1st Feb 11:30-12:30 (ICT)
Room 516

Low Earth Orbit PNT

Moderator

Dr. Masaya Murata
JAXA

- *Mr. JJ Miller, NASA*
- *Mr. Pietro Giordano, ESA*
- *Dr. Tyler Reid, Xona Space Systems*
- *Mr. Joshua Critchley-Marrows, ArkEdge Space*
- *Dr. Xu Mingliang, Centispace*
- *Dr. Masaya Murata, JAXA*

Low Earth Orbit PNT Overview

James J. Miller, Deputy Director,

Policy and Strategic Communications Division,
Space Communications & Navigation Program,
Space Operations Mission Directorate,
NASA Headquarters

Multi-GNSS Asia 14th Annual Conference
Jan. 30 – Feb. 2, 2024

LEO PNT from a GNSS Provider's Perspective: Why should government regulators care?

- As new LEO PNT systems are rapidly coming online, we want to ensure there is transparency on what these systems are doing
- Understanding LEO PNT systems
  - What types of services will be provided?
  - Who are the intended users?
  - Will LEO Systems compete with, or complement, Medium Earth Orbit (MEO) and Geosynchronous Orbit (GEO/IGSO) –based Global Navigation Satellite Systems (GNSS)?
- Technical issues we should address
  - Spectrum use and compatibility (mitigating interference) with MEO/GEO/IGSO GNSS
  - Developing performance standards for interoperability
  - Determining system time offsets
  - Ensuring consistent time/coordinate reference conventions
  - How will the signals be monitored
  - Orbit determination & dissemination
  - Orbital debris mitigation

LEO Mega-Constellations: Aiming to Provide a Variety of Specialized Services

Broadband Internet

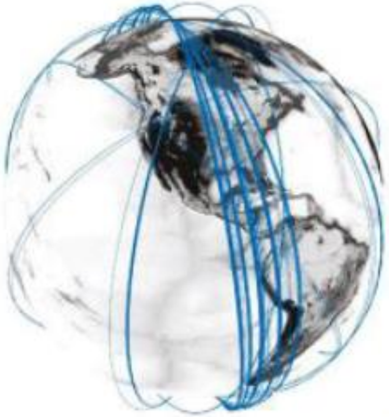
STARLINK

#Sats =5,500

OneWeb

#Sats = 634

Remote Sensing



planet.

#Sats = 175

spire

#Sats = 95

Position, Navigation, & Time

Several organizations are developing proliferated LEO PNT satellites, based out of US, Europe, and China.

Sats = 16 (total)
200 to 370 sats per constellation (planned)

(*) Variation as presented by PNTAB member Bryan Chan at PNTAB-29 Meeting

LEO PNT Discussions at the ICG

- LEO PNT first discussed at International Committee on GNSS (ICG) during 16th Meeting in 2022. Key questions raised:
  - How should ICG interact with purely commercial systems?
  - Should ICG include LEO PNT providers in discussions about standardization of GNSS performance standards?

- ICG WG-S (Systems, Signals & Services) organized a LEO PNT Workshop in June 2023
  - Objectives:
    - > Understand status and/or intent
    - > Establish a two-way information exchange
    - > Determine interest from commercial service providers about future ICG engagement
  - Five LEO PNT providers participated/presented – China (1), EU (1), and U.S. (3). See:
    - > https://www.unoosa.org/oosa/en/ourwork/icg/working-groups/s/wg-s-workshop-leo-pnt-2023.html
  - Other providers were identified, but they unable to participate. However, ICG outreach/engagement continues with these other providers.

ICG Workshop Summary: LEO PNT Presenters

Presenters:
DU Xiaodong & MU Xucheng
Beijing Future Navigation Tech

Presenters:
Marco ANGHILERI & Lionel RIES
European Space Agency

Presenters:
Chris DEMAY & Paul ANDERSON

Presenter:
Christina YOUN

Presenter:
Christina RILEY

ICG Next Steps:
A Balance of Optimism & Vigilance is Required Moving Forward

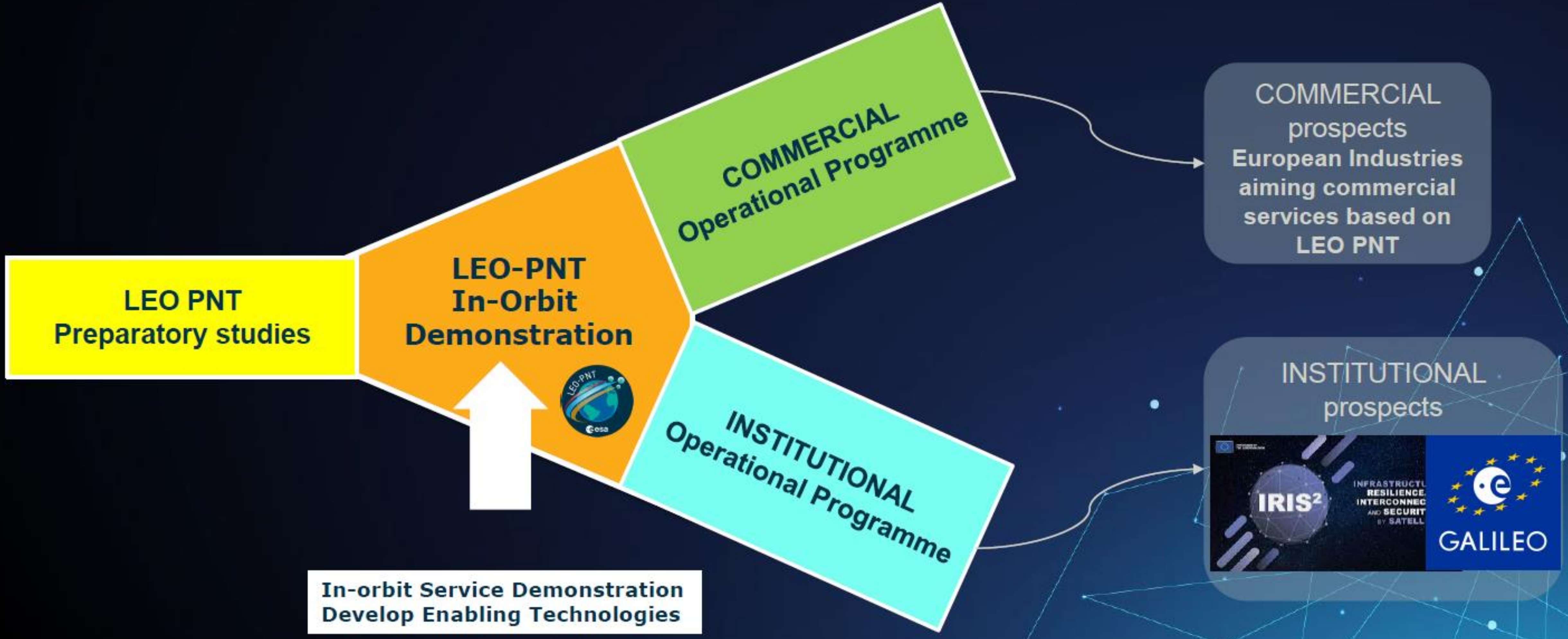
- Further discussions within ICG to determine most appropriate way to integrate commercial/emerging providers
- Continue outreach to LEO PNT system providers with invitation to ICG meetings and relevant activities
- Organize another workshop focused on both interoperability and compatibility issues
- U.S., ESA, and China are currently leading the ICG effort to organize this other workshop

FutureNAV In Orbit Demonstrator - a first step towards a European LEO-PNT component

Multi-GNSS Asia Annual Conference
LEO-PNT Panel
01/02/2024

Pietro Giordano

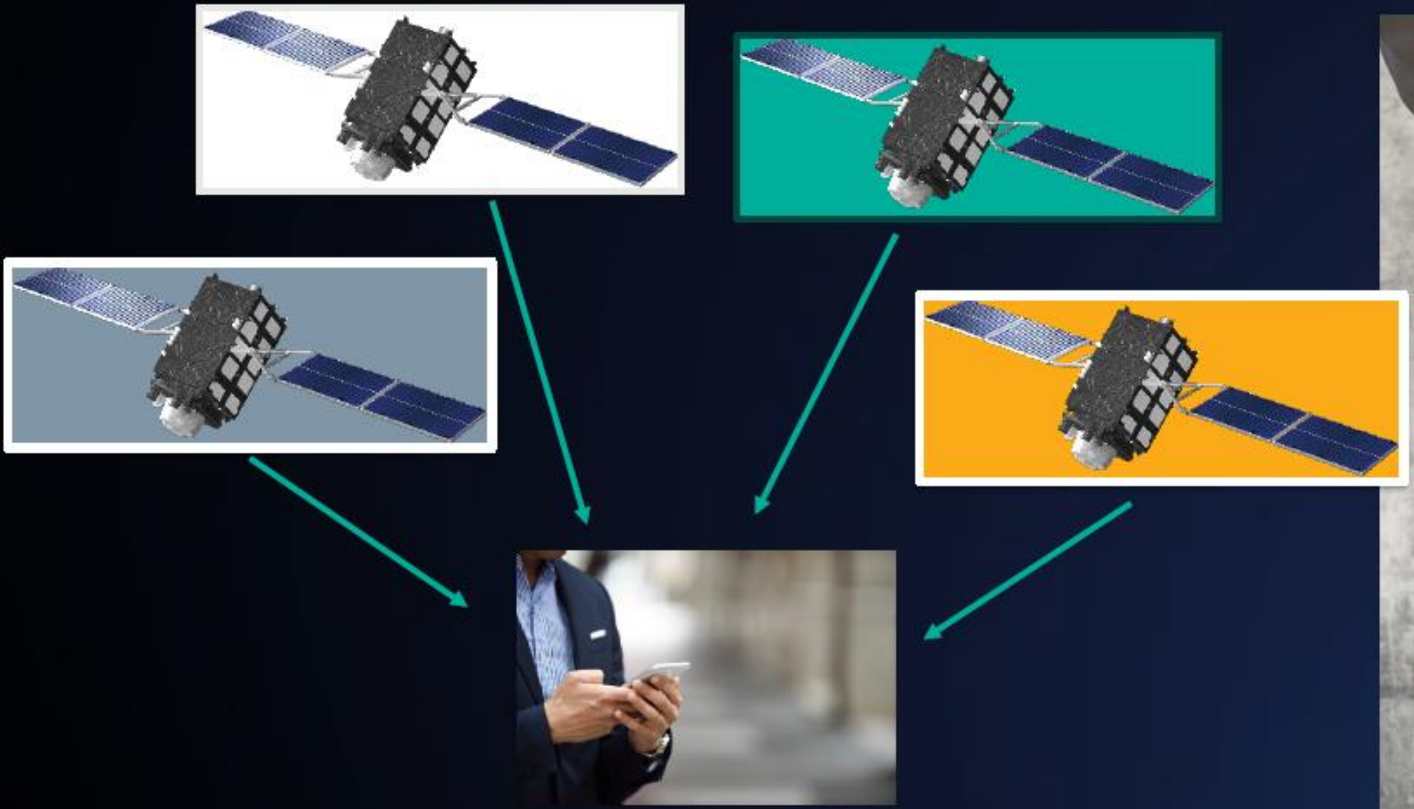
FutureNAV LEO-PNT



ESA Future NAV – LEO PNT In-Orbit Demonstration

- 2 parallel contracts
- ≥6 satellites per contract
- Constellation with more than 10 satellites by 2027
- End-to-end demonstration

Interoperable LEO-PNT system of systems



Seamless user experience
Faster time to market at global scale
Interoperability based on open standards

Dedicated Commercial LEO PNT

MGA LEO PNT Panel

Tyler Reid, CTO

xona space systems

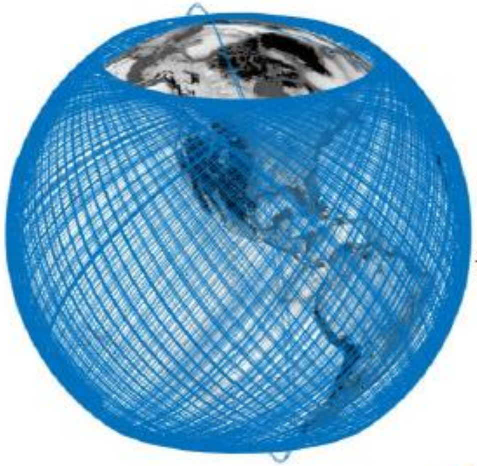
WHY LEO PNT?

