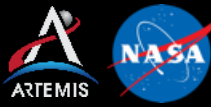




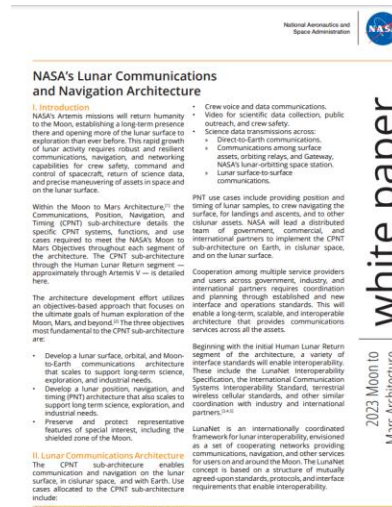
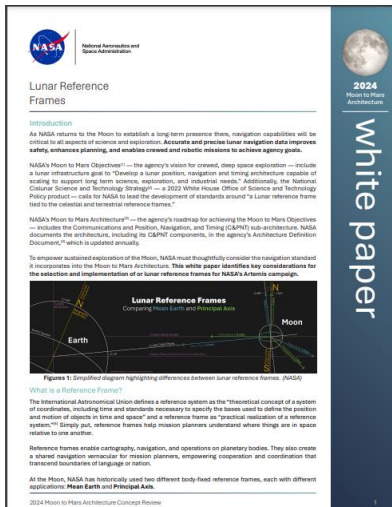
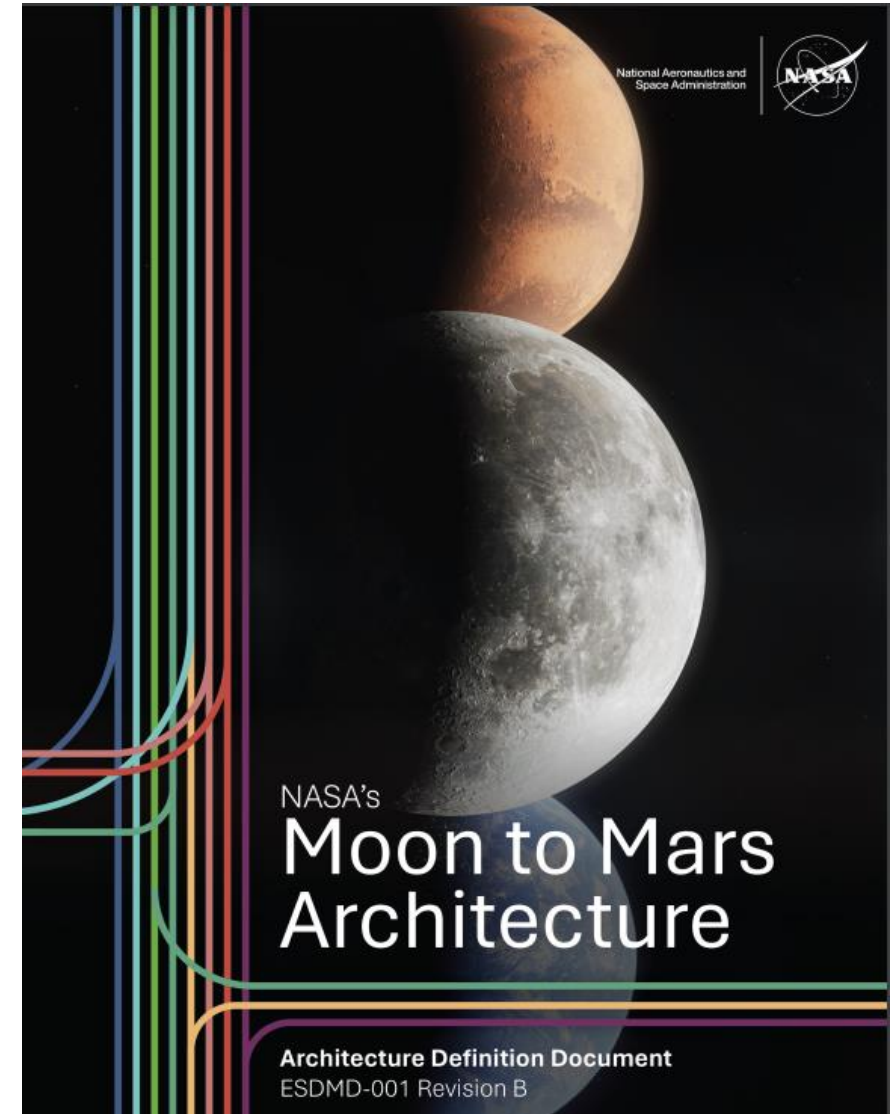
Artemis's Compass: Navigation Architecture and Challenges in Support of Initial Lunar Missions

