



Lunar Spectrum Considerations

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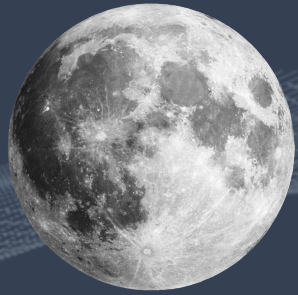
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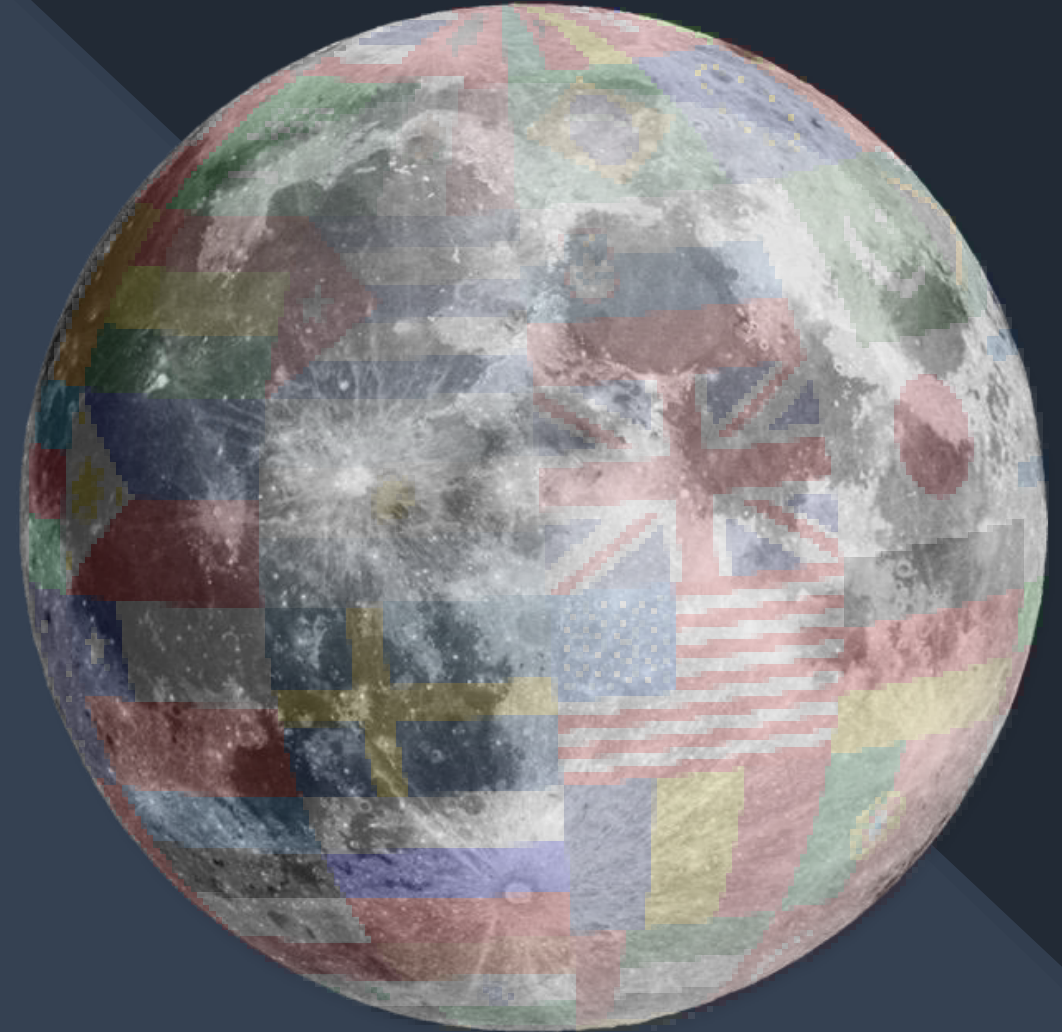


