

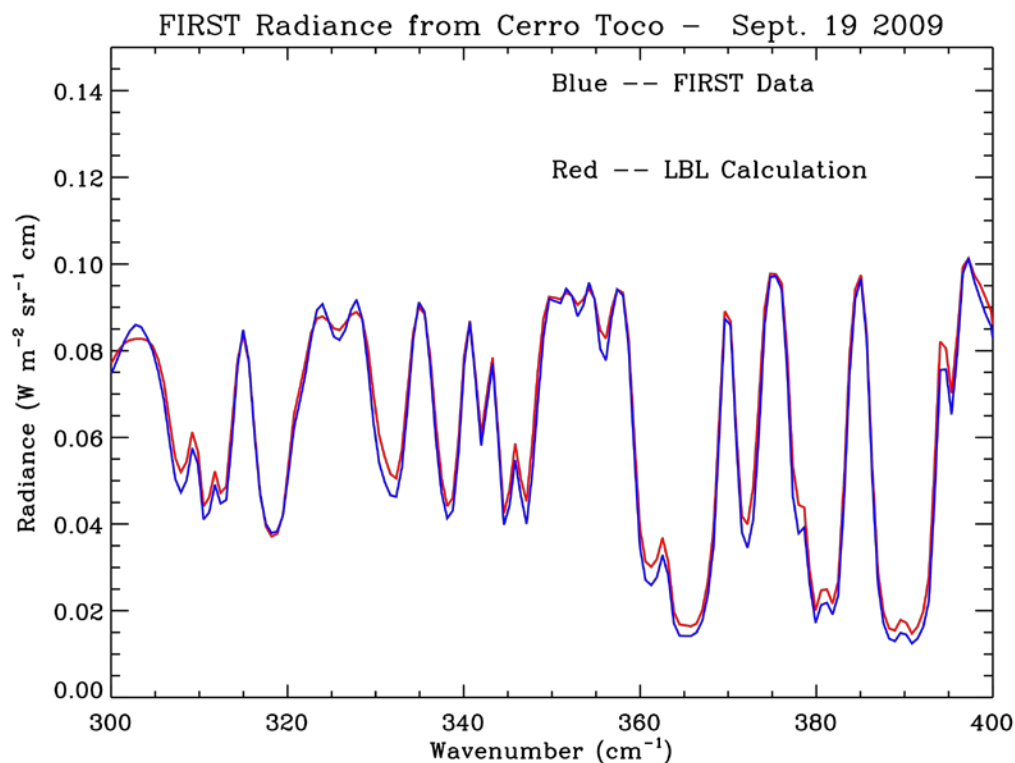


# FIRST Observations of The Far-Infrared Spectrum during the RHUBC-II Campaign

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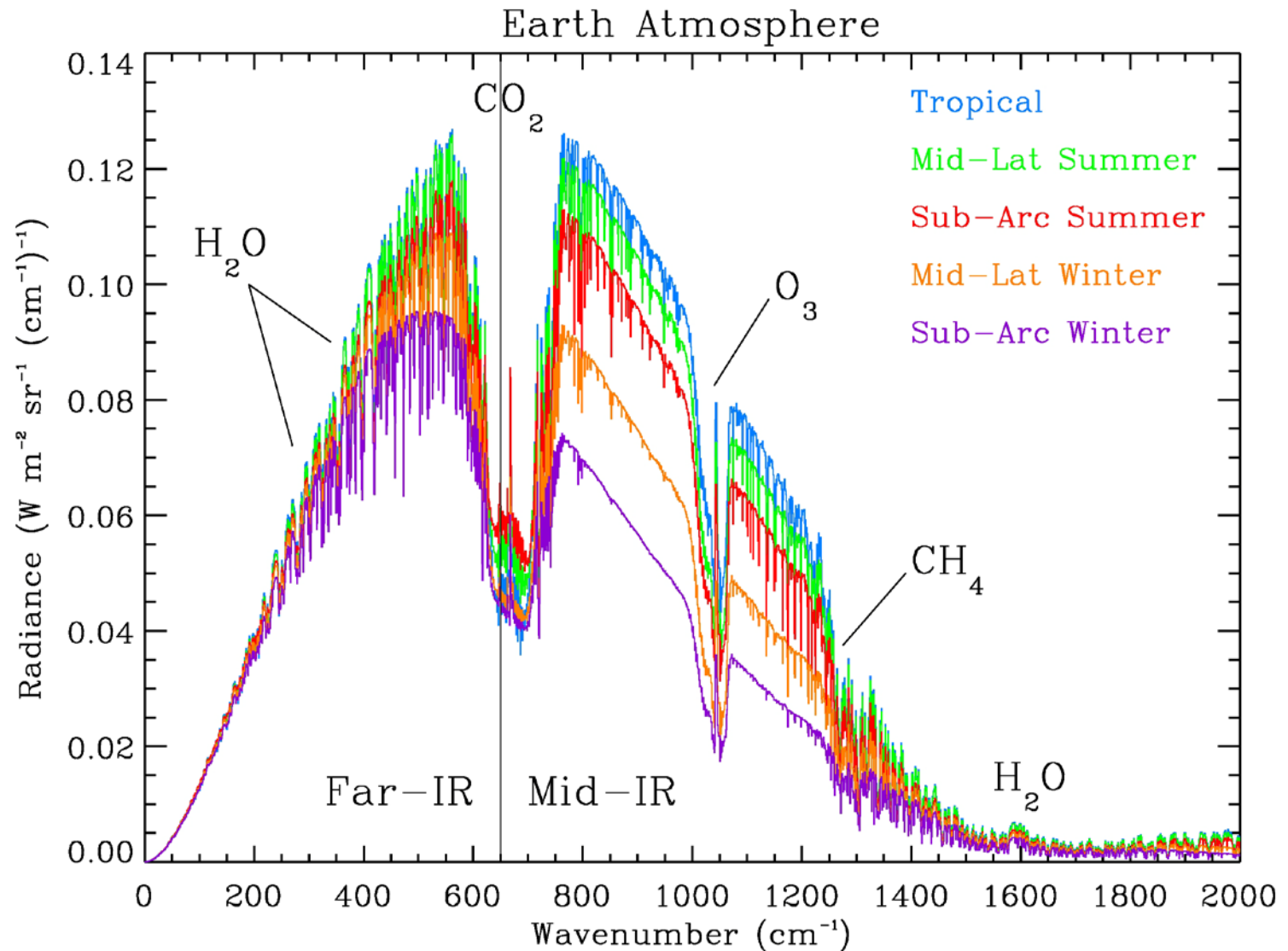
# FIRST and RHUBC-II

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## Outline

- Science Motivation and Justification for Far-IR Measurement
  - FIRST Science and Instrument Description
  - FIRST in Chile – First look at clear sky spectrum
  - Summary
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# Top-of-Atmosphere Spectral Infrared Radiance



# FIRST

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## Compelling Science of the Far-Infrared

- Up to 50% of OLR (surface + atmosphere) is beyond 15.4  $\mu\text{m}$
  - Between 50% and 75% of the atmosphere OLR is beyond 15.4  $\mu\text{m}$
  - Basic greenhouse effect (~50%) occurs in the far-IR
  - Clear sky cooling of the free troposphere occurs in the far-IR
    - Potential to derive atmospheric cooling rates directly from radiances
  - Upper Tropospheric H<sub>2</sub>O radiative feedbacks occur in far-IR
  - Cirrus radiative forcing has a major component in the far-IR
  - Longwave cloud forcing in tropical deep convection occurs in the far-IR
  - Addresses remaining “dimension” – the spectral dimension – of ERB sampling
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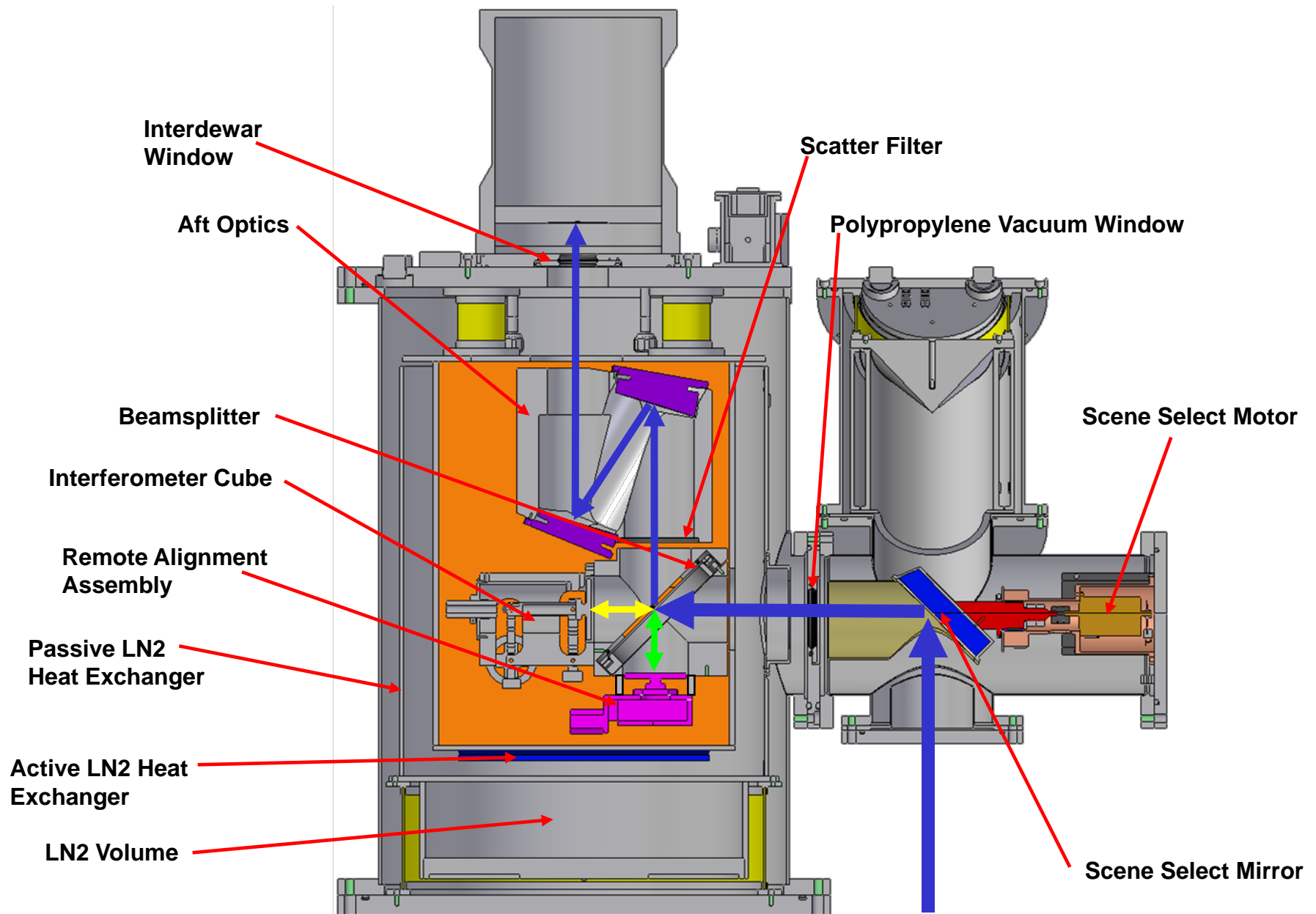
# FIRST - Instrument Description