Applications are seeking improved accuracy, resilient, and secure PNT

Opportunity for PNT with exponential growth in LEO

LEO MEGA-CONSTELLATIONS

Broadband

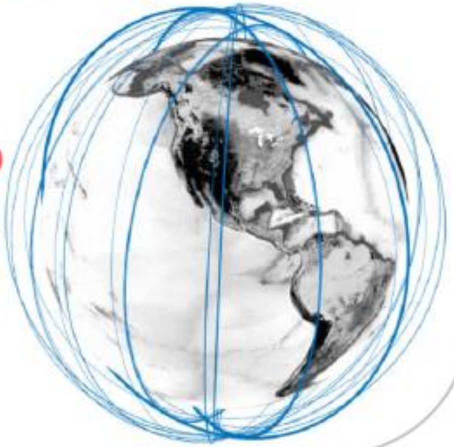


STARLINK

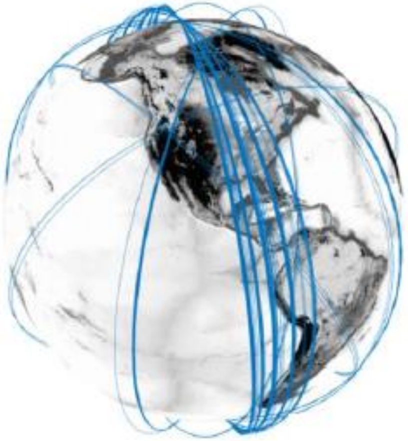
#Sats = 4626

OneWeb

#Sats = 636



Remote Sensing



planet.

#Sats = 175

spire

#Sats = 95

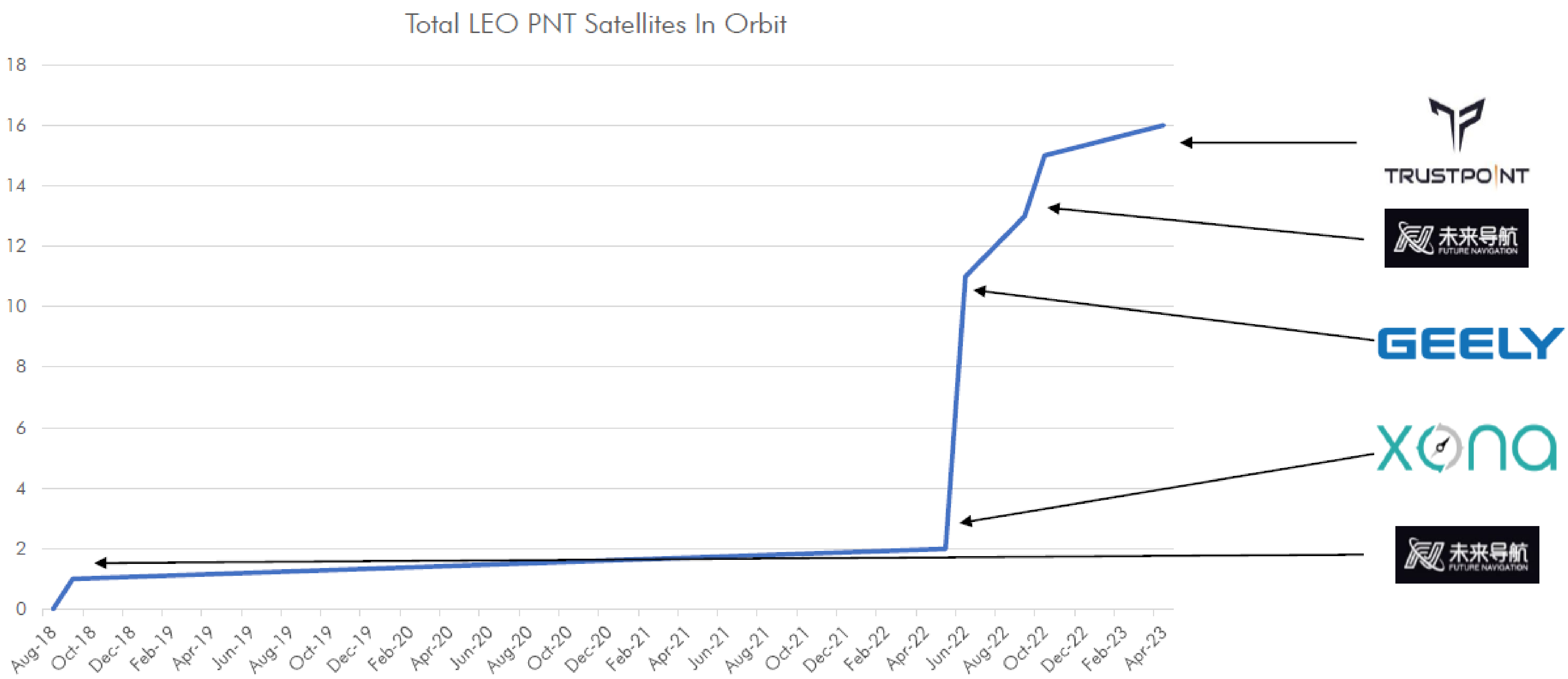
Position, Navigation, & Time

xona

258
(Planned)

	#Sats (Planned)
GEELY	240
TRUSTPOINT	288
未来导航 FUTURE NAVIGATION	160

RECENT LEO PNT LAUNCHES



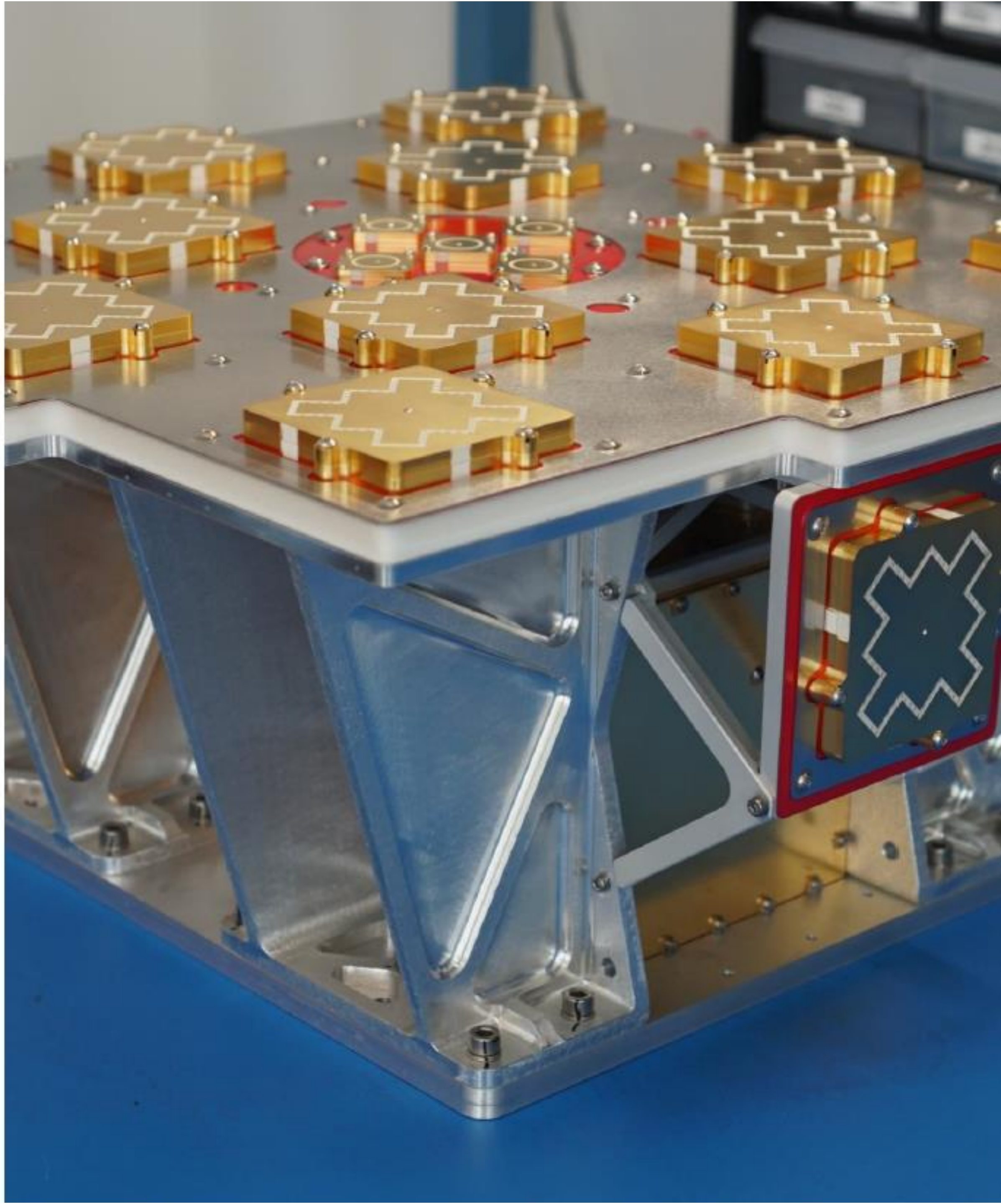
SATELLITE NAVIGATION BUILT FOR THE AGE OF AUTONOMY.

Xona is building PULSAR, the first commercial satellite navigation system designed to provide the global accuracy and integrity needed to ensure safe operation of modern technology.

