National Aeronautics and Space Administration

3-D flash lidar for hazard detection and precision navigation on planetary bodies

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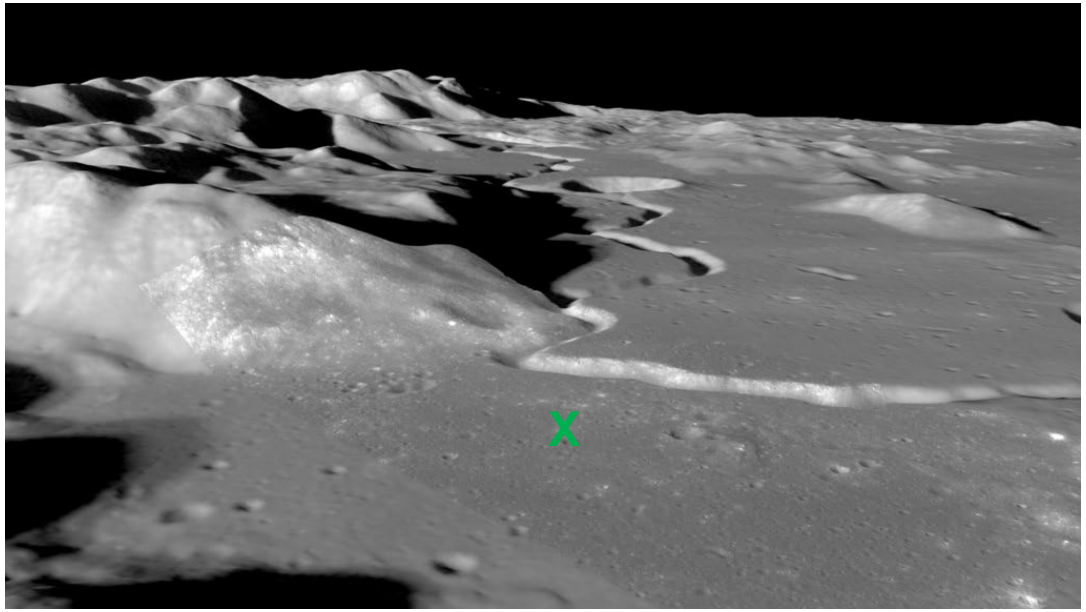
2023 P3DL CoP Conference

Landing missions are progressively more ambitious

- Past landing missions generally selected benign terrains
- Objectives of future landing missions:
  - Sustainable human presence at the Moon and continued human exploration on towards Mars
  - Exploration of Jupiter and Saturn Moons (e.g., Titan, Europa), and Asteroids

