The FIRMOS-B instrument flight at Timmins (Ontario)

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CNR-INO
ISTITUTO NAZIONALE DI OTTICA
CONSIGLIO NAZIONALE DELLE RICERCHE

FIRMOS-B instrument flight at Timmins (ON)

OVERVIEW

1. Intro to FIRMOS-B scope
   - Balloon flight
2. The FIRMOS-B system
   - Opto-mechanical setup
   - Electronics, control and acquisition
3. FIRMOS-B readiness
   - Validation tests
   - Thermal simulations

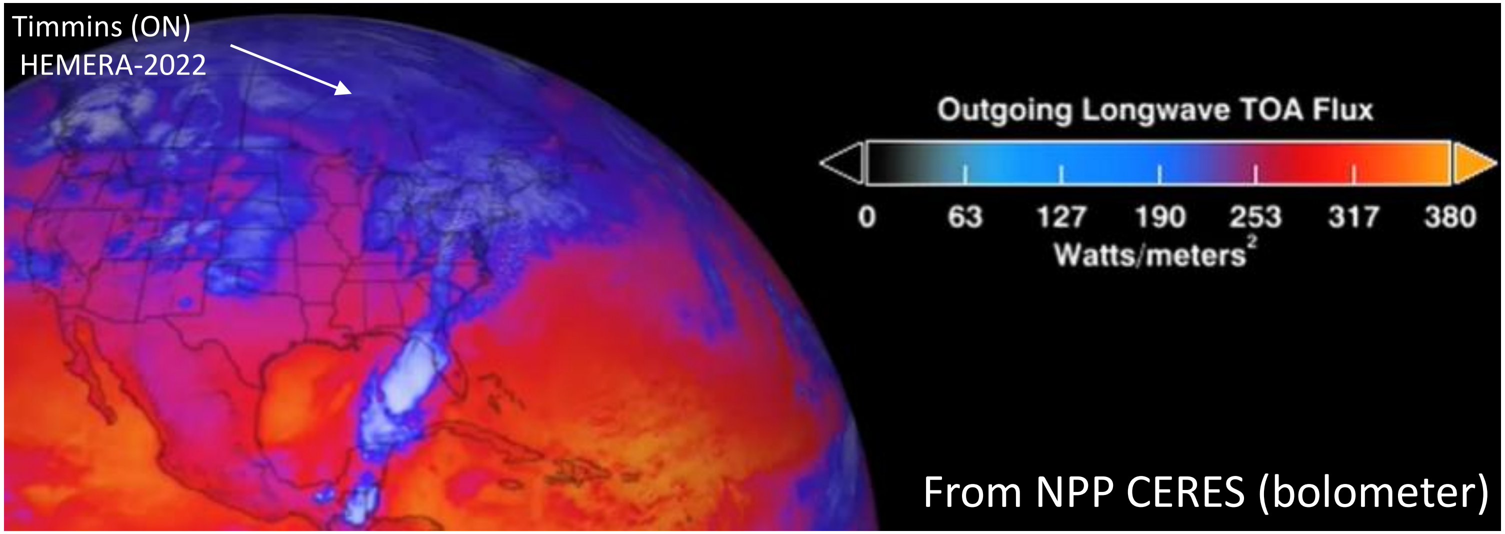
Introduction

Global steady-state TOA radiation balance: $(\mathbf{1}-\alpha_{eff})\boldsymbol{I}_{sun}=\boldsymbol{\varepsilon}_{eff}\boldsymbol{\sigma}\boldsymbol{T}^{4}_{skin}$

Locally, multiple factors are involved:

- H_2O concentration and phase (cloud types etc.), latent heat effects
- CO_2 , and other trace gases
- Earth inclination, winter/summer, night/day, latitude etc.
- Land surface properties (especially at high altitudes and/or dry sites)
- …

Radiative transfer calculations required for a quantitative description (spectrally resolved)



Wieliki et al. BAMS 1996

Introduction

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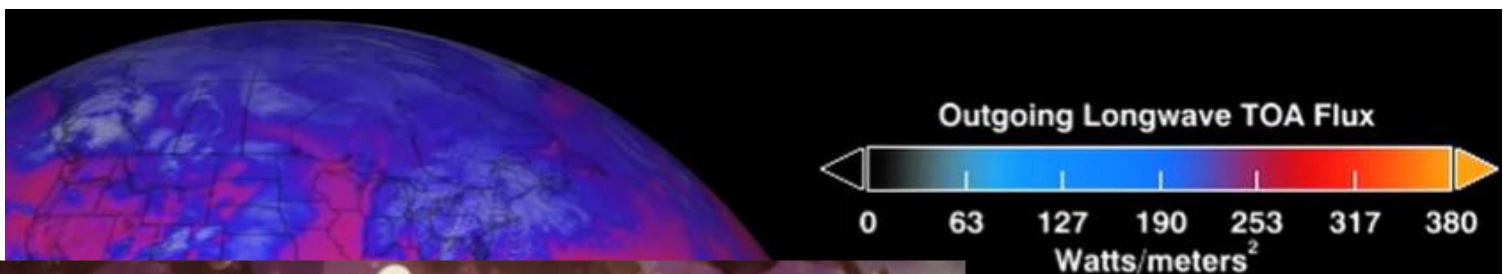
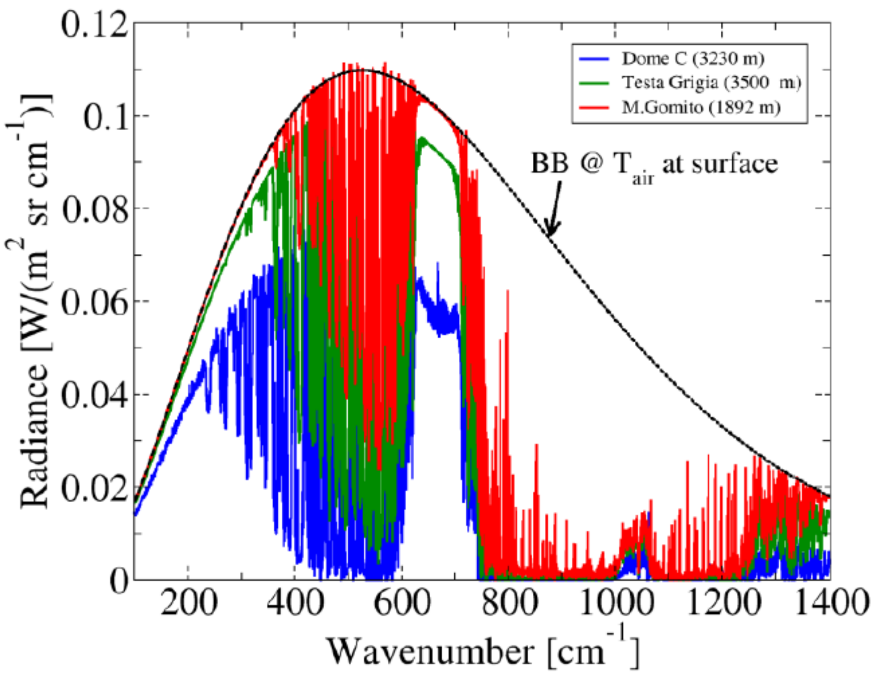


FIRMOS-B ground vs balloon-borne measurements

Ground-based zenith-looking observations require high-altitude and dry sites

FIR limited to wavenumber > 200-300 cm^{-1}



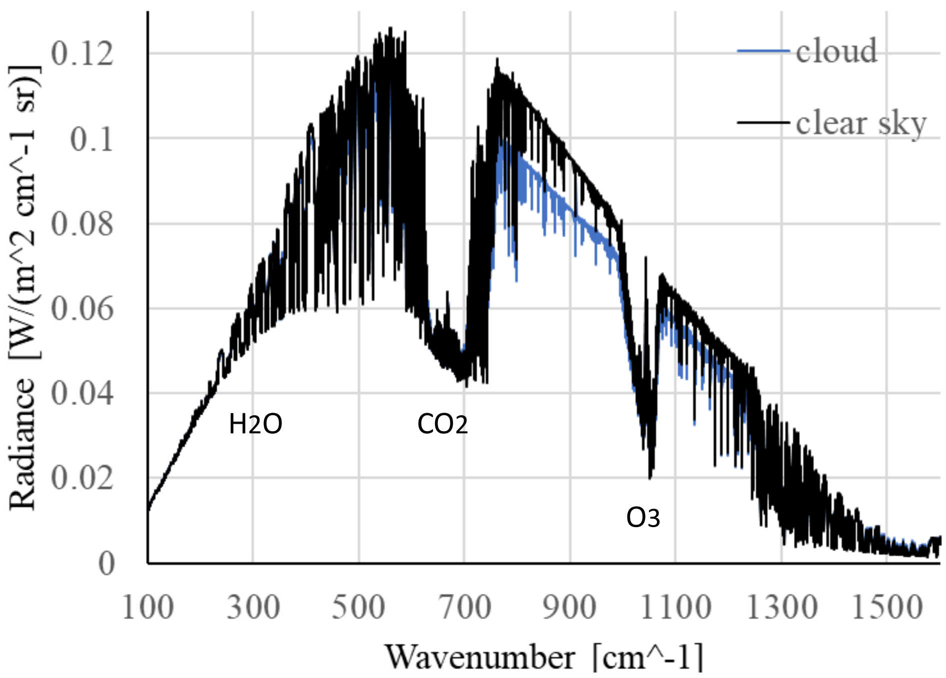
- FIRMOS: Palchetti et al., ESSD, 13, 4303–4312, 2021
- REFIR-PAD Dome-C Antarctica: Bianchini et al., Atmos. Meas. Tech., 12, 619–635, 2019

Simulated spectrum:

- No instrumental function

- Integrated Water Column from ERA5 over Timmins (ON) on 01/08/2021 12:00 UTC

- Cloud 7-12 Km, OD=0.44, De=20 um



- G. Di Natale and L. Palchetti, JQSRT, 2022, 108120.
- Di Natale et al., JQSRT, 2020; 246:106927

