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

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Madison, WI, USA

Summary

- 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.

Topics

1. Introduction
2. IR Measurement Requirements Summary
3. The UW-SSEC Absolute Radiance Interferometer (ARI)

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A Benchmark for Long-term Climate Trends

- 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)
- ASIC^3 Report: Achieving Satellite Instrument Calibration for Climate Change (2007)
- 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, ASIC^3, 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

2. IR Measurement Requirements Summary

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

- 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)

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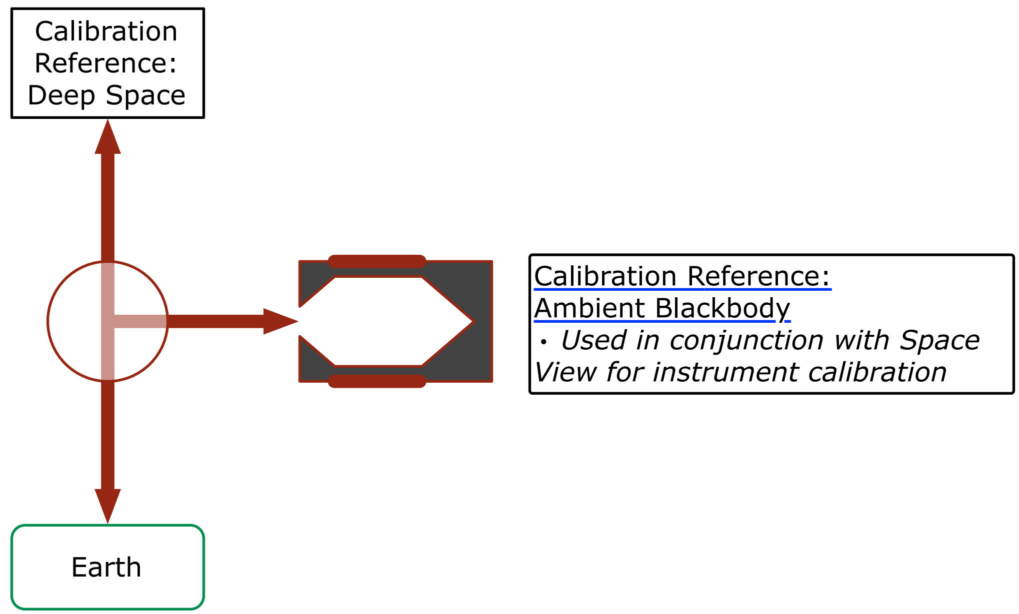
- Validation, On-orbit: On-orbit, variable-temperature standard blackbody, referenced to absolute physical standards
  (to maintain SI measurements on orbit)

1. CLARREO Introduction

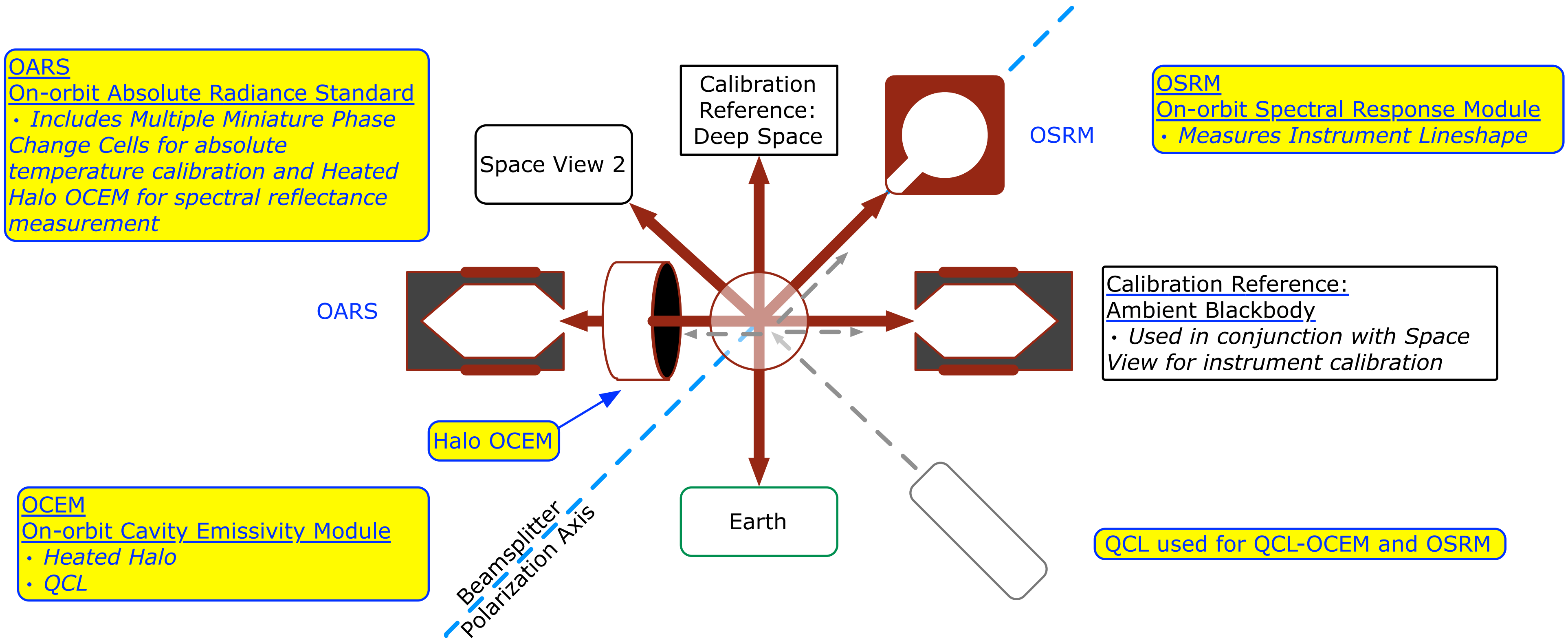
2. IR Measurement Requirements Summary

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

UW-SSEC & Harvard Technology Developments Under NASA IIP



UW-SSEC & Harvard Technology Developments Under NASA IIP

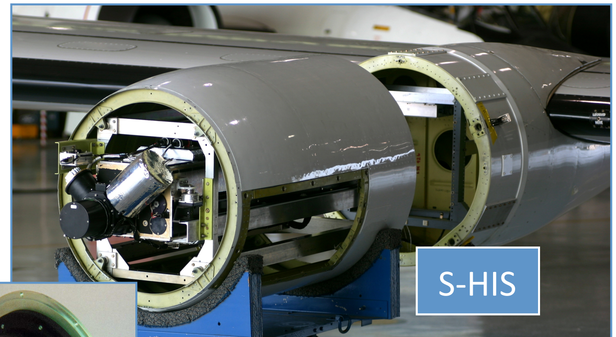


Viewing configuration providing immunity to polarization effects.

