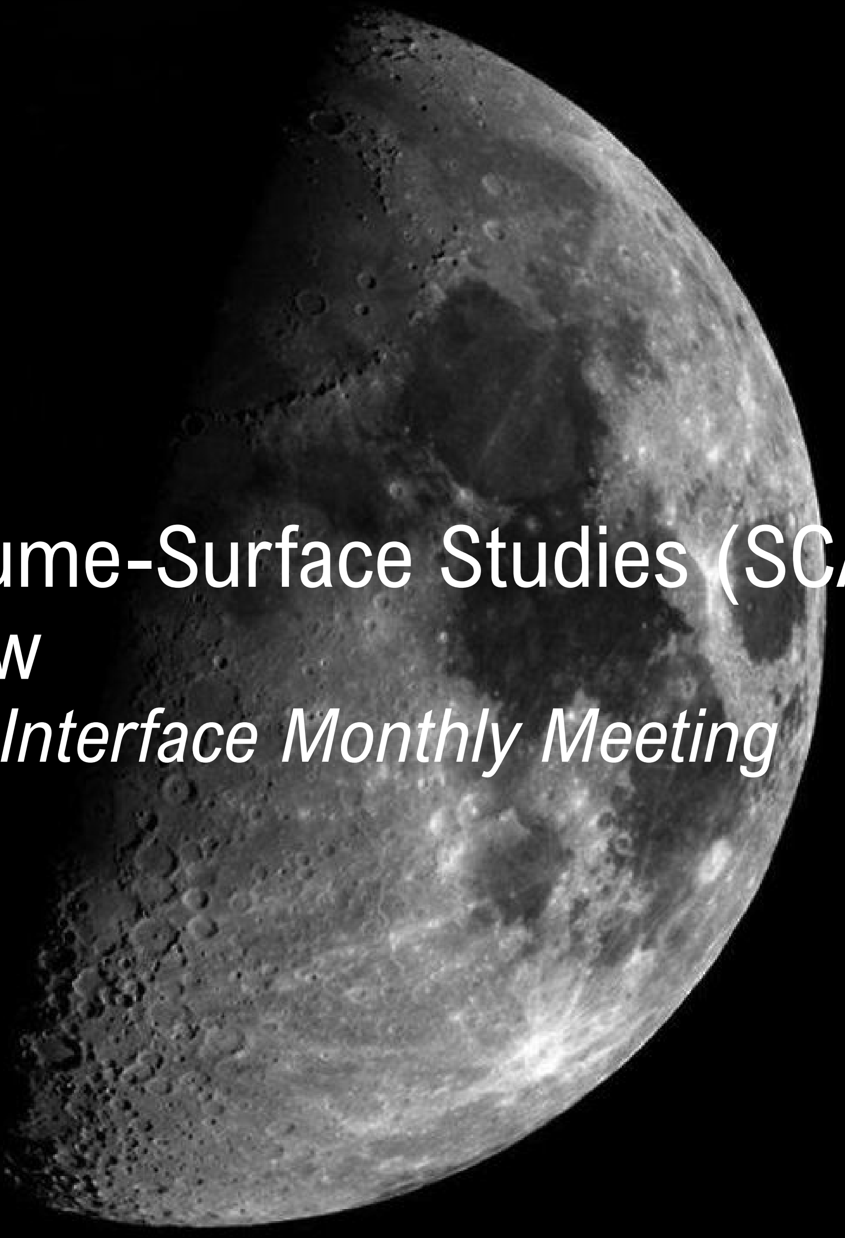
National Aeronautics and
Space Administration

Stereo Cameras for Lunar Plume-Surface Studies (SCALPSS) Science and Payload Overview

LSIC Dust, Regolith, and Surface Interface Monthly Meeting
22 July 2025



NASA Langley Research Center
Rob Maddock, Project Manager
Chi Nguyen, Technical Lead
Paul Danehy, Project Technologist
Olivia Tyrrell, Imaging/Science

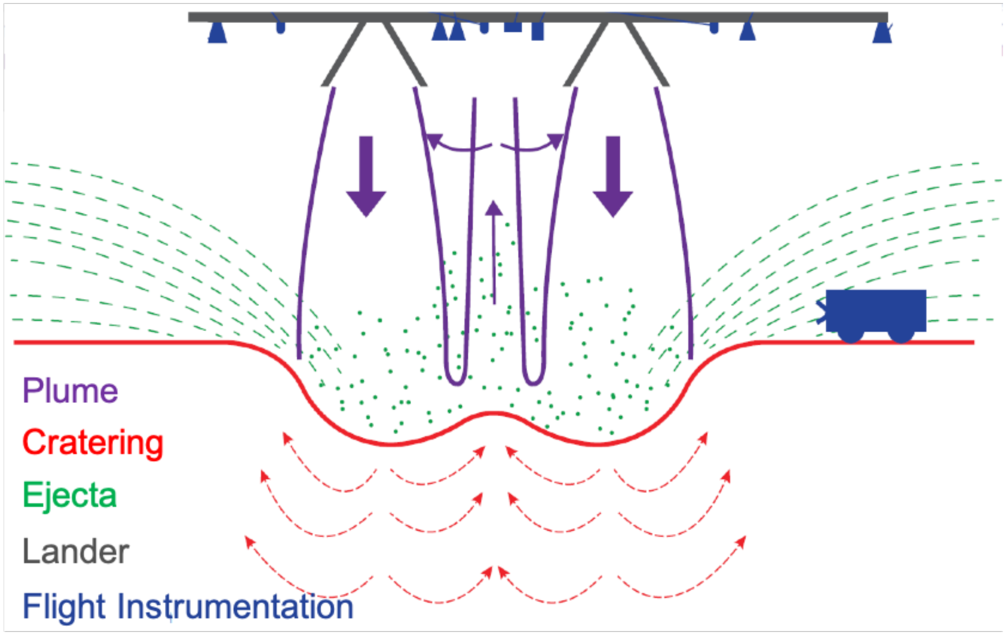
SCALPSS Payload Team

- NASA Langley Research Center:
  - project management
  - systems design and engineering
  - hardware development
    - electronics (MSE-lite)
    - SCALPSS cameras
    - illumination system (active and passive)
  - assembly, integration and testing
  - payload delivery
- NASA Marshal Research Center:
  - principle investigator
  - camera and lens characterization and performance
  - PSI pre-flight predictions
- NASA Glenn Research Center:
  - particle impact sensor
- NASA Johnson Research Center:
  - MLI

- Payload POCs:
  - Project Manager: Rob Maddock (robert.w.maddock@nasa.gov)
  - Principle Investigator: Wesley Chambers (wesley.chambers@nasa.gov)
  - Project Technologist: Paul Danehy (paul.m.danehy@nasa.gov)
  - Technical Lead: Chi Nguyen (dung-chi.p.nguyen@nasa.gov)
  - Electronics: Ray Lueg (raymond.t.lueg@nasa.gov)
  - Imaging / Camera and Laser System Configuration: Olivia Tyrrell (olivia.tyrrell@nasa.gov)
  - Imaging / Stereo Photogrammetry: Josh Weisberger (joshua.weisberger@nasa.gov)
  - Particle Impact Sensor: Michael Anderson (michael.d.anderson-1@nasa.gov)
  - Flight Software: Cornell Wilson (cornell.j.wilson@nasa.gov)
  - Thermal: Kim Martin (kimberly.martin@nasa.gov)
  - Mechanical: Nick Vitullo (nicholas.a.vitullo@nasa.gov)
  - Structural Analyses: TBD
  - Assembly, Integration and Test Lead: Josh Beverly (joshua.s.beverly@nasa.gov)

Understanding Plume-Surface Interaction

- Rocket plume-surface interaction (PSI) is a complex, multi-phase discipline that describes the lander environment due to the impingement of hot rocket exhaust on the regolith of planetary bodies.
- Understanding PSI means understanding the effects of, and being able to correctly model the:
  - surface regolith
  - rocket plume
  - erosion of the surface
  - characteristics of the ejecta (what and where)
  - induced environments underneath the lander
- Facilities and/or capabilities for ground testing (e.g., full scale engines in a vacuum into lunar regolith) do not currently exist.
  - Current (and planned) ground test data still requires significant extrapolations for estimating CLPS (and HLS) scale effects.
- There is currently a lack of lunar flight data from PSI effects during descent and landing which is necessary to anchor computational and engineering models to be used to enable safe and low risk design of future landers, surface elements and surface operations.

