16th Meeting of the International Committee on
Global Navigation Satellite Systems

LEO Enhanced PNT

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China Satellite Navigation Project Center
Oct. 2022

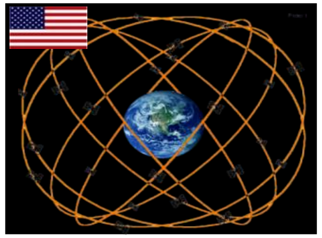
CONTENTS

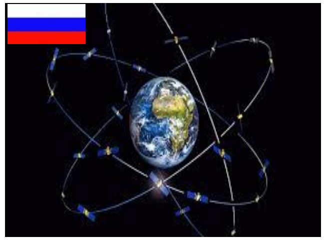

01 Status of Satellite Navigation System

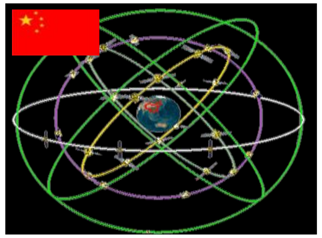
Major Global/Regional Navigation Satellite Systems

Global Navigation Satellite System

GPS **GLONASS** **BeiDou** **Galileo**







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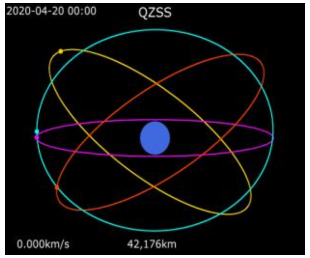
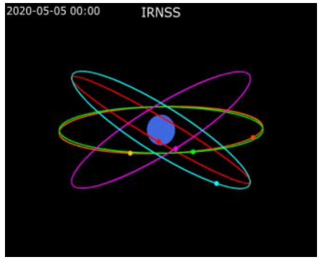
Regional Navigation Satellite System

