Far-Infrared Spectroscopy of the Troposphere

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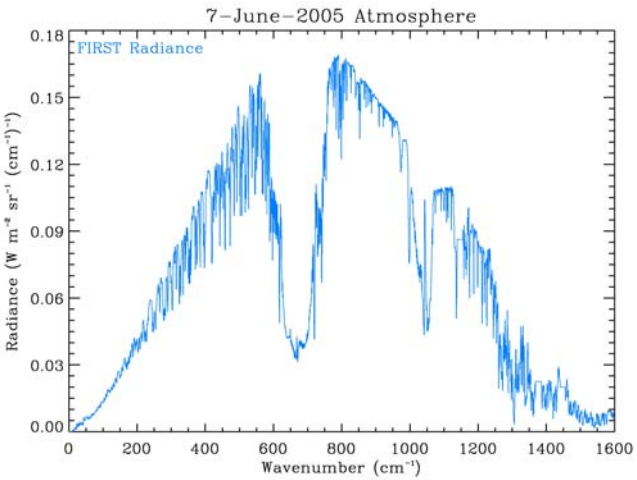
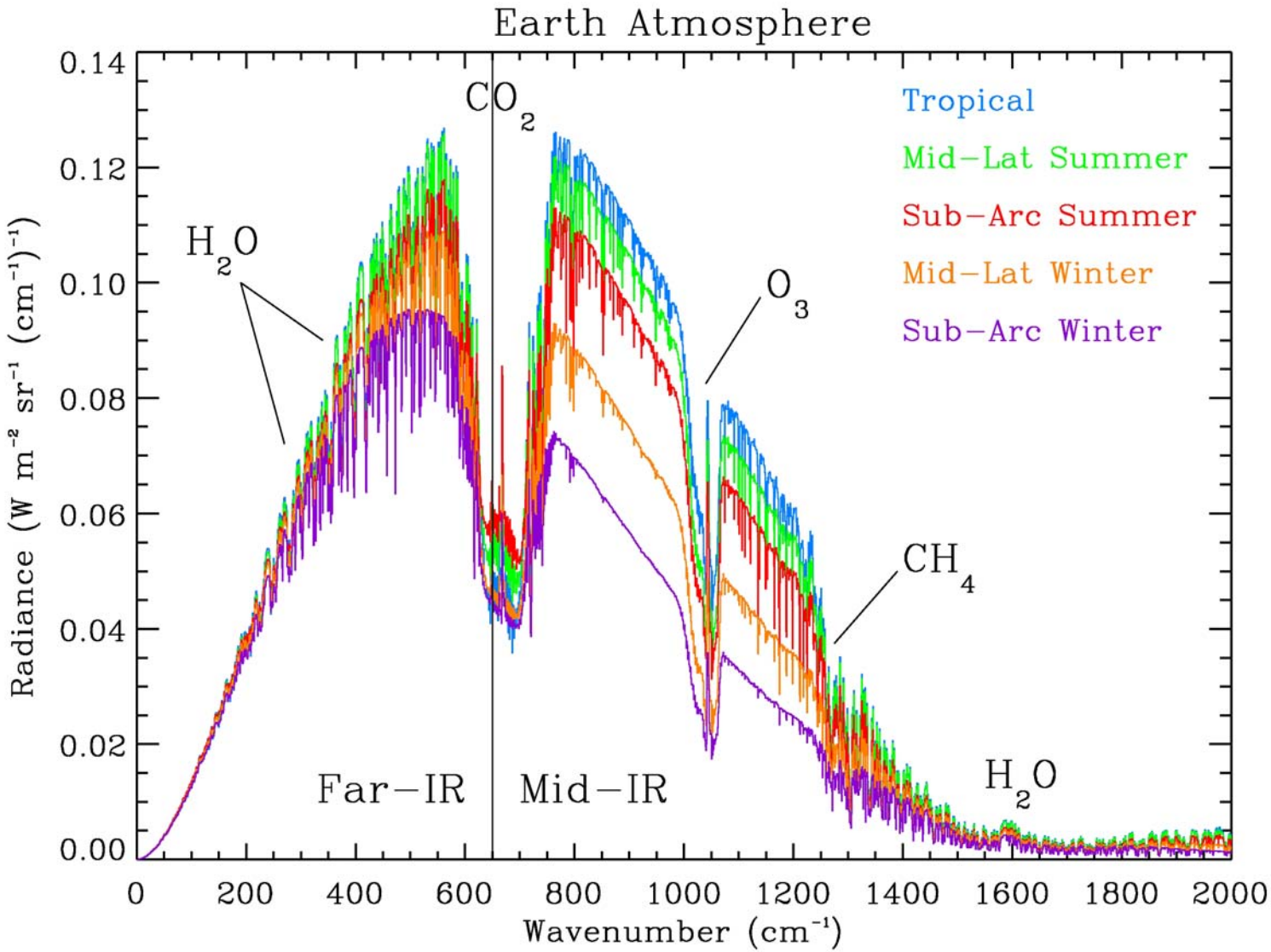


Outline

- Science Motivation and Justification for Far-IR Measurement
- FIRST Project Summary
- The Greenhouse Effect at the Ends of the Earth
- FIRST Relevance to GIFTS
- Summary

Top-of-Atmosphere Spectral Infrared Radiance

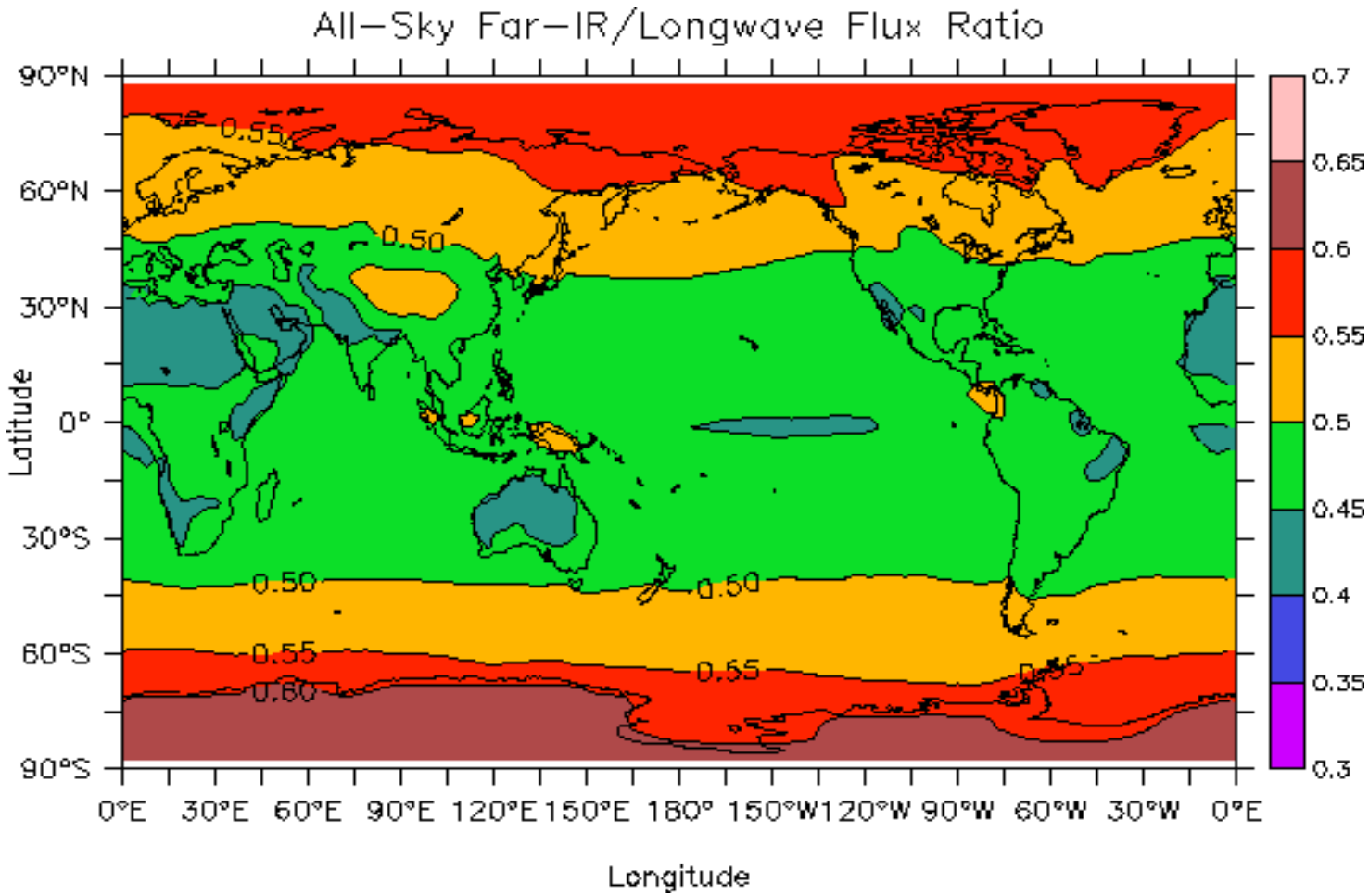


FIRST

Compelling Science of the Far-Infrared

- Up to 50% of OLR (surface + atmosphere) is beyond 15.4 μm
- Between 50% and 75% of the atmosphere OLR is beyond 15.4 μm
- 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_2O 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

