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: $$B_{\tilde{\nu}}(T) = \frac{2hc^2\nu^3}{\exp(h\nu c / k_B T) - 1}$$
- Blackbody radiance: $$I_{\tilde{\nu},Blackbody}(\varepsilon_{\tilde{\nu}}, T) = \varepsilon_{\tilde{\nu}} \cdot B(T)$$

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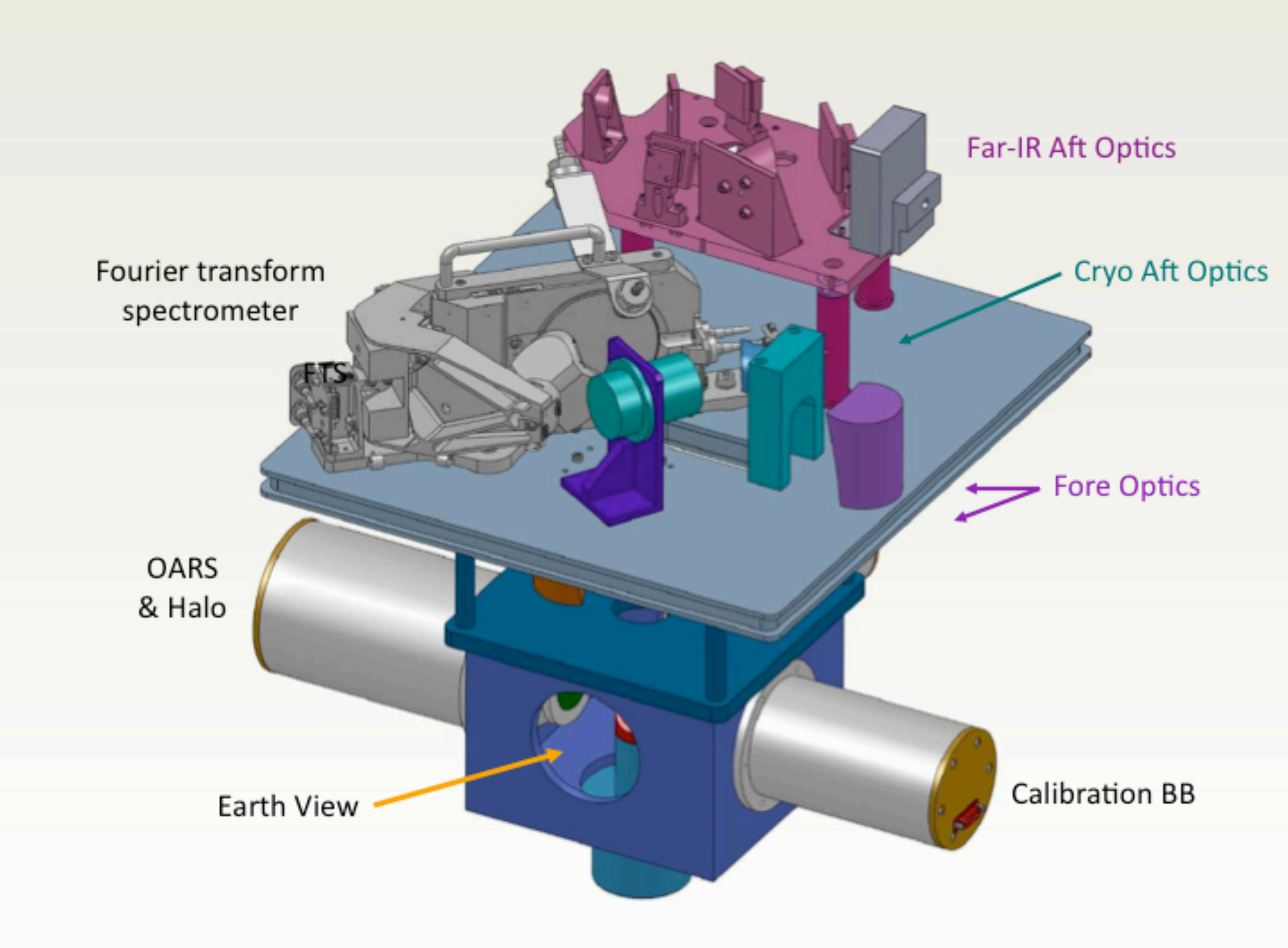
- Both temperature and emissivity of a blackbody must be known — on-orbit — throughout the lifetime of the instrument

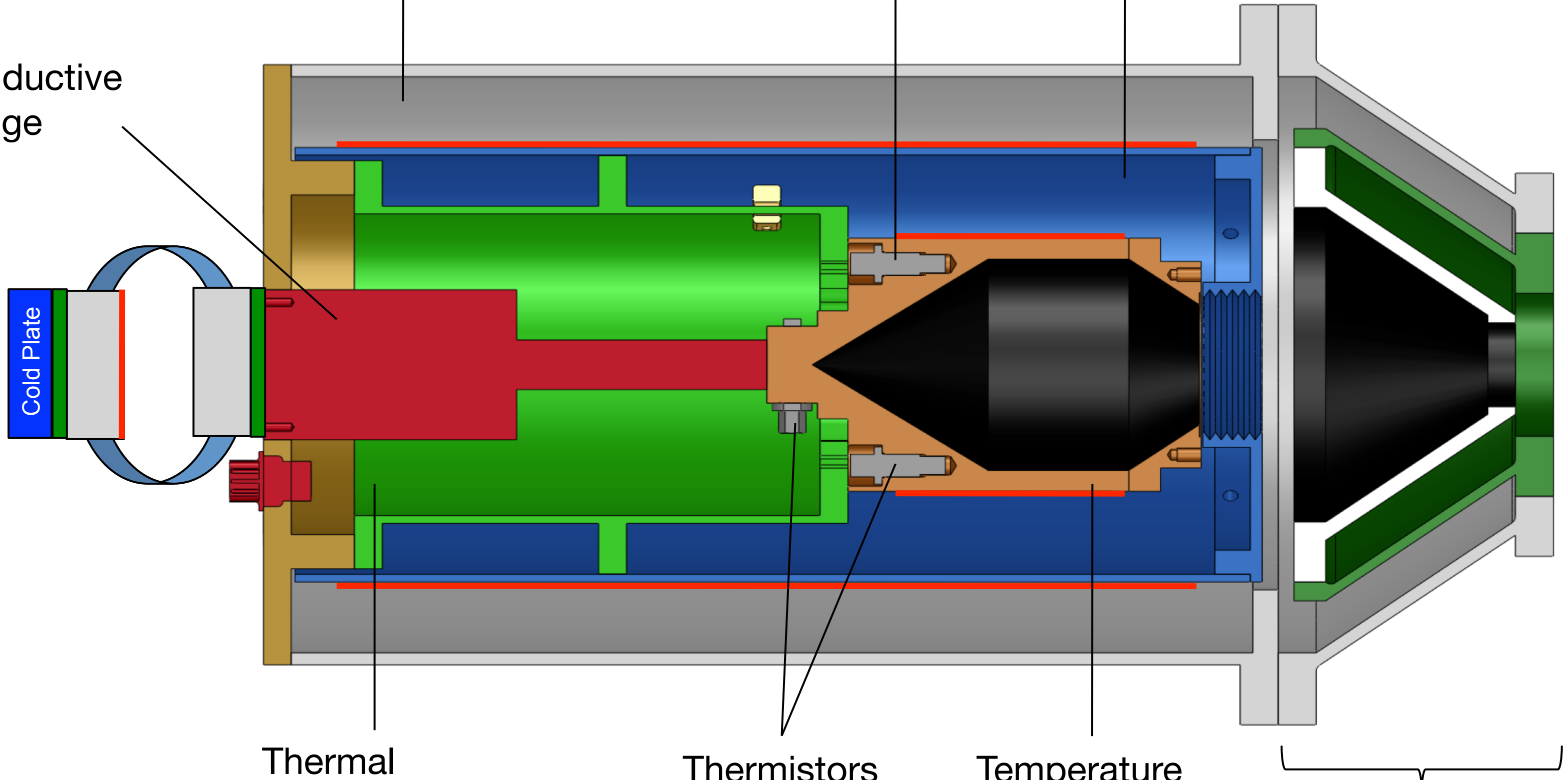
Traceable Measurements for Climate

- 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



Outer enclosure

Phase change cells
(Ga, H_2O, Hg)