QZSS **NavIC**





GNSS Error Budget

Ephemeris errors

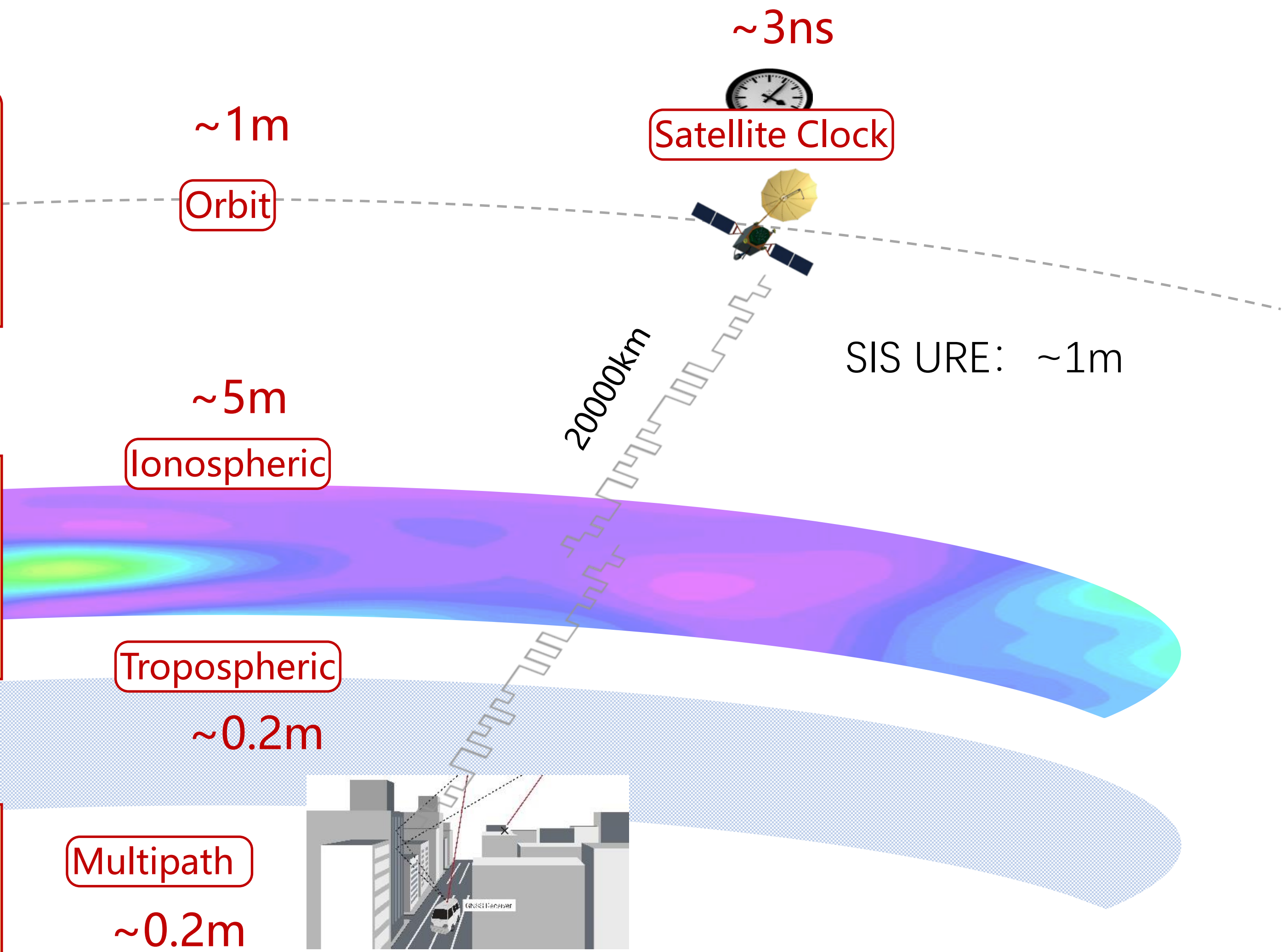
Satellite Orbit
Satellite Clock

Atmospheric errors

Ionospheric
Tropospheric

Receiver errors

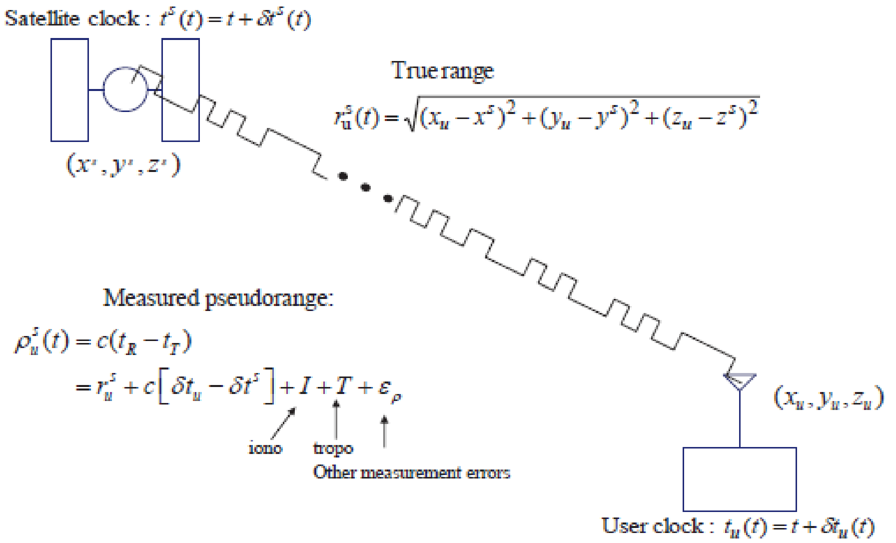
Multipath
Receiver Clock



Further error refinement: limited contribution for performance improvement

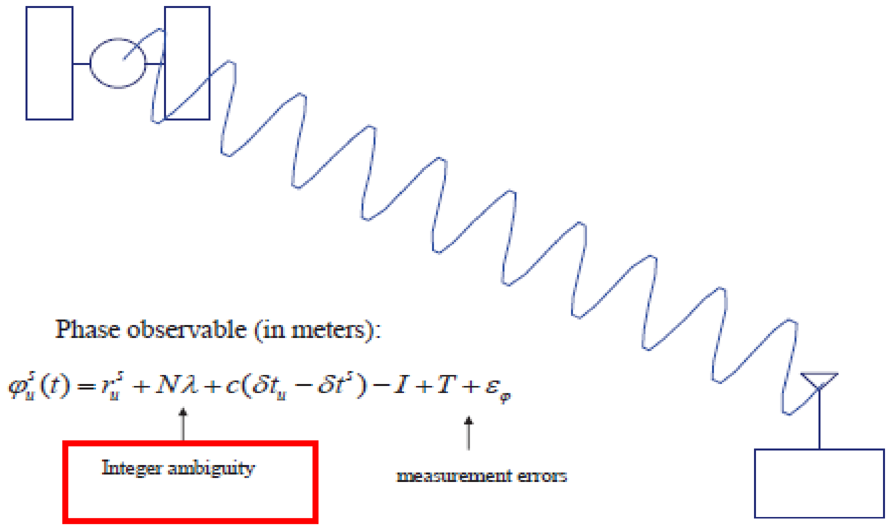
GNSS Measurements

- **Pseudo-range (code):**
  - New signal modulation and more precise URE
  - Noise reduced to 0.1m level by carrier-phase/doppler smoothing tech



$$P(Ambiguity) = f(\dot{s}, PDOP) = \kappa \frac{\dot{s}}{PDOP}$$

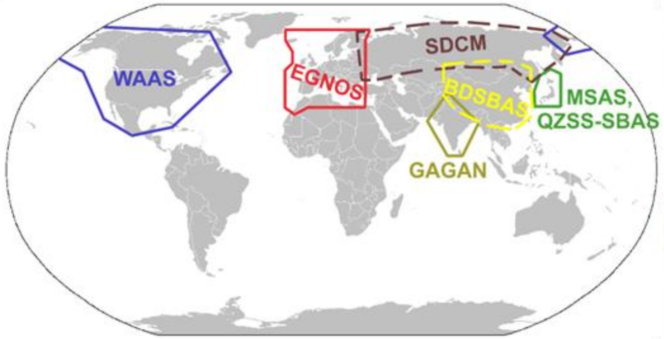
- **Carrier-phase (phase)**
  - Used for high-accuracy
  - Ambiguity is still hard to precisely fixed in short period



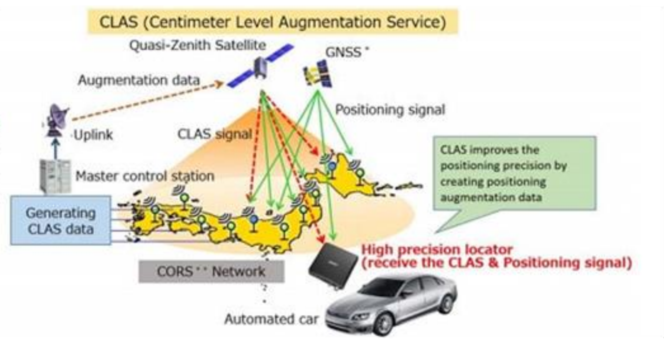
Satellite Orbit	Convergence time
LEO (1000km)	1minute
MEO (20000km)	20minutes
BDS IGSO (36000km)	120minutes