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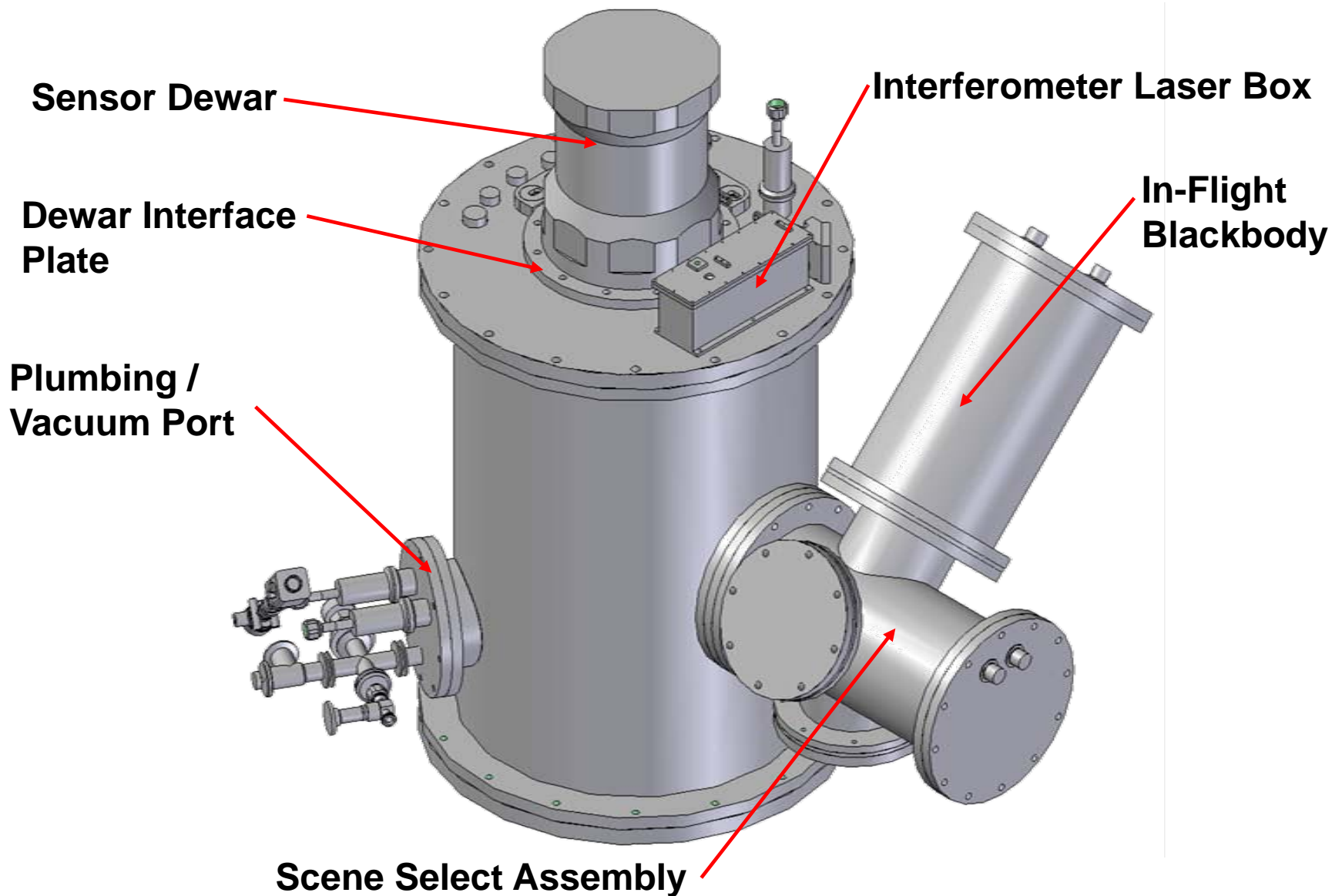
- Michelson Interferometer
- 6 to 100  $\mu\text{m}$  on a single focal plane
- 0.625  $\text{cm}^{-1}$  unapodized (0.8 cm OPD)
- 1.4 s scan time (nominal)
- 0.47  $\text{cm}^2$  sr optical throughput (realized)
- 10 discrete detector focal plane (sized for 100 @ 10 x 10)
- Germanium on polypropylene beamsplitter
- Bolometer (COTS) detectors @ 4 K
- NE $\Delta$ T – Realized 0.2 K over most of wavelength range
- Demonstrated on a high-altitude balloon flight June 7 2005
- Second balloon flight September 18 2006

**Designed to demonstrate technology to measure daily, the far-IR spectrum, globally, @ 10 km resolution**

# FIRST Balloon Payload System

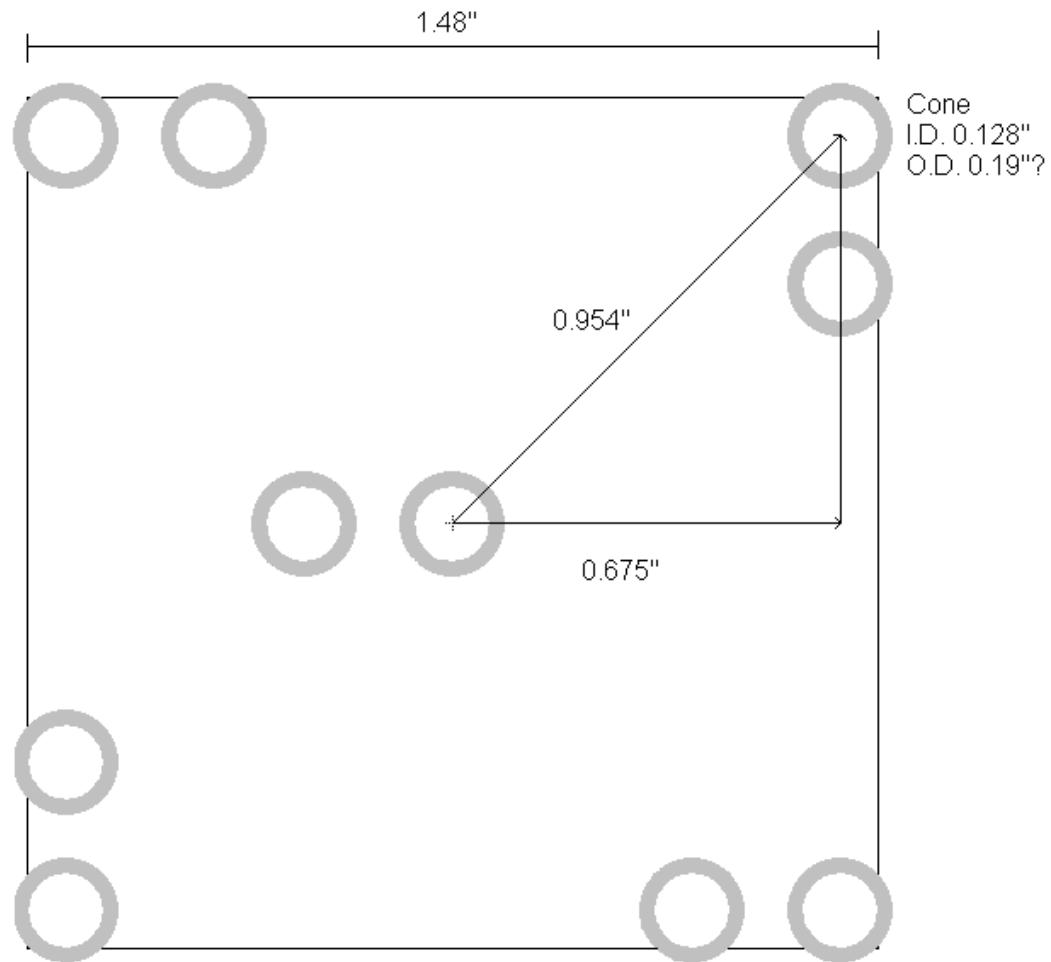


# FIRST Balloon Payload System





# FIRST Winston Cone Array





# FIRST – Calibration

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- **FIRST designed with absolute calibration in mind, from the start**
    - Instrument cooled to 180 K to simulate space environment and reduce instrument background
    - Full field external calibration sources
    - Multiple calibration sources (warm, cold) in laboratory
    - Multiple calibration sources in flight (warm, “space”)
  - **Spectral range designed to cover 10 – 15  $\mu\text{m}$  (+ far-IR)**
    - Allows verification against “standard” instruments, e.g, AIRS, AERI, in mid-IR
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# FIRST on the Flight Line June 7 2005



