China's roadmap for planetary exploration

China has approved or planned a string of several space exploration missions to be launched over the next decade. A new generation of planetary scientists in China is playing an important role in determining the scientific goals of future missions.

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China's 'Thirteenth Five-Year Plan', released on 17 March 2016, announced that planetary exploration is a national priority. For the first time, China explicitly indicated the intention to go further than the Earth–Moon system. For China's planetary research community, the emphasis on deep-space exploration in the current Five-Year Plan has been not only a new start, but also a turning point.

China's first purely scientific space mission, Double Star[1], was launched in 2003, more than three decades after the launch of its first satellite. Double Star studied the terrestrial space environment. Since 2015, China has put several new scientific satellites in Earth-orbit. These are the DArk Matter Particle Explorer (DAMPE, or Wukong)[2] in 2015, the QUantum Experiments at Space Scale (QUESS, or Micius)[3], the Shijian 10 mission (SJ 10)[4], the Chinese Carbon Dioxide Observation Satellite Mission (TanSat)[5] in 2016, the Hard X-ray Modulation Telescope (HXMT, or Huiyan) in 2017[6], and the China Seismo-Electromagnetic Satellite (CSES) in 2018[7]. Further missions are on the way, such as the Solar wind Magnetosphere Ionosphere Link Explorer (SMILE), in collaboration with the European Space Agency (ESA) (Fig. 1).

Most of these near-Earth missions have been somewhat similar to NASA's low-cost Medium-Class Explorers or Discovery Program[8]. They have been supported by the Chinese Academy of Sciences through its programme of strategic priority science and technology projects in space science. Solar System missions, however, are more high-cost and can be supported only as national-level projects of the Chinese government. The excellence of scientific goals is the core value of a space mission, and thus requires very careful evaluation. Unlike NASA's Discovery or New Frontiers programmes, which invite planetary scientists to propose targets for scientific exploration before evaluating and selecting from those proposals, China's planetary exploration is a national strategy: the target candidates are released first, after which point the scientists and engineers can begin to set priorities. The development of the Chinese planetary community and its procedures for seeking agreement on mission goals reflect in many ways the emergence of planetary science in the Western world. Early US and Soviet Union planetary missions, for example, were primarily technology-focused, but they quickly fostered scientific planetary research and a rapidly growing planetary community.

