Update on the UK ex EE-10 Candidate Mission LOCUS

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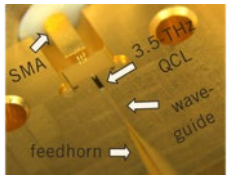
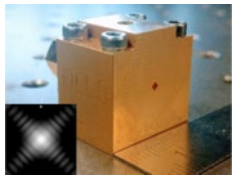
LOCUS

Linking Observations of Climate, the Upper-Atmosphere, and Space-Weather

"A mission concept for a unique Upper Atmospheric research satellite, to study the chemical composition of the least know region of the atmosphere, the Mesosphere – Lower Thermosphere, so that we can understand it's radiative behaviour as a geared indicator of Climate Change, and how it is affected by Space Weather forcing"

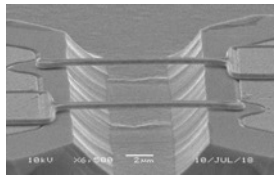
- Limb-sounder with four THz and five IR channels
  - First heterodyne detection of atomic oxygen, the main atmospheric constituent above 120 km
  - Helps unravel the MLT thermal balance by simultaneously measuring greenhouse gas heat fluxes (NO, CO, and CO_2) and their quenching rates with atomic oxygen
  - Quantifies Space Weather forcing of atmospheric composition by measuring NO, and possibly NO+
- Enabled by novel technologies developed in the UK
  - Novel UK quantum cascade laser technology (University of Leeds) makes the THz-Gap accessible for remote sensing for the first time
  - Exploits new mini space coolers (STFC Technology) and wideband spectrometers (STAR-Dundee)
  - Lauded (but unselected) ESA Earth Explorer 10 candidate mission - Looking for bilateral partners





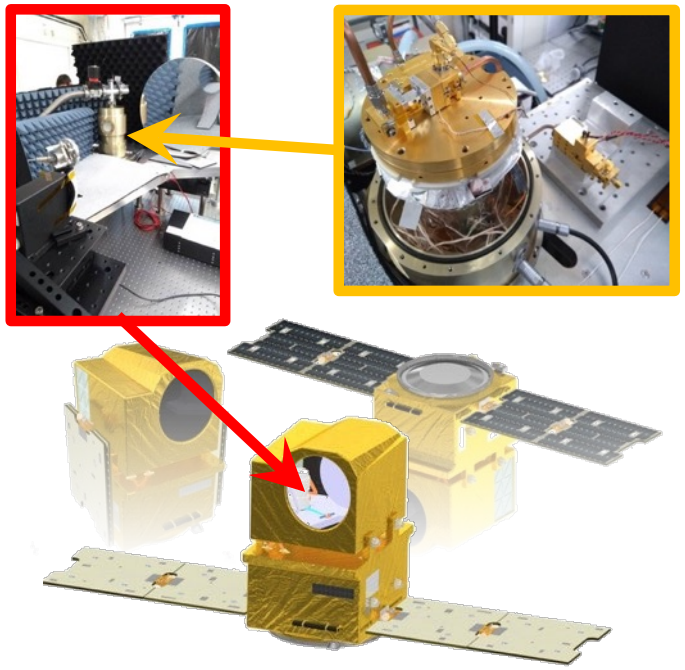
Quantum Cascade Laser (QCL) devices as a high-power source to pump heterodyne Schottky mixers

Miniature space coolers to provide QCL cooling (~70K)



Improved Schottky diode & mixer manufacturing for THz frequencies

Compact, high-speed, power efficient digital spectrometers



LOCUS ESA EE-10 space segment concept (on Airbus Astrobus platform) with photos of existing hardware through CEOI funded pre-development activities

The Upper Atmosphere

Thermosphere
53–375 Miles

In the thermosphere, molecules of oxygen and nitrogen are bombarded by radiation and energetic particles from the Sun, causing the molecules to split into their component atoms and creating heat. The thermosphere increases in temperature with altitude because the atomic oxygen and nitrogen cannot radiate the heat from this absorption.