GNSS Augmentation

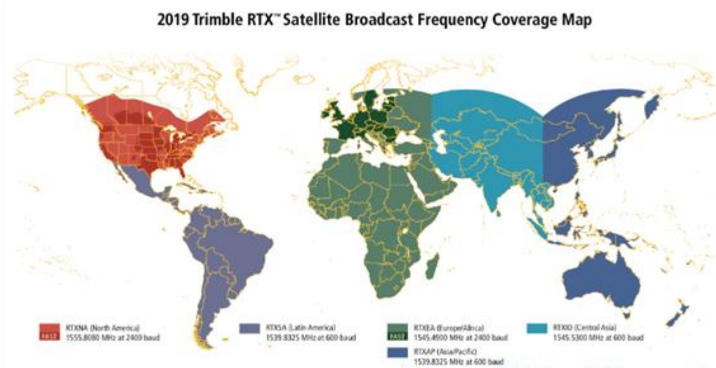
SBAS



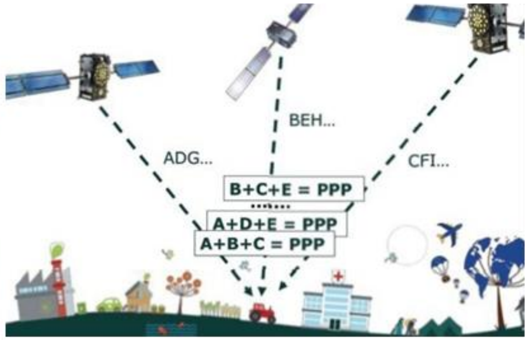
QZSS CLAS service



Trimble RTX

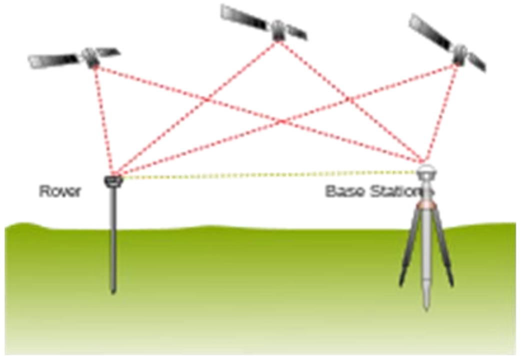


Galileo HAS / BDS B2b PPP



Satellite-Based Augmentation:

Accuracy is enhanced through the transmission of wide-area corrections for GNSS range errors



Real Time Kinematic Positioning

QianXun SI

Ground-Based Augmentation:

Provides differential corrections and covers a relatively small area

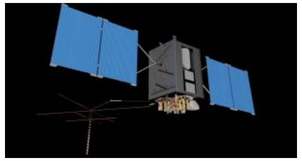
Current SBAS or GBAS cannot provide world-wide real-time cm-level positioning service

Contribution of LEO navigation

02

Satellite Navigation Started From LEO

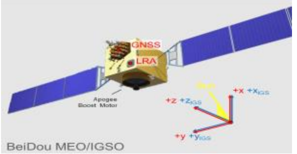
1960s,
LEO navigation



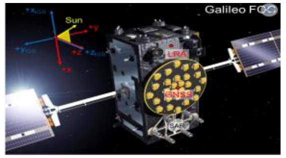
1978,
GPS

1982,
GLONASS

2000,
BDS-1



2007,
BDS-2



2011,
Galileo

2017,
BDS-3

2016,
Iradium/Next
(STL)

