Next Generation Infrared Sources

Dave Smith - Presenter

24th June 2020


NGenIRS Project Team

- Dan Peters, Tim Nightingale, Tom Morse, Gayatri Patel, Coraline Dalibot, Robert Hardie, Ben Cartwright, Luke Bushnell, Mike Shepherd, Adam Hughes, Connor McGurk, Nick Waltham – RAL Space

- Radka Veltcheva, Jonathan Pearce - NPL

- Ben Jensen, Steve Northam – Surrey Nanosystems

Thermal Infrared Measurements

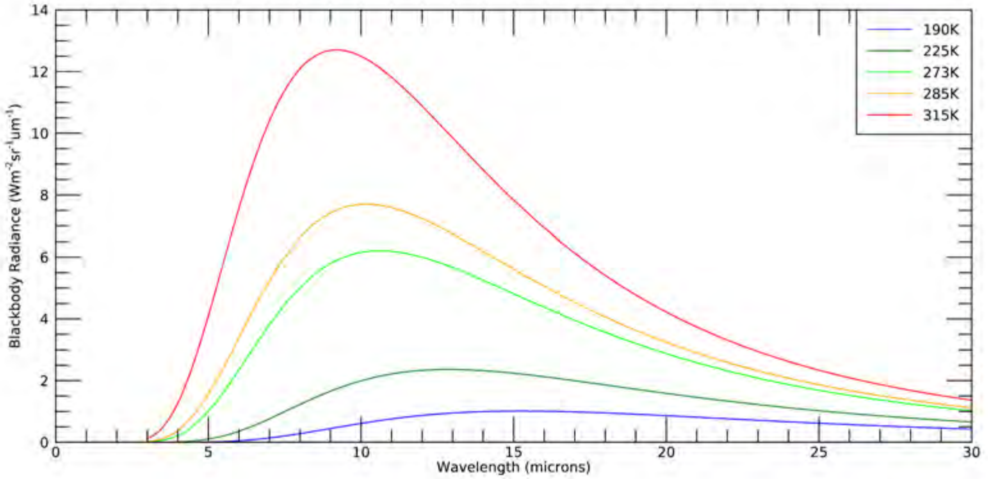
RAL Space

- Observations in the thermal infrared wavelength range (3-20microns) are useful for measurements of:

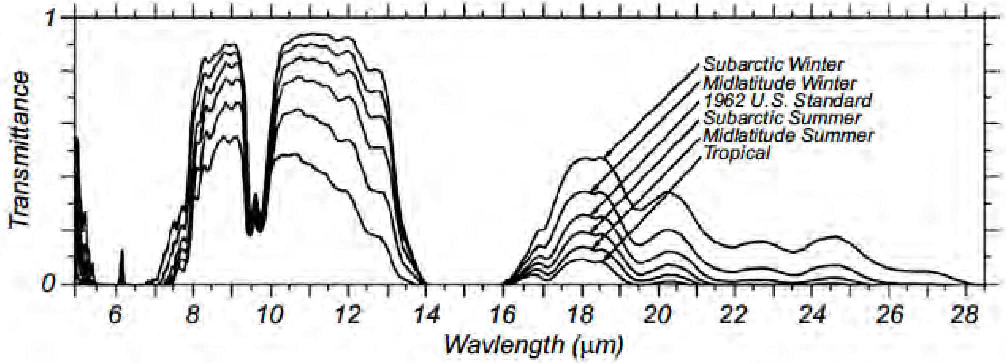
$$B(\lambda,T) = \frac{2hc^2}{\lambda^5\left(exp\left(\frac{hc}{\lambda k_b T}\right) - 1\right)}$$

h = Plank's constant
c = the velocity of light in vacuum
K_b= Boltzmann's constant

- Surface Temperature Measurements
  - Oceans
  - Inland waters
  - Land
  - Fires
  - Volcanoes

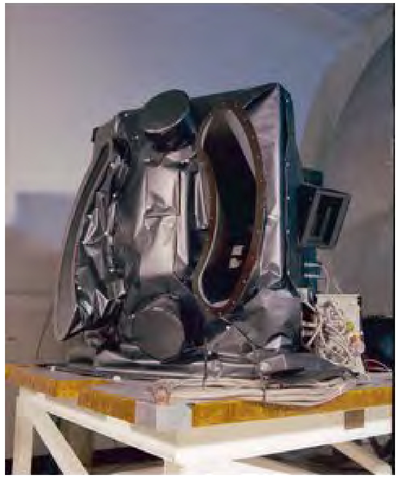


- Atmospheric Sounding
  - Temperature
  - Trace gases
  - Aerosols
  - Clouds



Calibrating IR Instruments (Concept)

