



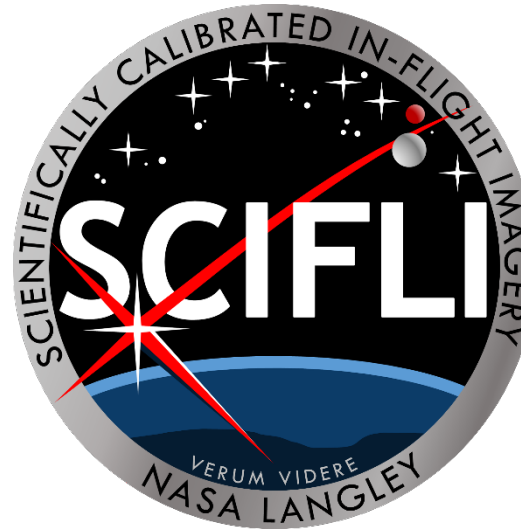
Chasing Spacecraft

2022 AIAA HRS Spring Technical Seminar

April 22, 2022



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Today's Seminar

- ❑ Origin Story – From HYTHIRM to SCIFLI
- ❑ SCIFLI capability supporting human spaceflight and science
 - Example mission
 - TPS Performance - Launch, Staging, Reentry
 - Contingency Flight Safety Systems
 - Hypervelocity
 - (Parachutes)
- ❑ SCIFLI 2.0: Partnership with DoD to develop SkyRange
- ❑ Thoughts on Leadership

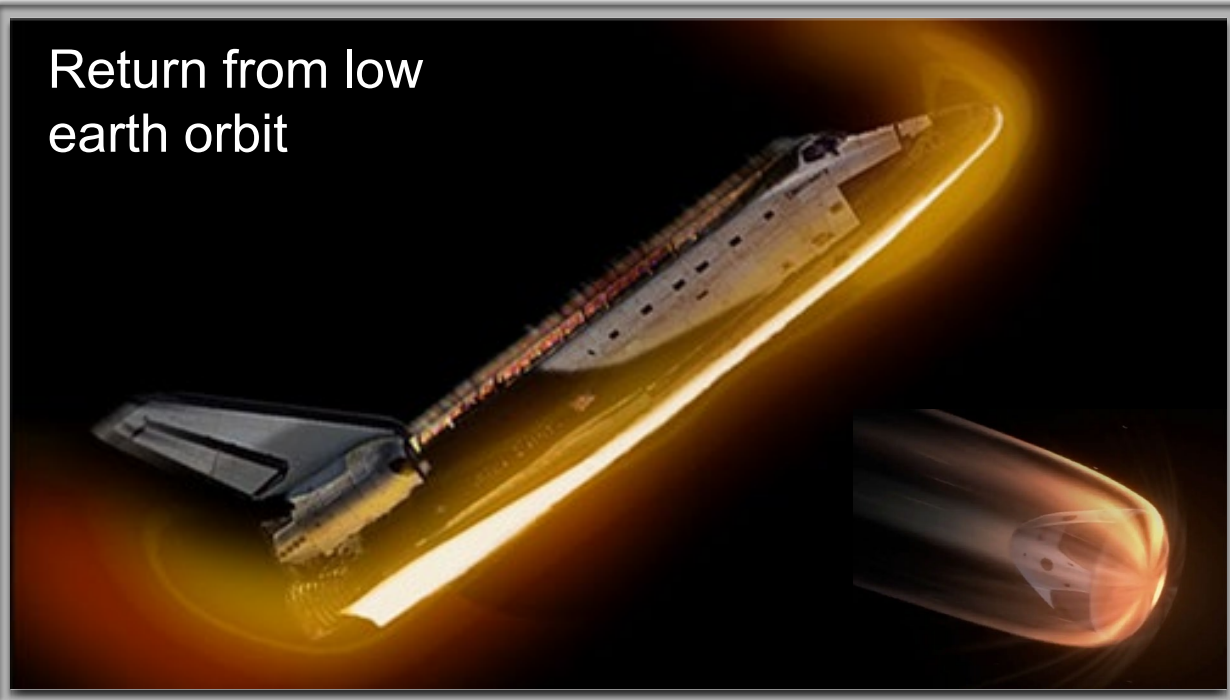
HYTHIRM – Hypersonic Thermodynamic Infrared Measurements

SCIFLI – Scientifically Calibrated In-Flight Imagery

TPS – Thermal Protection System

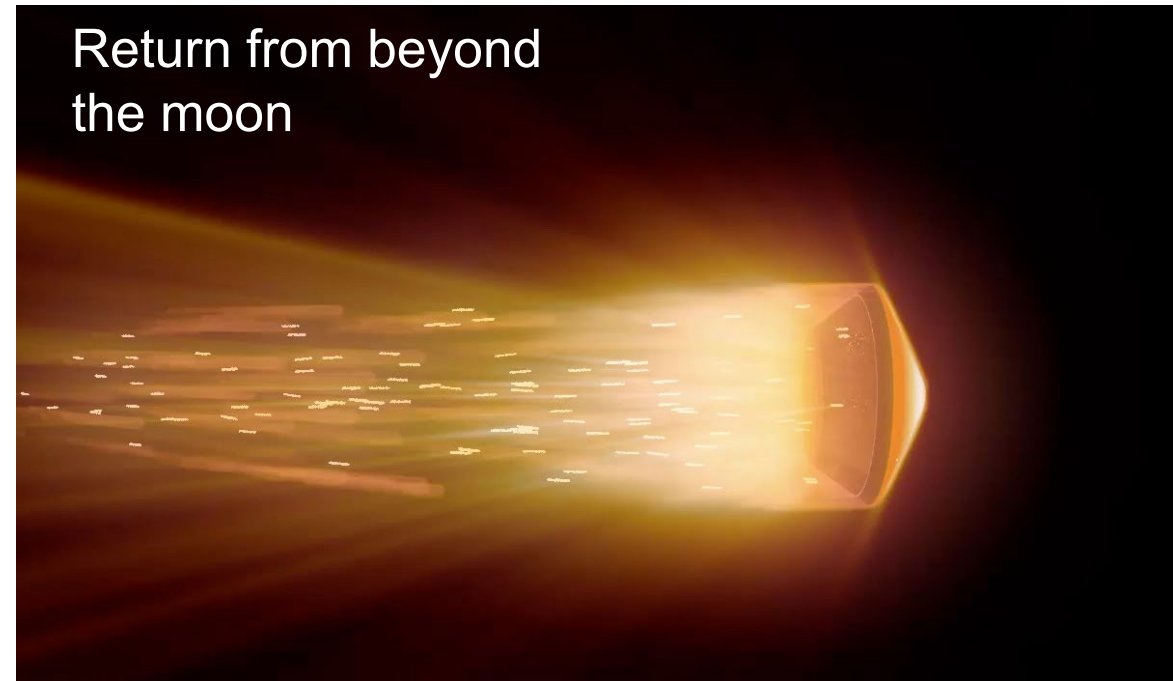
Extreme Environments During Spacecraft Reentry

Return from low earth orbit



- It's fast! (~18,000 mph or 26,000 ft/sec); Mach ~25
- It's hot! (peak temperatures ~2,000-3,000 deg F)
- Largely convective heating

Return from beyond the moon



- It's faster! (~27,000 mph or 40,000 ft/sec); Mach ~35
- It's hotter! (peak temperatures ~4,000-5,000 deg F)
- Convective and radiative heating

Thermal protection systems are required to protect crew and payloads.



The heavier the truck (heatshield), the less stuff (science instruments) it can tow.

First Flight of the Space Shuttle Columbia



- ❑ As a research center, Langley had a vital role in defining the Space Shuttle shape; providing technical insight into aerodynamics and **reentry heating**.
- ❑ Nominal processing and on-orbit operations primarily supported by NASA Kennedy, Marshall and Johnson

Everything Changes February 1st 2003

Break up of Shuttle
Columbia over Texas

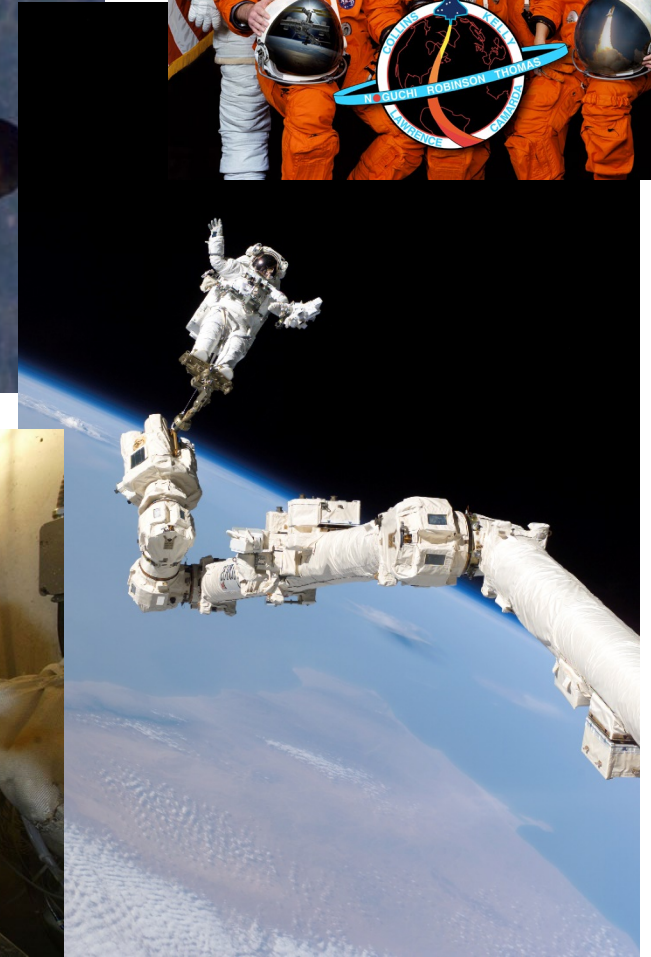


Memorial outside NASA
Langley Research
Center

In order to move forward NASA needed to understand the physical cause and then mitigate risk from a compromised thermal protection system - *required tool development by Research Centers*



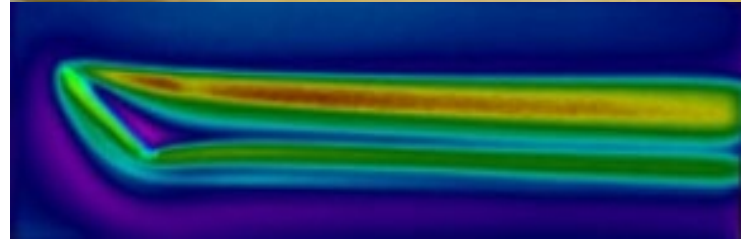
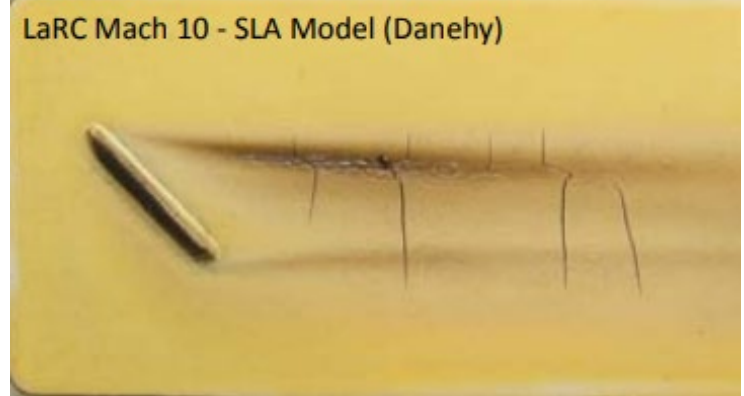
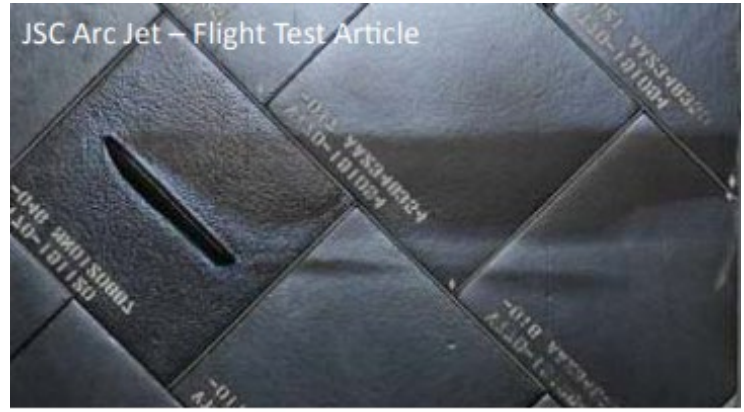
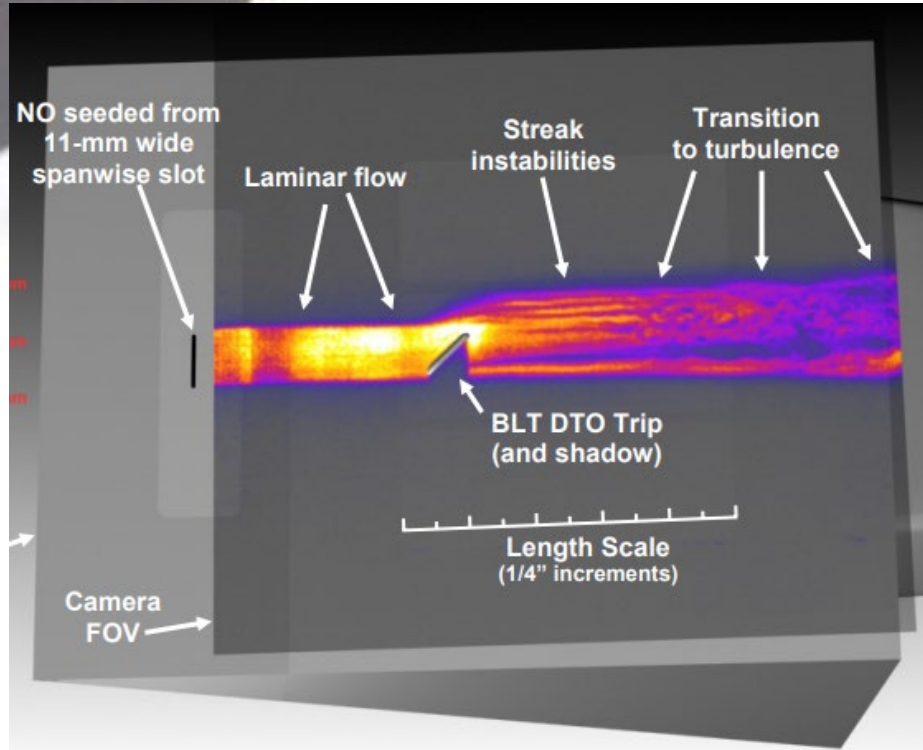
STS-107 and STS-114