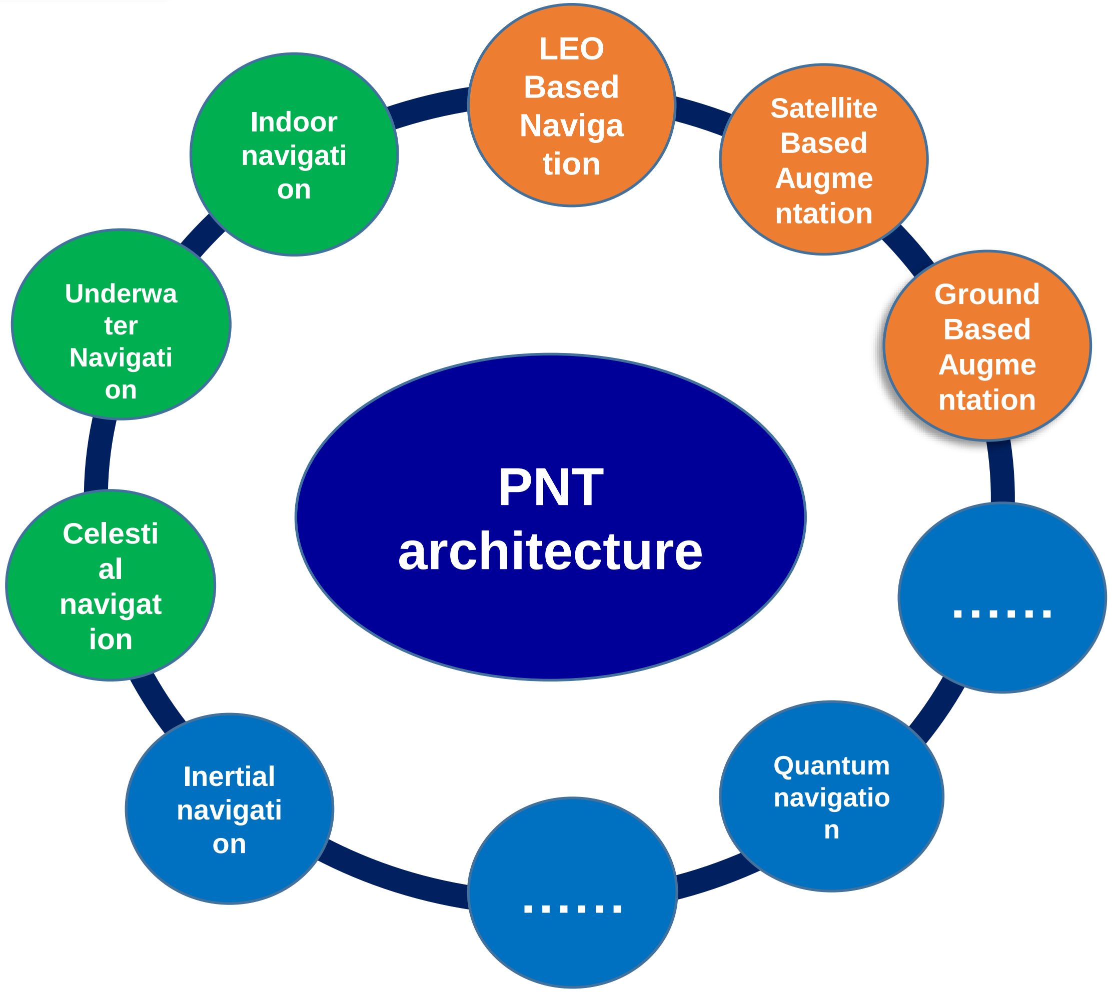
Orbit：LEO

- Measurement：Doppler

Orbit：MEO/GEO/IGSO

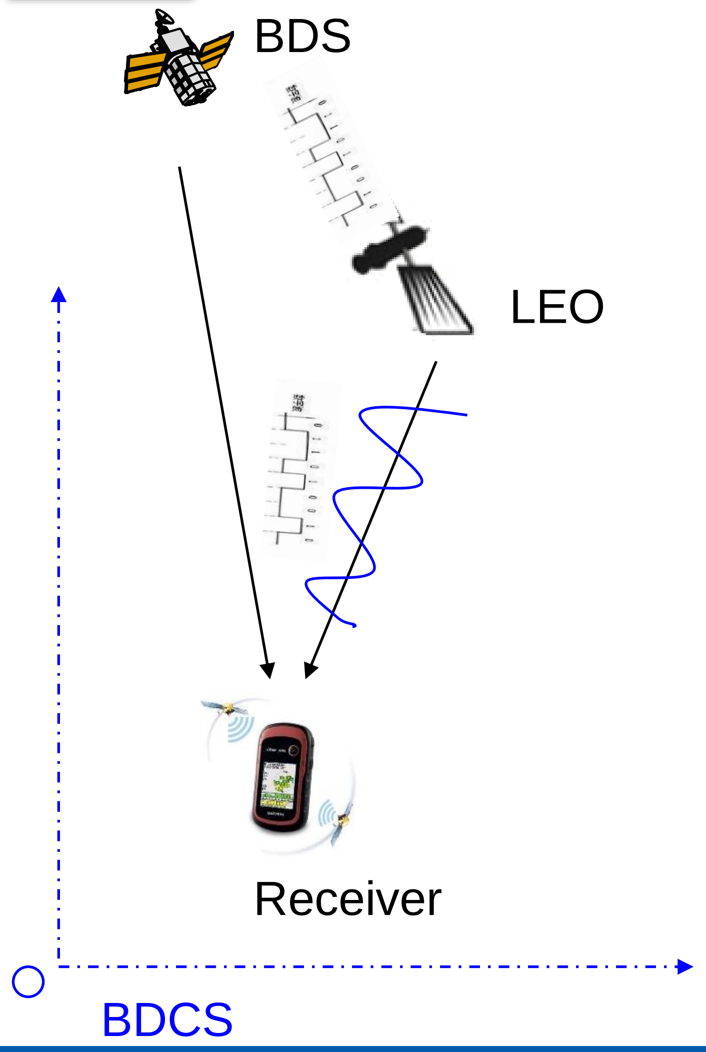
- Measurement：Pseudorange+ Carrier Phase +Doppler

LEO PNT Systems From China



- LEO constellation becomes a part of China comprehensive PNT infrastructure
- Chinese Commercial companies have been deeply involved in LEO navigation constellation construction
  - >10 LEO satellites have been launched over last 5 years for navigation tests
  - LEO constellation will be completed within 3-4 years

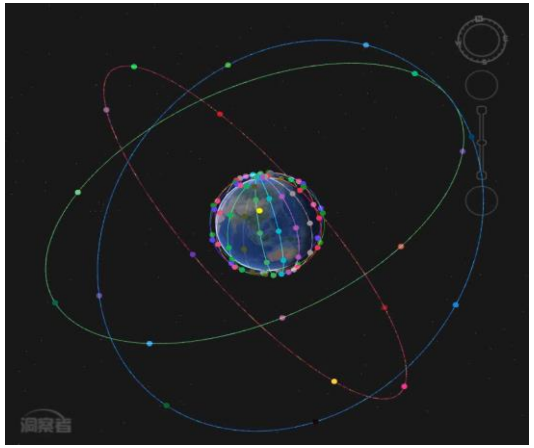
Advantages Of LEO navigation

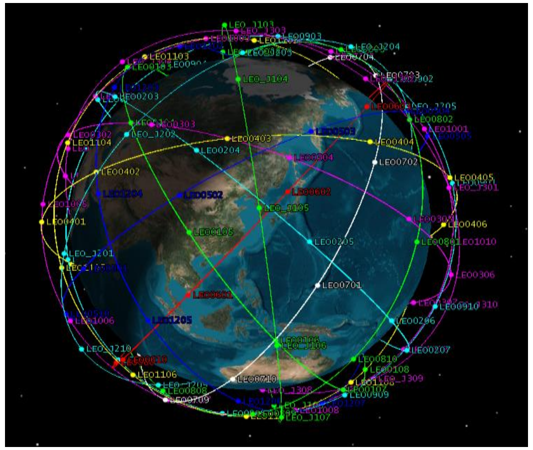


- Space-based GNSS Augmentation System
  - large data downlink bandwidth beneficial for real-time high-precision GNSS correction broadcast
  - two way confirmation to improve anti-spoofing capability
- User received Signal Power
  - signal power can 25–30 dB higher than GNSS （the orbit altitude is much lower than GNSS) (communication service)
  - GNSS C&I needs similar user received power level (RNSS)
- Accelerate the Convergence Speed of PPP
  - Improving PDOP with LEO-based navigation signals
  - reduce PPP convergence (~30 mins with GNSS → minute level)
- Enhanced Estimation of GNSS orbit/clock, EOP…
  - world-wide GNSS tracking with onboard receivers

