Current Status of Shock Layer Radiation Studies for Planetary Probes

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Basic Radiation Terminology

- **Radiative Heat Flux** is equal to the:
  - **Irradiance,** which is the integral of the:
    - **Radiance,** which is the integral of the:
      - **Spectral Radiance,** which is the integral of the:
        - **Volumetric Spectral Radiance**

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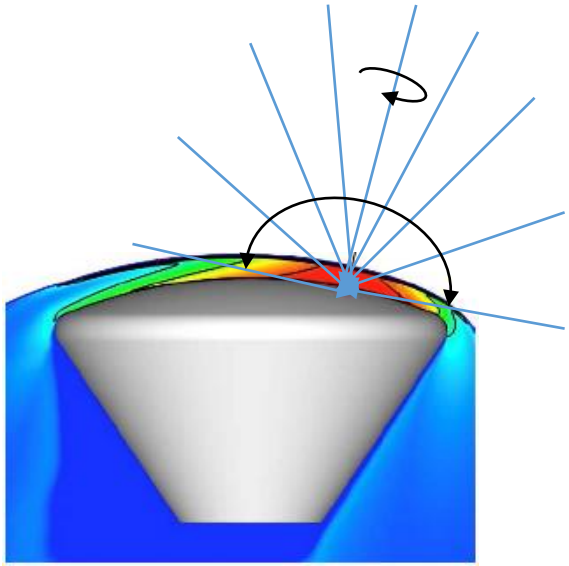
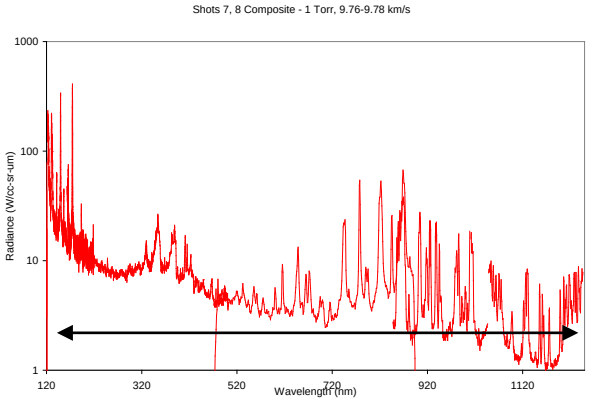
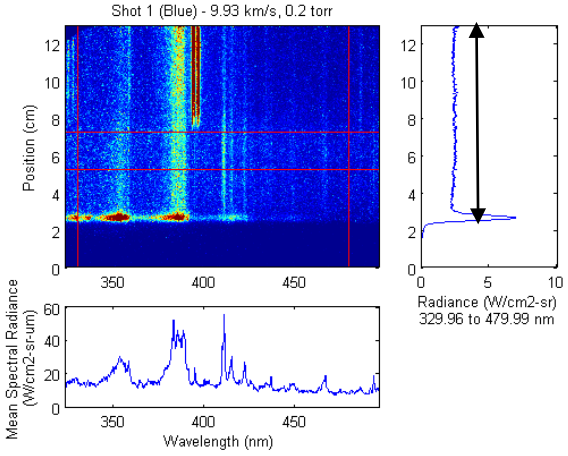
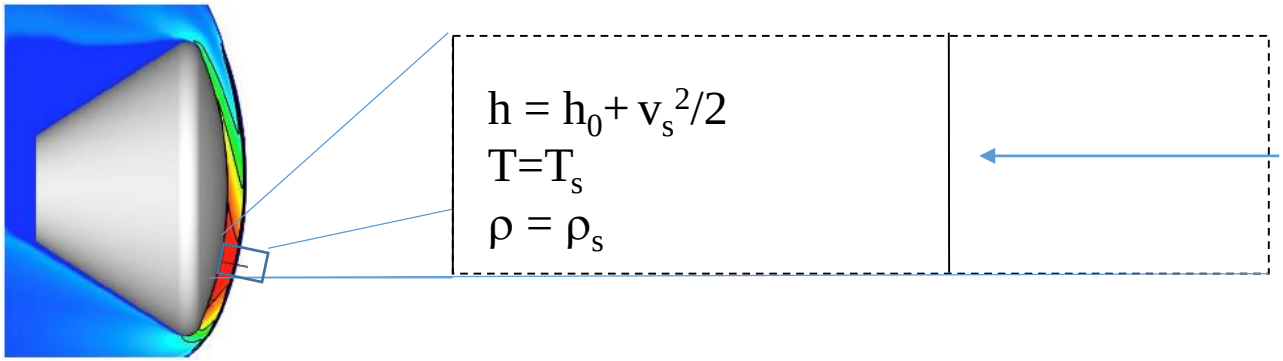




