Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

Radiometric characterization of a large aperture blackbody reference source in vacuum in the temperature range from -120 °C to 30 °C

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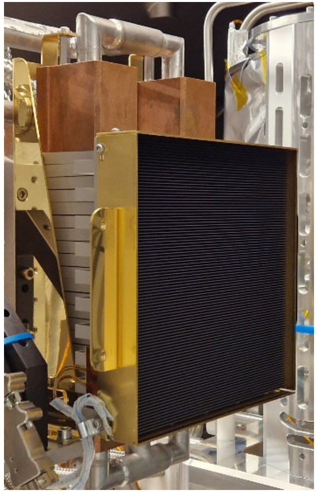
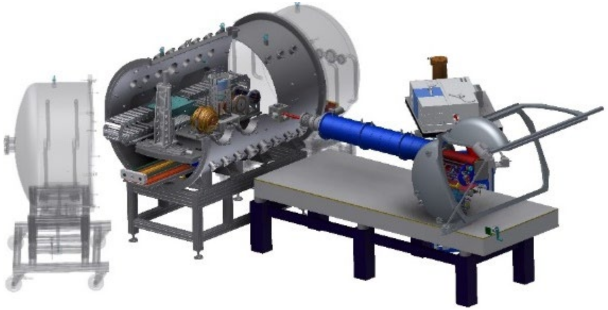
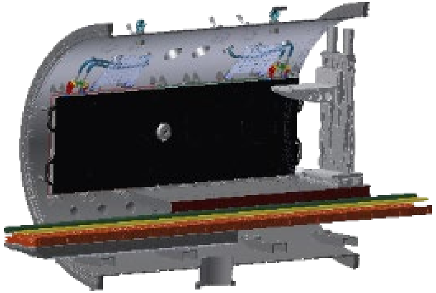
Gianluca Casarosa – **European Space Agency**







Infrared thermography in the ESA Test Centre

Since 2009, the Test Centre of the European Space Agency has made use of **thermography** during Space Craft testing.
Deployed as **complementarty tool** to traditional contact sensors (e.g. thermocouples or thermistors)
Thermography offers several **advantages** with respect to the former:

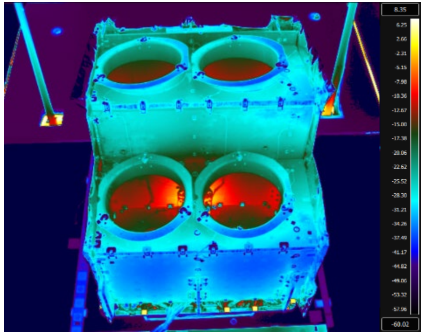
- Reduction of the instrumentation time
- A more detailed temperature mapping of the external surface of the test article (each pixel of the detector is a virtual sensor)
- Reduction of the perturbation to the test article
- Fast response time

IR cameras are calibrated typically down to -30°C (243 K), limiting quantitative measurement range

An extension of the calibration of the IR cameras to a range spanning from **-100 °C to 30 °C** in vacuum is envisaged to meet the requirements of **future ESA missions** (quantitative measurement of “cold” temperature)

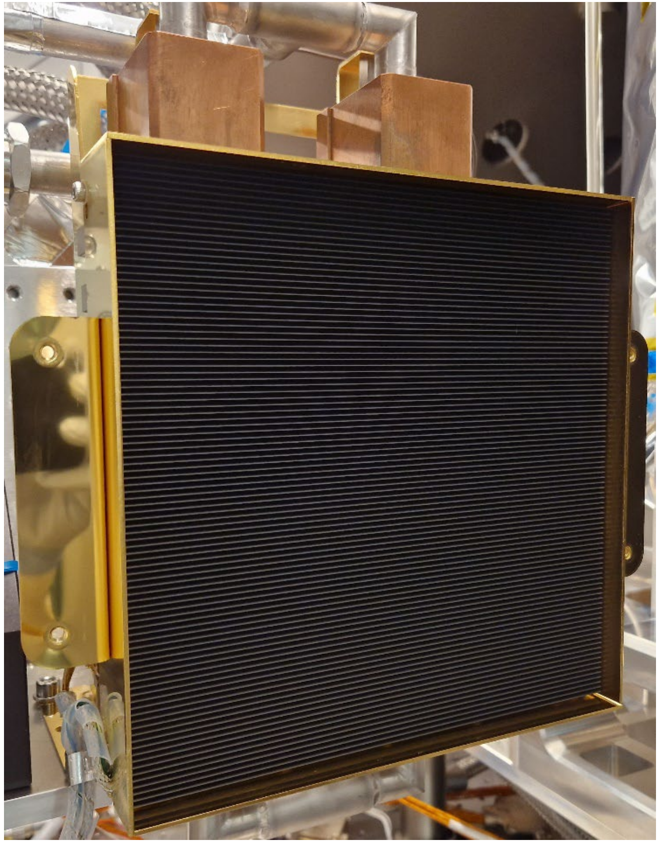
The use of a black body suitable for thermal vacuum operations and with an extended **calibrated temperature range** would address ESA‘s need.

