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CEOI

High Resolution Millimetre-wave Passive and Active Imaging

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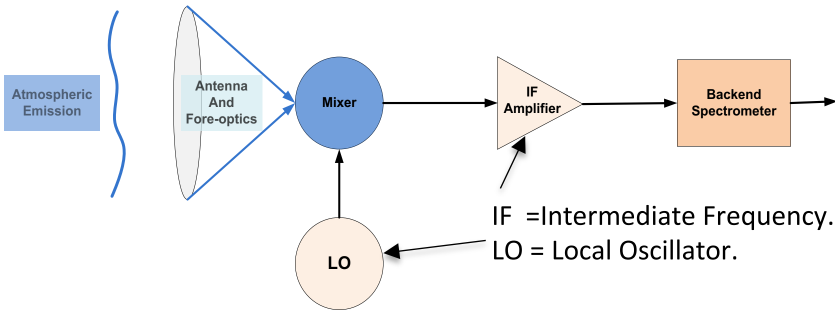
RAL Space

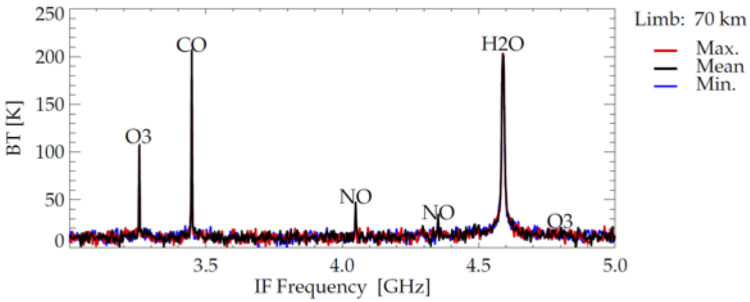
Technical Introduction

Passive/Active MM-wave Sounding

Presentation references heterodyne passive and active systems technology.

