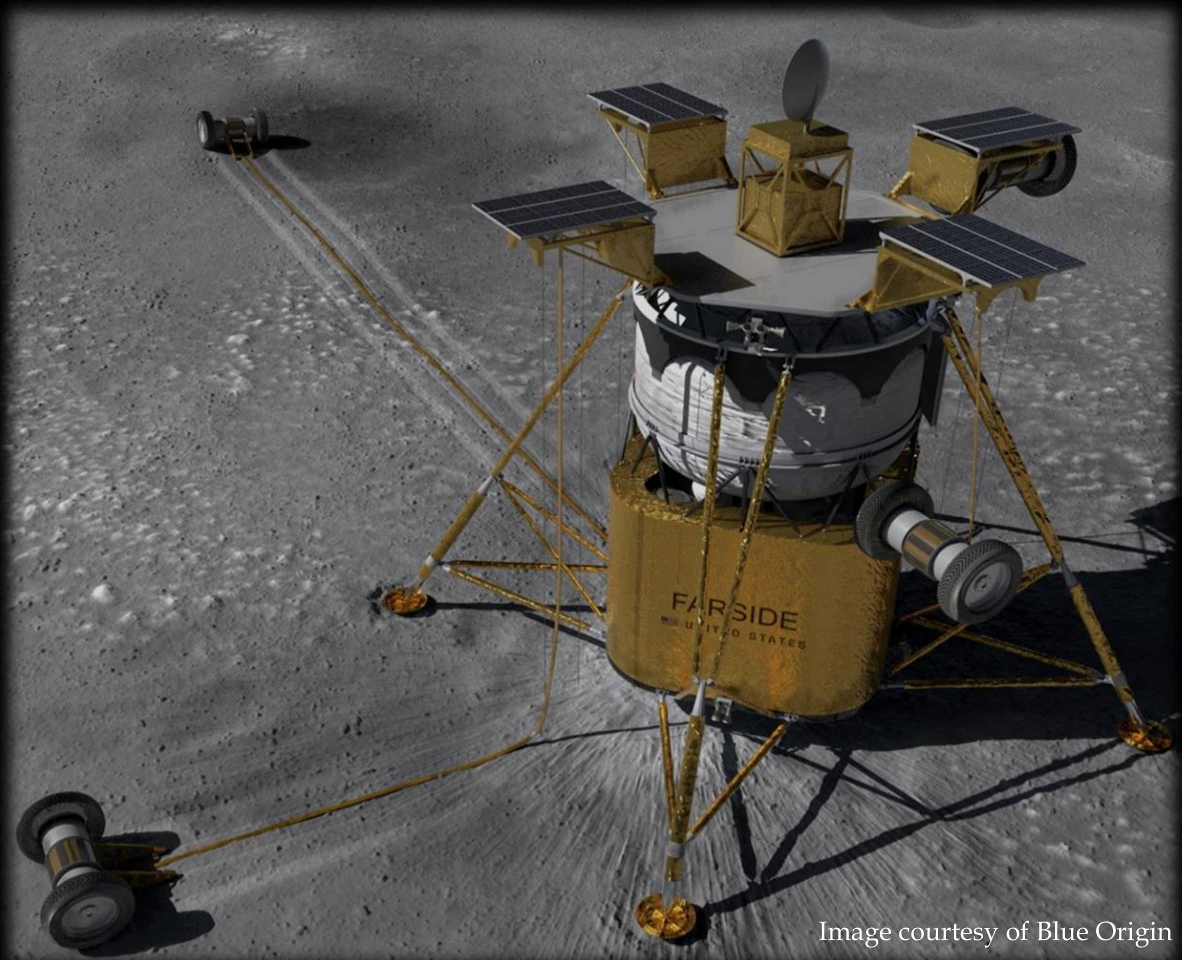
Deployment of Hydrogen Cosmology Radio Telescopes on the Moon

Jack Burns

Univ. of Colorado Boulder on behalf of the *ROLSES, LuSEE, DAPPER, FARSIDE,* & *FarView* teams

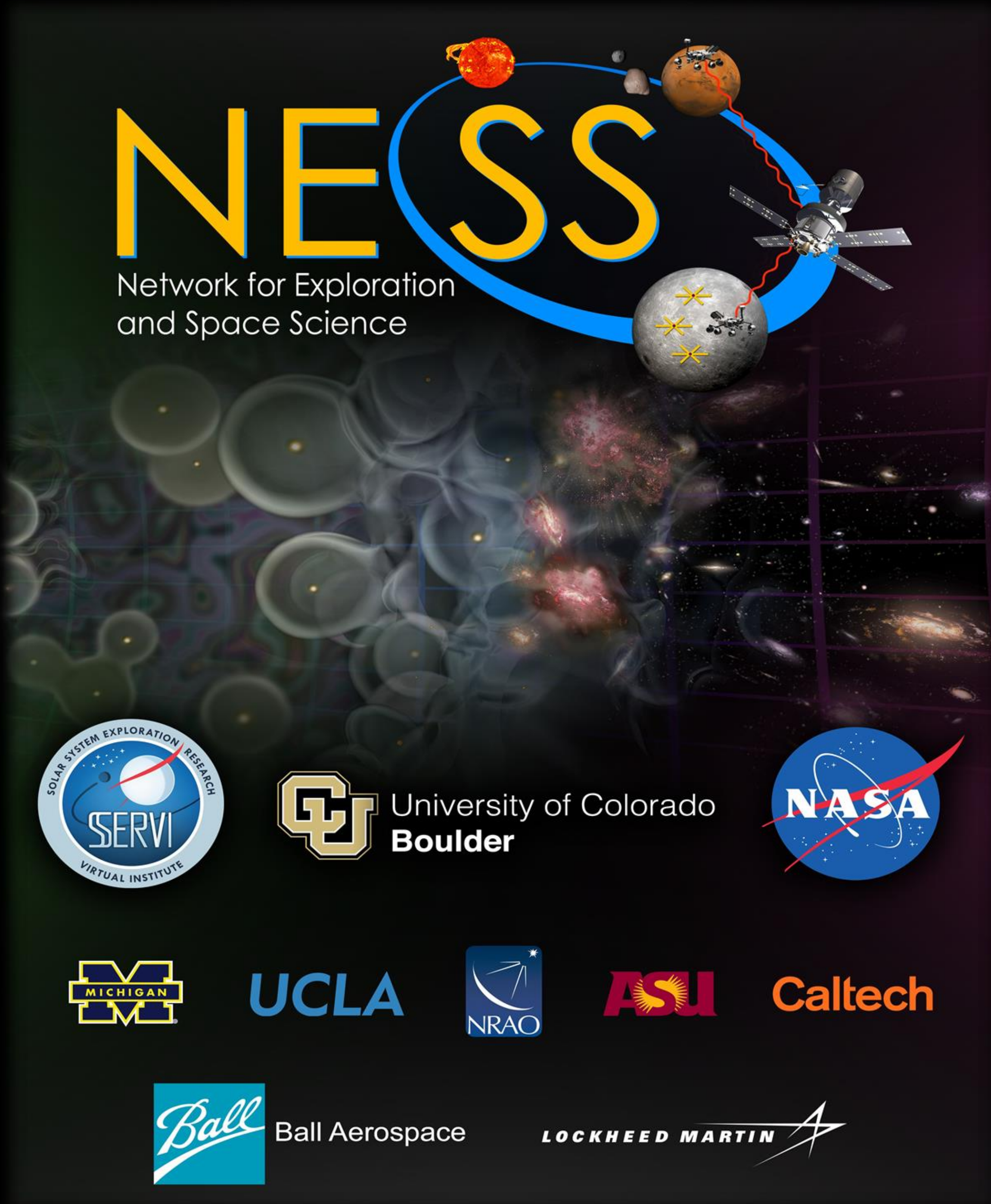


1st International Workshop on ***Gravitational-wave Detection on the Moon***

14 October 2021

NESS
Network for Exploration and Space Science

Burns et al., 2021, *Low Radio Frequency Observations from the Moon Enabled by NASA Landed Payload Missions*, Planetary Science Journal, 2:44, April 2021.



