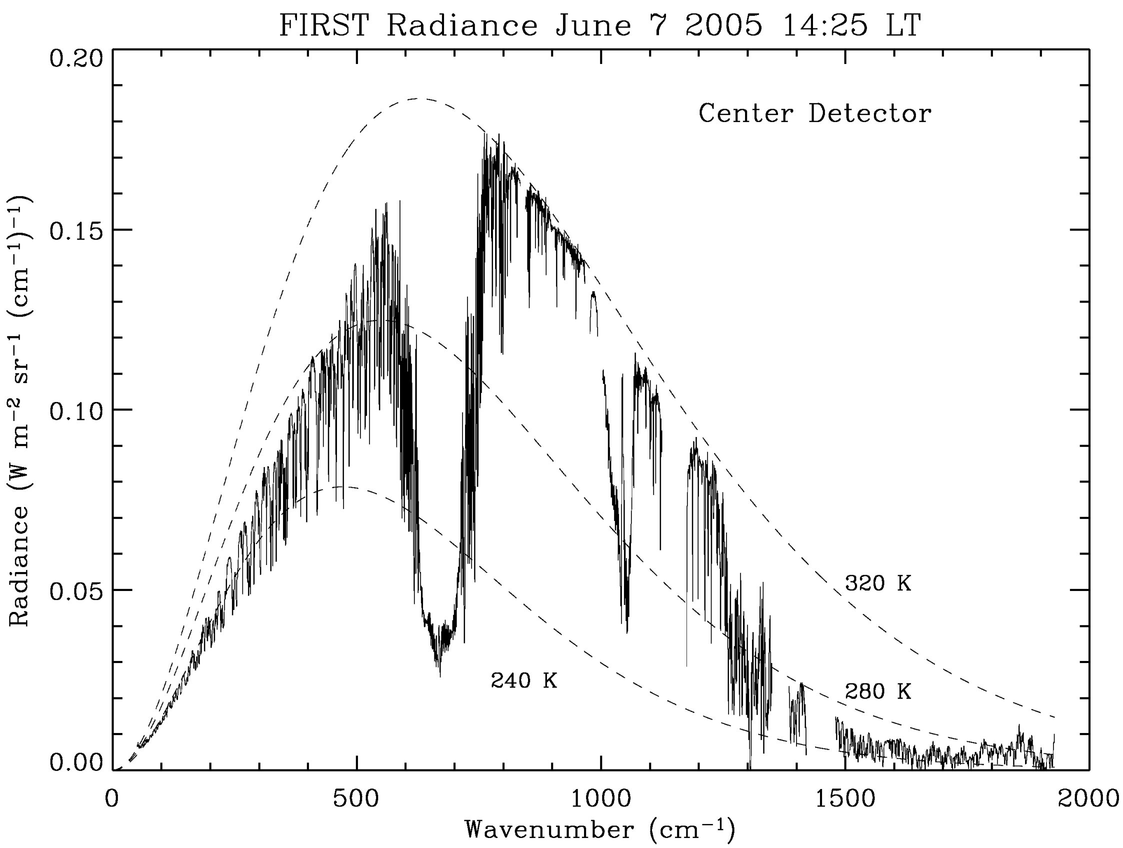
Opportunities for Achieving SI-Traceable Far-Infrared Radiance Measurements for Climate Change Detection



Marty Mlynczak, et al.

CalCon 2009

et al.

- **NASA Langley**
  - Sharon Graves, Nurul Abedin, Rich Cageao, Dave Kratz, Xu Liu, Dave Johnson, Irene Pang (SSAI), Joe Walker (SSAI), Jeff Mast (SSAI), Alan Little, Ron Huppi (SSAI)
- **ITT**
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- **Raytheon Vision Systems**
  - Jinxue Wang, Michael Gritz
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- **NIST**
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- **CORSAIR (Instrument Incubator Program)**
- **FIREBIB (Advanced Component Technology Program)**
- **FORGE (NASA Radiation Sciences Program)**
- **CLARREO (NASA Science Mission Directorate)**

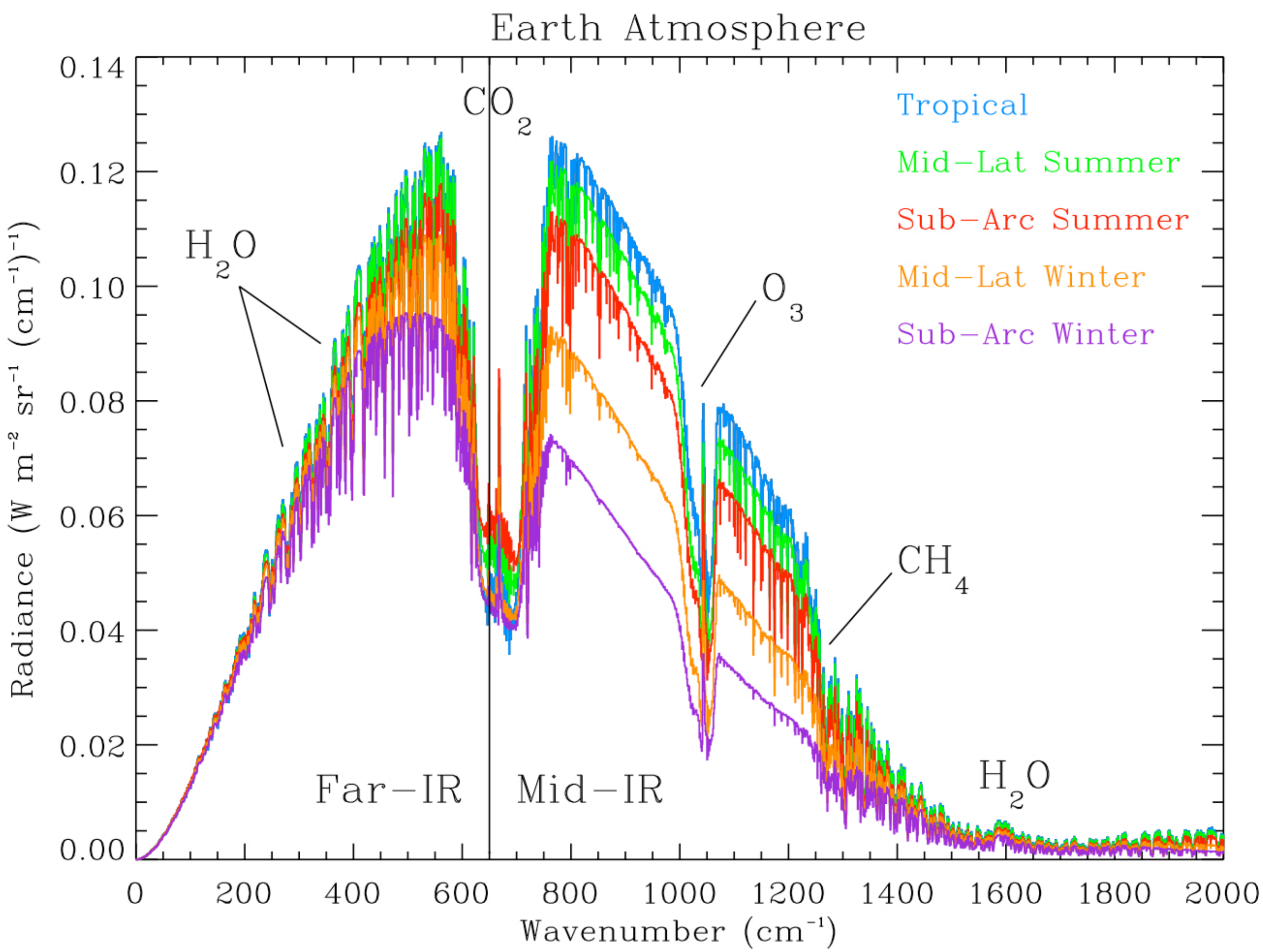
Outline

- **Opportunities in Far-Infrared Science**
  - Infrared radiative cooling
  - Detection of cirrus and role in climate/ climate change
  - Radiative budget closure

- **Ongoing Opportunities in Technology Development**
  - High Emissivity Blackbodies
  - Optical Beamsplitters for FTS Instruments
  - Detectors, cooled and uncooled

- **The Way Forward**
  - Learning how to calibrate the far-IR
  - To the Ends of the Earth for Calibration and Science

