Enabling Technologies for the “CLARREO” Mission

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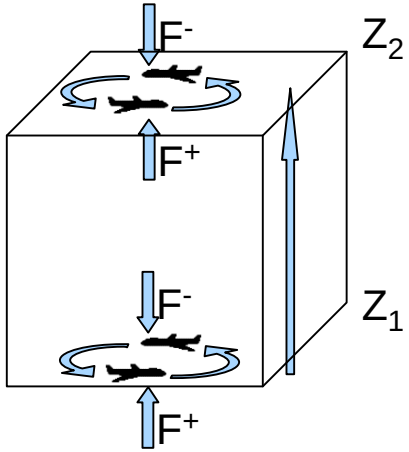
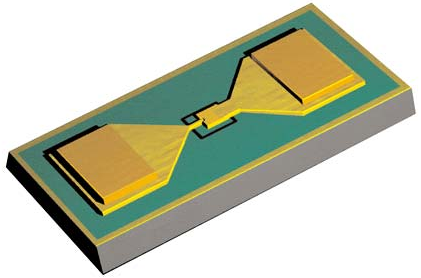
ESTC-2008 Workshop

FIRST

INFLAME



$$\frac{\partial T}{\partial t} = \frac{1}{\rho C_p} \frac{F_{net}(z_2) - F_{net}(z_1)}{(z_2 - z_1)}$$



CORSAIR

OUTLINE

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- CLARREO Basics
- The Road To CLARREO at Langley
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  - FORGE
  - CORSAIR
- Summary

Acknowledgement: Sponsors & Partners

- NASA ESTO
- NASA Radiation Sciences Program
- NASA UARP
- NASA Langley

- Space Dynamics Laboratory
- Harvard Smithsonian Center for Astrophysics
- Raytheon Vision Systems
- ITT
- DRS Technologies
- JPL
- NIST
- U. Wisconsin
- Imperial College
- Numerous members of scientific community

Overarching Objectives

- To improve understanding Earth's climate and climate change through a combination of new observations and innovative data analysis

- Work focuses on:
  - "Far-Infrared" part of the spectrum 15 - 100 μm
    - FIRST; INFLAME; CORSAIR; FIDTAP
  - Solar spectrum via measurement of atmospheric heating rates
    - INFLAME

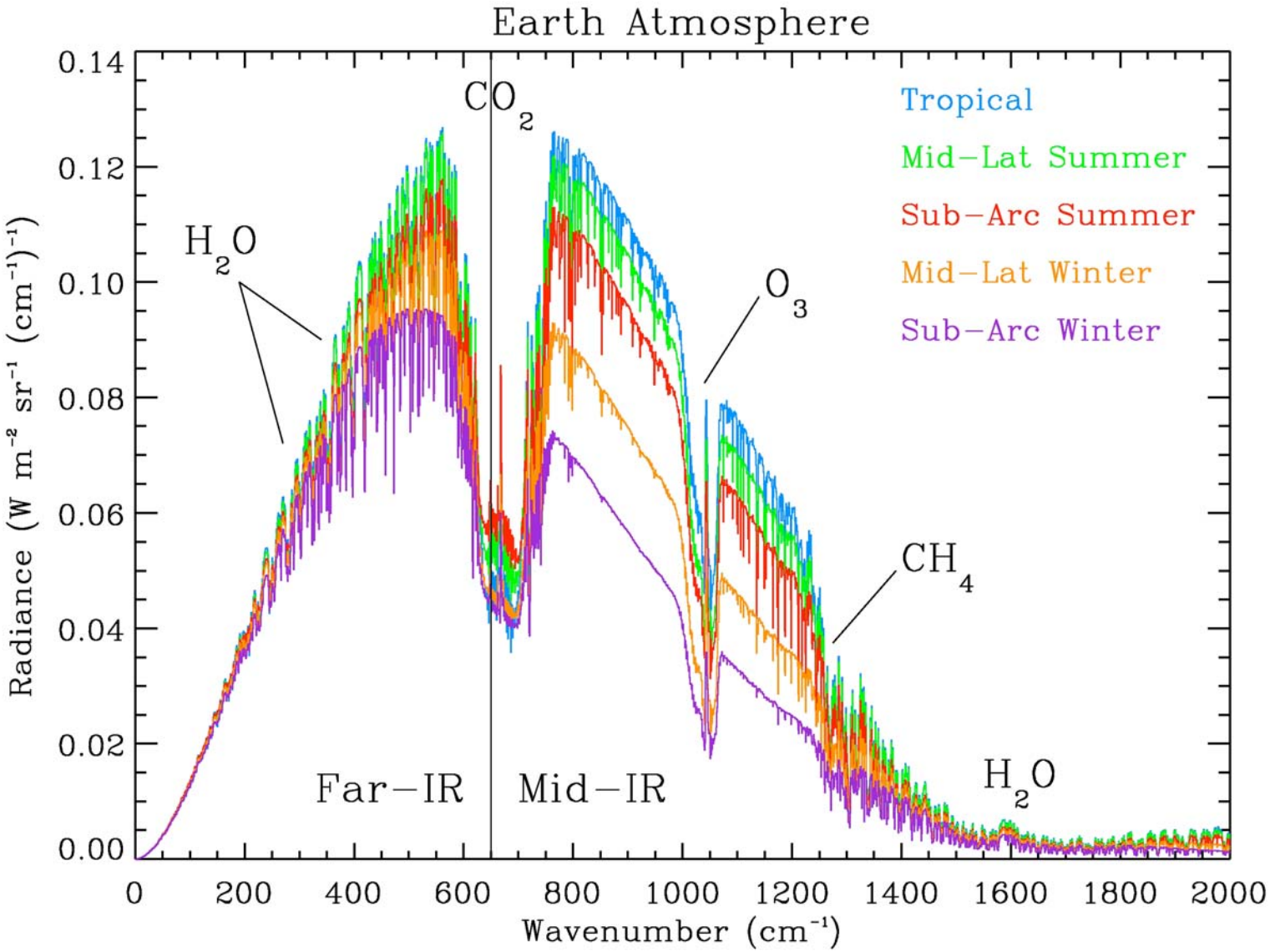
- Approach:
  - Develop new technology where needed (IIP, ATI, ACT)
  - Exploit existing data sets as applicable (EOS, IIP)
  - Generate new data sets to fill voids in knowledge (CLARREO)

Demonstrate accurate, stable instruments & related technology for space based on well-defined science measurement objectives

CLARREO Basics

- **"CLARREO"**
  - ***Climate Absolute Radiance and Refractivity Observatory***
- **Determine climate change magnitude and feedbacks**
- **Provide SI-traceable measurements of atmospheric radiance and refractivity**
  - **SI-traceability is essential to establishing any long-term climate record**
- **Very high accuracy to detect changes within ~ decade**
- **Improve climate model forecasts for purpose of informing public policy**
- **Measurements of atmospheric radiance by technique of Fourier Transform Spectrometry**
- **Atmospheric refractivity provided by GPS signals**

