中国航天

Evolution and Integration of BDS: Experience Sharing with the Moon

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China Academy of Space Technology
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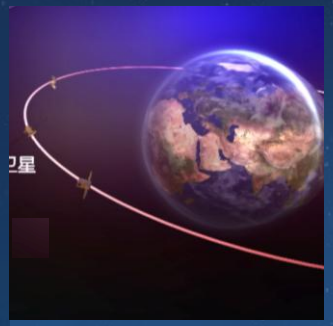
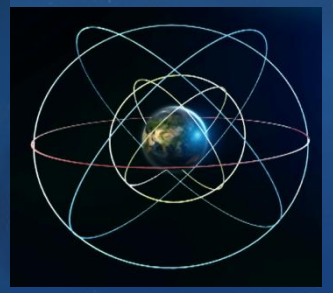
The Evolution of Constellation

Three-step Strategy of BDS Development

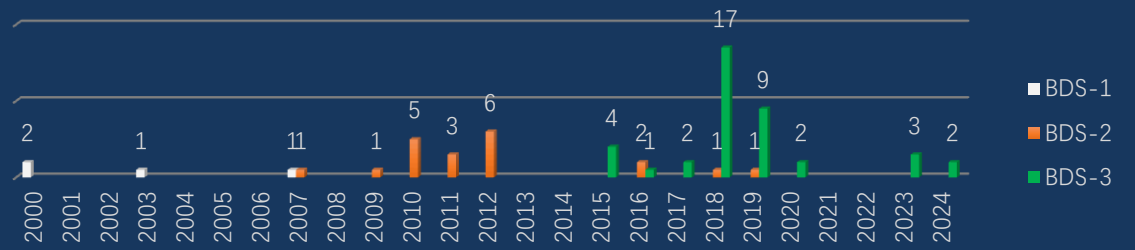


1994~2004
BDS-1(Demonstration System)
- China and surrounding areas
- 3 GEO

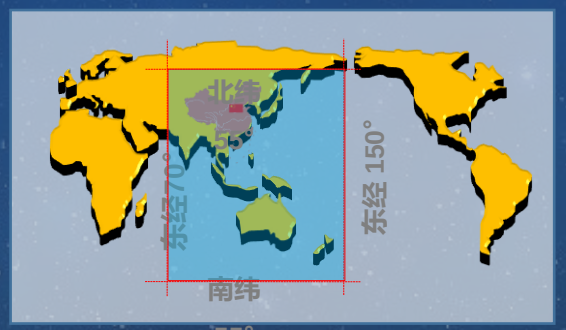


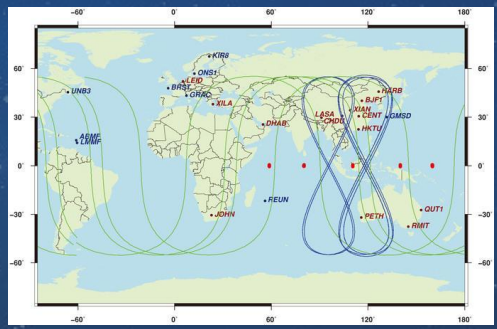
2004 ~2012
BDS-2 (Regional System)
- the Asia-Pacific region
- 5GEO, 5IGSO, 4MEO+Back-ups

2009~2020
BDS-3 (Global System)
- Global coverage with regional augmentation
- 24MEO, 3GEO, 3IGSO+Back-ups



- The hybrid constellation design, comprising GEO and IGSO satellites, provides an innovative solution for delivering key regional PNT services with an optimized constellation size.





Service Region of BDS-2

The Evolution of Constellation

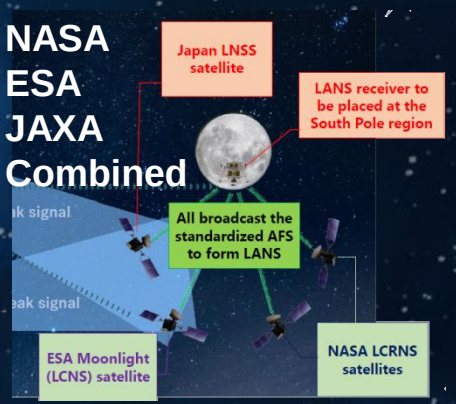
Are there key regions for Lunar PNT services similar to those of Earth's regional navigation satellite systems?

