

# Accurate in-situ monitoring of UTLS water vapor by laser absorption spectroscopy

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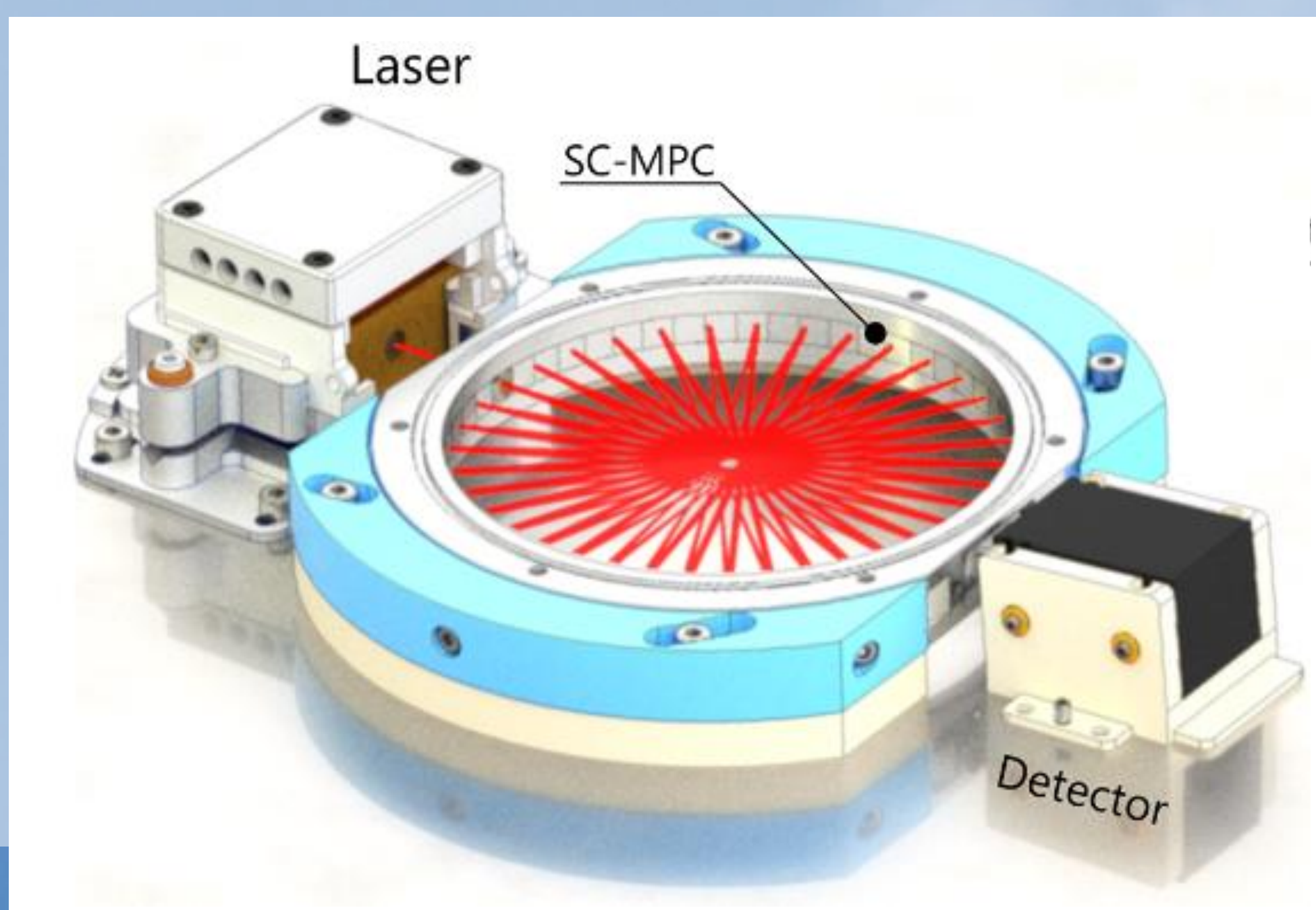