Top-of-Atmosphere Radiance



CLARREO
Nominal Requirements and Status

Nominal Measurement Requirements

- Spectral Range
  - 5 to 50 μm (2000 to 200 cm^{-1})
- Accuracy
  - 0.1 K (3-sigma) for ~ monthly means in 15 degree grid boxes
- IFOV
  - ~ 100 km

CLARREO Status

- NASA Langley is leading a large team involving NASA Centers, FFRDC's, and Universities in a pre-phase A study
- Study timeline: April 2008 through September 2009
- Study will conclude with Mission Concept Review with expectation to proceed into mission formulation (Phase A) in FY 2010

The Road to CLARREO @ Langley

Since 2001 six projects have been funded by NASA:

- **IIP's**
  - **FIRST (IIP 2001)**
  - **INFLAME (IIP 2004)**
  - **CORSAIR (IIP 2007)**
- **Advanced Technology Initiative (ATI)**
  - **FIDTAP (2006-2008)**
- **Campaigns (NASA Radiation Sciences Program)**
  - **FORGE/RHUBC**
    - **Wisconsin 2007**
    - **Atacama Desert, Chile, 2009**
- **Data analysis (EOS Science Team Re-Competition)**
  - **CERES/AIRS analysis and Far-IR residuals**

Where we are now

- **FIRST instrument**
  - **Demonstrated beamsplitter, FTS, focal plane technologies for far-IR**
  - **Participating in science campaign (FORGE/RHUBC)**
  - **Successful comparison against AERI; AIRS**
  - **Unique testbed available for evaluating new detectors, blackbodies, etc.**
- **INFLAME instruments**
  - **Entering build and calibration phase - flight demo in January 2009**
- **FIDTAP**
  - **Successfully demonstrates new far-IR detectors April 2008**
- **CORSAIR selected - in process of placing contracts**
- **CERES/AIRS far-IR studies well underway**
- **Planning for FORGE campaign. Campaign starts in ~ 1 year**

Instrument Incubator Program - IIP

Far-Infrared Spectroscopy of the Tropsophere - FIRST

PI: Marty Mlynczak/LaRC

Description and Objectives

Measure the Far-Infrared spectrum
of the Atmosphere and Earth (10 to 100 μm)

Far-IR observations are the key to understanding the greenhouse effect and the radiative feedbacks associated with increased anthropogenic forcings

Far-IR key to understanding cirrus effects, etc.

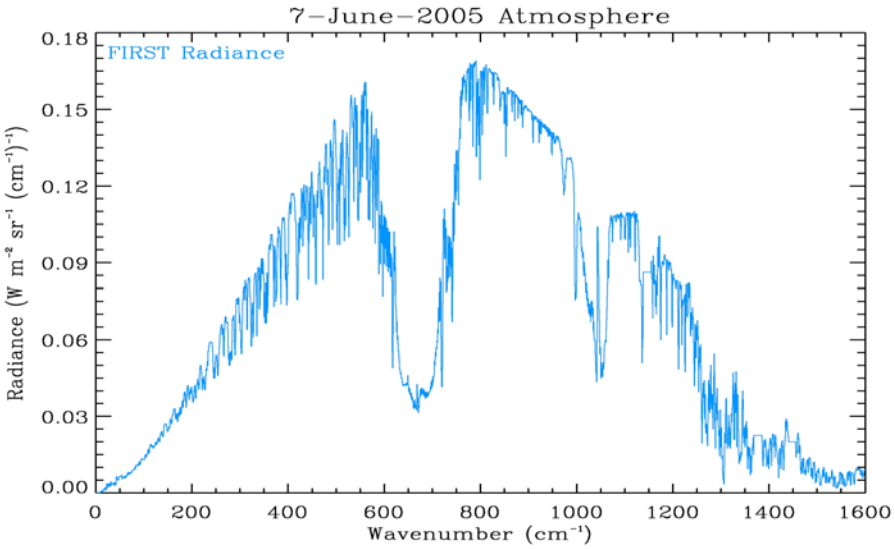
Approach

- Simulate space environ.

- Develop
  - High-throughput Michelson FTS
  - Broad-bandpass beamsplitter
  - Advanced detector system

Partners

Utah State Univ. – Interferometer
Harvard SAO – Beamsplitters
19-member science advisory team



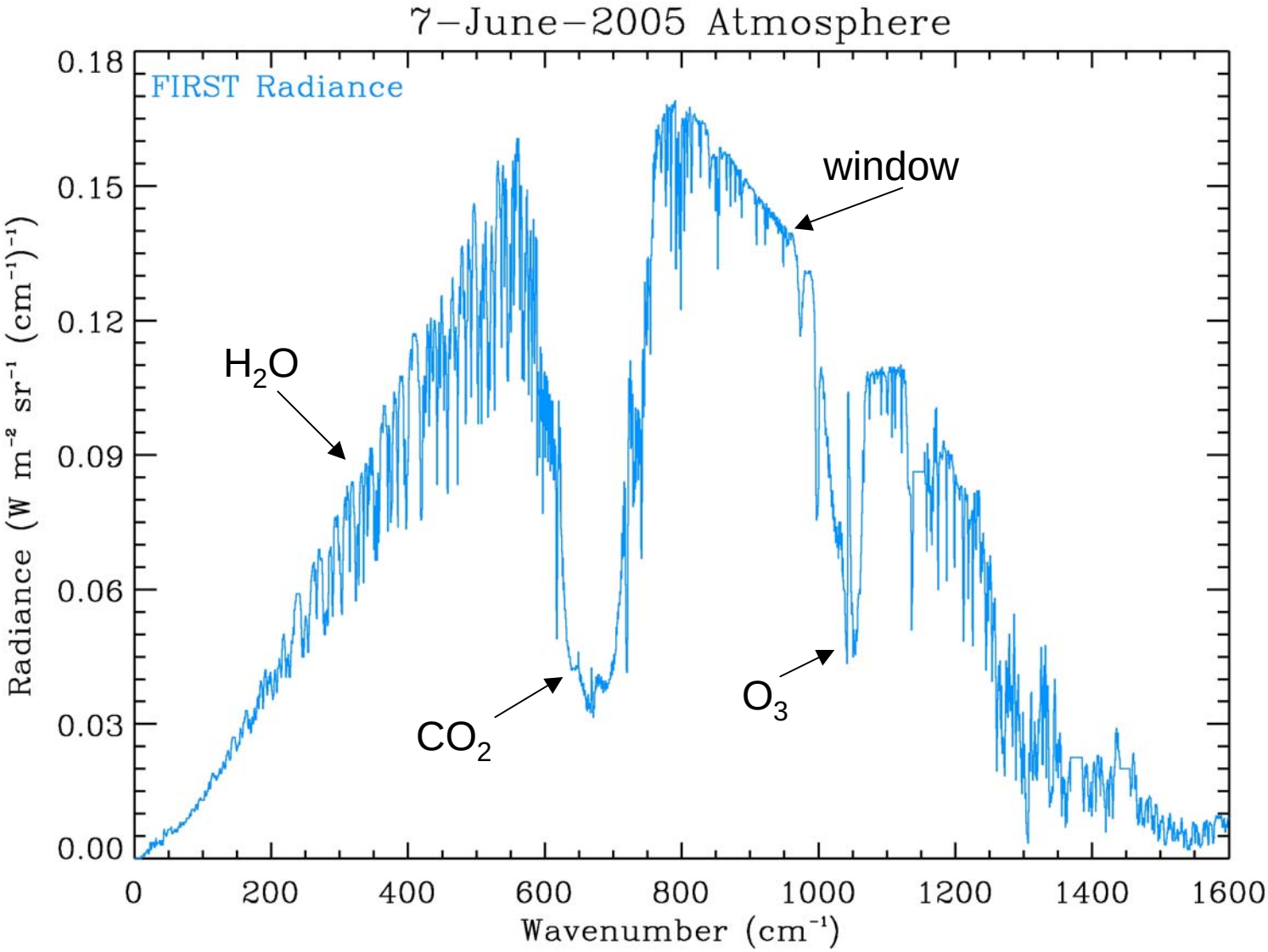
FIRST spectrum from flight demo 7 June 2005
Complete infrared spectrum observed

