



Lunar Surface Network Relay Terminal: A Lunar Communications Platform

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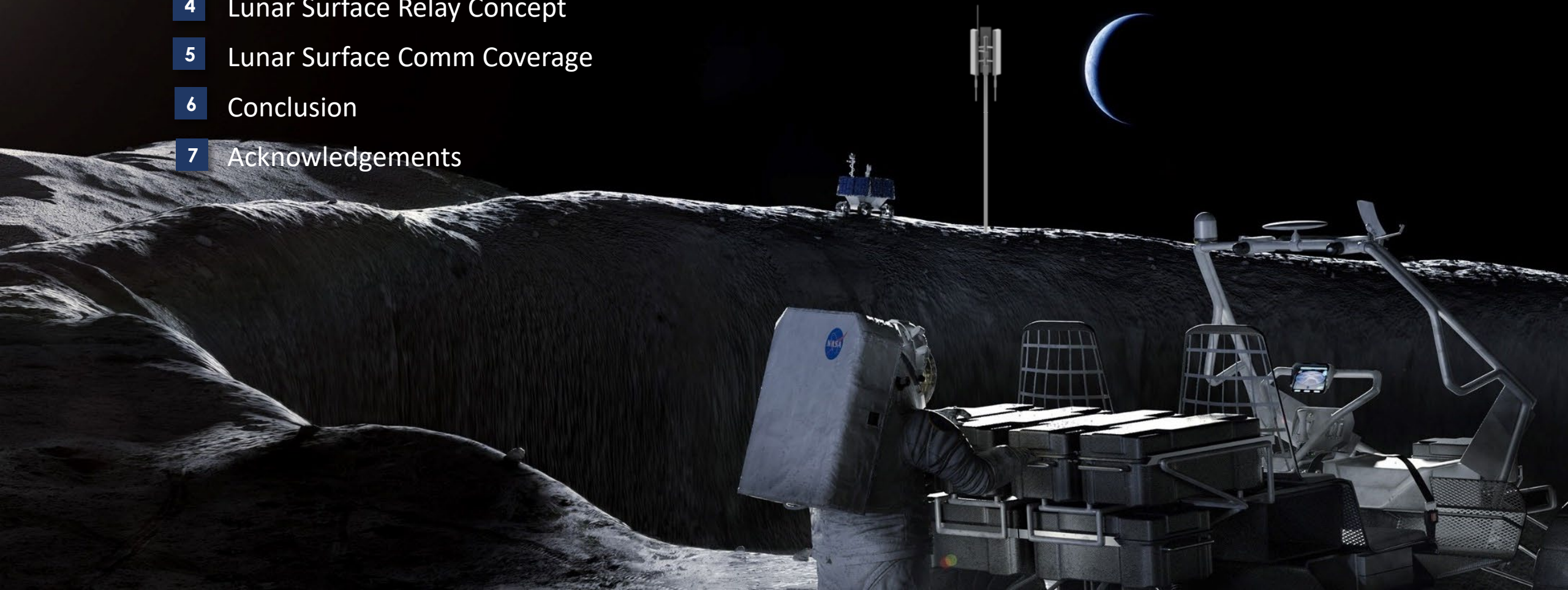
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Sponsor: Space Communications and Navigation Program

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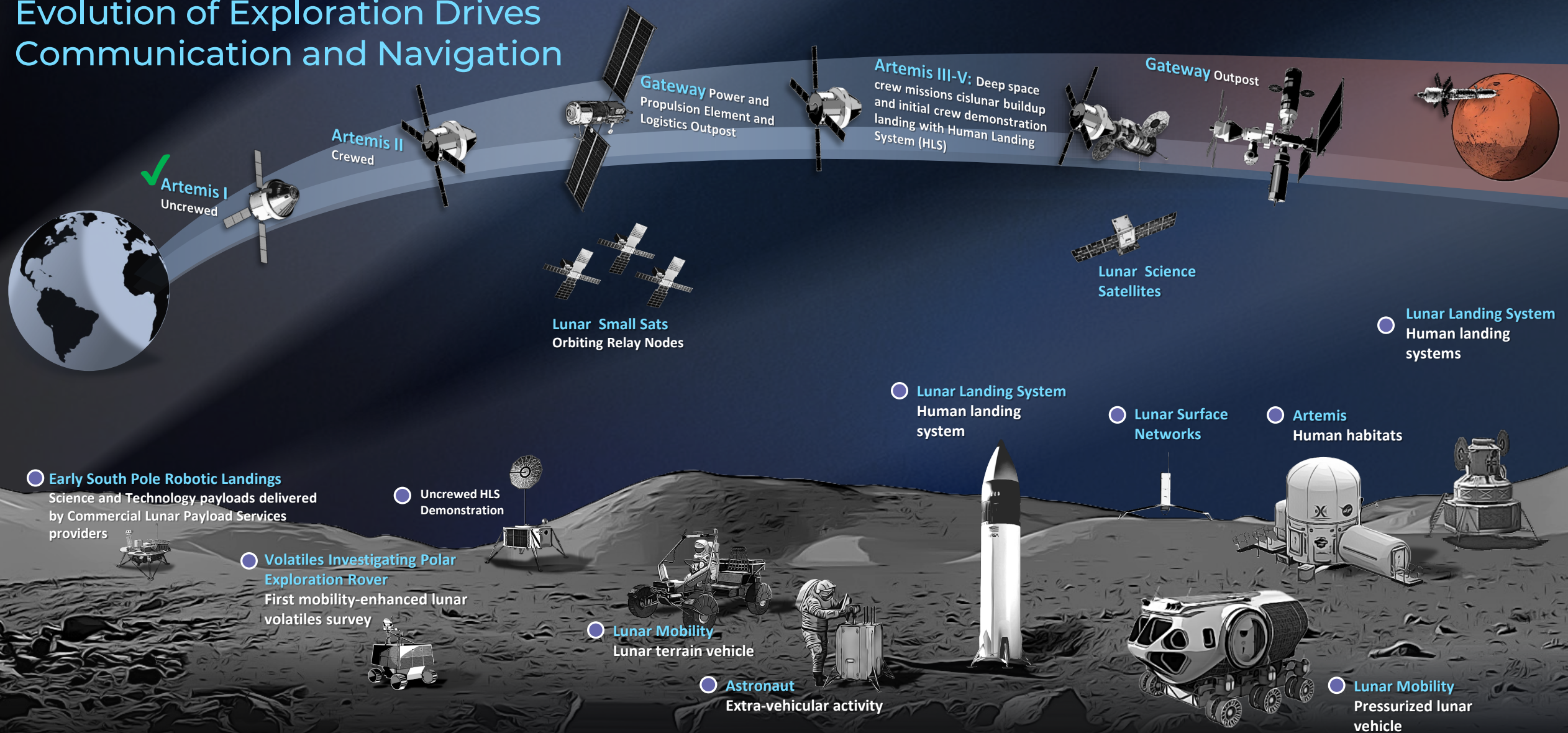
Presentation Agenda



- 1 Brief Introduction to Moon-to-Mars Program and Artemis Missions
- 2 Lunar Surface CPNT needs
- 3 Challenging Lunar Terrain
- 4 Lunar Surface Relay Concept
- 5 Lunar Surface Comm Coverage
- 6 Conclusion
- 7 Acknowledgements