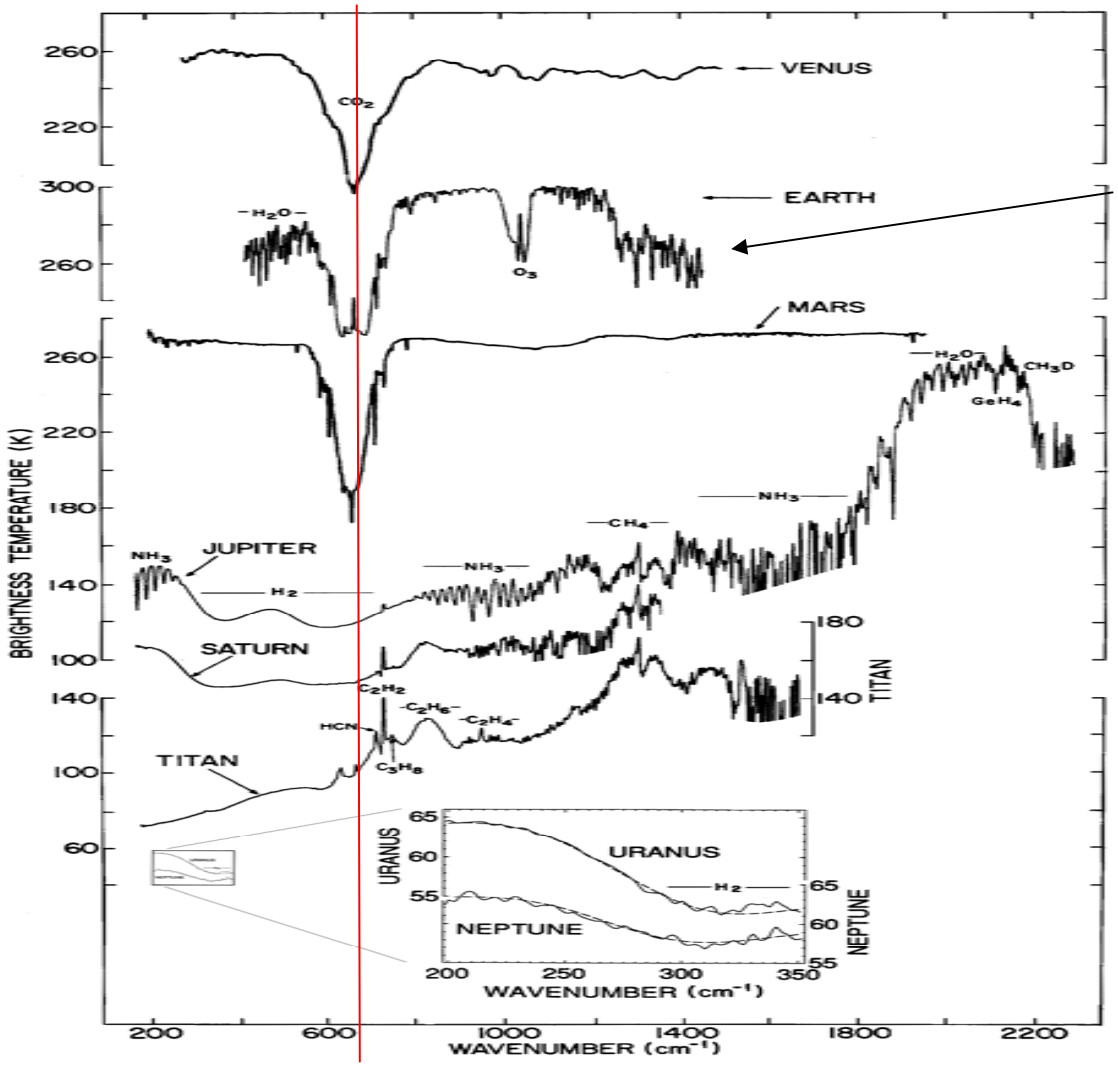
FIRST



Annual mean TOA fluxes for all sky conditions from the NCAR CAM

Reference: Collins and Mlynczak, Fall AGU, 2001

Far-IR Measurements in our Solar System

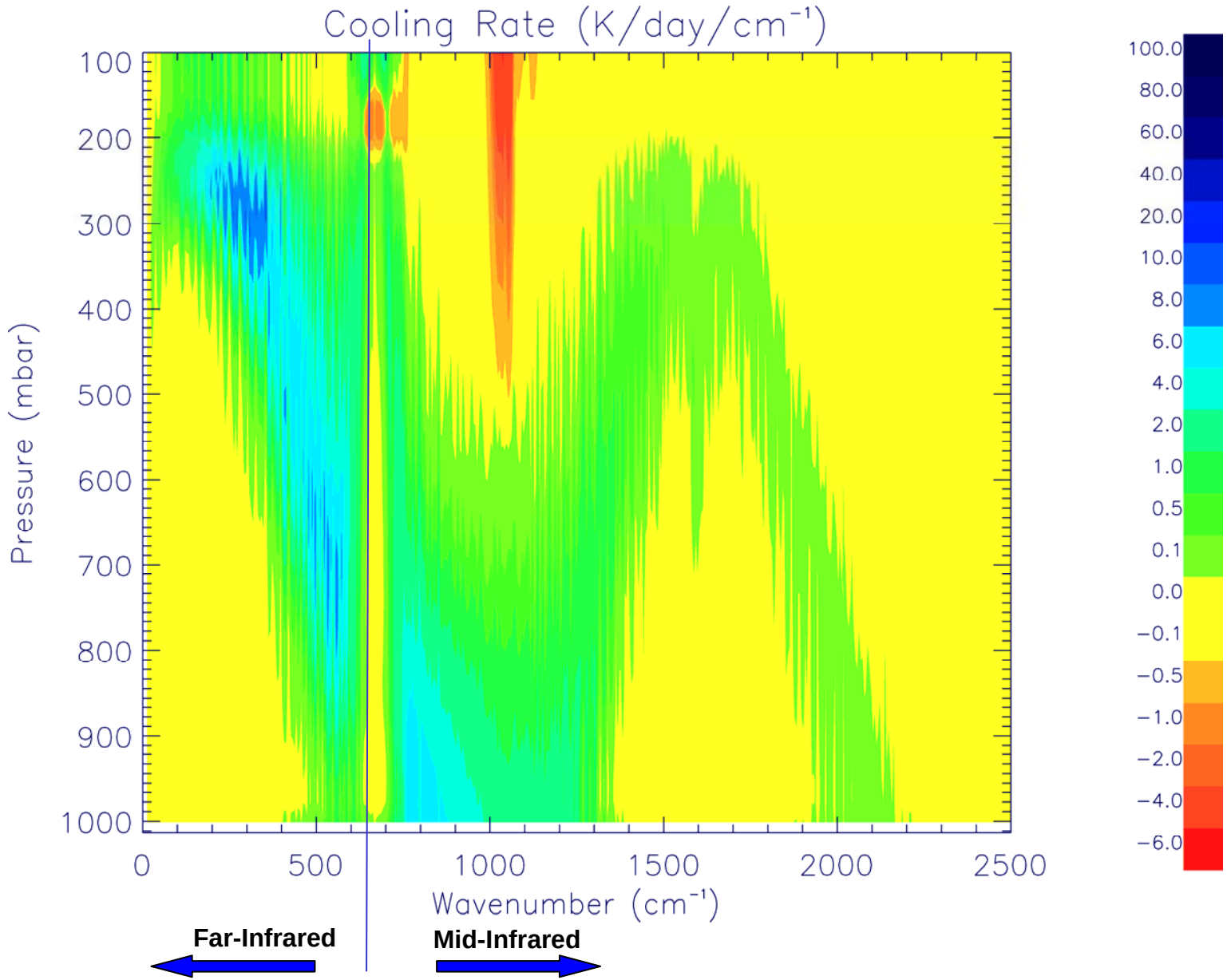


Nimbus III/IV, 1969/70

Far – IR least measured on Earth → FIRST project

Reference Hanel et al., 2003

Infrared Cooling Rate



FIRST

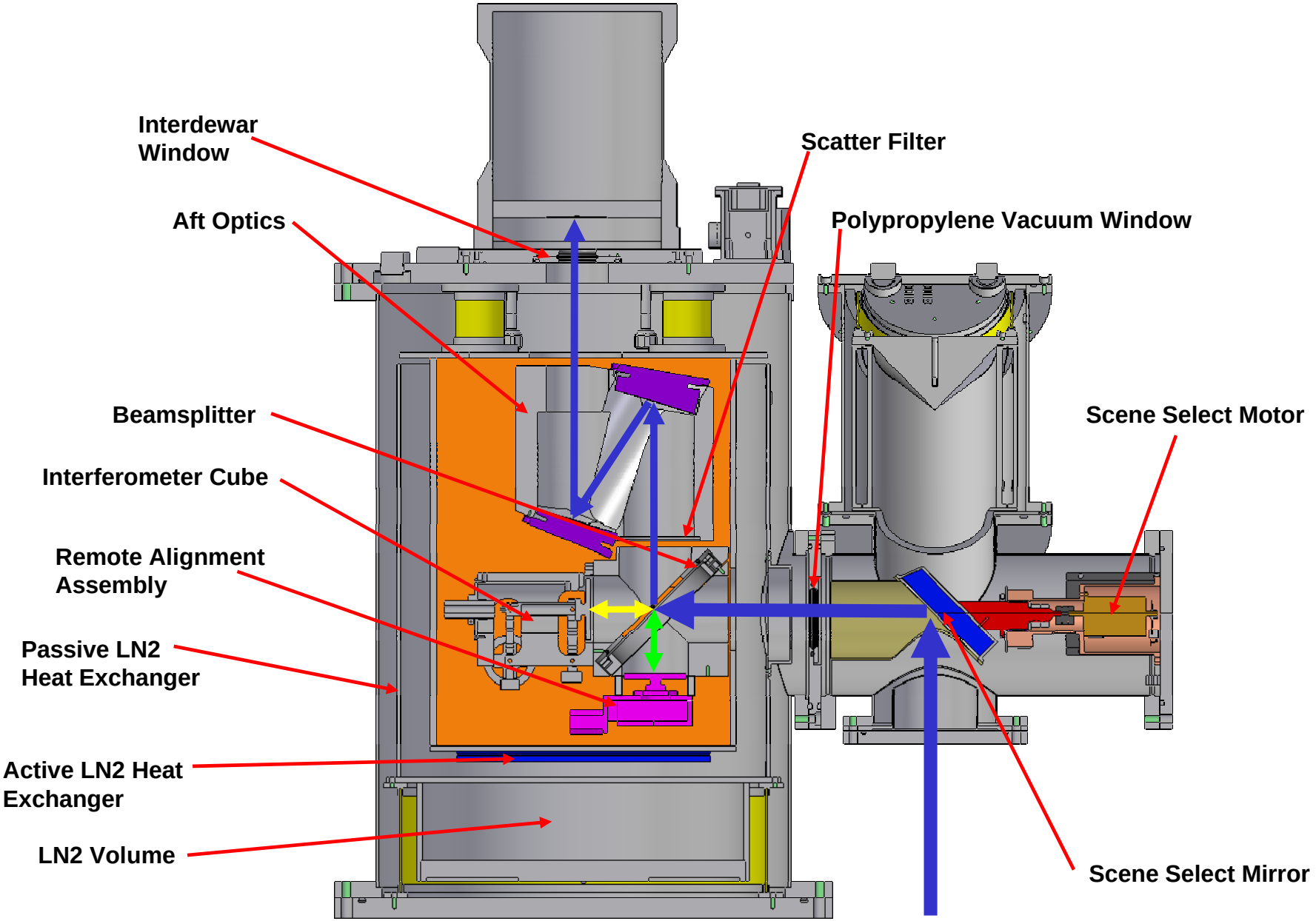
FIRST Instrument Description

- Michelson Interferometer
- 6 to 100 μm on a single focal plane
- 0.625 cm^{-1} unapodized (0.8 cm OPD)
- 0.643 cm^{-1} realized
- 1.4 s scan time (nominal)
- 0.47 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