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Co-PI – Robert MacDowall, NASA GSFC
Assist. Director – David Rapetti, CU/NASA ARC

Co-Investigators:
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Richard Bradley, NRAO
Terry Fong, NASA ARC
Steven Furlanetto, UCLA
Gregg Hallinan, Caltech
Justin Kasper, U. Michigan/BWX Tech.
Michael Reiner, NASA GSFC
Daniel Szafir, U. North Carolina

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Phaedra Curlin, U. Colorado
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Adam Trapp, UCLA
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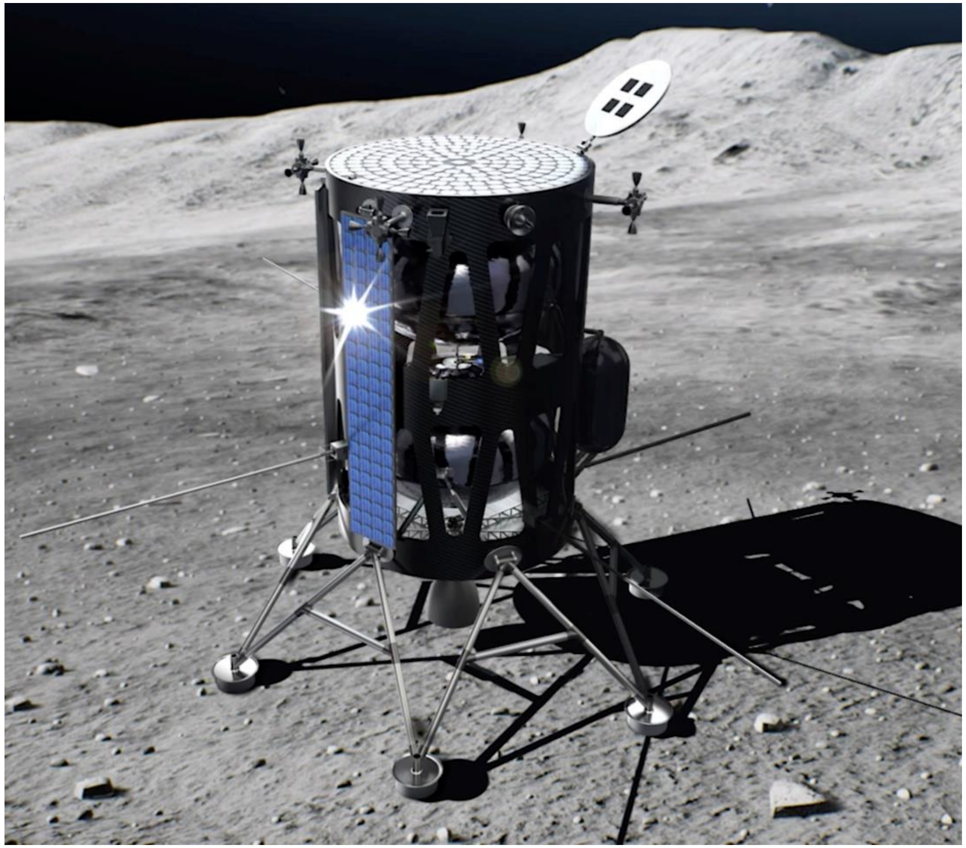


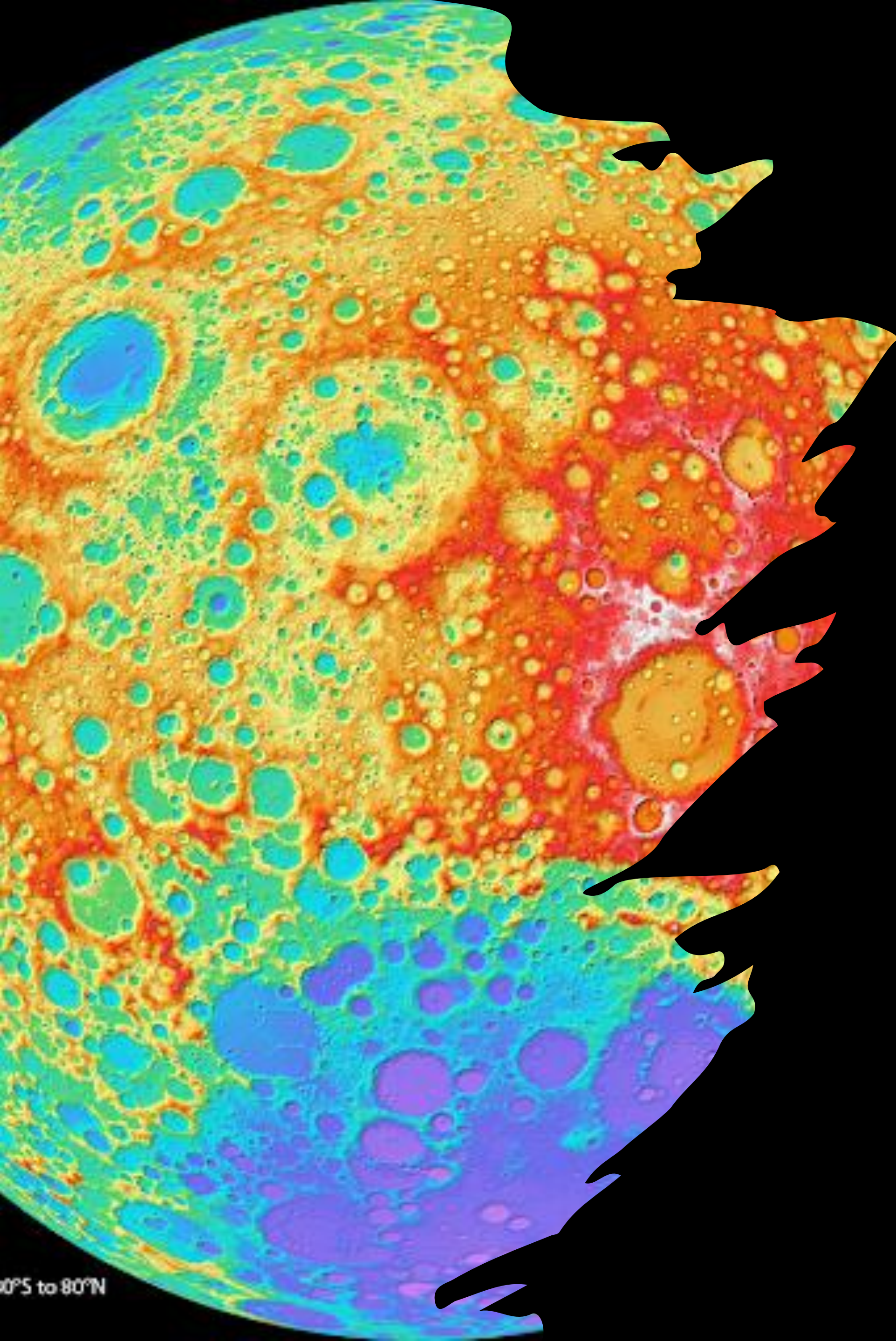
Science Goals:

- determine the photoelectron sheath density from ~1 to ~3 m above the lunar surface.
- demonstrate detection of solar, planetary, & other radio emission from lunar surface.
- measure reflection of incoming radio emission from lunar surface and below.
- measure Galactic spectrum at <30 MHz.
- Aid development of lunar radio arrays.

NASA-PROVIDED LUNAR PAYLOAD

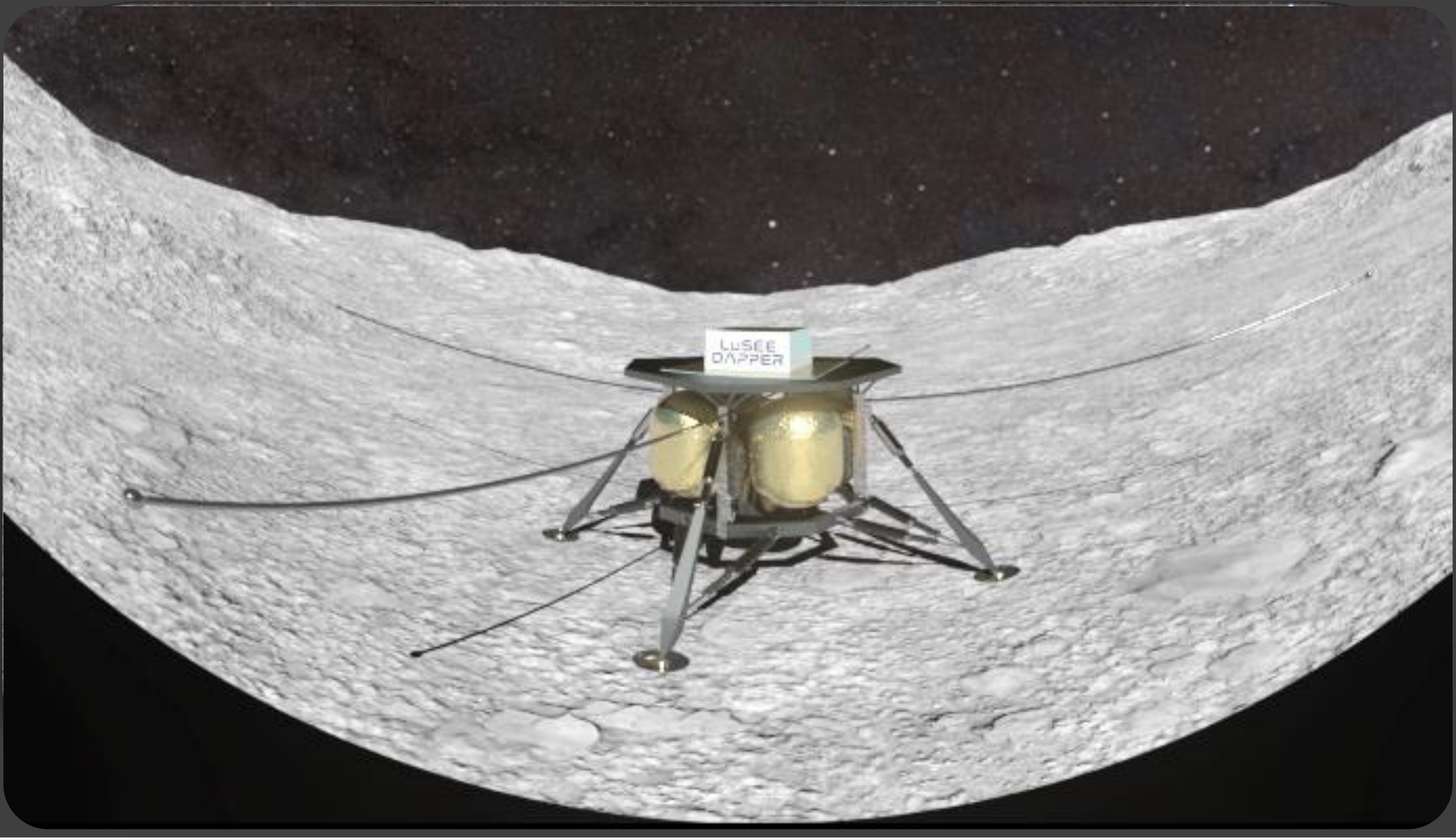
ROLSES: Radio wave Observations at the Lunar Surface of the photoElectron Sheath