Mesosphere
31–53 Miles

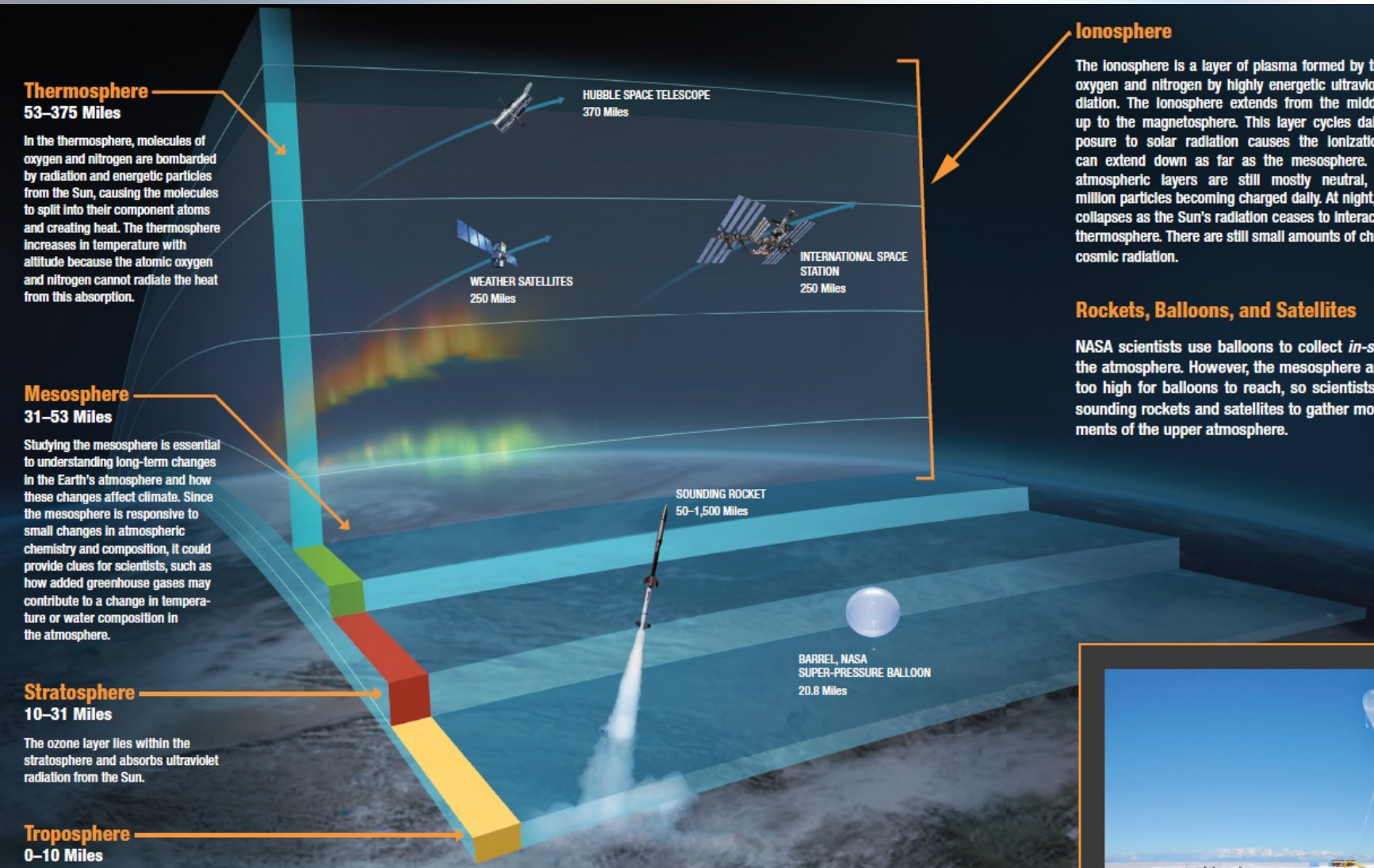
Studying the mesosphere is essential to understanding long-term changes in the Earth's atmosphere and how these changes affect climate. Since the mesosphere is responsive to small changes in atmospheric chemistry and composition, it could provide clues for scientists, such as how added greenhouse gases may contribute to a change in temperature or water composition in the atmosphere.

Stratosphere
10–31 Miles

The ozone layer lies within the stratosphere and absorbs ultraviolet radiation from the Sun.

Troposphere
0–10 Miles

The troposphere is the layer of the Earth's atmosphere where all human activity takes place.



Ionosphere

The ionosphere is a layer of plasma formed by the ionization of atomic oxygen and nitrogen by highly energetic ultraviolet and x-ray solar radiation. The ionosphere extends from the middle of the mesosphere up to the magnetosphere. This layer cycles daily as the daytime exposure to solar radiation causes the ionization of the atoms that can extend down as far as the mesosphere. However, these upper atmospheric layers are still mostly neutral, with only one in a million particles becoming charged daily. At night, the ionosphere mostly collapses as the Sun's radiation ceases to interact with the atoms in the thermosphere. There are still small amounts of charged atoms caused by cosmic radiation.

