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Instrumentation for 1 to 5THz Heterodyne Sounders

Brian Ellison

STFC – Rutherford Appleton Laboratory
Space Department
Millimetre Wave Technology Group

RAL Space

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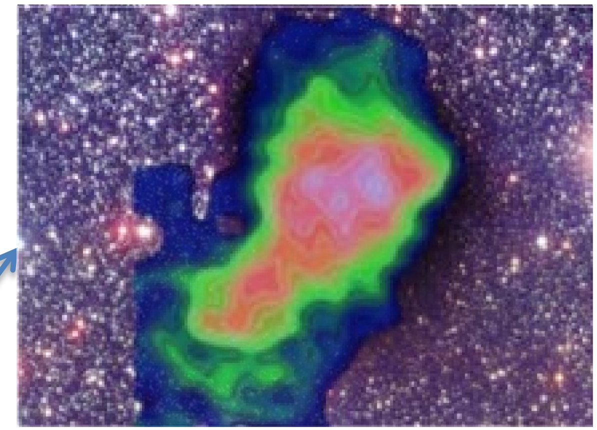
Presentation Outline

- Why THz Remote Sounding?
- Fundamental THz Detection Techniques
- High-resolution THz Heterodyne Spectroscopy
- Basic THz Heterodyne Terminology
- Innovative 1 to 5THz Remote Sounding Concept – LOCUS
  - Proposed Mission Description
  - Payload Technical Concept
  - Related UK Core Technology
  - In-Orbit Demonstration Concept
  - Mission Development Plan
- Summary

Why Use Terahertz Remote Sounding?

- **THz frequencies (submm-waves) penetrate dielectric media opaque at most other shorter wavelengths.**
- **Can detect and characterise molecular species through obscurants and located in a relatively low temperature environment.**
- **Offers higher spatial resolution than microwave/mm-wave range.**
- **Allows remote sounding of atmospheric constituents related to climate change on a local or global basis.**
- **Same technique provides information on the interstellar media, e.g. regions of star formation.**



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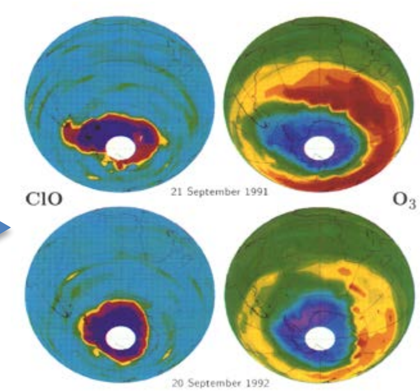
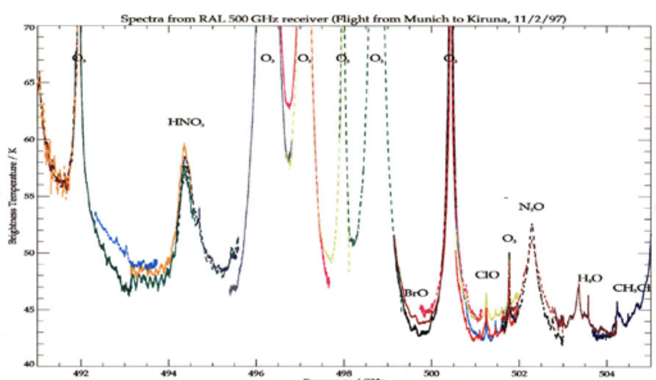


Enhanced ClO & depleted ozone in the Earth's atmosphere (UARS MLS)



0.5THz terrestrial atmospheric spectra (RAL)

THz Detection Techniques

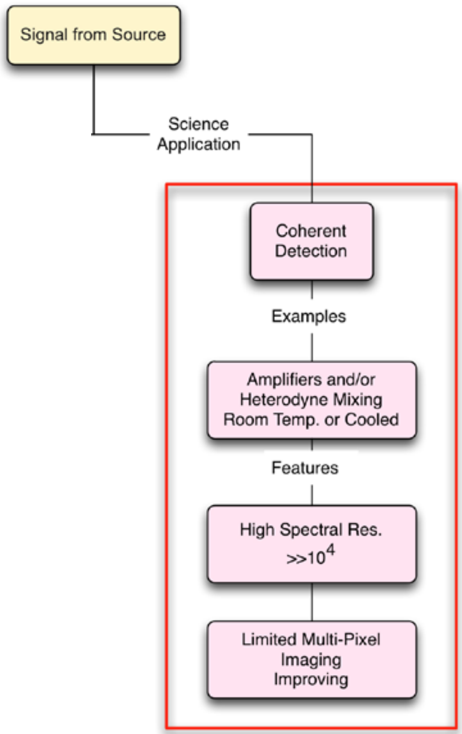
- **Two primary passive detection types:**
  - **Coherent** and **Incoherent**.