Status

6/2005 – Successful flight demo/balloon flight
9/2006 – Second flight for CALIPSO validation
3/2007 – Ground calibration vs. AERI at UW
4/-10/2009 - RHUBC/FORGE campaign Chile
10/2010 - CORSAIR detector evaluation @ LaRC

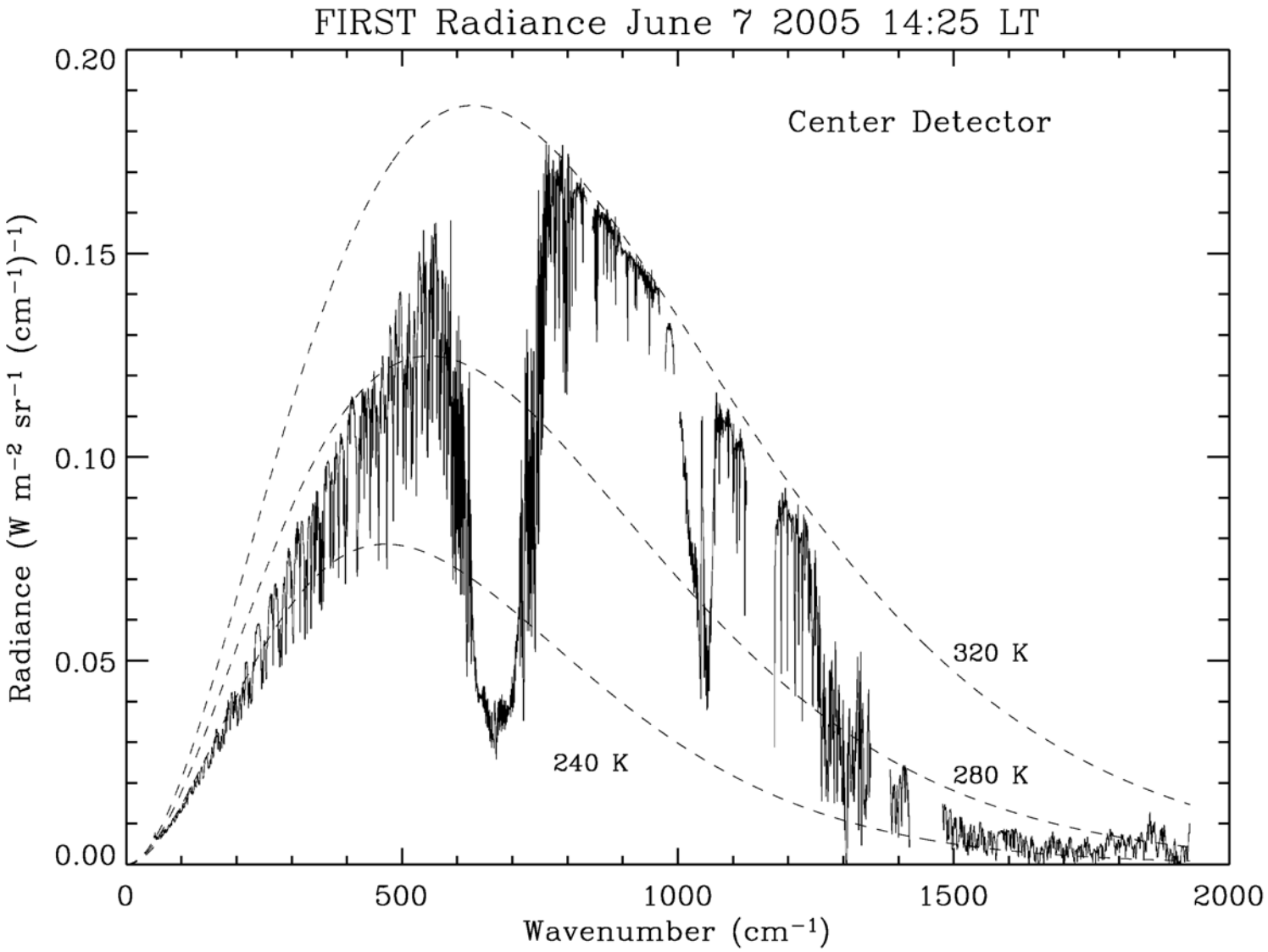
Journal articles forthcoming

FIRST "First Light" Spectrum



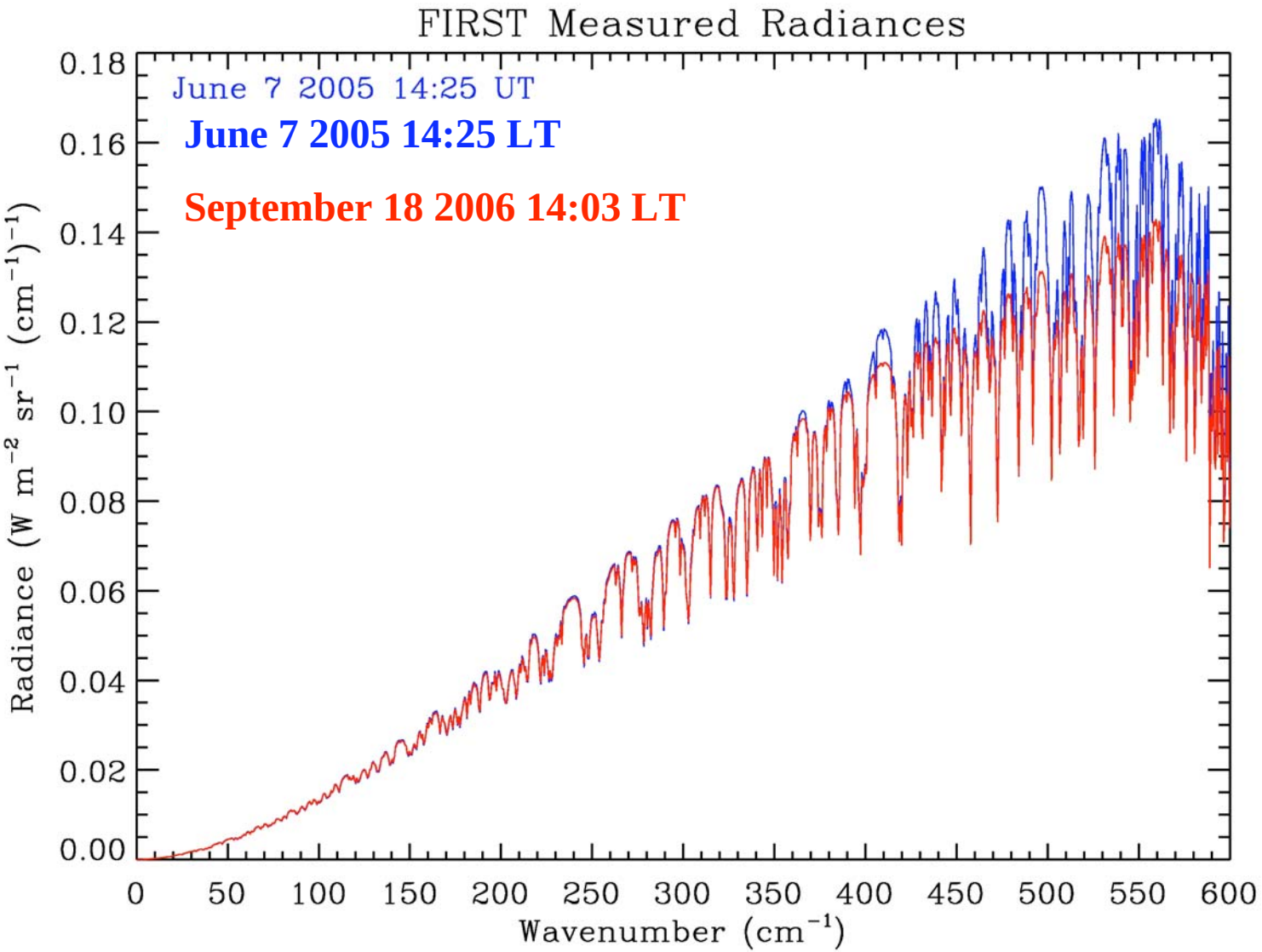
Reference: Mlynczak et al., 2006

FIRST Spectrum, Center Detector

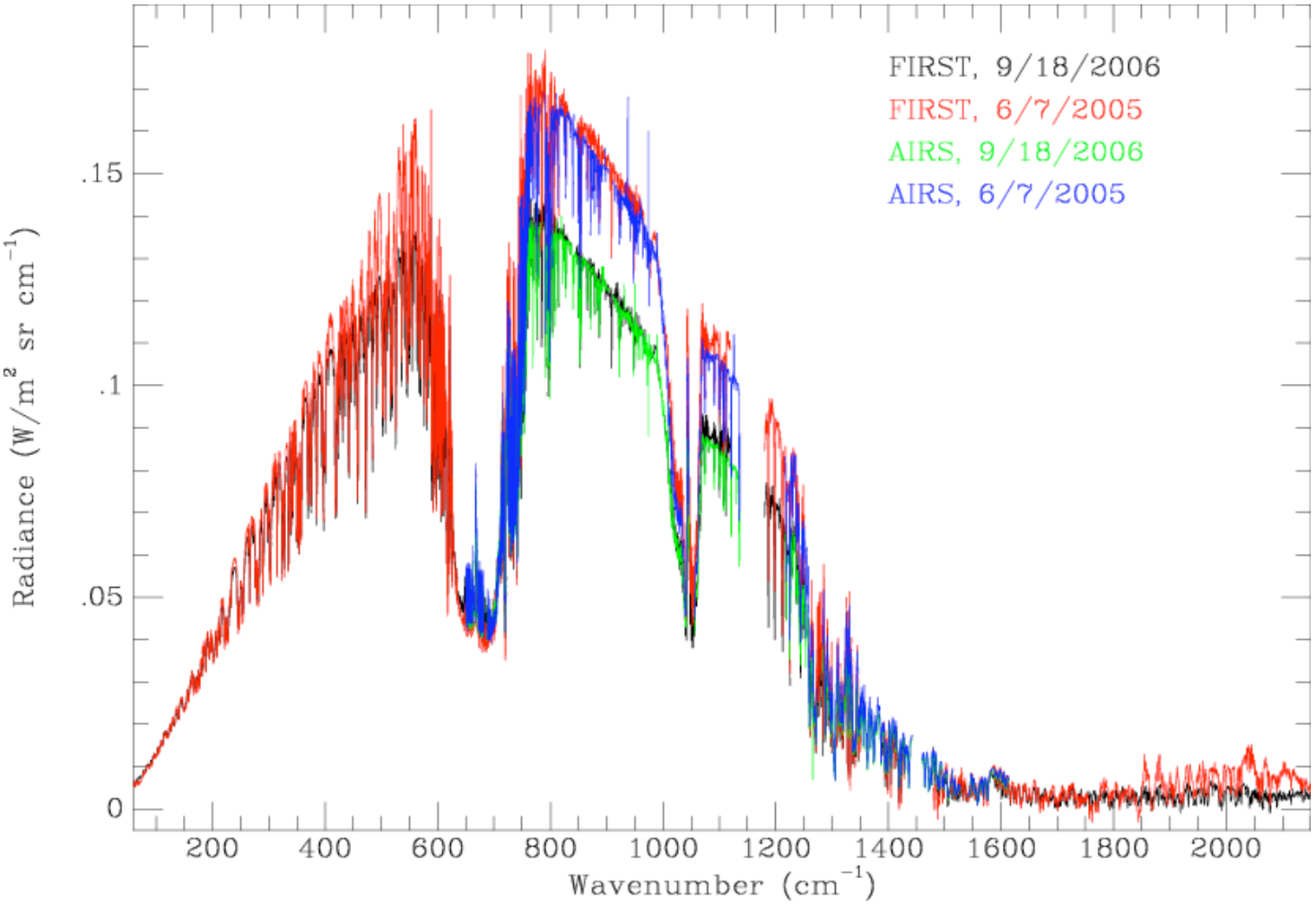


Mlynczak et al., GRL, 2006

