Arc Jet Assessment of MEDLI2 Radiometer Window Blockage Due to TPS Ablation Product Deposits

Ruth A. Miller[1], Brett A. Cruden[2], Jose A. Santos[1], and Todd R. White[1]
[1]NASA Ames Research Center
[2]AMA Inc. at NASA Ames Research Center

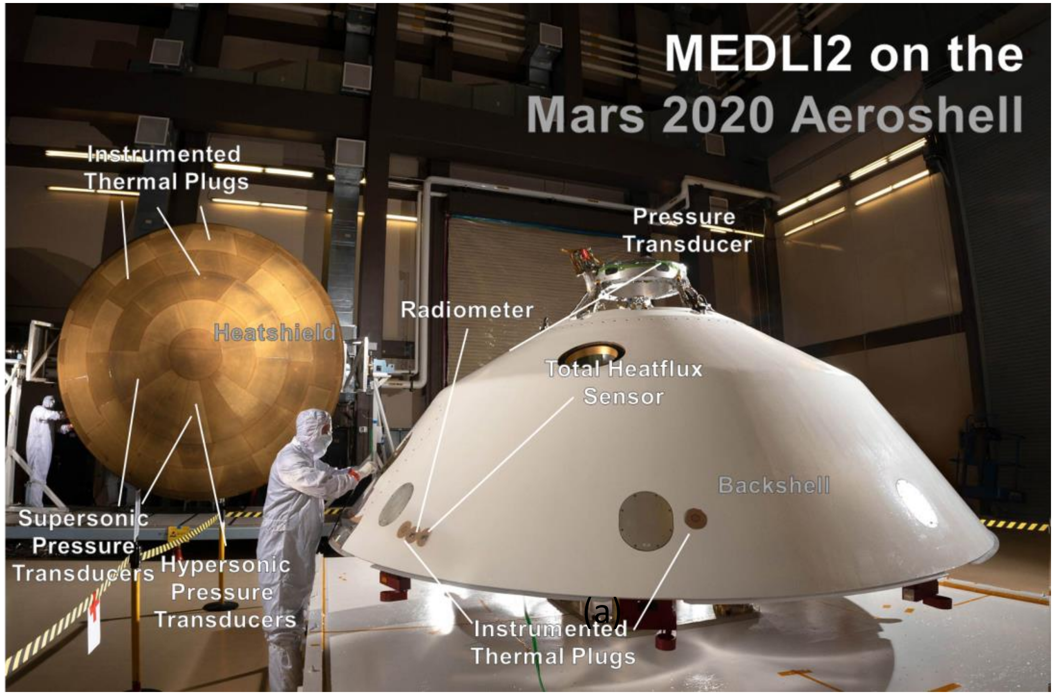
Presented By
Ruth A. Miller

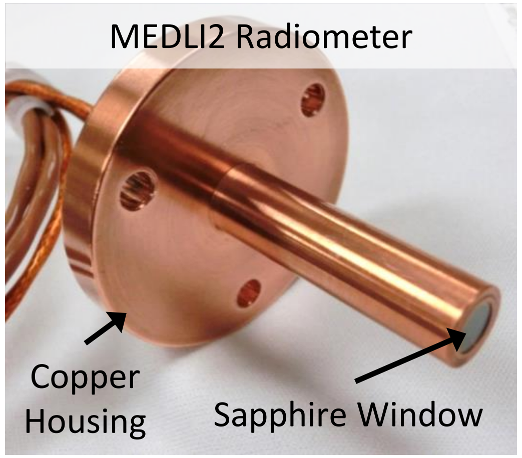
Thermal & Fluids Analysis Workshop
TFAWS 2022
September 6th-9th, 2022
Virtual Conference

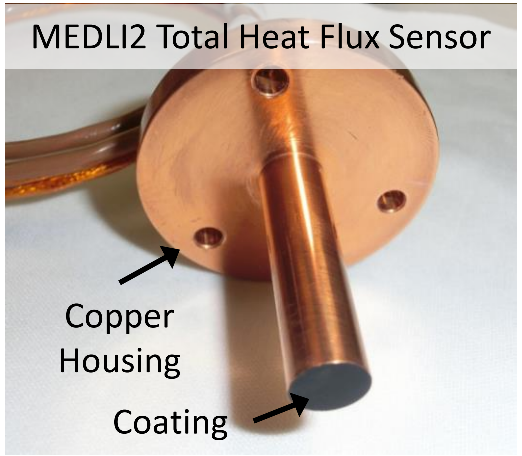
Background

- The Mars Entry, Descent, and Landing Instrumentation 2 (MEDLI2) sensor suite on the Mars 2020 aeroshell measured temperature, pressure, and heat flux during atmospheric entry.
- The focus of this talk is the MEDLI2 radiometer on the backshell at the MTB09 location (leeside)
  - Consists of a sapphire window above a Schmidt-Boelter gauge with a high emissivity coating
  - Calibration corrects for pristine window transmission and coating absorption
  - Measures radiation through a view factor
- Radiometer was located next to a total heat flux sensor at the MTB08 location
  - Consists of a Schmidt-Boelter gauge with a high emissivity coating
  - Calibration corrects for pristine coating absorption
  - Measures total heat flux

