National Aeronautics and Space Administration

Demonstration of Lidar Sensors for Precision Safe Landing on Planetary Bodies

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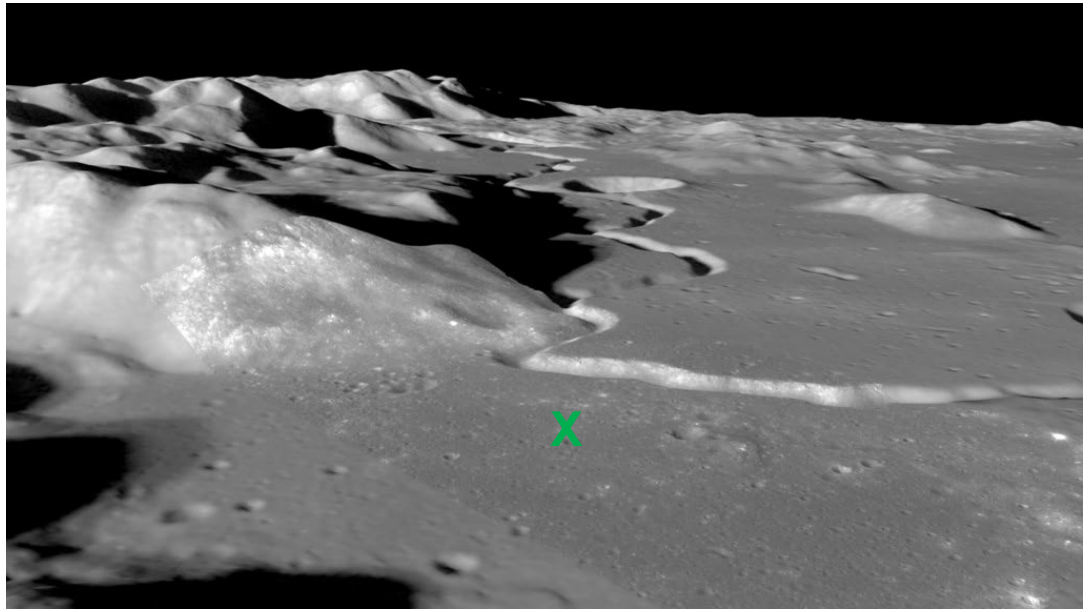
3rd International Workshop on Space-based Lidars

Landing missions are progressively more ambitious

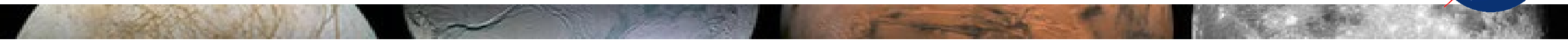
- Past landing missions generally selected benign terrains
- Objectives of future landing missions:
  - Sustainable human presence at the Moon and continued human exploration on towards Mars
  - Exploration of Jupiter and Saturn Moons (e.g., Titan, Europa), and Asteroids

Apollo 15 Landing Site



Artemis Landing Site

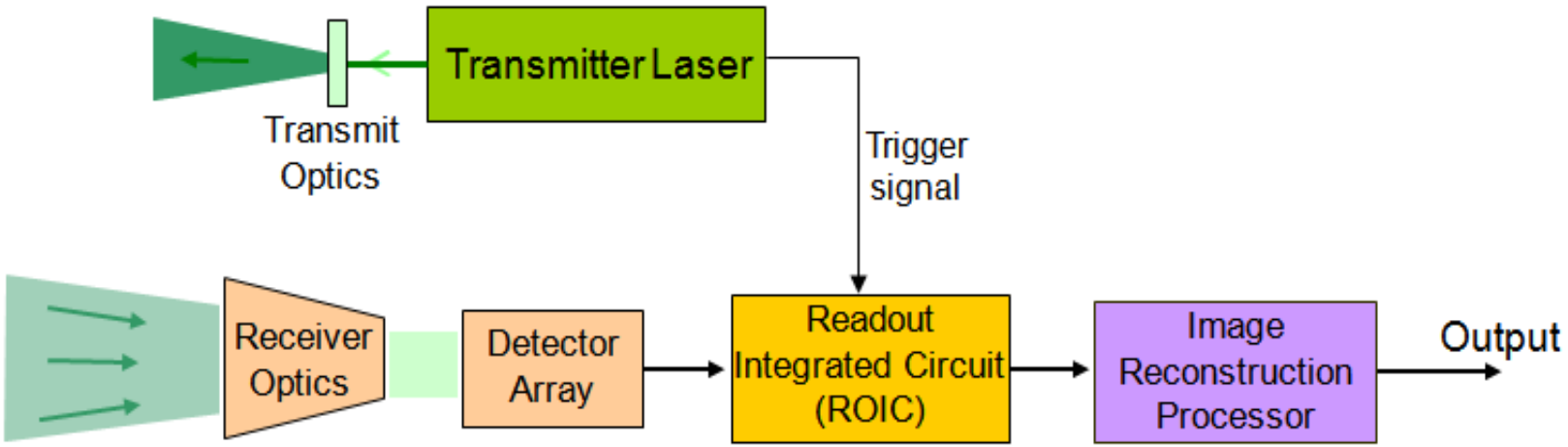
Lidar Plays an Important Role in Future Landing Missions



