

National Aeronautics and Space Administration



High resolution terrain sensing lidar for precision navigation and safe landing of space and aerial vehicles

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

NASA Langley Research Center

* Analytical Mechanical Associates

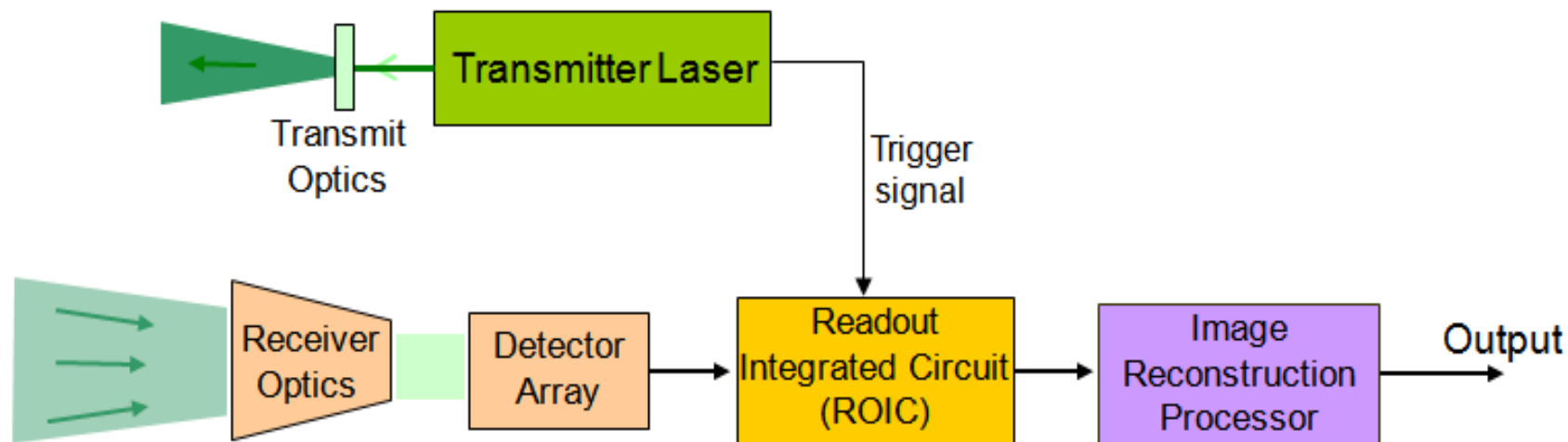
Photonic West 2025



Terrain Sensing Lidar (TSL)



- TSL is based on *flash lidar* technology utilizing real-time image enhancement and processing algorithms
- Flash lidar presents several advantages over scanning lidars for hazard detection and safe landing on planetary bodies
 - Does not require vehicle motion correction
 - Fast image acquisition time
 - Organized image pattern (does not need oversampling of the landing site)
 - Able to perform other functions critical for precision navigation





