National Aeronautics and Space Administration

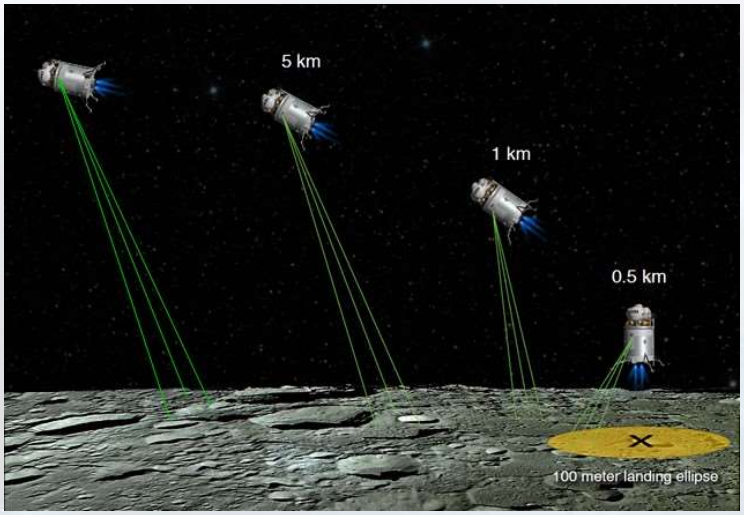


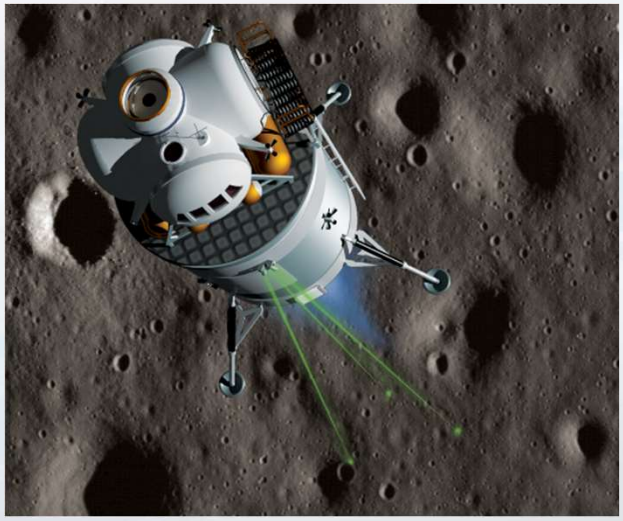
Development and Demonstration of Navigation Doppler Lidar for Planetary Landing Missions

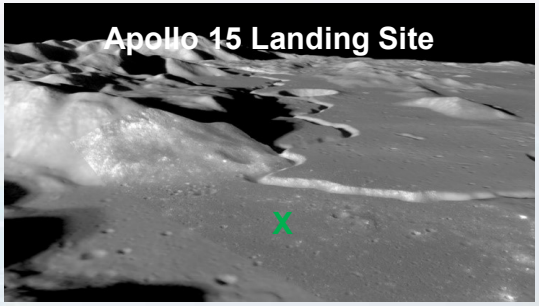
22nd Coherent Laser Radar Conference 2024

Navigation Doppler Lidar (NDL)

- **NDL provides vehicle precision vector velocity and altitude data**
- **Viable replacement for radars with over two orders 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



