Centre for eo Instrumentation

NATURAL
ENVIRONMENT
RESEARCH COUNCIL

# A Fully Integrated, Miniaturised Quantum Cascade Laser Heterodyne Radiometer for EO

Damien Weidmann, Rebecca Rose, Mike Jenkins

HOLLOWGUIDE LTD

RAL Space

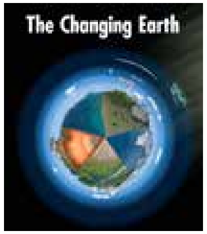
Science & Technology Facilities Council
Rutherford Appleton Laboratory

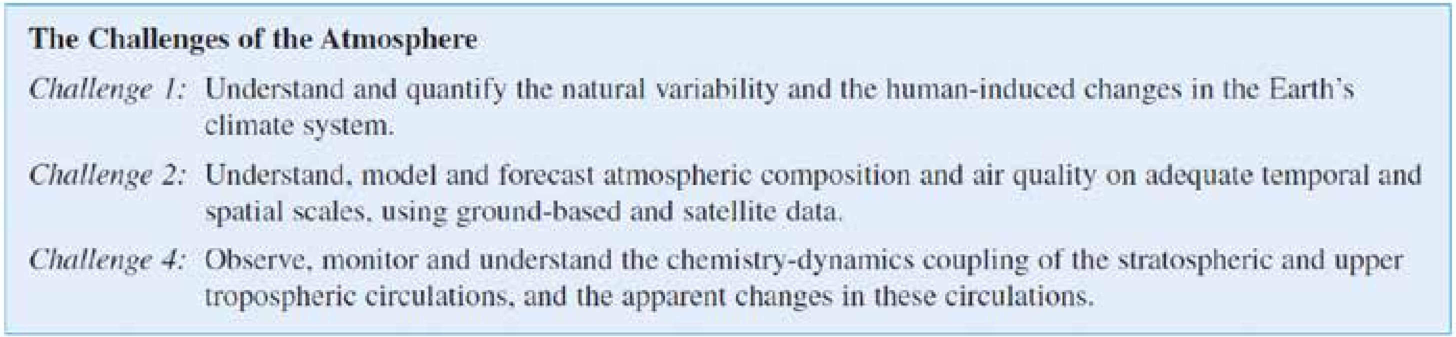
# Outline

- Ø Setting the scene
  - – Scientific motivation
  - – Principles and observational capabilities
- ØGround based demonstration
  - – Benchmarking against FTIR
- Ø Hollow waveguide integration
- Ø Prospects

# 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.

Ø Finer geographical coverage
  - Local/regional sampling (Air quality – Emission Monitoring)
  - Global coverage at a finer scale (Climate - Feedback)

Ø Higher vertical resolution
  - Nadir profiling Þ Improved SNR, improved spectral resolution
  - Limb sounding Þ Reduced FoV while keeping the SNR (UT/LS)

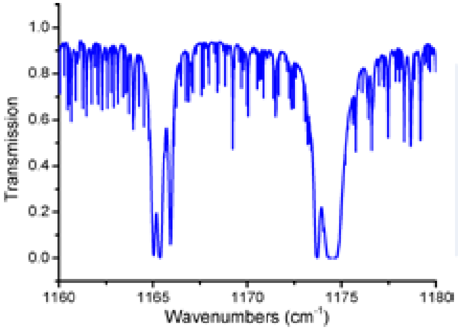
Ø Improve sensitivity
  - Further trace species like PAN, VOCs, …

