In-field absolute temperature calibration of a reference blackbody infrared source using phase transition cells

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Introduction

To ensure accurate radiometry in infrared remote Earth observation systems, it is essential not only to perform a precise calibration of the reference sources (**B**lack **B**ody) but also to reliably maintain this calibration over the entire mission lifetime.

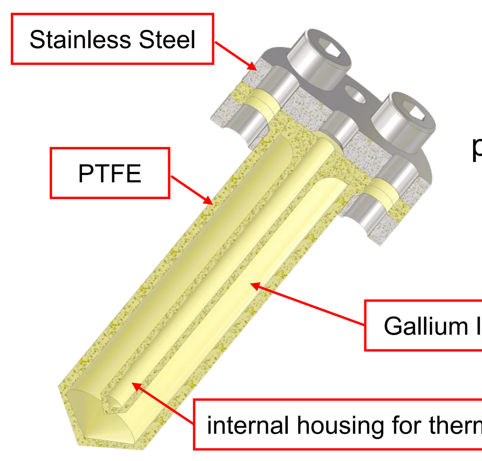
We present the design and a preliminary characterization of a compact modular **BB** infrared source prototype, which integrates a temperature control, a cavity temperature uniformity assessment and a SI-traceable re-calibration capabilities of the temperature sensors.

This activity was carried out within the **FORUM-Balloon** project, funded by the Italian Space Agency (**ASI**) and involving the participation of the National Institute for Metrological Research (**INRiM**). The project aimed at developing a new FTS spectrometer for use in balloon-borne remote sensing campaigns.

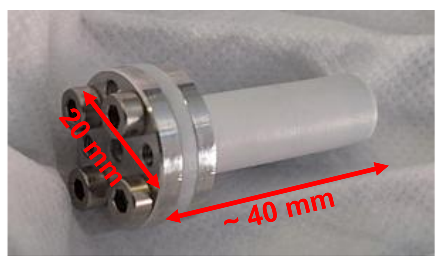
Mini Gallium phase-change cell

Miniature gallium fixed-point cells are widely used as temperature standards.

Due to their near-ambient transition temperature (29.7646 °C), they are employed in a variety of applications for accurate in situ calibration of thermometers traceable to the International System of Units.

