SCHOOL OF ELECTRONIC AND ELECTRICAL ENGINEERING

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LOCUS: A Low Cost Upper Atmosphere TeraHertz Sounder for In-Orbit Demonstration

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Steve Parkes (Star Dundee)

Funded by CEOI 7th EO Technology Call

The LOCUS concept

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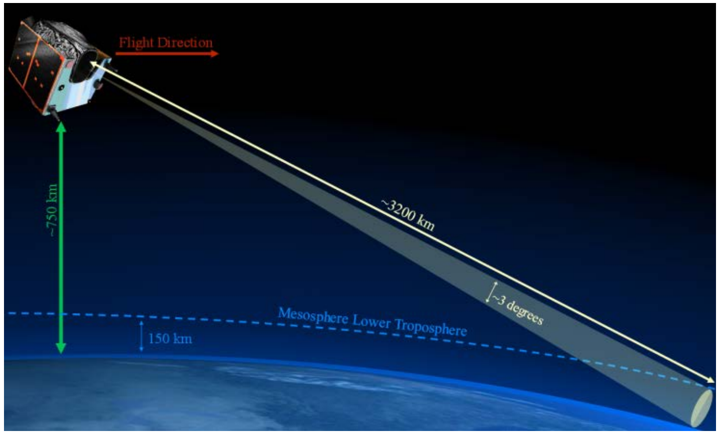
A breakthrough multi-terahertz remote sounder

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

– *but could also provide information on the interstellar media, e.g. regions of star formation.*



Small satellite sounder from LEO

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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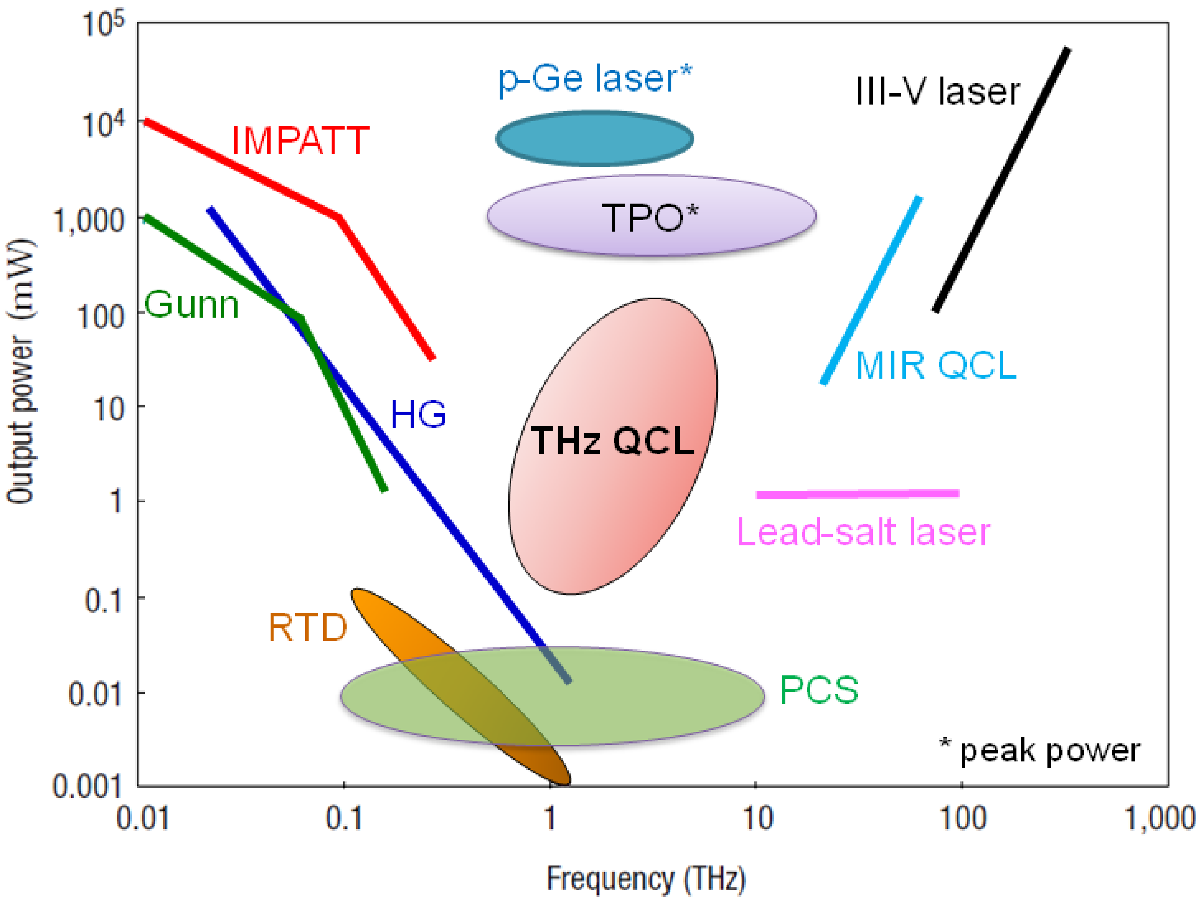

