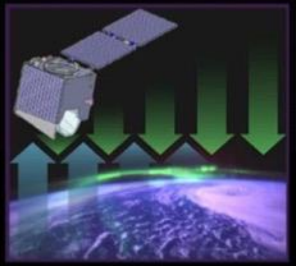
LINKING OBSERVATIONS OF CLIMATE, THE UPPER ATMOSPHERE AND SPACE WEATHER

LOCUS

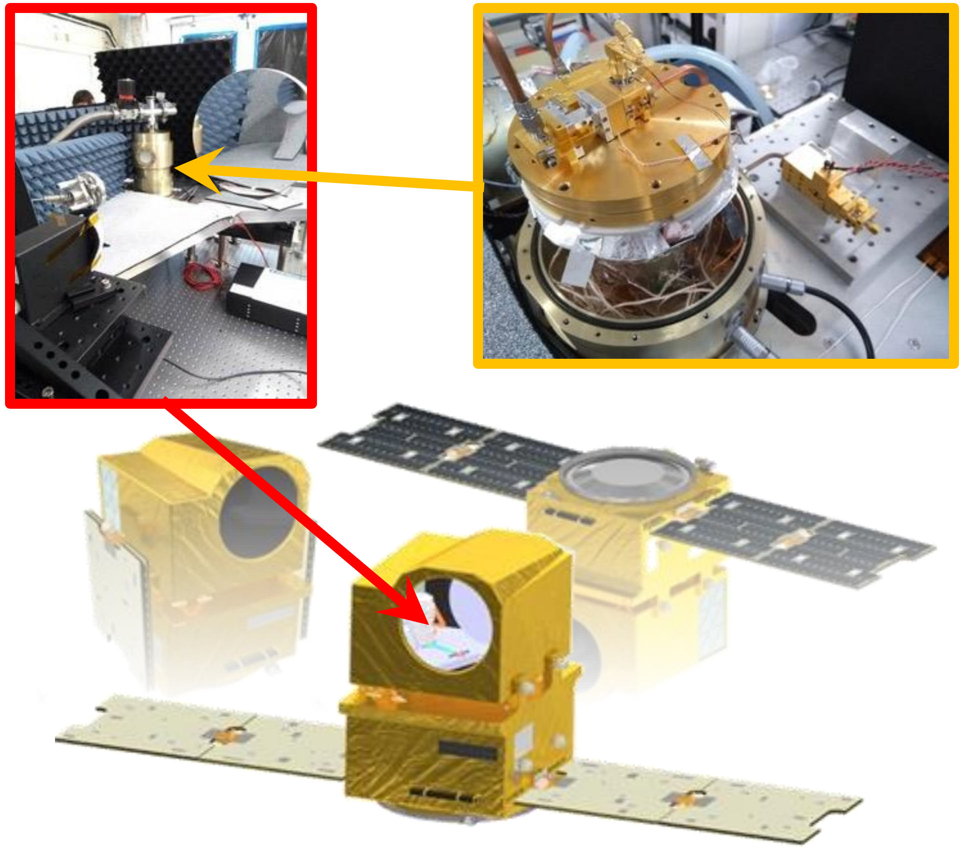


Presented by Brian Ellison, RAL Space, on behalf of the LOCUS Team

The LOCUS Mission

IN A NUTSHELL

- Small satellite mission.
- Study composition and thermal structure of Mesosphere – Lower Thermosphere (50km to 150km).
- Least well known region of our atmosphere!
- Gather missing data to improve climate and weather models.
- Uses new THz detection technology.



LOCUS EE-10 Concept on Astrobus platform

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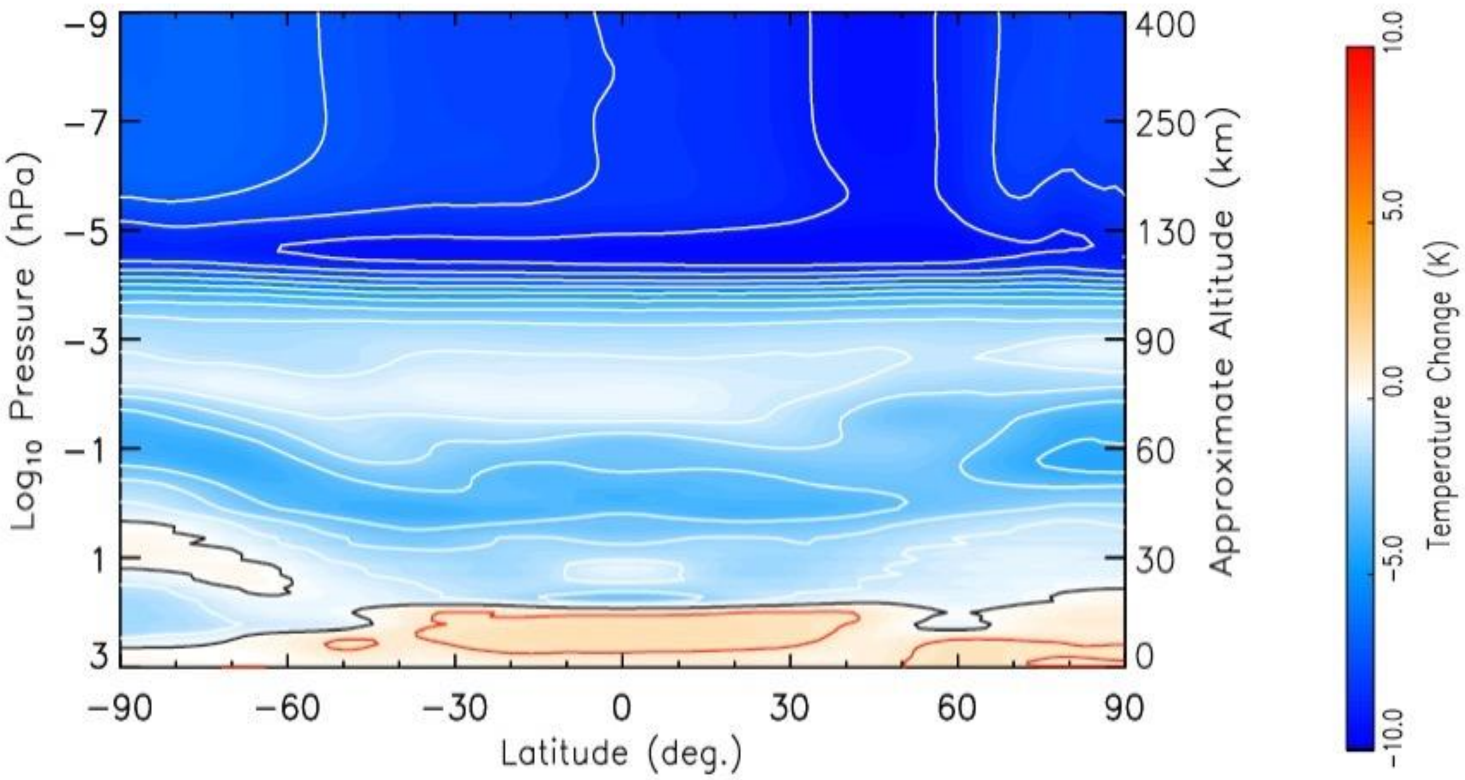
Climate Change in the Upper Atmosphere

