



NASA Langley Research Center

Efficient and Accurate Terrain Integration & Application to Modeling & Simulation of Planetary Landing Systems

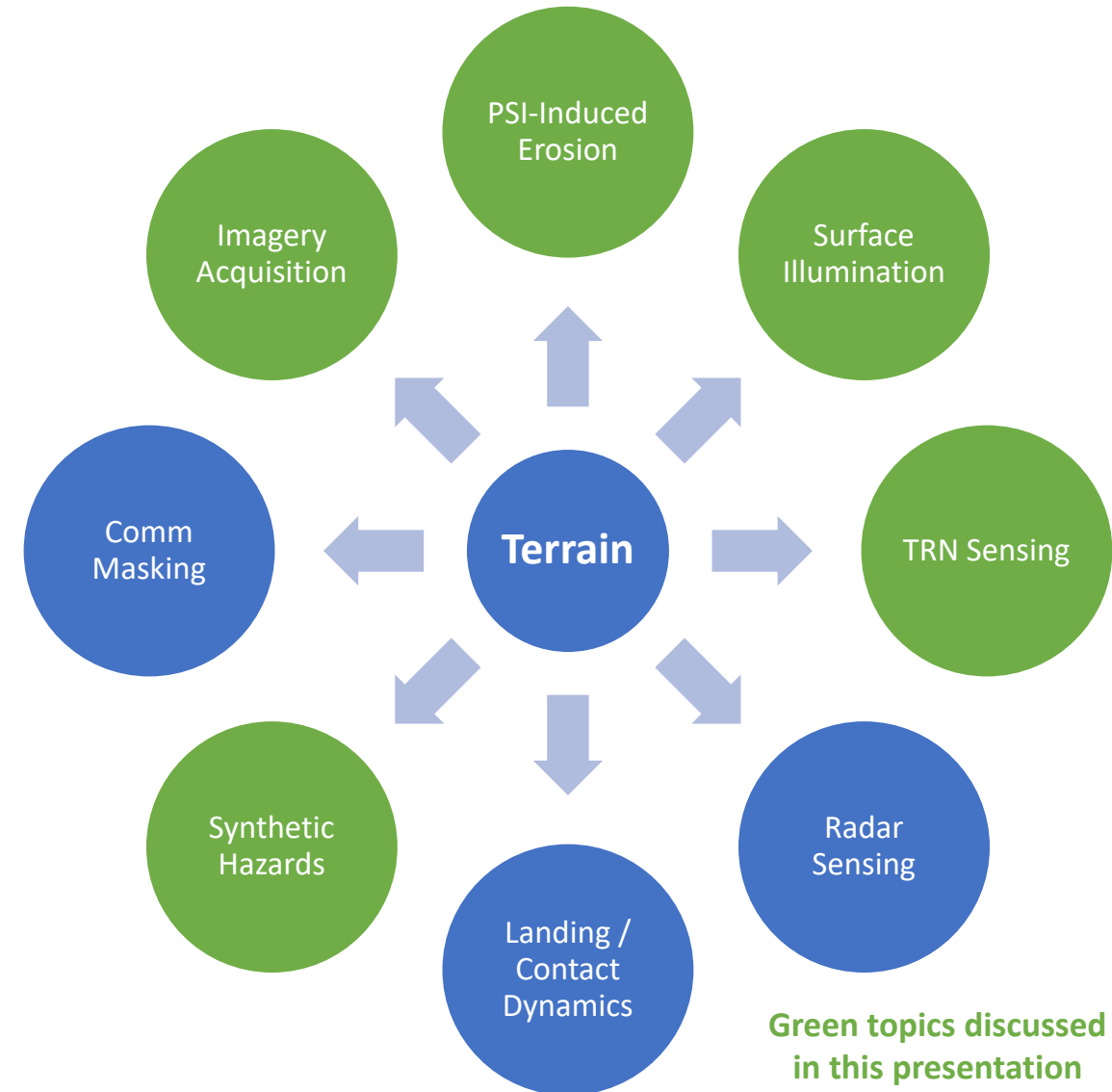
Rafael Lugo, Jeremy Shidner, R. Anthony Williams, and Soumyo Dutta

Atmospheric Flight & Entry Systems Branch (D205)

21st International Planetary Probe Workshop, June 8th-14th, 2024
Williamsburg, VA, USA

