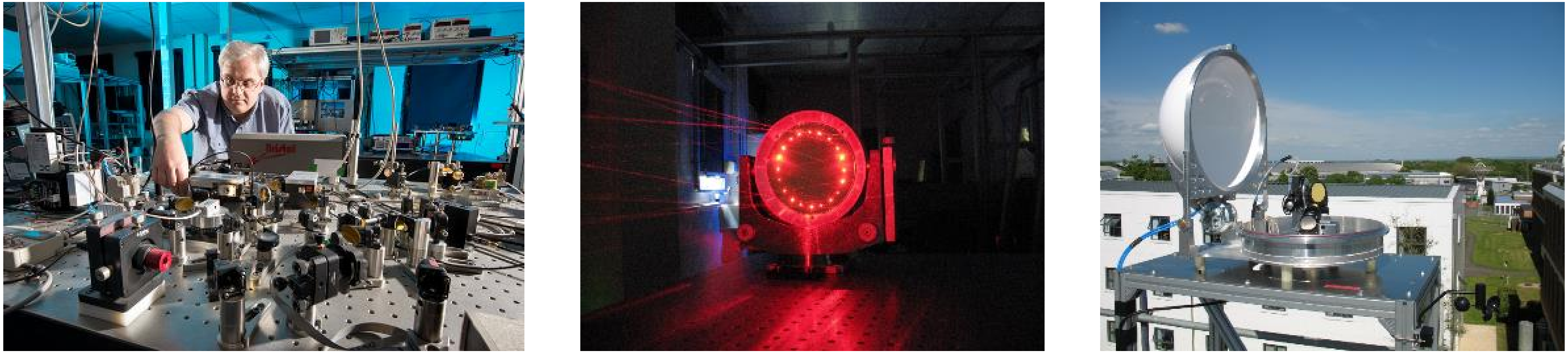
Photonics Integration Technologies for Small EO Platforms

Damien Weidmann



Scope & Outline

- Scope
  - Photonics technologies
  - Spectrometers for atmospheric composition sounding
  - System miniaturization for small payloads

- Outline
  - Drivers
  - Three miniaturization photonic technologies
    - Integrated LHR
    - MEMS FTS
    - Mid IR waveguide structures
  - Conclusion

Drivers

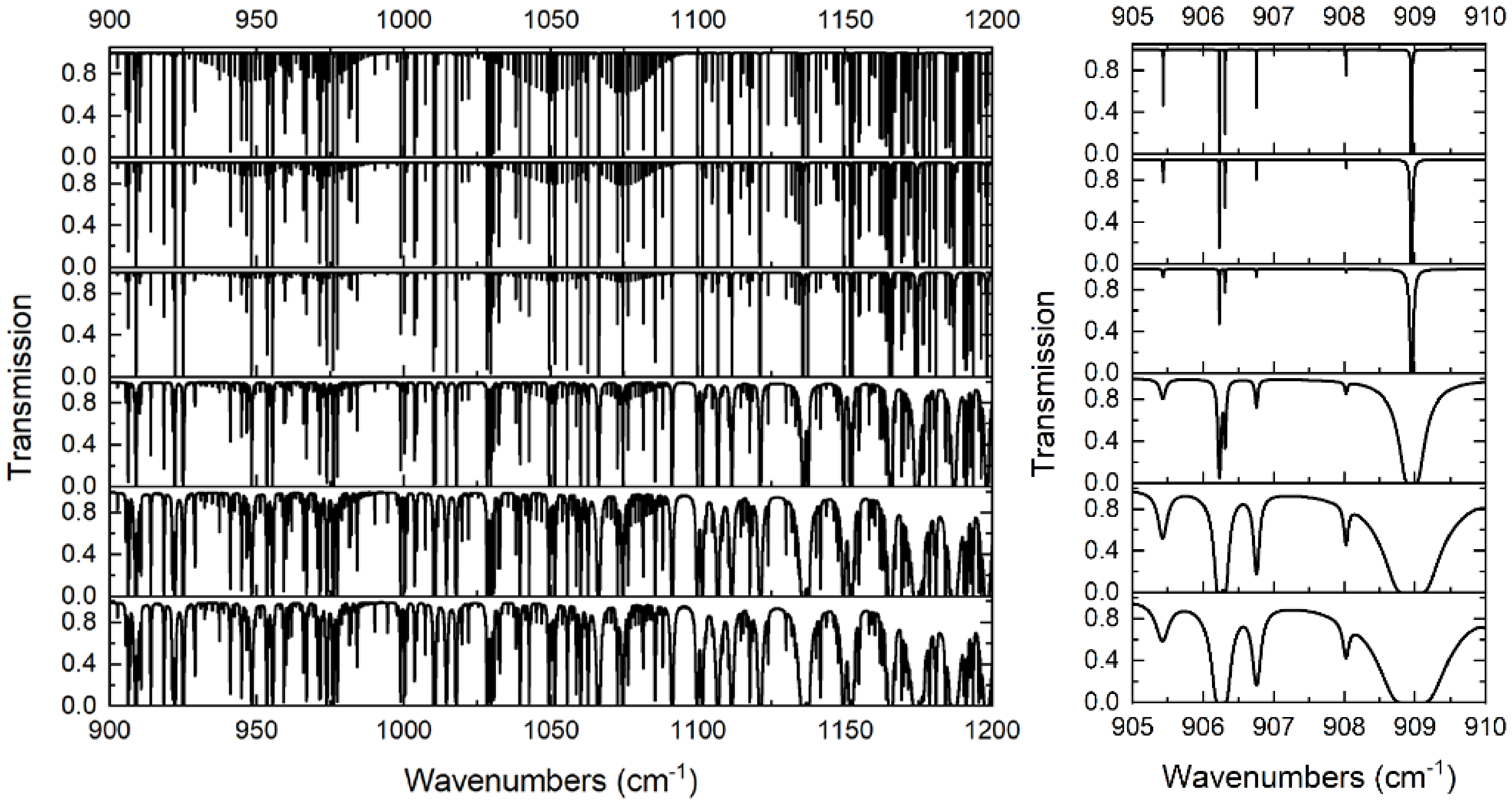
- Atmospheric composition sounding
  - GHG/Climate and Pollutants/Air quality

- Small is enabling!
  - Reduced costs and increased agility and sounding configurations
  - NanoSats / microSats
  - High altitude / long endurance platforms
  - Closer to the ground: UAV and robots

- Network of coordinated sensors vs a large high specs one
  - Cost benefits - Resilience - Economy of scale
  - Multi scale sensing, combining ground – air – space sensing

- Platform Hosting (Coms)