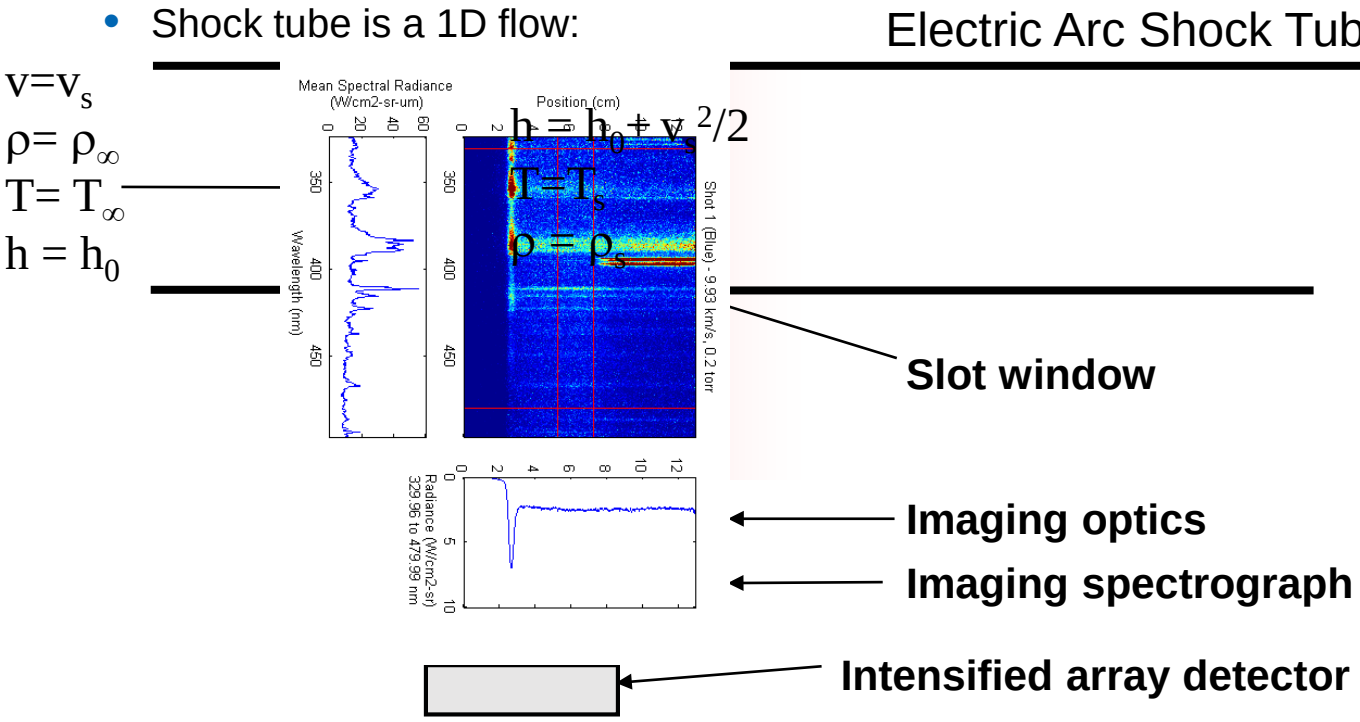


How to validate the radiation model

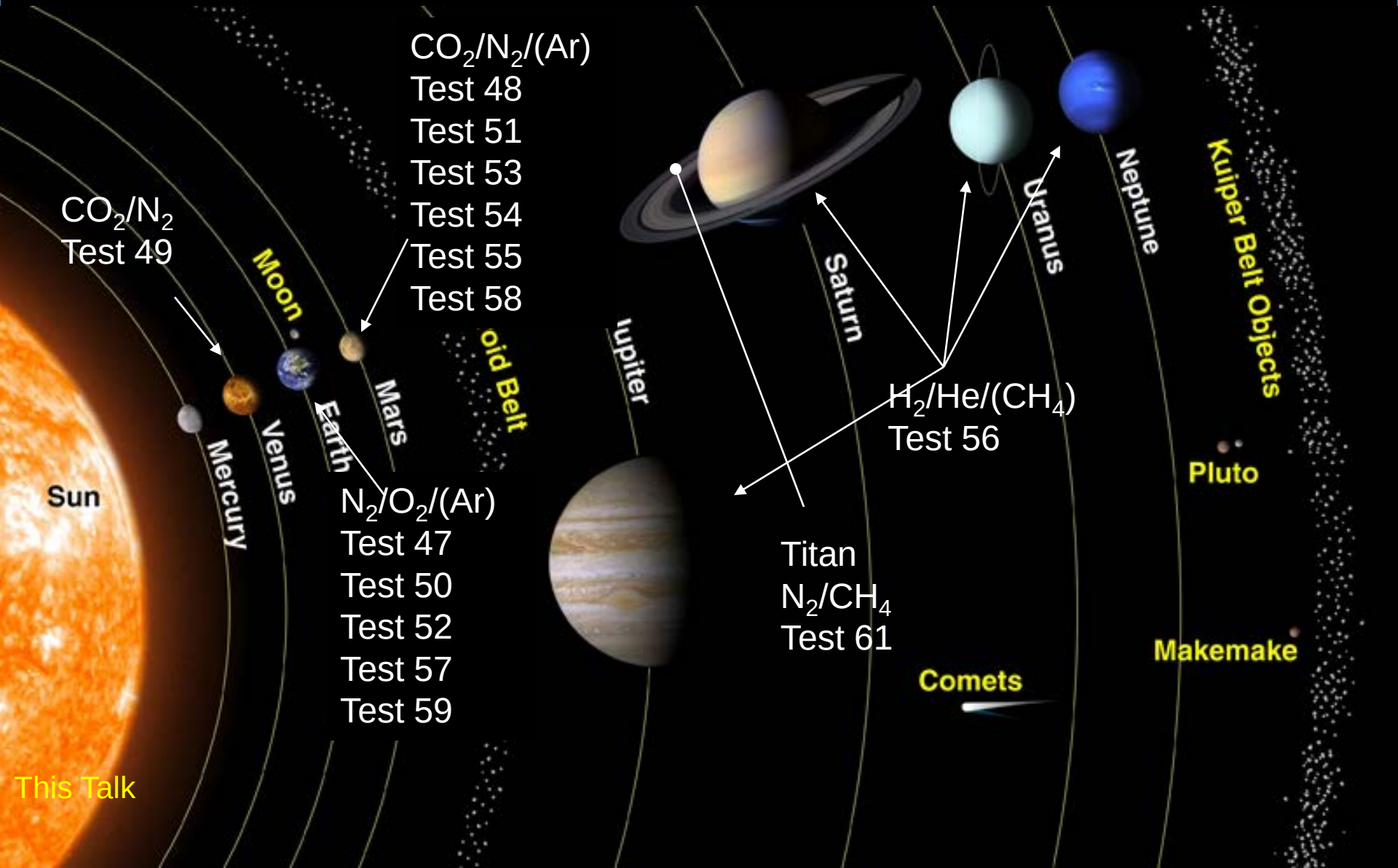
- Stagnation streamline is a 1-D flow:



- Shock tube is a 1D flow:

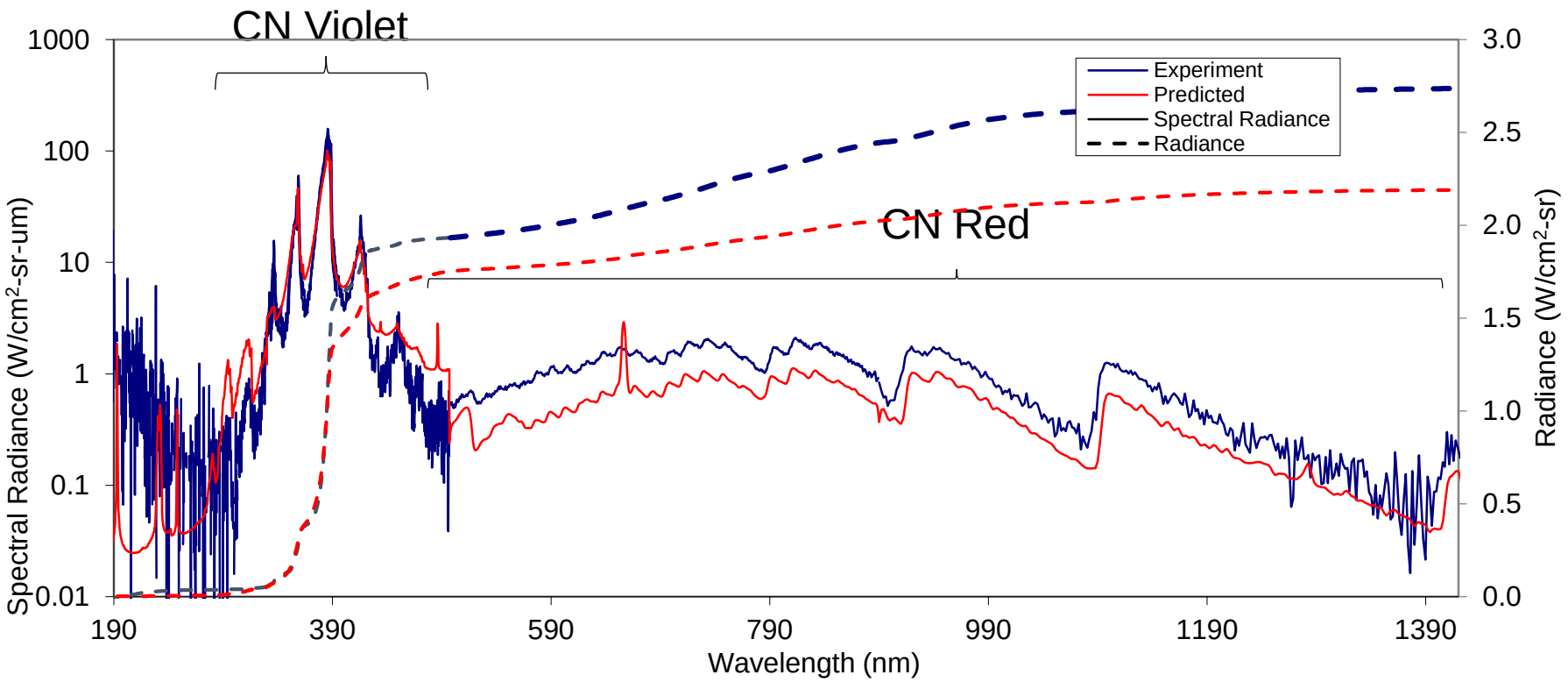


Planetary Atmospheres tested in EAST



