Lunar Communications and Navigation :

Lunar Communications, Position, Navigation,, and Time (CPNT) Architecture

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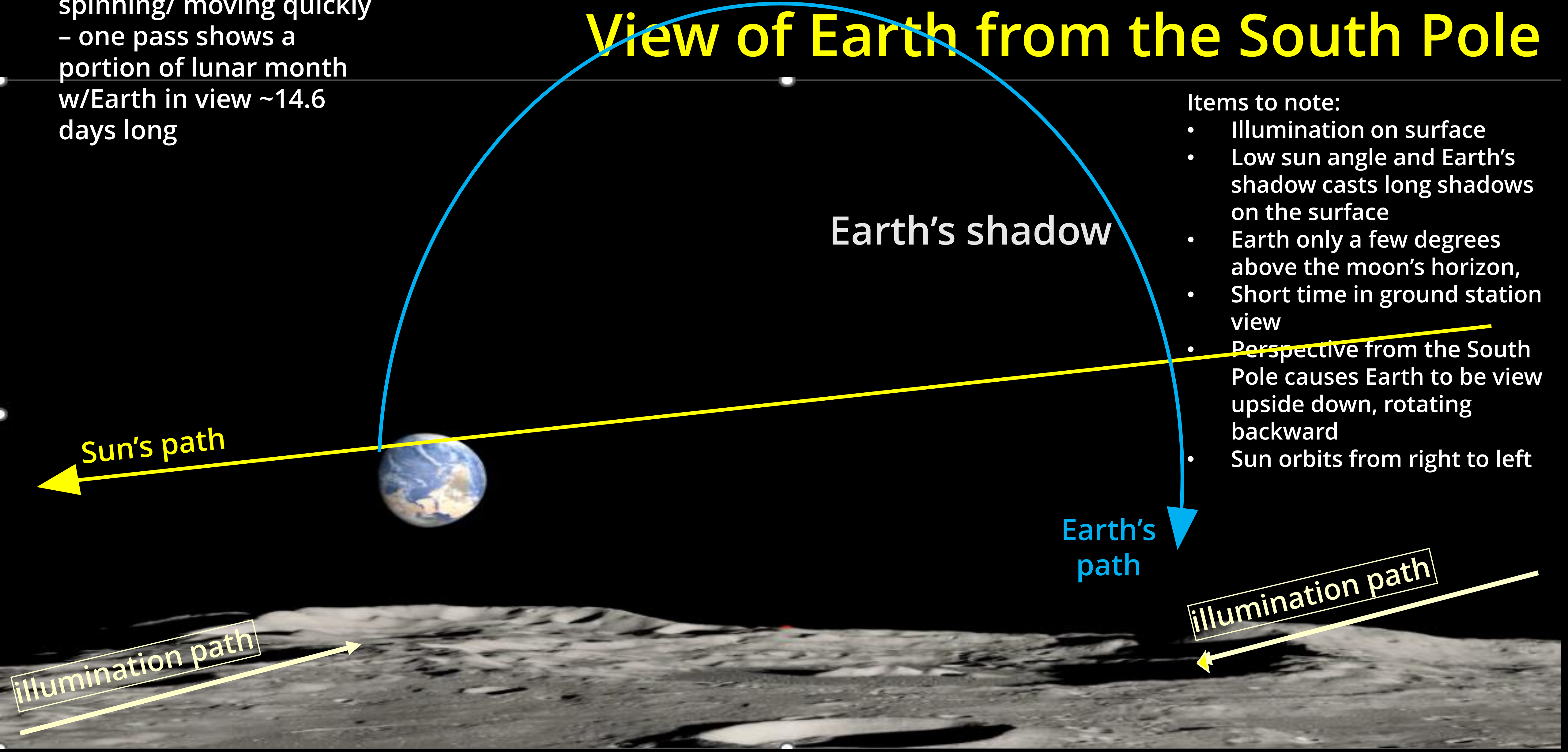
A whole new world: View of Earth from the South Pole

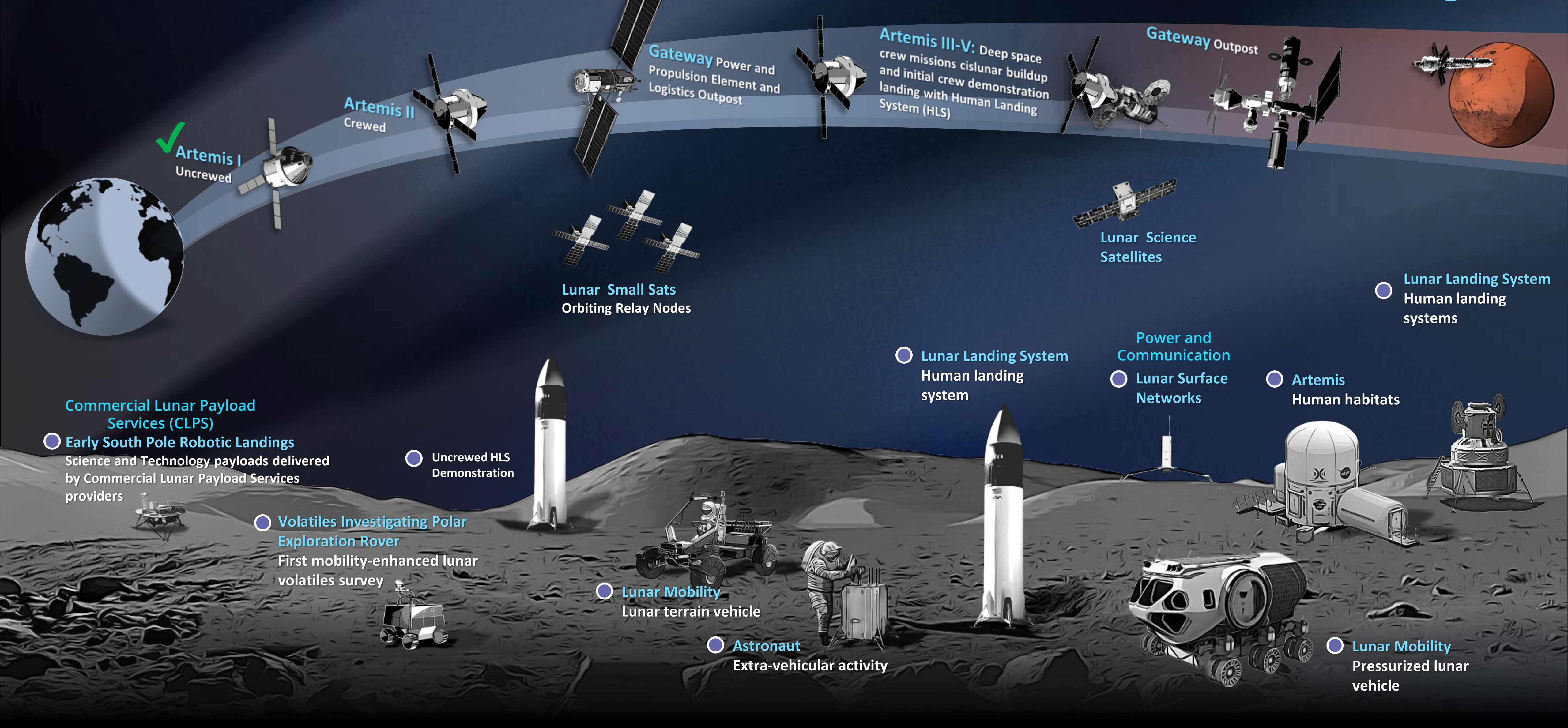
- Simulation – Earth spinning/ moving quickly – one pass shows a portion of lunar month w/Earth in view ~14.6 days long