Need for High Spectral Resolution Sounding



25-45 km – 5 mbar
R = 200,000

15-25 km – 25 mbar
R = 200,000

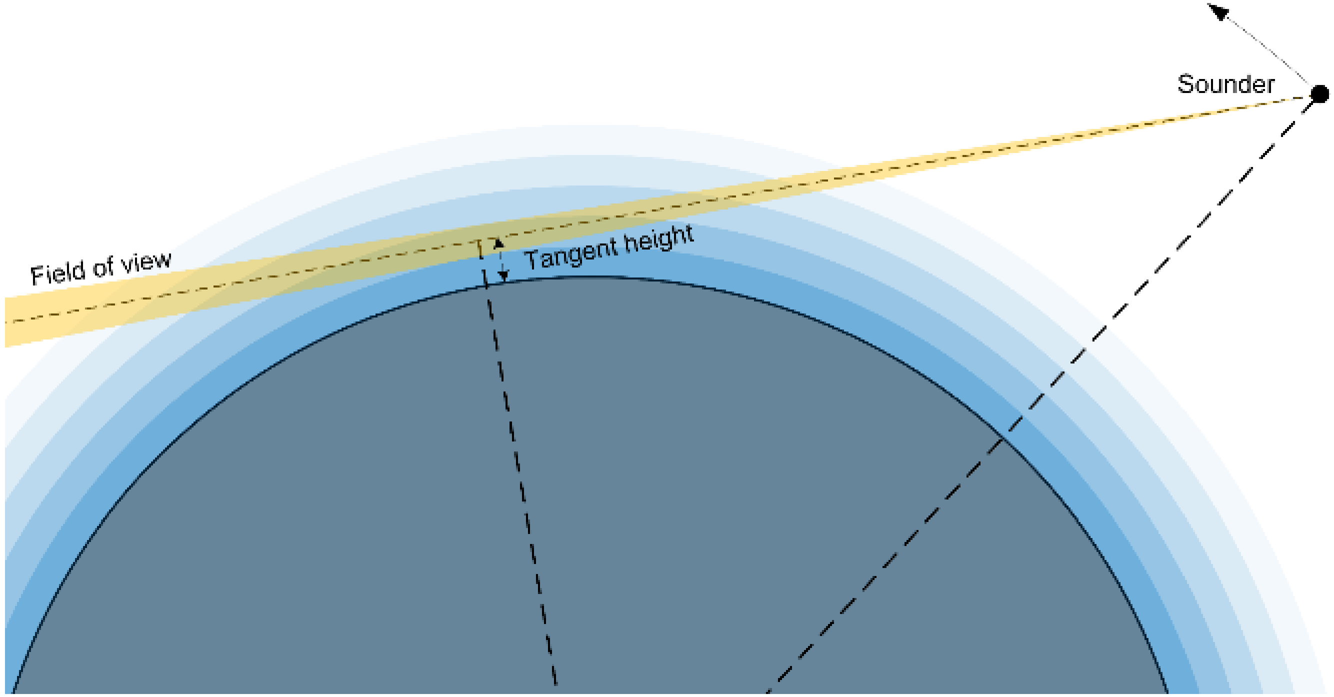
10-15 km – 70 mbar
R = 100,000

6-10 km – 370 mbar
R = 20,000

2-6 km – 600 mbar
R = 10,000

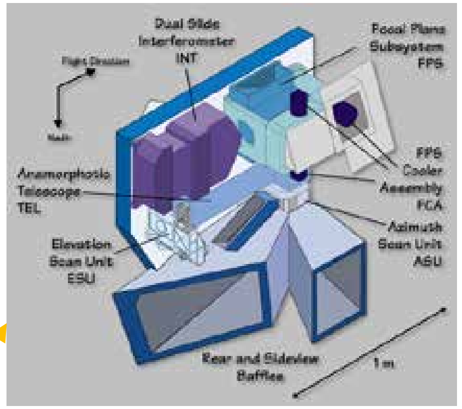
0-2 km – 900 mbar
R = 5,000

Limb Sounding



High Res FTS
e.g. MIPAS
330 kg
>1 m3

https://earth.esa.int



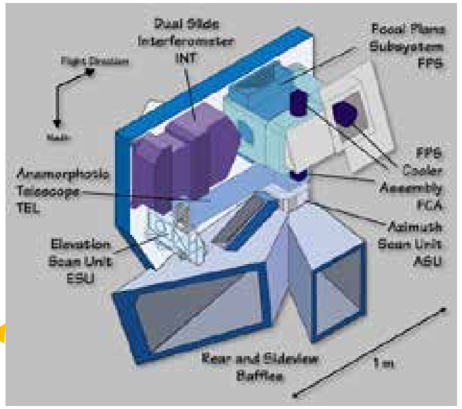
https://www.iaa.csic.es

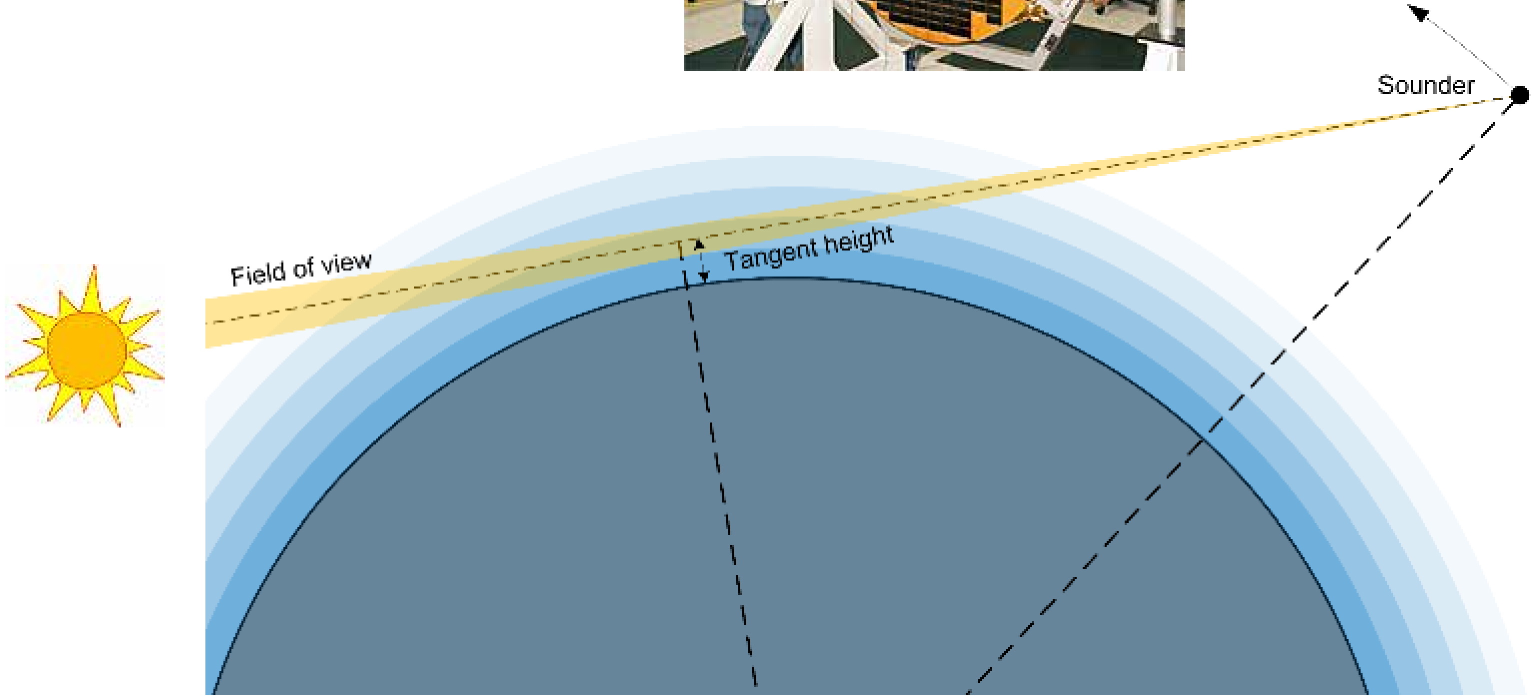
Solar Occultation Limb Sounding

Mid Res FTS
e.g. SCISAT
150 kg

High Res FTS
e.g. MIPAS
330 kg
>1 m^3

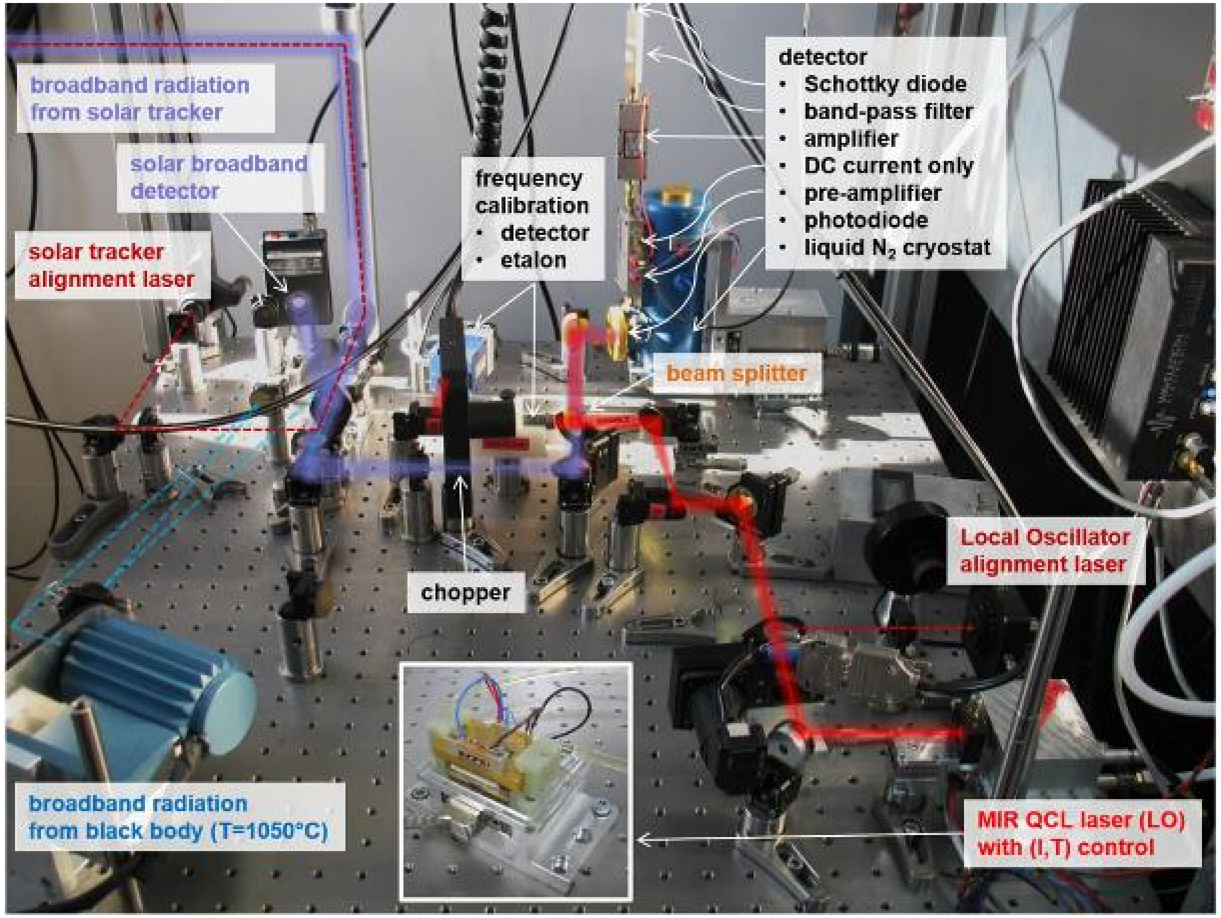
https://earth.esa.int

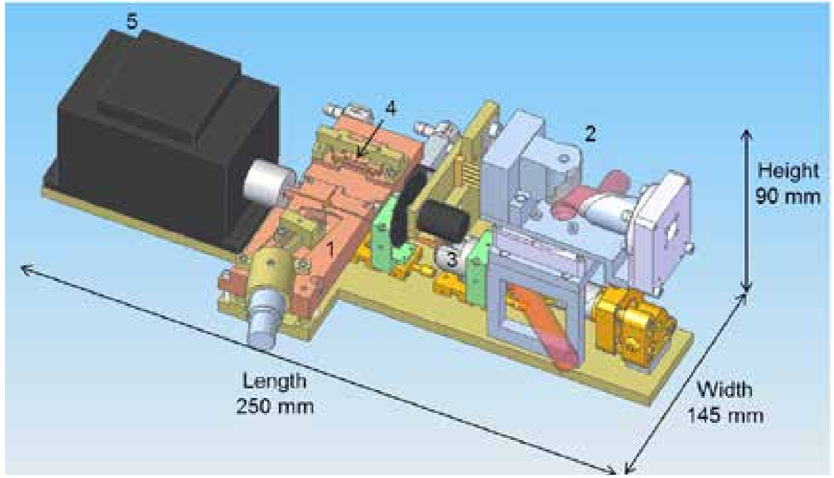




https://www.iaa.csic.es

Miniature LHR for CO_2 and H_2O Sounding





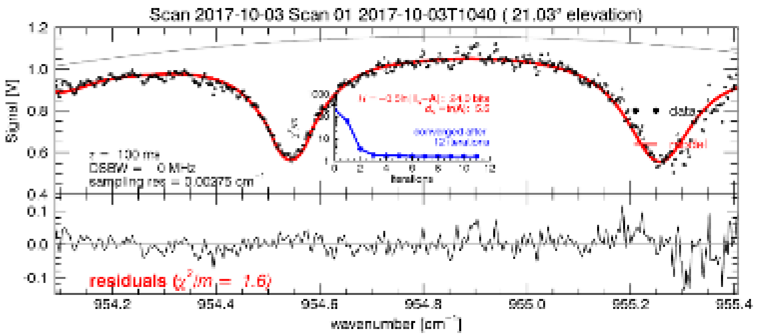
From Hoffmann et al., Atmos. Meas. Tech., 9, 5975–5996, 2016

doi: [10.5194/amt-9-5975-2016](https://doi.org/10.5194/amt-9-5975-2016)