ESA Moonlight
ELFO

JAXA LNSS
ELFO

NASA LCRNS IOC
ELFO

NASA
ESA
JAXA
Combined



Lunanet LANS Service Coverage

South Pole Service → Full Service

LNIS V005

Initial Service Region:
Lunar South Pole

The Evolution of Constellation

Needs of PNT Service ➔ Service Converge Requirement ➔ Constellation Configuration+ Deployment Plan

The hybrid constellation of BDS is designed to support the system's evolution from regional to global coverage, focusing on key service areas.

In alignment with lunar exploration priorities, lunar systems can opt for a wider variety of orbit types, constellation configurations, and deployment strategies.

Features of Typical Orbits:

- **ELFO**

  Long-term stability, and good coverage of the lunar polar regions.

  Queqiao-2 relay satellite.

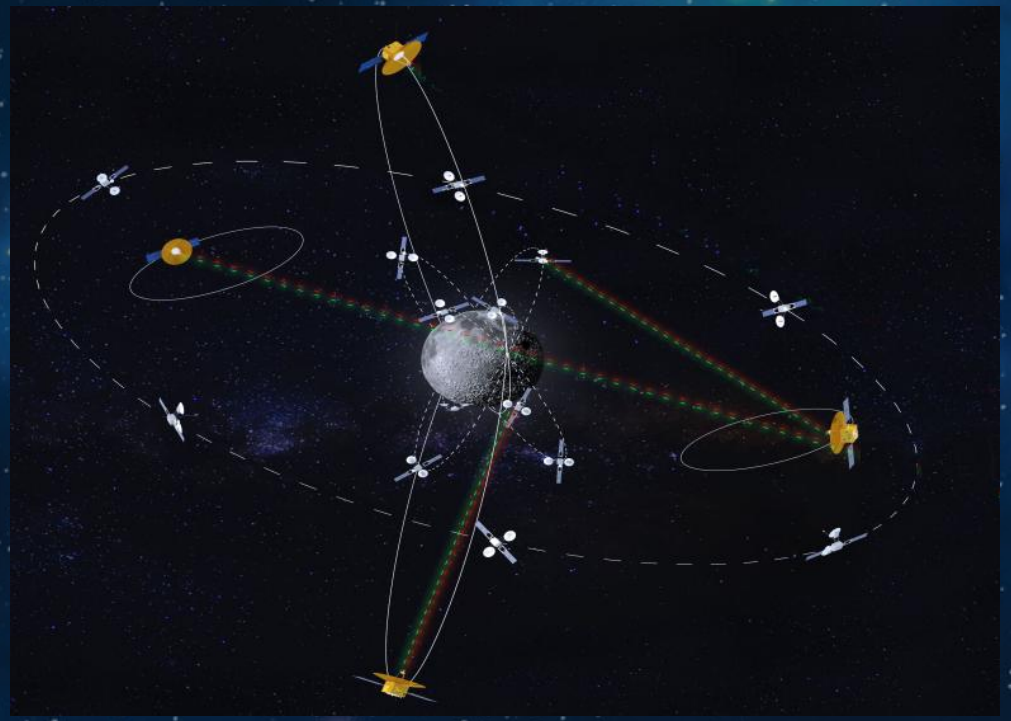
- **DRO**

  Long-term stability, and good coverage of full lunar surface.

  Chang'E 5 flight test.

- **Earth-Moon L1、L2 Halo (NRHO)**

  The trust requirements for orbital transfer and maintenance are low. The Queqiao satellite operates on the L2 Halo orbit, providing coverage of the lunar far side. The NRHO provides good polar coverage, and the Gateway mission will operate on this orbit.



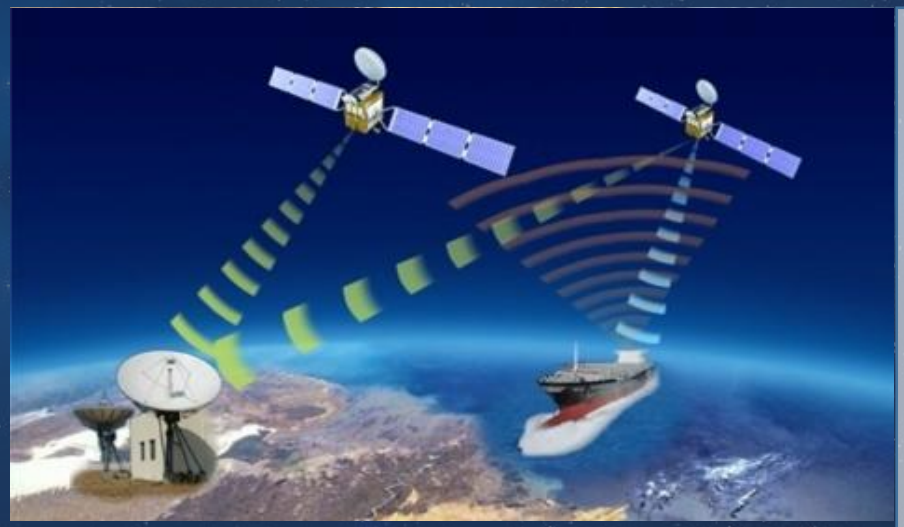
Analogy:
BDS Regional to Global
BDS Global with Regional Augmentation