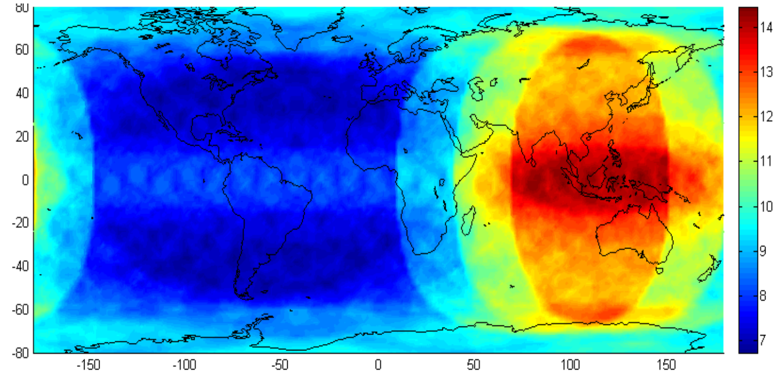
Advantages Of LEO navigation

- LEO constellation simulation
  - Walker 120/10/1, 975 km, 55°
  - Walker 30/3/1, 1200km, 85°
- LEO visibility

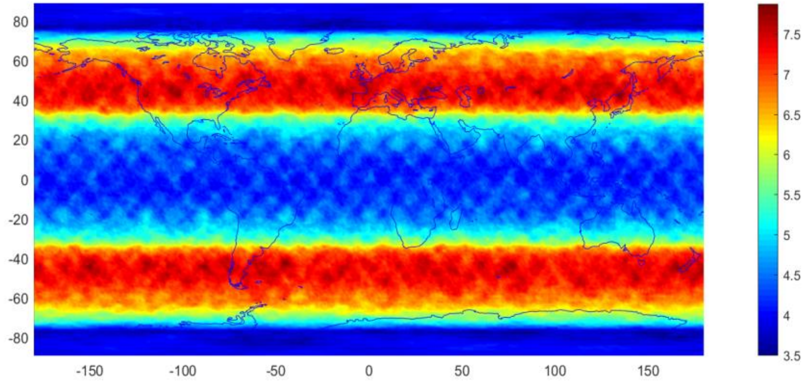




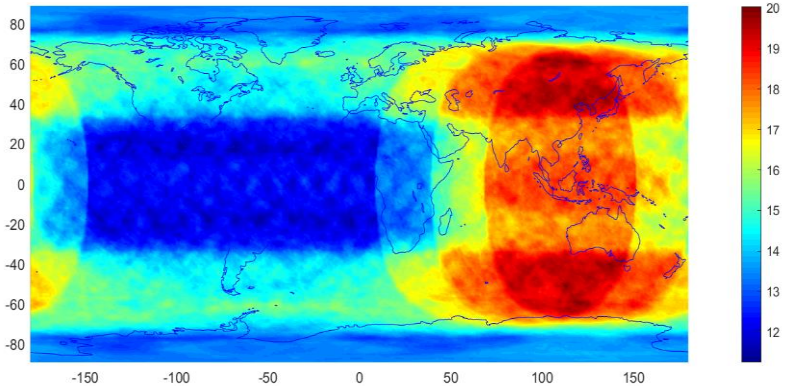
BDS satellite number



LEO satellite number



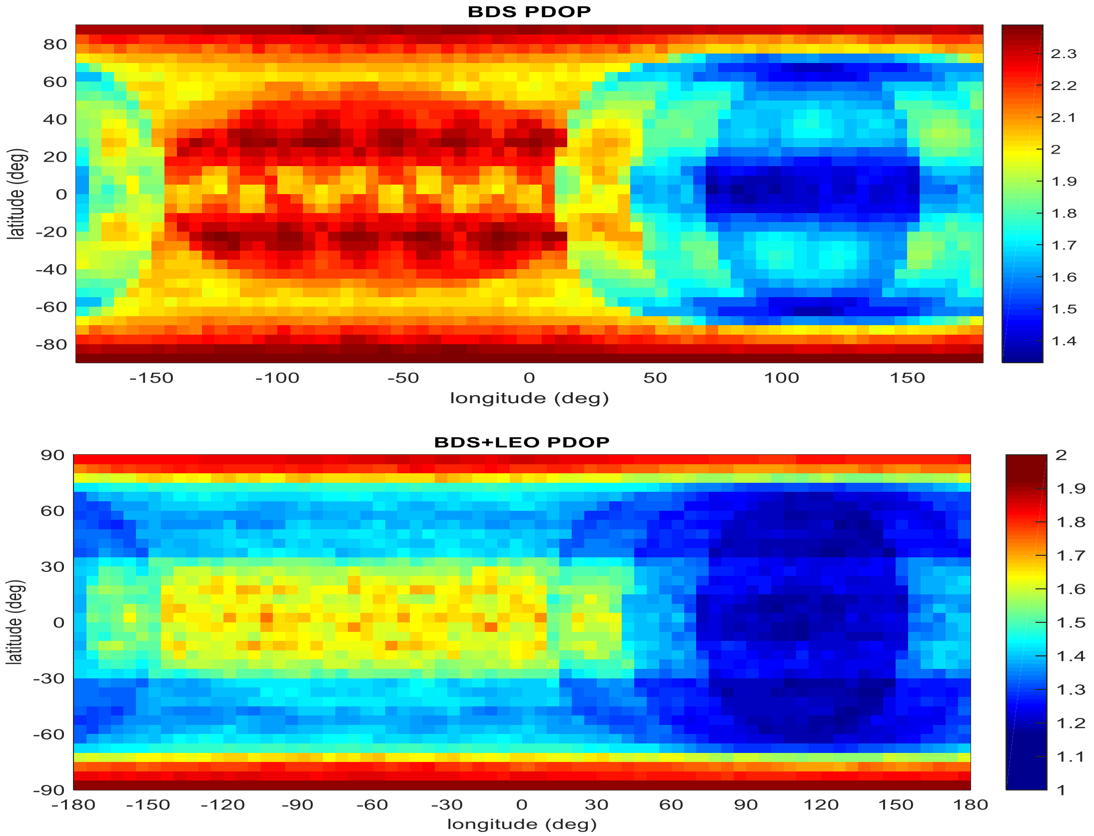
BDS+LEO satellite

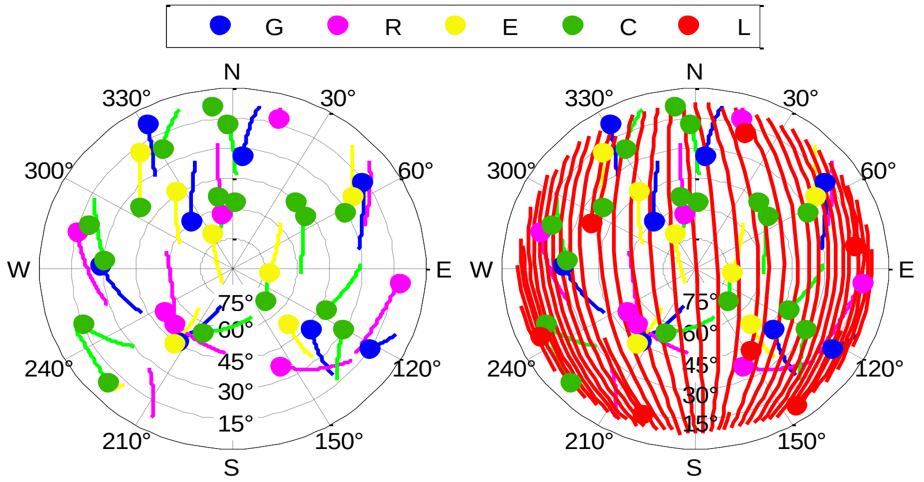


➢ **> 2 LEOs globally, > 6 LEOs for high latitudes, 4 LEOs on average**

Advantages Of LEO navigation

☐ PDOP improvement





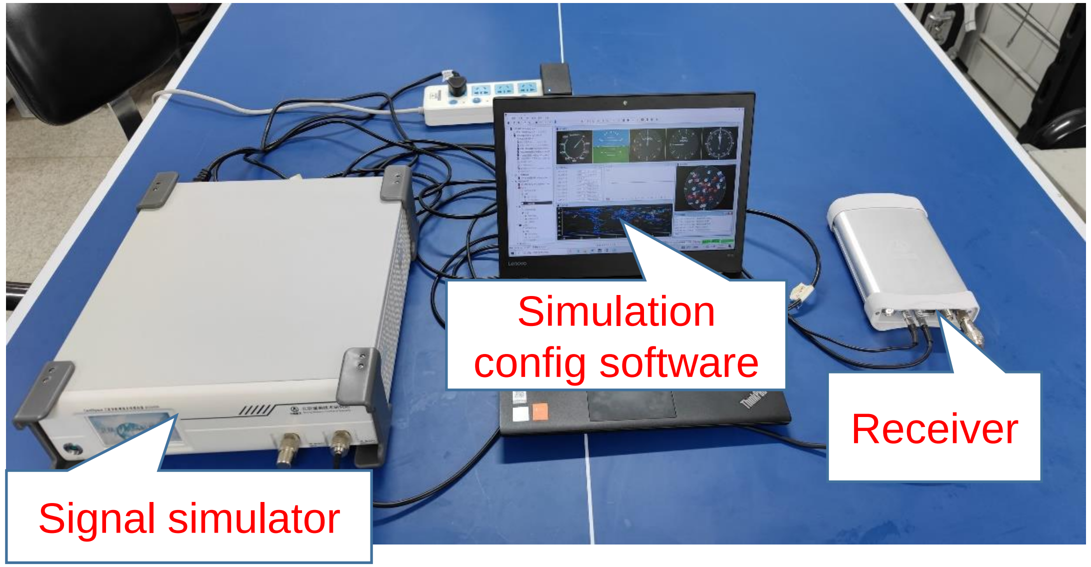
	PDOP MAX	PDOP MIN	PDOP AVE
BDS	2.39	1.13	**1.99**
BDS+ LEO	1.93	1.10	**1.48**

- **PDOP improvement 30%**

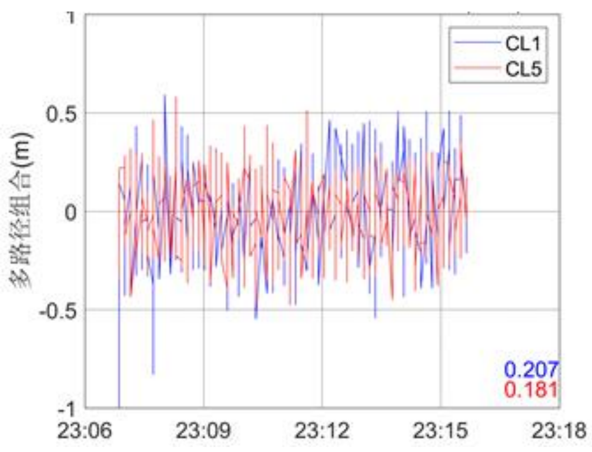
Advantages Of LEO navigation

PPP argumentation by LEO

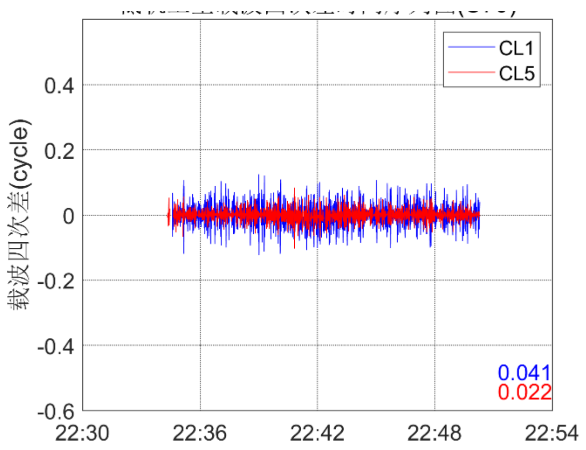
- Test data collected from a signal simulator
- LEO signal frequency: L1/L5



