Institute of Microwaves and Photonics
SCHOOL OF ELECTRONIC AND ELECTRICAL ENGINEERING,
FACULTY OF ENGINEERING
UNIVERSITY OF LEEDS

A low cost upper atmosphere sounder (LOCUS) mission

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Funded by CEOI 7th EO Technology Call

So what is LOCUS?

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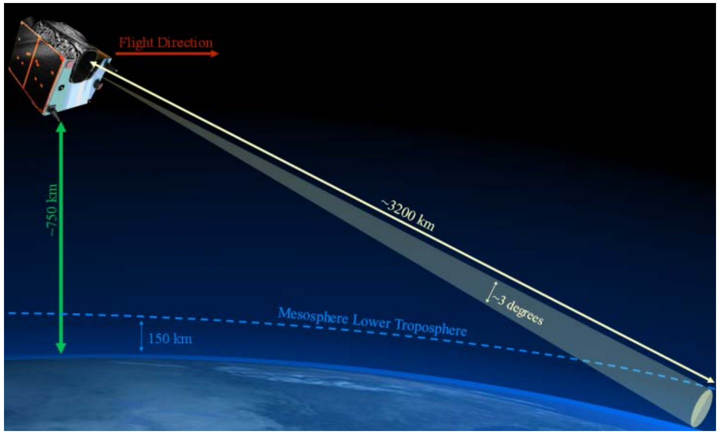
A breakthrough concept multi-terahertz remote sounder

Compact payload to be 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.



Small satellite sounder from LEO

Why use terahertz sounding?

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- **Terahertz (THz) frequencies (sub-mm-waves) penetrate dielectric media opaque at most other shorter wavelengths;**
- **Can detect and characterize 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.**

What science will be investigated?

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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.**

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

But, this requires terahertz instrumentation:

And therein lies one challenge…

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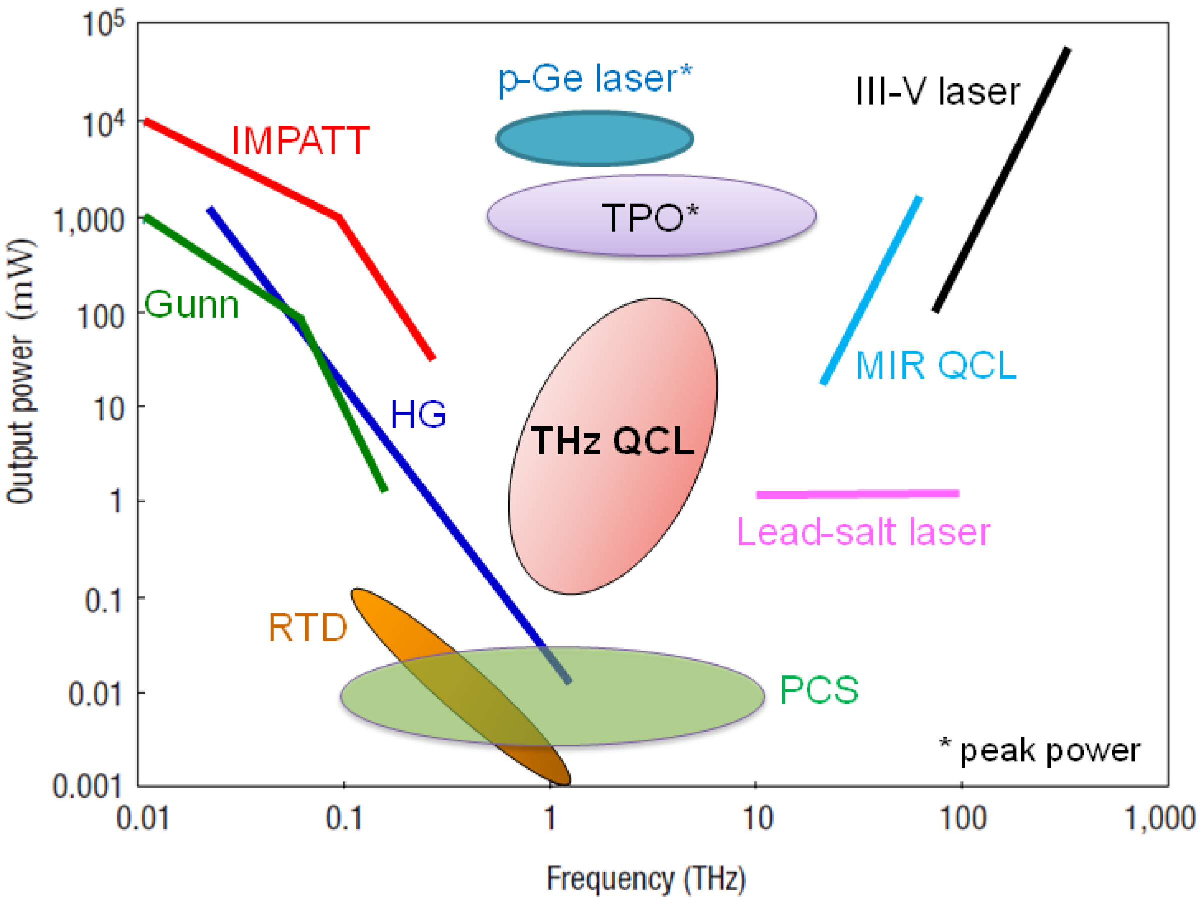


