

In the hot seat. The crew of Shenzhou 9 prepares for China's first mission to dock spacecraft with astronauts aboard.

A New Dawn for China's Space Scientists

China's crewed space program has won admiration for the engineering prowess on display earlier this week in the Shenzhou 9 mission. Upcoming science missions hope to steal some of the spotlight

BEIJING—When Shenzhou 9 gently fired its thrusters to pull to within several centimeters of the orbiting Tiangong module on 24 June, mission managers were on edge. For a fleeting moment, a question hung in the air: Would the astronauts succeed in China's first attempt to manually dock the two spacecraft, circling Earth at 7.8 kilometers per second? They'd performed the maneuver on the ground, in a simulator, hundreds of times before. This was the real test. The slightest miscalculation could have spelled disaster for Shenzhou's three-person crew, including the country's first female astronaut. No country had lost someone in space—and China didn't want to be the first.

One person with a big stake in the mission says he was not sweating out that tense

moment: Shenzhou's former chief designer, Qi Faren. "I wasn't nervous," he claims. Shenzhou's first flight in 1999, Qi says, was a far riskier roll of the dice. That landmark mission went well, as did the Shenzhou 9 docking maneuvers, completing a milestone on China's road to a sustained human presence in space. "It's a huge step," says Dean Cheng, an expert on China's space program with the Heritage Foundation in Washington, D.C. "Docking is essential to doing just about anything in space," he says, including China's plan to build a space station by 2020.

China's leaders had a lot riding on Shenzhou 9, too. The Communist Party, which is expected to begin a leadership transition this autumn, spent the first half of 2012 in damage-control mode over the fall of for-

mer governor Bo Xilai and the high-profile flight of blind activist Chen Guangcheng. For the party, the elegant pas de deux at 343 kilometers above Earth's surface was a timely propaganda triumph. "China's space program gives the party legitimacy," Cheng says. "The leaders can say, 'Look what we have done for the country.'"

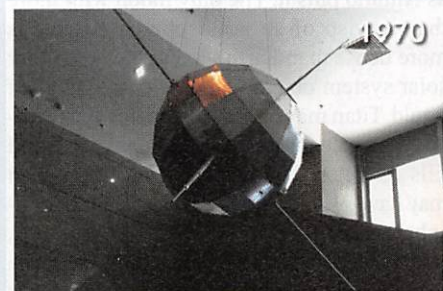
The engineering feat is indisputable. "China is emerging as a world leader in space," says Mark Stokes, executive director of the Project 2049 Institute, a think tank in Arlington, Virginia, that produced an analysis of China's space program last April for the U.S.-China Economic and Security Review Commission.

Soon, China's basic researchers will take a star turn. Over the next several years, the country plans to launch five scientific missions, including a dark-matter probe and an attempt at long-distance quantum communication. Four more innovative missions are in the design stage, *Science* has learned: an

MILESTONES OF CHINA'S SPACE PROGRAM



Space program founder Qian Xuesen returns home to a hero's welcome.



Debut satellite Dongfanghong 1 broadcasts "The East is Red."

CREDITS: (TOP) QIN XIANNAN/COLOR CHINA PHOTO/AP IMAGES; (BOTTOM LEFT TO RIGHT) BETTMANN/CORBIS/AP IMAGES; R. STONE/SCIENCE



PLANETARY SCIENCE

Cassini Spies an Ocean Inside Saturn's Icy, Gassy Moon Titan

To understand a planetary body, its origins and its history, it helps to look inside it. Planetary scientists have now done just that in the case of Saturn's big moon Titan, one of the solar system's most enigmatic bodies. Using only the subtly varying pitch of radio transmissions from the Cassini probe as it repeatedly flew by Titan, Cassini scientists have divined an ocean of water 100 kilometers beneath Titan's icy surface.

"It's an enormous technical achievement," says planetary physicist Francis Nimmo of the University of California, Santa Cruz. And it may help explain why the 5150-kilometer-diameter moon "confounds us at every turn," as Nimmo puts it. The only moon with more than a wisp of an atmosphere—Titan's is more dense than Earth's—and the only other solar system object with standing bodies of liquid, Titan may be steadily oozing the methane that sustains its dense cloaking haze and fills its lakes. The newly discovered ocean may have played a role in giving Titan's atmosphere its gas.

On Earth, it is seismologists who probe the interior, using seismic waves. But to peer inside Titan, Cassini scientists instead had to watch how the moon responded to incessant gravitational squeezing by Saturn. As Titan

revolves around Saturn every 16 days in its slightly elliptical orbit, the giant planet rhythmically squeezes the moon, something like the way the sun and the moon raise tides in Earth's oceans. The squishier Titan's interior is, the more the moon deforms under the tidal massaging. The more Titan deforms, the more its own gravity field—which depends on the shape of Titan's mass—is distorted.

