Laser Heterodyne Radiometry for EO Applications (Atmosphere)

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RAL Space

Science & Technology Facilities Council
Rutherford Appleton Laboratory

What is a Laser Heterodyne Radiometer ?
LHR

- A PASSIVE thermal infrared sounder
  - Even though there is a laser in it

- A SPECTRO-radiometer
  - Observes the unique spectral signatures of chemicals in the atmosphere

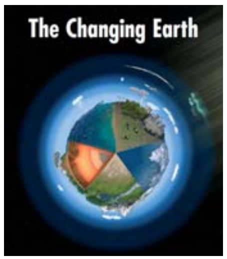
- A new remote sounding technology enabled by advances in semiconductor mid IR lasers
  - Never deployed in space so far

Outline

- Scientific motivation
- Principles of LHR
- Quantum cascade lasers
- Ground based demonstration
  - Ozone
  - Frequency agile LHR
- Miniaturization for deployment
- Outlook on applications
- Conclusion

Scientific Drivers

Implications on the next generation of EO instruments

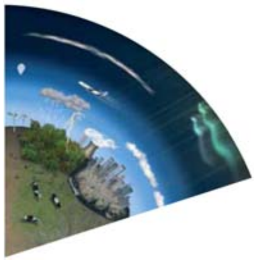


The Challenges of the Atmosphere

Challenge 1: Understand and quantify the natural variability and the human-induced changes in the Earth's climate system.

Challenge 2: Understand, model and forecast atmospheric composition and air quality on adequate temporal and spatial scales, using ground-based and satellite data.

Challenge 4: Observe, monitor and understand the chemistry-dynamics coupling of the stratospheric and upper tropospheric circulations, and the apparent changes in these circulations.



National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

Centre for eo Instrumentation

- Finer geographical coverage
  - Local/regional sampling (Air quality – Emission Monitoring)
  - Global coverage at a finer scale (Climate - Feedback)
- Higher vertical resolution
  - Nadir profiling $\Rightarrow$ Improved SNR, improved spectral resolution
  - Limb sounding $\Rightarrow$ Reduced FoV while keeping the SNR (UT/LS)
- Improve sensitivity
  - Further trace species like PAN, VOCs, …
- Compact, light
  - Low cost, micro-satellites, piggybacking

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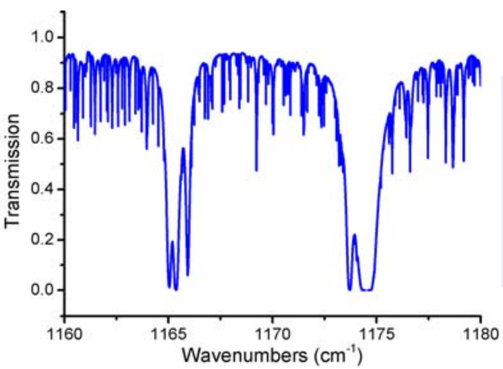
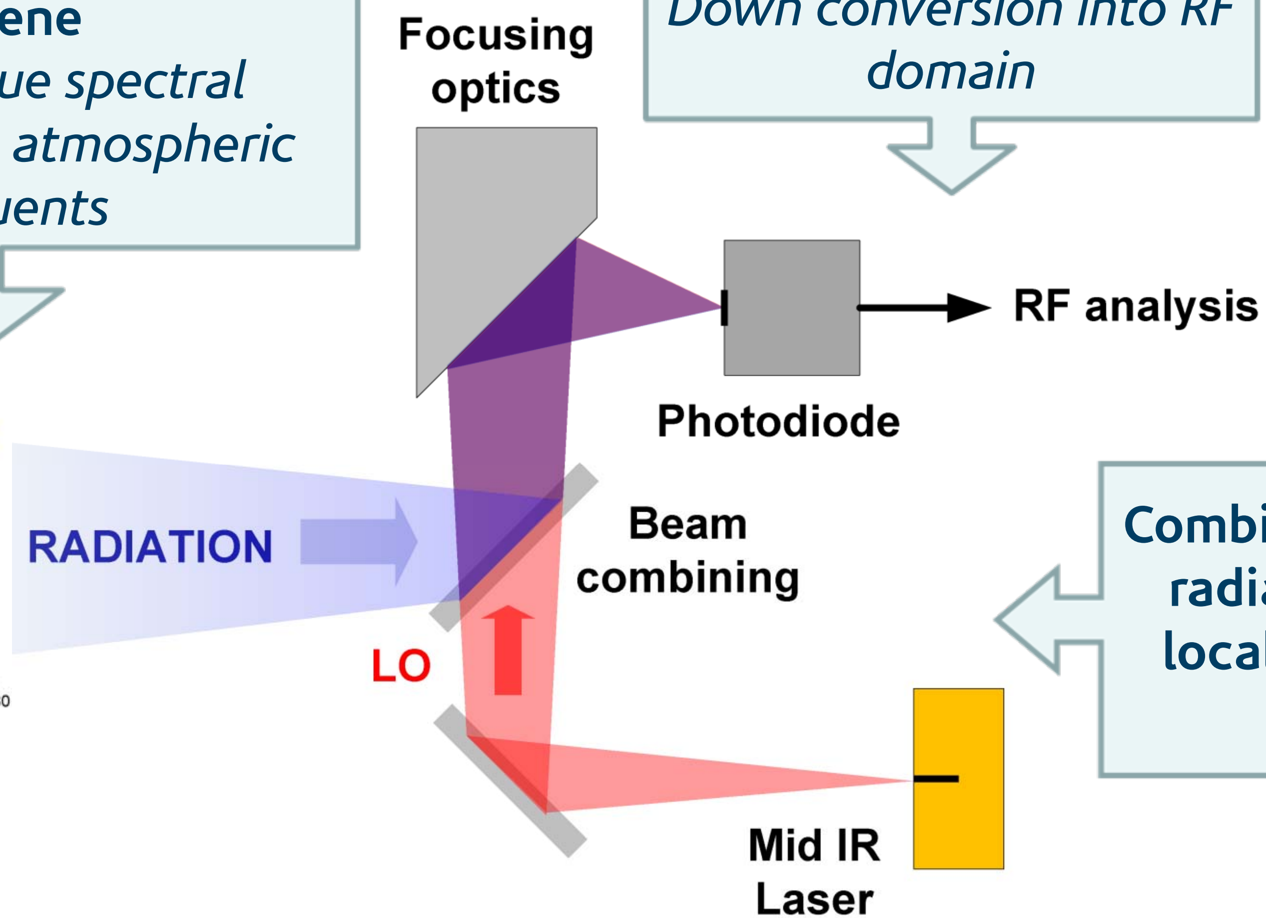
Principles of the LHR