- Team: Robert MacDowall, William Farrell, Damon Bradley, Nat Gopalswamy, Michael Reiner, Ed Wollack, Jack Burns, David McGlone, Mike Choi, Scott Murphy, Rich Katz, Igor Kleyner.
- Status: Scheduled to land on lunar nearside in Q1 of 2022 using *Intuitive Machines Nova-C.*



NASA's Commercial Lunar Payload Services (CLPS) provides regular access to the Moon (2 landers/yr) and, thus an unparalleled opportunity to perform low radio frequency cosmology due to the lunar farside's

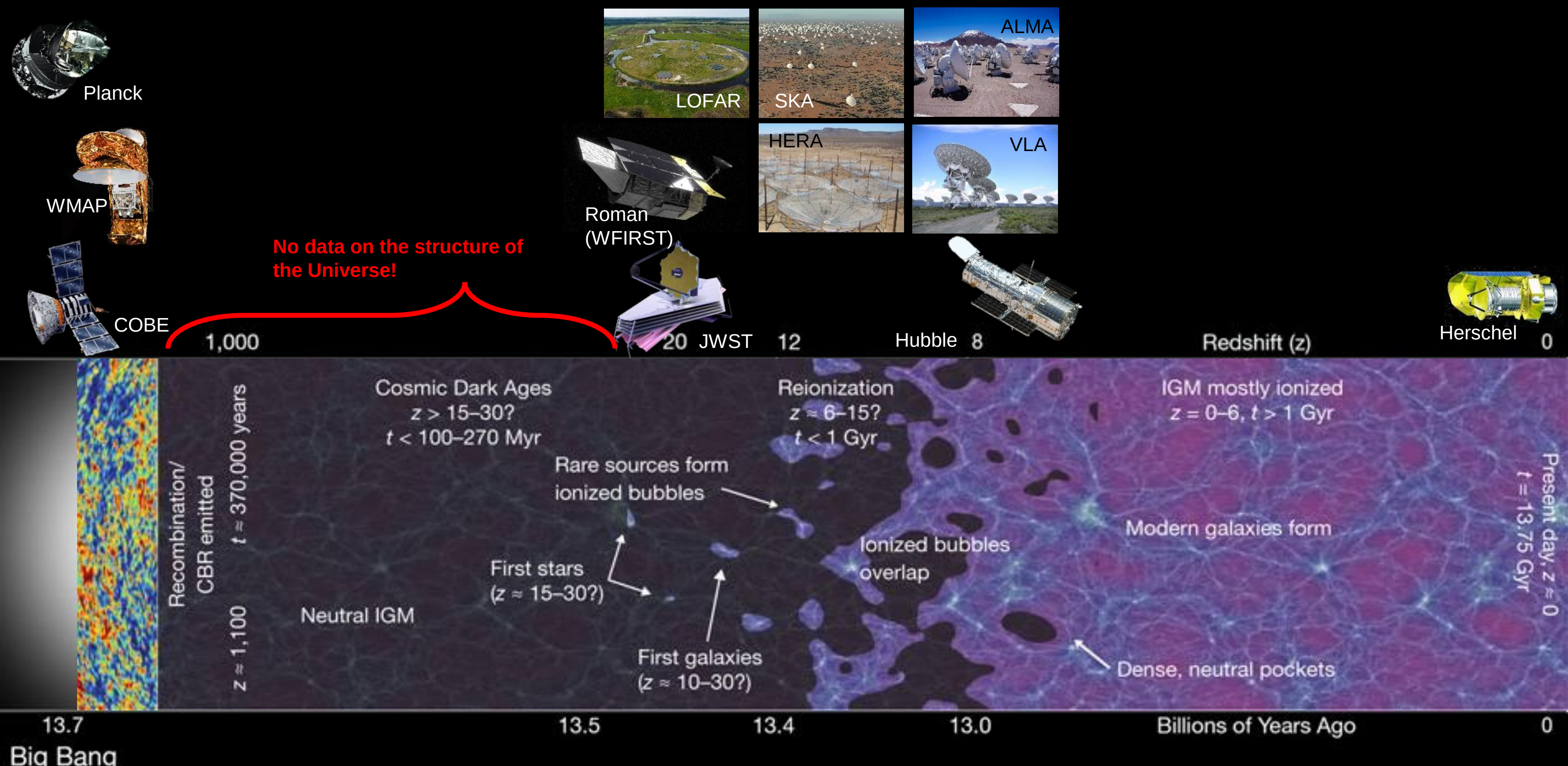
- unique radio-quiet,
- lack of a significant ionosphere,
- dry, stable environment.



Lunar Farside Low Frequency Radio Telescope on a NASA Commercial Lander

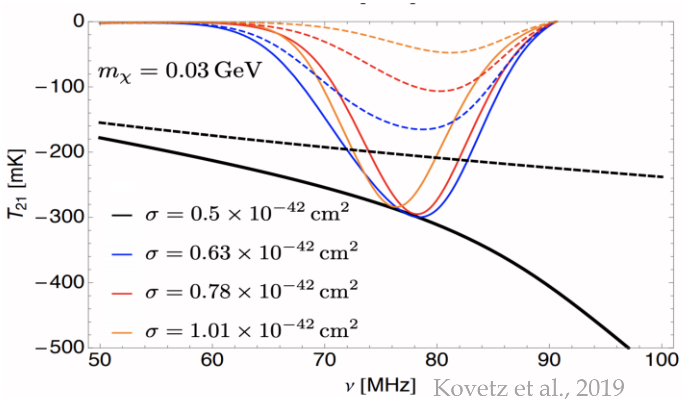
- LuSEE-DAPPER (LuSEE = Lunar Surface Electromagnetics Experiment; DAPPER = Dark Ages Polarimeter PathfindER) low radio frequency telescope on a CLPS lander. A Patch antenna (40-110 MHz) is on the lander top deck and STACER (spiral-tube) antennas (10-45 MHz) are deployed from 4 sides of the lander.
- Team: S. Bale (UC Berkeley), J. Burns (Colorado), R. Bradley (NRAO).
- Status: Landing in Schrödinger basin on lunar farside in 2025.

Evolution of the Universe



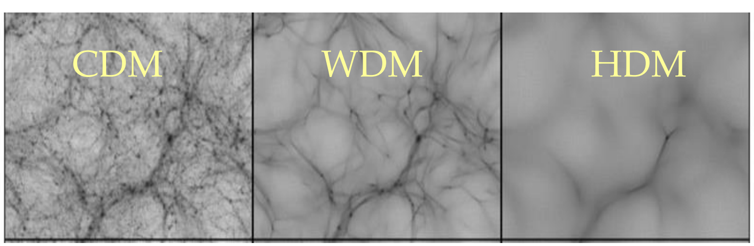
Probing Exotic Physics in an Unexplored Regime

Dark Matter - Baryon Interaction Beyond Gravity



Solid line: Models with baryon dark matter interaction

Dashed line: Models without baryon dark matter interaction



Measuring the 21-cm signal enables powerful probe of dark matter physics (Slayer 2016), testing particle physics models of dark matter in unconstrained regime:

- Dark matter annihilation (or decay) rate is higher in the denser, high-redshift Universe (Crelli et al. 2019). By-products of decay/annihilation heat and ionize the gas, imprinting on 21-cm signal.
- Non-minimal interaction between dark matter and baryons leads to a modified 21-cm signal (Tashiro et al. 2014).
- If dark matter is warm (WDM) and has a larger coherence scale (ultra-light axions, sterile neutrinos), then star formation is delayed leading to an extended Dark Ages.

