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China's Lunar and Deep Space Exploration Program for the Next Decade (2020–2030)*

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Abstract China has carried out four unmanned missions to the Moon since it launched Chang'E-1, the first lunar orbiter in 2007. With the implementation of the Chang'E-5 mission this year, the three phases of the lunar exploration program, namely orbiting, landing and returning, have been completed. In the plan of follow-up unmanned lunar exploration missions, it is planned to establish an experimental lunar research station at the lunar south pole by 2030 through the implementation of several missions, laying a foundation for the establishment of practical lunar research station in the future. China successfully launched its first Mars probe on 23 July 2020, followed in future by an asteroid mission, second Mars mission, and a mission to explore Jupiter and its moons.

Key words Lunar exploration, Deep space exploration, Lunar research station, Lunar south pole

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1 Lunar Exploration Mission

According to the plan of China's lunar exploration program, the three phases of orbiting, landing, returning (*i.e.*, lunar exploration phase 1, 2 and 3) will be completed by 2020. At present, the Chang'E-1 to Chang'E-4 missions have been successfully carried out, which means the exploration program for the two stages of "orbiting and landing" has been completed. The Chang'E-5 mission, to be launched at the end of 2020, will collect lunar rock and soil samples and return them to Earth, which means the third phase of returning will also be completed.

With the successful implementation and gradual promotion of China's Lunar Exploration Program (CLEP), China officially launched the demonstration of a new unmanned lunar exploration program, now known as lunar exploration phase 4 since 2017, namely the demonstration of the lunar exploration program from 2021–2030. The plan is to initially build the basic outline of a research station in the South Pole of the Moon around 2030 and carry out scientific exploration and technology experiments, so as to lay the foundation for the future construction of a longer-term lunar research station on the Moon.

The overall scientific goals are: (i) to detect and study the distribution, content, and source of water and volatile components; (ii) to acquire the characteristics of the chemical composition of the deep part of the Moon; (iii) to study the age of the South Pole Aitken basin and the early impact history of the solar system; (iv) to explore the near surface environment of the lunar south pole; (v) to carry out lunar resource in-situ utilization tests; (vi) to carry out bio-scientific experiment and study on the lunar surface; (vii) to carry out observation and research on macro-geological phenomena in the base of the Moon; and (viii) to carry out the Earth-Moon VLBI

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test and observation.

The fourth phase of CLEP consists of several missions, respectively.

The first mission, also named as Chang'E-7, which consists of a telecommunication relay, an orbiter, a lander, a rover and a flying detector, will be launched around 2024. Its main scientific goals are: (i) to investigate the topography and geomorphology, mineral element composition, and the distribution of water (or water ice) in the permanently shadowed area of the Moon, studying the distribution of the Moon's mineral resources; (ii) to perform geological investigation in the landing and patrol area, studying the geological structure and evolution history of the area, especially the composition and structure of the deep lunar interior; (iii) to probe the water ice in-situ on the Moon's permanent shadowed area, learning its source; (iv) to study the magnetic field characteristics of the lunar south pole; (v) to make observations of the Earth's magnetosphere, studying its physical laws and mechanisms; (vi) to construct an Earth-Moon VLBI experimental system and study astrophysics, astrometry and its applications.

The second mission which consists of a mobile lander, an ascender and a returner, will be launched around 2025. Its most important task is to collect soil and rock samples on the Moon's South Pole and return them to Earth, and a series of analyses and studies, including rocks, minerals, elements and isotopes, will be carried out to provide new evidence to the Moon's major scientific questions. It will also explore the topography and geomorphology, the structure of the lunar soil, and the mineral composition of the landing site.

The third mission, which consists of a lander, a rover and a flying detector, is planned to be launched before 2030. It will carry out scientific exploration of the Moon and conduct technical verification of relevant experiments on the lunar surface, laying the foundation for the future practical lunar research station. The main scientific objectives are: (i) to perform in-situ resource utilization experiment, including separation and extraction of rare gases from lunar soil, and verify the key technical problems involved; (ii) to carry out terrestrial mini-ecosystem experiments on lunar surface, revealing the rule of material circulation and energy moving on the terrestrial ecosystem-based bioregenerative life support system; (iii) to perform Moon-based observation on the Earth, so as to provide insight into the mechanism of Earth climate system energy imbalance and the global climate change; (iv) to investigate the topography and geomorphology, mineral composition, and substructure of the landing site; (v) to study the properties of space physics related effects and the coupling mechanisms at the Lunar South Pole.

