Observations of the far-IR Spectrum from the Ground, the Air, and from Space

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NASA Langley Research Center

Outline

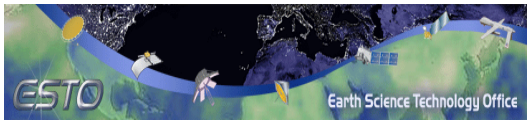
- Acknowledgements
- Measuring the Far-IR, Radiances and Fluxes
  - FIRST Instrument
  - INFLAME Instrument
- The Far-Infrared Explorer – FIREX – Mission
  - A proposal to the NASA Earth Venture – 2 Opportunity
- Summary

Acknowledgements

- NASA Earth Science Technology Office
  - IIP, ACT, QRS awards
- NASA Science Mission Directorate
  - Radiation Sciences Program
- NASA Langley Research Center
  - Science Directorate
  - Engineering Directorate
  - Research and Technology Directorate
- CLARREO Science Definition Team
- FIREX Science Team
- And a host of others….

Far-Infrared Spectrometry Team Members

Government



Langley, GSFC

COLUMBIA SCIENTIFIC BALLOON FACILITY

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

JPL

GFDL Geophysical Fluid Dynamics Laboratory

Academia

TEXAS A&M UNIVERSITY

SAO

THE FLORIDA STATE UNIVERSITY

Industry

Raytheon
Customer Success Is Our Mission

Ball

ABB

SSAI

International

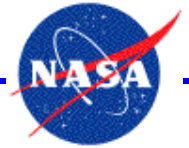
Imperial College London

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

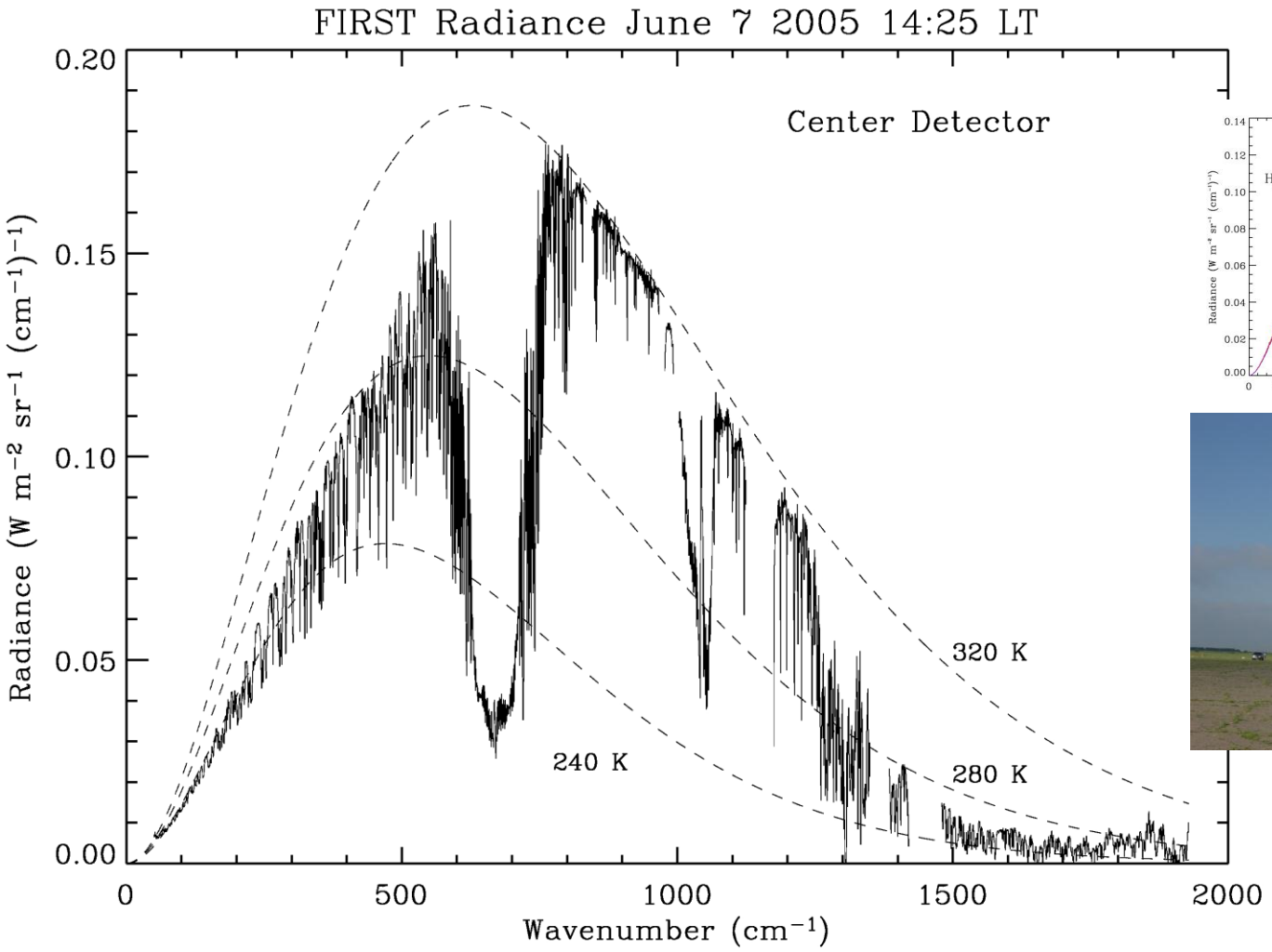
IFAC

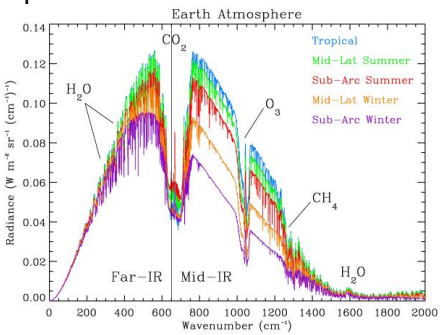
FIRST - Far-Infrared Spectroscopy of the Troposphere

- Michelson Interferometer
  - *6 to 100 μm on a single focal plane*
  - *0.625 cm^{-1} unapodized (0.8 cm OPD)*
  - *Germanium on polypropylene beamsplitter*
  - *Bolometer detectors @ 4 K*
- Demonstrated on a high-altitude balloon flight June 7 2005
- Second balloon flight September 18 2006
- Ground-based capability demonstrated March 2007
- FORGE Ground Campaign Atacama Desert Chile 2009
- Recalibration now underway at SDL and deployment 2012



FIRST Thermal Infrared Spectrum - TOA



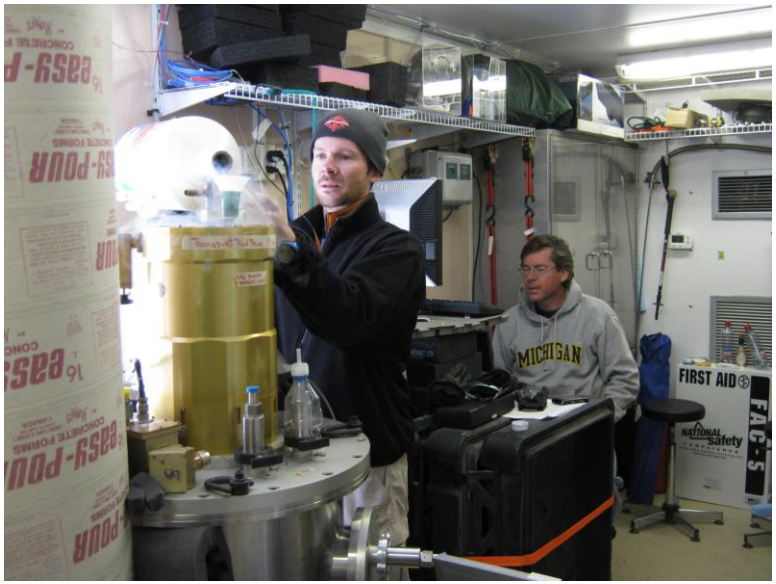


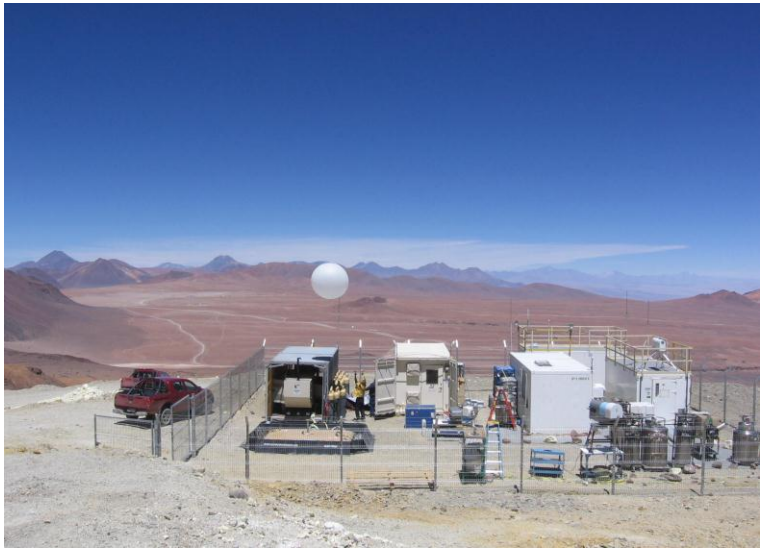
Mlynczak et al., GRL, 2006

FIRST Performance Summary

- FIRST underwent ground calibration in the lab at SDL in 2005
- Systematic Uncertainty: < 1 K for 190 to 310 K
- Precision (Random Uncertainty): < 1 K per spectrum
- Radiance accuracy @ Cerro Toco: ~ 1 K (~ 1% in radiance)
  - Averaging of spectra reduces random noise substantially
  - This is the best we know it today – it is likely a lot better!
- FIRST is now being recalibrated at SDL with standards transferred from NIST (LWIRCS in NIST LBIR)

