Miniaturized high performance spectrometers for microsat atmospheric mission

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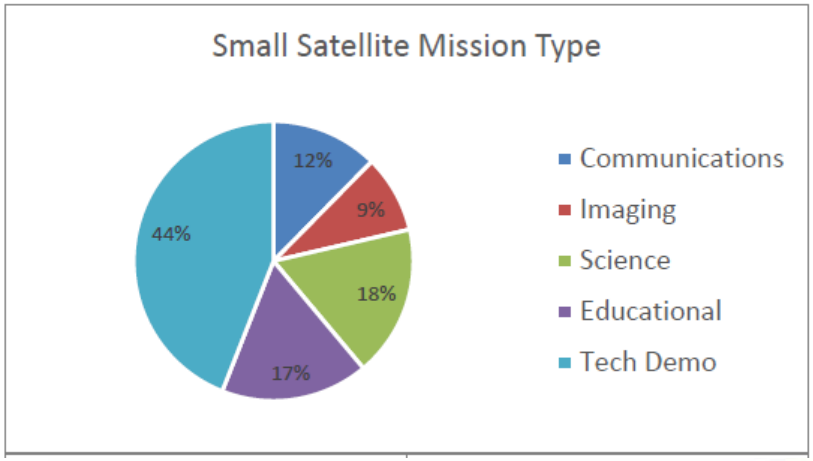
Outline

- The case for miniaturization
- Case of the TIR LHR
- MEMs based spectrometers
- 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

