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At the landing site of the Chang'e-5 probe, researchers examine a capsule carrying lunar soil and rocks.

Towards new frontiers

China sets lofty goals for itself as it vies for global leadership in highly competitive scientific fields.

China's space-faring and particle-wrangling researchers are reaping the rewards of heavy investment, as the nation makes big moves in a global race. In the emerging and hotly pursued area of nanocatalysis, China's scientists are forging ahead.

Bursting forth in the space race

China has been playing catch-up in space for years, but one step at a time, it's making strides, says Sun Kwok, an astronomer at the University of British Columbia in Canada. "The degree of progress is just incredible."

Until recently, China's scientific success in space has been "relatively modest", says Kwok, in part due to its long-time focus on mastering the technological aspects of spaceflight. In 2018, when China embarked on the fourth of its series of lunar missions, Chang'e-4, it had already launched hundreds of satellites, two orbiting space laboratories and several crewed flights, but had yet to make its mark in a field historically dominated by the United States and Russia.

This mission, however, achieved something that no other space-faring nation had done before: it successfully landed a spacecraft on the far the side of Moon, so-called because it's perpetually hidden from Earth's view. Accessing the lunar farside is so difficult, says Li Chunlai, deputy director-general of the National Astronomical Observatories of Chinese Academy of Sciences in Beijing, because the Moon blocks all radio signals, thwarting communications between spacecraft and Earth. "We had to launch a relay satellite to keep the connection," he says.

Data from the mission's rover, Yutu-2, provided the first observations of the chemical composition below the surface of the Von Kármán impact crater in the South Pole-Aitken basin. Measuring 2,500 kilometres in diameter (about half the width of China) and extending down more than 8 kilometres, the basin is the Moon's largest, deepest and oldest feature, and is thought to be the result of an ancient impact. Some of the earliest observations from Yutu-2 were described by Li and his colleagues in *Nature* in 2019, one of dozens of papers to which Li has contributed on China's lunar missions since the launch of Chang'e-1 in 2007

(C. Li *et al. Nature* **569**, 378–382; 2019). "The past years have witnessed great advancement in the development of Chinese astronomy," says Li.

China's space programme continues to gain momentum. In December 2020, Chang'e-5 returned to Earth with the first lunar samples collected in more than four decades. And earlier this month, China successfully landed the rover Zhurong on Mars as part of its Tianwen-1 mission, which aims to provide new information on the atmosphere, surface and subsurface of the red planet to help scientists piece together its climate and geological history.

Such a commitment to research is encouraging to the international scientific community, says Kwok, especially now that China is taking steps towards opening its space facilities to foreign academics. In March 2021, China announced that its Five-hundred-meter Aperture Spherical Radio Telescope, the world's largest single-dish radio observatory, can be accessed by astronomers from outside China – a welcome development, as the world's second-largest such installation, the Arecibo Observatory in Puerto Rico, irreparably collapsed three months earlier.

China also plans to open its new space station, the first module of which was launched in April, to international research projects. If completed by the end of 2022 as scheduled, it and the International Space Station will be the only fully operational space stations in orbit.

The space station, which has been designed to accommodate three astronauts for up to six months at a time, signifies China's desire not just to visit space, but also to facilitate long-term missions there. Its upcoming Chang'e missions 6 through to 8 aim to lay the groundwork for a base on the Moon's south pole – potentially constructed in cooperation with Russia – that would provide housing for astronauts and act as a deployment site for deeper space exploration. NASA has similarly proposed building a lunar research station, called the Artemis Base Camp, although neither plan has a clear timeline.

The national security and economic advantages of a fast-paced expansion into space are front of mind, says Namrata Goswami, an independent scholar on space policy based in Montgomery, Alabama, as China places key communications satellites into Earth's orbit. Last year, it launched the final satellite of the Beidou navigation network – its equivalent of the US's Global Positioning System – and what it claims is the world's first 6G satellite.

