

Frontiers of mid-IR Direct Absorption Laser Spectroscopy: Applications, Advances and Outlook

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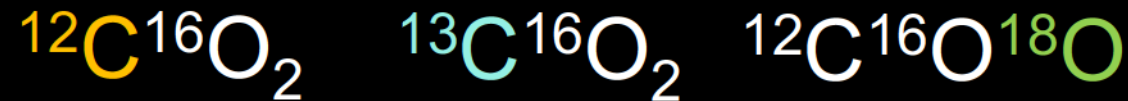


Outline

- ❖ High precision ↔ low footprint
 - ❖ High sensitivity ↔ multi-species
 - ❖ Outlook & Summary
-

High precision

isotope ratio measurements of trace gases



Natural abundance:

98.42%

1.11%

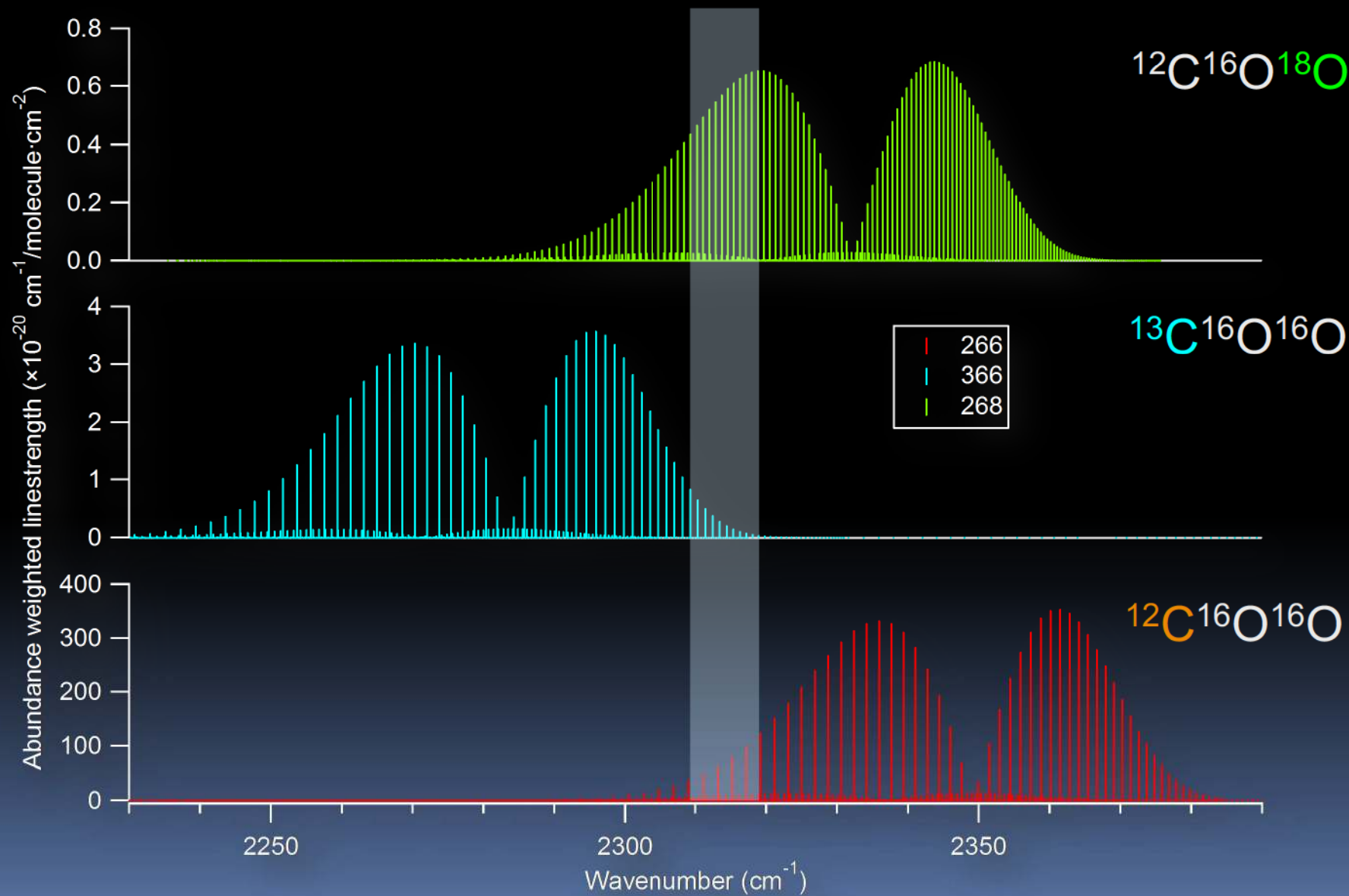
0.39%

Atmospheric mixing ratio: 395.3 ± 0.1 ppm (2013, NOAA)

Target sensitivity: 0.05 ‰ for $\delta^{13}\text{C}$ and 0.1 ‰ for $\delta^{18}\text{O}$

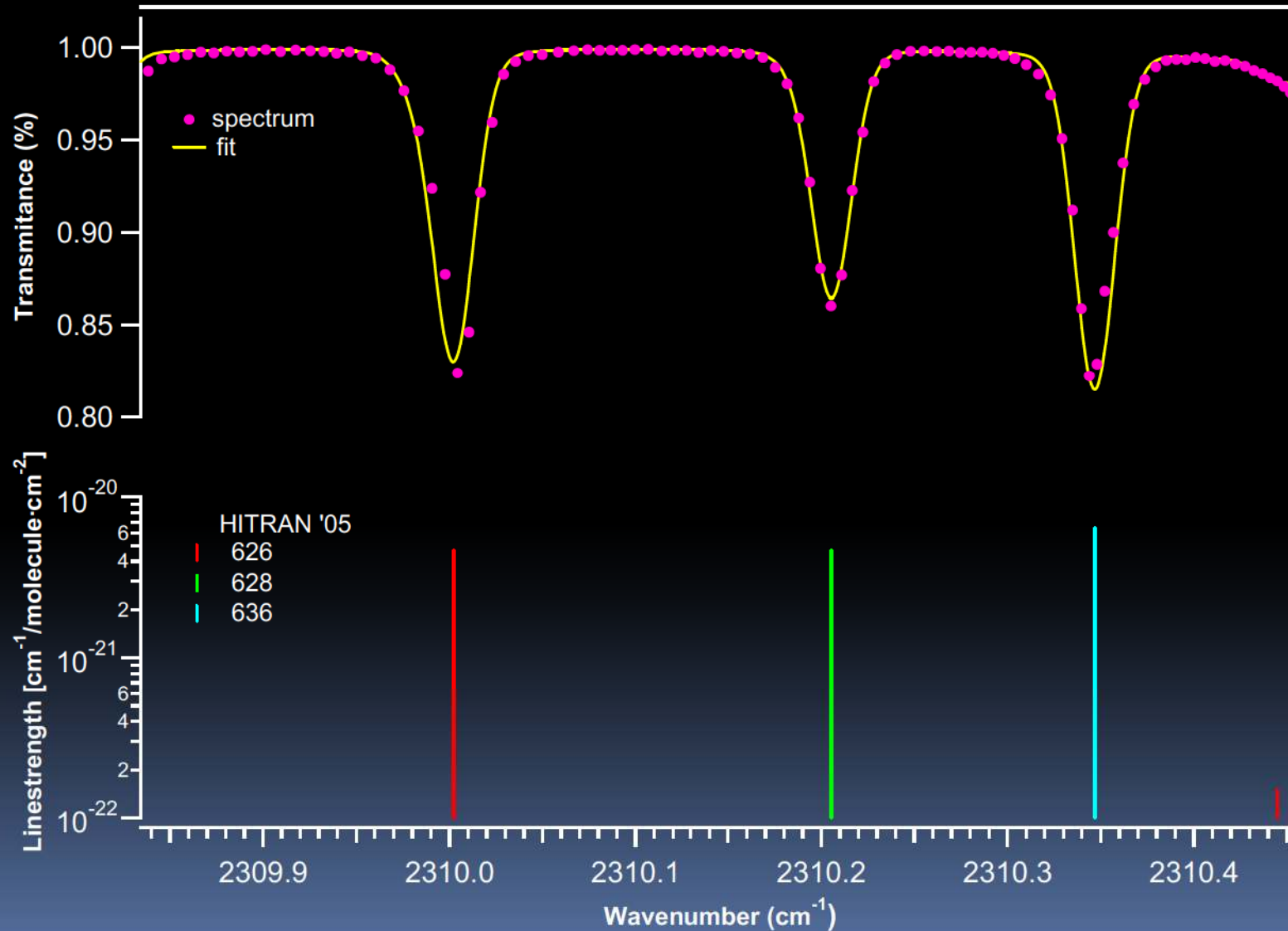
Variations to be analyzed: $\sim 2 \times 10^{-10}$

