SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

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CHINA

The Next Space Power?

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In July 2020 at the Wenchang Satellite Launch Center on the island province of Hainan, engineers will be preparing one of China's largest rockets for takeoff. The Long March 5 has a payload capacity similar to the Delta IV Heavy, which has carried craft such as NASA's Parker Solar Probe into space. The payload for the Long March 5's launch this summer will be the country's first independent interplanetary mission, joining NASA's Mars 2020 rover and the United Arab Emirates' Hope Mars mission this year in heading for the Red Planet.

The go-ahead for launch of Huoxing 1 ("Mars 1") depended on the successful return-to-flight of the Long March 5 in late December 2019, following the second launch's failure in 2017. While there's certainly pressure to succeed, China's fate is in its own hands. That wasn't the case less than a decade ago, when its first interplanetary adventure rode on another nation's rocket. The first attempt to reach Mars was a small orbiter that piggybacked on Russia's 2011 Phobos-Grunt sample-return mission. But an upper stage failure meant both spacecraft failed to leave Earth orbit.

With Queqiao in place to facilitate communications, China was poised to do something never before attempted.

The upcoming Huoxing 1 mission will be much more complex, reflecting China's growth in both capabilities and ambitions. The mission will consist of both an orbiter — equipped with a suite of science payloads and medium- and high-resolution cameras, the latter comparable to HIRISE on NASA's Mars Reconnaissance Orbiter — and a small, 240-kilogram rover. With a design lifetime of 90 days, the rover seeks to discover the distribution of water ice under the Martian surface using ground-penetrating radar — an instrument that has never been deployed on Mars's surface. It will also carry its own laser-induced breakdown spectroscopy instrument, similar to that of Curiosity, as well as equipment to analyze the climate, magnetic field, and surface composition. The landing site is expected to be within Utopia Planitia, south of the Viking 2 lander. Assessing Martian morphology, geology, and climate are all major science goals of the mission.

Placing an orbiter around Mars would match India's stunning 2014 achievement, but sticking the rover landing would be spectacular: Only NASA has successfully operated on the Red Planet for more than a minute. That China is ready to make such an attempt demonstrates the huge strides its space program has made.

HOW DO YOU SAY IT?

Chang'e is pronounced "chahng-uh," where the "uh" is like the e in "her."

Lunar Learning Curve

While they do have an element of seeking international prestige and domestic support, China's space efforts also have clear science objectives and even far-sighted goals. These are apparent first in its long-game approach to the Moon. China's plans for the Moon are extensive and make use of accumulated engineering capabilities and technological achievements. It has already landed twice on the lunar surface and has four more missions in the works.

First came Chang'e 3, which landed in Mare Imbrium in 2013. Quietly and somewhat surprisingly, Chang'e 3 is still running. While the Yutu ("Jade Rabbit") rover lost roving ability after two lunar days and ceased operating completely in 2016, the solar-powered lander still wakes up every lunar daytime, protected from the extreme cold of the night by a radioisotope heater unit. Updates these days come not from China, but from radio amateurs, who pick up signals sent from the lander to ground stations. Only one of eight payloads — the Lunar-based Ultraviolet Telescope (LUT) — was reported working by 2017. Scientists have used LUT's data to put an upper limit on the amount of water within the tenuous lunar exosphere.

Despite a limited drive that totaled 114 meters (374 feet), the Yutu rover used its ground-penetrating radar to reveal a surprising number of layers within the first dozen meters or so of the surface. The result hinted at a more complex geological history than researchers had previously thought happened. However, a 2018 follow-up study by Chinese and Italian scientists calls the interpretation into question, suggesting that some of these layers are actually artifacts.

When preparing Chang'e 3, China also manufactured a backup. After the successful 2013 landing, engineers repurposed this backup, Chang'e 4, for a more ambitious feat.

The first clue as to what Chang'e 4's mission would be came in 2014 from the test mission Chang'e 5 T1, when the spacecraft returned a stunning image of the lunar farside and distant Earth. Then in May 2018 a communications relay satellite, named Queqiao ("Magpie Bridge"), was launched and sent into a halo orbit around the second Lagrangian point of the Earth-Moon system, tens of thousands of kilometers beyond the Moon. From this orbit, Queqiao is able to maintain a constant line of sight with both terrestrial ground stations and the lunar farside, which due to tidal locking never faces Earth.

