NASA GNSS Update

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NASA Goddard Space Flight Center

ICG-16 WG-B
11 October 2022
Active Space Uses of GNSS at NASA

- Real-Time On-Board Nav
- Launch Vehicle Range Ops
- Attitude Determination
- Time Synchronization
- Earth Sciences
- Precise Orbit Determination
In accordance with ICG WG-B recommendation: “GNSS Space User Database”, 2016
International Operations Advisory Group

Forum for identifying common needs across multiple international agencies for coordinating space communications policy, high-level procedures, technical interfaces, and other matters related to interoperability and space communications

It undertakes activities it deems appropriate related to multi-agency space communications

Goal to achieve full interoperability among member agencies

For more information: www.ioag.org

ICG-IOAG Collaboration: GNSS Space User Database

- IOAG has observer status in the ICG
- ICG recommendations encourage providers, agencies, and research organizations to publish details of GNSS space users and to contribute to IOAG database
- Database last updated on 50 May 2022 for IOAG-25
- Key changes since previous update (13 Nov 2020):
  - Includes 139 total missions from 9 agencies + affiliates
  - We continue encouraging service providers, space agencies and research institutions to contribute to the GNSS space user database via their IOAG liaison or ICG WG-B

IOAG Missions & Programs Relying on GNSS

<table>
<thead>
<tr>
<th>Agency</th>
<th>Country</th>
<th>2021</th>
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*Includes affiliated organizations

https://www.ioag.org/Public%20Documents/Aggregate%20IOAG%20Missions%20Using%20GNSS%202022-05-20%20(IOAG-25).xlsx
## Selected US Mission Database Updates

<table>
<thead>
<tr>
<th>N°</th>
<th>Agency</th>
<th>Mission</th>
<th>GNSS System/s Used</th>
<th>GNSS Signals Used</th>
<th>GNSS Application</th>
<th>Orbit</th>
<th>Launch (Actual or Target)</th>
<th>Notes</th>
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<tr>
<td>114</td>
<td>NASA</td>
<td>OSAM-1</td>
<td>GPS</td>
<td>L1 C/A</td>
<td>Orbit determination, spacecraft timing, GNSS measurements part of multi-sensor nav filter for AR&amp;D with Landsat 7</td>
<td>Ep</td>
<td>2025</td>
<td>RUAG</td>
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<td>121</td>
<td>NASA</td>
<td>Geospace Dynamics Constellation (GDC) (6 satellites)</td>
<td>TBD</td>
<td>TBD</td>
<td>Orbit, time, radio occultation (dedicated instrument)</td>
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<td>2027</td>
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<td>122</td>
<td>NASA/A SI/ESA</td>
<td>UP Aerospace SL-15</td>
<td>GPS Galileo</td>
<td>GPS L1 C/A, L5 Galileo E1, E5a</td>
<td>Orbit, time</td>
<td>O</td>
<td>Nov. 2022</td>
<td>Suborbital flight test with two GNSS receivers provided by ASI and ESA. Each receiver will use the systems and signals indicated.</td>
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*Red* = updated in this release

See link on previous slide for full database
Lunar Activities
Development of High Altitude GNSS

Transition from experimentation to operational use, and move into cislunar space:

- **1990s**: Early flight experiments—Equator-S, Falcon Gold
- **2000**: Reliable GPS at GEO w/ bent pipe architecture
- **2001**: AMSAT OSCAR-40 mapped GPS main and sidelobe signals
- **2015**: MMS employed GPS operationally at 76,000 km
- **2016–Present**: GOES-16/17/18 employs GPS operationally at GEO
- **2019**: MMS apogee raise to 50% lunar distance
- **2024**: Lunar demonstration
Signal Reception in the GNSS Space Service Volume (SSV)

- **Earth shadowing**
- **Main lobe signal**
- **Side lobe signal**

GEO Altitude: 36,000 km
GNSS Altitude: 20,000 km
MEO GNSS
Signal Reception **beyond** the GNSS Space Service Volume (SSV)

**Challenges:**
- >30x weaker signals than GEO
- 10–100x worse DOP
Lunar Role of GNSS

Critical technology gaps identified in the Global Exploration Roadmap:

• Autonomous Rendezvous & Docking, Proximity Operations, Target Relative Navigation
• Beyond-LEO crew autonomy

GNSS on lunar missions would:

• enable autonomous navigation
• reduce tracking and operations costs
• provide a backup/redundant navigation for human safety
• provide timing source for hosted payloads
• reduce risk for commercial development

Recent advances in high-altitude GNSS can benefit and enable future lunar missions
Lunar Exploration: Roles for GNSS

Lunar Surface Operations, Robotic Prospecting, & Human Exploration

Human-tended Lunar Vicinity Vehicles (Gateway)

Robotic Lunar Orbiters, Resource & Science Sentinels

Earth, Astrophysics, & Solar Science Observations

Satellite Servicing

Lunar Exploration Infrastructure
Use of GNSS and lunar PNT services are considered as a key part of the broader navigation ecosystem including ground-based and on-board sources.
Evolution from Demonstrations to Flight Operations

Artemis-1 (LEO receiver) 2022
LuGRE 2024
Lunar Pathfinder (ESA) 2025
Gateway Payloads
LunaNet
Artemis-1
ARTEMIS I
The First Uncrewed Integrated Flight Test of NASA’s Orion Spacecraft and Space Launch System Rocket

1. LAUNCH
SLS and Orion lift off from pad 39B at Kennedy Space Center.
2. PERIGEE RAISE MANEUVER
Systems check with solar panel adjustments.
3. JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM
4. CORE STAGE MAIN ENGINE CUT OFF
With separation.
5. EARTH ORBIT
6. INTERIM CRYOGENIC PROPULSION STAGE (ICPS) SEPARATION AND DISPOSAL
The ICPS has committed Orion to TLI.
7. TRANS LUNAR INJECTION (TLI) BURN
Maneuver lasts for approximately 20 minutes.
8. OUTBOUND POWERED FLYBY (OPF)
60 nmi from the Moon; targets DRO insertion.
9. LUNAR ORBIT INSERTION
Enter Distant Retrograde Orbit.
10. OUTBOUND TRAJECTORY CORRECTION (OTC) BURNS
As necessary adjust trajectory for lunar flyby to Distant Retrograde Orbit (DRO).
11. DISTANT RETROGRADE ORBIT
Perform half or one and a half revolutions in the orbit period 38,000 nmi from the surface of the Moon.
12. DRO DEPARTURE
Leave DRO and start return to Earth.
13. RETURN POWERED FLYBY (RPF)
RPF burn prep and return coast to Earth initiated.
14. LUNAR ORBIT INSERTION
15. CREW MODULE SEPARATION FROM SERVICE MODULE
16. ENTRY INTERFACE (EI)
Enter Earth’s atmosphere.
17. SPLASHDOWN
Pacific Ocean landing within view of the U.S. Navy recovery ship.

MISSION DURATIONS:
Total: 26–42 days
Outbound Transit: 9–14 days
DRO Stay: 6–19 days
Return Transit: 9–19 days

Source [3]
LuGRE
LuGRE Overview

Payload objectives
1. Receive GNSS signals at the Moon. Return data and characterize the lunar GNSS signal environment.
2. Demonstrate navigation and time estimation using GNSS data collected at the Moon.
3. Utilize collected data to support development of GNSS receivers specific to lunar use.

Measurements
- GPS+Galileo, L1/L5 (E1/E5)
- Onboard products: multi-GNSS point solutions, filter solutions
- Observables: pseudorange, carrier phase, raw baseband samples

Utilization
- Data + lessons learned for operational lunar receiver development
- Potential collaborative science: heliophysics, lunar geodesy
- Lunar human and robotic real-time onboard PNT

Mission
- NASA HEOMD payload for CLPS “19D” flight
- Joint NASA/Italian Space Agency mission
- “Do No Harm” class
- Firefly Blue Ghost commercial lander
- Transit + surface observation campaign
- Expected surface duration: one lunar day (~12 Earth days)

**LuGRE Timeline**

<table>
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<tr>
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<td>CLPS Final RFP</td>
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<tr>
<td>LuGRE Checkpoint A</td>
<td>Mar 2021</td>
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<td>LuGRE Checkpoint B (SRR)</td>
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<td>ETU Delivery Perf Test</td>
<td>Sep 2021</td>
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<td>Payload Delivery</td>
<td>Dec 2022</td>
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<td>Payload Delivery to Firefly</td>
<td>2024</td>
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<td>Launch+Ops</td>
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<tr>
<td>Analysis</td>
<td>Late 2024</td>
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**LuGRE Checkpoints**