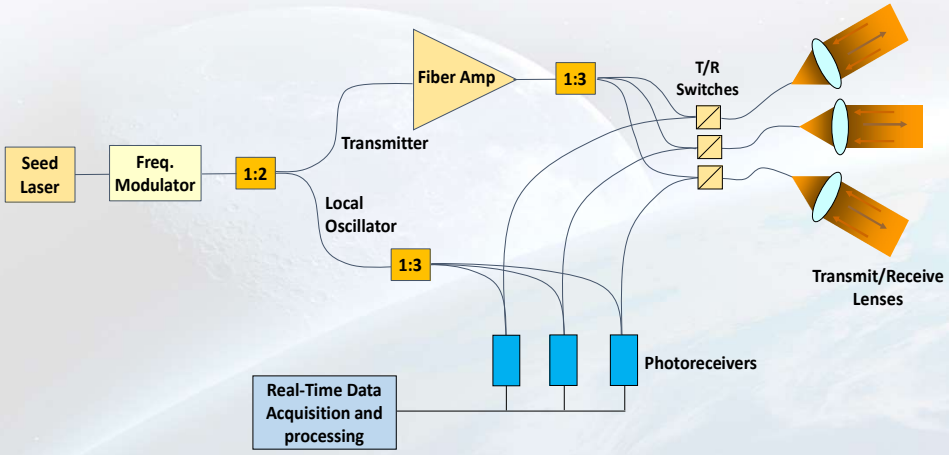


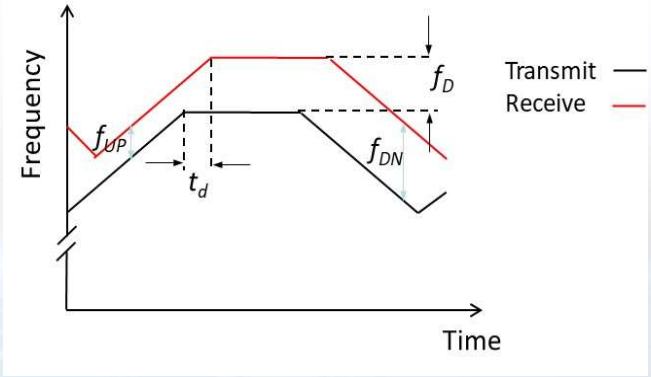


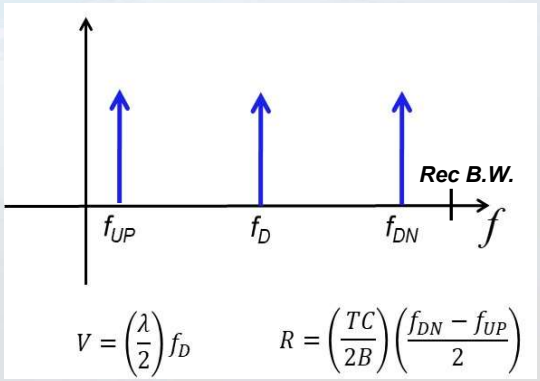


Navigation Doppler Lidar (NDL)

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







Spaceflight Engineering Test Units (ETUs)

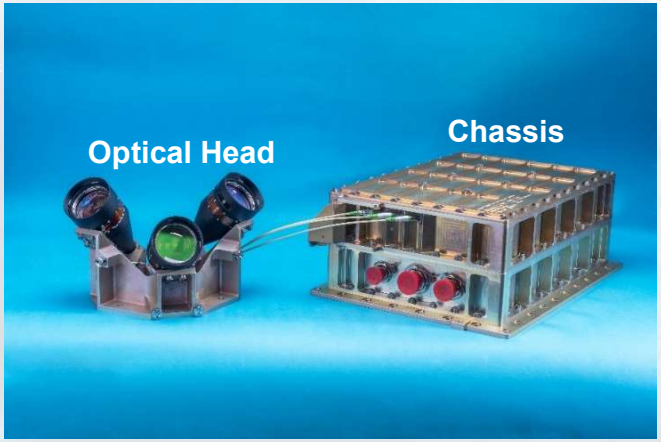
4 ETUs have been built and tested

 # 1 – Aircraft flight tests and integrated tests with other avionics

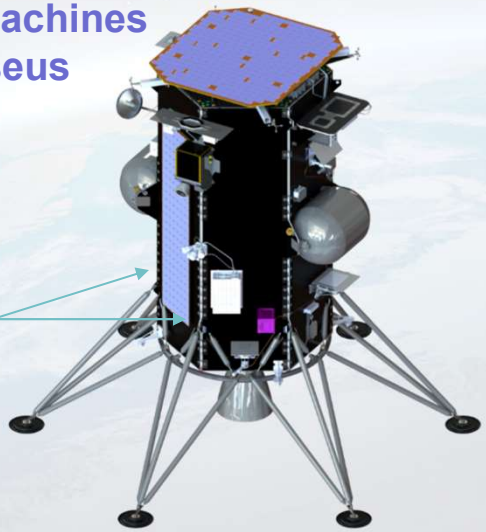
 # 2 – Suborbital flight test on Blue Origin New Shepard vehicle (2020 and 2021)