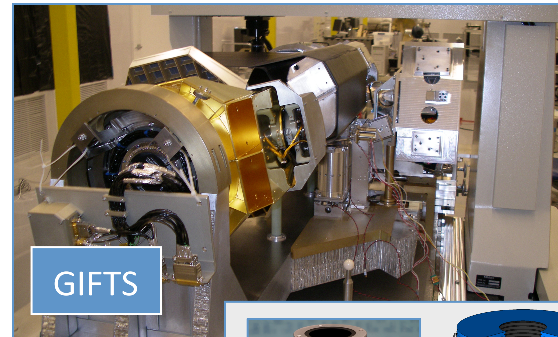
SSEC Spectrometer, Blackbody Heritage & Ties to NIST

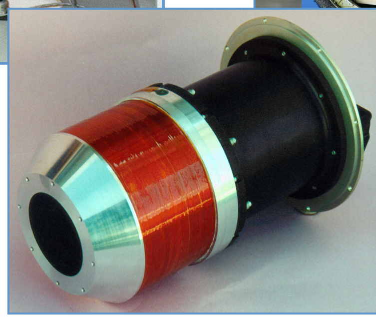
Ground-based

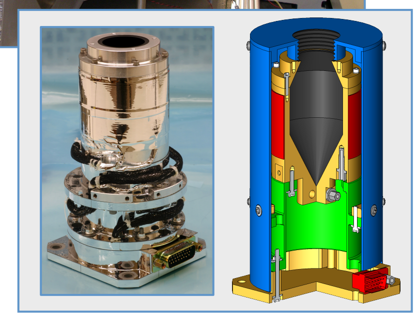
High-altitude Aircraft



Spaceflight



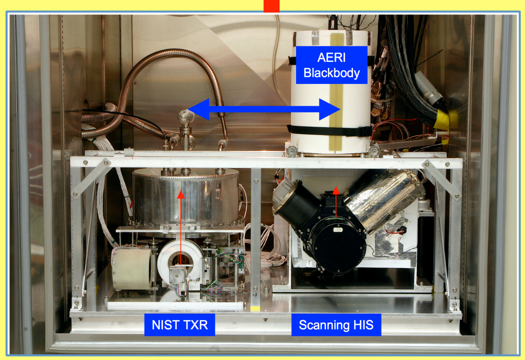




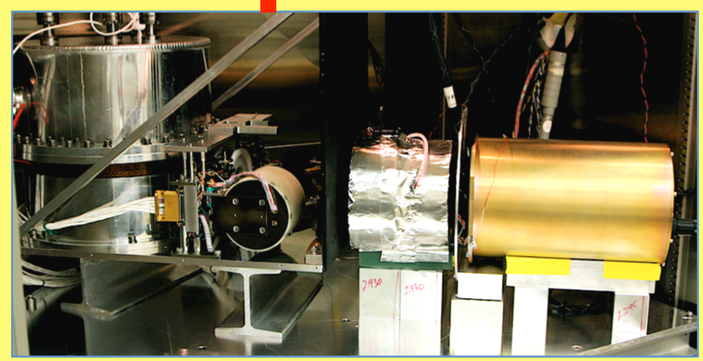
NIST
Water-bath
Blackbody

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

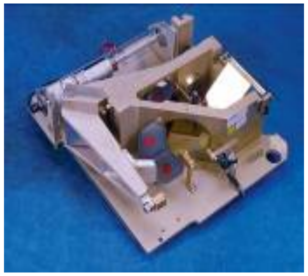
- The UW-SSEC Absolute Radiance Interferometer includes:
  - A scene selection mirror assembly;
  - Fore optics designed specifically for high radiometric accuracy;
  - A 4-port cube corner, rocking arm interferometer with a diode laser based metrology system;
  - Two aft optics assemblies, 1 at each 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*

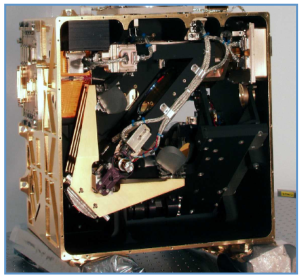
The Generic Flight Interferometer (GFI)

- 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.

MB series (1985)

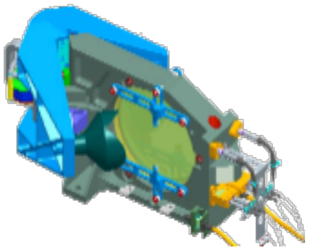


SCISAT (2003)