Temperature
controlled shroud

Conductive
Bridge

Thermal
isolator

Thermistors

Temperature
contolled cavity

Heated halo

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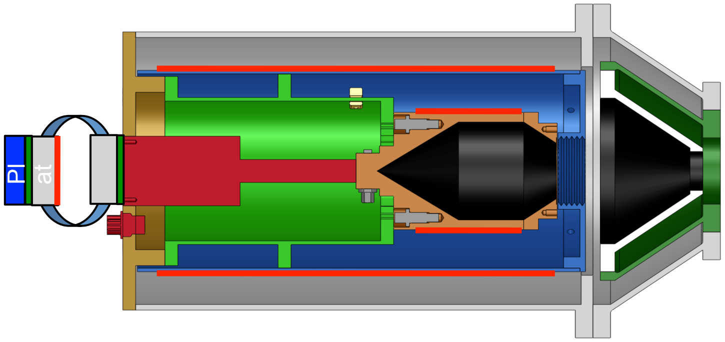
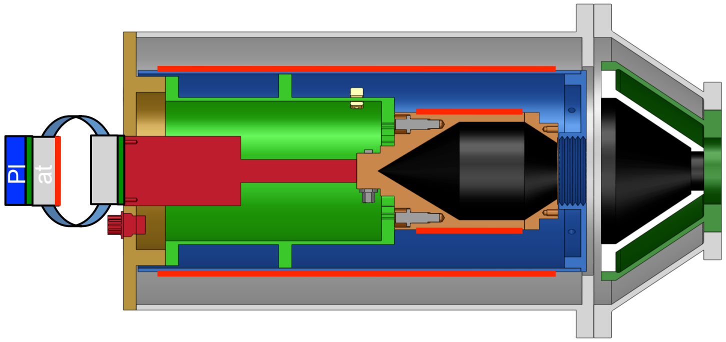
Heritage for the On-orbit Absolute Radiance Standard

- Krutikov *et al* 2006 *Metrologia*
- Gero *et al* 2008 *J. Atmos. Oceanic Technol.*
- Best *et al* 2008 *SPIE*
- Gero *et al* 2009 *J. Atmos. Oceanic Technol.*
- Gero *et al* 2011 *Metrologia (submitted)*



NEWRAD 2011: Absolute Radiance Interferometer

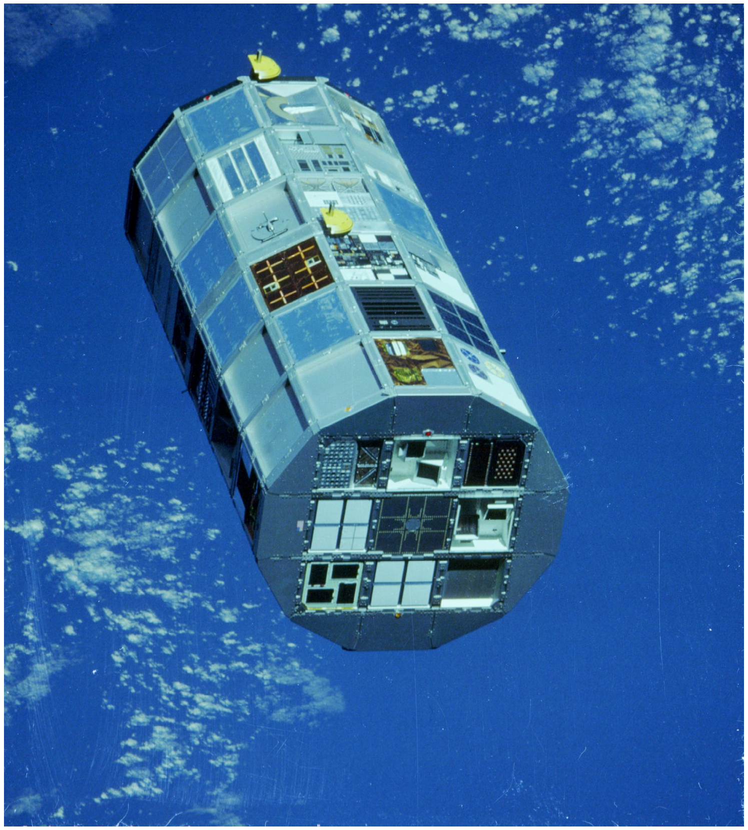
- Joe Taylor, The University of Wisconsin Space Science and Engineering Center Absolute Radiance Interferometer
- Fred Best, On-orbit absolute radiance standard for future IR remote sensing instruments
- John Dykema, Infared laser-based reflectance measurements for blackbody cavity emissivity determination



Paint Degradation in Space

Long Duration Exposure Facility

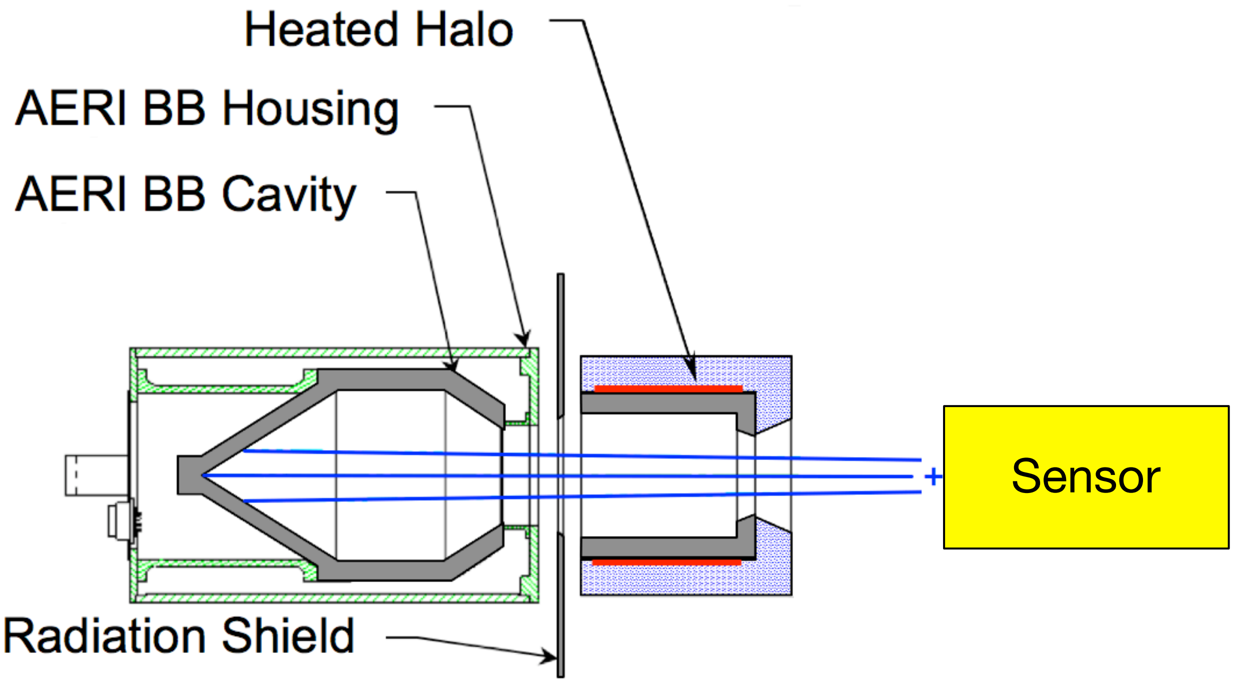
- Study effects of LEO exposure on various materials
- In LEO 1984-1990 (5.7 years)
- Samples of Z306 on Aluminum