Collects thermal radiation from the scene
contains unique spectral signatures from atmospheric constituents



Non linear mixing
Down conversion into RF domain



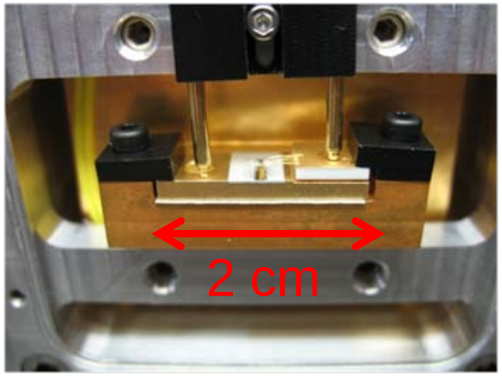
Combines thermal radiation with local oscillator
Laser

Advantages of LHR for EO

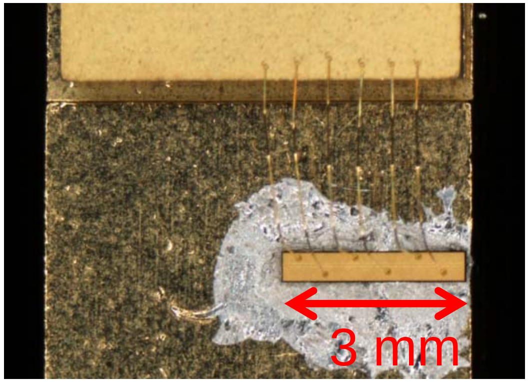
Merits	Figures	Remote sounding benefits
High sensitivity Shot noise limited	**NEP = 4.10^{-16} W** (λ=10µm - τ=1s) **NESR = 120 nW/cm^{-2}.sr.cm^{-1}**	**Detection of ultra-low concentration traces** **High accuracy**
High spectral resolution Set by electronic filters	**Resolving power > 10^6** Resolution down to **~10 MHz** Highest in the thermal IR	**Full lineshape resolution** **Deconvolution of altitudinal information** **Interference discrimination** **Usage of spectral micro-windows**
High spatial resolution Coherent FoV	10 cm aperture gives **FoV = 0.13 mrad = 27 arcsec** $\Rightarrow$~50 m LEO , ~4km GEO	**Ultrafine geographical coverage** **Higher altitude resolution (limb)** **Less cloud interferences** **Localized emission before dispersion** **Local sampling from GEO**
Electrical definition of **Instrument Lineshape**	**Directly measureable** to a high level of accuracy	**No ILS artefact** **ILS stability with sounding configuration**