Space Frequency Coordination Group (SFCG) Overview

- A forum for civil space agencies (in addition to the ITU framework) to discuss, identify solutions in a flexible environment on frequency usages, regulatory/policies, mission specific coordination matters of mutual interests.
- Concerned with effective use and management of radio frequency bands that are allocated by the Radio Regulations of the ITU to Space Research, Space Operations, Earth Exploration Satellite, Meteorological Satellite, Inter-satellite, Radionavigation-satellite services
- Technical and administrative agreements by member space agencies are expressed through SFCG Resolutions, Recommendations, and Reports. SFCG member space agencies strive to conform with SFCG Resolutions/Recommendations/Reports to achieve mutual goals in space and support education and advocacy within their respective Administrations.
- Through liaison groups, SFCG collaborates with other organizations to support interoperability and spectrum compatibility (IOAG, CCSDS, IUCAF, IEEE, etc.)
- Lunar Martian Spectrum Group (LMSG), founded at SFCG-26 (2006), works to coordinate and agree spectrum planning and usage for the Moon and Mars

Lunar Spectrum Planning: Opportunities & Challenges

- The Moon offers unique scientific value to radio astronomers; we must balance opportunities to explore it with the need to protect and preserve it.
- Aim to define a framework of mutually agreed-upon standards to be applied by users and service providers in a cooperative network supporting missions on and around the Moon
- **Selected issues for ICG Consideration:**
 - Protection of Radio Astronomy Observations in the Shielded Zone of the Moon
 - Spectrum for Lunar Region Positioning, Navigation, and Timing (PNT) Services & Search and Rescue (SAR)
 - Other SFCG Lunar Martian Spectrum Group (LMSG) Outputs of Interest

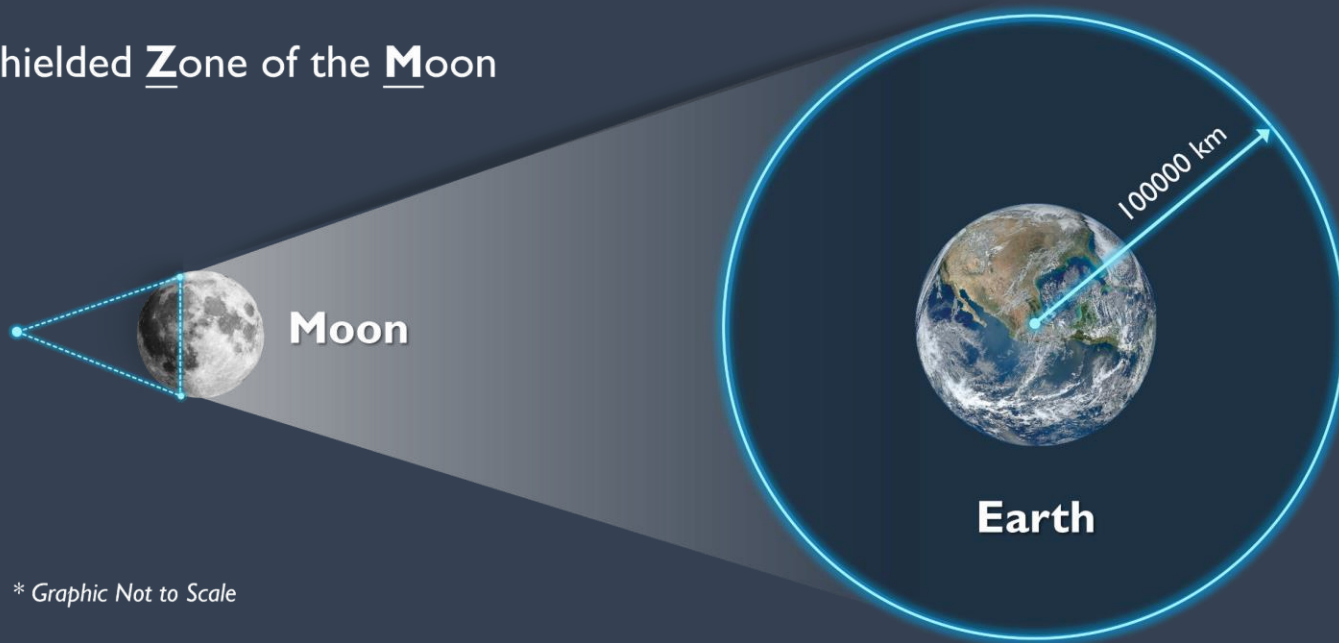


Protection of Radio Astronomy Observations in the Shielded Zone of the Moon

According to the ITU Radio Regulations, the Shielded Zone of the Moon (SZM) is as follows:

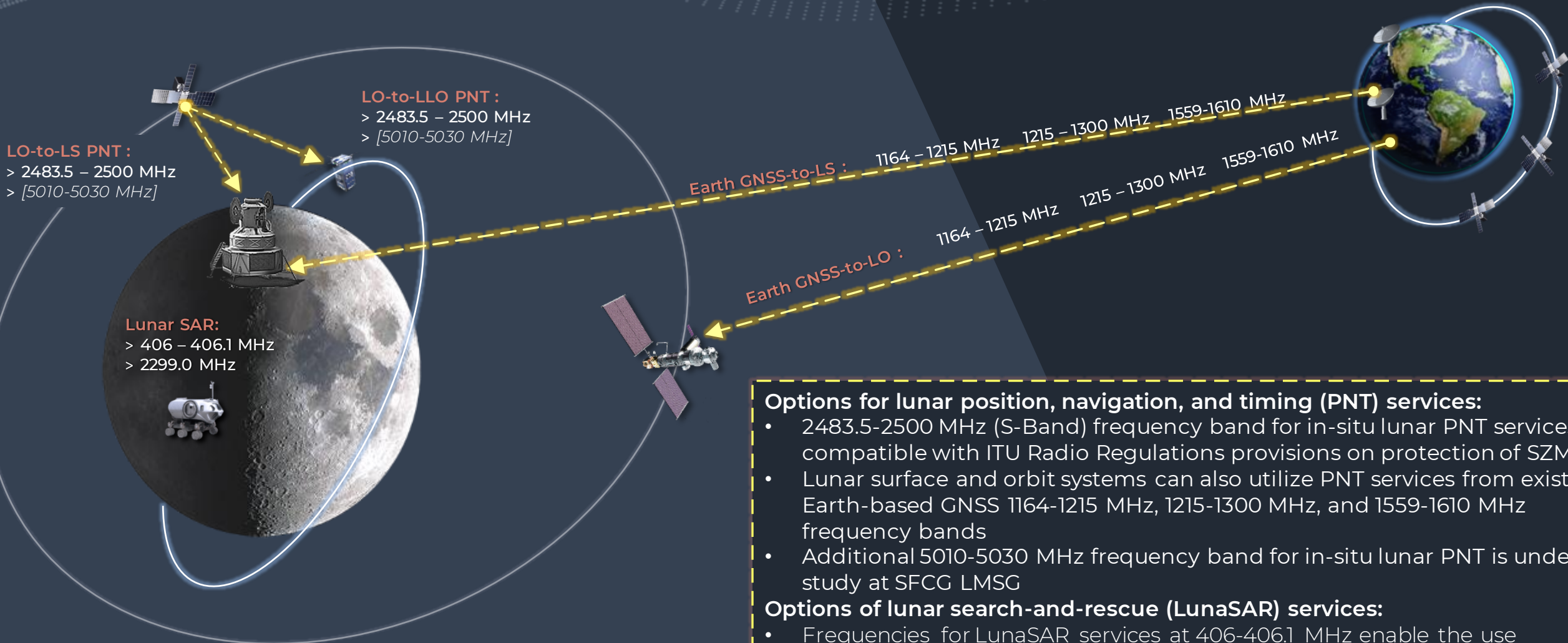
- Isolated from radio emissions from the Earth as well as satellites orbiting the Earth
- **A very low-noise environment**, ideal for **enabling observations in frequencies not possible from the Earth/Earth orbits**.
- **ITU Radio Regulations Article 22** protection extends to the entire radio spectrum; specific frequencies for space research data communications are permitted.
- ITU-R Recommendation RA.479-5, “**Protection of frequencies for radioastronomical measurements in the shielded zone of the Moon**”, recommends that frequencies below 2 GHz be reserved for the use of radio astronomy systems in the SZM