FARSIDE: Farside Array for Radio Science Investigations of the Dark ages and Exoplanets

Principal Investigator: Jack Burns, University of Colorado Boulder
Deputy P.I.: Gregg Hallinan, Caltech
Design Lead: Lawrence Teitelbaum, JPL

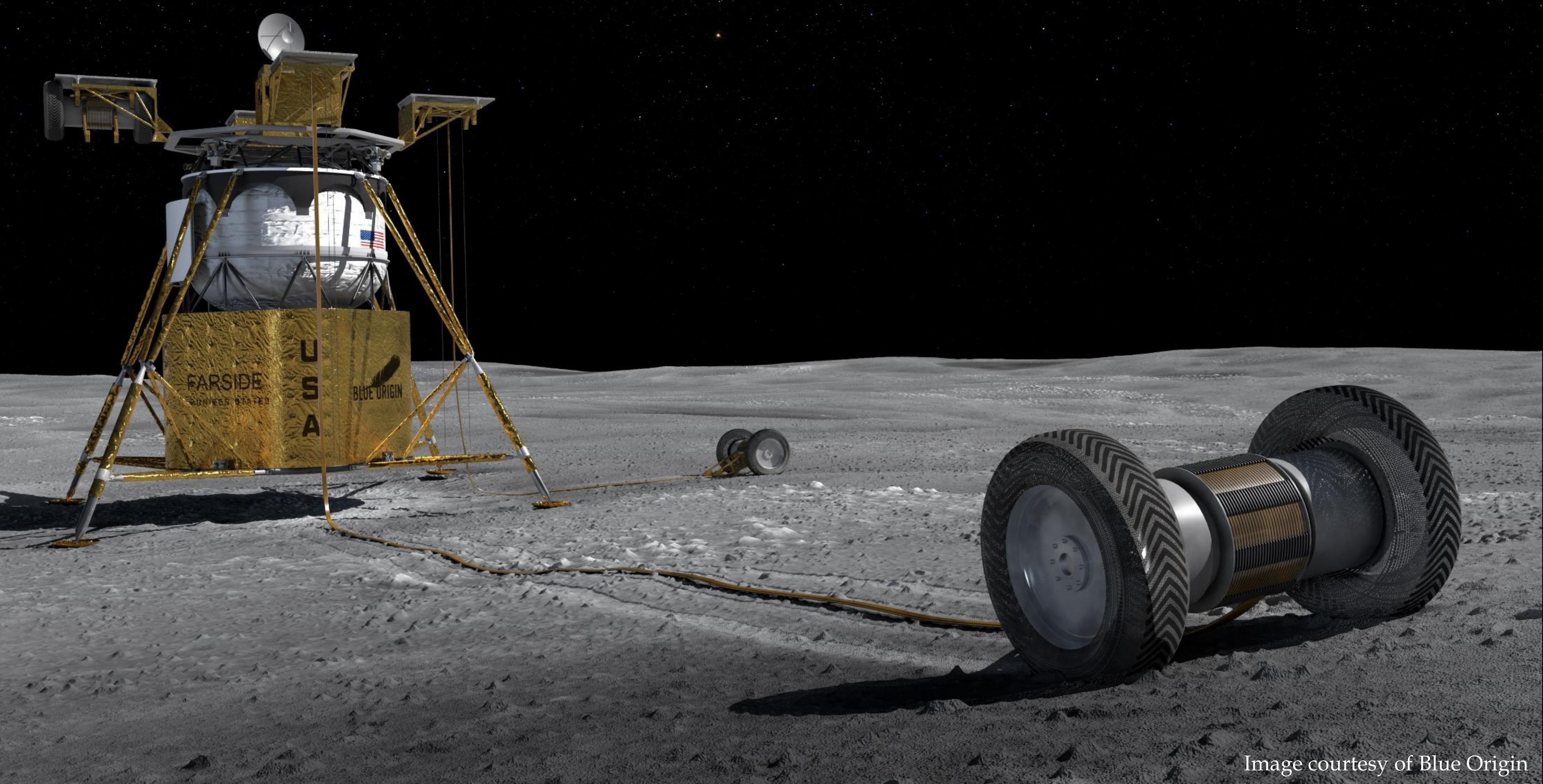