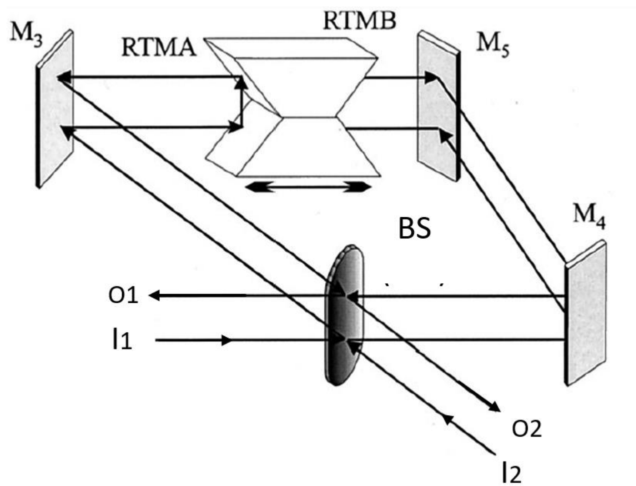
FIRMOS-B

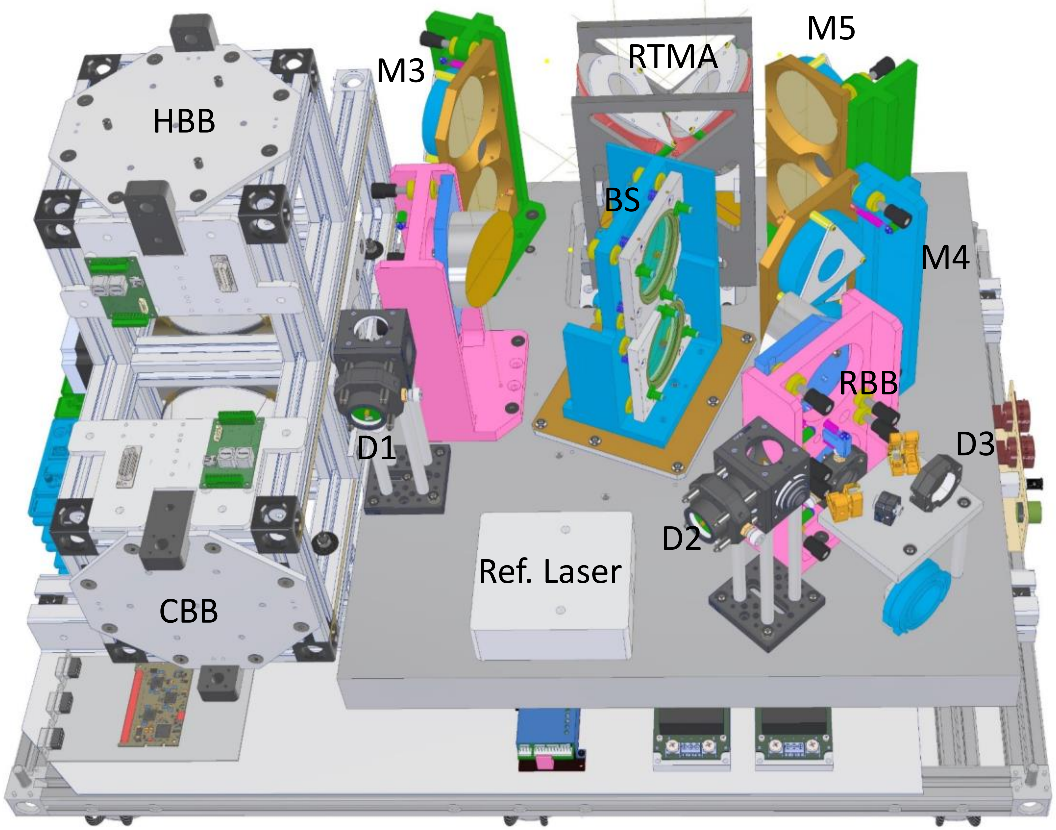
FIRMOS-B Scope:

- ➢ Improve FIR models of radiative transfer in the atmosphere and surface:
  - Water vapour spectroscopy, continuum absorption
  - Cirrus clouds radiative properties
  - Snow/ice/… emissivity (in future campaigns)
- ➢ Instrumental support:
  - provide real measurements to support the development of atmospheric retrieval software tools and analysis for the FORUM mission
  - Prepare a suite of instruments for calibration/validation purposes