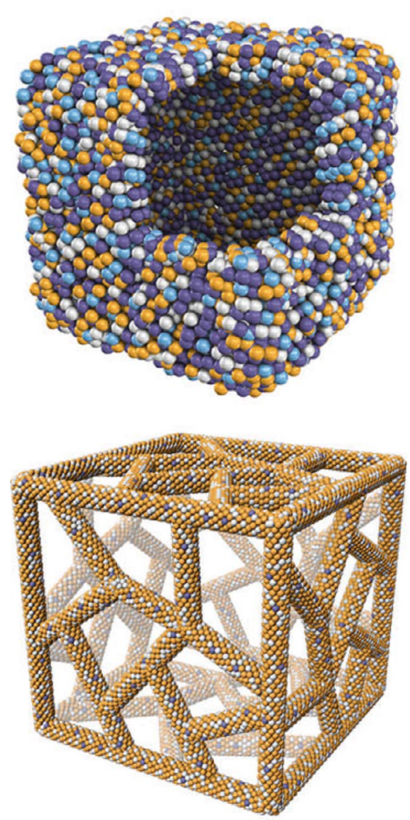
China's goals in space are lofty, but not unrealistic, says Goswami. If its Mars mission is successful, it will have proved that its capabilities have surpassed Russia's as second only to those of the United States, she says. "China has become extremely ambitious when it comes to space." **Kevin Schoenmakers**

Nanocatalysis research speeds up

Nanocatalysis, which uses ultrafine nanoparticles to increase the rate of a chemical reaction, has become one of the most active areas of research in China. Made from metals such as gold, as well as oxides, carbon and various compounds, nanocatalysts have the potential to drive major advances in renewable energy technologies, biofuels, water purification and chemical production. Over the past two decades, nanocatalysts have been the focus of an escalating number of scientific papers, particularly in China.

"When nanocatalysis research arose internationally, Chinese scientists had already developed excellent skills in nanomaterial synthesis," says Li Yadong, a nanoscientist at Tsinghua University in Beijing. "It was natural for many of us to march into this promising field."

Li and his colleague, Chen Chen, also from Tsinghua University, have developed several new nanocatalyst designs. In 2019, they described how their highly active 'nanonetcage' catalyst, which takes on a hollow, three-dimensional cube-shaped structure, can be scaled down to just 0.1 nanometres wide, roughly the size of a single atom. This allows for more catalysts to be used in a chemical reaction to further speed up the process (Z. Zhuang *et al. Nature Commun.* **10**, 4875; 2019). Li's and Chen's teams are now exploring the potential of using nano-netcages in processes that convert solar and wind power into hydrogen gas, a near-zero-emissions energy source.



End stages in the formation of a 'nanonetcage' catalyst.

Z ZHUANG,Y WANG

China's strength in chemistry, which makes up more than half of the county's total Share in the Nature Index, has given it a significant advantage in the pursuit of nanocatalysis and other nanotechnologies, a field that has grown rapidly in recent years. The number of nanoscience-related articles published globally increased from less than 1,500 in 1990 to more than 205,000 in 2018, according to a 2019 joint paper by *Nature's* publisher Springer Nature and the Chinese Academy of Sciences (CAS), which drew data from the Nature Index and Dimensions, Digital Science's database of publications, grants and clinical trials. In 2011, China surpassed the United States as the global leader in nanoscience publishing overall, and in 2018, overtook the United States for nano-related research in the 82 high-quality journals tracked by the Nature Index.

