Physikalisch-Technische Bundesanstalt
National Metrology Institute

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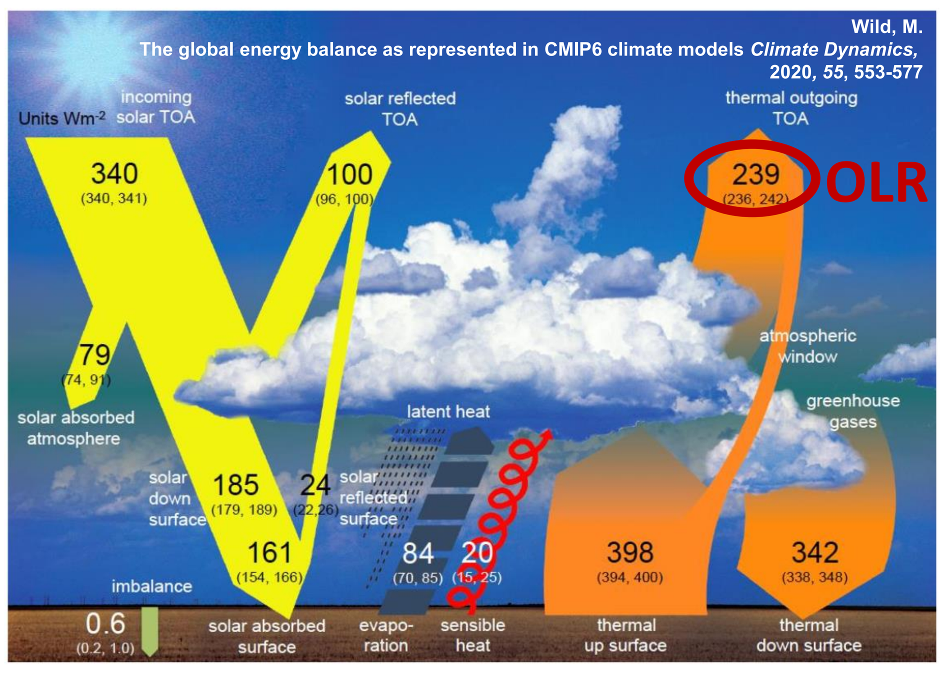
A Novel Vacuum FIR Calibration System in Support of ESA's 9th Earth Explorer Mission at PTB

Introduction

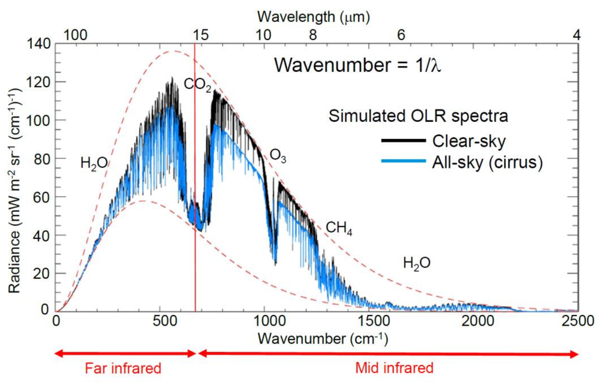
The Physikalisch-Technische Bundesanstalt (PTB), the national metrology institute of Germany, provides non-contact temperature measurement in the range from -170 °C to 962 °C at the highest metrological level, i.e. the realization and dissemination of the International Temperature Scale ITS-90 by radiation thermometry. The measurement of the spectral radiance from the near to the far infrared in the wavelength range from 1 µm to 1 mm and the measurement of the spectral emissivity in the temperature range from -40 °C to 1000 °C are closely related tasks. Here we present the work to build a novel vacuum FIR calibration system in support of ESA's 9th Earth Explorer Mission.

Far-infrared-Outgoing-Radiation Understanding and Monitoring (FORUM) Mission

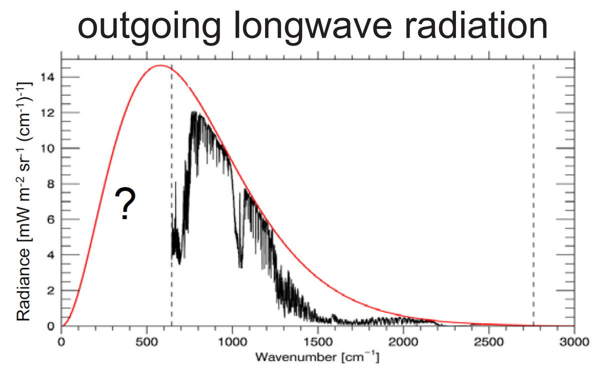
FORUM will deliver an improved understanding of the climate system, informing climate policy decisions by supplying, for the first time, a complete characterisation of the Earth's OLR spectrum.