Rockets, Balloons, and Satellites

NASA scientists use balloons to collect *in-situ* measurements in the atmosphere. However, the mesosphere and thermosphere are too high for balloons to reach, so scientists use instruments on sounding rockets and satellites to gather more detailed measurements of the upper atmosphere.

Communication

A unique property of the ionosphere is that it can refract short-wave radio waves, enabling communication over great distances by "bouncing" signals off this ionized atmospheric layer. Variability of the ionosphere can interrupt satellite communication, such as errors in GPS signals for commercial air navigation. During solar storms, this layer can even shut down communication between ground stations and satellites.

Noctilucent Clouds in the Mesosphere

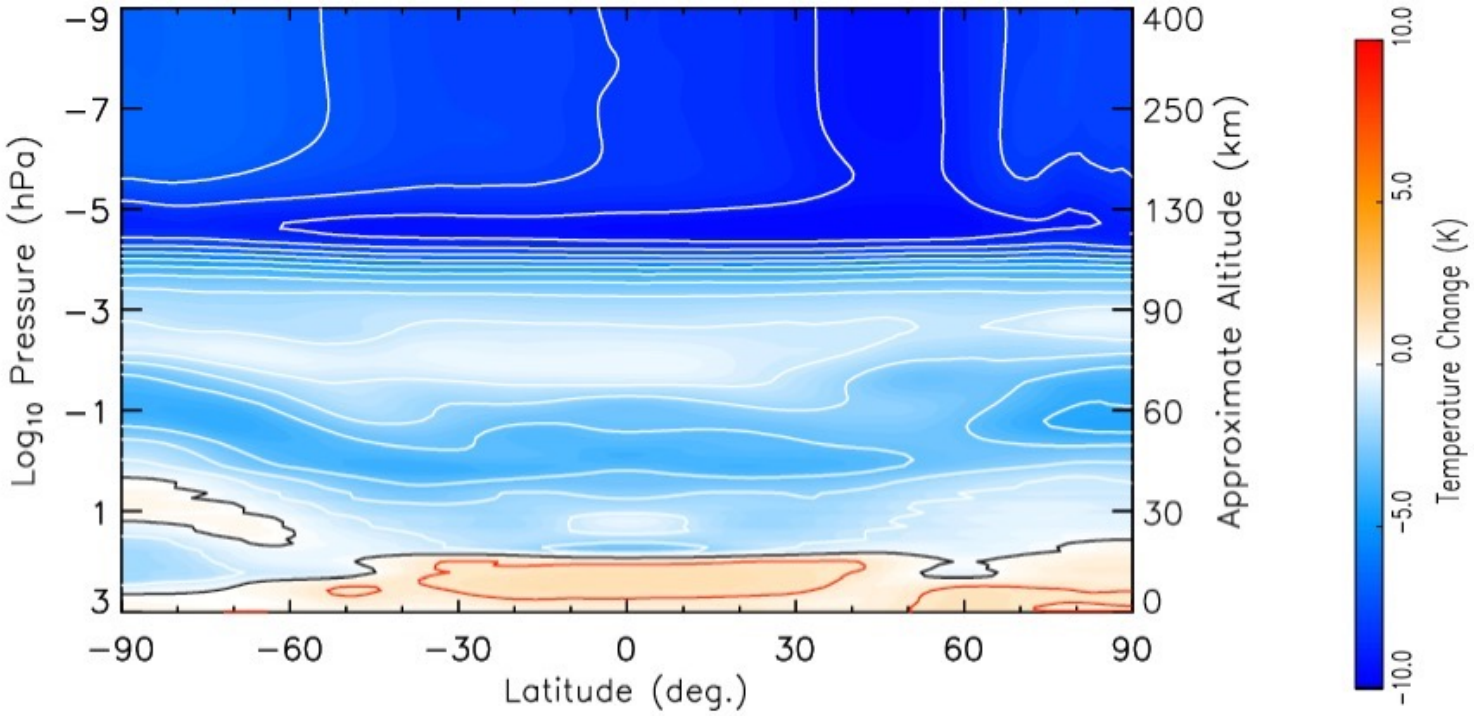
Evidence of change in the behavior of noctilucent clouds has been observed by the AIM mission. Recent data show dramatically lower ice content, leading scientists to speculate about changes in weather conditions and pole-to-pole atmospheric circulation.

