# Martian Entry Testing in the NASA Langley HYMETS Facility

**Scott C. Splinter, and Jeffrey G. Gragg**
NASA Langley Research Center, Hampton, VA

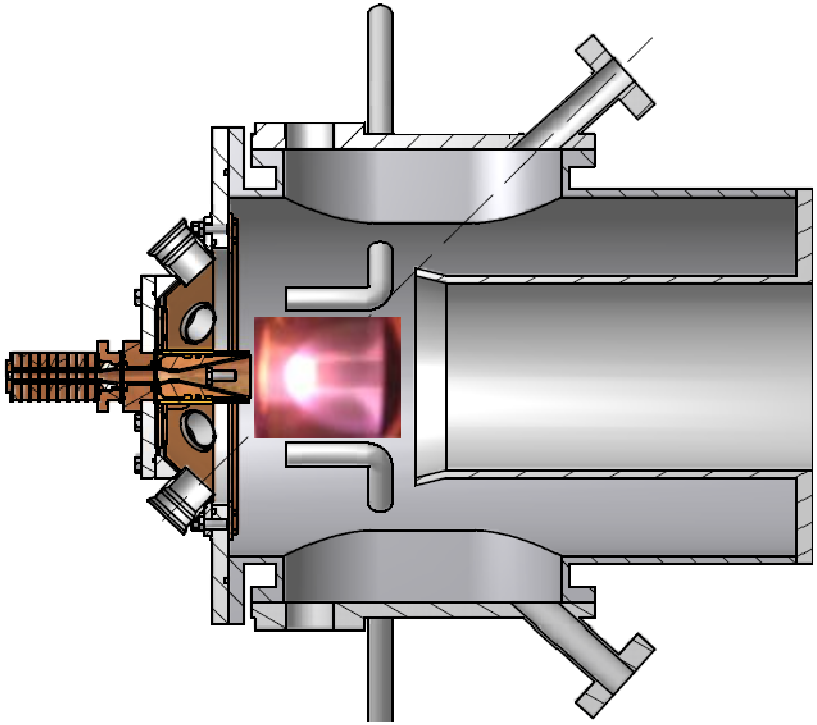
**Christine E. Szalai**
Jet Propulsion Laboratory, Pasadena, CA

**Amy R. Brewer**
Analytical Services and Materials, Inc., Hampton, VA

**35th Annual Conference on Composites, Materials, and Structures**
**Cocoa Beach, Florida**
**January 24th – 27th, 2011**

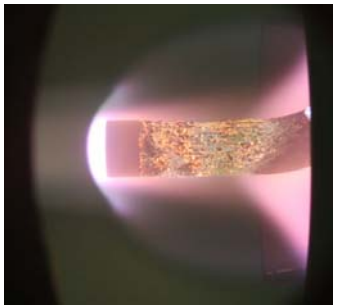
# Presentation Outline

- Introduction
- HYMETS Facility
- Test Approach
- Test Results
- Concluding Remarks

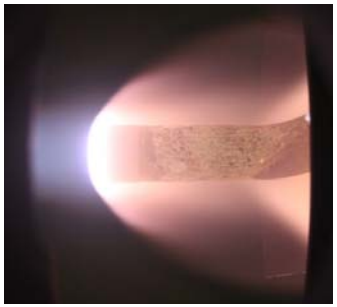


# Introduction

- **Arc-Jets (a.k.a. Arc Heaters or Plasma Wind Tunnels)**
  - Produce representative high-enthalpy flow environments
  - Evaluate heat shield materials for entry and hypersonic vehicles
  - Certify material performance
  - Validate or calibrate material response models
  - Earth Entry Simulation (79% $N_2$ to 21% $O_2$)
  - Martian Entry Simulation (3% $N_2$ to 97% $CO_2$)

