# ENABLING CISLUNAR EXPLORATION THROUGH NASA'S LCRNS SYSTEM PNT SERVICES

This presentation reflects the views of Intuitive Machines and does not represent the views of the United Nations, UNOOSA, or their Member States."

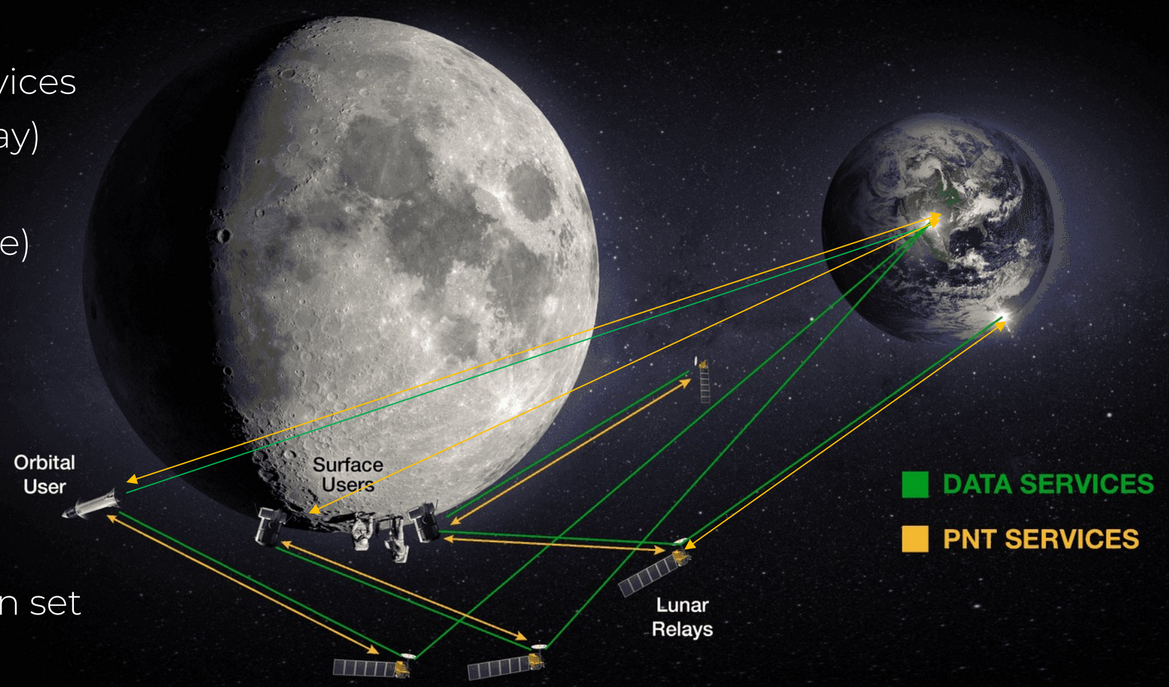
**UNOOSA WORKSHOP ON CISLUNAR POSITIONING, NAVIGATION, AND TIMING (PNT)**
**VIENNA, AUSTRIA, 10-13 FEB, 2026**

# IM'S LUNAR DATA NETWORK

- IM Lunar Data Services
  - IM's LDN includes cislunar in-situ Proximity, and Direct-to-Earth services
  - Communications to/from Earth (Space-Ground Links, Proximity Relay)
  - Communications between assets in Cislunar space (in-situ routed)
  - Position, Navigation, and Timing (PNT) services (Direct and GNSS-like)
  - Data services from instruments, payloads, etc.

- LDN encompasses the end-to-end data and PNT capability
  - IM is a communication and PNT Service Provider (like an ISP or cell phone company that also provides GNSS-like services)
  - Customers come to IM to "move data", obtain PNT information, and enable "OD as a service", as services, not as one-off dedicated mission set
  - LDN serves government, commercial, and IM-internal missions as a customer set (NASA is the "anchor tenant")

- LDN includes
  - Ground Stations (our ground network, upgraded and expanded)
  - Relay satellites in cislunar space (the focus of NASA's NSNS 2.2)
  - Terrestrial data transport (Internet connections, data centers, etc)
  - Operations, planning, and Control Centers
  - Customer commitment, test, integration, and mission planning services




IM's Lunar Data Network is an ISP, Cell Phone service provider, and GNSS constellation for cislunar space, providing integrated communication and PNT services to Government and commercial customers

Illustrative concept; Conceptual system representation provided for public technical discussion; configurations may evolve.