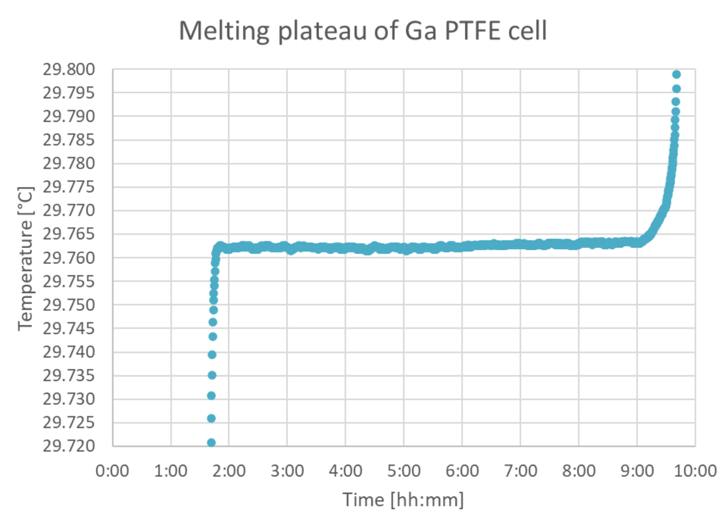


Miniaturized Ga phase-change cell



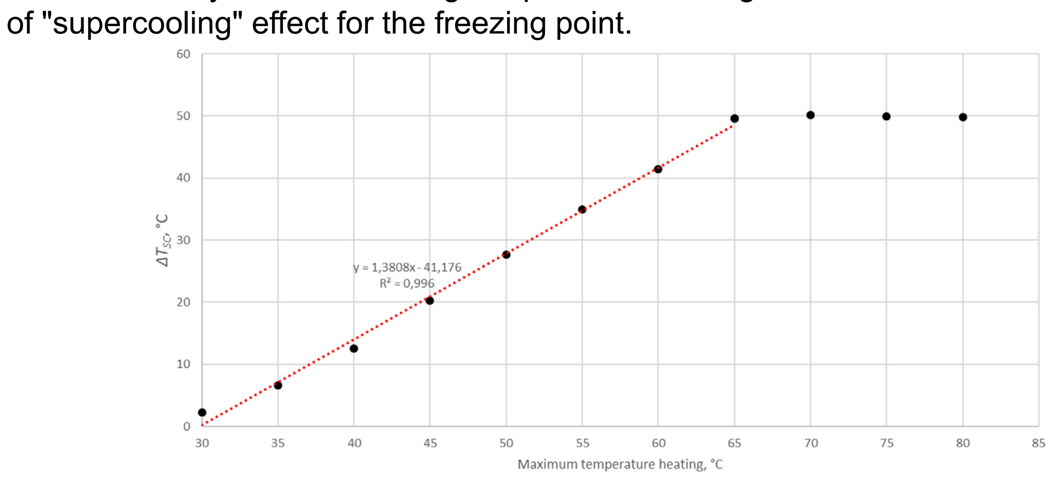
All the parts of the cell such as the container, the lid, and the thermometric well, were made of PTFE.

The cell configuration, for materials and geometry, was very similar to conventional ITS-90 primary standard fixed-point cells.



Typical melting plateau of gallium, recorded with a PT100 thermometer inside the housing of the PTFE cell.

Thermal history: the overheating temperature of the gallium cell influences the degree of "supercooling" effect for the freezing point.



Supercooling (ΔT_{SC}) in function of maximum temperature of Ga cell heating (T_{max})

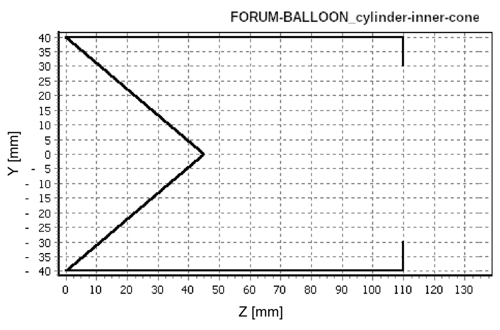
From: Lopardo, G., Bertiglia, F., Braccialarghe, G., Florio, M., Girard, F., Giraudi, D. and Santoro, F. (2025), Supercooling Effect in Miniature Gallium Phase Transition Cell. Adv. Eng. Mater., 27: 2402763. https://doi.org/10.1002/adem.202402763.

Opto-mechanical and radiometric aspects

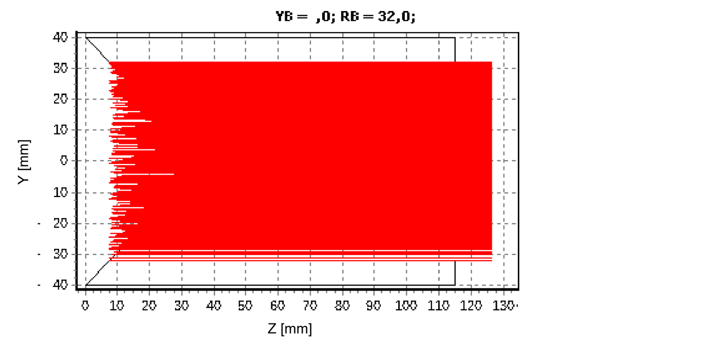
The design of the new **BB** was based on the optomechanical layout of the FIRMOS-B calibration sources, adapting them to the different requirements of the new ***FORUM-Balloon*** spectrometer.

