The University of Wisconsin Space Science and Engineering Center
Absolute Radiance Interferometer (ARI)

Joe K. Taylor¹, Henry E. Revercomb¹, Henry Buijs², Frederic J Grandmont², P. Jonathan Gero¹, Fred A. Best¹, David C. Tobin¹, Robert O. Knuteson¹, Daniel D. LaPorte¹, Richard Cline¹, Mark Schwarz¹, Jeff Wong¹

¹ Space Science and Engineering Center, University of Wisconsin-Madison,
² ABB-Bomem

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The University of Wisconsin-Madison Space Science and Engineering Center (UW-SSEC) and Harvard University (HU) submitted a successful joint proposal entitled “A New Class of Advanced Accuracy Satellite Instrumentation (AASI) for the CLARREO Mission” to the NASA Instrument Incubator Program (IIP). The UW-SSEC / HU team has a long history with the scientific and measurement concepts that have formed the foundation for climate benchmark measurements from space.

The objective of this effort is to advance the technological development of advanced accuracy instrumentation for the measurement of absolute spectrally resolved infrared radiances (3.3 – 50 μm) with high accuracy (< 0.1 K, k = 3, brightness temperature at scene temperature) for climate benchmark measurements from space.

The UW-SSEC, is building a demonstration test bed which includes an FTS instrument and calibration and validation system to demonstrate the feasibility of the far and mid infrared instrumentation for a Climate Benchmark Mission.
1. Introduction

2. IR Measurement Requirements Summary

3. The UW-SSEC Absolute Radiance Interferometer (ARI)
1. Introduction

2. IR Measurement Requirements Summary

3. The UW-SSEC Absolute Radiance Interferometer (ARI)
Current high spectral resolution infrared satellite remote sensors, for the most part, are not designed to provide:

- The radiometric accuracy required to detect the small trends associated with global climate change
- On-orbit calibration traceability to absolute standards
- Far infrared (FIR) coverage beyond the normal IR sounding region (typically some part or all of the 3-15 μm region)
A Benchmark for Long-term Climate Trends

- Satellite Instrument Calibration for Measuring Global Climate Change (NIST Publication NISTIR 7047, 2003)
- US NRC Decadal Survey (NRCDS, 2007): *Earth science and applications from space: national imperatives for the next decade and beyond*
  - Climate Absolute Radiance and Refractivity Observatory (CLARREO): Tier 1 (highest priority) mission
- NASA Implementation of CLARREO
  - Selected for development/implementation by NASA (lead: NASA LaRC)
  - Successful MCR (November 2010)
  - Guidance received in the President’s FY 2012 budget removed $1.24B from the $2.08B FY’11 proposed Climate Initiative during the years between FY 2012 and FY 2015 … directed cuts have been made to several activities, including two of the Tier 1 missions: CLARREO and the DESDynI.
A Benchmark for Long-term Climate Trends

• UW-SSEC / HU:
  • NISTIR 7047, ASIC³, NRCDS
  • NASA CLARREO Pre-phase A Studies, NASA CLARREO IR Instrument Integrated Product Team (IPT), NASA CLARREO Science Team (ST)
  • Related work presented here and in other HU / UW-SSEC Talks:
    • Hank Revercomb: “A New class of advanced accuracy satellite instrumentation for earth observation” (Wed 13:30)
    • Fred Best: “On-orbit Absolute Radiance Standard for the next generation of infrared remote sensing instruments” (Wed 14:50)
    • Jon Gero: “Far-infrared black body emissivity measurements with the Heated Halo method” (Wed 15:10)
1. Introduction

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• **Information Content**: Capture the *spectral* signatures of regional and seasonal climate change that can be associated with physical climate forcing and response mechanisms *(to unequivocally detect change and refine climate models)*

• **Absolute Accuracy**: < 0.1 K, \( k = 2 \), brightness temperature *for combined measurement and sampling uncertainty* for annual averages of 15°x30° lat/long regions *(to achieve goal of resolving a climate change signal in the decadal time frame)*