 # 3 – Lunar Landing Demonstration onboard Intuitive Machines lander (2024)

 # 4 – Lunar Landing Demonstration onboard Astrobotic lander (2024)

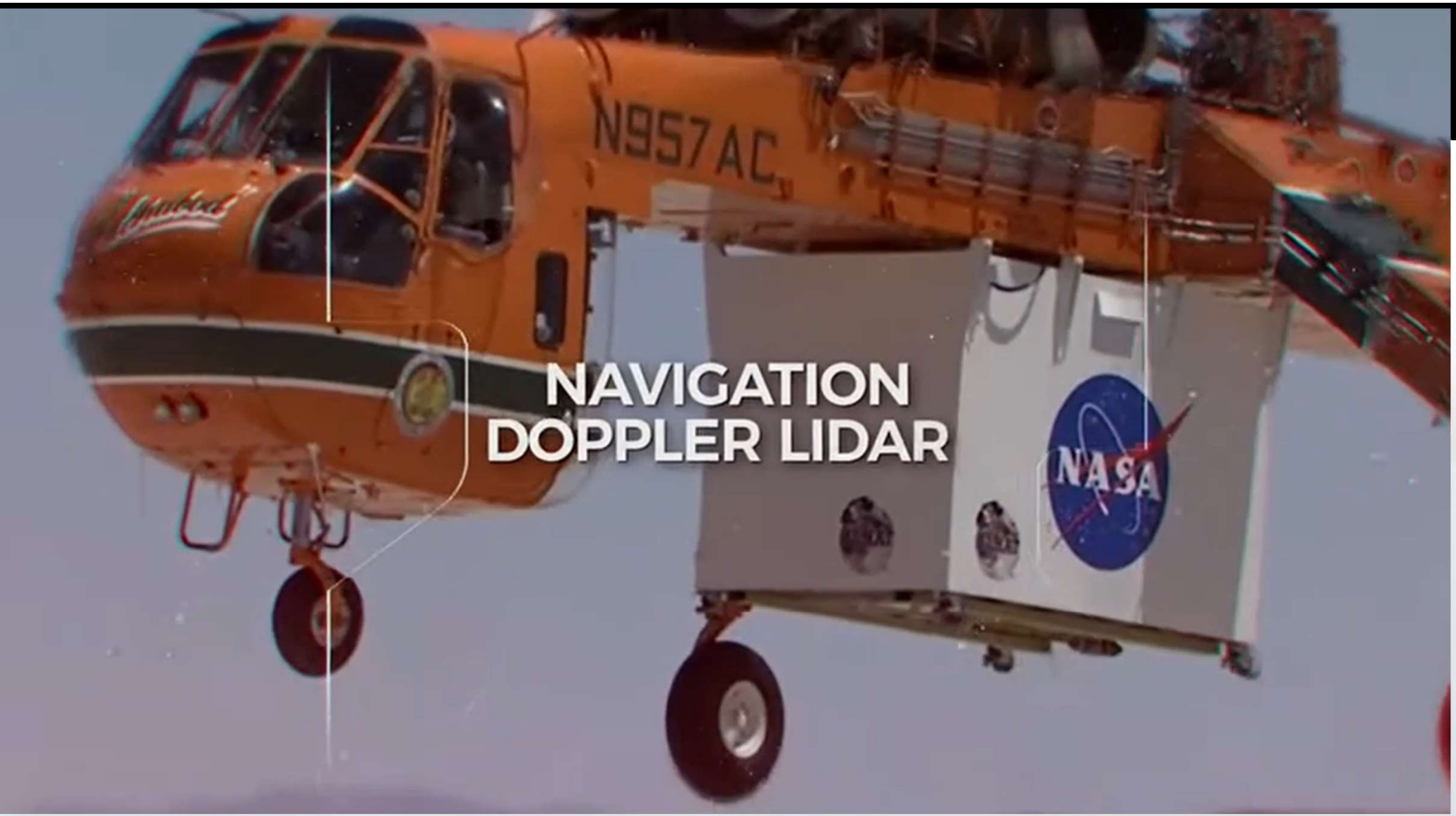


Intuitive Machines
Odysseus



Astrobotic
Peregrine




N957AC
NAVIGATION
DOPPLER LIDAR
NASA


0
25
50
75
100
125
150
175
200
225
250







Operational Range Measurements

- **Signal strength and measurements noise versus range**
  - **Chassis on vibration table**
  - **Telescopes in vacuum**