Credit: © ESA



Credit: © ESA / PLATO

Large aperture blackbody under test



HGH ECN100v7

- 190mm x 190mm surface dimensions
- microgrooved emissive surface with emissivity >0.99
- temperature range -125 °C to 150 °C @ 20°C environment
- temperature stabilisation better than 3 mK
- calibrated Pt100 sensors
- materials with controlled outgassing properties
- resistive film heater for temperatures up to 150 °C

Reduced Background Calibration Facility 2

Sourcechamber with vacuum blackbodies

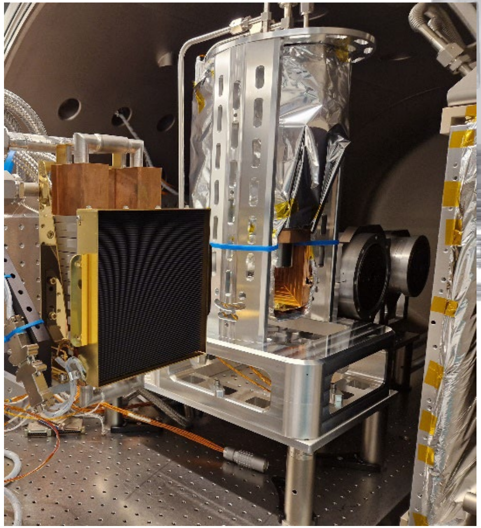
VLTBB: **-170 °C** to 170 °C

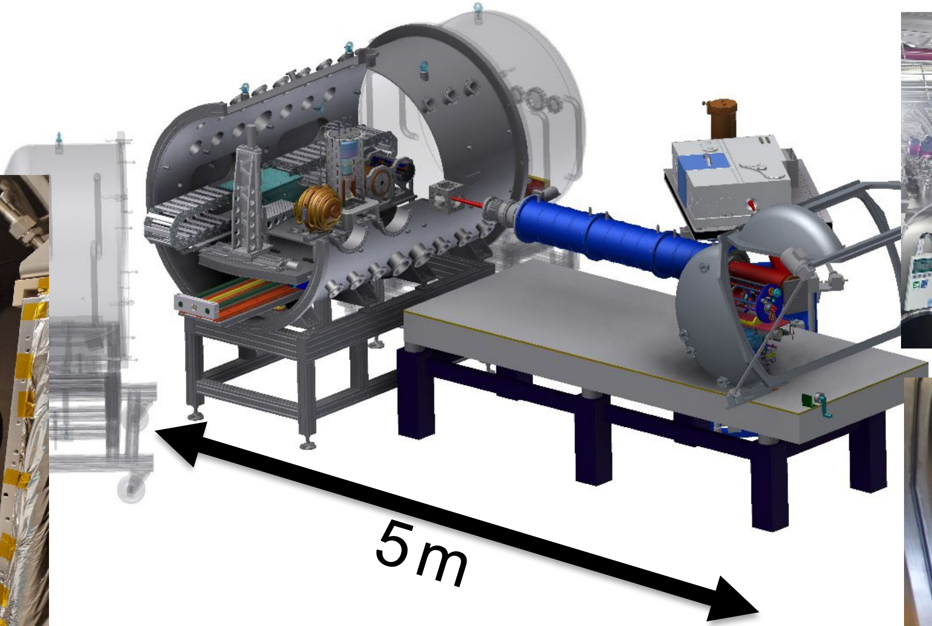
VMTBB: 80 °C to **450 °C**

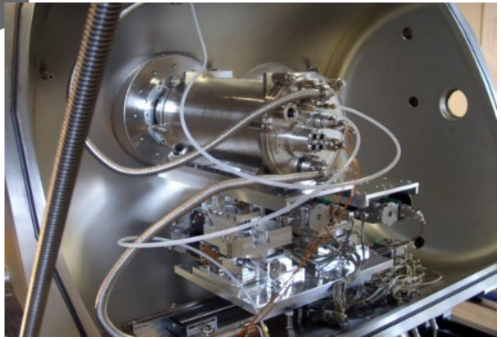
LN_2BB: -196 °C

Vacuum-Fouriertransform spectrometer

0.400 µm bis **1000 µm**



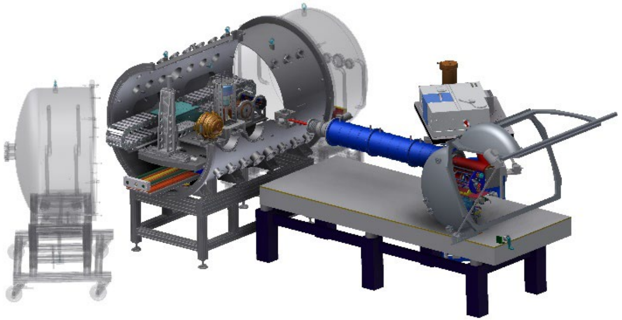




Vacuum Infrared Radiation Standard Thermometer

C. Monte et. al., The Reduced Background Calibration Facility for Detectors and Radiators at the Physikalisch-Technische Bundesanstalt, SPIE Remote Sensing, *Sensors, Systems, and Next-Generation Satellites XIII*, **2009**, *7474*

Summarized Capabilities of the RBCF2



- **Characterisation of Sources**
  - Radiance temperature: - 170 °C to 450 °C
  - Spectral radiance: 0.4 µm to 1000 µm
  - Aperture diameter up to: 250 mm

- **Characterisation of Detectors and Cameras**
  - With respect to calculable blackbody radiation: -170 °C to 450 °C
  - Field of view up to: 200 mm dia.