Spectral Simulation



So far measured outgoing longwave radiation



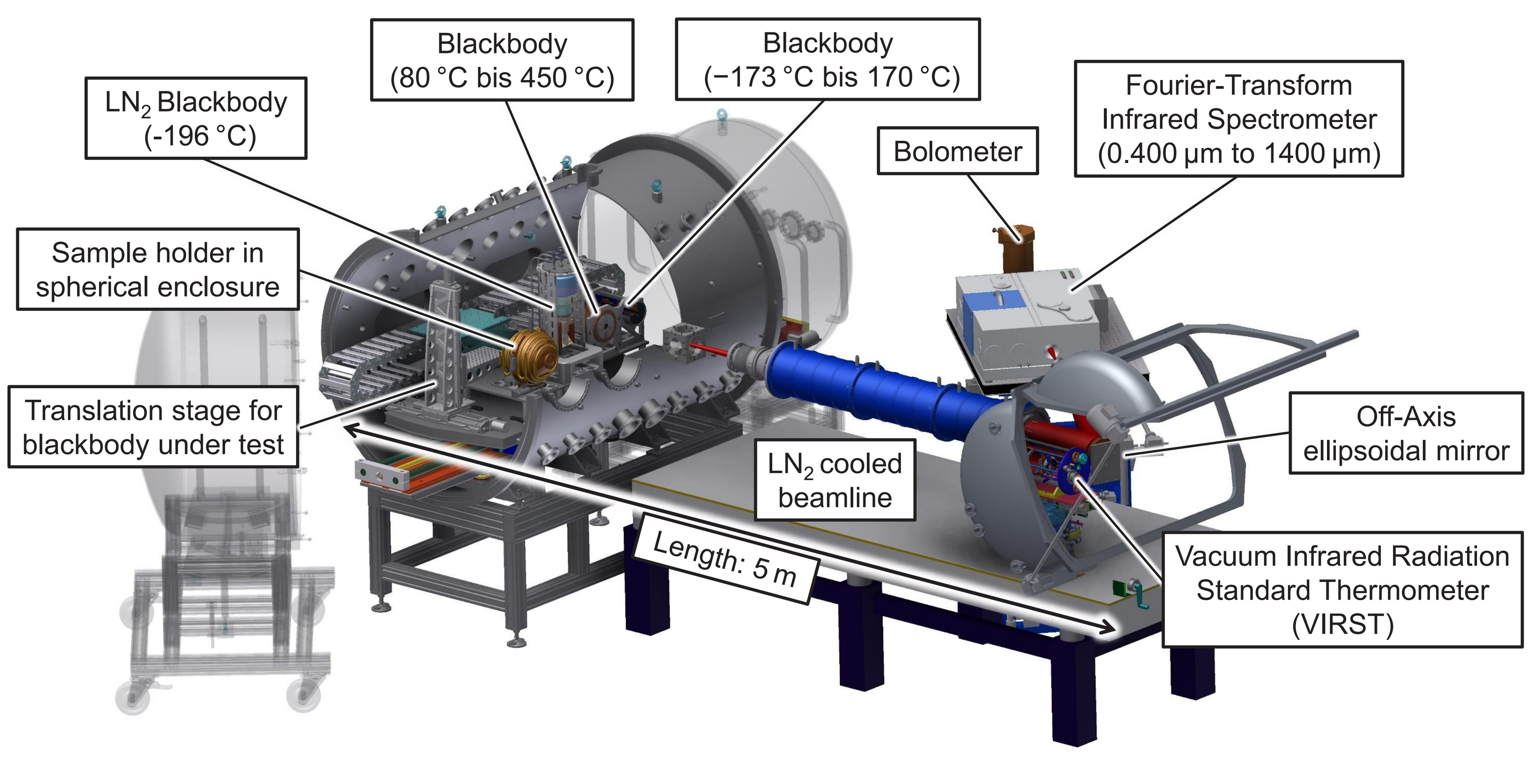
This goal will be achieved by spectral measurements that:

- cover the Earth's top-of-atmosphere (TOA) emission spectrum from 6.25 µm to 100 µm
- fill the observational gap across the far-infrared from 17 µm to 100 µm
- provide a **three-years dataset** benchmarked against international standards with an **absolute radiometric accuracy of at least 0.1 K ($k = 3$)** in the spectral range to 9 µm to 33 µm and 0.2 K in the other ranges.