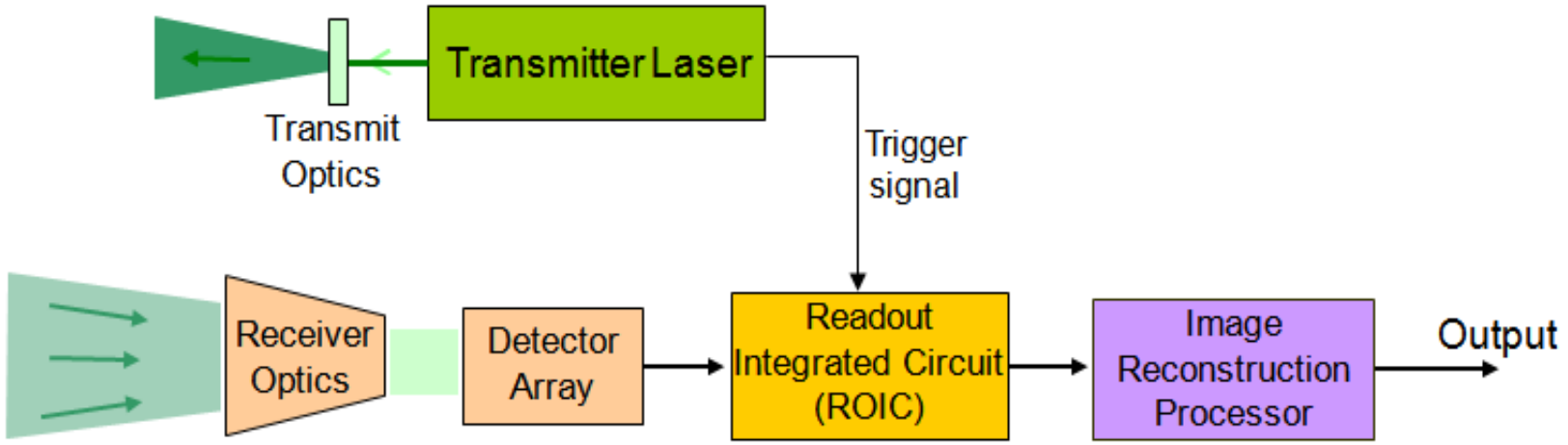
Apollo 15 Landing Site



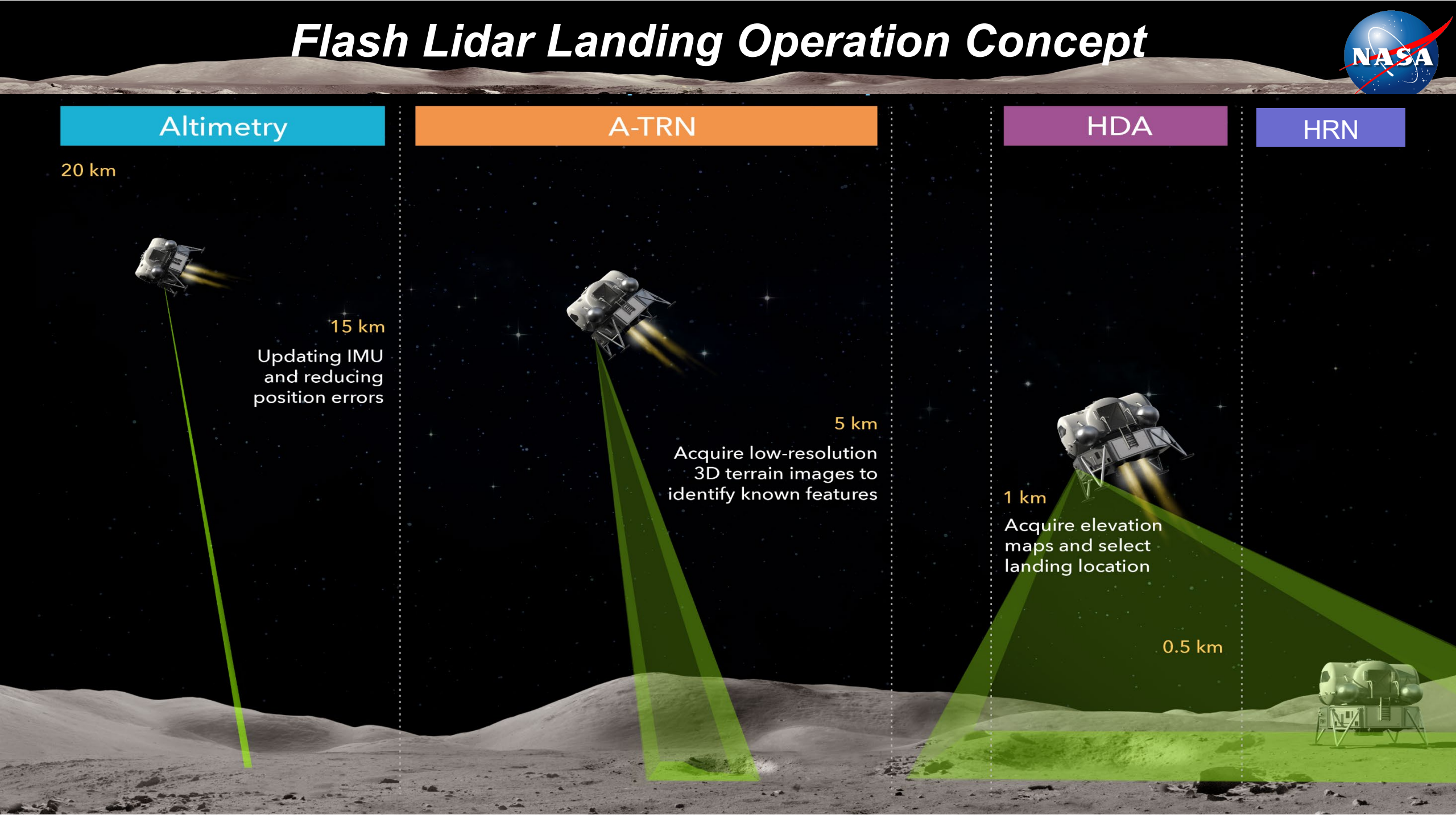
Artemis Landing Site

3-D Imaging Flash Lidar Sensor

- **Flash lidar presents several advantages over scanning lidars for hazard detection and safe landing on planetary bodies**
  - **Does not require extensive processing for vehicle motion correction**
  - **High frame rate**
  - **Able to perform other functions critical for precision navigation**



Flash Lidar Landing Operation Concept



ALHAT Technology Development and Field Tests

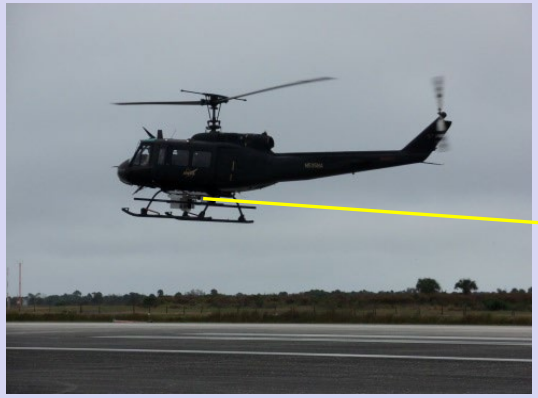
From Breadboard to Fully-Autonomous Prototype

