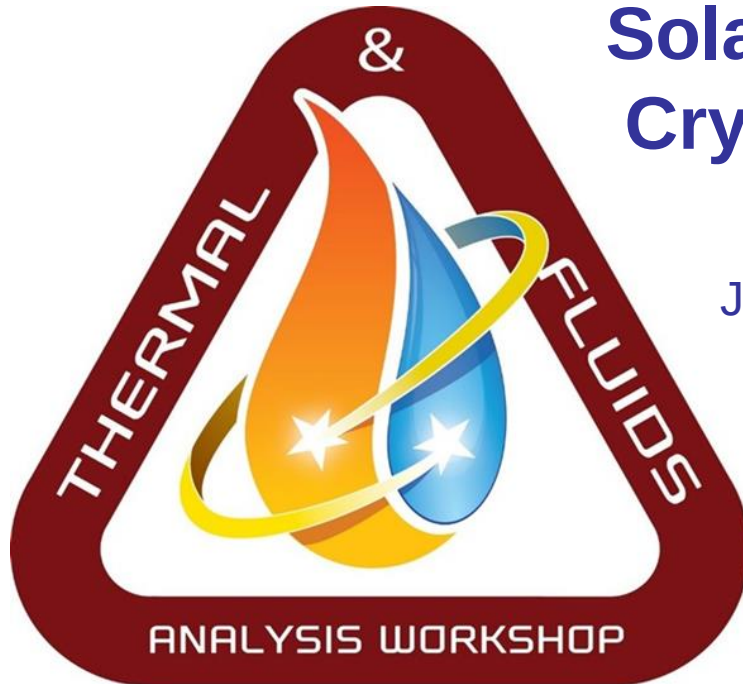




## Solar White Thermal Coating for Cryogenic Propulsion Systems

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Presented By  
Jarred Wilhite

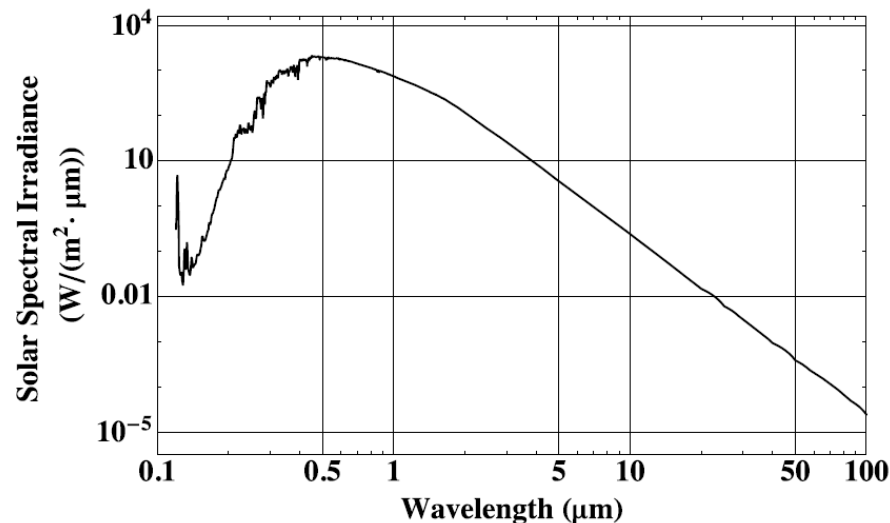
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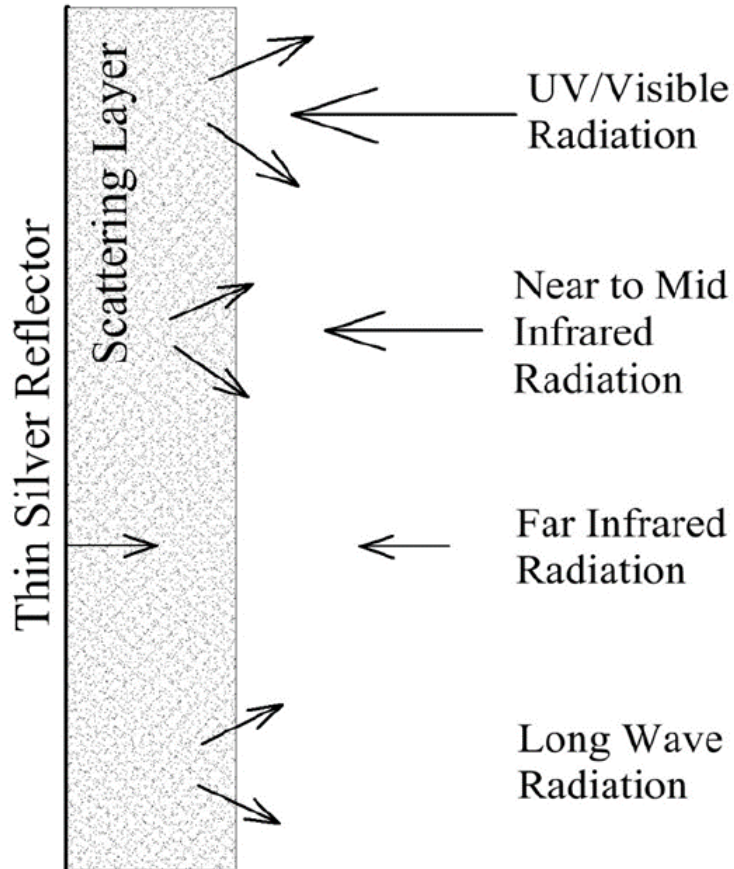
- Background
- Approach
- Model
- Results
- Conclusions



