Preliminary PNT Requirements for ILRS

Enabling Sustainable Lunar Exploration

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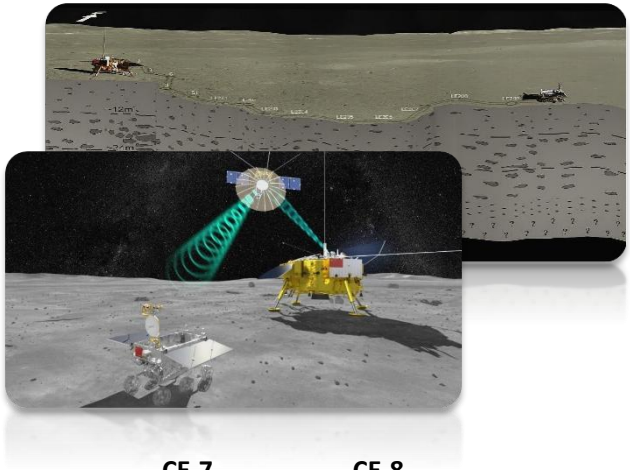
CONTENT

ILRS Overview

China's Lunar Exploration Program

- In 2004, China's Lunar Exploration Program (CLEP) including three phases "orbiting, landing, and sample return" was initiated.
- In 2021, the Phase IV of CLEP was approved.
- Seven Chang'E lunar exploration missions and two Queqiao lunar relay communication missions have been successful.



Chang'E-1 (CE-1) 2007.10

CE-2 2010.10

CE-5T1 Re-entry Test 2014.10

CE-5 2020.11

CE-7 ~2026

CE-8 ~2029

Sample Return

Landing

Phase IV

Orbiting

CE-3 2013.12

Queqiao 2018.5

CE-4 2018.12

Queqiao 2 2024.3

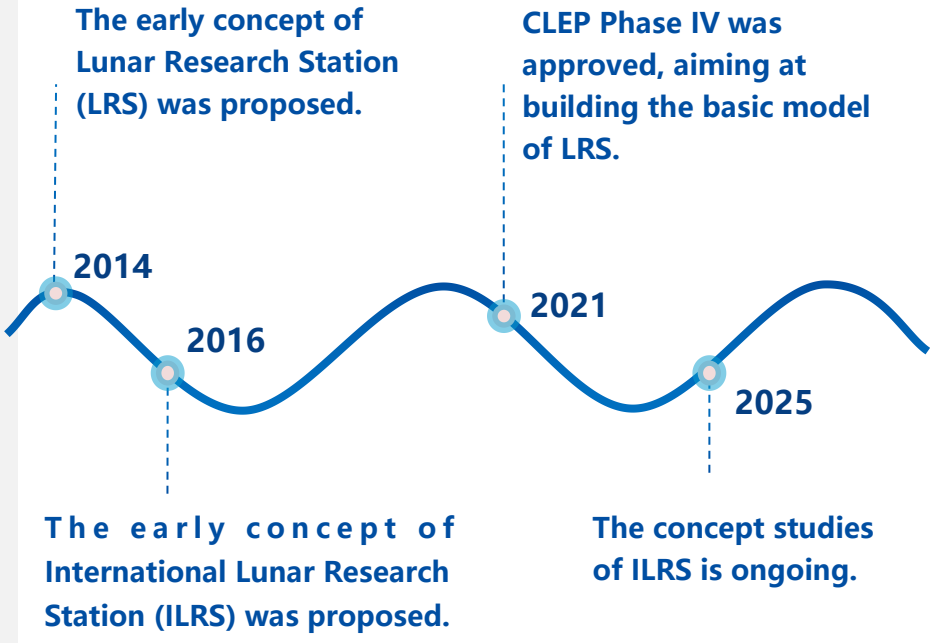
CE-6 2024.5

The Conception of ILRS

Trends in Lunar Exploration

- The exploration mode is shifting from single point and short-term exploration to long-term residency and large-scale exploration.
- The development stage is shifting from understanding the Moon to equal emphasis on understanding and utilization
- Widespread international cooperation and commercial participation have become important trends

Efficiency and effectiveness will be focus.