FIRST Operations at 17,600 Feet
Cerro Toco, Atacama Desert, Chile

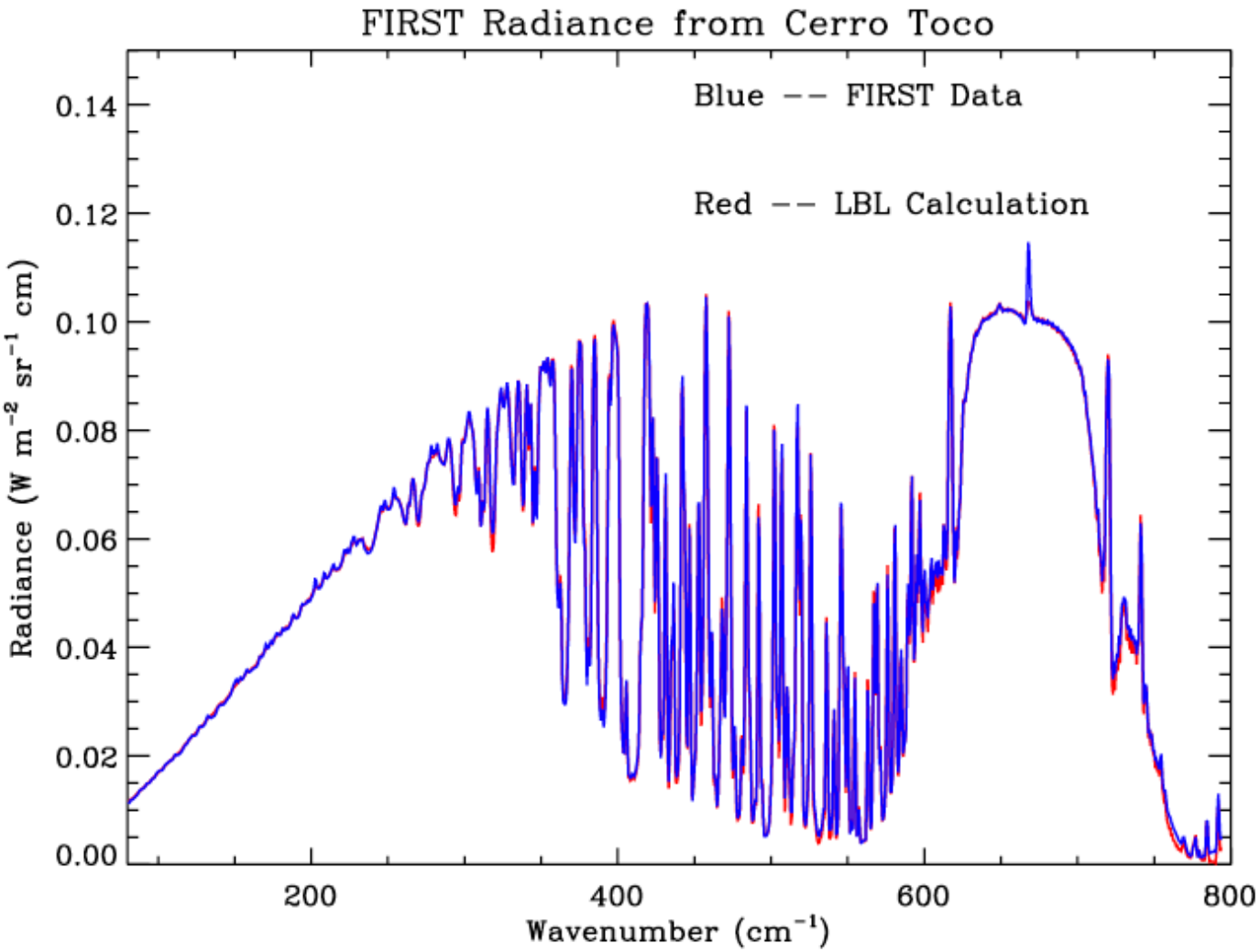




Summary of FIRST Data from RHUBC-II

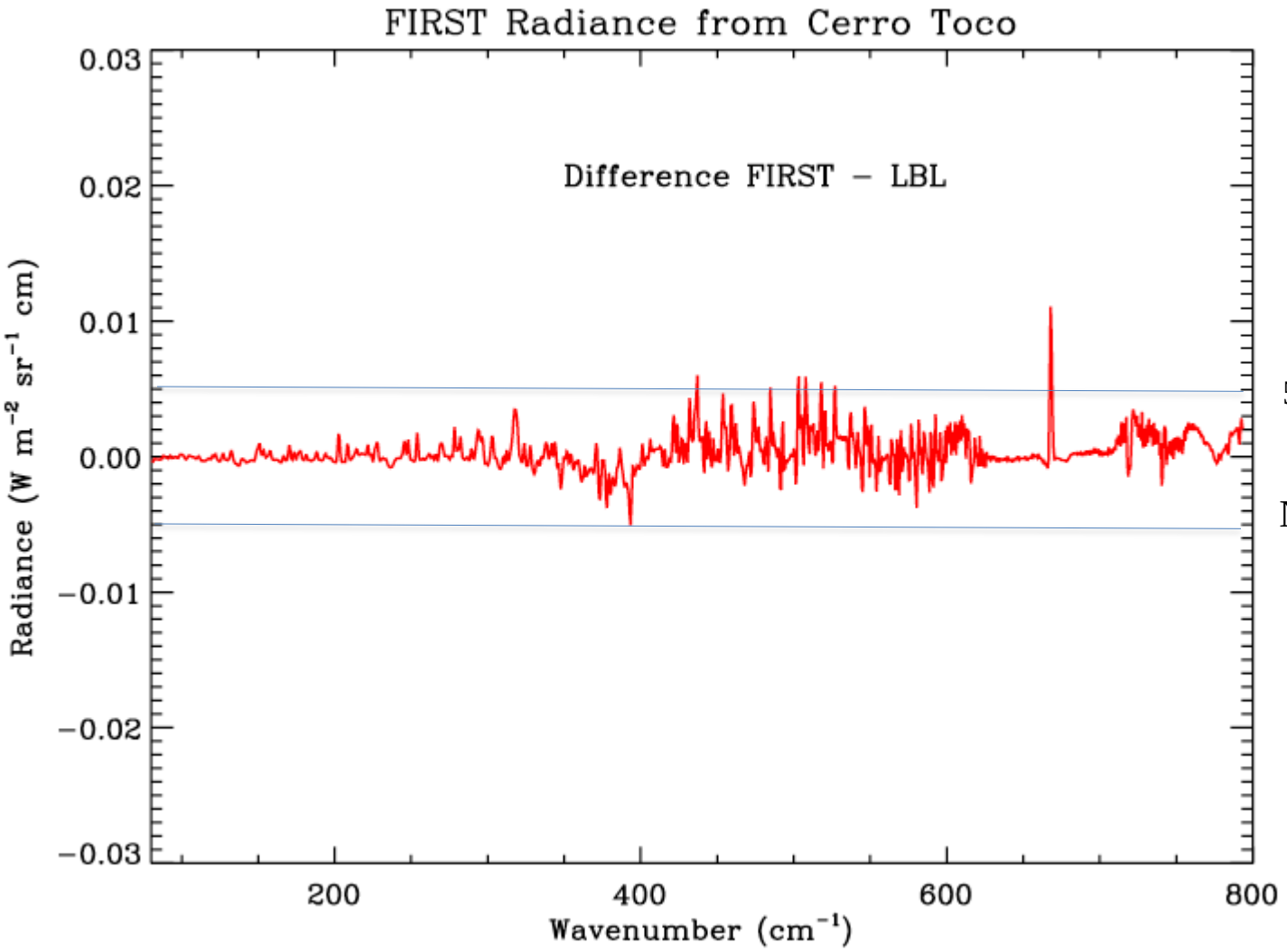
- Campaign yielded 105 raw datafiles (~350 Mbytes) that are analyzable (1 hour each)
- 67 have been processed with corresponding data uploaded to the DOE Atmospheric Research Measurement (ARM) ftp site
- 38 files indicate some kind of problem in the file itself (e.g., first file of day)
- Good data for 25 days of the campaign
- 399 spectra have been released, each is a 6 minute average (about 31 individual spectra)
- Spectral range 80 800 cm^{-1}
- Average precision is +/- 0.002 W / (m^2 sr cm^{-1}) [2 “radiance units”]

FIRST Far-IR Spectrum – 09/05/09



PWV = 0.75 millimeter (“wet” day)

