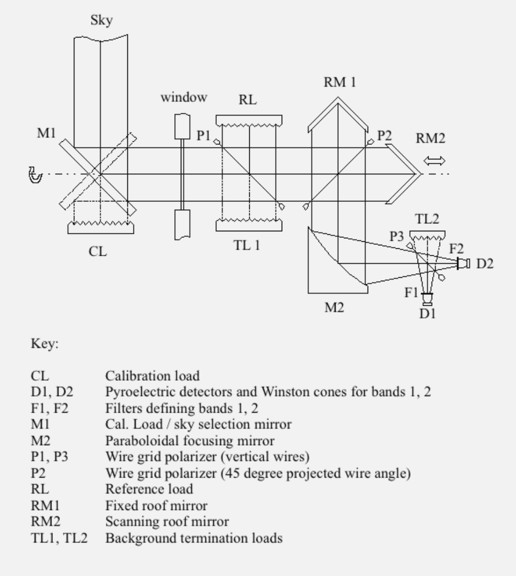
Atmospheric Modeling and Instrument Design for the Dome A FTS



Key:

CL	Calibration load
D1, D2	Pyroelectric detectors and Winston cones for bands 1, 2
F1, F2	Filters defining bands 1, 2
M1	Cal. Load / sky selection mirror
M2	Paraboloidal focusing mirror
P1, P3	Wire grid polarizer (vertical wires)
P2	Wire grid polarizer (45 degree projected wire angle)
RL	Reference load
RM1	Fixed roof mirror
RM2	Scanning roof mirror
TL1, TL2	Background termination loads

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Dome A Science Workshop – Nanjing – 2008 November 1

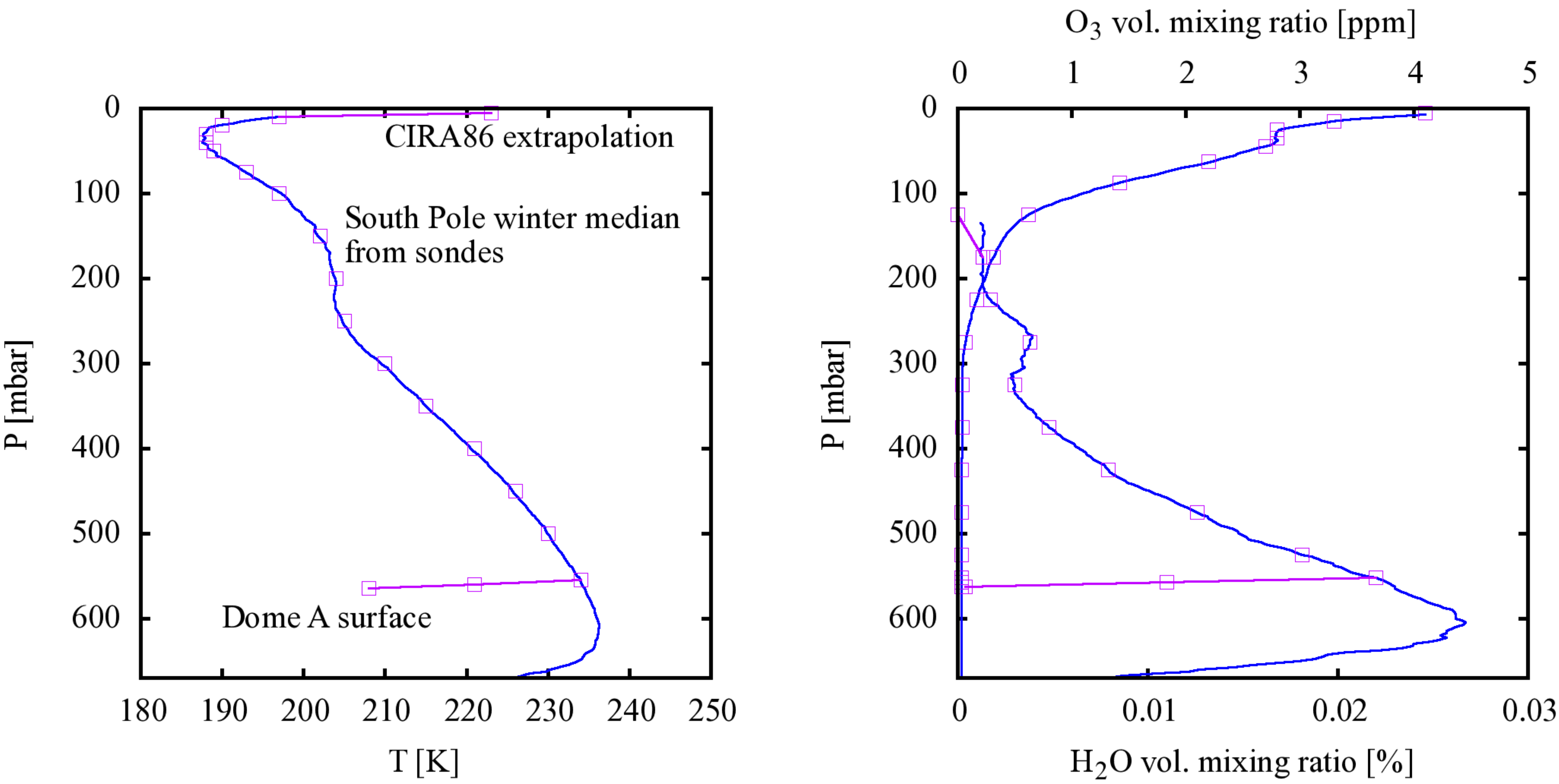
Outline

- An atmospheric model for Dome A
    - Estimated vertical profiles
    - Absorption by water vapor and other gases
    - Model radiance and transmittance
- FTS Design
    - Design constraints for Dome A
    - Optical layout
    - Sensitivity analysis
- Next steps

An atmospheric model for Dome A

- Serves as a starting point for instrument design
- Model profiles
    - Start with median winter profiles from NOAA CMDL South Pole ozonesondes, which carry chilled-mirror hygrometers.
    - Ground point based on Dome A weather station data
- Clear sky radiative transfer
    - Show contributions of different components
    - Most uncertain is H_2O continuum
- Compute using *am* code

Dome A model profiles (winter median)



- Model surface inversion is 10 mbar thick (e.g. J. S. Lawrence, PASP **116** 482 2004)
- Symbols indicate points used for *am* winter median model profiles.
- Model winter pwv quartiles are 115 μ m, 180 μm, 270 μm
- Dome A should be drier, and early Pre-HEAT data do imply lower median pwv, so use 75 μ m in examples

