# Miniaturization of High Sensitivity Laser Sensing Systems

Damien Weidmann

RAL Space

Science & Technology Facilities Council
Rutherford Appleton Laboratory

# Outline

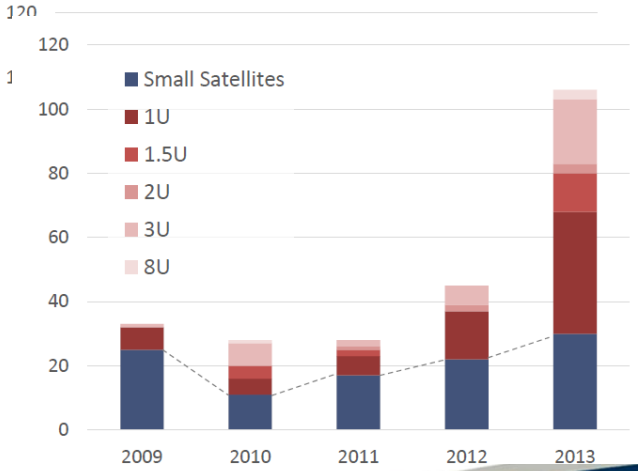
- Drivers for miniaturization
- Molecular fingerprinting in the Mid IR
- Optical integration technologies
- Forward looking examples
- Conclusion

# Miniaturization Drivers

## The small sat disruption

- Low cost
- Rapid development cycle
- Heritage building
- Less risk aversion
- Constellations
- Hands on training
- Lower barrier to entry for small businesses


400 micro satellites annually in 2020 +



# Miniaturization Drivers

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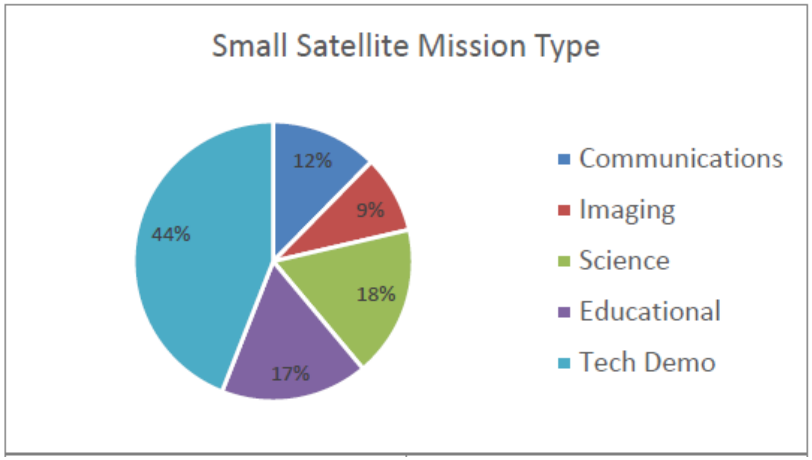
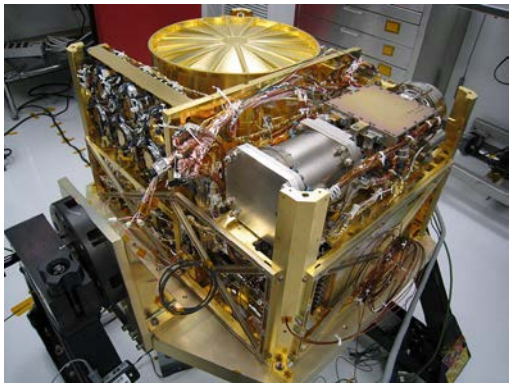
The Aerospace Corporation Pico Satellite Solar Cell (PSSC) Testbed 2 being loaded into its space shuttle compatible launcher for ejection from STS-135 on July 20, 2011.





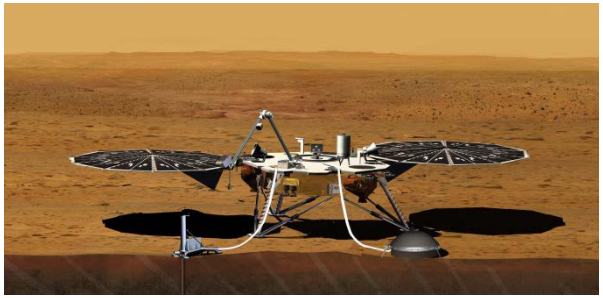
# Miniaturization Drivers

## Planetary landers

Sample Analysis at Mars (SAM)

