LEMON Instrument and Preliminary Results

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LEMON Final Public Workshop, 11 July 2023, Palaiseau, France

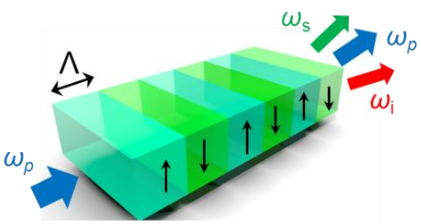
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 821868

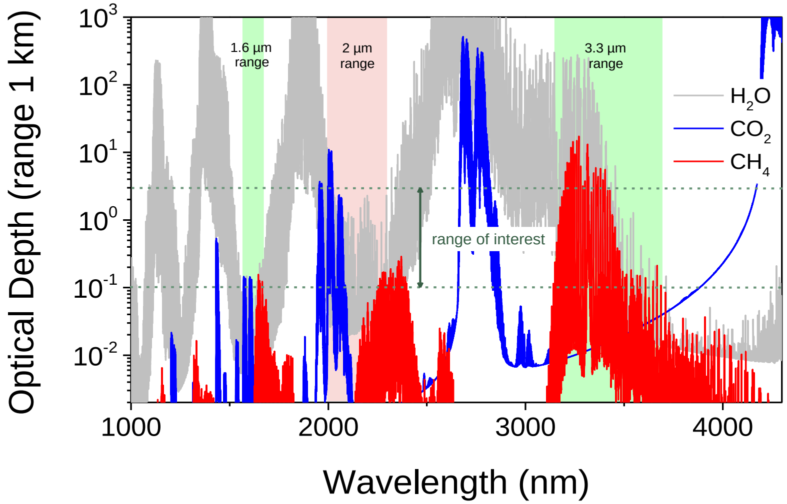
CONTEXT AND BACKGROUND

Parametric Sources for Differential Absorption Lidar

- ❑ Available and customizable nonlinear materials in the mid-IR up to λ=4 µm (KTA, LN, KTP, PPLN, PPKTP, …)

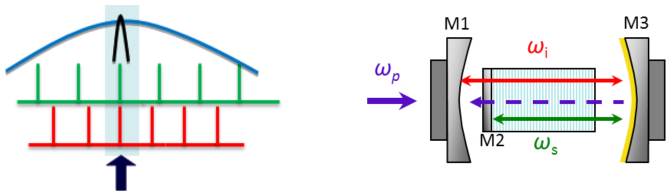
- ❑ Energy scalable ← heritage from 1 µm pump lasers





Background on NesCOPO/OPA sources @ONERA & spectral windows at 2 µm

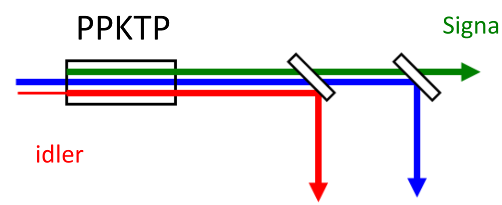
Doubly resonant OPO with Vernier Spectral filtering



NesCOPO Architecture

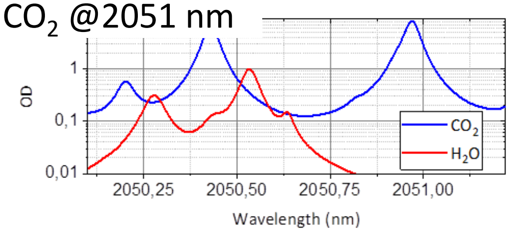
→

High energy OPA

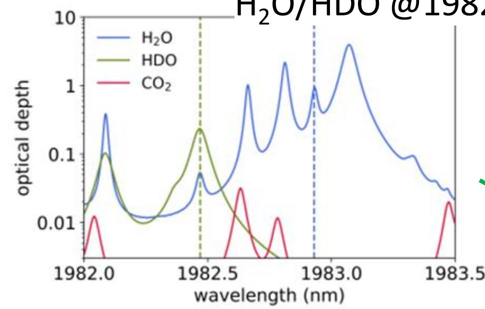


- Architecture & components (PPLN/PPKTP) applicable in multiple spectral windows
- Targeted applications:

CO_2 @2051 nm

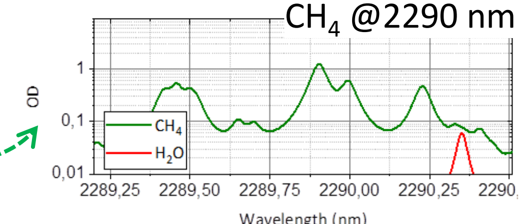


H_2O/HDO @1982 nm



Idler window

CH_4 @2290 nm



General Approach

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- ❑ Adress multiple-species @ 2 µm
- ❑ NesCOPO + PPKTP OPA baseline for high energy
- ❑ Maturation effort for airborne capability & future ground-based campaigns
- ❑ Demonstrate key performance for space

Dherbecourt, Jean-Baptiste, et al. "Design and pre-development of an airborne multi-species differential absorption Lidar system for water vapor and HDO isotope, carbon dioxide, and methane observation."

ICSO 2020. Vol. 11852. SPIE, 2021.

