Hollow Waveguide Integrated Laser Heterodyne Radiometer

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HOLLOWGUIDE LTD

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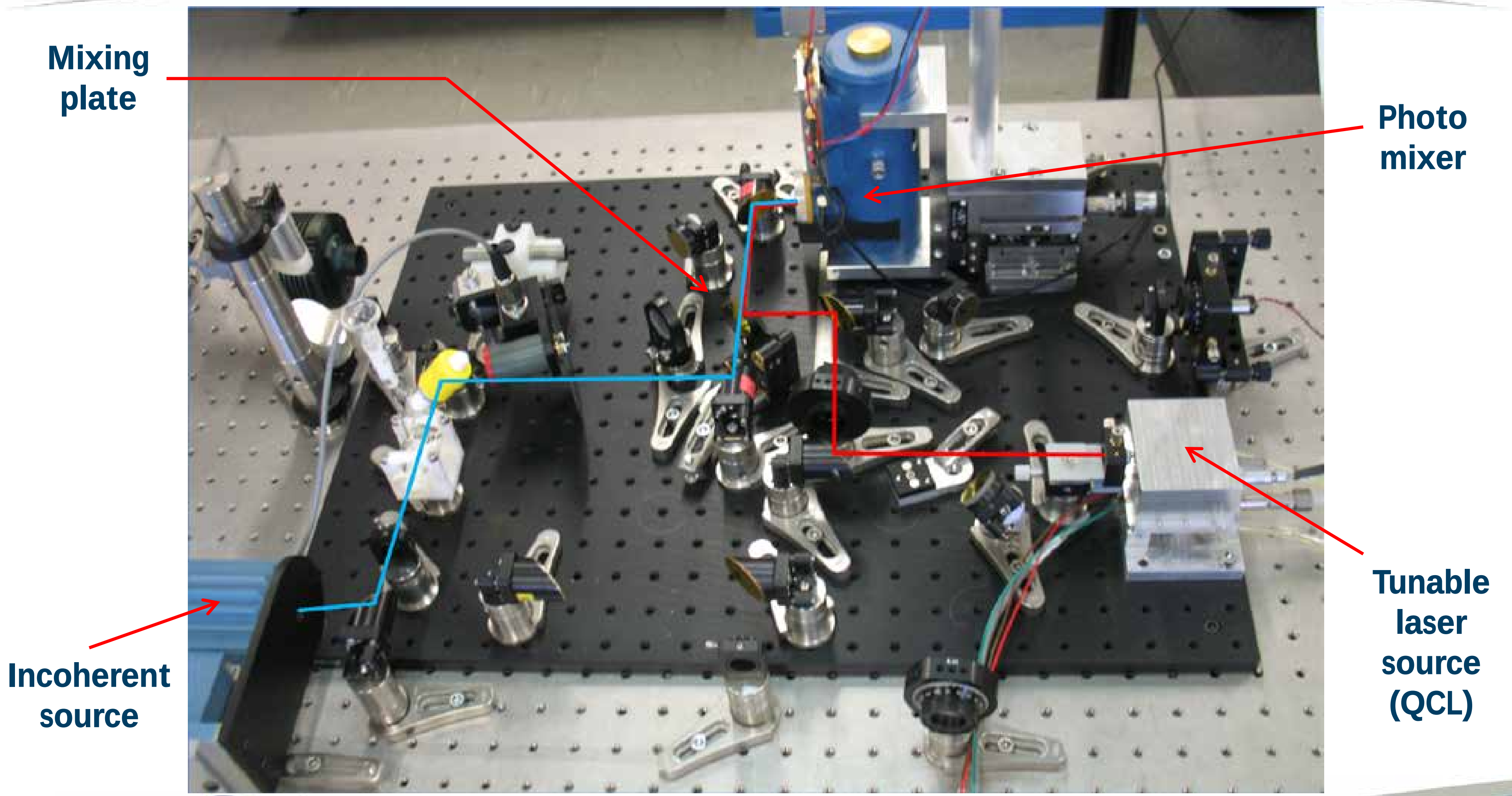
Outline

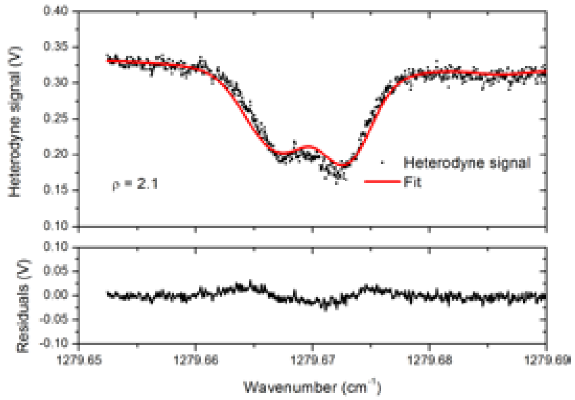
- Introduction on LHR
- Hollow waveguide hybrid integration
- Steps in miniaturizing the LHR
- Roadmap and applications

