Tunable Diode Laser Absorption Diagnostics for Atmospheric Entry Ground Test Facilities

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Motivation

https://www.nasa.gov/gallery/artemis-ii/

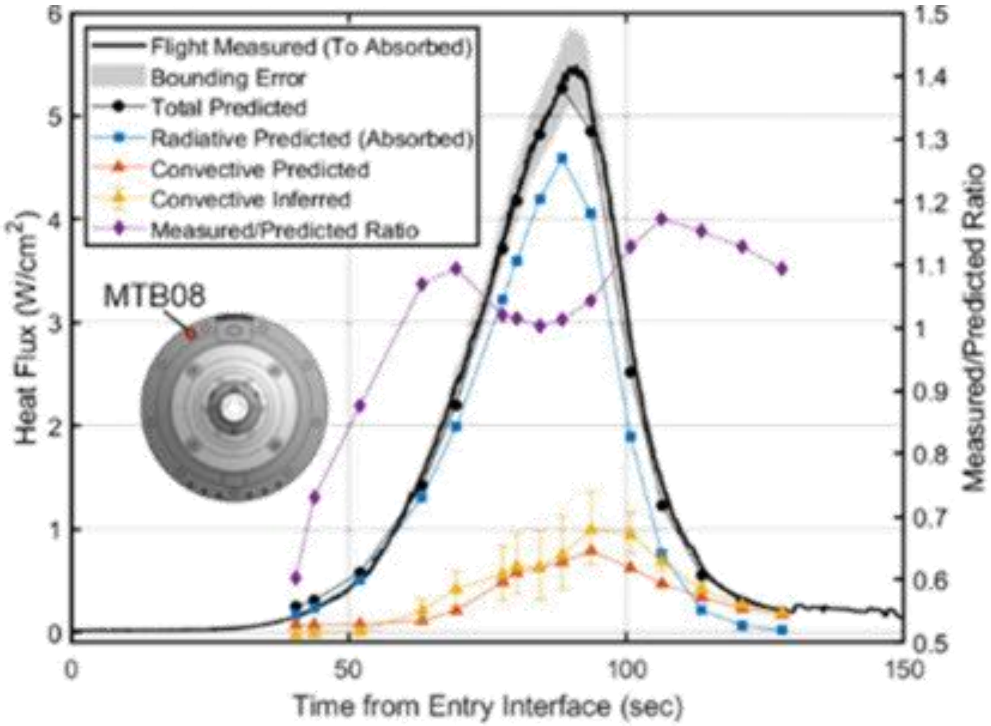
https://www.nasa.gov/general/five-things-well-learn-from-orions-first-flight-test/

Simulating Atmospheric Entry

- Cannot replicate atmospheric entry with a single ground test
  - Ground Test ≠ Flight
- Piecewise certification strategy
  - Arc Jets + Shock Tubes + Ballistic Ranges + …

    → Flight?
- Need modeling
  - Arc Jets, Shock Tubes, Ballistic Ranges, …

    ↔ Models → Flight
- Ground test facility diagnostics inform models
- Laser absorption spectroscopy is one method we use to quantify flow characteristics



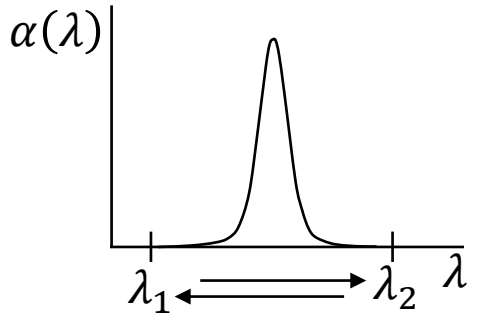
Miller et al., "Aftbody Heat Flux Measurements During Mars 2020 Entry," JSR, 61, 2, 2024.

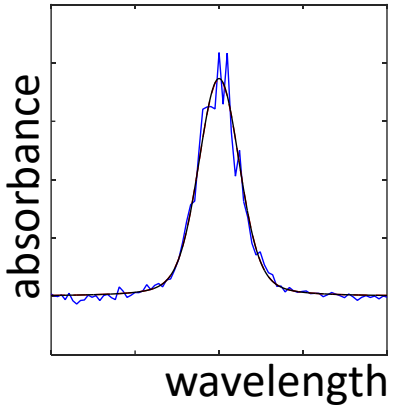
Tunable Diode Laser Absorption Spectroscopy (TDLAS)

- Each species has a unique absorption spectrum
- Select one or multiple absorption lines
- Beer Lambert Law

$$\alpha(\lambda) = -ln\left(\frac{I}{I_o}\right)$$

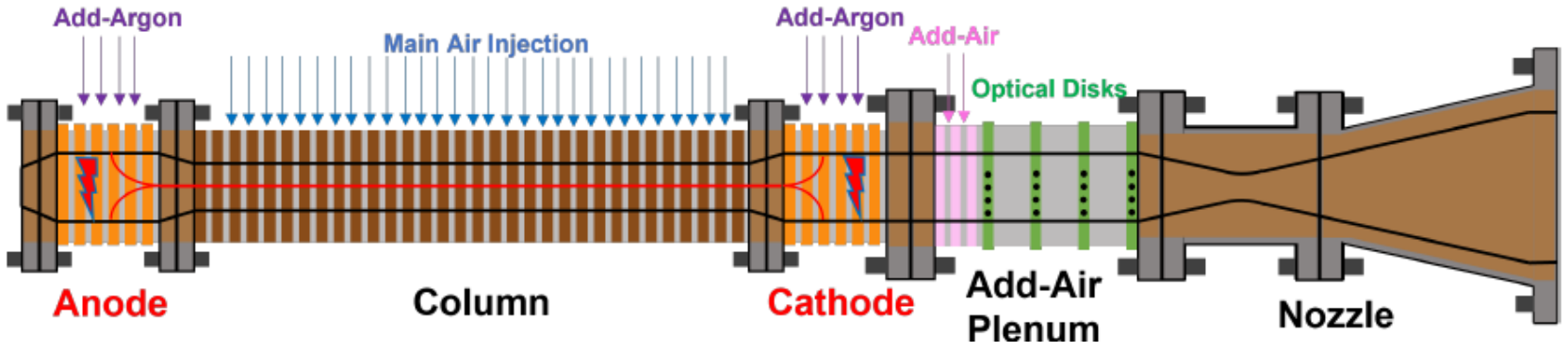
- Scanned-wavelength direct absorption
- Measure the lineshape
- Fit to measured absorbance
  - Voigt fit is common - convolution of Gaussian and Lorentzian profiles
- TDLAS can give temperatures, species concentration, pressure, velocity