Simulated ν_3 ro-vibrational bands of the CO₂

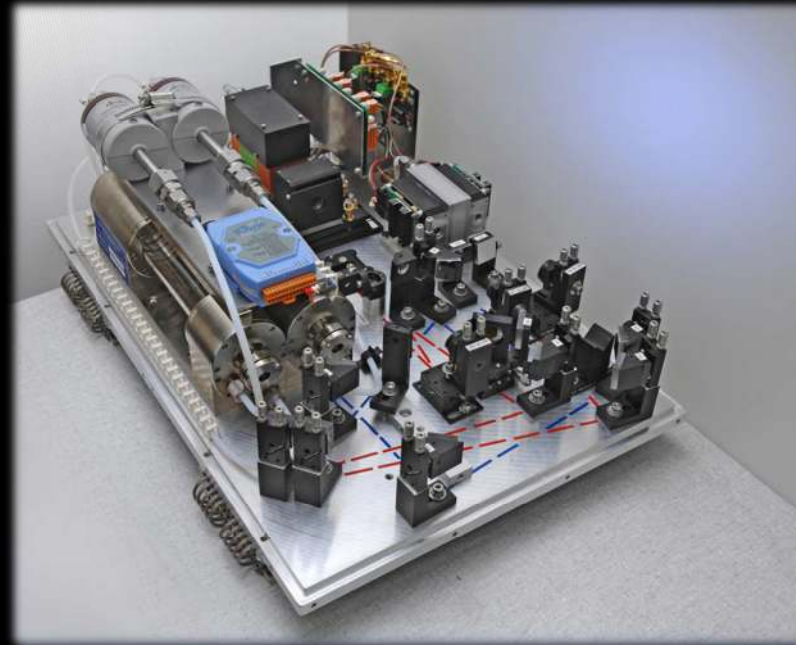


Measured vs. Simulated

absorption spectrum of the CO₂

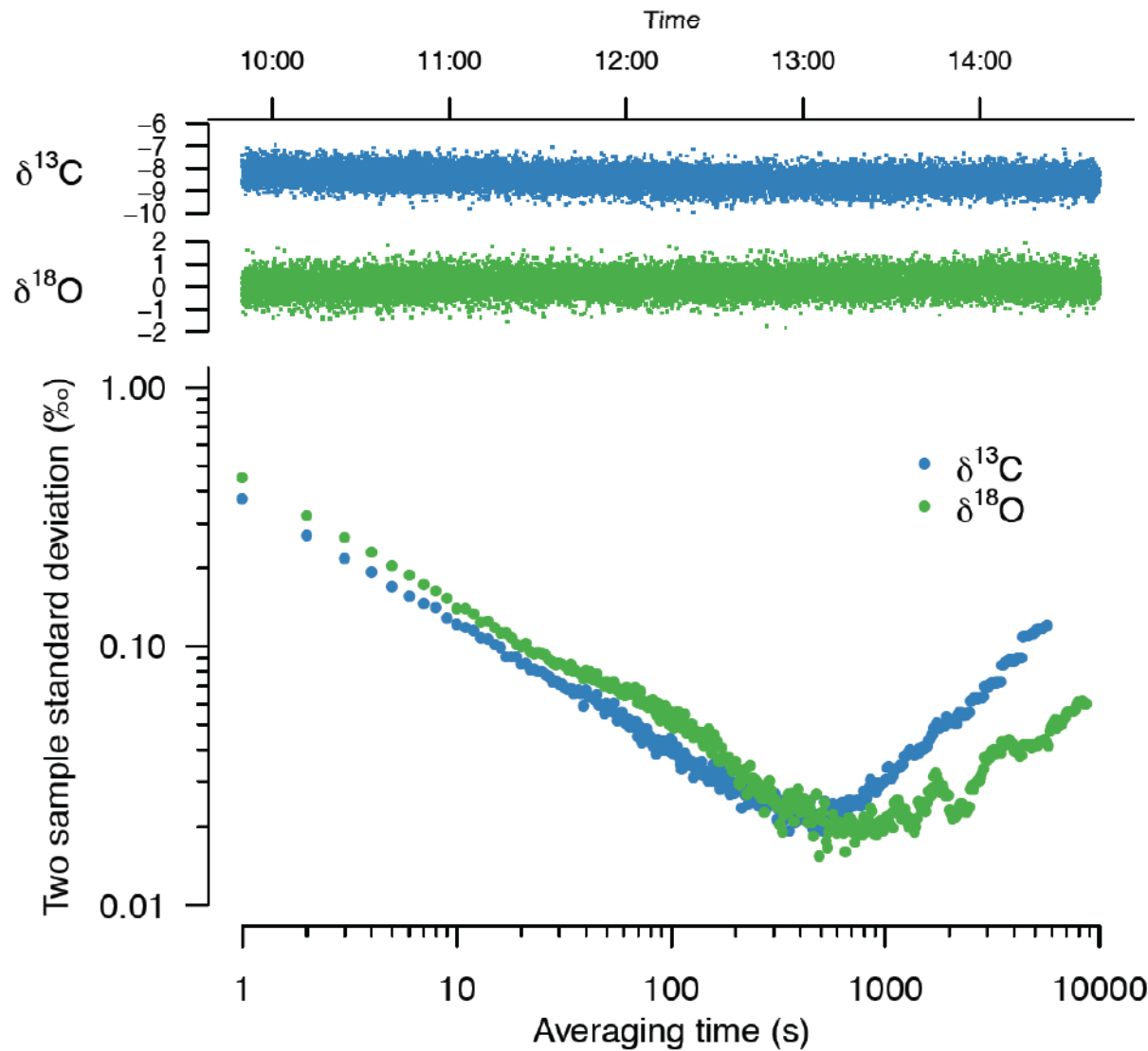


QCLAS combining Balanced-Absorption with Spectral Ratio method



Precision & Stability

Allan variance plot



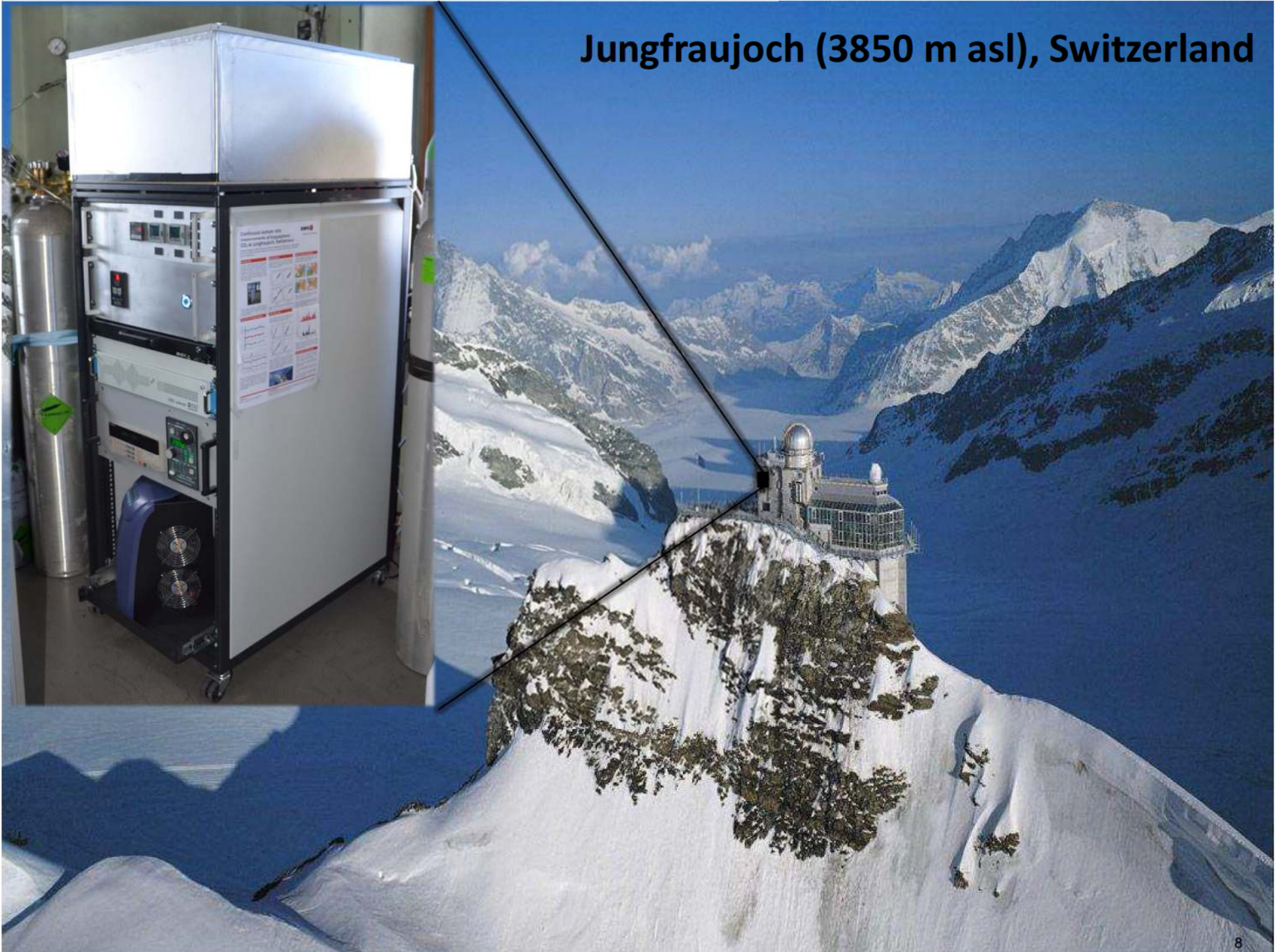
Precision (1σ)