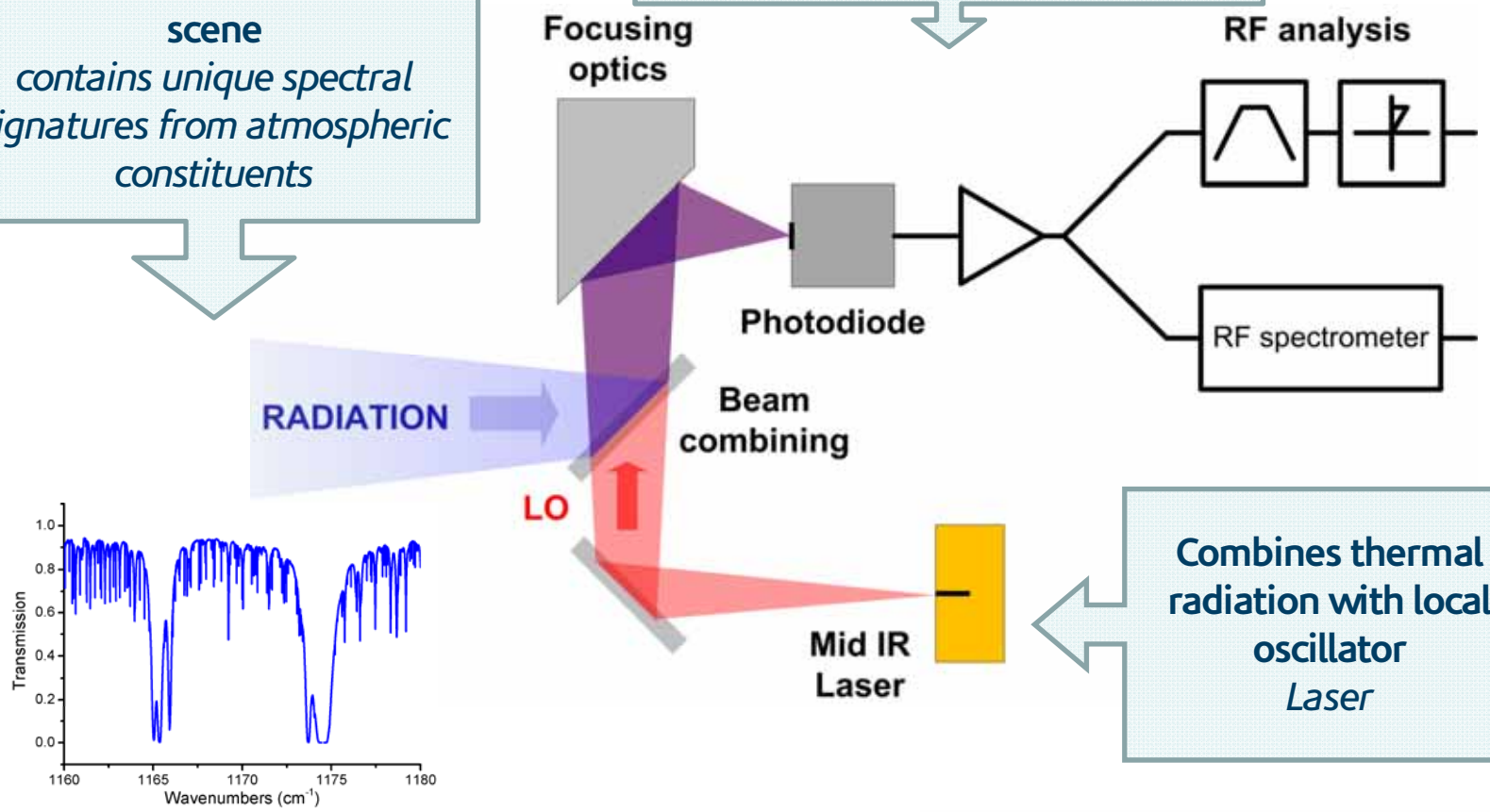


Optical Heterodyne Spectroscopy

Basic principles

Collects 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

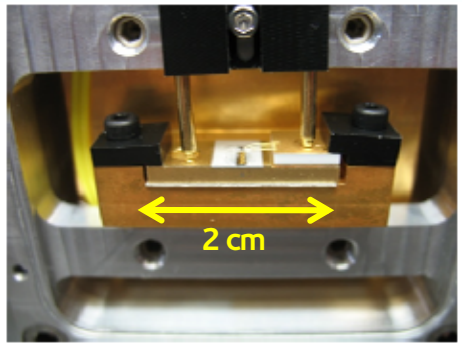
Laser Heterodyne Radiometers

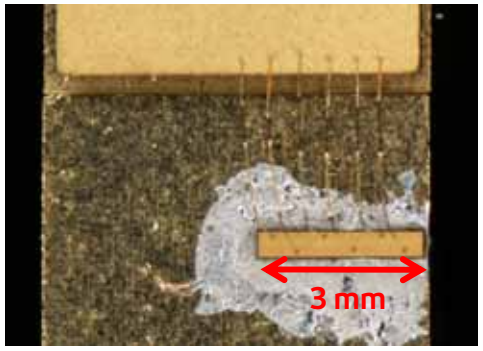
Benefits for Earth Observation

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**

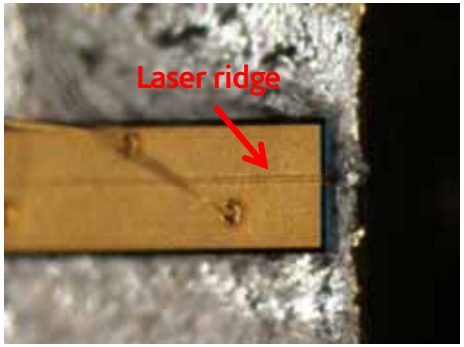
Mid IR Key Components

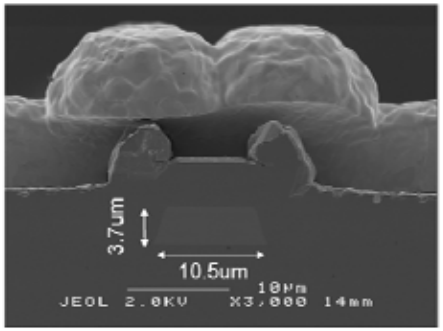
Ultra-miniature solid state devices



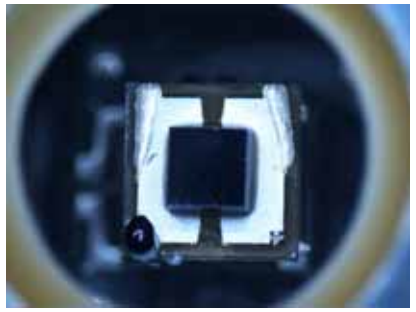


Quantum Cascade Laser





