CLARREO Advances in Infrared Spectral Calibration Accuracy

1. NASA Langley (R. Cageao – NASA LaRC)  
   Infrared Calibration Demonstration System

2. NIST (R. Cageao – NASA LaRC)  
   Mid- to Far-IR Surface Reflectivity and Blackbody Cavity Radiance Standards

   Absolute Radiance Interferometer (ARI) and On-orbit Verification and Test System (OVTS)
NASA Langley Research Center

CLARREO Infrared Calibration Demonstration System (IR CDS)

GSICS GDWG+GRWG Conference
March 4, 2013

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The CLARREO IR CDS is a Compact, Demonstration, Four-Port Fourier Transform Spectrometer

Mid- to Far-IR (5-50\( \mu \text{m} \)) with Resolution 0.5\( \text{cm}^{-1} \)

Measure brightness temperatures accurate to 0.1K \((k=3)\), for 200 – 320K scenes (CLARREO Req.)

- Characterize Systematic Radiance Measurement Uncertainty
- Refine the Instrument Performance Model
- Develop a Cost-Effective Instrument Design
- Flexible and Modular Instrument Design Testbed
  Operating in a Controlled Thermal and Acoustic Environment
IR CDS Optical Bench

- Output Port
- Beamsplitter / Compensator
- Ref. Input
- Output Port
- Scene Motor & Mirror
- Fixed Corner Cube
- Ref. System Receiver Optics
- Scanner w/ Corner Cube
- Temp. Controlled Optical Bench
Characteristics of the Current IR CDS Design

- Stacked/Planar Optical Ray Trace
- Cassini CIRS Linear Voice Coil Corner Cube Translation Stage
- Frequency Stabilized Position Reference Nd-YAG Laser
- Optical Bench Thermally and Acoustically Isolated in a Vacuum
- Temperature of Optical Bench Controlled at 30°C
- Thermistors Calibrated and Traceable in a 1mK Standard Bath
- Two Output Ports for Bolometer and Pyroelectric Detectors
- Cold (LN₂) and Ambient Temperature Calibration Sources
  - Cavity Reflectances Measured at 4 & 10.6µm at NIST
- VTBB has Hg/H₂O/Ga PCM & 9.6µm QCL Emissivity Monitor
Absorption in Detector Dewar Polypropylene window

IR CDS Measured VTBB Radiance

Single Spectrum Brightness Temp.

Brightness Temp. Bias < 0.05K (Noise ~0.15K rms, 600 – 1200 cm\(^{-1}\))
IR CDS Progress

Achieved:

• Optical Bench Optics Temp. Stability 30mK (1 hr.)
• Preliminary System Operation Analysis
  Design Upgrade Decision Inputs
  Measurement Uncertainty Estimate
• Software Development
  Instrument Responsivity Model
  Observed Blackbody Radiance Model
  Multiple-Scattering Angle Emissivity Modeling (Virial Inc.)

Planned:

• Installing Pyroelectric Detector and Stable Amplitude Ref. Laser
• Radiometric Accuracy Assessment w/ Current Design: late-Mar.
• Measurement Uncertainty Report: May 2013
NIST

Mid- to Far-IR Surface Reflectivity and Blackbody Cavity Radiance

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(with inputs from)
Joe Rice
Leonard Hanssen
Sergey Mekhontsev
1) **Measure Paint Sample Properties to Model Cavity Reflectance**

Near Normal Specular and Diffuse BB Paint Sample Reflectance: NIST and Surface Optics (SOC) Differences, 8 – 20μm

**NIST Extending Meas.:**
Total Reflect. to 50μm, Diffuse Reflect. to 25μm

2) **Measure Cavity Reflectance**

Spot Check Cavity Emissivity for 5 – 50μm STEEP3 Modeling

**NIST CHILR Spatial reflectance @ 4, 10.6, 23 μm**

\[
R = \frac{V_{sc} - V_{ap}}{V_r - V_{back}} R_r
\]

Longer Wavelength Sources & Reflective Integ. Spheres
3) Compare Modeled Cavity and Measured Radiances

Measured Blackbody Cavity Spectral Radiance

AIRI - Advanced IR Imaging Lab

CBS3 – Controlled Background Spectroradiometry

2.5 – 100μm
15 – 300mK (k=2)
[300 – 190K]

(Designs developed, awaiting funding)
IR Absolute Radiance Interferometer (ARI) with On-orbit Verification and Test System (OVTS) prototype demonstrates 0.1 K capability

(UW-Harvard project, NASA Instrument Incubator Program)

Hank Revercomb, Fred Best, Joe Taylor, Jon Gero, Doug Adler, Claire Petersen, John Perepezko, Dave Hoese, Ray Garcia, Bob Knuteson, Dave Tobin

University of Wisconsin-Madison
Space Science and Engineering Center

IIP Material presented to the CLARREO Science Team
Absolute Radiance Interferometer (ARI): Definitions of key components

- **Calibrated Fourier Transform Spectrometer (FTS):**
  - FTS with strong flight heritage
  - 3 Spectral bands covering 3-50 µm
  - 2 Cavity Blackbody References for Calibration