Hardware simulator development



LEO code MP

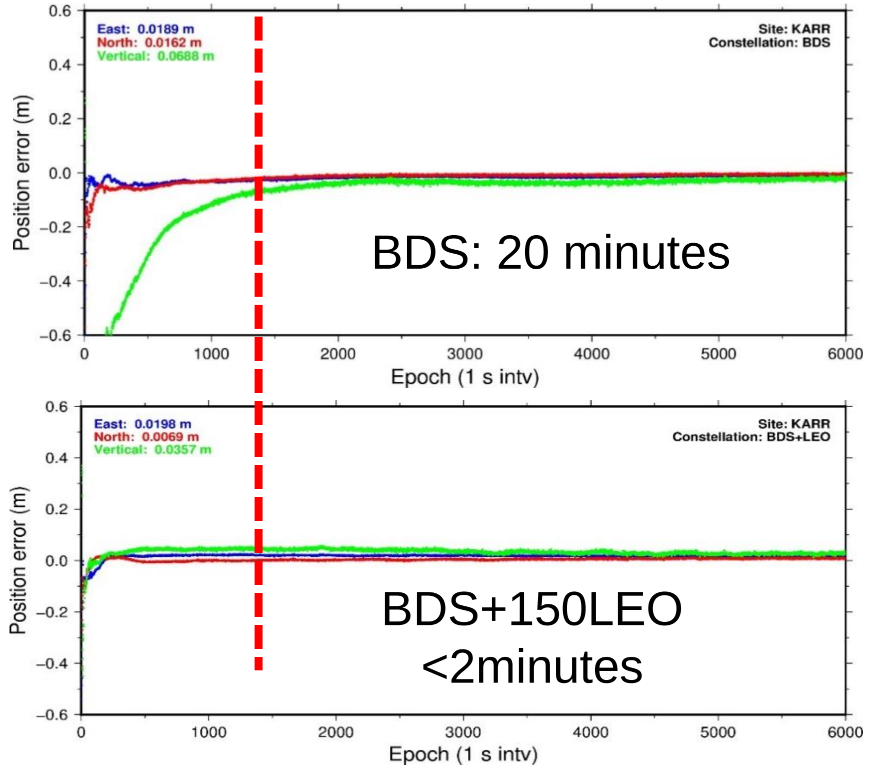


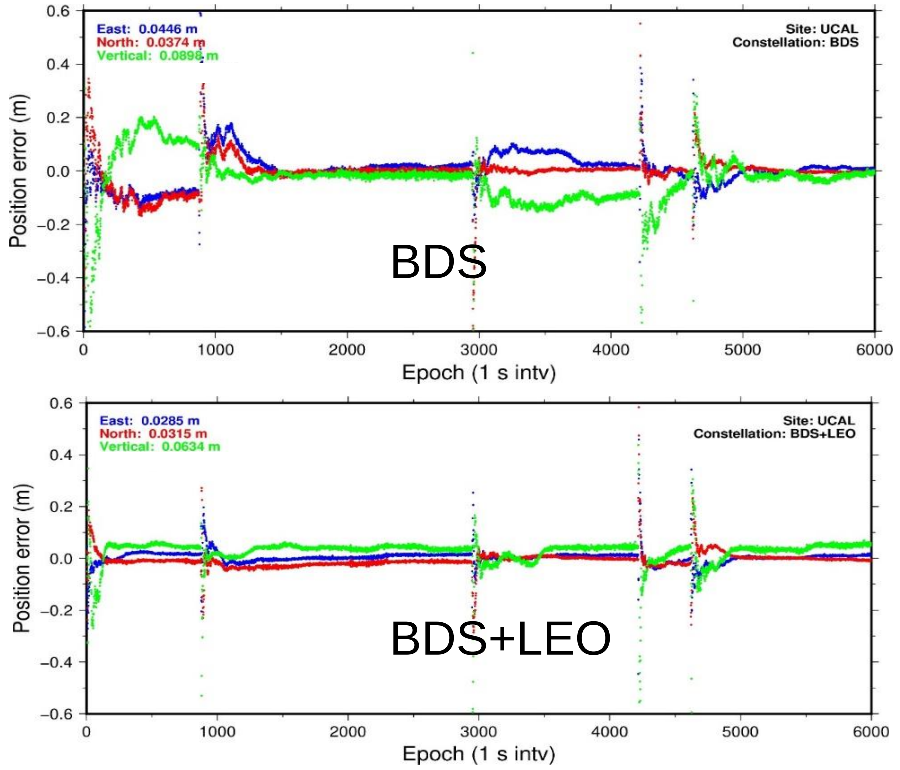
LEO phase 4-dif

> **LEO signal code noise: 0.2 m, phase noise: 0.03 cycle**

Advantages Of LEO navigation

□ Static PPP



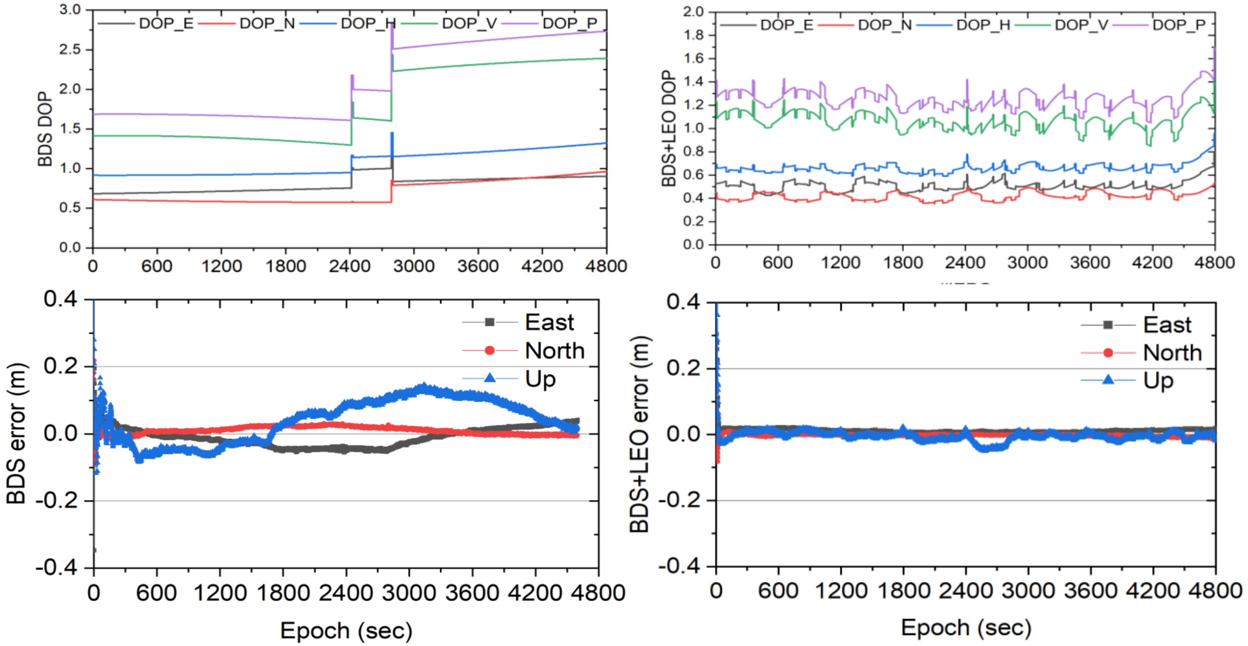


- ➢ **Reduce PPP convergence time to < 2min**
- ➢ **Fast re-convergence after signal interruption**

Advantages Of LEO navigation

Kinematic PPP

- INS: Simulated vehicle trajectory
- Signal simulator: BDS+LEO Signal



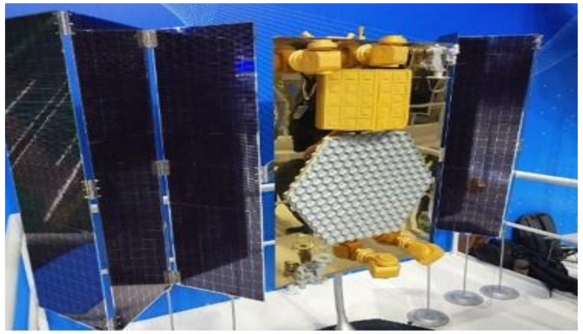
	E (cm)	N (cm)	U (cm)	3D (cm)
BDS	2.89	1.48	7.63	8.29
BDS+LEO	1.32	0.40	1.46	**2.01**

➢ **BDS+LEO: fast convergence: < 2 min, high precision: ~2 cm**

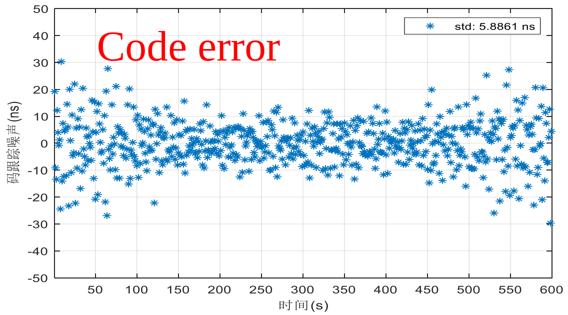
Onboard Test

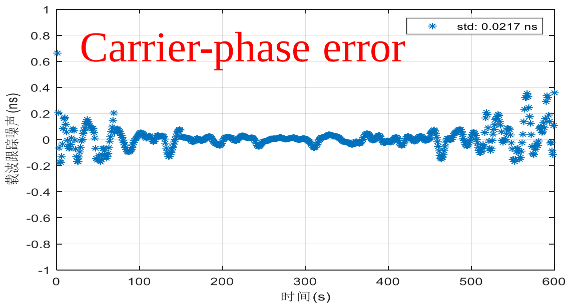
☐ Hongyan satellite

- LEO-based GNSS argumentation demonstration
- LEO real navigation signal quality demonstration