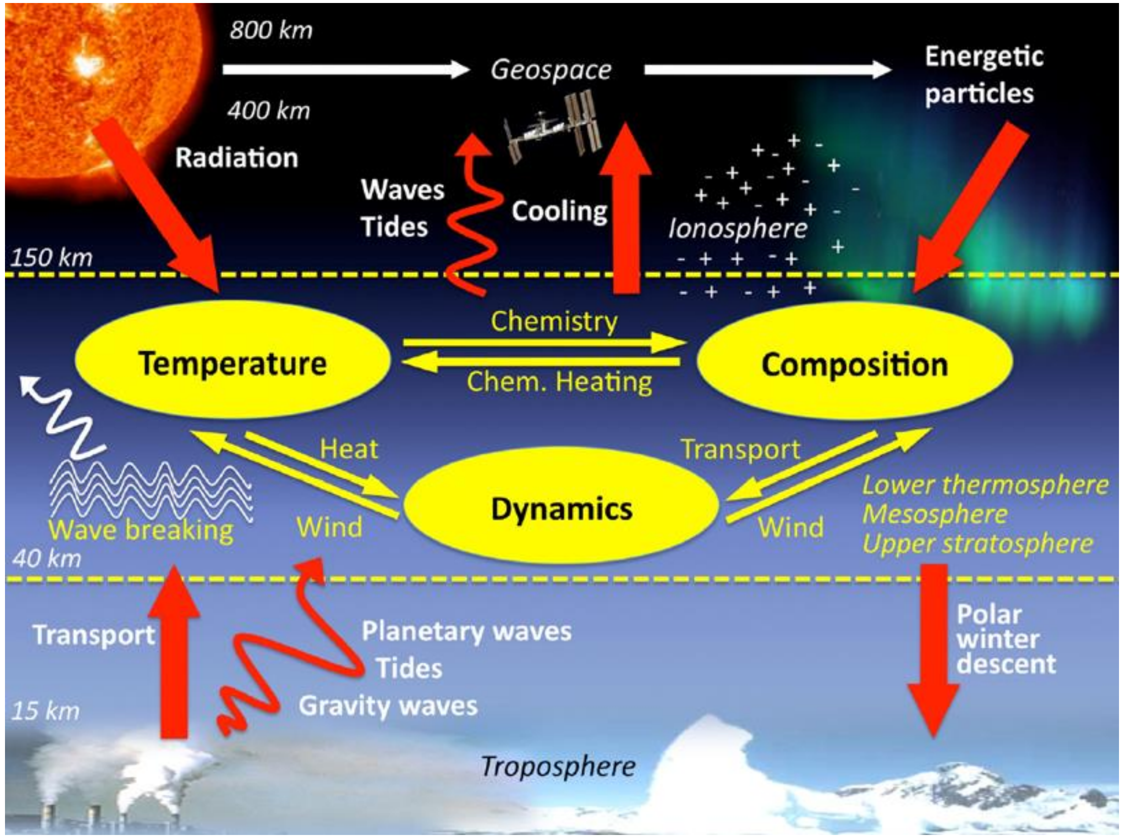
- There is a clear cooling trend in the MLT (**-10ºC**).
- Much stronger than the Tropospheric warming (**+2ºC**).
- We have no idea how much temperature change is from an increase in greenhouse gases.



[Solomon et al. 2018]

Why we Need LOCUS

- Measure and monitor a complex system to improve climate change knowledge.
- Current instruments (i.e. SABRE) estimate cooling rates by measuring the heat flux at infrared wavelengths.
- Above insufficient to understand Upper Atmosphere climate change. Need the abundance of O and should measure temperature directly.
- Also want to measure the chemical proxies of Space Weather forcing.



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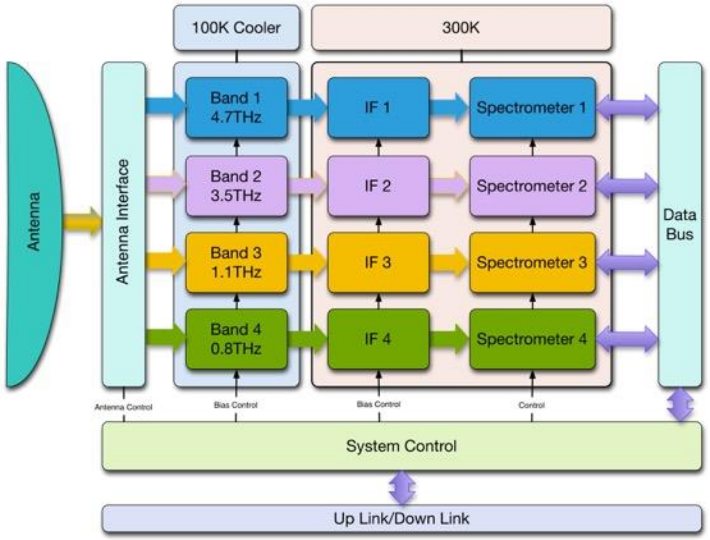
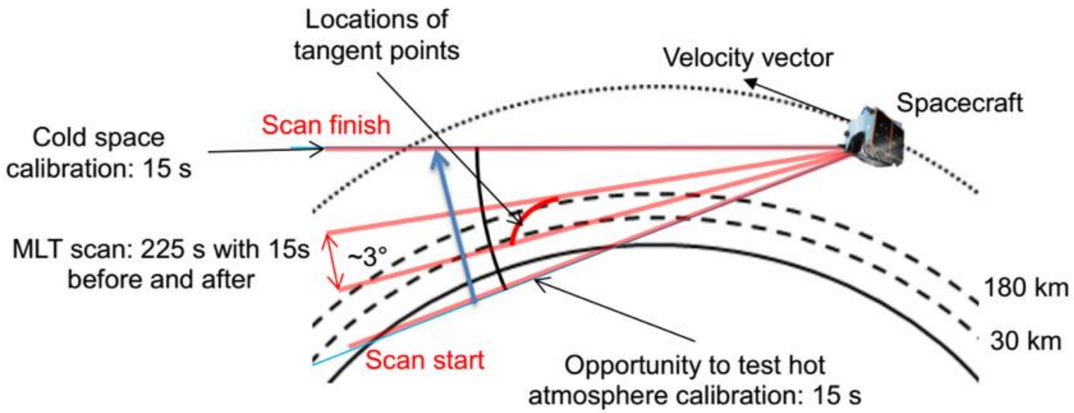
LOCUS Technical Concept

- 4 independent THz heterodyne radiometer channels (0.8THz, 1.15THz, 3.5THz and 4.7THz).
- Each channel targets key species – O2, NO, OH and O – with ~3MHz spectral resolution.
- Ability to self calibrate via on-board hot and deep space cold targets.
- 4 independent IR channels provide temperature measurement.
- Single highly integrated small satellite platform in sun-synchronous orbit at 800km altitude.





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LOCUS THz Receiver Technologies

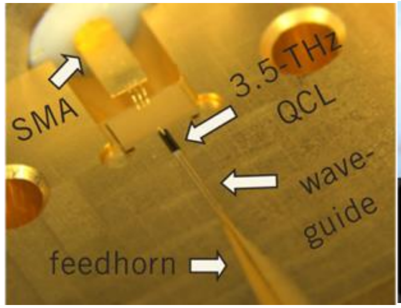
- LOCUS (Supra-) THz heterodyne instrument only becoming viable now through innovative (critical) UK technologies:

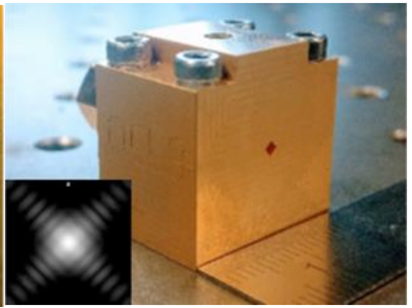
Quantum Cascade Laser (QCL) devices as a high-power source to pump heterodyne Schottky mixers

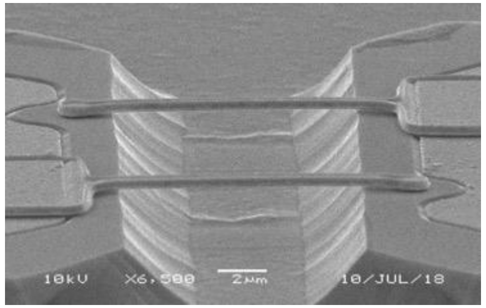
Miniature space coolers to provide QCL cooling (~70K)