- LuGRE Checkpoint C (SRR) | May 2021
- Payload Delivery to Firefly | Dec 2022
- Launch+Ops | 2024

**Launcher Information**

- Mare Crisium 18° N, 62° E
- Lander IRR, TRR, Ops Dry-runs, Launch rehearsal, etc.
- 2023-2024
**LuGRE**

0 Pre-Launch
- SpaceX Falcon 9

1 Launch
- Cape Canaveral, FL

2 Commissioning
- Collection via reorient
- Antenna stowed

3 Transit Operations
- 15hr total collection via reorient
- Antenna stowed

4 Powered Descent

5 Surface Operations
- 12 days collection
- Antenna deployed, Earth-tracking
- 2x-2.5s baseband sample collection

6 Extended Mission
- TBD duration during lunar night
- Continued collection

7 Decommissioning

8 Science Data Processing

**FIREFLY “BLUE GHOST” LANDER**

- LuGRE antenna
  - Co-located w/ lander X-band ant.
  - Earth pointing via gimbals
- LuGRE receiver and FEA
  - (internal)

(Lunar Phasing Orbits (17 days)

Mare Crisium
- 18° N, 62° E

GPS and Galileo
- (Downlink X-band via reorient)

(NASA Science Processing Center)

ASI Science Processing Center

LuGRE Data

Joint Operations

Public Dissemination

v1.2
LuGRE Outcomes

Characterize the GNSS signal environment
- GPS+Galileo, L1+L5, E1+E5a
- Signal availability
- DOP
- C/N0
- Observables
  - Pseudorange
  - Carrier phase
  - Doppler
- Raw baseband I/Q samples
- Transmit antenna patterns
- Multipath, surface environment

Characterize navigation performance
- Point solutions
- Onboard Kalman filter states
- Time to first position fix
- Formal errors, convergence
- Comparison to independent sources (lander, LRR)
- Application of GGTO

Share collected data
- GNSS receiver developers
- LuGRE science partners
- NASA missions (Artemis, Gateway, science)
- Commercial landers
- International space agencies
- GNSS community
- Science community
- Public

Facilitate adoption of capability
- Raw data availability
- LuGRE team reports + papers
- Calibration of lunar GNSS simulation models
- Application to future mission navigation studies
- Lessons learned to GNSS hardware and software developers

*Specific investigations are coordinated via LuGRE Science Team
LCRNS & LunaNet

Source:
Mr. Andrew Petro, NASA Space Communications and Navigation (SCaN)
Mr. James Schier, NASA Space Communications and Navigation (SCaN)
Lunar Communications Relay and Navigation Systems (LCRNS)

• Enabling a lunar communications and navigation infrastructure that meets NASA’s needs, represents a sustainable, long-term approach to human and robotic exploration, and embodies an extensible solution for future travels to Mars and beyond.
  • Enabling an interoperable approach
  • Directly supports science, technology, and demonstration missions; NASA’s Artemis missions; and the on-going creation of LunaNet
  • See: https://esc.gsfc.nasa.gov/projects/LCRNS?tab=overview

• May 2022: Preliminary LCRNS Lunar Relay Services Requirements Document released: https://esc.gsfc.nasa.gov/static/2fbc056474937c4e3ecfdba1dc595f06/ee60f0dad022948b2e8ce03ad6e86a2f0.pdf
  • Scope is communications relay PNT, and search & rescue services
  • Focus is on lunar south pole region (80°–90° south) and lunar far side
  • Timeline is to support Human Landing System (HLS) and CLPS as early as 2024
Diverse, evolving constellation with multiple users and providers

LunaNet
Framework of standards for open, interoperable networks - Data, PNT & other services

Communication and navigation infrastructure lowers the barriers to entry for new missions and capabilities and supports expanding robotic and human activities on the Moon.

September 2021
**Near-Term**

**NEEDS**
- Far Side science mission
- South Pole human exploration
- PNT services

**IMPLEMENTATION**
- Existing ground networks
- Initial relay capabilities
- LunaNet compatibility

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**Medium-Term**

**NEEDS**
- Global coverage
- Longer, more complex missions, greater mobility

**IMPLEMENTATION**
- Comprehensive relay network
- Surface comm & nav assets
- Full LunaNet services

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**Far-Term**

**NEEDS**
- Sustained surface and orbital presence

**IMPLEMENTATION**
- Evolution of infrastructure
- Infusion of new technology
**Networking Services (Data Transmission)**

Data transmitted to Earth in real time or aggregated and transmitted in store-and-forward mode.