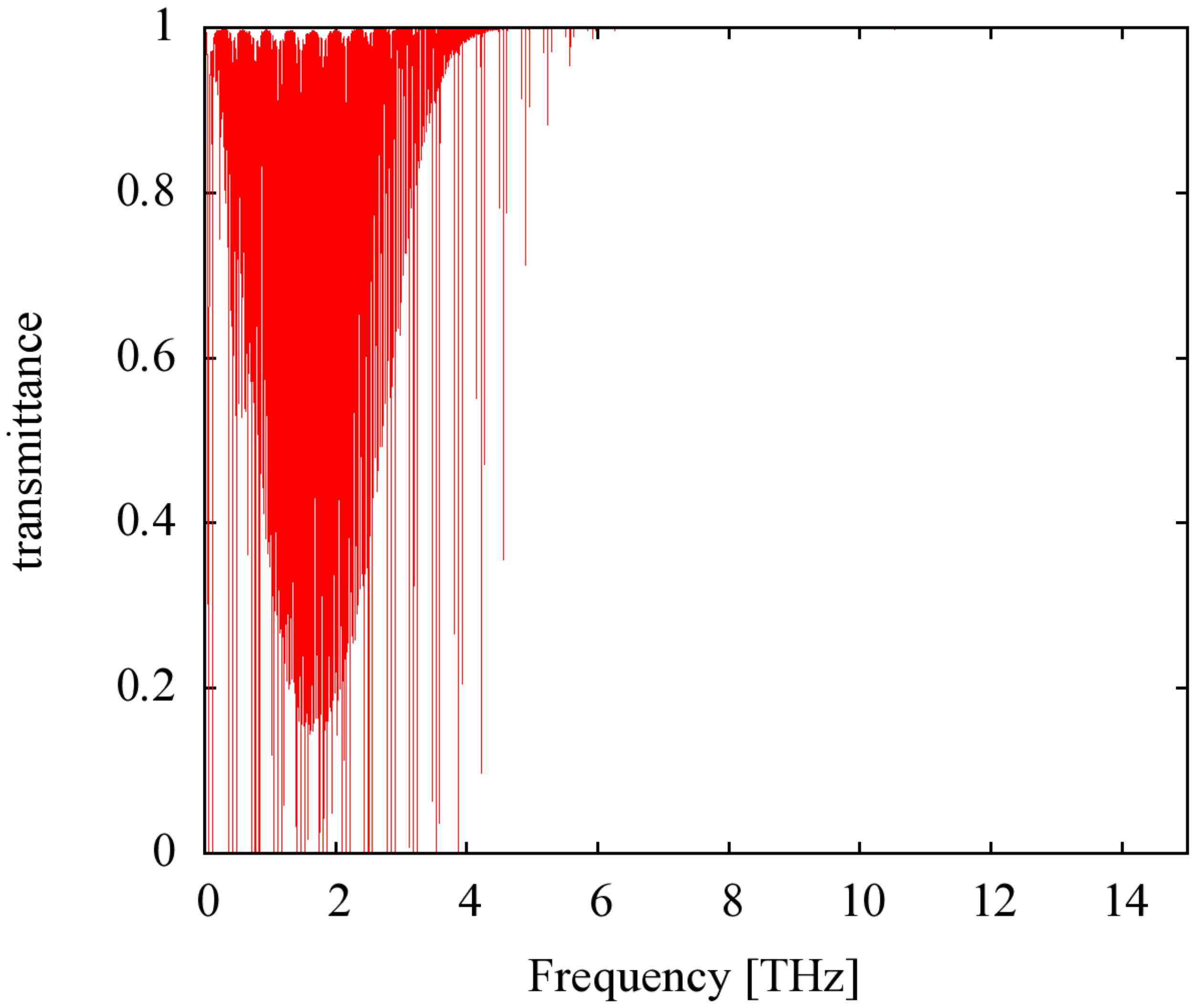
Atmospheric model absorption

Use model profiles in a radiative transfer model with:

- Dry line-by-line absorption – O_2, O_3, N_2O, CO, CH_4
- Dry collision-induced absorption – N_2, O_2
- H_2O line-by-line and continuum absorption

Look at each of these in turn, then put it all together...

Dome A dry line-by-line transmittance



Mainly O_2, O_3 pure rotation bands – occupied bandwidth is small

Collision-induced absorption (CIA)

- Broadband dry THz absorption is mainly N_2-N_2, N_2-O_2 CIA.
- Forbidden electric quadrupole and 16-pole rotational transitions acquire dipole coupling via polarization of collision partner.
- Binary process, so absorption depends on density squared.
- Collisions are brief (~10^{-12} s), so broad lines blend into an unresolved band.
- N_2-N_2 lab data is available to 90 K. N_2-O_2 can be estimated by scaling.
- O_2-x is less well-studied, but its contribution to atmospheric opacity is small.

Laboratory N_2-N_2 CIA spectrum

(Stone, et al. 1984)