<https://www.nasa.gov/image-feature/remembering-sts-107-and-her-crew>
https://www.nasa.gov/returntoflight/crew/EVA_gapfiller.html
https://www.nasa.gov/images/content/143114main_sts114armwalk-lg.jpg
https://www.nasa.gov/centers/langley/images/content/723947main_Horvath2_904.jpg
https://www.nasa.gov/images/content/118271main_114_crew_port_hires.jpg



But How MUCH Hotter?



Genesis of Remote Infrared Imaging Capability

Could wind tunnel based global temperature measurement techniques be applied in flight?



Jennifer pointing to the "bump" used to induce turbulence



Heating up Discovery's heat shield

Discovery will plunge back through Earth's atmosphere with a built-in "speed bump" on one of its thermal tiles. The quarter-inch protuberance will increase temperatures to simulate conditions NASA's next-generation Orion space capsules will encounter during atmospheric re-entries.

1 Protuberance
2 Sensors

Because of Orion's geometry, its tiles will be subjected to re-entry temperatures up to 3,400 degrees Fahrenheit, about 500 degrees higher than the shuttle re-entry.

Entry interface

Left wing

Area modified for this experiment

- The "speed bump" will disrupt airflow and induce turbulence that will increase re-entry heating.
- The tile and others downstream from it are equipped with sensors to capture temperature data.
- A Navy aircraft with a long-range infrared camera will fly below the shuttle's flight path to monitor heating on the underside of the orbiter. Imagery and sensor data will guide engineers designing Orion's heat shield.

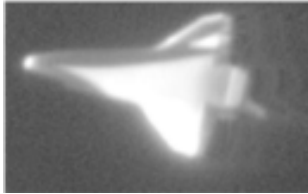
NASA expects the 4-inch-long "speed bump" to induce turbulent airflow at Mach 12 to Mach 14 as the orbiter soars over the Gulf of Mexico.

Sources: NASA, The Boeing Co., researched by James Dean, FLORIDA TODAY, Dennis Lowe, FLORIDA TODAY

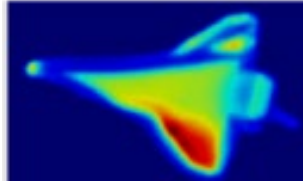
ALT	20553 FT	N	35 12.40
GSFD	298 KTS	W	106 27.48
HDG	104		



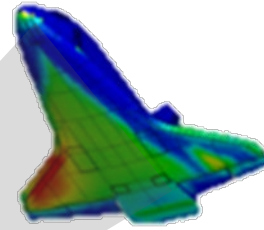
Obtaining *quantitative measurements in engineering units derived from calibrated imagery data*:



Data collection and calibration



2D Processed Data



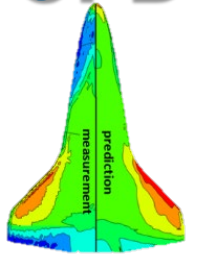
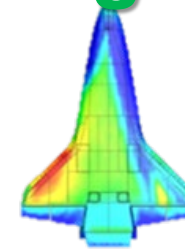
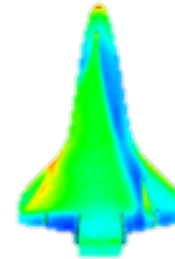
3D Mapping



Ground

Flight

CFD



Comparison and Model Refinement

The data are most often obtained from airborne platforms but have also been acquired from land- and ship-based assets.

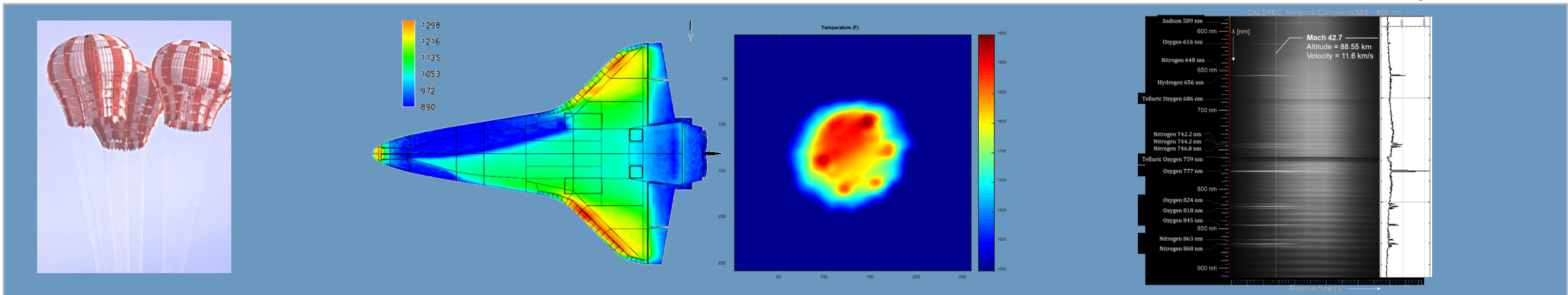
A Calibrated Pixel Provides a Wealth of Information

Visual

Infrared – spatially resolved

Visible & Infrared – spectrally resolved

Examples



Measurement

Flight Parameter

Insight

Spectroscopy of entry vehicle surface emission over wide wavelength range

Spatially averaged, time-dependent surface temperature

Validated TPS surface response models, aerothermal heating

Spectroscopy of entry vehicle shock emissions

Heat flux from shock

Radiative intensity to validate aerothermal predictions

Spectroscopy of entry vehicle ablation products

Ablation

Spectral signatures may provide insight to anomalies, fragmentation composition, loss of vehicle

Spectroscopy of entry vehicle wake emissions

Debris characterization; induced atmospheric chemistry & phenomenology

Spectral measurements of emission signatures to correlate with expected ablation rate and time variation

Spectroscopy of exhaust

Engine performance

Characterization of by-products; Health monitoring / prognostic data for precursor failure detection.

Narrow band infrared thermography

Spatially resolved surface temperature

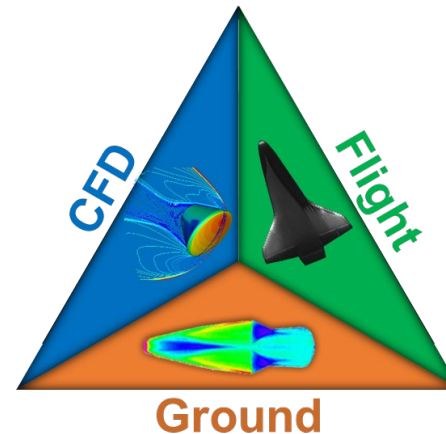
Validated aerothermal predictive models

High speed imaging/photometry

Aerodynamics; Trajectory

Trajectory reconstruction of vehicle. Fragmentation ejection velocities, rotation rates; debris modeling, hazard zone identification

Flight data sets are critical to advancing understanding of actual vehicle performance, particularly at the edges of the flight test envelope, where computational predictions and extrapolations from ground tests and past flight experiences have a high degree of uncertainty.



A high probability of mission success requires extensive mission planning, operational experience, and **maintaining complex relationships with people** who possess a wide range of diverse skill sets across multiple agencies and organizations.



Products & Services

Tailored To Meet Customer Expectations

Imagery Objectives

Virtual Camera Simulations

Radiometric Simulations

Airspace Coordination

Sensor Calibration

Mission Simulations

Mission Operations

Mission Operations Report

Initial Data Assessment

Data Processing & Analysis

Data Report

Mission Planning

Global Weather

Spatial Performance

Basing Options

Predicted Radiance

Radiance ($W/cm^2/sr$)

Google Earth

Mission Execution

Mission Operations

Airspace Coordination

Sensor Calibration

Data Processing & Analysis

Spectroscopy†

Shock patterns*

Recovery systems

Plume Interactions

Surface temperature*

Risk Reduction

Health Monitoring

Data Products & Reports

JAIAA AIAA-2010-243
Cast Glance Near Infrared Imaging Observations of the Space Shuttle during Hypersonic Re-Entry

JAIAA AIAA-2010-244
Application of a Near Infrared Imaging System for Thermographic Imaging of the Space Shuttle during Hypersonic Re-Entry

JAIAA AIAA-2010-245
HYTHM Radiance Modeling and Image Analysis in Support of STS-119, STS-128 and STS-129 Space Shuttle Hypersonic Re-entries

NAVY AIR

SCF1 Operations

Observation Site Weather

Launch 5-22-12

SCF1 Infrared Imagery

Fluores Count

Accumulation

Counters: 431 mm, 500 mm and 500 mm

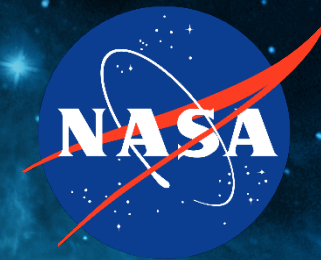
Counters: 110 mm, 100 mm and 100 mm

Accuracy of 8% in Stage System

2nd Stage System

†Image Credit: NASA Ames Research Center

*Image Credit: US Navy

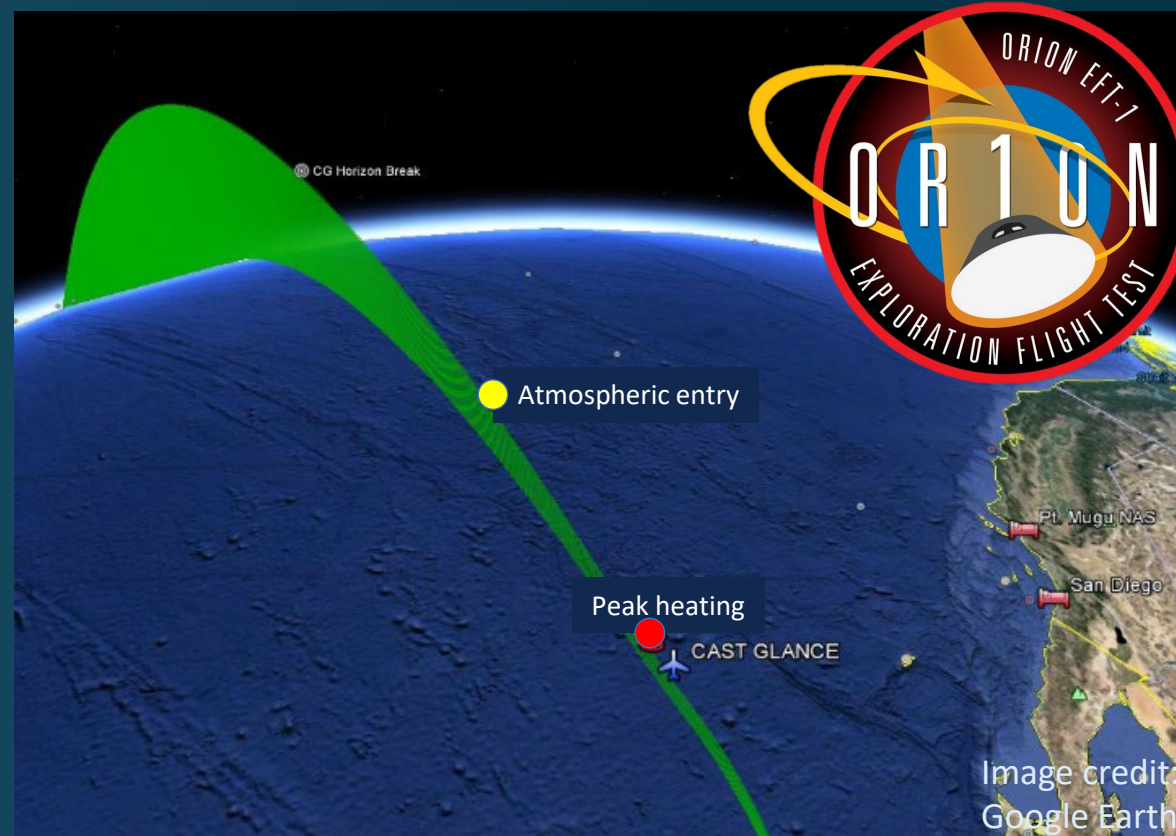
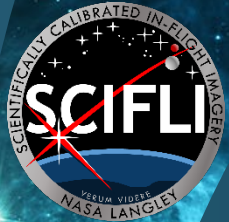