Items to note:
- Illumination on surface
- Low sun angle and Earth's shadow casts long shadows on the surface
- Earth only a few degrees above the moon's horizon,
- Short time in ground station view
- Perspective from the South Pole causes Earth to be view upside down, rotating backward
- Sun orbits from right to left



Image/video Credit: https://svs.gfsc.nasa.gov/5228/

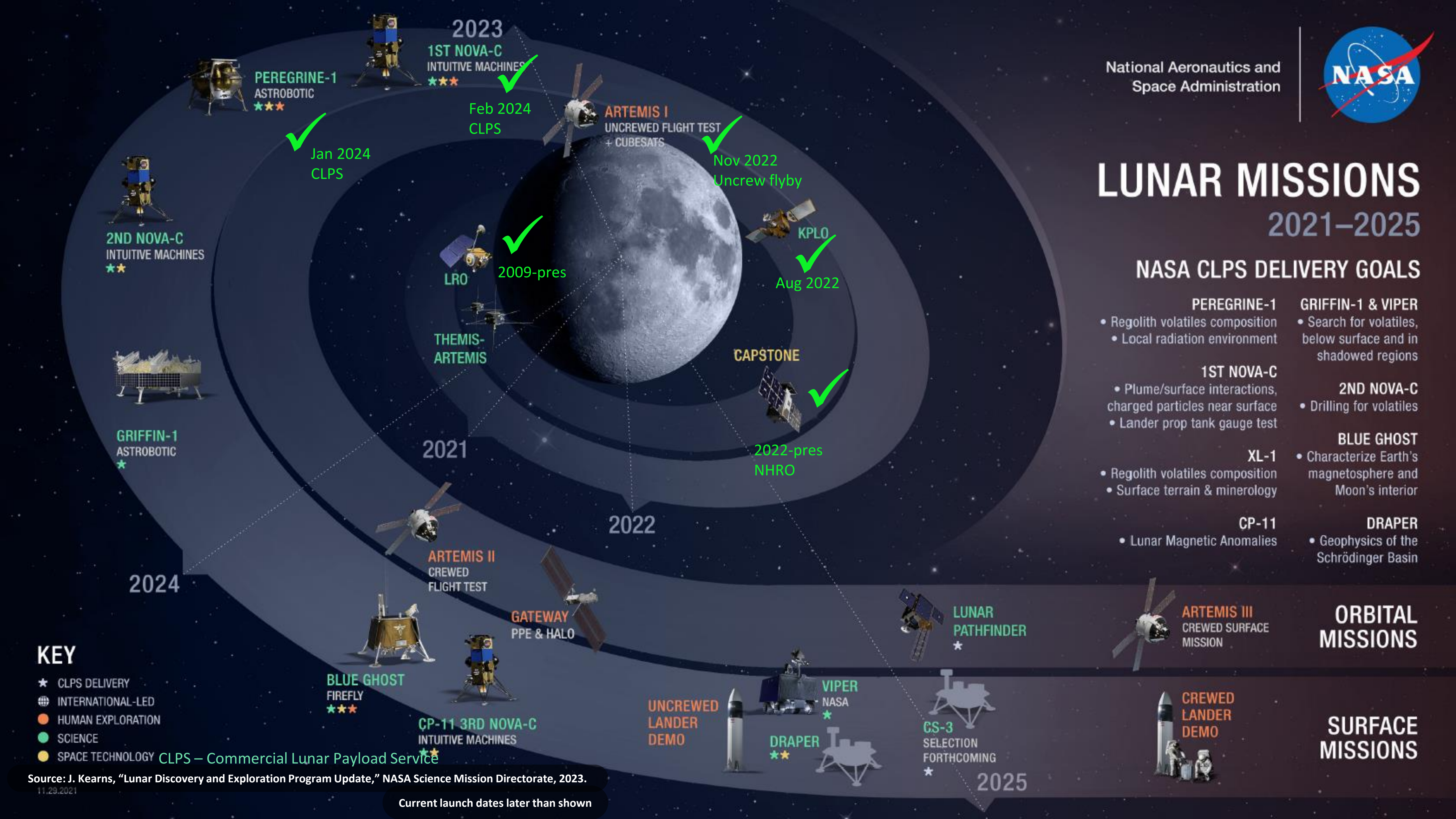
Evolution of Assets to the Lunar Surface and Cislunar drives Communication and Navigation



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

... plus Science, International Missions, and Commercial Missions

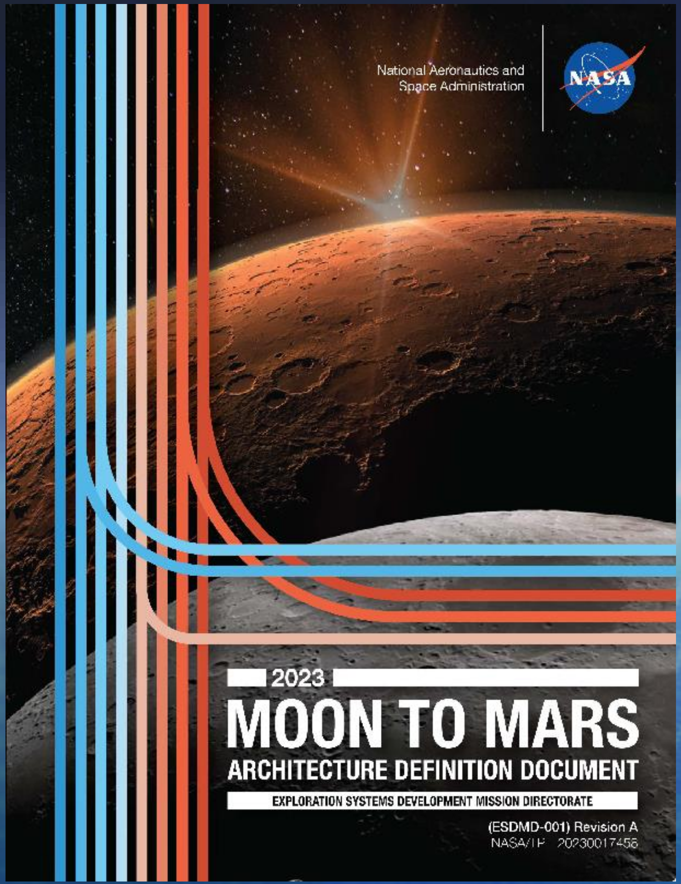
Lunar South Pole Region



Source: J. Kearns, "Lunar Discovery and Exploration Program Update," NASA Science Mission Directorate, 2023.