Laser Heterodyne Radiometer

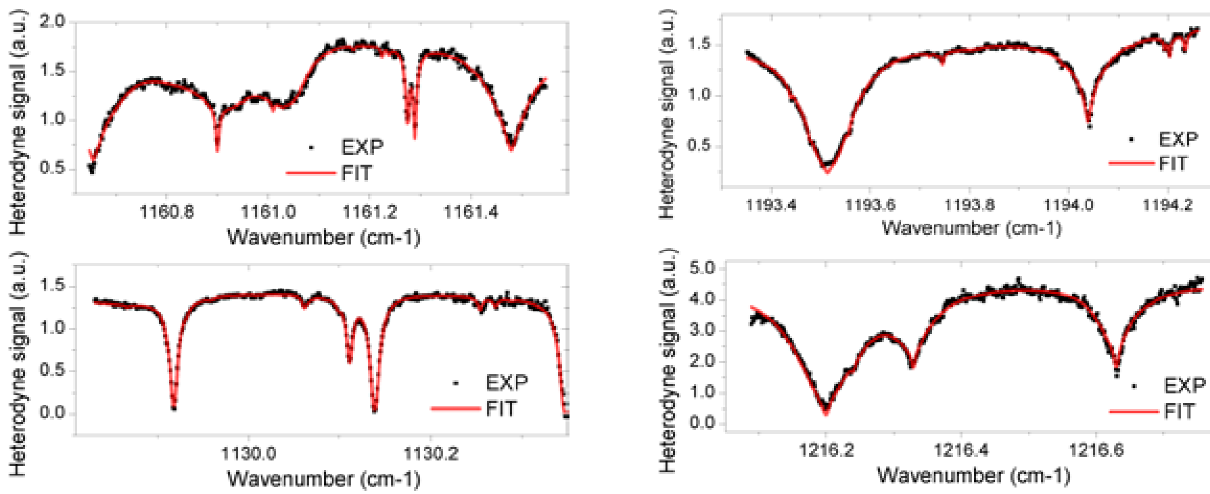


Ultra-high Resolution Spectra

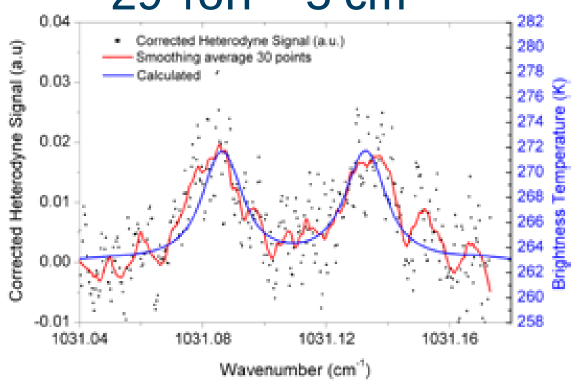
Methane – 10 Torr – 5 cm



Atmospheric transmission in several narrow windows



Emission from OCS
29 Torr – 5 cm



Full lineshape information recovered
- contains the integrated altitudinal lineshapes

Narrow spectral windows (< $1cm^{-1}$)
- can be optimized to increase information content
- limits interference
- Better control on error propagation

Faster retrievals

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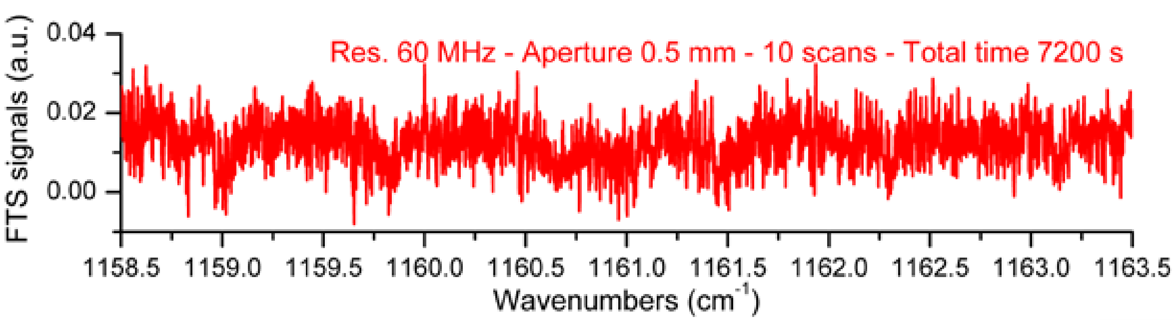
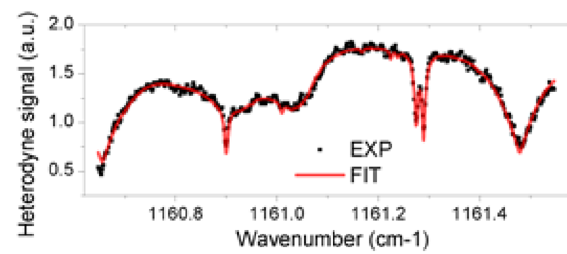
FTIR / LHR Side by Side Comparison