Example Mission: EFT-1

EFT = Exploration Flight Test

Spacecraft Trajectory: Define Mission Parameters

Exploration Flight Test 1 (EFT-1)



Flight path and vehicle orientation determines:

- Optical system cueing (pointing)
- Physical location of imaging system
- Logistics (airspace, transit times, etc.)
- Weather likely to be encountered

Predict Spatial Resolution



Synthetic Image of Capsule near the Point of Peak Heating

System = NIR
Camera = Prosilica
Pixels = 1024 x 1024
FOV = 0.21 deg horizontal

Ground Standoff = 29.5 NM
Slant Range = 37.04 NM
Elevation = 36.4 deg
Vehicle Altitude = 159,313 ft

Aircraft view of capsule at peak heating

Perfect imaging

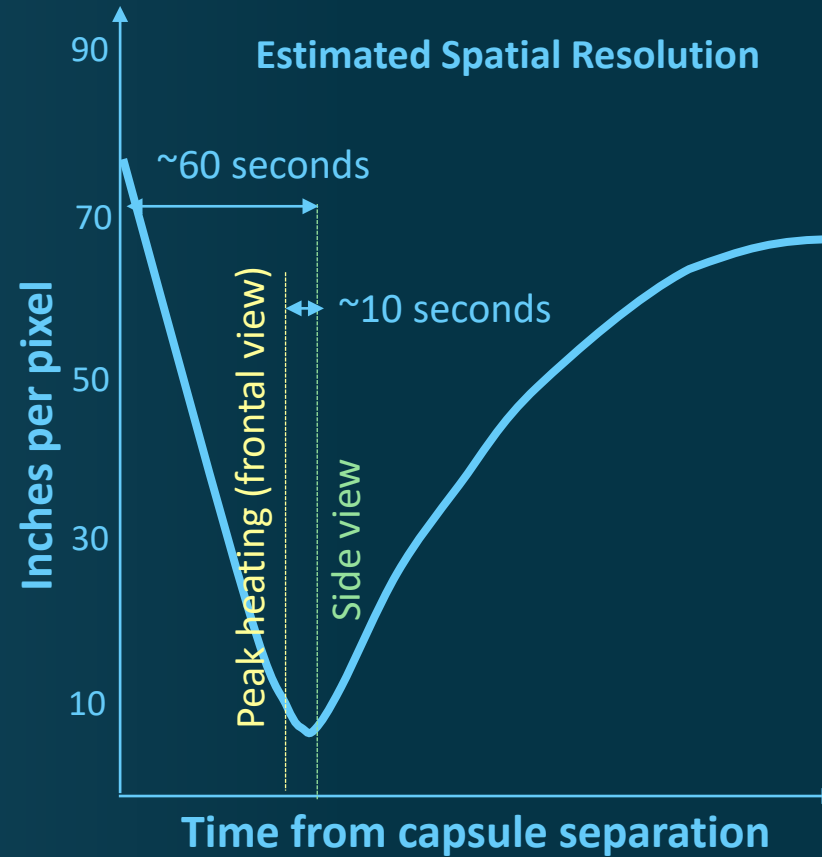


Inches per pixel = 10

Degradation from atmosphere



Estimated blurring



Compression pad
(attachment points)

12 inches

Spatially resolved imagery could be acquired for approximately 60 seconds

Radiance Modeling: Determine Sensor Settings

SCIFLI provided synthetic imagery to sensor operator of the capsule signature as it would appear on their tracking monitor and recommended integration (exposure) times to avoid saturation.



**Estimate of IR sensor counts
(Pre-Flight)**



**Actual IR sensor counts
(In-Flight)**

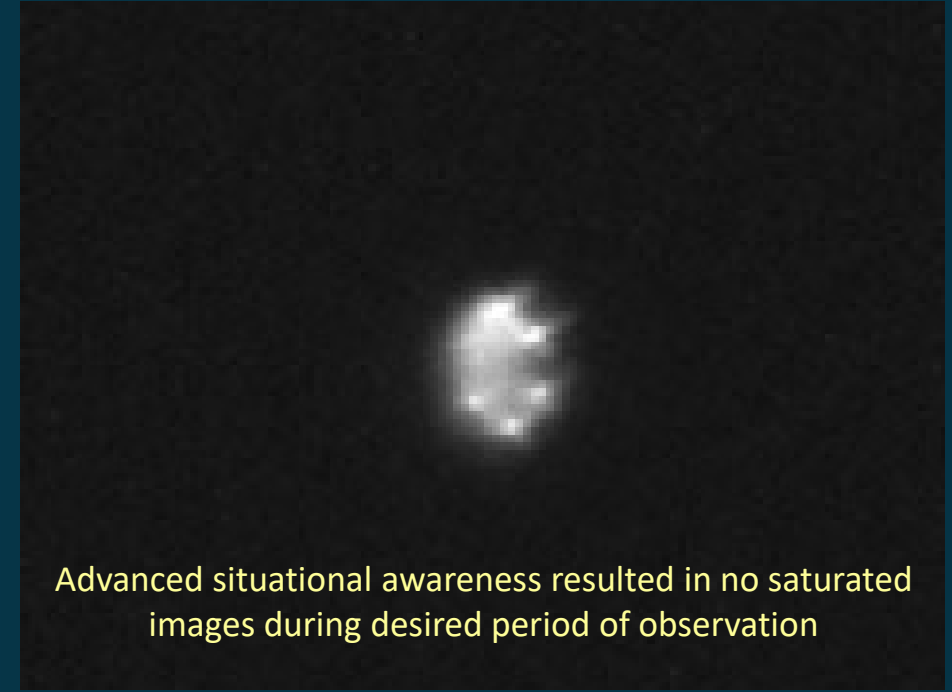


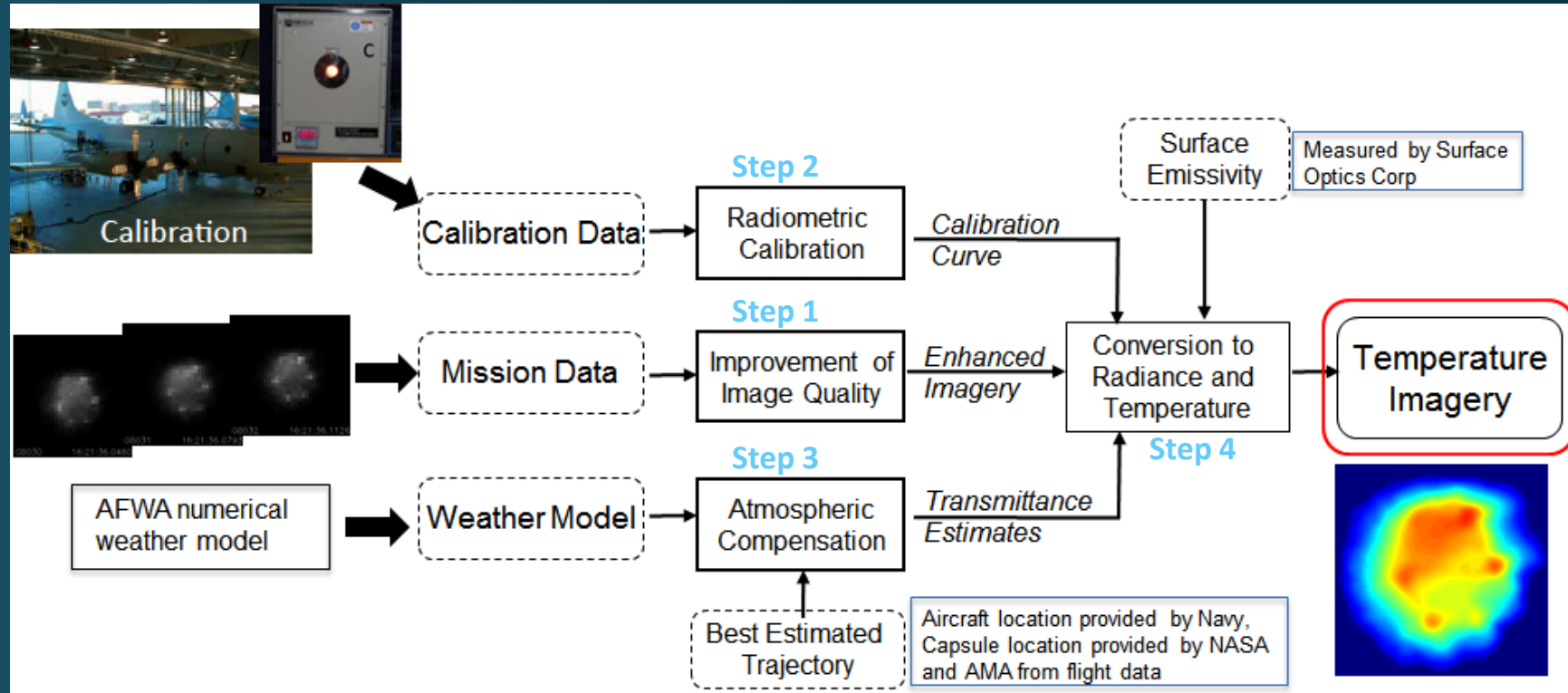
Image-Derived Temperature Maps



Image Frame Number:	7848	8028	8251	8474	8632
Image Frame Time Reference (GMT):	16:21:29.9917	16:21:35.9798	16:21:43.3983	16:21:50.8271	16:21:56.0939
Mach number:	9.91	9.33	8.66	8.04	7.63
Target Range (nmi):	65.1	57.2	49.2	43.3	40.6
Target elevation (deg):	15.4	17.4	20.2	22.7	24.1
Raw Image Pixel Footprint (inches):	17.1	15.0	12.9	11.4	10.7
Capsule apparent pitch (angle of attack;deg):	-19.1	-19.1	-19.2	-19.4	-19.4
Capsule "up" (reference to z-axis; deg):	18	18	18	-7	-9
Capsule bank angle (deg):	30.39	22.21	27.85	38.48	46.46
Angle of l.o.s. to heatshield normal(deg):	11.5	33.5	36.0	44.0	53.0
Peak temperature (deg F):	1940	1843	1760	1718	1643
Minimum temperature (deg F):	~1720	~1630	~1520	~1480	~1400
Temperature (deg F):					

Data Analysis

Process of extracting temperature data from infrared radiance measurements performed by John Hopkins University Applied Physics Lab (JHU-APL)



Step 1: Data Conditioning

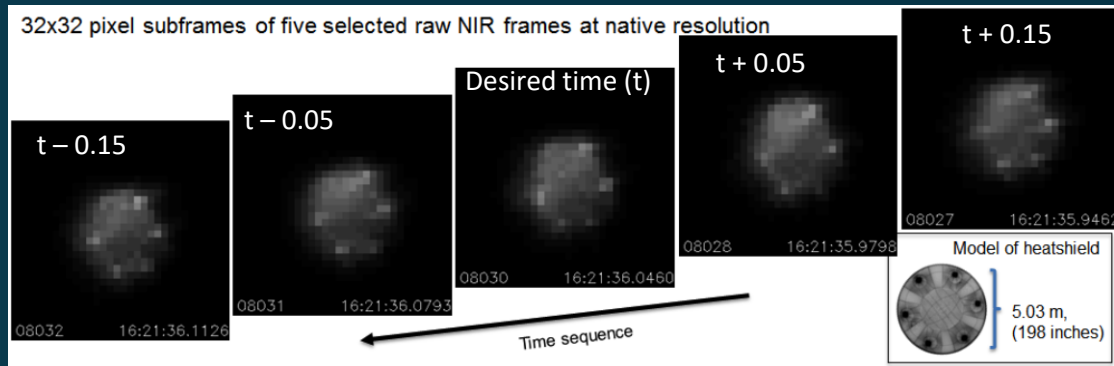


Identify general time with minimal jitter and atmospheric blurring, free of clouds and no reaction control jet firings