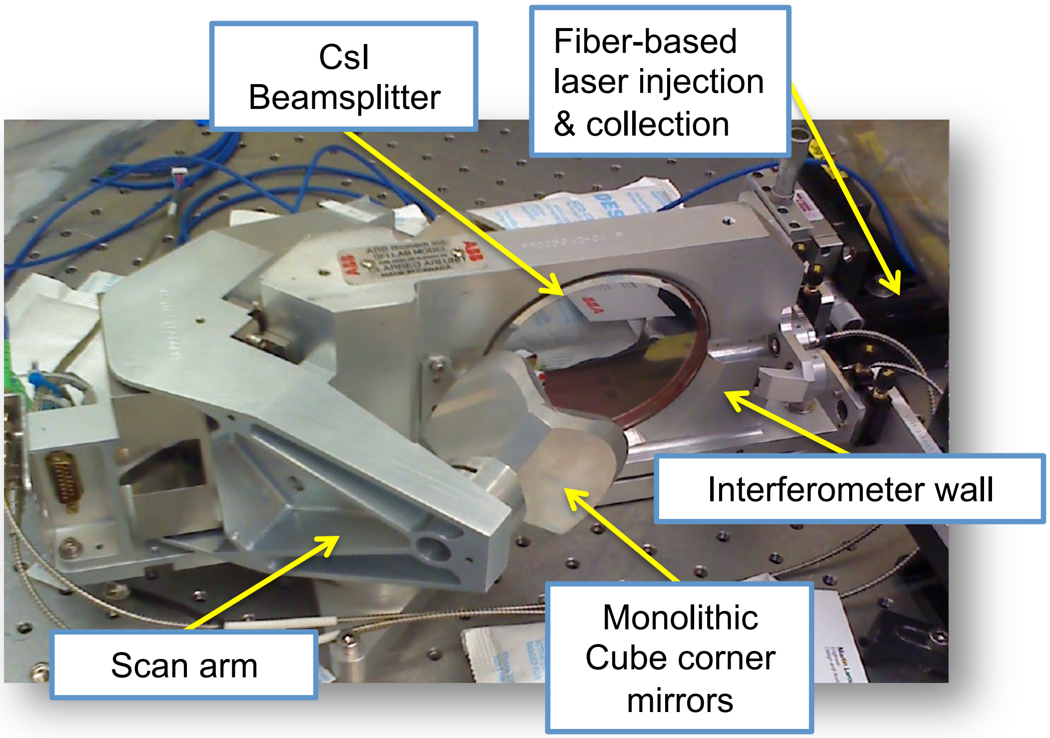
GOSAT (2009)

GFI



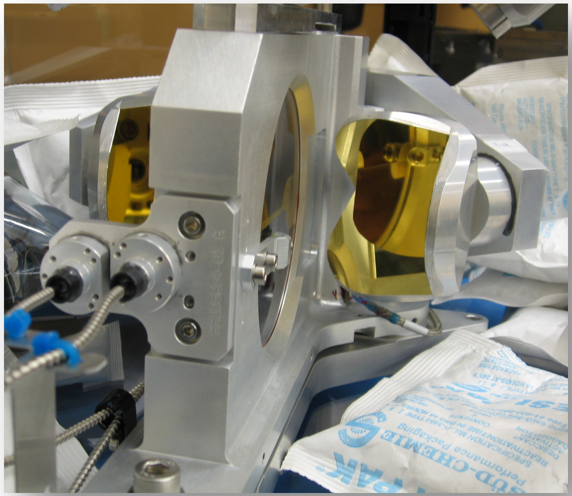
GFI → GICS (Generic Interferometer for Climate Studies)

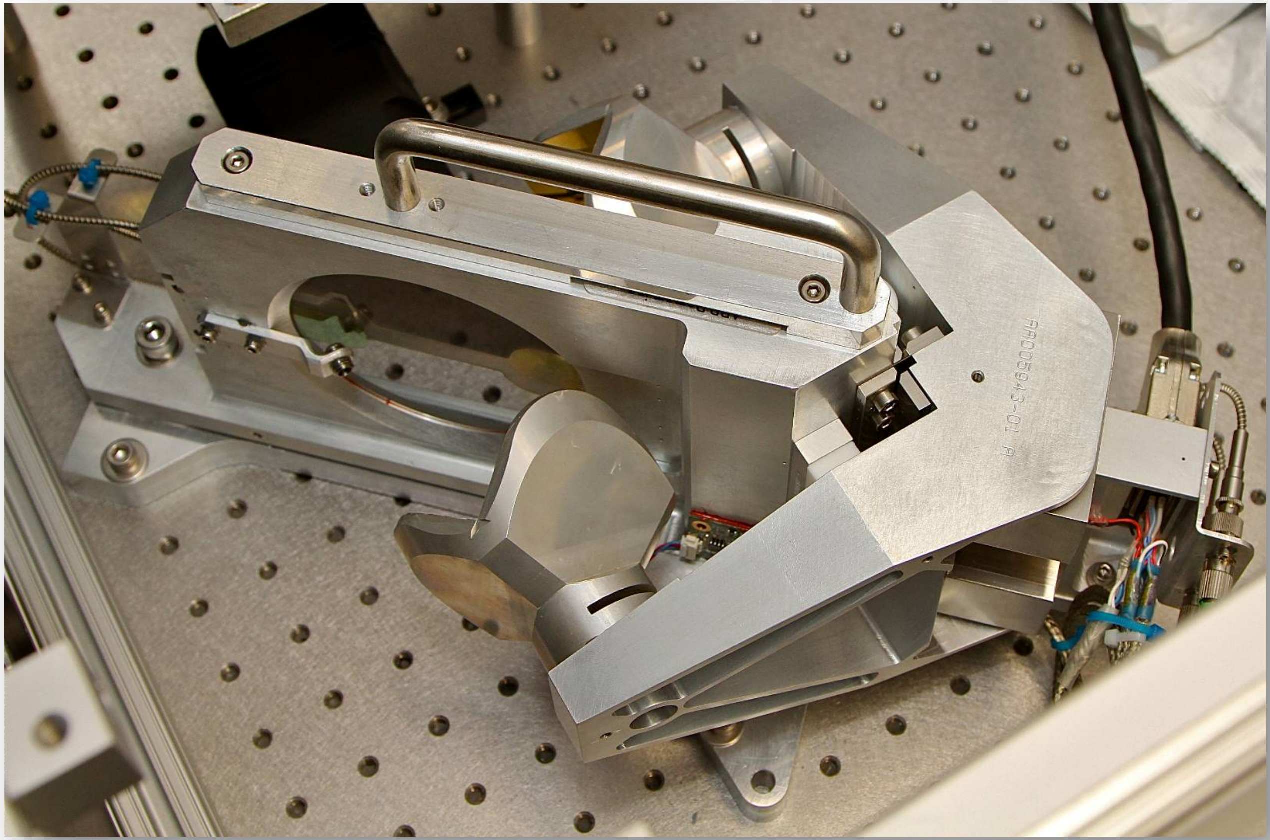
- 4 port
- Different laser path
- CsI beamsplitter to cover spectral range
- Mounting adapted for CsI
- Self compensated beamsplitter instead of substrate and compensator
- Replicated monolithic cube corner

