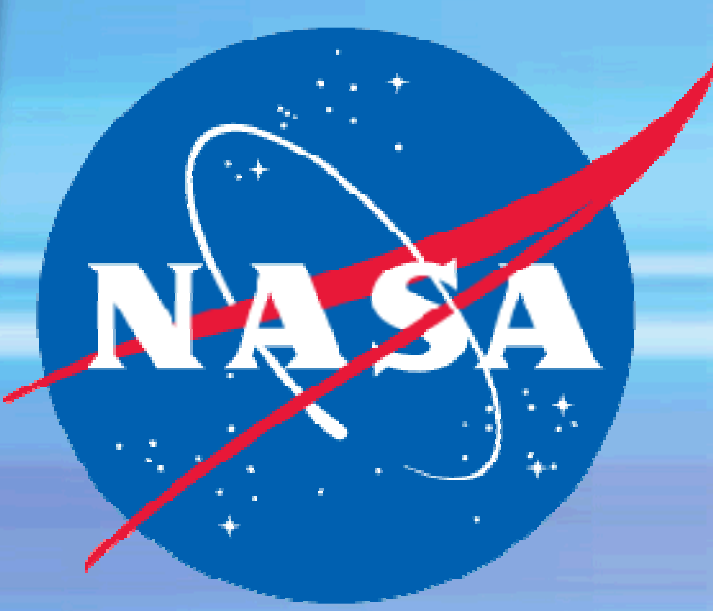




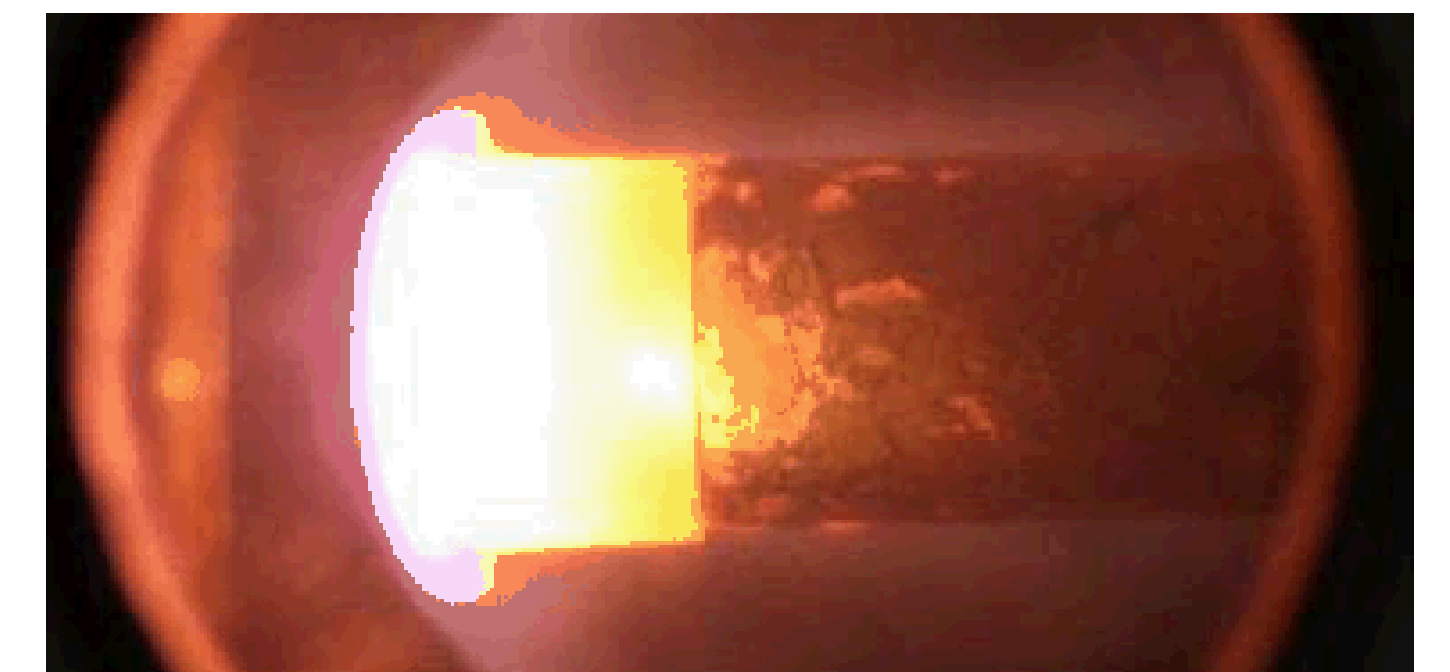
Quantitative Spectral Radiance Measurements in the HYMETS Arc Jet Facility



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- Overview:** *Nonintrusive spectral analysis of high enthalpy hypersonic flow, simulating atmospheric entry, was produced for passive and ablative heat shield materials. A calibrated fiber-optic coupled spectrometer was used to determine shock structure and prominent radiative chemical species.*