Identical resolution 60 MHz and field of view

Bruker IFS 125HR - 4m x 2m

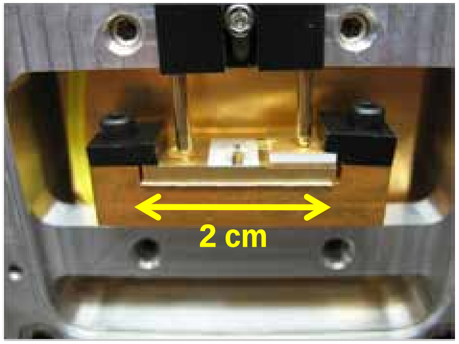
Bench top LHR - 1m^2 – 1min acquisition

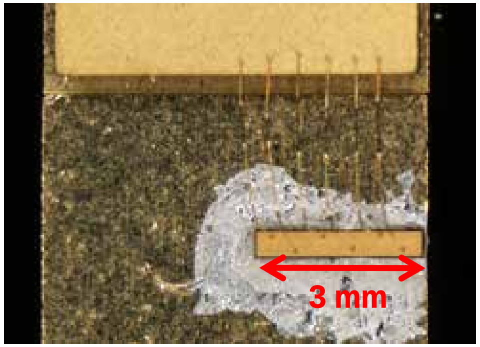




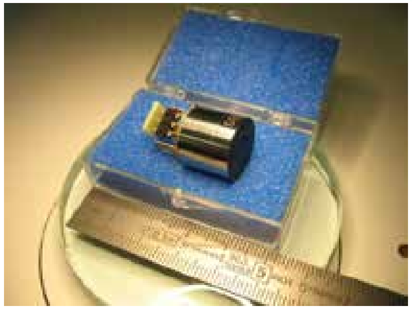
Key Components

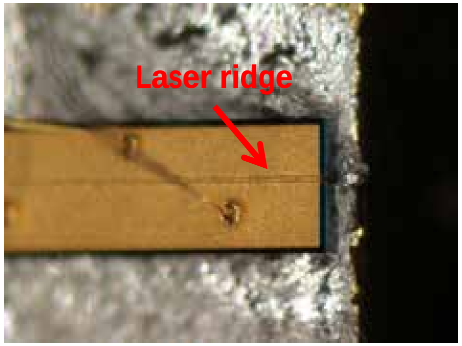
Local oscillator and photomixer

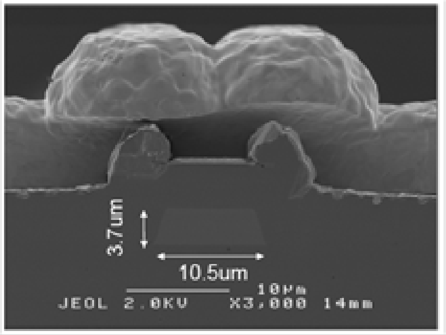




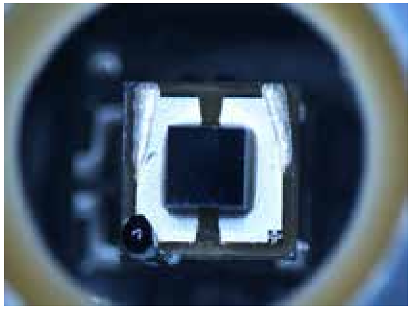
Quantum Cascade Laser







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

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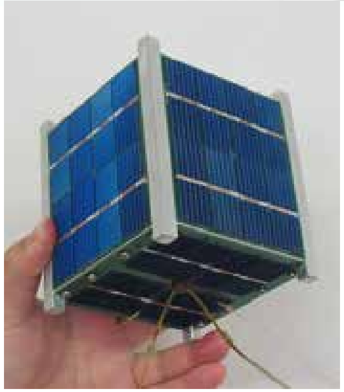
Hollow Waveguide (HW) Integration