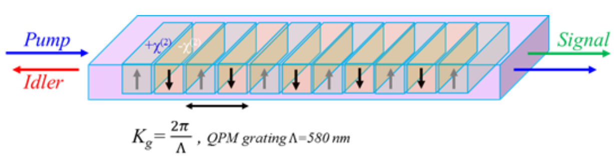
- ❑ Frequency comb referencing approaches

Schaefer, Hanjo, et al. "Development and test of a broadband absolute frequency reference with sub-MHz precision based on a GHz mode locked laser source."

ICSO 2022-14th International Conference on Space Optics. 2022.

- ❑ Exploratory studies

Backward Wave OPO (BWOPO)



Mølster, Kjell Martin, et al. "Pump Tunable Mirrorless OPO: an Innovative Concept for Future Space IPDA Emitters."

ICSO (International Conference on Space Optics) 2022.

Innovative versatile laser emitter integrated in a multi-species Instrument

SPECIFIC MULTI-SPECIES EMITTER

Emitter architecture

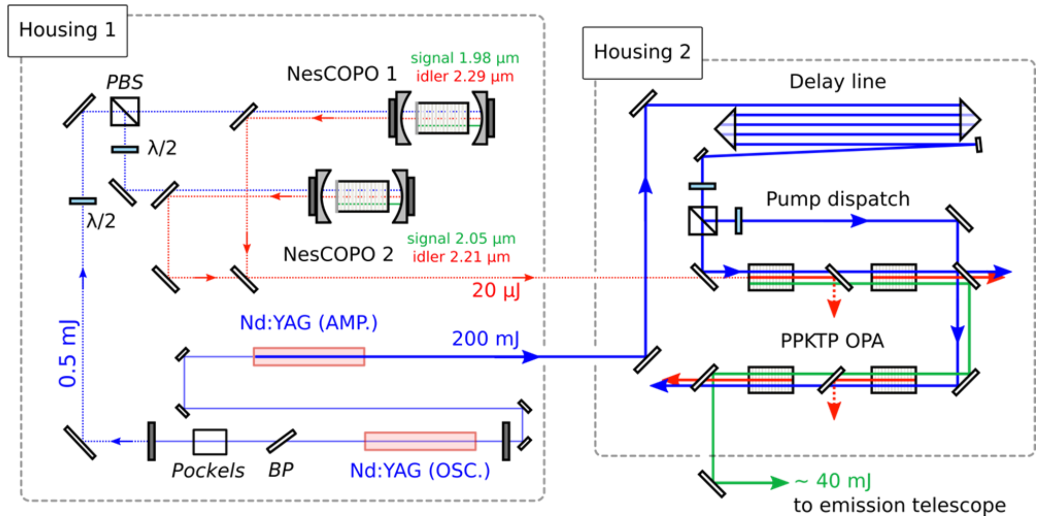
lemon

ONERA
THE FRENCH AEROSPACE LAB

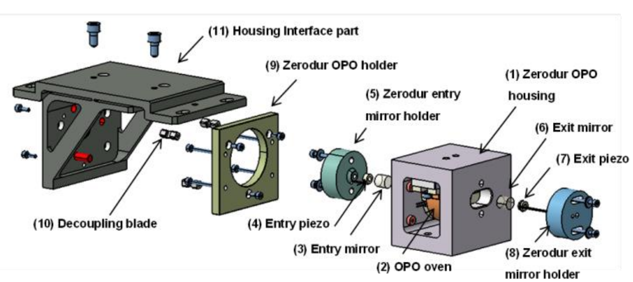
INNOLAS LASER

Fraunhofer ILT

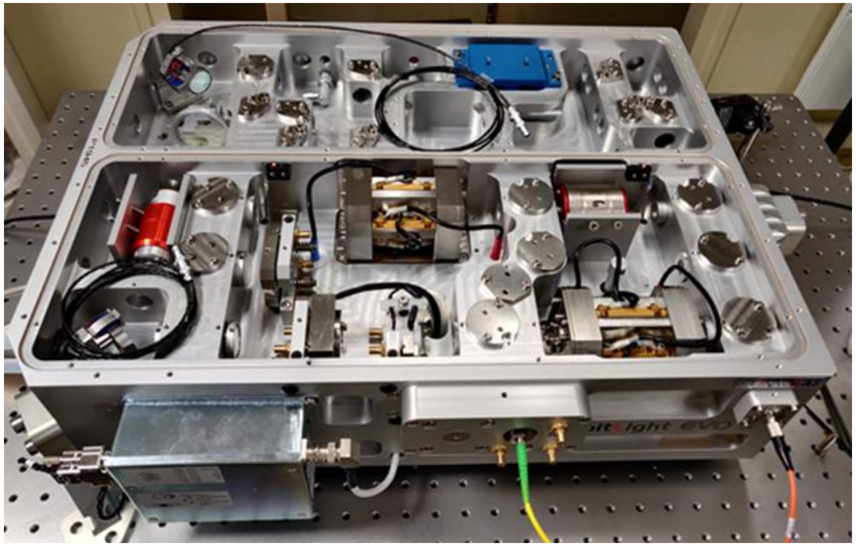
KTH VETENSKAP OCH KONST

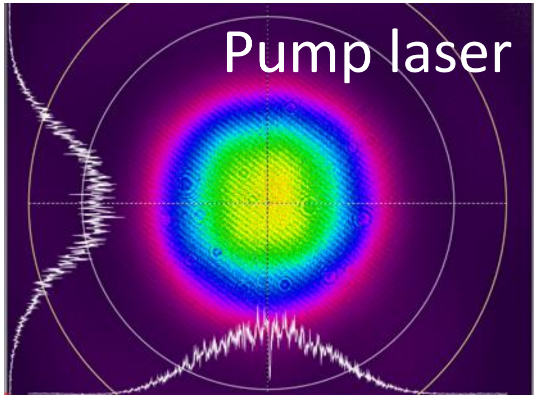


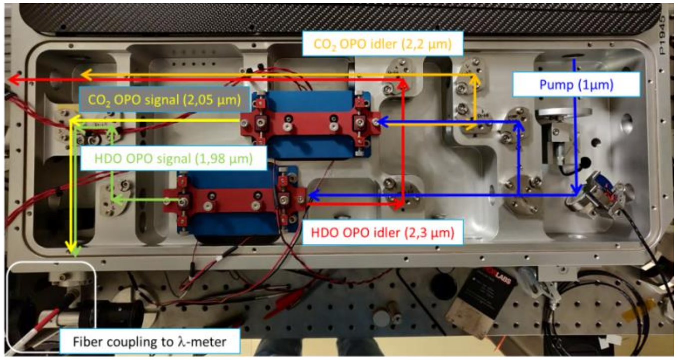
- ❑ Pump laser: MOPA (10 ns, 250 mJ, 75 Hz double pulse, high beam quality)
- ❑ Frequency conversion: MOPA (2 OPOs with ULE glass frames / single OPA line tunable with T°)



