

National Aeronautics and Space Administration



Development of a Compact Lidar Sensor for Terrain Relative Navigation and Terrain Hazard Avoidance

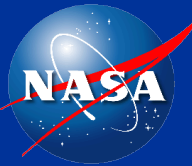
Farzin Amzajerian, Aram Gragossian , Alexander Bulyshev, Paul F. Brewster , Jacob M. Heppler ,
Frederick G. Wilson , Glenn D. Hines , Sean A. Laughter , and Daniel K. Litton

NASA Langley Research Center

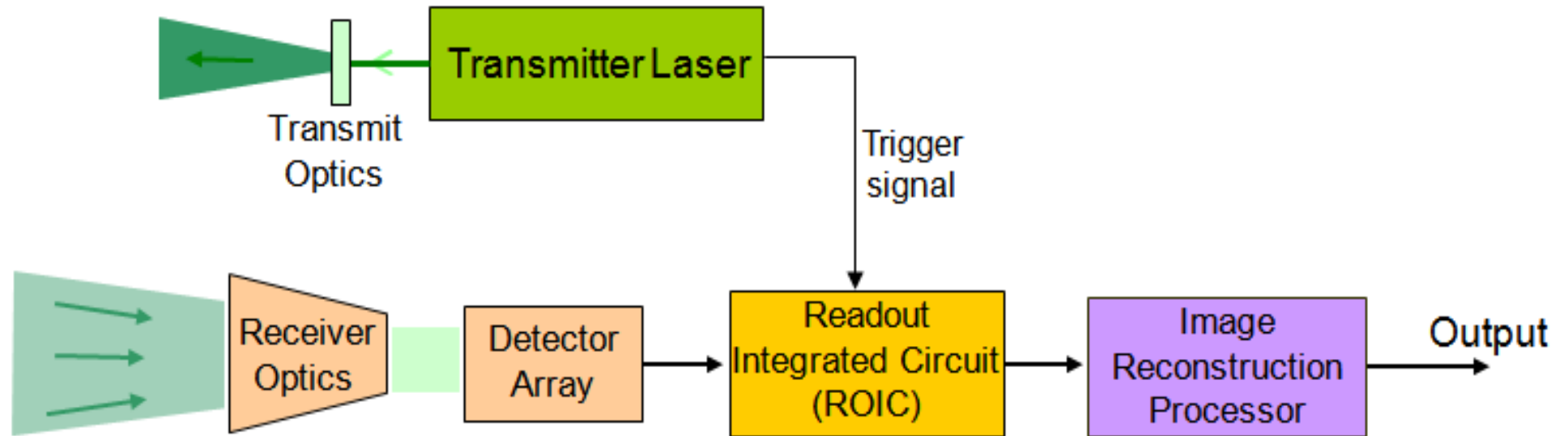
AIAA SciTech Forum 2025



Terrain Sensing Lidar (TSL)



- TSL is a multifunctional sensor based on *flash lidar* technology utilizing real-time image reconstruction and processing algorithms