So the problem of inferring the physical state of Titan's interior became a problem of mapping out Titan's gravity field at different points in its orbit. For that, Cassini team members led by Luciano Iess of Sapienza University of Rome and Robert Jacobson of NASA's Jet Propulsion Laboratory in Pasadena, California, used the Doppler effect. Orbiting Saturn, Cassini beamed radio signals back to Earth during six flybys of Titan. As reported online this week in *Science*, the team measured the varying pitch of those signals precisely enough to gauge Cassini's changing speed with an accuracy of 10 micrometers per second (<http://scim.ag/Iess1>). That's 36 millimeters per hour for an object that is 1 billion or 2 billion kilometers away.

From Cassini's varying speed, a group led by Iess calculated Titan's varying gravity field, which enabled them to infer its interior state.

The group found Titan to be as tidally pliable as if a liquid layer a couple of hundred kilometers thick—no doubt water—encircles the moon beneath 100 kilometers of ice. Another group within the team, led by Jacobson, got the same result using a different and independent method of analysis. "This tells us there must be a liquid layer beneath the surface," Iess says. Nimmo agrees: "I think there's an ocean there." But there seems to be more to Titan's surprisingly pliable interior. Its central region, beneath the ocean, may be solid but unusually soft; or, less likely, the ocean and overlying ice may be extra dense.

The discovery puts Titan in the inner-ocean club with Jupiter's moons Europa, Ganymede, and Callisto. And where there's an ocean, there might be life, right? Not so fast, says planetary physicist David Stevenson of the California Institute of Technology in Pasadena. Titan's ocean "doesn't have anything to do with life," he says. Inside Europa, planetary scientists believe hot springs on a rocky ocean floor may be belching all the nutrients and inorganic building blocks required by life. But other kinds of gravity studies show that Titan has a cold, icy ocean floor, so no hot water can be leaching life-giving chemicals into the ocean. "The interesting question," Stevenson says, "is to what extent is the interior ocean determining, or at least modifying, the geological history of Titan?"

Titan's ocean could conceivably be linked to surface geology as well as the atmosphere's methane, Stevenson says. The sun's ultraviolet radiation is continually cooking the atmosphere's large load of methane into complex organic molecules, the way it did on early Earth before life got started. But this prebiotic chemistry—lifeless but still of great interest to astrobiologists—destroys the atmosphere's methane so fast that it should have disappeared within a few tens of millions of years.

So either Titan got a big shot of methane in the geologically recent past, or methane is being resupplied from the interior. Either way, the ocean may have been involved. Changes in the ocean—perhaps by warming and thinning the overlying shell—may have freed up deep-seated methane. The methane and icy "lava" might then have erupted onto the surface. Some Titan geologists have said they can see the remains of ice volcano eruptions in Cassini radar images, but those claims have not gained much traction. After 8 years orbiting Saturn, Cassini has another 5 years to take quick looks at Titan, inside and out, but researchers would really like a new spacecraft that can linger in orbit about the still-mysterious moon.

—RICHARD A. KERR

CREDITS: (TOP) ZHANG LEI/COLOR CHINA/AP IMAGES AP PHOTO/XINHUA; (BOTTOM, LEFT TO RIGHT) AP PHOTO/EUGENE HOSHIKO; (INSET) IGNAT SOLOVEY/WIKIMEDIA COMMONS; AP PHOTO/ZHA CHUNMING

x-ray telescope to study black holes, a solar imager that would swing high above and far below the line of sight between Earth and the sun, a space-based very-long-baseline interferometer (VLBI) tuned to long-millimeter wavelengths, and a four-satellite cluster to study coupling of the magnetosphere, ionosphere, and thermosphere. Scientific payloads are being assembled for Tiangong 1 and for two more Tiangong modules, including a crewed space laboratory, which China plans to launch in the next 3 years. And scientists are designing experiments for the future space station.

It's a new dawn for China's space scientists. For decades, they have been left in the shadows by the generals and engineers who run China's space program. China's sole dedicated science missions to date were Double Star, in which it teamed up with the European Space Agency (ESA) from 2003 to 2007 to study magnetic storms, and the ill-fated Mars probe Yinghuo-1, which failed to leave Earth orbit.

"When I look at astronomy textbooks, none of the discoveries were made by people working in China. I don't see a single photo taken by a Chinese telescope. It's very frustrating," says Zhang Shuang-Nan, an astrophysicist here at the Institute of High Energy Physics of the Chinese Academy of Sciences (CAS). "We feel more and more pressure, not just from the top, but also from the bottom, to produce knowledge," adds Wu Ji, director general of CAS's National Space Science Center (NSSC). With the raft of missions now in the works, they may end up not just revising but rewriting textbooks.