ØCompact, light
  - Low cost, micro-satellites, piggybacking

# Principles of the LHR

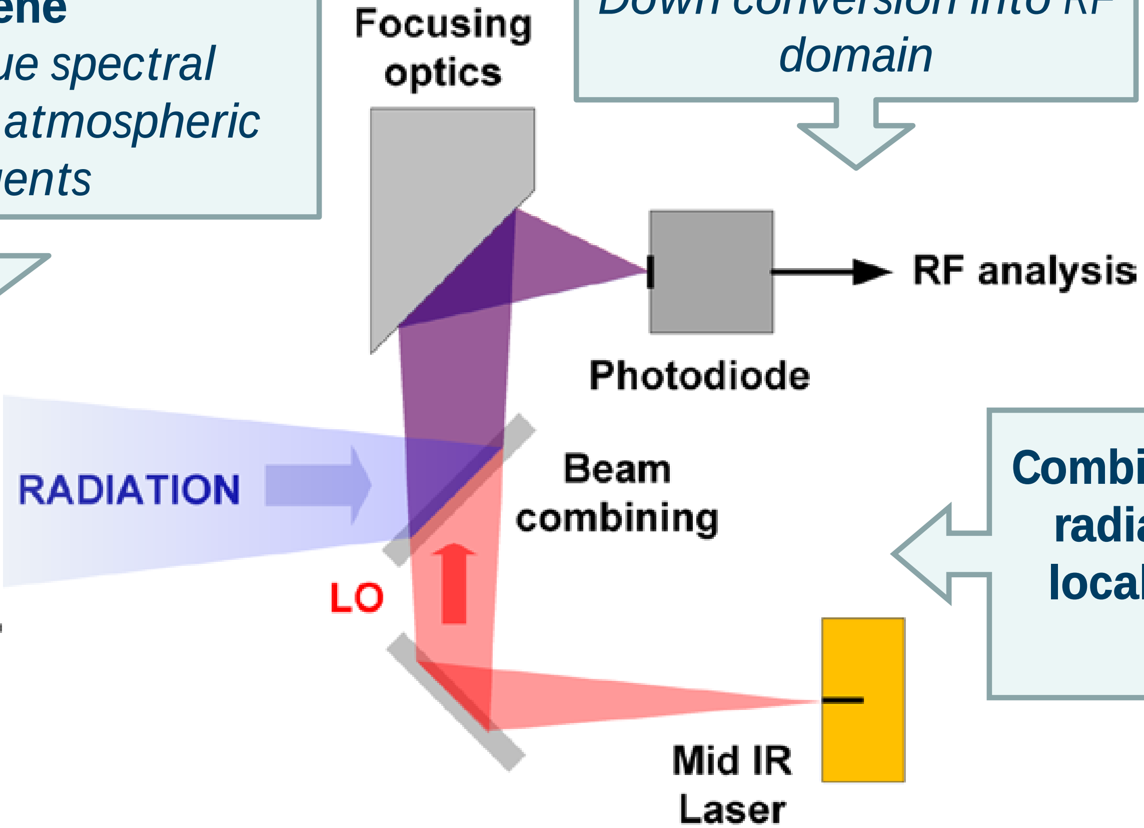
## Thermal infrared spectro-radiometry

**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

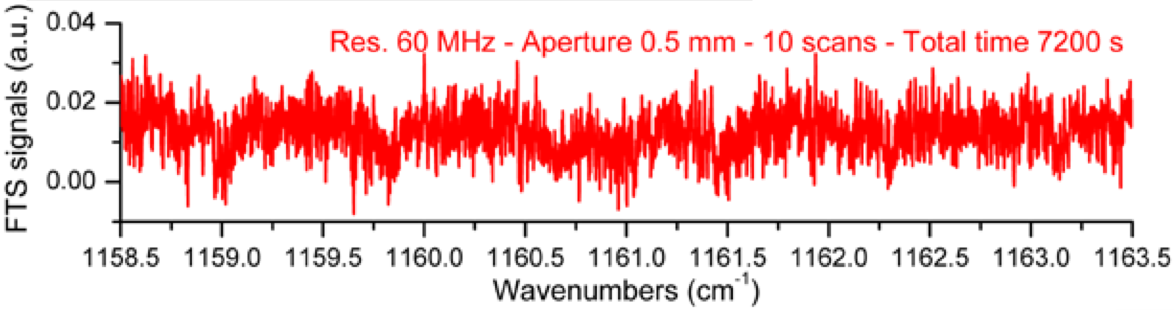
| Merits | Figures | Remote sounding benefits |
|---|---|---|
| **High sensitivity**<br>Shot noise limited | **NEP = $4.10^{-16}$ W**<br>(l =10µm - t =1s)<br>**NESR = 120 nW/$cm^{-2}$.sr.$cm^{-1}$** | **Detection of ultra-low concentration traces**<br>**High accuracy** |
| **High spectral resolution**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