BACKED BY

TOYOTA VENTURES

LOCKHEED MARTIN



PULSAR

Accuracy
Fast LEO + Data

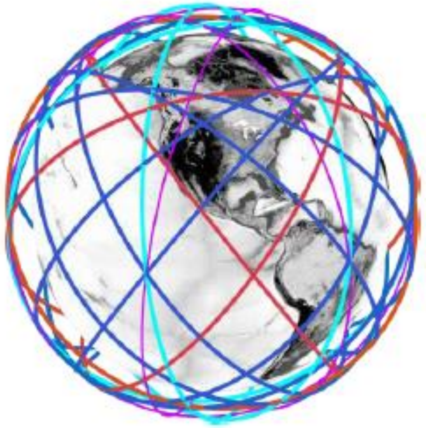
Resilience
Signals 100x Stronger vs GPS

Security
Authentication + Encryption

Initial Phase

32 Satellites
Mid-Latitude Coverage
1-in-view LEO Enhancement

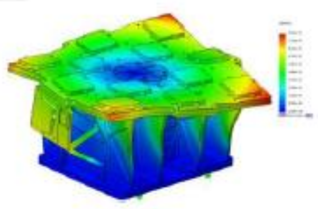
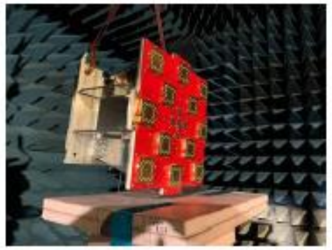
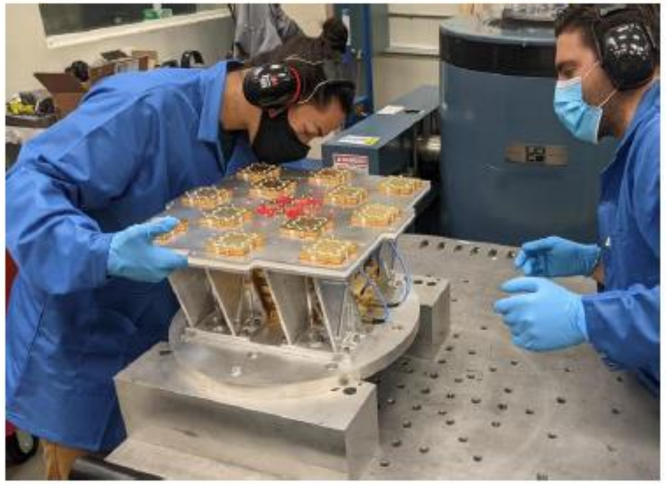
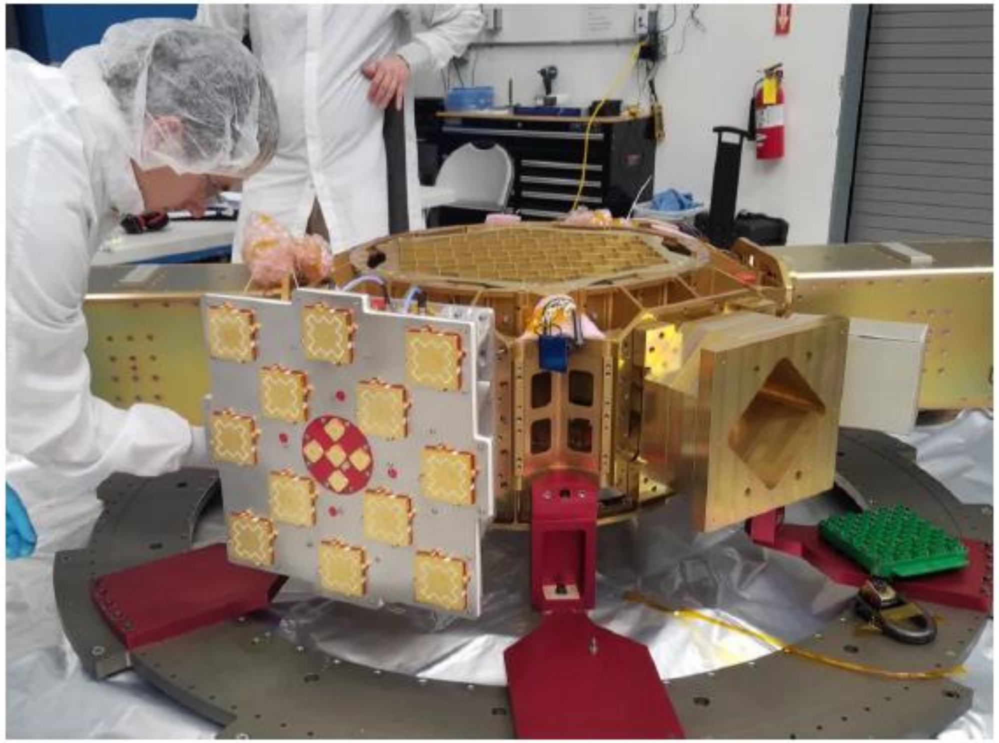
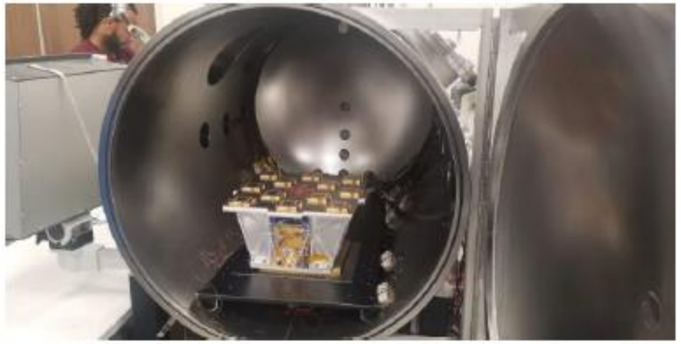
Final Phase

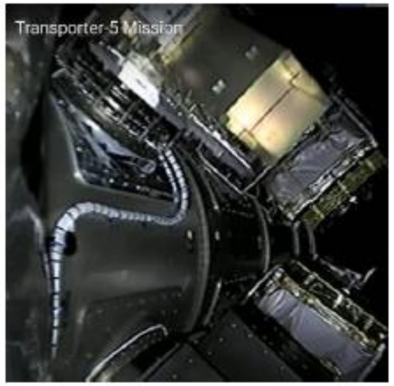


258 Satellites
Global Coverage
Full PNT

TECHNOLOGY PROVEN IN SPACE

Launched May 25, 2022

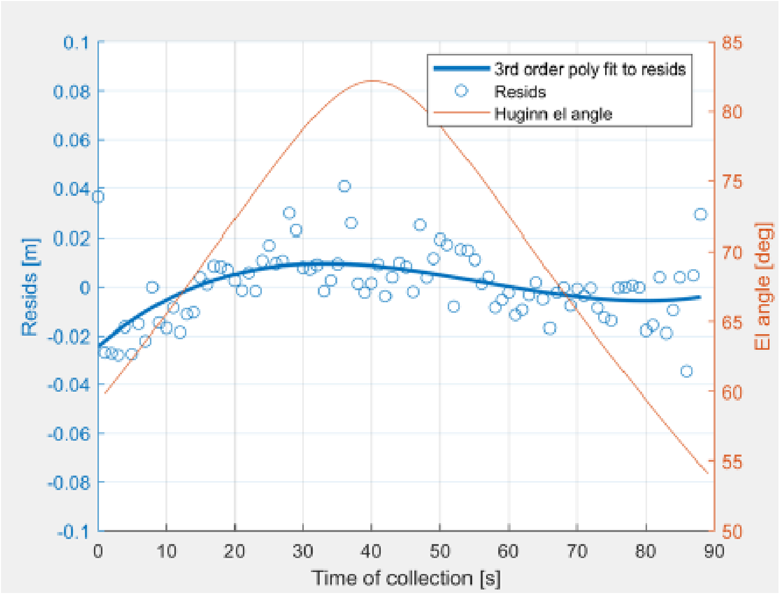








ON-ORBIT PERFORMANCE VALIDATION

- Successfully transmitted precision LEO PNT signals from space to ground.
- Demonstrated cm-level ranging capability.
- Demonstrated the on-orbit re-programmability of Xona's proprietary digital navigation waveform generator.
- Validated Xona's patented distributed clock architecture.

Proven that precision satellite navigation is possible using low-cost commercial-off-the-shelf components



Example cm-level residuals from Xona Satellite Pass

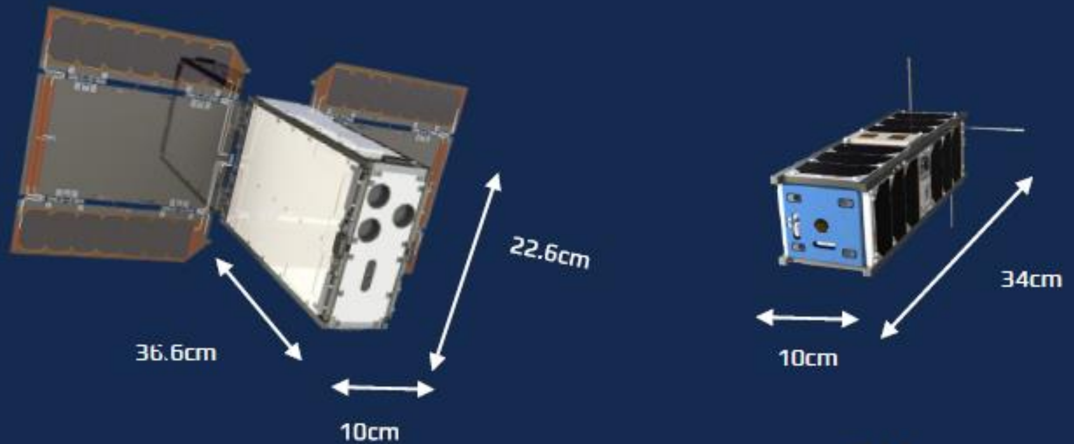
LEO PNT with Nano Satellites

Joshua Critchley-Marrows

Multi-GNSS Asia

1st Feb. 2024

Who We Are?



6U
10cm×22.6cm×36.6cm

3U
10cm×10cm×34cm

CEO Takayoshi Fukuyo

Small Satellite Developer and Space Service Provider

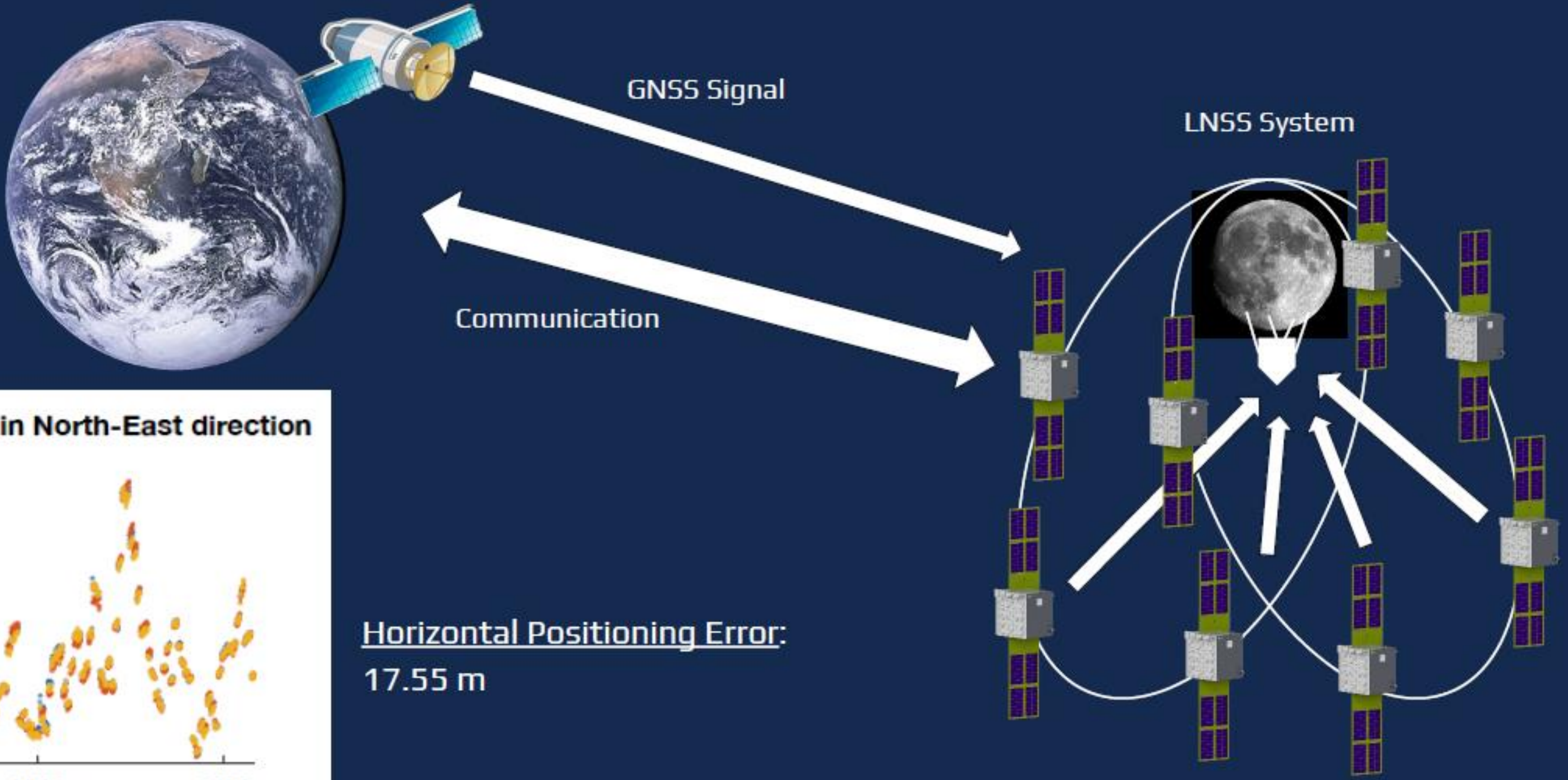
Established in 2018
$22 million capital
100 employees
Located in Tokyo, Japan

Solutions for PNT

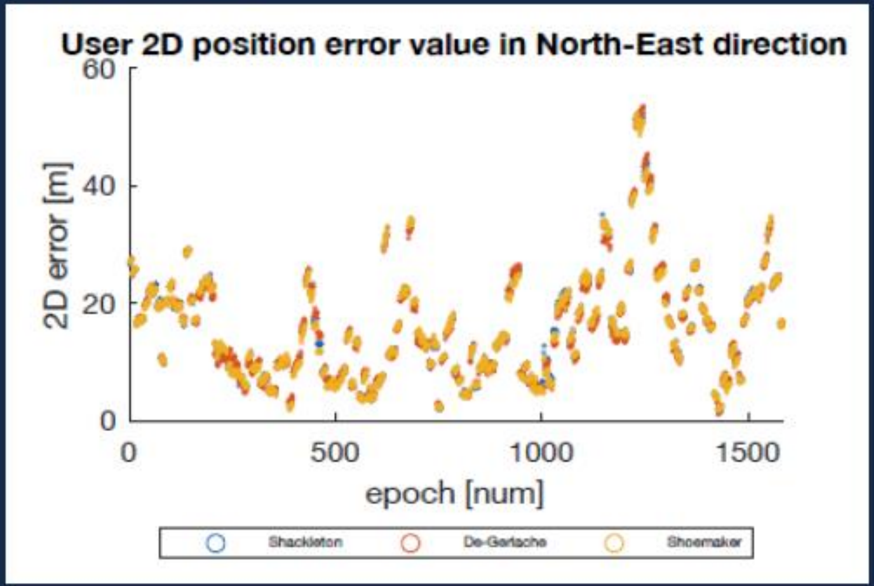
Lunar Navigation Satellite System

ArkEdge Space participates in concept study with JAXA to deliver a Lunar Navigation Satellite System.

