Working Group: Enhancement of GNSS Performance, New Services and Capabilities

► Joint Working Group Session on Lunar Positioning Navigation and Timing (PNT), 25 - 26 June 2024, Vienna, Austria (Hybrid Format)

月測位（Lunar PNT）

Working Group Systems, Signals and Services

► Workshop on Low Earth Orbit (LEO) Positioning Navigation and Timing (PNT) Systems, 26 - 27 June 2024, Vienna, Austria (Hybrid Format)

地球低軌道測位（LEO PNT）

Joint Lunar PNT Session at ICG Intersessional held on 25th and 26th June in Vienna

Day 1

<u>**Confirmed Presentations**</u>:

- **LNIS PNT WG**: LunaNet: Interoperability for Lunar PNT, Cheryl Gramling (NASA)
- **USA**: Lunar PNT System Update, Speaker: Cheryl Gramling (NASA)
- **USA**: Lunar GNSS Receiver Experiment (LuGRE), Speaker: Joel Parker (NASA)
- **Europe**: Moonlight LCNS and Lunar Pathfinder: European contribution to lunar Communication and Navigation Services, Speaker: Dr Javier Ventura-Traveset, Moonlight Programme Navigation Manager (ESA)
- **Japan**: Japan Lunar Navigation Satellite System (LNSS) and Its Contribution Towards Lunar Augmented Navigation Service, Speaker: Masaya Murata (JAXA)
- **China**: The Envision of the Earth-Moon and Deep Space Communication-Navigation-Remote Sensing Integrated Constellation System, Speaker : HE Xiongwen (CAST)
- **China**: Verification of BDS SSV and Analysis of BDS/GNSS Application in Lunar Vicinity, Speaker : WANG Yanguang (CAST Xi'an)
- **India**: Lunar Pseudolite system, Speaker: Ashish Shukla (virtual)

LunaNet: Interoperability for Lunar PNT

Presented by: Cheryl Gramling, NASA

Contributors:

Juan Crenshaw, NASA

Floor Melman, ESA

Richard Swinden, ESA

Masaya Murata, JAXA

June 25, 2024

International Committee on GNSS

Intercessional

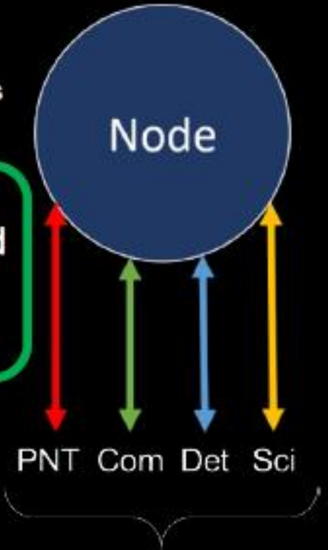
Vienna, Austria

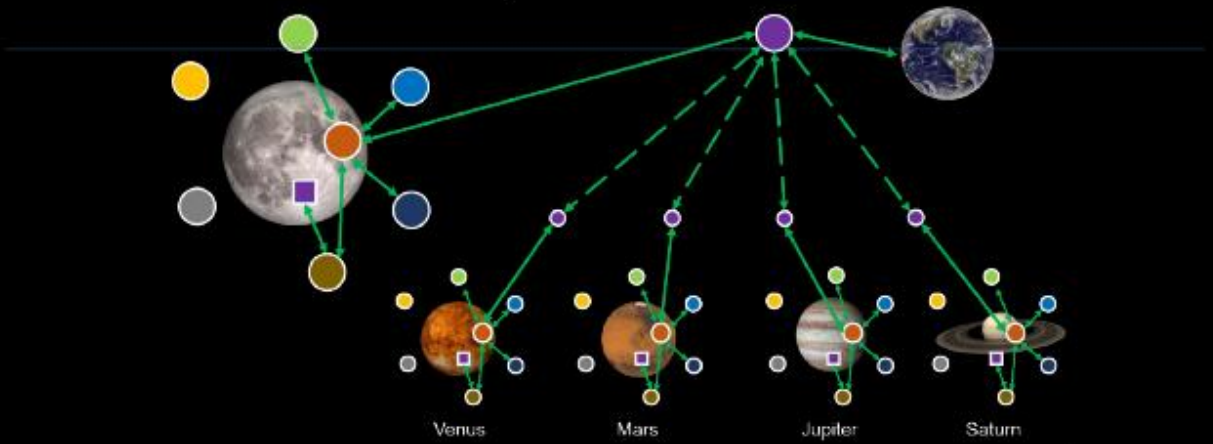
LunaNet Overview

- A flexible scalable architecture for providing communications and navigation services to all lunar missions
- Disaggregated approach allows for phased implementation of infrastructure as driven by user needs and technology developments
- Architecture implementation comprised of International and Commercial interoperable lunar surface, lunar orbiting, and earth-based elements
- Incorporates in-situ capabilities to detect events and distribute situational alerts
- Is fully compatible with and promotes future deployments at Mars or any other destination

LunaNet Service Types

1. **Communications Services (Com):** Data transfer services capable of moving addressable and routable data units between nodes in a single link or over a multi-node, end-to-end path via communications or networking services.
2. **Position, Navigation, and Timing Services (PNT):** Services for position and velocity determination, and time synchronization and dissemination. This includes search and rescue location services.
3. **Detection and Information Services (Det):** Services providing detection of events in order to generate timely alerts for human and asset safety and protection. These services publish other beneficial information to users as well.
4. **Science (Sci):** Services that use the RF and/or optical capabilities of the node as a science instrument or part of an instrument.





Just as the Internet and GNSS have transformed our lives on Earth, LunaNet will transform lunar science and exploration.

Lunar Systems Relationships

LunaNet

Framework for Standardized Interoperable Services, umbrella under which many providers collectively work.
Architecture **originally documented by IOAG Lunar Communications Architecture WG.**
Interoperability defined in a ***specification*****.**

Lunar Comm. Relay and Navigation System (LCRNS)

NASA's instantiation of LunaNet Services– a LunaNet Service Provider (LNSP)

Currently scoped for Initial Operating Capability

Moonlight

ESA's instantiation of LunaNet Services

Lunar Navigation Satellite System (LNSS)

Japan's instantiation of LunaNet Services

Others

e.g. other orbiting systems, 3GPP (surface cell towers), users

Lunar Reference System (LRS) Components
(includes Time)

A canonically defined set of components for consistent, accurate, and safe navigation.

Interoperability defined in Applicable Document 5 (AD5).

LunaNet Interoperability Specification Status

- LNIS Draft Version 5 *and* associated document LunaNet Signal-In-Space Recommended Standard - Augmented Forward Signal (AD1)* provided for public comment 1 September, 2023.
  - Comments received 1 December, 2023.
  - LNIS Working Groups dispositioned comments collectively among the three agencies.
  - Document updates currently underway, focusing on near-term needs for required services
    - Address comments
    - Confirm parameters based on analysis
- Future LNIS updates to complete LunaNet 1.0 specification that covers near term needs.