FIRMOS-B Opto-mechanical Setup

- Mach-Zehnder configuration with full tilt compensation

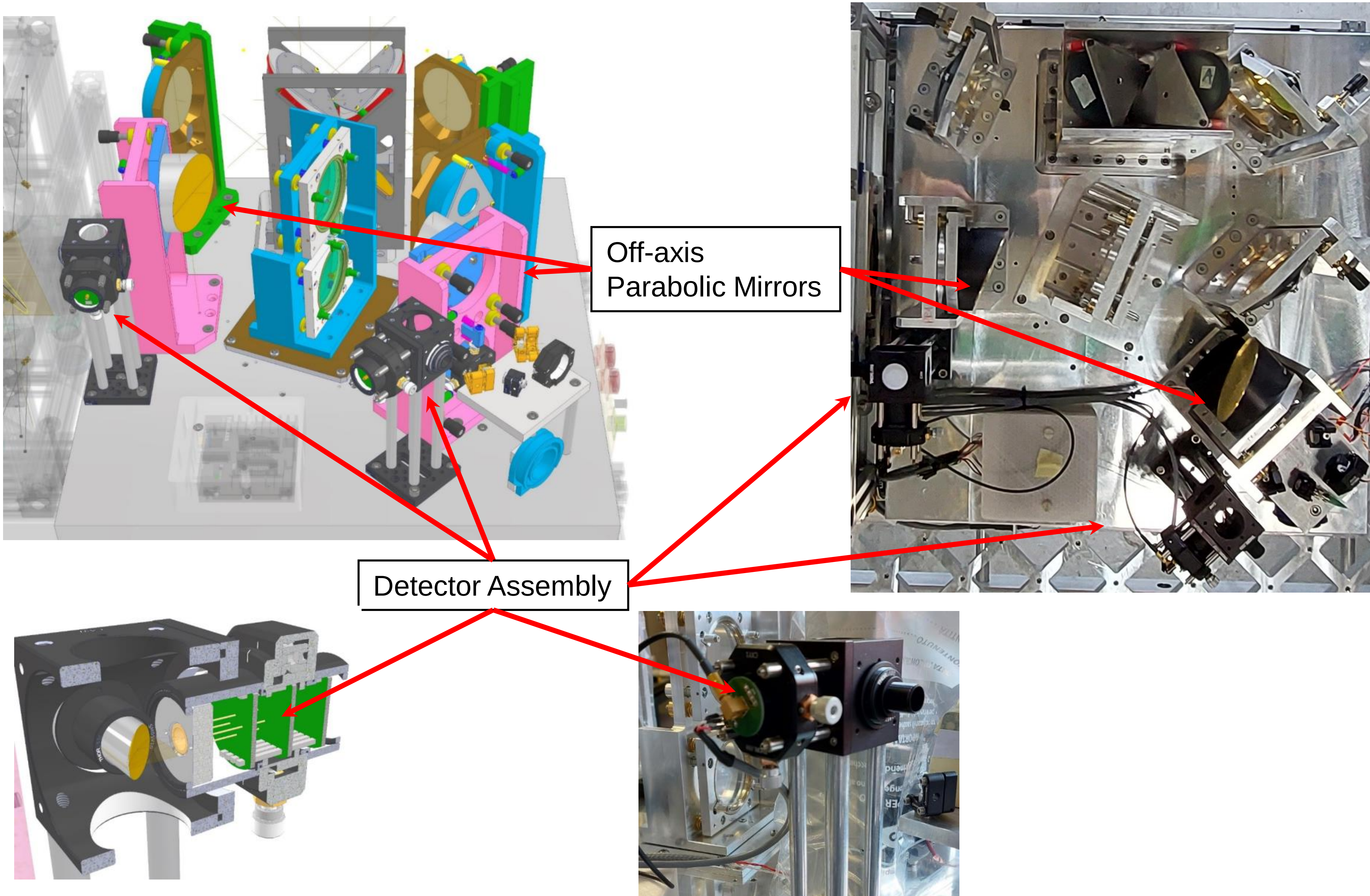




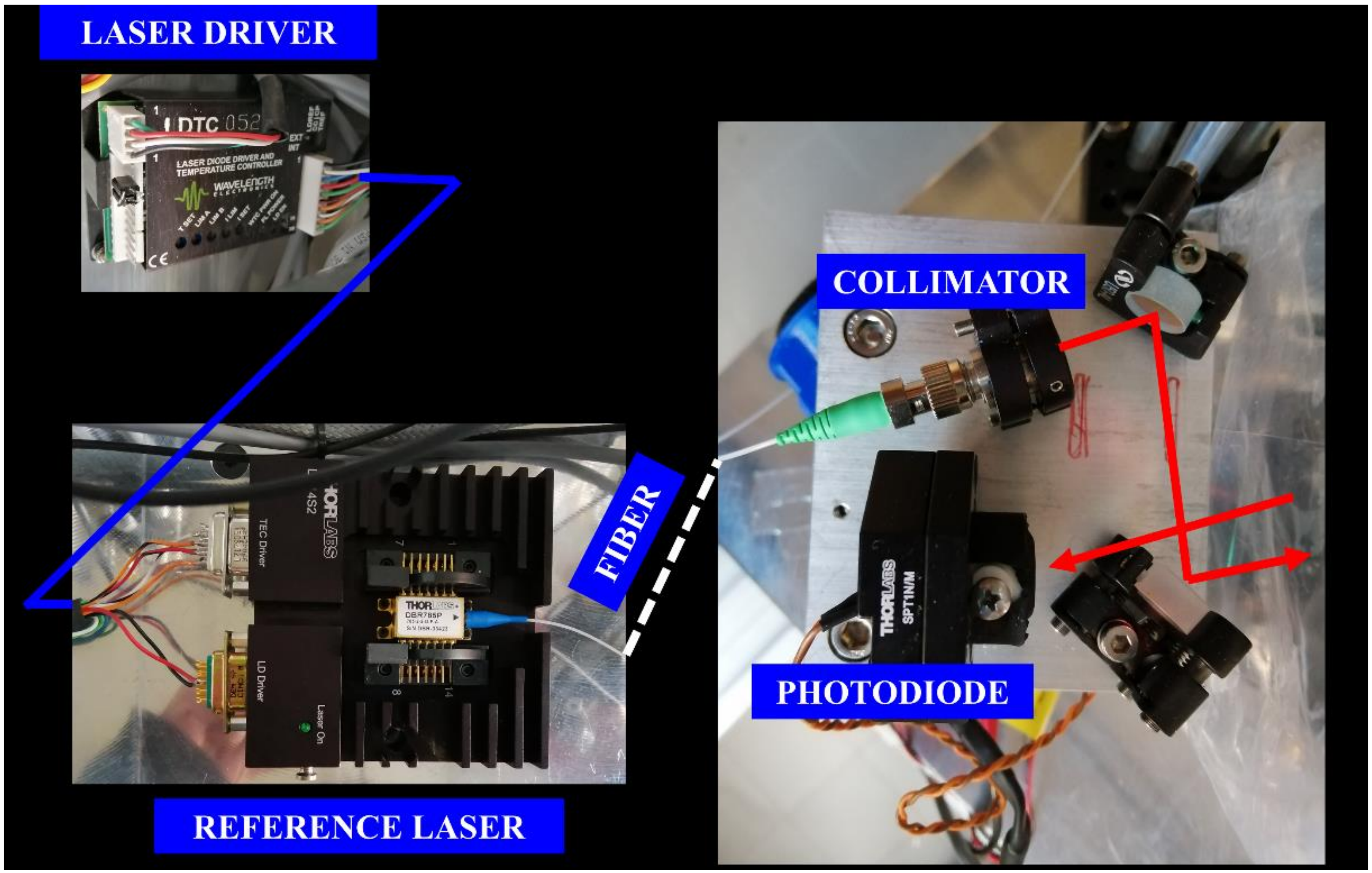
New FIRMOS-B setup:

- Two off-axis parabolic mirrors (f1=305 mm, f2=15 mm)
- Thicker flat mirrors
- Translation stage vacuum compatible
- Pointing mirror mechanism and calibration unit
- Distributed Bragg Reflector (DBR) Single-Frequency reference laser

FIRMOS-B Opto-mechanical Setup



FIRMOS-B reference laser system

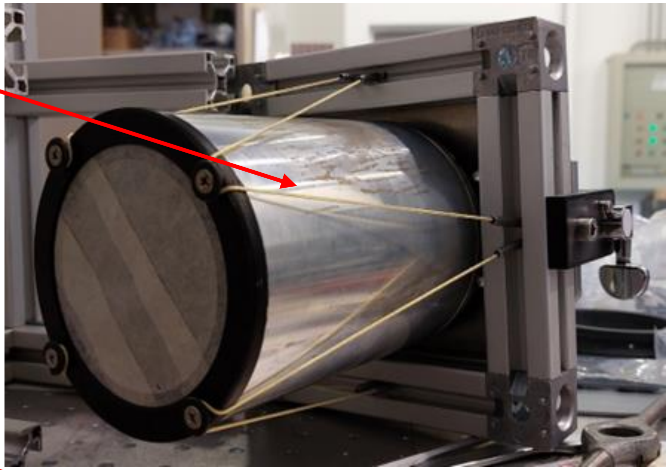


- P=35 mW
- Δv=3 MHz

FIRMOS-B Internal Reference Source Unit

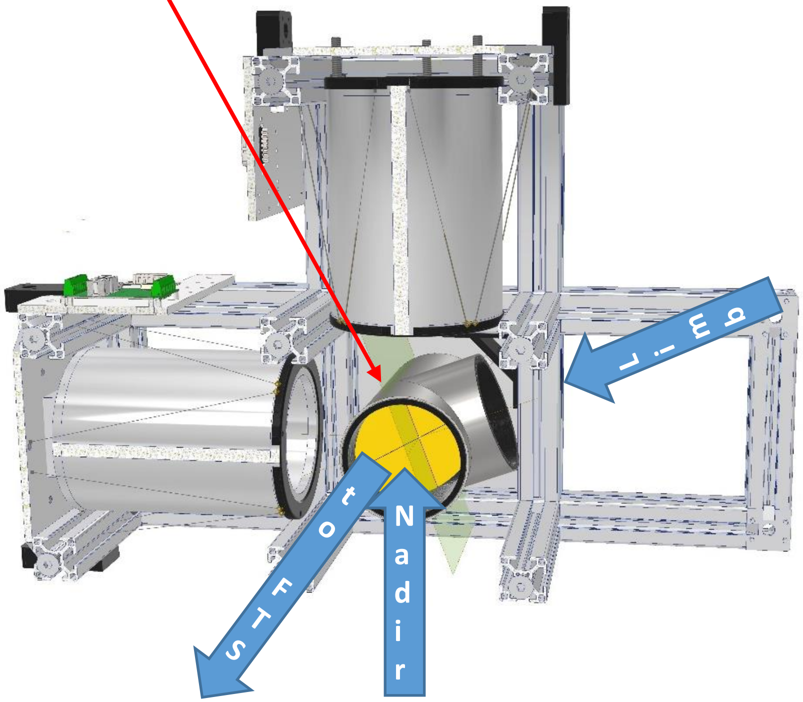
- Nextel Velvet coating 811-21 (ε≈0.98)