Evolution of Exploration Drives Communication and Navigation

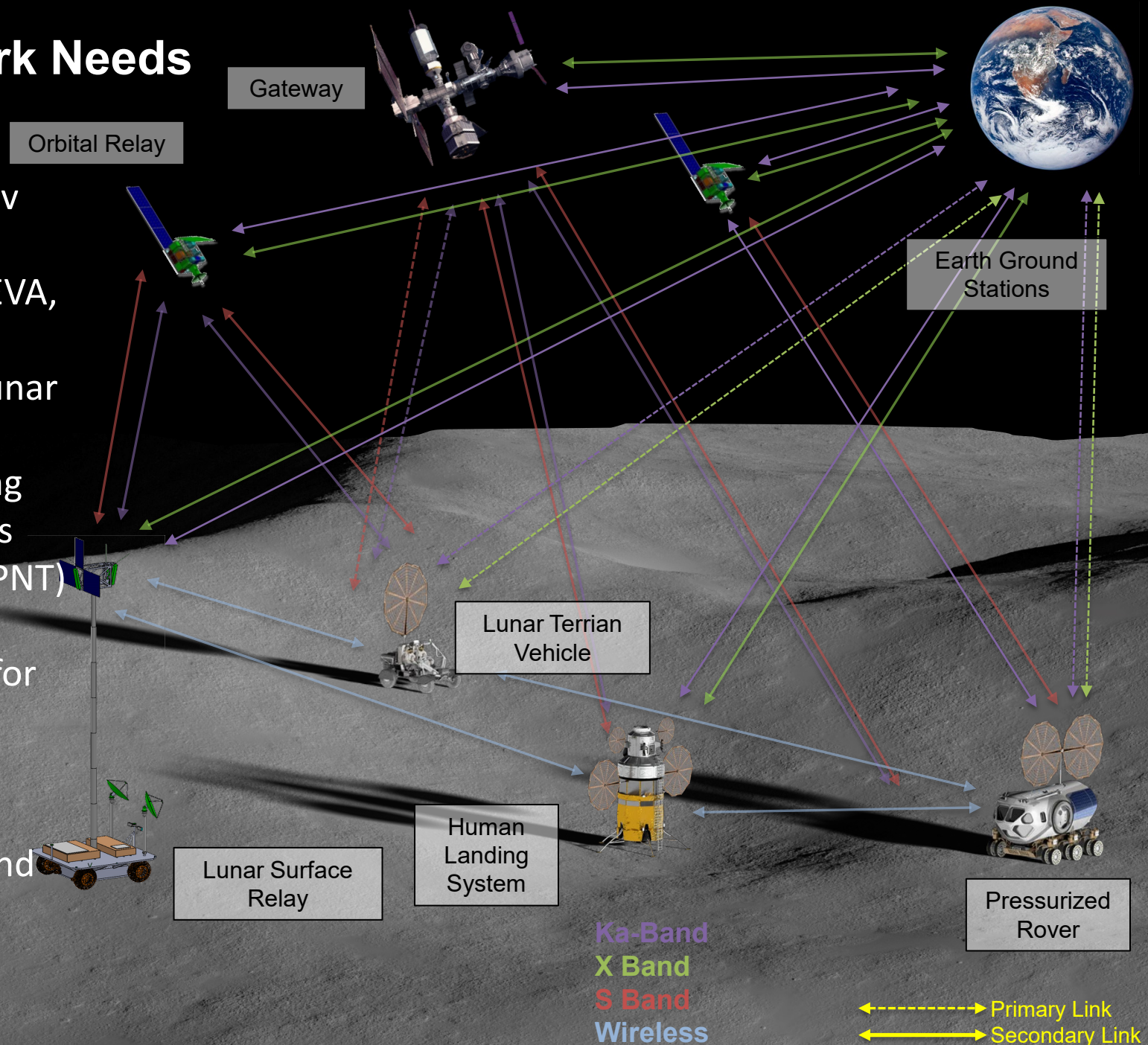


Source: G. Heckler, "Status of Commercial Communications Efforts and Opportunities at the Moon," NASA SCan, July 2023.

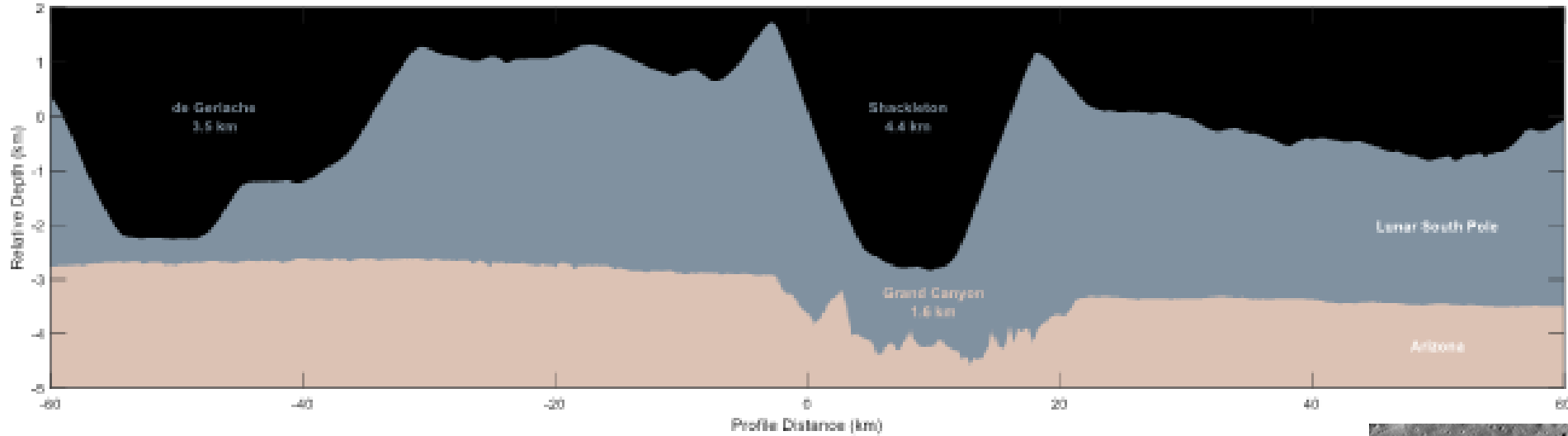
Lunar South Pole Region

Notional Lunar Surface Network Needs

- Require a robust and secure comm and nav system for lunar community
- Early Artemis surface assets include HLS, EVA, LTV, hab, and science
- Connection with Earth includes DTE and lunar orbital relays: LCRNS and Gateway
- Surface network enables comm/nav among landing spacecraft, EVA, and science assets
- Assets will have a comm and navigation (PNT) capability:
 - Monitoring and control and cameras for high-rate video back to Earth
 - Positioning and time for exploration
- Communicating with Earth or relays will require more power than surface comm and therefore require more mass/size.
- Challenging terrain: craters, temperature, illumination, slopes



Challenges of the Lunar Surface



Terrain

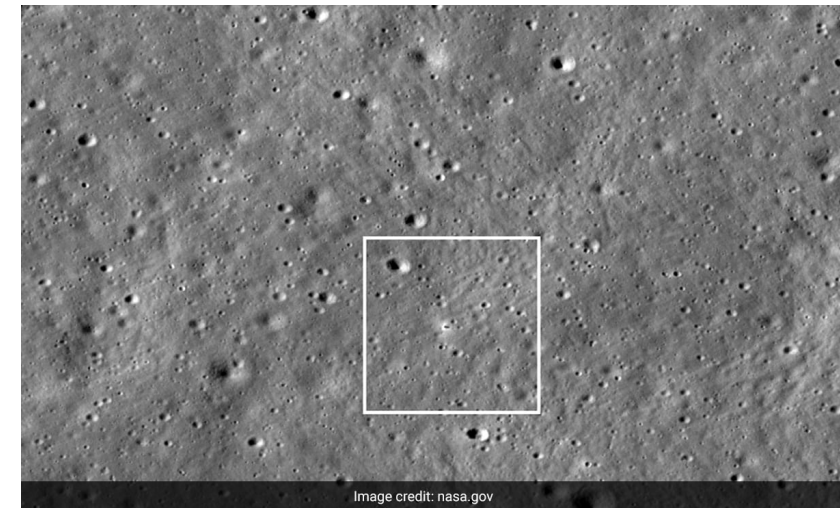
- Surface appears mild from lander view at a distance
- Craters larger than Grand Canyon
- Slope >20degree
- Dust

Temperature

- Extreme surface temperature can range from 18K to 439K, depending on location and time of year
- Surface temperatures are sensitive to local features.
- Dust coverage has a negative impact on radiator performance