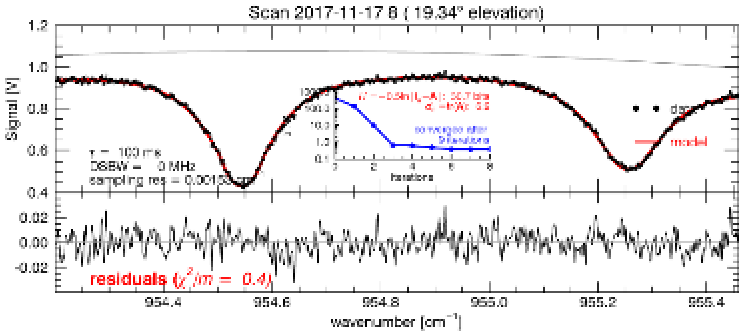
Ground-based demonstration

Demonstration in ground-based solar occultation @ 955 cm^{-1} (10.47 μm)
0.02 cm^{-1} resolution (Resolving power of 50,000)

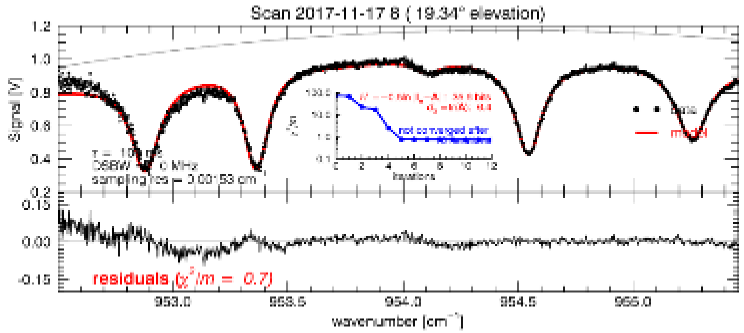
Current scan

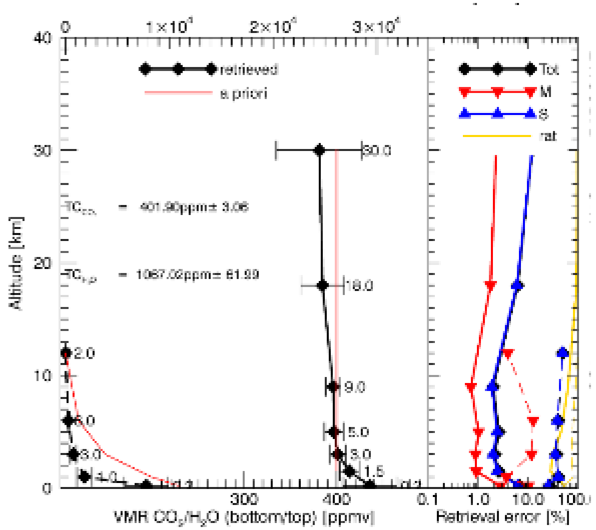


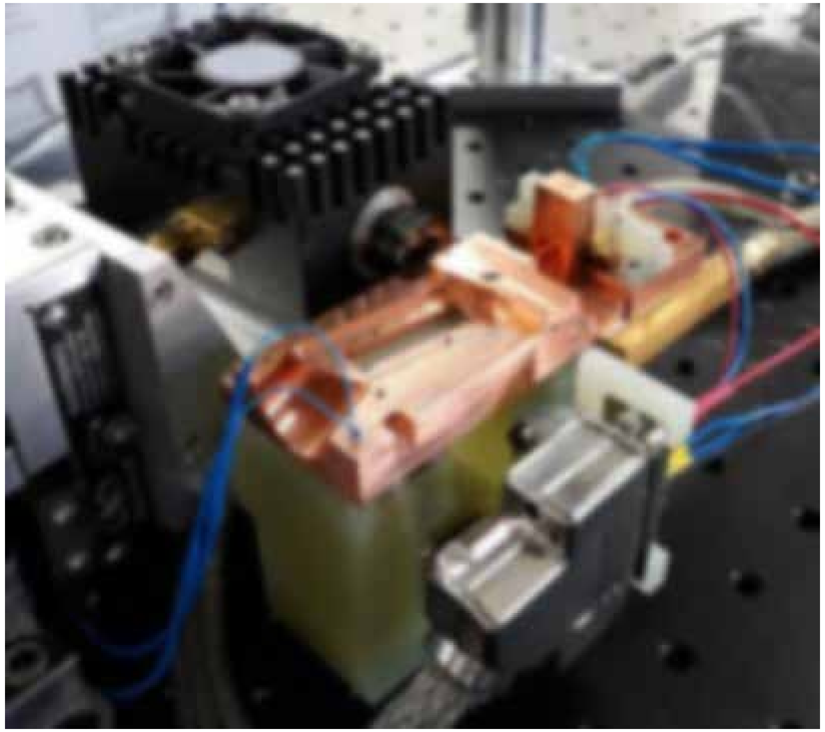
Temperature scan



Noise vector







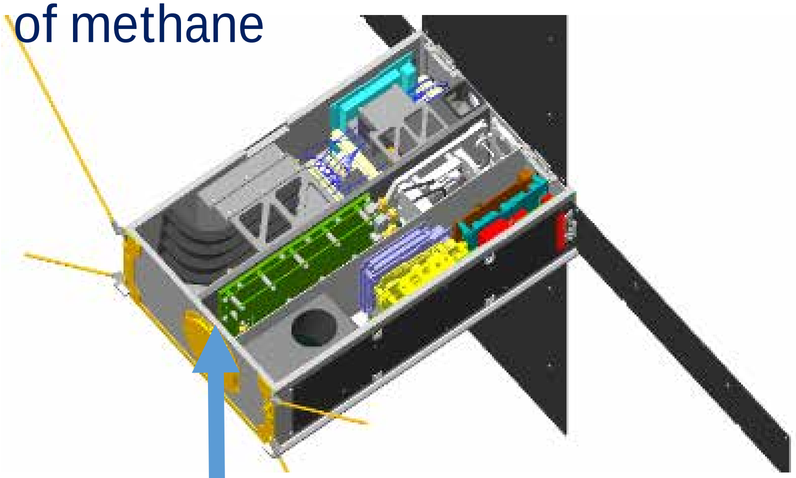
Payload for MicroSat Missions

RAL Space
Spectroscopy

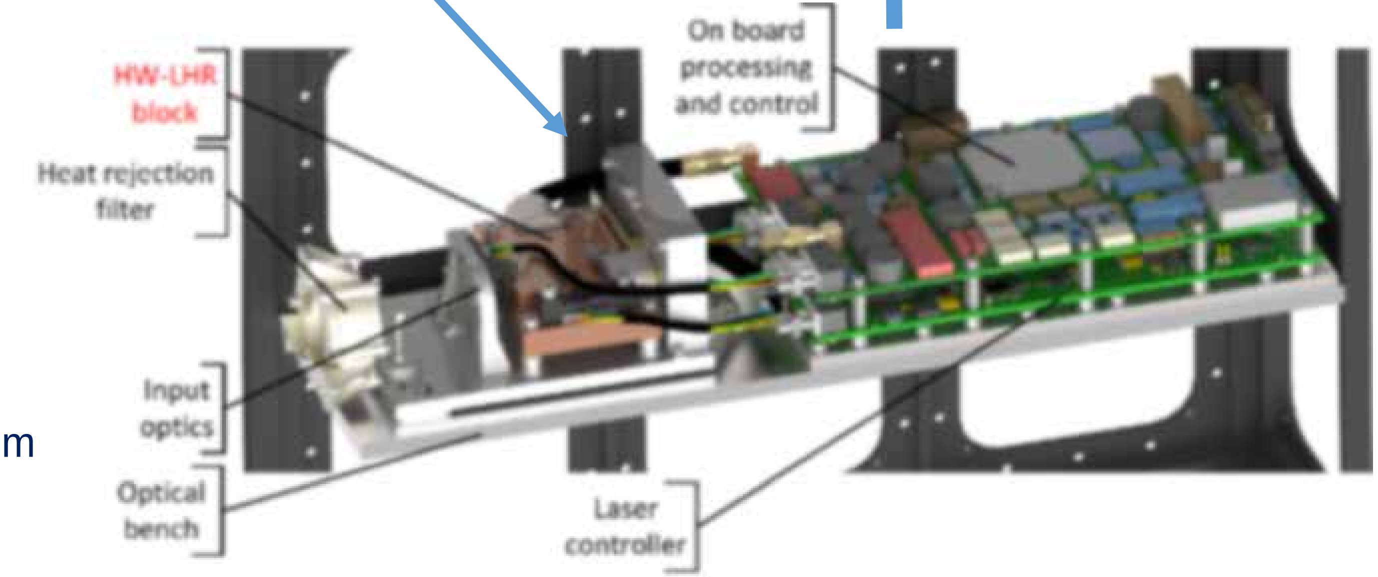
Phase a Study for MISO nanosat mission to provide high resolution profiling of methane