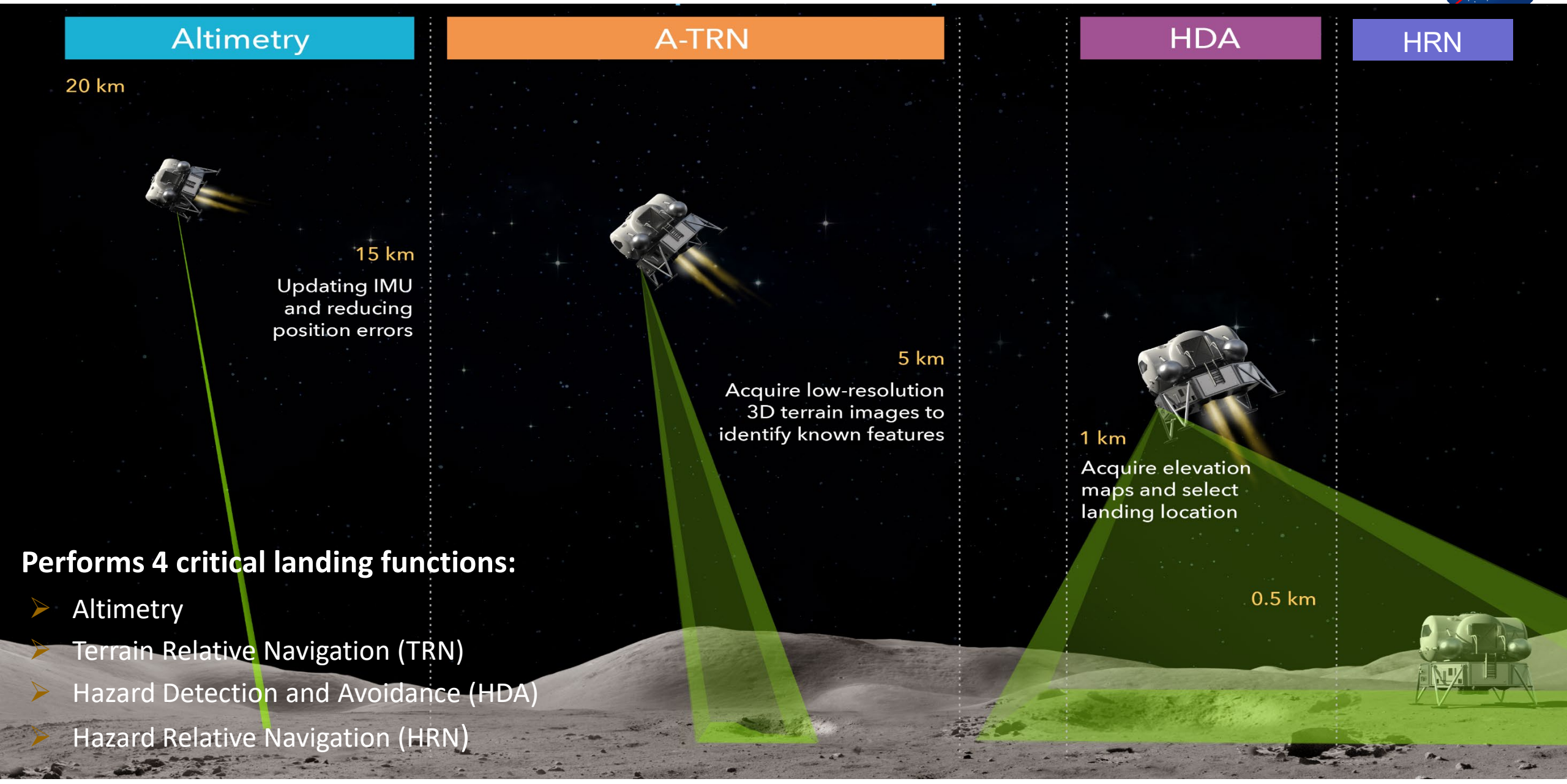
- **Two lidar sensors are being developed for landing payloads precisely and safely**
  - **3-D Flash Lidar: Provides relative position knowledge soon after de-orbit**
  - **Navigation Doppler Lidar: Provides vector velocity and altitude for precision navigation**
  - **3-D Flash Lidar: Detects terrain hazards and identifies safe landing locations**

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 vehicle motion correction**
  - **High frame rate**
  - **Able to perform other functions critical for precision navigation**



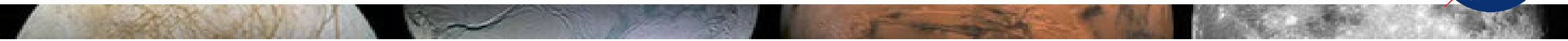
Flash Lidar Landing Operation Concept



Performs 4 critical landing functions:

- Altimetry
- Terrain Relative Navigation (TRN)
- Hazard Detection and Avoidance (HDA)
- Hazard Relative Navigation (HRN)