Quantum Cascade Laser

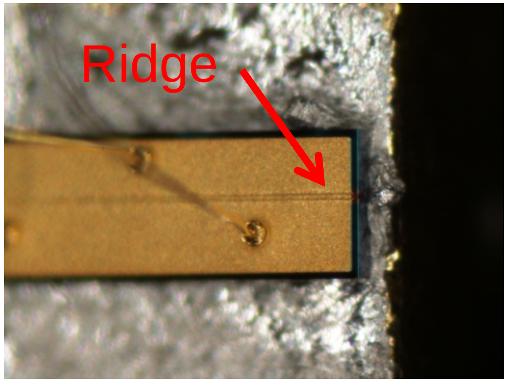
Enabling technology for LHR



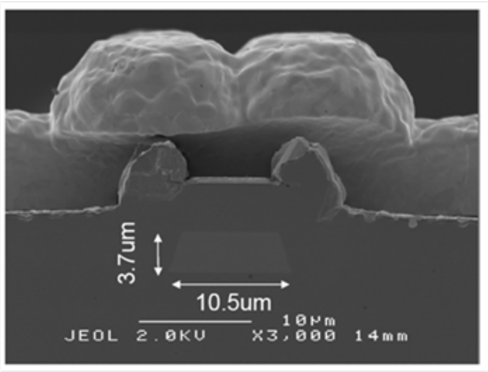
Laser in module



Laser chip on submount



Front facet & laser ridge



Output facet

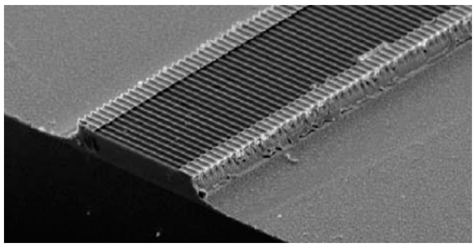
QCL advantages…	… Providing
Frequency tailoring	Optimum target frequency
Power	No detector noise
Single mode	High spectral selectivity
Beam Quality	Efficient long pass coupling
Fast modulation	Real time sensing

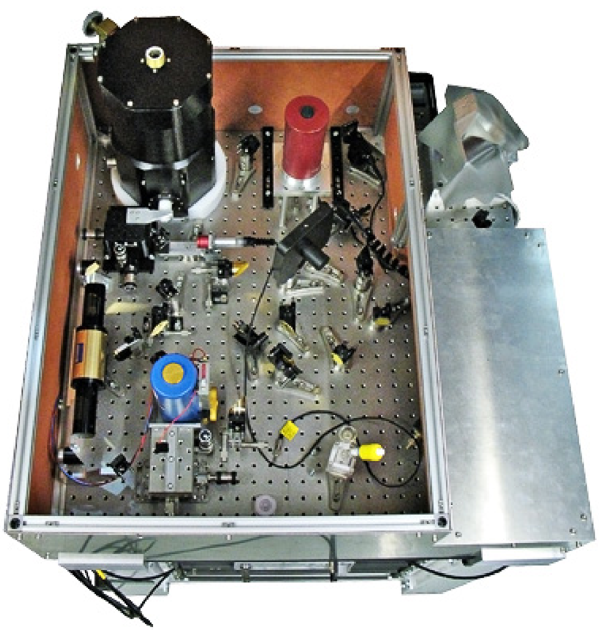
QCL advantages…	… Providing
Room temperature	No Consumables
Compact & Robust	Field deployable
Tunability	Wide spectral coverage
Long wavelengths	FIR and THz applications