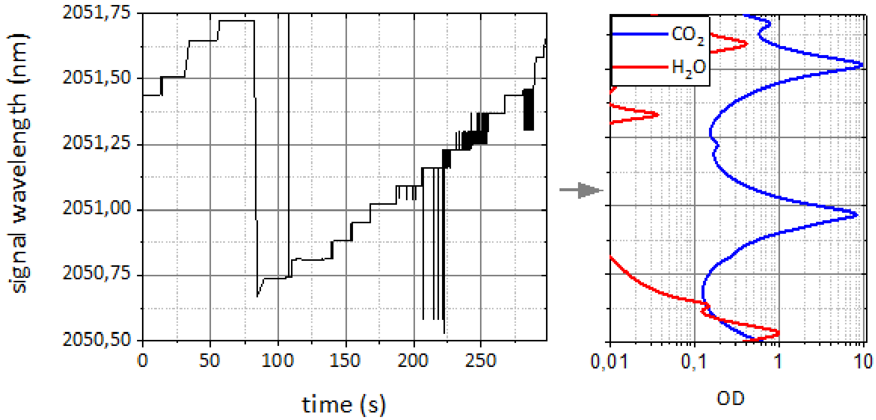
Housing 1 Laser and OPOs integration



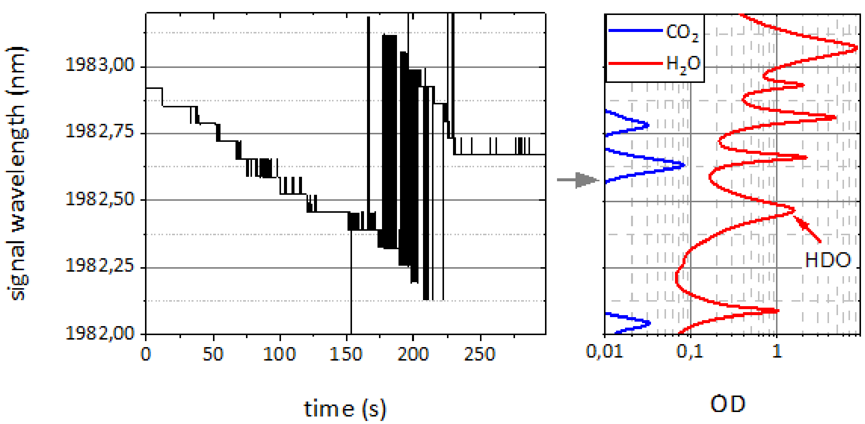




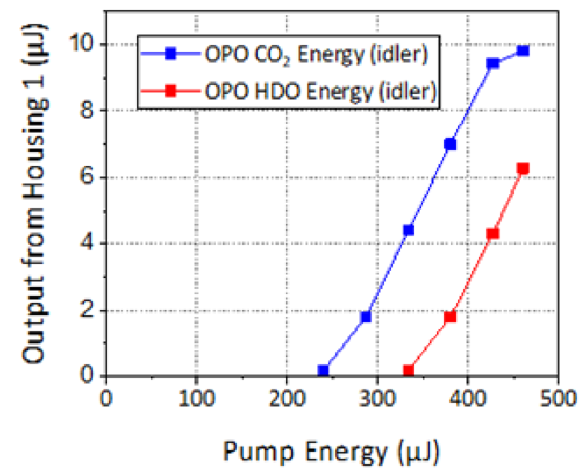
OPOs spectral coverage and Energy



Signal ok
for CO_2

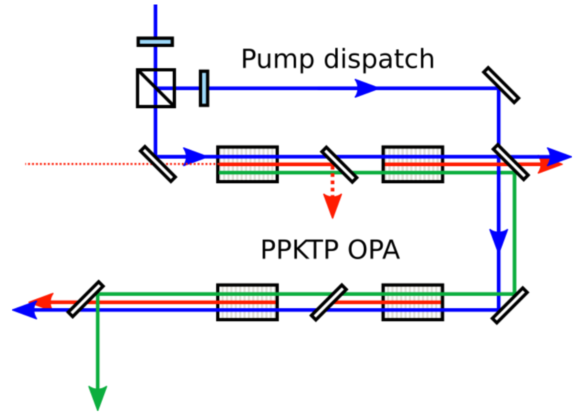


Signal ok
for HDO/H_2O



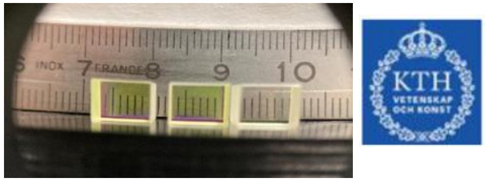
Housing 2 OPAs architecture

