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A CHANG'E-4 MISSION CONCEPT AND VISION OF FUTURE CHINESE LUNAR EXPLORATION ACTIVITIES

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Abstract: A novel concept for Chinese Chang'e-4 lunar exploration mission is presented in this paper at first. After the success of Chang'e-3, its backup probe, Chang'e-4 lander/rover combination, would be upgraded and land on the unexplored lunar farside by the aid of a relay satellite near the second Earth-Moon Lagrange point. Mineralogical and geochemical surveys on the farside to study the formation and evolution of lunar crust and observations at low radio frequencies to track the signals of the Universe's Dark Ages are priorities. Follow-up Chinese lunar exploration activities before 2030 are envisioned as building a robotic lunar science station by three to five missions. Finally several methods of international cooperation are proposed.

Keywords: Lunar exploration, Moon, Radio astronomy, Lunar science station, International cooperation

1. INTRODUCTION

The lunar farside is a virgin land and a unique scientific platform on which no humans or robots have ever landed. Although almost everything on the lunar farside is interesting for scientists, there are two major scientific advantages for the farside. Firstly, it is shielded from human-generated radio frequency interference (RFI) from the Earth and free from ionospheric attenuation, hence it is an ideal location allowing scientists to perform very low frequency (VLF) astronomical observations and fill gaps in radio astronomical observation in the unexplored 0.1–30 MHz band. Secondly, the Moon preserves the earliest rocks and craters after the formation of the Earth-Moon system which could not be found on the Earth's surface, and the oldest crust locates on the lunar farside. Hence high-precision in-situ mineralogical and geochemical data of the farside could make great contributions on the formation and evolution of lunar primordial crust and the evolution theory of terrestrial planets. These observations and surveys were identified as top priorities both in the Chinese decadal disciplinary development strategy in space science [1] and in the United States planetary science decadal survey [2]. Therefore, soft-landing and roving exploration mission to the lunar farside is of both remarkable engineering and scientific significances.

In order to support the farside mission, a relay satellite is necessary and the lunar L2 Lagrange point is an ideal location for relay. The lunar L2 point is a place where the combined gravity of the Earth and the Moon allows a spacecraft to be synchronized with the Moon in its orbit around the Earth, so that the spacecraft appears to hover over the farside of the Moon. As shown in Fig.1 and Fig.2, a relay satellite around the lunar L2 point would have continuous line-of-sight visibility to both the lunar farside and the Earth, thus would provide a much longer relay service than lunar orbiting satellite.

Fig.1. Both the farside of the Moon and Earth in the same view. This image was taken by the Chinese Chang'e-5 T1 service module in the Lissajous orbit around the lunar L2 point on October 28, 2014.

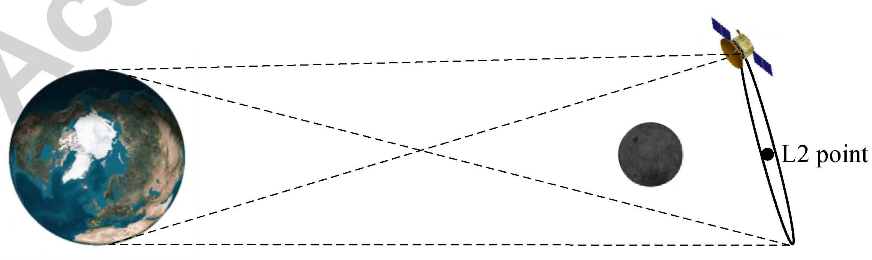

Fig.2. The line-of-sight visibility between the Earth and relay satellite around the lunar L2 Point.

Some lunar farside mission concepts have been proposed. Jack O. Burns et al. proposed a lunar L2-Farside exploration and science mission with the Orion Multi-Purpose Crew Vehicle and a tele-operated lander/rover [3]. David Mimoun et al. proposed a Cosmic Vision medium-size mission of the Moon called Farside Explorer [4] consisting of two landers and an instrumented relay satellite, which finally turns out to be the FARSIDE mission proposal [5] with only a lander and a relay satellite.