Illumination

- 14 days lunar cycle with varying shadows/illumination
- Permanently shadowed regions/craters



Chandrayaan-3 Lander Site

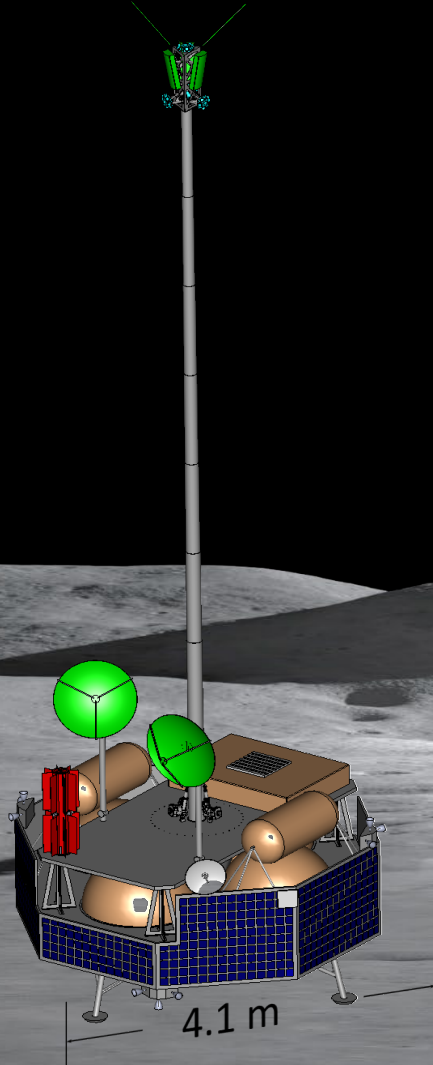
Lunar Surface Relay (LSR) Terminal

- Central terminal for lunar surface wireless comm (e.g. 3GPP, WiFi)
- Link to orbital relays and Earth
- Powered by:
 - Radioisotope/solar/battery
 - Solar/battery
- 10m deployable/retractable boom enhances surface coverage and illumination
- Mobility adds ability to optimize surface coverage and illumination
- LSR designed to survive the lunar night for future lunar missions
- Removes SWaP burden from the surface assets due to reduction in transmission range

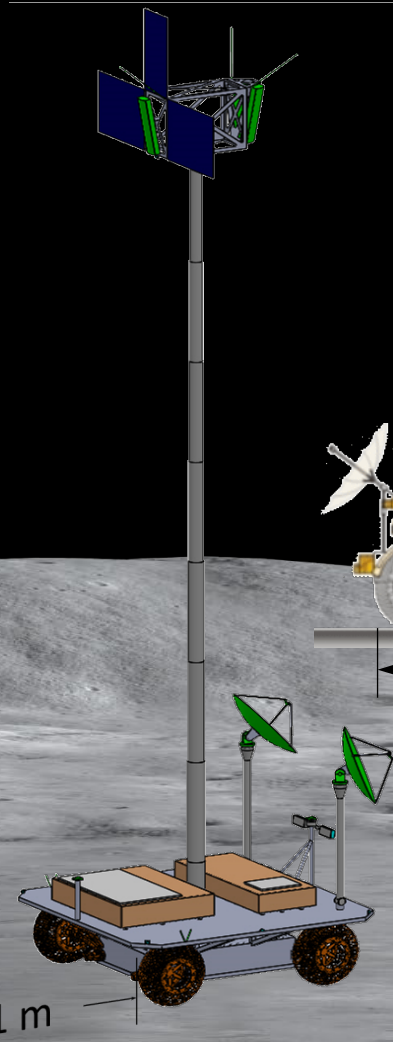


LSR Conceptual Designs

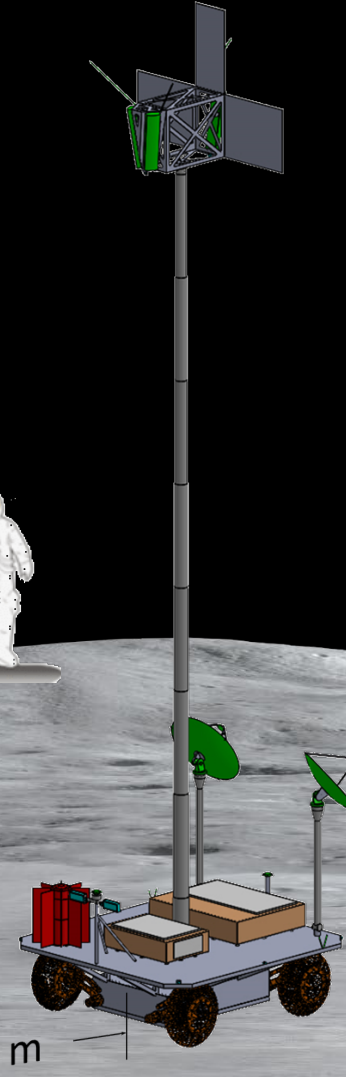
RTG Powered, Stationary



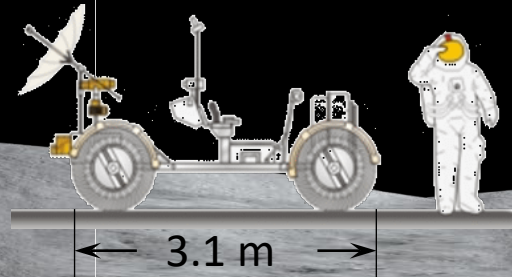
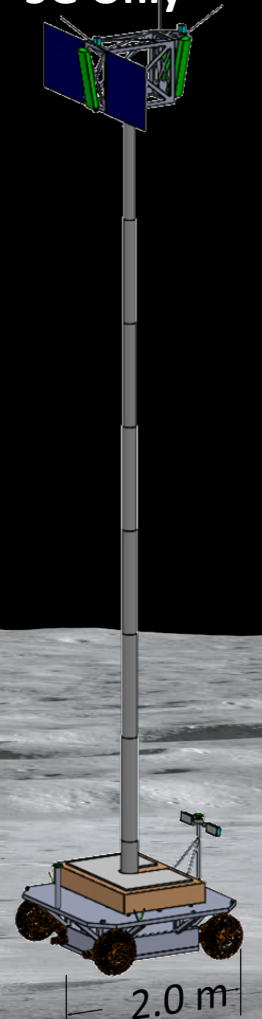
Solar Array Powered, Mobile