Interaction Heating Facility (IHF)

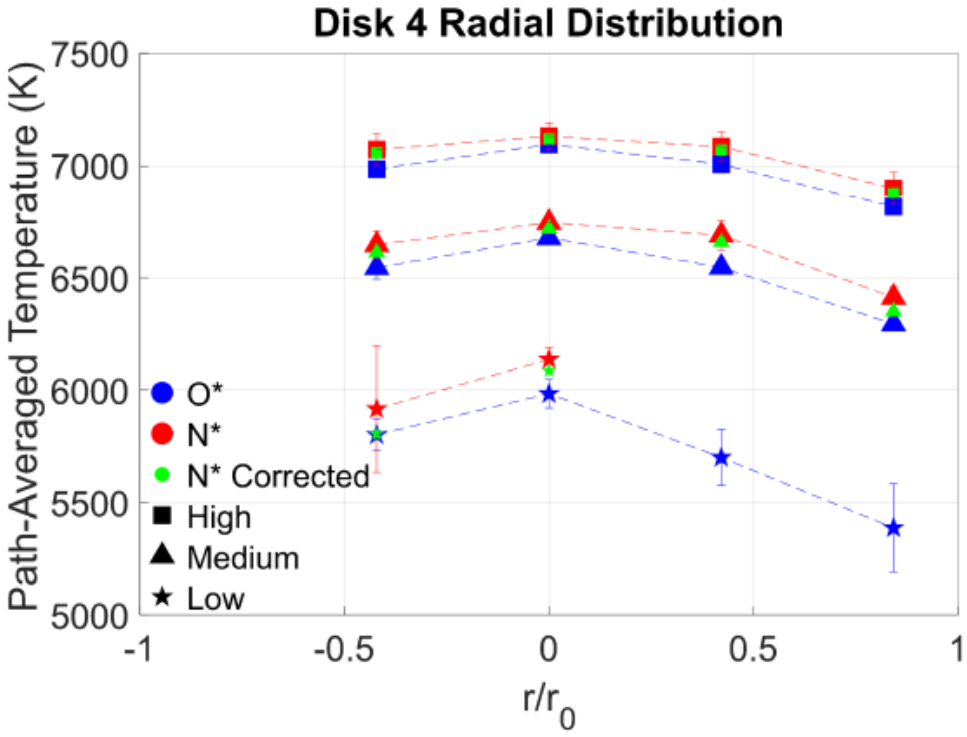
- Arc jets can match flight heat loads on Thermal Protection Systems
- Interaction Heating Facility is NASA's largest arc jet (60 MW)

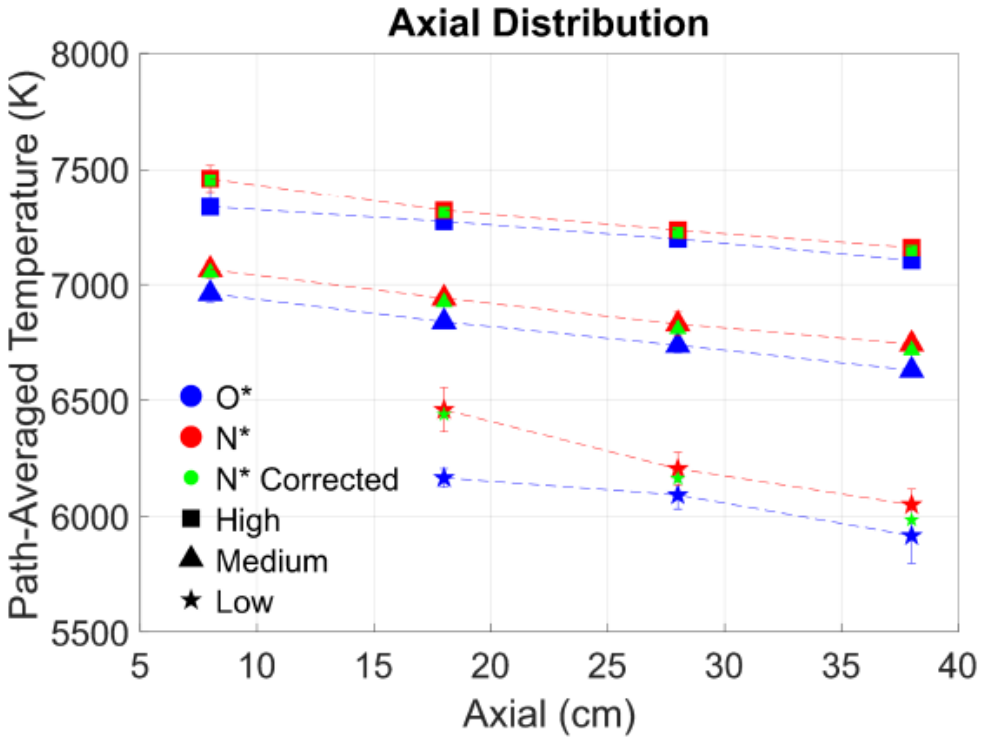


- DC arc maintained between anode and cathode
- Air injected along column
- Material sample inserted into hot supersonic jet downstream of nozzle

Temperature in IHF Plenum

- Collaborative Agreement with Prof. Ronald K. Hanson, Stanford University
  - Work completed by PhD student Peter Finch
- Radial and axial temperature profiles (assuming equilibrium)