Earth's Infrared Radiance Spectrum



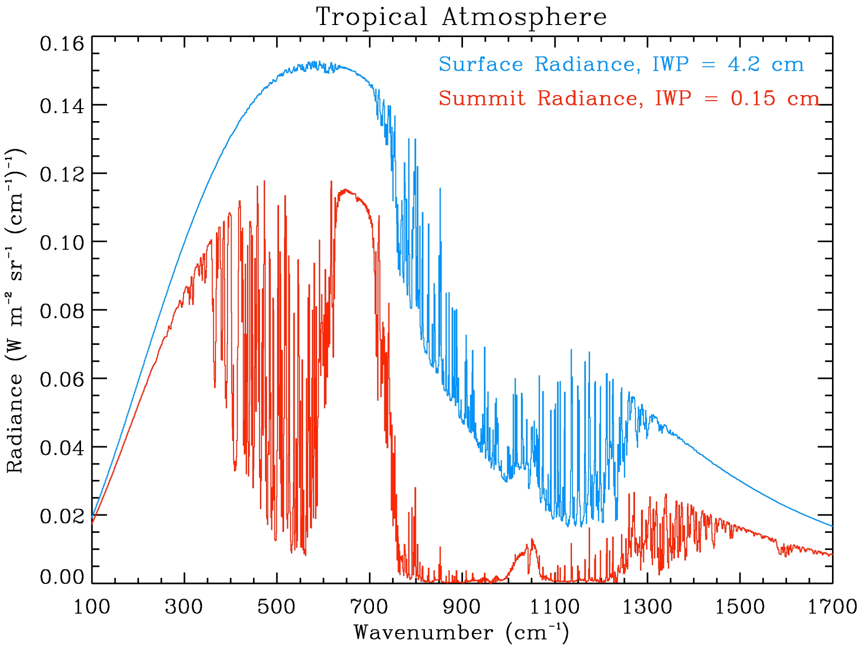
Way Forward: Calibrate, Calibrate, Calibrate!

- Achieving Far-IR accuracy for CLARREO requires much more than developing components and designing systems
- There is no equivalent measurement heritage in the far-IR comparable to the mid-IR (S-HIS; CrIS; IASI; AIRS; NAST-I)
- There are 4 Far-IR spectral instruments worldwide:
  - FIRST TAFTS REFIR AERI-ER
- Need to conduct viable atmospheric measurements and intercomparisons amongst various instruments
- Must validate our knowledge of Far-IR Calibration -- all aspects
- Example: RHUBC/FORGE Campaign, Atacama Desert, Chile, in 2009

RHUBC-II/FORGE Campaign Details

- 10 Aug - 21 Oct 2009
- Cerro Toco Plateau, Chile. 5.1 km altitude (17,500 feet). P = 500 hPa
- Minimum PWV: 0.2 mm observed 22 Aug 2009
- Key instrumentation:
  - Infrared FTS: FIRST, AERI-ER, REFIR-PAD
  - Microwave Radiometers: MP-183, RS-92, MPL, GVR
  - RS-92 radiosondes

Cerro Toco 17, 500 Feet



RHUBC-II/FORGE Campaign
Cerro Toco, Chile and Environs

Site prior to Campaign

Licancabur Volcano

Sulphur Mine
ACT
ACT-Princeton
TocoB
TocoA
Cerro Chajnantor
APEX
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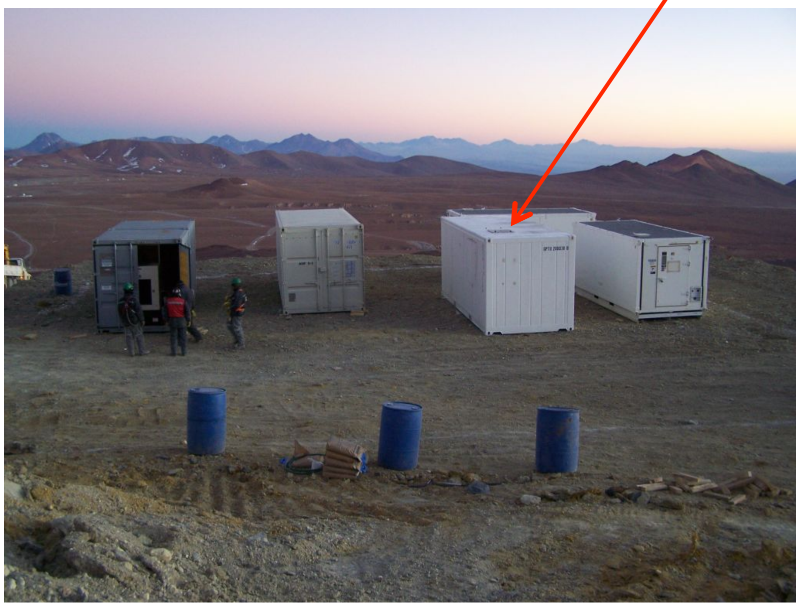
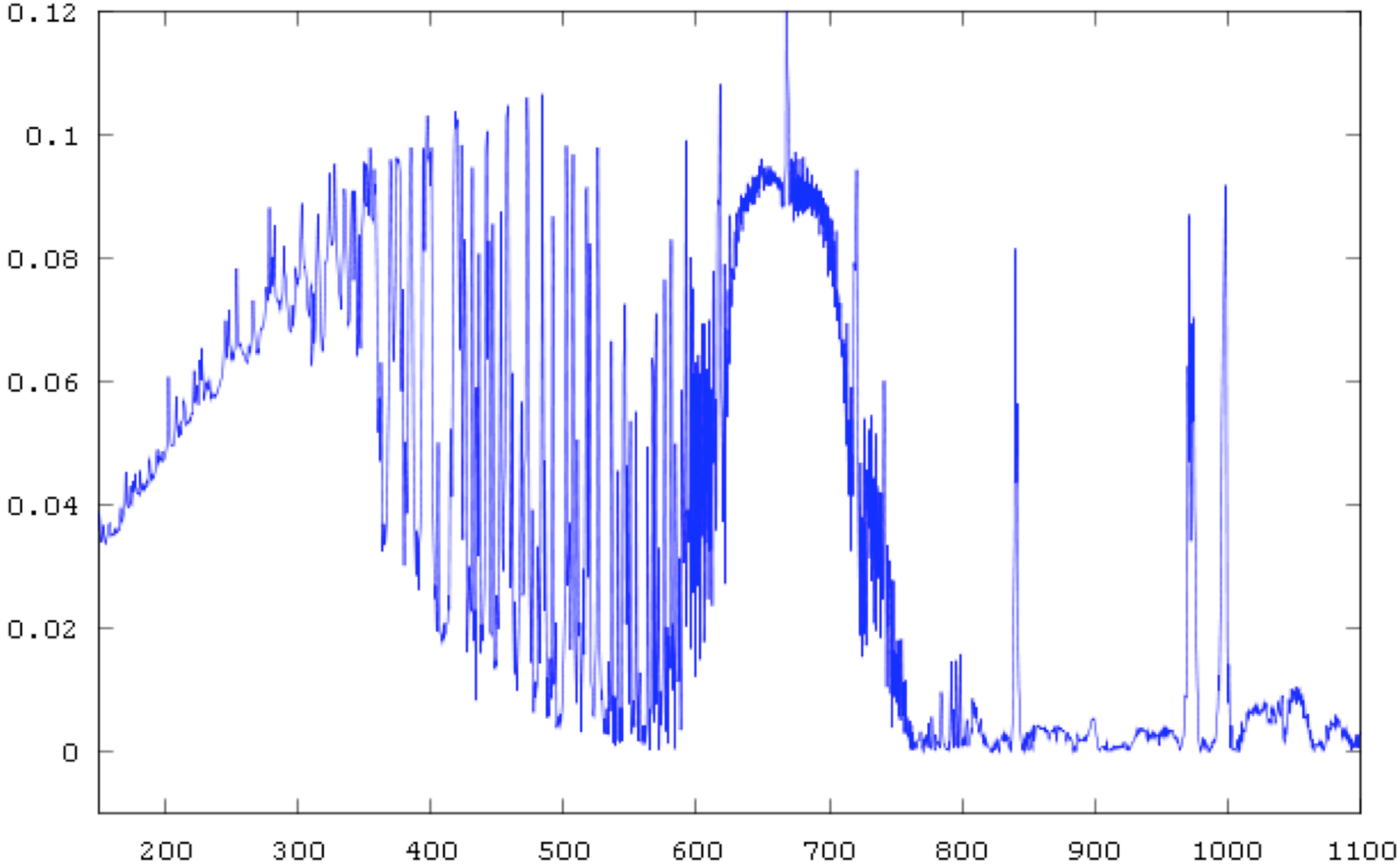
Far-Infrared Observations of the Radiative Greenhouse Effect (FORGE)

