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A Brief Introduction to the International Lunar Research Station Program and the Interstellar Express Mission*

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Abstract China has planned and implemented a series of lunar and deep space exploration programs since the first lunar exploration satellite Chang'E-1 launched in 2007. In the future, China has initiated the international lunar research station program, which aims to build a shared platform on the Moon jointly with many other countries for long-term and continuous lunar exploration, lunar-based observations and experiments, as well as *in-situ* resource utilization. In addition, China has also proposed an interstellar express mission to unveil the mysteries of the outer heliosphere, nearby interstellar space, and their interactions. This paper gives a brief introduction to the International Lunar Research Station program and the Interstellar Express mission.

Key words Lunar exploration, Deep space exploration, International lunar research station, Outer Heliospheric exploring, International cooperation

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1 International Lunar Research Station Program (ILRS)

Since the beginning of the 21st century, the Moon has once again become a hot spot of exploration, accompanying the trend change from launch of individual missions to establishing a research station via multiple missions, and both scientific research and applications of the Moon are equally concerned. ESA promoted the concept of Moon Village; Russia announced a series of lunar missions; NASA has granted the Artemis program, aiming to build a lunar base; Five missions of China's Lunar Exploration Program (CLEP) have been carried out, with the first probe Chang'E-1 launched in 2007 and Chang'E-4 landed for the first time on the far side of the Moon in 2019. Chang'E-5 has collected and returned the youngest lunar samples dated 2.0 Ga, marking the completion of all three phases of CLEP: orbiting, landing, and returning. The fourth phase of the CLEP, consisting of three missions Chang'E-6, 7 and 8, has been scheduled to explore the lunar south pole regions for multiple goals, including science investigations, Moon-based experiments and observations, *in-situ* resource utilization, and returning samples from the far side of the Moon. According to the overall plan of lunar exploration program, the fourth phase of the CLEP is the first phase of the International Lunar Research Station (ILRS) program.

1.1 Cooperation in Science

ILRS refers to a comprehensive scientific experiment fa-

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cility constructed jointly on the lunar surface and/or in lunar orbit by attracting potential international partners. The facility is designed for multi-discipline and multi-purpose scientific research activities, including exploration and utilization of the Moon, moon-based observation, basic scientific experiments, and technology verification, with the capability of long-term unmanned operation with the prospect of subsequent human presence. The research areas of ILRS are: (i) the geological survey of the Moon, (ii) lunar-based astronomy observations, (iii) space environment observation of the Sun-Earth-Moon system, (iv) lunar-based fundamental science experiment, (v) lunar *in-situ* resource utilization.

1.2 Scientific Mission Planning

The construction of ILRS is divided into three phases: reconnaissance, construction, and utilization.

Phase I (before 2026): "reconnaissance", mainly to explore the Moon with the approved missions, while selecting landing sites for subsequent missions and conducting related technical verification tests. China's missions include Chang'E-6 and Chang'E-7.

(1) Chang'E-6 will explore the far side of the Moon and return lunar samples to Earth.

(2) Chang'E-7 will explore the lunar south pole region of the Moon, including the morphology, composition and tectonics, deep interior structure and magnetic field, water ice and volatile matter, and the lunar surface environment. Furthermore, the Earth's magnetotail and plasmasphere will be observed from the Moon, and the Moon-Earth VLBI measurement and observation experiment system with a baseline of 400000 km will be constructed for the first time.

Phase II (before 2035): "construction". This phase may consist of two stages.

(1) Before 2030: China's mission includes Chang' E-8, which will detect the lunar multi-physical fields and regional geological features, make long-term and large-scale observations of the Earth's macroscopic phenomena, and carry out lunar terrestrial small ecosystem experiments and *in-situ* extraction experiments of rare gases.

(2) From 2031 to 2035: Five missions are scheduled to carry out detailed regional geological surveys, space physical observations of the Sun-Earth-Moon system, lunar-based astronomical observation, lunar *in-situ* utilization resources experiments, lunar-based life science experiments, fundamental physics experiments, and to collect the lunar samples and return to Earth. Through this stage of construction, the lunar research station will be completed.