Miniaturization and ruggedization

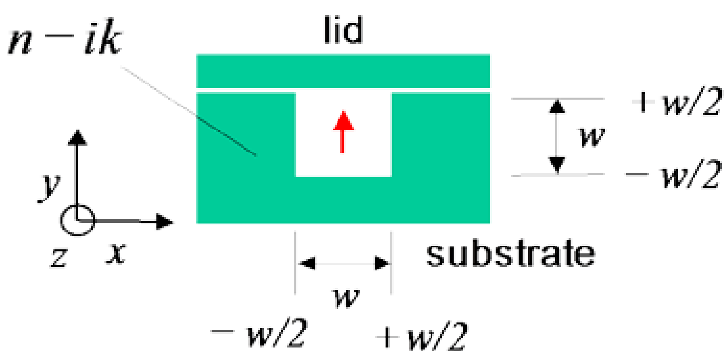


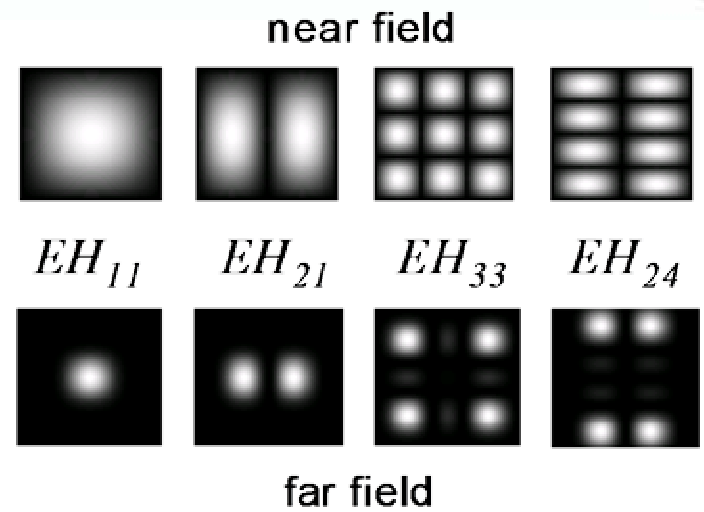
Ø Drivers for miniaturization / integration
- Small and micro-satellites platform
- Develop piggy-backing approach
- Cost reduction with no compromise on performance
- Denser ground-based networks

Ø Benefits of hollow waveguide integration
- Rugged
  - No manual alignment – no opto-mechanical mounts
  - Optics and optical paths all enclosed and fixed
  - Reduced sensitivity to vibrations
- Low mass – low volume
  - Inherently compact – higher packing density
- Optical
  - Optical guidance – Reduced path length – Reduced diffraction
  - Ease angular alignment tolerances
  - Broad waveband transmission

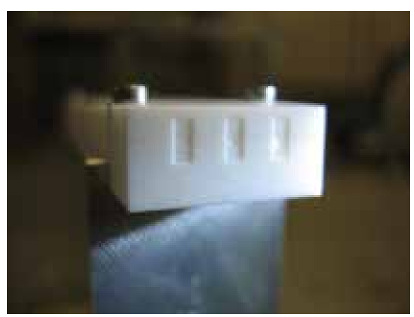
Concept of HW integration 1

Optical guiding and spatial modes





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



Hollow waveguide channels

HollowGuide Ltd

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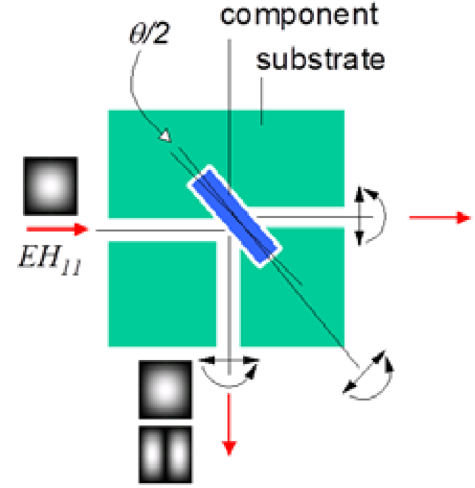
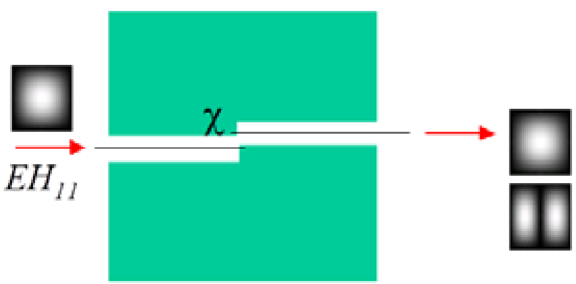
Concept of HW integration 2

Hybrid integration of optical components

Slot for optical component

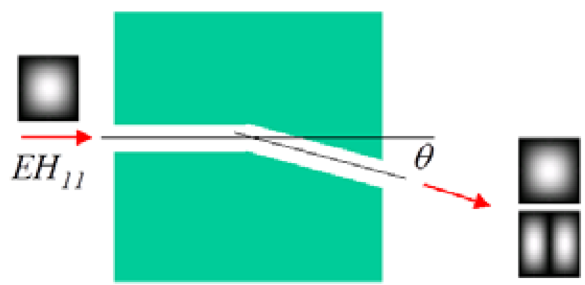


lateral misalignment



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

angular misalignment



design criteria

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

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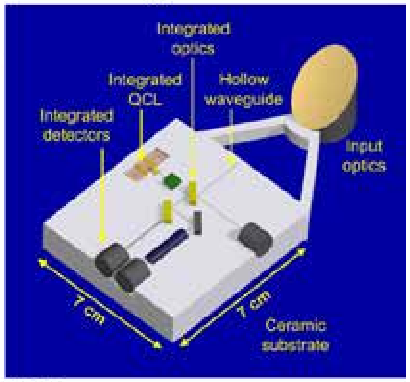
Path to HW - LHR Integration