Hg Cd Zn Te Photodiode



Micro- cooler if 80K operation required

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

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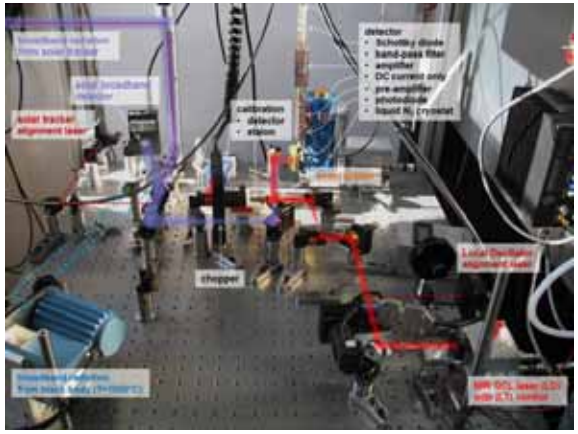
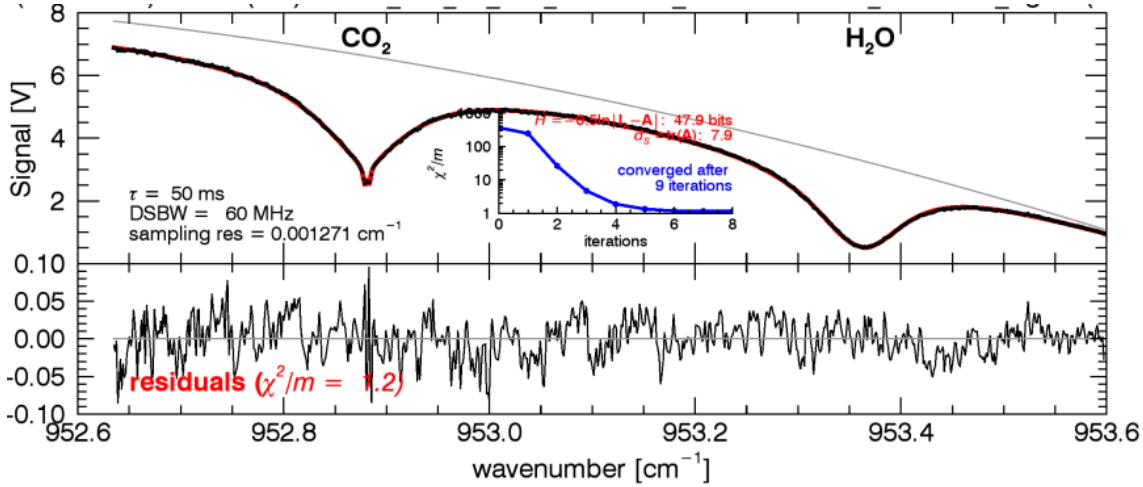
Miniaturization Path – Step 1

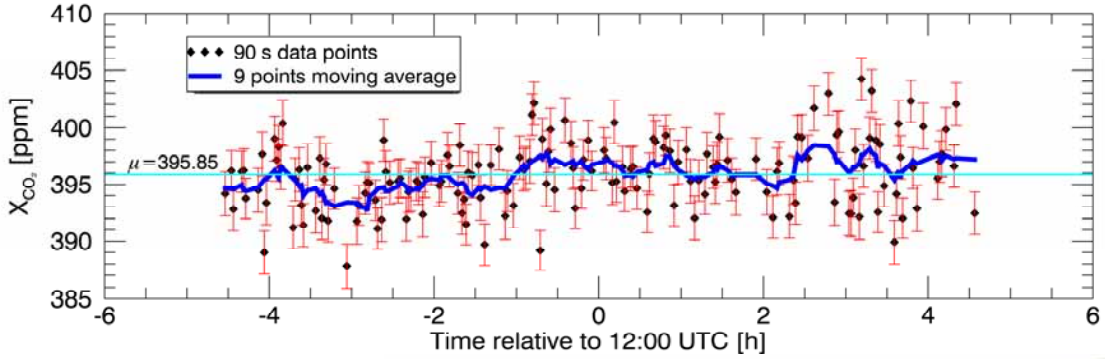
Bench-top Demonstrator



H2O and CO2 in high resolution atmospheric transmission



CO_2 dry total column



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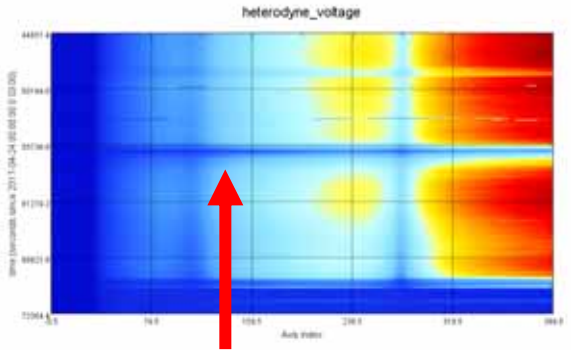
Miniaturization Path – Step 2