Phoenix lander

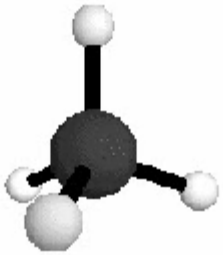


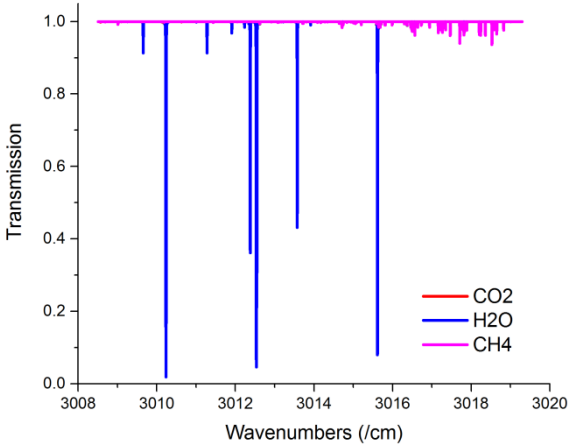
Insight lander

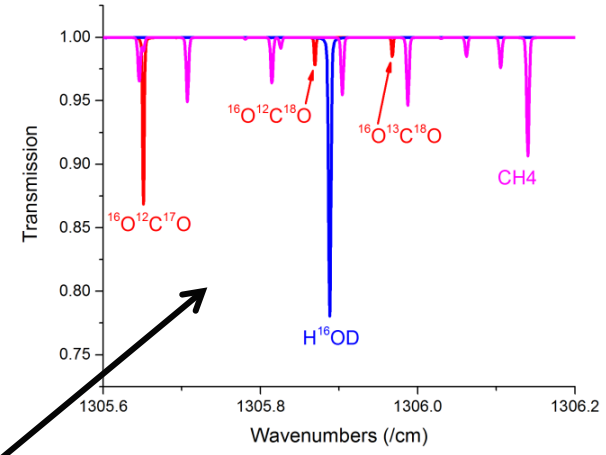
# Principles of Molecular Sensing

## High spectral resolution for fingerprinting

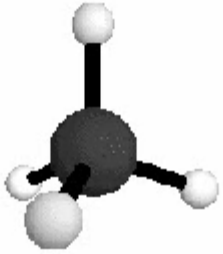
**Stretching - Vibration mode ν3 - 3157 cm$^{-1}$**

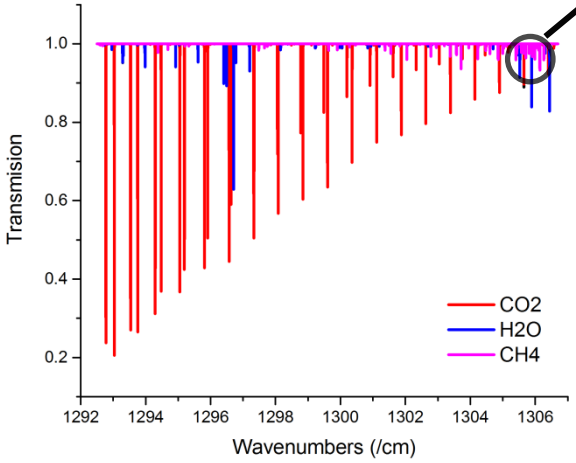





**Bending - Vibration mode ν4 - 1367 cm$^{-1}$**






- Narrow window sufficient
- Sounding optimization
- Information from a resolved line
  - Altitudinal information
  - Non LTE effects
  - Velocity
  - EM field information
  - Isotopologue discrimination

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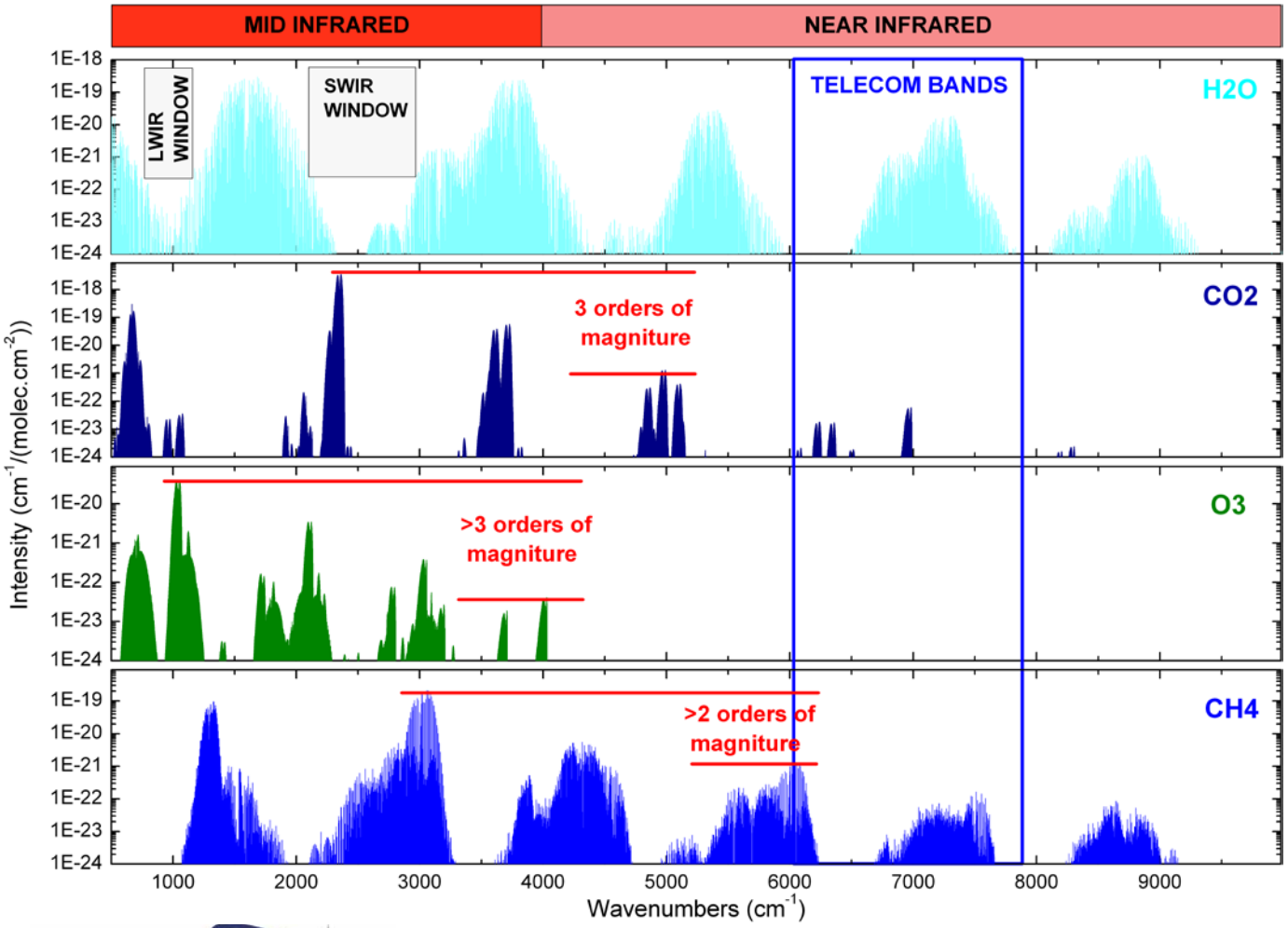
# Rationale for Mid-Infrared Sensing