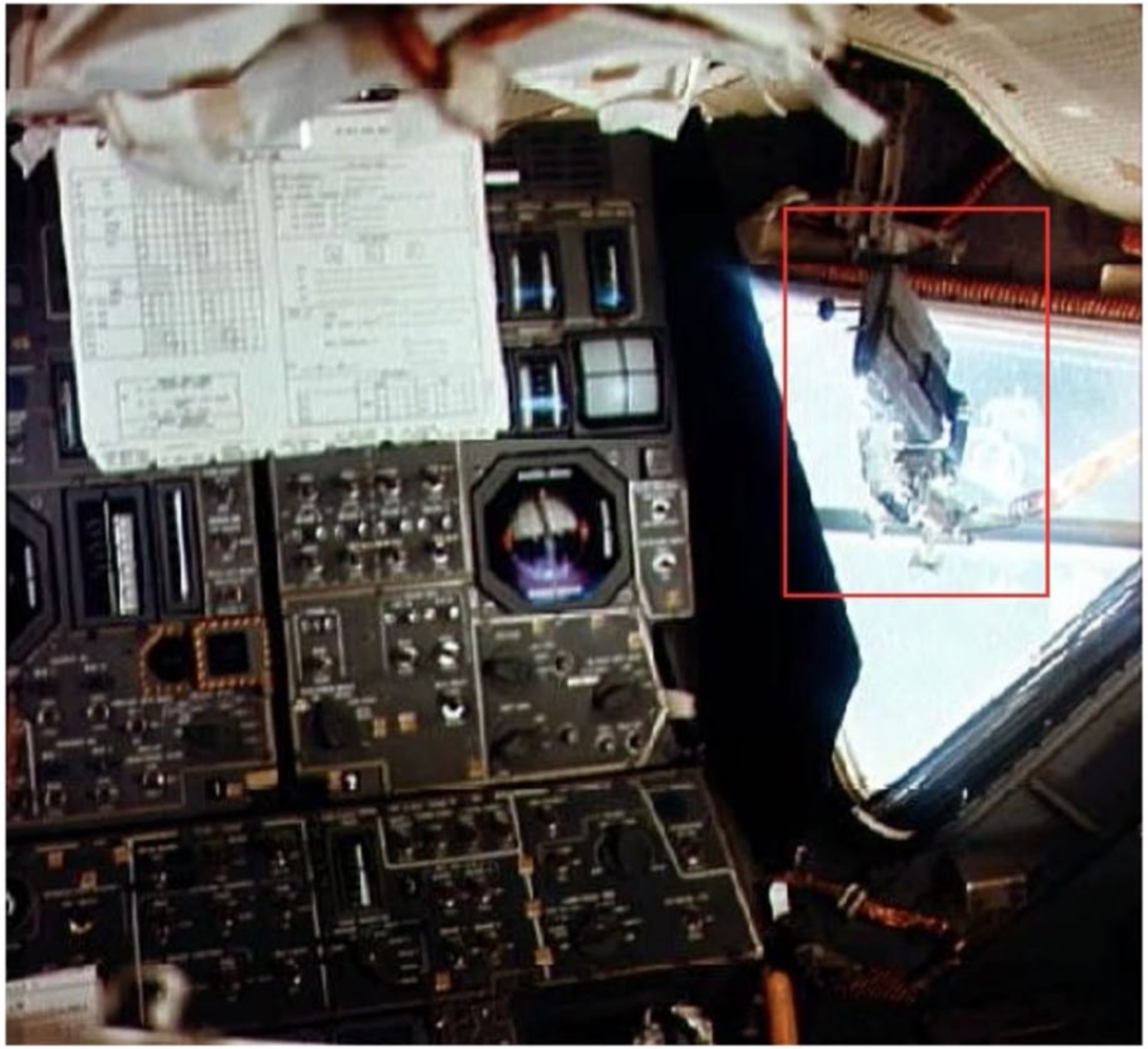


plume-surface interaction

spacecraft rocket exhaust interacting with unimproved planetary surfaces

fluid granular physics

Lunar Module Sequence Camera

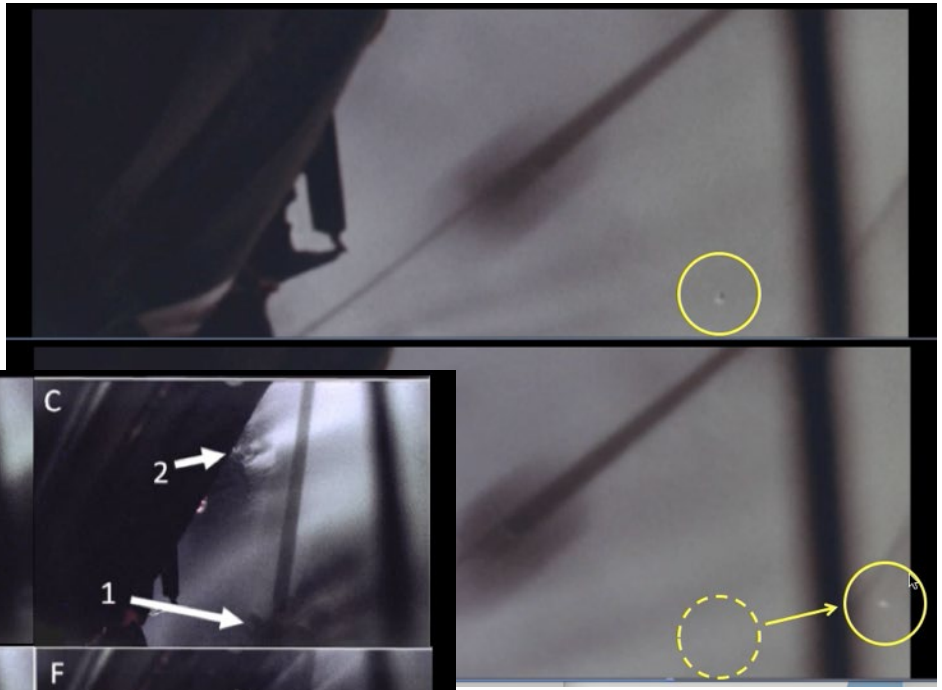


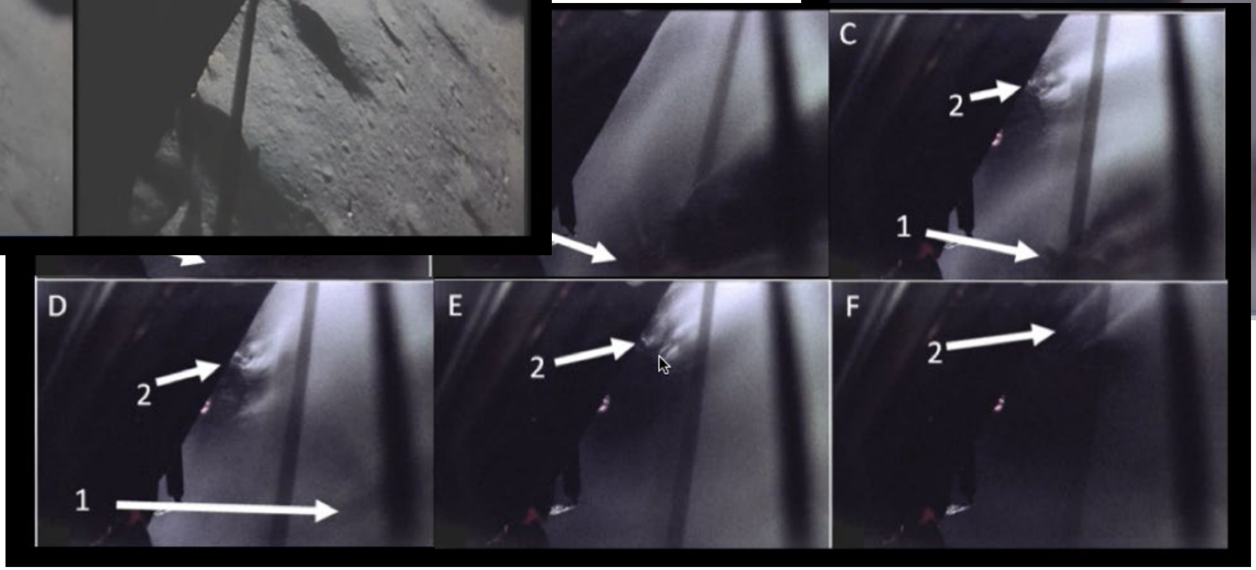
Apollo Experience

PSI Hazards

Dust

Blowing Rocks





Terrain Modification

PSI Aftereffects – Near Field

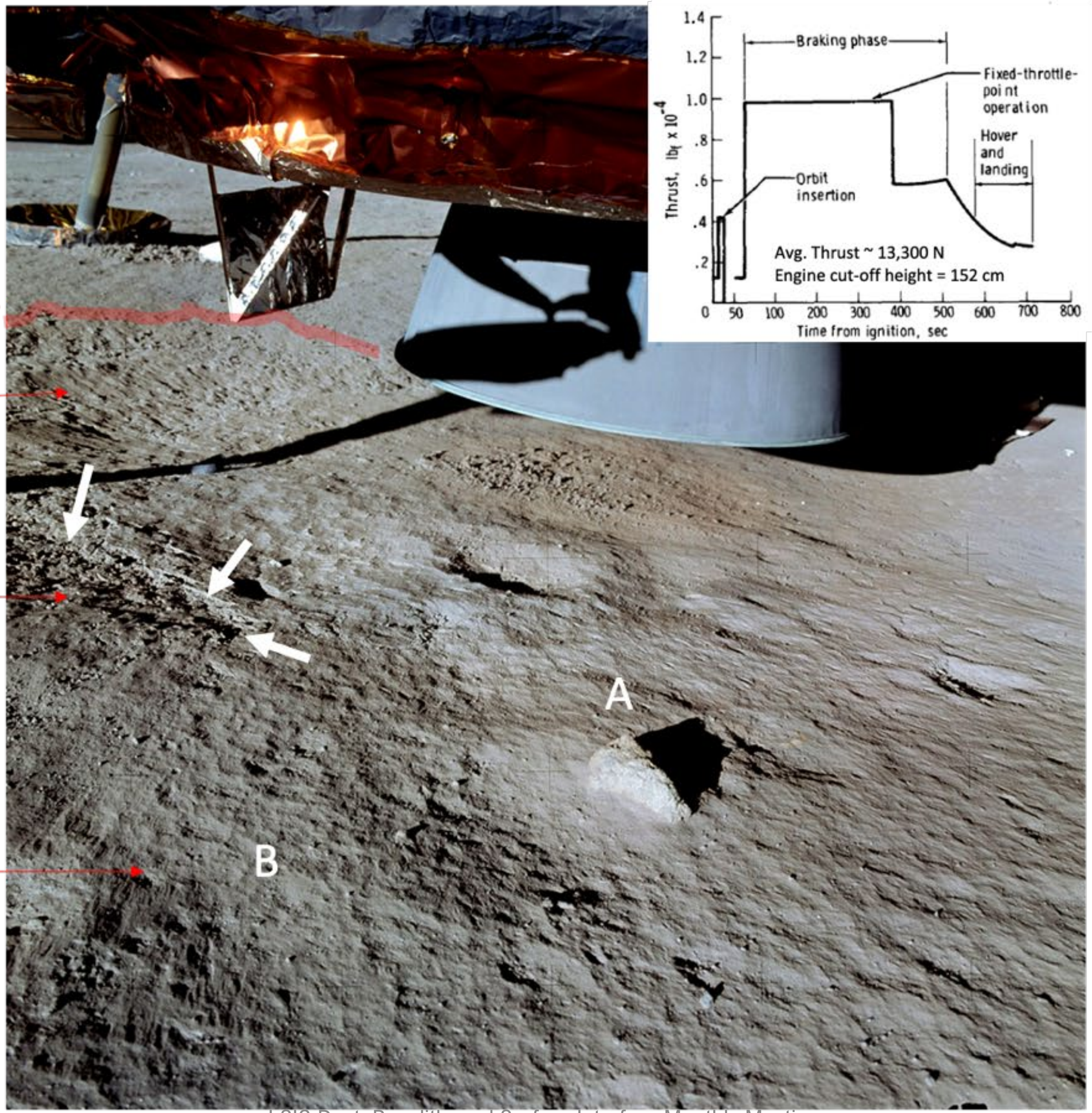
Toroidal Erosion Rim (Ideal to capture such erosion pattern and undisturbed terrain for SCALPSS)

Radial Striation Erosional Remnant (large and wide striations due to high plume shear)

Stair-Step Erosion Contact (Strips away regolith sublayers/discontinuity)

Hummocky Erosion Bed Forms (caused by gas flow unsteadiness and abruptly changing directions)

Metzger et al (2010)



__Pseudo-Stereo Images__

Photogrammetry Depth Error: $\pm 0.1\ cm$

Photogrammetry Spatial Error: $\pm 0.3\ cm$

__Stereo Images (SCALPSS):__

Theoretical Photogrammetry Depth Error: $\pm 0.01\ cm$ (TBD)

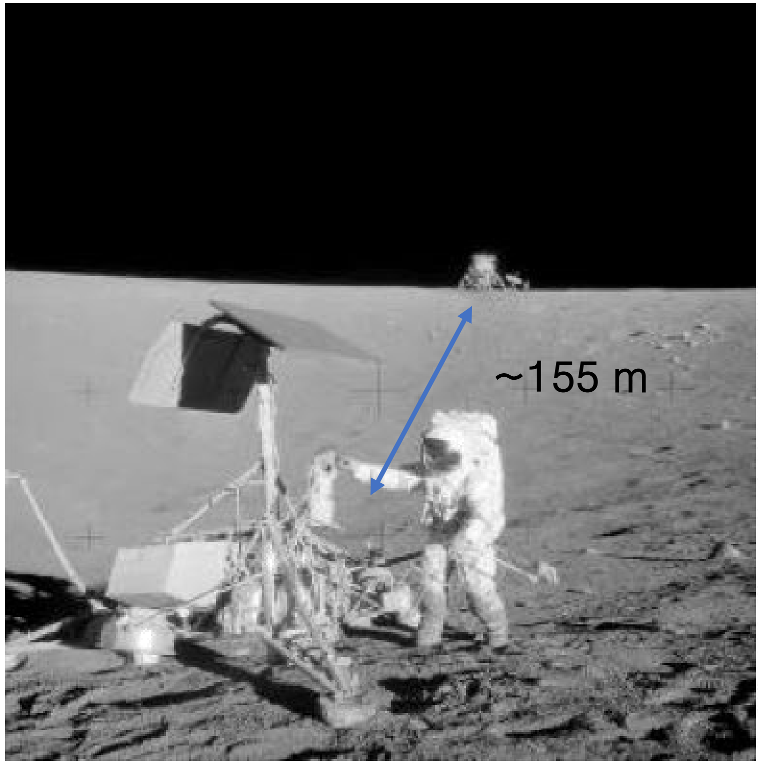
Theoretical Photogrammetry Spatial Error: $\pm 0.3\ cm$ (TBD)

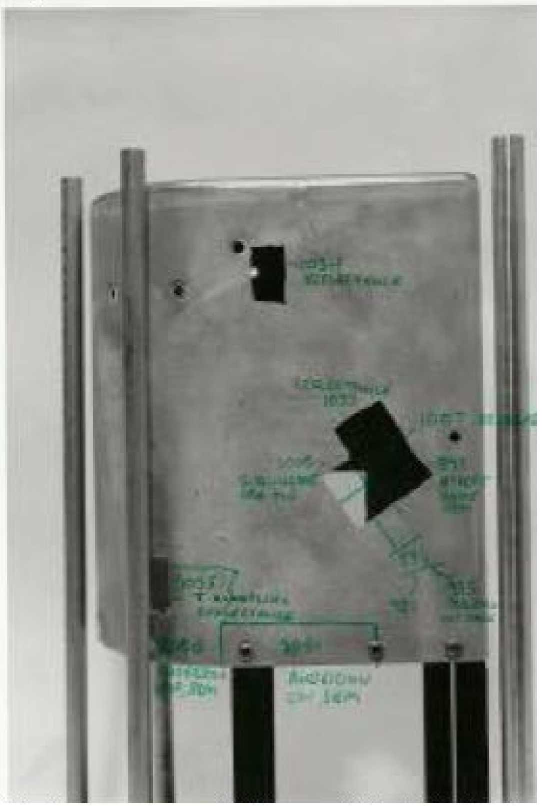
Large swept appearance under the lander indicates that all these regions were governed by erosion processes and no signs of deposition (this will make analysis easier in some respects and easier to visualize than our Mars counterpart)

High-resolution landing site morphology focusing on these erosion features under the lander will determine the amount of sublayers eroded as a function of spatial distributiion. Through this approach eroded mass and erosion rate can be estimated.

PSI Aftereffects – Far Field

Surveyor III Coupons

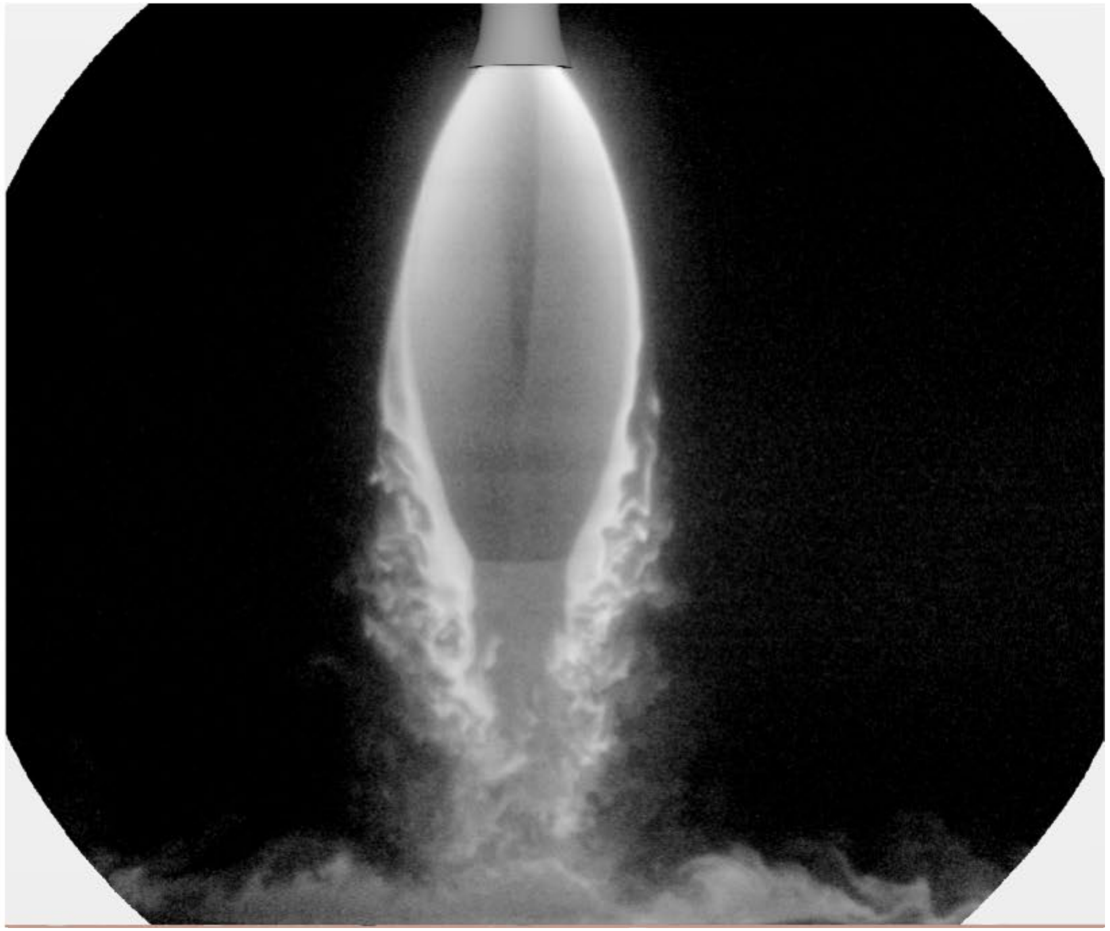




Plume Surface Interaction (PSI) Flowfields

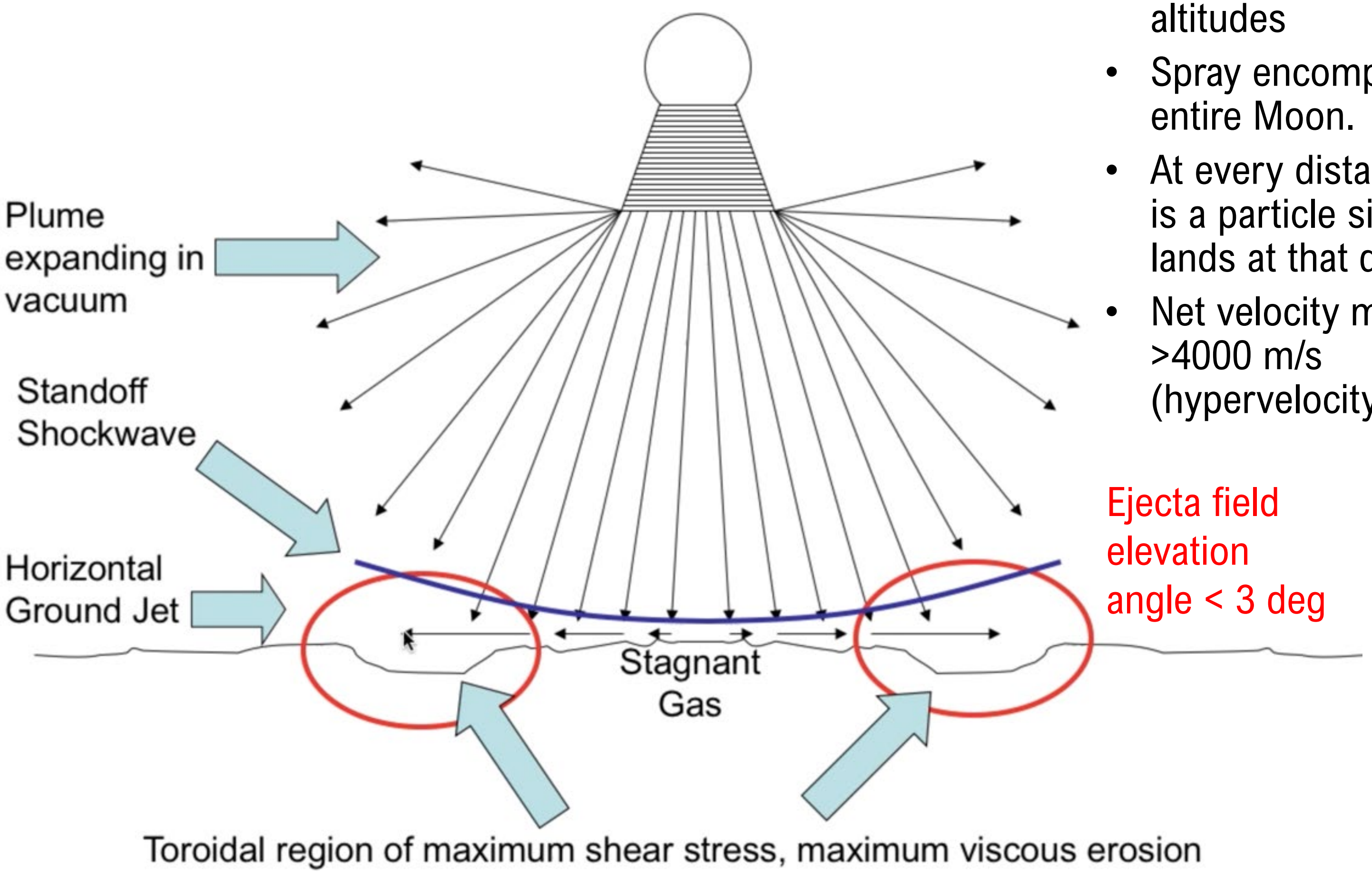
Lunar-relevant

Martian-relevant



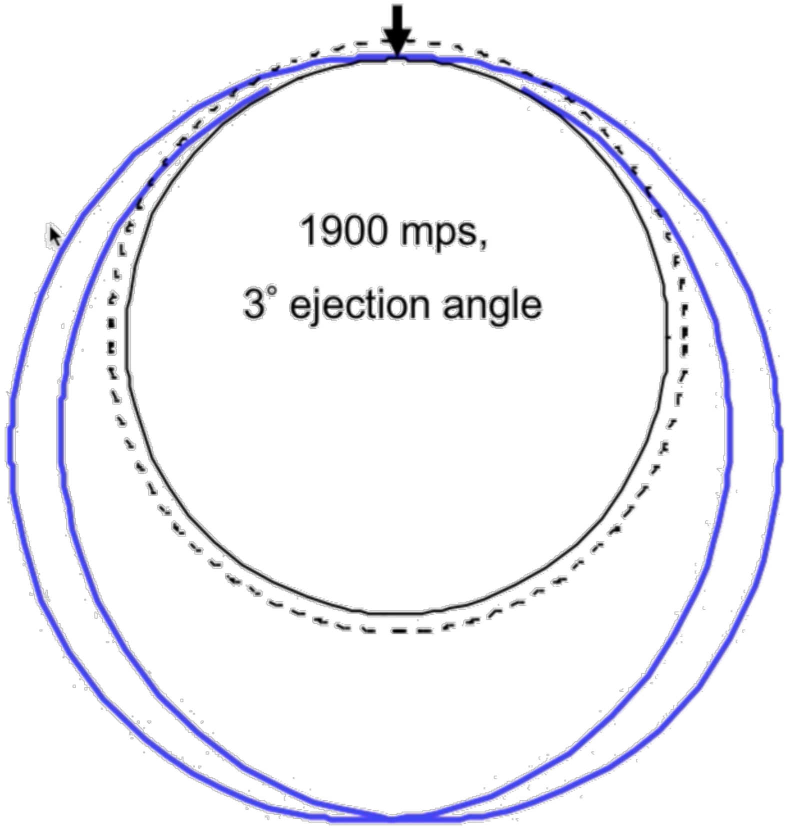
- Plume impingement visualization using planar laser induced fluorescence (PLIF) obtained as part of STMD-funded PFGT2 vacuum chamber test at NASA Marshall, 2022 (Rodrigues et al, at JANNAF, AIAA SciTech, Ascend and Physics of Fluids Journal).

