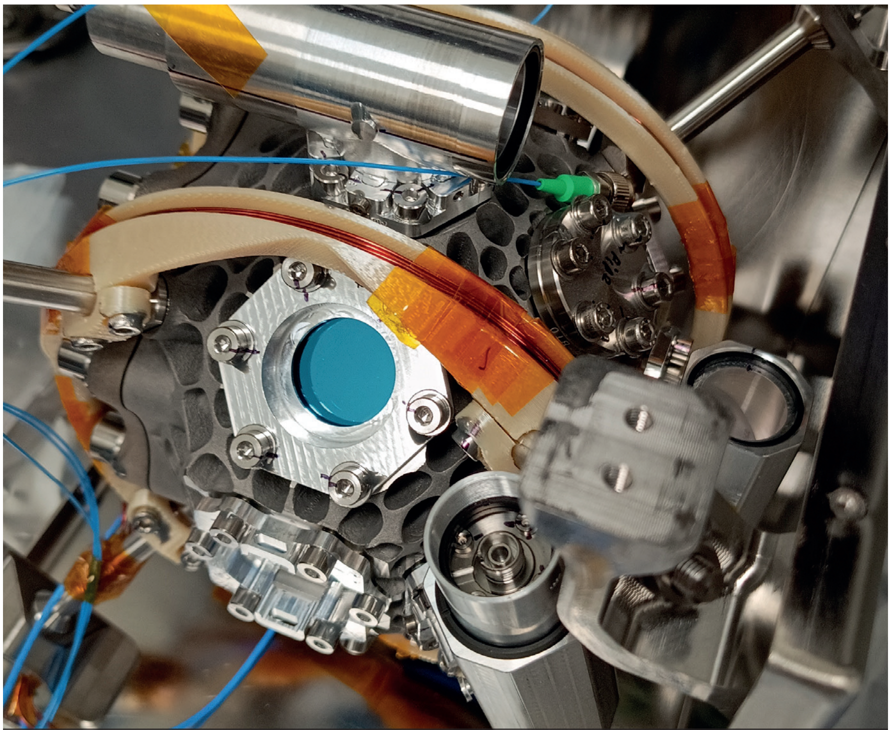
Secrets of the upper atmosphere could be unlocked with new sensor

The development of a ground-breaking sensor that measures the density of the upper atmosphere could provide valuable insights into the behaviour of the Earth's climate.

Understanding the behaviour and density of the upper atmosphere would shed light on the energy exchange between the Earth system and solar-wind influence of induced magnetosphere fluctuations, enabling better and more accurate climate modelling.

In addition, the density of the upper atmosphere has an impact on the lifetime of low Earth orbiting (LEO) satellites due to drift. Knowledge gaps in the fluctuations of the upper atmosphere make it difficult to accurately predict the trajectories and the exact time of re-entry of satellites, so a better understanding of this region would be of huge benefit to this industry.



View of the CAITDM vacuum chamber during the assembly process, showing the external coils, laser delivery system (and optical fibres) as well as one half of the external passive magnetic shield

Enter CAITDM

A data gap in atmospheric mass density at altitudes between 300 km and 500 km, in particular during periods of heightened solar activity, has led to the early development of a specialised sensor that has the potential to significantly improve climate modelling and provide more accurate measurements of atmospheric drag.

Current techniques to measure atmospheric drag are based on electrostatic accelerometers, but these measurements suffer from drift.

This led to the early development of CAITDM (Cold Atom Interferometer Thermosphere Drag Measurement), which is drift free and can provide absolute measurements with high sensitivity and without the need of calibration.

Electrostatic accelerometers experience drift because they provide results by comparing their measurements to a voltage reference – this voltage reference suffers from drift as a result of changes of temperature or the systematic effects that occur in satellites and also on the ground. Moreover, electrostatic sensors also suffer from 1/f noise (increased noise at low frequencies) due to their electronic readout systems.