M. Tonouchi, *Nature Photonics*, 1, 97 (2007)

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

LOCUS Instrumentation

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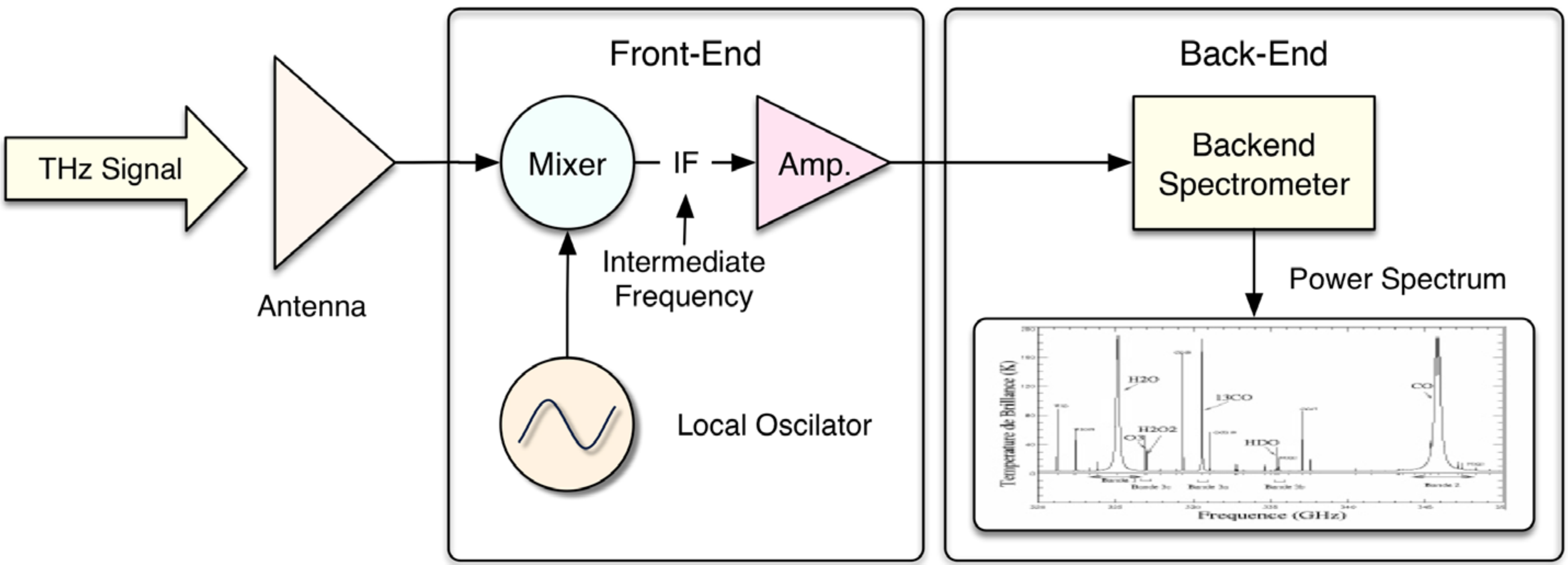
To be based on heterodyne receiver technology, which converts THz input signal to a lower intermediate frequency (IF) – typically GHz;

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

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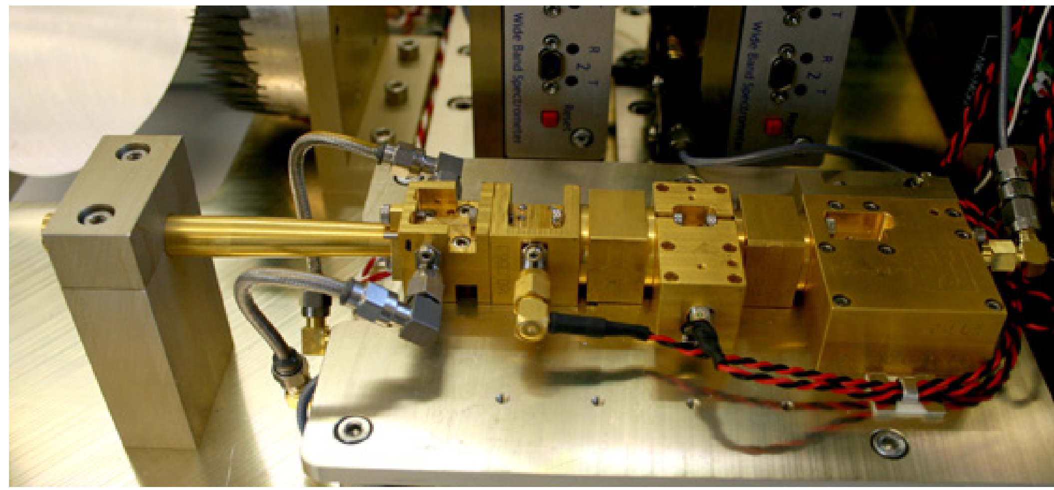
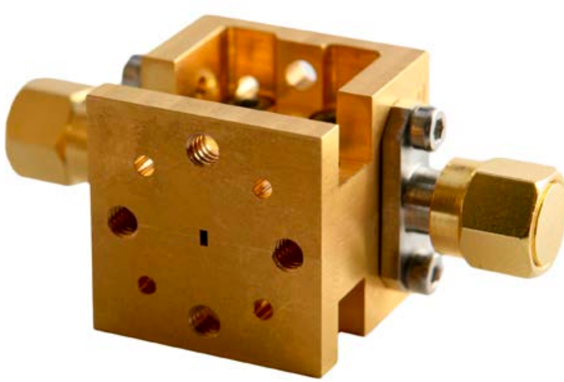
Optimum system performance requires:

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





See: RAL & STAR Dundee 350GHz SHIRM Heterodyne Radiometer (previous CEOI funding) – talks by Olivier Auriacombe (RAL Space & The Open University) and Daniel Gerber (RAL Space).

