China's ambitious program to develop its own astronaut corps is giving basic scientists a chance to push back the frontiers of science—and collaborate globally

Science Emerges From Shadows Of China's Space Program

BEIJING—Sometime in the next year or two China will attempt to launch a person into space. If it succeeds, it would become only the third nation to accomplish such a feat, and the achievement would be a powerful symbol of China's increasing technological sophistication.

But the media coverage of the buildup to the expected launch has so far taken little note of a less flashy development: The rocket and satellite capabilities that underpin the nation's piloted space effort (called the Shenzhou, or divine vessel, program) are being coupled with a growing budget for space science. Over the next 5 years, China is planning to double its launch rate of scientific satellites, with at least seven now on the drawing board (see table). The program, moreover, is moving beyond its traditional emphasis on telecommunications and meteorology toward more basic research, including international collaborations such as a joint project with European scientists to study Earth's magnetosphere (see sidebar, p. 1790). "China's space efforts are entering a new era," says Wu Ji, deputy director of the Chinese Academy of Sciences' Center for Space Science and Applied Research (CSSAR) in Beijing. Philippe Escoubet, a space physicist with the European Space Agency (ESA), predicts that China "will very quickly become an important power in space science."

Looking for partners. Guo Baozhu's civilian space agency is building ties with basic science programs in other countries.

Such a role would further transform a program that, thanks to military oversight, has long been a black box for Western scientists. That's beginning to change, however, as a civilian agency is now actively seeking international partnerships for science-related missions. But although *Science* reporters were given unusual access this spring to several of China's leading space science labs, old habits evidently die hard. The scientist reportedly in charge of Shenzhou's scientific program declined requests for an interview, for example, and a researcher involved in Shenzhou life science experiments initially granted but then abruptly canceled an interview on orders from superiors.

Now that the space science program is gaining resources and independence, China hopes that better ties with the U.S. program will follow. U.S. concerns over human rights and weapons sales are limiting space cooperation between the two countries and preventing Chinese scientists from access to some leading-edge technologies. "The United States not only does not cooperate with us, but it imposes many restrictions," says Guo Baozhu, deputy director of the China National Space Administration (CNSA), the country's civilian space agency. "It's really a pity."

Piggyback science

China joined the elite club of spacefaring nations with the launch of its first satellite in 1970. Since then, the country has successfully lofted more than 75 spacecraft—roughly two-thirds of them produced at home—and its Long March rockets now compete with U.S., Russian, and European rockets for commercial satellite launches.

Those launches provided opportunities for a small group of scientists nimble enough to find slots on existing missions. CSSAR, for example, built a series of five scientific satellites in the 1990s to study the effects of high-energy particles on satellite components and the behavior of fluids in microgravity, among other things. "We called them scientific missions, but they were more to test satellite [technologies]," says Wu about the Shijian (Practice) program. Shijian-5, for example, went up in 1999 alongside a meteorological satellite.

Liu Luxiang, a plant breeder at the Institute for the Application of Atomic Energy in Beijing, took advantage of China's efforts to develop recoverable spacecraft to hitch round-trip rides into space for plant seeds. Liu speculated that combining radiation and microgravity might produce more mutations than radiation alone. The effort has led to commercial production of new higher yielding, tastier varieties of rice, tomato, and green pepper. "This allowed us to breed new varieties in just 4 to 5 years, compared with 8 to 10 years for conventional breeding," Liu says.