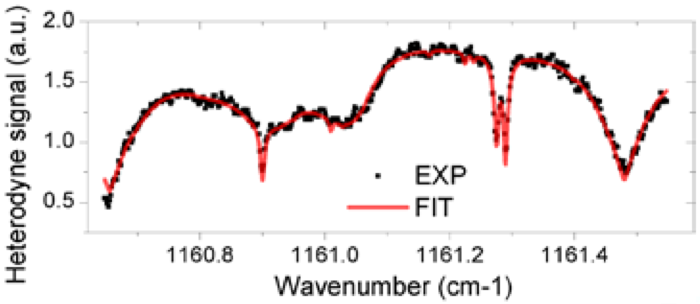
# FTIR / LHR Side by Side Comparison

## Identical resolution 60 MHz and field of view

**Bruker IFS 125HR - 4m x 2m**
**2 hours integration**

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





# Retrieved Profiles Comparison

## LHR vs FTS

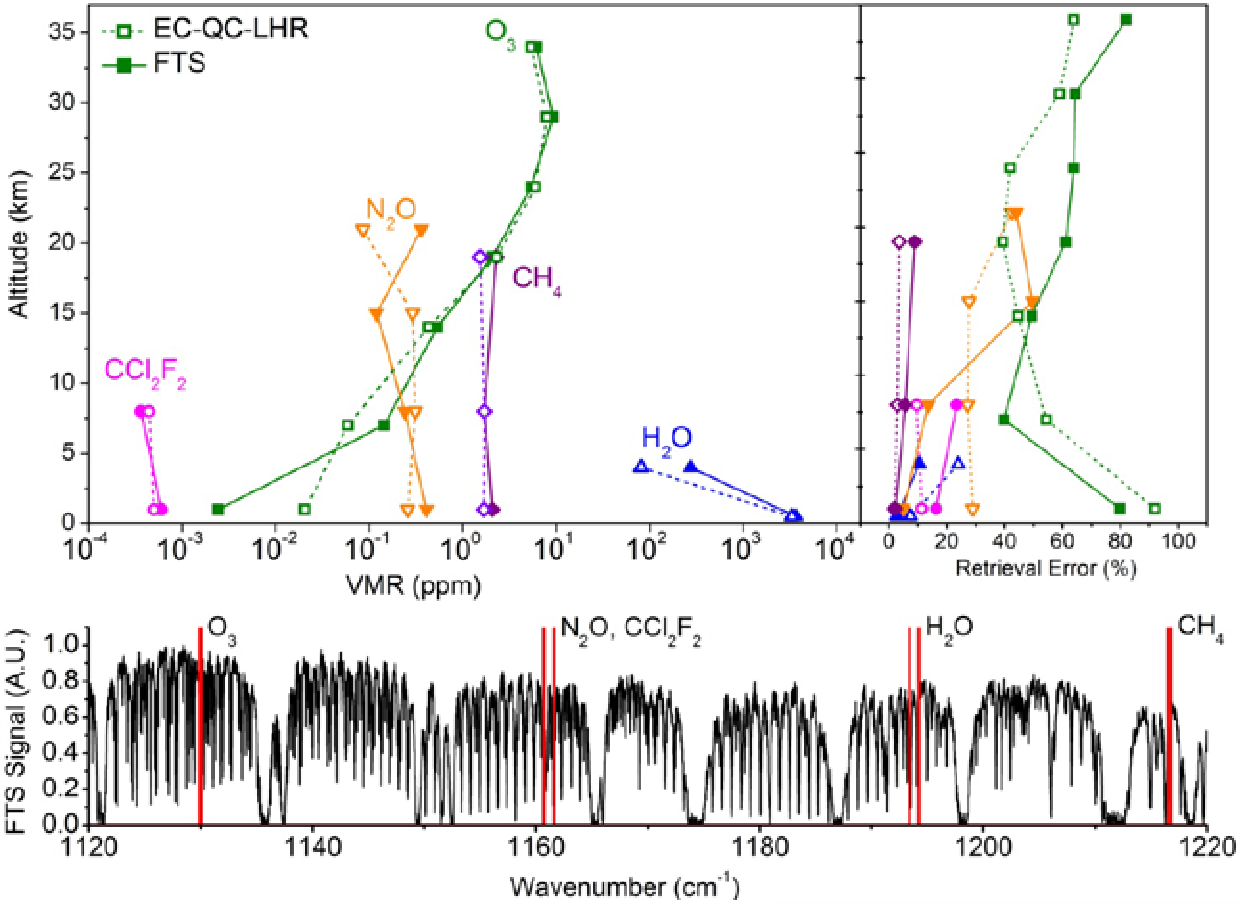
## LHR

**Spectral resolution 60 MHz**

**Field of view 1/40 solar disk**

**Acquisition 1 min**

**Window span $< 1$ cm$^{-1}$**