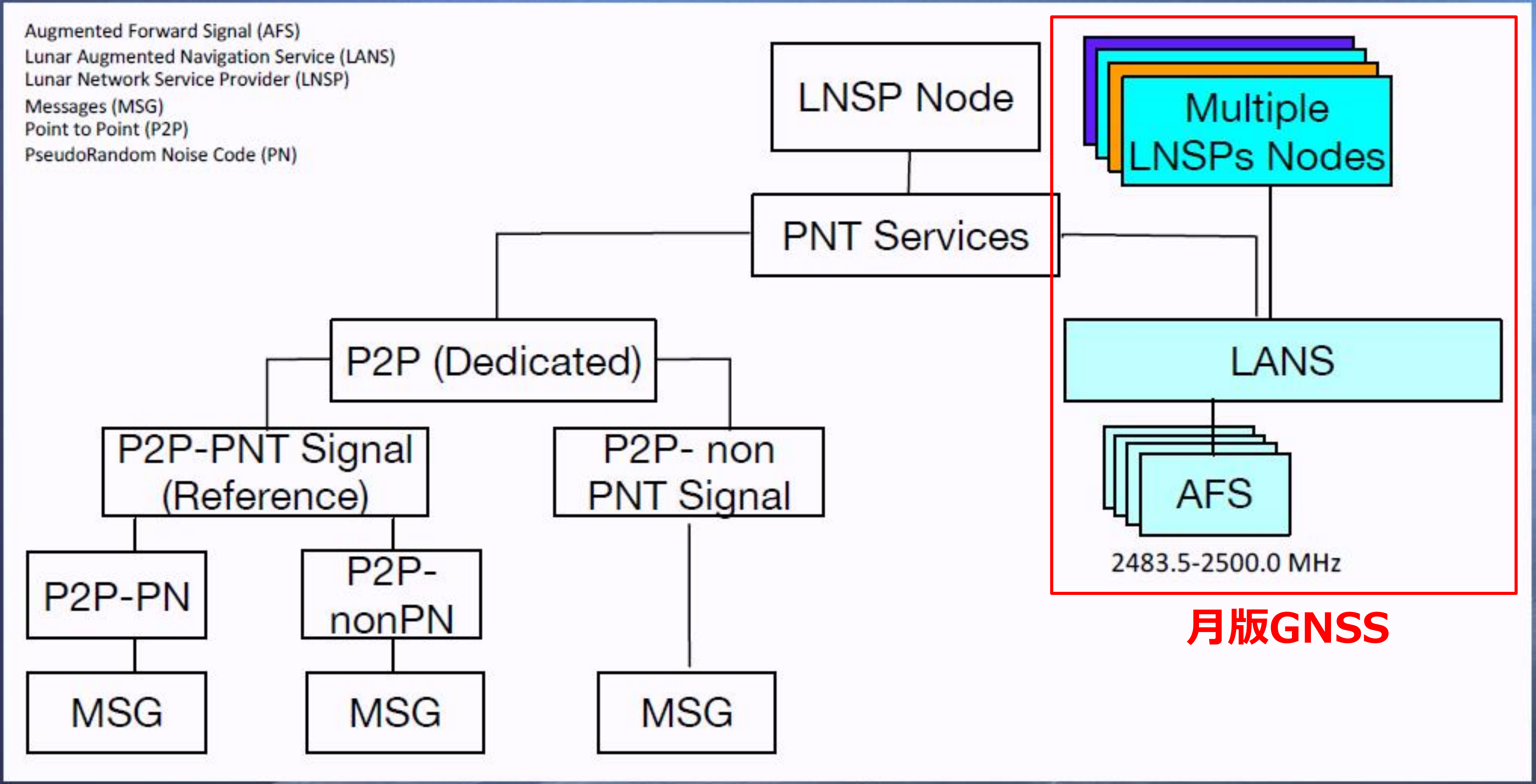
LunaNetのnear-term needsをカバーするLunaNet 1.0

LNIS version 5 and LSIS version 1 are available in Draft form.
https://www.nasa.gov/directorates/heo/scan/engineering/lunanet_interoperability


South Pole Region Service Volume

* Technical paper and presentation available in ION GNSS+ 2023 proceedings: https://www.ion.org/gnss/abstracts.cfm?paperID=12341

LunaNet Framework PNT Services



PNT Services rely on definition, adoption, and maintenance of common lunar geodetic and time systems.

NASA's LunaNet Lunar Communications and PNT

Presented by: Cheryl Gramling, NASA

Contributors:

Juan Crenshaw, NASA

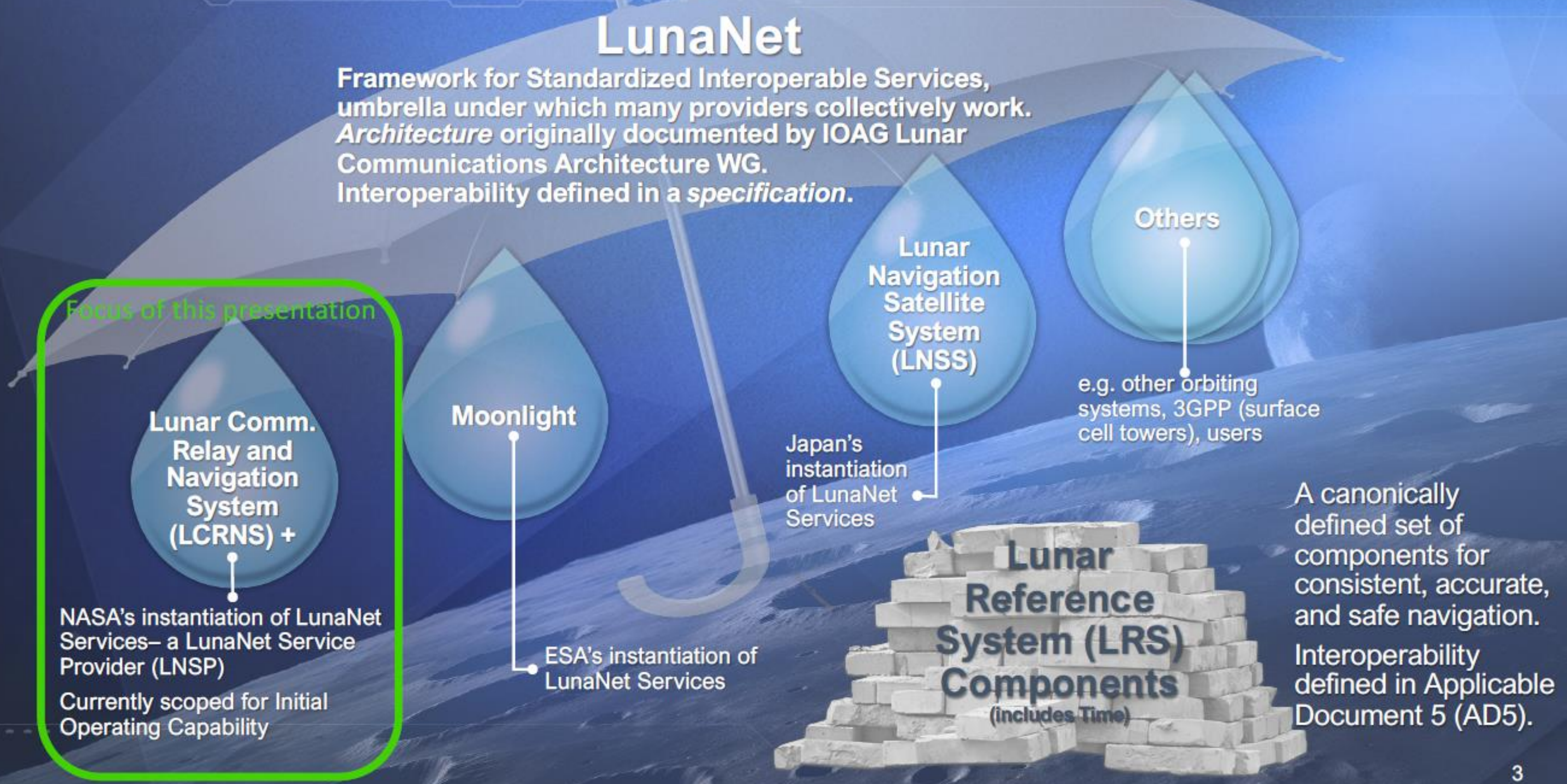
June 25, 2024

International Committee on GNSS

Intercessional

Vienna, Austria

Lunar Systems Relationships



Initial Capability Defined for **LCRNS**

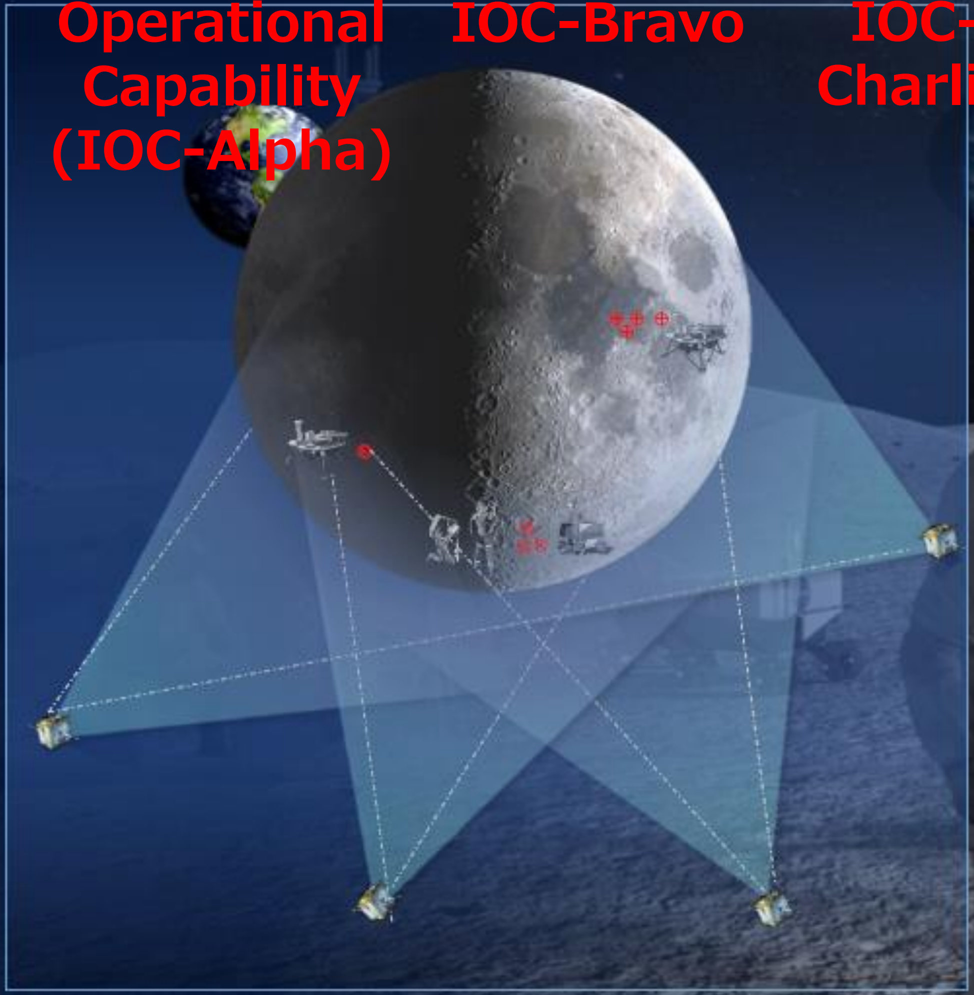
2026年9月に
Initial
Operational
Capability
(IOC-Alpha)

2028年中旬
までに
IOC-Bravo

2029年9月
までに
IOC-
Charlie

- IOC phase will begin Sept 2026 with IOC-Alpha with a minimum of one Augmented Forward Signal (AFS) broadcast over the South Pole region.
- IOC-Bravo by mid-2028 with a minimum of two AFS over the same South Pole region.
- Service continues over an expanded South Pole volume with IOC-Charlie broadcasting a minimum of four AFS by Sept 2029, also meeting a requirement for GDOP for a limited portion of an Earth day.

- The LCRNS AFS will comply with the LunaNet Interoperability Specification.
- LCRNS orbit(s) will be defined by the service provider and are expected to meet the Signal-in-Space-Error.
- It is expected that LCRNS will be capable of providing two-way measurements from Point-to-Point signals.
- Service delivery is reliant on defined lunar geodetic system and lunar time.



LCRNS IOC-C **Service Volume**

LCRNS IOC-C Nav Service Volume

South Pole Service Volume
(-90° up to -75° latitude, 200 km altitude);
AFS/LANS available with GDOP <6 for 40% of Earth Day;
P2P (PNT-over-comm) links expand the offerings.

FUTURE Minimum Service Volume

Full lunar nav global service volume;
Continuous service;
Global capability.

ICG International Committee on Global Navigation Satellite Systems

ICG Intercessional Meeting
Joint Working Group Session on Lunar PNT

Moonlight: LCNS, and Lunar Pathfinder

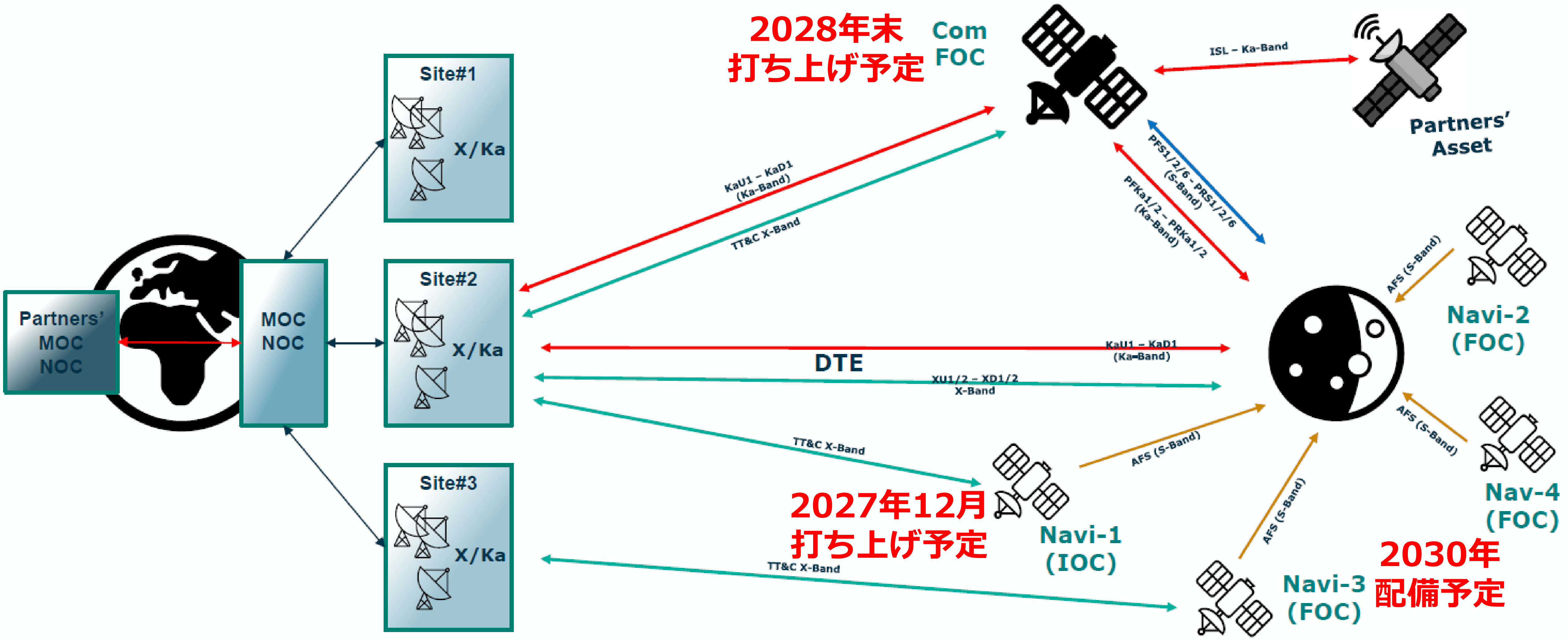
European contribution to lunar Communication and Navigation Services