- Thermal control coatings have specific radiative properties depending on the desired application
- Recent NIAC study developed a thermal coating that can enable cryogenic storage in space
  - Low absorption of solar radiation
  - High emittance of infrared energy
  - Need to reflect vast majority of Sun's irradiance at lower wavelengths while emitting radiation in longer wavelengths



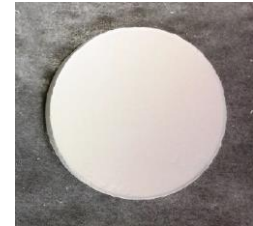
- Current state-of-the-art thermal control coatings
  - AZ-93 white paint absorbs 15% of solar spectrum
  - Single layer silver based TCC absorbs 10% solar spectrum
  - Qioptiq quartz on silver absorbs 6% of solar spectrum
- Yttrium oxide selected as the solar white material
  - Reflects UV above 0.235  $\mu\text{m}$  through IR up to 8  $\mu\text{m}$
  - 0.2% solar absorption
  - Lightweight, hydrophobic, chemically stable



- Scattering layer of  $\text{Y}_2\text{O}_3$  reflects UV/Visible and near-to-mid IR radiation
- Thin silver film reflects far-IR radiation
- $\text{Y}_2\text{O}_3$  emits longer wavelengths and radiates energy
- This combination can theoretically reflect 99.9% of Sun's energy when used in deep space