Apollo Viscous Erosion



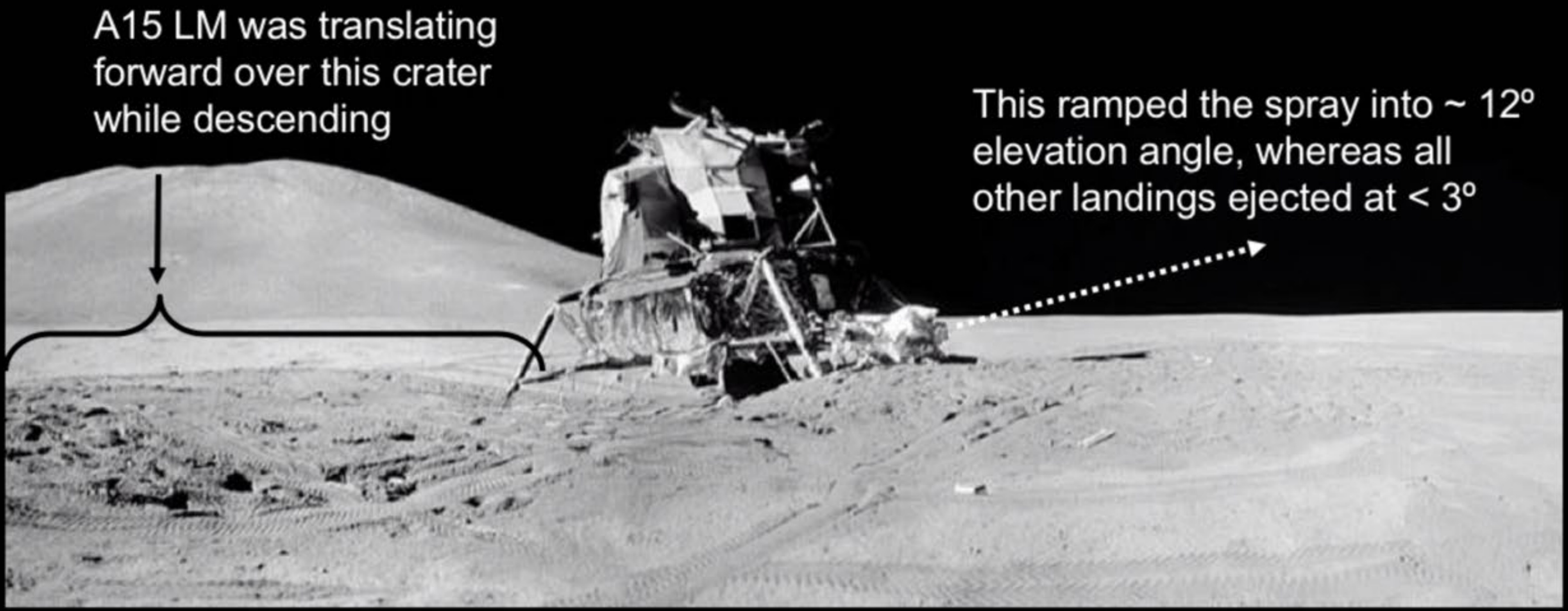
- Spray reaches orbital altitudes
- Spray encompasses the entire Moon.
- At every distance, there is a particle size that lands at that distance.
- Net velocity may be >4000 m/s (hypervelocity regime)

Ejecta field elevation angle < 3 deg



Ejecta Elevation

Exception: Apollo 15

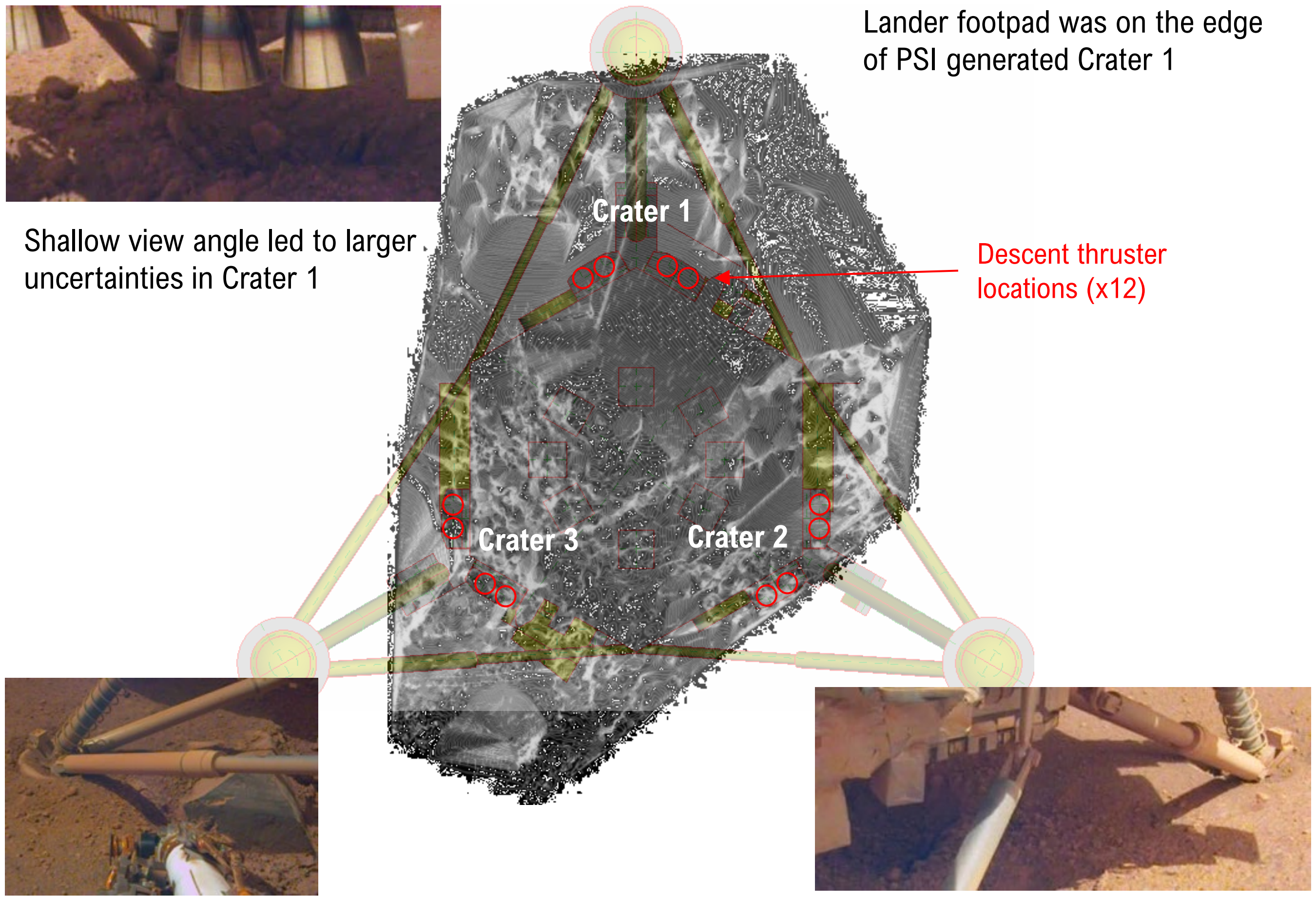


Other exceptions:

- dust streaks from small craters
- blast in terrain modification stage
- plume reflection planes for multi-engine landers

SCALPSS Science – Stereo Photogrammetry

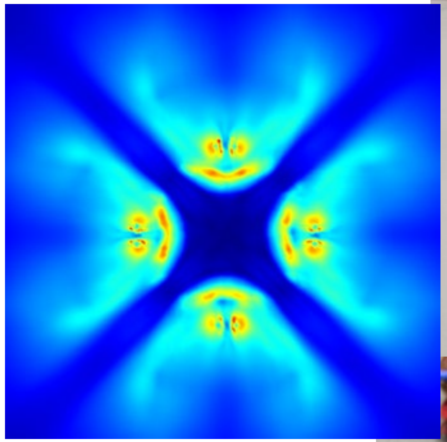
- SCALPSS is the first ever payload specifically designed to directly collect PSI measurements during lunar landing.
- Stereo Photogrammetry can be used to determine the morphology of a surface in 3D space through the process of comparing two or more images of that surface taken from **known** relative locations.
  - requires detailed characterization and calibration of the imaging system to reduce measurement uncertainties
- Not only can the onset of PSI erosion be determined, but by comparing surface morphology from before, during and after PSI, an accurate estimate of total erosion that occurs can be made.
- Stereo Photogrammetry can also be used to measure the shape of the ejecta sheet, track (large) ejecta movement, etc.



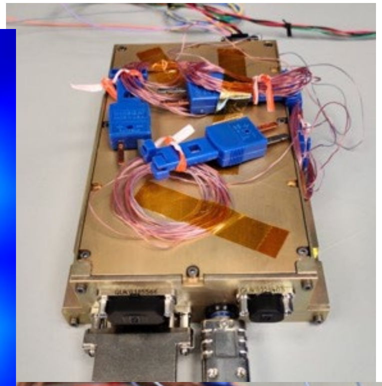
Example of using "pseudo" photogrammetry to measure erosion from the Mars Insight Lander

SCALPSS 1.1 Payload

- The Stereo Cameras for Lunar Plume-Surface Studies (SCALPSS) is the first ever dedicated instrument for directly measuring PSI erosion accurately.
  - pre-flight camera characterization and calibration (e.g., distortion coefficients)
  - high resolution images from known (e.g., measured and calibrated) camera locations and with known pointing directions) to estimate total erosion due to PSI
- Based on the Mars2020 EDLCam, SCALPSS provides a means by which existing technology can be "re-purposed" to provide high value science data at low cost and on shortened schedules.
  - 2x Long Focal Length (LFL) cameras for imaging from "high" altitude (e.g., prior to PSI onset)
  - 4x Short Focal Length (SFL) cameras for imaging from low altitude and the lunar surface

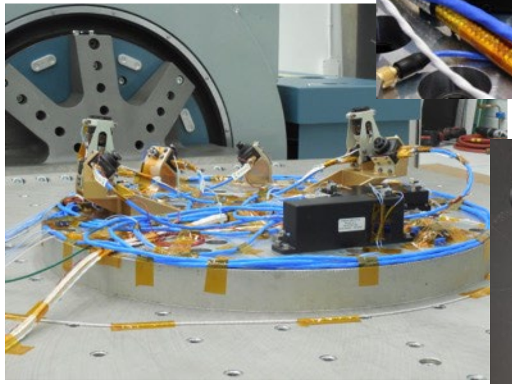


PSI predictions using CFD

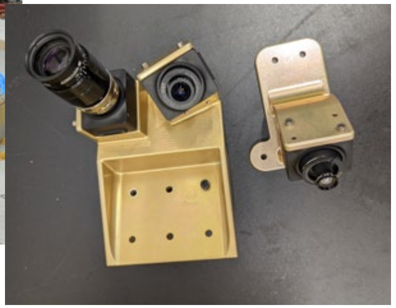


Data Storage Unit (DSU)

USB Hub



SCALPSS 1.1 flight hardware vibration testing



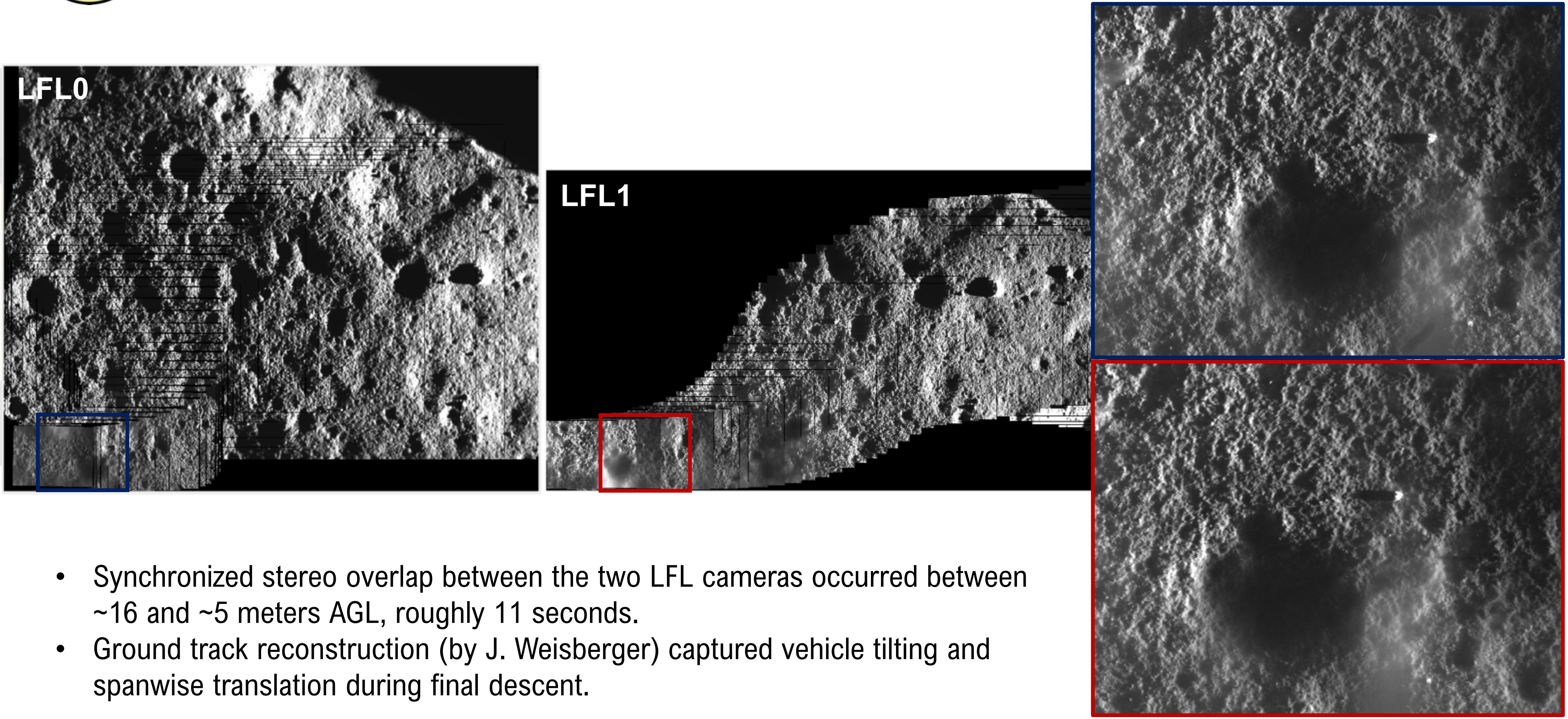
camera mounts (x2 ea.)

Blue Ghost Mission 1

- Launch: January 15th, 2025.
- 45-day transit.
  - SCALPSS successfully completed 4 transit checkout operations.
  - Lunar orbit insertion burn imaging on 02/24/2025.
- Landing: March 2nd, 2025.
  - LFL cameras captured at 10 fps from 50 m AGL until 5 m AGL.
  - SFL cameras captured at 8 fps from 30 m above ground level (AGL) until TD+10 seconds.
- Surface Mission: March 2nd – 16th, 2025.
  - High dynamic range (HDR) image captures on an hourly basis.
  - Image captures before/during/after sister CLPS payload operations.
  - Pause in payload operations from 03/04 – 03/14 due to elevated temperatures through lunar noon.
  - Lunar eclipse operations 03/14/2025 (limited).
  - Sunset operations 03/16/2025.

