Verification of BDS SSV and Analysis of BDS/GNSS Applications in Lunar Vicinity

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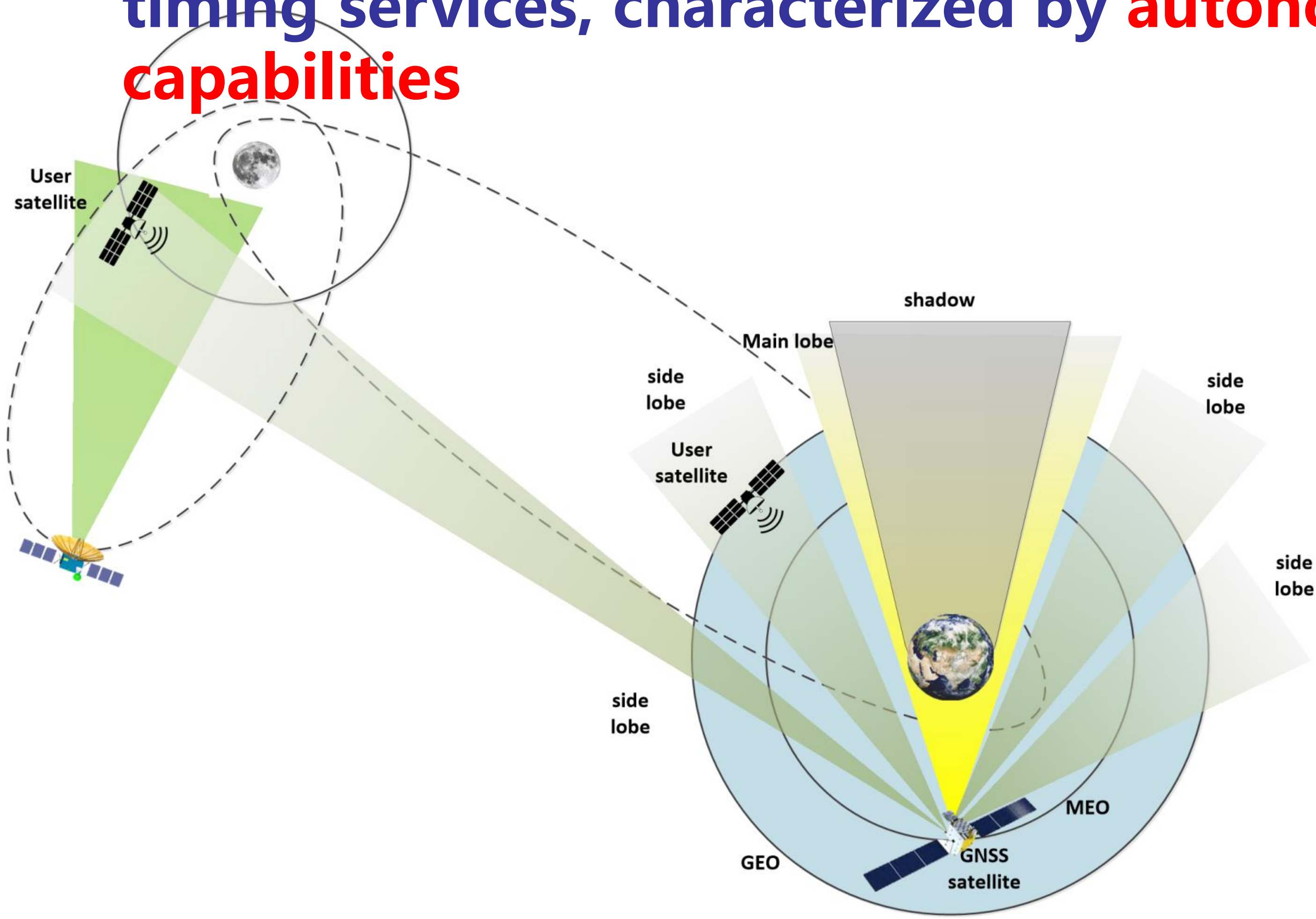
outline

1.Background of BDS/GNSS SSV

- **GNSS space applications are gradually expanding from low Earth orbit to high Earth orbit and into cislunar space.**
  - **GNSS can provide spacecraft with positioning, orbit determination, and timing services, characterized by autonomy, continuity, and real-time capabilities**



GNSS systems, including BDS, provide SSV services for high Earth orbit and cislunar space.

GNSS applications in GEO orbit determination accuracy reaching the order of 10 meters.

The accuracy can achieve several hundred meters in lunar orbit. The system based on GNSS or Lunar-AGNSS has become a hot topic in the research of extended applications for GNSS.

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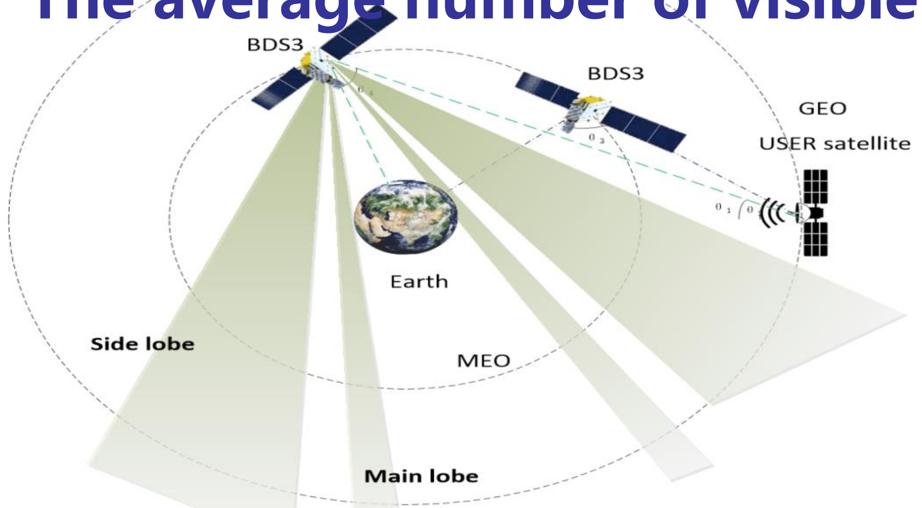
◻ High-Orbit HiSGR

A very high-sensitivity receiver (with a sensitivity of 18 dB-Hz) capable of achieving full-arc navigation in GEO orbit through the reception of BDS-3 signals has completed in-orbit testing.