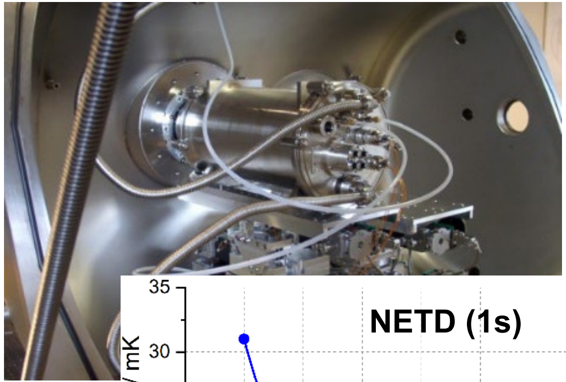
- **Emissivity**
  - Sample temperature: -40 °C to 800 °C
  - Spectral range : 0.4 µm to 200 µm

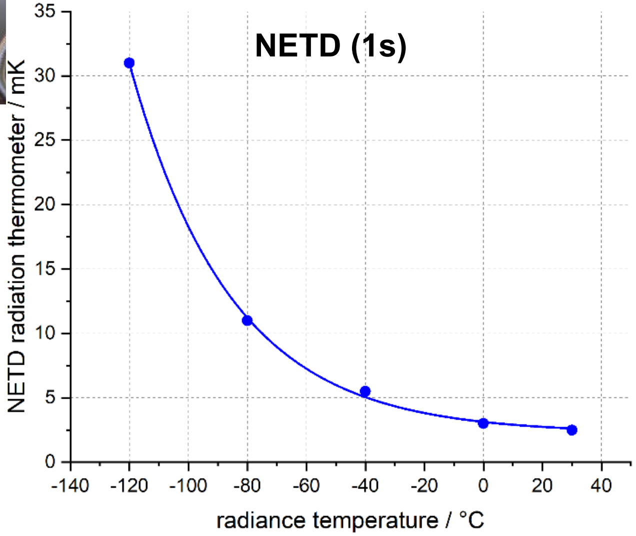
- **Transmissivity- and Reflectivity**
  - Spectral range: 0.4 µm to 1000 µm

- ***All in vacuum or under controlled pressure and gas purity***

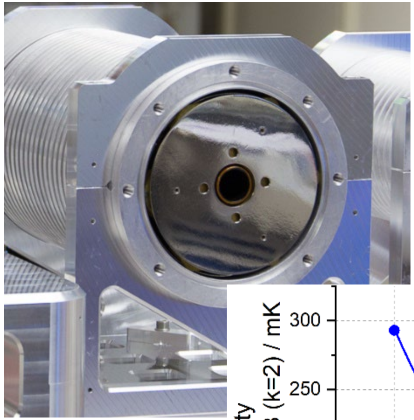
Low temperature performance (8µm to 14µm)

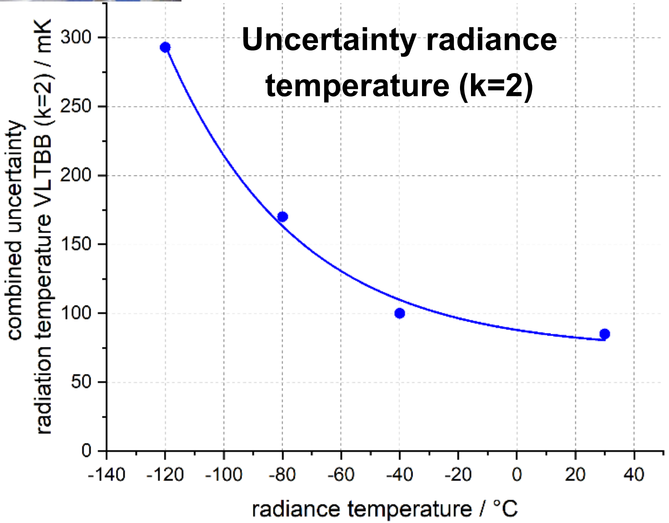
Vacuum Infrared Radiation Standard Thermometer (VIRST)



