

Field characterization during measurement campaigns of FIRMOS-B, a ground-based and balloon-borne far-infrared spectroradiometer developed to support the ESA FORUM mission

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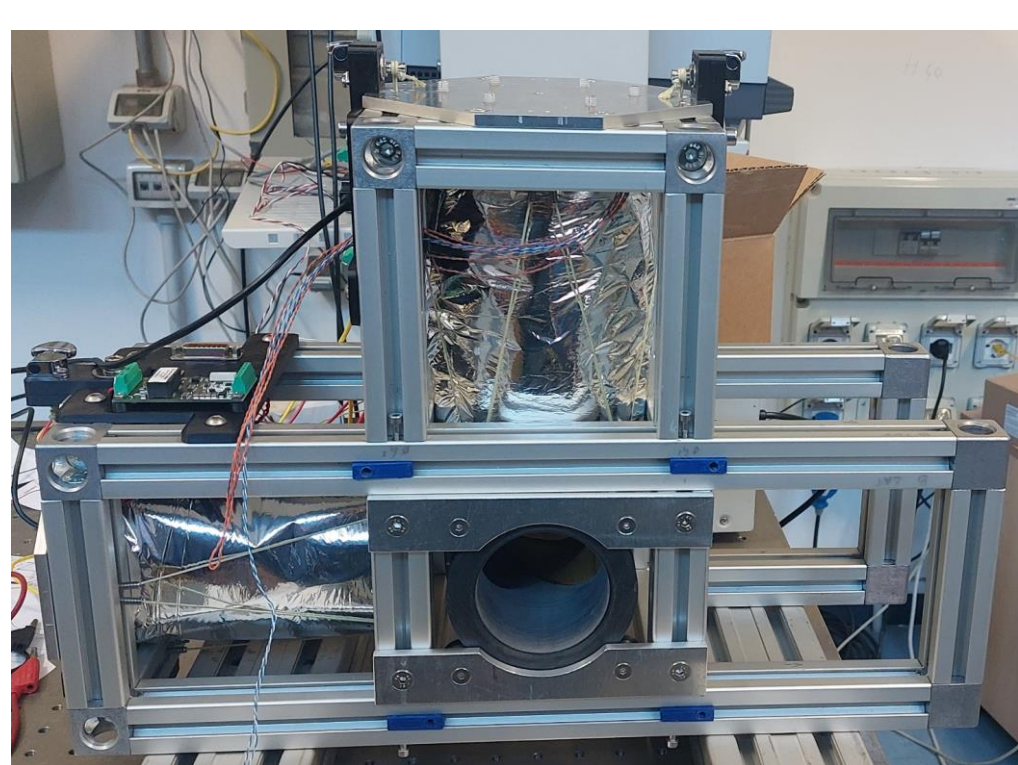
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THE FAR-INFRARED SPECTRORADIOMETER FIRMOS-B

FIRMOS (Far-Infrared Radiation Mobile Observation System) is a far-infrared Fourier-transform spectroradiometer, developed by CNR-INO to support the ESA ninth Earth Explorer mission **FORUM** (Far-infrared Outgoing Radiation Understanding and Monitoring). **FIRMOS-B** is the upgraded version to enable operations both on board stratospheric balloons and on the ground.



CALIBRATION UNIT:

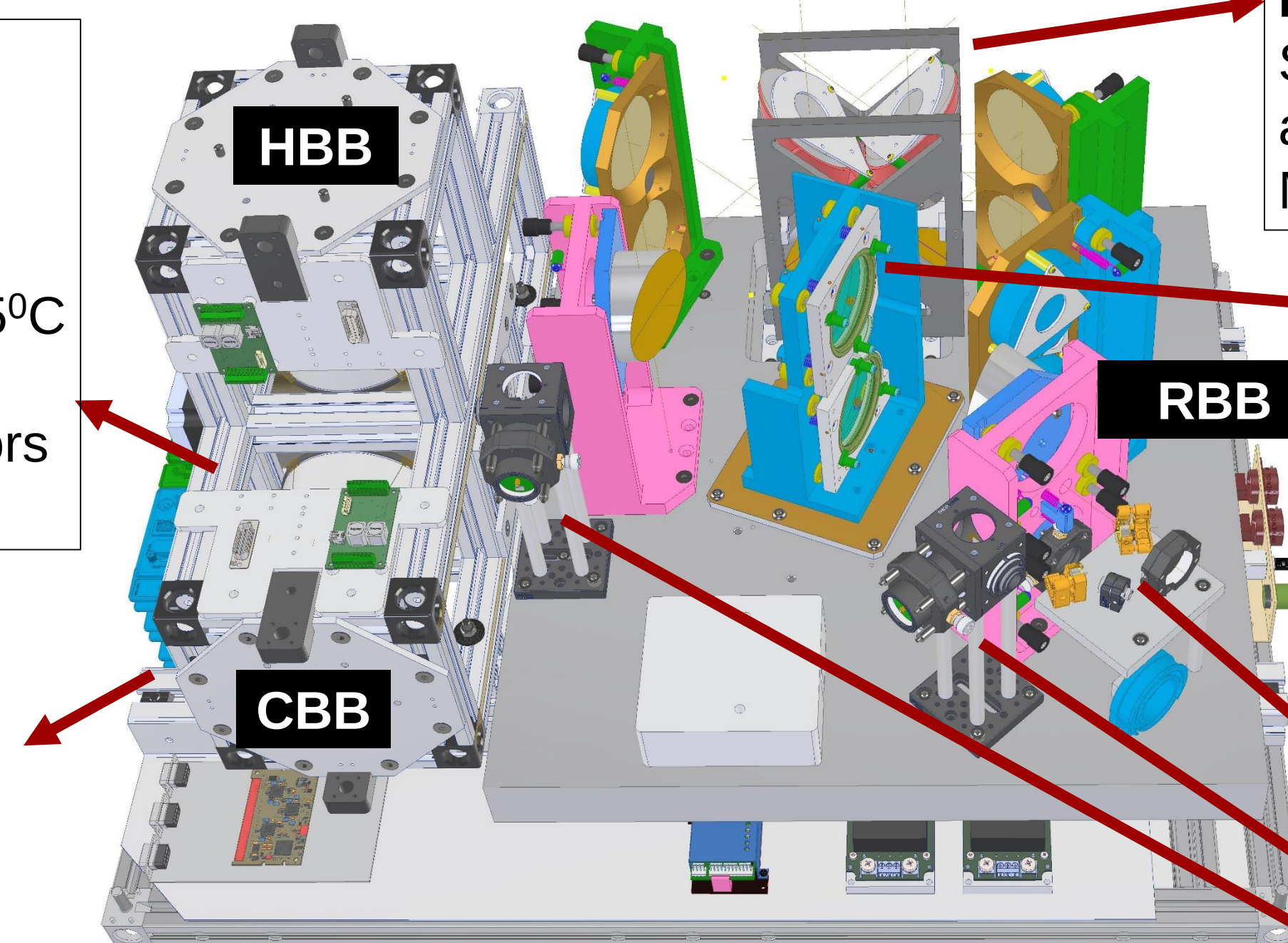
- Hot Black Body (HBB) stabilized at 70°C
- Cold Black Body (CBB) stabilized between 2 ÷ 15°C