TSL Landing Operation Concept



Altimetry

70 km

Updating IMU and reducing position errors

A-TRN

20 km

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

10 km

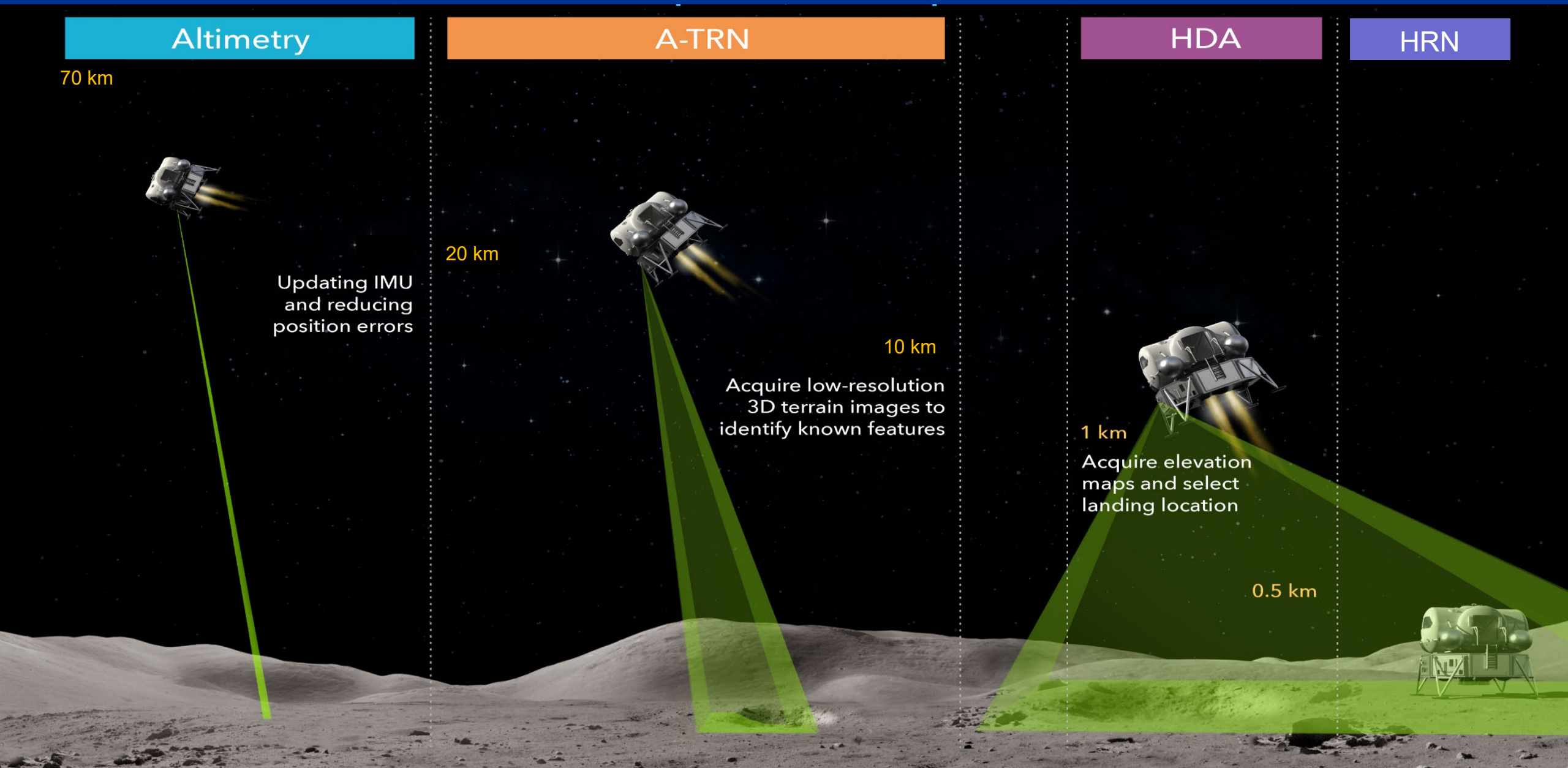
HDA

1 km

Acquire elevation maps and select landing location

HRN

0.5 km



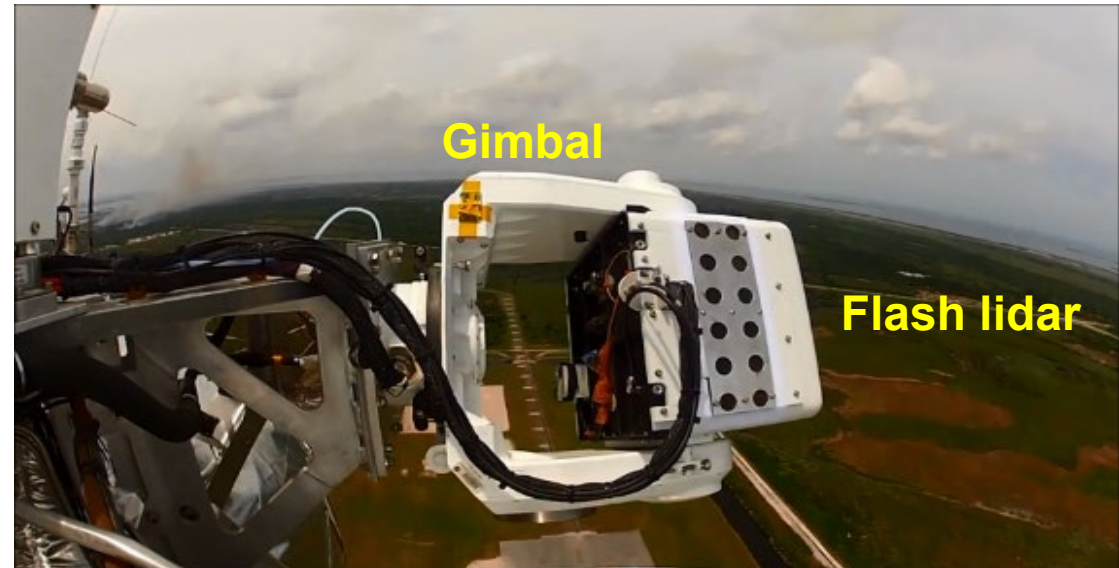


Hazard Detection and Avoidance Requirements

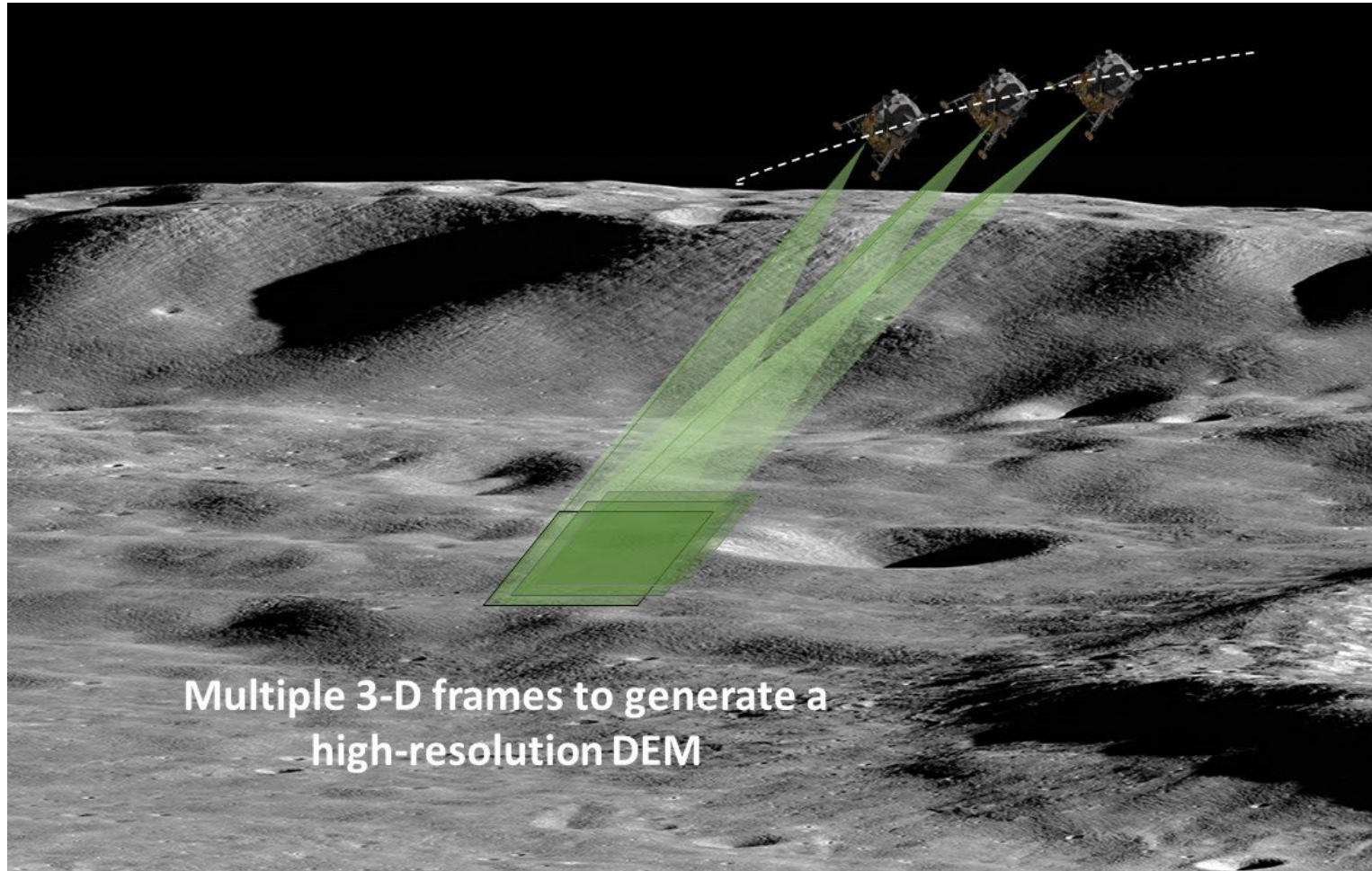


- Commercial linear-mode flash lidar camera has $128 \times 128 = 16.4\text{k}$ pixels
- Mapping $100 \text{ m} \times 100 \text{ m}$ area with 15 cm Ground Sample Distance (GSD) requires $\sim 0.5 \text{ M}$ pixels
- Developed a Super-Resolution algorithm to meet HDA requirements without the need for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