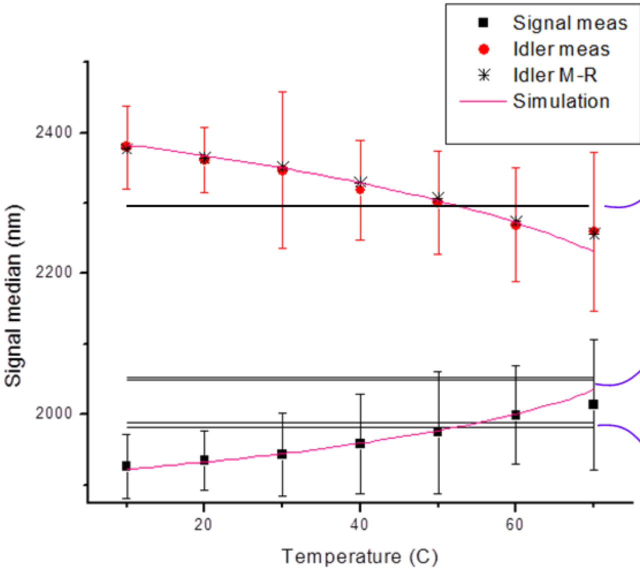
Design:



- PPKTP OPA
  - Highest nonlinear coefficient for KTP
  - No walk-off
  - No need to turn it to achieve phase matching

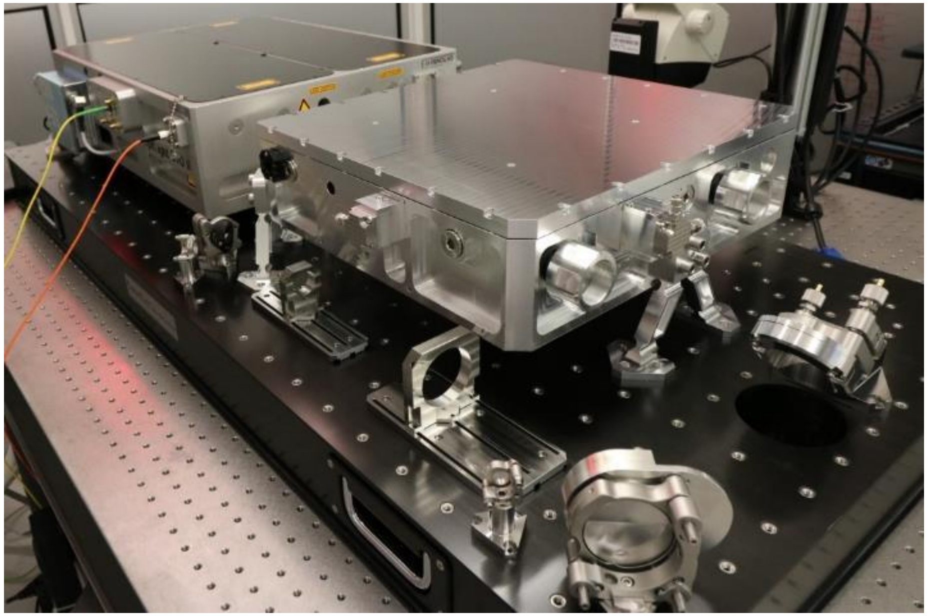
- OPA efficiency/beam quality optimization
  - 2 stages with pump refreshing
  - Idler filtering
  - Pump distribution optimization