The temperatures are measured by 3 PT100 sensors (accuracy 100 mK)

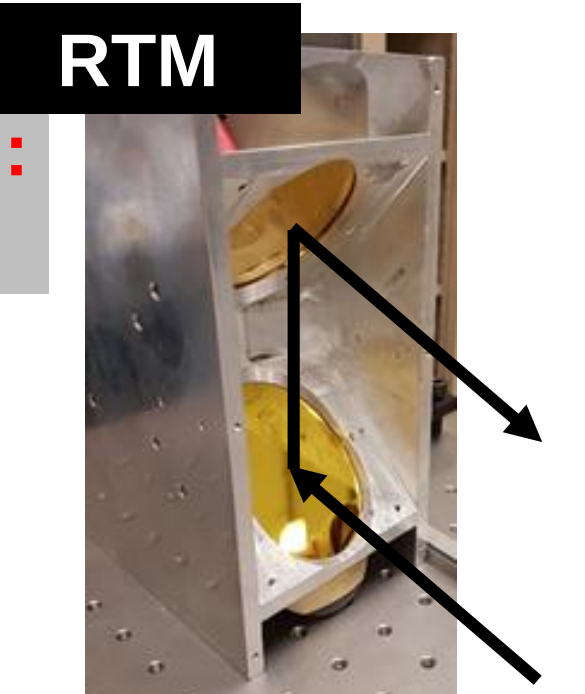
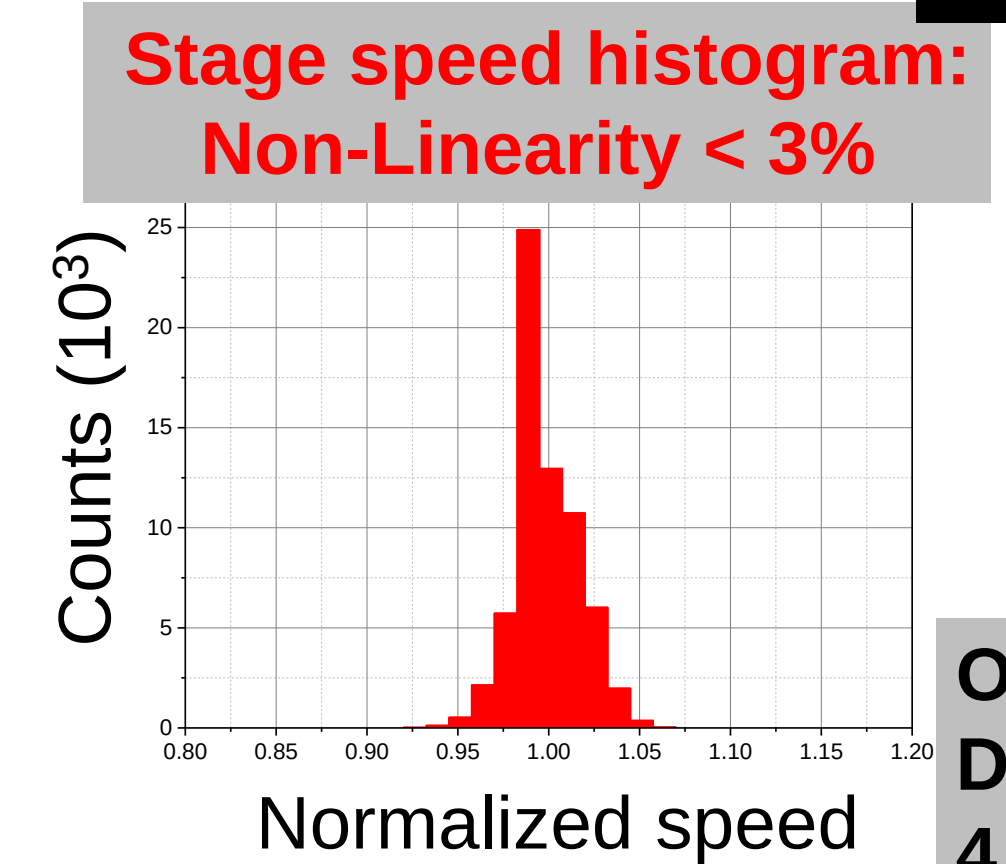