Shielded Zone of the Moon



* Graphic Not to Scale

Lunar Electromagnetic Spectrum Architecture Considerations for Lunar PNT & SAR Services



LO-to-LS PNT :
> 2483.5 – 2500 MHz
> [5010-5030 MHz]

LO-to-LLO PNT :
> 2483.5 – 2500 MHz
> [5010-5030 MHz]

Lunar SAR:
> 406 – 406.1 MHz
> 2299.0 MHz

Earth GNSS-to-LS : 1164 – 1215 MHz 1215 – 1300 MHz 1559-1610 MHz
Earth GNSS-to-LO : 1164 – 1215 MHz 1215 – 1300 MHz 1559-1610 MHz

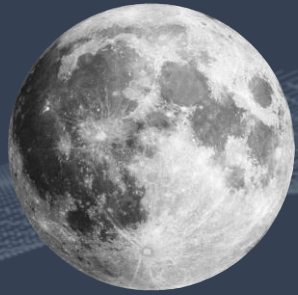
Options for lunar position, navigation, and timing (PNT) services:

- 2483.5-2500 MHz (S-Band) frequency band for in-situ lunar PNT services is compatible with ITU Radio Regulations provisions on protection of SZM
- Lunar surface and orbit systems can also utilize PNT services from existing Earth-based GNSS 1164-1215 MHz, 1215-1300 MHz, and 1559-1610 MHz frequency bands
- Additional 5010-5030 MHz frequency band for in-situ lunar PNT is under study at SFCG LMSG

Options of lunar search-and-rescue (LunaSAR) services:

- Frequencies for LunaSAR services at 406-406.1 MHz enable the use of existing terrestrial services, but would be limited to use outside the SZM
- SFCG has agreed services at 2299 MHz to support emergency services anywhere around the Moon.

S-band lunar PNT and LunaSAR bands added to REC SFCG 32-2R5



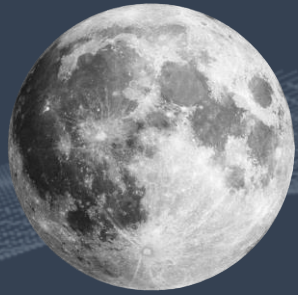
Compatibility between S-Band Lunar PNT & SAR and Lunar Surface Communications

- **PNT receivers are highly susceptible to performance degradation due to unintended in-band signals**
 - Need to manage out-of-band emissions (OOBE) from lunar wireless communications systems operating below 2483.5 MHz and above 2500 MHz into 2483.5-2500 MHz lunar PNT frequency range
- **Design of the PNT signals is equally critical in ensuring the performance integrity of lunar surface communications systems in adjacent bands**
 - Transmitted PNT signal energy must fit within the 2483.5-2500 MHz range
 - User PNT receiver's RF front end must be designed to achieve sufficient attenuation of energy outside of the 2483.5-2500 MHz frequency range
- **Appropriate balance needed between OOBE limits for lunar surface wireless communications and in-situ lunar PNT service design features to permit both services to coexist**



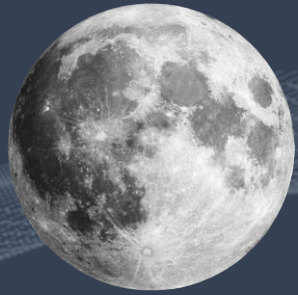
Spectrum for Lunar Region Positioning, Navigation, and Timing (PNT) Services

- The SFCG has studied compatibility in the lunar vicinity, and determined that the **2483.5 – 2500 MHz** band for lunar in-situ PNT services meets mission needs while complying with ITU Radio Regulations
- Additional frequency bands currently allocated to Radionavigation-satellite service are also candidates for continued SFCG studies for future capabilities in the lunar vicinity
- Includes continued study of **5010 – 5030 MHz** band for lunar in-situ PNT, taking into account special compatibility consideration wrt radio astronomy applications in the neighborhood of the **4990 – 5000 MHz** band and Article 22 provisions.
- GNSS (L-band) frequencies are not recommended for in-situ lunar PNT. Experiments to investigate navigation solutions via Earth-based **L-band** GNSS signals are planned to understand mission applications.