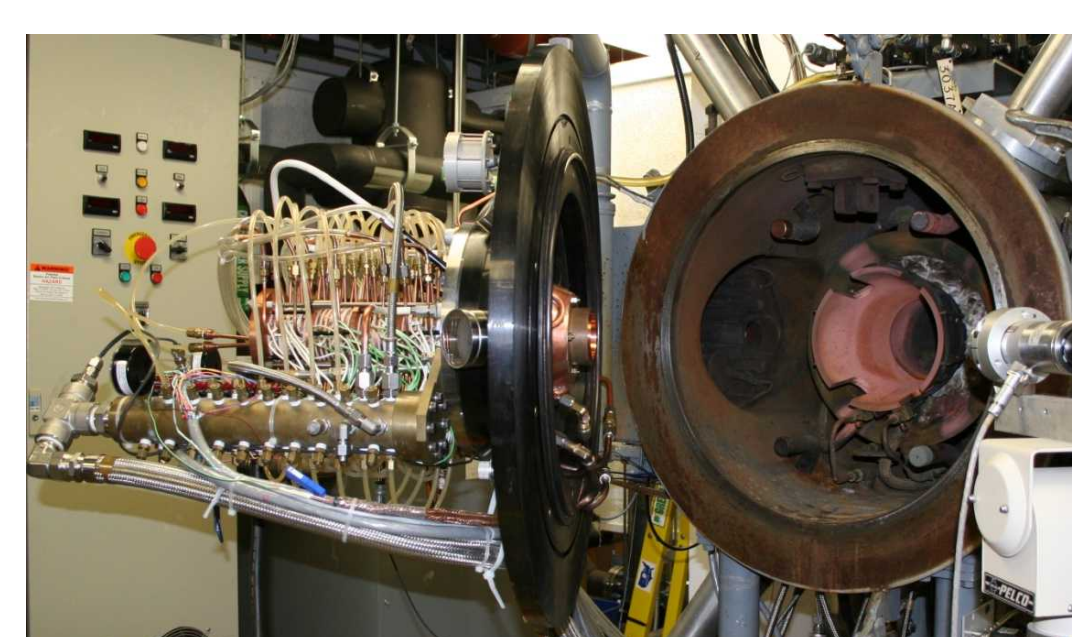


Arcjet Testing of a 1" Diameter Sample in HYMETS

Motivation and Techniques:

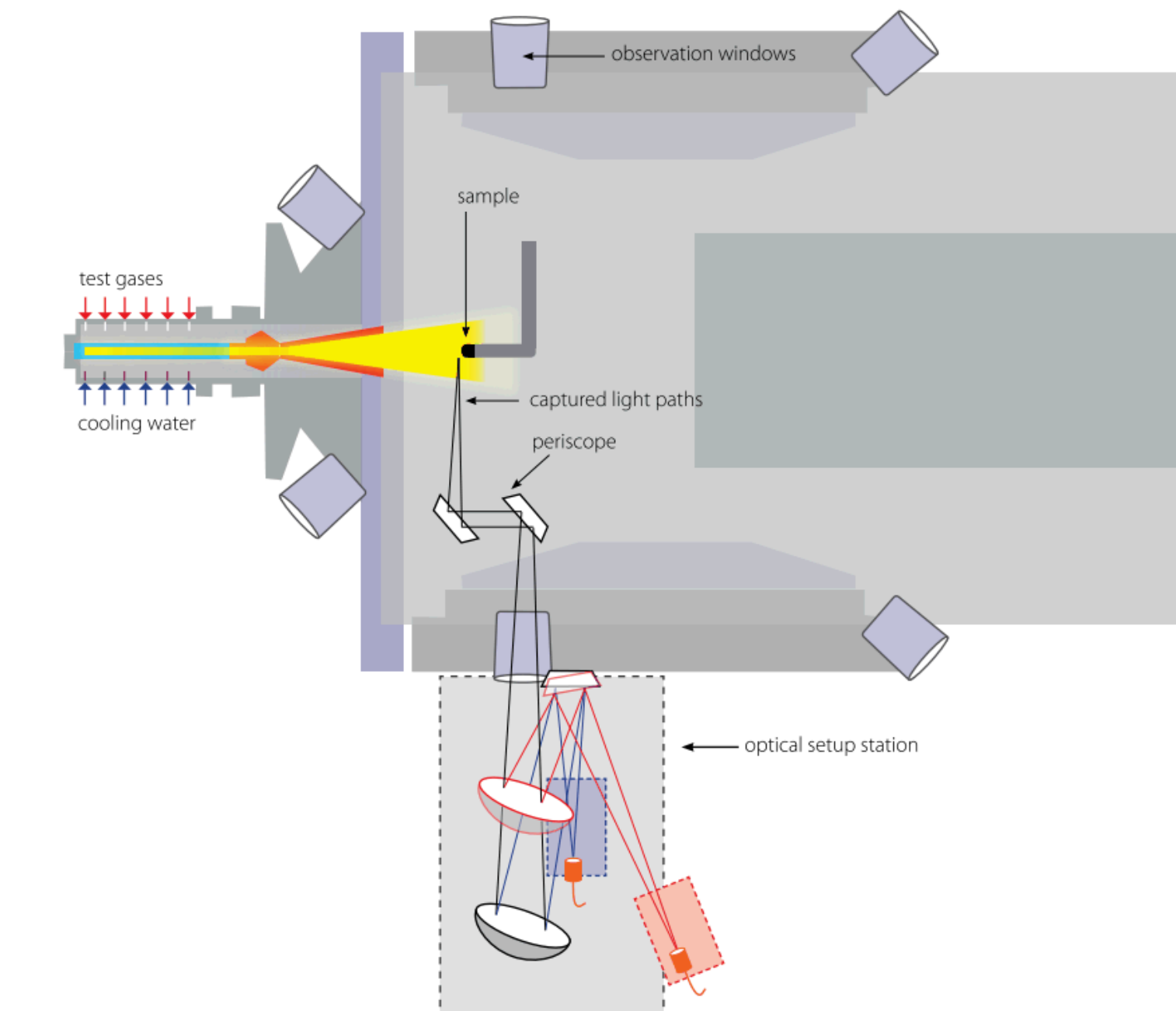
- Thermal Protection Systems (TPS) are critical components to hypersonic aircraft
 - Frictional heating above Mach 5 causes atmospheric gases to superheat space vehicles
 - Hypersonic vehicles are given blunt shapes to induce a bow shock layers that help insulate the craft and manage heat transfer
- Quantitative measurement of shock wave structure and ablation products are required to validate physics-based computational ablation models
 - Minimize TPS mass, maximize TPS protection
- Nonintrusive optical measurement systems must be developed to understand the system dynamics.
 - UV-Visible-Infrared Emission Spectroscopy