This system will harness weak GNSS signals from the Earth to assist in orbit determination and timing of a lunar system.



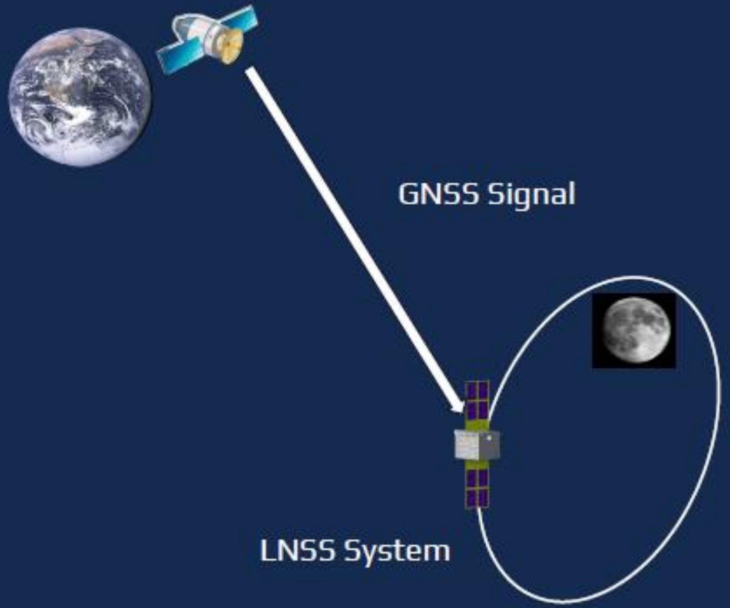
User Position Accuracy on Lunar Surface

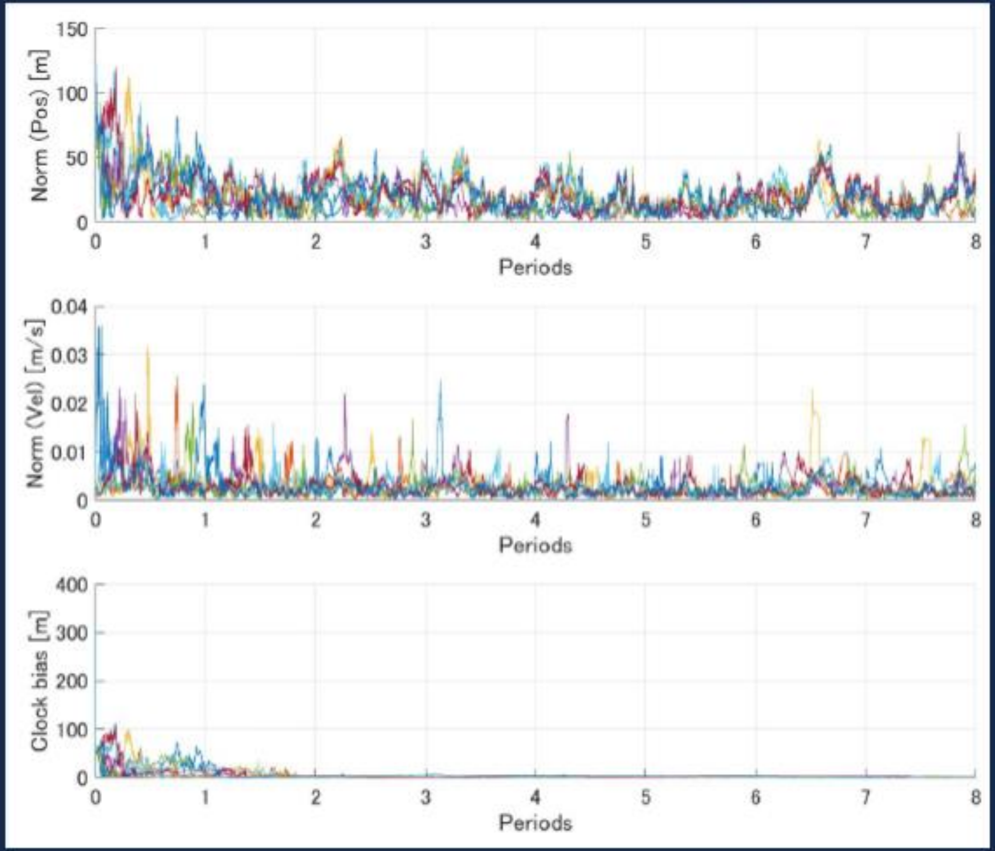


<u>Horizontal Positioning Error</u>:
17.55 m

Lunar Navigation Satellite System

The GNSS receiver is an especially challenging component to this system. We are developing a solution that can deliver accurate Orbit Determination and Time Synchronization (ODTS) from Earth orbiting GNSS side-lobes to the Moon.





<u>Clock Bias</u>: 0.52 m

<u>Clock Drift</u>: 7.0 μs/s

<u>Position</u>
Radial: 12.7 m
Cross-Track: 12.99 m
Along-Track: 9.35 m

<u>Velocity</u>
Radial: 2.2 mm/s
Along-Track: 1.7 mm/s
Cross-Track: 1.2 mm/s

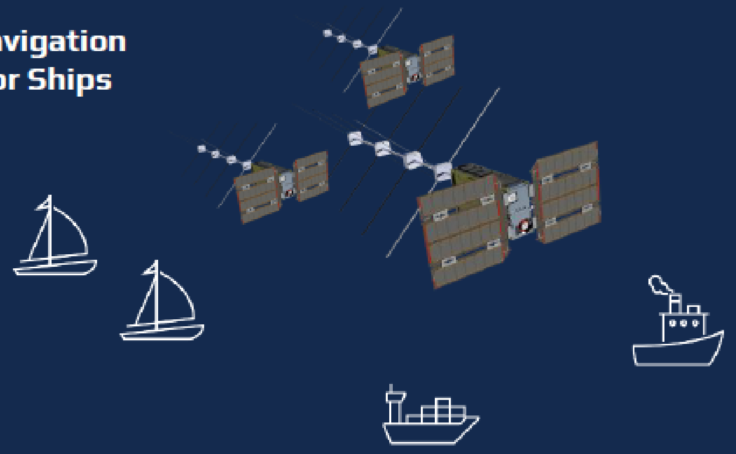
This technology is immediately transferable to a LEO PNT system – the LEO environment is a well-known case for precise ODTS technology.

Solutions for PNT

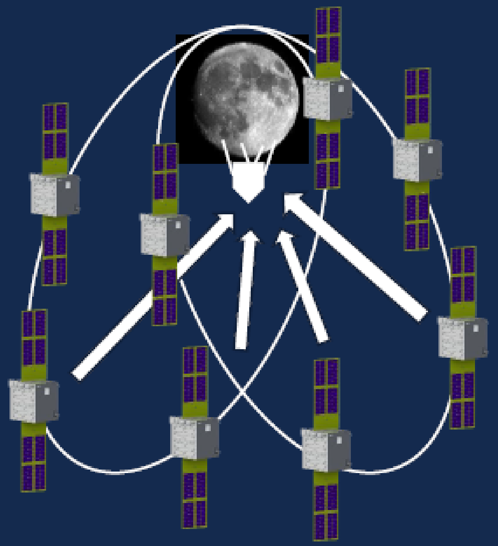
High-Precision and Critical Applications

ArkEdge Heritage

Navigation for Ships



Navigation for the Moon



Translating our Systems to Deliver

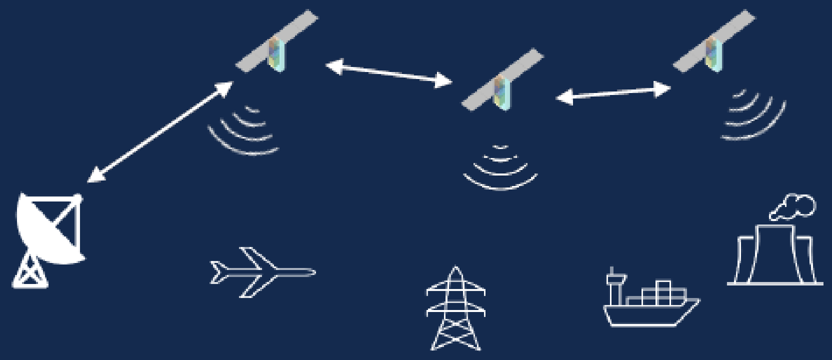
Service Depends on the... **Customer**

ArkEdge Future

Mass Market Applications

High-Precision PNT

- Higher SNR
- More orbital diversity
- Greater precision



Critical Applications

Back-Up PNT

- Independent from GNSS
- Timing and navigation support

未来导航
FUTURE NAVIGATION

Preliminary PPP Experiments and Future Applications of the CENTISPACE™ System

Jan, 2024

Beijing Future Navigation Technology Co., Ltd.

- **With the rapid growth of modern information industries like 5G, mobile internet, autonomous driving, and artificial intelligence, traditional meter-level precision navigation services are no longer sufficient to meet user demands. There is a rising demand for high-precision navigation services in various sectors.**

- **Traditional Professions**

  Surveying, mapping, disaster monitoring, smart grid, communication network, ocean engineering, and more, with demands ranging from sub-meter to millimeter level.

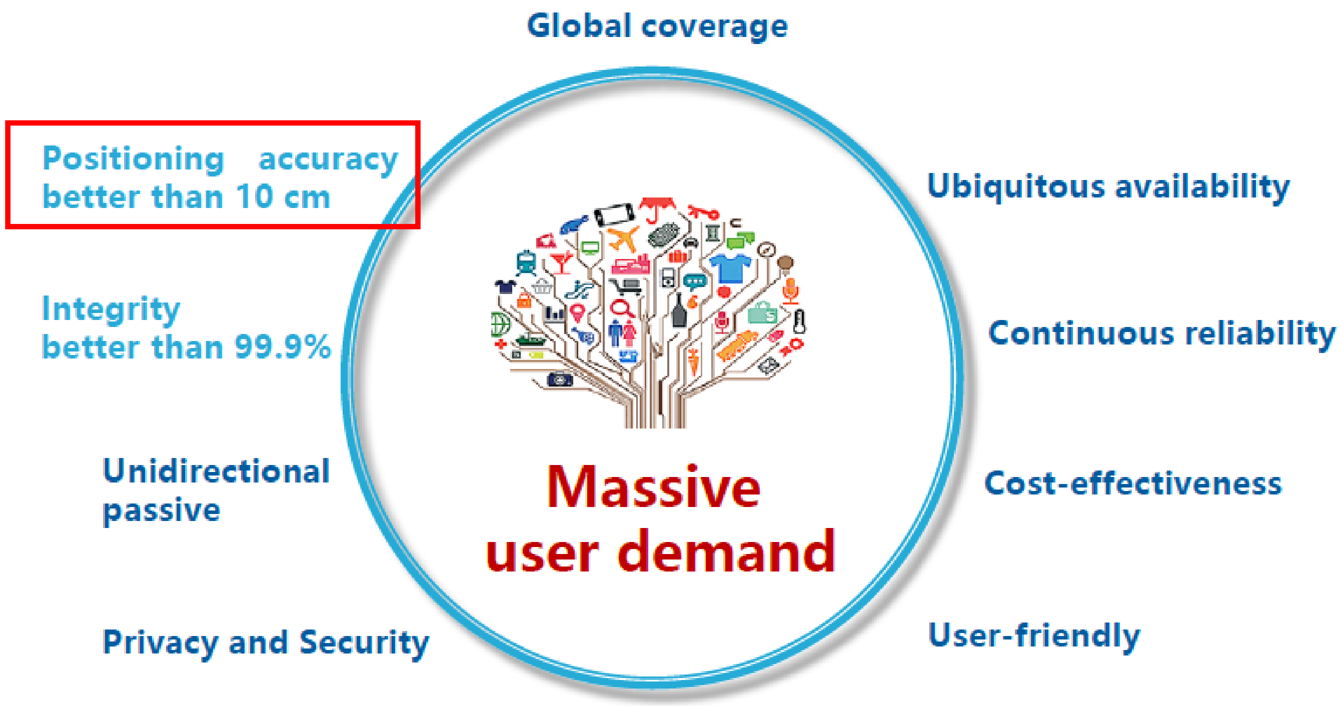
- **UAV Applications**

  With an Annual Shipment Volume of Nearly 4 Million Units, Fundamental Demand for Low-Cost and High-Precision Satellite Navigation.