IMPATT – Impact Ionization Avalanche Transit-Time diode

HG – Harmonic Generation

RTD – Resonant-Tunnelling Diode

TPO – THz Parametric Oscillator

PCS – Photoconductive Switch

QCL – Quantum Cascade Laser

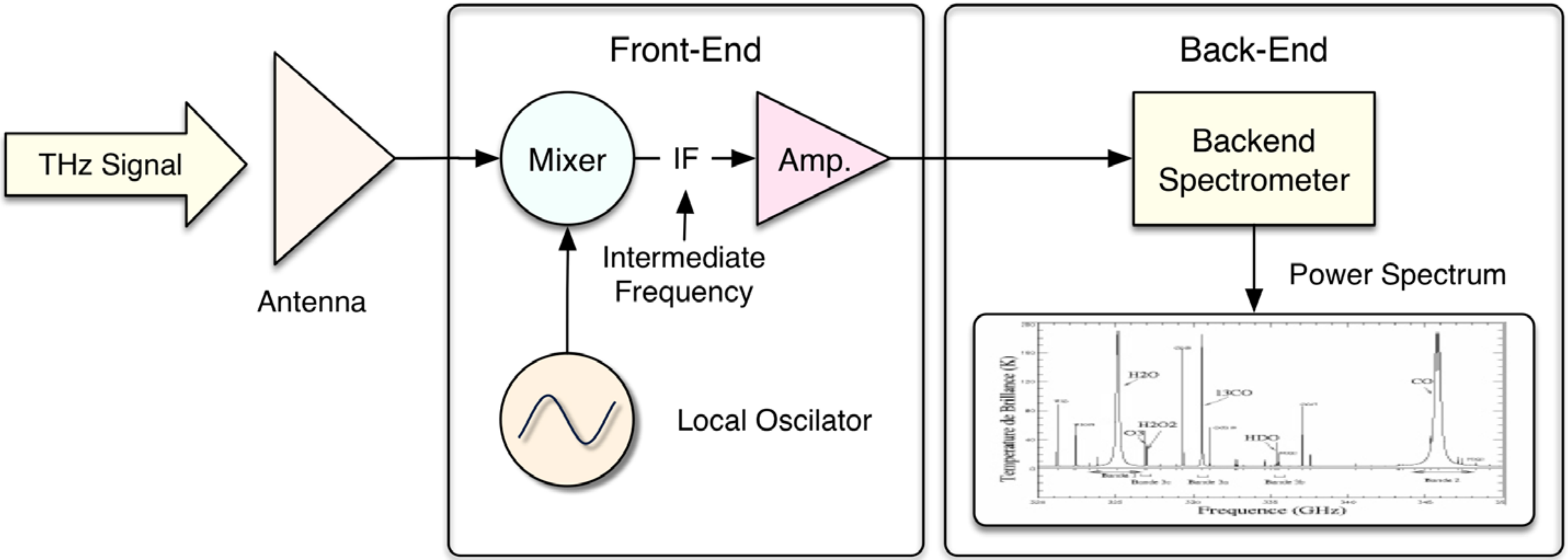
M. Tonouchi, *Nature Photonics*, 1, 97 (2007)