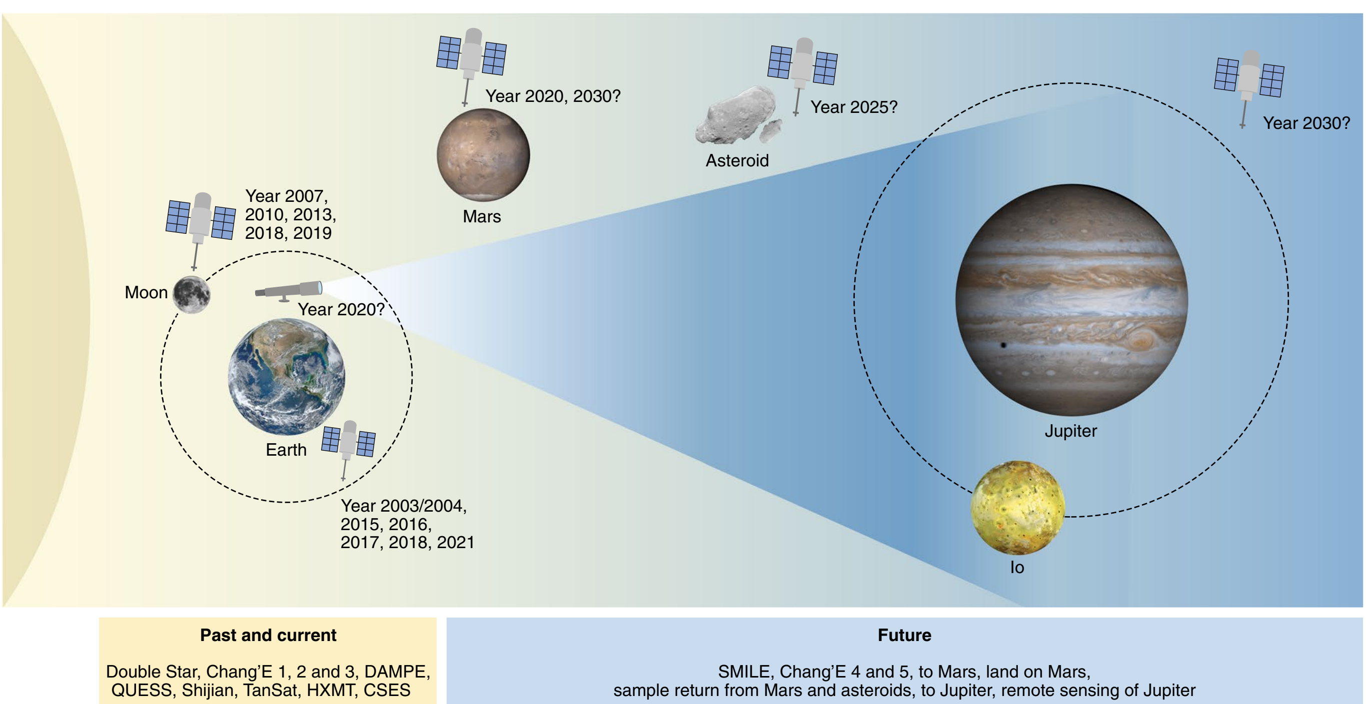

Fig. 1 | China's past, current and the near-future space missions, and their targets. Credit: Earth, NASA; Jupiter, NASA/JPL/University of Arizona; Io, NASA/JPL/University of Arizona; Mars, NASA/JPL/Malin Space Science Systems; Asteroid, NASA/JPL; Moon, NASA.

In fact, over the past ten years China has gone from having almost no planetary scientists to the establishment of its first official Planetary Physics Committee, announced by the Chinese Geophysical Society in 2017. More than 100 scientists from universities and institutes in China and abroad serve on this committee. Some have worked previously in China as geophysicists, while others have returned to China after some years of experience abroad as planetary scientists. Also in 2017, the first specialized journal of planetary science *Earth and Planetary Physics* published its first issue.

Our nearest neighbour, the Moon, was selected as China's first national-level target. The Moon is an ideal target for space exploration, given its natural resources and the current development state of space engineering. The first three Chinese Lunar missions, Chang'E (CE) 1, 2 and 3, were launched in 2007, 2010 and 2013, respectively. These missions achieved important results in topography, regolith structure and lunar-based astronomical observations[9,10]. They also provided precious engineering knowledge, such as soft-landing technology, the rover and scientific instruments, which can be utilized in future space explorations to the Moon and other planets. CE 4 is designed to land on the far side of the moon in 2018, and the first sample-return mission, CE 5, is expected to bring back about 2 kg of lunar soil from the near side of the moon in 2019. It is likely that these two CE missions may be delayed for a short time due to the schedule of the Long March 5 rocket. Although not yet fully determined, China is also planning three possible missions to the Moon's south pole.

Benefiting from the engineering heritage of the Moon missions, the Chinese national strategy could focus on the next target — Mars — which is of great interest to the international planetary community primarily for its scientific richness, but also partially for its potential as a habitable environment. In 2011, the orbiter Yinghuo-1, along with the Russian Fobos-Grunt sample-return spacecraft, was launched but failed to escape the Earth. A new Mars mission was officially approved in January 2016, and has been scheduled to arrive at Mars in early spring 2021, after a planned launch from Earth in the summer of 2020. With the landing technology inherited from CE 3 and new development, this Chinese Mars mission has been designed to consist of one orbiter and one rover.