- **Both methods measure the source brightness temperature, be it continuum or spectral emission.**

- **Coherent (amplifiers and frequency mixers):**
  - Ultra-fine spectral resolving power.
  - Phase information preserved.
  - Room temp. or cryogenic instrumentation.

- **Incoherent (e.g. bolometric and photo-conductive):**
  - Broad spectral range.
  - Relatively simple technology.
  - Phase information lost.
  - Usually cryogenic.

- **Detection method chosen mostly depends upon the scientific application.**



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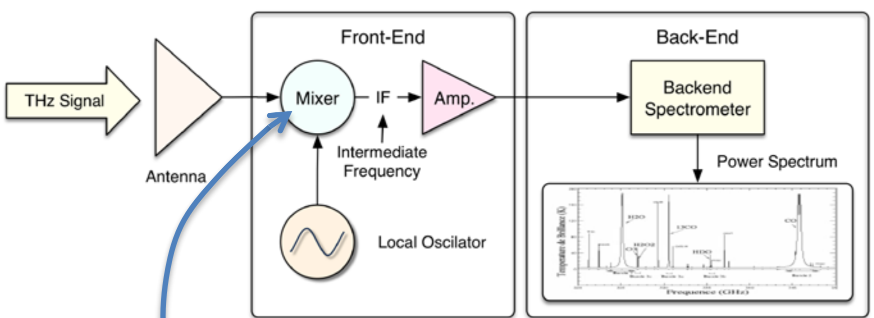
High Spectral Res. Spectroscopy

Heterodyne Detection

Simplified Heterodyne Radiometer



Heterodyne receiver converts THz input signal to a lower intermediate frequency (IF) range – typically GHz.

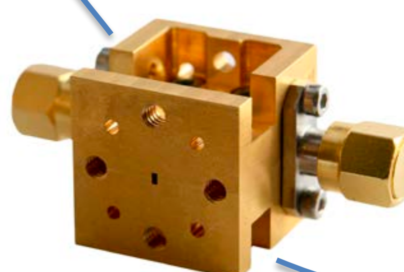
Frequency translation allows final detection and interrogation of input signal.

Provides low noise and high spectral resolving power - order >>10^4.

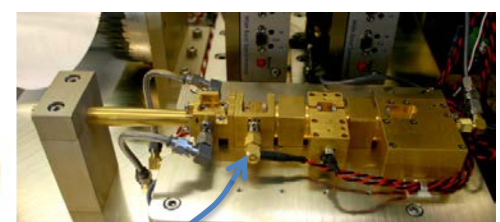
Key front-end components are the mixer and THz local oscillator (LO).

Optimum system performance requires:

- **Efficient signal frequency translation, i.e. low conversion loss.**
- **Minimal added system electrical noise.**
- **Provision of adequate THz LO source power.**



RAL & STAR Dundee 350GHz Het. Radiometer - CEOI



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THz Heterodyne Terminology

Normally use Rayleigh-Jeans approximation:

$$\text{Brightness} = 2kT_{source}/\lambda^2$$

Can represent radiometer performance in terms of noise equivalent system temperature by the relationship:

$$\text{Noise Power} = k\,T_{sys} \text{ per unit bandwidth}$$

For a simple radiometer system,

$$T_{sys} = T_m + T_{IF} * L_m$$

Mixer noise

IF Noise

Mixer Loss

and the minimum detectable signal is determined by:

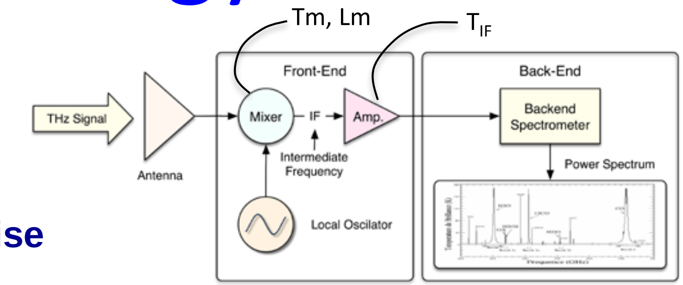
$$\Delta T_{source} \approx T_{sys}/(\tau.\Delta f)^{1/2}$$