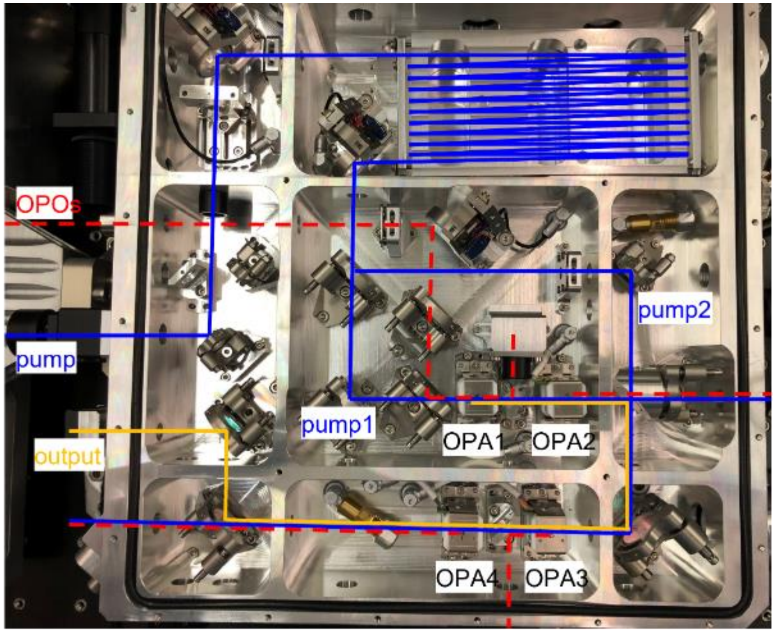




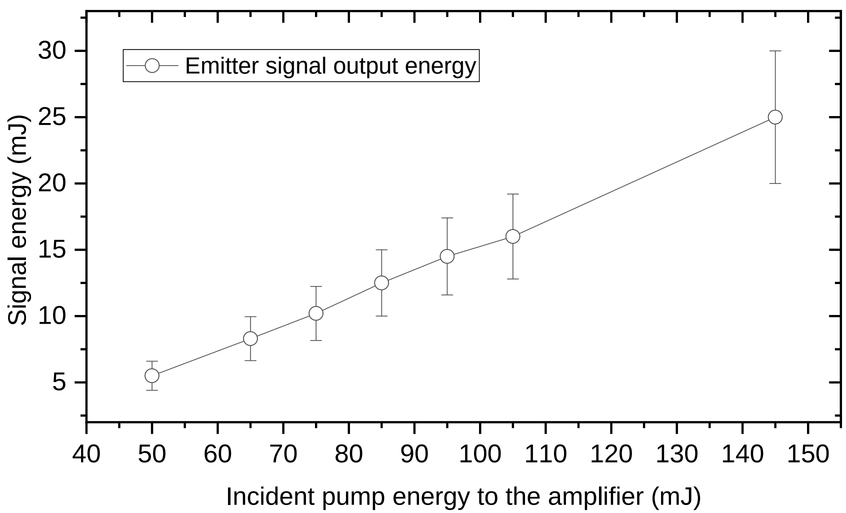
- 5 mm thick PPKTP crystals
  - LIDT > 4 J/cm²
  - Tested under radiation*

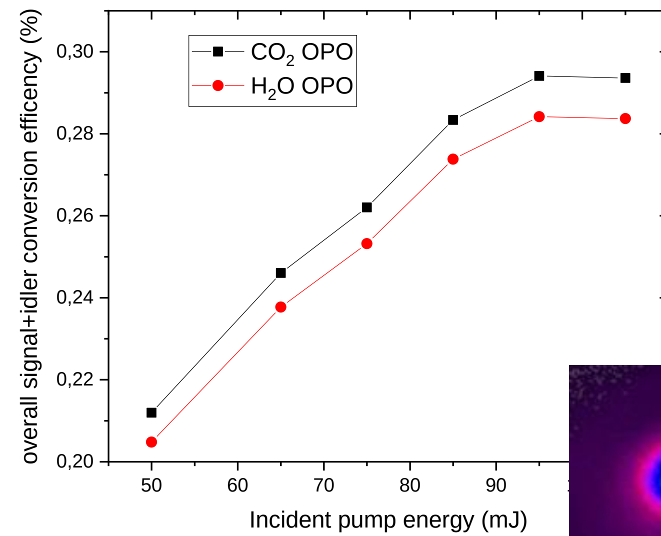
Housing 2 OPAs integration

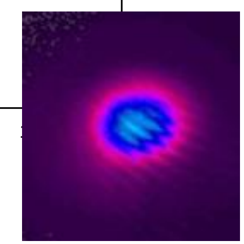




Housing 2 OPAs integration



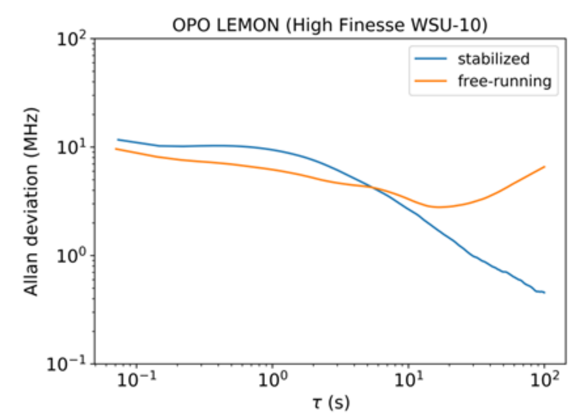




- ❑ High conversion efficiency OPA
- ❑ High beam quality $M^2 < 1.6$
- ❑ Up to 25mJ achieved for signal alone

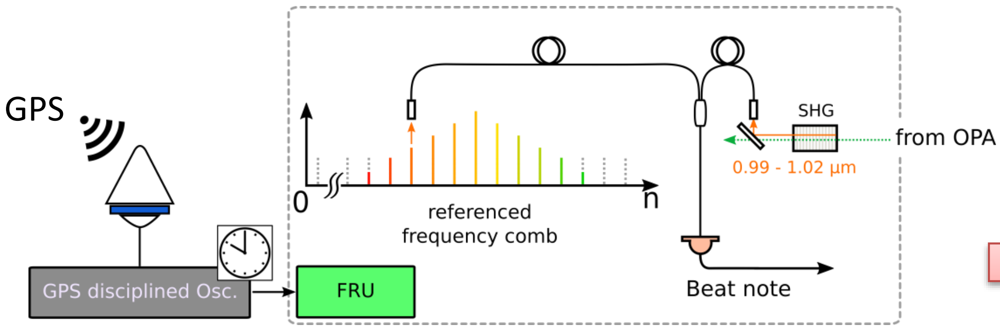
⇒ close to the 30mJ required for IP-DIAL from space (pump energy could still be increased)