- **The measured SPP accuracy is better than 45 meters (3σ), and the orbit determination accuracy is better than 5 meters (3σ).**
- **The average number of visible BDS satellites reached 9.8.**



GNSS SSV in GEO

CAST-GNT HiSGR

Longer PN code length and secondary code

↓

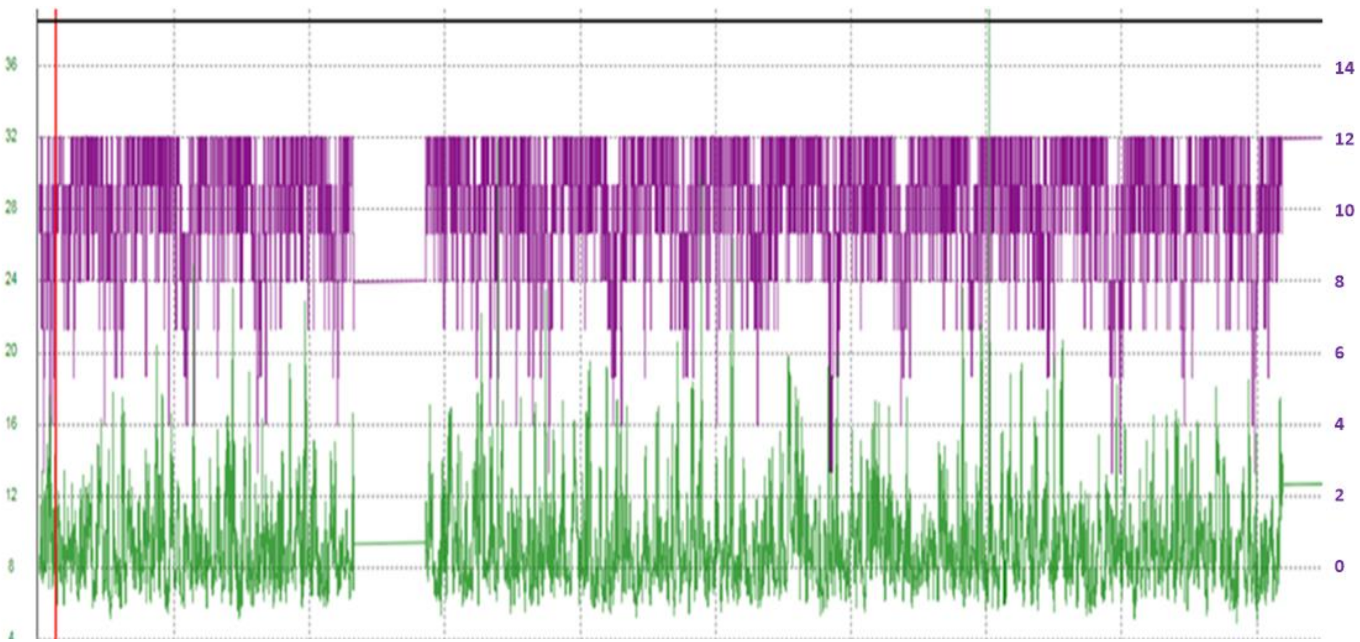
Pilot channel

↓

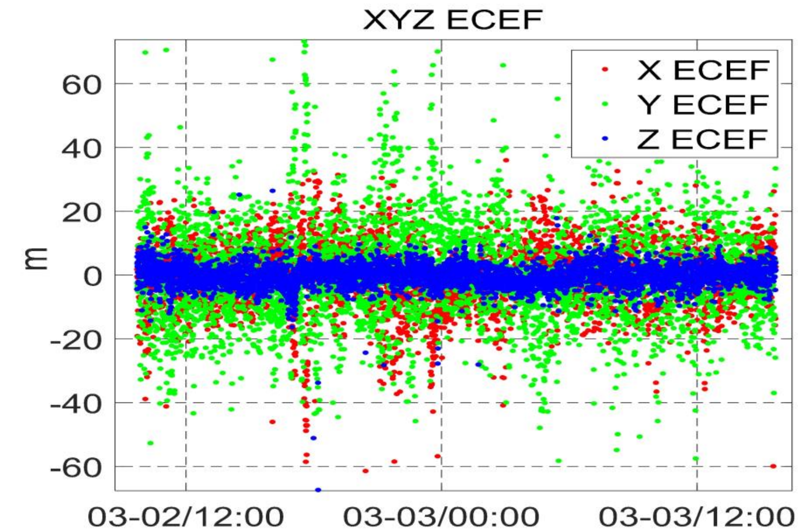
BOC signal effectively improves pseudorange measurement

□ High-Orbit HiSGR

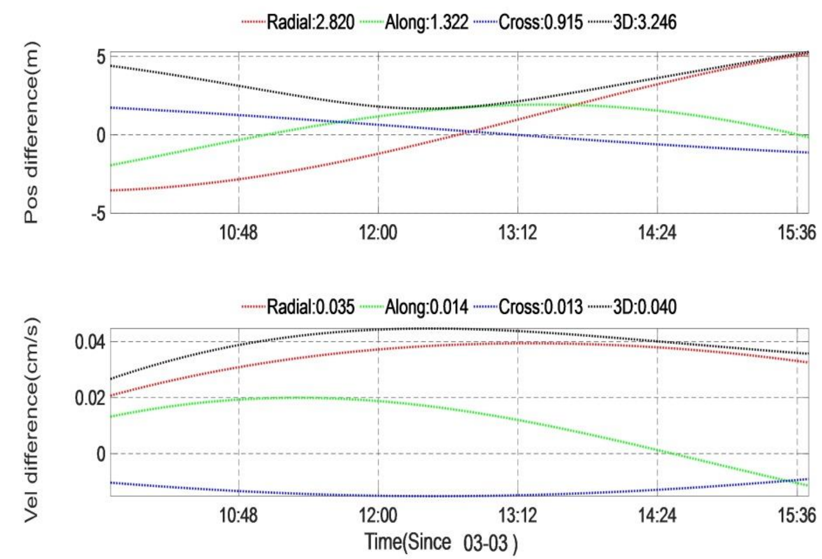
In-orbit measurement of BDS signal reception performance



