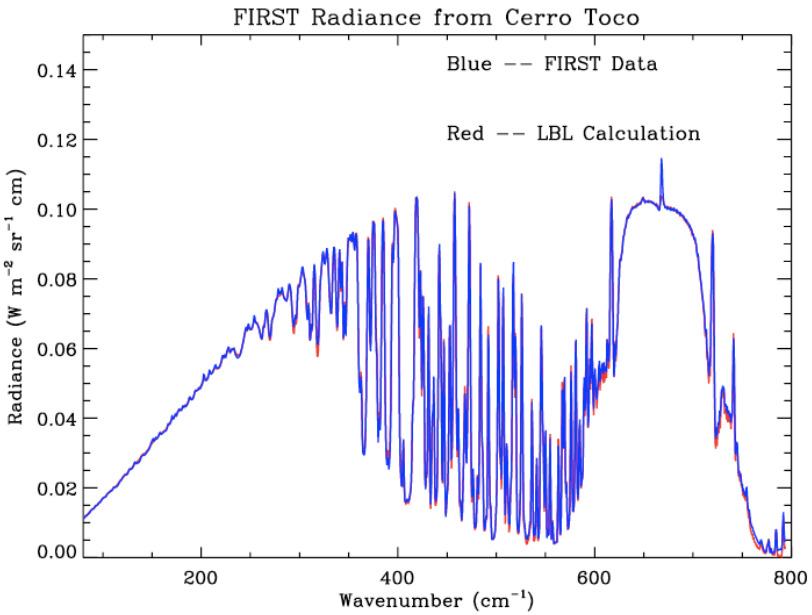
- FORGE -

Far-Infrared Observations of the Radiative Greenhouse Effect



Dr. Marty Mlynczak
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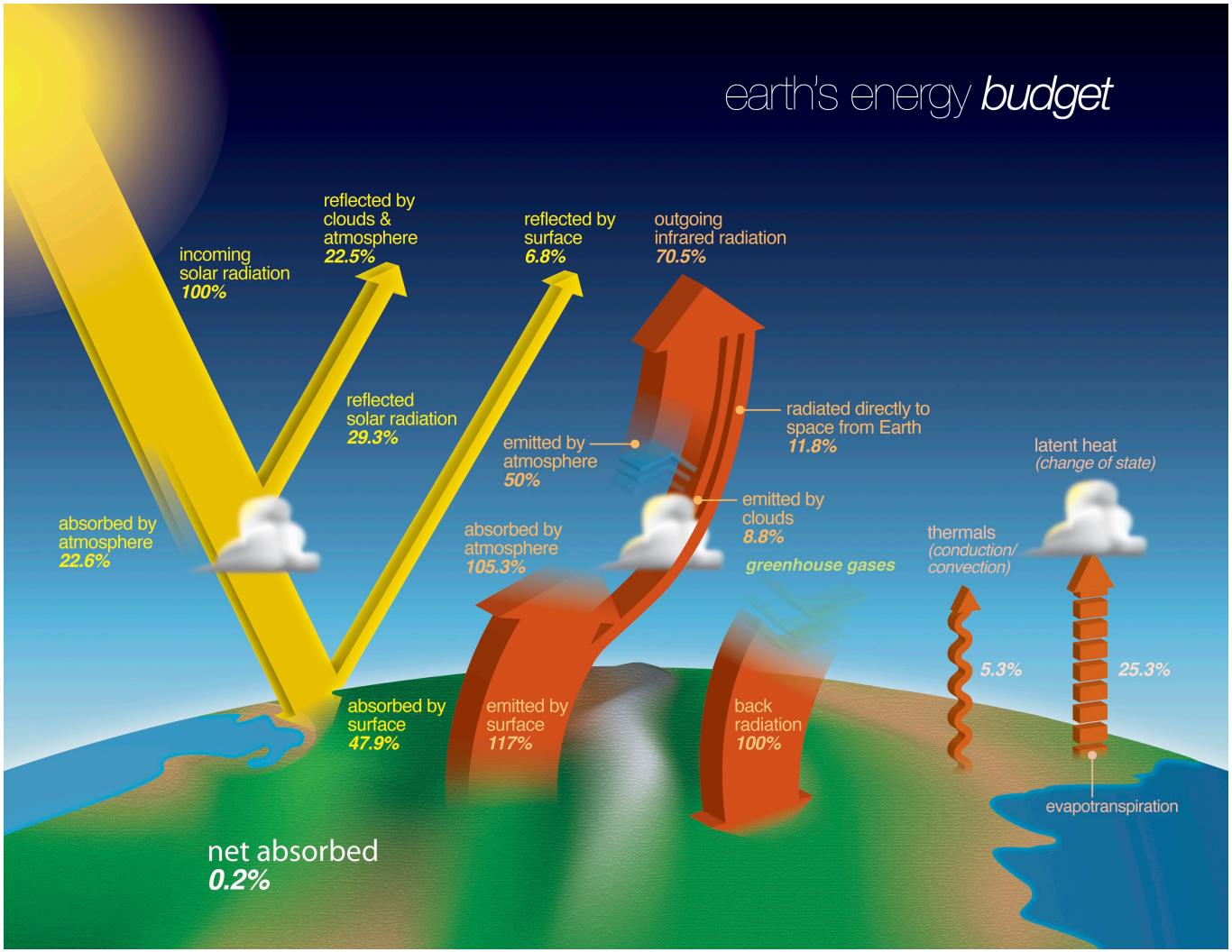
NASA Langley Research Center

April 29 2010

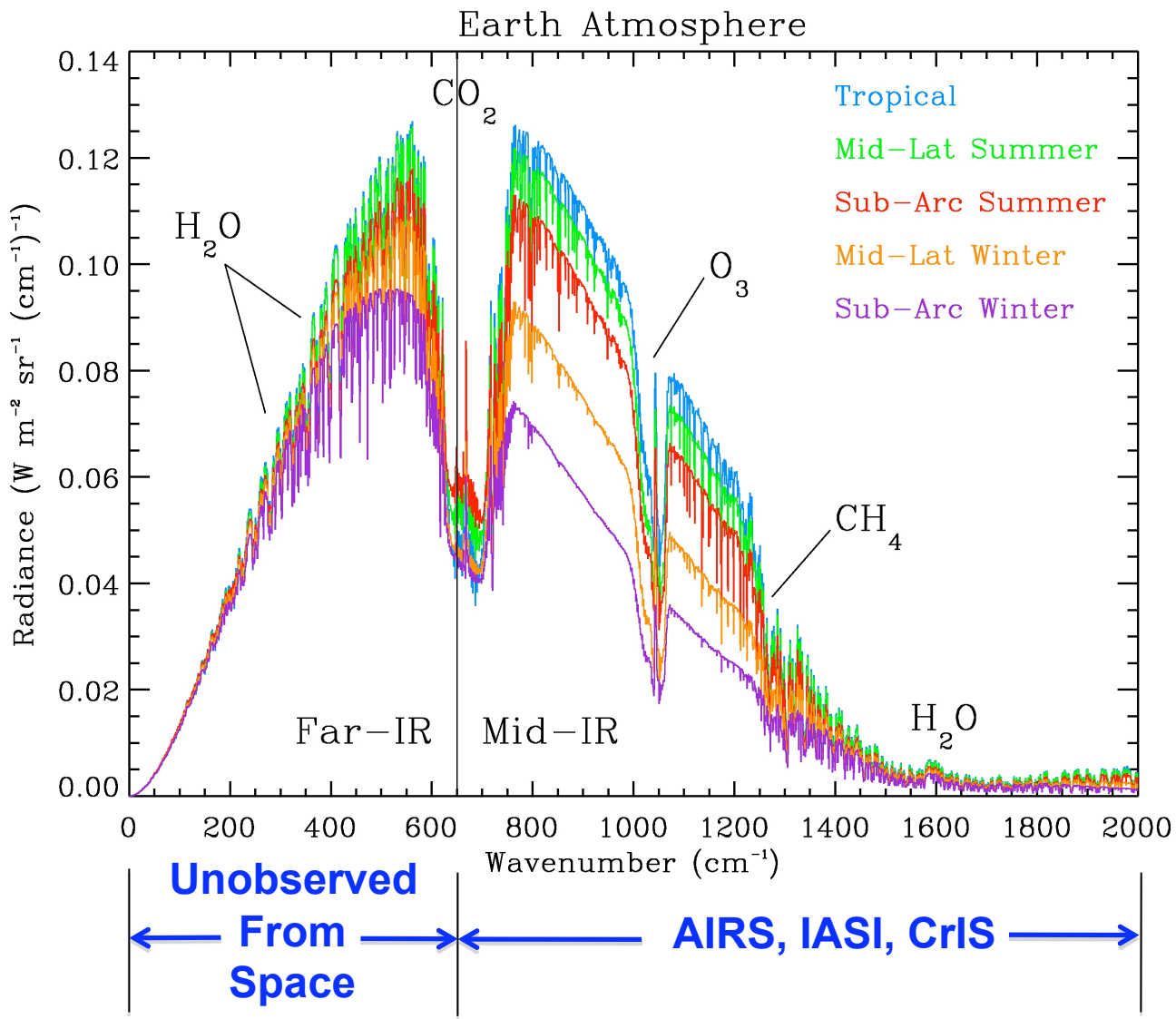
Outline

- Review of Earth's Energy Budget and Infrared Greenhouse Effect
- Development of the NASA FIRST Instrument
- Description of the FORGE campaign to Chile's Atacama Desert
- FIRST results from the FORGE Campaign
- Relation to CLARREO mission