# FIRST Flights

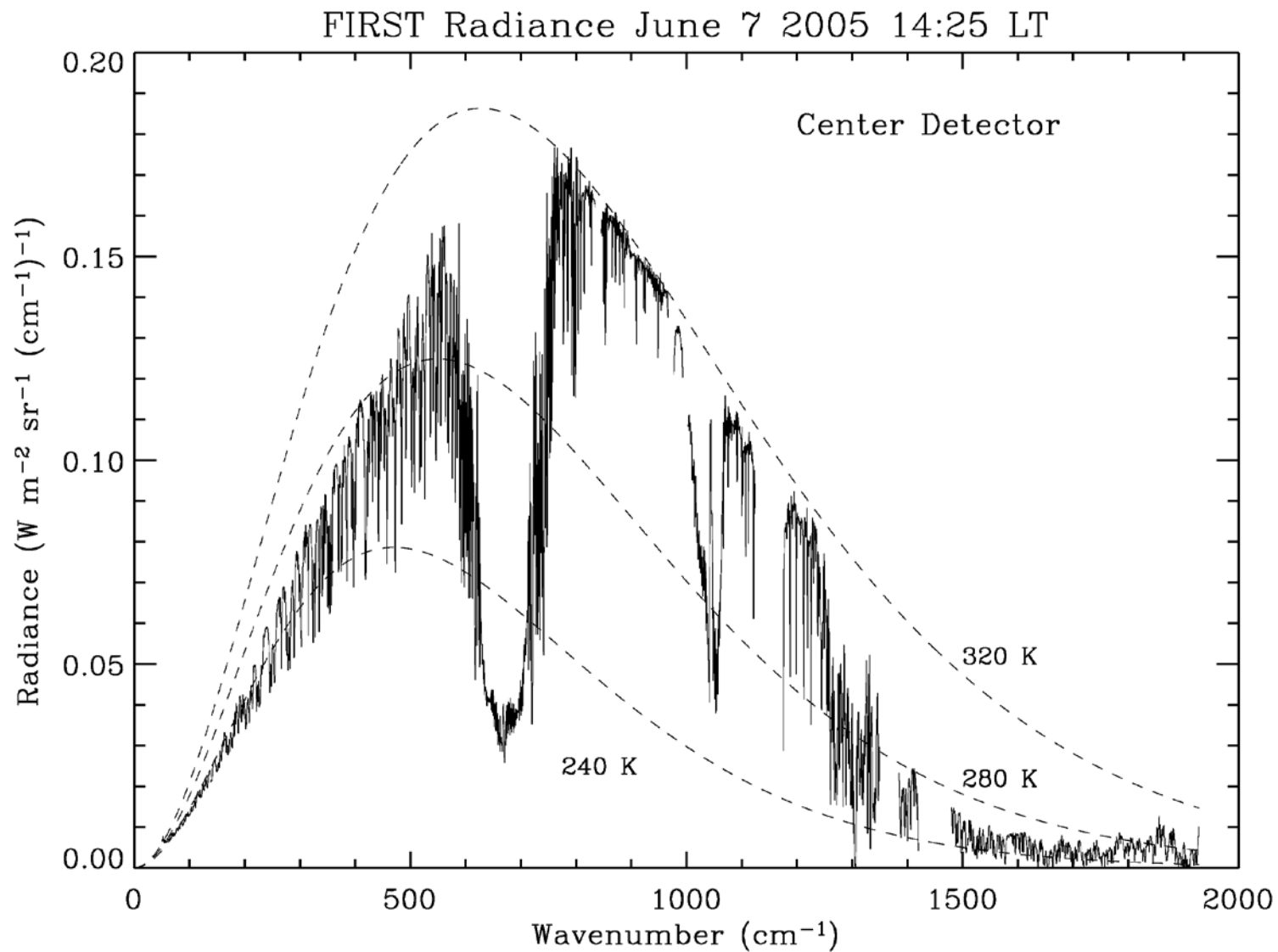
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- Launched on 11 M cu ft balloon June 7 2005; September 18 2006
- Float altitude of 27 km, 33 km
- Recorded ~ 6 hours of data at float
- 1.2 km footprint of entire FPA; 0.2 km footprint per detector
- 15,000 interferograms (total) recorded on 10 detectors
- Overflight of AQUA at 2:25 pm local time – AIRS, CERES, MODIS
- Essentially coincident footprints FIRST, AQUA instruments
- FIRST met or exceeded technology development goals
- FIRST, AIRS, CERES comparisons in window imply excellent calibration (better than 1 K agreement in skin temperature)

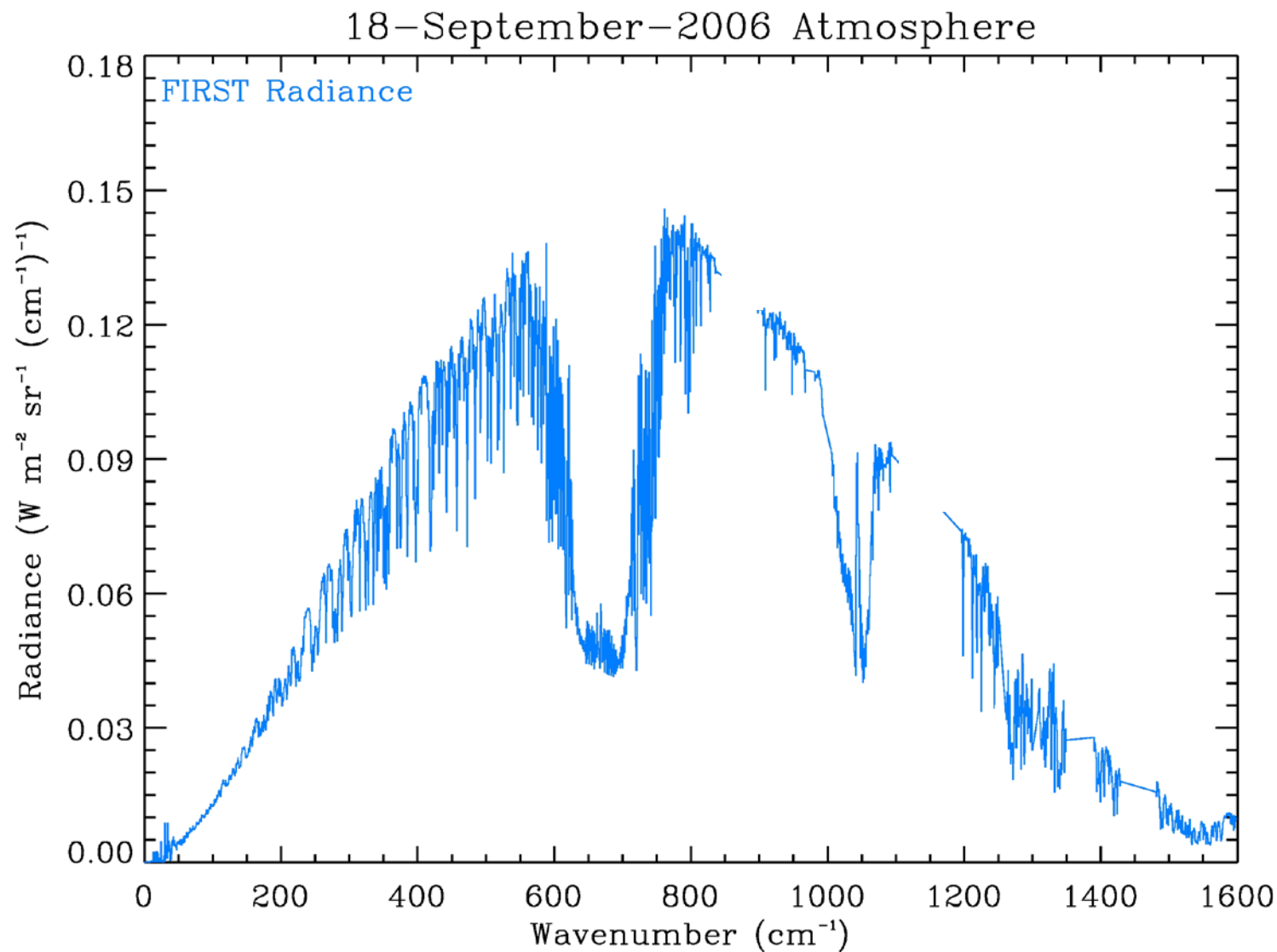
**FIRST records complete thermal emission spectrum  
of the Earth at high spatial and spectral resolution**

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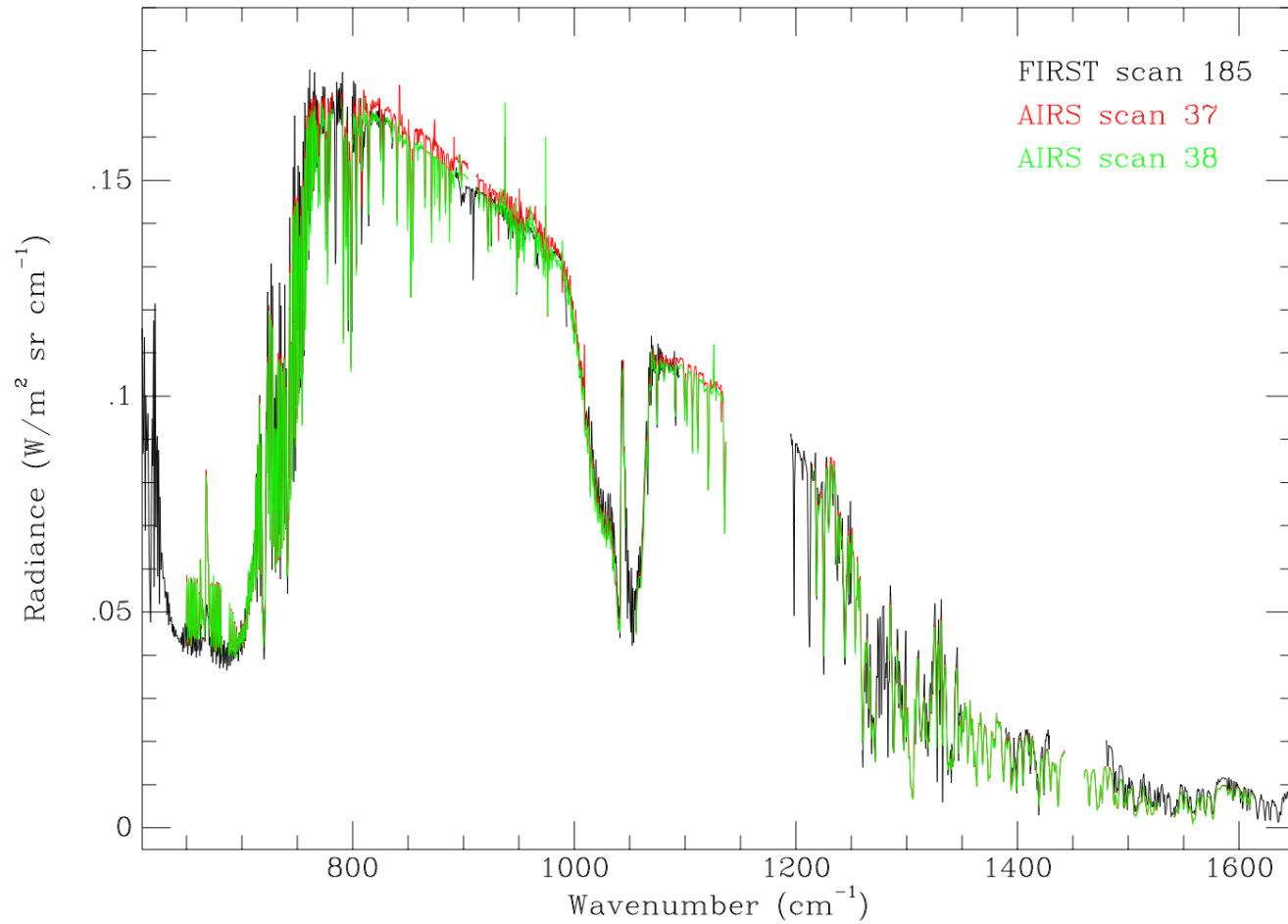
# FIRST Spectrum, Center Detector



