SHORT COMB ATMOSPHERIC LIDAR EXPERIMENT: PRINCIPLES, ACTIVITIES & PROSPECTIVES

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ROMAIN ARGUEL, MATHIEU BOUTILLIER, MARION COSTELLA, PHILIPPE J. HÉBERT, PIERRE LAFRIQUE, ALEX MATERNE,

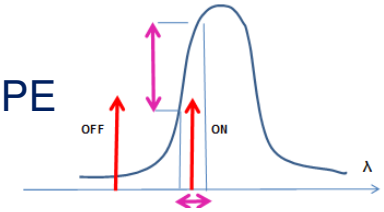
VÉRONIQUE PASCAL, JORDI ROUBICHOU, VÉRONIQUE TYROU

CNES

Why short frequency comb lidars?

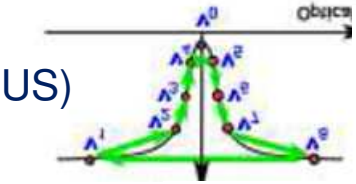
Atmospheric sounding & lidars issues: from mono-λ lidars to SCALE

- ex : MERLIN, A-SCOPE



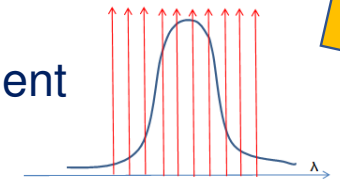
Increasing frequency amount

- ex : ASCENDS, IMPRESS (US)



Simultaneous emission + Perfect frequency step

- **S**hort **C**omb **A**tmospheric **L**idar **E**xperiment



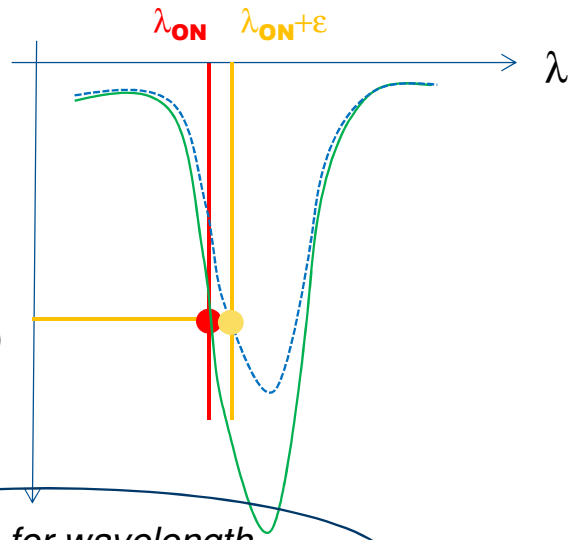
7 teeth:
- Available energy vs. Info content **compromise**

Accurate frequency step:
→ **Optimal multi-parameter retrieval**
→ Tolerance on λ_0

All frequencies at once:
→ Ground / atm. non uniformities OK
→ Carrier velocity OK