## FTS

**Spectral resolution 600 MHz**

**Field of view 1/40 solar disk**

**Acquisition 2 hours**

**Window span 100 cm$^{-1}$**

# Getting LHR to Space

Ø In space context LHR technology not mature
  – Need to get to TRL 7 (In Orbit Demonstration)
  – Need to built up space heritage

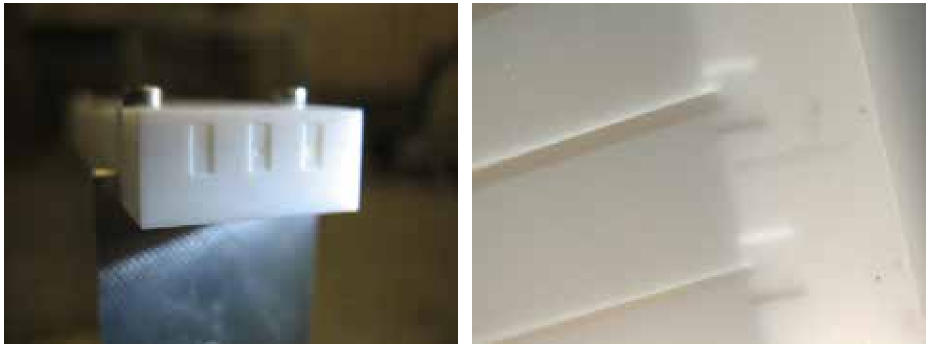
Ø Key enablers
  – Reduction in mass and volume
  – Increase robustness, reduce risk
  – Airborne deployment as a first step to space