Image courtesy of Blue Origin

FARSIDE deploys from a single medium-sized lander

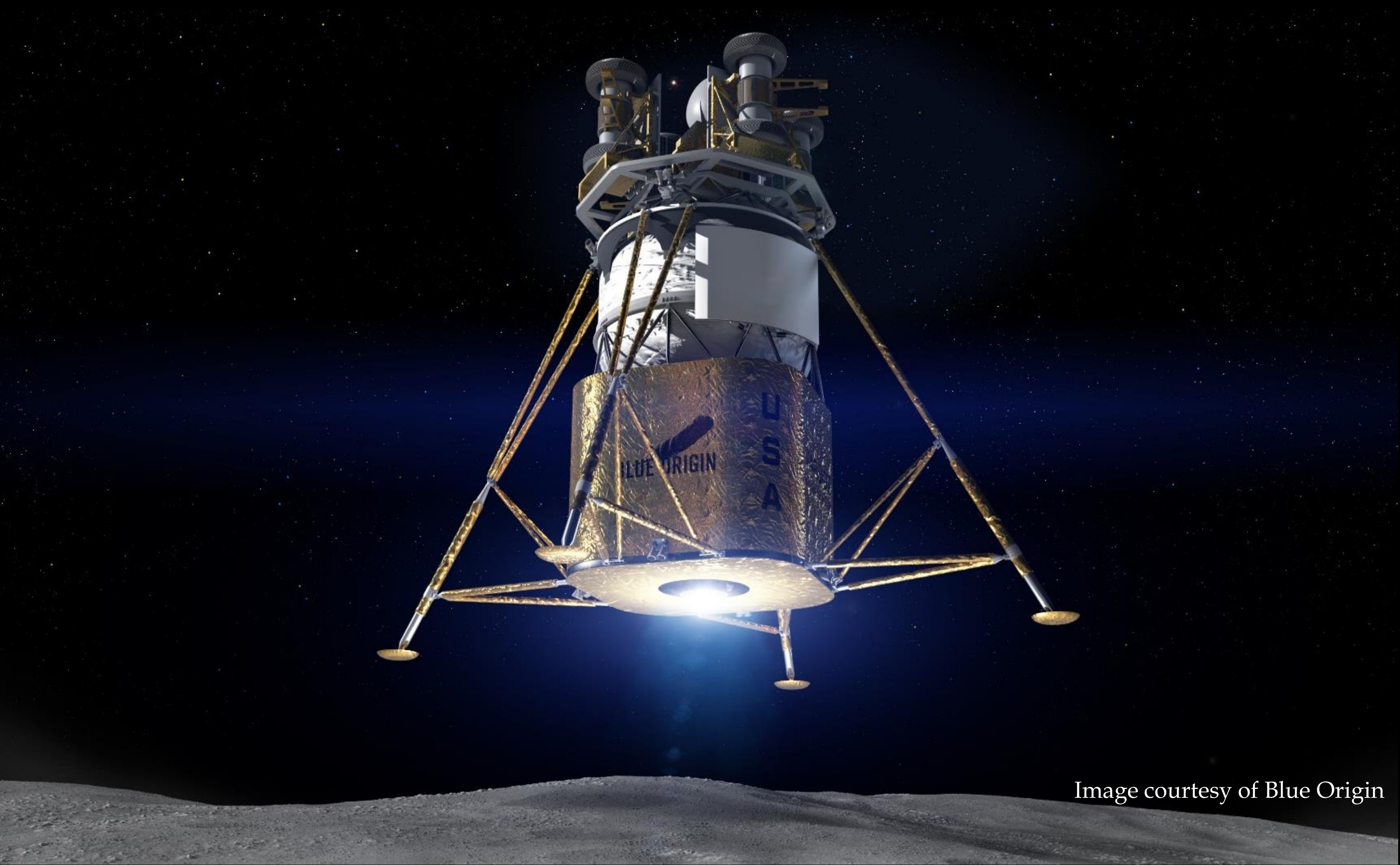


Image courtesy of Blue Origin

FARSIDE Mission Architecture

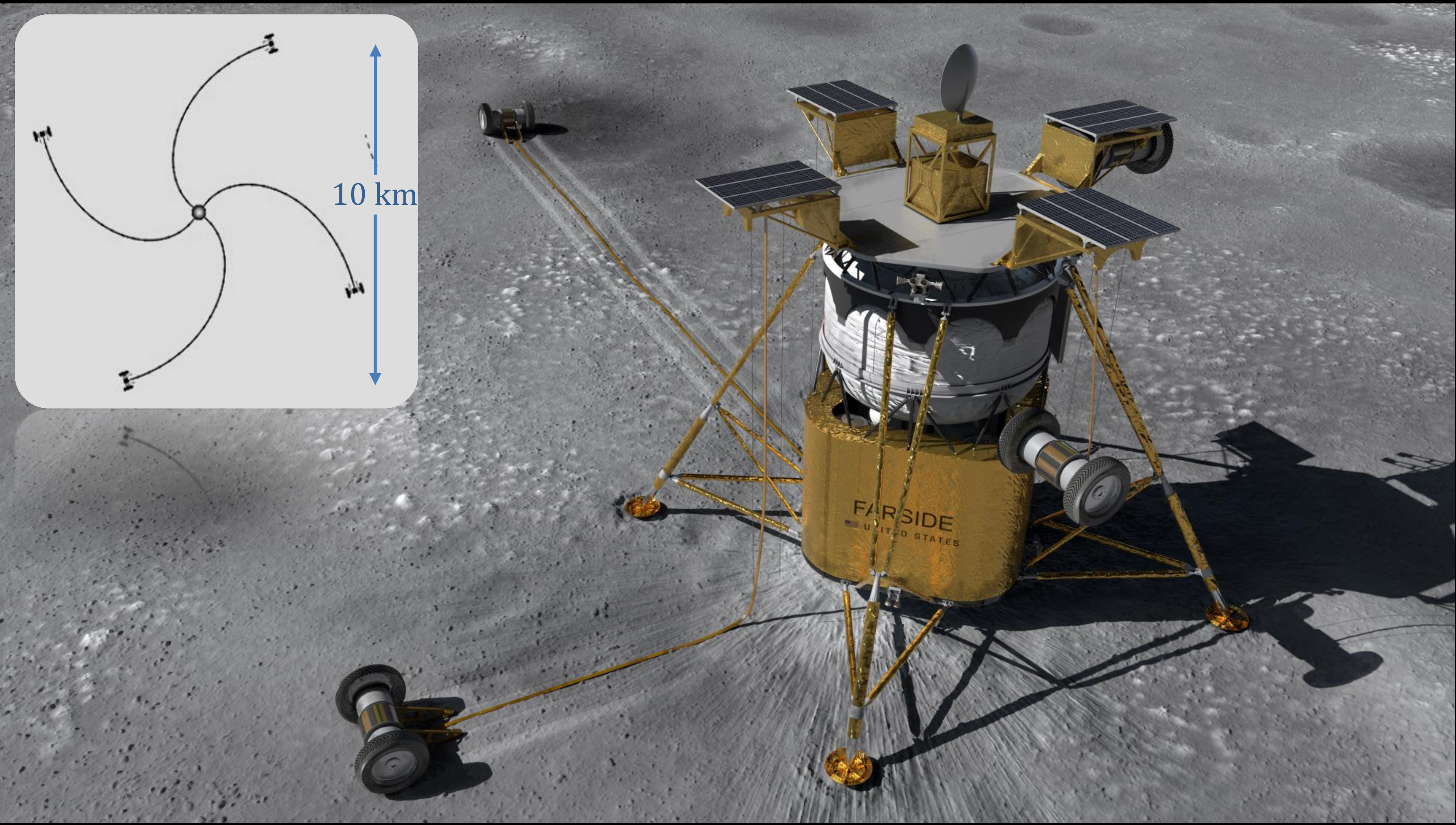
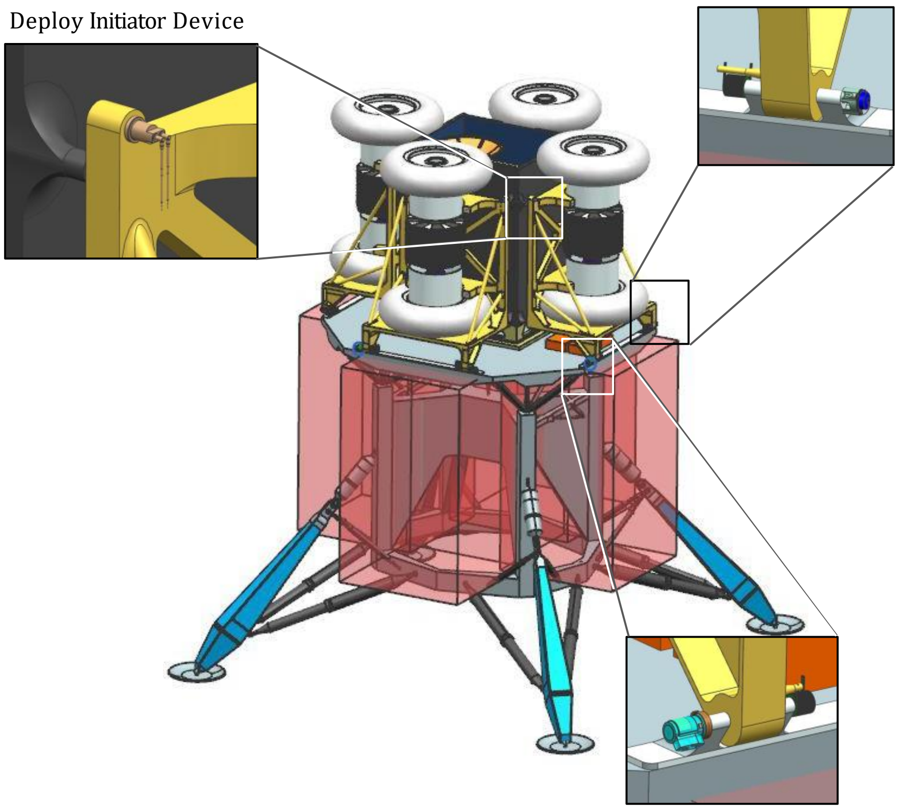