Radiance Difference – 09/05/2009

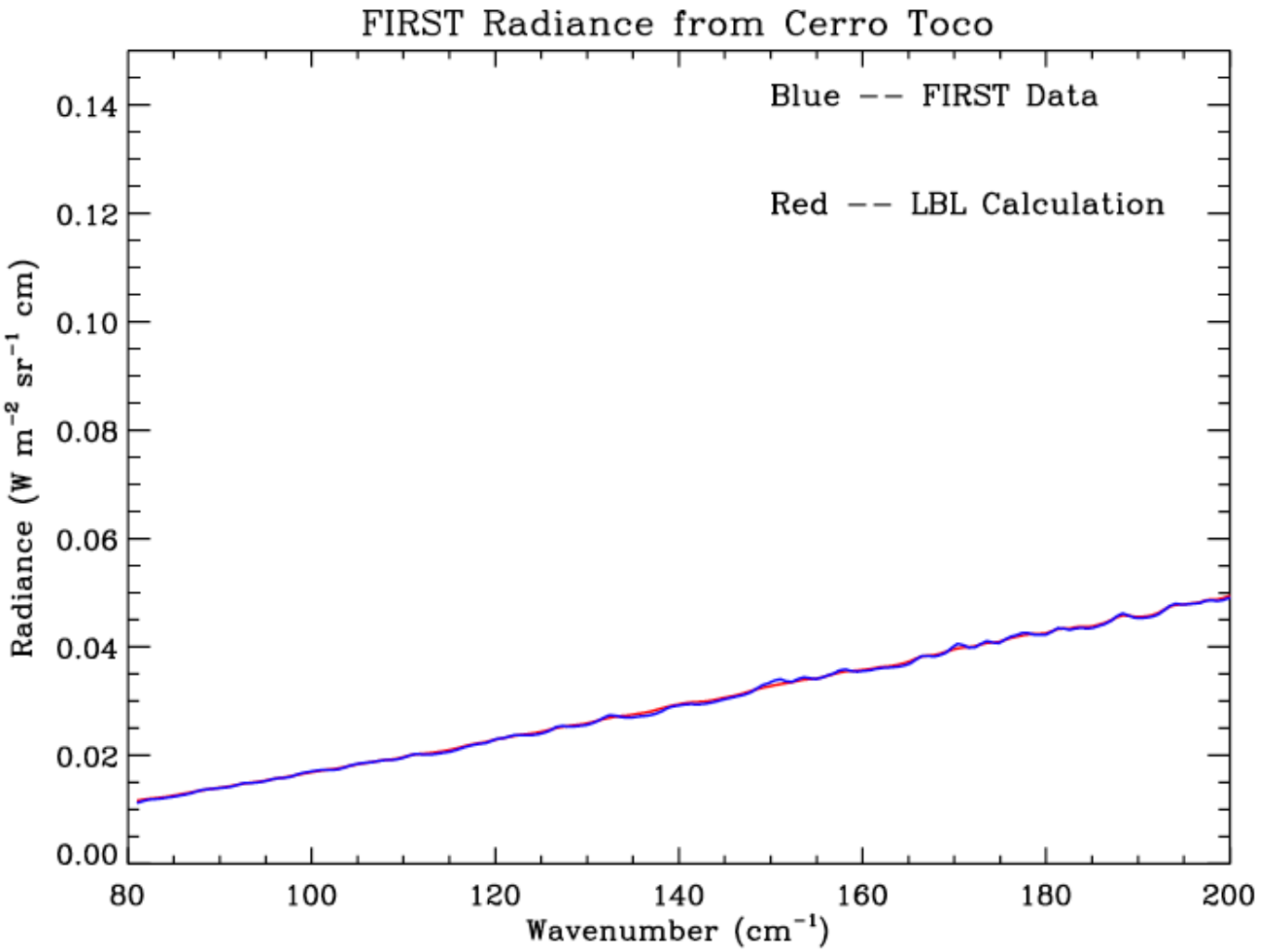


5 RU

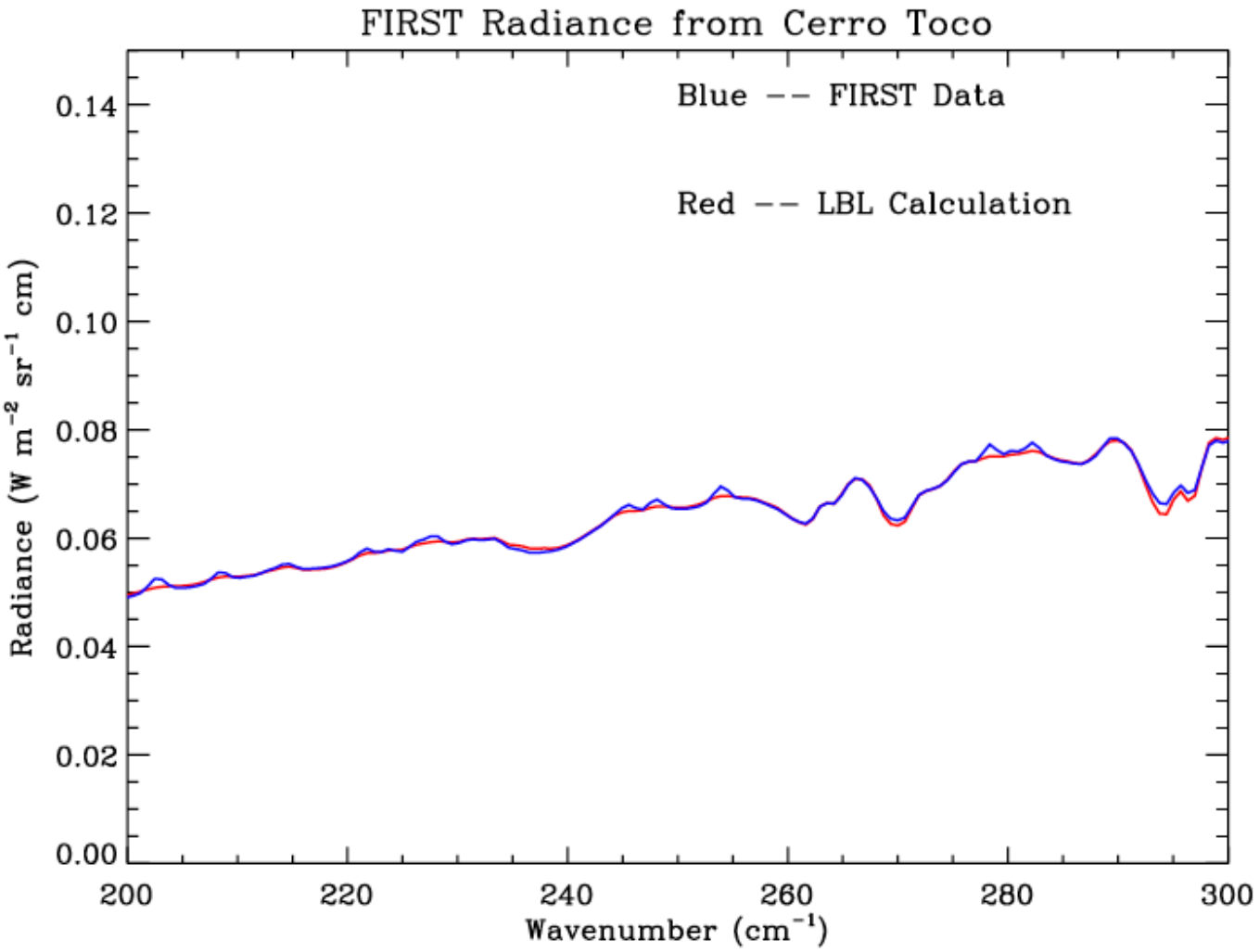
NeDT = 2 RU

T, H2O ~ 3 RU

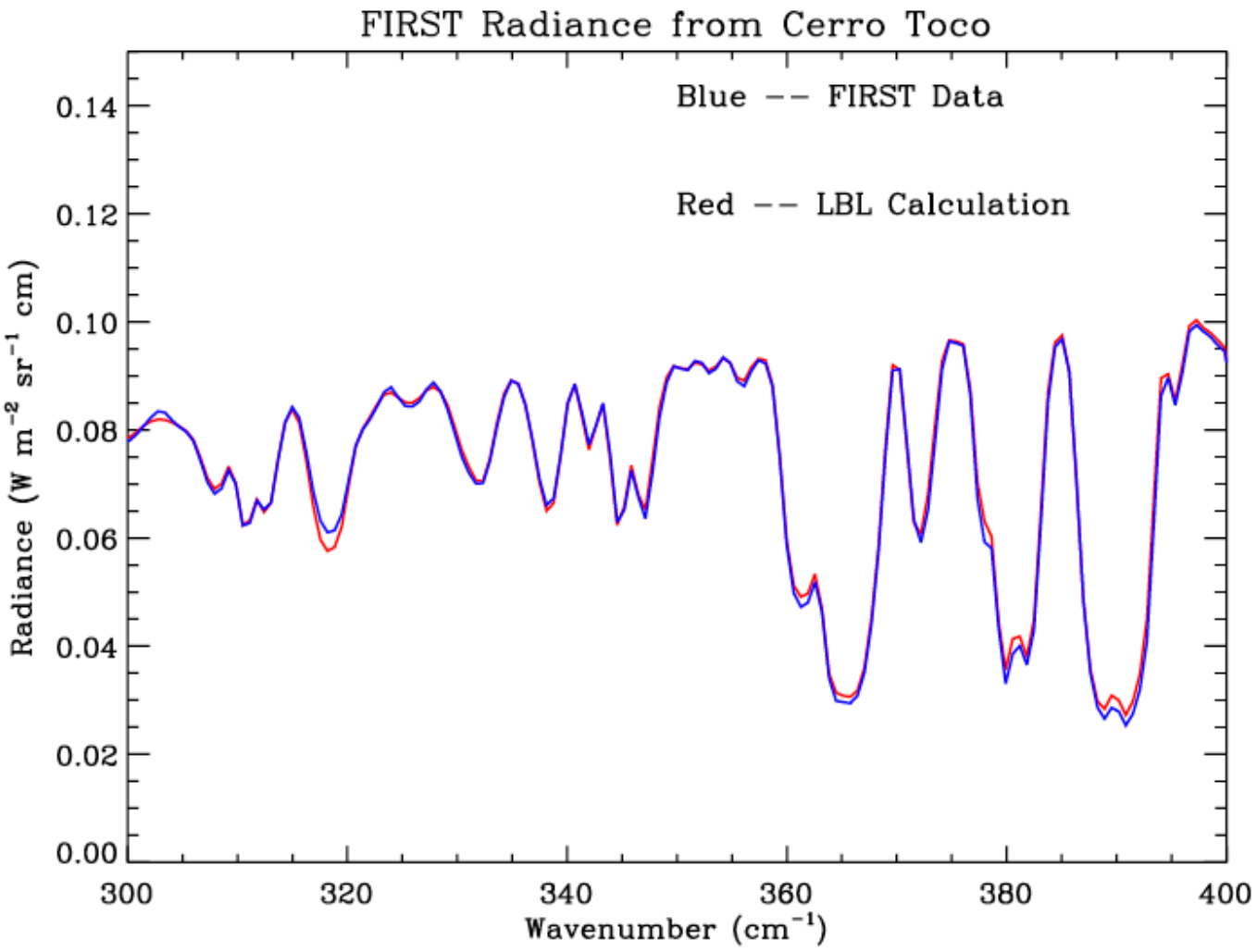
September 5 2009 – PWV = 0.75 mm



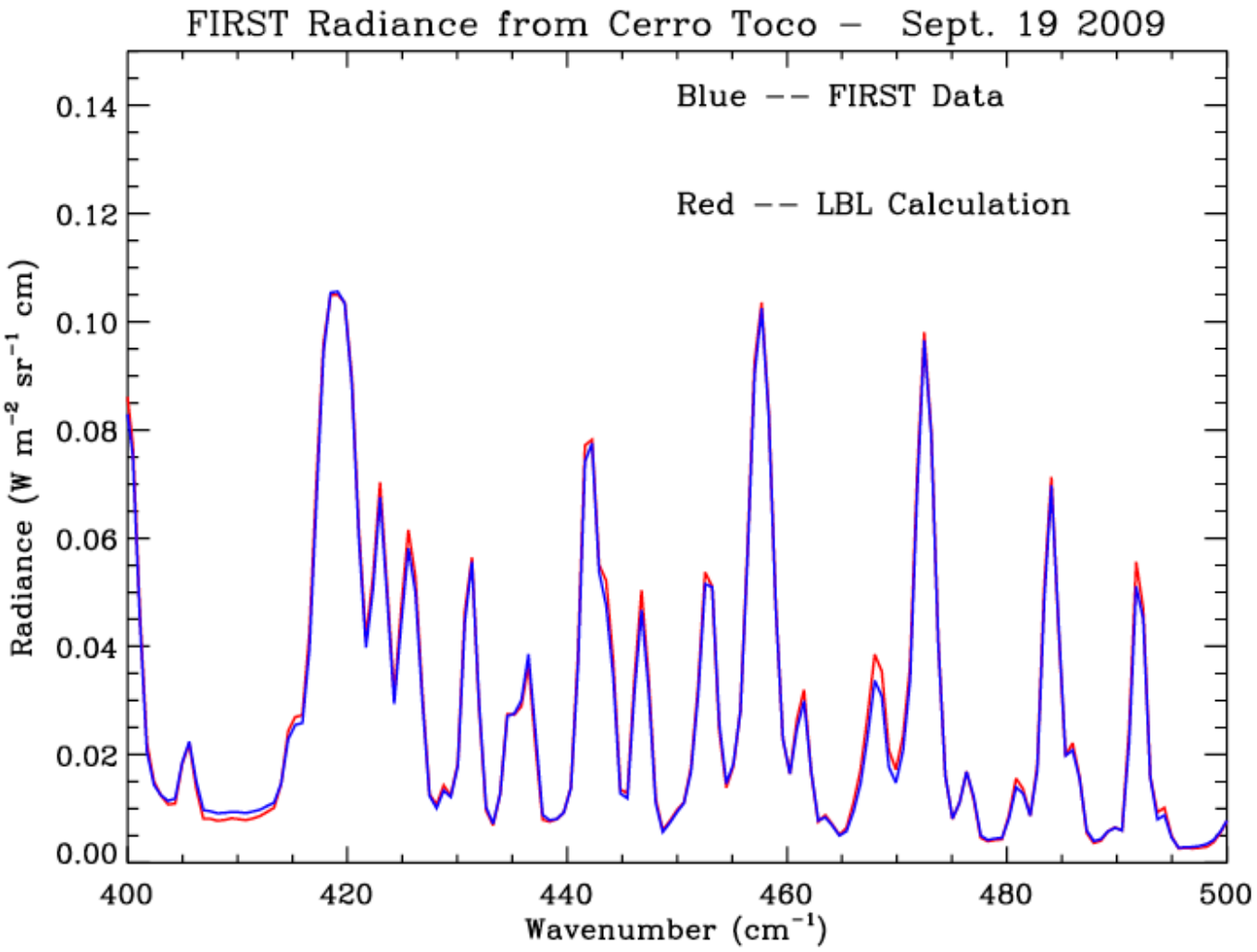
September 5 2009 – PWV = 0.75 mm



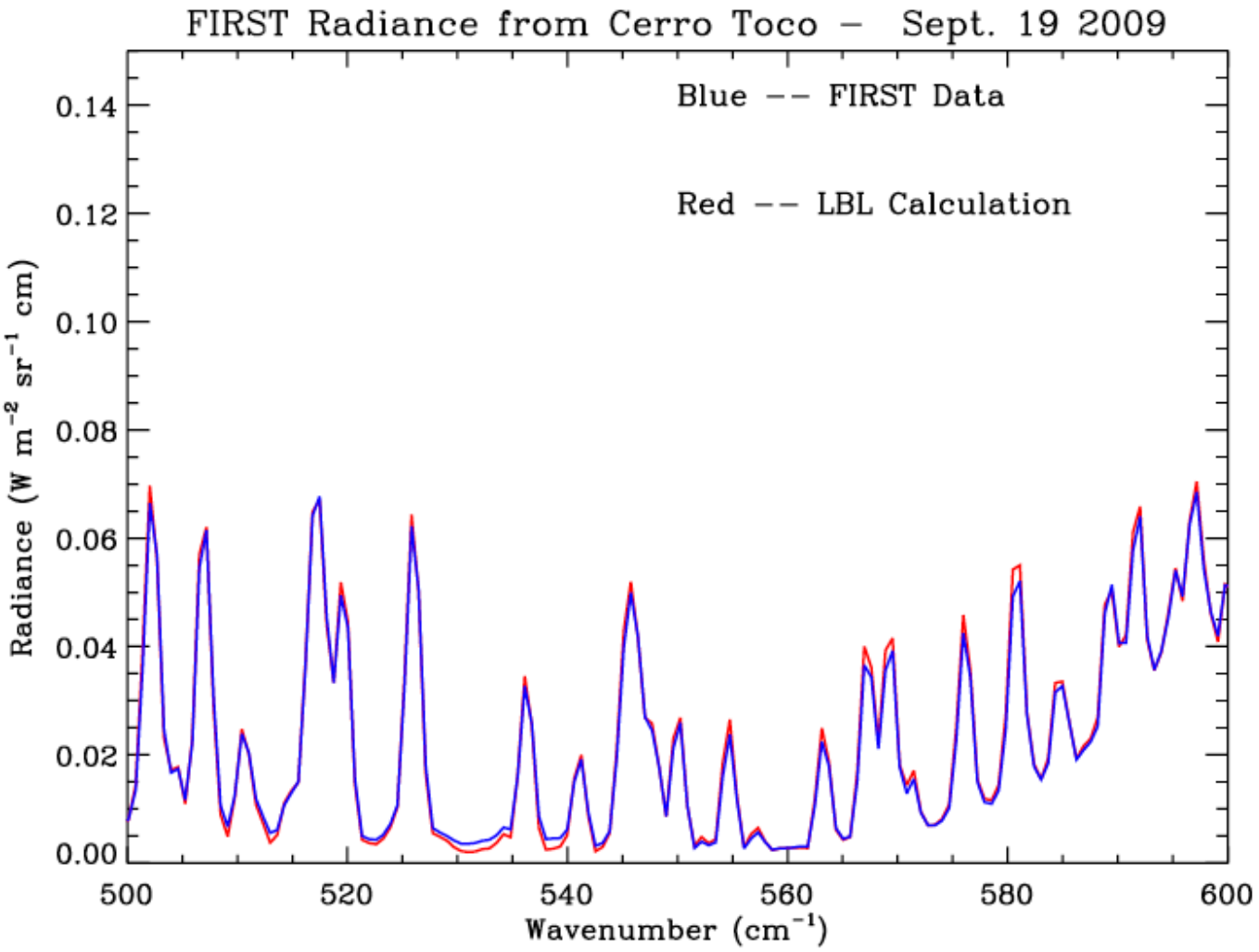
September 5 2009 – PWV = 0.75 mm



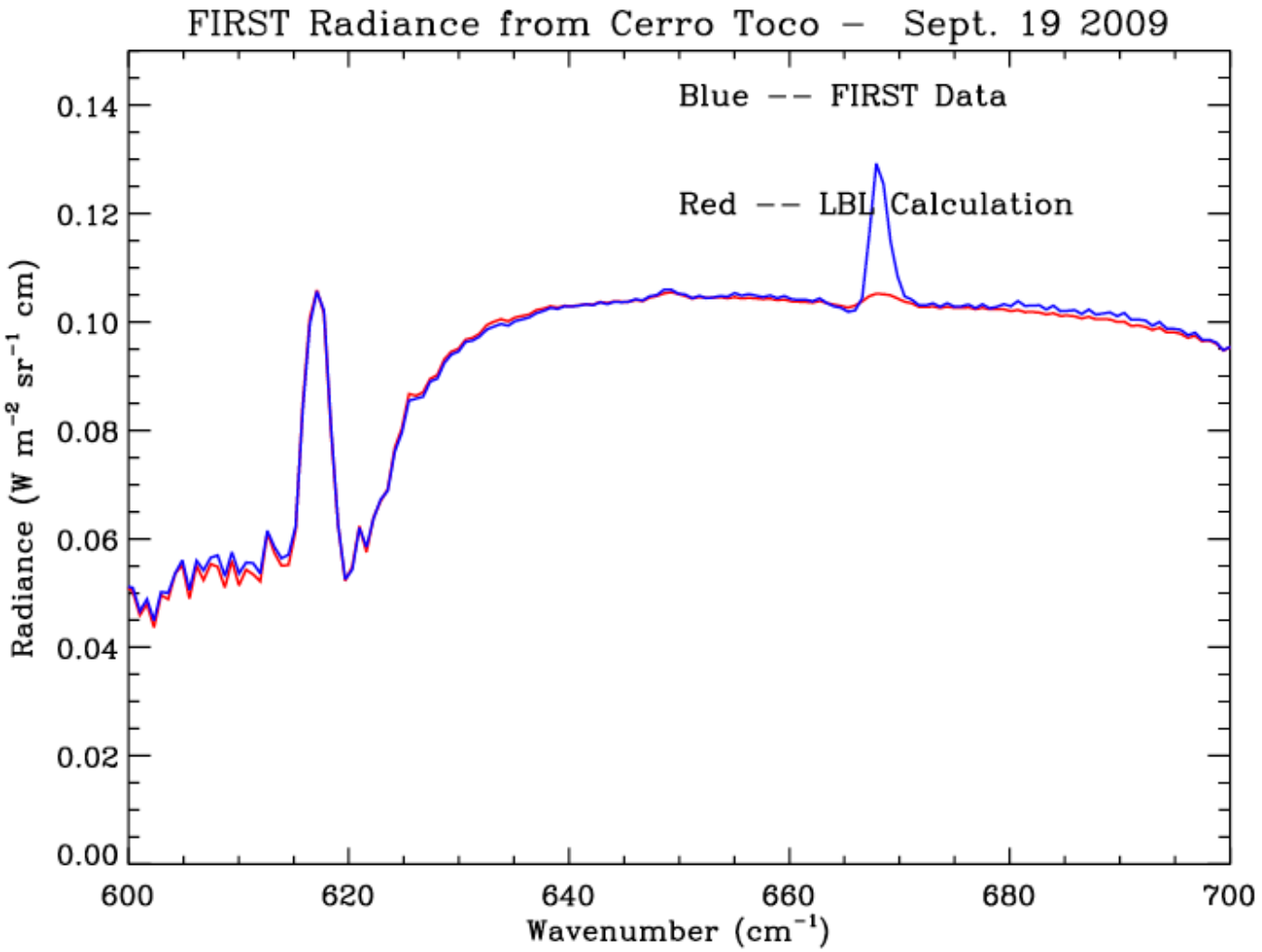
September 19 2009 – PWV = 0.4 mm



