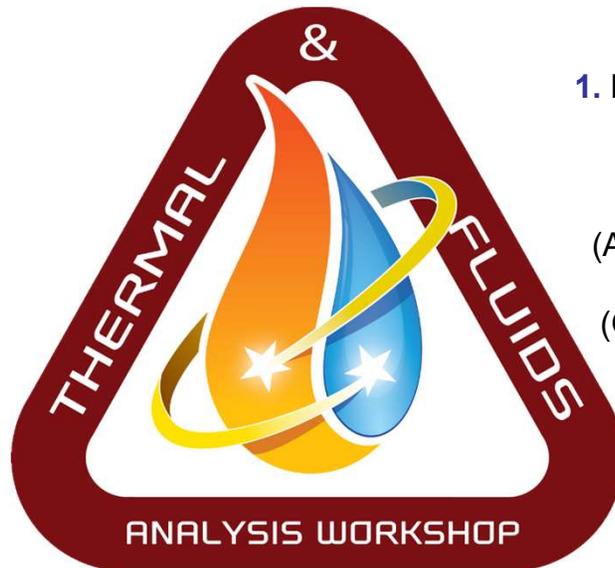




The SCIFLI Airborne Observation of Artemis 1 Ascent



TFAWS
GSFC · 2023

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Presented By

Kylel Scott

Thermal & Fluids Analysis Workshop

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NASA Goddard Space Flight Center

Greenbelt, MD



Presentation Outline



- Background
 - Collecting Flight Data
 - Scientifically Calibrated In-Flight Imagery (SCIFLI)
 - SCIFLI Airborne Multispectral Imager (SAMI)
 - Artemis 1 Ascent Observation
- Observation
 - Sensor Specifications and Imaging Objectives
 - FDA Evaluation Data Review
 - Post-Flight Radiometric Calibration
 - Temperature Extraction
 - Base Heatshield and 3D Mapping
- Conclusions
 - Lessons Learned
 - Summary





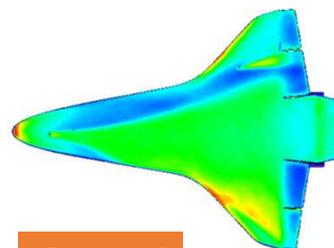
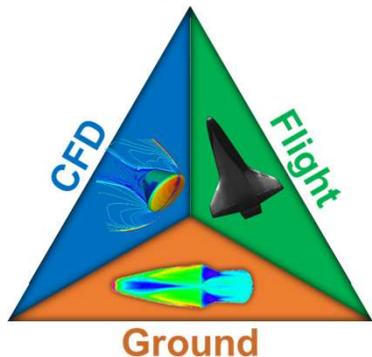
Presentation Outline



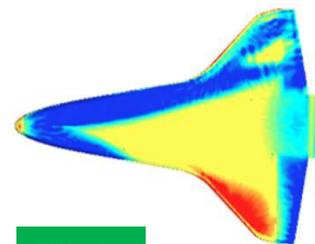
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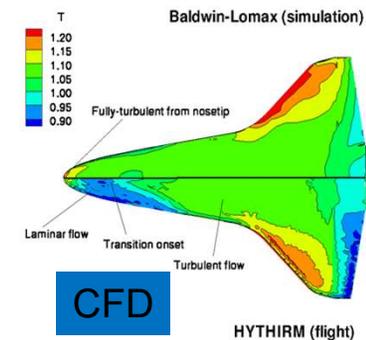
Why Flight Data?



Ground



Flight



Observing flight conditions is essential

- Misunderstanding flight conditions can have tragic consequences, such as the Columbia accident, the catalyst for SCIFLI's creation.
- Vehicle conditions during mission events are key to understanding performance of engineering & technology designs

Flight conditions are difficult to document

- Ground testing and simulations cannot fully capture in-flight vehicle performance.
- Onboard instrumentation can be challenging in extreme environments and is limited to discrete locations
- In-flight measurements can be used to validate other tools and data collection techniques



Background: *Scientifically Calibrated In-Flight Imagery*



- SCIFLI's Approach

In-flight imaging aims to make spaceflight safer by collecting information about vehicles under real flight conditions.

Flight-Specific Observations

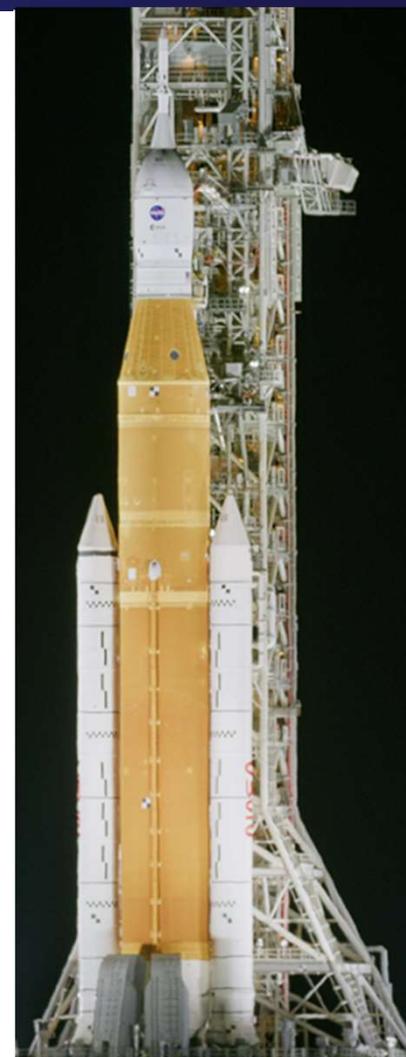
- High Altitude Plume Dynamics
- Parachute & Recovery Systems
- Engine Health Monitoring
- Boundary Layer Transition
- Booster Separation
- RCS Performance
- TPS Sizing