Hypersonic Material Environment Test System (HYMETS): 400 kW Arcjet Facility



- Power Supply: 400 kW
 - Johnson Space Center: 10 MW
 - Ames Research Center: 20 – 60 MW
- Specific bulk enthalpy: $5-28 \frac{MJ}{kg} \left(2-12 \frac{kBTU}{lb_m} \right)$
- N_2 , O_2 , and CO_2 process gases
 - Simulated Earth: 75% N_2 , 20% O_2 , 5%Ar
 - Actual Earth: 78% N_2 , 21% O_2 , 1%Ar
 - Simulated Mars: 71% CO_2 , 24% N_2 , 5%Ar
 - Actual Mars: 95.3% CO_2 , 2.7% N_2 , 1.6%Ar
- Mach 5 conical copper nozzle (~8° half angle)
- 25 mm (1 inch) diameter samples

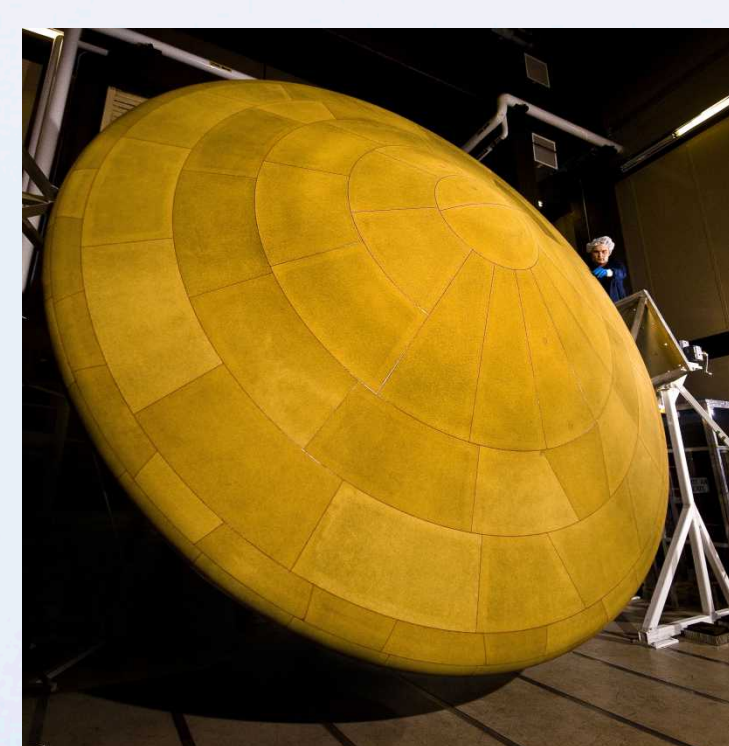
- Gas combinations simulating varying atmospheric environments are accelerated in an arc plasma generator, move through a converging-diverging Mach 5 nozzle, and into a low pressure diffuser.
- Blunt samples of heat shield material are placed in the path of the plasma flow, exposing them to high enthalpy and high velocity flows, replicating the harsh conditions to which TPS are exposed.