Improved Schottky diode & mixer manufacturing for THz frequencies

Compact, high-speed, power efficient digital spectrometers







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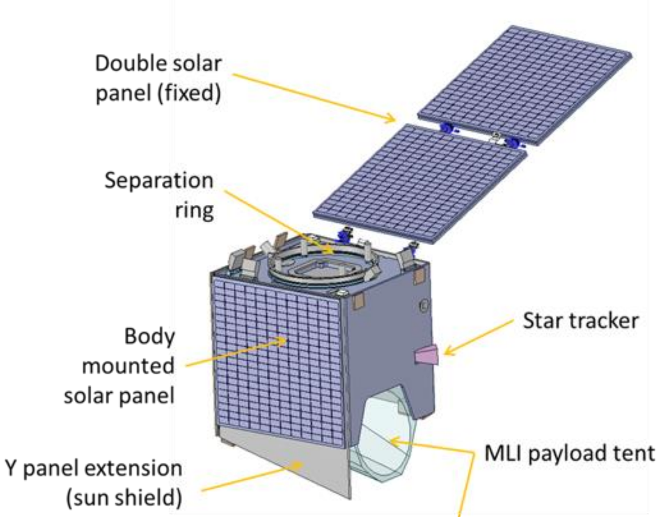
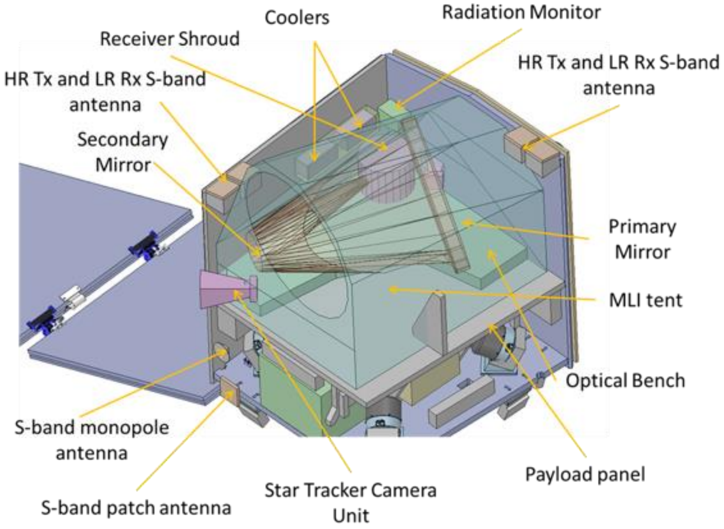
LOCUS Satellite Concepts

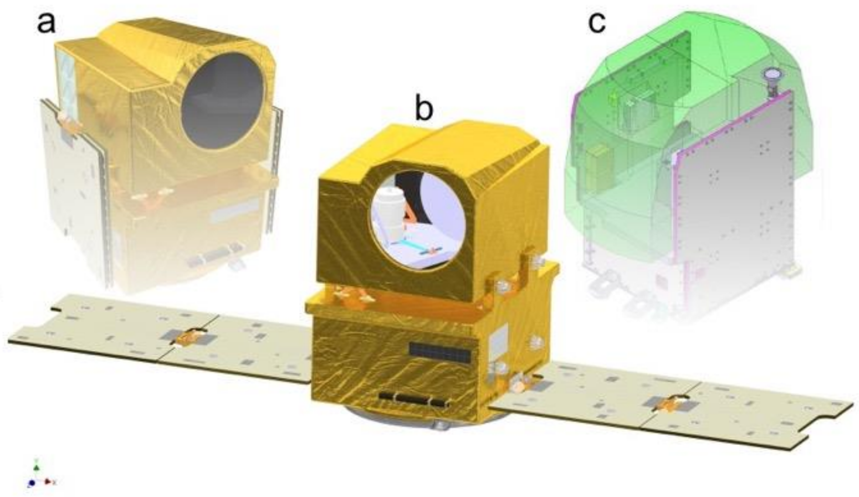
SSTL 150 Platform





[SSTL 2014, *ESA IOD Study*]

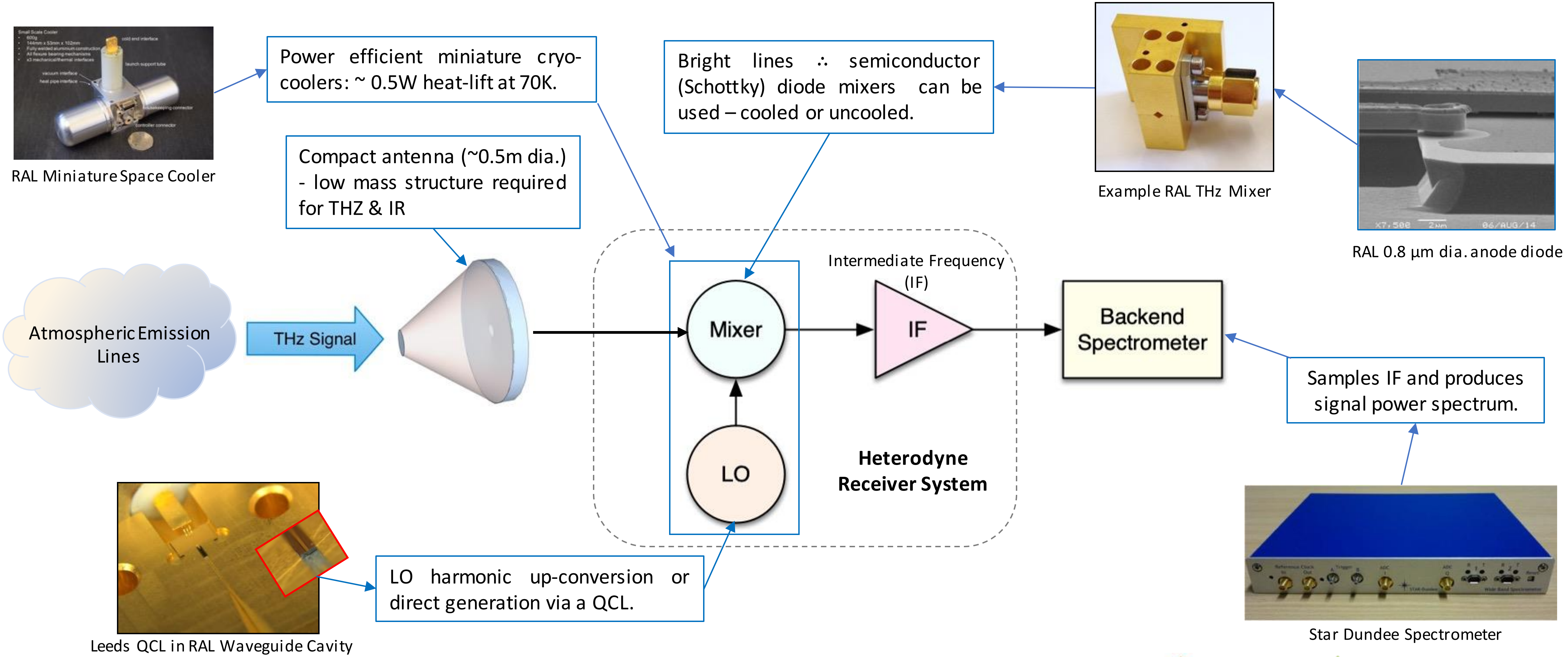
Airbus Astrobus Platform



[*Airbus 2018, CEOI EE-10 Preparatory Activities*]

Critical Technology Breadboarding

- LOCUS Heterodyne process translates THz input signal to lower frequency.
- Objective: Raise Technology Readiness Level (TRL) of associated key components.