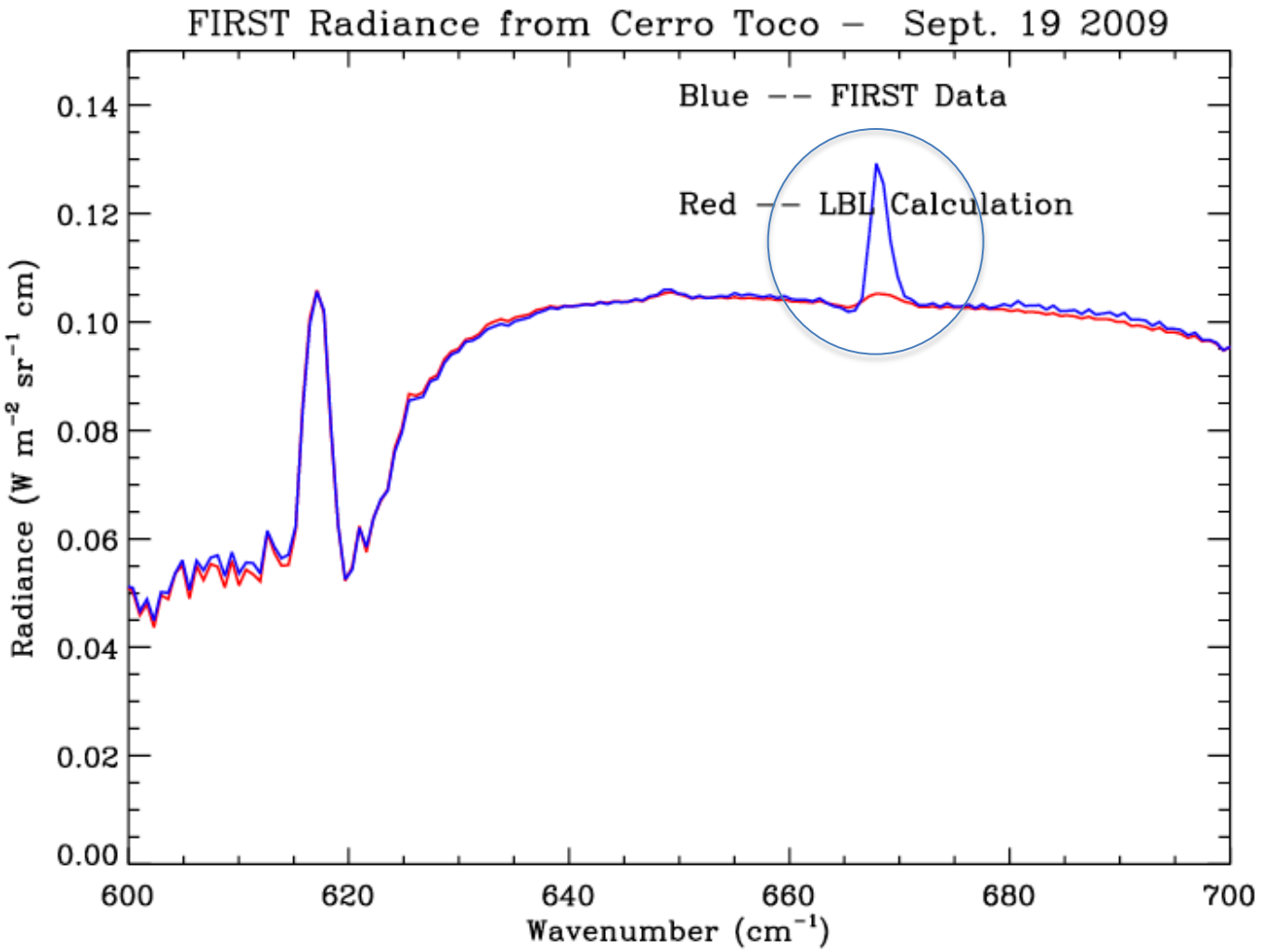
September 19 2009 – PWV = 0.4 mm



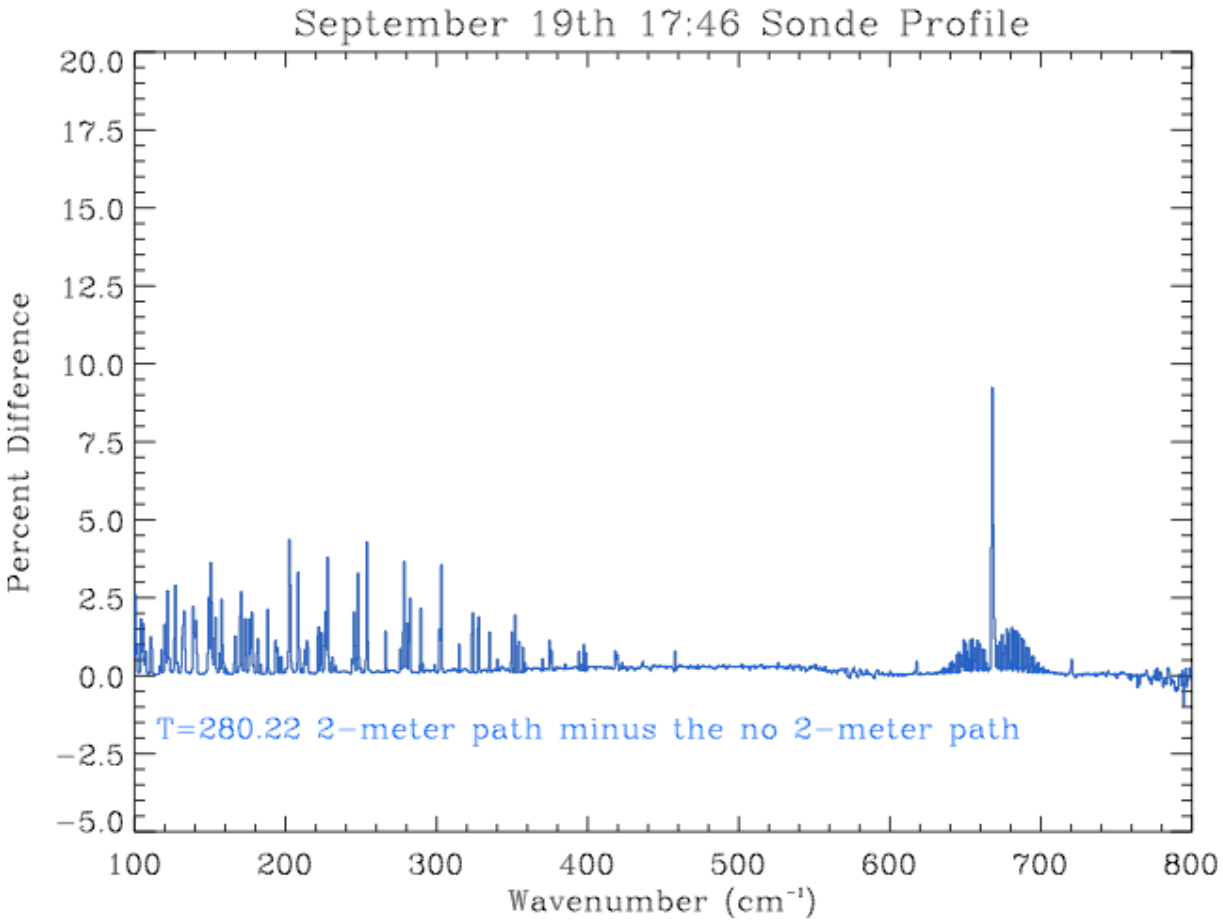
September 19 2009 – PWV = 0.4 mm



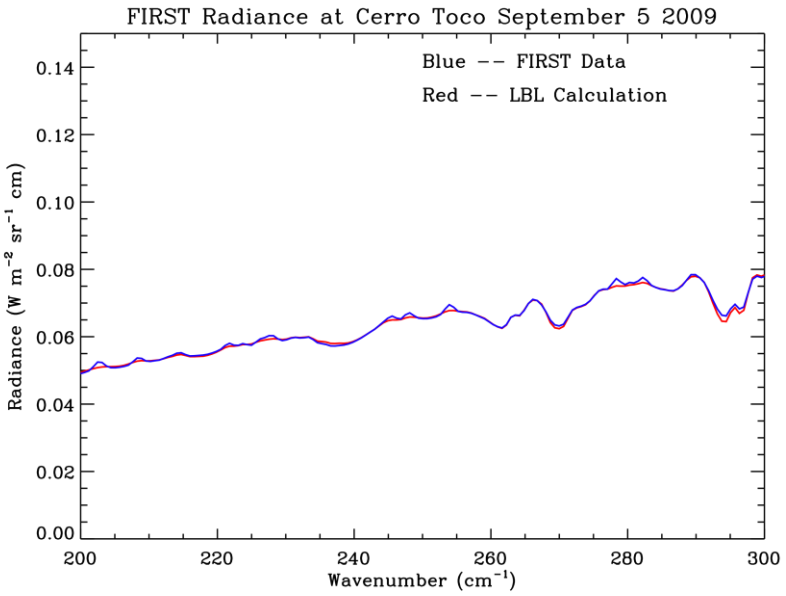
September 19 2009 – PWV = 0.4 mm

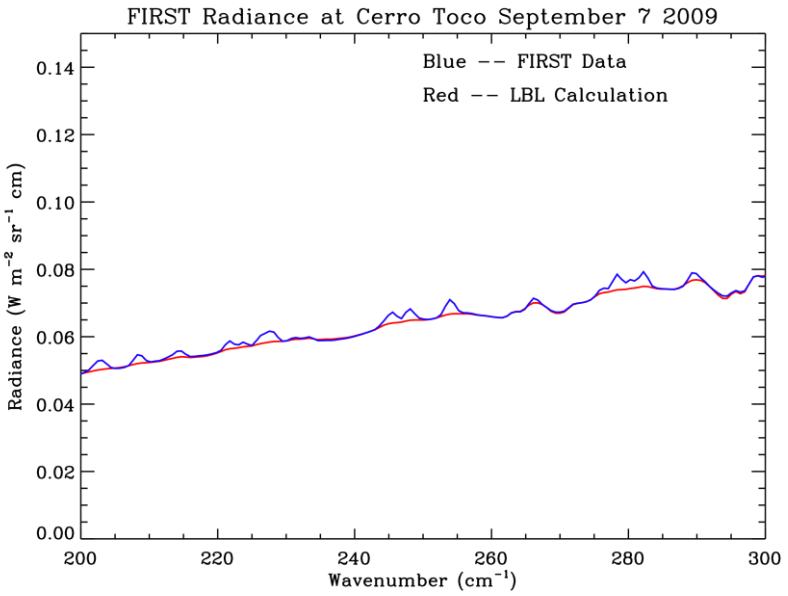


Impact of 1.6 meter path on radiance @ Cerro Toco

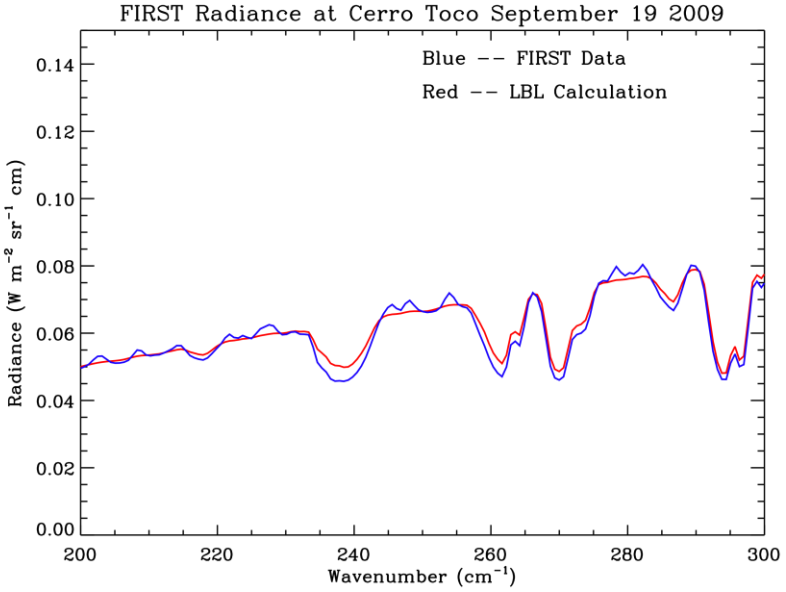


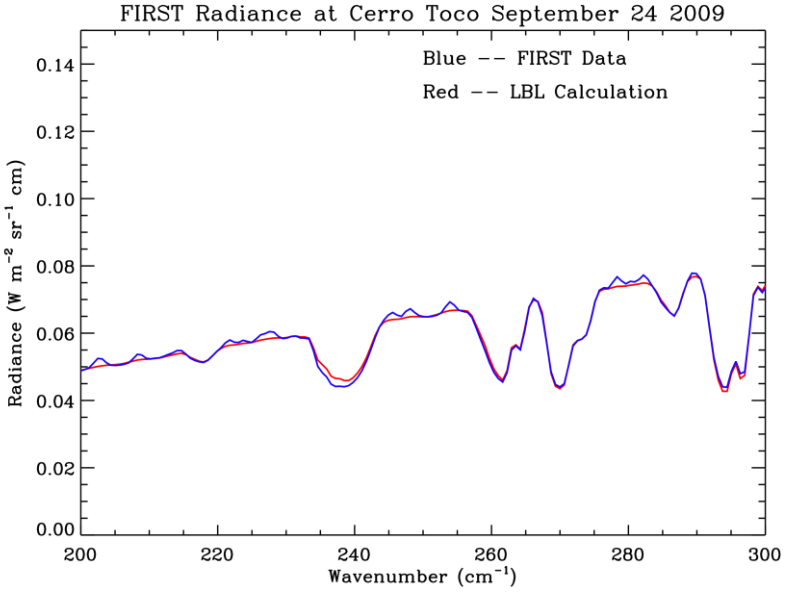
Effect typically less than 2% in the far-IR