SCENE SELECTOR: rotating mirror for selection of:

- Calibration view (HBB or CBB)
- Nadir or Zenith or Limb view depending on the assembly of the BBs



MOVEMENT UNIT: Stage (15 µm position accuracy) + Roof Top Mirror (RTM)



Optical Path Difference = 4 * Stage Move

BEAM-SPLITTER (BS) UNIT:

- Bilayer: 2 µm BoPET + 670 nm Germanium
- BS mounting equipped with PZT for remote optical alignment
- Two absorption bands: ~ 1120 and 1260 cm⁻¹

REFERENCE LASER UNIT: single-frequency diode fiber laser @ 786 nm + photodiode

ACQUISITION/CONTROL SYSTEM and SOFTWARE:

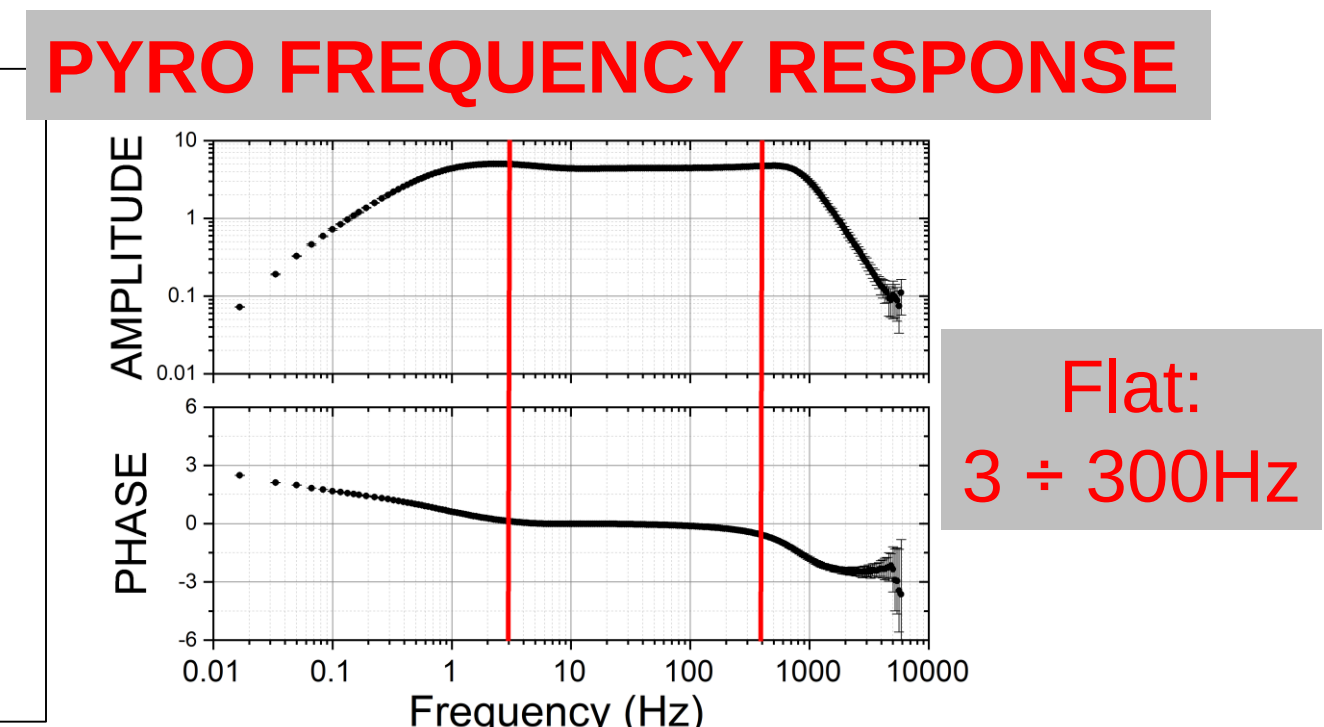
- Acquisition of 3 channels: 2 interferograms + reference laser signal
- Acquisition and control based on CompactRIO (cRIO)
- Completely autonomous operation**
- Software for WiFi control via Labview Remote Panel
- Software for low rate communication (< 56 kbit/s) via UDP protocol during balloon flights

INTERFEROMETRIC LAYOUT: Mach-Zehnder configuration with double-input and double-output ports on two levels.