Evan Anzalone, NASA/Marshall Space Flight Center
AAS GNC 2025, February 4, 2025
evan.j.anzalone@nasa.gov

Moon to Mars Architecture

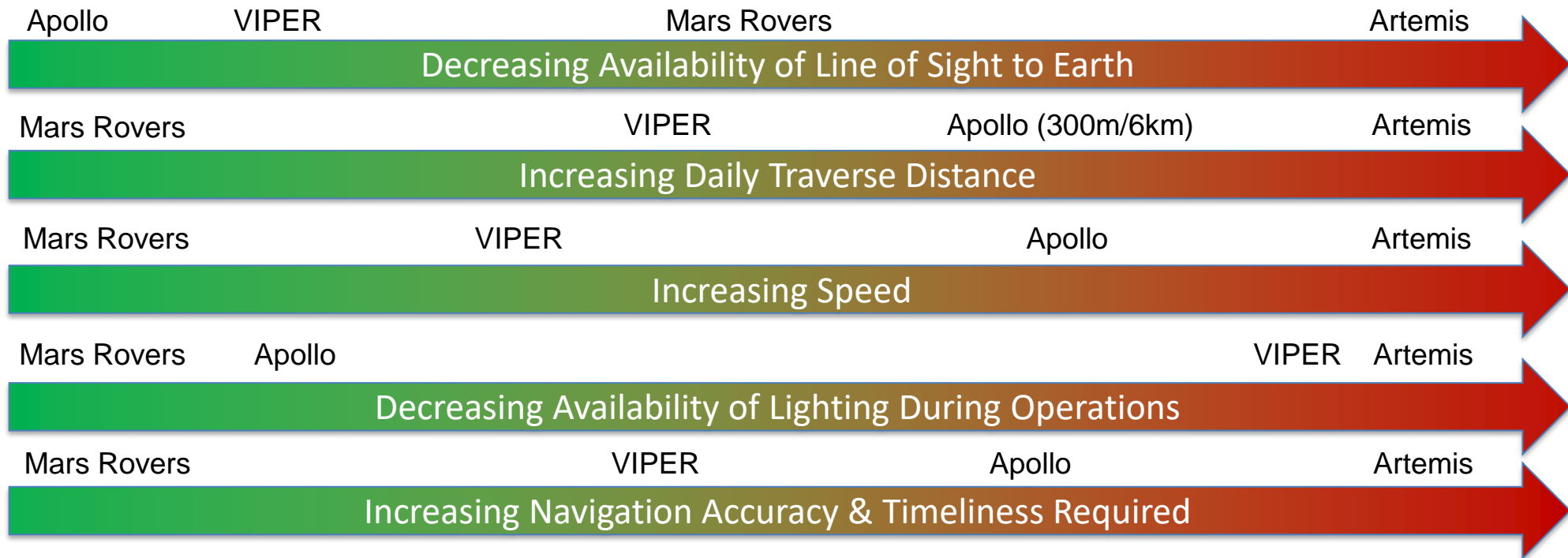
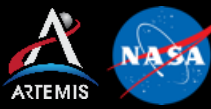


- Moon to Mars Architecture captures and defines overall exploration goals, objectives, and elements needed
 - Lays out primary Con-ops, use cases and functions that need to be met in order to achieve goals
 - White papers capture detailed information on sub-architectures and key technology drivers
- Being matured in parallel with continued program execution:
 - Execute from the left, Architect from the right
- Architecture elements lay groundwork for development and integration at the implementing program and project level
- Focus here is on implementation challenges from SEI perspective



<https://www.nasa.gov/moontomarsarchitecture/>

Comparison of Artemis to other NASA Planetary Surface Missions



Artemis at Lunar South Pole presents more stressing distance, lighting, earth availability, and navigation challenges than previous programs.