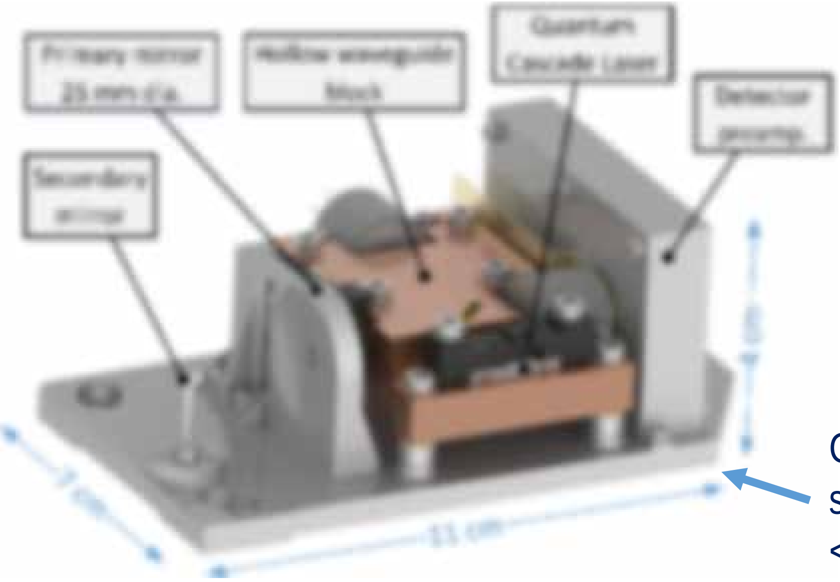
The Methane Isotopologues by Solar Occultation (MISO) Nanosatellite Mission: Spectral Channel Optimization and Early Performance Analysis, D. Weidmann et al., Remote Sens. 2017, 9, 1073, doi: 10.3390/rs9101073

Instrument payload < 1.5 U
< 20 W peak
< 2 km vertical resolution from 7 to 50 km



Optical Subsystem + control & acquisition electronics





Optical subsystem < 0.5U

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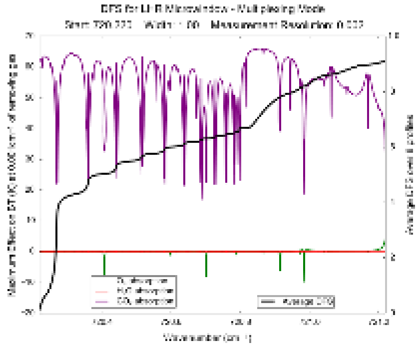
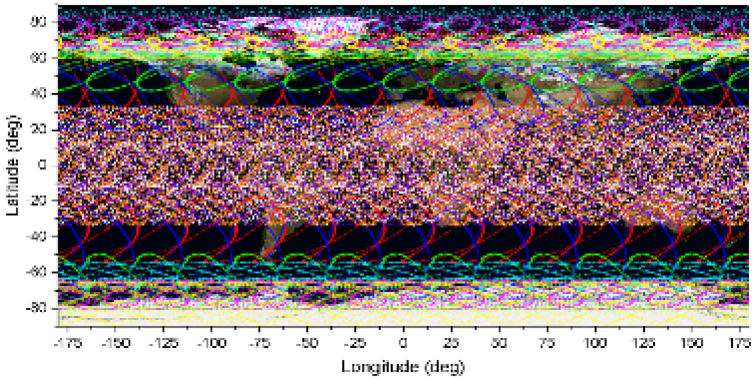
Further Missions Proposed

Small sat based meteorology missions



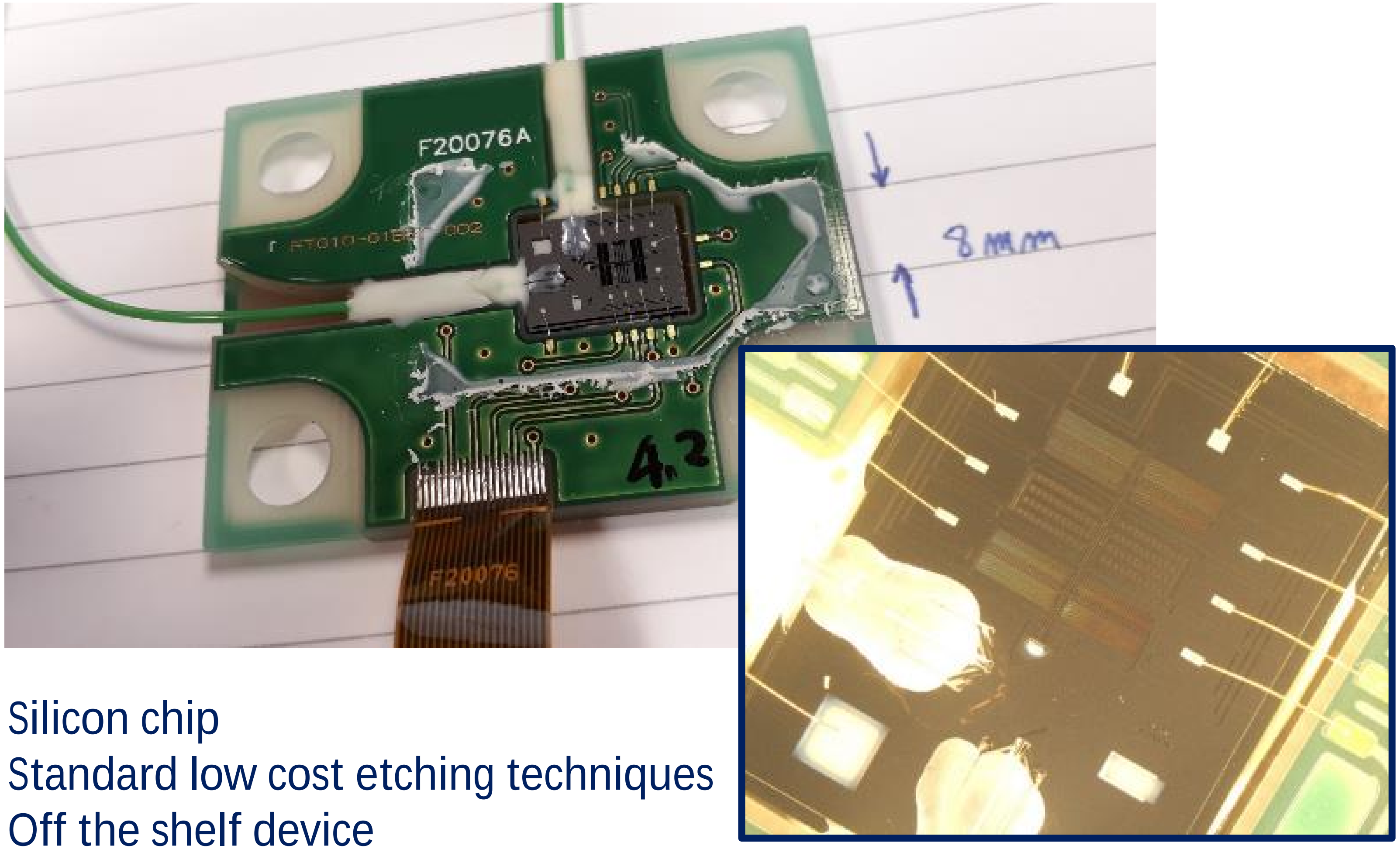
- IASI taken as benchmark
  - H_2O and T sounding
- Best configuration identified
  - Geostationary / point and stare LEO
  - Stratosphere/mesosphere T sounding
  - Gap filling in upper atmosphere NWP infrastructure
- ***Evaluation of laser heterodyne radiometry for numerical weather prediction applications***, F. Smith et al., QJR Meteorol Soc., 1–20, 2018, doi: 10.1002/qj.3365