RAL Space


Instrument

←


Blackbody Source

←


S-PRT

←


Fixed Point Cells

UK SPACE AGENCY

CEOI

NPL National Physical Laboratory

UKRI Science and Technology Facilities Council

surrey nanosystems

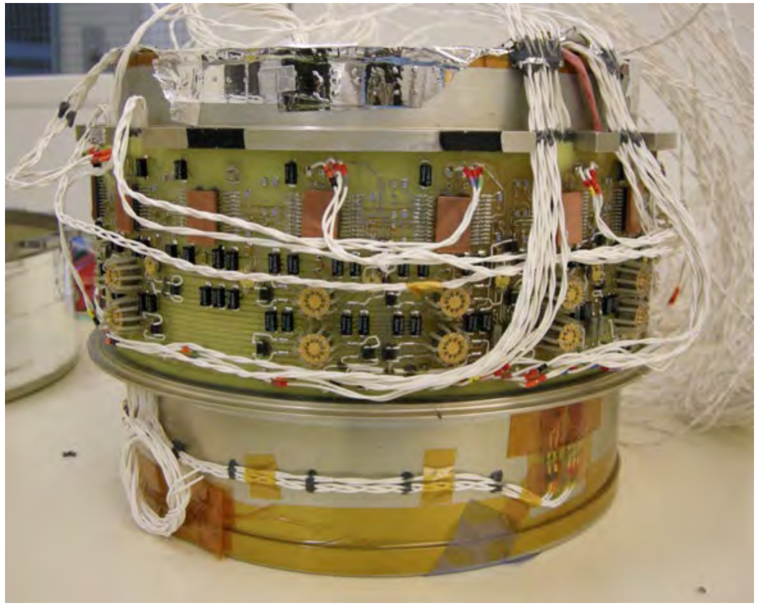
Blackbody Heritage

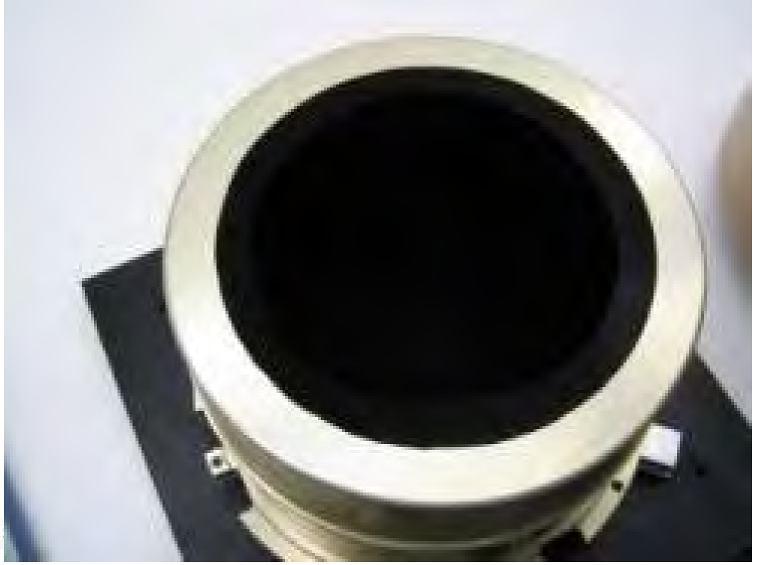
- Design was a direct development of the ATSR design for the Sentinel-3 SLSTR instrument.