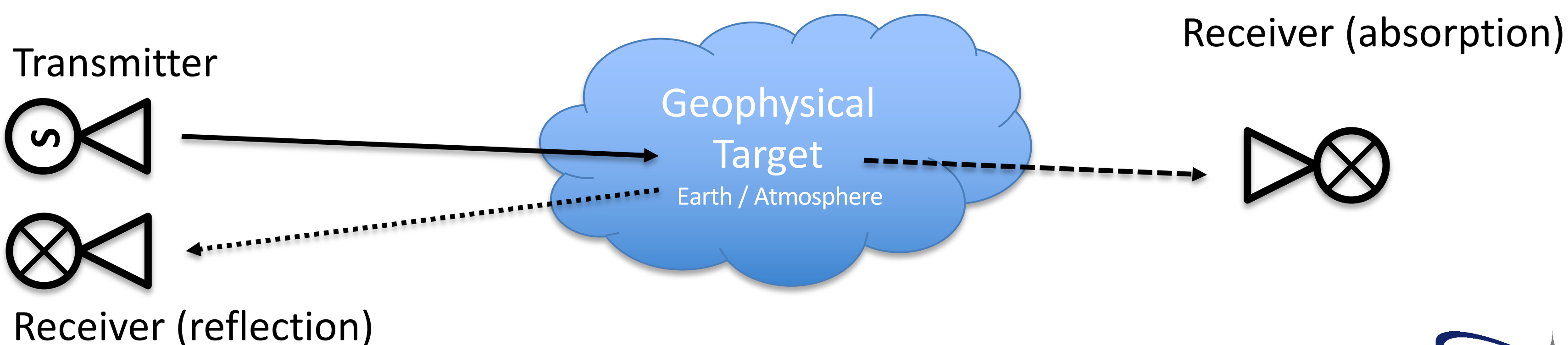
Passive Sounding - Basic Example



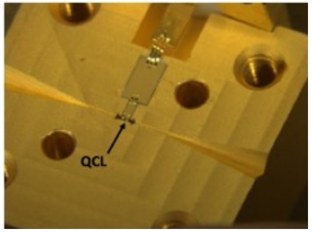


Spectral Simulation (@ 1.14 TH)z

Active Sounding - Basic Example

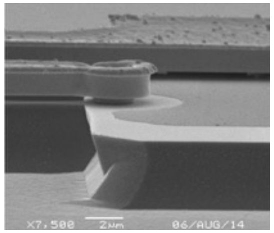


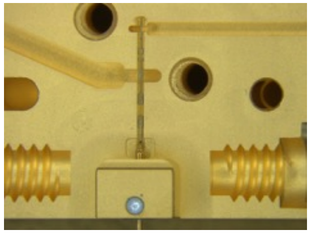
CEOI Past Investment Benefit



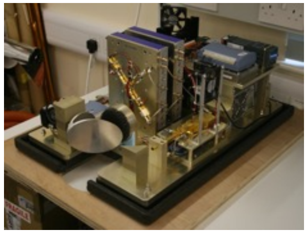
Leeds QCL+RAL Waveguide Cavity

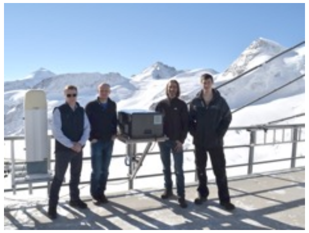
- Has strengthened the UK in relation to passive mm-wave technology:
  - *Subharmonic (SHM) and subharmonic image rejection mixer (SHIRM) & systems (RAL);*
  - *Schottky barrier diodes for mm-wave mixers and sources to THz frequencies (RAL);*
  - *High-speed digital spectrometers for spectroscopy (STAR Dundee);*
  - *Spaceflight compatible metal optics (Huddersfield and Glyndŵr);*
  - *Terahertz technologies (mixers and quantum-cascade laser local oscillator sources) and systems (above institutes plus Leeds, UCL, MSSL and JCR Systems Ltd).*
  - *EO science and mission preparations, e.g. LOCUS, and instrument deployment, e.g. SHIRM receiver.*
- The above has directly/indirectly contributed to UK industrial positioning. E.g. provision of support (RAL) to Airbus for MetOp-SG.


Schottky Diode

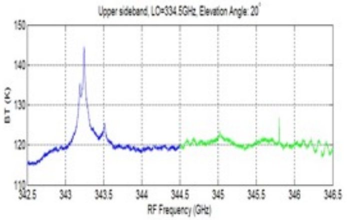

183GHz SHM


Digital Spectrometer


SHIRM Receiver


SHIRM Deployment

EO Science Data



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MM-wave Imaging

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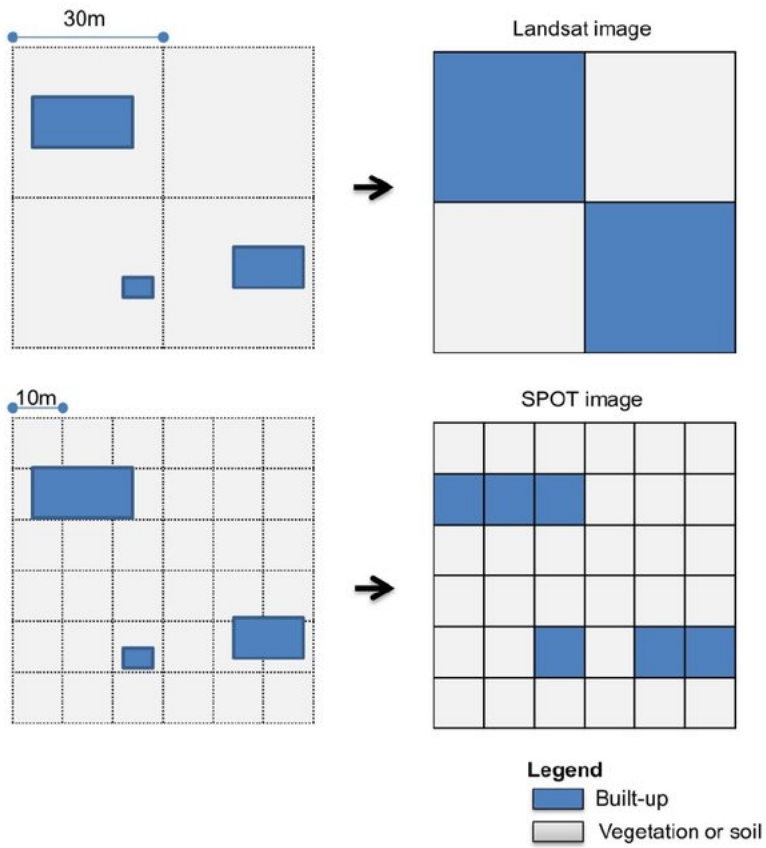
Imaging Themes