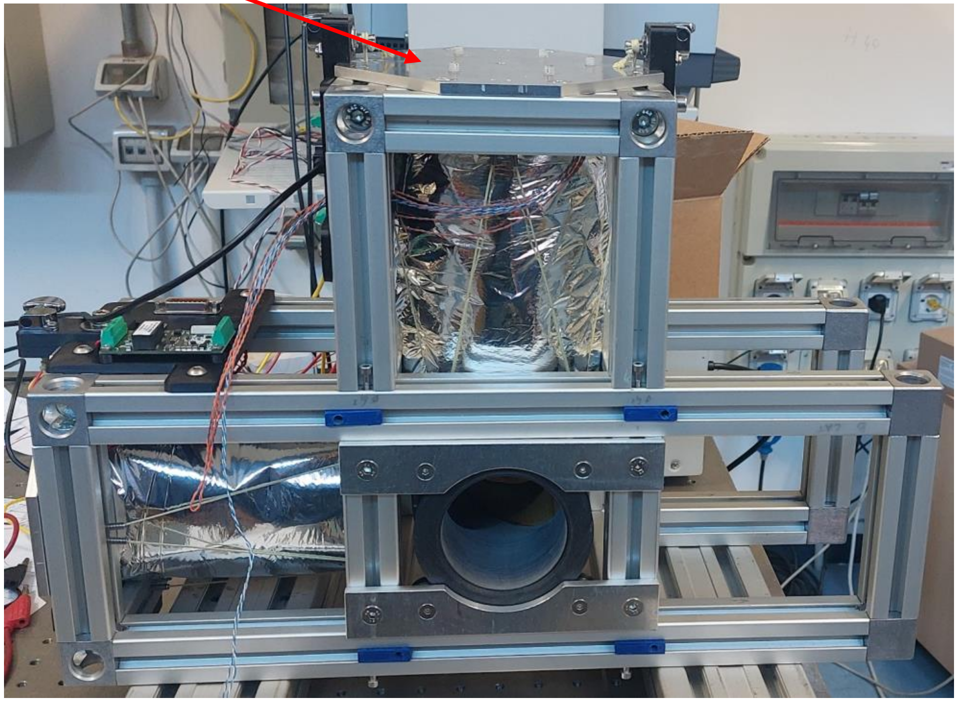
Kevlar threads



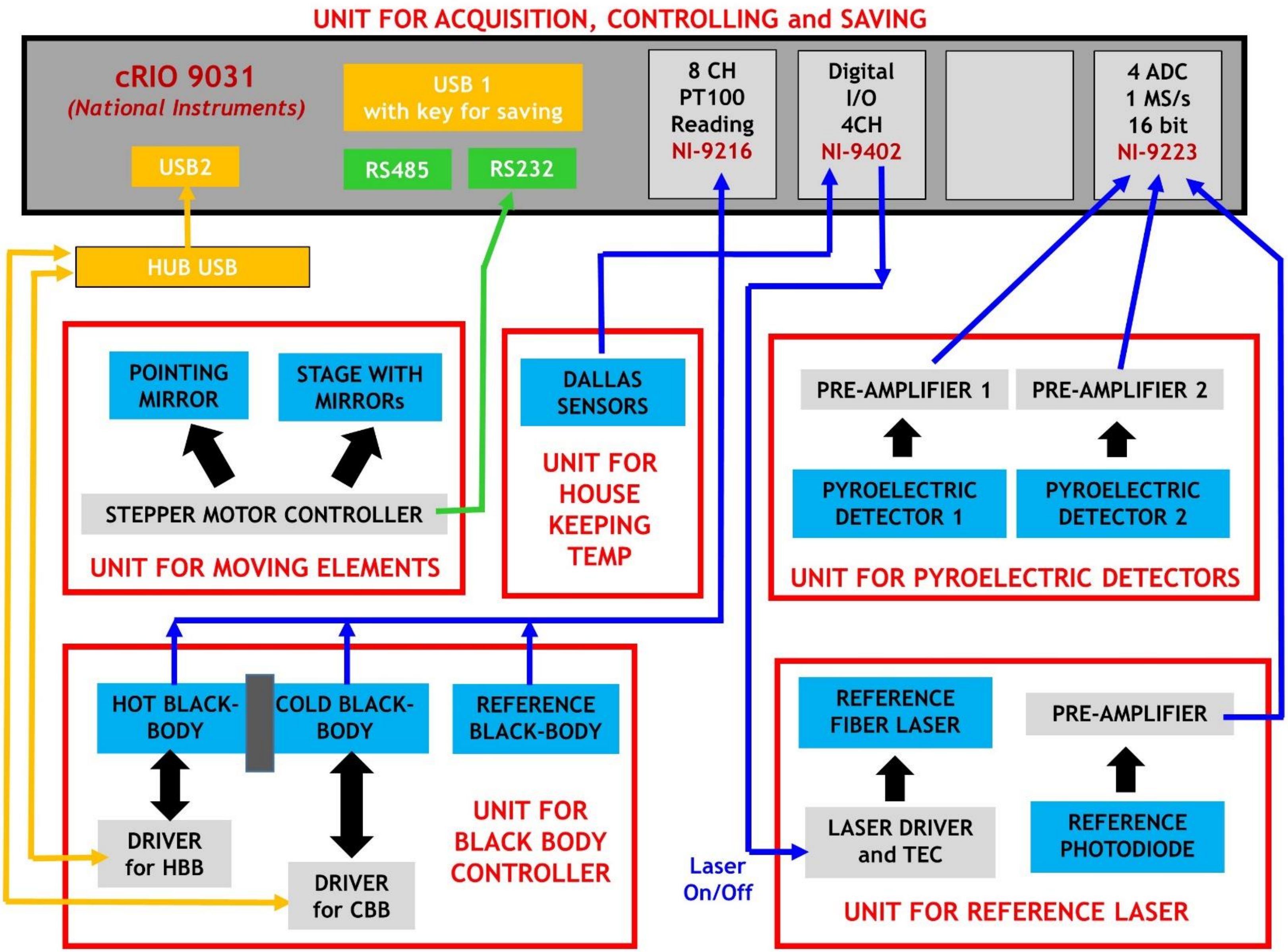
Glass-fiber screws

Rotating Mirror

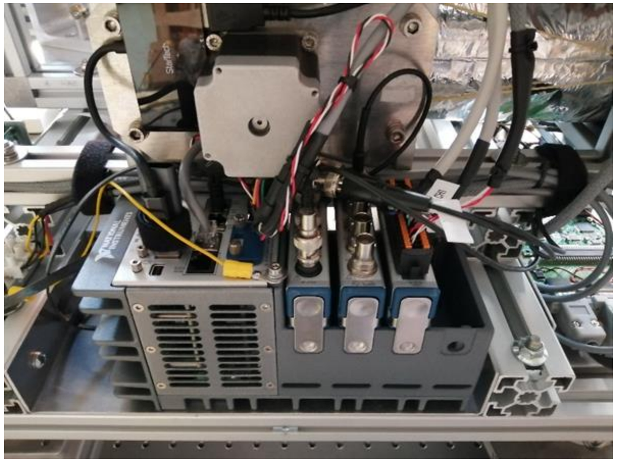




FIRMOS-B Control & Acquisition Architecture



FIRMOS-B Motion and thermal control



cRIO 9031 (National Instruments) controller: 1.33GHz, 1GB RAM, x2 serial, x2 RS485, x2 Ethernet ports, -40 °C to +70 °C

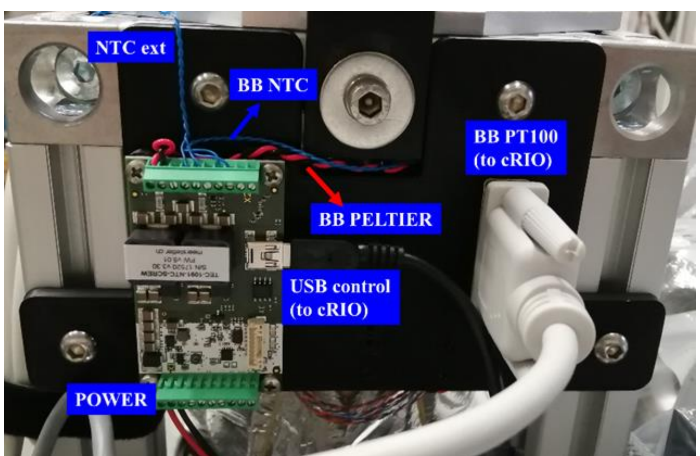
Acquisition Modules:

- ADC module (NI9223), x4 channels (x2 Pyroel., x1 Ref. Laser), 1 MS/s @ 16 bit
- Sensor Acq. (NI9216): x8 channels (PT100: x3 HBB, x3 CBB, x1 RBB, x1 BS)
- Digital I/O (NI9402): x4 channels (x2 LED, x1 Laser Pointer)

Motion control PCB: TMCM-3230 (*Trinamic Motion Control), x3 axis*

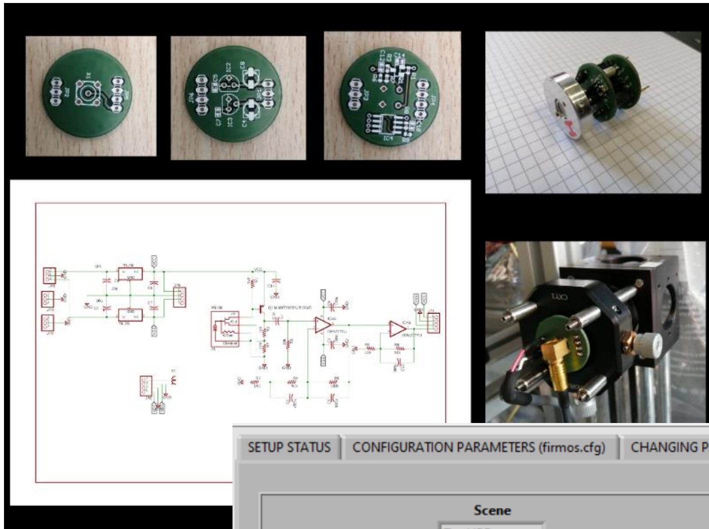
- **Translation Stage:** stepper (2 phase), max. length 25.4 mm, microstep size 0.00467 um, repeatability < 3 um

- **Rotative Mirror:** stepper (2 phase), NEMA23, 1.8°/step



- **HBB/CBB control:** TEC-1091 (*Meerstetter Engineering*), controlled from cRIO via USB. X1 NTC input, x1 for BB, x1 external. Precision < 0.01 °K, with autotuning. Heating&cooling or heating only mode.

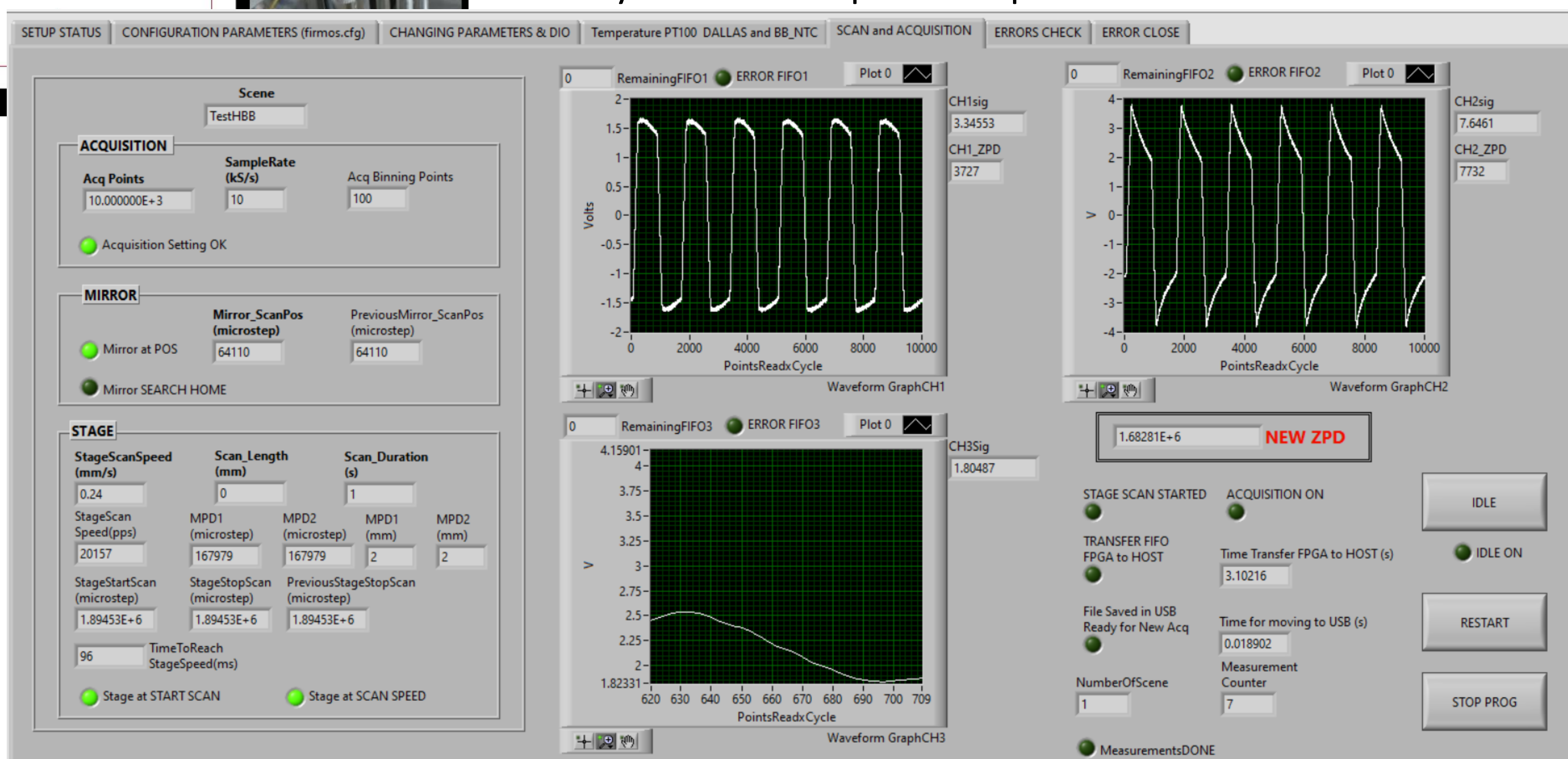
FIRMOS-B pre-flight validation: detectors



New miniaturized PCB for pyroelectric detectors (designed by CNR-INO electronics workshop)

Labview GUI developed for acquisition, monitoring and control of FIRMOS-B.