2008 - Hazard Detection

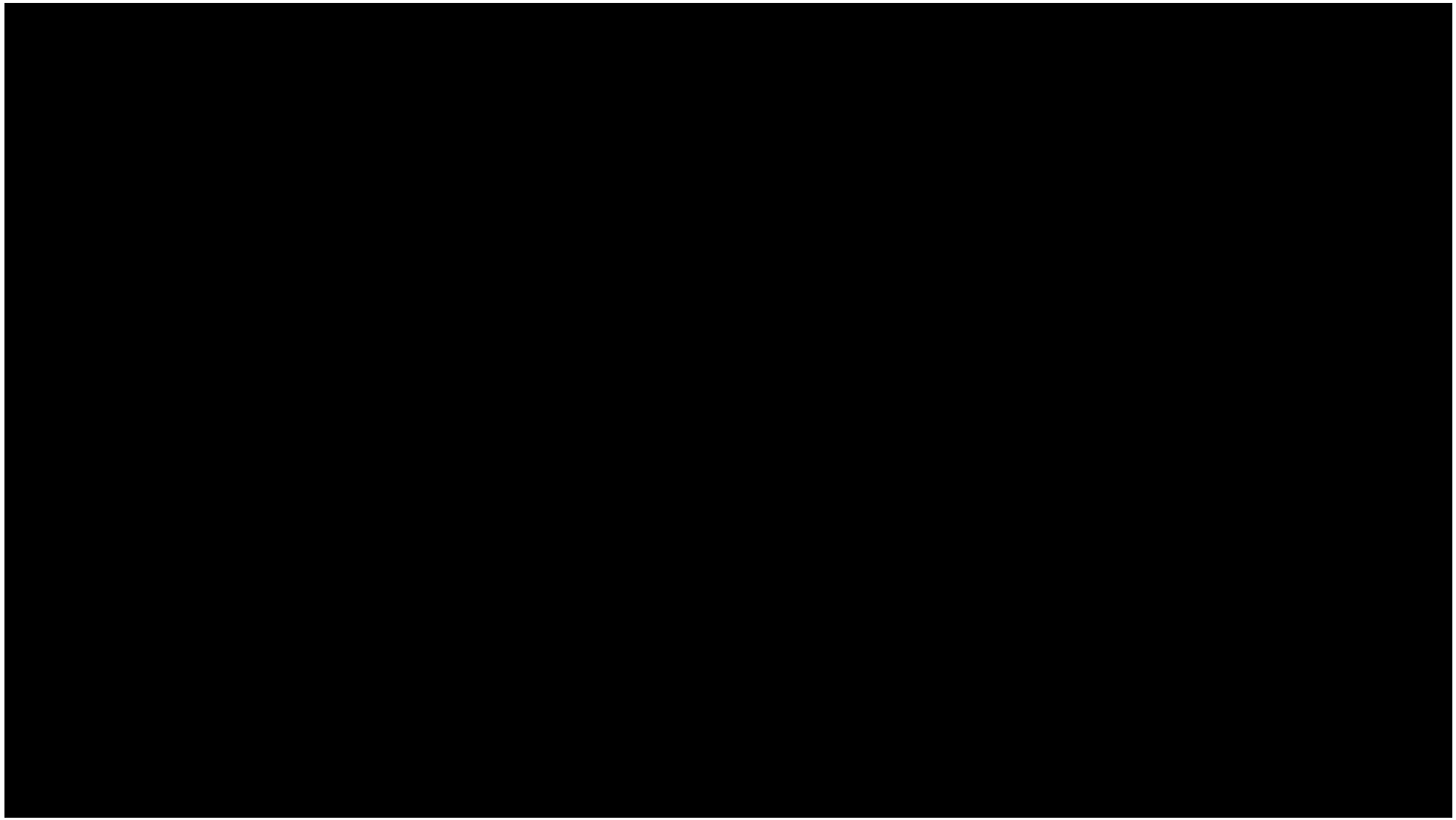
2009 – TRN and Altimetry

2010 – Hazard Detection

2012 - Hazard Detection



Closed-loop demonstration onboard rocket-powered Morpheus vehicle (2014)