Cold atom accelerometers do not rely on the comparison of any microscopic voltage reference or other factors that may change with time. The result of their measurements is drift free because it can be traced back from fundamental constants of nature (like the electron charge, atomic masses, Plank's constant) that do not change over time.

The sensor would provide a better understanding of the temporal and spatial variations of the density of the upper atmosphere, impacting on atmospheric science and climate modelling. It would enable atmospheric scientists to apply actual data to their existing models of the atmosphere, allowing for refinement and better accuracy.

It is an important step towards understanding the dynamics of both the energy deposited in the troposphere by human activity, and ground thermal fluctuations.

CAITDM would also provide a solution to the non-negligible drag that, unless satellites have a propulsion mechanism, slows them down, making them lose altitude and eventually re-enter. This has a significant impact on the sustainability and availability of LEO orbits, which are in high demand.

CAITDM is thought to be the most advanced quantum sensor-based system to measure the density of the upper atmosphere currently in development.

Current status of the project

The Centre for Earth Observation Instrumentation (CEOI) provided, as a result of its 16th Call, an initial £1.3m in July 2025 to fund the bread board study underpinning CAITDM, a collaboration between RAL Space, the University of Nottingham and Metamorphic Additive Manufacturing Ltd.

Following this, the project was awarded a further £150,000 to allow for the final functional testing of that bread board study. This allowed for the assembly and evacuation of the fully functional vacuum chamber, the re-assembly/re-build of the optics damaged during vibration testing, the assembling of the full physics package and running the atom laser cooling experimental sequence.

This is set to raise its Technology Readiness Level (TRL) to around 4, as an average across all elements of the project.

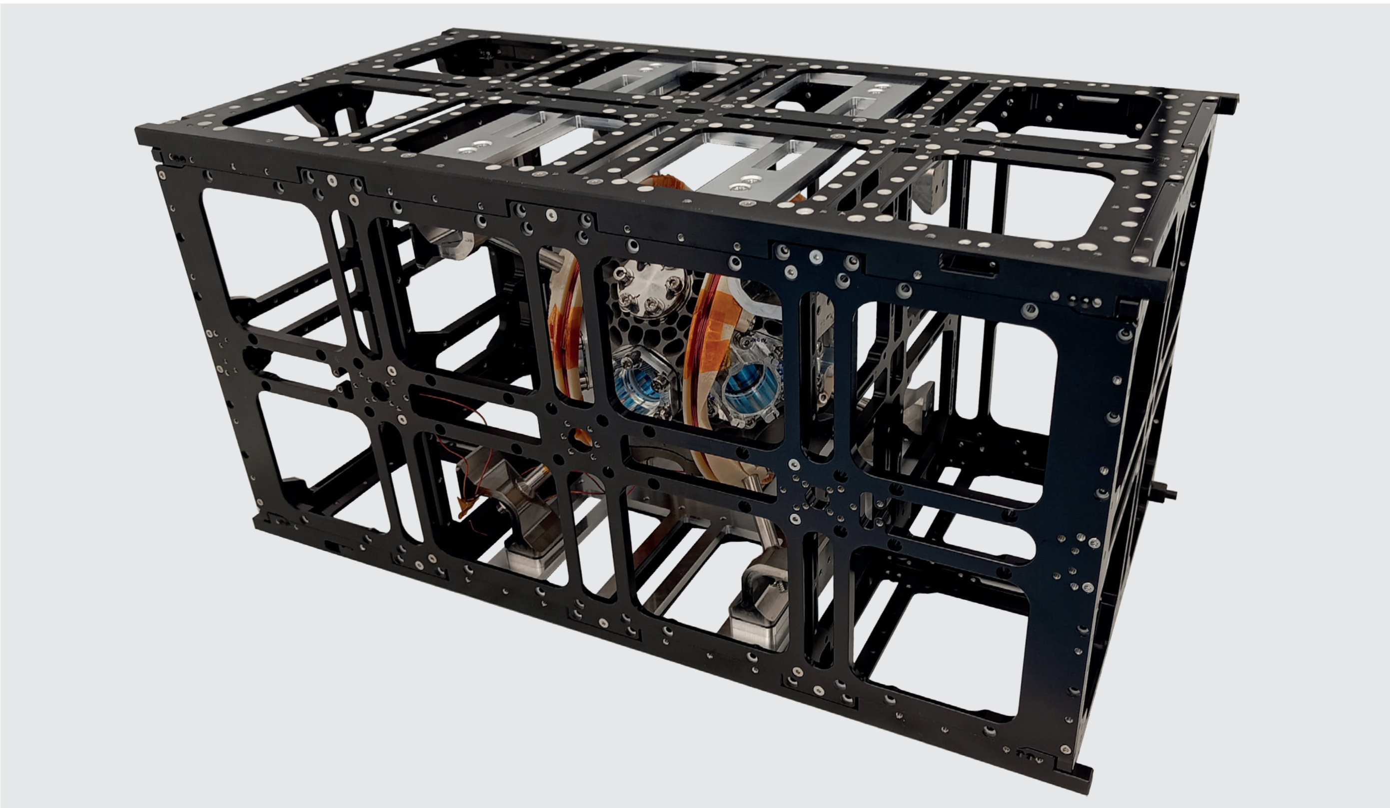
What's next?