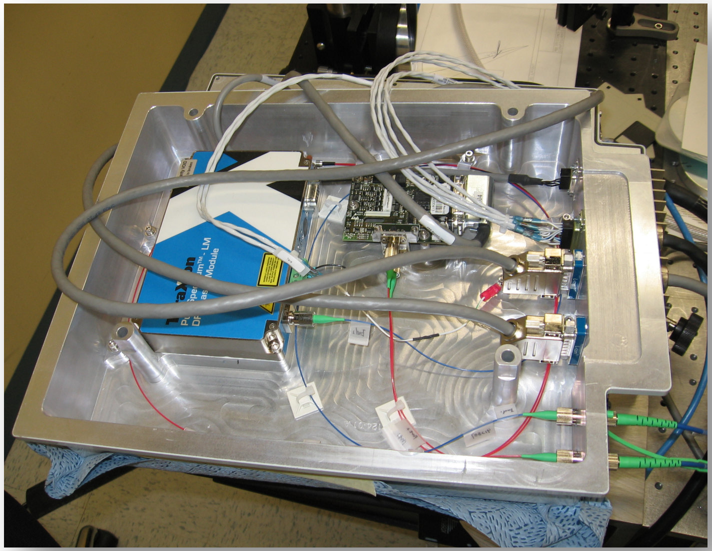


- Vacuum compatible Interferometer
- Modified COTS electronics and software used for IIP
- Mass: < 7 kg (GICS, Aluminum)
- Power: Avg 18 W / Pk 23 W (flight design)