Absorption line profiling relaxes spectral calibration requirement

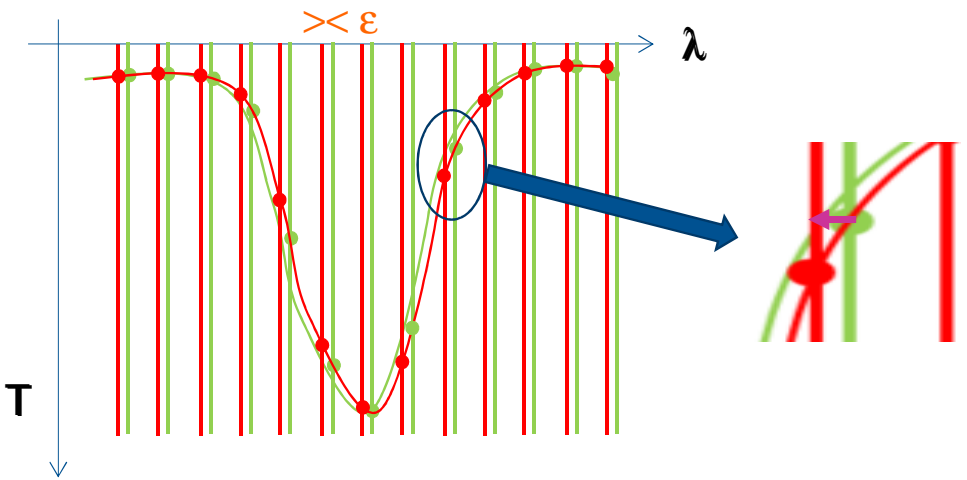
DIAL



$T_{ON}(X[CO2]_2)$
$=T_{ON+\varepsilon}(X[CO2]_1)$

One small step for wavelength…
… but one giant leap for optical depth

Short combs



Global frequency shift… but no error in line depth

Proprietary 2 step processing:

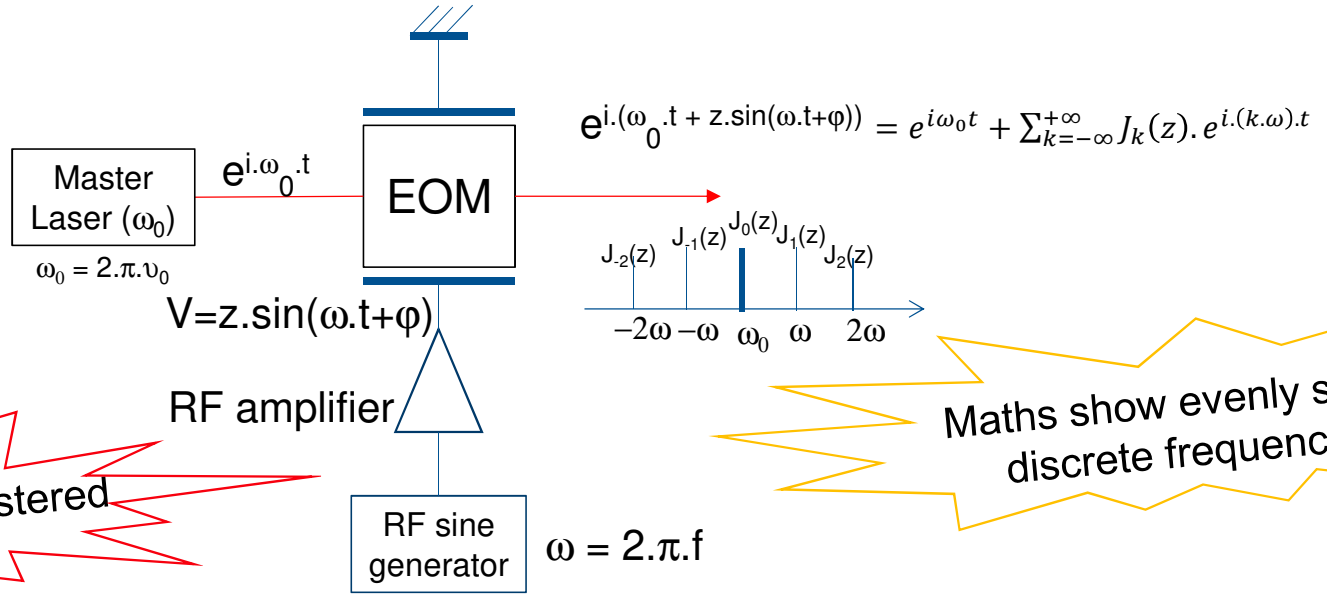
± 0.5 GHz frequency calibration → 0.025 ppm bias on XCO2

Remark : ± 20 kHz would be necessary for 0.025 ppm with DIAL

C. Rodgers « Inverse method for atmospheric sounding »

Some technical issues

Electro-Optic Short Frequency Combs (EOFC) generated by EOM

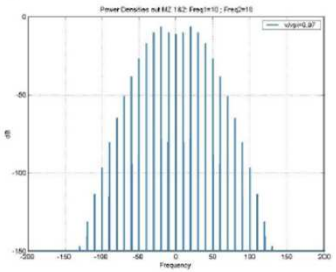


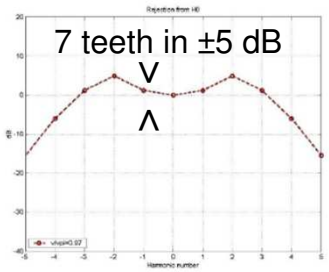
RF technics → ω well mastered

Maths show evenly spaced discrete frequencies!