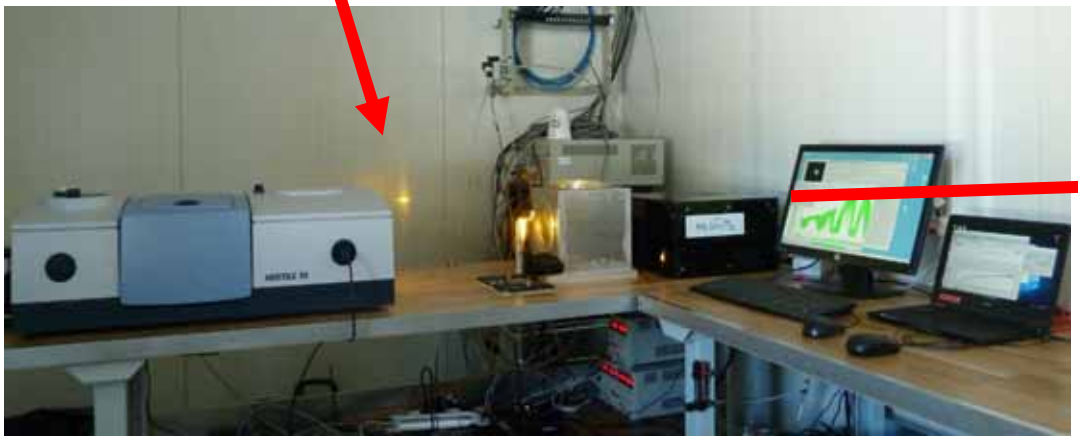
Re-engineered for ESA ground-based field Campaign