- **On-orbit Verification and Test System (OVTS):**
  - 1. **On-orbit Absolute Radiance Standard (OARS) cavity blackbody** using three miniature phase change cells to establish an accurate temperature scale from -40, to +30 C
  - 2. **On-orbit Cavity Emissivity Module (OCEM) using a Heated Halo source** that allows the FTS to measure the broadband spectral emissivity of the OARS to better than 0.001
  - 3. **OCEM-QCL** using a quantum cascade laser source to monitor changes in the mono-chromatic cavity emissivity of the OARS
  - 4. **On-orbit Spectral Response Module** (OSRM) using the same QCL to measure the FTS instrument line shape

*Not fully implemented in prototype—demonstrated separately*
UW Absolute Radiance Interferometer (ARI) Prototype

components of Calibrated FTS

On-orbit Verification & Test Sources & Calibrated FTS Blackbodies (HBB & ABB)

Abb Bomorem Interferometer
Modulator “Wishbone”

Input Port 2
Source

Aft Optics 2/
Pyro-detector

Aft optics 1 (MCT/InSb)
Sterling Cooler Compressor

Sky View

OSRM sphere

OARS with Halo
OCEM

HBB

ABB
On-Orbit Calibration Verification

OARS Provides End-to-End Calibration Verification On-Orbit Traceable to Recognized SI Standards
On-orbit Absolute Radiance Standard (OARS)

- Inner Shield & Isolator
- Heated Halo & Halo Insulator
- Cavity
- Assembly Diagram
Melt Signatures Provide Temperature Calibration

Phase Change Cell (Ga, H₂O, or Hg)

Thermistor (plotted above)

Blackbody Cavity

Plateaus (shown in plots) provide known temperatures to better than 10 mK
Meeting these uncertainty bounds in the laboratory environment demonstrates the capability to meet the 0.1 K (3-σ) uncertainty requirement on-orbit.

Also Excellent Agreement between DTGS and MCT with NLC.

ARI Absolute Radiometric Accuracy Calibration Verification, DTGS, 450 cm\(^{-1}\)
NASA ESTO currently supporting additional ARI testing in vacuum

- While all new technology components achieved TRL 6, NASA ESTO considered the rolled up ARI to be just under 6
- Therefore, NASA ESTO made funding available to bring the ARI to TRL 6, by verifying operation and performance in a vacuum environment.

- Bringing the ARI to TRL 6 is a huge step because it provides the US with a flight-like IR prototype instrument ready to support CLARREO or other Climate Benchmark Missions, a high priority of the NRC.
  (final testing to be performed in March/April).
Summary

CLARREO IR Spectral Calibration Accuracy

• Have Developed Systems that can Provide On-orbit Traceability to Fundamental Physical Standards

• NIST is Developing Methods and Standards for Mid- and Far-IR Reflectivity and Radiance Measurements

• 0.1K (k=3) Brightness Temperature Accuracy has been Demonstrated in a Laboratory Environment

• Independent and Collaborating Efforts at our Institutions, which are Regularly Reviewed
Backup Slides
IR CDS Acknowledgements

**Engineering and Technical:**

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CLARREO

Scene Motor & Mirror

Vacuum Chamber

Dual Output Ports

Beamsplitter / Compensator

Au Coated OAP’s & Flat Mirrors

Scanner w/ Corner Cube

IR Beam and Control / Reference Interferometers

Temp. Controlled Optical Bench
Internal reference \( \sim 303 \text{ K} \)

CSS interferogram divided by 10 to fit on same scale.

Individual interferograms offset by 500 for clarity.

Only the central region is shown.
IR CDS Operational Analysis

With Blackbody Temp. Dropping ~ 6K / hr.

Brightness Temp (K)
IR CDS Operational Analysis

Average Radiance (W / m² ster cm⁻¹)

Radiance Difference

1%

0.5%
Model includes all important geometry
- BB cavity is Z302 glossy black paint
- All else is semi-rough Al

STEEP3 results for 8 temperatures indicate significant variations in temp corrections
IR CDS measurement of target radiance requires accurate knowledge of the blackbody (BB) radiances:

\[ L_{bb}(\lambda, T_{bb}) = \varepsilon_{bb}P(\lambda, T_{bb}) + (1 - \varepsilon_{bb})P(\lambda, T_e) \]

Effective emissivity of BB is evaluated by:
- Meas. of cavity reflectance at 4 and 10.6 μm (NIST)
- Modeling of cavity emissivity over wavelength range
- Comparison of model results with cavity reflectance measurements

First Order Model (FOM), from basic principles:

- Commercial software from Virial International, Inc. (VII)
  - STEEP323 for axially symmetric cavity - conical back of BB
  - INCA333 for inclined plane back of BB
- Modeling based on measured paint coupon 5 – 50um reflectance

Good agreement with NIST CHILR results
FTIS: BRDF Experimental Setup

System features:

- Out-of-plane capability w/ sample tilt & normal rotation
- Retro-reflection setup w/ beamsplitter
- Set of interchangeable sample mounts
- Mueller Matrix w/linear polarizers & retarders
- 1.32, 3.39, 0.78 µm, 1 - 5 µm tunable lasers in process to be added