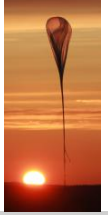
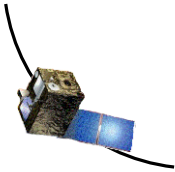




SPECIES: An example of interoperable instrument (stratospheric balloon and aircraft)

V. Catoire, C. Robert, P. Jacquet, M. Chartier, D. Romanini, G. Krysztofiak

HEMERA workshop: 5 July 2022, Rome (Italy)

Context and issues

Scientific Interest:

- characterization of local, regional and global pollutions
- characterization of air mass circulation using gaseous tracers
- reference measurements (in-situ) for the GHGs and stratospheric ozone drivers (CO_2, CH_4, N_2O) in relation with satellite validations of CNES(-DLR), ESA, CSA, NASA, JAXA...
- input data for chemistry-transport modeling from the ground to the stratosphere (0-40 km alt)

Extreme measurement conditions:

- in-situ : -80 < T < +40 °C and 3 hPa (40km) < P < 1030 hPa (ground)
- fast: in < 2 seconds → low sampling volume → Resolution: 10 m vertically in balloon/aircraft and 200 m horizontally in aircraft
- online → optical spectrometry
- multi- and variable species → modular design: 2 to 4 racks (measurement channels)
- sensitive: trace gas mixing ratios from 0.1 ppbv to 1% (H_2O)
- precise: 1‰ to <10% (NO, CH_2O)

→ Infrared laser absorption spectroscopy (near & mid IR)

Costly flights → Failure forbidden → Balloon: Telemetry and remote control
→ Aircraft: Manual/automatic control on board

The requirement specification

Instrument to be integrated in a balloon gondola (CNES) & a research aircraft (SAFIRE)

→ Use of CNES certified gondola & SAFIRE certified rack (in relation with DGAC)

→ Design: several points in common between the Balloon and the Aircraft

→ Anticipate the 2 uses and their certifications

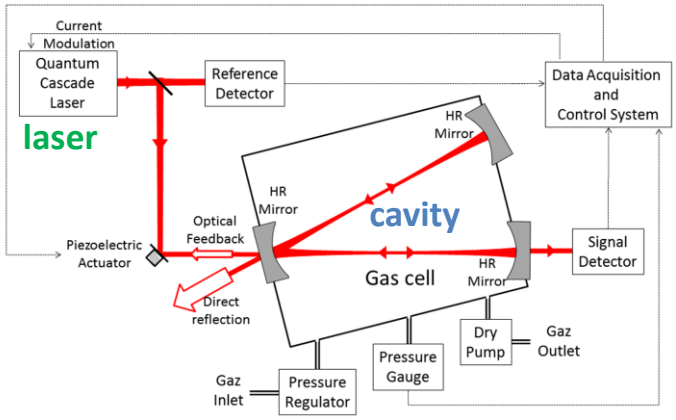
	Zero Pressure BALLOON (BSO)	**Research AIRCRAFT** (instrument in cabin)
Electricity	28 V DC, < 800 W during 10h Batteries with voltage fluctuations	28 V DC, < 1000 W Voltage fluctuations, referenced connectors and wires + EMC tests
Thermal control of the instrument	> -25 °C rather overheated (lack of air at altitude)	10 to 50 °C
Acceleration resistance	Mostly vertical (< 8 g)	Vertical (< 6,5 g) Horizontal (< 9 g)
Vibrations Fixings	Very low in flight, important during recovery → anti-vibration systems. Screw locking systems	Variable according to the aircraft → anti-vibration systems. Screw locking systems
Materials	Stainless steel (O_3 and UV resistant)	Non-flammable → aeronautical standards
Instrument-specific caution	Laser	Laser & cell under vacuum (50 hPa)

SPECIES: SPECtromètre Infrarouge à lasErs in Situ

PRINCIPLE of OFCEAS (*Morville et al., Appl.Phys. B 2005; Romanini et al., Appl.Phys. B 2006*)

Optical-Feedback Cavity-Enhanced Absorption laser Spectroscopy

Each individual rack contains:



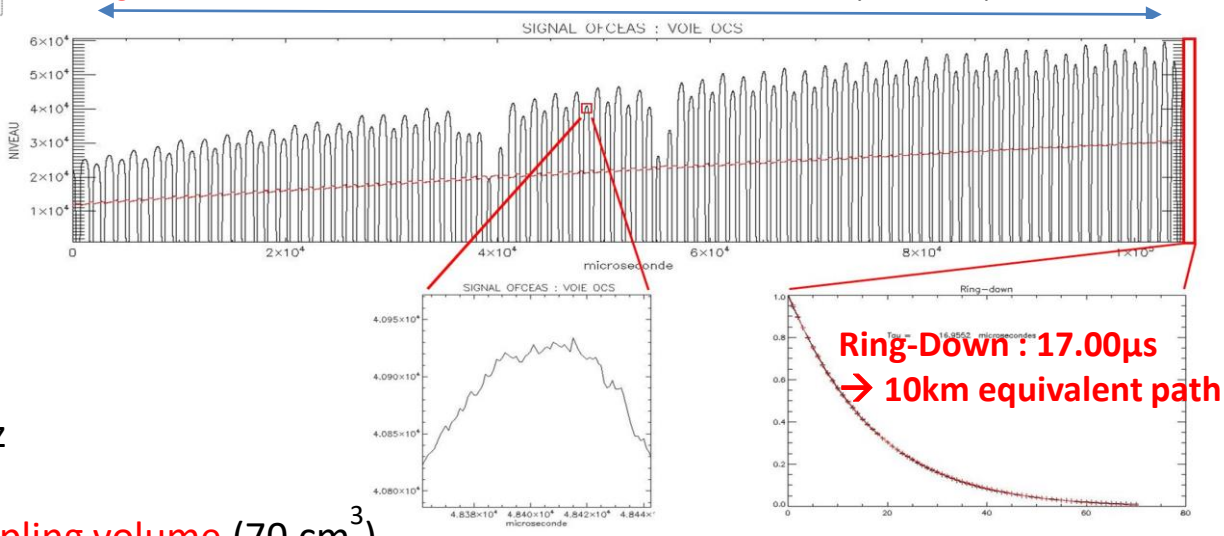
Efficient coupling of the **laser** source ($\tilde{\nu}_i$) with the **cavity** (*L=50cm*) by optical feedback at $\tilde{\nu}_i = k_i/4L$ (k_i : integer)