First Ground-based Prototype

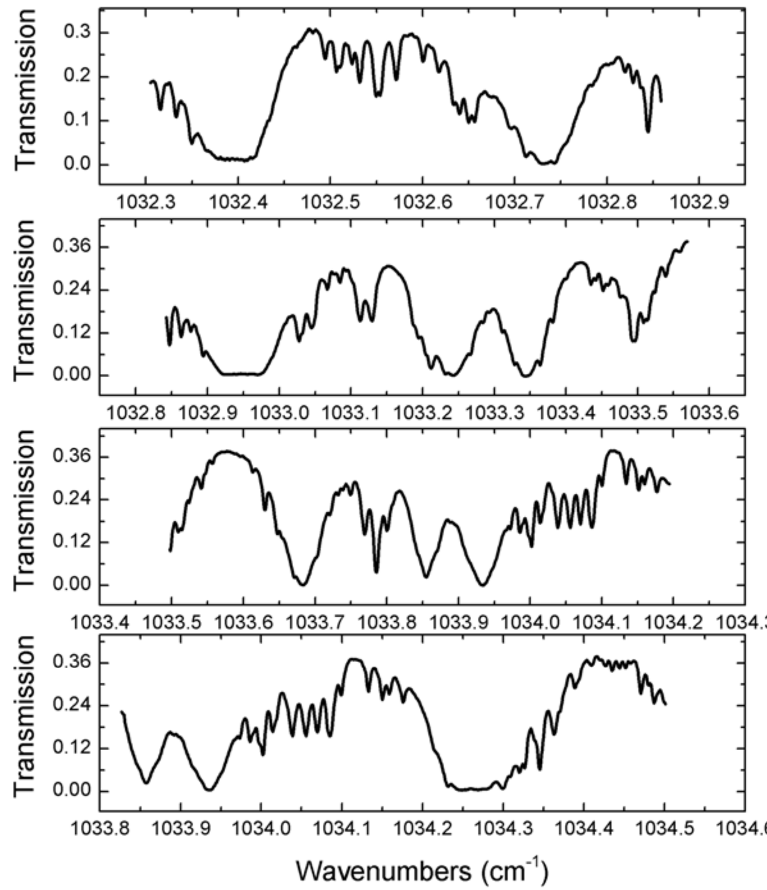
9.7 µm micro-window – O_3 profiling

Instrument using DFB laser

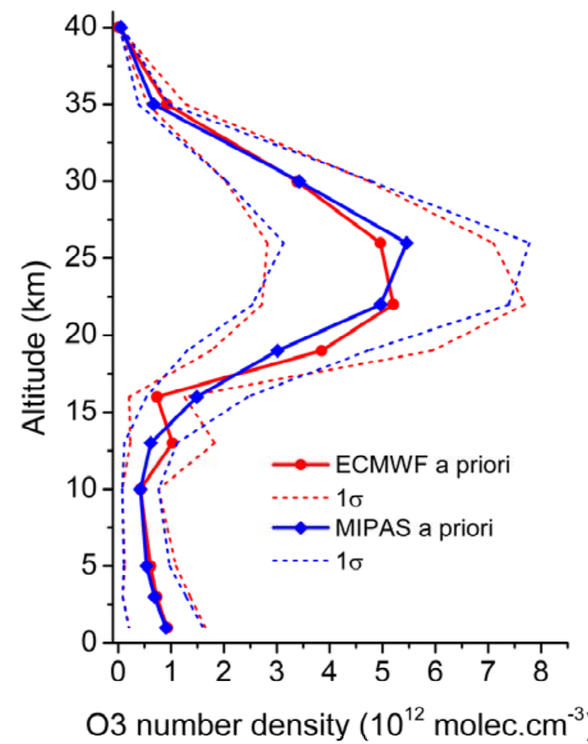




Atmospheric transmission
Solar Occultation
Resolution 200 MHz



Retrieval O3 profile
Up to 40 km
2 to 5 km vertical resolution



Frequency-Agile LHR

Covering >100 cm^{-1} – Observation of 5 atmospheric species

January 2011

High Spectral resolution
60 MHz (0.002 cm^{-1})

Narrow field of view
1/40 solar disk

Range 1120-1230 cm-1
(8-9 µm)