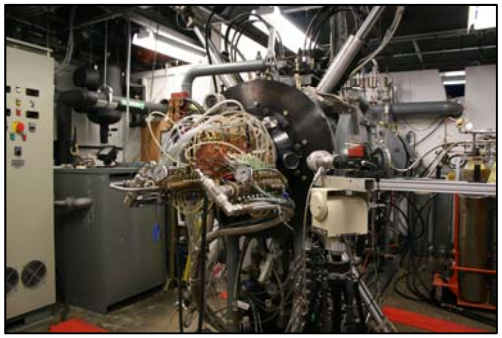


**Earth Entry Simulation**



**Martian Entry Simulation**

**HYMETS, Langley Research Center**



**Earth Entry**

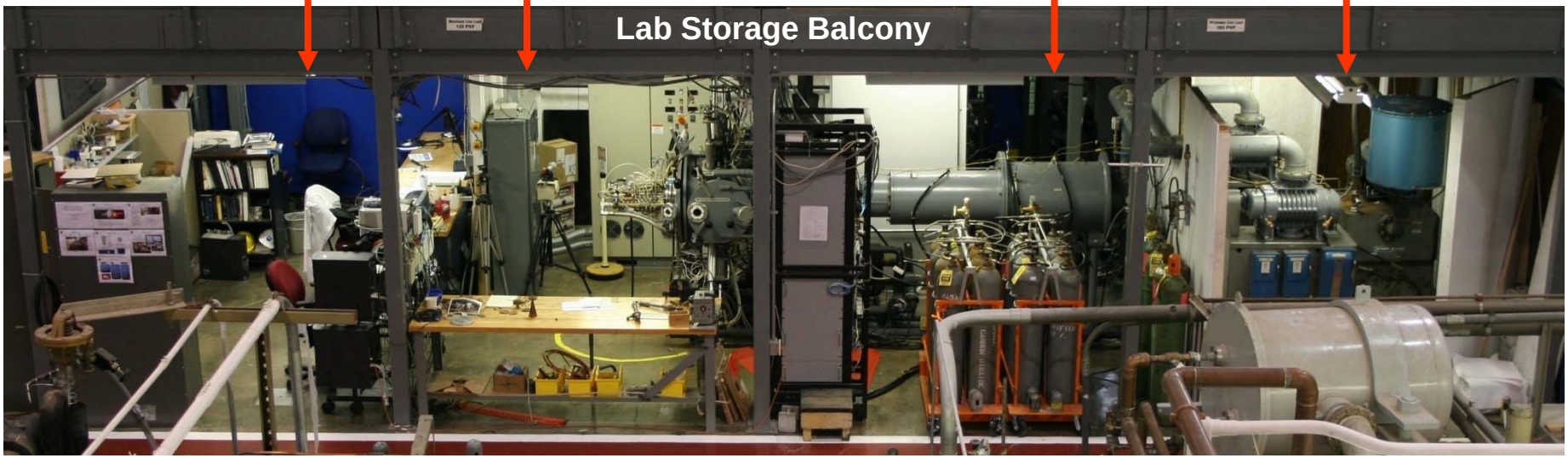


**Martian Entry**



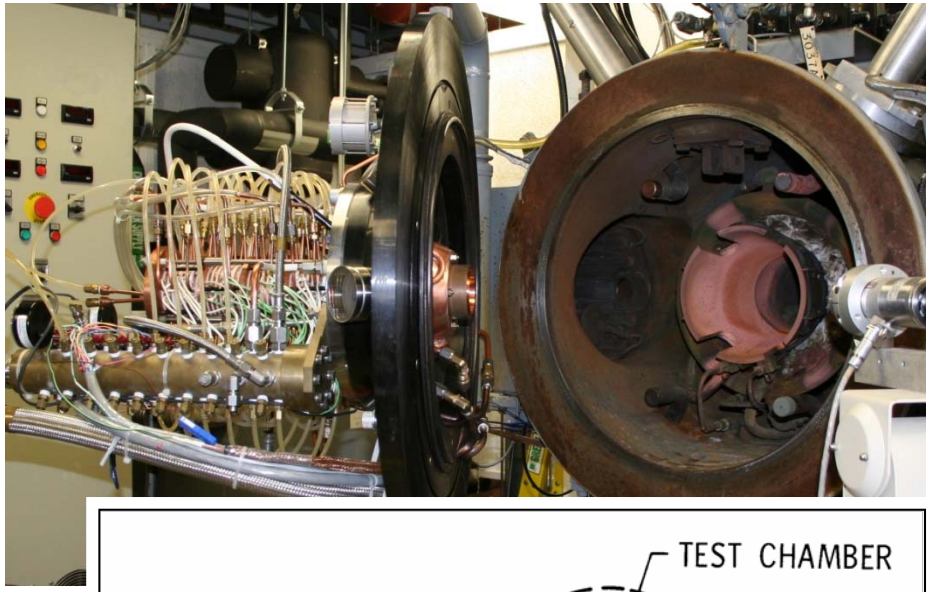
# HYMETS Facility

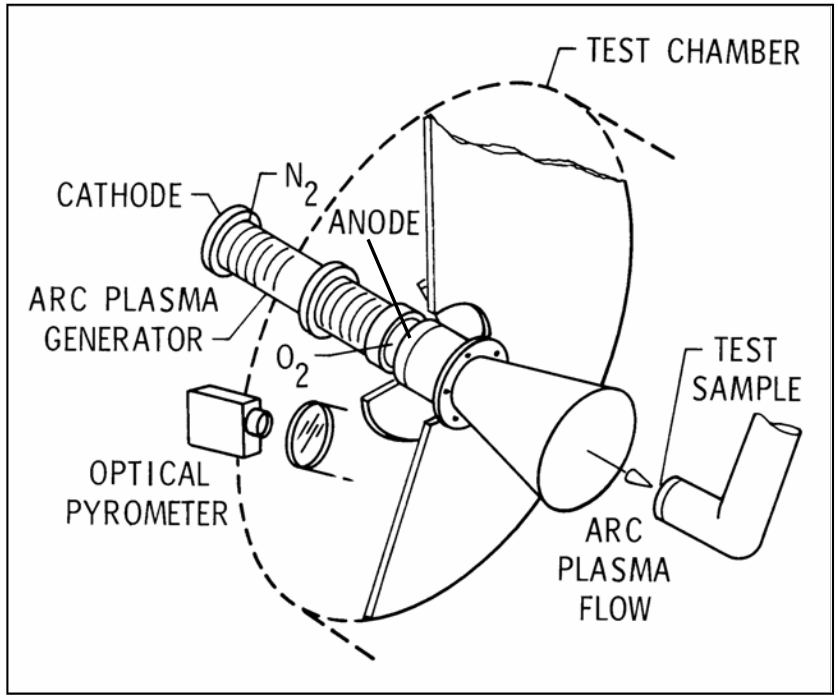
- **Hypersonic Materials Environmental Test System (HYMETS)**
  **NASA Langley Research Center**
  - Installed in 1968 as a 100 kW arc-jet
  - Upgraded in 2005 to a 400 kW arc-jet
  - Fast and relatively inexpensive testing facility



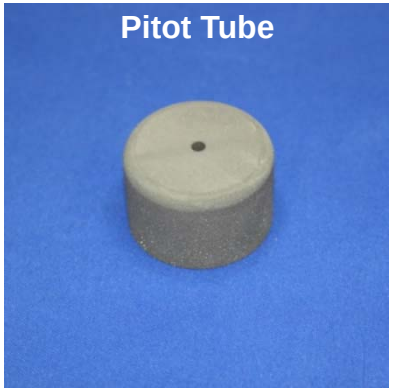