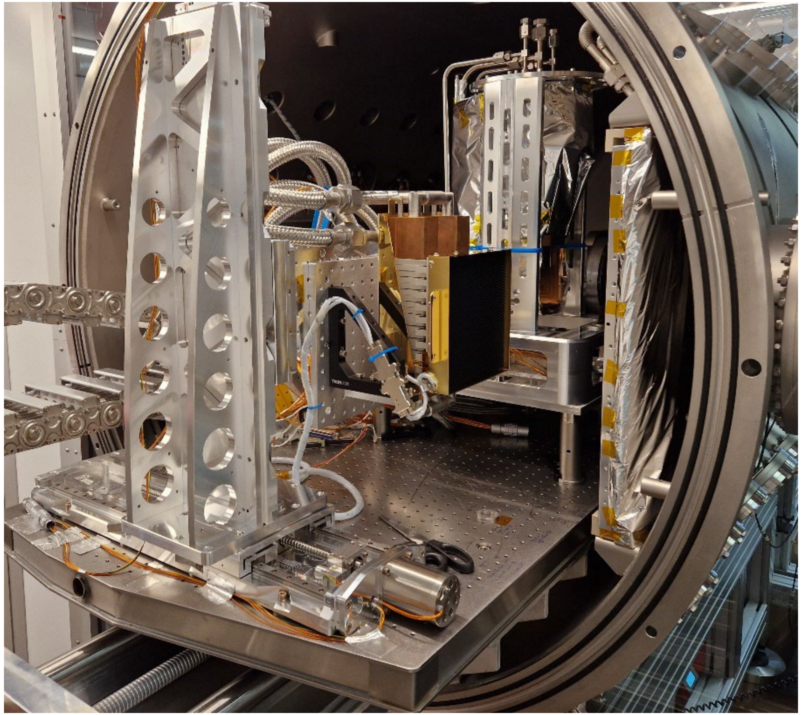


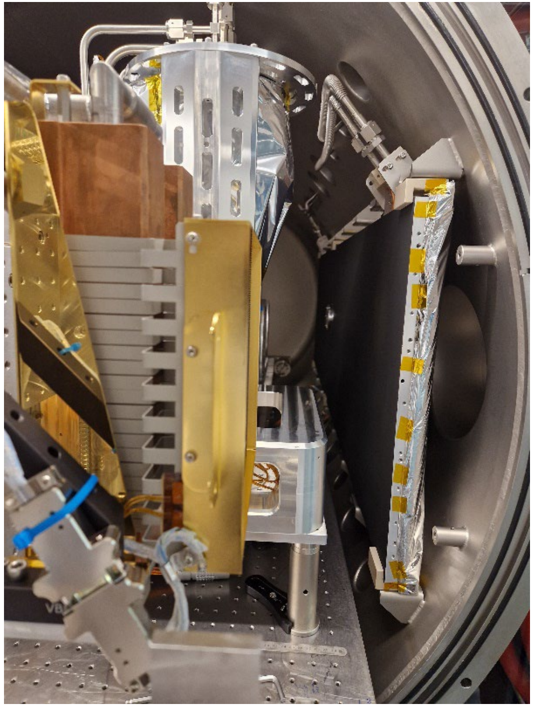
Vacuum Low Temperature Blackbody (VLTBB)