On December 14, 2013, Chinese Chang'e-3 probe (including a lander and the Yutu rover) successfully landed on Mare Imbrium at 44.12°N, 19.5°W and became the first visitor to the lunar surface since the Soviet Luna-24 rover of the last century. A lot of scientific data have been obtained by Chang'e-3 especially the Yutu rover despite of its locomotion failure in the second month, and some important results with these data have been reported. Xiao et al. [6] reported that the rover Lunar Penetrating Radar (LPR) detection and integrated geological interpretation have identified more than nine subsurface layers, suggesting that this region has experienced complex geological processes since the Imbrian and is compositionally distinct from the Apollo and Luna landing sites. Zhang et al. [7] pointed out that the LPR measurements suggest underestimation of the global lunar regolith thickness by other methods and reveal a vast volume of the last volcano eruption. The in situ spectral reflectance and elemental analysis of the lunar soil at the landing site suggest that the young basalt could be derived from an ilmenite-rich mantle reservoir and then assimilated by 10–20% of the last residual melt of the lunar magma ocean.

The Chang'e-4 probe was once a backup of Chang'e-3. It should be given new tasks and objectives after the success of Chang'e-3. In this paper, a Chang'e-4 mission concept aiming to place an unmanned lander and rover on the lunar farside and to put a relay satellite into a Halo orbit around the lunar L2 point is proposed. It would fulfill some of the top science goals in planetary science, astrophysics and astronomy.

This paper begins with a more detailed introduction of the Chang'e-4 mission concept in Section 2. In Section 3, follow-up Chinese lunar exploration activities before 2030 are envisioned. In Section 4, several approaches of international cooperation on Chinese space exploration missions are proposed. A summary of this paper is given in Section 5.

2. A CHANG'E-4 LUNAR EXPLORATION MISSION CONCEPT

2.1. Overview

Chang'e-4 mission is a lunar farside landing and roving mission that consists of a lander, a rover, and a relay satellite. The lander and rover, an improved version of Chang'e-3, would land on a major basin (probably the Apollo basin) of the lunar farside. The relay satellite would be sent to a Halo orbit around the lunar L2 point. For consideration on product lifespan, the lander/rover combination would be launched in the first half of 2019, and the relay satellite would be launch in the end of 2018.

2.2. Landing Site

The landing site of Chang'e-4 is still under discussion and not yet determined. Candidate landing sites (shown in Fig. 3) include Apollo basin, Moscoviense basin, Orientale basin, Ingenii basin and Australe basin. The Apollo basin would be the most likely target. It is a double ringed basin that measures about 483 km across located in the northeast corner of South Pole-Aitken basin (SPA), shown in Fig.3. With the imaging spectral data by Chandrayaan-1 Moon Mineralogy Mapper, exposures of mafic material and anorthositic material were found on the Apollo basin [8]. It is possible that some of the materials excavated and/or uplifted by the basin impact event may have originated at lower crust, perhaps even down to the lunar mantle. In-situ investigations would procure high-resolution data on mineral composition and elementary composition, and contribute to understanding lunar formation and evolution. On the other hand, Apollo basin is one of few flat mare basins on the farside of the Moon, and its latitude is numerically close to the landing site of Chang'e-3, Sinus Iridum. Hence the Chang'e-4 lander/rover combination is easy to land on the basin and adapt to the environment with no need of large improvements.