BARREL

The Balloon Array for Radiation-belt Relativistic Electron Losses (BARREL) is a balloon-based mission to augment the measurements of NASA's RBSP spacecraft. BARREL seeks to measure the precipitation of relativistic electrons from the radiation belts during two multi-balloon campaigns operated in the Southern Hemisphere.

Climate Change in the Upper Atmosphere

- There is a clear cooling trend in the MLT (**-10ºC**) – much stronger than the Tropospheric warming (**+2ºC**) – but we have no idea how much of it is from an increase in greenhouse gases.

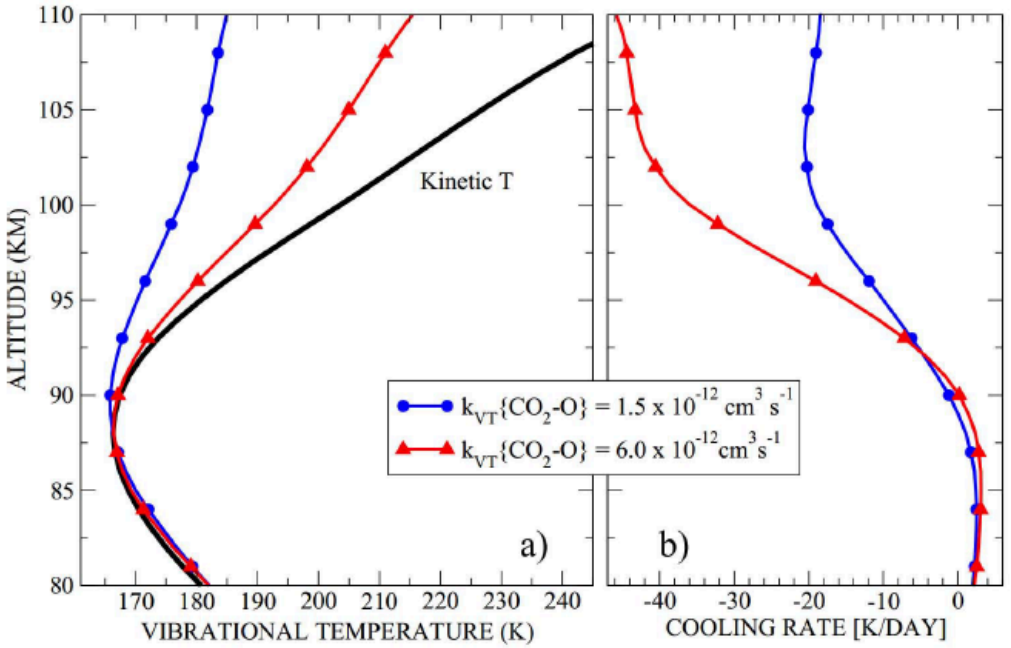


[Solomon et al. 2018]

Quenching Rates and MLT Cooling

- To convert heat fluxes to cooling rates and Temperatures, one has to know the collision rates, aka. *quenching rates*
- Upper atmospheric collision rates are dominated by O, by far the most abundant species at altitudes above 120km, but:
- → We've never measured the global distribution of MLT O, so our estimates of collision rates, aka. quenching rates, is highly inaccurate!

Factor 4 Uncertainty!



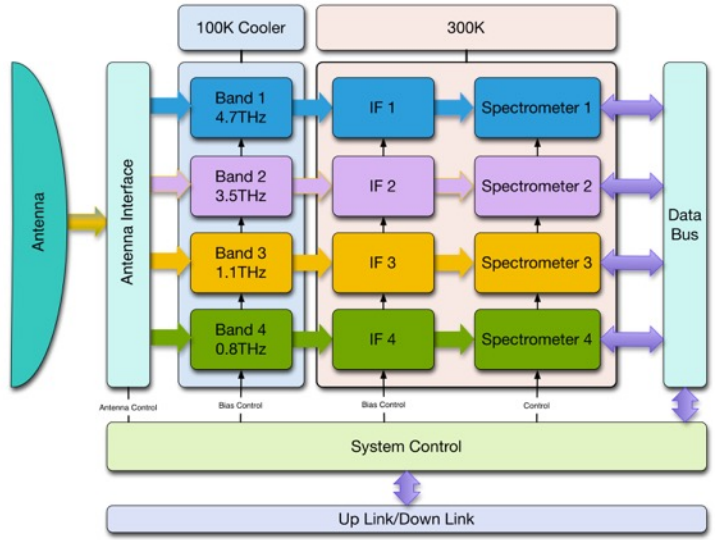
[Feofilov et al. 2012]