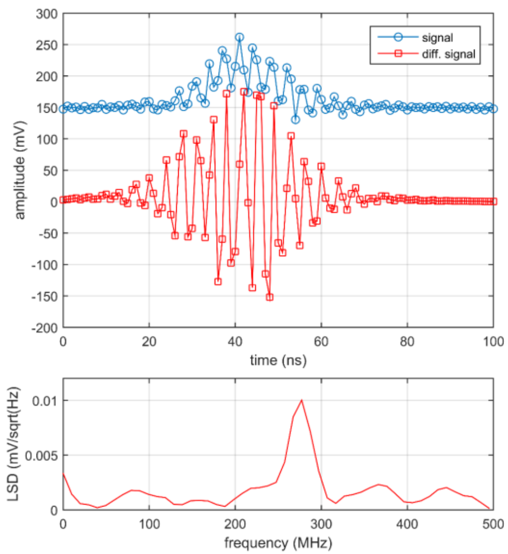
- ❑ High intrinsic frequency stability (locking procedure to be optimized after the project end)

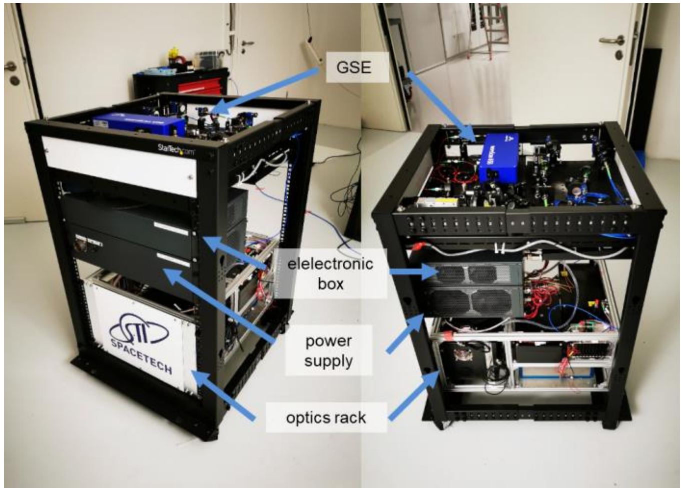


Multi-frequency referencing approach

Broadband FRU concept based on referenced frequency comb → sub-MHz absolute reference







- ❑ Mostly tested with 1 µm laser sources
- ❑ One lab test opportunity lab in 2021
  - ➢ to be further interfaced and investigated with LEMON output

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New measurement demonstration in support of Earth Observation (meteorological and climate studies)

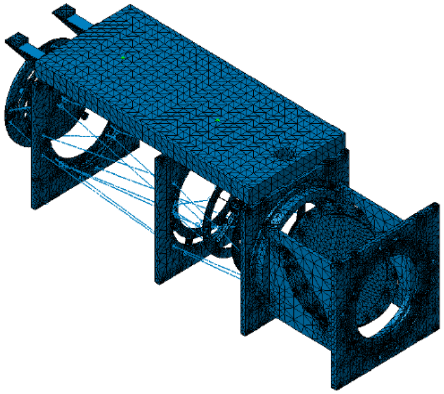
TRL 6 instrument validation

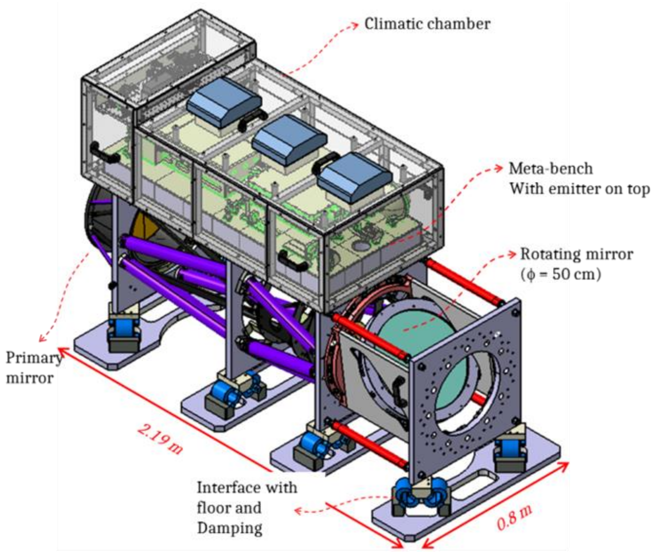
- Ground-based RR-DIAL (CO_2, H_2O, HDO)
- Airborne demonstration (H_20/HDO – CO_2 if enough flight time)