Phase III (after 2036): "Utilization". This phase will use this scientific research station to carry out continuous scientific exploration and technical verification. It will support manned lunar missions, and expand and maintain the modules for each system as needed.

2 Exploration for Deep Space and Outer Heliosphere

2.1 Deep Space Exploration Mission

Mars is the closest and most similar to Earth among the eight planets in our solar system. As a result, it logically becomes a top priority for space exploration. So far, missions for Mars exploration have been established by the United States, Russia, Europe, Japan, and India. China's first Mars program, Tianwen-1, which has completed orbiting, landing, and wandering in a single mission, was successfully launched in July 2020. On 10 February 2021, Tianwen-1 arrived at Mars with the goal of investigating Martian surface geology and interior structure, searching for evidence of present and historic water presence, and characterizing Mars' space environment and atmosphere.

The Tianwen-1 mission is only the start of China's planetary exploration, and many new endeavors are in the pipeline. For instance, the next Tianwen-2 mission will orbit the main belt comet, 133 P, and discover the near-Earth asteroid, 2016 HO3. It will also collect surface samples and return them to Earth. The project design is now complete, and the prototype development process has moved on to the next phase. The Tianwen-3 mission, designed to retrieve samples from Mars, is also in work. It will land on Mars, collect surface samples, meanwhile gather ambient geological field data through *in-situ* measurements, and then fly back to Earth. In addition to Mars, Tianwen-4 will also explore Jupiter and its moon system, as well as undertake interplanetary exploration beyond Jupiter.

2.2 Heliospheric Boundary Exploration Mission

In addition to planetary exploration, China has also proposed an interstellar exploration mission to explore the

outer heliosphere and its boundary, and the typical celestial bodies in the outer solar system during its journey. The heliosphere is a great bubble due to the interaction between the solar wind and the interstellar wind, which prevents solar system planets from being hit by cosmic rays with very high energy. However, there exists an extreme imbalance between inner heliospheric exploration and outer heliospheric exploration. A specially designed mission with well-chosen modern instruments is needed to unveil the mysteries of the outer heliosphere, nearby interstellar space, and their interactions.

The concept of the first Chinese outer heliospheric exploration mission focusing on the heliospheric boundary region, namely Interstellar Express, was proposed in 2015. The China National Space Administration (CNSA) kicked off the pre-study to investigate the scientific objectives, technical readiness, and economic affordability, *etc*. in 2021. With the aim of perceiving the deep space environment of our Earth's homeland and exploring typical celestial bodies in the outer solar system, this mission designs four scientific tasks.

(1) Directly measuring the unexplored heliosphere.

(2) Heliosphere panoramic imaging.

(3) The detection of the giant planet system during a fly-by.

(4) Archaeological study of the solar system.

The mission consists of two spacecraft traveling in opposite directions, one heading for the heliospheric nose region and the other for the tail region. The preliminary mission profile of payload configuration, trajectory design, and related engineering issues are being discussed as well.

3 Summary

The International Lunar Research Station program is an international cooperation plan first initiated by China, which will jointly establish a new science and application platform on the Moon with many other countries based on the approved and planned missions. Using this platform, it will be possible to carry out long-term, continuous exploration and observation on the Moon, leading to innovational achievements in lunar science. The platform will support fundamental experiments in life science and physics, and will also develop key techniques for in-situ lunar resource utilization to support sustainable activities on the Moon.

Complementary to the ILRS program, China has also designed a preliminary roadmap for deep space and outer heliosphere explorations. Following Tianwen-1, China also plans to return samples from asteroids and Mars, and explore Jupiter system, through these missions from Tianwen-2 to Tianwen-4 missions. In addition, China has also conducted a conceptual study of deep space and outer heliosphere exploration, the Interstellar Express mission, which plans to launch two satellites toward the nose and tail directions of the heliosphere, respectively, in order to reveal the properties of the heliosphere and its interactions with the interstellar medium.