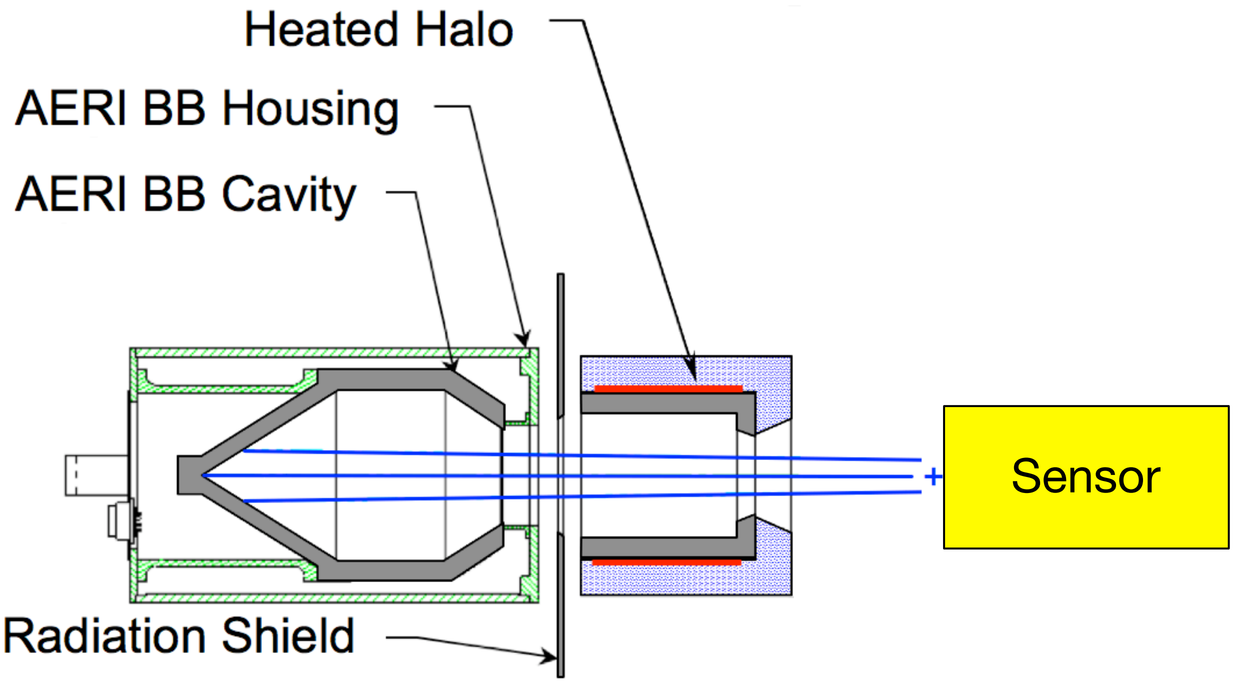
Results

- Evidence of oxidation, erosion, removal of resins, appearance of silicate residues, cracking
- Quantitative changes in optical properties

Heated Halo Concept



Heated Halo Concept



$$R_{\mathrm{obs}} = \underbrace{\varepsilon \bullet B(T_{\mathrm{bb}})}_{\textit{Direct radiance from BB}} + \underbrace{(1-\varepsilon) \bullet [F \bullet B(T_{\mathrm{halo}}) + (1-F) \bullet B(T_{\mathrm{room}})]}_{\textit{Reflected radiance from BB}}$$

Emissivity Calculation

Observed radiance:

$$R_{\mathrm{obs}} = \varepsilon \bullet B(T_{\mathrm{bb}}) + (1 - \varepsilon) \bullet R_{\mathrm{bg}} ,$$

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Emissivity Calculation

Observed radiance:

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$$R_{\text{bg}} = [F \bullet B(T_{\text{halo}}) + (1-F) \bullet B(T_{\text{room}})]$$

Emissivity/reflectivity measurement:

$$\left\langle 1-\varepsilon(t) \right\rangle_t = \left\langle \frac{R_{\text{obs}}(t) - B[T_{\text{bb}}(t)]}{R_{\text{bg}}(t) - B[T_{\text{bb}}(t)]} \right\rangle_t$$

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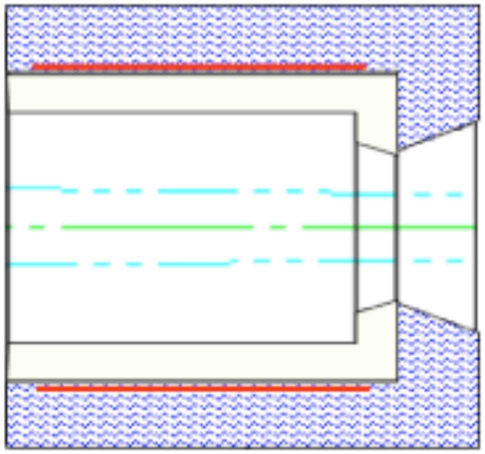
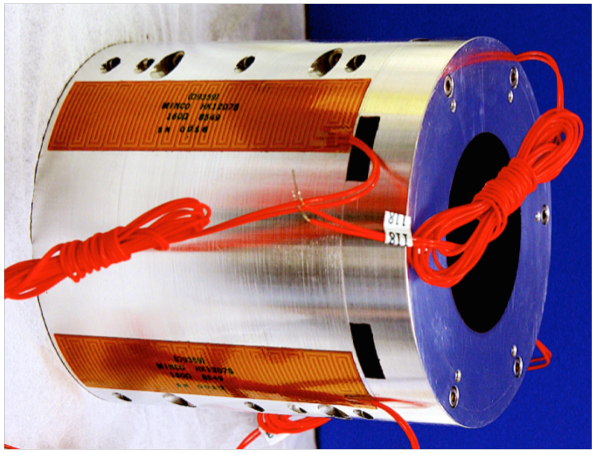
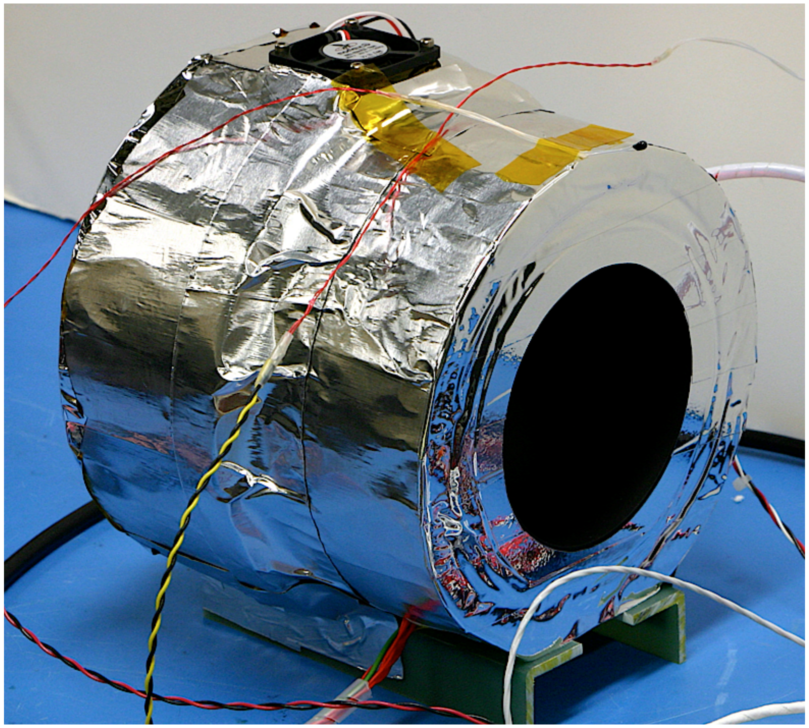
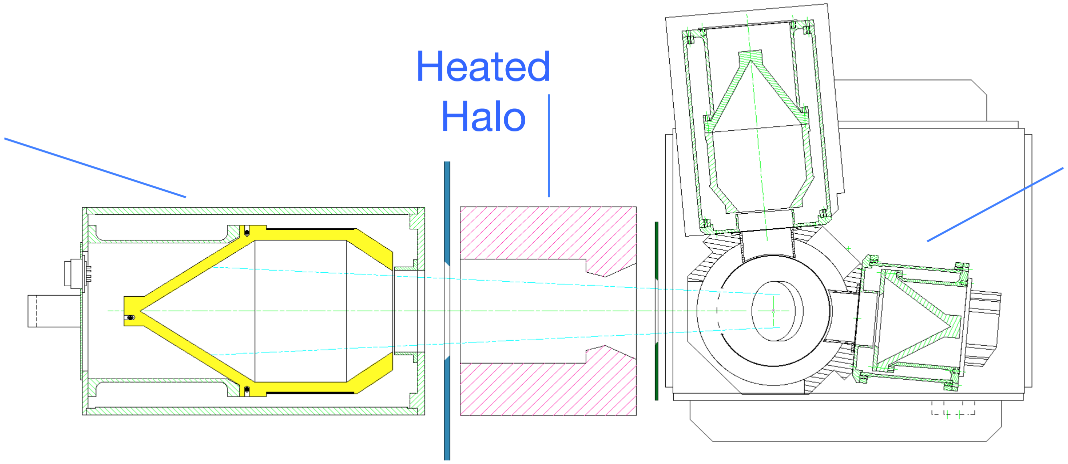
Heated Halo Gen. 1