SCALPSS 1.1 *(CLPS 19D – Firefly Aerospace BGM1)*

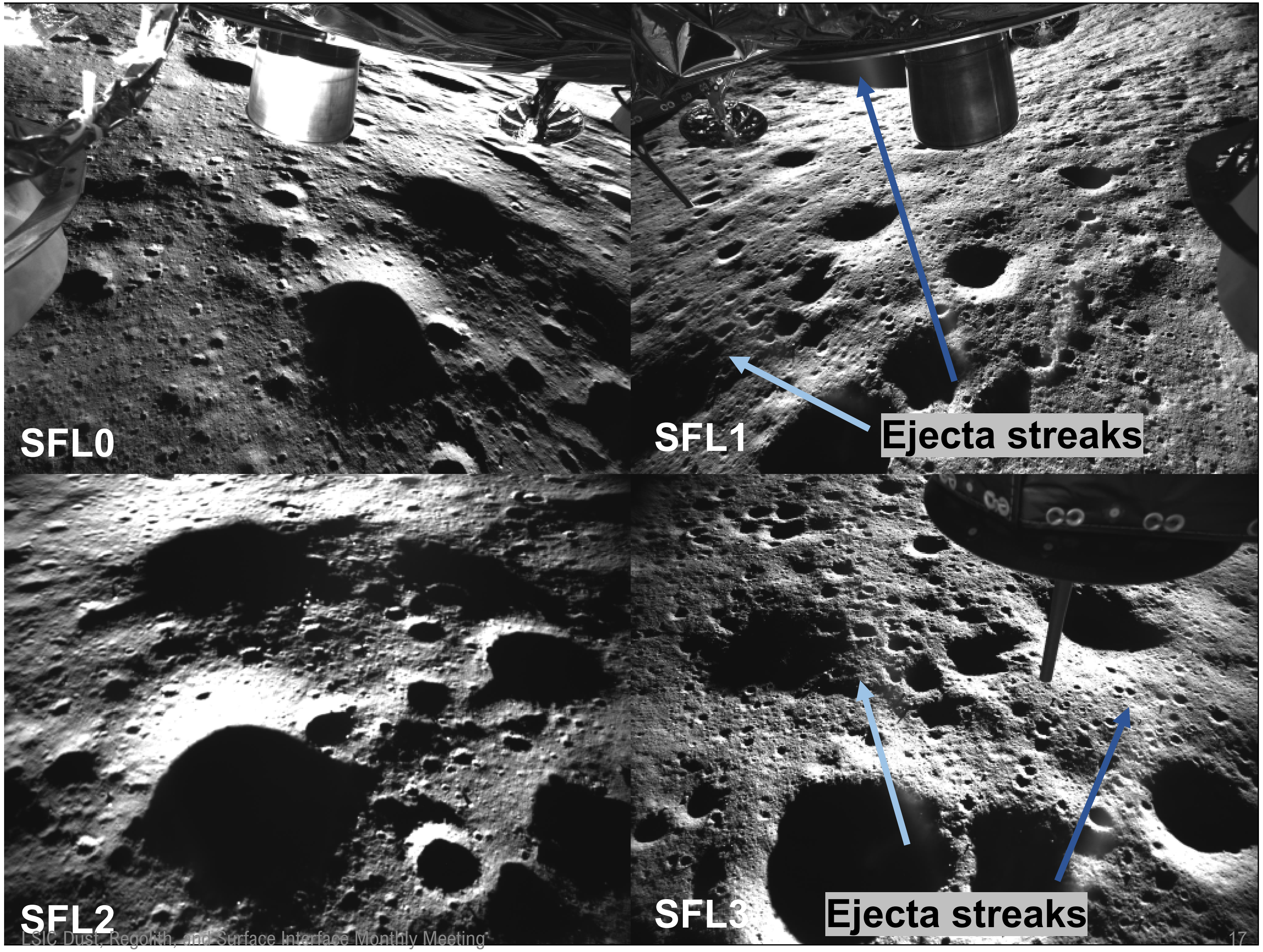
SCALPSS 1.1 LFL Descent Data



- Synchronized stereo overlap between the two LFL cameras occurred between ~16 and ~5 meters AGL, roughly 11 seconds.
- Ground track reconstruction (by J. Weisberger) captured vehicle tilting and spanwise translation during final descent.

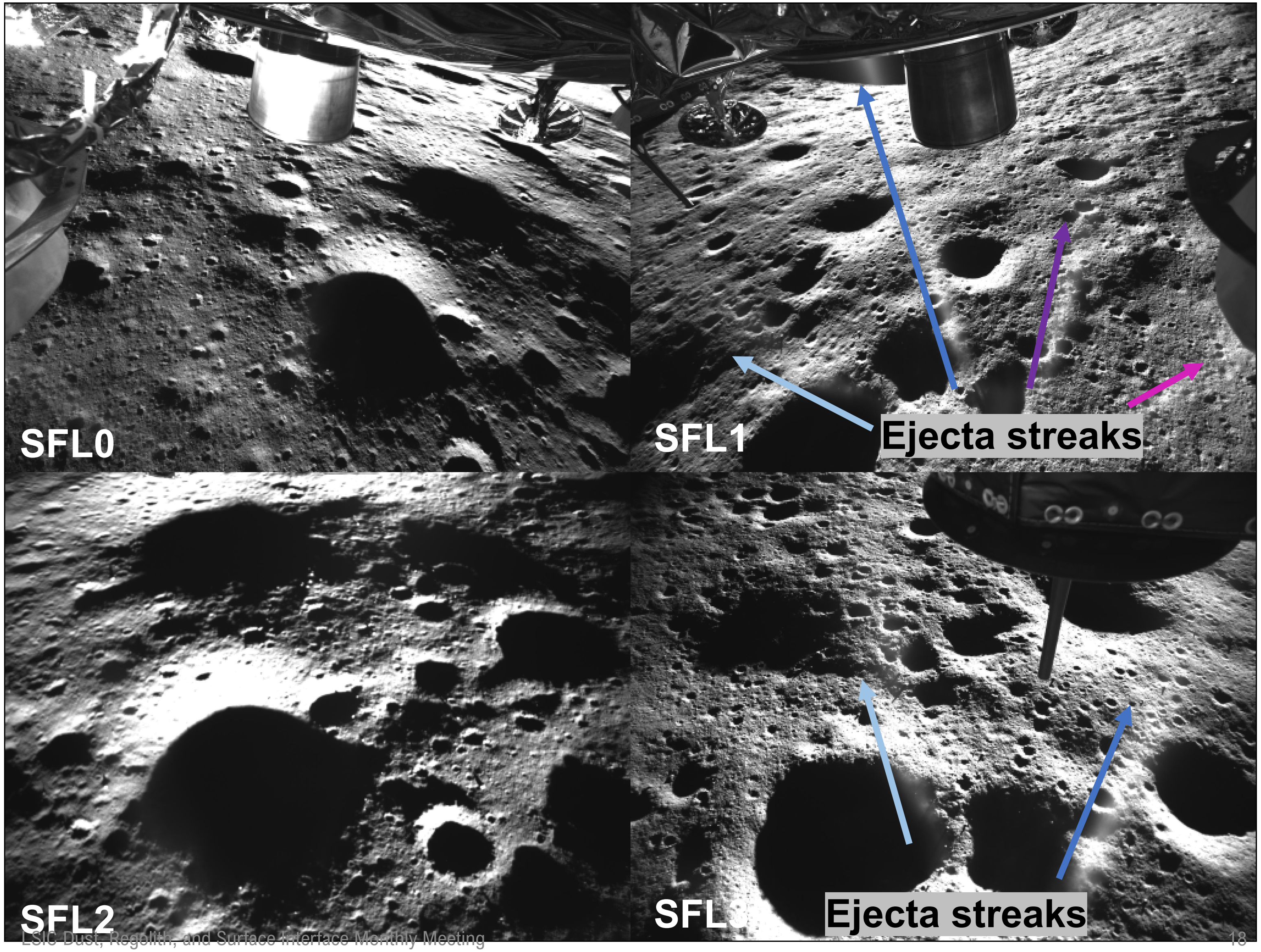
SCALPSS 1.1 SFL Descent: onset of dust movement

Altitude ≈ 17.3 m AGL
Time to TD ≈ 20.1 s



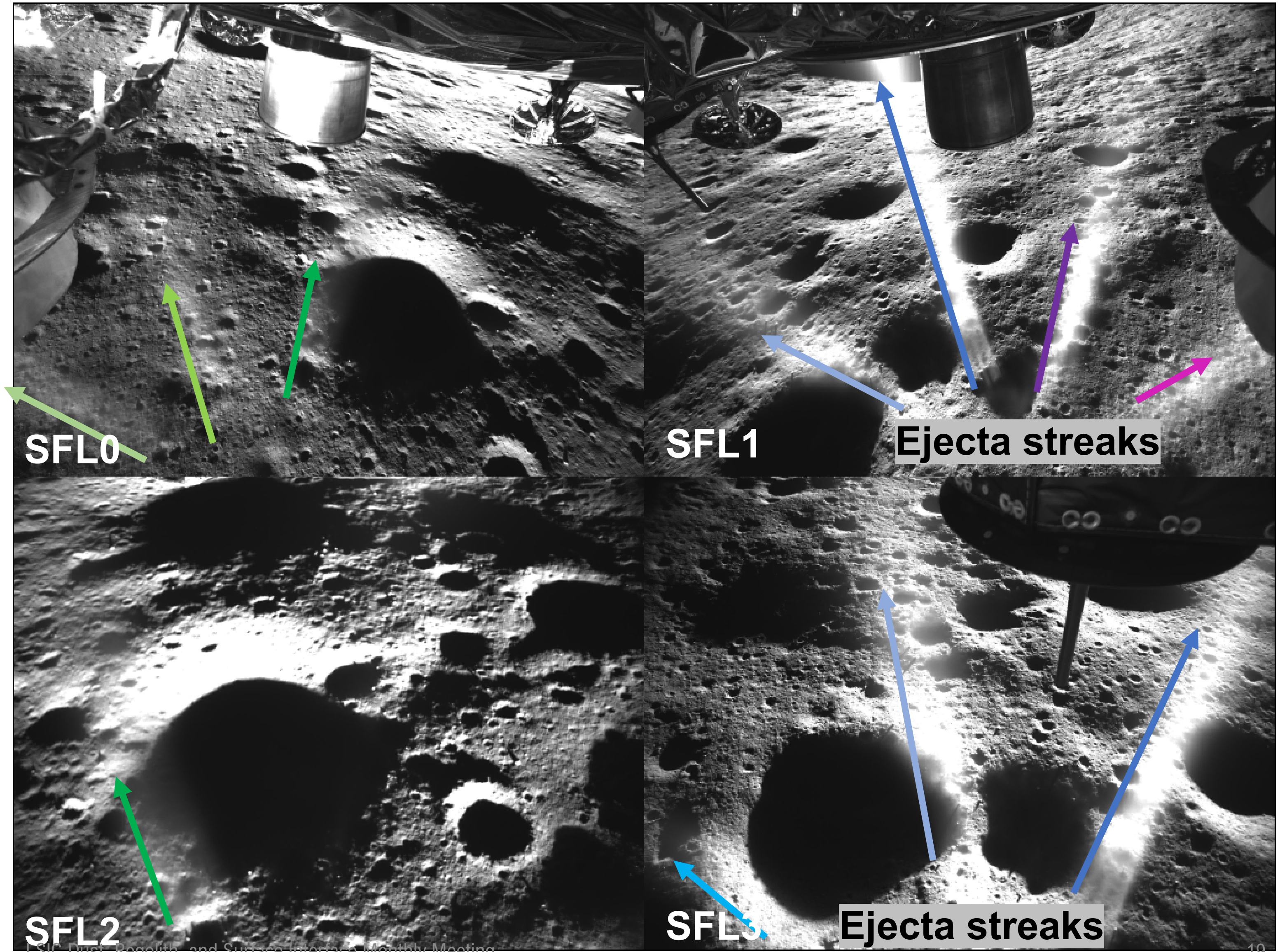
SCALPSS 1.1 SFL Descent: onset of dust movement

Altitude ≈ 16.2 m AGL
Time to TD ≈ 19.2 s



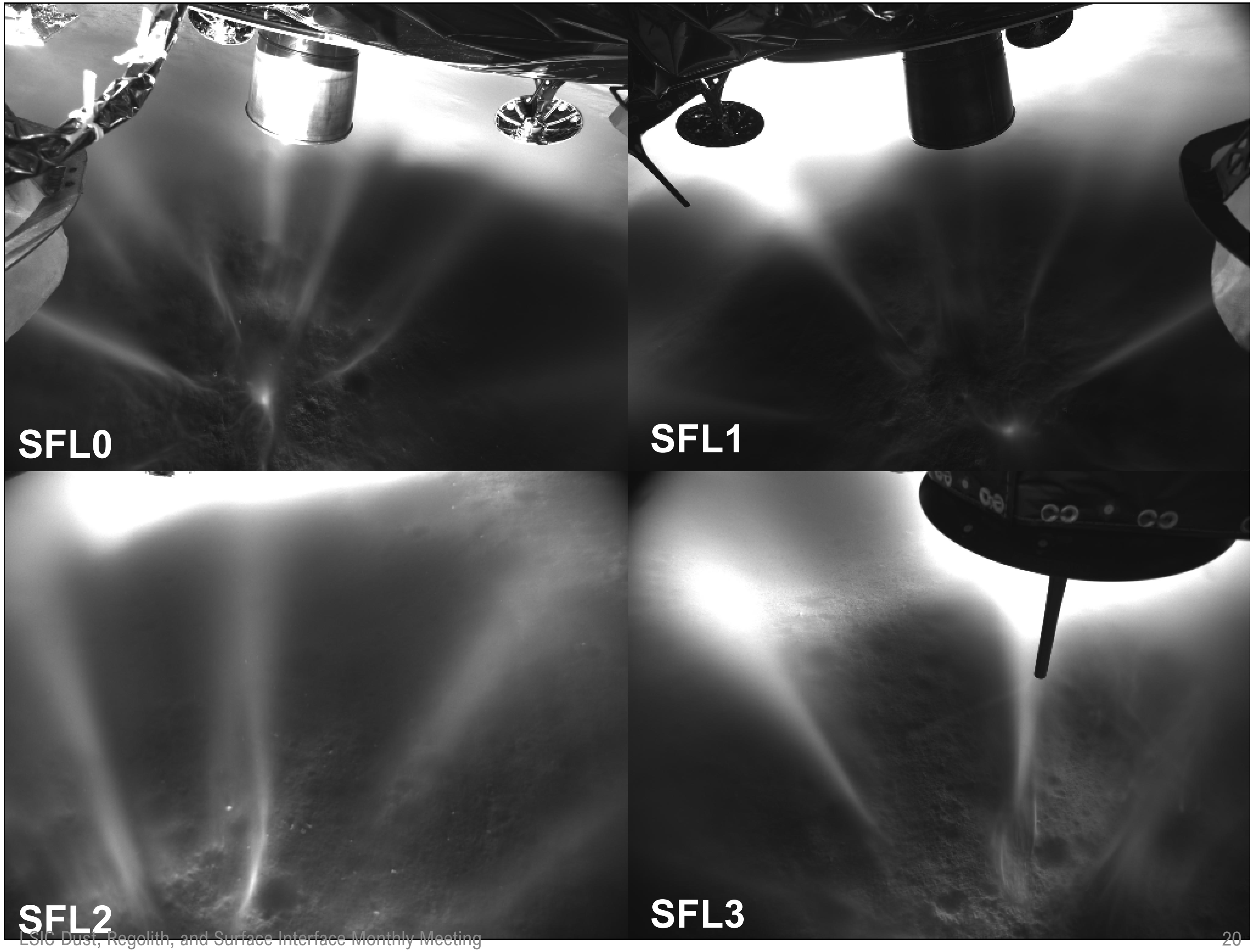
SCALPSS 1.1 SFL Descent: onset of dust movement