Few outside China know the details of this research, however. This spring Bruce Bugbee, a crop physiologist at Utah State University in Logan who studies the possibility of future space farming for NASA, removed some of the mystery after a visit to Liu's lab. Bugbee, who was impressed with Liu's work, says that it's hard to replicate on Earth some types of radiation found in space. In addition, he says that long-distance space missions could require astronauts to grow their own food, which presupposes a knowledge of how plants grow in space. However, Bugbee says that similar U.S. and Russian experiments failed to produce mutated seeds and that better controlled experiments are needed. Liu defends his work but

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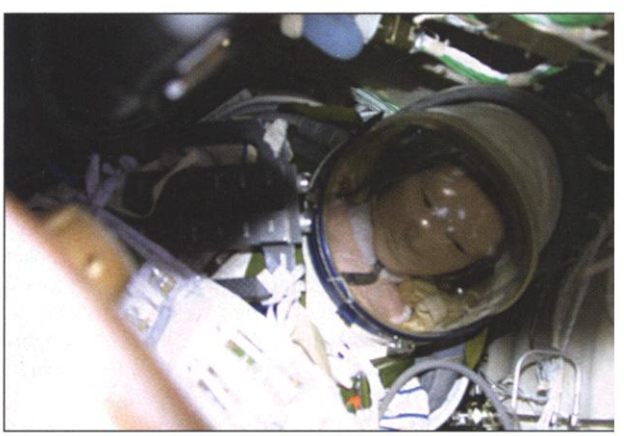


No-brainer. Space experts say it won't be long before live astronauts replace dummies in China's Shenzhou program.

admits that he is now planning further experiments to address Bugbee's concerns.

Lifting the veil

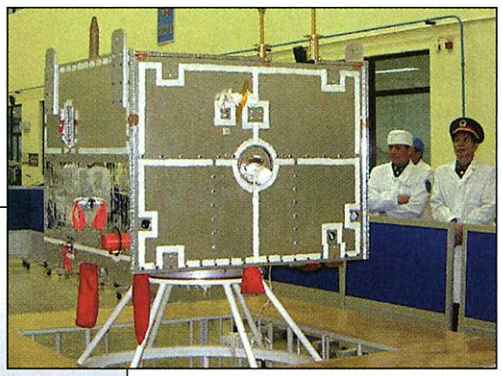
Unfortunately, few of China's space research programs have benefited from such discussions. "There were restrictions on the openness of space projects in the past," notes Liu Zhen-Xing, a space physicist at CSSAR. The first three Shijian missions were not publicized outside China, he says. Liu, the space plant breeder (who is not related to CSSAR's Liu), says that interactions with foreign scientists have also been hindered by geographical isolation and the language barrier.

The beginning of the new era dates to the late 1990s, when planners started work on China's 10th 5-year plan for space activities. The plan, which covers 2001–05, reflects a shift in the focus of space efforts. "Over the past several decades, China concentrated on developing rockets and satellites," says CNSA's Guo. "But people became aware that space activities can be put to use to develop science and technology and the national economy."

CNSA was set up in 1998 explicitly to foster closer ties with the international space community. In late 2000, CNSA translated and posted on the Internet a white paper "to explain China's purposes and goals for space science and technology," Guo says. It was the first time such a document, which doesn't cover the piloted program, had been made public.

China's space community responded to the new opportunity with what Guo calls "a long list of demands." One of the winners was Earth remote sensing. Although China has agreements with the United States and ESA for access to remote-sensing data from their satellites, officials felt the need to produce their own. Guo Jianning, director of the China Center for Resources Satellite Data and Application, says the foreign remote-sensing satellites don't provide sufficient coverage of the sprawling country.

China has at least partly filled this gap with the joint China-Brazil Earth Resources Satellite (CBERS) program. The first of the series was launched in October 1999, the second is scheduled for August, and future CBERS launches are being planned. The data are used to forecast agricultural production, improve land planning, and monitor desertification and environmental pollution in China and Brazil. "And we can provide this data at less than half the cost of the data provided by foreign satellites," Guo boasts.



Double duty. Last month's launch of the Haiyang satellite will contribute data to China's global change program as well as monitor coastal conditions and marine pollution.