With Queqiao in place to facilitate communications, China was poised to do something never before attempted: Chang'e 4 made the first-ever soft landing on the farside of the Moon in January 2019. The spacecraft descended automatically, avoiding hazards to set down on a relatively flat area of Von Kármán Crater within the massive South Pole-Aitken (SPA) Basin — a gigantic, ancient impact crater. Shortly after landing, Chang'e 4 deployed the 140-kilogram,

China Launches to Center Stage

A bold series of successful and proposed missions are catapulting China to prominence in space.

XIAO CHEN

LIFTOFF The Long March 5 rocket launches from Wenchang in December 2019.

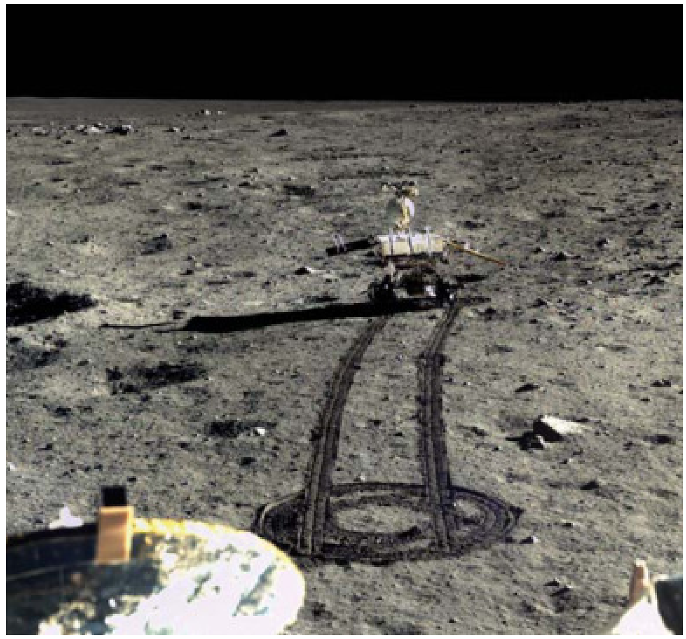
six-wheeled Yutu 2 rover on the surface.

The Chang'e 4 lander is equipped with a low-frequency radio spectrometer that takes advantage of its unique position on the lunar farside, where it's shielded from electromagnetic interference from Earth. This instrument will make unprecedented observations at frequencies blocked by Earth's atmosphere. A similar instrument, the Netherlands-China Low Frequency Explorer, flies aboard Queqiao. Both instruments could eventually detect neutral hydrogen in the cosmic dark ages that preceded the universe's first galaxies.

The lander also carries the Lunar Lander Neutron & Dosimetry experiment from Germany, which will measure the radiation environment. Those readings could be instructive for future crewed lunar missions.

The first major results returned from Chang'e 4, however, came courtesy of Yutu 2's Visible and Near-Infrared Imaging Spectrometer (VNIS), which detects light reflected off materials on the surface. Similar instruments are also aboard Chang'e 3 and the future Mars rover. In May 2019, Chunlai Li (Chinese Academy of Sciences, Beijing) and colleagues reported that VNIS readings suggest the presence of olivine and low-calcium pyroxene within the regolith near the landing site — materials that may originate from the Moon's mantle. A second study by Sheng Gou (also Chinese Academy of Sciences, Beijing) and others supports this claim. They conclude that lunar regolith and rock fragments likely contain materials excavated from the upper mantle by the impact that created the nearby crater Finsen.

Yutu 2 has also given us a look at the lunar subsurface. The first published results from the rover's Lunar Penetrating Radar 2 indicate three distinct layers of regolith extending to a depth of 40 meters below the surface and embedded with boulders of various sizes, providing a unique insight into the geological history of Von Kármán (see page 10).



▲ **INTREPID YUTU** This four-image mosaic from the Chang'e 3 lander shows the 1.5-meter-tall Yutu rover driving southward on the Moon on December 23, 2013.