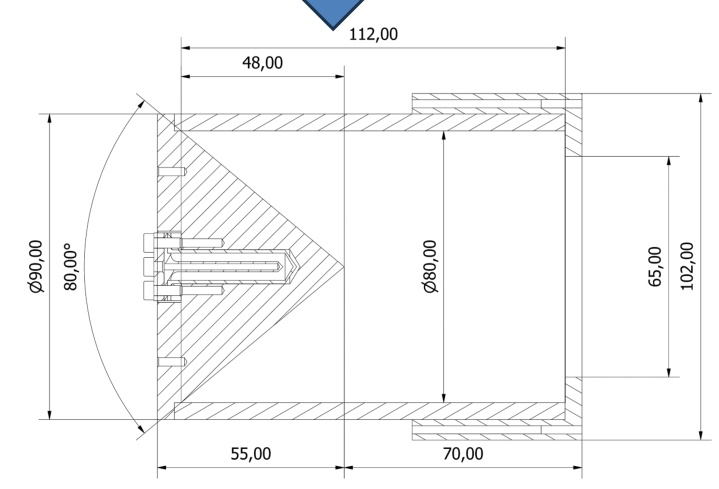
Constrains:

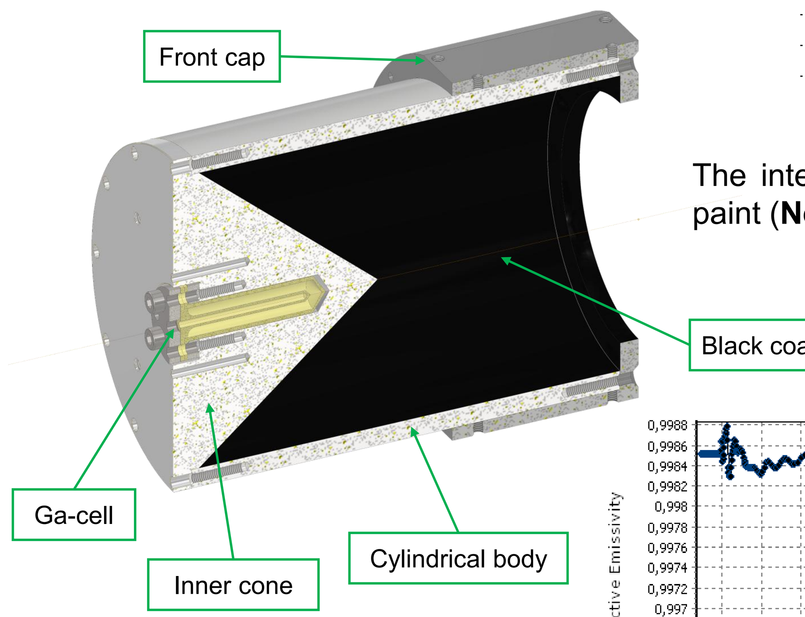
- more compact and lightweight;
- output aperture ≥ 60 mm;
- high effective spectral emissivity;
- inside housing for the Ga phase-change cell.
- “Interchangeable” function: HOT/COLD **BB**



A simplified ray-tracing model was used to find the most efficient geometry that maximize the number of the internal reflections.



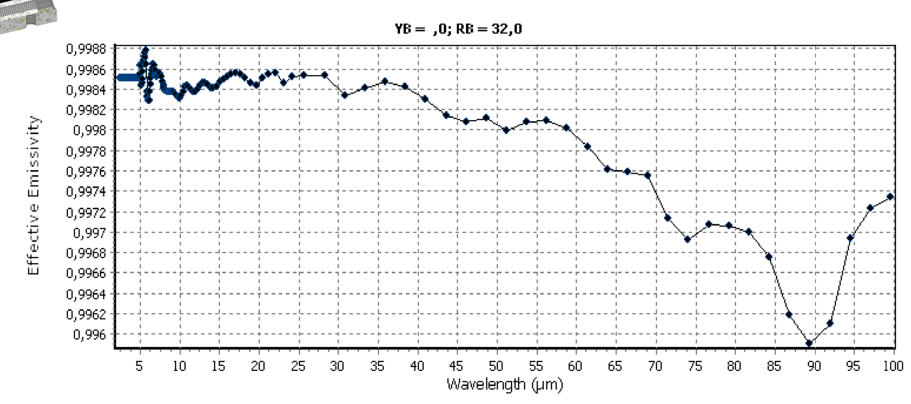




The internal surface has been blacked with a special paint (**Nextel Black Velvet-Coating 811-21**)