LOCUS Instrumentation

To be based on heterodyne receiver technology, which converts THz input signal to a lower intermediate frequency (IF) – typically GHz;

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

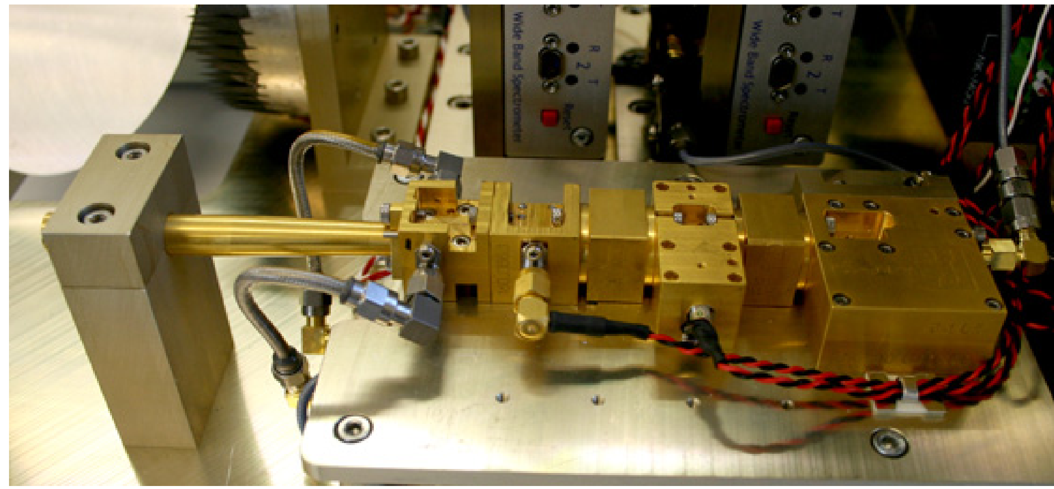
Key front-end components are the mixer and THz local oscillator (LO).



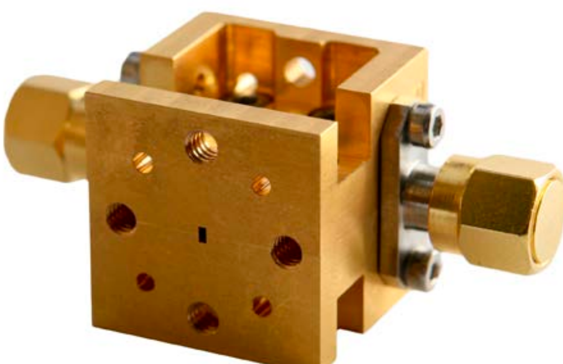
The heterodyne approach

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.



e.g. RAL & STAR Dundee 350GHz Heterodyne Radiometer (previous CEOI funding)