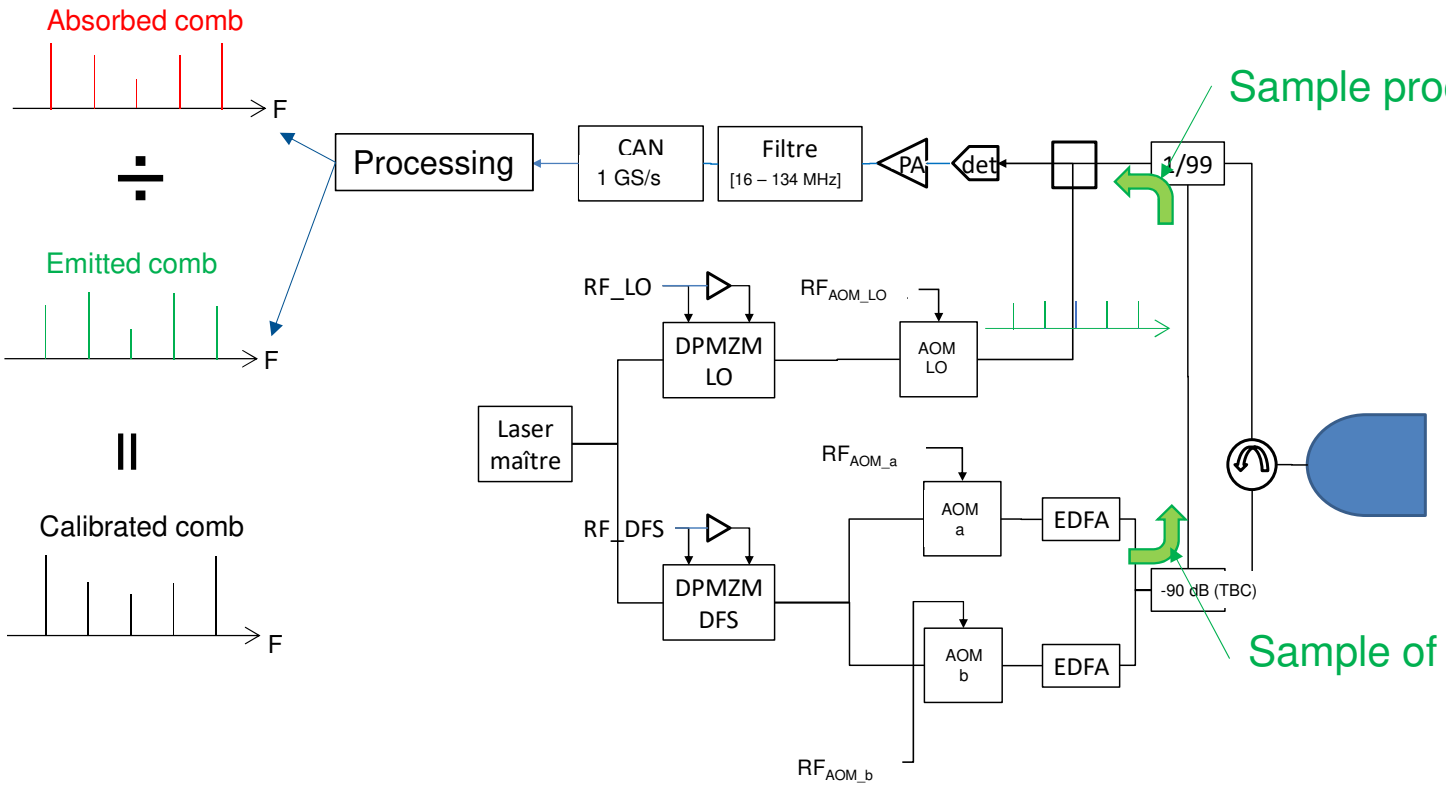
z = 0.97.π rd

V=0.97 Vπ, "7th harmonic Flatness" : 5dB





Calibration: how to deal with non flat combs



Sample processed as per the sounding combs

Flight time ≈ 3 ms for space
0.03 ms for airborne

Sample of the emitted combs

Instrument layout: Double Heterodyne Detection

Analogue detection signal:

1rst beat tone « 1 – LO - φ_r»
(1rst freq. diff.)