Data exchange among lunar users (avoid transfer to and from Earth).

Multiple relays used interchangeably, as needed.

**PNT Services (Position, Navigation, Timing)**

LunaNet nodes generate and exchange PNT information.

Nodes can share PNT data to support and enhance their operations.

**Messages, Alerts, Radio/Optical Science**

LunaNet nodes can host sensors and disseminate space weather alerts, conjunction alerts, and science measurements.
Lunar Communications and Navigation Interoperability Standards

In collaboration with other agencies, international partners and private companies, NASA is seeking to define a framework of mutually agreed-upon standards to be applied by lunar users and service providers in a set of cooperating networks.

The framework would apply to communication transmission services for science, exploration and commercial operations, distribution of navigation and timing references, and sharing of information. These standards can be introduced as part of the earliest missions and accommodate expansion as new commercial and government users and service providers join in an open and evolving architecture.

An initial version of proposed Lunanet standards has been drafted and can be found at the link below. https://go.nasa.gov/3BQrCOk

Lunanet articles of note:
https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=4773&context=smallsat
https://doi.org/10.1109/AERO47225.2020.9172509
Enabling Lunar PNT: GPS Initiatives

- **GPS III Space Service Volume**
  - Stabilized main lobe signal with spillover to support high-alt. users

- **NASA-USAF Memorandum of Understanding**
  - Signed in 2017 to ensure SSV signal continuity for future space users
  - Provides for release of antenna data + NASA representative in the GPS IIF procurement cycle

- **GPS data availability**
  - 2001: AO-40 initial gain pattern measurements
  - 2015: Initial IIR/IIR-M antenna gain pattern data release
  - 2018: GPS ACE flight-measured patterns released by NASA
  - Late 2020: IIR/IIR-M antenna gain pattern data (re-release), GPS III SVN 74-77 phase center, group delay, and inter-signal bias data
  - 2021: GPS III SVN 74–78 data updates
  - 2022: GPS III antenna pattern release
GPS III antenna pattern release

- GPS has released key technical data for GPS III SVN 74–78, including:
  - Antenna gain patterns
  - Antenna phase center
  - Group delay
  - Inter-signal corrections

- This is responsive to recommendations from both WG-B and WG-D.

- This type of data is critical to support high-accuracy applications and use within the Space Service Volume, including new lunar applications of GNSS.

- Gain pattern data includes ground-measured directivity and phase for all open signals: L1, L2, L5 w/ resolution 2° in theta, 10° in phi

All data is available from USCG NAVCEN: https://www.navcen.uscg.gov/gps-technical-references
Technology Updates
SL-15 Launch with AFTS and GNSS

- NASA has two International Agreements with the Italian Space Agency (ASI) and with the European Space Agency (ESA) to fly two GPS-Galileo receivers on a sounding rocket
- Builds on the success of the SL-14 launch [https://www.youtube.com/watch?v=fE_S88wzWzM](https://www.youtube.com/watch?v=fE_S88wzWzM)
- SL-15 Objective: Assess GPS-Galileo performance in a highly dynamic environment, including potential to augment GPS in range safety system
- Includes two multi-GNSS receivers, one GPS receiver, and two AFTUs on UP Aerospace Space Loft (SL)-15 sounding rocket

SL-15 Mission provided by NASA’s Flight Opportunities Program:
- Scheduled for launch in November 30, 2022 from Spaceport America, NM
- Utilizing L1/E1/L2/E5a

Mission profile
- Launch and boost phase (12 s)
- Ascent coasting until 100 km Apogee
- Descent, re-entry, and landing
- Total duration: 13 minutes
- Maximum speed: 1400 m/s
- Maximum acceleration: 13.5 G
- Maximum Spin rate: 7 Hz
SL-15 Multi-GNSS Payload Hardware

AFTU:
- **Weight**: 1.3kg
- **Size**: 5cm x 14cm x 19cm
- **Power**: 7W, 5.5A, 28V DC

Javad Receiver:
- **Weight**: 1.3kg
- **Size**: 2cm x 5cm x 8cm
- **Power**: 5.3W, 5.3A, 28V DC