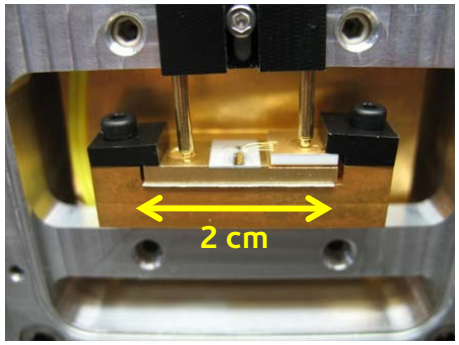

Fundamental ro-vibrational molecular absorption bands

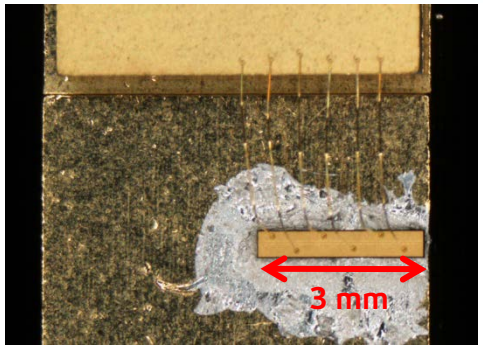
Absorption cross sections much greater

8-12 μm and 3-5 μm atmospheric window

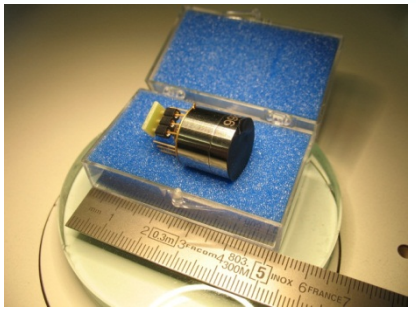
Less scattering

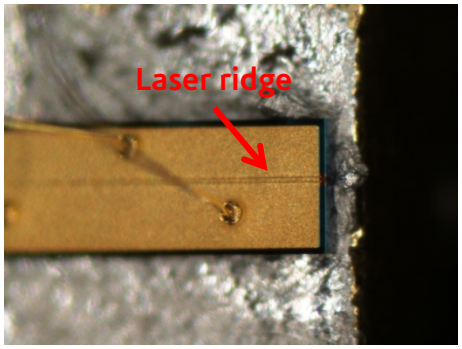
# Mid IR Key Components

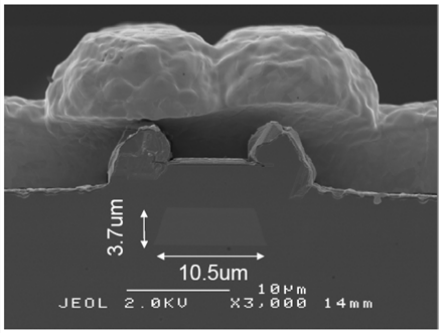


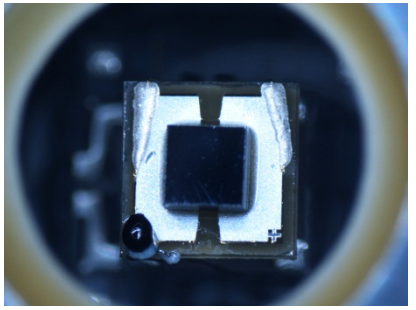

Quantum Cascade Laser






Hg Cd Zn Te Photodiode

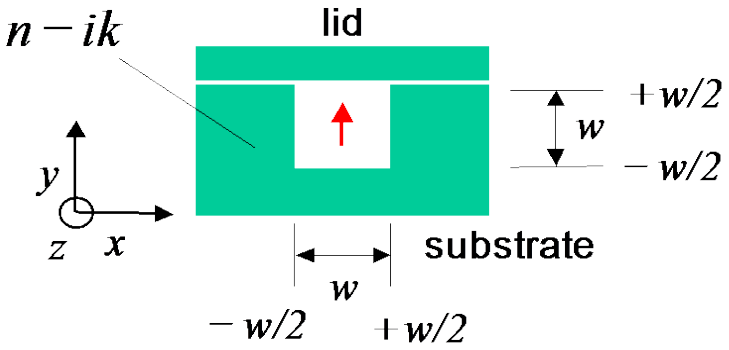


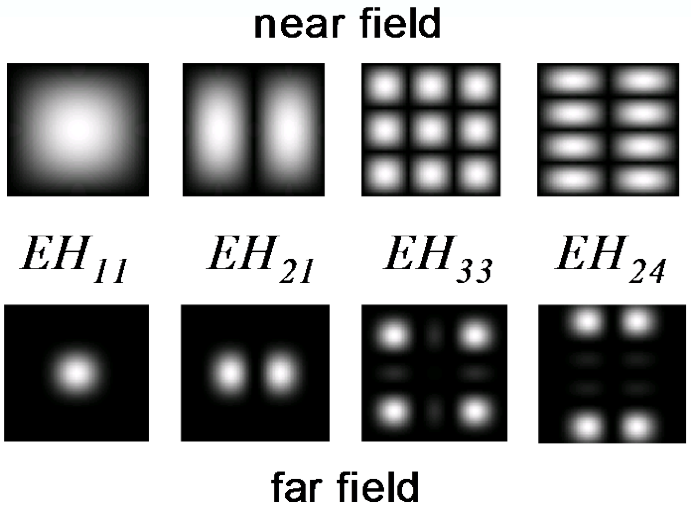
QCL advantages include:

- Frequency tailoring
- High power
- Single mode operation
- Ambient T operation
- Frequency tunable
- Good beam quality
- Fast modulation
- Long wavelengths
- Compact and robust