FIRST Instrument Trailer

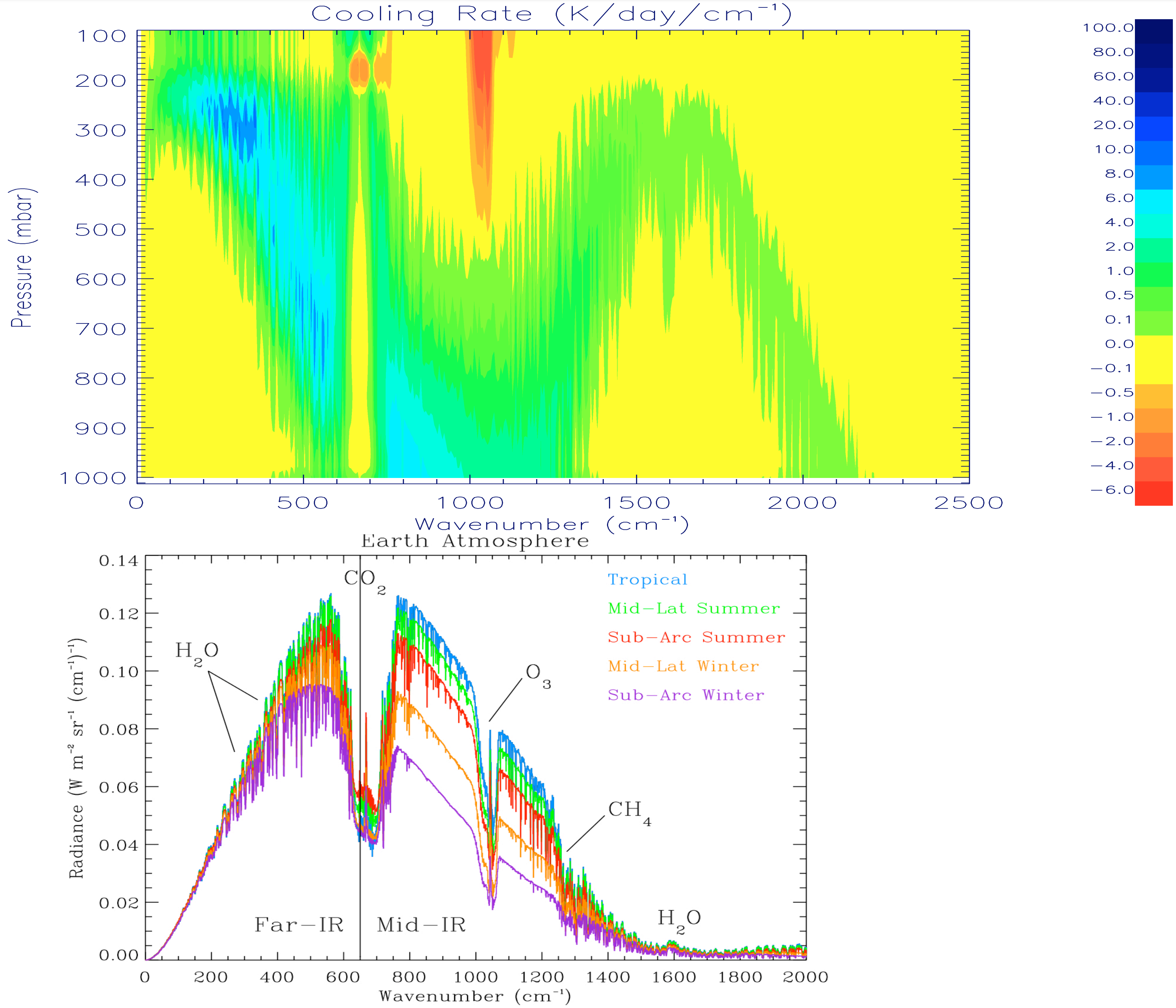


First Light from FIRST
Cerro Toco, Chile, August 21, 2009



PWV = 0.57 mm

Far-Infrared Science – Radiative Cooling



Far-IR Science: Detection of Cirrus Clouds

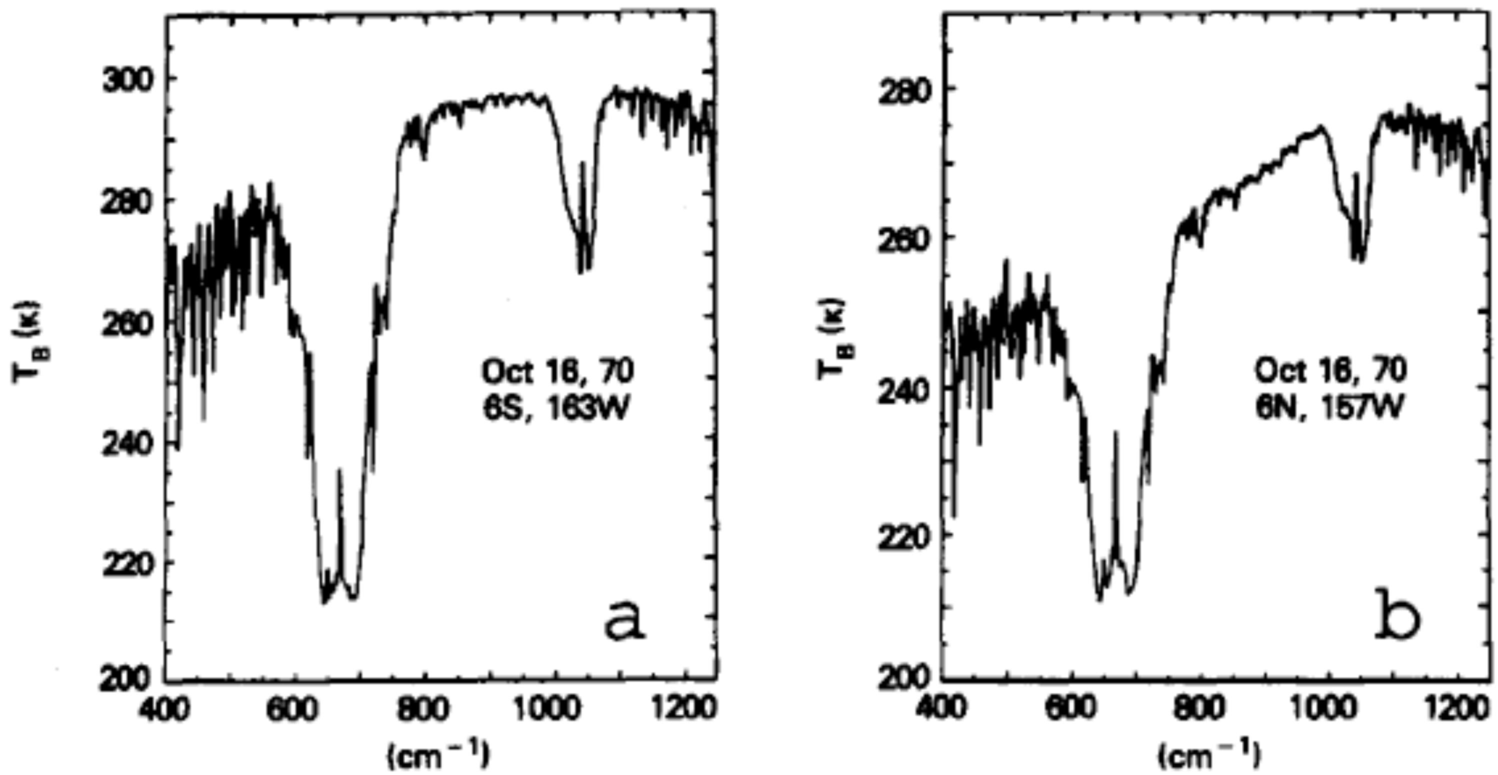
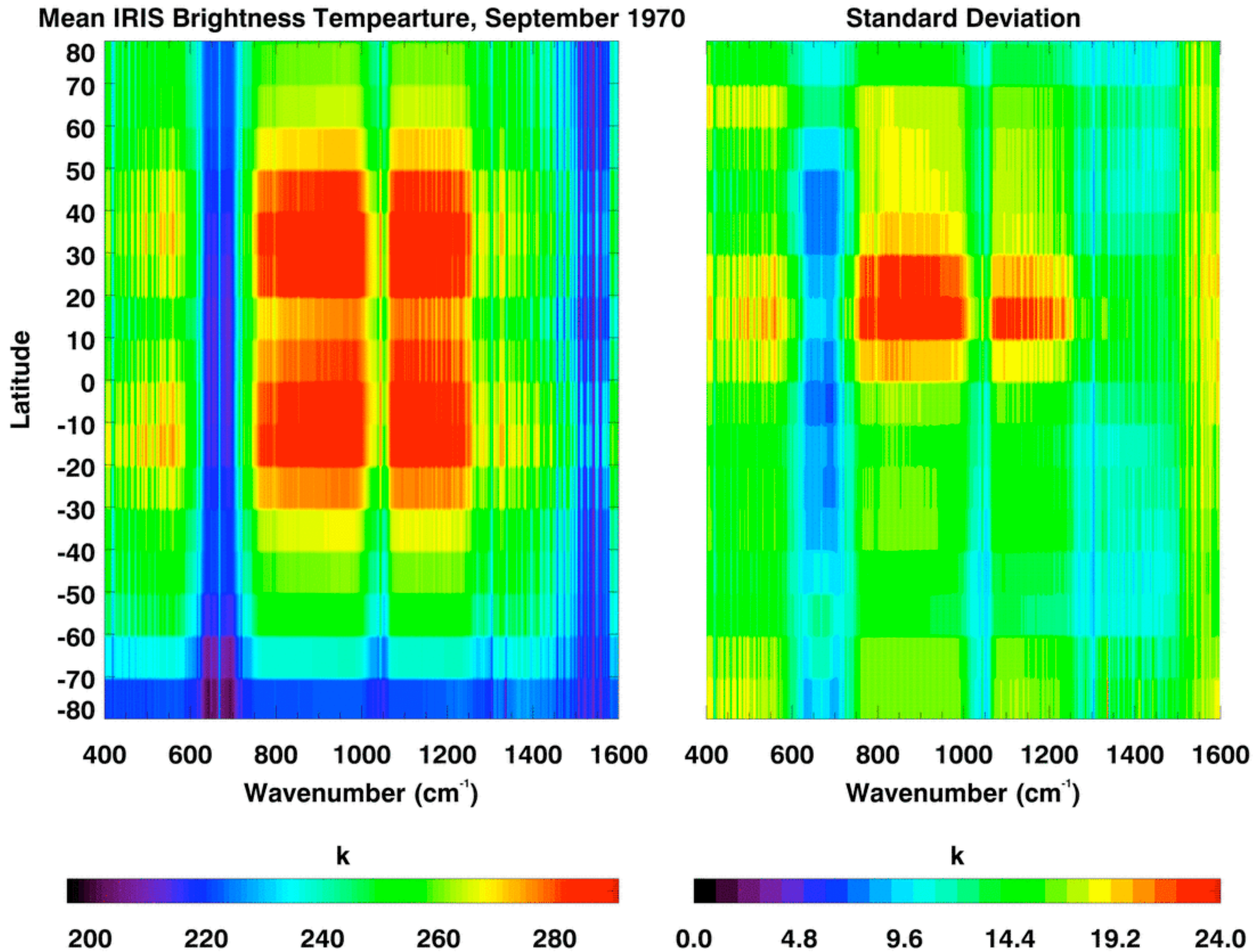