Function Integration

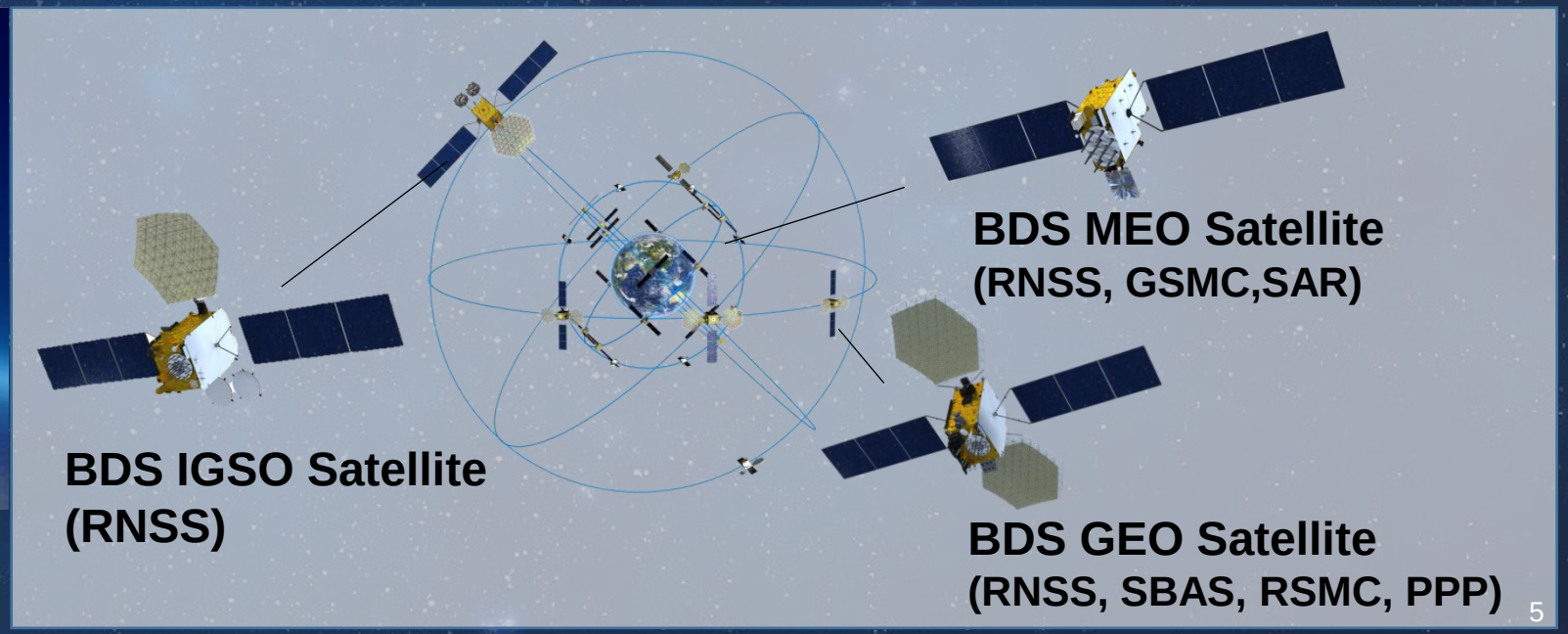
Navigation and Communication Integrated

- BDS has demonstrated dual-satellite radio determination. The ground control center performs range measurements from the user to two GEO satellites, processes the user's position, and then informs the user, thereby accomplishing both location reporting and user position sharing simultaneously.

- BDS-3 integrates three types of global services—RNSS, Global Short Message Communication, and International Search and Rescue, as well as four types of regional services— SBAS, Regional Short Message Communication, PPP and GBAS.