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

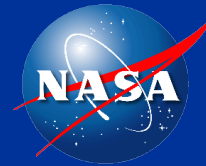


- Super-Resolution (SR) technique uses a set of consecutive frames, from slightly different positions and angles (resulting from platform motion), to generate a high-resolution DEM
- Generates high-res DEMs at 1 Hz rate using 20 frames
- No external sensor data is required
- Provides 6-DOF relative state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





Helicopter Flight Test



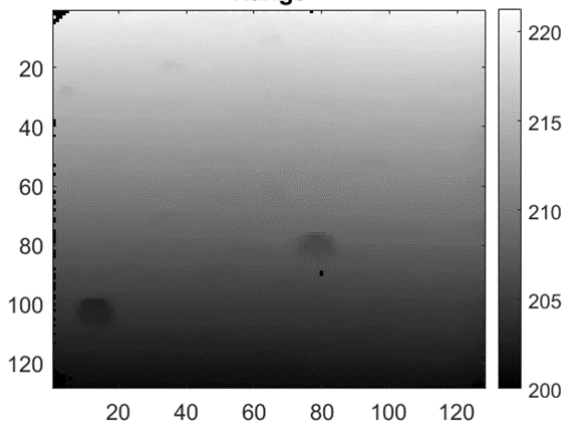
Blue Origin West Texas Facility, August 2023

➤ 100% hazard detection from 250 m @ 45° look angle

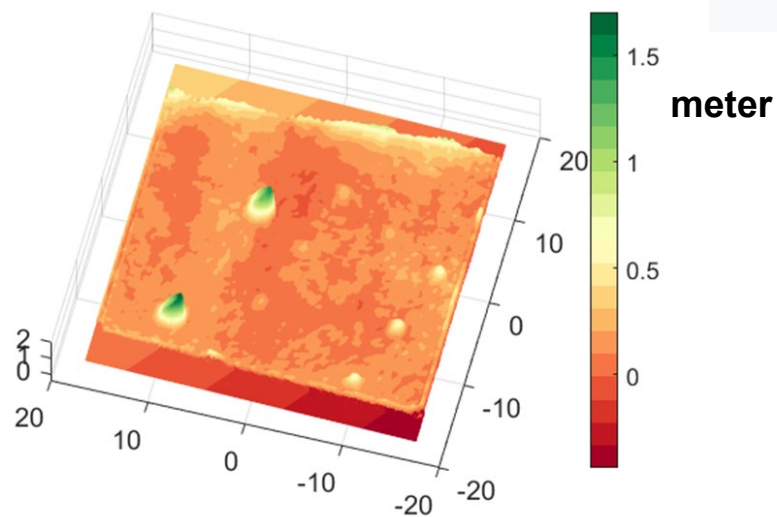
- Smallest hazard: 25 cm dia x 35 cm height