Bench-top >10^5 cm^3

Integration path

HW integrated 100 cm^3



Assessment

Manufacturing

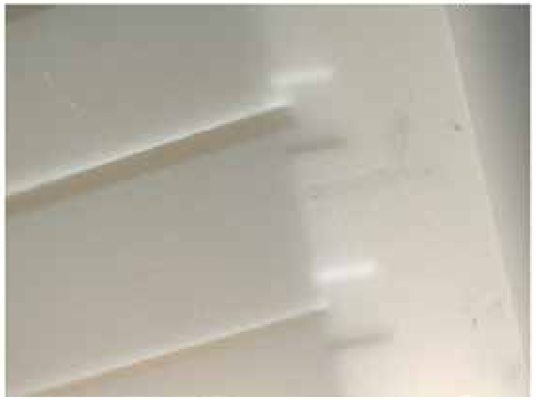
Design - modelling

Metrology

Hollow waveguide channels

Passive component integration

Active component integration



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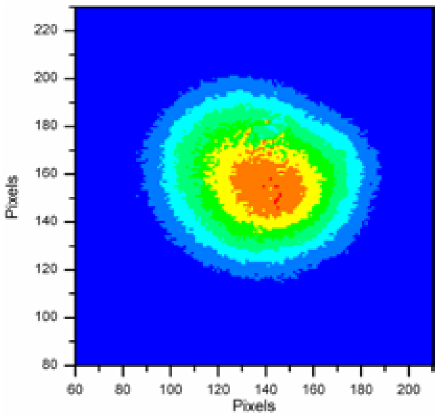
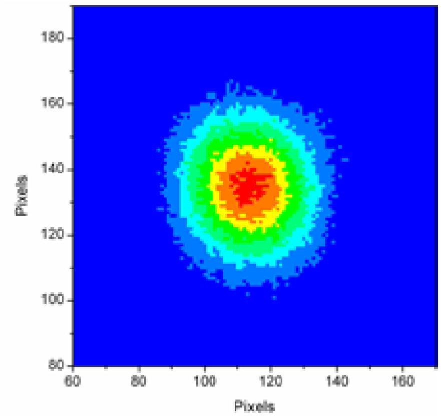
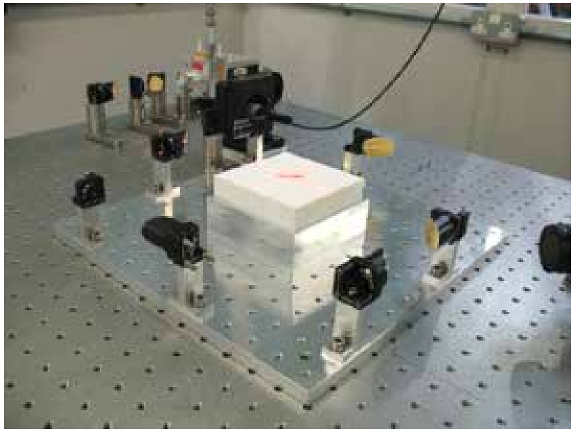
LHR Integration

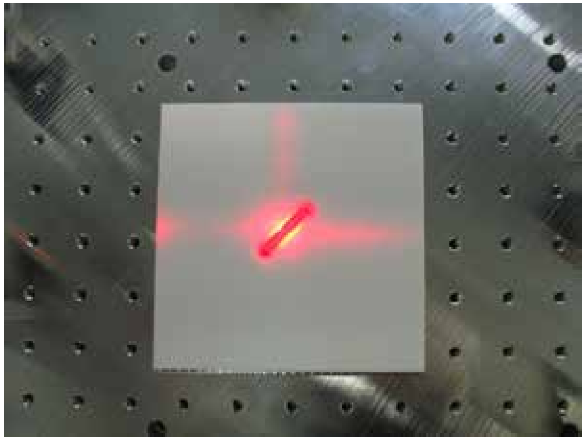
Step 1: passive components

- Ø Mixing plate integration
- Ø Heterodyne mixing assessment









- **Spatial mode cleansing**
- **Improve heterodyne efficiency**
- **Longer temporal stability**
- **Improved immunity to optical feedback**

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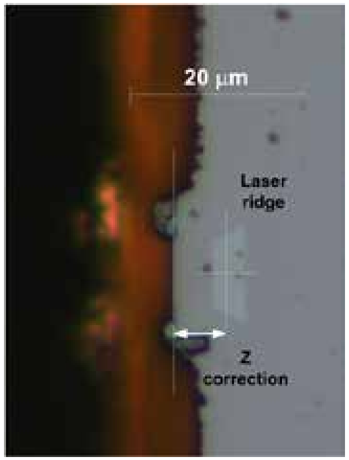
LHR Integration

Step 2: active components

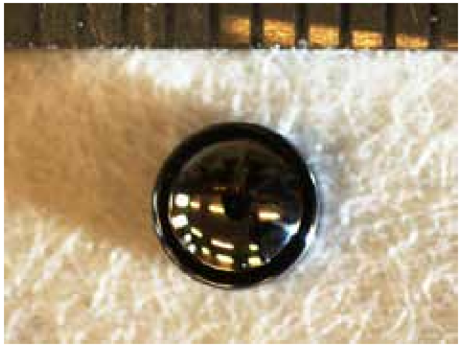
- QCL integration challenges:
  - Coupling from single to heavily multi-mode waveguide
  - Thermal management of the integrated laser
  - Near field Fresnel diffraction