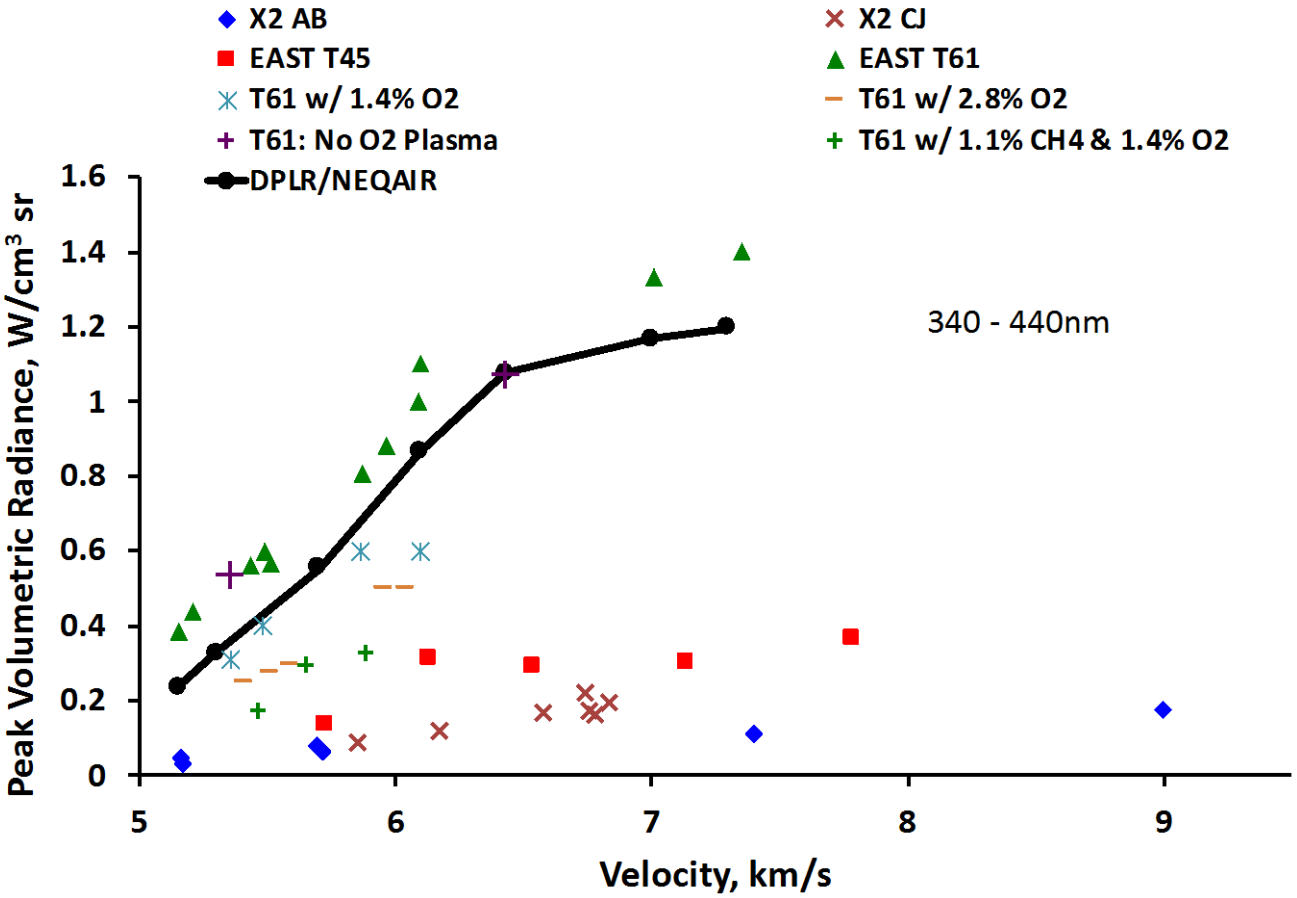
Titan

EAST Shot 61/53: 1.1% CH_4 (molar) in N_2, 5.36 km/s, 1.5 x 10^{-4} kg/m^3 (Huygens)