PRINCETON UNIVERSITY

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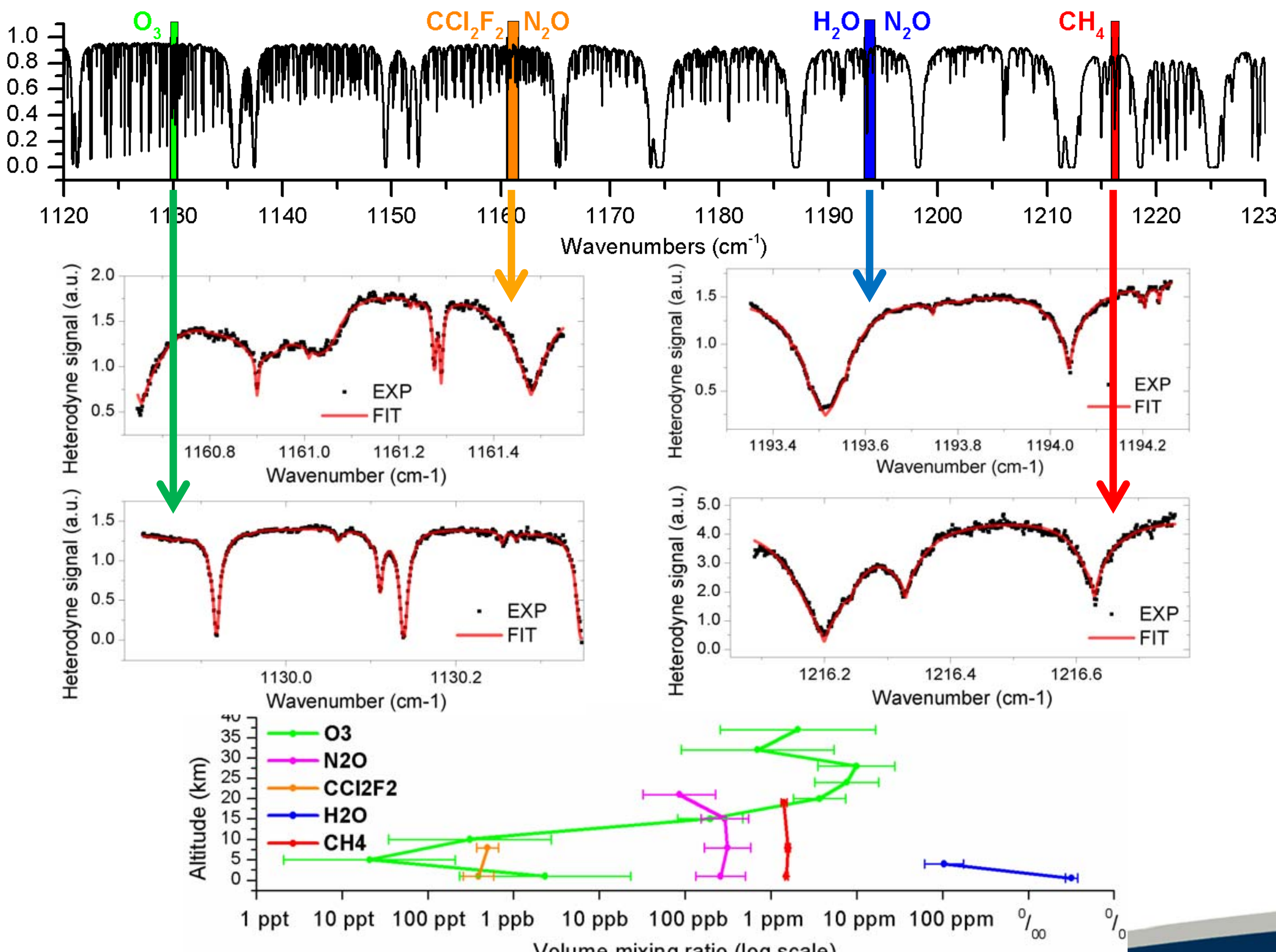
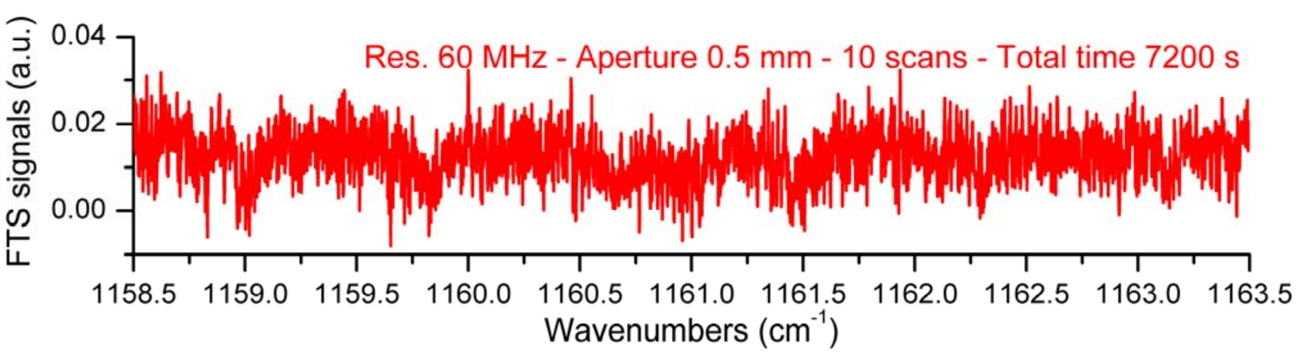