GICS Interferometer



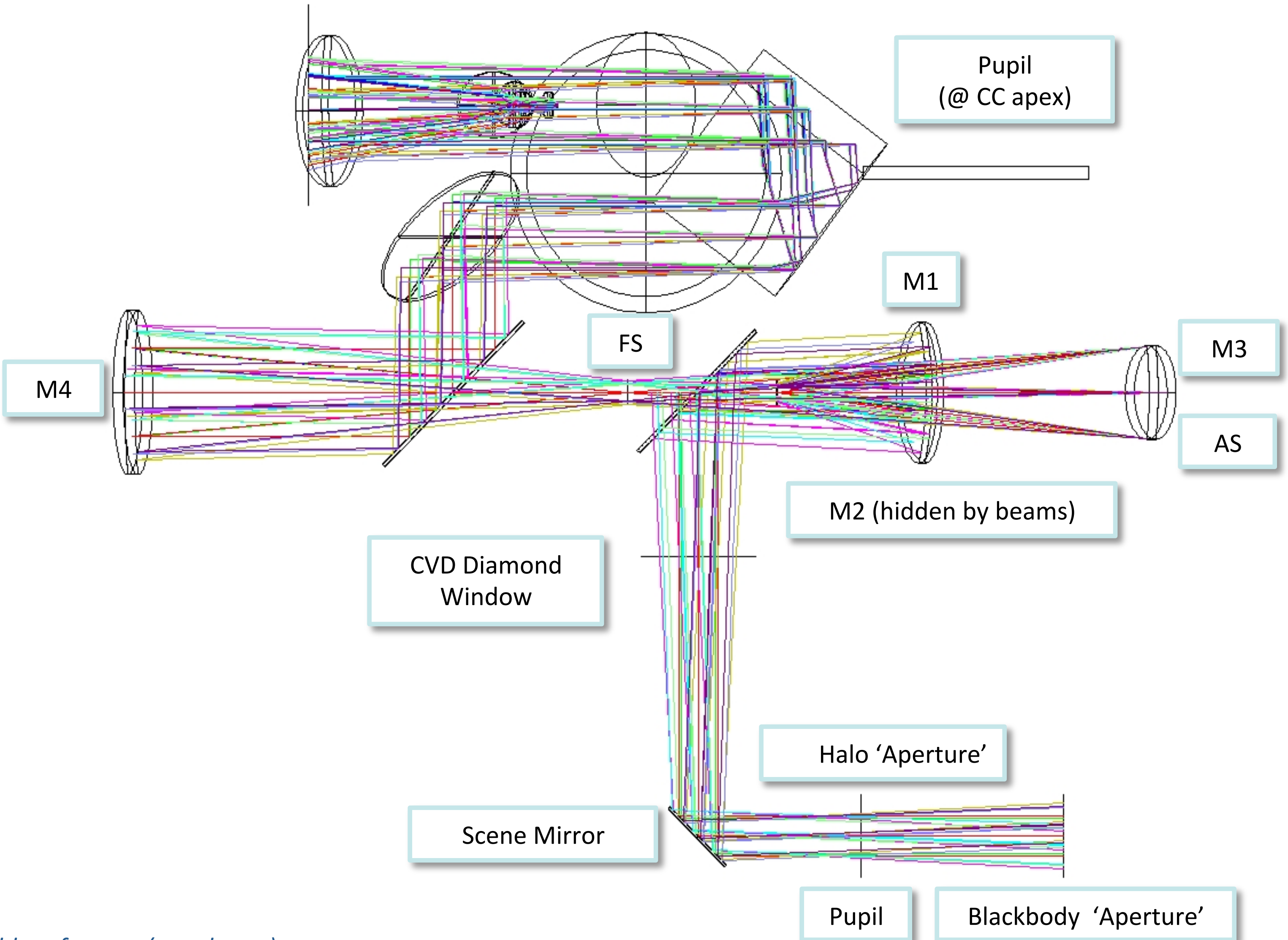




Fore Optics Design Drivers

- 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

Optical Model – "Side" View



4 port configuration

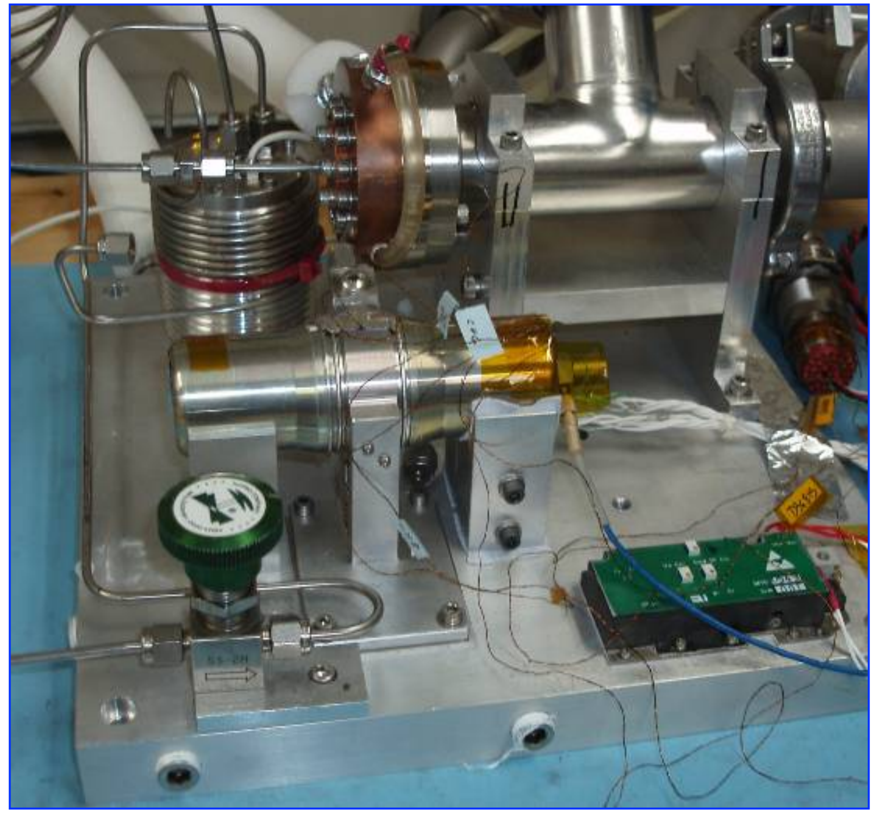
- *Input port 2: Stable reference (not shown)*
- *Output port 1: FIR (not shown)*
- *Output port 2: IR*

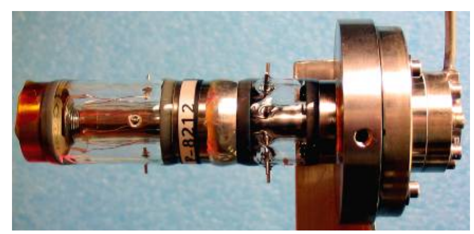
Output Port 1: FIR Output Subsystem

- 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

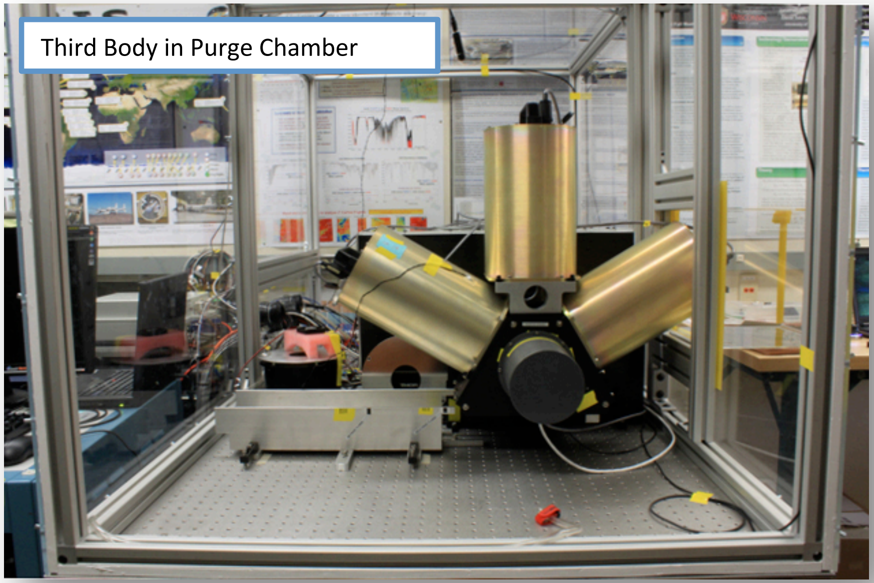
Output Port 2: IR Output Subsystem

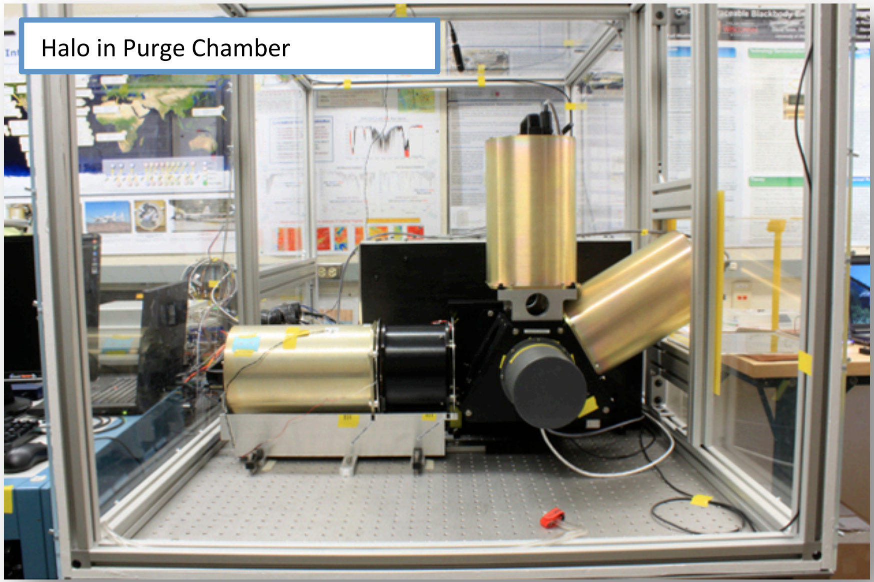
- UW-SSEC Prototype Aft Optics and Detector/ Dewar
- Combination of reflective (ambient T) and cooled (77K) refractive optics
- Option 1: NGST micro pulse-tube cooler
  - NGST (former TRW group) is developing a small scale pulse tube microcooler with significant space flight heritage, including AIRS.
  - 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