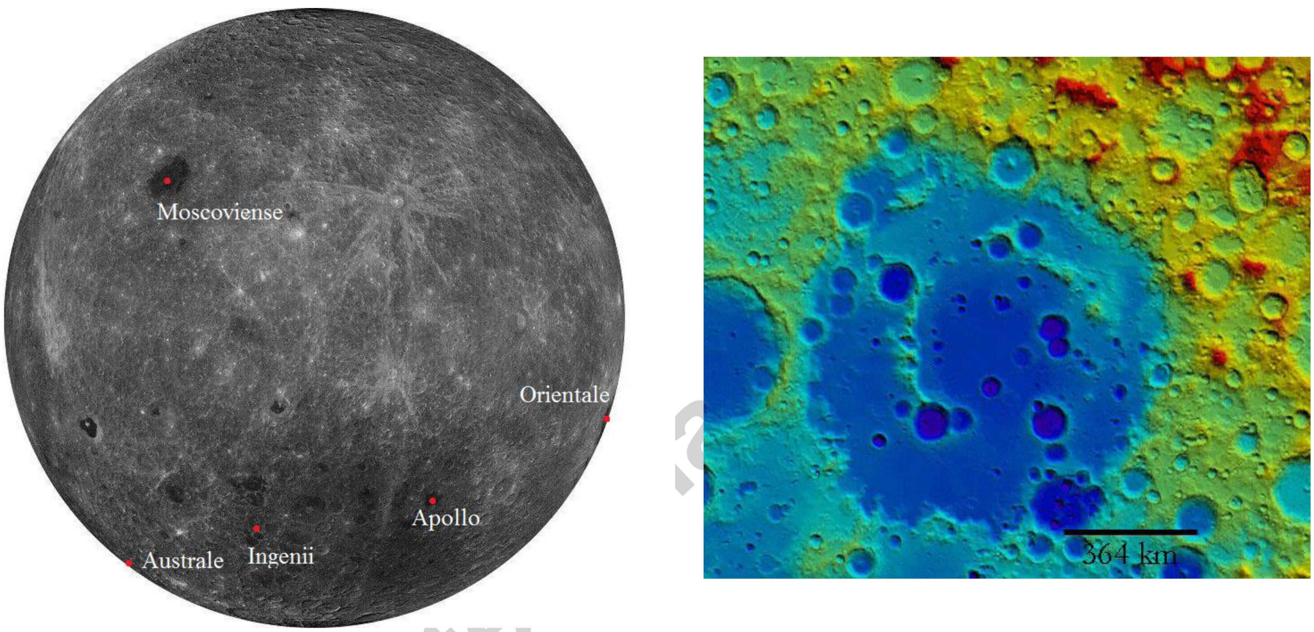

Fig. 3. (Left) Candidate landing sites of the Chang'e-4 lander/rover combination on the lunar farside. The 7m-resolution map of the lunar farside hemisphere was captured by the Chinese Chang'e-2 orbiter. (Right) Digital Elevation Map of the Apollo basin with the LOLA data [9].

2.2. Mission objectives

Engineering objectives of the Chang'e-4 mission include:

(1) To realize the first soft landing and scientific exploration on the lunar farside in human history.

(2) To demonstrate technologies of lunar data relay, landing and roving on difficult terrains, and etc.

(3) To perform further detailed survey on lunar environment and lay a foundation for follow-up lunar exploration missions.

Following scientific objectives of the Chang'e-4 mission are provisional and not yet determined.

(1) To study the interaction of Earth wind and solar wind with the Moon.

Magnetic field intensity, energetic electron and plasma characteristics at the landing site would be continuously measured. With these data, the following issues could be studied by scientists: components and motion status of lunar plasma, evolution process of plasmoid and high-speed flow in the Earth's magnetotail, evolution process of magnetic island, transmission of high-energy electrons in solar wind to the magnetosphere, effects of interaction between the solar wind and the Moon on high-energy electrons, and etc.

(2) To study the generation and formation mechanism of lunar dust.

Exploration tasks include: measurements on physical characteristics and motion status of floating lunar dust, investigations on lunar dust distribution with the variation of time, height and position, studies on charging/discharging and transportation mechanisms of floating lunar dust.

(3) To perform lunar-based VLF astronomical observation.

The radio interference from the Earth would be deeply suppressed on the lunar farside. Astronomical observation of space electromagnetic waves with frequencies below 30 MHz which could not be studied on the Earth is available in this unique region. Realizing the first VLF band imaging of the Universe, would contribute to discovering new phenomena and laws of cosmogony, such as signals of the Dark Ages of the early Universe, VLF radiation characteristics of the Galaxy, distribution of ionized hydrogen (HII), time-variation characteristics of transient objects and etc. The gaps in radio astronomical observation in the unexplored 0.1–30 MHz band would be filled enabling potential breakthroughs in cosmogenesis research.

(4) To study regional geochemistry and tectonic dynamics.

Exploration tasks include: stereo imaging of lunar topography, surface structure studies of typical craters, mineral composition investigations, shallow-layer structure and internal structure survey. A generalized geological section integrating topography, material composition and geological structure would be established. It would contribute to understanding lunar formation and evolution.

(6) To monitor impacts to the Moon.