Dr Javier Ventura- Traveset
Moonlight-Navigation Manager
European Space Agency

esa Moonlight

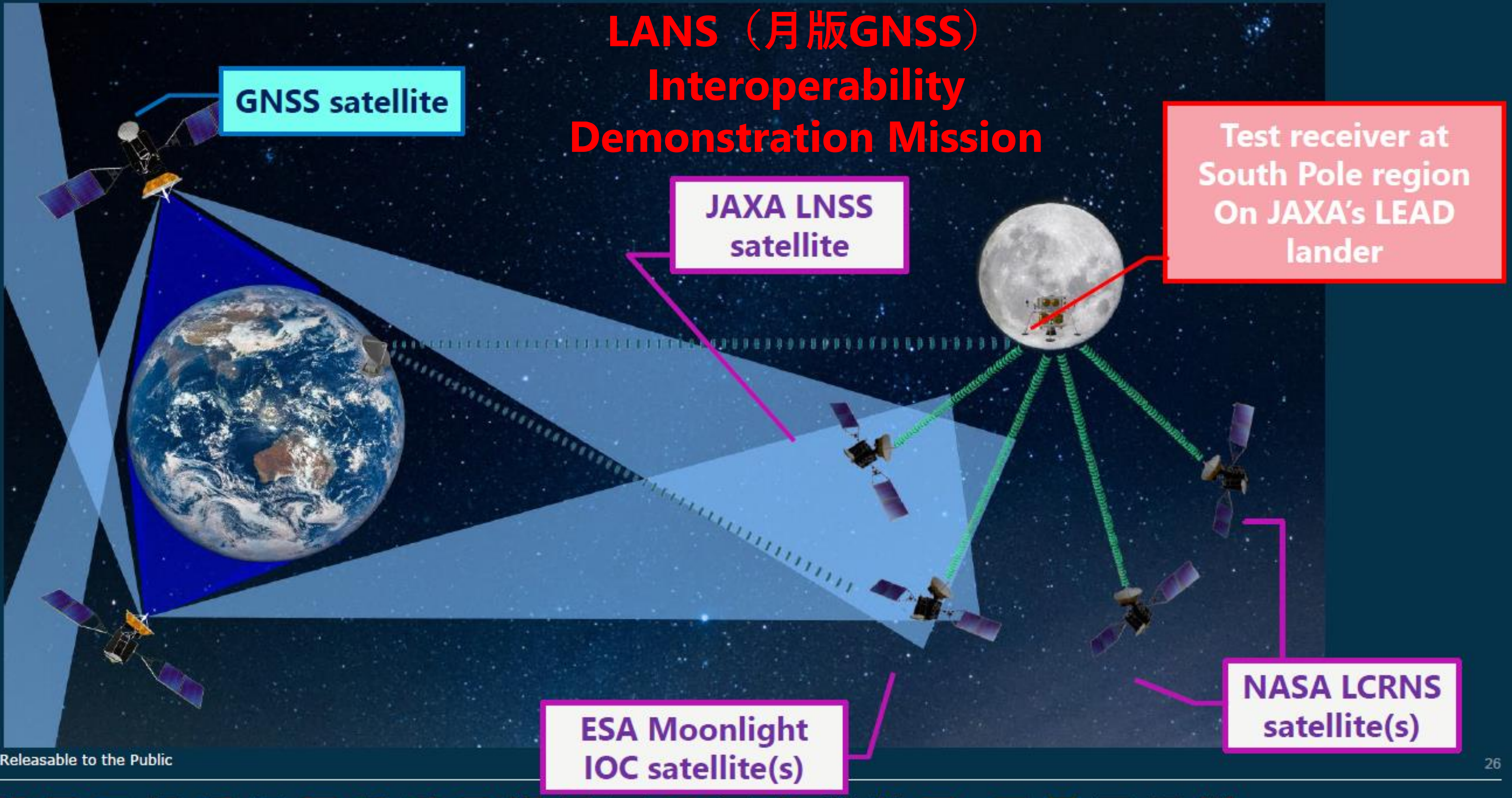
European Roadmap under coordination with ESA

Moonlight: Mission Architectural Concept (notional)



Links are named in-line with LunaNet spec

First-ever lunar PNT interoperability demonstration planned for 2028
ESA / NASA / JAXA: Towards an international LANS System



The Envision of Earth-Moon and Deep Space Communication-Navigation-Remote Sensing Integrated Constellation System

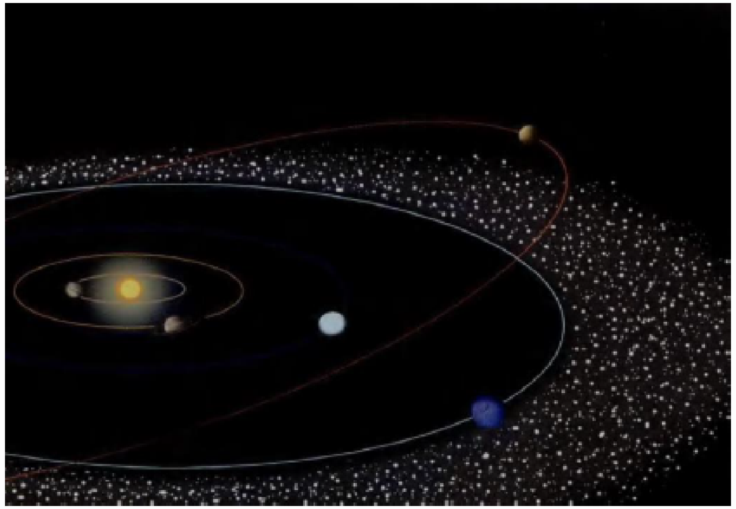
Beijing Institute of Spacecraft System Engineering, CAST