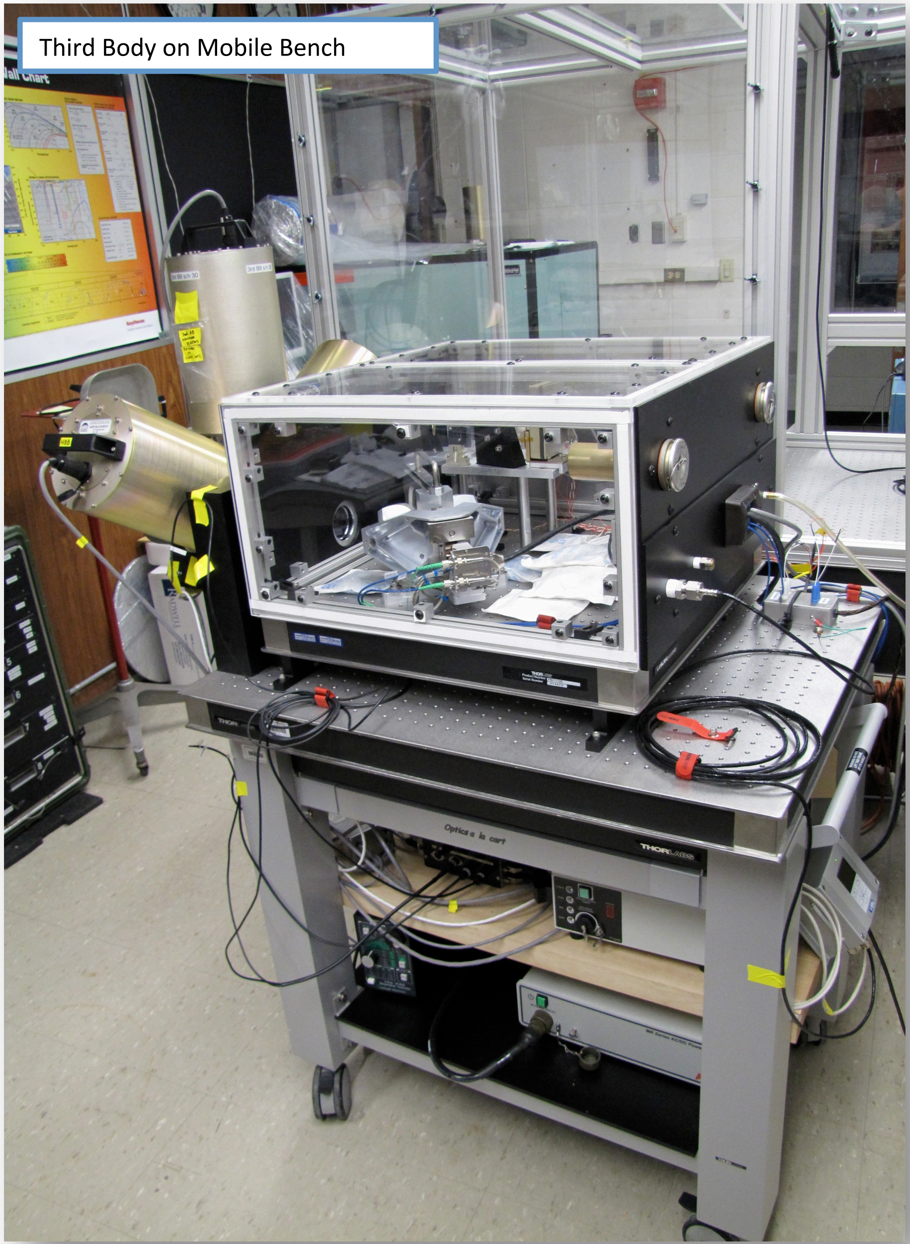




Breadboard 1

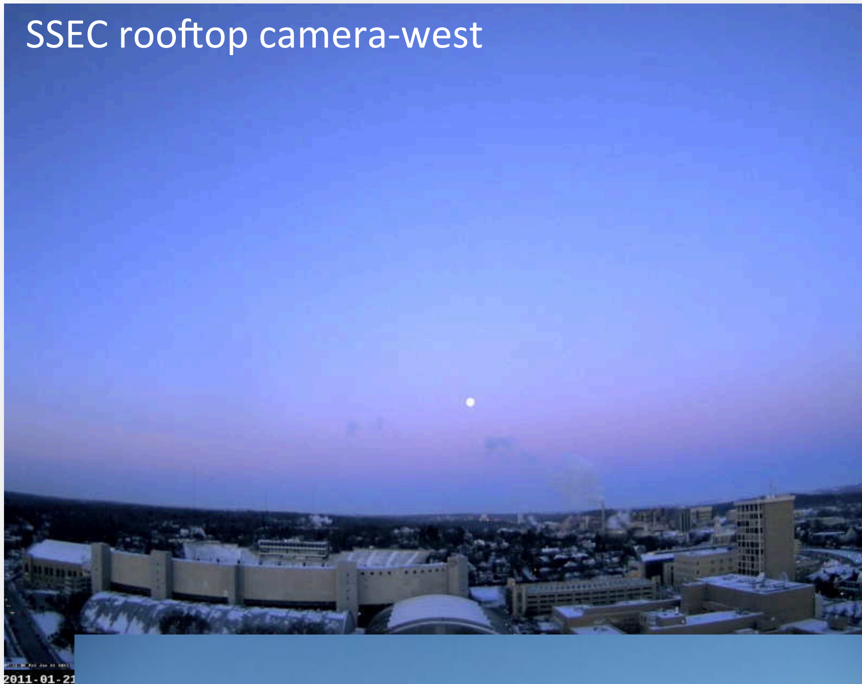

Third Body in Purge Chamber


Halo in Purge Chamber


Third Body on Mobile Bench

Breadboard 1

Sky View: Cold and Dry

