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CEOI

Instrumentation for 1-5 THz Heterodyne Sounders

Brian Ellison
Millimetre-wave Technology and
Chilbolton Radio Propagation Group Leader

RAL Space

Presentation Outline

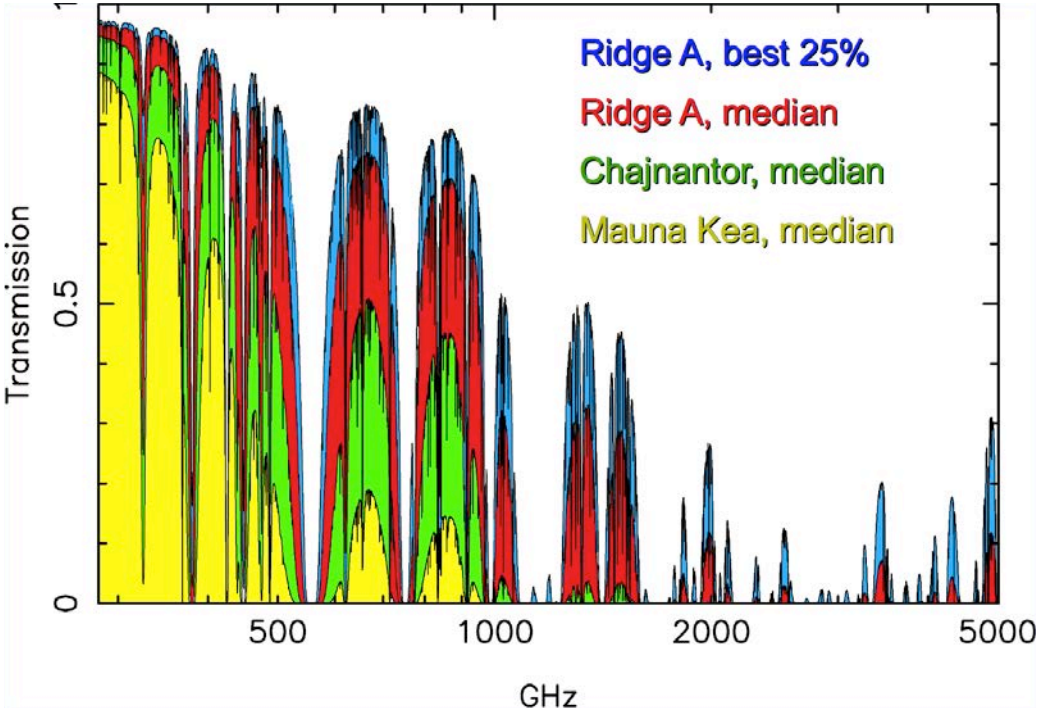
- Atmospheric Terahertz (THz) Sounding
  - *Why and from where?*
- The Heterodyne Technique
  - *Spectral resolution advantage*
- THz Instrumentation Advancement
  - *Primary components and system examples*
- Summary

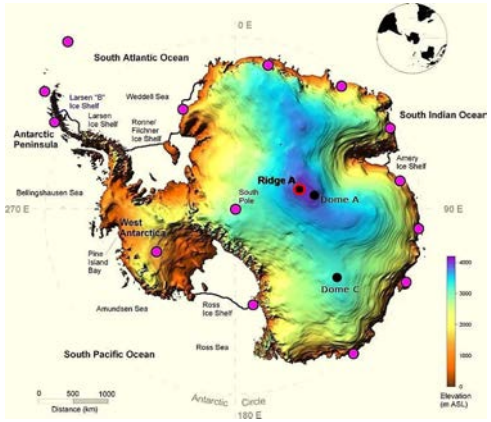
THz Atmospheric Remote Sounding

- Important atmospheric species (e.g. atomic oxygen, NO, OH and HO_2) have emission lines in the THz spectral range. (Here we assume the spectral range as ~1 to 5 THz.)
- THz spectral measurements provide knowledge of atmospheric composition - relates to climate change and weather effects (atmospheric and space).
- Increased atmospheric opacity, especially in the upper THz range and predominantly from water vapour, means that:
  - THz atmos. remote sounding restricted to very high & dry sites, high-altitude aircraft or satellite platforms.