# NASA LCRNS REQUIREMENTS SUMMARY

- IM's Lunar Data Network meets the requirements of NASA's LCRNS and LunaNet 1.0 in addition to "pure commercial" capabilities
- NASA requirements specified in three places:
  - Contract Statement of Work
  - LCRNS System Requirements Document
  - LunaNet Interoperability Specification (including ADs and invoked CCSDS specs)
- Requirements from NASA are for NASA services. IM's capability will exceed this set.
- Requirements are phased into three initial "Increments": A,B,C, and a single final "End Operational Condition" (EOC)
- Requirements sized to meet Artemis mission concepts, lunar surface exploration
- EOC envisioned as future capability

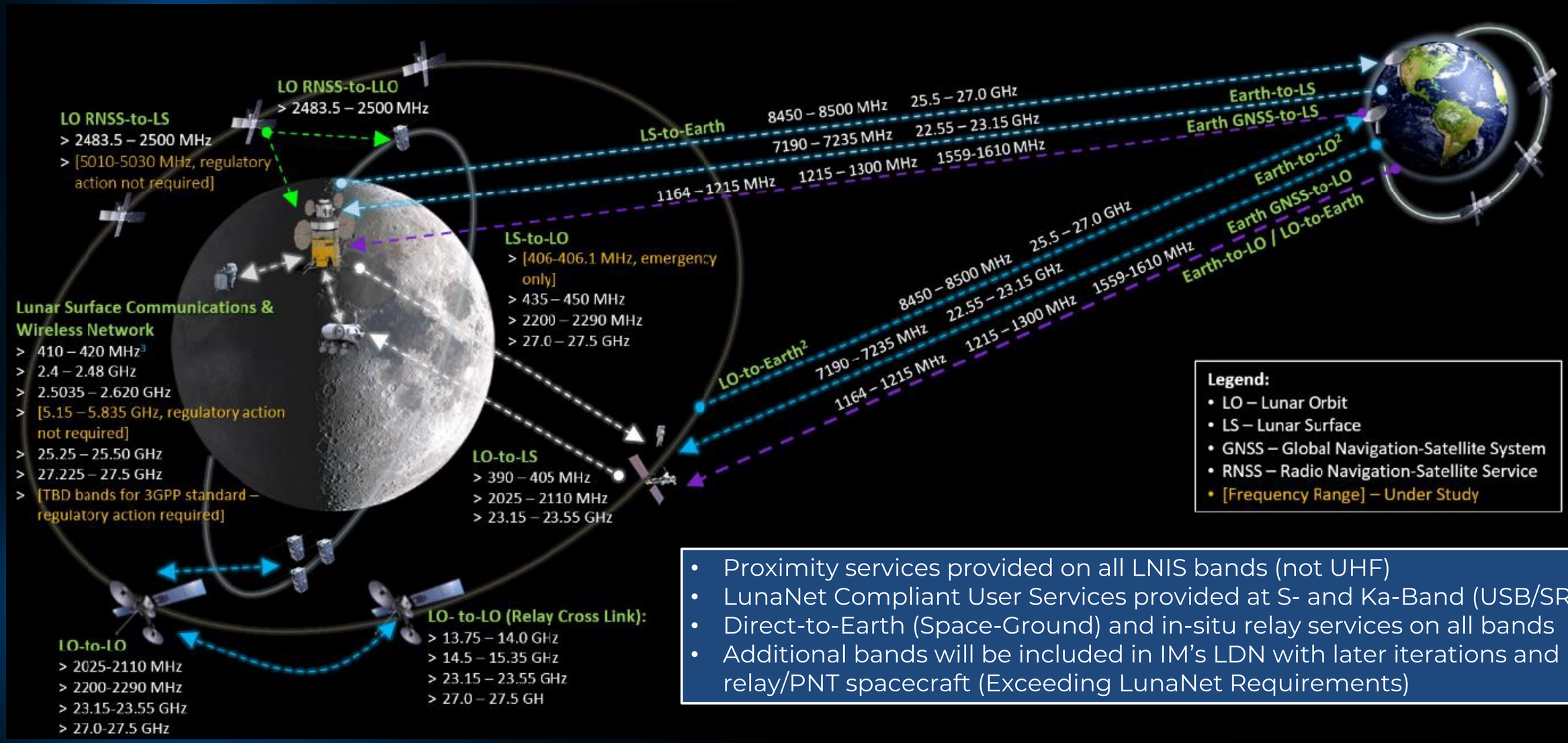
## NASA LCRNS Capability Requirements

| | CAPABILITY | INC A | INC B | INC C | EOC |
|---|---|---|---|---|---|
| SERVICE | Data Volume Return | 3.1 Tbit/day | 3.3 Tbit/day | 6.5 Tbit/day | TBD |
| | Service Volume | SV1 -80°, 125 km | | SV2 -75°, 200 km | SV3 Full, 200 km |
| | Service Availability (Nominal) | 75% | 85% | 95% | 98% |
