

National Aeronautics and
Space Administration

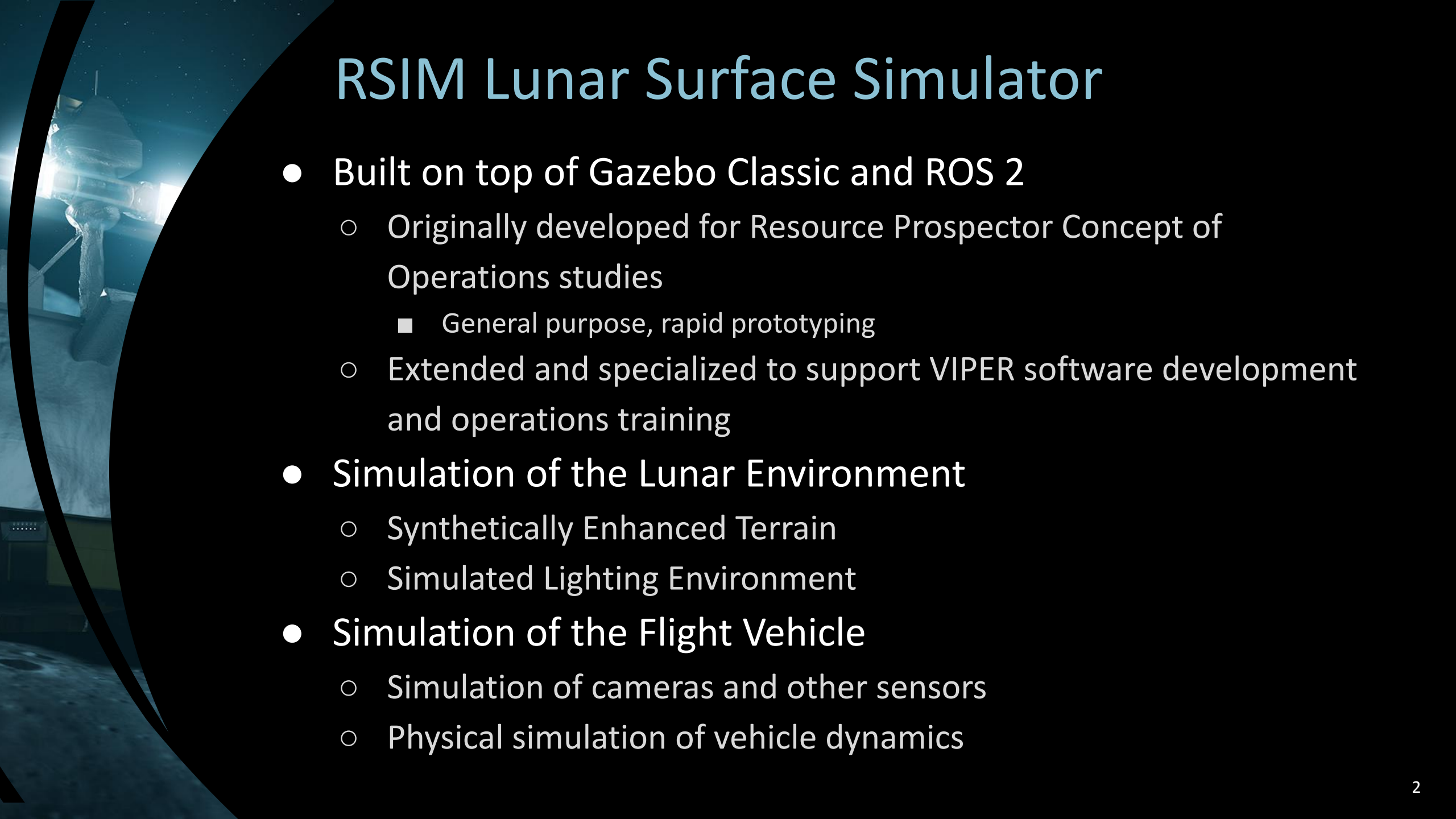


Lunar Surface Simulation

Mark Allan

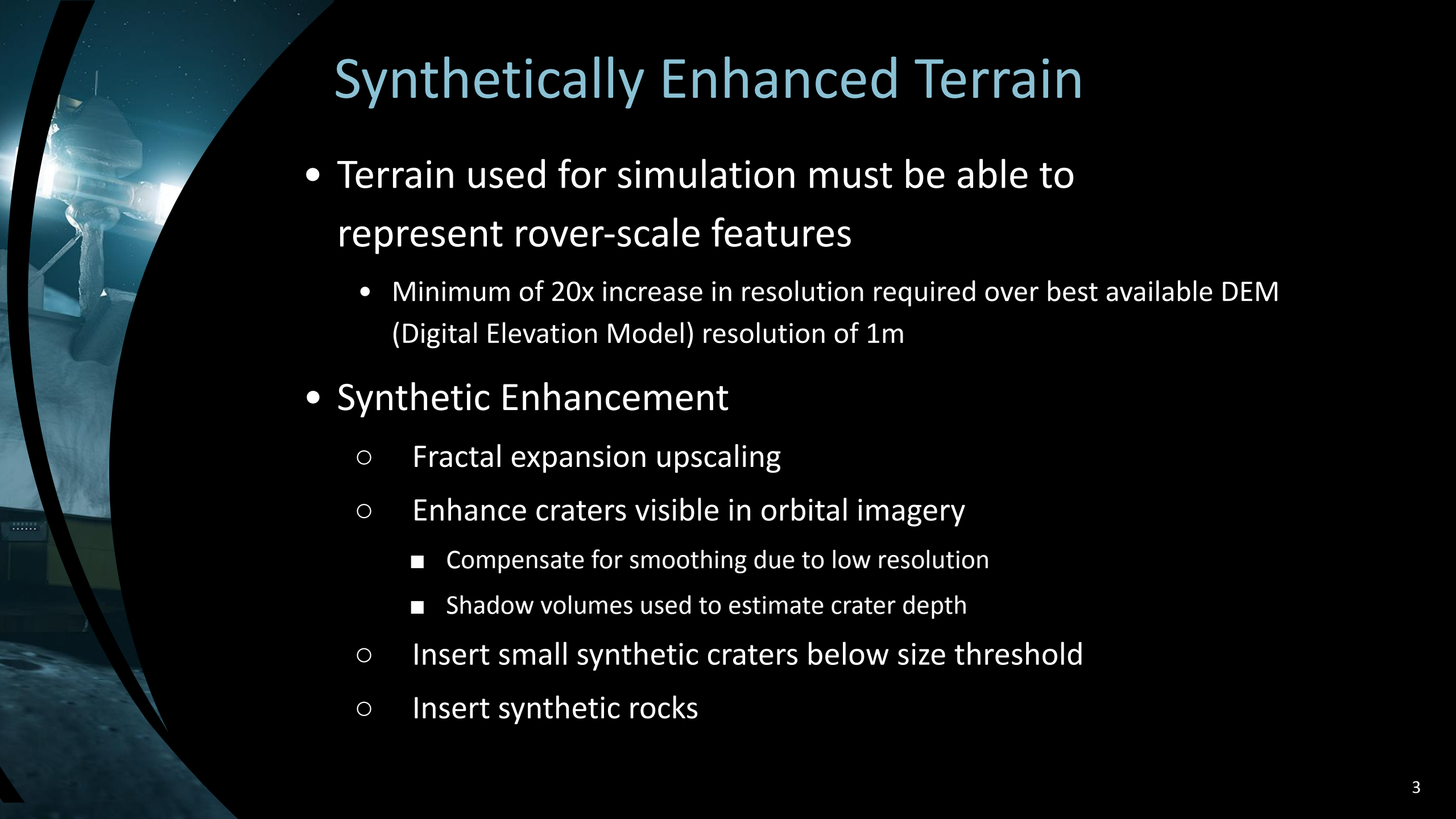
VIPER Rover Simulation Lead

February 10, 2025



RSIM Lunar Surface Simulator

- Built on top of Gazebo Classic and ROS 2
 - Originally developed for Resource Prospector Concept of Operations studies
 - General purpose, rapid prototyping
 - Extended and specialized to support VIPER software development and operations training
- Simulation of the Lunar Environment
 - Synthetically Enhanced Terrain
 - Simulated Lighting Environment
- Simulation of the Flight Vehicle
 - Simulation of cameras and other sensors
 - Physical simulation of vehicle dynamics



Synthetically Enhanced Terrain

- Terrain used for simulation must be able to represent rover-scale features
 - Minimum of 20x increase in resolution required over best available DEM (Digital Elevation Model) resolution of 1m
- Synthetic Enhancement
 - Fractal expansion upscaling
 - Enhance craters visible in orbital imagery
 - Compensate for smoothing due to low resolution
 - Shadow volumes used to estimate crater depth
 - Insert small synthetic craters below size threshold
 - Insert synthetic rocks

Synthetically Enhanced Terrain

- Generate synthetic orbital images to
 - Sanity check against available ground truth
 - Ensure simulated terrain matches traverse planning expectations