Micro- cooler if 80K operation required

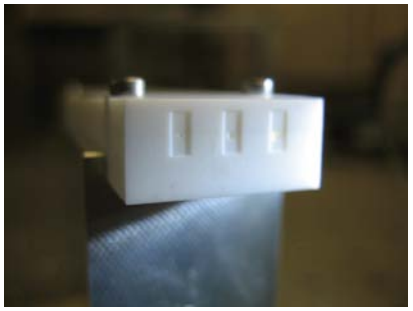
# Multimode Hollow Waveguide




$$T_{pq\,dB} = -4.35\,\frac{\lambda^2}{w^3}\left[\,p^2\,Re\left(\frac{1}{\left\{(n-ik)^2-1\right\}^{1/2}}\right)\;+q^2\,Re\left(\frac{(n-ik)^2}{\left\{(n-ik)^2-1\right\}^{1/2}}\right)\right]$$

Hollow waveguide channels



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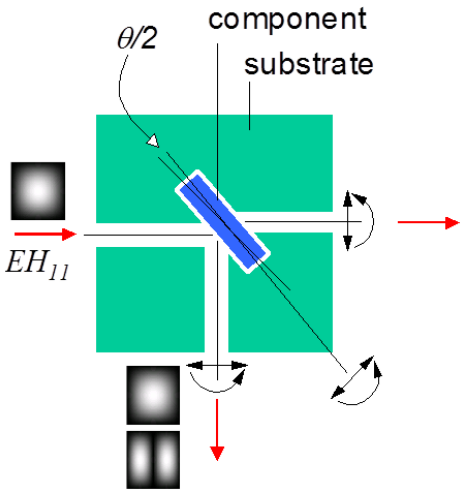
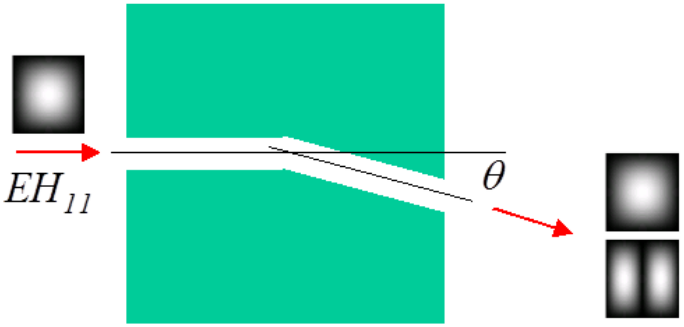
# Optical Integration & Tolerancing



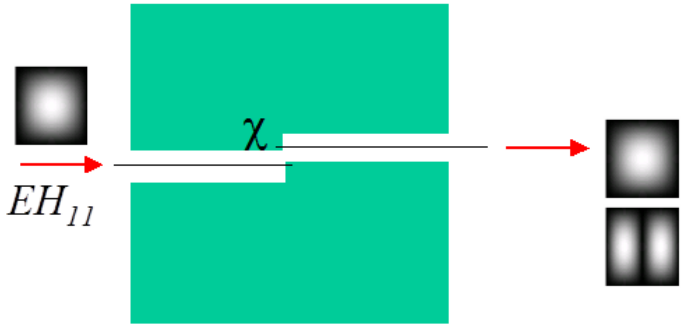

angular misalignment



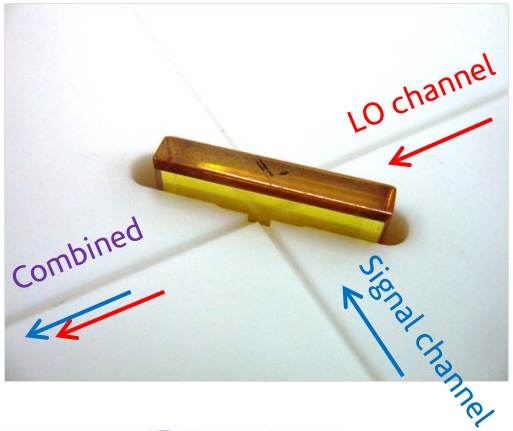

design criteria

$$\theta \leq \frac{\lambda}{5w}$$

lateral misalignment




$$\chi \leq \frac{w}{15}$$

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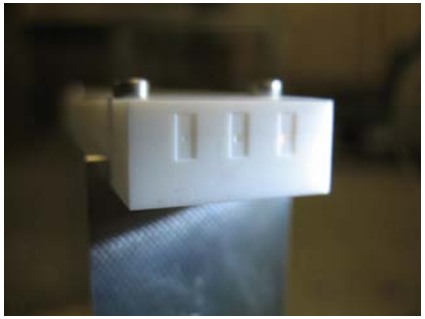
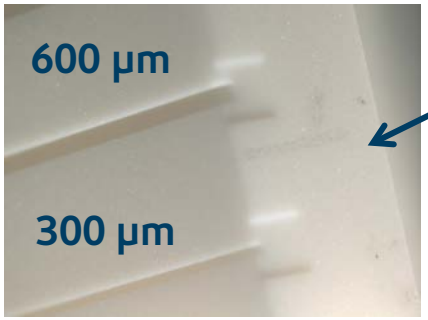
# Building Blocks

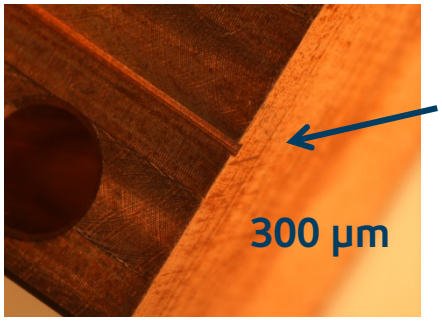
## Study and modelling of individual functions