FIRST Radiances June 2005 and September 2006
- Clear Sky -



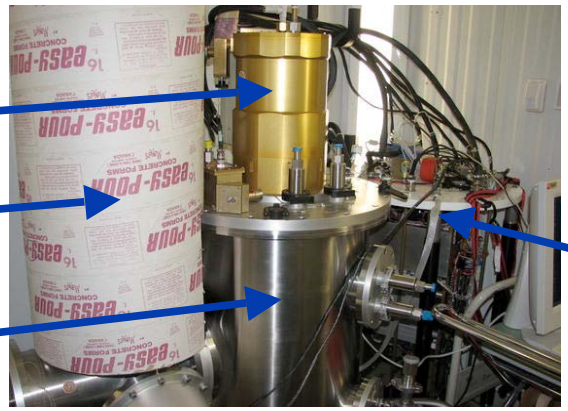
FIRST & AIRS Radiance comparison



FIRST at University of Wisconsin
March 2007

FIRST port

AERI port



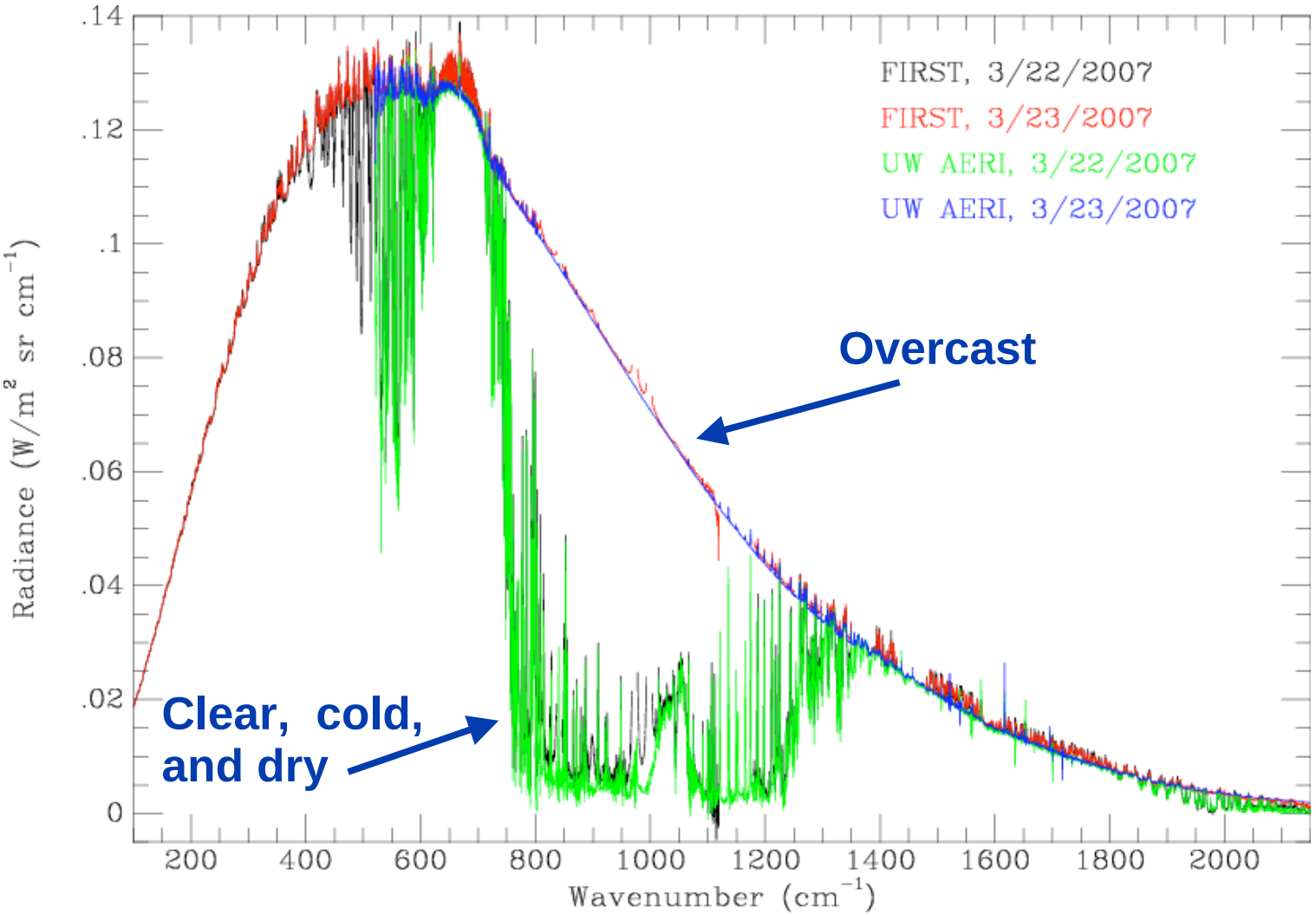
Detector dewar

Zenith port

Spectrometer

Electronics

AERI & FIRST Comparison



The Road to CLARREO after FIRST

- FIRST demonstrated the following technologies:
  - Fourier Transform Spectrometers
  - Broad bandpass beamsplitters (far-IR)
  - Focal plane arrays