Earth's Energy Budget



Earth's Outgoing Longwave Radiation

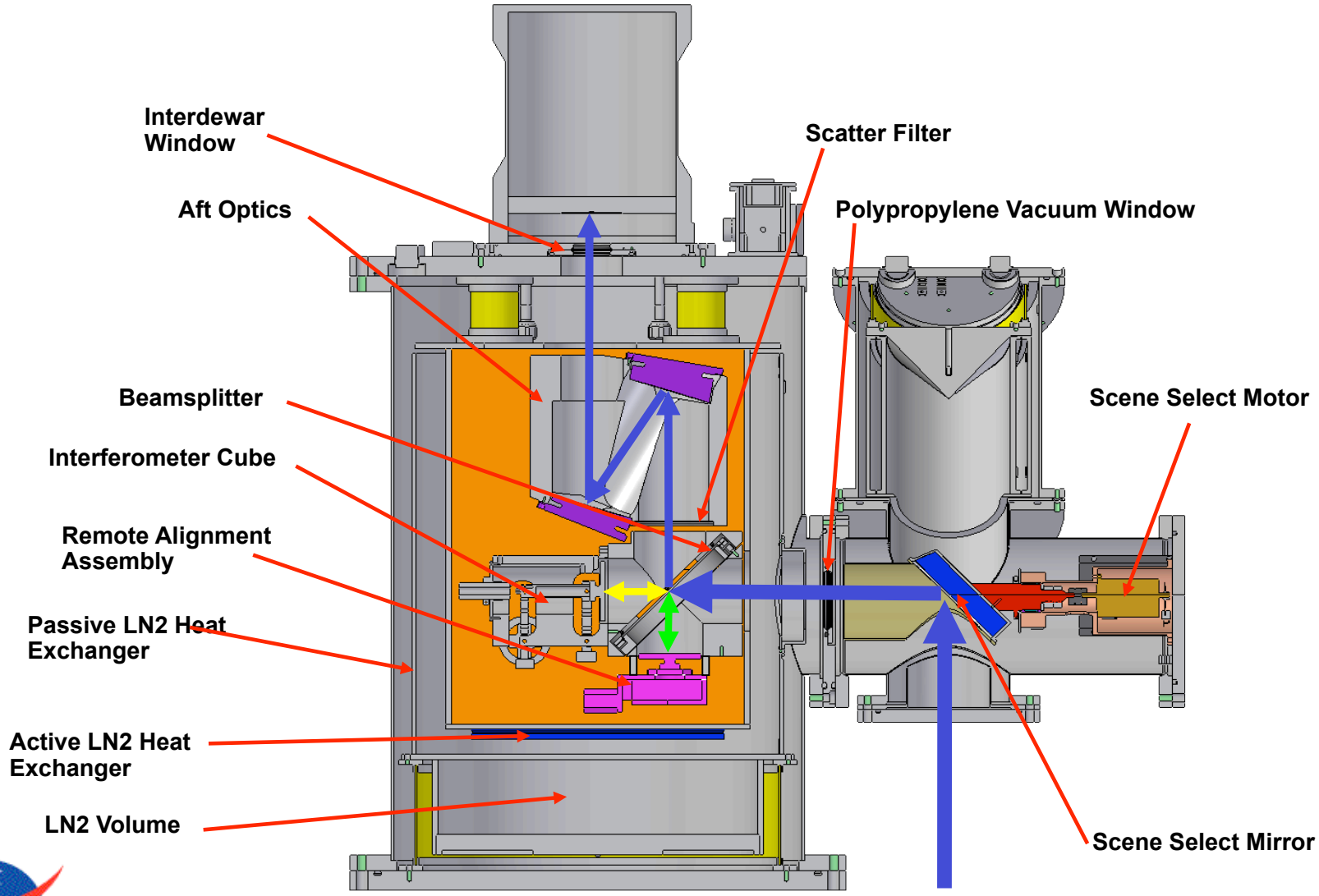


FIRST Instrument

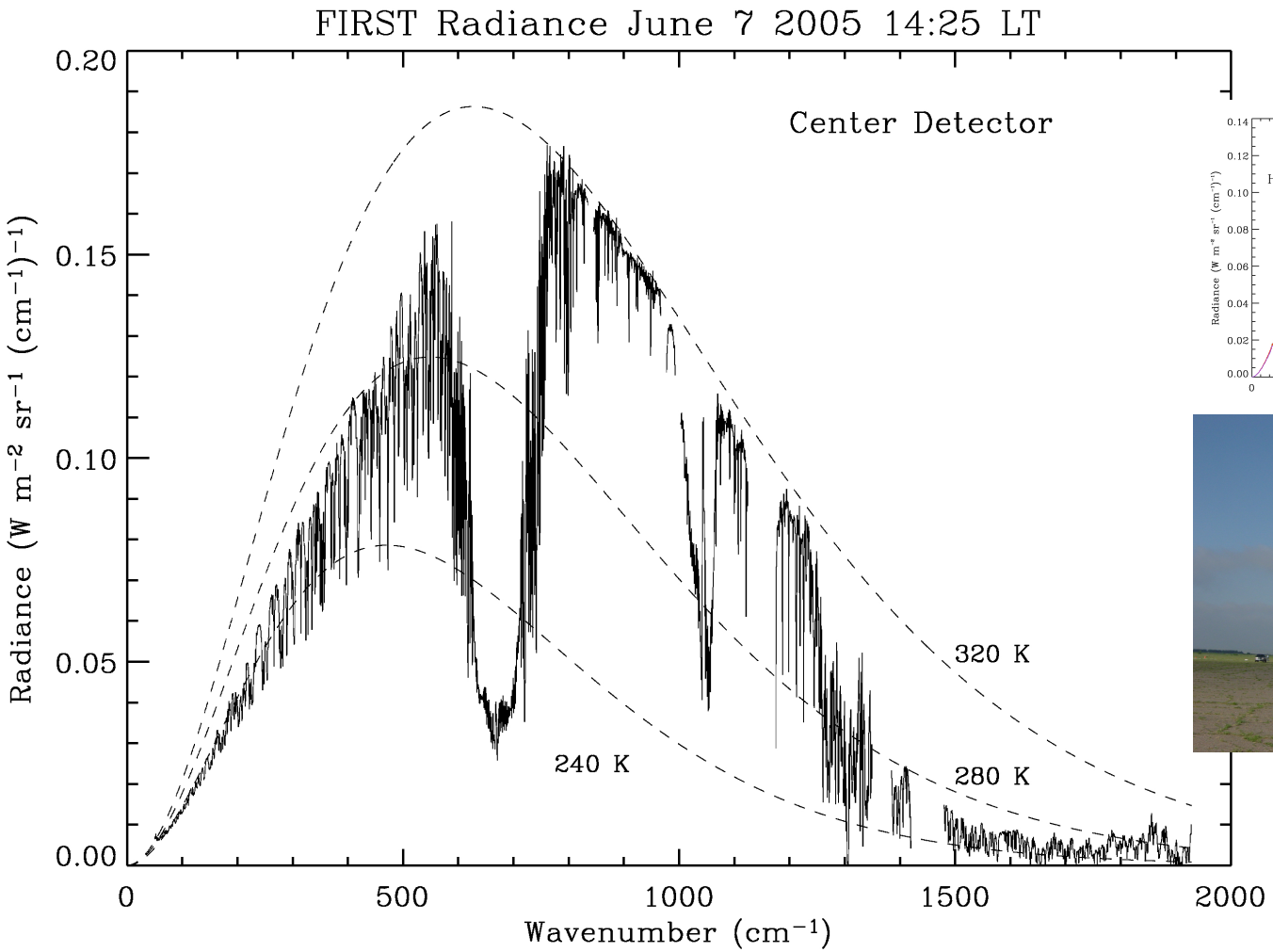
FIRST - Far-Infrared Spectroscopy of the Troposphere

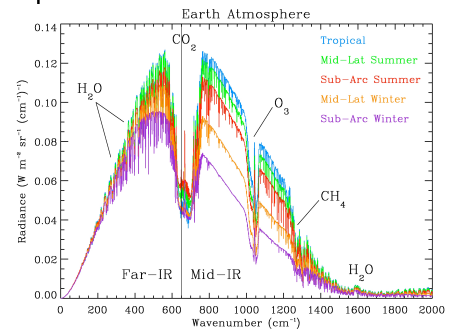
- Developed under NASA Instrument Incubator Program of ESTO
- Michelson Interferometer
  - *6 to 100 μm on a single focal plane*
  - *0.625 cm^{-1} unapodized (0.8 cm OPD)*
  - *Germanium on polypropylene beamsplitter*
  - *Bolometer detectors @ 4 K*
- Demonstrated on a high-altitude balloon flight June 7 2005
- Second balloon flight September 18 2006
- Ground-based capability demonstrated March 2007
- Selected by NASA for FORGE Campaign in Chile in 2008
- FORGE Campaign August – October 2009