Materials Science and Technology

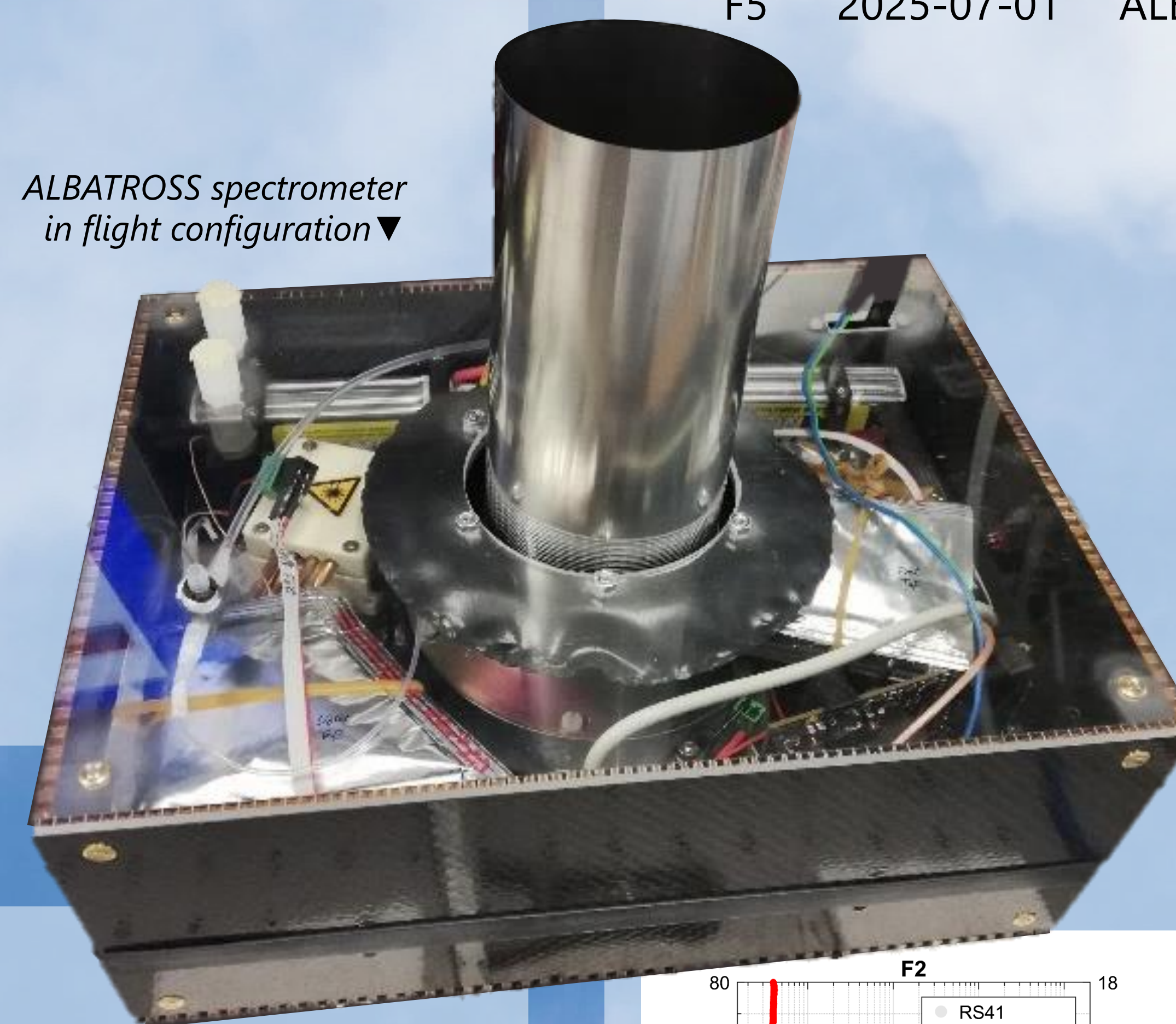
## The ALBATROSS spectrometer

- ALBATROSS is a compact, mid-IR laser absorption spectrometer for *in-situ* measurements of UTLS H<sub>2</sub>O aboard weather balloons.
- It incorporates a quantum-cascade laser (QCL) and a specially-designed segmented circular multipass cell (SC-MPC) [1]

Sampling technique	Open path
SC-MPC diameter	10.8 cm
Optical path length (OPL)	6.1 m (56 reflections)
H <sub>2</sub> O transition	1662.8 cm <sup>-1</sup> (~6.01 μm)
Acquisition rate	1 Hz (3000 co-averaged spectra)
Power consumption	15 W
Size	30×23×12 cm <sup>3</sup>
Weight	<b>3.6 kg</b>



▲ Schematics of the optical setup of ALBATROSS [2].