Definition of ILRS

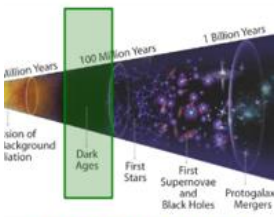
ILRS is a set of comprehensive scientific experimental facilities jointly constructed by multiple countries on the surface and in the orbit of the Moon

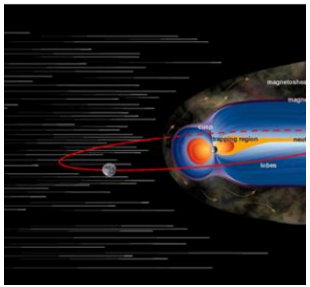
- with scalability and maintainability
- with the capability of long-term autonomous operation and short-term human participation.
- With the support capabilities including energy supply, central control, communication and navigation, Earth-Moon round trip, lunar scientific research, ground support and etc.
- Continuously carry out multidisciplinary, multi-objective, large-scale scientific and technological activities such as scientific exploration, resource utilization, and frontier technology verification.

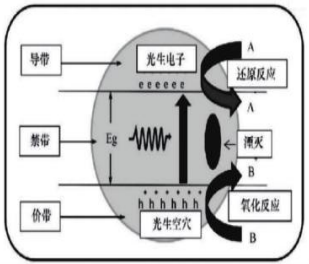
ILRS (artist's concept)

Scientific Goals

Geological survey of the Moon	Astronomy observations	Sun-Earth-Moon space environment observation	Fundamental science experiment	In situ resource utilization



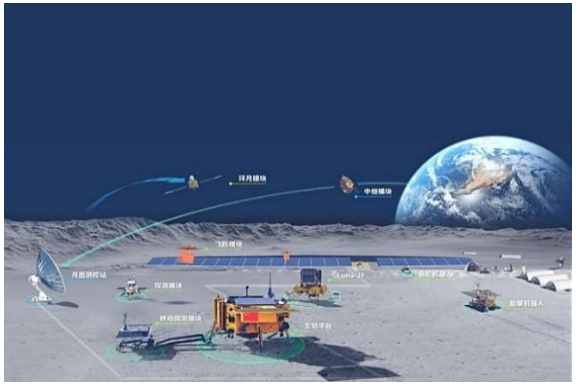




Engineering Goals

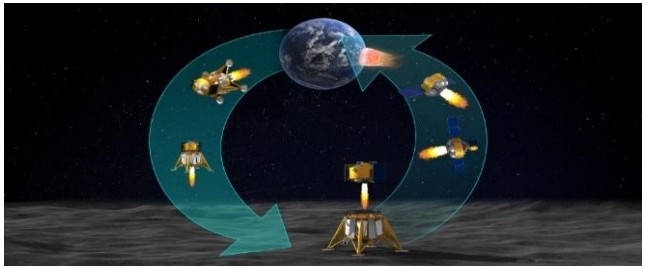
Build comprehensive scientific research sharing platforms