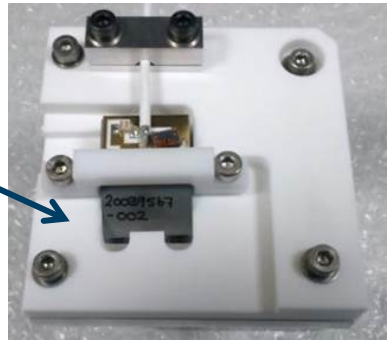
HW in ceramic



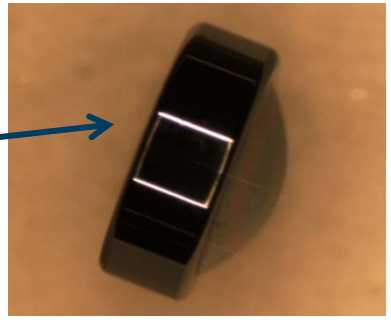

HW in metal




Opto-acoustical device

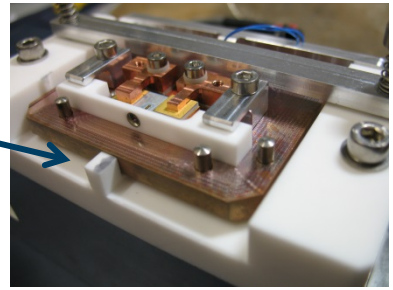


Mini-asphere



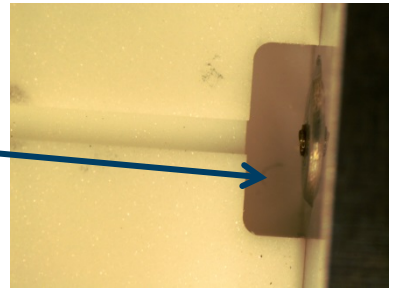
Beam-splitting

Laser coupling



Laser alignment

Fibre coupler





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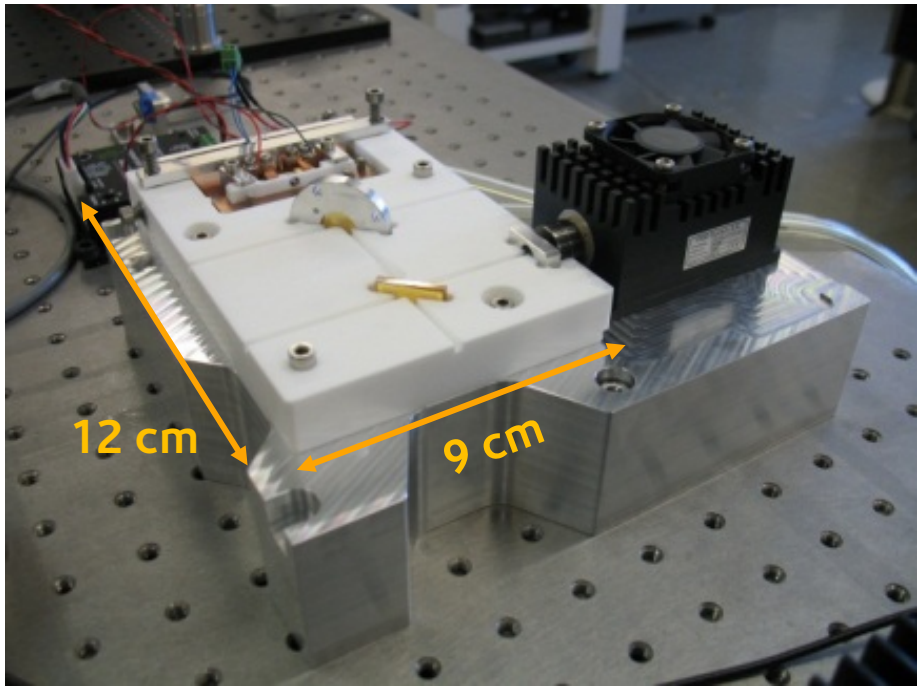
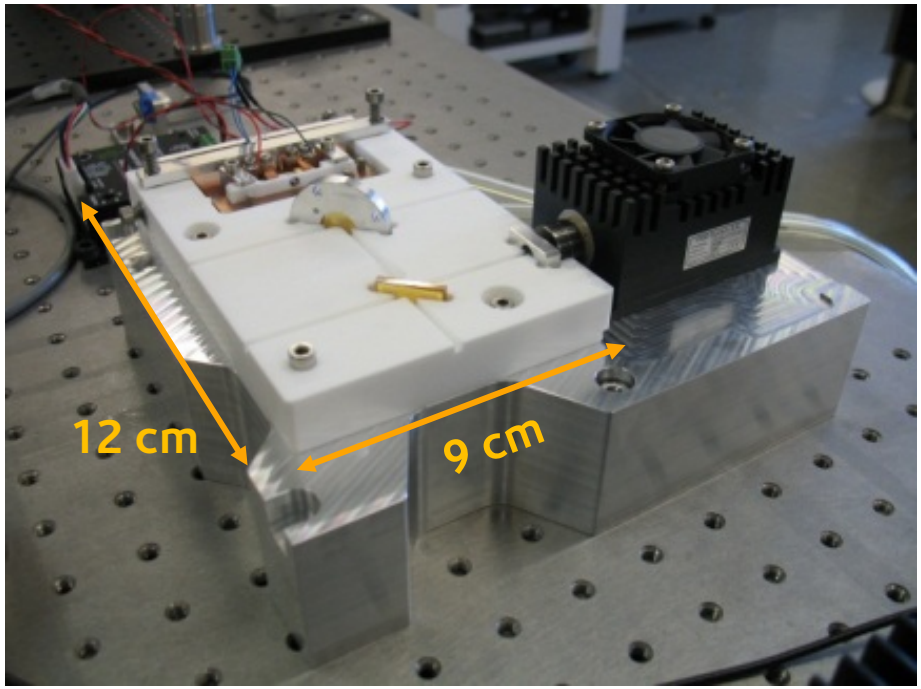
# First Miniature LHR Demonstration

