correspondence

China's ambitions and challenges for asteroid–comet exploration

To the Editor — Rubble-piled and irregular-shaped small celestial bodies (SCBs) contain abundant pristine information about the early Solar System, providing a unique window into its origin and evolution. SCBs have also recently attracted interest beyond science due to applications in planetary defence, space mining, and the like. During the past three decades, nearly twenty probes explored SCBs with great success[1,2], including the European Rosetta mission[3], the Japanese Hayabusa 1 and 2 missions[4], and the US OSIRIS-Rex mission[5] to sample regolith for return or in situ analysis.

In recent years, China has achieved remarkable progress in space exploration, as illustrated by the Chang'e and Tianwen-1 missions[6–8]. With substantial technology accumulation in space science and technology, China is now actively pursuing an ambitious plan to sample a near-Earth asteroid and orbit an active asteroid through one single probe in the forthcoming decade (Fig. 1). As China's first mission to explore SCBs, this mission, which has been under engineering implementation since the start of 2021, is viewed as a milestone in the Chinese journey of developing its space capabilities. The multistage and multitask mission, likely to be named Zhenghe[9] after a famous Chinese mariner, explorer and diplomat in the early Ming dynasty, is planned to visit two remote objects in an effort to minimize cost while maximizing efficiency.

The first target of the mission is planned to be asteroid (469219) 2016 HO_3 (Kamoʻoalewa), a quasi-satellite of our Earth. It is an Apollo-type asteroid that measures ~40–100 metres in diameter and is likely to have a very pristine composition, as suggested by its lack of strong spectral features[10]. The second target is the active asteroid 311P/PANSTARRS, which measures ~320–585 metres in diameter. It may have abundant volatile substances, including water ice, as implied by the comet tail observed at its perihelion passage, suggesting the tail is produced by heat-waving. Its exploration would provide much-needed in situ constraints on the ongoing debate concerning the cometary origin of Earth's water and would elucidate the differences in surface features and composition between active asteroids and classic comets.

The mission payload will include eight instruments: a mid-field colour camera, a thermal emission spectrometer, a UV–Vis–NIR spectrophotometer, a multispectral camera, a detection radar, a magnetometer, a charged and neutral particle analyser, and an emissions analyser. They will characterize their targets' orbital and intrinsic characteristics, such as their topography, composition, internal structure and thermal properties, with the goal of understanding the formation and evolution mechanism of typical SCBs in the Solar System. The regolith sample returned from 2016 HO_3 will be analysed in terrestrial laboratories to compare its microscopic properties with meteorites and the samples from the other sample return missions. In the case of 311P/PANSTARRS, the probe aims to provide clues for the origin and evolution of the early Solar System by detecting evidence of water and organics and studying the mechanism of gas activity. Finally, assessing its surface weathering and ionospheric evolution will allow the mission to study the interaction between the solar wind and MBCs.

As the successful Hayabusa 2 and OSIRIS-Rex missions have shown recently, extracting a sample from rubble-pile SCBs requires careful planning. There are two typical approaches to sample SCBs, namely anchor-and-attach architecture and touch-and-go architecture. The former requires a complex thrusting and anchoring system, which is extremely sensitive to the properties of the surface regolith but allows for long-time operations and thus more controlled sampling. The latter option, used by both the aforementioned spacecraft, eliminates any need to land and anchor because surface sampling is completed through a short-time interaction, resulting, however, in more complicated navigation, guidance and control. The planned Chinese mission will follow the sampling strategy of the Chang'e 5 mission by using both architectures to guarantee that at least one works. It should be noted that there is still no successful precedent for the anchor-and-attach architecture.

From the engineering side, this ambitious ten-year plan aims at developing comprehensive planetary exploration capabilities in China by providing detection data and regolith samples for fundamental scientific research and promoting the coordinated development of space science and technology. Although China has accumulated some successful experience from their previous missions, this project is still extremely challenging. To succeed, a series of critical technologies will need to be mastered. These include remote and long-time interplanetary cruises with high-efficiency, long-life propulsion engines and high-precision navigation, guidance and control during orbit transfer at well-designed manoeuvring points. For the sample acquisition, fully autonomous descent-anchoring-and-sampling due to communication delay, anchoring and attaching mechanism with broad terrain adaptability, and excellent flight trajectory design and optimization with low-thrust and gravity-assist jointed propulsion have to be developed. Finally, adaptive thermal control in extreme interplanetary environments, novel aerodynamic configuration and thermal protection design for ultra-high-speed small-capsule re-entry, and new terrestrial verifying methods and test rigs are also required. While a relative newcomer to the field of space exploration, China is feeling up to the task! ❐