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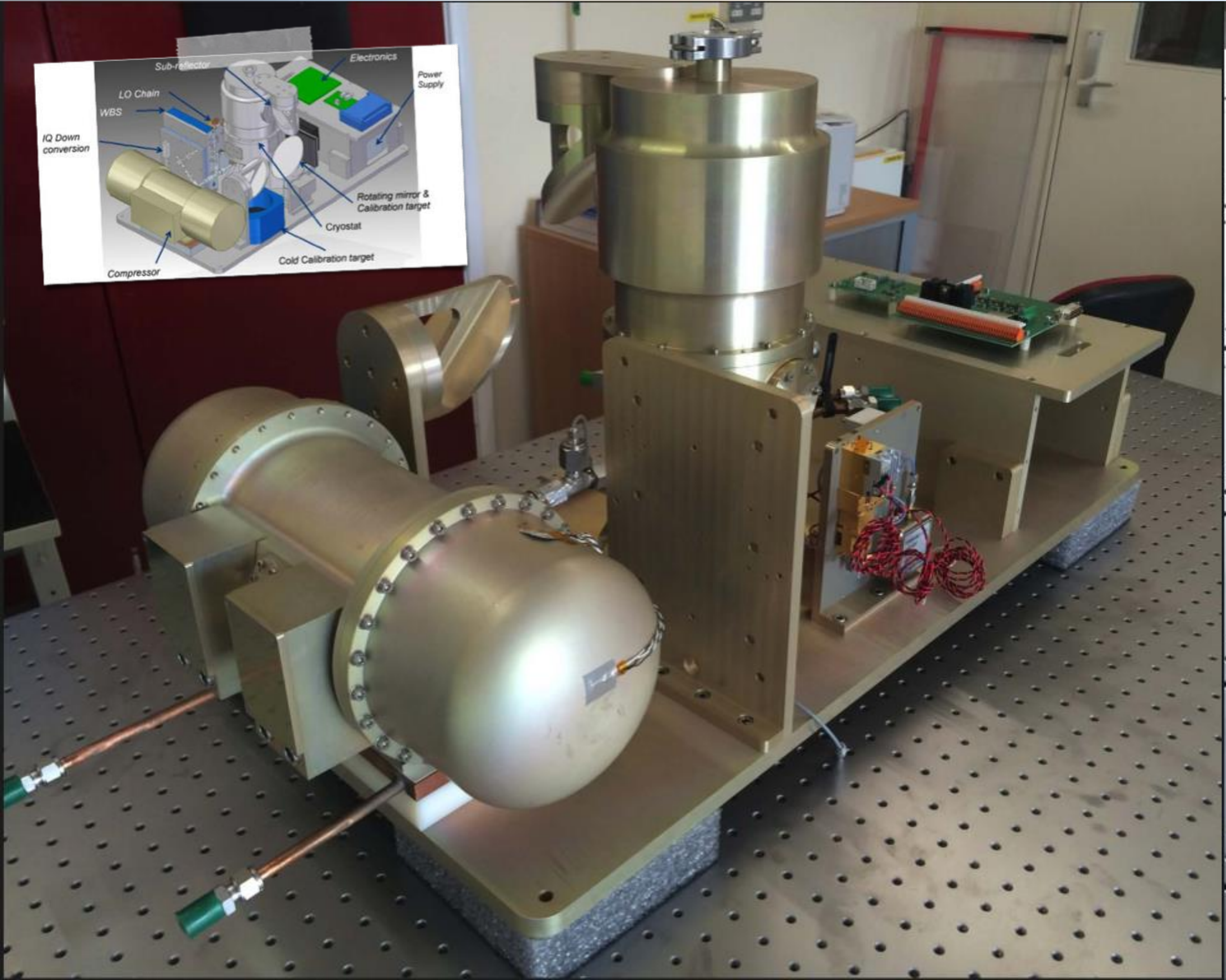
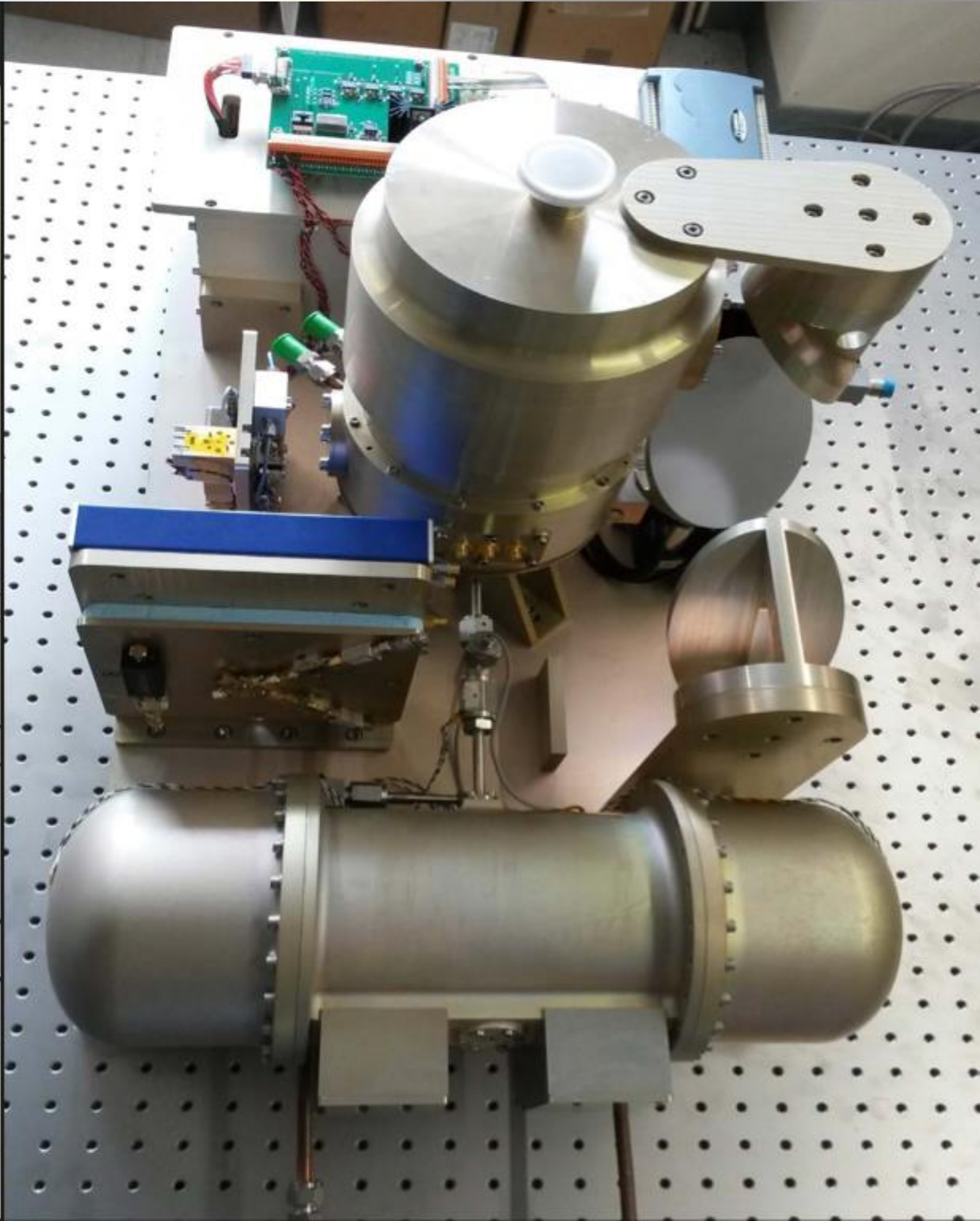
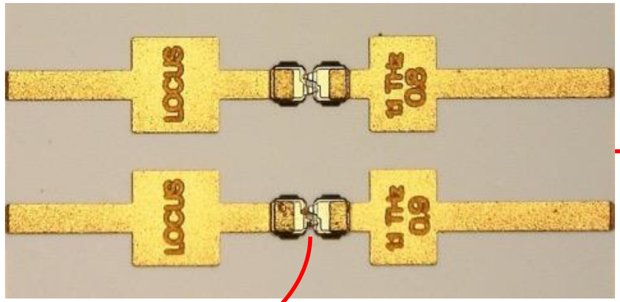
Critical Technology Breadboard (1.15THz)

