Characterization Of Thermal Protection Systems

An Analysis of Optical & Thermal Properties

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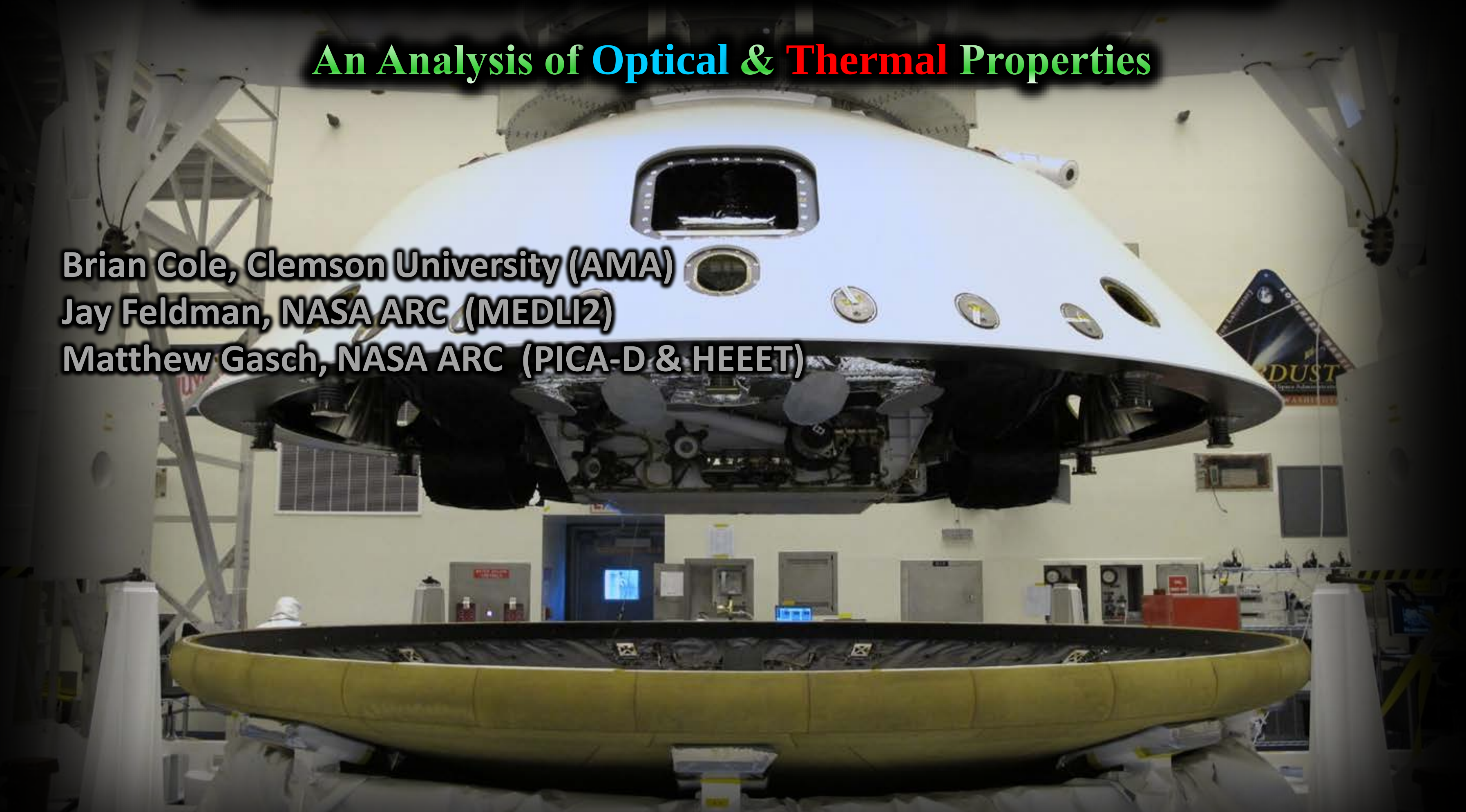


NASA ARC Annual Research Symposium

Moffett Field, CA August 8th, 2019

Outline

Background

– Background & Objectives

Materials Introduction

– Various Ablative Thermal Protection Systems (TPS)

Optical Properties

– Infrared, Ultra-Violet, & Visible Radiation Spectra

– Emissivity & Absorptivity Calculations

Thermal Properties

– Specific Heat & Thermal Conductivity

Summary

– Research Accomplishments & Contribution Towards Mars 2020

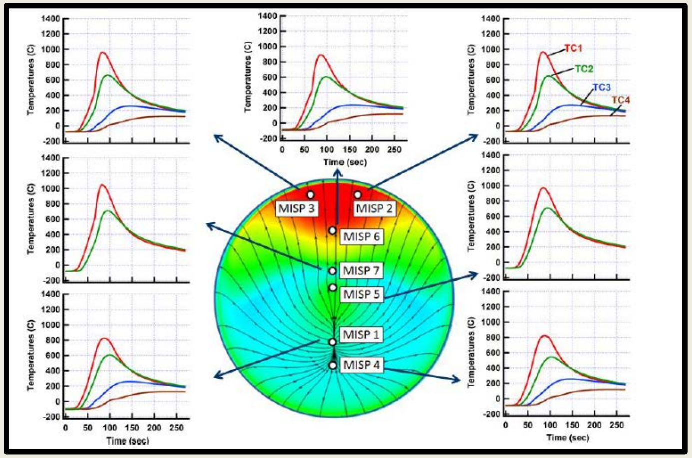
Background & Objectives

We Aim To Measure Physical Properties:

MEDLI Example

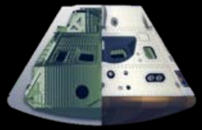
Improve Thermal Response Models

Reconstruct Flight Environments



Design TPS For Future Missions

Background & Objectives



- **Objective:** Characterize Properties of TPS Materials
  - Optical properties
  - Thermal properties