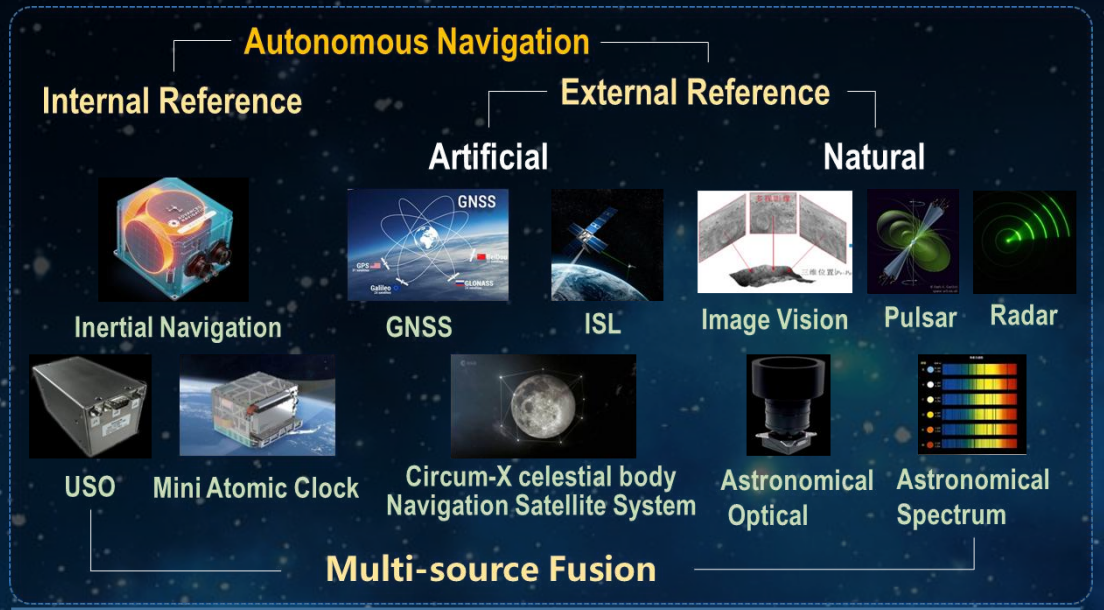


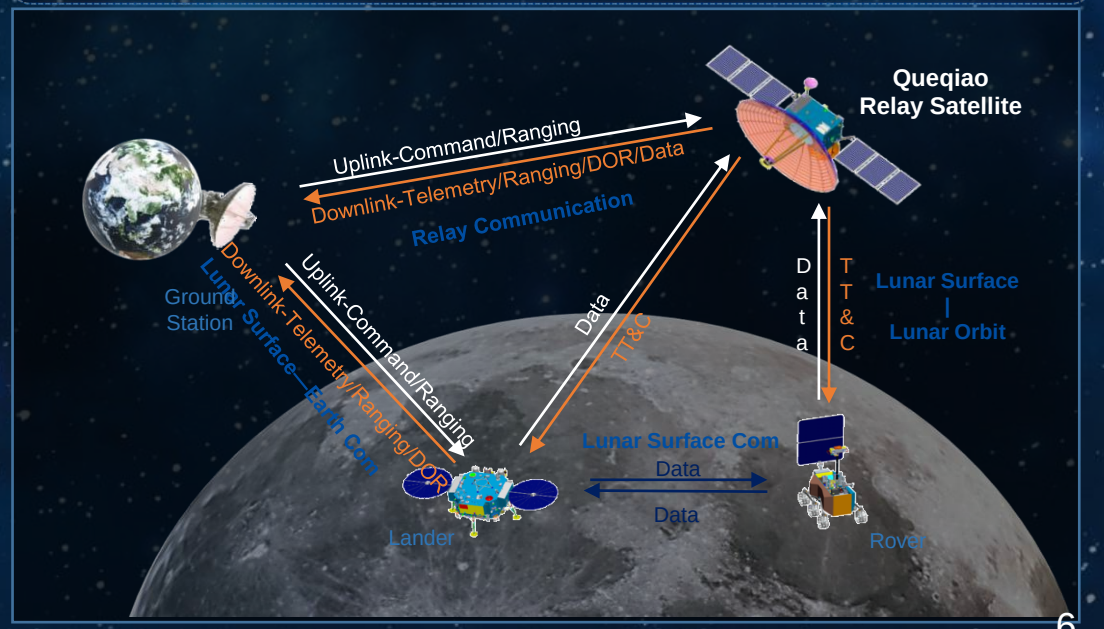
BDS RDSS - Active-positioning Scheme



Function Integration

- Lunar users can achieve enhanced Positioning, Navigation, and Timing (PNT) performance through the integrated utilization of lunar satellite navigation services in conjunction with GNSS and other autonomous navigation technologies.
- The lunar system should support multiple navigation service modes, TT&C (Tracking, Telemetry, and Command) communications, and high-speed data relays at the satellite, constellation, or system levels.
- The downlink frequency band for BDS RDSS/RSMS is the S band (2483.5 to 2500 MHz). This frequency band can also be considered a candidate for cislunar and lunar Positioning, Navigation, and Timing (PNT) services.