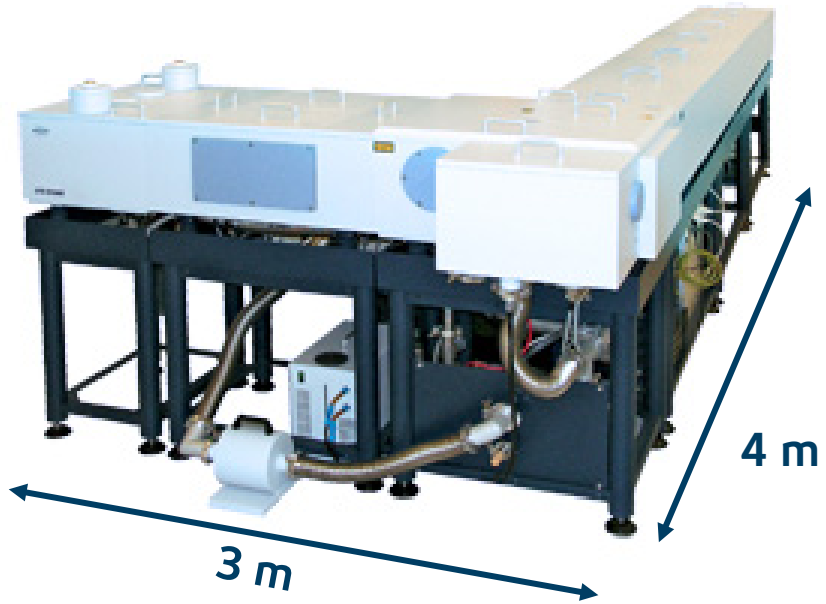



- Spectral Resolution: 0.002 $cm^{-1}$
- NESR 120 $nW/cm^{-2}.sr.cm^{-1}$
- Power < 10W

# First Miniature LHR Demonstration



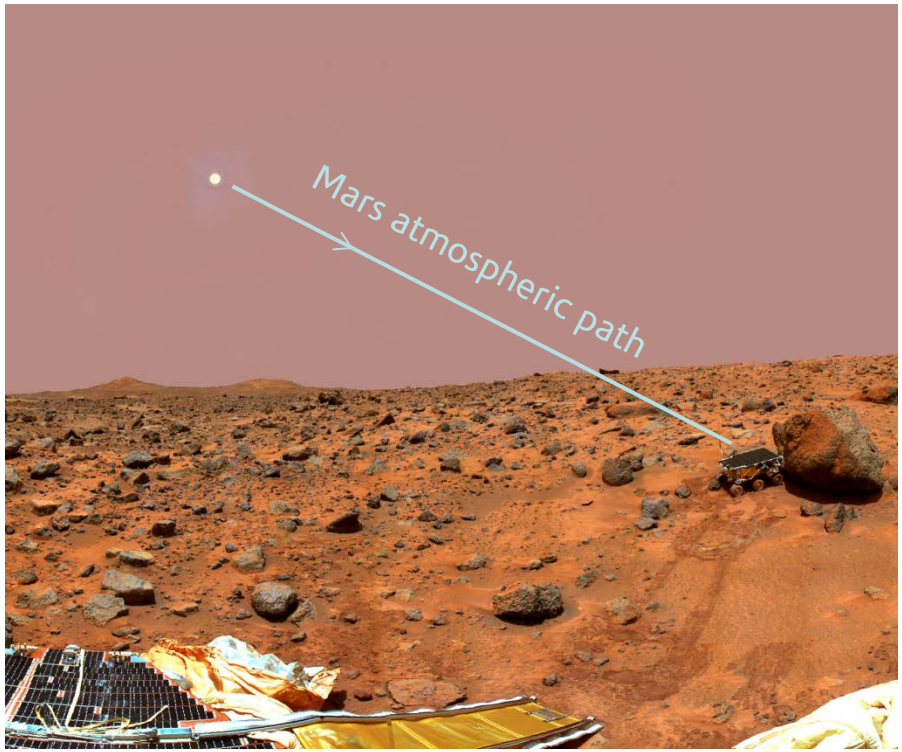

- Spectral Resolution: 0.002 $cm^{-1}$
- NESR 120 $nW/cm^{-2}.sr.cm^{-1}$
- Power < 10W
- Spectral range : 10 $cm^{-1}$