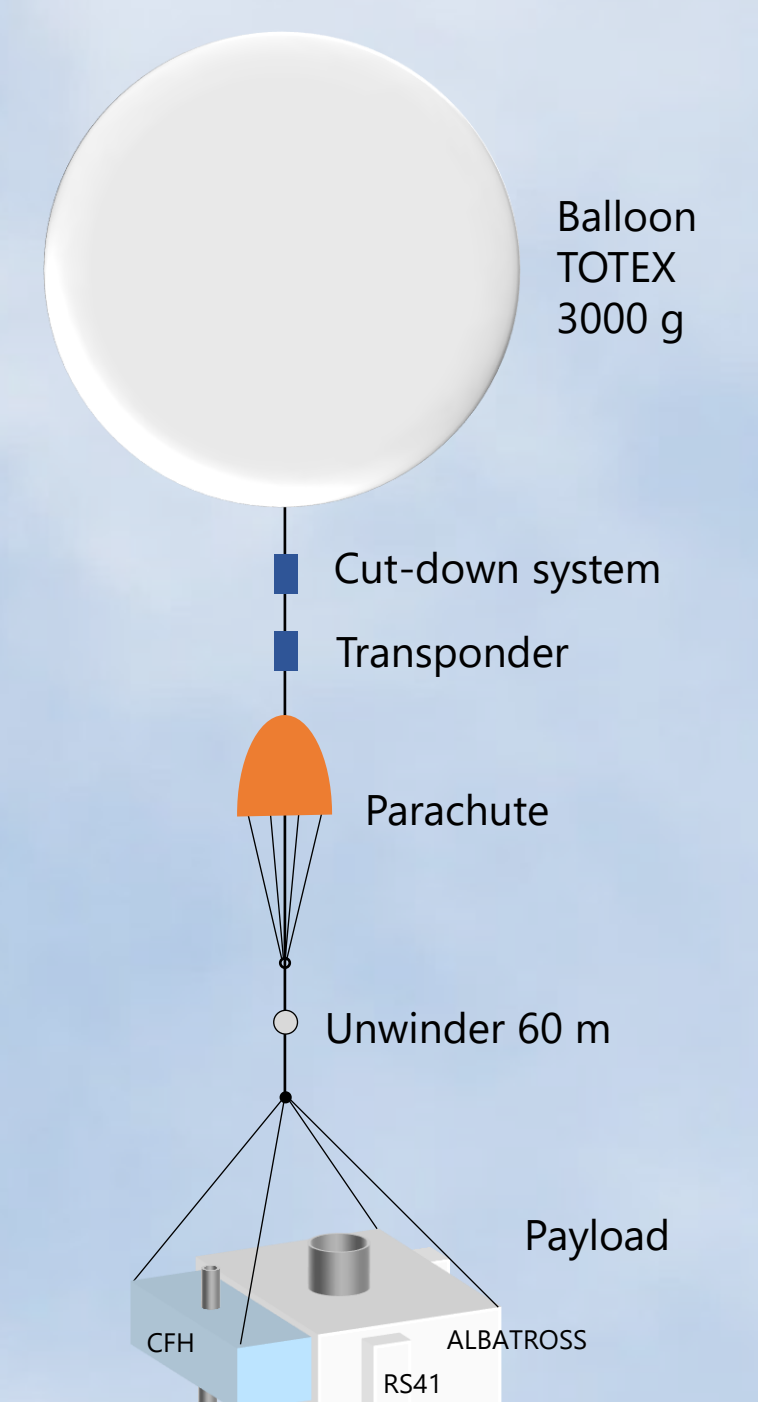
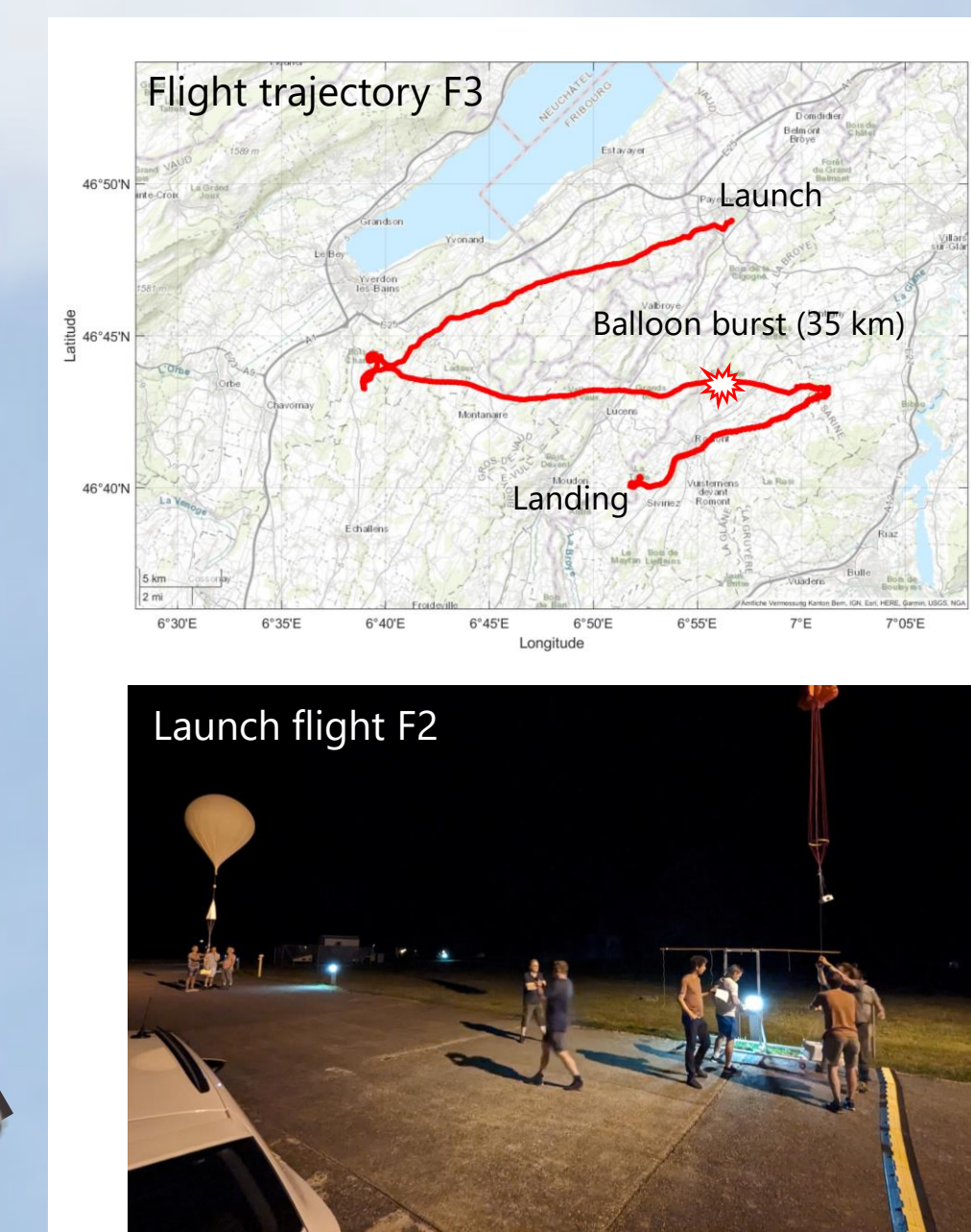
ALBATROSS spectrometer in flight configuration ▼