GDOP Trackiing BDS-3 satellite number



SPP performance



Orbit overlap is performed for Arc1 and Arc2

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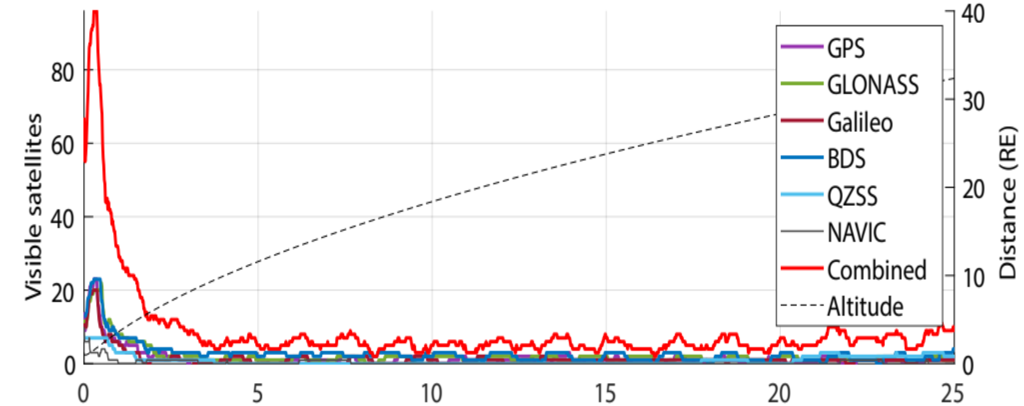
GNSS applications are expanding from GEO to lunar space

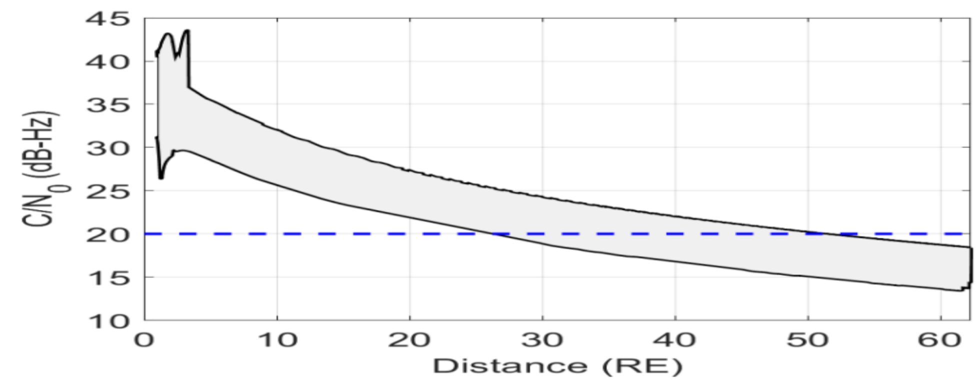
The GNSS SSV can provide an efficient solution for users in Earth-Moon space.

There is a strong need to introduce a new navigation method.

GNSS SSV can provide navigation and positioning accuracy on the order of 100 meters in Earth-Moon space.

The ICG explores the possibility of using interoperable signals for Earth-Moon space applications.





Simulated C/N0 range for lunar trajectory with 20 dB-Hz analysis threshold marked
source: THE INTEROPERABLE GLOBAL NAVIGATION SATELLITE SYSTEMS SPACE SERVICE VOLUME SECOND EDITION

Challenges of GNSS space applications in Earth-Moon space

Low Power

Due to the most emitted signals being in the antenna side lobes and long distance, received power is very low, making acquisition, tracking, and demodulation difficult.

Poor Positioning Accuracy

Low pseudo-range accuracy, few received satellites, and high DOP values severely affect positioning accuracy.

Simultaneous Illumination of Main Lobe and Side Lobes

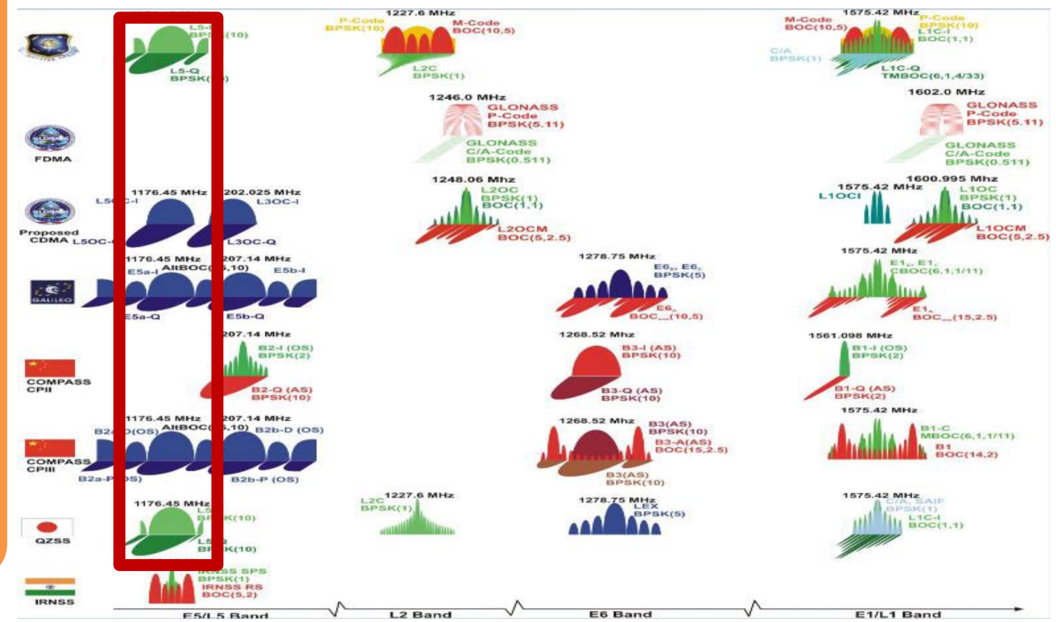
GNSS side lobe signals and GNSS main lobe signals simultaneously illuminate the receiver, causing significant self-interference.