Towards a Lunar Research Base

Chang'e 1 and 2, launched in 2007 and 2010, respectively, were orbiters that mapped the Moon — with the latter also performing a flyby of near-Earth object Toutatis in 2012. Chang'e 3 and 4 were landing and roving missions. Next up will be the third phase of China's lunar exploration project, initially conceived in the early 2000s: sample return. The Chang'e 5 mission, currently slated to launch in late 2020, aims to collect up to 4 kilograms from a site near Mons Rümker in Oceanus Procellarum on the Moon's nearside.

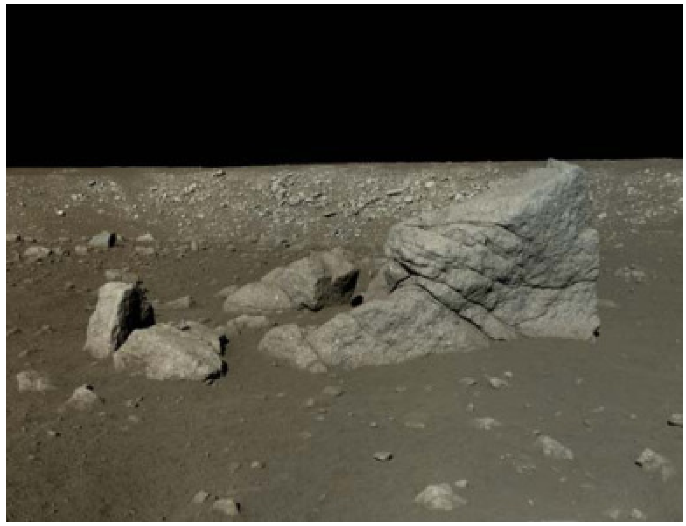
VIEW FROM CHANG'E 3 This section of a panorama taken three days after Chang'e 3's December 2013 landing shows the rover, Yutu, as well as a crater with bright rocks on its rim.

Rather than a direct sample return like the last such mission, the 1976 Soviet Luna 24, Chang'e 5 will employ a robotic lunar orbit rendezvous. An ascent vehicle will launch from the lunar surface and meet up with a waiting service module, which will then head back to Earth and release a return capsule. The capsule will land in the same area as China's crewed Shenzhou missions.

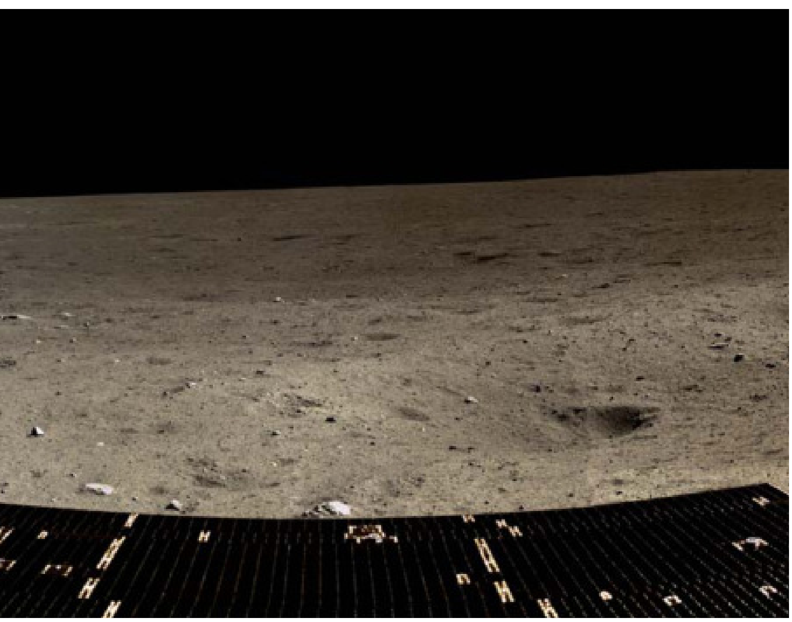
This otherwise unnecessary complexity has been taken as a signal that China is looking to use the mission to prove technologies for future crewed lunar missions, which could take place in the 2030s. If Chang'e 5 succeeds, the backup Chang'e 6 will target the lunar south pole. It will also carry the French Detection of Outgassing Radon instrument, which aims to study the transport of volatiles through the lunar regolith and in the lunar exosphere.