## The Swiss H<sub>2</sub>O-Hub project

- Five successful test flights performed at MeteoSwiss Payerne Observatory in 2023–2025
- Reference instruments: cryogenic frostpoint hygrometer (CFH; EnSci, USA), RS41 radiosonde (Vaisala, Finland)
- Payload recovery mandatory:** accurate flight planning and landing point prediction required!



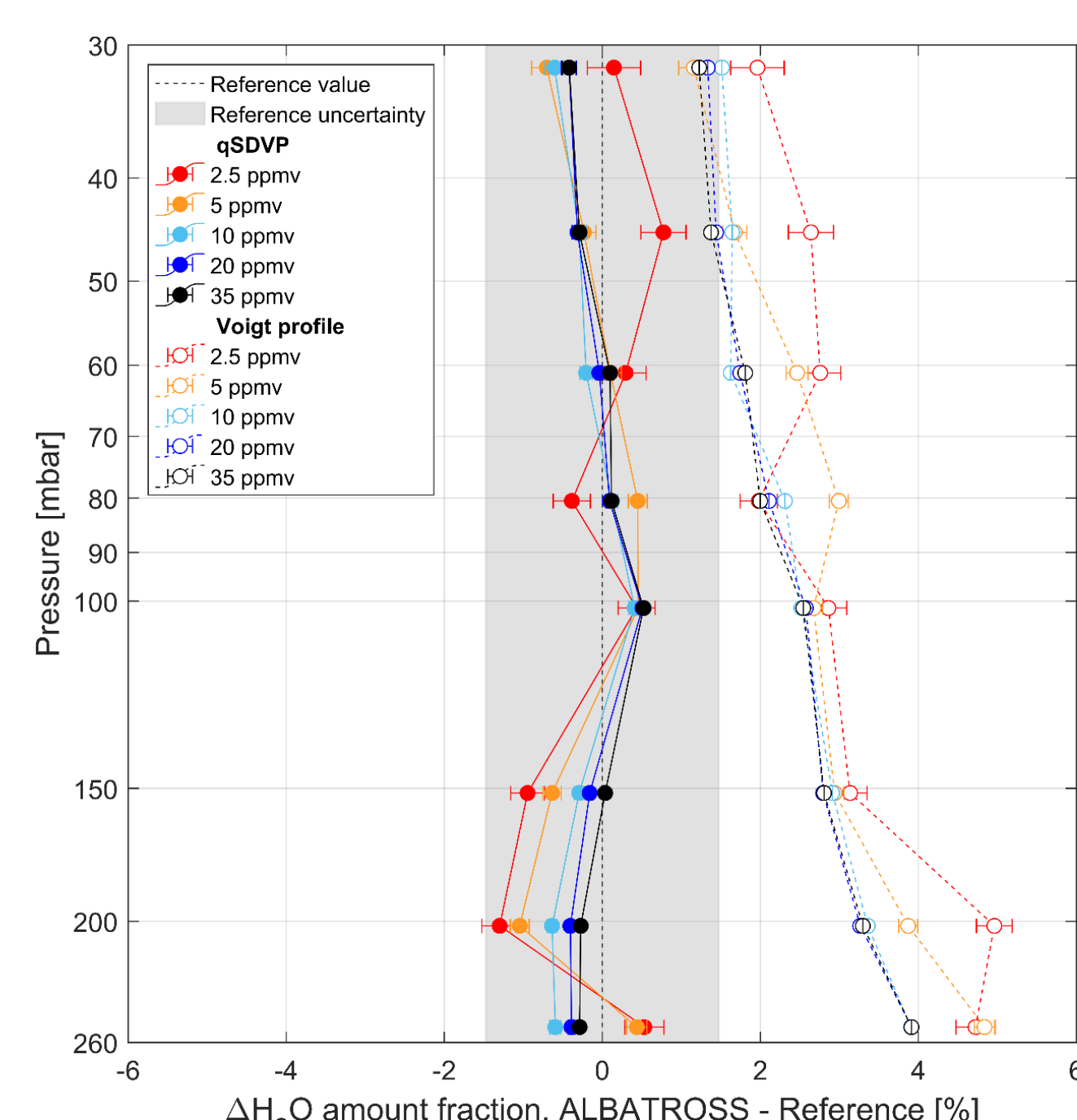
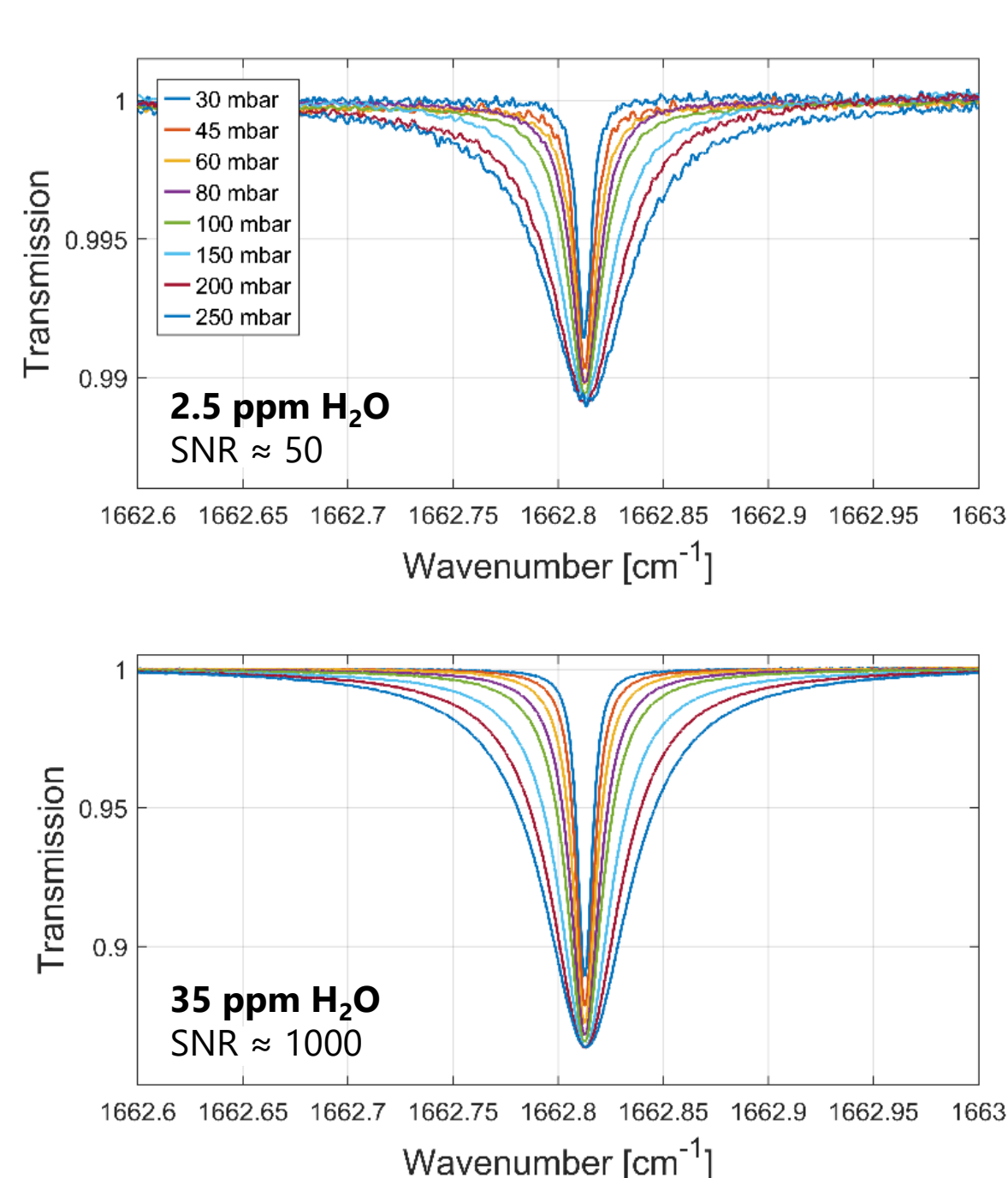
ID	Date	Payload balloon #1	Payload balloon #2	Ceiling
F1	2023-08-17	ALBATROSS/RS41	CFH/RS41	28 km
F2	2024-06-18	ALBATROSS/RS41	CFH/RS41	15 km
F3	2024-09-19	ALBATROSS/RS41	CFH/RS41	35 km
F4	2025-03-27	ALBATROSS/CFH/RS41	-	25 km
F5	2025-07-01	ALBATROSS/CFH/RS41	-	27 km