Single Frame

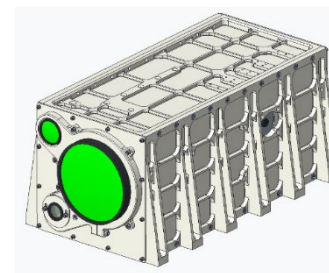
Range



Real-Time Elevation Map



Breadboard Flash Lidar

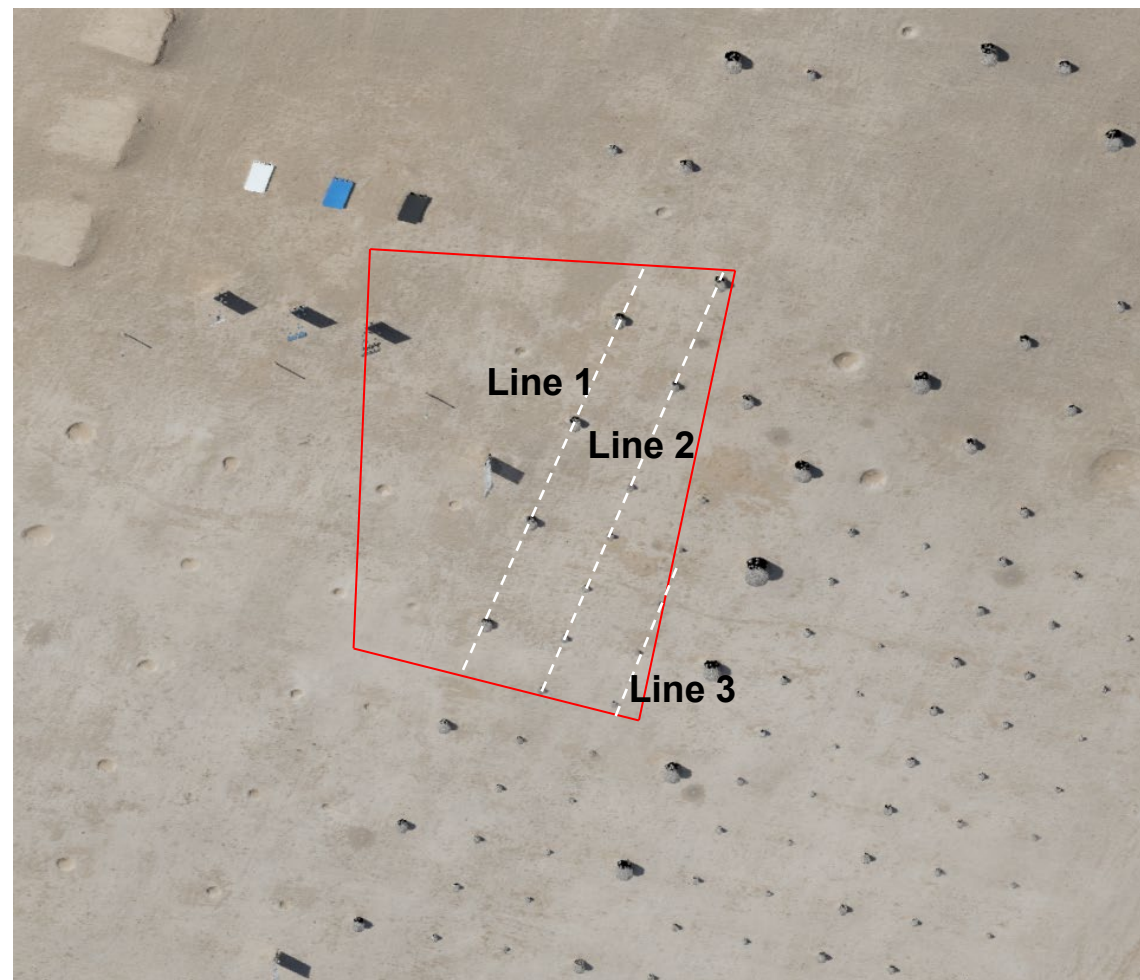




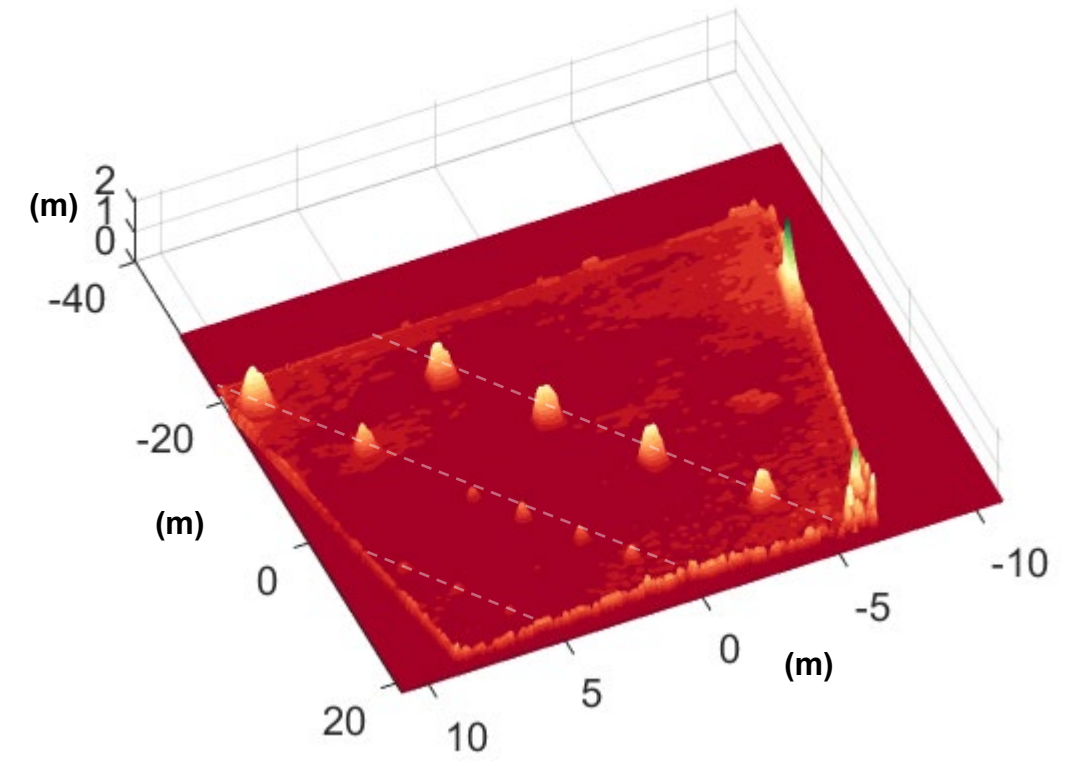