- NEΔT – 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

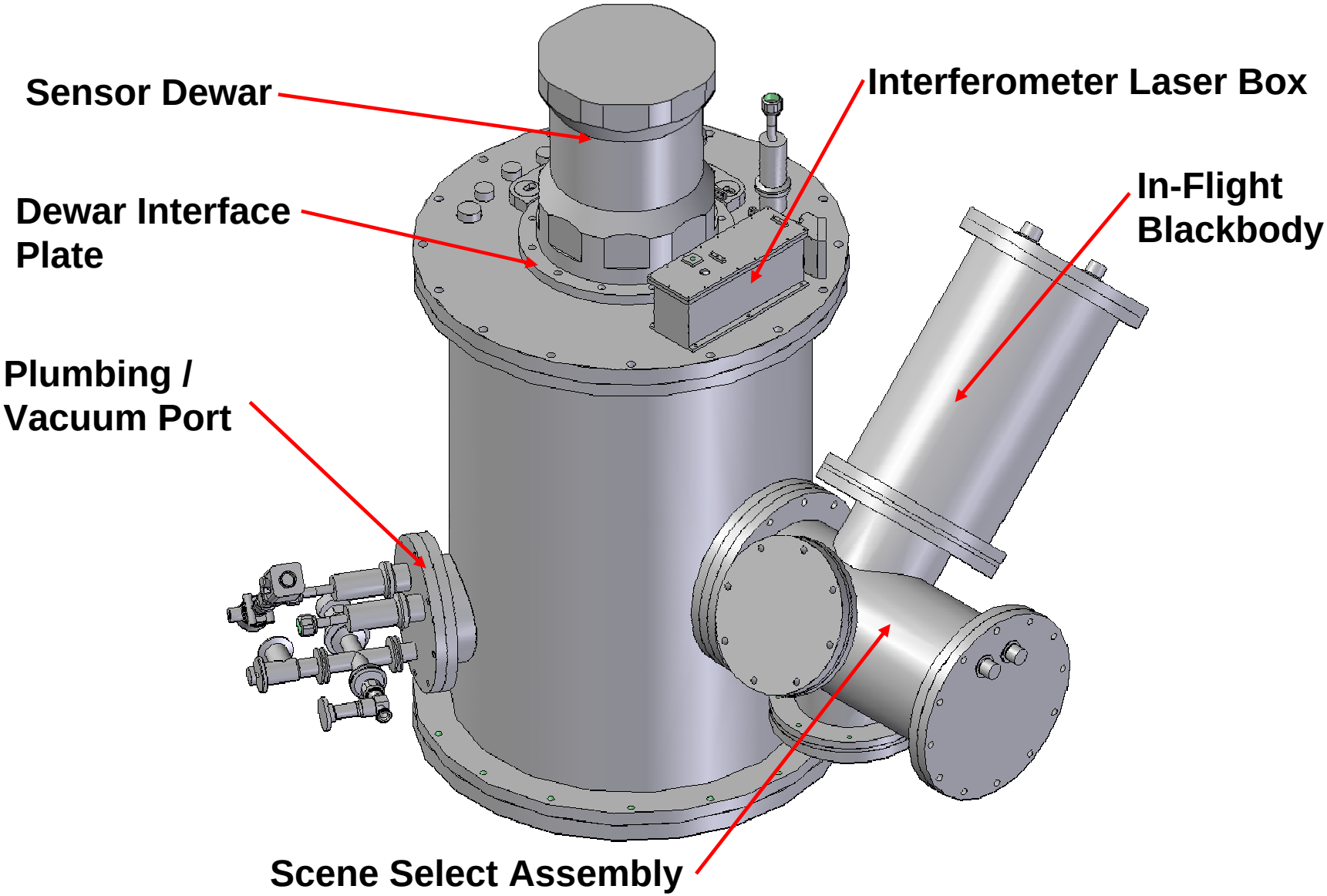
Developed under NASA ESTO Instrument Incubator Program

In Partnership with USU/SDL and Harvard Smithsonian CfA

FIRST Balloon Payload System



FIRST Balloon Payload System



FIRST – Calibration

- **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 μm (+ far-IR)**
  - **Allows verification against "standard" instruments, e.g, AIRS, AERI, in mid-IR**

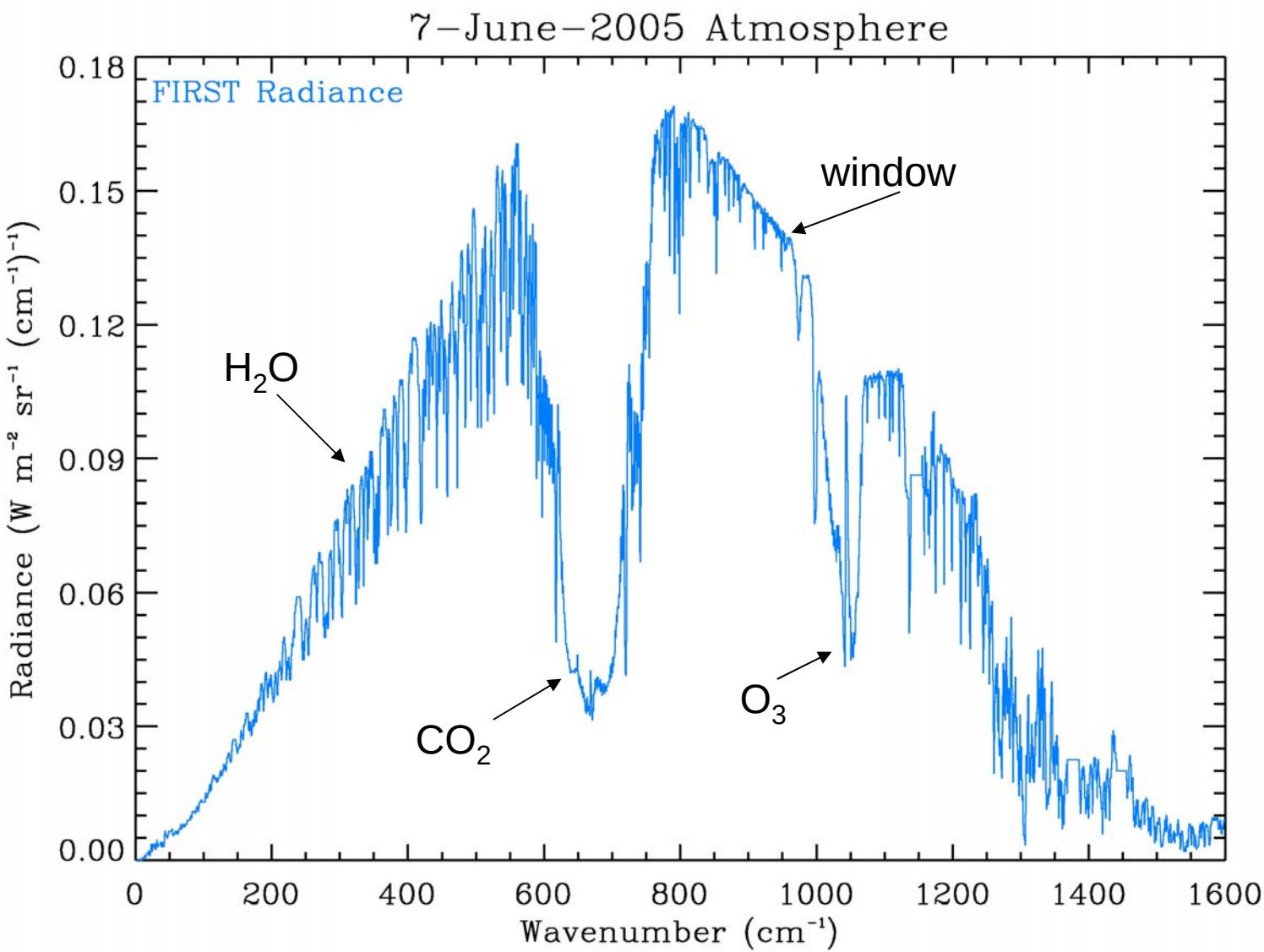
FIRST on the Flight Line June 7 2005

FIRST Flight Specifics

- Launched on 11 M cu ft balloon June 7 2005
- Float altitude of 27 km
- Recorded 5.5 hours of data
- 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)