# FIRST Spectrum September 2006

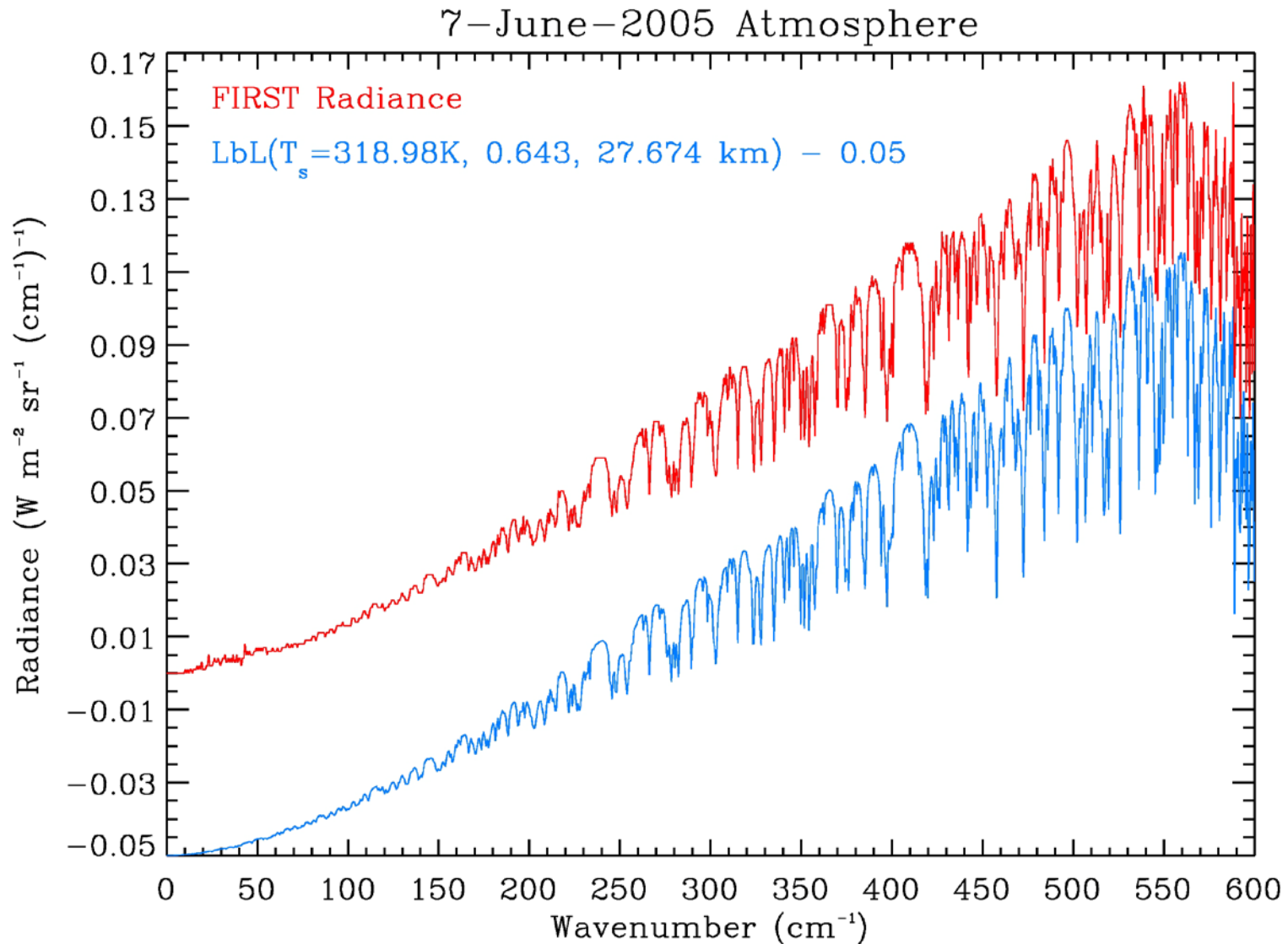


# FIRST and AIRS Radiance Comparison June 2005



# FIRST Spectra Compared with L-b-L Simulation

## Demonstration of FIRST Recovery of Spectral Structure



*Note: FIRST, LbL spectra offset by 0.05 radiance units*

# FIRST and RHUBC-II

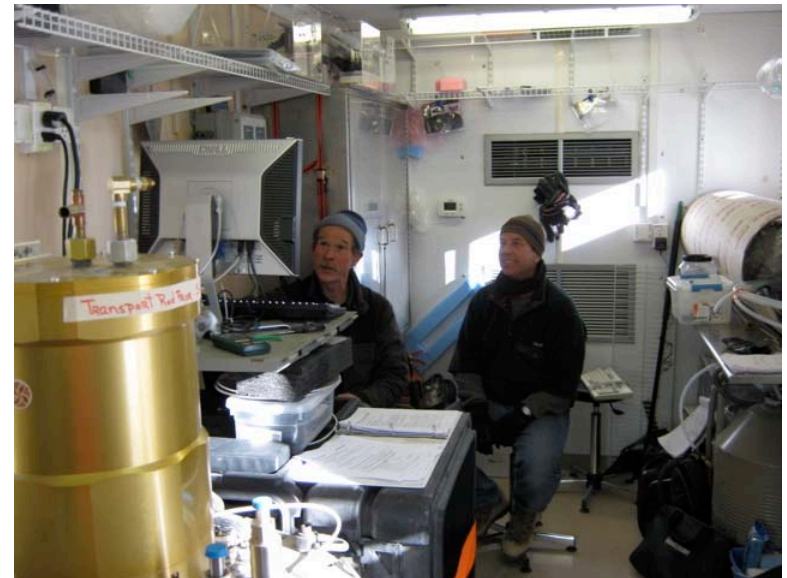
**Observations August to October 2009**

**Thirty eight days on the mountain to take data**

**Over 100 hours of data taken at Cerro Toco**

**Data reported are 6 minute average spectra**

**Nearly 400 high quality spectra uploaded to RHUBC-II archive  
80 to 800  $\text{cm}^{-1}$**





# **FIRST Calibration Procedure**

- 1) FFT of double-sided interferogram (no zero-padding, sampled once per He-Ne laser fringe, or 6x over-sampling of IR fringes) trimmed and centered for  $0.643\text{cm}^{-1}$  unapodized resolution.**
- 2a) Two temperature reference blackbody calibration (observed ambient:  $\sim 280\text{K}$  and warm:  $\sim 320\text{K}$ , relative to Planck curves). Complex responsivity and offset determined for each detector.**
- 2b) Phase correct each interferogram, minimizing complex imaginary part in transformed spectra to correct for sampling, beamsplitter dispersion, and other linear and non-linear frequency phase offsets.**
- 3) Average three simultaneous detector spectra, then average this result over 6 min. for  $80$  to  $800\text{ cm}^{-1}$  spectra.**

# FIRST Data – Comparisons with Theory

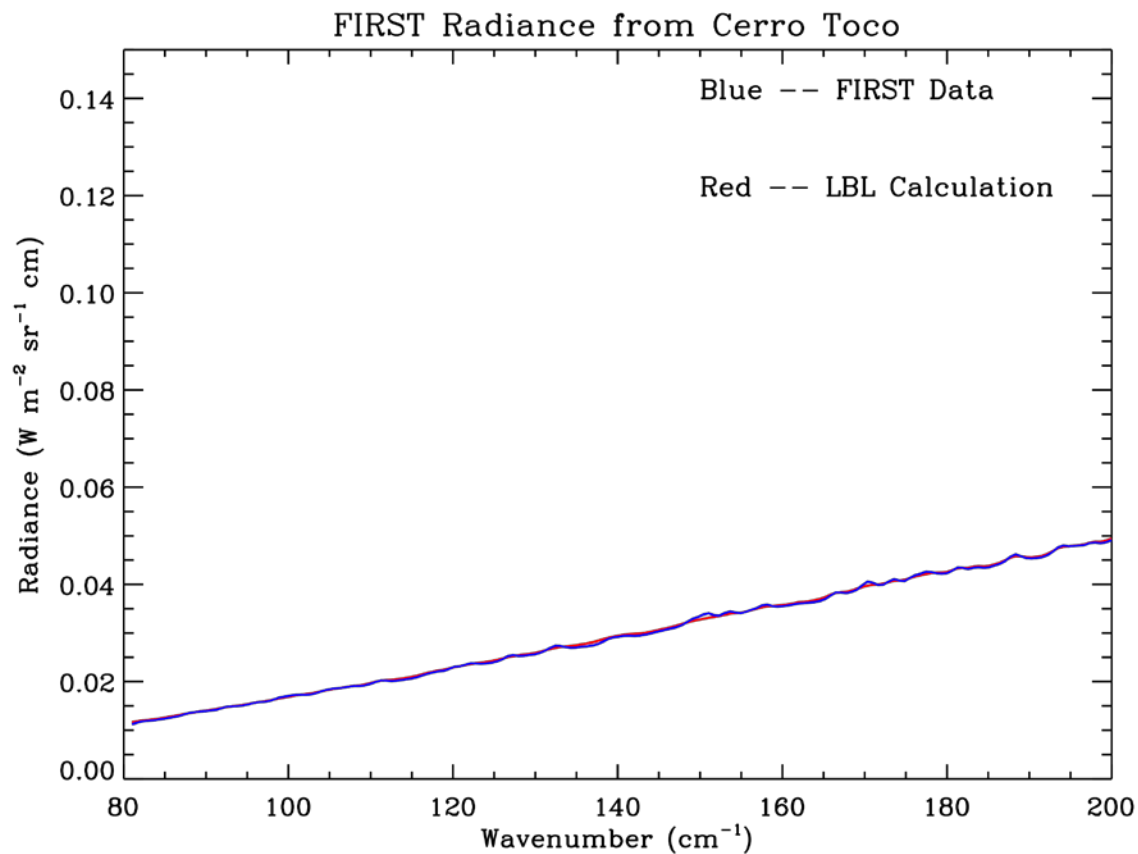
## Monochromatic Radiative Transfer Algorithm (MRTA)

[Specifications for FIRST/RHUBC-II spectral simulations]

- Spectral Resolution: 0.005 cm<sup>-1</sup>
- 2008 abundances of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, CO, CFC-11, CFC-12, CFC-22, CCl<sub>4</sub>, CF<sub>4</sub>, SF<sub>6</sub>
- O<sub>3</sub> from Mid-latitude Winter atmosphere
- H<sub>2</sub>O, temperature & pressure from Radiosonde Profile
- 2008 HITRAN Database
- MT\_CKD 2.1 Continuum code
- Calculations run for selected cases using the original and v1 Radiosonde databases.
- MRTA has been used to calculate the radiative forcings attributed to minor trace species, to simulate the infrared spectra of the outer planets, to establish the stability of satellite instruments, to produce correlated *k*-distribution routines for satellite channels, to model the far-infrared at high spectral resolution, to analyze the results from the FIRST, FORGE & INFLAME field campaigns, and to run simulations for the proposed CLARREO mission.