EE10 CAIROS

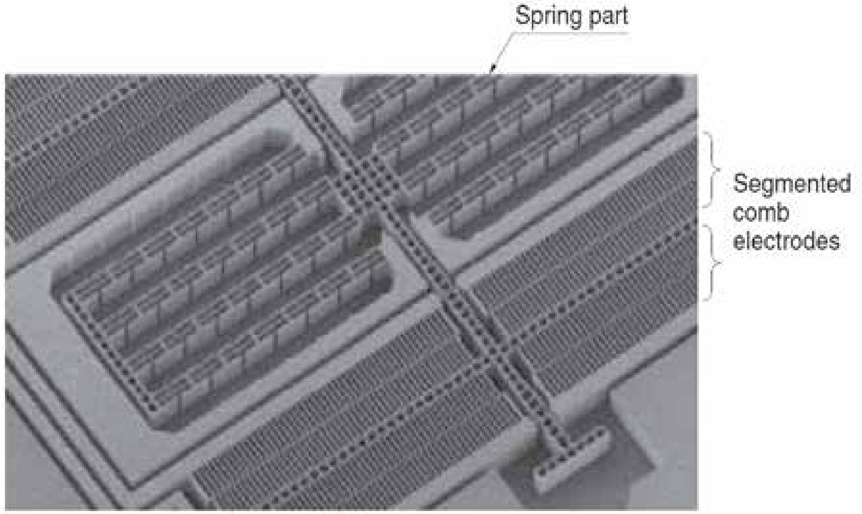


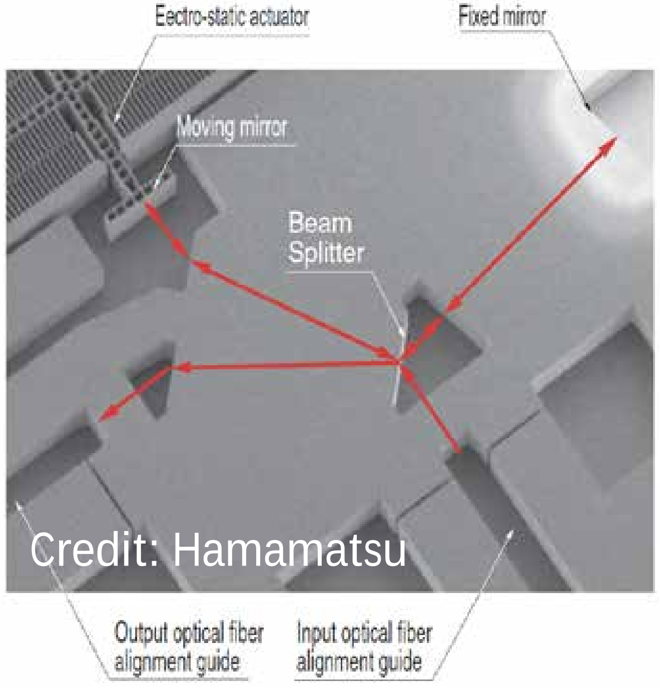
- Constellation of 12 configurable satellites for middle atmosphere studies
- Addressed scientific questions
  - Quantify H2O in UTS and understand climate feedbacks
  - Quantify and understand gaseous and particulate composition in UTS, response to emission and exchanges
  - Provide accurate representation of vertical distribution of GHG and O3 precursors
  - Evolution of O3 stratospheric layer
  - Impact of UV and charged particules in the US and links to climate.

Miniaturized MEMS FTS



Silicon chip
Standard low cost etching techniques
Off the shelf device

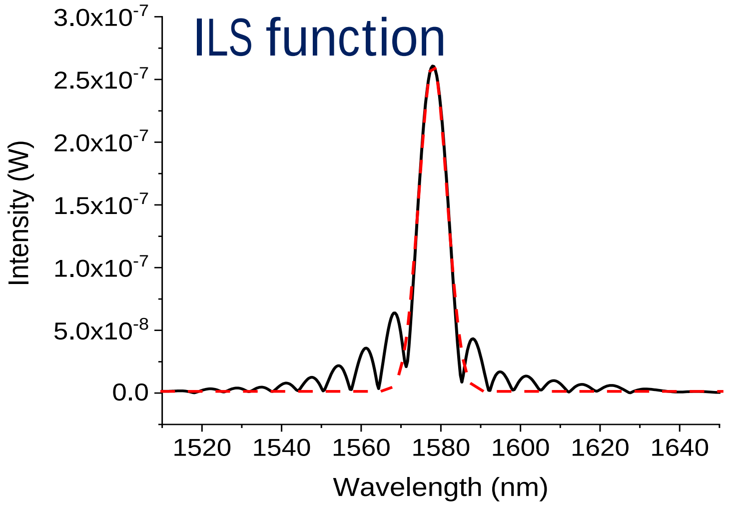


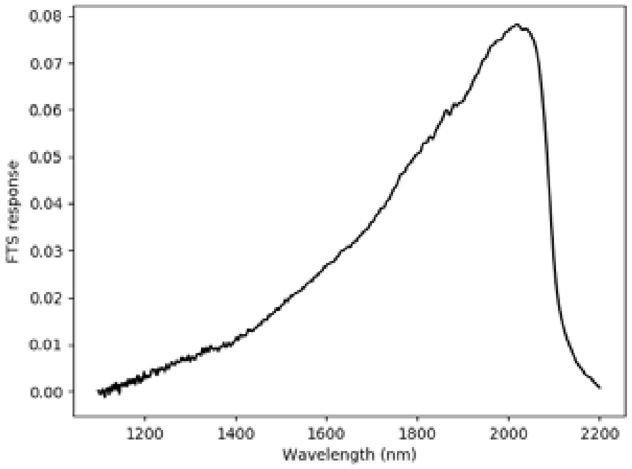


Credit: Hamamatsu

Evaluation for EO applications

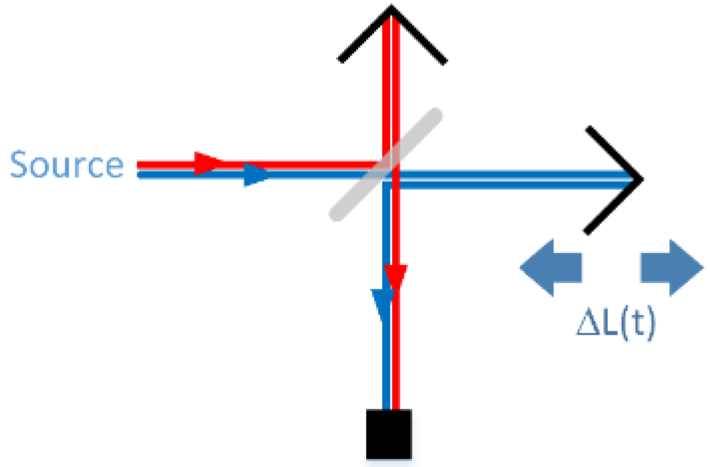
- Spectrometer performances
  - Resolving power 200 @ 1580 nm
  - Operating range 1150-2050 µm
  - 5 ms scan
  - Peak response efficiency 0.08
  - SNR 0.01X theoretical expectation for ideal FTS
- Environmental tests
  - MEMS structure survived vibration testing
    - Cubesat launch scenario