The LOCUS payload concept

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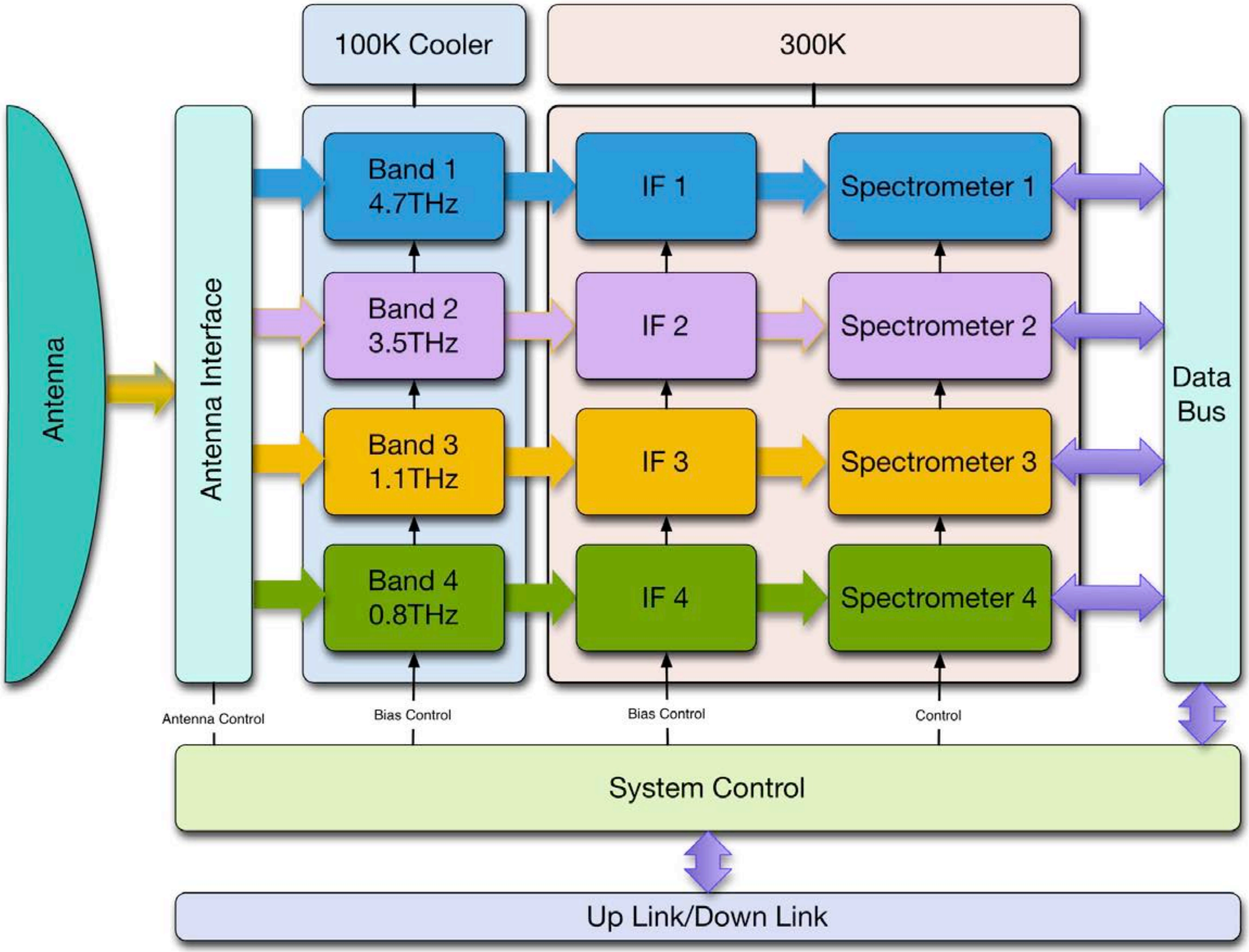
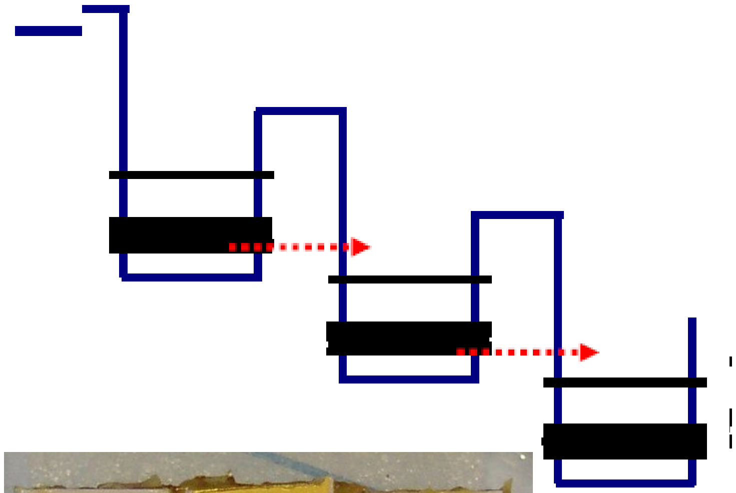
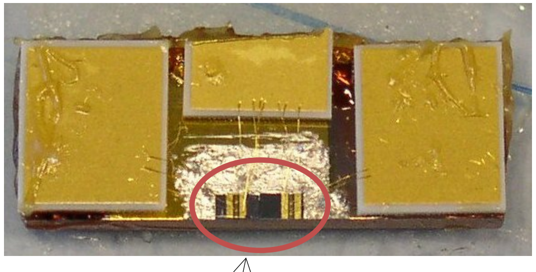


Key features:

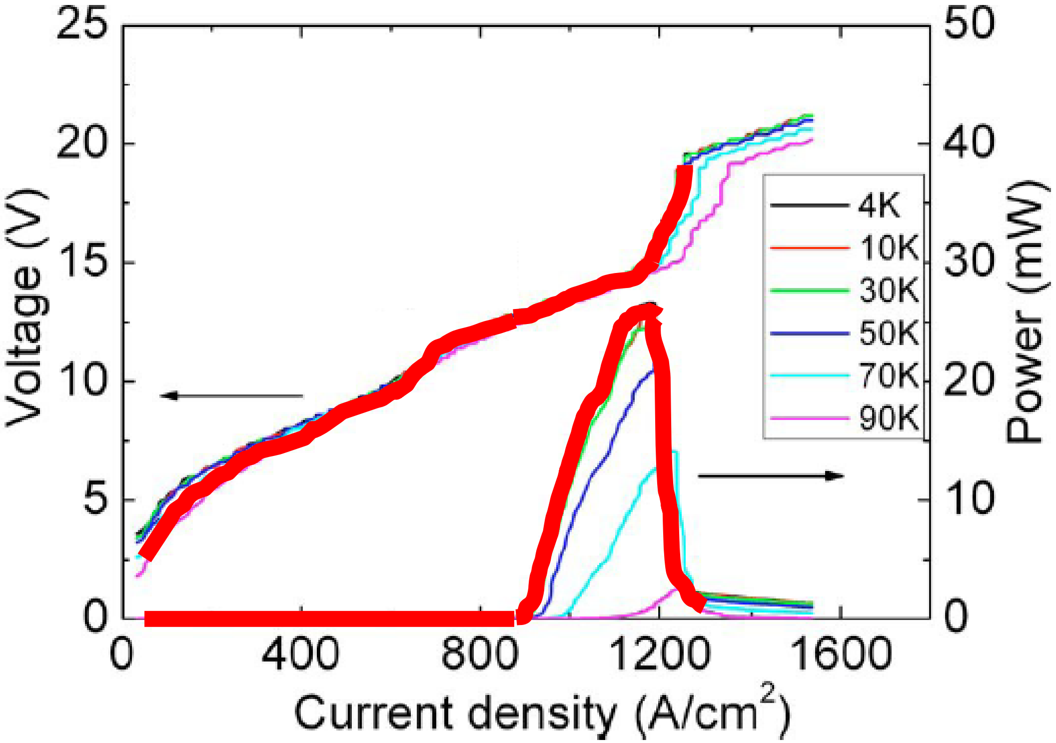
- **Highly integrated multi-channel THz radiometer system;**
- **Four separate bands identified that accommodate the required spectral windows;**
- **Schottky semiconductor diode mixer technology;**
- **Quantum Cascade Laser used a LOs for 1 and 2, harmonic up-conversion for 3 and 4;**
- **Fast Fourier 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.**

Electronic behaviour





2 QCLs



Peak performance corresponds to efficient injection of current

Device dimensions are typically 1 mm × 150 μm × 10 μm

Quantum Cascade Lasers (2)