- This allows us to develop Thermal Response Models for TPS

- The models enable design of TPS for Flight Missions and analysis of flight data to understand Aerothermal Environments experienced on the mission

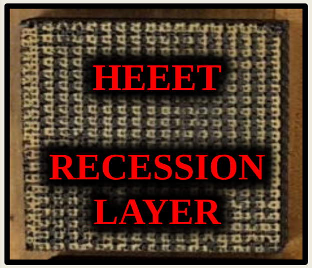
- Comparing pre-flight predictions with actual flight data can allow us to reduce TPS margins and improve designs
  - **MEDLI** and **MEDLI2** are examples of this to be discussed

Materials Studied

TPS Materials

Low Density Ablative

Sustainable Material
Made in USA



High Density
3D Woven Material

Opens Doors For
Venus & **Saturn**

Lower Density
3D Woven Material

Lower Thermal Conductivity

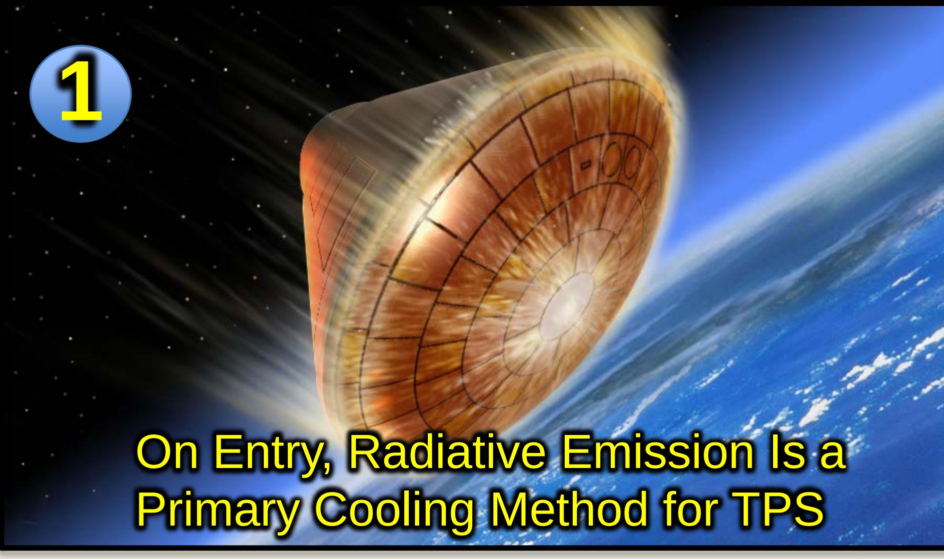
Thermal Control Coatings

$440.00 per pint
Standard White Inorganic Coating

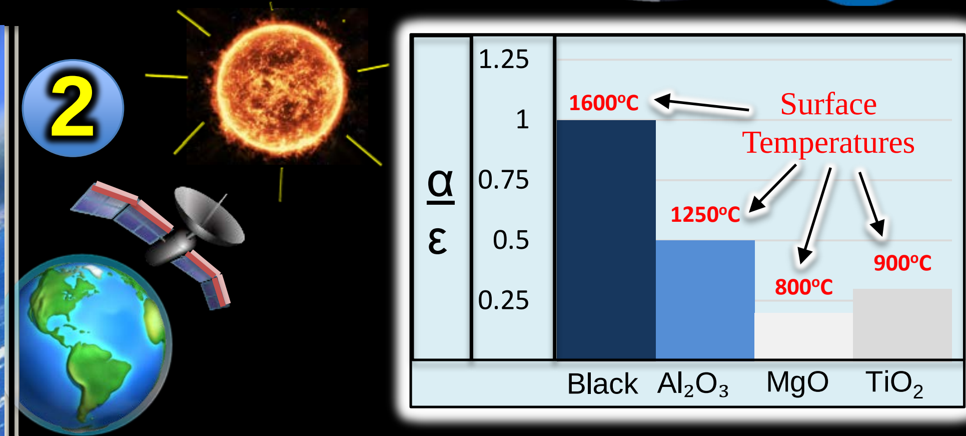
$1800.00 per pint
Electrically Conductive