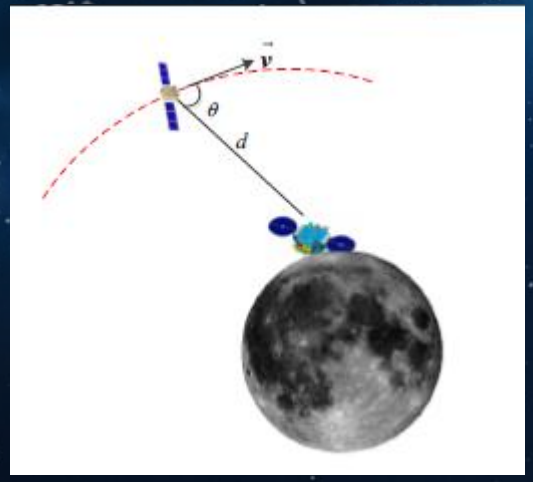


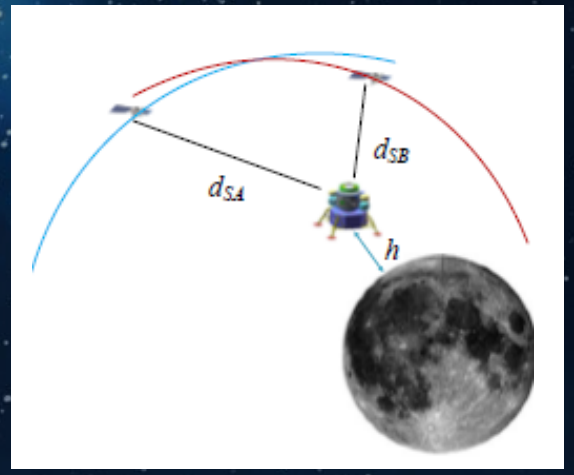


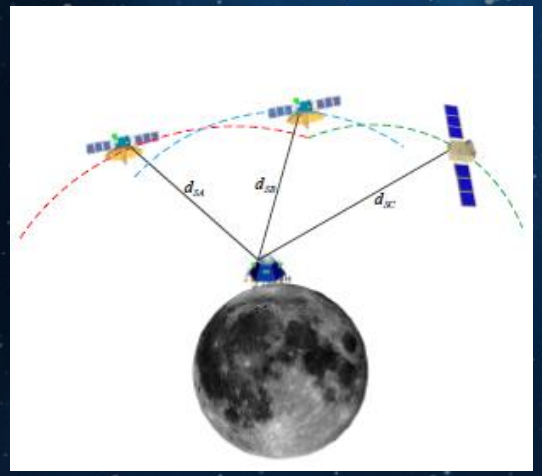
Function Integration

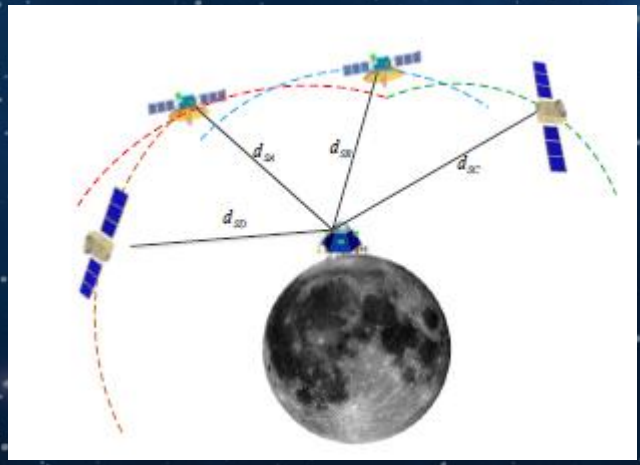
Optimization of lunar navigation satellite service modes

