On-orbit Absolute Blackbody Emissivity Determination Using the Heated Halo Method

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Overview

• Introduction
  – Traceability of infrared blackbody radiance
  – Paint degradation in space
  – On-orbit Absolute Radiance Standard

• Heated Halo Emissivity Monitor
  – Test configuration
  – Emissivity results and uncertainty
  – Comparison between S-HIS, ARI and NIST measurements

• Summary
Traceable Blackbody Radiance

- Planck function: 
  \[ B_\nu(T) = \frac{2hc^2\nu^3}{\exp(h\nu c / k_B T) - 1} \]

- Blackbody radiance: 
  \[ I_{\nu, Blackbody}(\epsilon_\nu, T) = \epsilon_\nu \cdot B(T) \]
Traceable Blackbody Radiance

- Planck function:
  \[ B_\nu(T) = \frac{2hc^2\nu^3}{\exp(h\nu c / k_BT) - 1} \]

- Blackbody radiance:
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- Both temperature and emissivity of a blackbody must be known — on-orbit — throughout the lifetime of the instrument
Traceable Measurements for Climate

- Goody et al 1998 BAMS
- Anderson et al 2004 JQSRT
- Revercomb et al 2005 OSA
- Dykema and Anderson 2006 Metrologia
- National Research Council 2007 Decadal Survey
- Best et al 2007 CALCON
- Ohring 2008 ASIC3
- Leroy et al 2008 J. Climate
Absolute Radiance Interferometer
On-orbit Absolute Radiance Standard

- Cold Plate
- On-orbit Absolute Radiance Standard
- Conductive Bridge
- Outer enclosure
- Phase change cells (Ga, H$_2$O, Hg)
- Temperature controlled shroud
- Thermal isolator
- Thermistors
- Temperature controlled cavity
- Heated halo
Heritage for the On-orbit Absolute Radiance Standard

- Krutikov et al 2006 *Metrologia*
- Best et al 2008 *SPIE*
- Gero et al 2011 *Metrologia (submitted)*
NEWRAD 2011: Absolute Radiance Interferometer

- **Joe Taylor**, The University of Wisconsin Space Science and Engineering Center Absolute Radiance Interferometer
- **Fred Best**, On-orbit absolute radiance standard for future IR remote sensing instruments
- **John Dykema**, Infrared laser-based reflectance measurements for blackbody cavity emissivity determination
Paint Degradation in Space

Long Duration Exposure Facility

• Study effects of LEO exposure on various materials
• In LEO 1984-1990 (5.7 years)
• Samples of Z306 on Aluminum

Results

• Evidence of oxidation, erosion, removal of resins, appearance of silicate residues, cracking
• Quantitative changes in optical properties
Heated Halo Concept

Heated Halo
AERI BB Housing
AERI BB Cavity
Radiation Shield
Sensor
Heated Halo Concept

\[ R_{\text{obs}} = \varepsilon \cdot B(T_{\text{bb}}) + (1 - \varepsilon) \cdot [F \cdot B(T_{\text{halo}}) + (1 - F) \cdot B(T_{\text{room}})] \]

Direct radiance from BB
Reflected radiance from BB
Emissivity Calculation

Observed radiance:

\[ R_{\text{obs}} = \varepsilon \cdot B(T_{\text{bb}}) + (1 - \varepsilon) \cdot R_{\text{bg}}, \]
Emissivity Calculation

Observed radiance:

\[ R_{\text{obs}} = \varepsilon \cdot B(T_{\text{bb}}) + (1 - \varepsilon) \cdot R_{\text{bg}}, \]

\[ R_{\text{bg}} = [F \cdot B(T_{\text{halo}}) + (1 - F) \cdot B(T_{\text{room}})] \]
Emissivity Calculation

Observed radiance:

\[ R_{\text{obs}} = \varepsilon \cdot B(T_{\text{bb}}) + (1 - \varepsilon) \cdot R_{\text{bg}}, \]

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Emissivity/reflectivity measurement:

\[ \langle 1 - \varepsilon(t) \rangle_t = \left\langle \frac{R_{\text{obs}}(t) - B[T_{\text{bb}}(t)]}{R_{\text{bg}}(t) - B[T_{\text{bb}}(t)]} \right\rangle_t \]
Heated Halo Gen. 1
Heated Halo Gen. 1 Test Configuration (S-HIS)

AERI Blackbody

Heated Halo

Scanning HIS Aircraft Instrument

MCT, InSb detectors
AERI Blackbody Emissivity (Halo 1, S-HIS)
Emissivity Uncertainty (Halo 1, S-HIS)

Type B measurement uncertainty ($k = 3$)
Heated Halo Gen. 2
Heated Halo Gen. 2 Test Configuration (ARI)
Heated Halo Gen. 2 Test Configuration (ARI)
AERI Blackbody Emissivity (Halo 2, ARI)
Emissivity Uncertainty (Halo 2, ARI)

Type B measurement uncertainty $(k = 3)$
AERI Blackbody Emissivity (Halo 1, Halo 2)
AERI Blackbody Emissivity Comparison

Comparison with NIST measurements

Continued work corroborates earlier results and helps reduce uncertainty
Next Generation Heated Halo

Gen. 1

Gen. 2

Gen. 3

TRL 4

TRL 5

TRL 6
Summary

• Spectral emissivity measurement has been demonstrated with the Heated Halo configured with both the S-HIS and the ARI, using an AERI blackbody as the target
• 0.0006 measurement uncertainty achievable across most of the thermal infrared
• Primary “lesson learned” is the importance of controlling stray light contributions
• Agreement between observations using two different instruments validates the process for emissivity measurement with the Heated Halo
On-orbit Absolute Radiance Standard

- Outer enclosure
- Phase change cells (Ga, H$_2$O, Hg)
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AERI Blackbody Emissivity Comparison

![Graph showing emissivity comparison with wavenumber in cm⁻¹ on the x-axis and emissivity on the y-axis, with different lines and markers representing various models and measurements.]