Recent SFCG Lunar/Martian Spectrum Group (LMSG) Outputs of Interest (1 of 2)

- **SFCG RES A 40-1, “Assistance in the Assignment of Frequencies to Missions in the Lunar Region”:**
 - Process to provide assistance with the selection of frequency assignments to SFCG Member Agencies and non-SFCG organizations for lunar missions
- **SFCG REC 41-1, “Efficient Spectrum Utilization for Space Research Systems in the Lunar Region”:**
 - Technical conditions for Earth-to-space and space-to-Earth links, as well as in-situ lunar links (space-to-space) and relay links
- **SFCG Provisional REC 42-1, “Frequency Channel Plan for In-situ Lunar Data Relay Satellites”:**
 - Support interoperability by defining dedicated frequencies in S-band for single access and multiple access services, and also S-band Prox-1 channels
 - Definition of Ka-band channels for in-situ lunar relay services is under study



Recent SFCCG LMSG Outputs of Interest (2 of 2)

- **SFCCG REC 29-2, “Frequency Assignment Guidelines for Active Remote Sensing in the Lunar Region”:**
 - Currently in forced recommendation includes science-focused frequencies for lunar exploration.
 - Work in progress to evaluate existing & proposed active remote sensing frequencies including compatibility with passive missions, including radio astronomy observations in the SZM.
- **SFCCG REC 22-1R4, “Frequency Assignment Guidelines for Communications in the Mars Region”:**
 - Ongoing activities on a major review, including frequencies for PNT services and Mars surface-to-surface links
 - Planned alignment with the Lunar Recommendation SFCCG REC 32-2
 - Initial considerations of spectrum regulations and practical actions to support moon-to-Mars exploration goals
- **SFCCG RES 23-5, “Protection of Radio Astronomy Observations in the Shielded Zone of the Moon”:**
 - SFCCG members will limit uses of active systems in the SZM as described by ITU RR Article 22, Nos. 22.22 through 22.25.
 - SFCCG members will coordinate the envisioned uses of active systems in the SZM with the Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science (IUCAF) through the SFCCG.

Way Forward



Technical Collaboration

- NASA is collaborating with partners on defining a lunar spectrum architecture for communications and navigation that balances lunar surface and lunar orbit activities, Earth-orbiting missions, and radio astronomy systems in the SZM



Forward-Looking Spectrum Strategy

- Planning for in-situ lunar communications services links
- Transitioning to 7/8 GHz and 23/26 GHz spectrum for DWE communications
- Identifying spectrum for in-situ lunar PNT services
- Planning for LunaSAR services for the safety of crews on the lunar surface
- Identifying appropriate frequency ranges and system characteristics for lunar surface communications networks



Careful Planning

- Appropriate balance needed between out-of-band emission limits for lunar surface wireless communications and in-situ lunar PNT service design features to permit both services to coexist



Backups

Lunar Spectrum Environment

- Humans are returning to the Moon in cooperation across government, private industry and international partners

- Advanced spectrum architecture planning through active regulatory engagement has facilitated effective coordination across government, commercial, and international stakeholders to manage the complex spectrum environment.