- Fully redundant electronics and thermometers
  - Increased number of components
  - Increased power dissipation into cavity – affecting uniformity
  - More complex integration

- Increased diameter to accommodate 2 optical beams (nadir + oblique views)

- Demands from S3 budgets led to mass and volume reductions





Towards In-Flight Traceability

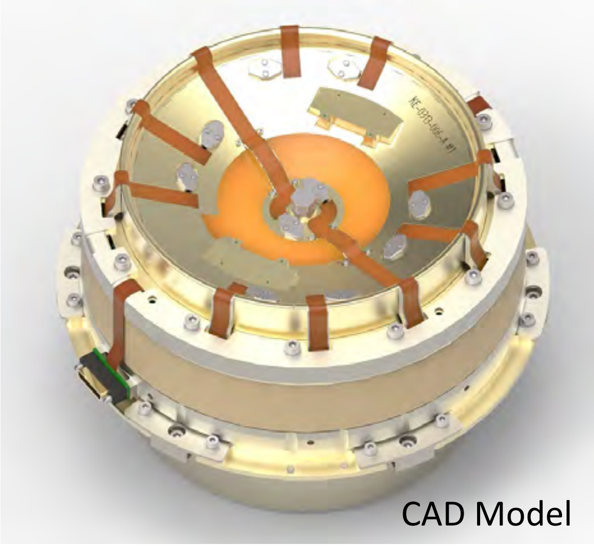
- Despite having on-board calibration systems, pre-launch calibration, in-flight monitoring, cross-calibration methods, demonstrating traceability to SI in the TIR is very difficult!

- Many assumptions are made:
  - Knowledge of on-board source radiances
  - Stability of on-board sources
  - Stability of spectral response
  - Etc...

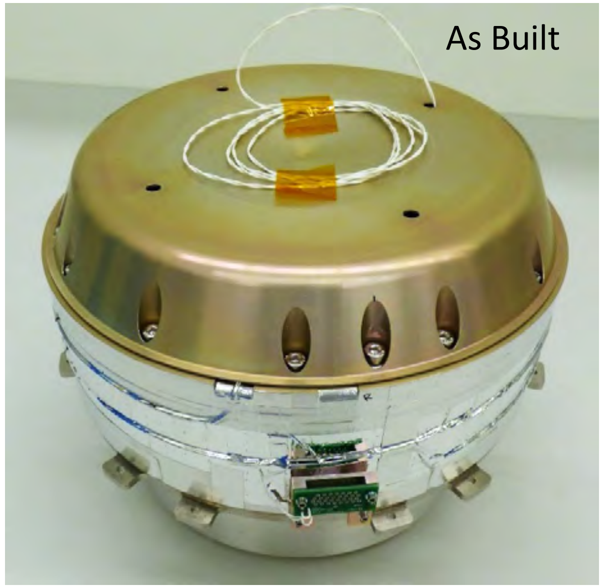
- How to provide on-orbit traceability?

CEOI-11 NGenIRS Project

- **N**ext **Gen**eration **I**nfra**R**ed Calibration **S**ources
- Project Objectives:
  - To build and characterise a fully functional prototype flight blackbody demonstrator whilst advancing key technologies:
    - Critical electronics for lower power and high accuracy thermometry;
    - Phase change cells to allow on-orbit temperature;
    - Utilisation of carbon-nano coating process for infrared calibration sources.
  - Demonstration in operational environment to achieve TRL-5/6.
  - Advancement of flight blackbody sources that may be exploited for future Earth Observation and Meteorological missions.
- Building upon heritage from the SLSTR and 3 successful NSTP pathfinder precursor projects.



CAD Model



As Built

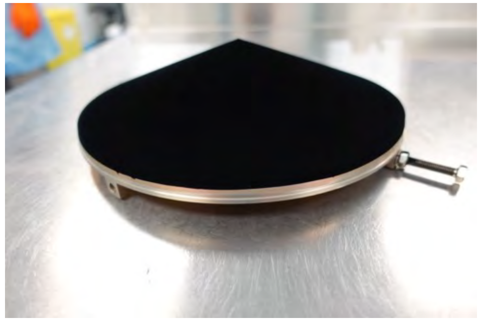
Target Missions and Benefits

- Target Missions – Earth Observation:
  - The Land Surface Temperature Mission (LSTM) for the Copernicus Sentinel extension programme;
  - Earth Explorer-9 Far-infrared Outgoing Radiation Understanding and Monitoring (EE9 FORUM) which plans to measure the Earth's entire emission spectrum from 3.62 µm – 100 µm;
  - Sentinel-3 next generation which would replace the current Sentinel-3A – D.

- Main Benefits:
  - To provide in-orbit traceability to international standards (ITS-90) that is not currently available for flight missions;
  - Advancement of flight black body sources that may be exploited for future Earth Observation and Meteorological missions;
  - Brings together work from three successful NSTP Pathfinder precursor projects (TRL-2/3) into a fully functional, flight-representative black body (TRL-5/6).