1 s	0.5 ‰
60 s	< 0.07 ‰
600 s	< 0.03 ‰

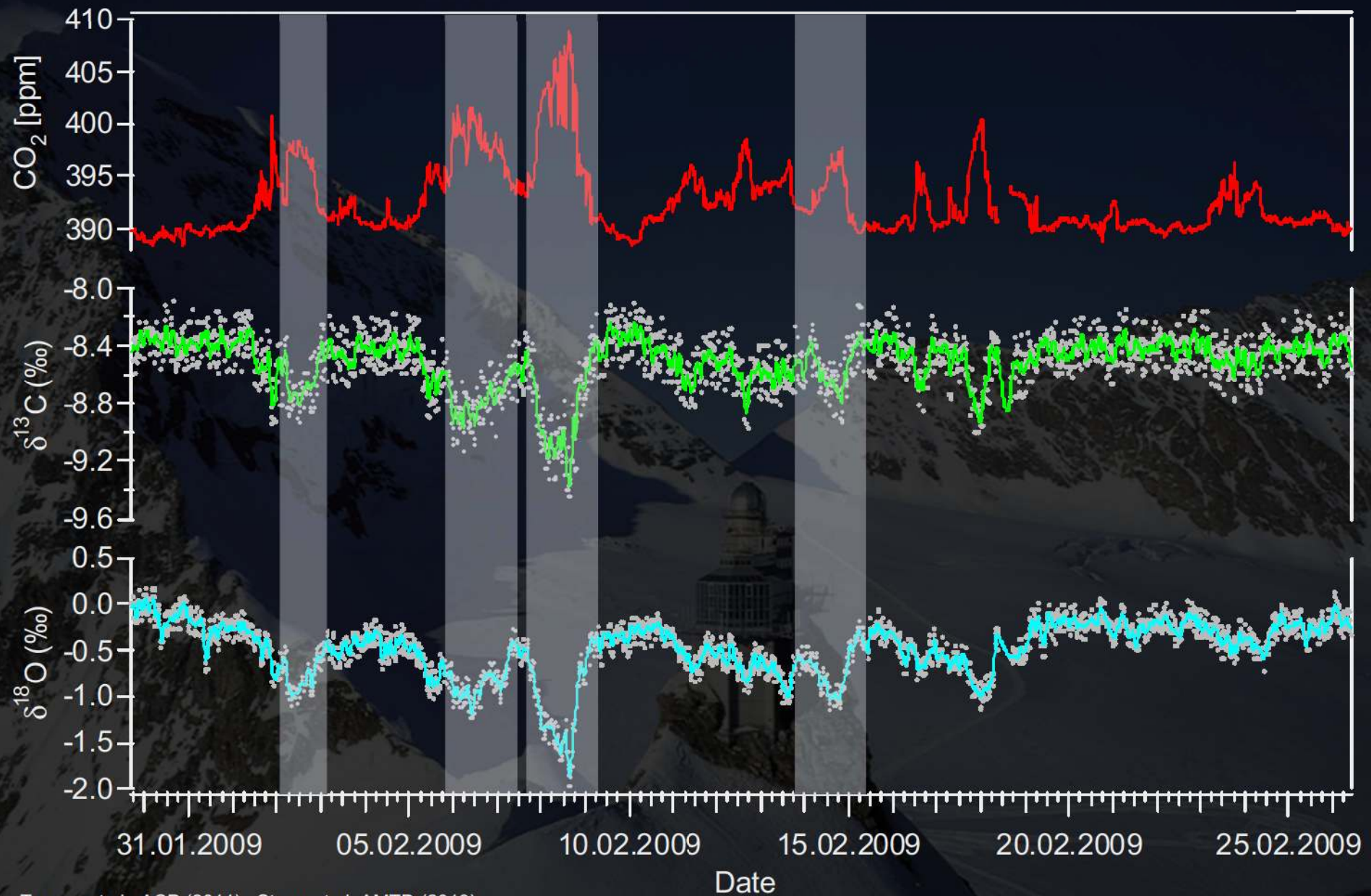
Year

Year	$1\sigma_{\text{min}}$
2006	0.16 ‰
2009	0.046 ‰
2012	0.025 ‰

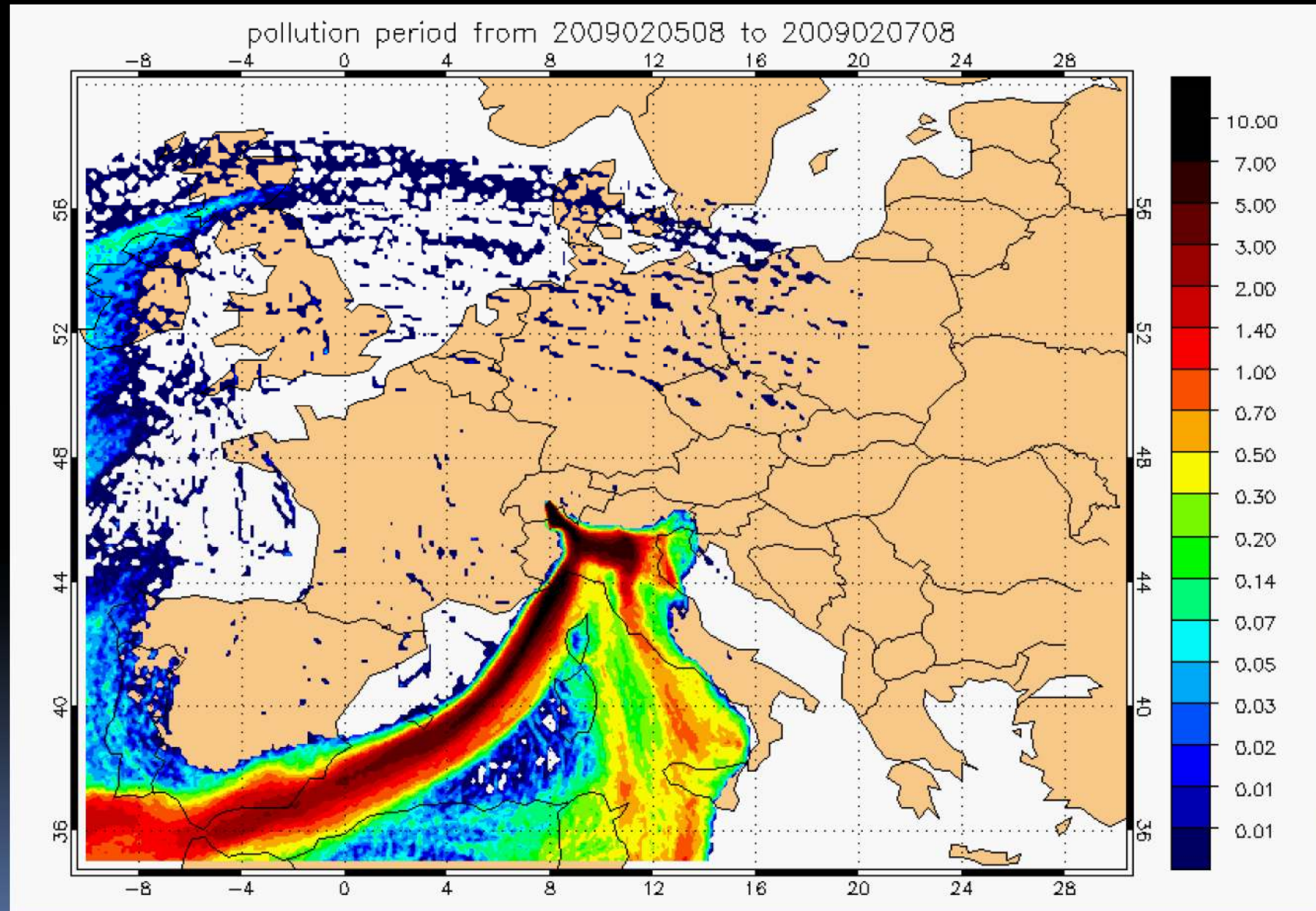
Jungfraujoch (3850 m asl), Switzerland



Short term variations of CO₂ stable isotopes

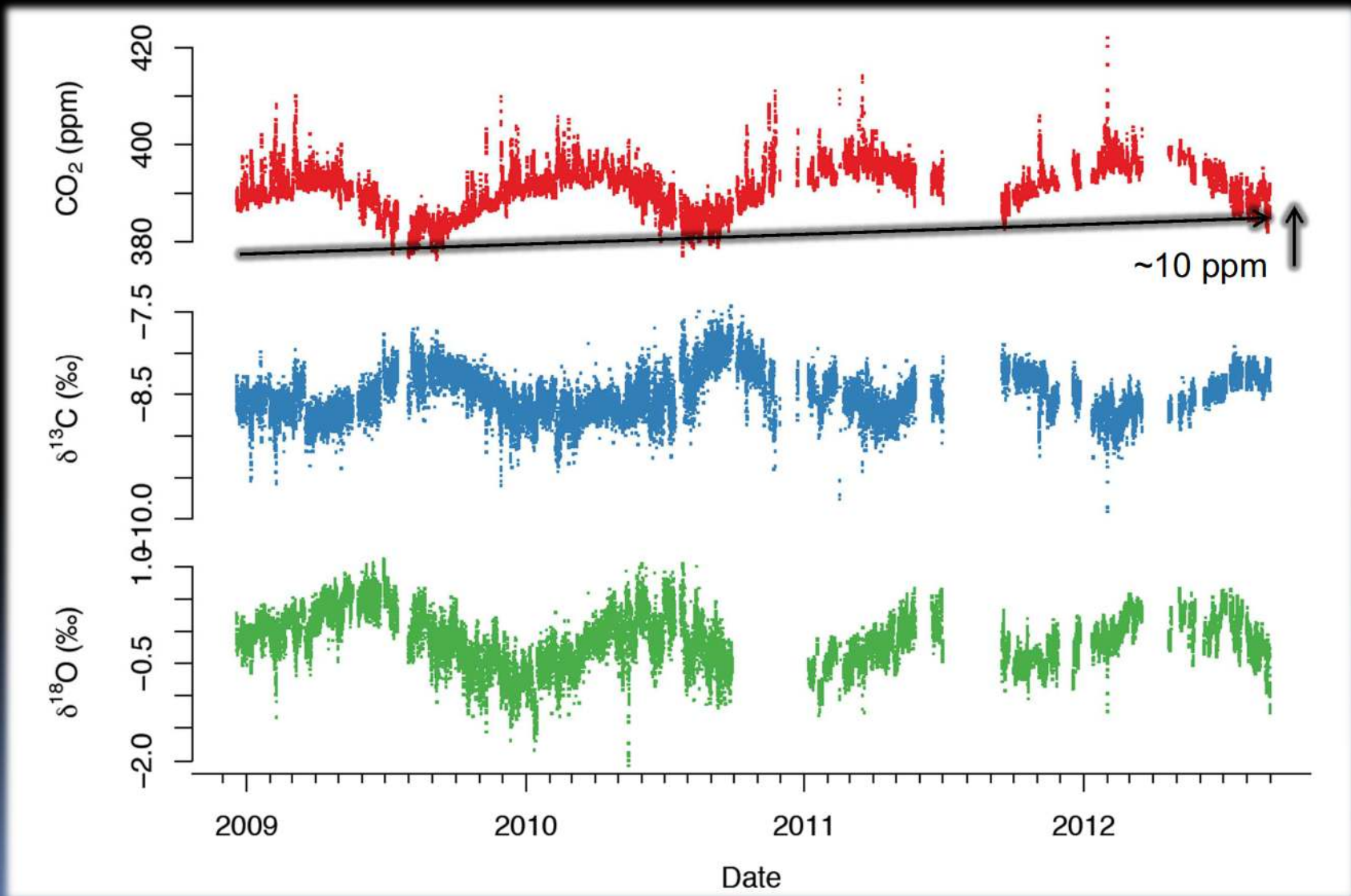


Regional Pollution Events



Long-term time series of tropospheric CO₂

6 years continuous monitoring; $\sim 2 \times 10^{14}$ laser pulses

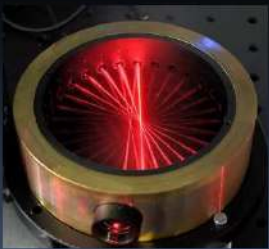


Low footprint ?

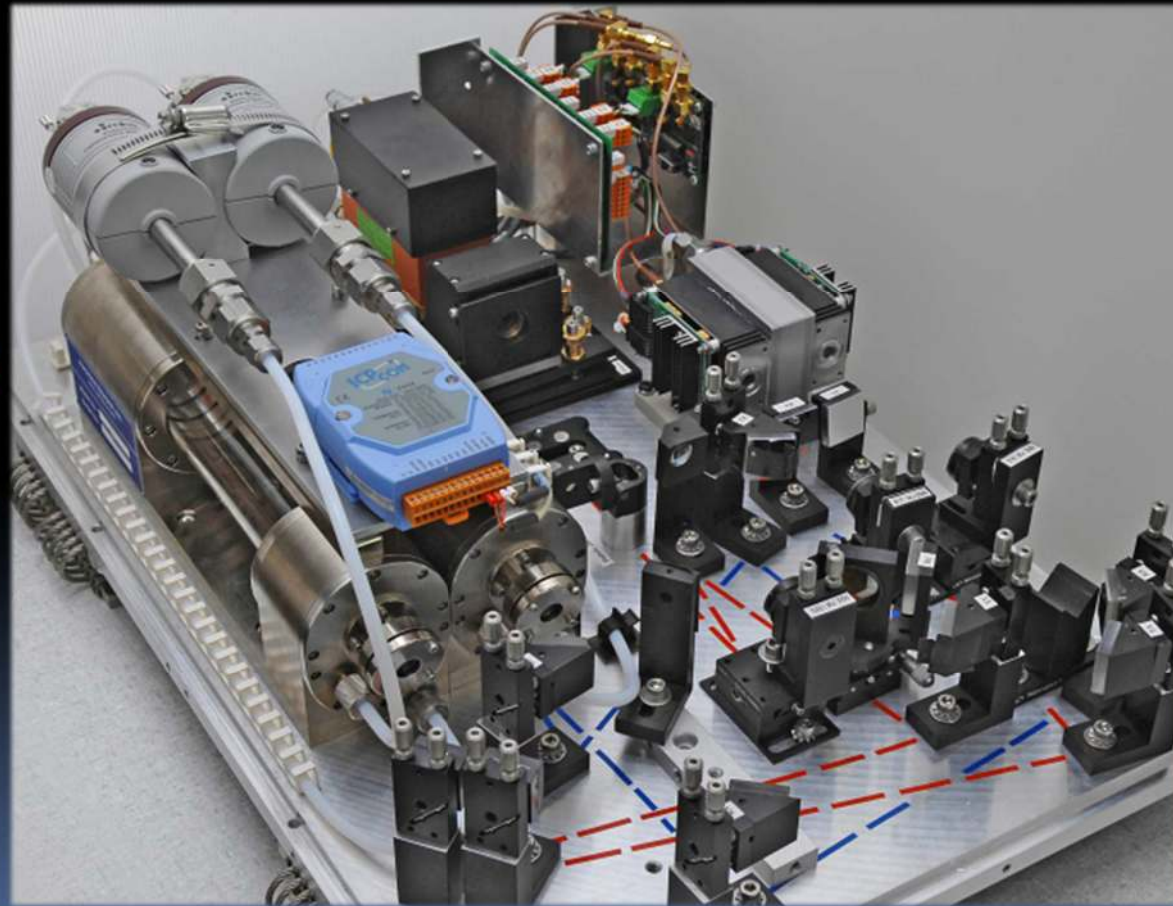
- optics



(1: 10)