LRO NAC Image M1164797684LE



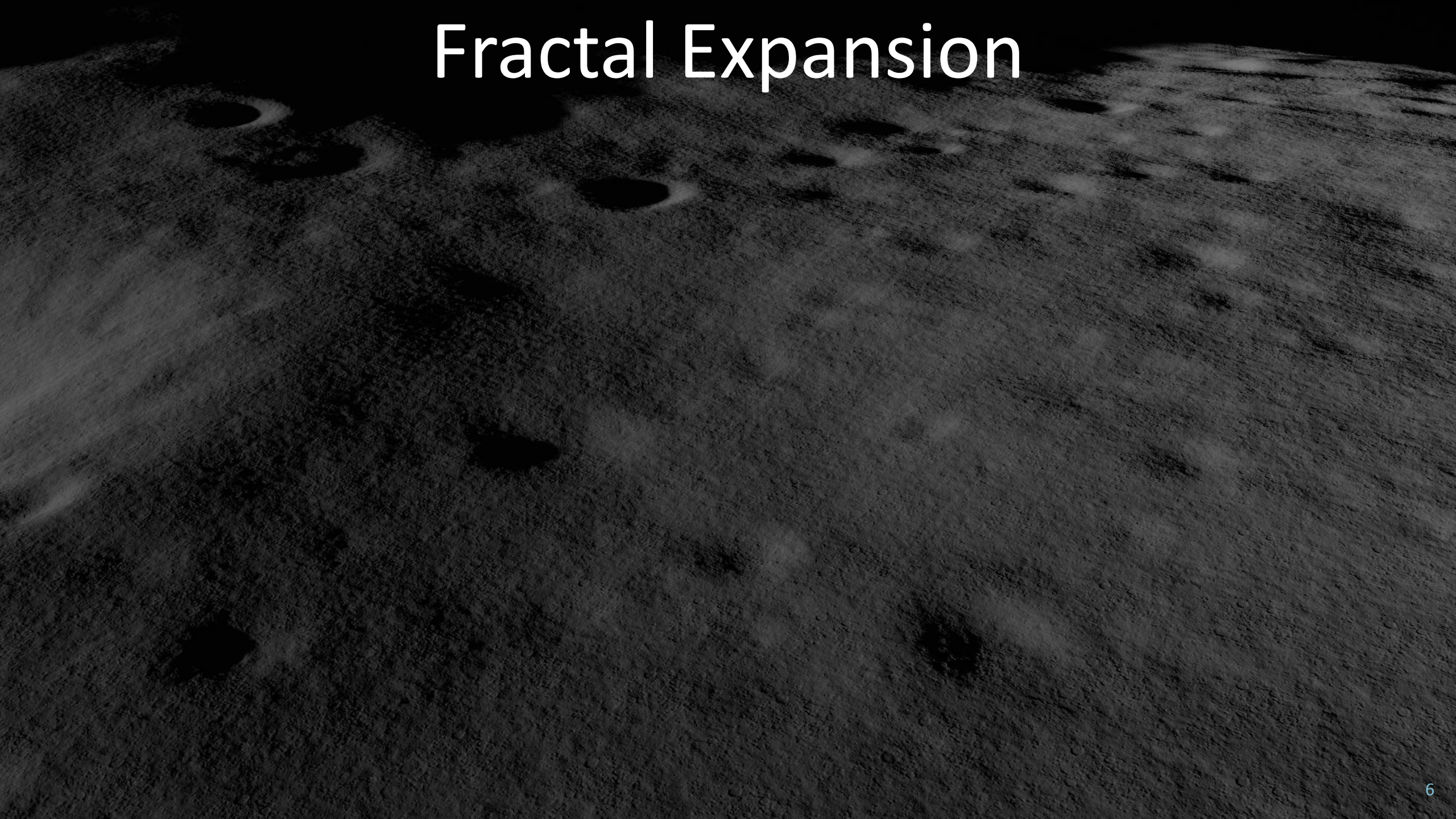
Simulated Orbital Image



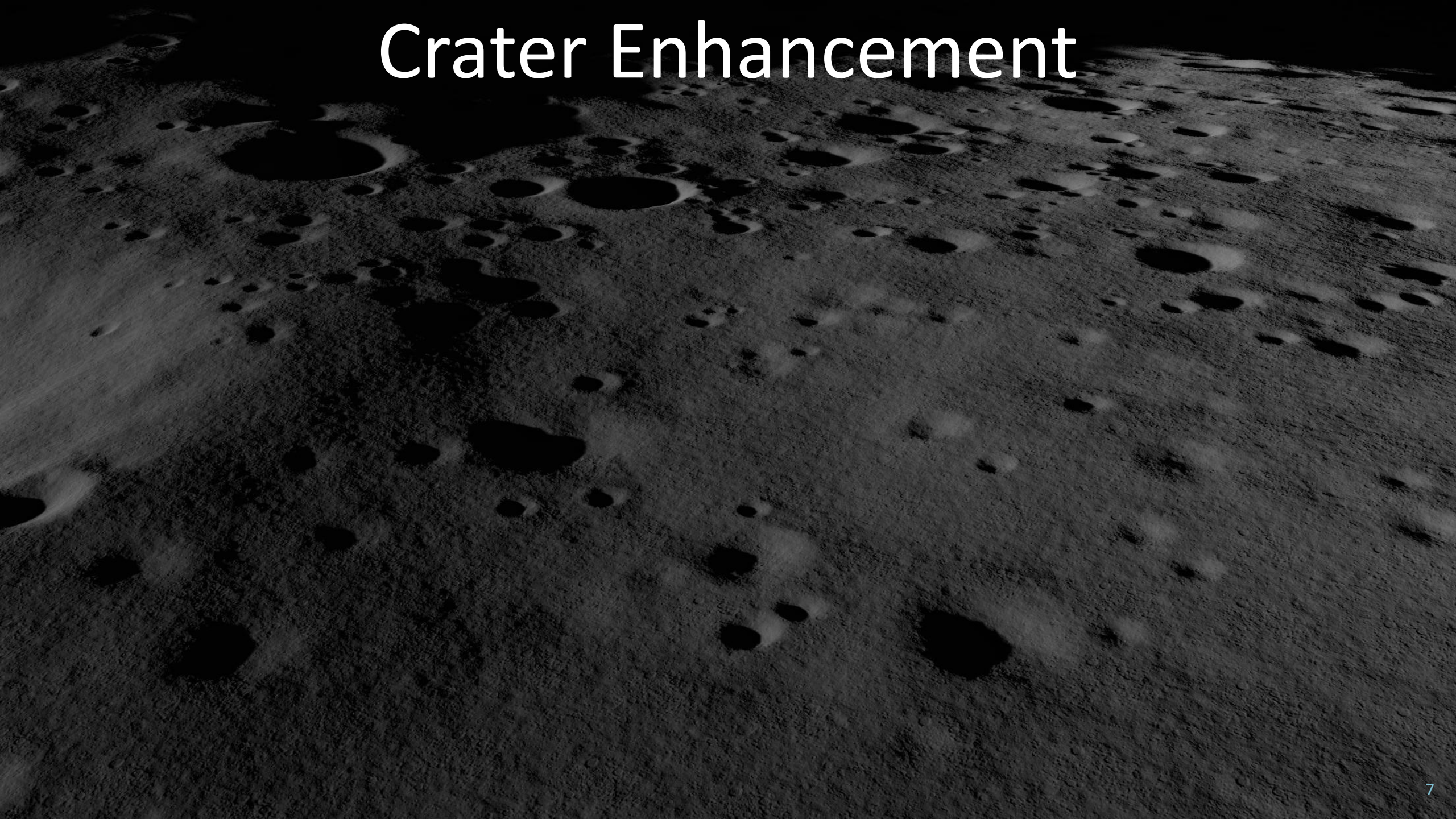