# HYMETS Facility

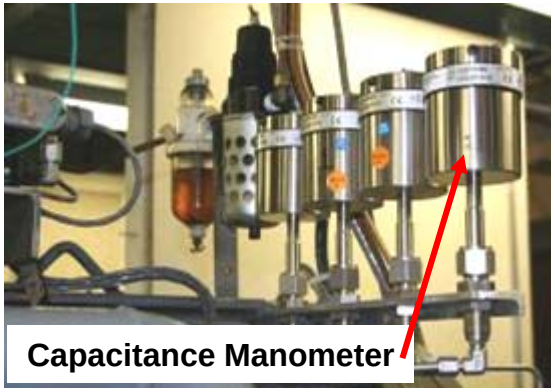
- **Facility Attributes**
  - Segmented Arc Plasma Generator with a 0.5 inch diameter core
  - Puck Cathode - Copper with Tungsten Button
  - Multiple 3 inch dia. 0.25 inch thick segments - Copper
  - Divergent Anode - Copper
  - Convergent-Divergent Mach 5 Nozzle - Copper
  - Argon shield gas injected at the anode
  - $N_2$, $O_2$, and $CO_2$ process gas
    (AIAA-2011-1014 $CO_2$ Implementation)
  - Stagnation Test Specimens:
    - 1-inch diameter, up to 0.5-inch thick specimen with holder
    - 1.3-inch diameter, 0.85-inch thick specimen without holder