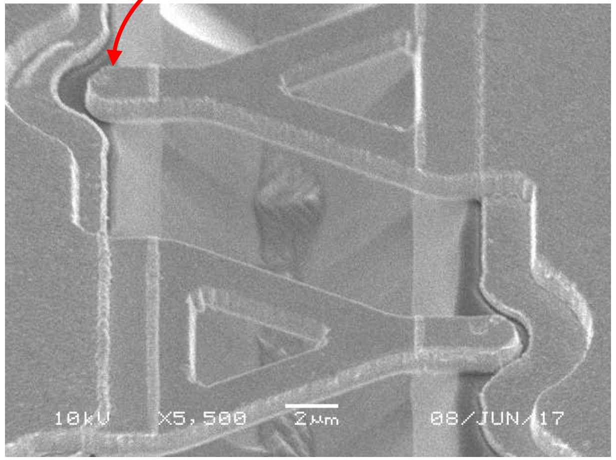




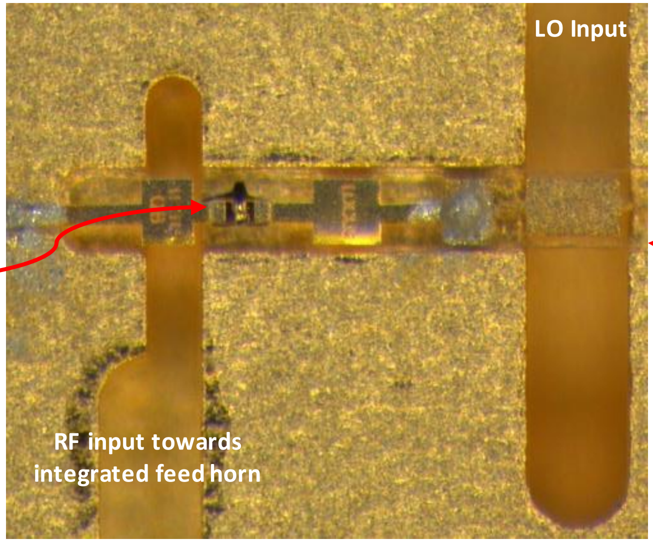
1.15THz Mixer Development

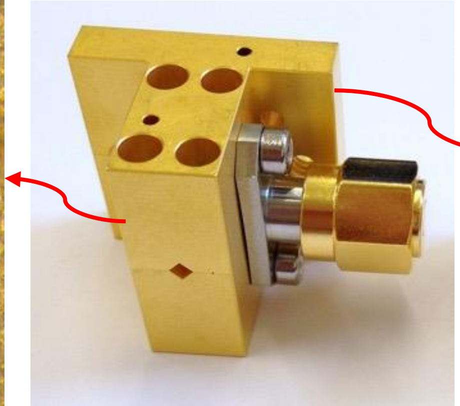
Optical image of mixer circuit with integrated Schottky diodes. Anode dia. ~ 0.8µm.



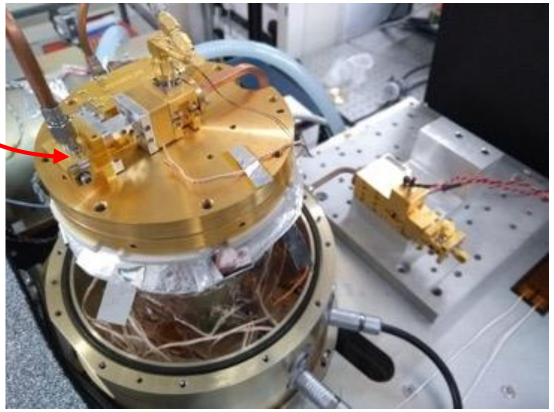


Internal view of lower block with mixer circuit



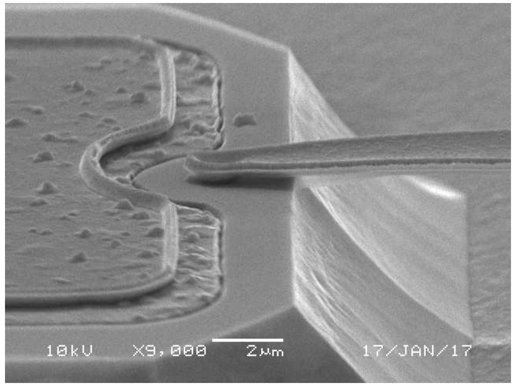


1.15THz mixer block



1.15THz Receiver

E-beam fabricated diode



- Receiver integrated into space cooler. Performance enhancement required.
- Needs smaller diode anodes - difficult fabrication task.
- Move to E-beam diode lithography demonstrated.
- Anodes <0.5µm dia. being developed.

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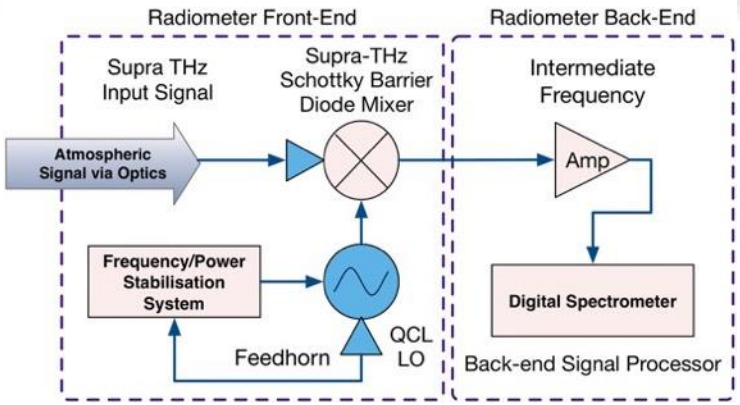
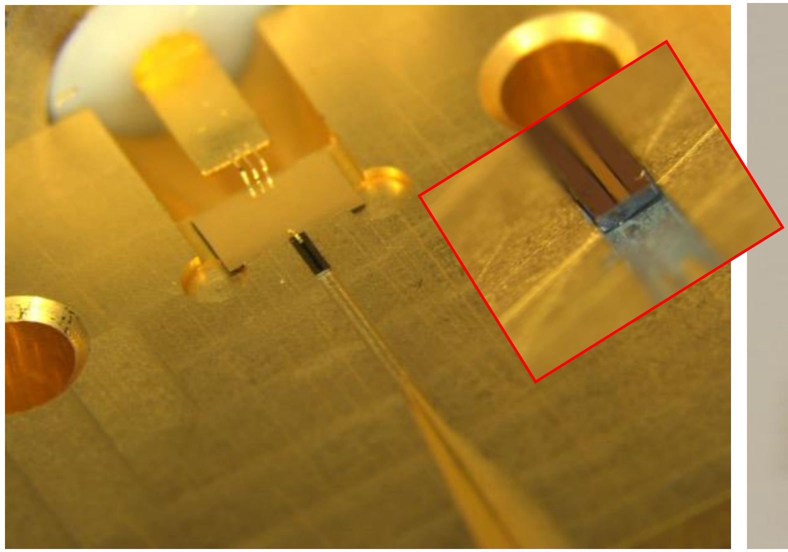
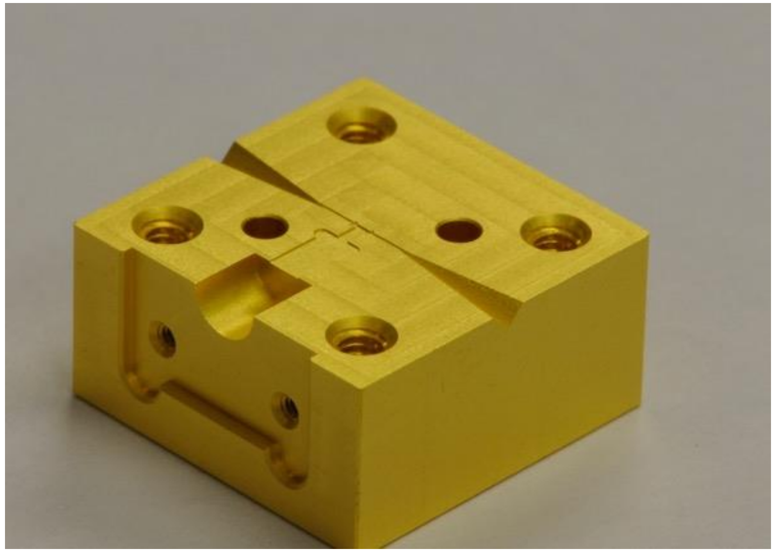
QCL Integration and Beam Measurement

- Leeds developed 3.5THz and 4.7THz QCL devices.
- Waveguide blocks with integrated feedhorns fabricated by RAL.
- Waveguide integrated QCL tested in a space cooler system.
- Output power measured and 2D antenna measurements made.
- Operational temperature and polarisation effects also studied at 3.5THz.