| | Service Availability (Critical) | N/A | 85% | 98% | 99.5% |
| COMM | Ka-Band Forward | N/A | 1 (75%) | 2 (75%) | 2 (75%) |
| | Ka-Band Return | 1 (70%) | | | |
| | S-Band | 1 (70%) | 1 (90%) | 2 (90%) | 2 (95%) |
| NAV / PNT | AFS | 1 | 2 (70%) 3 (40%) | 4 (40% GDOP<6) | 5 (99%) |
| | MISE Range | 0.93 m (3σ) @ 10 sec | | | |
| | MISE Doppler | 0.33 mm/s (3σ) @ 10 sec | | | |
| | SISE Position | 13.43 m (3σ) | | | |
| | SISE Velocity | 1.2 mm/s (3σ) @ 10 sec | | | |

From NASA LCRNS SRD ESC-LCRNS-REQ-0090

Illustrative performance values shown for discussion purposes and not as operational commitments.

# LUNAR DATA NETWORK – FREQUENCY PLAN




- Proximity services provided on all LNIS bands (not UHF)
- LunaNet Compliant User Services provided at S- and Ka-Band (USB/SRS)
- Direct-to-Earth (Space-Ground) and in-situ relay services on all bands
- Additional bands will be included in IM's LDN with later iterations and relay/PNT spacecraft (Exceeding LunaNet Requirements)

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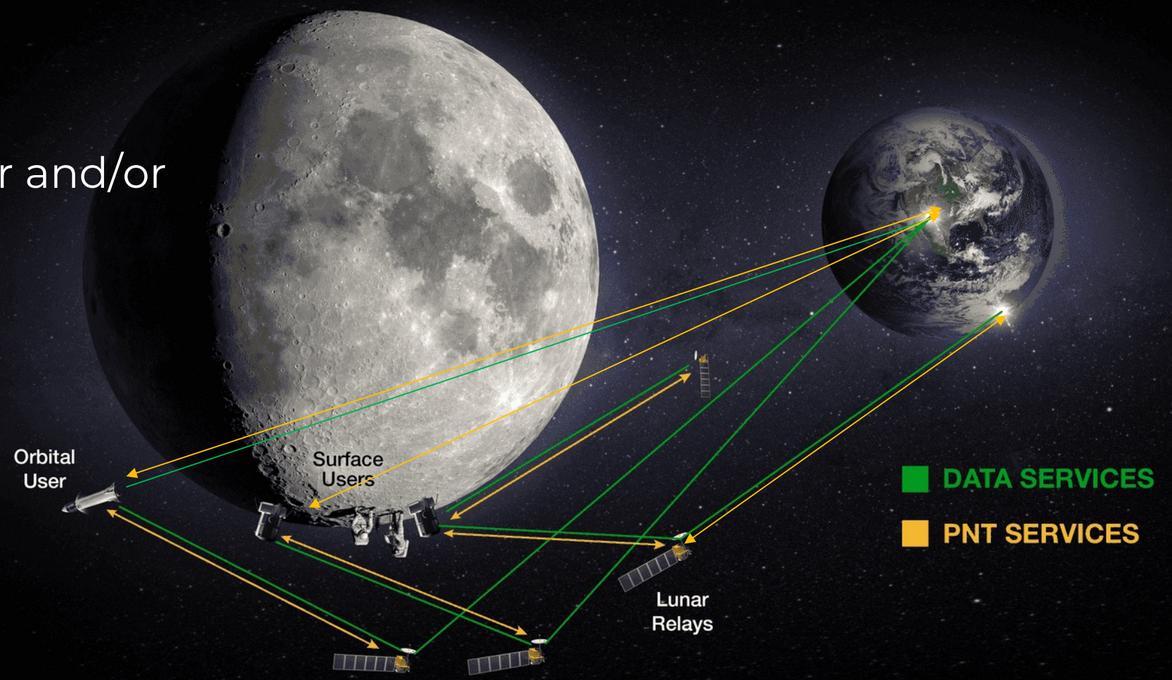
# PNT SERVICES