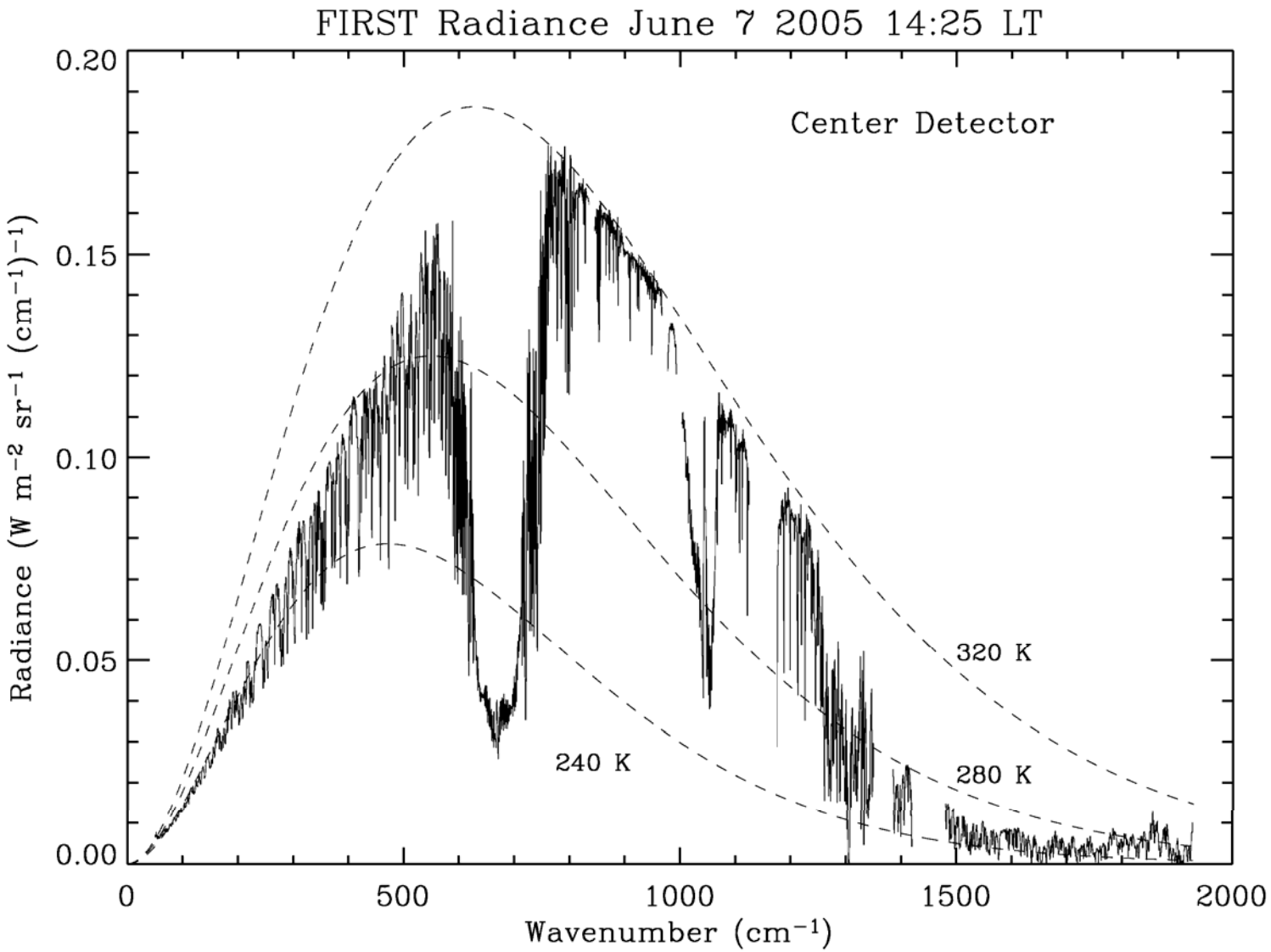
FIRST records complete thermal emission spectrum of the Earth at high spatial and spectral resolution