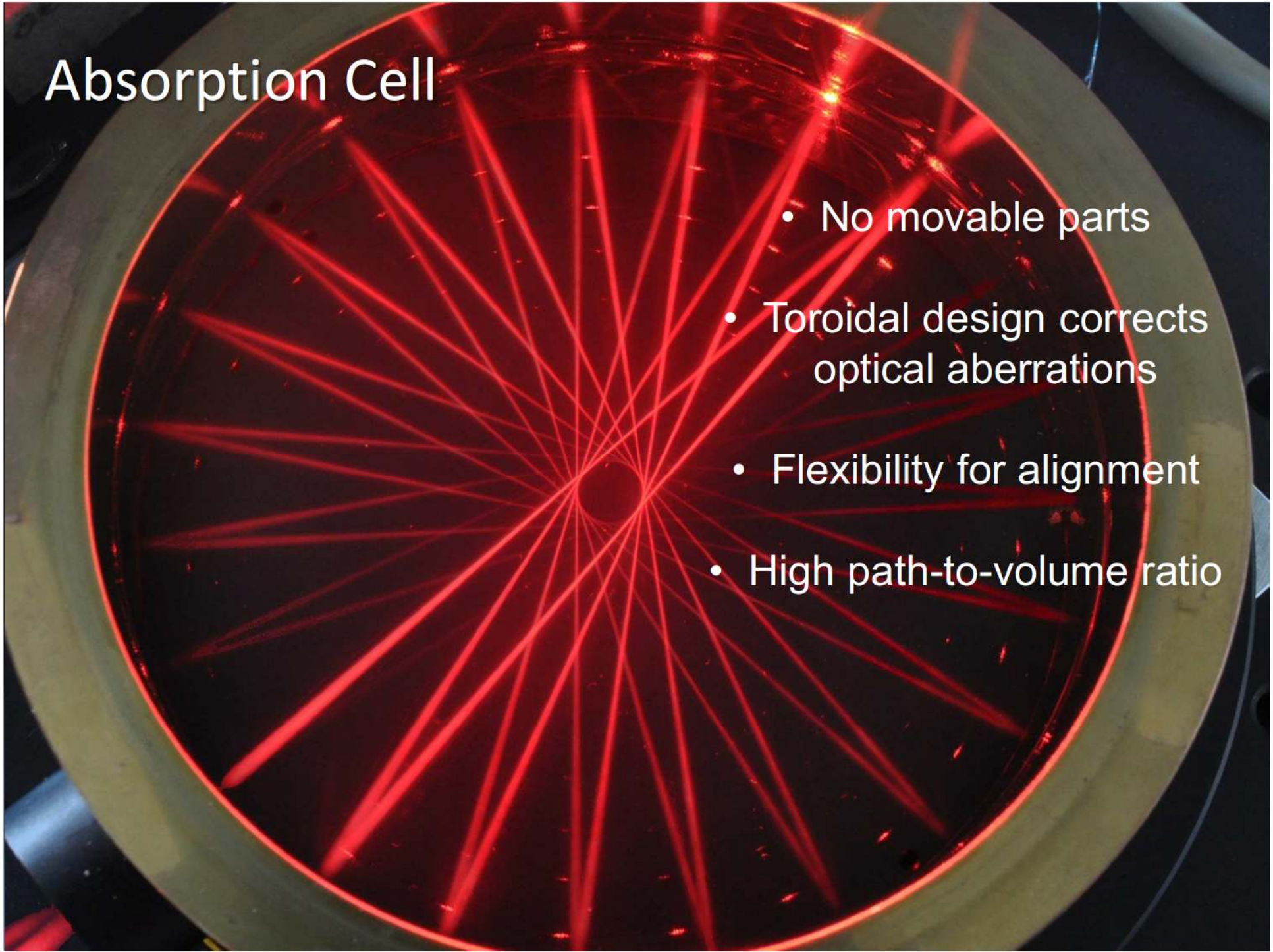


(1: 8)



Absorption Cell

- No movable parts
- Toroidal design corrects optical aberrations
- Flexibility for alignment
- High path-to-volume ratio



QCL in HHL package

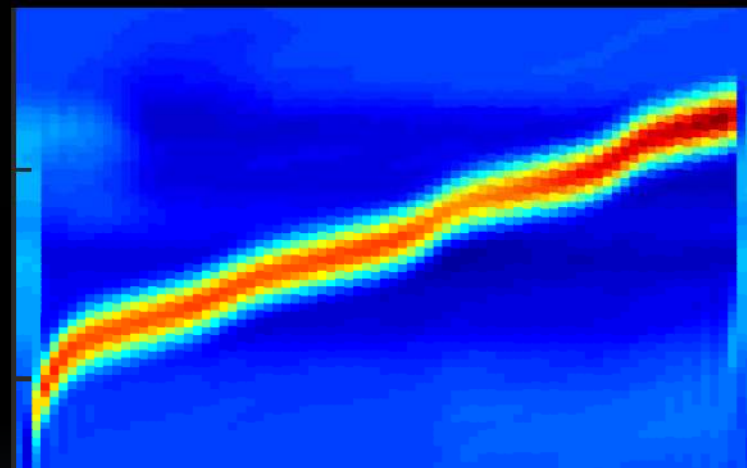
Fringes in QCL output



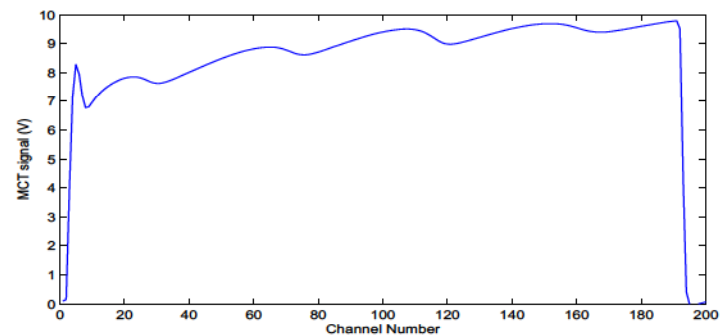
Wavenumber (cm^{-1})

2310.4

2310.8

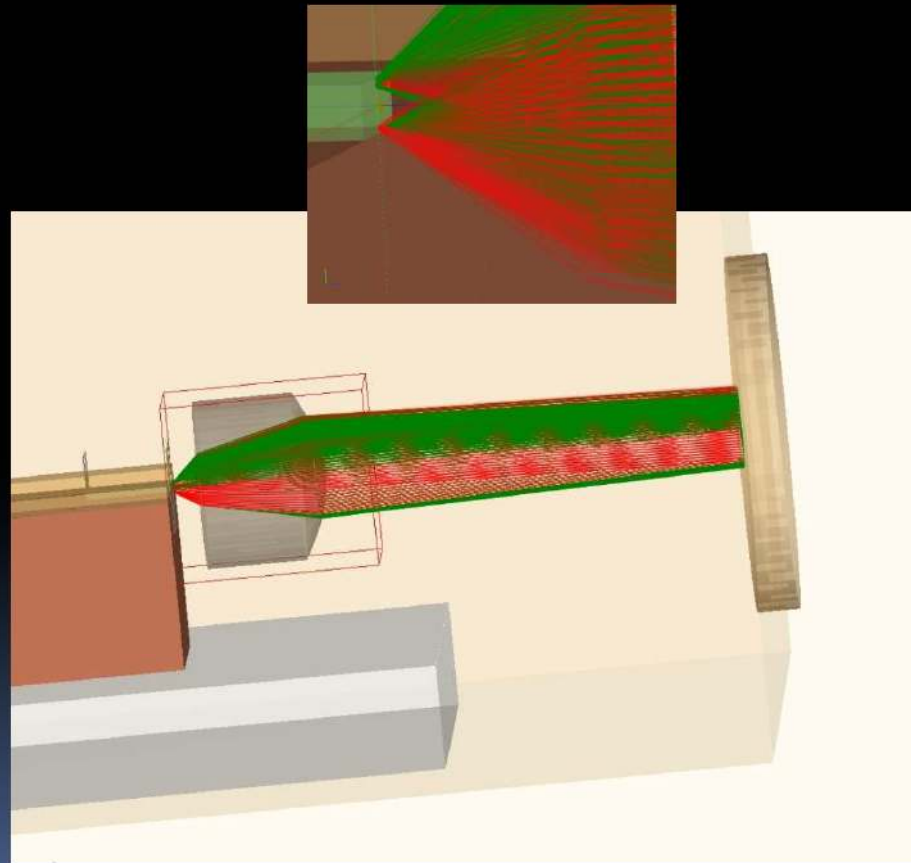


Light intensity

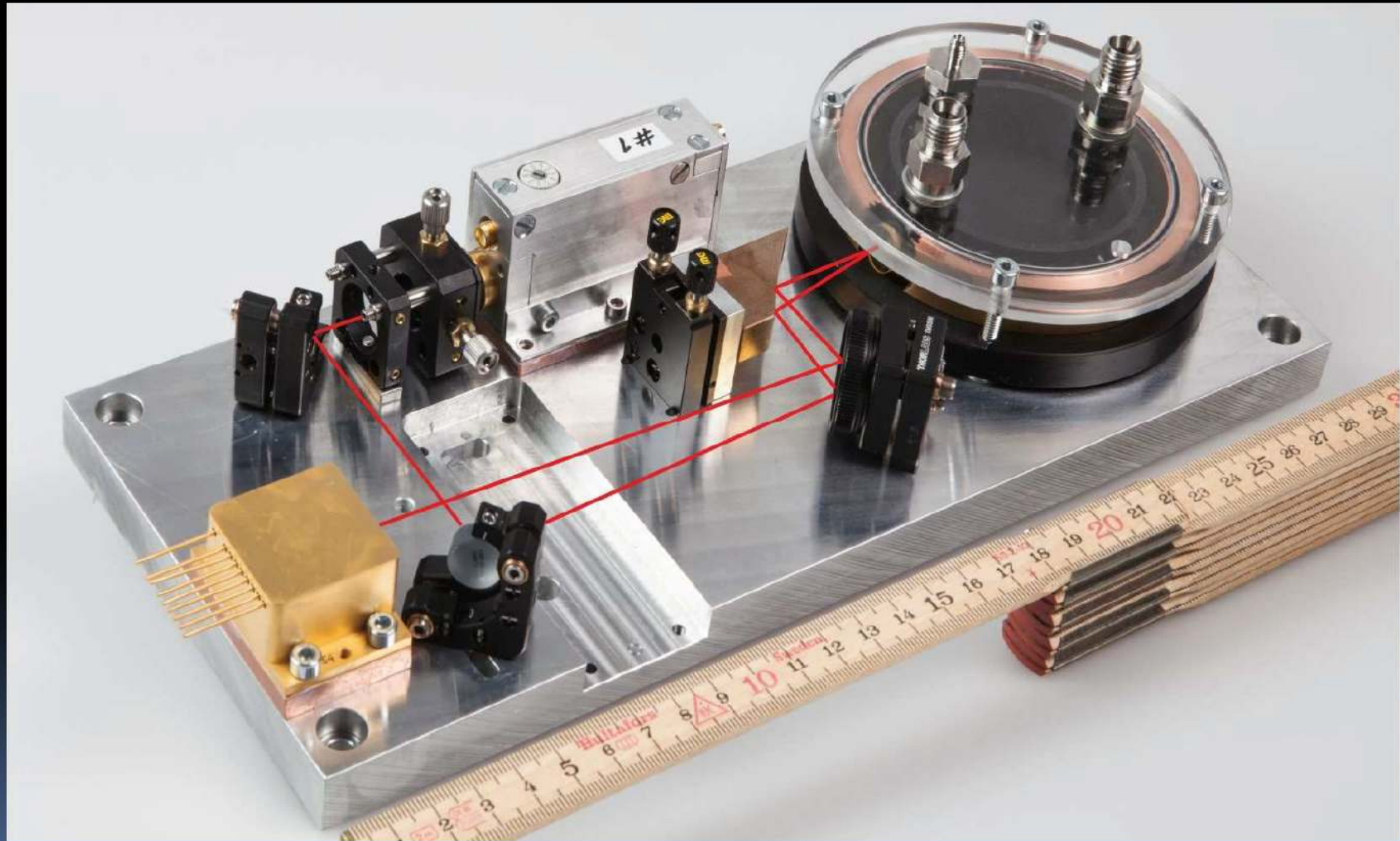


QCL in HHL package

Finding and removing the problem



Shoe-box size instrumentation

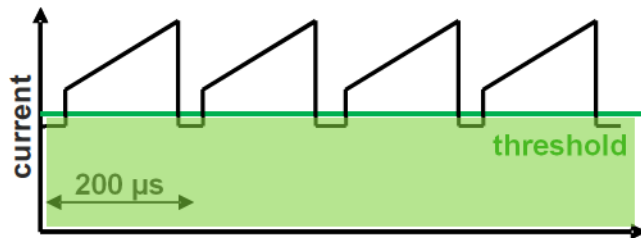


Jouy et al., Analyst, (2014).

