Peltier Cooled Frost Point Hygrometer (PCFH)

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GRUAN ICM-16, Tenerife, 20 November 2025

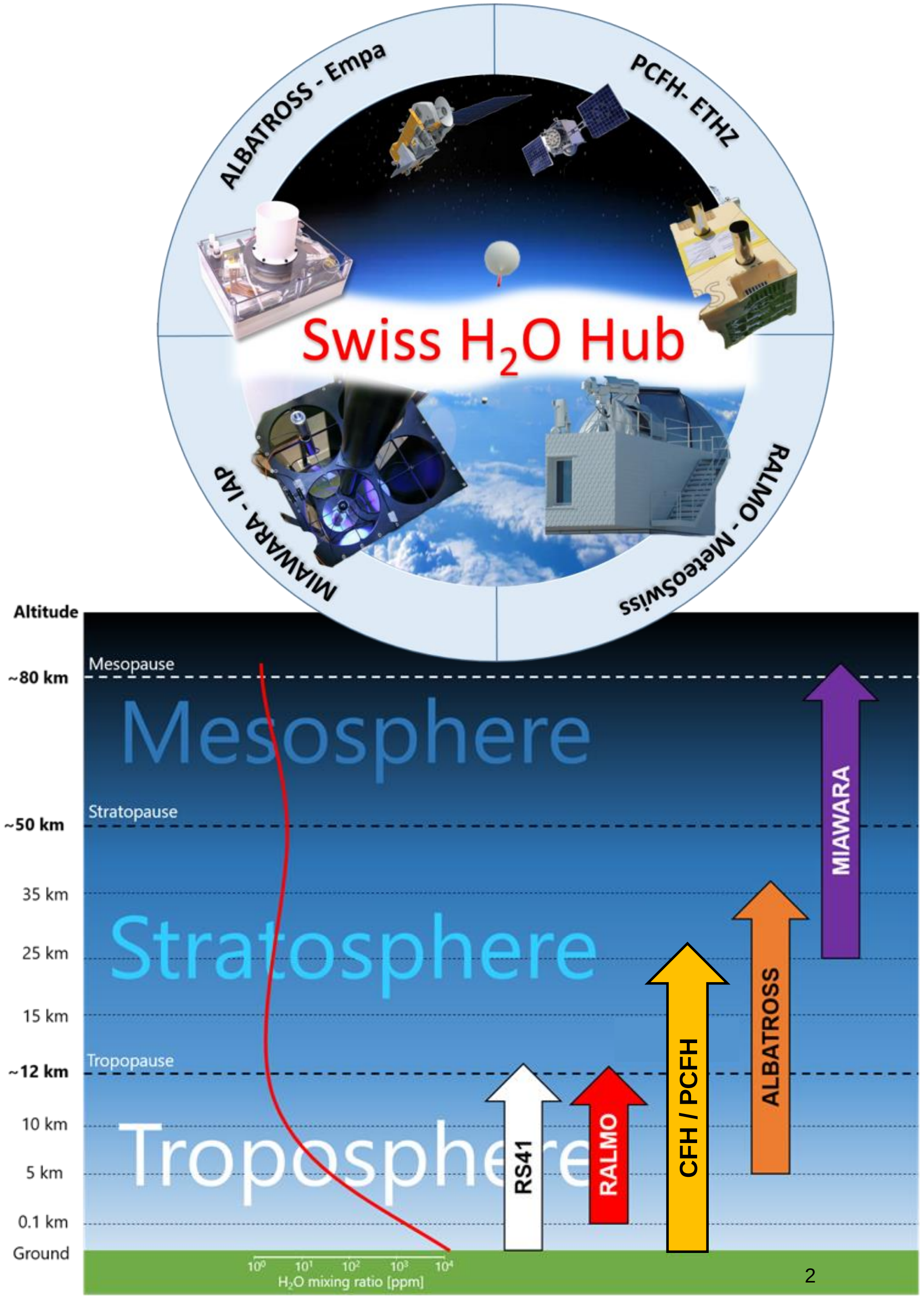
Joint GAW / GCOS Switzerland Project

The Swiss H_2O Hub – high quality water measurements from ground to space (now in its 3rd year)

- IAP University of Bern: MIAWARA microwave radiometer
- MeteoSwiss Payerne (GRUAN station):
  RALMO lidar, Balloon sounding facility
- Empa Dübendorf: ALBATROSS H_2O tunable QC diode laser
- ETH Zurich: PCFH

➢ close critical observational gaps in the water cycle by combining in-situ and remote sensing observations in a development and testing phase and a monitoring phase.

➢ continuously re-visiting calibration, traceability,
and homogeneity of this Essential Climate Variable (ECV)
in order to guarantee their usability for climate monitoring and climate change detection.



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Challenges for Frost Point Hygrometers

Principle:

→ control of the mirror temperature by optical detection tries to keep the condensate thickness constant

→ establish that / or identify when the condensate is in thermodynamic equilibrium to the air exposed

→ here the mirror temperature equals the **frost point temperature** by definition

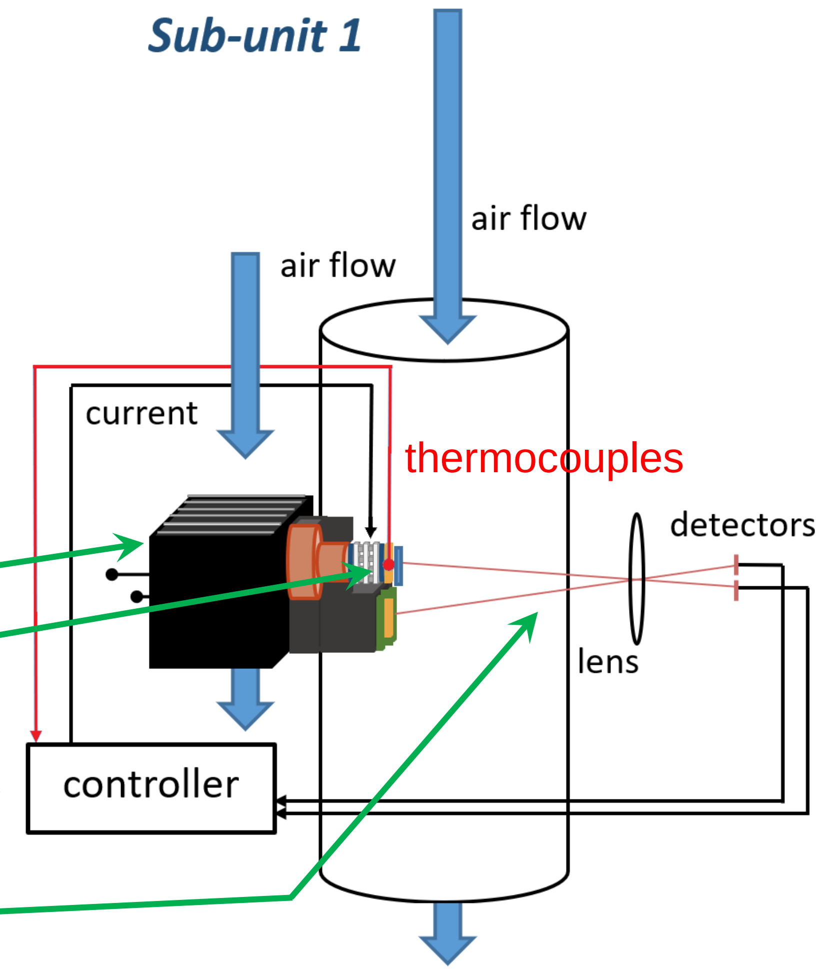
Important issues:

❖ adequate cooling

❖ temperature measurement

❖ temperature control

❖ mirror signal detection



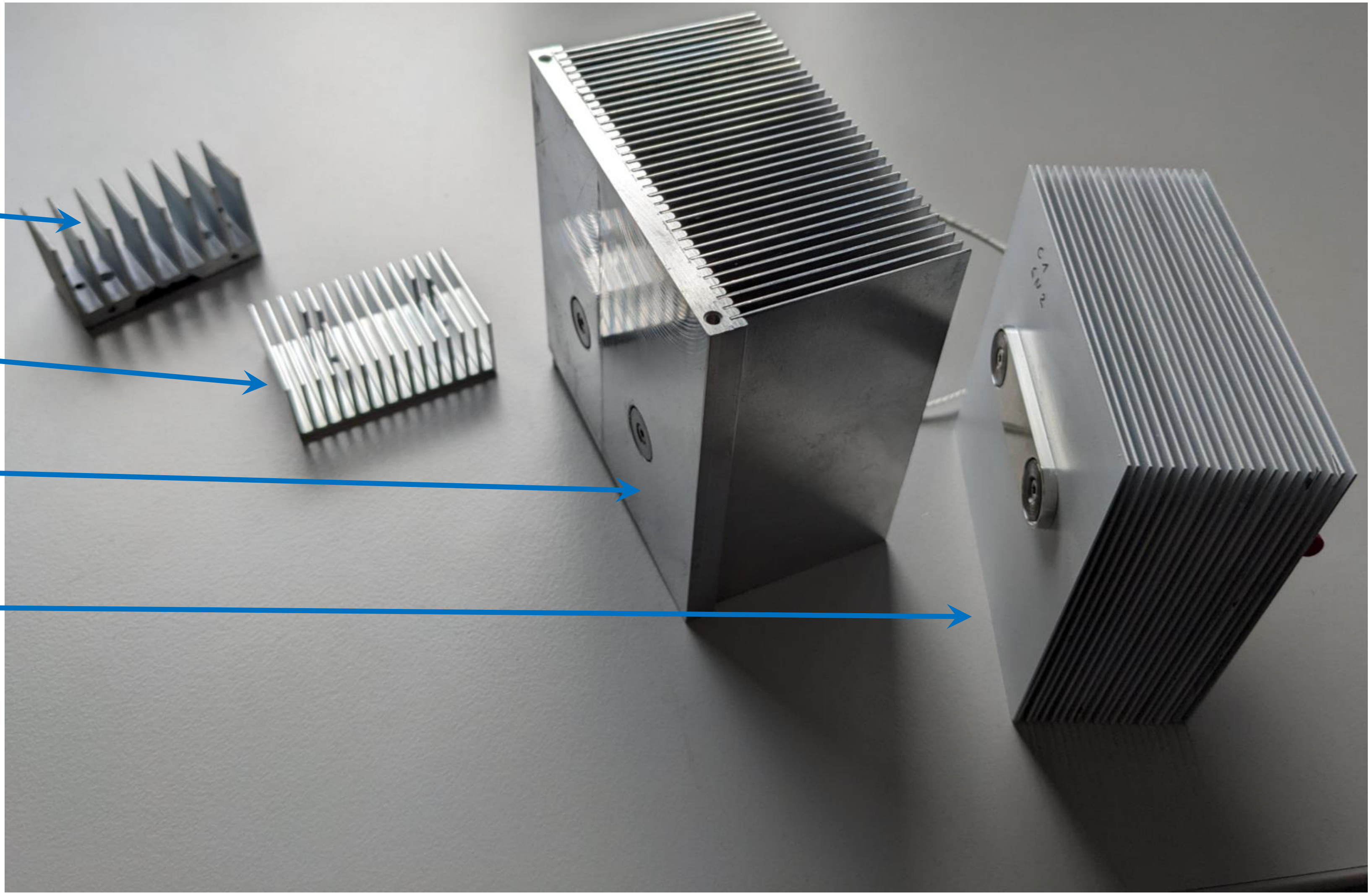
Heatsink History

original (43 g, discontinued)

replacement (52 g, commercial)

new, heavy for testing, 560 g

new, custom made, 260 g



using Peltier coolers instead of cryogen asks for custom made heatsinks, adapted to pressure and flow conditions

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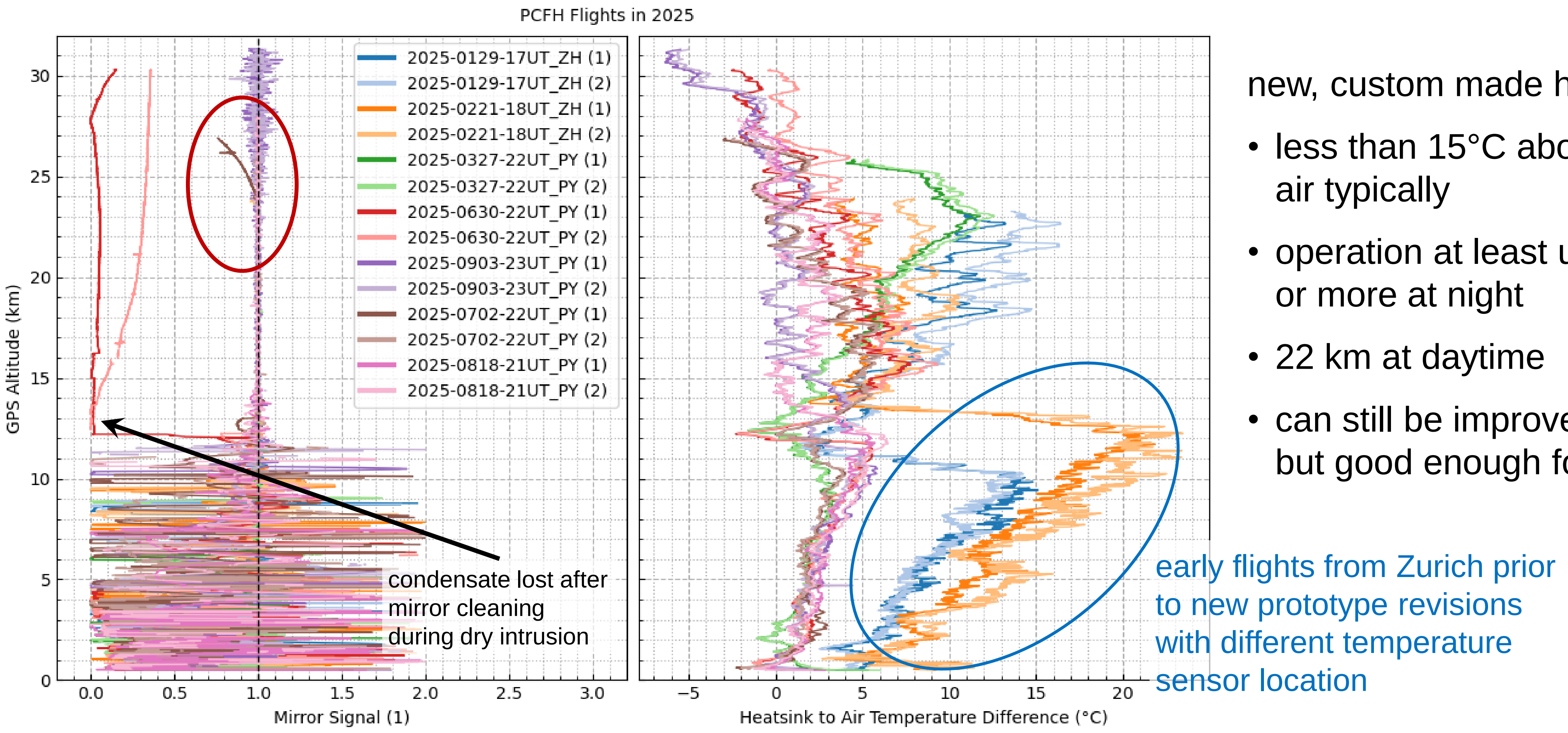
Heatsink Flight Results



new, custom made heatsink:

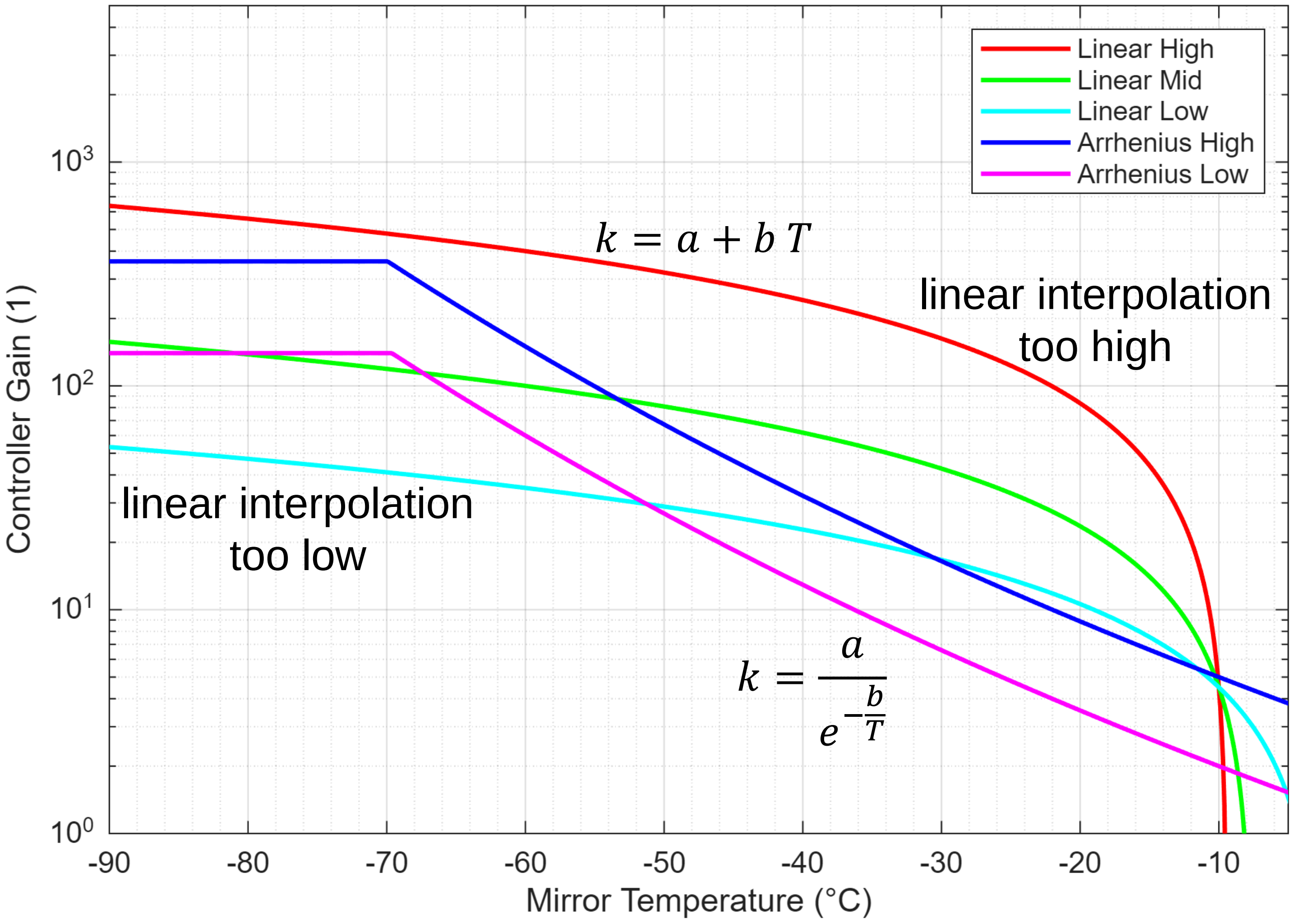
- less than 15°C above ambient air typically
- operation at least up to 25 km or more at night
- 22 km at daytime
- can still be improved, but good enough for now