Mitigates Risk of Data Loss

- Embedded Sensor Failure
- Trajectory Reconstruction
- Unrecoverable Data
- Vehicle Termination
- Telemetry Blackout
- Night Launch

Supplements Onboard Instrumentation

- Global vs Discrete Measurement
- Embedded Sensor Validation





Background: SCIFLI Airborne Multispectral Imager



A customizable & cost-effective aircraft-agnostic multispectral imaging testbed designed to collect plume and surface temperatures during Artemis I ascent.

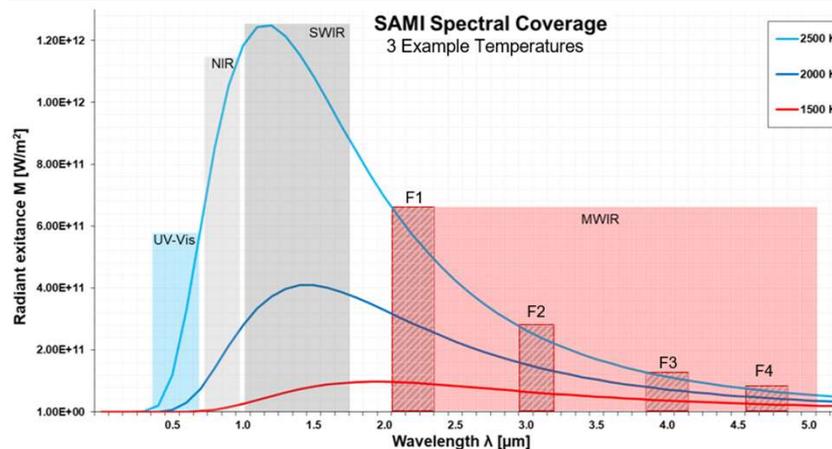
Key Capabilities

- Passive and active thermal control
- Integration within pre-existing platforms
- Multiple sensors (UV-VIS to MWIR)
- High image quality
- Semi-modular design to support mission adaptability

Mission Portfolio *to date*

- NASA Artemis 1 Launch
- SPACEX Starship Launch
- SPACEX CRS-27 Return
- NASA OSIRIS-REx Capsule Return (Sept '23)

SAMI WB-57 aircraft config.



SAMI G-IV Aircraft config. (in development M.A.R.S. and O.K.S.I.)



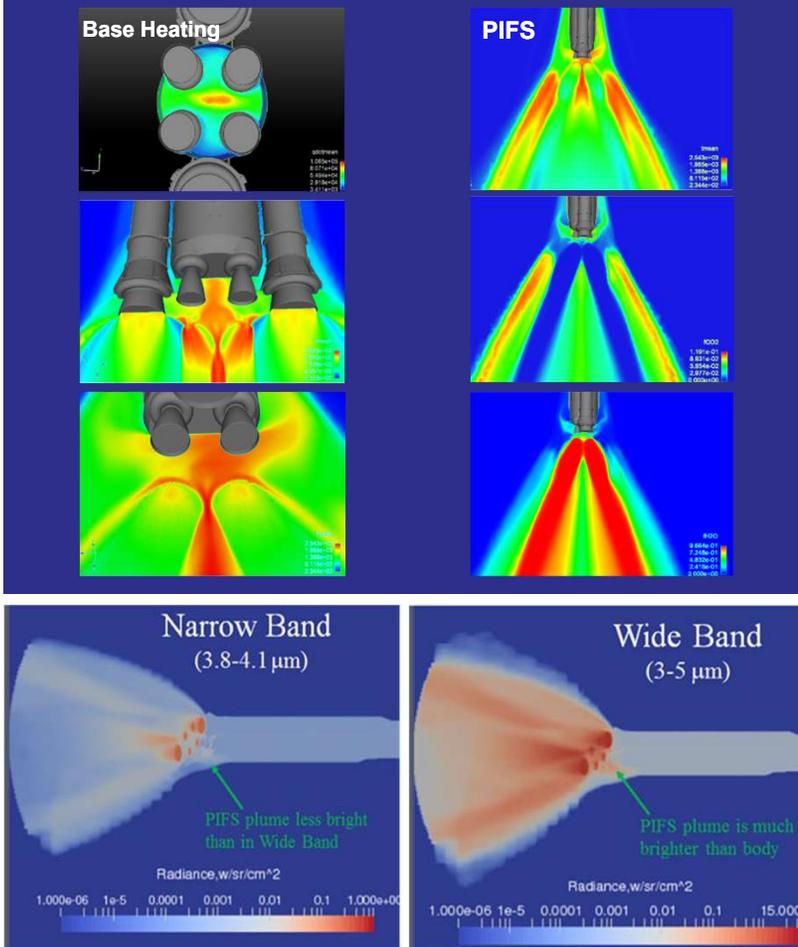
Feasibility Analysis:

- Broadband (3-5 μm) MWIR for PIFS imaging; high temp surface data available at 2 μm
- **Multispectral Imaging**
 - simultaneous observation of plume *and* hardbody thermal signatures
 - high spatial resolution
 - Low uncertainty

Technical Challenges

- ❑ Large temperature range between regions of interest
- ❑ Emissivity variation with temperature and view angle
- ❑ Hot plume gas obscuring regions of interest
- ❑ Hot plume gas causing radiative heating

CFD Solutions for Mach 4 (110 kft) Plume Structure



Goal: Collect calibrated temperature images of the base region of SLS core stage and exhaust plume dynamics during boost phase.