- Main feature of Titan Radiation is CN
  - Comes from CH_4 + N_2

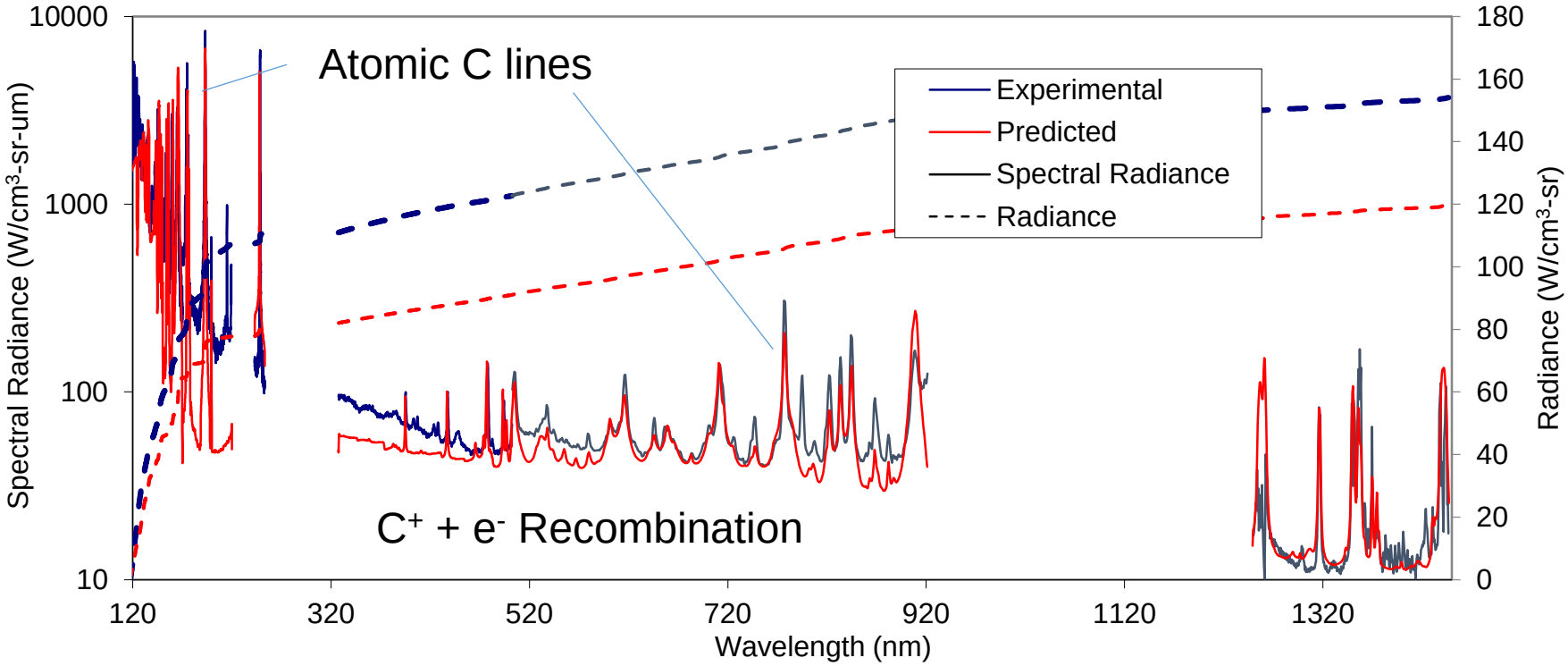
What is interesting about Titan?



- Until recently, the models were thought to be very conservative
- Newer tests showed models to be close
- Discrepancy was shown to be due partly to contamination (air leaks) in old test data, and some factors still unknown