Current launch dates later than shown

M2M Architecture Highlights



Architecture Definition Document
Revision A (ADD Rev-A)

National Aeronautics and Space Administration

NASA

white paper

2023 Moon to Mars Architecture

Mars Mission Abort Considerations

Overview

Throughout the history of human spaceflight, astronauts have never been more than a few days (and rarely more than a few hours) from Earth. Aborts for missions to low-Earth orbit or the International Space Station are relatively short. Aborts for lunar missions may be longer than aborts from Earth vicinity but are still measured in days.

On the transit to Mars, mission abort is a much more complicated event because of the sheer distance between Earth and Mars. The distance and scale differences between missions to the Moon and Mars mean lessons learned from lunar mission aborts will have limited direct applicability for Mars. Depending on when an abort is initiated in a Mars mission timeline, the heliocentric nature of transit — in orbit around the Sun — may require many months to return to Earth, regardless of the transportation system selected.

For transportation architectures that refuel in Mars vicinity, mission abort during outbound transit may not even be possible. In many cases, transit abort may not be a practical response to an emergency because the time to return the crew may exceed the crew's ability to stave off the emergency.

Early human Mars missions will also have limited abort options for descent to and ascent from the surface.

- **For descent** — where abort means returning to orbit — Mars' atmosphere and gravity will make it difficult to carry sufficient on-board propellant to initiate an abort for a human-scale payload.
- **For ascent** — where abort means returning to the surface — Mars will initially lack the specialized surface infrastructure and staffing needed to aid crew after the abort. Even a successful abort to the surface may leave crew stranded, far away from assets necessary for a safe return to Mars orbit.

Both of these challenges will require an entirely new contingency operations paradigm relative to our flight experience nearer to Earth.

Transit Abort Analysis

Due to the nature of celestial mechanics, abort maneuvers are inherently more challenging than nominal mission maneuvers. To understand the fundamental nature of these abort maneuvers, NASA evaluated three propulsion concepts for a crewed Mars mission. This initial scoping assessment assumes an example trajectory with a roundtrip duration of 850 days with a short stay in Mars vicinity.

The three transportation propulsion concept scenarios analyzed were:

- A hybrid abort, where a low-thrust hybrid nuclear electric propulsion (NEP) and chemical propulsion system utilizes both stages to perform abort maneuvers.
- A NEP-only abort, where the hybrid NEP and chemical propulsion system jettisons the chemical propulsion stage and utilizes only the low-thrust electric propulsion system.
- A ballistic abort, where a high-thrust propulsion system (e.g., a nuclear thermal propulsion [NTP] or all-chemical propulsion system) performs the abort maneuvers.

In all three cases, the analyses assumed that the transportation systems depart Earth with only enough propellant for the expected round-trip mission. Scenarios in which the propulsion system carries abort-specific contingency propellant were outside the scope of this initial assessment.

2023 Moon to Mars Architecture Concept Review 1

White Papers

The **Moon-to-Mars Architecture Definition Document** is a NASA-published reference document that presents the current state of the human spaceflight architecture and exploration strategy.

- Decomposes Moon to Mars objectives into functions and use cases for allocation to implementable programs and projects.
- It includes current partnerships present in the architecture, identifies architectural gaps, and presents opportunities for further collaboration.
- It is **NOT** a mission definition document, a planning manifest, or a procurement strategy.
- The current version was published March 2024.
- NASA plans to publish yearly updates to the Architecture Definition Document,

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

M2M Sub-Architectures

- Moon-to-Mars Architecture consists of sub-architectures - a task, technology, or process that NASA must master to achieve the Moon to Mars objectives.

Not pictured:

- In-situ Resource Utilization (ISRU) Systems
- Autonomous Systems
- and Robotics
- Data Systems and Management
- Infrastructure Support

Communications, Navigation, Positioning, and Timing Systems
Enable transmission and reception of data, determination of location and orientation, and acquisition of precise time.

Utilization Systems
Enable science and technology demonstrations.

Power Systems
Generate, store, condition, and distribute electricity for architectural elements.

Logistics Systems
Package, handle, transport, stage, store, track, and transfer items and cargo.

Transportation Systems
Convey crew and cargo to and from Earth to the Moon and Mars.

Mobility Systems
Move crew and cargo around the lunar and Martian surfaces.

Human Systems
Execute human and robotic missions; this includes crew, ground personnel, and supporting systems.

Habitation Systems
Ensure the health and performance of astronauts in controlled environments.

Ref: Moon to Mars Architecture Executive Overview
https://www.nasa.gov/moontomarsarchitecture/