Controller Improvement: Gain Compensates Arrhenius Characteristic

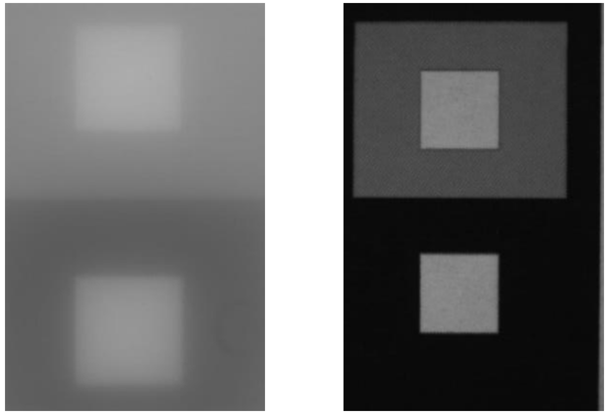
The response of the mirror condensate depends on water vapor abundance and diffusivity.

It decreases by several orders of magnitude from ground level to the lower stratosphere.

We fit the temperature dependence of the reflex controller gain to an inverse Arrhenius law to better match the kinetics of condensate formation and sublimation (as compared to linear interpolation).



Contrast and Operation Improvement



the quality of the optics is quantified by **contrast** $\frac{I_{sat} - I_{clean}}{I_{clean}}$

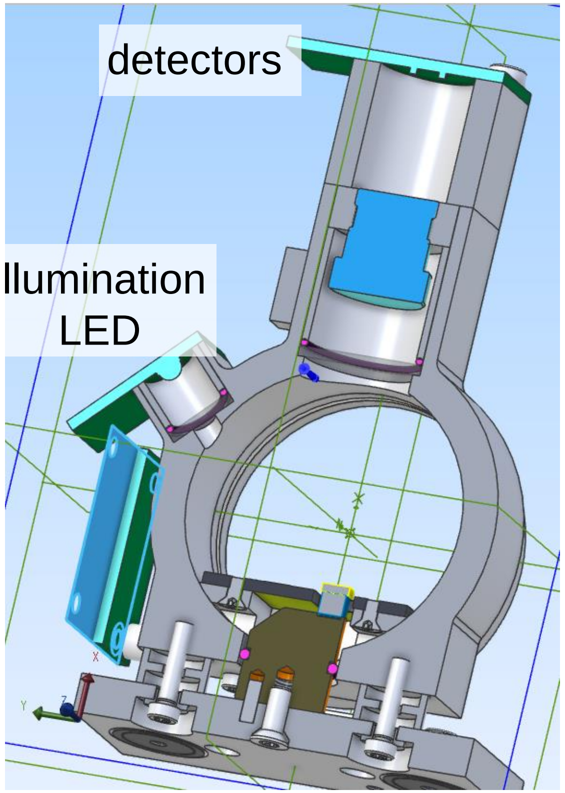
laboratory investigation
$\rightarrow$ imaging can improve contrast from 2..3 to > 10

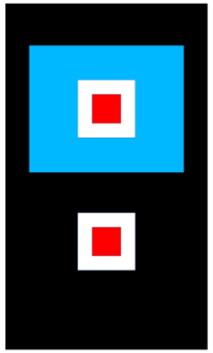
geometric margins allow for manufacturing tolerance

intermediate solution for concurrent electronics development:
hybrid composition with the existing electronics

pre-flight checkout contrast measurements
  validate the setup
  define flight operation points systematically

flight deployments demonstrate enhanced sensitivity by
new ice formation strategy and operating points





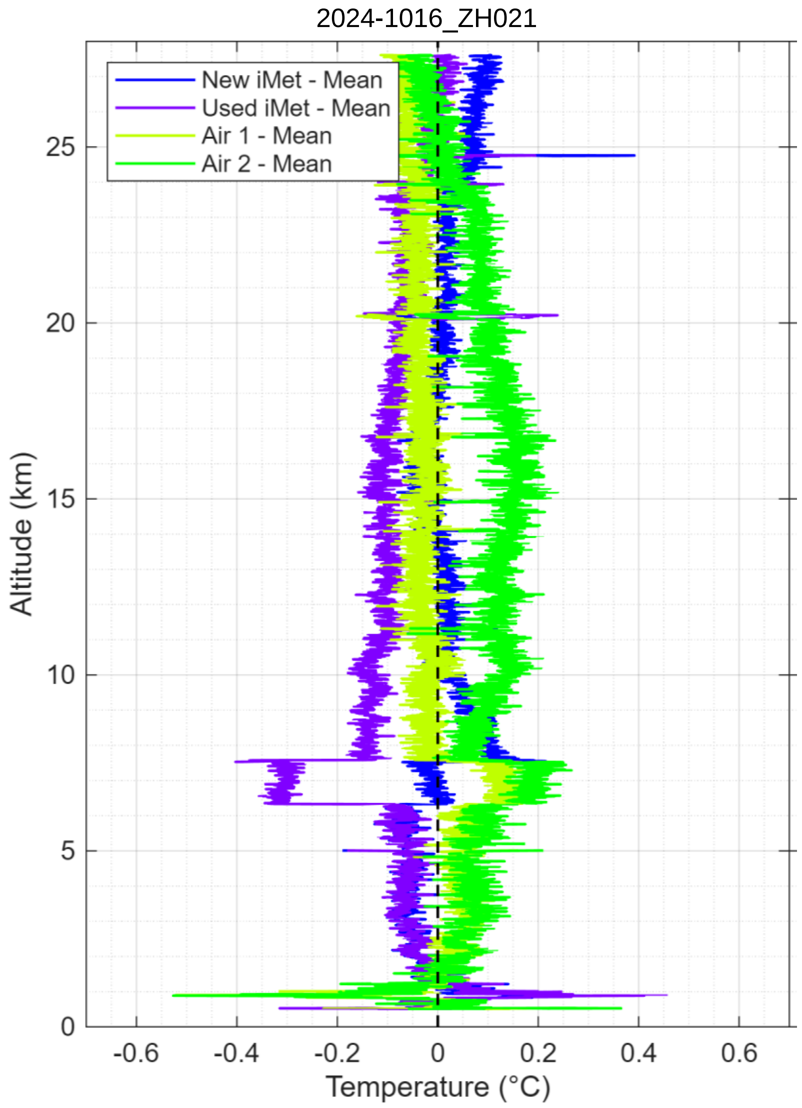
Thermocouple Temperature Measurement

observed warm bias for both mirror and air temperature

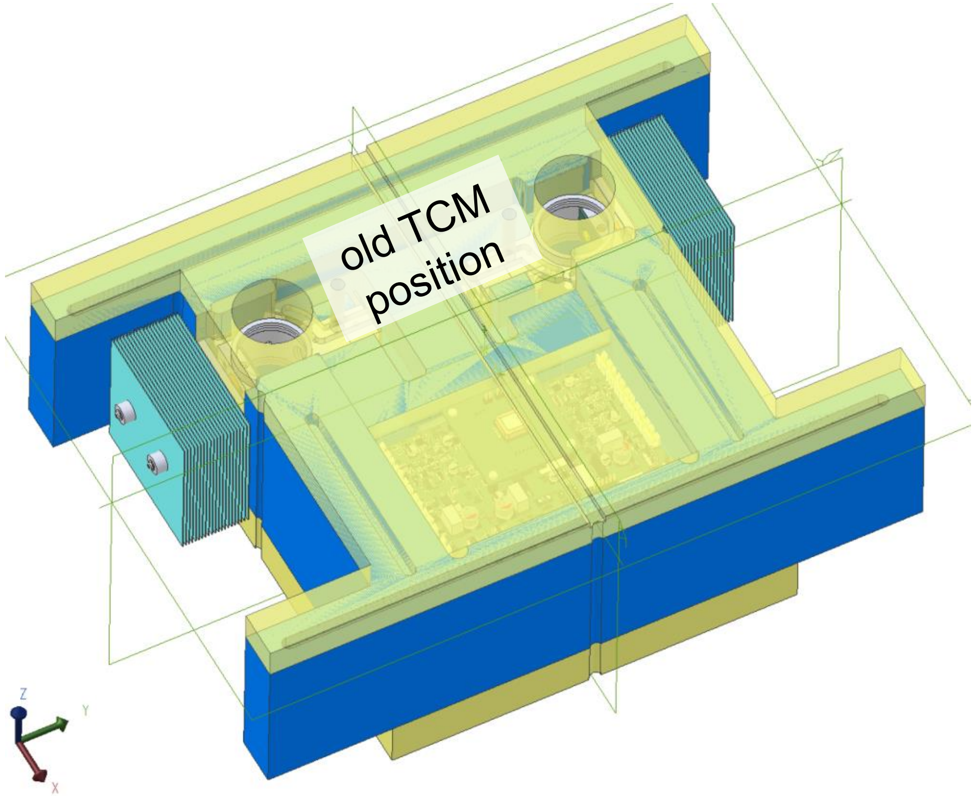
test flight with isolated thermocouple module (TCM) with two radiosondes confirms the measurement strategy chosen