$$q_{total} = q_{convective} + \alpha q_{radiative}$$



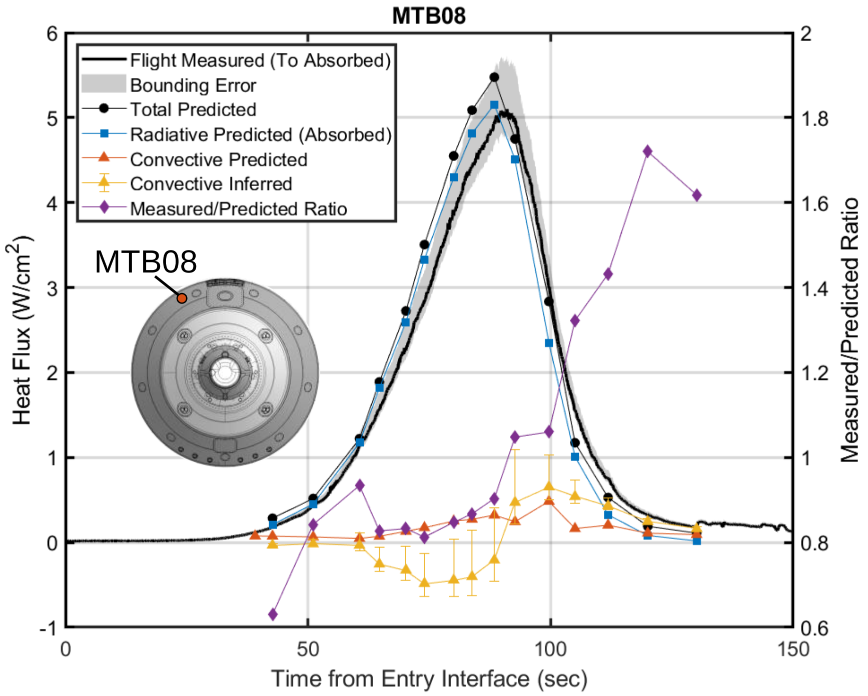




MEDLI2 Flight Data Compared to Predictions

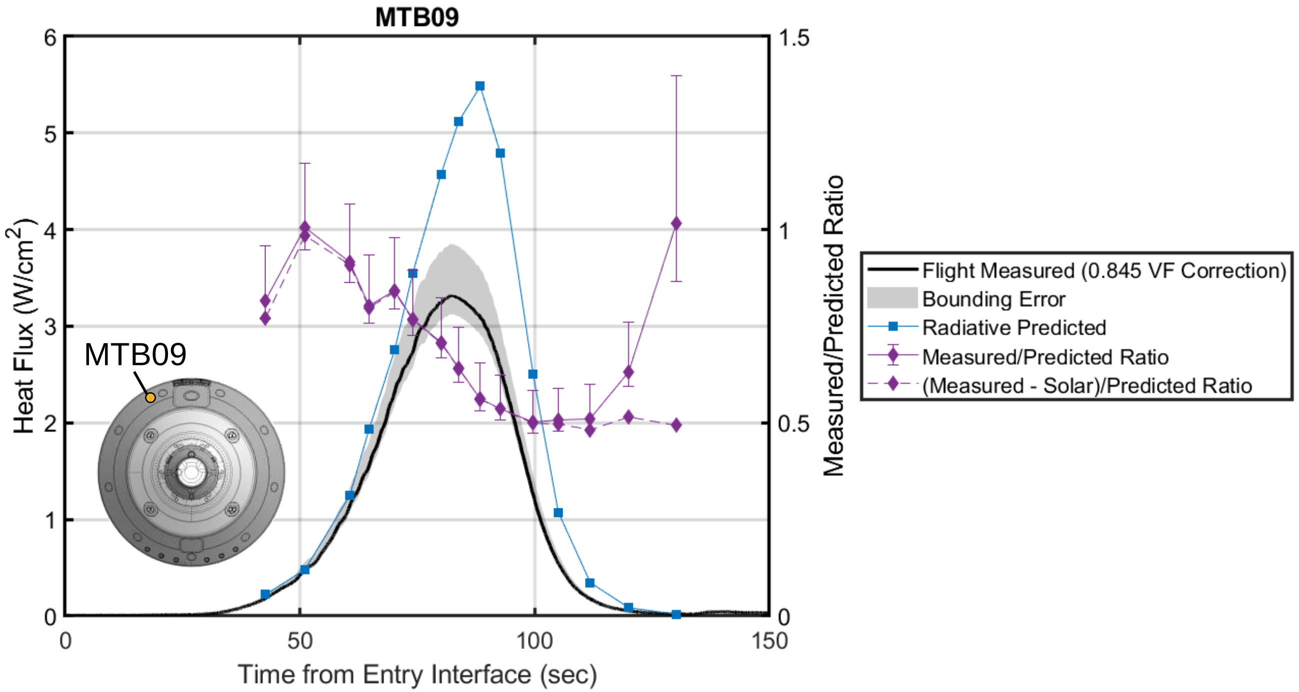
Total Heat Flux Sensor

- Excellent agreement between the total heat flux sensor flight measurements and the model predictions – at peak heating, the difference is within 12%



Radiometer

- Since measured and predicted heating at MTB08 exhibited excellent agreement, assume predictions at MTB09 are reasonable.
  - Measured/Predicted ratio approx. linearly decreases through the entry heat pulse and then flattens out – consistent with blockage due to ablation product deposits
  - At the end of the heat pulse, Measured/Predicted = 0.50 (= 50% signal loss).
  - **Motivates additional characterization**



- For full flight heat flux sensor results see: Miller, R.A, et al., AIAA SciTech 2022-0551.

Figure Credit: Miller, R.A., et al., AIAA SciTech 2022-0551

Pre-Flight Arc Jet Testing

- Miniature Arc Jet (mARC) Testing (November 2017)
  - Radiometer windows embedded in PICA and SLA-561V samples
  - Pre- and post-test window transmission measured to quantify the attenuation due to the deposits
  - XPS analysis performed to quantify the elemental composition of the deposits
  - For full results see Miller, R. A., et al., AIAA AVIATION 2018-3590
- PTF162 Backshell Qualification Testing (September 2019)
  - Radiometers embedded in backshell SLA-561V panels
  - Applied heat flux and pressure were close to the flight measurements, but heat load was more than double the flight heat load
  - Post-test calibration, blackbody, laser tests performed to quantify the attenuation due to the deposits
  - Post-test window transmission measured to quantify the attenuation due to the deposits
  - XPS analysis performed to quantify the elemental composition of the deposits
  - For full results see Miller, R. A., et al., AIAA SciTech 2022-0551