ASI/Qascom GARHEO Receiver:
- **Weight**: 0.7 Kg
- **Size**: 16.8cm x 12.6cm x 3.5 cm
- **Power**: 5W, 1A, 5V

ESA/Fraunhofer GOOSE Receiver:
- **Weight**: 1.591 kg
- **Size**: 6.9 cm x 12.0 cm x 14.55 cm
- **Power**: 15W, 1.67A, 12V
Receiver Development

Source:
TriG/Cion: Dr. Yoaz Bar-Sever, Jet Propulsion Laboratory, California Institute of Technology
NavCube: Mr. Munther Hassouneh, NASA Goddard Space Flight Center
Space Geodesy Infrastructure and Operations

JPL continues to operate the NASA Global GNSS Network (GGN) - the largest centrally-managed network contributor to the IGS

• Initiated in 1991 as the first global civilian GPS network
• Now tracks GPS, GLONASS, BeiDou, Galileo, QZSS, NAVIC
• ~60 sites streaming real-time tracking data
• Public access via CDDIS

JPL’s Terrestrial Reference Frame (JTRF) is derived from a time series of coordinates of tracking station for all four geodetic techniques, and reduces the degradation over time of the TRF

JPL has been certified by the IERS as one of three International Terrestrial Reference System (ITRS) Combination Centers
Orbit determination of all GNSS constellations is needed foundation for many NASA’s science missions and applications
• GPS, GLONASS, BeiDou, Galileo, QZSS (real-time only), NAVIC (real-time only)
• Full spectrum of accuracy vs latency: Weekly (‘Final’), Daily (‘Rapid’), Hourly (‘Ultra’), Seconds (real-time)

A wide variety of science missions depend on the JPL GNSS products on the reference frame they represent
• GRACE-FO, Sentinel-6, DSAC, SWOT, NISAR, COSMIC-2,…

GNSS monitoring and situational assessment for all NASA missions
by JPL’s Global Differential GPS (GDGPS) System
• For example, real-time GPS Flex Power
NavCube 3.0 mini GNSS Receiver

NC3m Description

- A low SWaP multi-GNSS receiver for cislunar/lunar space
  - Combined fast acquisition and weak signal acquisition
  - GPS L1 C/A and L2C currently available
  - GPS L5 and Galileo E1 and E5a in development
  - Flight software follows NPR7150.2C
- Builds on flight proven GSFC MMS Navigator software and firmware
- On-orbit upgradable, FPGA-based radiation tolerant
- Integrated GEONS navigation filter
  - Heritage dating back to 1990’s and operational on MMS, GPM, NICER/SEXTANT
  - Provides critical filtering for high altitude applications with sparse visibility and poor geometry

Status

- Standalone version of NC3m completed TRL6 testing in July 2022
NC3m Applications and Benefits

- Provide precise position, velocity, and time (PVT) for missions in all orbit regimes including lunar space
- Provides 1PPS output referenced to GPS time
- Raw GNSS signal measurements can be directly used for science in some cases (e.g., study of TEC=total electron content)
- Support reliable onboard autonomous navigation and time, reducing reliance on ground-based navigation
Conclusions

• NASA reports GNSS use on at least 52 current and future missions in every orbit regime, including LEO, GEO, HEO, and soon lunar.

• Ongoing technology development targets high-precision, high-altitude, and high-dynamic use cases.

• Lunar PNT remains the next frontier in space use of GNSS. NASA is pursuing this capability via multiple open, collaborative activities, including Artemis, LuGRE, and LunaNet.

• Policy coordination, including via the ICG, enables robust utilization of GNSS in space.

• New lunar PNT architectures are being devised now. We must work within the ICG and IOAG to enhance the use of GNSS services in the lunar environment and to develop and expand lunar PNT capabilities that are available to all users and interoperable and compatible with all region-developed PNT systems.
Backup
Lunar Exploration

• The Moon is again a top space exploration priority
• Current lunar exploration efforts more diverse and collaborative
  • >80 national space agencies
  • numerous private companies and partnerships
• Over 20 nations have signed the Artemis Accords to cooperate in the exploration and use of the Moon
• International Space Exploration Coordination Group (ISECG) currently comprised of 27 international space agencies
  • Global Exploration Roadmap (GER) identified 14 planned Moon missions
  • 100-m performance target for precision landing
• International space agencies are developing lunar PNT capabilities NOW; need to ensure these are interoperable, compatible and available to all
• GNSS will play a meaningful role in Lunar PNT
Lunar Gateway