$7200.00 per pint
Very Low Solar Absorbance

Optical Properties Overview



On Entry, Radiative Emission Is a Primary Cooling Method for TPS

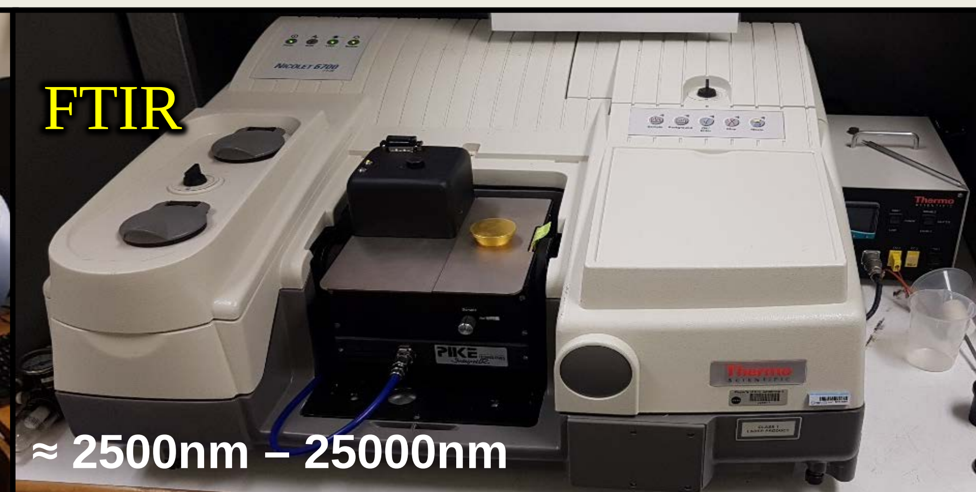


On Orbit, Re-Emitting Solar Rays Reduces The Equilibrium Surface Temperature

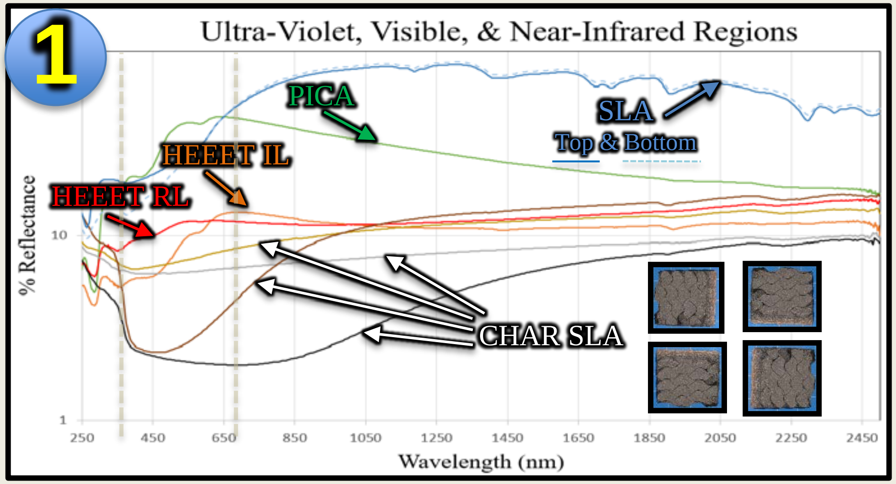
FTIR (Fourier Transform Infrared Spectroscopy**)**

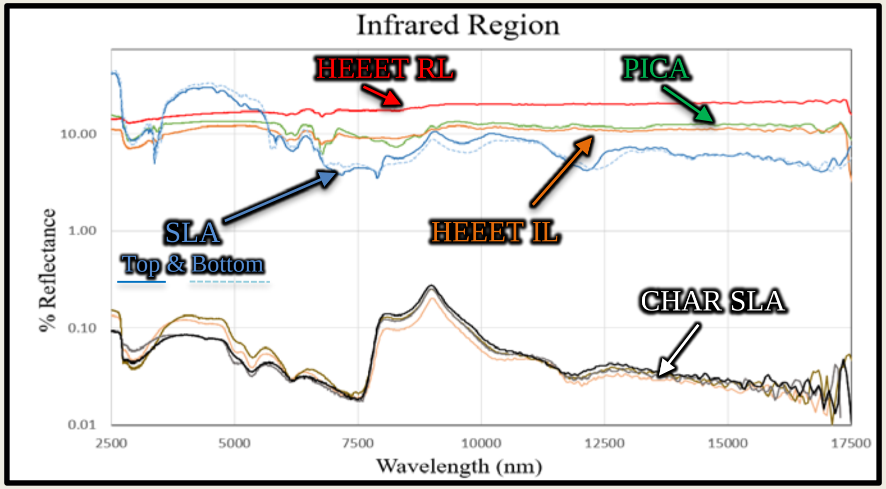
UV-Vis (Ultra-Violet & Visible Light Spectroscopy**)**

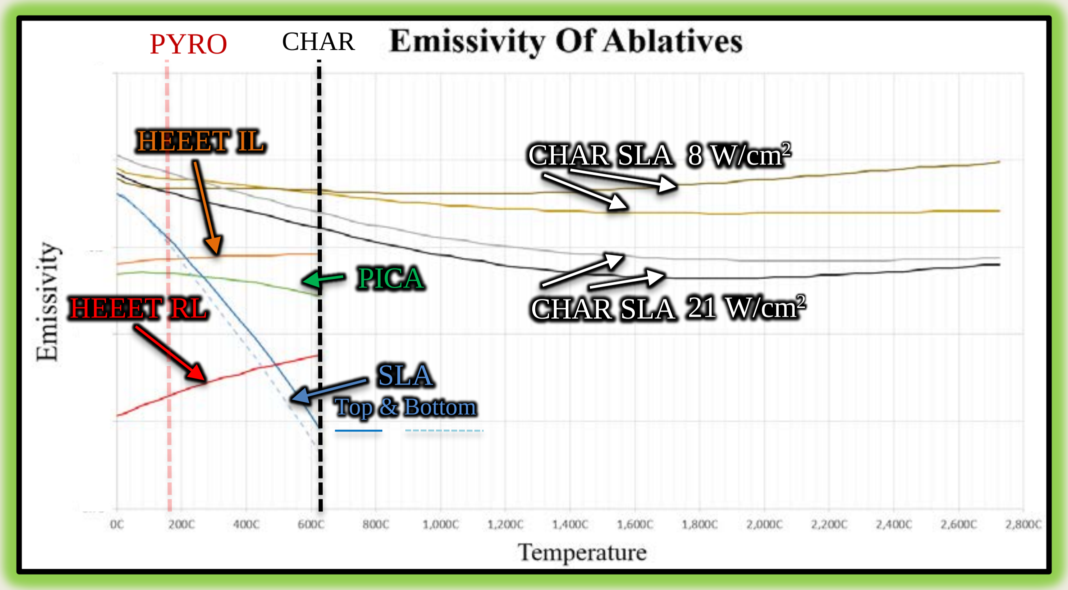
→ Calculate **Emissivity & Absorptivity**



SLA Optical Properties







UV & VISIBLE REGIONS

- Char Consistent With Expectations (Absorbs Visible Light)