No Enhancement



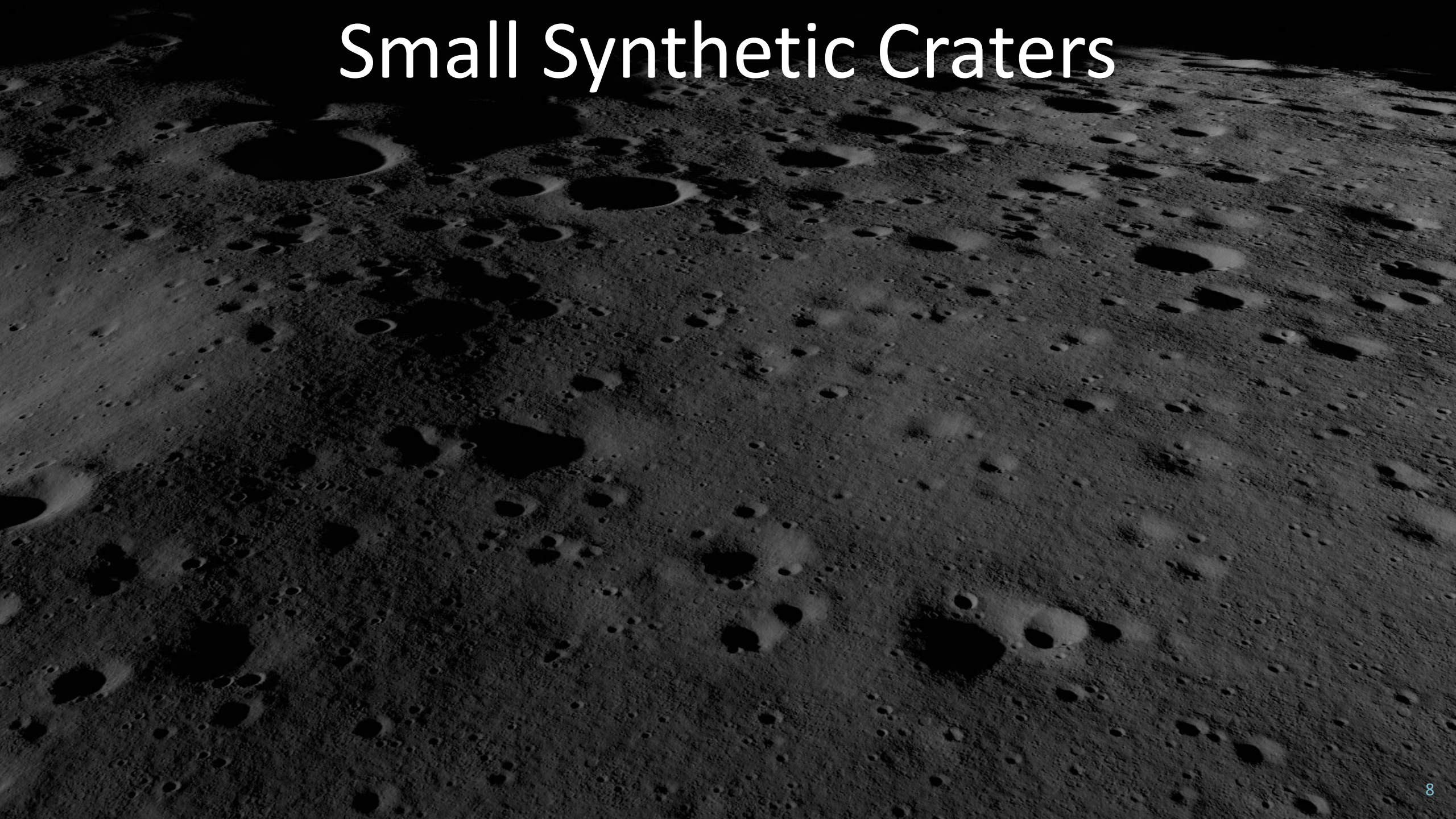
Fractal Expansion



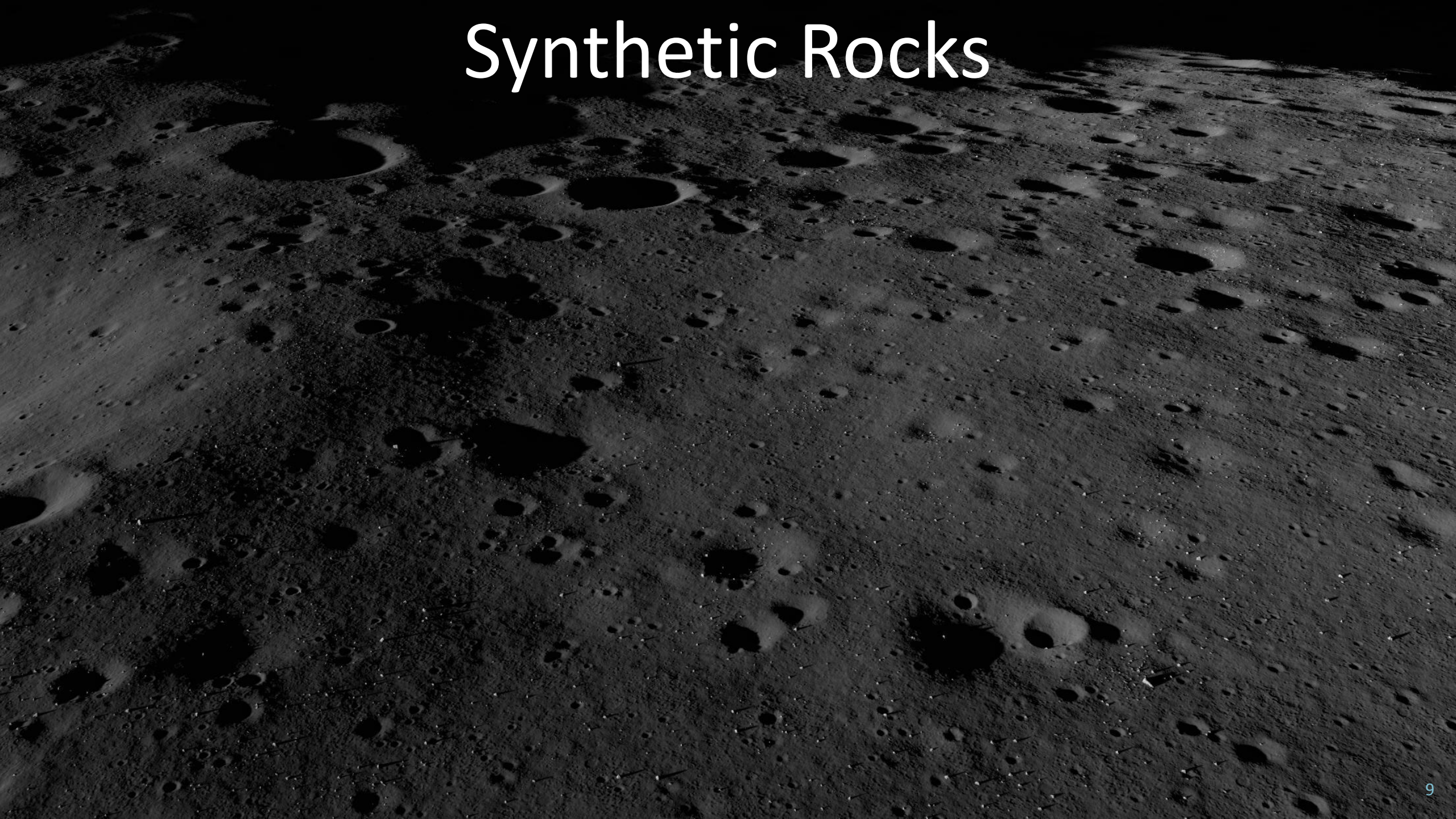
Crater Enhancement