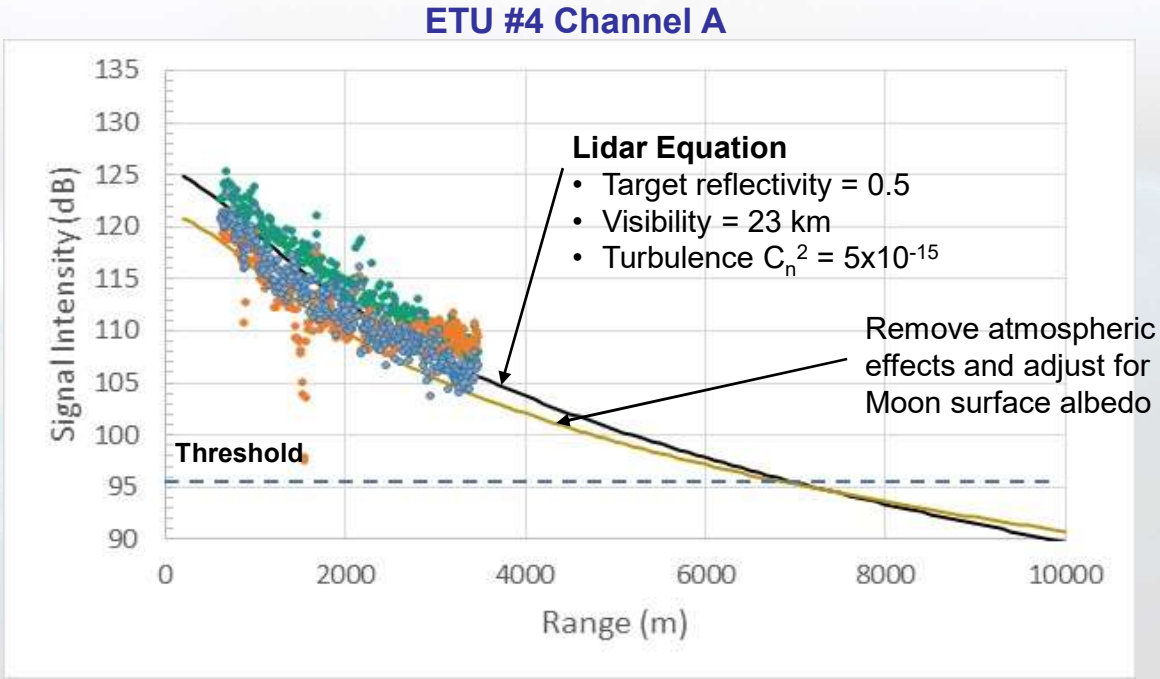






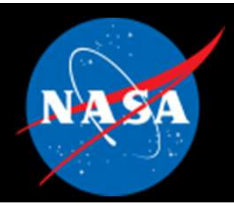
Maximum Operational Range

- **Signal intensity measured over a horizontal path at ~ 2 m above the ground: highly susceptible to *atmospheric turbulence*, *absorption*, and *scattering***
- **Maximum operational range in Moon environment is extrapolated from measured data**





NDL Lunar Landing Missions



- **NDL was on two commercial lunar landers launched in January and February under NASA Commercial Lunar Payload Services (CLPS) initiative**
- ***Astrobotic*: NDL was the primary navigation sensor**
  - **Not a CLPS payload**
- ***Intuitive Machines*: NDL was planned to be used as a secondary sensor for velocity**
  - **CLPS contract did not allow the use of NDL as a primary/critical sensor**

Astrobotic Mission



- Launched on Vulcan rocket on January 8, 2024
- Experienced an anomaly with propulsion system about 7 hours after launch and could not complete its mission
- Spacecraft operated 10 days and 13 hours in space before returning to Earth
- NDL operated nominally for 6.5 hours

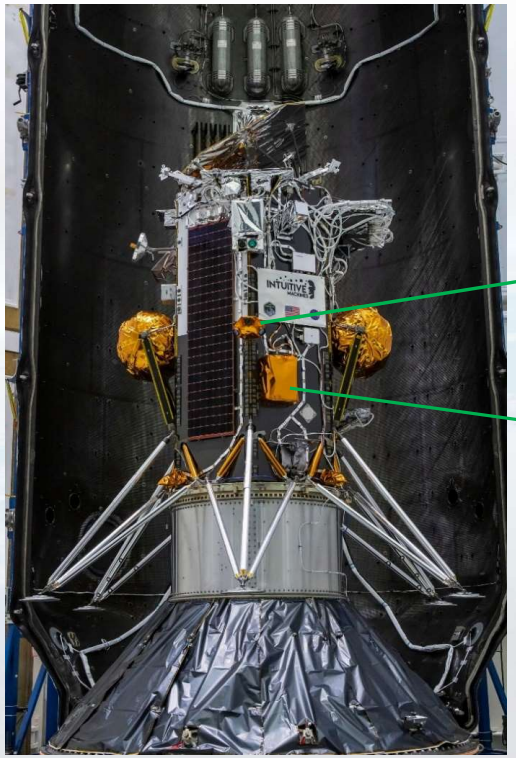


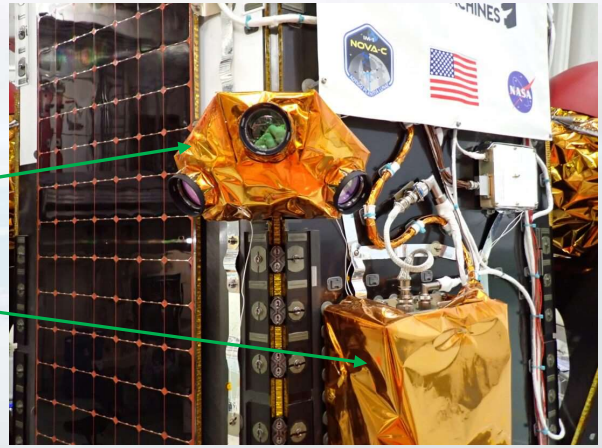
Intuitive Machines Mission

- Launched on Falcon 9 rocket on February 15, 2024
- Landed on the Moon on February 22, 2024



