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ВСЕРОССИЙСКИЙ
НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ
ИНСТИТУТ ОПТИКО-ФИЗИЧЕСКИХ ИЗМЕРЕНИЙ
ФЕДЕРАЛЬНОГО АГЕНТСТВА ПО ТЕХНИЧЕСКОМУ
РЕГУЛИРОВАНИЮ И МЕТРОЛОГИИ РФ

VNIIOFI ACTIVITIES IN RADIOMETRY AND PHOTOMETRY for Earth observation

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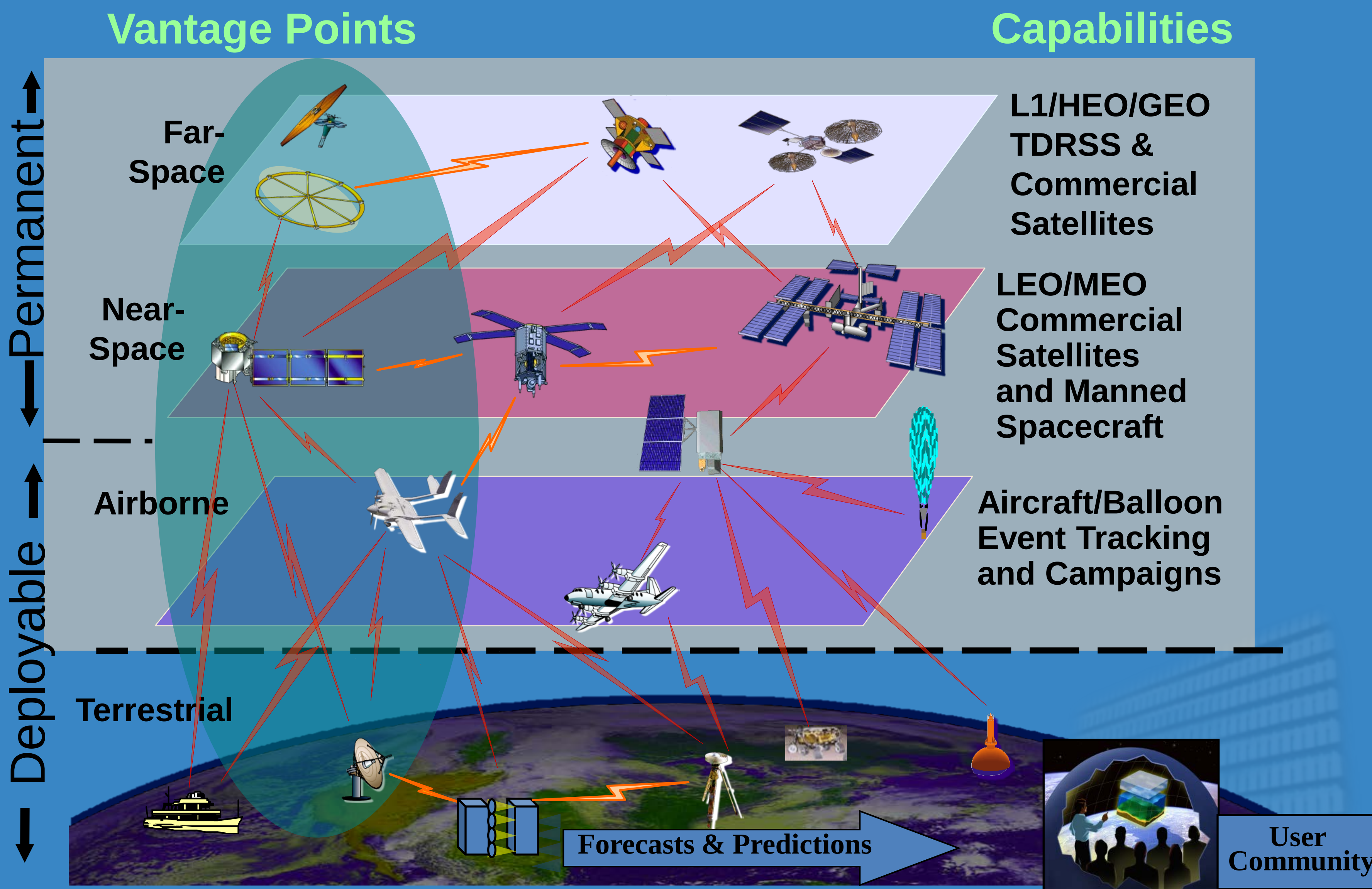
Consultative Committee for Photometry and Radiometry (CCPR)

(September 2016)

Global Earth Observation System of Systems (GEOSS)



1

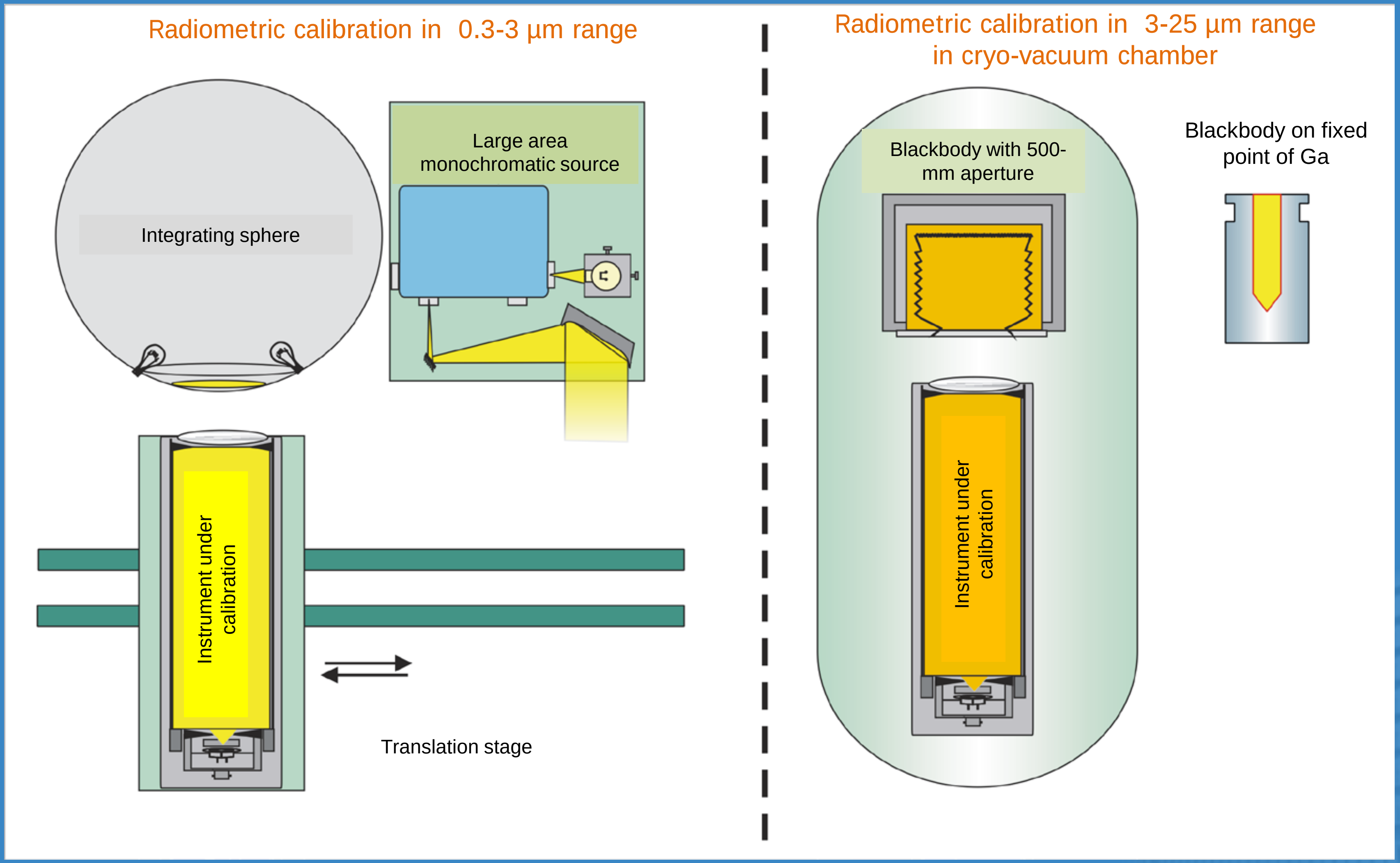
Standard Radiometric Facility
for ground high-accuracy Pre-flight calibration
of the Earth observation instruments
with apertures up to 500 mm
in (0.3÷25) μm wavelength range

Maximum accuracy requirements for observation of object parameters and required accuracy and stability of satellite instruments *

Parameter	Required accuracy	Required radiometric accuracy	Required radiometric stability (per decade)
Cloud base height	0.5 km	1 K	0.2 K
Cloud top height	0.15 km	1 K	0.2 K
Cloud top pressure	15 hPa	1 K	0.2 K
Cloud top temperature	0.5 K	0.5 K	0.2 K
Cloud optical thickness	10%	5%	1%
Spectrally resolved thermal radiance	0.1 K	0.1 K	0.04 K
Atmosphere temperature	0.5 K	0.5 K	0.04 K
Water vapor	5%	1 K	0.03 K
Ozone profile	3%	1%	0.1 %
Surface albedo	0.01	5%	1%
Normalized differential vegetation index	1%	less 0.5 %	0.8 %
Land surface temperature	0.3 K	0.3 K	-
Snow cover	2%	5%	10%
Sea ice area	2%	5%	10%
Sea surface temperature	0.1 K	0.1 K	0.01 K

*) NISTIR 7047. G. Ohring, B. Wielicki, R. Spencer, B. Emery, and R. Datla, Satellite Instrument Calibration for Measuring Global Climate Change (Report of a Workshop), March 2004.