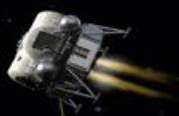


TSL Landing Operation Concept



Altimetry

50 km



20 km

Updating IMU
and reducing
position errors

A-TRN

10 km



Acquire low-resolution
3D terrain images to
identify known features

HDA

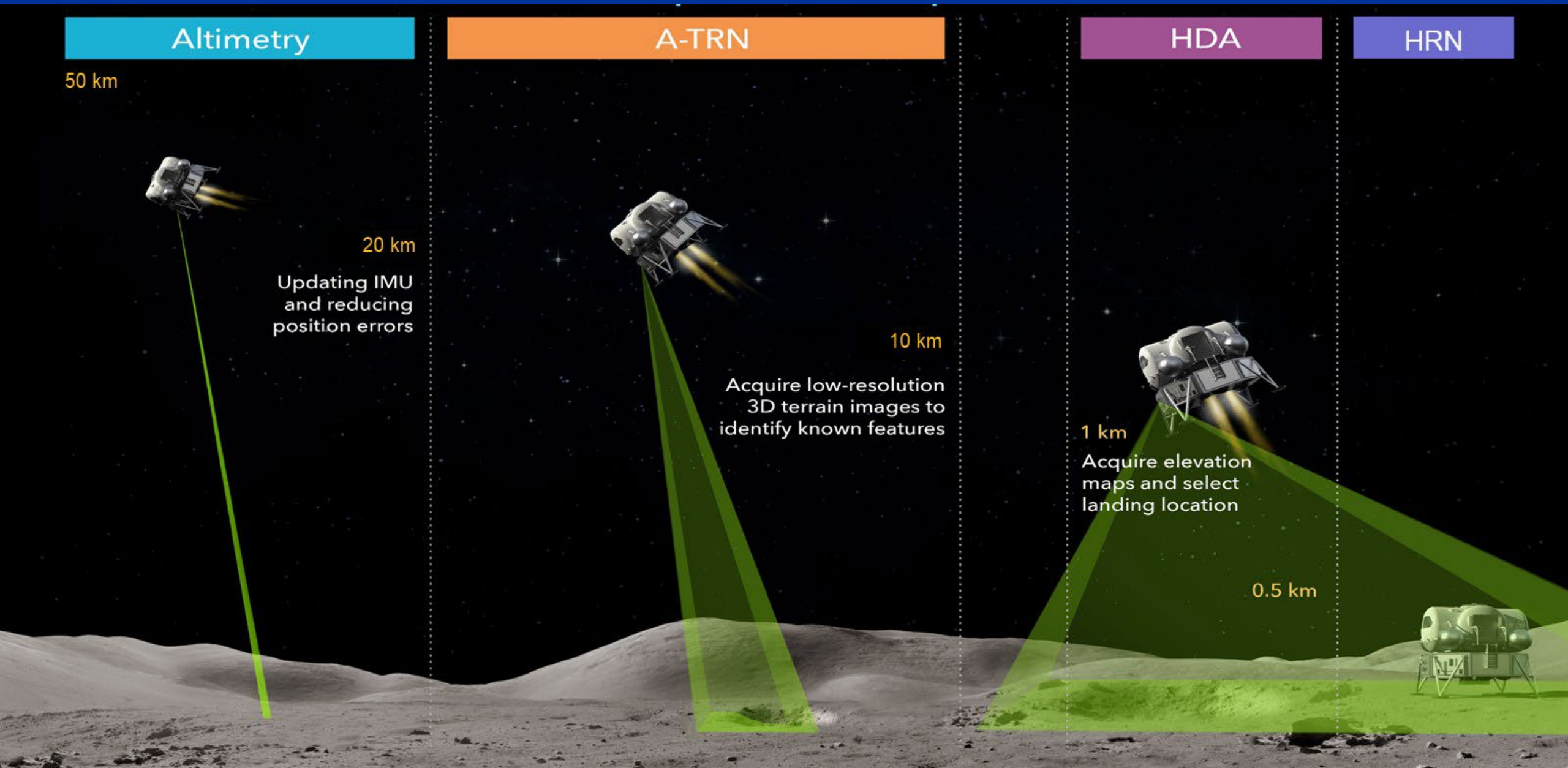
1 km



Acquire elevation
maps and select
landing location

HRN

0.5 km





Major Attributes of 3-D Imaging Flash Lidar



Does not require vehicle motion correction	<ul style="list-style-type: none">• Eliminates extensive processing power and time
Generates organized 3-D pattern	<ul style="list-style-type: none">• No need for oversampling of the landing site• Simplifies HDA and TRN algorithms and reduces processing time
Fast image acquisition time	<ul style="list-style-type: none">• Reduces hazard detection time• Allows for video navigation (HRN)
Limited number of detector pixels	<ul style="list-style-type: none">• Operate in hybrid configuration (scanning)• Employ image enhancement algorithm