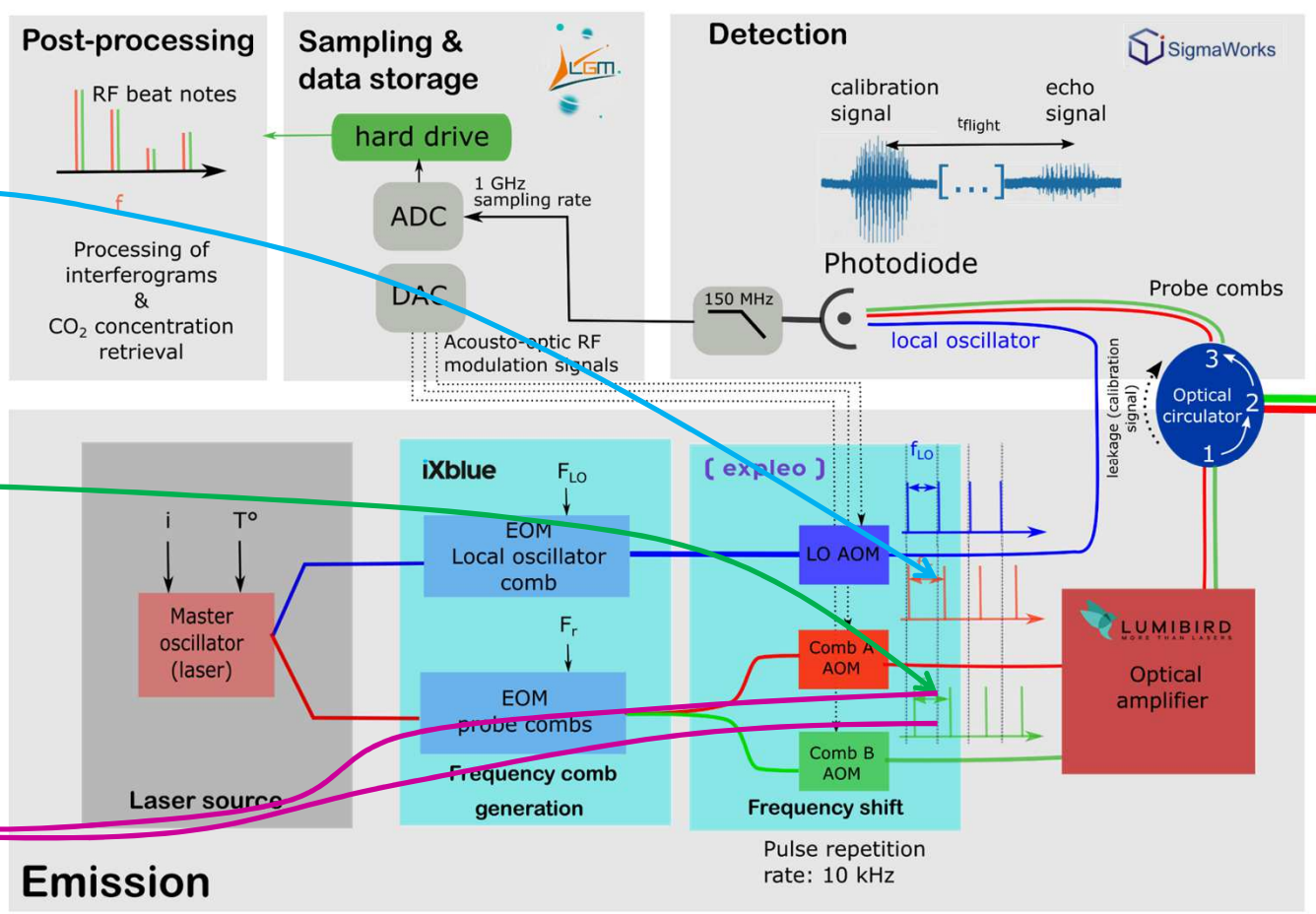
+

1rst beat tone « 2 – LO - φ_r»
(1rst freq. diff.)