VNIIOFI's Standard Radiometric Facility for preflight calibration of the Earth observation instruments (0,3-25 μm)

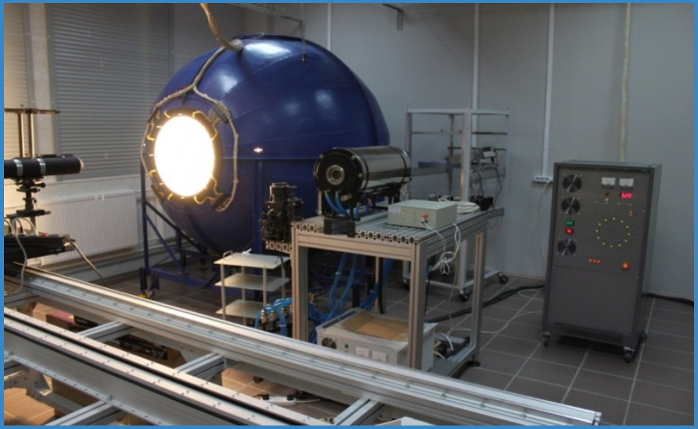


VNIIOFI's Standard Radiometric Facility for preflight calibration of the Earth observation instruments

0.3÷3 μm

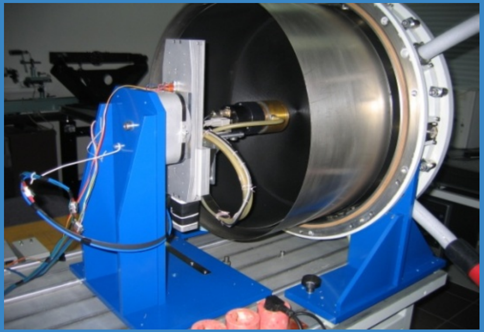
Monochromatic source

Integrating sphere,
high temperature blackbody

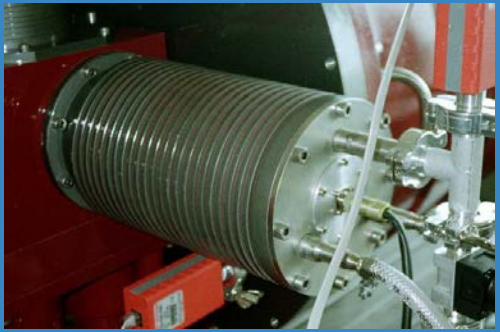


3÷25 μm

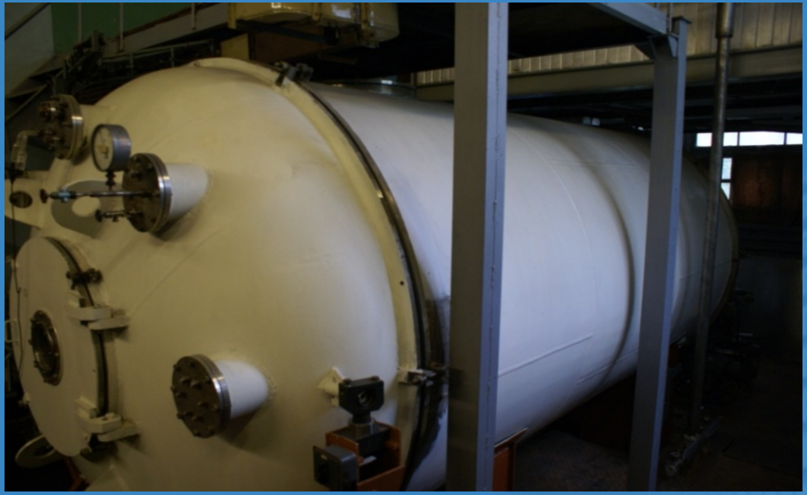
Large-area low temperature blackbody



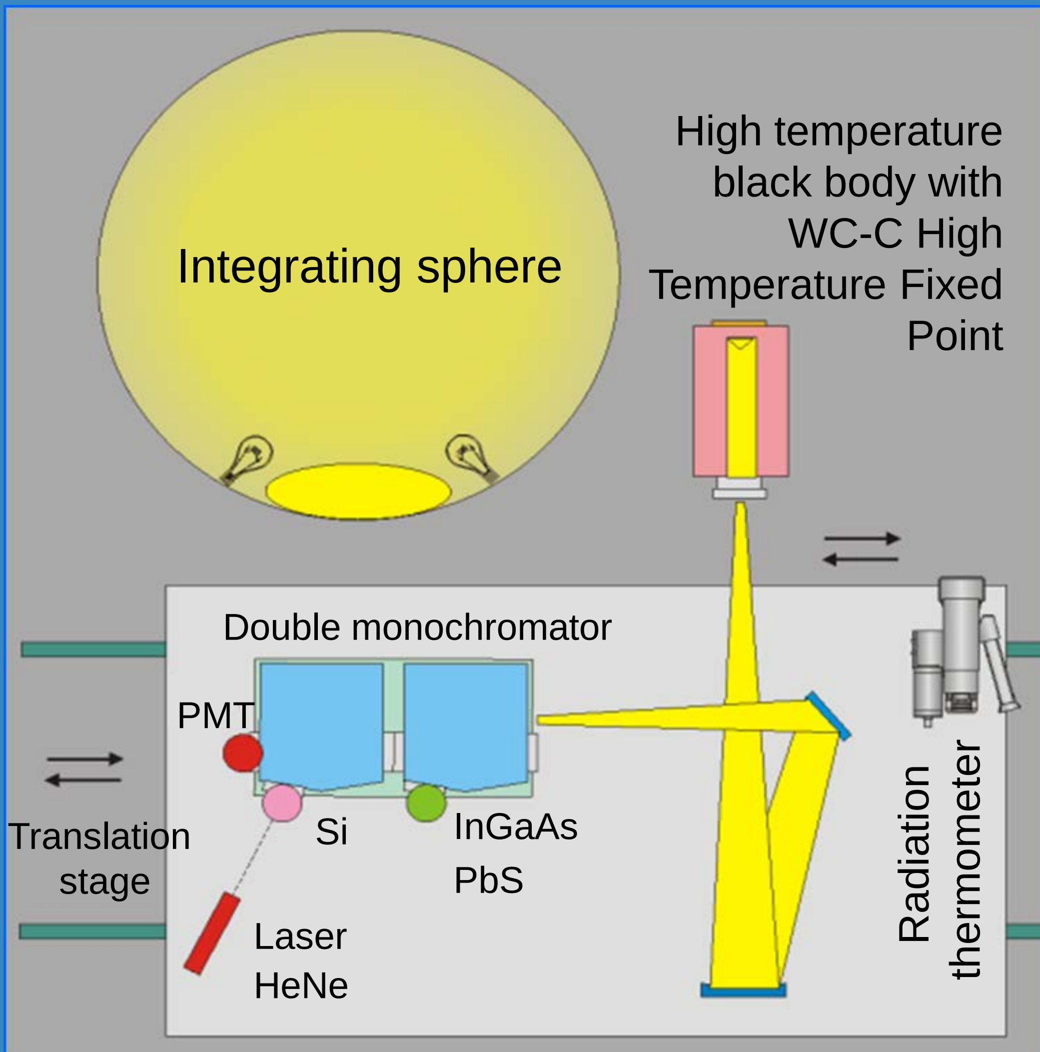
Ga fixed-point blackbody



Cryogenic vacuum chamber



Calibration of Integrating Sphere by comparison against high temperature blackbody



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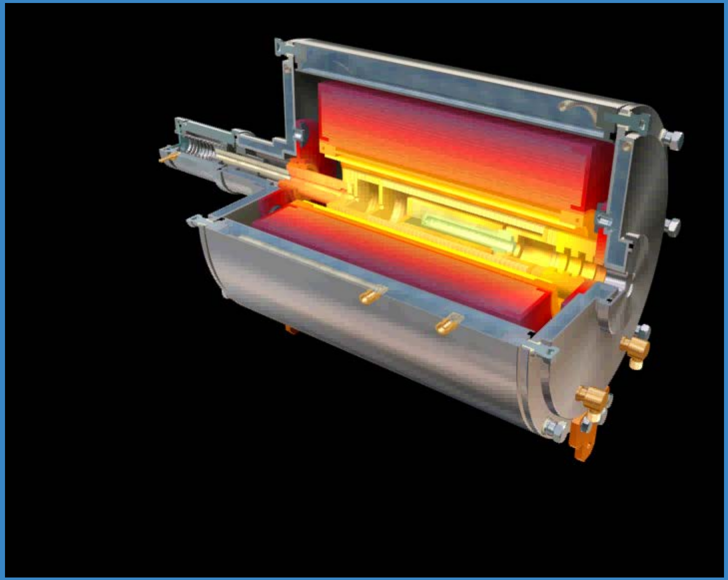
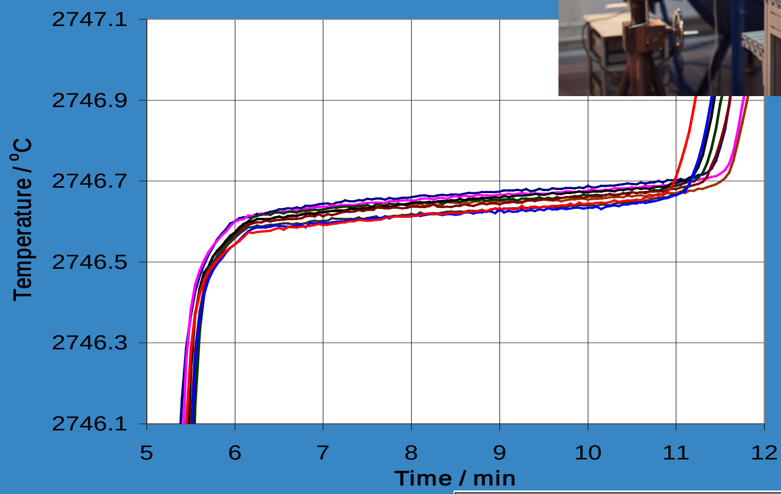
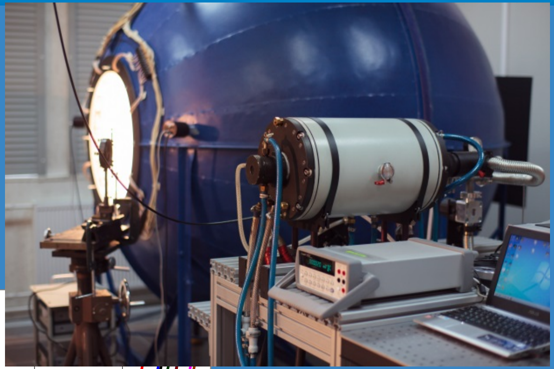
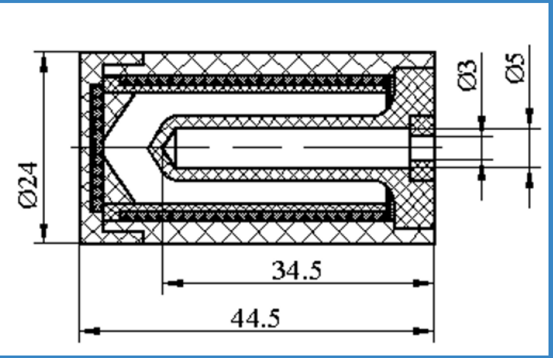
Calibration of Integrating Sphere by comparison against high temperature blackbody with WC-C HIGH TEMPERATURE FIXED POINT