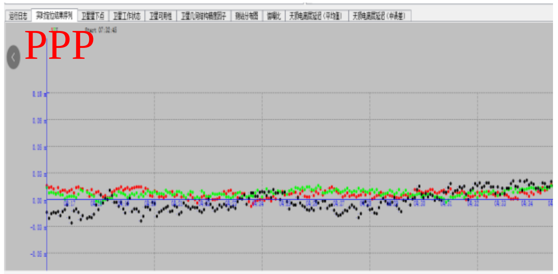


First test satellite launched in 2018





Real LEO navigation signal



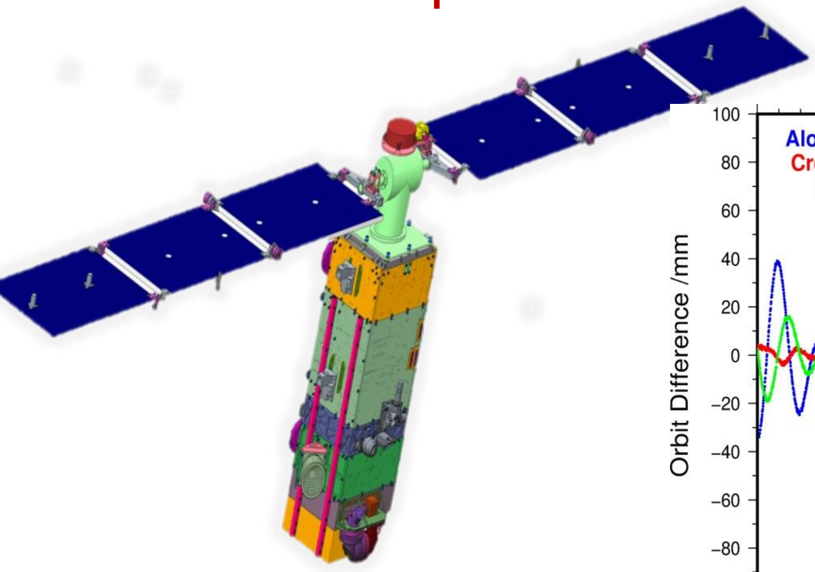
PPP error series

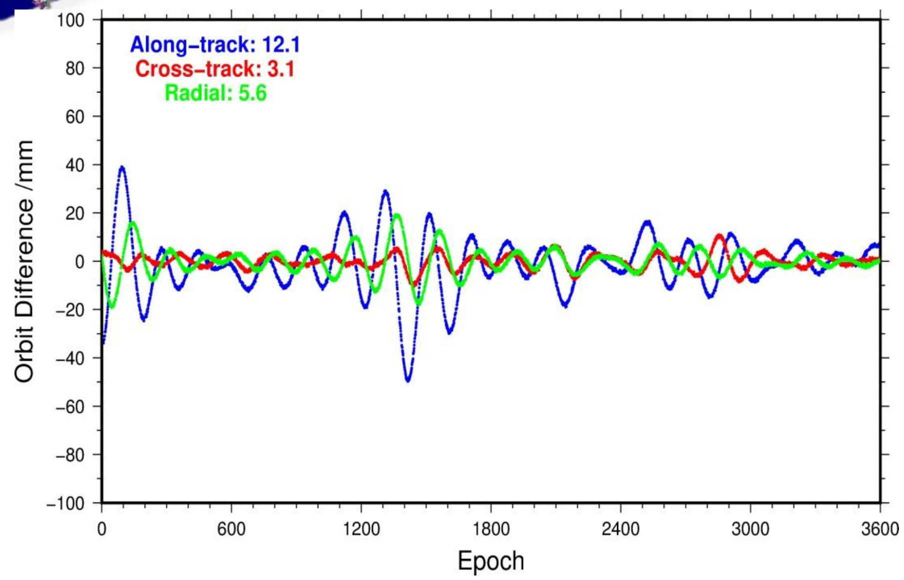
➢ **Real LEO signal noise: Code (2.1 m), Phase(0.6 cm). PPP accuracy: ~5 cm**

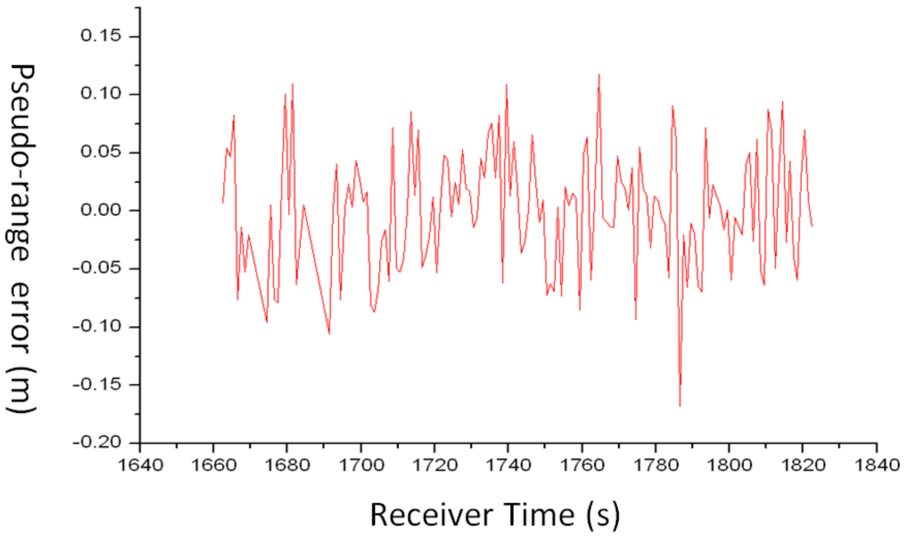
Meng, CNSC presentation, 2019

Onboard Test

☐ CentispaceS1 satellite







First test satellite launched in 2018

LEO Satellite orbit 3D determination error

Pseudo-range error

➤ **Real LEO signal : LEO Satellite orbit determination error: ~3cm; Pseudo-range error :~6cm**

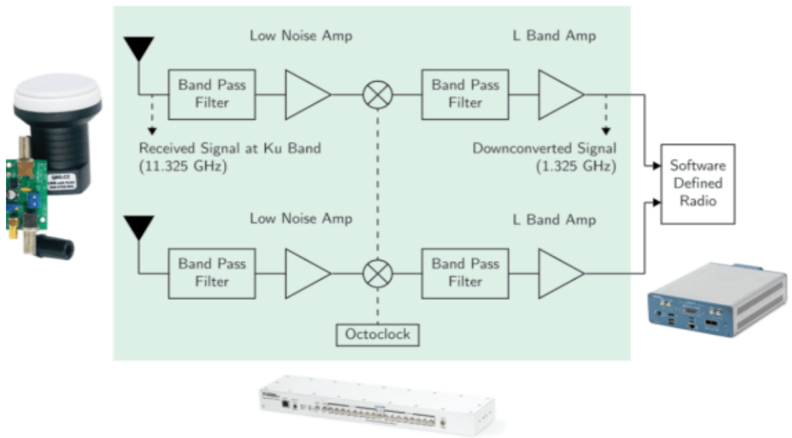
03

Conditions on Future development of LEO navigation

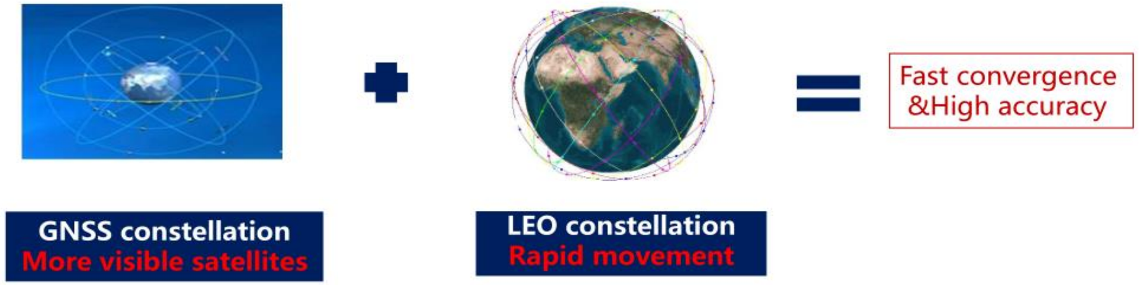
Considerations on Future development of LEO navigation

C&I between LEO constellation and GNSS needed to be analyzed

Compatible and interoperable with GNSS receiver



Modifies software under the existing hardware architecture of user terminals to obtain high performance navigation services and achieve low cost



ID number (SNS)	adm	Satellite name	long_nom	Date of receipt	ssn_ref	ssn_no	WIC/IFIC (ific.mdb)	WIC/IFIC date
up down	up down	up down	up down	up down	up down	up down	up down	
118520283	CHN	CENTISPACE-2	N-GSO	11.09.2018	API/C	539	2881	16.10.2018
118545172	CHN	CENTISPACE-2	N-GSO	11.09.2018	API/A	12252	2885	11.12.2018
118520283	CHN	CENTISPACE-2	N-GSO	11.09.2018	CR/C	4847	2886	08.01.2019
118545172	CHN	CENTISPACE-2	N-GSO	11.09.2018	API/B	1071	2896	28.05.2019

FREQUENCY INFORMATION

BEAM NAME	EMISS/REC	FREQUENCY (MHz)	BANDWIDTH (kHz)	FREQUENCY MIN (MHz)	FREQUENCY MAX (MHz)	CLASS OF STN
L1D	E	1575.42000	12276	1569.282	1581.558	EN
L1D	E	1575.42000	12276	1569.282	1581.558	EO
L1D	E	1575.42000	12276	1569.282	1581.558	EQ
L5D	E	1176.45000	12276	1170.312	1182.588	EN
L5D	E	1176.45000	12276	1170.312	1182.588	EO
L5D	E	1176.45000	12276	1170.312	1182.588	EQ

L1&L5 frequencies are approved for LEO satellite navigation for Centispace satellites (Beijing Future Navigation Co.) by ITU