Last month China's fledgling space science program took another step forward with the launch of the Haiyang satellite. Its primary mission is to monitor China's coastal oceans for fisheries management and to track pollution and coastal development. But the satellite's data on ocean temperatures, for example, "will help our research on global change," says Ni Yuefeng, vice administrator of the State Oceanic Administration. And space research doesn't get more basic than the Double Star mission, a cooperative effort with ESA to study Earth's magnetosphere. CNSA's Guo says that expenditures on science missions over the next 5 years will more than double, although he says that the multiplicity of sources makes it impossible to provide a specific amount.

The human element

The piloted program, which is run separately by a military organization called the General Armament Department, will also have a science component. "If we just send taikonauts [after *taikong*, the Chinese word for universe] into space, it would be a repeat of what the U.S. and Russia did 40 years ago," says Wu. China began its crewed program in 1992 and made its first unpiloted test of the Shenzhou spacecraft in November 1999, with some life science experiments and instruments to monitor the cabin environment. The second launch, in January 2001, was less successful, as the capsule apparently lost cabin pressure during flight and the onboard experiments were lost. This past March Shenzhou 3 completed more than 100 orbits before landing safely in the desert.

A dozen fighter pilots are currently training for future missions, including what appears to be the ultimate goal: a landing on the moon. But officials aren't saying when they will get the green light. Although CNSA's Guo predicts "within 2 years," foreign observers think such official statements mask more optimistic plans. Phillip Clark, a space consultant based in Heston, U.K., believes the first group could go up in the next 12 months aboard Shenzhou 5. "The real question is whether they will launch two or three people," he says.

More importantly for researchers, the Shenzhou spacecraft has a forward module that remains in space, operating for 6 months or more after the crew capsule returns to Earth. The taikonauts are likely to return with some of the experiments, says Wu, while leaving others running on the orbiting module.

Liu, the space breeder, has sent seeds aloft on previous Shenzhou missions, and Shenzhou 3 reportedly carried chick eggs that later hatched normally. Liu says such experiments also provide a way to check the craft's radiation shielding, and the absence

CHINA'S EXPANDING PLATE OF BASIC RESEARCH

Satellite	Launch date	Objective	Key instruments
China-Brazil Earth Resources Satellite (CBERS)	CBERS-1 (Oct. 1999), CBERS-2 (Aug. 2002); more planned	Earth remote sensing	5-band CCD camera, infrared scanner, wide-field imaging
Haiyang 1	15 May 2002; more planned	Ocean remote sensing	10-band color scanner, 4-band CCD camera
Double Star (jointly with ESA)	June 2003 and December 2003	Magnetosphere measurements	16 instruments
Small, multi-mission spacecraft (with Iran, Thailand, and other partners)	Three by 2005; five more planned	Remote sensing for disaster and environmental monitoring	Optical and infrared

CREDITS: (TOP) LI GANG/*CHINA FEATURES*; (BOTTOM) SOURCE: CHINA NATIONAL SPACE ADMINISTRATION

China Teams With Europe on Exploration of Magnetosphere

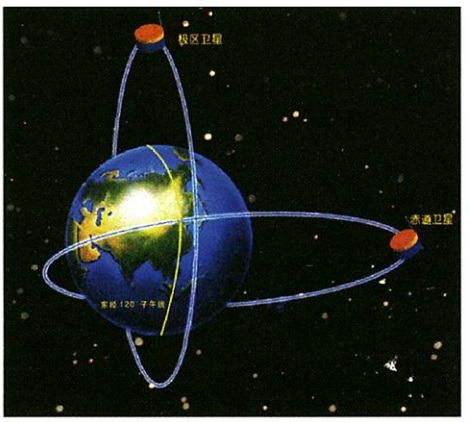
BEIJING—China's space science efforts are dominated by applied studies of Earth resources, meteorology, and oceanography. But the country is also planning one mission that is purely basic research: Double Star, a two-satellite collaborative project of the China National Space Administration (CNSA) and the European Space Agency (ESA).