Rags to riches

The visionary who set China's sights on space also played a key role in the early days of the U.S. program. In the 1940s, Chinese-born aeronautical engineer Qian Xuesen was one of the founders of the Jet Propulsion Laboratory in Pasadena, California. Considered a



All systems go. Shenzhou 9 lifts off on 16 June.

genius by his peers, Qian, known in the United States by the older spelling of his name, Hsue-Shen Tsien, fell victim to the Red Scare and in 1950 was accused of being a Communist. The United States revoked his security clearance and—after 5 years of house arrest—exiled him to China. Qian returned home to a hero's welcome and soon proposed that the young nation start a missile program.

A year after a small team set to work, the Soviet Union shocked the world on 4 October 1957 with the launch of Sputnik 1, the world's first artificial satellite. China wanted one, too. "However, we didn't even have a rocket at that

time," says Qi, now a dean at Beijing University of Aeronautics and Astronautics. China turned to the Soviet Union for help; hundreds of engineers poured in. Key facilities were set up across the hinterlands to avoid offering fat targets. But several months after embarking on this vast enterprise, China, strapped for cash, aborted its space program to focus on guided missiles.

Qian bided his time working on weapons. Then, in a report to top leaders in 1965, Qian argued that China needed to reboot its space program because satellites were indispensable for military surveillance and communication. The government concurred and revived its space program. By then, though, the Sino-Soviet split meant that China had to go it alone. "They weren't talking to anyone, not the Soviets, certainly not the Americans," Cheng says. That's why, he says, "much of China's space program is domestically produced."

After a failed attempt in 1969, China on 24 April 1970 put its first satellite in orbit, becoming only the fifth country to do so. For 1 month, Dongfanghong 1 took readings of the ionosphere and transmitted data back to Earth. In a patriotic touch, it broadcast the song "The East is Red," for which it was named. "It was a simple satellite," says Qi, who served on the engineering team. But the 1-meter-wide debutante, heavier than the first satellites of the Soviet Union, United States, France, and Japan combined, made a powerful statement.

China then set its sights on a crewed program—but didn't get very far. "There were some key technical problems beyond our ability at that time," Qi says. In 1975, he recalls, "Premier Zhou Enlai convinced us to not try to match the Soviet Union and U.S., and first develop more satellites."

China hatched plans for a new crewed program in 1986. Work began in earnest in 1992, the year that Qi succeeded Qian as China's general spacecraft designer. Sanctions on



Shenzhou 1 marks the start of the crewed space program.



Yang Liwei orbits Earth for 21 hours aboard Shenzhou 5.



Double Star is the first bona fide space science mission.

Entangled Secret Messages From Space

SHANGHAI—Last summer, a stream of photons arced northwest across Qinghai Lake—China's biggest—traveling about 100 kilometers in the blink of an eye before impinging on a detector on the opposite shore. This was no ordinary beam of light: The photons were entangled, meaning they were produced in pairs with identical quantum states. At Qinghai, measuring the entangled pairs provided a key that could be used to unlock a coded message, decipherable to only those who know the photon pair's quantum state. The beauty is that any attempt to read the key alters it, making it theft-proof. The technology is expected to become the gold standard of cryptography. Several groups have tested quantum communications on Earth. But Qinghai was a proving ground for distributing quantum keys in the final frontier: space.

About 5 years from now, China plans to launch a spacecraft that will transmit entangled photon pairs to ground receivers. The European Space Agency may deploy a similar system on the International Space Station, and scientists in Canada and Singapore have proposed quantum microsatellites. China is moving faster. "We hope we will be the first real experiment in space," says the Chinese project's leader, Pan Jianwei, a physicist at the University of Science and Technology of China in Hefei. His team faces daunting challenges in sending quantum keys across great distances. But few scientists in China come more highly rated. "In quantum communication and multiphoton quantum optics, he's certainly in the top echelon," says quantum physicist Anton Zeilinger, whose group at the University of Vienna has distributed quantum keys by laser more than 144 kilometers in the Canary Islands and will participate in China's quantum-spacecraft project. The satellite, he

says, will also be a platform for fundamental experiments probing the nature of entanglement, dismissed by Albert Einstein as "spooky action at a distance," over unprecedented distances. If it succeeds, China intends to deploy a fleet of spacecraft that could make global quantum communication a reality. Potential users would include commercial banks and China's armed forces.

China's program is building on a steady stream of homegrown advances in generating entangled photons and quantum-key distribution over the past decade. In 2004, Pan's group transmitted entangled photons from a mountaintop to the ground near Hefei, demonstrating quantum-key distribution in the atmosphere. At that point, he says, "We started to think very seriously about doing this in space." The research is demanding. "We are working at the single-photon level. It's invisible to the eye," Pan says. In 2011, his team was the first to entangle eight photons at once. That feat "was really outstanding," Zeilinger says. "It required some elegant ideas."