Container Lab at Finnish Arctic Research Station

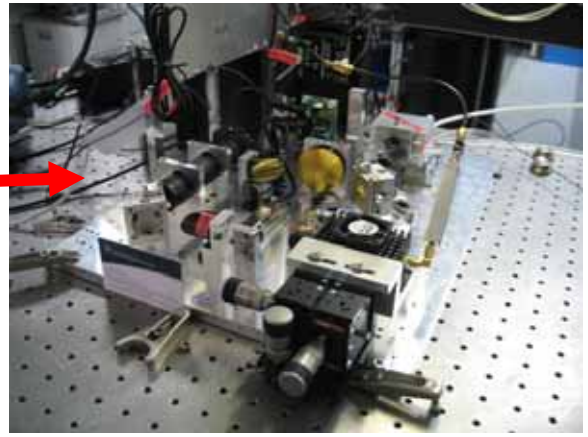
Last week CO2 spectra



40x40x20 cm³ LHR installed inside

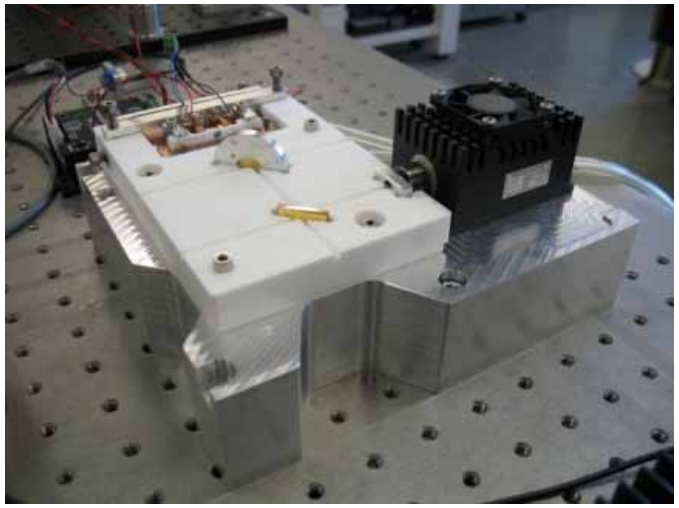


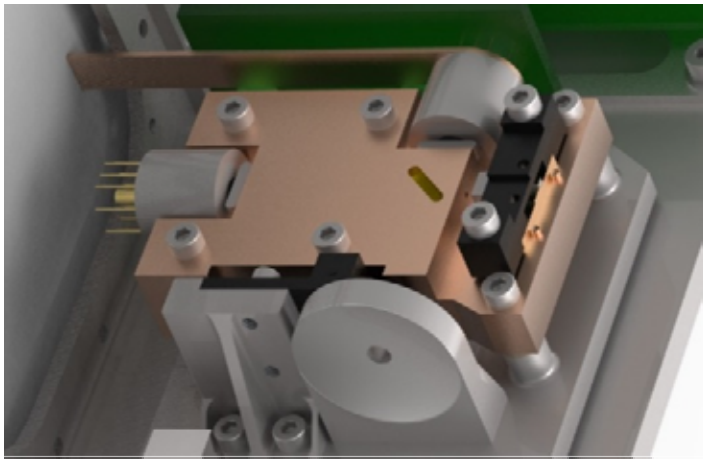
LHR optical breadboard



Miniaturization Path – Step 3

Hollow waveguide integration





- Ceramic HW demonstrator
  - 9x12 cm^2
  - Improved stability
  - Improved heterodyne efficiency
- Metal HW for cubesat
  - 5x6 cm2
  - Currently under study

MISO micro-satellite mission

Methane Isotopologues by Solar Occultation

Technology push

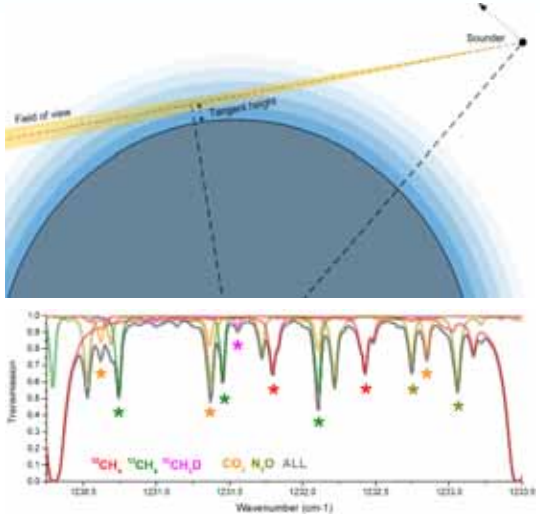
In orbit demonstration mission of:

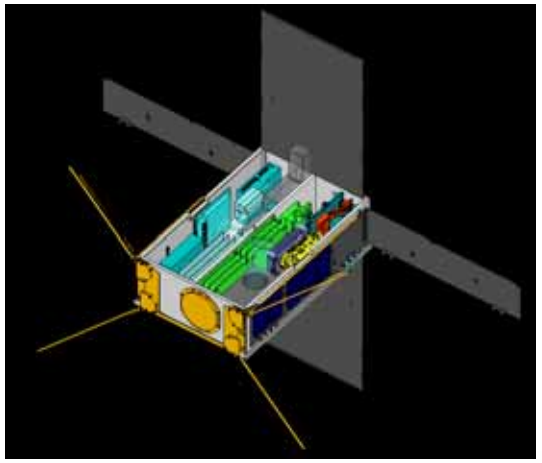
- LHR spectrometer and component
- Dual band high res isotope sensing
- Hollow waveguide miniaturization technology
- Solar occultation limb from a small sat