RTG Powered, Mobile



Solar Array Powered, Mobile
5G Only



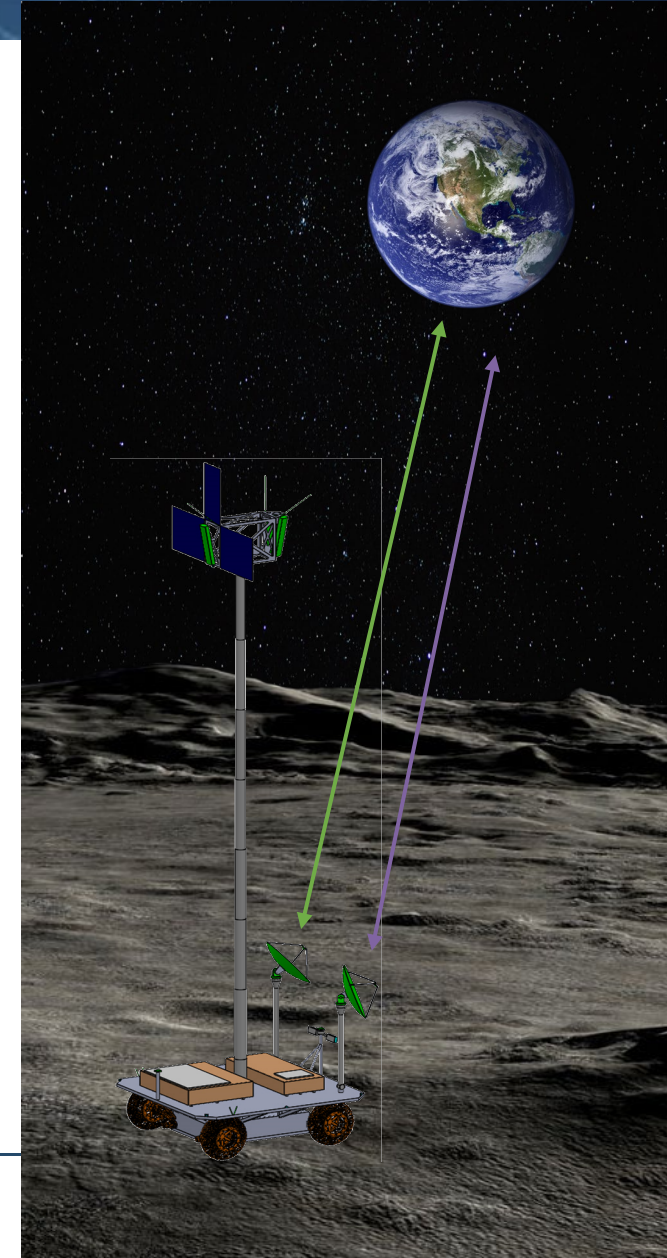
LSR Orbital Relay and DTE Comm

LSR DTE Links

- X- and Ka-band compliant with International Communications Systems Interoperability Standards (ICSIS)
- X-band link provides voice, telemetry, tracking and control (TT&C) and data
- Ka-band link provides more bandwidth and higher rate service for video applications including HD video
- Send and receive information to Earth primarily through NASA's SCAN Near-Earth Network, Lunar Exploration Ground Stations (LEGS)
 - LEGS equipped with 18m-class high gain dish antennas

LSR Orbital Relay Links

- When Earth is not visible (nominally 14 days every month) both Gateway and LCRNS can provide service to route information to Earth from LSR
- S- and Ka-band links (ICSIS)
- S-band voice, TT&C and data, Ka-band provide high-rate data and video
- Gateway will transmit/receive data via LEGS while LCRNS will rely on commercial Earth ground stations



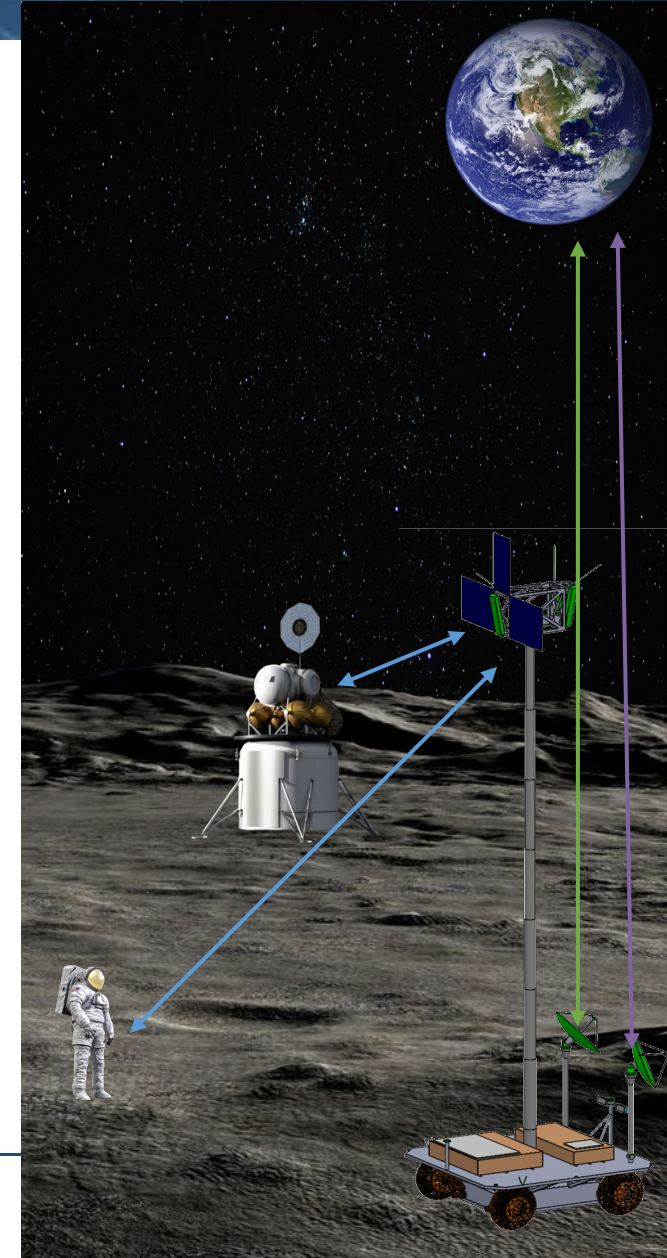
LSR Surface Comm and Nav

Communications

- 3GPP-based/Wi-Fi network services to surface assets supporting voice, data and video communications.
- LSR serves as a base station/access point for EVA, LTV, PR, etc and relieves surface assets of additional communication hardware to send/receive with lunar orbitals and/or DTE
- Equipped with 10 m (20 m possible) deployable/retractable boom to improve surface comm and illumination
- 3GPP 10 km range and Wi-Fi range of up to 300 m; subject to specific terrain
- Limited number of surface assets for early Artemis missions allows simplified network

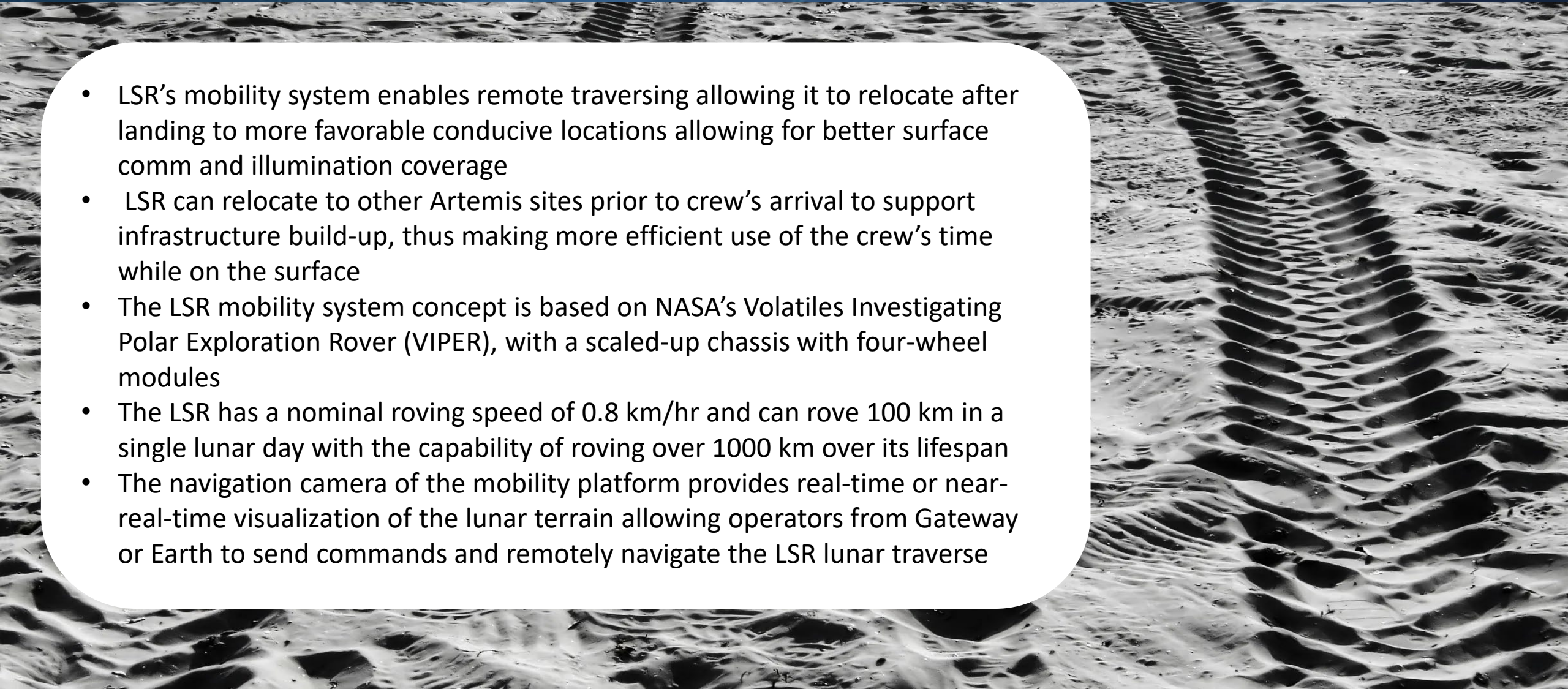
Positioning, Navigation and Timing (PNT)