The team behind CAITDM are exploring funding opportunities to enable the mission to move to TRL 5 and beyond.

Longer term, there are plans to extend the sensor's capabilities so it can be used for different applications and move into the fundamental physics realm to conduct physics experiments, which may include tests of general relativity or gravitational wave detection.

Similar devices to CAITDM are already deployed on the ground so additionally, there is scope to apply the knowledge, technology and advancements that were needed for space deployment, to existing ground-based technologies. These modifications, based on the CAITDM mission, will ensure these technologies are smaller, more reliable and more robust. They are already used in the fields of geophysics and civil engineering for operations such as measuring changes to the water cycle and measuring changes to the density of what is underground. This could include how magma accumulates under volcanoes or looking for the presence of sinkholes or underground voids of any kind.

Improving these existing technologies demonstrates the impact CAITDM could have beyond its primary remit.



View of the CAITDM vacuum chamber inserted in the 16U CubeSat frame during the test of the fit and interfaces with the future satellite platform

In the words of Dr Tristan Valenzuela

Quantum Sensors and Technology Programme Lead, RAL Space

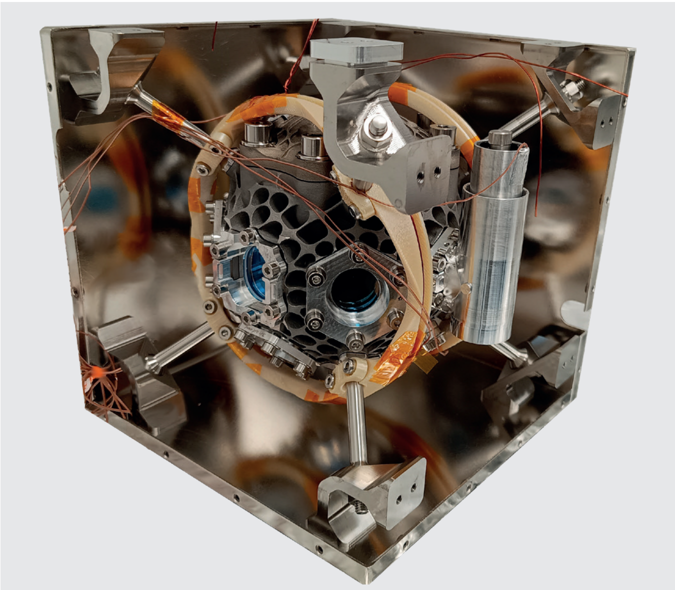
"This project clearly demonstrates the importance of CEOI in supporting emerging, low TRL technologies towards applications in Earth observation and atmospheric science. CEOI is doing a critical job in supporting early technology development – it's very difficult to find support for this kind of development elsewhere.