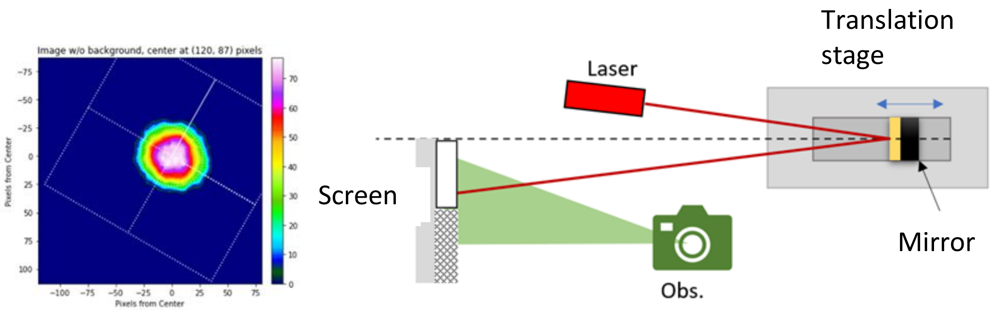
- Pyroelectric response step test:



FIRMOS-B pre-flight validation: motion control

Translation stage:

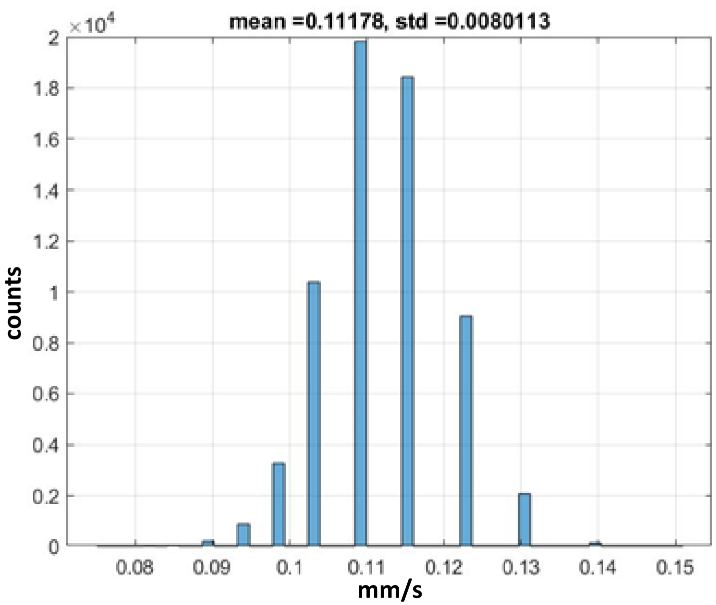
- motion validation: pitch/roll/yaw:

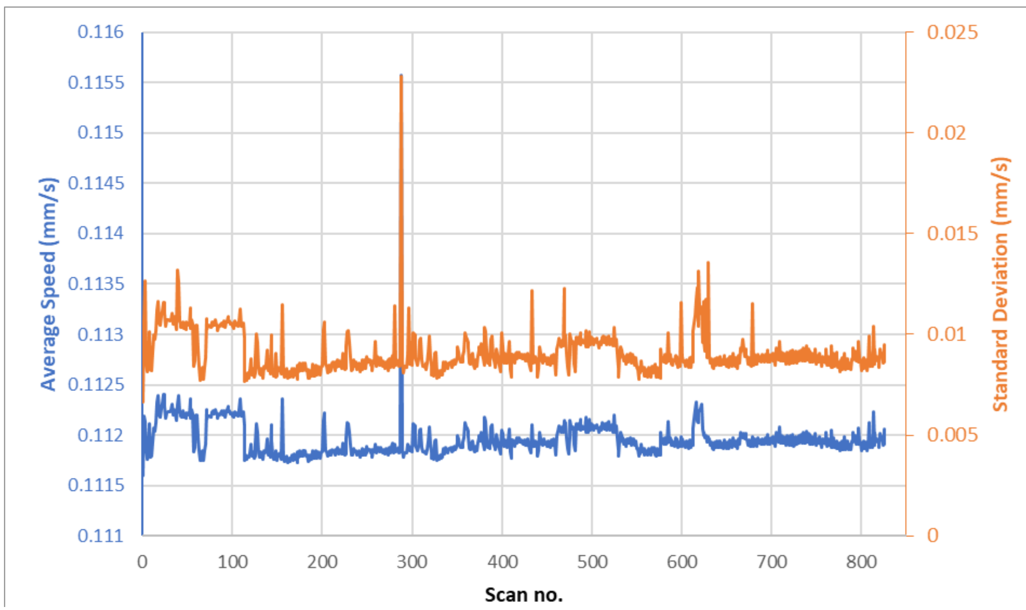


Max. Peak to Valley Error (mrad)			
Coord.	// beam	Coord.	⊥ beam
X (yaw)	0.16	X (yaw)	N/A
Y (pitch)	0.18	Y (roll)	0.30
	// beam+mir.		⊥ beam + mir.
X (yaw)	0.16	X (yaw)	0.36
Y (pitch)	0.29	Y (roll)	0.23

* Zaber stage spec.: < 35 mrad

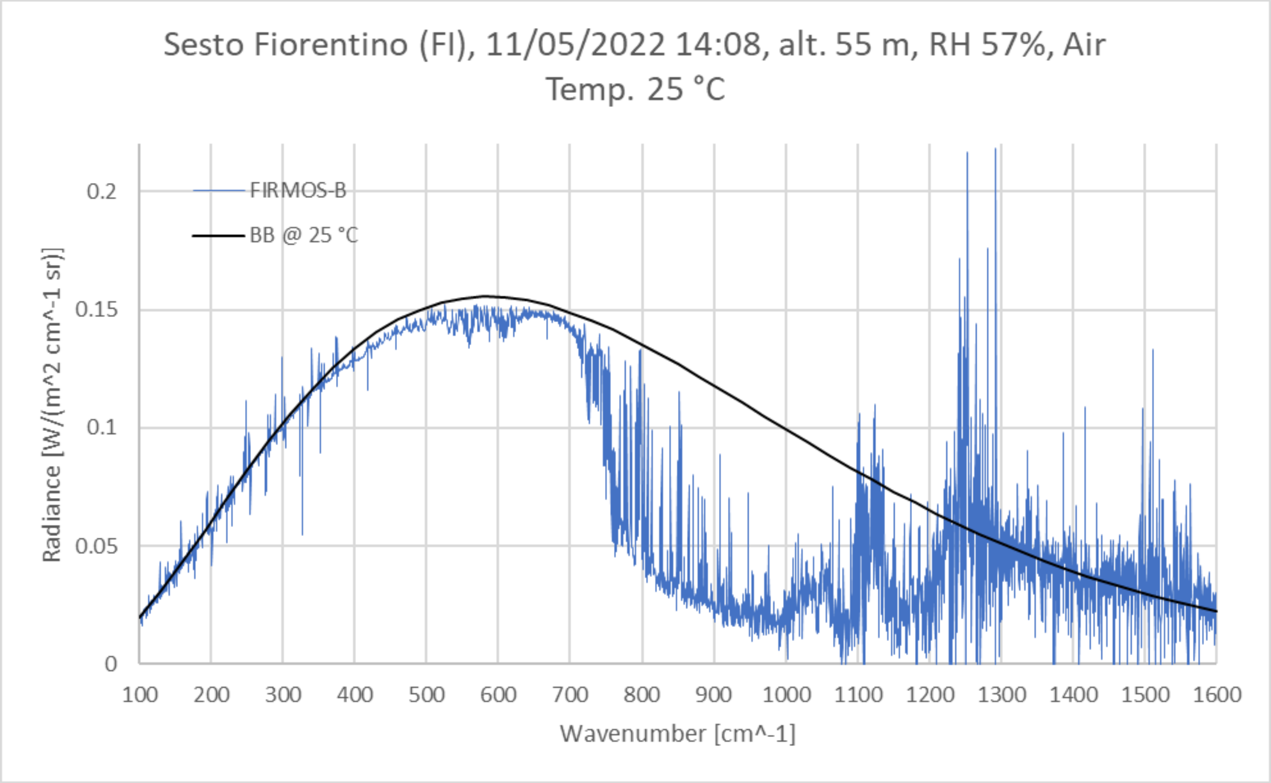
- Analysis of speed statistics from interferogram:



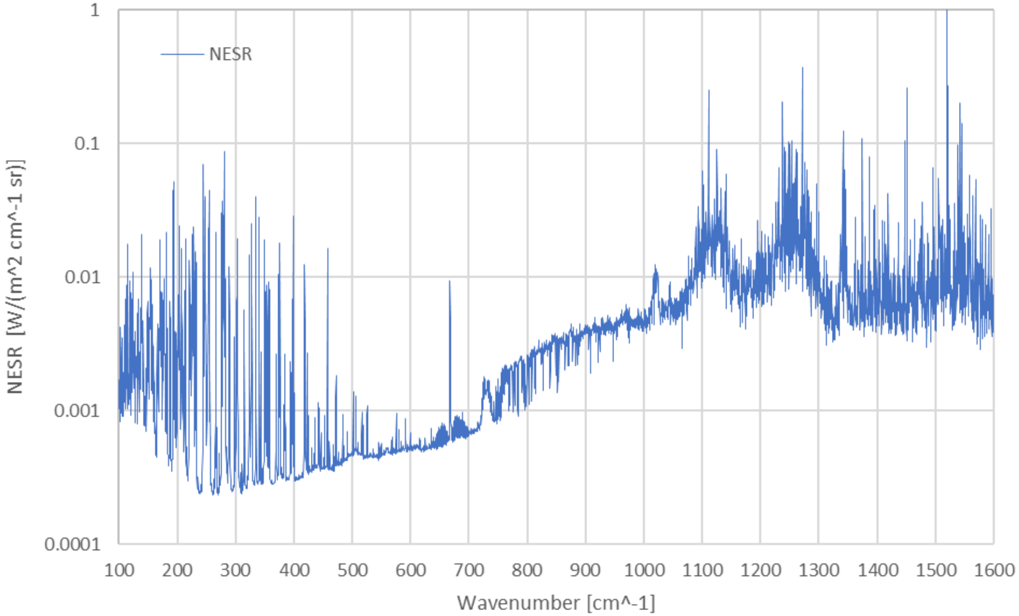


FIRMOS-B pre-flight validation: measurement

- ΔOPL=+/- 12 mm
- Resolution: Δv=0.4 cm^-1
- Scan Speed= 0.11 mm/s
- Interf. Max/min freq.= 4.4-66 Hz
- Sampling Freq. = 20 KS/s