BB Technology Developments

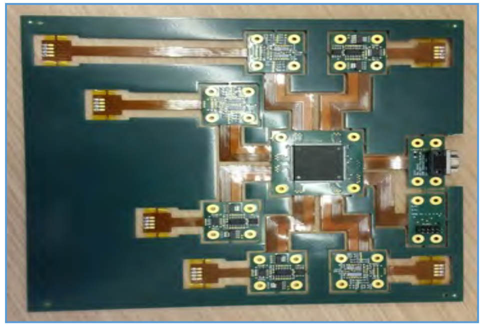
Black Coating Technology



Surrey Nano Systems (SNS) black coating based on carbon nano-tubes with high intrinsic emissivity

Applied to SLSTR BB target Geometry

Integrated BB electronics



Very high accuracy, low power, low mass, locally redundant thermometers, all-digital interface

Phase Change Cells

Height 420 mm

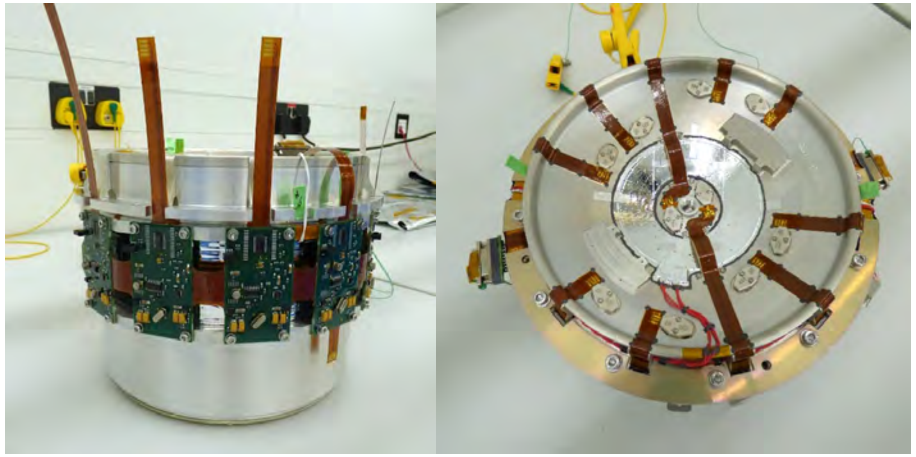
Melting point of Ga 29.7646 ºC

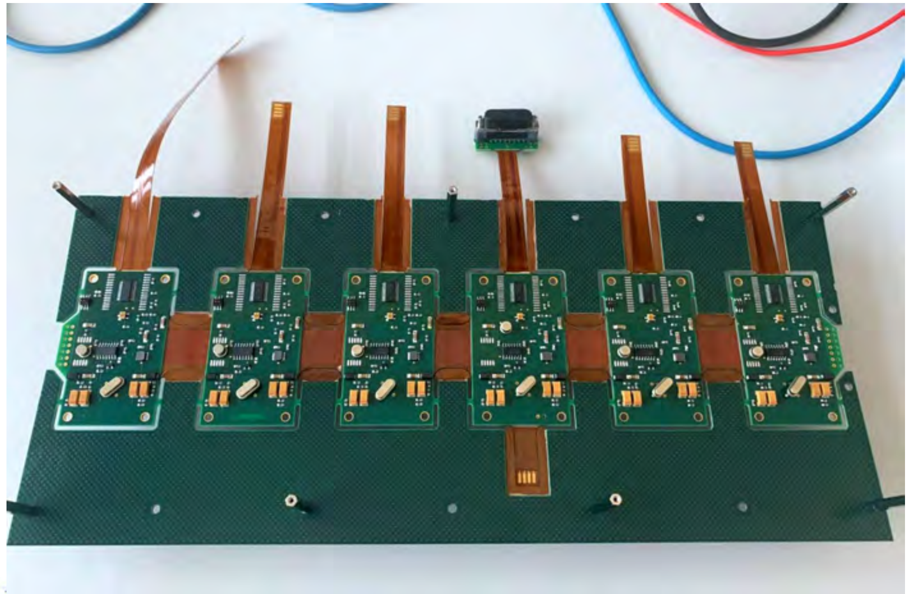
Traceable to SI kelvin

Uncertainty < 1 mK (standard cell)

Thermometry Electronics

- Pairs of semi rigid PCBs, each made up of interleaved thermometer sensor nodes;
- Extremely compact, lightweight, consumes little power, low noise and is mechanically robust;
- Provides an extremely simple Interface to the host spacecraft and requires no external circuitry beyond what is installed on the cavity.
- Uncertainty in thermometry calibration **<10mK at k=1** traced to ITS-90.