• Joint NASA/ESA performance study. NASA GPS-only results summarized here.
• Assumptions: MMS-like navigation system with Earth-pointed high-gain antenna (~14 dBi) and Goddard Enhanced Onboard Navigation System (GEONS) flight filter software
• Calibrated with flight data from MMS Phase 2B; Employs GPS ACE-derived antenna patterns, IGS yaw model, solar noise model
• L2 southern Near Rectilinear Halo Orbit (NRHO), 6.5 day period
• Cases for both crewed and uncrewed perturb. models:
  • GPS only with Rubidium Atomic Frequency Standard (RAFS)
  • DSN only without atomic clock
  • GPS + DSN

Ground tracking assumptions
• Three contacts per orbit (uncrewed) or continuous (crewed)
• Data Cutoff (DCO) 24 hrs before orbit maintenance maneuvers

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<th>Noise/Bias Type</th>
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Lunar Gateway Study – Sep 2020
GPS Expected Performance

- Update to Feb 2019 preliminary study
- Position and velocity goals: 10 km and 10 cm/s, respectively
- Analyzed max OD error at the Data Cutoff (DCO) and at the final two perilunes and apolunes
- Observations:
  - GPS can provide greatly improved performance vs. DSN
  - GPS is real-time, on-board, without reliance on ground-based assets.

Max steady-state errors, crewed assumptions

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Lunar Architecture Solution to Meet Capacity Drivers

**Deep Space Network (DSN) Lunar Exploration Upgrades (DLEU)**
- Upgrades to two 34-m DSN antennas at each of the three complexes (totaling six upgraded antennas)
- Simultaneous operations – S+Ka-band or X+Ka-band, simultaneous Ka-band
- Low latency data processing for > 150Mbps
- Increased data rates – greater than 100Mbps downlink in Ka-band

**Lunar Exploration Ground Segment (LEGS)**
- Initial relay deployment targeted at South Pole and Far-Side, with range and range rate services – nominal commercial service procurement approach
  - Removes DTE line-of-sight comm constraint– reduces user burden
  - Continuous communication during HLS descent is easier supported through a relay link than a DTE link
- Growth in relay satellite nodes / associated services to provide more robust service and coverage
- Alternate options for a government-developed solution
- NASA pursuing build of LEGS sites #1-3
  - Dedicated new set of antennas– 18m or greater equivalent capability– designed to support lunar missions
  - Alleviate the user load on the current 34-meter subnet, to allow for a focus on deep space support
  - Minimum of three sites around the Earth for continuous coverage
  - Commercial services for LEGS 4-6 and beyond – add assets as demand grows and to meet redundancy / resiliency needs

**Lunar Communications Relay and Navigation Services**

*DLEU, LEGS, LCRNS, surface wireless, LNS and optical are components of a future cooperative lunar network → LunaNet*
Lunar Architecture Solution to Meet Capability Drivers

**Surface Wireless Communications***
- 3GPP/5G cellular technology for a robust lunar surface C&N infrastructure that is scalable to meet long-term needs
- Essential to address surface and orbital link proliferation
- Enables direct surface/local communication and aggregates data for transition to backhaul
- Technology demonstration on Artemis III
- Fully implemented for Artemis V – connectivity between HLS, LTV, and EVA

**Lunar Navigation Services***
- “Like GPS, but at / for the Moon”
- Support near term needs for 10-m surface positioning and 50-m HLS landing knowledge requirements
- Long-term support of complex surface ops, Search and Rescue (SAR) functionality, situational awareness, prediction and avoidance
- LNS deployment of minimum nodes for Artemis V

**Lunar Optical Communications***
- Operational optical communications between the Earth and Moon (coherent, multi-gigabit) supports high bandwidth needs, data aggregation and relieves spectrum pressure
- LunaNet compatible, with high-speed Disruption Tolerant Networking (DTN)
- 1 m class operational optical ground station w/ adaptive optics
- Complete prototype (TRL 6) optical relay payload system

*DLEU, LEGS, LCRNS, surface wireless, LNS and optical are components of a future cooperative lunar network → LunaNet*