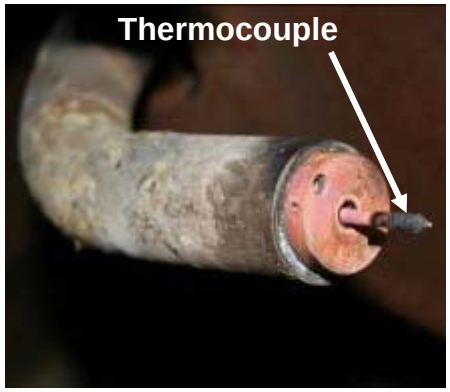
# HYMETS Facility Instrumentation










- **Stagnation Pressure:**
  - SiC Conversion Coated Graphite Probe
  - Absolute Capacitance Manometer
  - 6.6 x $10^{-5}$ atm to 0.13 atm (0.05 torr to 100 torr)
- **Fully-Catalytic Cold Wall Heat Flux:**
  - Medtherm Corporation Copper Slug Calorimeter
  - Up to 500 Btu/$ft^2$.s
  - Uncertainty assumed to be +/-10% (AIAA-2010-4905)
- **Back Face Temperature (Thermocouple):**
  - 1 - 3 connections/channels available
  - All thermocouple types

## Bulk Enthalpy Calculation

$$H_O = \frac{E * I * C_1 - C_2 * CW * C_p * \rho * \Delta T}{M_{Total}}$$

$H_O$ = Total bulk enthalpy, (Btu/$lb_m$)
$E$ = Arc heater voltage, (Volts)
$I$ = Arc heater current, (Amps)
$C_1$ = 9.48 E-4 (Btu/s.W)
$C_2$ = 2.23 E-3 (min.$ft^3$/s.gal)
$CW$ = Cooling water flow, (GPM)
$C_p$ = Specific heat of water, (1 Btu/$lb_m$.°F)
$\rho$ = Water density, (62.4 ($lb_m$/$ft^3$)
$\Delta T$ = Cooling water temp. difference, (°F)
$M_{Total}$ = Total gas mass flow, ($lb_m$/s)

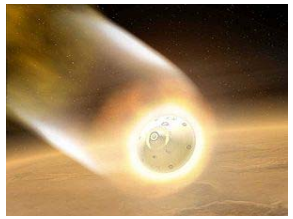
Range: 2,500 to 14,000 Btu/$lb_m$

# Test Approach

- **Entry, Descent, and Landing (EDL) Technology Development Project (TDP) Rigid Ablator Screening Test Objectives**
  - Assess survivability of PICA in Earth and Martian entry environments
  - Obtain recession data of PICA in Earth and Martian entry environments
  - Obtain surface temperature and back-face thermal response of PICA in Earth and Martian entry environments



- **Test Approach**
  - Determine PICA exposure duration
    - Limit char depth
    - Maximize recession depth
  - Establish both Earth and Martian entry environments to have
    - Heat Flux = 264 Btu/ft$^2$.s (300 W/cm$^2$)
    - Stagnation Pressure = 0.037 atm (28.12 torr)
  - Test four identical 1 inch dia. 0.5 inch thick PICA specimens; two in each entry environment



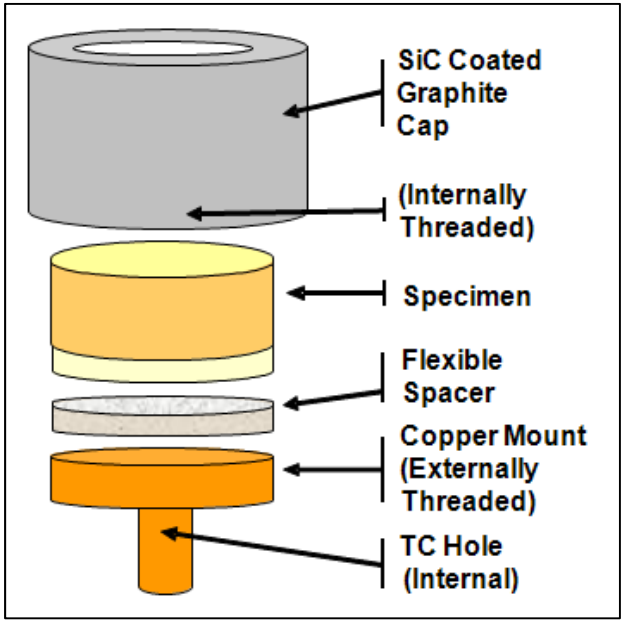
| Entry Environment Composition | Test Gases | | | | Measurement Basis |
|---|---|---|---|---|---|
| | $N_2$ | $O_2$ | $CO_2$ | Ar | |
| Standard Earth Environment | 75% | 20% | --- | 5% | By Volume (or Mole) |
| Simulated Martian Environment | 24% | --- | 71% | 5% | By Volume (or Mole) |