The LOCUS payload concept

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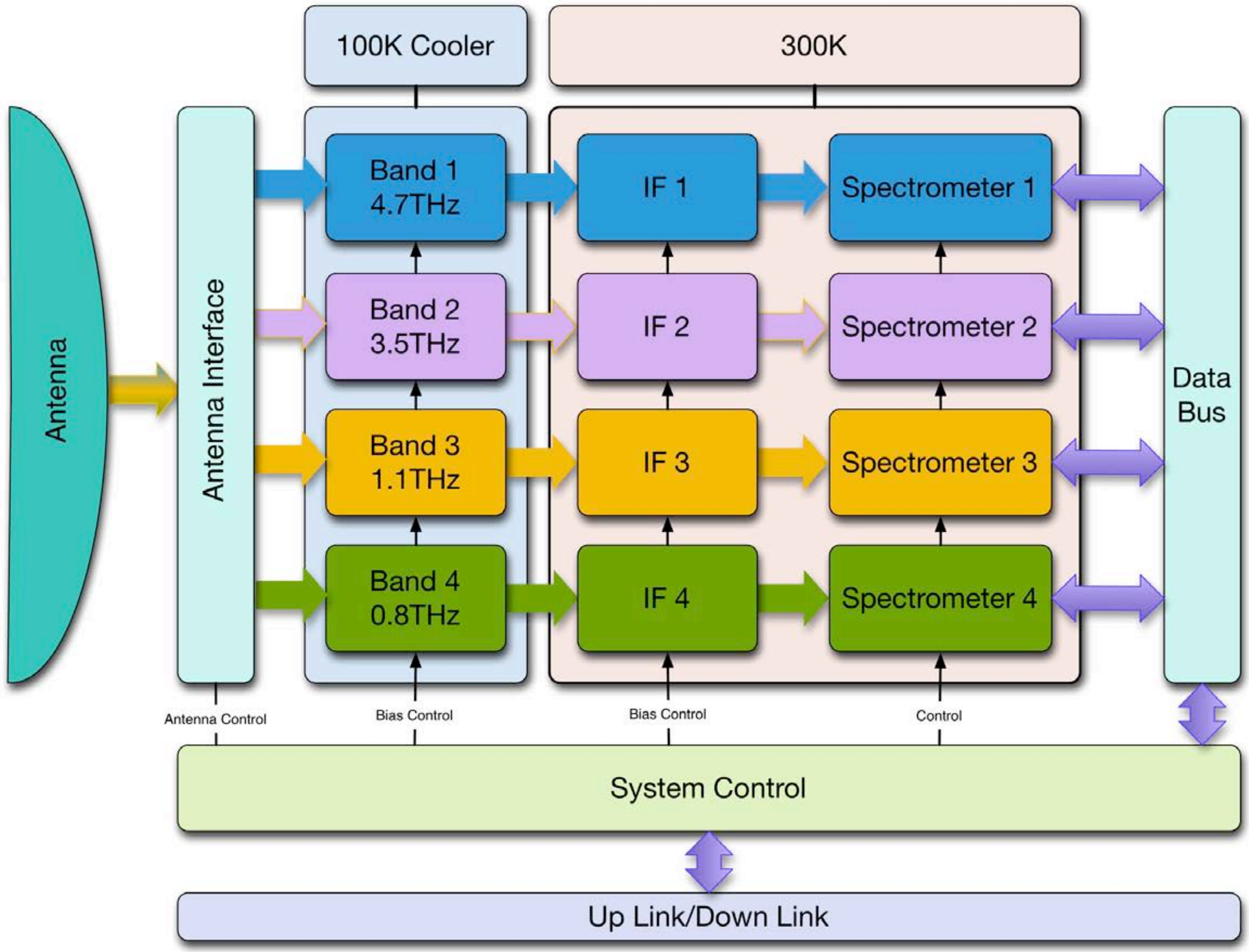

1.1 THz Breadboard

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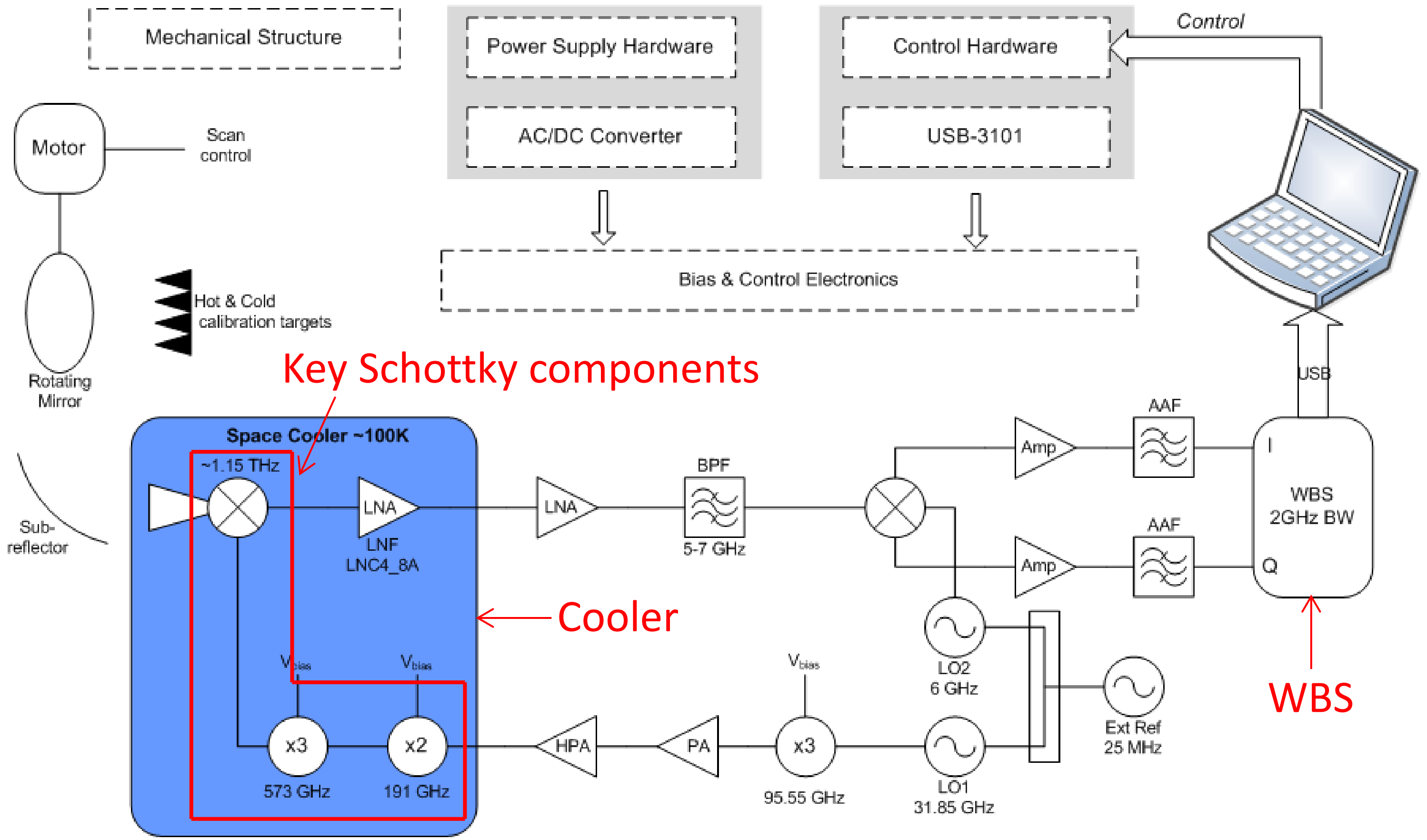
Similar to the SHIRM breadboard – see poster by Olivier Auriacombe (RAL Space & The Open University).