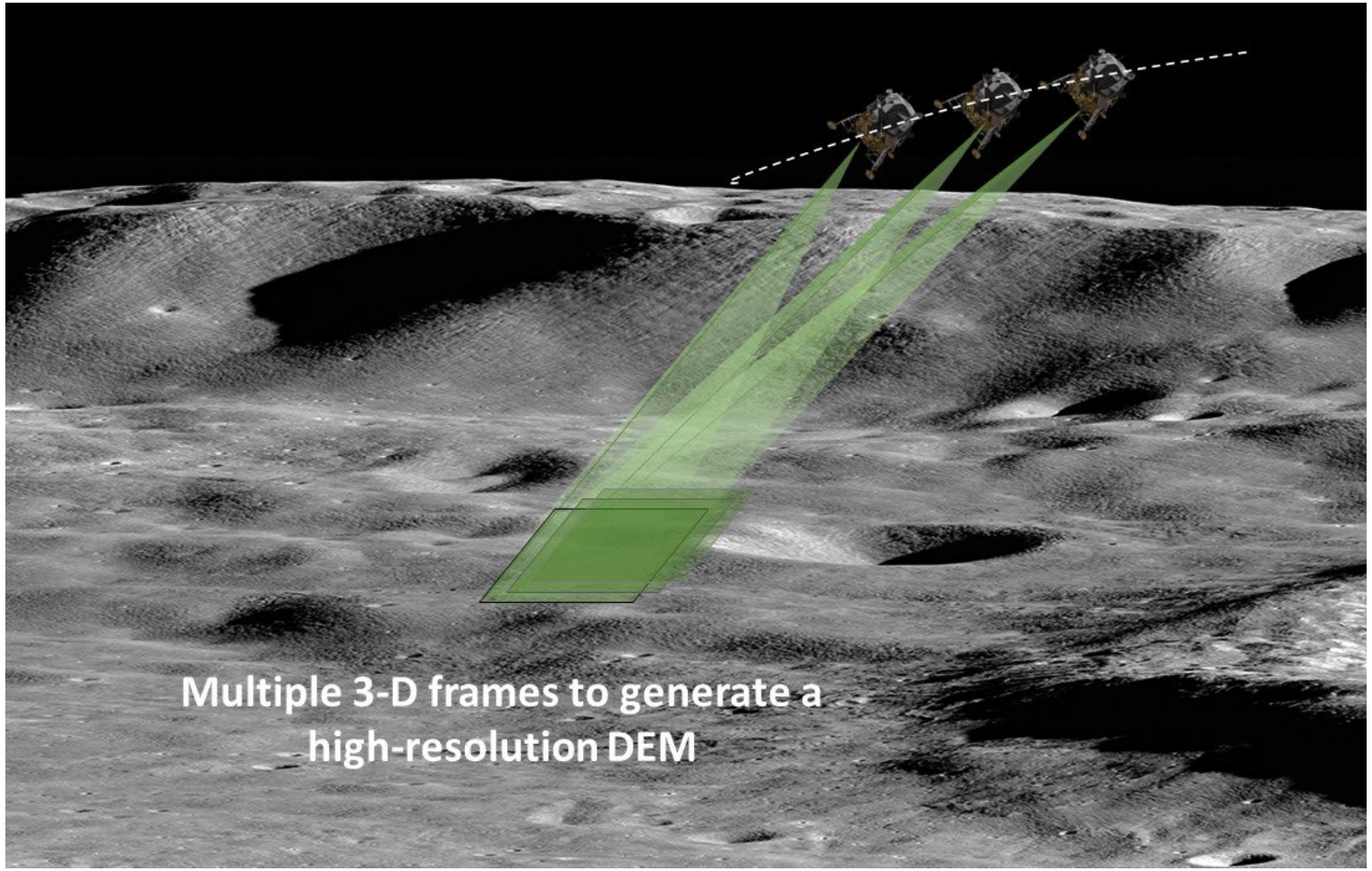
Descent and Landing Flash Lidar Sensor



- Commercial linear-mode flash lidar camera has 128 x 128 = 16.4k pixels
- 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 diameter hazards
- Developed a Super-Resolution algorithm to meet HDA requirements without a need for a mechanical gimbal

Flash Lidar Super-Resolution Algorithm

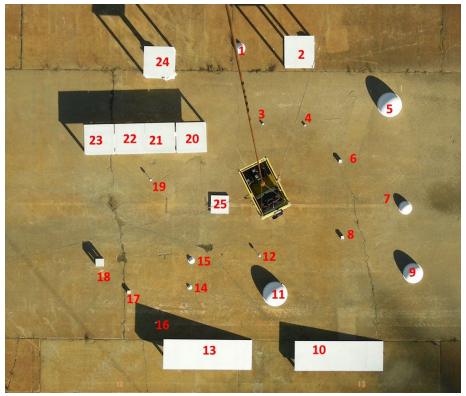
- Super-Resolution (SR) technique uses a set of consecutive frames, from slightly different positions and angles (resulting from platform motion), to generate a high-resolution DEM
- Generates high-res DEMs at 1 Hz rate using 20 frames