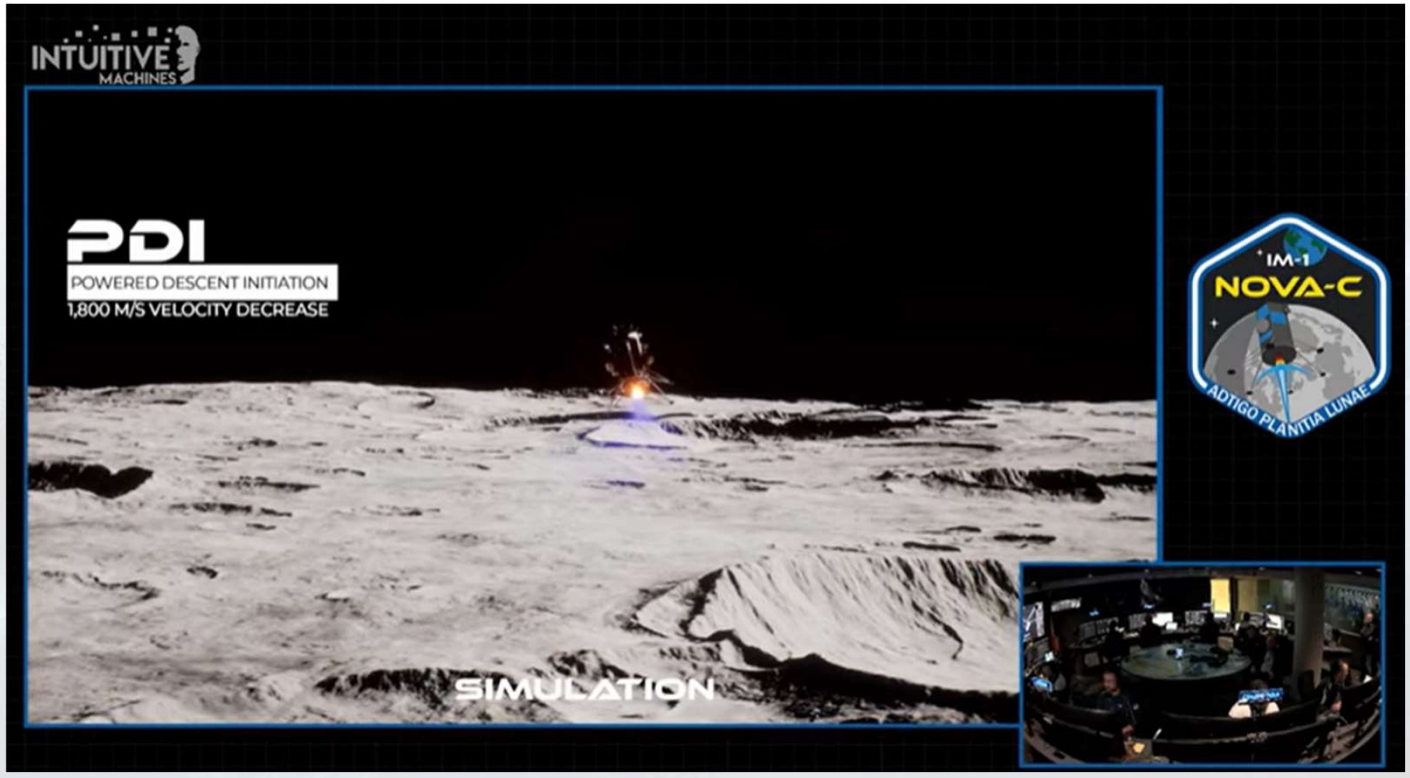
NDL on Odysseus Lander





NDL on Intuitive Machines Odysseus Lander

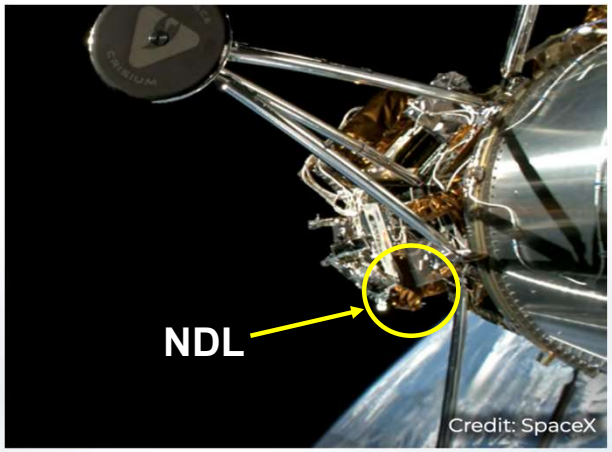
- **NDL was planned to be used as a secondary sensor for velocity data during descent from about 5 km altitude to ground**