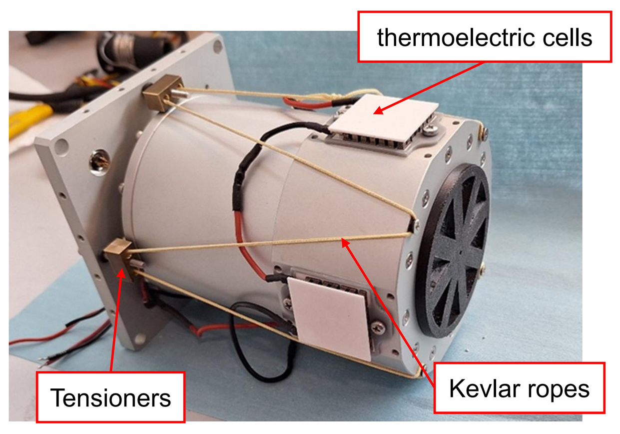
BB cavity specifications:

- material: AL6063
- inner cone with phase change cell housing;
- cylindrical body, 5 mm wall thickness;
- front cap with output aperture;
- total mass < 1 Kg
- estimated emissivity ≥ 0.996 (5 ÷ 100 μm)



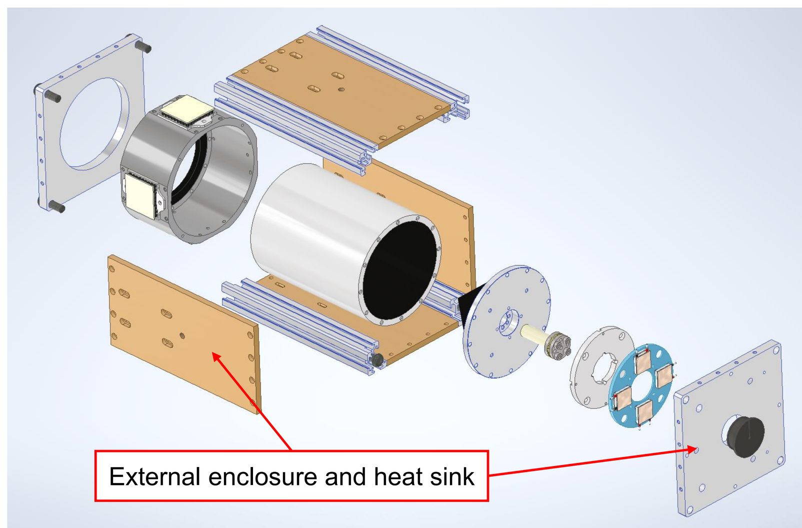
Estimation of the spectral emissivity of the designed BB cavity.