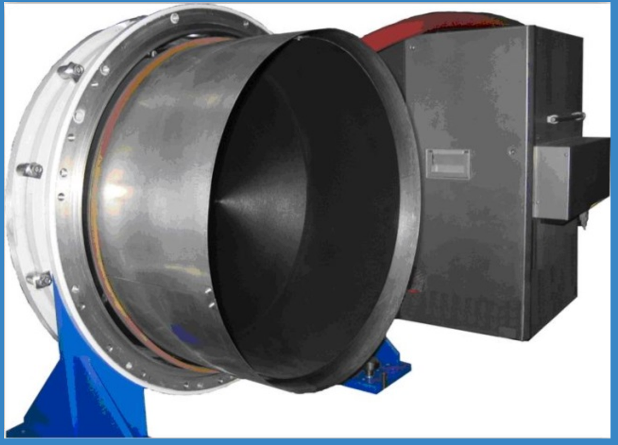


Specifications of the Cells	
Cell diameter	24 mm
Cell length	44.5 mm
Cavity opening	3 mm
Cavity diameter	5 mm
Cavity depth	34.5 mm
Cell type	Hybride
Graphite type	SGL Croup R4550
Nominal purity	4N8
Filling method	Drop
Carbon Composition during filling	4%
Emissivity	0.9997

Melting temperature of six cells agreed within ±45 mK.

Metrological facility for radiometric calibration within 3 μm to 14 μm range

The large-area blackbody model (LABB)



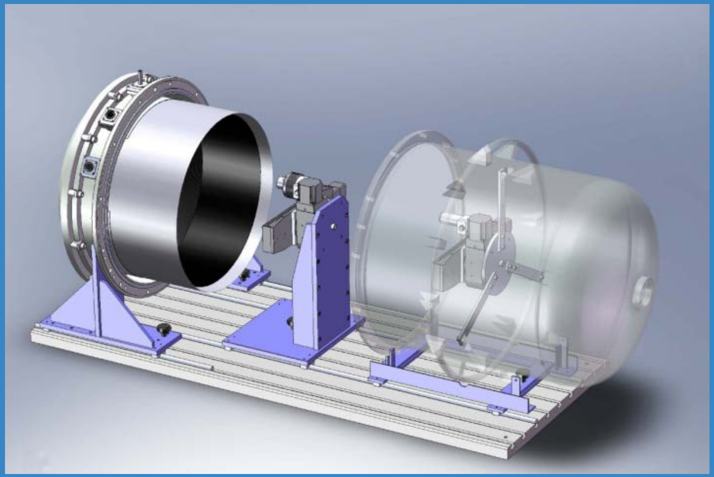
The large-area blackbody model (LABB) characteristics	Value
Working temperature range, °C	**-60 to 150**
Temperature stability, °C	**±0,02**
Opening aperture diameter, mm	**500**
Effective emissivity at -60°C, wavelength λ=14 mkm	**≥0,99**

The Variable Temperature Blackbody model (VTBB)

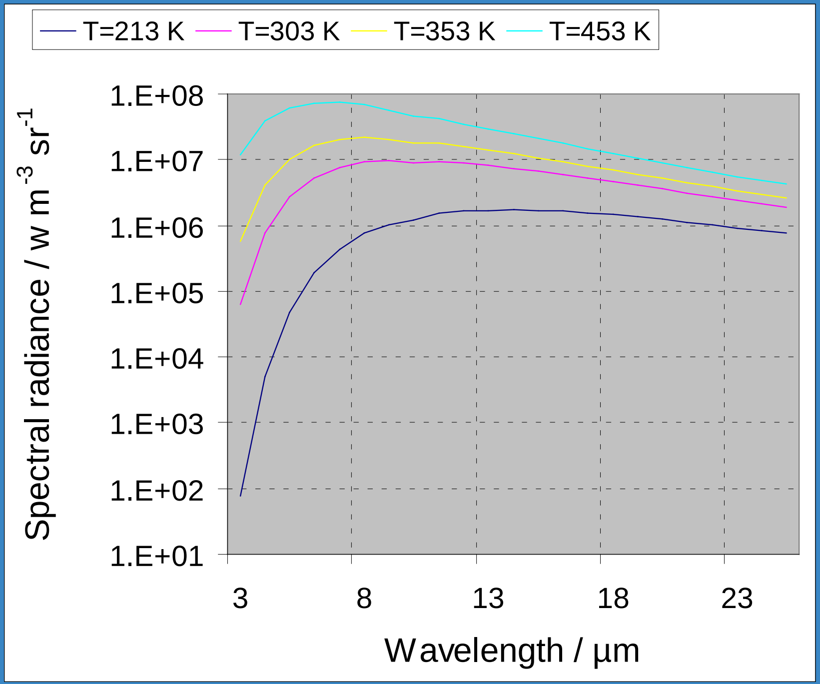
VTBB Specifications	Value
Working temperature range, °C	-60 to 150
Temperature stability, at -10°C	± 0.02
Opening aperture diameter, mm	20
Temperature gradient along cavity at -10°C, °C	≤ 0.1
Cavity inner diameter, mm	40
Effective emissivity	≥0,9997

Large area low temperature blackbody (LABB)

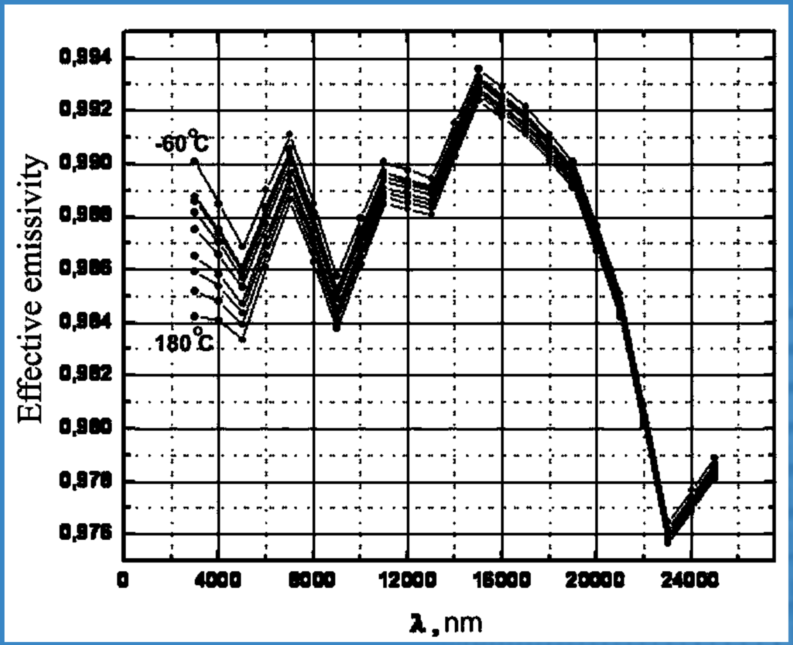
Range of working temperatures	- 60°C ÷ 180°C
Stability of working temperature (maintained by a liquid thermostat)	± 0.02°C
Diameter of radiator	500 mm
Thickness of radiator	10 mm



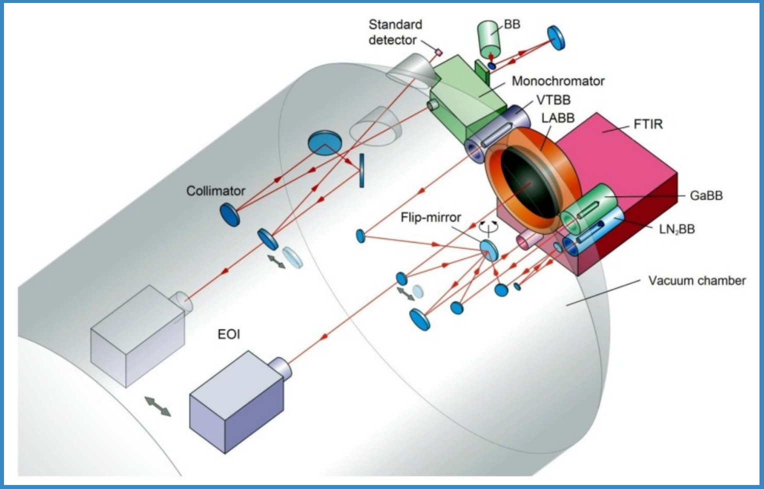
Spectral radiance



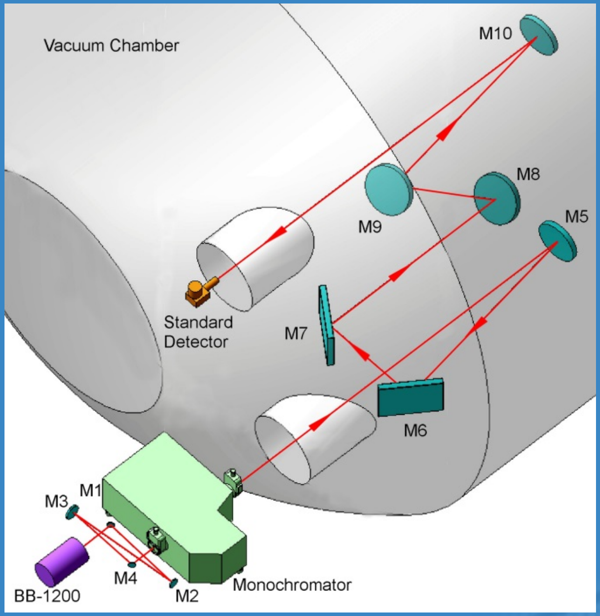
Effective emissivity



Blackbody-Based IR Monochromatic Radiation Source for Preflight Spectral Radiance Calibration Facility



Scheme of calibration within IR spectral range of EOI placed in vacuum chamber by means of MRS on the basis of BB-1200 blackbody source.