□ Standalone GNSS Solutions for Earth-Moon Space

The advantage of modernized GNSS signals

- All employ longer spreading codes and secondary codes
- All include pilot channels
- The GNSS new signal schemes use a 10.23 Mbps chip rate
- B2a/L5 GNSS compatible interoperable frequencies

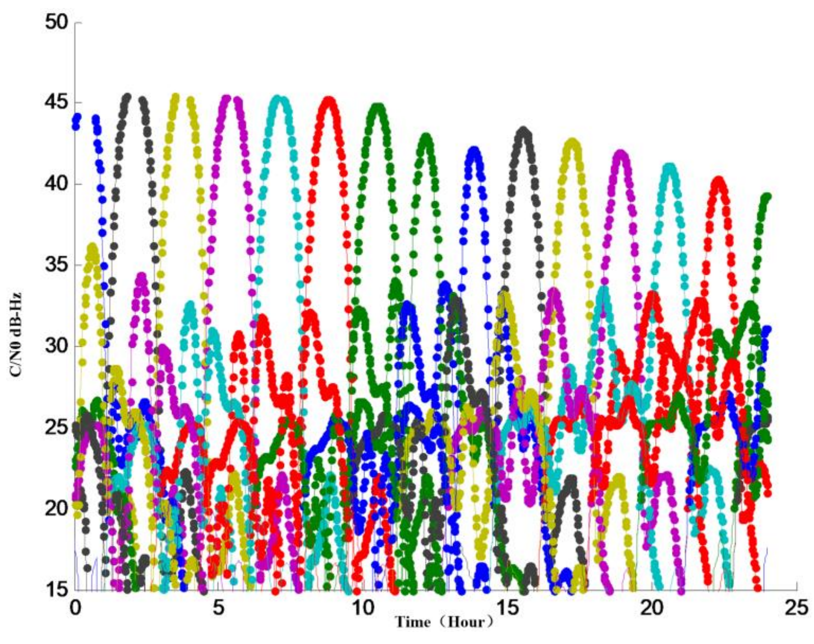
GNSS System	GPS	GPS
Service Name	L5 I	L5 Q
Centre Frequency	1176.45 MHz	1176.45 MHz
Frequency Band	L5	L5
Access Technique	CDMA	CDMA
Spreading modulation	BPSK(10)	BPSK(10)
Sub-carrier frequency	-	
Code frequency	10.23 MHz	10.23 MHz
Signal Component	Data	Pilot
Primary PRN Code length	10230	10230
Secondary PRN Code length	10	20



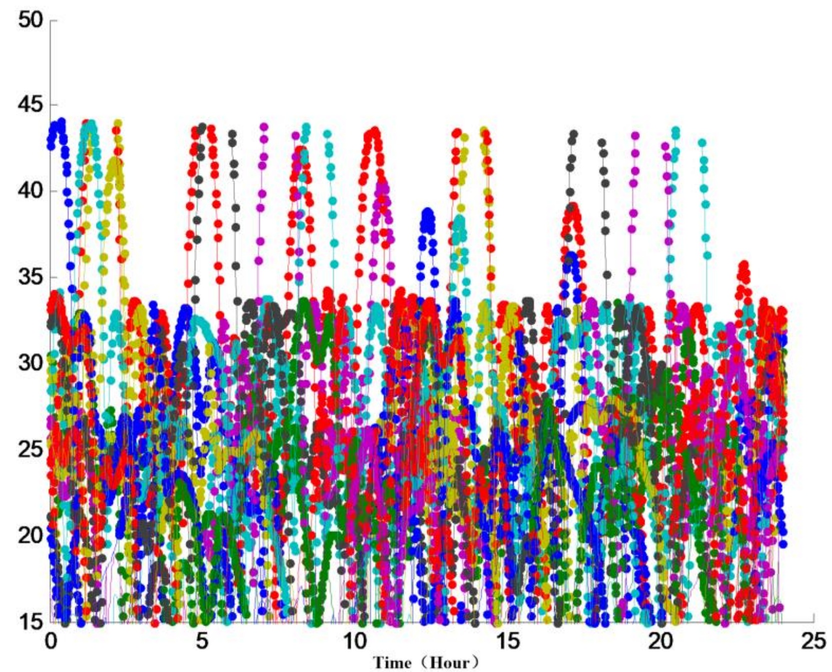
source: https://gssc.esa.int/navipedia/index.php/GNSS_signal

Simulating the Navigation Performance in Cislunar Space Based on the modernized BDS and GPS signals