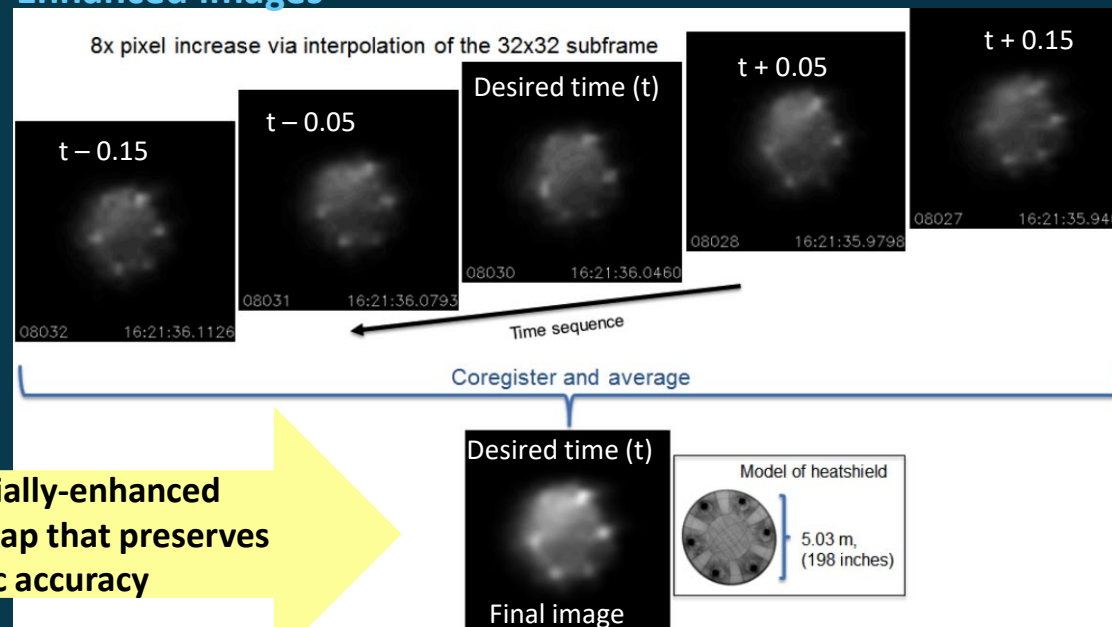
Select 5 quality frames within ~ 0.3 sec of this time

Increase effective spatial resolution with interpolation (8x)

Native images

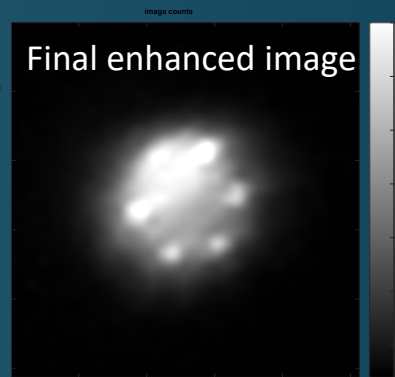


Enhanced images

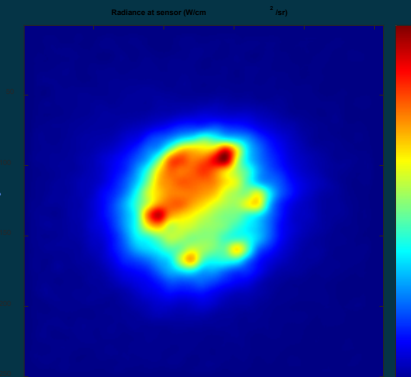
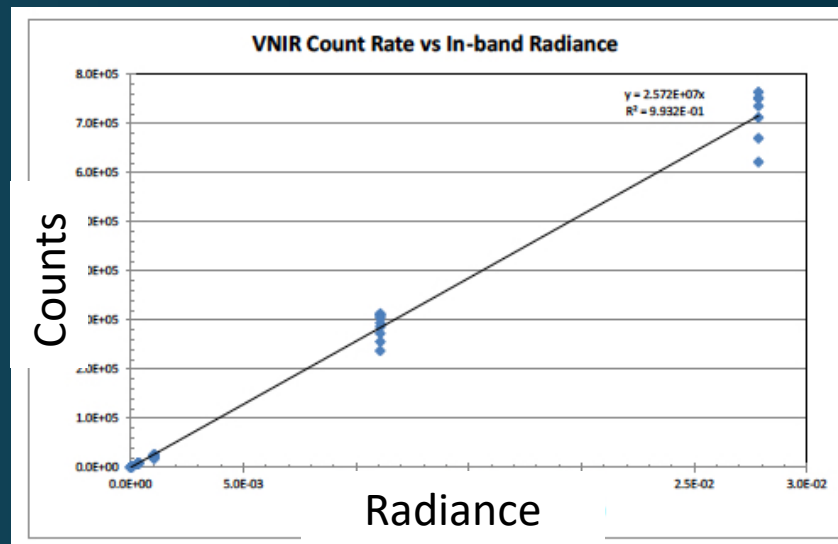


Single spatially-enhanced intensity map that preserves radiometric accuracy

Step 2: Apply Radiometric Calibration

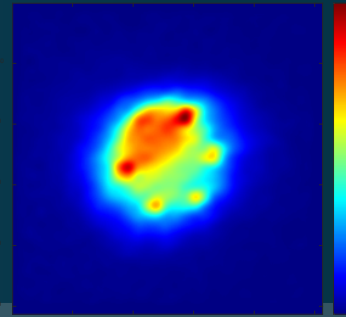


Counts measured at infrared sensor focal plane array



Irradiance measured at infrared sensor focal plane array

Step 3: Atmospheric Compensation

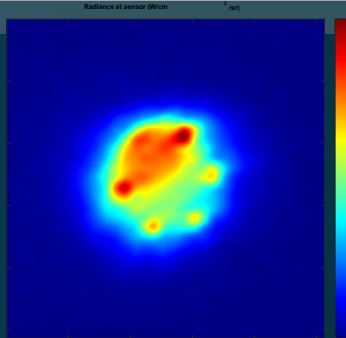
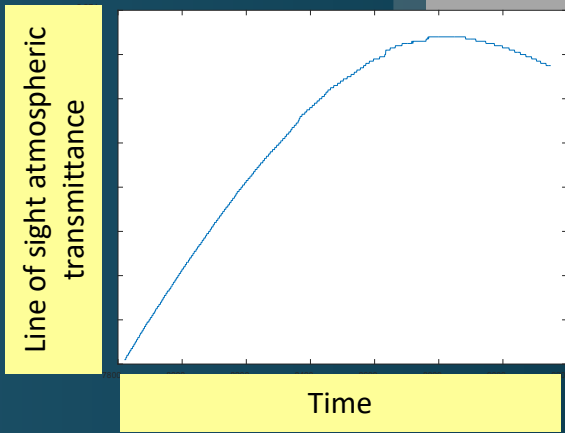


Irradiance from heat shield

We want irradiance from heat shield surface

Second largest source of temperature error

Atmospheric Layer
(Clouds, aerosols, etc.)



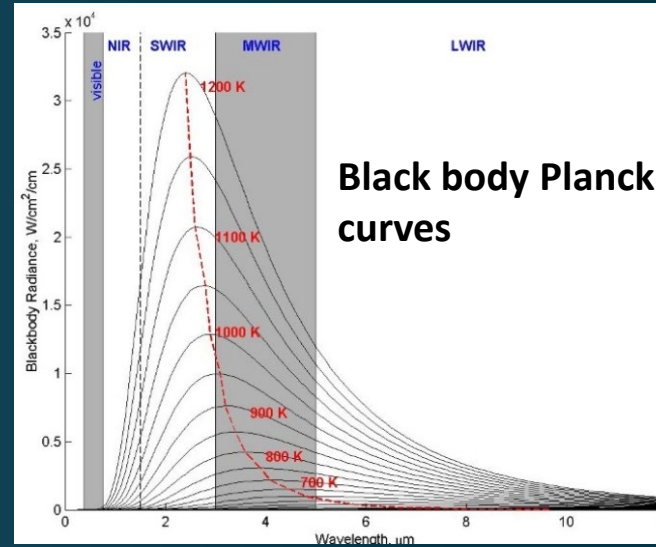
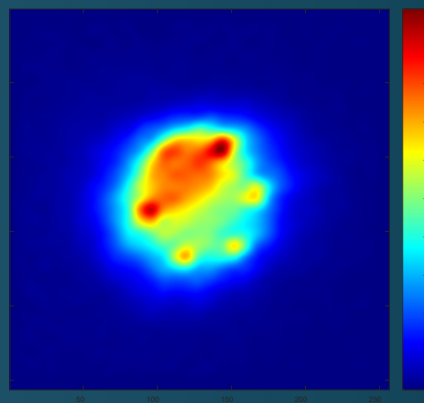
We made irradiance measurement at sensor focal plane array



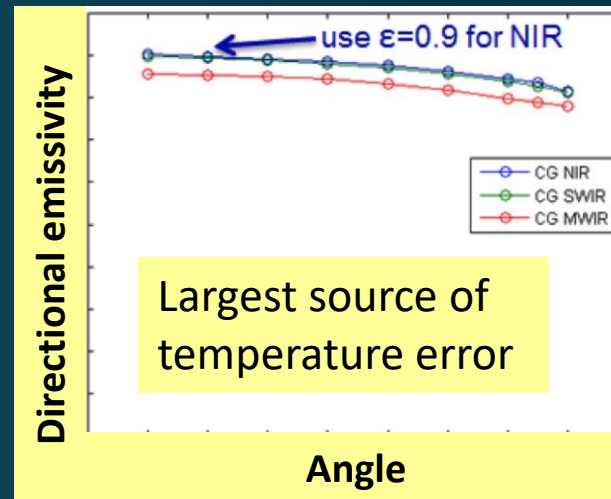
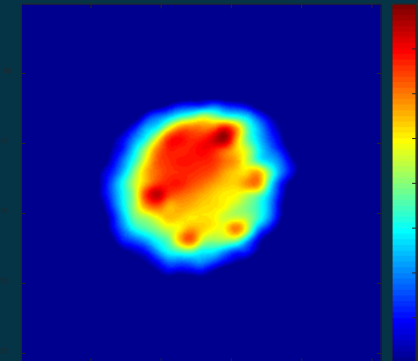
Step 4: Conversion to Temperature



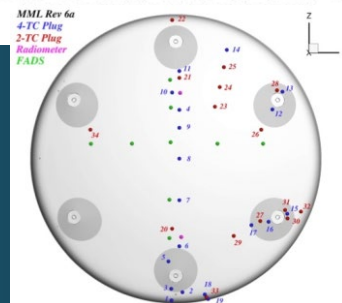
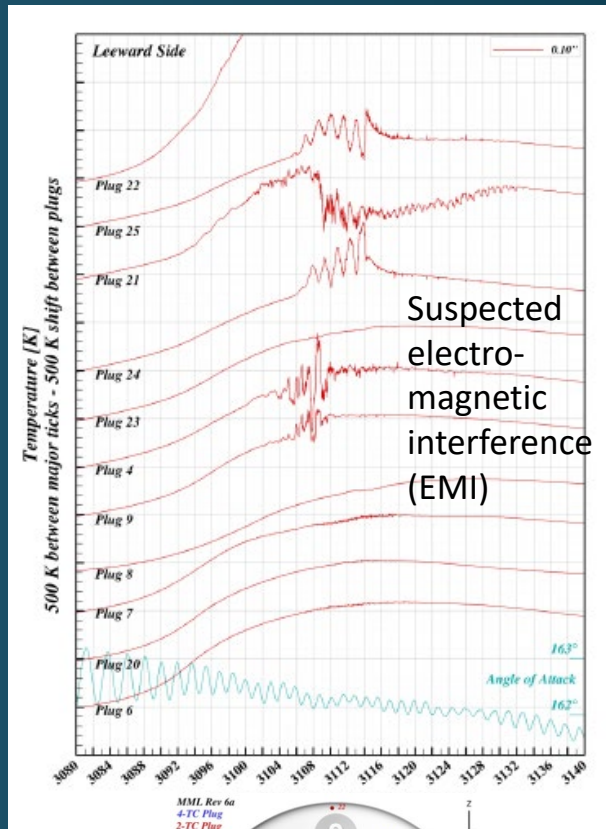
Irradiance from heat shield



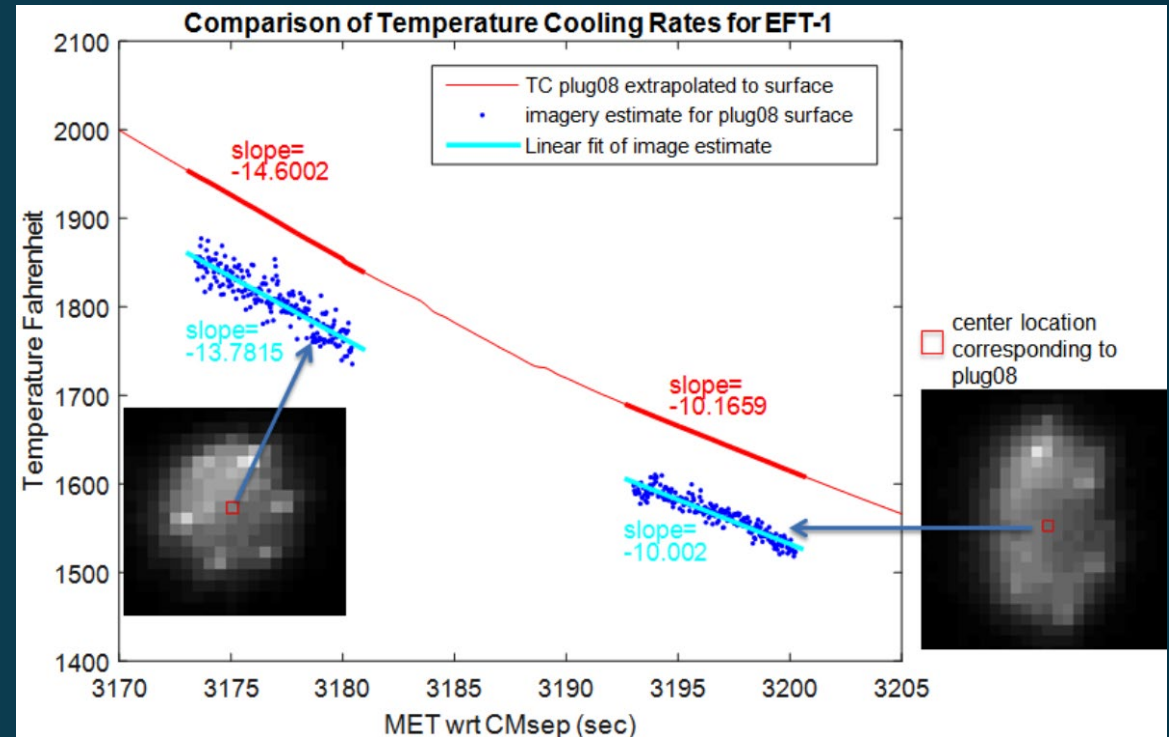
Surface temperature of heat shield



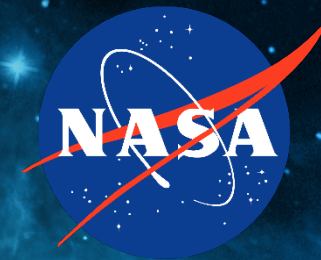
Comparison to Other (Onboard) Flight Data