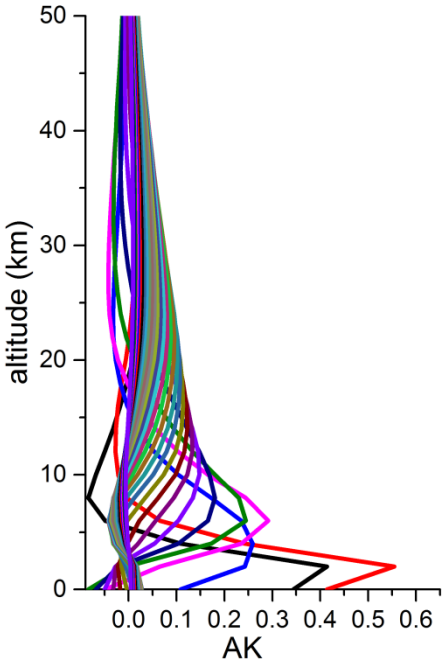


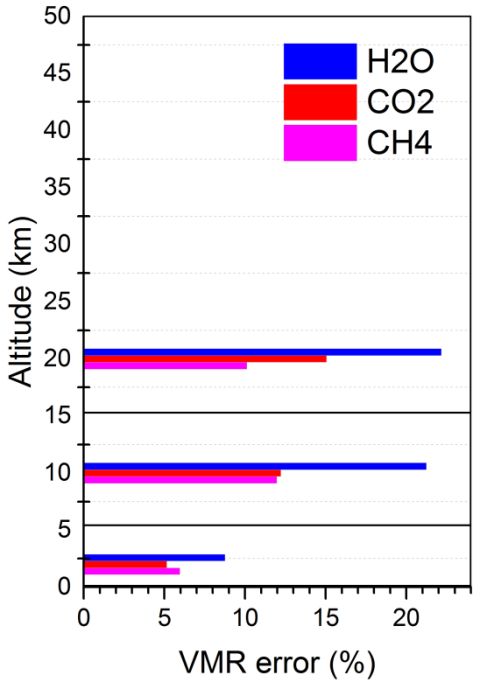

- Spectral Resolution: 0.002 $cm^{-1}$
- Spectral range : 4000 $cm^{-1}$

# Atmospheric Sounding From Landers

## Ground solar occultation




**Benefits:**

- Measurements throughout Martian day
- Temporal resolution (1 meas/min)
- High VMR sensitivity
- Some vertical profiling

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# MISO mission

## Methane Isotopologues by Solar Occultation

### Technology push

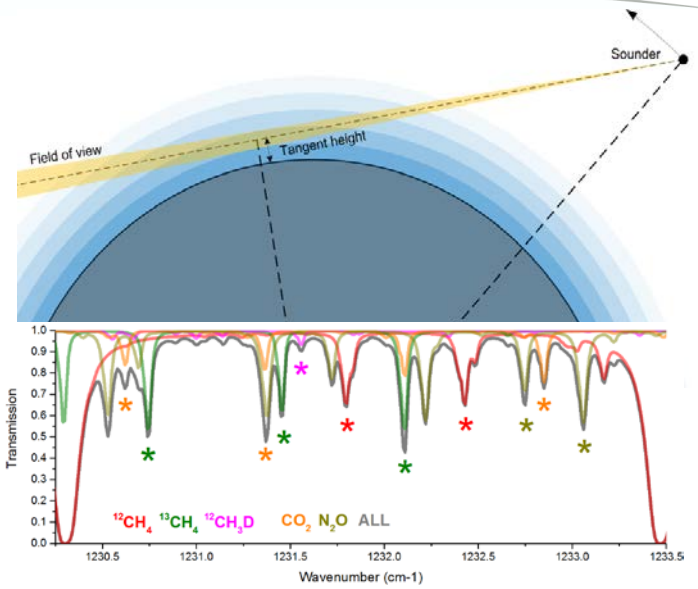
In orbit demonstration mission of:

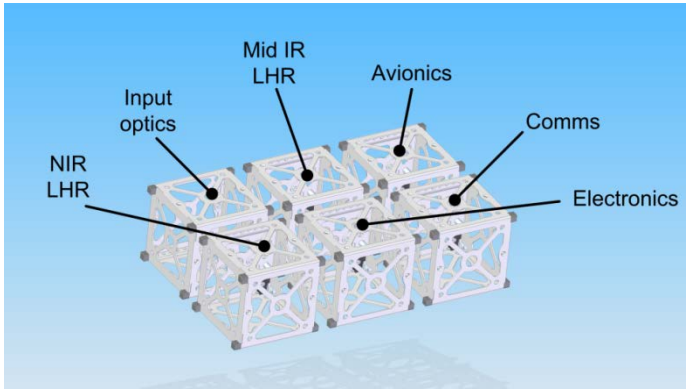
- LHR spectrometer and component
- Dual band high res isotope sensing
- Hollow waveguide miniaturization technology
- Solar occultation limb from a small sat

### Science pull

Study the methane cycle and its change through:

- Component to a methane observing system
- Constraining further the methane budget and cycle
- UT/LS transport
- Improved emission estimates

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# Conclusion

- Mission-enabling technology
  - Mid IR Laser spectroscopy in space
  - Instrument with unprecedented size/performance ratio

- Genuine platform technology for molecular sensing
  - Atmospheric sensing
    - Passive spectrometers, lidars, In-situ sensors
  - Laser communications
    - Miniaturized transmitters / receivers
  - Laser occultation in formation flying
  - In flight diagnostics laser systems
  - Many terrestrial applications to benefit as well

- Next is to shrink further : mid IR photonics

# Acknowledgements


- Collaborators
  - Helen Butcher
  - Neil Macleod
  - RAL Space PDF
  - Mike Jenkins
  - Russ Boyce
  - Doug Griffin