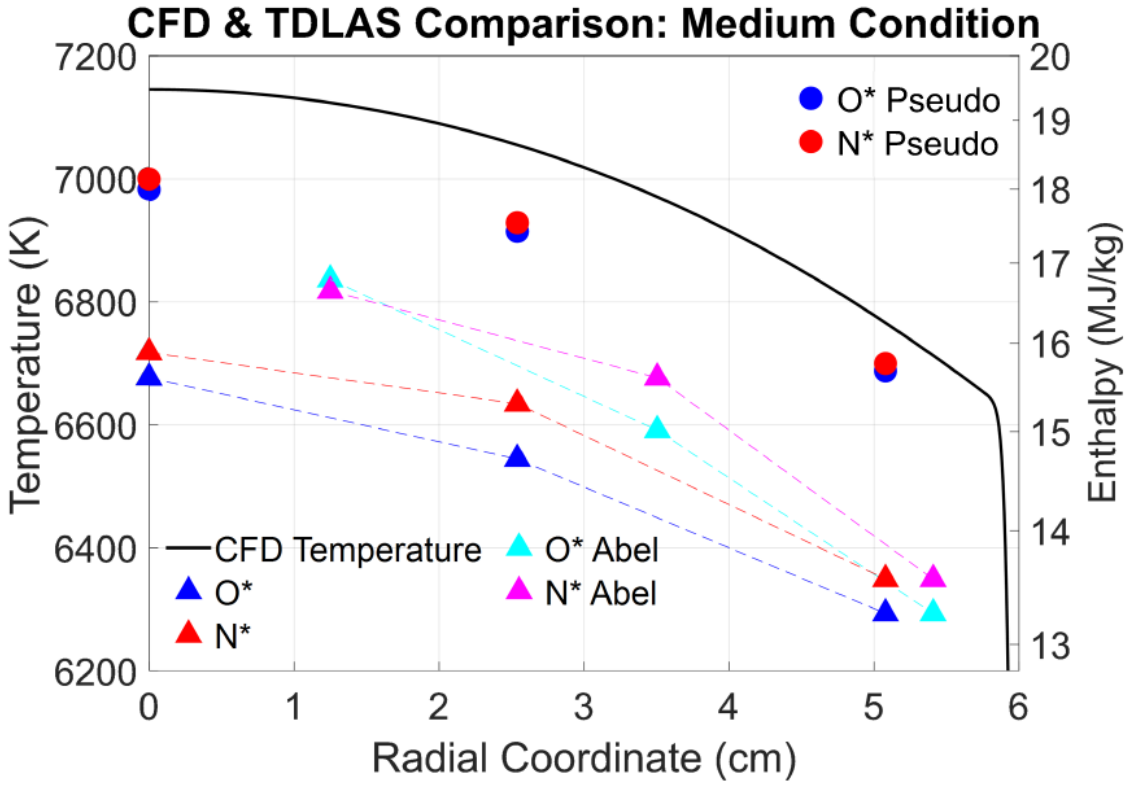




P. M. Finch, Z. N. Granowitz, C.L. Strand, R. K. Hanson, M. E. MacDonald, F. C. L. Hui, T. Gokcen, "Temperature and Enthalpy Characterization of NASA Ames IHF Arc jet using Oxygen and Nitrogen Absorption," submitted to AIAA Journal, June 2024.

Temperature in IHF Plenum

- Direct comparison to computational model of IHF flow



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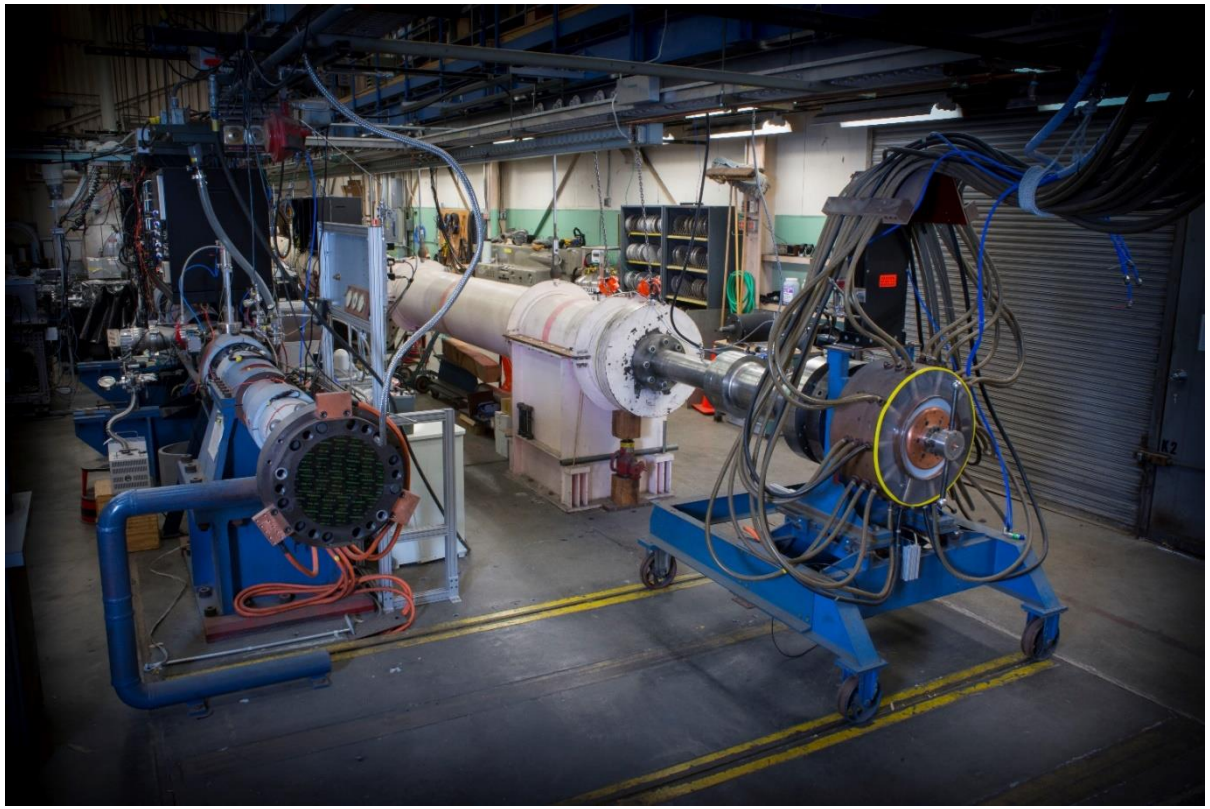
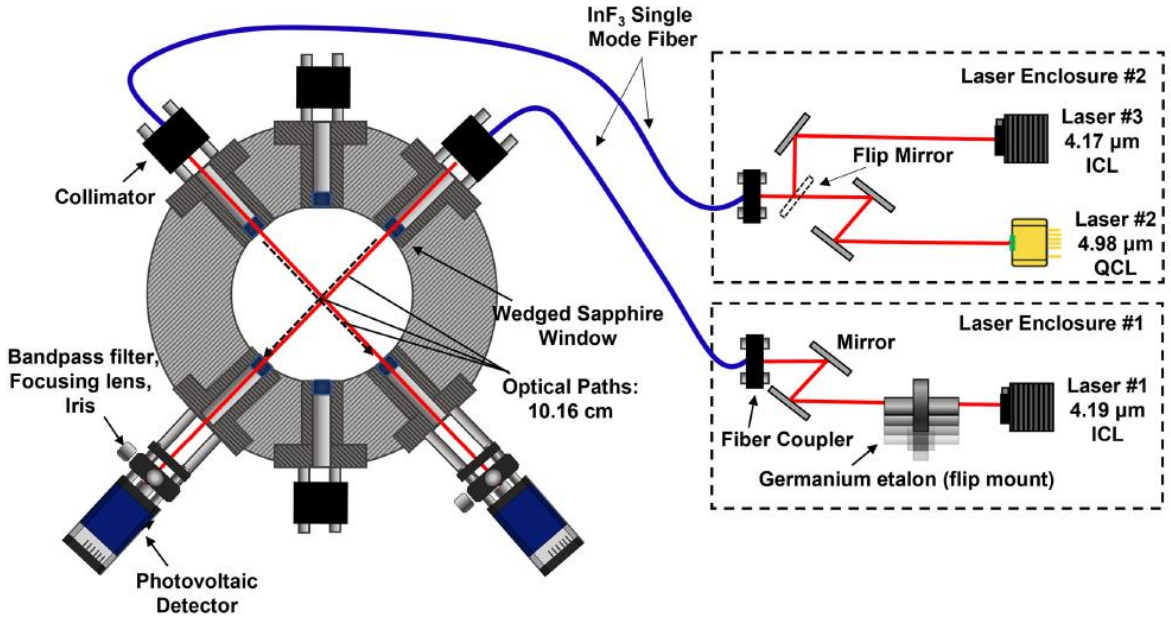
Electric Arc Shock Tube (EAST)