This mission is focused on the atmospheric escape and loss of liquid water. The orbiter will collect data regarding global processes in the near-Mars plasma environment, and the rover will explore local features around the landing site. Combining measurements from the orbiter and the rover will provide a feature resolution ranging from the global scale to local details. Both the orbiter and the rover will carry cameras, radar systems and magnetometers. The orbiter will also have plasma analysers on-board for measuring the surface magnetic field along the rover's trajectory. These data, including the first magnetic field measurements from the Martian surface, are expected to resolve the daily variations in the interaction between the solar wind and the Martian ionosphere, together with the associated changes in the electrical current system. Having the same kind of instruments on-board the rover and the orbiter allows two-point simultaneous measurements between space and the ground, thus providing a unique opportunity to understand the interactions between space plasma and the near-ground environment, and the consequent energy dissipation. Moreover, both the orbiter and the rover can also coordinate with ESA's Mars Express (MEX) and NASA's Mars Atmosphere and Volatile Evolution (MAVEN) missions.

CE 2 has already conducted one flyby observation of an asteroid in 2012, and CE 5 will provide essential knowledge for sample return. A sample-return mission from a comet or asteroid is therefore naturally expected to be next. Following the 'Thirteenth Five-Year Plan' planetary strategy, China's next three planetary missions, currently in their planning phases, are a comet/asteroid sample-return mission whose launch is planned around 2025, a Mars sample-return mission with a tentative launch around 2030, and a mission to Jupiter and its moons with a tentative launch time also around 2030. The sample-return mission to Mars, however, will strongly rely on the development of a future rocket — Long March 9 — that would have a capability similar to the US Saturn V rocket. Although these missions are all addressed in the government planetary strategy, their official approvals and relative priorities will be based ultimately on the merits of their scientific goals and engineering challenges. The goals and priorities of these three missions are hotly debated. Scientific goals are at the heart of the debate. The decision-making process seeks a balance between innovative scientific goals and feasibility of the technology needed to reach those goals. Scientists tend to put high value on the exploration of unknown regions and on cooperating with scientists from other countries in present and future missions. Engineers tend to focus on the reliability of current technology and how to build on the heritage of China's previous missions. Both sides must work together to ensure the success of a mission and the accomplishment of the proposed scientific goals.

China's broad scientific goal is to explore planetary evolution. Comparing planets will help us to better understand the evolution of our own planet, Earth. The future Lunar missions are expected to resolve the structure and composition of the lunar deep interior, reveal the mechanisms of magma ocean crystallization and crust–mantle differentiation, and provide direct evidence of the presence of water (ice) on the Moon (and its origin).

The future possibilities of Chinese Jupiter missions are also likely to attract attention from the international planetary community. Jupiter research is currently a hot topic, as exemplified by NASA's Juno mission, and will likely remain so in the coming decades, during which several future missions to Jupiter are expected (such as NASA's Europa Clipper and ESA's JUpiter ICy moons Explorer (JUICE)). Although the scientific goals of the Chinese mission have not yet been fully decided, among those being considered by the planning team are Jupiter's magnetosphere–ionosphere coupling, the dynamics of its atmosphere and exploration of Jupiter's moons.

The Chinese exploration of Jupiter will also involve the creation of a ground telescope observatory. Unlike most ground telescope observatories, which are led by astrophysicists, this telescope project will be led by planetary scientists from the Institute of Geology and Geophysics, part of the Chinese Academy of Sciences. It will be used to study the interaction between Io (the most active moon of Jupiter) and the Jovian magnetosphere, and how this interaction affects Jupiter's magnetosphere–ionosphere coupling system. This project will require significant international collaboration (for example, with the University of Liège's astrophysics and planetary teams). China's contribution is expected to include two 1-m-diameter telescopes in an ideal observatory location in Tibet. This planetary science-oriented telescope is expected to be operational by 2020. As Jupiter is the scientific priority for the observatory, it will also provide important support for ESA's, NASA's and China's spacecraft missions to the Jupiter system planned in the course of the next decade.

Scientists are taking stronger-than-ever leadership positions in Chinese space exploration, driving the goals farther than mere technological demonstration. To maximize the scientific returns of these space missions, international collaborations are highly regarded. More and more young scientists who have acquired training in the USA and Europe are choosing to come back to China, thus offering many opportunities to collaborate with the international community. China is undoubtedly embracing the world in its planetary explorations and is on the road to becoming an important participant in planetary science research. ❒

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