The lunar L2 point orbit provides much better observation conditions because of the absence of Earthshine and closer distance in comparison to Earth-based detections. Impacts of small celestial bodies onto the lunar farside would be monitored. And risks of future scientific activities on the Moon would be evaluated.

2.3. Payload

The lander would contain a suite of astronomical, geophysical and geochemical instruments, including: a Descent Camera (DeCam) for landing area terrain analysis and lunar dust observation, a Landform Camera (LaCam) for landing site landform investigations, a Lunar Dust Analyser (LDA) for lunar dust physical characteristics measurements, an Electric Field Analyser (EFA) to measure magnitude of electric field at different elevations, a Plasma and Magnetic Field Observation Package (PMFOP), a Lunar Seismometer (LS) for lunar internal structure and impact investigations, a VLF Radio Interferometer (VRI) for radio astronomical observation. Except that DeCam and Lacam would be the same as those on Chang'e-3, the other payloads would be developed from scratch or acquired through international cooperation.

The rover payloads would include: a pair of Panoramic Cameras (PanCams) for roving area topography analysis, a visible to near-infrared imaging spectrometer and shortwave infrared spectrometer (VNIS) for mineral composition and distribution investigations, a Lunar Penetrating Radar (LPR) for lunar shallow structure surveys, an Active Source Hammer (ASH) for active source seismic experiments, and a second VLF Radio Receiver (VRR) for interferometric measurements. Because some important discoveries have been made with the data from LPR and VNIS of Chang'e-3, these two payloads would be kept and improved. The PanCams would keep the same status as the Chang'e-3 PanCams.

The relay satellite would probably contain an Impact Flash Camera (IFCam) for monitoring impact hazards and a Sodium Emission Monitor Camera (SEMCam) for monitoring lunar atmosphere variation in sodium emission. The IFCam and SEMCam would be developed from scratch or acquired through international cooperation.

Table.1. Relationship of scientific objectives and scientific payloads

Scientific Objectives	Lander payload	Rover payload	Relay satellite payload
(1) To study the interaction of earth wind and solar wind with the Moon	Plasma and Magnetic Field Observation Package		
(2) To study the generation and formation mechanism of lunar dust	Lunar Dust Analyser Electric Field Analyser Descent Camera		
(3) To perform lunar-based astronomical observation	VLF Radio Interferometer	VLF Radio Receiver	
(4) To study regional geochemistry and tectonic dynamics	Descent Camera Landform Camera Lunar Seismometer	Panoramic Cameras Visible to Near-infrared Imaging Spectrometer and Shortwave Infrared Spectrometer Lunar Penetrating Radar Active Source Hammer	
(5) To monitor impacts to the Moon			Impact Flash Camera Sodium Emission Monitor Camera

2.4. Mission profile

Flight profile of the relay satellite is shown in Fig. 4. The relay satellite would be first launched into a lunar transfer orbit of 28.5° inclination, 500km perigee height and about 400,000km apogee height. It would start its Earth-to-Moon journey alone after the separation from the upper stage, and fly past the Moon for a gravity slingshot maneuver towards the L2 point. It would use its propulsion system to enter a Halo orbit around the L2 point. From this vantage point, 65,000 km above the farside of the Moon, the satellite would have continuous line-of-sight visibility to both the farside of the Moon and the Earth.