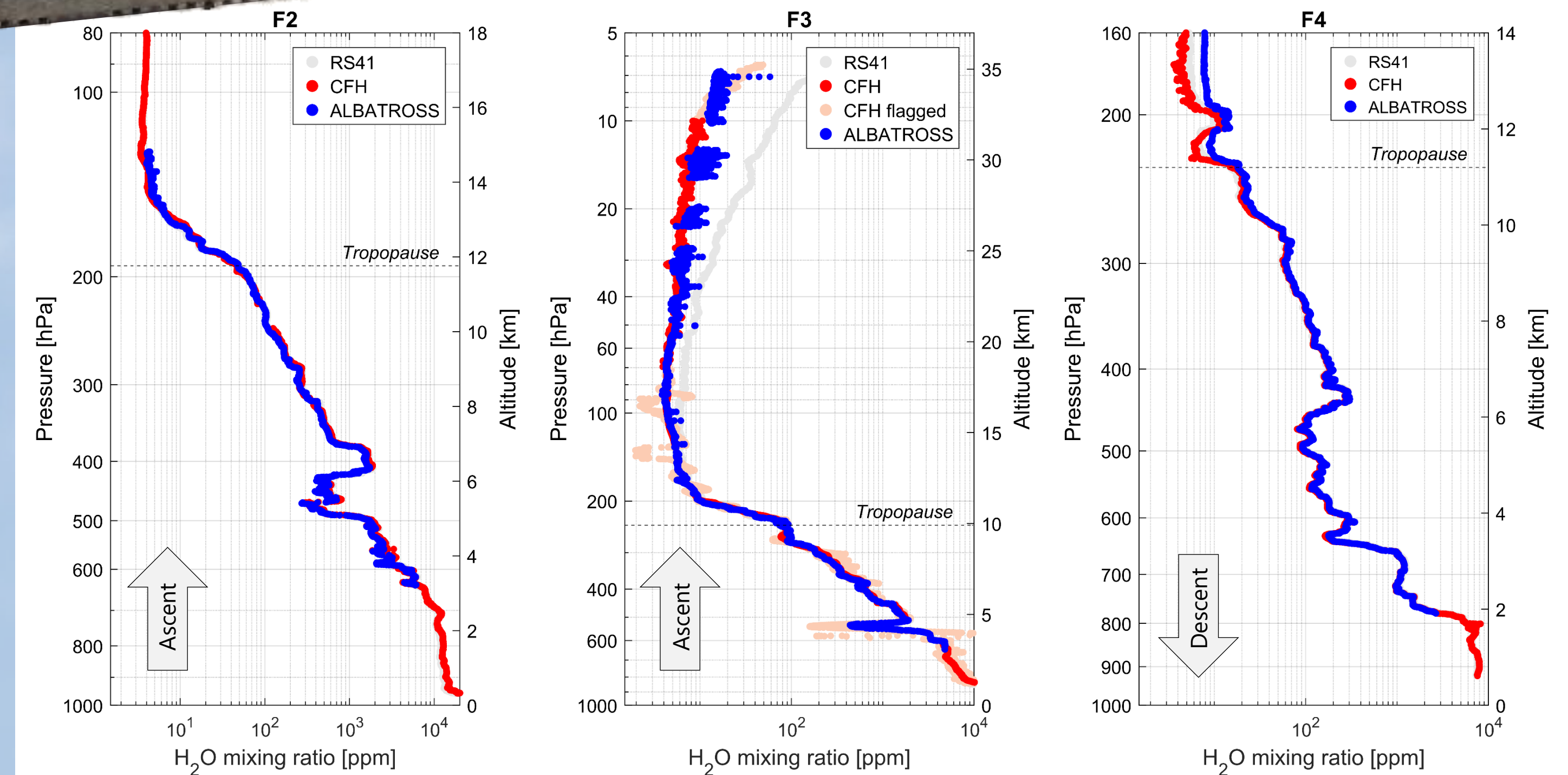
▲ Example of balloon flight trajectory and payload configuration.