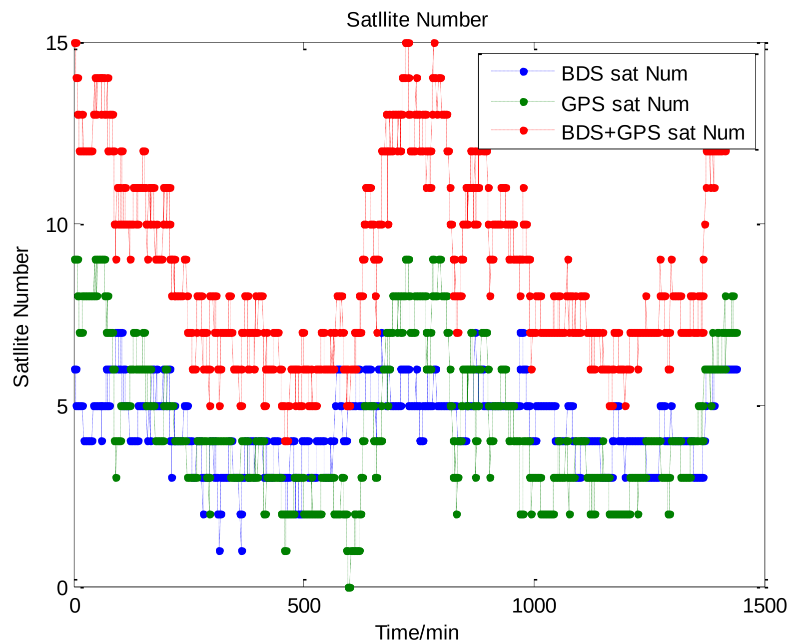
The number of visible satellites under conditions where the receiver sensitivity is 18 dB-Hz with a 15 dBi gain antenna.