Craters

- Impact craters, pit craters
- Descend into, perform science tasks, ascend out (with appropriate equip)



Permanently Shadowed Regions

- Acquisition of ice water and volatiles samples
- Goal of 2 hours inside of shadowed regions

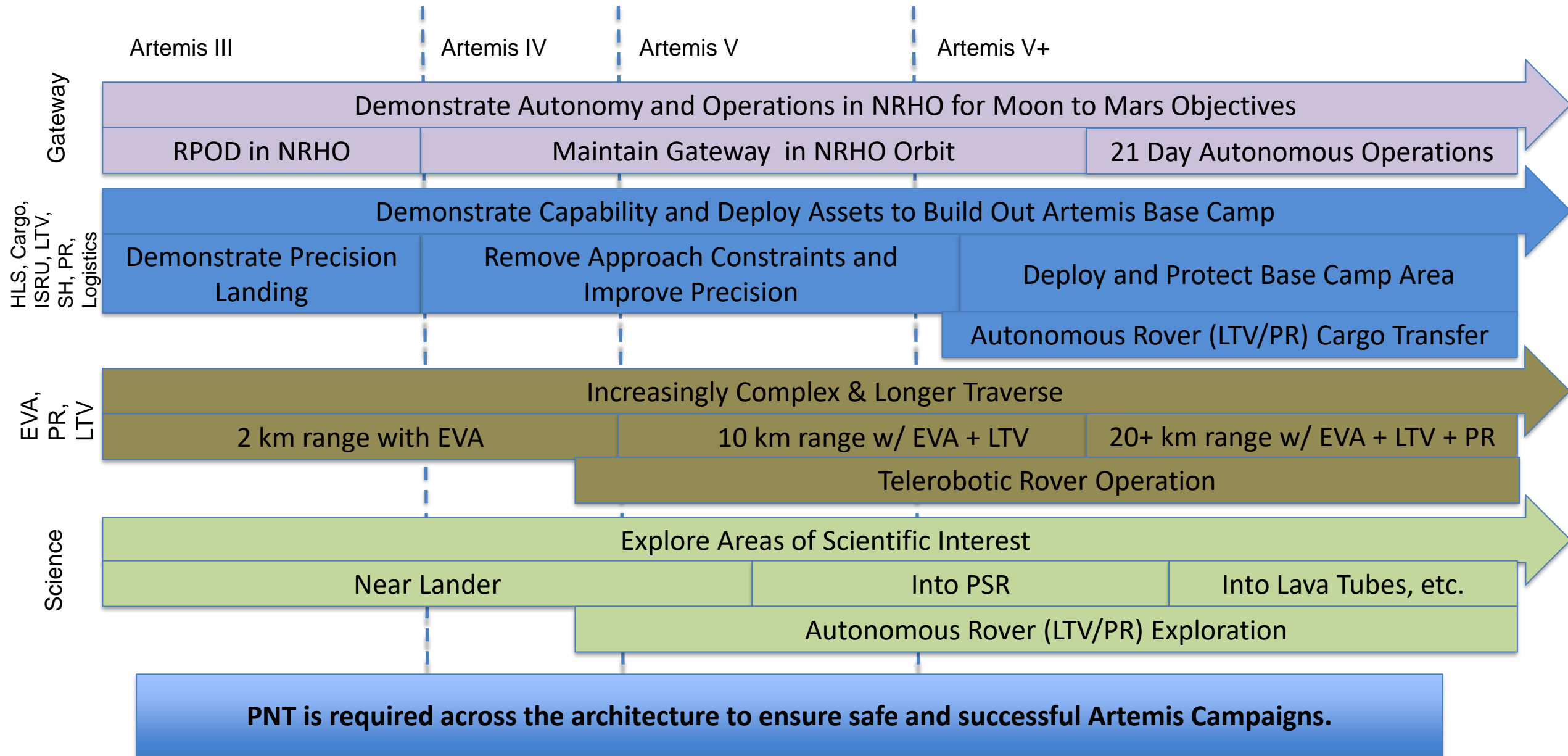
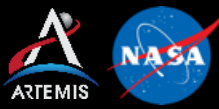


Volcanic Terrain

- Ingress into, perform science tasks, exit lava tube/flow
- May require equipment ancillary to the xEVA suit



Artemis Exploration Goals Dependent on PNT



ARTEMIS I

First mission
(uncrewed flight test)