- Technologies still needed are:
  - High sensitivity detectors for far-IR @ “room temperature”
  - Blackbody radiance standards for far-IR that are SI-traceable
  - Broad bandpass beamsplitters for *entire* IR
- These needs formed the basis for the CORSAIR IIP proposal selected by NASA ESTO
- Also need basic research into far-IR properties of the atmosphere

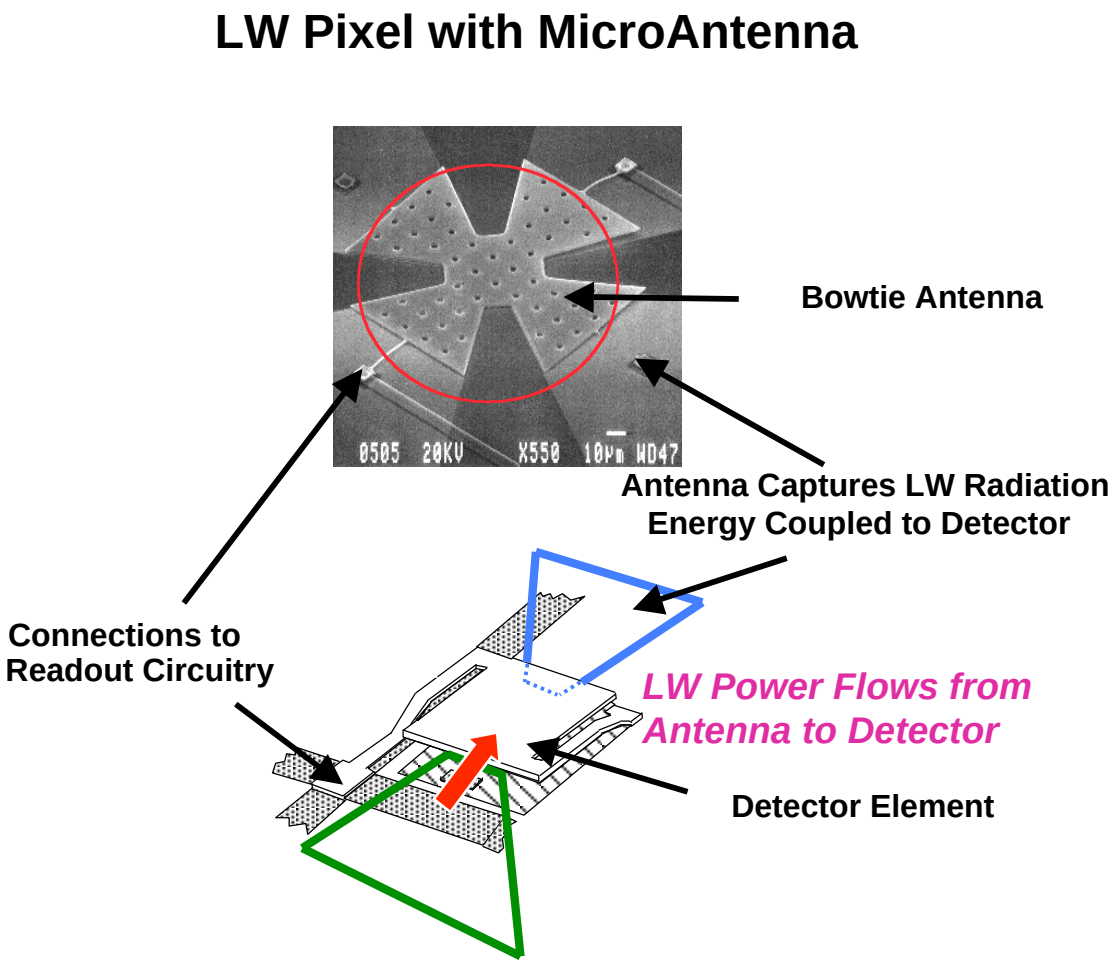
Calibrated Observations of Radiance Spectra from the Atmosphere in the far-InfraRed - CORSAIR