An example of TSL Helicopter Flight Test Data 71 degrees Trajectory Path Angle



Hazard Field synthetic image and TSL footprint



Corresponding DEM generated in real-time @ 1 Hz



Note that the axes are not in scale

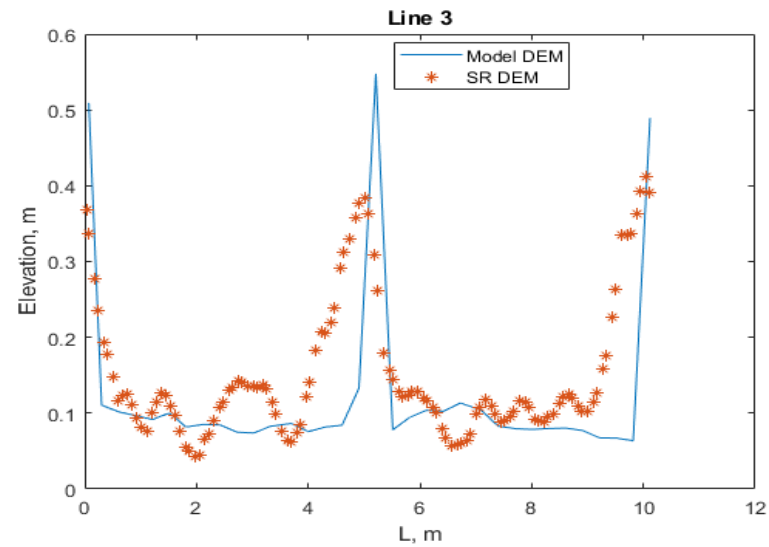
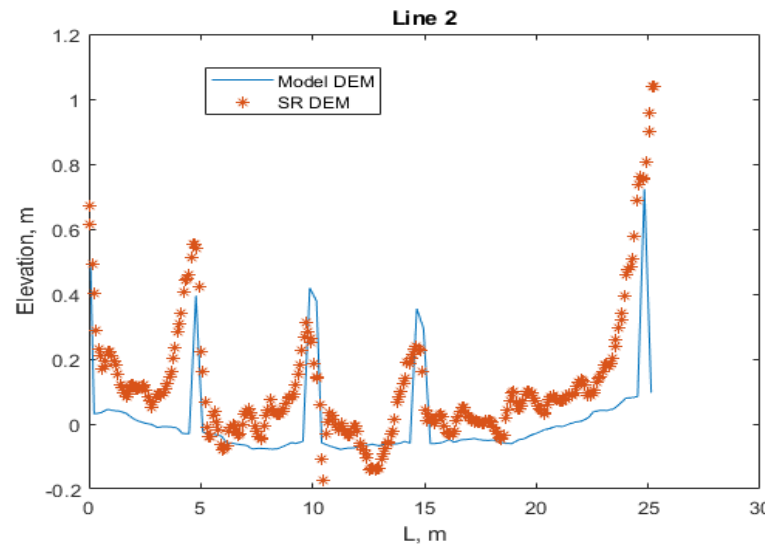
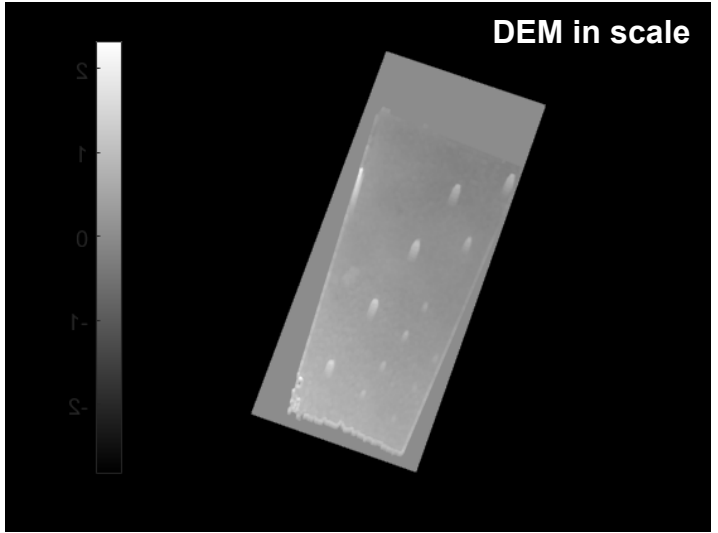
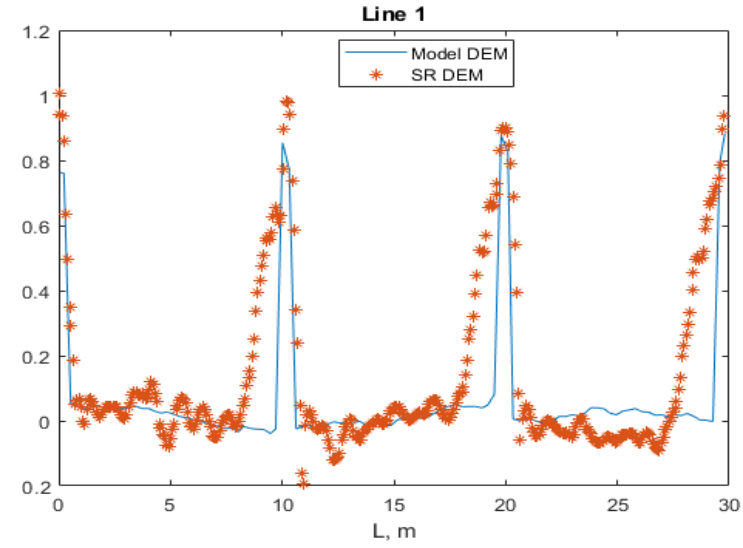
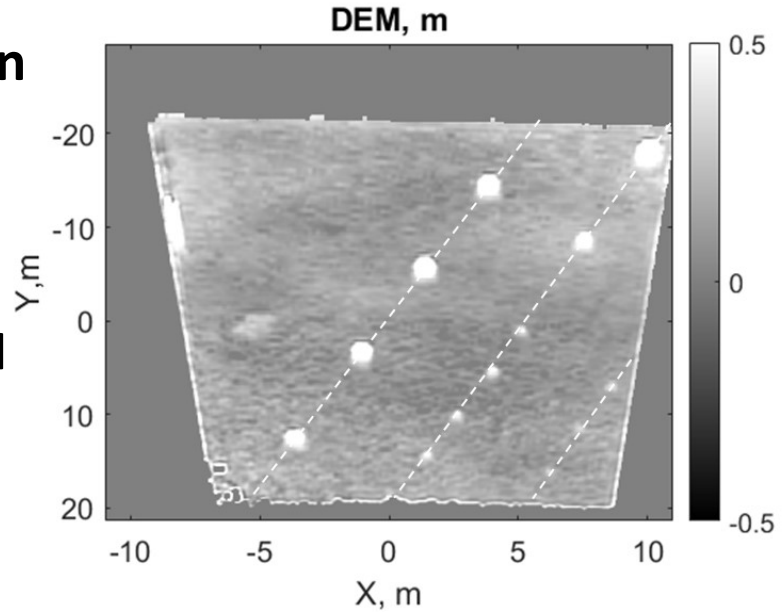