2 Deep Space Exploration Mission Planning beyond the Moon

China has so far planned four missions in deep space exploration, namely an asteroid mission, second Mars mission, a Jupiter mission (Jupiter and its moons), and interplanetary exploration in addition to the first mission to Mars in July 2020.

China has planned a mission to asteroid. A near-Earth asteroid named 2016HO3 will be detected and returned with samples, and a main belt comet named 133P will be orbited. The main scientific goals are: (i) to determine the relevant physical parameters, physical characteristics of the target small body, further understanding the origin and evolution of the early solar system; (ii) to detect the topography, composition, structure, and water and organic matter of the target body; (iii) to collect samples from the target asteroid and return them to Earth for detailed research.

The most important scientific goal of China's second Mars exploration mission is aimed at collecting the soil and rock samples of the Mars and return them to Earth for detailed research, which will help us further our exploration into the origin and evolution history of Mars. It will also carry out scientific investigations on the landing site.

A mission to Jupiter is also planned. It will detect Jupiter and its moons (Callisto or Ganymede), as well as conduct interplanetary exploration beyond

Jupiter. The main scientific goals are: (i) to detect changes in the composition and structure of Jupiter's atmosphere; (ii) to explore the space environment, surface features, and internal structure of its moon; (iii) to study the interaction between the solar wind and the planetary magnetosphere and compare the responses of different types of planetary magnetosphere to the solar wind.

3 International Cooperation

China has always attached great importance to international cooperation in its lunar exploration. During Chang'E-1 to Chang'E-4 missions, China conducted in-depth and pragmatic cooperations with Russia, ESA, the Netherlands, Germany, Sweden, Saudi Arabia and other countries (agencies), and achieved fruitful results in science and technology.

Especially in Chang'E-4 mission, the lander is equipped with Germany-China Lander Neutrons and Dosimetry (LND), Sweden-China Advanced Small Analyzer for Neutrals (ASAN), and the Chang'E-4 probe's relay satellite is equipped with Netherland-China Low-frequency Explorer (NCLE) and the cubsat which piggybacks the relay satellite is equipped with Saudi Arabia's camera, together to complete the human first mission to the moon's farside. On 18 April 2019, China released a global announcement of opportunity for scientific payloads on the orbiter and lander for the asteroid mission. In addition, Chang'E-7 also has weight reserved for international payload, and the announcement of opportunity will be made. International payloads have become an important part of international cooperation in China's lunar and deep space exploration mission.

Since the launch of the lunar exploration program, China has always adhered to the principle of openness. International cooperation has always been a priority in both project implementation and scientific research, reflecting China's openness in space science exploration. China, providing global carrying platforms and scientific payloads carrying opportunities, as well as the scientific data open to the world, is welcoming more and more countries to participate, especially in strengthening international cooperation and exchanges in sciences in the field of lunar and deep space exploration.

At present, more and more countries or agencies have put forward the lunar exploration plans to build scientific research facilities on the lunar surface, focusing on the Moon's South Pole. China has also put forward plans to build an international lunar research station. It is the first landmark platform built and operated by a number of countries at the Moon's South Pole, initiated by China. It will follow the principle of extensive consultation, joint contribution, and shared benefits. The platform will support not only unmanned lunar exploration but also manned lunar missions, as well as a combination of unmanned and manned modes, paving the way for deep space exploration. Based on the fourth phase of the lunar exploration program, the plan will focus on global strengths and carry out comprehensive cooperation in science, technology, and project tasks. International cooperation will also take many forms and have different contents, including joint scientific research, payload carrying, formation of joint research teams, joint laboratories, joint data centers, and so on.

Through extensive international cooperation, China will work with countries interested in participating, including those along the One Belt One Road route to carry out joint planning, exploration and use of the Moon. China will contribute its efforts to the lunar exploration in accordance with the cooperation mode of openness and mutual benefit.

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