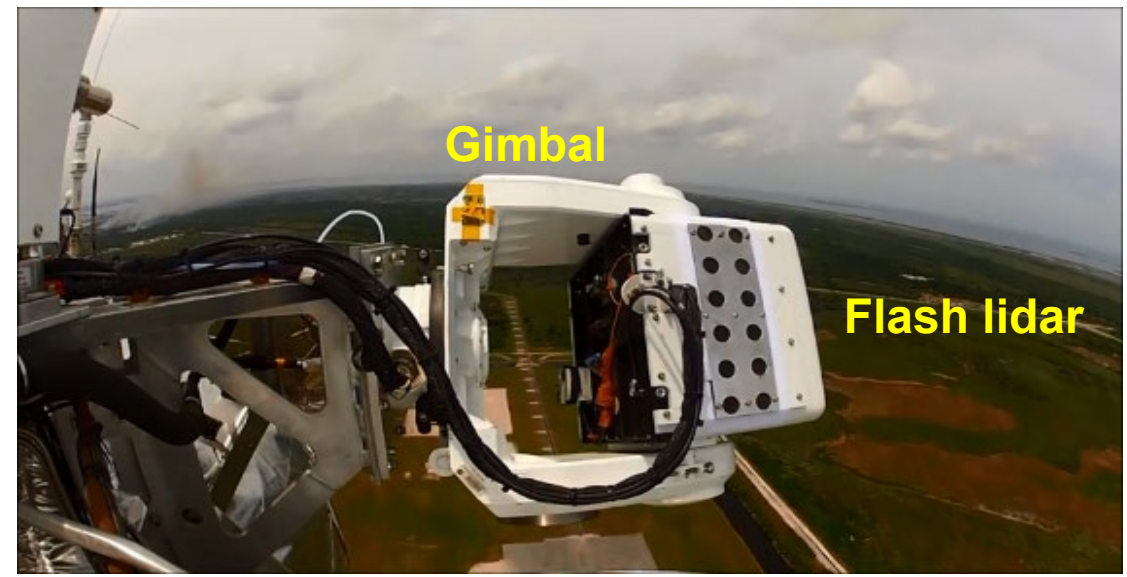


Hazard Detection and Avoidance Requirements

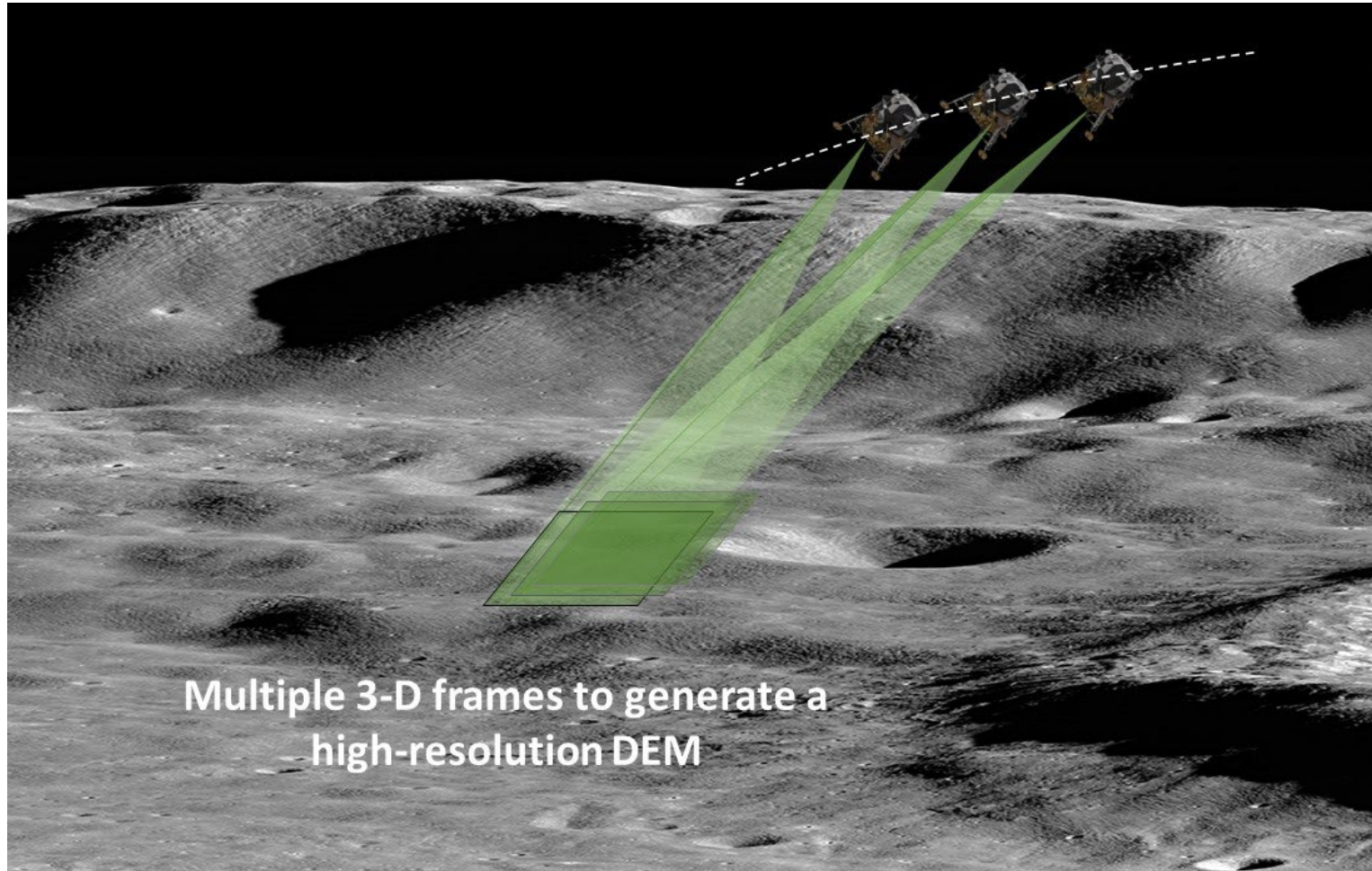


- Commercial linear-mode flash lidar camera has $128 \times 128 = 16.4\text{k}$ pixels
- Mapping $100 \text{ m} \times 100 \text{ m}$ area with 15 cm Ground Sample Distance (GSD) requires $\sim 0.5 \text{ M}$ pixels
- Developed a Super-Resolution algorithm to meet HDA requirements without the need for a mechanical gimbal or scanning mirror

Flash lidar closed-loop demonstration onboard rocket-powered Morpheus vehicle (2014)



- Super-Resolution (SR) technique uses a set of consecutive frames, from slightly different positions and angles (resulting from platform motion), to generate a high-resolution DEM
- Generates high-res DEMs at 1 Hz rate using 20 frames
- No external sensor data is required
- Provides 6-DOF relative state vector

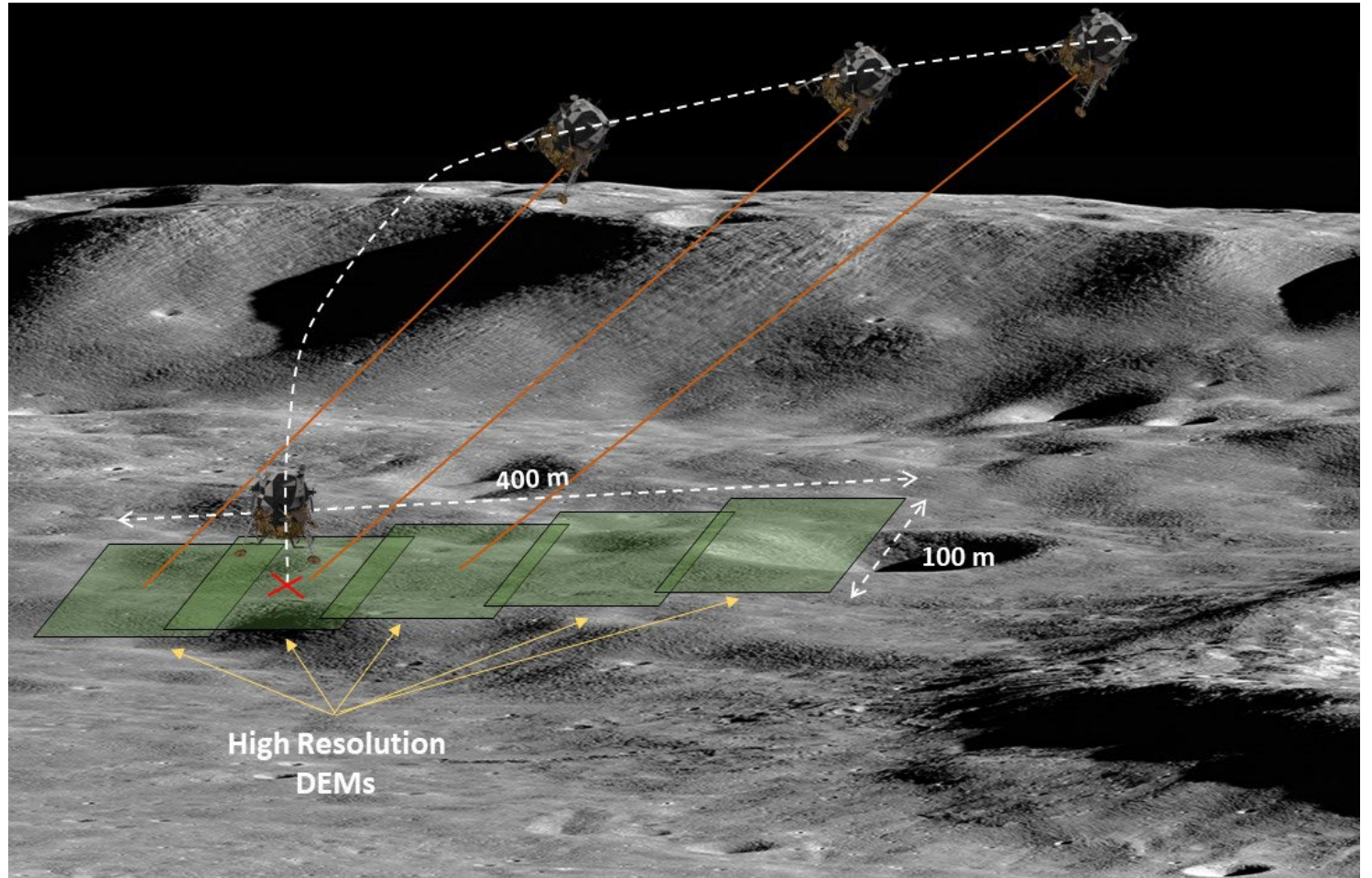




TSL Generates Multiple High-Resolution DEMs



- DEMs and Hazard Maps are generated every 1 second with 30 msec latency
- Can cover up to 100 m x 400 m area and identify safe landing locations in 5 seconds