FIRST Spectrometer Overview



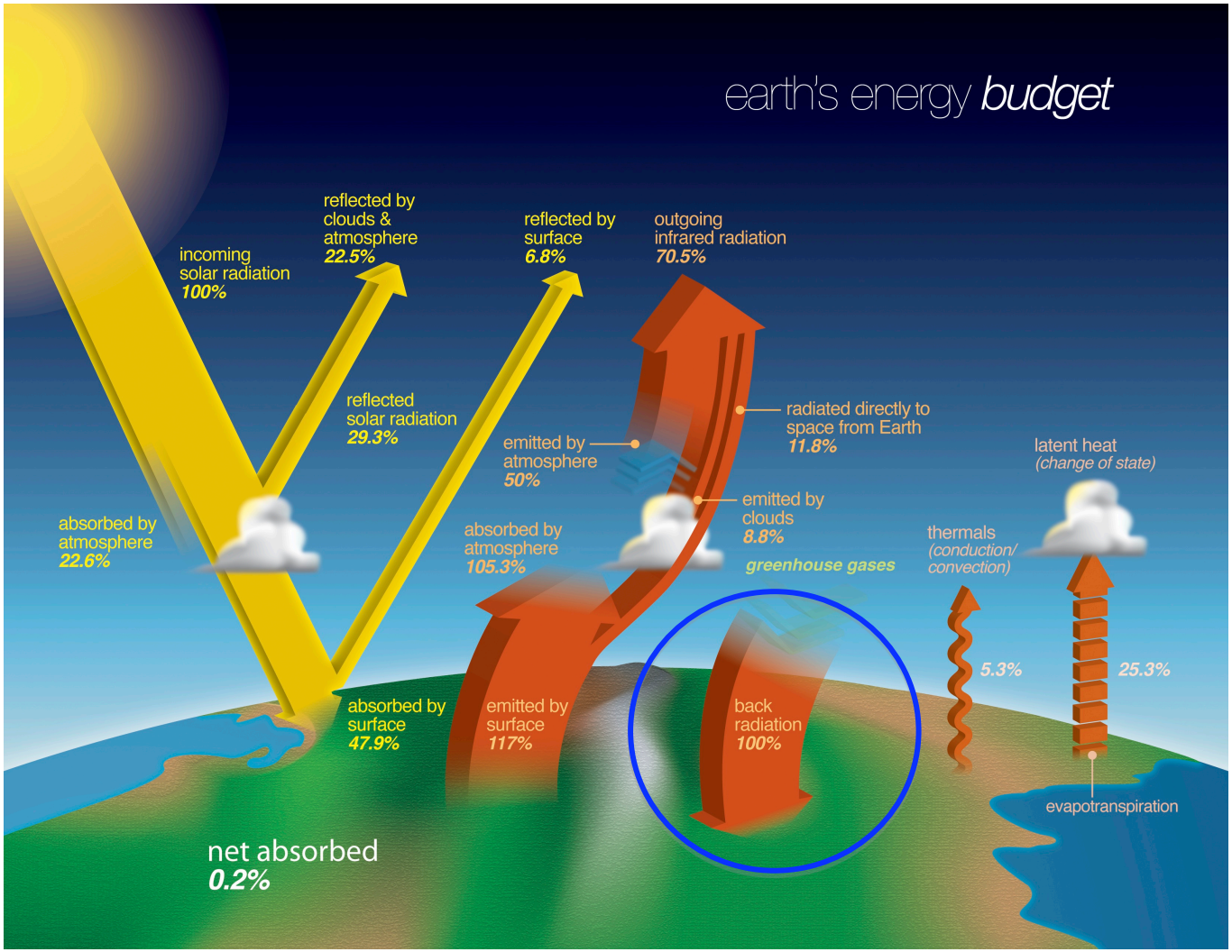
FIRST Thermal Infrared Spectrum - TOA





Mlynczak et al., GRL, 2006

Earth's Energy Budget



The FORGE Project – Scientific Objective

- **Use new observational capability provided by FIRST to directly observe and quantify entire infrared greenhouse effect**

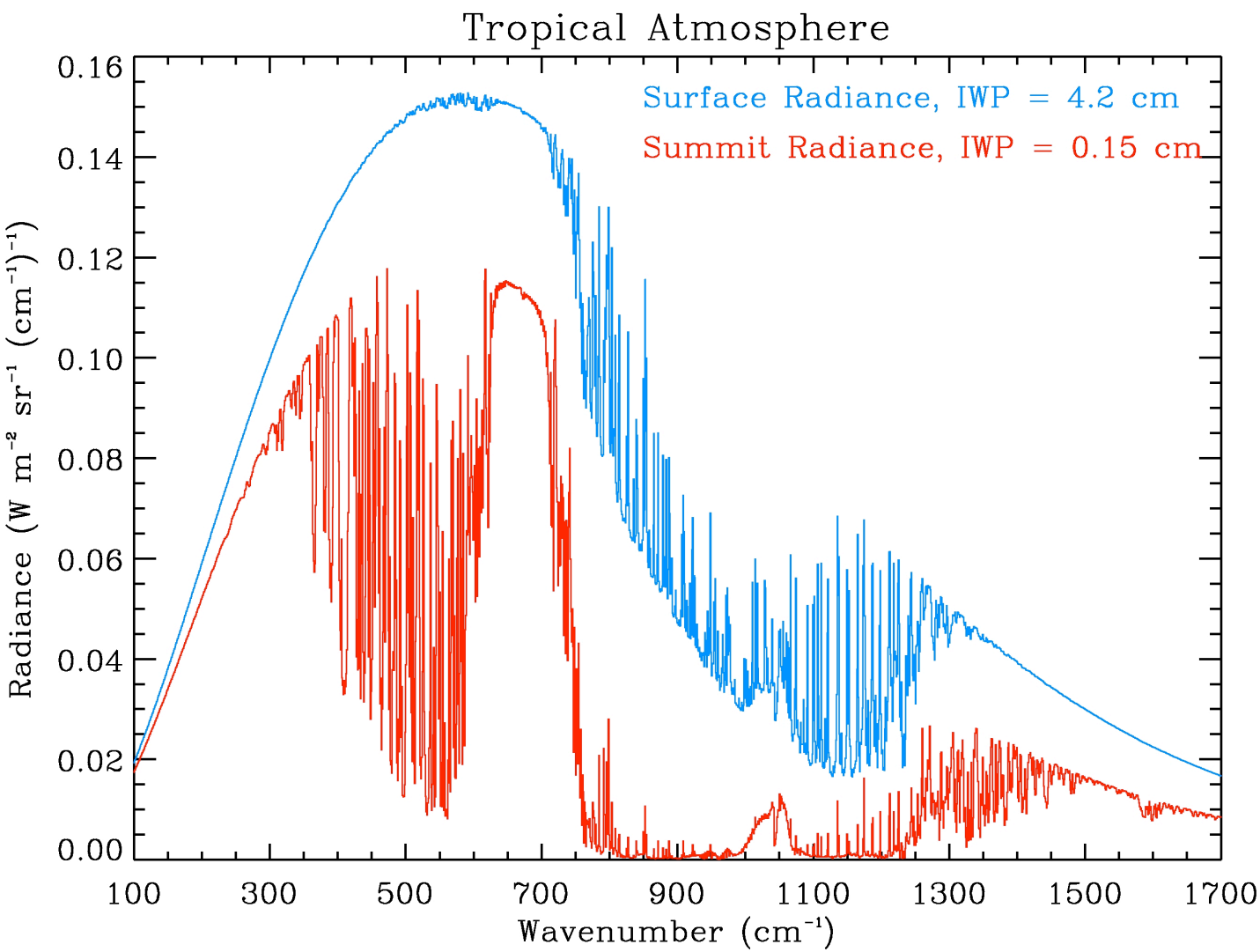
- **Conduct "radiative closure" experiment**
  - **Measure infrared radiation emitted by the atmosphere – *at Earth's surface looking up***
  - **Simultaneously measure temperature and water vapor profiles to provide inputs for theory**
  - **Comparison provides fundamental test of knowledge of greenhouse effect**

- **Conduct experiment at high, dry location – Cerro Toco, Atacama Desert, Chile**
  - **Enables observations of fully-developed infrared spectrum at all significant wavelengths**
  - **Altitude: 17, 600 feet above sea level. Mean pressure ~ 0.5 Atmosphere**
  - ***Precipitable Water Vapor < 1 millimeter***

- **Part of larger "RHUBC-II" Campaign run by Dept. of Energy**
  - **Teams from U. Wisconsin, AER Inc., Italy, Germany, PNNL, Los Alamos NL, U. Denver, NASA Langley**
  - **Four separate FTS instruments covering 10 to 1800 cm^{-1} (1000 μm to 5.5 μm)**

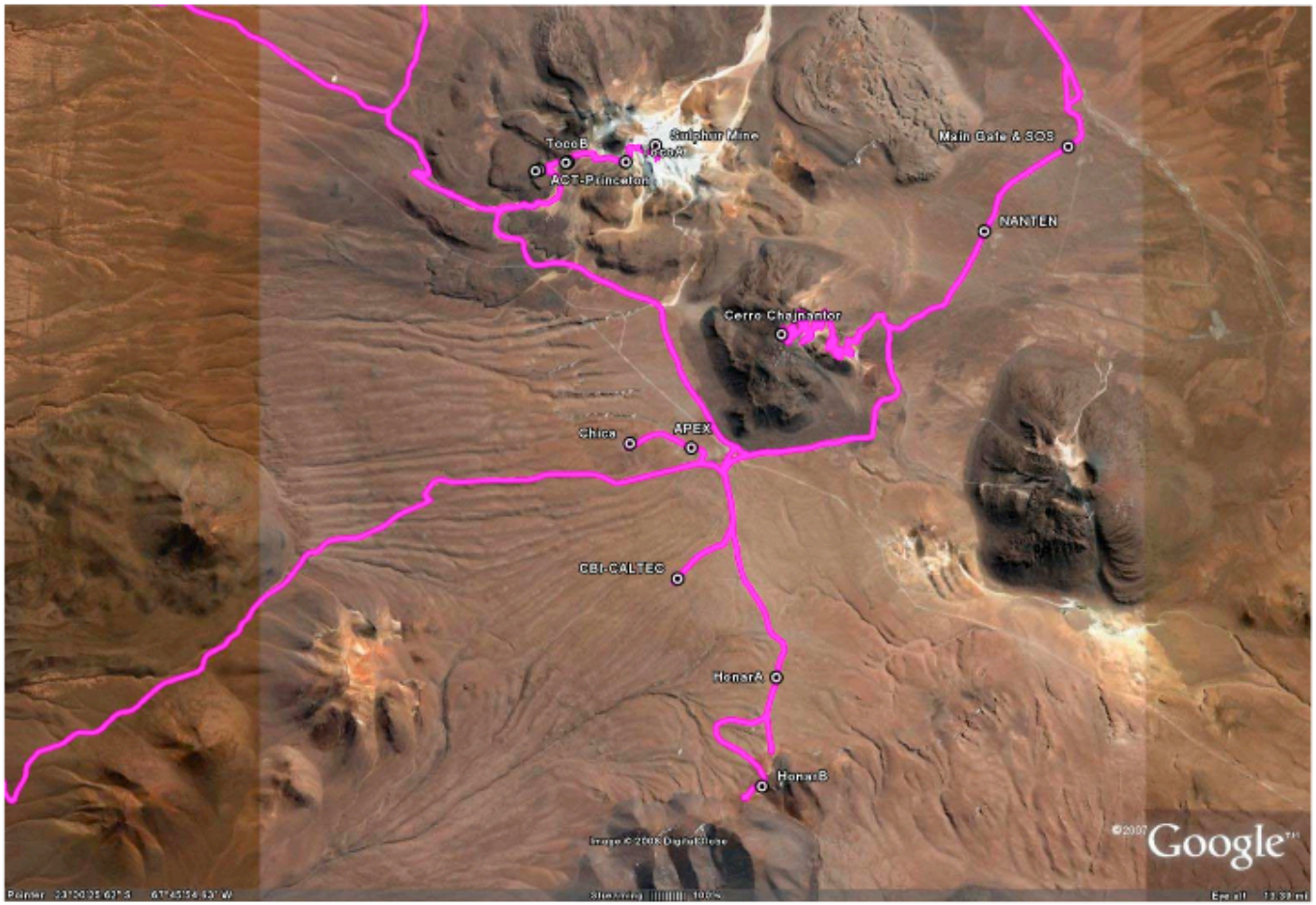
Safety of Team during deployment at altitude was paramount