↓

Digital processing: $(1+2)^2 \rightarrow 1\times2$

2nd beat tone (2nd freq. diff.)
« 1 – LO - φ_r »-« 2 – LO - φ_r »
= « 1 - 2 »



Phase noise (laser, turbulences) φ_r is canceled!

Activities at CNES

History and heritage:

2014 – 2019: R&D contracts with ONERA

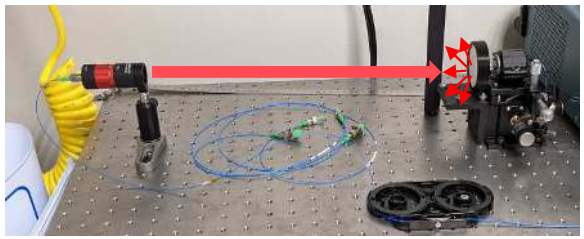
Hébert, Lemaître « SCALE: validations and prospects for a novel type of sounding lidar using short frequency combs », ICSO 2018 proceedings

2019 – 2020 : System level study

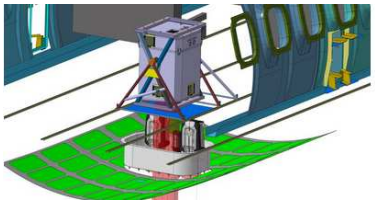
2021+: see next slide

Current 3foilled activity:

Laboratory



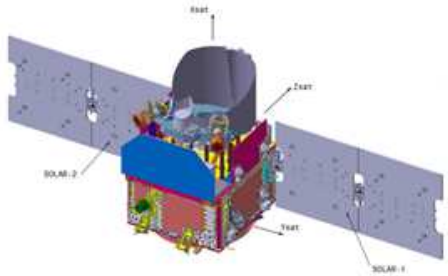
Development of an A-PoC



2.5 year development

1rst flight expected mid-2023

Advanced « phase 0 » study



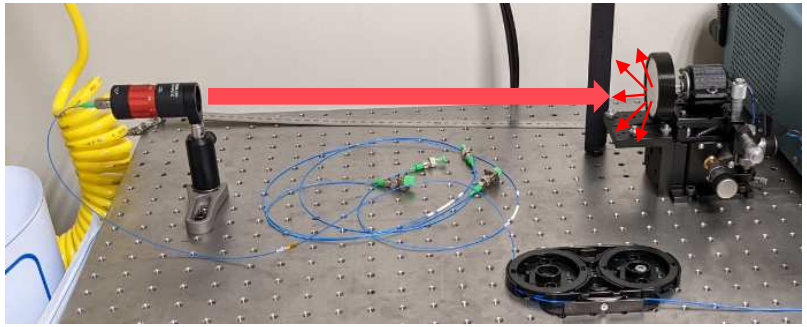
with ADS-France
9 months
Available technology @ 1.5 µm (telecom)
- Column XCO_2 random error < 1 ppm
- Column XCO_2 bias < 0.2 ppm
- 2 independant measures along the vertical

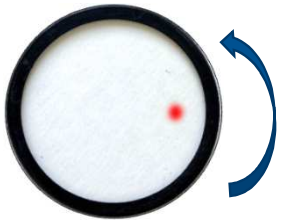
→ To confirm the feasibility of a spaceborne SCALE instrument on a Micro-satellite (« Myriade Evolution » type)

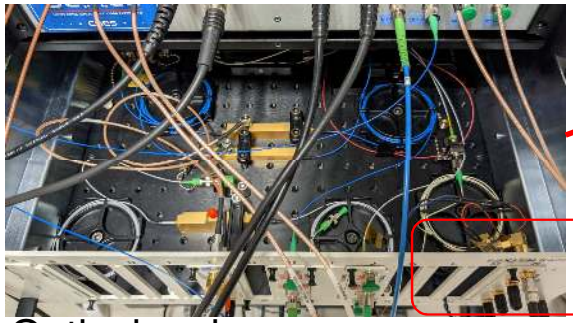
Case study: atmospheric CO_2 measurement