- Use calibrated multispectral imagery to conduct surface temperature retrieval for base heat shield (BHS) and aft region of SLS core stage.

Best Effort – Observe plume recirculation phenomena or Plume Induced Flow Separation (PIFS).

Best Effort – Observe Booster and Core Stage separation dynamics.



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Observation: Sensor Specifications and Imaging Objectives

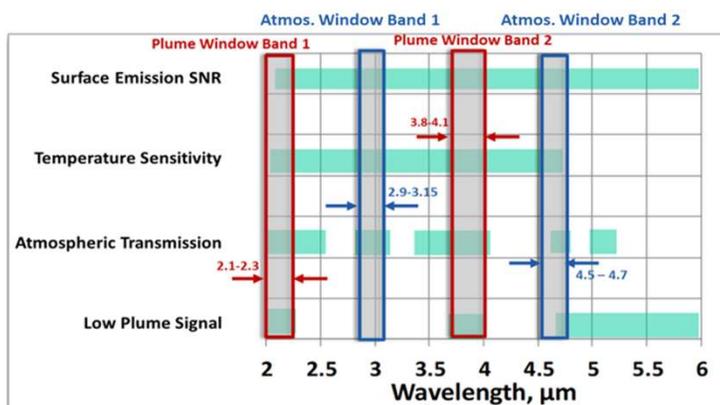


SAMI was deployed for multispectral coverage of Artemis 1 SLS launch. The system is designed to acquire scientific data of several physical and aerothermal events of interest during SLS Ascent and was configured to cover Visible through Mid-Wave Infrared wavelengths of interest for the observation.

SAMI Sensor Specifications

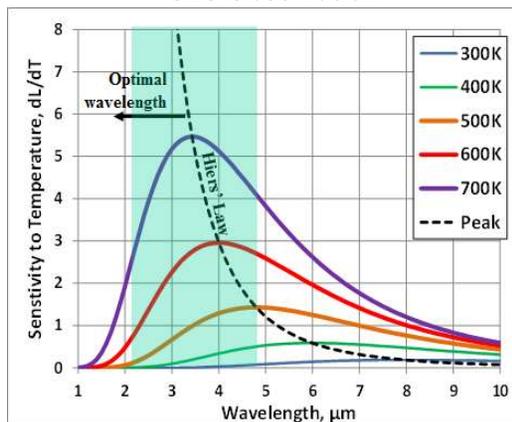
| Channel | Spectral Range | Sensor Type | H pix | V pix | Pixel Pitch (μm) | IFOV (μRad) | Frame rate (fps) | Bit depth |
|-----------|----------------|-------------|-------|-------|------------------|-------------|------------------|-----------|
| MWIR | 2 – 5 μm | nBn | 1280 | 1024 | 12 | 7.38 | 120 | 16 |
| SWIR | 900 – 1700 nm | InGaAs | 1280 | 1024 | 12.5 | 7.69 | 60 | 12 |
| NIR | 370 – 1100 nm | sCMOS | 2650 | 2160 | 6.5 | 4.00 | 100 | 16 |
| UV-Vis | 310 – 750 nm | CMOS | 1936 | 1216 | 5.86 | 3.60 | 50.8 | 12 |
| WFOV-MWIR | 3 – 5 μm | InSb | 640 | 512 | 15 | 54.5 – 789 | 30 | 14 |
| WFOV-Vis | 300 - 1100 nm | CCD | 1280 | 960 | 3.75 | 15.6 – 312 | 33.3 | 14 |

Optimal Wavebands to Meet All Imaging Objectives



SAMI Filter Wheel Bands for MWIR Channel

Estimated Temperature Ranges During SLS Observation



SCIFLI Contributions to Artemis-1 Flight Test Objectives

| FTO-STE-AT-01 FDAs | Airborne Imagery Contributions |
|---|--|
| FDA-STE-AT-1.1 Ascent Aerothermal | Core Stage surface temperatures |
| FDA-STE-AT-1.2 Plume Radiation Heating | Exhaust plume radiation (thermal signature characterization, shape, size) |
| FDA-STE-AT-1.3 Plume Convection Heating | Core Stage and Booster surface temperatures |
| FDA-STE-AT-1.4 Plume Induced Flow Separation (PIFS) Heating | Core Stage and Booster plume recirculation |
| FDA-STE-AT-1.5 Plume Impingement – (Booster Separation) | Booster Separation Motors (BSM) activations, general plume direction/spray |