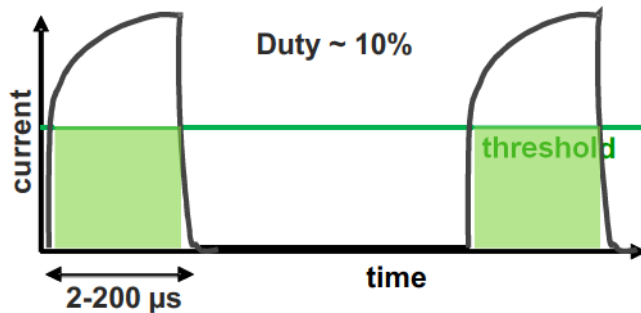
Towards compactness and portability...

- driving electronics

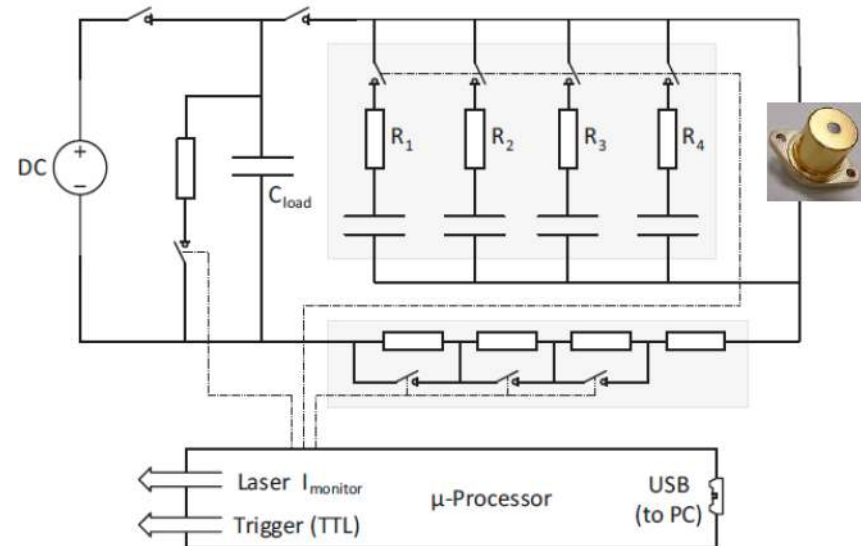
■ Continuous Wave (CW)



■ intermittent Continuous Wave (iCW)

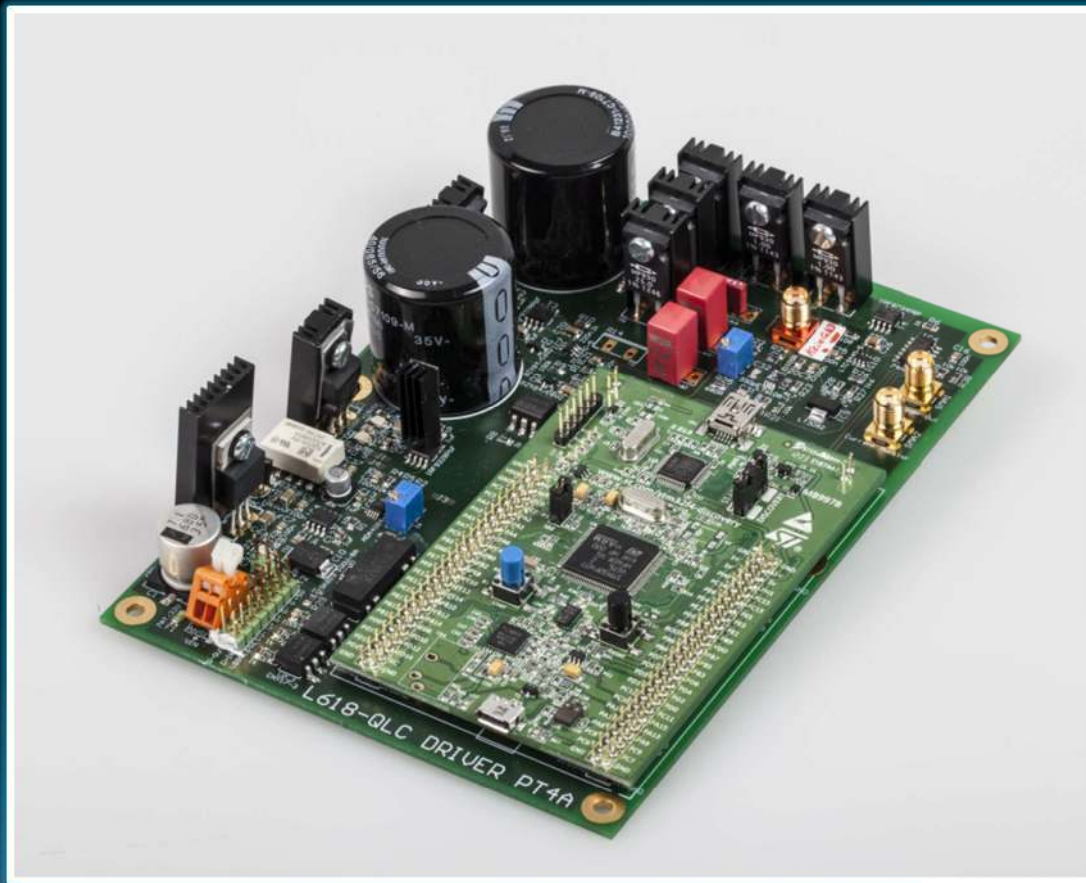


Fischer et al., Opt. Express (2014)



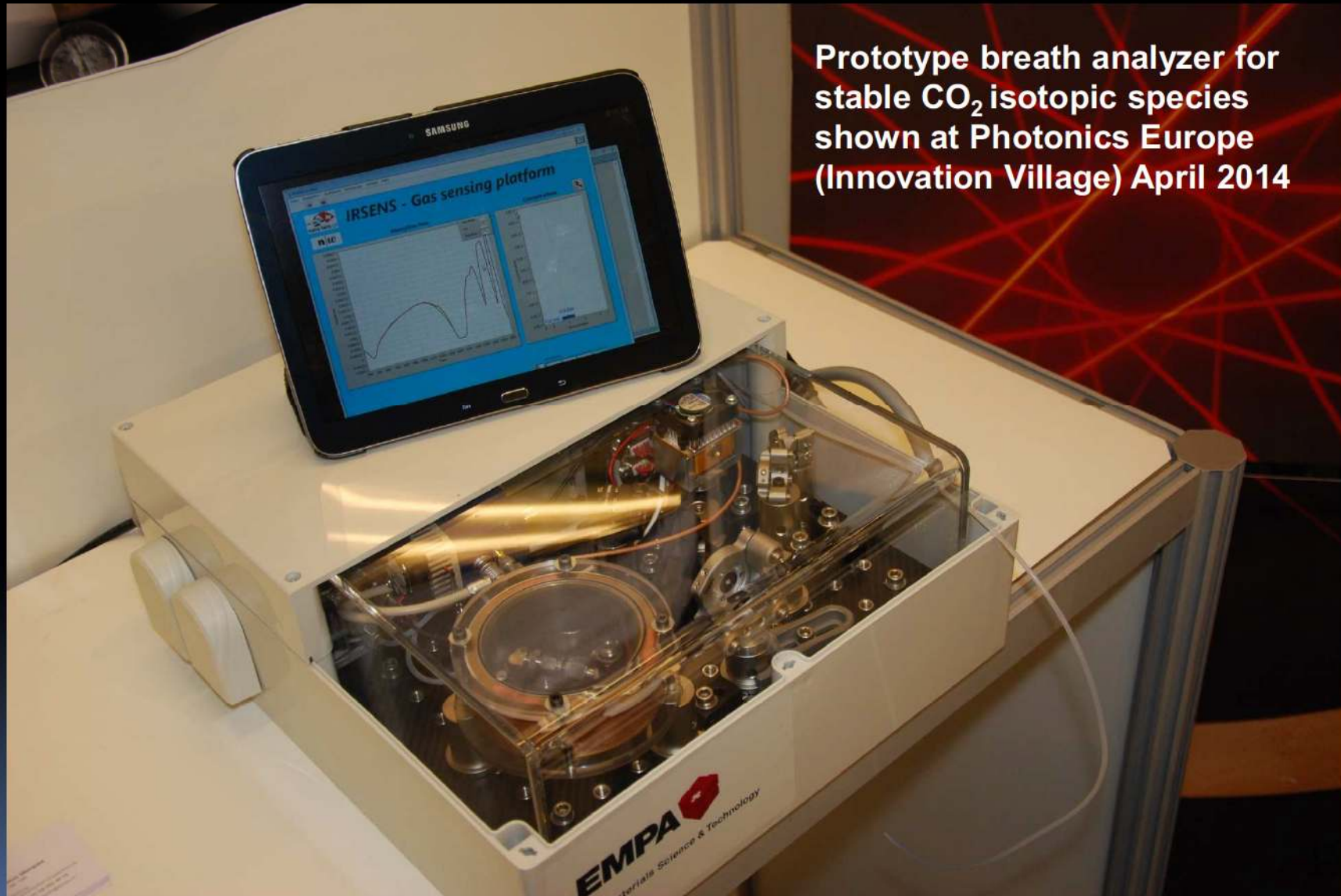
Intermittent cw driving - characteristics

icw-QCL driver



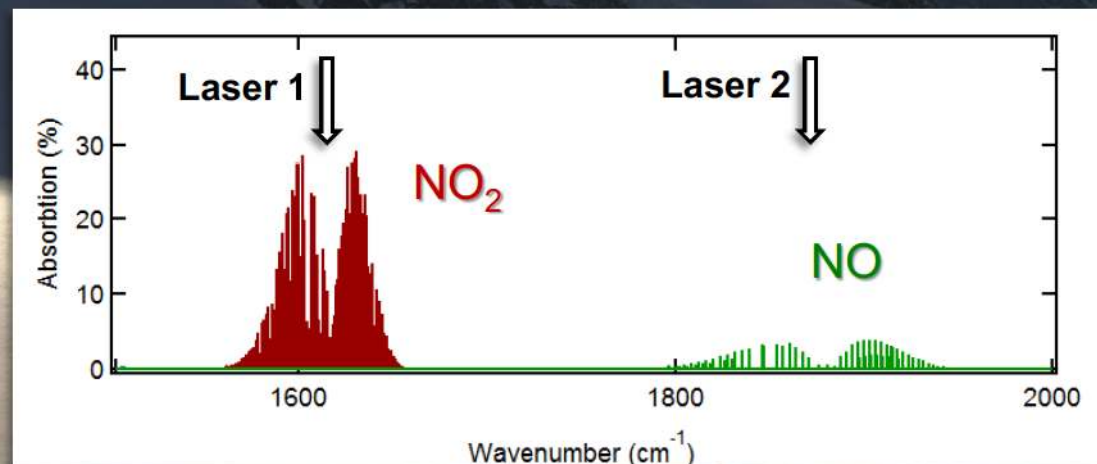
- fully analog
- on-board trigger
- < 1 W power consumption
- decoupled from power supply during lasing