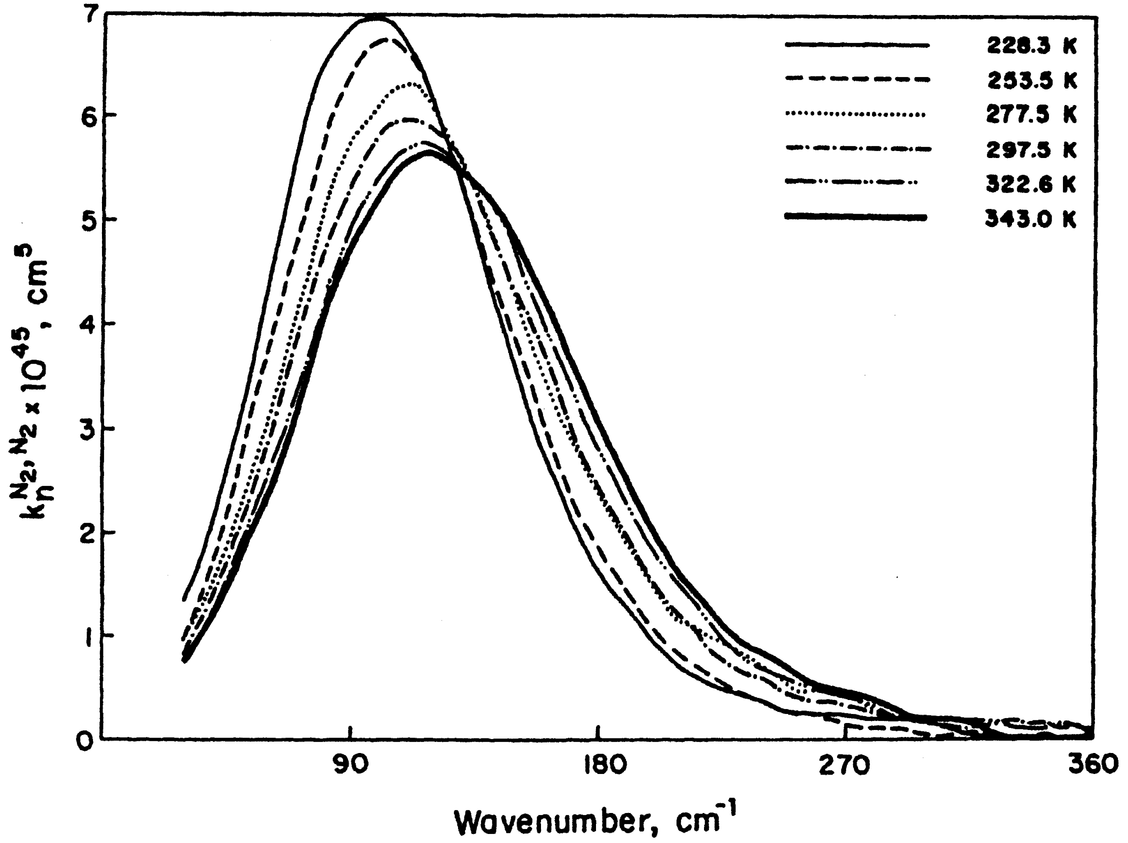
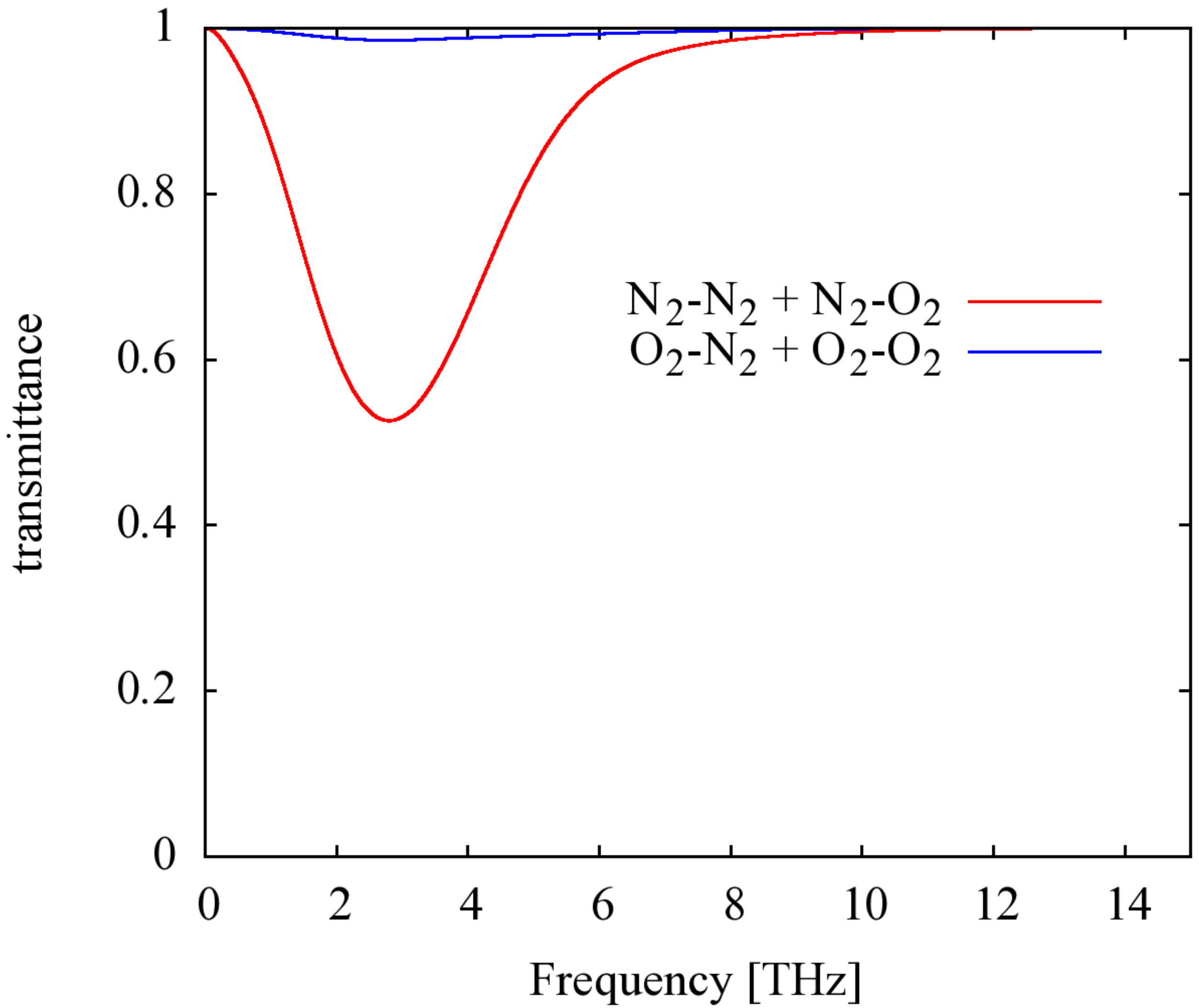


FIG. 5.2. The collision-induced rotation band of pure nitrogen (nitrogen–nitrogen collisions). The vertical axis is the binary absorption coefficient, as defined in (3.88). After Stone et al. (1984).