Exploratory lab activities at CNES

Practical application of instrument layout

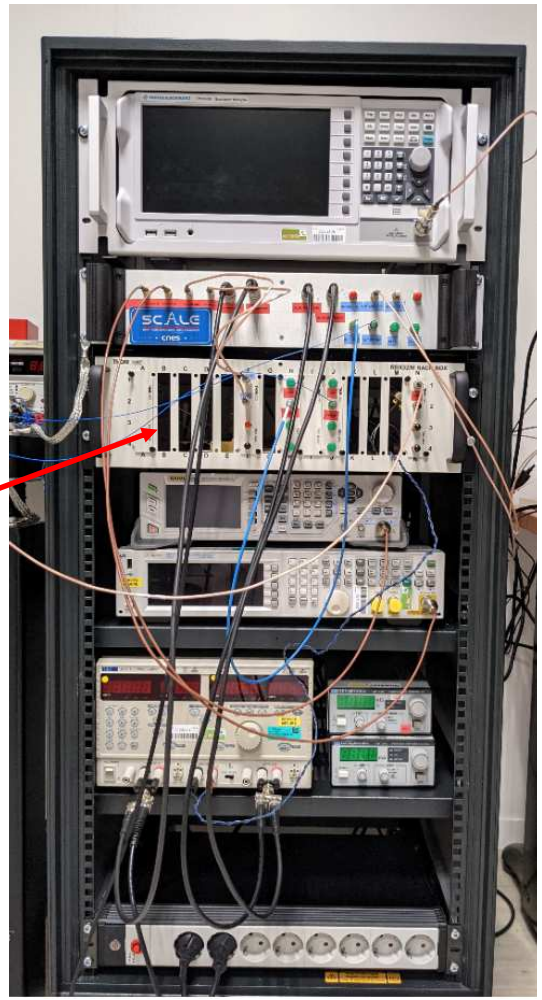






Optical rack

PIN photodiode



RF spectrum analyzer

RF amplifiers and AOM

Laser source and EOM

RF synthetizers

DC power and I/T° laser controlers

Detection

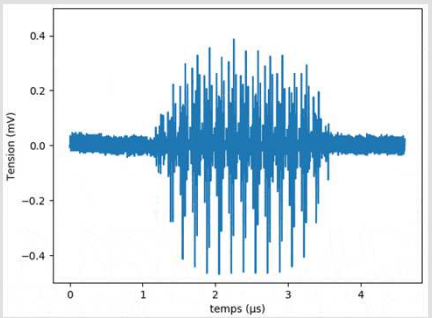
Telecom photodiode
(BW = 10 GHz)

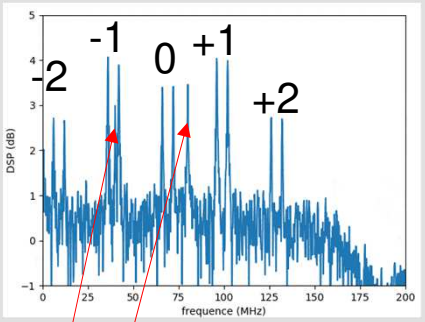
DC block + Low pass filter + amplifiers

Digitizing: 1GS/sec, 8 bits

Examples of signals: 20 pulses interferograms and spectra (no absorption line in the path)