Ablation Product Coated Windows Post-mARC Testing

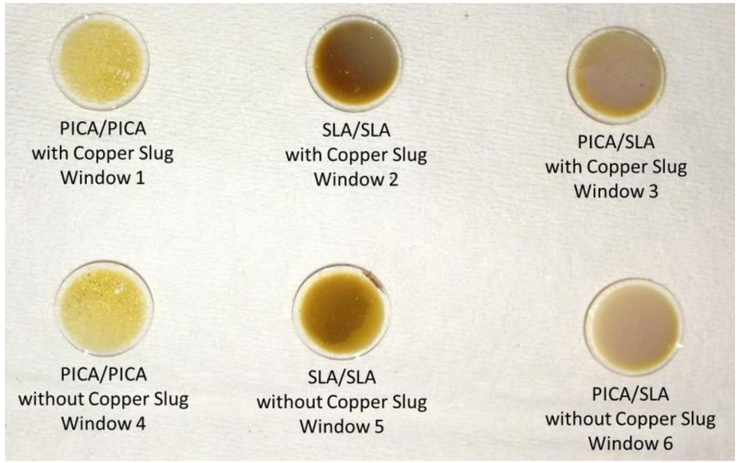


Image Credit: Miller, R.A., et al., AIAA AVIATION 2018-35390

Post-PTF162 Testing

Ablation Product Deposits

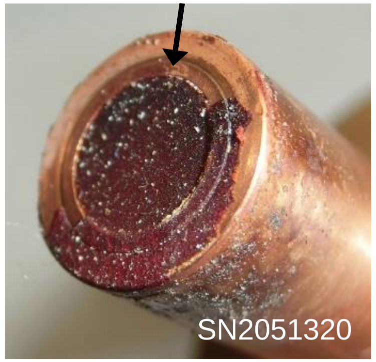


Image Credit: Miller, R.A., et al., AIAA SciTech 2022-0551

Post-Flight Arc Jet Testing

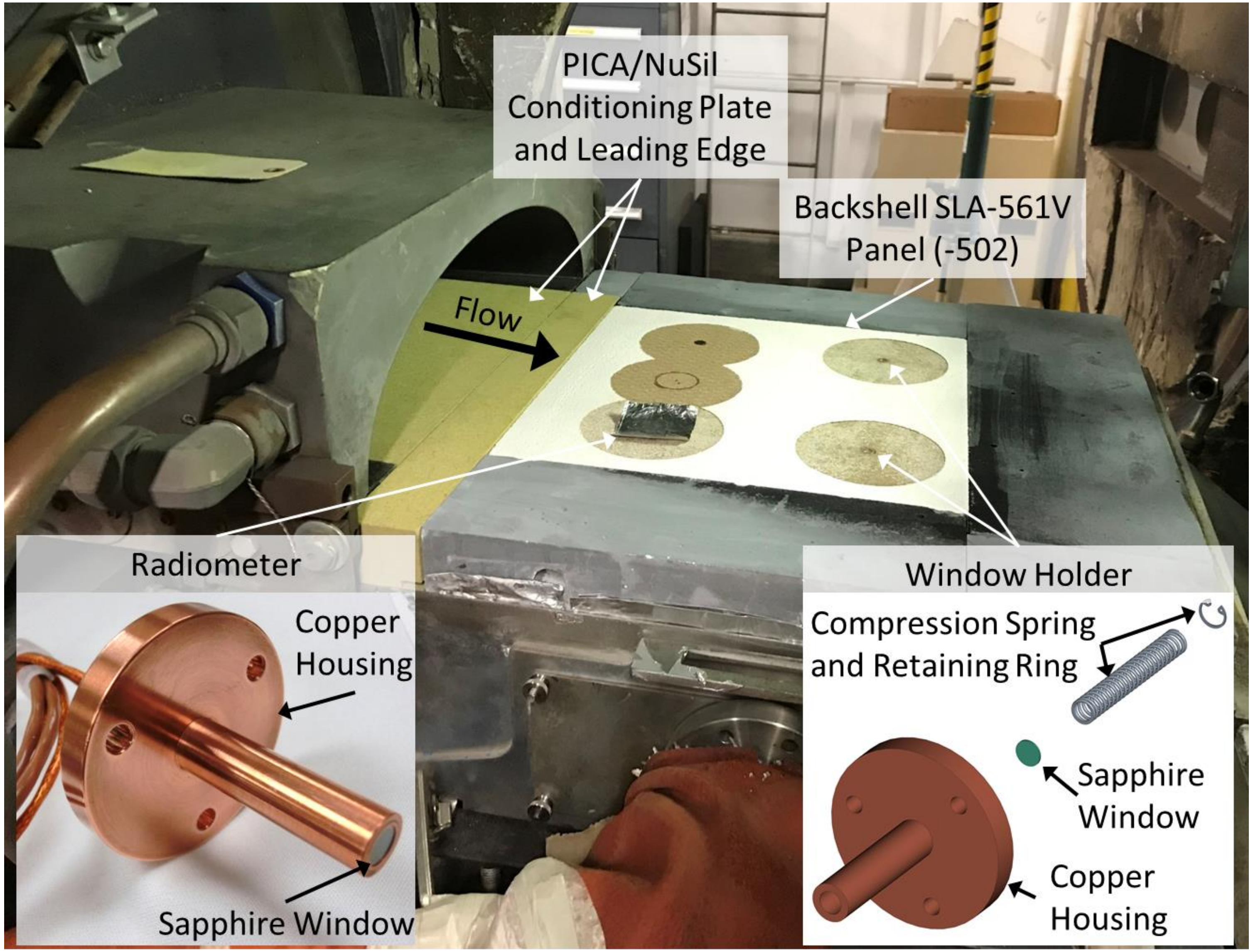
PTF166 Post-Flight Backshell Instrumentation Testing (October 2021)

Test articles:

- 4 backshell (SLA-561V) panels with embedded MEDLI2 instrumentation
  - 1 radiometer and 2-3 window holders per panel
  - 3 panels had white thermal control paint to mimic the flight configuration
  - 1 panel did not have paint

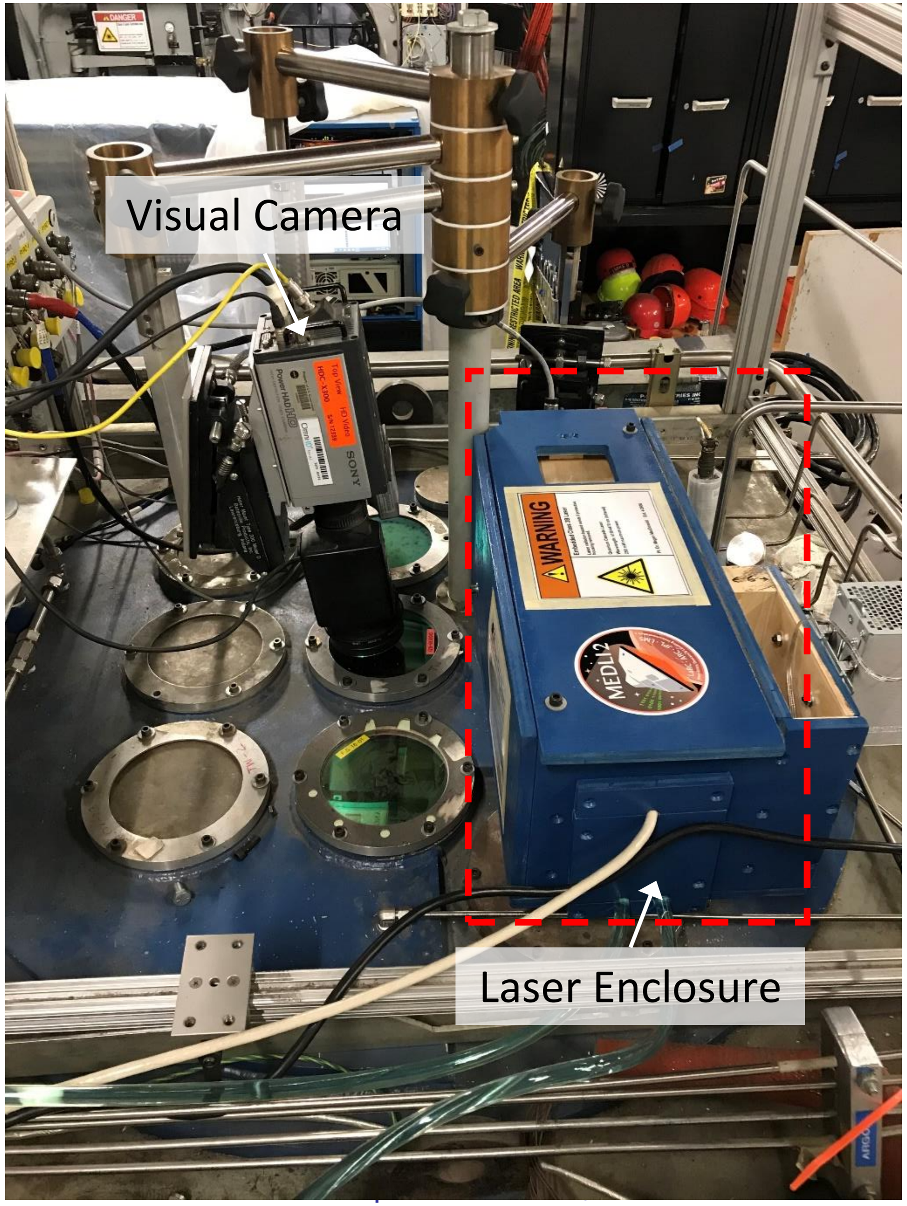
Test objectives:

1. Select test conditions to approx. flight conditions
   - Heat flux: 4.9 W/cm^2 (CW)
   - Pressure: 320 Pa
   - Duration: 33 sec
2. Measure the time-varying ablation product deposition on the radiometer window.
   - Use a laser outside the PTF chamber to illuminate the radiometer in each panel.
3. Include PICA ablation products (best effort)
   - Use PICA/NuSil conditioning plate and close-out frame leading edge in a best effort to mimic the flight configuration which used PICA as the forebody TPS.