Promote technology to leap across generations in batches

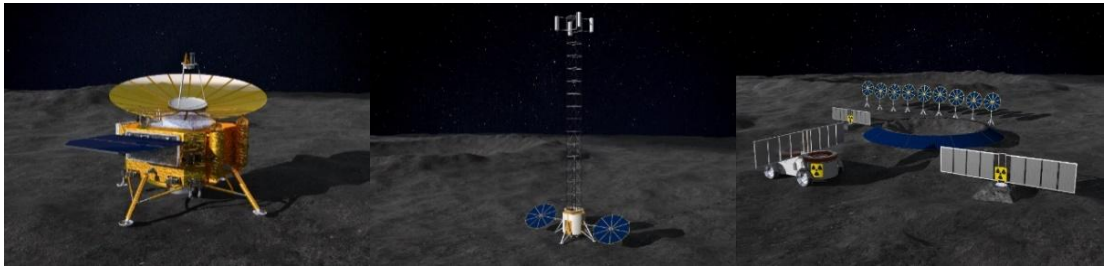


Lay the foundation for future large-scale application

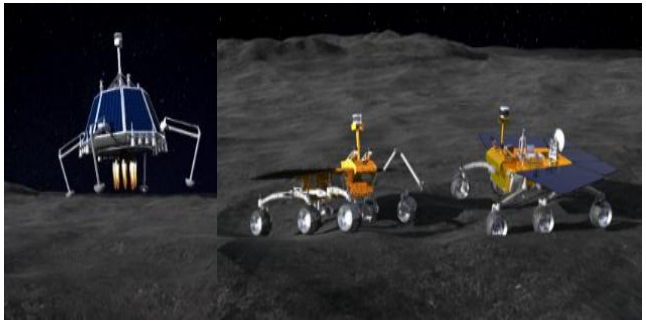
Facilities



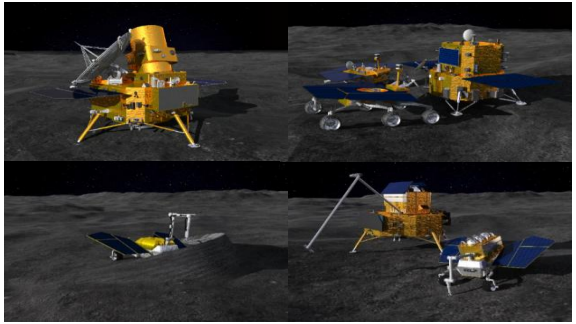
Cislunar Transportation Facilities



Lunar Long-term Support Facilities



Lunar Transportation and Operation Facilities



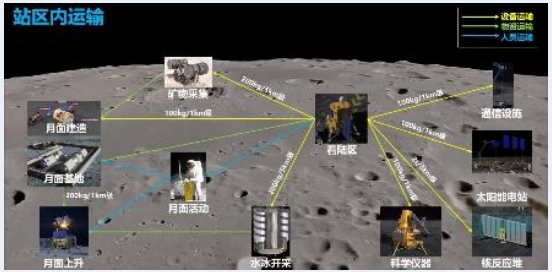
Lunar Scientific Facilities

Ground Support and Application Facilities

Preliminary PNT Needs for ILRS Lunar Surface Activities

Main Lunar Surface Activities of ILRS

Ranges of Activities



~10km ~100km

Within the main station area

- Deployment of support facilities
- Deployment of scientific facilities
- EVA and transportation of astronauts

Within the south pole area

- Long distance scientific investigation covering multiple PSRs
- Long distance transportation and deployment of scientific facilities

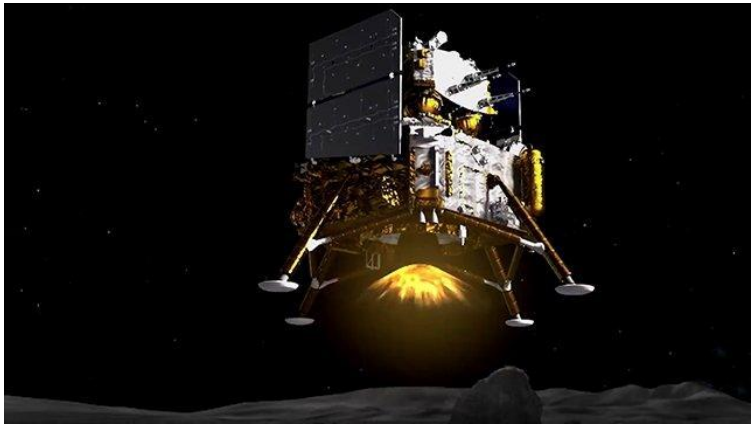
Within the whole lunar surface

- Deployment of ultra-long distance joint exploration facilities, such as Lunar Far-side Low-frequency Radio Telescope Array, Lunar Seismometers, VLBI Antenna Array, and etc.