Major Technology Elements

- Passively Cooled Detectors (Raytheon Vision Systems)
  - Antenna Coupled Terahertz Devices
  - Potential for 100 to 1000 times more sensitive (D*) than pyroelectric
  - Substantial prior DARPA and Homeland Security investment
- SI Traceable Blackbodies in Far-IR (SDL; NIST)
  - Flight prototype blackbody w/ well-characterized emissivity
  - On-orbit, SI-traceable temperature measure for blackbody
  - On-orbit emissivity monitor in far-IR
- Broad Bandpass Beamsplitters (ITT)
  - Cover 5 to 50 μm region in 1 beamsplitter
  - Potentially enables 1 instrument to cover CLARREO range
- Detector evaluation to take place in FIRST @ Langley in Year 3
  - LaRC; JPL; Raytheon

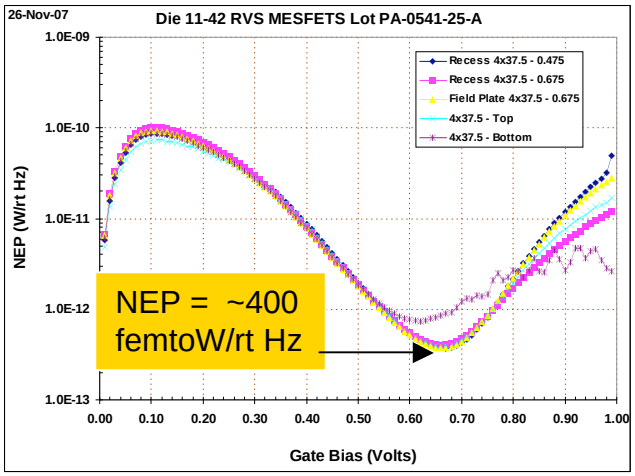
Antenna-Coupled Technology

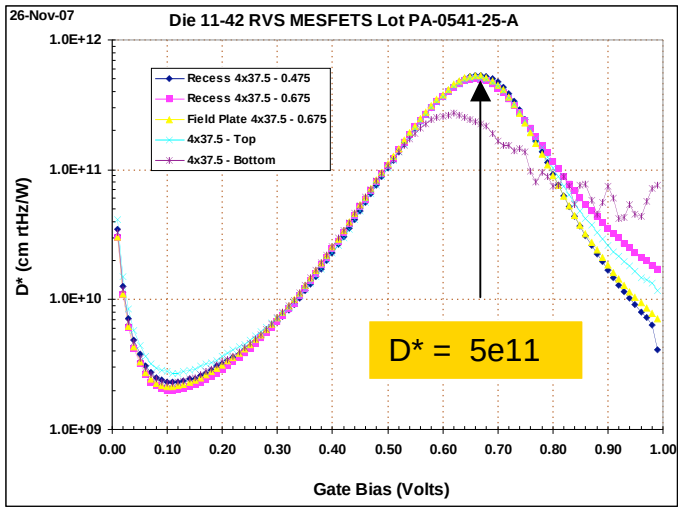
- LW Energy Couples to Antenna Optimized for Specific LW Band & Bandwidth
- Antenna Passes Current to the Detector (Diode)
- Detector Connects to ROIC through Conducting Leads
- ROIC Reads Out Resistance for Each Pixel & Multiplexes Output



Derivation of the NEP and D*

- **NEP is calculated from the shot-noise and the responsivity (α) of the detector**
  - **NEP = I_{Shot} /[α (1 - Γ^2)]**
- **D* is calculated from the NEP and the area of the detector**
  - **D* = sqrt(A_D)/NEP**
  - **Indicates D* ~ 10^{11}**
    - **Based on diode noise measurements**
  - **Operates at room temperature**
  - **Very linear response anticipated**