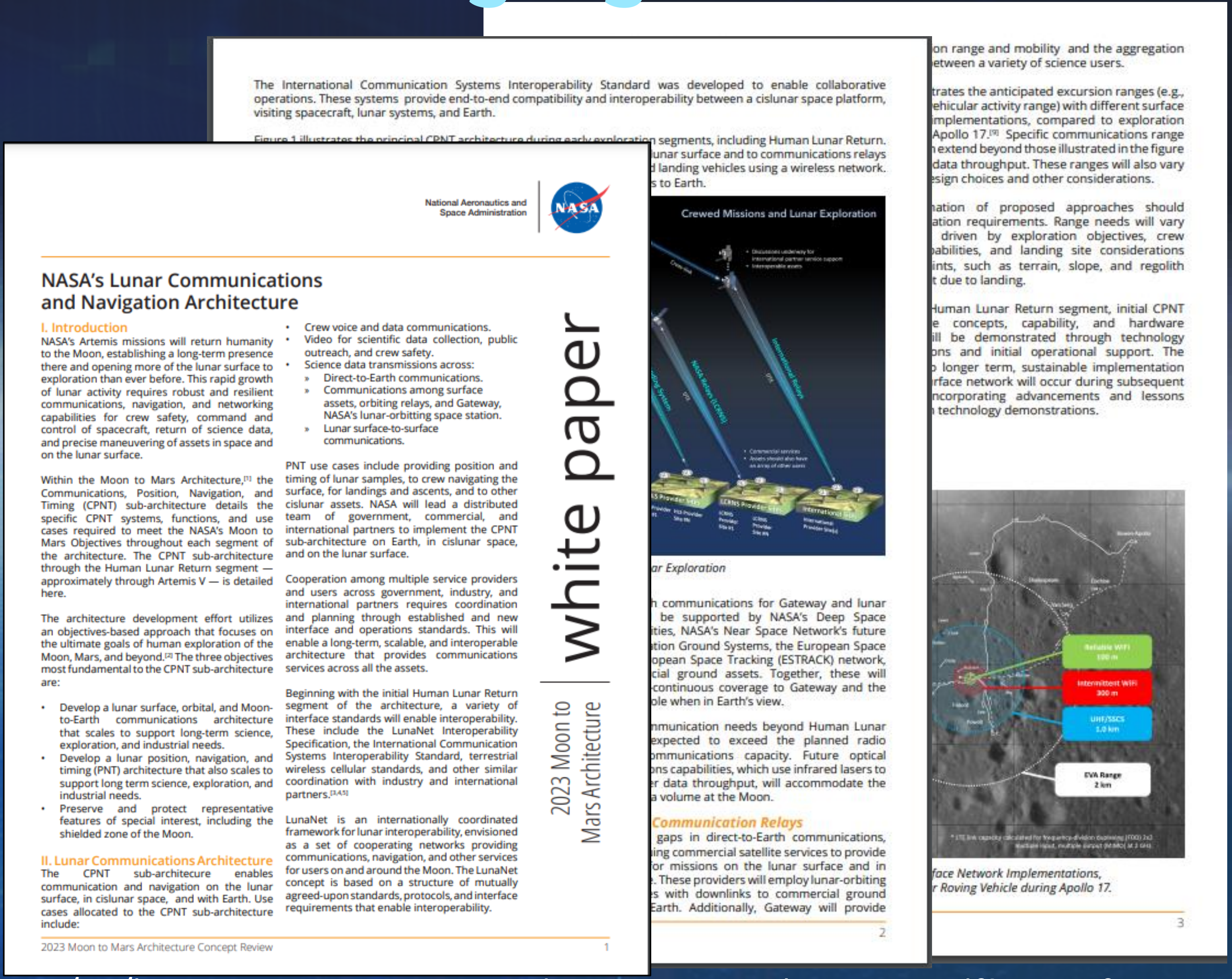
M2M CPNT Sub-Architecture Highlights

M2M White Papers provide additional context on Moon to Mars Architecture development activities and associated analyses

CPNT Use Cases
- Crew voice and data communications.
- Video for scientific data collection, public outreach, and crew safety.
- Science data
- Telerobotics

Communication Paths
- Direct-to-Earth
- Lunar relays
- Surface network
- Gateway

PNT
- Radiometric from Earth
- Lunar Relay "GPS-like" signal
- Lunar Time Reference



National Aeronautics and Space Administration

NASA's Lunar Communications and Navigation Architecture

white paper

2023 Moon to Mars Architecture

I. Introduction

NASA's Artemis missions will return humanity to the Moon, establishing a long-term presence there and opening more of the lunar surface to exploration than ever before. This rapid growth of lunar activity requires robust and resilient communications, navigation, and networking capabilities for crew safety, command and control of spacecraft, return of science data, and precise maneuvering of assets in space and on the lunar surface.

Within the Moon to Mars Architecture,[1] the Communications, Position, Navigation, and Timing (CPNT) sub-architecture details the specific CPNT systems, functions, and use cases required to meet the NASA's Moon to Mars Objectives throughout each segment of the architecture. The CPNT sub-architecture through the Human Lunar Return segment — approximately through Artemis V — is detailed here.

The architecture development effort utilizes an objectives-based approach that focuses on the ultimate goals of human exploration of the Moon, Mars, and beyond.[2] The three objectives most fundamental to the CPNT sub-architecture are:

- Develop a lunar surface, orbital, and Moon-to-Earth communications architecture that scales to support long-term science, exploration, and industrial needs.
- Develop a lunar position, navigation, and timing (PNT) architecture that also scales to support long term science, exploration, and industrial needs.
- Preserve and protect representative features of special interest, including the shielded zone of the Moon.

II. Lunar Communications Architecture

The CPNT sub-architecture enables communication and navigation on the lunar surface, in cislunar space, and with Earth. Use cases allocated to the CPNT sub-architecture include:

- Crew voice and data communications.
- Video for scientific data collection, public outreach, and crew safety.
- Science data transmissions across:
  - Direct-to-Earth communications.
  - Communications among surface assets, orbiting relays, and Gateway, NASA's lunar-orbitting space station.
  - Lunar surface-to-surface communications.

PNT use cases include providing position and timing of lunar samples, to crew navigating the surface, for landings and ascents, and to other cislunar assets. NASA will lead a distributed team of government, commercial, and international partners to implement the CPNT sub-architecture on Earth, in cislunar space, and on the lunar surface.

Cooperation among multiple service providers and users across government, industry, and international partners requires coordination and planning through established and new interface and operations standards. This will enable a long-term, scalable, and interoperable architecture that provides communications services across all the assets.

Beginning with the initial Human Lunar Return segment of the architecture, a variety of interface standards will enable interoperability. These include the LunaNet Interoperability Specification, the International Communication Systems Interoperability Standard, terrestrial wireless cellular standards, and other similar coordination with industry and international partners.[3,4,5]

LunaNet is an internationally coordinated framework for lunar interoperability, envisioned as a set of cooperating networks providing communications, navigation, and other services for users on and around the Moon. The LunaNet concept is based on a structure of mutually agreed-upon standards, protocols, and interface requirements that enable interoperability.

2023 Moon to Mars Architecture Concept Review 1

https://www.nasa.gov/wp-content/uploads/2024/01/lunar-communications-and-navigation-architecture.pdf?emrc=f1a91a

Communications and Navigation Infrastructure

NATIONAL INFRASTRUCTURE: NASA SCaN-led communications and navigation infrastructure capable of scaling to support long term science and exploration

- Moon-to-Earth
- Orbital
- Lunar surface

APPROACH DRIVEN BY:

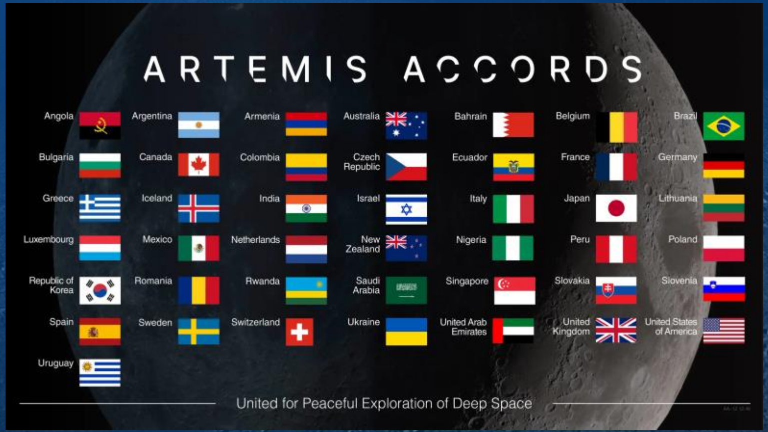
- Earth independence
- Robustness, resilience
- Multi-asset surface ops
- Lunar robotics autonomy
- Highly dynamic scenarios (e.g., landing, rendezvous / proximity operations)

Commercial/International Partnerships

INTEROPERABILITY: Interoperable lunar infrastructure. U.S., industry, and international partners can maintain continuous robotic and human presence with NASA as a customer of commercial services.