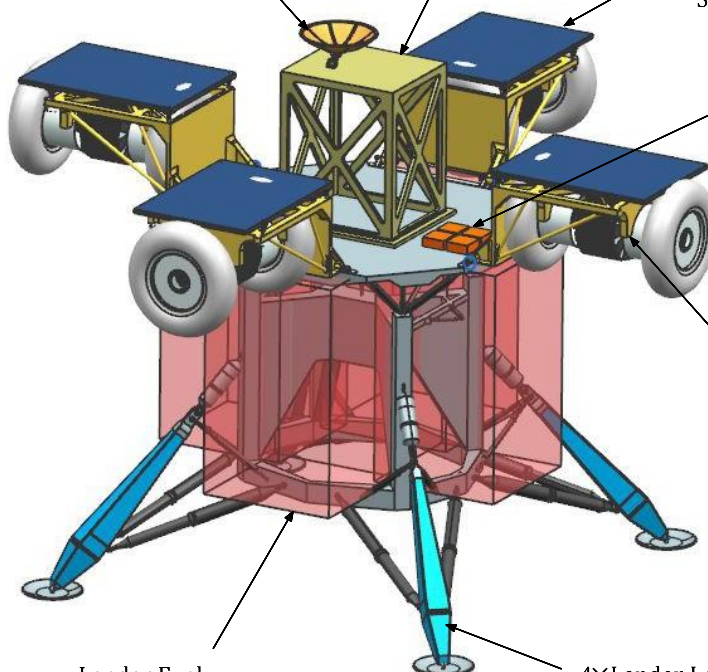
Image courtesy of Blue Origin

Lander/Rover Configuration Overview

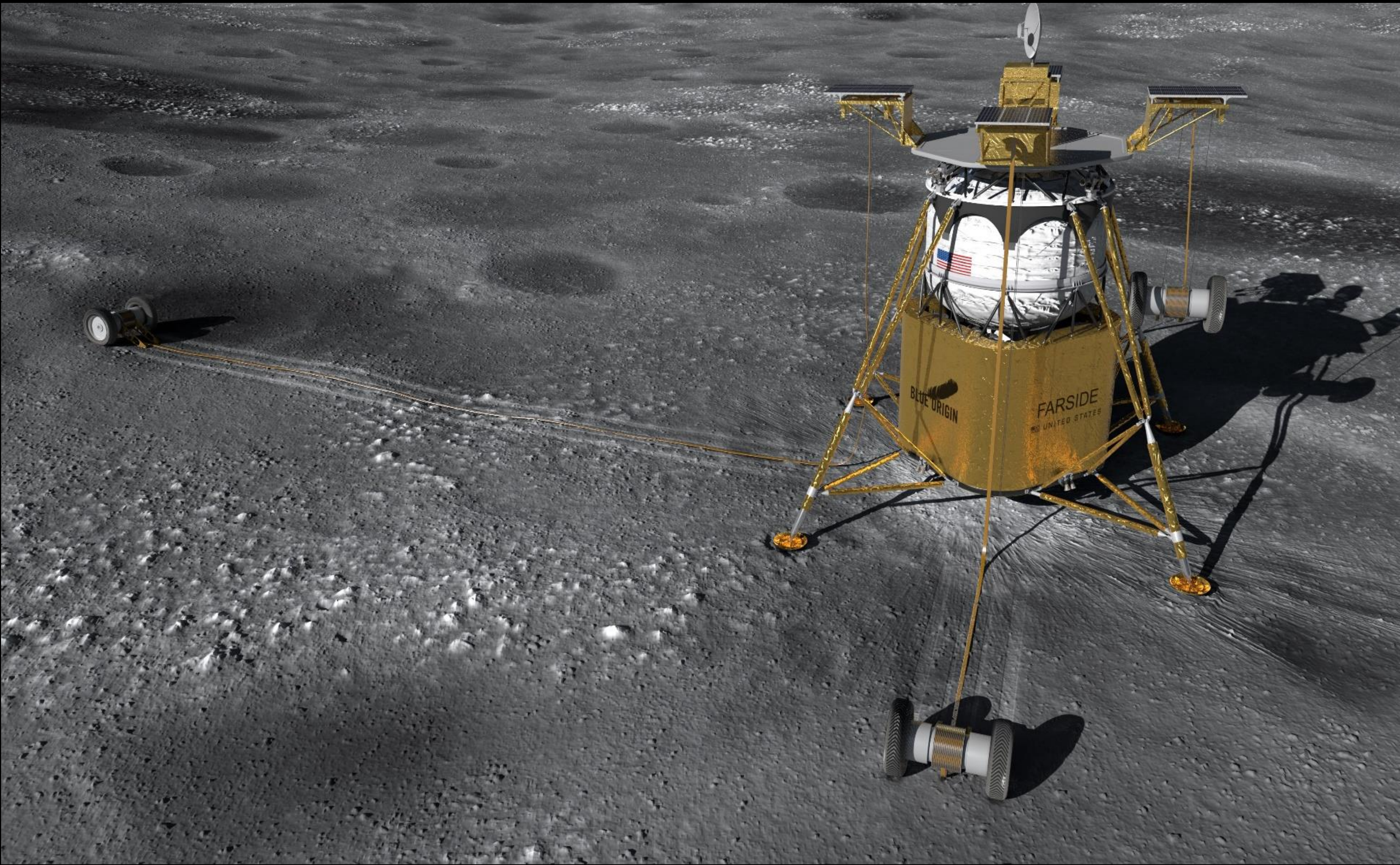
Stowed/Landing Configuration



Mid-Deploy Configuration

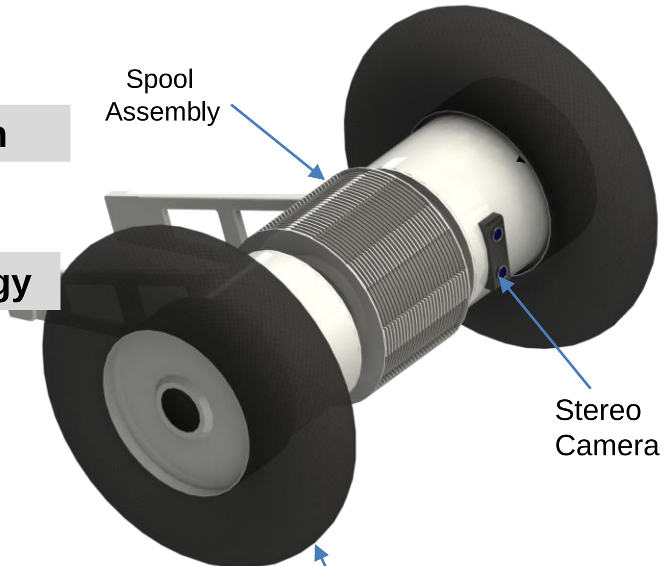


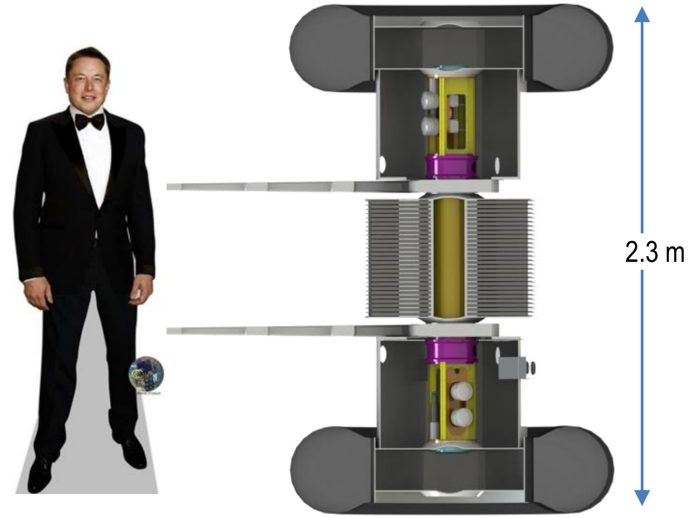
Tethers have embedded dipole antennas and convey power and communications

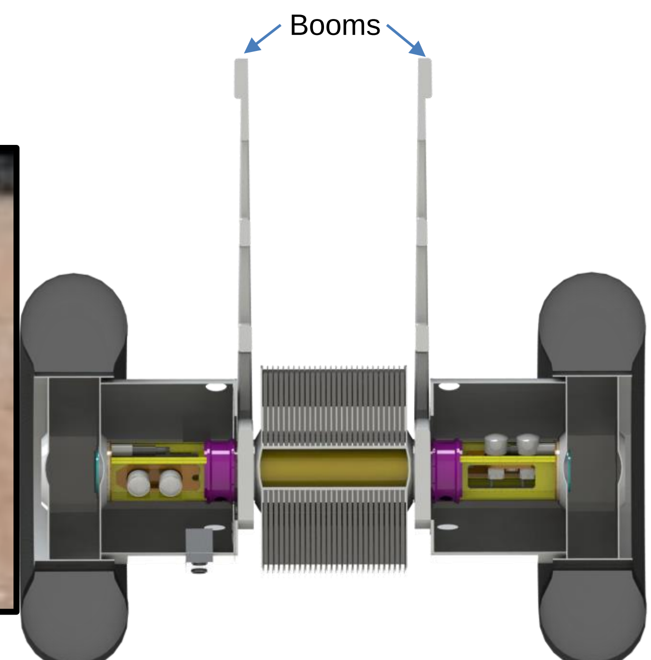


Design Strategy

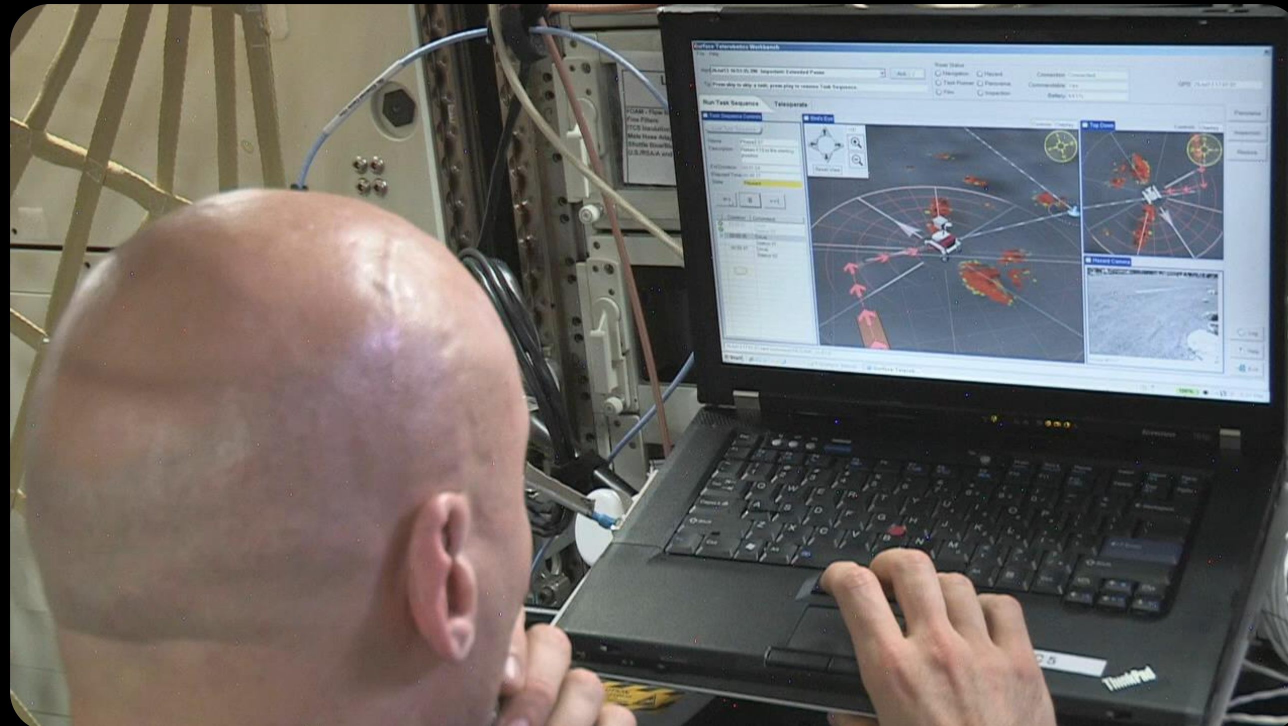
Node Sizing
↓
Node / Tether Integration
↓
Spool Deployment Strategy
↓
Spool Sizing
↓
Rover Design
↓
Egress Strategy
↓
Lander Accommodations
↓
Lander Configuration







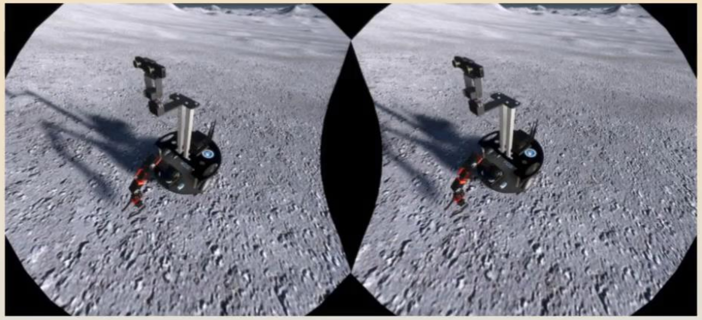
Astronaut
Luca Parmitano (Italy) orbiting Earth on the ISS teleoperates the K10 rover at NASA Ames Research Center to simulate deploying a lunar farside radio telescope.