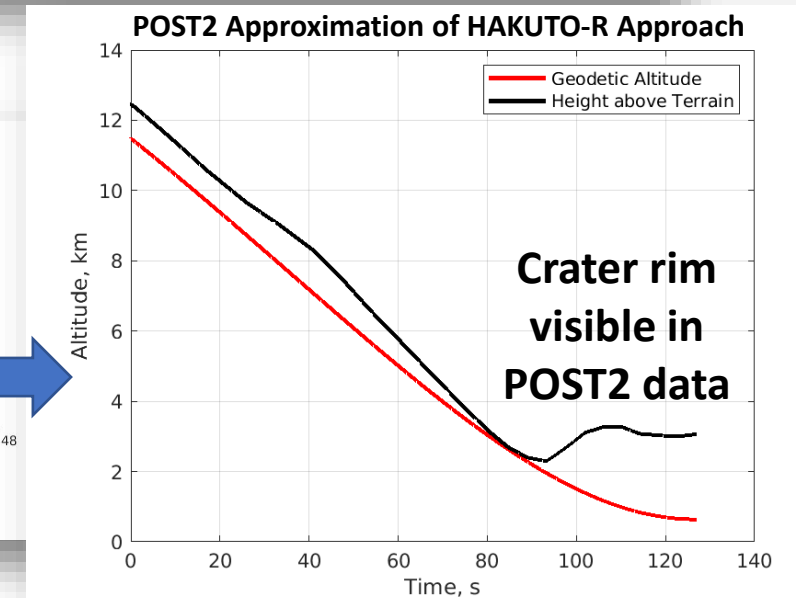
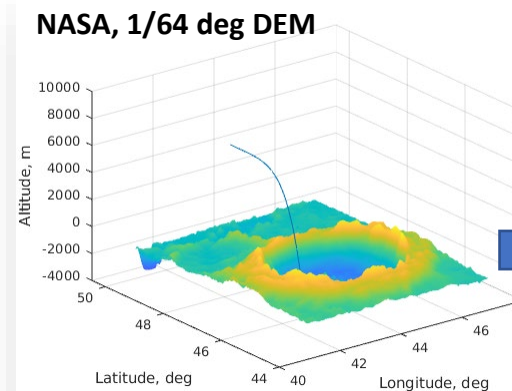
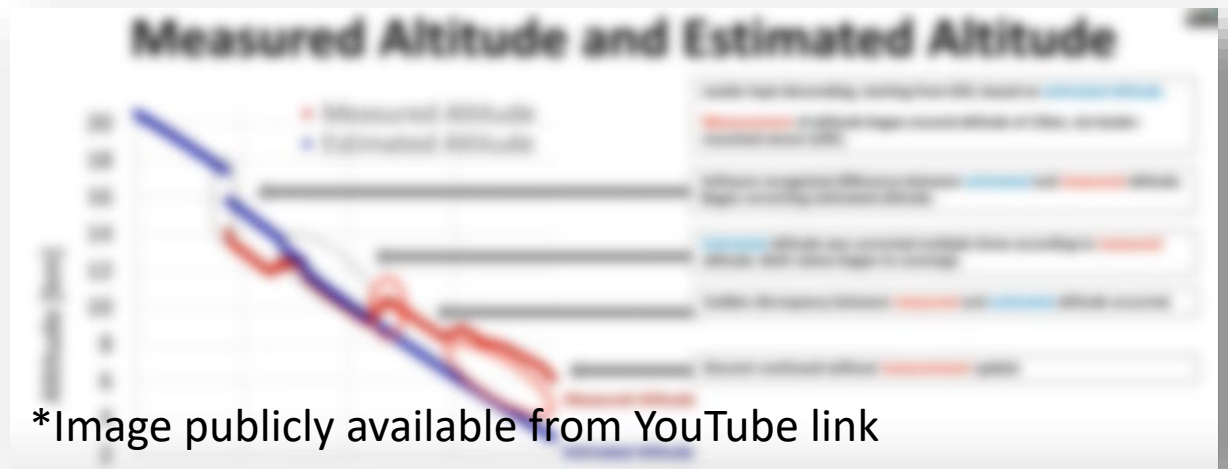
Introduction

- **Deorbit/entry, descent, and landing (D/EDL) systems increase in complexity when considering precision landing and hazard avoidance (PL&HA)**
 - Crewed missions also lead to increased complexity
 - Thus, integrated performance assessments include correspondingly more detailed and complex models
- **Programs such as NASA's Mars landers and Artemis have emphasized the relevance and criticality of planetary terrain modeling**
 - Multiple mission elements require accurate terrain models
 - This makes terrain integration a cross-discipline challenge!