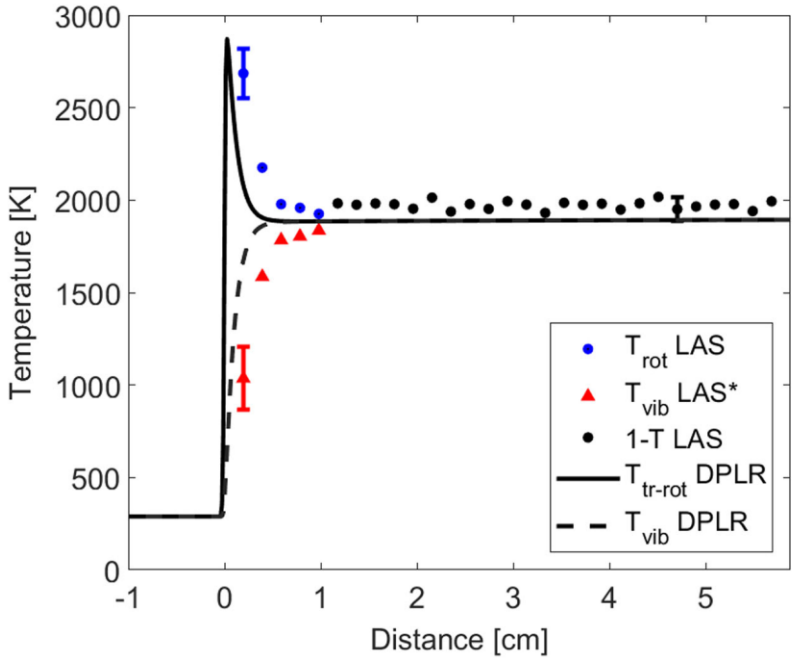
- Shock tubes can match flight velocity and shock chemistry
- EAST Facility at NASA Ames
  - Driver gas is arc heated by a 1.25 MJ capacitor bank
  - Two driven tubes
    - High Velocity Shock Tube with 10 cm diameter
    - Low Density Shock Tube with 54 cm diameter
- Shock speeds up to 46 km/s
- Wide variety of test gases to simulate planetary atmospheres



Mars Tests at EAST

- Shots in simulated Martian atmosphere (95.4% CO_2, 2.6% N_2, 2.0% Ar)
- Work completed by NASA Space Technology Research Fellow Christopher Jelloian
- Measured rotational, vibrational, and equilibrium temperatures + CO_2 number density
- Informing models for interpretation of post-flight Mars2020 entry data