Þ **Technological solution: hollow waveguide integration**

# Miniaturization / Ruggedization

## Easing deployment through Hollow Waveguide integration

Hollow waveguides in ceramic

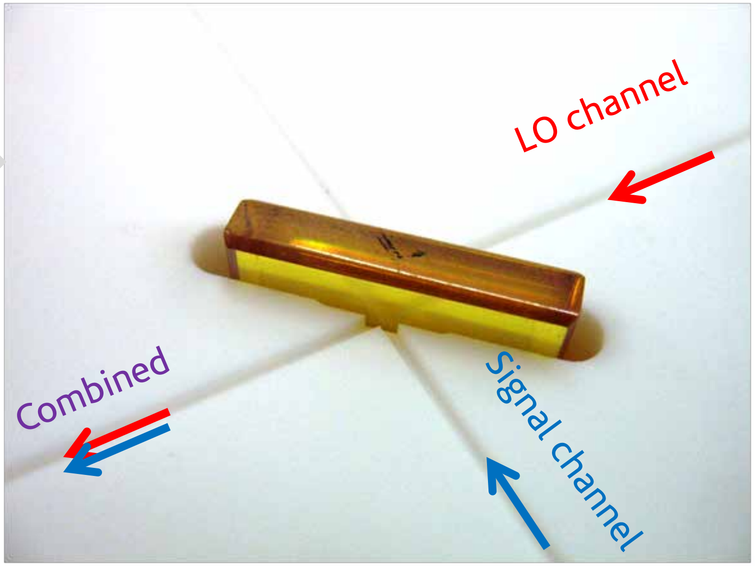


- Fully integrated optical systems
- Compact – Robust – Lightweight
- Low cost
- Relaxed alignment constraints
- Requires machining with 1 µm tol.

Example of heterodyne mixing module integrated in Hollow Waveguide

HIGHER STABILITY

BETTER HETERODYNE EFFICIENCY

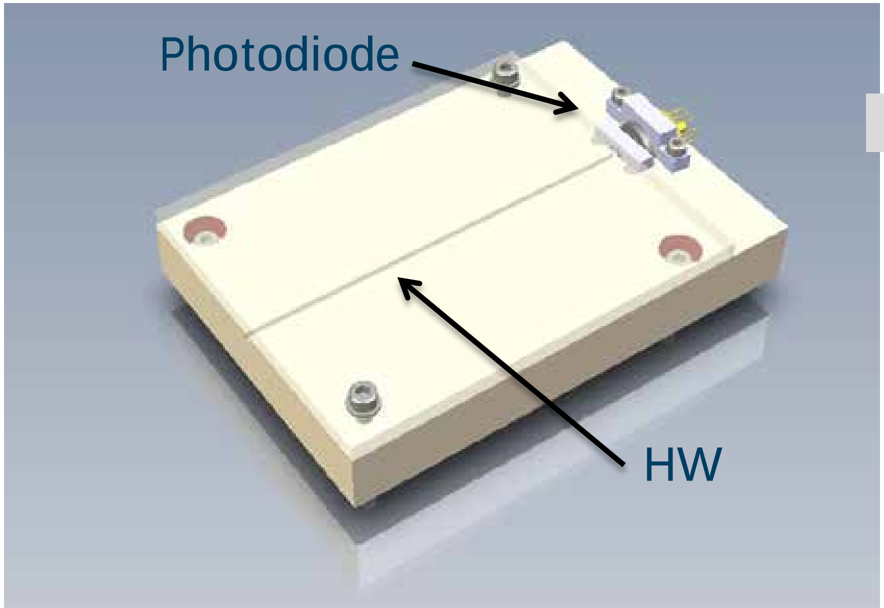


# Active Component Integration

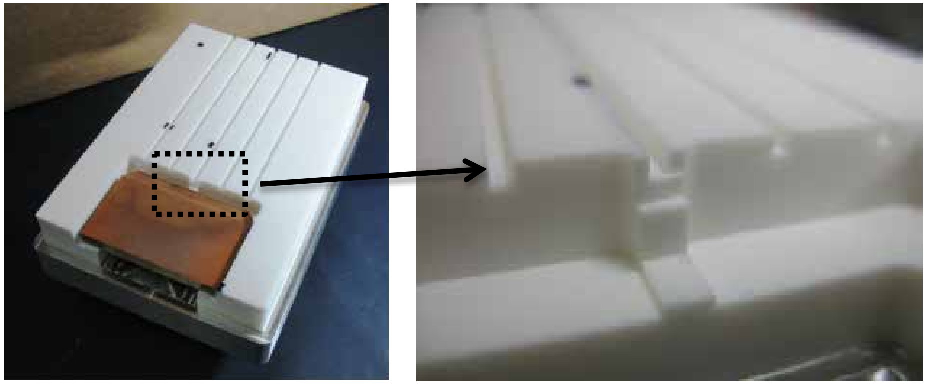
## Laser & photodiode

- Lasers and photodiodes are semiconductor chips
  - Small enough for full integration