QCL output 4x10 μm²



HW input ~1x1 mm²

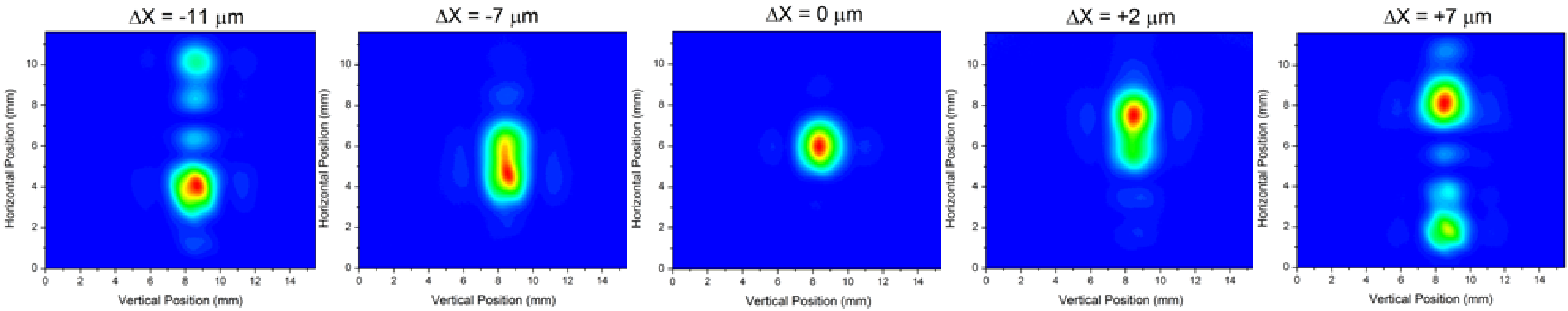
Custom Asphere for coupling ~ 1.5 mm dia.



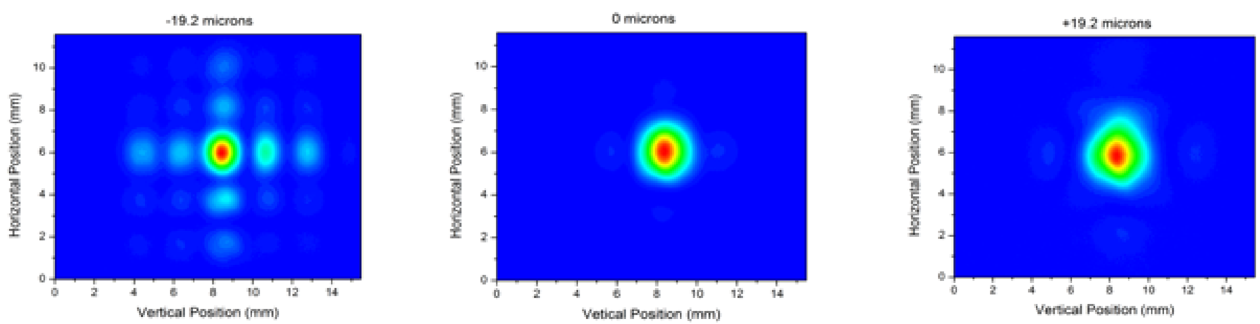
Optimum Coupling Assessment

Far field profiles (0.750 mm guide width)

Lateral coupling : sensitivity < 2 μm



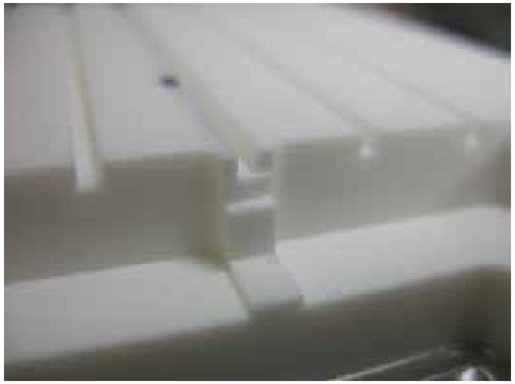
Waist position sensitivity < 10 μm

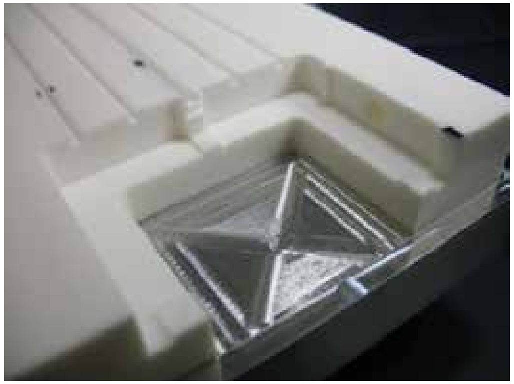


High Accuracy Manufacturing

Ø Kern Machine
- Most accurate in the world (< 1um)
- And the skills that go with it!