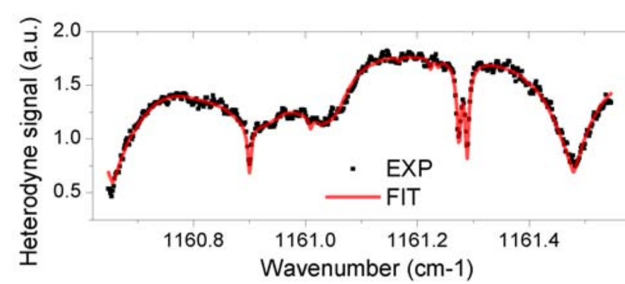
FTIR / LHR Side by Side Comparison

Identical resolution 60 MHz and field of view

Bruker IFS 125HR - 4m x 2m

Bench top LHR - $1m^2$ – 1min acquisition





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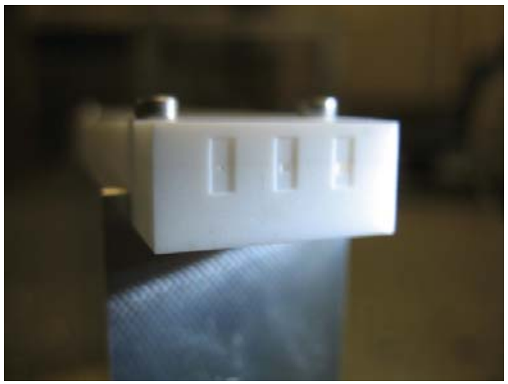
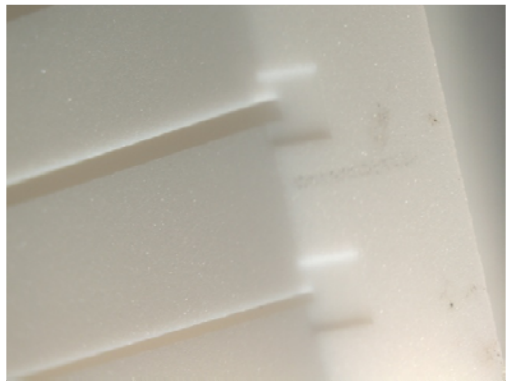
Miniaturization / Ruggedization
Easing deployment through Hollow Waveguide integration

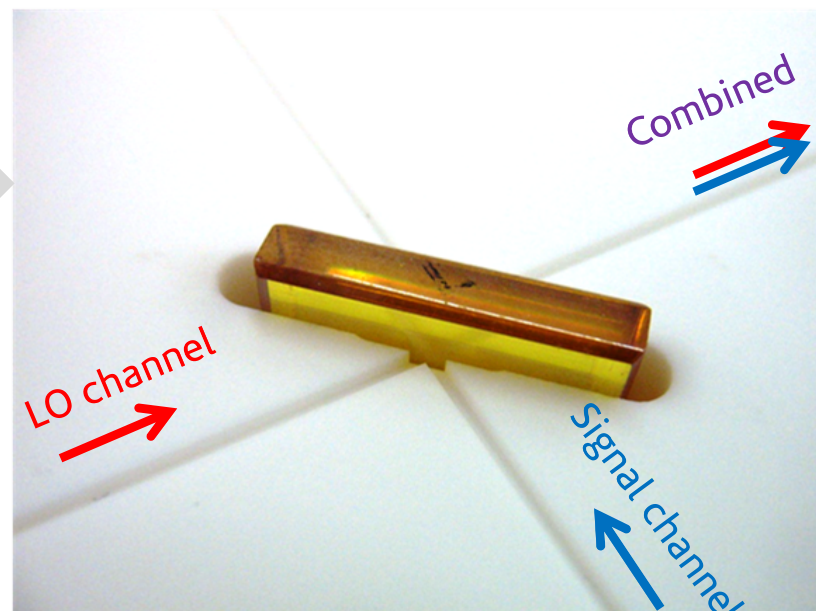
Hollow waveguides in ceramic





- Fully integrated optical systems
- Compact – Robust – Lightweight
- Low cost
- Relaxed alignment constraints
- Requires machining with 1 µm tol.