COMPLETE



ARTEMIS II

First crew

CREW SELECTED



Crew

ARTEMIS III

First human
surface landing

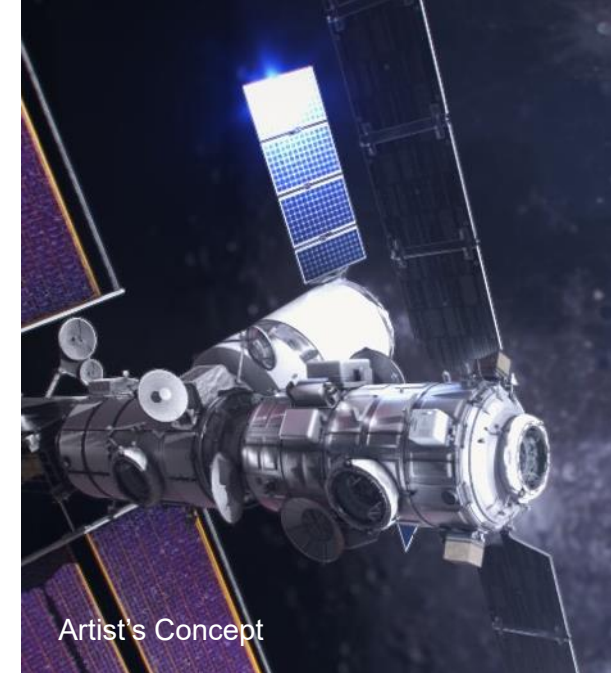


Artist's Concept

Human landing system, spacesuits

ARTEMIS IV

First lunar space station
assembly mission



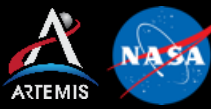
Artist's Concept

Gateway space station

Space Launch System rocket, Orion crew spacecraft, Exploration Ground Systems

Conducting science and demonstrating technology in orbit and on the surface

Navigation Functions and Applicability



Use Case	Arch. (A) or Der. (D)	SLS	Orion	Gateway	HLS	EVAS	LTV	PR
Insertion into Earth Orbit	D	X	X	X	X		X	X
Orbit Corrections and Maintenance	D		X	X	X		X	X
Insertion into and transfer between Lunar Orbit(s)	D		X	X	X		X	X
Rendezvous in Lunar Orbit(s)	D		X	X	X			
Lunar Landing	D				X		X	X
Surface Exploration	A				X	X	X	X
Surface Rendezvous and Proximity Operations	A/D						X	X
Lunar Ascent	D				X			
Earth Entry	D	X	X					
Disposal	D.	X	X	X	X	X	X	X

- **Multiple reference frames must be consistently used across all elements**
 - Inertial frames (Earth-centered J2000, Moon-Centered J2000, etc)
 - Fixed-body frames (WG84, Lunar Principal Axis, Lunar Mean Earth Polar Axis)
- **Ephemeris models must also be synchronized in pre- and during-flight**
 - Relative location and orientation of Earth, the Moon, and the Sun
 - Drives surface exploration conditions and ability for independent elements to rendezvous in lunar orbit
- **Coordination needed across multiple programs, elements, providers, both for new and existing programs**
- **As move towards Lunar operations, local operations may begin to rely on a lunar-centric time (drift of tens of microseconds a day)**
 - Demonstrates approach for Mars missions with unique local time (i.e. 24.6 vs 23.9 hrs/day)
- **Multiple international efforts underway**
 - Lunar Coordinated Time
 - Lunar Reference Systems
- **Push towards long-term deployment of local lunar clocks and monitoring stations to develop local frame and orientation parameters**

Resolutions Approved at IAU 2024 General Assembly:

Commission A3 Fundamental Standards
Resolutions for consideration for the XXXII General Assembly
15 April 2024

Resolution to establish a standard Lunar Celestial Reference System (LCRS) and Lunar Coordinate Time (TCL)