- **Single-satellite mode: Non-real-time Doppler positioning and bidirectional time synchronization, provide PNT services for static or quasi-static users on the lunar surface.**
- **Dual-satellite mode : Bidirectional measurement for real-time positioning, user-satellite time synchronization, user-configurable elevation measurement, similar to the BDS RDSS.**
- **Triple-satellite mode : Bidirectional measurement for real-time positioning, user-satellite time synchronization, providing real-time PNT services to a limited number of users.**
- **Quad-satellite mode : Unidirectional measurement for real-time PNT, similar to GNSS RNSS.**





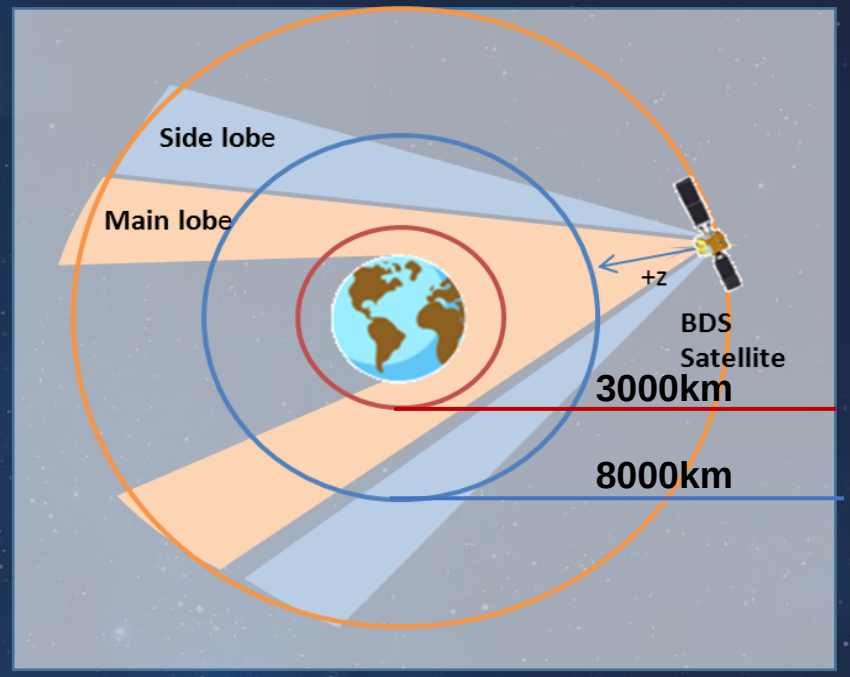




Service Volume Expansion

Interoperable GNSS Space Service Volume

- The GNSS service volume is expanding to GEO orbit and beyond. The ICG WG-B and its Space Use Subgroup (SUSG) have been working to establish an interoperable GNSS space service volume.
- BDS plans to extend its navigation services from terrestrial regions to near-Earth and cislunar space, enhancing the cislunar space service capabilities of the next-generation BDS constellation.

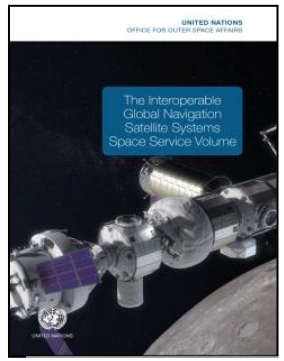


International Committee on Global Navigation Satellite Systems

WG-B Space Use Subgroup (SUSG)