TC plug08

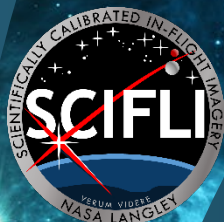


- Cooling rates (slopes) between TC and image derived temperature measurement are nearly identical
- Suggests temperature difference between measurement techniques is a bias error
- Remote imagery not susceptible to EMI effects



TPS Performance – Launch, Staging, Reentry

Launch: Plume-Induced Flow Separation

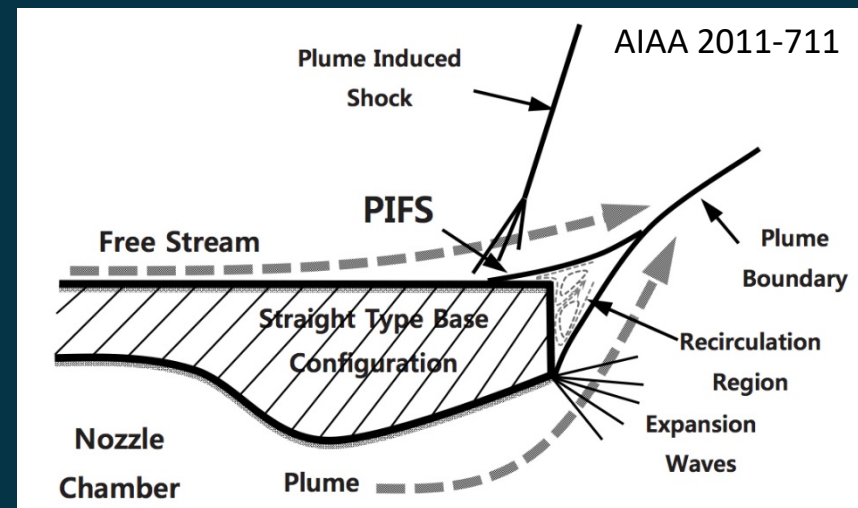


Seen on Saturn V – “dirty” kerosene flames are visible*

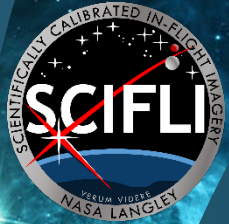
*The Airborne Lightweight Optical Tracking System (ALOTS) was used to observe the flow separation location on the Saturn V AS-506 (Apollo 11) vehicle in flight.

Flight data needed for validation of design models and the accurate assessment of thermal margin

SCIFLI will use infrared imaging to look for PIFS on SLS during Artemis I launch – invisible H₂/O₂ flames



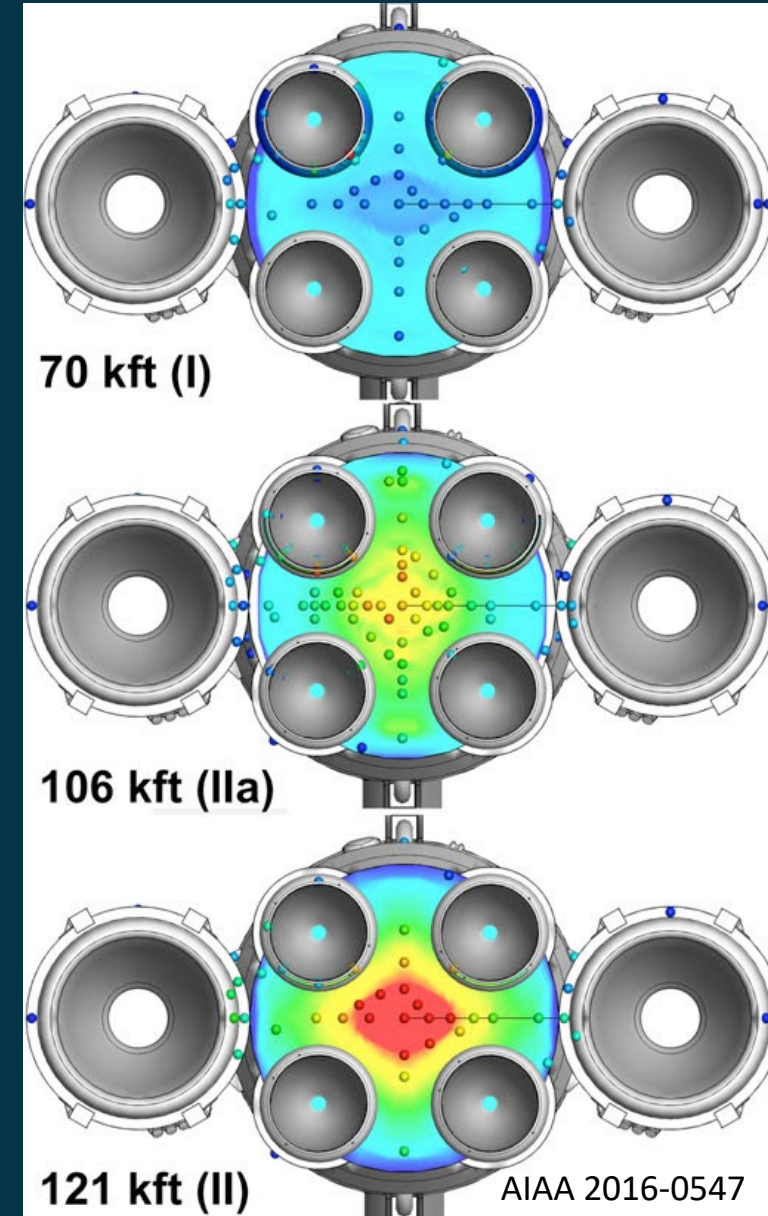
Launch: SLS Core Stage Base Heating

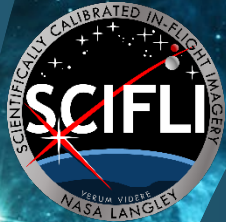


- Baseflow physics expected to be significantly different than Saturn V, Delta IV Heavy, Atlas V, Falcon 9, and Falcon Heavy
- Experimental test data at CUBRC indicated higher base heating than predicted by CFD
- Flight data needed for validation and accurate assessment of thermal margins



SCIFLI tasked with making thermal measurements of SLS Core Stage base region during Artemis I launch

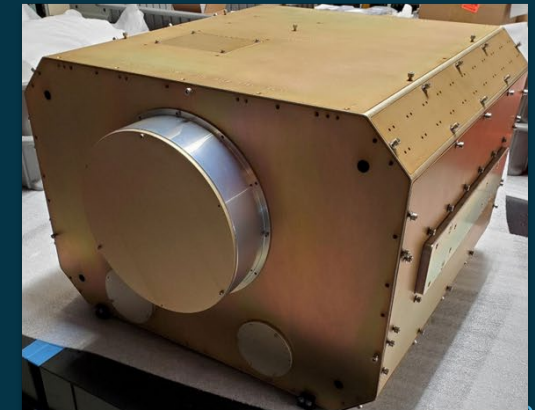
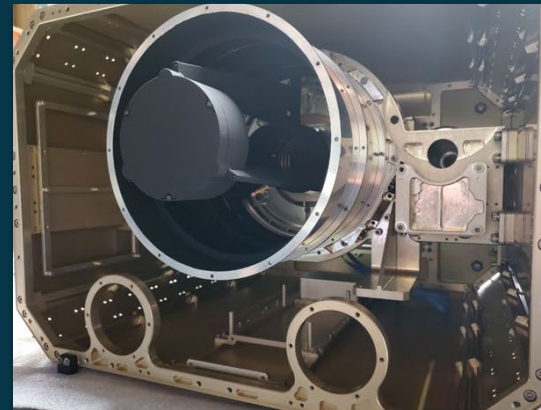
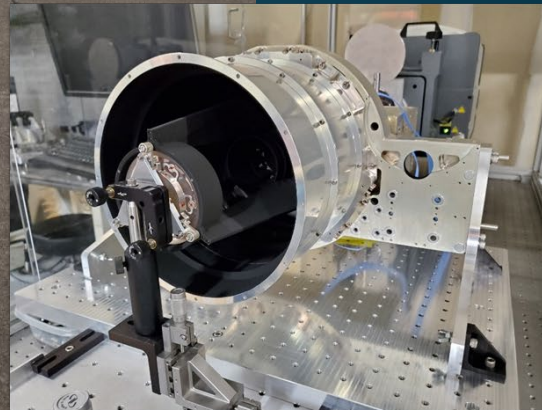
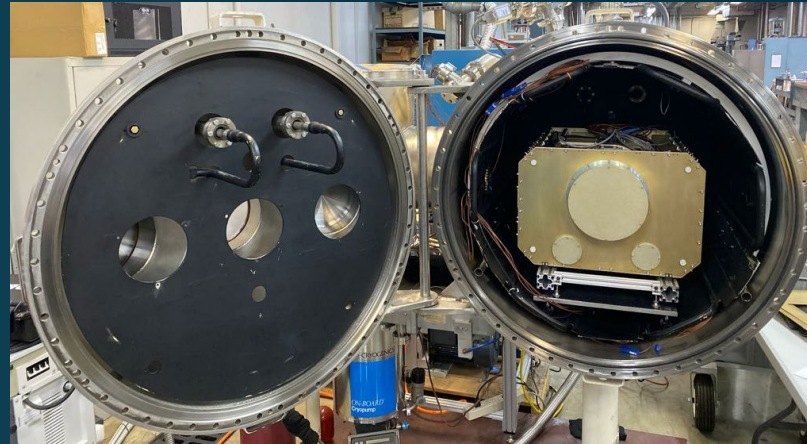




SAMI

SCIFLI AIRBORNE MULTISPECTRAL IMAGER

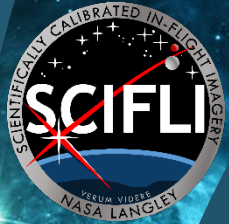
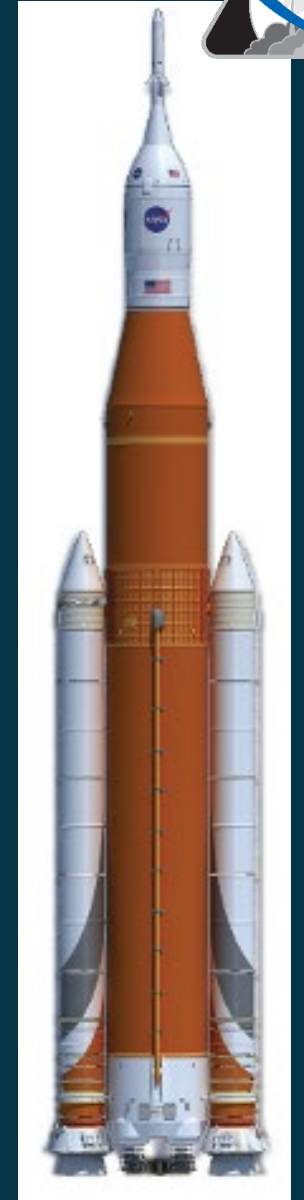
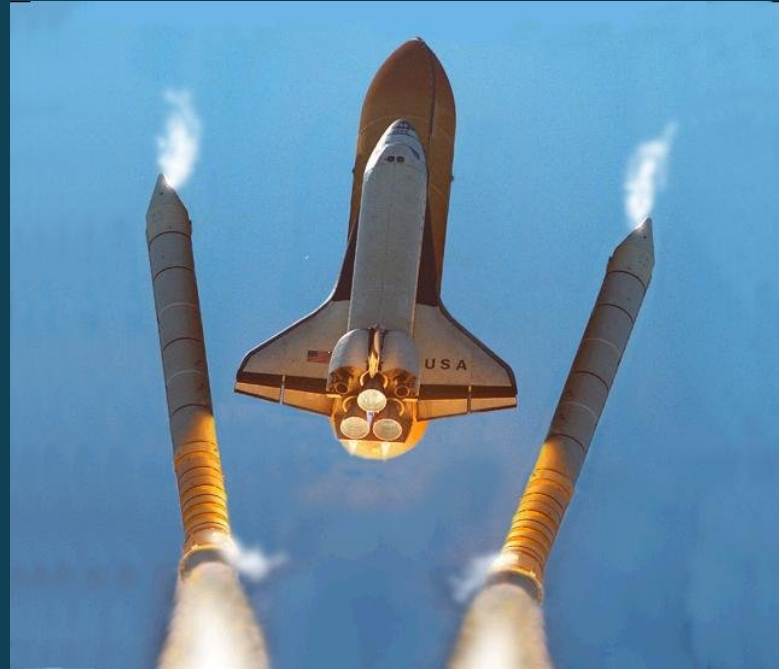
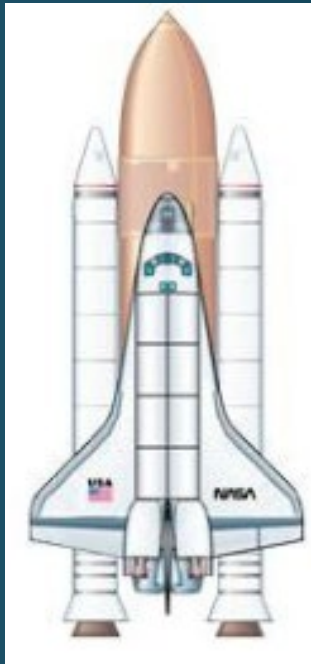
- State of the art sensors UV / Vis / IR
- Customizable narrowband filters
- Wide field of view – tracking
- Narrow field of view – spatial resolution