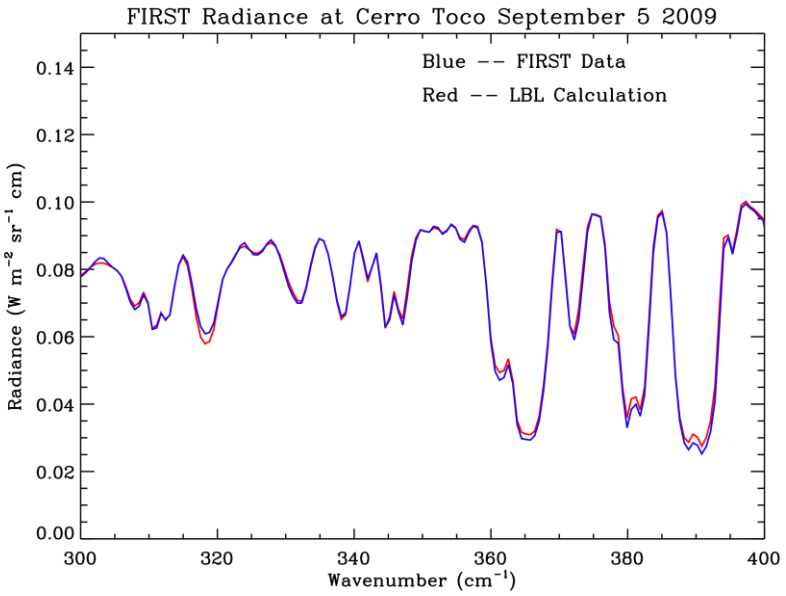


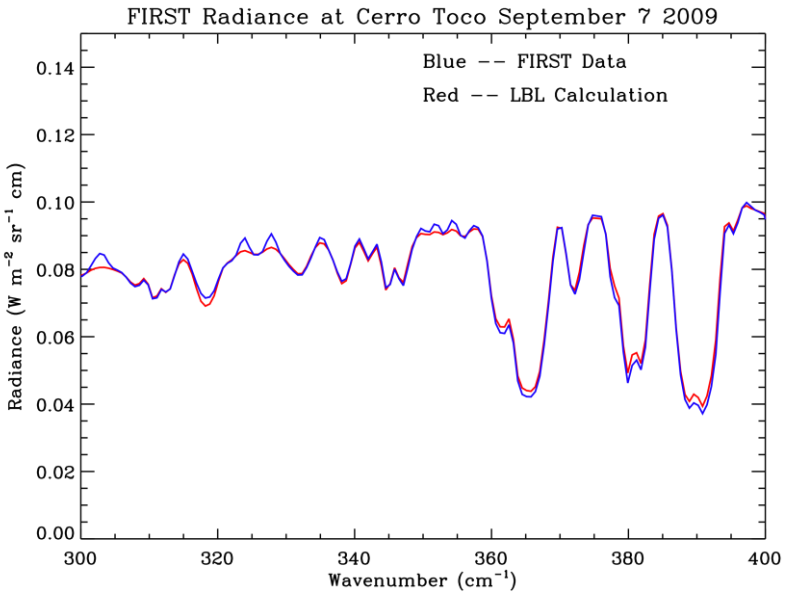


FIRST Data 200 – 300 cm^{-1}; September 5, 7, 19, 24

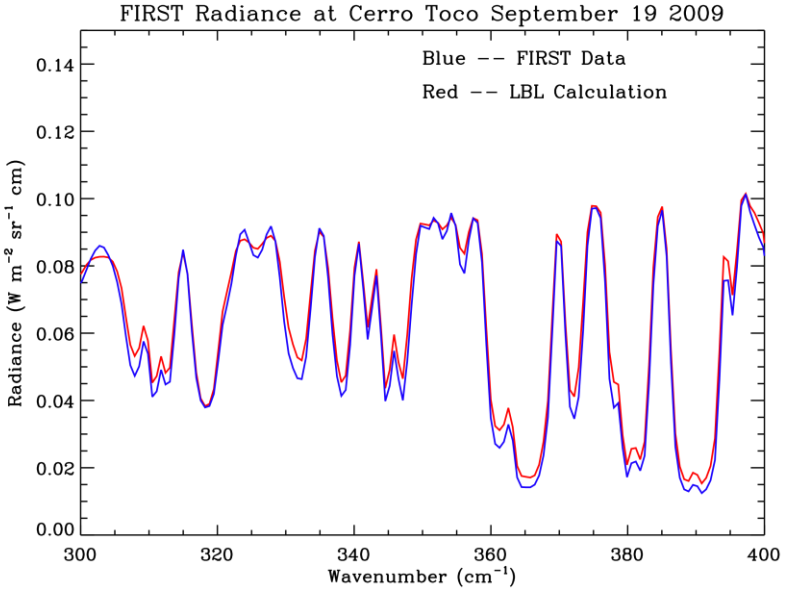


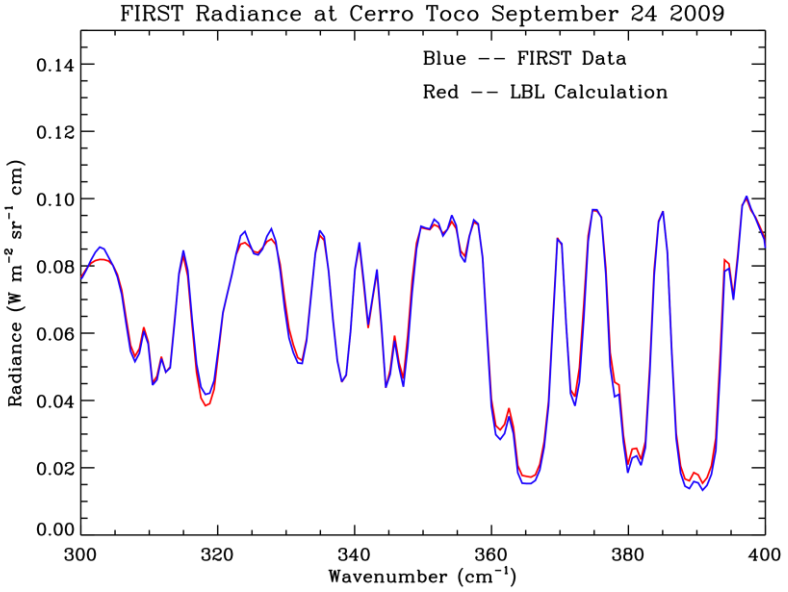


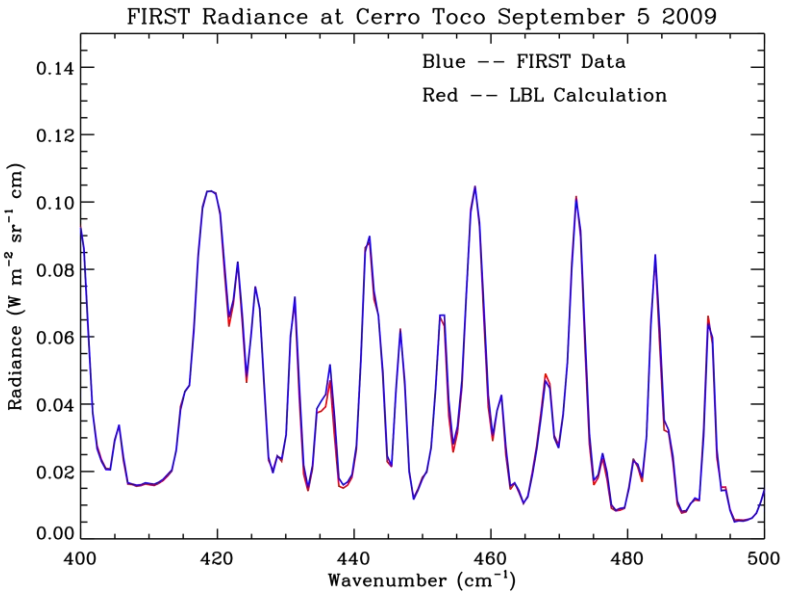


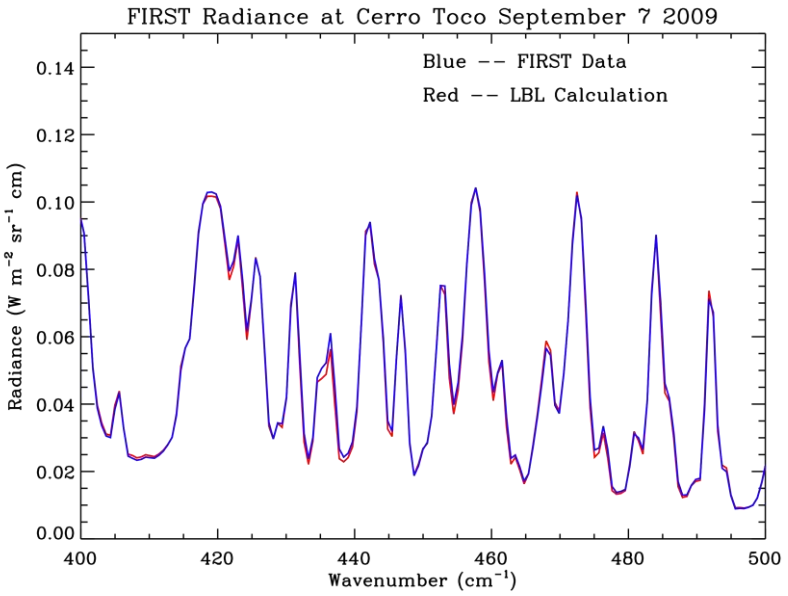


FIRST Data 300 – 400 cm^{-1}; September 5, 7, 19, 24

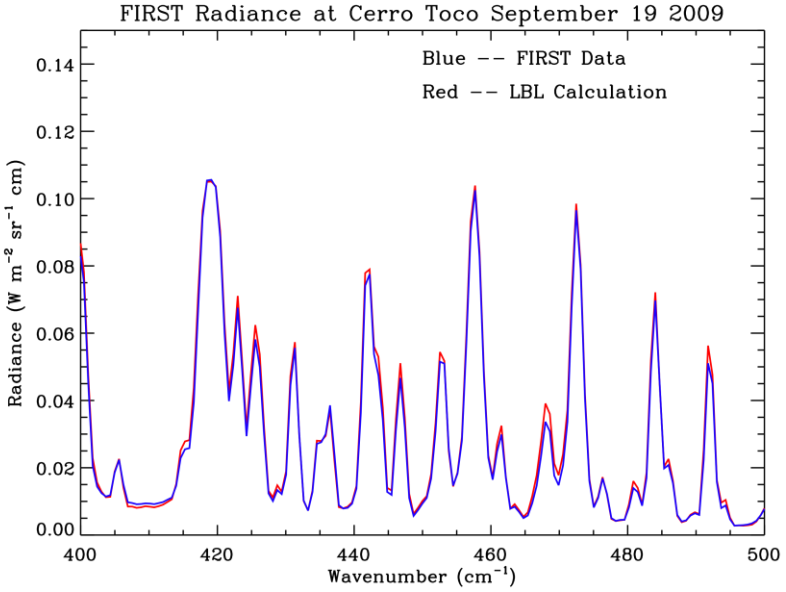


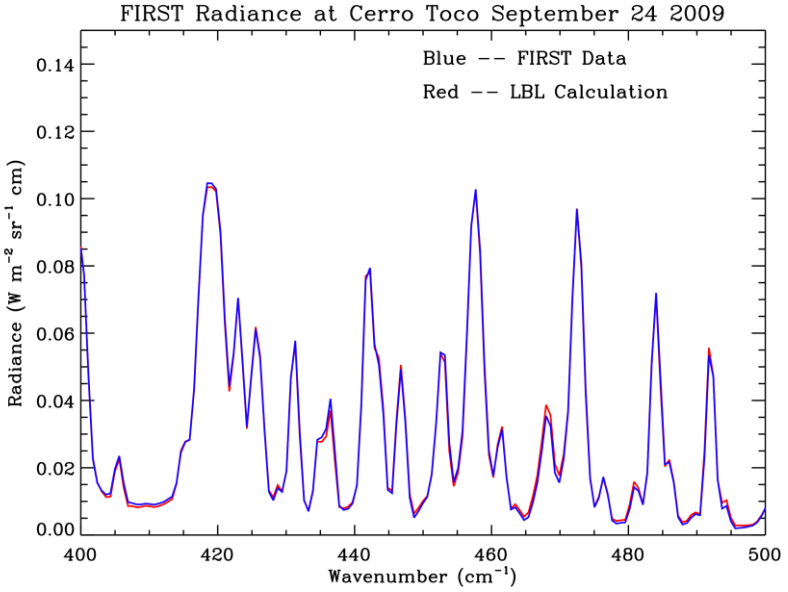


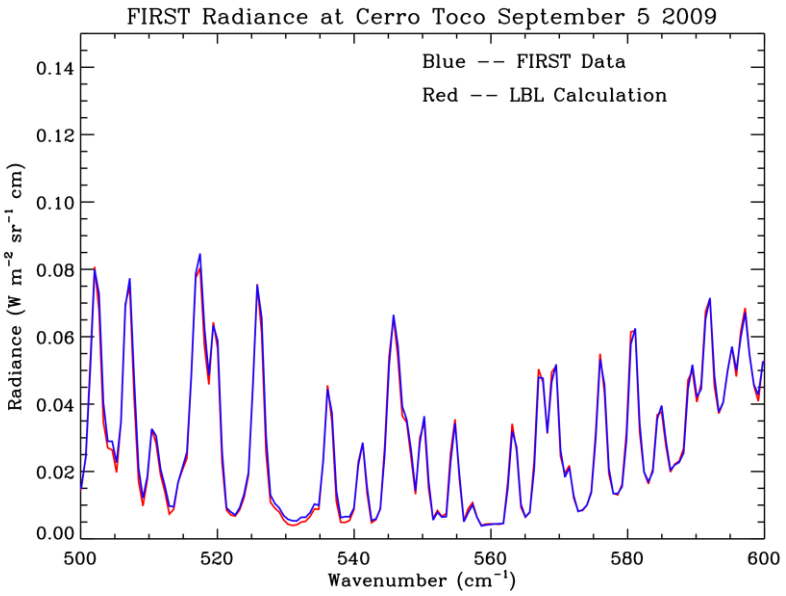


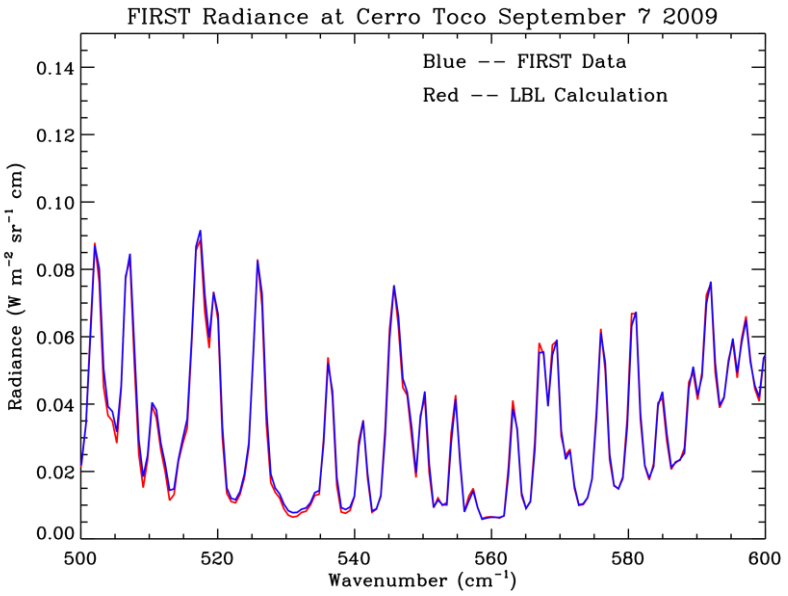


FIRST Data 400 – 500 cm^{-1}; September 5, 7, 19, 24

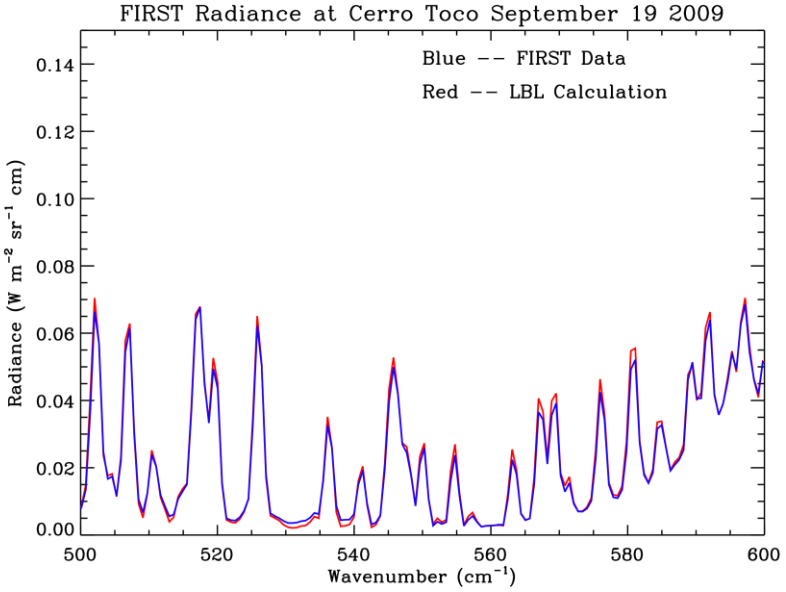


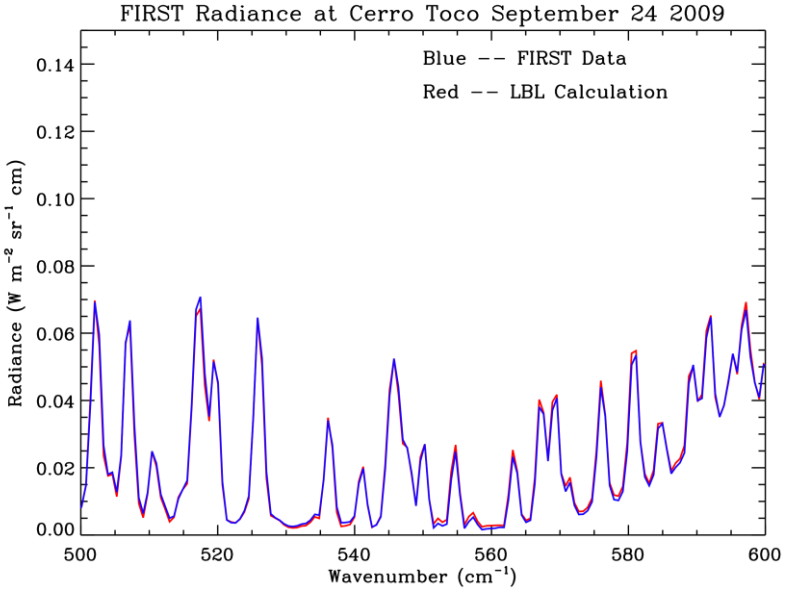






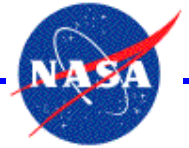
FIRST Data 500 – 600 cm^{-1}; September 5, 7, 19, 24