THz Sounding from Ground Sites

- Water vapour dominated atmospheric opacity is disproportionally confined to the lowest atmospheric layers (mainly because of the temperature induced phase changes).

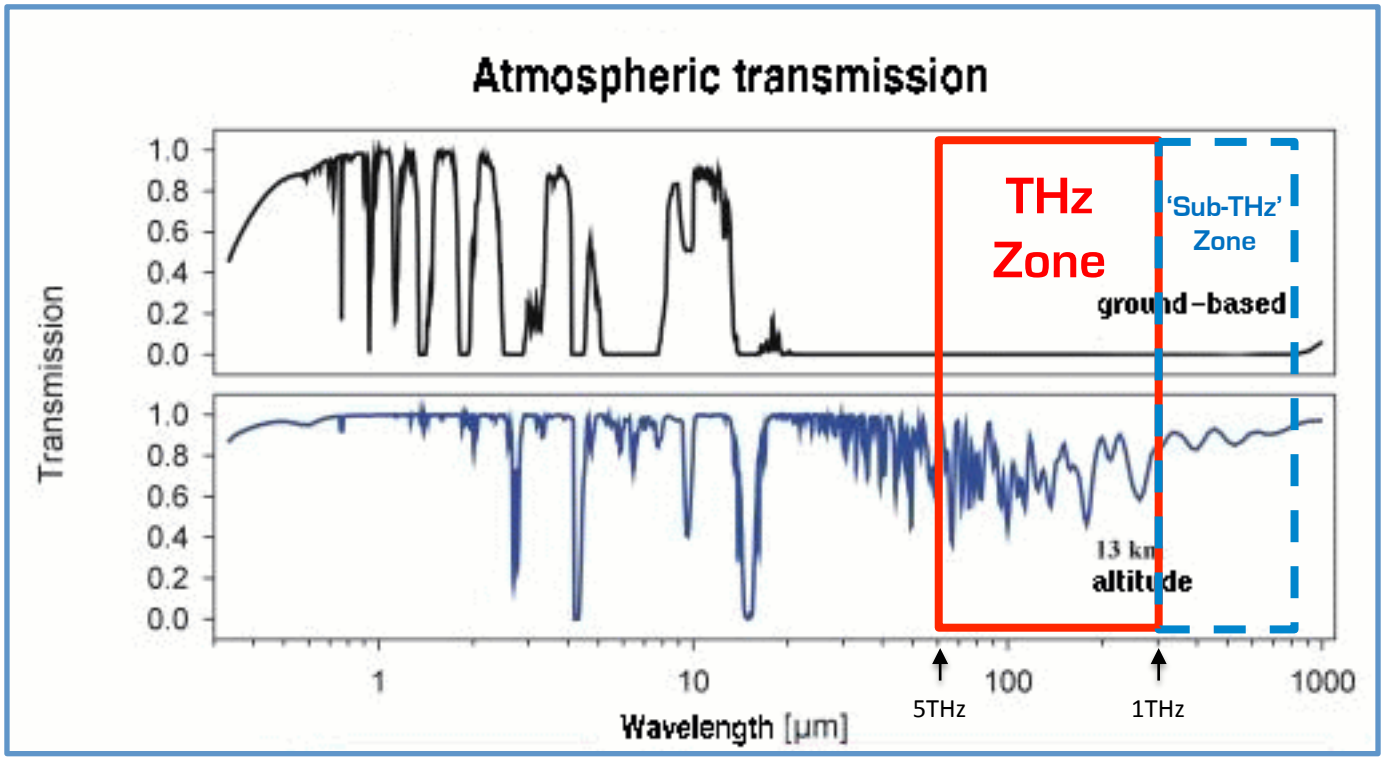




All images © Stewart Observatory, Arizona

Airborne Offers Potential

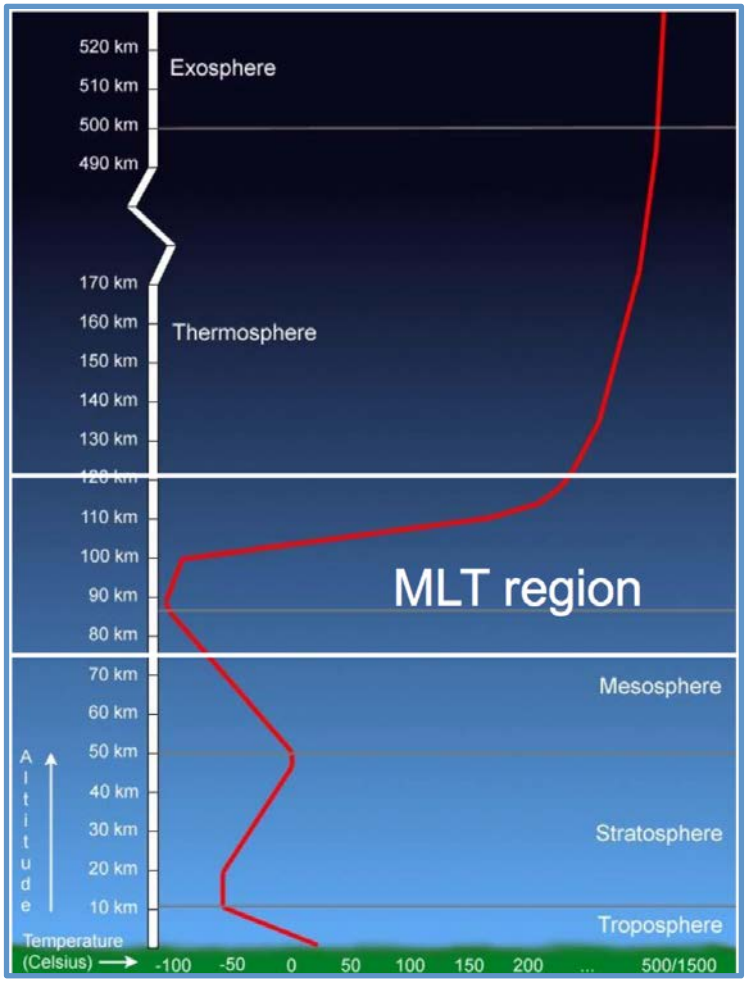
- Airborne THz remote sensing could be partially viable for specific applications (avoid water vapour lines and limb-viewing geometry).



© DRL (modified)

Satellite Platform Best for Upper Atmos.

- Mesosphere and lower thermosphere (MLT) important interface between atmosphere and space (space weather).
- Indicative of climate change through:
  - Increased cooling rates;
    Beig et al., JGR, 2011
  - Increase of mesospheric clouds.
    DeLand et al., JGR, 2015
- Least well known part of the atmosphere, because it is:
  - Too high for aircraft & balloons; too low for *in situ* sampling orbiters;
  - Key species (O, NO and OH) detectable at THz frequencies.
- Need a satellite observation platform for full <u>global</u> monitoring.