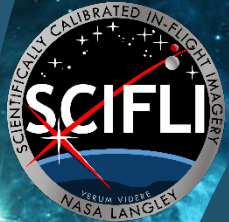
Staging: Solid Rocket Booster Separation



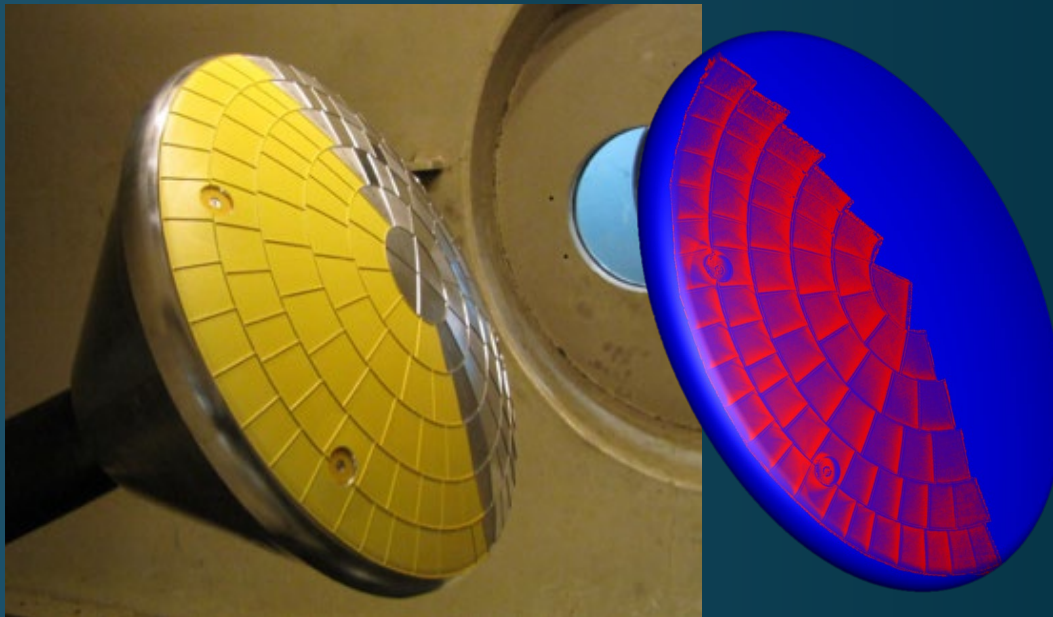
- Space Shuttle design – SRBs extended below main engines
- SLS design – SRBs are even with core stage
- CFD shows potential for re-contact after SRB separation
- SCIFLI tasked with imaging SRB separation during Artemis I
- Working with SpaceX on staging observations



Reentry: Peak Heating



- New heatshield design—segmented ablator.
- Shuttle embedded thermocouples exhibited anomalous behavior and delivered unreliable, discrete surface temperature results
- SCIFLI actively seeking funding to conduct thermal observation

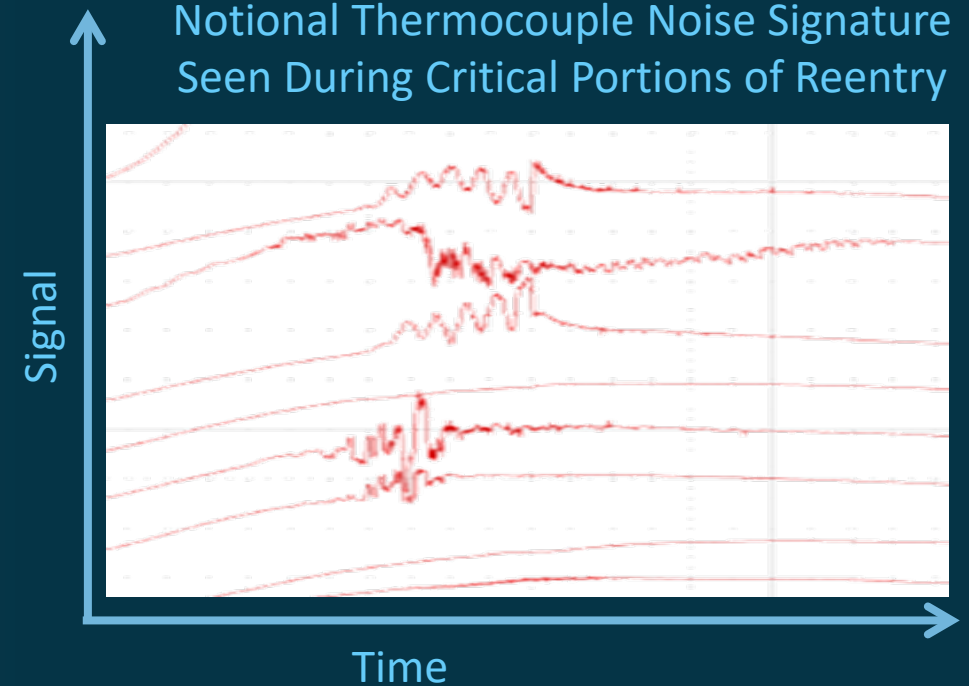


https://www.nasa.gov/centers/ames/images/content/671692main_MarsScienceLabHeatshield017a%5B2%5D.jpeg
Testing representative block-TPS layouts in 20-Inch Mach 6 with global phosphor thermography

Approximate reentry Mach numbers:

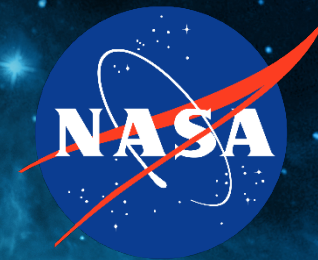
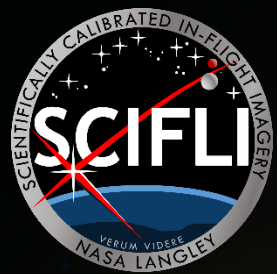
- Shuttle: 25
- EFT-1: 28
- Apollo: 36
- **Artemis I: 40**

Notional Thermocouple Noise Signature Seen During Critical Portions of Reentry



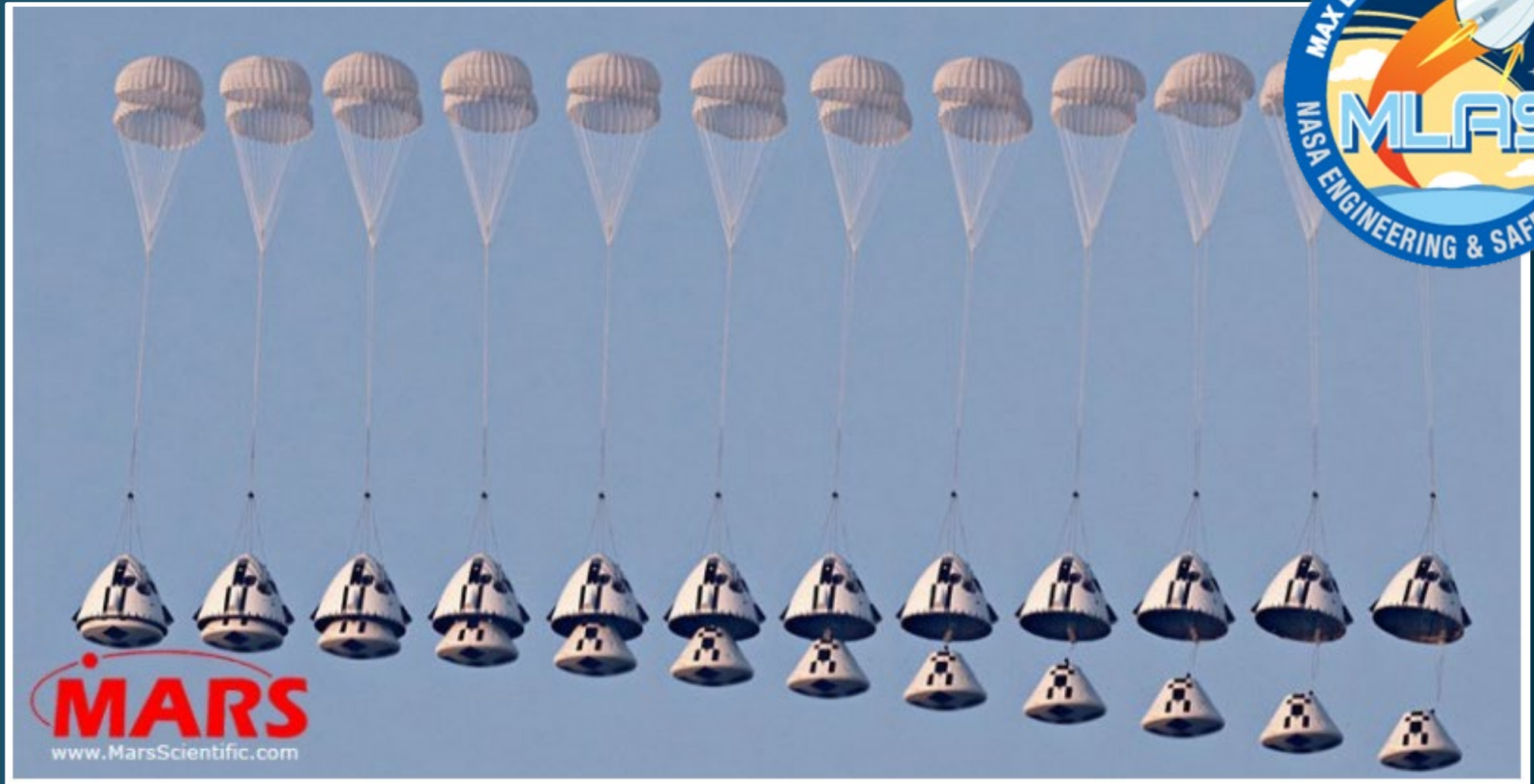
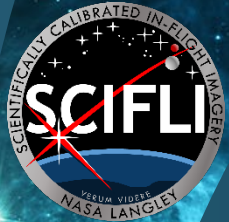
Behavior has been observed on:

- Shuttle Orbiter
- Dragon Capsule
- Orion Capsule



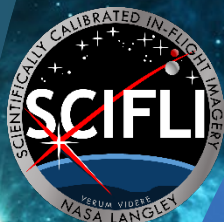
Contingency Flight Safety Systems

Orion Max Launch Abort Test (MLAS)



08 July 2009

Soyuz MS-10 Launch Abort (Expedition 57)



11 Oct 2018



NASA/Bill Ingalls - images-assets.nasa.gov/image/NHQ201810110007/NHQ201810110007~orig.tif

NASA/Bill Ingalls - images-assets.nasa.gov/image/NHQ201810110018/NHQ201810110018~orig.tif

Orion Ascent Abort 2 (AA-2)

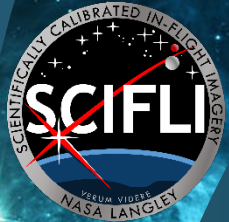
02 July 2019



Photo credit: Tom Parent

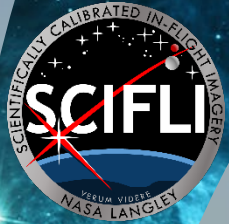
Photo credit: NASA/Tony Gray and Kevin O'Connell

<https://blogs.nasa.gov/aa2/>



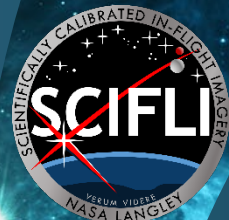
Boeing Pad Abort Test (PAT)