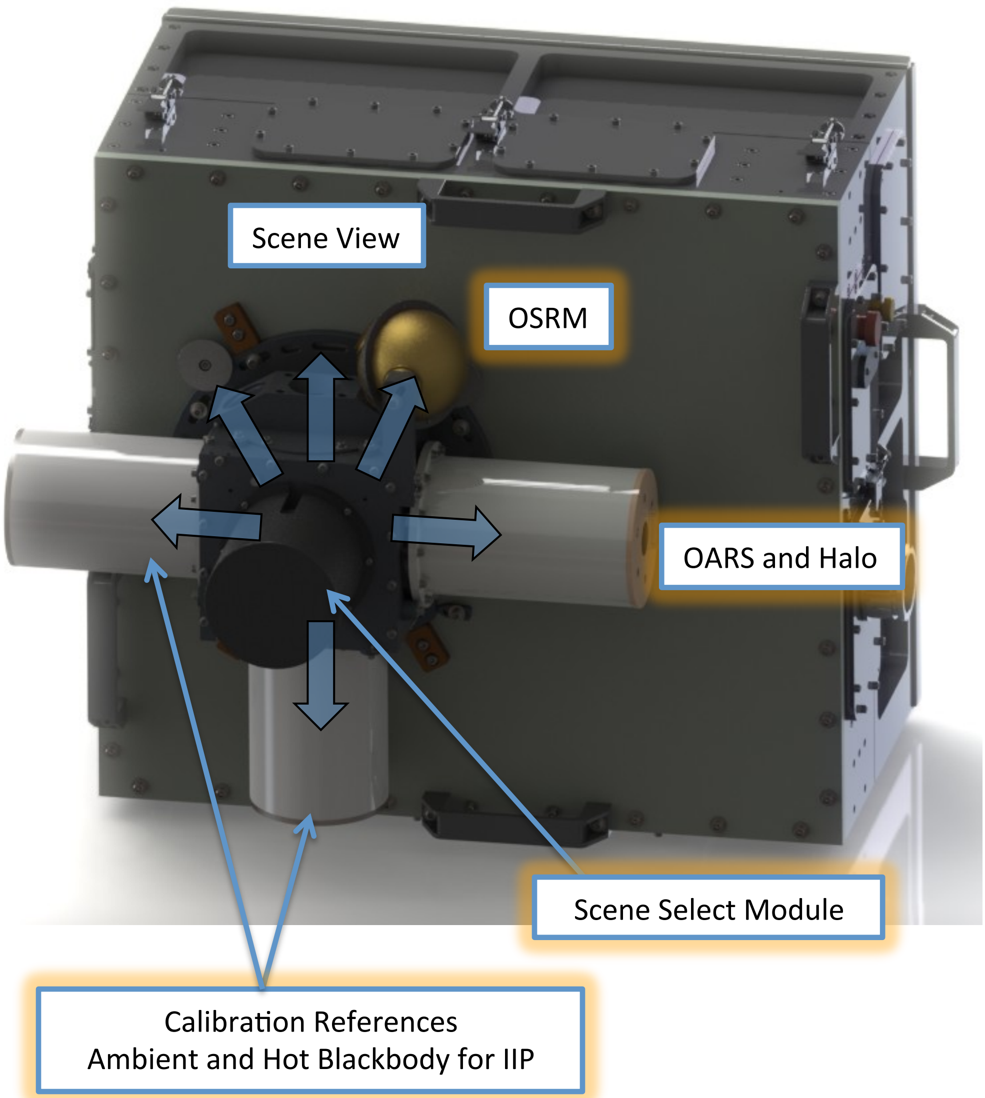


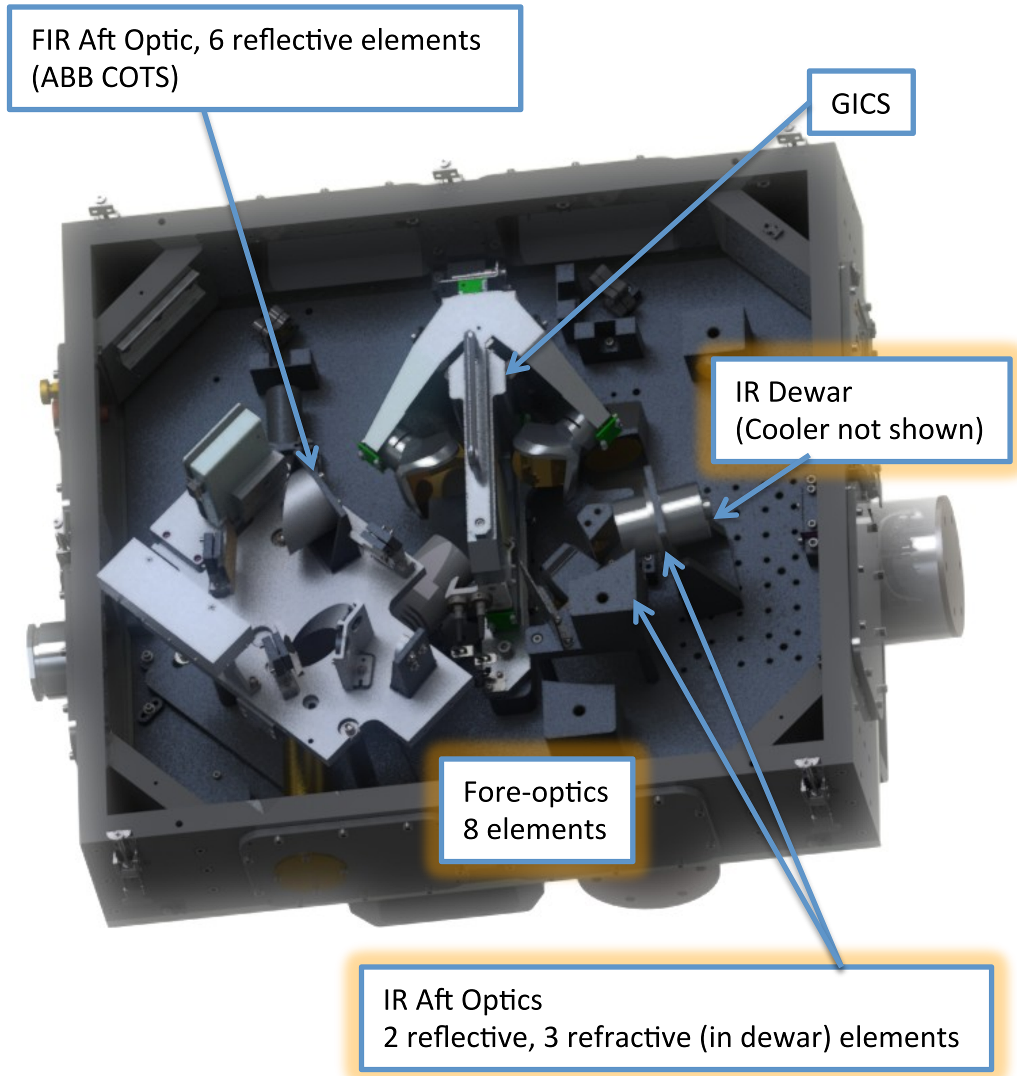
21 January 2011

Breadboard 1

- 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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