→ Amplification of the laser signal at successive regular $\tilde{\nu}_i$

→ Auto-calibration of the spectral scale

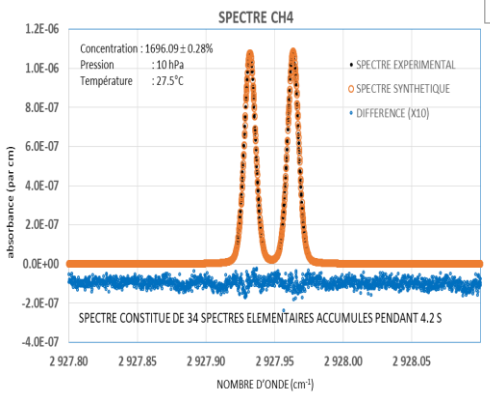
Ultra-high resolution: 0.005 cm^{-1} → 104 resonant modes for the cavity → total spectrum: 0.52 cm^{-1}

Example: spectrum obtained for the channel at 4.87µm →

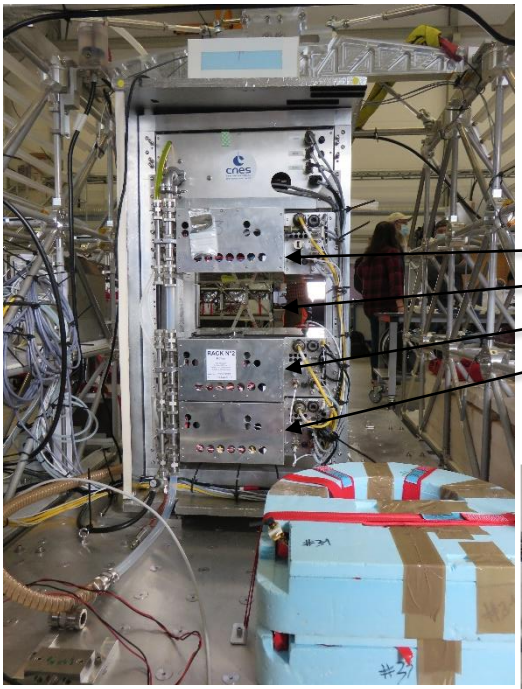


- Spectrum acquisition frequency: 8 Hz
- Dynamic measuring range > 10^4
- Response time: 2 s, due to small sampling volume (70 cm^3)
- Materials adapted to sticky molecules: electropolished stainless steel, PFA, or amorphous silica coating