Following the success of its first set of Moon missions and the shift in international interest toward lunar exploration over the last 10 years, Chinese scientists and officials have been formulating an expanded project to explore our celestial neighbor. In the afterglow of the successful Chang'e 4 landing, China stated that prospective missions beyond Chang'e 6 will go ahead. These will attempt comprehensive exploration of the lunar south pole, including analysis of topography, composition, and the space environment. They will also test key technologies to lay the groundwork for the construction of a science and research base on the moon, Yanhua Wu, deputy head of the China National Space Administration, said in January 2019.

Slated for the mid-2020s, Chang'e 7 will consist of a relay satellite, orbiter, lander, rover, and hopping detector. Chang'e 8 will follow. Both missions will likely use the Long March 5 for transport. Chang'e 8 will test extraction of volatiles, in-situ resource utilization, and 3D printing on the Moon. These technologies will support future crewed lunar landings and resource utilization. The missions will also carry out unspecified biological experiments. Additionally, scientists may conduct a Very Long Baseline Interferometry experiment, combining data from Earth-based radio dishes with one on the relay satellite.



▲ **PYRAMID ROCK** The Yutu rover visited this block of impact ejecta, called Long Yan (Pyramid Rock), southwest of the Chang'e 3 lander. The view is a six-image mosaic.



Into Deep Space

China's lunar engineering achievements have built a platform to journey deeper into the solar system. Members from the team behind these landings have been involved in preparing for the greater challenges posed by Mars, including the remote distance, a thin atmosphere (which demands an aeroshell and parachute system for entry), and a propulsive landing in a different gravity field. Meeting all these challenges is crucial to entry, descent, and landing.

With its 2020 Mars mission apparently set to go — China announced in November with a short, public propulsive test that its landing technology was ready — other projects are now under way. The next spacecraft in the pipeline has an ambitious, two-target mission. Tentatively named after Zheng He, the 15th-century eunuch admiral and explorer, the 10-year mission will visit a near-Earth asteroid (NEA) and then rendezvous with a main-belt comet.

The target for the first visit is 2016 HO_3, also known as 469219 Kamoʻoalewa, a roughly 40-meter-diameter NEA. The plan is to collect up to 1 kilogram of regolith and return this sample to Earth within three years of launch.

After dropping off a reentry capsule containing the samples, the spacecraft will then head for Mars, using a Red Planet flyby to set course for Comet 133P/Elst-Pizarro. The aim is to reach the comet ahead of its perihelion in 2030 and remain there for one year, carrying out remote-sensing and in-situ measurements. Such a mission would, in a few daring maneuvers, demonstrate the kinds of capabilities shown by the European Rosetta and Japanese Hayabusa missions.

▲ **FARSIDE** Chang'e 5 T1 took this image of the lunar farside and distant Earth in 2014, as it looped around the Moon in a test flight for future orbiter and sample-return missions.

Chinese scientists have opened a call to both domestic and international institutions for science payloads.