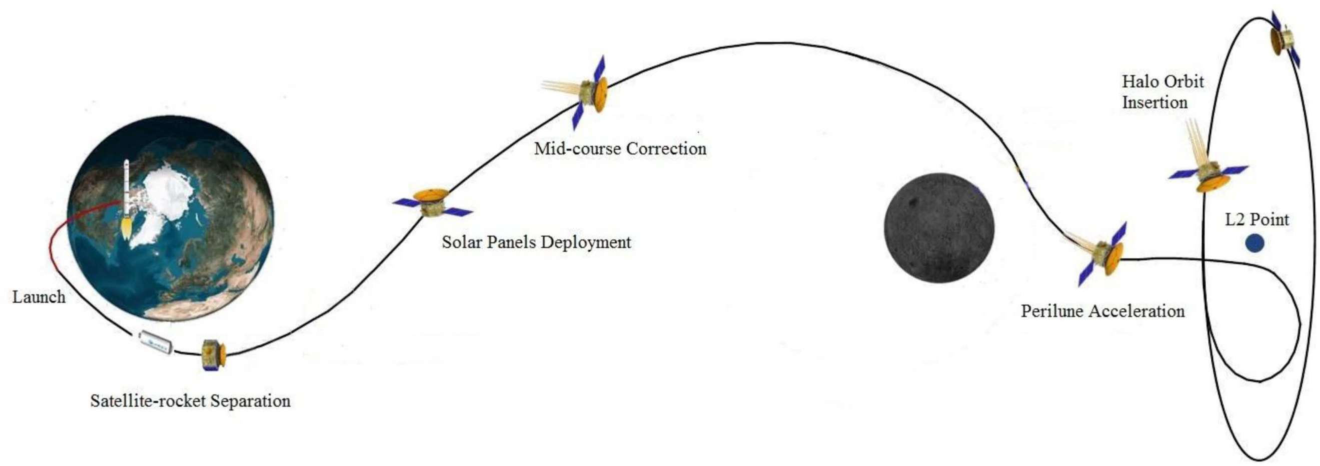

Fig. 4. Flight profile of the relay satellite

Once the relay satellite is ready in its orbit, the Chang'e-4 lander/rover combination would be launched into a lunar transfer orbit which is the same with the Chang'e-3. During its 112-hour flight in trans-lunar orbit, two or three midcourse corrections would be carried out. After braking at the perilune, it would enter a 100km×3000km lunar orbit. After two maneuvers, the probe would enter a 100km×15km orbit and start its soft landing procedures at appropriate case. The soft landing process, shown in Fig. 5 [10], would comprise seven phases: (1) Preparation for landing, (2) primary deceleration, (3) quick adjusting, (4) approaching, (5) hovering, (6) hazard avoidance, and (7) constant low velocity descent.

After touchdown, the rover would be sent to the lunar surface from the lander by a four-bar transport mechanism. Then the rover would move and carry out scientific exploration alone.