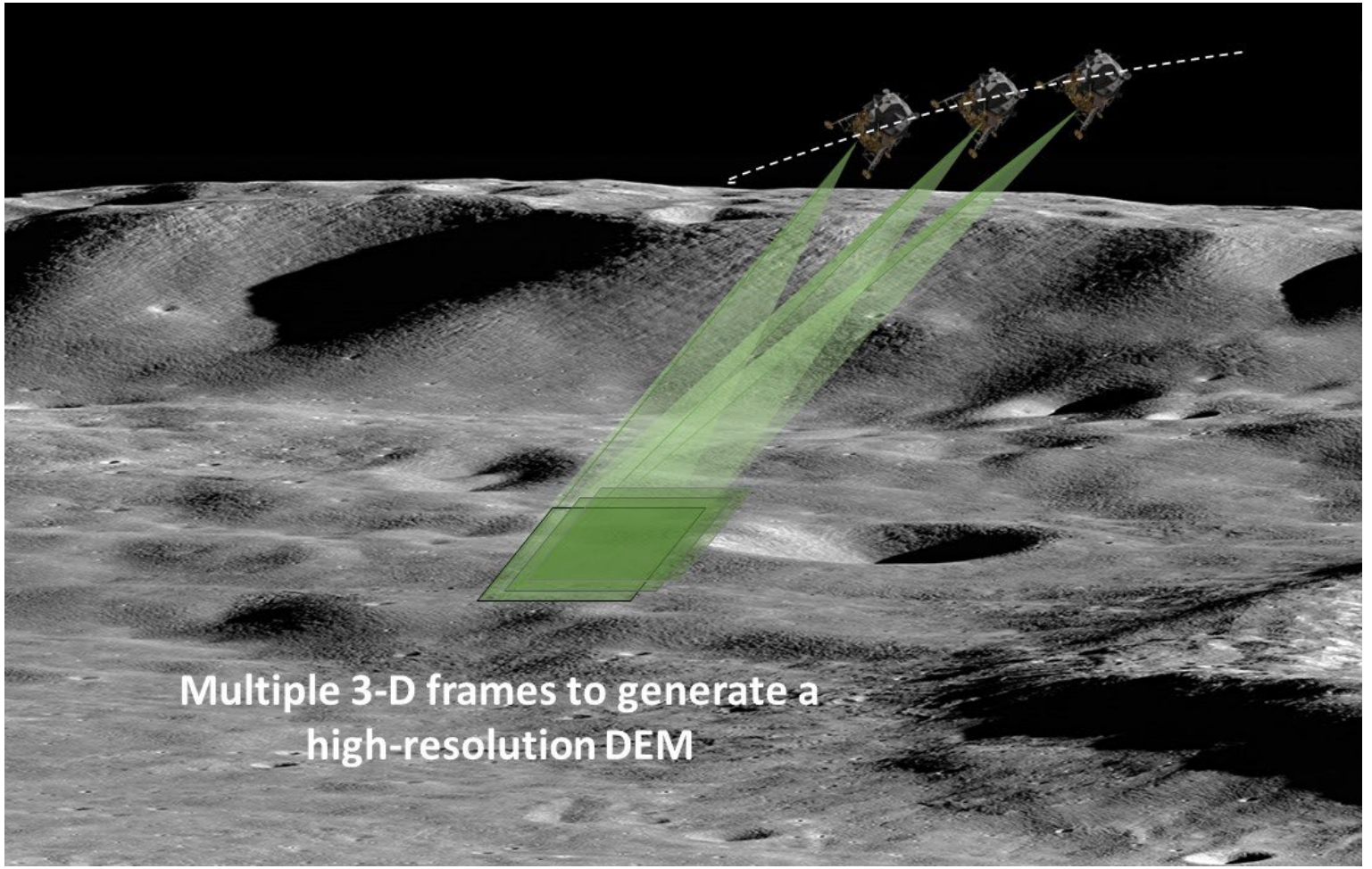


Flash Lidar Descent and Landing Requirements

- Mapping 70 m x 70 m area with 10 cm Ground Sample Distance (GSD) requires 0.5 M pixels
  - 10 cm GSD is required to detect 30 cm radius hazards
- Commercial flash lidar camera has 128x128 = 16.4k pixels
- Developed a Super-Resolution algorithm to meet HDA requirements without a need for a mechanical gimbal

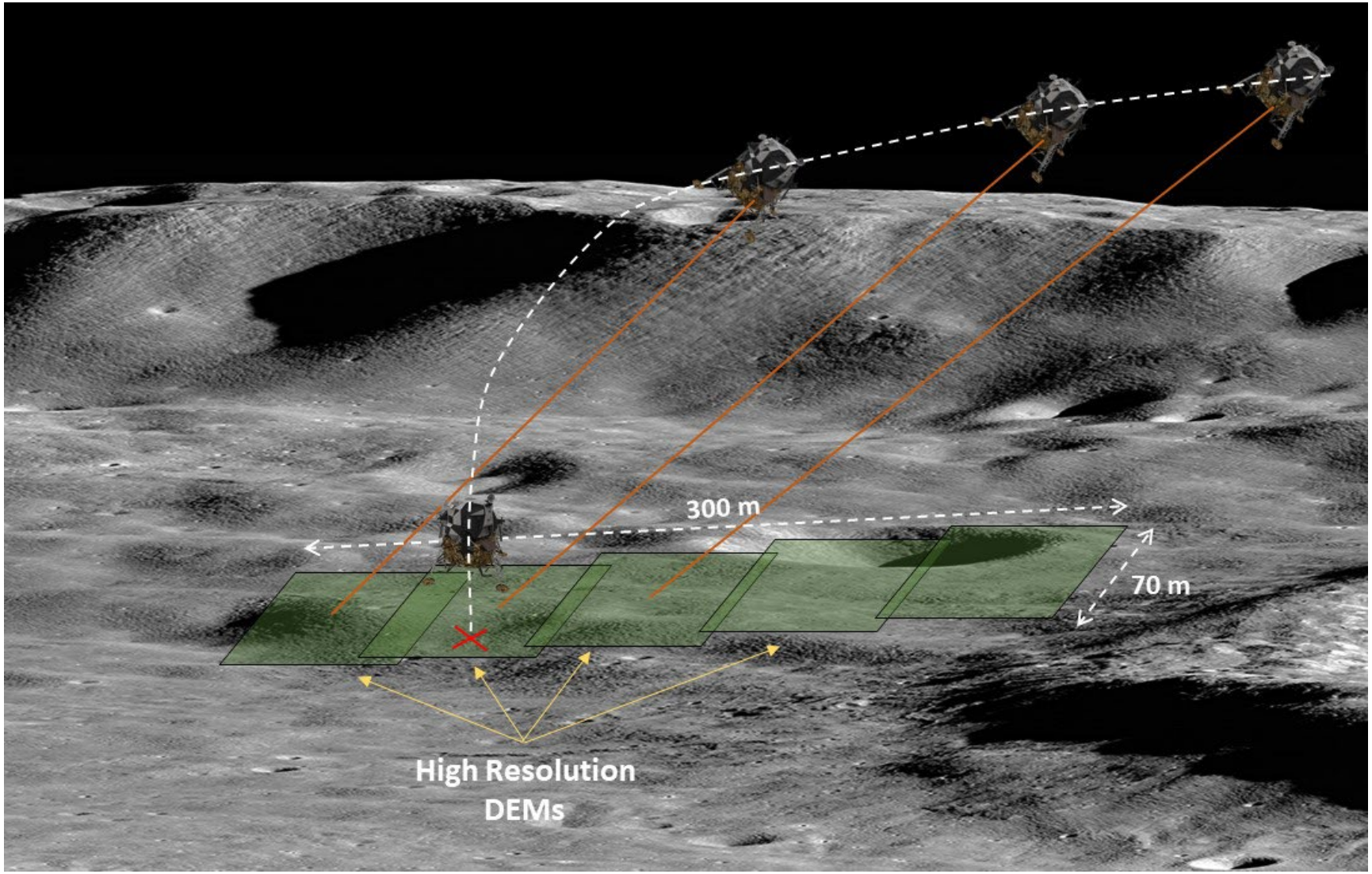
Flash Lidar Super-Resolution Algorithm

- 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



Flash Lidar Generates Multiple High-Resolution DEMs

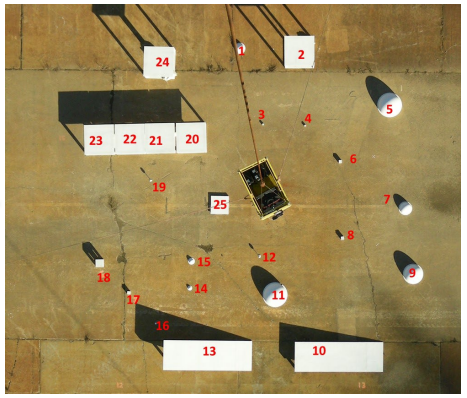
~ 70 m x 300 m high-resolution DEM for hazard detection and safe landing location selection