- **Consumer Electronics**

  With over 5 billion smartphones worldwide, real-time dynamic positioning accuracy of better than 0.3m is essential for pedestrian navigation, and interactive gaming.

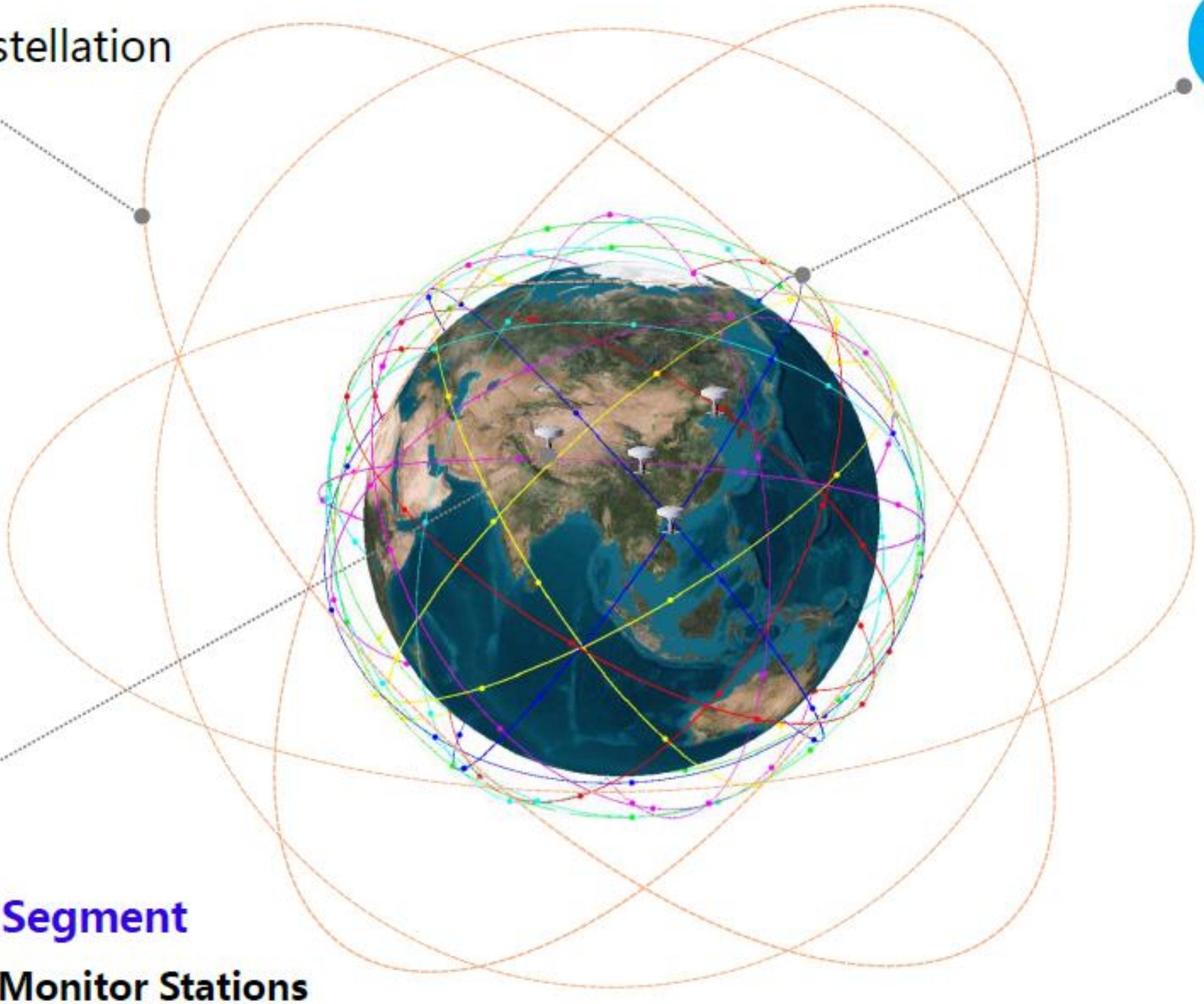
- **Internet of Vehicles, Internet of Things**
  - Global vehicle market: 2 billion vehicles require real-time lane-level navigation accuracy better than 0.3m; autonomous driving demands 10cm.
  - Global terminal device network: 50 billion devices require positioning accuracy of 0.05-0.5m for IoT.



A centralized system is needed with the **SERVICE FEATURE:** As convenient as basic navigation services, high-accuracy.

The CENTISPACE System has two main segments:

GNSS Constellation



Space Segment

190 LEO satellites

- **Sub-constellation I**
  - Constellation : WALKER120/12/1
  - Orbit altitude : 975km
  - Inclination : 55°
- **Sub-constellation II**
  - Constellation : WALKER 30/3/1
  - Orbit altitude : 1100km
  - Inclination : 87.4°
- **Sub-constellation III**
  - Constellation : WALKER 40/4/1
  - Orbit altitude : 1100km
  - Inclination : 30°

Ground Segment

Multiple Monitor Stations

During the Signal Design Process, the Following Factors Were Considered:

- **Lower user device complexity :**

  Common hardware (antenna, filter, A/D, etc.)

- **Interoperability with MEO system :**

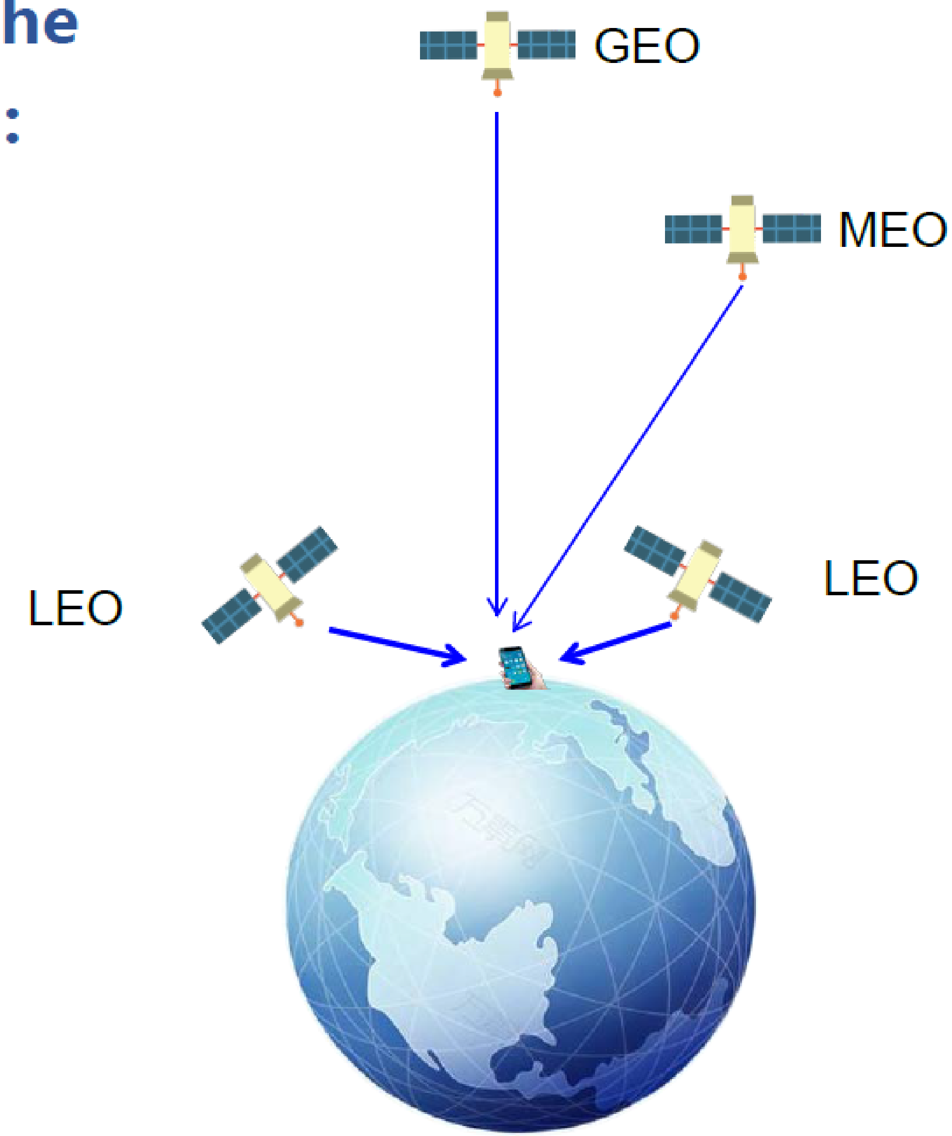
  Common frequency band and reference frame

- **Interoperability with GEO augmentation system:**

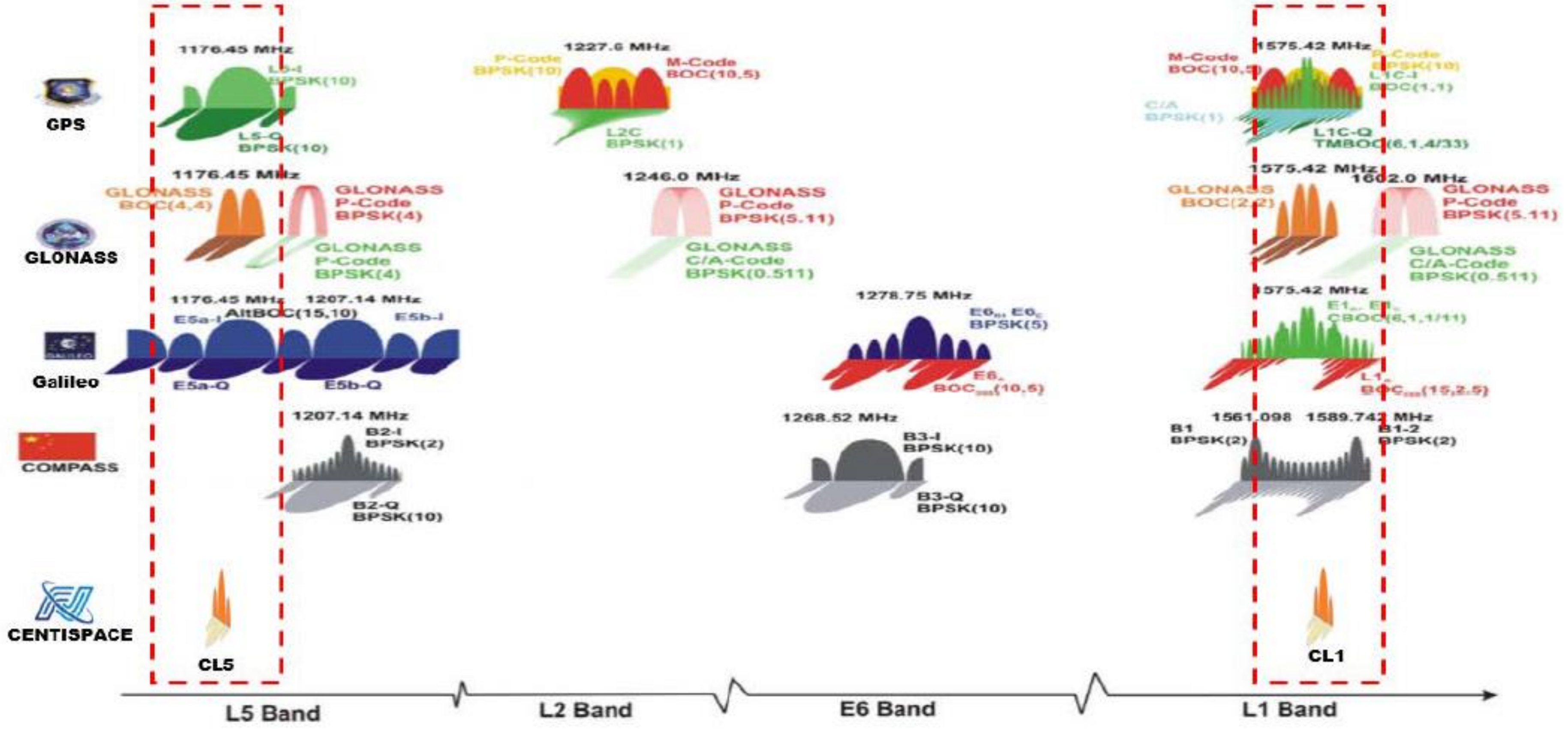
  Common frequency band and reference frame

- **Compatibility with MEO and GEO systems :**

  No signal interference



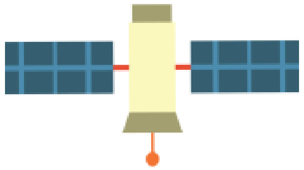
Signal Frequency



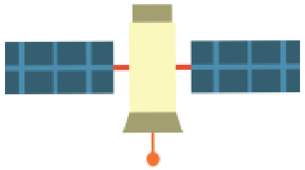
Finally, the combination of L1 and L5 bands is the preferred option.