PNT Needs for Activities in the Main Station Area

Fixed-point landing

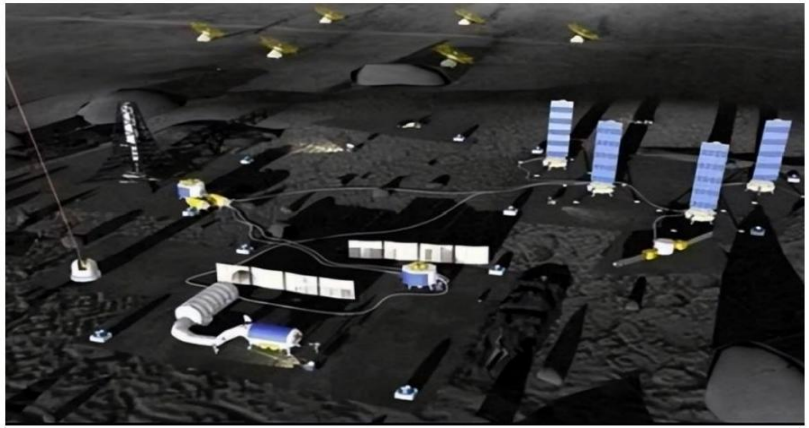
- **Positioning and Navigation**
  - ✓ Positioning accuracy: 100-meter level (early stage), 10-meter level (late stage)
  - ✓ Data update period: second level
- **Timing:** No special requirements



PNT Needs for Activities in the Main Station Area

Deployment of General Support Facilities and Scientific Facilities

- **Positioning and Navigation**
  - ✓ Positioning accuracy: meter level
  - ✓ Data update period: month level
- **Timing:**
  - ✓ Timing accuracy: millisecond level



PNT Needs for Activities in the Main Station Area

Driving and Operation of Mobile Modules, Astronauts EVAs

- **Positioning and Navigation**
  - ✓ Positioning accuracy : meter level (early stage), centi-meter level (late stage)
  - ✓ Speed measurement accuracy: dm/s level (early stage), cm/s level(late stage)
  - ✓ Data update period: minute level (early stage), second level (late stage)
- **Timing**
  - ✓ Timing accuracy: millisecond level

PNT Needs for Activities in the Main Station Area

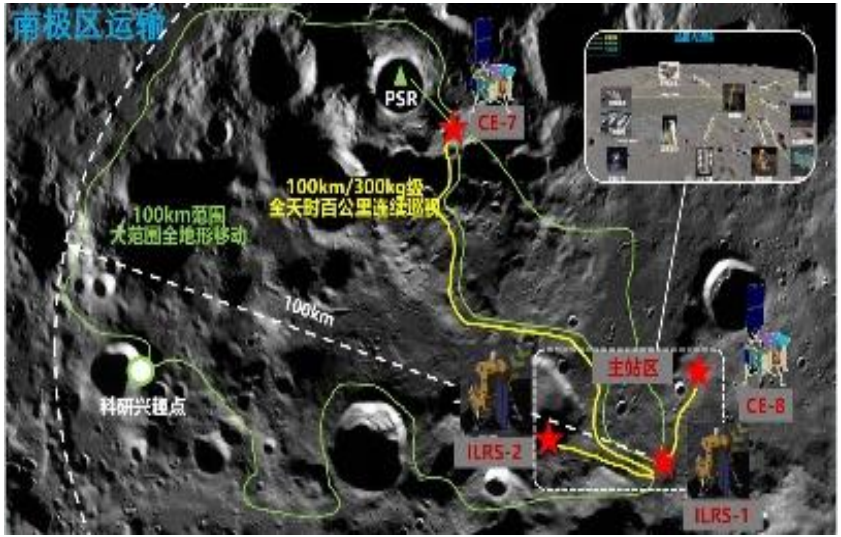
Deployment of lunar-based optical telescope

- **Positioning and Navigation**
  - ✓ Positioning accuracy: 10 meters level
  - ✓ Data update period: minute level
- **Timing:**
  - ✓ Timing accuracy: microsecond level