Earth's Downwelling Infrared Radiation – at Surface

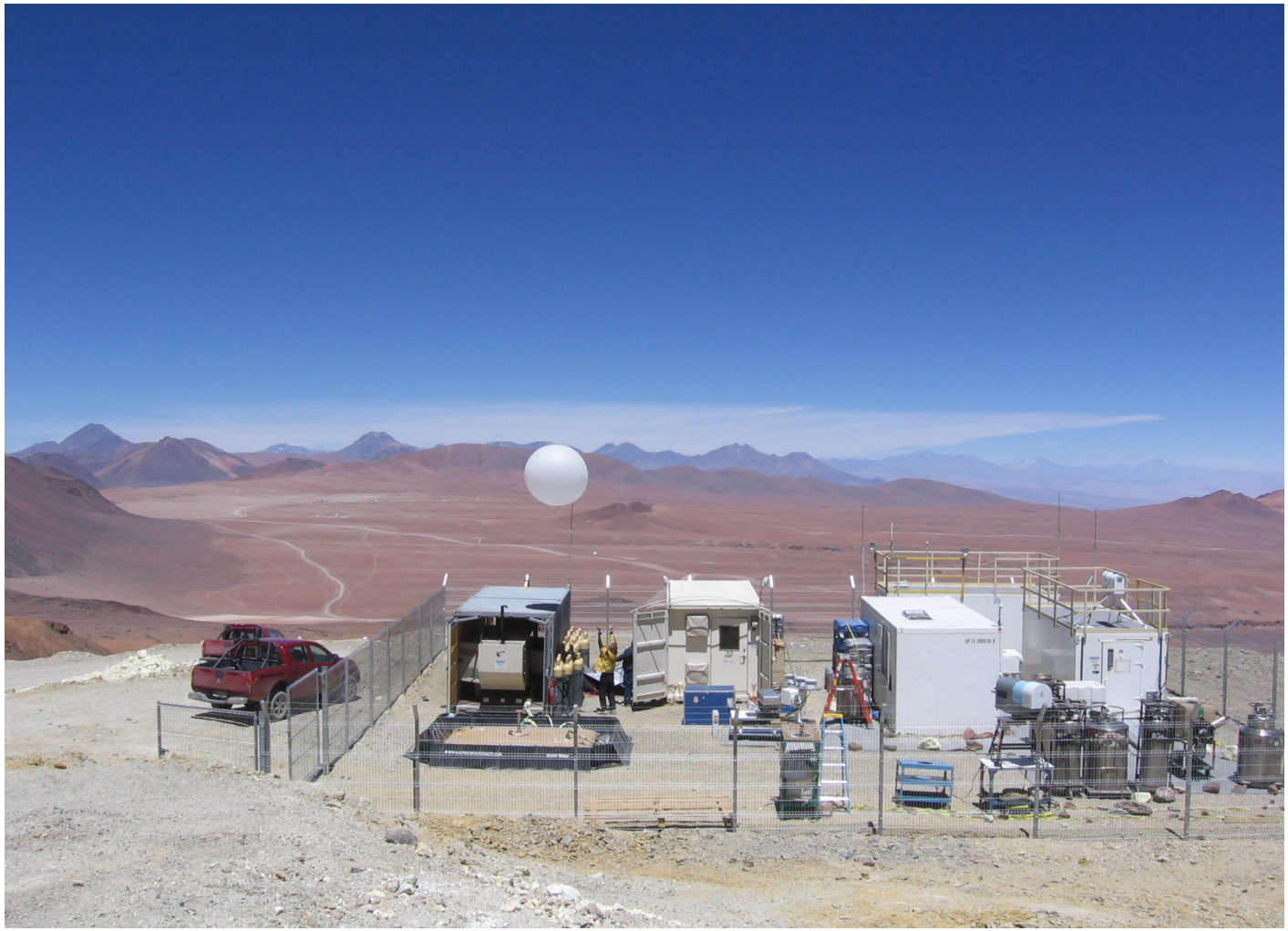


Where is Cerro Toco ?