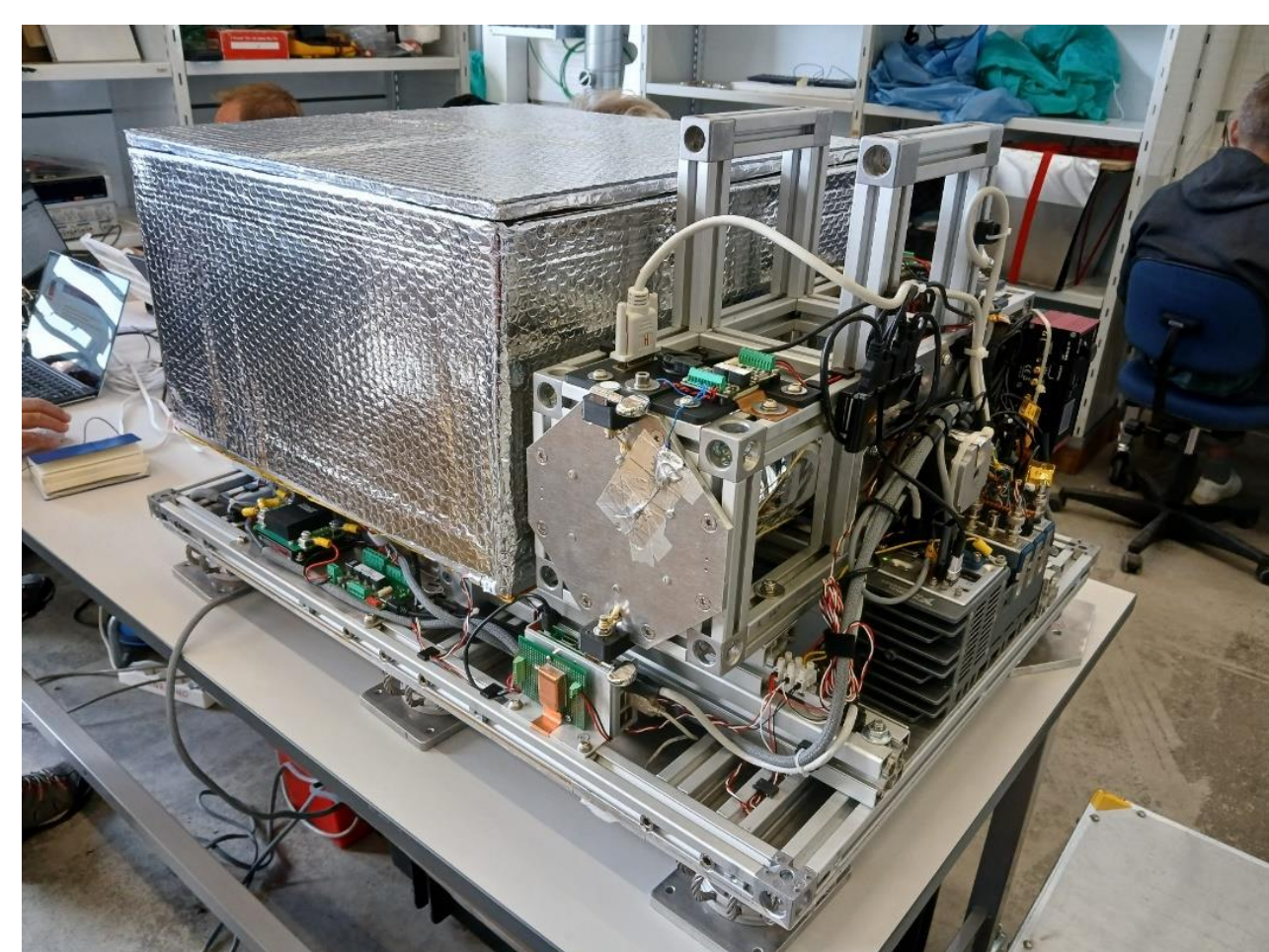
- Input port 1: scene to measure
 - Input port 2: Reference Black Body (RBB) with measured temperature (PT100)
- The optical plate is thermally stabilized

HOUSE-KEEPING: Temperatures + WebCam + GPS + Accelerometer + Pressure + Humidity

DETECTOR UNIT: 2 DLATGS pyroelectrics (2 mm of diameter) without cooling + parabolic mirrors



FIRMOS-B SPECIFICATIONS



SPECTRAL COVERAGE	100 ÷ 1600 cm ⁻¹
RESOLUTION	0.4 cm ⁻¹
FREQ. RANGE	~ 4 ÷ 100 Hz
NESR	0.3 ÷ 1 mW / (m ² sr cm ⁻¹)
CALIBRATION ERROR	< 300 mK
PAYLOAD	84x62x58 cm, 80 kg
POWER	max 200 W, typical 100 W