- Radiometrics
  - Two-way Range and Doppler measurements
  - One-way Doppler (Reference signal transmitted to user and/or user signal measured at the relay spacecraft)
  - Raw observables provided to end-user as product
- Lunar Augmented Navigation Service (LANS)
  - Augmented Forward Signal (AFS)
  - GNSS-”Like” data and PNT service capability
  - Specified in the LNIS / LunaNet architecture
- Future Concepts
  - “OD as a Service” providing processed tracking data and finished trajectory / OD solutions
  - Optical Range and Doppler (optimetrics)
  - Precision one-way Range (pseudo-range measurement) on directed link (not broadcast)
  - Precision two-way time transfer and time synchronization

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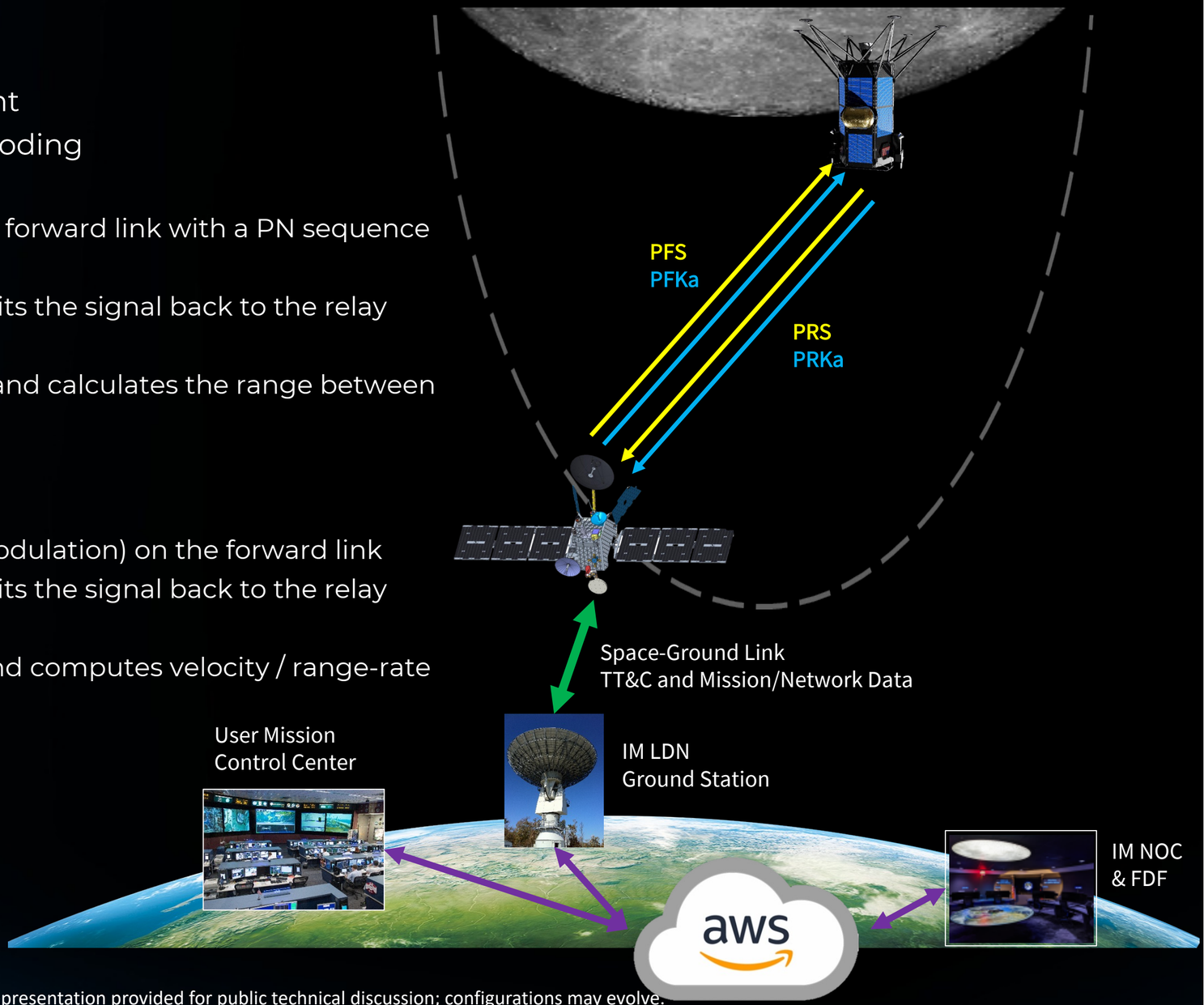
# PNT SERVICES
# TWO-WAY RADIOMETRICS