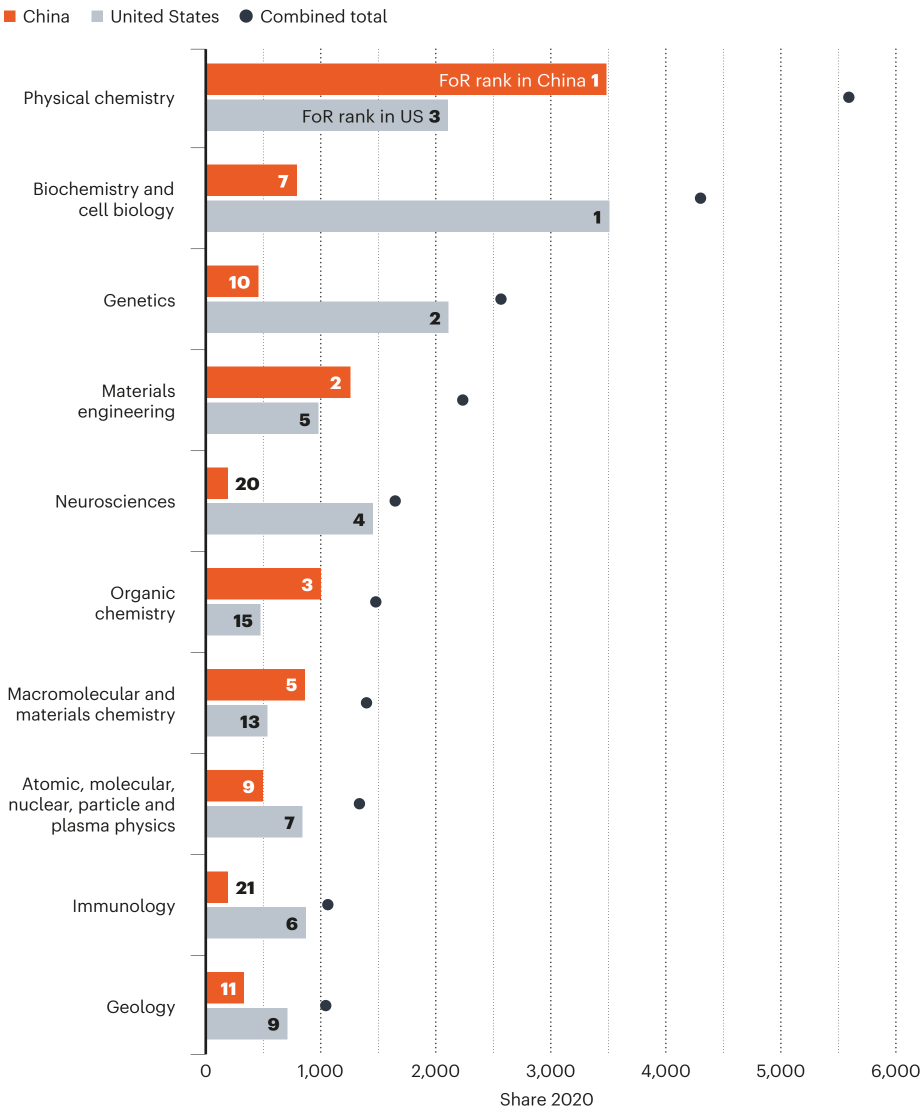
In research articles published between 2010 and 2018, when global nanotechnology research took off, nanocatalysis was the second-largest application area discussed, the report states, after electronics (see go.nature.com/2Q5XpIT; *Nature* is editorially independent of its publisher).

Given the potential for nanocatalysts to significantly speed up some manufacturing processes, China's industrial sector has great interest in supporting new discoveries. Bao Xinhe, president of the University of Science and Technology of China (USTC) in Hefei, runs the State Key Lab of Catalysis at the CAS Dalian Institute of Chemical Physics in Dalian, China's northernmost port city. His team has developed nanocatalysts that can convert methane to ethylene, which forms the basis of many plastics, at room temperature – a major step towards making the process more cost-effective.

Each year, scientists working on nanocatalysis feature prominently among the 300 Distinguished Young Scholar recipients who receive a grant of between 2 million and 4 million yuan (US$308,947–617,894) from the National Natural Science Foundation of China. Access to funding and advanced facilities incentivize China's rising stars in nanocatalysis to continue their research at home after spending

TOPICAL RIVALS

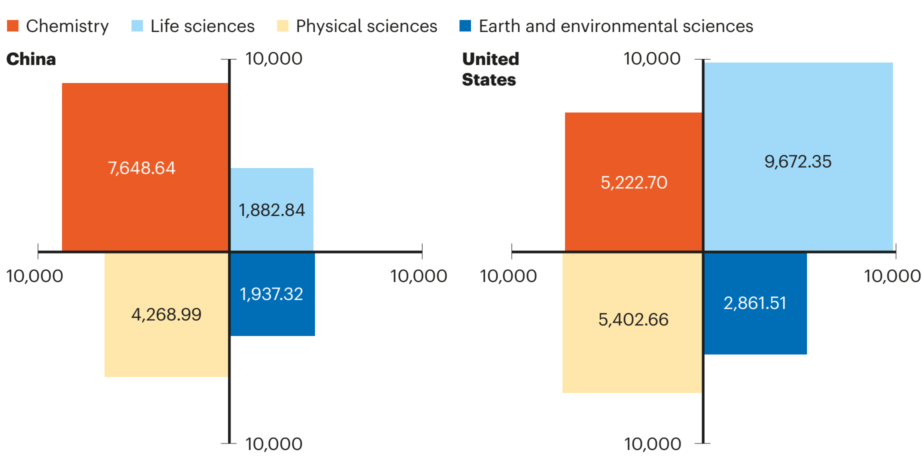
A comparison of Share for China and the United States in 10 fields of research (FoRs) selected from the top 10 FoRs by Share in each country.