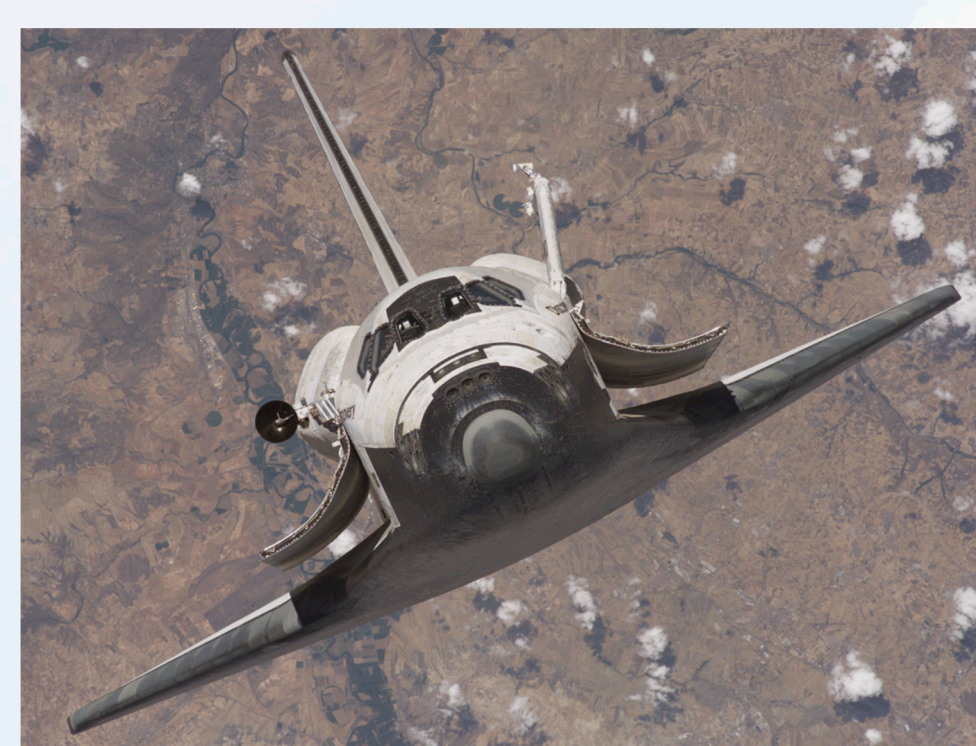
- A bow shock layer forms in front of the sample and the different species radiate light at specific wavelengths.
- A fiber-optic-coupled spectrometer mounted to translation stages gathers data from a focused region in the flow
- The translation stages allow the focused region to move within the flow, providing a map of the region.

Materials Background

- Two TPS material classes are explored: Passive and Ablative.
- Passive materials do not chemically react to the hypersonic flow.
 - Reusable
 - Most effective at lower enthalpy regimes
 - Radiate thermal energy and insulate
 - Example: Space Shuttle Tile
- Ablative materials react chemically with the hypersonic flow
 - Non-reusable
 - Most effective at higher enthalpy regimes
 - Endothermic surface reactions and pyrolysis absorb heat
 - Example: Unmanned Probes
- Test Samples:
 - Silicon Carbide (SiC): used on the nose and wing tips of the Space Shuttle
 - Phenolic Impregnated Carbon Ablator (PICA): TPS material for the Mars Science Lab and the Orion MPCV



PICA forms the TPS for the Mars Science Lab



SiC coats the space shuttle nose and forward wing edges

Future Directions

- Improving the resolution of the spectrometer may allow for the identification of distinct vibrational and rotational molecular emission bands.
- An Abel transform may be applied to the data and used to produce a spatially-resolved thermodynamic and chemical map of the flow field.
- Optimization of the ultraviolet-visible-infrared spectrometer, as well as infrared absorption techniques and laser based characterization tools such as NO laser induced fluorescence (NO-LIF) will accurately characterize the flow.