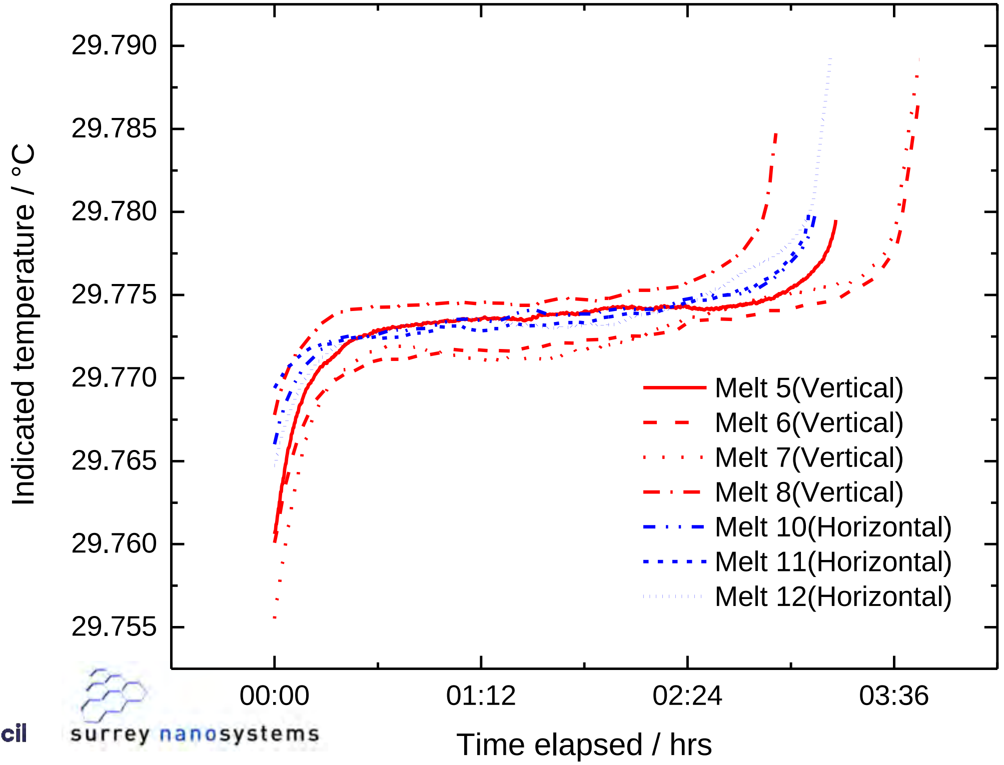




Miniaturised Phase Change Cells

- Gallium fixed point cell to allow in-orbit traceability to ITS-90 for in-orbit thermometry calibration;

- Key results:
  - Melting plateaux of several hours duration with temperature ranges of less than 5mK;
  - High degree of reproducibility (within 5 mK);
  - Consistent with the goal of **calibration uncertainties of better than 10 mK**;
  - Offset from the ITS-90 temperature of gallium was less than 8 mK under the specified conditions;
  - Freezing of the gallium has been established on a routine basis with only a minimum undercool.