1.1 THz Breadboard

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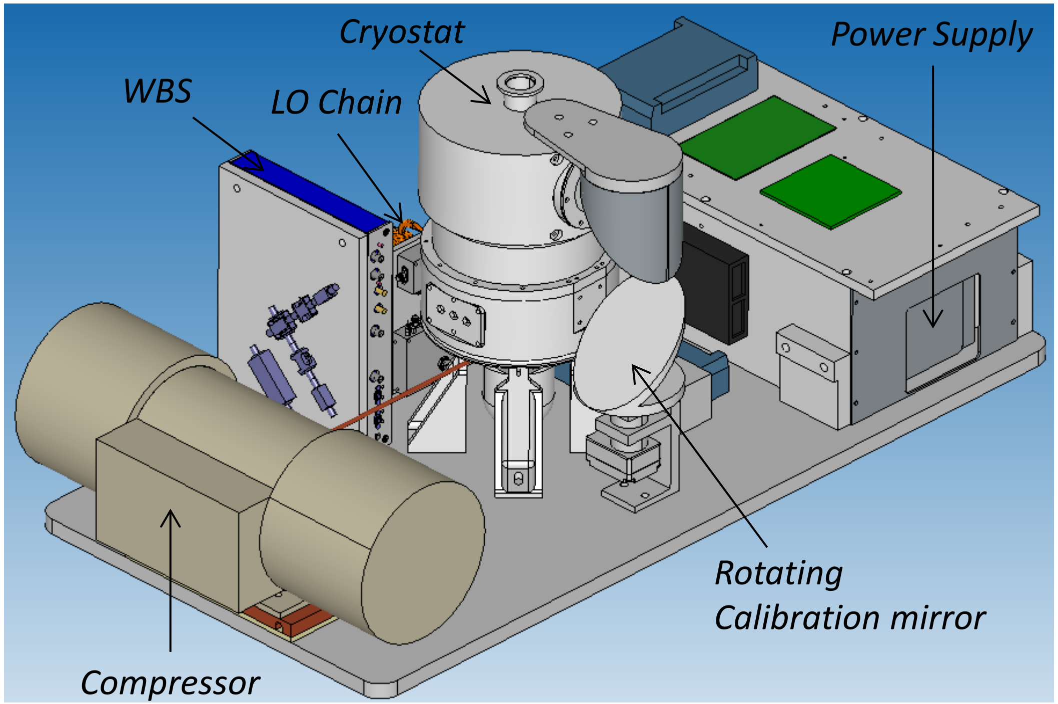
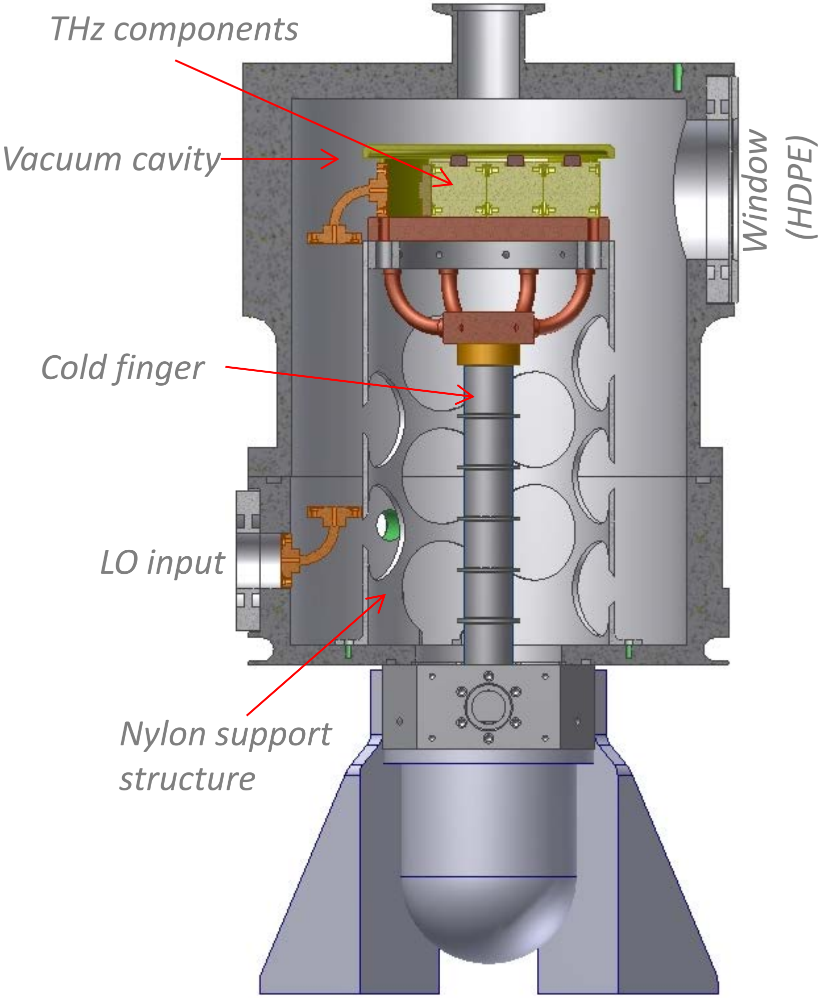
Preliminary Instrument Model



Cryostat for LOCUS Breadboard



Development of a stand-alone total-power radiometer.