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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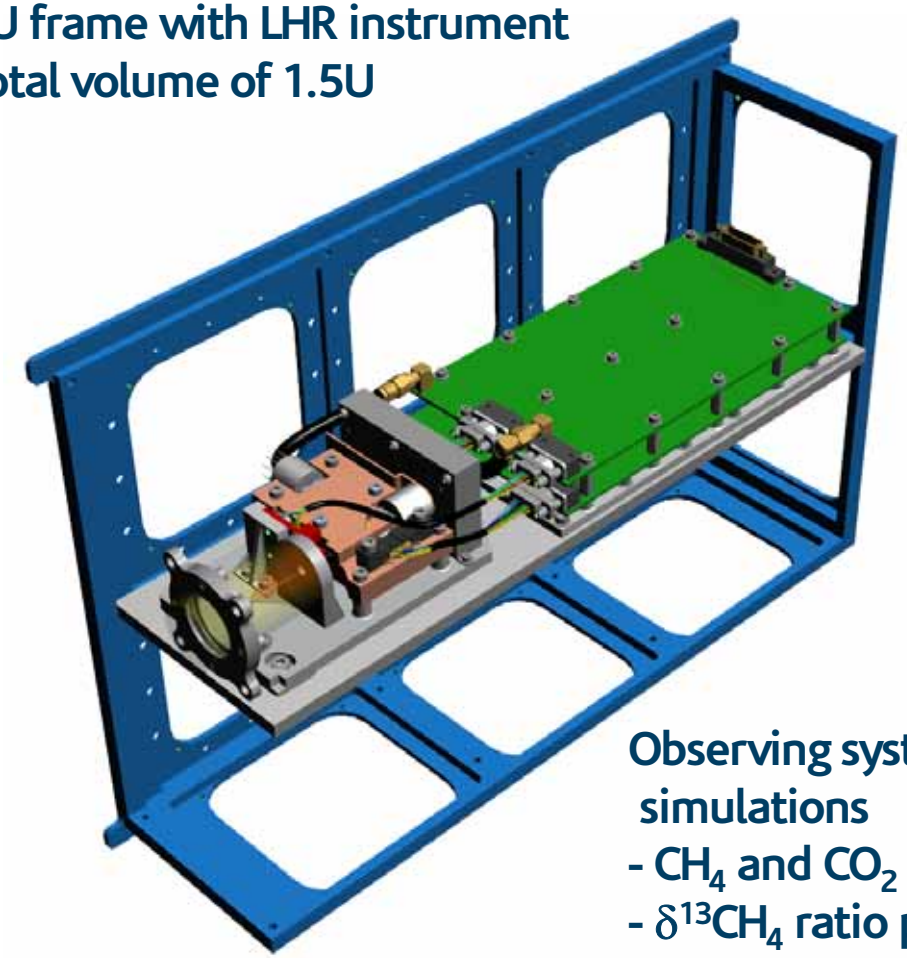
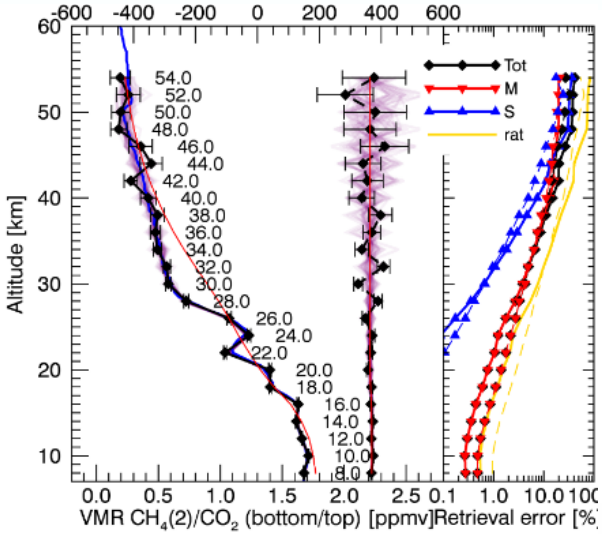
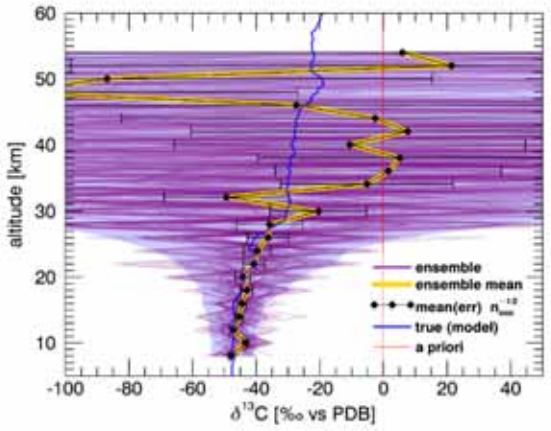
Phase A Study Outcomes

6U frame with LHR instrument
Total volume of 1.5U







Observing system simulations
- CH_4 and CO_2 profiles
- $\delta^{13}CH_4$ ratio profiles

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Improving Measurements
Additional complementary information