Thermo-mechanical aspects and BB assembly

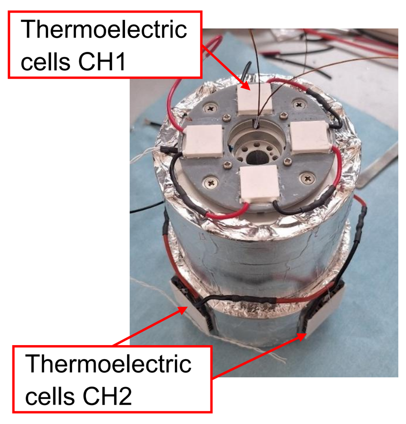


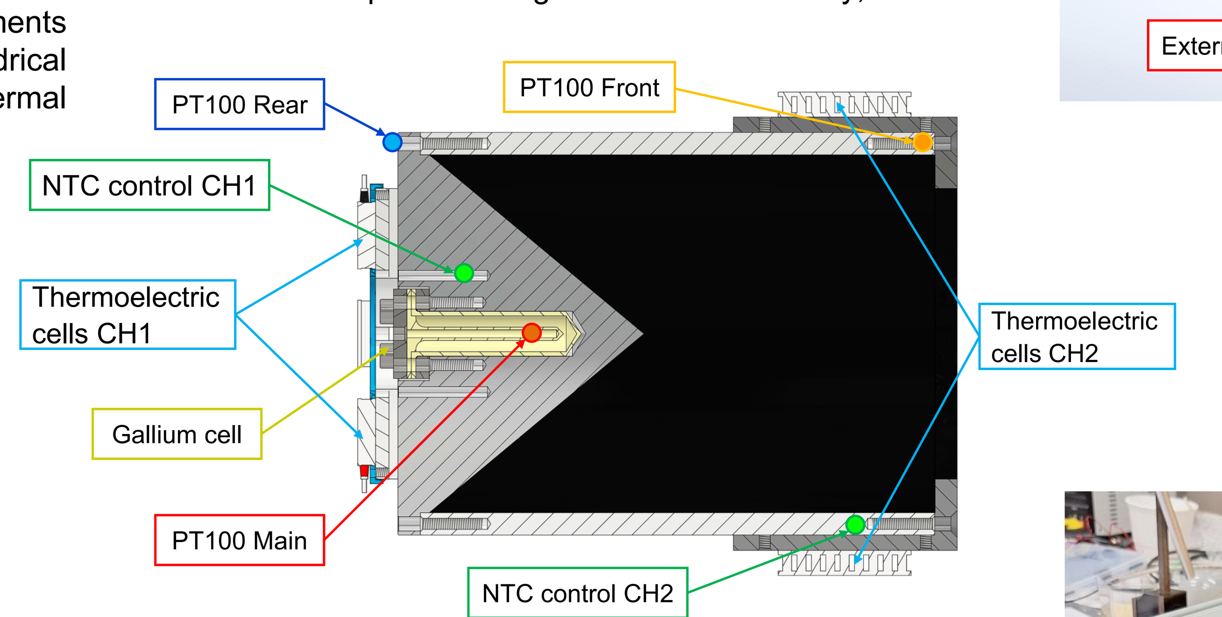
Main features:

- BB cavity “suspended” by 8 Kevlar ropes;
- thermal isolation with multilayer of aluminium/mylar foils;
- 2 independent groups of thermoelectric heating/cooling elements;
- 2 NTC control sensors;
- 3 PT100 thermometers for temperature monitor;
- modular layout: HOT/COLD **BB** function;
- Ga phase-change cell inside the cavity;

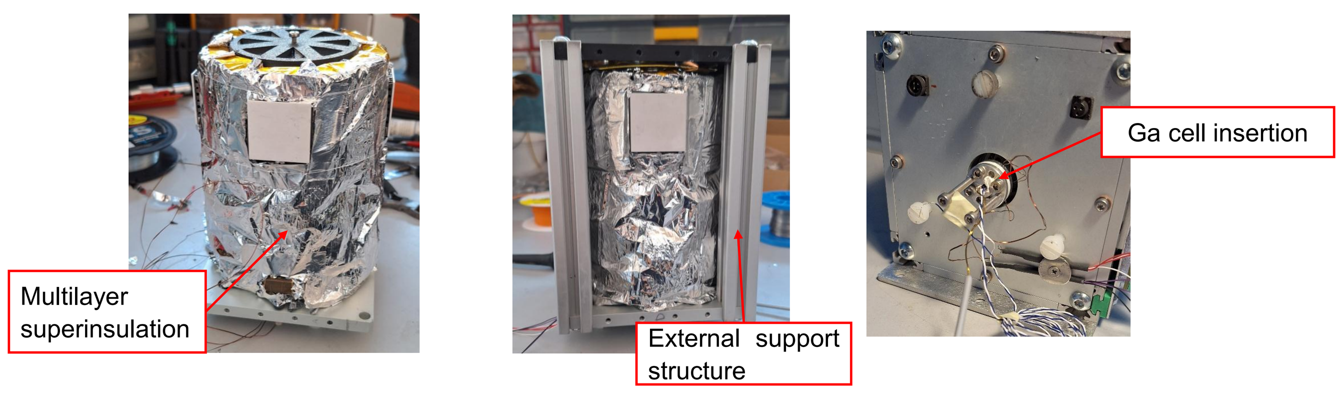


The heating/cooling elements are distributed in cylindrical symmetry to reduce the thermal gradients of the BB cavity.