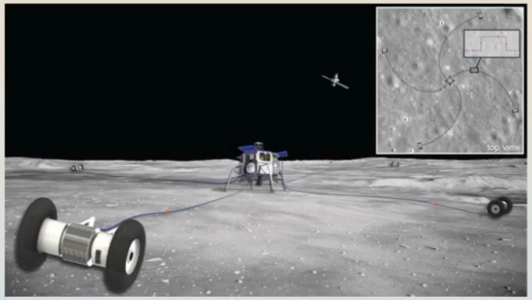


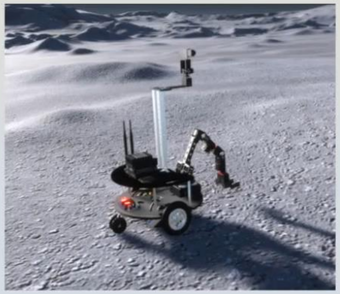
Technology Supporting the Assembly of Lunar Infrastructure

2021 Development Update

M. Bell, P. Curlin, M. Muniz, J. Burns







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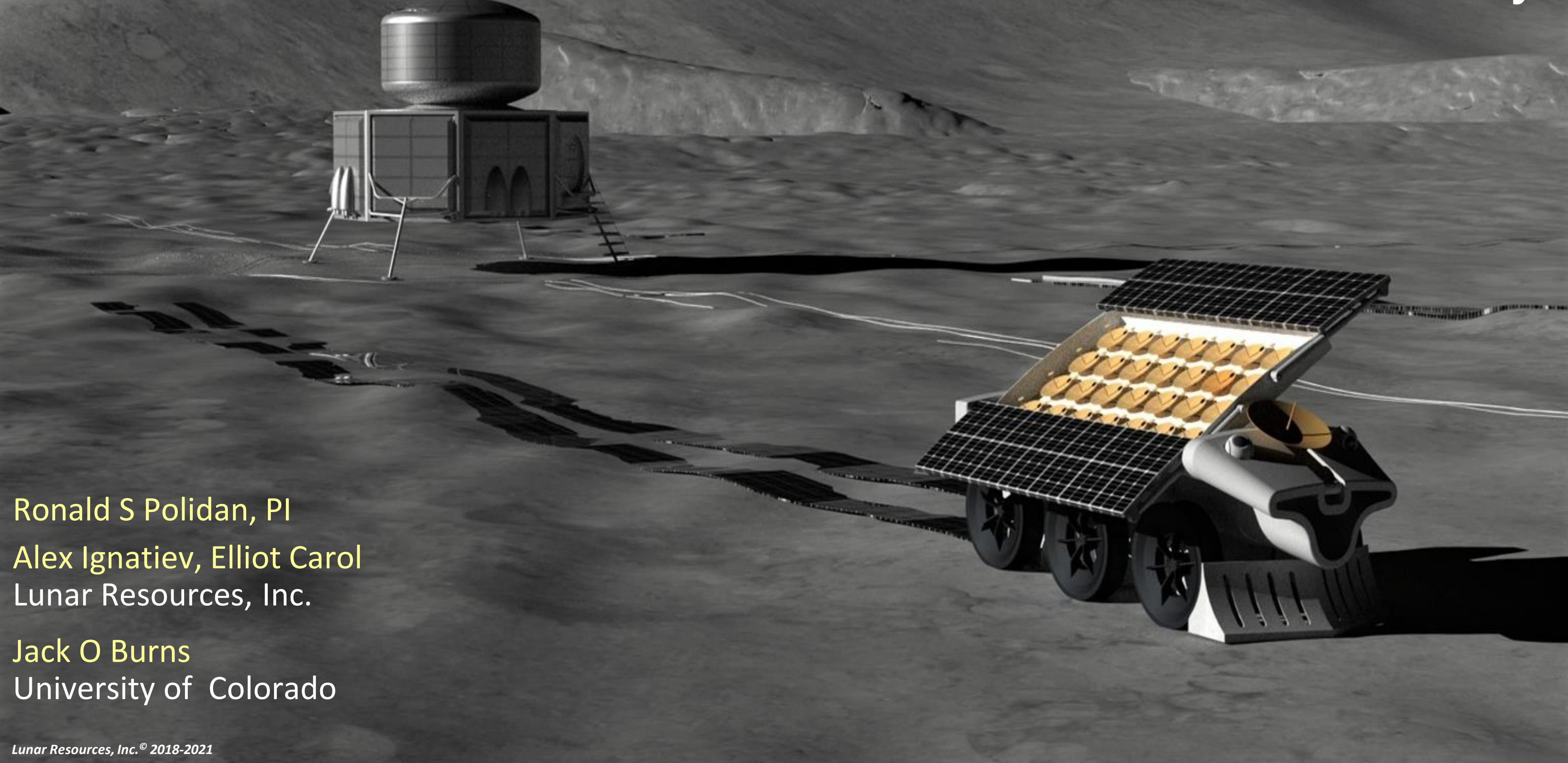
100,000 Dipole Antenna Radio Array

FarView - An In-Situ Manufactured Lunar Far Side Radio Observatory



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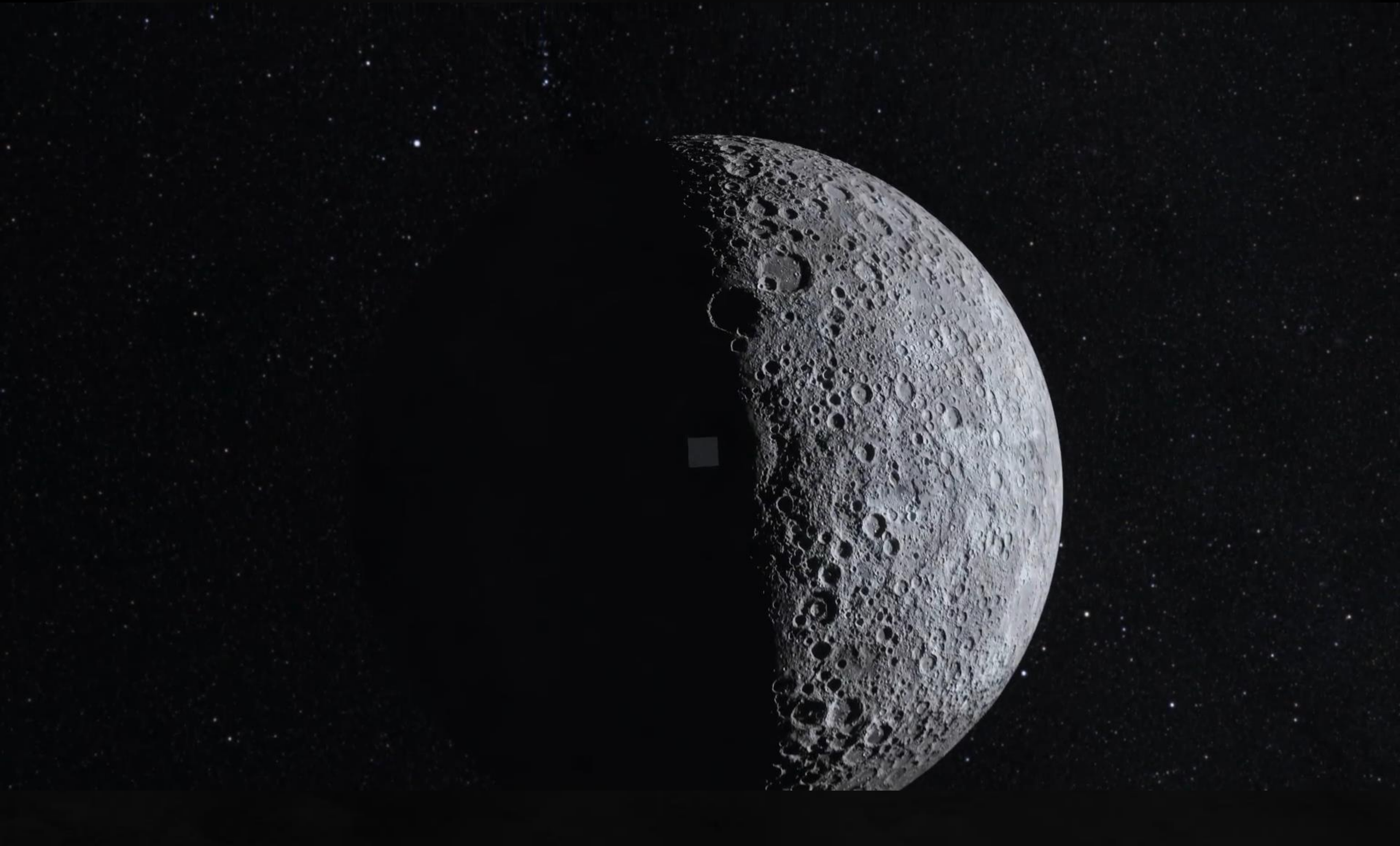
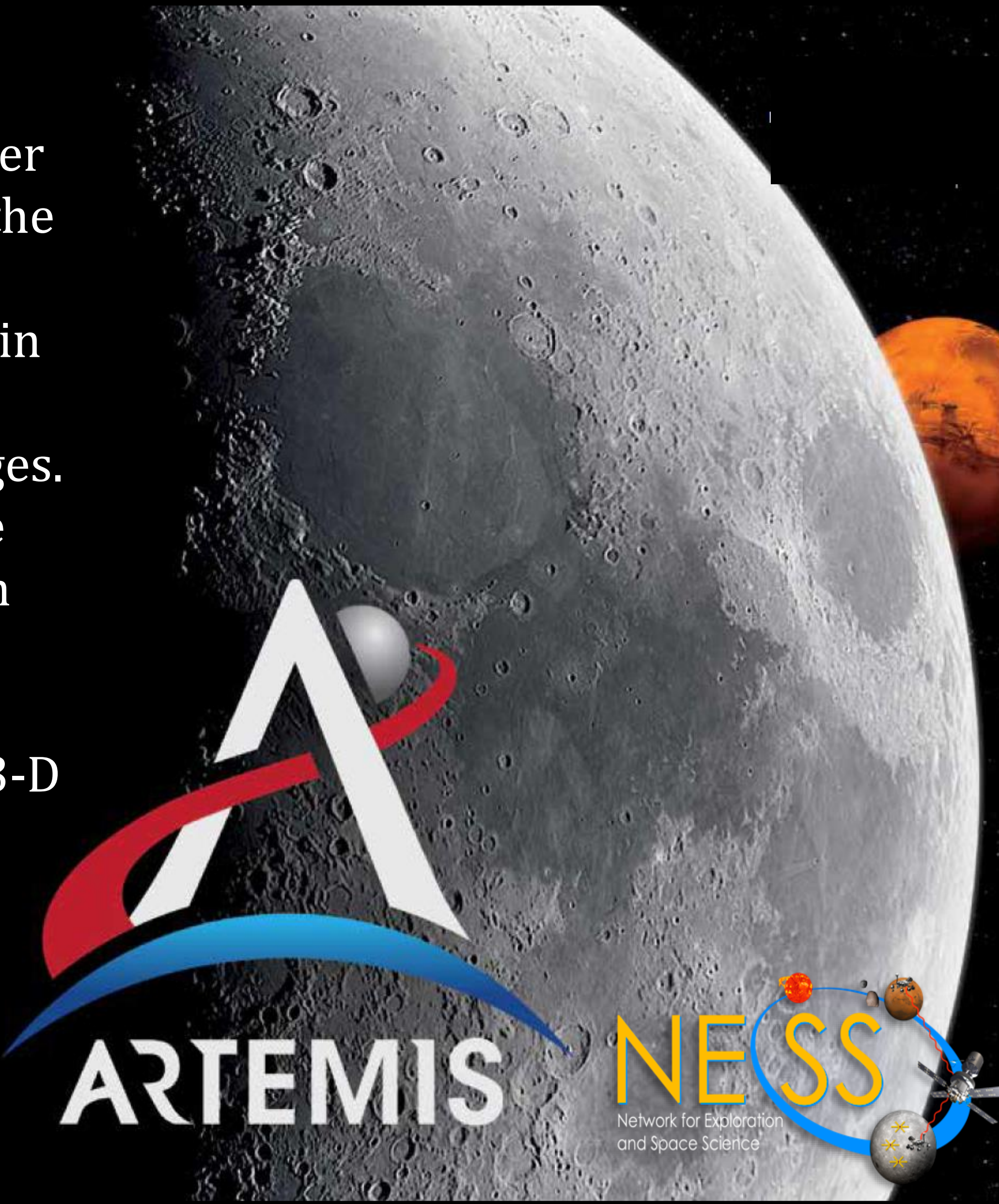
Phase I study funded by NASA Innovative Advanced Concepts (NIAC)