• **Calibration transfer to other spaceborne IR sensors**: Accuracy approaching 0.1 K, \( k = 3 \), using Simultaneous Nadir Overpasses *(to enhance value of sounders for climate process studies - actually drives few requirements)*
Basic Requirements (Infrared)

- **Spectral Coverage:** 3 - 50 μm (200 - 3000 cm\(^{-1}\))
  (includes Far IR to capture most of the information content and emitted energy)

- **Spectral Resolution:** \(~0.5\) cm\(^{-1}\) unapodized (1 cm max OPD)
  (to capture atmospheric stability, aid in achieving high radiometric accuracy, and allow accurate spectral calibration from atmospheric lines)

- **Noise:** NEdT(10 sec) < 1.5 K for climate record,
  < 1.0 K for cal transfer
  (not very demanding)

- **Spatial Footprint & Angular Sampling:** Order 100 km *or less*, nadir only
  (no strong sensitivity to footprint size, nadir only captures information content).

- **Coverage:** Contiguous coverage *not* required
Basic Requirements (Infrared)

- **Pre-launch Calibration/Validation**: Characterization against NIST primary infrared standards and evaluation of flight blackbodies with NIST facilities *(recent “best practice”)*

- **On-orbit Calibration**: Onboard warm blackbody reference (~300K), with phase change temperature calibration, plus space view, supplemented with characterization testing *(to detect any slow changes)*
Basic Requirements (Infrared)

- **Pre-launch Calibration/Validation**: Characterization against NIST primary infrared standards and evaluation of flight blackbodies with NIST facilities (recent “best practice”)

- **On-orbit Calibration**: Onboard warm blackbody reference (~300K), with phase change temperature calibration, plus space view, supplemented with characterization testing (to detect any slow changes)

- **Validation, On-orbit**: On-orbit, variable-temperature standard blackbody, referenced to absolute physical standards (to maintain SI measurements on orbit)
1. CLARREO Introduction
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Calibration Reference:
Deep Space

Earth

Calibration Reference:
Ambient Blackbody
- Used in conjunction with Space View for instrument calibration
Viewing configuration providing immunity to polarization effects.
SSEC Spectrometer, Blackbody Heritage & Ties to NIST

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Ground-based

High-altitude Aircraft

Spaceflight

AERI

S-HIS

GIFTS

NIST Water-bath Blackbody

NIST TXR

< 0.065 K error (293 to 333 K)

< 0.06 K error (220 to 333 K)

ε > 0.9994 (within estimated uncertainty)
UW-SSEC Absolute Radiance Interferometer

- The UW-SSEC Absolute Radiance Interferometer includes:
  - A scene selection mirror assembly;
  - Fore optics designed specifically for high radiometric accuracy;
  - A 4-port cube corner, rocking arm interferometer with a diode laser based metrology system;
  - Two aft optics assemblies, 1 at each output port of the interferometer;
  - A 77 K multiple semi-conductor detector (400 – 2500 cm\(^{-1}\)) and dewar assembly, and associated mechanical cooler;
  - A DTGS pyroelectric detector (200 – 1800 cm\(^{-1}\)) assembly.

Each chosen for their strong spaceflight heritage such that detailed performance testing can be conducted on a system with a clear path to space. For compatibility with an IIP budgets, the electronics are not flight designs.
The Generic Flight Interferometer (GFI)

- The UW ARI is based on ABB’s Generic Flight Interferometer (GFI) architecture: a flex blade-based frictionless double pendulum scanning mechanism with 25 years of heritage and a direct evolution of 2 successful spaceborne interferometers:
  - **SCISAT / ACE-FTS (2003):** Initial design life of 2 years and still operating in compliance with performance requirements after 8 years
  - **GOSAT / TANSO-FTS (2009):** Currently meets all performance requirements in flight