04 November 2019



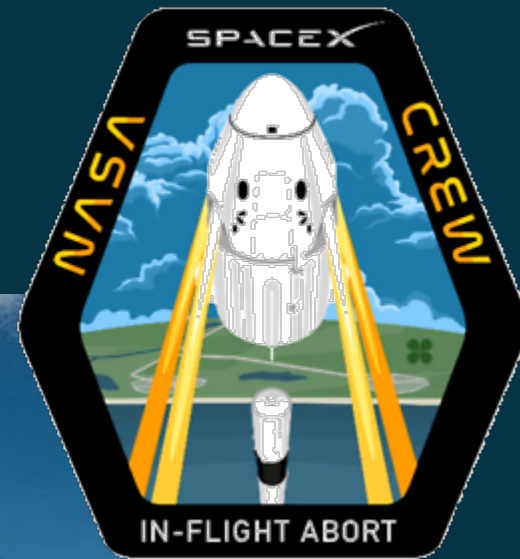
SpaceX In-Flight Abort (IFA)

19 January 2020



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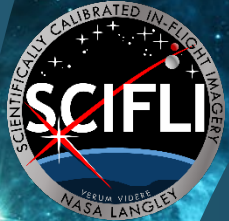


NASA/Tony Gray
<https://www.flickr.com/photos/nasakennedy/49420609803/in/photostream/>



Hypervelocity– Entry Systems Modeling Group

Stardust



Target: Coma of Comet Wild 2

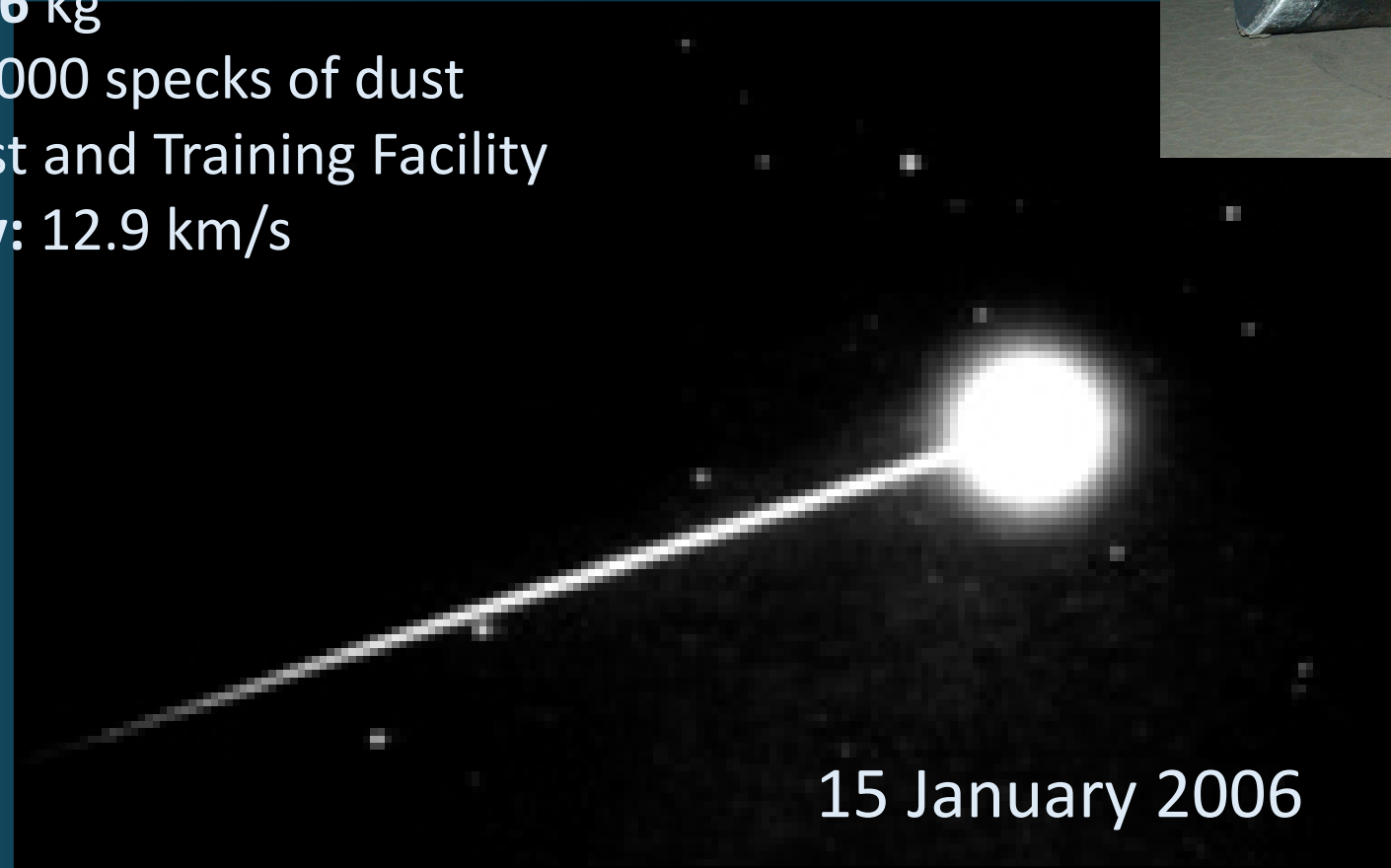
Capsule Diameter: 0.81 m

Capsule Mass: 46 kg

Sample: >1,000,000 specks of dust

Return: Utah Test and Training Facility

Reentry Velocity: 12.9 km/s

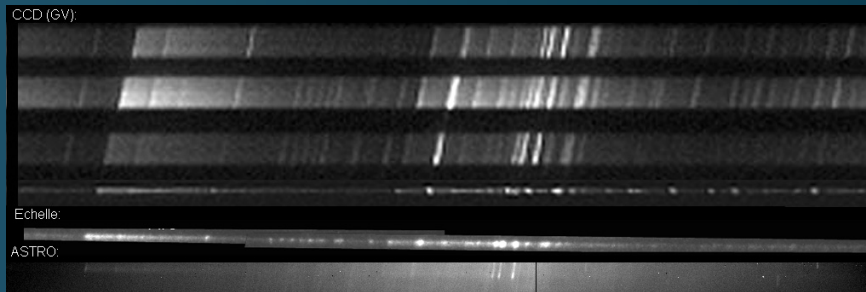
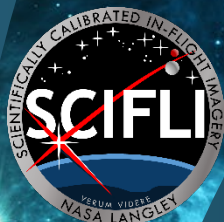
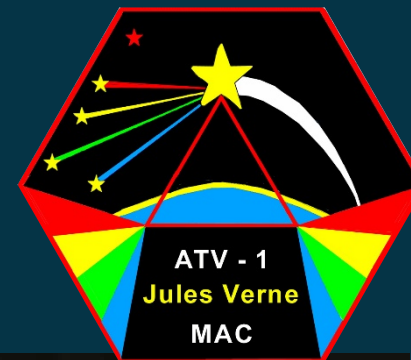


15 January 2006

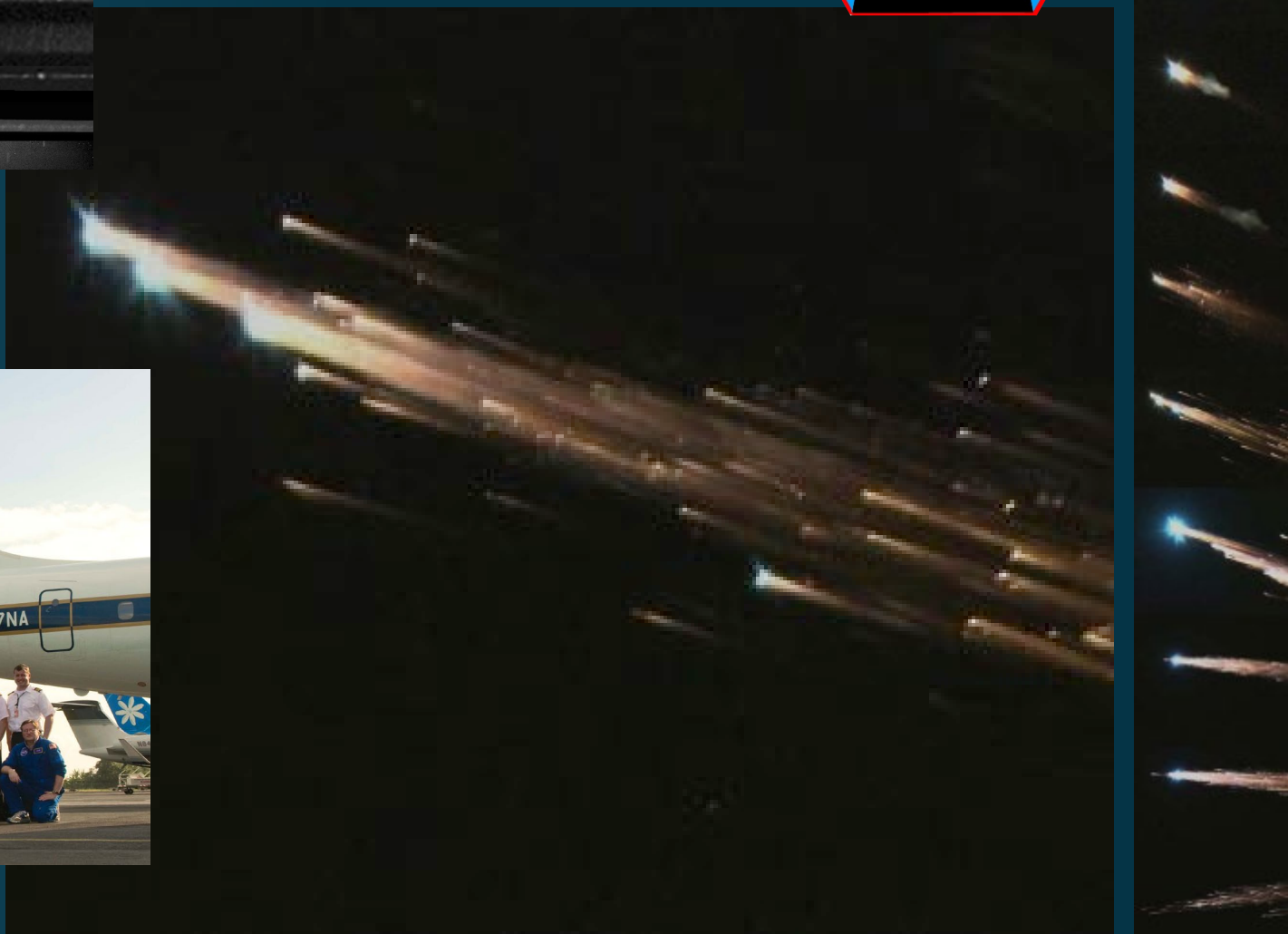
European Space Agency ATV

29 September 2008

Automated Transfer Vehicle – destructive reentry

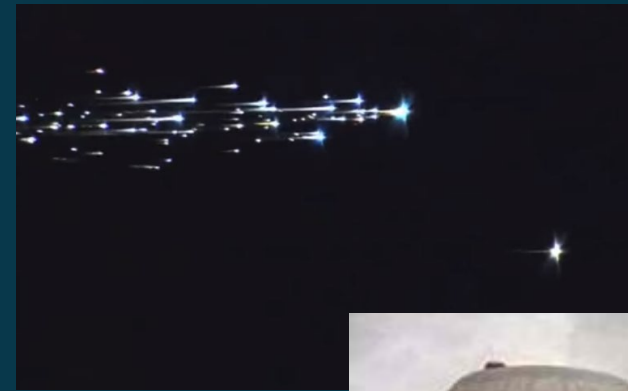
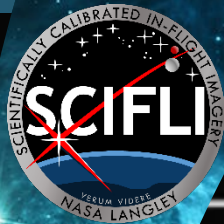