Wideband Spectrometer

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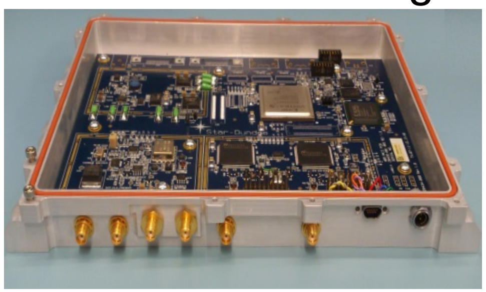
Research & Development

WBS III: Aircraft Flight

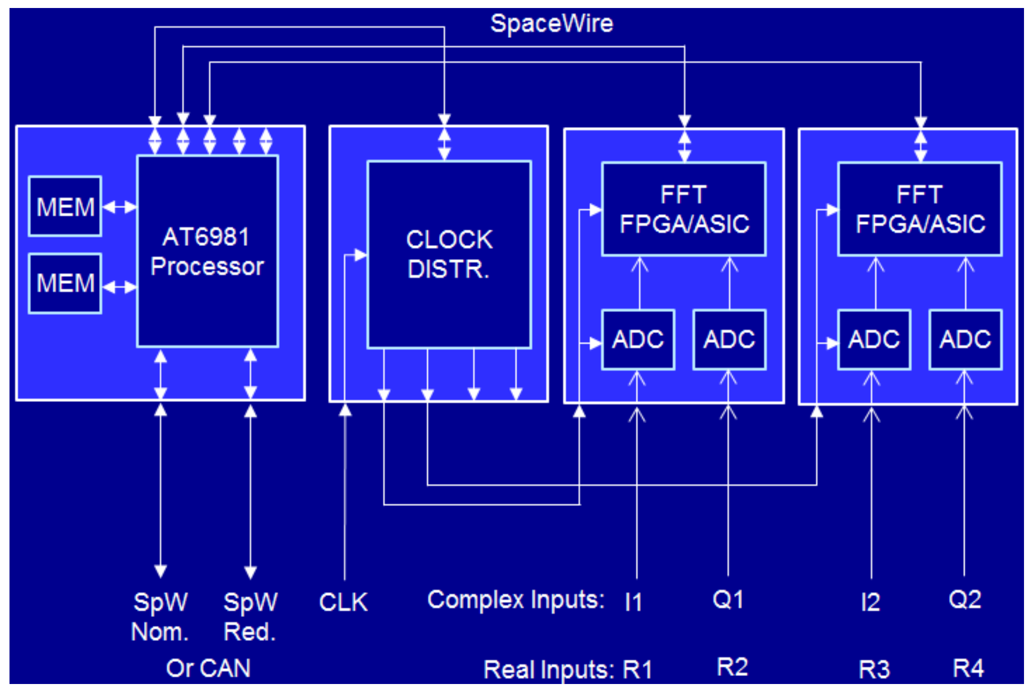


WBS II: 2 GHz BW

WBS I: 1 GHz BW

WBS IV Objectives

- Reduced power consumption
- Increased performance
- Higher TRL
- Representative of a spaceflight unit
- Suitable for laboratory and airborne testing



Supra-Terahertz Channels – THz Quantum Cascade Lasers (1)

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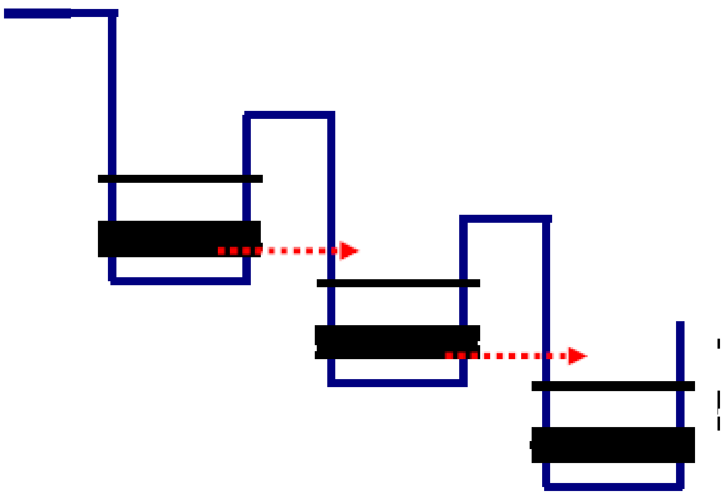
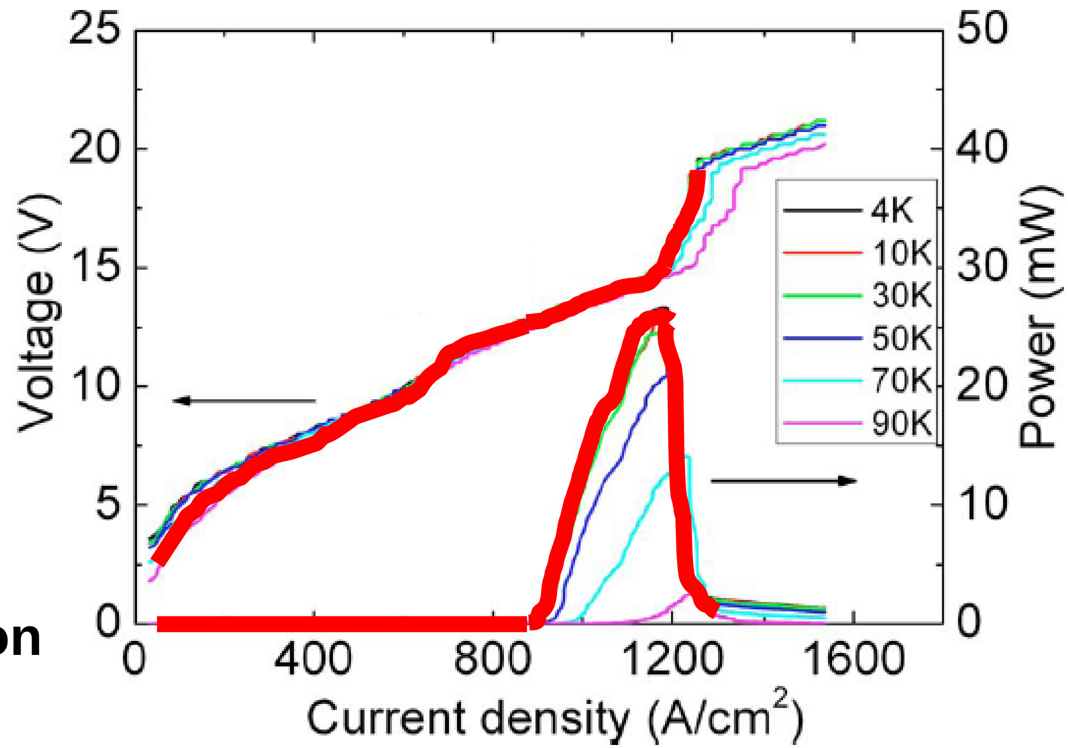
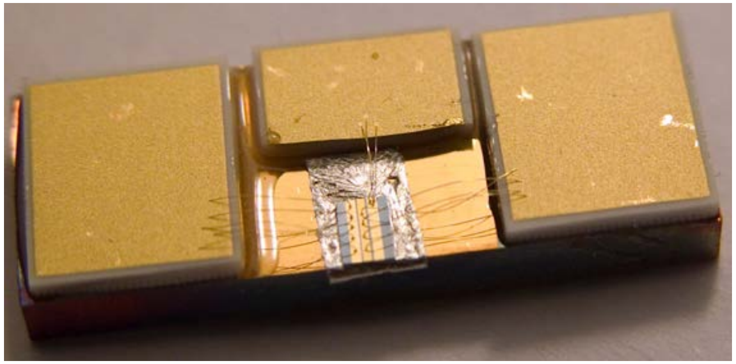