BDS-3

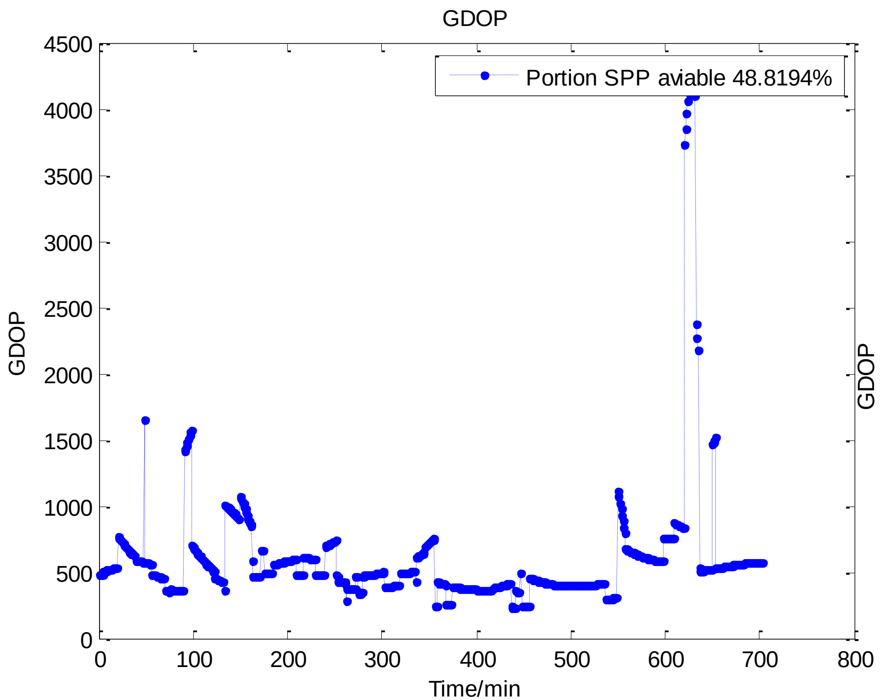


GPS

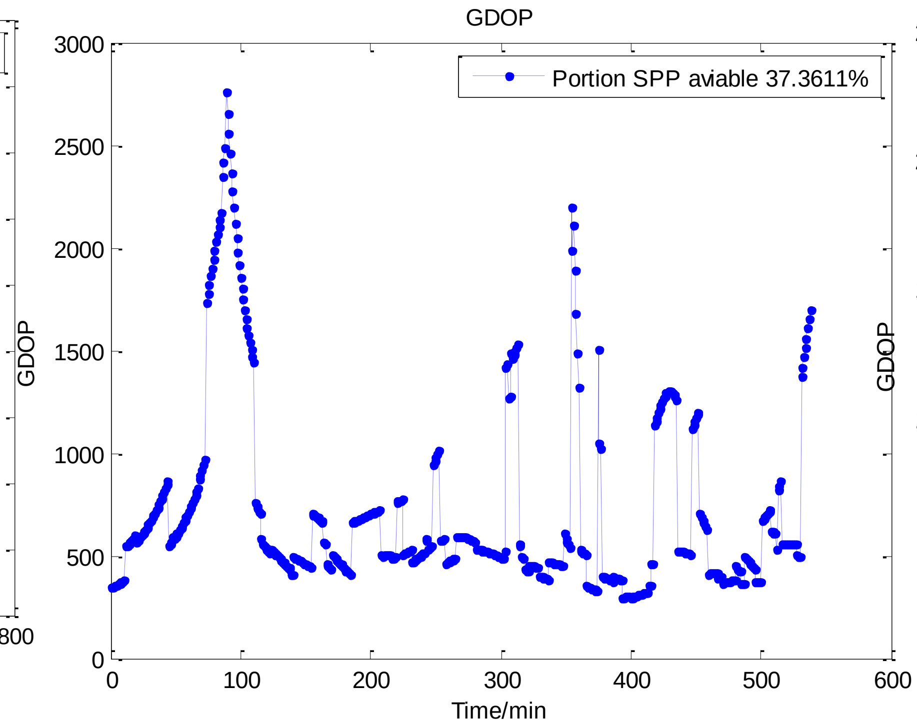


GPS\BDS and GPS+BDS visible satellite

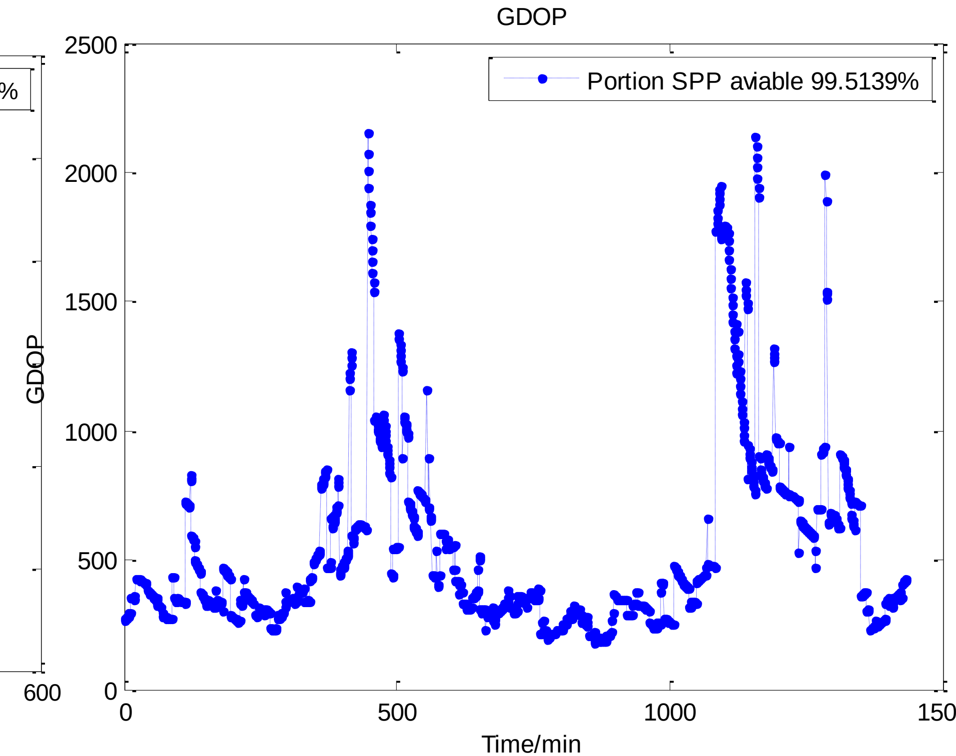
Simulating the Navigation Performance in Cislunar Space Based on the modernized BDS and GPS signals



GPS GDOP



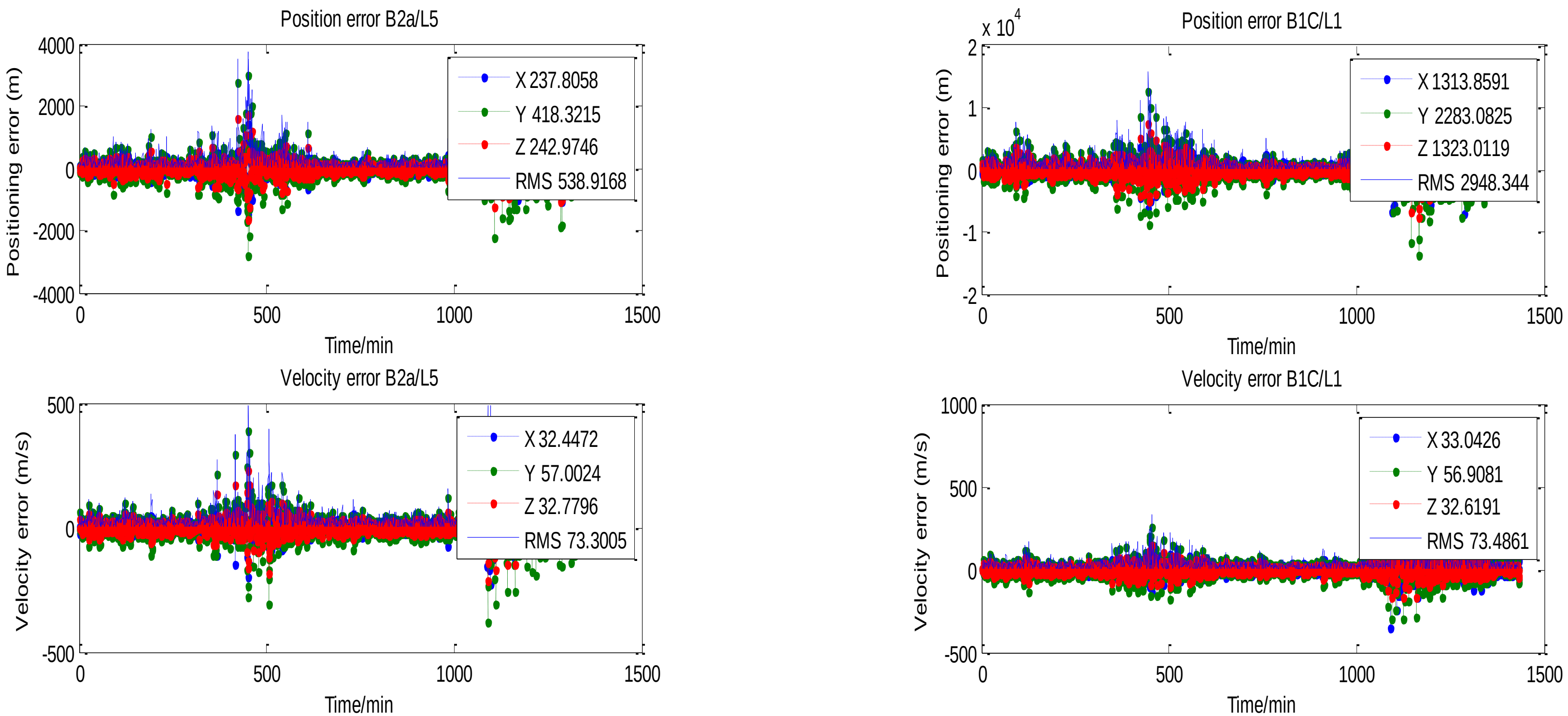
BDS GDOP



BDS+GPS GDOP

Integrating multiple systems results in an increased number of visible satellites. Coupled with better pseudo-range accuracy, this effectively enhances the positioning accuracy of navigation solutions.