Development and Testing of Flash Lidar with Real-Time SR Algorithm at NASA LaRC

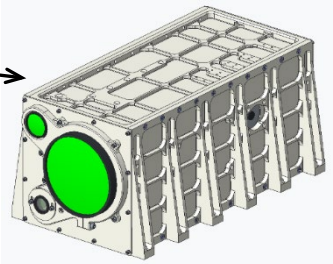
Gantry Test

Flash Lidar

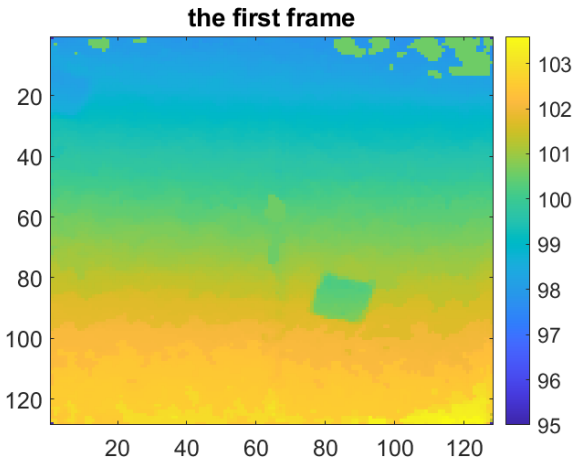


Drone Test

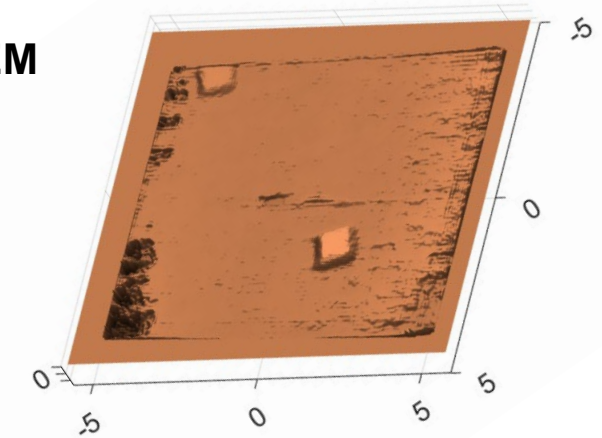
Breadboard Flash Lidar



Drone Flight Tests at LaRC



SR DEM

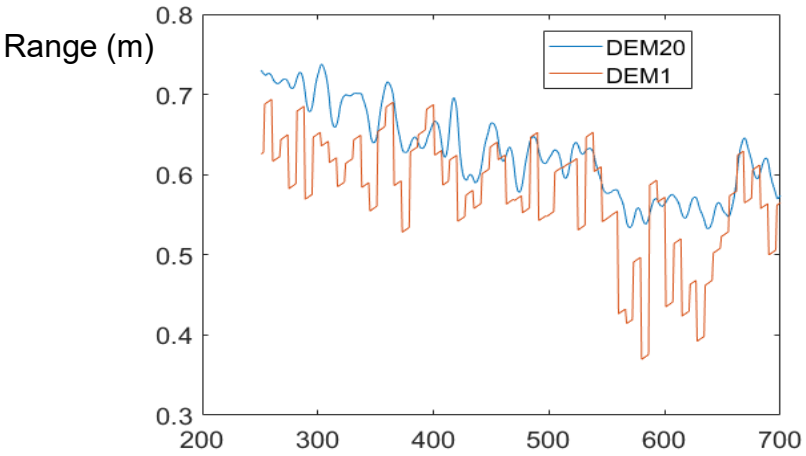


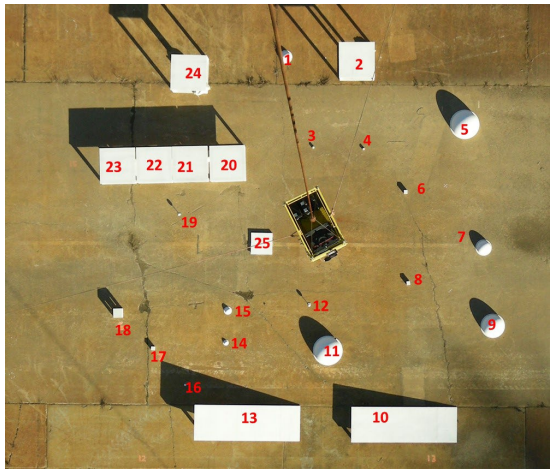
Dimensions in meters

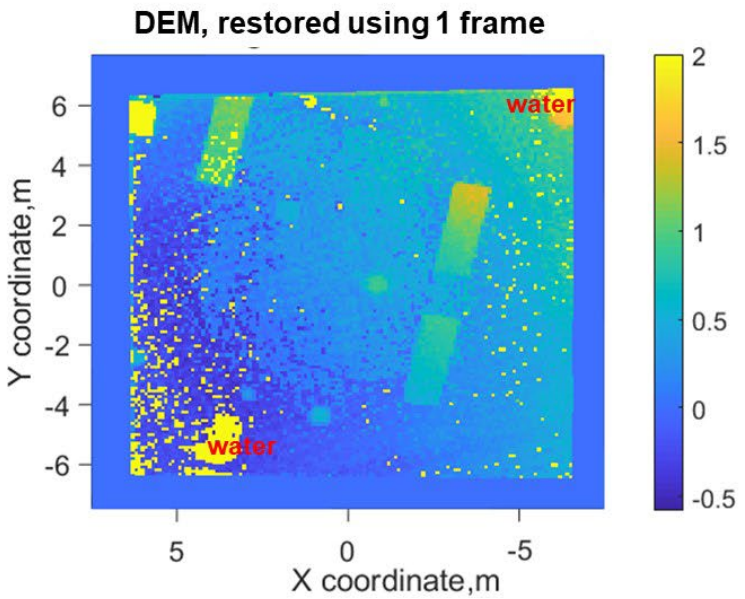
Distance (m)

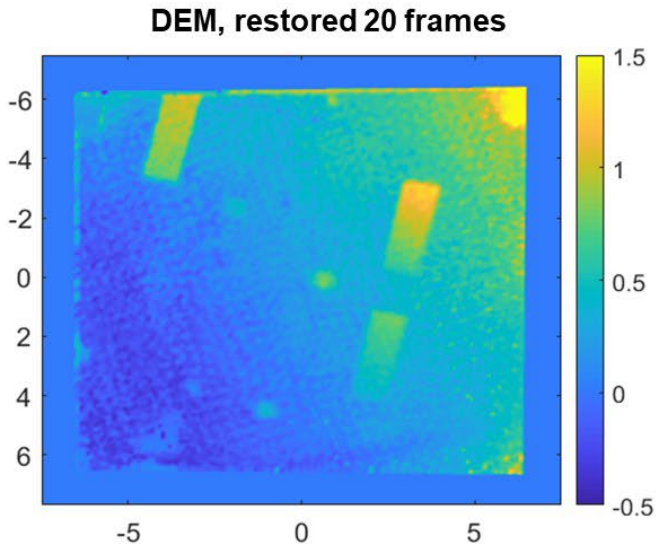
Performance of Real-Time Super-Resolution Algorithm

- Generated DEMs at 1 Hz rate
- Resolution enhancement by 25X (0.4M pixels)
- Range noise reduction by 2X (3 cm)
- Effectively recovered dark pixels