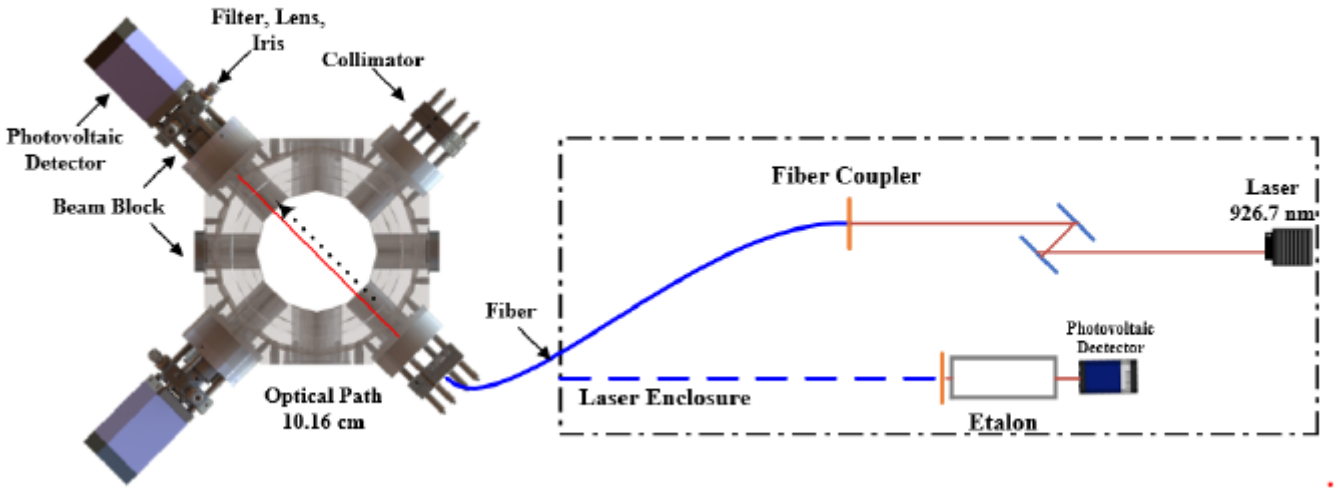


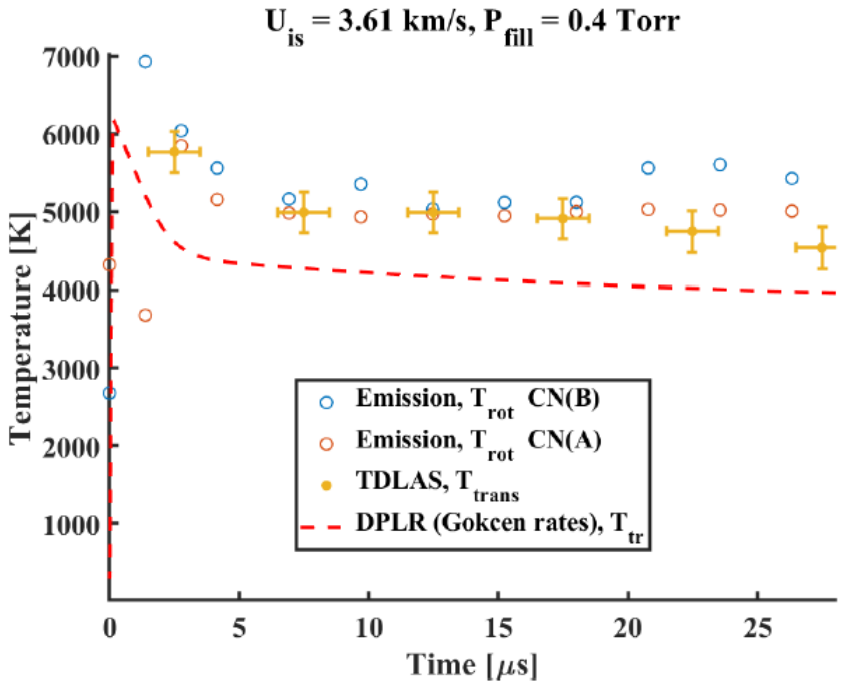


C. C. Jelloian, N. Q. Minesi, R. M. Spearrin, A. Tibère-Inglesse, M. E. MacDonald, and B. A. Cruden, "Mars2020 entry shock layer thermochemical kinetics examined by megahertz-rate laser absorption spectroscopy," JTHT 38, 1, 129-144 (2024).

Titan Tests at EAST

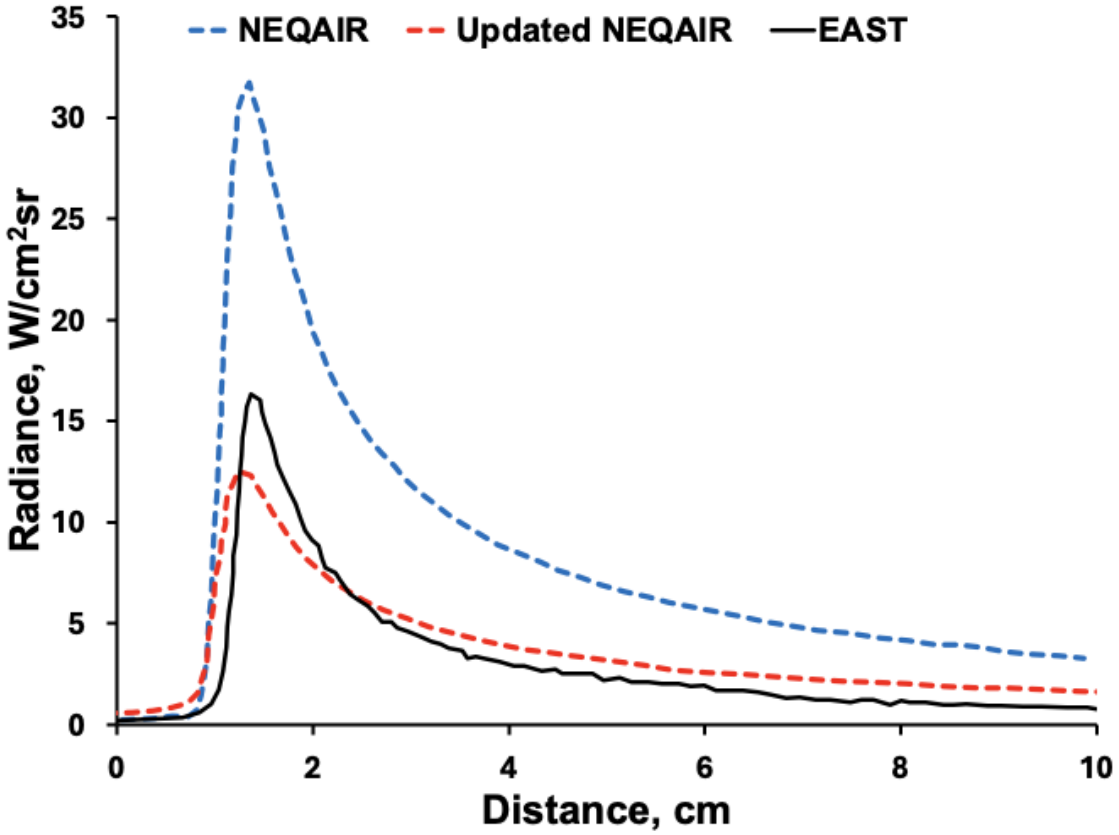
- Shots in 2.2% CH_4 in N_2 (by mole)
- Work completed by NASA Space Technology Graduate Research Opportunity fellow Efaine Chang
- Measured translational temperature and CN number density
- Data used to inform Dragonfly entry models