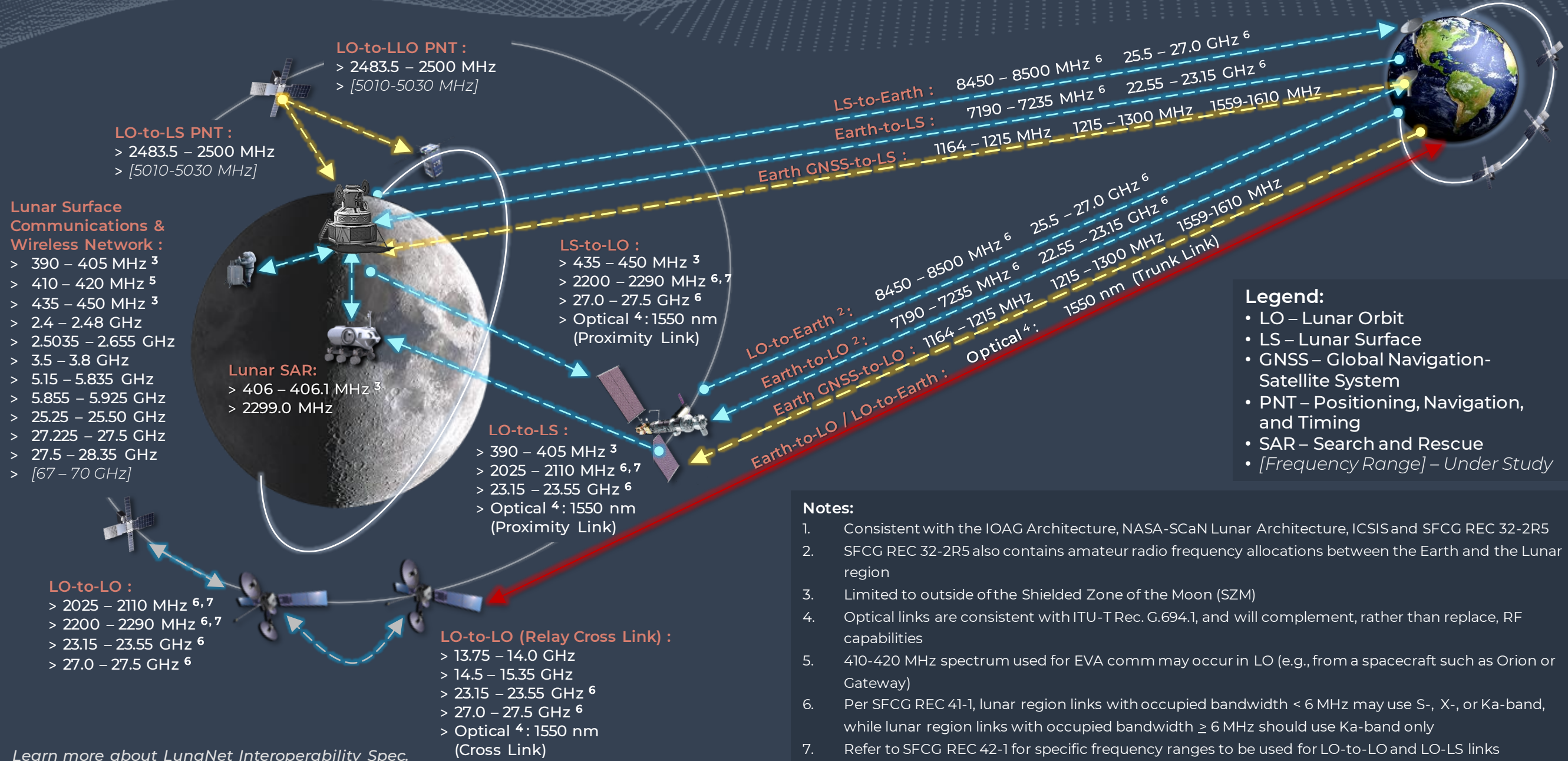
Lunar Orbit



Lunar Surface

Lunar Electromagnetic Spectrum Architecture

Radio Frequency¹ and Optical⁴



Legend:

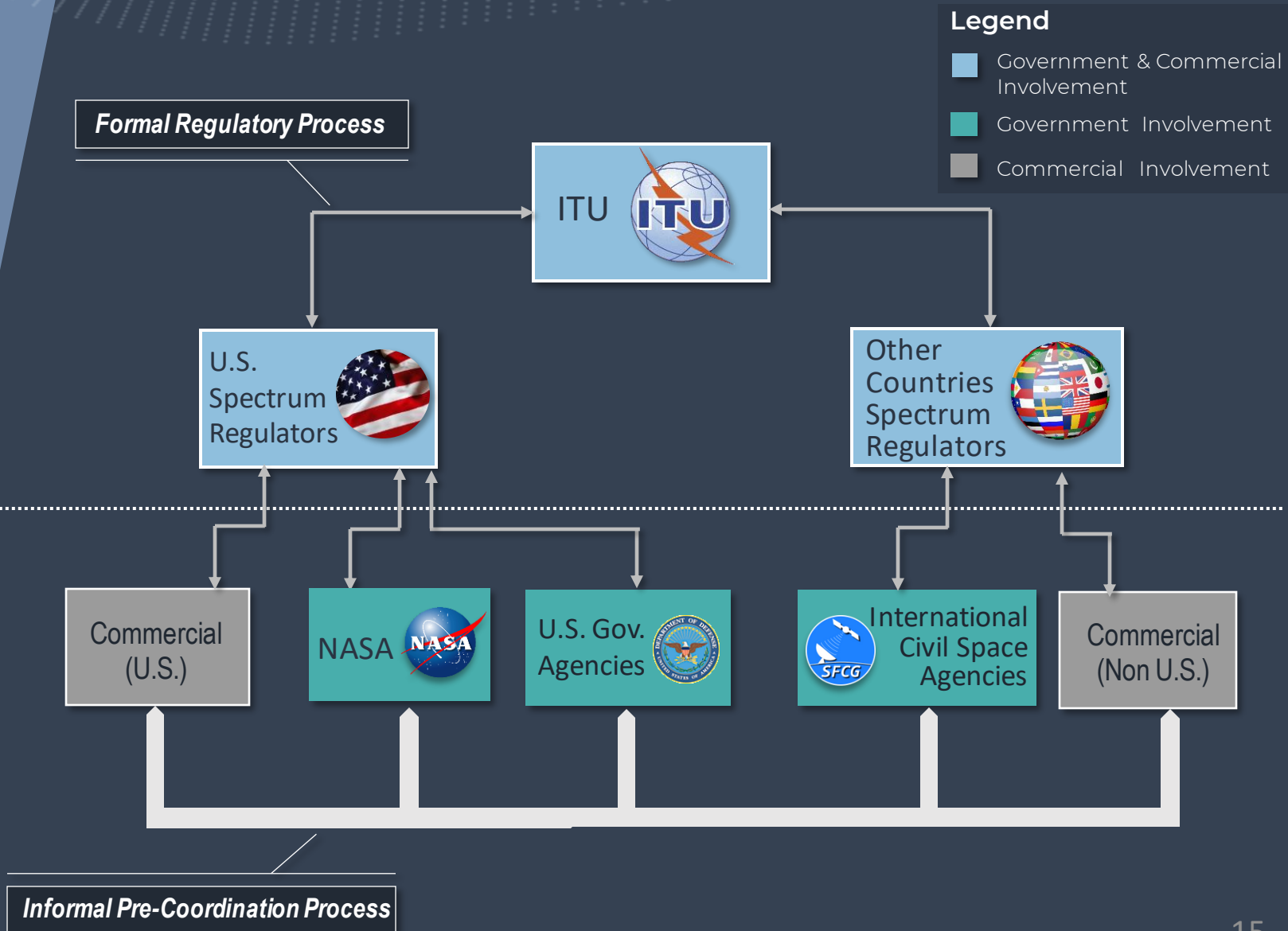
- LO – Lunar Orbit
- LS – Lunar Surface
- GNSS – Global Navigation-Satellite System
- PNT – Positioning, Navigation, and Timing
- SAR – Search and Rescue
- [Frequency Range] – Under Study

Notes:

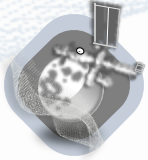
1. Consistent with the IOAG Architecture, NASA-SCaN Lunar Architecture, ICSIS and SFCG REC 32-2R5
2. SFCG REC 32-2R5 also contains amateur radio frequency allocations between the Earth and the Lunar region
3. Limited to outside of the Shielded Zone of the Moon (SZM)
4. Optical links are consistent with ITU-T Rec. G.694.1, and will complement, rather than replace, RF capabilities
5. 410-420 MHz spectrum used for EVA comm may occur in LO (e.g., from a spacecraft such as Orion or Gateway)
6. Per SFCG REC 41-1, lunar region links with occupied bandwidth < 6 MHz may use S-, X-, or Ka-band, while lunar region links with occupied bandwidth ≥ 6 MHz should use Ka-band only
7. Refer to SFCG REC 42-1 for specific frequency ranges to be used for LO-to-LO and LO-LS links