Terrain Integration: Why is it Important?

- [ispace](#) HAKUTO-R Mission 1: April 26th, 2023
 - Measured altitude during powered descent changed abruptly as lander flew over a crater rim, resulting in nav erroneously rejecting subsequent altimeter data
 - Lander then entered vertical descent at 5 km altitude (too high) and ran out of fuel as it descended at 1 m/s
- [ispace](#) **identified** the following contributing factors (to be addressed for Mission 2):
 - Selected site was changed post- Critical Design Review (CDR) and there was insufficient timeline to properly vet/assess the new location
 - Old sites were over essentially flat terrain, new site was in a crater
 - Onboard navigation filter was not properly tuned to account for the significant change in terrain variation
 - Simulation & analysis of the new trajectories did not include detailed terrain models due to computational limitations
- **NASA quick look corroborated crater elevations**

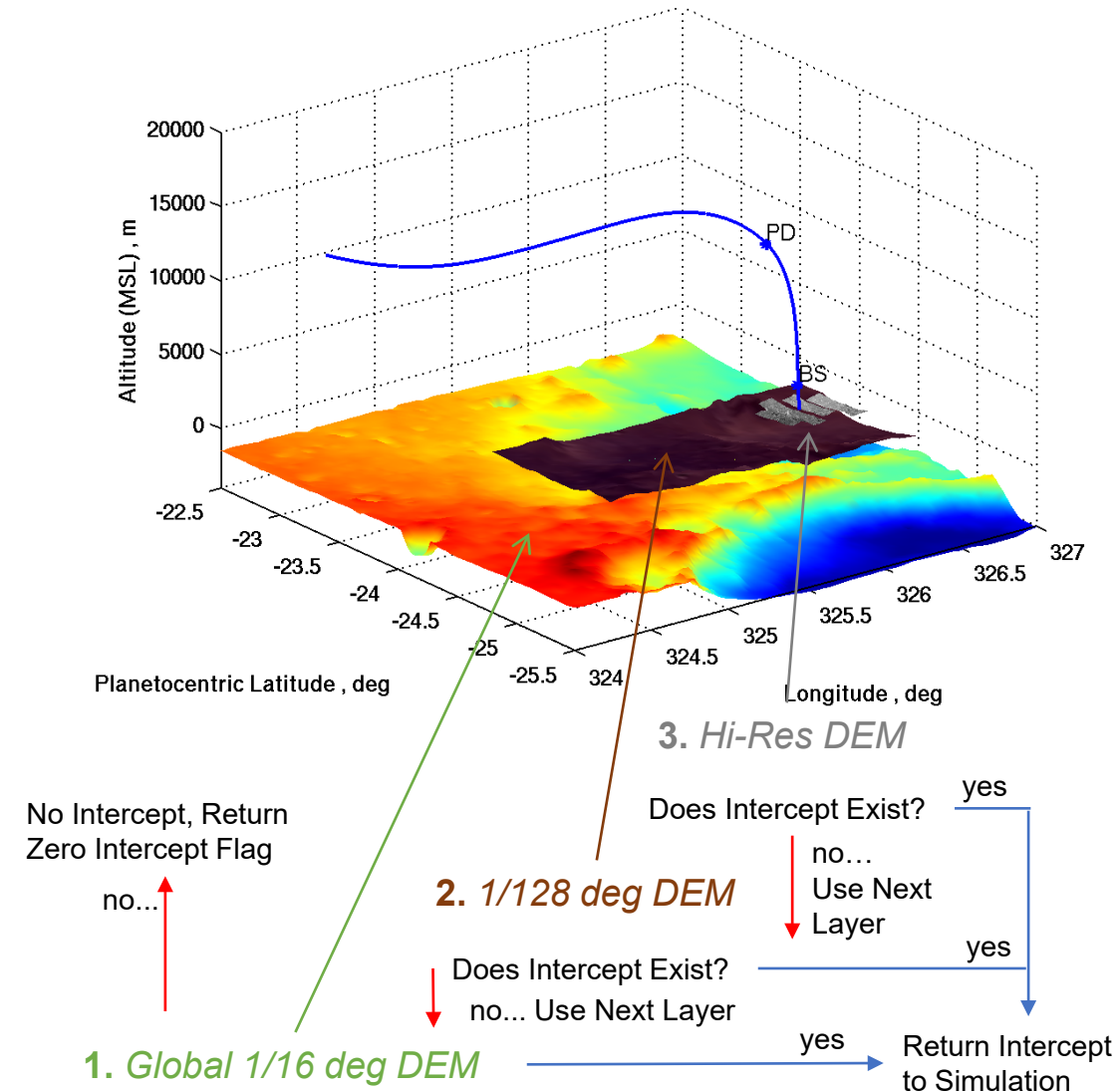


Efficient Terrain Modeling

- **Flight mechanics simulation of the Mars Science Laboratory (MSL) EDL system was performed using the Program to Optimize Simulated Trajectories II (POST2)**
 - Digital elevation models (DEMs) of the Mars surface were loaded in varying levels of detail using NetCDF standard
 - An efficient method of determining the intercept location of a ray on a DEM was developed, implemented, and flight-validated
 - Result: Ability to quickly obtain the height of the EDL system above the surface throughout all phases of flight, both in nominal and off-nominal (i.e., Monte Carlo analysis) senses
- **Since the successful MSL landing, this terrain engine has continued to be used in dozens of NASA projects with POST2**
 - Additionally, terrain engine may be packaged as a Matlab MEX function and used in a standalone sense

Challenge

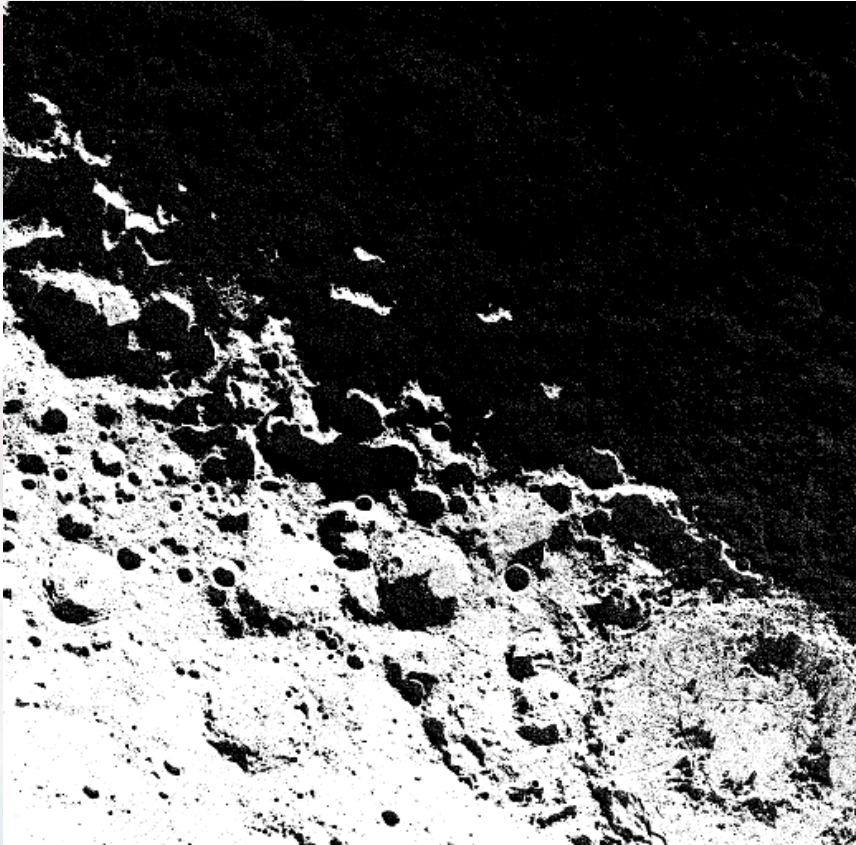
- How can we more effectively leverage this capability?