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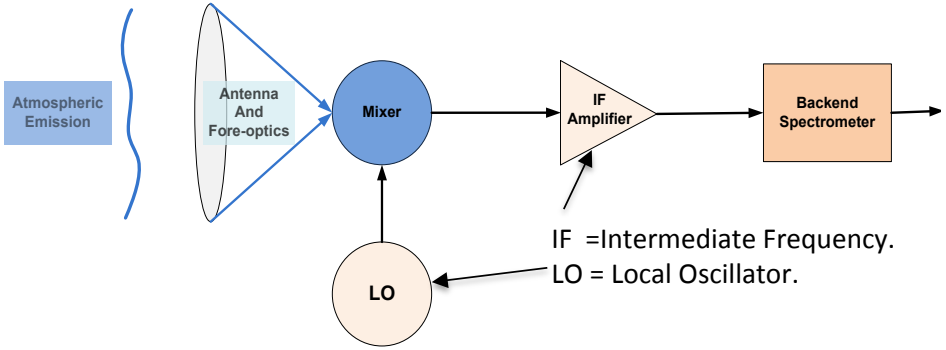
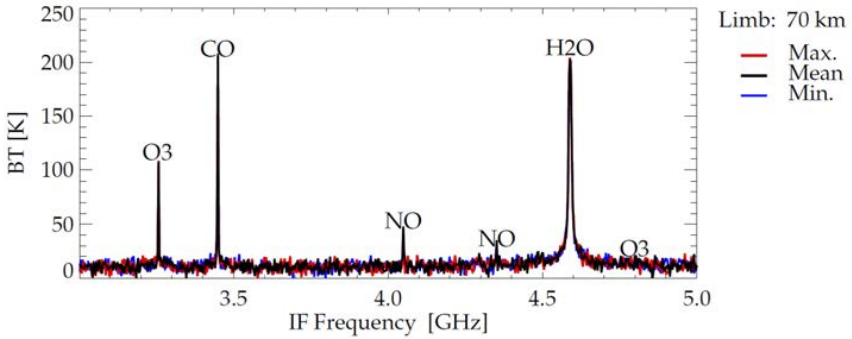
Heterodyne Technique and Advantage

THz Heterodyne Instrument

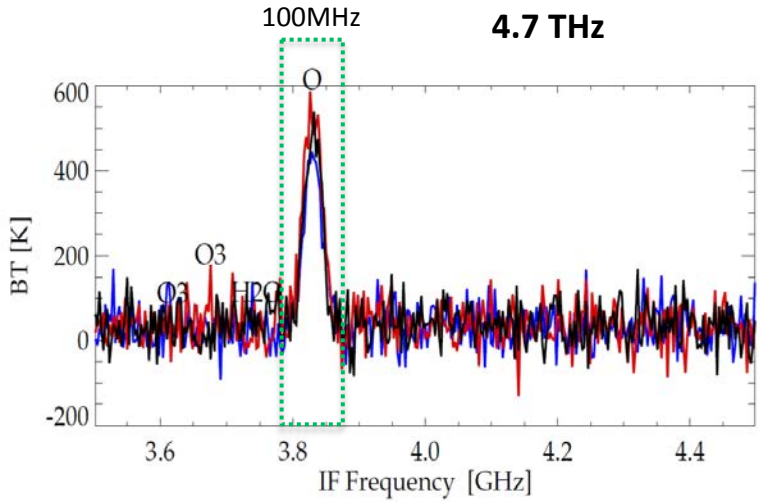
- Fundamentally, a high-frequency radio – THz in, low GHz (IF) out.
- Provides high-resolution spectroscopic capability (R>>10^4).
- Can provide spectral lineshape characterisation and height resolved retrieval of atmospheric species, particularly MLT.
- Spectral resolution is arbitrarily fine - limited by the local oscillator (LO) stability and IF signal processing capability.
- Near quantum limited (QL) system sensitivity feasible - better than 5xQL achieved at ~1 THz.