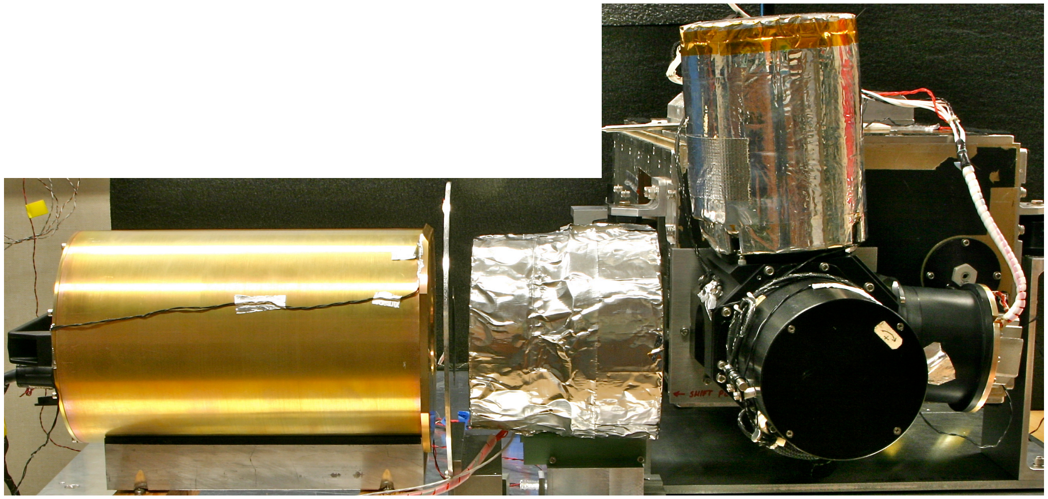
Heated Halo Gen. 1 Test Configuration (S-HIS)



AERI Blackbody

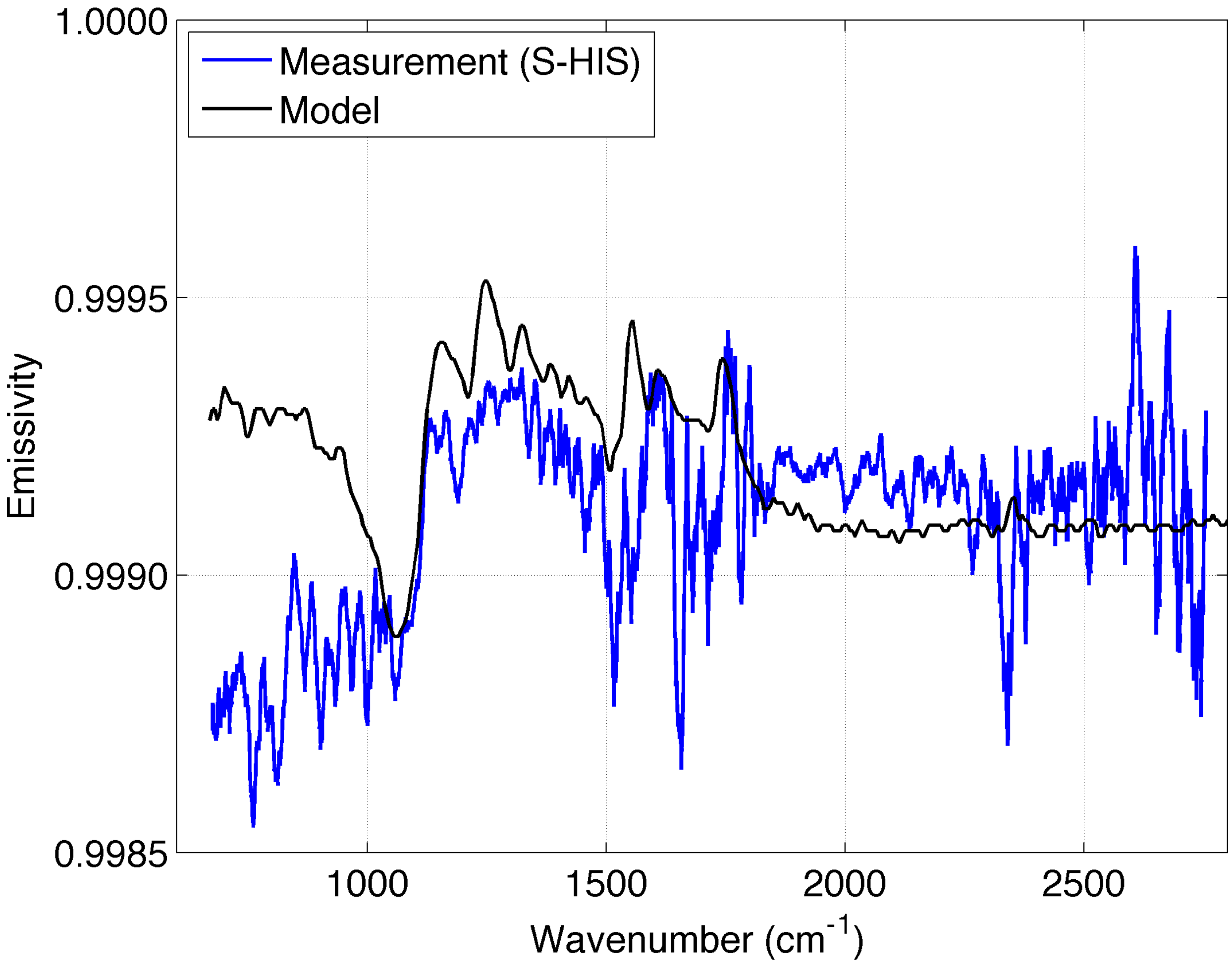
Heated Halo

Scanning HIS Aircraft Instrument

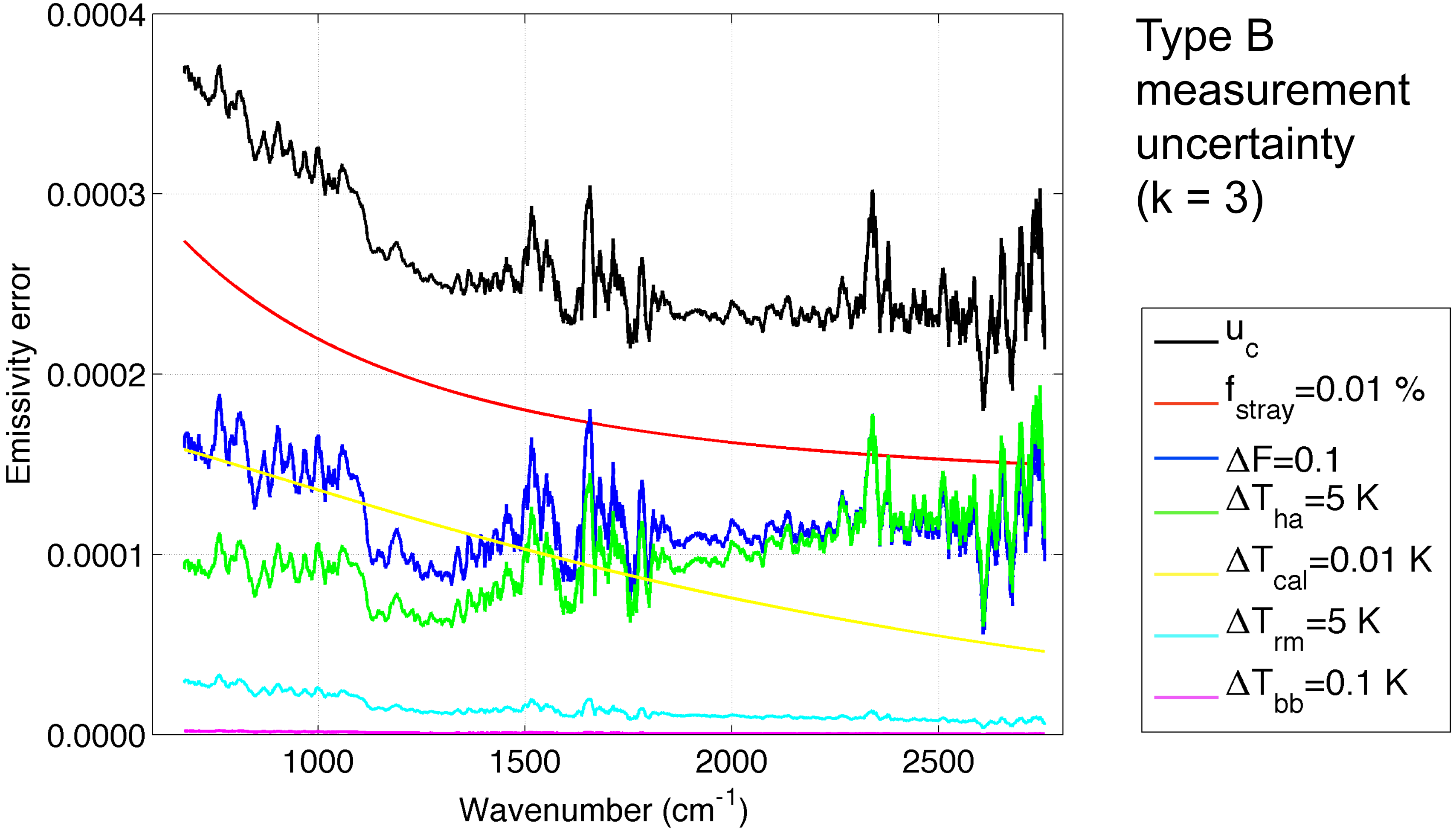


MCT, InSb detectors

AERI Blackbody Emissivity (Halo 1, S-HIS)