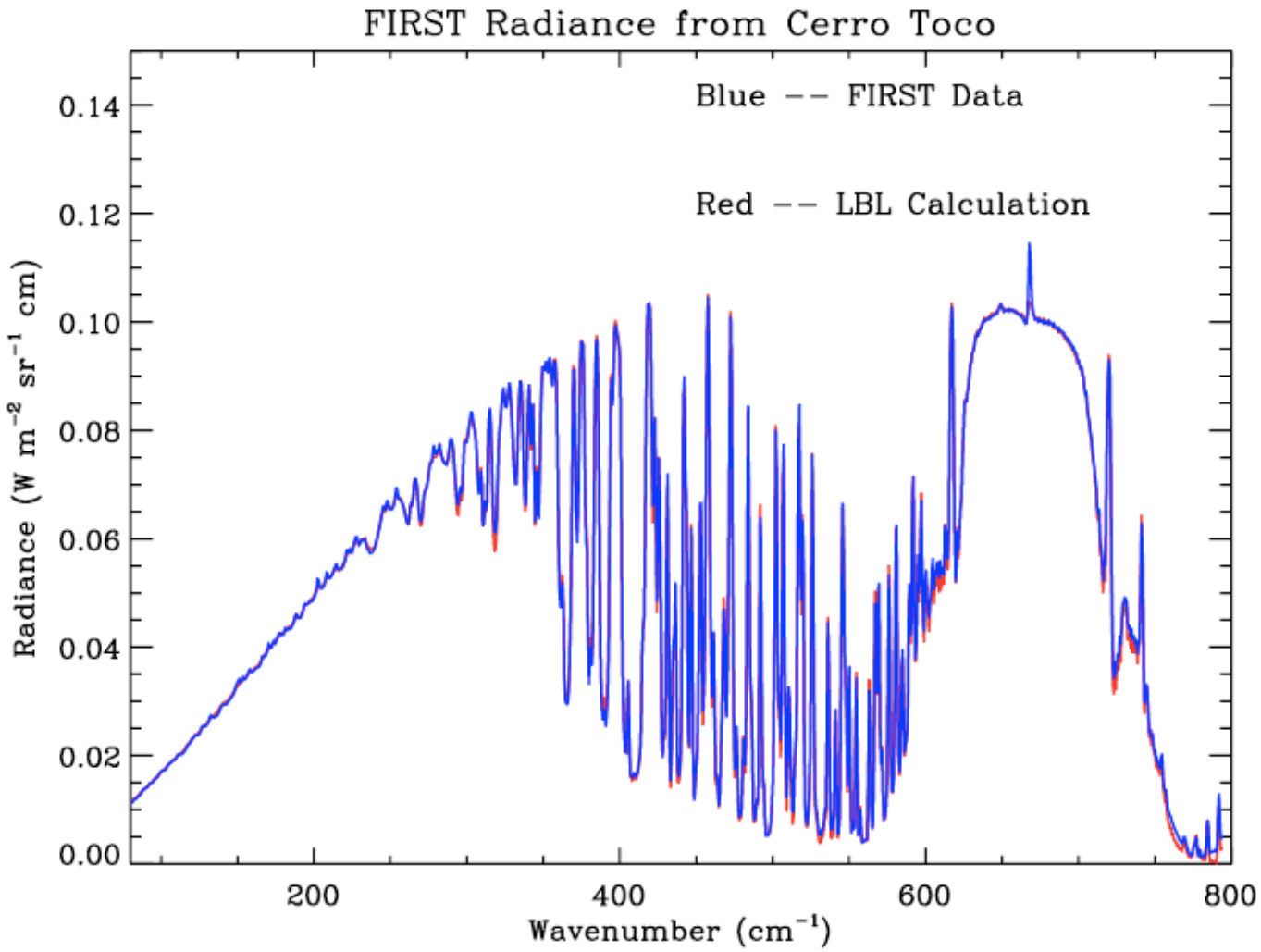
The Chajnantor Plateau, Chile



Operations at 17,600 Feet

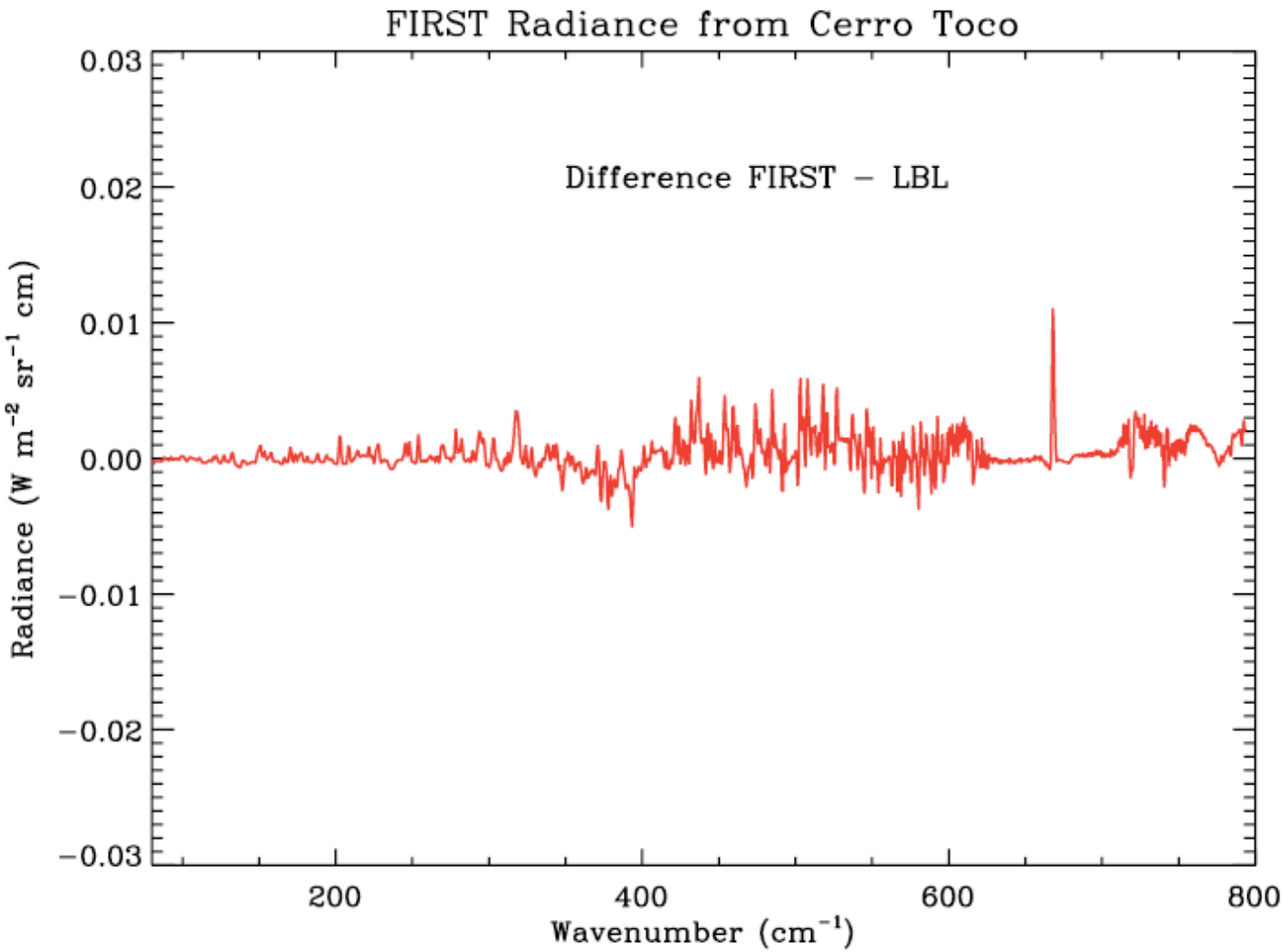


FIRST Far-IR Spectrum – 09/05/09

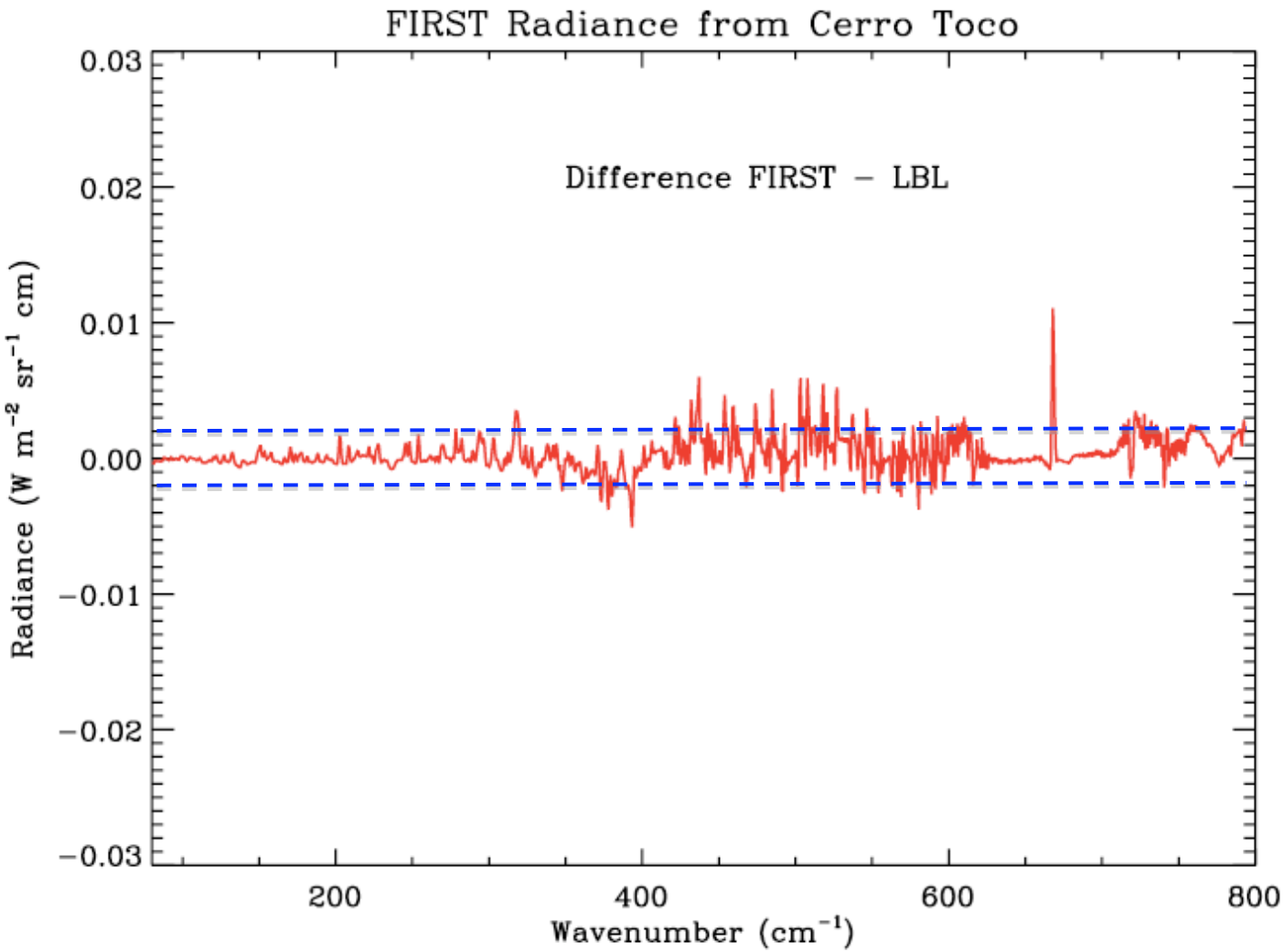


PWV = 0.75 millimeter ("wet" day)