Helicopter Flight Test

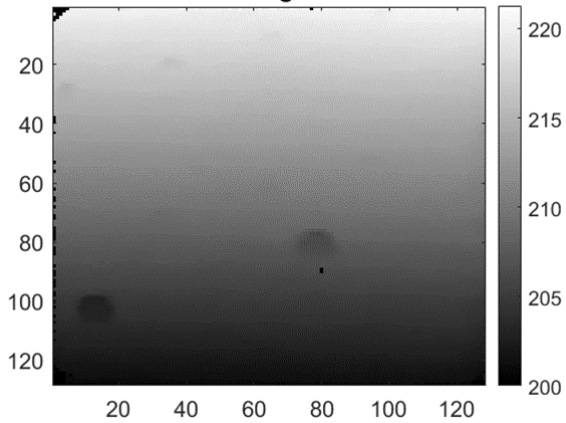


Blue Origin West Texas Facility, August 2023

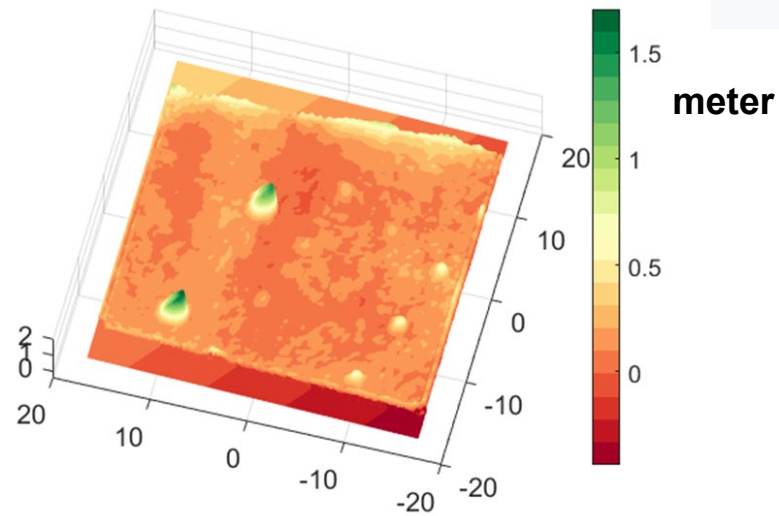
- 100% hazard detection from 250 m @ 45° look angle
 - Smallest hazard: 25 cm dia x 35 cm height