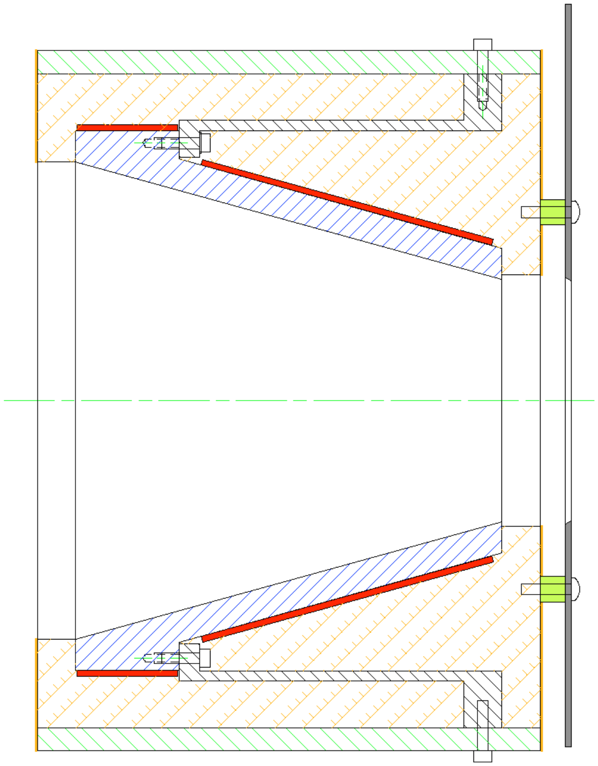


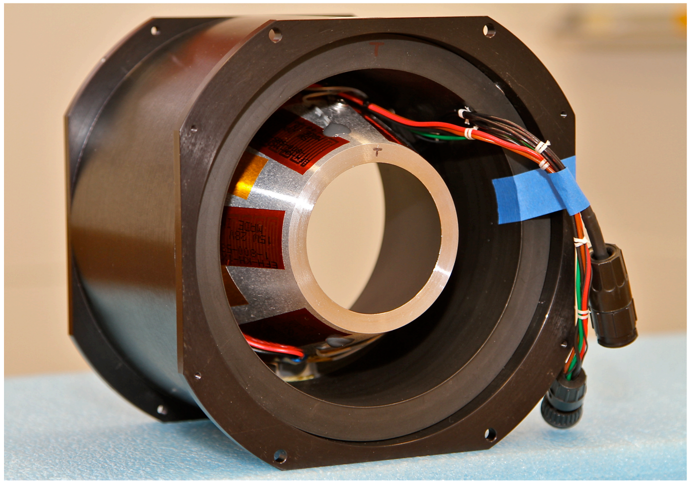
Emissivity Uncertainty (Halo 1, S-HIS)



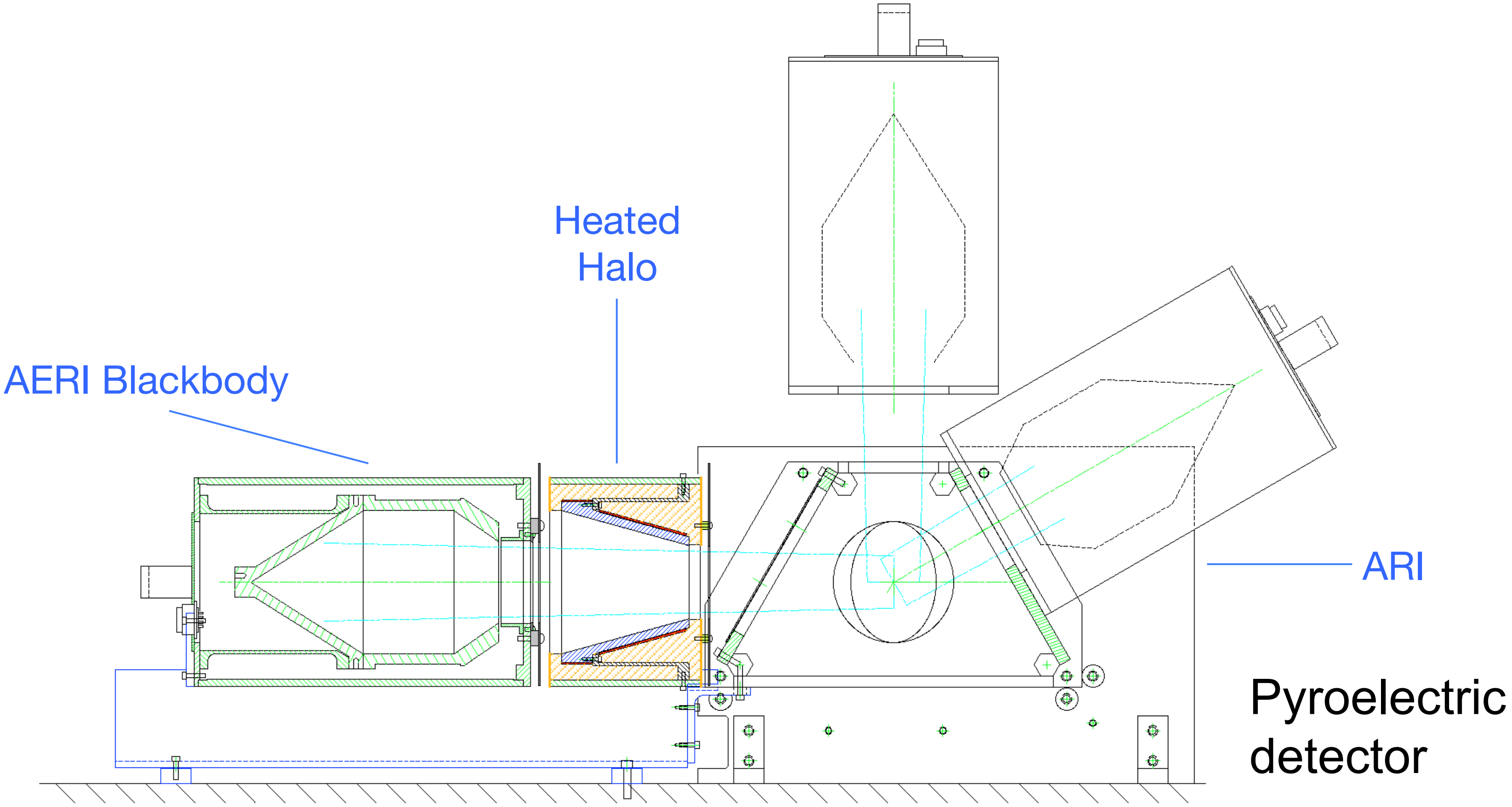
Type B measurement uncertainty (k = 3)

Heated Halo Gen. 2





Heated Halo Gen. 2 Test Configuration (ARI)