Measurement scheme of MRS calibration on relative spectral power by means of combined standard IR "sandwich" detector consisting of two sensitive elements on the basis of InSb and CdHgTe.

Summary of MRS basic features

Characteristic	*Value*
Spectral range (μm)	3 to 14
Output beam diameter (mm)	150
Spectral resolution (nm)	0.125
Output beam divergence	1:10
Spectral range (μm)	3 to 14

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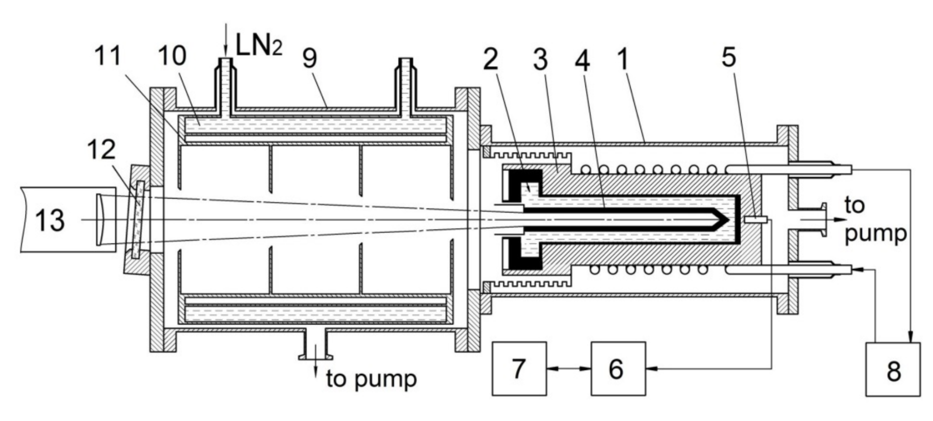
Facility for Preflight studying of Gallium Cells in a Space-based Blackbody model



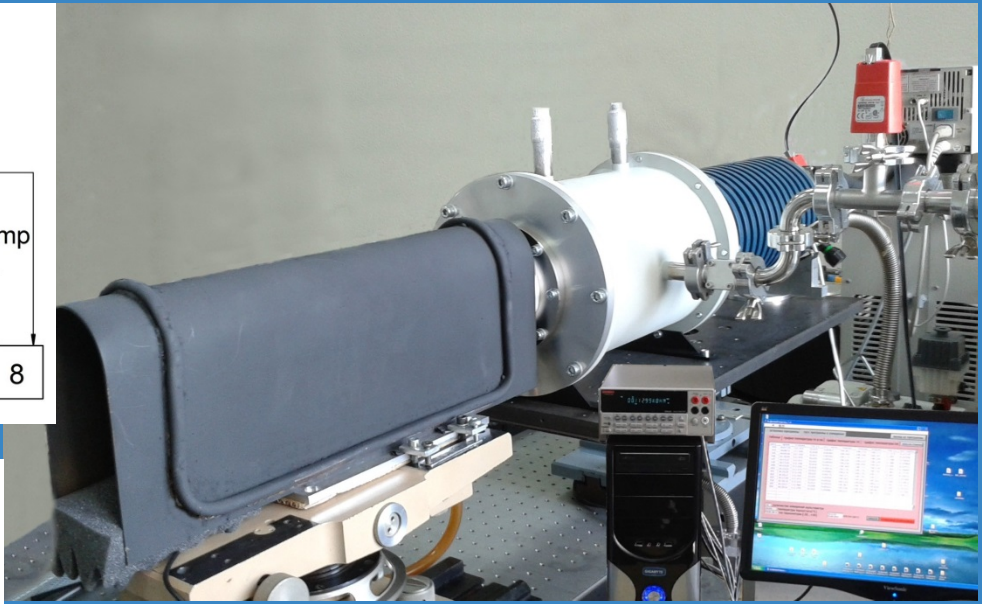


Figure 2. *Facility for Studying Space-Based Blackbody Model Gallium Cells. 1 - Blackbody model at gallium m.p., 2 - Changeable Teflon cell filled with gallium, 3- Heat exchanger with a removable liner, 4 - Emitting copper cavity, 5 - Platinum resistance thermometer, 6 - Digital multimeter, 7 - Computer, 8 - Liquid thermostat, 9 - Vacuum chamber, 10 - Liquid nitrogen vessel, 11 - Radiation shields, 12 - Input window, 13 - Precision pyrometer.*

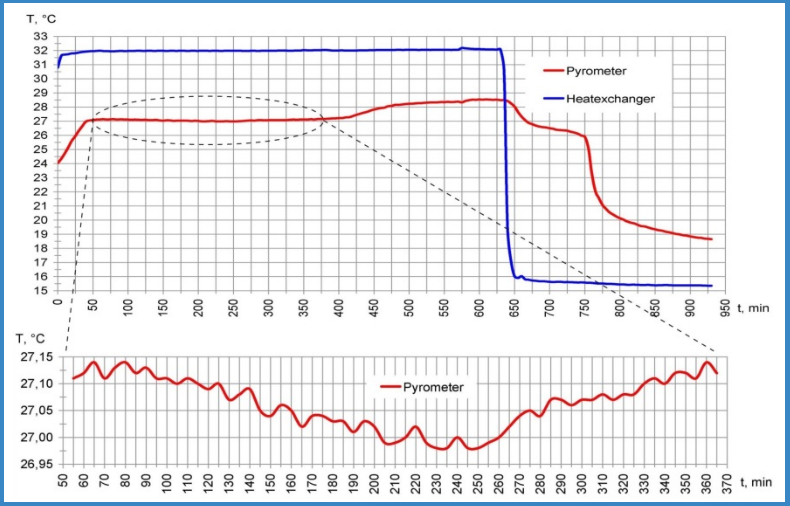


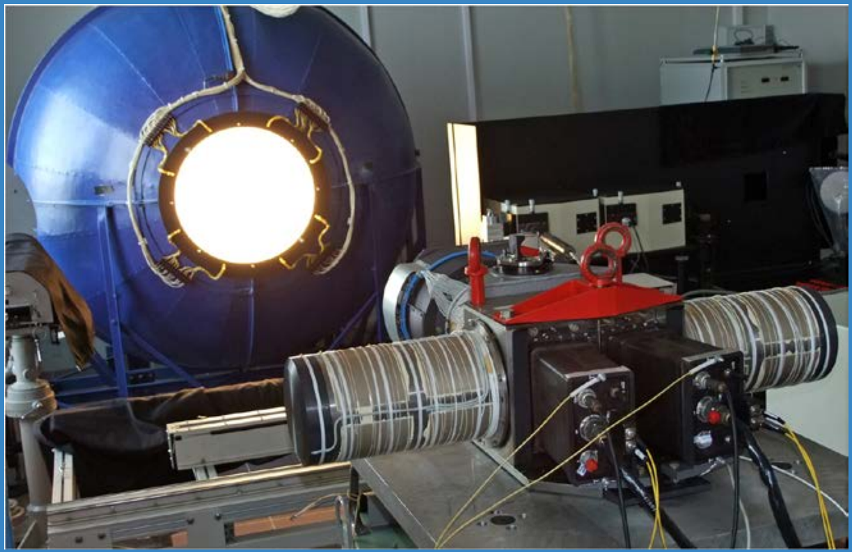
Figure 5. *The phase transition temperature plateau of the Gallium cell for a case when the black body is connected to the vacuum chamber but without a liquid nitrogen in the reservoir.*

Hyper-Spectral Earth Observation Instrument and its Pre-flight Calibration

Hyper-spectral Earth observation instrument GSA-RP intended for operation onboard the Resurs-P spacecraft was designed under the contract with Space Rocket Center TsSKB-Progress, to be used for space-borne earth observation in the spectral range 400 - 960 nm.