FarView - An In-Situ Manufactured Lunar Far Side Radio Observatory

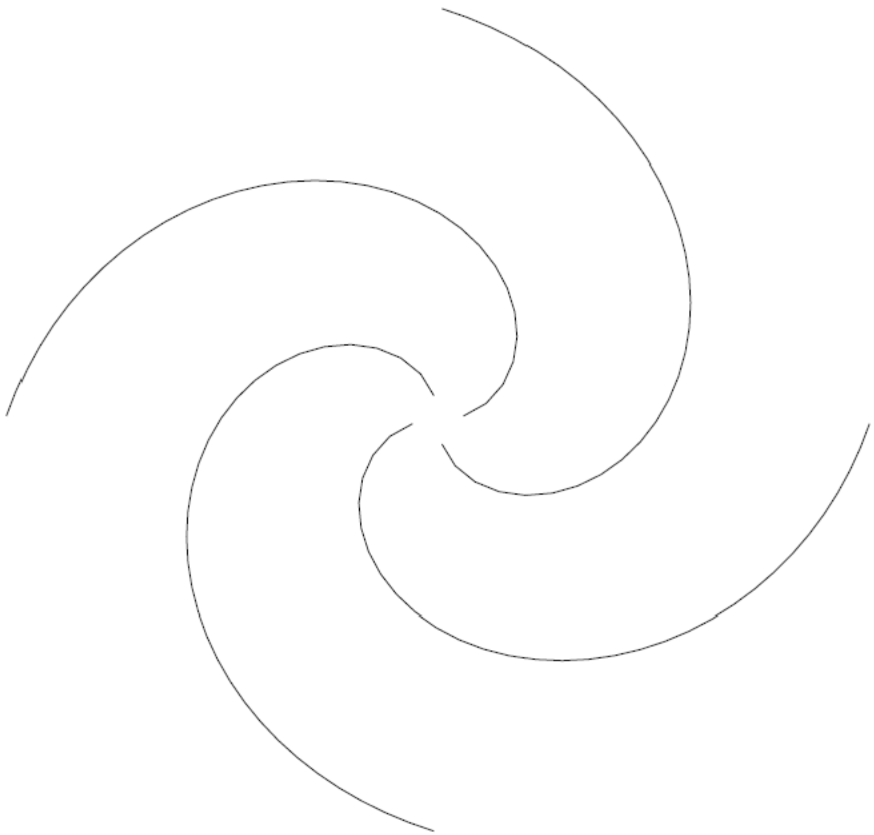


Summary & Conclusions

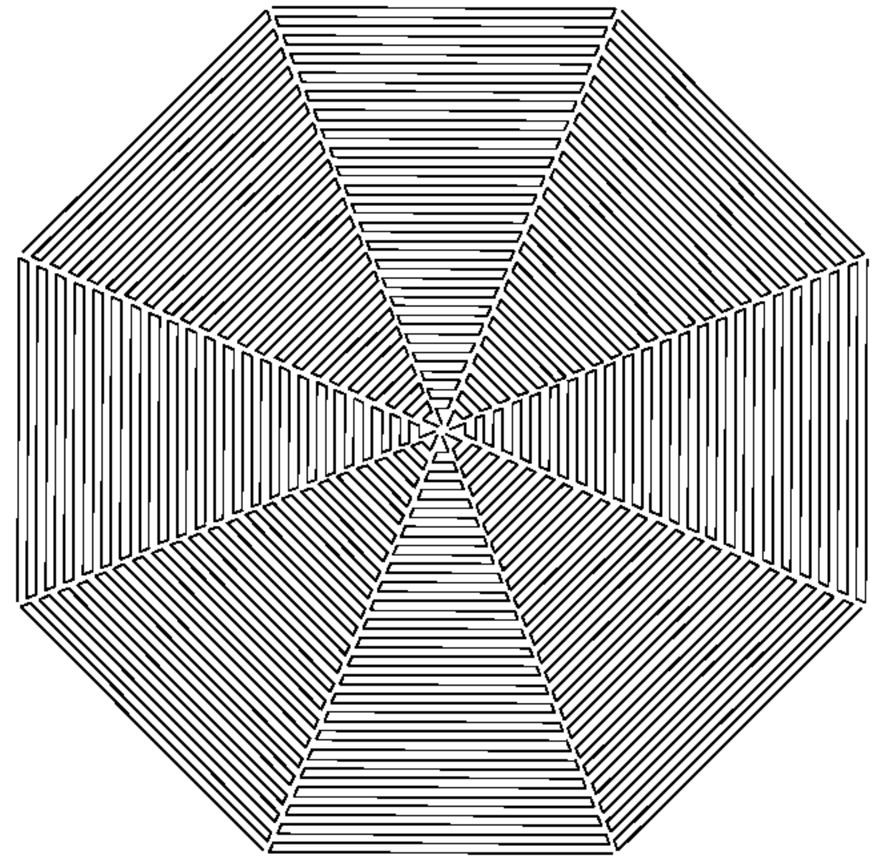
- NASA Commercial Lunar Payload Services (CLPS) program will deliver science payloads to the surface of the Moon beginning in 2022.
- ROLSES & LuSEE-DAPPER will begin to explore the lunar plasma environment & the cosmic Dark Ages.
- FARSIDE will take advantage of the transportation and communication infrastructure associated with NASA's Artemis.
- FARSIDE & FarView will measure 3-D spatial/spectral fluctuations to explore new physics including multiple flavors of dark matter, neutrinos, & inflation.



FarView: A radio array of 100,000 dipoles



FARSIDE
128 dual polarized antennas - 100m per polarization
4 rovers - 8.9 km per rover



Farview
100,000 dual polarized antennas - 5m per polarization
8 rovers - 125 km per rover

NIAC P.I. Ron Polidan, Lunar Resources,
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