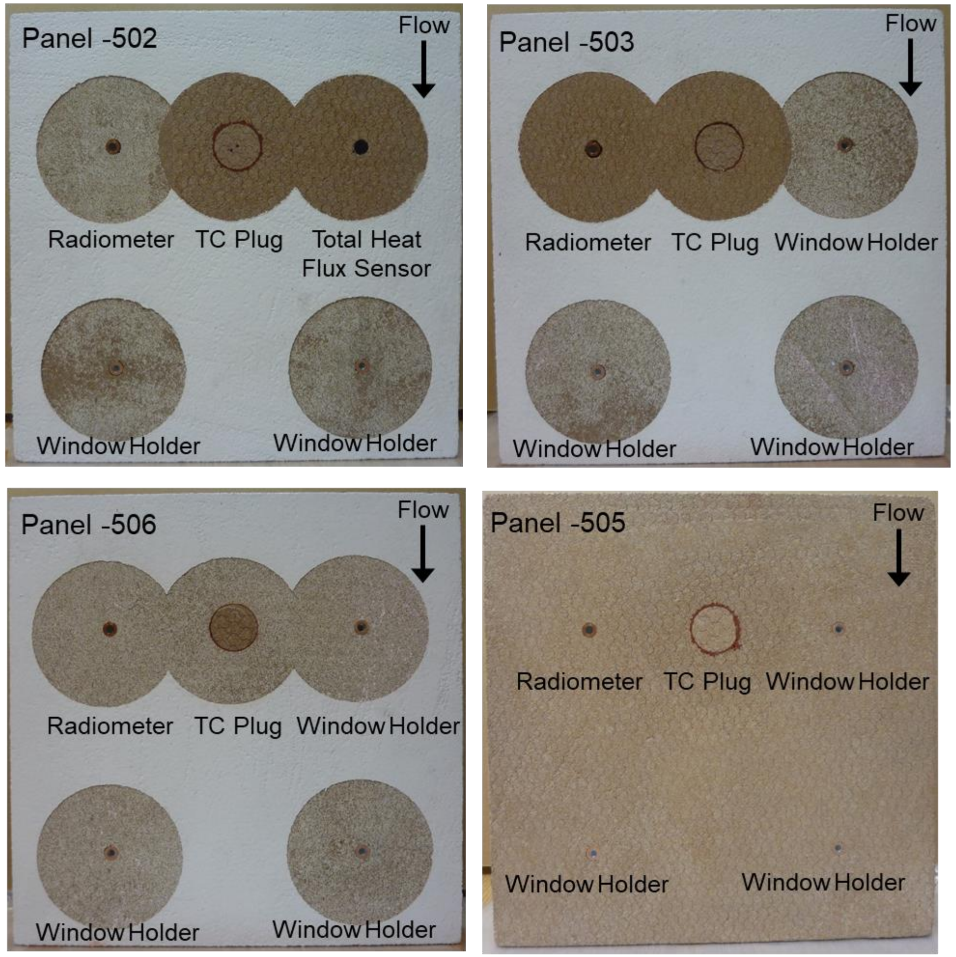
Laser Setup on Top of the PTF

- The radiometer installed in each panel was excited with an external cavity quantum cascade laser (center wavelength 4.3 µm)
  - The 4.3 µm wavelength was chosen since it has been shown to be one of the major contributors to radiative heating for Mars entry
- Enabled measurement of the time dependance of the ablation product deposition on the radiometer window
- The laser was mounted on top of the PTF test chamber and directed through a sapphire window using a protected aluminum mirror

