China's touch on the Moon

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As well as being a milestone in technology, the Chang'e lunar exploration programme establishes China as a contributor to space science. With much still to learn about the Moon, fieldwork beyond Earth's orbit must be an international effort.

When China's Chang'e 3 spacecraft touched down on the lunar surface on 14 December 2013, it was the first soft landing on the Moon since the Soviet Union's Luna 24 mission in 1976. Following on from the decades-old triumphs of the Luna missions and NASA's Apollo programme, the Chang'e lunar exploration programme is leading the charge of a new generation of exploration on the lunar surface. Much like the earlier space programmes, the China National Space Administration (CNSA) has been developing its capabilities and technologies step by step in a series of Chang'e missions of increasing ambition: orbiting and landing have been accomplished, sample return is planned for 2017, and a crewed mission will be launched by 2030. Over the past decade, space agencies in the US, Europe, Japan, India and China have all put spacecraft into orbit around our closest satellite. The accomplishments of China should be shared and built on in what has become a multinational effort to understand the Moon.

The Chang'e 1 and Chang'e 2 orbiters launched in 2007 and 2010, respectively, and successfully imaged the entire lunar surface in three dimensions[1]. In addition to high-resolution images and digital elevation models, Chang'e 1 also measured the thickness of lunar soils, estimated the abundance of He-3 implanted in the soils by the solar wind[2,3] and studied the lunar plasma and radiation environment between 100 and 200 km in altitude — a zone neglected by previous missions.

Initially built as a back-up spacecraft if Chang'e 1 failed, Chang'e 2 had its objectives reset to prepare for the landing of Chang'e 3. The orbiter acquired high-resolution images for landing site selection and tested technologies required for a soft landing on the Moon. It improved on the 100 m spatial resolution of the Chang'e 1 camera, with a spatial resolution of about 7 m that seamlessly covers the whole Moon — the highest resolution of a global digital image map of the Moon so far. There was lunar

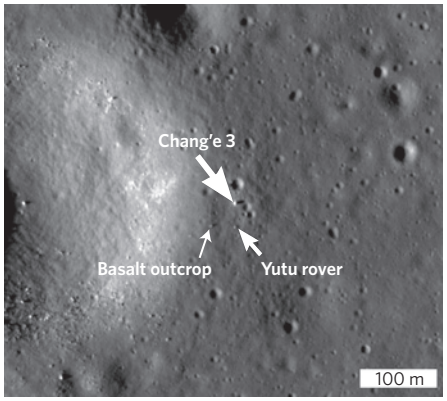

Figure 1 | The Chinese Chang'e 3 spacecraft and its rover Yutu on the lunar surface, as imaged by NASA's Lunar Reconnaissance Orbiter on 24 December 2013. A large outcrop of porphyritic basalt that has been studied by Yutu (Fig. 2) is also labelled. The successes of the Chang'e missions contribute to an increasingly multinational effort to understand the Moon. Modified from image LROC NAC M1142582775R.

science involved, too: for example, the detection of a weak magnetosphere on the Moon at the antipodal region of Mare Serenitatis is consistent with predictions that a basin-forming impact induced a weak magnetosphere at its antipode[4].

The Chang'e 3 lander and its rover Yutu ('Jade Rabbit') were the first visitors from China to land on another world, touching down on the rim of a small crater in the northern Mare Imbrium[5] (Fig. 1). Chang'e 3 and Yutu are equipped to study the surface and subsurface of lunar crust, the Earth and the stars overhead. Their payloads include ground-penetrating radar and a wide-angle ultraviolet camera.

Unfortunately, although originally planned to rove the lunar surface over a period of 3 months — or 3 lunar days — Yutu encountered mechanical problems and has not moved since 25 January 2014. But Yutu's science instruments are still operational and continue to send back plentiful data, revealing the complex geological history of the landing site. High-resolution images have shown rocky terrain with outcrops of porphyritic basalt, such as Loong Rock (Fig. 2). Analysis of data collected by the penetrating radar should lead to identification of the underlying layers of regolith, impact breccia and basalt.

China's robotic field geologist Yutu has stalled in its traverse of the lunar surface, but plans for the Chang'e 5 sample-return mission are moving forward. The primary objective of the mission will be to return 2 kg of samples from the surface and depths of up to 2 m, probably also in the relatively smooth northern Mare Imbrium. Sampling a mare terrain about 2.5 billion years old should return different types of rocks than the Apollo missions, which sampled mostly ancient highland and older mare terrains. However, the mission will face the challenge of drilling and coring through the loose soils and hard rocks imaged by Chang'e 3. Because of such technical difficulties, the three unmanned Soviet sample-return missions between 1970 and 1976, Luna 16, 20 and 24, only returned about 0.32 kg of samples in total[6]. Thus, detailed study of candidate landing sites, careful landing site selection, and improved landing and sampling technology, are essential for the success of the Chang'e 5 mission.

The scientific goals of China's Chang'e programme complement those of other space agencies, with a primary focus on investigations into geochemical and structural heterogeneities of the lunar crust, lunar soil properties and potential resources. Like other space agencies, CNSA is also interested in understanding the Moon's interior structure, and plans to install a seismometer on the lunar surface at some stage to detect the passage of seismic waves from Moon quakes. But, as for seismic investigations on Earth, seismic stations in multiple locations are needed for an array, a daunting and expensive task for a single space agency to accomplish. Such investigations should yield insights into the evolution of the lunar interior, surface

Figure 2 | Loong Rock. The porphyritic rock outcrop, about 1.5 m in height, is located about 3 m away from the Yutu rover. In the background is a young crater that is 450 m in diameter, with a rocky wall.

processes and space weathering, as well as the formation of the Earth–Moon system.

CNSA views long-term and sustainable lunar and space scientific exploration as its duty to mankind. The lunar exploration data from the Chang'e 1 and Chang'e 2 missions has been made publicly available for anyone to access and download through CNSA's Science and Application Center for Moon and Deepspace Exploration[7]. Likewise, data acquired by Chang'e 3 will also be released in due course. In addition, China continues to collaborate with the European Space Agency, which assisted the Chang'e 3 mission in tracking the spacecraft's entry into lunar orbit and precisely locating the lander and rover on the lunar surface. Chinese and European scientists recently met in Chengdu, China, to explore the possibility of a joint space mission between the two space agencies[8]. This follows the collaboration between CNSA and the Russian Federal Space Agency on the Phobos-Grunt and Yinhuo-1 mission to Mars, which sadly failed to leave Earth orbit.

Unfortunately, collaboration with the world's largest space agency, NASA, is currently not an option. Citing security concerns, the US Congress banned collaboration between NASA and CNSA in 2011. According to the law, NASA funds cannot be used for any bilateral activities with China. So, for the time being, there are no formal joint space projects between NASA and CNSA. Furthermore, scientists based in mainland China are unable to access NASA's official website and download mission data. But that is not to say that there has been no interaction between American and Chinese missions, albeit indirectly via the spacecraft themselves: NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) detected the dust kicked up by Chang'e 3's landing, as well as volatiles injected into the soil by its landing rockets. The Lunar Reconnaissance Orbiter has also imaged a birds-eye view of the Chang'e 3 lander and rover on the lunar surface (Fig. 1).

The Moon is a witness to 4.5 billion years of solar system history[9]. We will be most efficient at exposing its secrets if we join forces and combine existing data from earlier programmes with new acquisitions. With the increasing openness of China's lunar and space exploration, multinational collaboration would greatly benefit and improve our understanding of our closest celestial neighbour, the Moon. ❐

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