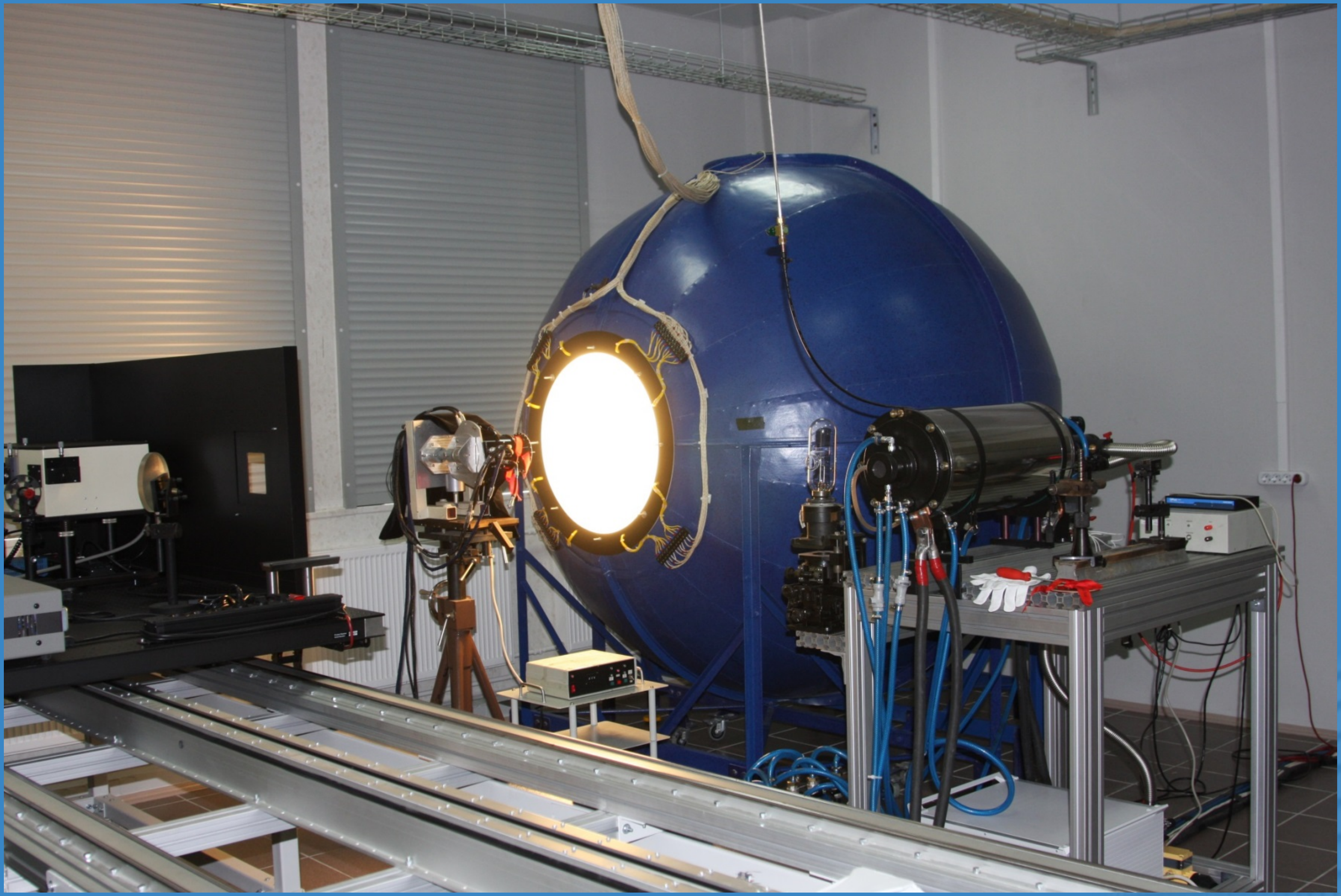
The instrument was calibrated at VNIIOFI against an IS spectral radiance source (600 mm aperture), which was compared with a high-temperature BB traceable to SI via a set of high-temperature fixed points.

Hyper-spectral Earth observation instrument GSA-RP located atop the Resurs-P satellite.



Calibration of GSA-RP unit at VNIIOFI against National Standard

Calibration of space-borne radiometer (IKI Russia Ac.Sci) at FGUP "VNIIOFI"



2

In-flight calibration of Earth Observation Instruments

Development of the novel space-borne standard blackbodies that incorporate the phase transition phenomenon

Current techniques cannot ensure proper verification of stability and consistency of radiometric scales at the stated level. Potentially this task can be solved through the development of the novel space-borne standard blackbodies that incorporate the phase transition phenomenon.

For this purpose individual substances and eutectic alloys with the phase transition temperatures lying in the dynamic range of temperature measurements with Earth observation systems (~ 230÷350 K) are to be studied.

Investigations in this field at VNIIOFI were started from laboratory experiments with the suitable phase-change materials (PCMs), and further proceeded with flight tests of the PCMs and the novel space-borne fixed-point BB prototypes (with different PCMs) in zero-gravity environment.

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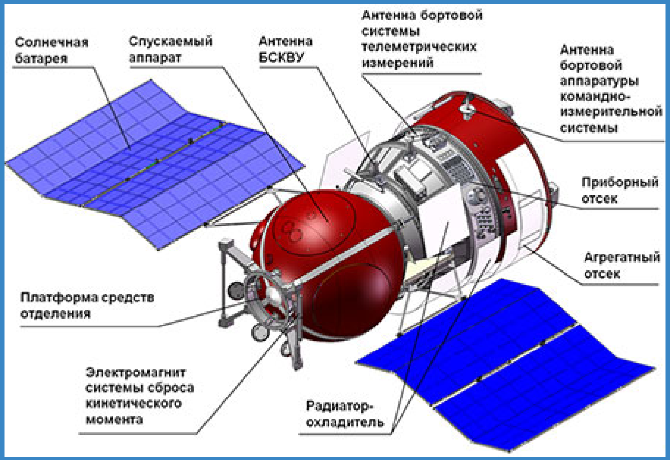
Flight tests

		Experiment "KALIBR" on board the "Foton-M" #4 Flight test of the novel high stable space-borne BB prototype (completed in 2014)	Planned experiment "REPER-KALIBR" on board the ISS In-depth study of the PCMs in zero-gravity environment (is being prepared)		Planned experiment "KALIBR-2" on board the "Bion-M" #2 Flight test of the novel high stable space-borne BB prototype (is being prepared) (launch – 2021)
PCM	Approximate melting T, K		1-st stage (launch – 2018)	2-nd stage (launch – 2021)	
H_2O	273.15				
Ga-In	288.8				
Ga-Sn	293.6				
Ga-Zn	298.3				
Ga	302.9	The space-borne fixed-point BB test model with the Ga as a PCM			
In-Bi	345.7				The space-borne fixed-point BB test model with the eutectic alloy In-Bi as a PCM

SPACE EXPERIMENT "KALIBR"

PURPOSE:
Studies of the effect of zero-gravity on the temperature characteristics of phase transitions to be used as the fixed points in the calibration of equipment for radiometric measurements within the framework of Global Earth Observation System (GEOSS);

The FIRST FLIGHT TEST of the prototype of the novel high-stable space-borne calibration blackbody incorporating the phase transition phenomenon.

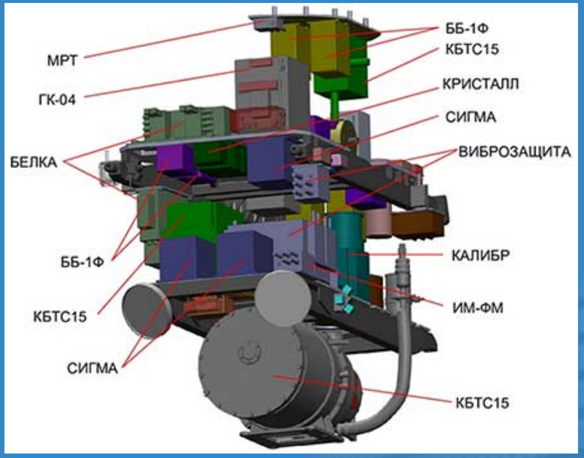


"PHOTON-M" No.4 spacecraft

The device KALIBR designed for the flight test on board the "PHOTON-M" No.4 spacecraft

a – prototype of the novel space-borne calibrator based upon the phase transition (the Ga fixed-point blackbody)

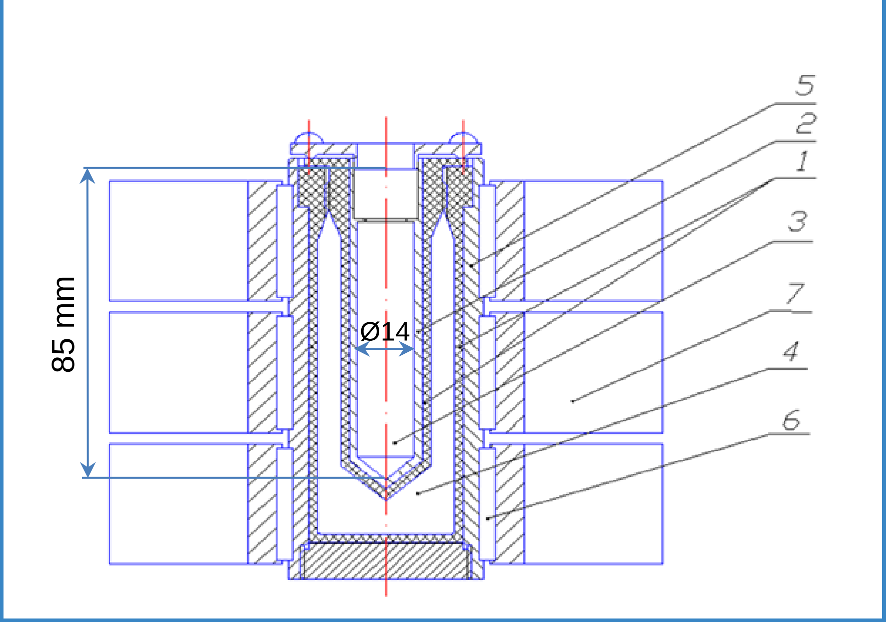
b – control unit



Placement of scientific equipment inside the lander of "PHOTON-M" No.4 spacecraft

SPACE EXPERIMENT “KALIBR”

The first space experiment with the novel high-stable space-borne fixed-point blackbody prototype KALIBR was carried out by VNIIOFI and Central Research Institute of Machine Building (TSNIIMASH, Russia) on board the “PHOTON-M" No.4 spacecraft in 2014.