# Test Approach

- PICA Test Specimen



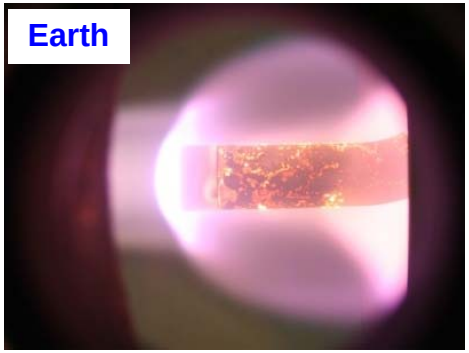
- Specimen Test Configuration




- Stagnation Test Configuration



- Stagnation Tests

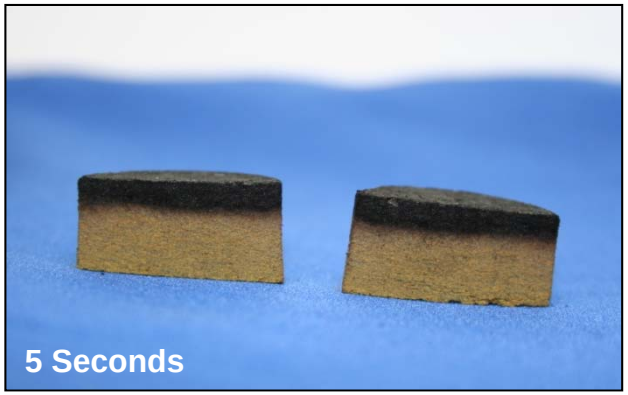


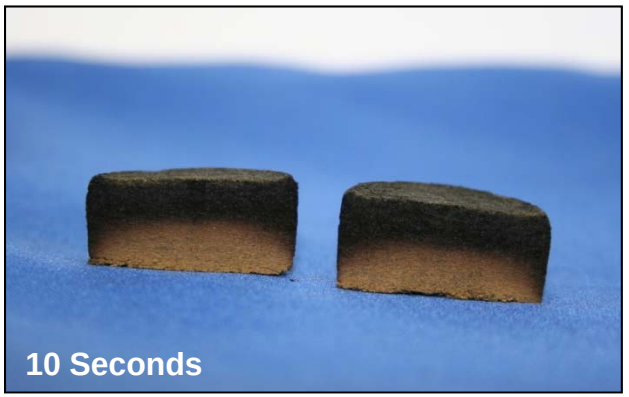


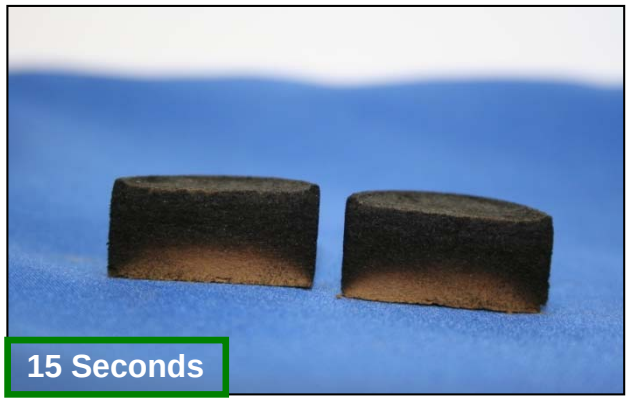

# Test Results

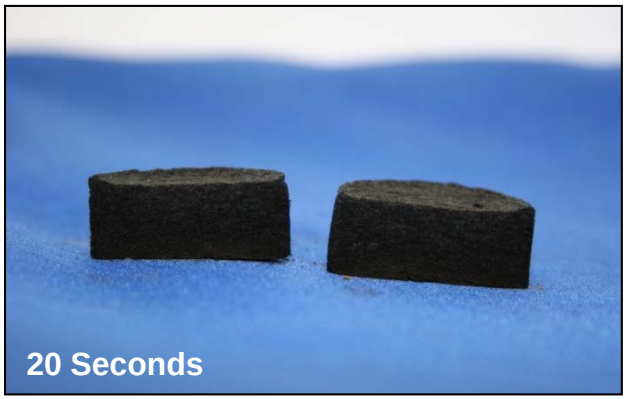
- **PICA Exposure Duration (Selected to be 15 seconds)**