European Space Agency

ROSCOSMOS



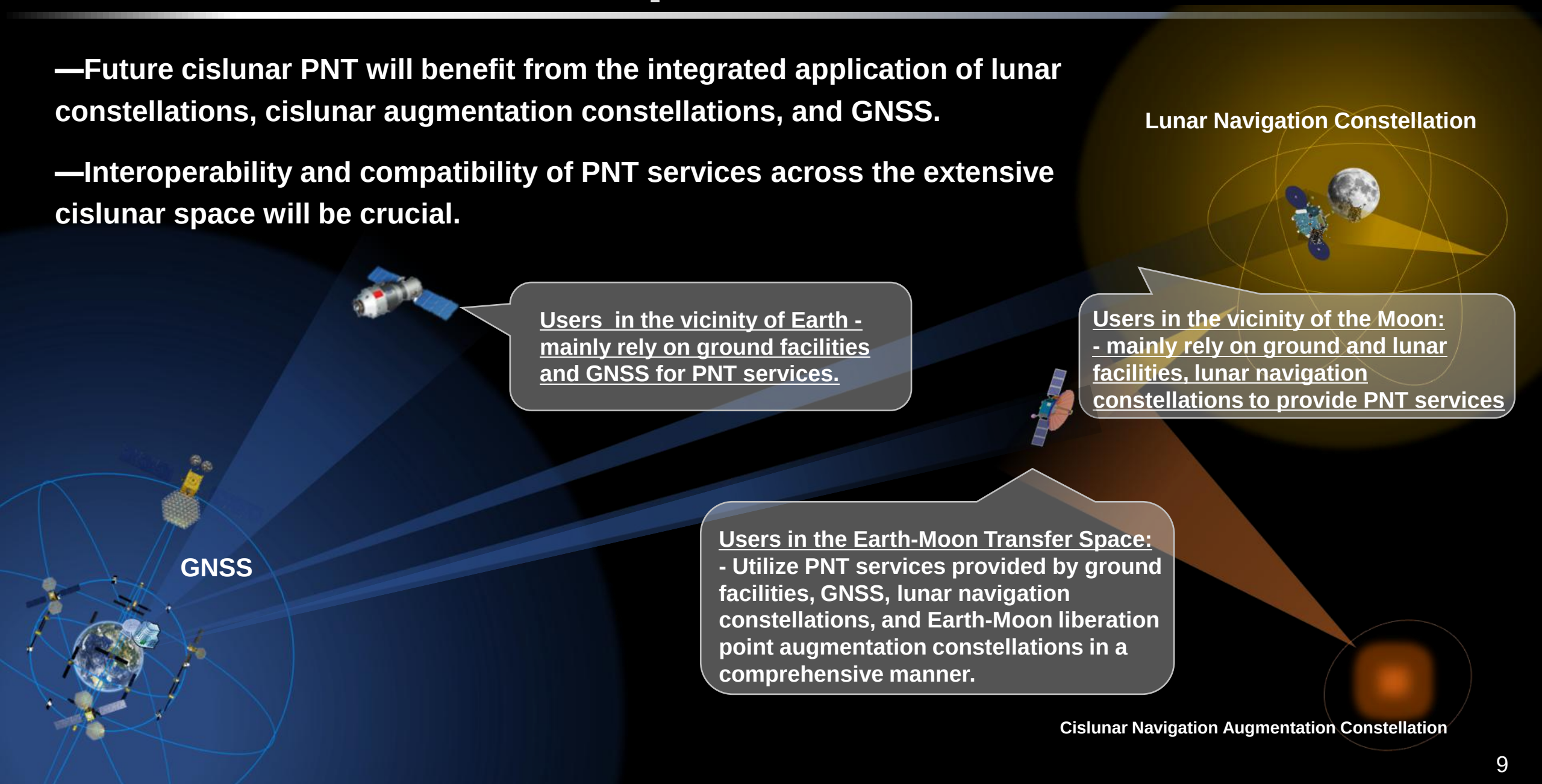
2018

2021

Service Volume Expansion

—Future cislunar PNT will benefit from the integrated application of lunar constellations, cislunar augmentation constellations, and GNSS.

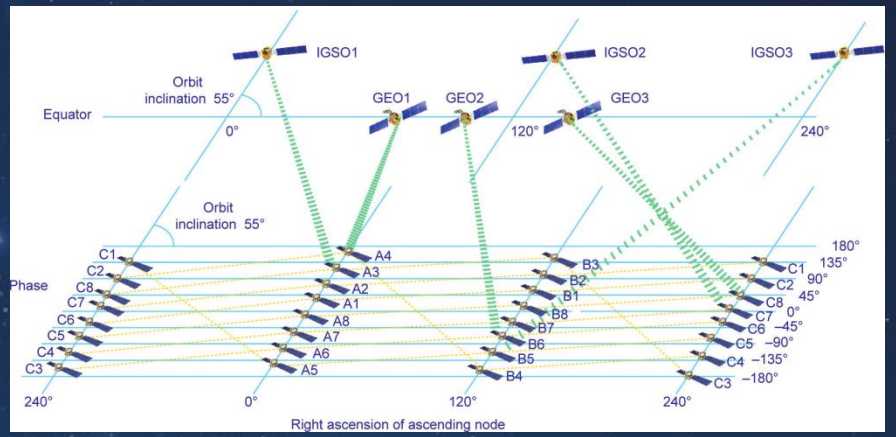
—Interoperability and compatibility of PNT services across the extensive cislunar space will be crucial.



Spatial-temporal Information Network

BDS satellites are equipped with Ka-band phased array antennas to achieve inter-satellite link measurements and communications, thereby establishing a spatial-temporal information network, which can

- reduce the requirement for ground monitoring stations layouts.
- overcome the limitations of ground station tracking arcs and observation geometry.
- enhance the autonomous operation capabilities of the navigation satellite constellation.