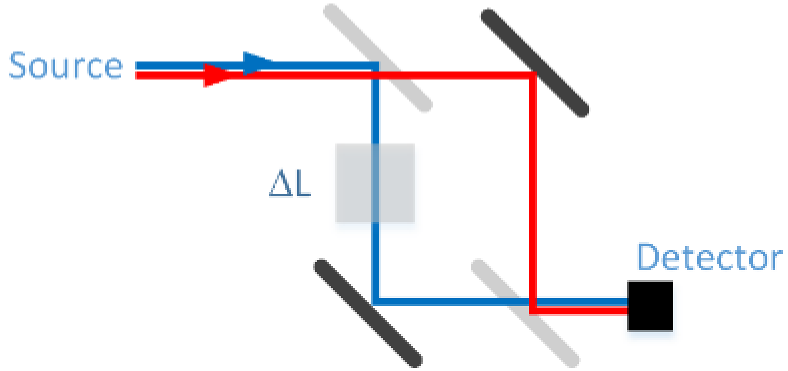


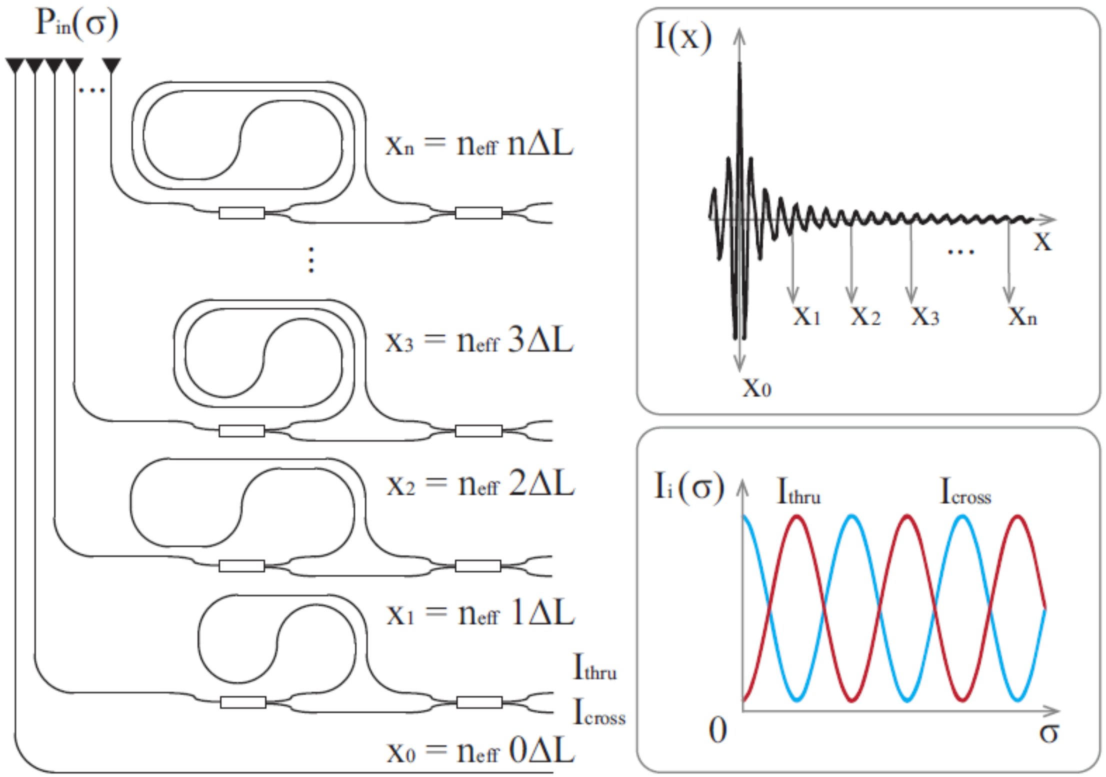
Static Planar Waveguide FTS

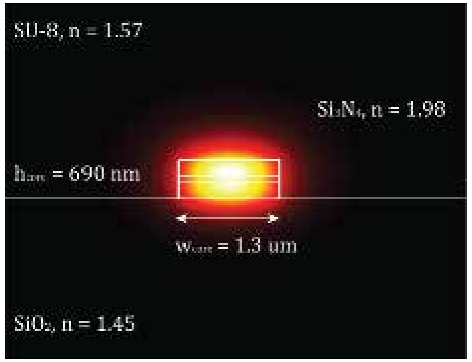
Michelson Interferometer

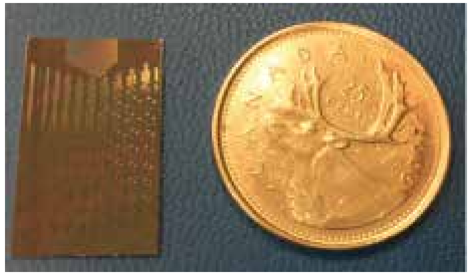


Mach Zehnder Interferometer



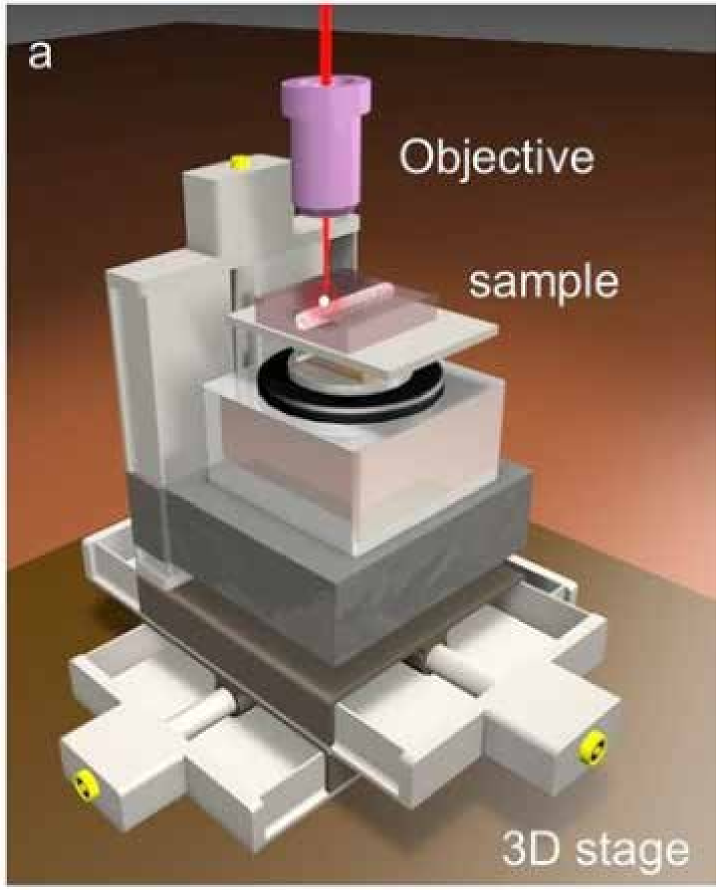


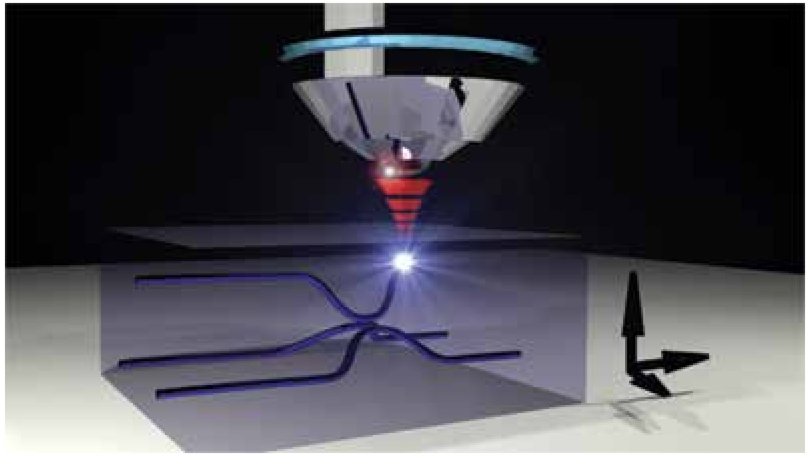




Taken from: Podmore et al., “Athermal planar-waveguide Fourier-transform spectrometer for methane detection”, 25, 26, 2017, 33018 DOI: 10.1364/OE.25.033018

3D Waveguide Structures for 1-11 µm





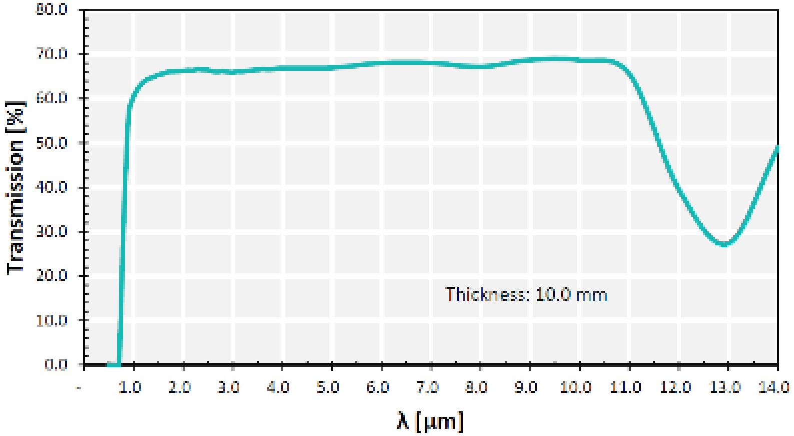
Ultra fast laser source
360 fs – 1030 nm – 500KHz rep rate
13 nJ pulse energy
Focused to ~1 µm x 3 µm

Chalcogenide glass $Ge_{33}As_{12}Se_{55}$ (IG2)

Collaboration with ATC and HW

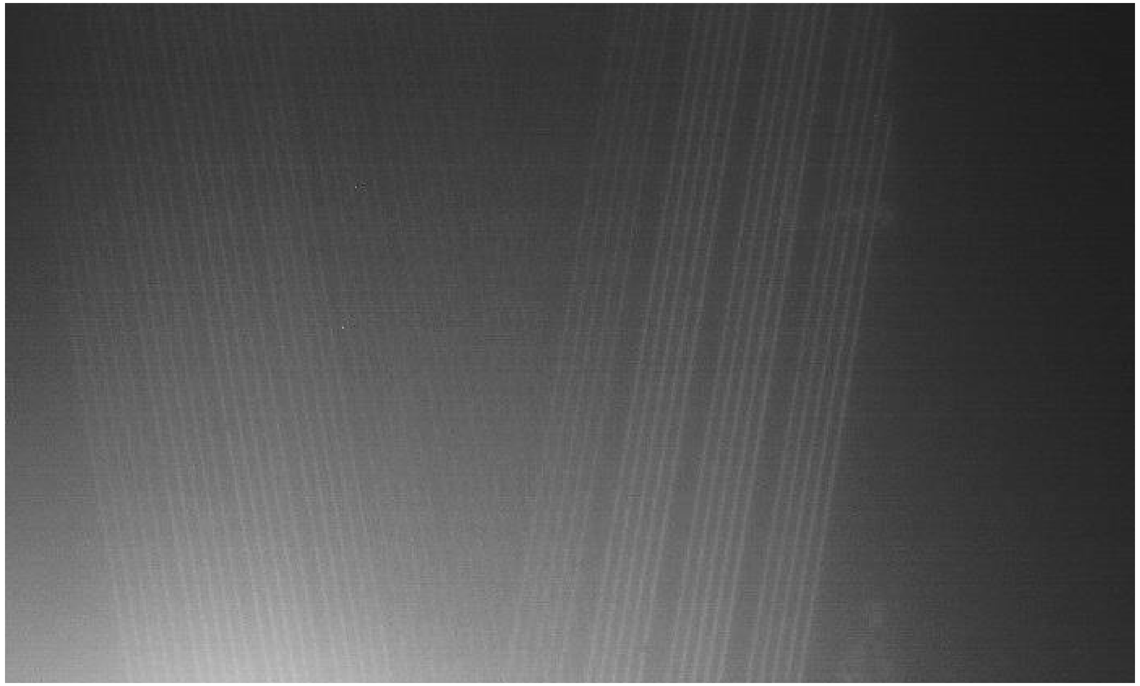
Science & Technology Facilities Council
UK Astronomy Technology Centre