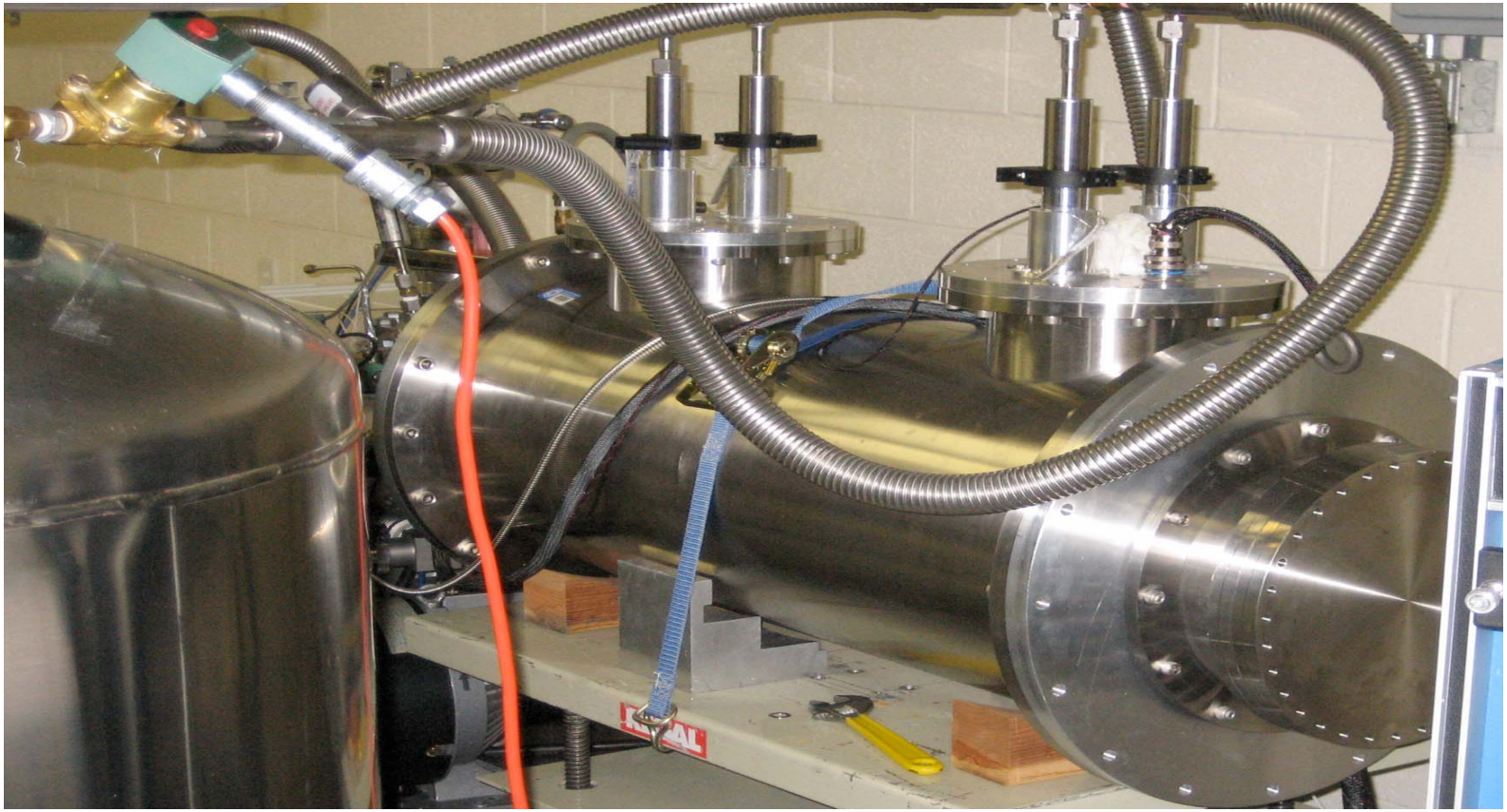


CORSAIR - Far-IR Calibration

- Far IR Calibration Background
  - FIRST's 2-port calibration system contained a blackbody operating at ambient temperatures and an open port used to observe cold space.
    - Cost limitations limited exposure of the FIRST blackbodies to SI standards as required for the CLARREO mission.
    - Techniques to test and monitor the emissivity must also be demonstrated.

- SDL and Langley will continue to develop source evaluation capabilities – including SI-traceability
  - NIST certification of the FIRST calibration source
  - Phase change materials for long term flight monitoring
  - Far IR flight emissivity monitoring
  - Demonstration Flight BB

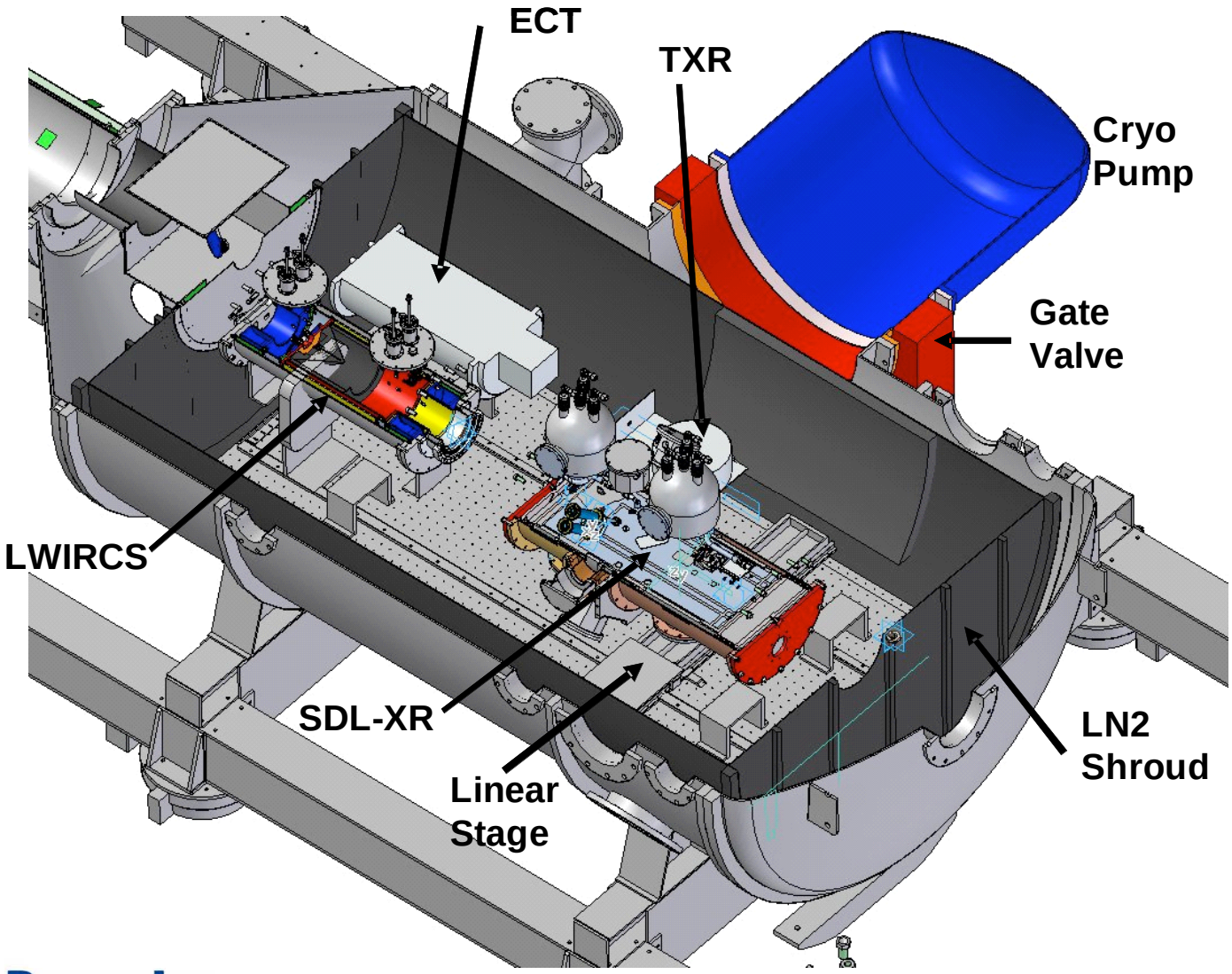
Long Wavelength IR Cavity Source (LWIRCS)



This is the upgraded FIRST Calibration Source being readied for calibration at NIST's LBIR.