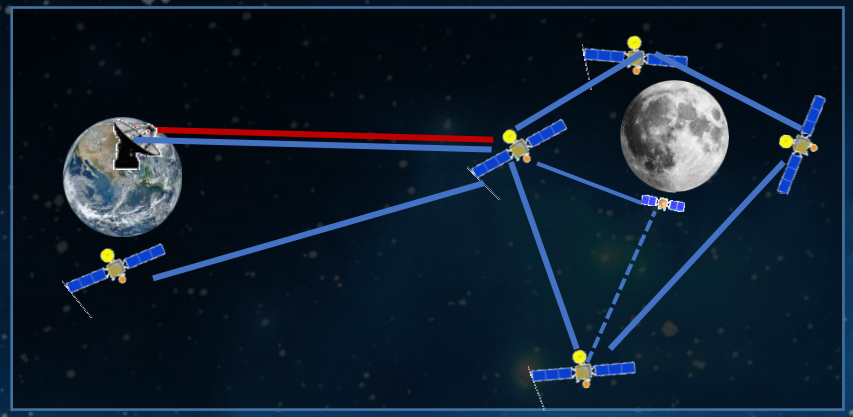
Spatial-temporal Information Network

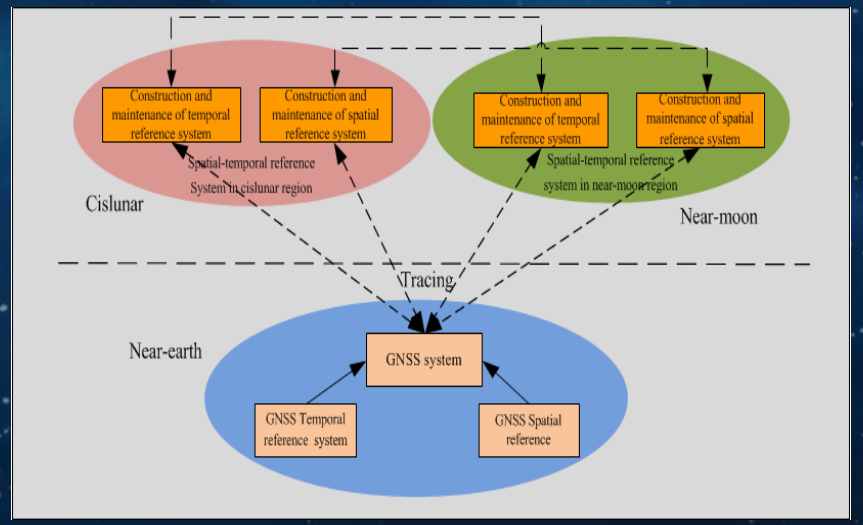
Given the constraints of ground-based infrastructure, the lunar navigation system will primarily rely on space-based measurement techniques, such as Global Navigation Satellite Systems (GNSS) and Inter-Satellite Links (ISL).

- In anticipation of future deep space exploration, the communication links within cislunar space can utilize an integrated optical and microwave network to achieve greater accuracy and broader bandwidth.

- The operation and control of lunar infrastructures can be significantly enhanced by the spatial-temporal information network, thereby achieving higher levels of automation and intelligence.

- The inter-satellite link to BDS can serve as one of the means for interconnecting the Earth-Moon Spatial-temporal reference network.





Conclusions and Suggestions

Constellation Evolution: The satellite constellation should be designed in alignment with lunar exploration priorities and long-term service plans, optimally selecting from a variety of orbit types.

Function Integration: Multiple navigation and communication services should be integrated at the satellite, constellation, and system levels. By comprehensively considering deployment progress, operation control, application modes, and user capacity, different navigation schemes can be effectively applied.

Service Volume: The lunar system should achieve the integration of services volume of the GNSS constellations and cislunar constellations, with a greater emphasis on openness and interoperability.

Spatial-temporal Information Network: The operation and performance of lunar systems can be enhanced by inter-satellite link (ISL) measurements and network communications.

Augmentation Services: Lunar system can construct a PNT augmentation architecture comprising facilities on Lunar orbits, surface and around liberation points.

Monitoring and Assessment: The monitoring and assessment of the lunar systems have higher requirements for satellite autonomous monitoring as well as user terminal integration.

Science Applications： Lunar navigation systems will have high accuracy cislunar space-time information, which can make unique contribution to scientific exploration.


Thanks for your attention!