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

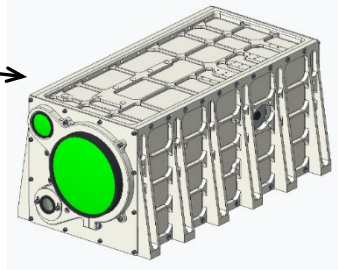
Gantry Test

Flash Lidar



Drone Test

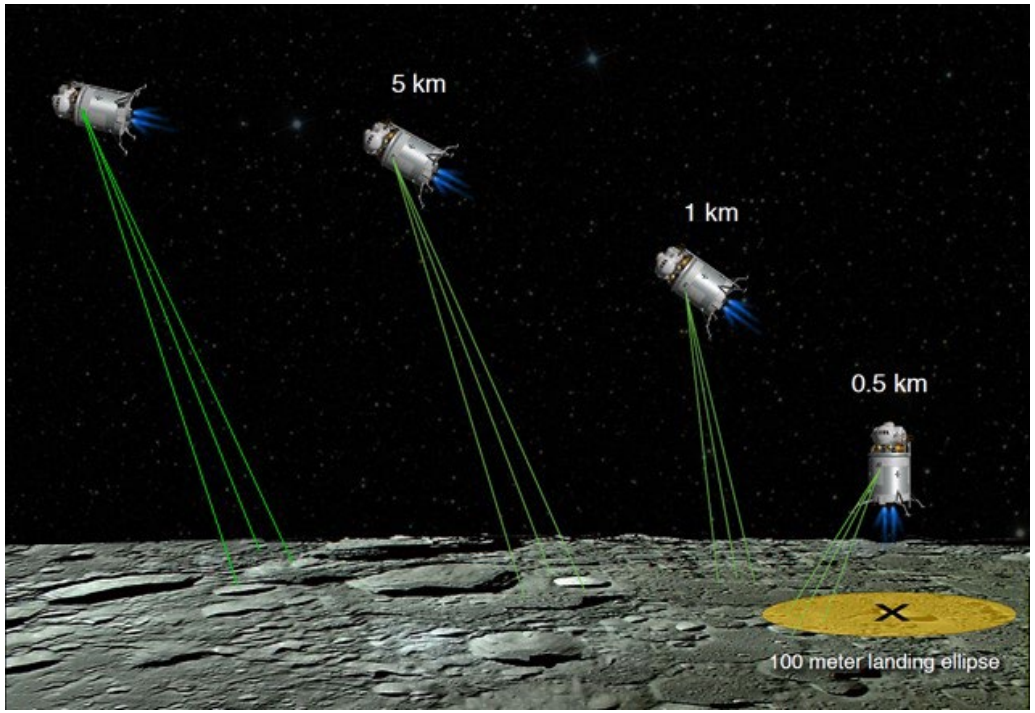
LaRC Breadboard Flash Lidar

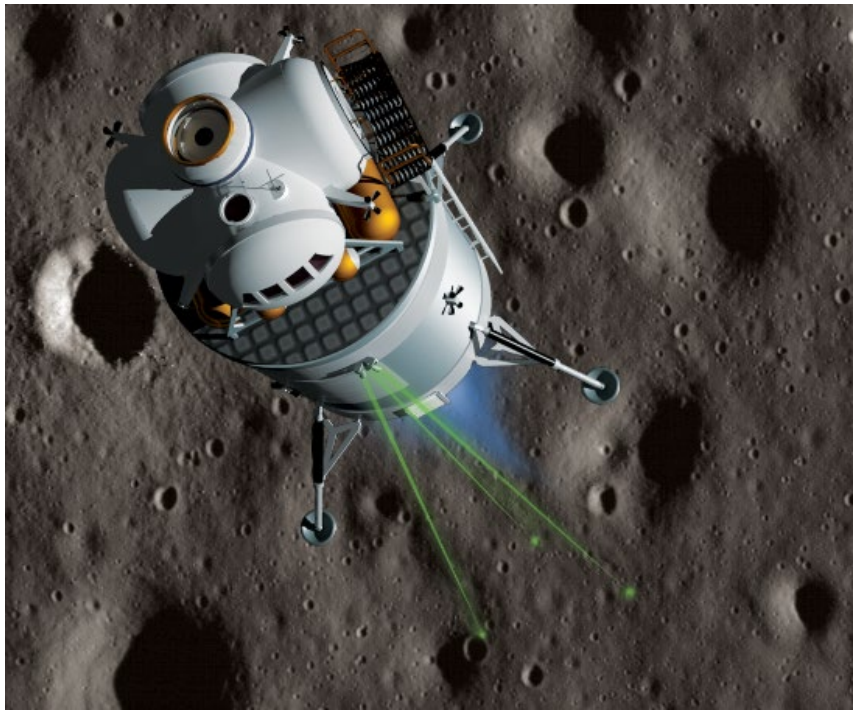


- Plan for reminder of 2023
  - Next generation breadboard
  - Aircraft flight tests

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





Spaceflight Engineering Test Units (ETUs)