- **Operation of lasers based on quantum engineering;**
- **3.5 THz and 4.7 THz channels;**
- **Compact semiconductor structures (typically 1 mm x 100 µm x 10 µm).**



THz Quantum Cascade Lasers (2)

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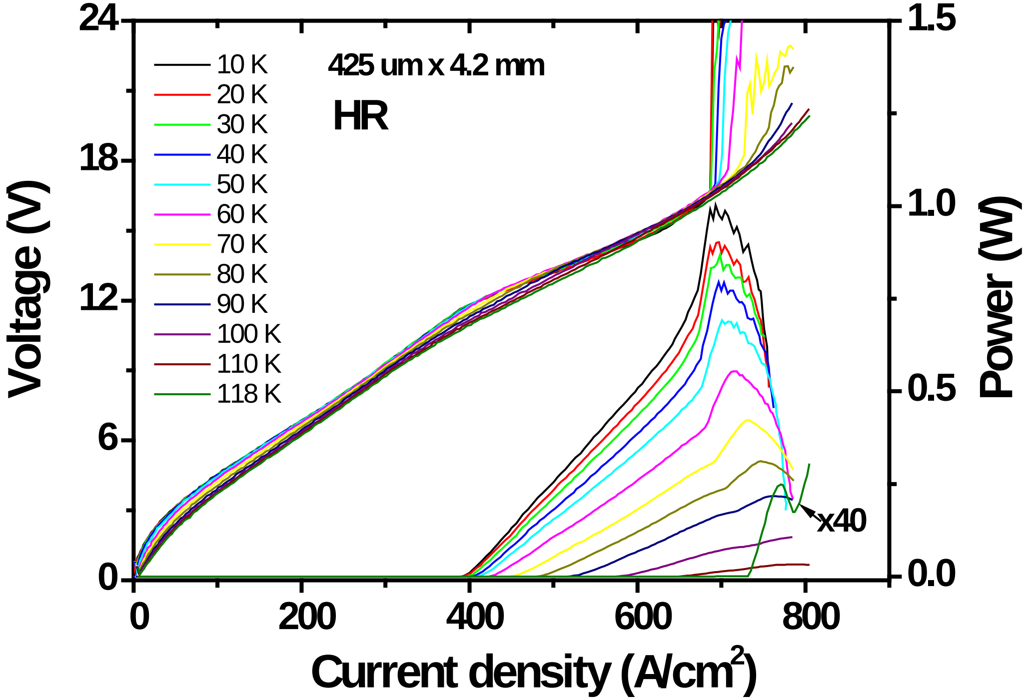
- **1 W peak power is possible, and 10s of mW continuous-wave power, *but cooled*;**
- **QCLs have an intrinsically narrow linewidth (<20 kHz);**
- **Precise frequencies can be defined using periodic gratings defined into the ridge waveguides;**
- **Operation has been demonstrated over the 1 – 5 THz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



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

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

THz Quantum Cascade Lasers – CEOI Developments (1)