- Funding

Science & Technology Facilities Council

STFC | Innovations Ltd

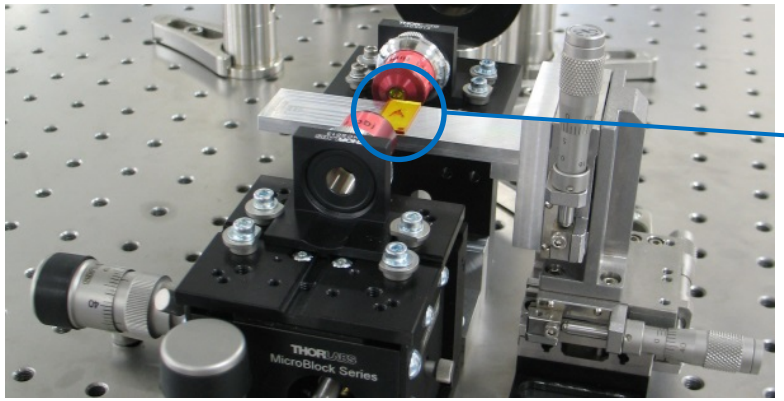
UK SPACE AGENCY

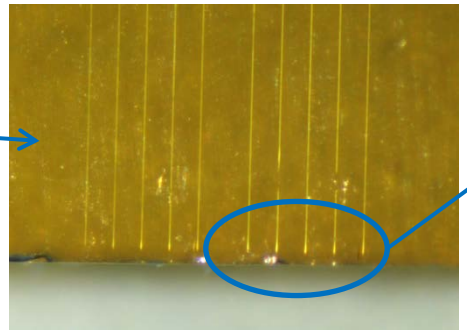
Centre for eo Instrumentation

Innovate UK
Technology Strategy Board

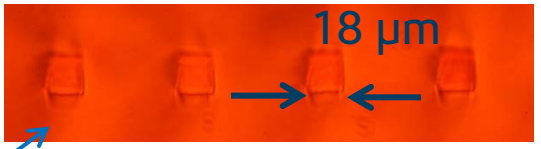
# Shrinking Further : Mid IR Photonics

## Novel mid IR glasses and photonic structures

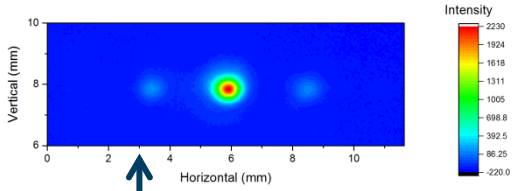


Ultra-Fast Laser Inscribed
GLS waveguide

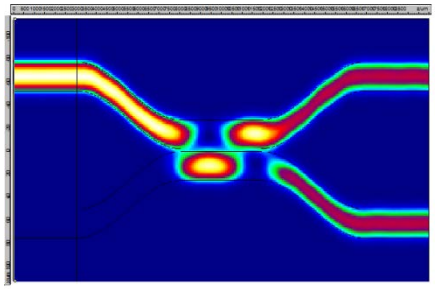



Input facet

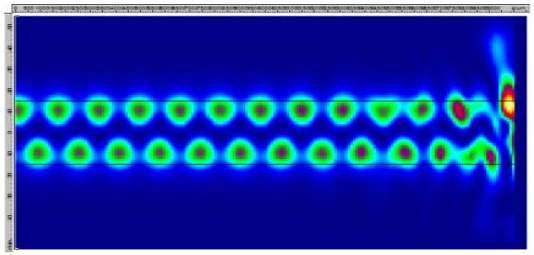


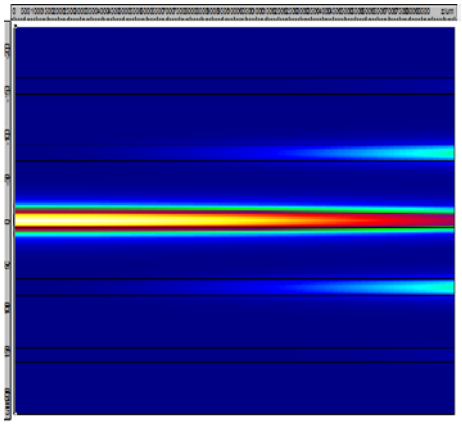

Experiment and modelling

Modelling of novel structures
Evanescent X coupler



Modelling of optical feedback
impact





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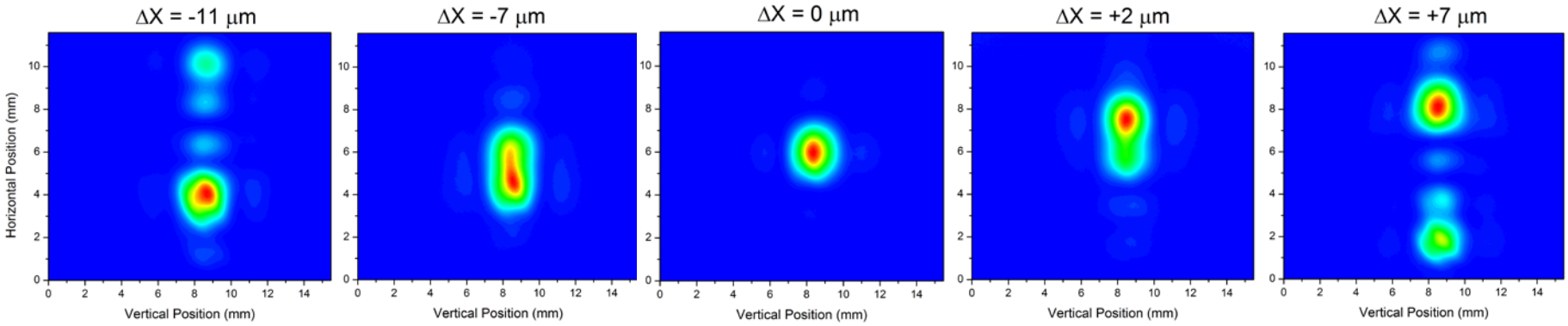
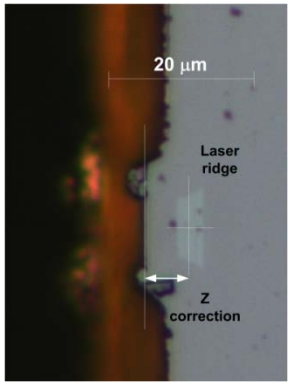
# Optimum Coupling Assessment

## Far field profiles (0.750 mm guide width)

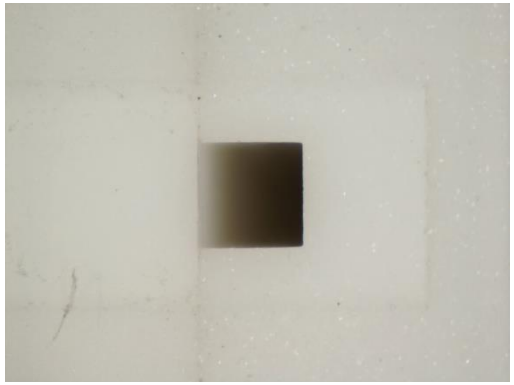
### Lateral coupling : sensitivity < 2 μm




### QCL output 4x10 μm²




### HW input ~0.75x0.75 mm²



### Waist position sensitivity < 10 μm