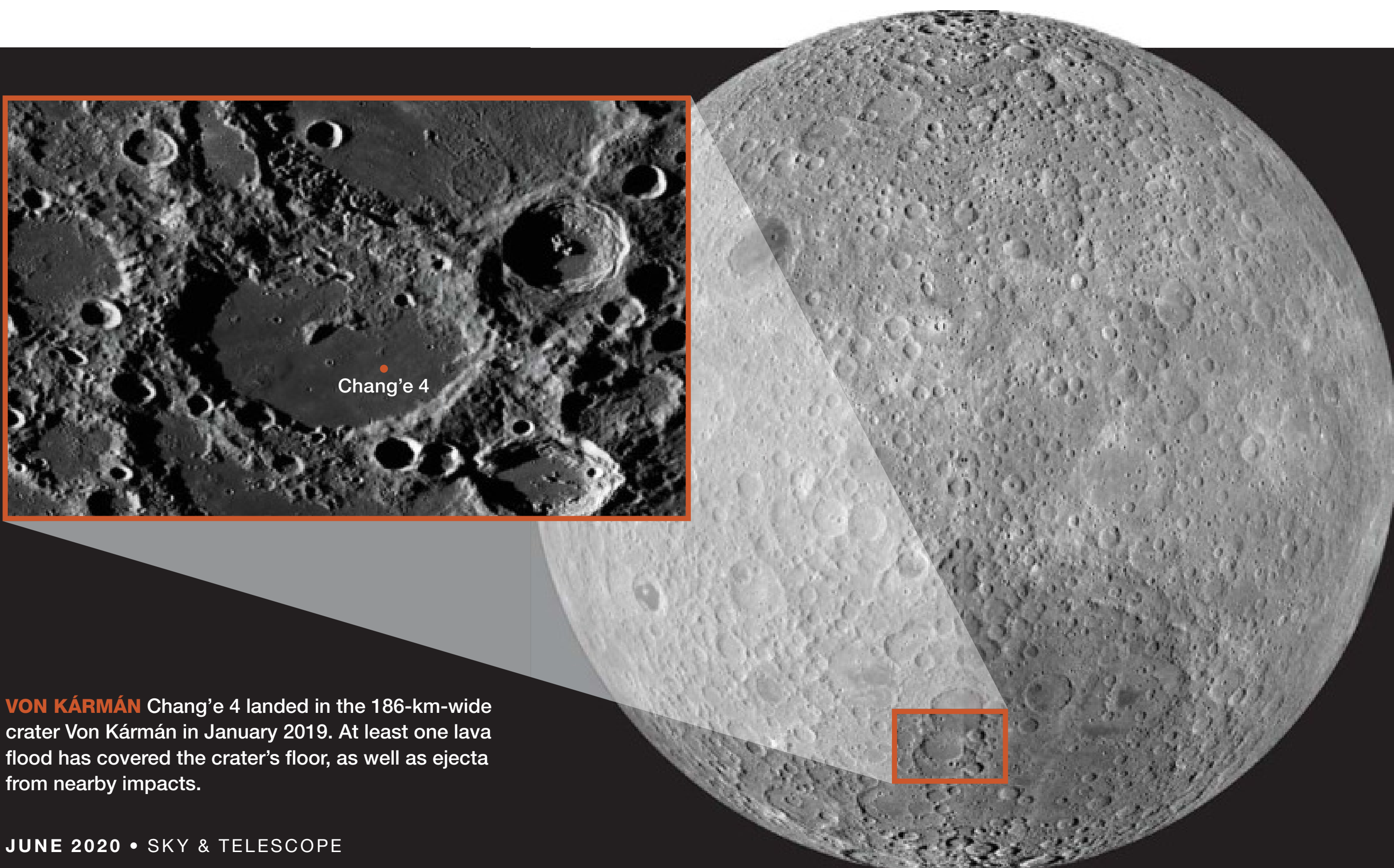
Another emerging target for China is an interstellar project along the lines of NASA's Voyager missions. Although there is no fortuitous planetary alignment such as that which provoked the Voyagers' Grand Tour of the outer solar system, two 200-kilogram Interstellar Heliosphere Probes will launch around 2024 and use flybys of Jupiter to target the head and tail of the heliosphere, respectively. The latter will also release an impactor during a Neptune flyby before flashing past a yet-to-be-determined Kuiper Belt object. Science objectives

After detecting more than a billion cosmic-ray events, DAMPE data showed more than the expected amount of particles with energies around 1.4 teraelectron volts – a possible signature of dark matter.

for the mission include determining whether the tail of the heliosphere is open or closed, studying the wall of hydrogen atoms at the heliopause, and investigating the processes that accelerate ions at the heliosphere's boundary to become anomalous cosmic rays.

A dedicated mission to the outer solar system will come in 2030 with the planned launch of a Jupiter orbiter, which will follow the trail blazed by NASA's Galileo and Juno missions. It will target the Jovian moons, shedding light on how the lunar system formed. The mission is expected to be given the name Gan De, for the Chinese astronomer in the 4th century BC who made some of the most detailed early observations of Jupiter and, it is claimed, even observed Ganymede without optical aid.