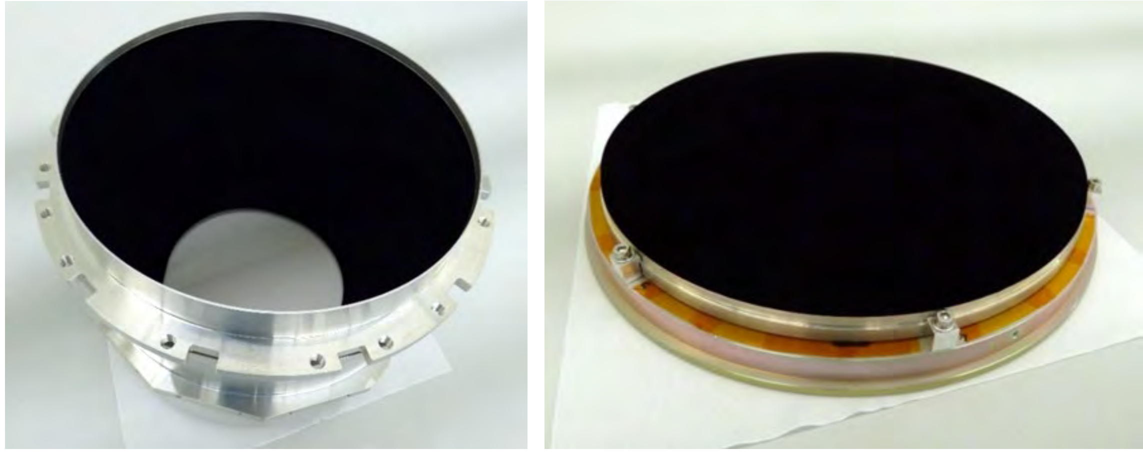


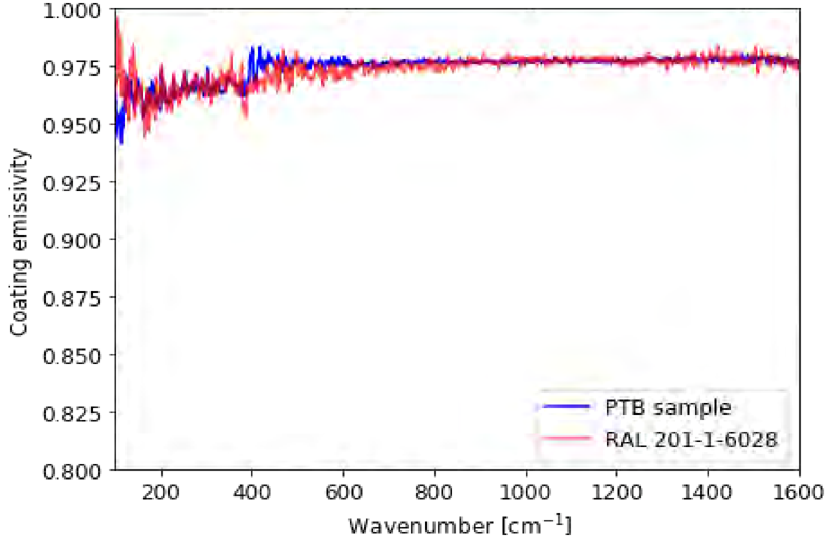
UK SPACE AGENCY   CEOI   NPL National Physical Laboratory   UKRI Science and Technology Facilities Council   surrey nanosystems

Vantablack® S-VIS coating

RAL Space

- An ultra-black carbon nanotube coating
- Emissivity > 0.95 over very wide wavelength range up to 100µm
    - Candidate coating material for EE9 FORUM and future BB sources
- NGenIRS black body cavity wall and base coated





S-VIS black coating emissivity measurements performed by PTB.