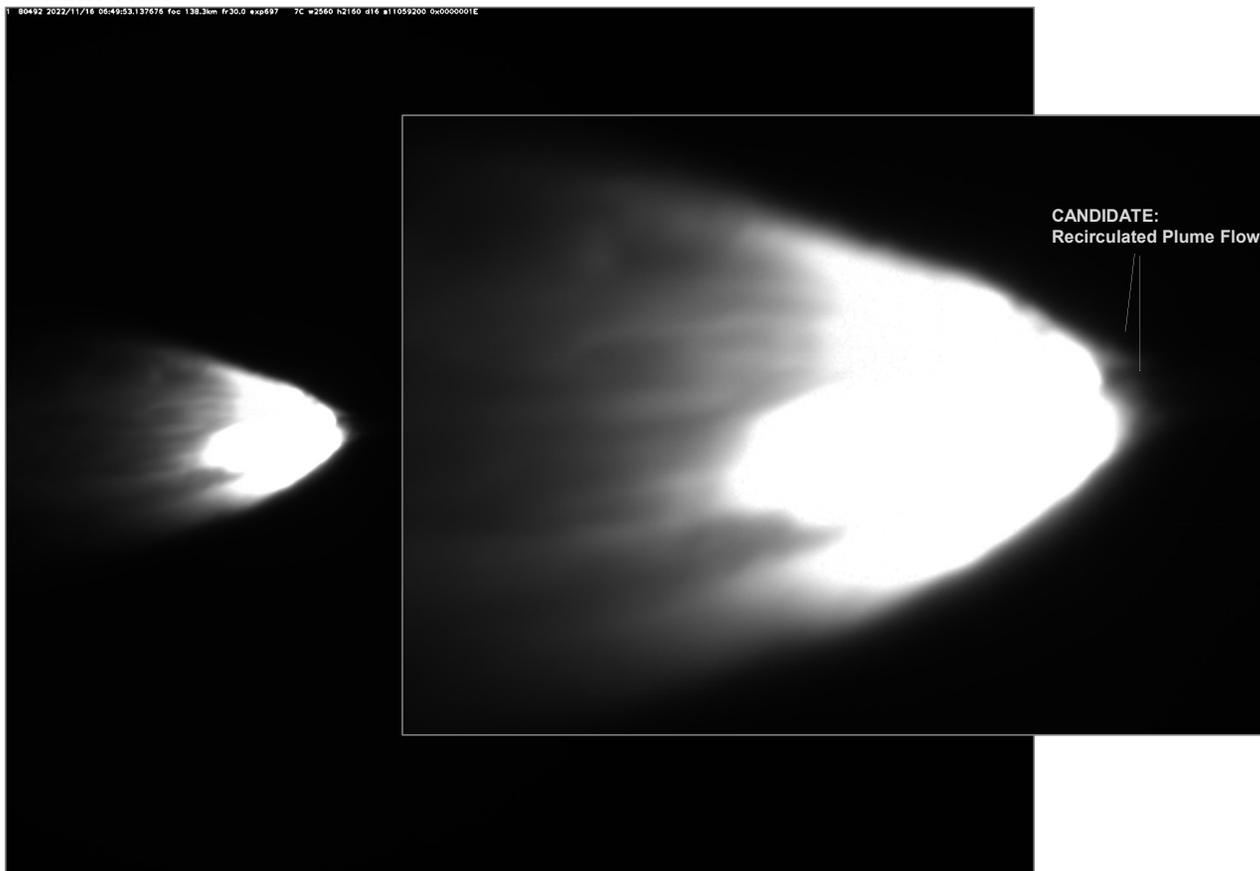
FDA: Flight Data Analysis
FTO: Flight Test Objective