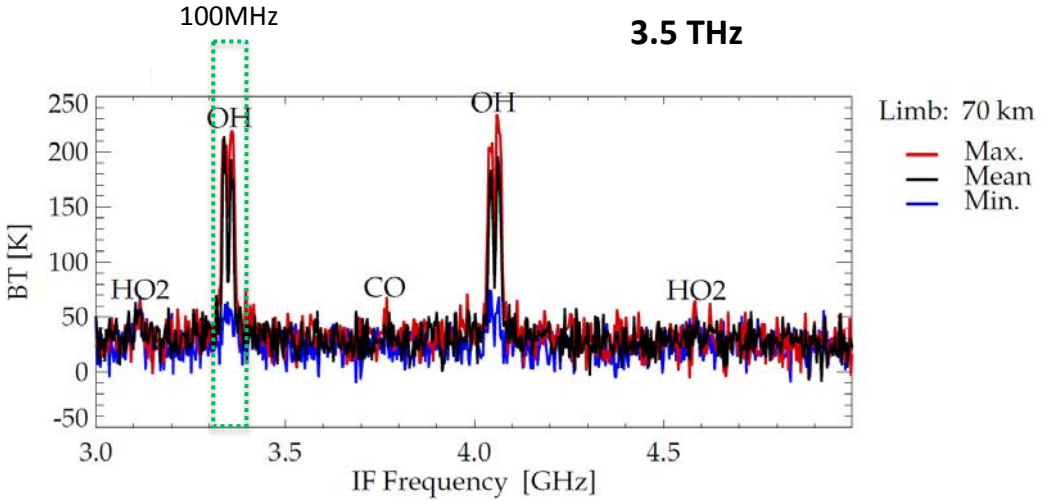


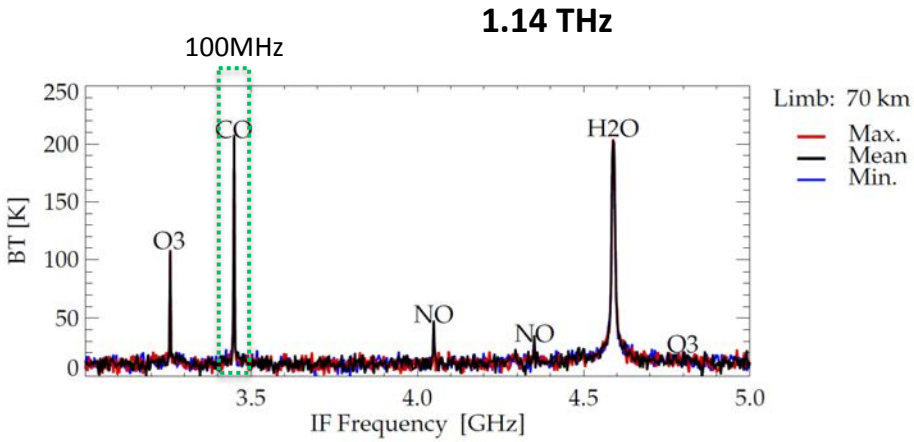


Spectral Simulation @ 1.14 THz

THz Limb Viewing Spectra Examples







- Simulated upper atmospheric (MLT) spectra − D. Gerber, RAL
- Shows corresponding example 1 to 5 THz spectral windows.
- Filter box indicates that << 100 MHz resolution required to characterise line profile.