Single Frame

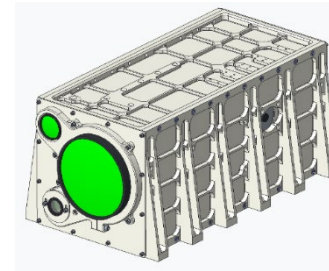
Range



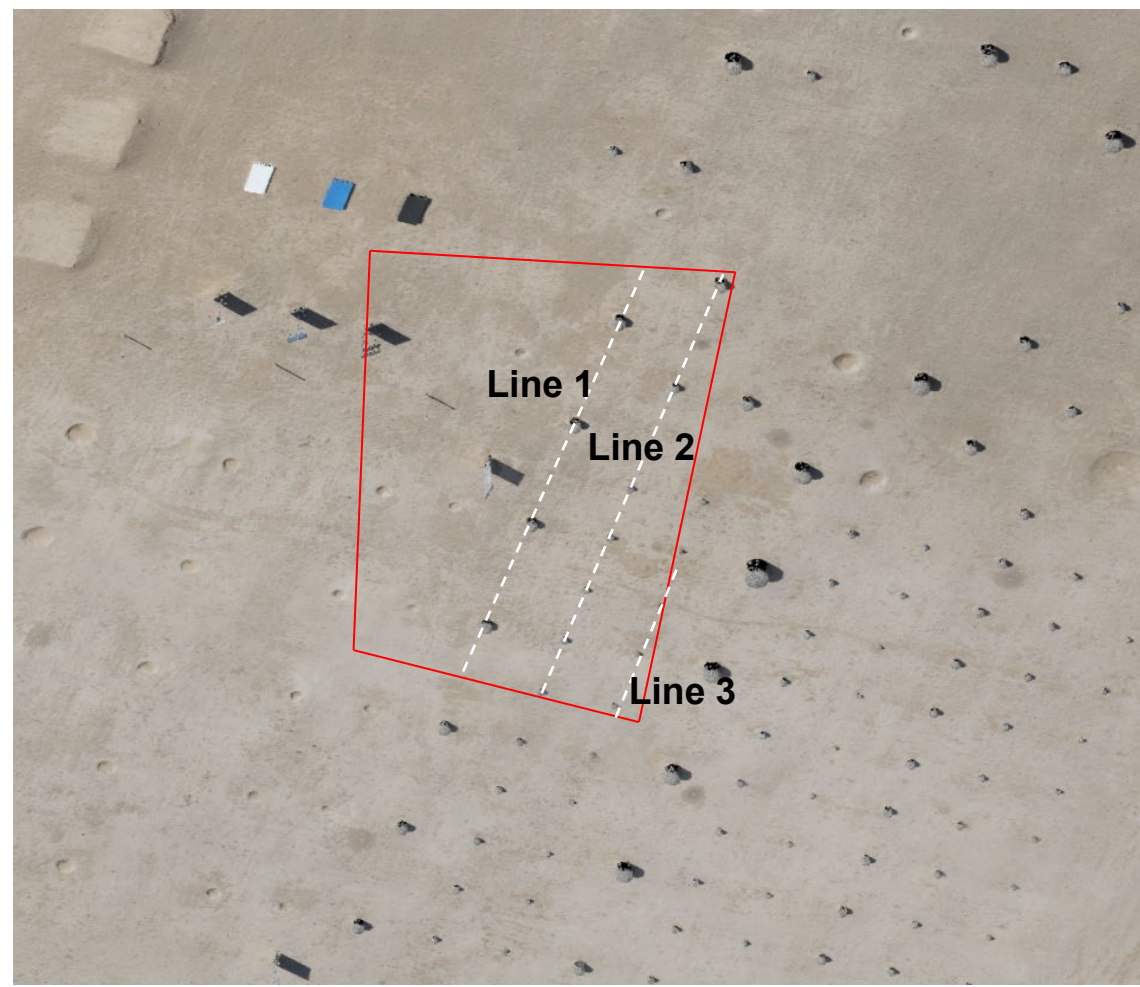
Real-Time Elevation Map



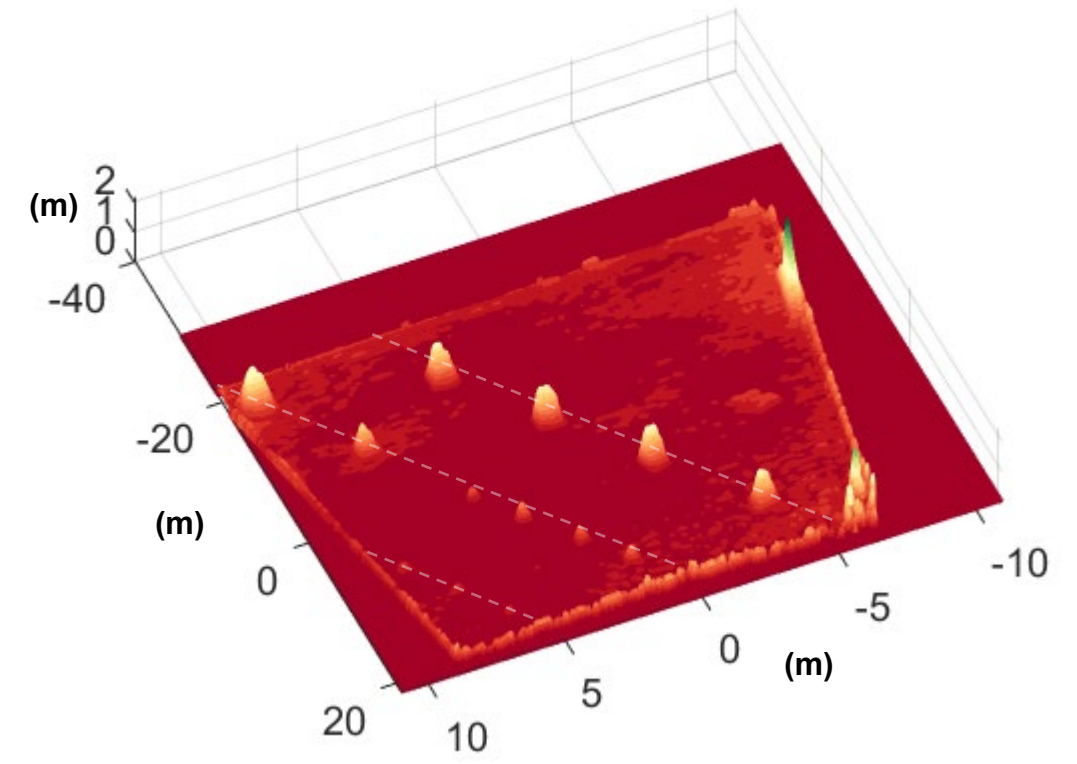
Breadboard Flash Lidar



Hazard Field synthetic image and TSL footprint



Corresponding DEM generated in real-time @ 1 Hz