Space Segment

- **2 experimental satellites in orbit.**



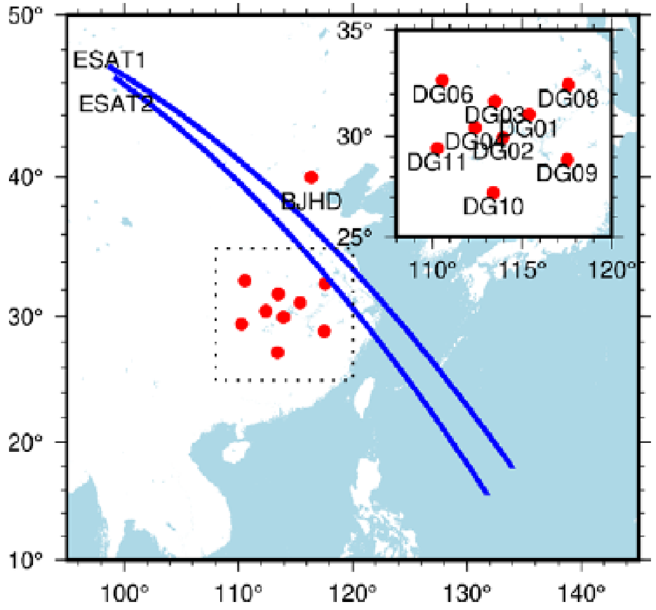
CENTISPACE-ESAT1
(Launch: 6 Sep 2022)



CENTISPACE-ESAT2
(Launch: 7 Oct 2022)

Ground Segment

- **2 stations(DG03 and BJHD) are selected.**

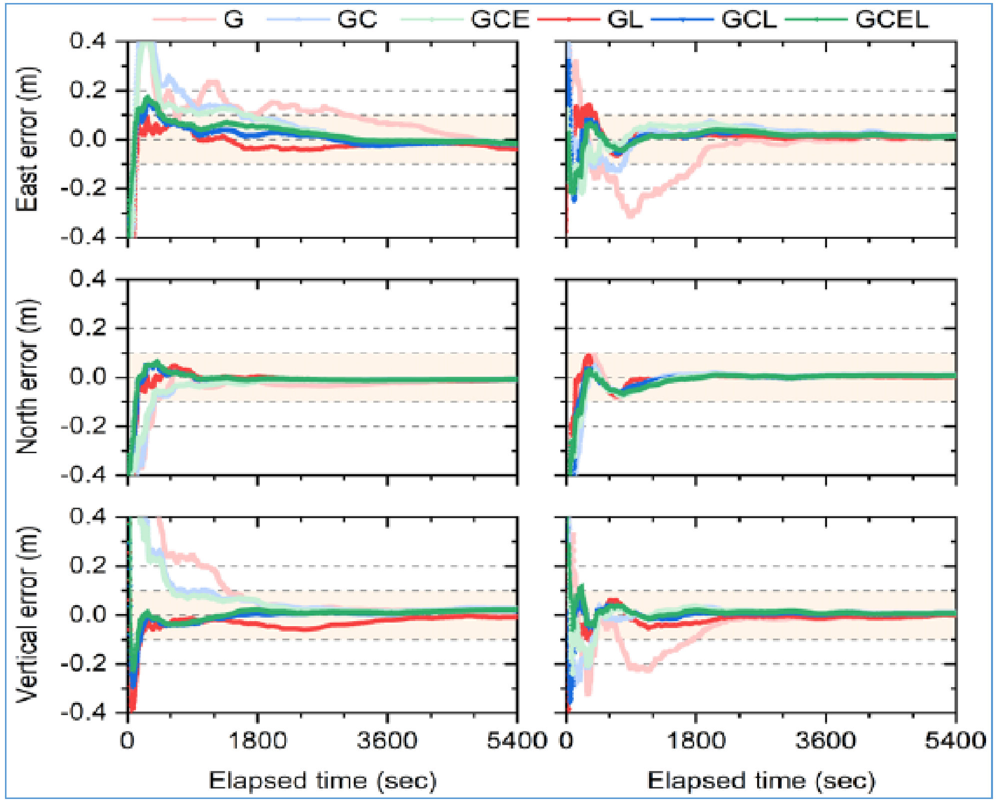


Distribution of the ground stations

Ground tracks of ESAT1 and ESAT2 experimental satellites during 03:40:00-03:50:00 on April 1, 2023.

■ Augmentation of Two LEO Satellites: Potential for PPP

(Precise Point Positioning)



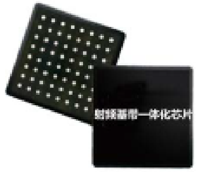
- **Compared in different scenarios, with and without LEO augmentation.**
- **Benefits of LEO augmentation:**
  - **Reduced Convergence Time(about 50% for this data)**
  - **Improved Positioning Precision**

GNSS system number	W/O LEO		With LEO	
	Convergence time (min)	3D precision (cm)	Convergence time (min)	3D precision (cm)
1	32.7	6.1	16.7	5.2
2	17.9	4.6	8.9	3.9
3	14.2	4.6	5.7	3.8

These findings highlight the potential of LEO augmentation, and larger improvements can be achieved with more LEO satellites to be deployed in the future.

Accelerate the Development of LEO-augmented Navigation Basic Products utilizing Existing Application Industries

- **Upgrade products quickly:** To achieve rapid development, we collaborate with chip manufacturers for quick product upgrades.
- **Expand to various fields:** Expand LEO augmentation to various fields, may starting with drones and lane-level navigation.

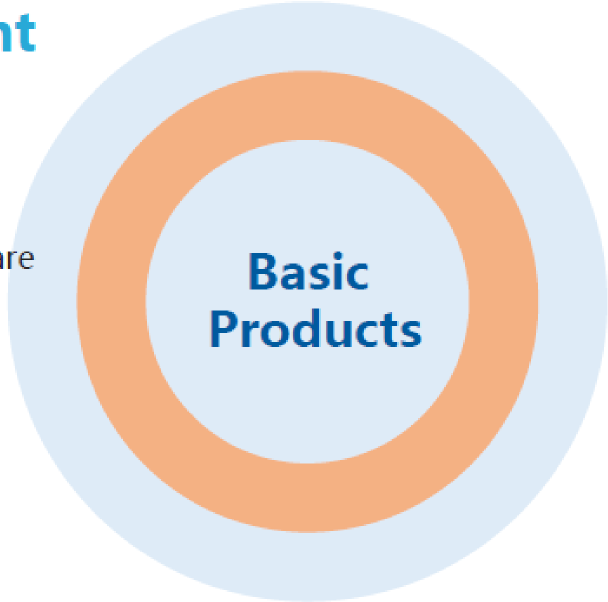


Chip development

The functionality of LEO augmentation can be added through software upgrades while utilizing existing hardware resources.

Antenna development

Simultaneous reception of navigation signal and LEO enhanced signal with similar frequencies.



Board/module development

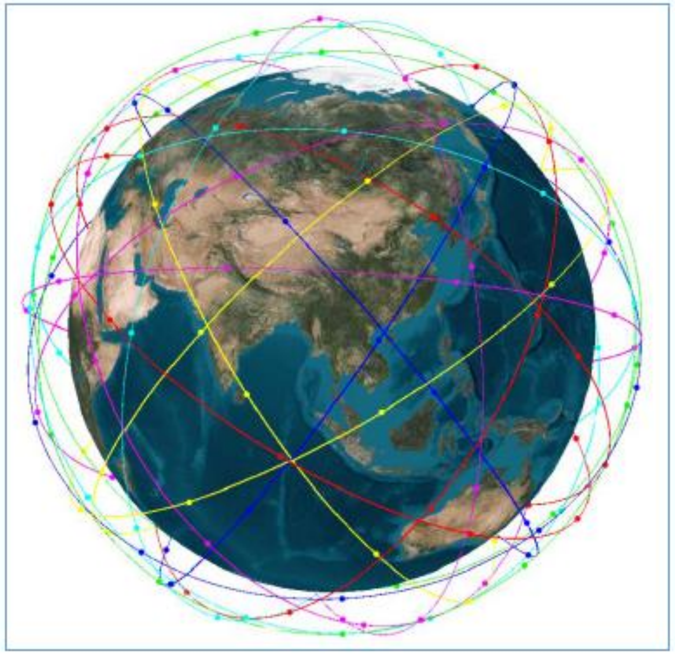
Can be designed for integrated use in various professional devices through chip customization.

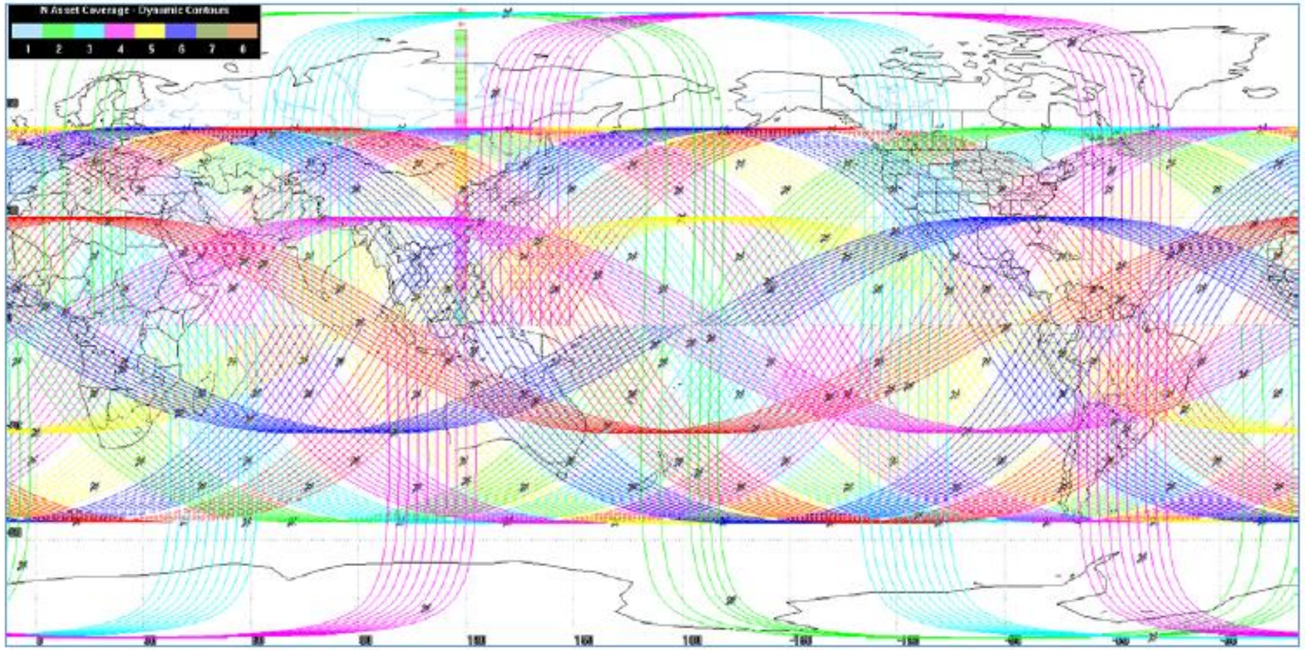
Terminal integration

Customizing User-Oriented Terminal Machines with Added Communication and Storage Modules.