- **Spatial** sampling (passive/active) – produces an image of the scene.
- **Spectral** sampling (passive) – characterises spectral signatures.
  - *Passive systems can combine spatial and spectral detection to form a spatial mm-wave hyperspectral imager.*
  - *Active (radar) systems offer range resolution and often velocity (Doppler) sampling to provide a temporally varying, multi-dimensional image.*
- Both are very powerful independent mm-wave observational tools.
- In some circumstances they can be combined to form a single instrument.

Spatial (Angular) Imaging

- Spatial resolution defines scene radiometric sampling (surface or atmosphere). Increasing resolution leads to:
  - A more detailed (accurate) reproduction of the scene.
- Resolution controlled by observational wavelength (λ) and antenna size: *Ang. Res.* $\approx \lambda / (Antenna\ Diameter.)$
- Depending upon the application, *MM-wave antennas are relative large*.
  - *Example: 500mm antenna dia. in LEO (800km) produces ~5km dia. sampling beam at Earth's surface for* $\lambda = 3mm$ *(100GHz).*

Benefits of high spatial resolution



- Revealing critical features (i.e. land use / urbanisation)
- 1-to-1 attribution of radiance to source (i.e. forest fires)
- Accessing new science areas (i.e. hydrology of lakes and rivers)

MM-wave Imaging Enhancements

Improving Spatial Resolution

- Increase antenna diameter:
  - *Payload mass penalty, particularly where steering is required. Consider exploring;*
    - *Low mass composite (3D printed?) materials;*
    - *Deployable reflector technology.*

- Reduce wavelength (increase frequency).
  - *Passive/active system technology driver.*
    - *Must improve detection, source and system technologies.*
  - *Science may require specific frequencies, e.g. spectral signatures.*
    - *Perform careful assessment and optimisation of science requirements.*

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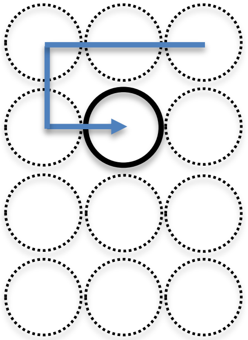
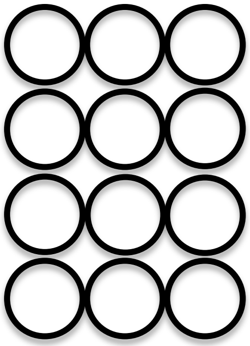
Improving Spatial Imaging



- Most heterodyne passive/active 'imagers' are single-pixel.
- Antenna scanning is required to sample ('image') the scene.
  - Increases payload mass and power demands. Pointing errors!
- Multi-pixel (focal plane array) sensors can provide 'instant' imaging benefit, certainly for passive and potentially active.
  - *Reduces scanning and increase overall observational efficiency.*
  - *Can perform tomographic imaging.*
    - *Need grater system integration to allow large pixel densities, i.e. >>1.*
    - *Enhanced component/sub-system technology to reduce mass and power.*
    - *Consideration of system calibration methods.*



- Also benefits future small sat. constellations via tightly integrated, lower mass and power consuming systems.