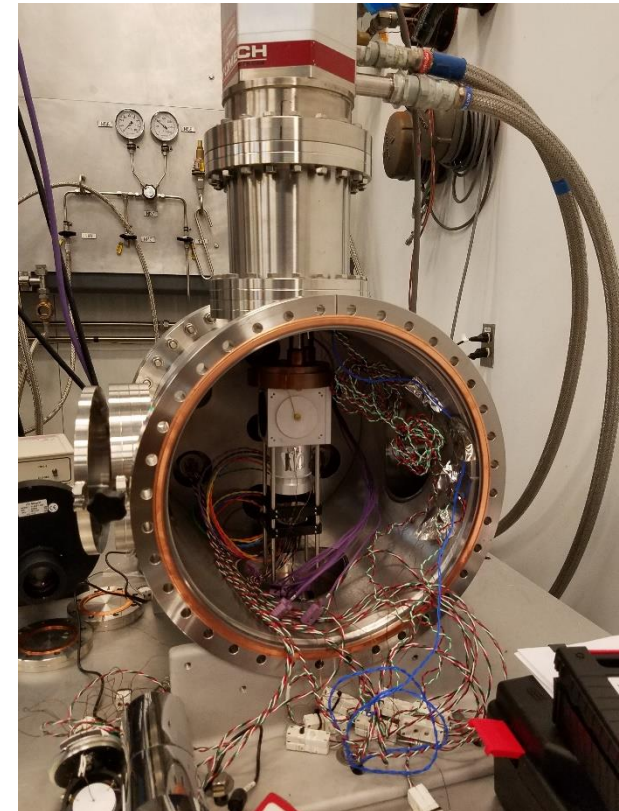
- Fabrication

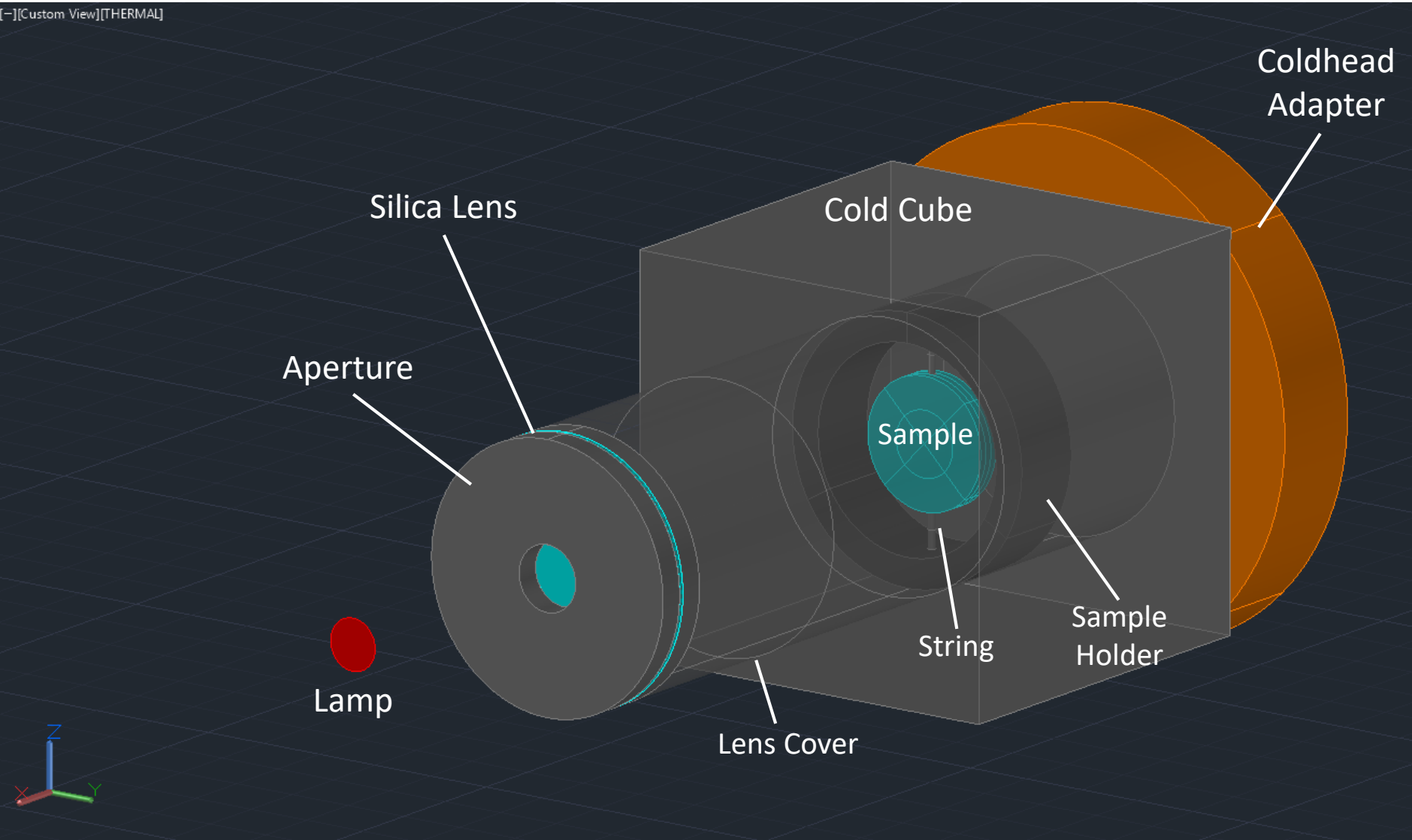
- $Y_2O_3$  powder compressed, then sintered in oven to make sample