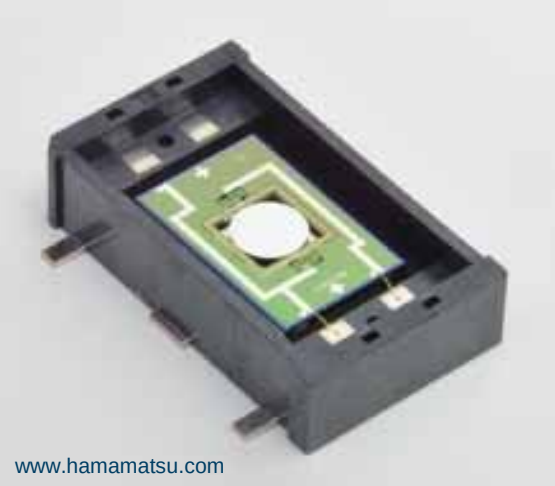
- LHR offers:
  - Thermal IR information (emission)
  - High spectral resolution (individual lines)
  - Narrow spectral micro-window

- Possible complementarities with
  - Short wave IR (solar scattering)
  - Low spectral resolution (full bands)
  - Wide coverage

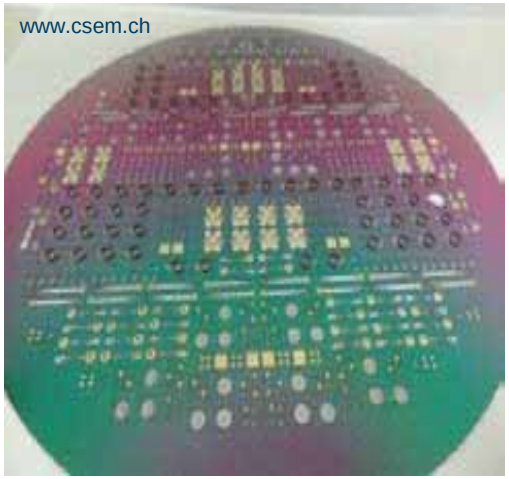
- Case for dual miniaturized instrument system

Silicon MEMS

- Advanced technology: large scale, low cost production developed in electronics industry

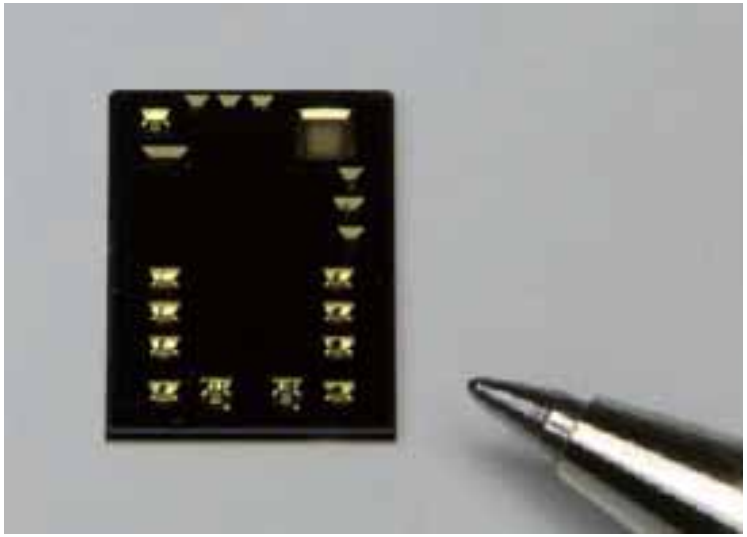


- Demonstrated optical performance (MOEMS)
- Etched and grown micron-scale features
- Wafer scale production