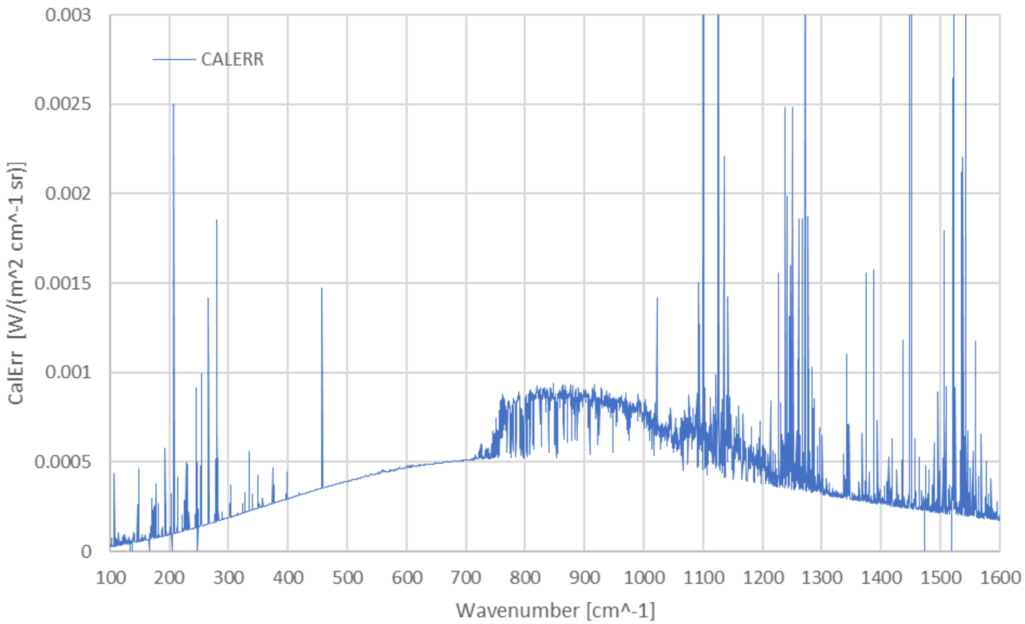


FIRMOS-B pre-flight validation: measurement



$$L(\sigma) = \Re\left\{\frac{S(\sigma)}{F1(\sigma)} + \frac{F2(\sigma)}{F1(\sigma)} B_r(\sigma)\right\}$$

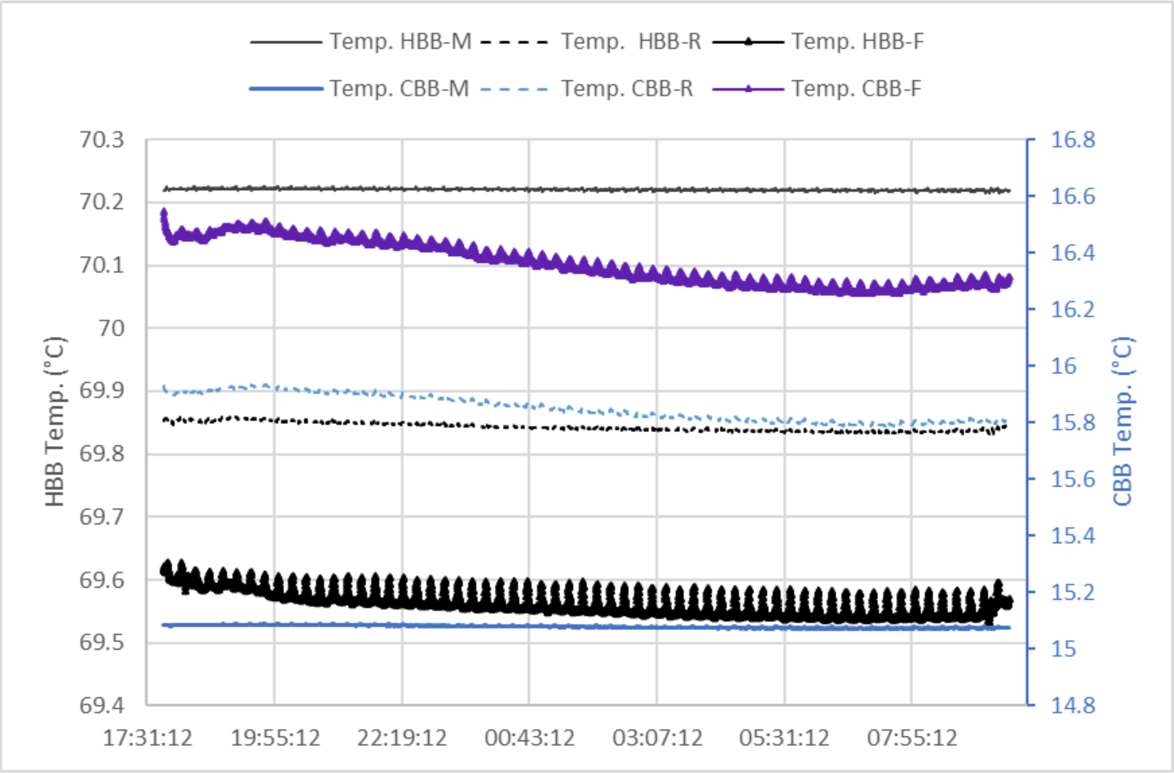
$$\mathrm{NESR} = \sqrt{\frac{1}{N} + \frac{2}{n}\left(\frac{S}{S_h - S_c}\right)^2} \frac{\Delta S}{F1}$$

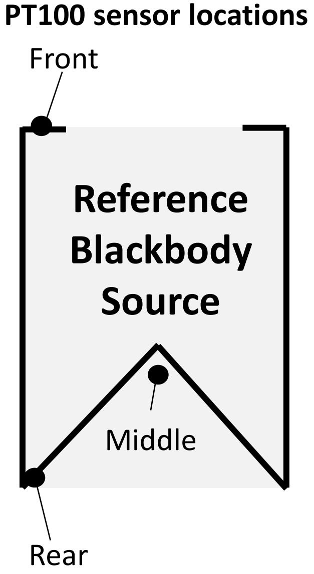


$$CalErr = \sqrt{\Delta B_r{}^2 + \left(\frac{S}{S_h - S_c}\right)^2 (\Delta B_h{}^2 + \Delta B_c{}^2)}$$

FIRMOS-B pre-flight validation: environmental

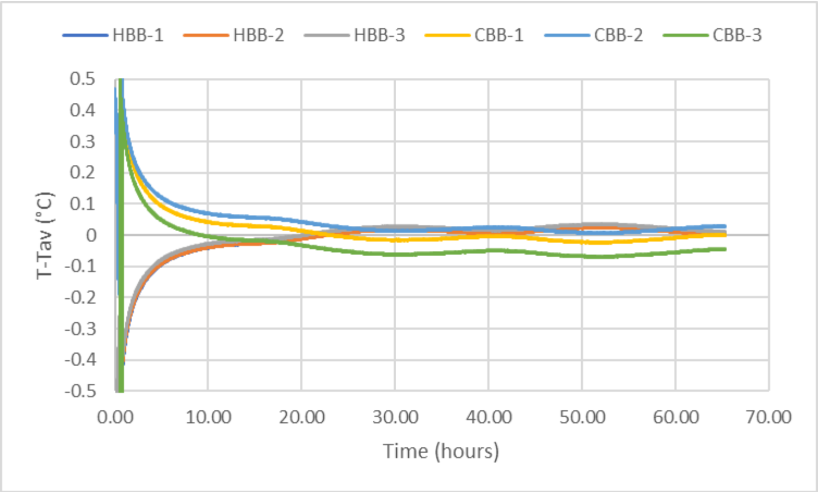
- Internal reference sources stability over 15 hours (box open):
  - T_set_HBB=70 °C
  - T_set_CBB=15 °C