Note that the axes are not in scale

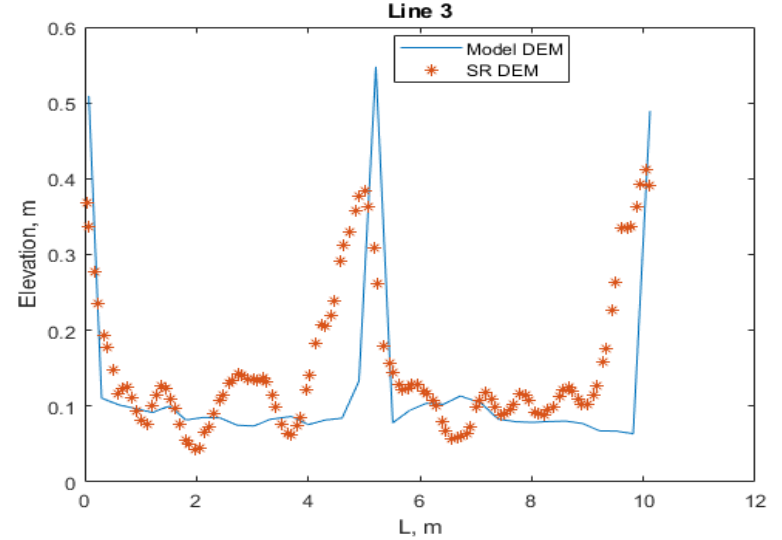
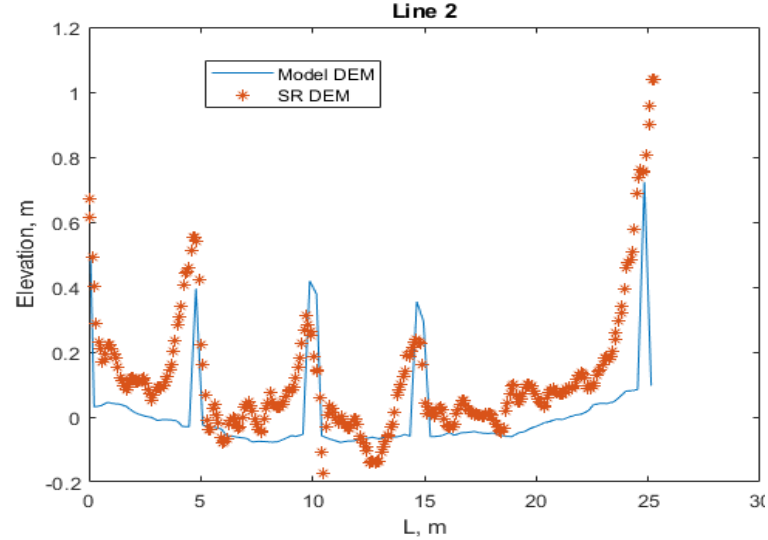
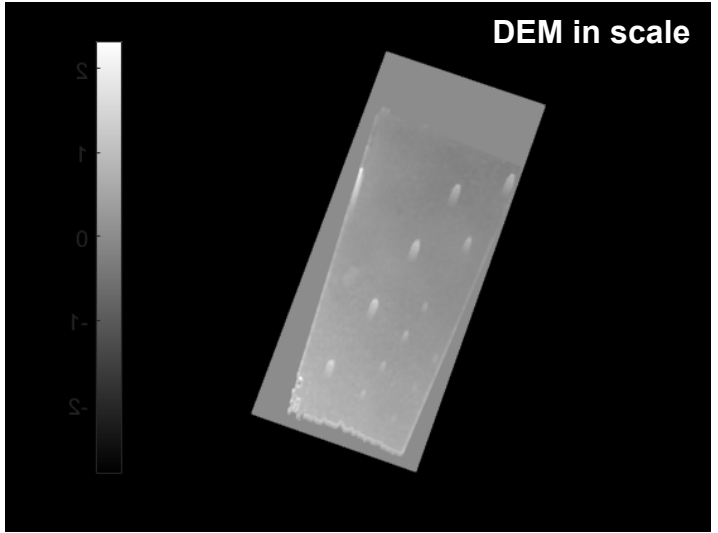
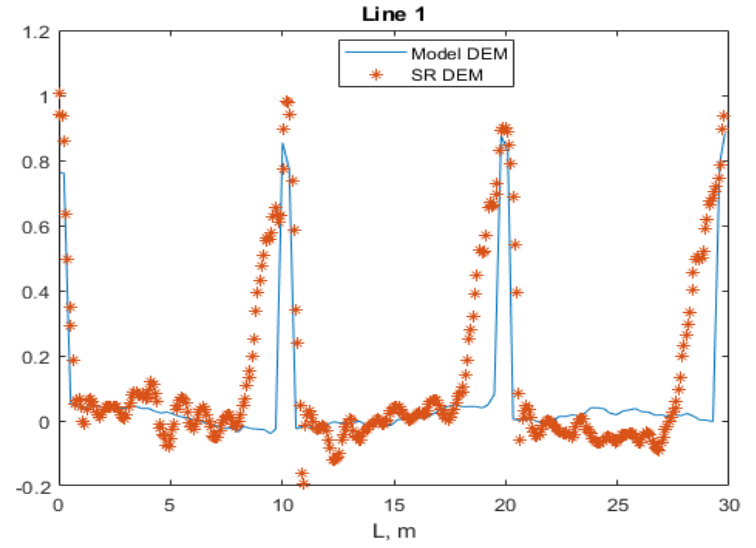
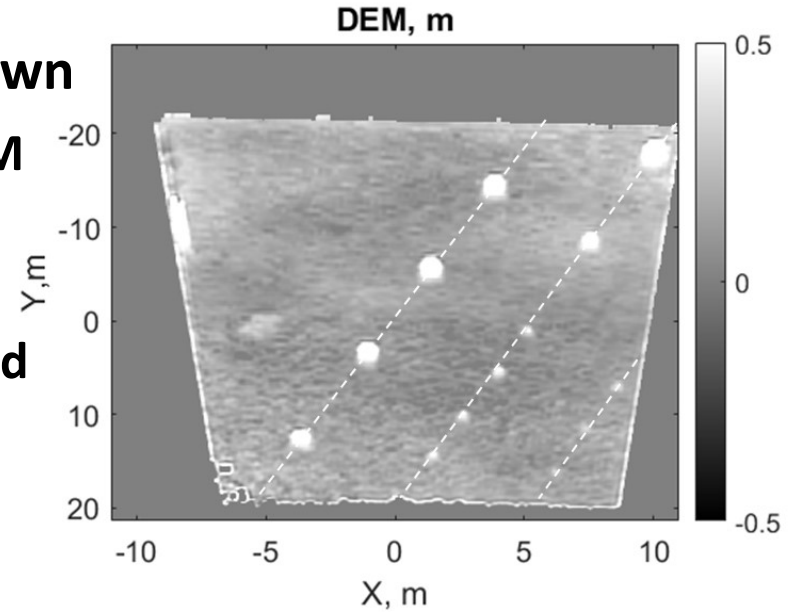


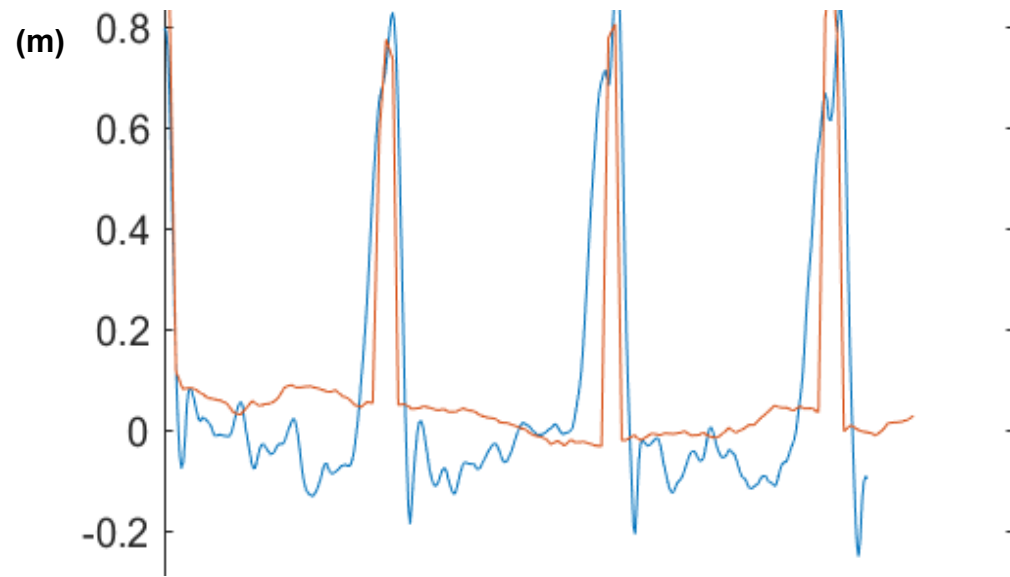
An example of TSL Helicopter Flight Test Data