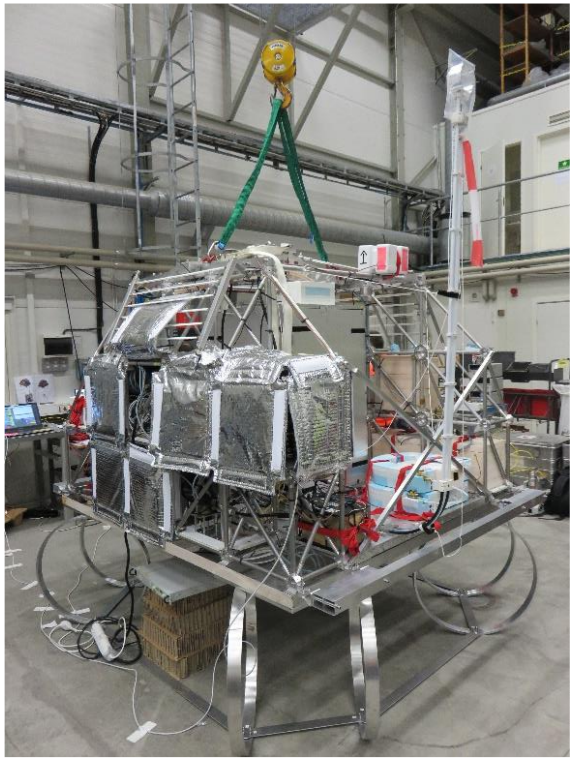
SPECIES: Instrumental schematic

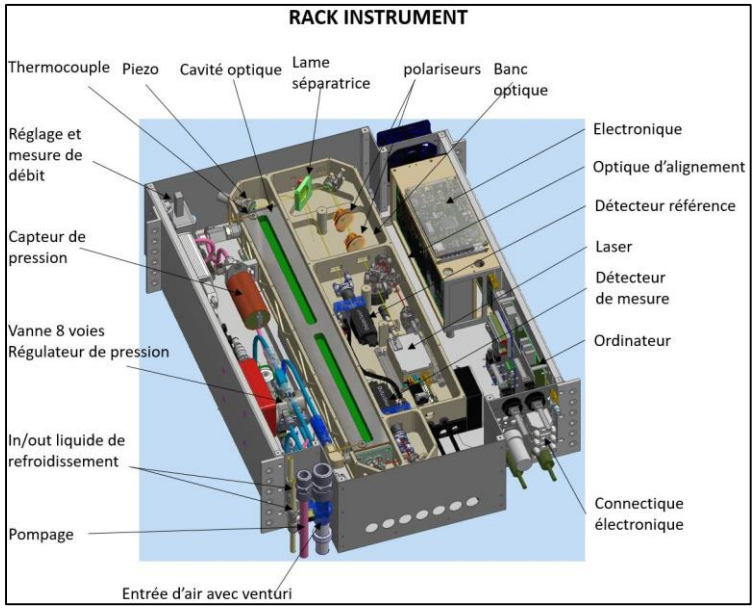


SPECIES instrument integrated in the balloon payload



4 racks = 4 channels





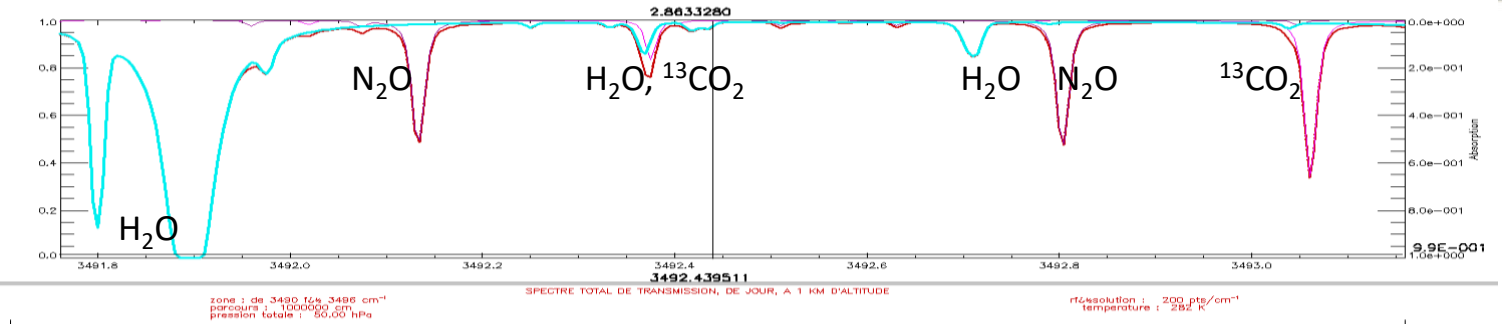
- Optical bench thermostated at 40°C and suspended on vibration dampers,

- HgCdTE detectors cooled by ThermoElectric Cooler (TEC) Peltier at -80°C,

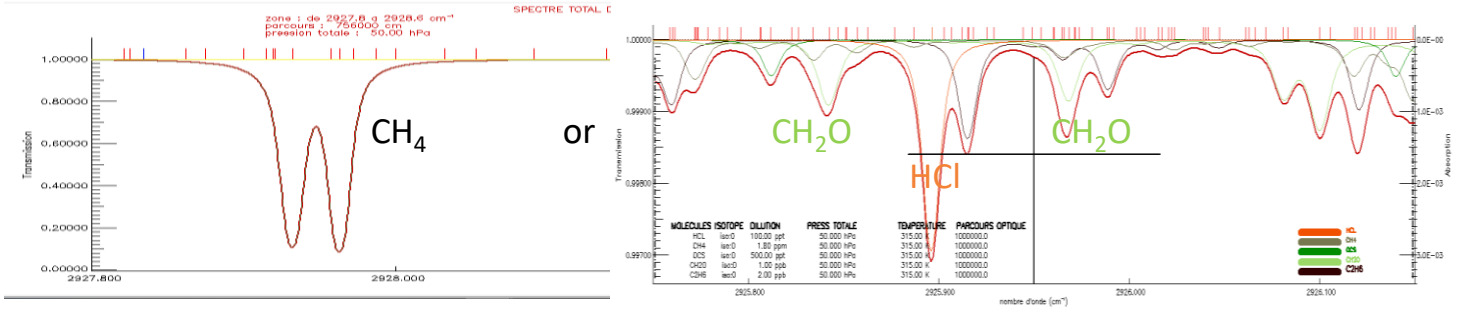
- Lasers: QCL regulated at -30°C and ICL at -60°C by TEC,

- Wide range electronics functioning (-40; +70 °C).

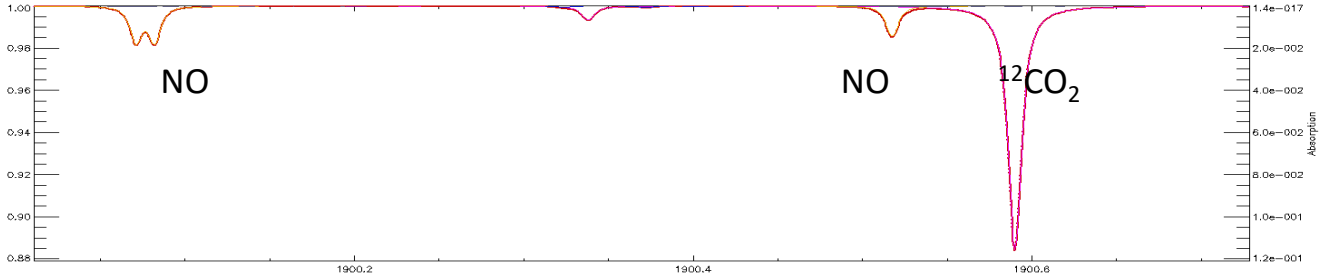
4 channels max → 4 spectra at ultra-high spectral resolution without interferences