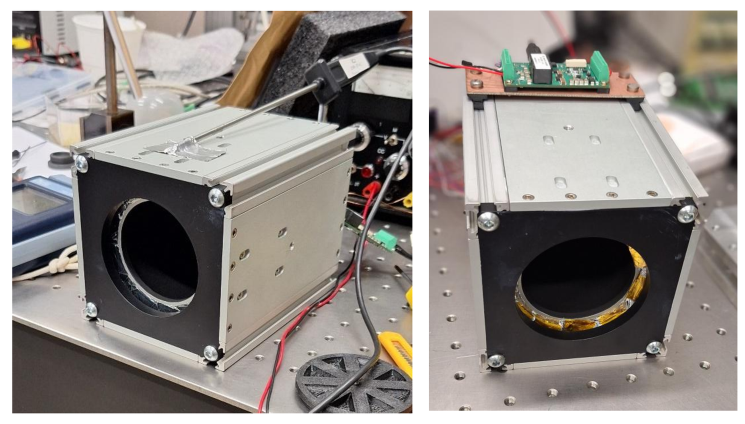




The position of each temperature monitoring sensor (PT100) and NTC temperature control sensors has been carefully chosen to control and minimizes residual temperature gradients during cavity operation.



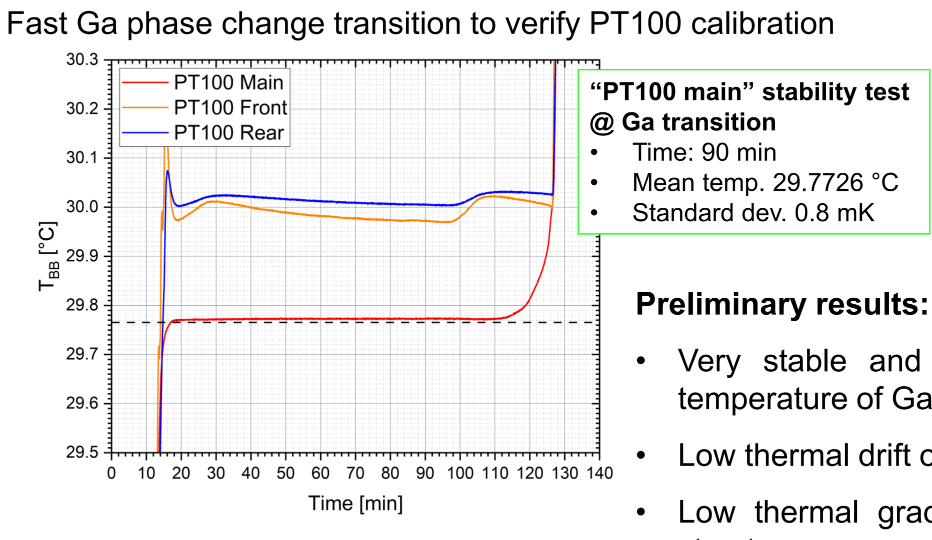
Assembly phase of the BB calibration source



The first assembled BB calibration source

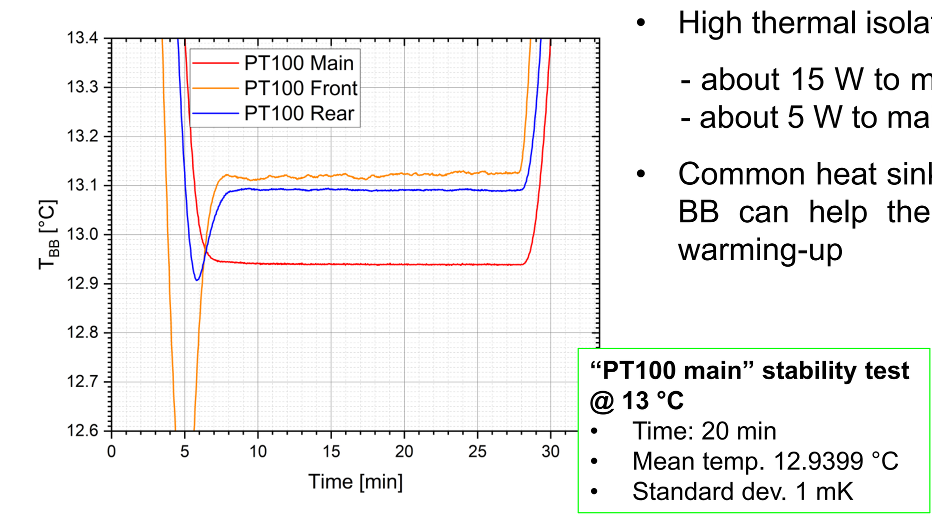
Results of preliminary tests and integration