The XXXIInd International Astronomical Union General Assembly,

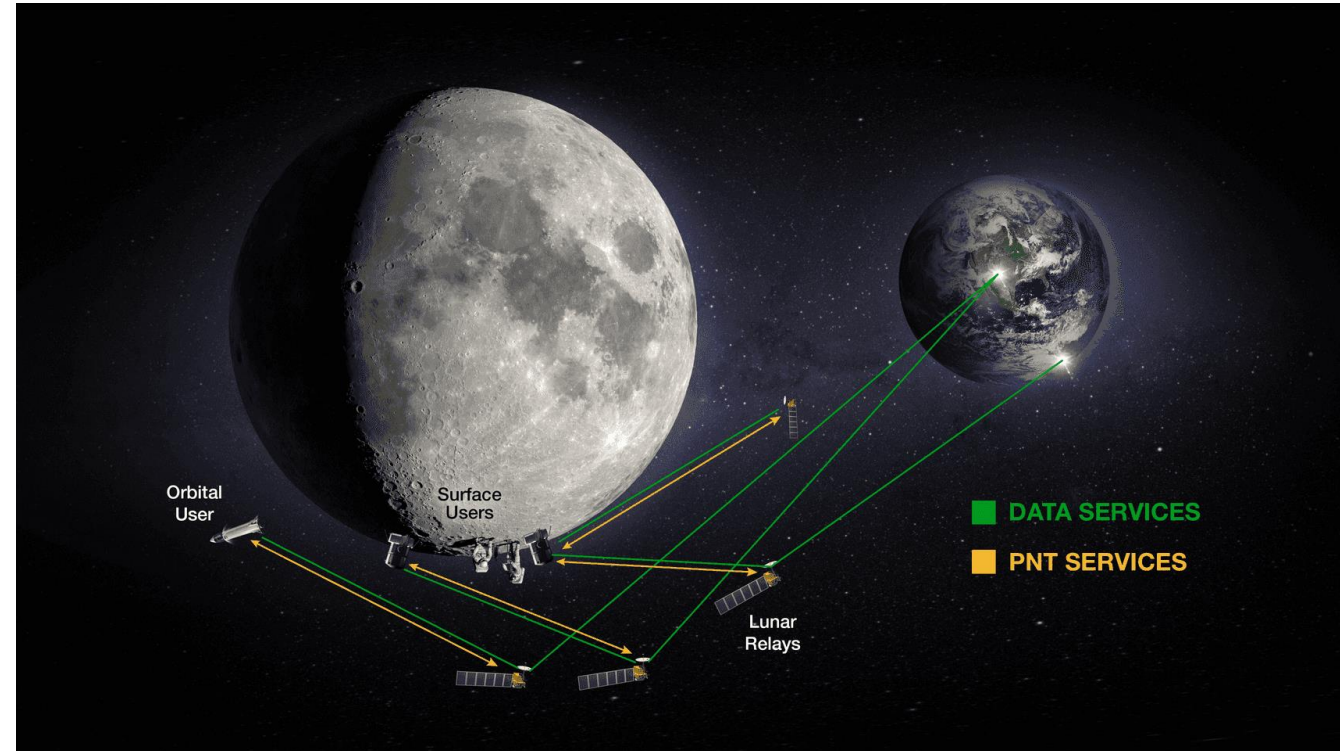
Commission A3 Fundamental Standards
Resolutions for consideration for the XXXII General Assembly

Resolution on the establishment of a coordinated lunar time standard by international agreement

- **Backbone tracking capability provided by ground network, including NASA (SCaN/NEN + DSN) as well as international (i.e. ESTRACK) and commercial networks (LEGS)**
- **Provides fundamental communication and navigation capability for many spacecraft**
- **Until Lunar Systems comes online, primary source of tracking in cislunar space**
- **Use of multiple tracking modes: Two-way Ranging, two-way Doppler, delta-DOR to meet vehicle requirements**

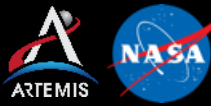


- **Deployment of Lunar Constellation to support comm and navigation needs**
 - Lunar Communication Relay and Navigation Services SRD provides representative user needs and deployment
- **Intuitive Machines selected in Fall 2024 under two awards**
 - Demonstrate LCRNS capabilities
 - Mature LunaNet user terminal
- **Planned development of initial capability for real-time nav at South Pole ahead of Artemis V mission to enable broad surface capability**
 - Support for surface and orbital users
- **Use of common LunaNet specifications to enable cooperative use of international networks (i.e. Moonlight and LNSS)**
- **Evaluation of long-term deployment dependent on architecture needs and use cases**