CAITDM will enable a better understanding of the upper atmosphere, which has various implications both for climate science and the economic impact on the low Earth orbit industry, which is now exploding due to the demand for satellites.

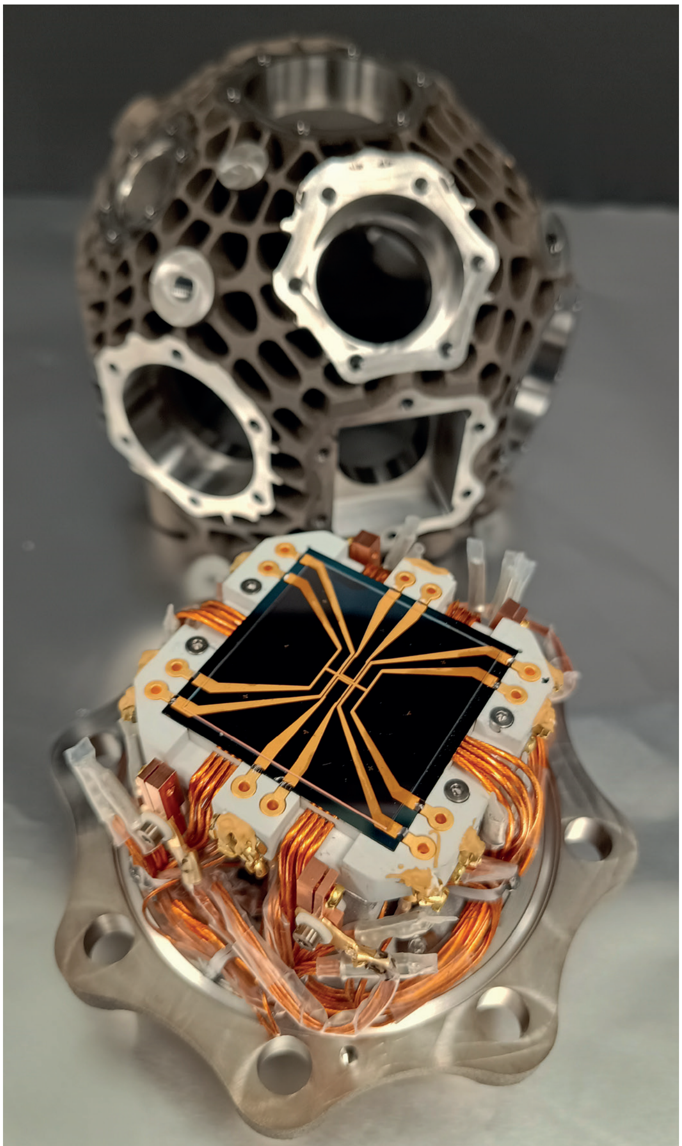
It also has implications for future deployment of other quantum technologies in space as CAITDM would serve as an in-orbit demonstration of quantum technologies with various levels of applications in geophysics and fundamental physics, as well as in future secure communication networks. These include gravity sensing from space, in space weather monitoring, and through synergises on all the sub systems that are required in communications and beyond."

At a glance

- More than **£1.4m** of funding from CEOI
- **Other funding steams:** UKSA NSIP, ESA, potential NQTP funding
- **15** people involved in the development of CAITDM
- **5** years of development so far, including previous iterations
- **Capability of CAITDM:** Measurement of density of the atmosphere at altitudes between 300km and 400km, with sensitivity in the range of 1×10^{-15} g/cm^3 to 20×10^{-15}g/cm^3



CAITDM vacuum chamber during the assembly process for TVAC testing – visible are external coils, thermocouple wires (to monitor thermal behaviour of the system), one of the laser delivery telescopes and one half of the passive magnetic shield.



In the foreground, assembled atom chipmounted of its feedthrough flange ready for fit testing in the CAITDM main chamber body (background)