Fast Ga phase change transition to verify PT100 calibration



“PT100 main” stability test @ Ga transition

- Time: 90 min
- Mean temp. 29.7726 °C
- Standard dev. 0.8 mK



“PT100 main” stability test @ 13 °C

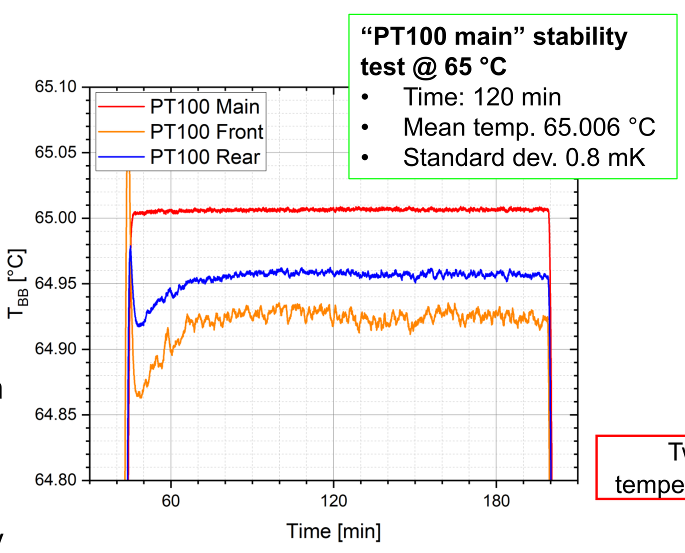
- Time: 20 min
- Mean temp. 12.9399 °C
- Standard dev. 1 mK

Preliminary results:

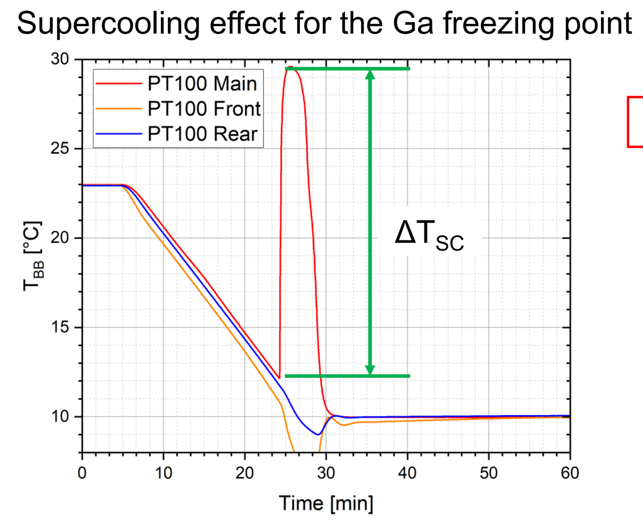
- Very stable and reproducible transition temperature of Ga-cell.
- Low thermal drift of each thermometers.
- Low thermal gradients within the cavity structure.
- High thermal isolation:
  - about 15 W to maintain the BB @ 65 °C
  - about 5 W to maintain the BB @ 13 °C
- Common heat sink between Hot and Cold BB can help the dissipation during the warming-up