Ø Engineering complex substrate
- 70 tolerances
- Assessment of accuracy





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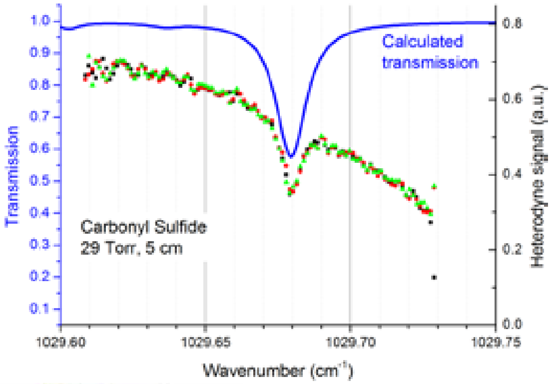
First Miniature LHR Demonstration

Carbonyl sulphide absorption

Iteration 1

Iteration 2 – size further reduced



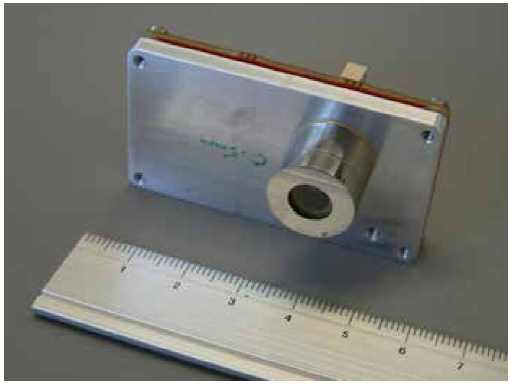
Level of performance achieved almost identical to “open space” traditional LHR using LN2 cooled detector

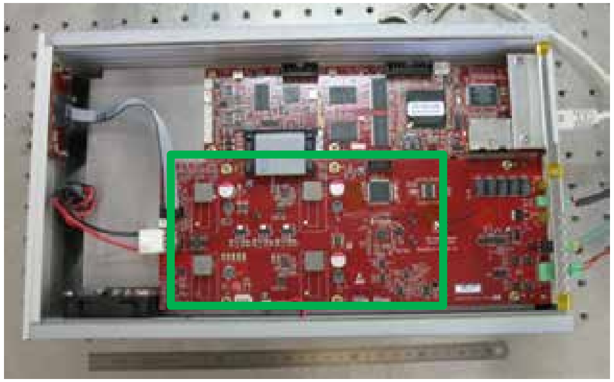
Still issue with the focusing on the detector -> understood and addressable