Altitude ≈ 14.1 m AGL
Time to TD ≈ 17.5 s



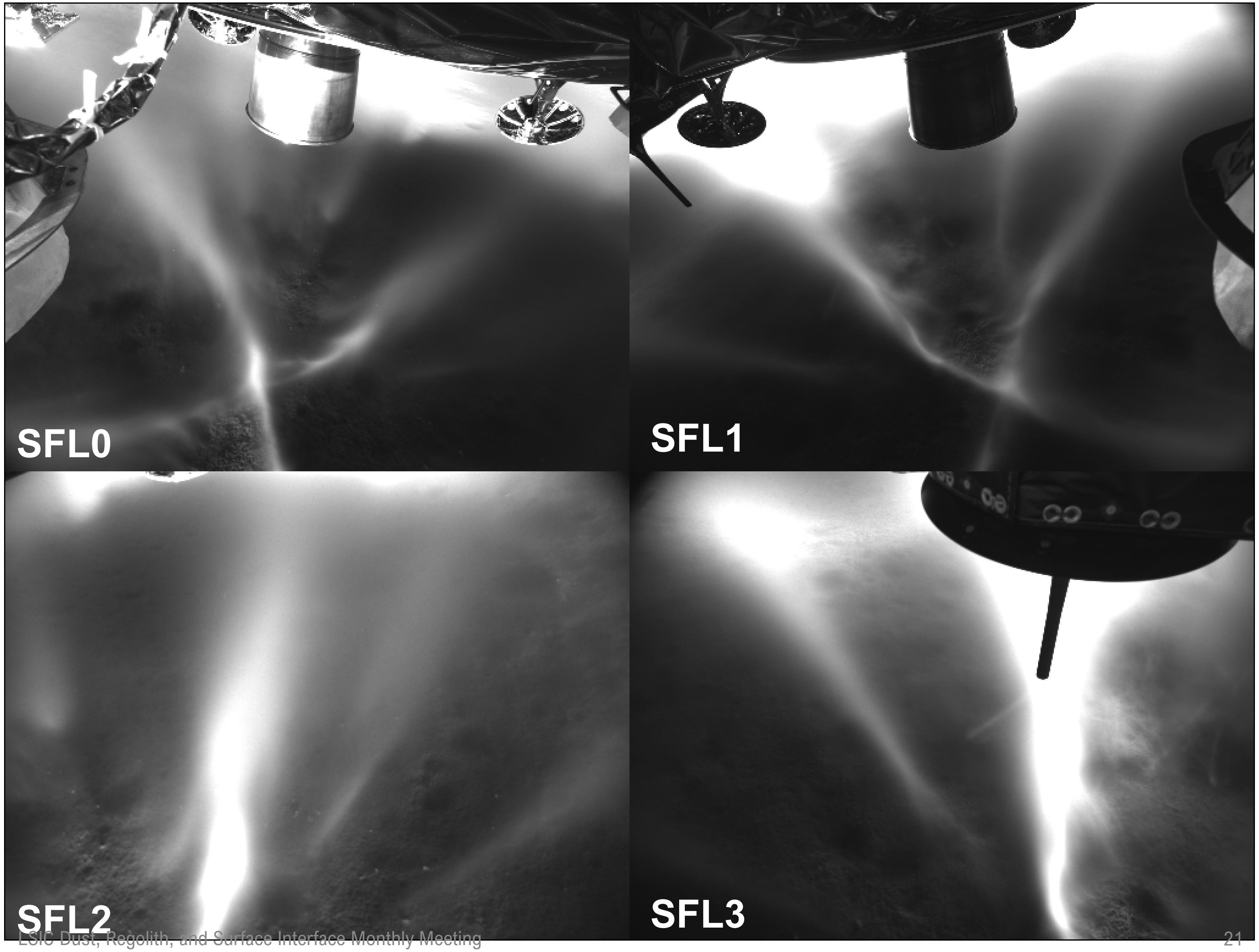
SCALPSS 1.1 SFL Descent: Multiple-jet interaction

Altitude ≈ 5.1 m AGL
Time to TD ≈ 8.5 s



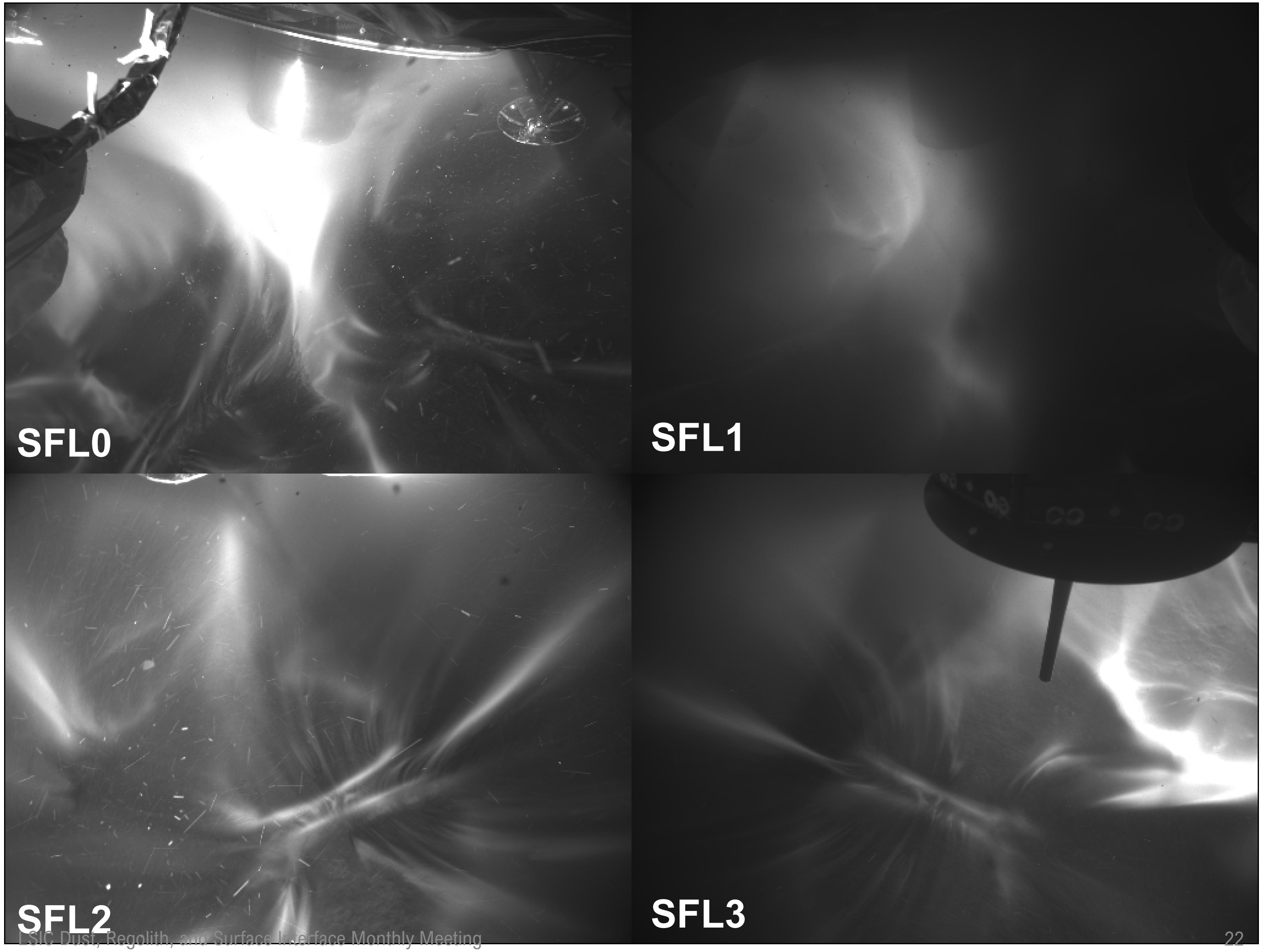
SCALPSS 1.1 SFL Descent: Multiple-jet interaction

Altitude ≈ 3.9 m AGL
Time to TD ≈ 7.4 s



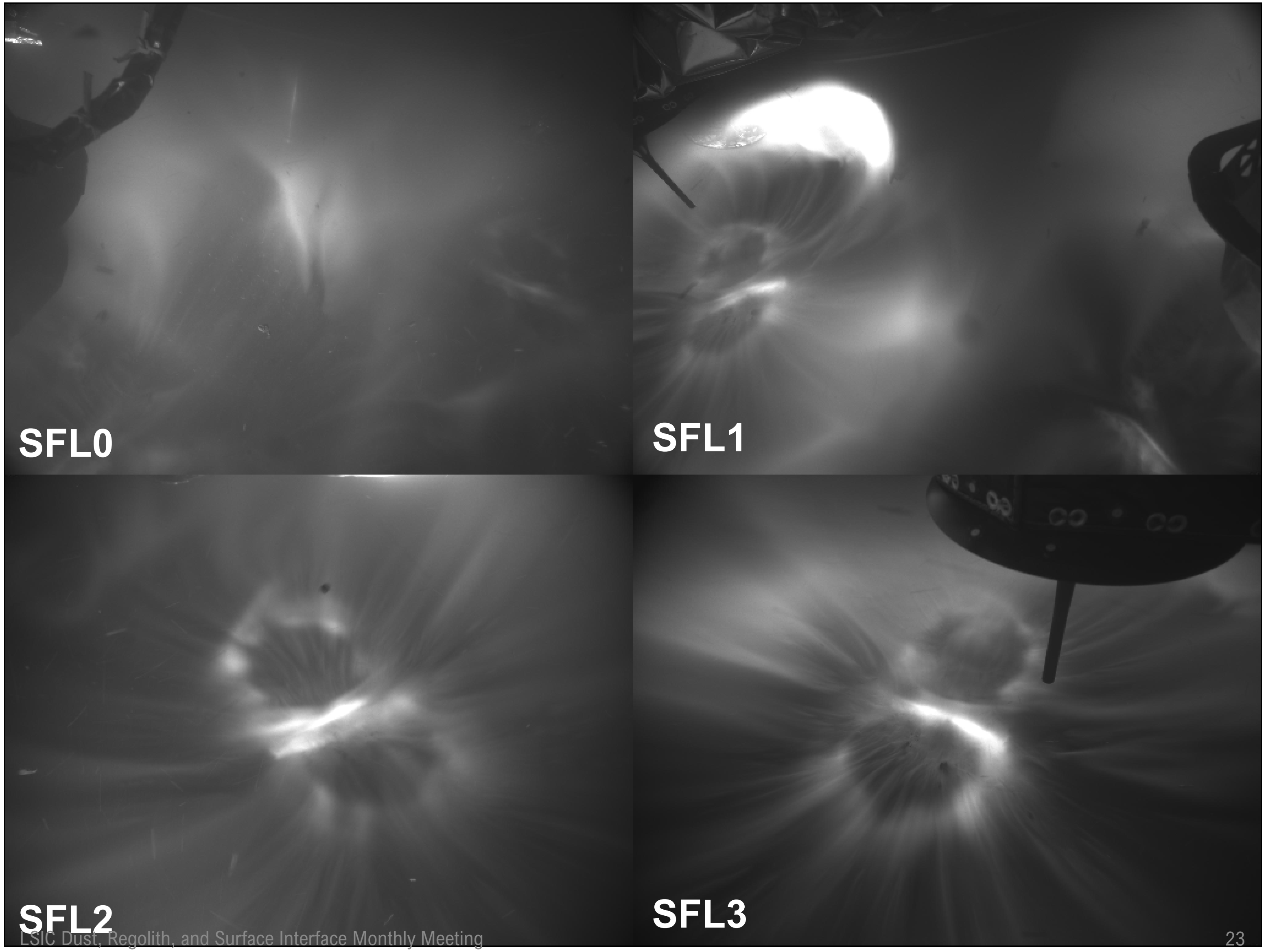
SCALPSS 1.1 SFL Descent: Particle motion

Altitude ≈ 1.3 m AGL
Time to TD ≈ 4.5 s



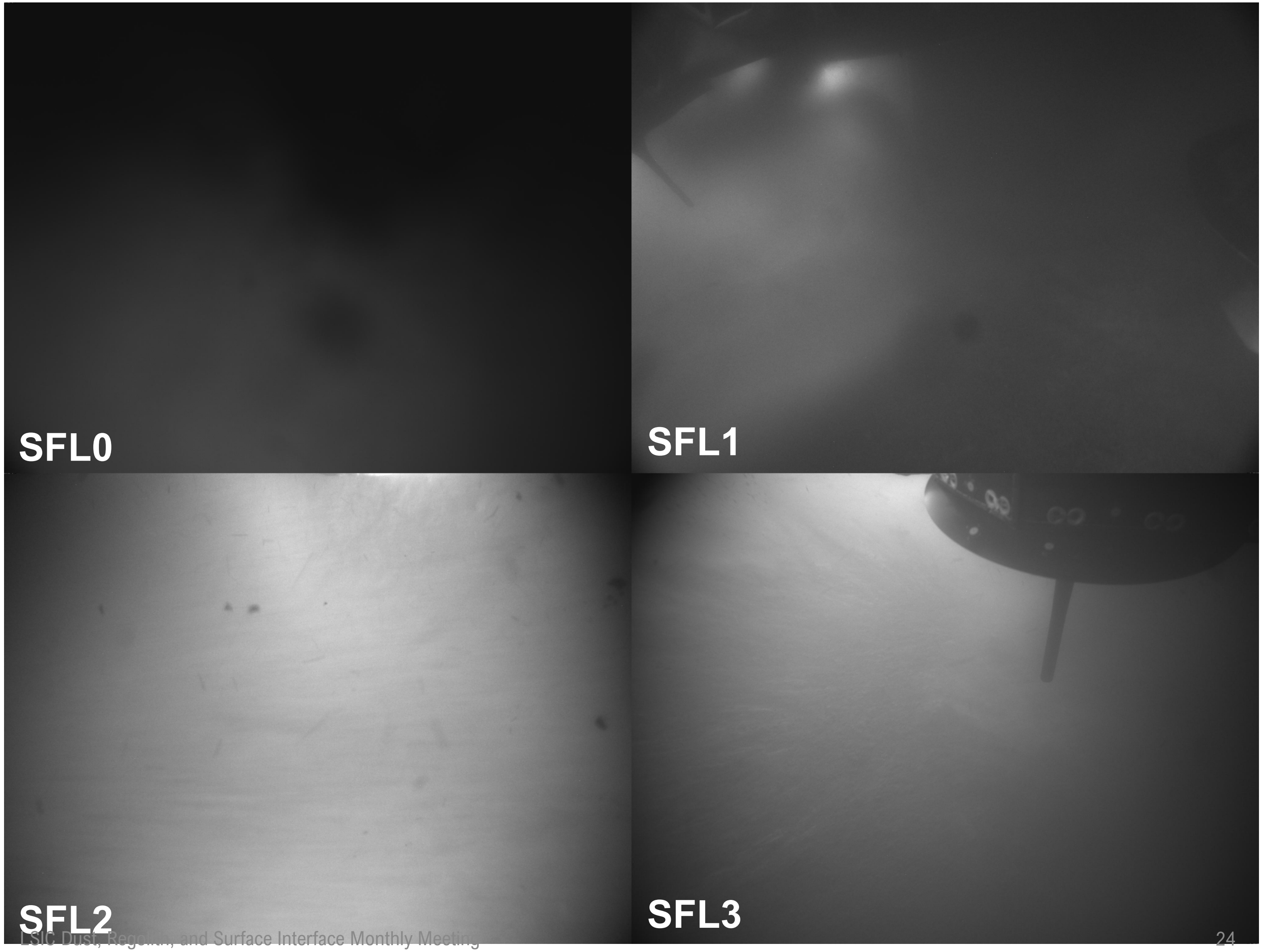
SCALPSS 1.1 SFL Descent: Plume Impingement

Altitude ≈ 0.7 m AGL
Time to TD ≈ 3.5 s



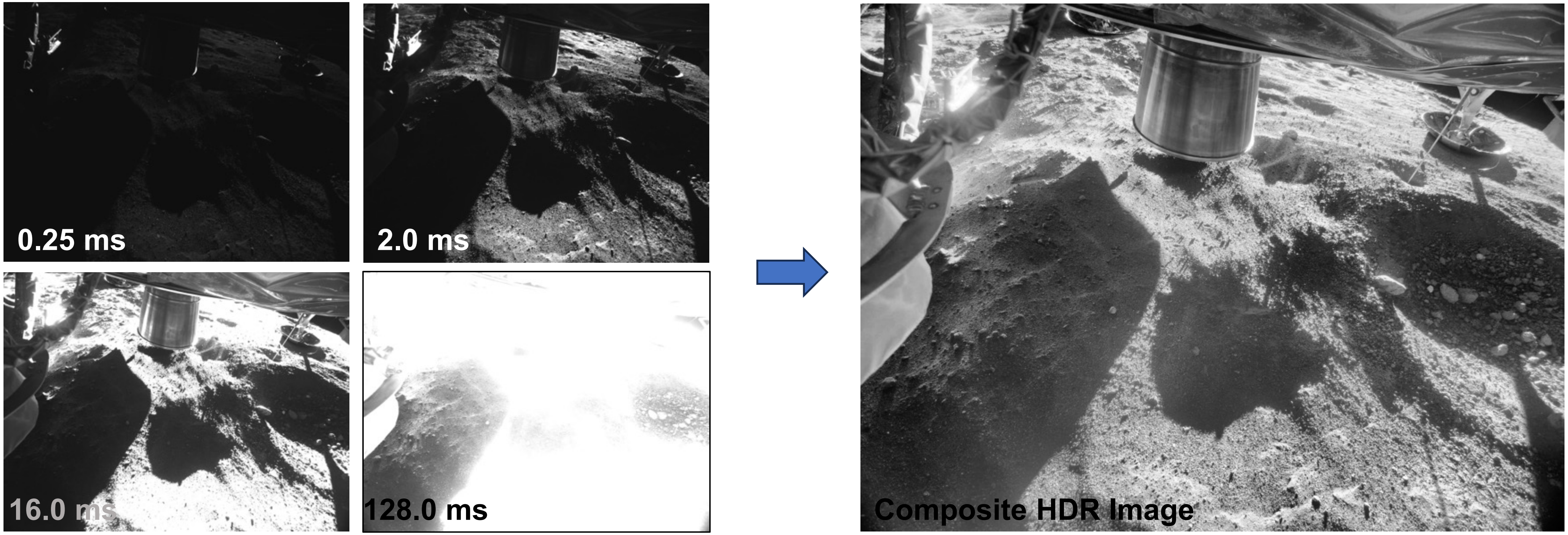
SCALPSS 1.1 SFL Descent: Touchdown & Dust Settling

- Dust partially coated camera lenses during touchdown.
- After touchdown, the payload entered surface mode, where images were taken with fixed exposures to create high dynamic range (HDR) composite images.