INFRARED REGION

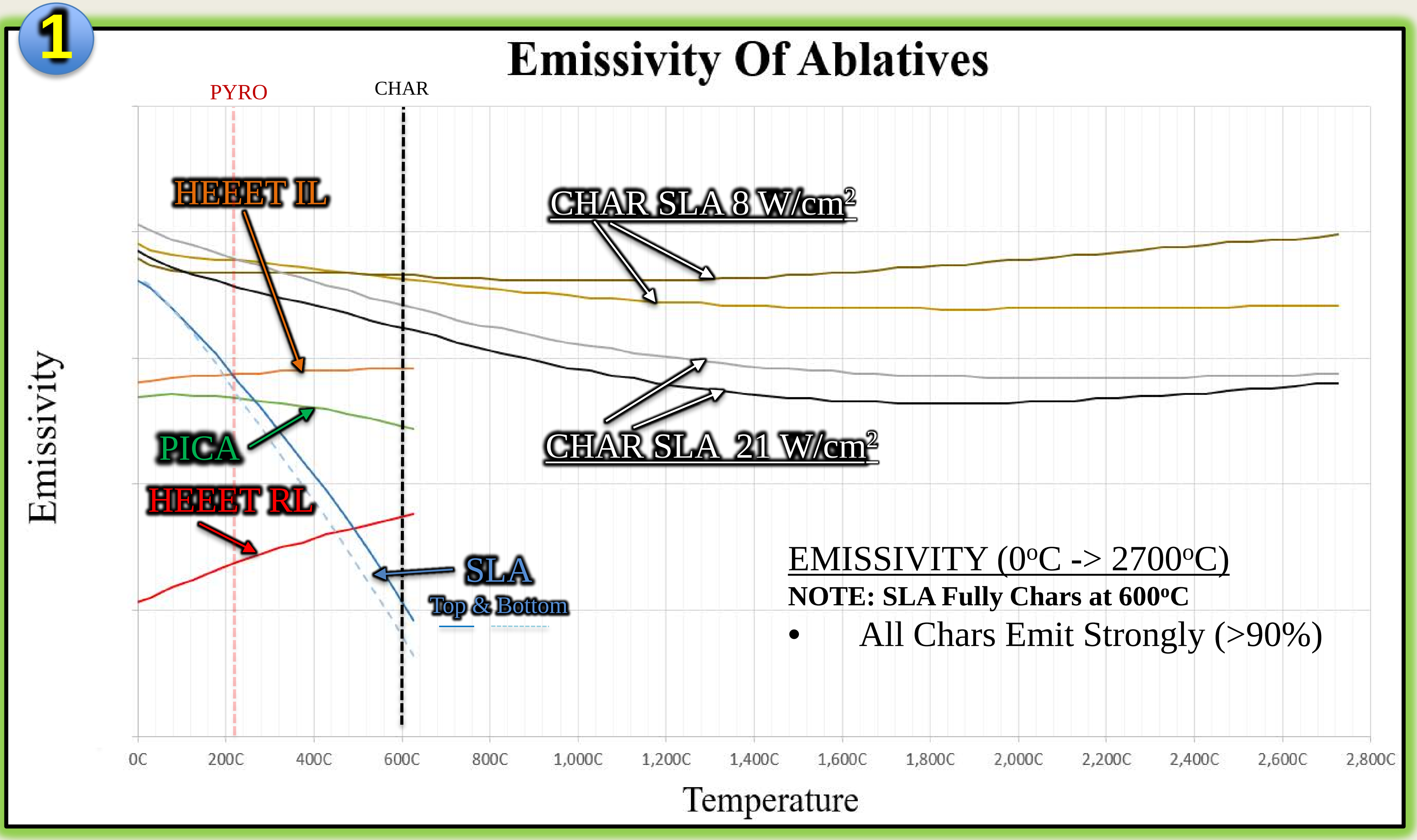
- Evidence of OH & CO Chemistry

EMISSIVITY (0°C -> 2700°C)