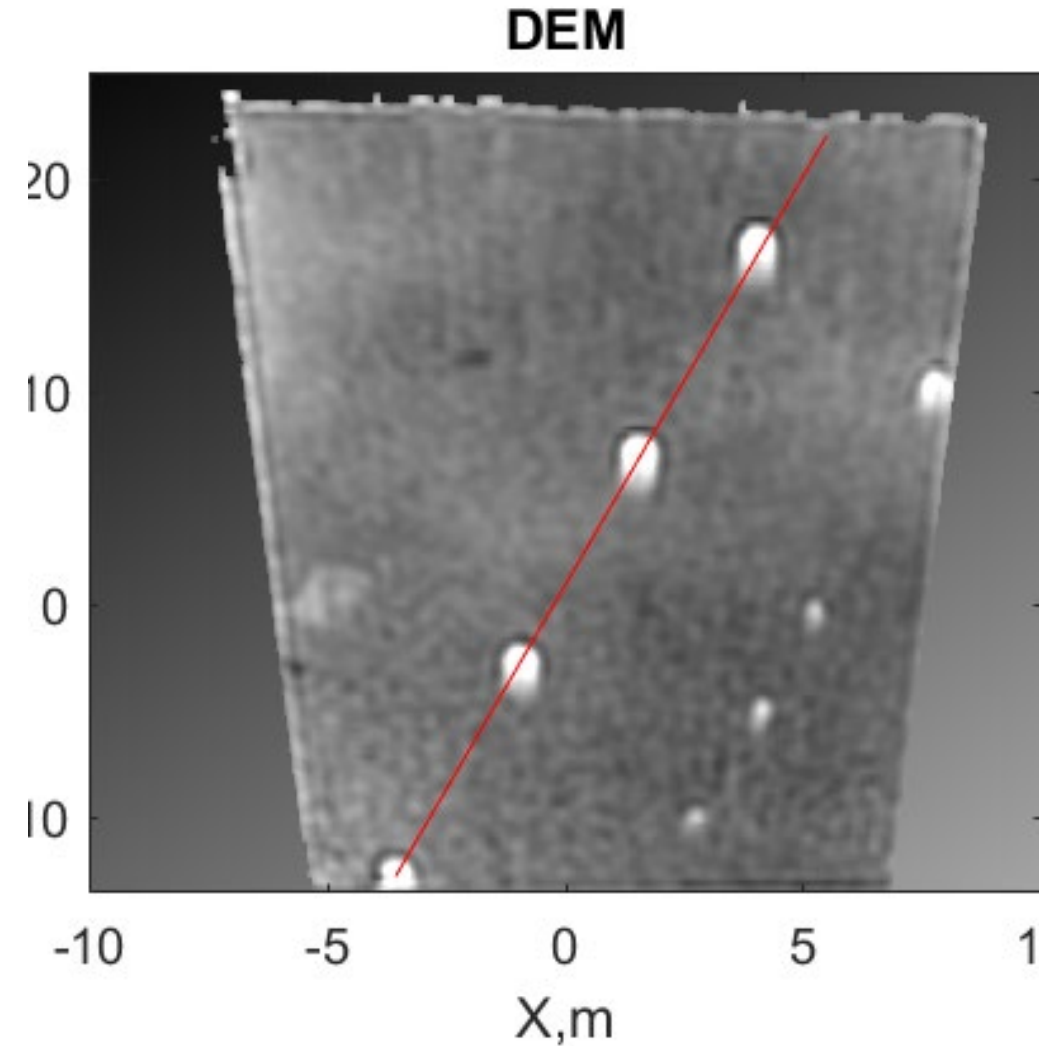
➤ Rock piles along each line are shown

- Solid line is the synthetic truth DEM generated by ground-based laser scans
- Red dots are pixels of TSL generated DEM





- Red is the elevation data from the "True DEM"
- Blue is restored TSL DEM





Terrain Sensing Lidar (TSL) Prototype



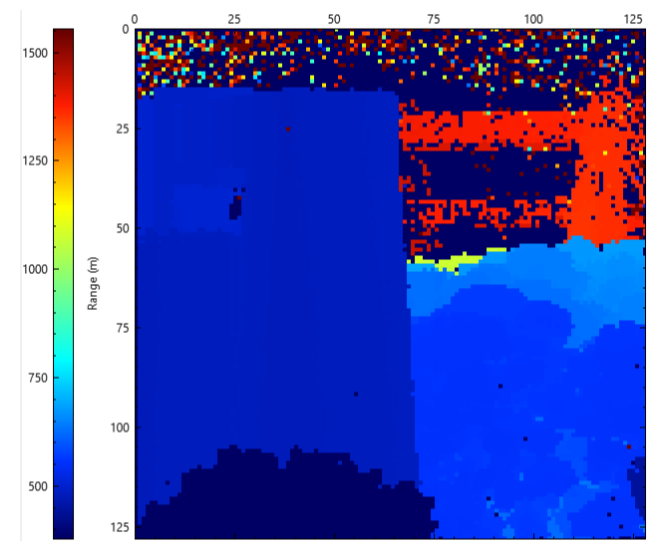
Upgrades over breadboard

- Extended HDA operational range to 1.4 km
- Updated image enhancement algorithms
- Incorporated long range *Altimetry* and active *Terrain Relative Navigation* functions
- Compact design