"It's an exciting [opportunity] to measure many of the dynamic processes of the magnetosphere," says Wu Ji, deputy director of the Chinese Academy of Sciences' Center for Space Science and Applied Research (CSSAR) in Beijing, which sponsors the mission. "Double Star brings another set of data to studies of magnetospheric systems," says Philippe Escoubet, ESA project scientist for Double Star.

Double Star grows out of theoretical work by Liu Zhen-Xing, a CSSAR space physicist who has long studied magnetospheric substorms: sudden, violent releases of magnetic energy known to occur 10 to 20 times a day. Liu says his theoretical studies were held back "because there have been little data." In the late 1980s, European scientists won ESA backing for a constellation of four satellites, called Cluster, that would observe the interaction between the charged particles of the solar wind and Earth's atmosphere. When the Cluster group called for proposals to use its data, Liu offered his theories on what triggers substorms. "We weren't expecting to get a proposal from China," Escoubet says.

Liu's impressive theoretical work earned him a slot as co-investigator, and in 1993 CSSAR set up a ground observation station to supplement the satellite measurements and a center to distribute Cluster data. A failure of Europe's Ariane 5 rocket in June 1996 wiped out the first payload, but in 2000 two Russian rockets successfully launched the replacement mission, Cluster 2. Meanwhile, CSSAR was using its participation in Cluster as a magnet for younger researchers, several of whom were sent to Europe to study and train under senior Cluster scientists.

By the late 1990s, the space physics group was itching for its own mission, and its scientists spotted a gap in observational coverage. The Cluster satellites—which fly in an elliptical polar orbit ranging from 19,000 to 119,000 kilometers from Earth—focus on the outer edge of the magnetosphere, leaving the core relatively unexplored. Although researchers had once thought the center was not very interesting, more recent findings suggested otherwise. So in the late 1990s, when CNSA solicited proposals for basic science missions, Liu seized the opportunity.



Seeing double. Double Star is a joint Chinese-European mission to monitor the magnetosphere.

The result became Double Star: two satellites, one in a near-equatorial orbit passing within 550 kilometers from Earth, the other in a polar orbit 700 kilometers at its perigee. After an extensive review, the proposal was selected for the country's 10th 5-year plan. In addition to its scientific merits, Double Star meshes with China's current launch and satellite capabilities, Wu notes. That allows it to leapfrog other proposed science missions, particularly a well-publicized Space Solar Telescope proposal, that require a new generation of more powerful rockets.

Data reward. Liu Zhen-Xing (left) and Wu Ji hope the mission will confirm Liu's theoretical work on magnetospheric substorms.

Double Star became an international mission after Cluster scientists knocked on CNSA's door. About half of Double Star's instruments will be identical to those on the Cluster satellites, allowing scientists to combine observations from all six satellites to build a better three-dimensional model of the processes affecting the magnetosphere. "We are very happy with this opportunity," says ESA's Escoubet. The two satellites, with eight Chinese and eight European instruments, will be launched by Long March 2 rockets starting in June 2003. "Double Star will be the first Chinese space science program for this new national space agency," says Wu.

It's not likely to be the last. Although Double Star will be the only basic science mission through 2005, Guo Baozhu, CNSA's deputy director, says he personally believes more basic research missions will be part of future 5-year plans because "science is a very important part of our space activities." Wu says other groups at his academy are working up proposals for astronomy missions and experiments in microgravity.

The results of Cluster and Double Star are likely to raise new questions about the magnetosphere. There is also talk of a moon probe, aimed at questions not addressed by the U.S. Apollo missions. "It is more important for us to do something unique," says Wu.

–D.N.

With reporting by Ding Yimin.

CREDITS: (TOP TO BOTTOM) D. NORMILE; ESA

of mutated seeds suggests that the shielding works well. Some researchers have made references to experiments involving protein crystallization and materials science. But details are hard to substantiate.