Example of heterodyne mixing module integrated in Hollow Waveguide



HIGHER STABILITY

BETTER HETERODYNE EFFICIENCY

QinetiQ

HOLLOWGUIDE LTD

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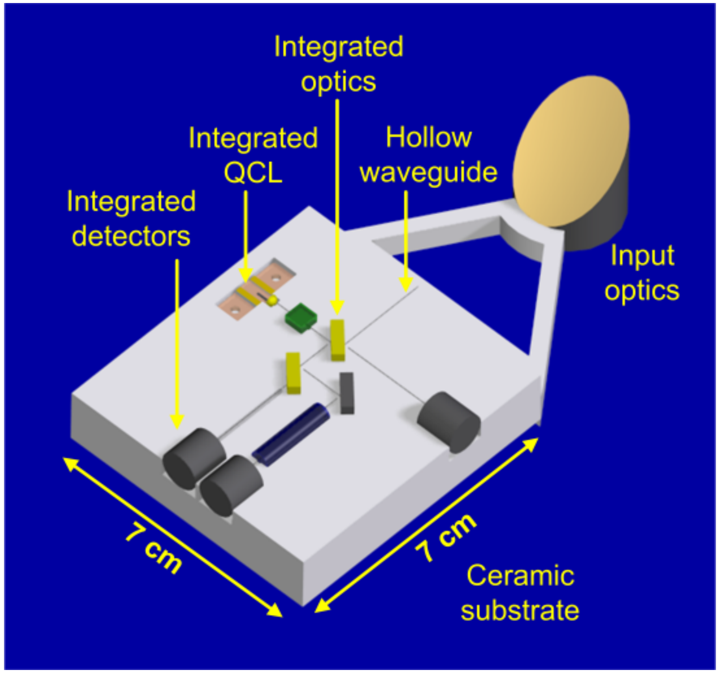
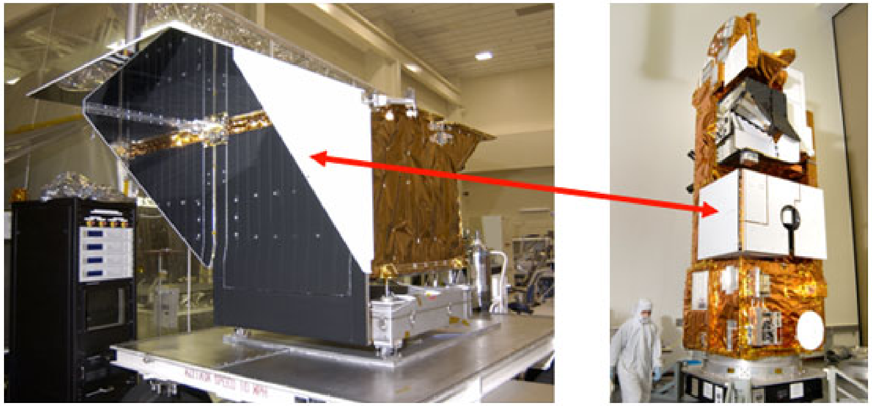
Concept of Fully Integrated LHR

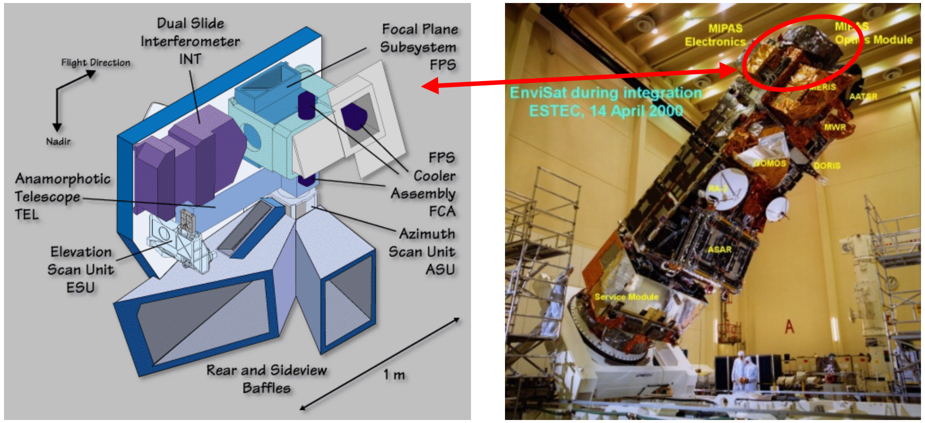
Shoe box size with unprecedented specifications