Next Steps

- Complete the construction of the entire constellation within several years.
- Provide worldwide augmentation navigation services.
- This will augment existing navigation systems and provide precise positioning.



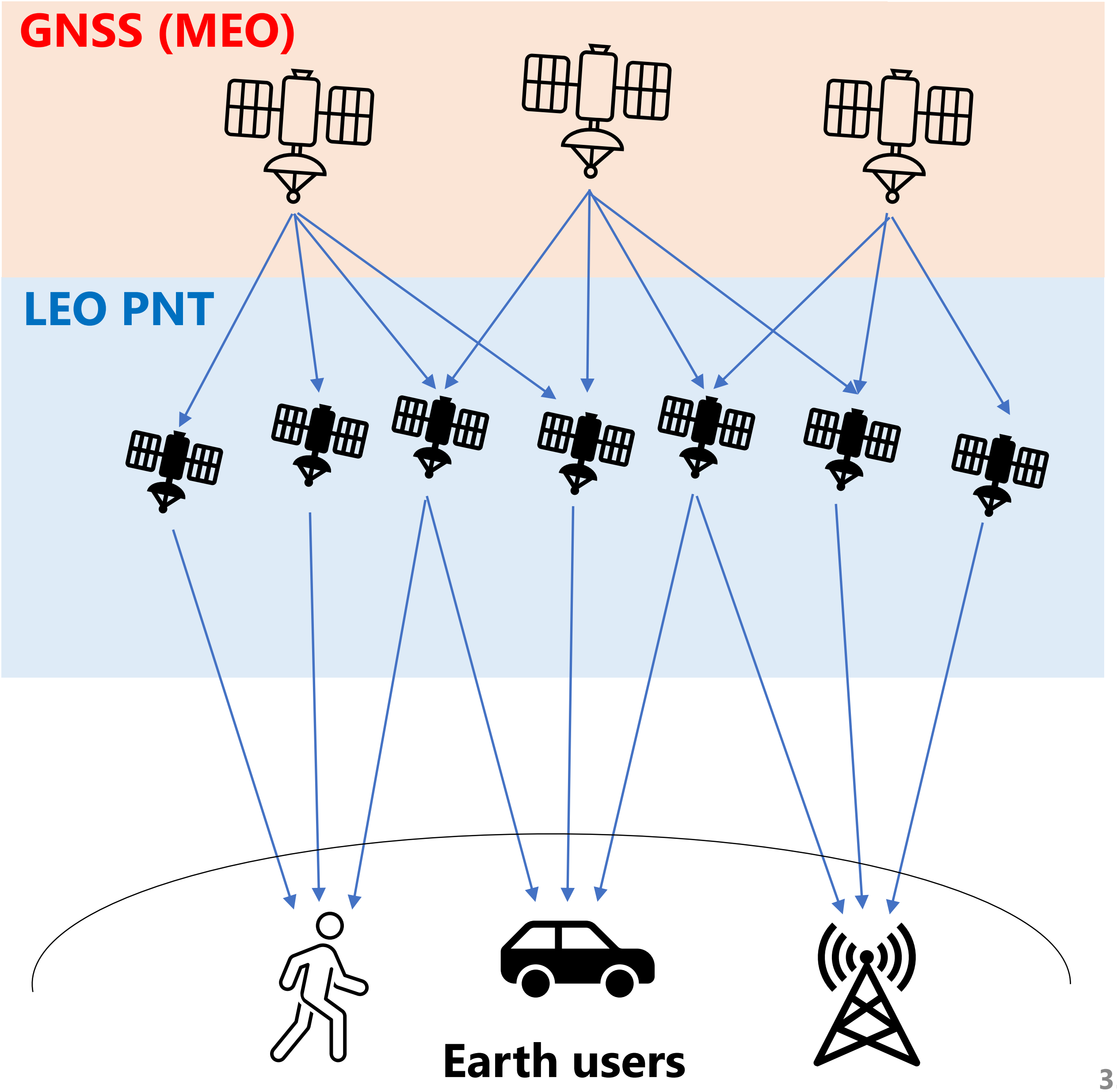


Preliminary Study on JAXA LEO PNT System

Masaya Murata (JAXA)

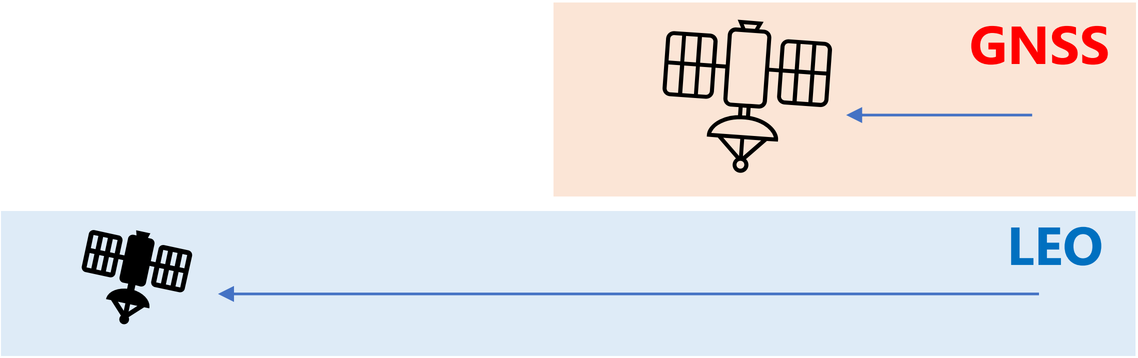
Our LEO PNT Concept

- ☐ LEO PNT augmentation for the existing GNSS
- ☐ Provision of an alternative PNT service to the GNSS
- ☐ Highly autonomous LEO PNT system driven by onboard GNSS navigation for LEO sats
- ☐ Enabling the ultra-rapid precise point positioning (PPP) convergence service for Earth users



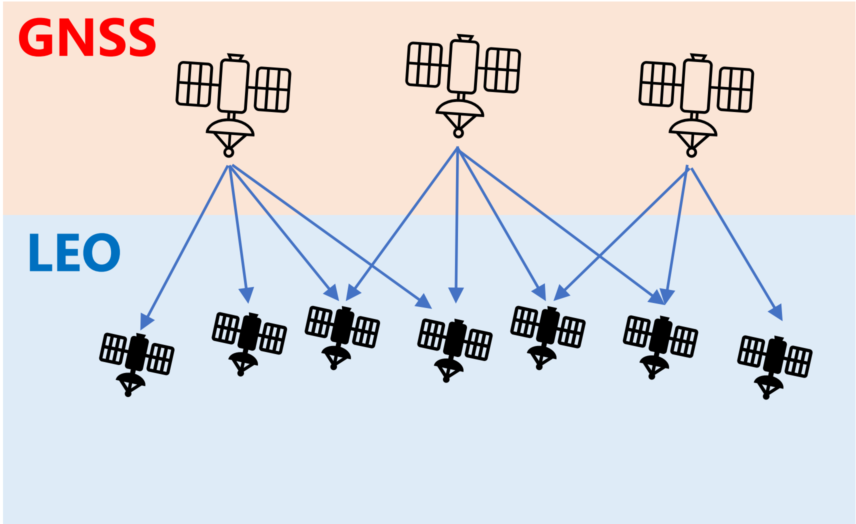
Acceleration of PPP Convergence by LEO PNT

1.



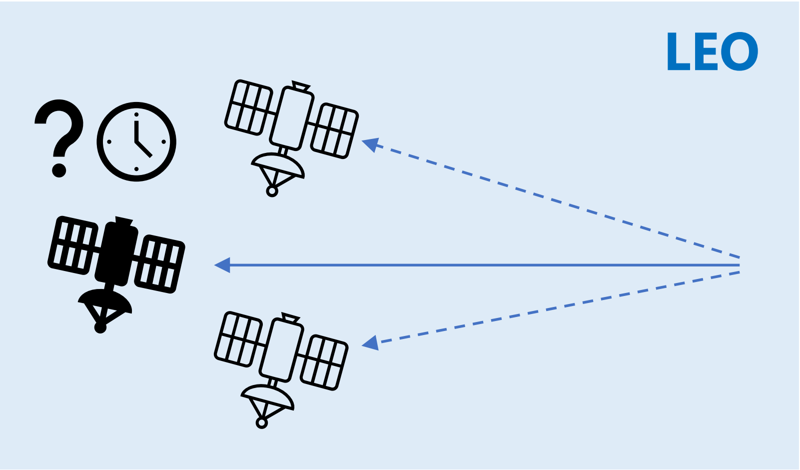
・Much faster satellite movement than GNSS, yielding temporally diversified measurements

2.



・Much larger number of satellites than GNSS, yielding spatially diversified measurements

3.



・Precise orbit and clock estimation for LEO sats by using precise GNSS measurements

Overall Results on PPP Convergence Time

- **Effect of the number of LEO sats and SISE values on the PPP convergence time. ○ and ○○ show the confirmed convergence times less than three minutes and one minute, respectively**

# of LEO satellites	SISE=2cm	SISE=10cm	SISE=20cm	SISE=30cm	SISE=40cm
30	×	×	×	×	×
60	○	×	×	×	×
120	○○	○	○	×	×
240	○○	○	○	○	×
480	○○	○○	○	○	○

3 mins PPP

Selected as our phase I LEO PNT system using 240 sats with SISE of 20cm (RMS)

1 min PPP

Selected as our phase II LEO PNT system using 480 sats with SISE of 10cm (RMS)

Reference:

	standard EKF	proposed EKF (3)
< 10 mins	11%	12%
< 20 mins	55%	56%
< 30 mins	76%	76%
< 40 mins	84%	86%
< 50 mins	86%	88%
< 60 mins	88%	90%
< 70 mins	91%	92%
< 80 mins	92%	94%
< 90 mins	94%	96%
< 100 mins	94%	97%
< 110 mins	96%	98%
< 120 mins	97%	100%
Average CT	28 mins and 32 secs	25 mins and 48 secs