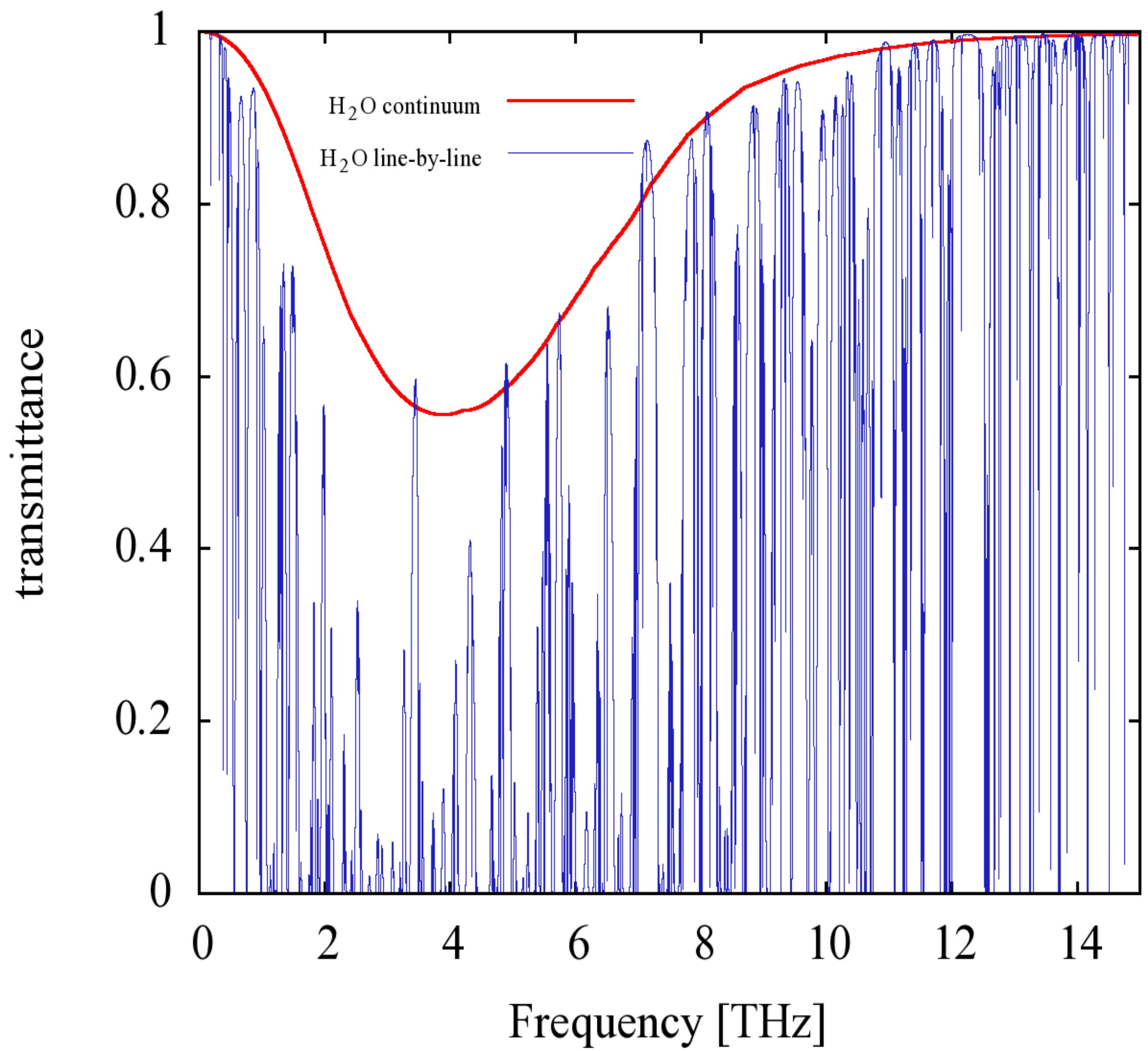
Dome A winter CIA transmittance



H_2O Continuum

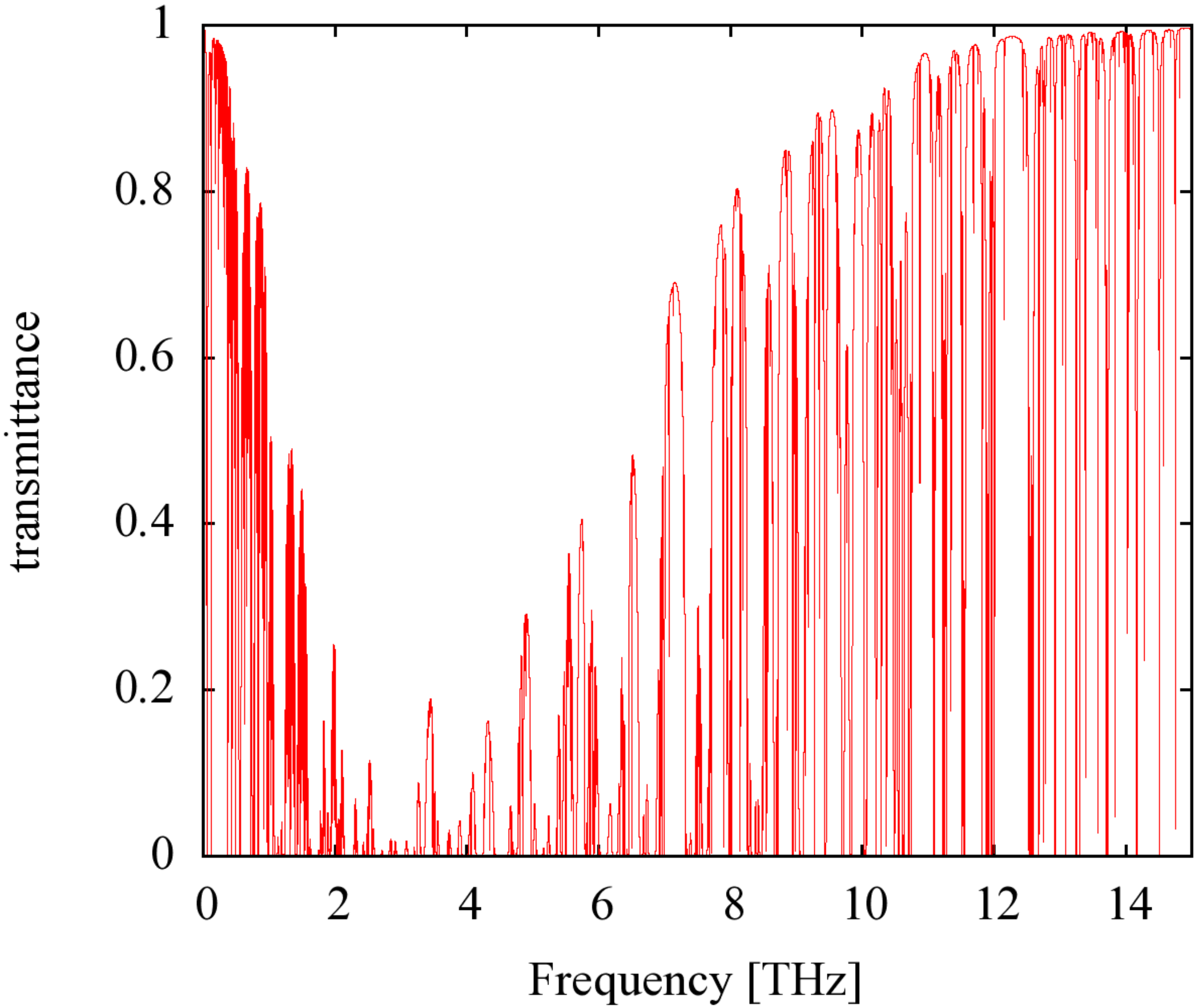
- Associated with short-range collisions
- Dipole-allowed transitions are affected, may also have a CIA component
- Difficult to study experimentally
  - Hard to disentangle from allowed line spectrum
  - H_2O vapor hard to control experimentally at low T
- Best model is MT_CKD (Mlawer, et al., see rtweb.aer.com)
  - Self-continuum defined for 260 K < T < 298 K
  - T-dependence not developed for air-induced continuum, which dominates in the dry conditions at Dome A
  - Probably not accurate at low Dome A temperatures
  - Improvements needed for RT component of climate models