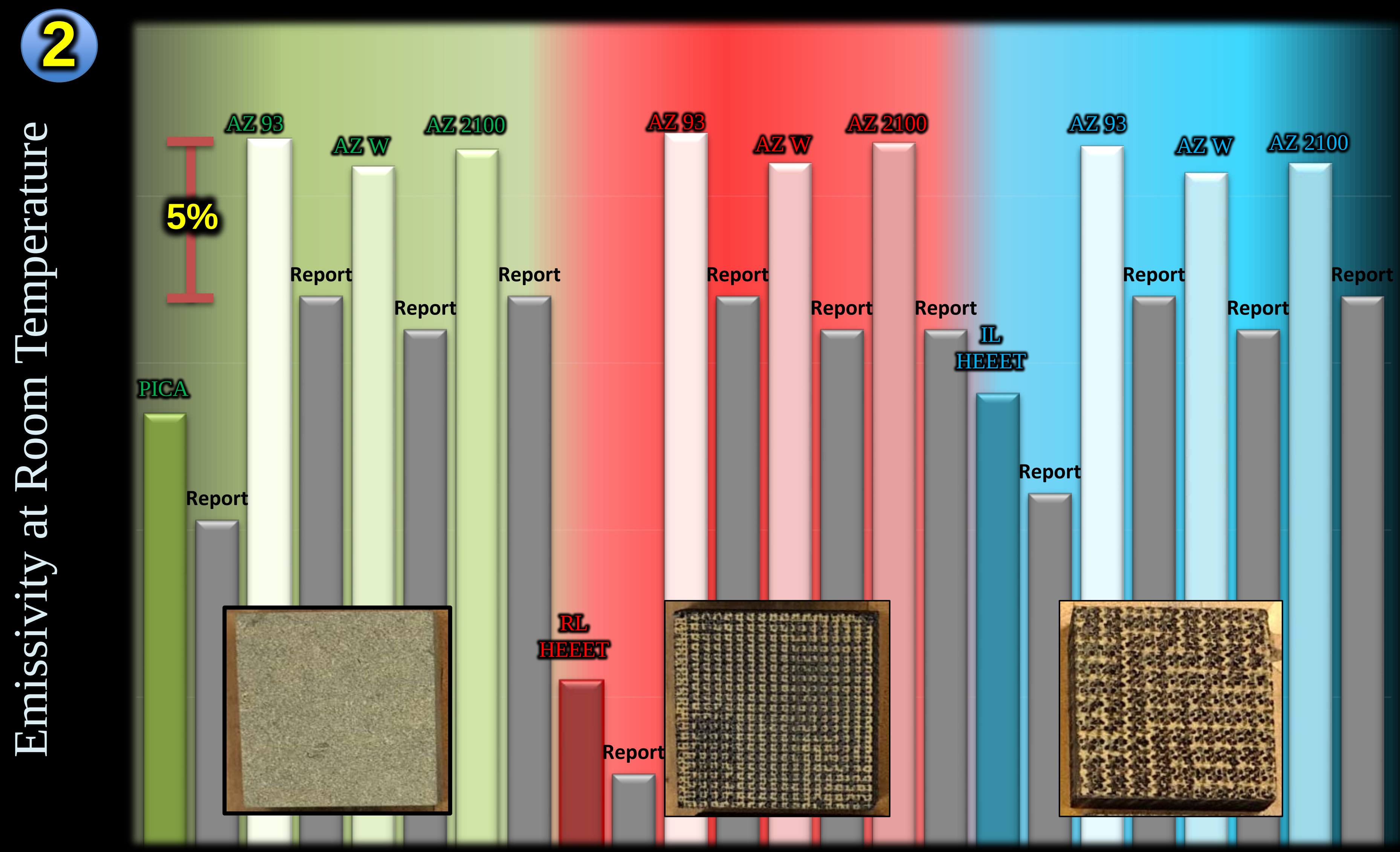
NOTE: SLA Fully Chars at 600°C

- All Chars Emit Strongly (>90%)