In accordance with ITU rules and interoperable with GNSS

Considerations on Future development of LEO navigation

C&I among LEO constellation needed to be analyzed

Constellations	Satellite numbers	Frequency
Iridium	66	L and Ka
Globalstar	48	S and C
SpaceX Starlink	42000	Ku, Ka and V
Boeing	1767	V and C
Samsung	4600	V
Oneweb	882	Ku, Ka
XONA	300	L, S and C
Centispace	150	L
SATNET	504	L
UAE NSAT01	96	L, S
……		

Supply side

- **Augmentation Information**
- **Augmentation Signal**
- **Constellation fusion**

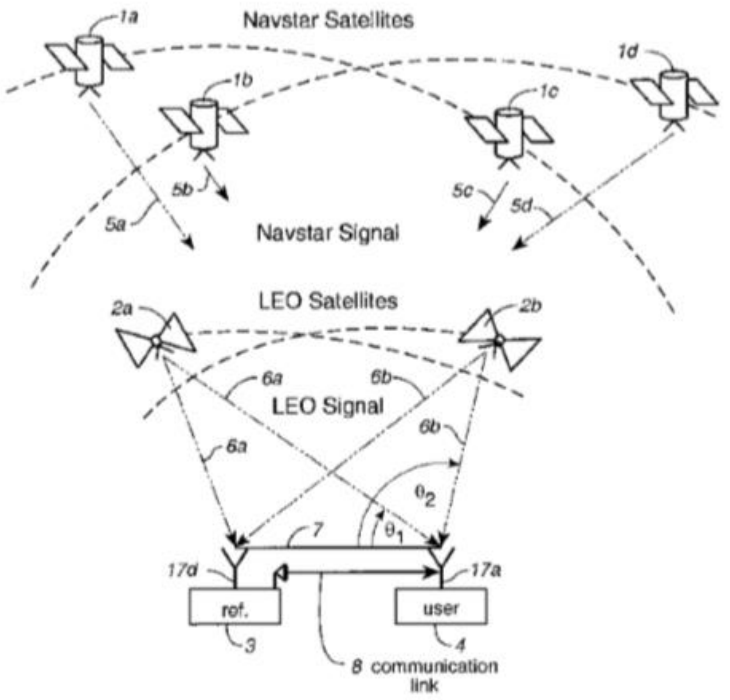
Demand side

- **Diversity of users**

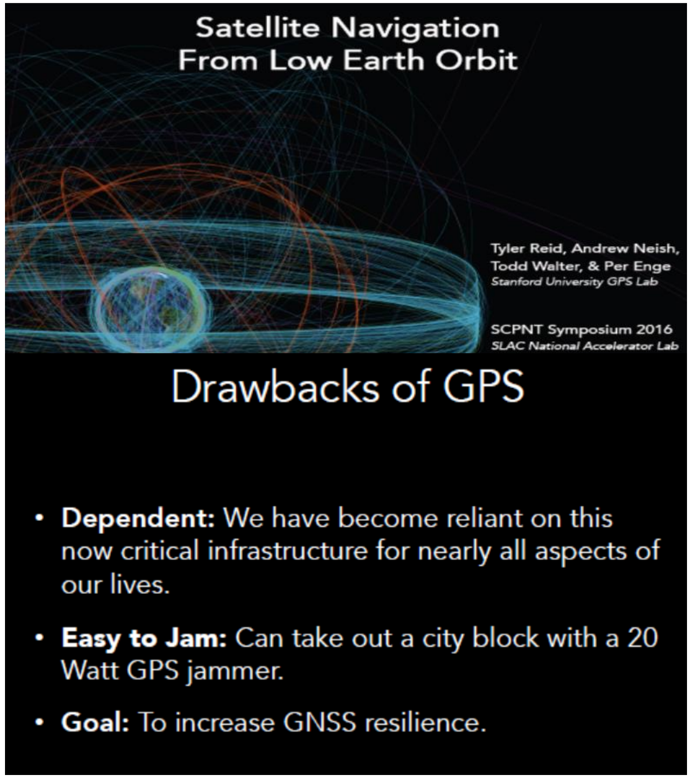
Coordinate the development of LEO constellations to achieve integration and empowerment with GNSS

Considerations on Future development of LEO navigation

- GNSS + LEO : Extended application, such as : ‘south wall effect’



RABINOWITZM (1998)



Tyler Reid (2016)

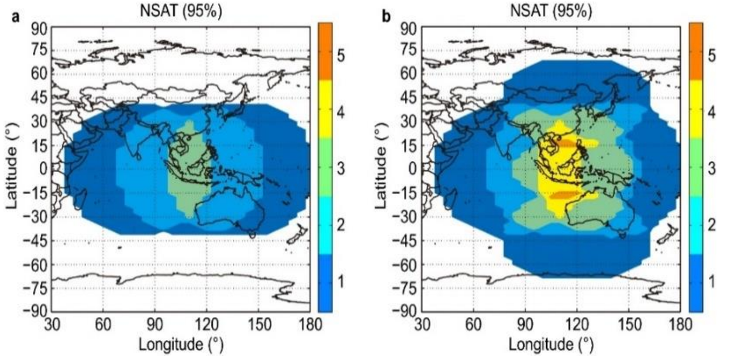


Table 5 Convergence time of PPP-B2b + LEO

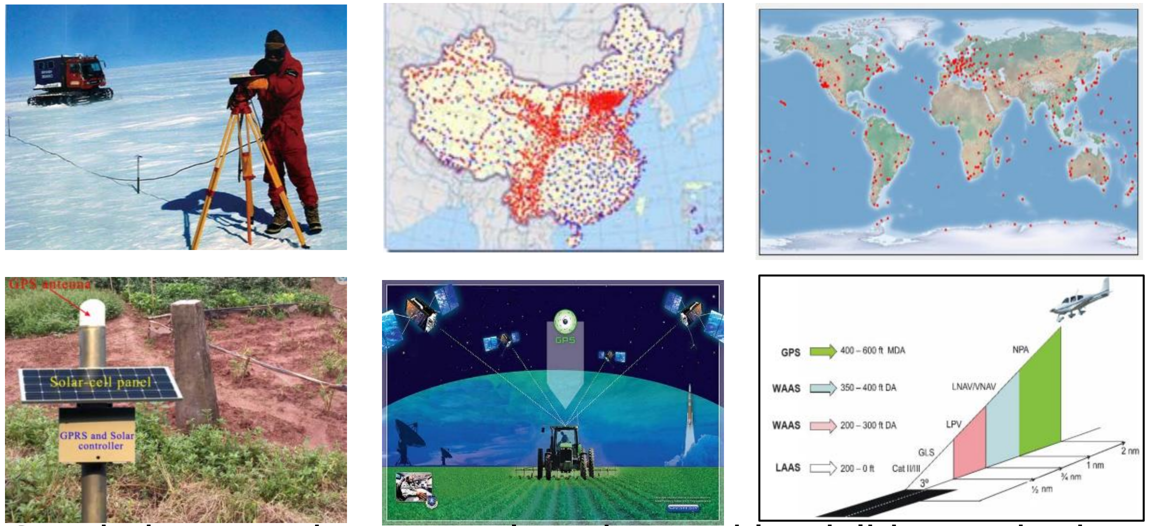
Stations	Convergence time of 10 cm accuracy (s)	Convergence time of 100 cm accuracy (s)
Beijing	44	7
Wuhan	59	17
Kunming	49	19
Shanghai	68	7

Yuanxi Yang (2022)

Considerations on Future development of LEO navigation

- Real-time worldwide PPP: real-time high-precision service from the professional applications to mass market.

Professional applications



Geodetic surveying, crustal motion and landslide monitoring, reference frame construction, precision farming, precision approach, etc.

Mass market applications

Auto-driving

04

Summary

Summary

- LEO Navigation: GNSS augmentation, Potential signal power enhancement capability, Integration with satellite communication
- LEO-Based Augmentation: PDOP improved by 30%, convergence time reduced to 1-2 minute
- Future BDS : next-generation of BDS plans to add LEO satellite constellation
- Future development: Compatibility, Interoperability, Extended application

Thanks for your attetion