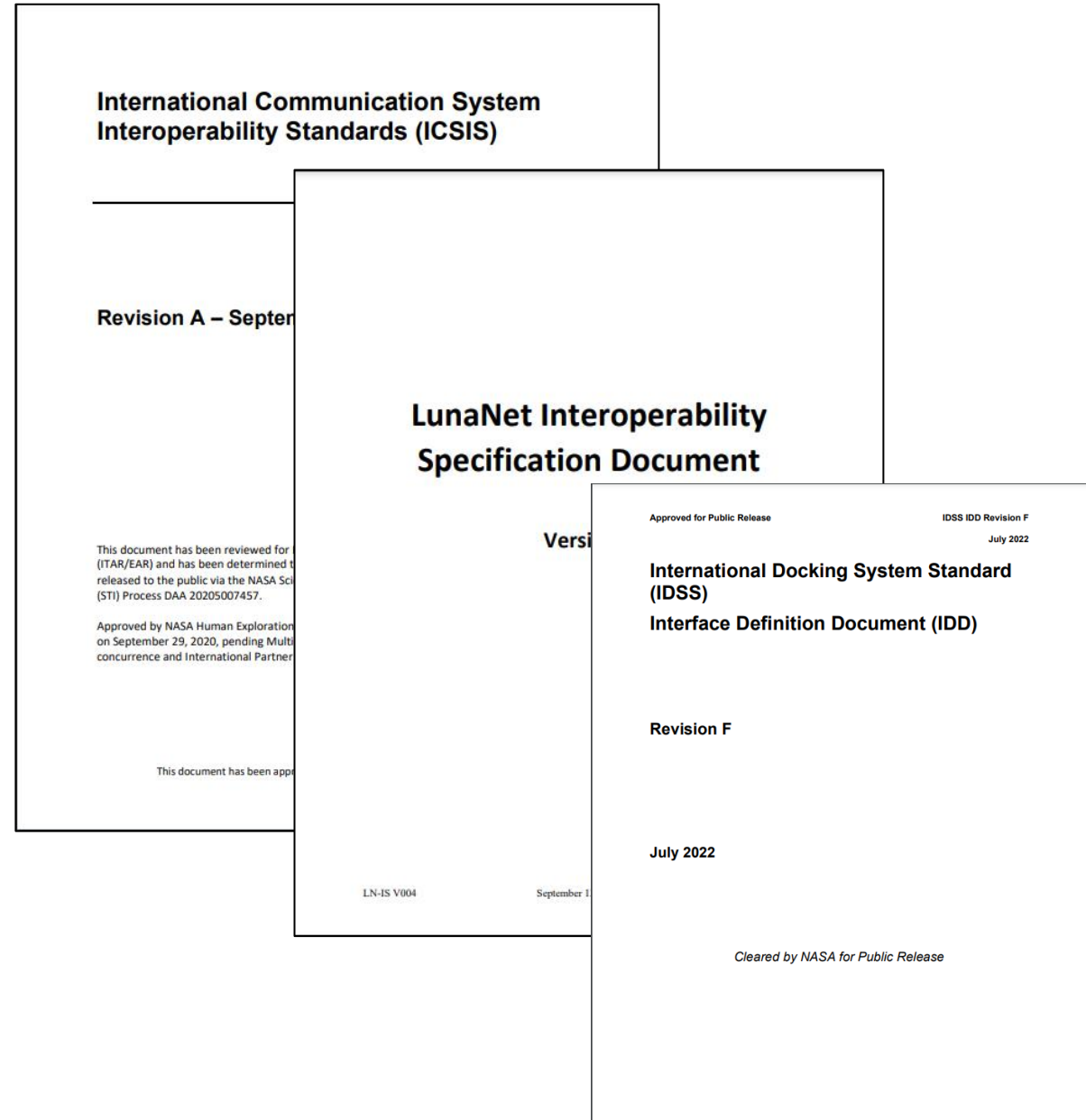


NASA/David Ryan

Pillar 3: Interoperability and intra-vehicle Navigation (Docking)



- **Use of key interoperability specifications to ensure collaborate activities**
 - Ensure consistency between users and providers and among vehicles
- **ICSIS: defines recommendations for comm and tracking modes for users that is compatible with Earth tracking and relays**
 - Rev B currently in work
- **LunaNet Interoperability Spec: defines standards for providers of lunar comm and nav services**
 - V5 Final Release imminent
 - Includes LunaNet Signal in Space Specification to define in-situ navigation Augmented Forward Signal
- **International Docking System Standard and Gateway specifications define docking approach**