| Test Time (seconds) | Heat Flux Slug Calorimeter Btu/ft$^2$.s (W/cm$^2$) | Stagnation Pressure atm (torr) | Recession Depth (in.) | Char Depth (in.) |
|---|---|---|---|---|
| 5 | 235.99 (269.02) | 0.0353 (26.79) | 0.012 | 0.1250 |
| 10 | 238.30 (271.66) | 0.0353 (26.86) | 0.031 | 0.1875 |
| 15 | 231.81 (264.26) | 0.0354 (26.91) | 0.043 | 0.2500 |
| 20 | 251.15 (286.31) | 0.0355 (26.96) | 0.057 | Through |



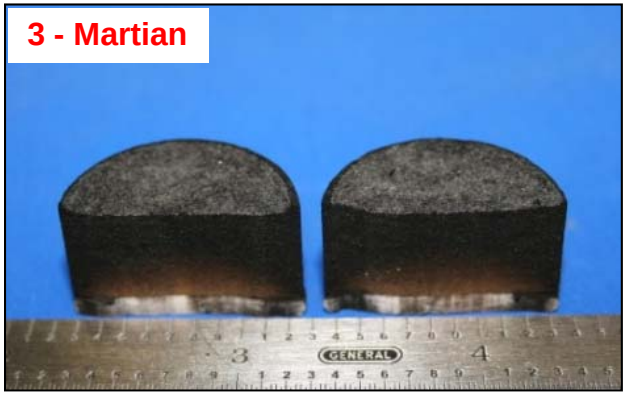



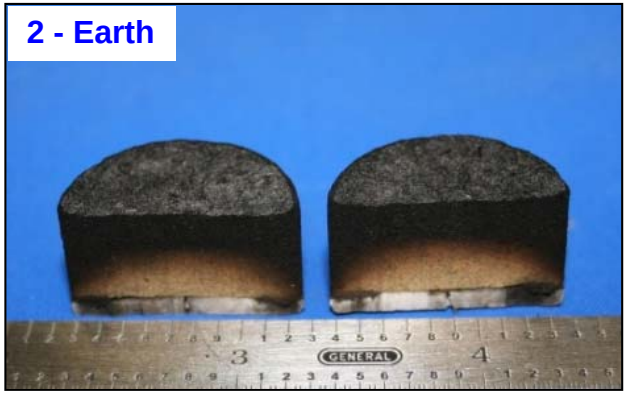
# Test Results

- **Earth and Martian Entry Environment PICA Specimen Comparison**

| Specimen Number - Entry Environment | Heat Flux Slug Calorimeter Btu/ft$^2$.s (W/cm$^2$) | Stagnation Pressure atm (torr) | Recession Depth (in.) | Back Face Temperature (Deg F) |
|---|---|---|---|---|
| 1 - Earth | 257.01 (291.87) | 0.0347 (26.38) | 0.048 | 939 |
| 2 - Earth | 257.96 (292.95) | 0.0348 (26.49) | 0.044 | 871 |
| 3 - Martian | 272.87 (309.88) | 0.0393 (29.84) | 0.057 | 1044 |
| 4 - Martian | 279.12 (316.99) | 0.0393 (29.11) | 0.052 | 1040 |






# Test Results

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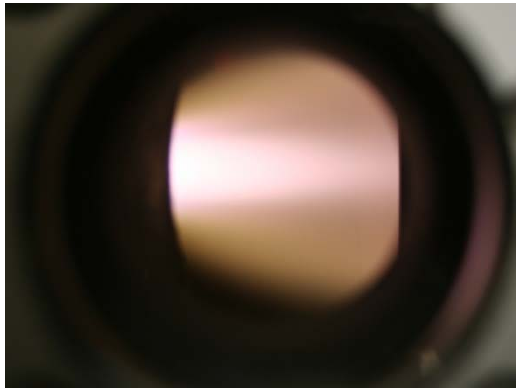
- **General Test Observations**
  - Max difference between Earth and Martian Stagnation Pressures = 13.3%
    - Tested in “diffusion limited” regime (between 100 and ~800 Btu/ft$^2$.s) for carbonaceous materials
    - Therefore mass loss rate is limited by oxygen diffusion which is not explicitly dependent on pressure
  - Max difference between Earth and Martian Heat Flux measurements = 8.6%
    - Difference within stated uncertainty for measurements (i.e. +/-10%)
    - Mass loss rate (i.e. recession depth) primarily dependent on oxidation
    - Backface temperature also dependent on oxidation (exothermic reaction)
  - Conclusion
    - Expect more recession and higher backface temperatures for PICA in the simulated Martian entry environment because there is more oxygen available for oxidation of the carbon
    - Test results support this conclusion