SINGLE INTERFEROGRAM ACQUISITION

ACQUISITION SAMPLING RATE	20 KS/s
STAGE SCAN: TIME, SPEED, LENGTH	56 s - 0.0111 cm/s - 0.625 cm

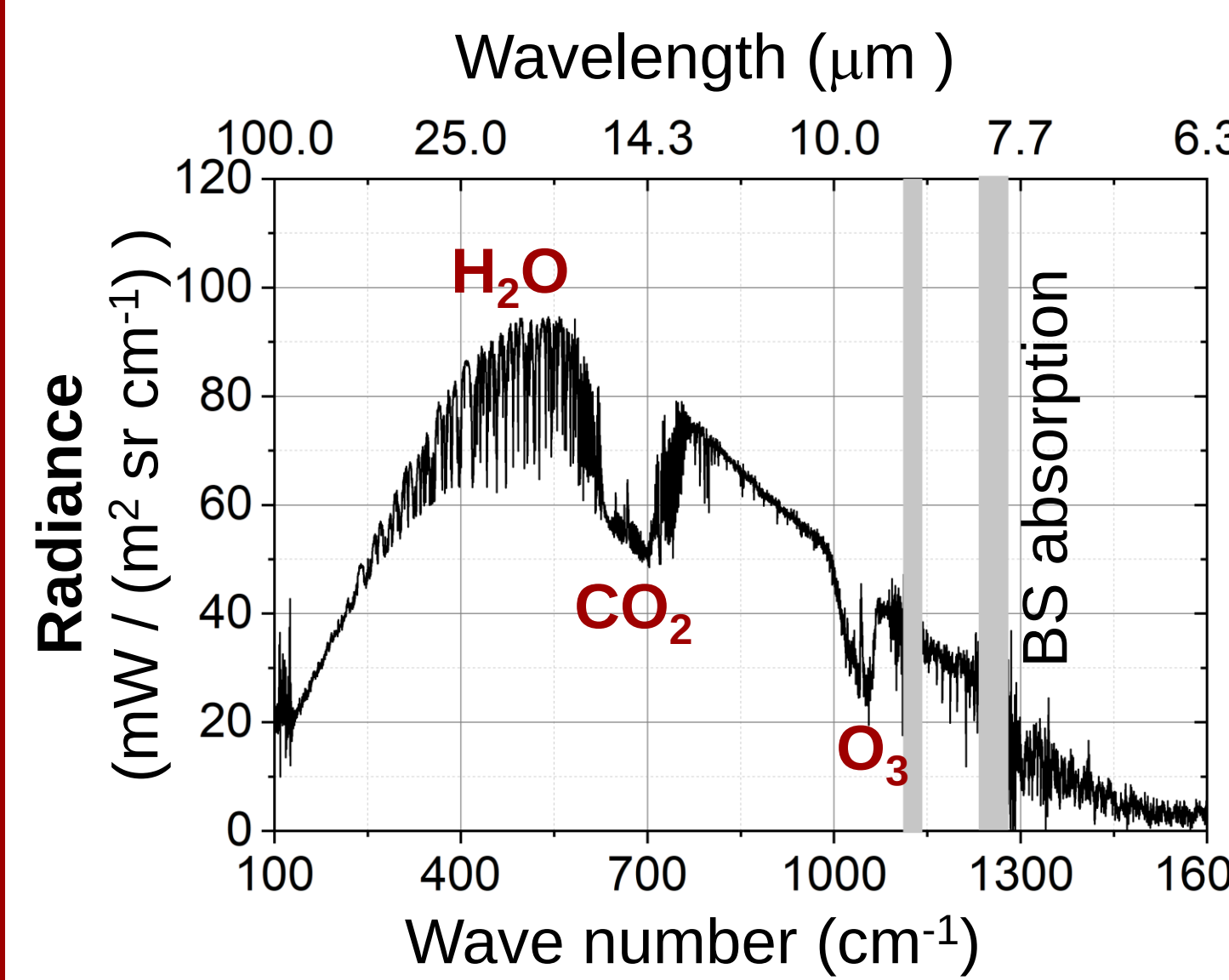
EXAMPLE OF FIRMOS-B FIELD RADIANCE and NESR

Each FIRMOS-B **CALIBRATED SPECTRAL RADIANCE** is obtained by a **SEQUENCE** of single acquisitions (Calibration + Observation):

	flight ascent	flight ceiling	on ground
Calibration	2 HBB + 2 CBB	2 HBB + 2 CBB	2 HBB + 2 CBB
Observation	4 NADIR	10 NADIR	4 ZENITH