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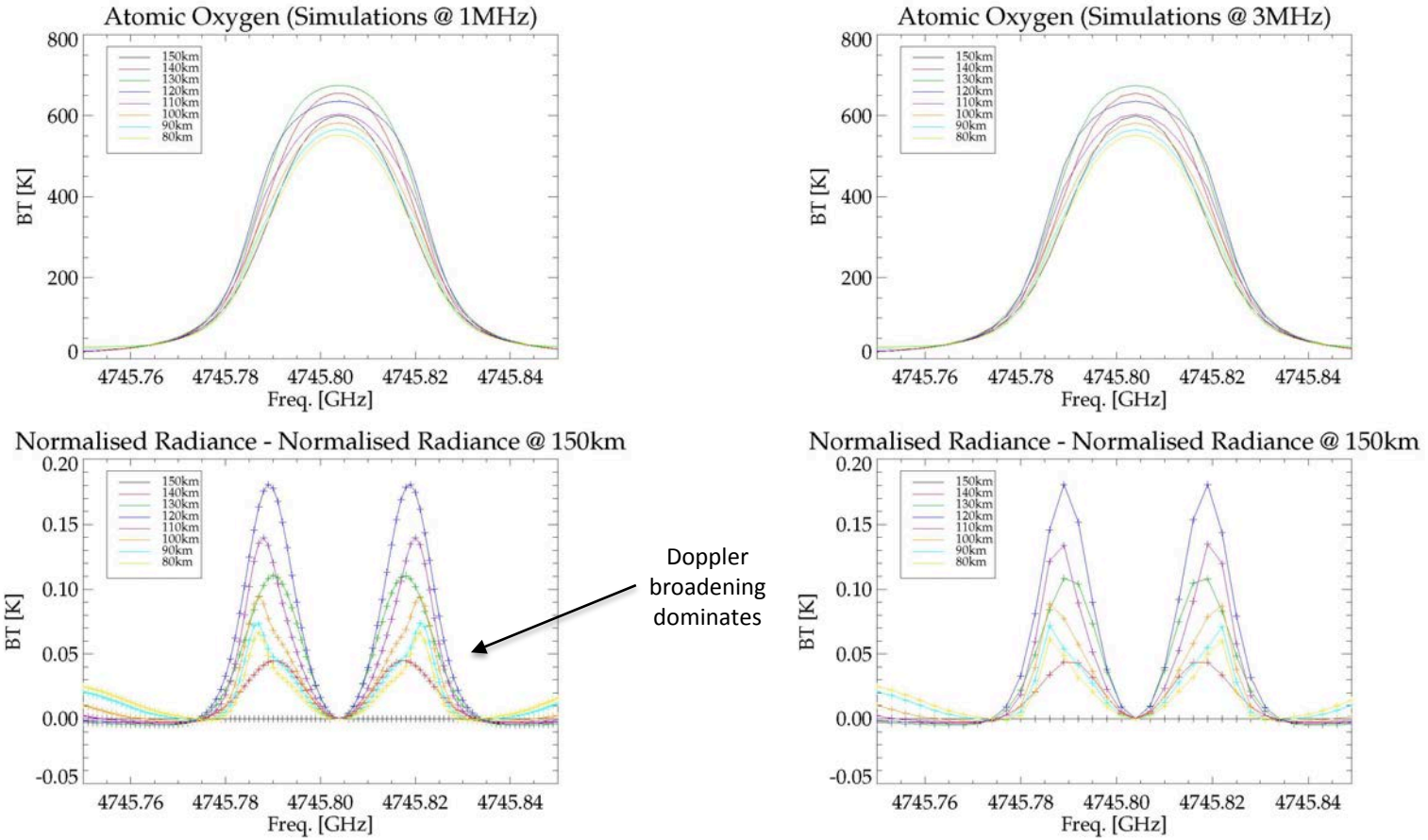
THz High Spectral Resolution

Simulated 4.7 THz atomic oxygen spectra & normalised radiance – D. Gerber, RAL



Instrument resolution influences line retrieval accuracy and therefore climate modelling.

Resolution = 1 MHz, very good; = 3 MHz, acceptable; >>3 MHz, unacceptable loss in precision.

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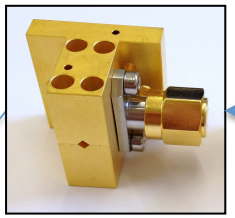
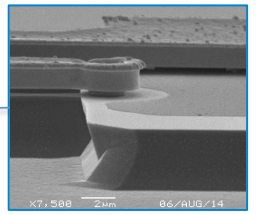
THz Heterodyne Instrumentation Advancement

THz Heterodyne System Anatomy

- Heterodyne process translates THz input signal to lower frequency.
- Critical component technology – mixer, LO and digital spectrometer.
- LO instrument driver – quantum cascade laser (QCL)/harmonic.