- Two rubidium clocks, operating continuously, provide lunar timing to surface elements and orbital relays
- High accuracy clocks, synchronized with the orbital relay satellite reference, to provide PNT services to surface assets
- Two retroreflectors provide positioning and ranging sources for the orbital relays and Earth



LSR Mobility

- LSR's mobility system enables remote traversing allowing it to relocate after landing to more favorable conducive locations allowing for better surface comm and illumination coverage
- LSR can relocate to other Artemis sites prior to crew's arrival to support infrastructure build-up, thus making more efficient use of the crew's time while on the surface
- The LSR mobility system concept is based on NASA's Volatiles Investigating Polar Exploration Rover (VIPER), with a scaled-up chassis with four-wheel modules
- The LSR has a nominal roving speed of 0.8 km/hr and can rove 100 km in a single lunar day with the capability of roving over 1000 km over its lifespan
- The navigation camera of the mobility platform provides real-time or near-real-time visualization of the lunar terrain allowing operators from Gateway or Earth to send commands and remotely navigate the LSR lunar traverse



LSR Surviving the Night

- Surviving the lunar night is essential for surface assets to be used and relied upon for multiple missions over an extended time -- If the surface asset cannot survive the lunar night, it is limited to single mission use, requiring expensive replacement for subsequent missions
- A lunar day/night cycle is approximately 29.5 Earth days (708 hrs) which results in a lunar day equivalent of approximately 14.75 days (354 hrs) and the same for the lunar night – the 14.75 lunar night cycle is a worst-case scenario
- Depending on the location at the lunar south pole, and boom height, future designs could reduce the night cycle to as little as 100 hours
- Night periods can extend beyond the 354-hour case, especially in the lunar winter periods, but careful positioning could allow the rover to avoid these locations
- All four conceptual LSR designs have thermal management systems which allow them to survive the lunar night with differing capabilities during night operation

LSR Power and Mass

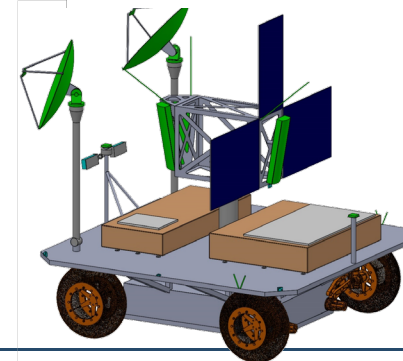
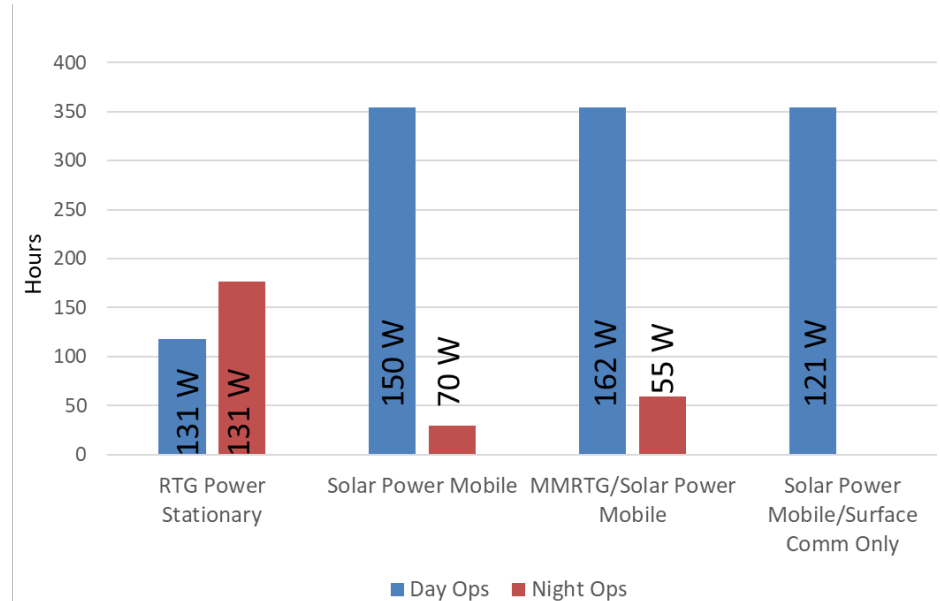
- Power: solar array (top of boom) or RTG/MMRTG (deck)
- The amount of power needed to operate the various systems on the LSR depend on the duty cycle of the operational concepts which varies with each LSR design

Required communication sub-system power to provide the high data rate (HDR) services for both lunar day and night operation for the four LSR design concepts

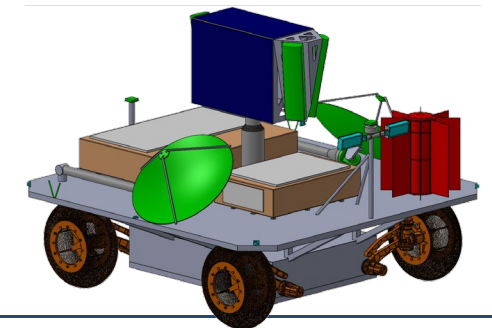
Each design has slightly different operation concepts and attributes (e.g., throughput, memory capacity, power)

- Three mobile LSRs capable of continuous HDR Day Ops (354 hrs) but power requirement differ data throughput
- Night Ops for the Solar Mobile requires 70W for 2 hrs per 24 hrs for surface communications and MMRTG power of 55W for 4 hrs per 24 hrs for surface communications
- No high-rate Night Ops for the Surface Comm Only LSR

Comm Subsystem Power vs. Day/Night Operation



Solar array (stowed) config.



RTG/MMRTG config.

LSR Power and Mass

- Total and the major sub-system contributors of the mass for the four LSR designs
 - RTG Stationary is the lightest of the four LSR concepts -- Due to the RTG power system which is roughly 70 kg, lower battery capacity, and absence of a mobility system compared to the Mobile LSR
 - Solar Mobile LSR: heaviest of the LSR concepts due to the battery and mobility sub-systems (mobility unit is approximately 190 kg)
 - MMRTG Mobile is second heaviest due to a 20% decrease in battery mass which is offset by the MMRTG power system
 - Surface Comm only LSR is the lightest -- mass reduction due to decrease in communication payloads, reduced PNT functions, and associated reduction in the mobility platform mass