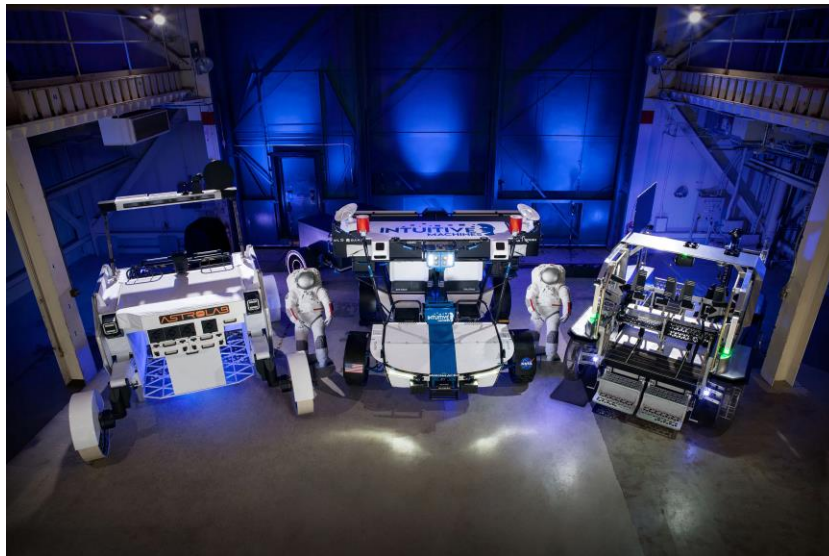


Pillar 4: Vendor Designs/Onboard Capability

- **Via Service Provider Model, key navigation performance metrics are the responsibility of the vendor.**
- **Requirements focused on functional use case**
 - landing accuracy, surface navigation accuracy needed to enable exploration and safety
- **Deployed capabilities are key enablers of the mission architecture**
 - NASA primary role in focused insight and review



SpaceX



NASA/Bill Stafford



Blue Origin

- **Operations in Near-Rectilinear Halo Orbit**

- Multiple vehicles (Orion, HLS, Gateway Logistics, Gateway additions) must all be docked and operate in close proximity of Gateway
- Dynamics in NRHO very difficult from history of docking in Earth orbit (lower gravity and different orbit)
- Dependency on Earth-based tracking for far-field approach and absolute navigation
- Multiple radio systems and vehicles operating nearby with potential for blockages or interference

- **Landing**




- High precision landing of large vehicles for extended surface stays at rugged terrain of Lunar South Pole
- Landing process initially dependent on local lighting conditions with increased capability for Sustaining
- Need for autonomous aborts and onboard re-targeting