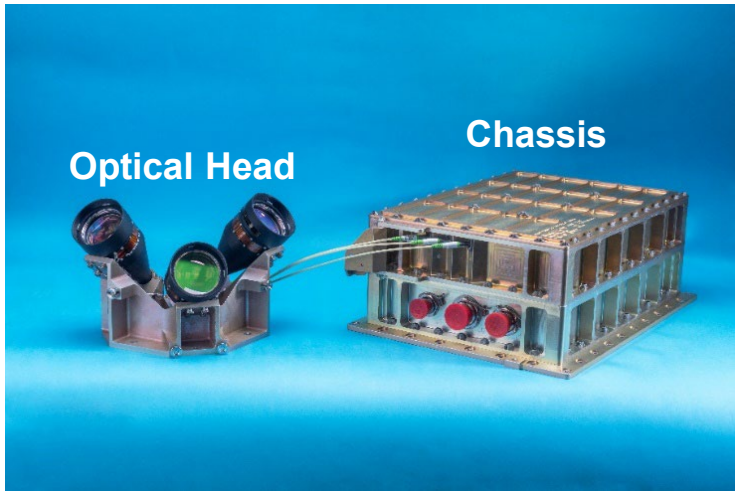
4 ETUs have been built

 # 1: Aircraft flight tests (2021 - 2023)

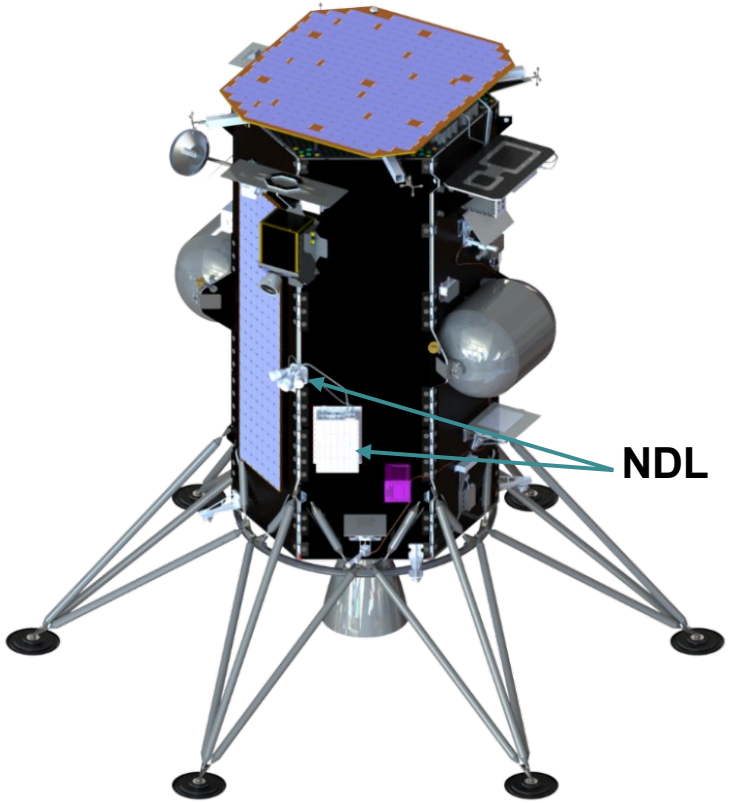
 # 2: Suborbital flight test on Blue Origin New Shepard vehicle (2020,2021)