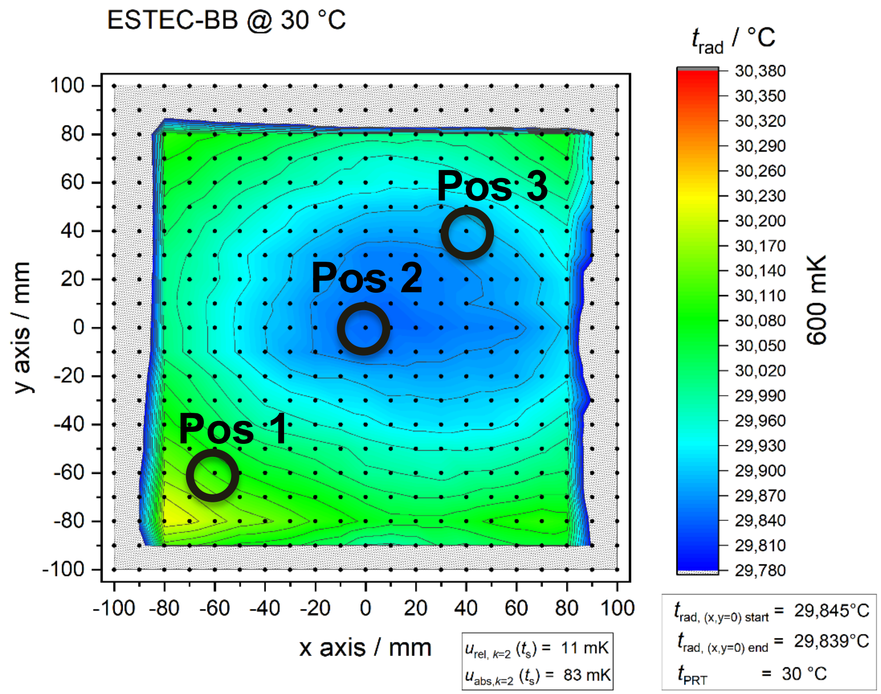


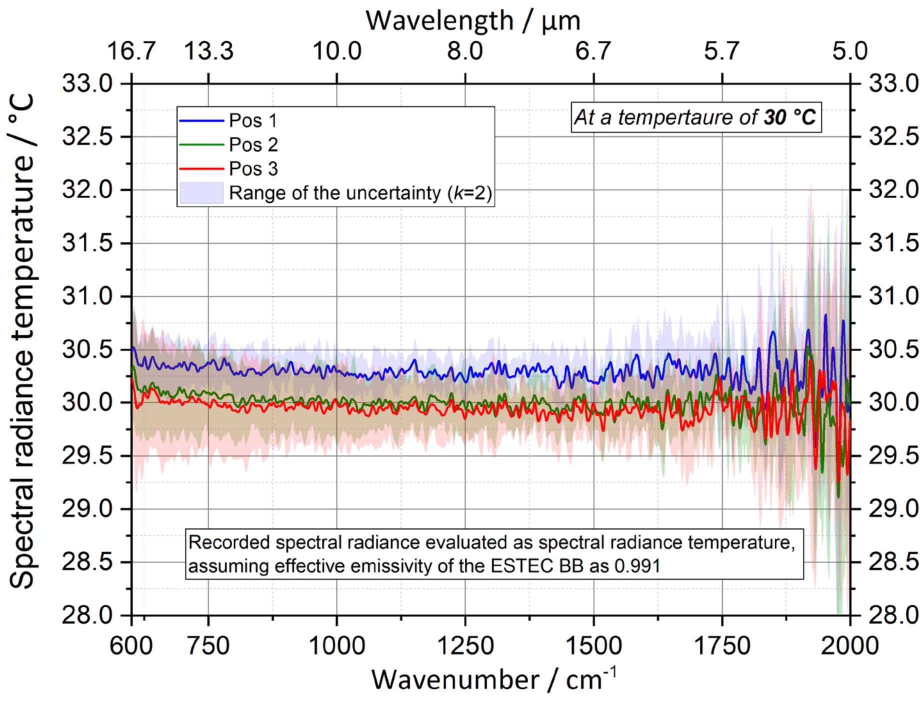
Blackbody under test @ RBCF2





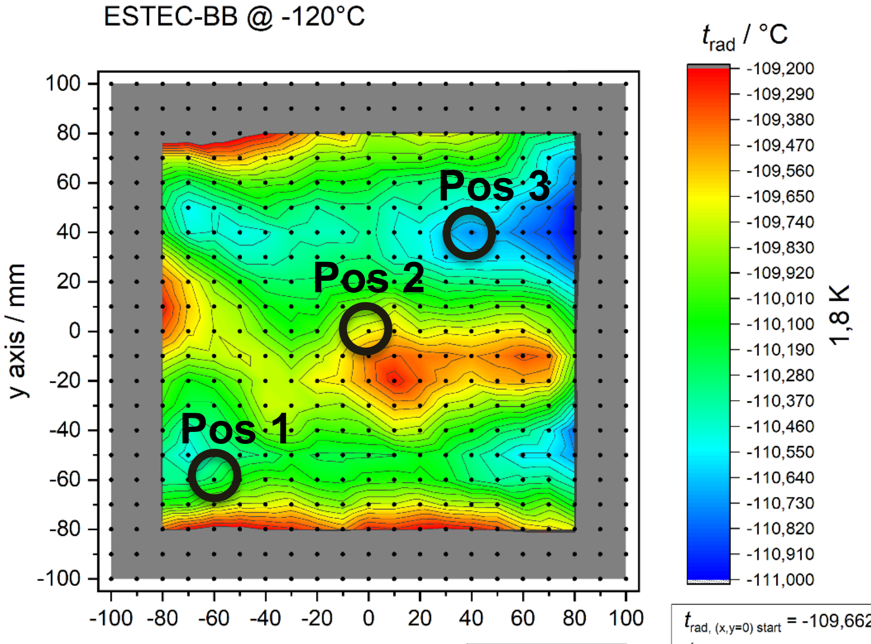
Characterisation @ 30 °C





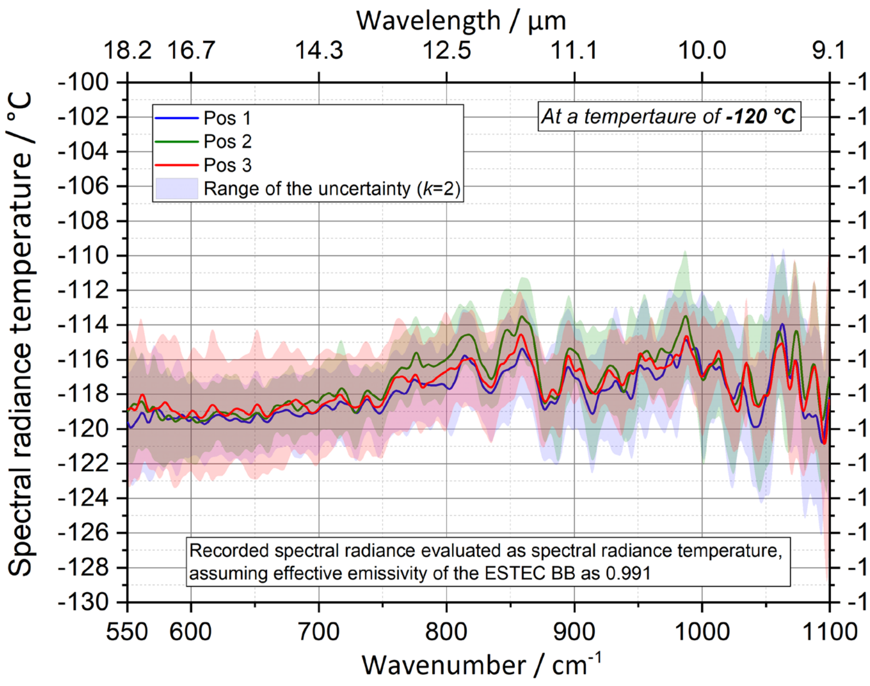
MCT / KBr

Characterisation @ -120 °C



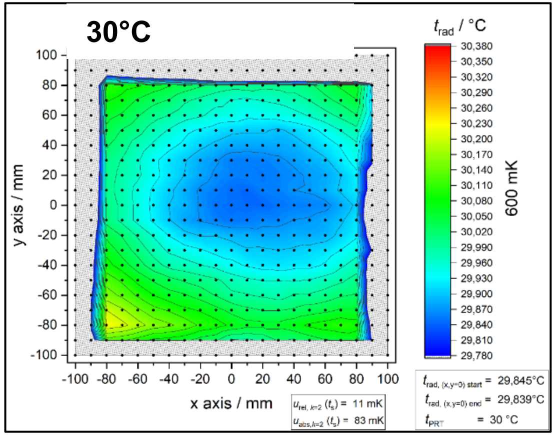
$u_{rel,\,k=2}\,(t_s)$ = 137 mK
$u_{abs,\,k=2}\,(t_s)$ = 285 mK