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Results: PICA

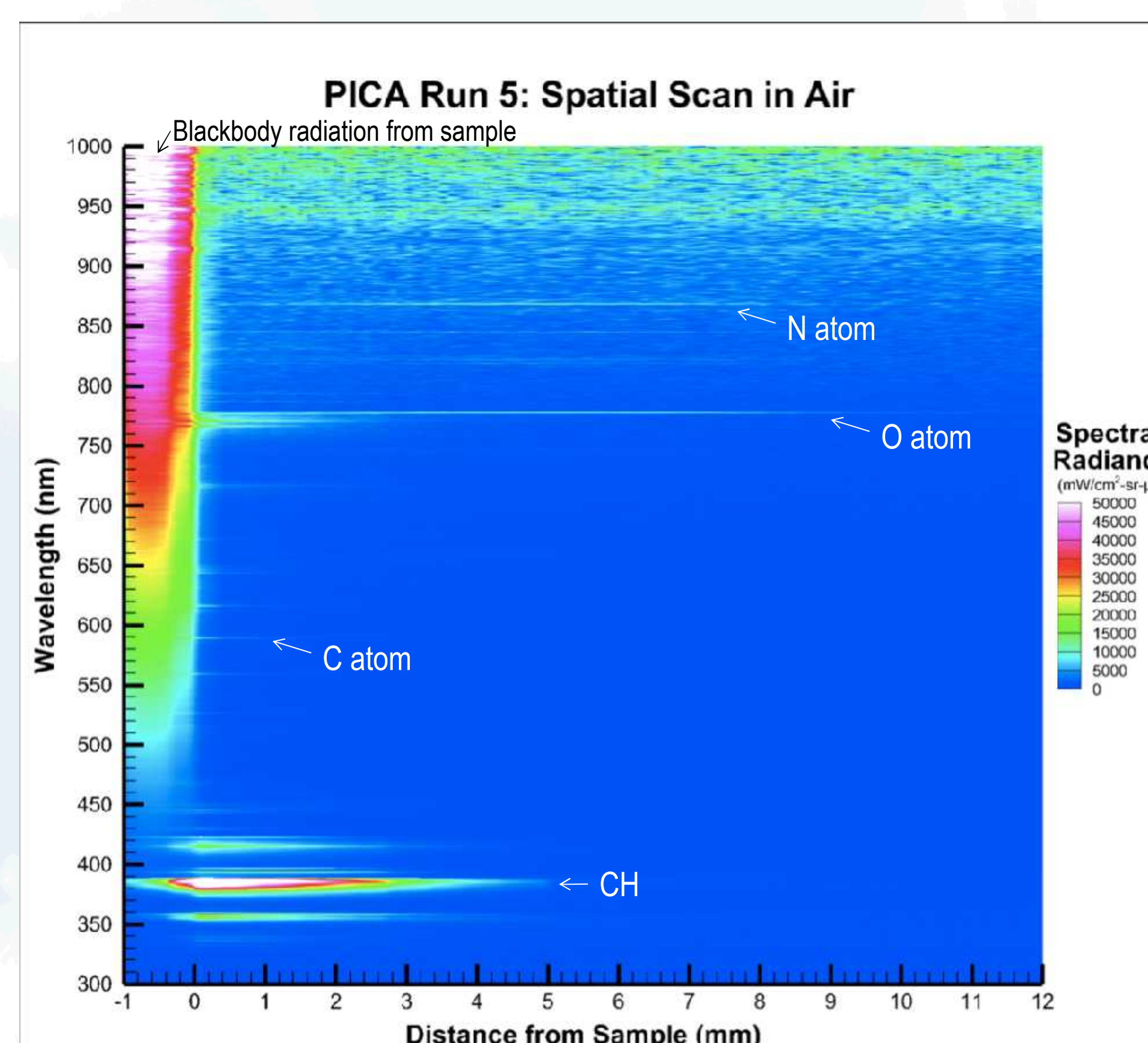


Figure 1: Compilation of continuously-gathered spectra from PICA specimens, obtained by continuously scanning the measurement volume normal to the surface. The sample surface is located at zero.