HERIOT
WATT
UNIVERSITY

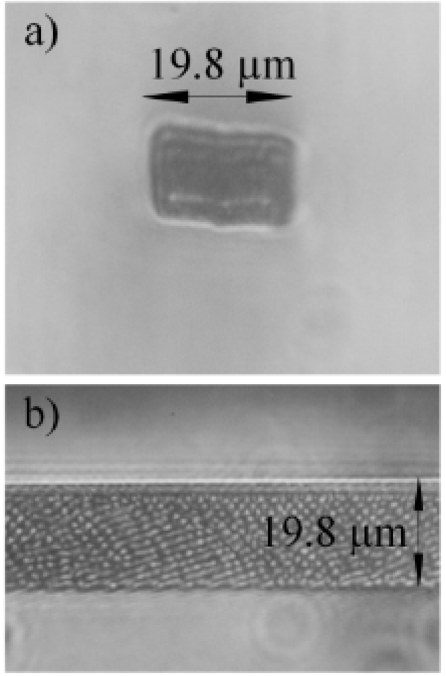


Building block 1 : Single Mode Waveguide

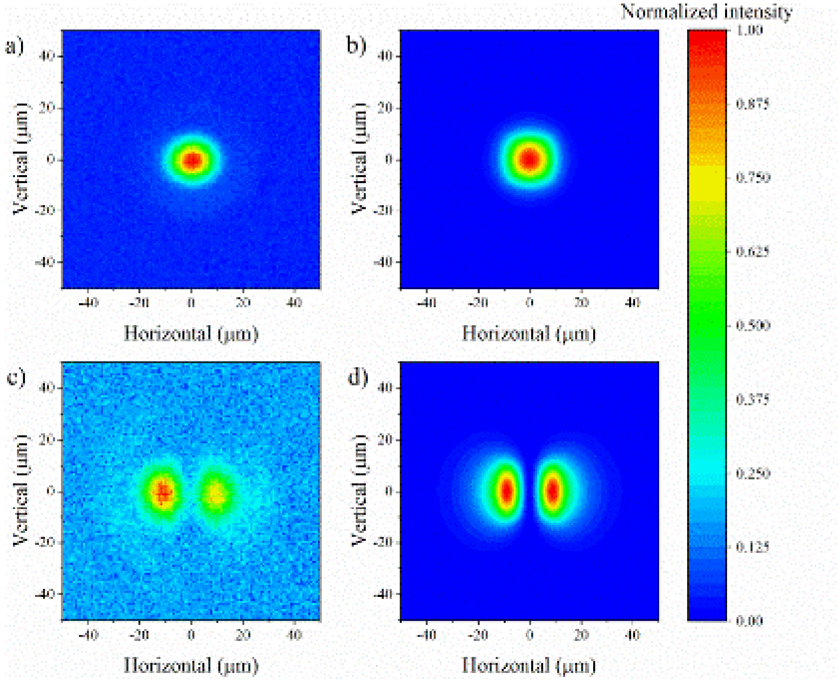
Photograph of a series of waveguides



Propagation loss 1 – 1.5 dB/cm



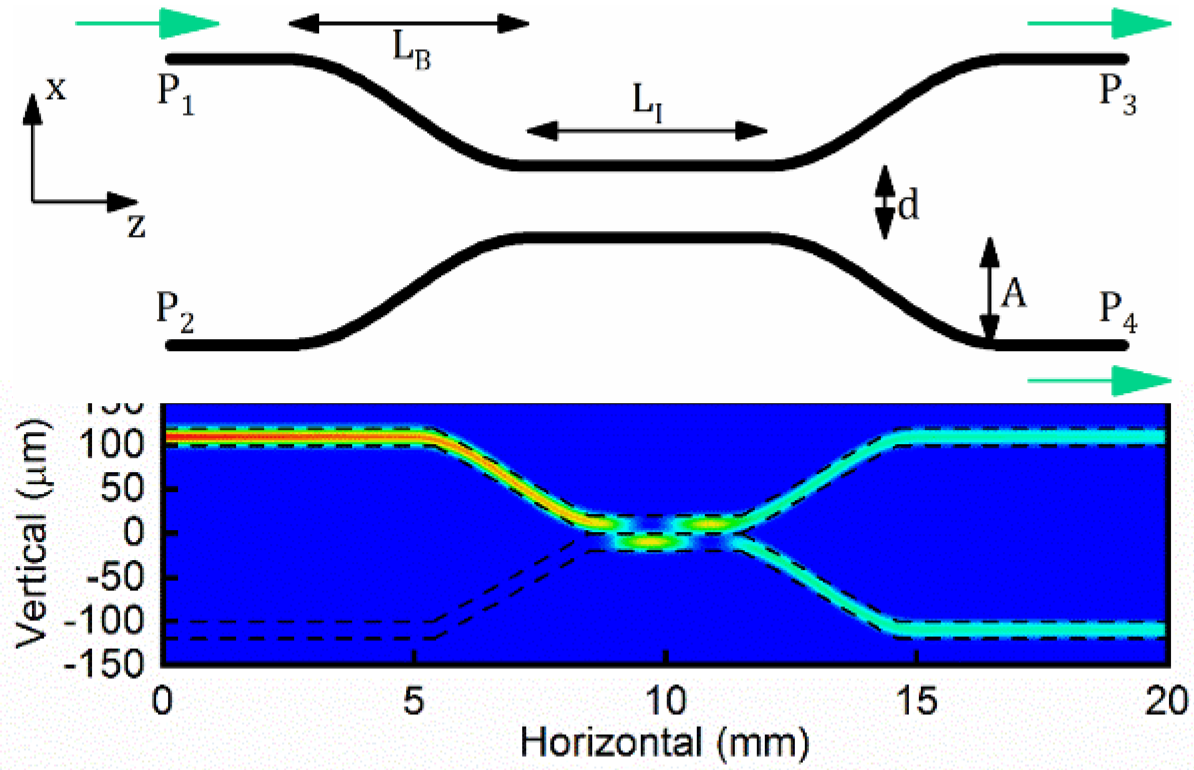
Spatial profiles
measured and modelled



Demonstration and characterization of ultrafast laser-inscribed mid-infrared waveguides in chalcogenide glass IG2, H. L. Butcher, Optics Express, 8, 26, 10930, 2018, doi: 10.1364/OE.26.010930

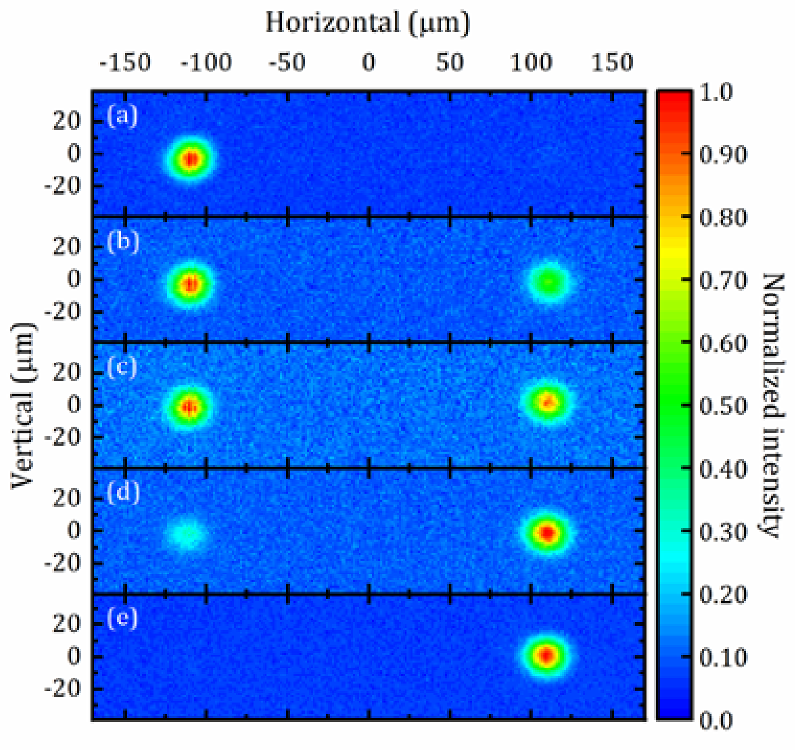
Building block 2 : Bend & Couplers

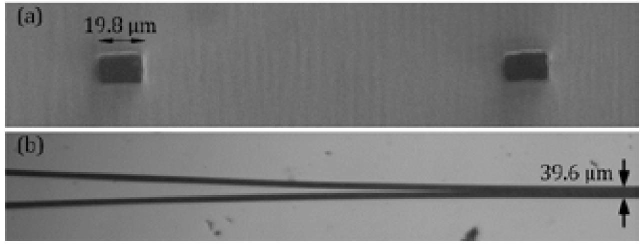
Evanescent wave couplers



Ultrafast laser-inscribed mid-infrared evanescent field directional couplers in GeAsSe chalcogenide glass

H.L. Butcher, OSA Continuum, 1, 1, 221, 2018, doi: [10.1364/OSAC.1.000221](https://doi.org/10.1364/OSAC.1.000221)





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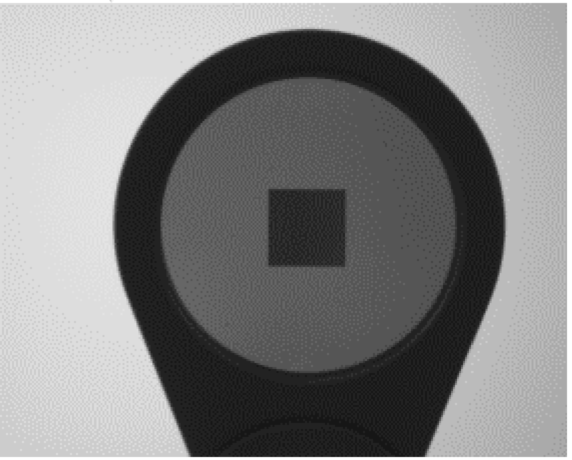
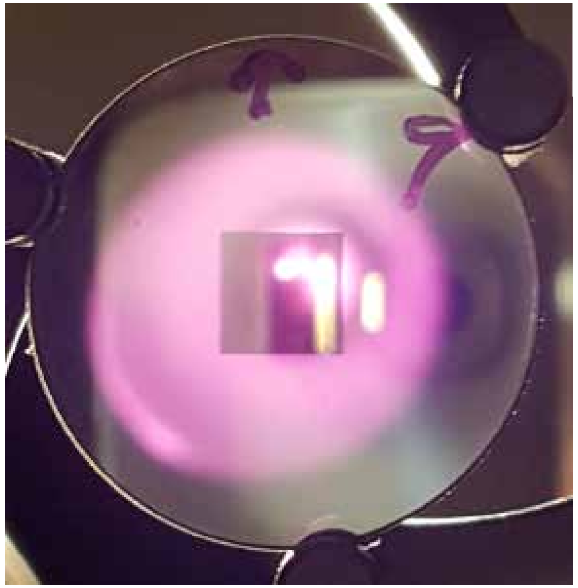
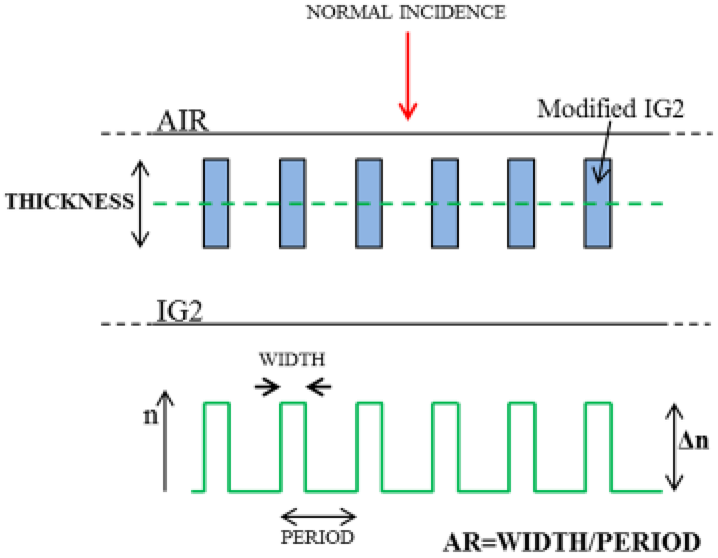
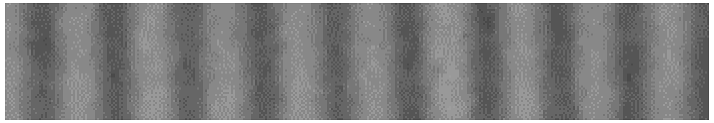
Building Block 3 : Volume Grating