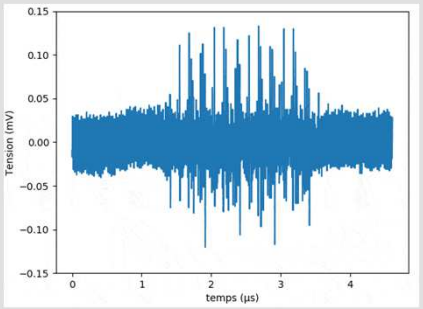
Fibered setup

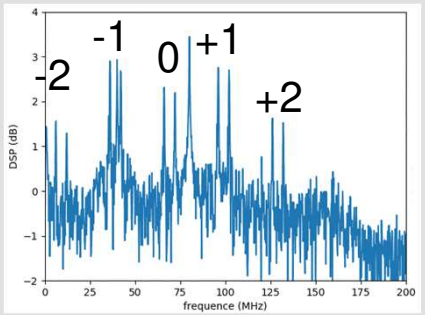




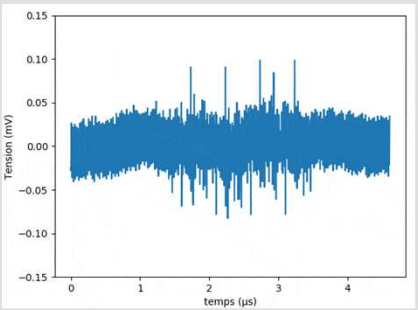
parasitics

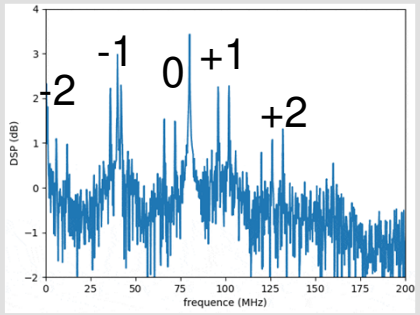
Reflection on a fixed scattering surface





Reflection on a rotating scattering surface

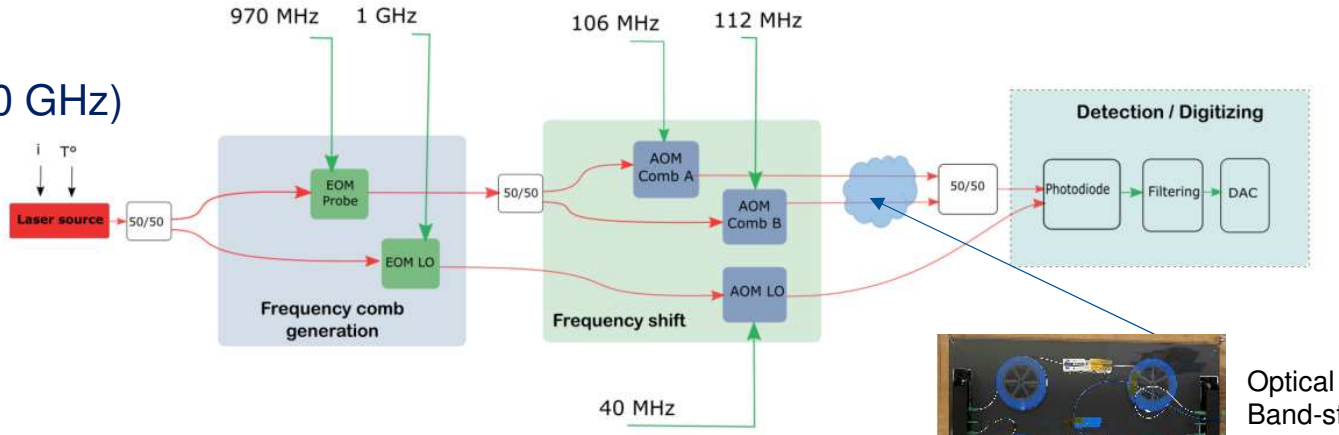




- Lower SNR with a reflection on a scattering surface
- 2 effects when the surface is rotating:
  - Defocus
  - Speckle

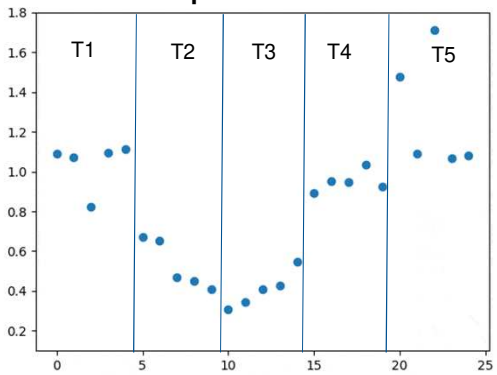
Retrieving an absorption line (preliminary): all fibered layout