In this way, FORUM will deliver a truly unique dataset of the Earth's entire emission spectrum up to 100 µm which can be used to probe FIR energetics but will also efficiently complement existing and planned future missions.

It will provide a stringent test of our understanding of, and ability to model, the links between key underlying physical processes driving climate change, their spectral signatures, the Greenhouse Effect, and the overall ERB.

The Reduced Background Calibration Facility 2 at PTB – RBCF2



Capabilities of the RBCF2		Temperature range	Spectral range
Characterisation of Sources	Radiance temperature and Spectral radiance	- 70 °C to 450 °C	0.4 µm to 1000 µm
Characterisation of Detectors and Cameras	Radiance temperature	-170 °C to 450 °C	0.4 µm to 1000 µm
Optical properties	Emissivity	-40 °C to 800 °C	0.4 µm to 200 µm
	Directional Transmissivity- and Reflectivity	Ambient	0.4 µm to 1000 µm

All in vacuum or under controlled pressure and gas purity and ISO 5 cleanroom conditions

Uncertainty improvement of RBCF2

Currently the RBCF2 can provide uncertainties for the required FORUM spectral- and temperature range of 30 mK ($k = 1$). The uncertainties of the FORUM on-board blackbody is defined to be 30 mK ($k = 1$) which leads to a required uncertainty of the reference blackbody on-ground of around 15 mK ($k = 1$). To reach this very ambitious aims the uncertainties for the RBCF2 must be improved by factor of 2.

Based on a feasibility Study of 2020 to improve the RBCF2 to achieve the targeted uncertainties a new ESA Project was signed in 11.2021:

Novel Reference/Calibration System to Measure Spectral Radiance on the Range 4 µm to 100 µm

Based on the sensitivity analysis on the governing equation by investigate the spectral distribution of the partial derivatives of $L_{\lambda,Rad}(\lambda, T_{BB})$ with respect to T_{BB}, ε_{BB} and T_{Back} in terms of temperature the results can be stated as follow:

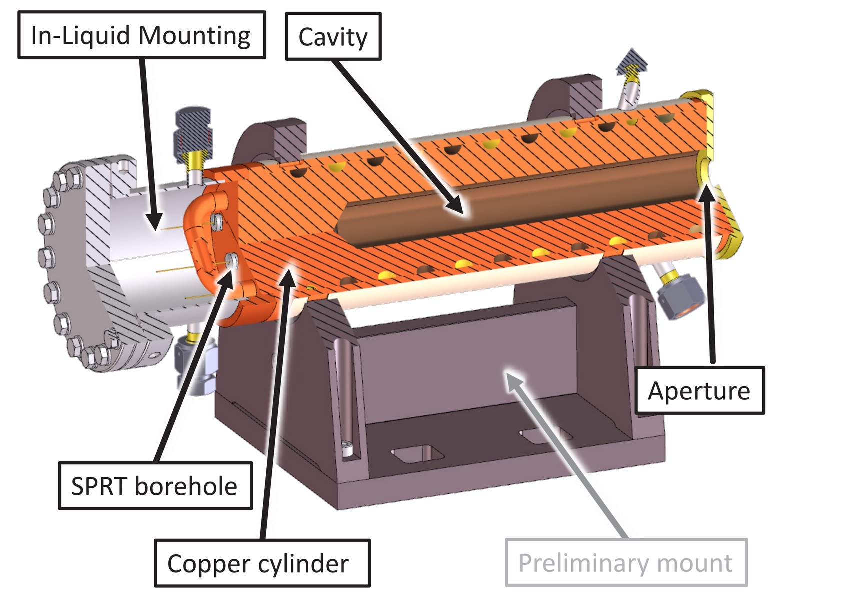
$$L_{\lambda,Rad}(\lambda, T_{BB}) = \varepsilon_{BB} \cdot L_{\lambda,Planck}(\lambda, T_{BB}) + (1 - \varepsilon_{BB}) \cdot L_{\lambda,Planck}(\lambda, T_{Back})$$