Use of international Comm/Nav Standards:

International Partners



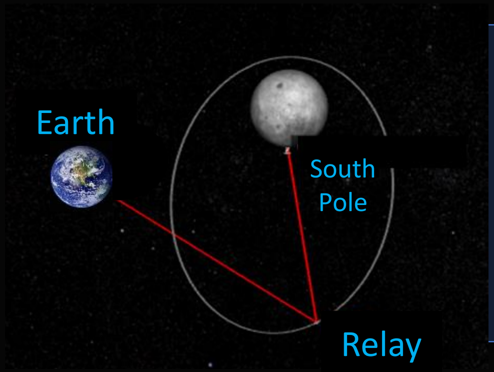
Space Communications and Navigation (SCaN): Plan for Cislunar Infrastructure

DSN 34-Meter Antenna Upgrades

- Upgrades to Deep Space Network (DSN) antennas at each of the three complexes
  - Simultaneous operation – S+Ka-band or X+Ka-band
  - Increased data rates – >100 Mbps downlink/Ka-band

NSN 20-Meter Antenna Subnet Development (LEGS)

- A dedicated set of antennas designed for lunar missions.
  - Help alleviate the operations load on the DSN
- Three sites around the Earth for continuous coverage
- Commercial services to add capacity as demand grows



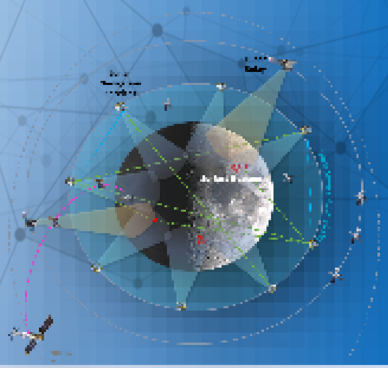
Lunar Relay and Interoperable Lunar Network

- Relays critical to remove Direct-to-Earth (DTE) line-of-sight comm constraint
- Initial relay deployment aimed at South Pole and Far-Side
- Communication, Networking and PNT services
- Commercial service procurement approach

Future Capabilities Under Study to Meet Growing Needs

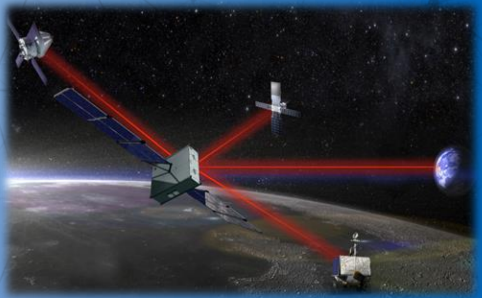
Surface Wireless Communications

- 4G/5G cellular technology for a robust lunar surface network Infrastructure that is **scalable** to meet long-term needs
- Enables **surface comm and aggregates data** for transition to backhaul



Lunar Navigation Services

- “Like GPS, but at/for the Moon”
- Support near term needs for surface positioning and HLS (Human Landing System), logistics, etc. landing
- Long-term support of complex surface ops, Search and Rescue (SAR), situational awareness, prediction and avoidance



Lunar Optical Communications

- Optical communications between Earth and Moon
- Provides High-rate link, data aggregation and relieves spectrum pressure

Lunar Surface Network based on 5G Cellular Standards

Surface communication studies currently underway (* Note - Figure references Apollo 17 traverses for range comparisons)

Use of 4G/5G terrestrial cellular standards could provide for long range, multi-user surface network for EVA, science payloads, habs/vehicles/logistics