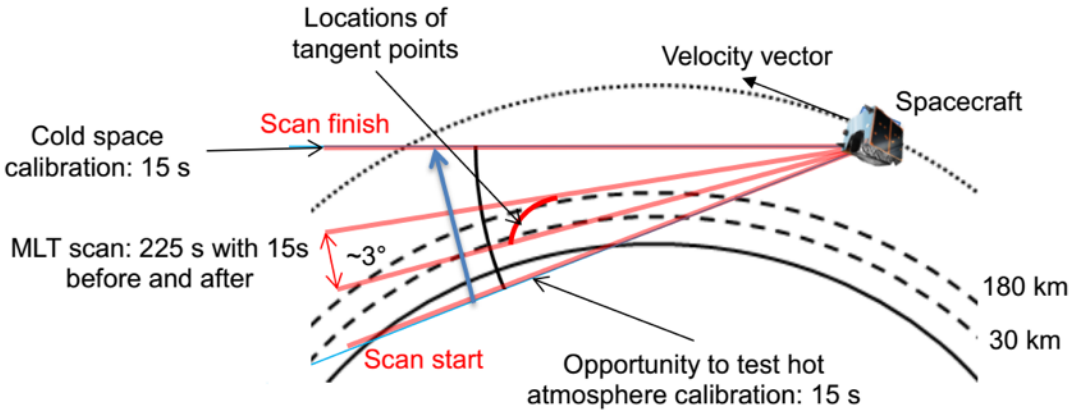
The LOCUS Mission

- LOCUS aims “To understand Upper-Atmospheric greenhouse gas cooling by solving the quenching rate conundrum”
- This is achieved by simultaneously measuring the chemical abundance of atomic oxygen, and the collision induced infrared heat fluxes (CO2, NO, O)
  - THz heterodyne radiometer for composition remote sensing
  - Infrared radiometer for heat flux measurements
- Several secondary science objectives around Space Weather, NO_X and stratospheric ozone, and providing assimilation measurements to next generation climate and weather models

The LOCUS Payload

- 4-5 independent THz heterodyne radiometer channels: 0.8THz, 1.14THz, (2THz), 3.5THz and 4.7THz
- Each channel targets key species – O_2, NO, (O), OH and O – with ~3MHz spectral resolution
- Ability to self calibrate via on-board hot and deep space cold targets
- 5 independent IR pixels provide heat fluxes
- Single highly integrated small satellite platform in sun-synchronous orbit at 800km altitude





The ESA EE-10 Outcome

- Extremely positive review. LOCUS among the 5 down-selected missions in the peer review (out of 21), with no major risks
- Room for improvement:
  - TRL of THz instrument considered low (but perceived as low risk)
    - Two ESA TDP activities targeted at LOCUS since: 4.7THz receivers and miniature coolers (but none went to the UK)
  - Links between Upper and Middle-atmosphere considered tenuous
    - Sufficient published academic research to counter that argument
  - Science area considered “too niche”
    - Ionospheric community (e.g. “Daedalus”) is larger than MLT community

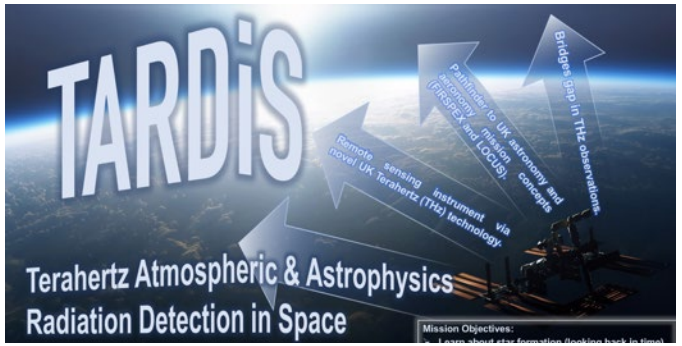
Possible Roads for EE-11

Tandem Mission

- Identify tandem mission for synergy
- Split THz and IR payloads
  - E.g. bilateral with NASA / SABRE 2
- Combined Upper- and Middle-atmospheric limb-sounders
  - Which one?

Small Sat / Constellation

- Simplify the instrument and make it cheaper
  - Most basic science could be done with 1 THz channel and 3 IR pixels
- Interesting option, but it's not an "EE"



Combine MLT-Ionosphere

- Synergy with EE-10 "Daedalus" mission
  - Depends on Phase-B down-selection…
- DARPA AtmoSense project
  - Pie in the sky?

Summary

We should try again for EE-11 with an updated mission proposal, but it's not obvious which changes would improve our chance of success

Any ideas..? ☺

Thank you

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