QCL Mounted into Waveguide Block



QCL Block With Diagonal feedhorns at each end

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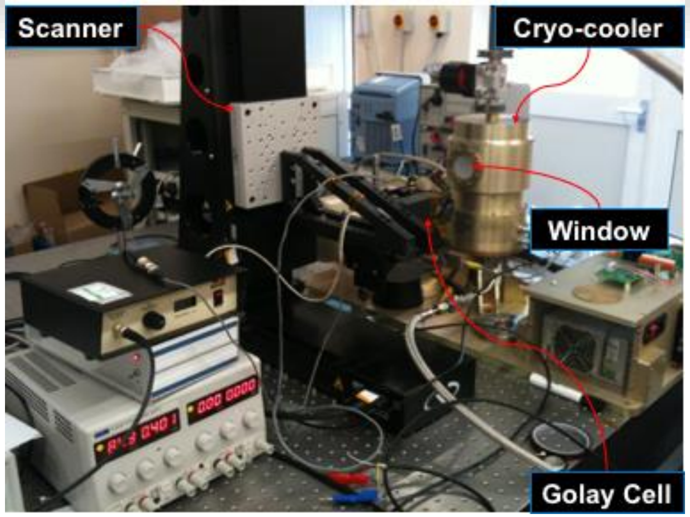
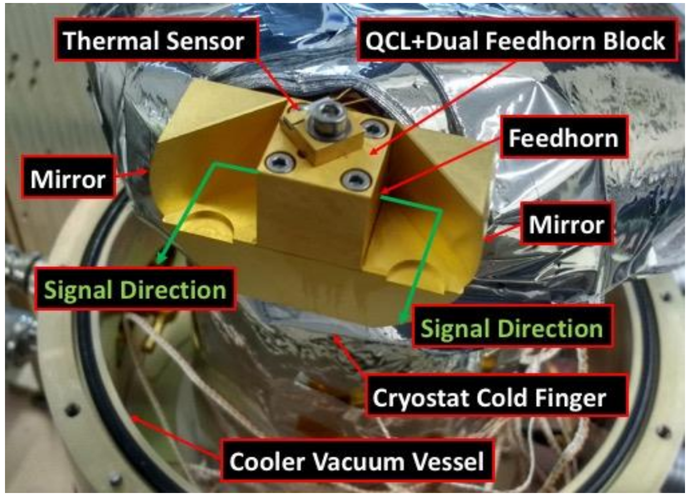
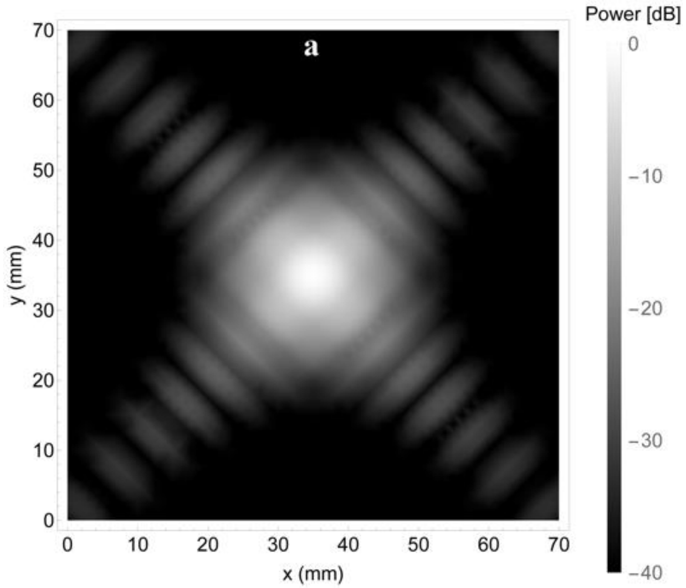
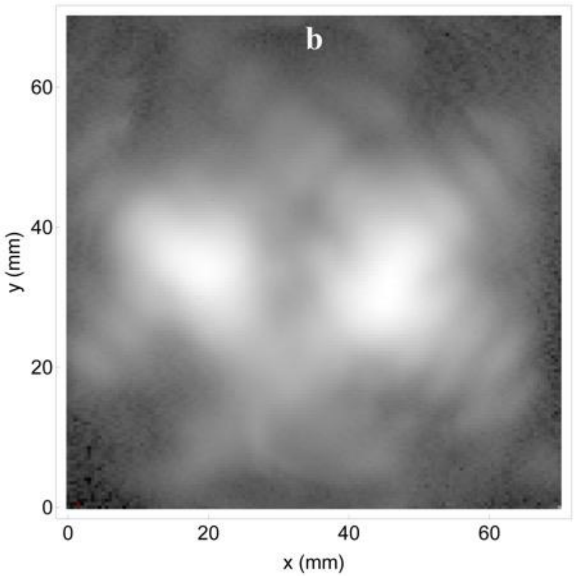
Integrated QCL Beam Measurement





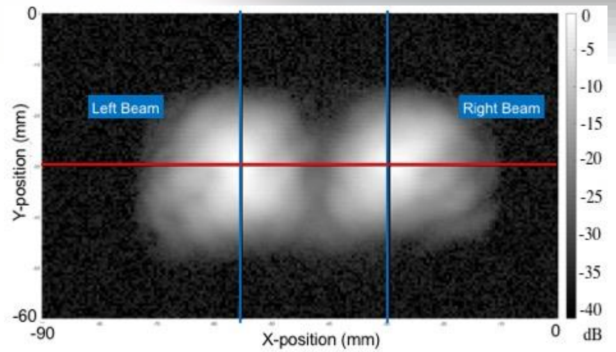
- **Dual feedhorn block + QCL cooled to ~65K.**
- **Scanning Golay cell used to measure dual output beams.**
- **QCL bias modulated to reduce background effects.**
- **Images: a) simulation, b) dual feedhorn measurement.**
- **Suggests single waveguide (TE_{10}) mode of propagation.**



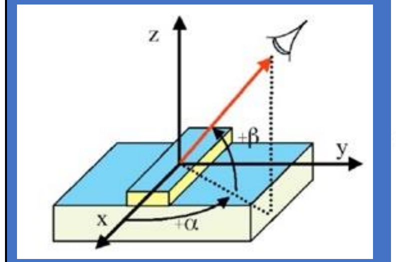


Integrated QCL Measurements at 3.5THz

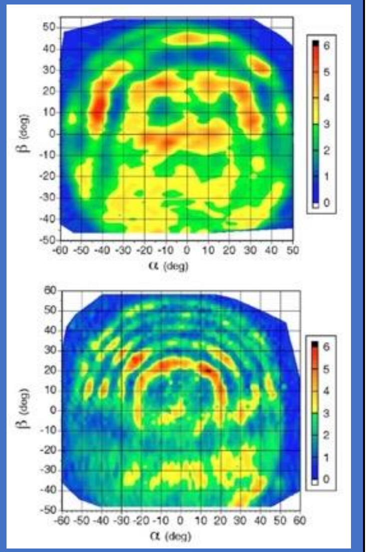
- **Beam profiles measured with reduced aperture Golay detector (2mm dia.).**
- **Good agreement obtained with theoretical plot re. FWHM.**
- **Good Gaussian distribution.**



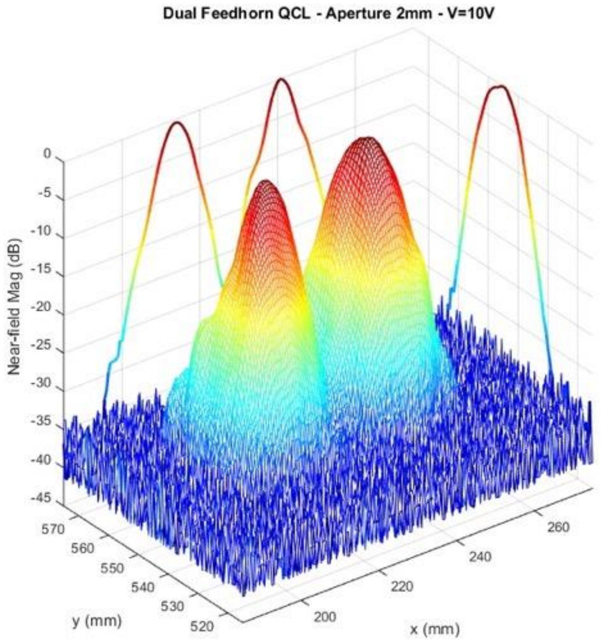
a.