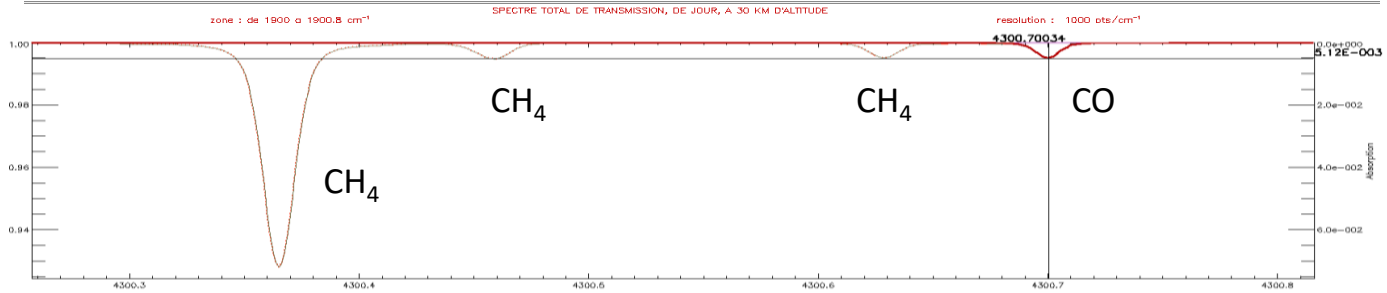
DFB around 2.863 µm (3493 cm^{-1})



ICL around 3.416 µm (2926 or 2928cm^{-1})