Observation: FDA Evaluation Data Review



SAMI NIR



SCIFLI Contributions to Artemis-1 Flight Test Objectives

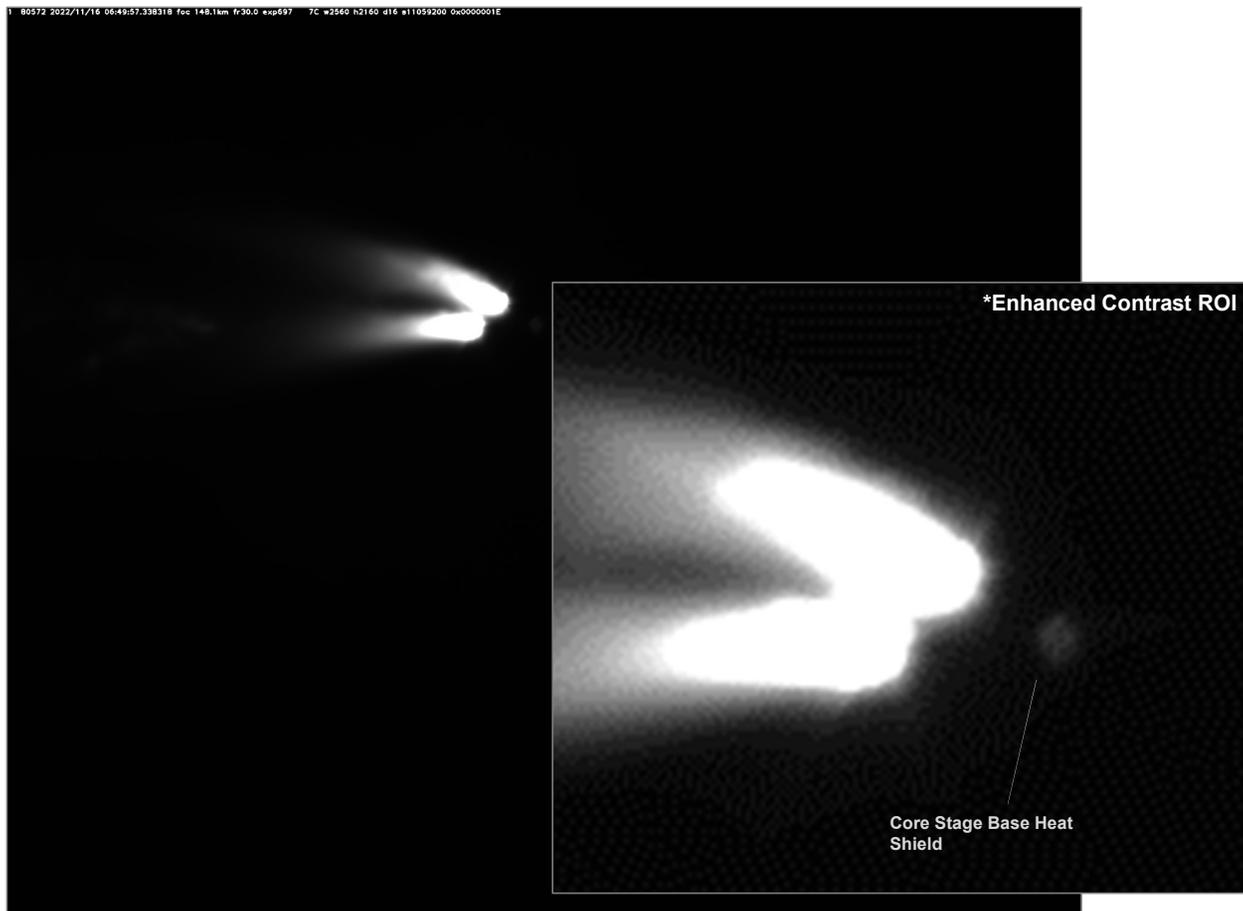
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Observation: FDA Evaluation Data Review



SAMI NIR



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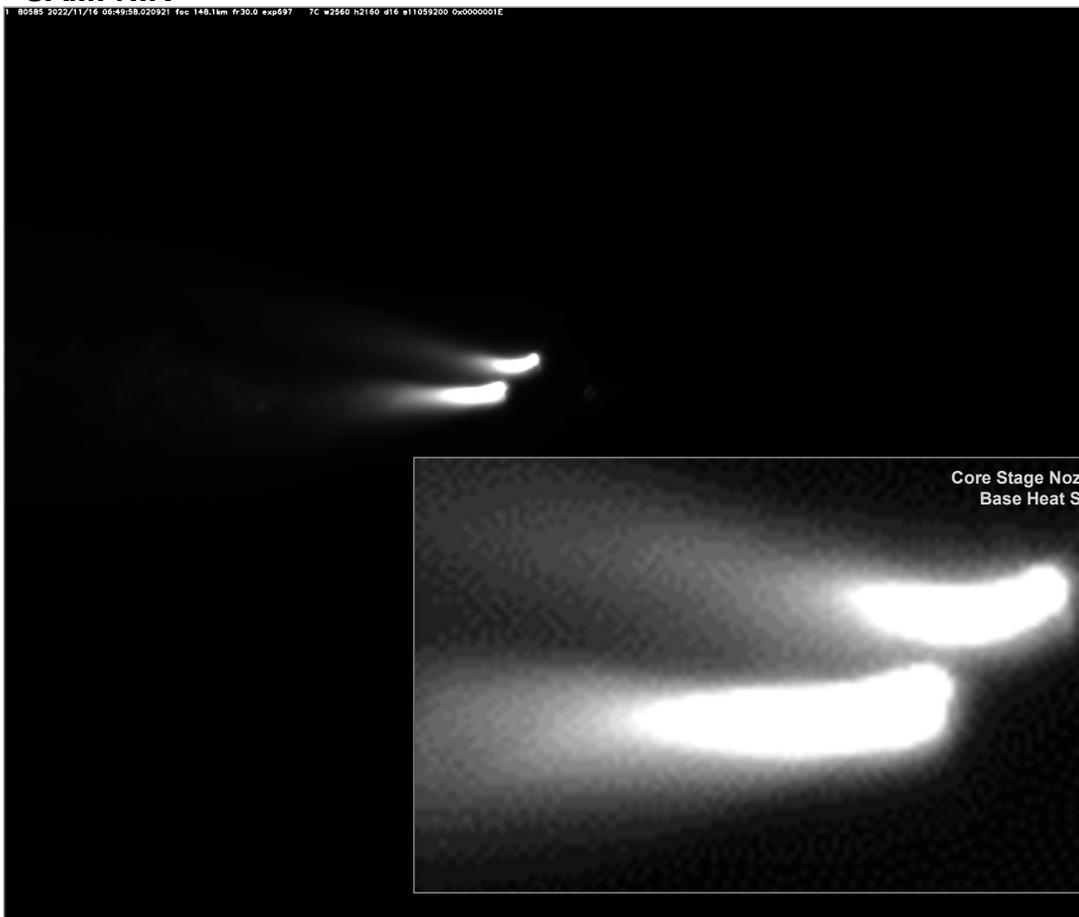
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Observation: FDA Evaluation Data Review



SAMI NIR



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Observation: Temperature Extraction Candidate Selection