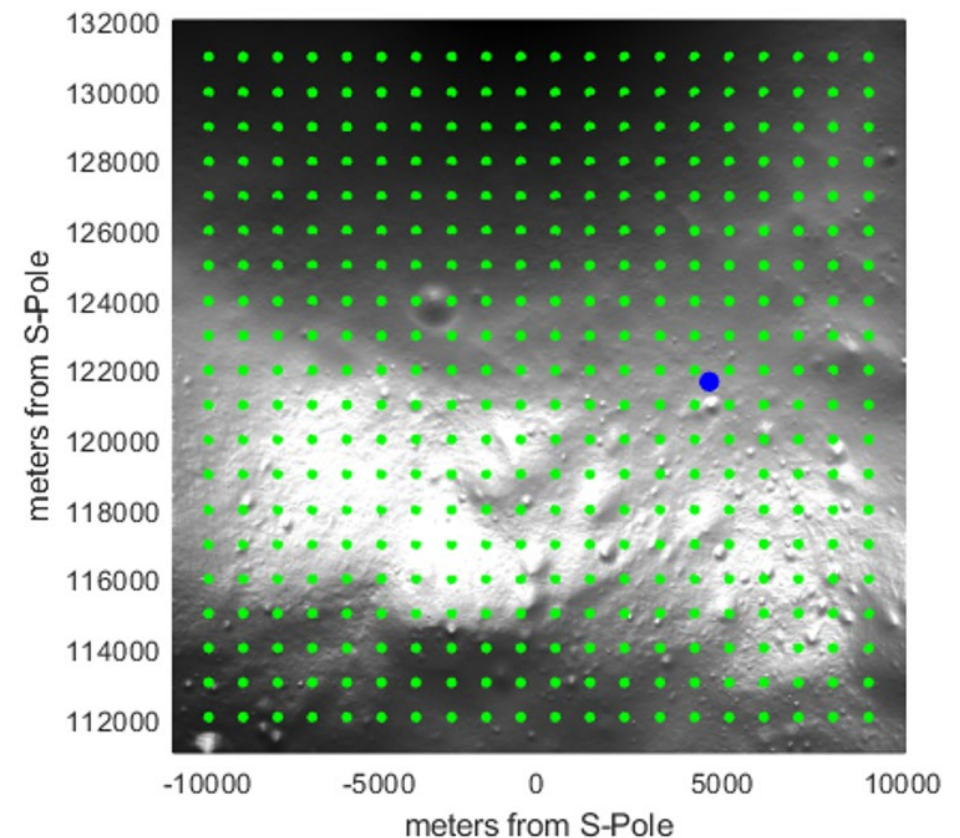
Mass Comparison with Baseline Design

	Total Mass (kg)	Mass Driver
RTG Stationary	547	Baseline
Solar Mobile Surface Comm only	700	+ Mobility + Battery - DTE Comm & PNT clocks (removed)
MMRTG Mobile	1003	++ Mobility + Structures + Battery
Solar Mobile	1218	++ Mobility + Structures ++ Battery

Lunar Surface Communication Coverage

- Lunar terrain near the South Pole makes constant communications very challenging
- Examine criteria to analyze a notional scenario
 - Malapert Massif, comm tower and habitat
 - 20 km by 20 km region, 20 and 4 m tower height, 2 m receiver (blue indicates habitat, green tower locations)
 - Tower locations every ~1 km (400 towers total)
 - Habitat landing site is the highest point within the region (blue)
- Criteria could be: Line-of-sight (LOS), slope, best coverage, solar illumination, DTE link availability, lunar orbit link availability, surface RF quality are a few

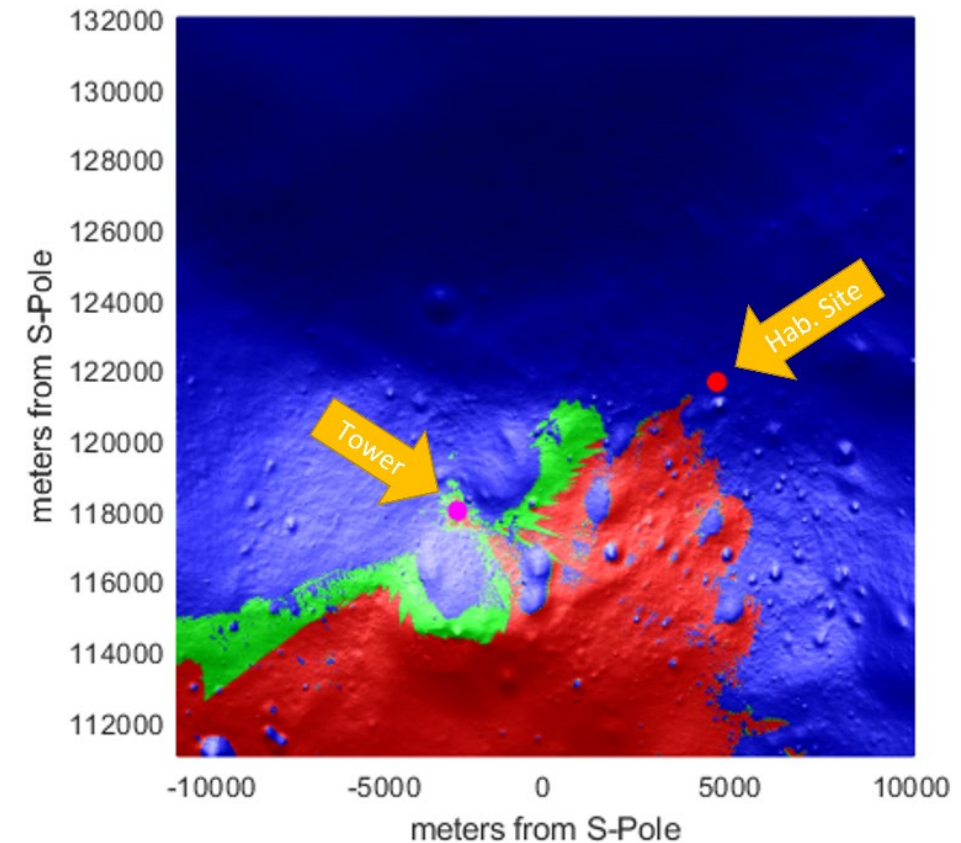
Notational Habitat and Tower Locations



Lunar Surface Communication Coverage

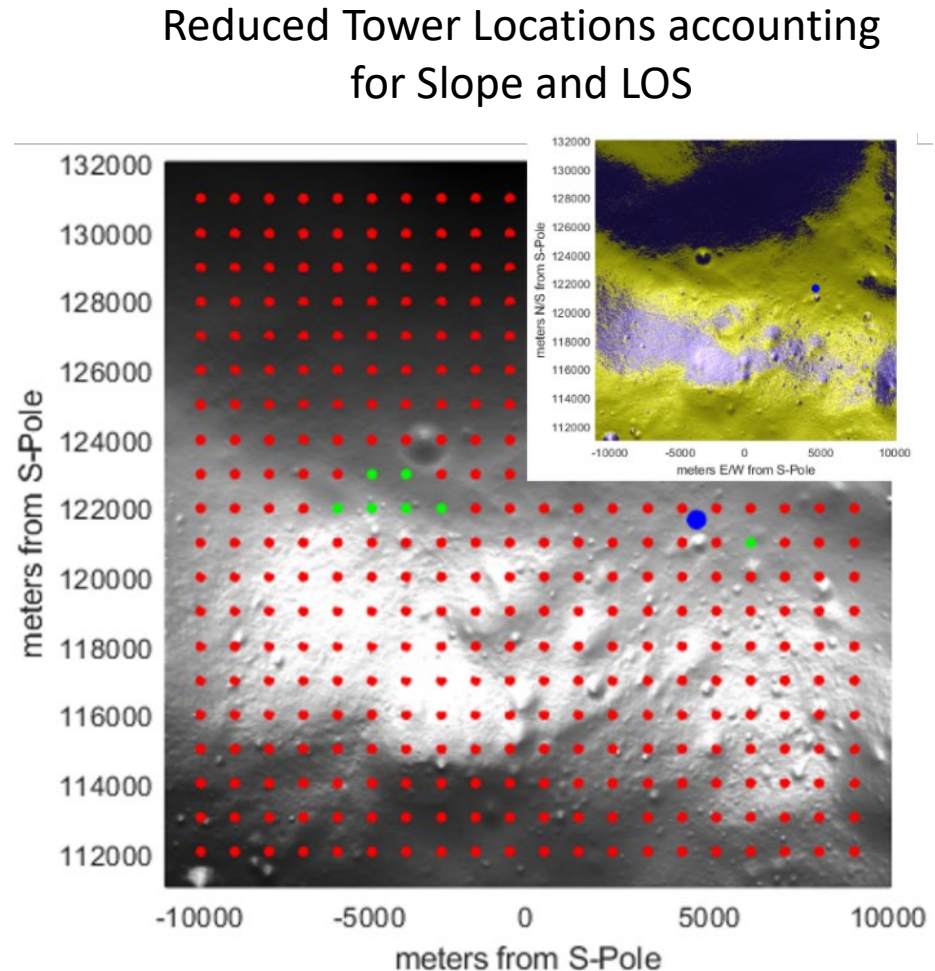
- Criteria: Tower location with best coverage:
 - Tower with best coverage located 8.3 km from habitat
 - Viewsheds:
 - 4 m tower (red) covers 23.7%
 - 20m tower (red and green) covers 29.2%
 - Tower height increase from 4 to 20 m only provides modest increase in coverage
 - Tower with the best coverage does not have line of sight to habitat
 - Note: The use of tower sites with max coverage do not always provide the best coverage for mission requirements