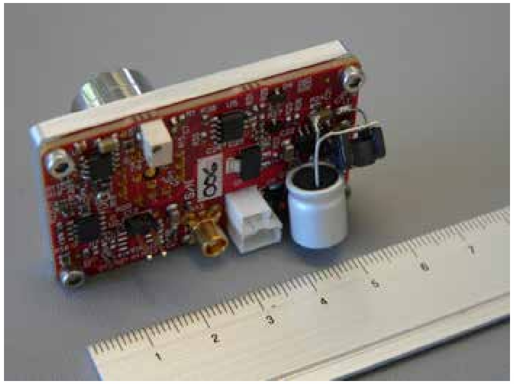
Miniaturization of Control Electronics

QCL Driver – Photomixer

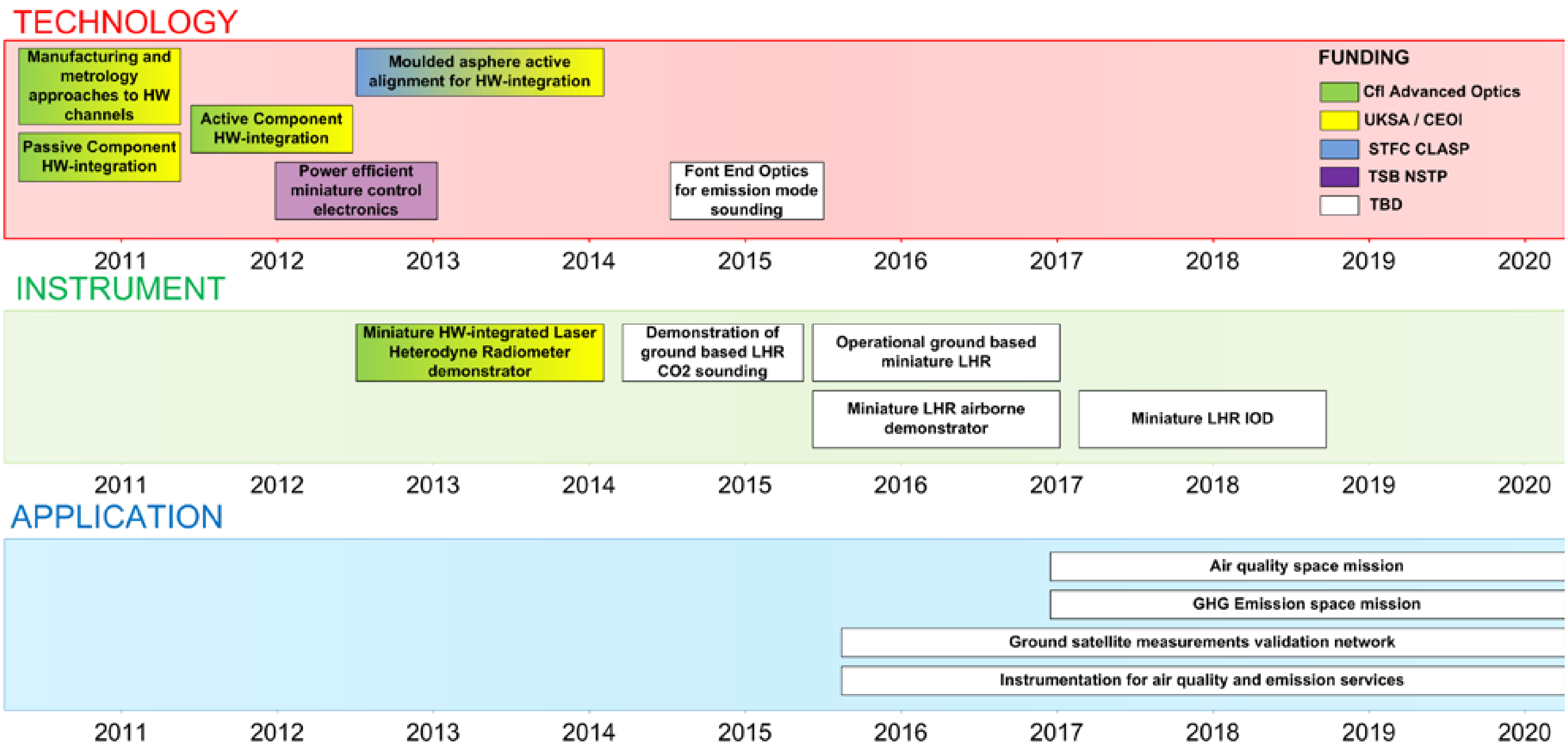
- Ø Miniaturization QCL control
  - – 10 x 20 cm board
  - – While power efficiency X2
  - – While stability X4
- Ø Miniaturisation of detector electronics
  - – T control and preamp







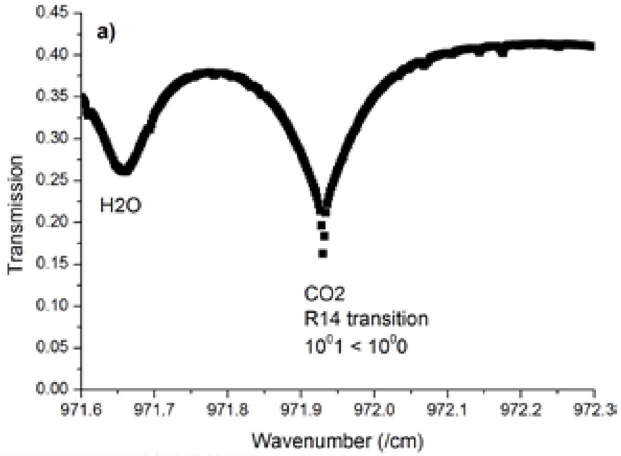
Simplified Roadmap

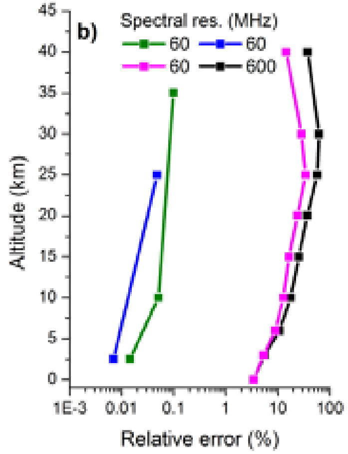


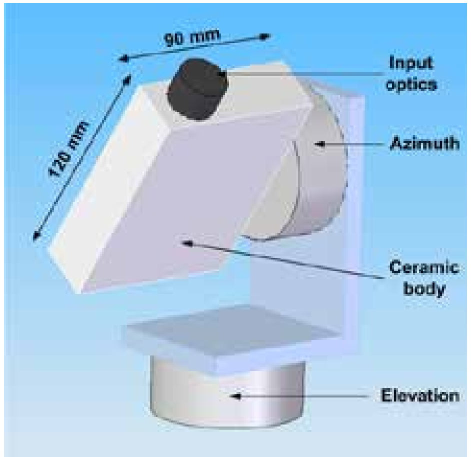
Applications

Ground-based component of EO system

- Ø Emission monitoring and air quality applications
- Ø Autonomous ground-based network
  - – Validation of forthcoming fleet of CO2 sounders
  - – Part of integrated emission services
  - – Low cost and compact -> denser network
- Ø Prior analysis on ground based CO2
  - – Precision from 0.01% to 1%







Applications

Towards a GEO IOD

- Ø Air quality / emission monitoring
  - – E.g. Ozone / CO_2
  - – First step needs to be an airborne demonstrator
- Ø Very high spatial resolution (~1km)
- Ø Point and stare
- Ø Piggy-backing on large com sat
- Ø Evolve toward a combined SWIR – TIR instrument to improve tropospheric sensitivity