Dome A H_2O transmittance (75 μm pwv)

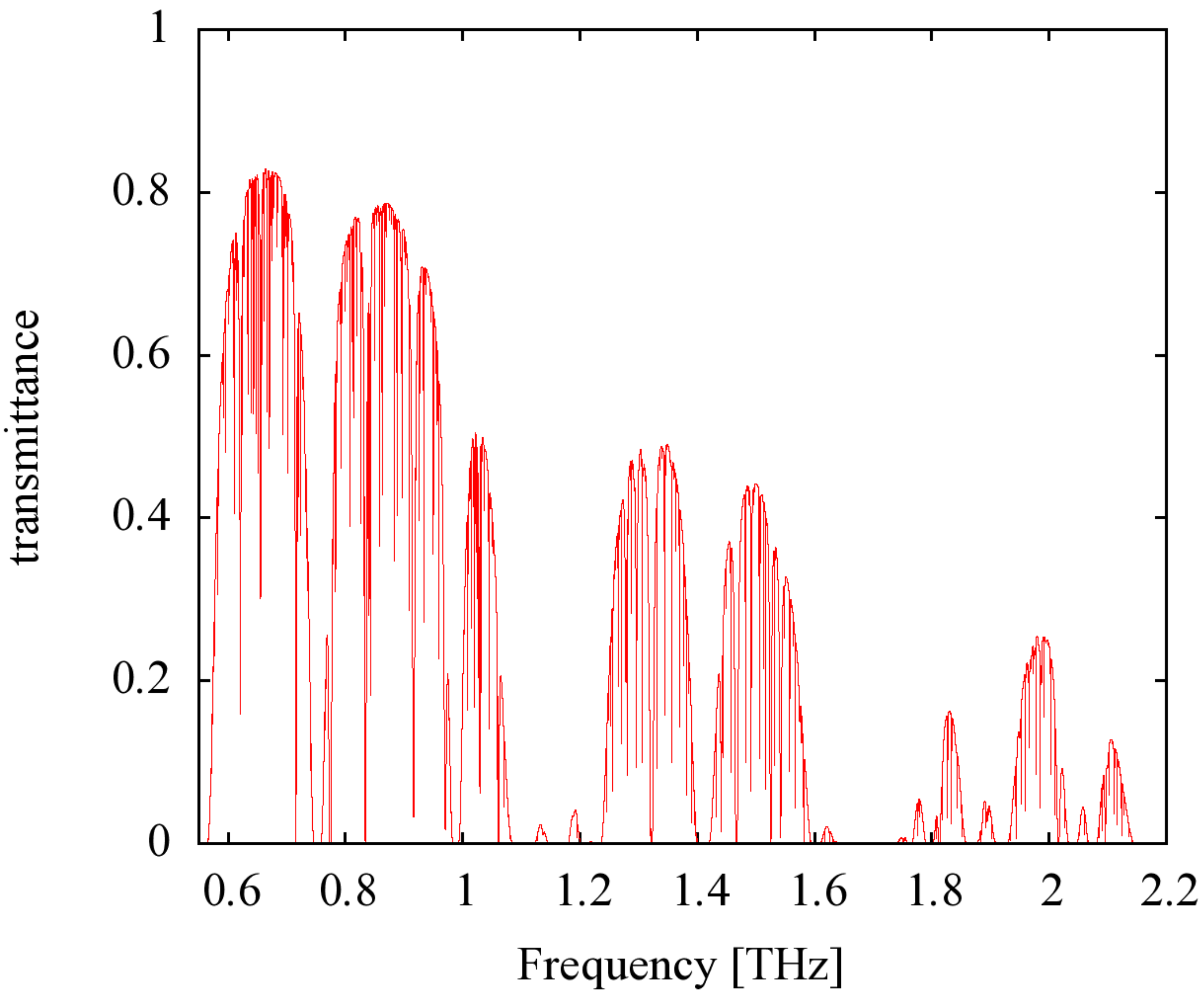


Accuracy of the T-independent MT_CKD self-continuum is questionable at such low temperatures (T < 240 K). The band can be expected to move down in frequency and sharpen. (Compare with line-by-line.)