- Two-way radiometric range and Doppler measurement
- Range measurement uses CCSDS 414.1 modulation / coding
- Two-Way Range Technique:
  - Relay satellite generates ranging signal, modulating the forward link with a PN sequence per CCSDS 414.1
  - User spacecraft “turns the signal around” and re-transmits the signal back to the relay satellite on the return link.
  - Relay satellite measures time-of-flight to/from the user and calculates the range between them.

- Doppler technique:
  - Relay satellite generates carrier (with or without data modulation) on the forward link
  - User spacecraft “turns the signal around” and re-transmits the signal back to the relay satellite on the return link.
  - Relay satellite measures the frequency shift (Doppler) and computes velocity / range-rate

| PERFORMANCE METRIC | VALUE | REMARK |
|---|---|---|
| MISE Range | 0.93 m (3σ) @ 10 s | Error represented as one-way |
| MISE Doppler | 0.33 mm/s (3σ) @ 10 s | Error represented as one-way |



# PNT SERVICES
# ONE-WAY RADIOMETRIC SERVICES

- One-way radiometric Range (pseudo-range) and Doppler
- Forward Service: LDN provides radiometric reference signals (modulated time-stamped frames, reference carrier) as a forward link service for user spacecraft to observe and process
- Return Service: LDN receives and processes one-way radiometric signals (pseudo-range, Doppler) from user spacecraft, time stamps measurements, collates for processing / delivery to the user and/or IM flight dynamics processing
- Range measurement uses CCSDS 414.1 modulation / coding with frame time stamping
- Measurement is made relative to relay satellite precision frequency and time reference (plus corrections if available)