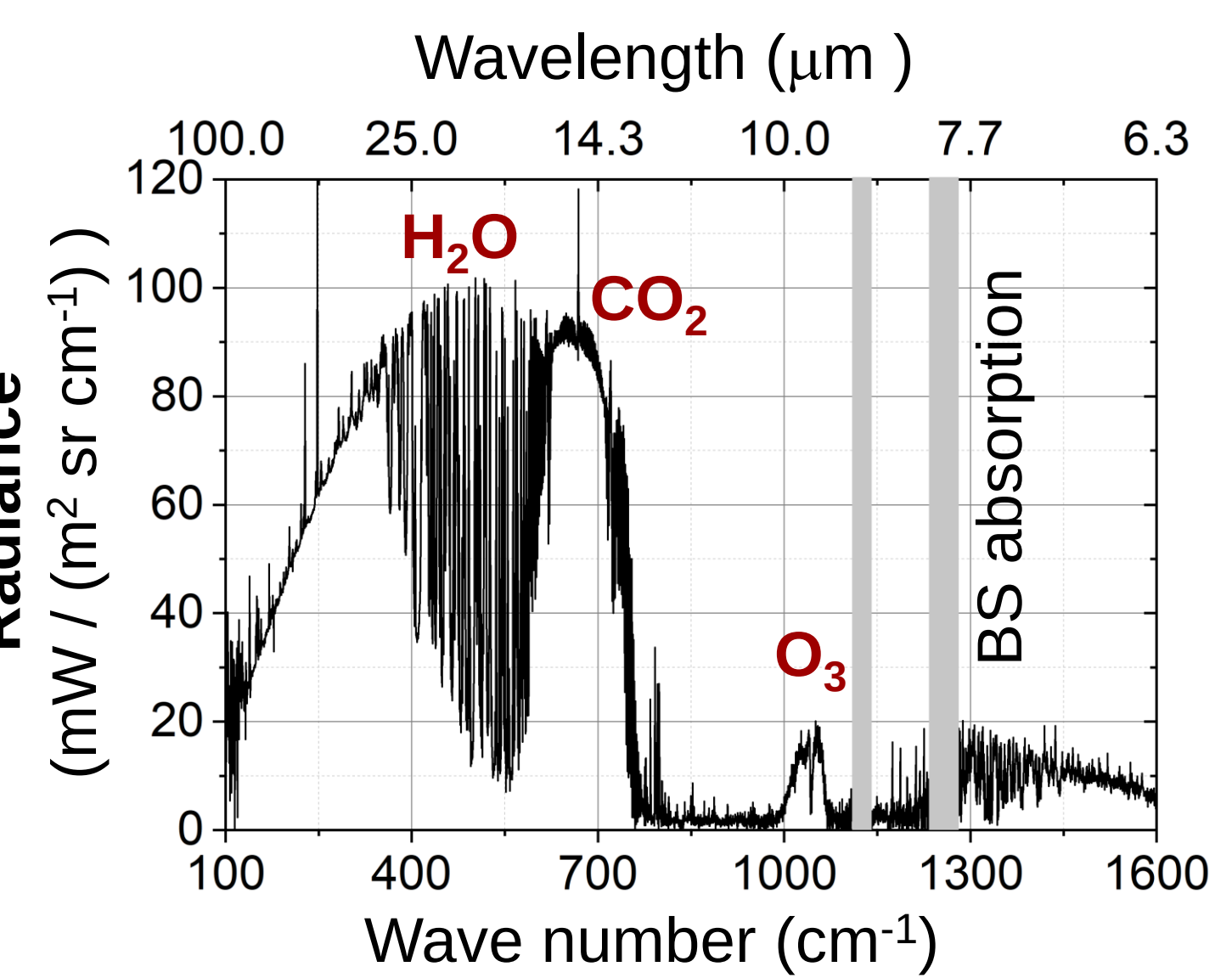
UPWELLING SPECTRAL RADIANCE emitted by the Earth

Onboard balloon, 27 Jun 2024, 02:19 UTC
Sweden, Altitude 32 Km, Pressure 10 hPa



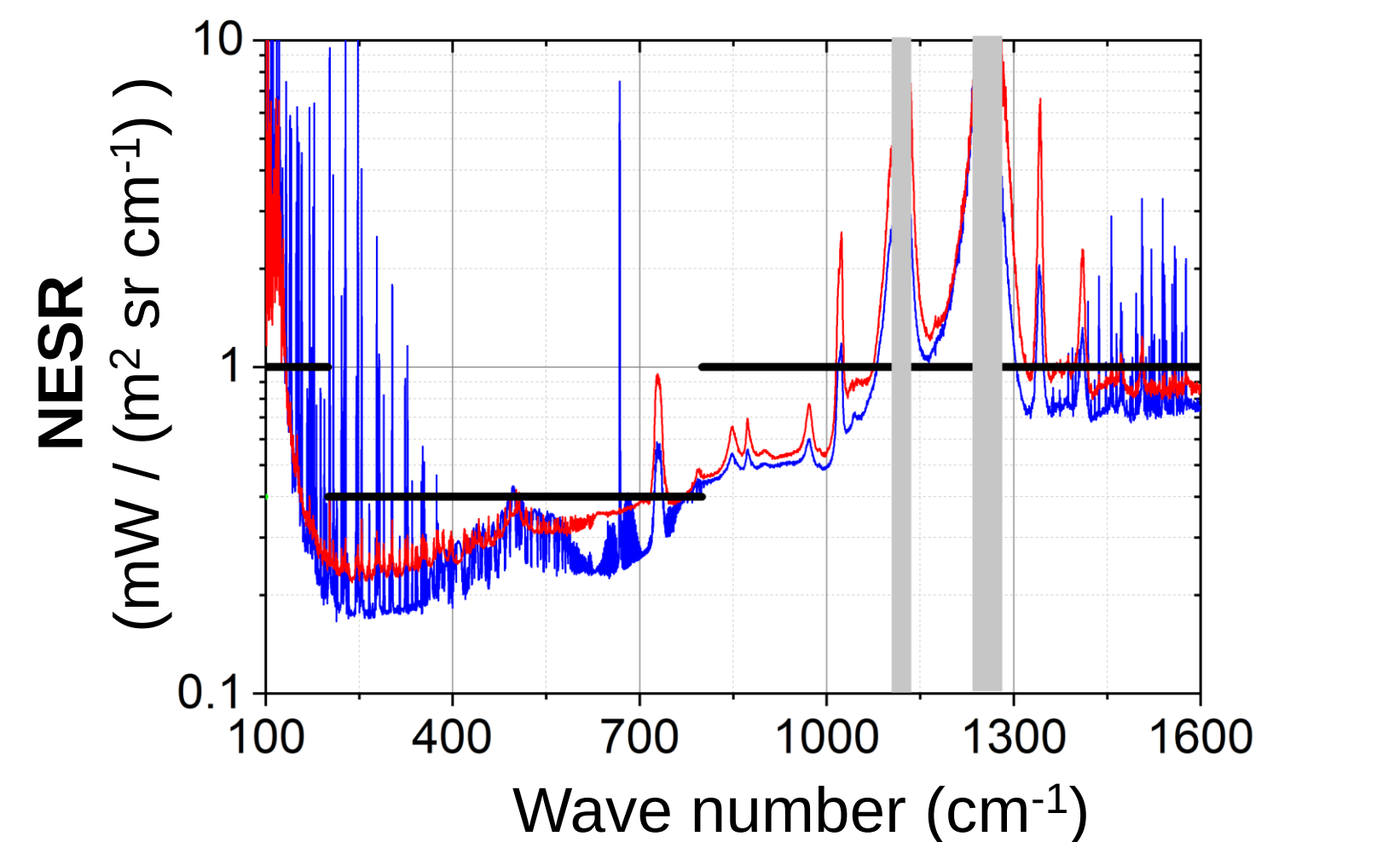
DOWNWELLING SPECTRAL RADIANCE emitted by the atmosphere