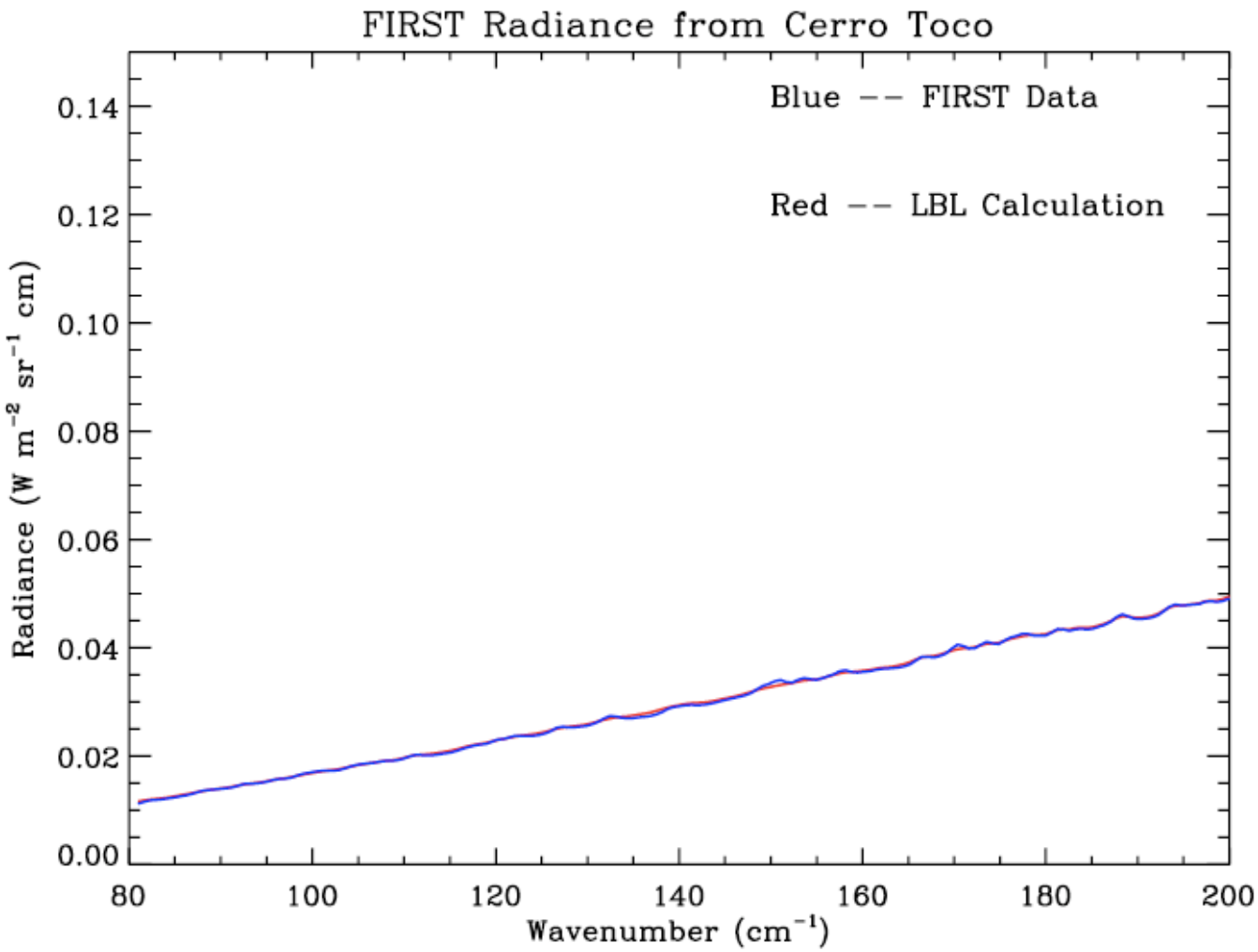
Radiance Difference – 09/05/2009



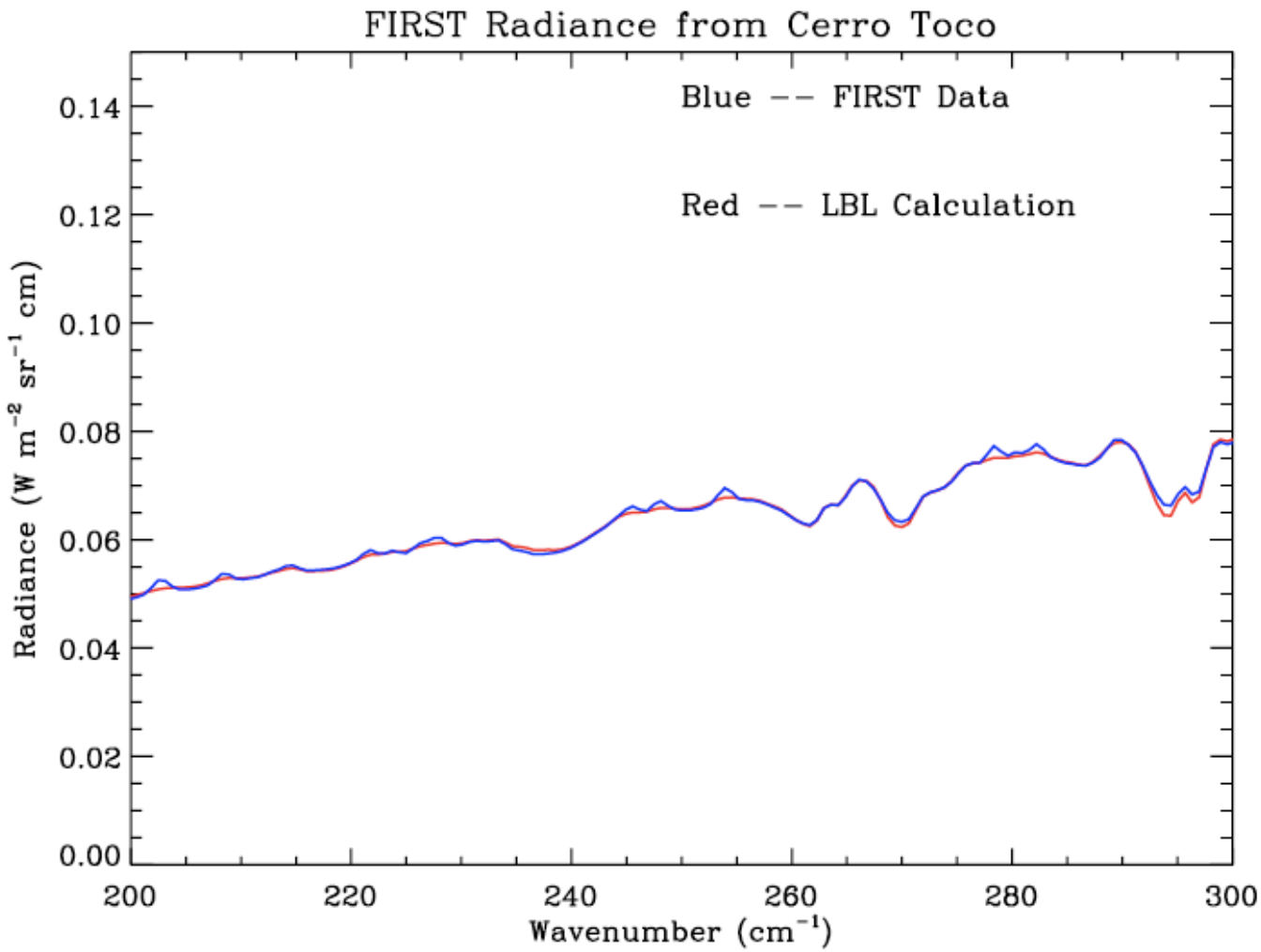
Radiance Difference – 09/05/2009



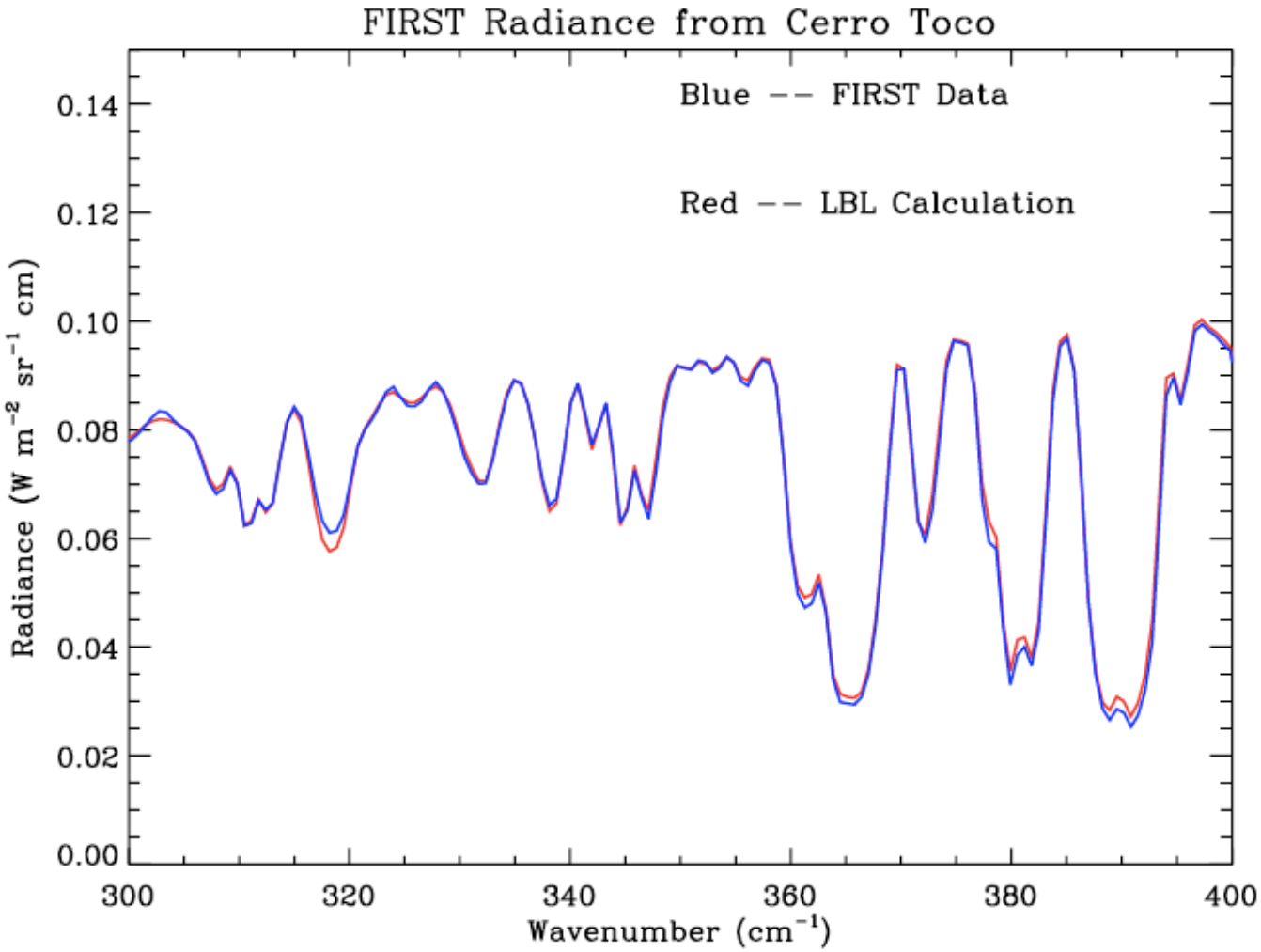
September 5 2009 – PWV = 0.75 mm



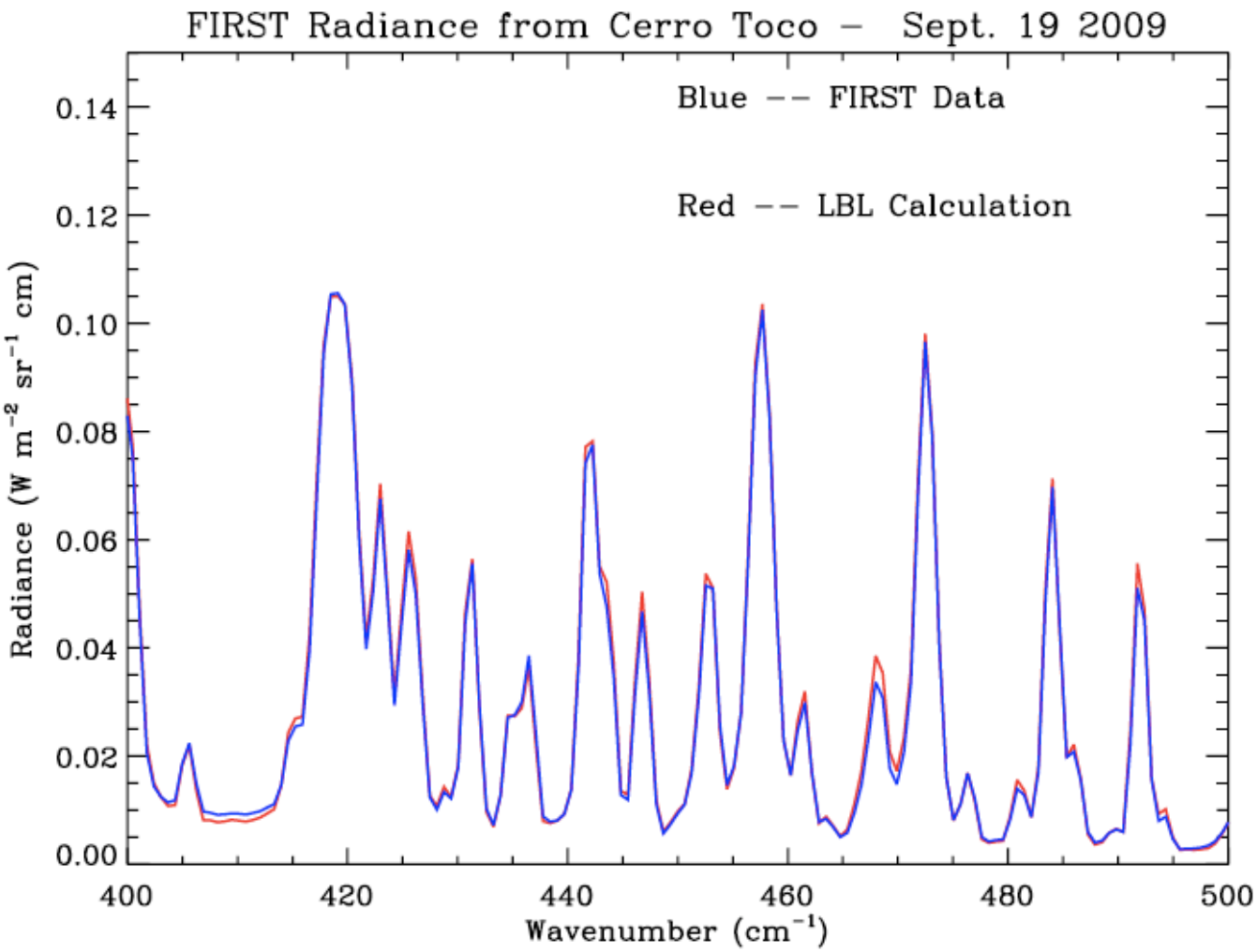
September 5 2009 – PWV = 0.75 mm



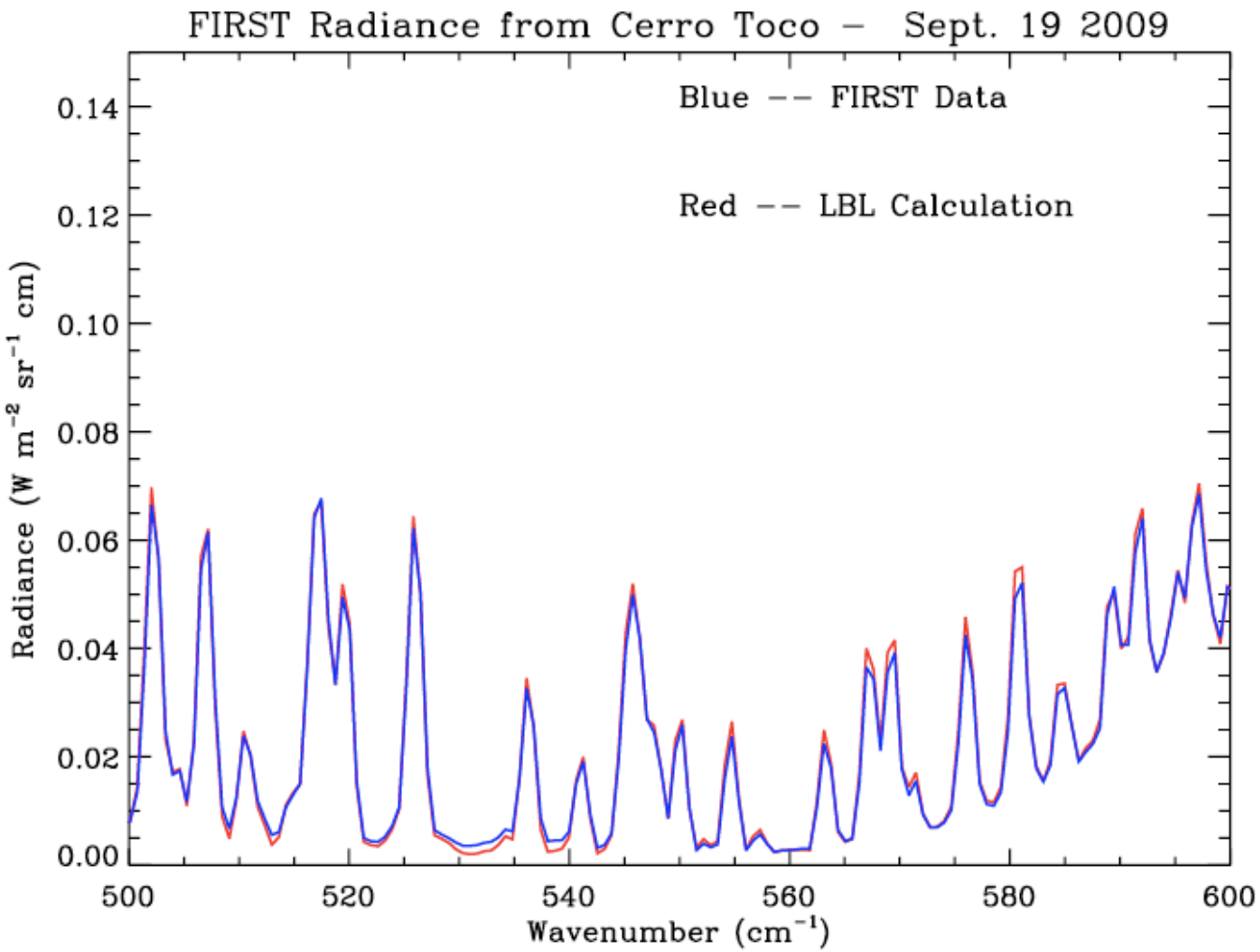
September 5 2009 – PWV = 0.75 mm



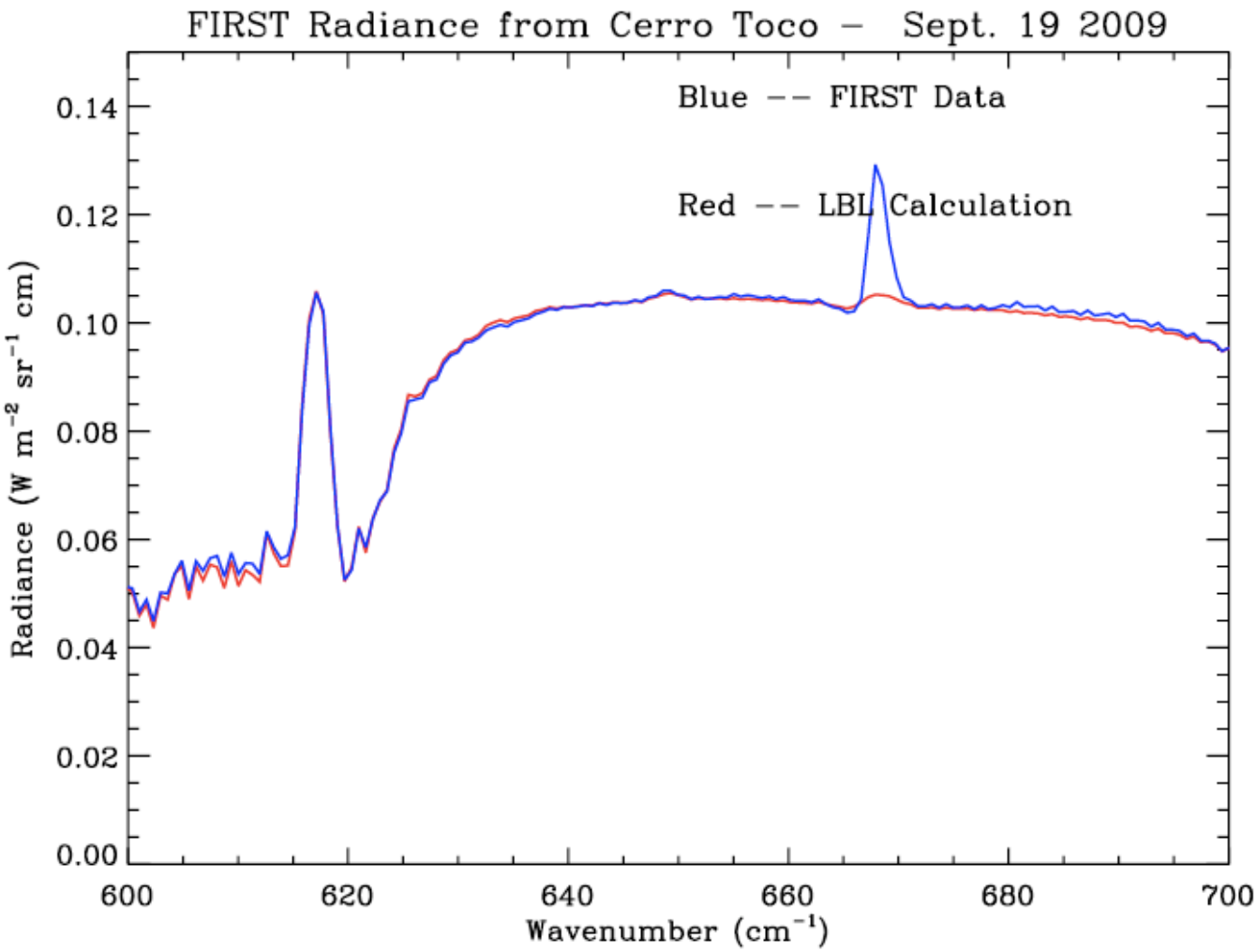
September 19 2009 – PWV = 0.4 mm



September 19 2009 – PWV = 0.4 mm

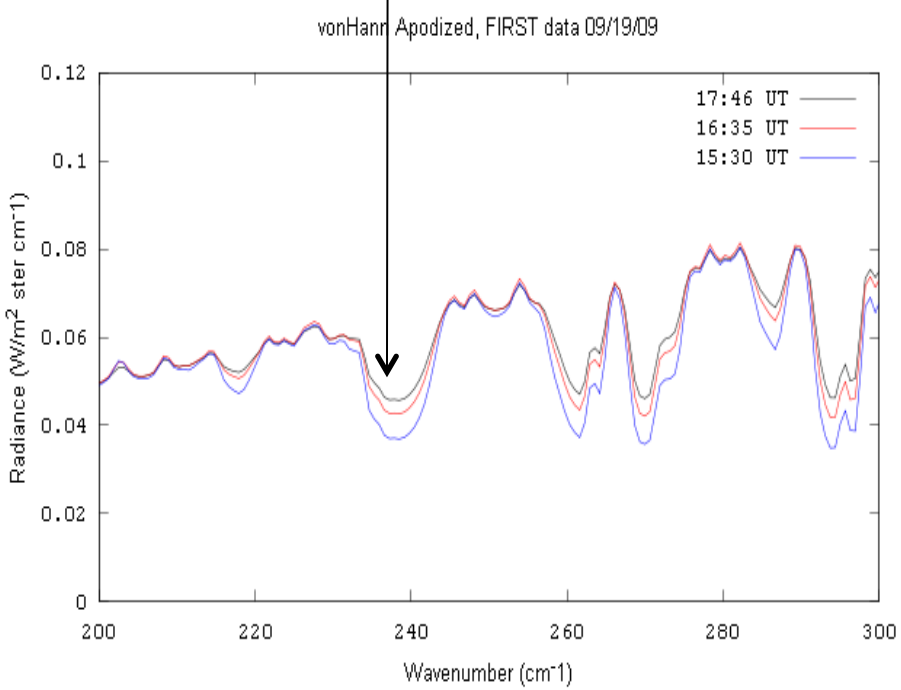


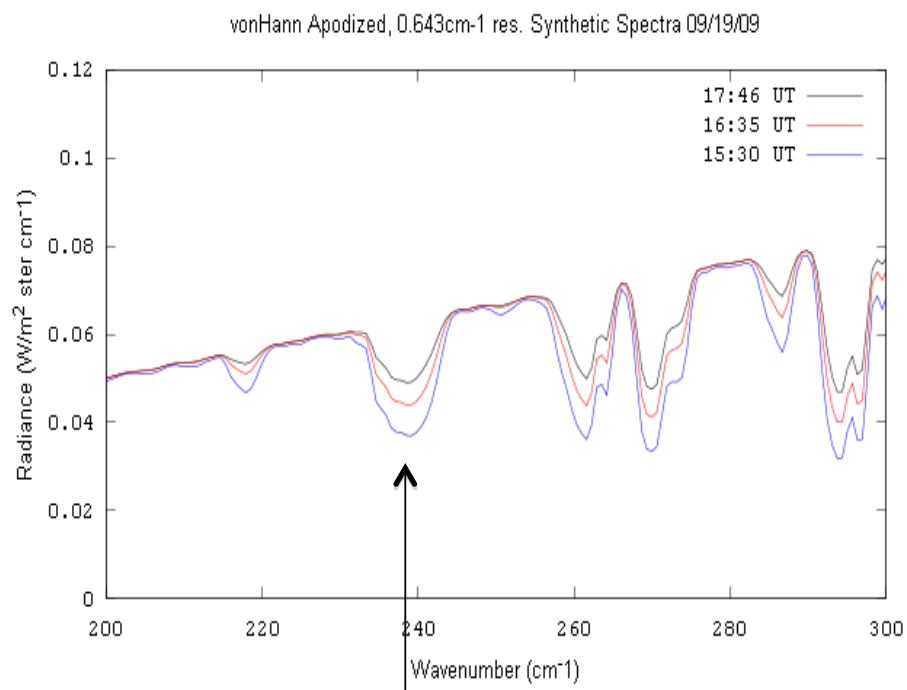
September 19 2009 – PWV = 0.4 mm



Variation of Far-IR spectra over two hours

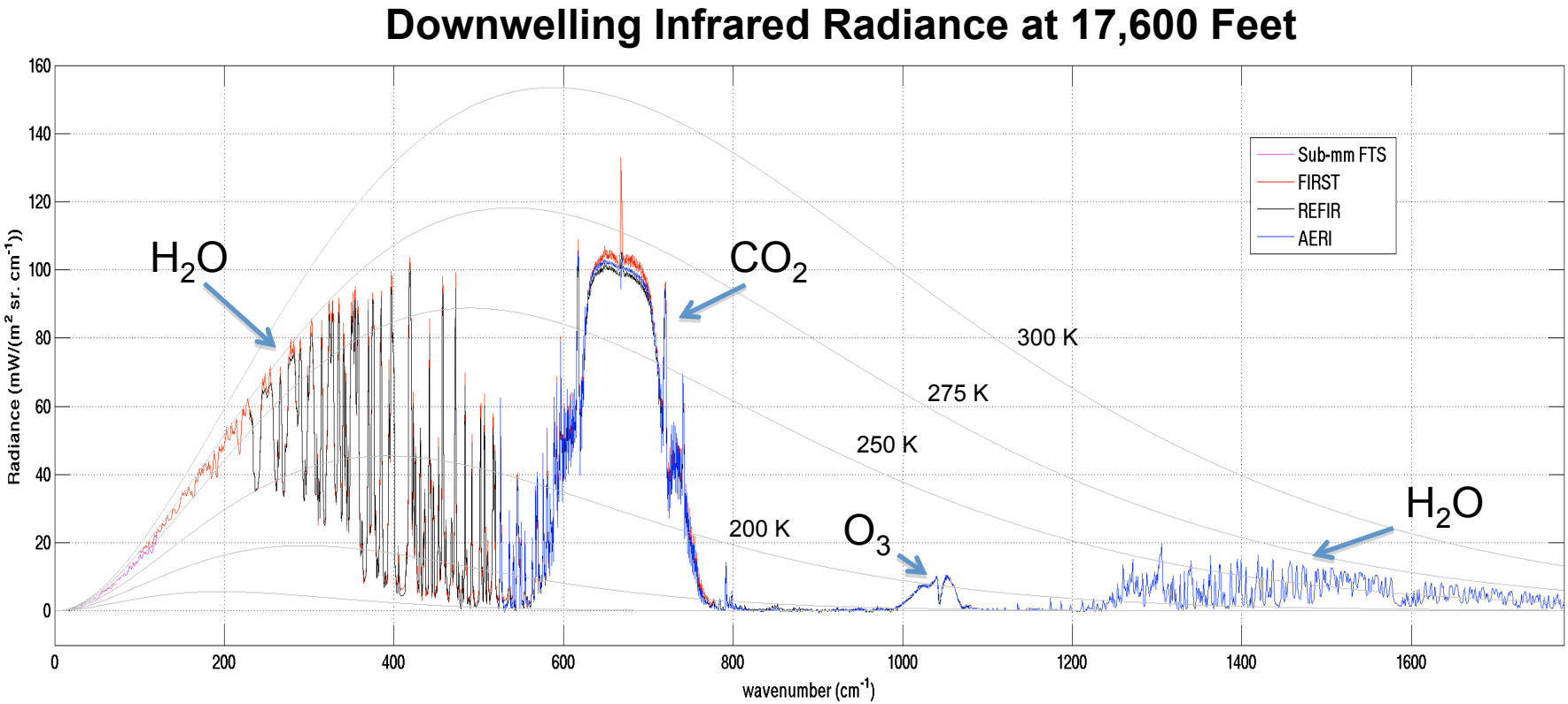
Increase of H_2O evident in measurements





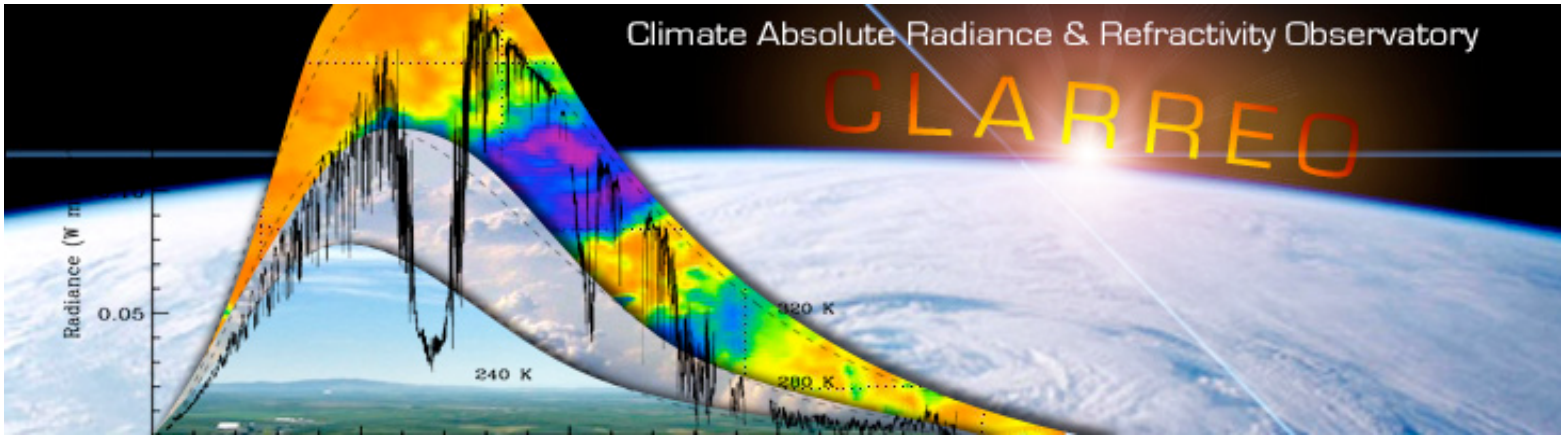