E. Chang, J. Streicher, C. L. Strand, R. K. Hanson, and B. A. Cruden, "Laser absorption spectroscopy measurements of post-shock non-equilibrium species in the NASA Ames Electric Arc Shock Tube," AIAA SciTech Forum, AIAA 2023-2713.

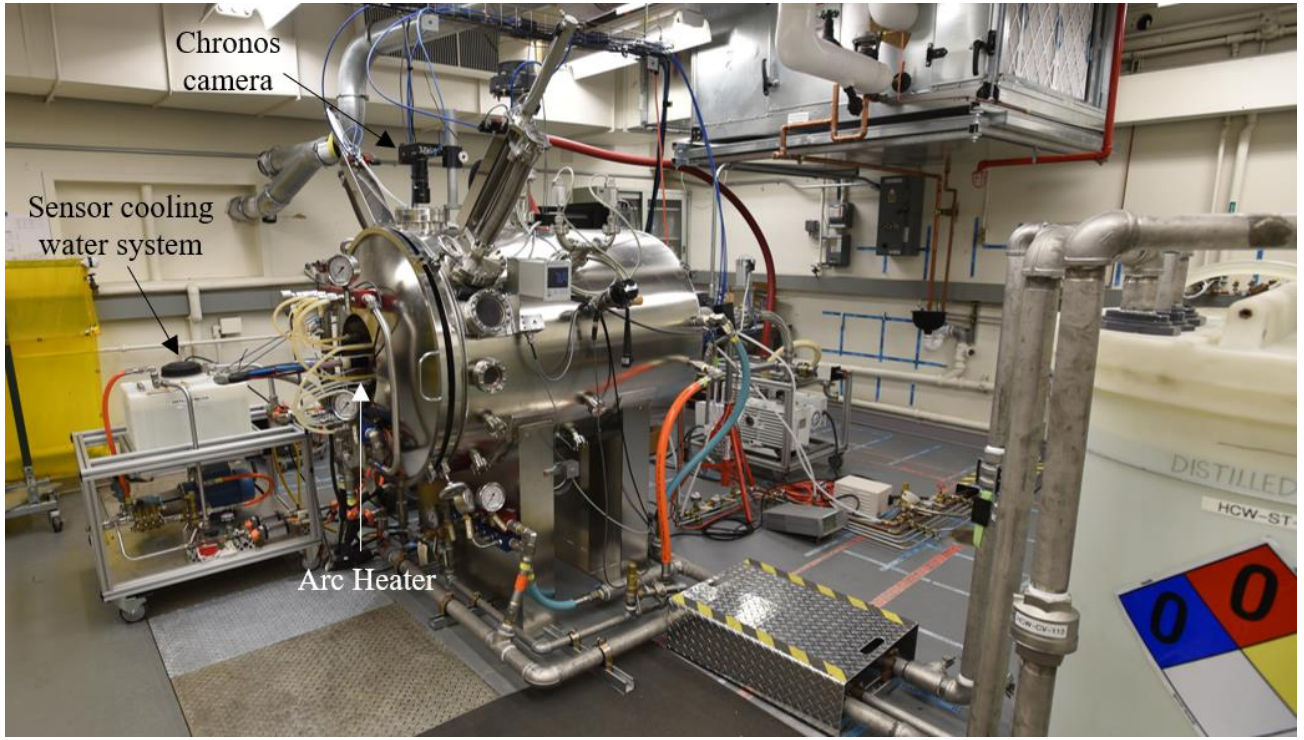
Titan Improvements



Aaron Brandis, Chris Naughton, Milad Mahzari, Eric Stern, Christopher Johnston and Thomas West, "Mitigating Dragonfly TPS Design Risks Through Improved Aerothermal Environments," IPPW2024.

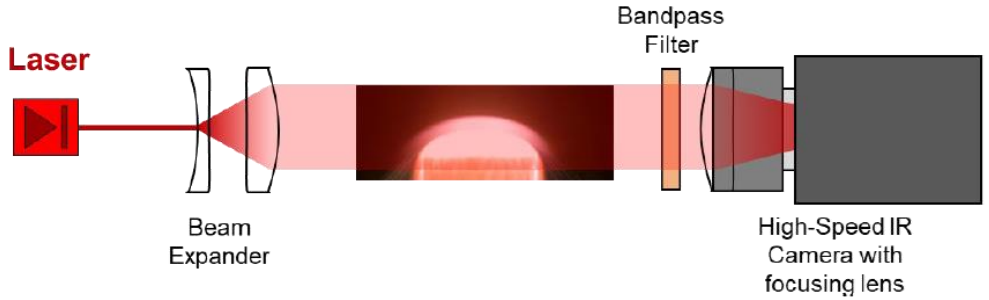
Miniature Arc jet Research Chamber (mARC II)