PNT Needs for Activities in the South Pole Area

Long-distance Scientific Investigation and Instruments Deployment

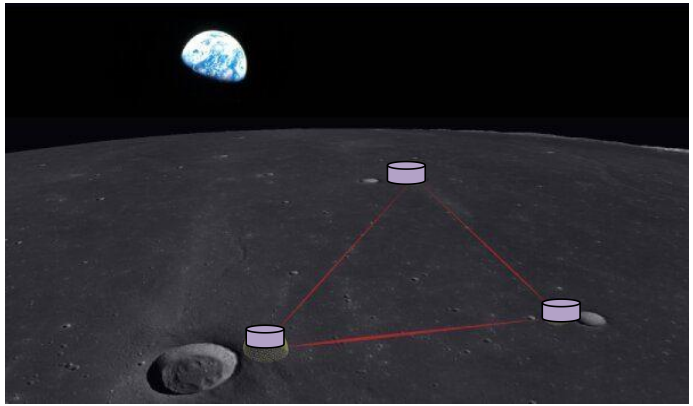
- **Positioning and Navigation**
  - ✓ Positioning accuracy: meter level
  - ✓ Speed measurement accuracy: decimeter/second level
  - ✓ Data update period: minute level
- **Timing**
  - ✓ Timing accuracy: millisecond level



PNT Needs for Activities at Greater Distances

Deployment of Lunar Seismometers and Lunar Gravitational Wave Detectors

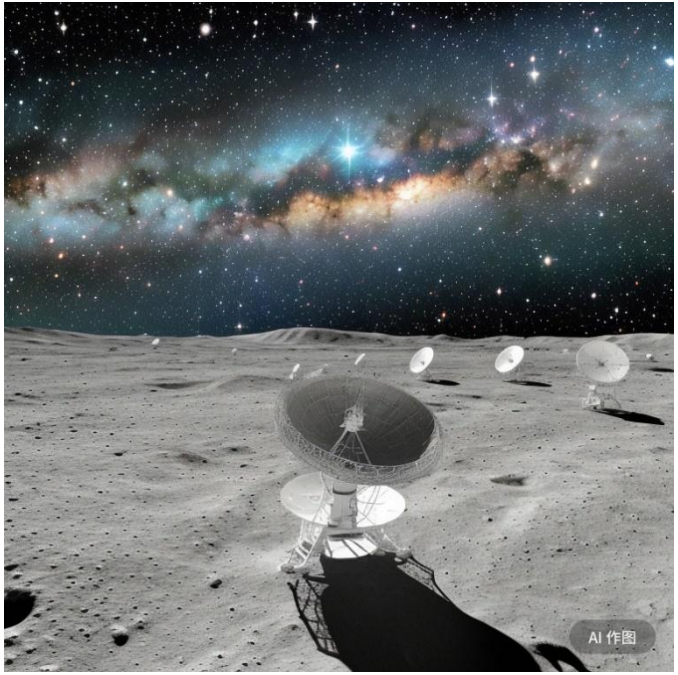
- **Positioning and Navigation**
  - ✓ Positioning accuracy: meter level
  - ✓ Data update period: month level
- **Timing**
  - ✓ Timing accuracy: 500 nanoseconds level



PNT Needs for Activities at Greater Distances

Deployment of Lunar Far-side Low-frequency Radio Telescope Array

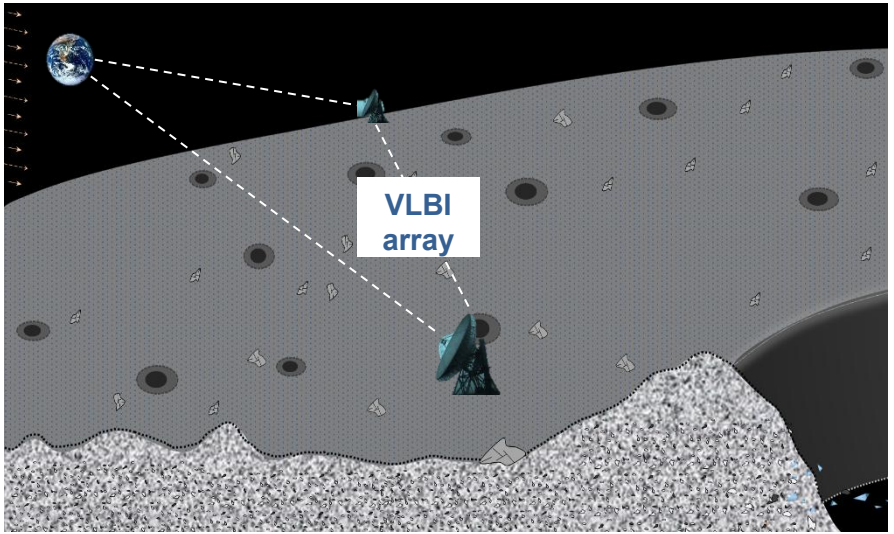
- **Positioning and Navigation**
  - ✓ Positioning accuracy: meter level
  - ✓ Data update period: month level
- **Timing**
  - ✓ Each substation shares the same on-board clock with good frequency stability, or synchronize external timing with accuracy at 1000 nanoseconds level