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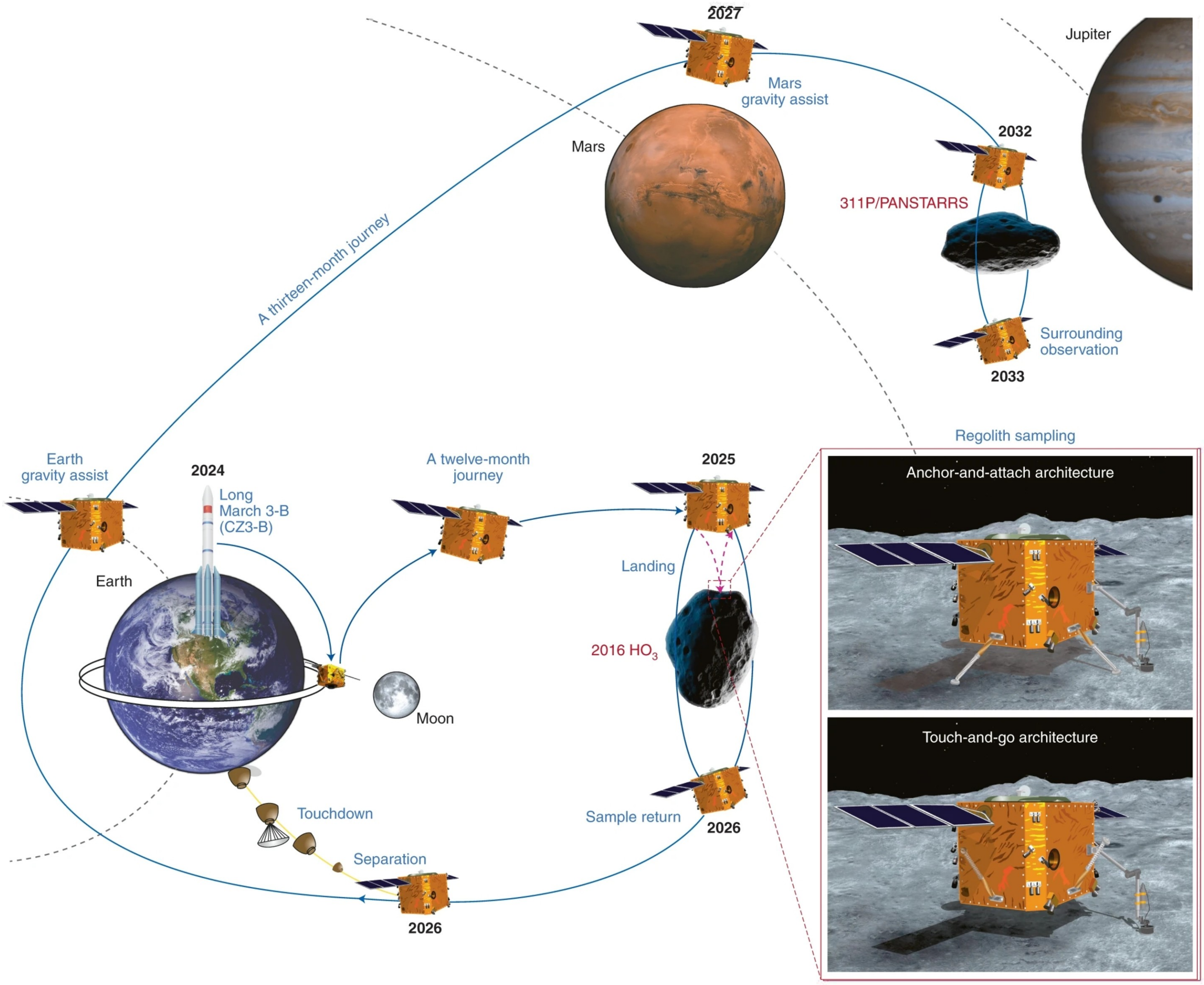

Fig. 1 | Overview of China's asteroid–comet exploration mission. The probe is planned to be launched at Xichang Satellite Launch Center through a CZ3-B carrier rocket in 2024. It will arrive at near-Earth asteroid 2016 HO$_3$ in 2025, conduct a series of remote sensing measurements, land and anchor to sample regolith, take off from the asteroid, and fly towards the Earth in 2026. When the probe flies back into Earth's proximity, it will release a re-entry capsule to return the collected regolith samples and will then continue its flight to the second target in the main asteroid belt (MAB), with gravity assists from Earth and Mars. It will finally arrive at comet 311P/PANSTARRS around 2034 and orbit it for a year. The first phase will take ~2–3 years and the second phase about 7 years. Credit: NASA/JPL (asteroid image); NASA/JPL/University of Arizona (Jupiter image); NASA/Goddard/Lunar Reconnaissance Orbiter (Moon image); NASA/USGS (Mars image); NASA (Earth image).

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Author contributions

X.D., K.X. and T.Z. designed the framework. K.X. and T.Z. wrote the content and X.D. revised it.

Competing interests

The authors declare no competing interests.