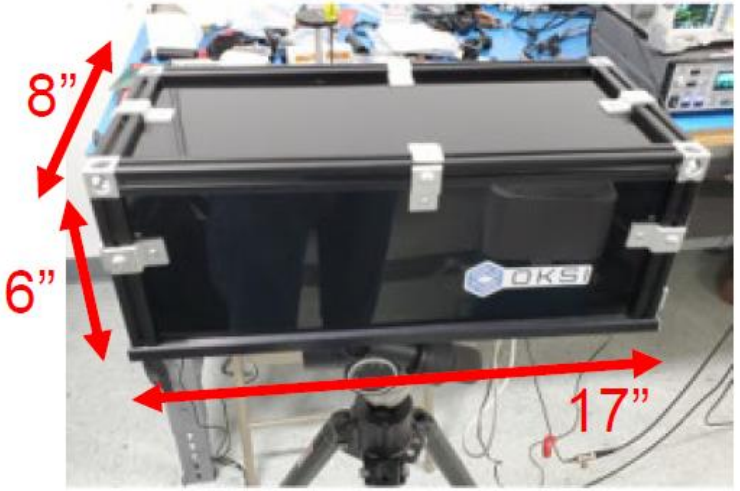
- Smallest of NASA Ames' arc jets (30 kW)
- Covers much of the operational envelope of the MW-scale arc jets, but on a smaller scale
- Testbed for diagnostics and arc jet development



Laser Absorption Spectroscopic Imaging (LASI)

- Similar to single line-of-sight absorption, but with expanded beam and a camera
- Fundamentals of concept under study at University of California – Los Angeles
- OKSI has partnered with UCLA to produce a prototype for use at ground test facilities

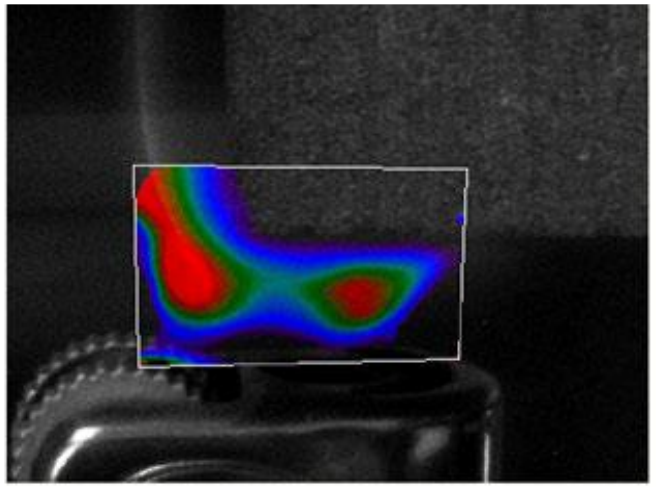




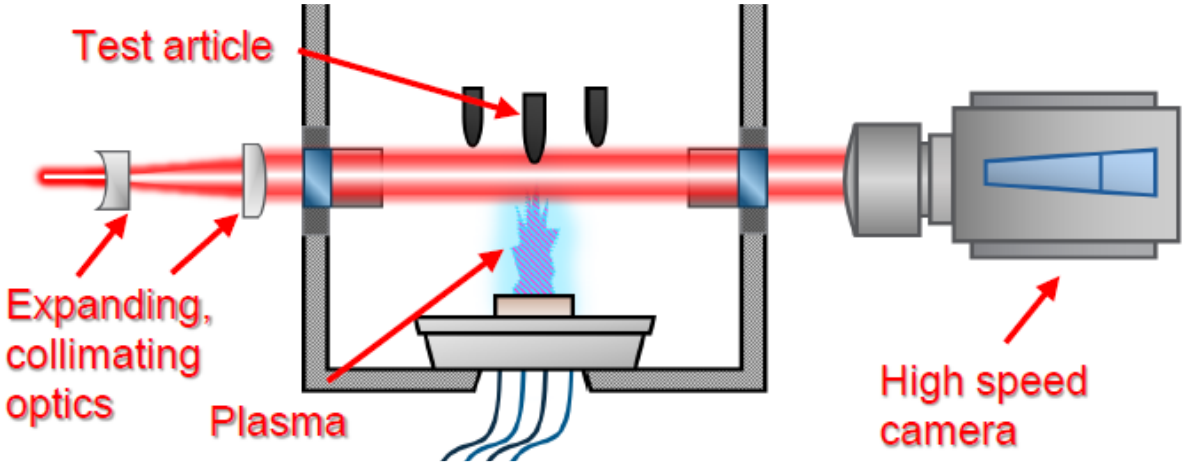
C. Wei, D. I. Pineda, C. S. Goldenstein, and R. M. Spearrin, “Tomographic laser absorption imaging of combustion species and temperature in the mid-wave infrared,” Optics Express 26, 16, 20944-20951 (2018).

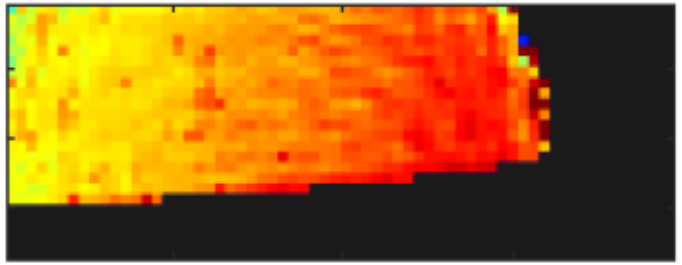
Initial Tests with LASI

- 2D measurements of temperature and number density
- Exploring use as a validation tool for coupled material and flow models