TSL Helicopter Flight Test Data



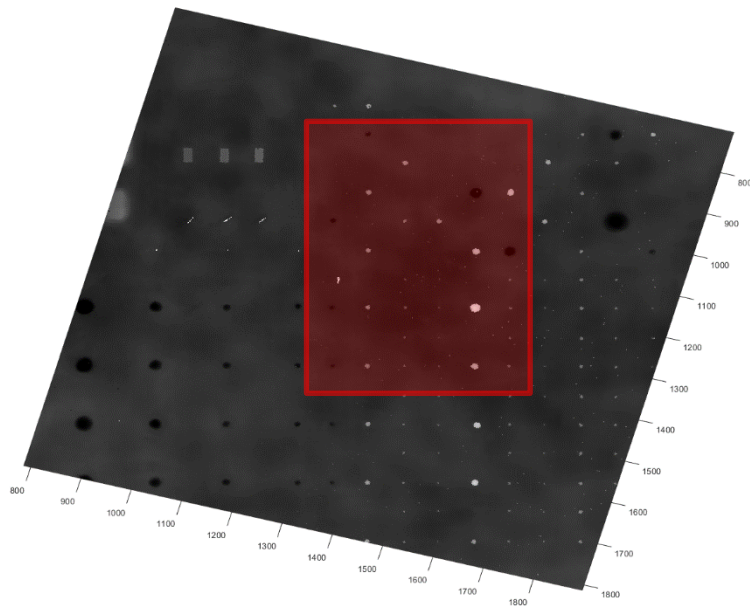
➤ Rock piles along each line are shown

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

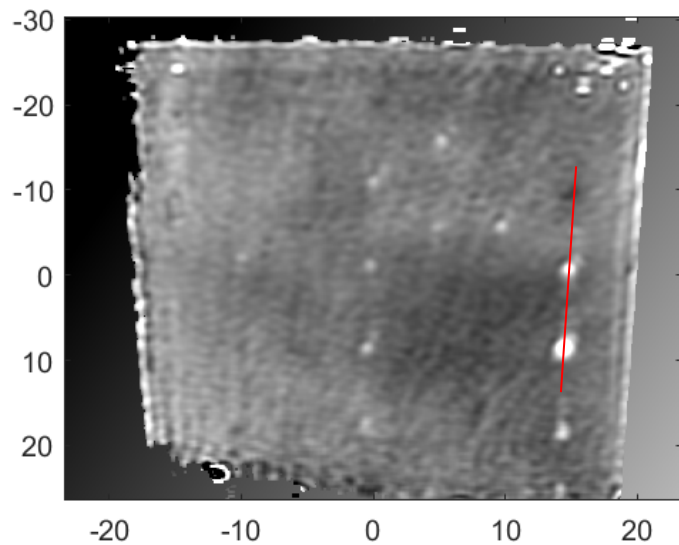


- Much of discrepancies in measurements of the surface is due ground erosion due to weather

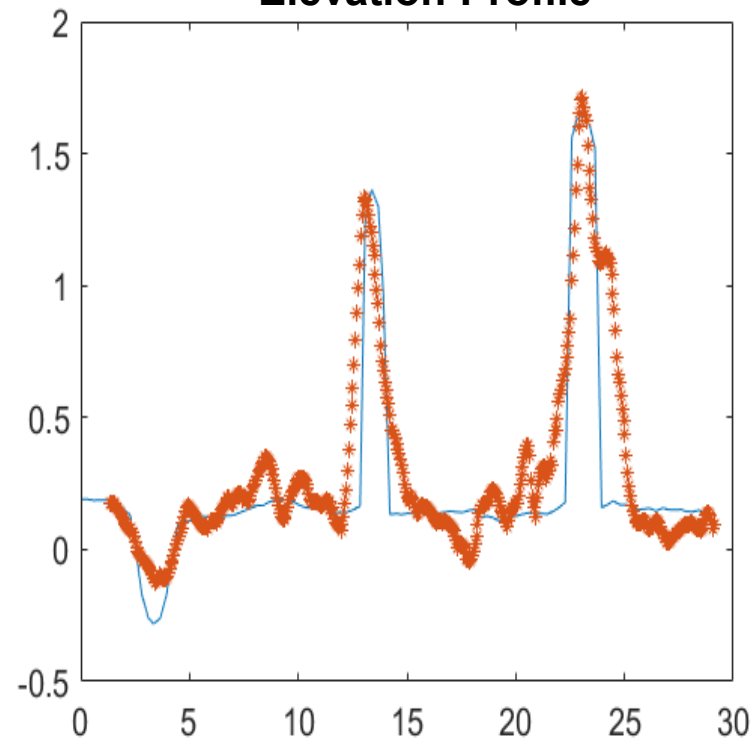
Truth DEM



TSL-generated DEM



Elevation Profile



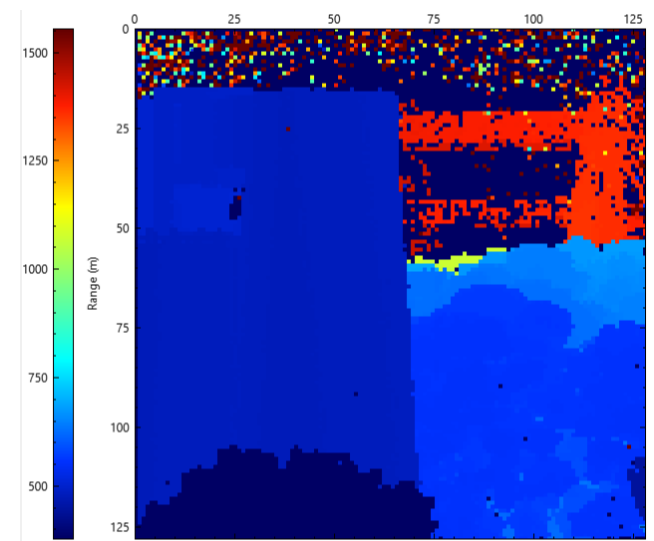
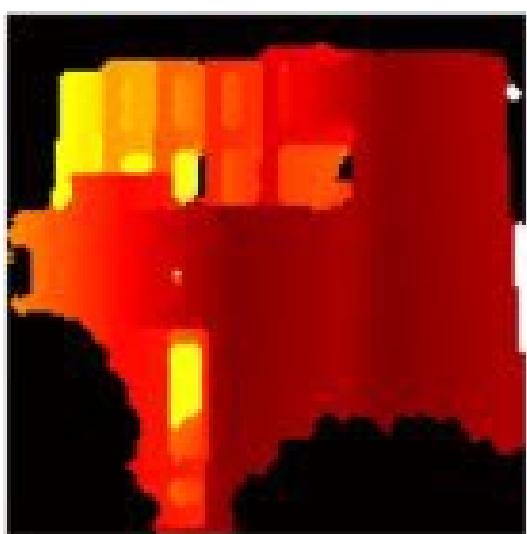
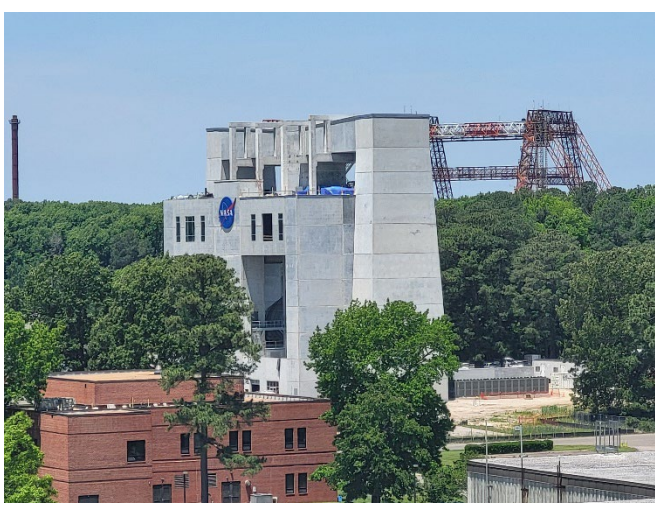
Upgrades over breadboard