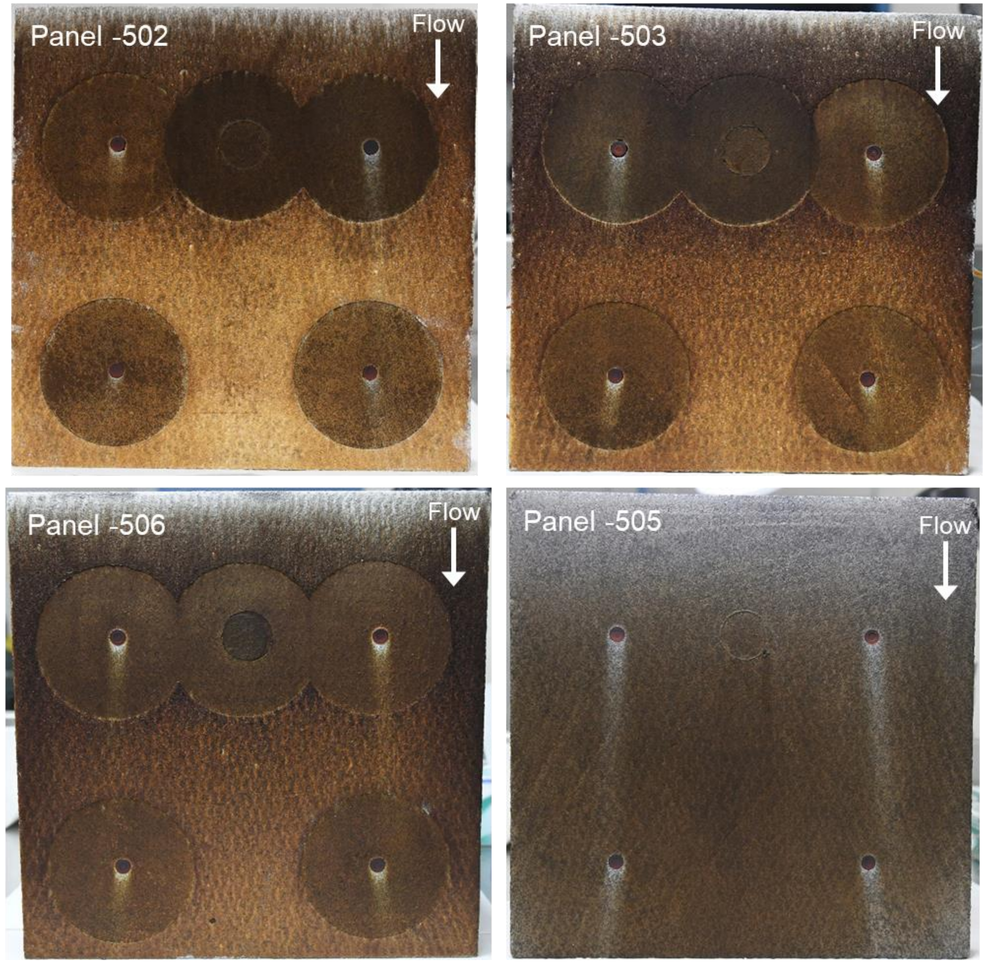


Photos

Pre-Test



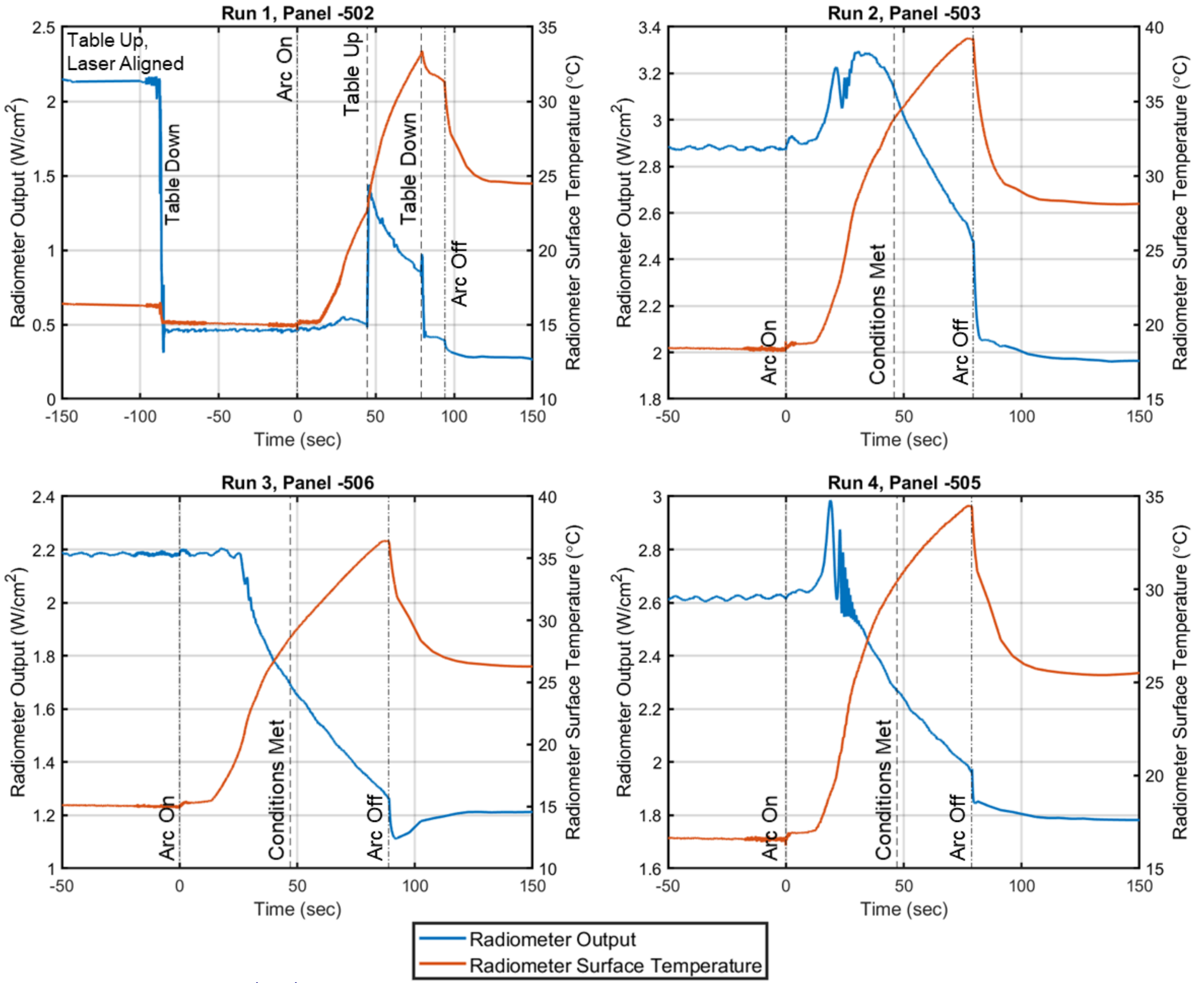
Post-Test



Post-Test Windows

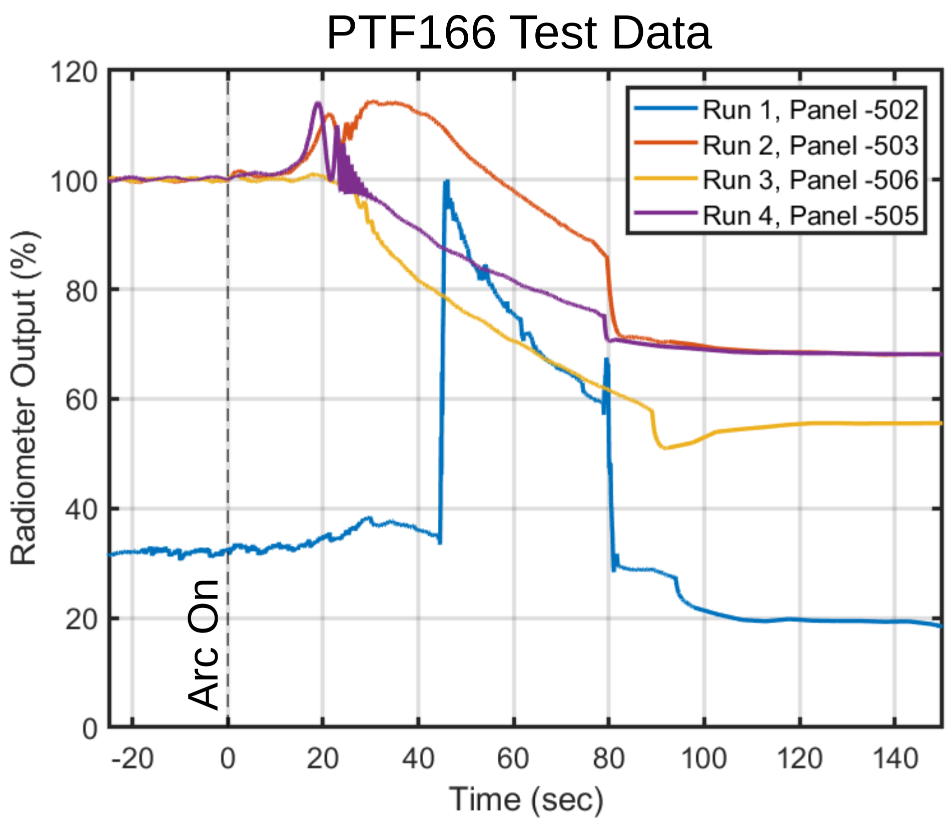
PTF166 Test Results

- Table angle:
  - Run 1 was conducted using the standard facility -5° table angle while setting the condition, 0° table angle during the test time, and -5° table angle before arc off
    - Raising and lowering the table resulted in laser misalignment
  - Table angle was set to 0° for the entire duration during Runs 2, 3, and 4
- For Runs 2, 3, and 4, after arc-off, during cool-down, the laser was realigned to assess the impact of laser misalignment.
  - Run 2: signal did not increase during realignment indicating the laser remained aligned.
  - Run 3: the signal increased from ~1.2 W/cm^2 to 1.4 W/cm^2 during realignment.
  - Run 4: the signal increased slightly (< 0.05 W/cm^2) during realignment.
- The radiometer output increased at arc on and rapidly decreased at arc off
  - Attributed to flow radiation since the same magnitude was measured during PTF162