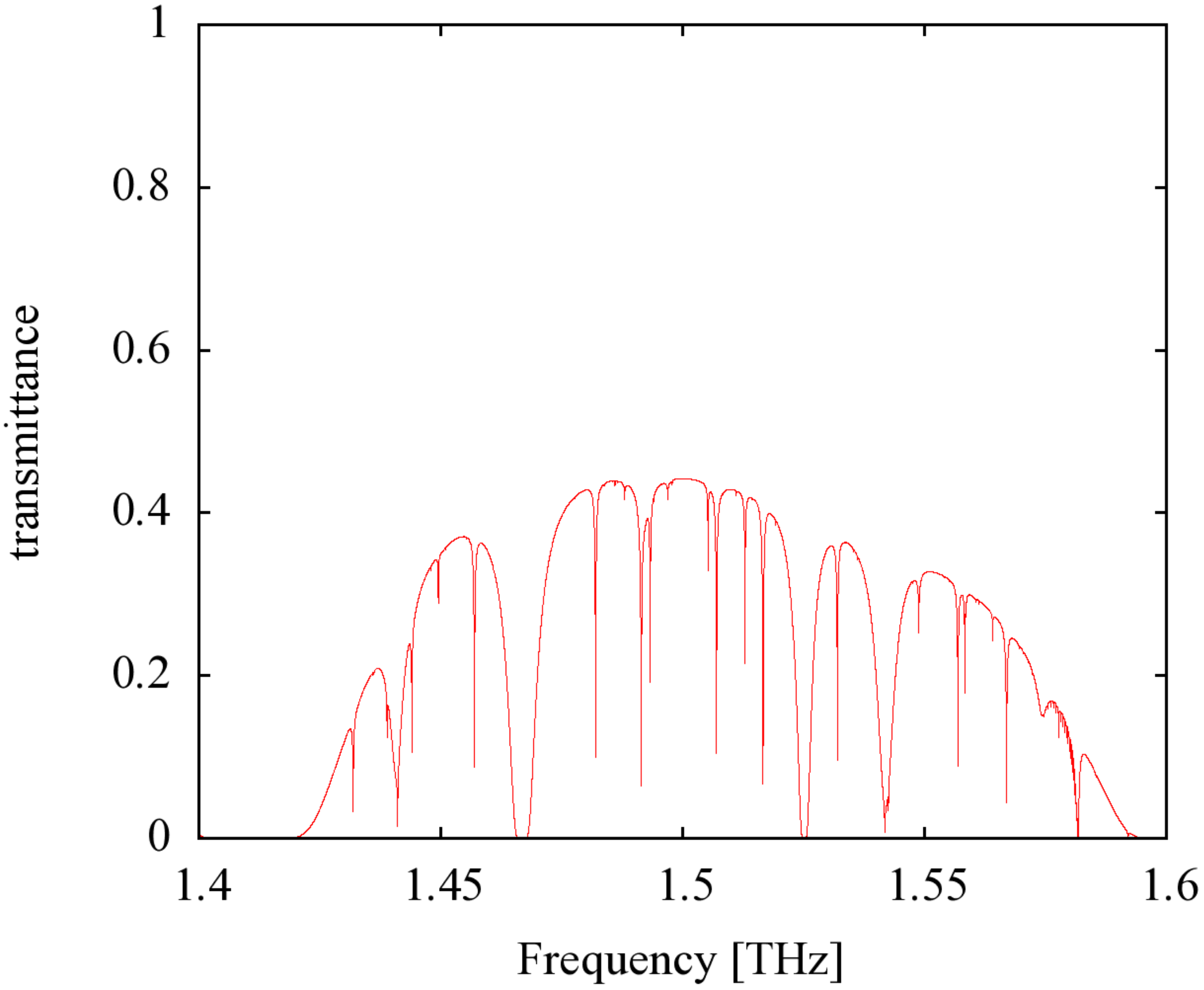
Net model transmittance (75 μm pwv)



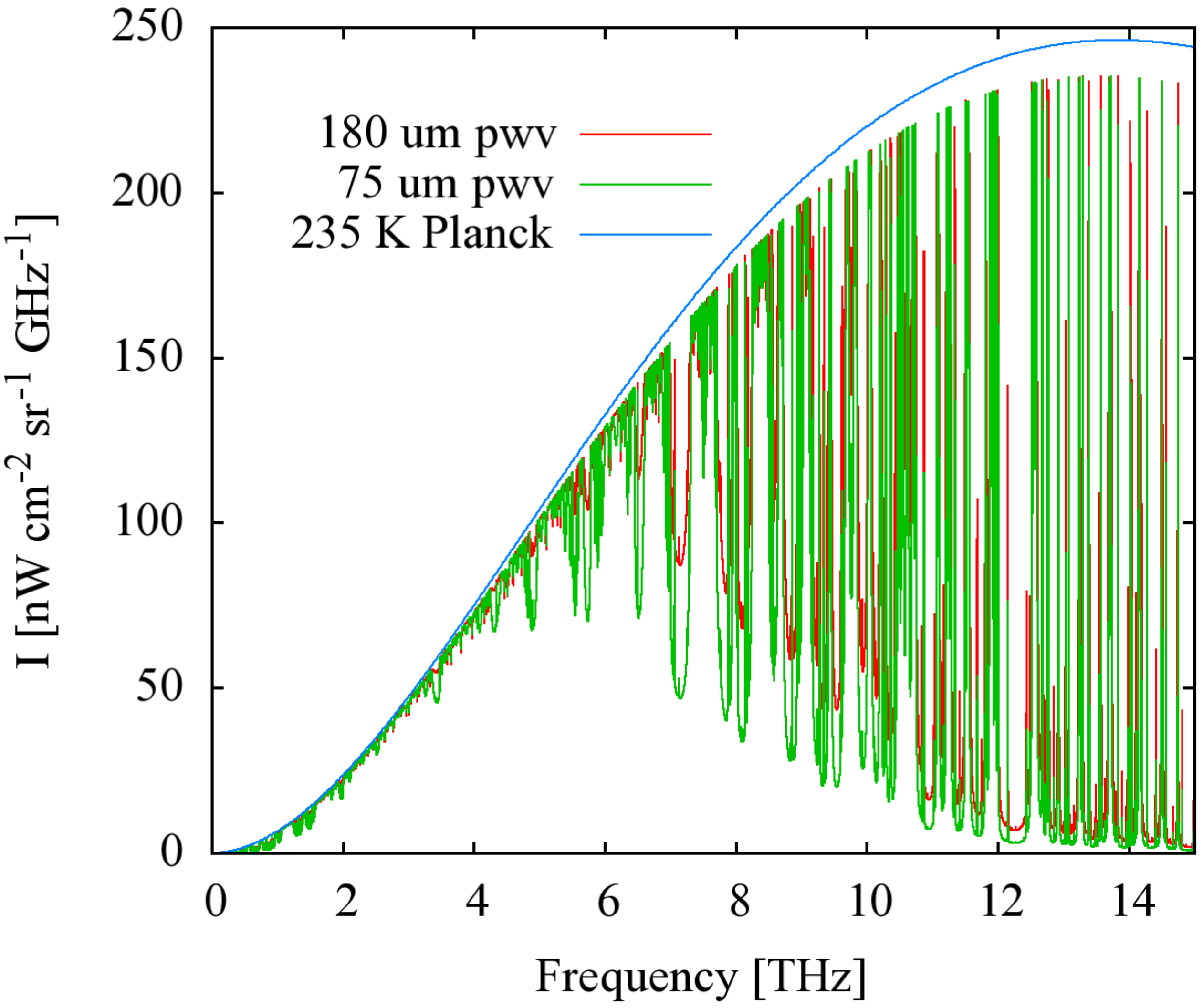
Net model transmittance (75 μm pwv)



Net model transmittance (75 μm pwv)