6.5 kg and 45 W including processor



Single Frame Images

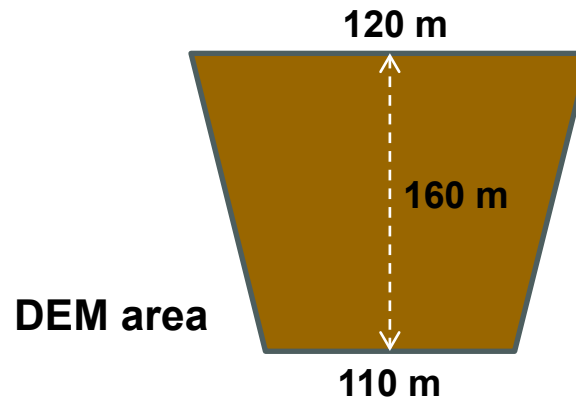




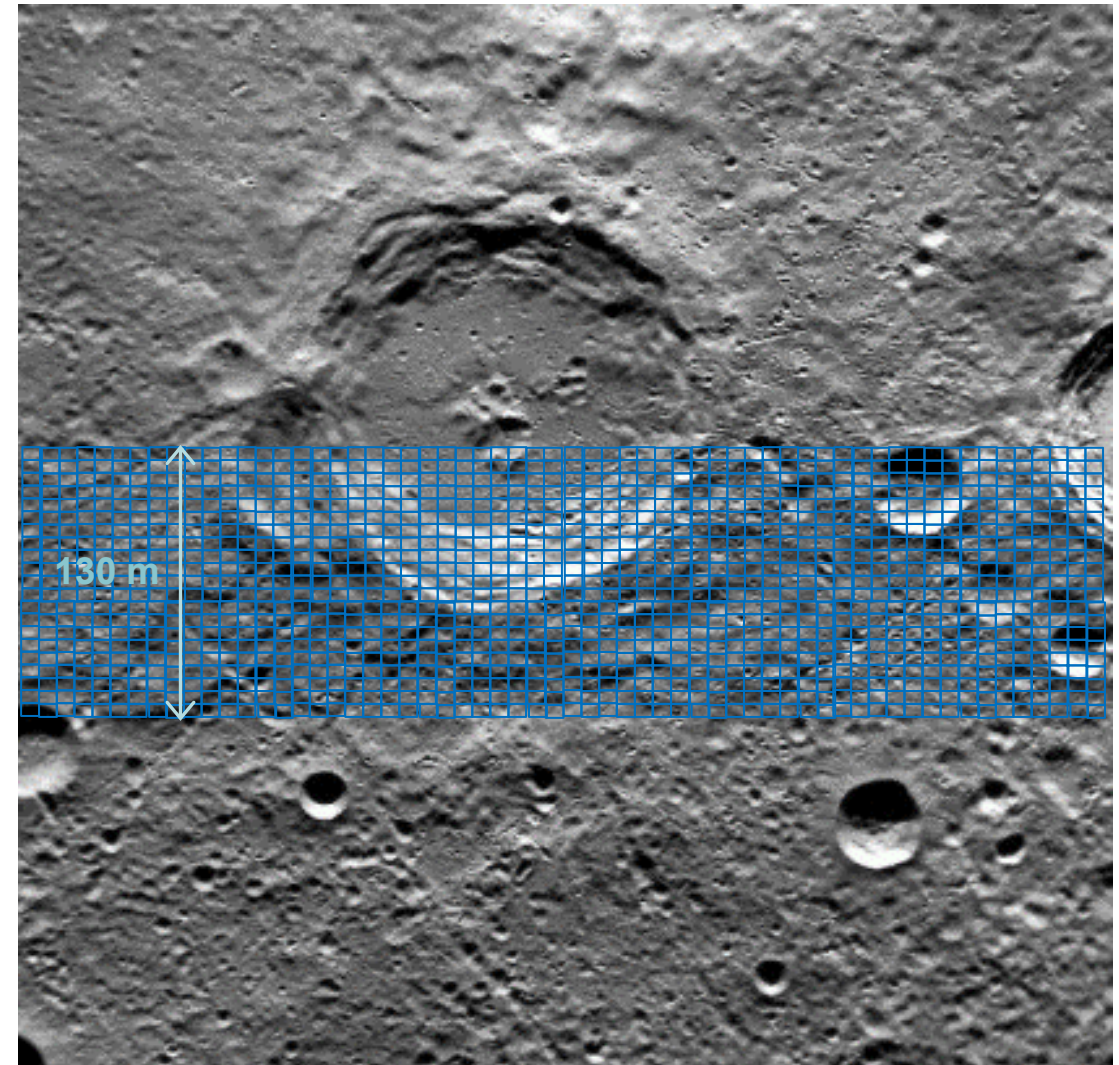
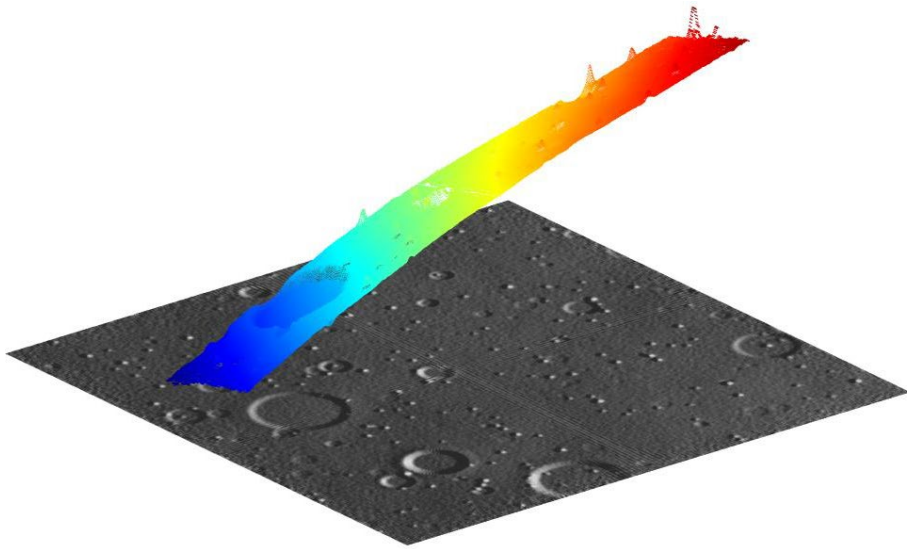
TSL - HDA Specifications



Digital Elevation Map (DEM) size	160 m x 110 m @ 1.3 km 45° slant range 125 m x 85 m @ 1.0 km 45° slant range
Number of DEM pixels	1.05M (1024 x 1024)
DEM and Hazard Map Update Rate	1 Hz with 30 msec latency
Minimum Detectable Hazard	25 cm radius
Elevation Noise	3 cm 1-σ



- Generates 130 m wide swath
- Sufficient overlap of individual frames for image enhancement and state vector estimation
- Sufficient resolution for matching with LOLA elevation maps (< 5 m)





TSL and NDL together make a powerful sensor suite



Terrain Sensing Lidar

Altitude

TRN

HDA

HRN

50 km

20 km

10 km

1 km

500 m

**Landing
"Anywhere/Anytime"**

**Navigation Doppler Lidar
Precision Vector Velocity and Altitude**