Prototype of a portable QCLAS



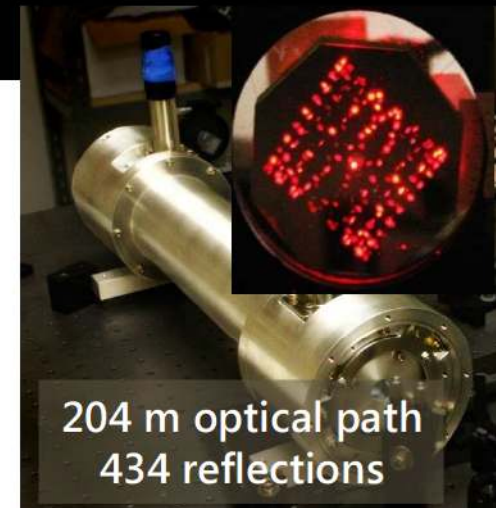
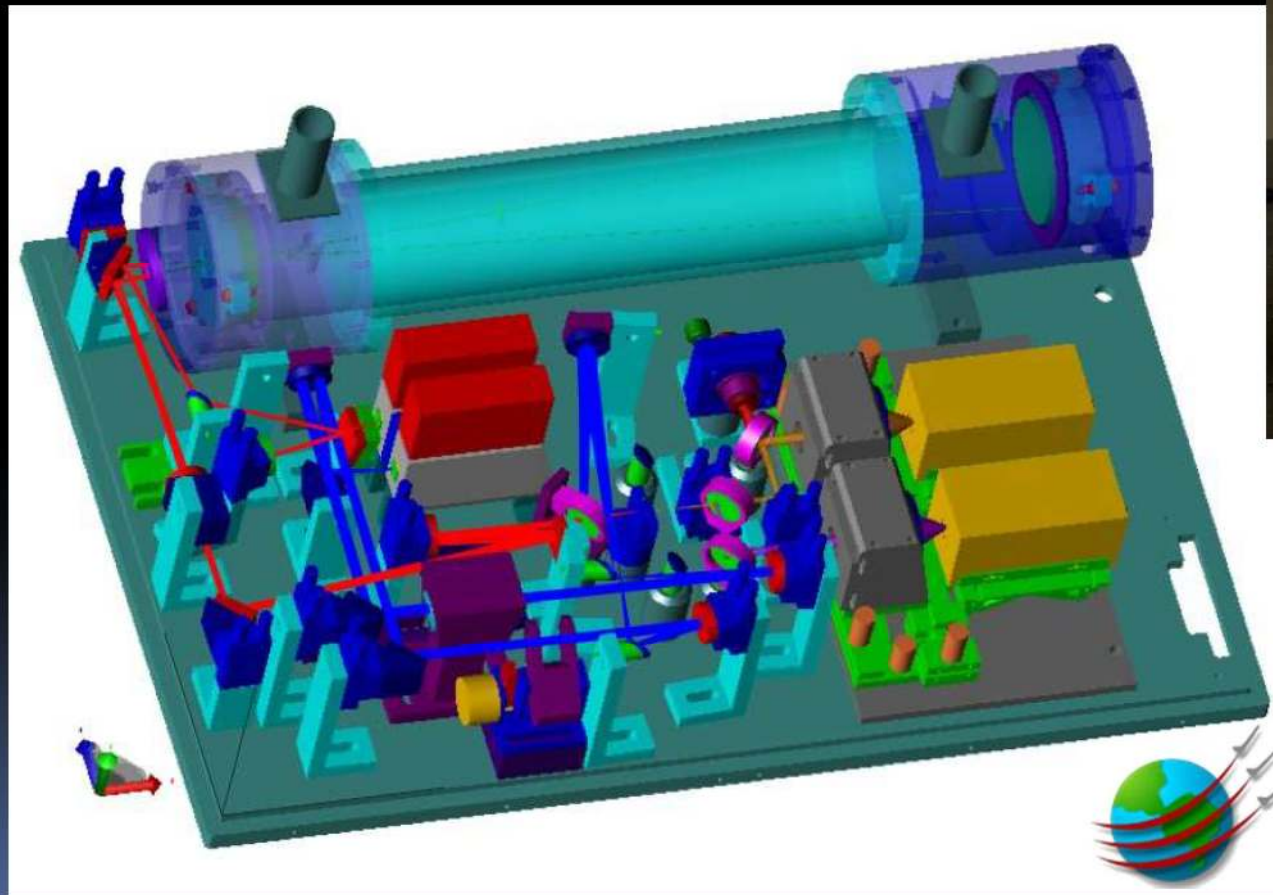
Prototype breath analyzer for
stable CO₂ isotopic species
shown at Photonics Europe
(Innovation Village) April 2014

High Sensitivity & Multispecies



Simultaneous measurements of NO and NO₂ by QCLAS

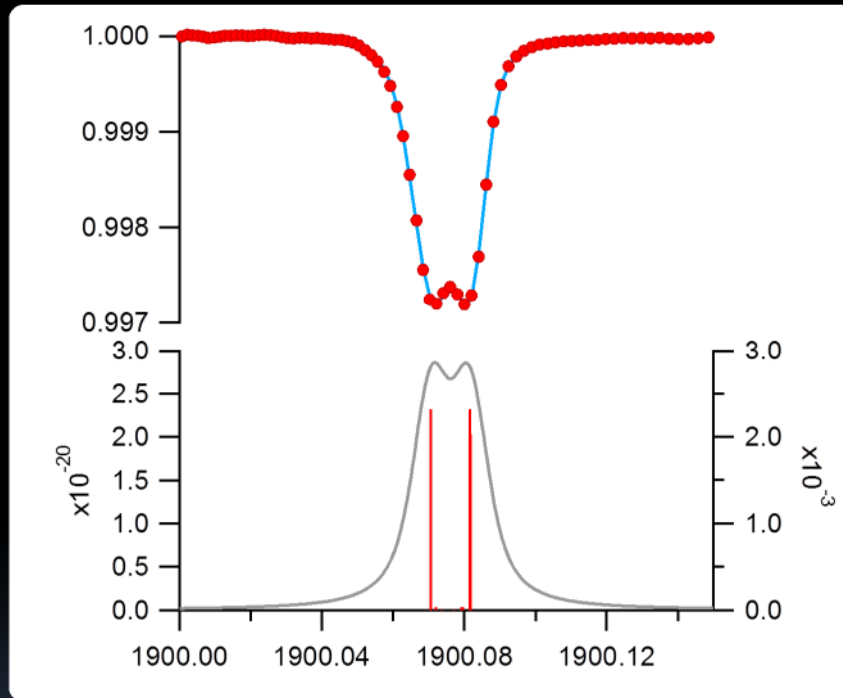
- Optical Setup



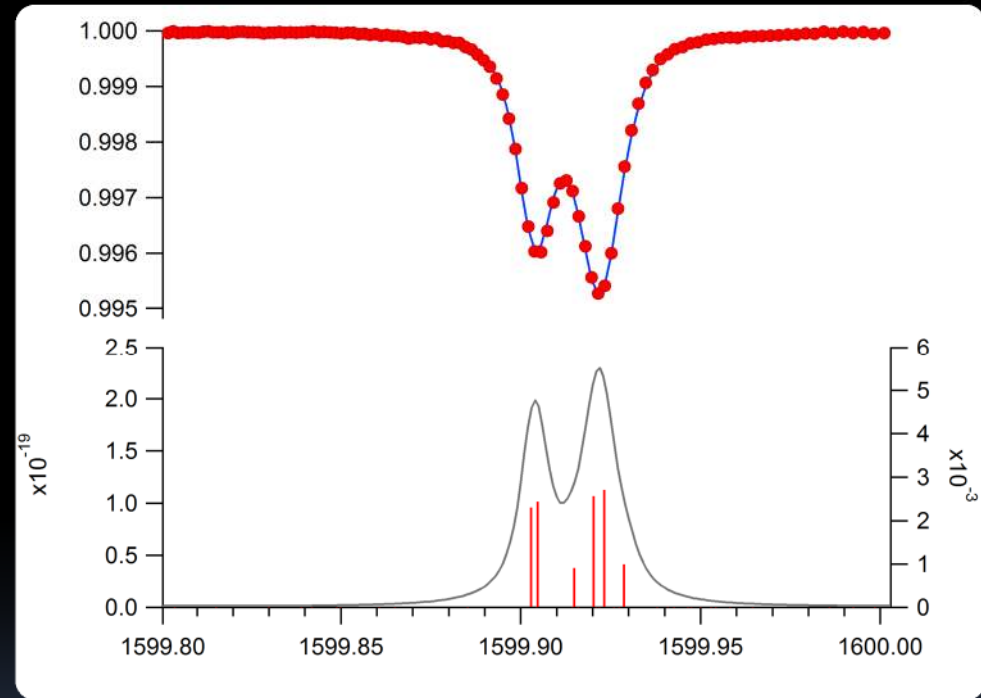
Simultaneous measurements of NO and NO₂ by QCLAS