SOURCE: NATURE INDEX

COMPARATIVE EFFORT

China's Share in 2020 is more focused on chemistry, while the life sciences dominate the US effort.



SOURCE: NATURE INDEX

time abroad, says Li Yanguang, a nanoscientist at Soochow University in Suzhou. "Many Chinese scientists became pioneers of nanocatalysis overseas before returning to China."

Li Yanguang spent eight years in the United States working on nanomaterials synthesis during his doctoral studies at Ohio State University in Columbus before focusing on nanocatalysis as a postdoctoral researcher at Stanford University in California. He returned to China in 2013, and is now among the most highly cited chemists in the world, having earned more than 30,000 citations to his papers by 2019, according to Philadelphia-based information-services firm, Clarivate Analytics.

As an emerging area of research, nanocatalysis offers scientists an opportunity to make their mark early, says Li Yanguang. But some researchers are concerned that the disproportionate attention and resources spent on nanocatalysis research could hold back progress in other areas of chemistry in China. "Some classic questions in chemistry, such as the mechanisms underlying the synthesis of certain basic chemicals, are being neglected," says Zhao Dongbing, professor of chemistry at Nankai University in Tianjin. "Studying these takes years, and we risk falling behind."

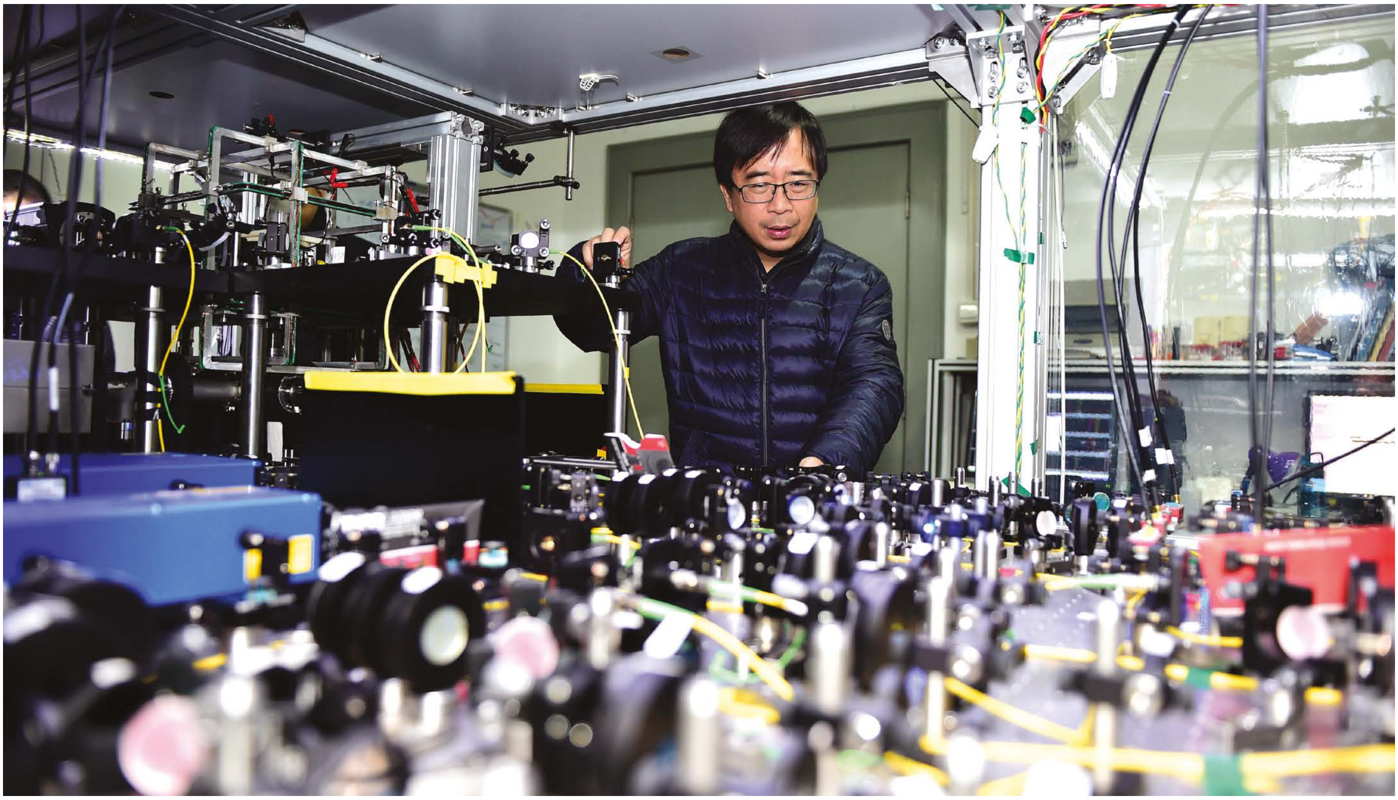
Hepeng Jia

Weaving an entangled web

Since China launched the world's first quantum-enabled satellite, Micius, in 2016, the nation has sought to position itself as a leader in quantum research, a field that aims to harness the peculiar and particular properties of matter at the atomic level. The satellite, operated by a team led by Jian-Wei Pan, professor of physics at USTC, made quantum key distribution possible over long distances for the first time – technology that could lead to unhackable global communications.

Quantum-secure communication uses quantum-entangled particles, a group of particles that cannot be described independently of each other in terms of certain physical and behavioural properties, and that act as a system, even when physically far apart. In 2017, Micius enabled quantum-entangled particles to be delivered as encryption keys to researchers in ground stations near Vienna and Beijing, some 7,400 kilometres apart. The event played out as the world's first quantum-encrypted teleconference.

Micius has helped put China, a relative latecomer to the burgeoning field, on the quantum science map. In June 2020, Pan and his team published a paper in *Nature* describing an experiment that further tightened the security


XINHUA/ALAMY

Jian-Wei Pan in a lab at the University of Science and Technology of China in Hefei.

of the communications over a distance of more than 1,120 kilometres (J. Yin *et al. Nature* **582**, 501–505; 2020). Nations such as the United States, the United Kingdom, Japan and India are racing to develop comparable technologies.