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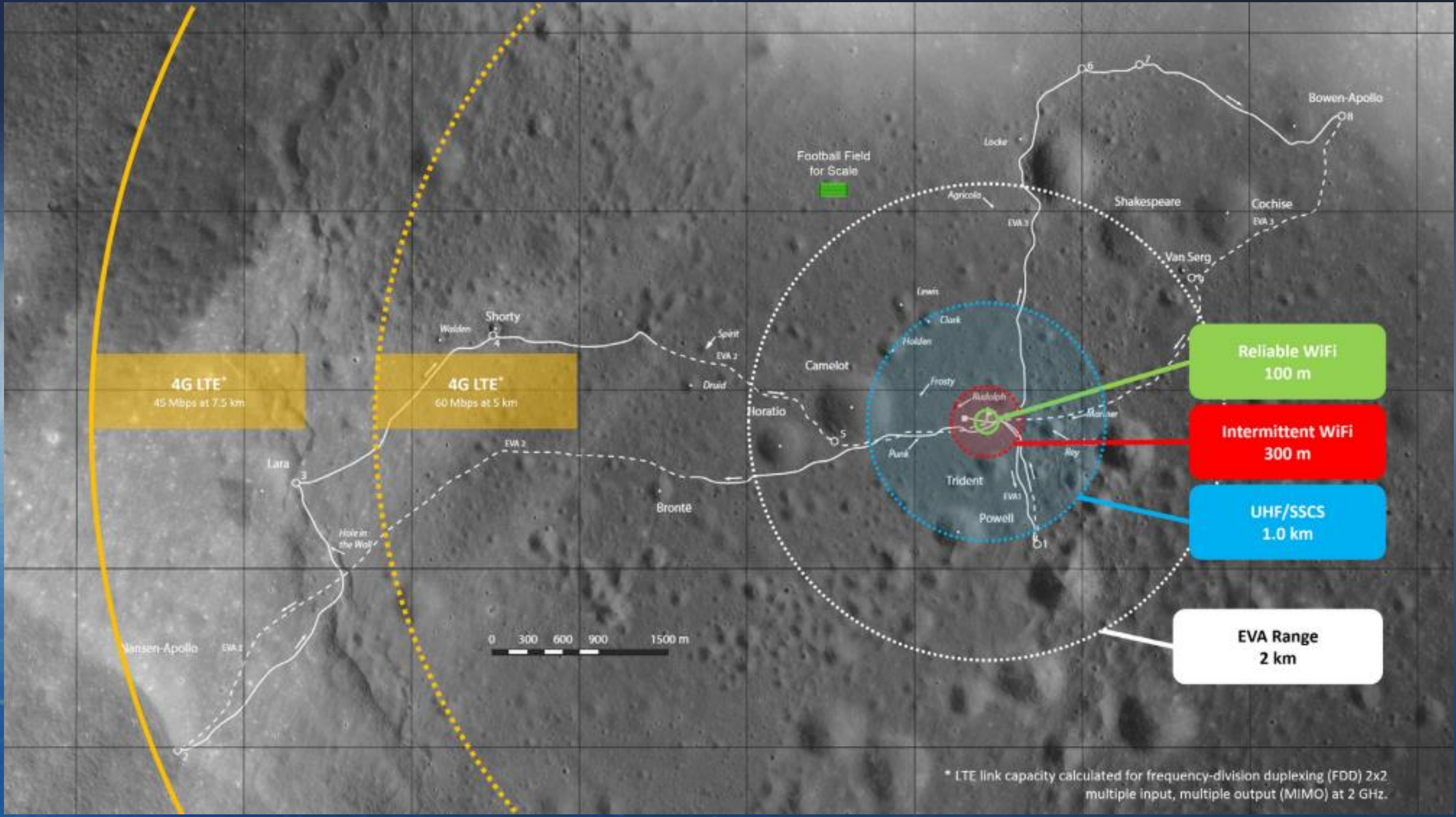
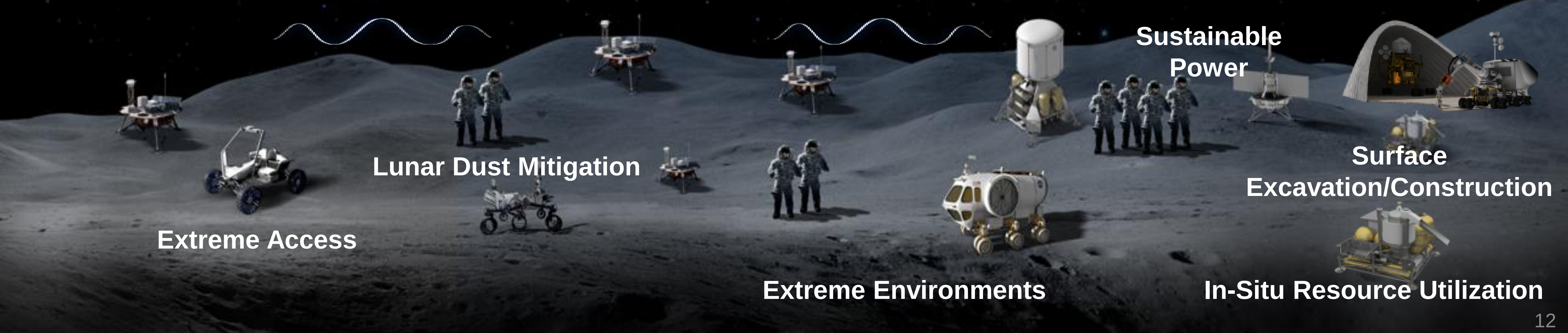
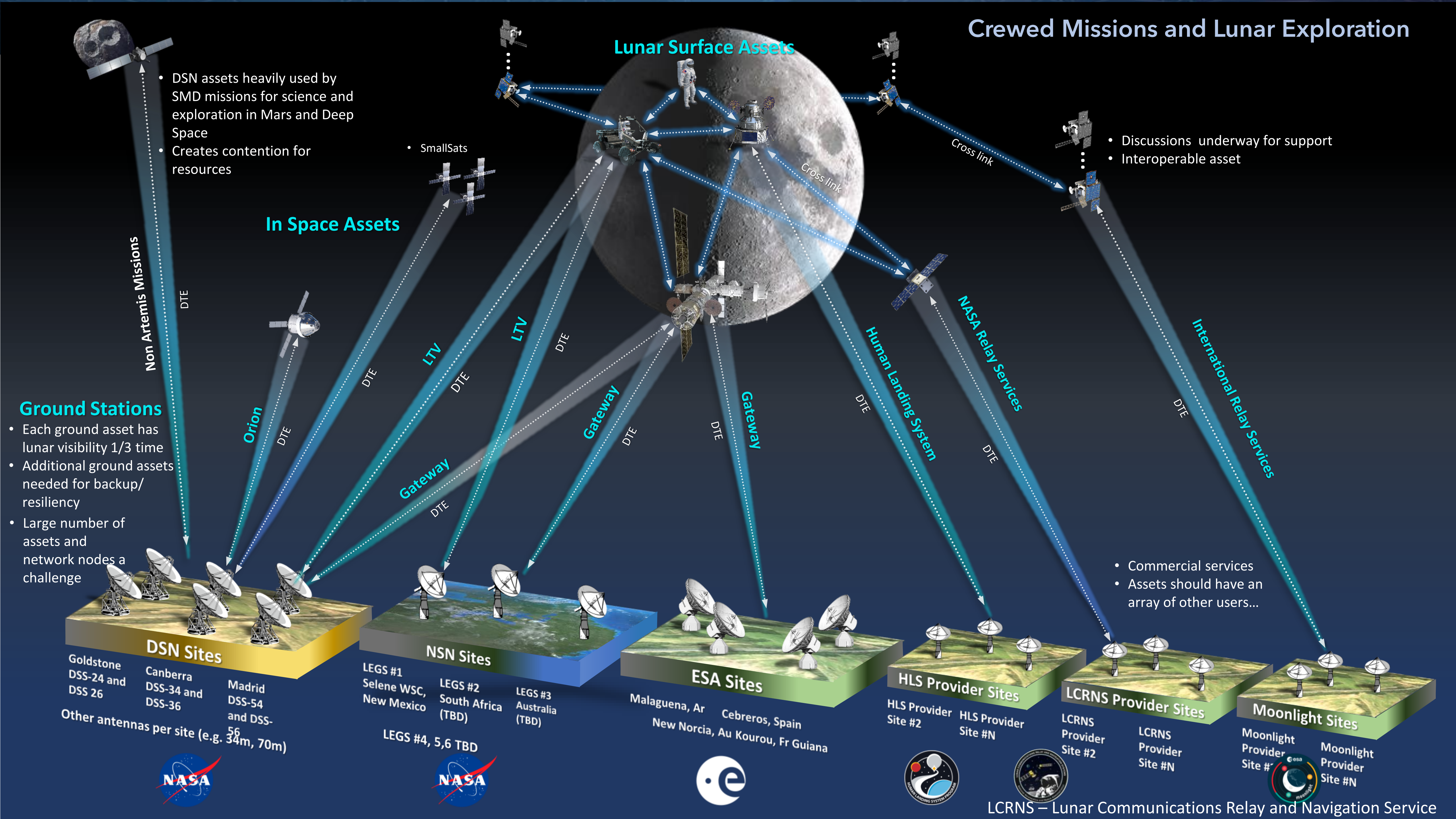
White paper discusses analysis of applying terrestrial cellular standards (3GPP - 3rd Generation Partnership Project) to lunar surface – 5G network on the lunar surface (* Note – WiFi ranges vary by versions)