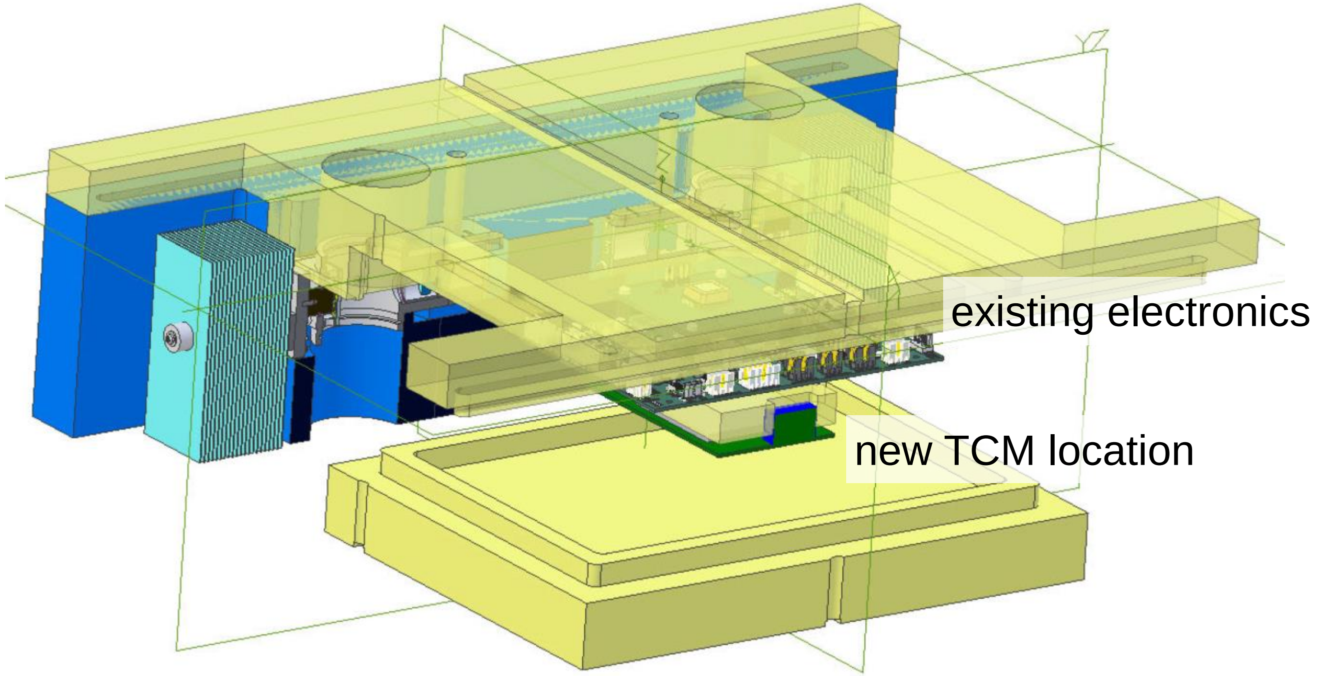
in-flight diagnostics indicate that temperature transients in the TCM are tolerable, while gradients are not yet acceptable