Fig. 2. IRIS spectra observed over the tropical oceans. (a) Cloud-free tropical ocean spectrum, and (b) Maritime tropical spectrum contaminated by optically thin cirrus.

After Prabakhara et al., *JQSRT,* 1993

Far-IR Natural Variability from IRIS



Far-IR: Climate Change Trends

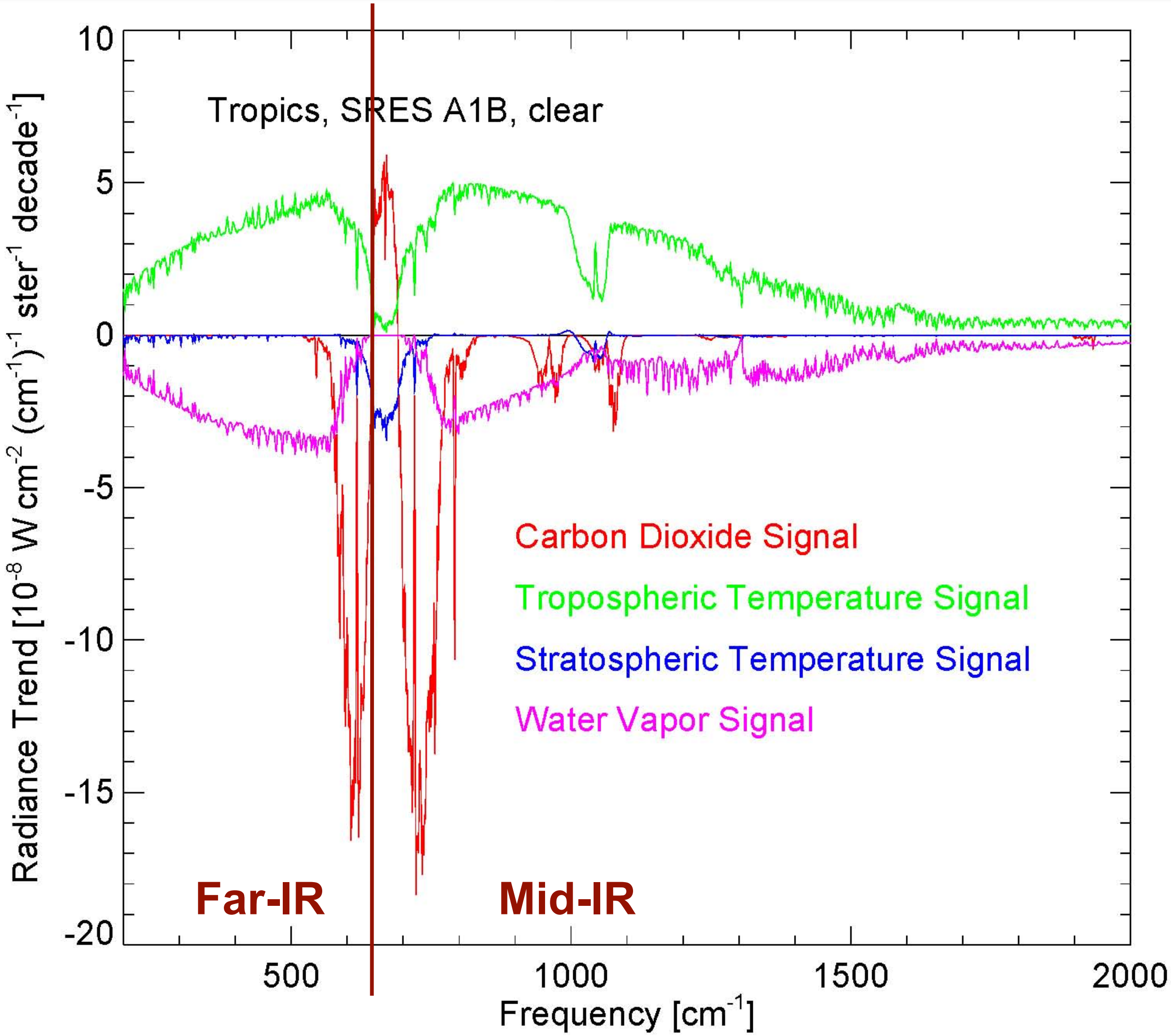


Figure courtesy of S. Leroy, J. Anderson et al., Harvard university

CLARREO Infrared Requirements

- **Measurement Requirements:**
  - Wavelength span: 200 to 2000 cm^{-1} (2700 cm^{-1} goal)
  - Radiometric Systematic Error: < 0.1 Kelvin