UK SPACE AGENCY

CEOI

NPL National Physical Laboratory

UKRI Science and Technology Facilities Council

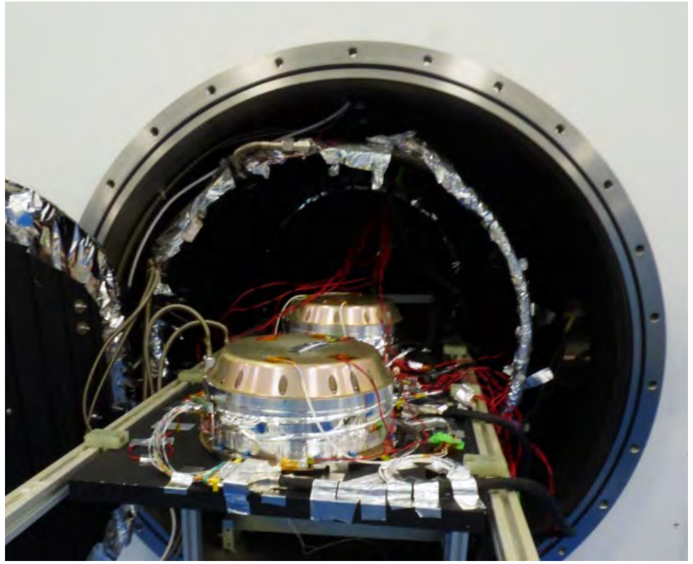
surrey nanosystems

Integrated System Tests

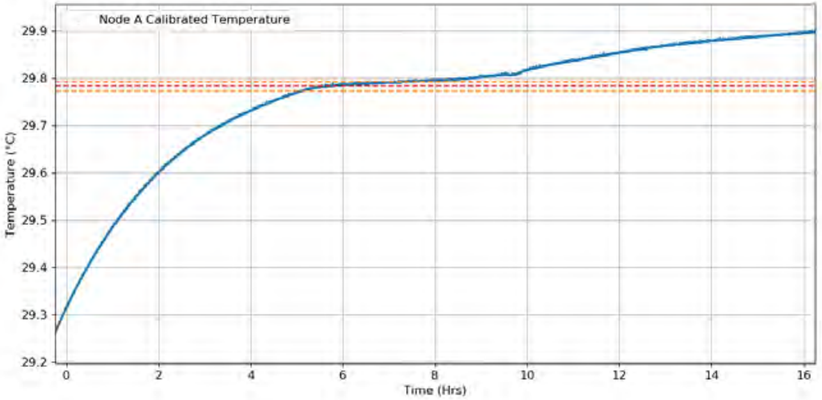
- Fully integrated NGenIRS BBC tested under flight representative thermal vacuum conditions.
    - Test plan was based on that used previously for SLSTR flight units
    - 4 thermal cycles including hot/cold non-operational and operational cases.
    - Thermal characterisation of BB temperatures at cold-operational case (worst case).
    - Thermometry system calibration referenced to SPRTs mounted on cavity (as for SLSTR, AATSR)
    - Demonstration of phase change transition in blackbody cavity

- Radiometric tests at PTB scheduled for September 2020
    - Validation of end-to-end radiometric performance against reference blackbody sources

NGenIRS (front) + Dummy (rear) in TVAC facility



Phase Change Transition as measured by BB thermometry (PRT + electronics)



Achievements and Current Status

- Demonstration of the ability to provide a fixed calibration reference within an existing flight blackbody cavity design to ensure on-orbit traceability to the SI kelvin.
- Demonstration of novel thermometry electronics and black body cavity could be calibrated as a system with uncertainties <10mK (k=1)
- Verification of performance of the critical functions within a flight representative thermal environment to demonstrate TRL-5.
- BB design has been selected as the baseline for the calibration system for one of the competing Phase A/B1 studies of the the EE9 FORUM mission.

Thank You

IOP Publishing
Measurement Science and Technology
Meas. Sci. Technol. **30** (2019) 124003 (11pp)
https://doi.org/10.1088/1361-6501/ab38e4

Miniature gallium phase-change cells for *in situ* thermometry calibrations in space

J V Pearce[1], R I Veltcheva[1], D M Peters[2], D Smith[2] and T Nightingale[2]

[1] National Physical Laboratory, Teddington, United Kingdom
[2] RAL Space, Harwell, United Kingdom

E-mail: jonathan.pearce@npl.co.uk

Received 1 June 2019, revised 23 July 2019
Accepted for publication 6 August 2019
Published 30 September 2019

Abstract

The melting point of gallium, 29.7646 °C, makes it a very convenient fixed point for *in situ* calibration of thermometry in space applications such as Earth observation. NPL and RAL Space have collaborated to develop a miniature 'phase-change cell' using gallium. This report describes the modelling, construction and thermal metrological performance of miniature phase change gallium cells. These cells are intended to be embedded in the calibration blackbody structure, near the temperature sensors, for the purpose of *in situ* recalibration of those sensors. In this study, the blackbody structure was simulated by a monolithic aluminium block, and the phase-change cell and thermometers were embedded within the block. A thermal model of the system was also developed using Comsol Multiphysics® and validated against the experimental results, which provides useful information on further optimisation of the system. Under the (realistic) test conditions in this study, the phase-change cell, containing 2.1 g of gallium, was able to produce clearly defined melting curves with a duration of several hours and melting range of less than 5 mK, which represents sufficient performance for the envisaged application. Overall it has been shown that the current design methodology is fit for purpose and represents a solid foundation for raising the technology readiness level sufficiently for in-flight use.