Opportunities for Involvement

- World Radio Conferences (**WRC**) sets International Radio Regulations on **3-4 year cycle** on a **consensus basis**
- U.S. regulators (National Telecommunications and Information Administration (**NTIA**) & Federal Communications Commission (**FCC**)) must **coordinate to adjudicate issues** that span federal and non-federal spectrum (respectively)
- Pre-Coordination** before formal regulatory actions are taken enables mission planners and spectrum planners to consult and make informed design decisions that take the complex spectrum landscape into account. These processes collectively can take **several months** to complete, but can **avoid costly changes** to equipment or licensing and filing later on



LSM Portal



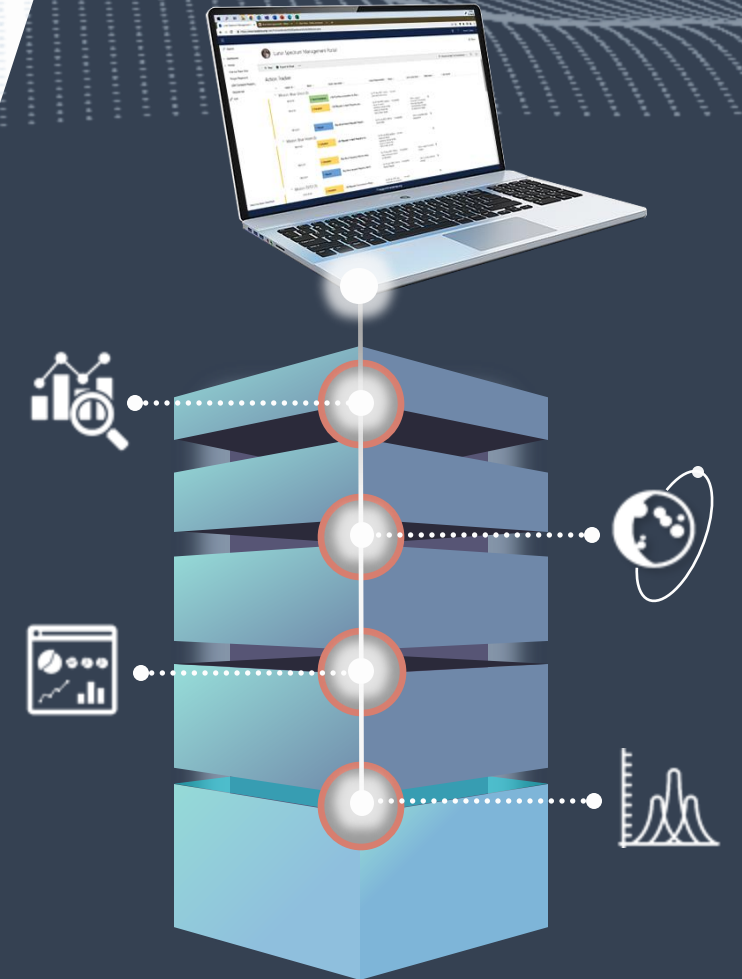
The LSM Portal is a hub for information about the LSM and the Lunar Pre-Coordination Process

Key Functions

- Track status on missions under pre-coordination with the LSM
- View summary information about known lunar missions
- Find information about spectrum planning in the lunar region

Key Resources

- Overview of relevant regulations and policies, and other government documents
- Summary information about known lunar region missions
- Overview of LSM role and Pre-Coordination Process
- Downloadable Lunar Frequency Selection Input Form to initiate Lunar Pre-Coordination Process
 - Permissions-based approach to control sharing of all information, including proprietary details



www.nasalsmp.org

For more information about the Portal, contact
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