LIDAR INTEGRATION & FIRST TESTS

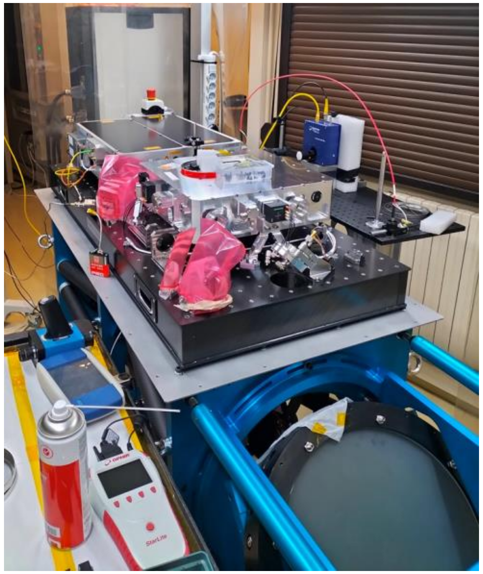
Lidar receiver platform

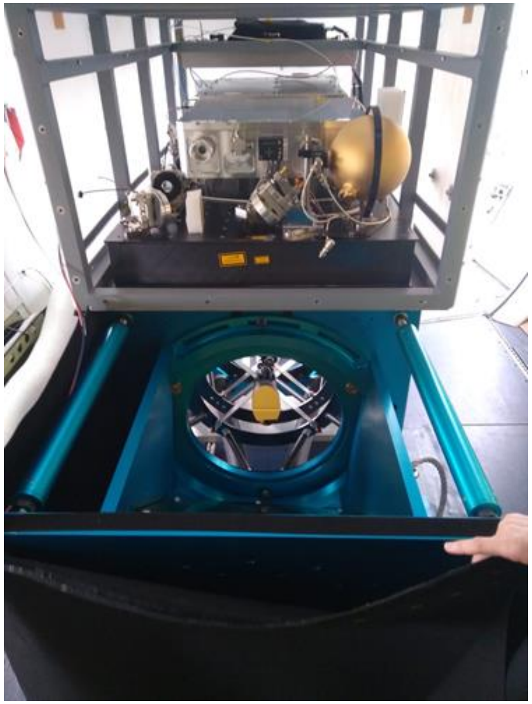
- Also a versatile approach:
  - Can be used for ground-based or airborne tests
  - Can welcome other emitters than LEMON’s
  - Fiber coupled Newton telescope: can be coupled to different detectors
  - Carbon fiber Newton telescope structure, specific mechanical design for horizontal position & rotative mirror for line of sight changes





Lidar integration





1st Range-resolved DIAL PoC

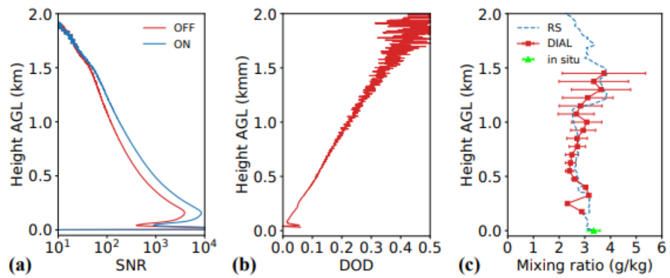
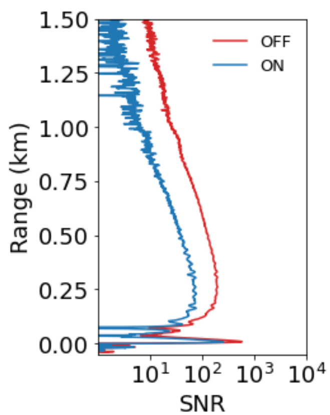
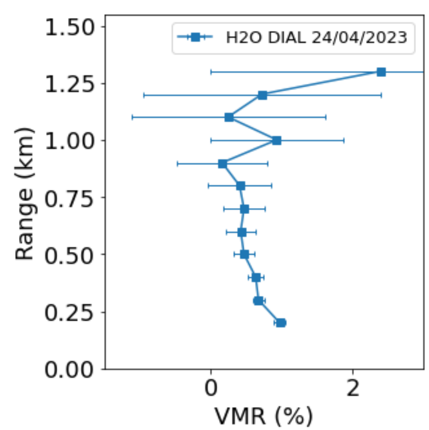


Fig. 6. DIAL measurement results for H_2O from 12:25 to 12:50 UTC (ca. 60 000 valid on/off shot pairs). (a) Raw (no energy normalization) signal-to-noise ratios of the on- and off-line LIDAR returns. (b) Recorded differential optical depth. (c) DIAL-retrieved profile of the H_2O mixing ratio (150 m range cells and 75 m sampling) compared to radiosonde (RS) profile and ground-based in situ sensor (accuracy ca. 0.25 g/kg).