Viewshed of the Malapert Massif Region



Lunar Surface Communication Coverage

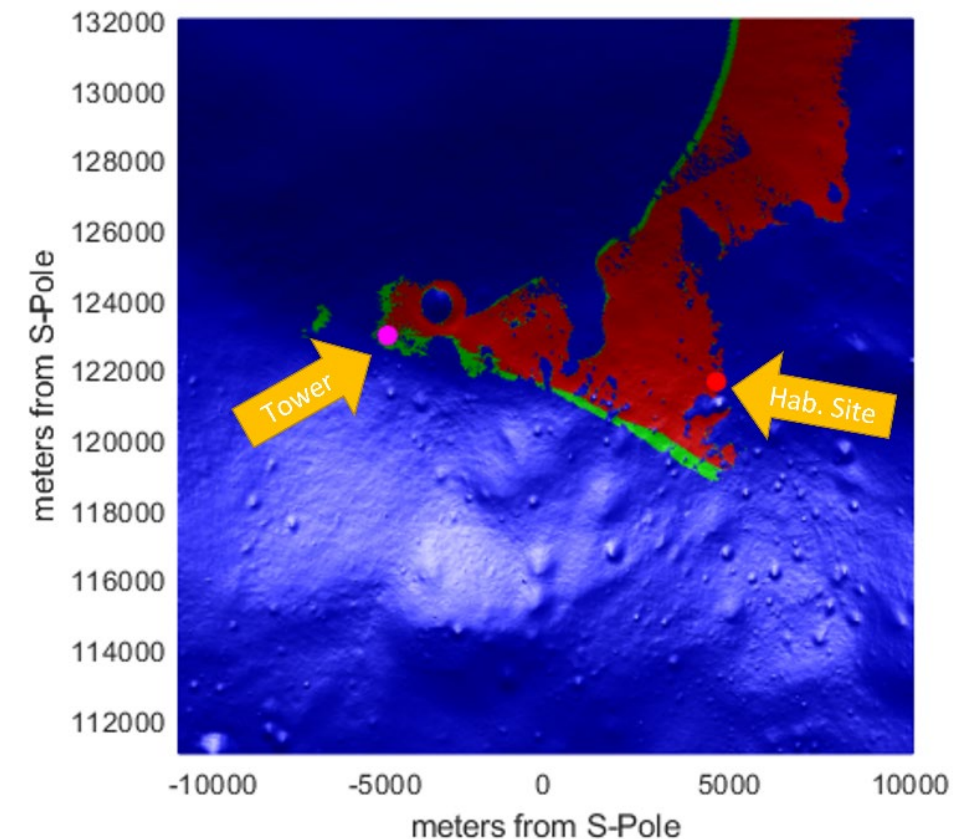
- Criteria: Tower location with slope less than 20° and LOS
 - Habitat site is highest point in region
 - Habitat (blue)
 - Tower (green) that meet criteria (only 7 meet criteria)
 - Tower (red) that DO NOT meet criteria (either LOS or slope criteria)
 - Inset figure shows terrain slope of region
 - Gold indicates slope less than 20°
 - Small blue dot indicates habitat site



Lunar Surface Communication Coverage

- Criteria: Tower location with slope less than 20° and LOS and best coverage
 - Habitat site is highest point in region
 - Tower with best coverage located 9.5 km from habitat
 - Viewsheds:
 - 4 m tower (red) covers 10.6%
 - 20m tower (red and green) covers 12.1%
 - Tower height increase from 4 to 20 m provides 1.5% increase in coverage

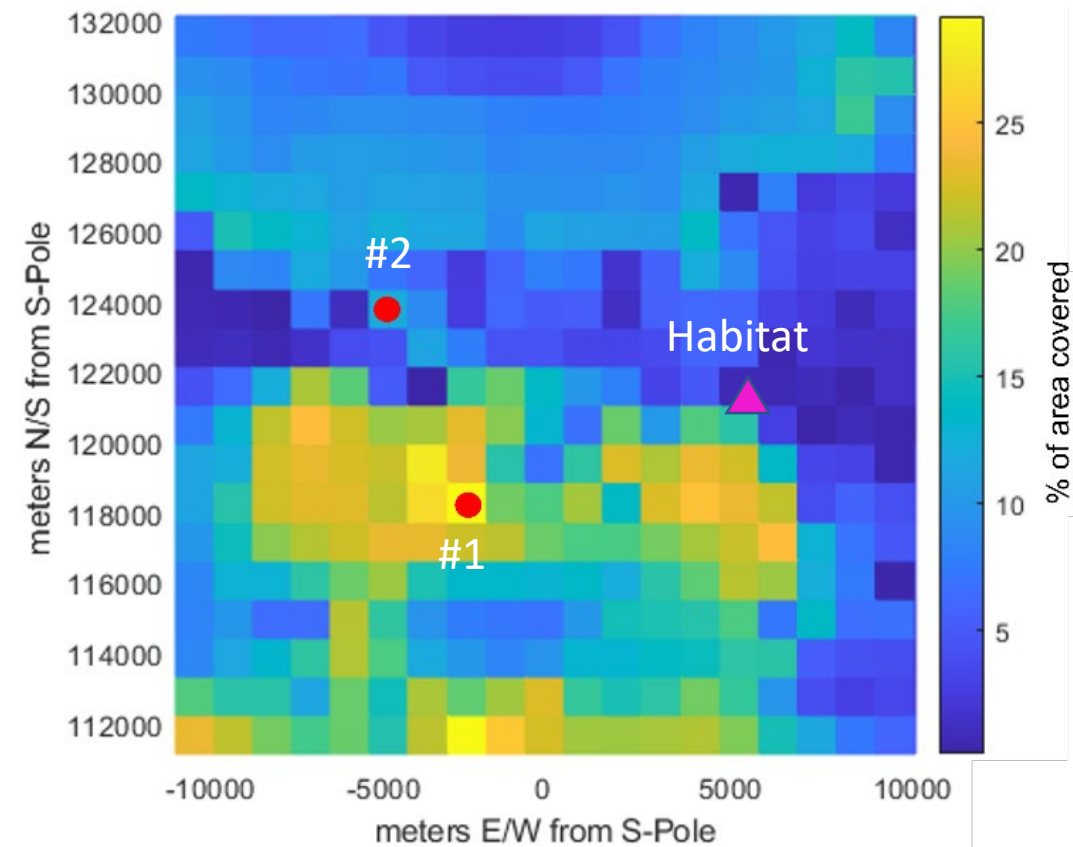
Viewshed of tower with best coverage, LOS and slope $<20^\circ$