FIRMOS-B pre-flight validation: environmental

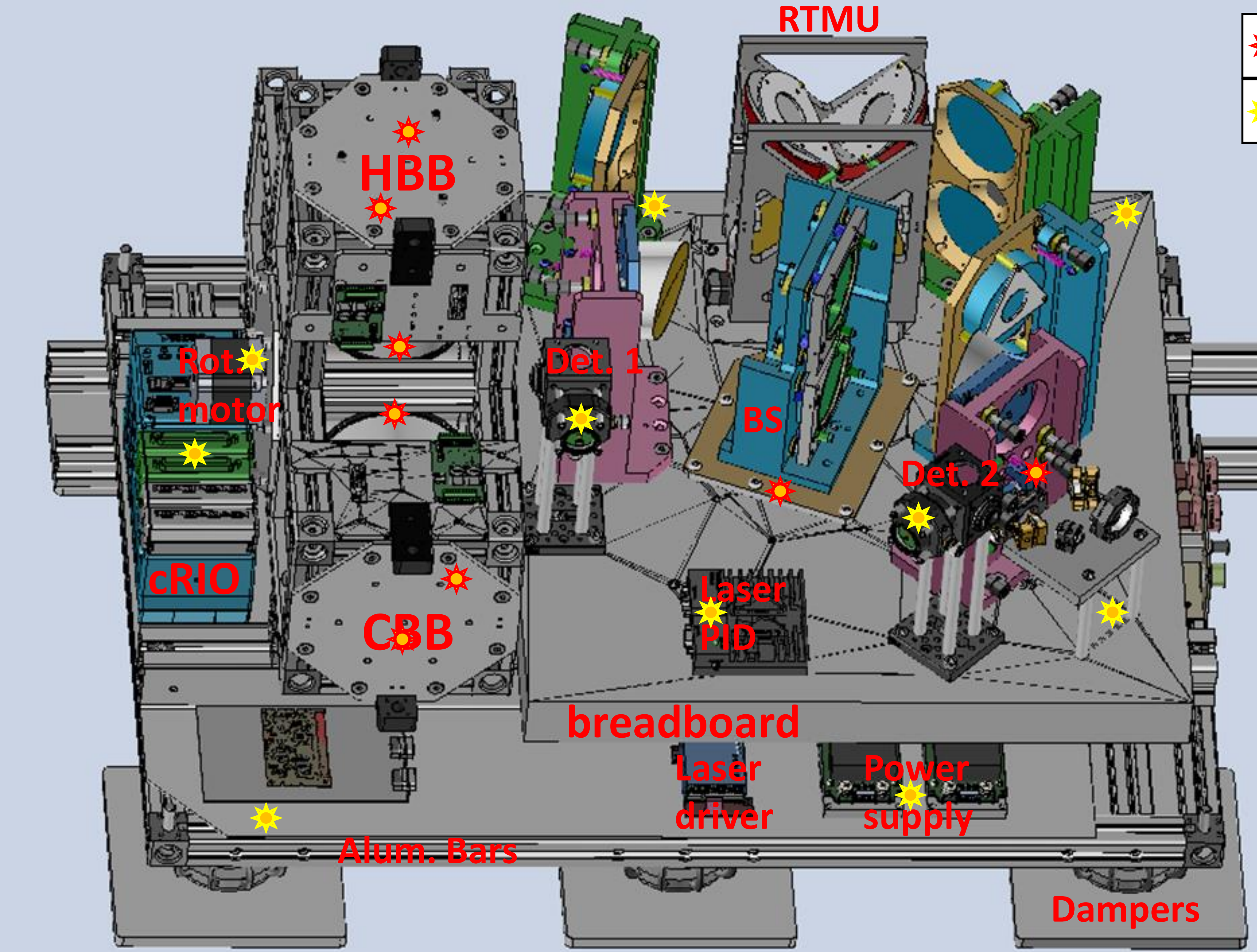
- Blackbodies PT100 sensors readings validation within thermally isolated box



- cRIO and Calibration Unit validation under flight pressure conditions.

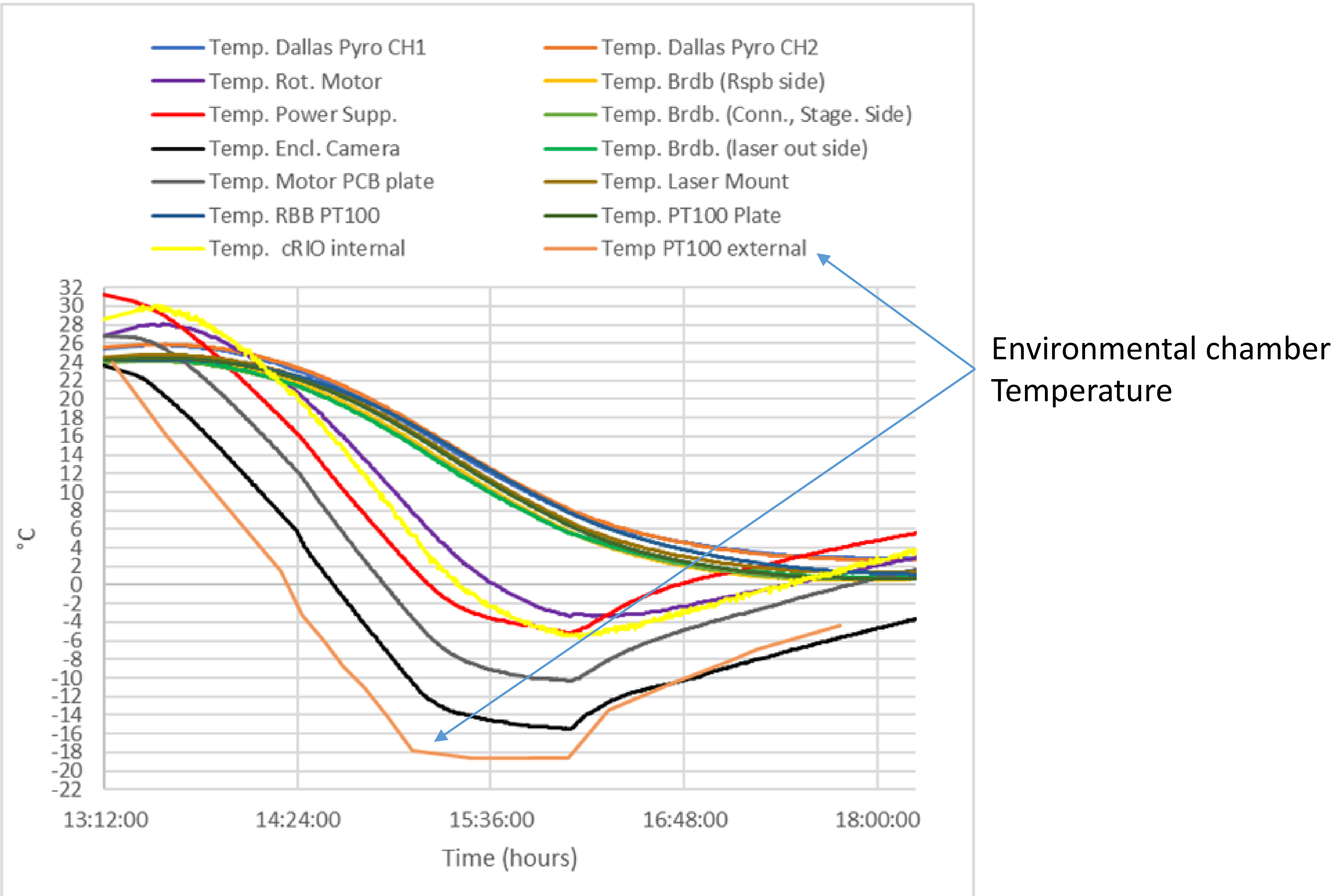
- Around 10 W reduction in power consumption observed when pressure is reduced to 3 mBar

FIRMOS-B housekeepings

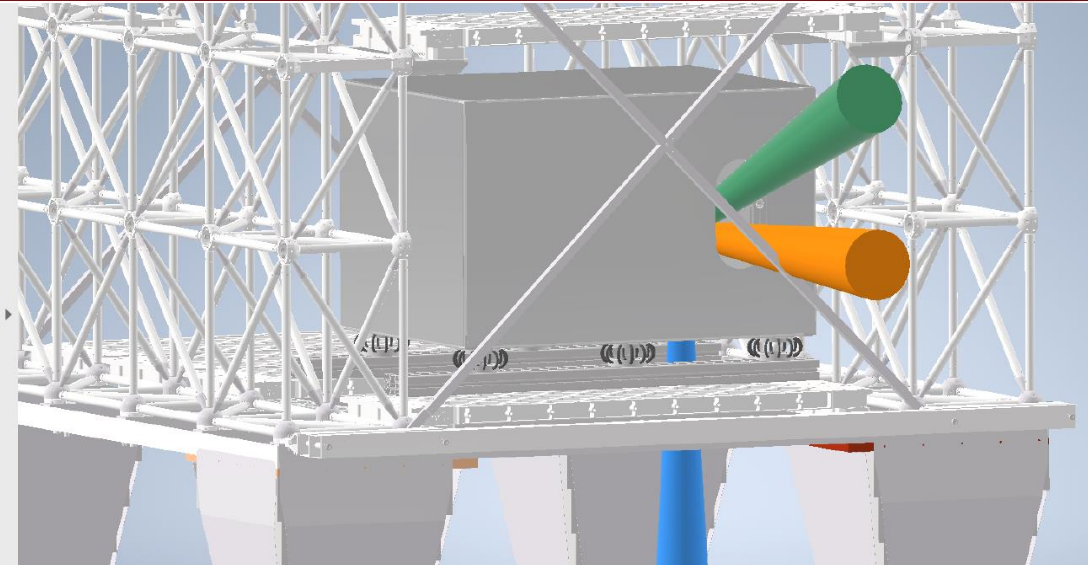


FIRMOS-B pre-flight validation: environmental

- Temperature monitoring within environmental chamber (25° to -20 °C)