## Laboratory-based validation

- Accuracy and precision of ALBATROSS at UTLS-relevant conditions characterized using **SI-traceable** reference mixtures generated by a dynamic-gravimetric permeation method [3]
  - ✓ **Accuracy < 1.5 %** at all conditions (30–250 hPa, 2.5–35 ppm H<sub>2</sub>O)
  - ✓ **Precision < 30 ppb** (i.e., 0.1 % at 35 ppm) at 1 s resolution
- ALBATROSS participated in the **AquaVIT-4** international intercomparison of atmospheric hygrometers at the AIDA climate simulation chamber (KIT, Germany), where the performance of four airborne hygrometers was evaluated at a wide range of challenging environmental conditions (185–245 K, 15–500 hPa, 0.5–500 ppm H<sub>2</sub>O) [4]

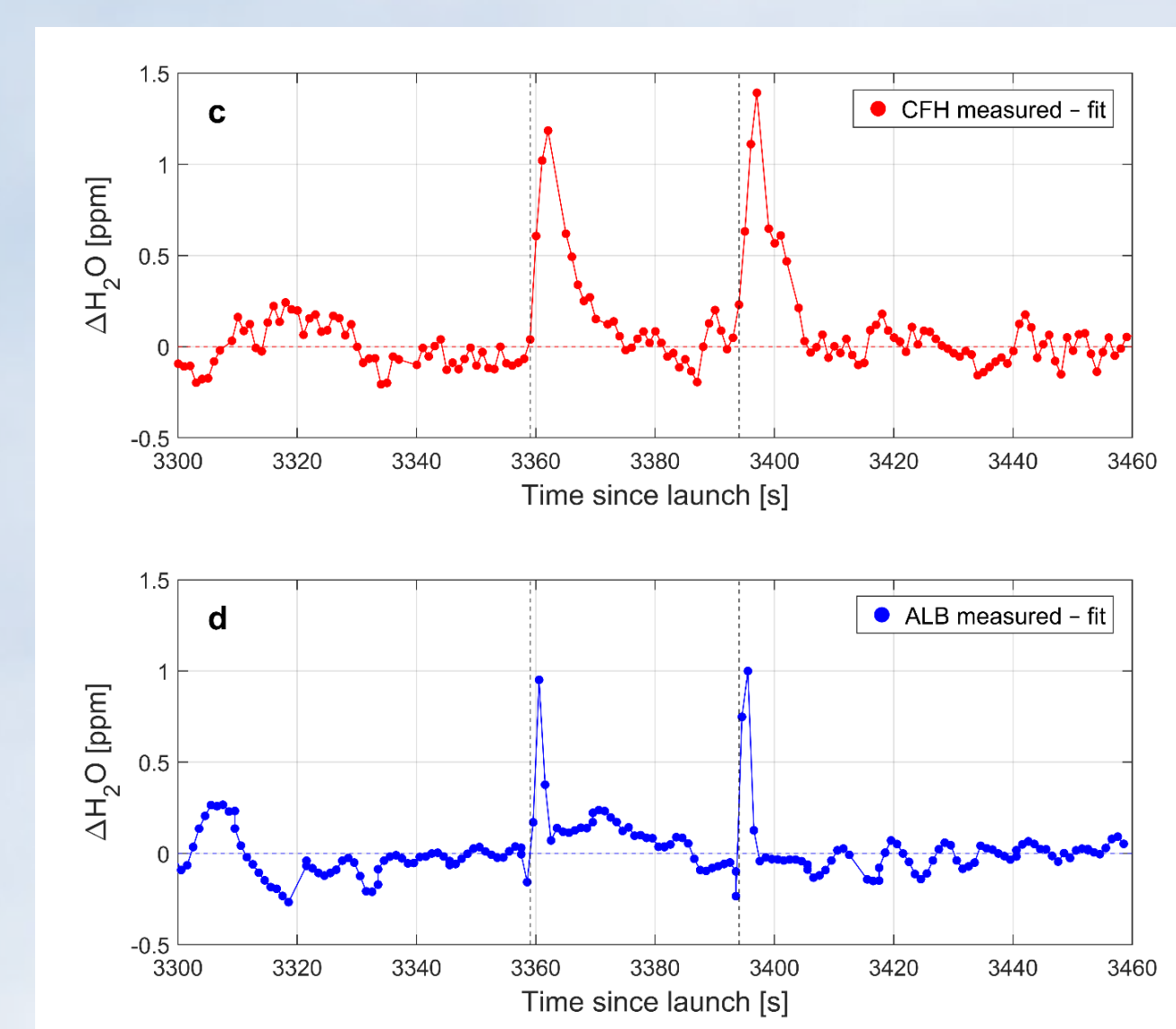


▲ Left: transmission spectra measured at 2.5 ppm and 35 ppm and different pressures during the SI-traceable validation (integration time: 50 s). Right: relative difference between ALBATROSS and the reference values, as function of pressure (see [3] for details).



▲ Vertical profiles of H<sub>2</sub>O mixing ratio measured by ALBATROSS, CFH and RS41 in flights F2, F3, F4.

- Troposphere (z < 12 km)**
  - ✓ Good agreement with CFH/RS41 (±10 %) in all flights
  - ✓ Including fine structures in vertical distribution, cirrus clouds
- Stratosphere (z > 12 km):**
  - ✓ *In-flight purging system* developed to minimize contamination effects
  - ✓ Good agreement with CFH (±10 %) up to ~25 km (flight F3)
  - ✓ **Faster response** compared to CFH demonstrated by "balloon spikes"



▲ Timeseries of CFH and ALBATROSS data at ~23 km altitude during F4 showing evidence of "balloon spikes" (i.e. increase in H<sub>2</sub>O due to contamination from the wet balloon skin).

## References

- [1] Graf, Emmenegger, and Tuzson, *Opt. Lett.*, doi.org/10.1364/OL.43.002434, 2018  
 [2] Graf et al., *Atmos. Meas. Tech.*, doi.org/10.5194/amt-14-1365-2021, 2021.  
 [3] Brunamonti et al., *Atmos. Meas. Tech.*, doi.org/10.5194/amt-16-4391-2023, 2023.  
 [4] Brunamonti et al., *Atmos. Meas. Tech.*, doi.org/10.5194/amt-18-5321-2025, 2025.

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