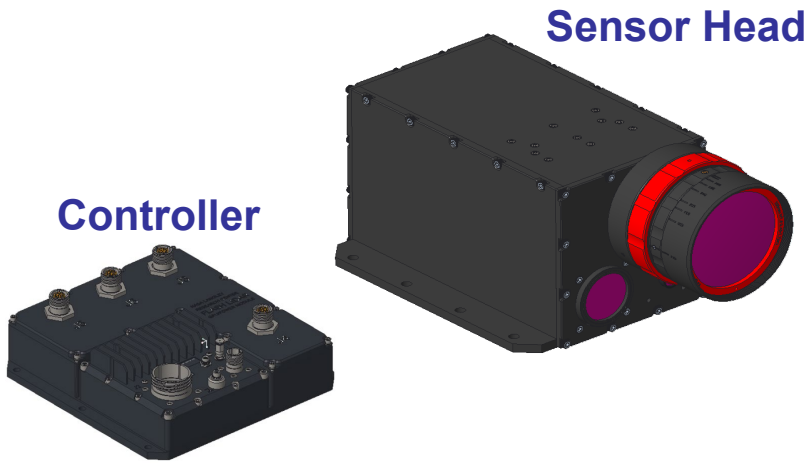




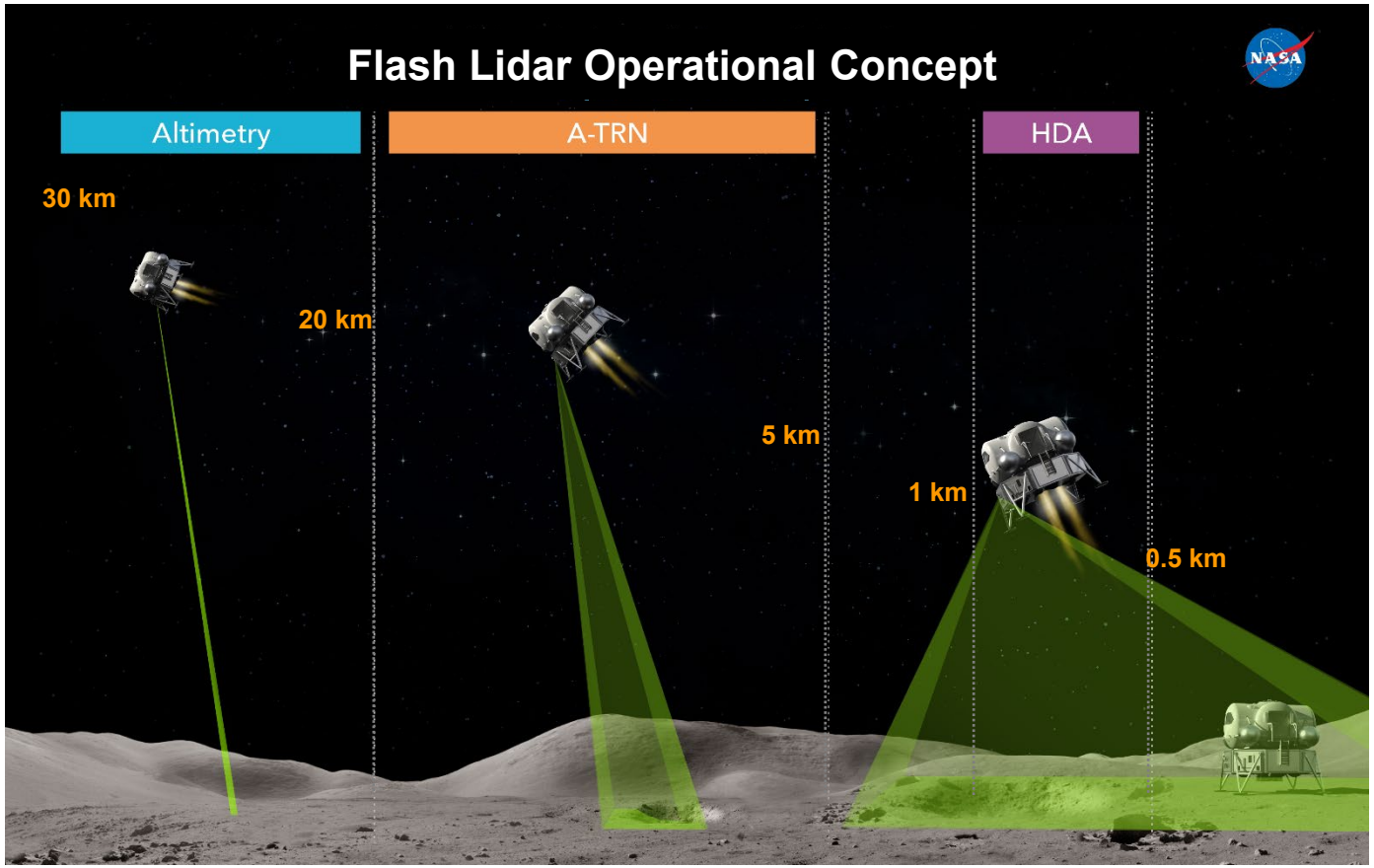


Plan for Remaider of 2023

- Helicopter flight test using existing breadboard unit
- Complete next generation Flash Lidar with Multi-Functional capability