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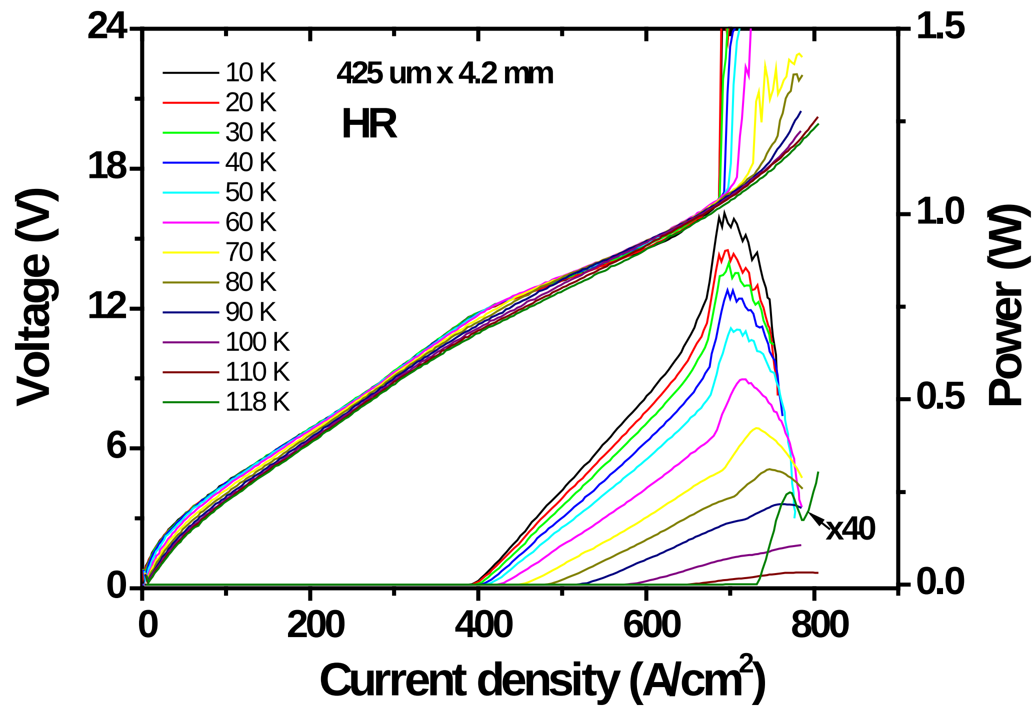
- **1 W peak power is possible, and 10s of mW continuous-wave power, *but cooled*;**
- **QCLs have an intrinsically narrow linewidth (<20 kHz);**
- **Precise frequencies can be defined using periodic gratings defined into the ridge waveguides;**
- **Operation has been demonstrated over the 1 – 5 THz frequencies;**
- **Radiation hardness has been demonstrated.**



2% duty cycle; ;asing up to 1.01 W (peak) at ~ 3.4 THz; > 400 μW at 77 K, T_{max} = 118 K:

L. Li *et al*, *Electronics Letters* 50, 309 (2014).

LOCUS Core Technology

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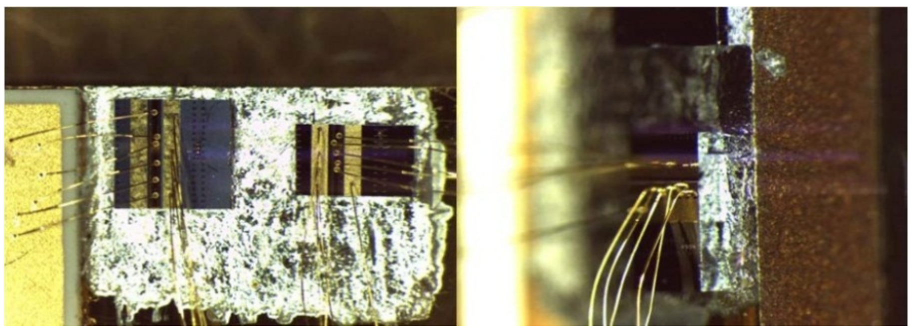
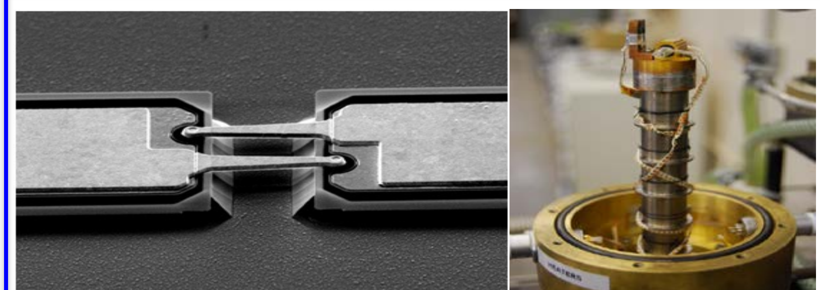
QCL Local Oscillator
University of Leeds



Schottky Barrier Diode
& Space Coolers RAL



Digital Spectrometer
STAR-Dundee

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

Small Satellite
Surrey Satellites Ltd

In-orbit demonstration – satellite concept

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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 calibration;**
- **Approx. <u>total</u> 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.**