NASA TES on AURA



ESA MIPAS on ENVISAT

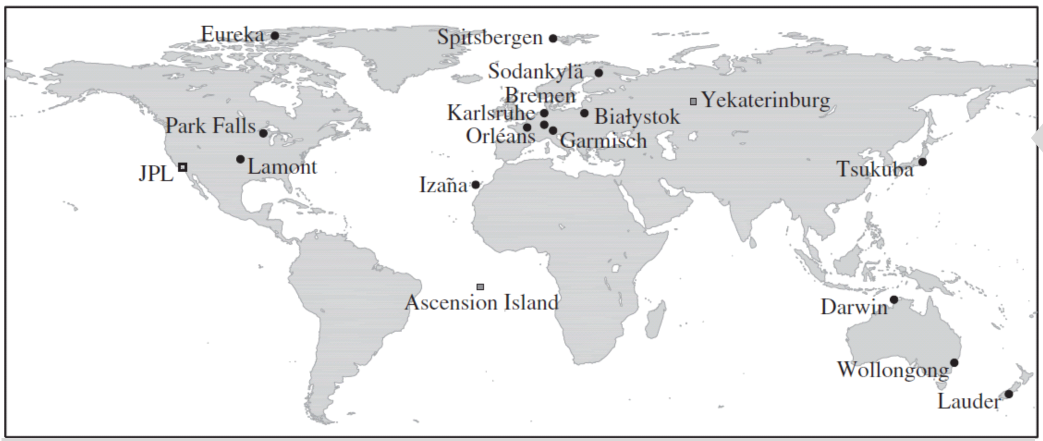


	Spatial (km)	Spectral (/cm)	Noise	Weight (kg)
MIPAS	3 x 30	0.035	100	330
TES	0.5 x 0.5	0.06	100	390
HW-LHR	0.2 x 0.2	< 0.01	200	20 ?

Prospect for Validation

LHR for ground-Based observation network

- Global satellite observations requires validation
  - against accurate ground–based networks
- Example of the Total Carbon Column Observing Network

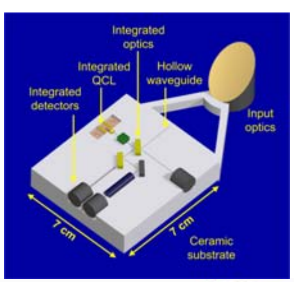


Wunch et al., Phil. Trans. R. Soc. A 2011 369, 2087-2112

TCCON MAP
18 sites worldwide

18 large and expensive instruments

Bruker HR125 FTS



- Case for miniature autonomous LHRs for ground validation
  - Excellent remote sounding performances
  - Low cost -> denser network for same budget
  - Lower operational and infrastructure cost

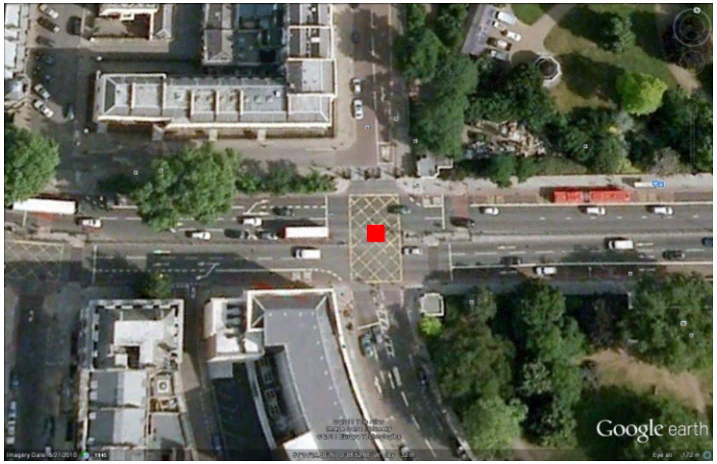
Prospect for Airborne Deployment

Aircrafts / UAVs / HAPs

- Unmanned Aerial Vehicles
  - E.g. NASA global Hawk
  - 20 km ceiling
- Miniature LHR deployment
  - Upper Troposphere / Lower stratosphere exchange
  - Water vapour, ozone
  - Ultra-high vertical resolution
  - High spectral resolution
- High Altitude Platforms
  - Stabilized platform
  - 25 km above cities
- Miniature LHR deployment
  - Street scale spatial resolution
  - Urban Pollutant monitoring
  - Urban chemical transport
  - Emission sources monitoring


NASA Global Hawk


Lockeed Martin HAP



Prospect for Space Deployment

1st step: in orbit demonstration

- In orbit demonstration required
  - To demonstrate the technology from a space platform
  - To built space heritage for future EO missions
- Small platforms currently available
  - CubeSat from Clyde Space
  - TechDemoSat 2
- Piggy backing ?

3U CubeSat
few kilos
few 10's W

TechDemoSat
150 kg
50 W

Conclusion

- LHR offers thermal IR sounding with
  - High sensitivity
  - High spectral resolution
  - High spatial resolution
  - Miniaturization

- This unique set of advantages makes it well suited to EO from
  - Ground based platforms
  - Airborne platforms
  - Space platform (micro-sat, GEO)

- Relevant to planetary applications as well

Acknowledgements

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