Xiongwen He   Hui Yang

June 2024

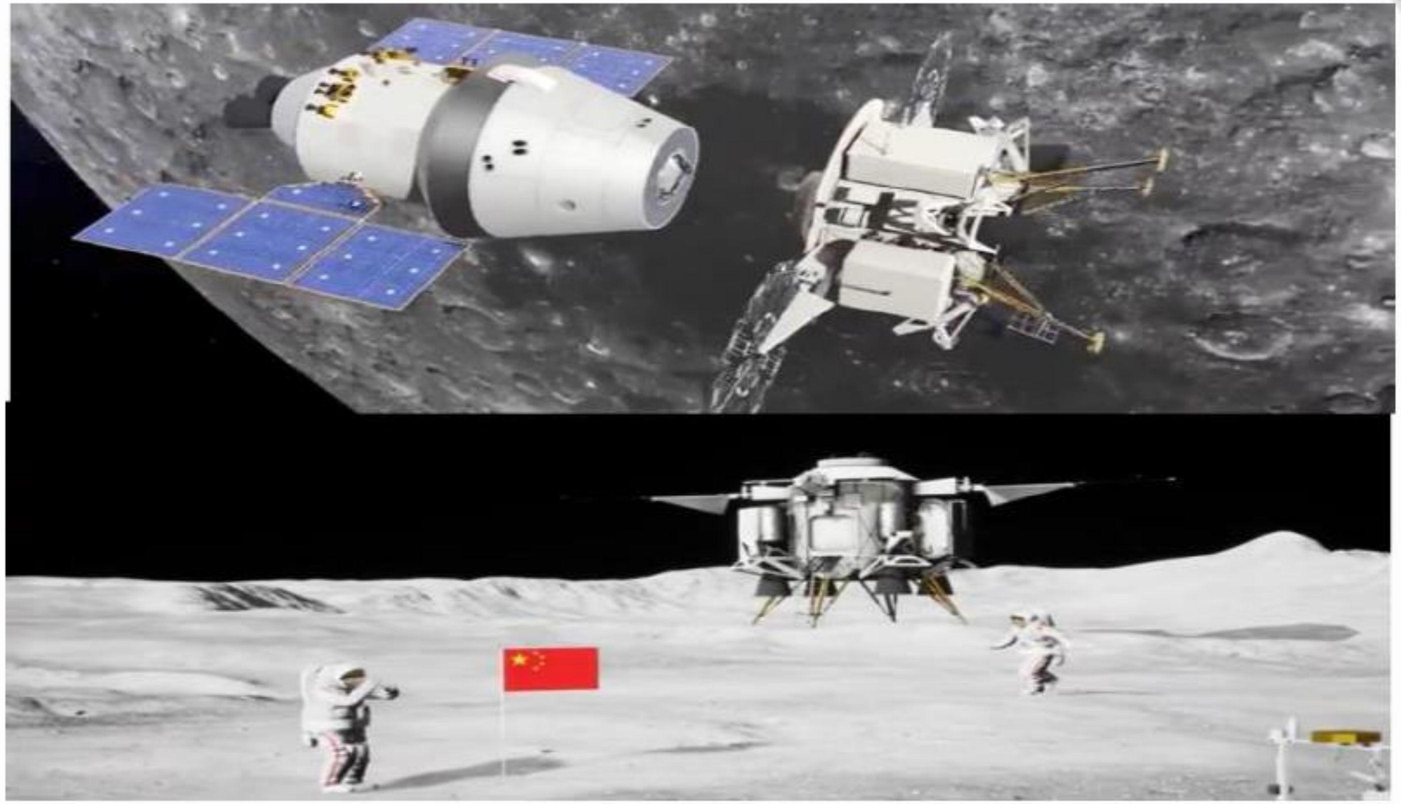
Current Situation and Envision of Deep Space Exploration in China

- In the coming year, China will continue to carry out Lunar exploration project, such as high-precision Lunar polar region landing ,and carry out the construction of International Lunar Research Station(ILRS).
- China will continue to carry out planetary exploration project, complete missions like sampling and returning from Mars, exploring the Jupiter scope, sampling from near-Earth asteroids, exploring the comets belt, and demonstrate plans for exploring the margin of solar system.



Current Situation and Envision of Deep Space Exploration in China

- **Before 2030, China will achieve a manned landing on the moon, and in the long term, it will further promote the development of new industries such as the utilization of in-situ lunar resources.**

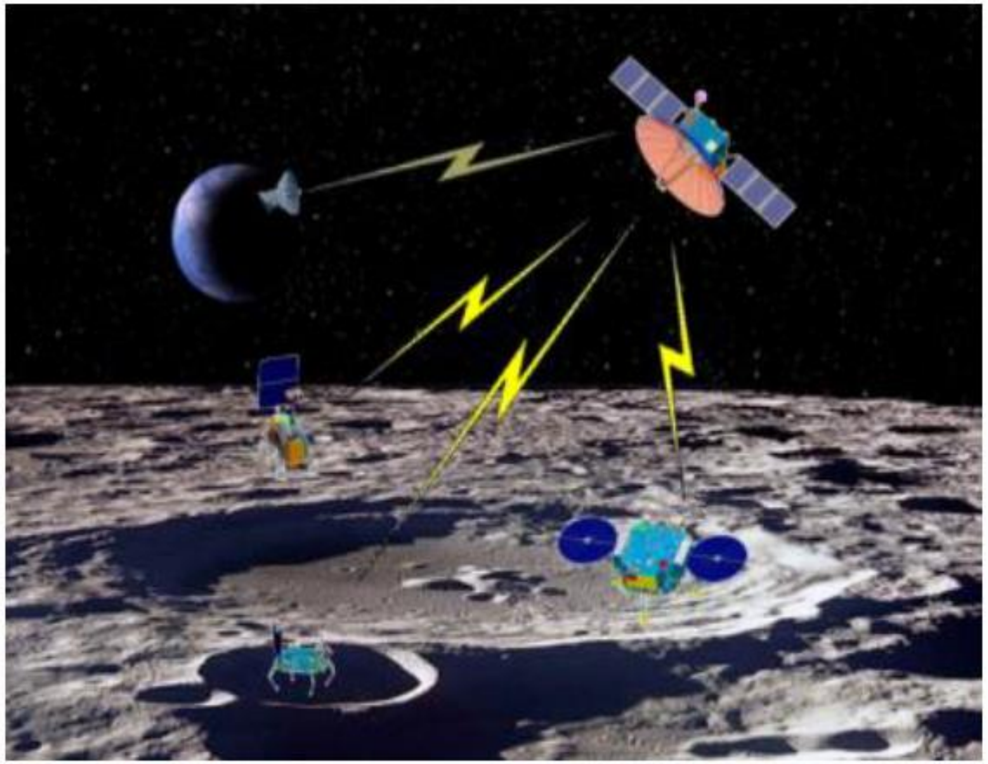


2.2 Analysis of existing GNSS and Lunar Communication capabilities

鵲橋（じゃっきょう）2号

(2) Capability of Lunar relay communication

- In March 2024, China launched a new lunar relay satellite, QueQiao-2 which operates in the lunar elliptical frozen orbit and supported Chang'e-6 , will also support follow-up missions and carry out a serial of experiments.