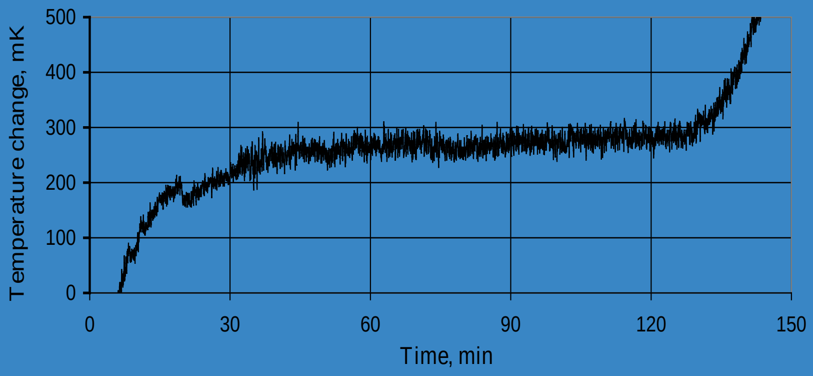


Scheme drawing of the prospective space-borne blackbody test model KALIBR utilizing the Gallium as a phase-change material:

1- Teflon cell; 2 – Metallic inlay; 3 – Cavity;
4 – Phase change material (Ga); 5 – Heat exchanger;
6 – Thermoelectric module; 7 – Heat sink

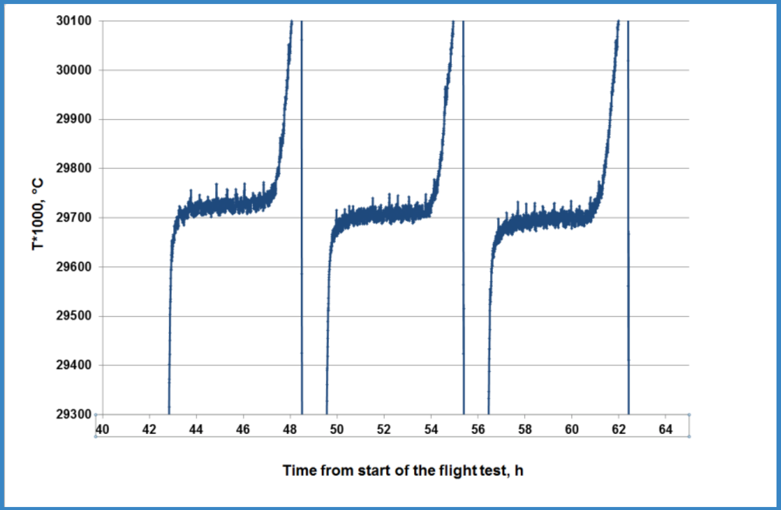
SPACE EXPERIMENT "KALIBR"

Pre-flight studies:



Stabilization of the space-borne BB test model KALIBR cavity temperature during the Gallium melt transition

Flight test:

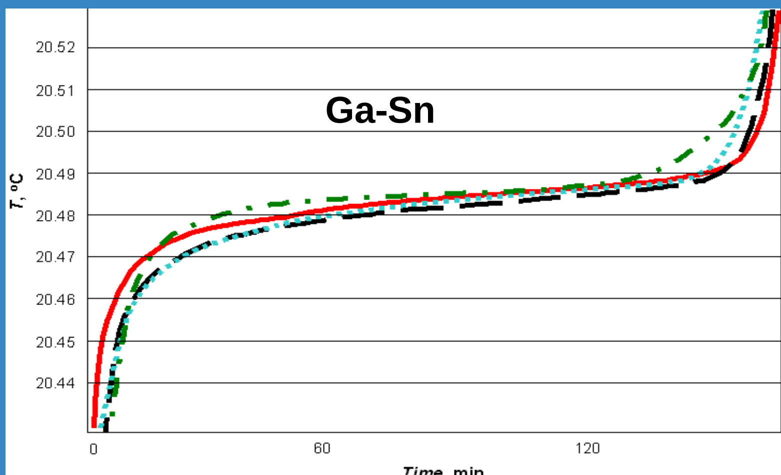


Typical series of Ga melting plateaus obtained under zero-gravity conditions in flight test

Obtained in zero-gravity melting plateaus demonstrate rather good repeatability: about 15 mK (1σ)

“REPER-KALIBR” experiment (1st STAGE)

Pre-flight laboratory studies of the phase-change materials selected for the flight test (Ga-based eutectics)



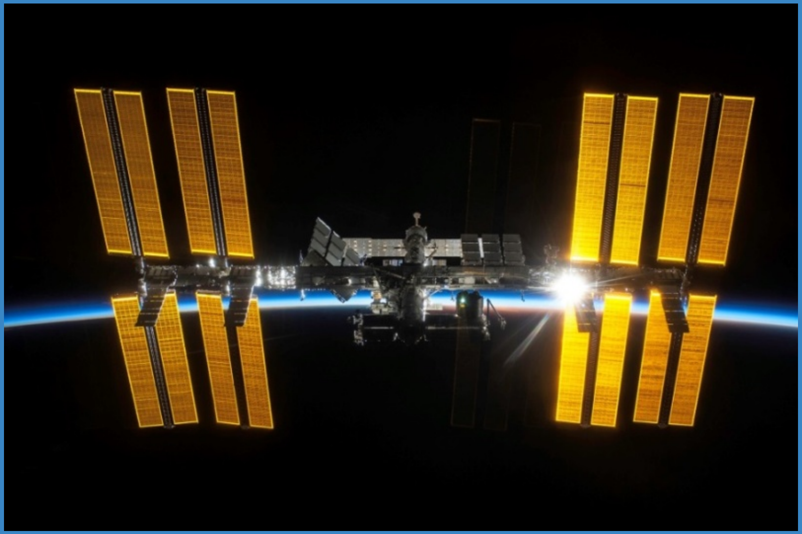
Demonstration of the selected PCMs melting plateaus repeatability by example of Ga-Sn eutectic alloy.
(at realization in small-sized cells)

Substance	Melting temperature (approximate) K	Repeatability (δ) (individual sequences) mK	Overall repeatability (δ_{ov}) mK
Ga	302.91	1 – 1.5	2.5
Ga-In	288.81	1 – 2	3.0
Ga-Sn	293.63	1 - 2	3.0

Repeatability of fixed points of the most promising PCMs to be studied in “REPEP-KALIBR “flight test.
(at realization in small-sized cells)

Pre-flight preparation: development of the equipment

Flight test “REPER-KALIBR” with the PCMs potentially suitable for on-orbit temperature and radiometric references - within the dynamic temperature range - is being prepared at VNIIOFI and Russian Space Corporation "Energia“.



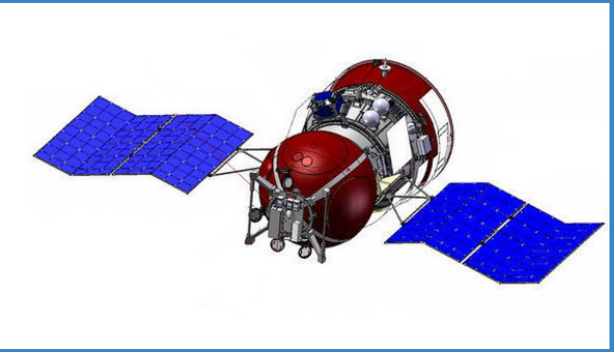
The equipment to be delivered to the ISS for realization “REPER-KALIBR” experiment with Ga-based eutectics (1st stage)

1 – Control block
2 – Container for changeable thermal blocks (individual block for every PCM to be studied)

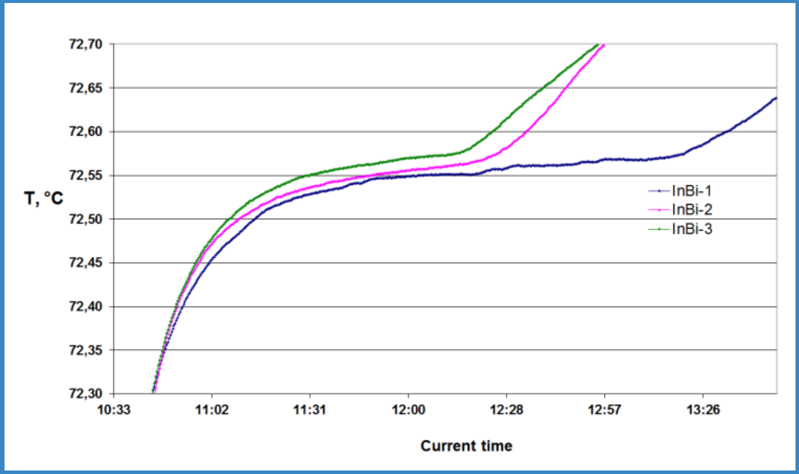
SPACE EXPERIMENT "KALIBR-2"
Pre-flight laboratory studies

In-Bi eutectic alloy was selected as a phase-change material for the novel high-stable space-borne blackbody prototype KALIBR-2

Eutectic alloy	Cell marking	Alloy mass, g	Composition, mass%	Nominal eutectic composition, mass%
In-Bi	InBi-1	150	33,27% Bi	~ 33,26 % Bi
	InBi-2	150	37,1% Bi	
	InBi-3	150	24% Bi	



In-Bi fixed points in small-sized cells



Typical melting plateaus of InBi-1, InBi-2, InBi-3 fixed points
(at realization in small cells)

The spacecraft model "Bion-M"

Conclusion:
Development of the novel space-borne standard blackbodies incorporating the phase transition phenomenon

The experiment on board the "Foton-M" No.4 spacecraft with the Ga fixed-point BB (~ 302.9 K) is the first step to establishing "on-orbit radiometric temperature scale" based on the space-borne low-temperature fixed-point standard blackbodies.

The next important step in this direction will be experiment with the space-borne blackbody test model KALIBR-2 (on board the “Bion-M” No.4 spacecraft) utilizing the fixed point of eutectic alloy In-Bi of higher temperature (~ 345.7 K).

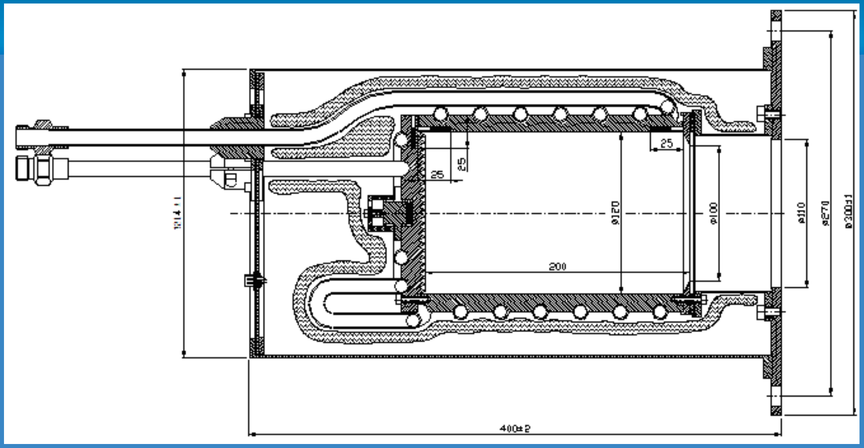
Establishing "on-orbit radiometric temperature scale" is targeted at ensuring compatibility of data on different IR instruments within the dynamic range of temperature measurements with Earth observation systems (~ 230÷350 K).