HW – Detector integration

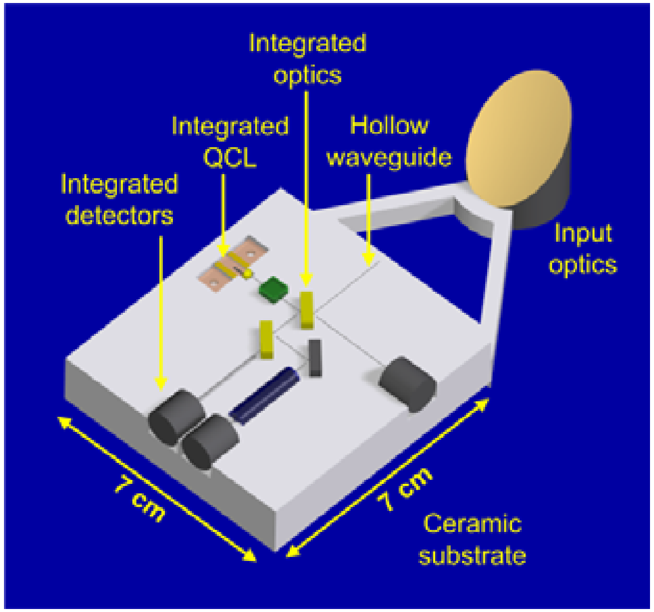


Engineering HW substrate with 70 dimensional tolerances of ~1 μm



# Concept of Fully Integrated LHR

## Shoe box size with unprecedented specifications



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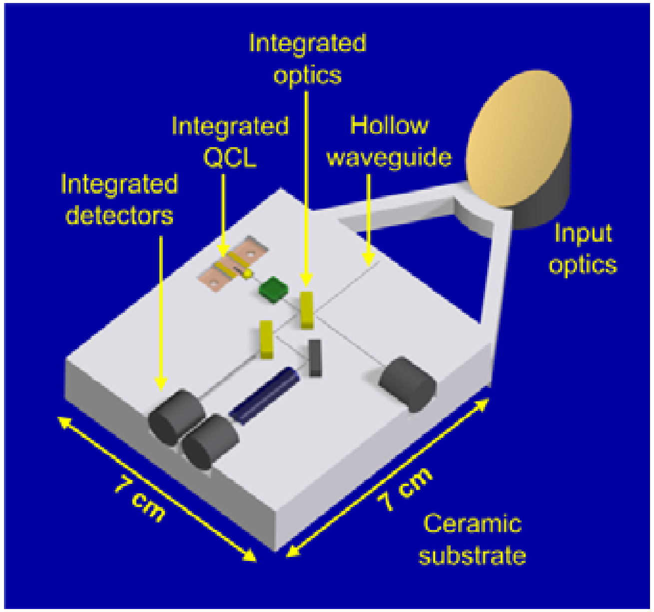
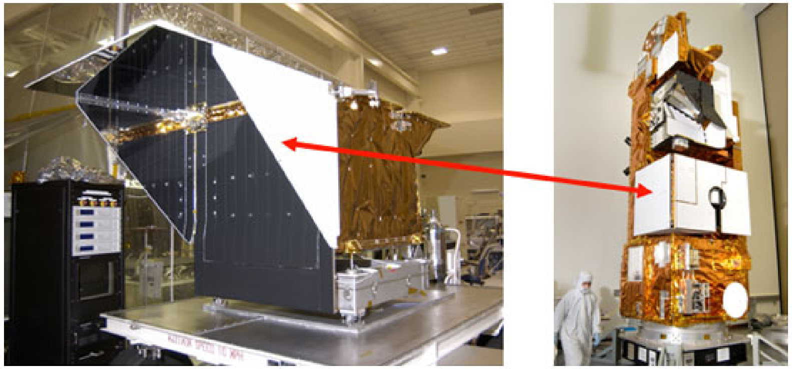
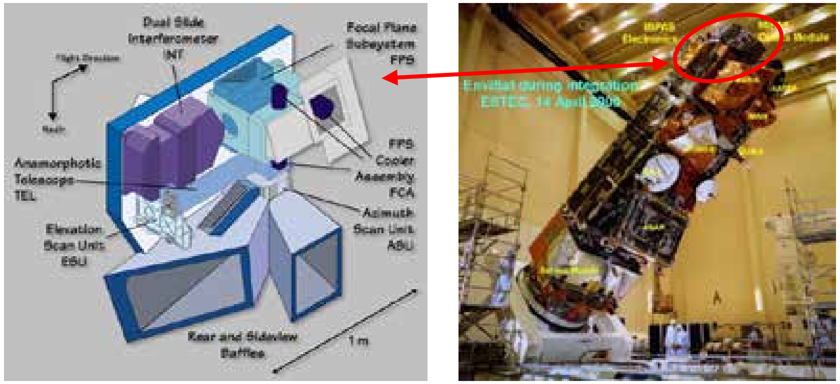