Net model radiance

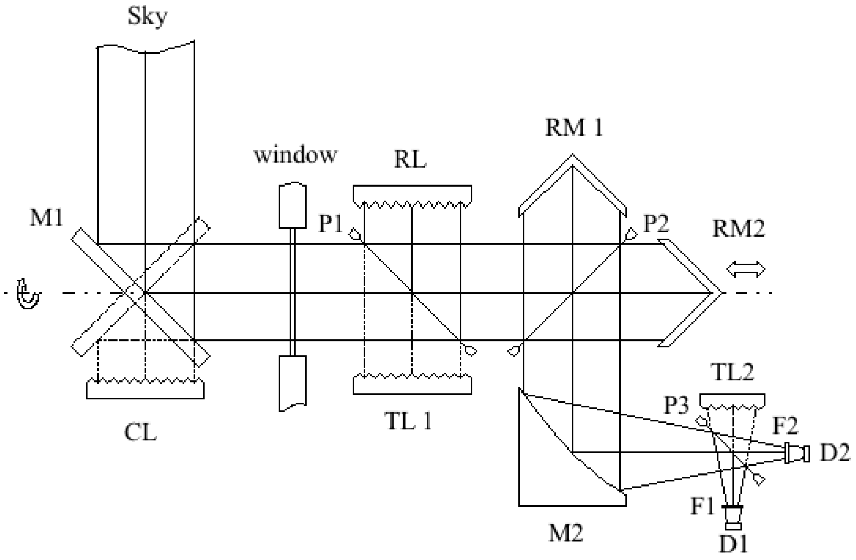


- The large dynamic range in this spectrum is a key design driver for the FTS
- Solution – split into bands

FTS design considerations

- Dome A requires low power, and no cryogens
    - ambient temperature pyroelectric detector
    - passive calibration loads
- Broad spectral coverage (0.75 THz – 10 THz)
    - cover both sides of H_2O rotation band
    - split into bands to reduce dynamic range and maximize low frequency throughput
- Measurement time ≈ 10 minutes / spectrum
    - drives optical throughput, spectral resolution, and low-frequency cutoff

Optical design concept



CL	Outside passive calibration load
D1, D2	Pyroelectric detectors and Winston cones
F1, F2	Low-pass filters
M1	Tipping mirror
M2	Paraboloidal mirror
P1, P2, P3	Wire grid polarizer
RL	Reference load
RM1, RM2	Roof mirrors
TL1, TL2	Background termination loads

- Based on JASCO-built NRO site testing interferometer design (Matsuo, et al. PASJ **50** 359 1998)
- Commercialized by JASCO as FARIS-1 lab spectrometer
- Modify for access to both polarizations at input and output

FTS sensitivity

$$SNR = \frac{P}{NEP \cdot t^{-1/2}} \qquad P = I \cdot E \cdot \Delta f \cdot \eta$$

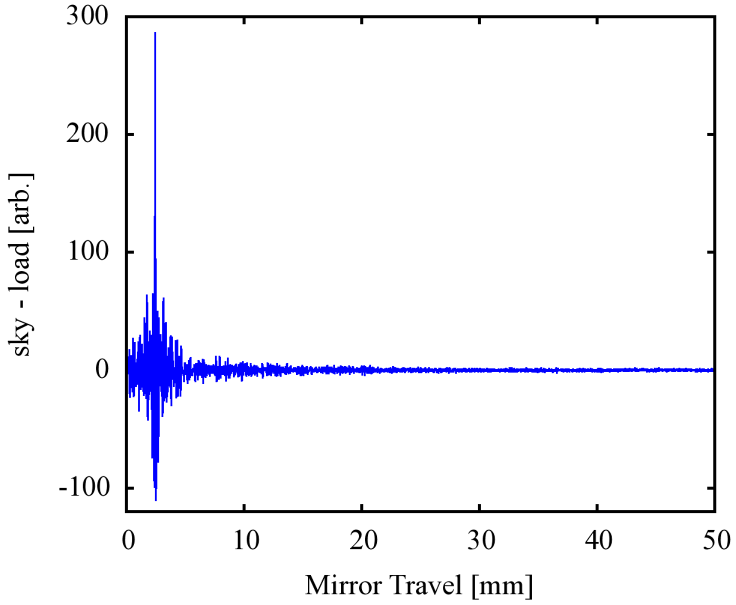
$I =$ radiance

$\Delta f =$ resolution bandwidth

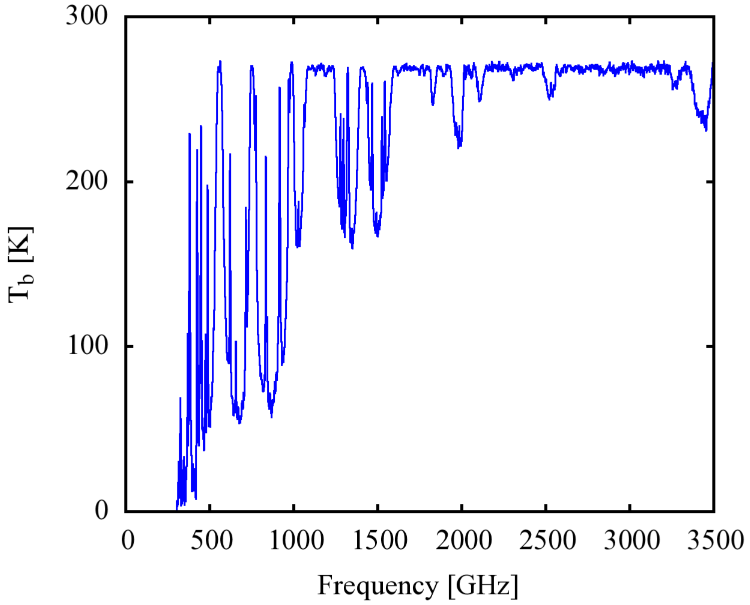
$E =$ optical throughput

$\eta =$ efficiency (assume 0.1)