RAL Space

Spectroscopic Imaging

- For high spectral resolution sampling ($\mathrm{R} = \frac{\lambda}{\Delta\lambda} \gg 10^4$) heterodyne down-conversion is a well proven approach.
- Typical spectral resolution is 1 MHz for atmos limb sounding.
- Improving spectral precision has direct science and operational benefit:
  - Upper atmosphere studies, e.g. MLS (LOCUS) where lines are narrow.
  - Numerical weather prediction for weather forecasting (MetOP-TG?).
- Requires receiver front-end sensitivity and spectrometer efficiency enhancement (radiometer equation).
- Simultaneous spatial and spectral sampling allows mm-wave hyperspectral imaging.

Access to Missions

Technology Penetration

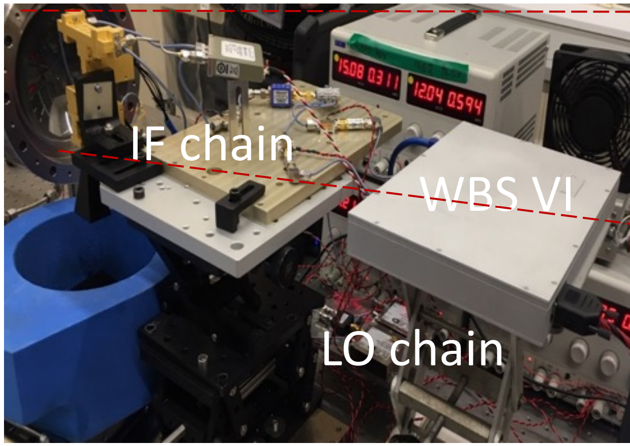
- Strong potential for UK space sector involvement in ESA, bilateral and other missions. E.g. imaging for:
  - Future constellation passive sounding for rapid weather monitoring (ESA and independent).
  - Small satellite scientific payload passive sounding for atmospheric studies (ESA, bilateral with USA).
  - Next generation operational satellites – future MetOp and others.
  - UK technical exploitation aboard active sounding missions, e.g. for ESA, China…
- Disruptive technology integration using new core components offers increase potential for small satellite/constellation satellite adoption.
- New digital processing technology providing ultra-wide bandwidth sampling with ultra-high spectral resolution.

Commercial Exploitation

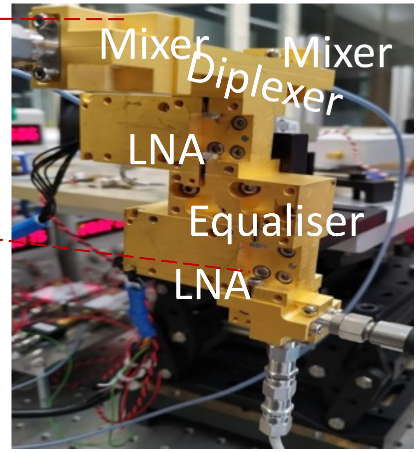
- Constellation satellites provide rapid weather commercial data stream of value to a broad user base. Provides new services to:
  - Aircraft, marine, agriculture, disaster prevention, insurance sectors.
- Improved weather accuracy via larger more precise (MetOp like) satellites provide direct societal benefit and commercial return.
- Component integration reduces payload volume, mass, power thereby reducing platform demands, launch costs for future satellite generations.
- Potential for deployment from future UKSA small sat. launch site(s).