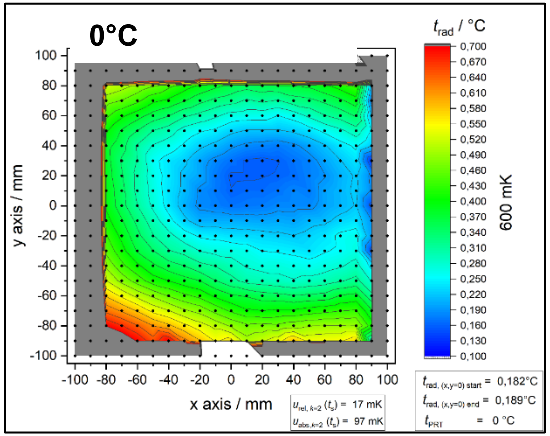
$t_{rad,\,(x,y=0)\,start}$ = -109,662°C
$t_{rad,\,(x,y=0)\,end}$ = -109,734°C
t_{PRT} = -120 °C

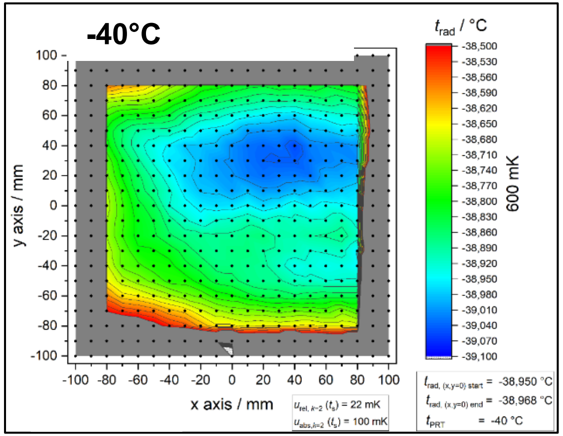


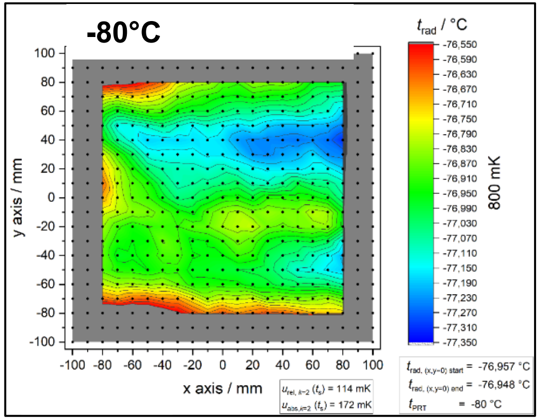
MCT / KBr

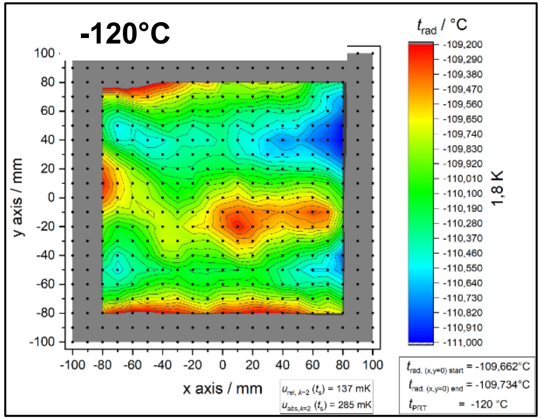
Uniformity: 30 °C to -120 °C











Emissivity identification

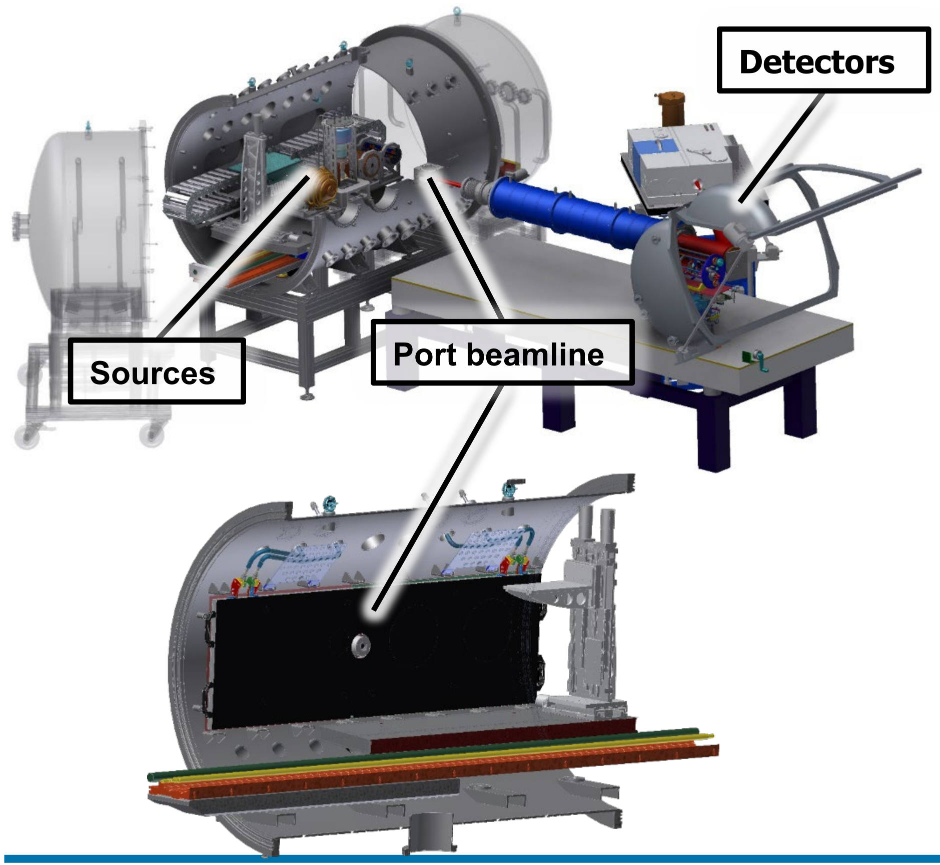
$$L_{\mathrm{obs}}(T) = \varepsilon_{\mathrm{BB}}\, L_{\mathrm{p}}(T_{\mathrm{BB}}) + (1-\varepsilon_{\mathrm{BB}})\varepsilon_{\mathrm{CS}} L_{\mathrm{p}}(T_{\mathrm{CS}}) + (1-\varepsilon_{\mathrm{BB}})(1-\varepsilon_{\mathrm{CS}}) L_{\mathrm{p}}(T_{\mathrm{amb}})$$