1st world DIAL H_2O/HDO sensing
Laboratory breadboard **WAVIL**

⇒ More robustness & sensibility expected with LEMON





15000 shot integration (100s)

1st testing so far with **LEMON** on H_2O in May 2023 in Palaiseau

To be continued beyond the LEMON project

Aircraft integration & 1st tests

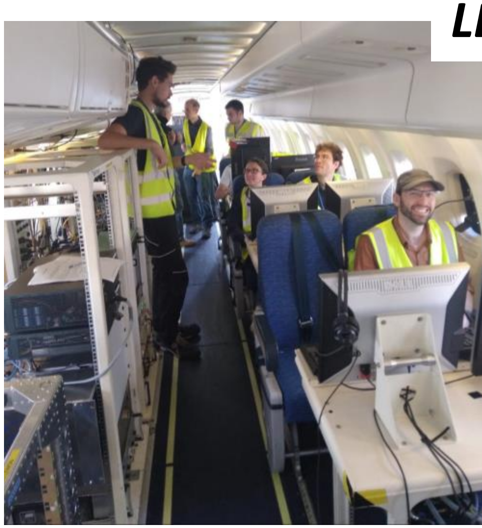
- Airborne certification obtained (with help of Safire)
  - In situ CRDS
  - LEMON DIAL & Fruit rack

- 2 Objectives for the campaign
  - 1st IP-DIAL tests (HDO probing) & retex
  - Science flights (in situ sensors & IP-DIAL if possible)

- Quick retex & ways of improvements for next campaigns
  - CRDS in situ sensors calibration setup operationnal & science flights performed
  - IP-DIAL acquisitions to be analyzed beyond LEMON & Retex
  - Possibility to loose some weight on some mechanical parts (easier integration)
  - Change of laser head set temperature & cooling group (the one used failed and limited the measurement time during the flights)
  - Automatisation of more functions (set wavelength & switch protocols) …

Aircraft integration & first IP-DIAL tests

In situ CRDS & calibration setup

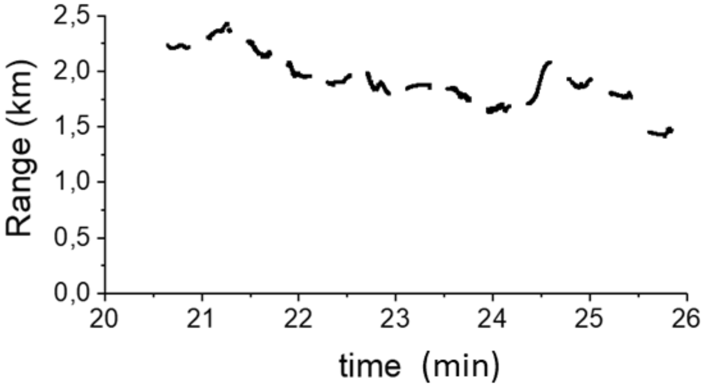


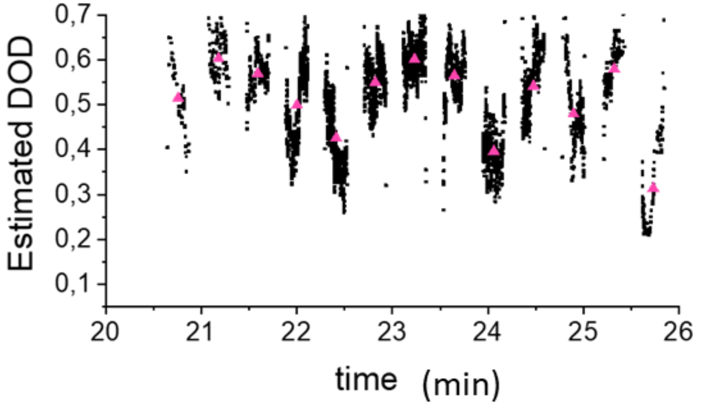
LEMON DIAL

Aircraft integration & first IP-DIAL tests

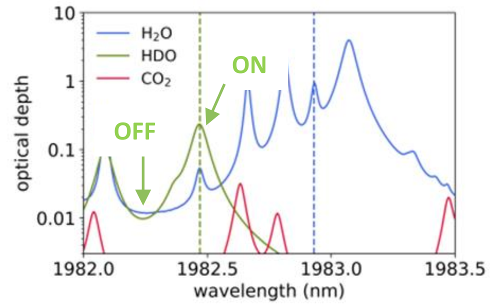
lemon

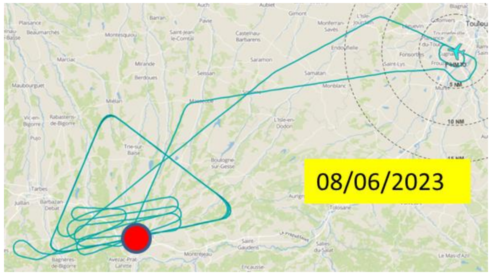
Preliminary quick look on HDO:





H_2O/HDO @1982 nm





- ❑ Low SNR and few exploitable data essentially due to laser cooling group failure in flight

However

- ❑ Ranges and DOD could be observed
- ❑ To be further analyzed, investigated and compared with picarros' data

CONCLUSION

A great platform for future DIAL experiments & many lessons learned

- Emitter: some very attractive and promising sub-units for space
  - Frequency conversion MOPA approach based on PPKTP
  - New BWOPO approach to be further evaluated
  - NesCOPO/OPA very efficient for ground-based multi-species Lidar
  - New frequency referencing methods

- DIAL experiments
  - 1st Lidar to probe HDO & H_2O using WAVIL laboratory prototype
  - LEMON DIAL is very promising as a robust setup for future ground-based H_2O/HDO, CO_2 probing
  - The tool is available; it requires further testing and development, further comparison and then deployment in future campaigns, in synergy with other sensors such as CRDS in situ sensors.

Visit our website: www.lemon-dial-project.eu

Follow LEMON-DIAL project on

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 821868