PTF166 Test Results

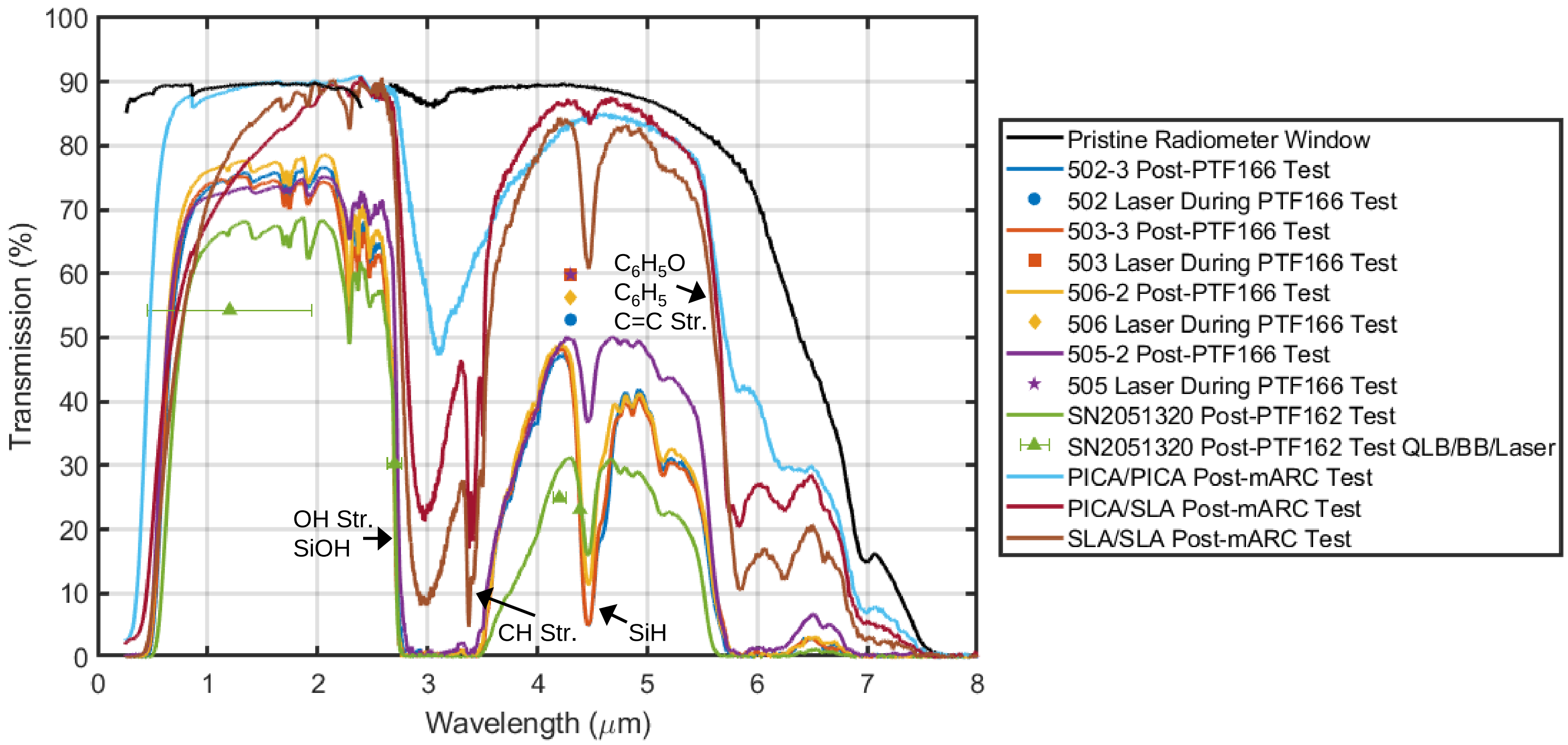
- For all four runs, the radiometer output decreased approximately linearly throughout the test time
  - Similar result as the measured/predicted ratio calculated from the flight data
- Signal loss:
  - For Runs 2 and 4 the signal loss at the end of the test was ~32%
    - Nearly identical signal loss indicates minimal difference between paint vs no paint at 4.3 µm
  - For Run 3 the signal loss at the end of the test was ~36%
    - Compared to Runs 2 and 4, Run 3 had an ~8 second (~24%) longer duration.
    - Run 3 also had a fresh PICA/NuSil conditioning plate and leading edge – more Si deposition?
  - Determining the signal loss for Run 1 is more difficult due to the laser misalignment. If signal loss is defined with respect to the radiometer output at table up, the signal loss directly before table down was ~40%



Post-Test Transmission

- The windows from Runs 1, 2, and 3 have similar post-test transmissions (i.e., panels with paint)
- The absorption feature at 4.5 µm is less severe for the windows from Run 4 (i.e., panel without paint)
- Compared to PTF162, the PTF166 post-test transmission is higher except for the 4.5 µm absorption feature.
  - 4.5 µm absorption feature was previously attributed to SiH
  - SiH is known to be unstable in air and expected to oxidize to Si-OH
    - PTF162 transmission measurements were taken ~1.5 years after testing
    - PTF166 transmission measurements were taken ~1 month after testing
  - PTF166 included NuSil coated PICA upstream. Additional Si deposition?