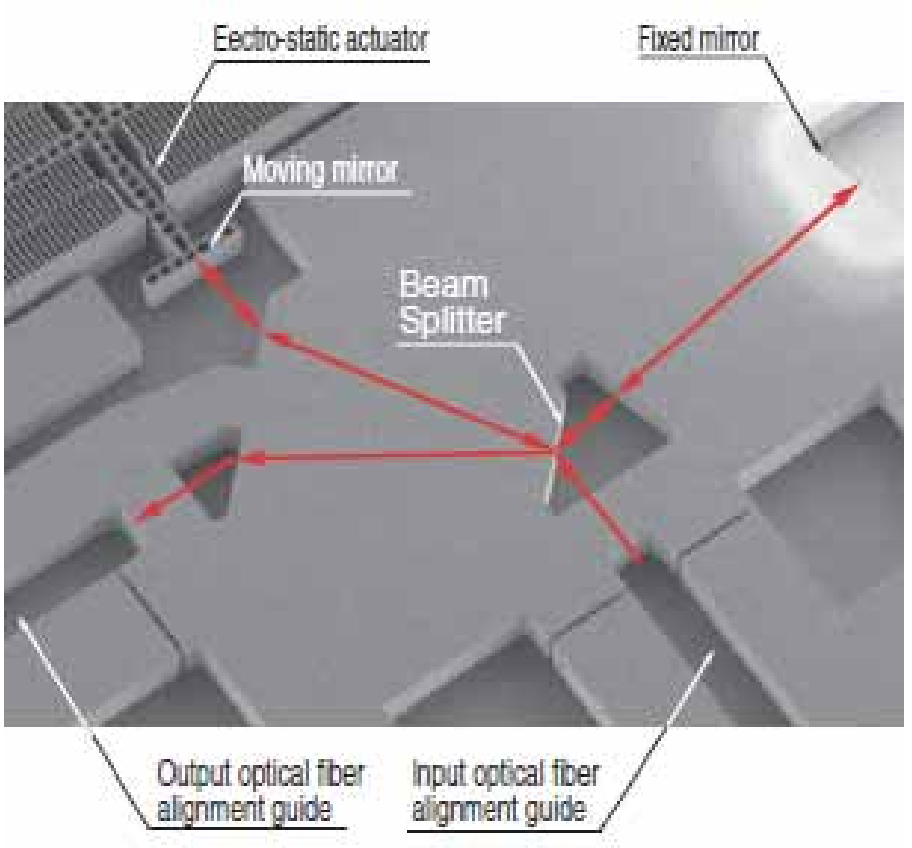


- Silicon transparent in SWIR: waveguide integration

MEMS SWIR FTIR



Silicon wafer with
integrated MEMS FTIR

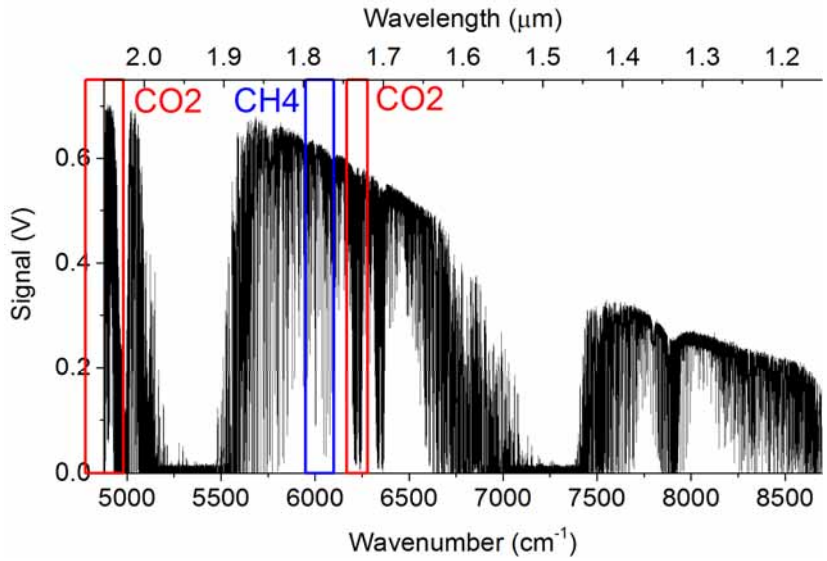


Pictures courtesy HAMAMATSU

Programme of work

CEOI pathfinder

- Investigate CO2 and CH4 spectroscopy
  - 12 nm resolution
  - 1.15 - 2.05 µm band
- Analyse radiometric and spectral performances
- Quantify impact of space environment testing
  - Temperature cycling
  - Vibrations



- Run atmospheric simulations
  - Retrieval performances
  - Added value of LHR / MEMS FTS

Conclusion

- Very disruptive trend towards small satellite
  - New technologies needs to follow the miniaturization agenda
  - Great opportunity for IOD programme
- TIR LHR and SWIR MEMS FTS fulfils the size/power constraints
- Excellent ratio sounding performance/size and cost
- Relevant to private business venture (e.g. GHGsat or Bluefield)
- Relevant to cost effective planetary exploration

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