PNT Needs for Activities at Greater Distances

Deployment of VLBI Array

- **Positioning and Navigation**
  - ✓ Positioning accuracy: meter level
  - ✓ Data update period: month level
- **Timing**
  - ✓ Timing accuracy: 100 nanoseconds level



Summary of Preliminary PNT Needs

Lunar Surface Activities	Positioning and Navigation Requirements	Timing Requirements
Fixed-point Landing	Early stage: 100m level positioning accuracy, sec. level update period late stage: 10m level positioning accuracy	No special requirements
Driving and engineering operations and astronauts EVAs within the main station area	Early stage： Meter level positioning accuracy, dm/s level speed measurement accuracy, min. level update period late stage： Centimeter level positioning accuracy, cm/s level speed measurement accuracy, sec. level update period	ms level timing accuracy
Long-distance Scientific Investigation and Deployment of Instruments	Meter level positioning accuracy, dm/s level speed measurement accuracy, min. level update period	ms level timing accuracy
Deployment of general scientific payloads	Meter level positioning accuracy, month level update period	ms level timing accuracy for joint exploration payloads
Deployment of lunar-based astronomical telescopes	10m level positioning accuracy, month level update period	1000ns level timing accuracy
Deployment of low frequency radio observation array	Meter level positioning accuracy, month level update period	1000ns level timing accuracy
Deployment of VLBI array	Meter level positioning accuracy, month level update period	100ns level timing accuracy
Deployment of Lunar Seismometers and Gravitational Wave Detectors	Meter level positioning accuracy, month level update period	500ns level timing accuracy

Preliminary PNT Requirements

Within the main station area:
Meter level positioning accuracy,
dm/s level speed measurement accuracy,
100ns level timing accuracy

Within the south pole area:
10 Meter level positioning accuracy,
dm/s level speed measurement accuracy,
100ns level timing accuracy

Early Stage

Within the main station area:
Centimeter level positioning accuracy,
cm/s level speed measurement accuracy,
100ns level timing accuracy

Within the whole moon:
Meter level positioning accuracy,
sub dm/s level speed measurement accuracy,
100ns level timing accuracy