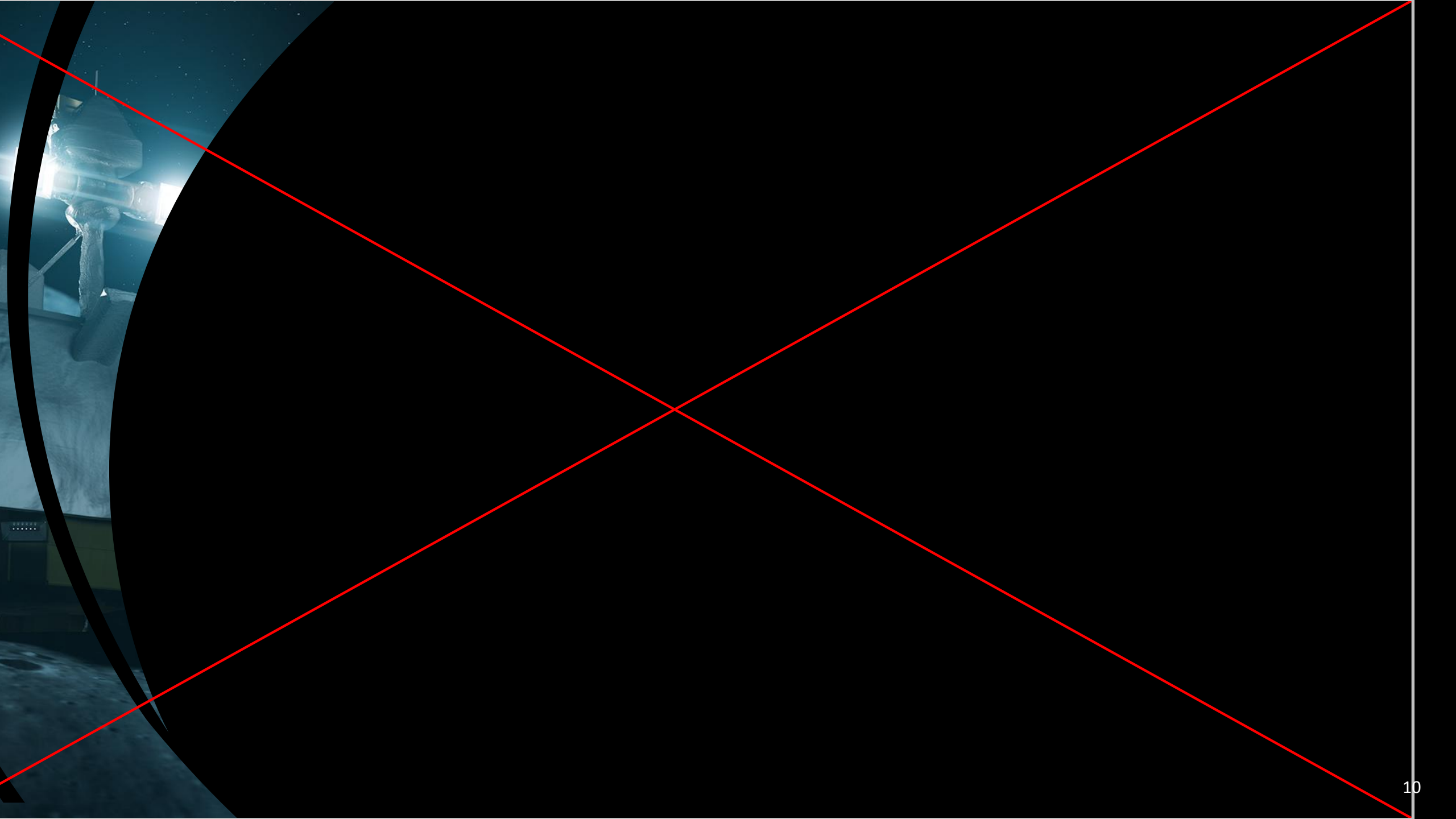


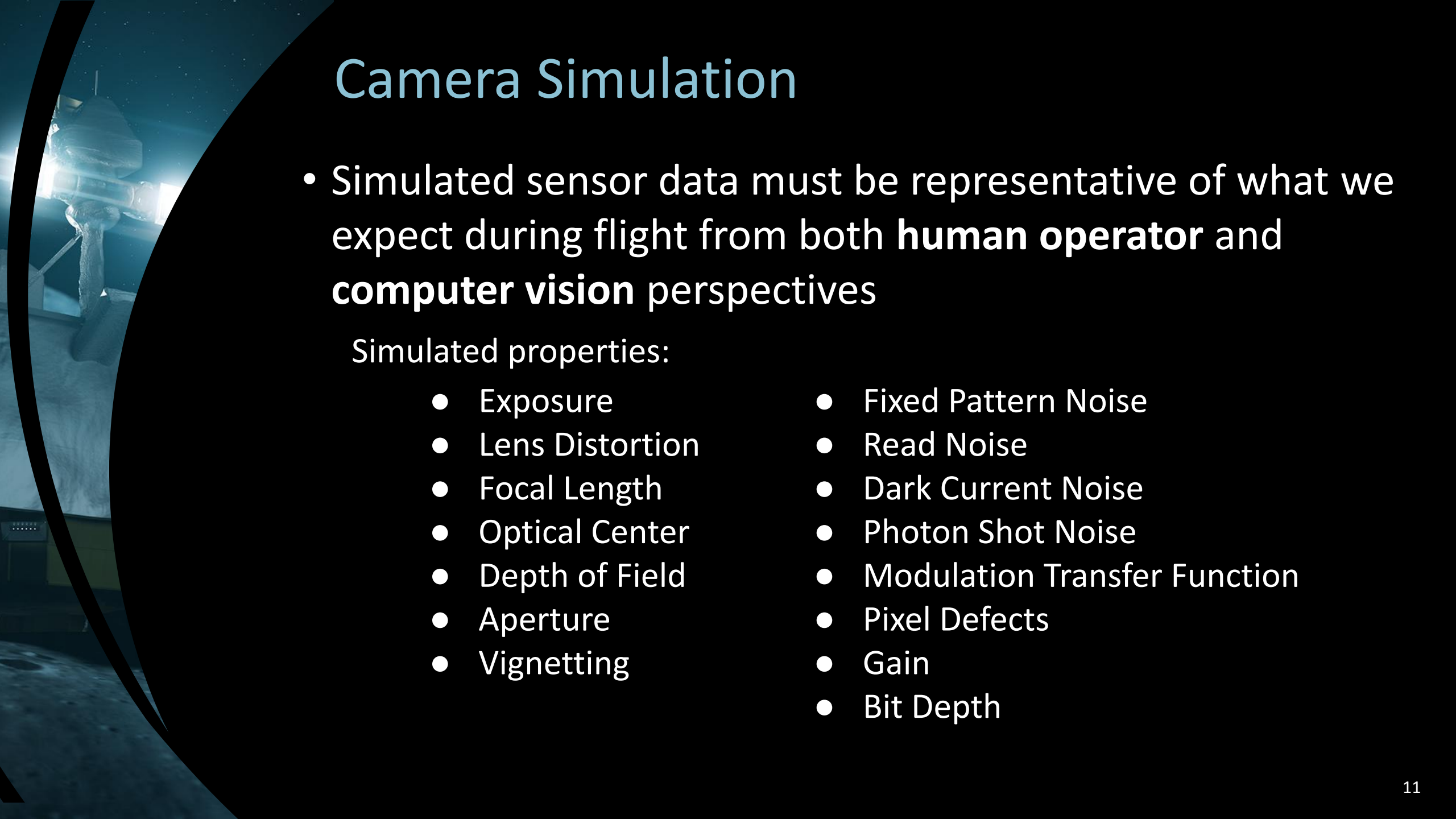
Small Synthetic Craters



Synthetic Rocks





A background image showing a satellite or space station in orbit above a planet's surface, with a large black arc overlaying the scene.