conclusion: separate housing of the TCM for improved thermal insulation

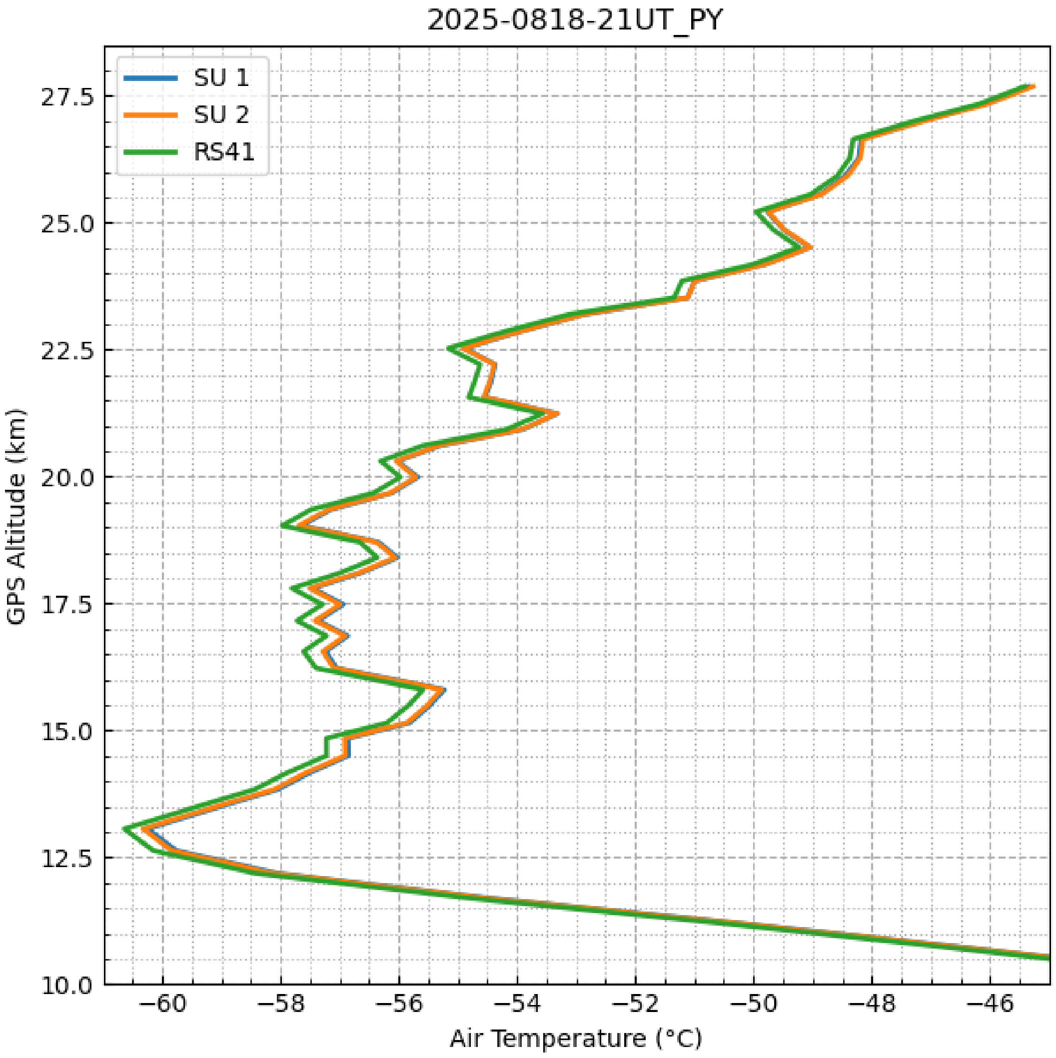


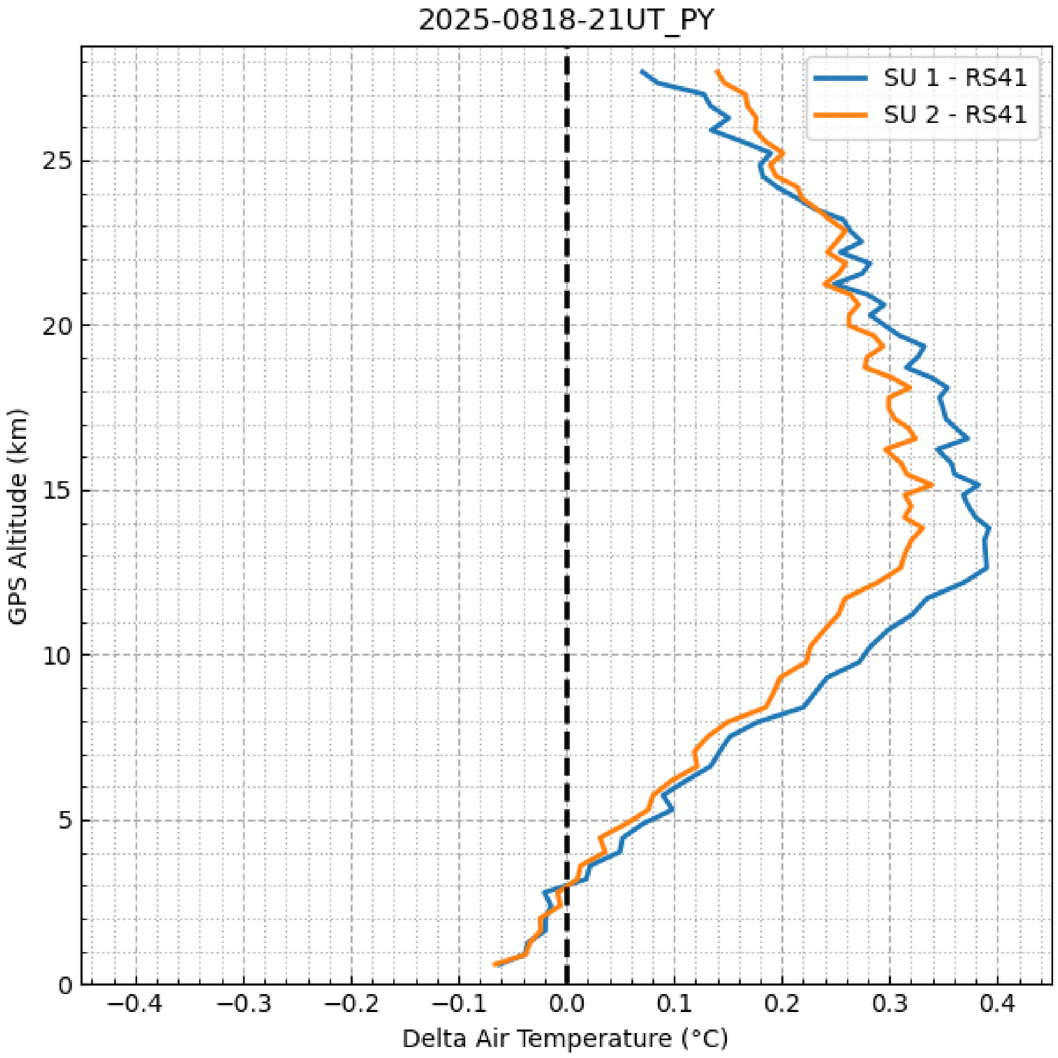
Revised Thermal / Mechanical Setup





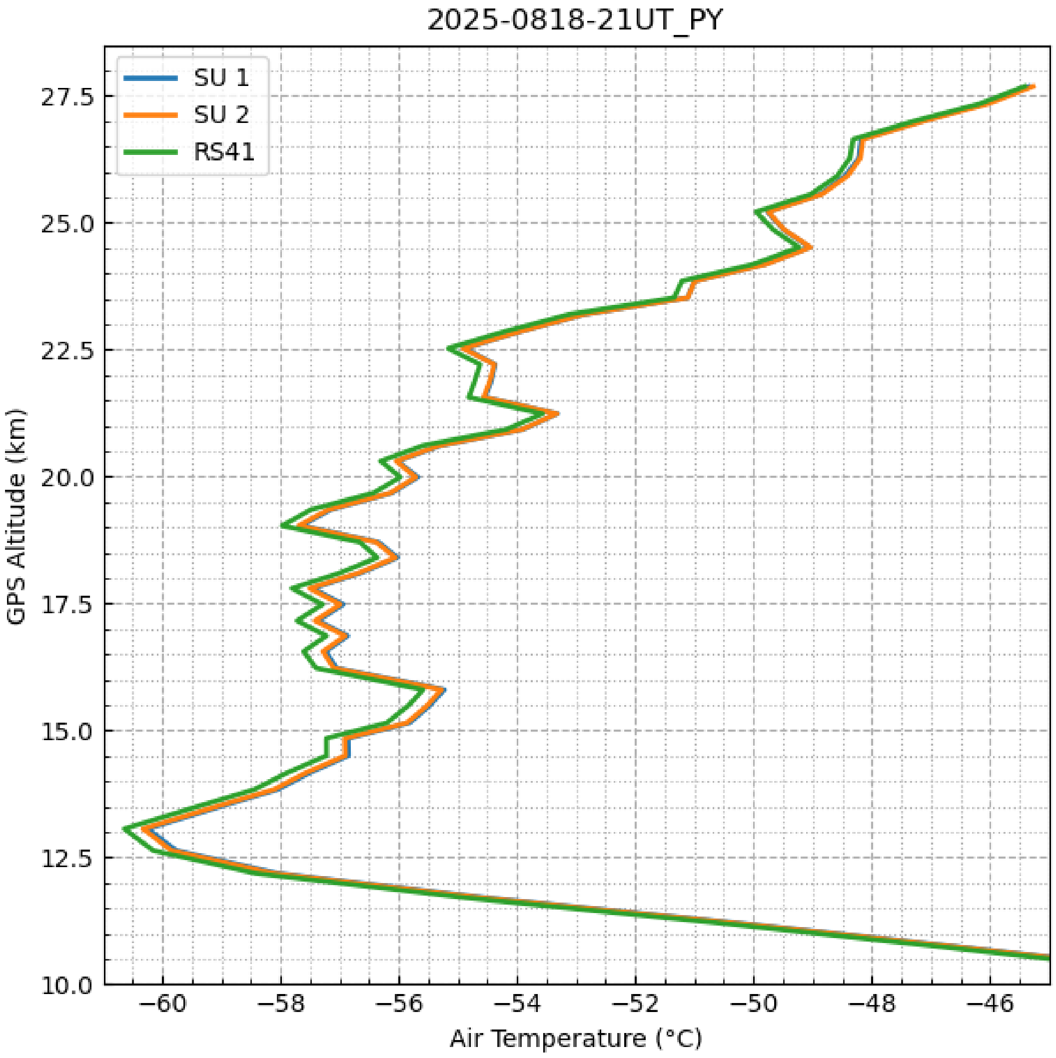
Air Temperature: Validation