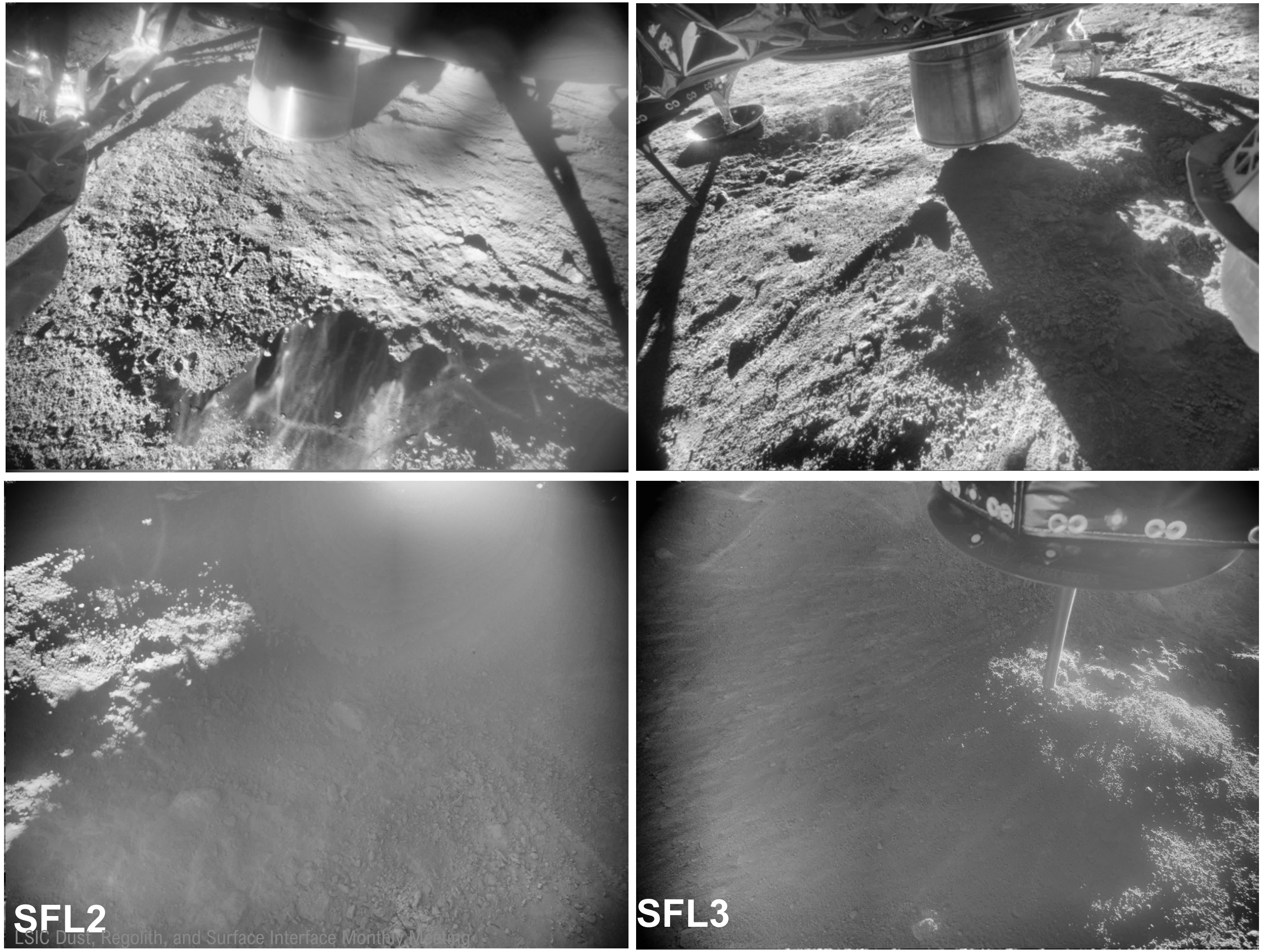
SCALPSS 1.1 Surface Operations: High Dynamic Range

- HDR settings chosen pre-flight:
  - Exposures of 0.25, 2.0, 16.0, 128.0 milliseconds.

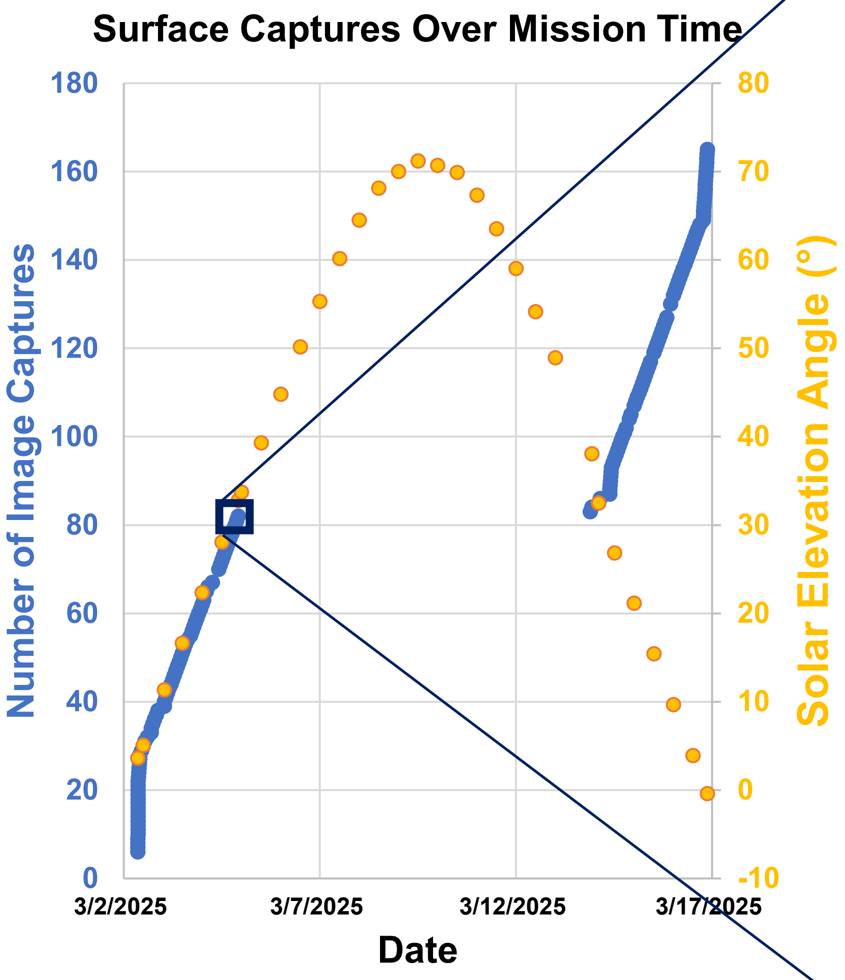


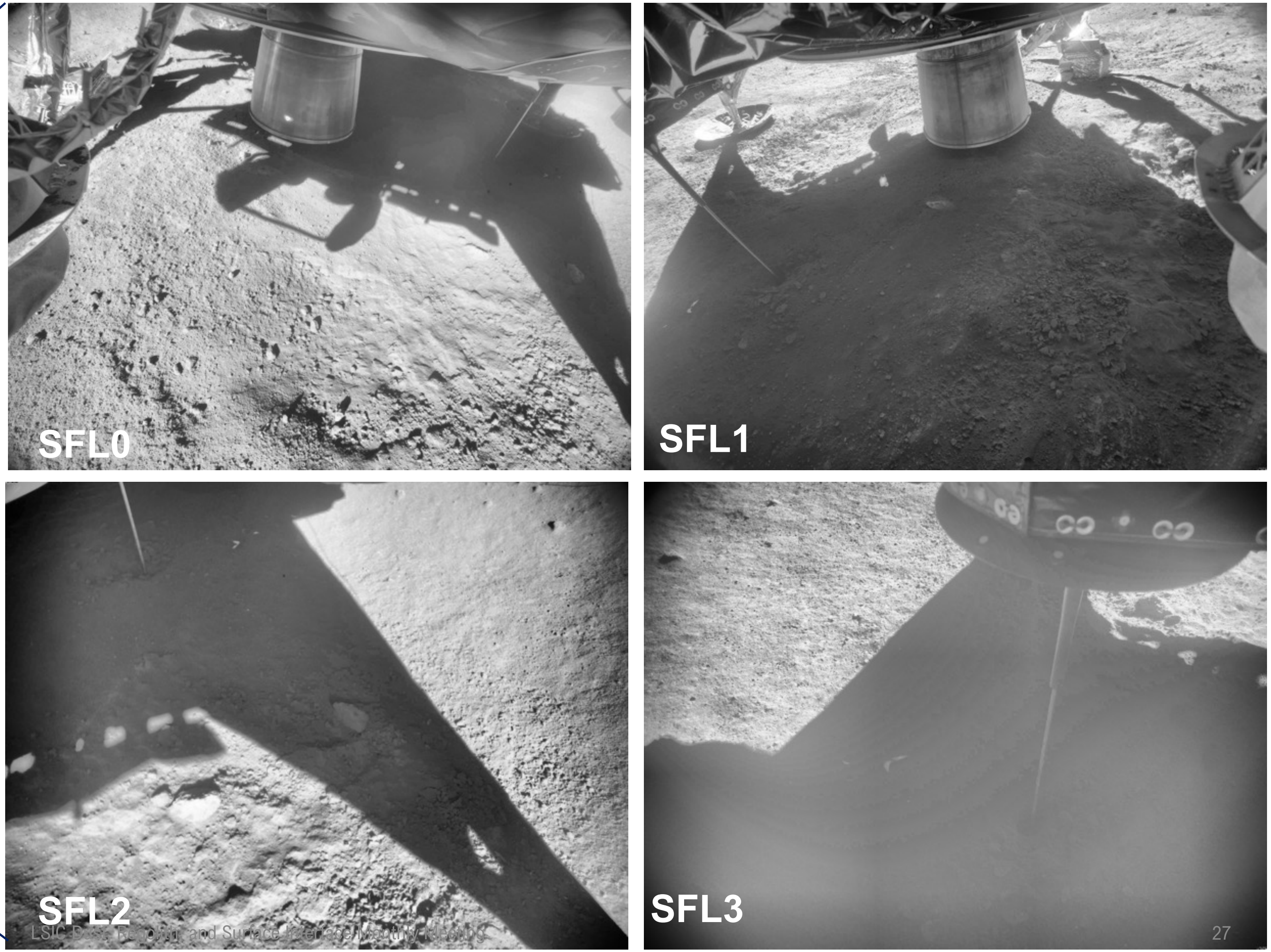
SCALPSS 1.1 Surface Timelapse: TD+21 hours

- More terrain features revealed as Sun traversed through the sky.
- Shadow edge tracking provides easy-to-correlate features.
- Terrain changes due to other payload operations observed.
- After first LPV operation, lenses appear to have been “dusted off” (TD+22 hours).