The variety of missions and their capabilities and destinations — comets, asteroids, inner and outer planets, and even interstellar space — suggests that China is looking to match many of the exploration achievements of established space-faring nations. But, as demonstrated by the Chang'e 4 lunar



VON KÁRMÁN Chang'e 4 landed in the 186-km-wide crater Von Kármán in January 2019. At least one lava flood has covered the crater's floor, as well as ejecta from nearby impacts.

FARSIDE: CNSA; LANDING SITE: FARSIDE AND VON KÁRMÁN: NASA / GSFC / ARIZONA STATE UNIV.

farside landing, China is also working to surpass what's been done before.

Another example of that goal is China's planned second mission to Mars, tentatively launching around 2028-2030. This one is to be a sample return. The mission has the potential to be a major space first, depending on the progress of joint NASA and ESA plans for such a project. The deliverer of Martian samples could change history, should evidence of previous or extant life be discovered in the soil. Initial plans outline a one-launch mission using the in-development Long March 9, a super-heavy-lift launch vehicle comparable to the Saturn V. Alternate plans would send the landing and return segments separately.

Entry into Space Science

China has been a space-faring nation since 1970, when a Long March 1 lofted the country's first satellite. But space science is an area in which China is only just emerging. A first batch of four missions was approved early last decade, developed under the auspices of the Chinese Academy of Sciences and launched between 2015 and 2017.

The first in action was the Dark Matter Particle Explorer (DAMPE) space telescope. Also known as Wukong, or Monkey King, from the 16th-century novel *Journey to the West*, it launched in December 2015. Designed to detect high-energy gamma rays and cosmic rays, DAMPE's specific aim was to look for an indirect signal from the decay of a hypothetical dark matter particle.

After detecting more than a billion cosmic-ray events, DAMPE data showed more than the expected amount of particles with energies around 1.4 teraelectron volts — a possible signature of dark matter. While in itself not conclusive, the result opened a new avenue for dark matter research.

The mission also had a big impact domestically. "As the first Chinese astronomical satellite, the successful performance and the significant results of DAMPE highlight the country's rise in space science and have convinced the community that China is able to make significant contributions to astrophysics and space science," says Yizhong Fan, science

Astronomy & Space Science Launches

LAUNCHED

- 2007 — **CHANG'E 1:** Moon orbiter
- 2008
- 2009
- 2010 — **CHANG'E 2:** Moon orbiter, near-Earth asteroid flyby
- 2011
- 2012
- 2013 — **CHANG'E 3:** Moon lander (Mare Imbrium); **YUTU:** Rover (*traveled with Chang'e 3*)
- 2014 — **CHANG'E 5 T1:** Moon flyby
- 2015 — **DAMPE (WUKONG):** Dark matter
- 2016
- 2017 — **HXMT (INSIGHT):** X-ray telescope
- 2018 — **QUEQIAO:** Orbiter (Earth-Moon L_2 point); **CHANG'E 4:** Moon lander (Von Kármán Crater); **YUTU 2:** Rover *(traveled with Chang'e 4)*
- 2019