CNSA's Guo emphasizes that his program is separate from the military and operates under its own rules. Far from being secretive, CNSA has been actively forging international ties. Those efforts get rave reviews from CNSA's partners. José Raimundo Coelho, manager of the CBERS project for Brazil's National Institute for Space Research, says the CBERS program gave Brazil an opportunity to design a remote-sensing satellite "to our own needs." He points to the Wide Field Imager, which gives a one-shot picture of much larger areas of Brazil than are available from U.S. or European satellites. The bigger picture is very useful to land planners and mappers, he says, adding that "it would be very difficult for a country like Brazil to get involved in a cooperation like this with a developed country."

Karl Bergquist, an ESA official who oversees relations with China, says that European scientists studying Earth's magnetosphere "were extremely happy" with the agreement to make Double Star a Sino-European cooperative mission because it complements a European magnetosphere mission. Guo adds that various neighboring countries are interested in participating in a constellation of small remote-sensing satellites planned for launch in 2005 and later.

There are even signs that the United States might be rethinking its hard-line position. Current restrictions limit export of sensitive technologies to China because of U.S.

concerns over China's sales of missile systems to developing countries and its human rights record. And exports of U.S. satellites for launch on Chinese rockets—a lucrative business for China—have been more tightly controlled since the late 1990s, when a U.S. company was accused of sharing technological secrets with Chinese technicians.

But NASA's new administrator, Sean O'Keefe, said in March that he has discussed the idea of Chinese cooperation on the international space station with Richard Armitage, the deputy secretary of state. Any move would require White House approval, and NASA officials say they don't think anything will happen soon. China has not formally asked to be part of the station effort, but its human space program is widely viewed as a way to prove its technological competence. "It's always seemed to me that China's piloted program is predicated on being a station partner," says John Pike, director of GlobalSecurity.org in Alexandria, Virginia.

Regardless of whether taikonauts ever visit the station, they seem certain to find their way into space. "Peaceful development and mutual benefit should be the basic principle for Sino-American cooperation in space," says Guo. But China is also prepared to go its own way, he says. Either way, the result should be new opportunities for space scientists.

–DENNIS NORMILE, WITH DING YIMIN

Ding Yimin writes for *China Features* in Beijing. Additional reporting by Andrew Lawler.

ARCHAEOLOGY

Report of Oldest Boat Hints at Early Trade Routes

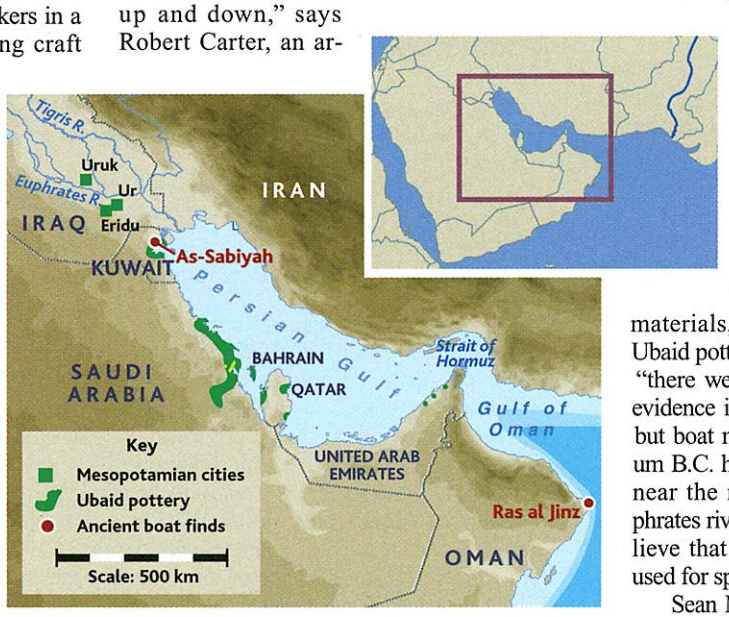
A Kuwaiti site yields 7000-year-old bitumen slabs thought to be from a seafaring vessel; a second team reconstructs a younger ship found in Oman

LONDON—As-Sabiyah, an isolated piece of Kuwaiti desert surrounded by mud flats, seems an unlikely place to store boats, much less sail them. But a team of British and Kuwaiti archaeologists working there believes that more than 7000 years ago, when the Persian Gulf lapped nearby, workers in a small village took apart a seagoing craft made of reeds and tar, its underside still coated with barnacles, and stored it carefully in a stone building. Last year they uncovered those undisturbed remains, which they say represent the world's oldest known boat.