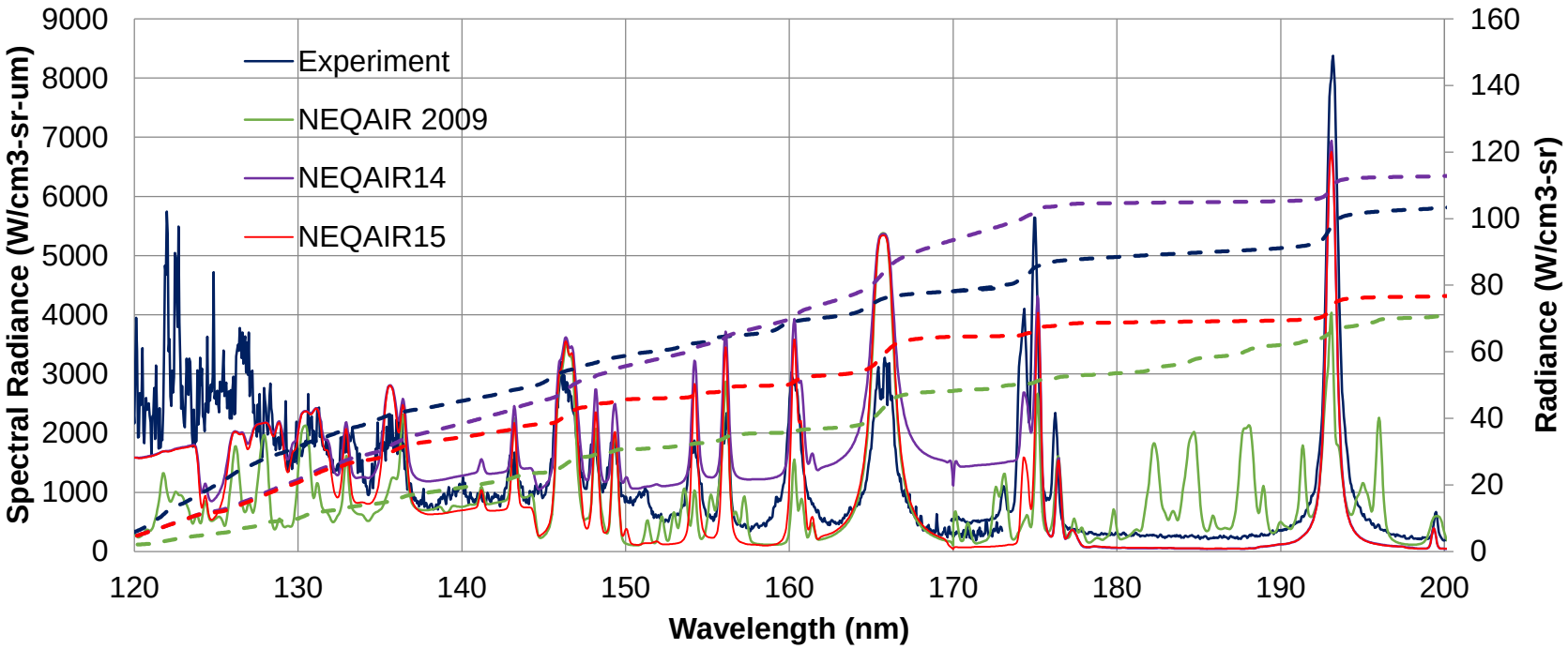
Venus

EAST Shot 49/22&27: 3.5% N_2 (molar) in CO_2, 11.4 km/s, 1.2 x 10^{-3} kg/m^3 (Pioneer)



- Main features of Venus Radiation is Atomic Carbon
  - Atomic lines
  - $C^+ + e^-$ recombination continuum
  - At lower velocity, molecular CO and CN radiation contribute

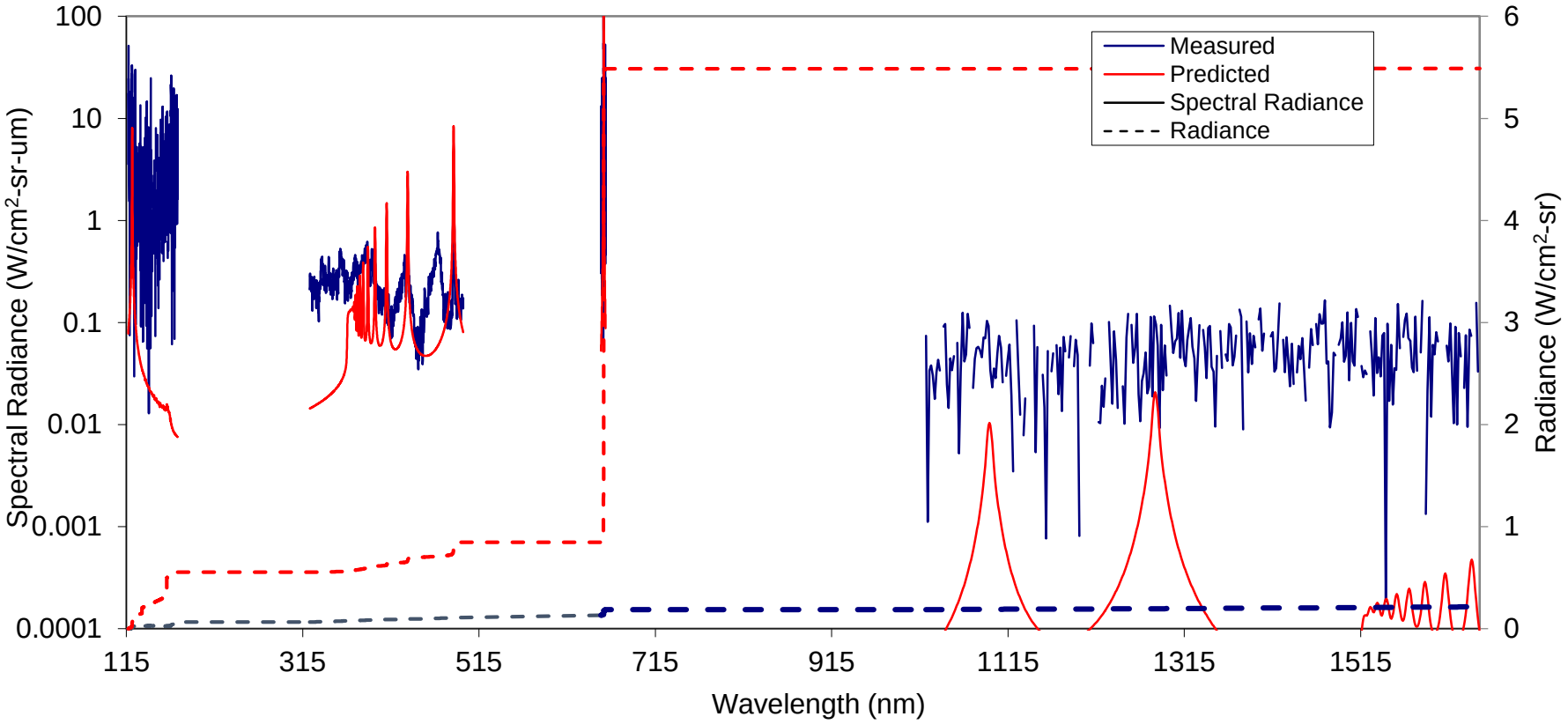
What is interesting about Venus?