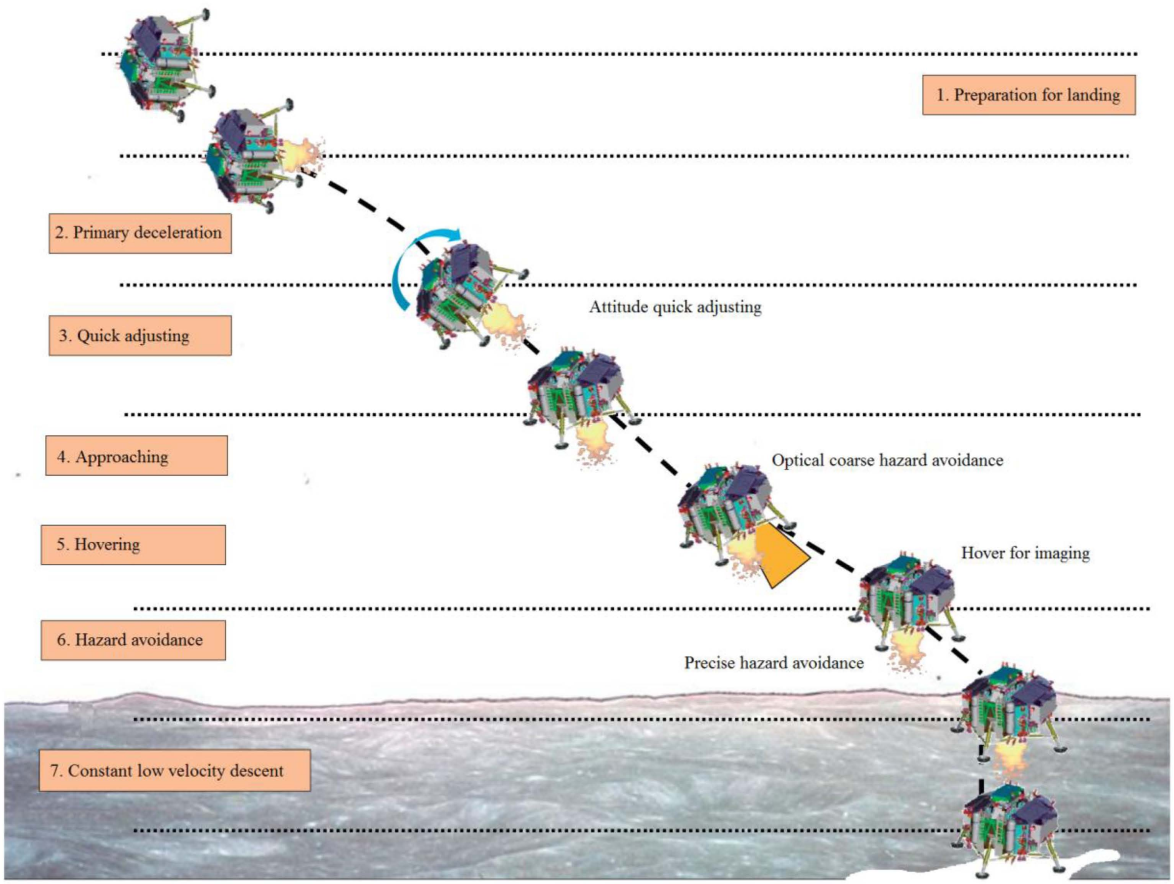

Fig. 5. Soft landing process of the Chang'e-4 lander/rover combination [10]

Based on the on-board velocity, range and hazard sensors, the Chang'e-4 lander/rover combination could realize autonomous guidance, navigation and control in the soft landing process as well as Chang'e-3, despite the lack of direct Telemetry, Tracking and Command (TT&C) support from ground stations. The main difference is the terrain conditions. Compared to the Mare Imbrium landing area of Chang'e-3, the terrains of candidate Chang'e-4 landing sites would have greater elevation changes. Hence the Guidance, Navigation and Control (GNC) subsystem should be improved to get better terrain adaptability.

2.5. Mission systems

Compared to Chang'e-3, the lander and rover platform would be slightly improved in environment adaptability and performance. Improvements mainly include GNC strategy adjustment caused by different landing site, communications subsystem modifications caused by the requirement of relay communications. and changes on scientific payload interfaces.

The total mass of the lander/rover combination is 3780kg. The dry mass of the lander is about 1080kg, which allows for 30kg scientific payloads. During the 14-day lunar night, 5W electric power are provided by a Radioisotope Thermo-electric Generator (RTG) allowing temperature measurements during lunar night, and 240W thermal power are provided by the RTG and a Radioisotope Heater Unit (RHU) allowing the lander spend the cold night in a minimum working mode.

The mass of the rover is about 140kg, which allows for 18kg scientific payloads. It still has a maximum driving speed of 200m/h, a grade ability of 20°, an obstacle clearing capability of 20cm. Its locomotion control system would be improved to be more reliable and the remote operation efficiency would be increased. The rover would have an RHU providing 120W thermal power.

With a mass of about 400kg, the relay satellite would accommodate 20kg scientific payloads. It would provide continuous visibility of both the Moon and Earth with a relatively low transmission rate of the Moon to satellite link. Compatible to existing lander/rover equipment, X band would be adopted in communications link between the lander/rover and relay satellite. For data transmission between the satellite and ground, both S and X band are optional and the latter is preferred due to the high data rates. Standard CCSDS protocols would be adopted in satellite design to ensure international compatibility. We expect that it could support follow-up lunar farside spacecraft from other countries or organizations in its 3-year life cycle.

Like its predecessor, the Chang'e-4 lander/rover would be launched by a Long March 3B rocket from the Xichang Satellite Launch Center (XSLC), and the relay satellite would be launched by a Long March 4C rocket from the XSLC.

Ground TT&C network consists of a deep space TT&C network, a unified S/X band TT&C network and a Very Long Baseline Interferometry (VLBI) network. The deep space TT&C network would be completed around 2017 comprising the Jiamusi 66-meter antenna, the Kashgar 35-meter antenna and the under-construction Argentina 35-meter antenna. The addition of the Argentina station would significantly extend TT&C duration as well as ESA's support. The data receiving network consists of two existing antennas with respectively 50-meter and 40-meter diameter, and an under-construction 35-meter antenna. These two networks would successively serve the Chang'e-5 nearside sample-return mission and the Chang'e-4 farside mission