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

6.5 kg and 43 W including processor



Single Frame Images





TSL and NDL together make a powerful sensor suite



Terrain Sensing Lidar

Altitude

TRN

HDA

HRN

70 km

20 km

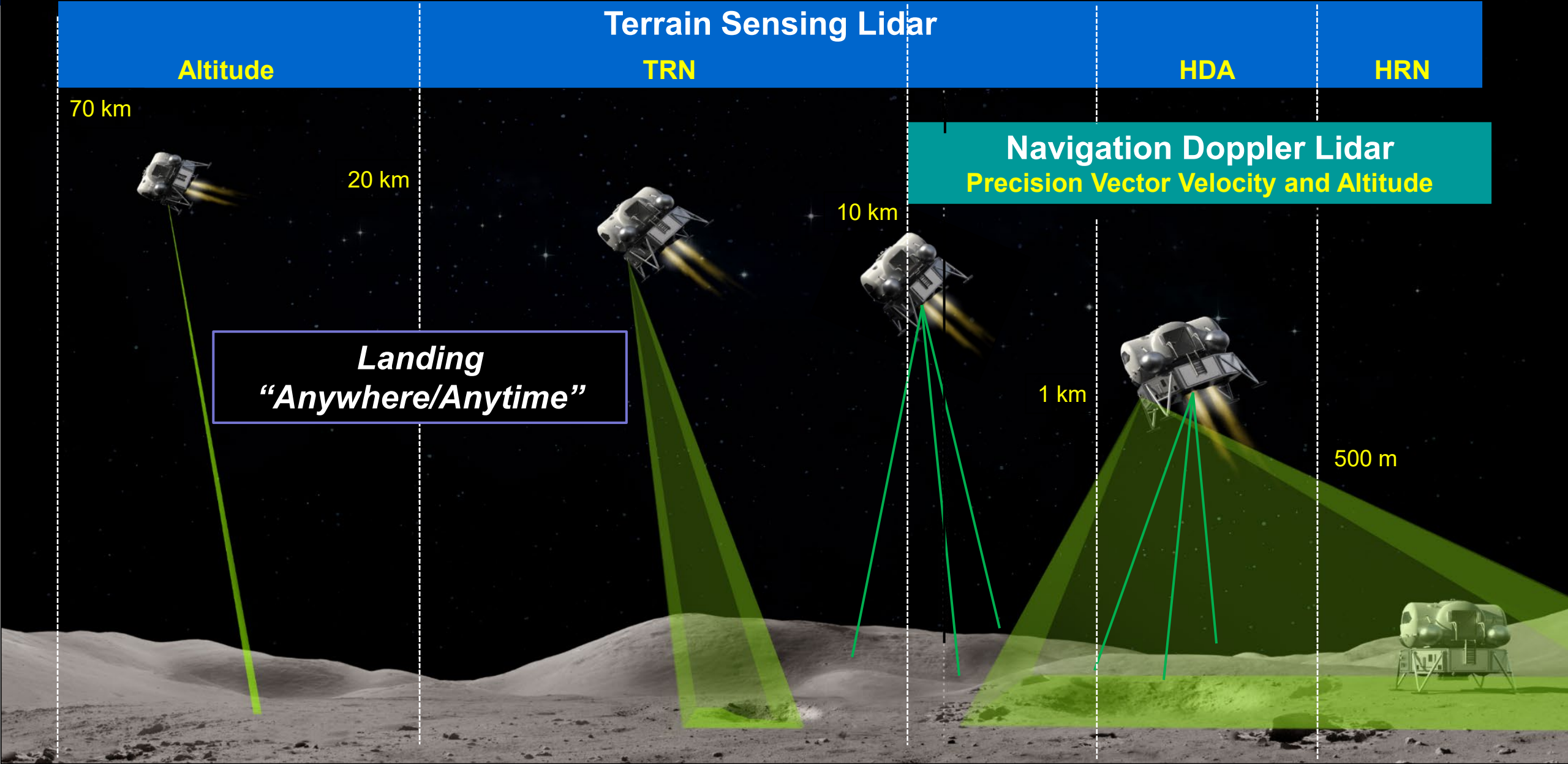
10 km

1 km

500 m

**Landing
"Anywhere/Anytime"**

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





Accurate Lunar Surveyor and Terrain-mapping Autonomous Rover (ALSTAR) Lidar



- **ALSTAR Lidar is a variant of TSL capable of providing**
 - **Obstacle identification**
 - **Assistance with route planning**
 - **Situational awareness**
 - **Relative velocity, position, and heading**
 - **Necessary data for mating with pressurized habitats**
 - **Local area terrain maps for resource exploration and scientific purposes**