Lighting Impacts

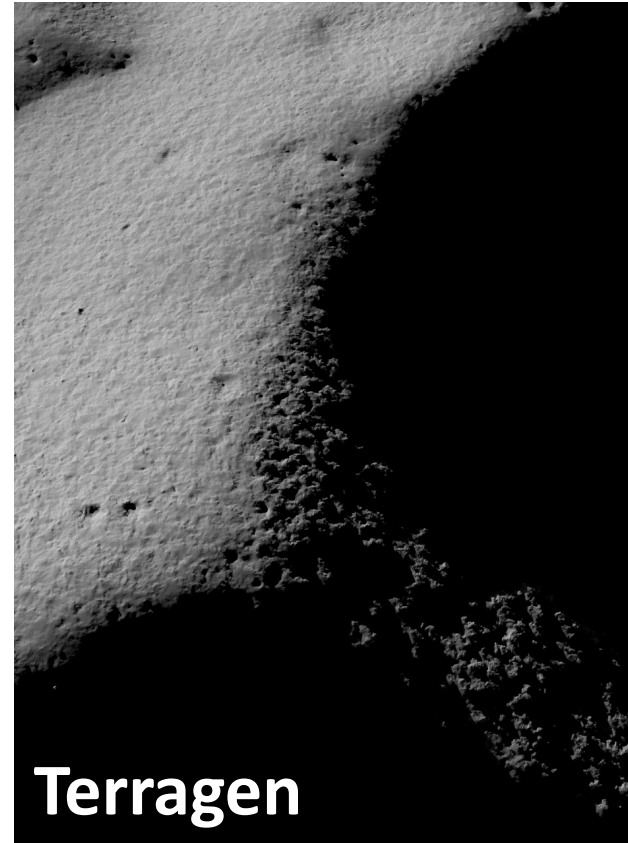
Challenge

- Package this feature as a standalone tool



• TRN Lighting Masks (online)

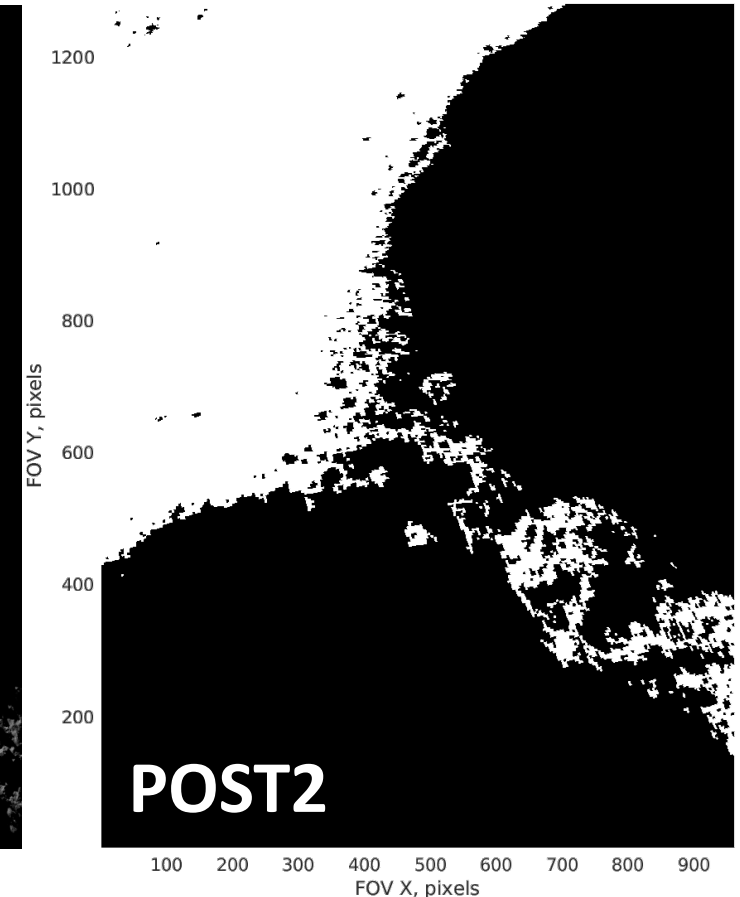
- Use ray tracing engine to map TRN camera pixels to DEM & query illumination mask
- Compute illumination fraction, pass to TRN model
- Can map every pixel (~1.0 s), every other pixel (~0.5 s), etc.