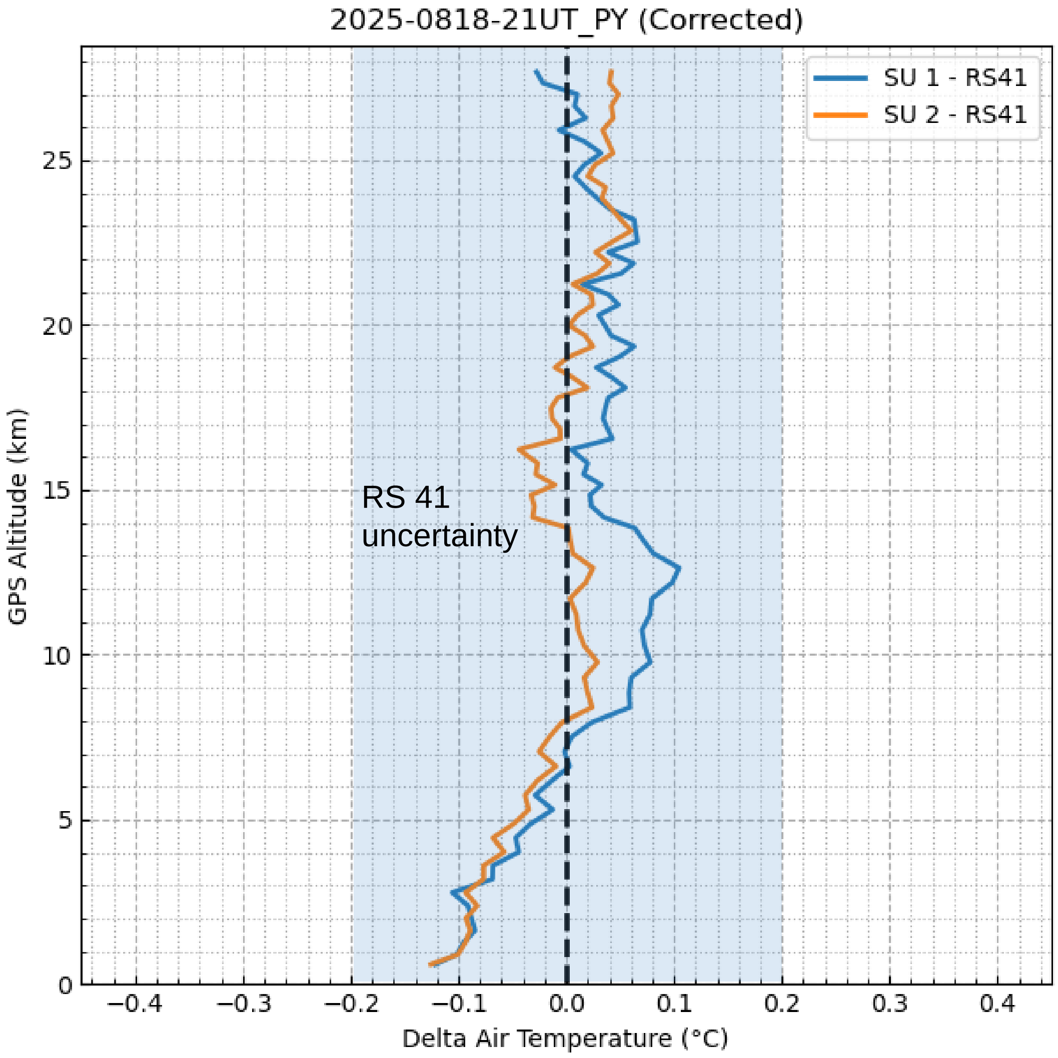




Air Temperature: Validation and Correction

using measured internal gradients only





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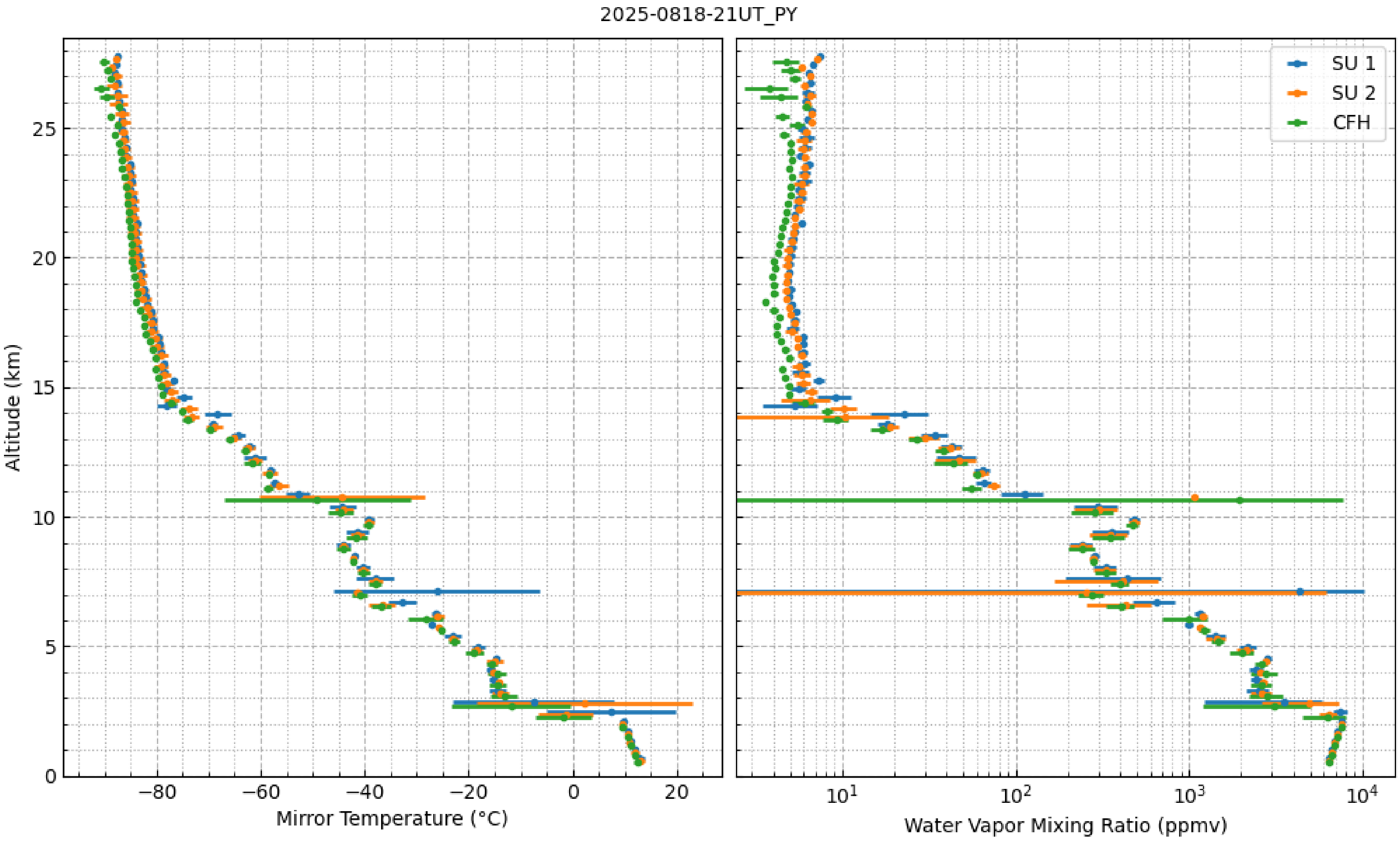
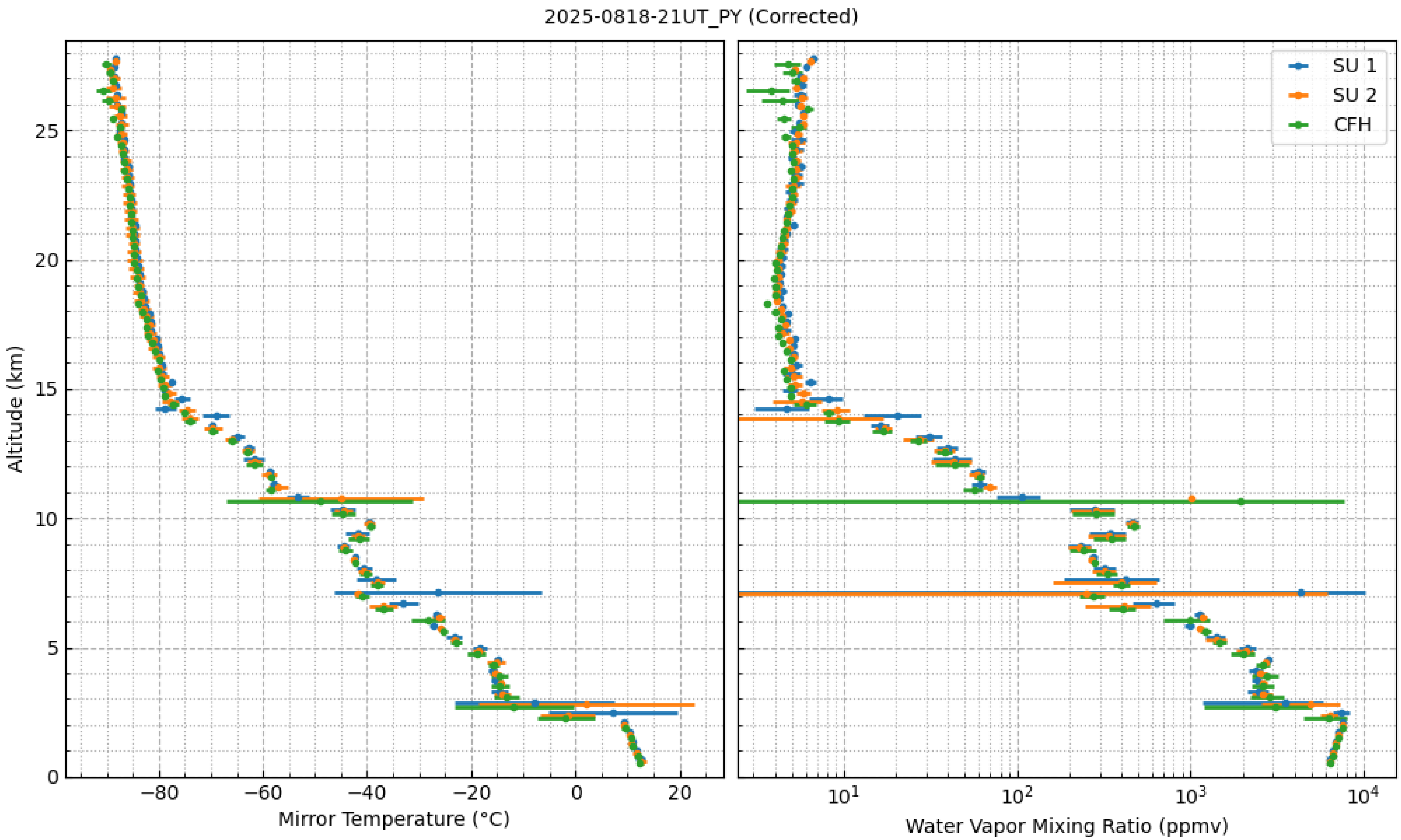
Frost Point and Water Vapor Comparison