Panel Number	Measured Transmission at 4.3 µm	Transmission Calculated from 4.3 µm Laser Data
502	45%	53%
503	45%	60%
506	47%	56%
505	50%	60%

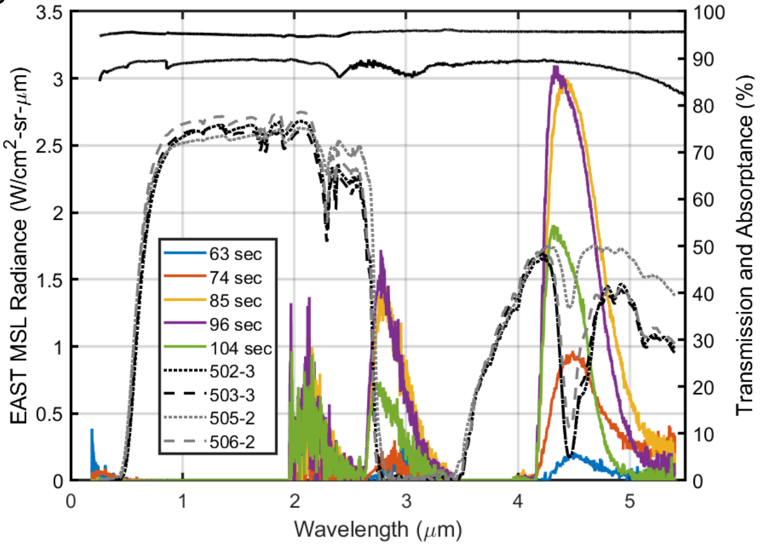


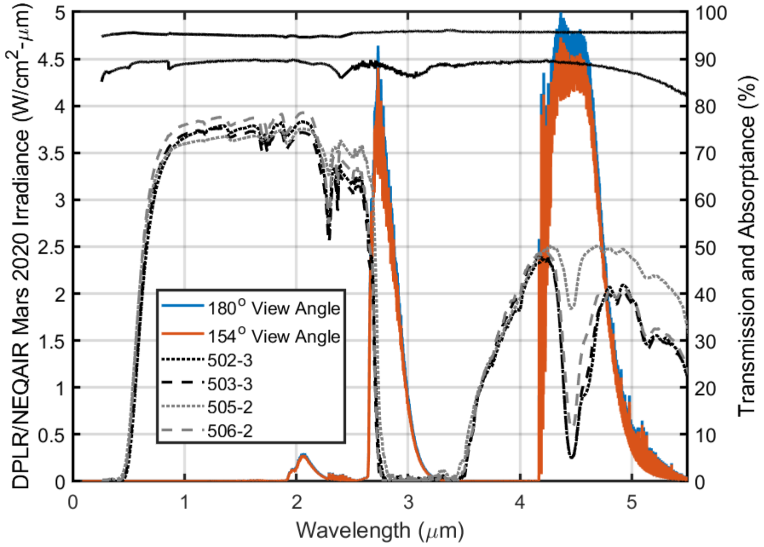
Inferred Signal Loss

- The signal loss at Mars entry relevant wavelengths was inferred using the transmission measurements combined with DPLR/NEQAIR predictions and EAST experimental measurements
- Inferred signal loss is approx. the same between PTF162 and PTF166 Runs 1, 2, and 3.
  - PTF162 and PTF166 transmissions both drop to 0% at ~2.76 μm and thus cut off the majority of the 2.7 μm peak.
  - The PTF162 and PTF166 transmissions cut off about the same amount of the 4.3 μm peak due to the stronger absorption feature at 4.5 μm in the PTF166 transmission.
- PTF166 Run 4 has a lower inferred signal loss
  - This is the panel without paint
- 50% signal loss calculated from comparing the flight data to predictions falls with the 30% to 75% signal loss inferred from arc jet testing
  - Applicability of these arc jet tests to flight requires further investigation

$$S_{loss} = \left(1 - \frac{\int \tau(\lambda)\alpha(\lambda)L(\lambda)\, d\lambda}{\tau_{cal}\alpha_{cal} \int L(\lambda)\, d\lambda}\right) x\ 100$$

		EAST	DPLR/NEQAIR
Pristine Window		1.8%	4.6%
Post-mARC Test	PICA/PICA	12-13%	11-12%
	SLA/SLA	28-29%	28-29%
	PICA/SLA	19-20%	17-18%
Post-PTF162 Test	SN2051320	73%	76%
Post-PTF166 Test	Run 1, 502-3	71%	75%
	Run 2, 503-3	71%	75%
	Run 3, 506-2	67%	71%
	Run 4, 505-2	54%	58%





Summary and Conclusions

- MEDLI2 has conducted 3 rounds of arc jet testing to characterize the ablation product deposits on the MEDLI2 radiometer window
- Post-flight arc jet testing included a measure of the time-dependence of the ablation product deposits
  - A linear decrease in signal as seen during the PTF test which is consistent with the linear decrease calculated by comparing the flight data to predictions.
- Post-test window transmission measurements were significantly attenuated compared to the pristine window transmission.
  - The signal loss calculated from comparing the flight data to predictions was 50% which falls with the 30% to 75% range inferred from arc jet testing
- The applicability of these arc jet tests to flight is under investigation.
  - Heat flux and heat load were nearly matched to flight
  - Heating profile was a square pulse as opposed to the time-varying heat pulse experienced in flight.
  - Length scale of the arc jet test article is different than the flight configuration
  - In flight, the radiometer was in a recirculating flow region and the degree to which the PICA byproducts flow over the shoulder and are entrained in the recirculation region is not known.
  - This test was conducted in air + Ar, while the Martian atmosphere is composed of 95% CO_2, 2.6% N_2, and 2.0% Ar (by mole).
  - Other unanswered questions include how the window transmission and deposition are impacted by cold soak during transit to Mars.

Thank you for your attention!

Questions?

Acknowledgements

- The authors would like to acknowledge everyone who assisted with the post-flight PTF arc jet test series including Kristina Skokova, Kristen Price, Megan MacDonald, Eric Noyes, and the NASA Ames TSF arc jet personnel.