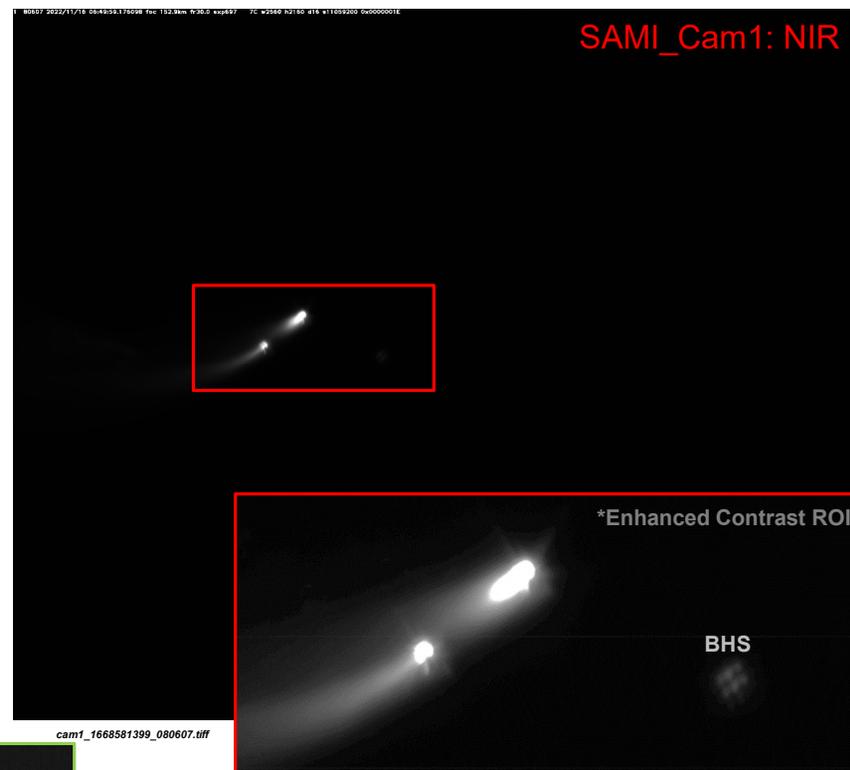


- Candidates from the raw imagery were selected and assessed for radiometric quality during the initial review of the Post-flight data assessment
- Imaging of the base heatshield in the **NIR** was determined to have **high SNR**, spatial resolution, and **minimal motion blur** during the time of interest (post-SRB Separation)