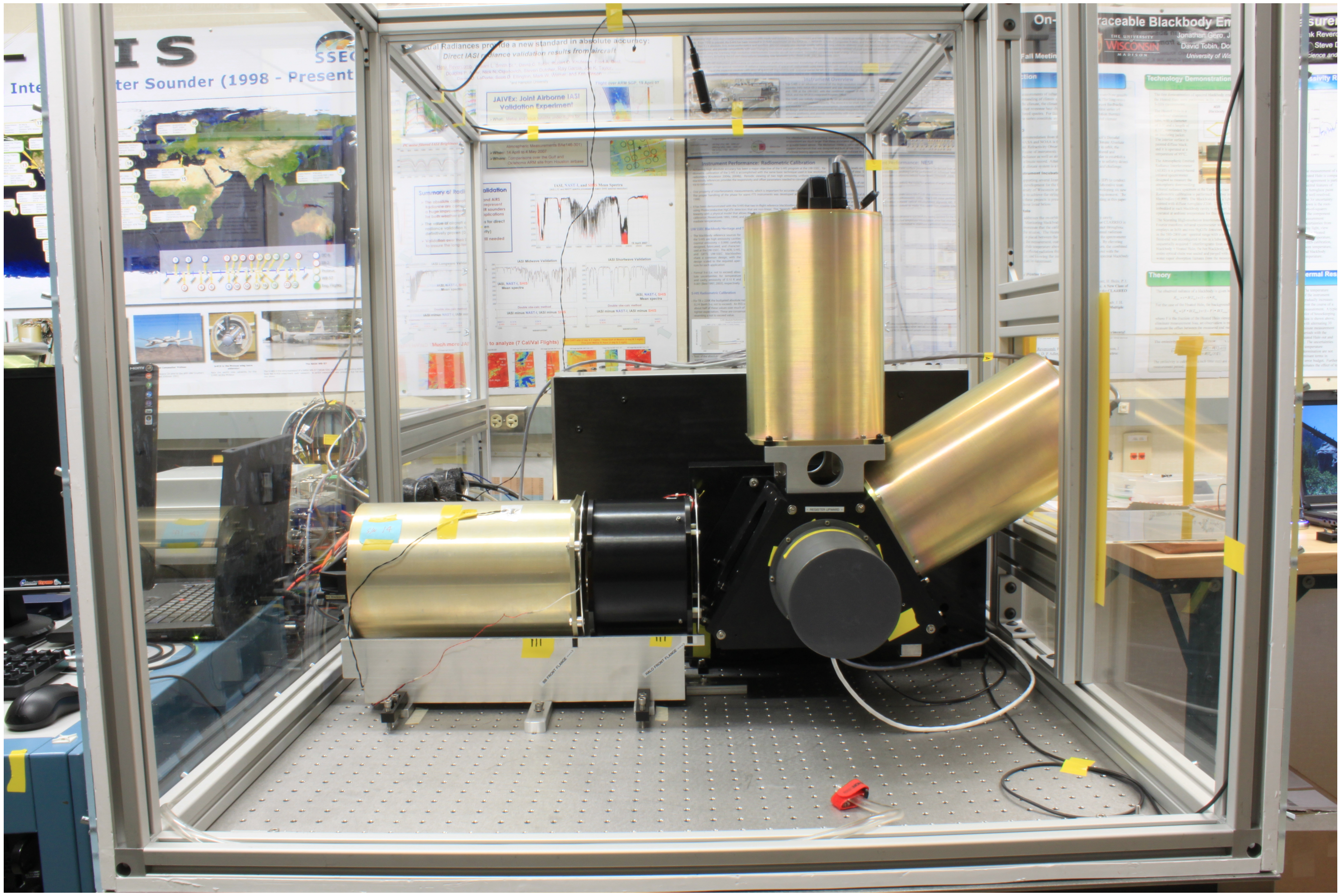
Heated Halo

AERI Blackbody

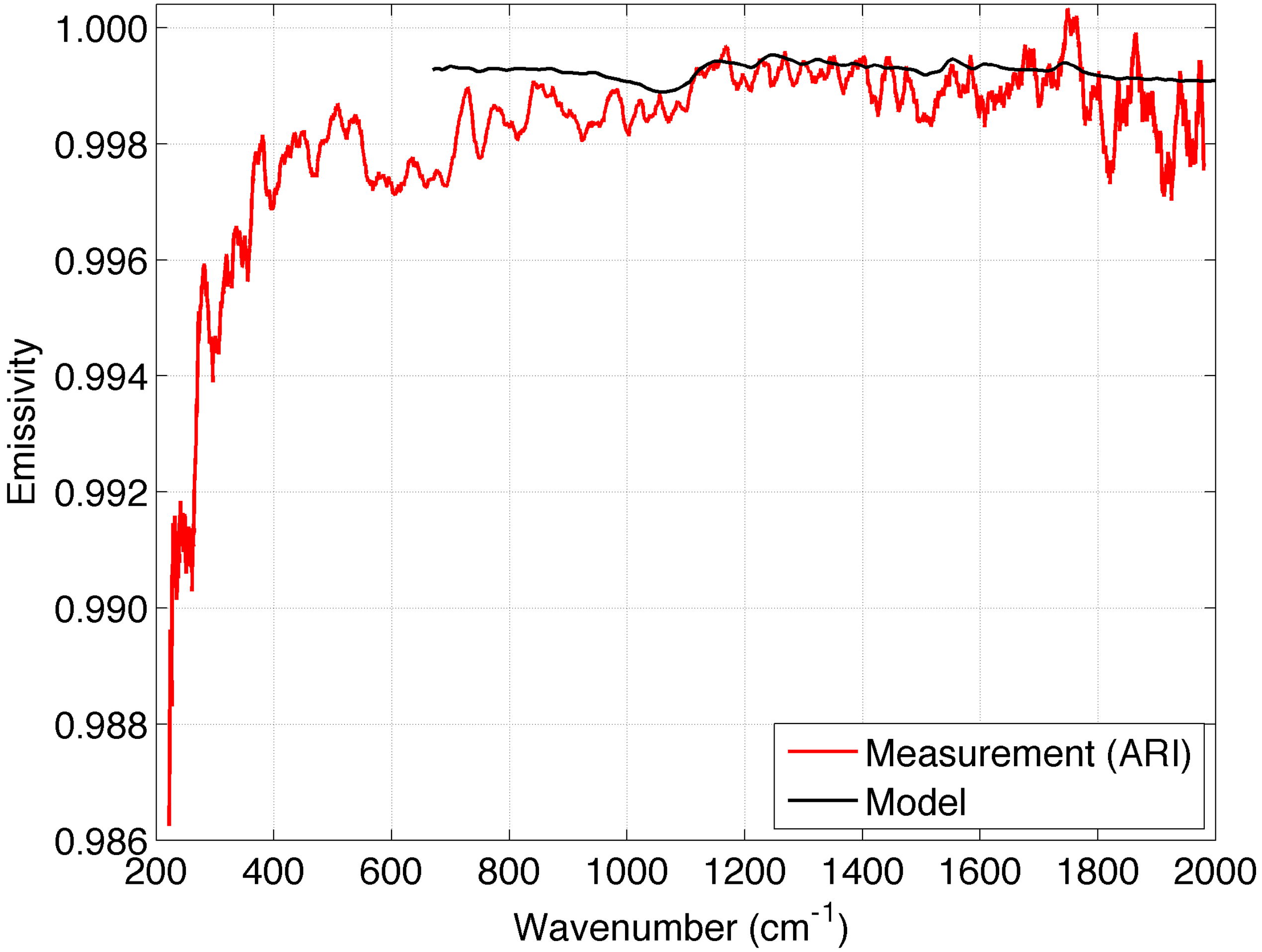
ARI

Pyroelectric detector

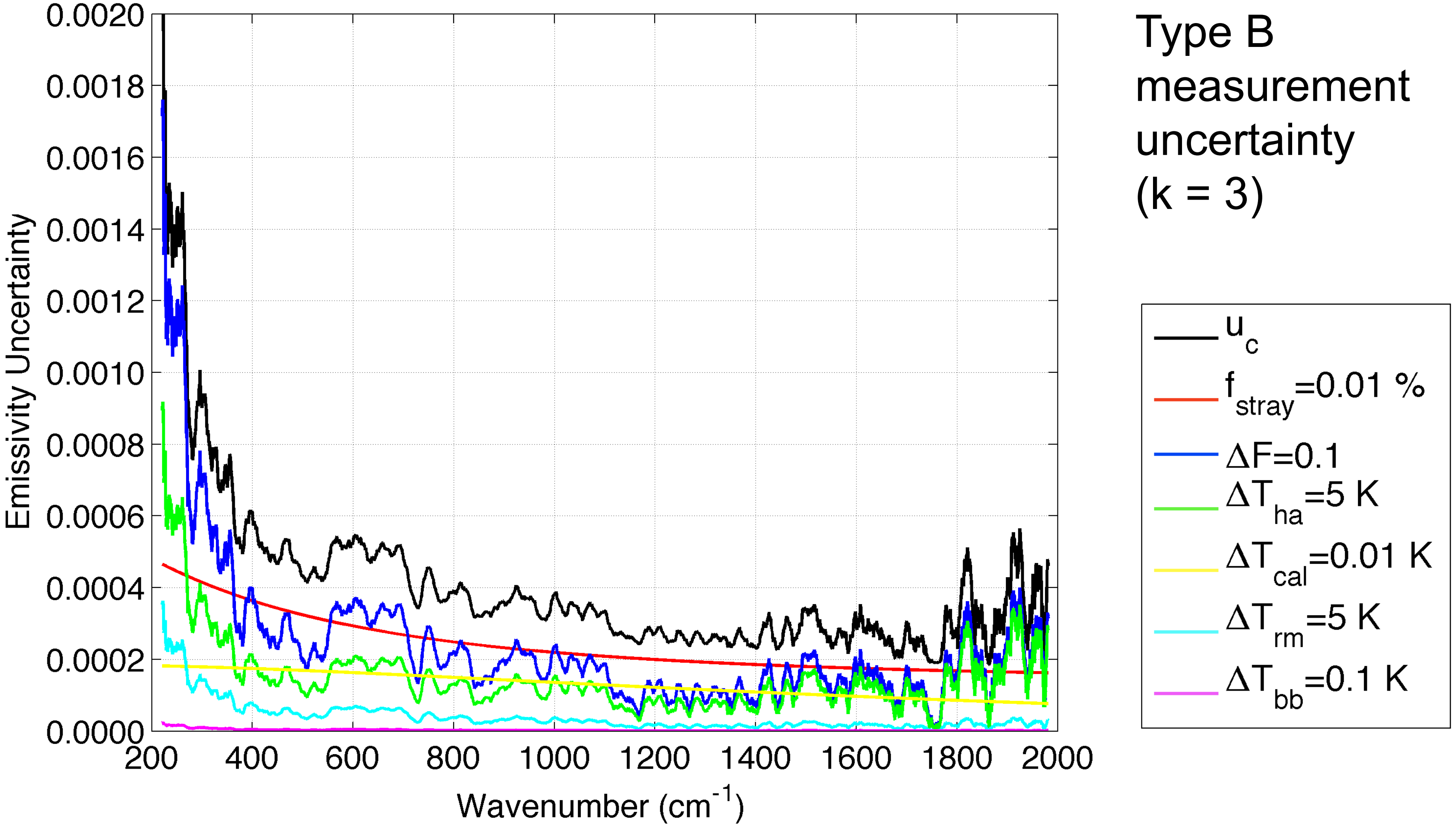
Heated Halo Gen. 2 Test Configuration (ARI)