20 Jan 2025, 21:14 UTC
Ottawa airport, Clear Sky, Cold&Dry



IN-FIELD NESR:

- balloon-borne operation (TRANSAT: ATMOSFER campaign)
- ground operation (WHAFFERS campaign)
- FORUM REQUIREMENT**



FIRMOS-B CAMPAIGNS

<https://www.forum-ee9.eu/category/campaigns/>

STRATOSPHERIC BALLOONS CAMPAIGNS:

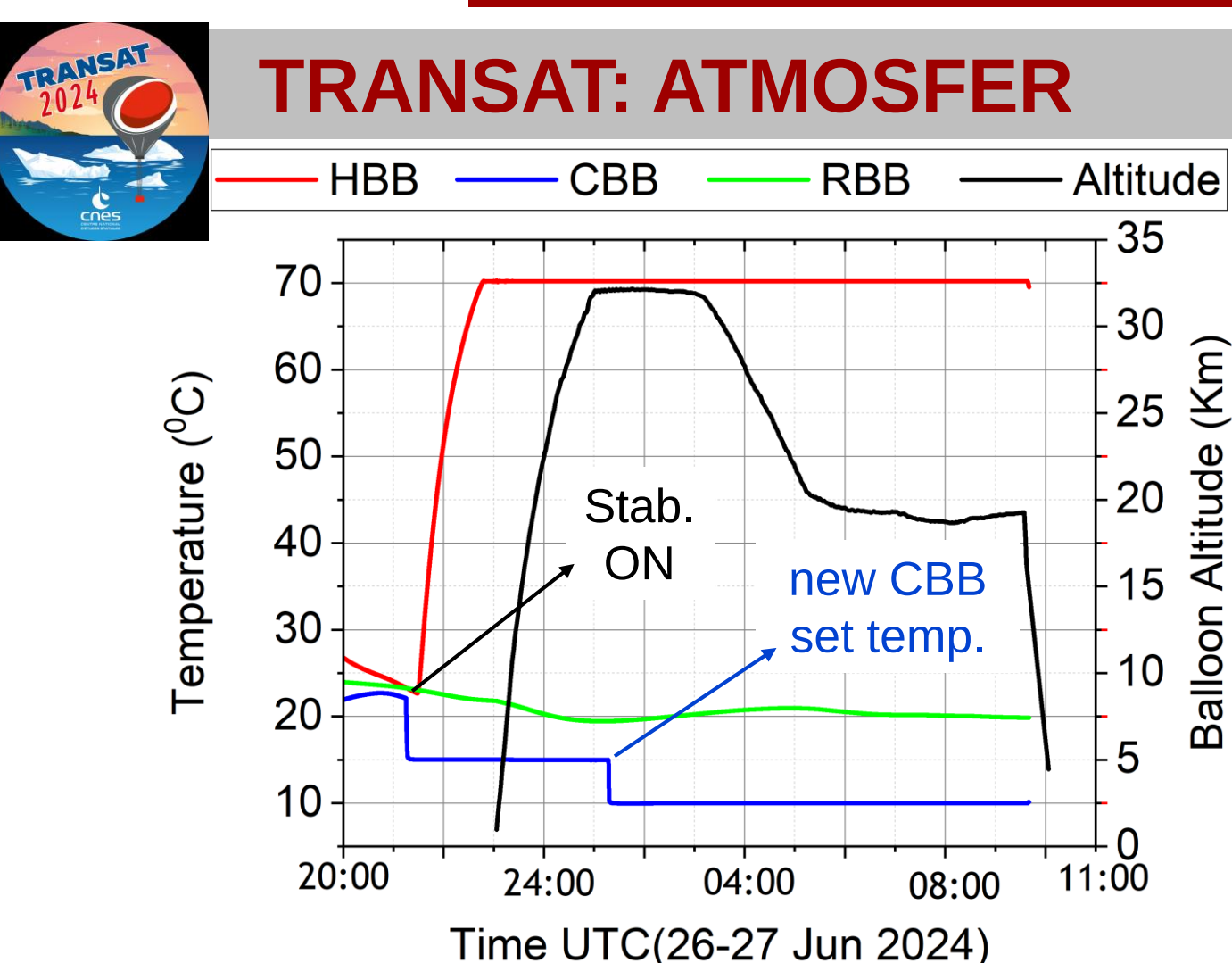
- STRATOS: HEMERA3** (Stratospheric Science) Timmins (Canada), August 2022
13 flight hours, 230 measured spectra, Limb/Nadir view
- TRANSAT: ATMOSFER** (balloon-borne evaluation of atmospheric hygrometers and Synergistic efforts for the preparation of the forum mission), Kiruna (Sweden), June 2024
11 flight hours, 500 measured spectra, Nadir view

ON-GROUND CAMPAIGN:

- WHAFFERS** (W-band, HiSRAMS, AERI, FIRR2, FINESSE and FIRMOS Experiment on Remote Sensing) Ottawa and Gault Natural Reserve (Canada), 14 Jan – 14 Feb 2025: 3163 measured spectra, Zenith view - Quasi-Nadir&Zenith views for Snow/Ice Emissivity



FIRMOS-B THERMAL BEHAVIOUR DURING THE ATMOSFER AND WHAFFERS CAMPAIGNS

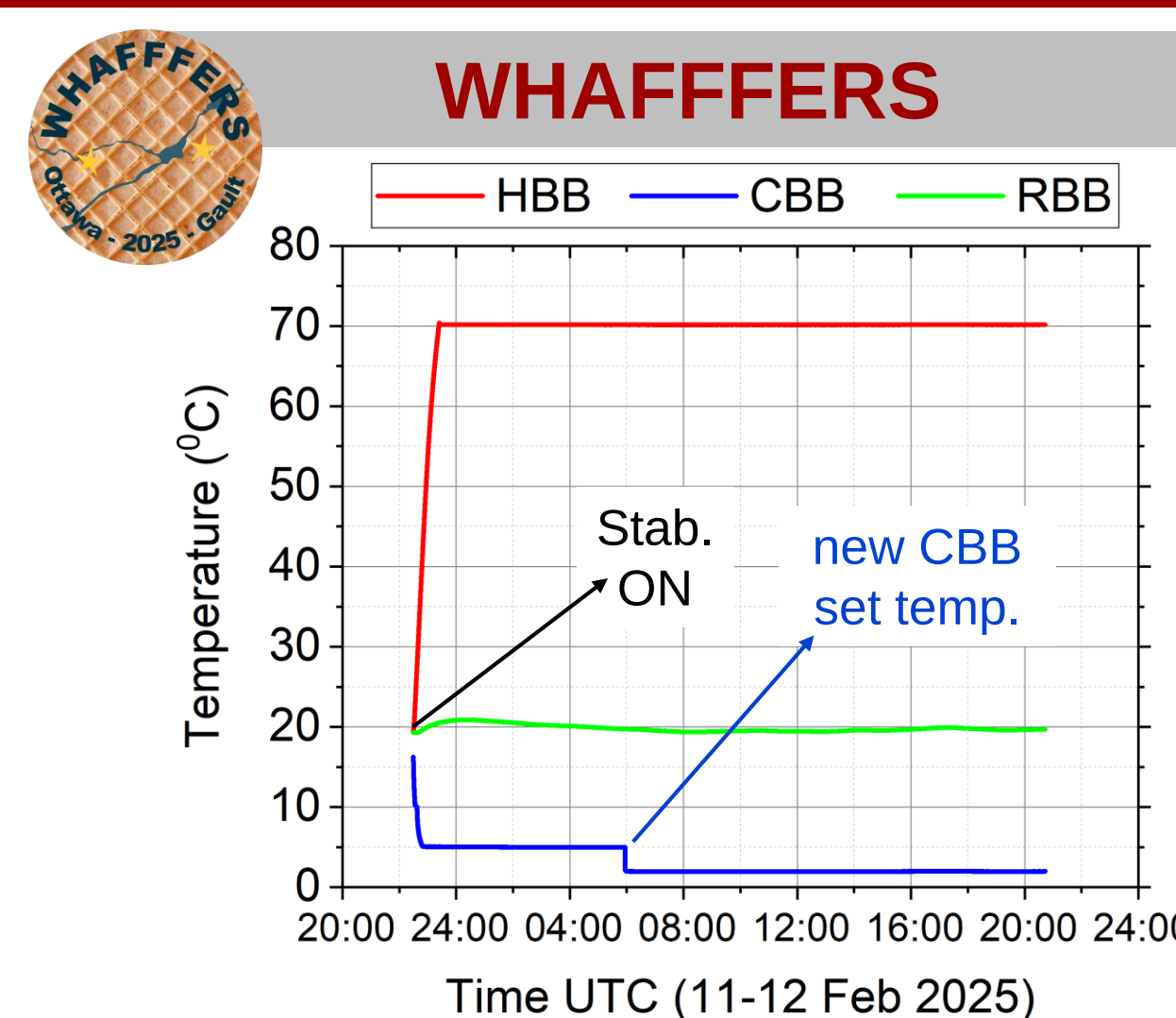


11 HOURS BALLOON FLIGHT

In-flight BB Stability on 11 hours:
HBB@ 70°C ΔT-1σ = 8 mK
CBB@ 15°C ΔT-1σ = 22 mK
CBB@ 10°C ΔT-1σ = 12 mK

In-flight BB Thermal Homogeneity
HBB: ΔT_{max} < 400 mK CBB: ΔT_{max} < 500 mK

In-flight Interferometer Stability
Plate stabilized @ 22°C
RBB Temperature Range = 19.4 ÷ 21.9 °C



21.5 HOURS OF MEASUREMENTS at GAULT

BB Stability:
HBB@ 70°C: ΔT-1σ = 10 mK
CBB@ 5°C: ΔT-1σ = 25 mK
CBB@ 2°C: ΔT-1σ = 8 mK

BB Thermal Homogeneity:
HBB < 400 mK CBB < 1500 mK

Interferometer Stability:
Plate stabilized @ 22°C
RBB Temperature Range = 19.3 ÷ 20.9 °C