• Surface Lighting (offline)

- Use ray tracing engine in standalone C program to map center of Sun to each point on DEM and create lighting "mask"
- Parallelized computations to generate illumination mask for full DEM
 - ~45 min for 900+ million ray traces
- Validated qualitatively against external tools such as Terragen

Illumination Mask
Illumination Fraction = 0.31992

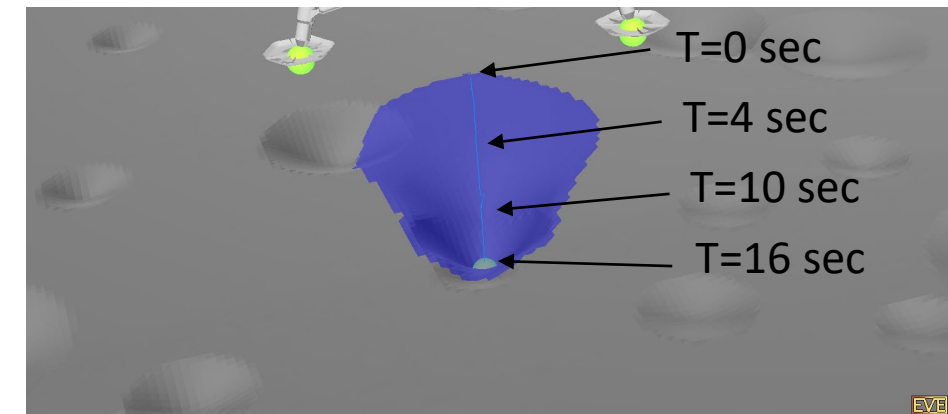


Hazard Injection

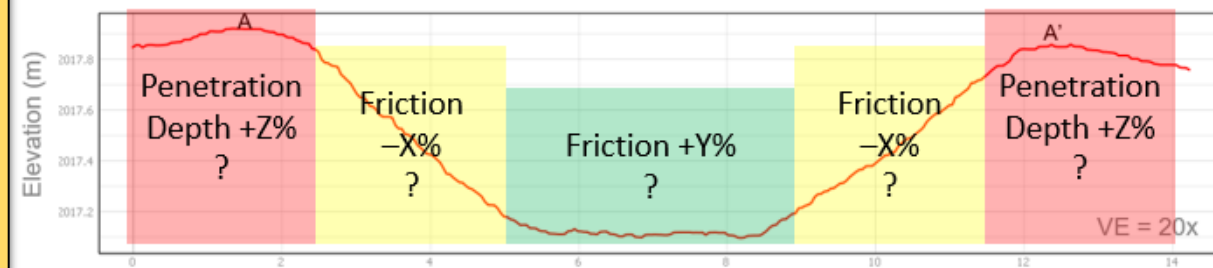
- **Plume Surface interaction (PSI)- Induced Regolith Erosion**
 - Method developed to adjust/deflect individual DEM elements in real-time based on lookup tables
 - Parameterization scheme & values are unknown – current intent is to demonstrate DEM erosion method
 - Enables variety of analyses
 - Sensitivity studies & stress case identification
 - Factors of safety
 - Pathological testing of requirements
 - Guidance & control mode transition testing
 - Impacts on touchdown dynamics
- **Artificial Upsampling & Synthetic Hazards**
 - Ensure simulation can ingest DEMs with appropriate hooks for contact variability in synthetic hazards
 - Can simulations consider representative layers of contact parameters for synthetic hazards co-aligned with known hazards?
 - Need to model different crater profiles based on age, depth, and size
 - Extensive literature exists on crater and block distribution frequency

Challenges

- What is an appropriate PSI effect parameterization scheme?
- How does PSI impact contact parameters (and therefore landing dynamics)?
- How to ingest known hazards (e.g., via database)
- Understand sensitivities of landing dynamics to surface contact parameters across crater profile