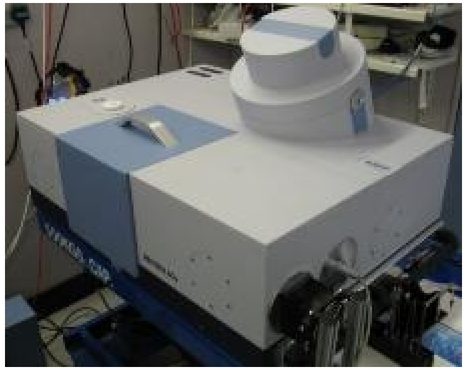


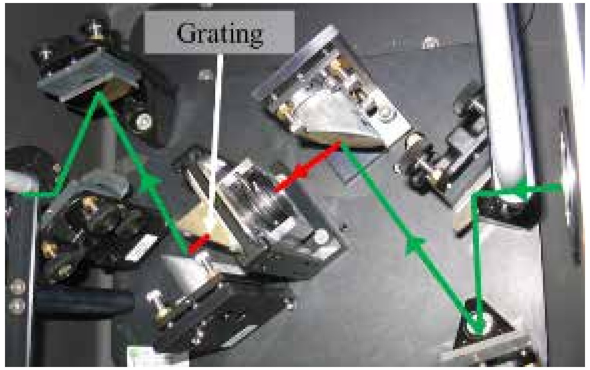


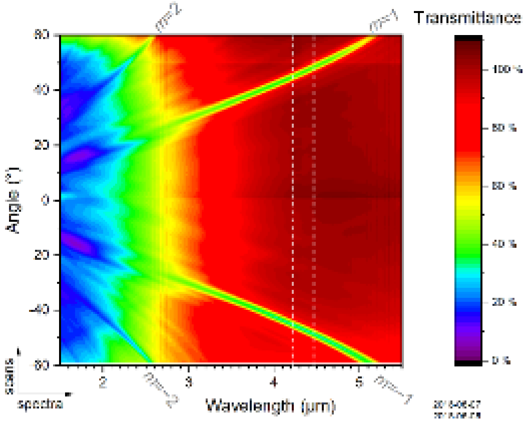


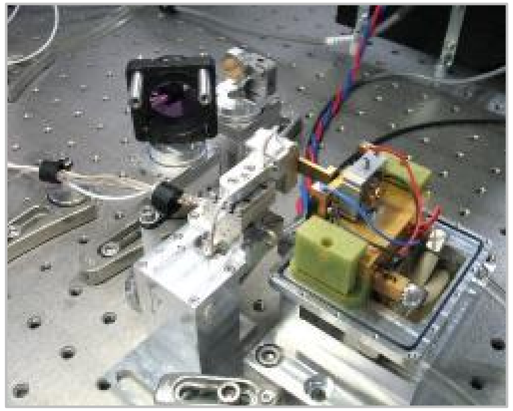
6 mm square
Period 3 µm
30 layer -> 128 µm thick

Optics Express, 8, 1, 33617, 2018,
doi: 10.1364/OE.25.033617



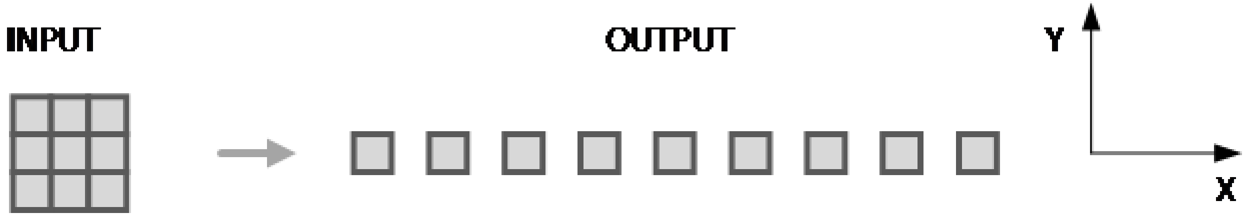




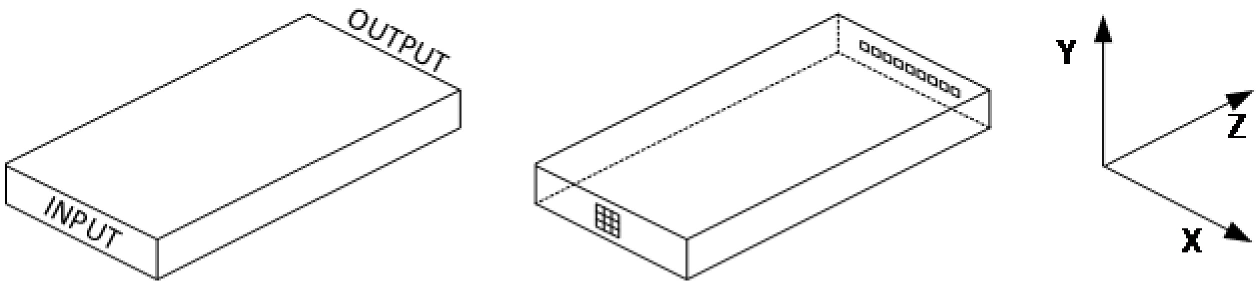


Efficiency >89% (better than reflection grating)
Insensitive to polarization
Higher system stability observed
Less fragile (in volume, no delicate structure exposed)

Building Block 4 : Photonic Lantern



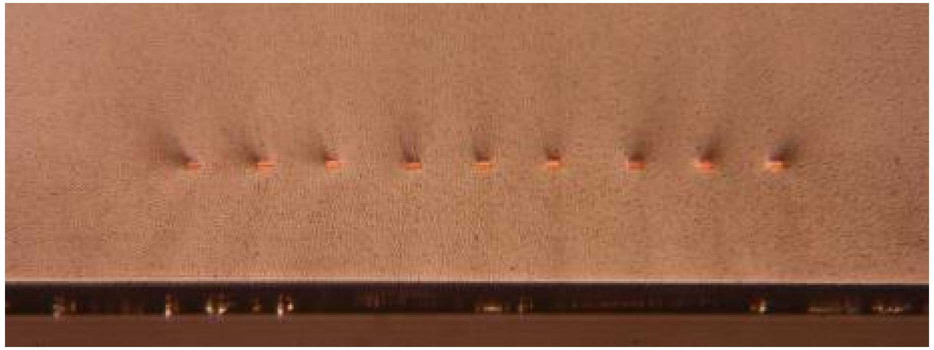
3x3 multi-mode input to 9x1 single mode output
Output waveguide spacing >100µm



IG2 substrate is X×Y×Z = 10mm × 1mm × 20mm

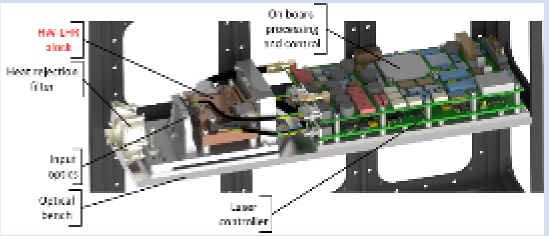
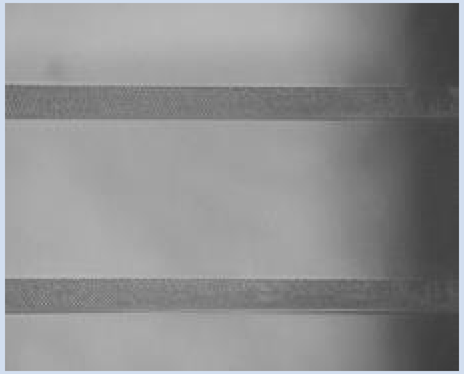
Multimode to single mode conversion
Spatial multiplexing with coherent systems

Highly relevant to LHR and Interferometers



Summary & Outlook

MATURITY / TRL

HIGH **Integrated LHR**	**MEDIUM** **MEMS based FTS**	**LOW** **Spectrometer on chips**
- Validated on the ground - Cubesat IOD ready (MISO) - Solar occultation limb - Constellation (ESA CAIROS) - High resolution vertical profiling - Complementary to nadir - GHG/climate - Mid atmosphere/climate feedback  	- Principles demonstrated in the lab - Dedicated improved MEMS needed - Need to improve resolution - Need to improve coupling  	- Building blocks developed - Relevance demonstrated - Develop spectrometer lab demonstrator - Develop system integration 

Acknowledgements

- People
  - Iain Robinson
  - Neil Macleod
  - Helen Butcher
  - Jerome Bredin
  - Alex Hoffmann
  - Marko Huebner
  - David Lee
  - CAIROS team
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Centre for EO Instrumentation

UK SPACE AGENCY

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