 # 3: Lunar Landing Mission onboard Intuitive Machines lander (2023)

 # 4: Lunar Landing Mission onboard Astrobotic lander (2023)



Intuitive Machines Nova-C Vehicle



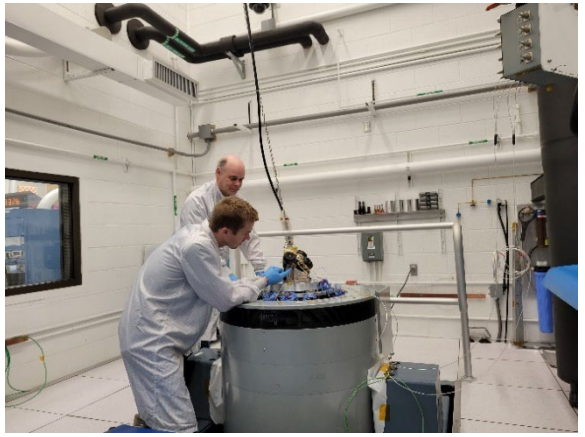
Astrobotic Peregrine Vehicle

NDL Functional and Environmental Tests

Aircraft Flight Tests

High-Speed Rocket Sled Test

Environmental Tests



New Shepard Flight Test

Rocket-powered vehicles

Long Range Functional Test

Comprehensive Functional Test

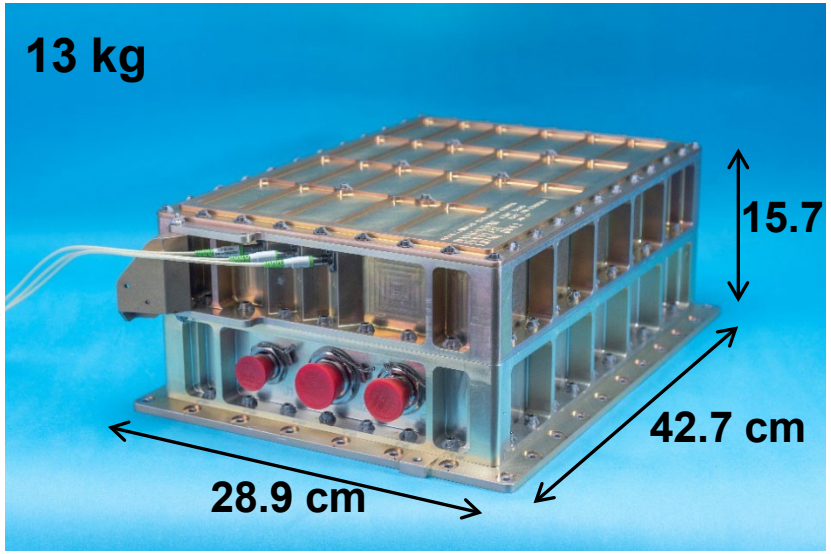
- Signal strength and measurements noise versus range
  - Chassis at different vibration loads
  - Telescopes in vacuum

NDL ETU Specifications

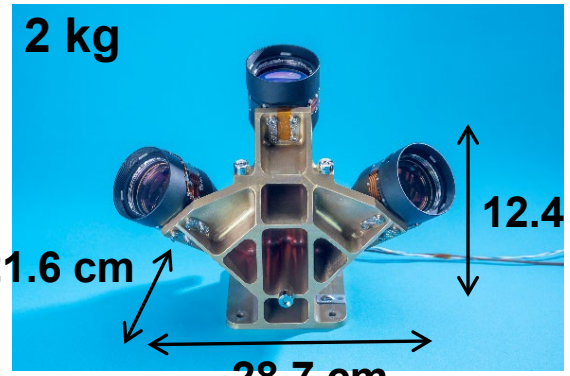
Parameter	Performance on Lunar Landers
Maximum LOS Range	7.0 km
Maximum LOS Velocity	+/- 218 m/sec
LOS Velocity Noise	3.5 cm/s @ 1km, 7.3 cm/s @ 3 km
LOS Range Noise	4.0 m @ 1 km, 8.2 m @ 3k
Data Rate	20 Hz