A number of onboard reference blackbodies utilizing suitable PCMs, including Ga (PCM of the KALIBR) and alloy In-Bi (PCM of the prospective KALIBR-2), should be developed to achieve this goal.

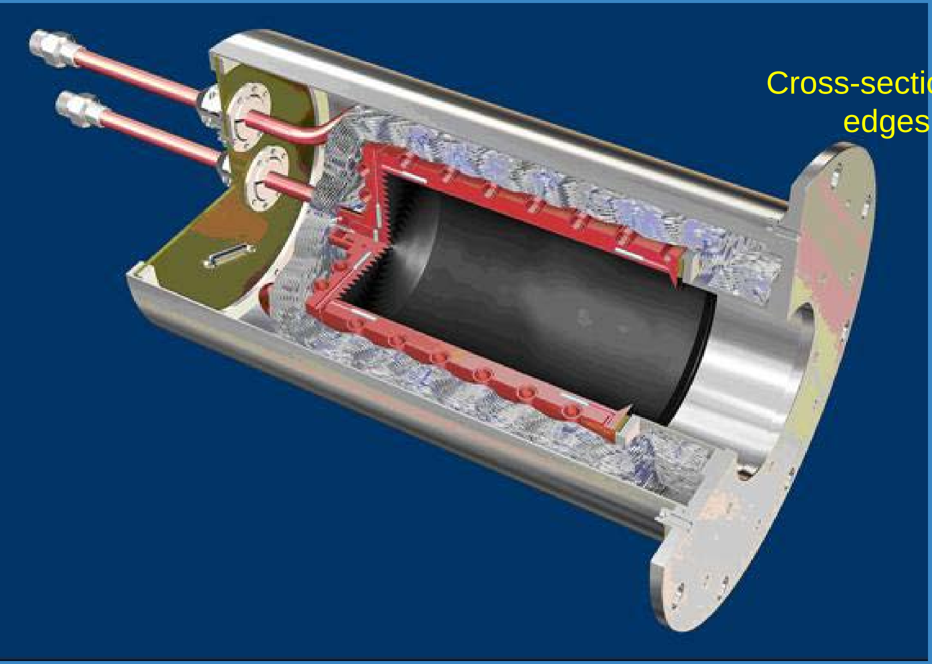
3

Low-temperature BBs for remote-sensing instruments' calibration

Low-temperature blackbody **BB-100V1** for JAXA and NEC-Toshiba Space Systems, Japan



Cross-section of BB100-V1 blackbody. The PRT-100 sensors are located at the edges and in the middle of cavity bottom, and in lateral walls – close to the cavity bottom, and in the vicinity of blackbody opening aperture.

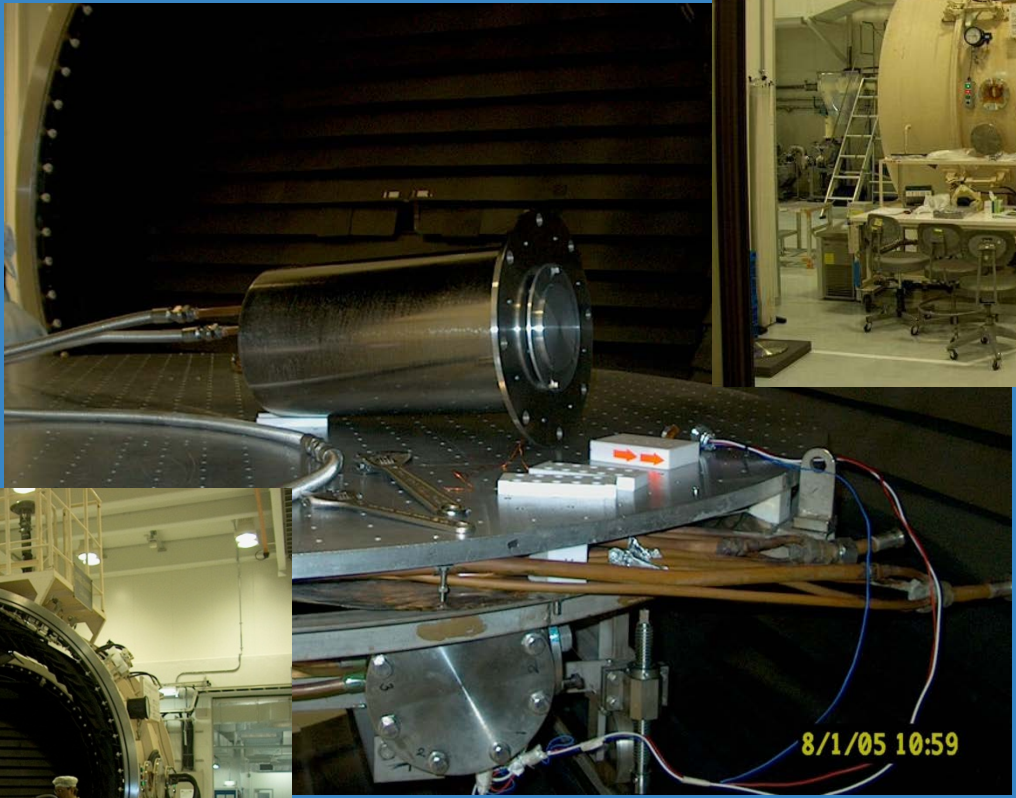


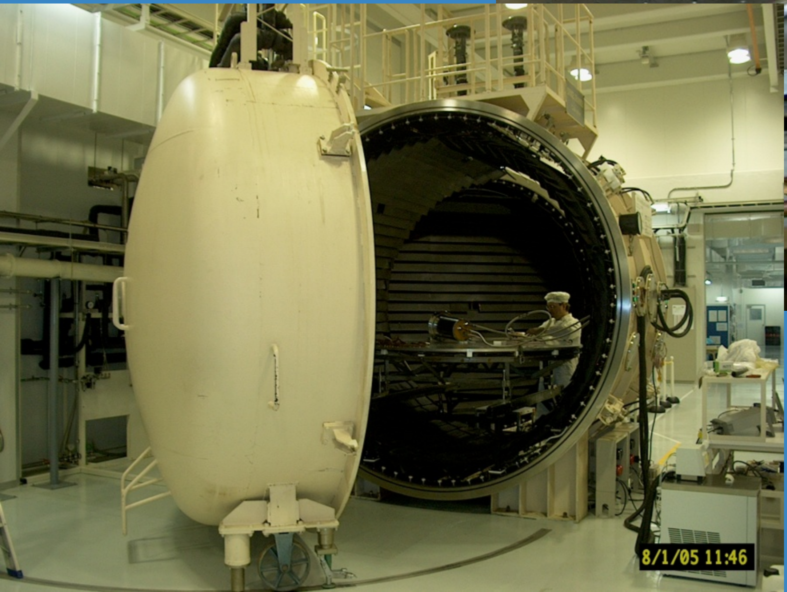
3-D view (computer ACAD simulation) of BB100-V1 blackbody.
The screen-vacuum insulation around black radiating cavity is made of multilayered polyethlenetheraftalat film

Specifications

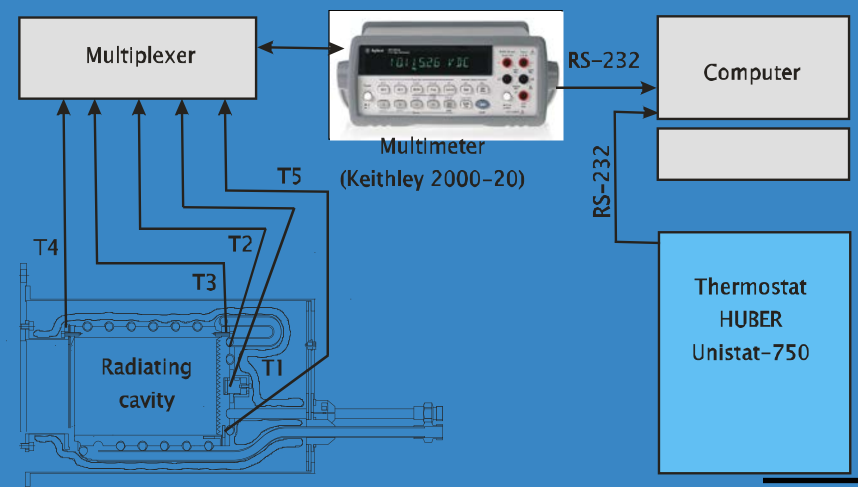
Maximum operating temperature	350 K (77ºC)
Minimum operating temperature	240 K (-33ºC)
Spectral range	1.5 μm – 15 μm
Cavity effective emissivity	0.997 ± 0.001 (estimated from STEEP3 computer modeling)
Opening (non-precision aperture)	Ø100 mm
System Field-of-View (FOV)	12 mrad (0.688º)
Environment operation conditions	
Vacuum chamber:	10^{-6} Torr, below 100 K
Air environment	clean room at 23 ± 3ºC
T non-uniformity across opening	0.04 K
Temperature set point resolution	0.01 K
Maximum T instability under thermostabilization	± 0.02 K (1-hr measurement)