SLA Emissivity

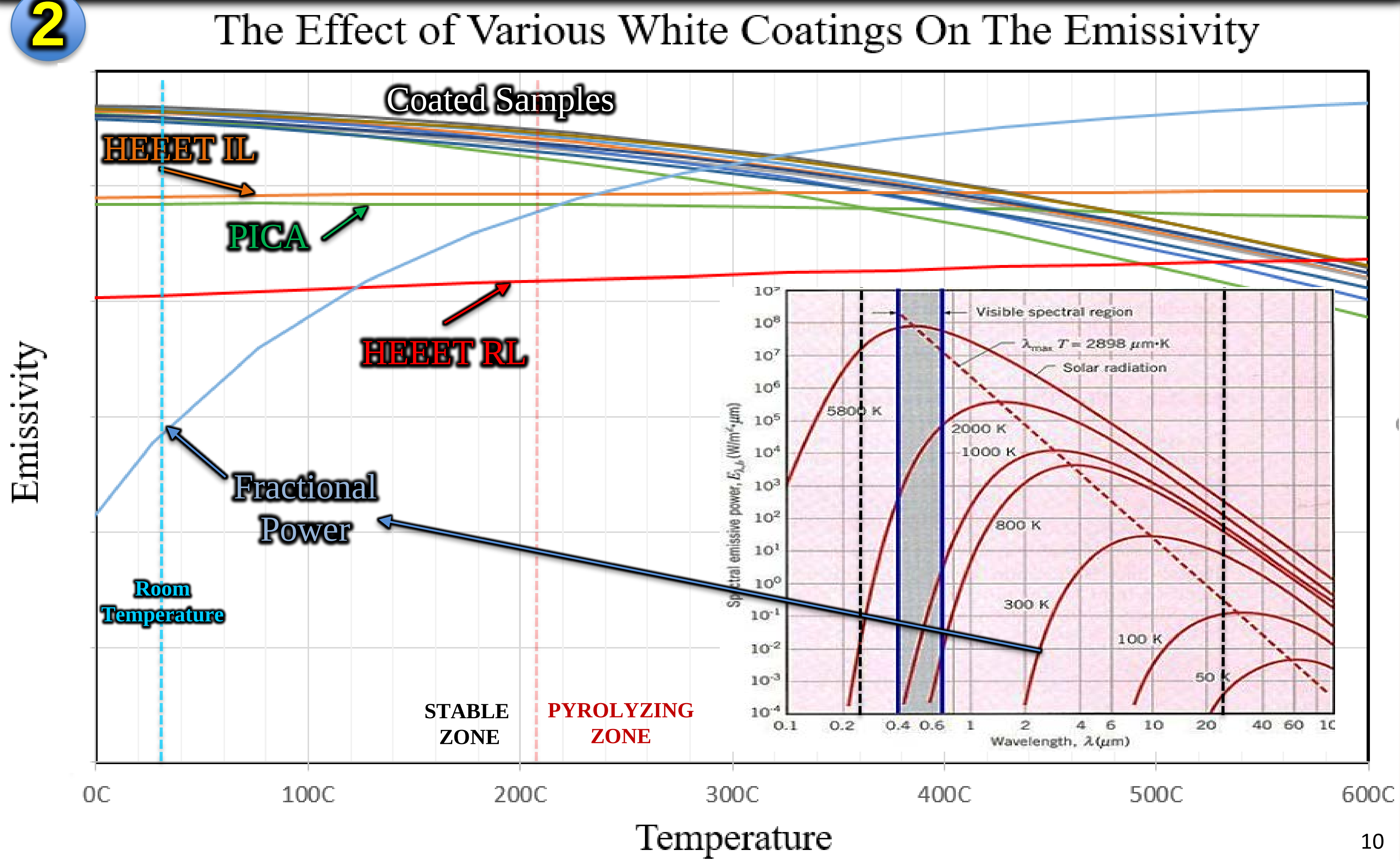


Thermal Control Coating Emissivity



Emissivity as a Function of Temperature

2

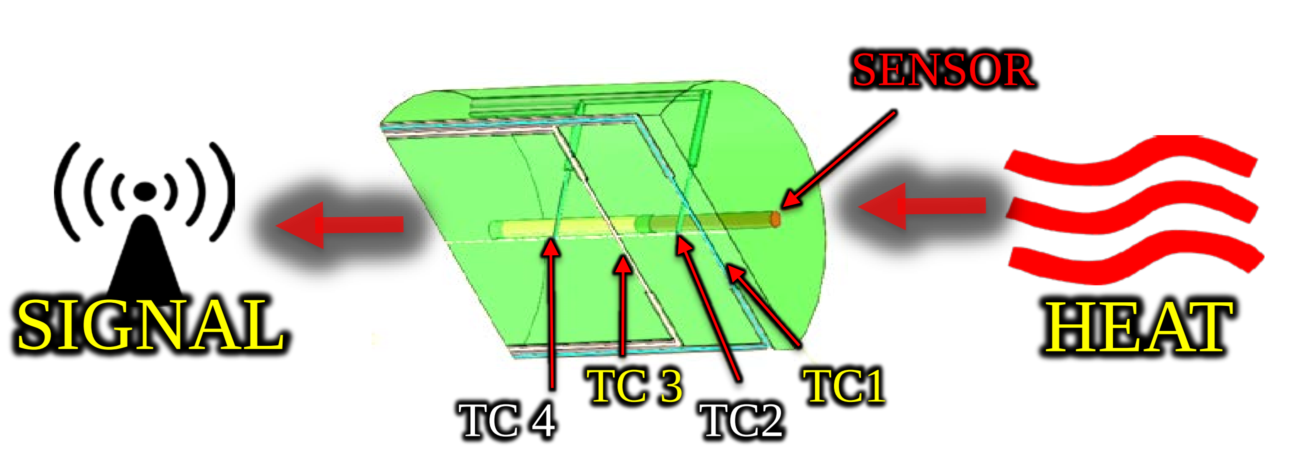


Thermal Properties Overview

- Mars Science Laboratory (MSL) launched in Nov **2011** & landed Curiosity Aug **2012**

cp (Heat Capacity)
&
λ (Thermal Conductivity)

Allows Us To Infer
The In-Depth
Thermal Response



<u>**Example: Original MEDLI**</u>

- Improved Engineered Models for Future Missions
- Predicted T & P Response of TPS
- Improved Margins Allowing an Increased Payload

Solid State Heat Flow Meter Fox 50

Instrument Specifications

- Sample Size [2”-2.5” Diameter]
- Range [-10°C – 185°C]
- Accuracy [± 4%]
- Reproduciblity [± 2%]

Methodology

1. Obtain Contact Resistance of Rubber Matt
   – Via two dx exp. with Perspex Standard
2. Measure λ of Standards & Samples
3. Correct λ by Rubber Matt Subtraction

Rubber Matt Subtraction Formula

Assumptions

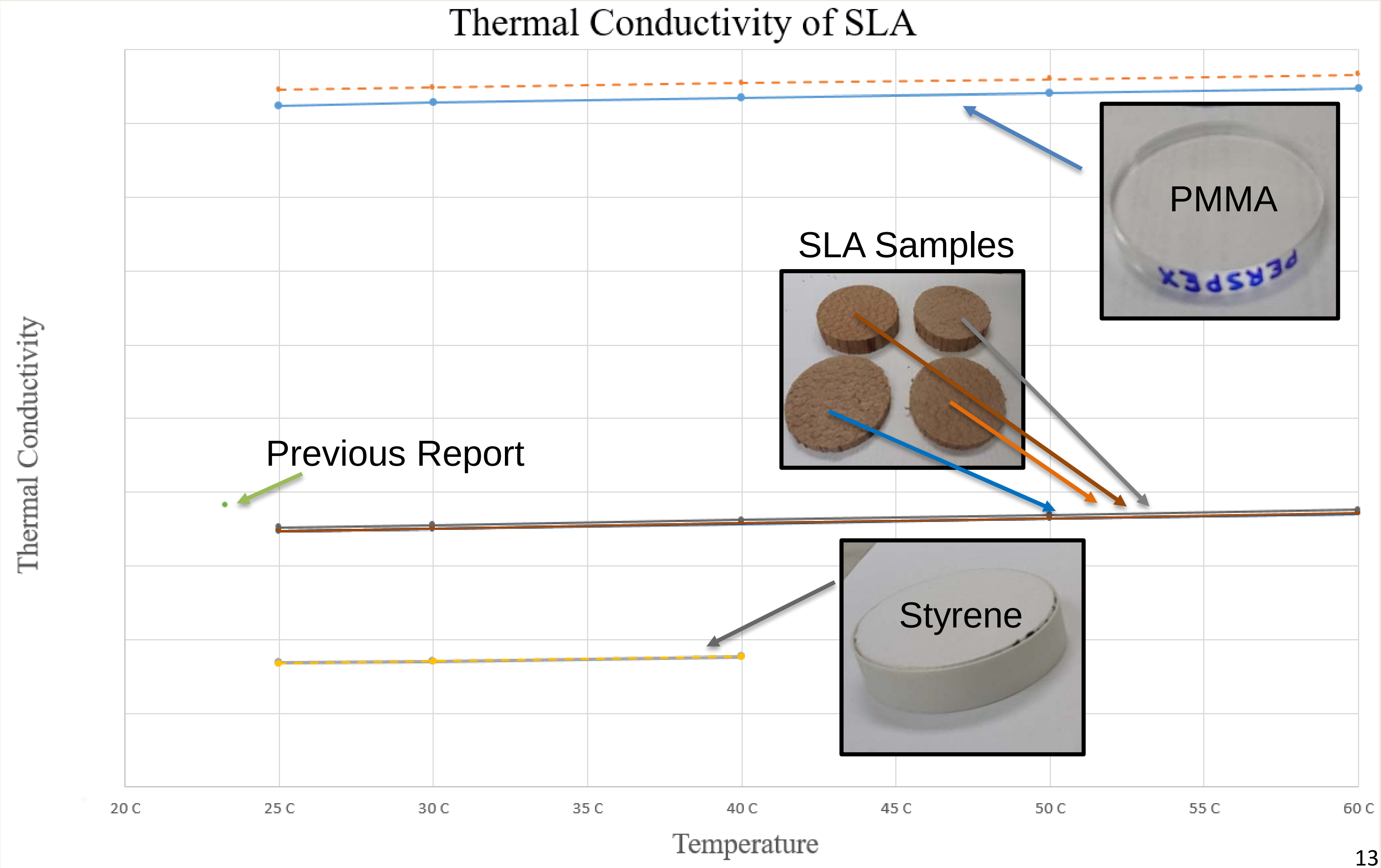
1) $[\lambda_T - \lambda_R \; is \; Neglgible]$