- Deep Space Solar Simulator (DS<sup>3</sup>)

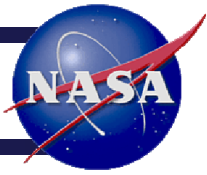
- Designed to simulate deep space conditions
- High vacuum
- 12 K background using coldhead adapter
- Xenon lamp solar simulator
- Silicon diodes to measure temps. of sample & simulator environment
- Can measure energy input at sample
- 8 test series completed consisting of “no light” and “light on” conditions





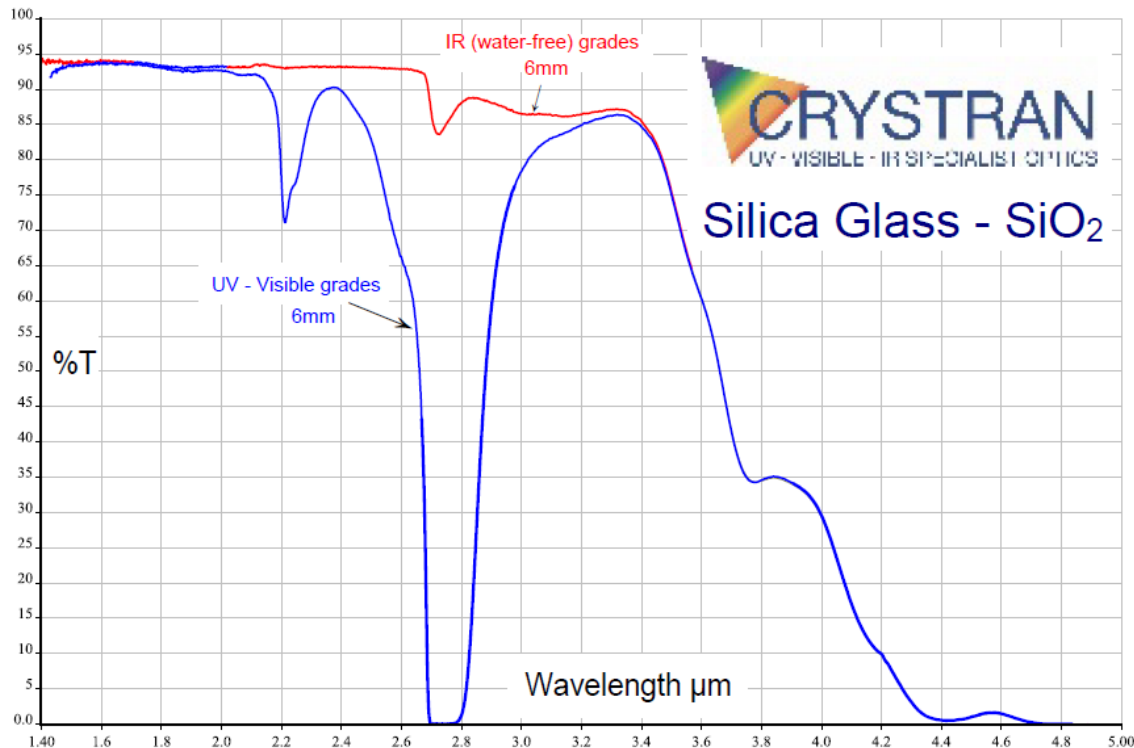


# Model (cont.)



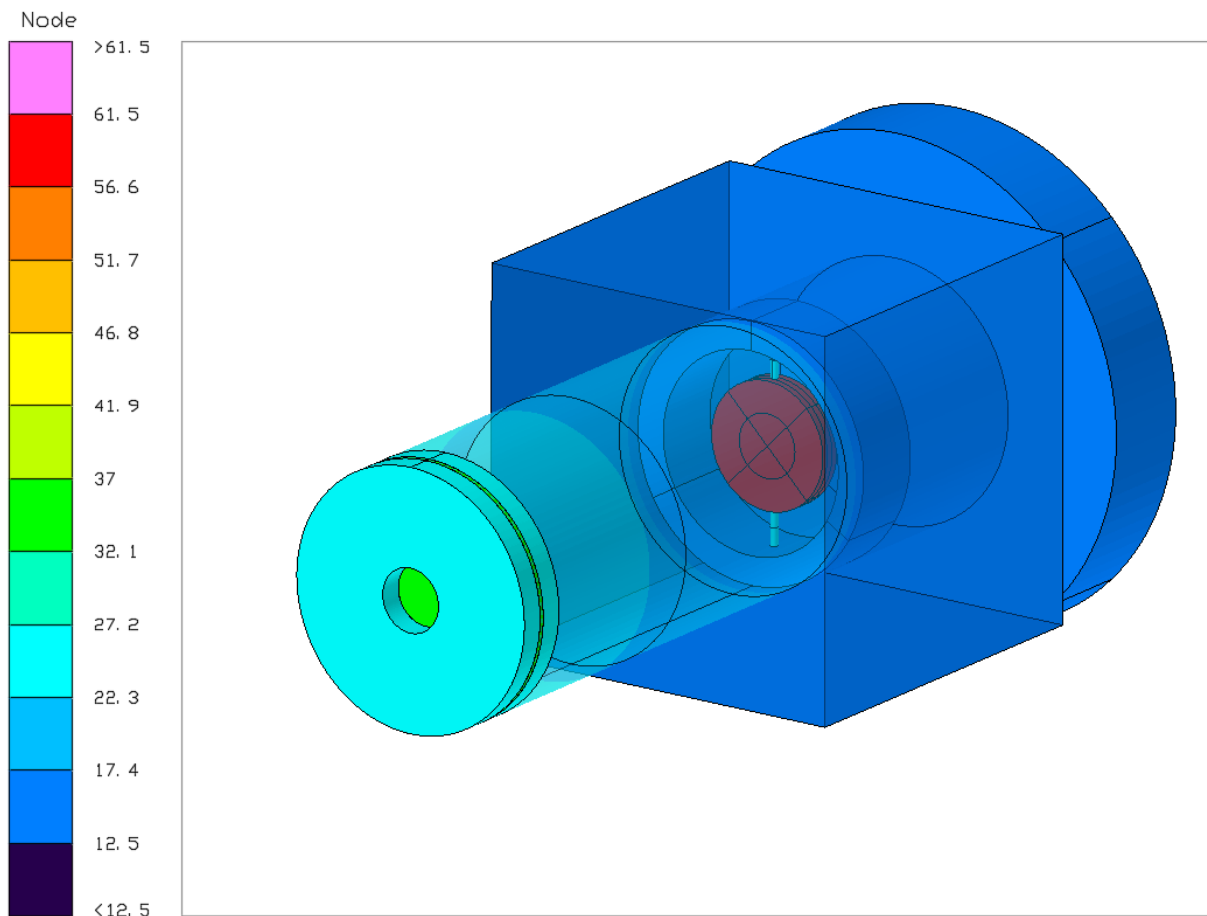
- Developed thermal model to
  - Better understand energy inputs to the sample
  - Verify results obtained in testing
  - Determine how IR affects simulator environment
- Solar lamp
  - Single node, thin surface
  - NORMAL optical property on active side
  - Surface not generated (disabled Cond/Cap tab)
- 2 different radiation analysis groups
  - Ensures that light from solar lamp is only applied to silica lens & sample
- Radiation tasks
  - Lamp surface set to output radks as heating rates