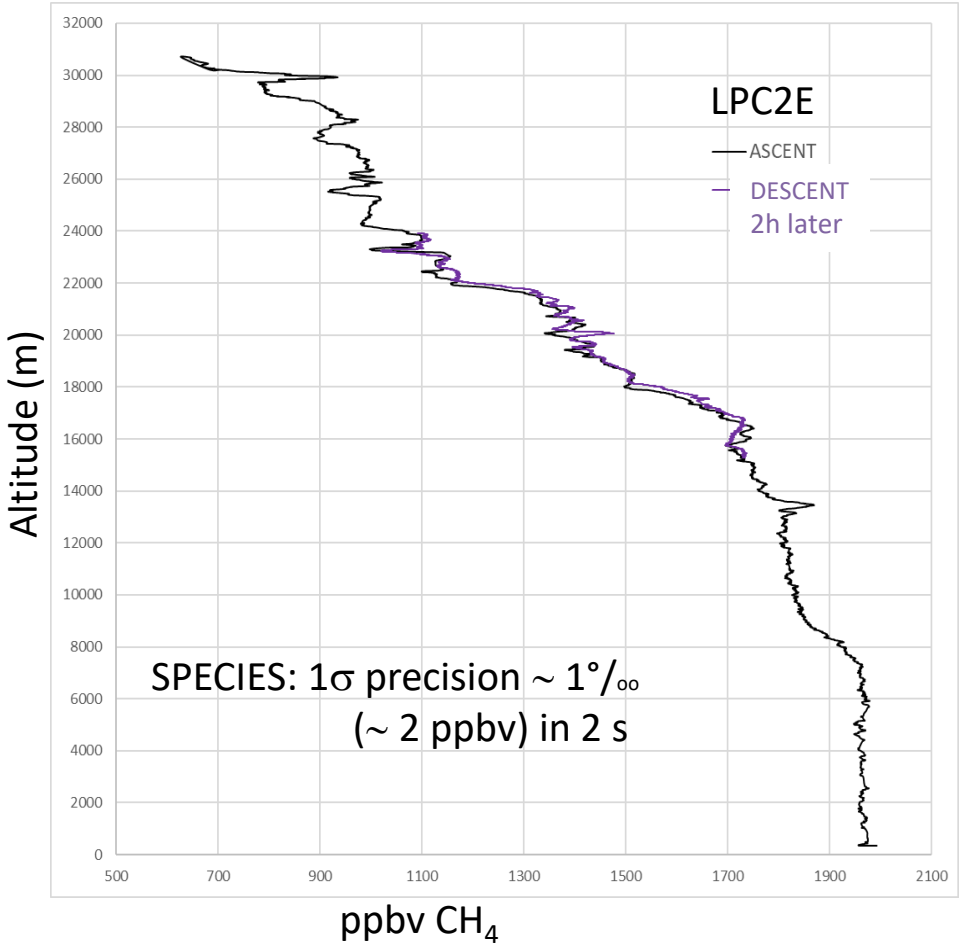


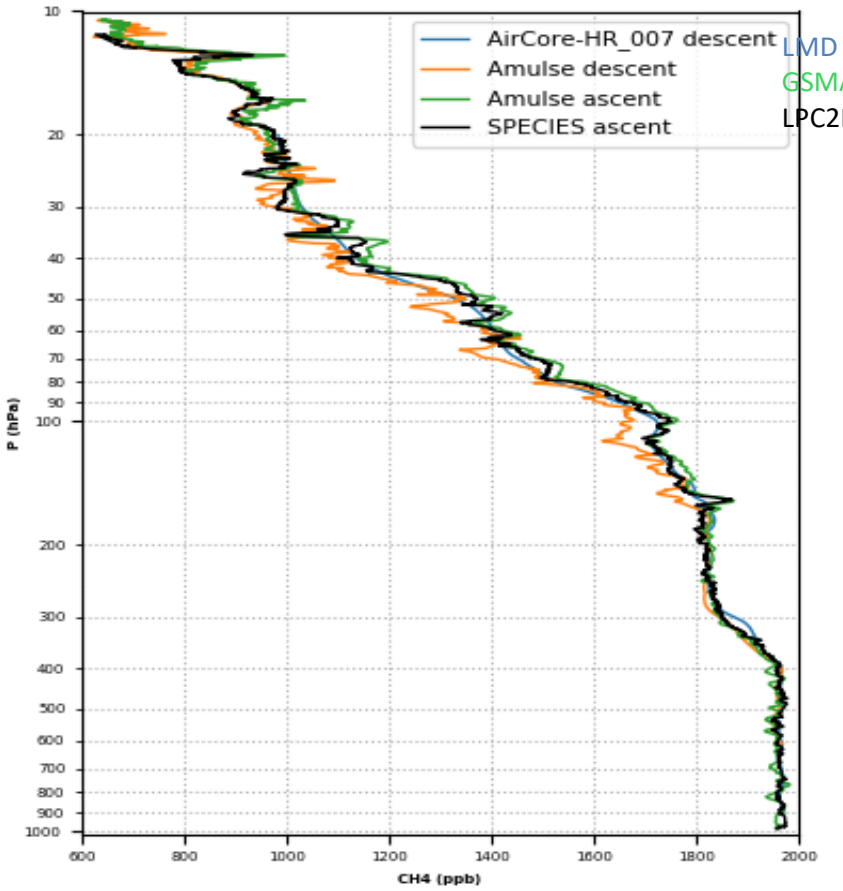
ICL around 5.262 µm (1900.5 cm^{-1})



DFB (LIPhy) around 2.325 µm (4300.5cm^{-1})

Results: vertical profile of CH_4, Kiruna (68°N) 23/08/2021





Comparison with the other instruments on board the same gondola

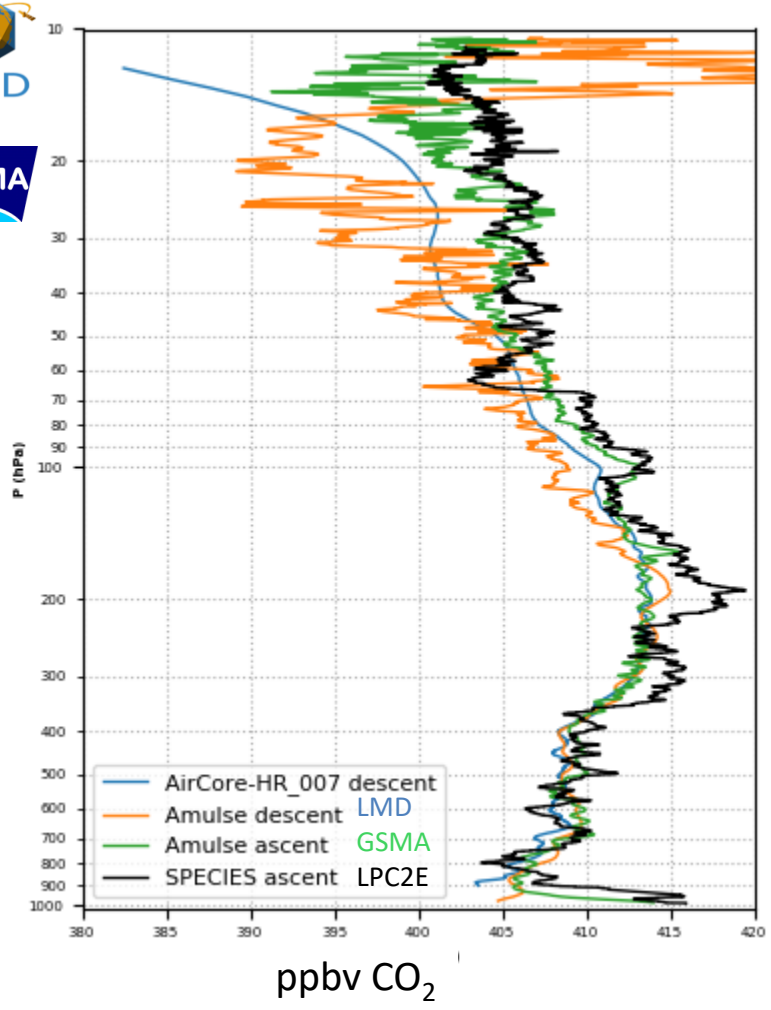
→ Differences over the total column:

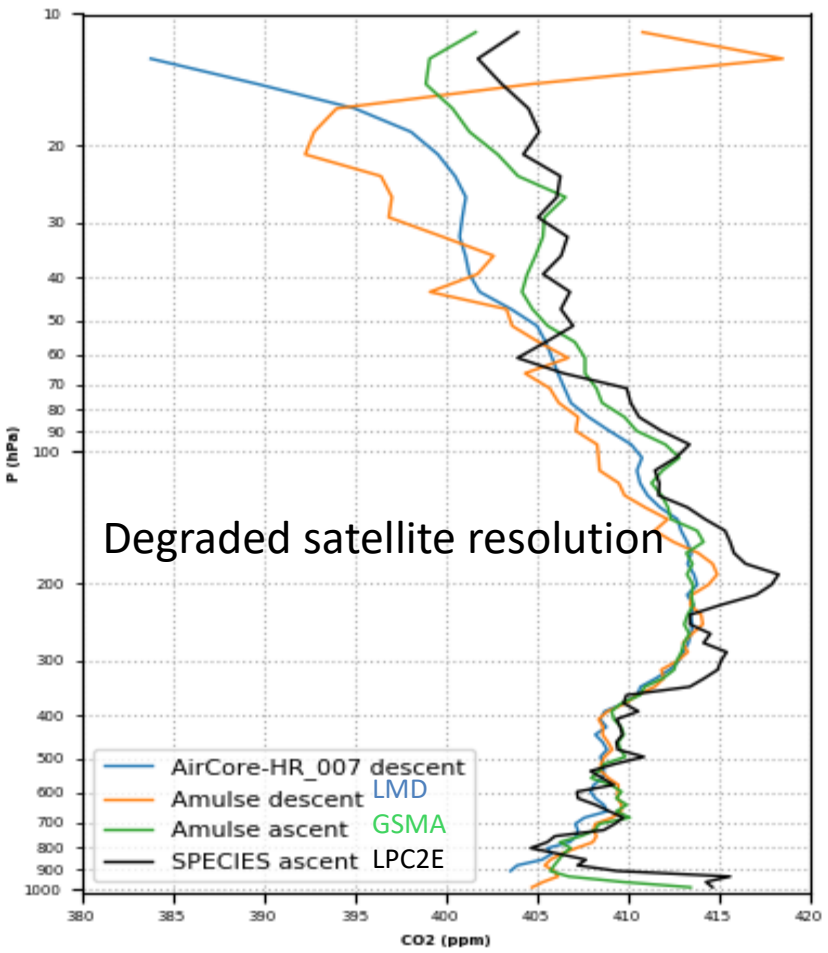
AirCore-HR - SPECIES = -1.4 ppb

Amulse-ascent - SPECIES = 3.4 ppb

→ **Consistent with evaluation of MERLIN accuracy: 4 ppb**

Results: vertical profile of CO_2, Kiruna (68°N) 23/08/2021





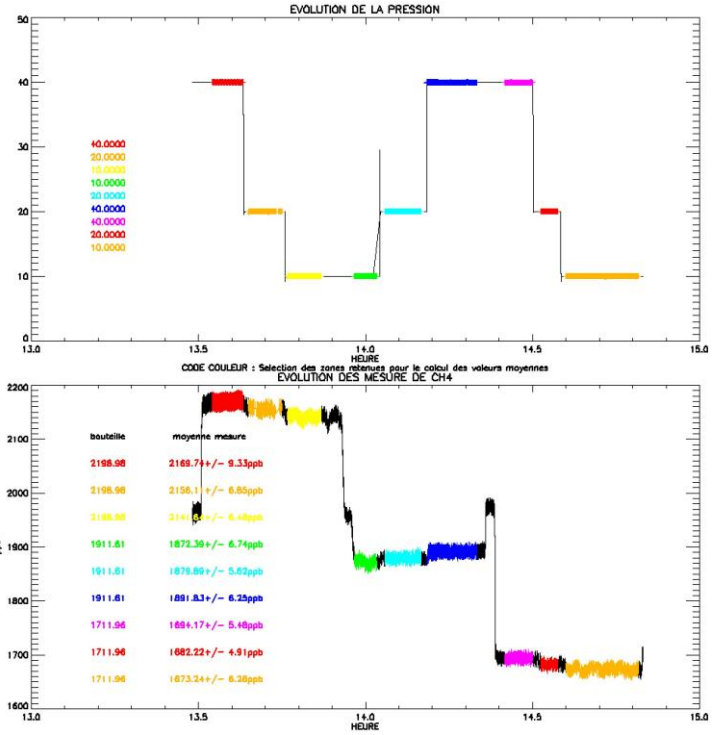
SPECIES: 1σ precision ~ 2.5°/₀₀ (1 ppmv) in 2 s

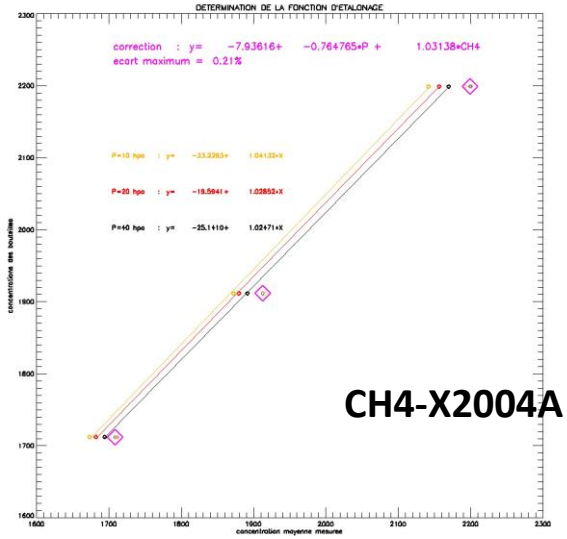
Differences over the total column: **AirCore-HR - SPECIES** = -1.7 ppm & **Amulse-ascent - SPECIES** = -0.9 ppm