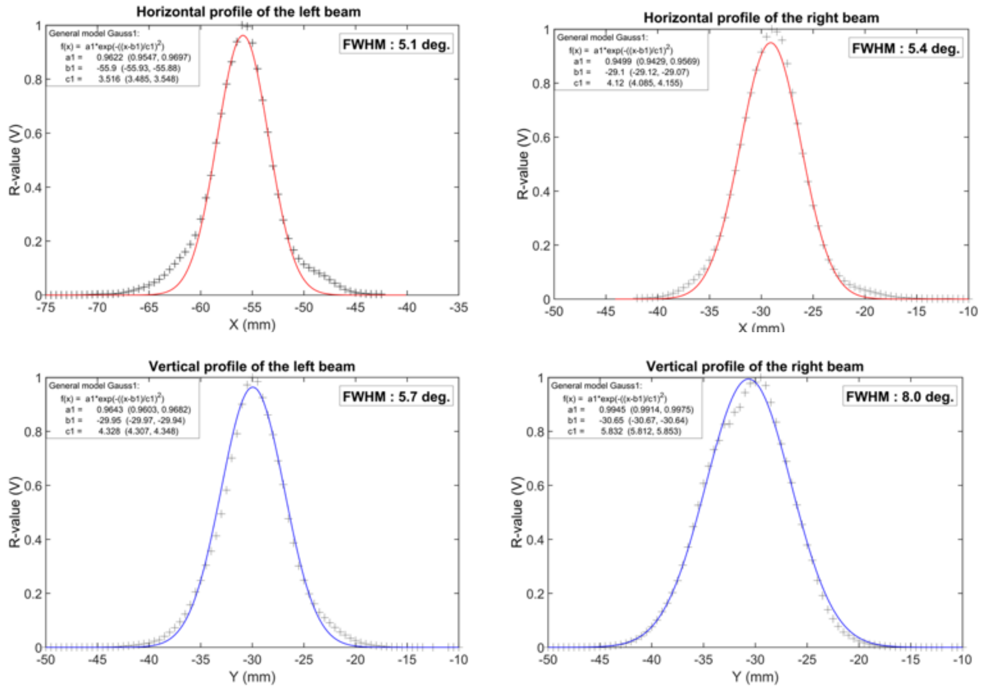


b.



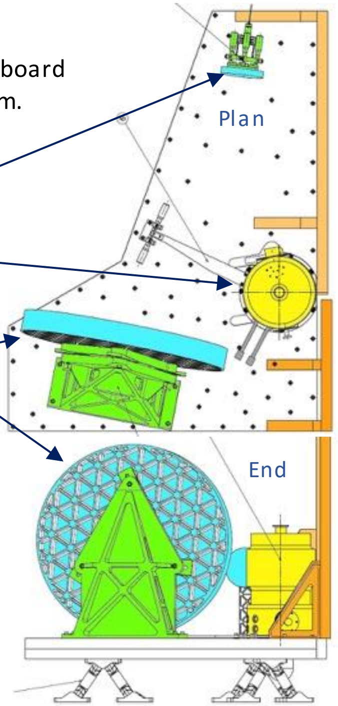
Example unmounted QCL device (a) and antenna patterns (b) from Adam *et al*, Appl. Phys. Lett. 88, 151105 (2006).

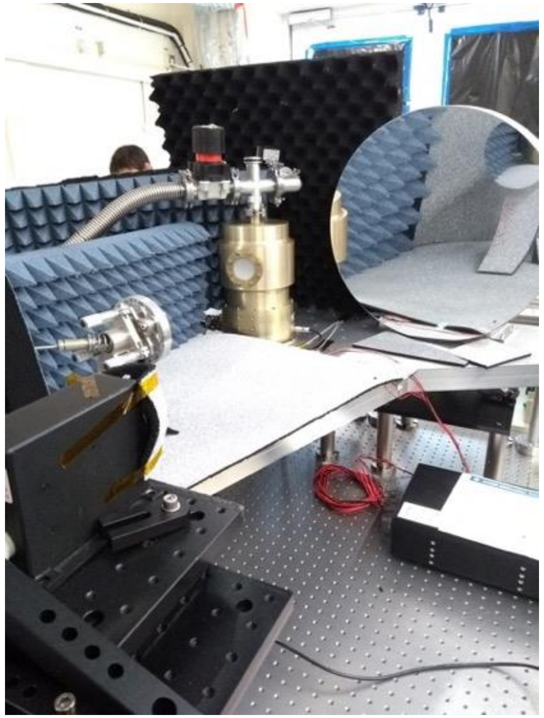




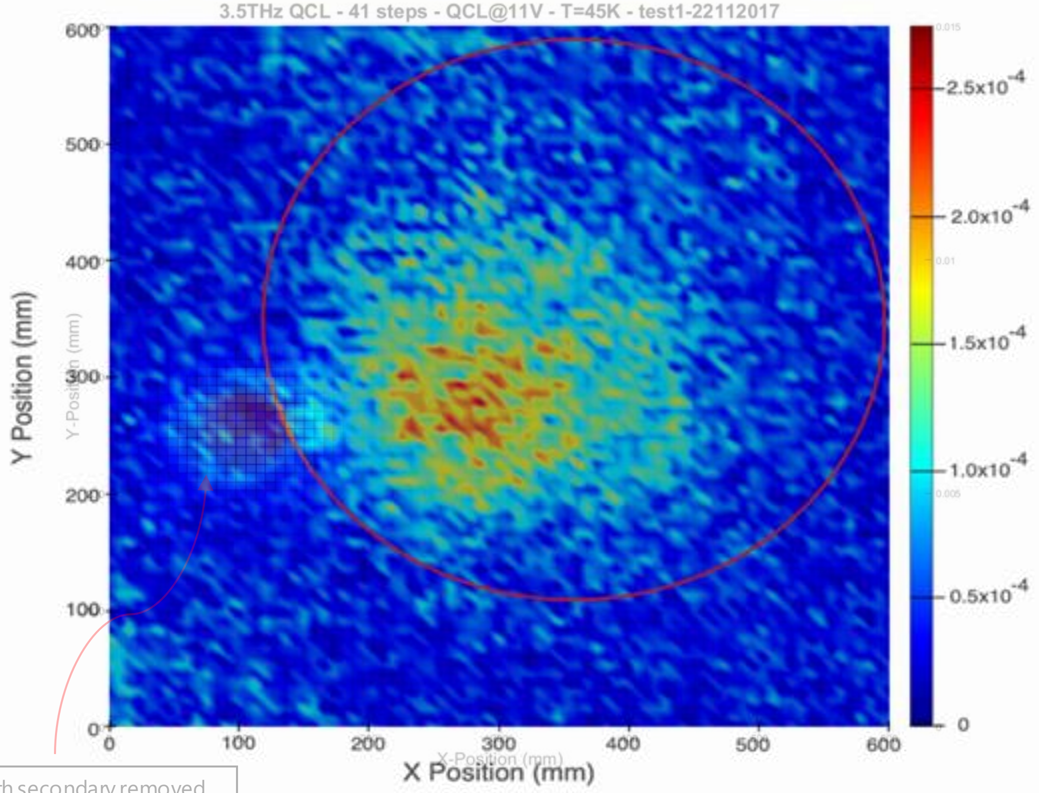
Integrated Optical System Measurement

CEOI THz Breadboard concept ~1mx1m.





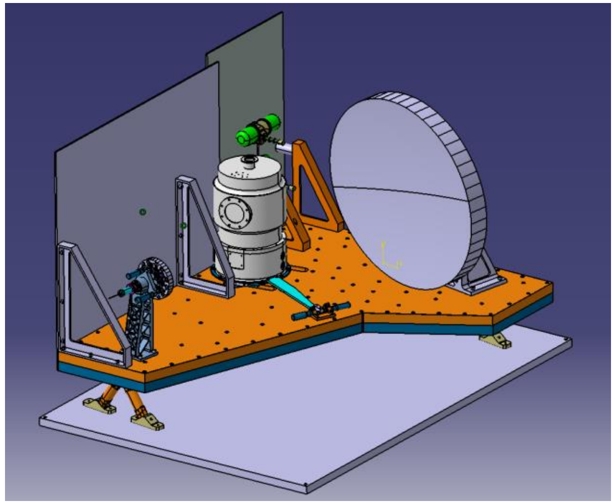
Mirror and breadboard supplied by UCL/MSSL