SURFACE TECHNOLOGY CHALLENGES

- **In-situ resource utilization** technologies for collecting, processing, storing, and using material found or manufactured on the Moon
- **Surface power technologies** that provide the capability for sustainable, continuous power throughout the lunar day and night
- **Dust mitigation technologies** that diminish dust hazards on lunar surface systems such as cameras, solar panels, space suits, and instrumentation
- **Extreme environment technologies** that enable systems to operate throughout the range of lunar surface temperatures
- **Excavation and construction technologies** that enable affordable, autonomous manufacturing or construction
- **Surface communications signal propagation** compensation to optimize communications across the lunar surface




Crewed Missions and Lunar Exploration
Lunar Surface Assets
DSN assets heavily used by SMD missions for science and exploration in Mars and Deep Space
Creates contention for resources
SmallSats
In Space Assets
Non Artemis Missions
DTE
Orion
LTV
Gateway
Cross link
Human Landing System
NASA Relay Services
International Relay Services
Discussions underway for support
Interoperable asset
Ground Stations
Each ground asset has lunar visibility 1/3 time
Additional ground assets needed for backup/ resiliency
Large number of assets and network nodes a challenge
Commercial services
Assets should have an array of other users...
DSN Sites
Goldstone DSS-24 and DSS 26
Canberra DSS-34 and DSS-36
Madrid DSS-54 and DSS-56
Other antennas per site (e.g. 34m, 70m)
NSN Sites
LEGS #1 Selene WSC, New Mexico
LEGS #2 South Africa (TBD)
LEGS #3 Australia (TBD)
LEGS #4, 5,6 TBD
ESA Sites
Malaguena, Ar
Cebreros, Spain
New Norcia, Au Kourou, Fr Guiana
HLS Provider Sites
HLS Provider Site #2
HLS Provider Site #N
LCRNS Provider Sites
LCRNS Provider Site #2
LCRNS Provider Site #N
Moonlight Sites
Moonlight Provider Site #2
Moonlight Provider Site #N
LCRNS – Lunar Communications Relay and Navigation Service

Theme: Increasing the Thrust of Space Sustainability
Panel Discussion: Lunar Surface Communications Architecture

- **Richard Reinhart**, GRC (Moderator) – Status of Lunar Architecture studies
  - Senior Technologist, GRC Aerospace Communications
  - Co-lead, Communication, Positioning, Navigation, and Time (CPNT) Sub-Architecture
- **Michael Zemba**, GRC – Challenges of operating in the lunar environment
  - Principal Investigator, Lunar Surface Propagation
  - Deputy Principal Investigator, 3GPP 4G/5G Lunar Communications
- **Ray Wagner, PhD**, JSC – Collaboration with commercial and international partners
  - Principal Investigator, 3GPP 4G/5G Lunar Communications
- **Thierry Klein**, NOKIA – 4G/LTE communications network demo on CLPS (Commercial Lunar Payload Service) Intuitive Machine (IM-2) Mission
  - President of Bell Labs Solutions Research at Nokia Bell Lab

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NASA

- Backup

LunaNet – “Lunar Internet” Overview & Interoperability

LunaNet concept is a set of cooperative communication and navigation networks composed of assets from commercial and government providers serving users at the Moon;

Trunk Links, Proximity Links, Surface Network, Navigation

LunaNet: a flexible, extensible, and interoperable lunar comm/nav architecture with key services:

- Communications
- Networking
- Position, Navigation and Timing (PNT)

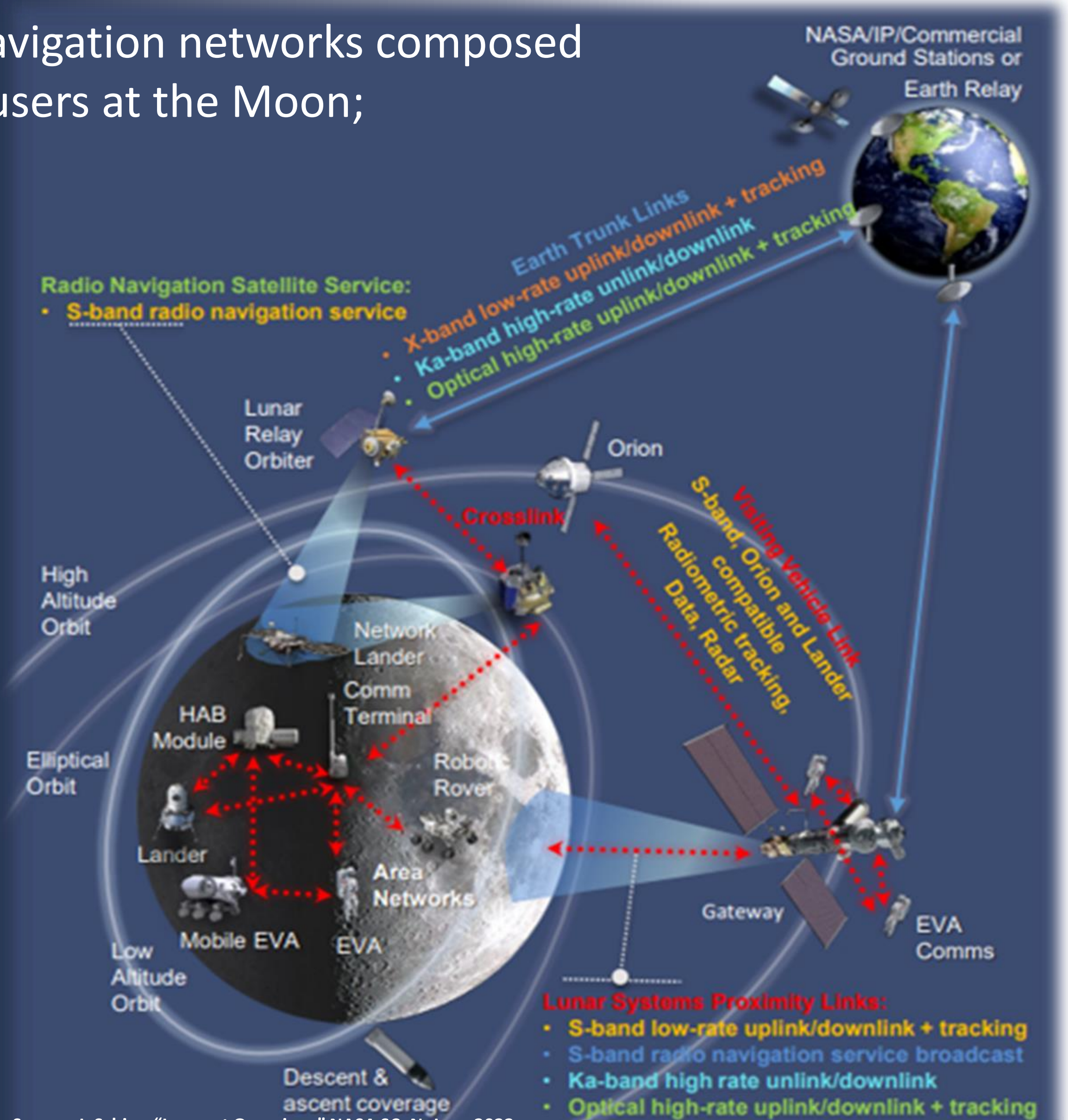
LunaNet is a collaboration focused on interoperability