AERI Blackbody Emissivity (Halo 2, ARI)

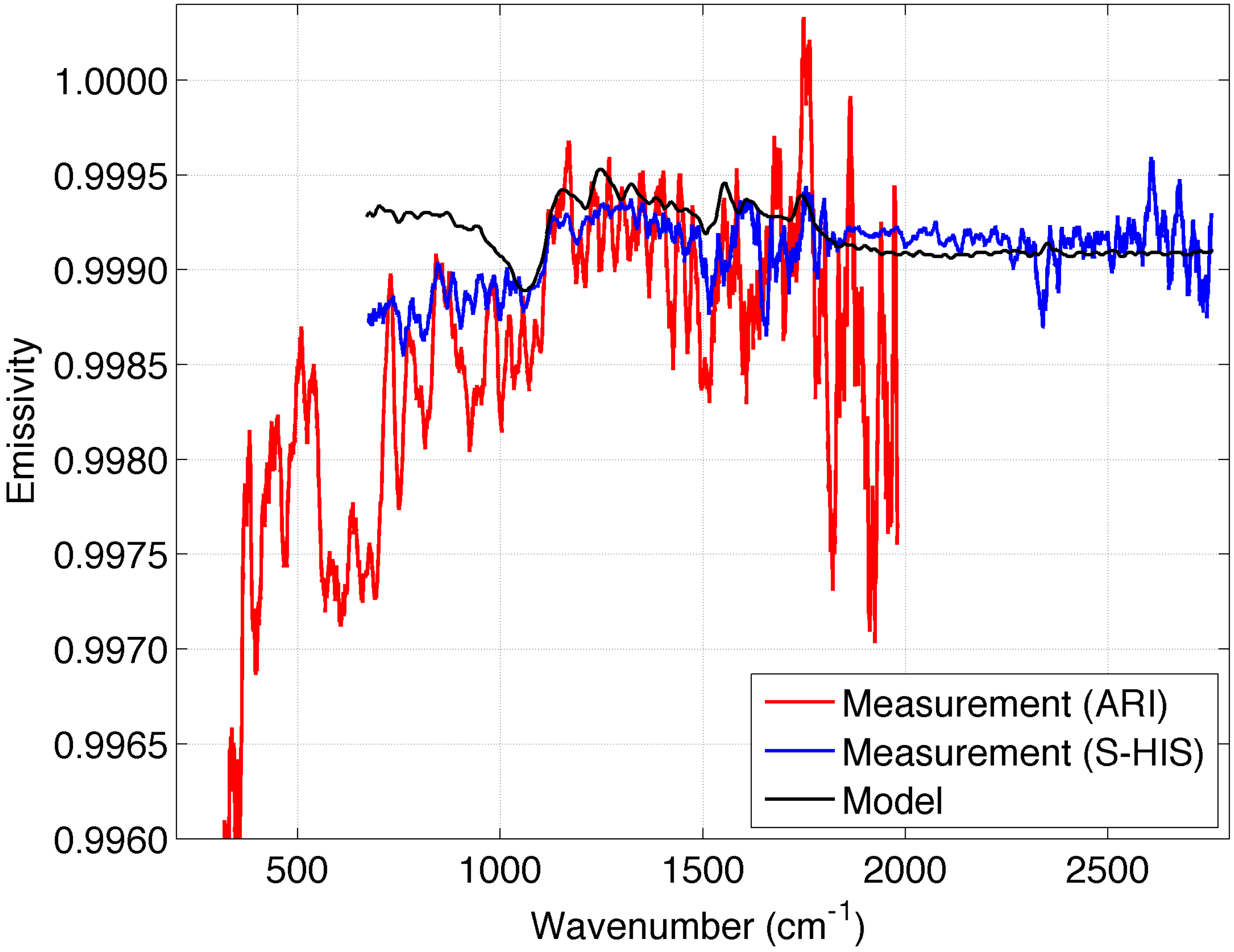


Emissivity Uncertainty (Halo 2, ARI)

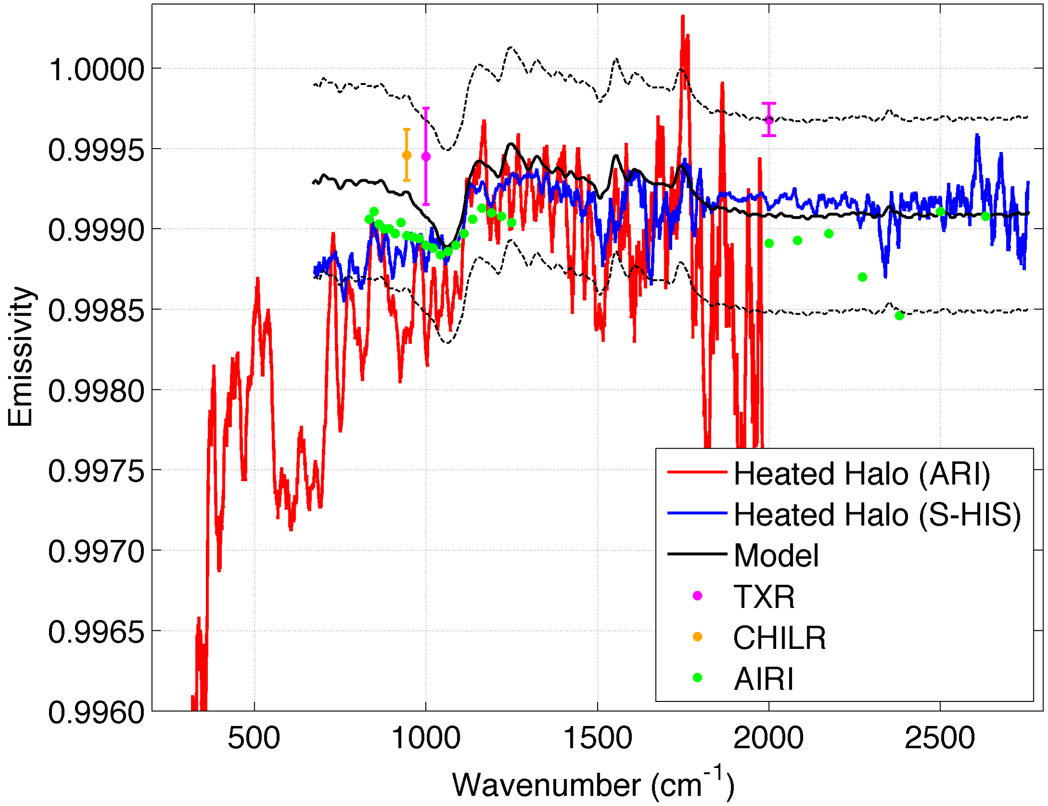


Type B measurement uncertainty (k = 3)