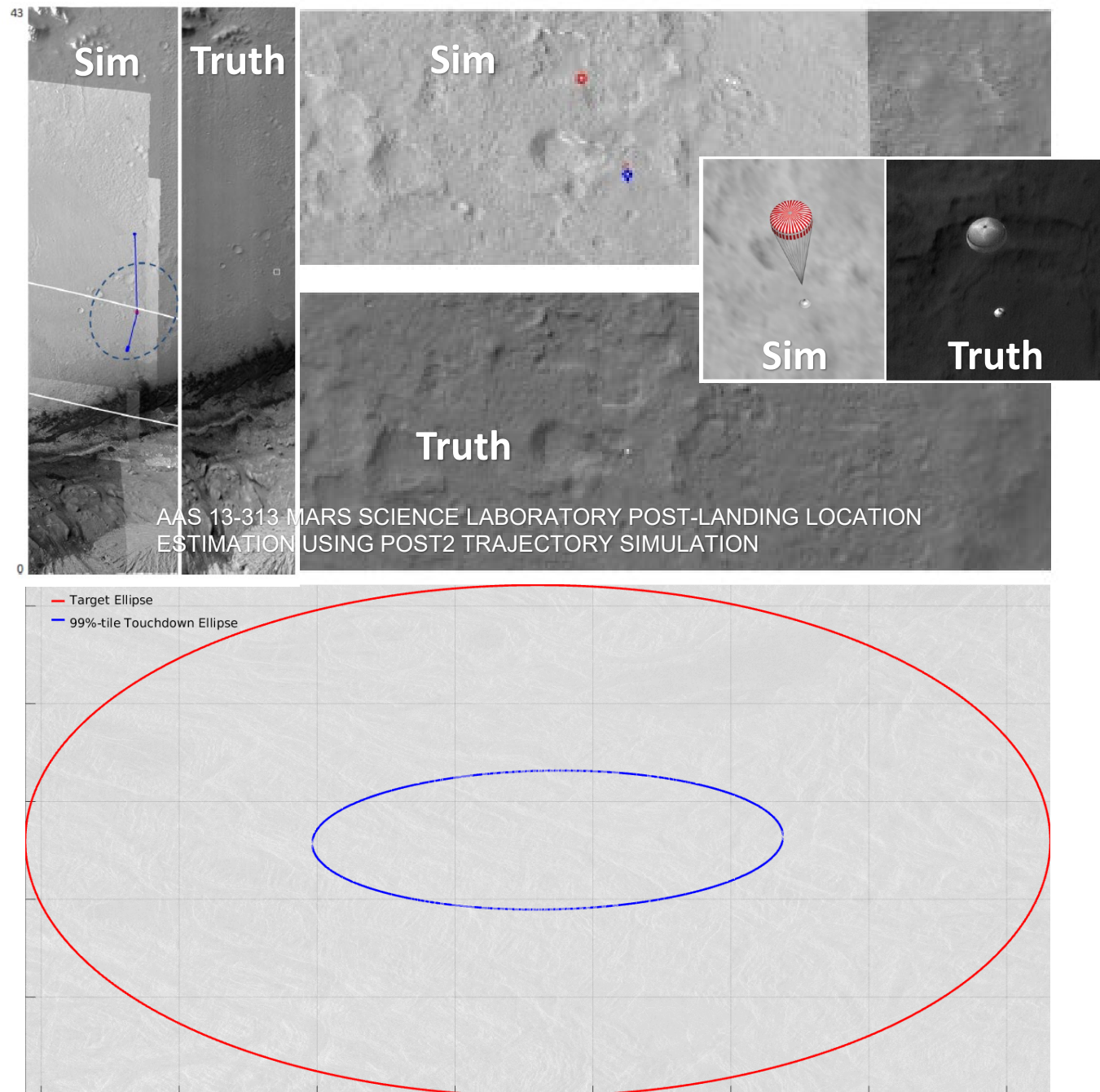


Synthetic hazard impact*



Imagery Acquisition

- **MSL, Phoenix, InSight, Mars2020**
 - 3D rendering of terrain in an observing camera's frame projection can be used to plan image acquisition and target location in truth image for faster searching
- **DAVINCI* Venus Descent Imager (VenDI)**
 - Ray tracer used to map FOV bounds to terrain in real-time
 - FOV bounds then overlaid on terrain map as post-process
 - Enables rapid assessment of image overlapping



Summary & Forward Work

- **We have developed and implemented an efficient ray-trace-based method to query DEMs**
 - Used in a wide variety of applications, with more D/EDL system driven applications coming online
- **DEMs can be very large and memory-intensive (on the order of MB or GB depending on resolution)**
 - This can be challenging within simulation environments – recall ispace citing computation limitations as forward work for Mission 2
 - Terrain engine has capability to load a subset of the DEM (an area of interest), decreasing memory pressure
 - This feature permits execution of 8k-sample Monte Carlos with online TRN illumination fraction calculations in 20-60 minutes
 - Speed is critical: Fast simulation means fast analysis turnaround
- **Challenges outlined in this presentation are forward work**
 - Parameterize and assess sensitivities of induced regolith erosion
 - Implement and assess sensitivities of regolith properties of surface hazards
 - Inject known craters