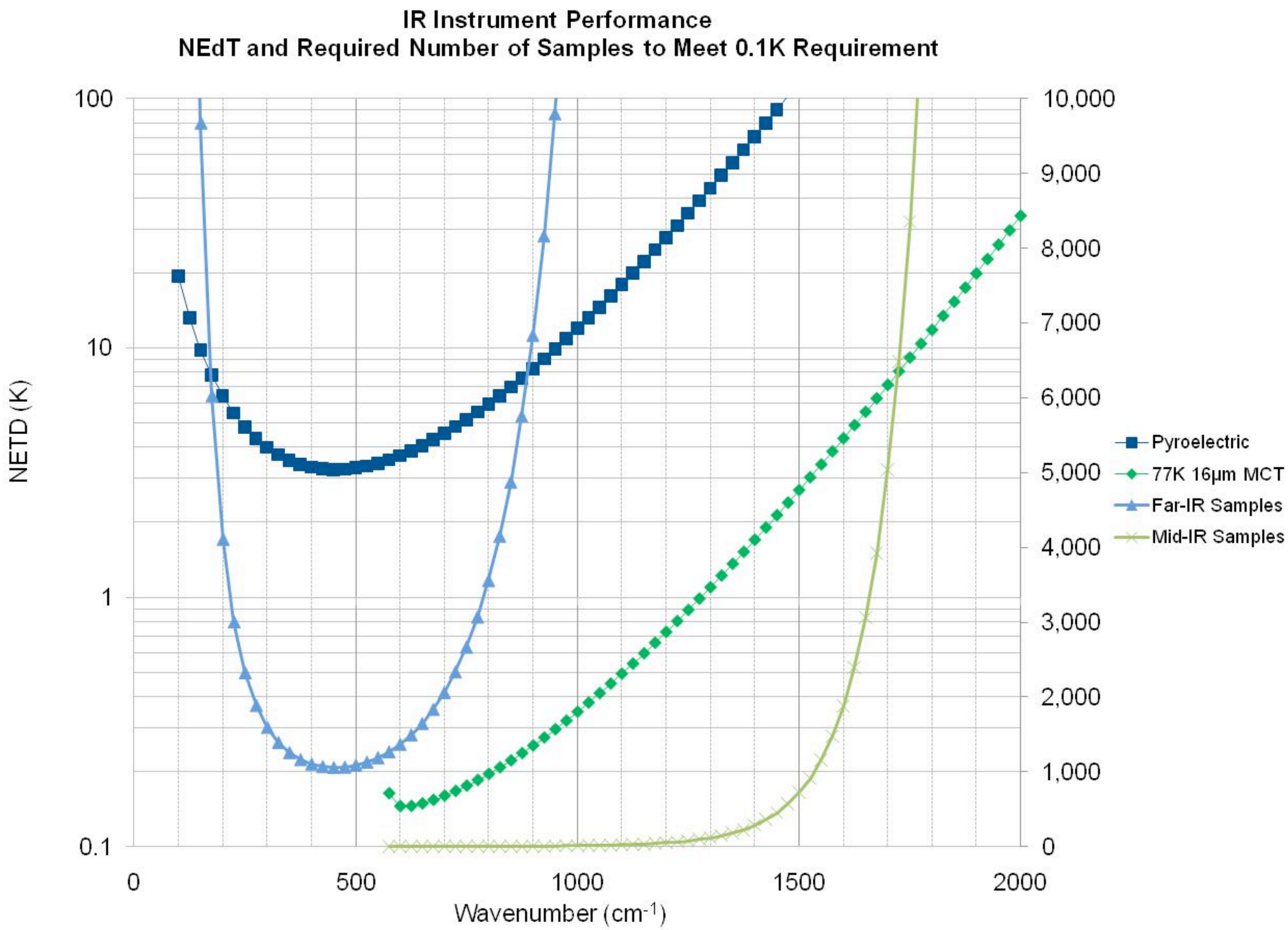
- **Challenges to Meeting the Requirements:**
  - Covering the entire bandpass in 1 instrument
  - Achieving the systematic error levels on orbit
  - Validating the results

- **Opportunities for Technology Development:**
  - Beamsplitters
  - Blackbodies
  - Detectors

Issues: Far-IR Detectors

- **Options: Limited**
  - Sensitive silicon bolometers (e.g., FIRST), but require LHe
  - Less sensitive microbolometers – tend to be too slow
  - Pyroelectrics – sufficient speed, but low responsivity (D*)
- **Consequences**
  - Requires averaging ~ 1000's of spectra to achieve accuracy
  - **May preclude post-flight validation by conventional aircraft or ground-based measurements**
- **Technology Development for Improved Sensitivity**
  - Uncooled: Antenna coupled devices
  - Cooled: Si:BIB detectors but at 10-12 K, accessible by extant cryocoolers
  - Can give noise performance 100 to 1000 times better than Pyroelectric devices

Modeled IR FTS Noise Performance

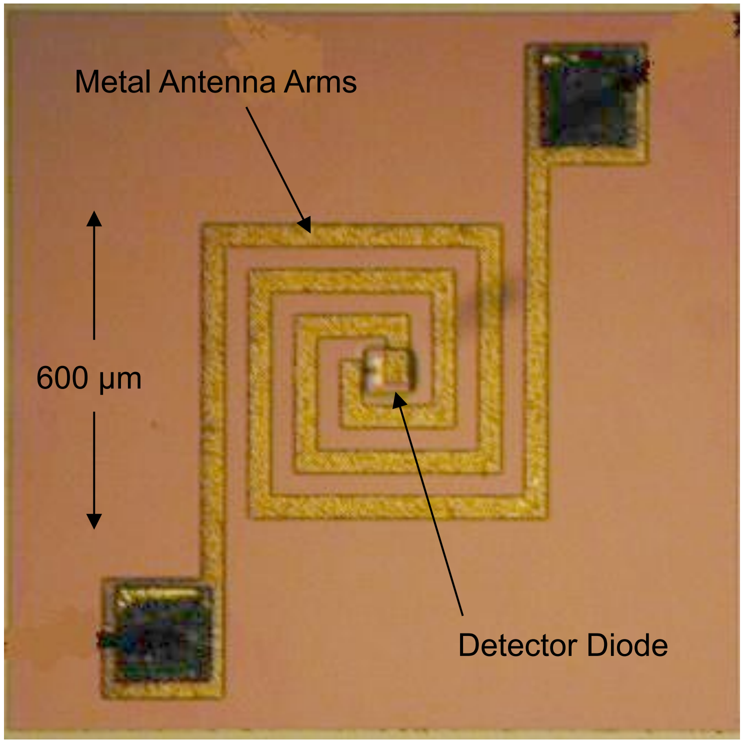


Courtesy D. Johnson, A. Little, NASA LaRC

Antenna Coupled Terahertz Devices

- Transition TRL-3 Antenna-Coupled THz Detector (ACTD) developed for millimeter wavelengths (mmW) to Far-IR
- Device sensitive in Far-IR From 15 to 50 µm with projected D* > 10^{10} Jones
- Far-IR radiation falls on antenna, sets up current in diode with bias voltage applied
- Current varies as intensity of radiation varies with wavelength
- Signal is calibrated to provide responsivity (Amps per Watt)
- Status
  - First lot (of 4 total) fabricated
  - Response obtained in mm wavelengths as before
  - Proved ability to couple antenna to diode
  - Second lot under development, with design and device structure for far-IR wavelengths
  - Second lot fabrication due in September 2009