Thermal Modelling of FIRMOS-B during flight



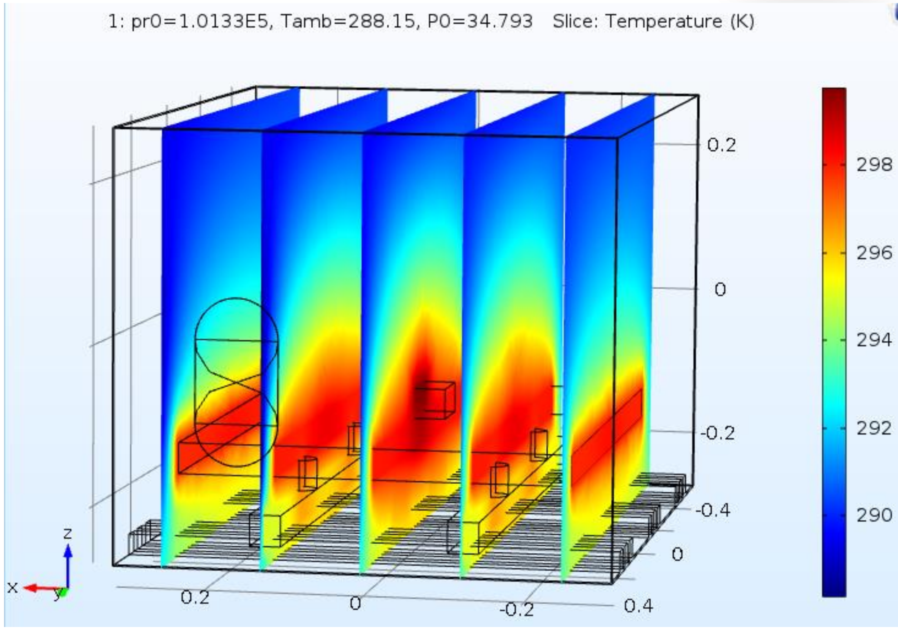
FIRMOS-B thermal problem initial simplification:

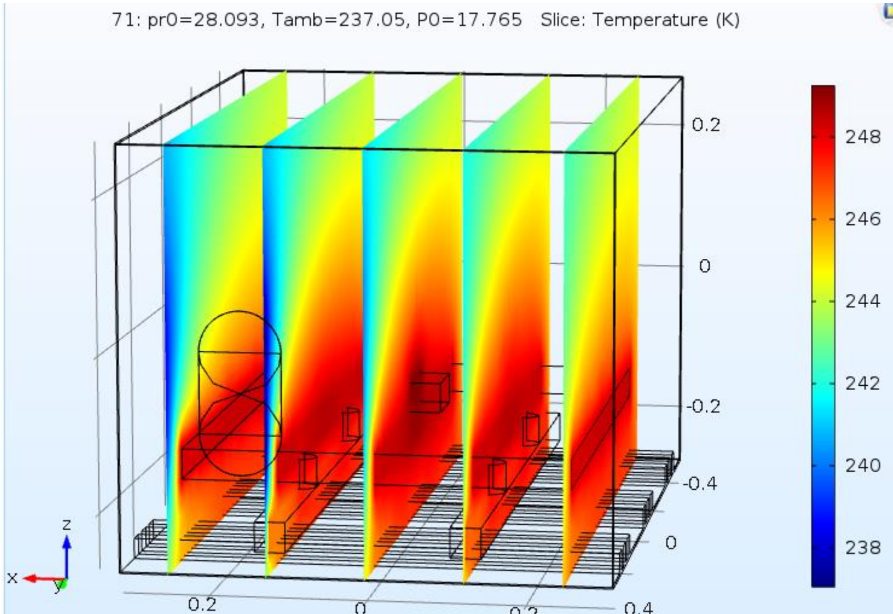
- **Sources**: electronics, blackbodies. **Sinks**: outside air, gondola
- Perfect contacts between materials
- Overnight flight and no irradiance from gondola
- Constant power dissipated from electronics (except blackbodies)
- No wind (irrelevant above 13000 m)
- Gondola as an ideal sink/source
- Discarded internal air convection (at high altitude)
- Empirically modelled objects: superinsulation, damper springs
- Omitted objects: a) optics and their mounts, b) superinsulation BBs, c) breadboard internal box
- Simplified geometry objects: a) Aluminium bars, b) breadboard, c) BBs assembly, f) cables
- Emissivity= 0.1 for all materials <u>except</u> rods below breadboard, superinsulation and BBs

Stationary state calculations

Preliminary calculation: steady state

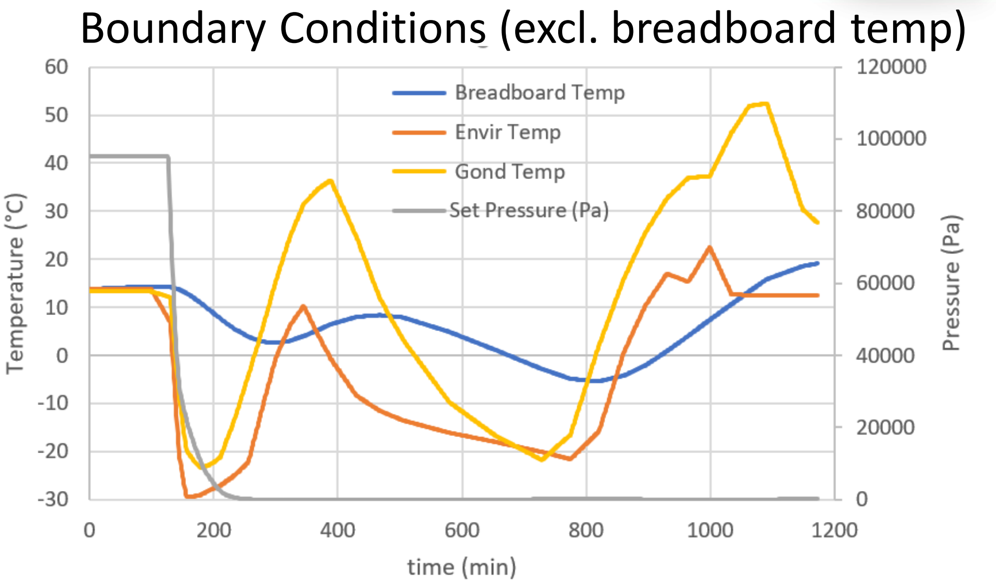
- <u>Isolated instrument, no gondola</u>
- External box dimention as actual instrument, all other geometries are approximated
- No superinsulation on enclosure
- All surfaces are radiating (except the opening)
- The opening is a heat sink (T=Tamb)
- Separate calculation to derive BBs emitted power (BBs have no superinsulation)

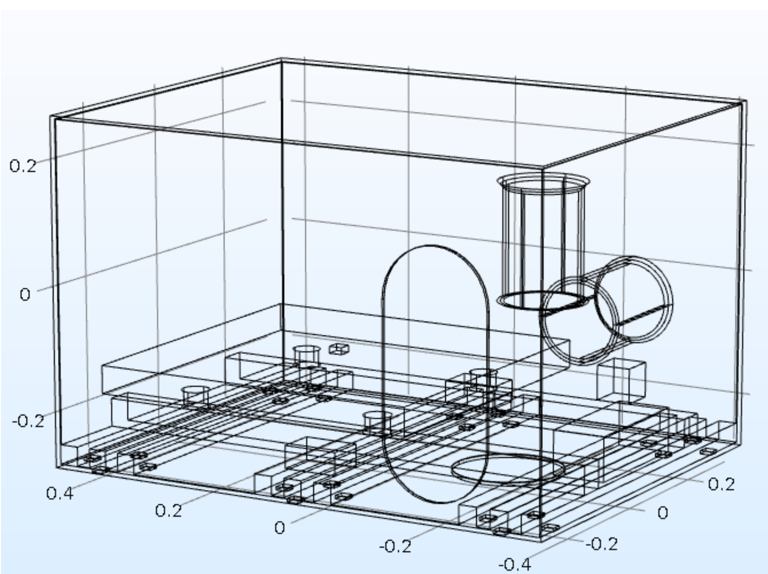


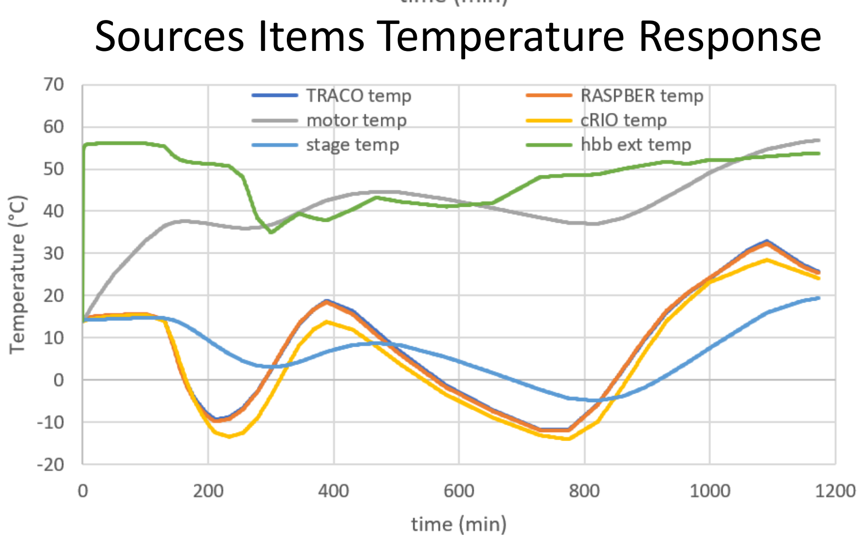


Time resolved calculations

- Real Dimensions (still some approx. geom.)
- Separately derived material properties: superinsulation (10 layer, 0.5 mm, k1D≈0.022-0.0257 W/m °K) and damper springs (k1D≈3.2- W/m °K).
- Fixed BBs temperature (with superinsulation, ε=1 internally)
- Pressure, Tamb e Tgond change with time (fron HEMERA- Kiruna-2021 flight).
- Fixed dissipated power (excluding BBs)







Summary

- FIRMOS-B is a FT spectrometer operating in the MID-FIR (100-1600 cm^-1)
- Calibrated radiance measurement (x3 BBs), < 0.3 °K accuracy
- Pyroelectric detectors technology, and DBR fiber reference Laser
- HEMERA-2022 stratospheric balloon campaign: Timmins (ON), August 2022 (first test flight for FIRMOS-B)

FIRMOS-B was supported by:

Agenzia Spaziale Italiana

ASI contract "FORUM scienza" for supporting the Italian national scientific community working on the FORUM mission, 2019 – to date.

ESA FIRMOS (Technical Assistance for a Far-Infrared Radiation Mobile Observation System) Project, ESA Contract No. 4000123691/18/NL/LF, 2018-2020.

HEMERA H2020 V2 Program for integrated access to balloon-borne platforms for innovative research and technology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