- Wavelength dependent properties for silica lens and sample
  - Used for optical properties and radiation analysis
  - 0 to 25  $\mu\text{m}$



- Two cases evaluated based on test conditions
- **No Light**
  - Solar lamp off
  - Simulates ambient, emissive environment
  - Lamp outputs  $43.1 \text{ mW/cm}^2$  - ambient IR contribution
- **Light On**
  - Solar lamp on + ambient IR contribution
  - Lamp outputs  $223.1 \text{ mW/cm}^2$

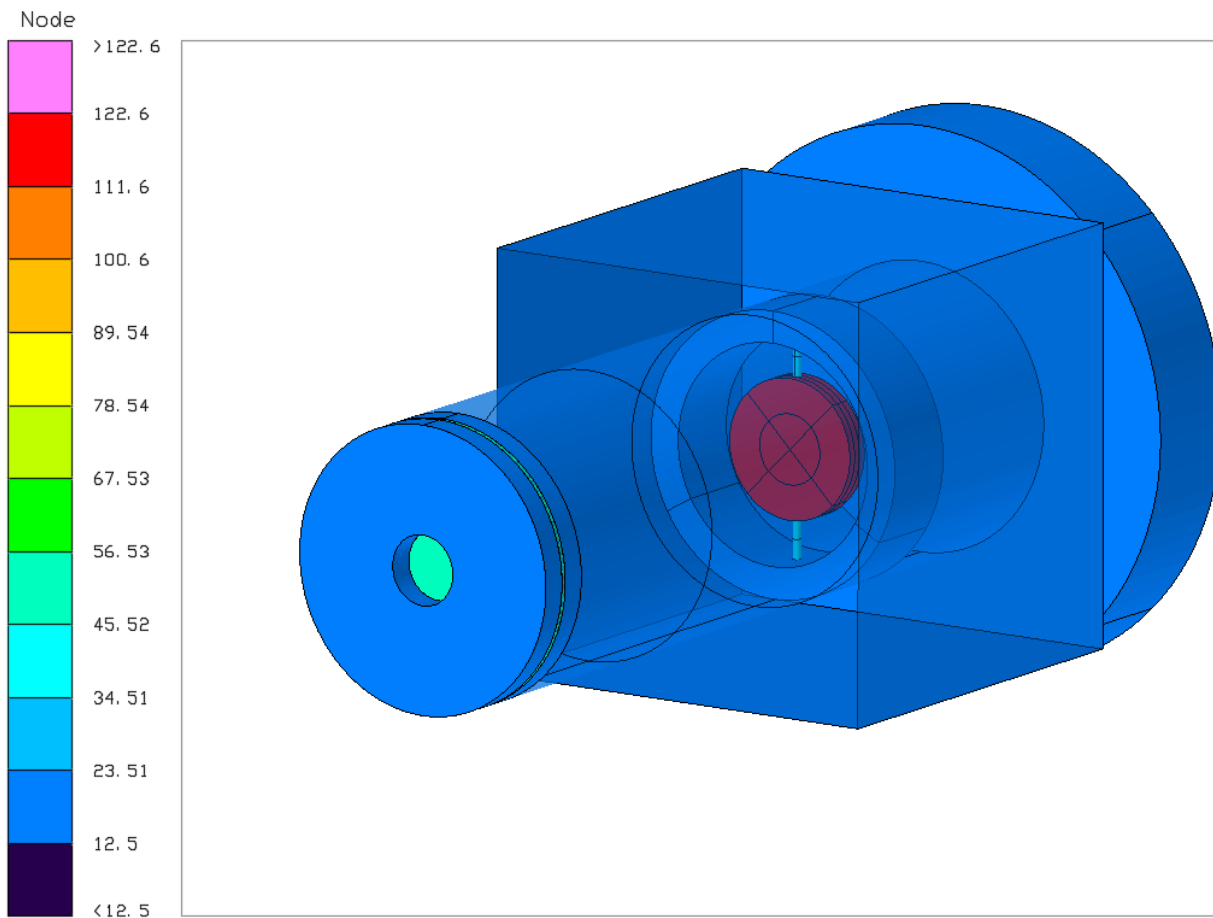
# Results – No Light Case



Temperature [K], Time = 0 s, Steady State, Loopct=5/100

| Steady State - No Light Temperatures (K) |          |             |                     |                     |             |        |                  |                         |              |                     |
|------------------------------------------|----------|-------------|---------------------|---------------------|-------------|--------|------------------|-------------------------|--------------|---------------------|
| Light Intensity<br>(mW/cm <sup>2</sup> ) | Aperture | Indium Foil | Silica<br>Lens (ID) | Silica<br>Lens (OD) | Sample      | String | Sample<br>Holder | Lens<br>Cover<br>(avg.) | Cold<br>Cube | Coldhead<br>Adapter |
| 43.1                                     | 23.1     | 23.1        | <b>35.8</b>         | <b>34.6</b>         | <b>61.5</b> | 27     | 15.3             | 19.5                    | 12.5         | 12.5                |

# Results – Light On Case



| Steady State - Light On Temperatures (K) |          |             |                     |                     |        |        |                  |                         |              |                     |
|------------------------------------------|----------|-------------|---------------------|---------------------|--------|--------|------------------|-------------------------|--------------|---------------------|
