the rarified atmosphere at altitudes above 70 km and at frequencies from 1–5 THz will be a major technical and scientific breakthrough. Thanks to UKSA CEOI funding over several years, the UK is strongly positioned to have a major involvement in this unique mission.

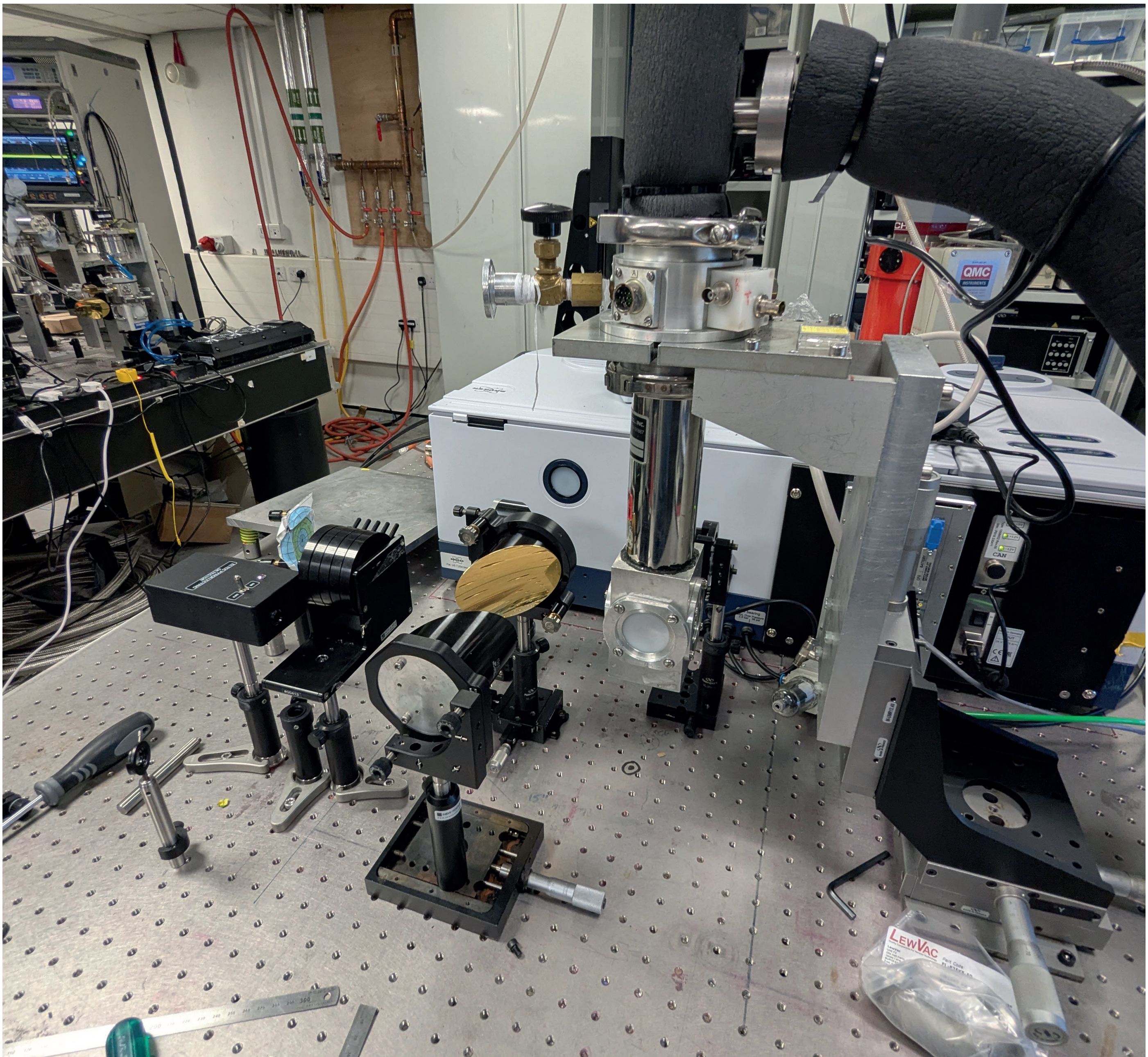
This part of the atmosphere – from 70 km to 250 km up – is very poorly studied. You can't see it from the ground at these frequencies because the lower atmosphere is opaque, and it is becoming increasingly important as knowledge of its behaviour offers a way of studying the effects of climate change.

This very upper bit of Earth's atmosphere is not stable – when it changes due to solar activity or global warming, the molecular drag on satellites and space debris varies. Predicting the orbits of objects and when and where they are likely to re-enter is increasingly important as space becomes ever more cluttered. For example, if you operate a satellite you need to know well in advance if something will present a collision hazard, so that you can move the satellite to a slightly different orbit. Accurate prediction of orbits is critical to this, and knowledge of drag is a factor here.

I, together with colleagues at the University of Leeds, are very pleased to acknowledge the sustained financial support Keystone technology development has received from the UKSA's CEOI. This type of funding is unique in the UK and complements what is available from the Research Councils. It supports critical EO technology development at low-to-mid readiness levels and puts us in a position where we can credibly bid for provision of space instrumentation."

At a glance

- **First** high-precision remote-gas sensors to operate in the 2 THz band
- Quantum-cascade lasers (QCLs) yield **>1,000 times the power** of any similar-sized device
- **100x improvement** in the resolution of spectral 'fingerprints' compared with lab-based Fourier Transform Infrared spectrometers.
- Enables **continuous worldwide mapping** of gases in the upper atmosphere in future satellite missions
- **2 years** of development for the 2 THz receiver
- **10** people involved in the 2 THz project
- Approximately **£2 million** in total funding from CEOI when including all the THz technology and facility upgrades for Keystone



New Bruker Vertex 80 FTIR spectrometer and QCL cooling system installed at the University of Leeds, in second phase of facility upgrade