Simulating the Navigation Performance in Cislunar Space Based on the modernized BDS and GPS signals



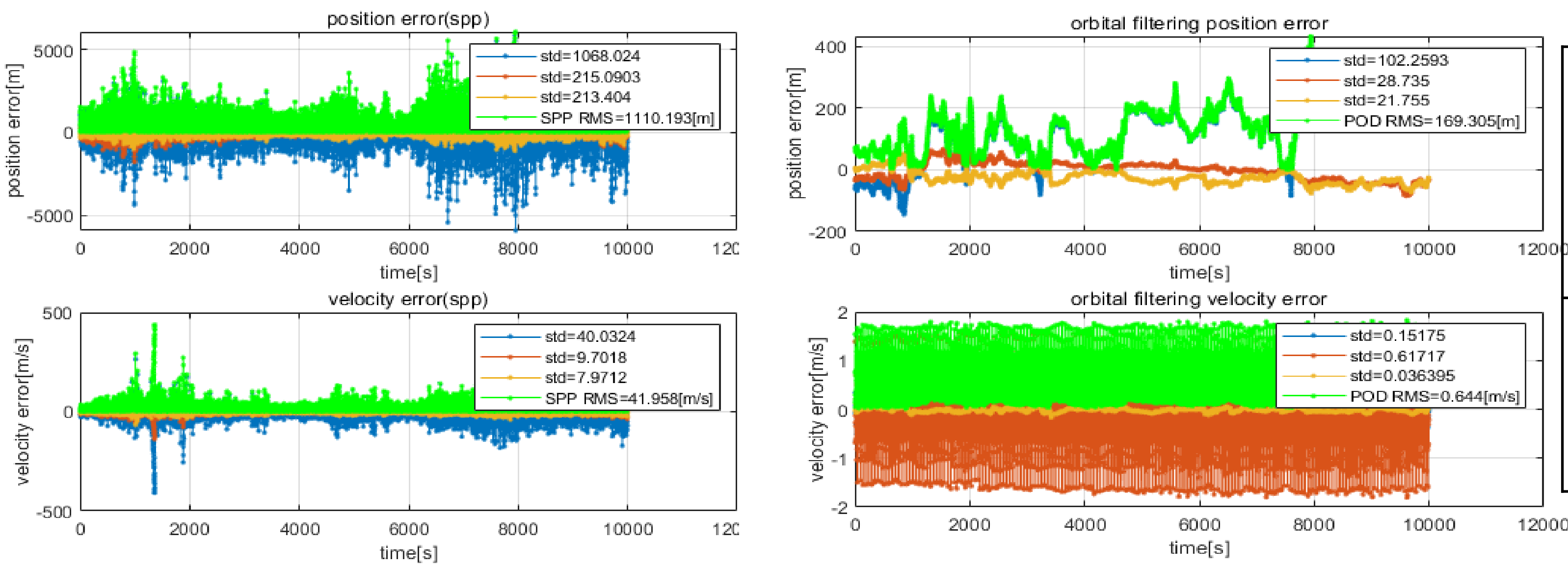
BDS+GPS B2a/L5 (Left) B1C/L1 (Right) signal based positioning result

Orbit altitude [1000km]	Position error		Velocity error	
	RMS [m]	RMS [m]	RMS [m/s]	RMS [m/s]
400	B1C/L1	B2a/L5	B1C/L1	B2a/L5
	2948.3	538.9	73.49	73.30

in lunar orbit, the fusion of BDS and GPS signals on B2a/L5 frequency points can achieve continuous single-point positioning performance within less than 1000 meters.

➢ HIL

Using a HiGSR, conducting Hardware in Loop (HIL) testing in a lunar orbit scenario simulated by the Hardware signal simulator. With an orbit altitude reaching 400,000 km, analysis of test data indicates that continuous navigation positioning can be achieved in lunar orbit using BDS+GPS systems, with single-point positioning accuracy consistent with expectations.



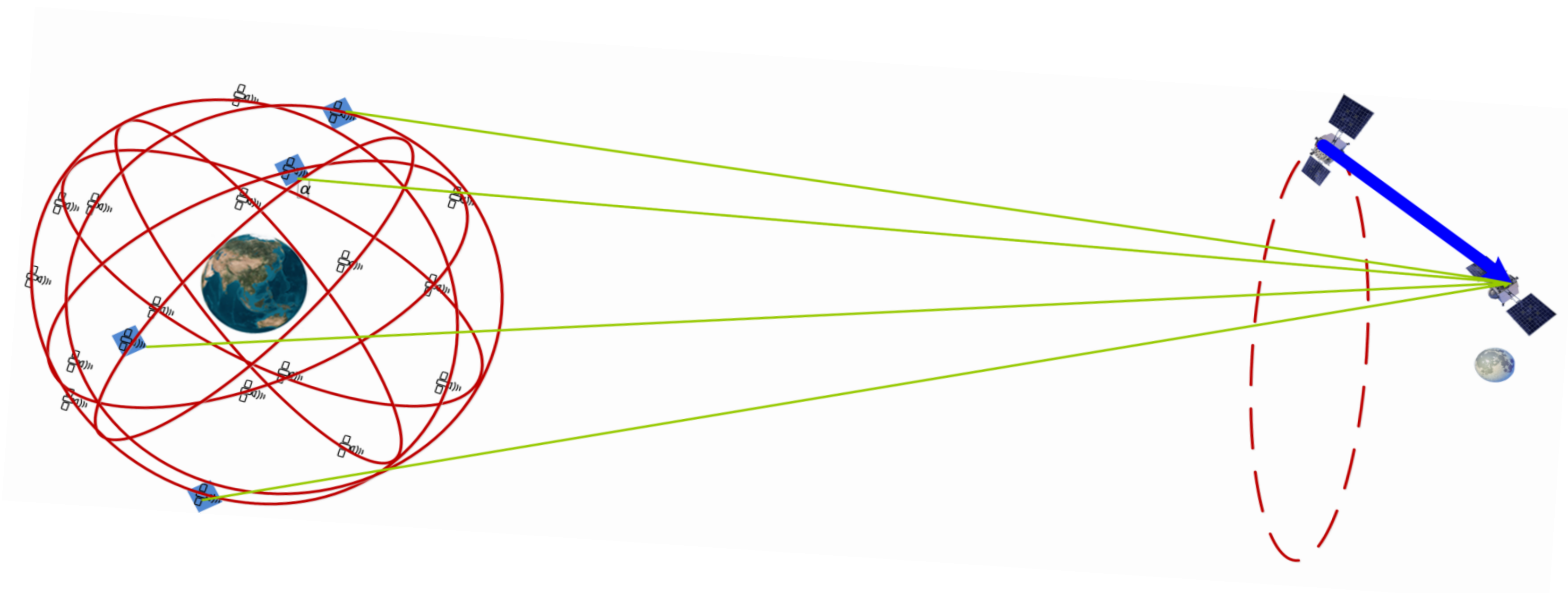
Results of lunar orbit navigation and positioning accuracy testing