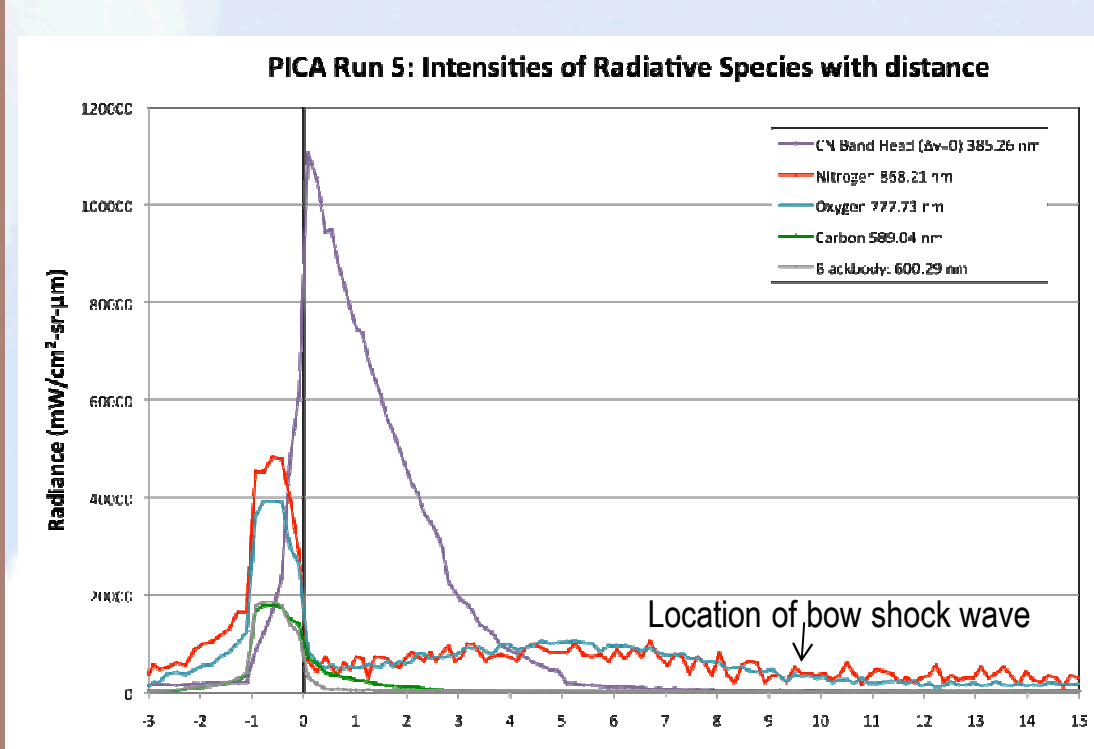


Figure 2: Intensities of radiative species in the flow versus distance in front of the sample. N-atom, and O-atom emission help to map the shock structure. N_2 and O_2 molecules dissociate in the shock wave, while carbon sublimates and recombines with nitrogen atoms to forms CN, a strong radiator which only occurs close to the sample. The shock standoff distance is 9.5 mm in front of the sample.

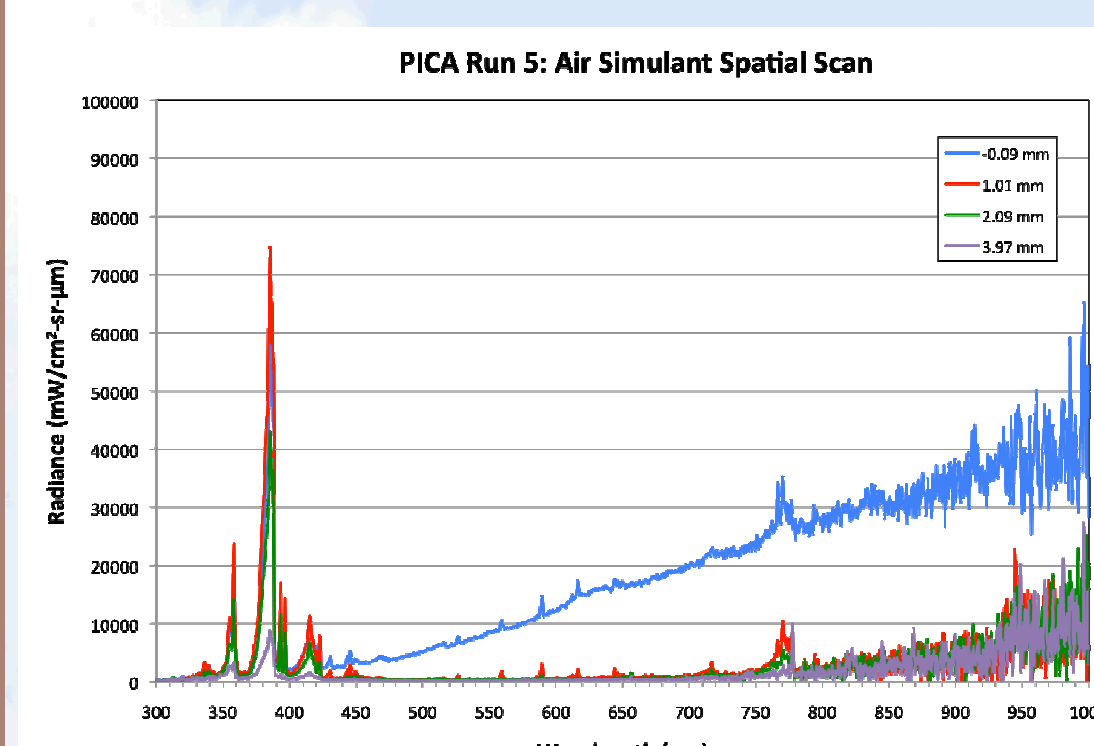


Figure 3: Discrete spectra from a PICA specimen run with simulated air composition. Spectra at different distances in front of the sample are shown. Prominent emission bands are found in the near ultraviolet. The spectrum taken at the surface (blue) includes blackbody radiation from the incandescent PICA specimen.