3.2 Envision of Prospective Scheme

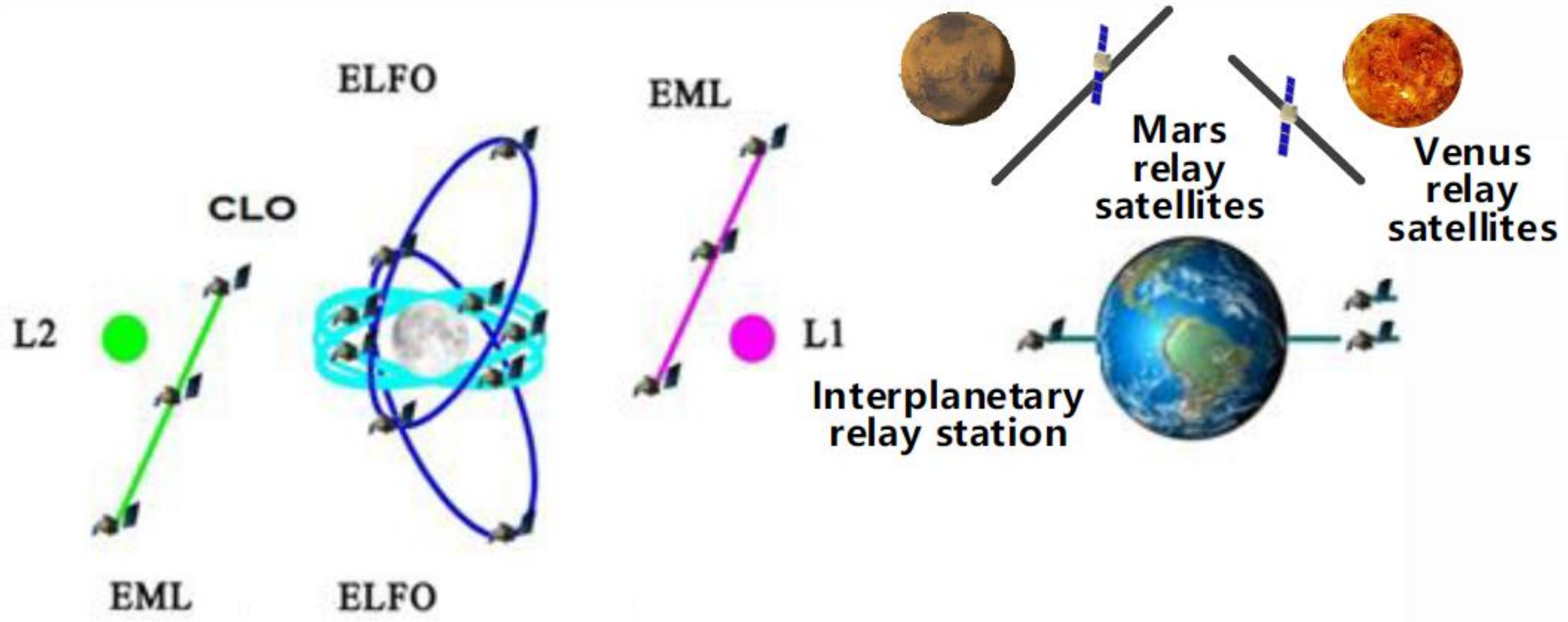
2、 Physical Architecture

Elliptical Lunar Frozen Orbit

■ Support users on the lunar surface and orbit through ELFO and CLO satellites.

■ Build backbone link between Earth and Moon through Interplanetary Relay Station and EML satellites.

■ Build backbone link between Earth and Mars/Venus through Interplanetary Relay Station and Mars/Venus relay satellites.



Pseudolite System for Lunar PNT

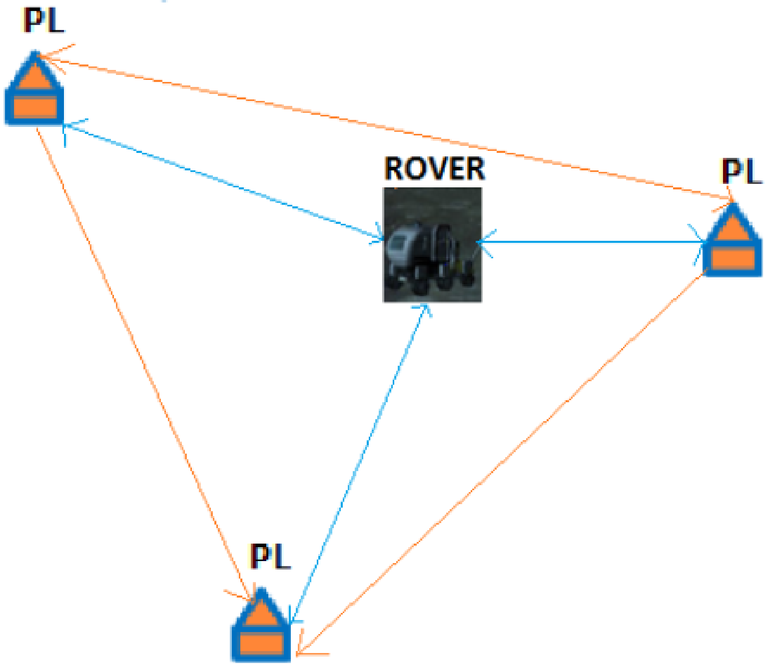
ICG Intersessional Meeting

Vienna, 25 June 2024

Dr. Ashish K Shukla
SAC- ISRO, INDIA

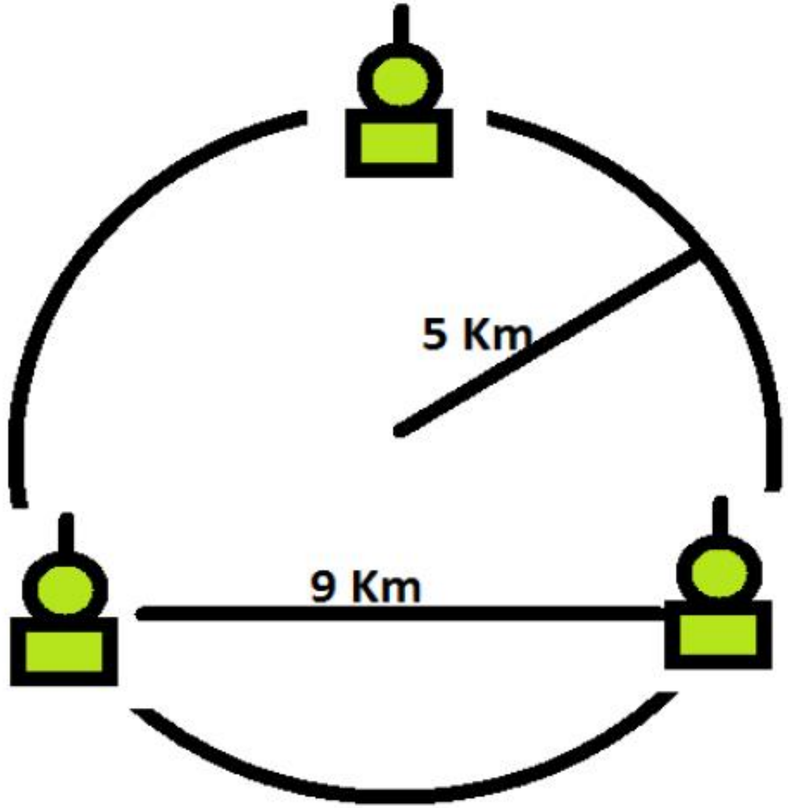
Relative Reference Frame

- In the absence of any Lunar navigation system, standalone Pseudolite System is one of the possible options.
- Pseudolite **relative Self-Positioning** using Bi-directional Ranging in case absolute locations of Pseudolite transceivers are not available.
- Autonomous system & independent of any satellite based system for Lunar PNT.



Configuration , Service Area & Targeted Accuracy

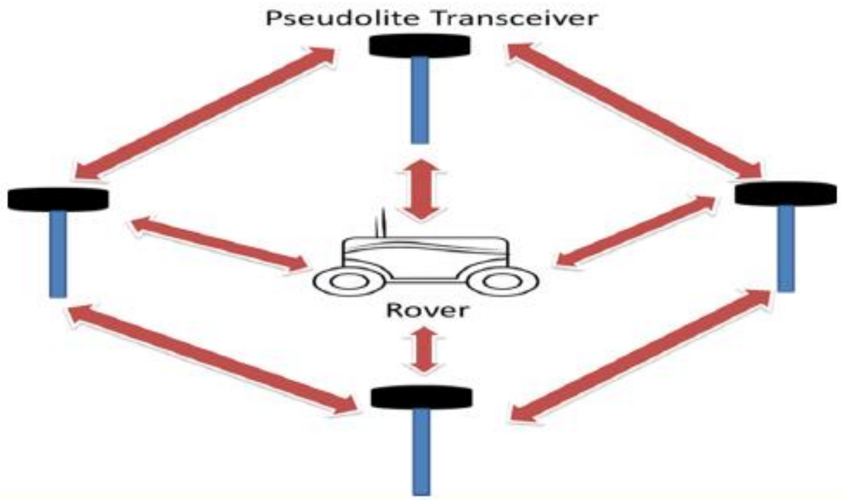
- A circular area with radius of 5 km is proposed to be the considered as the service area.
- Minimum 3 Pseudolite Transceivers are required for 2D position.
- Maximum distance (LoS) between Pseudolite Transceiver & Rover is 10 km.
- Distance between the Pseudolites is around 9 Km.