- Optical band-stop filter to simulate an atmospheric absorption line (FWHM = 10 GHz)
- DHD setup & processing, all fibre
- EOM RF amplifiers BW limited to 1 GHz: 5 measurements concataneted



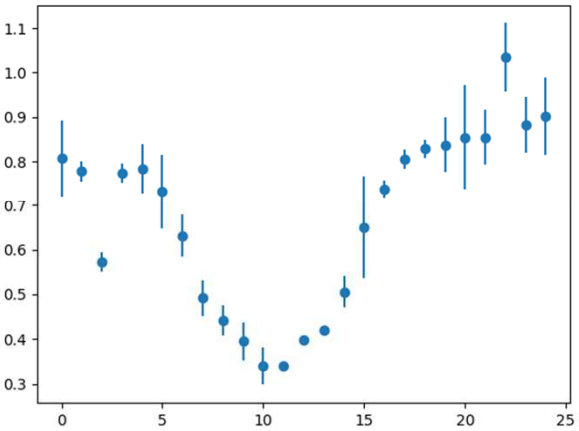
Optical Band-stop filter (iXblue)

100 pulse movie

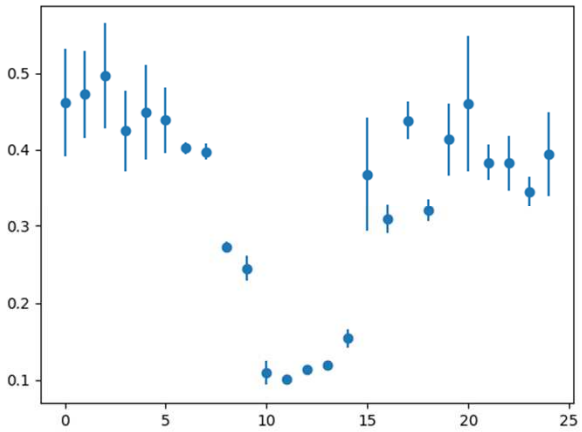


Retrieving an absorption line (preliminary): effect of speckle

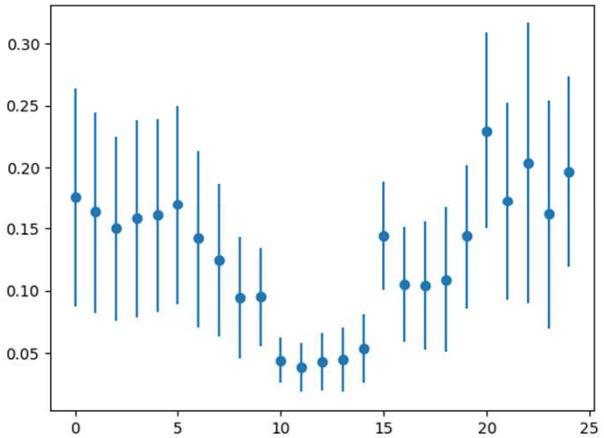
100 pulse average and std deviation



Fibered setup



Reflection on a fixed scattering surface



Reflection on a rotating scattering surface

➔ Need to average many shots on a moving target

Conclusions & perspectives

- SCALE: a conceptual & technological innovation in lidar science:
  - (short) combs introduced in sounding lidars
  - Double Heterodyne Detection

  → Spectral calibration requirement ↓
  → Architecture & technics (fiber optics & components ☺)
  → On the shelf technology @ 1.5 µm
- Perspectives for a SOA performance onboard a microsat
- Can be adapted to other molecules than CO_2 (CH_4, H_2O, NO_x, O_2…)
- Lab & outdoors validations with retroreflectors (R&D ONERA)
- Need to confirm concept advantages:
  - Laboratory experiments
  - Advanced “phase 0” study @ CNES + ADS
  - Airborne demonstrator: on progress @ CNES

…by end 2023.

➔ To have a complete overview to begin setting up a possible SCALE space mission

Thanks for attention!