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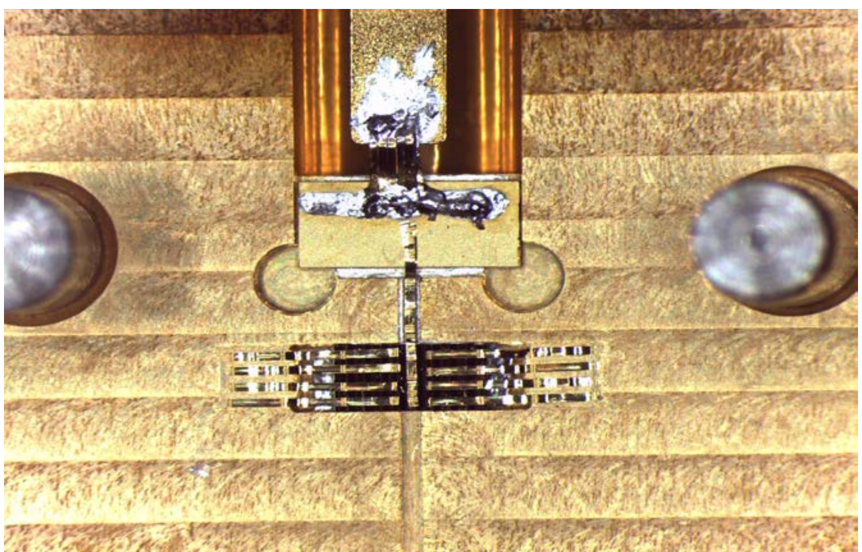
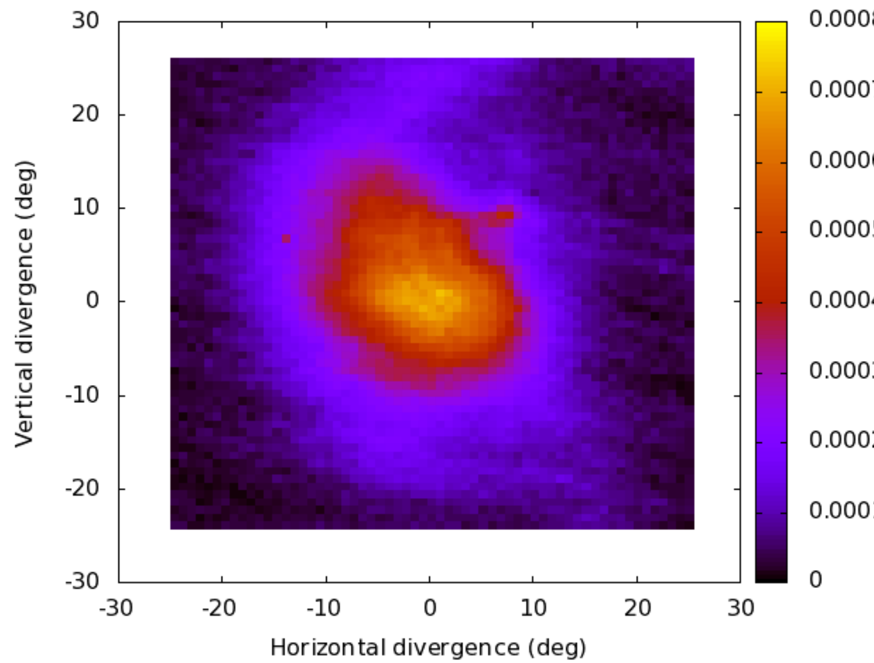
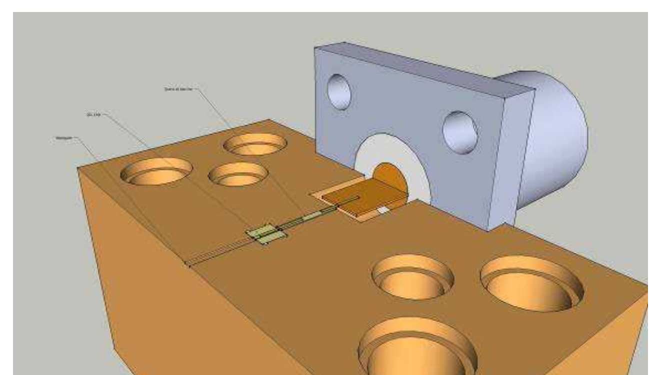
- **Operation demonstrated at 3.5 THz and 4.7 THz.**
- *But require cryogenic operation (~77 K), and large input powers*.
- **Integration into micro-machined waveguides with RAL.**
- ***First design operational in 2014.***







THz Quantum Cascade Lasers – CEOI Developments (2)

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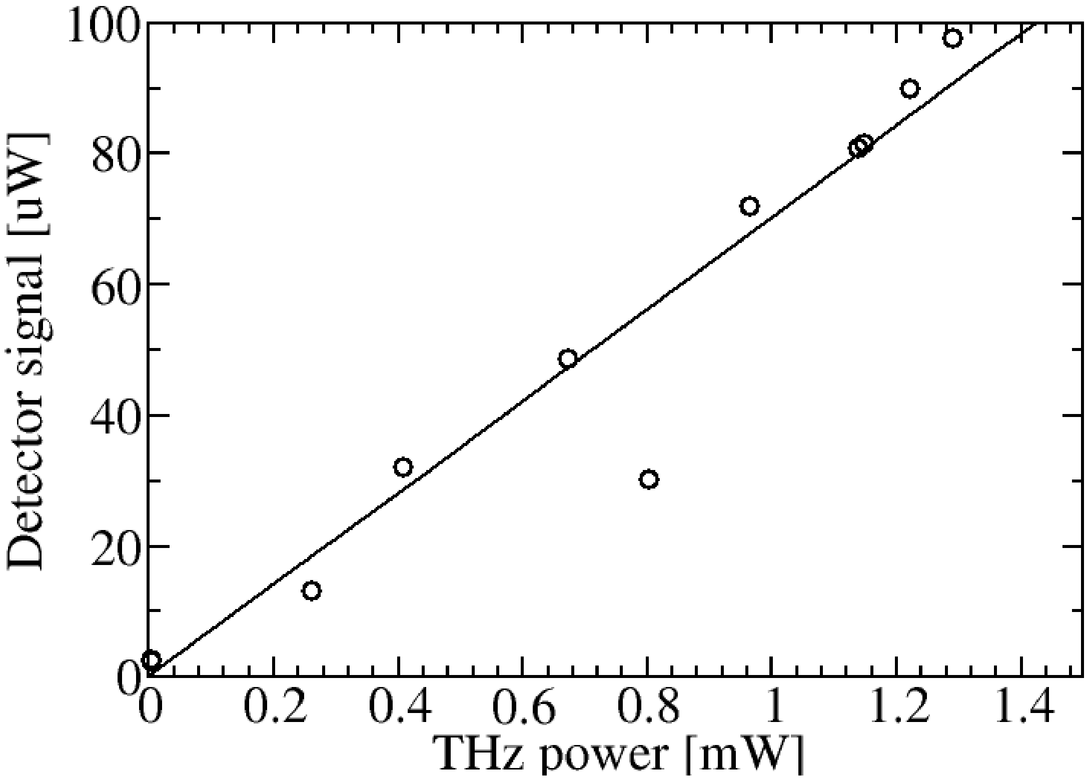
- **Direct detection of 3.5 THz QCL radiation (Leeds) by RAL Schottky diodes has been demonstrated through free-space coupling.**
- **Schottky diodes now being integrated into the QCL micro-machined blocks to give a compact supra-THz heterodyne spectrometer.**