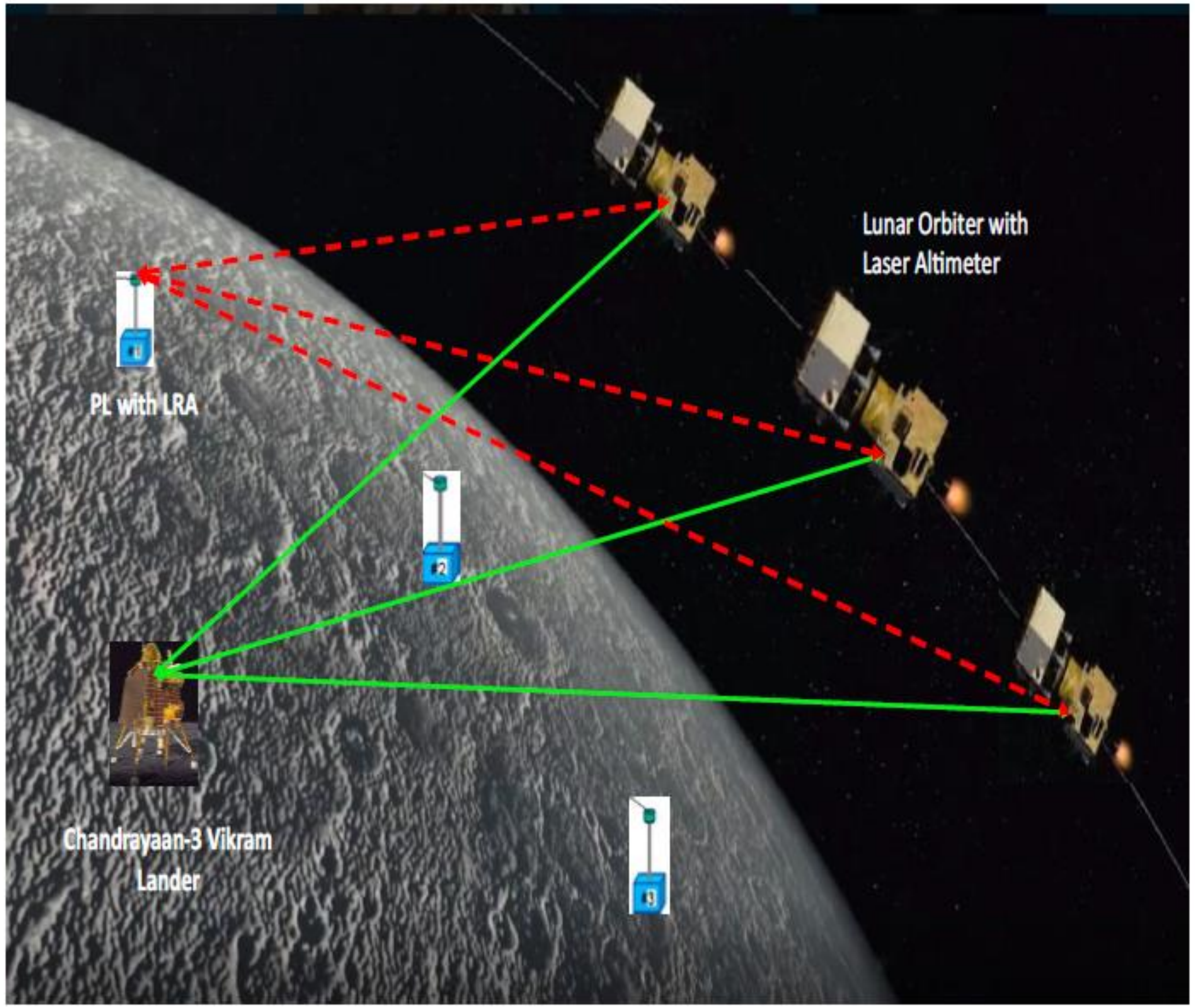


2D Position Accuracy (m)	Service Area
Sub- metre Level	10 Km LoS

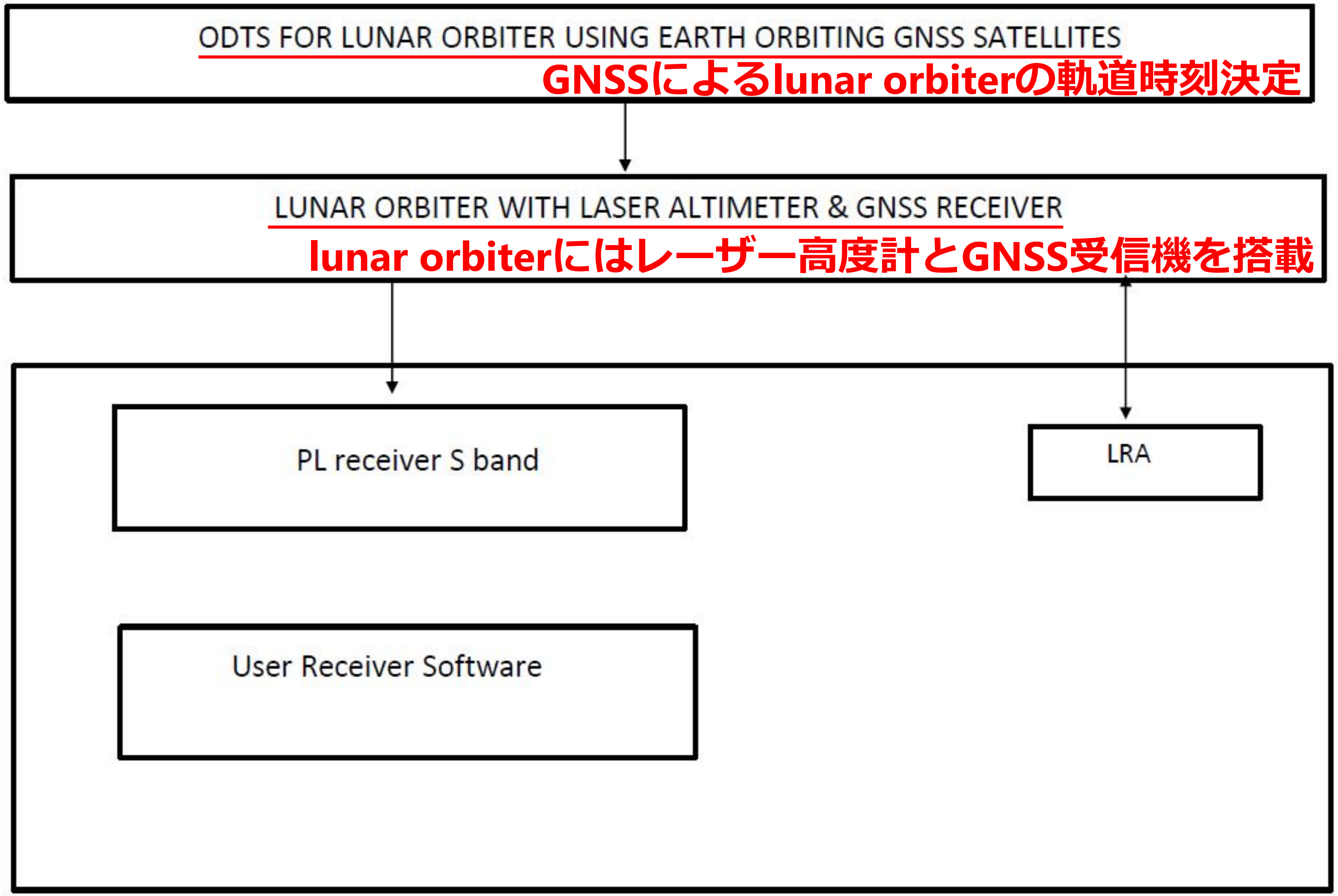
Absolute Positioning using Pseudolite System with LRA, orbiter & GNSS satellites

- Location determination of Pseudolite transceivers can be done with Laser Retro-Reflector Array (LRA) on-board lunar lander.
- A small LRA (shown as placed on Chandrayaan-3 lander) on the Moon can be detected by an orbiting Laser Altimeter on-board lunar orbiter.
- Once Pseudolite transceiver locations are determined in lunar reference frame, absolute positioning of rover can be done using bidirectional ranging.