→ **Consistent with evaluation of MicroCarb accuracy: 1 to 3 ppm**

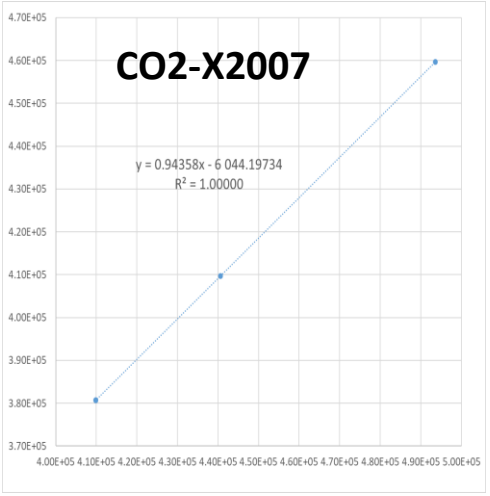
Quality control: ground calibrations after the flight

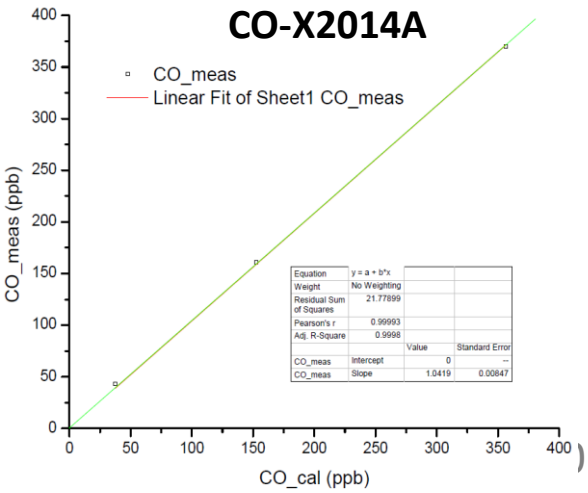
Profiles calibrated at different pressures with 3 primary standards from WMO scale (collab. LSCE)