To achieve the best instrument sensitivity we need to:

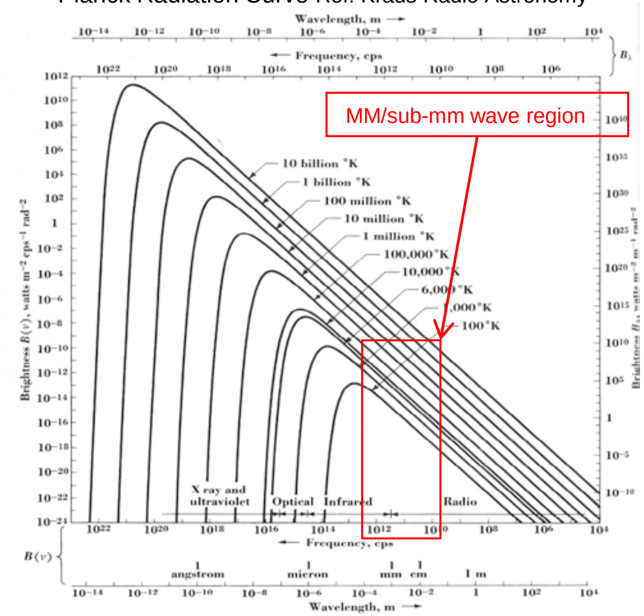
Minimise $T_{m,}$ Lm and T_{IF} and Maximise τ and Δf.

Note that τ and Δf are often observation dependent.

k= Boltzmann's constant, τ = integration time and Δf = spectral resolution.



Planck Radiation Curve Ref: Kraus Radio Astronomy



Departure form R-J approximation should to be considered at frequencies >>1THz, and for low brightness temp. source.

1 to 5 THz Remote Sounder

Low Cost Upper-atmosphere Sounder - LOCUS

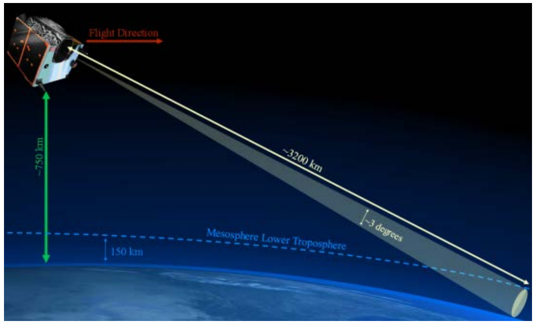
- Breakthrough concept multi-terahertz remote sounder -

Compact payload flown on a 'standard' small satellite that will:

- **Measure key species in the upper atmosphere, i.e. the mesosphere and lower thermosphere (MLT).**
- **Increase understanding of natural and anthropogenic effect on climate change.**
- **Allow study of the 'gateway' between the Earth's atmosphere and near space environment.**

LOCUS science achieved through:

- **Tracing O, OH, NO, CO, O_3, H_2O, HO_2, O_2 spectral emission signatures globally and from low Earth orbit (LEO)**
- **Using a limb sounding technique with cold space as a background to achieve height distribution.**
- **Provision of ultra-high spectral resolution (1MHz).**
- **Accurate spatial sampling with ~2km footprint at tangent heights from ~ 55km to 150km.**