Absolute Location Determination of Pseudolite Transceiver



Day 2

1. **Lunar spectrum (30 minutes)** 月測位で使う周波数帯に関する議論
    - Lunar PNT Spectrum Overview and World Radio Conference update, Cathy Sham (NASA), Chair, Lunar Martian Spectrum Group, Space Frequency Coordination Group (SFCG) (virtual)

2. **Lunar reference frames & timing (1 hour)** 月測位で使う座標系・時系の議論

Topics: Approach, development status, challenges, cross-region collaboration/integration, approach to interoperability and compatibility

Presentations:

- Lunar Foundational Reference Systems and Time: LunaNet Perspective, Masaya Murata (JAXA), for the LNIS PNT WG
- USA Timing Policy Document Overview, Cheryl Gramling (NASA)
- Lunar Reference Frame and Time Reference, Werner Enderle (ESA)

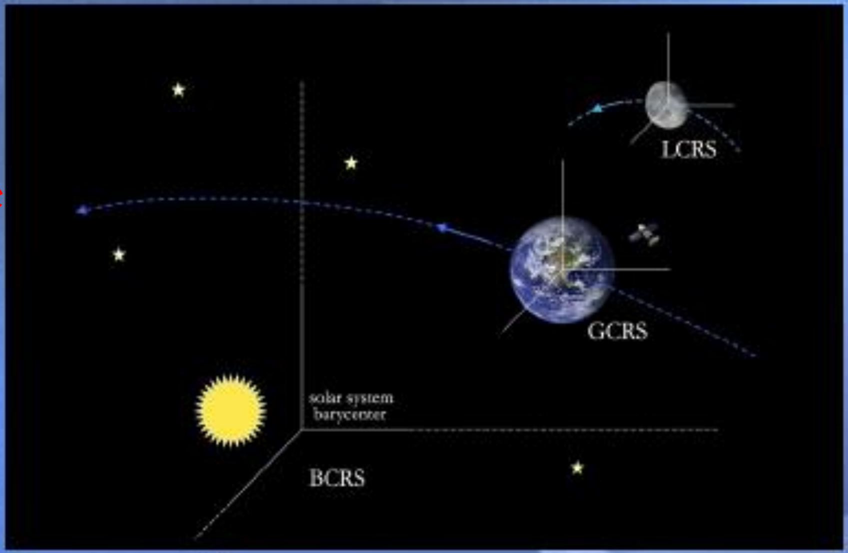
Lunar Reference Frame

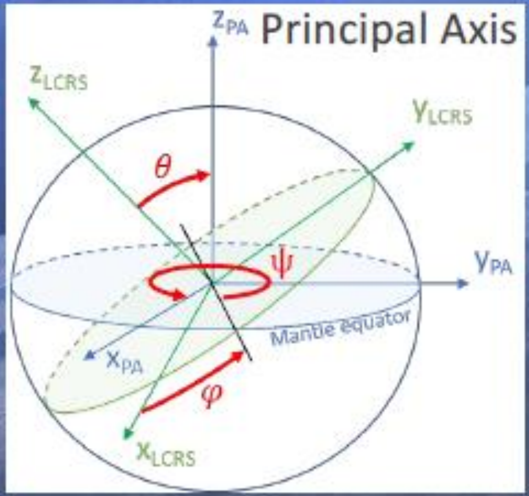
- **Inertial: Lunar Celestial Reference System (LCRS)** 月中心慣性座標系
  - Analog to locally inertial Geocentric Celestial Reference System that is realized by International Celestial Reference Frame (ICRF).

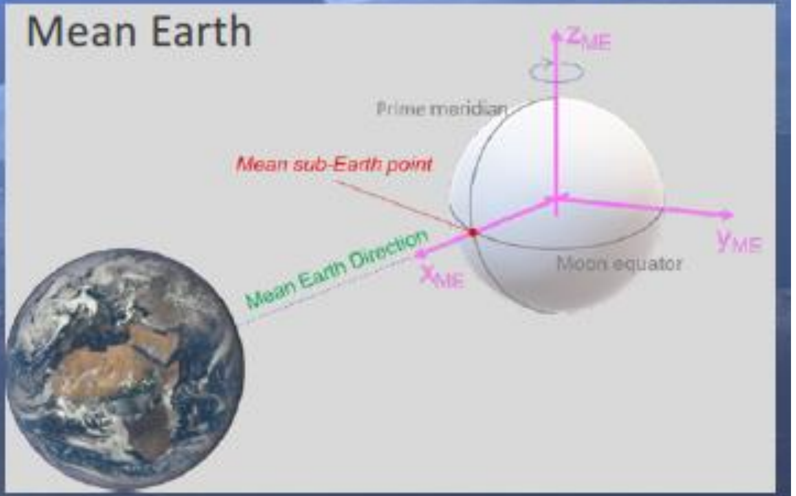
- **Body-Fixed: International Lunar Reference System (ILRS)** 月中心回転座標系
  - Would be realized by the International Lunar Reference Frame (ILRF).
  - Two currently established frames:
    - **PA**: The Principal Axes reference frame is connected to the moments of inertia of the body (and thus derived from the angular momentum vector); the system where the axes align to the directions of the three largest moments of inertia.
    - **ME**: The Mean Earth reference frame defines the z-axis as the mean rotational pole, and the prime meridian is defined by the mean Earth direction
  - A constant, three-angles rotation relates PA to the derived ME frame; the constants depend on the gravity field and a physical libration theory.
  - Differ by 860 m on the lunar surface.
  - The current ME definitions (used by LRO, etc) were established circa 2008, at the time of DE421, using pre-GRAIL gravity model LP150Q (Konopliv et al. 2001, Icarus).

Preference for Navigation (→ PA)

- *ILRF: Additional (including in-situ) observations likely to inform an improved frame in the future.*







Lunar Time

Following the GNSS paradigm, LunaNet PNT services will distribute time.

Options are under evaluation; and must consider both the provider and user aspects.

Considerations:

- what accuracy is required for navigation and science precision;
- which geoid should the time scale represent;
- are there aspects to be defined by convention;
- how to format time in the message;
- ensure the ability to refer time to UTC;
- make it easy to achieve consistency among community.

地球のGNSSと同様に、
LunaNetは月に時刻情報を提供する

Understanding of multi-body relativistic effects

Primary secular drift is ~58.7 microseconds/day from Earth Geocentric Coordinate Time (TCG) to Lunar Coordinate Time (TCL);

Periodic terms introduce additional variability.

座標系と同様に、月の時系に関する
国際的な議論が続いている

Consultation is underway with international subject matter experts in time systems and relativity.