NDL ETU Performance is dominated by the vehicle dynamics

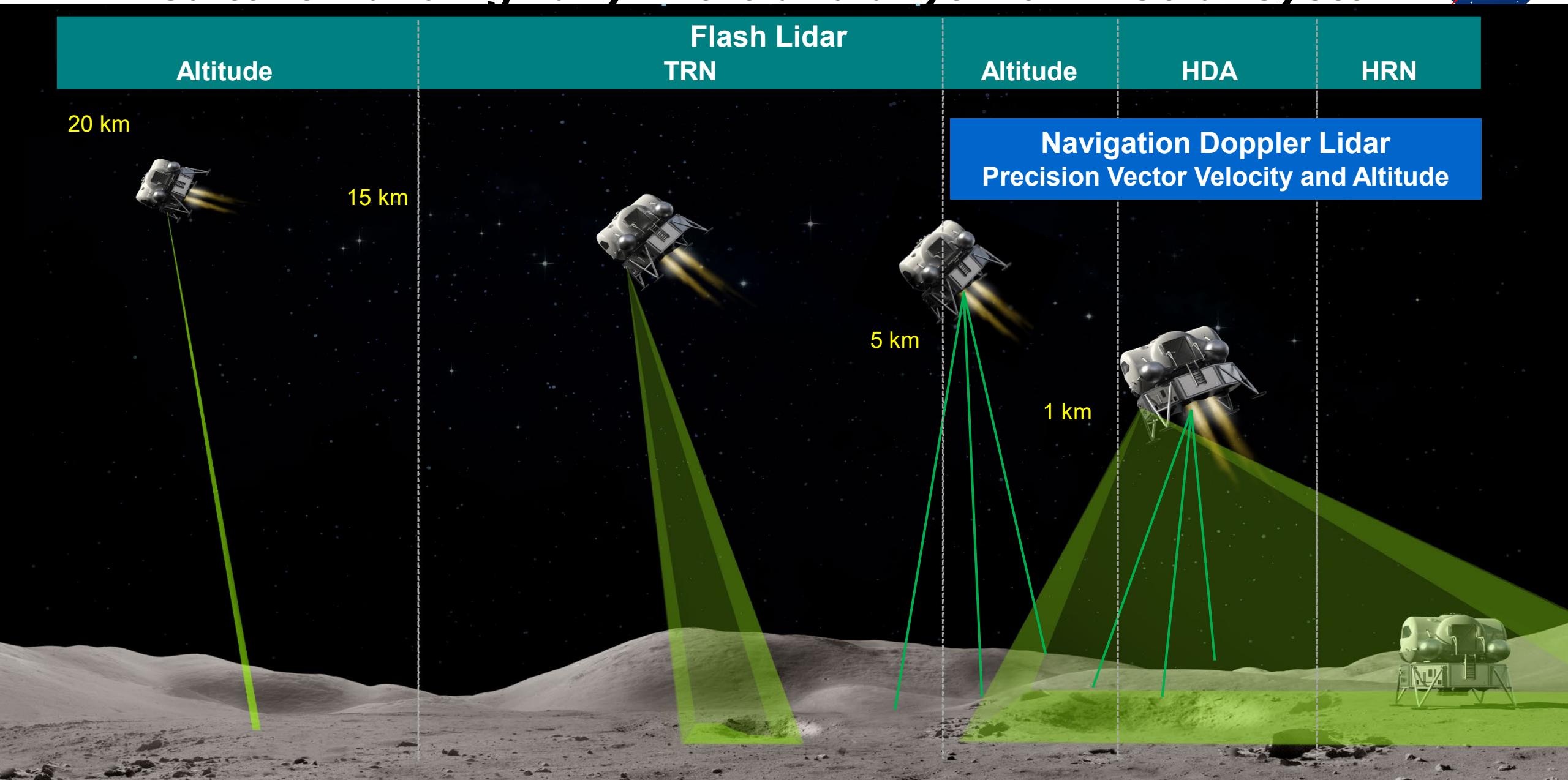
Chassis



Optical Head



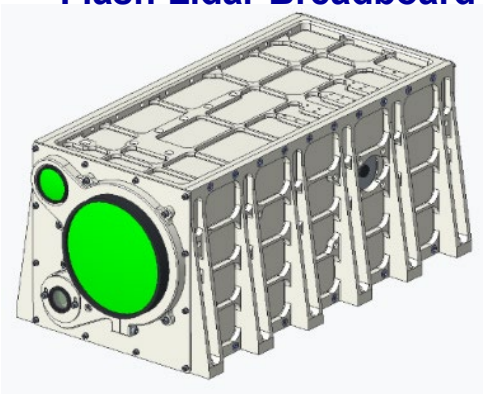
NDL and Flash Lidar together make a powerful sensors suite for landing "anywhere and anytime" in solar system



Closing Remarks

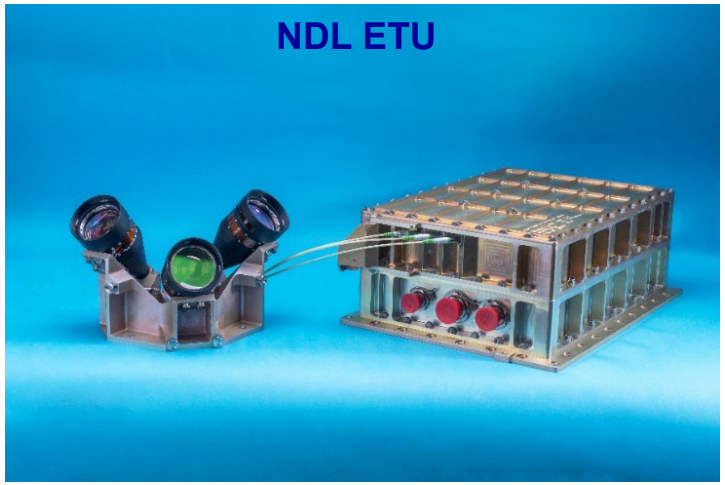
- **Two lidar sensors are being developed for future landing missions**
  - **Flash Lidar**
    - Multifunctional sensor: Long-Range Altimetry, Terrain Relative Navigation, Hazard Detection and Avoidance
    - Conducted drone flight tests with a breadboard unit
    - Helicopter and airplane flight tests are planned for summer 2023

Flash Lidar Breadboard

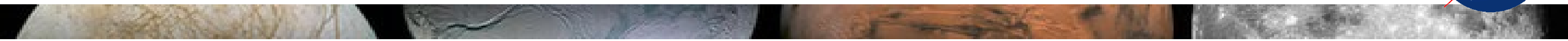


  - **Navigation Doppler Lidar (NDL)**
    - Capable of providing precision vector velocity and altitude data
    - 4 ETUs have been completed and delivered
    - Conducted several helicopter and airplane flight tests
    - Two lunar missions this summer pave the path for large robotic and human missions

NDL ETU



- **Flash Lidar and NDL can be used as standalone sensors or as a sensor suite to enable landing *"anywhere"* and *"any time (any lighting condition)"***