2) $[\lambda_R \cong \lambda_S] \rightarrow \left[\frac{\lambda_S}{\lambda_R} \cong 1\right]$

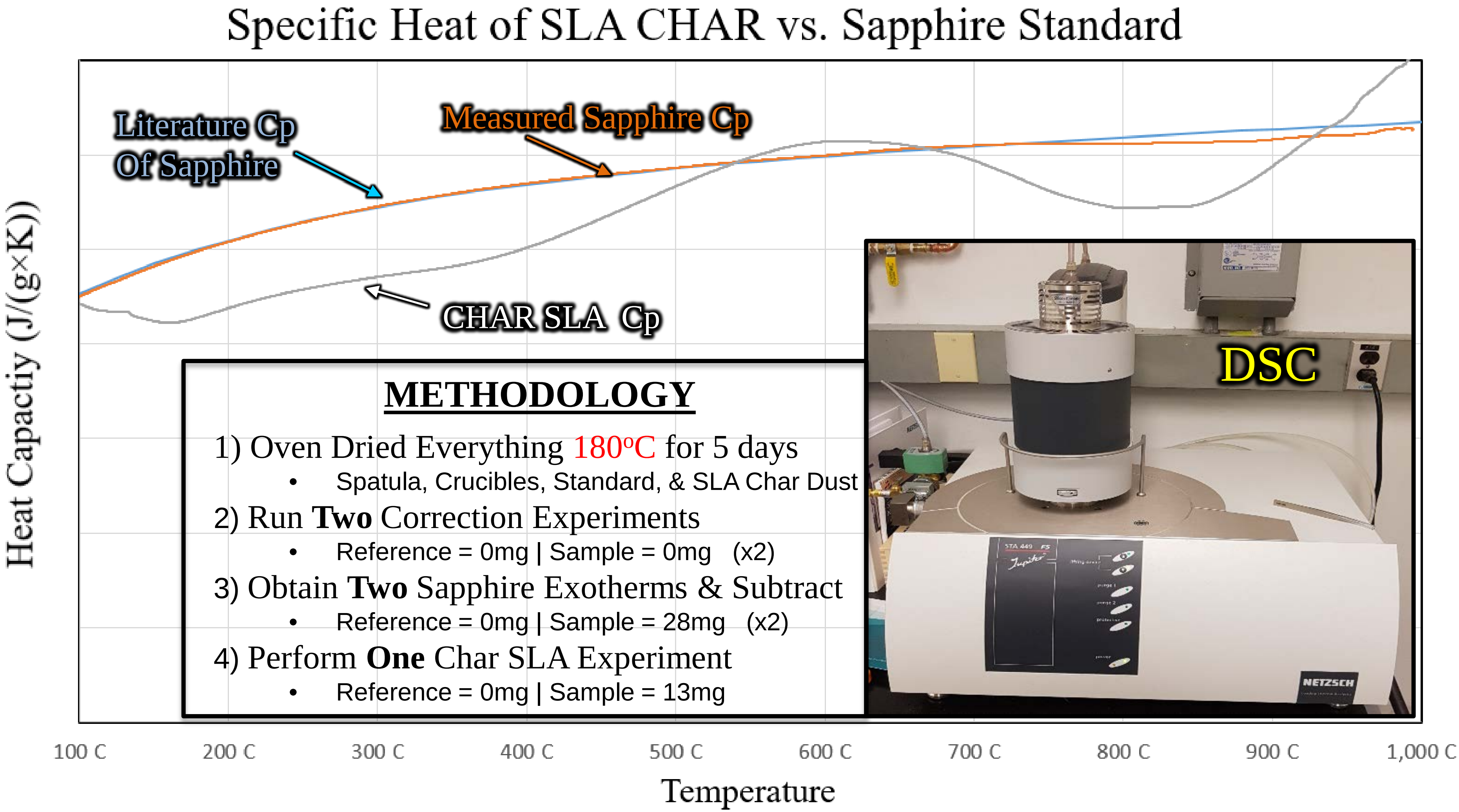
3) $[T_t \cong S_t - R_t]$

$$\frac{(T)_t - R_t}{\frac{(T)_t}{\lambda_T} - \frac{R_t}{\lambda_R}} = \lambda_S$$