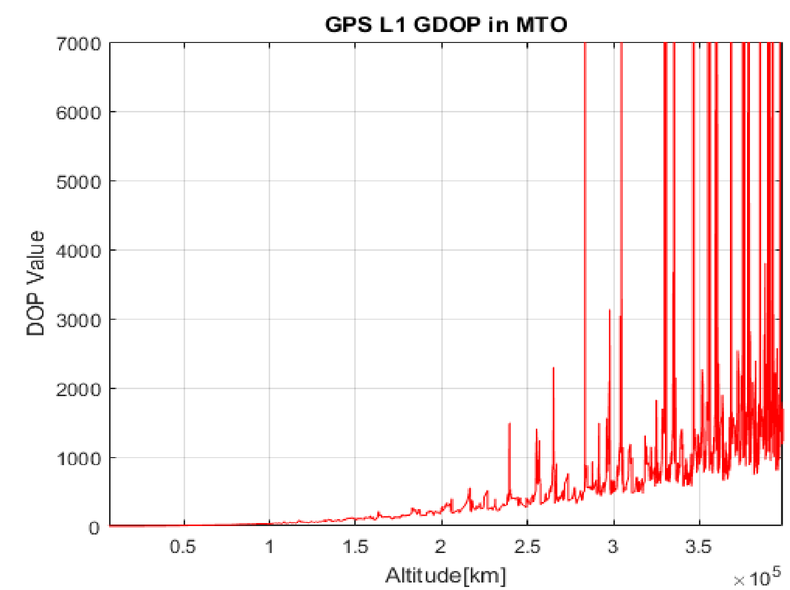
Orbit altitude [1000km]	Position error		Velocity error	
	RMS [m]	RMS [m]	RMS [m/s]	RMS [m/s]
400	SPP	EKF	SPP	EKF
	1110	169	42	0.6

Results of lunar orbit navigation and positioning accuracy testing

□ Lunar-AGNSS Solution for Earth-Moon Space

By utilizing lunar space data relay satellites and other cislunar space infrastructure as sources for navigation data augmentation or signal enhancement, it is possible to effectively improve Dilution of Precision (DOP) values, enhance real-time navigation positioning performance, and increase system acquisition and tracking capabilities, thereby enhancing user experience.





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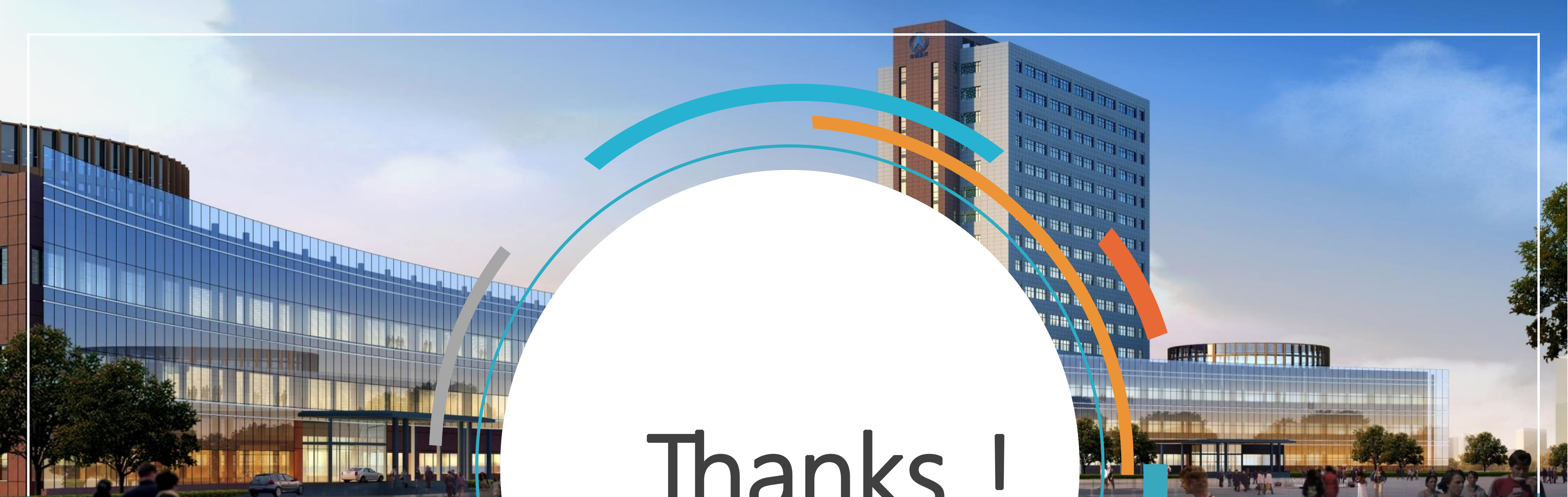
4.Conclusion

- Using **BDS sidelobe signals** and highly sensitive GNSS receivers, continuous positioning for GEO orbit users can be achieved, the accuracy could reach **5 meters**.
- In lunar space ,**high-gain antennas** combined with **high-sensitivity receivers** leveraging the advantages of **GNSS-compatible interoperable signals**, can effectively enhance navigation performance, providing lunar space users with continuous navigation services,the accuracy could reach **hundreds of meters**.
- Integrating lunar space infrastructure to achieve **Lunar-AGNSS system** significantly improves system performance.



Thanks！