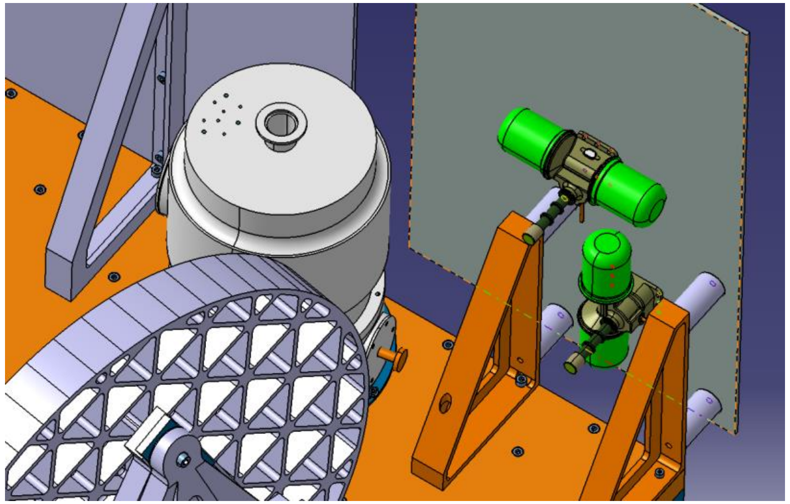


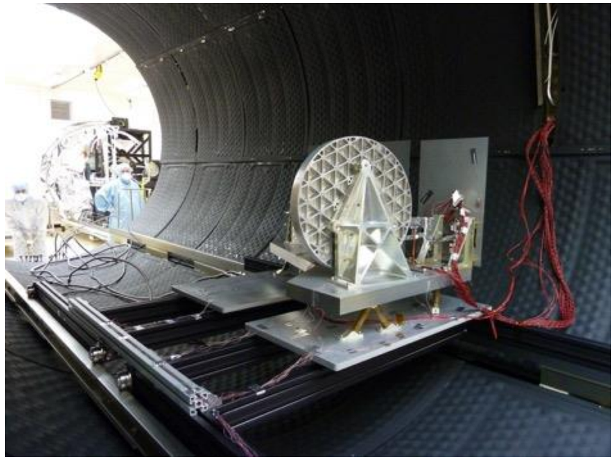
View with secondary removed

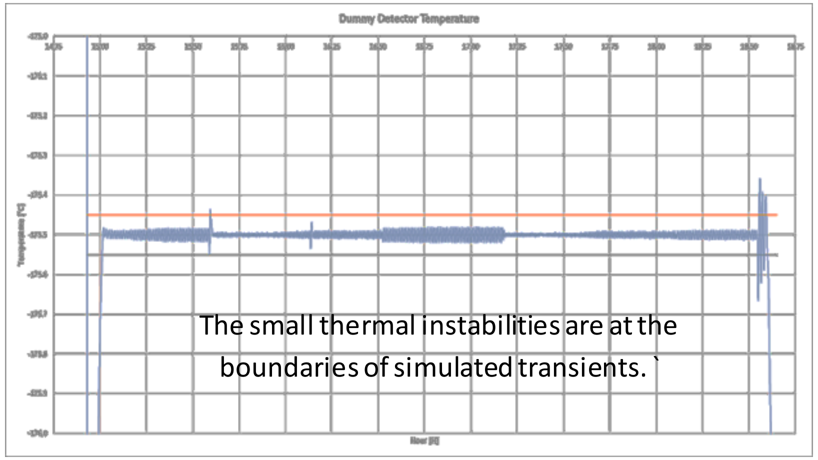
LOCUS Breadboard Development

- Design and manufacture of an elegant breadboard to test:
  - Optical bench.
  - Mirrors + alignment.
  - Radiators.
  - Mini space cooler.
- Performed Thermal Vac. Test
  - Demonstrated cooler operation and stability.









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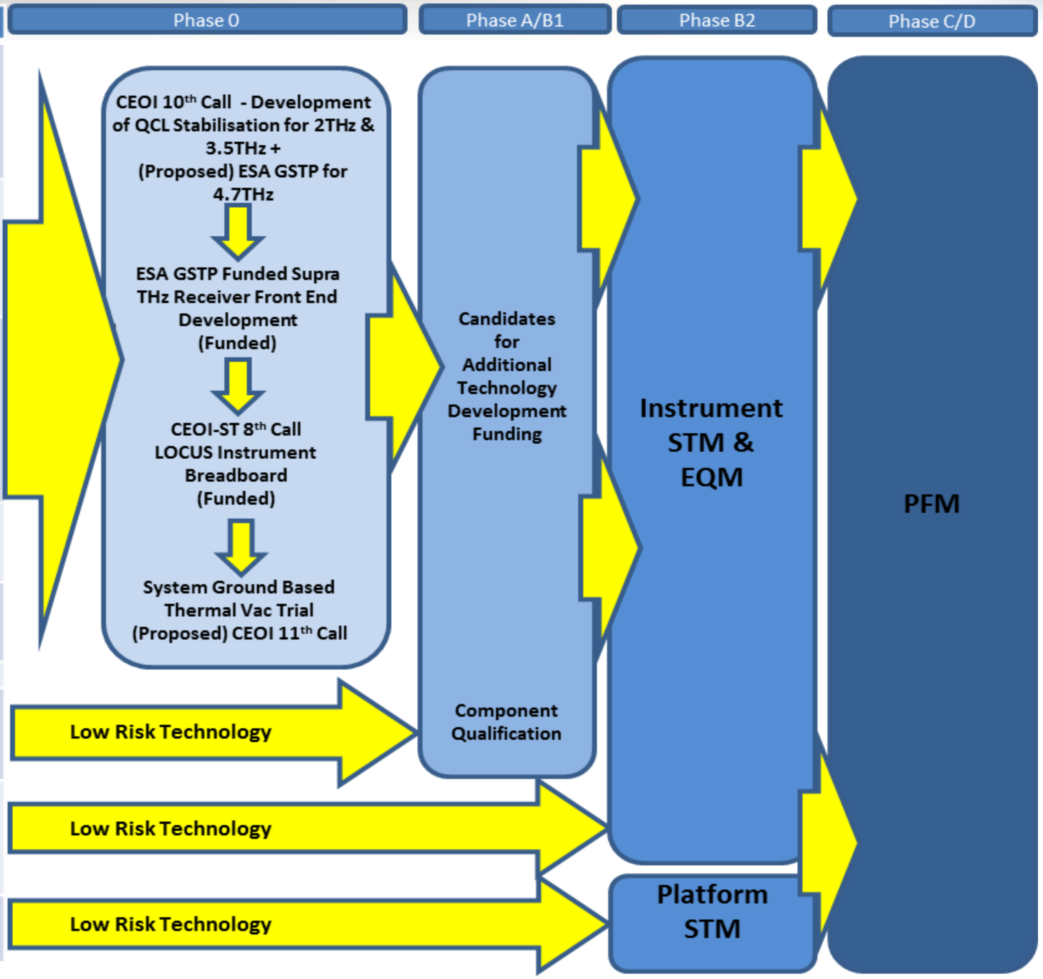
LOCUS TRL Roadmap

Component	TRL at Start of Phase 0
Quantum Cascade Laser Local Oscillators	TRL 4/5 The diodes are routinely operated in the lab at compliant operating temperatures and output power
Conventional (Schottky) Local Oscillators	TRL 5/6 Operated in the lab as part of a complete 1.15THz breadboard radiometer. Similar technology up to 1THz has already flown (Herschel)
THz Schottky Mixers (<2.5 THz)	TRL 9 Single diode mixers up to 2.5 THz (Demonstrated in space operationally by EOS MLS) Subharmonic diode mixers (planned for LOCUS) up to 1.1THz at TRL4/5 (exist in JUICE)
THz Schottky Mixers (>2.5 THz)	TRL 3 For 3.5 THz and 4.7 THz
Integrated QCL-Schottky Mixers (>2.5 THz)	TRL 3 4.7 THz
Space Cooler	TRL 4/5 (alternatives available)
WideBand High – Resolution Spectrometer	TRL 4/5 Module has undergone laboratory testing and field trials
Infrared Detectors	TRL 9 Identical technology demonstrated in space by SABER (same detectors and manufacturers)
Platform	TRL 9 Astrobus-S Standard Product



[Airbus 2018, CEOI EE-10 Preparatory Activities]

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Summary

- LOCUS, e.g. EE10, science justification established and community engagement achieved.
- Mission concept defined with major payload and small sat. platform attributes assessed (support from CEOI and ESA).
- Critical component technology TRL advanced.
- Optical breadboard system developed and small cooler technology evaluated.
- More work to do, e.g. full supra-THz receiver needs to be demonstrated, inc. freq. stabilization, and integrated payload performance tested in TV.
- Flight opportunity (EE11?) needs to be acquired along with full additional, e.g. Phase A/B1, funding.

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Thanks for Listening