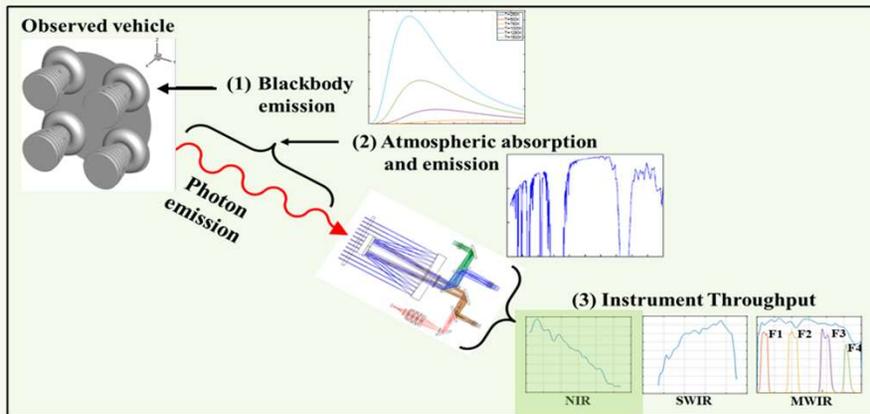
SAMI_Cam3: MWIR



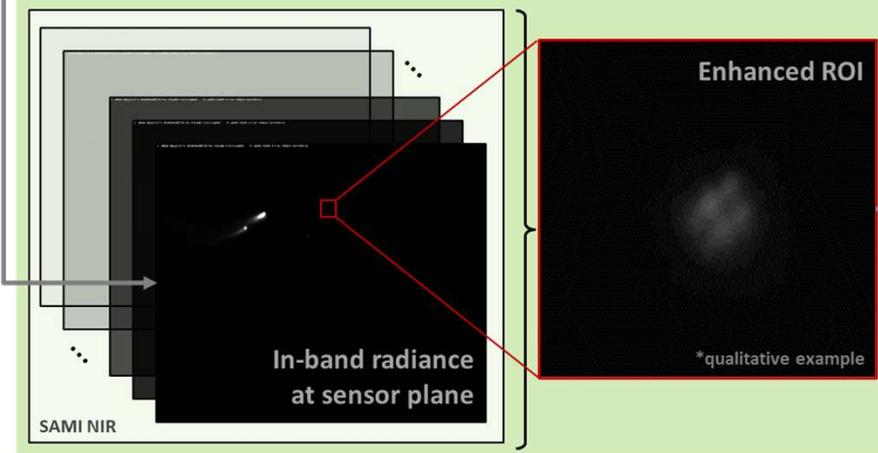
SAMI_Cam2: SWIR



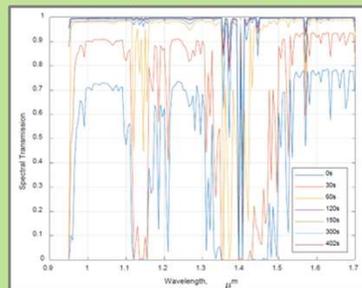
Infrared Optical Path Diagram



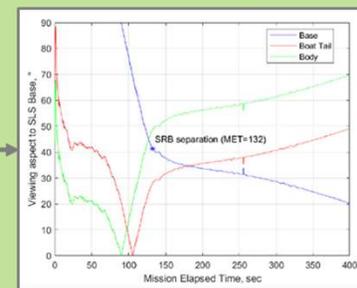
Dataset Enhancement



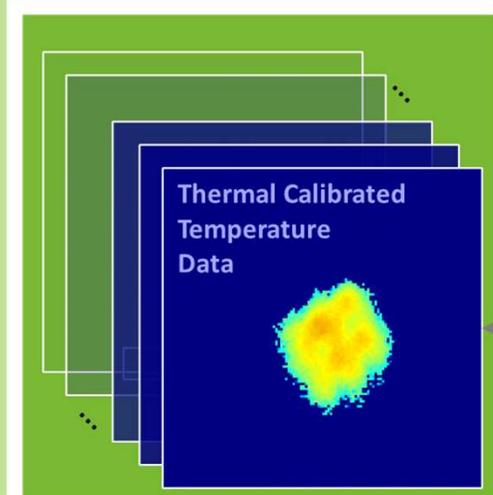
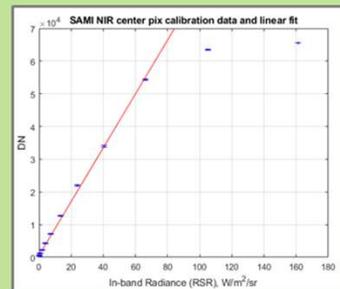
Atmospheric Correction



Directional Emissivity Correction



Radiometric Calibration



Total Expanded Temperature Uncertainty:

For 95% confidence level for integrated U_c :

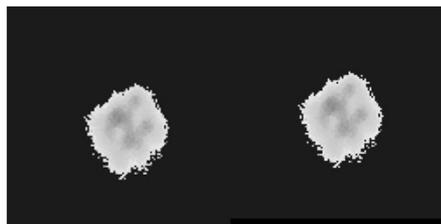
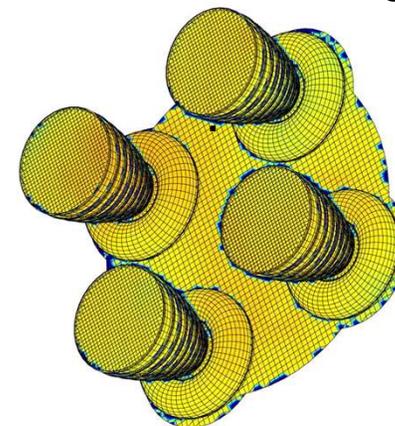
$$U_{max} = 7.8\%$$

- **WB-57 acquired approx. 43 seconds of useable NIR thermal data.**
- These data were corrected for:
 - ☑ Atmospheric path length
 - ☑ View angle to BHS w.r.t. aircraft gimbal orientation
 - ☑ Emissivity of the BHS material

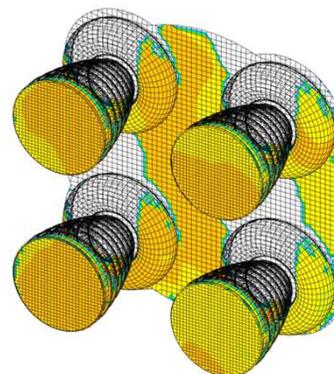
Notes:

- Nozzles and blankets are **excluded** in this calculation.
- Alignment between the temperature image and the mesh is carried out manually with only 3 parameters free – horizontal and vertical translation of the image, and roll rotation (about the body axis) of the SLS base mesh.
- The bright nozzles provide the main reference points for this alignment, as they are bright in the imagery and are distinct in the mesh. It is assumed that the bright features of the images correspond to the exit planes of the nozzles.
- Roll alignment has an ambiguity of $n \cdot 90^\circ$, where $n=1,2,3$, as we have no way to distinguish between the different nozzles. Roll was found to be nearly constant over the period of interest. For times after about MET = 159.32s, the alignment becomes more challenging.

View from WB-57 in flight.