Passive spectral: HyMS

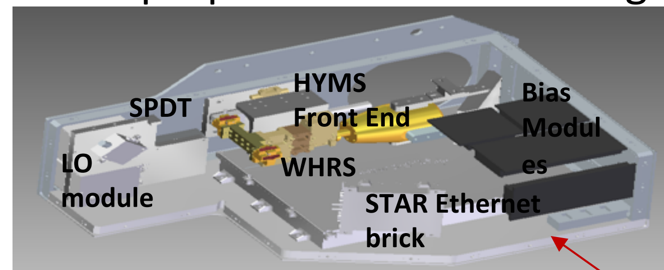
HYMS Full Rx Under Test



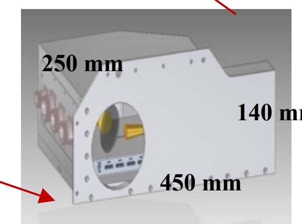
HYMS RF Front-End



HYMS proposed airborne testing



FAAM Aircraft

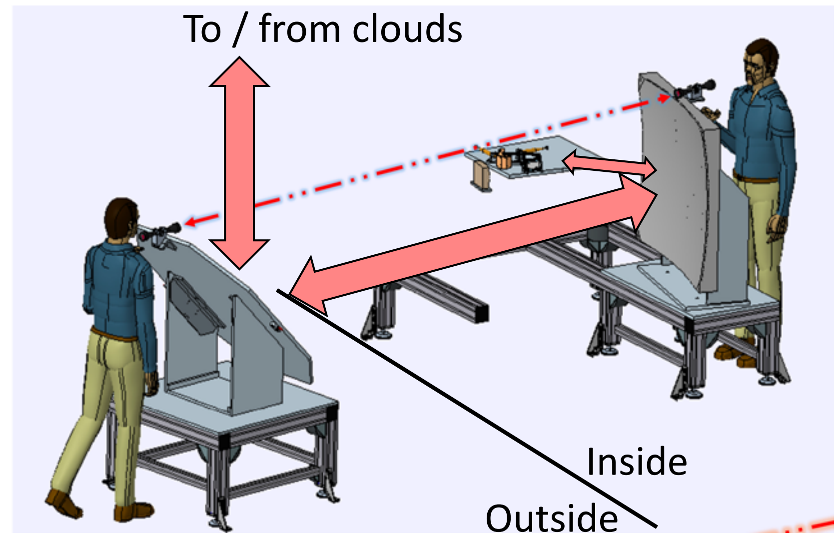


DEIMOS Pod

- High spectral resolution (i.e. low BW) incurs a noise penalty
  - Radiometer equation: $NE\Delta T = \frac{T_{sys}}{\sqrt{BW * \tau}}$
- Receiver sensitivity (i.e. T_{sys}) needs to compensate for this, or else precision is lost
- T_{sys} of HYMS radiometer is less than 190 K over the band 50 GHz - 68 GHz
- This performance equates to an NEΔT of ~0.25 K in a 10 MHz spectral bandwidth, 0.3 s integration time, which is state-of-the-art
- Project lead: Manju Henry (RAL Space MMT)

Active: GRaCE

- Ground based mm-wave radar demonstrator for ice cloud measurement and future space use.
- Monostatic, pulsed, Doppler, zenith view, system operating at 199.5GHz radar and with 100mW output.
- Development supported via the CEOI-11th Call.
- Uses RAL GaAs Schottky devices and TK EarthCARE quasi-optics heritage.
- Deploy at Chilbolton and compare with existing (lower frequency) radars.
- Project Lead P. Huggard (RAL Space MMT), science A. Battaglia (Leicester), radar engineering support D. Robertson (St Andrews), optics via Thomas Keating Ltd.