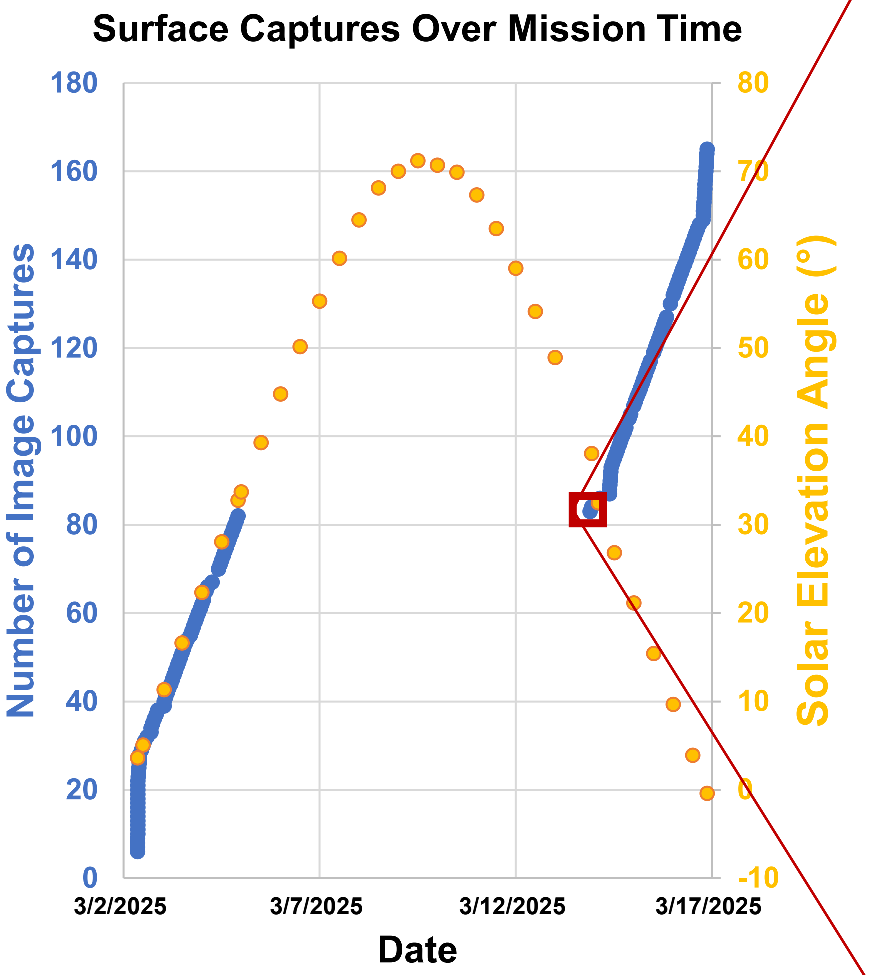


SCALPSS 1.1 Extended Operations



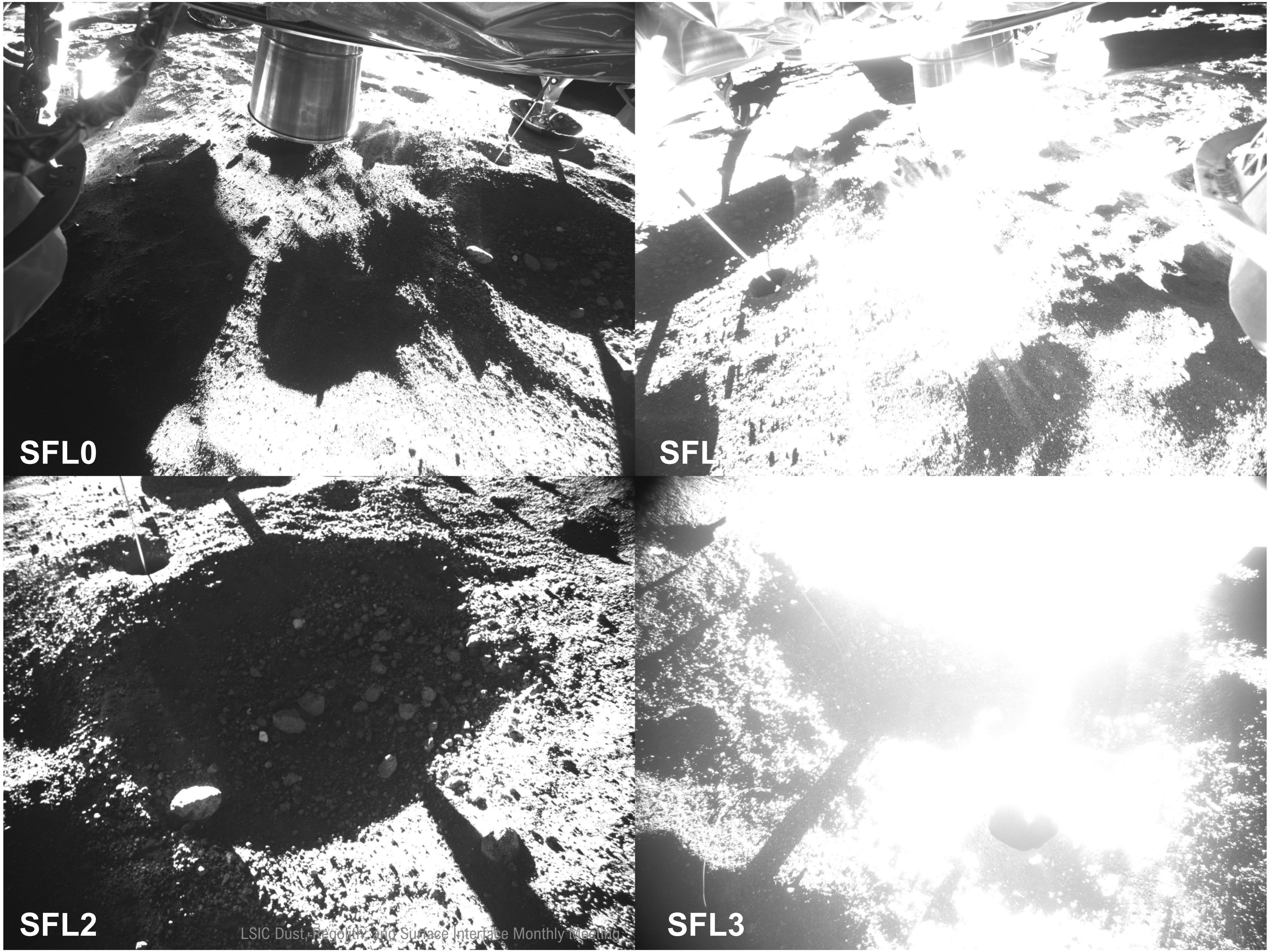


SCALPSS 1.1 Extended Operations



Sunset

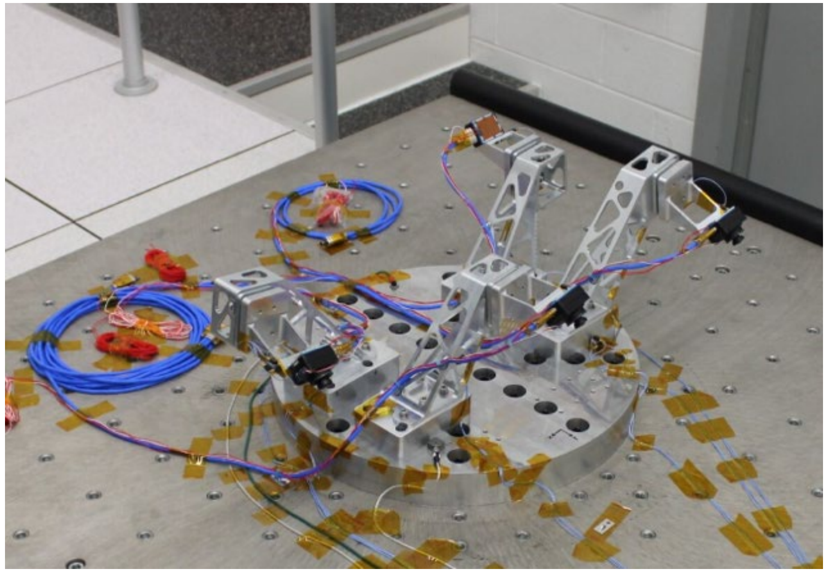
- Local sunset: 03/16/2025, 19:38 UTC.
- SCALPSS performed captures every 10 minutes during sunset.
- Long exposure settings used to capture terrain with waning illumination.



Upcoming Flight Opportunities for SCALPSS 1.x

- SCALPSS 1.x will be the sole NASA payload onboard the Blue Origin MK1-SN101 first demo flight to the Lunar South Pole, “Blue Moon MK1 Pathfinder”.
  - 4-camera system focusing on centralized area beneath the main engine.
  - Mission anticipated in late 2025.

MK1 Lunar Lander
Image credit: Blue Origin

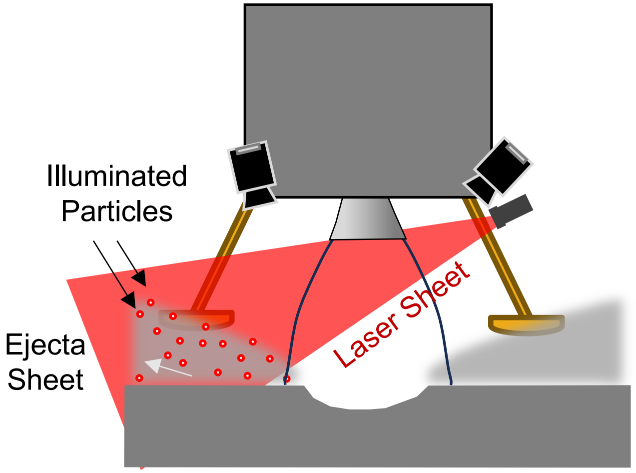


SCALPSS 1.X System at Vibration Testing

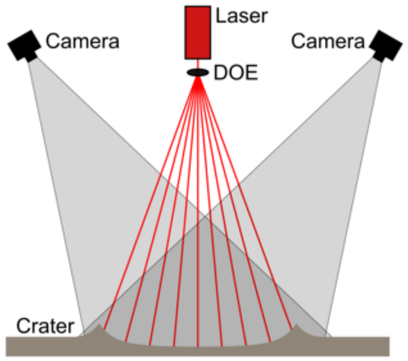
Upcoming Flight Opportunities for SCALPSS 2.0

- SCALPSS 2.0 is currently under development for future CLPS flights (CS-6 and CT-4).
  - Improved custom avionics to support ethernet cameras, lasers and more.
  - Higher resolution and/or increased FOV cameras
  - Plans to include an illumination system and improved camera resolution for enhanced measurement capabilities.

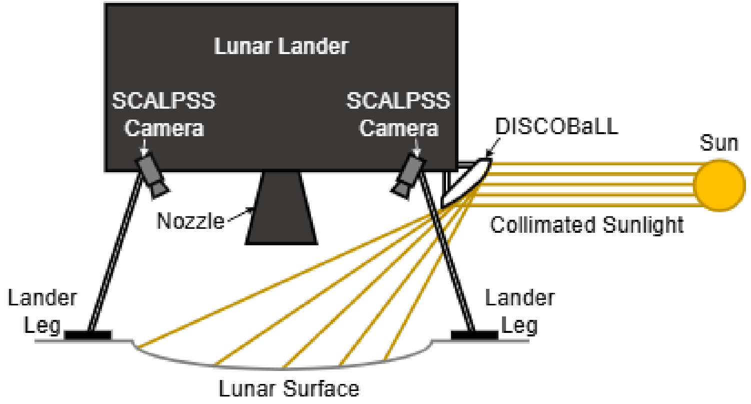
Mini-Suite Electronics LITE (R. Lueg)



Laser Sheet Illumination



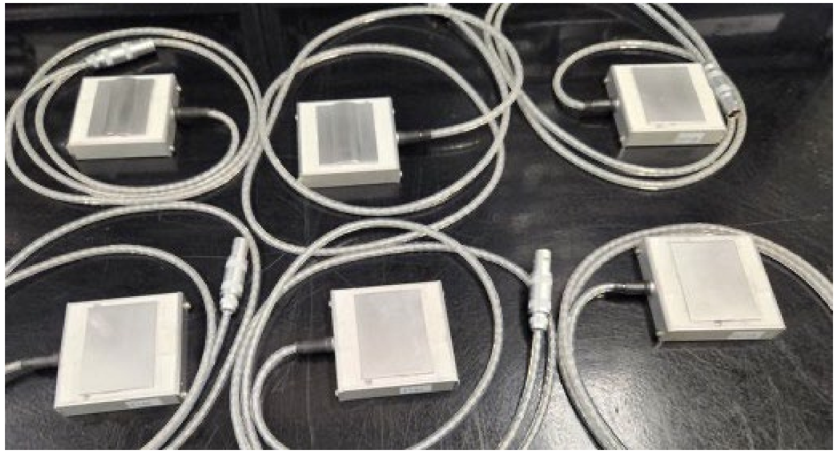
Laser dot projection
(Weisberger et al., SciTech 2024)



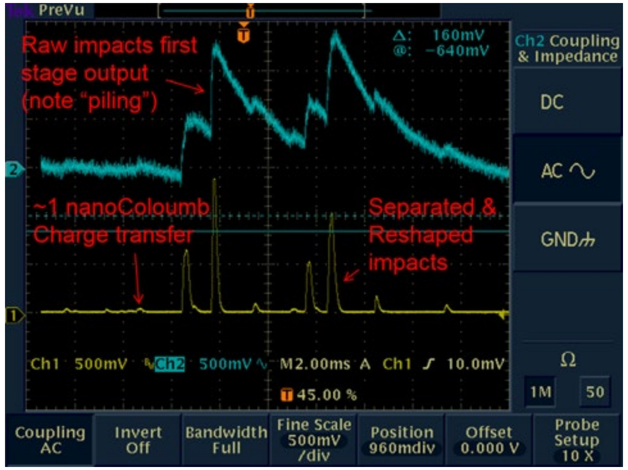
Passive Illumination
(Eshleman et al., SciTech 2025)

SCALPSS Payload Components: Particle Impact Sensor

- During lunar descent, the particle impact detector captures both the relative time between particle impact events and the event magnitudes to determine the energy and flux of the plume ejecta (at ~100 kHz).
- Data can be used to validate computational particle transport models on the moon (with a specific emphasis on the effects caused by PSI).
- The sensor utilizes a single piezoelectric sensor that is enabled with logarithmic data processing for a range of particle energies (multiple velocities and sizes).
  - Similar sensor / technology developed for saltation sensor applications at Mars.
  - Each particle impact with the piezo sensor generates a charge which “piles” with the charges from subsequent impacts.
  - A gaussian shaper circuit separates the signals from multiple impacts into easily identifiable gaussian pulses whose amplitude is representative of the impact energy.
  - The sensor and electronics can be tailored to accommodate the high flux rates and high energy levels during a PSI experiment.

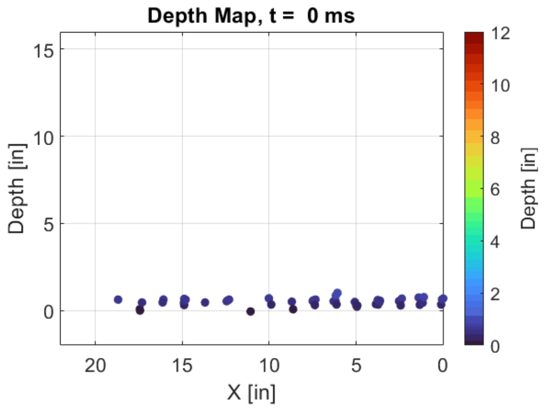


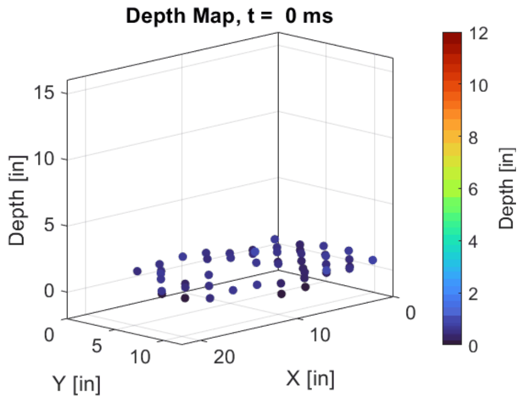
Prototype sensors (2 curved front & back, 2 flat front, curved back, 2 flat front & back)