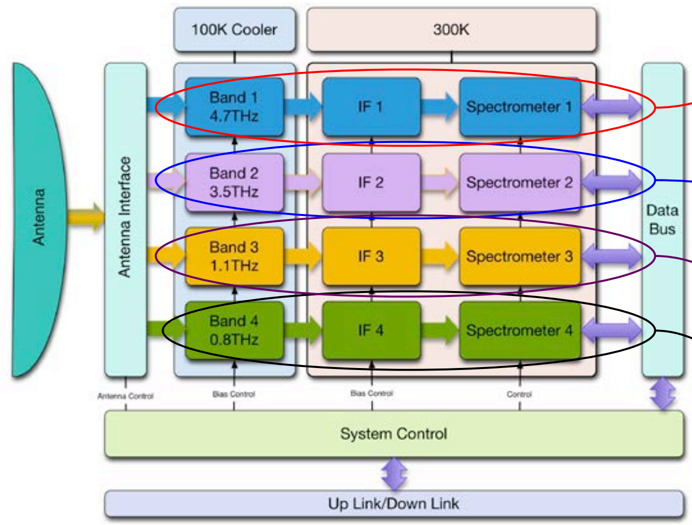


Small satellite sounder from LEO

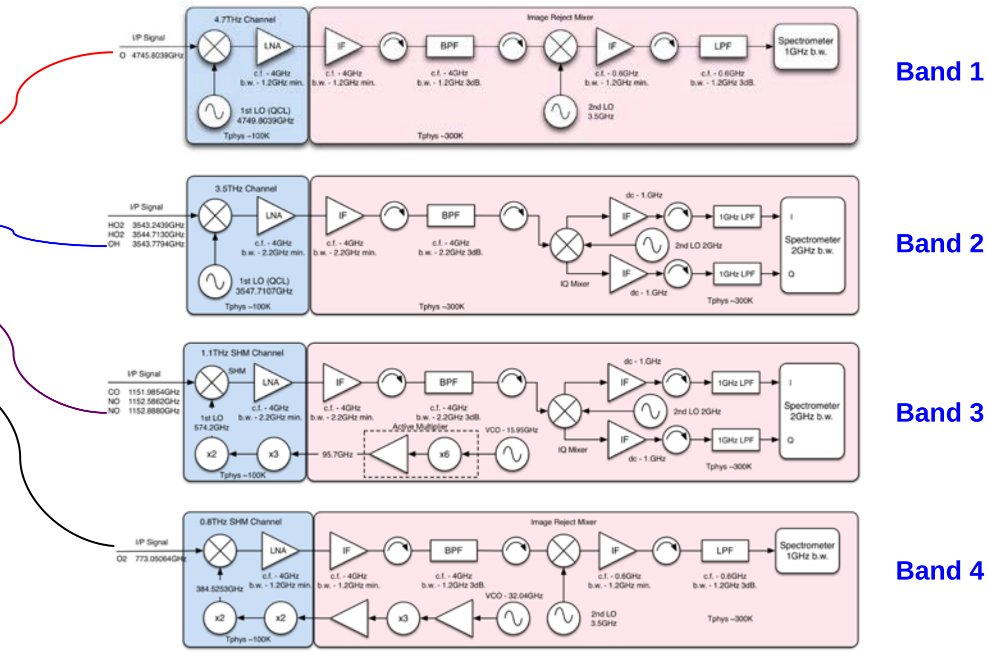
Species	Transition Frequency (THz)
O	4.745
OH	3.544
HO_2	3.543
	3.544
NO	1.153
	1.153
CO	1.152
O_2	0.773

Example species frequency list

LOCUS Payload Concept



System schematic



- **Highly integrated multi-channel THz radiometer system.**
- **Four separate bands identified that accommodate the required spectral windows**
- **Schottky semiconductor diode mixer technology.**
- **Quantum Cascade Laser used a LOs for 1 and 2, harmonic up-conversion for 3 and 4.**
- **Fast Fourier Transform digital spectrometers provide 1MHz spectral resolution.**
- **Single primary ~ 40cm diameter and miniature coolers – 100K operational goal.**
- **UK sourced technology with critical elements support by the CEOI and NERC.**

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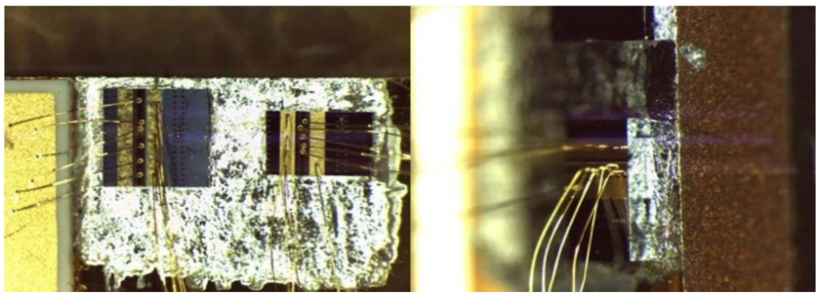
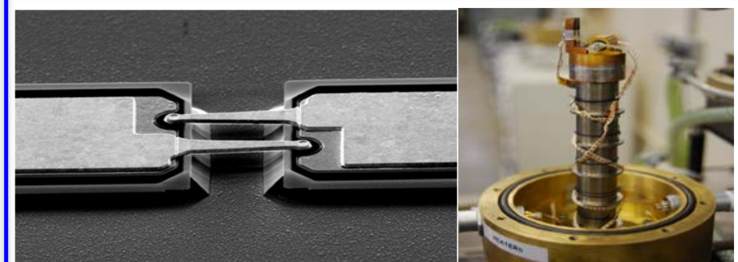
LOCUS Core UK Technology