| PERFORMANCE METRIC | VALUE | REMARK |
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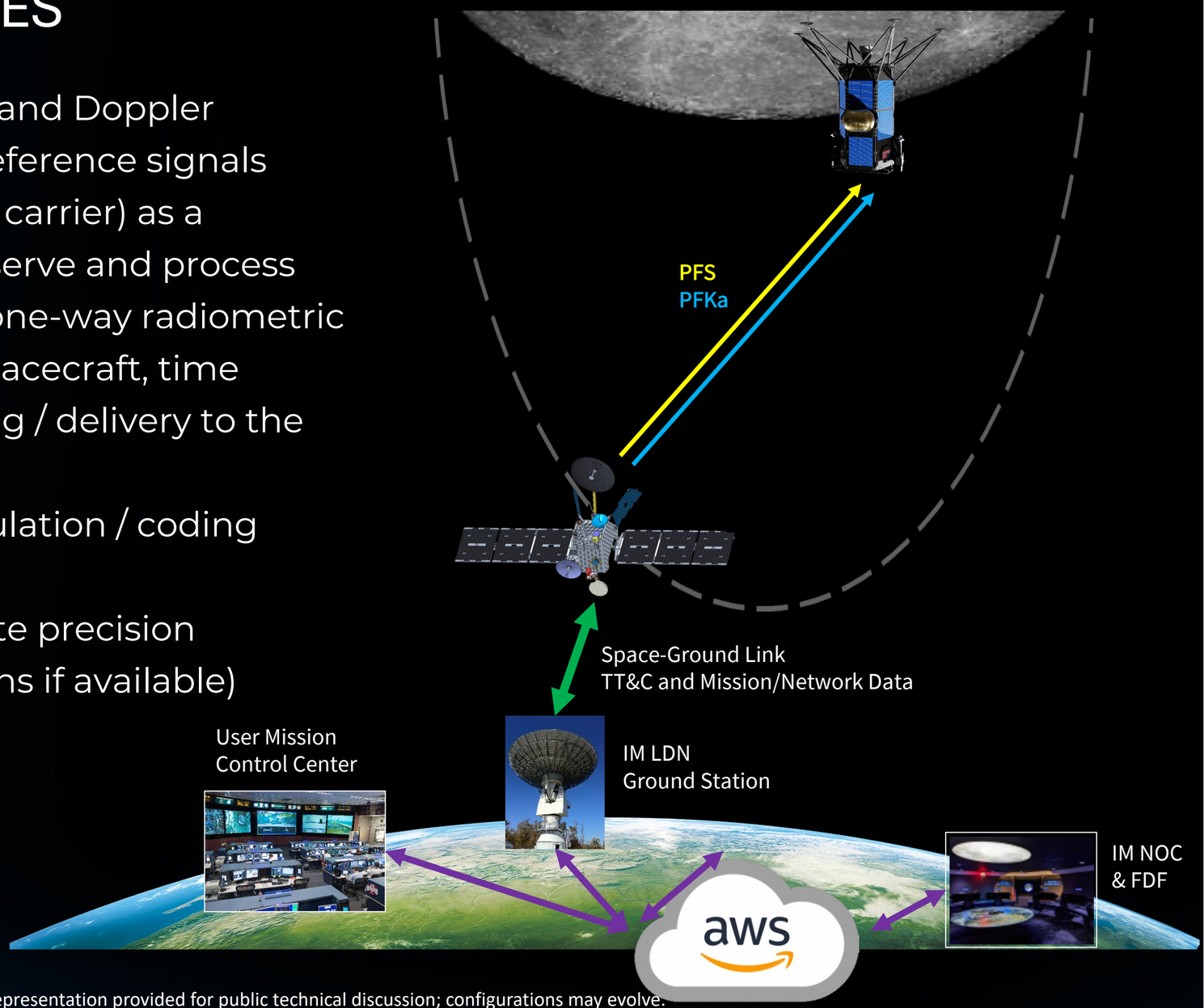
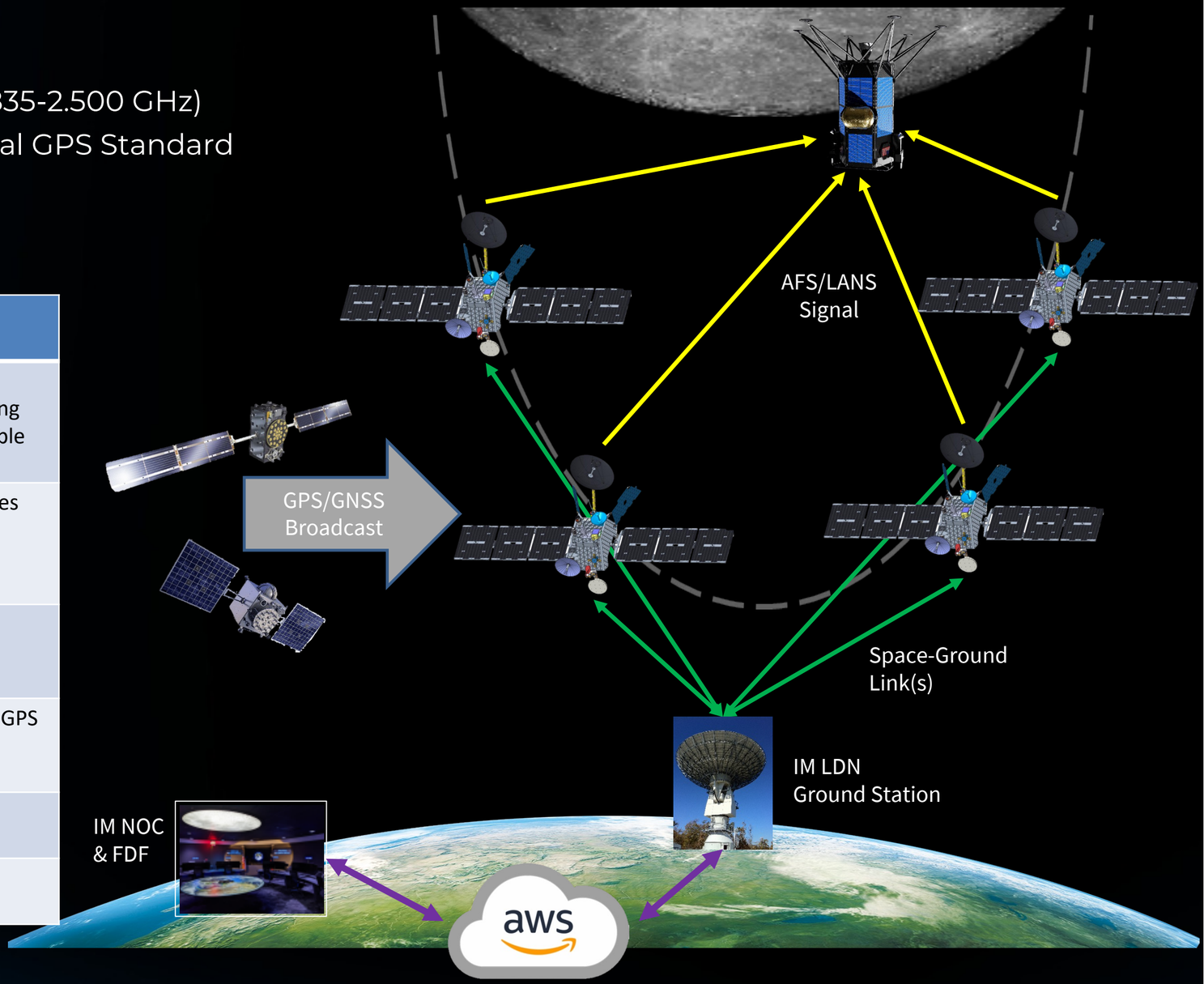