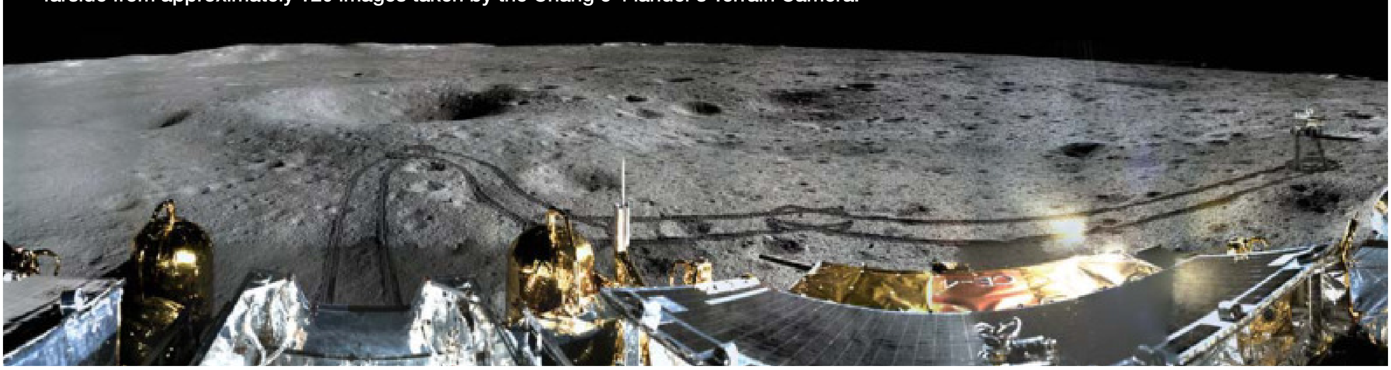
SCHEDULED

- 2020 — **HUOXING 1:** Mars orbiter and rover; **CHANG'E 5:** Moon sample return (Oceanus Procellarum)

PROPOSED, LAUNCH ORDER UNCERTAIN

- 2020s —
  - **SVOM:** Gamma-ray, X-ray, and visible-light observatory
  - **EINSTEIN PROBE:** High-energy transient phenomena
  - **ASO-S:** Solar observatory
  - **CHANG'E 6:** Moon sample return (south pole)
  - **CHANG'E 7:** Moon relay satellite, orbiter, lander, rover, and hopping detector
  - **XUNTIAN:** 2-meter space telescope
  - **CHANG'E 8:** 3D printing, resource extraction
  - **ZHENG HE:** Near-Earth asteroid sample return, comet rendezvous
  - **INTERSTELLAR HELIOSPHERE PROBES:** Heliosphere, Neptune impactor, Kuiper Belt
  - **MARS SAMPLE RETURN**
- 2030s — **JUPITER ORBITER**

THE FARSIDE JPL's Doug Ellison assembled this panorama (half shown) of the lunar farside from approximately 120 images taken by the Chang'e 4 lander's Terrain Camera.



PANORAMA: CNSA / CLEP / DOUG ELLISON; TIMELINE: TERRI DUBÉ / S&T

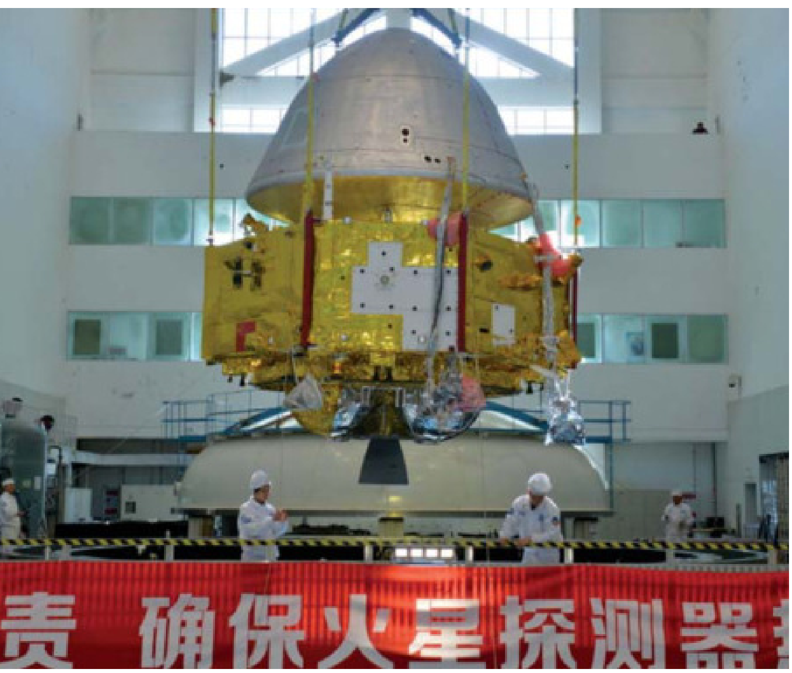
team head. "This certainty gives the government the confidence for organizing future explore missions."