“PT100 main” stability test @ 65 °C

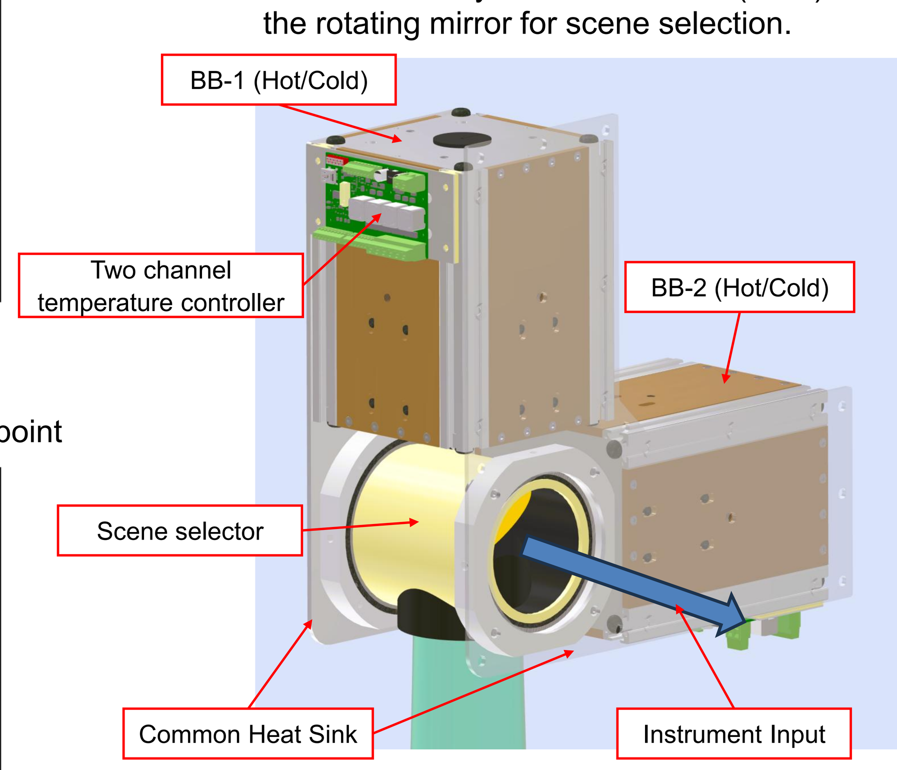
- Time: 120 min
- Mean temp. 65.006 °C
- Standard dev. 0.8 mK



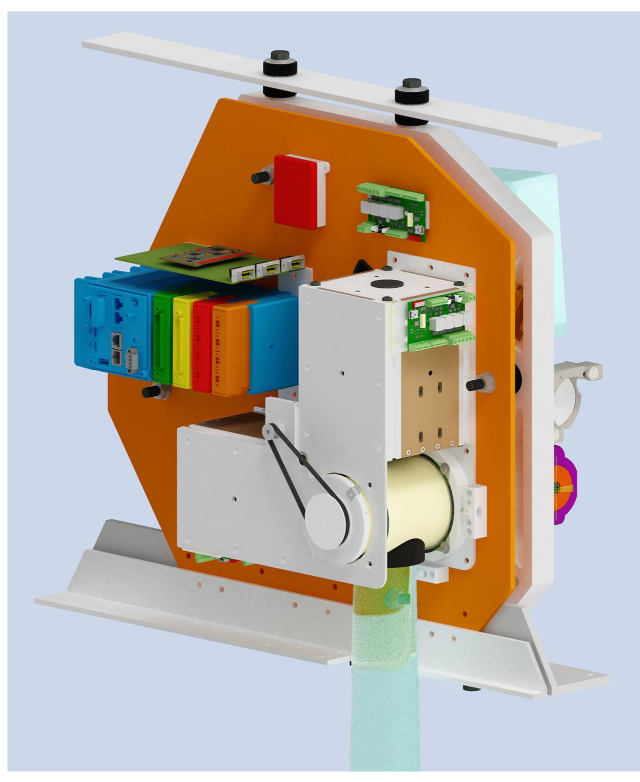
Supercooling effect for the Ga freezing point



The Black-Body Calibration Unit (BCU) with the rotating mirror for scene selection.



The Black-Body Calibration Unit (BCU) installed on the FORUM-Balloon instrument.



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