# PNT SERVICES
# AFS/LANS

- One-way, “GNSS-Like” signal operating at S-Band (2.2835-2.500 GHz)
- Better navigation and timing accuracy than the original GPS Standard Positioning Service (SPS) requirements

| PERFORMANCE METRIC | GPS SPS (1993) | AFS / LANS (2025) | REMARKS |
|---|---|---|---|
| Position Accuracy (95%) | ≤ 100 m (95%) | ≤ 100m (LLO) ± 10m (Surface) | Per LCRNS SRD. AFS SISE includes all position & timing broadcast errors; comparable metric |
| Velocity Accuracy (1σ) | ≤ 0.3 m/s (95%) | ≤ 0.01 m/s (1 cm/s) | Per LCRNS SRD. AFS provides much tighter velocity from coherent dual frequency tracking |
| Timing Accuracy (1σ) | ≤ 340 ns (~102 m) | ≤ 6 ns (~2 m) | Derived from SISE time component; LRT reference |
| Signal-in-Space Range / Rate Error (SISRE/SISRRE) | ≤ 33 m ≤ 0.04 m/s (95%) | ≤ 9 m ≤ 0.0008 m/s (95%) | AFS goal similar to original GPS SISRE threshold |
| User Geometry (GDOP) | 4-12 Typical | 3-6 in Service Volume | AFS modes positioned for regional lunar coverage |
| Service Availability | ≥ 99.0% (Global) | ≥ 98.0% (Per Service Volume) | Comparable for sustained service continuity |