mean and variability from 60 sec bins

≈ 300 m vertical resolution

Frost Point and Water Vapor Comparison



mean and variability from 60 sec bins

≈ 300 m vertical resolution

air temperature correction used for frost point temperature

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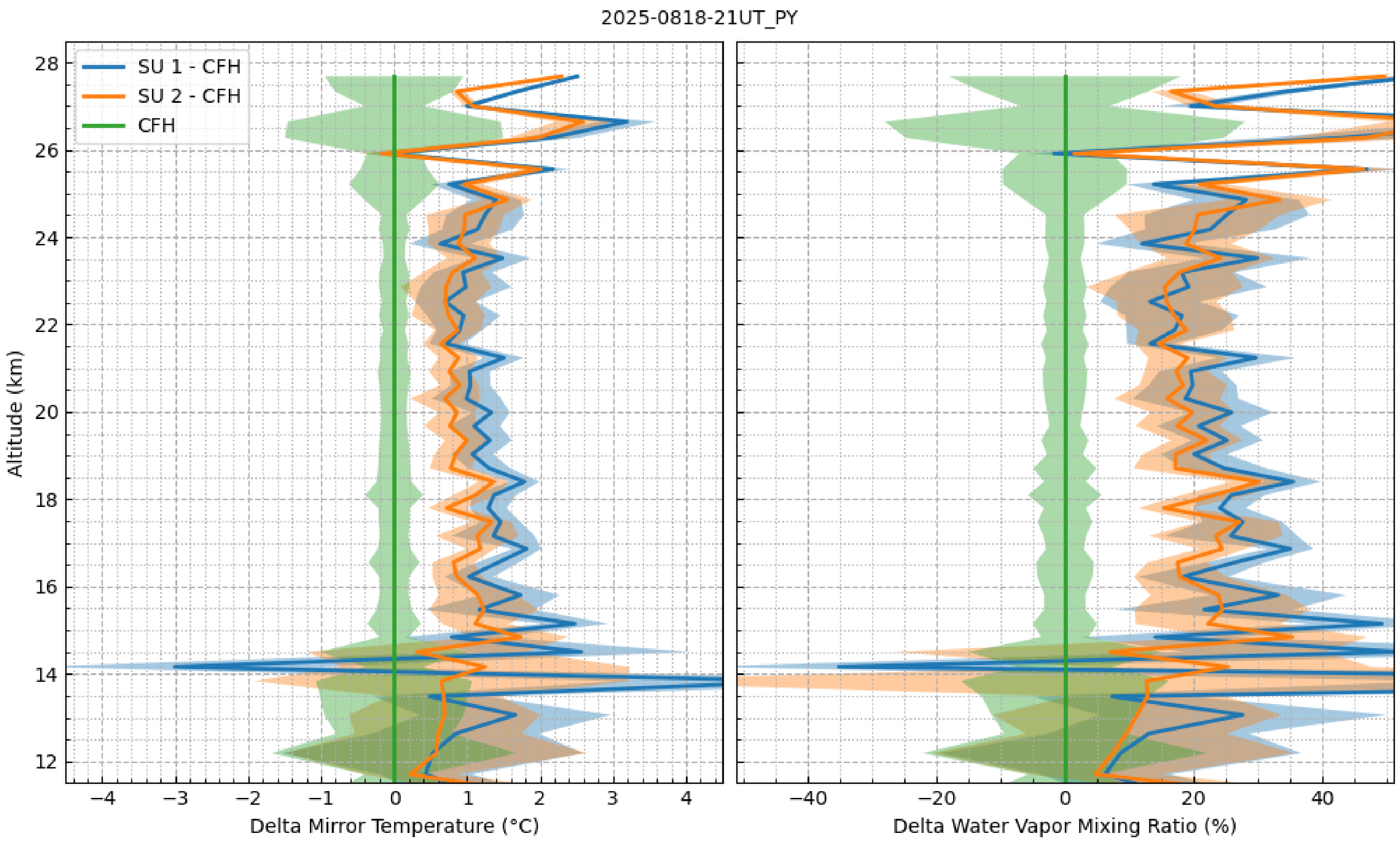
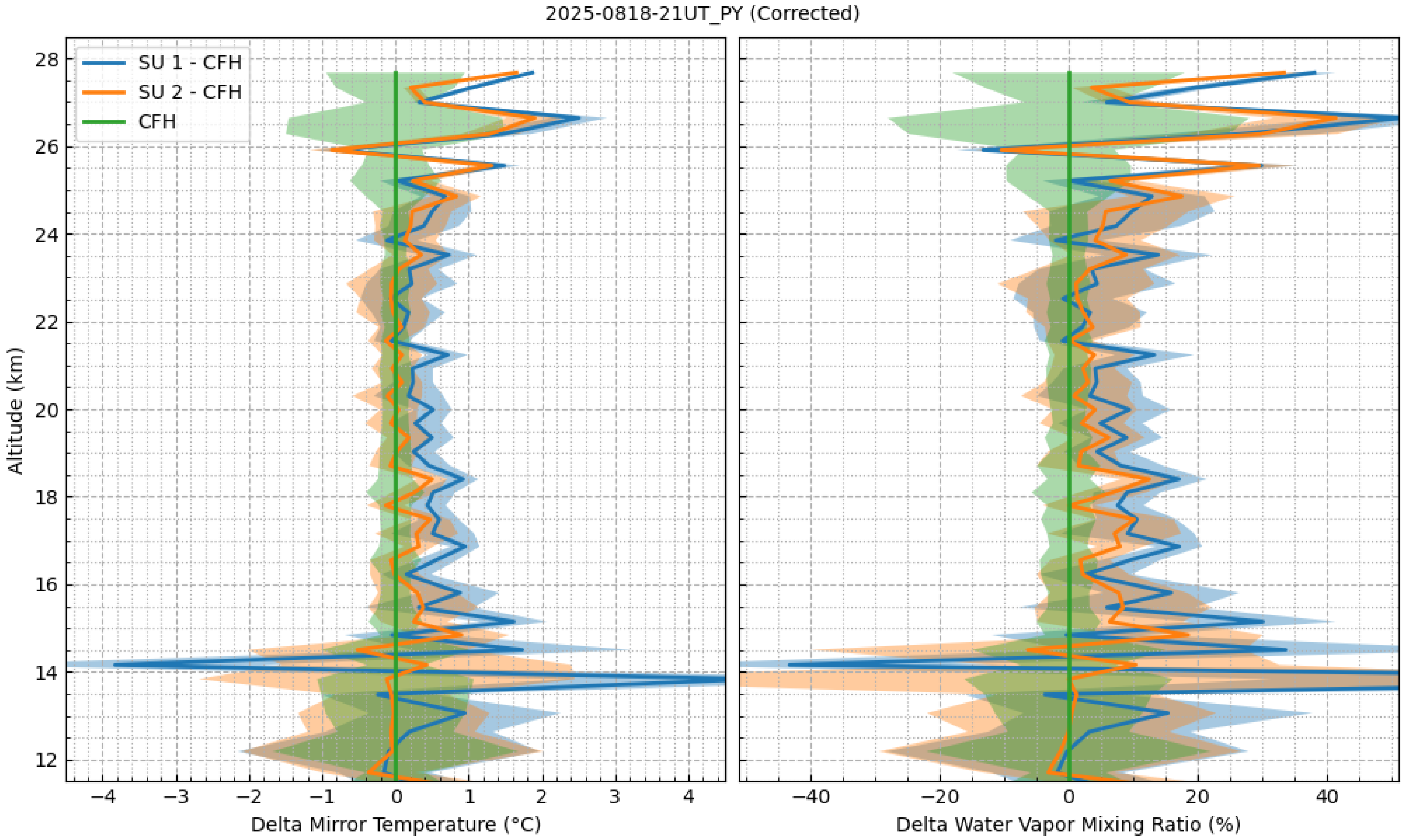


Frost Point and Water Vapor Comparison



Conclusions

internal TCM gradient diagnostics improve air temperature agreement to < 0.1°C

similar correction for water vapor yields margins of
1°C for frost point temperature,
1 ppmv for H2O mixing ratio

this is well within the observed atmospheric variability

alternative ‘material approach’ to reduce thermal gradient sensitivity is ready for flight

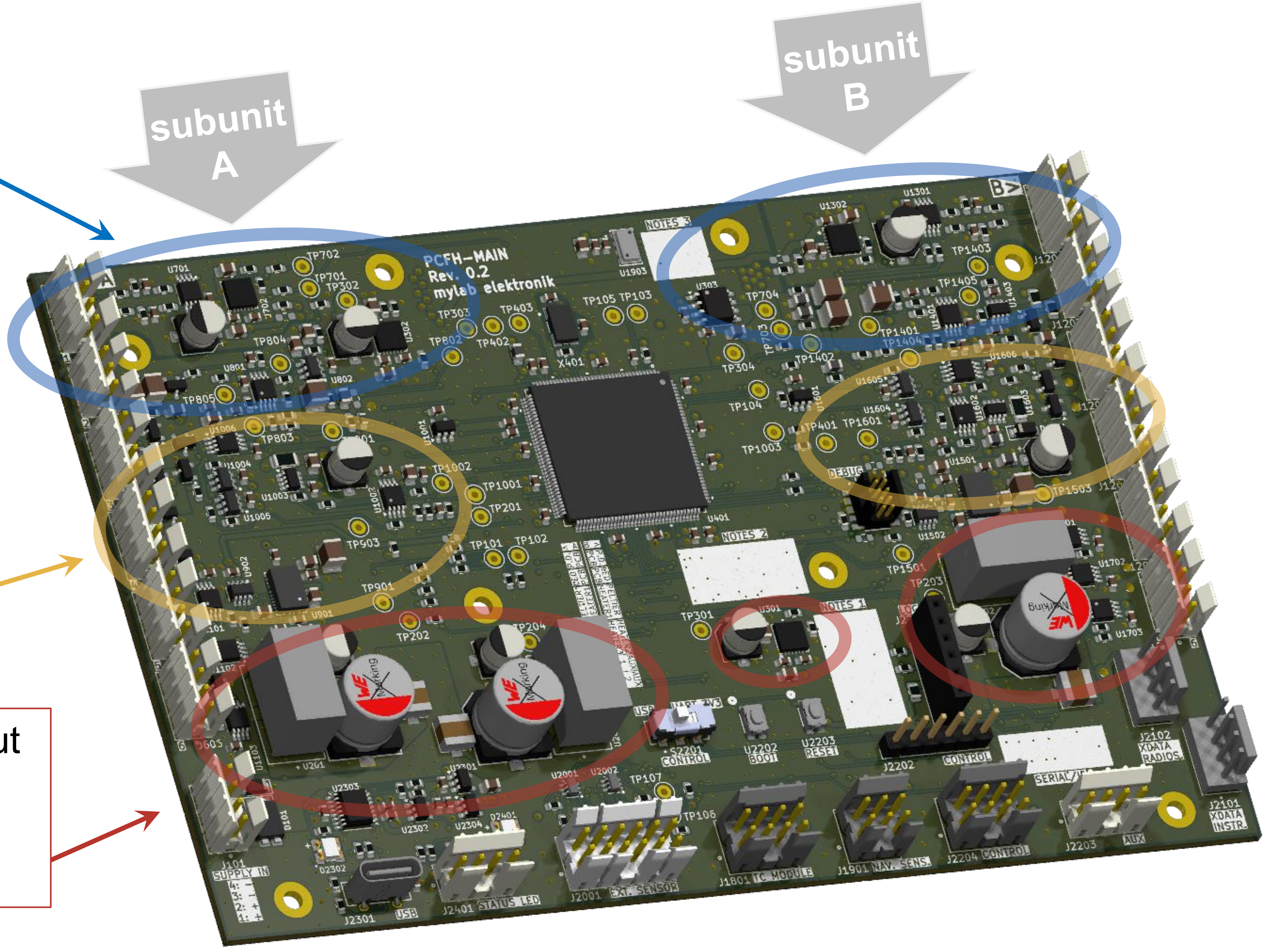
thermal hot-spots will be avoided

Highlights of Current Electronics and Firmware Development

enhanced reflectivity measurement fully exploiting microcontroller-integrated peripherals
- increased measurement rate
- improved stability
- higher sensitivity (currently under evaluation)

revised Peltier driver circuit
- reduced weight and PCB footprint

new power supply design for 9…32 V input
- supporting wide range of batteries
- allowing future extensions such as inlet tube heating