Camera Simulation

- Simulated sensor data must be representative of what we expect during flight from both **human operator** and **computer vision** perspectives

Simulated properties:

- Exposure
- Lens Distortion
- Focal Length
- Optical Center
- Depth of Field
- Aperture
- Vignetting
- Fixed Pattern Noise
- Read Noise
- Dark Current Noise
- Photon Shot Noise
- Modulation Transfer Function
- Pixel Defects
- Gain
- Bit Depth

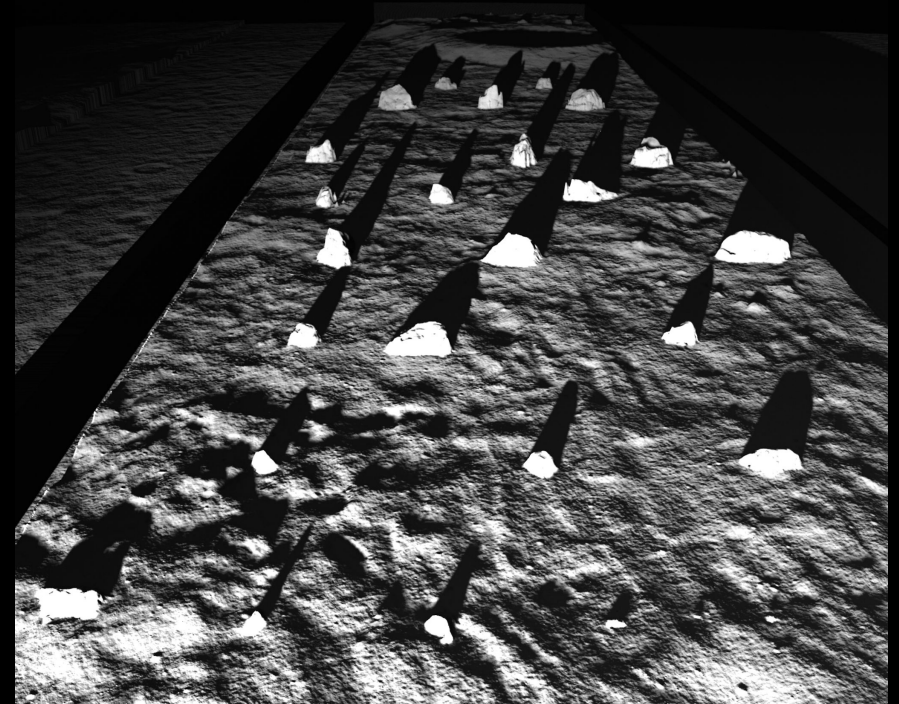
Camera Simulation

- Simulated imagery is tuned through comparison with imagery from the Lunar Lab physical testbed

Lunar Lab Image



RSIM Image

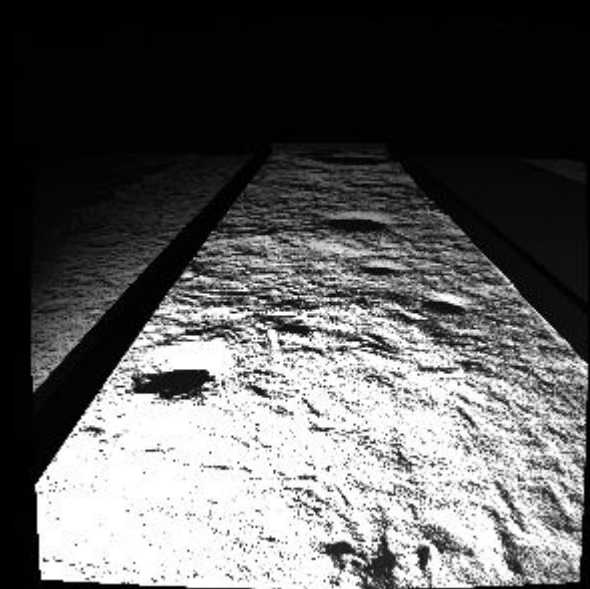


Exposure

Real

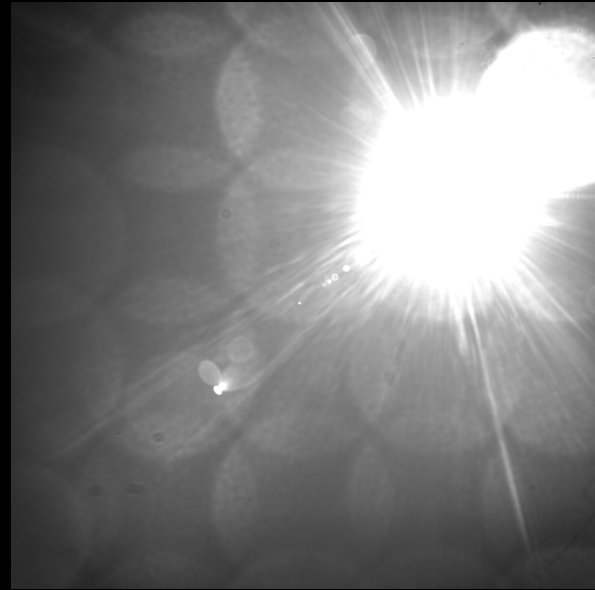
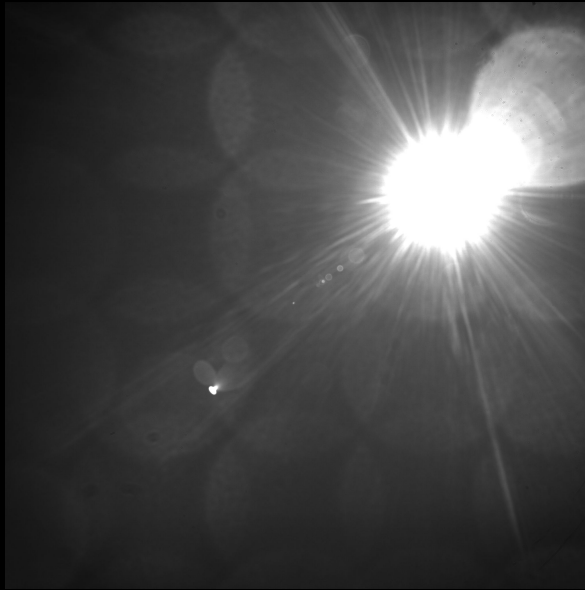