If their interpretation of the material is correct, the discovery pushes back physical evidence of boats by more than 2000 years and sheds light on what later became trading routes linking two ancient civilizations: those of the Indus River valley and Mesopotamia. In particular, it offers concrete evidence to explain how pottery made in the first cities of ancient Mesopotamia ended up at sites hundreds of kilometers to the south on the Persian Gulf's western shores.

Next month Italian and French archaeologists hope to add another piece to the emerging picture of how sailing developed when they finish a controversial reconstruction of a similar vessel, found in Oman and dating from 2400 B.C. They intend to build another version in Oman next year and sail it to Pakistan and India. But the puzzle is complex, warns Harvard University archaeologist Carl Lamberg-Karlovsky. The Omani boat provides little data on how ancient mariners mastered the Indian Ocean, he says, and the Kuwaiti boat was built before true sea-trading networks emerged.

The highlight of the As-Sabiyah find consists of 22 slabs of bitumen, a tarry substance used for a variety of purposes in that region. "I got quite excited and started jumping up and down," says Robert Carter, an archaeologist at University College London and field director for the expedition. "The barnacles on the bitumen give us confidence it's a seagoing craft." Rope, string, and reed-bundle impressions left on the bitumen are thought to be materials used to build the boat.



Gulf stream. Boat evidence from Kuwait and Oman suggests how ancient pottery and, later, trade spread throughout the region and to the Indus River valley.

The age of the site is not in dispute. It was abandoned after the Ubaid period, and calibrated carbon-14 tests put the date at 5511 B.C. to 5324 B.C. Archaeologists working along the Euphrates River in Syria have found similar bitumen slabs dating to 3800 B.C., along with impressions of long-decayed reed bundles, but the slabs lack the barnacles unique to boats used in seas and oceans.

Preliminary analyses show surprisingly advanced planning in the gathering of the materials needed to build the Kuwaiti boat. The bitumen came from a site nearly 100 kilometers distant. And the tarry substance is not pure but mixed with a variety of ingredients—such as fish oil and crushed coral—that match those used in the Oman bitumen 3000 years later. "It's a very sophisticated mixture," says Serge Cleuziou, an archaeologist at the University of Nanterre who has closely studied the Omani amalgam.

Few researchers have looked closely at the As-Sabiyah finds, now at the National Museum in Kuwait City. Joan Oates, an archaeologist at Cambridge University, U.K., who has not seen the materials, says that the prevalence of Ubaid pottery at shore sites makes it clear "there were boats at this time." Textual evidence is absent in this prehistoric era, but boat models from the fifth millennium B.C. have been found at Eridu, a site near the mouth of the Tigris and Euphrates rivers. Even so, some scholars believe that they might have been bowls used for spinning.

Sean McGrail, a maritime archaeologist at Southampton University, U.K., who has seen pictures of the Kuwaiti material, notes that the bitumen "is very fragmentary" and that "it's not necessarily a boat." Then he adds, "but if it is, it will be the earliest around." The earliest undisputed boat is from an Egyptian tomb dated around 3000 B.C., although log canoes built around 8000 B.C.—considered to be more rafts than boats—have been found in the Netherlands and France.

Aside from pushing back the start of modern boatmaking, the Kuwaiti find would help explain how Mesopotamian pottery reached so far south at such an early date.

MAPS: A. STONEBRAKER