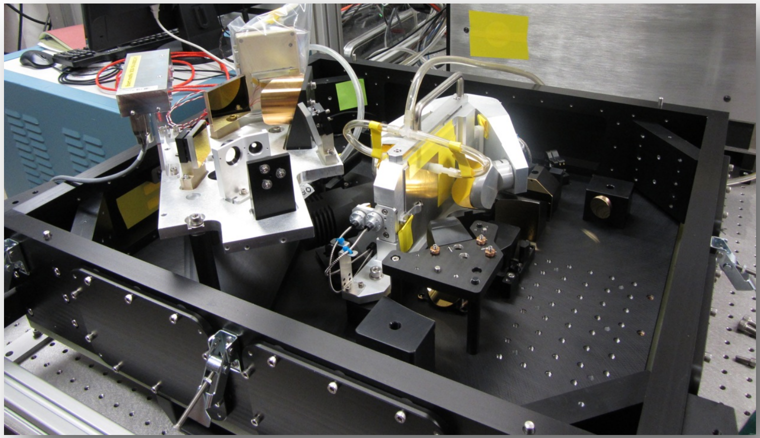

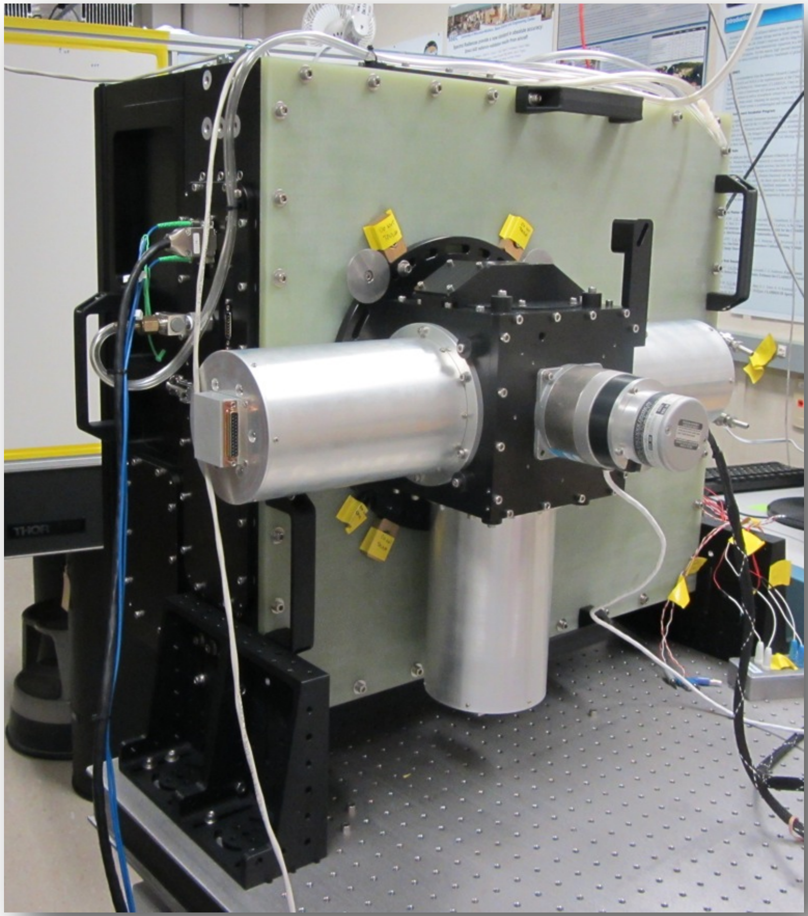

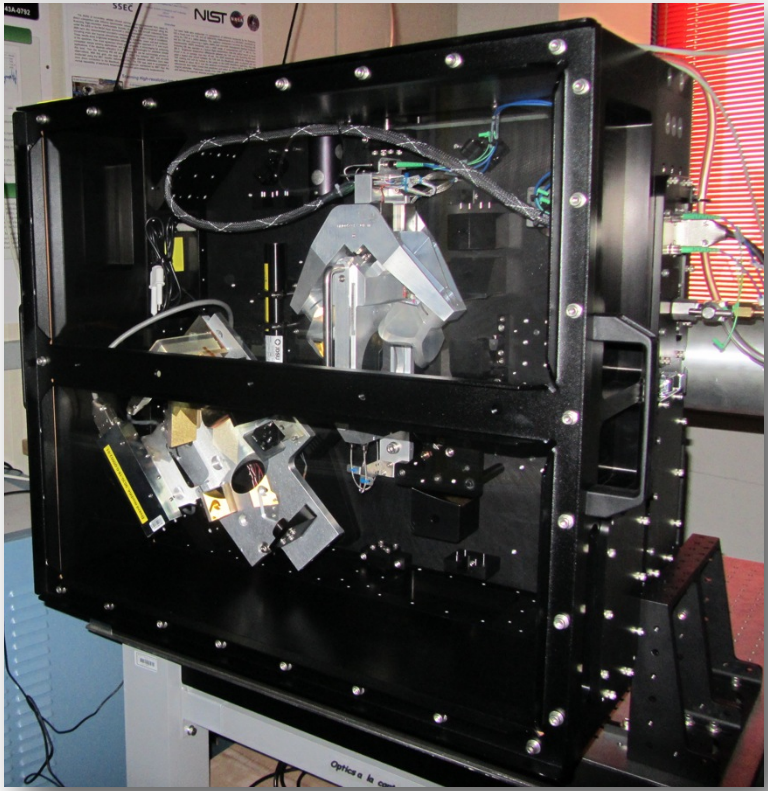

Assembly and Alignment - October

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