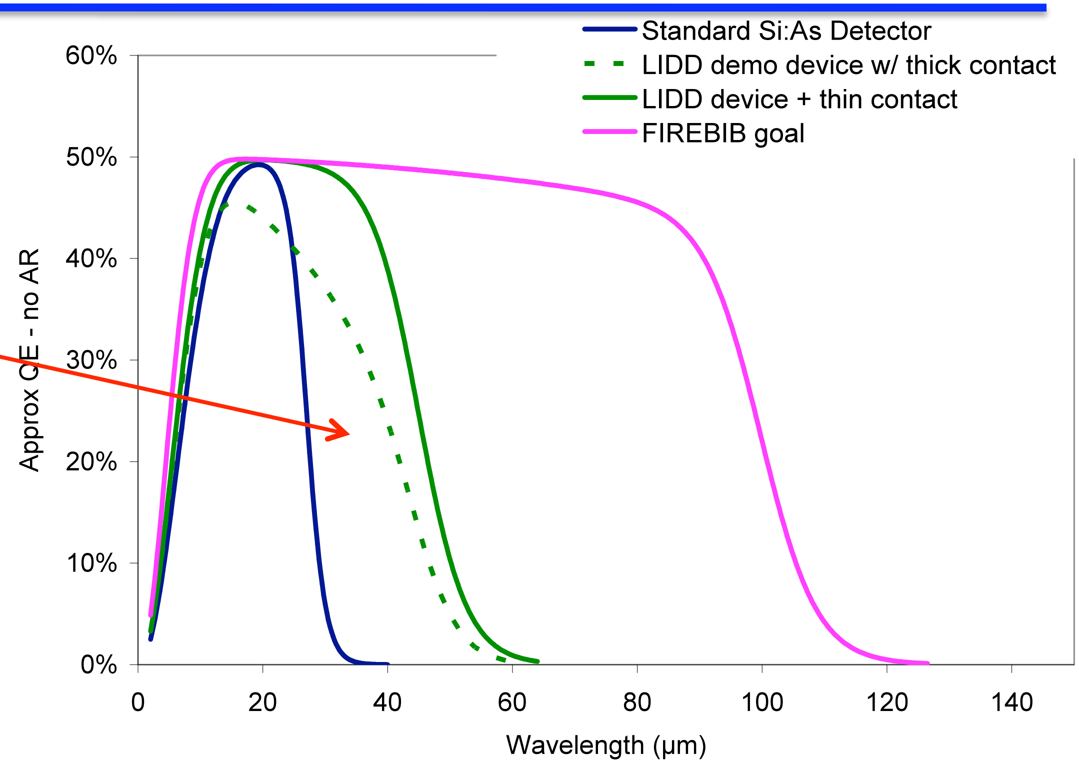
ACTD Square Spiral Design

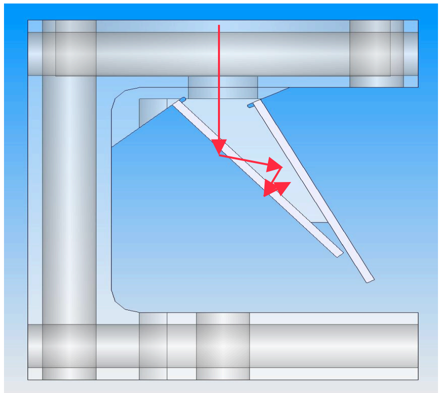


Courtesy Raytheon Vision Systems

Si:BIB Detectors at 12 Kelvin

- Extend proven Si:BIB to Far-IR
- Concept proven in 2008 under NASA-DRS FIDTAP Program
- 10 to 60 μm
- 4 to 100 μm (goal)
- D* > 10^{10} Jones
- Operating temp ~ 10-12 Kelvin
- Quantum efficiency nearly 100% in trap design developed with NIST
- Detector materials being grown 9/2009
- Package, evaluate in GFY 2010





Courtesy DRS Technologies

Far-IR: Blackbody Design

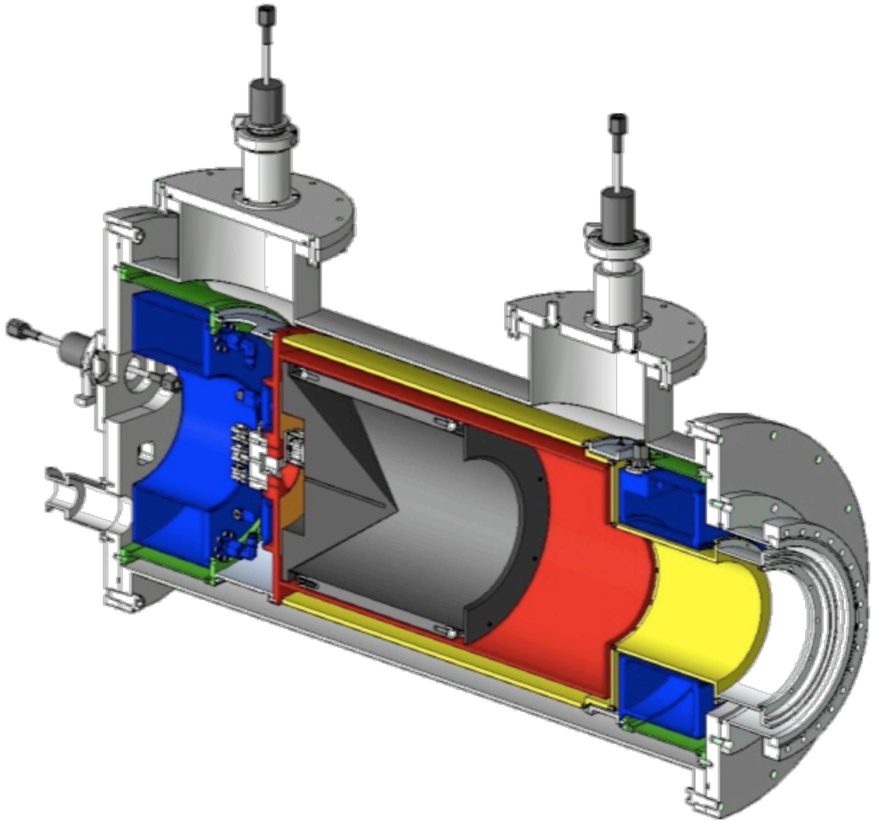
- Design goal is emissivity of ~0.9999, 100 mK accuracy

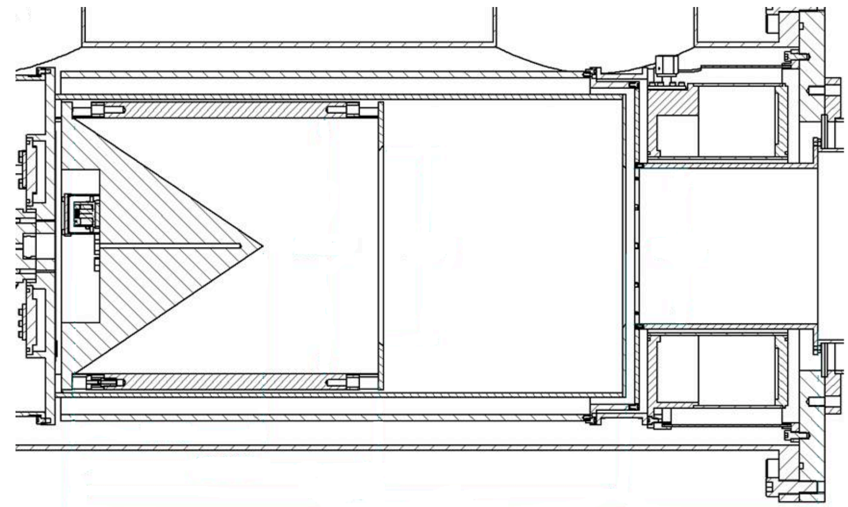
- SDL BB will use an LWIRCS type cone and cylinder design
  - It is compact in size with good thermal control of critical surfaces
  - Based on coating properties, specular and diffuse BB's need to be about same size to achieve same emissivity

- Specular design, Z302 paint
  - Z302 is simpler than fragile, porous diffuse surfaces
  - Z302 has established flight heritage

- Status
  - Extensive paint characterization to date
  - Blackbody design underway
  - LWIRCS transfer standard in characterization at NIST