Intuitive Machines (IM) Mission

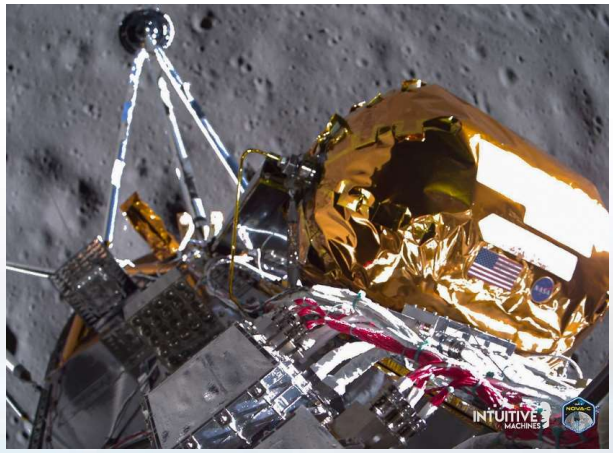
- **NDL operated flawlessly for 1.6 hour during checkout and 1.5 hour during deorbit/descent/landing**
- **Remained in operational mode on the ground for another ~ 4 hours**

Transit Checkout on Feb 19





Landing on Feb 22





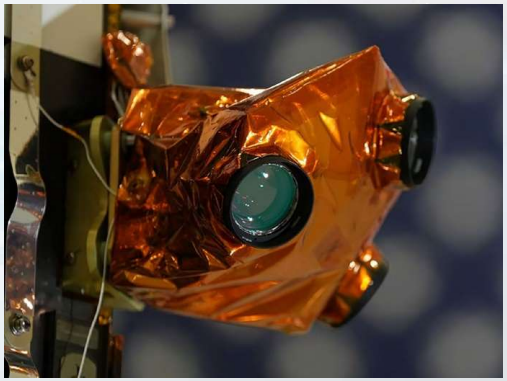
NDL Operation During Lunar Descent

- **IM realized hours before landing that their laser range finders couldn't be turned on since the manual safety pin was not removed**
- **IM asked NASA and the project for permission to use the NDL as their primary sensor for range data (velocity data was already planned to be ingested by IM)**
- **They did an extra orbit to buy 1.5 hour time to prepare and upload a software update for ingesting the NDL range measurements during descent and landing maneuvers**

9:26 p.m. ET, February 22, 2024

This is the NASA instrument that saved Odysseus' mission

From CNN's Jackie Wattles



NASA's Navigation Doppler Lidar.

NDL Operation During Lunar Descent

- **IM realized that the NDL data was not used after analyzing the GNC telemetry data**
- **There were errors in the last-minute SW update**
  - **GNC was still getting status flags from laser rangefinders**
  - **Neither range nor velocity data were used**
- **Intuitive Machines landed using data from their IMU and cameras, however they did not land upright and were short of their original target by ~ 2.5 km**

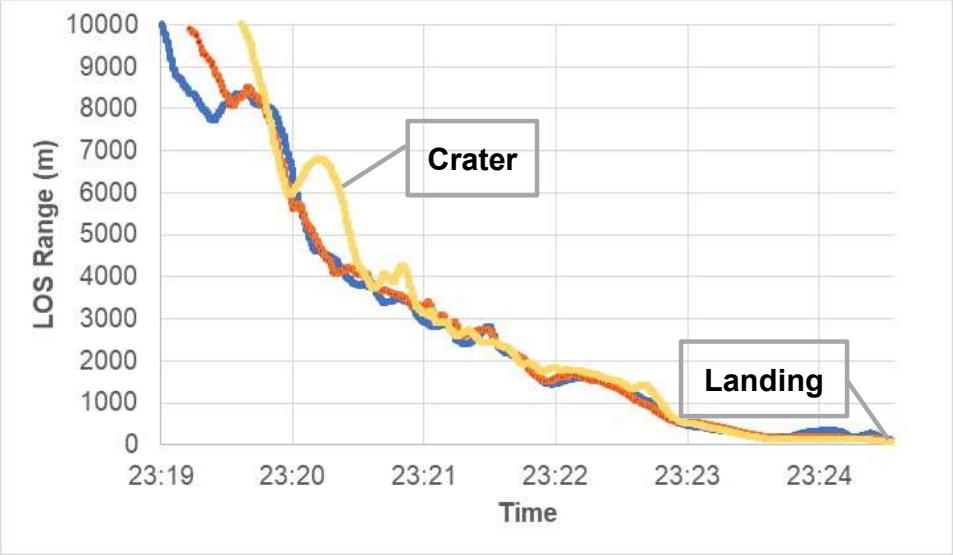
STEVE ALTEMUS, IM CEO, comments on NDL:

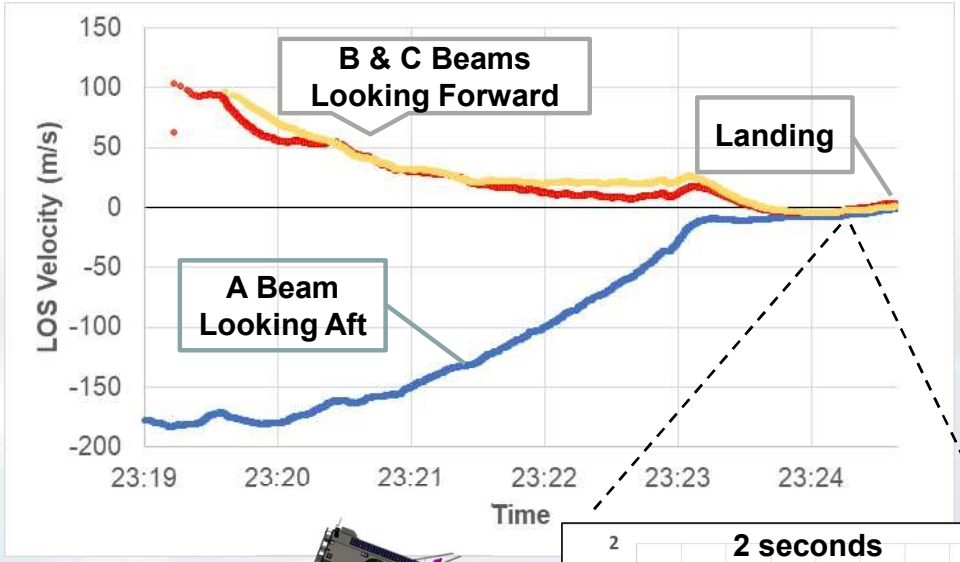
As it turns out though, as we worked all day to write that software, to solve the problem with the NASA Doppler LiDAR, as we went into power descent, **we did not receive those NDL measurements**. And so we landed without the laser altimeters in the end. But we had done some work, you know, to get us there. **And we looked at NASA's Doppler LiDAR telemetry, and boy, did it track perfectly so it would have really put us down softly if we could have read those measurements.**

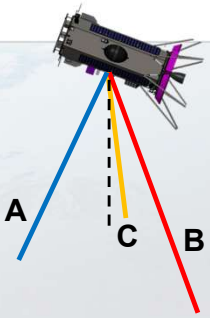
https://mastersofscale.com/landing-on-the-moon/

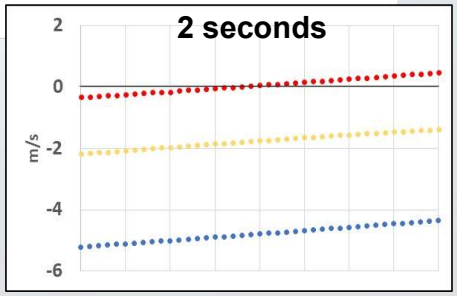
NDL Data from IM Lunar Mission

NDL provided 100% valid measurements from 10 km to surface





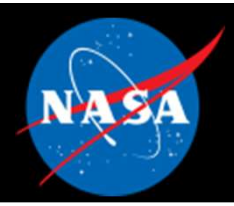




- **Measurements precision is over 2 orders of magnitude better than Mars Lander Radar (1 cm/s velocity, 80 cm range)**



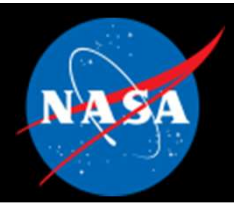
Projected Performance vs. Actual



Parameter	Projected Performance	Flight Results
Maximum LOS Range	6.0 km	10.0 km
Maximum LOS Velocity	+/- 218 m/s	+/- 218 m/s
LOS Velocity Noise @ 3 km	8.3 cm/sec	0.4 cm/s
LOS Range Noise @ 3 km	8.2 m	0.4 m
Data Rate	20 Hz	20 Hz

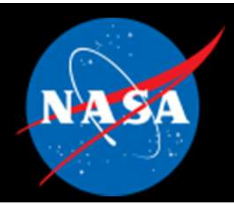
- **Odysseus lunar landing was an excellent demonstration of the NDL for future landing missions**