Results: SiC

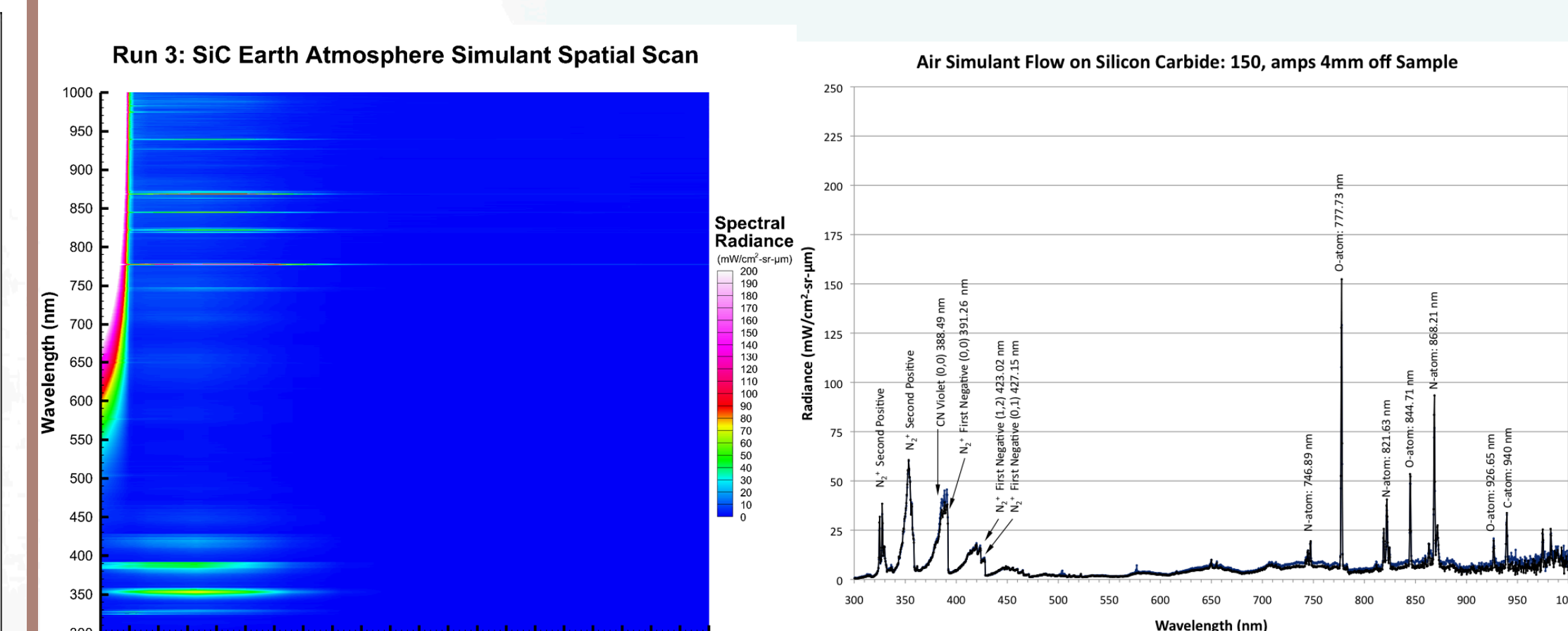


Figure 4: Compilation of emission spectra from a SiC specimen exposed to simulated air plasma. The measurement volume was incrementally moved to different spatial locations during the run.