<http://atv.seti.org/>



Hayabusa

13 June 2010



Courtesy of JAXA

<https://ntrs.nasa.gov/api/citations/20160000307/downloads/20160000307.pdf>

Target: Asteroid Itokawa

Capsule Diameter: 0.4 m

Capsule Mass: 16.3 kg

Sample: ~1,500 rocky particle grains

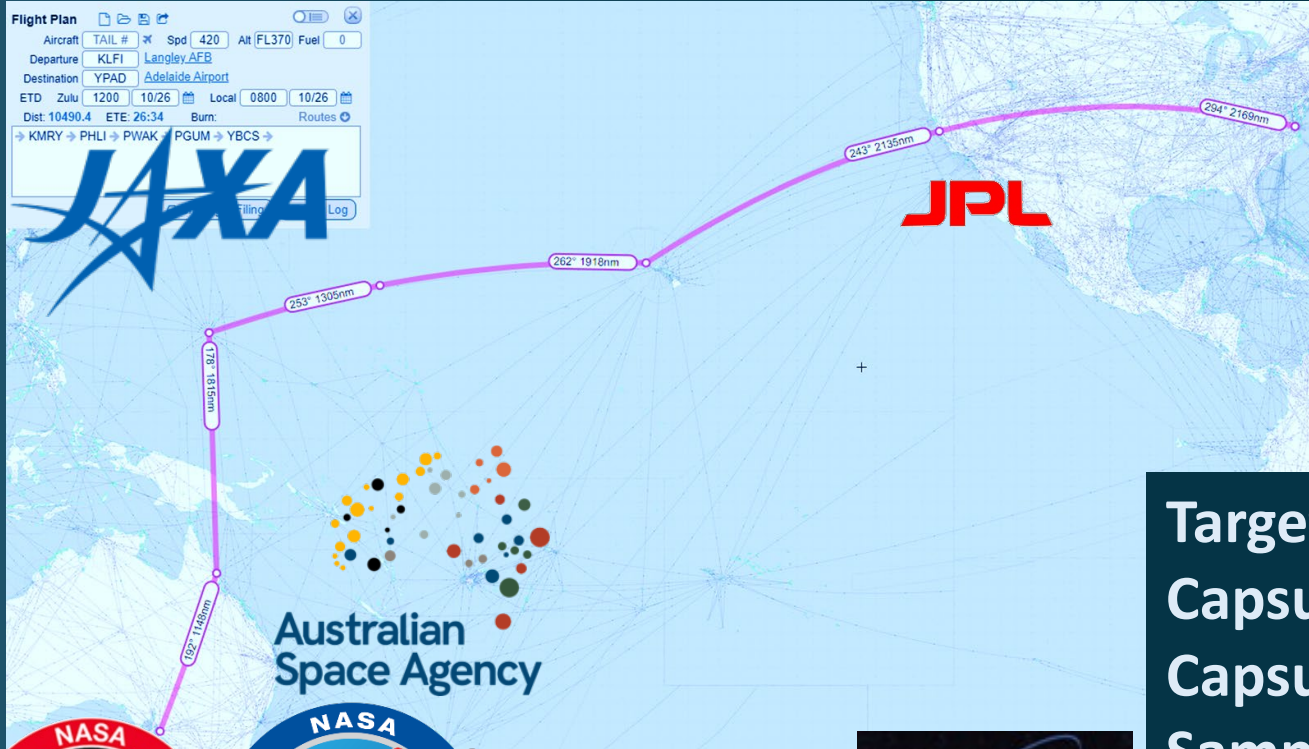
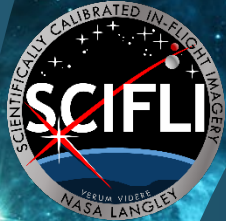
Return: Woomera Prohibited Area, Australia

Reentry Velocity: 12.2 km/s

Hayabusa 2: SHARC

SCIFLI Hayabusa 2 Airborne Reentry Observation Campaign

05 December 2020



Target: Asteroid Ryugu
Capsule Diameter: 0.40 m
Capsule Mass: 16.3 kg
Sample Mass: 5.4 grams
Return: Woomera Test Range, Australia
Reentry Velocity: 12 km/s

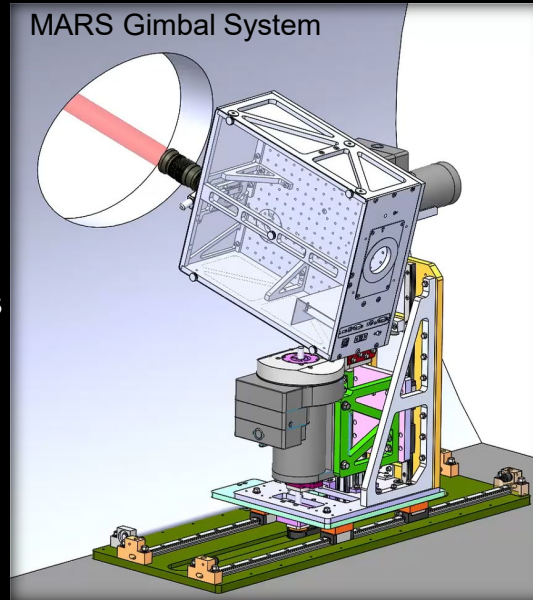


SHARC Mission Operations

Mission Hardware:

- 2 NASA Aircraft
- 6 Science Windows
- 4 Gimbal Systems
- 14 Imaging Payloads

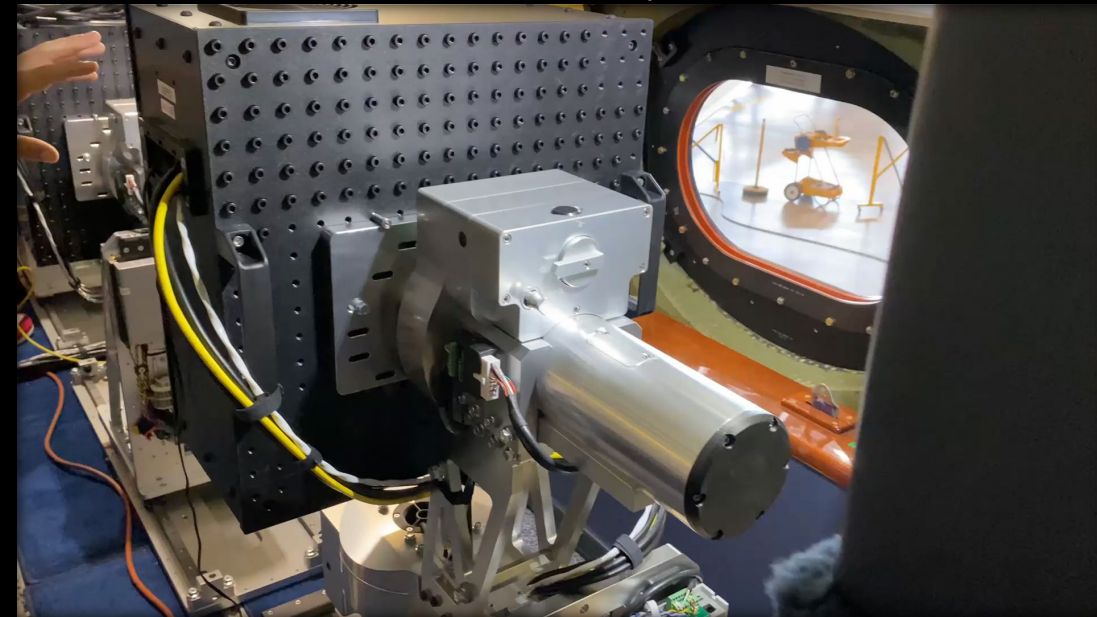
Overlapping broad & narrow spectral data with complimentary views



SEOs Reviewing Star Maps Pre-Flight



MARS Gimbal + Spectrometer Payloads on NASA 520



Platform	Payload	Nominal Bandpass [nm]	Spectral Resolution [nm/pix]
NASA 520	CALSPEC	320 – 950	0.306
	USPEC	320 – 480	0.104
	VSPEC2	380 – 670	0.066
	NIRSPEC	570 – 1000	0.085
	NIRSPEC2	570 – 1000	0.083
	SWIRSPEC	950 – 1650	1.72
	WAKESPEC	320 – 950	0.364
NASA 992	VSPEC	370 – 700	0.067
	SWIRSPEC2	950 – 1650	1.67
	WAKESPEC2	400 – 900	0.193

SHARC

SCIFLI Hayabusa 2 Airborne Reentry Observation Campaign

06 December 2020



Hayabusa-2 Reentry

December 6th, 2020

CALSPEC Data Visualization

Location: N520NA Gulfstream III
32.226451° S, 136.444627° W
41,000 Feet Altitude

MARS: Ronald F. Dantowitz
RDantowitz@MarsScientific.com
www.MarsScientific.com
TEL: 602-888-MARS

NASA: Jennifer Inman, PhD
Jennifer.A.Inman@nasa.gov
<https://SCIFLI.larc.nasa.gov>
TEL: 757.864.8076

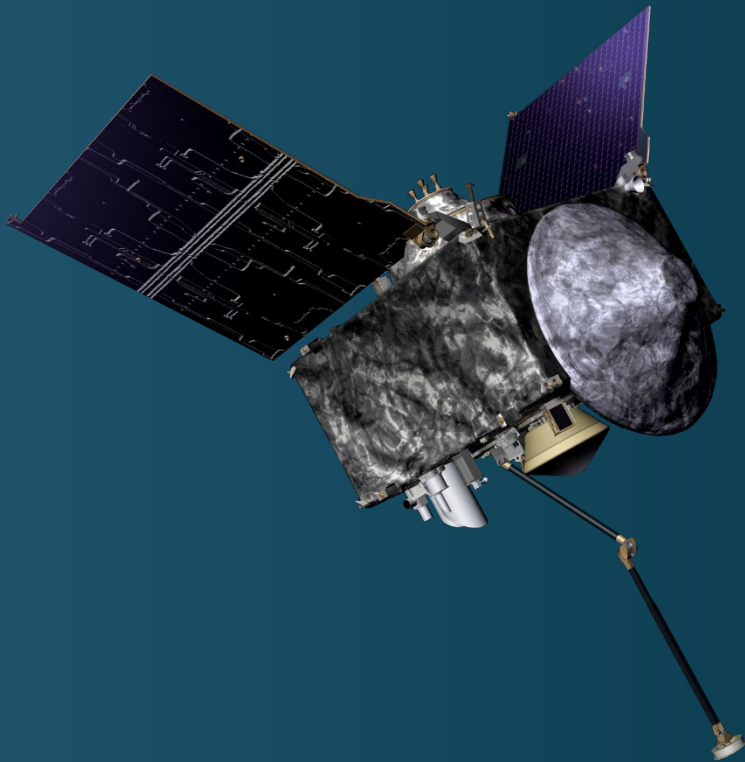
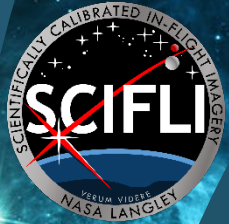
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OSIRIS-REx

Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer

24 September 2023



Target: Asteroid Bennu

Capsule Diameter: 0.81 m

Capsule Mass: 46kg

Sample Mass: >60 grams

Return: Utah Test and Training Range

Reentry Velocity: 12.2 km/s



Looking to the Future

SkyRange and Range Hawks



Who is Developing SkyRange?

The DoD Test Resource Management Center (TRMC) in Partnership with NASA.

What does TRMC provide?

TRMC provides the resources for developing the SkyRange architecture including the hosted payloads and sensors

What does NASA provide?

NASA provides the Agency Global Hawks and experience/expertise for conversion into the SkyRange configuration including payload integration and subsequent demonstration in an operational flight environment

What happens after the developmental phase?

The Agency Global Hawks and supporting ground control systems are to be transitioned to a government entity. Follow on FY23-26 7600 between AFRC & TRMC being developed

Opportunity:

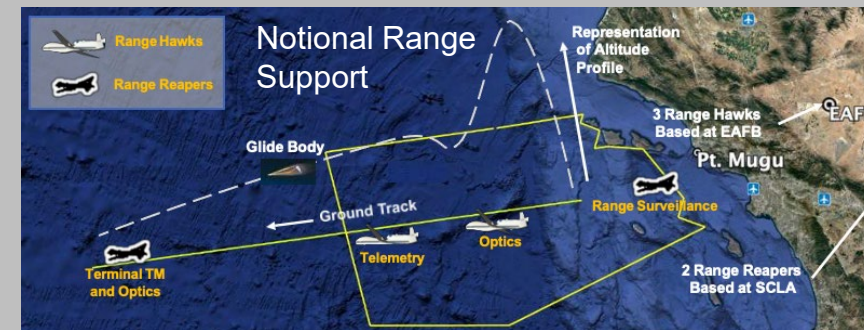
Utilize DoD SkyRange assets under development to provide near term support to HEOMD (Artemis; Orion). Fosters relationship for potential future support to the Agency STMD (LOFTID/Sierra Space/SpaceX); SMD (OSIRIS REX); ARMD (HTP)



SkyRange:

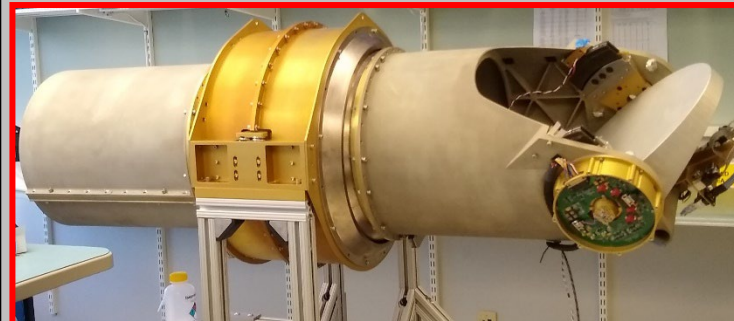
“Pop-up Range” concept utilizing rapidly deployed high and medium altitude, long-endurance Unmanned Aerial Systems with novel sensor suites to support hypersonic flight test and evaluation

Range Hawks: Global Hawks configured to host multiple sensors to enable a flexible, cost-effective capability to collect critical data throughout a flight test on the Range

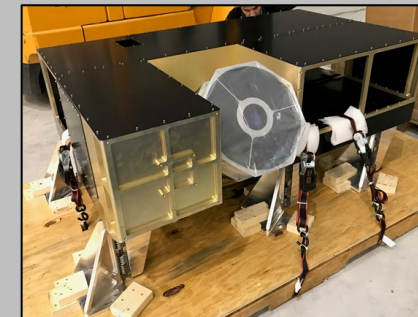


Current NASA / TRMC Interagency Agreement IA1-24848 (2017-Sept 2022):

Conversion of NASA Global Hawks to demonstrate hosted payload technology



Electro-optical imaging
Informs on flight environments



LIDAR based atmosphere
Launch decisions; Aero reconstruction



Telemetry
Data relay