| Light Intensity<br>(mW/cm <sup>2</sup> ) | Aperture | Indium Foil | Silica<br>Lens (ID) | Silica<br>Lens (OD) | Sample | String | Sample<br>Holder | Lens<br>Cover<br>(avg.) | Cold<br>Cube | Coldhead<br>Adapter |
| 223.1                                    | 14       | 14          | 53.4                | 51                  | 122.6  | 39.1   | 12.8             | 13.4                    | 12.8         | 12.5                |

- Sample temperature greater than silica lens for both cases
  - Transmissivity of silica glass varying with wavelength
  - Heat generated by diodes (10  $\mu$ W) and IR leak to sample
  - Light intensity (Light On case)
- Model helped to gain understanding of energy inputs to solar white sample
  - Effect of IR on components
  - Validated results obtained during test
- Overall project findings verify that solar white can be used for cryogenic applications
- Will explore ways to apply modeling strategies to other deep space models where solar white can be applied

- <sup>1</sup>Kleiman, J. et al., “Black & White Thermal Control Coatings Comparison Experiment”. Acktar Advanced Coatings. 2018. <https://www.acktar.com/about-us/technical-reports/black-white-thermal-control-coatings/>
- <sup>2</sup>Youngquist, R., et al., “Cryogenic Deep Space Thermal Control Coating”. Journal of Spacecraft and Rockets. Vol. 55, No. 3, 2018.
- <sup>3</sup>Youngquist, R., et al., “Cryogenic Selective Surfaces, NIAC Phase II Study Final Report.” NASA. 2018.
- <sup>4</sup>Krenn, A., et al. “Cryogenic Thermal Control Coatings, An Overview”, NASA Technical Review Presentation. 2020.
- <sup>5</sup>“Silica Glass (SiO<sub>2</sub>)”. Crystran. <https://www.crystran.co.uk/optical-materials/silica-glass-sio2>