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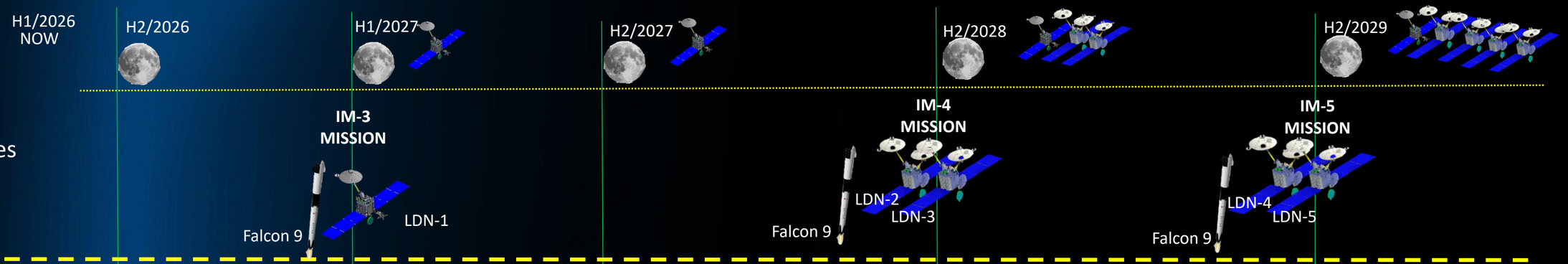
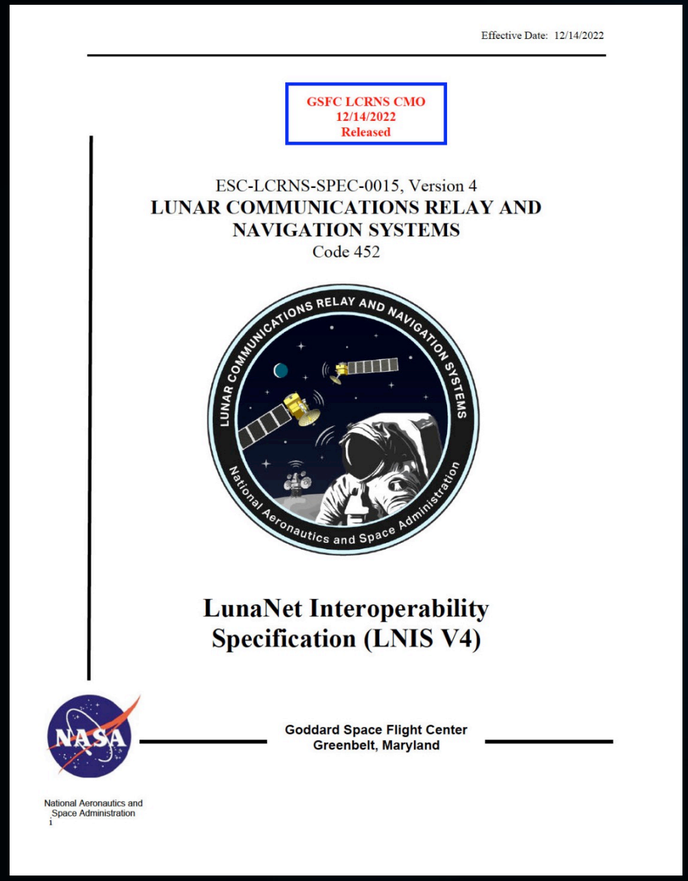
# INTUITIVE MACHINES LUNAR ARCHITECTURE AND SERVICES




Projected timelines are subject to change based on program execution and mission needs.

# LNIS IMPLEMENTATION

- IM's Lunar Data Network implements the internationally coordinated LunaNet architecture
  - Modulation/Coding specifications (LNIS)
  - Spectrum utilization (LNIS)
  - User Signal Structure (AD1)
  - Measurement Schema (AD2)
  - Detailed Message Definition Document (AD3)
  - Lunar Time System & Reference Frame Standard (AD5)
  - Lunar Data Services Standard (AD6)



Effective Date: 12/14/2022

GSFC LCRNS CMO
12/14/2022
Released

ESC-LCRNS-SPEC-0015, Version 4

**LUNAR COMMUNICATIONS RELAY AND NAVIGATION SYSTEMS**

Code 452

**LunaNet Interoperability Specification (LNIS V4)**

NASA

National Aeronautics and Space Administration

**Goddard Space Flight Center**
**Greenbelt, Maryland**

# Questions and any additional topics not covered in this presentation

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