FIRST "First Light" Spectrum



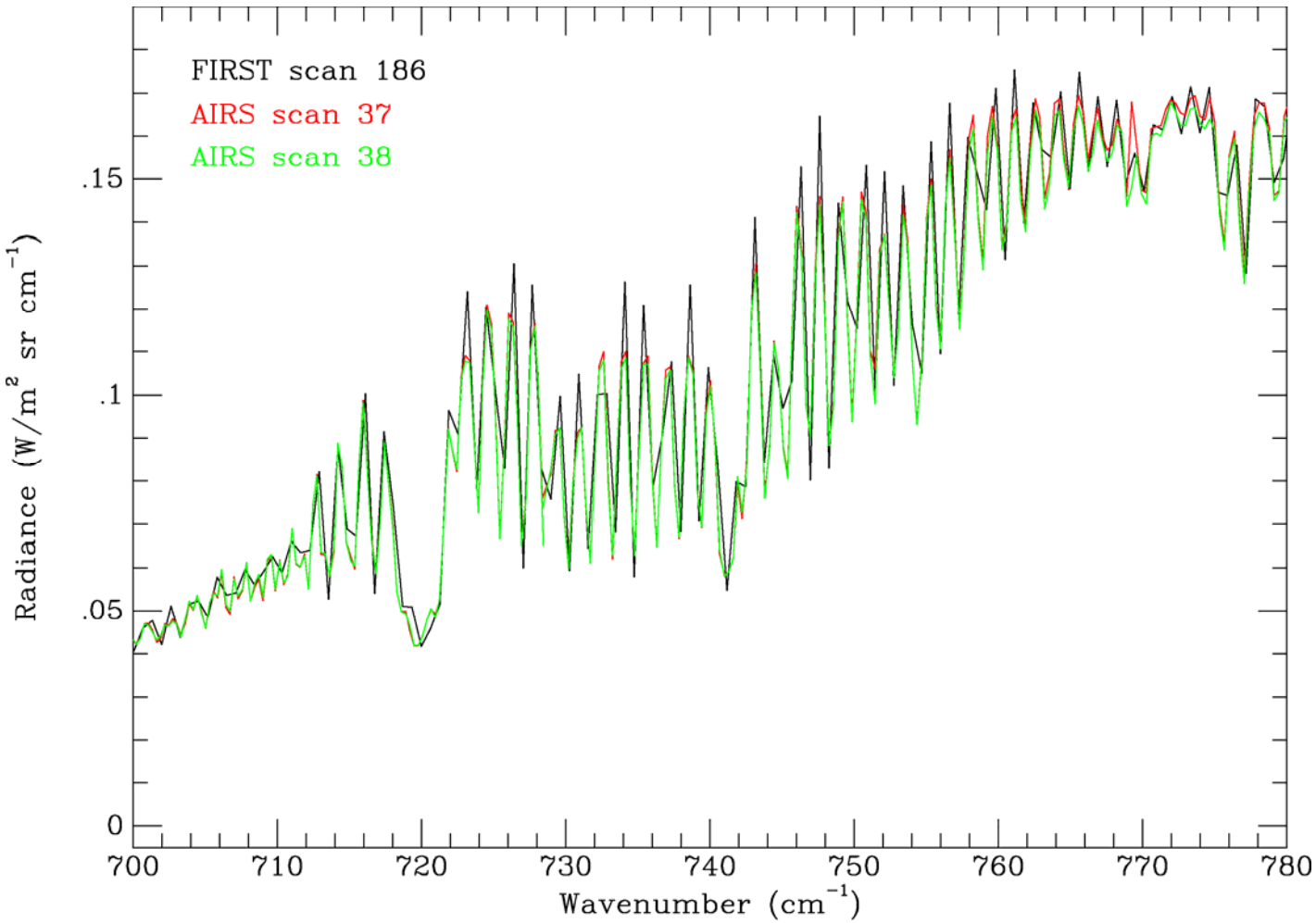
Reference: Mlynczak et al., 2006

FIRST Spectrum, Center Detector

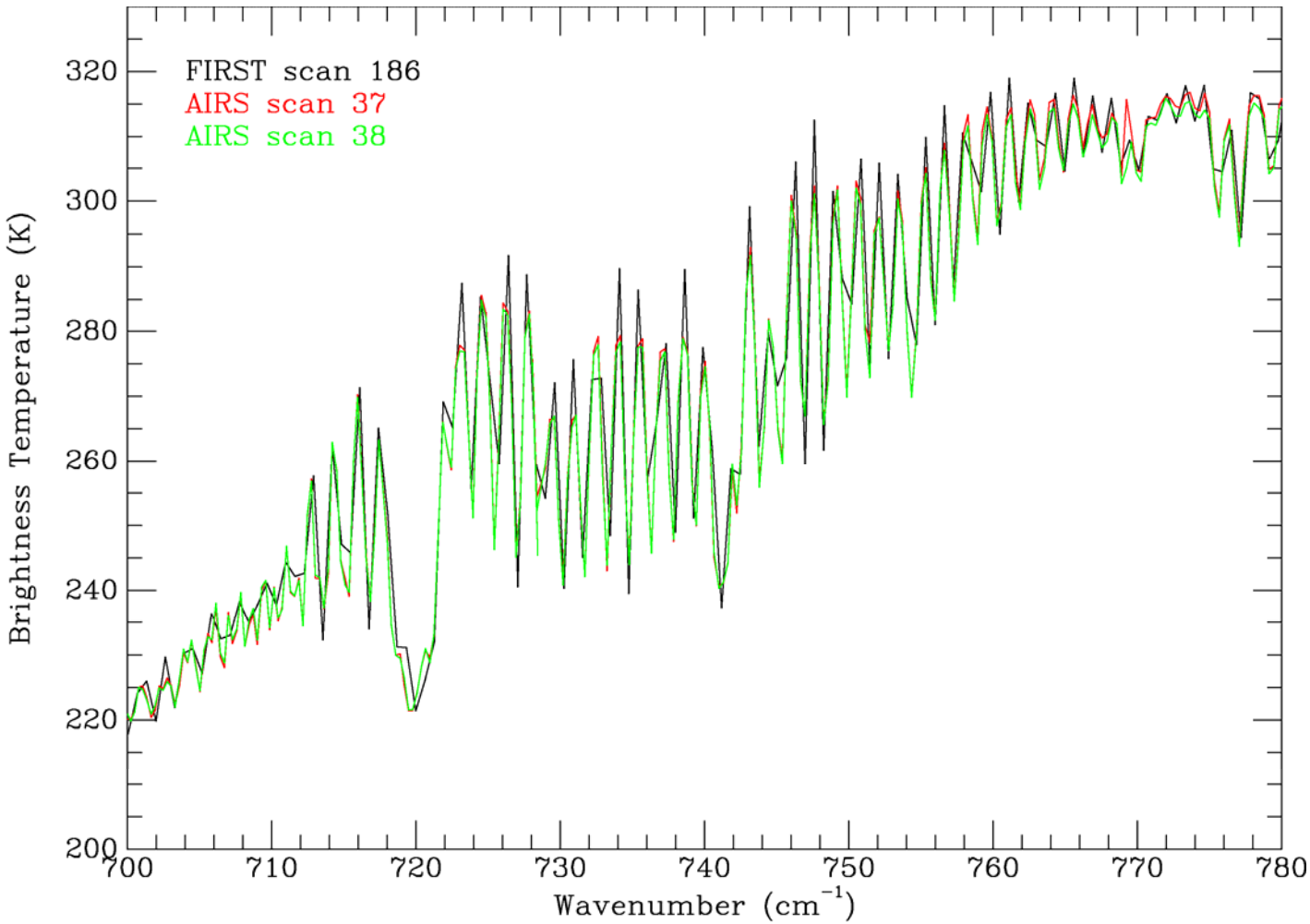


Mlynczak et al., GRL, 2006

FIRST and AIRS Radiance Comparison



FIRST and AIRS Brightness Temp. Comparison



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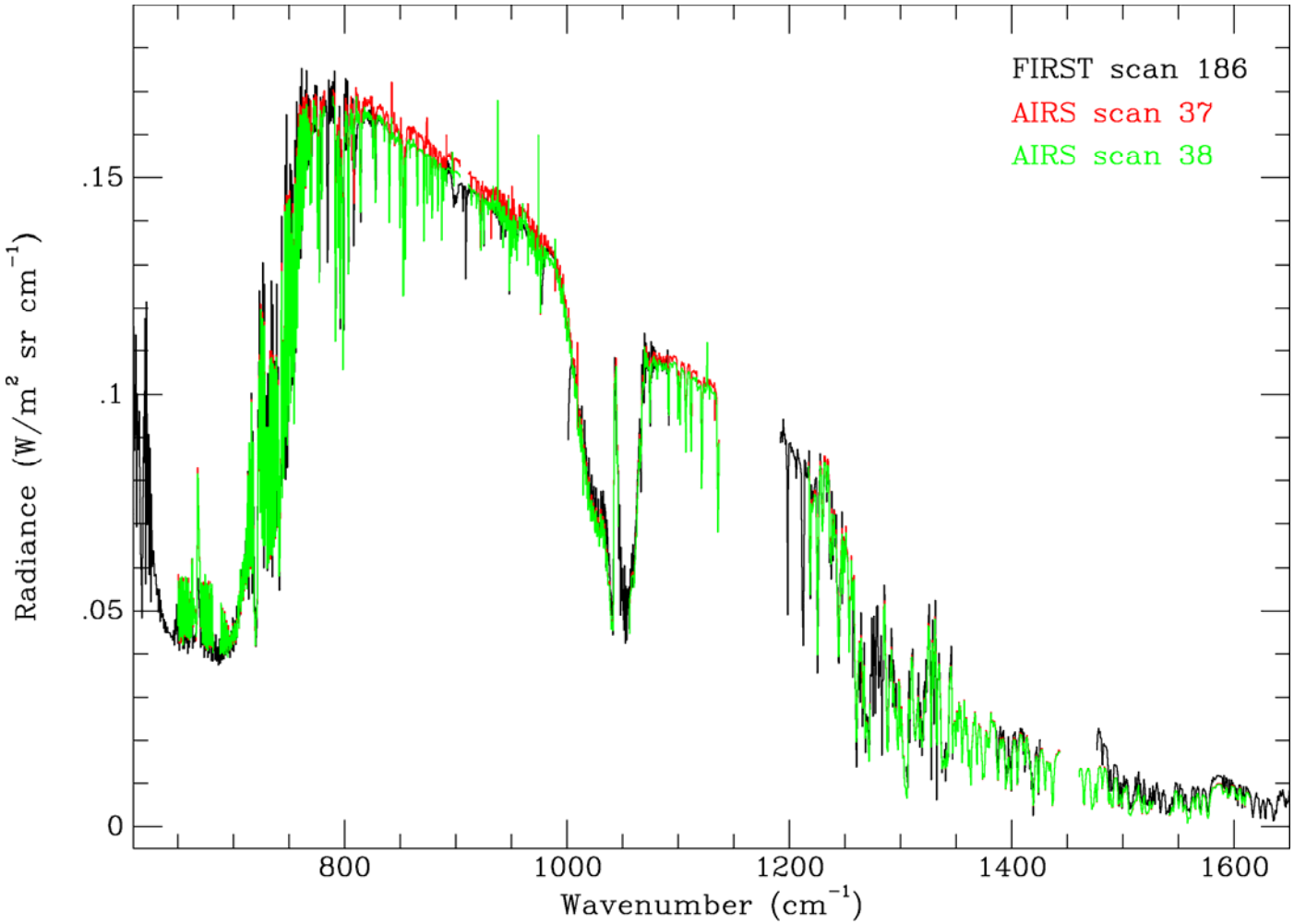