Tests **BB-100V1** in space chamber of NEC-Toshiba Space Systems, Japan

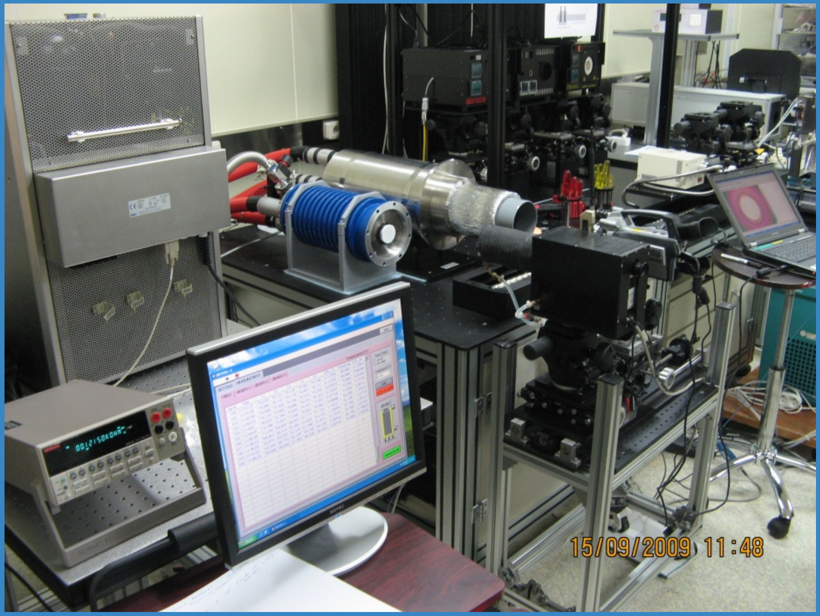




Low temperature **BB100K1** for KRISS, South Korea

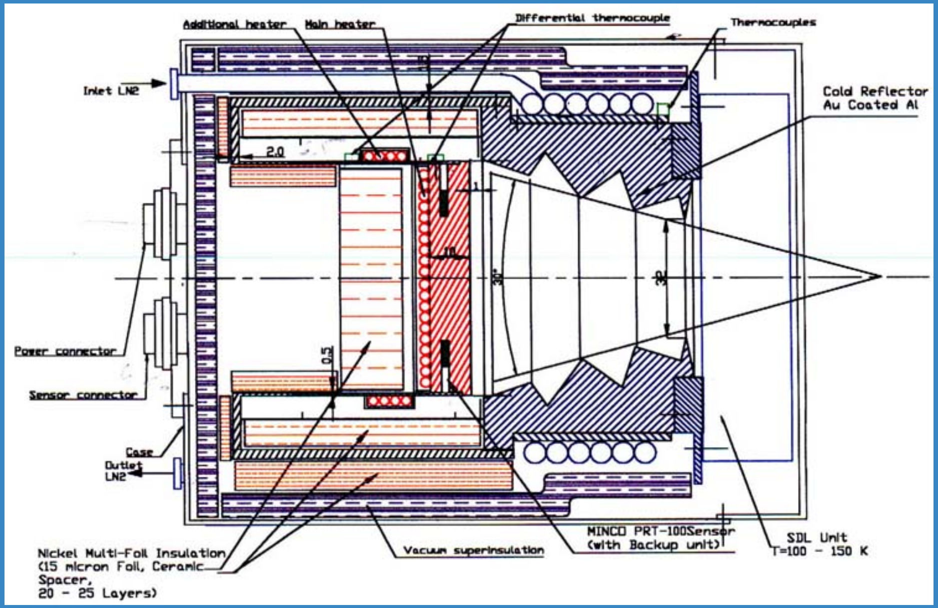


Blackbody BB100K1



Parameter	Value
Environment operation conditions:	vacuum (10^{-4} Torr) or inert or N_2 gas purge or open air (with special measures below dew point)
Working Temperature range:	(- 60 to 90) °C – in vacuum (- 40 to 90) °C – in inert gas or dried air (- 20 to 90) °C – at open air
Cavity inner diameter:	120 mm
Opening diameter:	100 mm
Temperature gradient along cavity:	≤ ± 0.1 °C
Temperature Instability:	≤ ± 0.05 °C
Temperature control:	by means of external thermostat-circulator
Incorporated temperature sensors:	5 PRTs (100 Ω)

Middle-temperature blackbody
BB1000
for SDL, USA

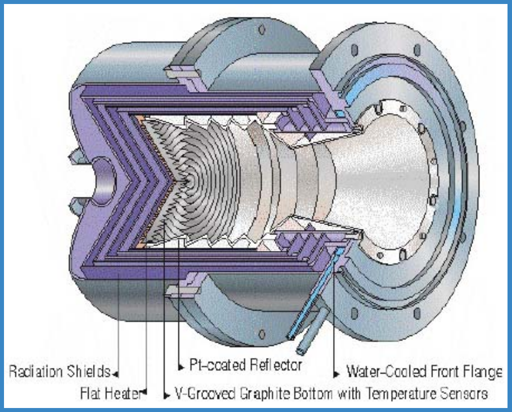


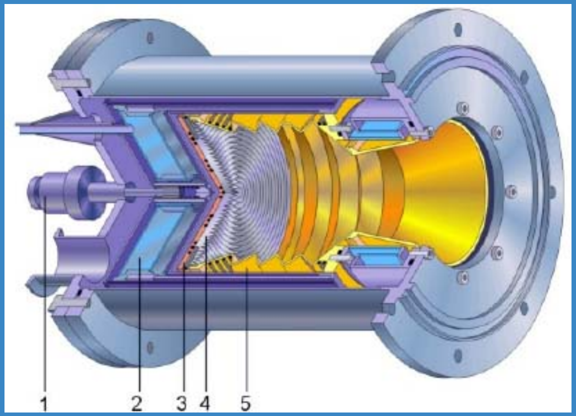
Parameter	Realized
Aperture diameter at blackbody interface plate	6.4 to 32 mm
Operating temperature	400 …1000 K
Temperature of radiative environment	80 K to 300 K
Maximum absolute radiometric Temperature uncertainty for 2.7 to 5.5 mm bandwidth < 0.5K (1s), of temperature (1s) from 500 to 800 K	400 to 500 K < 1%
Spectral Range	2.7 to 5.5 mm
Emissivity	> 0.99
Maximum Spatial Spectral non-uniformity	0.8% (1s) flux at 2.7 mm < 800K
System field of view	30^0
Maximum temperature instability	0.3% (1s) flux at 2.7 mm < 800 K
Operating environment Pressure	10^{-6} torr

Middle-temperature blackbodies

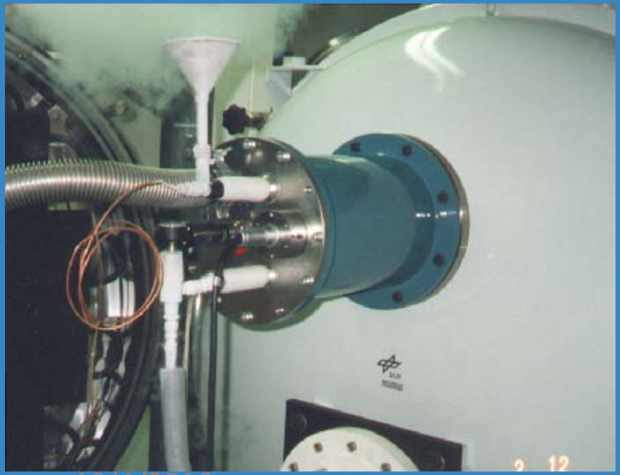
BB900-BB100

for DLR, Germany





Calibration of sensitive IR optical sensors, such as spaceborne radiometers, requires operation at reduced levels of background radiation. For characterization of complete systems in absolute units, extended sources of radiation are usually used, while measurements of relative parameters allow use of smaller sources with collimator.



Specifications	
Aperture Diameter, mm	**100**
Viewing Angle, °	**±12**
Effective Spectral Emissivity in 3 µm to 15 µ m Band	**0.995**
Temperature Range, K	**400-900**
Temperature Uniformity Across Aperture, K	**0.2**
Temperature Setting and Measuring Accuracy, K	**0.5**

ФГУП
ВСЕРОССИЙСКИЙ
НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ
ИНСТИТУТ ОПТИКО-ФИЗИЧЕСКИХ ИЗМЕРЕНИЙ
ФЕДЕРАЛЬНОГО АГЕНТСТВА ПО ТЕХНИЧЕСКОМУ
РЕГУЛИРОВАНИЮ И МЕТРОЛОГИИ РФ

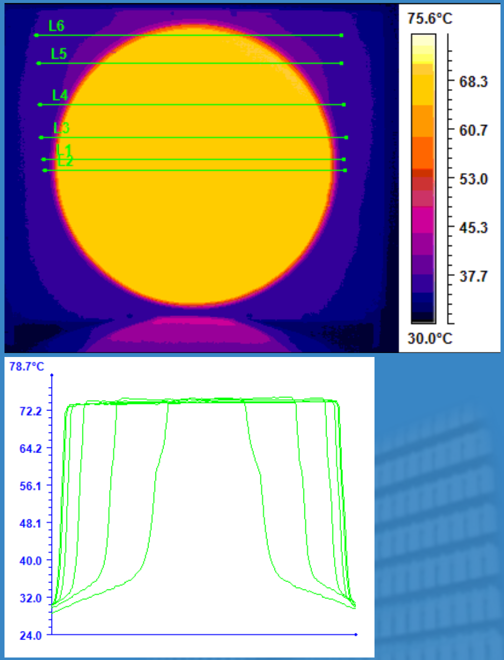
Low-temperature blackbody
BB80/350
for RNIIKP [RISDE], Russia

Specifications

Operating temperature range	220-350 K
Additional set point	313 K
Working aperture	350 mm
Spectral range	2.5…15 μm
Emissivity	0.96 ± 0.02
Max. temperature instability under thermostabilization	0.1 K
Temperature non-uniformity across opening (at 280…300 K)	± 0.1 K
Confidence uncertainty of radiation temperature reproducibility at 300 K (at 0.95 confidence probability)	0.5 K
time period of temperature change on 5 K	< 10 min
Continuous operation time	8 hrs

Working conditions:

(1)in housing	Dry Nitrogen gas atmosphere, normalized pressure; $T_{environment}$ 0…30 ^{0}C ;
(2) in vac. chamber	P = 10^{-5}…10^{-8} Torr; T of chamber walls 77 K



BB-80/350 aperture scan at T = 72.2 ^{0}C.

Thank you !