- VUV continuum radiation was underpredicted (v13)
- Correcting NEQAIR database (v14) led to overprediction
- An error in the database interpretation routine (corrected v15) eliminated the overprediction
  - Model is not conservative
- Additional database data (Quantum Mechanics Calculation) required

Uranus

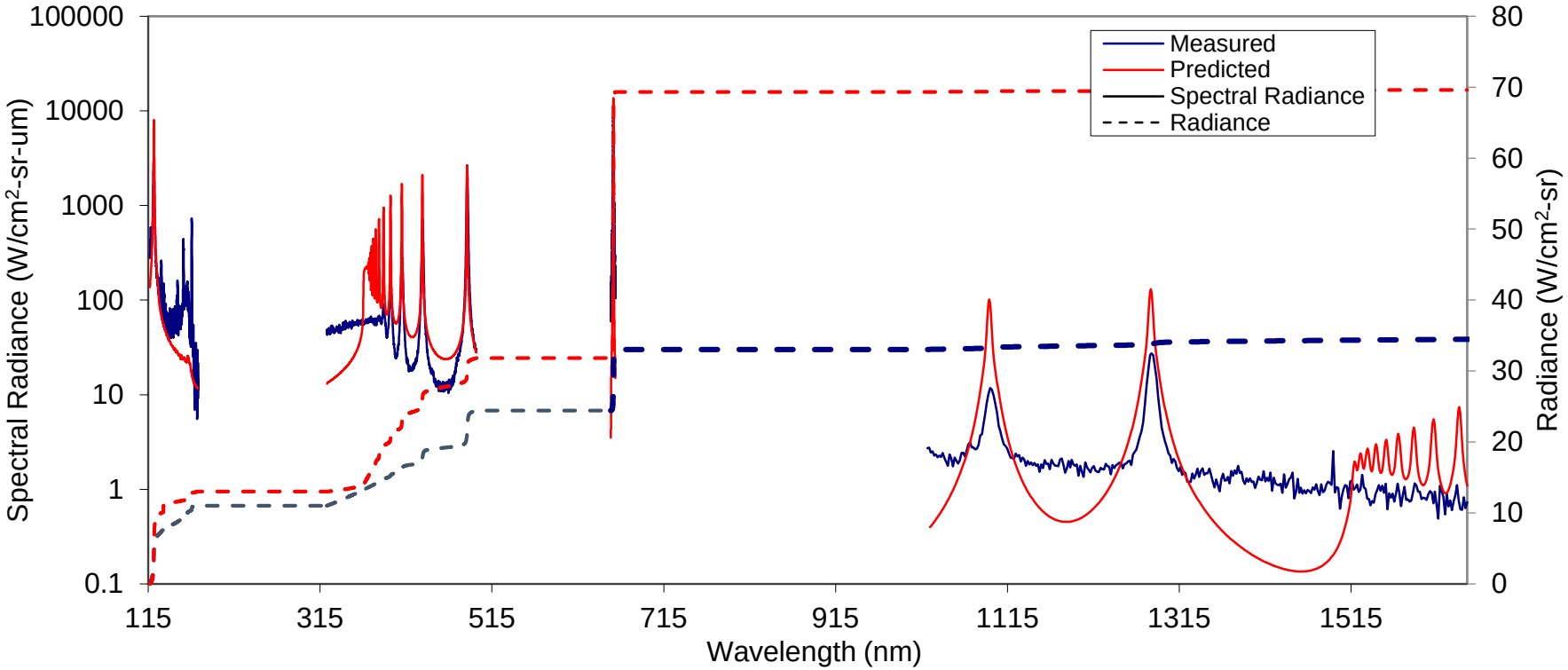
EAST Shot 56/18: 11% He (molar) in H_2, 25.69 km/s, 1.2 x 10^{-5} kg/m^3 (Tauber-Wiercinski)



- Most of the data is spectrometer noise floor
  - Radiance nearly insignificant
  - Prediction is small in magnitude, but significantly over measurement