- The GFI baseline includes some improvements over former successful TRL-7 implementation:
  - Fiber-linked metrology for reduced heat load on interferometer and simplified alignment / redundancy management
  - Monolithic cube corner mirror for increased robustness to launch vibration
  - These improvements were qualified at TRL-5 in dedicated CSA sponsored Space Technology Development Programs. The GFI is backward compatible with former TRL-7 design elements.
GFI → GICS (Generic Interferometer for Climate Studies)

- 4 port
- Different laser path
- CsI beamsplitter to cover spectral range
- Mounting adapted for CsI
- Self compensated beamsplitter instead of substrate and compensator
- Replicated monolithic cube corner

- Vacuum compatible Interferometer
- Modified COTS electronics and software used for IIP
- Mass: < 7 kg (GICS, Aluminum)
- Power: Avg 18 W / Pk 23 W (flight design)
Fore Optics Design Drivers

- Gold coated Aluminum (no AR coating) reflective components
- Design goals include:
  - Optimize interferometer throughput
  - Maximize Stray light control
  - Minimize instrument mass and volume
  - Optimize heated halo fill factor, f
  - Compatible with 1” aperture Blackbody
  - Allow ‘tuning’ of polarization null locations
4 port configuration
- Input port 2: Stable reference (not shown)
- Output port 1: FIR (not shown)
- Output port 2: IR
Output Port 1: FIR Output Subsystem

- Option 1: ABB AERI aft optics system delivered with ABB GICS interferometer
  - All reflective
  - Includes FIR detector module (Selex DTGS)
  - Aft-optics compatible with existing AERI detector and dewar module

- Option 2: UW-SSEC custom design.
  - All reflective
  - DTGS detector optimized for application
Output Port 2: IR Output Subsystem

• UW-SSEC Prototype Aft Optics and Detector/Dewar

• Combination of reflective (ambient T) and cooled (77K) refractive optics

• Option 1: NGST micro pulse-tube cooler
  • NGST (former TRW group) is developing a small scale pulse tube microcooler with significant space flight heritage, including AIRS.

  • 0.65cc HEC compressor
  • Heat Load: 500 mW
  • Detector Temperature: 77K
  • Reject Temperature: 298 - 310 K

• Option 2: Split Cycle Stirling Cooler
  • Similar to that used on AERI, S-HIS
Breadboard 1

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Breadboard 1

Sky View: Cold and Dry

SSEC rooftop camera-west

21 January 2011
• Data acquisition completed, and analysis in progress
• Preliminary analysis does not indicate any outstanding issues
  • Detector Performance Testing (Pyro)
  • Interferometric Noise Characterization
  • Spectral Calibration Verification
  • Radiometric Calibration Verification
  • Clear sky view testing (comparison to LBLRTM)
  • Heated Halo
Breadboard 2 (Sensor Prototype)

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- **FIR Aft Optic**, 6 reflective elements (ABB COTS)
- **GICS**
- **IR Dewar** (Cooler not shown)
- **Fore-optics** 8 elements
- **IR Aft Optics** 2 reflective, 3 refractive (in dewar) elements
- **Calibration References** Ambient and Hot Blackbody for IIP
- **Scene Select Module**
- **OARS and Halo**
- **OSRM**
- **Scene View**

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Breadboard 2 (Sensor Prototype)
Summary

• An excellent, low cost, climate benchmark mission has been defined

• The proposed IR measurement requirements are supported by good technical readiness

• The UW-SSEC ARI (and OT/V)
  
  • Will allow us to demonstrate the technology necessary to measure IR spectrally resolved radiances (3.3 – 50 µm) with ultra high accuracy (< 0.1 K, k = 3, brightness temperature at scene temperature) for a benchmark climate mission.

  • Subsystems have been selected and developed to provide a system with a clear path to space.

  • Testing to be completed in upcoming months
THANK YOU