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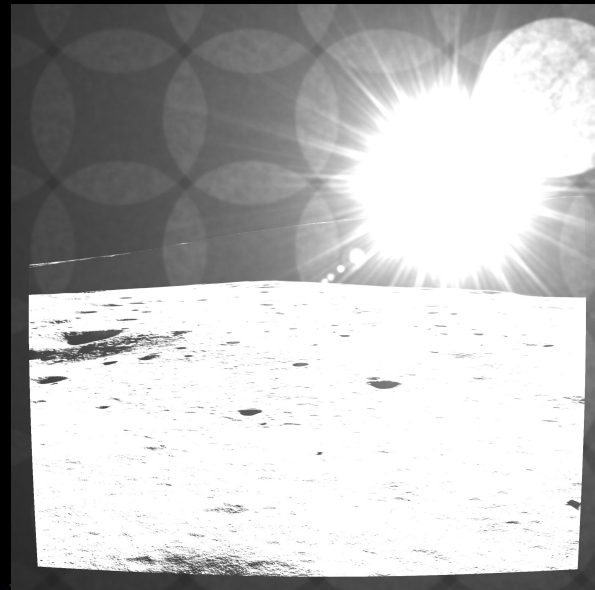
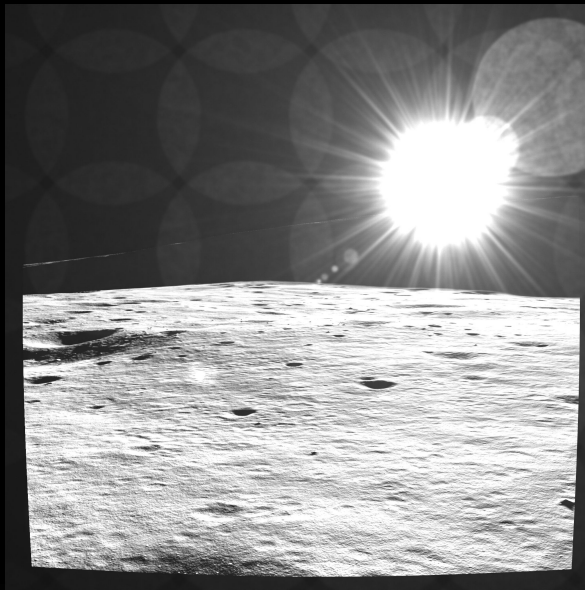
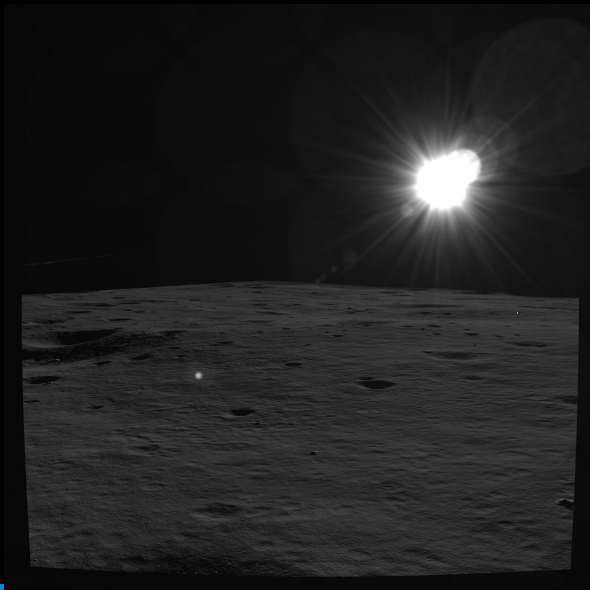


Lens Flare

Real



RSIM

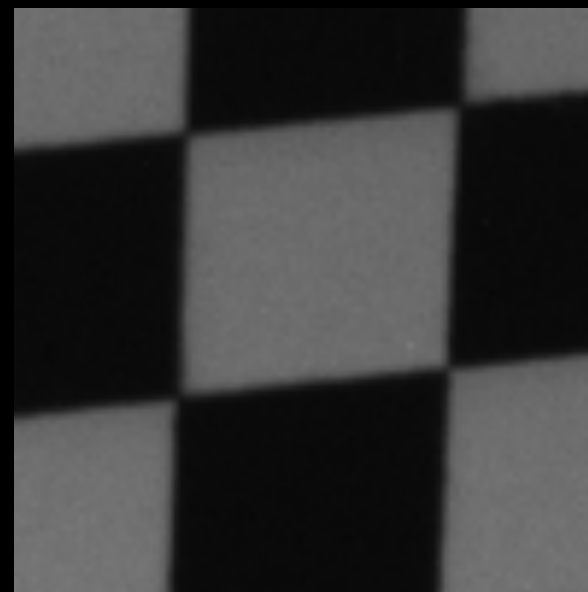
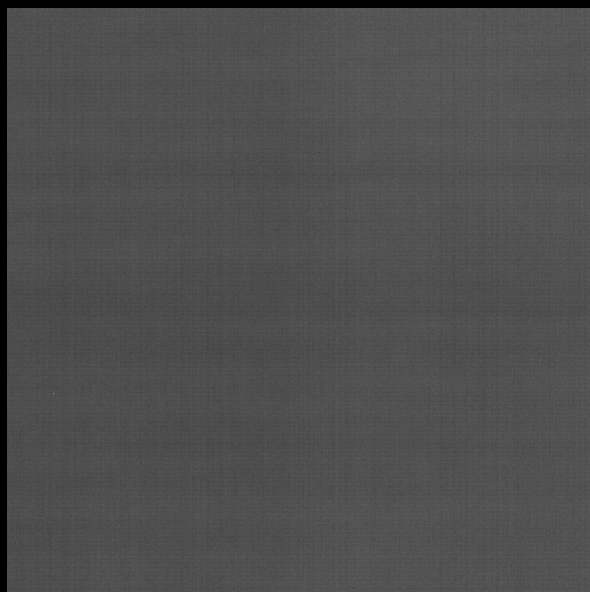


Fixed Pattern Noise

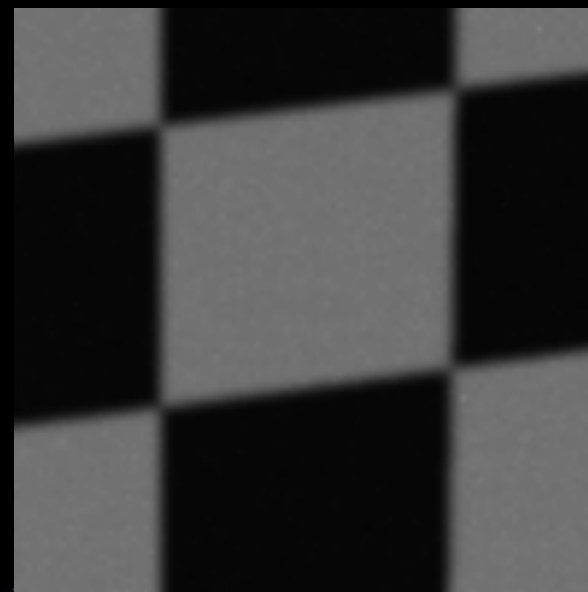
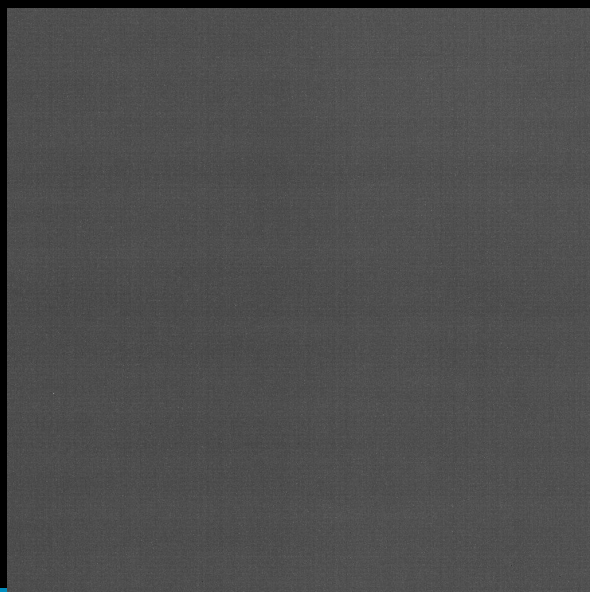
Flat Field Effects