QCL Local Oscillator
University of Leeds



Schottky Barrier Diode
& Space Coolers RAL



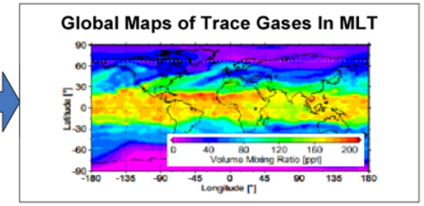
Digital Spectrometer
STAR-Dundee

Small Satellite
Surrey Satellites Ltd

UK also leading LOCUS science definition via Leeds, UCL and RAL

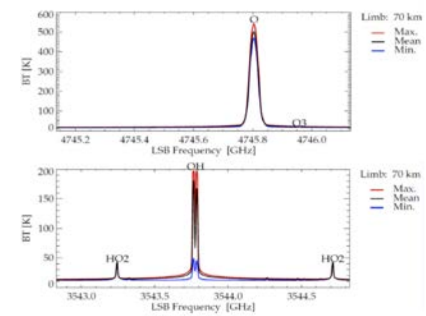
In Orbit Demo. - Satellite Concept

LOCUS: Payload Integrated compact THz sounder → **LOCUS: Platform** Low cost high performance space platform → **Observations** Measurements of trace gases of interest → **Atmospheric Models** Incorporate LOCUS payload data with other atmospheric data →



Objective: Prove core payload and platform technology in space.

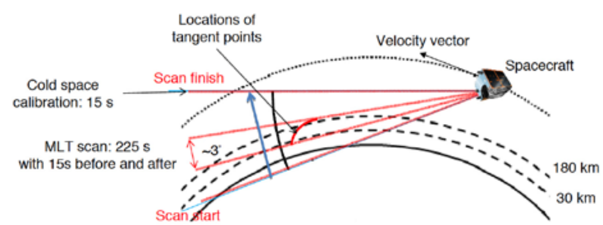
- **Polar sun synchronous orbit.**
- **Perform global species measurement.**
- **Novel approach to scene scanning via spacecraft nodding.**
- **Cold-space view and on-board c300K target provide payload cal.**
- **Approx. total spacecraft volume, mass & power: 1m^3, 150kg, 70W.**
    - **Compare with NASA AURA @ 43m^3, 3tonne, 4kW & MLS: ~8m^3, 500kg, 550W)**
- **IOD mission lifetime ~ 2 years, tbc.**



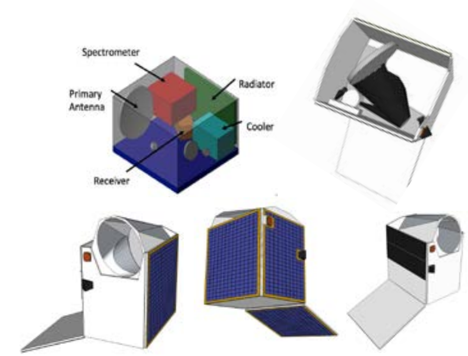
Example spectra. D. Gerber, RAL

Designation	Band Centre (THz)	Primary Target Species	System Noise (K)	NEΔT (K)
Band 1	4.7	O	80,000	46
Band 2	3.5	OH	20,000	12
Band 3	1.1	NO, CO	3,500	2
Band 4	0.8	O_2	2,500	1.5

Summary of radiometer band performance. NEΔT assumes 1MHz res. and 3s integration. System assumed cooled to operational temperature of 100K



LOCUS observation concept



Schematic of LOCUS concept aboard SSTL150 small satellite

Mission Concept Development Plan

ESA IOD Study Programme (SSTL PI):