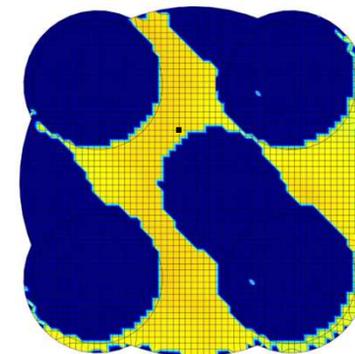


Stabilization of BHS data post-SRB separation



Depiction of nozzle occlusion on BHS data collection

View normal to BHS





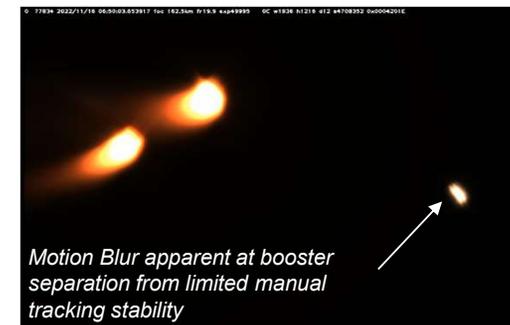
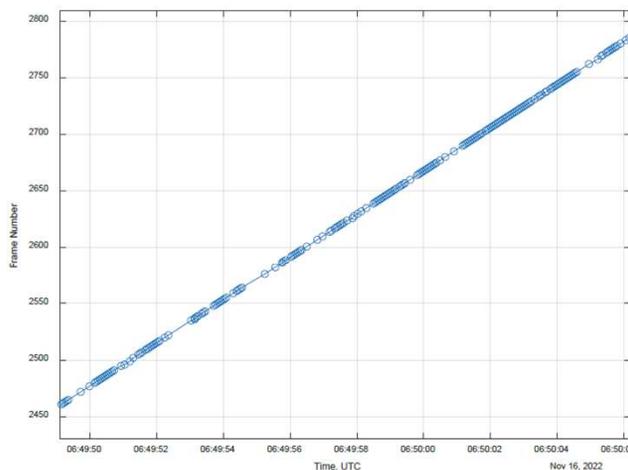
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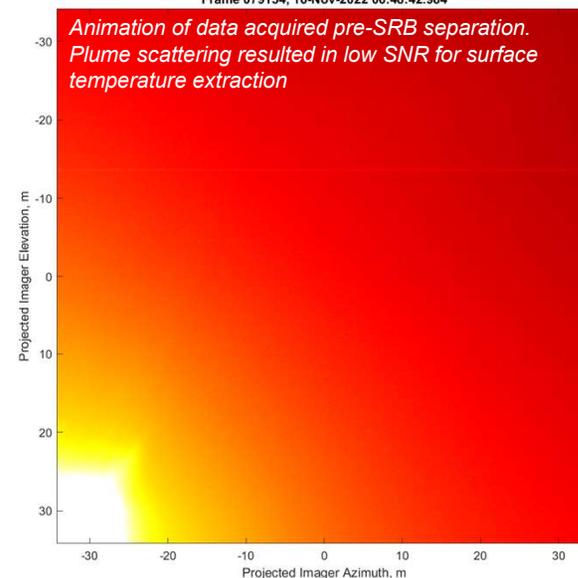
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- Several factors influenced the imaging performance and data quality during the observation
 - Night observation and scattering
 - Non-optimal sensor settings resulted in substandard imagery in some wavebands
 - Inconsistent frame buffer writing
- Moving Forward
 - Software updates to SAMI DAC
 - Updated radiometric modeling into preliminary mission planning for finetuning of sensor settings (integration time)
 - Preliminary mission modeling to include mission-day condition case studies



Cropped NIR image - log scale
Frame 079154, 16-Nov-2022 06:48:42.984

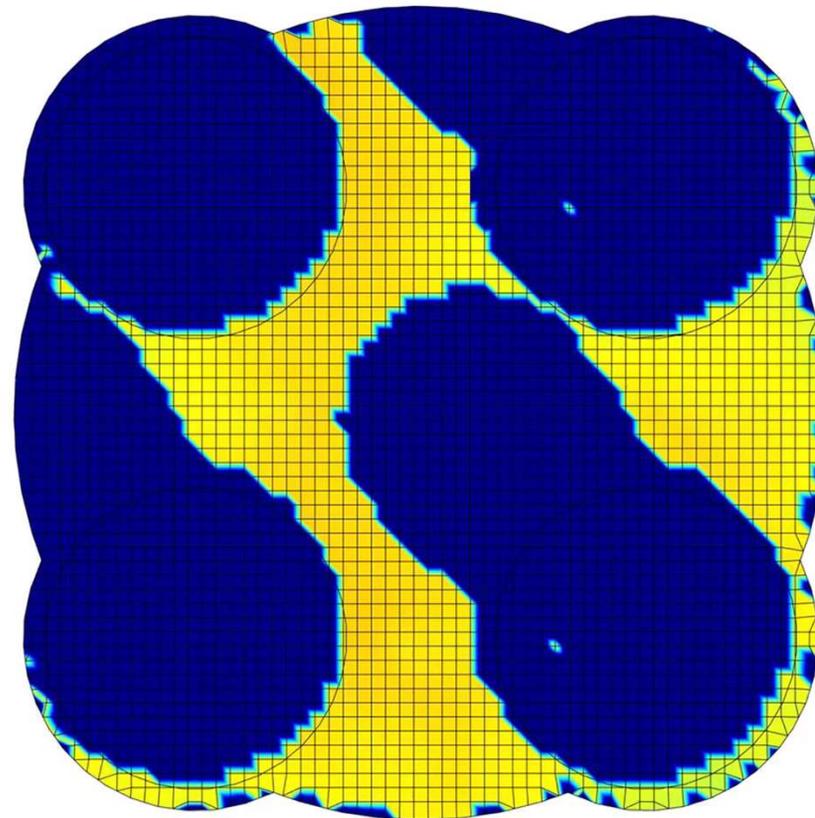




Conclusions: *Summary*



- **SCIFLI** produced a **multispectral** dataset for Artemis 1 Ascent
- **SCIFLI's** solution **SAMI** was designed to assess complex thermal environment in SLS Base region
 - Provide a unique dataset against ground and CFD to evaluate vehicle performance
- **SAMI** successfully measured base heatshield temperatures with a maximum 2σ uncertainty of 7.8%
- Temperature data has been handed off and are currently being evaluated by **SLS program**



Thank you