L_{obs} - observed radiance
T - measured radiation temperature (± 80mK to 300mK)
$\varepsilon_{\mathrm{BB}}$ - emissivity of the blackbody under test
L_{p} - Planck's law
T_{BB} - effective blackbody temperature
$\varepsilon_{\mathrm{CS}}$ - is the emissivity of the coldscreen (0.975 ± 0.01)
T_{CS} - measured temperature of the coldscreen (± 60mK to 200mK)
T_{amb} - measured temperature of the chamber walls (± 5K)

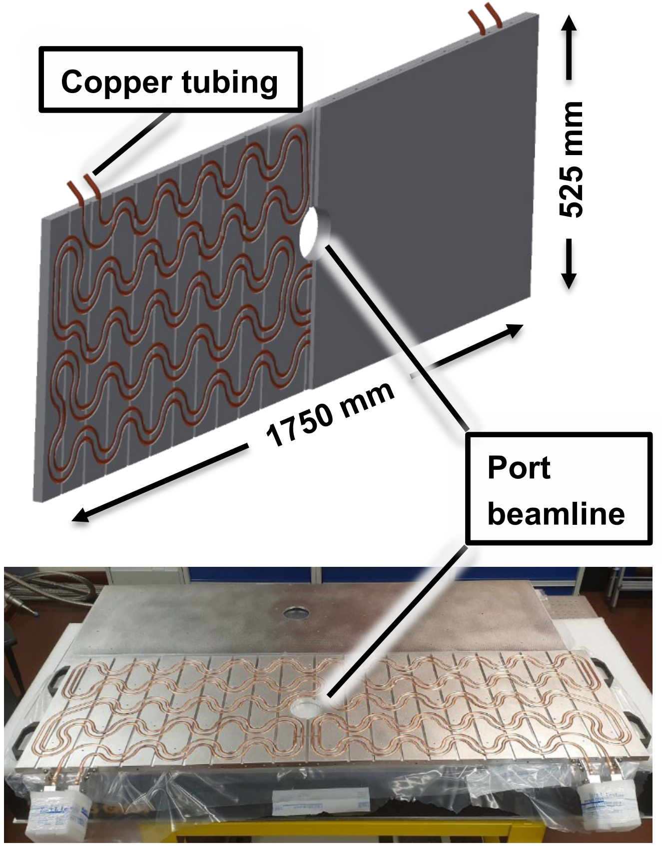
To retrieve the two unknowns $\varepsilon_{\mathrm{BB}}$ and T_{BB}, two independent measurements must be realized.