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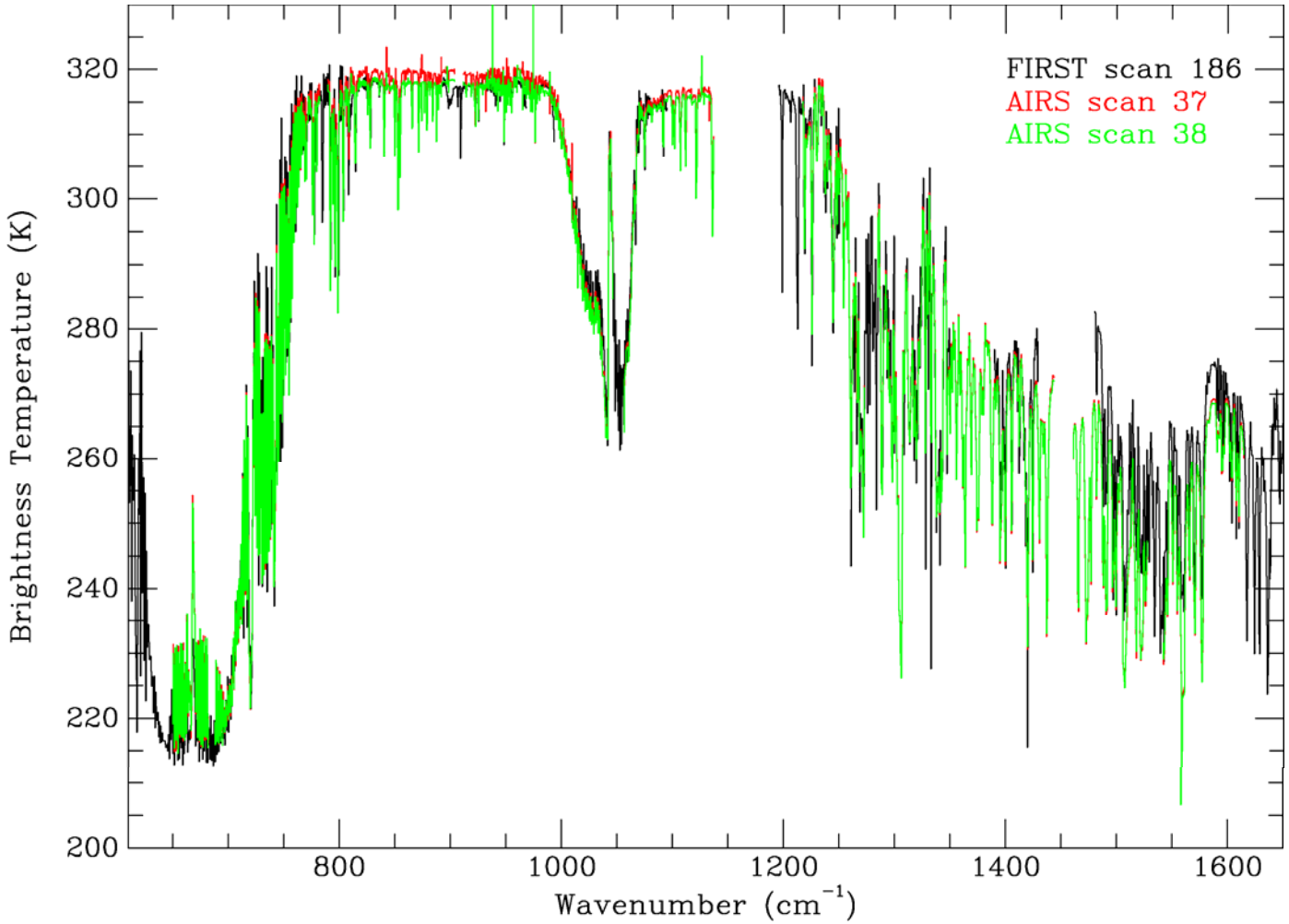
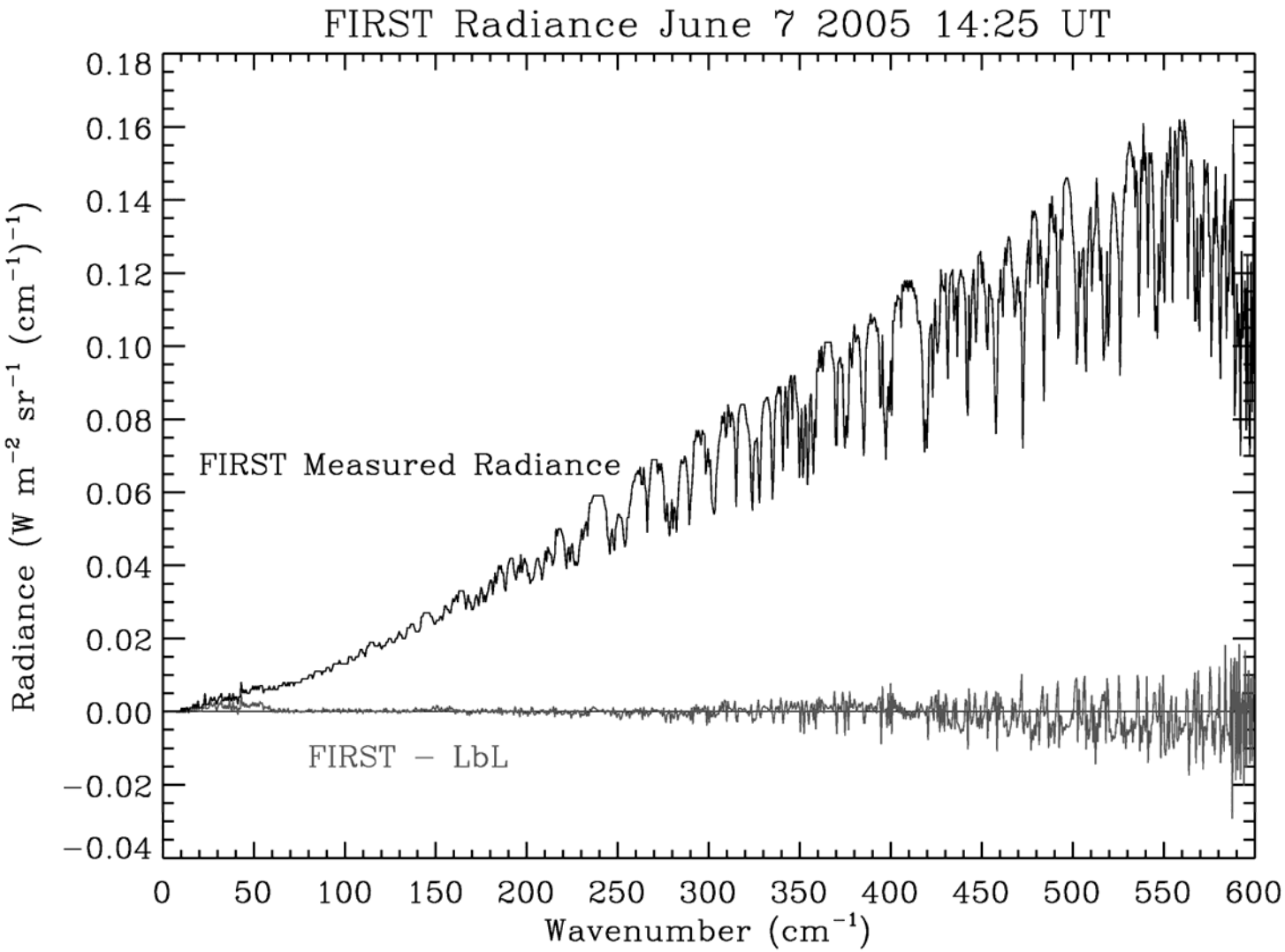


FIRST Measured, Calculated Radiance



Mlynczak et al., GRL, 2006

The Greenhouse Effect at the Ends of the Earth

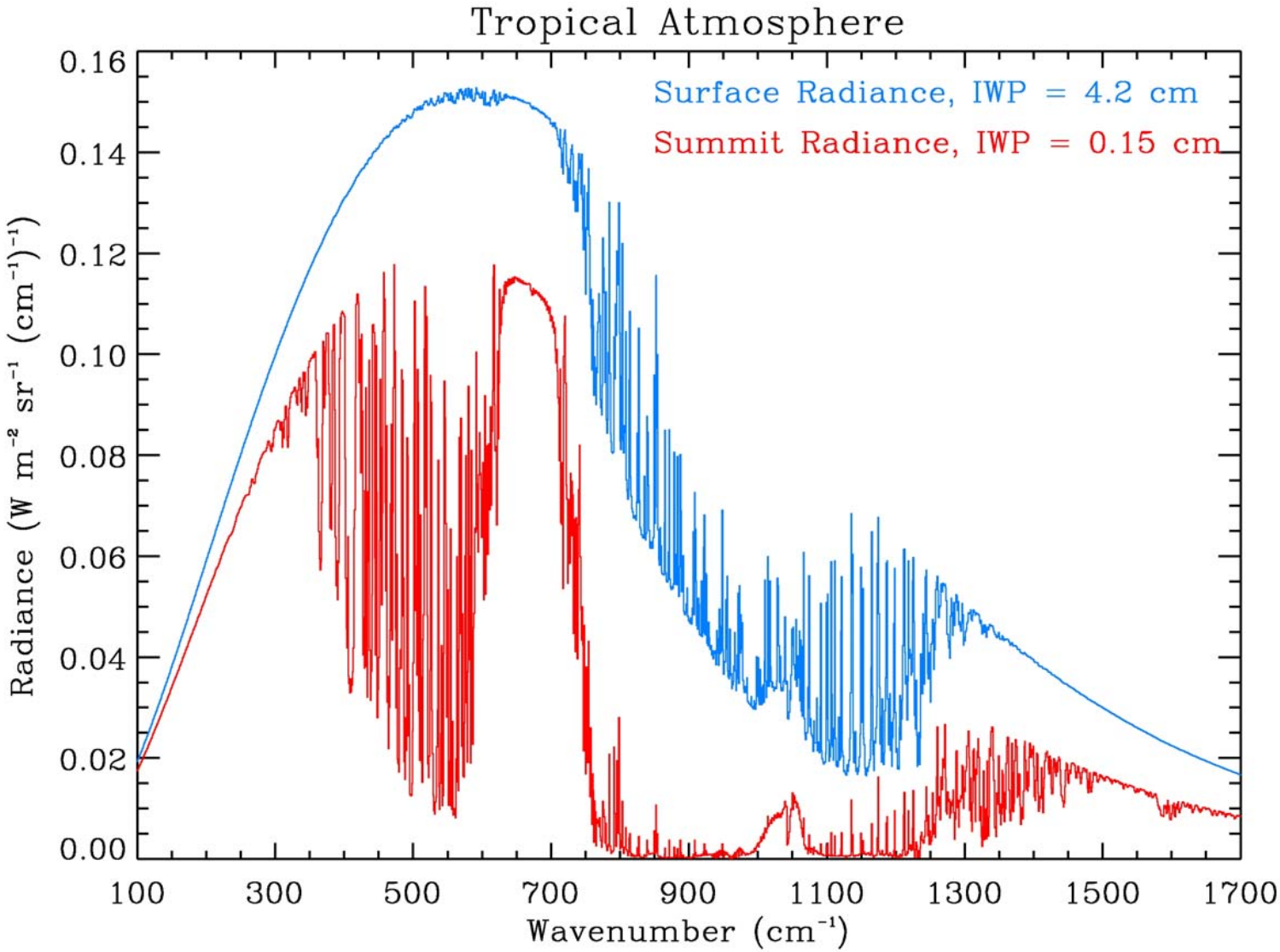
- Far-IR Measurements – Ground based (zenith view)

- Cold and dry locations (less than 2mm PW)
  - Barrow, AK
  - Mauna Loa Observatory, HI
  - South Pole Station, Antarctica
  - Atacama Desert, Chile

- Far-IR open up to perhps 275 cm^{-1}
  - Derive radiative cooling of mid-troposphere
  - Observe far-IR optical properties of cirrus in windows
  - Validate far-IR water vapor spectroscopy

DoE/NASA RHUBC/FORGE Campaign in Barrow, AK Feb. 2007

Surface and Summit Zenith Radiances at MLO



FIRST – Relevance to GIFTS Validation

- **FIRST on the balloon platform is essentially "geostationary"**
  - **Balloon moves with wind at ~ 30 km altitude**
  - **Flights from mid-latitudes (Ft. Sumner, NM) in Spring, Fall**

- **Records entire infrared spectrum 100 – 1600 cm^{-1} in a few seconds**
  - **Balloon moves ~ 100 feet per interferogram**

- **Well calibrated as demonstrated with AIRS**

- **Up to ~ 15 hours of data possible given hold time of dewar**
  - **Day and night coverage possible**