3. VISION OF FUTURE CHINESE LUNAR EXPLORATION ACTIVITIES BEFORE 2030

The first two steps of the Chinese Lunar Exploration Program (CLEP), i.e. orbiting mission and landing/roving mission, have already been accomplished on schedule. The last step, i.e. sample return mission, would be finished around 2018. After the CLEP, consecutive lunar exploration activities should be carried out to obtain continuous scientific gains. Future development of Chinese lunar exploration could be divided into two directions: robotic exploration and manned exploration. Towards the former, robotic resource survey and in-depth scientific exploration could be the next step, and large-scale robotic lunar base should be built finally. Towards the latter, astronauts landing on the Moon could be the next step followed by construction of lunar base which could accommodate long-term residence of human astronauts. Issue of choosing development direction is under discussion. In the authors' opinion, for the stake of technical span, rocket selection, economic affordability, cost-effectiveness and etc, the former is more feasible for China before 2030, but the latter would be possibly activated once conditions are ready in future and some technical preparations could be made from now on [11]. The Chang'e-4 mission could be treated as a pure science mission and also a pioneer of future robotic exploration activities.

Toward the direction of robotic exploration, a robotic lunar station program comprising several missions is envisioned in this paper. Its general goal is to build a science station with capabilities of multiple-platform networking work, autonomous management, long-term power supply and intelligent operation, used for lunar scientific exploration, scientific experiments, resource survey, and key technology demonstrations related to long-term facilities construction and resource development. The science station could serve as an appropriate link between past Chinese lunar exploration projects and future robotic lunar base projects or manned lunar landing projects.

Three to five robotic lunar soft-landing missions are initially planned to accomplish the station before 2030. Several landers, carrying about a dozen robots, would land on the same region near the lunar nearside south-pole area. Every mission has its own focus on engineering and scientific objectives but also has connection with each other. At present, landing site, scientific objectives and payloads of each mission are still under discussion.

4. INTERNATIONAL COOPERATION OPPORTUNITIES

CNSA has been carrying out some effective bilateral space cooperation projects, including Sino-French SVOM project and CFOSAT project, Sino-Brazilian CBERS project and etc. CNSA expects to promote international cooperation on space exploration. Cooperation intentions from countries and organizations on Chinese future space exploration activities including the on-going Chang'e-4 mission and Mars landing/roving mission are welcomed. Several possible ways of cooperation are proposed as follow.

(1) On mission level. Participants may respectively launch their probes which would land on the same region; or participants may develop some rovers or robots carried by the Chinese lander; or participants may develop a satellite realizing relay communications with landers and rovers. After landing, joint scientific exploration would be carried out.

(2) On equipment level. Participants may provide some scientific payloads or other small experimental equipment which could be carried by Chinese lander, rover or satellite; or China may provide some equipment carried by participants' probes.

(3) On other aspects. TT&C cooperation, scientific data exchange and application, and joint scientific research are always welcomed.

Furthermore, the lunar science station could be developed to an international lunar station comprising a series of landed stations from interested space-faring countries. Interface protocols such as charging and communications could be unified so that the landers, rovers, robots, or satellites from various countries could exchange power and data.

5. SUMMARY AND CONCLUSIONS

In this paper, we have proposed a Chang'e-4 mission concept that would probably be the first to explore the lunar farside in human history. The lander and rover would probably land on the Apollo basin of SPA and carry out innovative scientific exploration including VLF astronomical observations and high-precision in-situ mineralogical and geochemical measurements. The relay satellite in a Halo orbit around the lunar L2 point is expected to support not only the Chang'e-4 mission but also follow-up lunar farside spacecraft from various countries or organizations during its life time. We envision follow-up Chinese lunar exploration activities before 2030. A robotic lunar science station conducting scientific exploration, scientific experiments, resource surveys and technology demonstrations would be built by three to five missions. We welcome international cooperation on future Chinese space exploration activities including the on-going Chang'e-4 mission and Mars landing/roving mission. Participants' contributions could be landers, rovers, robots, orbiters, instruments, scientific data or communications support.

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Highlights

- A Chang'e-4 mission concept of lunar farside in-situ exploration is proposed.
- VLF observation and in-situ survey would enable potential science breakthroughs.
- Robotic lunar science station is envisioned as the next feasible step for China.
- International cooperation is welcomed in Chinese deep space missions.