- Conduct drone and aircraft flight tests



Dimensions	Sensor Head	11.8”x6.6”x4.7”
	Controller box	9.0”x9.0”x2.5”
Weight	Sensor Head	9.0 lb
	Controller box	6.0 lb
Power		55 W



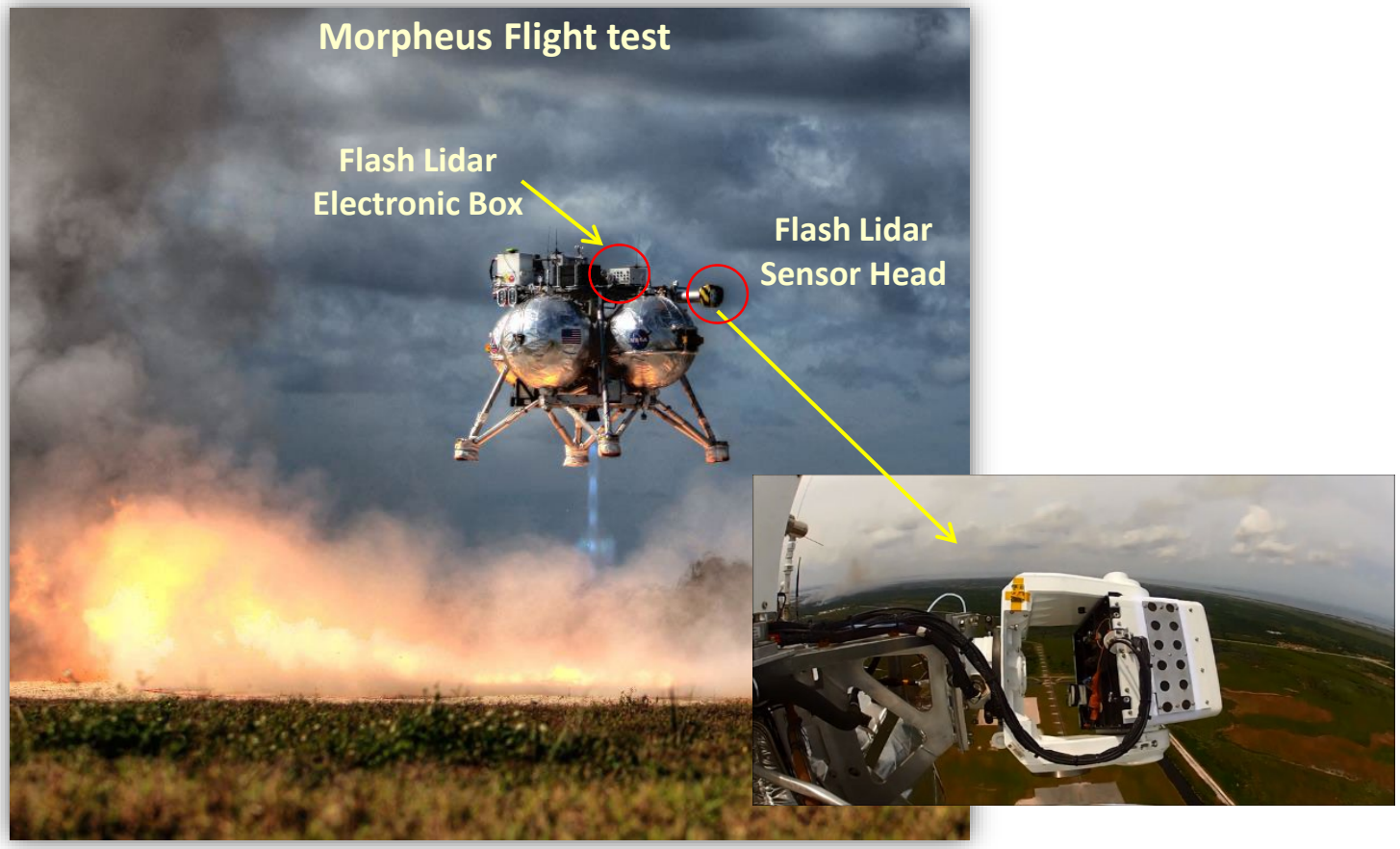
Other Landing Lidar Sensors Under Development at NASA