# Concluding Remarks

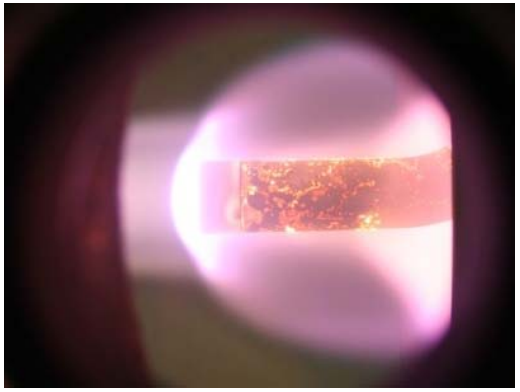
- **Test Results**
  - PICA survived the exposure to both the standard Earth and simulated Martian entry environments
  - Recession rates for PICA in a simulated Martian entry environment are greater than recession rates in a standard Earth entry environment
  - Backface temperatures for PICA in a simulated Martian entry environment are greater than backface temperatures in a standard Earth entry environment
  - Slight variability between standard Earth and simulated Martian entry environment test conditions does not impact comparison due to being in the “diffusion limited” regime for carbonaceous materials (i.e. PICA)

- **Future Work**
  - Consider designing the specimen configuration in the shape of the graphite cap, thus eliminating the need for the cap, and allowing for thicker samples
  - However, side heating needs to be considered then if backface thermal response is desired

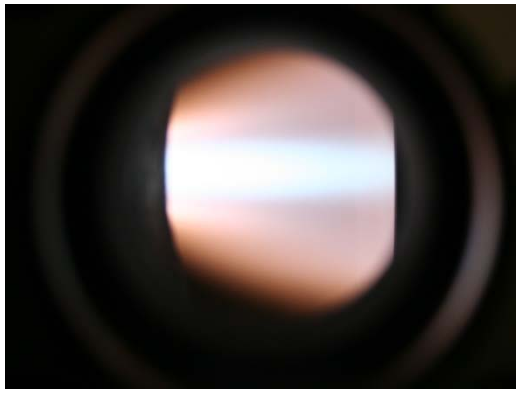
# Questions?!?



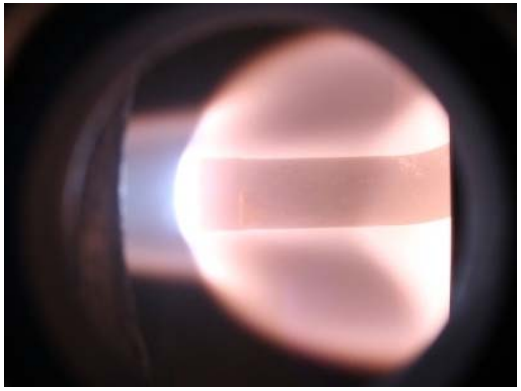
Standard Earth Entry Plasma
79% $N_2$ to 21% $O_2$



# QUESTIONS?!?



Simulated Martian Entry Plasma
25% $N_2$ to 75% $CO_2$



# Backup Slide

- **HYMETS Facility POCs**

David N. Brewer
Branch Chief
NASA Langley Research Center
Structural Mechanics and Concepts Branch
Building 1148, Room 233
Mail Stop 190
Hampton, Virginia 23681
Phone: (757).864.3558
David.N.Brewer@nasa.gov

Scott C. Splinter
HYMETS Test Engineer
NASA Langley Research Center
Structural Mechanics and Concepts Branch
Building 1148, Room 130
Mail Stop 190
Hampton, Virginia 23681
Phone: (757).864.9602
Scott.C.Splinter@nasa.gov

Jeffrey G. Gragg
HYMETS Facility Technician
NASA Langley Research Center
Structures Experiments Branch
Building 1148, Room 104
Mail Stop 188D
Hampton, Virginia 23681
Phone: (757).864.3155
Jeffrey.G.Gragg@nasa.gov