|  | Spatial (km) | Spectral (/cm) | Noise | Weight (kg) |
|---|---|---|---|---|
| **MIPAS** | 3 x 30 | 0.035 | 100 | 330 |
| **TES** | 0.5 x 0.5 | 0.06 | 100 | 390 |
| **HW-LHR** | 0.2 x 0.2 | < 0.01 | 200 | 2 |

NASA TES on AURA

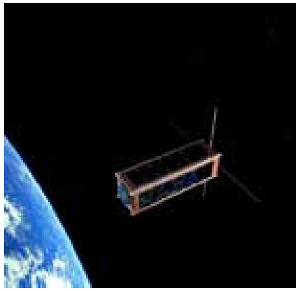


ESA MIPAS on ENVISAT



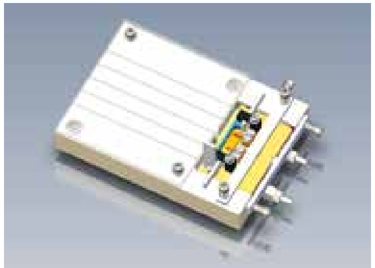
# In Orbit QC-LHR Demonstrator

## Example of 3U CubeSat



**Input port**

- Collection mirror
- View switcher
- Calibration load



**Integrated LHR**

- Integrated Optics
- QCL
-Detector
- QCL control
- Detector control

**Payload control**

- Altitude control system
- Transmission system
- Antenna system
- Power distribution

# Further Prospects of Miniature LHR

## Airborne

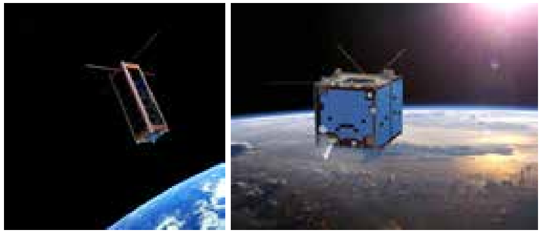
- Step to space

- UAVs
  UT/LS dynamics
  Ozone / water

- HAPs
  Air quality
  Street resolution
  Emission sourcing

## In Orbit Demo

- CubeSat
- TechDemoSat
- ESA IOD
- Build heritage



## TRL 9

- Mission Ready

- NanoSat
  Constellation

- Piggy backing

- GEO
  GHGs & Emissions
  Subcity scale

- Planetary

## Ground

- Ground network
- Validation
- Lower cost