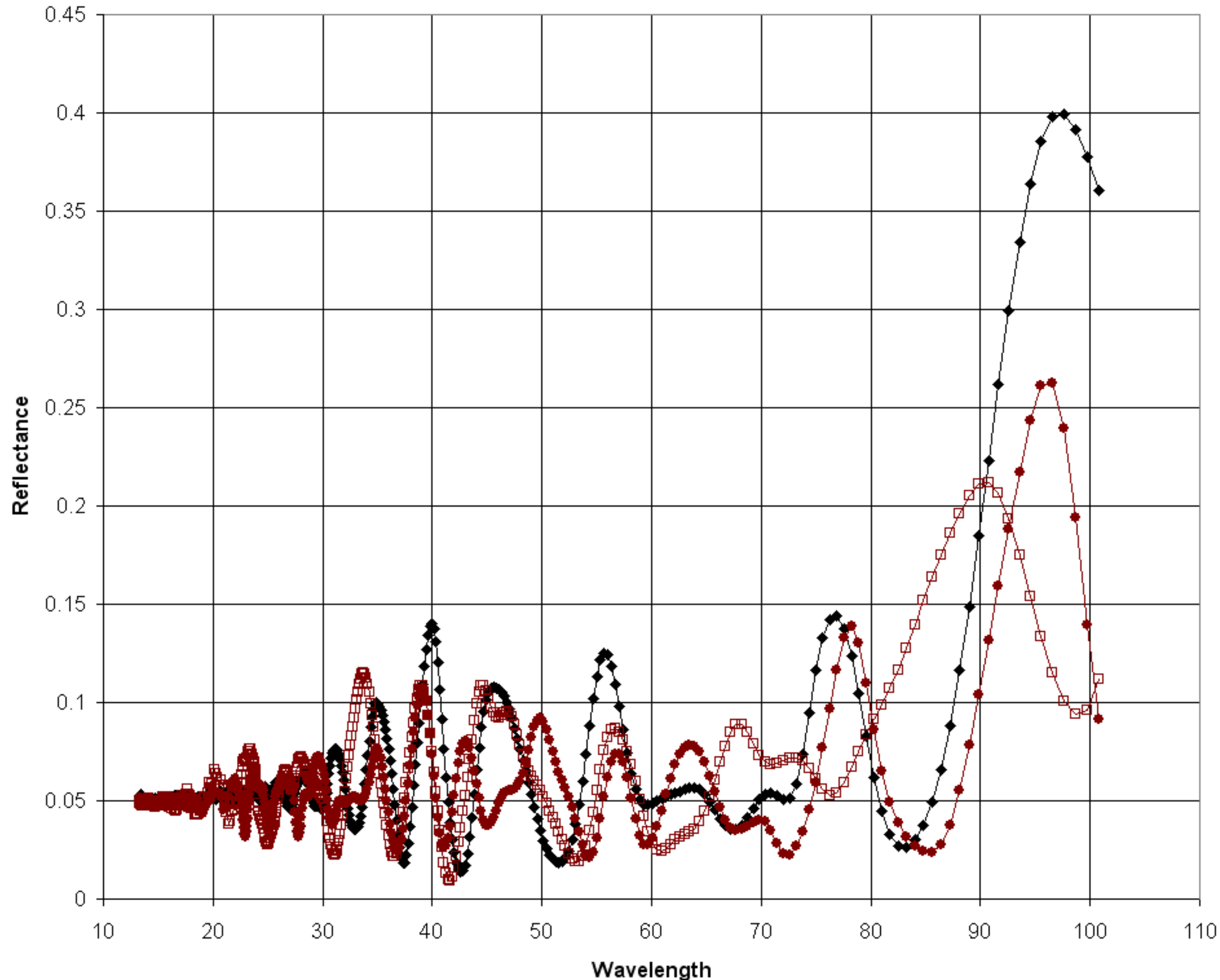
Far-IR: Blackbody design





Cone/cylinder specular blackbody design under development by SDL, NASA, NIST

Measured Far-IR BB Paint Reflectance



Courtesy SDL

Infrared Beamsplitters for CORSAIR Project

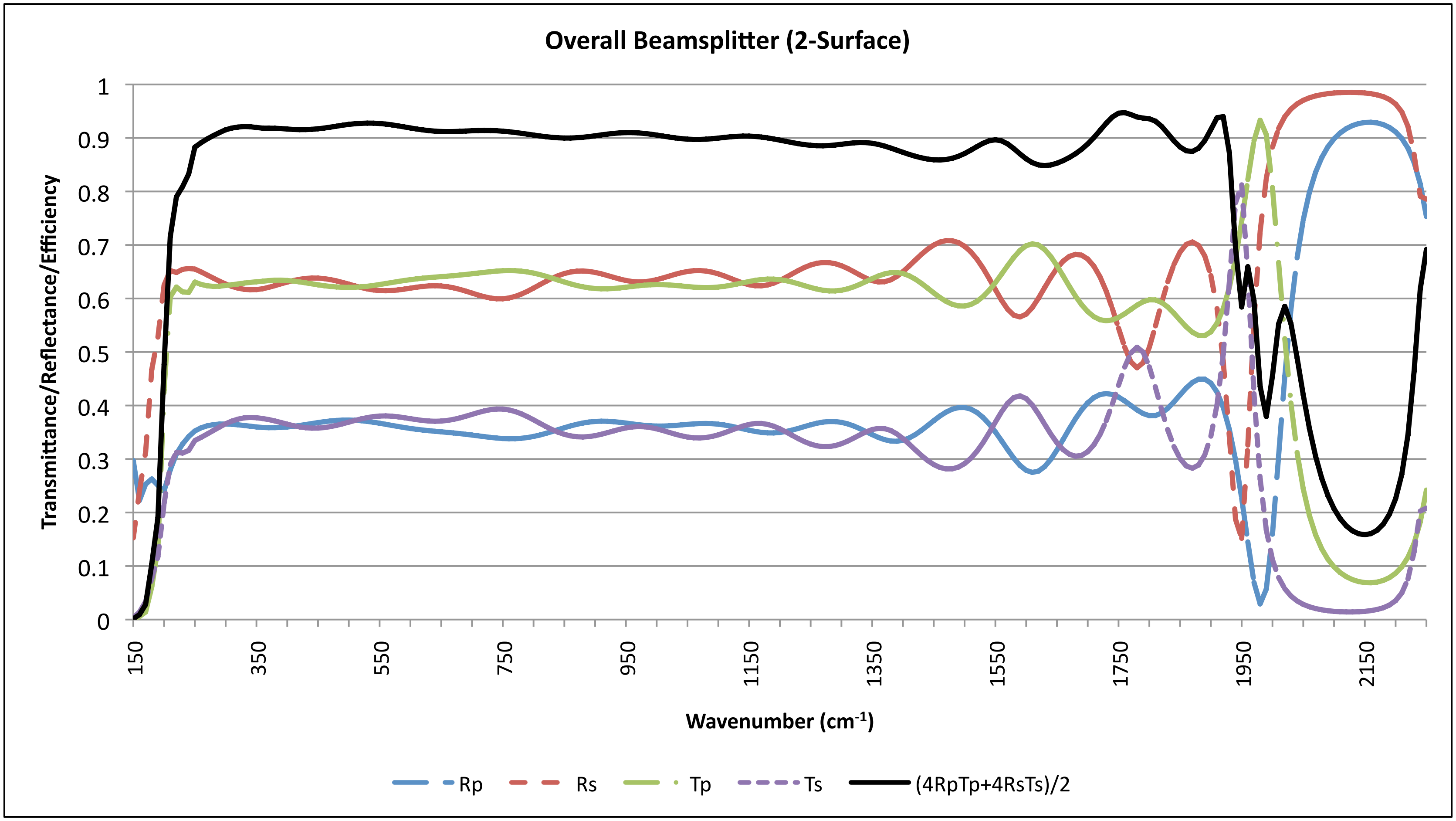
Currently in Phase 1 with ITT Space Systems

Design Criteria:

- 5 to 50 μm
- Diameter 2" w/ ≈90% clear aperture
- Flatness better than 0.22 waves P-V at 632.8 nm both sides
- Side 1:
  - $0.5 \cdot [4R_p(\lambda) \cdot T_p(\lambda) + 4R_s(\lambda) \cdot T_s(\lambda)] > 0.80$ $5\mu < \lambda < 40\mu$ ($250 cm^{-1}$ to $2000 cm^{-1}$) at 45° angle of incidence
  - $0.5 \cdot [4R_p(\lambda) \cdot T_p(\lambda) + 4R_s(\lambda) \cdot T_s(\lambda)] > 0.65$ $40\mu < \lambda < 50\mu$ ($200 cm^{-1}$ to $250 cm^{-1}$) at 45° angle of incidence
- Side 2: AR coat
- 7 year lifetime
- Target humidity resistance up to 60%
- 250K to 330K storage temperature
- 260K to 320K operating temperature