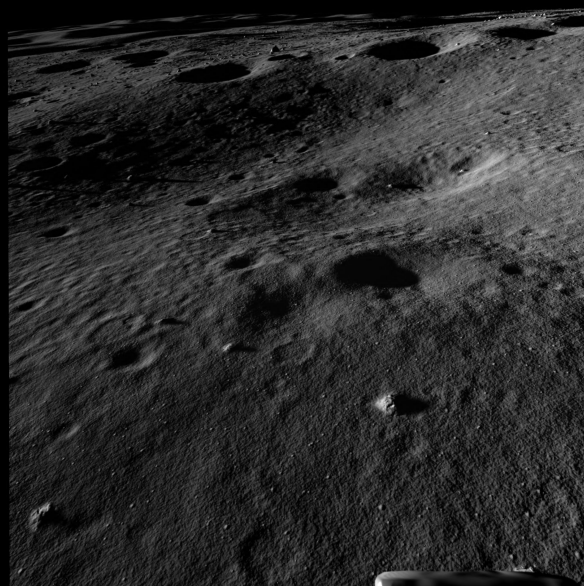
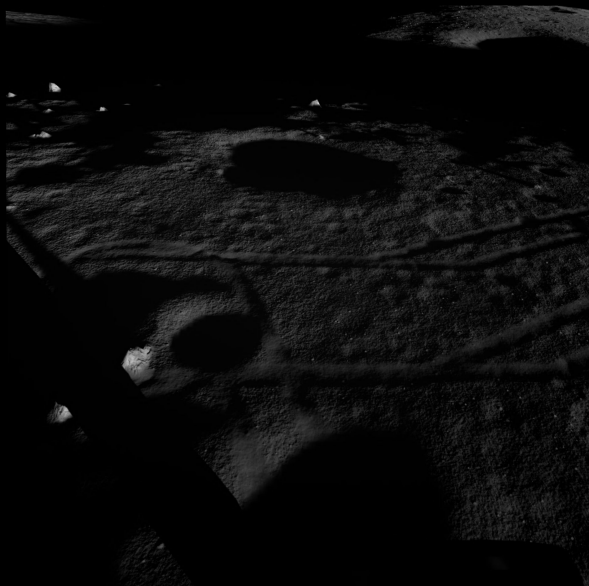
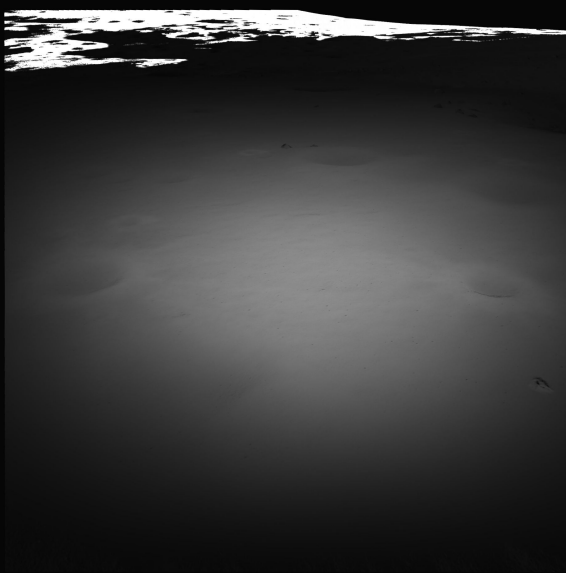
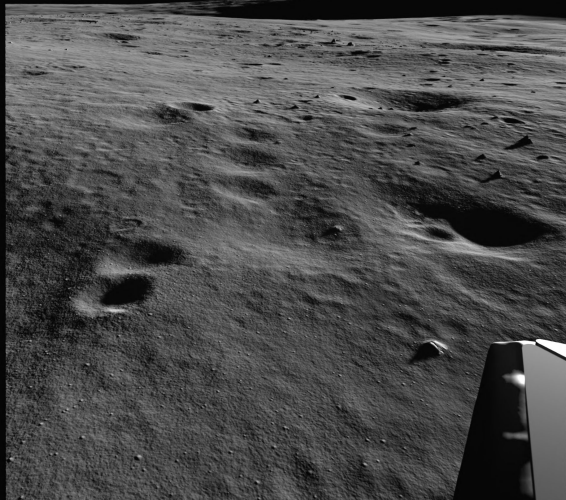
DoF, Sensor Noise

Real



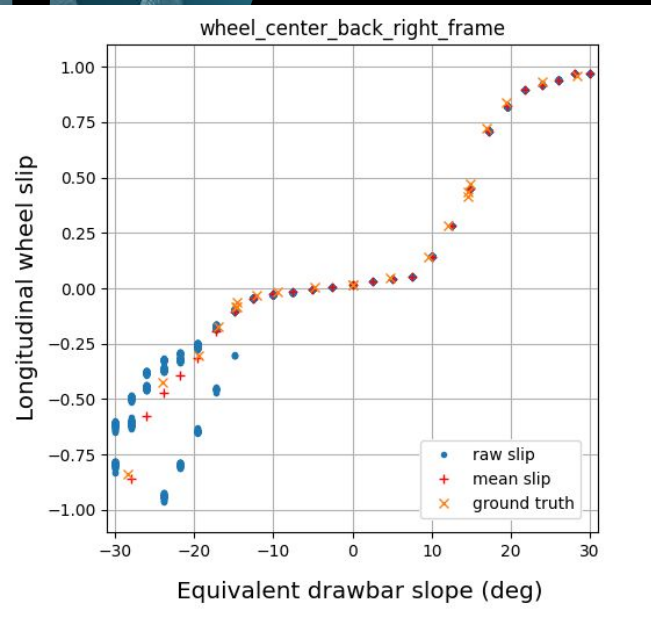
RSIM





Physical Simulation

- Wheel slip plugin approximates terramechanics of driving on unconsolidated soil



simulated wheel slip vs physical testbed ground truth

- Modulates Force-Dependent Slip (FDS) parameter and surface contact normal
- Tuned to match physical testbed results
- Negligible impact on runtime performance
- Slip compliance and friction are modulated by a 'slip map' on a per-wheel basis to account for soil compaction and rocks