- Spectrum

NO



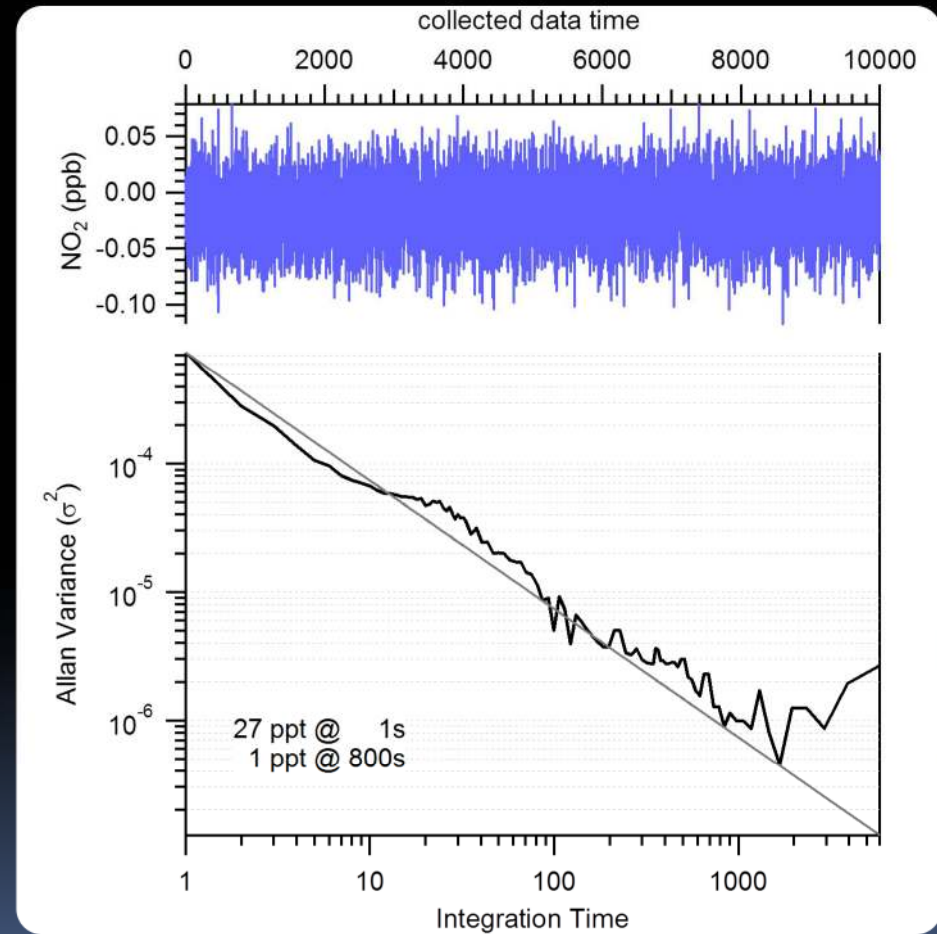
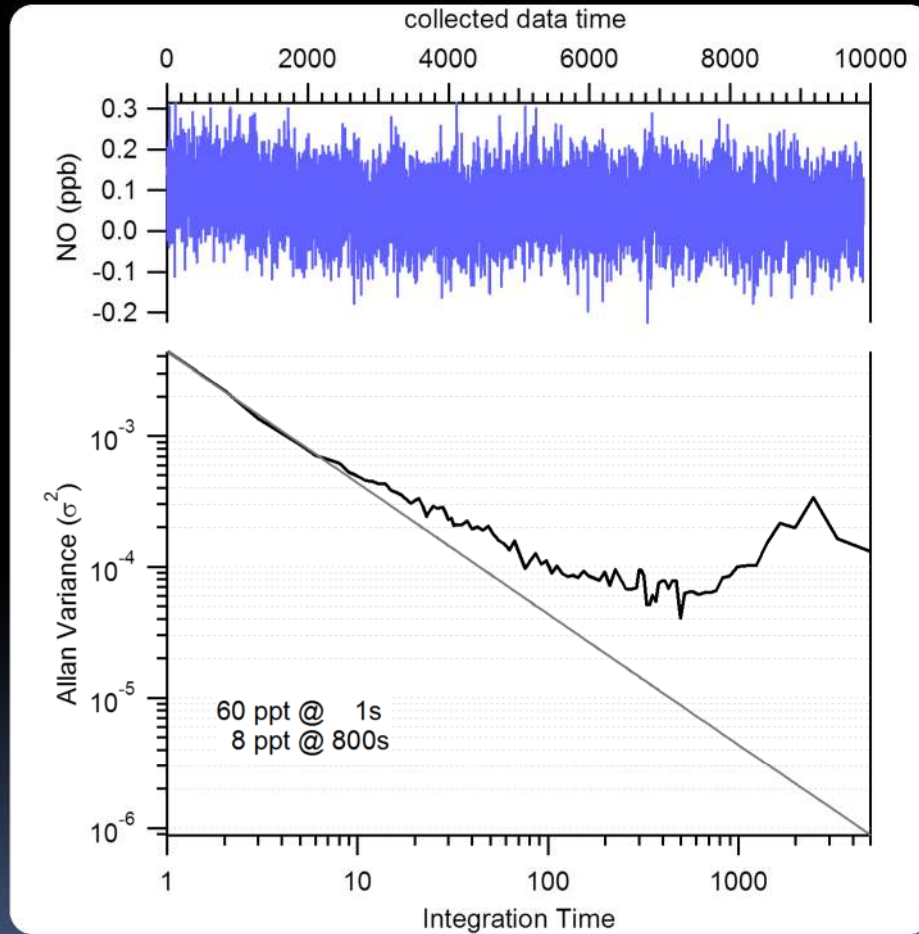
NO₂



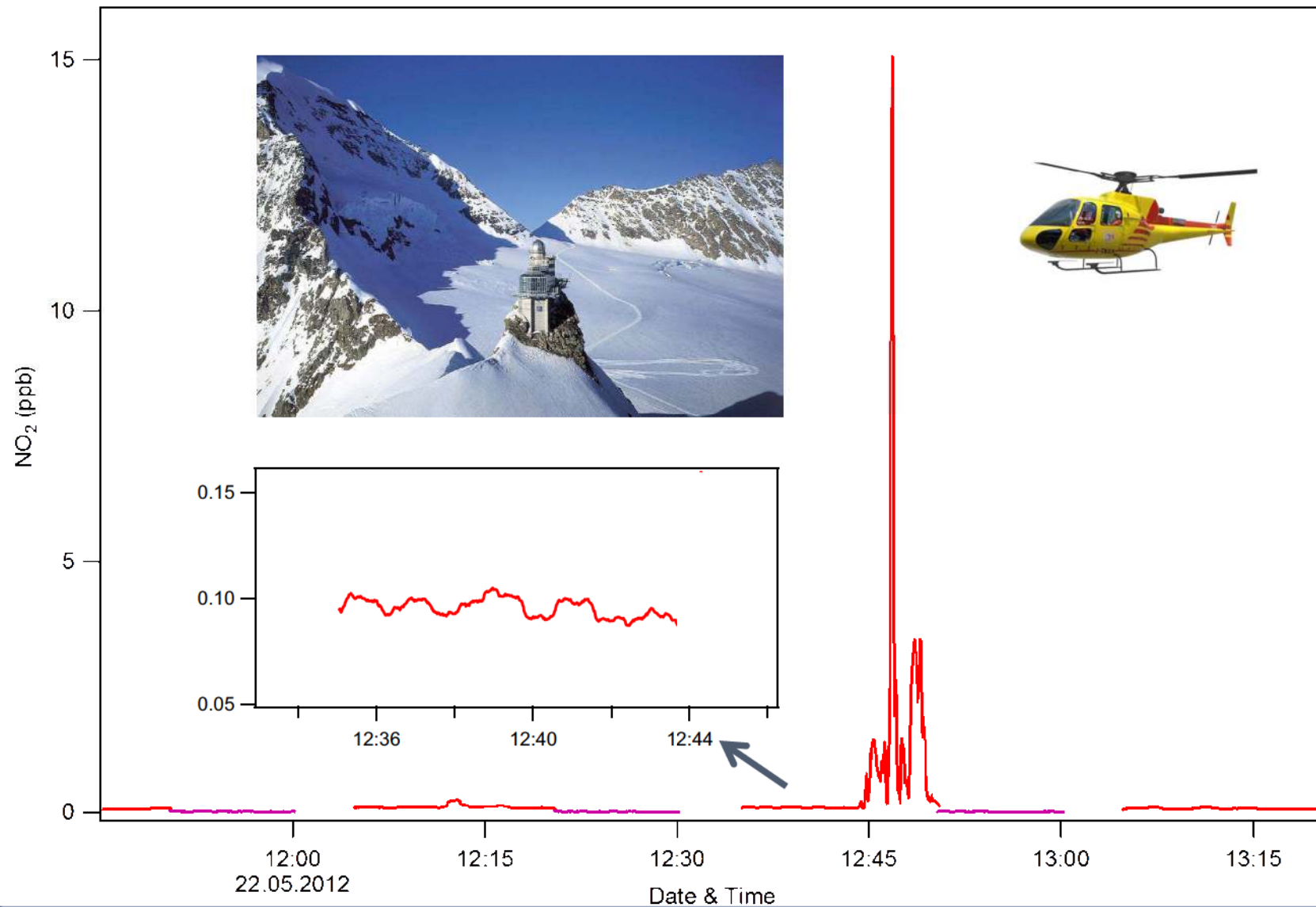
1 s average of 5 kHz spectra of ambient air (<10 ppb NO_x) at 50 hPa; simulation (lower part) based on HITRAN

Simultaneous measurements of NO and NO₂ by QCLAS

- Allan plots



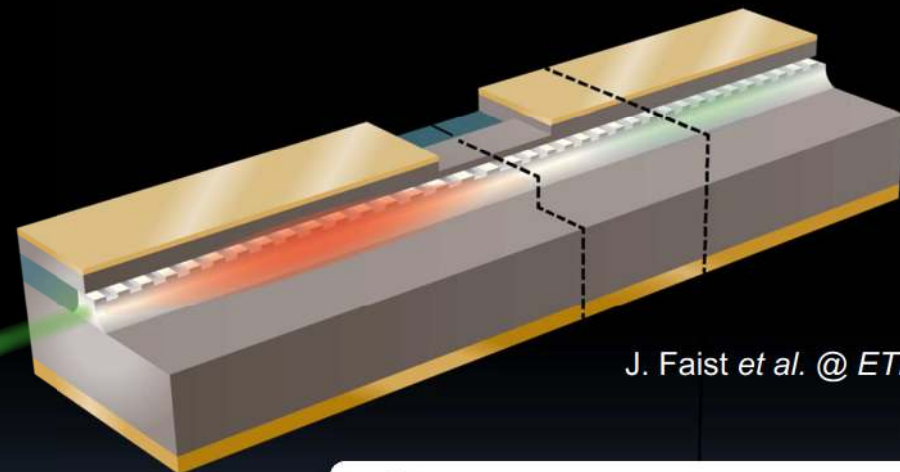
Sensitivity «test»



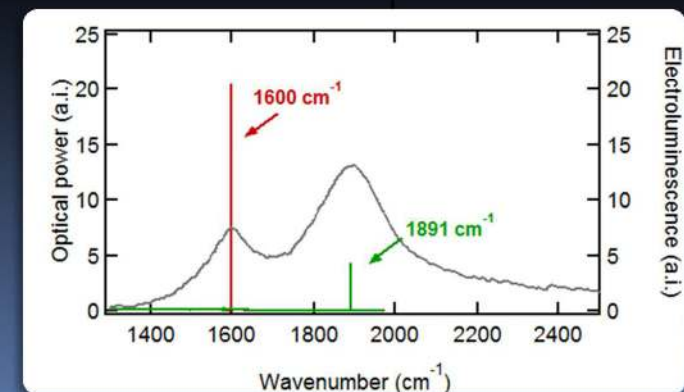
Q: Multiple trace gases in a compact instrument? A: Multi-wavelength lasers