Late Stage

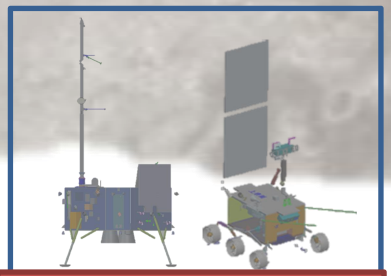
Optional Solutions

Optional Solutions

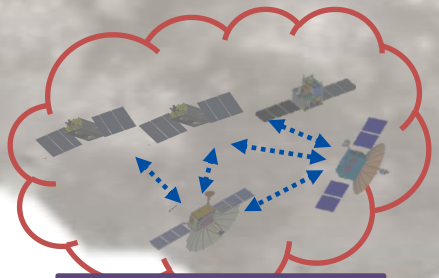
Earth TT&C Network

PNT requirements of ILRS

GNSS Service

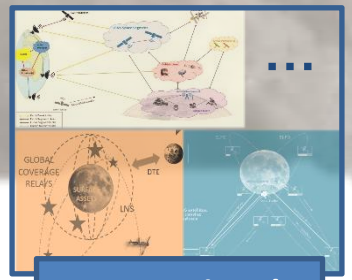


On-board Navigation Devices

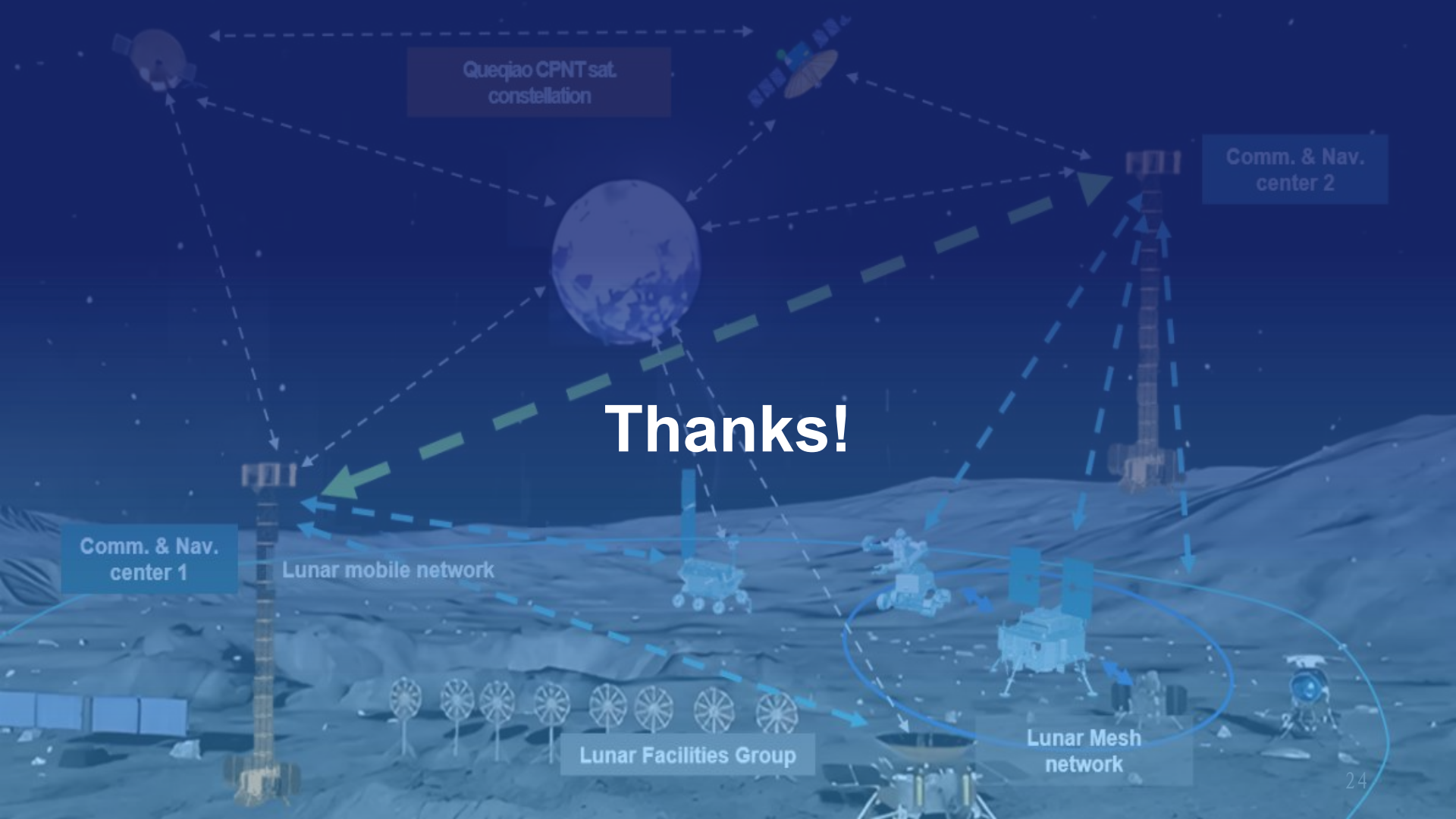


Queqiao CPNT System

Comm. and Nav. Infrastructures on Lunar Surface



International Cooperation


Queqiao CPNT sat. constellation
Comm. & Nav. center 2
Comm. & Nav. center 1
Lunar mobile network
Lunar Facilities Group
Lunar Mesh network

Thanks!