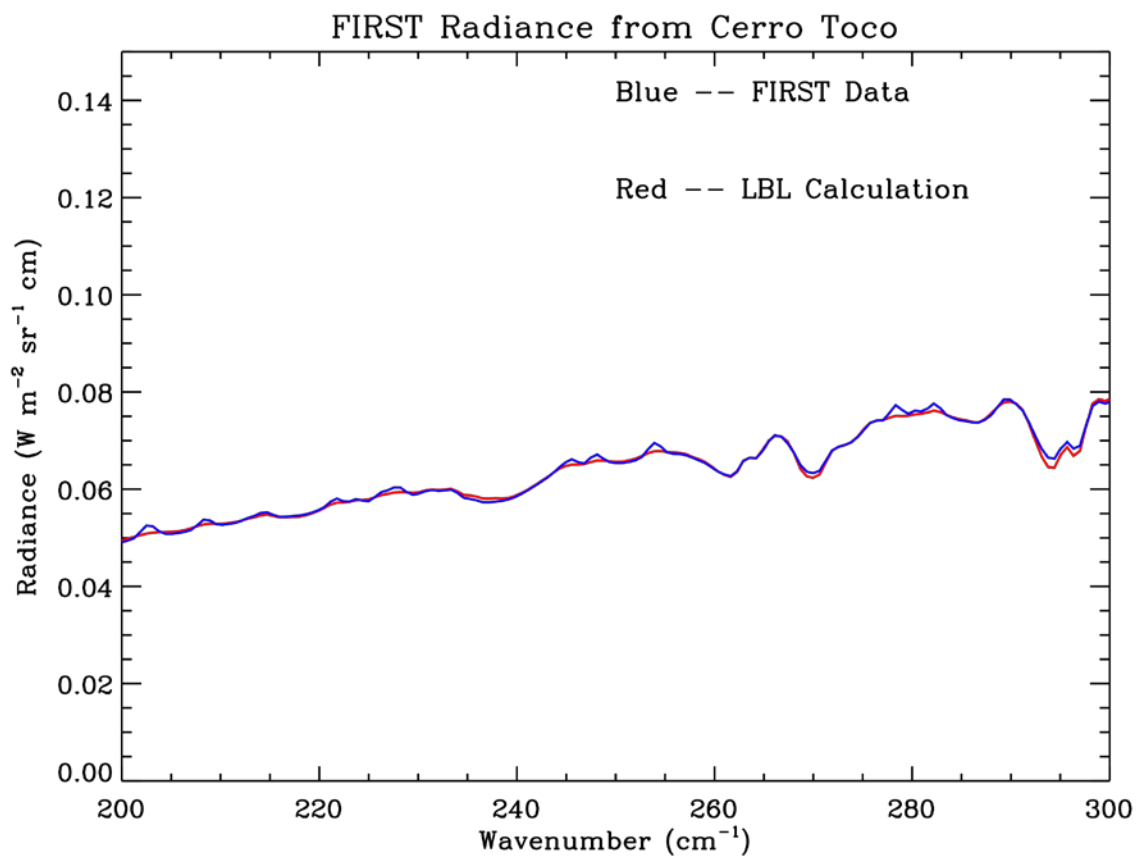
# FIRST Data and Theory

September 5 2009 – PWV = 0.75 mm



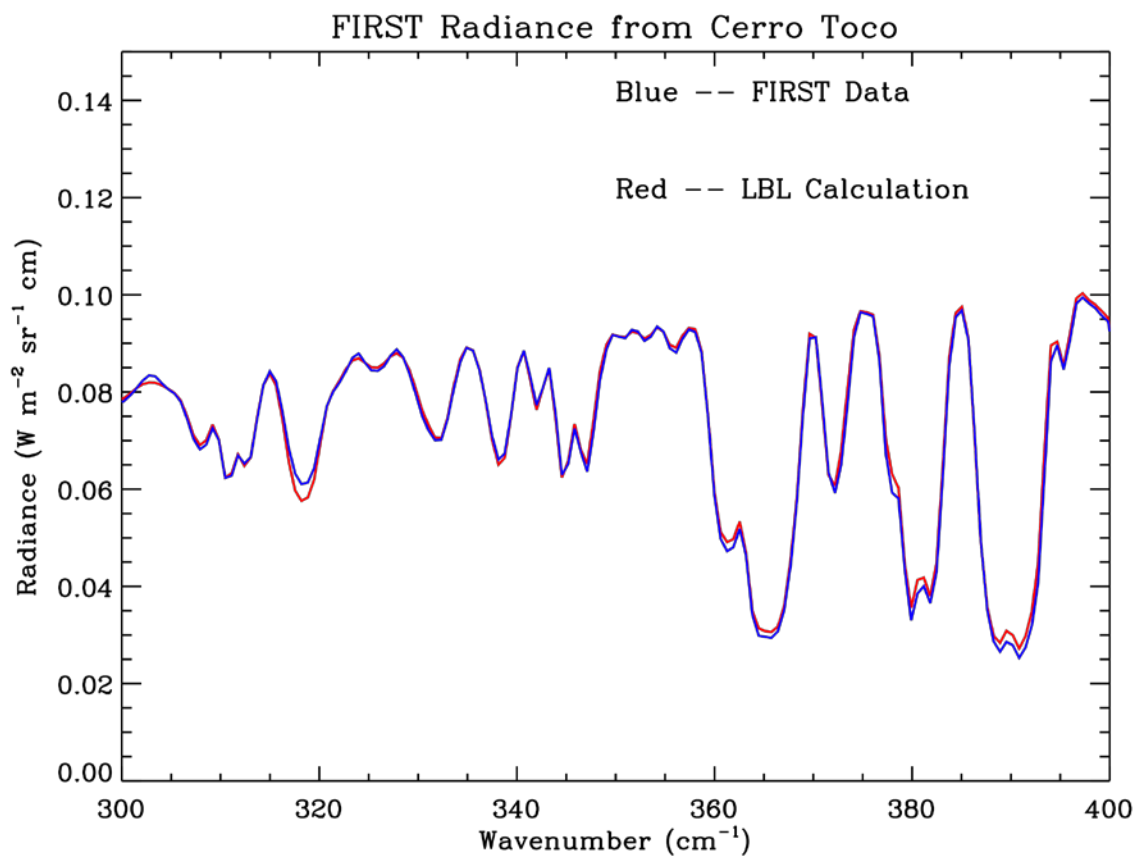
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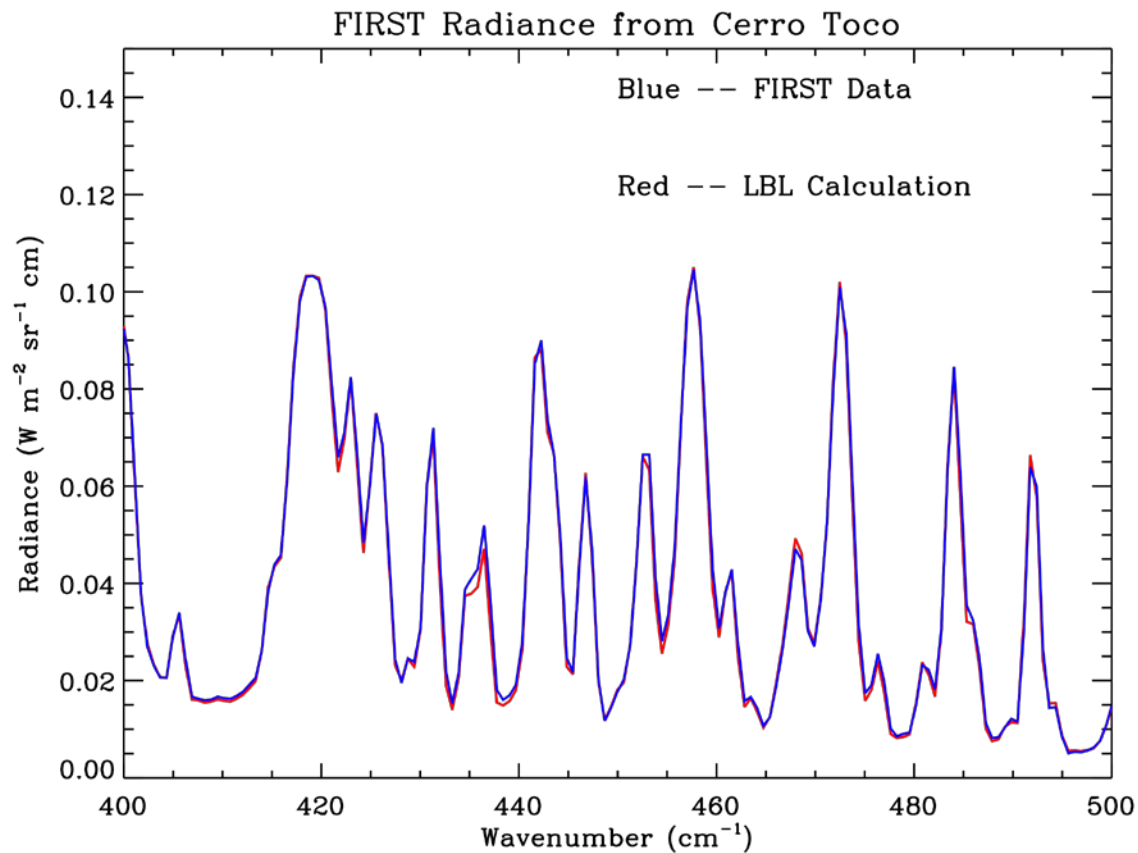
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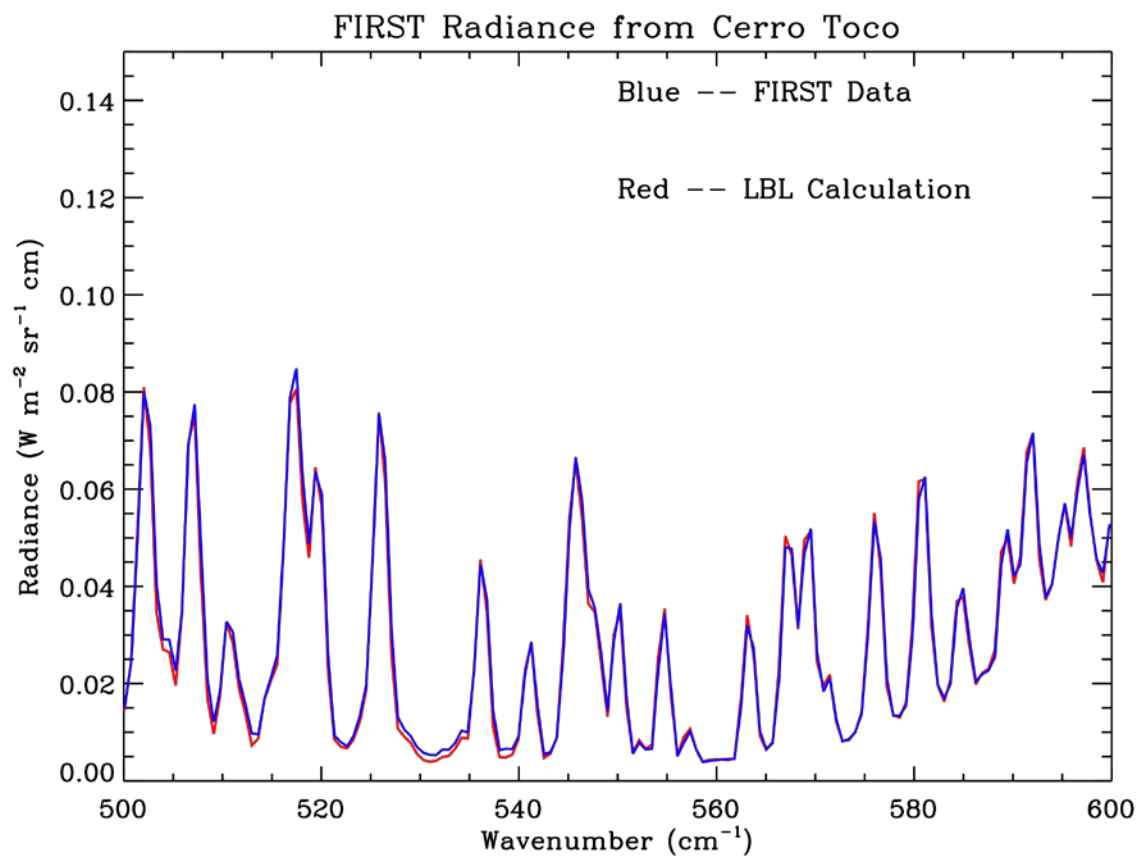
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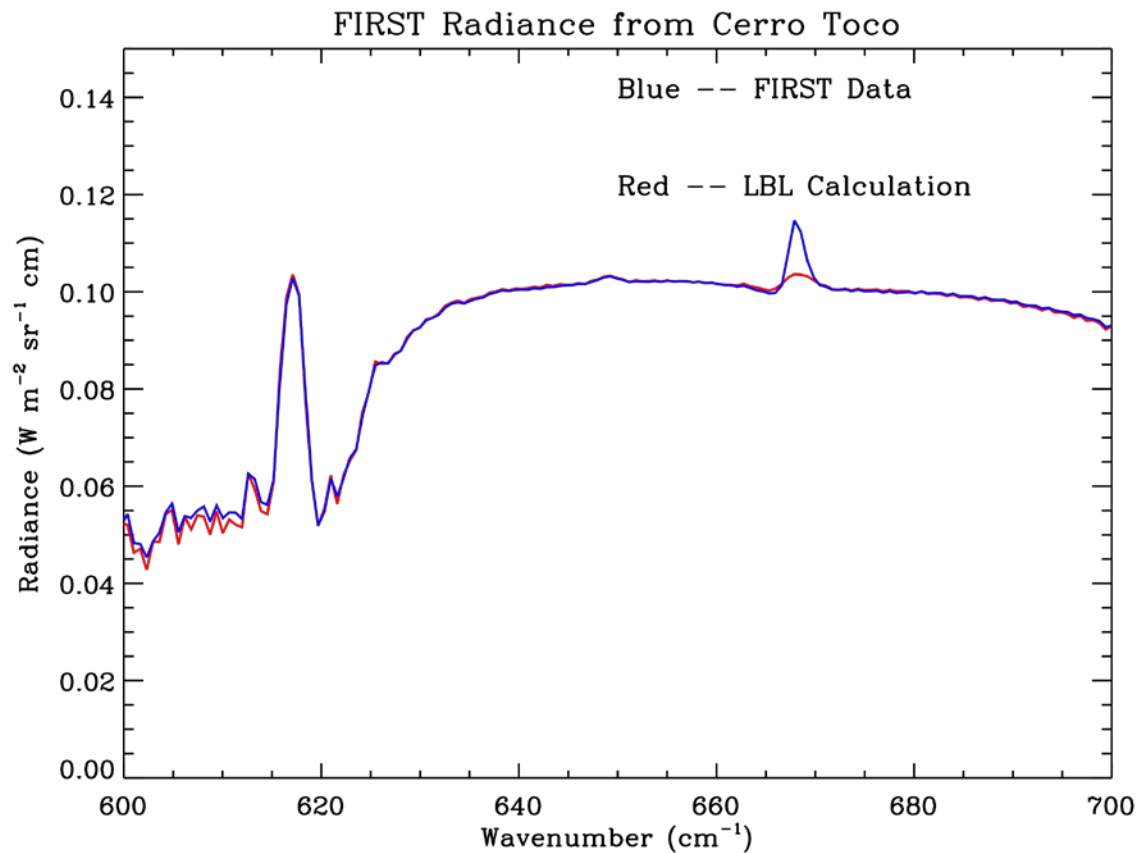
# FIRST Data and Theory