Summary of Results from Cerro Toco and Future Plans

- Instrument operated nominally – recorded data on every day we went up the mountain
- Measured far-IR spectrum 80 to 800 cm^{-1}
  - Observed spectral structure down to 240 cm^{-1}
- **Measured spectra show no substantive differences with two different radiative transfer codes, LBLRTM/LBLDIS and MRTA**
  - **This is at the < 1-2% level. Finer differences may exist**
- FIRST undergoing recalibration now at SDL
  - Will reprocess Cerro Toco data and also remove "1.6 m path" radiance
- Deploy newly calibrated FIRST to Table Mountain or MLO in 2012



INFLAME

- INFLAME -

In-Situ Net Flux within the Atmosphere of the Earth

INFLAME Goal: Measure the rates of heating & cooling of the atmosphere by visible and infrared radiation

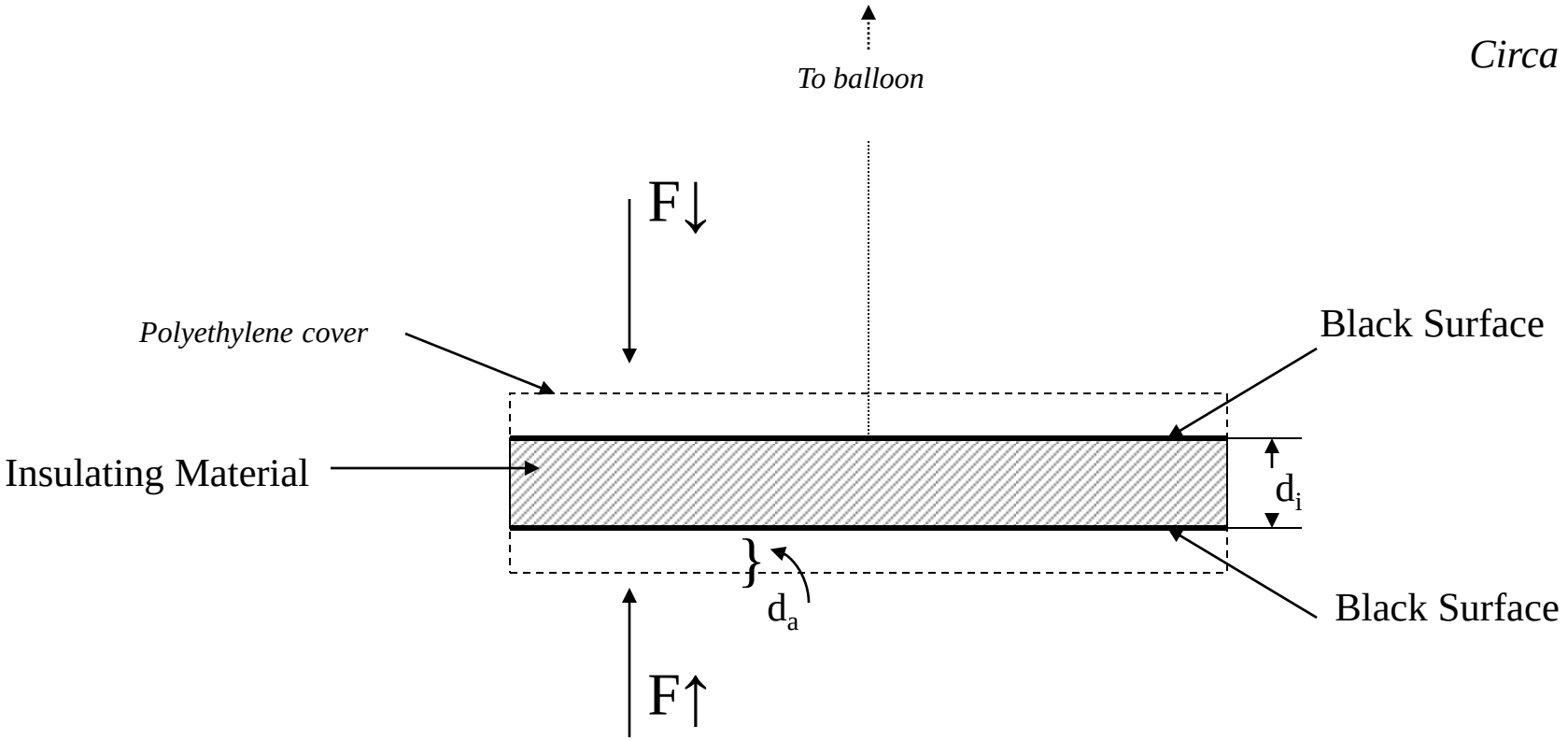
Developed under Instrument Incubator Program

Successful Demo Flight on LearJet January 2010

Net Flux Measurement – At the Beginning

The Suomi "Economical Net Flux Radiometer"

Circa 1960



$$\frac{\partial T}{\partial t} = f(T_b, T_t, T_a, r, a, d_i, d_a, k_i, k_a)$$

In-Situ Net Flux within the Atmosphere of the Earth

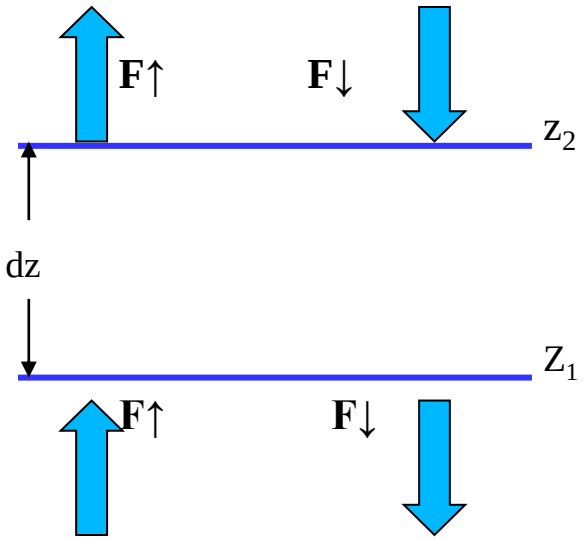
Atmospheric Heating and Cooling Rates

$$F\uparrow(z) = \int_0^1 I(z)\,\mu\,d\Omega$$

$$F\downarrow(z) = \int_{-1}^0 I(z)\,\mu\,d\Omega$$

$$F_{net}(z) = F\uparrow(z) - F\downarrow(z)$$

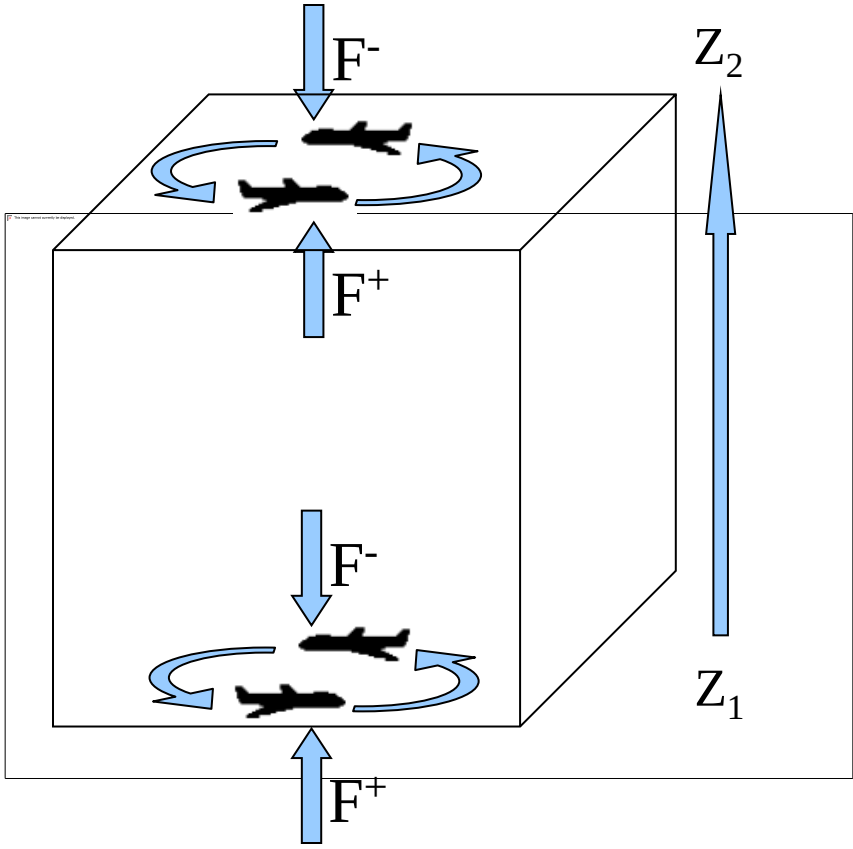
$$\frac{\partial T}{\partial t} = \frac{1}{\rho C_p}\frac{\partial F_{net}(z)}{\partial z}$$



Require an instrument to *directly* measure the net flux

Measuring Net Flux Divergence

- **From an airborne platform:**
  - **Measure Net Flux at Z_1**
  - **Measure Net Flux at Z_2**

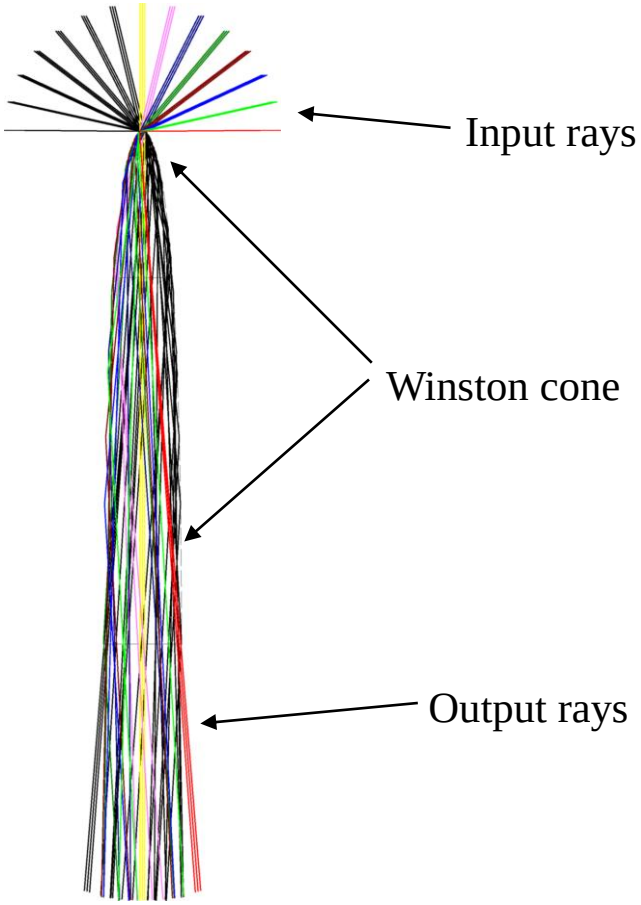


- **Approximate Heating Rate by:**

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

INFLAME Approach: F+ and F-

- Most instruments measure radiance, not flux.
- Measuring flux requires collecting light over a full hemisphere.
- We use a non-imaging Winston cone to collect radiation and collimate it into an f/6.8 beam.
  - Input aperture is 1 mm diameter.
  - Output aperture is 13.6 mm diameter.



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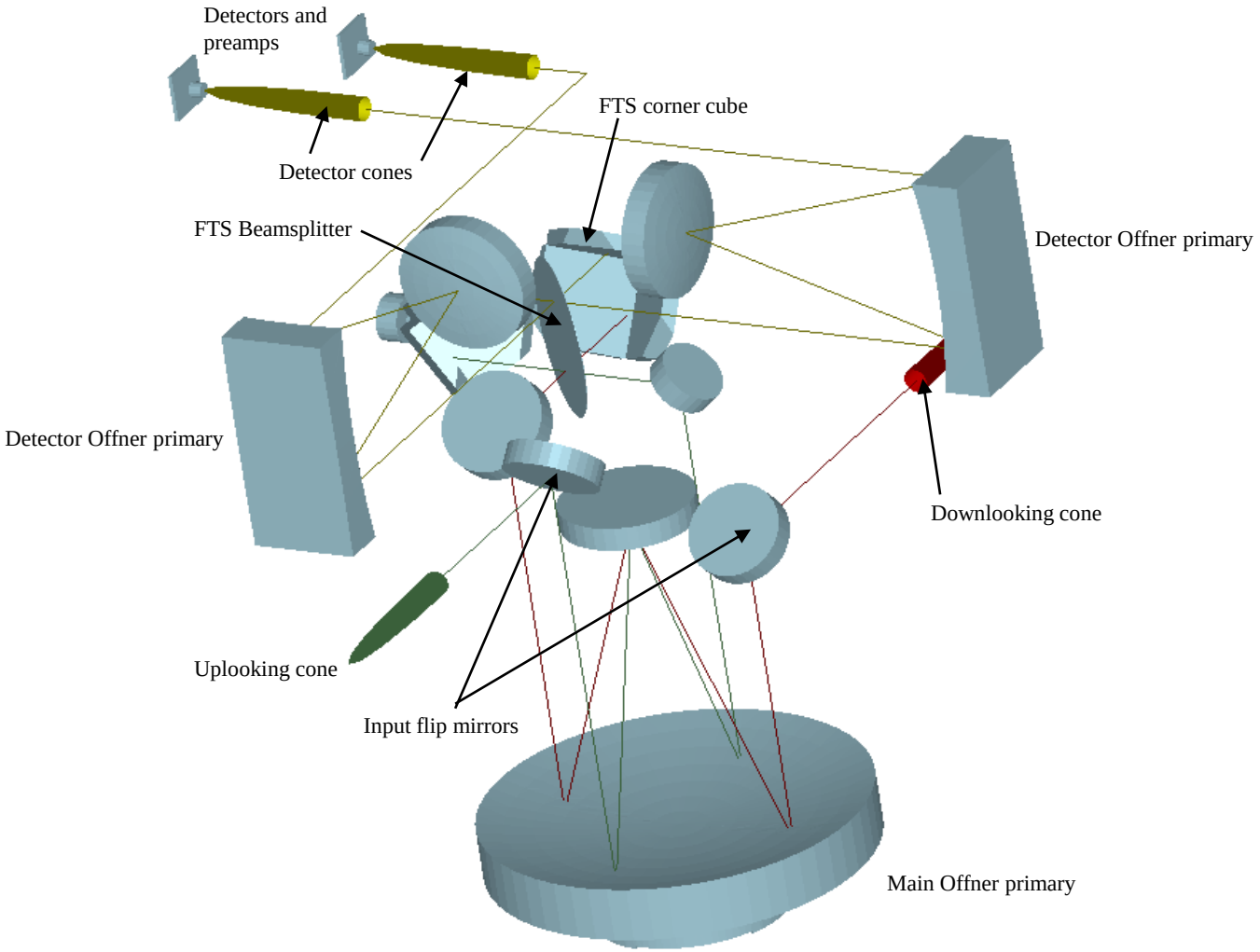
INFLAME Optical Layout