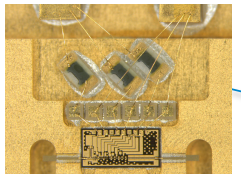


RAL 1.1THz Mixer



RAL 0.8 µM dia. diode

Atmos lines bright. ∴ semiconductor (Schottky) diodes can be used for mixer – cooled or uncooled.



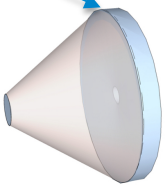
RAL packaged 0.2THz MMIC

Low noise amplifier. Reduces mixer sensitivity requirement Not available > 0.25THz.

Antenna <0.5m dia.

Emission Lines

THz Signal



LNA

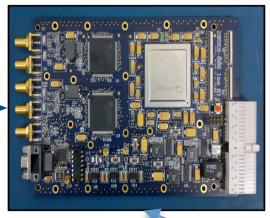
Mixer

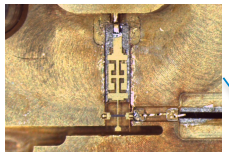
IF

LO

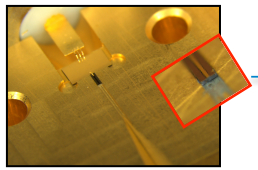
Receiver System

Digital Spectrometer





RAL harmonic multiplier



Leeds waveguide integrated QCL

Harmonic up-conversion or direct generation via a QCL.

Samples IF and produces signal power spectrum.

STAR Dundee Digital Spectrometer

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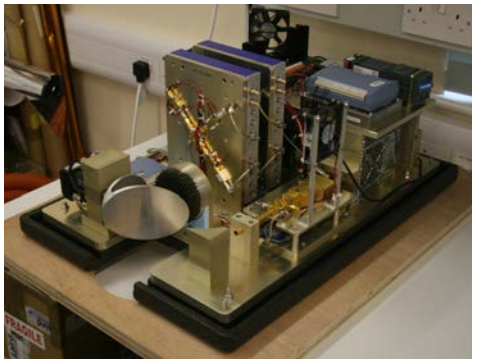
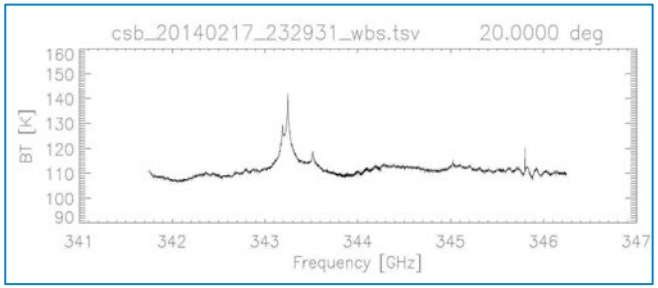
CEOI THz Heterodyne Evolution

Ground

0.35 THz Subharmonic Image Rejection Mixer (SHIRM) Receiver

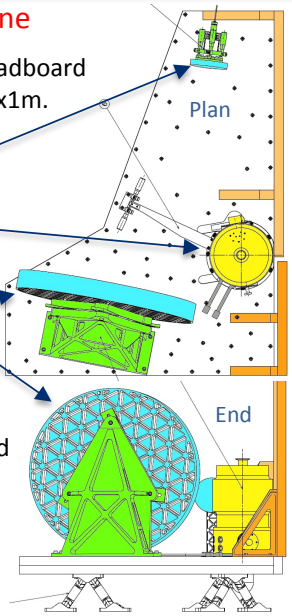




First-light atmospheric spectra of CO

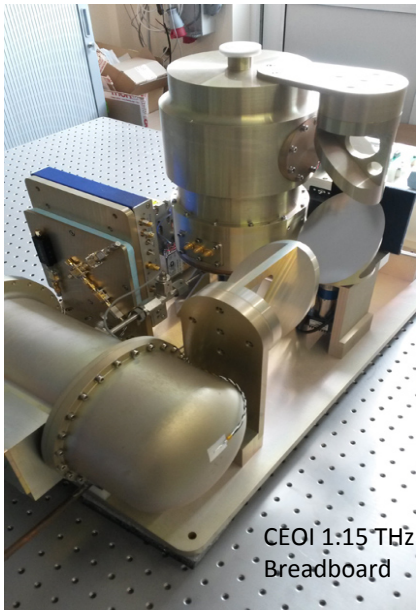
Spaceborne

CEOI THz Breadboard concept ~1mx1m.