## September 5 2009 – PWV = 0.75 mm



# FIRST Data and Theory

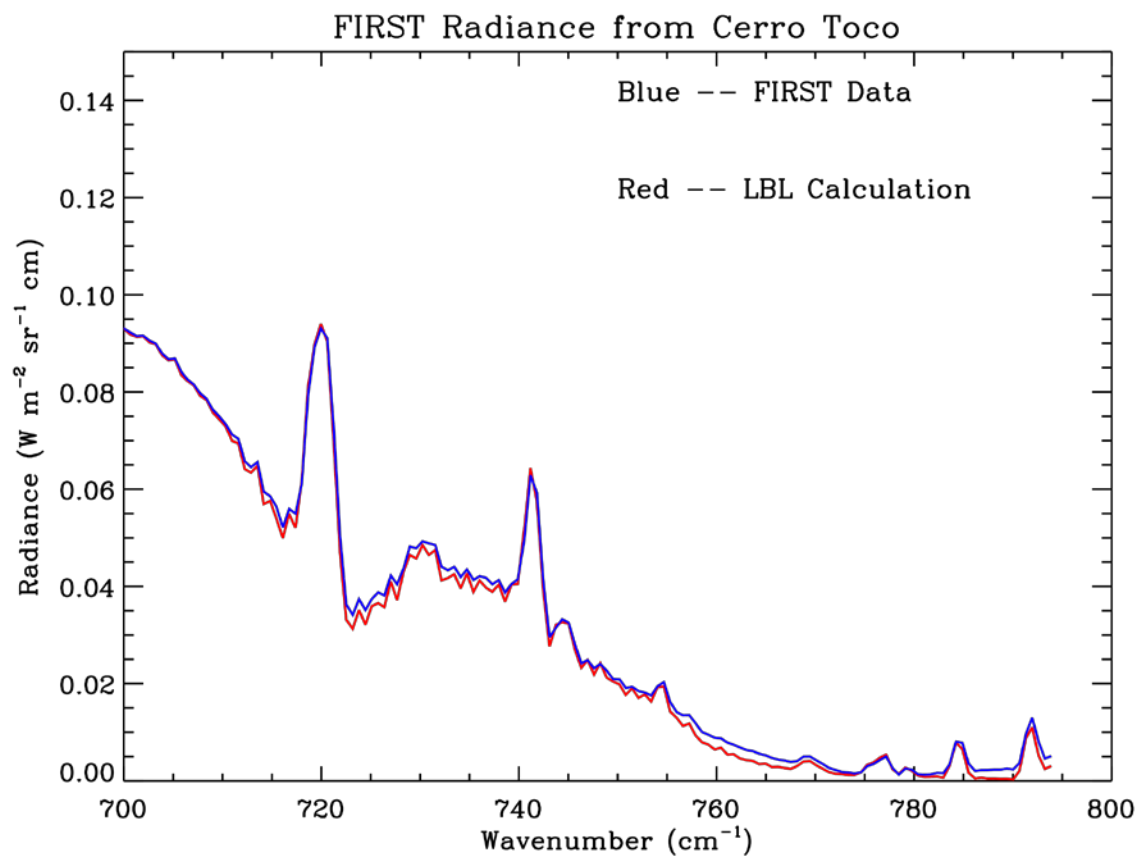
September 5 2009 – PWV = 0.75 mm





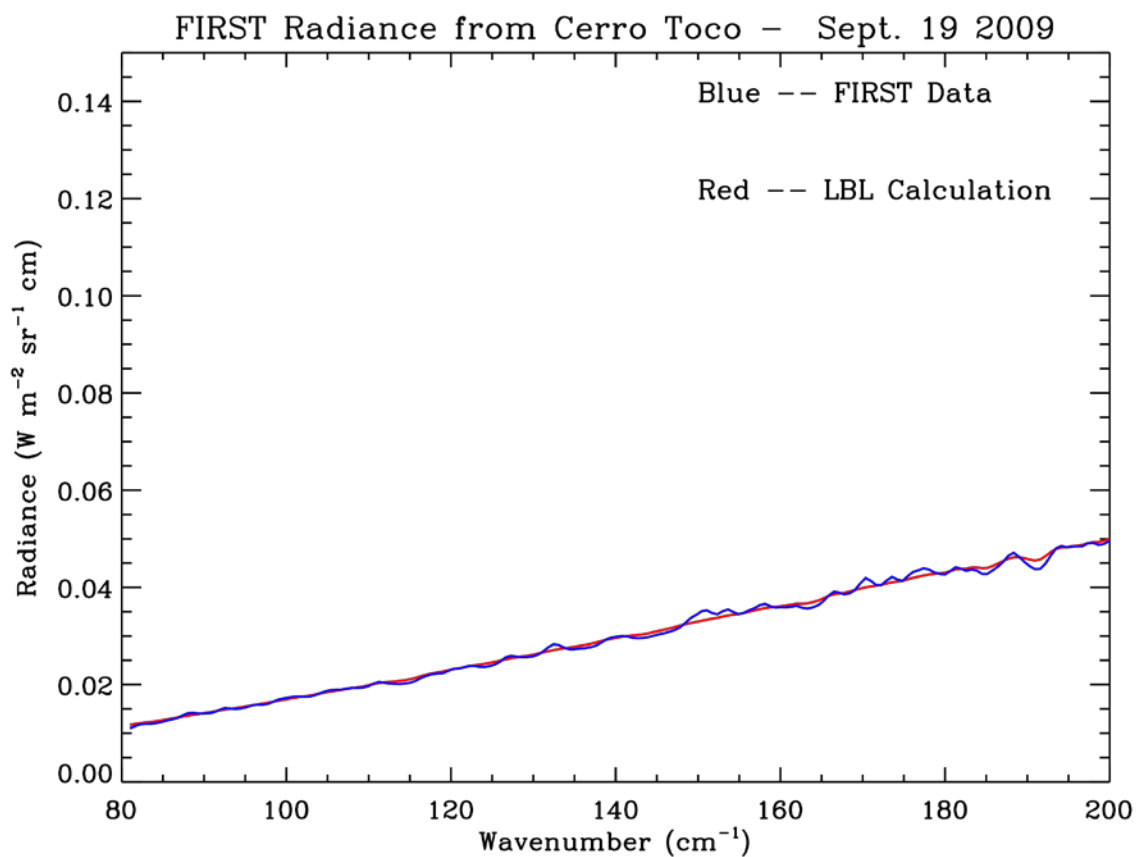
# FIRST Data and Theory

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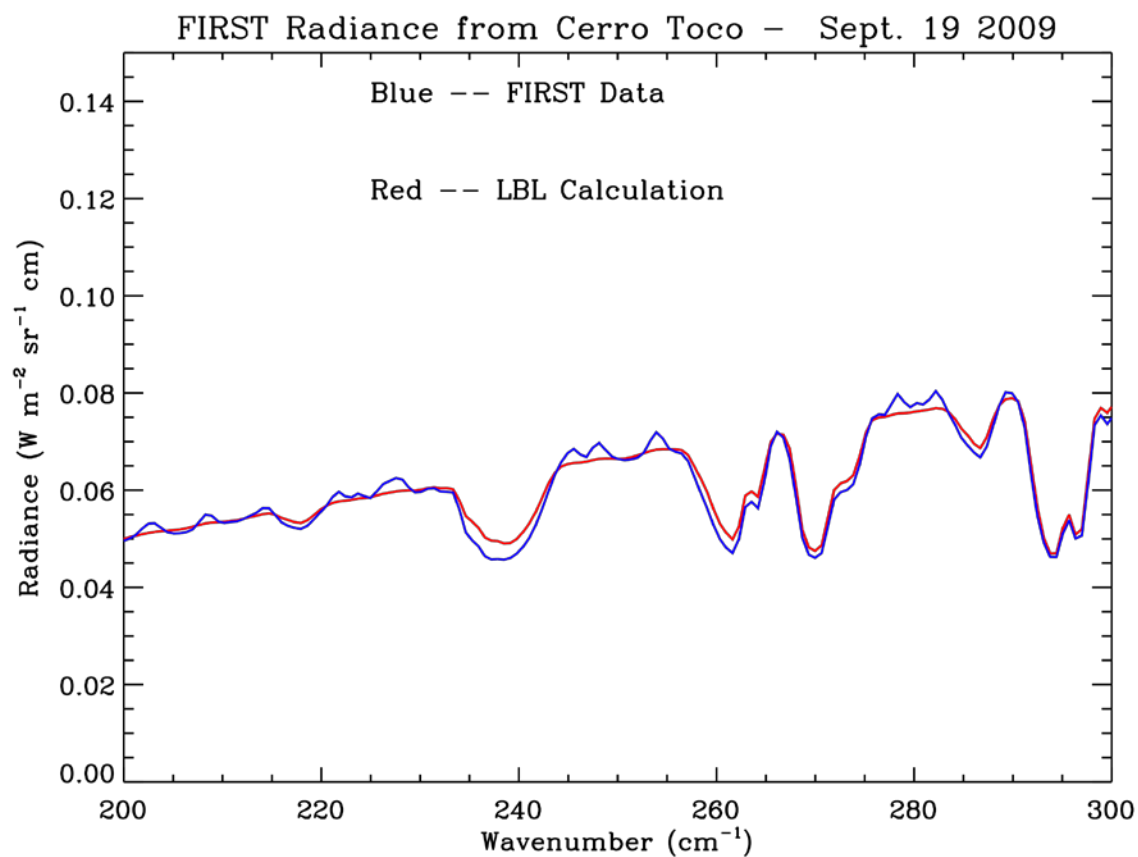
# FIRST Data and Theory