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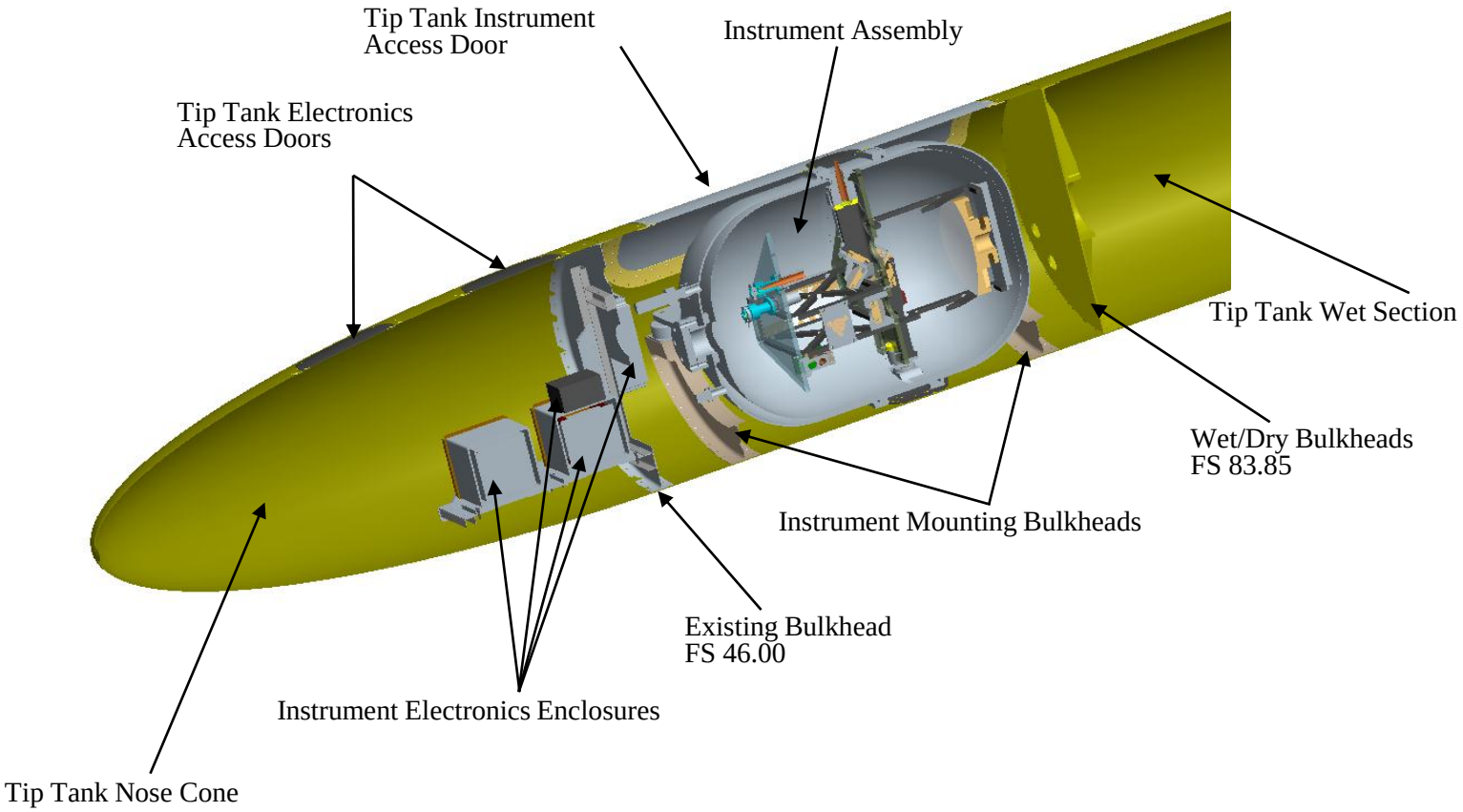
INFLAME Measurement Platform

INFLAME mounted in wingtip fuel tanks

Fuel Tank Integration



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LW Flight Install: 1/4/2010

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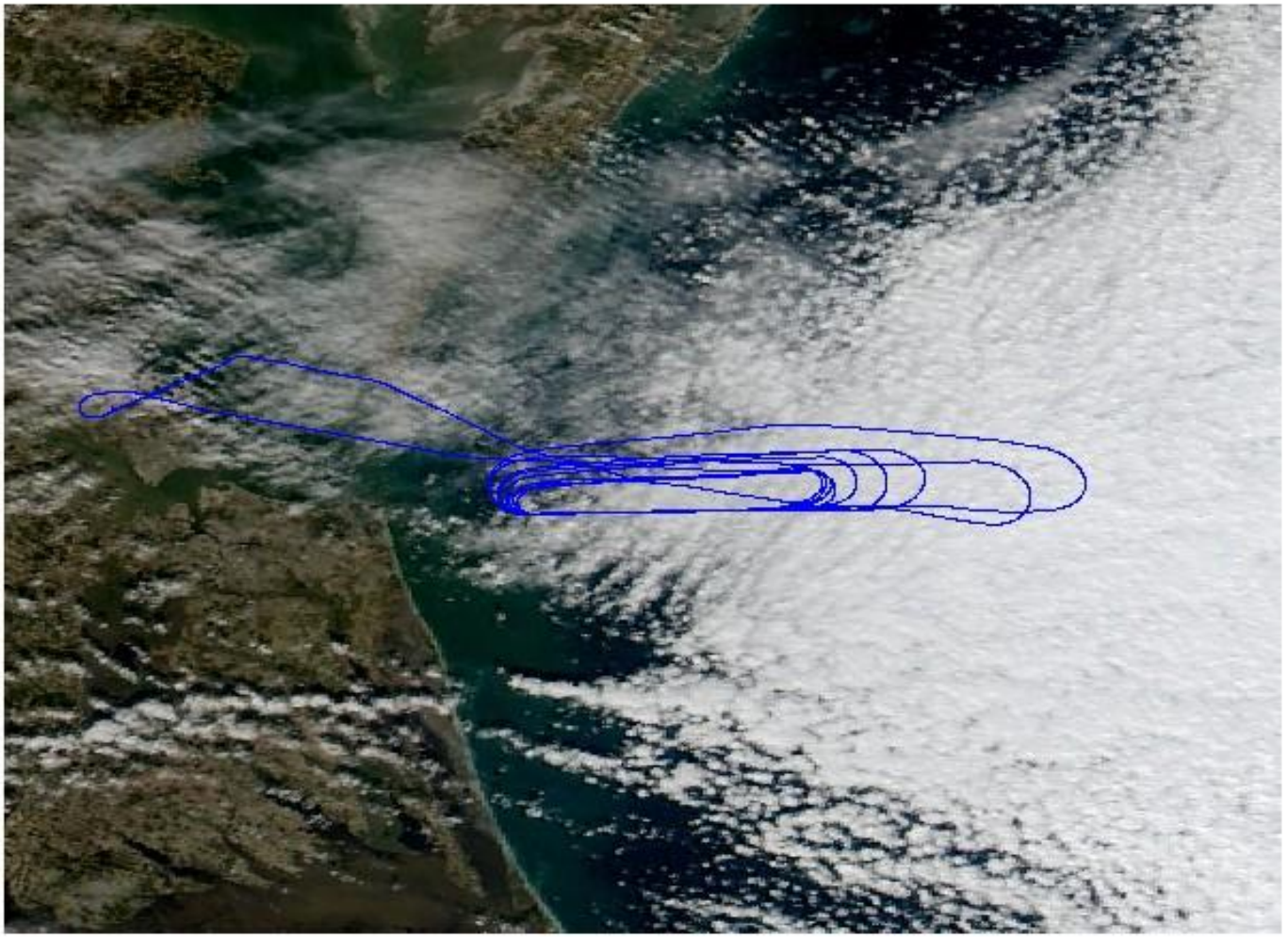
MODIS Visible Imagery 5 Jan 2010



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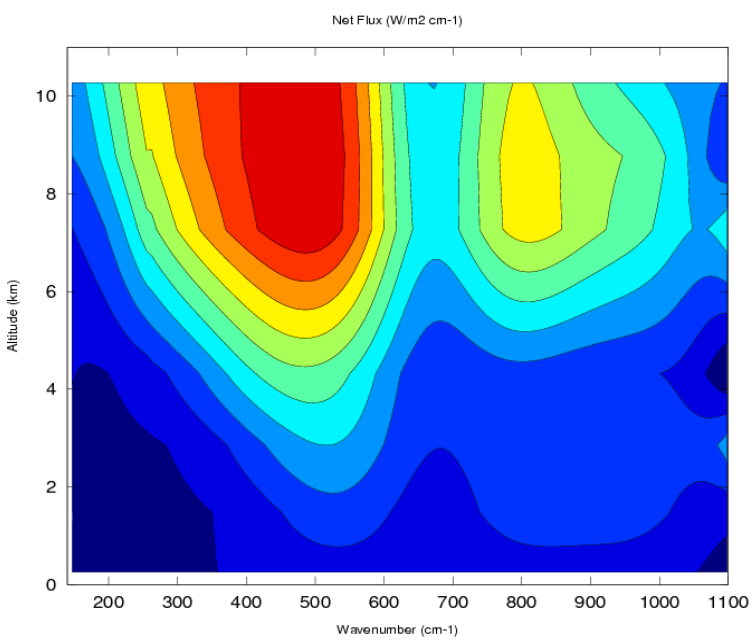
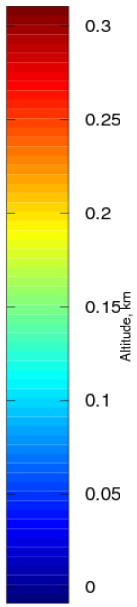
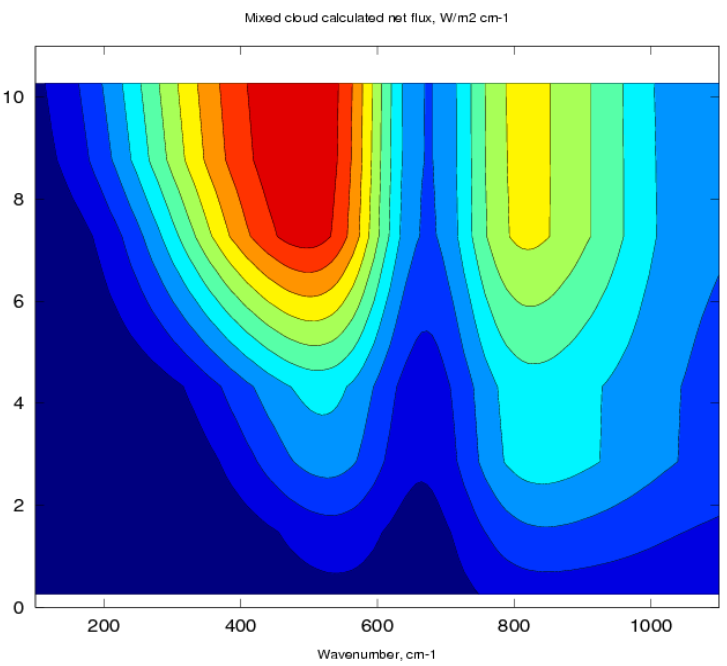
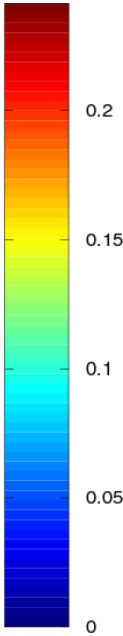
INFLAME LW Net Flux