AERI Blackbody Emissivity (Halo 1, Halo 2)



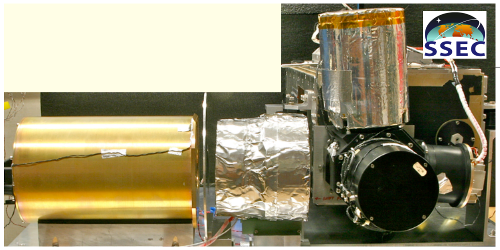
AERI Blackbody Emissivity Comparison



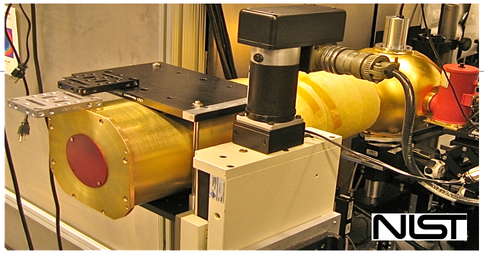
Comparison with NIST measurements

Continued work corroborates earlier results and helps reduce uncertainty

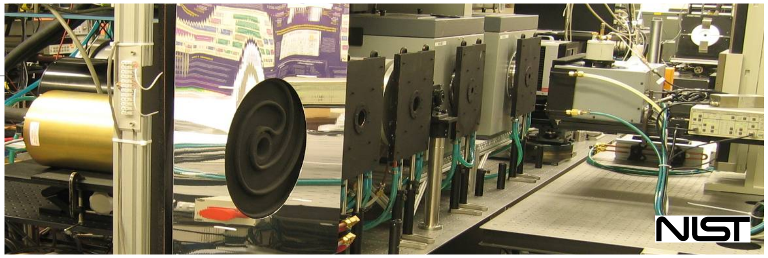
UW Heated Halo



NIST CHILR

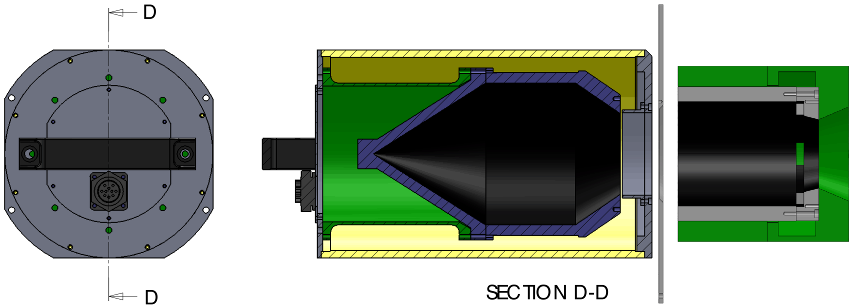


NIST AIRI



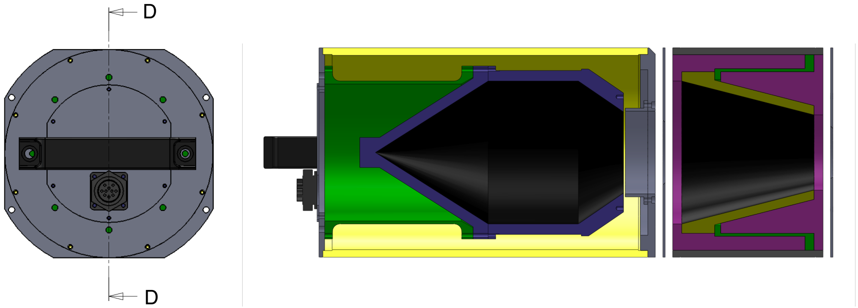
Next Generation Heated Halo

Gen. 1



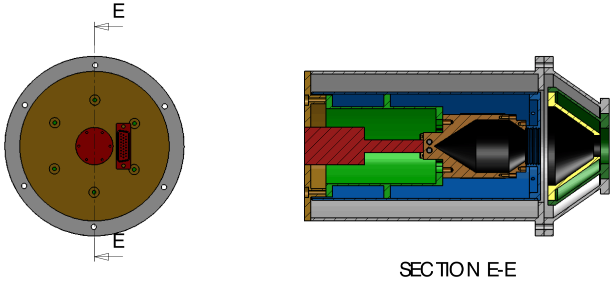
TRL 4

Gen. 2



TRL 5

Gen. 3



TRL 6

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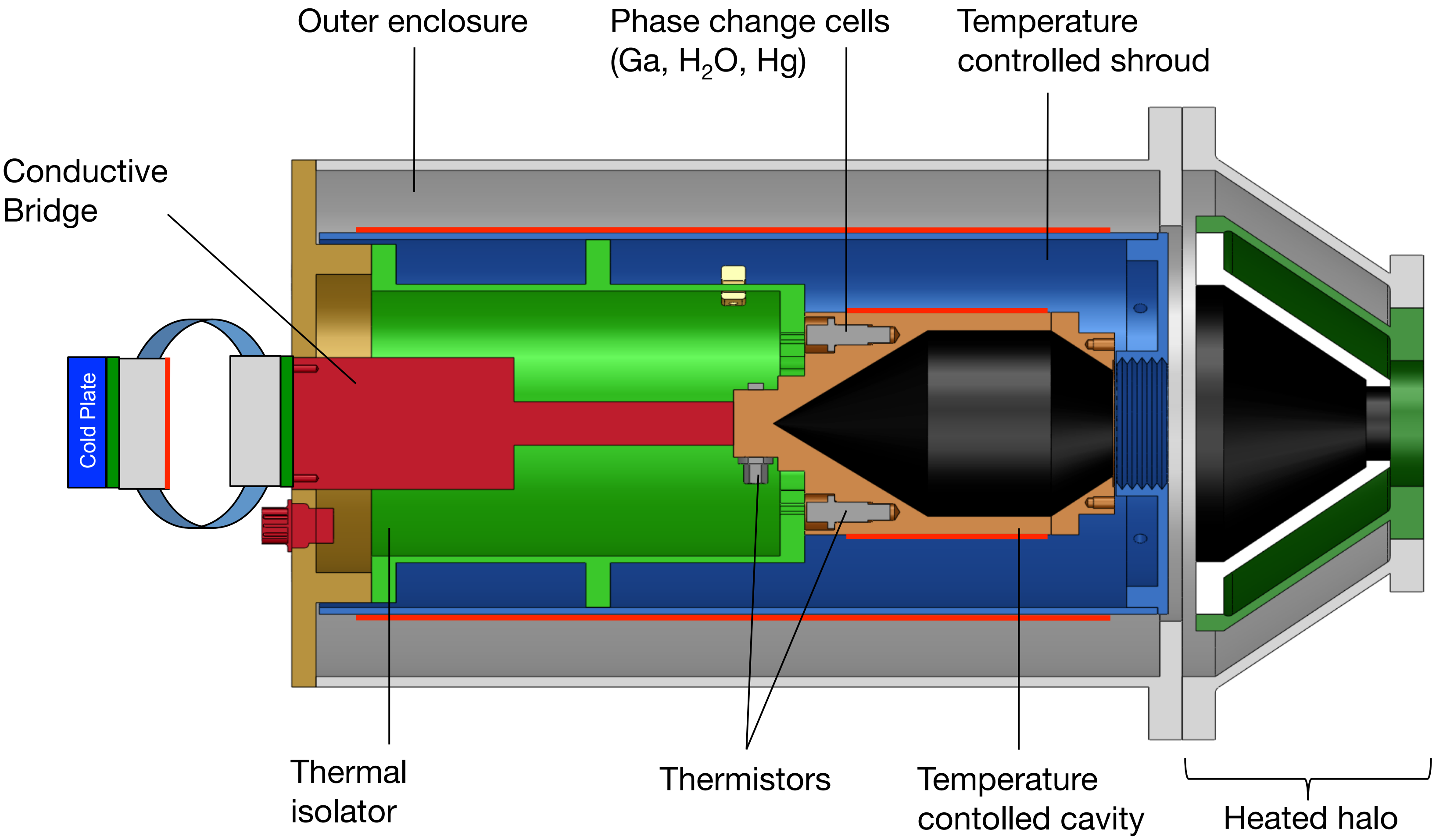
Summary

- 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



AERI Blackbody Emissivity Comparison