- Uncertainty of effective emissivity (ε_{BB}) of cavity is dominant if background temperature (T_{Back}) is different to blackbody temperature (T_{BB})
- For warmer background temperatures the uncertainty of background temperature is also relevant

The required uncertainties of 15 mK ($k = 1$) can be reached by the following measures:

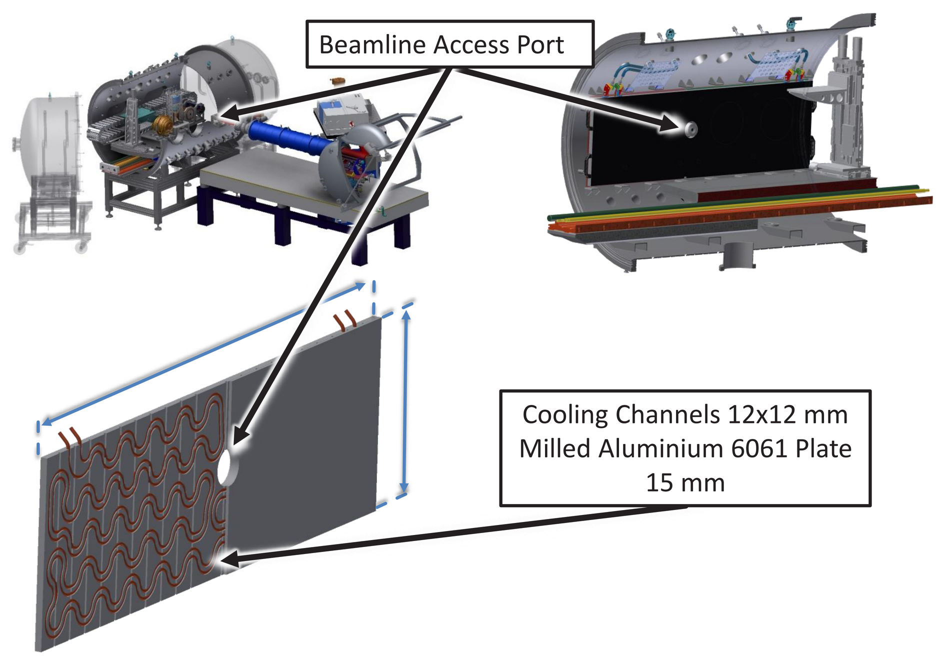
- Adjust background temperature to be slightly below black body temperature – Radiation screen (Coldscreen) is indispensable
- Measure black body temperature with $u(T_{BB}) < 10$ mK
- Realize highest possible blackbody emissivity
- However, ε_{BB} =0.999 is sufficient to achieve $u_{combined}(T_{rad})$ of 15 mK

New vacuum reference blackbody (VRBB) with 15 mK uncertainty



- Coating with VANTABLACK S-IR
- Bifilar wound fluid channel uniformity < 19 mK
- Effective emissivity $\varepsilon_{BB} > 0,9997$
- Contact temperature measurement with capsule type SPRT uncertainty $u(T_{BB}) < 5$ mK
- Use of in-liquid mounting

Coldscreen for thermal uniform environment



- Coating with Nextel 811-21
- Complete area of Coldscreen uniformity < 10 K
- Integrated FoV of VRBB uniformity < 2 K, entire range
- Coldscreen uniformity sufficient to achive uncertainty requirements on background
- Effective emissivity $\varepsilon_{CS} > 0,95$
- Contact temperature measurement with PRT uncertainty $u(T_{CS}) < 30$ mK

Summary

$u(t_{Rad})$ ~ 15 mK is achievable by the following means

- Use ***capsule type SPRTs*** with appropriate readout electronics to achieve few mK uncertainty of cavity temperature
- Use ***in-liquid mounting of SPRTs*** for good thermal contact and easy recalibration to maintain this uncertainty over a long period
- A ***liquid operated blackbody*** with bifilar heat exchanger and aluminum body is sufficient to achieve cavity temperature uniformities of 20 mK
- A ***radiation screen*** operated at similar temperature as the reference blackbody improves its radiance temperature uncertainty significantly
- The ***radiation screen minimizes time dependent thermal loads*** on the reference blackbody and the blackbody under test during typical calibration schemes when blackbodies are moved with respect to the comparison instrument
- The ***radiation screen might be used to simulate the later application conditions*** and corresponding thermal load of the blackbody under test.

The design and manufacturing of the VRBB and Coldscreen is on its way and the **RBCF2 will be extended by both in 2023**

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