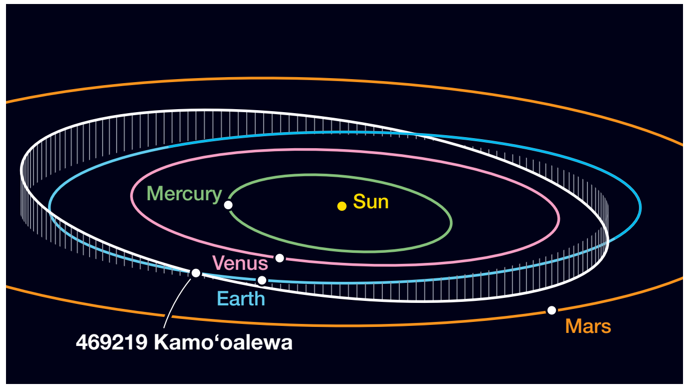
The next science missions weren't astronomy-related. Shijian 10 was a retrievable satellite experiment, which in 2016 tested the growth of mouse embryos in the microgravity environment of low-Earth orbit. Then the Quantum Experiments at Space Scale, launched later that same year, made waves as the first quantum science satellite. It used the phenomenon of entanglement to test encrypted communications between China and Austria.

The final mission of the set was the Hard X-ray Modulation Telescope (HXMT), aka Insight, which launched in June 2017. Shortly after, it joined international follow-up observations of the GW170817 neutron star merger detected by LIGO (*S&T:* Feb. 2018, p. 32), setting a strict upper limit on X-rays produced by the event. In October 2019 the HXMT team also investigated the accretion disks around black hole and neutron star X-ray binaries. The observations verified a decades-old theory that structural changes in the accretion disks come from the radiation pressure of light. Since coming into operation, HXMT has returned more than 29 TB of scientific data.

The successful launch of these four missions helped win approval for a new batch of space-science projects that will begin launching in 2021. Some of these have a strong terrestrial focus, such as the Water Cycle Observation and the Magnetosphere-Ionosphere-Thermosphere Coupling Exploration missions. In addition, the Solar Wind Magnetosphere Ionosphere Link Explorer, a space-weather observatory, is a joint endeavor with the European Space Agency.

▼ **RED PLANET TEST** China's Mars spacecraft enters its space environment testing in this image released in October 2019.





▲ **TARGET ASTEROID** China's planned Zheng He spacecraft will visit the asteroid 469219 Kamo'oalewa, which crosses Earth's orbit. After it delivers its samples to Earth, it will continue outward via Mars to fly by Comet 133P/Elst-Pizarro in the main belt.

But other planned projects will continue forays into off-Earth astronomy. Three of these will focus on high-energy phenomena:

The Space-based Multi-band Astronomical Variable Objects Monitor, produced in collaboration with the French Space Agency, is a gamma-ray, X-ray, and visible-light observatory. Following launch in 2021, it will study the intensely powerful gamma-ray bursts thought to come from the death of certain kinds of stars.

Meanwhile, the 1,400-kilogram Einstein Probe should launch by the end of 2022 to look for short-lived, high-energy sources. These include gamma-ray bursts, supernovae, magnetars, and the electromagnetic counterparts of gravitational-wave events. With a large field of view, it will also monitor variable objects across the sky, such as accreting supermassive black holes at the centers of galaxies, and carry out an all-sky survey.

A third mission, the Advanced Space-based Solar Observatory, is also scheduled for 2022 and will study solar flares and coronal mass ejections.

If all this weren't enough, the Xuntian 2-meter space telescope should launch in the mid-2020s. The Hubble-class instrument is designed to co-orbit with China's planned modular space station and dock with it for occasional maintenance and repair.

Speaking at the Global Space Exploration Conference in Beijing in 2017, Ji Wu, then director of the National Space Science Center that oversaw China's first space science missions, explained how he sees the country's growing role in space. China, he says, has made a major contribution to the global economy. Now it will (once again) contribute to scientific knowledge with a new decade of exploration and discovery.

■ **ANDREW JONES** is a space journalist based in Finland who reports on China's space-related activities in particular. Follow him on Twitter for insights into a far-reaching and expanding space program: **@AJ_FI**.

MARS MISSION: CNSA; ORBITS: LEAH TISCIONE / *S&T*