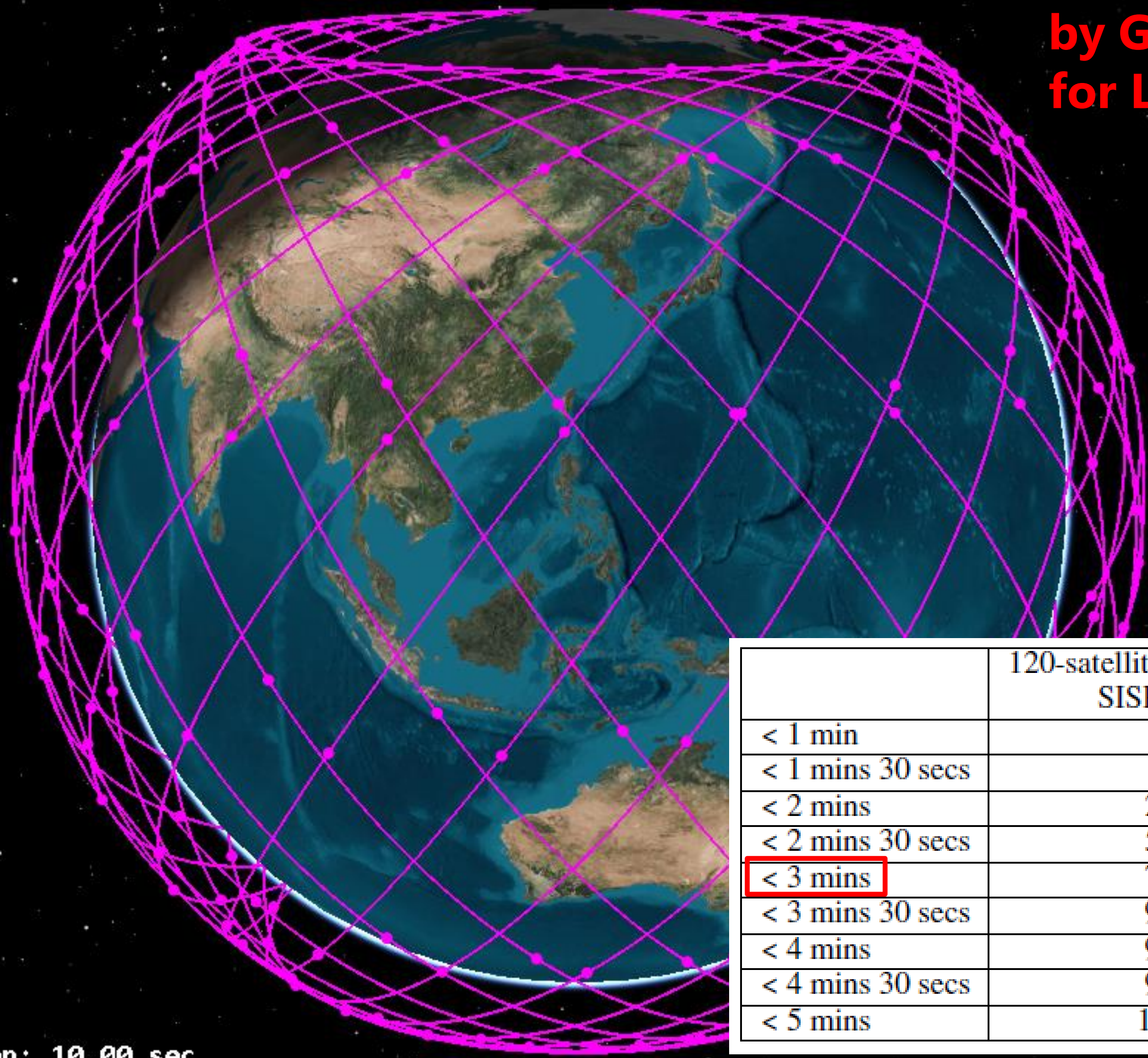
PPP convergence time by GPS was about 25-30 minutes

Phase I (2030)

Our LEO PNT Constellation Plan Using 240 Satellites

Walker 55° :240/24/1 (Altitude = 975km)

SISE of 20cm (RMS) by GNSS onboard navigation for LEO sats



LEO PNT navigation signal in C-band (5030-5250 MHz)

10cm-level horizontal PPP convergence less than three minutes

	120-satellite constellation, SISE=20cm	240-satellite constellation, SISE=20cm
< 1 min	0%	1%
< 1 mins 30 secs	3%	22%
< 2 mins	23%	67%
< 2 mins 30 secs	57%	96%
< 3 mins	78%	99%
< 3 mins 30 secs	90%	100%
< 4 mins	96%	100%
< 4 mins 30 secs	99%	100%
< 5 mins	100%	100%

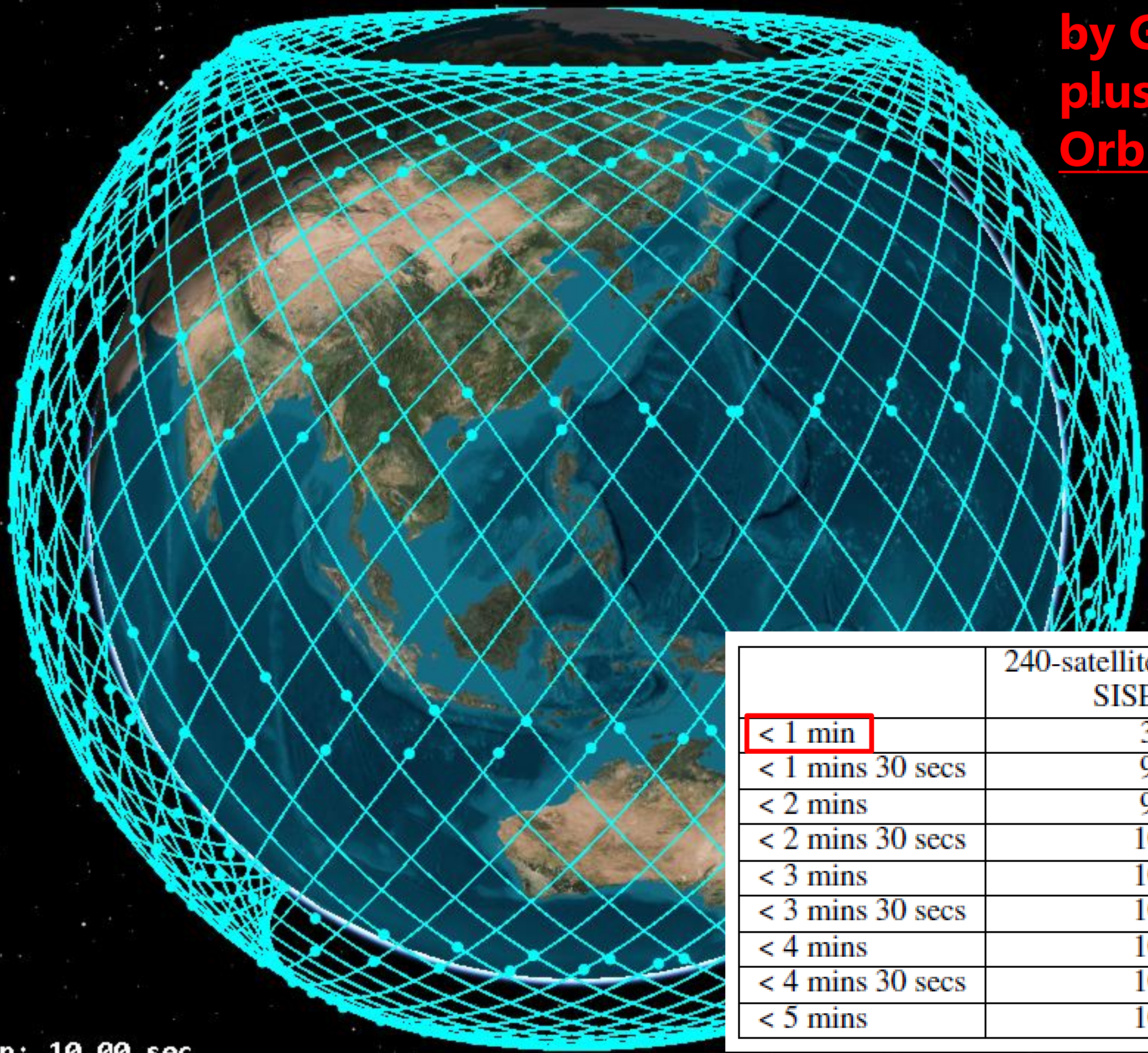
Phase II (2035)

Our LEO PNT Constellation Plan Using 480 Satellites

JAXA

Walker 55° :480/48/1 (Altitude = 975km)

SISE of 10cm (RMS) by GNSS onboard navigation plus on-ground POD (Precise Orbit Determination)



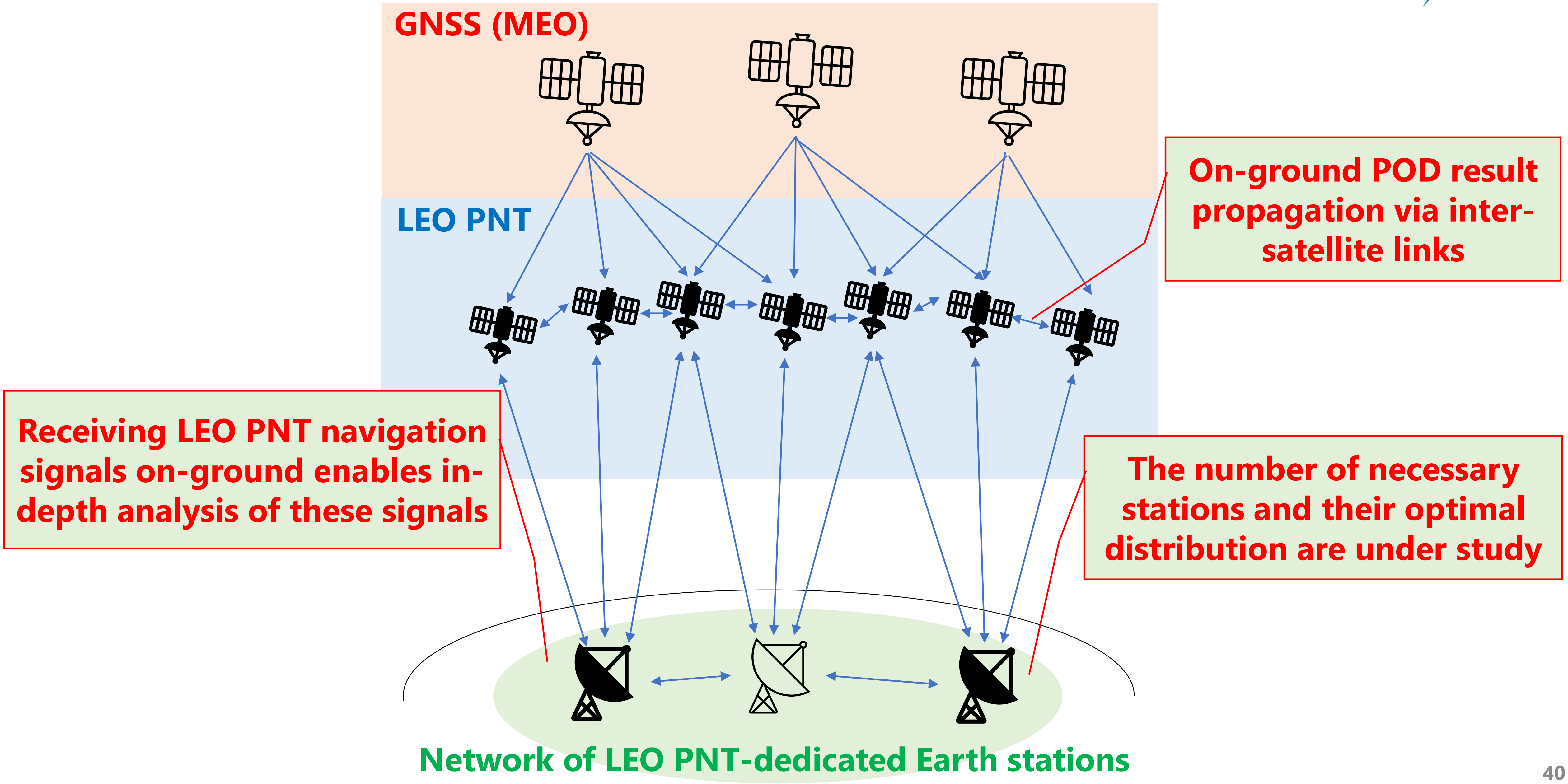
LEO PNT navigation signal in C-band (5030-5250 MHz)

10cm-level horizontal PPP convergence less than one minute

	240-satellite constellation, SISE=10cm	480-satellite constellation, SISE=10cm
< 1 min	33%	77%
< 1 mins 30 secs	90%	99%
< 2 mins	99%	100%
< 2 mins 30 secs	100%	100%
< 3 mins	100%	100%
< 3 mins 30 secs	100%	100%
< 4 mins	100%	100%
< 4 mins 30 secs	100%	100%
< 5 mins	100%	100%

Phase II (2035)

On-Ground POD to achieve SISE level of 10cm



Takeaways

- **JAXA started the design of the LEO PNT system and our initial design results were shown in this talk**

- **Our phase I LEO PNT system aims to provide the ultra-rapid PPP convergence service less than three minutes by the onboard GNSS navigation for the LEO satellites**

- **At phase II, we aim to provide the PPP convergence service less than one minute by also using the LEO PNT-dedicated ground stations and the on-ground POD results**

- **We design our system to be interoperable and compatible with the other LEO PNT systems under development. We are happy to join such international interoperability discussion!**