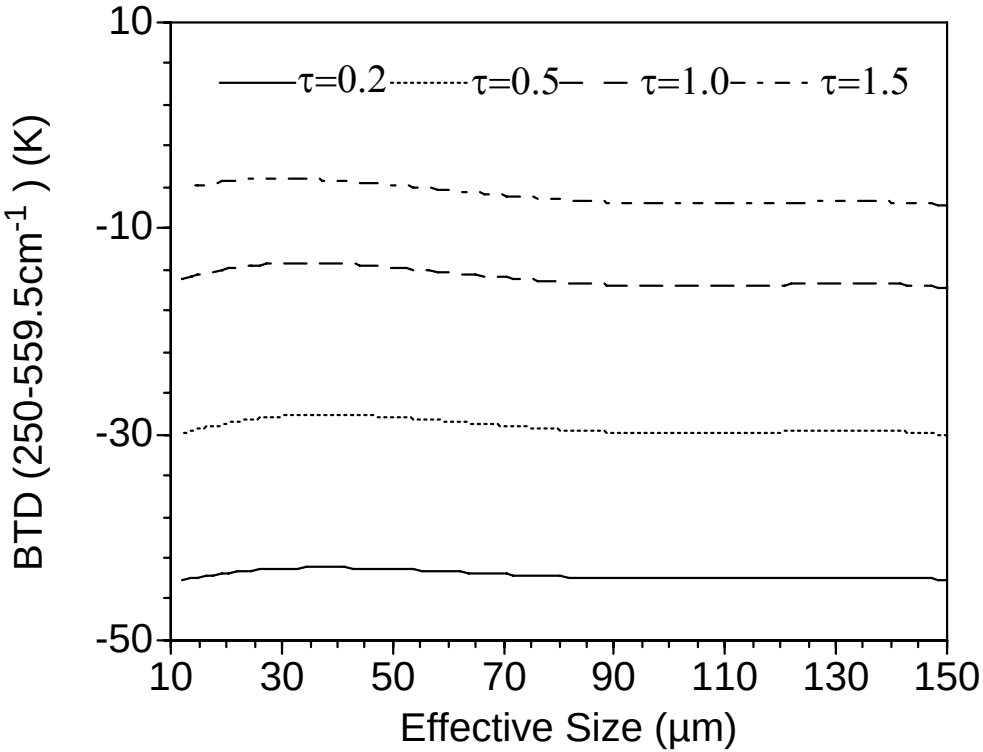
- **Comparable spectral resolution of FIRST & GIFTS**
  - **0.643 cm^{-1} realized on FIRST**

FIRST - Summary

- **FIRST instrument successfully developed and demonstrated**
  - **Met or exceeded all technology development goals**
  - **Measures energetically significant spectrum 6 to 100 μm**
- **Calibration appears to be excellent**
- **Substantial new science to be obtained from zenith views**
  - **Low H_2O venues such as Arctic, Antarctic, or high altitude**
  - **Cooling, H_2O spectroscopy, cirrus forcing**
- **On a path with related technology developments to achieve space based measurement**
- **Substantial potential for contributing to GIFTS validation and science**

Backups

FIRST – Sensitivity to Cirrus Clouds

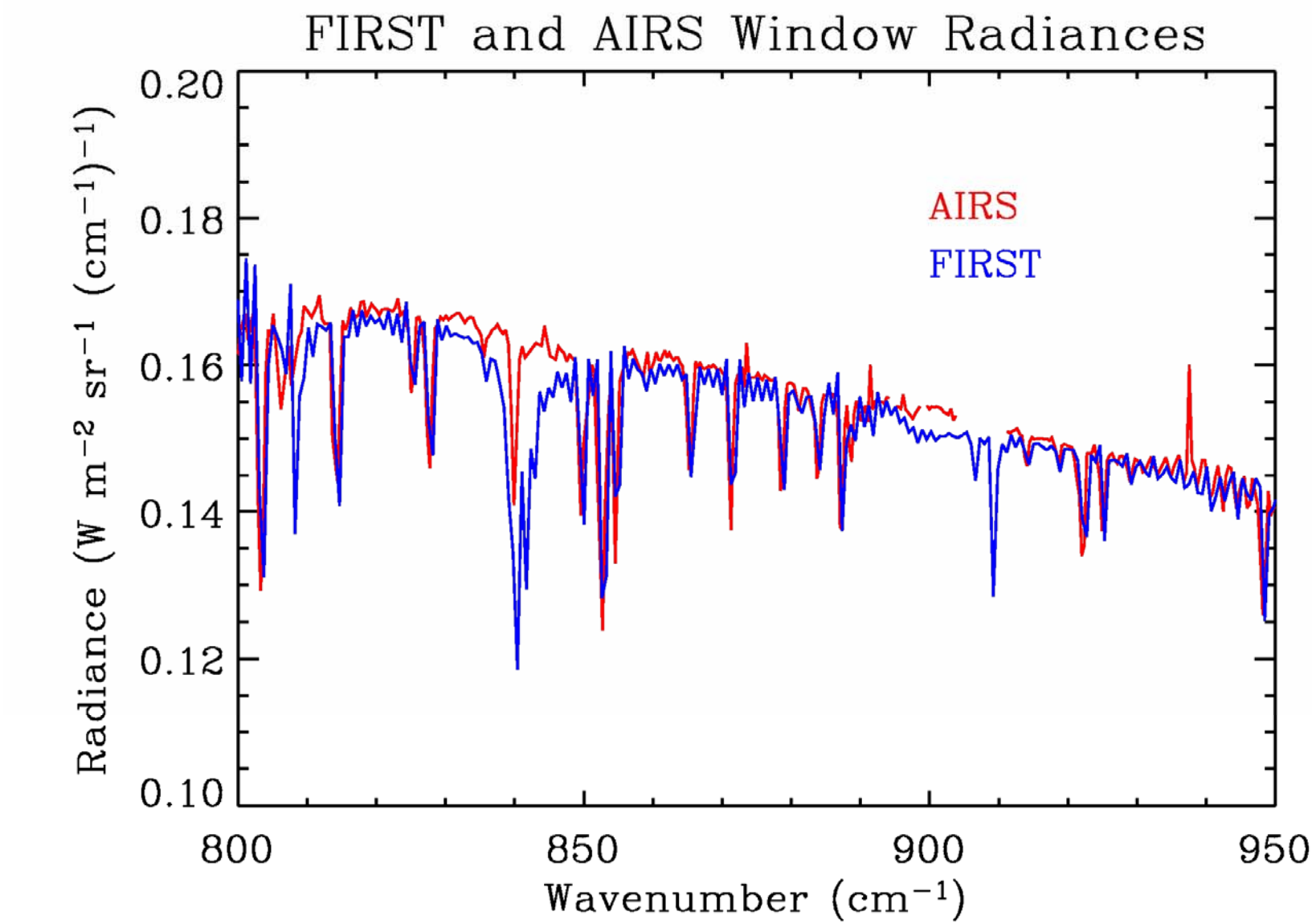


Brightness temperature difference between two channels ν_1=250.0 cm^{-1} and ν_2=559.5 cm^{-1} as a function of effective particle size for four cirrus optical thicknesses

FIRST spectra can be used to derive optical thickness of thin cirrus clouds (τ < 2)

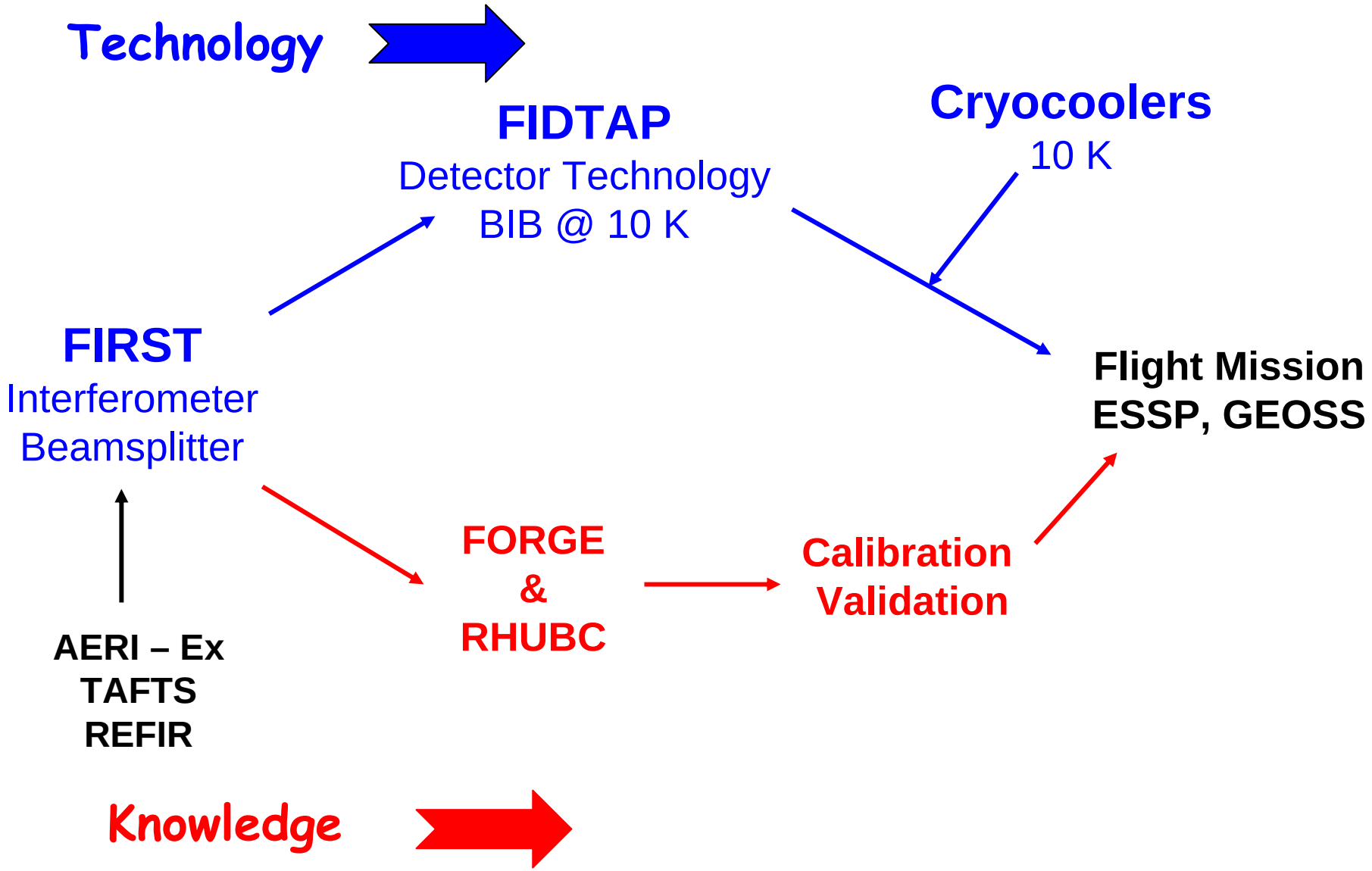
Reference: ***Yang et al.*****, JGR, 2003**