## September 19 2009 – PWV = 0.4 mm



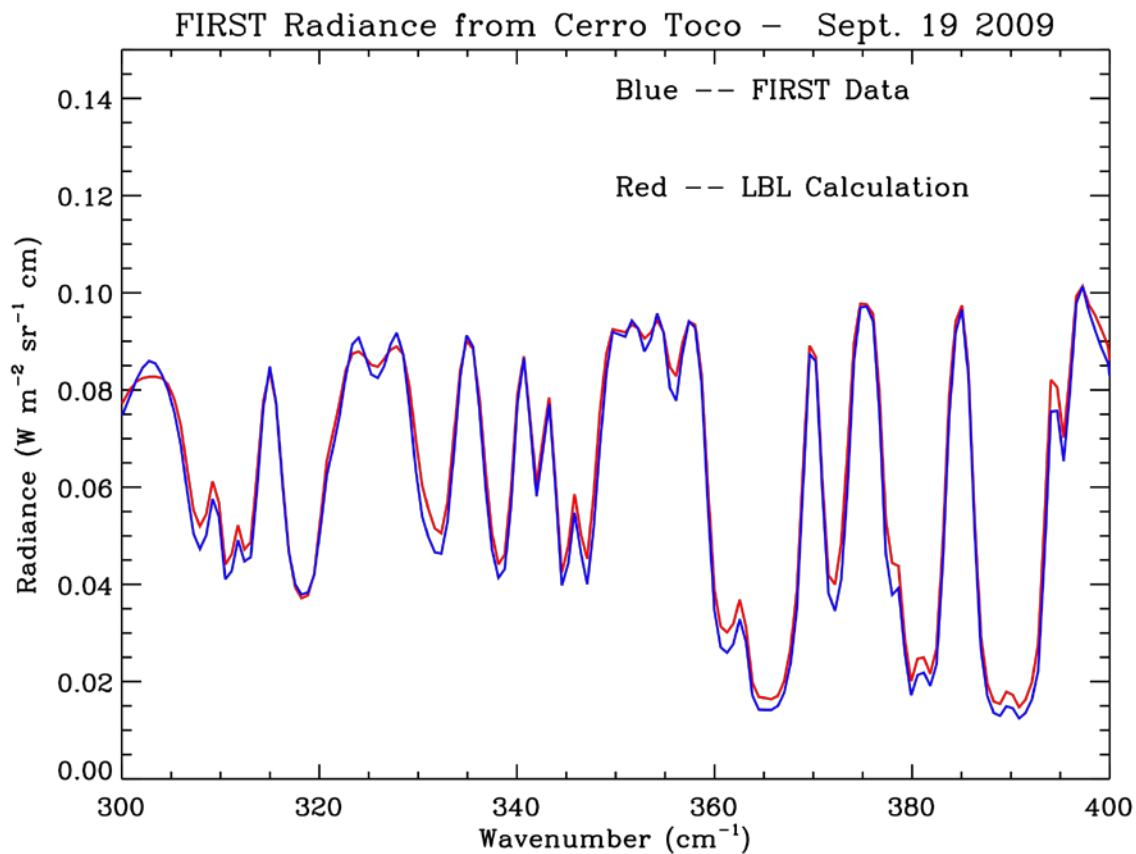
# FIRST Data and Theory

## September 19 2009 – PWV = 0.4 mm



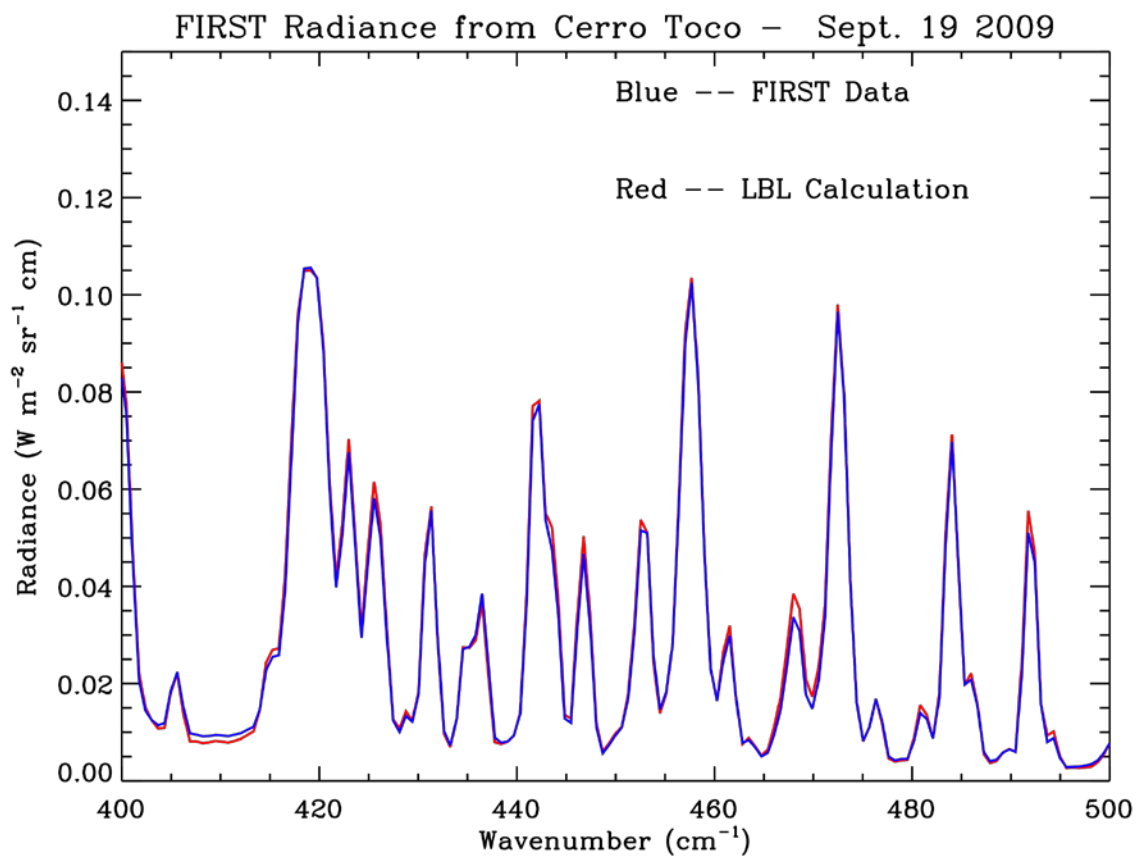
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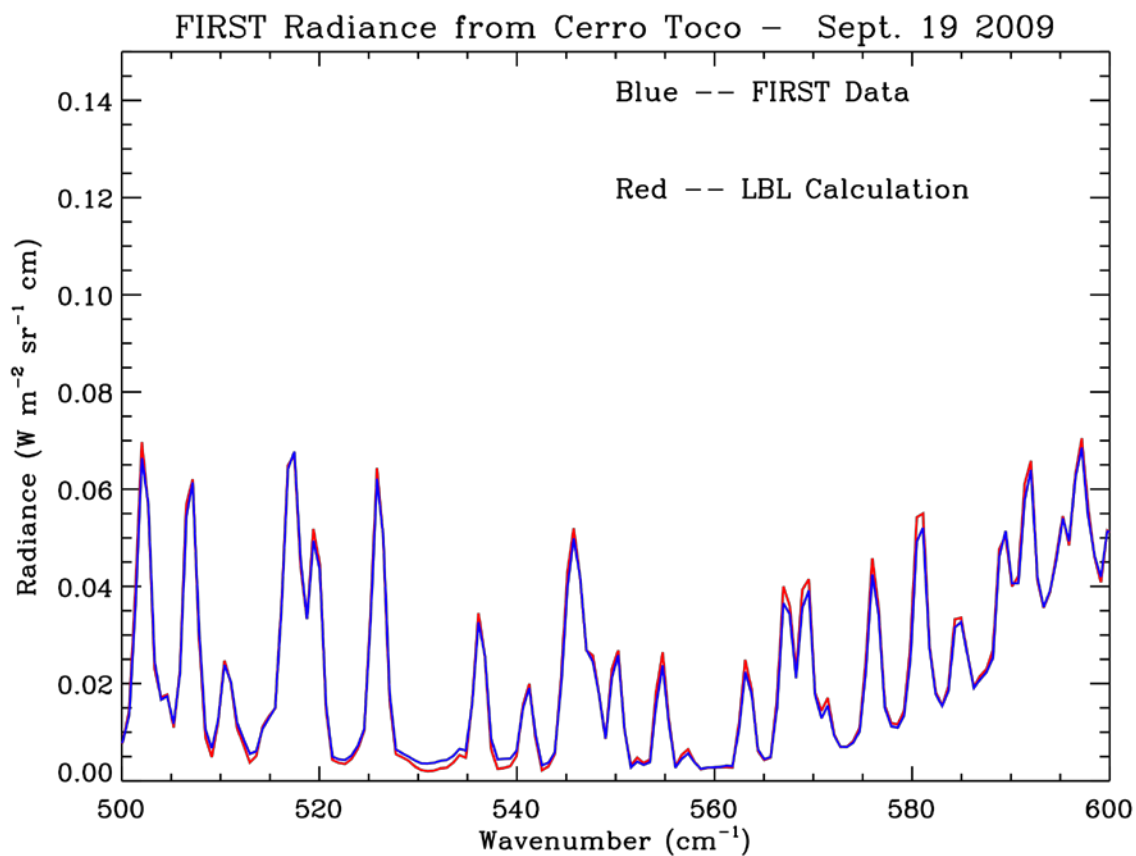
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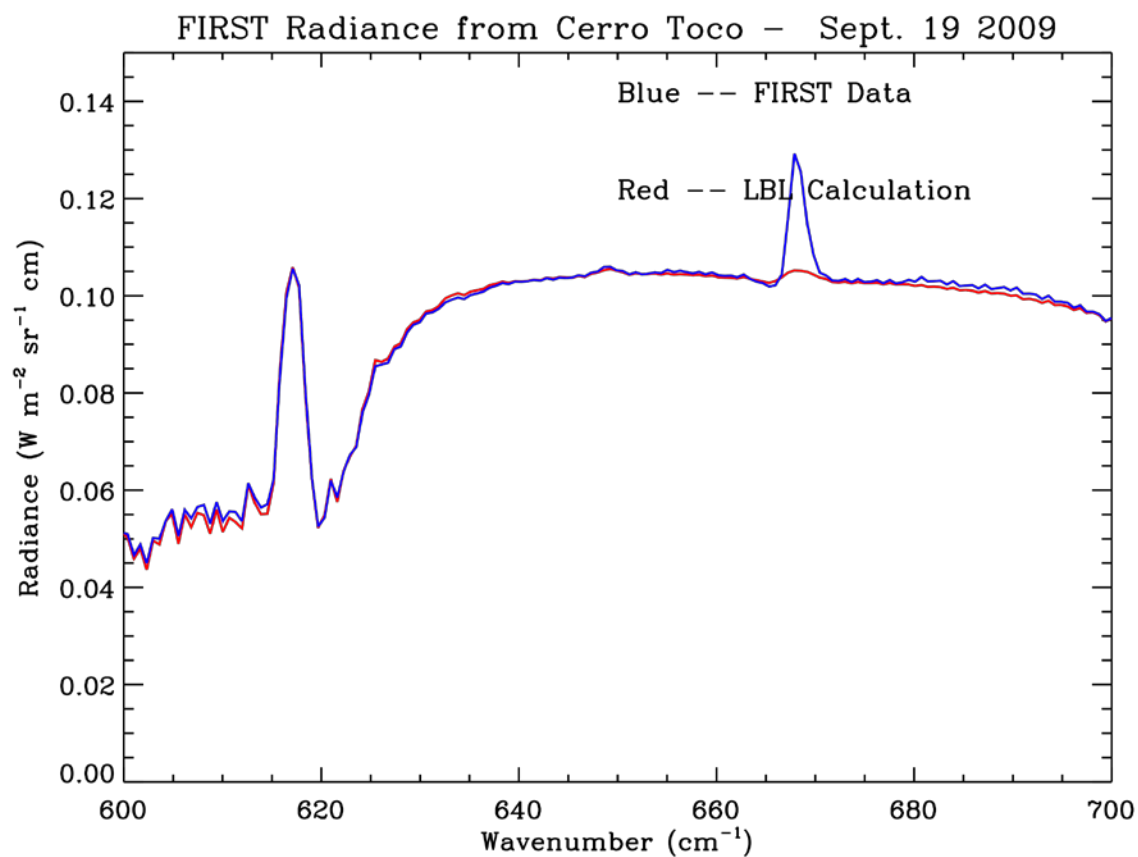
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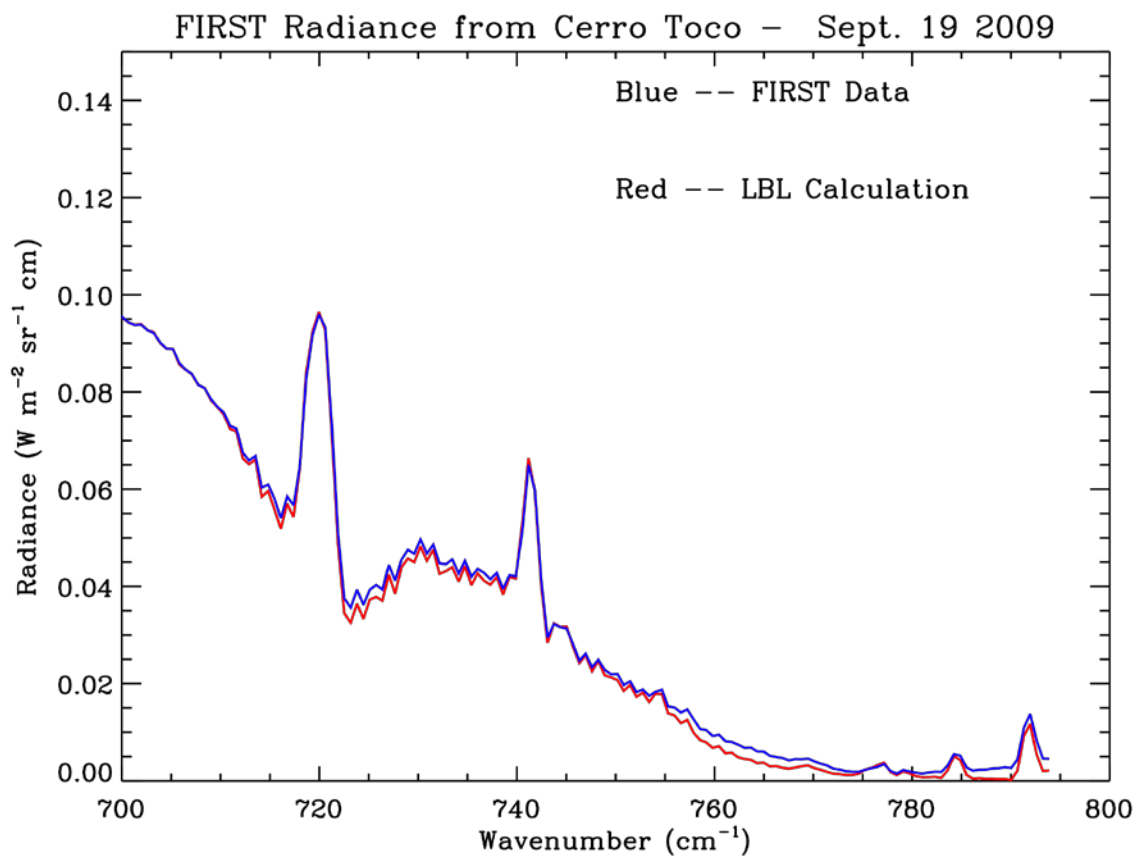
# FIRST Data and Theory

## September 19 2009 – PWV = 0.4 mm



# FIRST Data and Theory

## September 19 2009 – PWV = 0.4 mm





# FIRST - Summary

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- **FIRST instrument successfully developed and demonstrated**
    - Met or exceeded all technology development goals
    - Measures energetically significant spectrum 6 to 100  $\mu\text{m}$
  - **Calibration appears to be excellent**
  - **Substantial new science to be obtained from zenith views from RHUBC-II campaign**
  - **Initial dataset looks remarkable – excellent agreement across far-infrared spectrum over range of PWV**
    - Also have cirrus days
  - **Agreement with other measurements (e.g., REFIR) also looks excellent**
  - **Anticipate meeting all RHUBC-II science objectives**
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