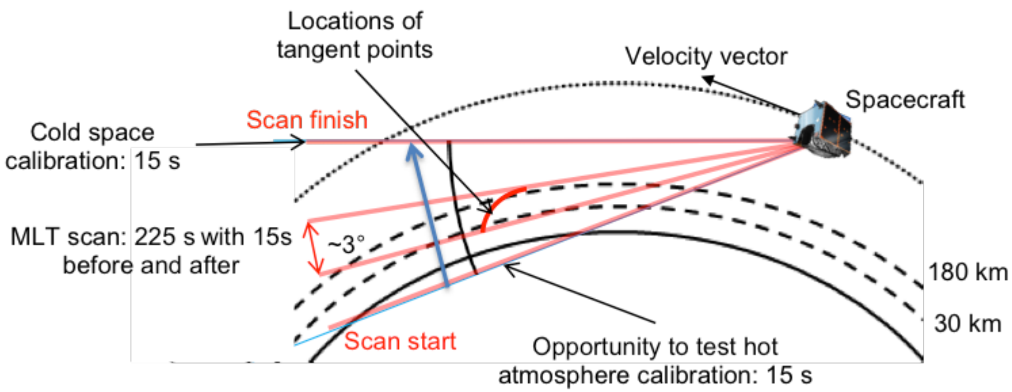


GRaCE Active Sensor System Concept

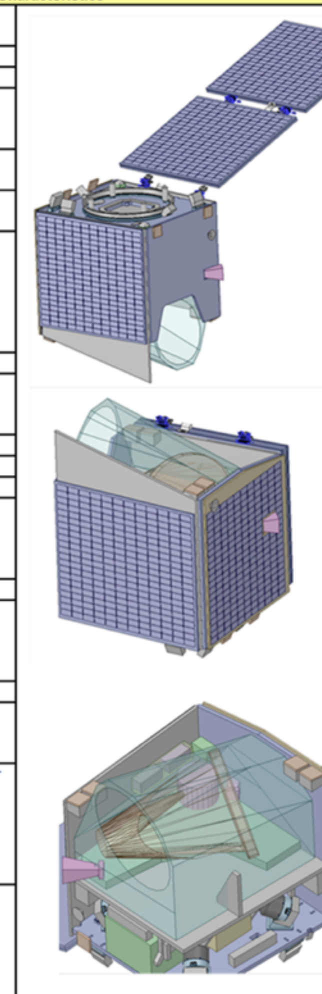
Passive: THz LOCUS

- Scanning LEO THz sounder targeting key MLT species
- Multi-THz Schottky diode heterodyne receivers.
- High spectral resolution, better than 3 MHz.
- QCL LO for band 1 and 2.
- Compatible with small satellite platforms.
- Support by CEOI previous calls.
- Project lead: Daniel Gerber (RAL Space MMT)

Designation	Band Centre	Primary Species	Secondary Species
Band 1	4.7 THz	O	O_3
Band 2	3.5 THz	OH	CO, HO_2
Band 3	1.1 THz	NO, CO	H_2O, O_3
Band 4	0.8 THz	O_2	O_3



Platform and Payload Characteristics		
	Dry mass	262.3 kg
	Propellant mass	12 kg
	3-axis stabilised	
	Interface	2 x AIM
	Sensors	2 x Star Tracker 3 x Sun Sensor 2 x GPS reciever
	Actuators	4 x Reaction wheels 3 x Magnetorquers
	Propulsion	1 x µQCT 1 x Xenon tank
	Solar Arrays	Solar Cells: 27.5% 3J GaAs 2 x Body mounted panels 2 x Deployed panels 4 x Hinge 2 x HDRM OAP: 194W
	Battery	1 x 15Ah Li-Ion
	Conditioning	2 x BCM 1 x PDM 28V unregulated bus
	OBC	2 x OBC386
	Data Storage	2 x HSDR
	Interface	2 x PIU
cations	S-band	2 x High Rate Tx (4 Mbps) 2 x Low rate Tx/Rx (19/38 kbps) 8 x Patch Antenna 2 x Monopole Antenna
	MLI,heaters, thermistors, FSM, SSM, tapes etc.	
	Aluminium honeycomb panels Microtray stack Support struts 610mm launch adapter ring	
	Mounting	Optical Bench
	Antenna	Primary mirror Secondary mirror Calibration flip mirror
	Radiometer	2 x Integrated QCL & diode mixer 2 x Conventional diode mixer 4 x IF stage 4 x Wide band spectrometers 1 x Reciever housing 4 x IR detectors
	Thermal	Hot radiator & heater Cold radiator 2 x Small cryo coolers MLI thermal tent MLT reciever tent ML cooler tent



Courtesy SSTL, ESA IOD Final Report, 2014

Summary

- Pushing the boundaries of spatial and spectral imaging technologies has clear scientific (and thus societal) benefits:
  - You can see some things that you couldn't see before (i.e. small surface structures)
  - You can measure some things better than before (i.e. humidity profiling instead of total columns)

Thanks for listening