Manufactured

Nearing test readiness



LOCUS Multi-THz System, with STAR Dundee spectrometer

Technology upgrade to MARCHALS/ISMAR airborne systems

Airborne

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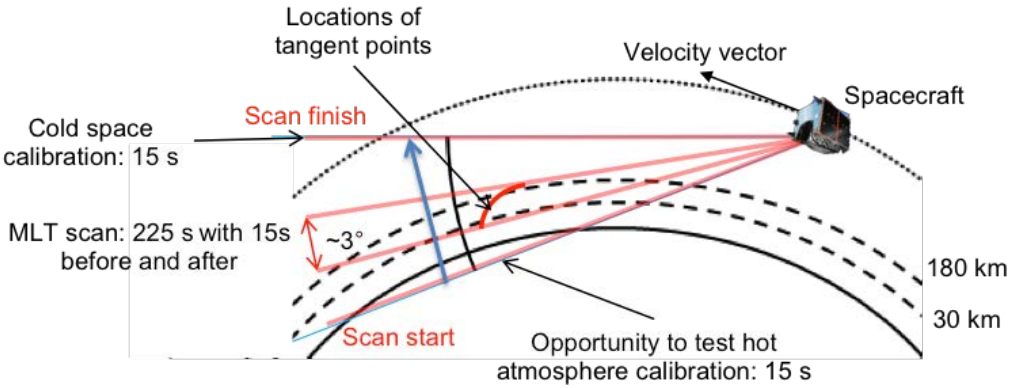
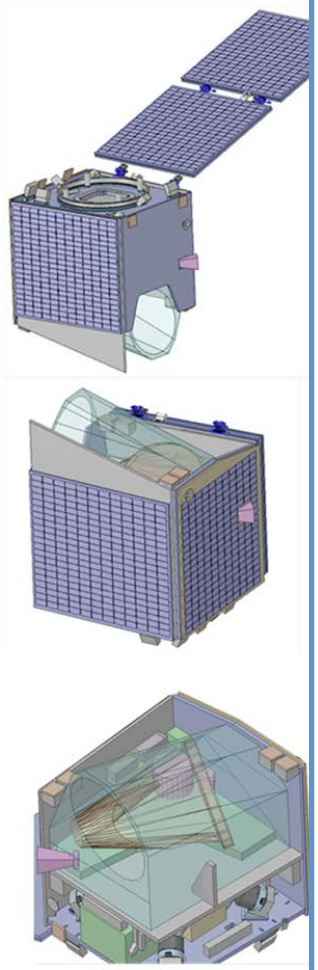
THz Satellite Concept - LOCUS

- 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 (see Alex Valavanis talk).
- Compatible with small satellite platforms.

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

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Summary

- THz sounding the atmosphere, particularly the MLT, provides key indicators of global climate change.
- THz observations affected by water vapour - need high-dry, airborne or ideally spaceborne platform.
- Heterodyne detection provides ultra-high-res. spectroscopy capability needed for spectral line shape characterisation.
- Semi-conductor mixers need not be cooled to 4K – considerable advantage for air and space flight.
- Local oscillator technology is a key instrument driver – QCLs >≃ 2 THz.
- High-speed digital sampling allows high-resolution spectral analysis.
- Future MLT THz mission (LOCUS) being developed with CEOI support.
- Thanks to Daniel Gerber for presentation contribution.

Thanks to you for listening

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