- Collaboration with industry on the next version (Draft Version 5) of the LunaNet Interoperability Specification – Ver 4 released in Sept 2022
  - > https://www.nasa.gov/directorates/heo/scan/engineering/lunanet_interoperability/
  - > Past industry days with NASA
- The specification defines standards for lunar communications relay and navigation services and interfaces

Interagency Operations Advisory Group (IOAG)

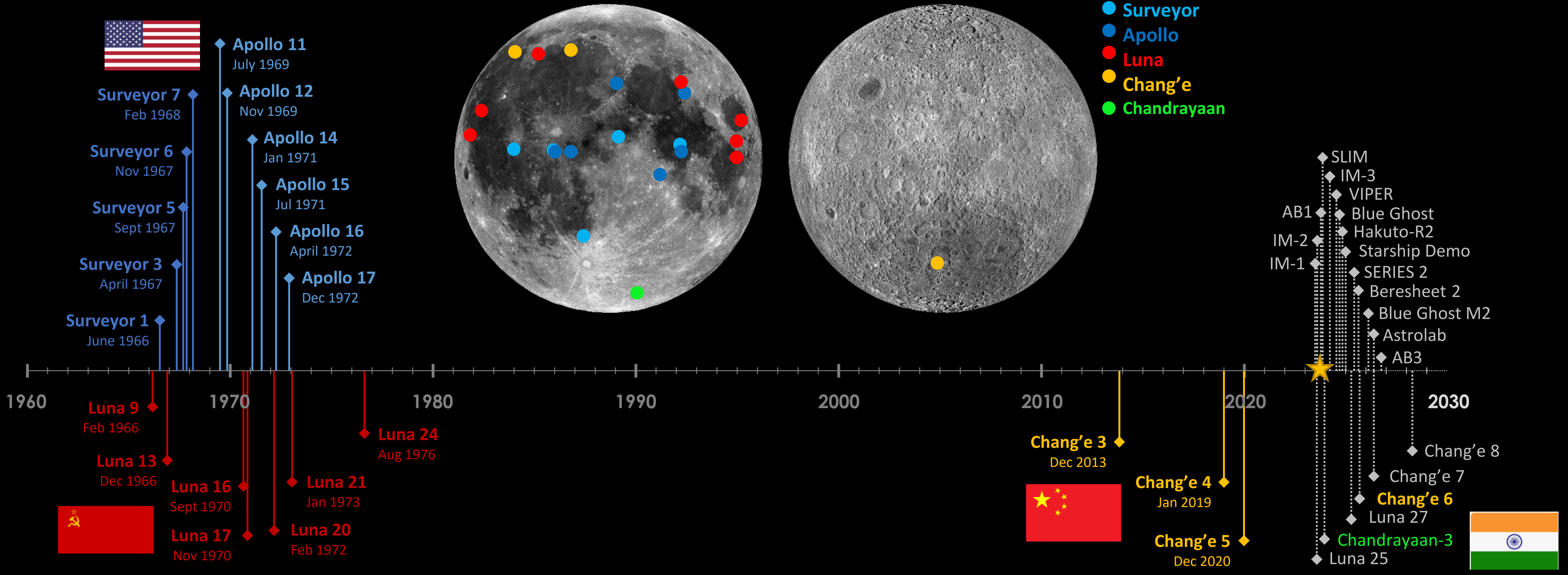
- The Future Lunar Communications Architecture
- International Communication System Interoperability Standards (ICSIS)

Spectrum Planning: ITU, SFCG and NTIA Processes

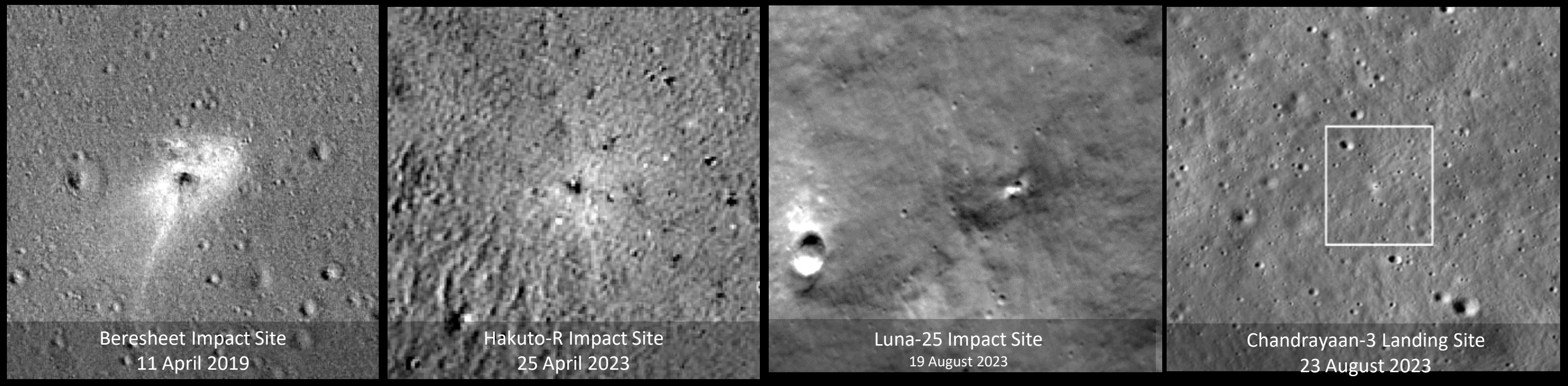


Source: J. Schier, “Lunanet Overview,” NASA SCaN, June 2022.

The Rapid Increase in Lunar Missions



- Total Successful Soft Lunar Landings: **22**
- Three Chang'e and Chandrayaan-3 landers are presently the only successful landings since 1976.
- Chandrayaan-3 is the closest to the South Pole at 69.3 °S lat, 32.3° E long, ~600km from the pole
- Chang'e 4 is the only landing on the far side



Lunar Reconnaissance Orbiter Camera (LROC) Imagery of recent impact sites. NASA Goddard Space Flight Center

M2M Architecture Segments

Human Lunar Return

Foundational Exploration

Sustained Lunar Evolution

Future Segments

Humans to Mars