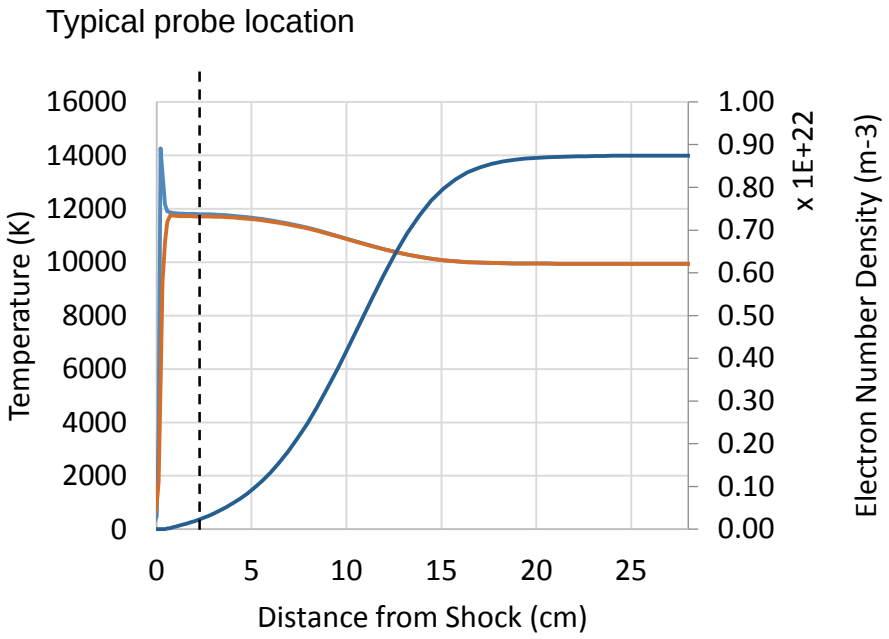
Saturn

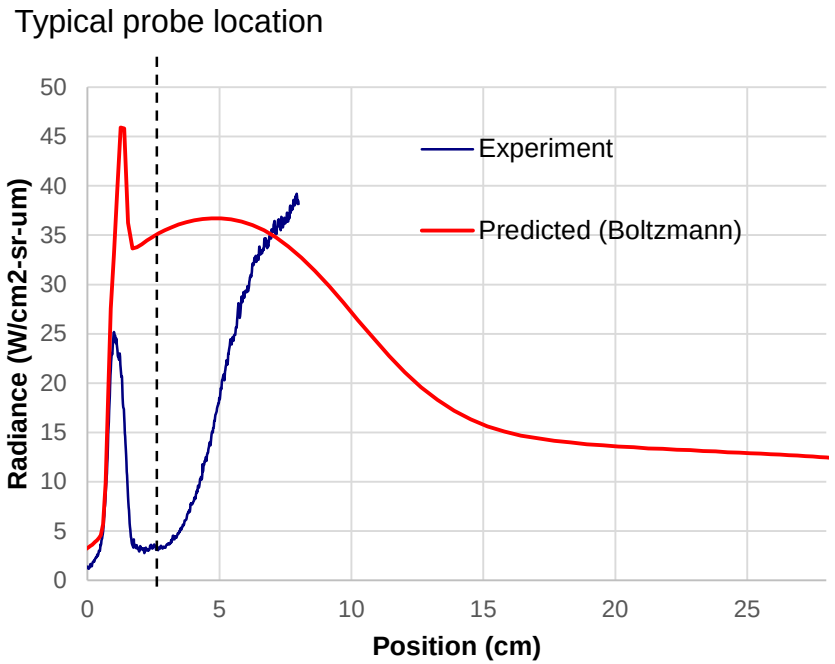
EAST Shot 56/22: 11% He (molar) in H_2, 27.66 km/s, 6.0 x 10^{-5} kg/m^3 (Prabhu)



- Main feature of Saturn Radiation is atomic H
  - Molecular H in non-equilibrium

What is interesting about Saturn Radiation?





- Ionization in Saturn Entry is very slow
  - Does not come to equilibrium
  - Temperature is elevated
- Boltzmann significantly overpredicts non-equilibrium (conservative)
- Trace amount (0.5%) of CH_4 may change ionization rate?

Summary/Recommendations

- EAST Facility provides a way to test radiative heating models
  - Has been used for building margin policy, revising best practices
- Discussed general features and questions about radiation for Titan, Venus and Saturn probes
- Approximate Heating Magnitude (1m sphere)/Confidence:

	q_{Rad} (W/cm^2)	Fraction of Total Heating	Confidence
Titan	10	3%	± 30%
Venus	5800	40%	± 30%
Uranus	5	0.5%	Conservative (Boltzmann)
Saturn	15	0.5%	Conservative (Boltzmann)

Note: Significant dependence on probe size and velocity

- This talk has not addressed backshell radiation!
  - Backshell radiation is always (?) less than forebody radiation
  - But it often exceeds convection (e.g. Titan, Mars)
  - May have different mechanisms than forebody heating

Backup

Basic Radiation Terminology

- **Radiative Heat Flux** is equal to the:
  - **Irradiance** is the integral (over *solid angle*) of the:
    - **Radiance** is the integral (over *wavelength*) of the:
      - **Spectral Radiance** is the integral (over *distance*) of the:
        - *Radiative Transport Equation*, which to first order is the
          - **Volumetric Spectral Radiance**

How we model radiation

- Flowfield solution gets a map of species number densities, temperatures at every grid point
- Extract a “line of sight” (LOS) through the flow field to the body
- Pass the LOS to NEQAIR
- NEQAIR solves
  - Non-Boltzmann Equation (density of excited states)
  - Atomic and Molecular emission and absorption coefficients (**Volumetric Radiance**)
  - Radiative transport equation (**Radiance**)
  - Tangent Slab or Full Angular Integration (**Irradiance**)
  - Integrate over wavelength