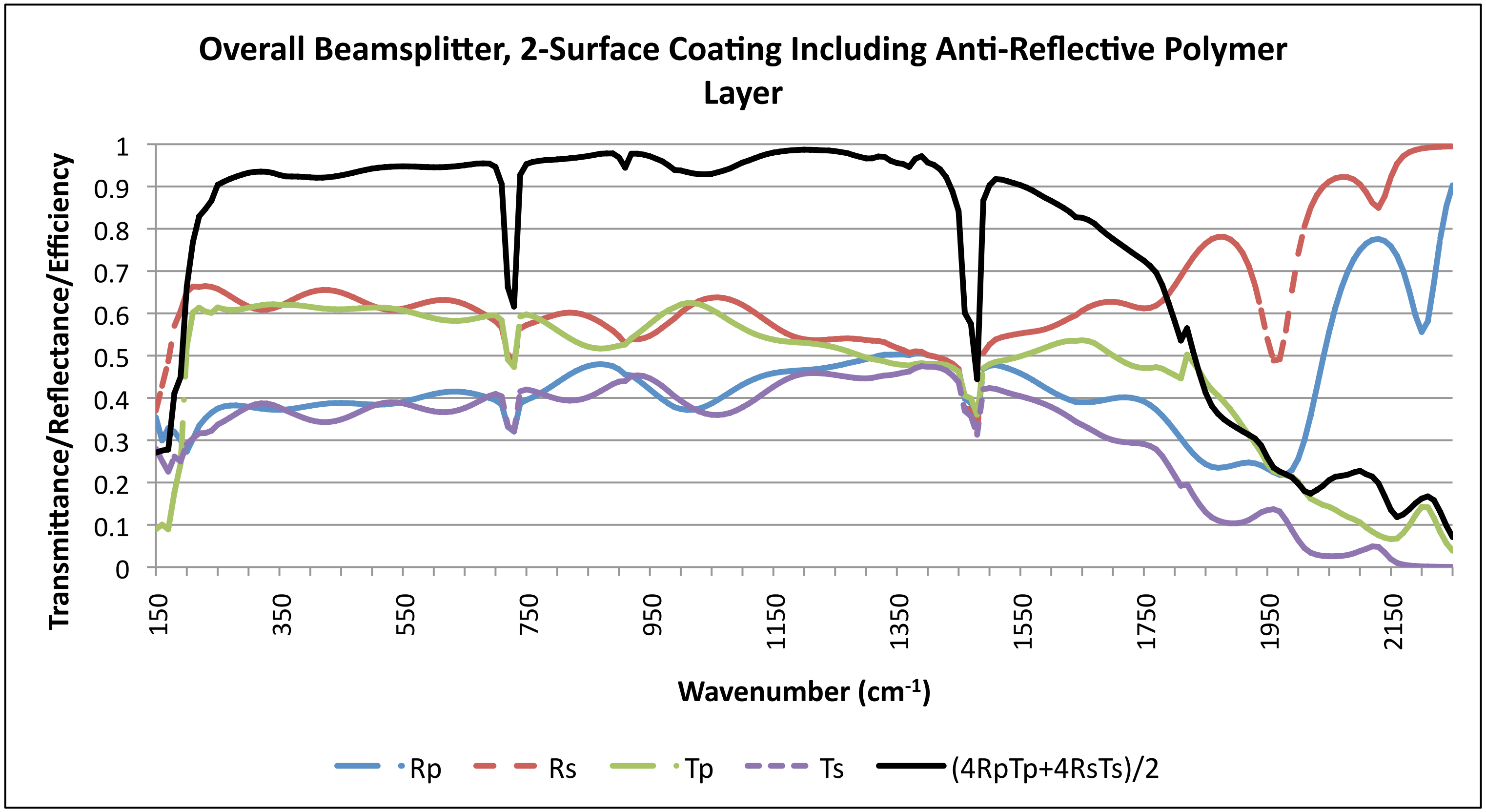
Substrates Examined: Cesium Iodide; Silicon; Diamond; Germanium; KBr

CORSAIR FIR Beamsplitter Detail
CsI Substrate Coating Performance



Data calculation and design
courtesy of ITT Space Systems

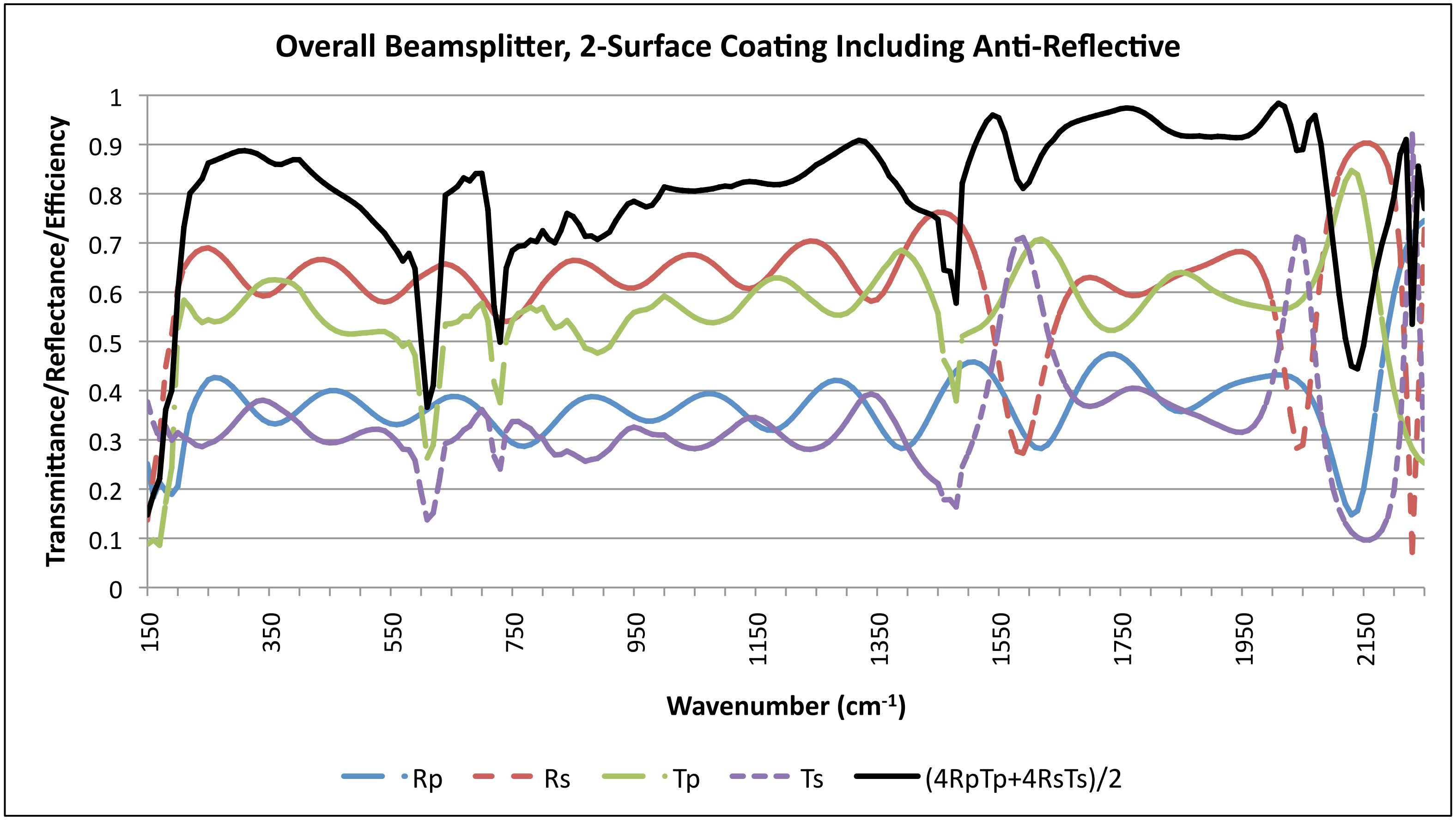
CORSAIR FIR Beamsplitter Detail
Diamond Substrate Coating Performance



For this particular optimized coating pair, theoretical performance was inferior to that of the optimally coated CsI especially in the short wavelength region.

Data calculation and design courtesy of ITT Space Systems

CORSAIR FIR Beamsplitter Detail
Silicon Substrate Coating Performance



For this particular optimized coating pair, theoretical performance was inferior to that of the optimally coated CsI in most spectral regions.

Data calculation and design courtesy of ITT Space Systems

Summary

- Far-Infrared is a frontier of scientific research
- Many processes fundamental to climate occur in the far-IR
- Substantial effort underway to develop technologies needed for accurate measurement of the far-IR from space:
  - Detectors, cooled and uncooled
  - Beamsplitters, broad bandpass to enable 1 instrument for entire IR
  - Blackbodies, accurately characterized to SI standards
  - Field campaigns at the "ends of the earth" to learn how to calibrate

Closing thought:

How often do you get to open up half the spectrum?

- Warren Wiscombe, NASA GSFC