Mission Concept Development Plan

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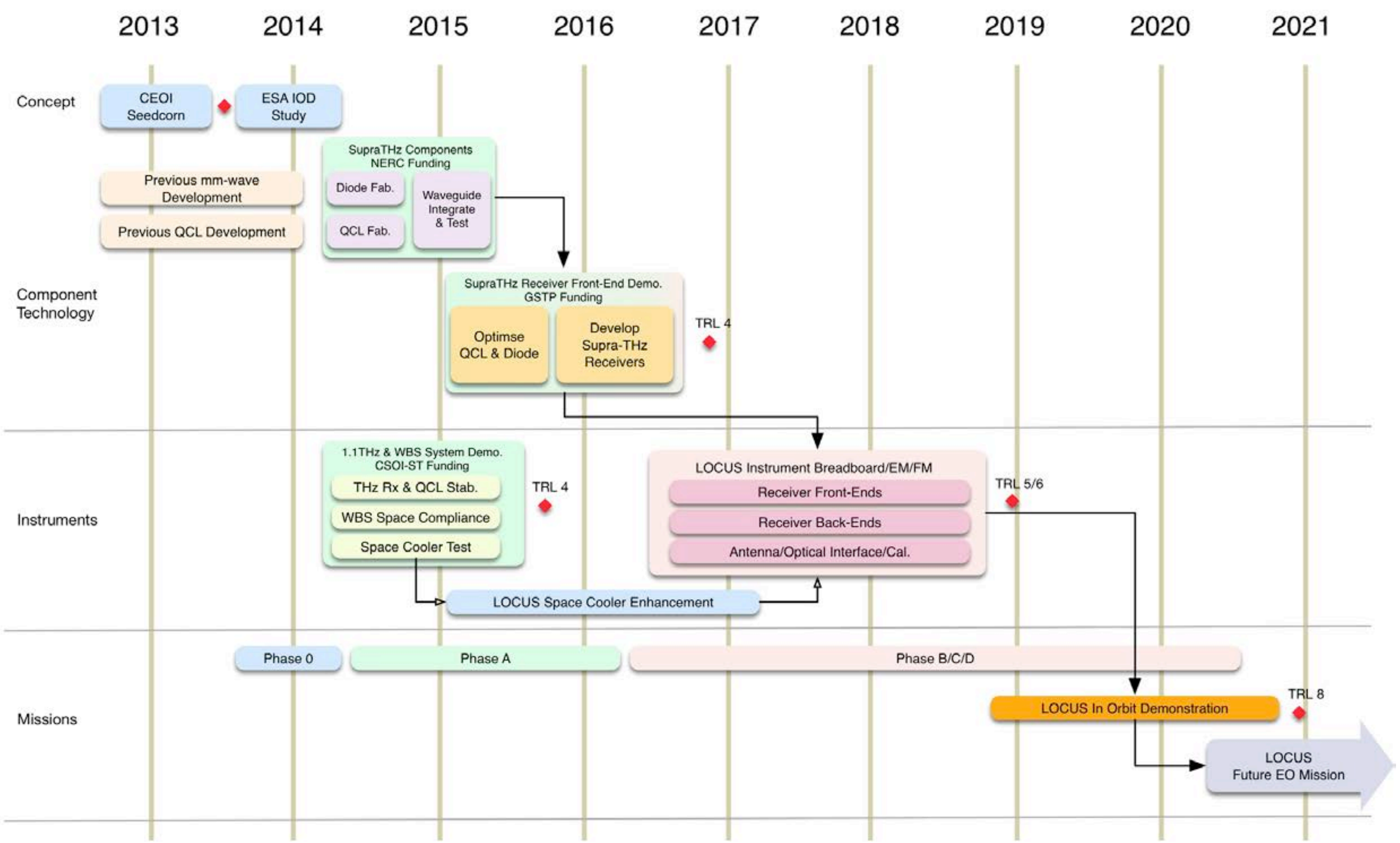

Funding (with thanks)

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ESA In-orbit Demonstration 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 demonstration;
- THz Schottky diode development;
- Integrated QCL & Schottky proof of concept.

CEOI-ST Critical Payload Development (Leeds PI):

- 1.1 THz (Band 3) full development including:
    - Mixer, LO and spectrometer;
- QCL frequency stabilisation.

Summary

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- **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 5 THz 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.**

The LOCUS Team Members

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RAL Space

SURREY SATELLITE TECHNOLOGY LTD

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UCL

STAR-Dundee

Thank you for your attention