LWIRCS will be a SI-traceable radiance standard after calibration at the NIST facility

SDL's SI-Traceable Source Evaluation



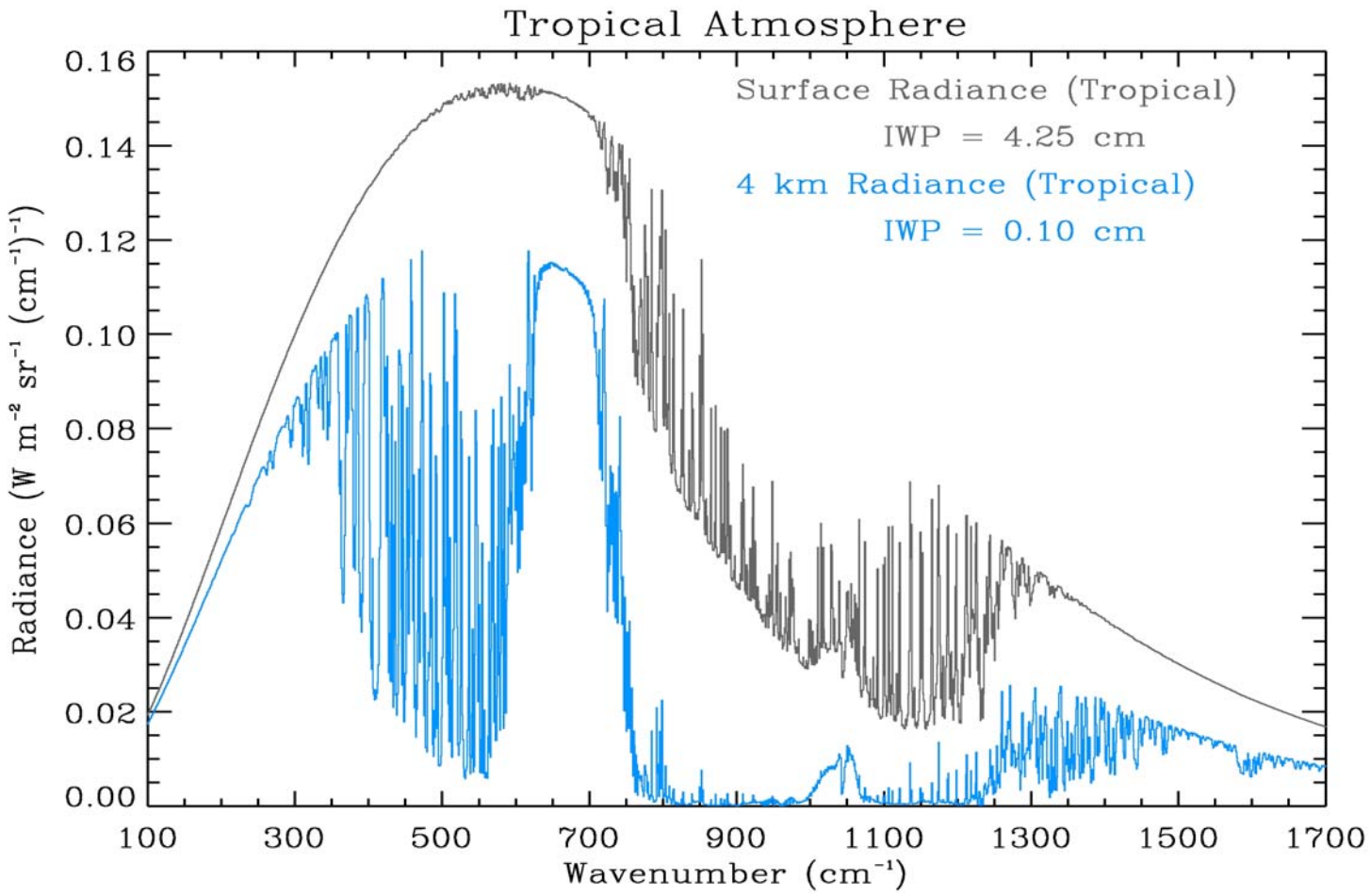
CORSAIR Calibration Tasks

- Achieve SI traceable calibration of blackbodies beyond 15 μm, calibrated to better than 0.1K (3σ), with the calibration capable of being maintained on orbit.
- Establish absolute temperature calibration transfer to orbit by adding phase transition cells to the blackbodies.
  - These phase transition cells will allow absolute calibration of the blackbody temperature sensors to the 10 mK level or better.
  - Phase transition cells will be added to LWIRCS and an additional blackbody to be developed at SDL.
- Improve our knowledge of the emissivity of the Far IR blackbodies to determine if the design meets CLARREO requirements.
  - Includes extending our capability to measure spectral emissivity to 100 μm.
  - Develop on orbit emissivity monitoring for CLARREO Far-IR sources.
- Develop a flight prototype BB for the Far-IR.
- Coordinate with NIST in all of the above!

Where we will be upon completion of CORSAIR

- Three FTS instruments well characterized across spectrum
  - Entire IR (FIRST; INFLAME)
  - Visible (INFLAME)
  - Absolute calibration and stability evaluated and documented
- New detector technologies developed and demonstrated for far-IR
  - Uncooled antenna-coupled detectors (CORSAIR)
  - Cooled BIB detectors (FIDTAP; ACT)
    - Evaluated against COTS pyroelectrics in FIRST
  - Offers evaluation and range of technologies for CLARREO
- Beamsplitters (FIRST; CORSAIR)
  - Far-IR specific and Broadband 5-50 μm
- SI-traceable blackbodies in far-IR (CORSAIR)
  - Flight far-IR propotype NIST certified
  - With on-orbit far-IR emissivity monitoring & phase change cells
- Detailed evaluation of far-IR properties of middle troposphere and cirrus optical properties (FORGE/RHUBC)
- Extensive experience in all aspects of FTS design, calibration, flight, and data reduction

RHUBC/FORGE
Ground-based, Uplooking, Low H_2O



RHUBC/FORGE

- August to October 2009
- Chajnantor, Chile
- ARM Mobile Facility; FIRST; other instruments
- Radiosondes launched during daily observing periods
- Science
  - Spectroscopy of far-IR
  - Radiative cooling
  - Cirrus forcing
  - Extensive cross-calibration against AERI-ER
  - Extensive evaluation against LBL codes

View from Chajnantor, Chile site for RHUBC/FORGE
H = 17,500 feet; p = 500 mb; H_2O < 0.4 mm

Summary

- Very active program in spectral sensing at Langley
  - FIRST demonstrates beamsplitter, FTS technology for far-IR
  - INFLAME investigates flux divergence, visible and IR, in troposphere -- FTS systems built in-house at Langley
  - CORSAIR aims to develop new class of detectors for CLARREO at room temperature operations
  - RHUBC/FORGE provides fundamental test of radiative transfer in far-IR and potentially excellent observations of cirrus in far-IR
  - **Cumulative contributions of these projects provides technology and knowledge to execute the (far-IR) CLARREO measurements**