Lidar Sensor	Type	NASA Center	Functions
Ocellus	Scanning	GSFC	Hazard Detection and Altimetry
SPLICE HDL	Scanning	GSFC	
ELSA MIT-LL Lidar	Hybrid Scanning/Flash	JPL	Hazard Detection, Altimetry and Terrain Relative Navigation (TRN)
ELSA Sigma Space Lidar	Hybrid Scanning/Flash	JPL	
Multi-Functional Lidar	Flash	LaRC	
Navigation Doppler Lidar	FMCW	LaRC	Velocity and Altimetry

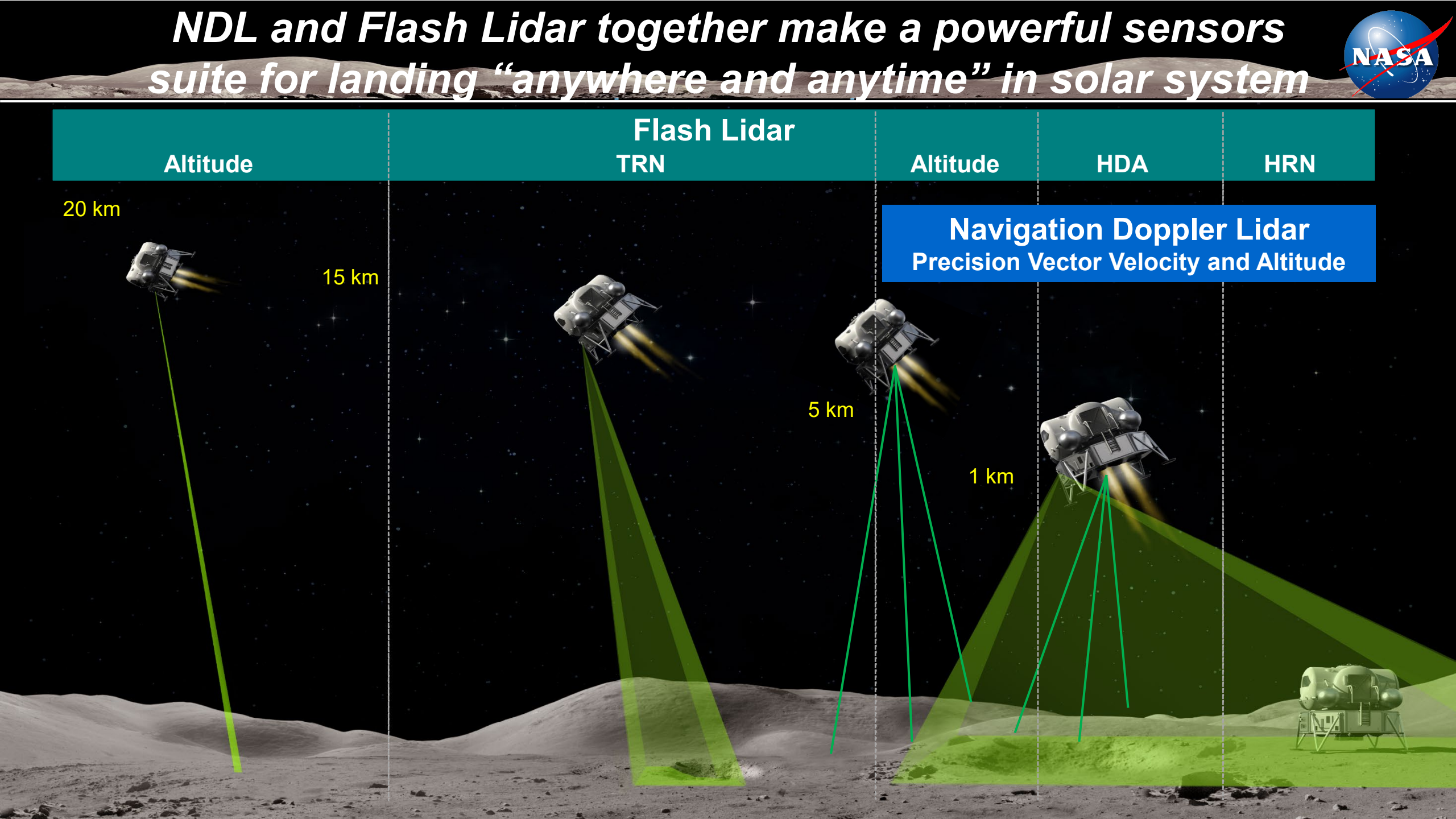
Backup

State of Technology at Conclusion of ALHAT

- Closed-loop demonstration onboard rocket-powered Morpheus vehicle (2014)
- Insufficient number of FPA pixels for mapping required area with desired resolution
- Used a mechanical gimbal to generate several 3-D image frames and stitch them together



NDL and Flash Lidar together make a powerful sensors suite for landing "anywhere and anytime" in solar system



Navigation Doppler Lidar (NDL)

- **NDL provides vehicle precision vector velocity and altitude data**
- **Viable replacement for radars with an order of magnitude higher precision and much better data quality**
  - Enables "***precision navigation***" to the designated landing location
  - Enables "***well-controlled***" descent, landing, and ascent maneuvers to within a few cm/sec