- keeping the nominal blackbody temperature constant and varying the coldscreen temperature

Coldscreen

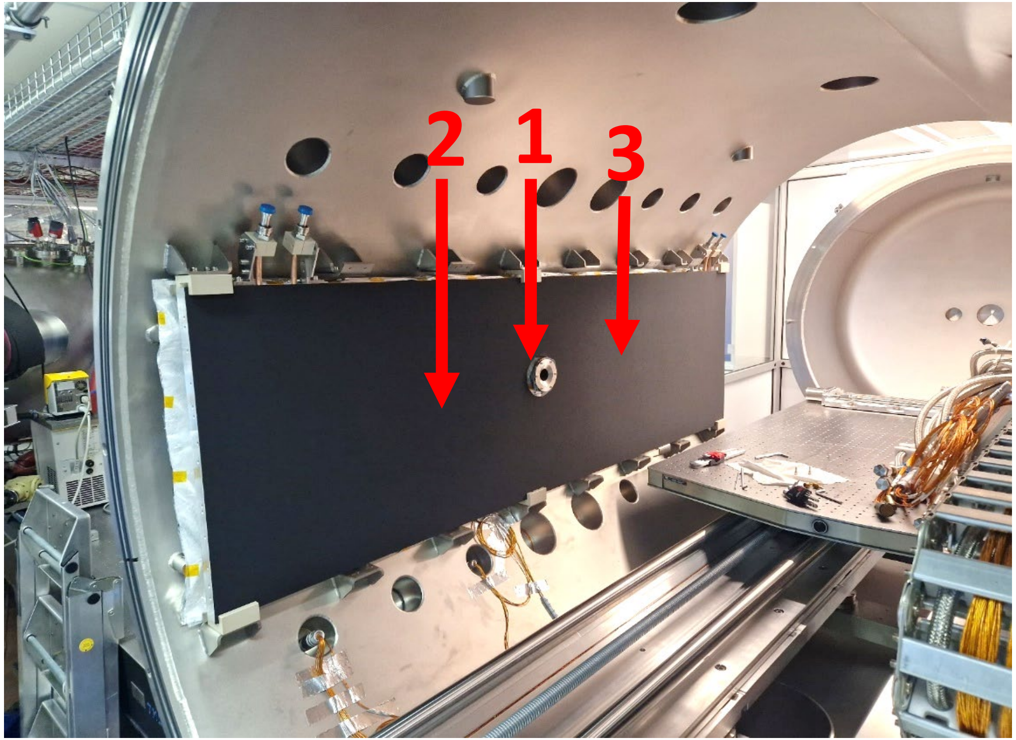


Detectors
Sources
Port beamline



Copper tubing
525 mm
1750 mm
Port
beamline

Coldscreen



Uniformity between the three sensors(1,2,3) after stabilisation and without load and any optimizations:

@ 40°C **~40 mK**

@ 0°C **~60 mK**

@ -40°C **~200 mK**

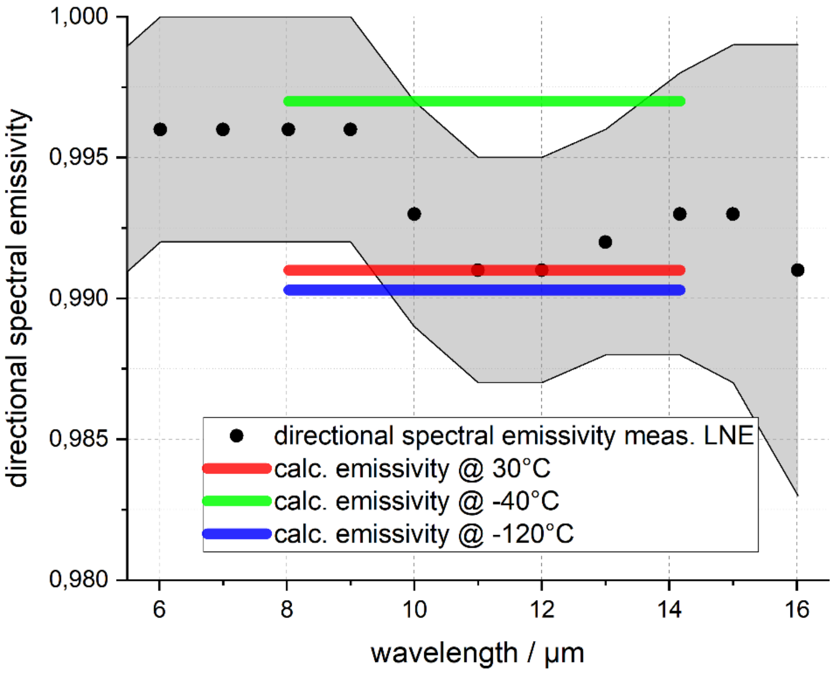
Comparison: model results to measurements

Nominal blackbody temperature
@ 30°C, -40°C and -120°C

Coldscreen for each blackbody temperature
@ 40°C, 0°C and -40°C

9 combinations in total and 3 results for emissivity and effective temperature

Nominal blackbody temperature / °C	30	-40	-120
Effective blackbody temperature T_{BB} / °C	29.867	-39.692	-118.231
Prelim. uncertainty effective blackbody temperature *(k=1)* / mK	176	375	502
Blackbody emissivity ε_{BB}	0.991	0.997	0.9903
Prelim. uncertainty blackbody emissivity *(k=1)*	0.0053	0.0033	0.00064



directional spectral emissivity measured by LNE and HGH
Test report: file P196787 - Document DMSI/3

Conclusion

- Details on RBCF low temperature performance
- Coldscreen for stabilization and defined background
- We characterized a large area blackbody down to -120 °C for space craft testing @ ESTEC
  - Results on uniformity, radiance temperature and spectral radiance
  - First result on emissivity evaluation and comparison with directional emissivity measurements

Next steps:

- Improve the radiometric model
  - Geometric viewing factors, spectral resolved