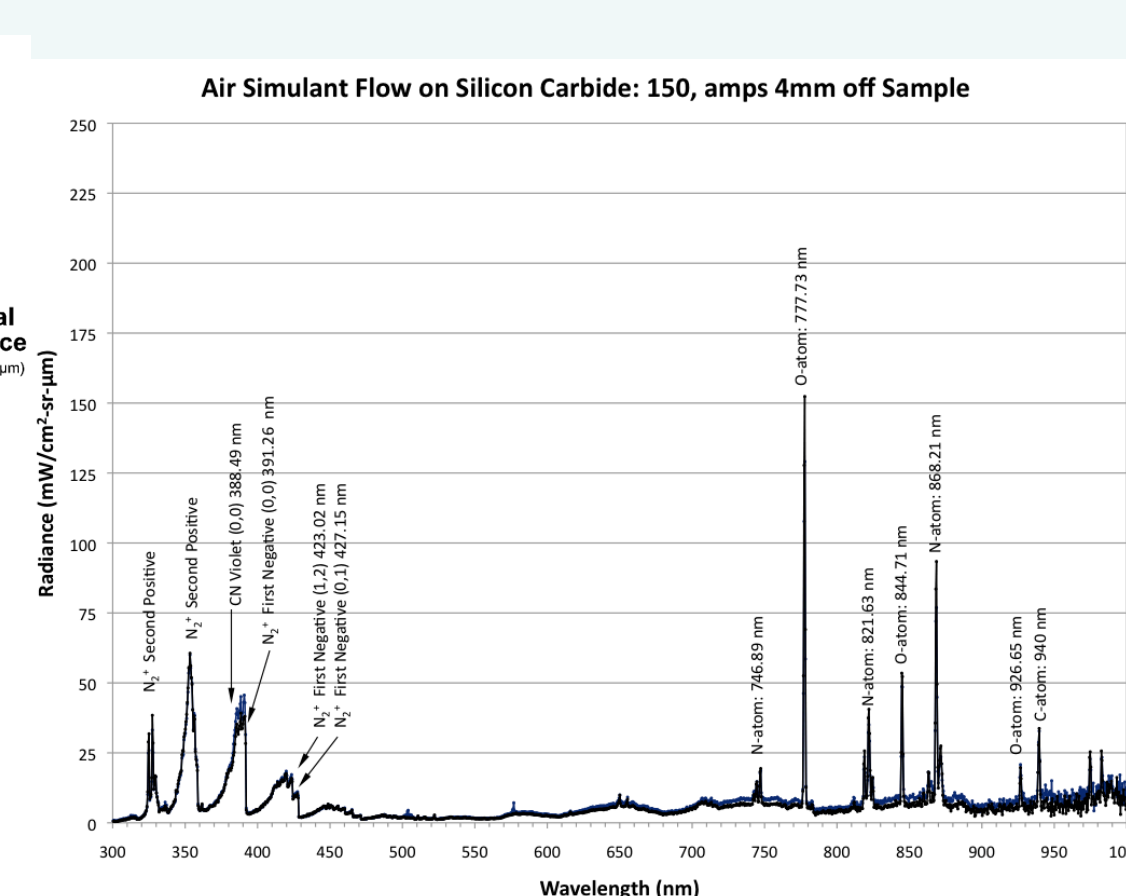


Figure 5: Calibrated emission spectrum from SiC. Prominent radiative species have been annotated. The near-infrared range is dominated by nitrogen and oxygen single atom peaks and N_2^+ bands dominate in the ultraviolet range.

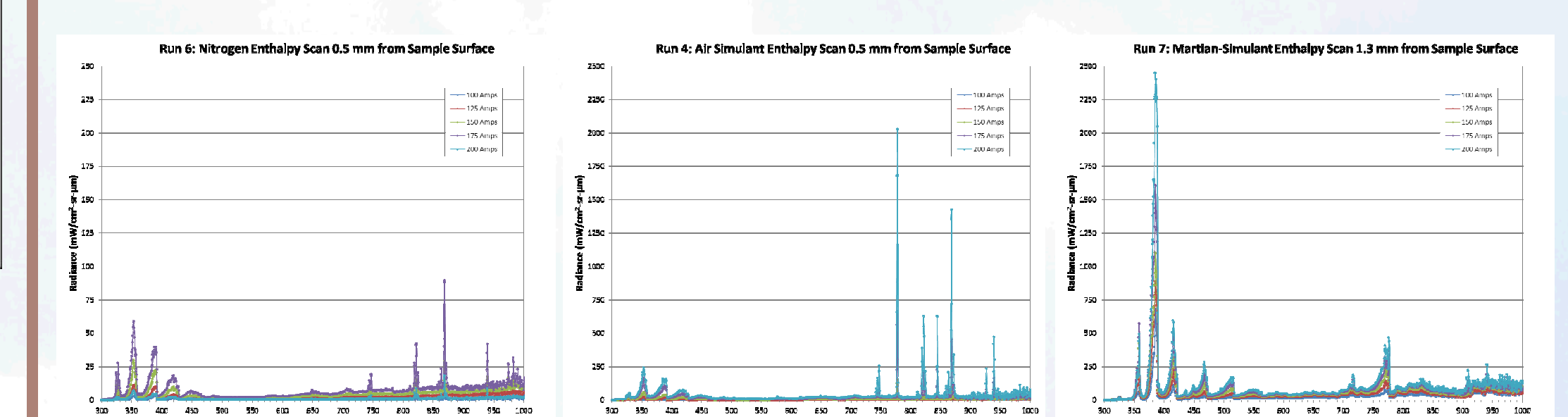


Figure 6: Comparison of spectra in different atmospheres over SiC specimens: A primarily nitrogen atmosphere (left) allows for oxygen-based interactions to be identified in an air simulant atmosphere (center). A Martian environment is also studied (right). In these tests, current of the arc plasma generator was manipulated to change the flow enthalpy.

Conclusions

- Hypersonic flow and bow shock formation was characterized for ablative and passive heat shield materials. Shock standoff distances of 9.5 ± 1.1 mm were found and compare well with prior flow visualizations.
- Quantitative values were assigned to emission spectra, which can be compared to computational models.
- Radiative atoms and molecules were identified by emission spectra. Molecular dissociation, ionization, and recombination were observed.
- A fast, inexpensive method for analyzing high enthalpy hypersonic flow was developed.

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