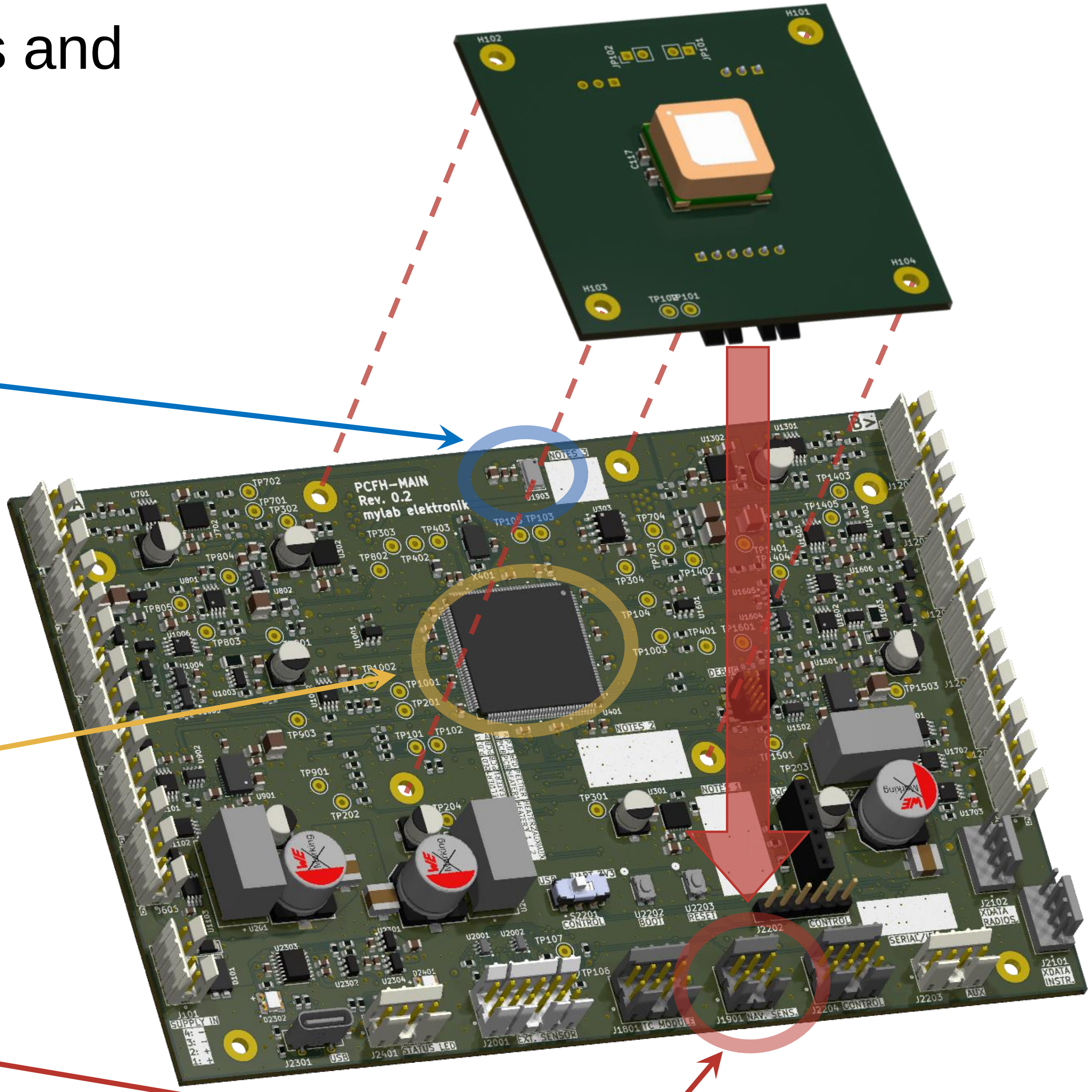


Highlights of Current Electronics and Firmware Development

on-board pressure sensor enabling in-flight tuning of control parameters and altitude-based event handling (e.g., detect launch and burst)

new firmware architecture
- improved flexibility for future extensions
- layered design enabling integration into simulation framework
- common platform for related instruments
  (e.g., new COBALD revision)

interface for additional/optional sensors like GNSS, gyroscope,…



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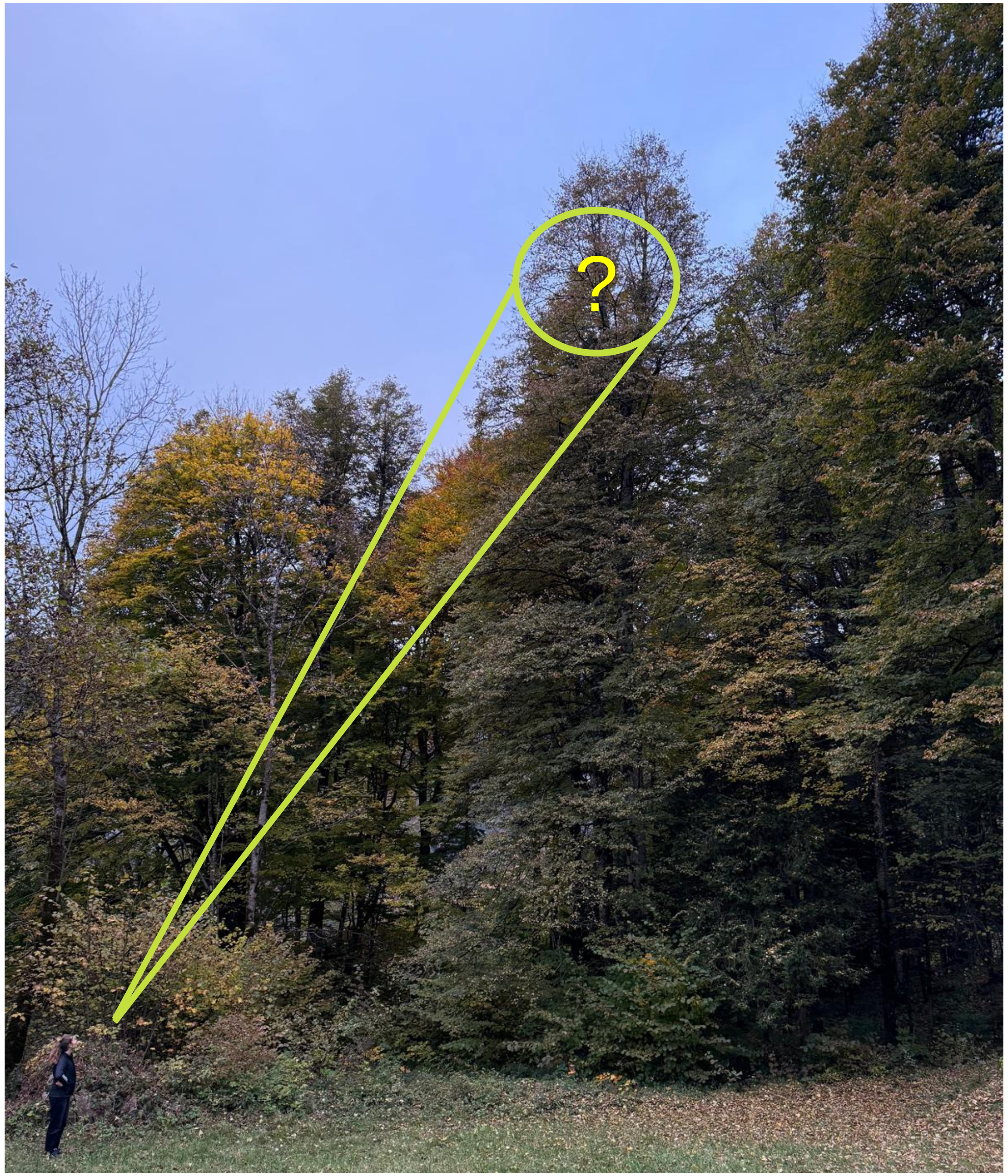
Payload Recovery

Can you help spotting the payload??

The position is known within a range of 3..5 m

Please take a close look …



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Payload Recovery

☺ ah – there it is

Thank you for your attention!