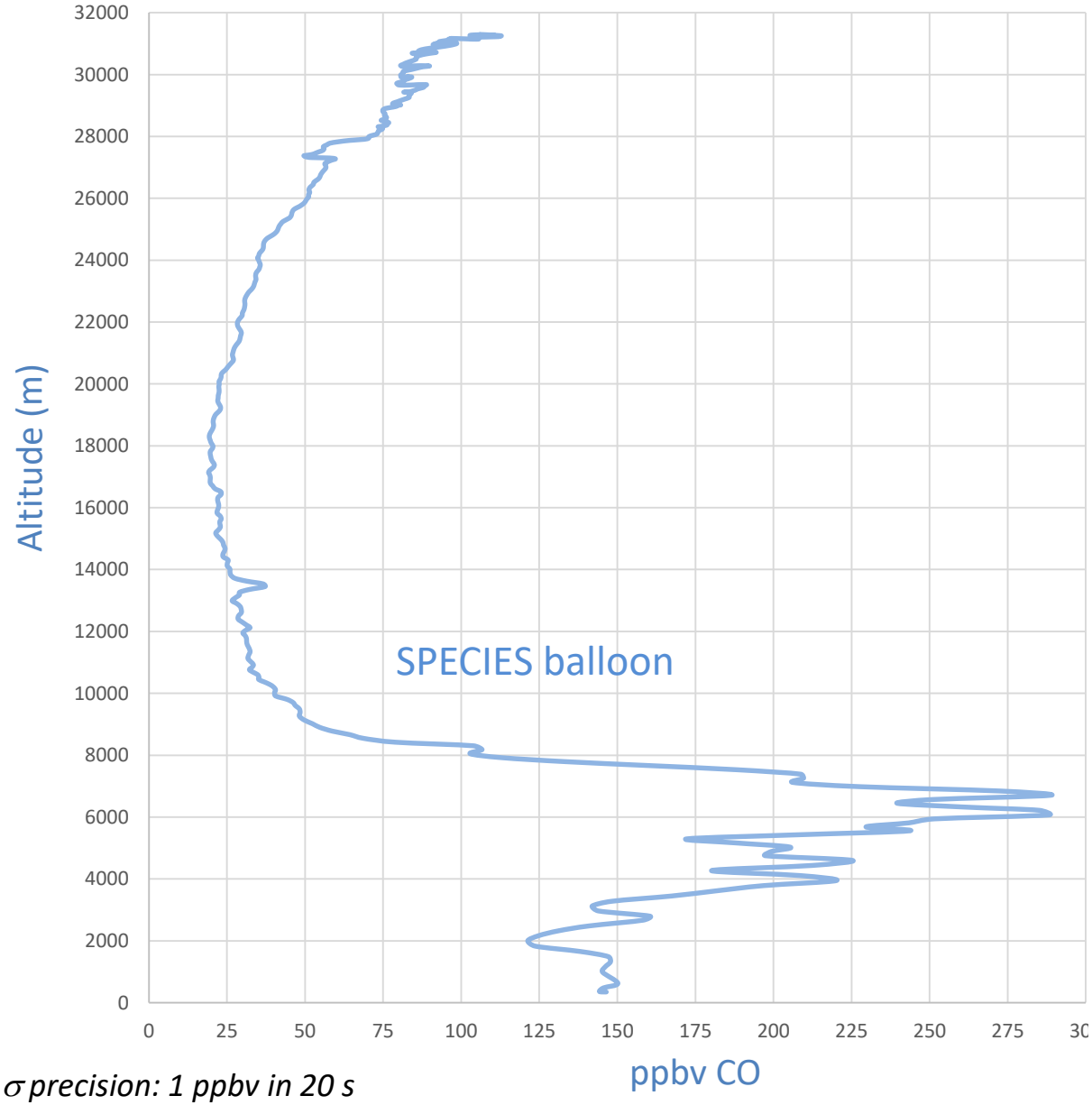


CH4-X2004A





Results: vertical profile of CO, Kiruna (68°N), 23/08/2021

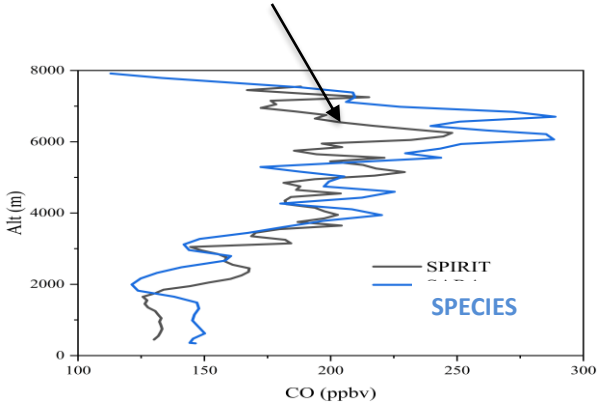


An example of the interest to perform multiplatform and multispecies measurements:

- what is the origin of this increase?

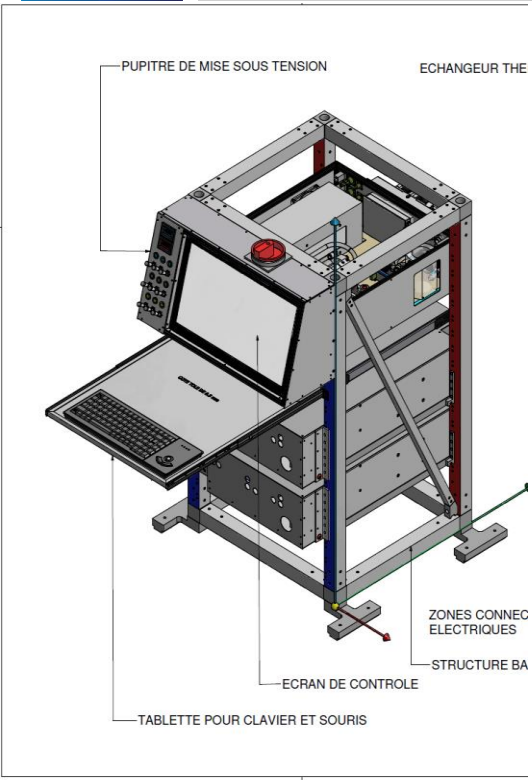
- does it extend to higher altitudes?

SPIRIT **in aircraft** 4h later



1σ precision: 1 ppbv in 20 s

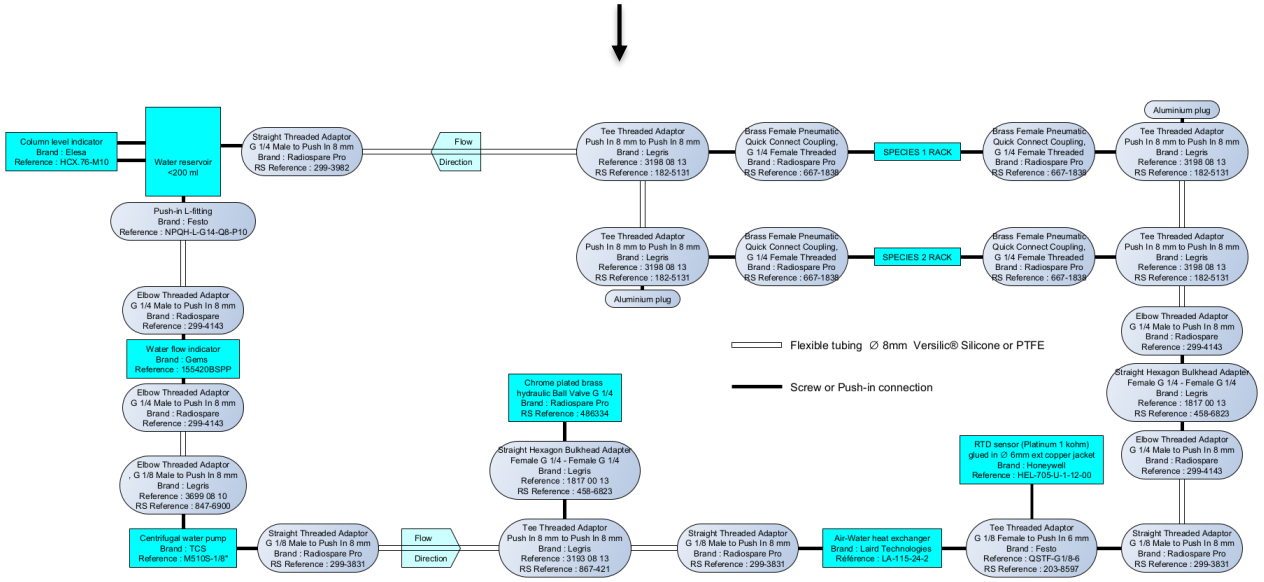
Current Development: SPECIES in aircraft



Specific to aircraft:

← Manual control on board using computer

Water circuit with pump dissipating the heat from the Peltier TECs (balloon: heat naturally radiated to space)



Test-flight in aircraft planned in Feb. 2023

SPECIES the D day Kiruna (68°N) 23/08/2021

Thank you for your attention!