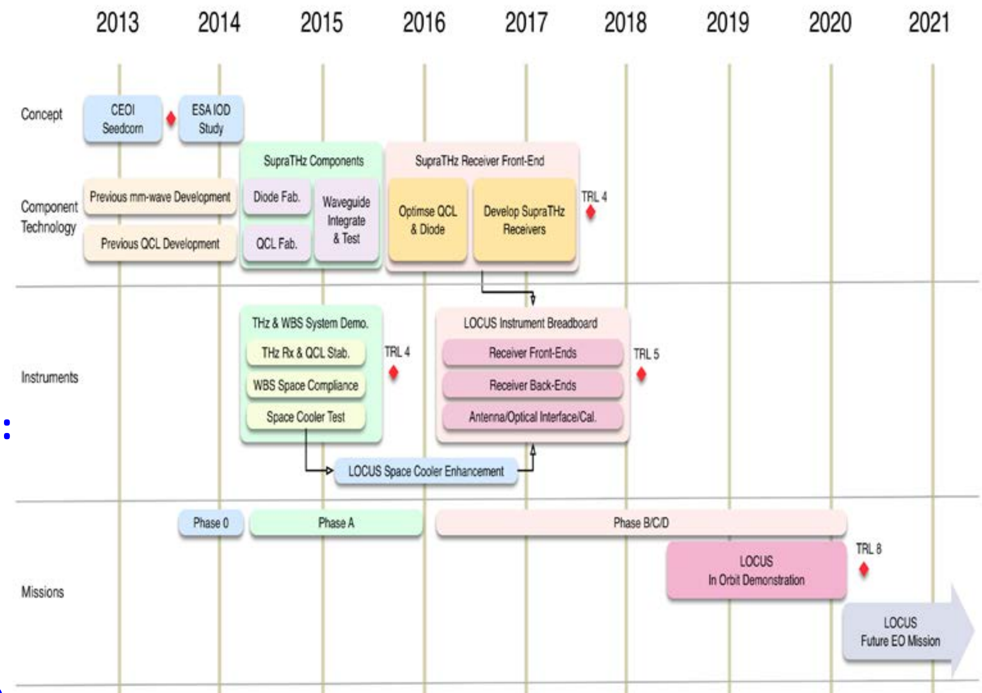
- Science refinement.
- Payload concept definition.
- Spacecraft concept definition.
- Mission plan and cost estimate.

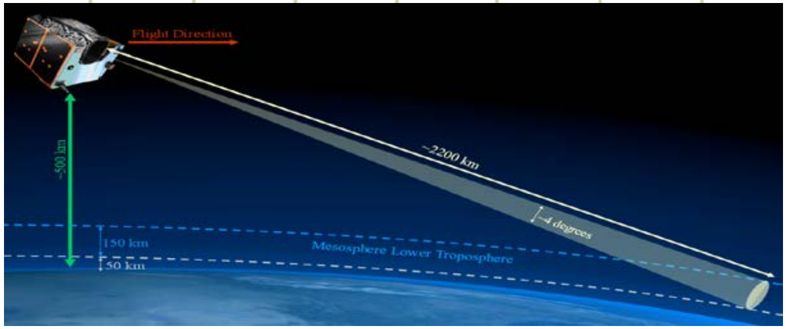
NERC Critical Component Development (RAL PI):

- QCL development and waveguide demo.
- THz Schottky diode development.
- Integrated QCL & Schottky proof of concept.

CEOI-ST Critical Payload Development (Leeds PI):

- 1.1 THz (Band 3) full development inc.
    - o Mixer, LO and spectrometer.
- QCL frequency stabilisation.





Summary

- **THz remote sounding provides important information in relation to the Earth's climate evolution and its monitoring.**
- **The THz detection method depends upon the nature of the defined science return.**
- **Where the science requires high spectral resolution and high sensitivity, THz heterodyne detection is the instrumentation of choice.**
- **In the 1 to 5THz frequency range, novel heterodyne instrumentation is being conceived and developed that will allow novel scientific study.**
- **A UK initiated and presently majority UK funded instrument, LOCUS, is being developed to study the relatively unexplored supra-THz spectral range.**

LOCUS Team Members

RAL Space

SURREY SATELLITE TECHNOLOGY LTD

UNIVERSITY OF LEEDS

UCL

STAR-Dundee

Thanks for listening