Measured LW Net Flux

1/5/2010

Calculated LW Net Flux

1/52010

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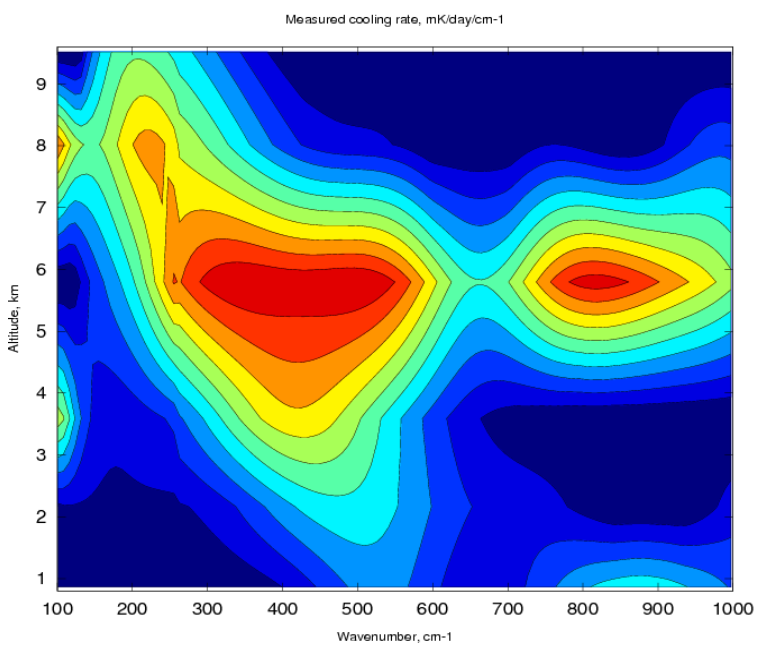
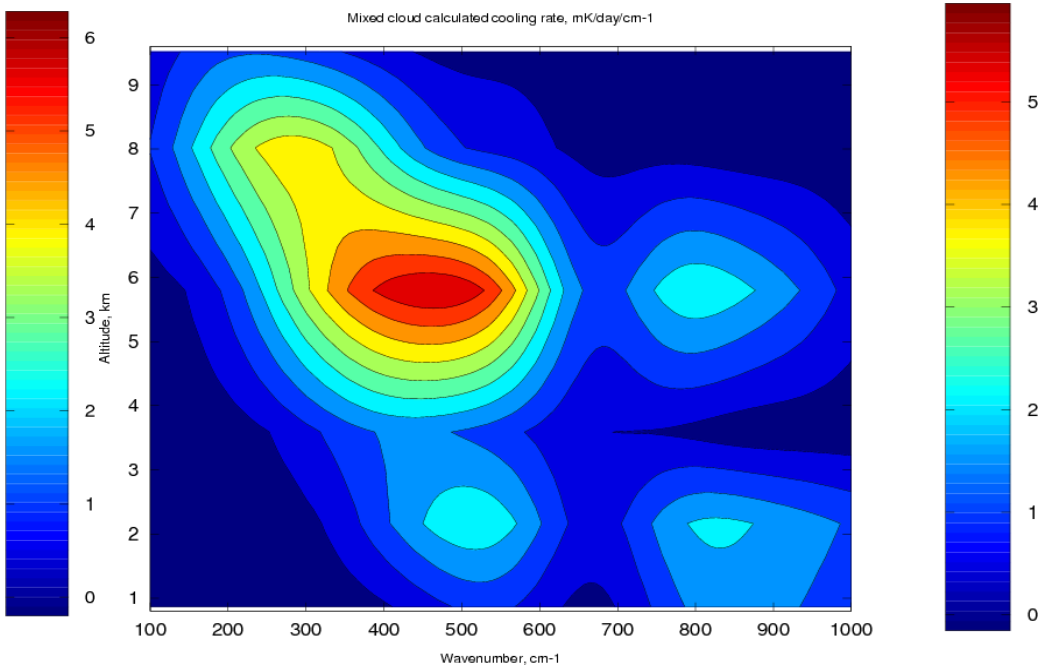
INFLAME Derived LW Cooling Rates



Measured LW Cooling mK/Day/cm^{-1}

1/5/2010 flight.



Calculated LW Cooling mK/Day/cm^{-1}

1/5/2010 flight

INFLAME Flight Results

Summary

- IR FTS (LW) Successfully demonstrated during flight
  - First direct measurement of net fluxes and spectral cooling rates within the atmosphere
  - Analysis is ongoing

- UV-NIR FTS (SW): No useful flight spectra obtained.
  - Commercial controller failed due to excessive drift with temperature before takeoff.

FIREX
The Far-Infrared Explorer

A Proposal to the NASA Earth Venture-2 A/O
Submitted September 2011

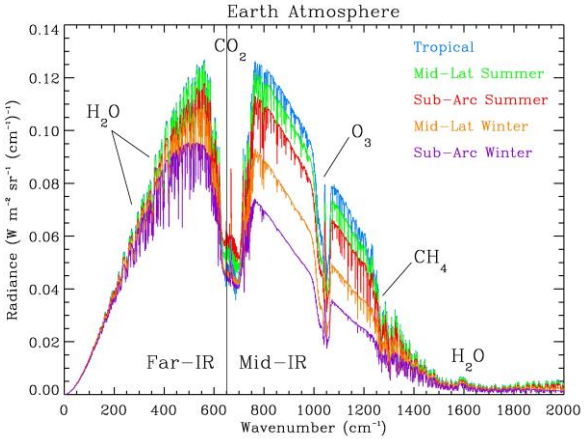
FIREX – The Far-Infrared Explorer

A Proposal to the NASA Earth Venture-2 Opportunity

Science Objectives

- Determine Earth's spectral greenhouse effect across the entire IR spectrum, including the far-IR
- Determine spectral cloud radiative forcing across the entire IR spectrum, including the far-IR
- Determine the radiative cooling rate profile consistent with entire IR spectrum, including the far-IR
- Enable the first verification of climate model performance across the entire IR spectrum

FIREX Measures the Complete IR Spectrum Including the Unobserved Far-IR



Mission and Instrument Parameters

- Spectral Range: *200 to 1800 cm^{-1}*
- Spectral Resolution: *1 cm^{-1}*
- Accuracy: *0.5%*
- Instrument: *Fourier Transform Spectrometer*
- Platform: *International Space Station*
- Local time sampling: *Every 30 days*
- Mission Duration: *2 years*
- Launch Readiness Date: *FY 2017*
- All instrument components at TRL 6 or higher
- Builds on decade of NASA investment at Langley in far-IR science and technology

Science Team

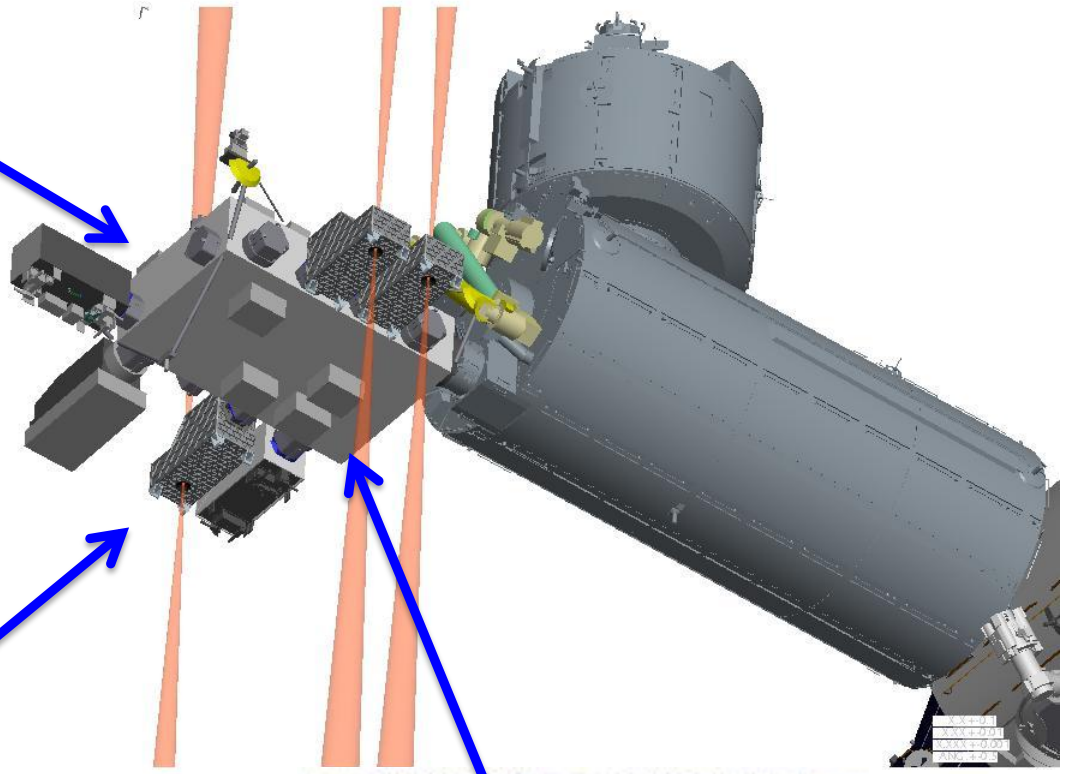
NASA Langley (M. Mlynczak, PI)
NASA GSFC
U. C. Berkeley
U. Michigan
Imperial College, London
Applied Physics Institute, Italy
U. Quebec Montreal, Canada

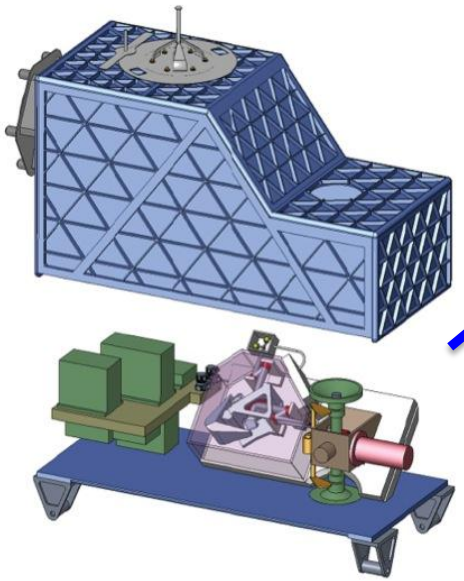
Industry Team

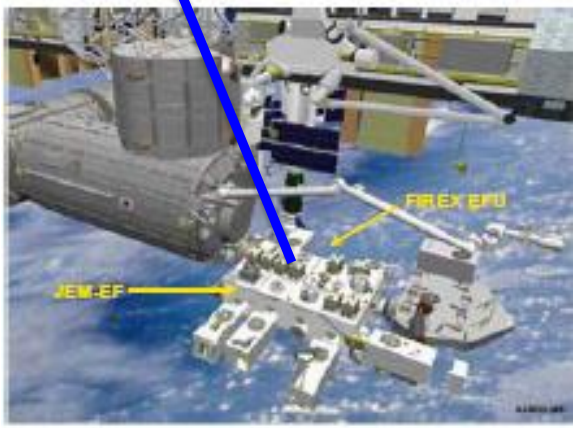
Ball Aerospace, Boulder, CO
Space Dynamics Laboratory, Logan, UT
ABB, Quebec City, Canada

FIREX on JEM Module on ISS

- 3 potential locations on JEM:
  Bays 3, 4, and 6.
- Figure shows FIREX payload in
  all 3 locations with clear FOV's







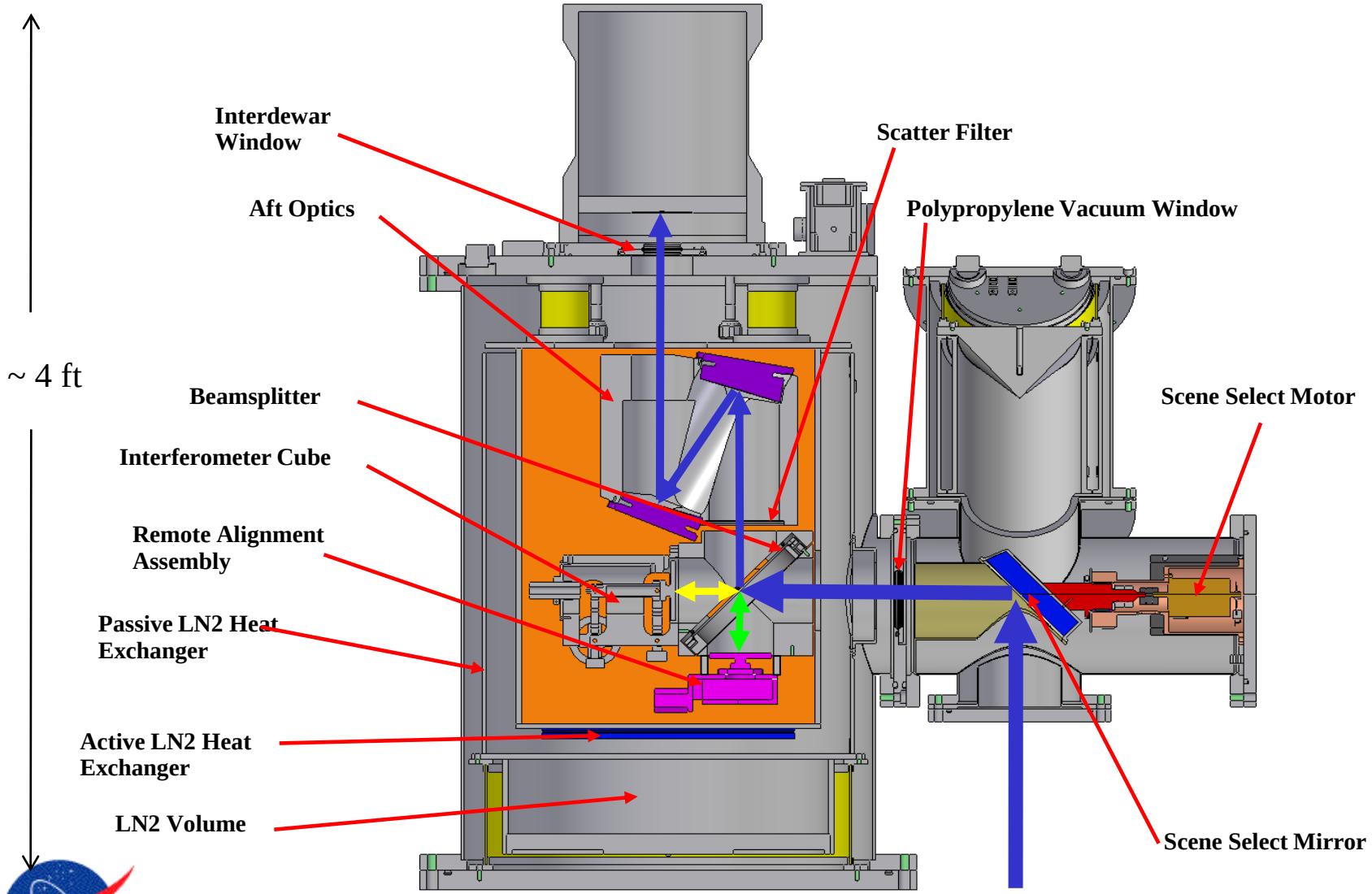
FIREX Instrument in Payload Interface Unit

Backups

FIREX Science Impact

- FIREX observations will enable fundamental improvements of climate and general circulation models in the far-IR where only calculations exist
  - Expect improvements in calculations of thermal structure and dynamics of atmosphere
- FIREX data will enable basic radiative transfer processes within Earth's atmosphere to be validated
  - Define just how large the natural water vapor greenhouse effect is relative to carbon dioxide and other greenhouse gases
- Anticipated advances in understanding of atmospheric physics will enable improvement in climate model physics and parameterizations, improving climate model predictions
  - Improve knowledge needed to tie down water vapor feedbacks

FIRST Spectrometer Overview



TIMELINE of Far-IR Projects at Langley

- FIRST Instrument
  - IIP 2001
- INFLAME Instruments
  - IIP 2004
- FIDTAP (Detector Technology)
  - ATI 2006
- FORGE (NASA component of RHUBC-II)
  - Radiation Sciences Program
- CORSAIR
  - IIP 2007
- FIREBIB (Detector Technology)
  - ACT 2008
- FIRST Recalibration & Deployment
  - QRS 2011