Lunar Surface Communication Coverage

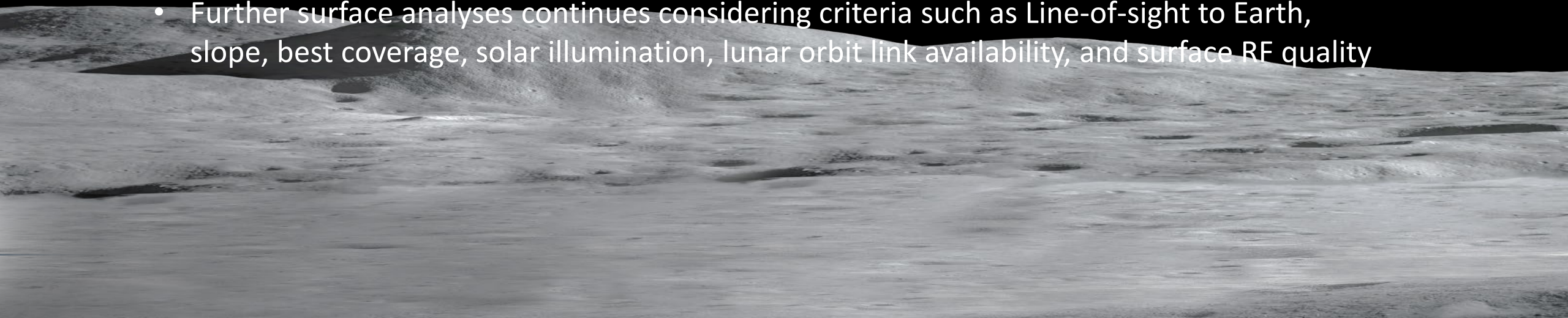
- Further analysis of each tower location's coverage (regardless of constraints) was compared to examine the sensitivity of surface coverage to the exact tower placement.
- The figure illustrates the total % of coverage by color coding for that tower
 - Tower #1 location with the best coverage in region (29%)
 - Tower #2 location of best coverage and LOS (12%)
- Landing inaccuracies may have significant impacts on the specific landing site.
- Overall coverage from a tower will be dependent upon the locations and could change considerably with landing accuracy

Location coverage sensitivity for 20 m tall tower



Conclusions

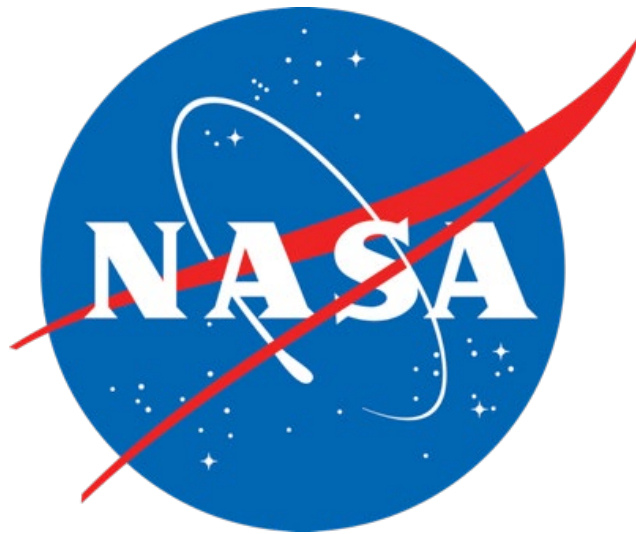
- NASA and its international and commercial partners look to explore the lunar surface which will require a surface network for communications and navigation
- Surface user communication needs include: science instrument data, voice, video, and telerobotic vehicle command and control
- Surface network enhanced by adding lunar surface relays (LSR) that provide 3GPP-based surface network and relay data to Earth via orbital relays or direct with Earth
- Mobile LSR's provide flexibility that can greatly improve the success of surface network
- Surface analyses illustrates the challenging lunar terrain at the South Pole
- Analyses indicates tower landing site inaccuracies greatly impact comm network coverage, indicating mobility could be a necessity
- Further surface analyses continues considering criteria such as Line-of-sight to Earth, slope, best coverage, solar illumination, lunar orbit link availability, and surface RF quality

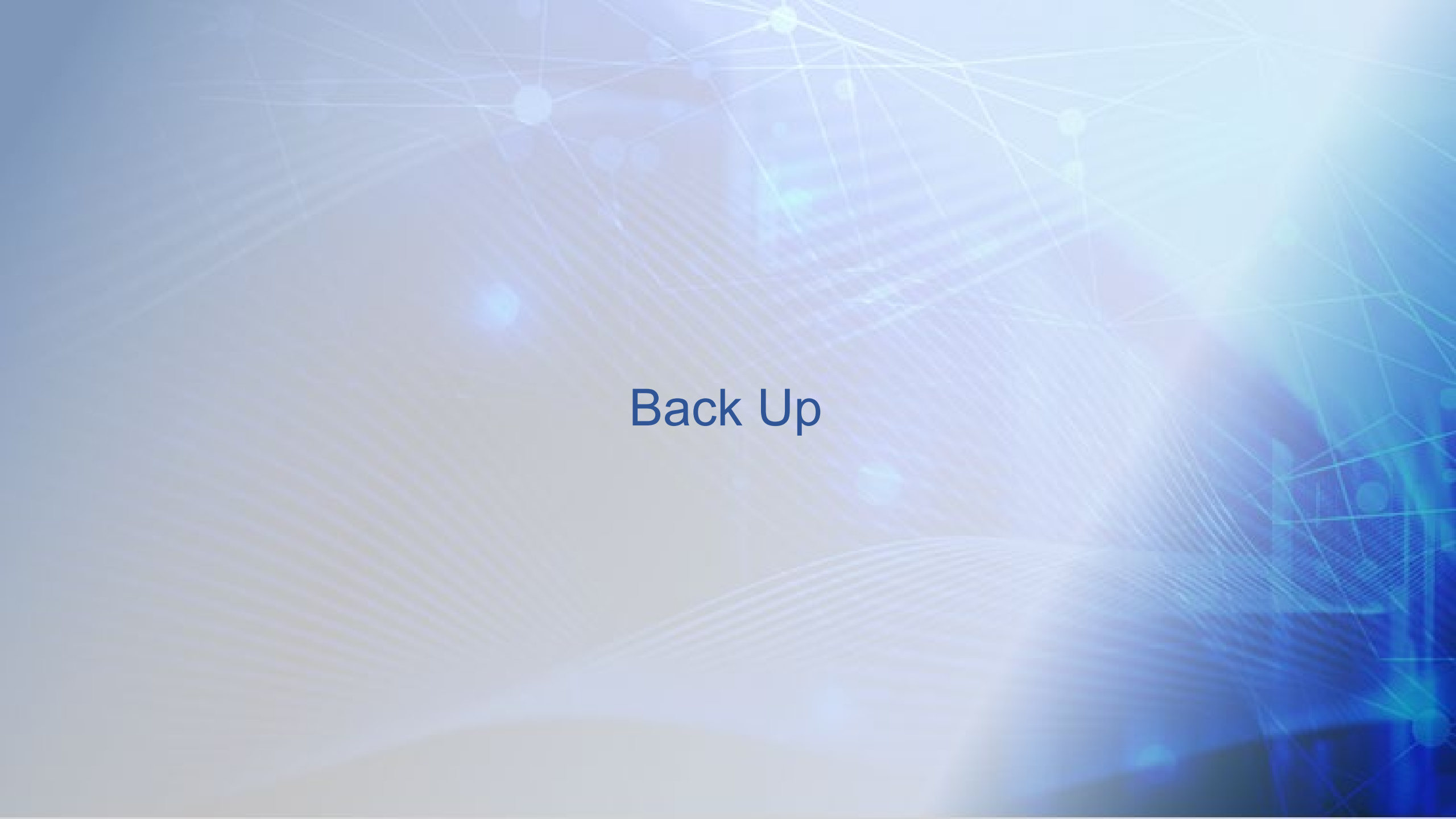


Acknowledgements

- NASA Glenn Research Center **Compass Design Team**, led by Steve Oleson, lead system engineer, Betsy Turnbull and sub-system leads: Benjamin Abshire, Anthony Colozza, Bushara Dosa, Brent Faller, James Fittje, John Gyekenyesi, Brandon Klefman, Thomas Packard, Lucas Shalkhauser, Paul Schmitz, and David Smith
- NASA's **SCaN Program** who sponsored the trade study and mobile design concepts and for their vision and guidance
- **RPS Program** who sponsored the RTG Stationary design concept study
- The communication and navigation teams across **NASA Centers including JSC, GSFC, and MSFC** who contributed to the studies.

Questions





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