Thermal Conductivity of SLA



Heat Capacity by DSC



METHODOLOGY

1) Oven Dried Everything 180°C for 5 days
   - Spatula, Crucibles, Standard, & SLA Char Dust
2) Run **Two** Correction Experiments
   - Reference = 0mg | Sample = 0mg (x2)
3) Obtain **Two** Sapphire Exotherms & Subtract
   - Reference = 0mg | Sample = 28mg (x2)
4) Perform **One** Char SLA Experiment
   - Reference = 0mg | Sample = 13mg

Summary

- Reviewed Various Ablative Materials
  - Purpose & Utility In NASA Missions

- Contributed Values For MEDLI2 Thermal Response Models and PICA-D and HEEET thermal response models
  - Optical Properties (Emissivity & Absorptivity)
  - Thermal Properties (Heat Capacity & Thermal Conductivity)

- Some of This Work is Not Complete and Highlights Questions To Investigate in The Future

Acknowledgments

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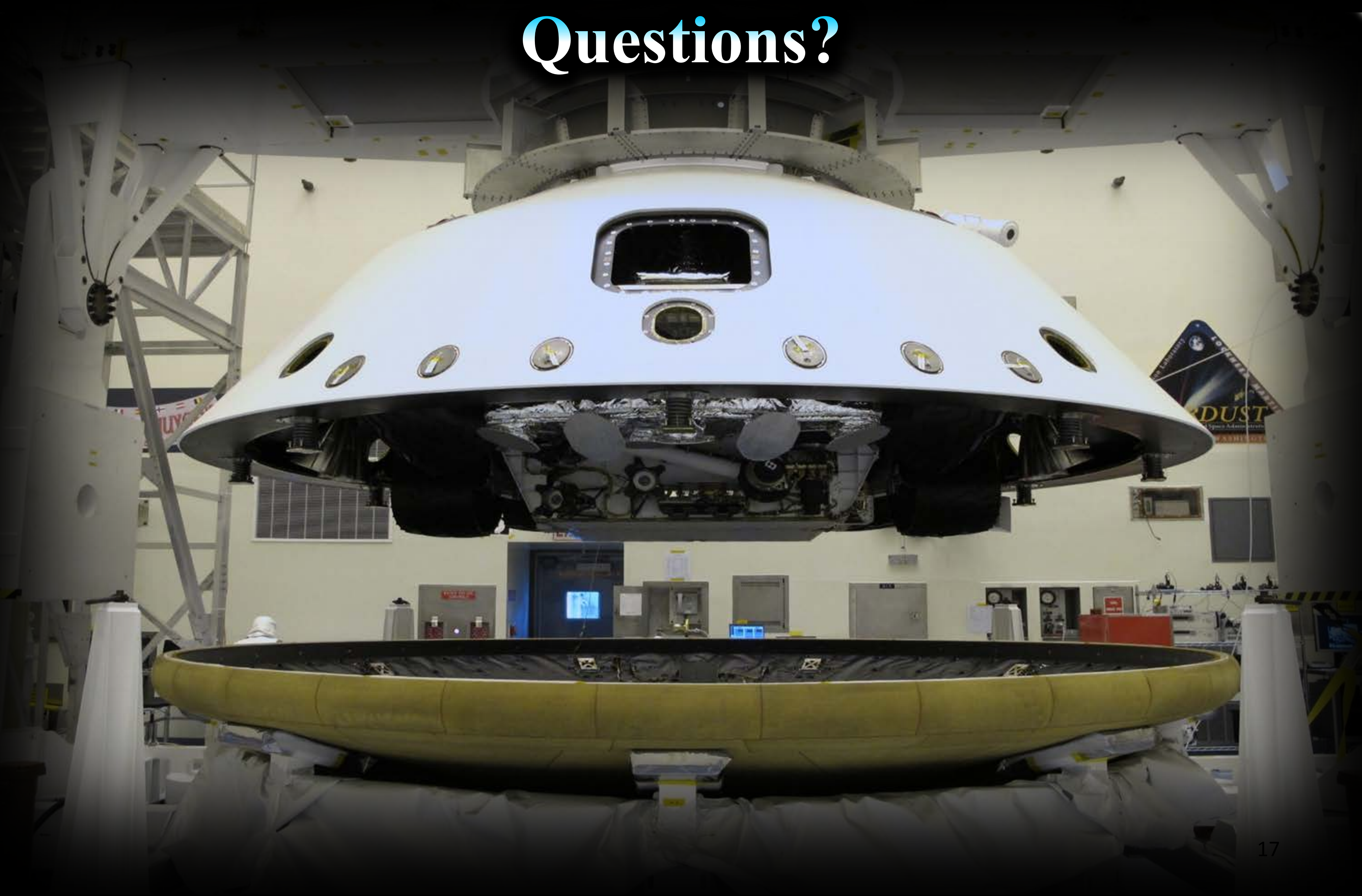
Questions?



Solid State Heat Flow Meter Fox 50

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- Accuracy [± 4%]
- Reprod[…]

$$\left(\frac{(T)_t - R_t}{\frac{(T)_t}{\lambda_T} - \frac{R_t}{\lambda_R}}\right) = \left(\frac{(S_t - R_t) - R_t}{\frac{(S_t + R_t)}{\lambda_S} - \frac{R_t}{\lambda_S}}\right) = \left[\frac{S_t}{\frac{(S_t)}{\lambda_S}}\right] = \left[\frac{1}{\frac{1}{\lambda_S}}\right] = \left[\lambda_S\right]$$

1. Obta[…]

   –

2. Meas[…]
3. Corre[…]

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