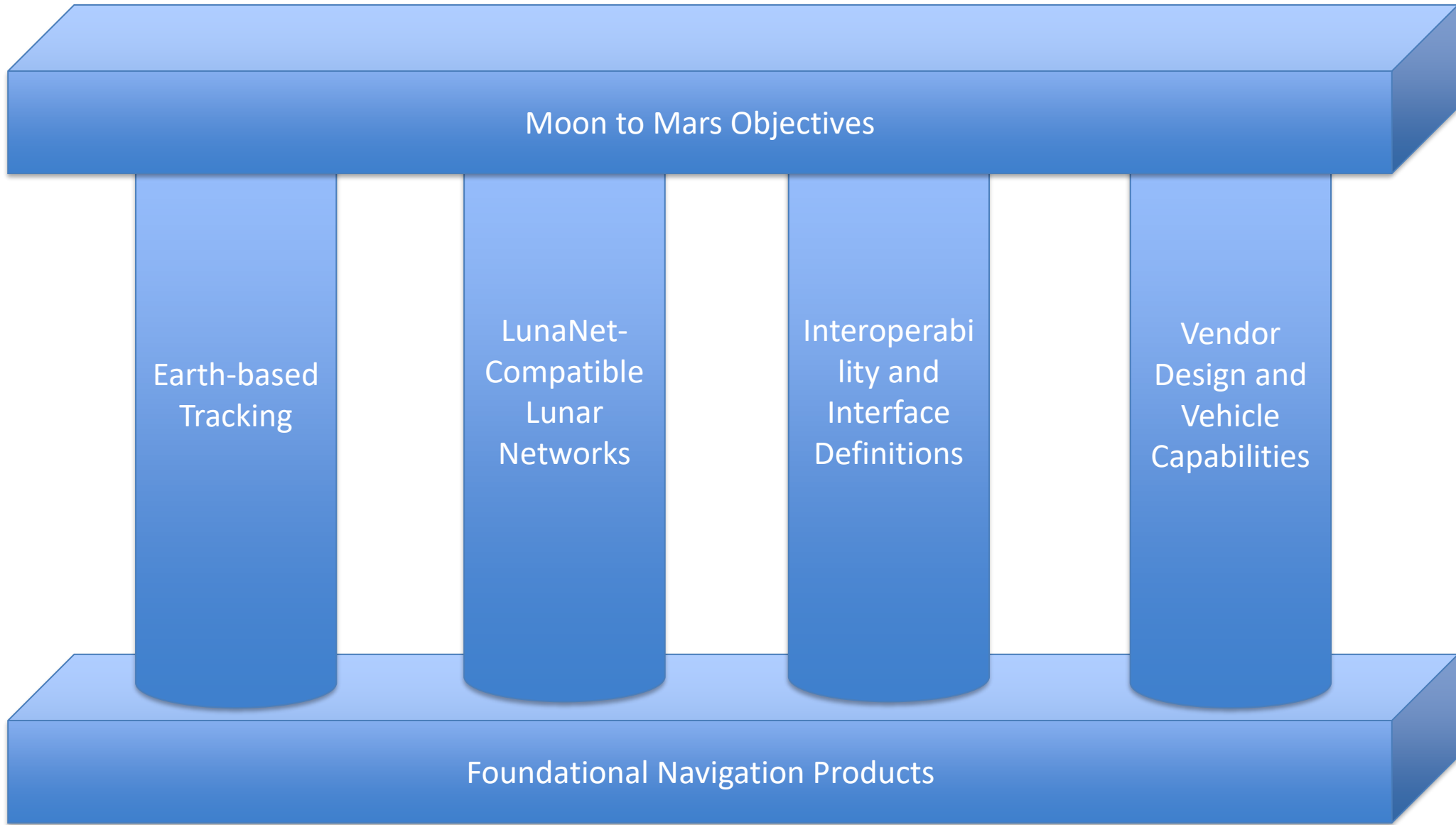
- **Surface Exploration**

- Terrain and lighting challenges (low sun angle) will provide a challenge to human crews
- Extended operational range and activities pushes boundary of capabilities
- Need for development and deployment of crew-and vehicle-level robust navigation capability that can operate under a range of conditions

- **Integration testing**
 - Multiple vehicles from multiple vendors that need to operate together
 - Expansion of Artemis I testing of Orion, SLS, ICPS, EGS, and DSN emulators
 - Strict management of Interface Requirement Documents and Interface Control Documents
 - Focused end to end and compatibility testing will be needed to ensure operation
- **Balancing provider unique data between providers**
 - NASA has limited-to-no ownership of designs and must maintain confidentiality for all partners, even when partners have direct integration and operations (i.e. EVAS + HLS)
 - Multiple levels of services provides
 - Service provider providing services to other service providers (i.e. LCRNS)
- **Multiple systems maturing at the same time**
 - Current development of DRMS to identify end states defined by vehicles and capabilities
 - Assumes schedule alignment among all service providers
 - Mission execution will require flexibility and understanding of interaction of available capabilities

- **New elements will bring new challenges**
 - Extended traverses
 - Increased presence on the lunar surface
 - Expanded surface network needs
- **New products be available:**
 - LTC
 - Lunar Reference System
 - South Pole LCRNS nav and comm
 - Multiple international contributions

ARTEMIS V	ARTEMIS VI	ARTEMIS VII AND BEYOND
<p>First unpressurized rover</p>  <p>Artist's Concept</p>	<p>Gateway assembly complete</p>  <p>Artist's Concept</p> <p>Gateway airlock module</p>	<p>Longer missions = preparation for human Mars missions Access to more of the Moon = new scientific discoveries</p>  <p>Artist's Concept</p> <p>Pressurized rover, surface habitat, and other new elements</p>
<p>Lunar terrain vehicle; Gateway refueling and robotics</p>		
<p>Crew conducting science and demonstrating technology in orbit and on the surface; Space Launch System rocket; Orion crew spacecraft; Exploration Ground Systems; Gateway space station</p>		



Thank you! Any Questions?