Temperature Map

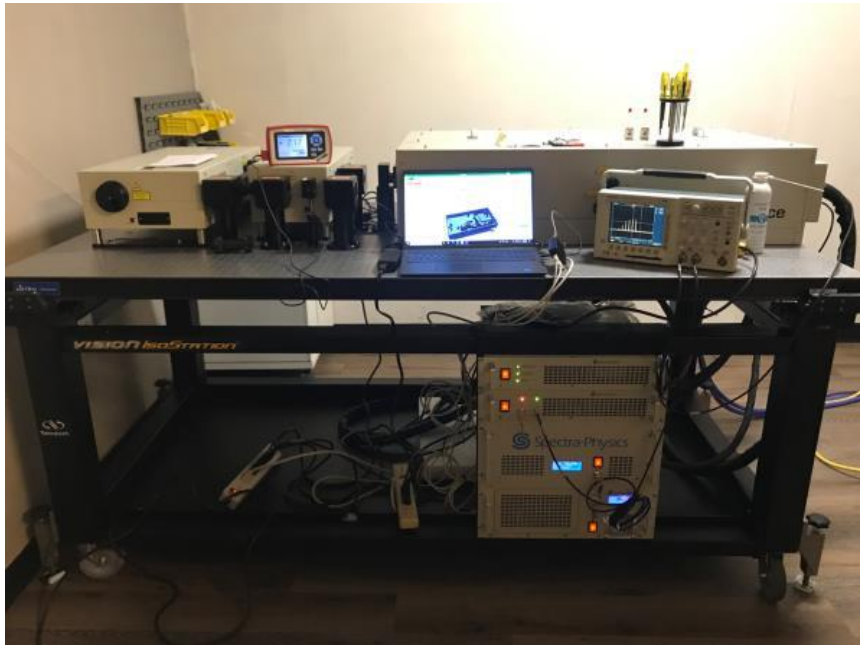


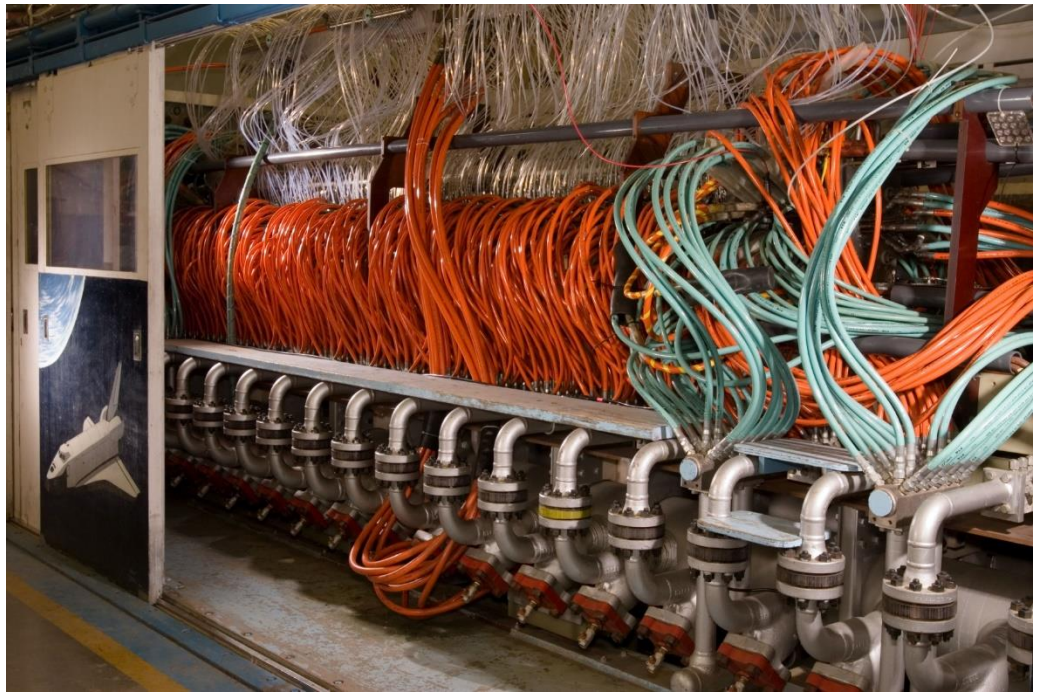


Number Density Map

Future Work: TALIF and FLEET

- Recently acquired the equipment to run additional flow diagnostics at IHF
  - fs-TALIF for N and O atom concentrations
  - FLEET for flow velocity





Summary

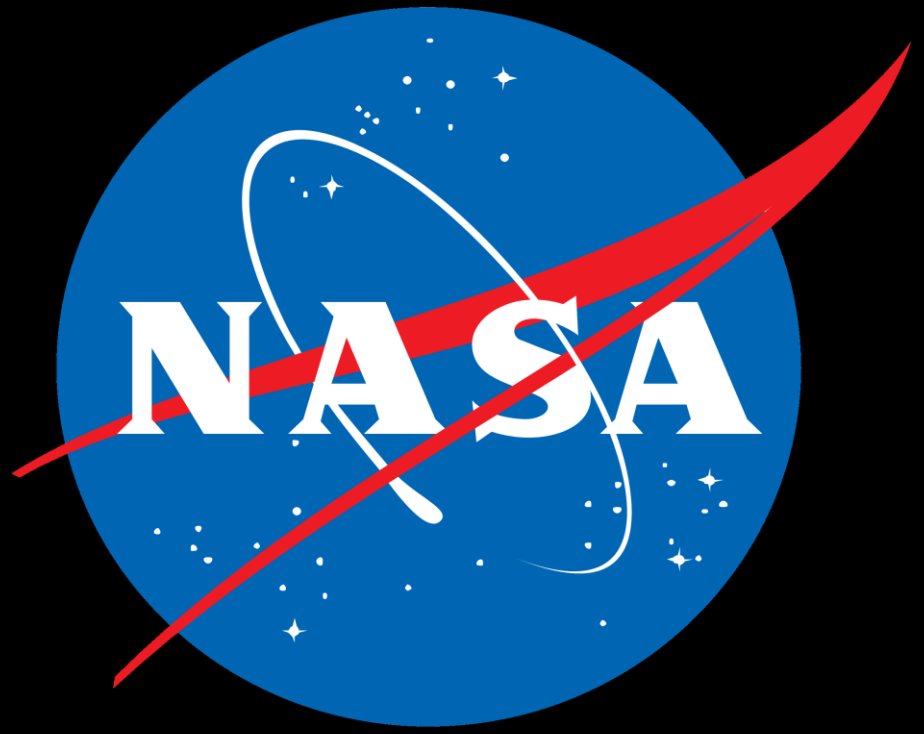
- Need multiple ground test facilities to simulate atmospheric entry
- Need models to link ground test to flight
- Need measurements of ground test conditions to validate models
  - TDLAS at Interaction Heating Facility
  - TDLAS at Electric Arc Shock Tube
  - LASI at miniature Arc jet Research Chamber
- Continuously looking for new measurement techniques

Questions?

Acknowledgements:

Peter Finch, Christopher Jelloian, Efaine Chang, OKSI, Brett Cruden, Aaron Brandis

National Aeronautics and Space Administration



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