Keywords: phase change cell, gallium, ITS-90, *in situ* calibration, calibration blackbody, self-validation

(Some figures may appear in colour only in the online journal)

1. Introduction

The difference between the amount of energy impinging on the Earth from solar radiation and the amount emitted back into space, known as the Earth radiation imbalance (ERI) or sometimes Earth's energy imbalance (EEI) [1] is perhaps the single most important parameter for predicting the path of global warming and climate change over the next few decades [2, 3] because the net energy is absorbed mainly (around 90%) by the ocean. The ERI is less than 1% [4] and extremely difficult to measure accurately; traceability is a crucial feature of related measurement efforts. There are two ways of approaching the measurement of this effect, namely by (a) satellite-borne measurement of the sunlight reflected by Earth and heat radiated to space, and (b) measurement of changes in the heat stored in the ocean and other heat reservoirs on Earth. Both approaches are being vigorously pursued on a global basis, and this paper is concerned with an aspect of the former approach, namely improving the traceability of satellite-borne measurements.

Satellite-borne radiometric measurements rely on on-board blackbody cavities at known temperatures to provide *in situ* calibration at regular intervals. The calibration blackbodies must themselves be traceably calibrated. Early attempts at measuring the ERI in this way suffered from large discrepancies and separate satellites yielded inconsistent results [3]. Absolute accuracy is crucial [2]. Recent emphasis has therefore been on improving the accuracy and traceability of the radiometric measurements. Problems arising from the unknown time-dependent calibration drift of the on-board temperature sensors in the calibration blackbodies, even when they are carefully prepared [5], are best avoided by having an

1361-6501/19/124003+11$33.00

remote sensing
MDPI

Letter

Challenges for In-Flight Calibration of Thermal Infrared Instruments for Earth Observation

David Smith [1,*], Daniel Peters [1], Timothy Nightingale [1], Jonathan Pearce [2] and Radka Veltcheva [2]

[1] RAL Space, Science and Technology Facilities Council, Harwell, Oxford OX11 0QX, UK; daniel.peters@stfc.ac.uk (D.P.); tim.nightingale@stfc.ac.uk (T.N.)
[2] National Physical Laboratory, Teddington TW11 0LW, UK; jonathan.pearce@npl.co.uk (J.P.); radka.veltcheva@npl.co.uk (R.V.)
[*] Correspondence: dave.smith@stfc.ac.uk; Tel.: +44-1235-445996

Received: 28 April 2020; Accepted: 3 June 2020; Published: 5 June 2020

Abstract: Satellite instruments operating in the thermal infrared wavelength range >3 µm provide information for applications such as land surface temperature (LST), sea surface temperatures (SST), land surface emissivity, land classification, soil composition, volcanology, fire radiative power, cloud masking, aerosols, and trace gases. All these instruments are dependent on blackbody (BB) calibration sources to provide the traceability of the radiometric calibration to SI (Système International d'Unités). A key issue for flight BB sources is to maintain the traceability of the radiometric calibration from ground to orbit. For example, the temperature of the BB is measured by a number of precision thermometers that are calibrated against a reference Standard Platinum Resistance Thermometer (SPRT) to provide the traceability to the International Temperature Scale of 1990 (ITS-90). However, once calibrated the thermometer system is subject to drifts caused by on-ground testing, the launch and space environments. At best the uncertainties due to thermometer ageing can only be estimated as there is no direct method for recalibrating. Comparisons with other satellite sensors are useful for placing an upper limit on calibration drifts but do not themselves provide a traceable link to the SI. In this paper, we describe we describe some of the technology developments, including phase change cells for use as reference standards, thermometer readout electronics and implementation of novel coatings, that are in progress to enhance the traceability of flight calibration systems in the thermal infrared.

Keywords: thermal infra-red; calibration; black-bodies; phase change cells; ITS-90

1. Introduction

The Planck radiation law predicts that for temperatures that cover the typical range of earth scenes from 180 to 350 K, the peak of the radiation distribution occurs within the range 3–20 µm. Also, the radiances cover a wide dynamic range, particularly at wavelengths <5 µm. This makes observations in the thermal infrared range particularly useful for measurements of the Earth's surface temperatures and atmospheric sounding. Thermal InfraRed (TIR) measurements from satellite instruments have a range of applications ranging from global climate change monitoring, improved weather forecasting through assimilation of data into Numerical Weather Prediction (NWP) [1] and monitoring urban pollution, Table 1, presents a summary of applications from hyperspectral TIR imagers [2].

Remote Sens. **2020**, *12*, 1832; doi:10.3390/rs12111832
www.mdpi.com/journal/remotesensing