Backup





NDL is probably the first real demonstration of Coherent Lidar in Space

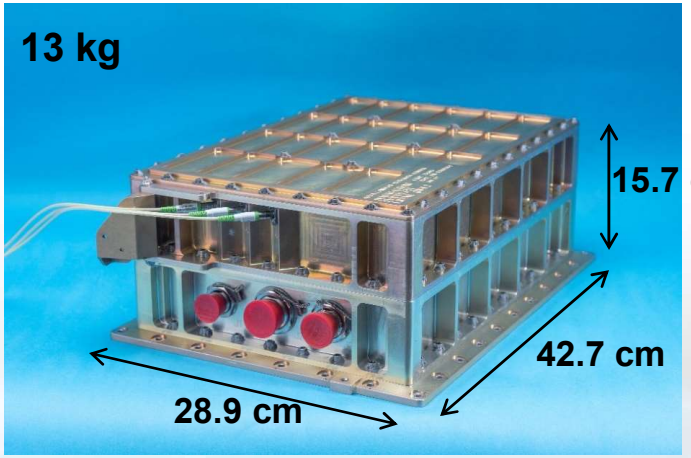
- **NDL is not the first coherent lidar in space**
  - **First coherent lidar in space was Delta 181 Mission flown in 1988 as part of the Strategic Defense Initiative (nicknamed Star Wars)**
  - **Delta 181 mission used a CO_2 coherent lidar built by Litton**
  - **No data on performance of the Delta 181 lidar is publicly available**
- **NDL is not the second coherent lidar in space**
  - **Indian lunar lander Chandrayaan-3 deployed a Doppler lidar for ground velocity measurements from a few hundred meters (August 2023)**

NDL ETU Specifications

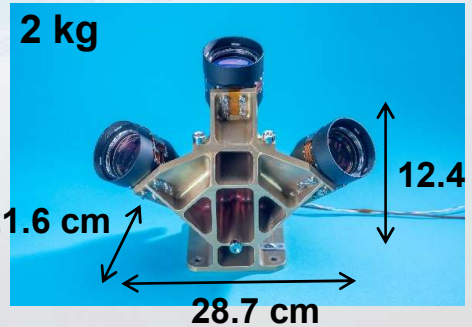
Parameter	Static Platform	Landing Vehicle [2]
Maximum LOS Range[1]	14 km	6.0 km
Maximum LOS Velocity	+/- 218 m/sec	+/- 218 m/sec
LOS Velocity Noise @ 3 km	0.1 cm/sec	8.3 cm/sec
LOS Range Noise @ 3 km	0.10 m	8.2 m
Data Rate	20 Hz	

1. **Max range is defined as when data dropouts and false alarms exceeds 20%**
2. **Max operational range and measurement precision is dominated by platform vibration**

Chassis

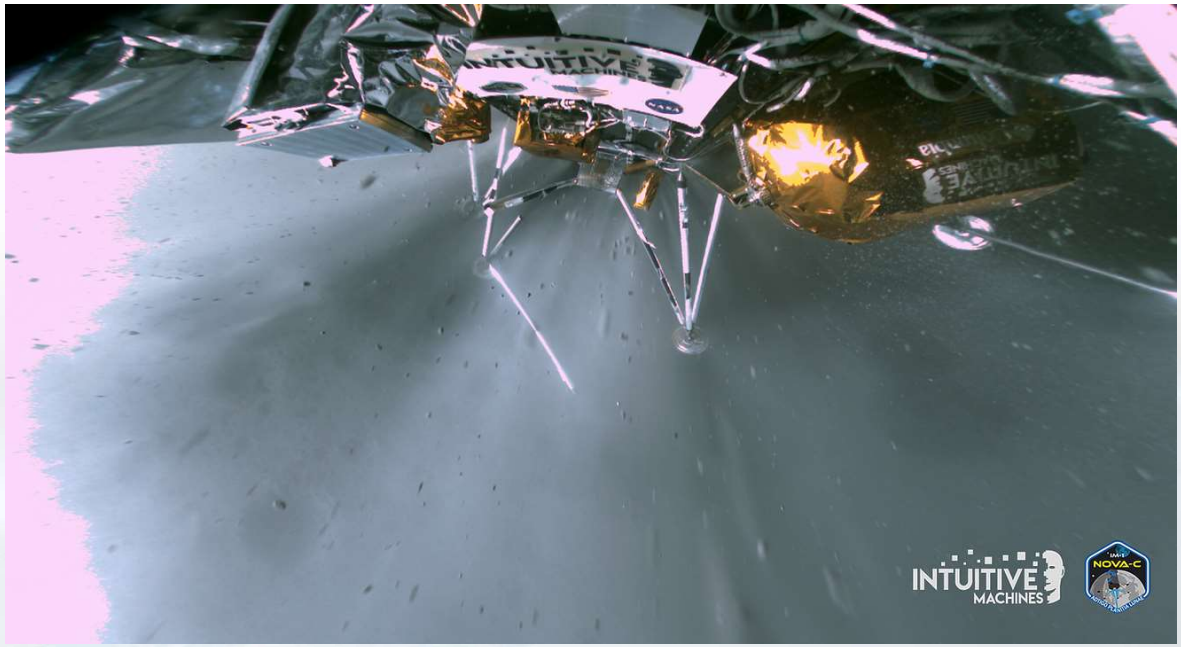


Optical Head




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