Theory matches this observation

Composite Infrared Spectrum at Earth's Surface



Combined Spectra from all 4 Instruments at Cerro Toco

Onto the Future – The CLARREO Mission



- FIRST data pave way for us to understand science and instrument
- Pushes the envelope in calibration and climate system measurement
- Enables us to learn how to achieve the on-orbit accuracy goals of CLARREO

Summary

- FIRST instrument successfully developed and demonstrated
- Successfully and *safely* completed the FORGE campaign to Chile
- Nearly 400 datasets spanning 3 months are now available
- Preliminary data shows no major gaps in theory and observation of the far-infrared, in clear sky
- Agreement with other instruments (not shown) appears excellent
- Cirrus cloud days need to be examined still
- NASA ESTO Instrument Incubator Program a huge success
- Leading the way to CLARREO via science and instrument technology

Acknowledgements

- Hal Maring, Radiation Sciences Program
- George Komar, Earth Science Technology Office
- Department of Energy
  - Infrastructure support and logistics (as part of RHUBC-II)
  - Multiple instruments (e.g., radiosondes, water vapor radiometer, AERI, others)
  - RHUBC-II principal investigators Dave Turner (U Wisconsin) and Eli Mlawer (AER)
- Space Dynamics Laboratory, Utah State University
- Science Systems and Applications, Inc.
- NASA Langley Research Center
- The FORGE "Away Team" and Science Team @ Langley
- Institute of Applied Physics , CNR, Florence Italy
- Smithsonian Astrophysical Observatory
- University of Cologne