FTS dynamic range



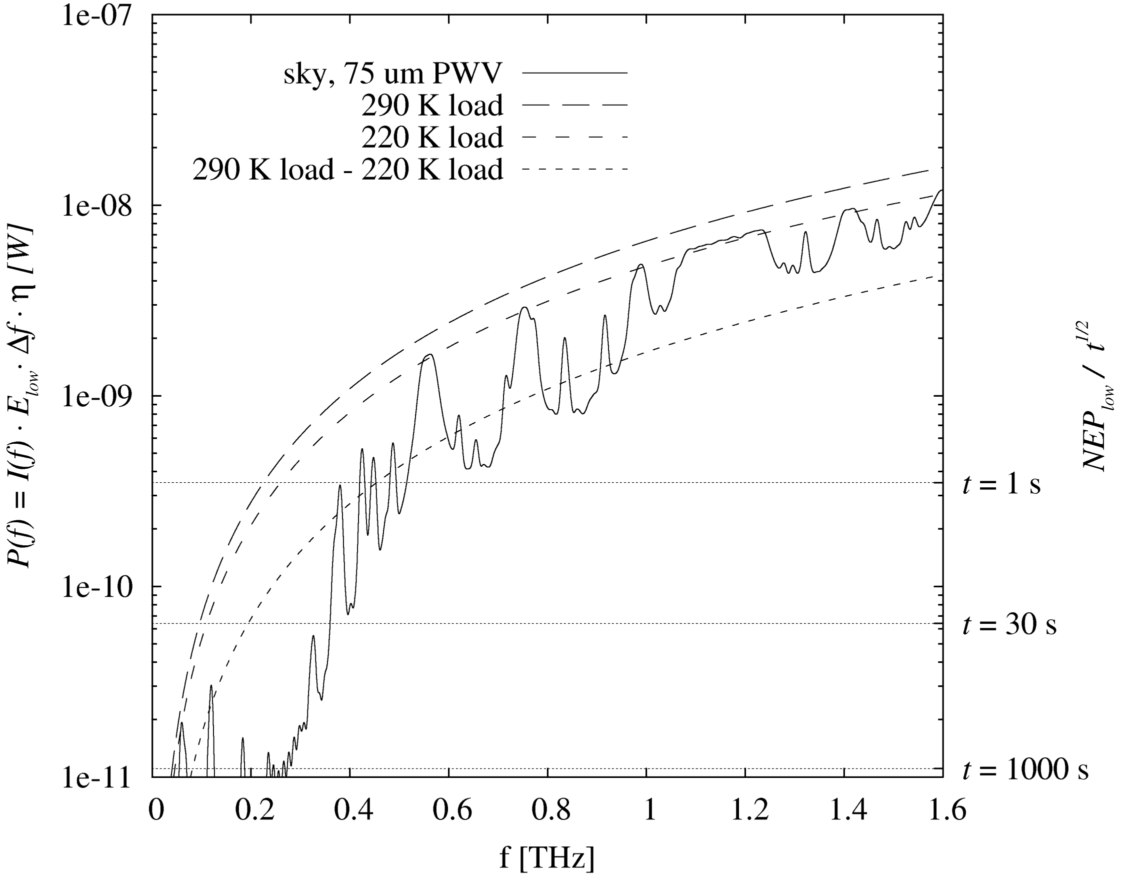
Measured interferogram



Resulting spectrum

Because of the large dynamic range of the interferogram, good linearity and stability are needed to achieve theoretical sensitivity.

Low band sensitivity



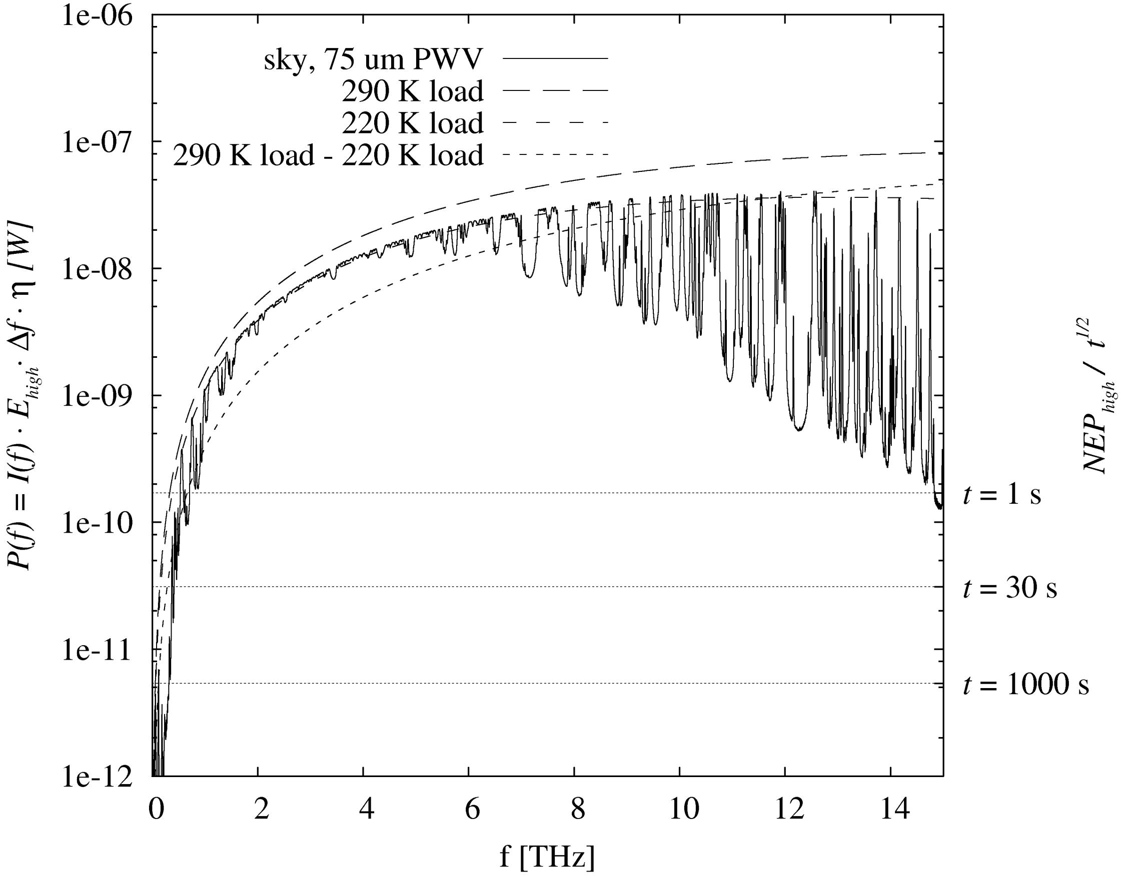
Assumptions:

$E_{low} = 0.79\ \mathrm{cm}^2 \cdot \mathrm{sr}$ (maximum possible for JASCO interferometer)

$NEP_{low} = 3.5 \cdot 10^{-10}$ watt · $\mathrm{Hz}^{-1/2}$ (DLATGS detector)

$\Delta f = 10$ GHz

High band sensitivity



Assumptions:

E_{high} = 0.18 $\mathrm{cm}^2 \cdot \mathrm{sr}$ (limited by shortest wavelength)

$NEP_{high} = 1.7 \cdot 10^{-10}$ watt · $\mathrm{Hz}^{-1/2}$ (DLATGS detector)

Δf = 10 GHz

Next steps

- Meet with vendor to finalize spectrometer design
  - This week
- Establish integration and deployment timeline
  - This week
- Window, sky mirror, and cal load design and fabrication
  - copy pre-HEAT tipping mirror design?
- Computing and software
  - Migrate vendor system to low-power embedded hardware and OS compatible with existing systems at Dome A