With the potential to impart major military and economic advantages, quantum science has become a multibillion-dollar race, and China and the United States are the lead competitors. It's a key area of focus in China's latest five-year plan, a social and economic blueprint approved in March 2021. Pan, who is often referred to in Chinese media as 'the father of quantum', is encouraged to see support for the field at a national level. "We hope that … in the next five years we can make major breakthroughs in the fields of large-scale quantum communication, scalable quantum computing and simulation, and quantum metrology [the use of quantum techniques in high-precision measurement]," he says.

The United States also asserted its commitment to quantum research in March, emphasizing in an official statement on national security the need to "reinvest in retaining our scientific and technological edge and once again lead" in emerging technologies such as artificial intelligence and quantum computing.

With significant investment from tech giants including IBM, Google and Microsoft, the United States is the clear leader in quantum computing, the most high-profile segment of the field. Although China had nearly twice the number of patent filings as the United States for quantum technology overall in 2018 – including communications and cryptology devices – the United States has a significant lead in patents related to quantum computing, according to a *Washington Post* report based on data from market research firm Patinformatics (see go.nature.com/3b8mrte).

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But China's efforts in quantum computing are quickly gaining momentum. In December 2020, a team led by Pan and his colleague Chao-Yang Lu, also a professor of physics at USTC, claimed to be the first in the world to reliably demonstrate a quantum advantage over classical computing. A quantum advantage is achieved by performing a calculation on a quantum system, which uses quantum bits as the information carrier, that would be impossible for a classical supercomputer, which uses binary 1s and 0s, to complete. China's quantum computer, Jiuzhang, performed a calculation in 200 seconds that would take a supercomputer 2.5 billion years to complete (H.-S. Zhong *et al. Science* **370**, 1460–1463; 2020). It was a direct challenge to researchers at Google's quantum-computing laboratory in Santa Barbara, California, who had made a similar claim a year earlier using their Sycamore quantum system.

The USTC and Google quantum systems have limitations. Critics say it's unclear whether the problem Sycamore solved was truly beyond the capabilities of a conventional machine, whereas Jiuzhang is not easily reprogrammable to solve more than one problem, an issue Lu says they're working to address. "We hope to upgrade our experiment to be fully reconfigurable by the end of this year."

Lu says people often have "unrealistic" expectations that quantum computing will drive an imminent overhaul of all aspects of computing. They should instead consider whether or not it is a good investment, he says.

"My best guess is that quantum computing will first emerge as a useful tool, like lasers, for scientists, over the next five years or so," says Lu. "Then it might find some small-scale applications in commercial use in the following ten years."

Sian Powell