Summary – LOCUS Technology

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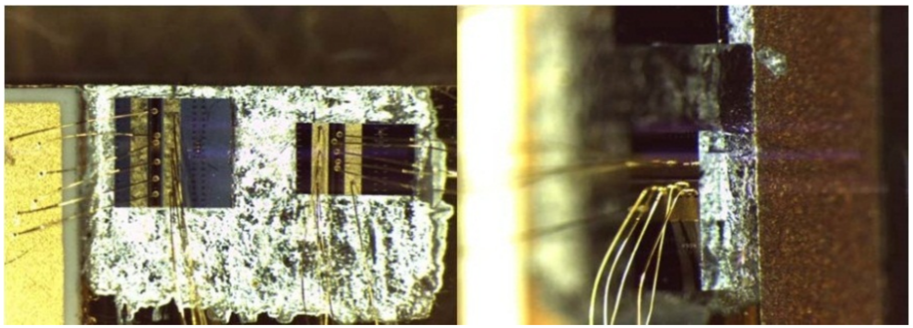
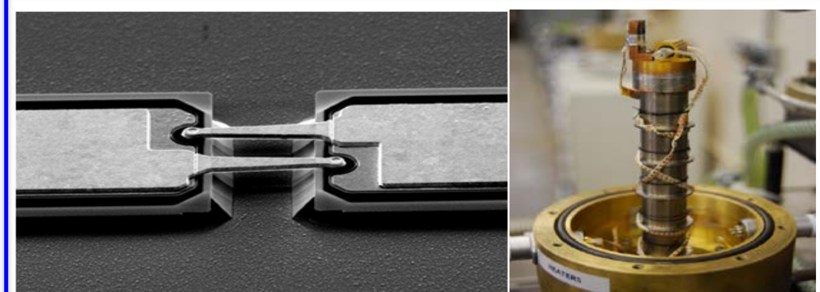
QCL Local Oscillator
University of Leeds



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.**

LOCUS Roadmap

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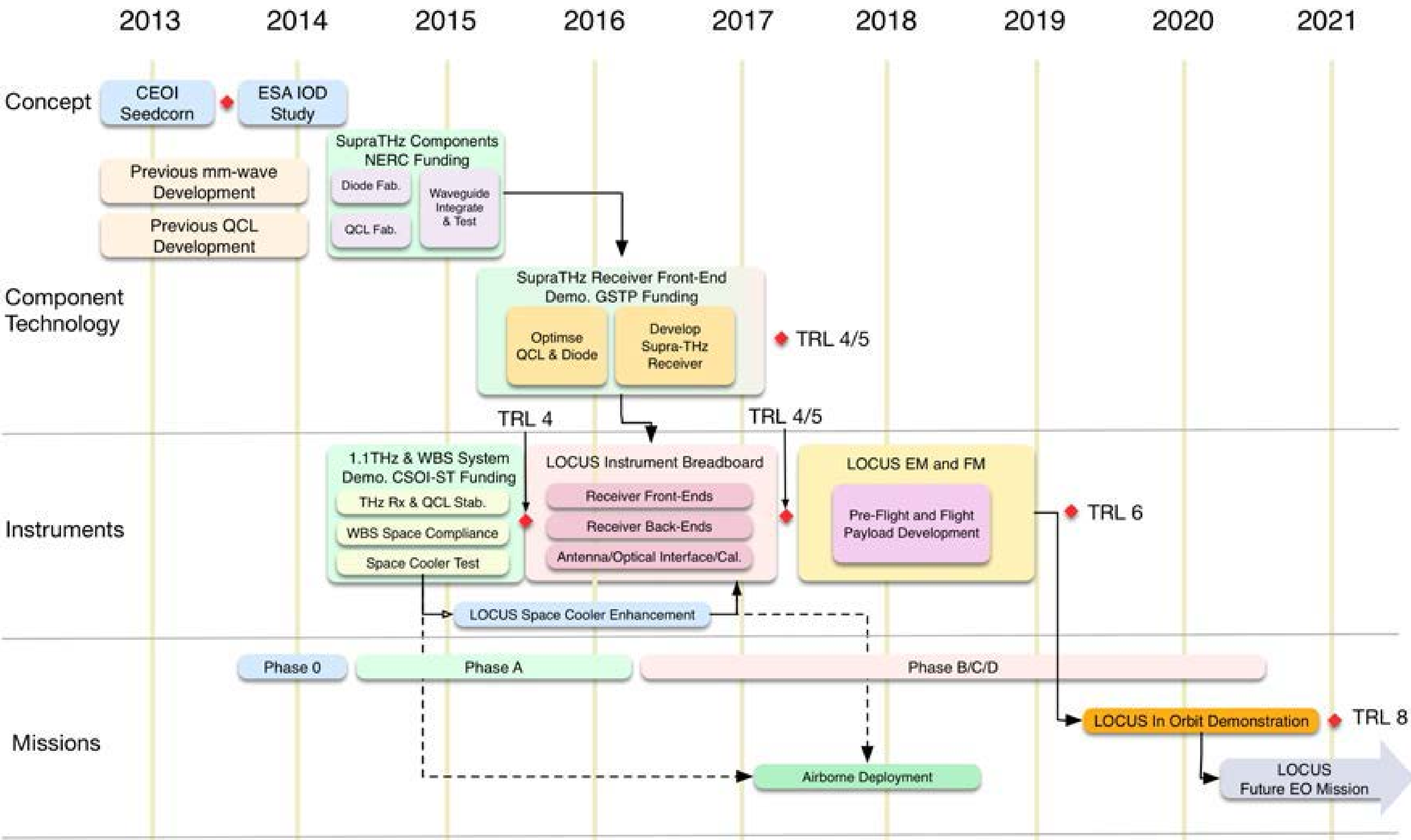

Summary

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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.**

Key features:

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- **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 as 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.**

The LOCUS Team Members

Thank you for your attention