Dual-wavelength QCL

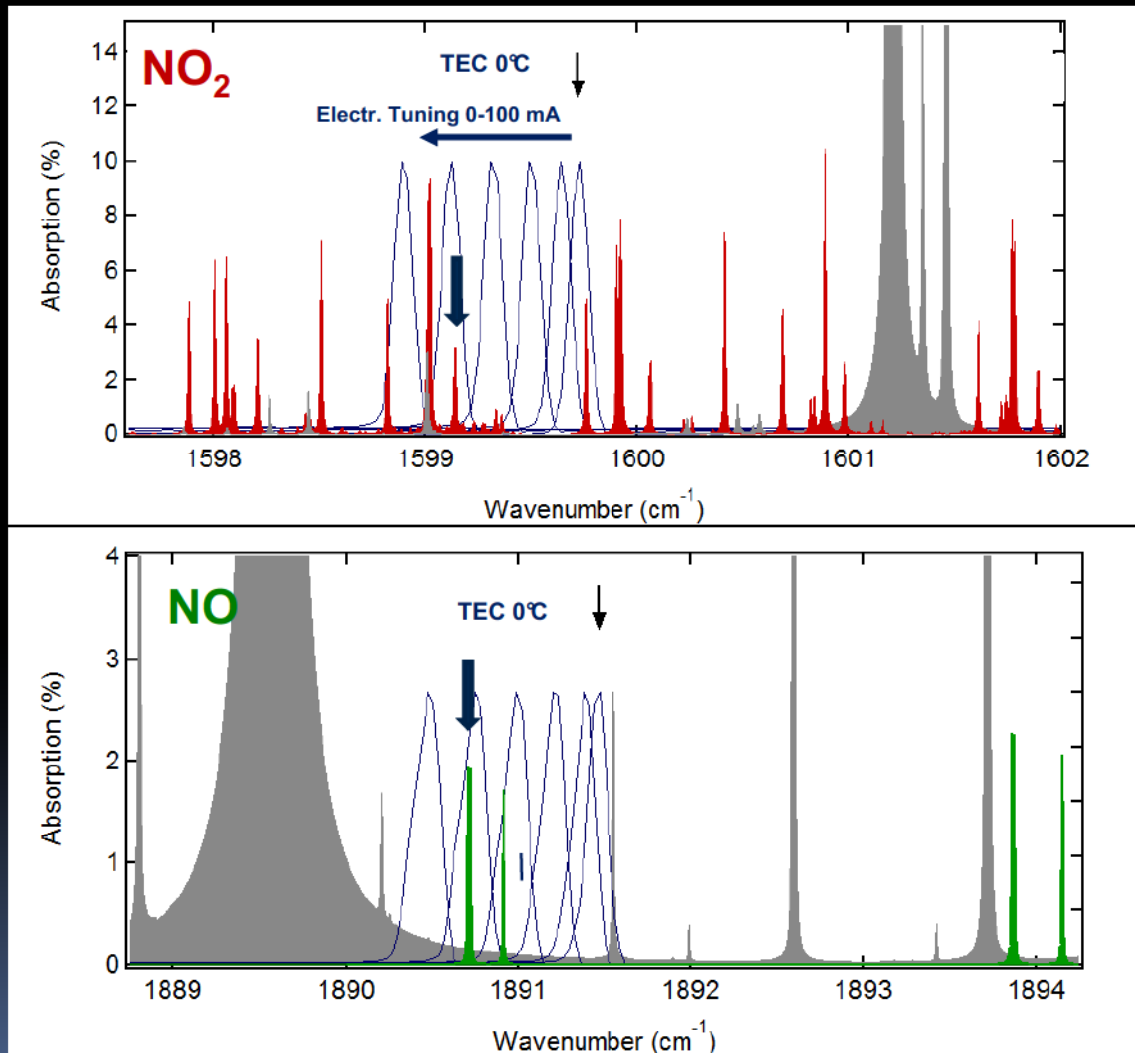
- Heterogeneous cascade active region design
- Emission 1600 cm^{-1} and 1900 cm^{-1} for NO_2 and NO detection
- Sequential operation due to electrical separation



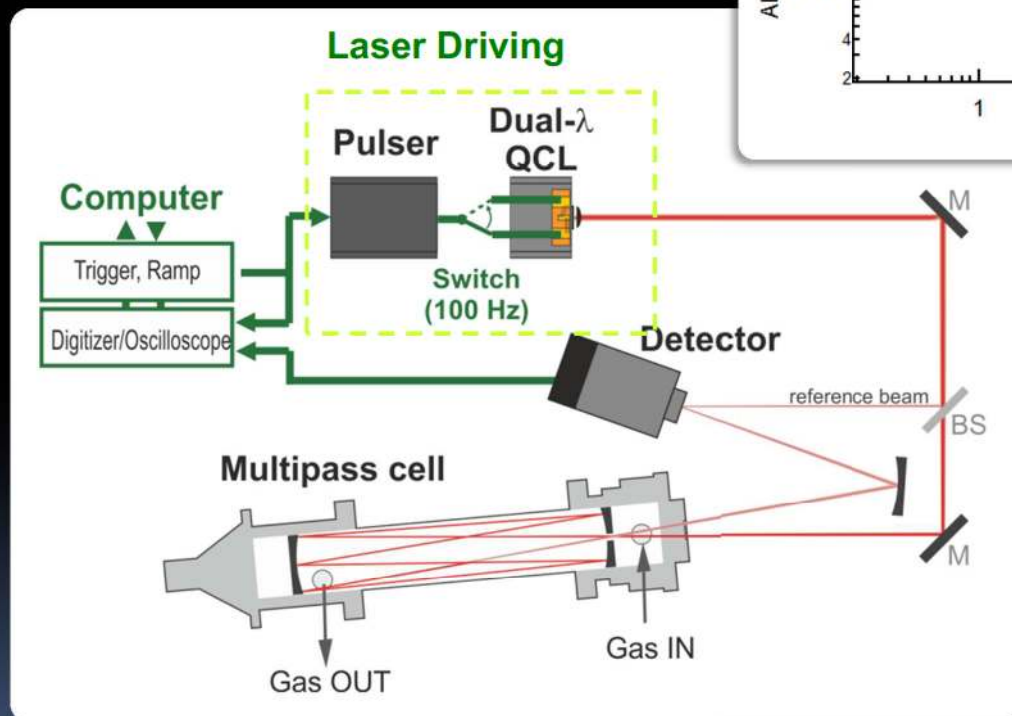
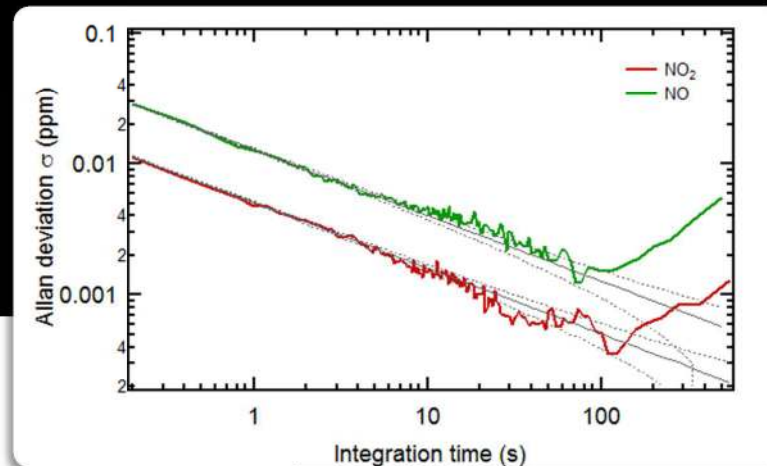
J. Faist et al. @ ETH



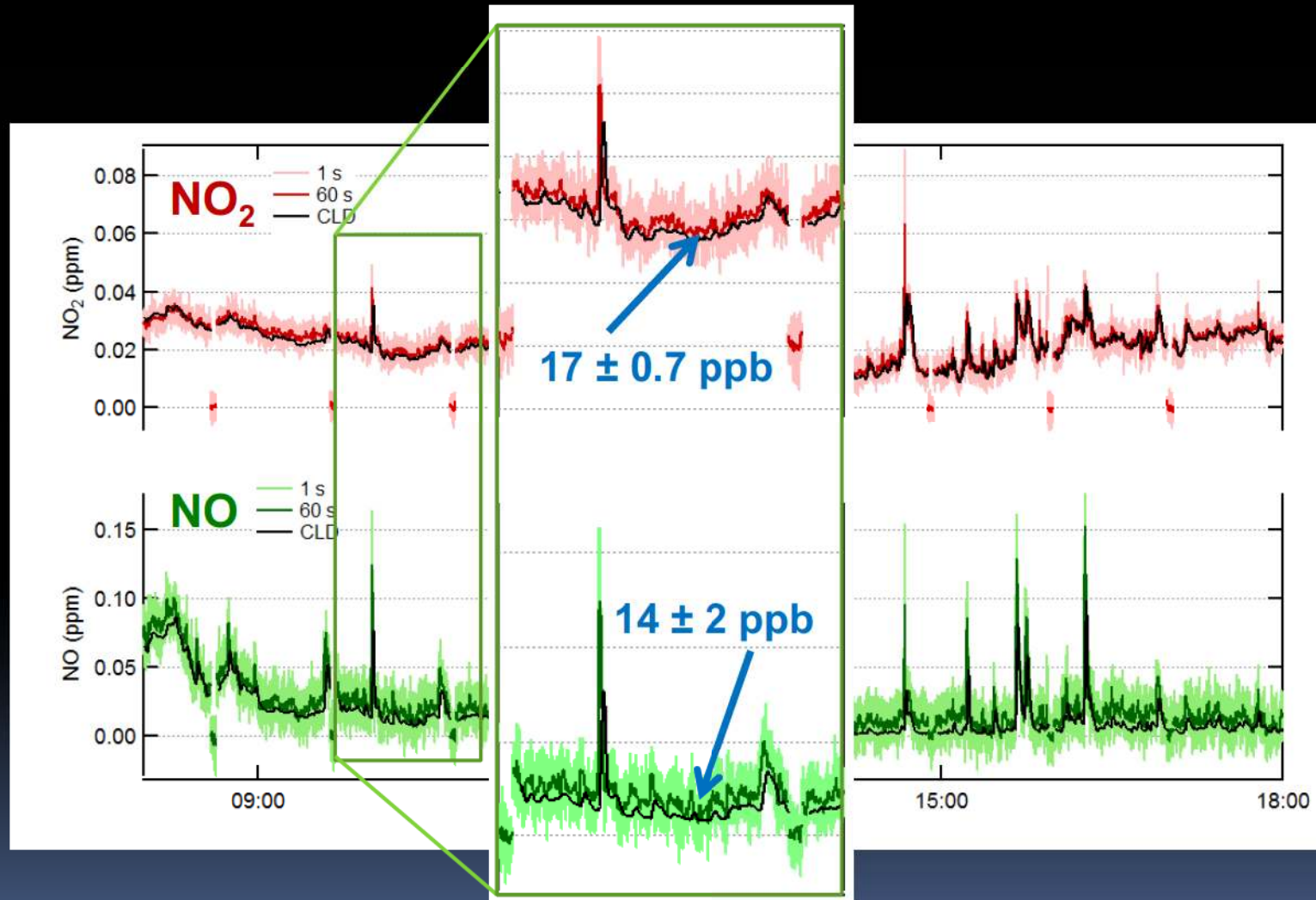
Emission spectrum



Spectroscopic Setup



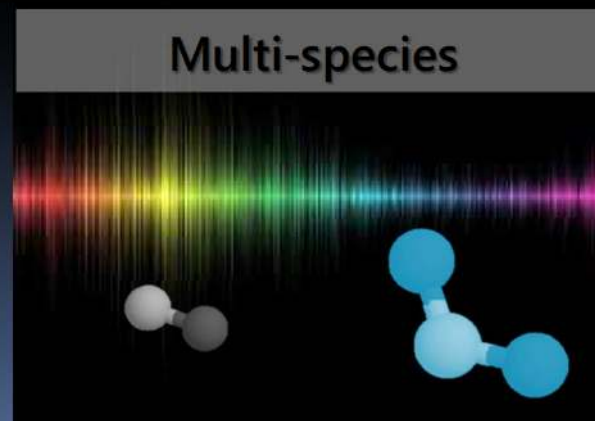
Atmospheric measurements



Outlook: The vision of «multi-species» analytics



Summary



Acknowledgements

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*Thank You
for your attention.*