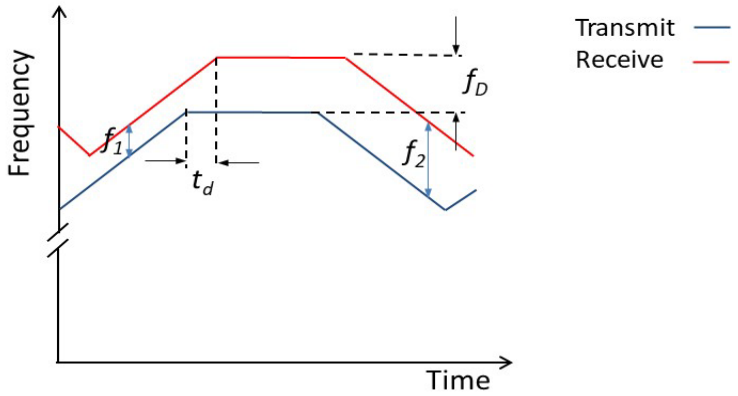
Backup

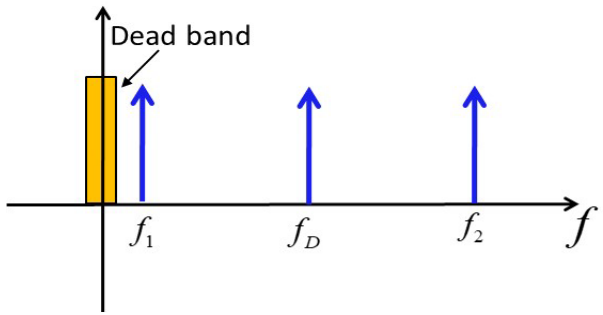
https://youtu.be/ocDzndmmE8I

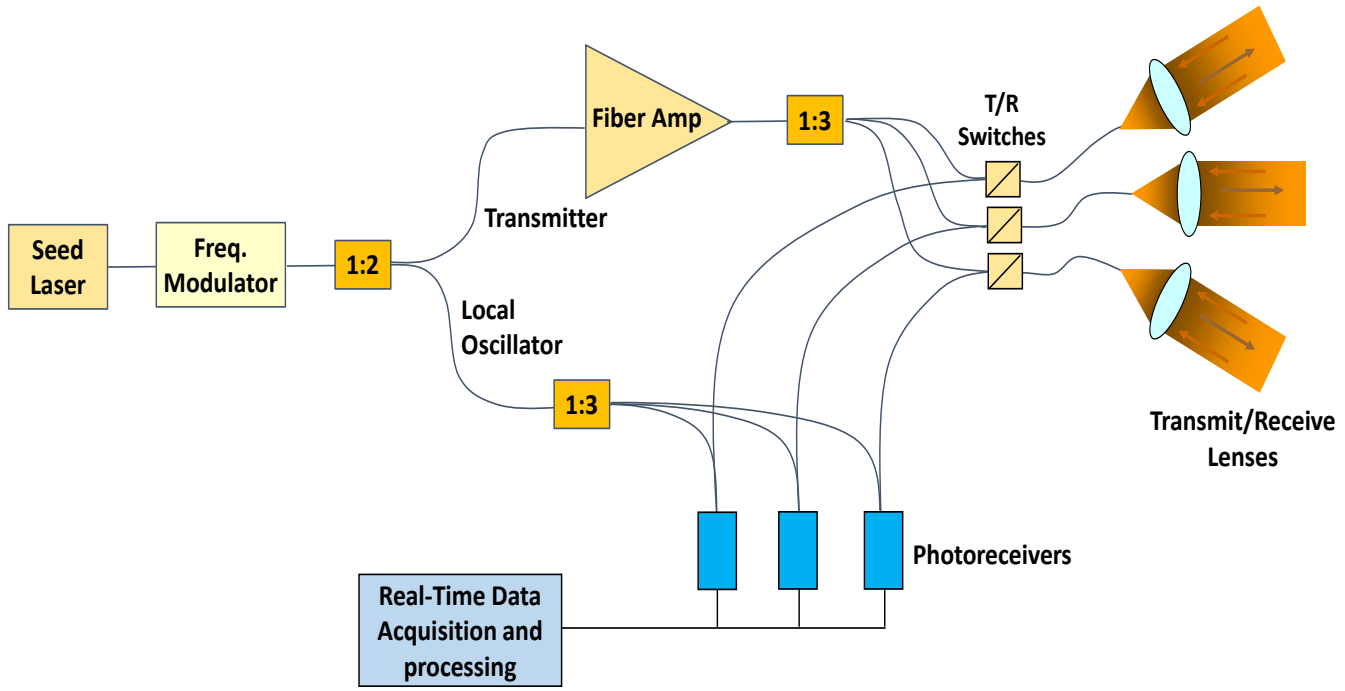
NDL Principal of Operation

- Utilizes FMCW technique to measure velocity and range along three laser beams
- Simultaneous line-of-sight measurements are used to estimate:
  - Velocity Vector (V)
  - Altitude relative to local ground (No external data required)

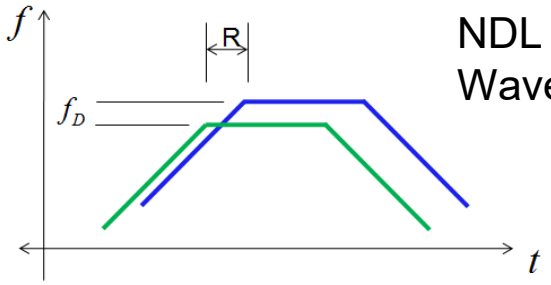
Frequency Modulated, Continuous Wave (FMCW) Technique







NDL Processor & System Controller



NDL Modulation Waveform