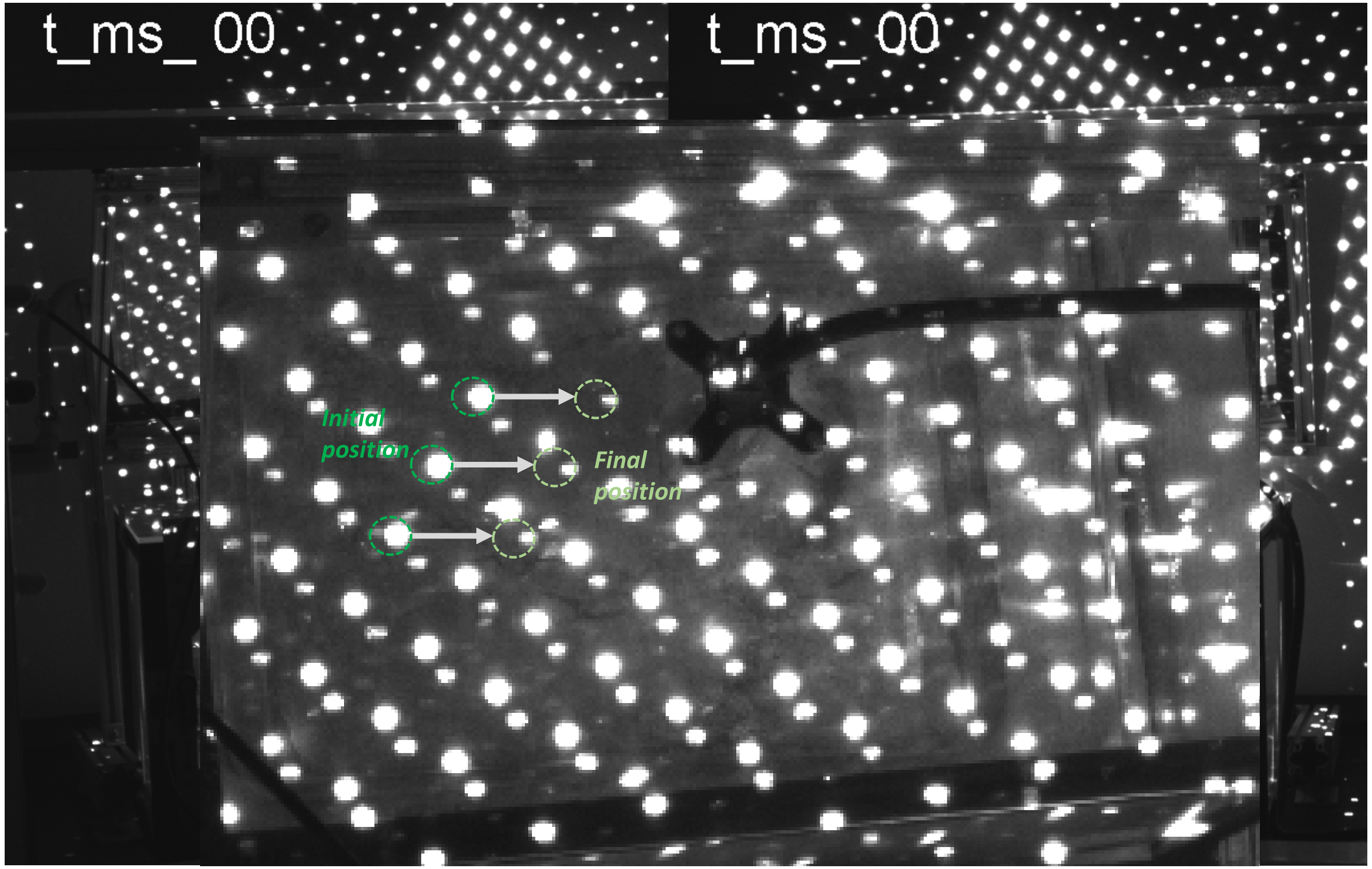


Impact sensor scope trace of sand impacts from 1 cm height

Laser Dot Projection Illumination Lab Demo

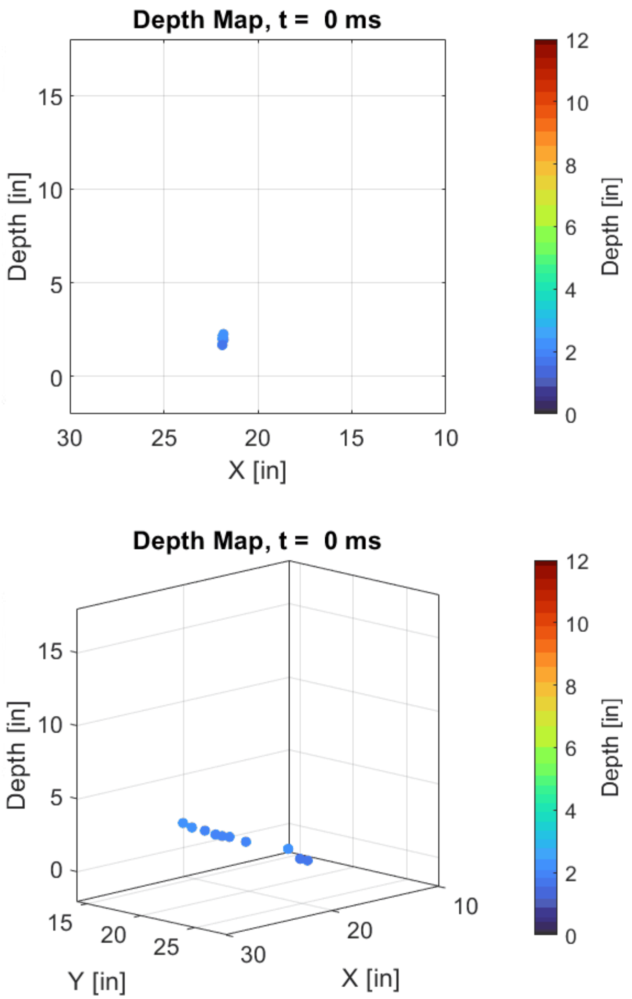


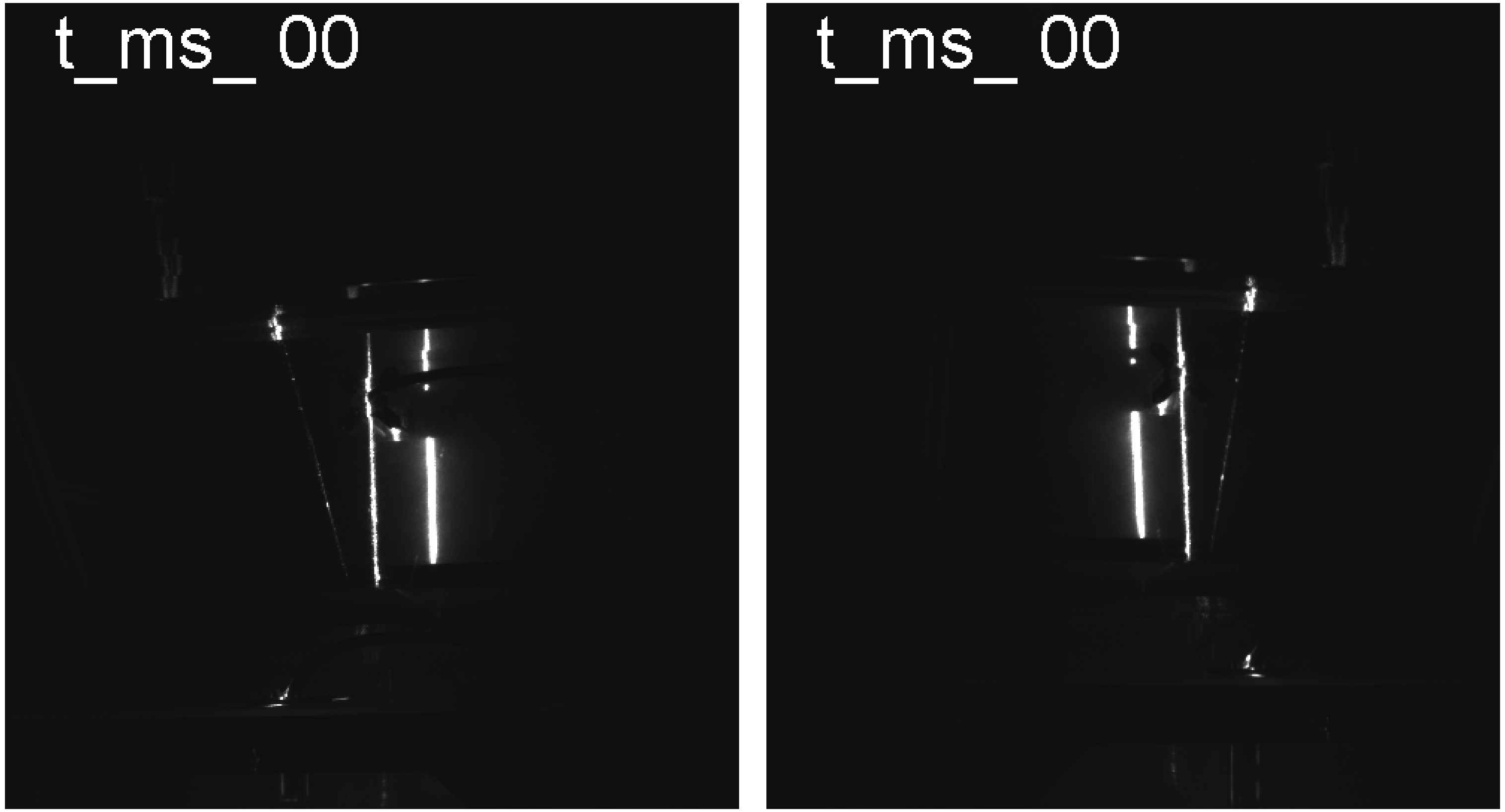




Data processed using manual point matching and centroid/feature detection.

Laser Sheet Illumination Lab Demo

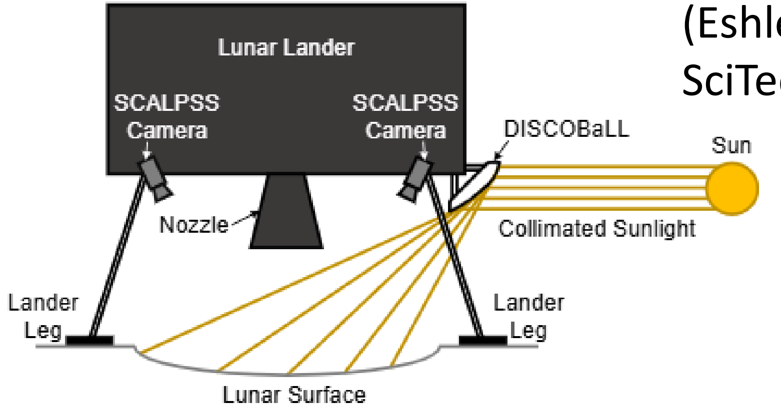




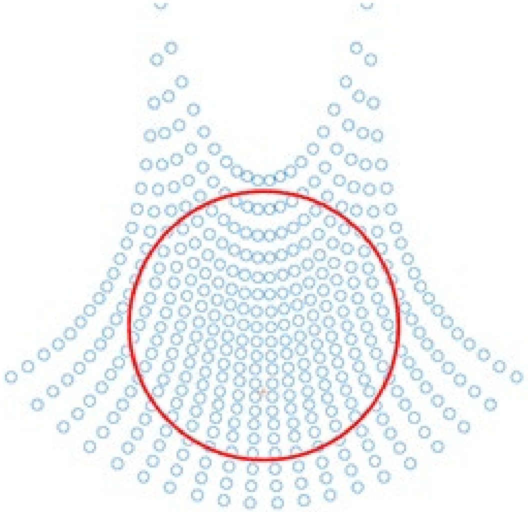
Data processed using manual feature selection and matching.

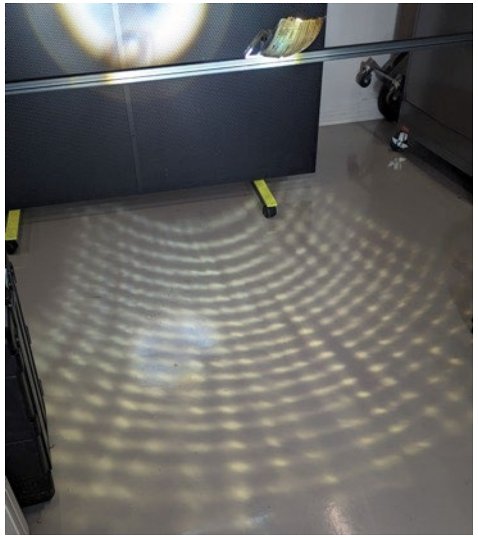
Directed Illumination of Sunlight Collimated and Observed Beneath a Lunar Lander (DISCOBaLL)

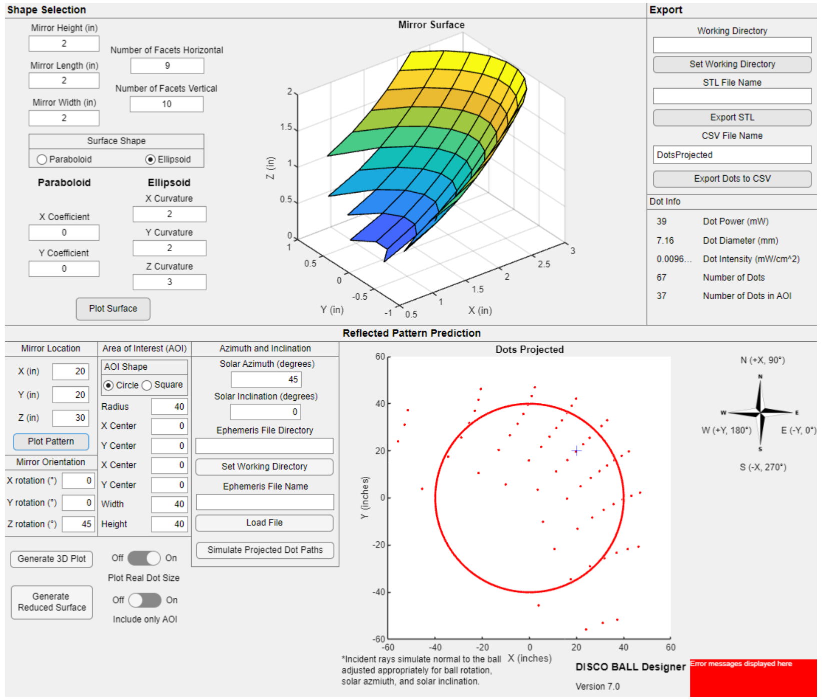
- Passive (solar), patterned illumination of landing site. No laser. Low SWAP.
  - Photogrammetry
  - Ejecta sheet visualization
- Developed simulation tool and multiple prototypes for lab testing.



(Eshleman, SciTech 2024)







DISCOBaLL Prototype V 2.0 Lab Demo

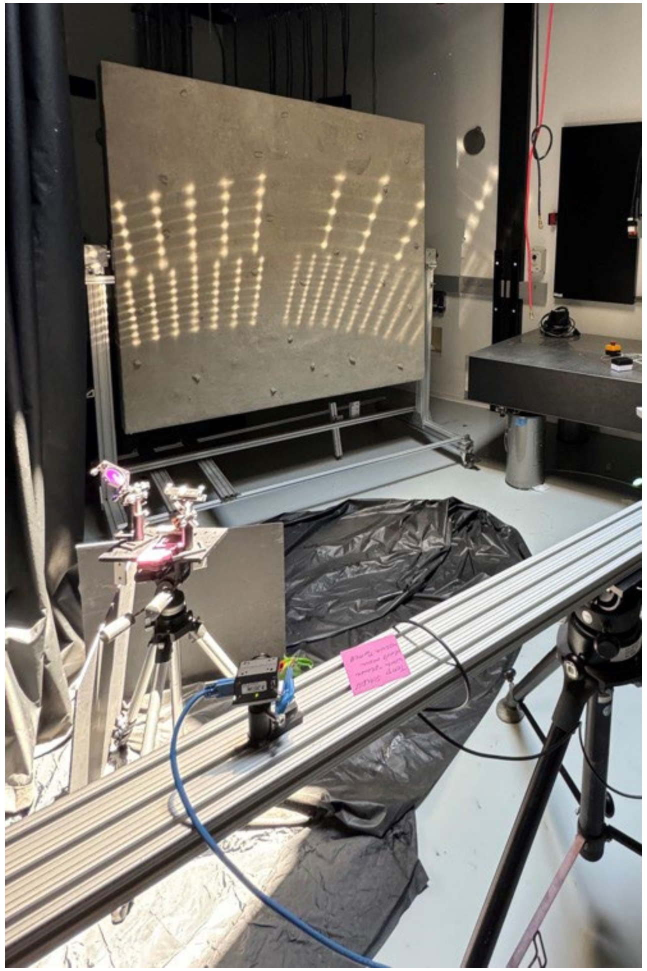
3 x 3 mm Facets

2 x 2 mm Facets

4 x 4 mm Facets

5 x 5 mm Facets

DISCOBaLL prototype V 2.0



Skylight in MSL penthouse

Conclusions

- SCALPSS 1.1: Successful Mission on Firefly Blue Ghost Mission 1 Landing
  - Data processing still in work.
- SCALPSS 1.x: Payload shipped to Blue Origin with integration to the lander upcoming (August) and launch expected later this year.
- SCALPSS 2.0:
  - Manifested for CLPS CS-6 and CT-4
  - New Electronics
  - Faster, higher-resolution, increased FOV cameras
  - Laboratory work under development for laser-dots, laser-sheet, and DISCOBaLL
  - Additional impact energy measurement using PIE
  - Science goals include estimating erosion volume and ejecta sheet characteristics
  - Stretch science goals: Particle size, velocity, concentration, real-time altimeter (no laser)

Additional Questions?

SCALPSS Payload Evolution

	SCALPSS 1.0 **Intuitive Machines IM-1 (CLPS TO#2): Q1 CY2024**	**SCALPSS 1.1** **Firefly BGM1 (CLPS 19D): Q1 CY2025**	**SCALPSS 1.x** **Blue Origin Mk-101 (CLPS CT-3): Q4 CY2025**	**SCALPSS 2.0** **CLPS CS-6 & CT-4: CY2029 target**

Measurement Objectives	• Capture post-landing 3D site alteration morphology
	  - Measure crater depth/size and erosion volume
	• *Capture pre-PSI (2D) landing topography*
	• *Detect PSI onset*
	• *Record transient site alteration morphology*
	• *Measure ground obscuration (onset and extent)*
	• *Measure dust settling density as a function of time*
	
	Primary objective
	Secondary objective
		• Capture post-landing 3D site alteration morphology
		  - Measure crater depth/size and erosion volume
		• **Capture pre-PSI 3D landing site morphology**
		• **Detect PSI onset**
		• **Record transient site alteration morphology**
		• *Measure ground obscuration (onset and extent)*
		• *Measure dust settling density as a function of time*
		
		New primary objective
		New secondary objective
			• Capture post-landing 3D site alteration morphology
			  - Measure crater depth/size and erosion volume
			• *Capture pre-PSI (2D) landing topography*
			• *Detect PSI onset*
			• *Record transient site alteration morphology*
			• *Measure ground obscuration (onset and extent)*
			• *Measure dust settling density as a function of time*
				• Capture post-landing 3D site alteration morphology
				  - Measure crater depth/size and erosion volume
				  - **improved coverage and/or resolution**
				• Capture pre-PSI 3D landing site morphology
				  - **improved coverage and/or resolution**
				• Detect PSI onset
				• Record transient site alteration morphology
				  - **improved coverage and/or resolution**
				• **Measure ground obscuration (onset and extent)**
				• **Measure ejecta sheet structure**
				  - **Ejecta angles, sheet morphology, energy, energy flux, etc.**
				• ***Measure ejecta particle velocities***
				• ***Measure ejecta particle sizes***
				• *Measure dust settling density as a function of time*

Camera System	• (4) FLIR Chameleon 3 USB (Monochrome)
	  - 3.2 MP, 3.45 μm/pixel
	  - 3.37 mm focal length lens (14 fps descent; NDR post-landing)
	  - Configuration / coverage optimized for post-landing surface imagery
		• (**6**) FLIR Chameleon 3 USB (Monochrome)
		  - 3.2 MP, 3.45 μm/pixel
		  - **(2) 50 mm focal length lenses (10 fps pre-onset and early descent)**
		  - **(2) 5.4 mm focal length lenses (8 fps descent; HDR post-landing)**
		  - (2) 3.37 mm focal length lenses (15 fps descent; HDR post-landing)
		  - Configuration / coverage optimized for **both pre-onset and** post-landing surface imagery
			• (4) FLIR Chameleon 3 USB (Monochrome)
			  - 3.2 MP, 3.45 μm/pixel
			  - 3.37 mm focal length lens (8 fps descent; NDR post-landing)
			  - Configuration / coverage optimized for post-landing surface imagery
				• (6) FLIR **Blackfly S GigE** (Monochrome)
				  - **12.3 MP**, 3.45 μm/pixel
				  - 3.37 – 25 mm focal length lenses (10-14 fps pre-onset and descent; HDR post-landing)
				  - camera/lens trade on-going
				• **Laser projection / active illumination**
				• **(≥2) Particle Impact Event sensors**

Electronics	• Mars 2020 EDLCam Data Storage Unit (DSU) “build-to-print”
	  - (1) USB 3.0 data port to USB Hub to (4) cameras
	  - RS-422 data interface to lander (limited to 3 Mbps)
		• Mars 2020 EDLCam Data Storage Unit (DSU) “build-to-print”
		  - (1) USB 3.0 data port to USB Hub to (4) cameras
		  - **(2) USB 2.0 data ports to (2) cameras**
		  - RS-422 data interface to lander (limited to 3 Mbps)
		• **Utilized full data handling capabilities**
		  - **Limited to 450 MBps write speed to memory**
		
		New to design
		Design limit
			• Mars 2020 EDLCam Data Storage Unit (DSU) “build-to-print”
			  - (1) USB 3.0 data port to USB Hub to (**2**) cameras
			  - (2) USB 2.0 data ports to (2) cameras
			  - RS-422 data interface to lander (limited to 3 Mbps)
				• **Mini-Suite Electronics (MSE-lite)**
				  - **(6) 1 Gbps ethernet ports to up to (6) cameras**
				  - **Improved data interface(s) to lander (100+ Mbps capability), including serial, USB, and LAN**
				  - **Improved data interface(s) to sensors, including serial, USB, and LAN**
				• **Improved data handling capabilities**
				  - **Capable up to 2 GBps write speed to memory**