Comparison of AIRS, FIRST in Window Region

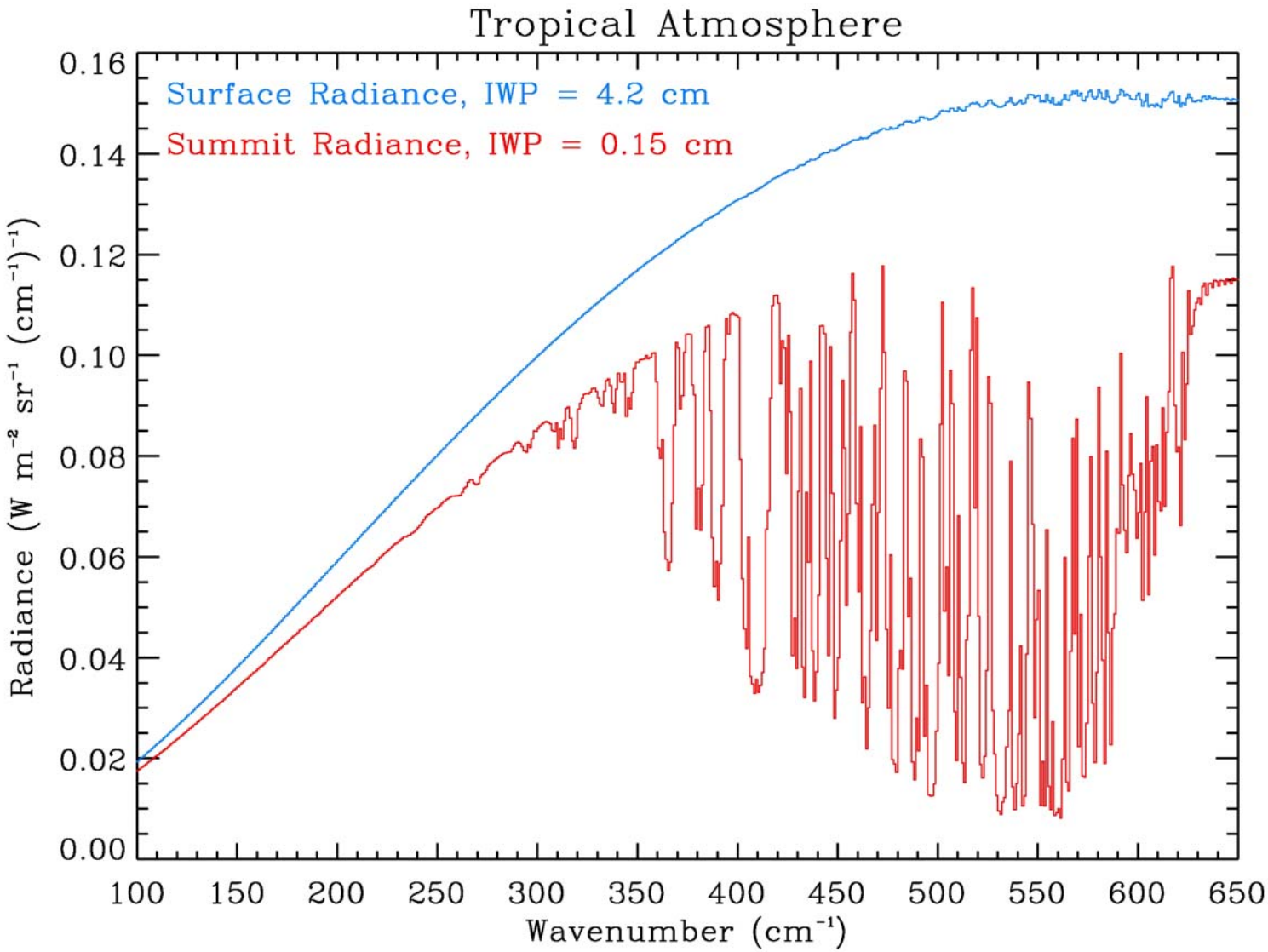


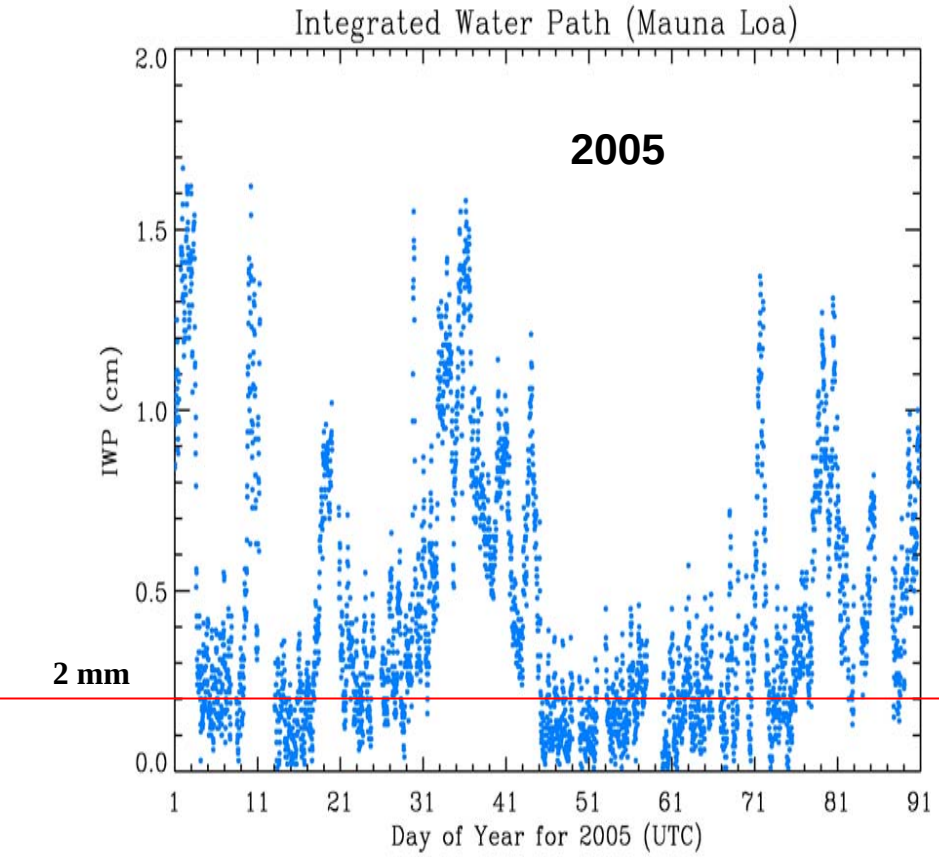
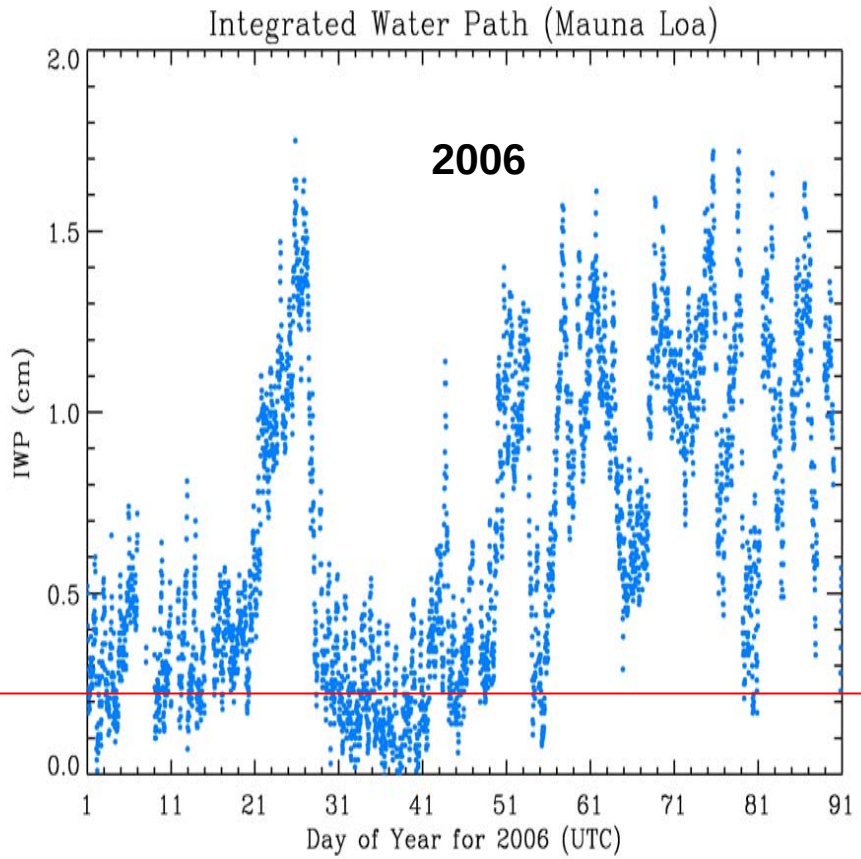
Mlynczak et al., GRL, 2006

Far-Infrared – Future Directions



Far-IR Surface and Summit Zenith Radiances at MLO



PWV at MLO 2005, 2006

PWV < 2 mm often in February, March