Crucial to the satellite effort, Pan's team is becoming defter at generating multiphoton entanglement. "The probability of creating a four-photon entanglement is small," Pan says. In 2004, they managed a few four-photon events per second. Now, he says, they churn out a few thousand per second. To devise their high-intensity entangled photon source, Pan says, "We had to develop some new technology and use some new tricks."

They put these tricks to work in a real-life setting in 2008. That year, Pan's



high-tech exports to China forced Qi's team to toil in isolation. As a result, he says, China "spent too much time and resources" developing the Shenzhou spacecraft, the workhorse of the crewed program. "On one hand, we felt uncomfortable about the restrictions. On the other hand, those restrictions helped us a lot," Qi says. "Although our spacecraft may not be the best, we successfully made it by ourselves." The second watershed event of China's space program came in 2003, when Shenzhou 5 carried astronaut Yang Liwei into orbit. China became the third country to independently send a person into space.

While other spacefaring nations have set up civilian agencies for peaceful explora-

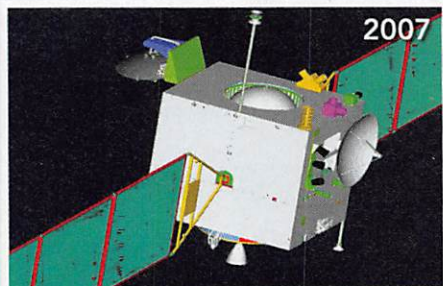
tion of space, in China the army has always run the show. For that reason, China's ultimate intentions are debated (see p. 1634). One concern is that China's space-industrial complex is bigger than any other country's. Two state-owned space enterprises together employ more than 267,000 people. Add in staff at space-related R&D institutes and university-based researchers, and the number of Chinese involved in the space program may top 300,000. This gargantuan ground force has propelled China into the upper echelon of spacefaring nations. China "is one of the elite," Cheng says.

China's space science community hasn't gotten there quite yet.

Rising from the ashes

On 9 November 2011, China thought it was on its way to the Red Planet. Early that morning, Russia launched the Fobos-Grunt spacecraft on a Proton rocket with the aim of landing on Mars and returning 200 grams of soil to Earth in 2014. China was hitching a ride. A small probe called Yinghuo-1, built by CAS's Center for Space Science and Applied Research, would separate from Fobos-Grunt before the spacecraft entered Mars orbit. Its aim was to take the most detailed measurements yet of the planet's magnetic field. "It really was our dream to go with the Russians," says Wu, who led the Yinghuo-1 design team.

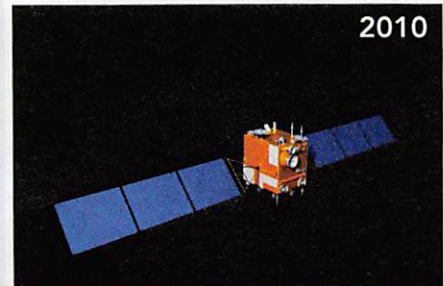
Seconds after Fobos-Grunt had separated



Lunar exploration program kicks off with Chang'e 1.



Zhai Zhigang goes for a 22-minute spacewalk outside of Shenzhou 7.



Chang'e 2 maps future lunar landing sites.

CREDITS: (TOP) ZHANG DONGDONG; (BOTTOM LEFT TO RIGHT): NASA IMAGES; IMAGINECHINA VIA AP IMAGES; SPACEBABA/WIKIMEDIA COMMONS

CREDITS: (TOP) JIANWEI PAN; (BOTTOM LEFT TO RIGHT) IMAGINECHINA VIA AP IMAGES; AP PHOTO/ RUSSIAN ROSCOSMOS SPACE AGENCY, HO-SUN ZIFA/COLOR CHINA PHOTO/AP IMAGES

group distributed quantum keys to three stations linked by 20 kilometers of fiber-optic cable. The keys were used to decipher encrypted phone conversations between the stations. That approach works fine for short distances, such as within a city, but the transmission efficiency by fiber optics diminishes with distance. "Beyond 100 kilometers, the loss is huge," Pan says. Quantum-key distribution between cities and continents will require exploiting the vacuum of space, where there is no photon loss.

Pan's achievements are all the more impressive considering that he started out as a theorist. After joining Zeilinger's lab to pursue his doctorate in 1996, Pan was intrigued by the group's hands-on work. "It took him a while to get used to the way we do experiments," Zeilinger recalls. "But he started coming up with his own ideas, and I realized this guy had talent." Thanks to his stellar work, Pan was elected to the Chinese Academy of Sciences last year at the tender age of 41, becoming one of the youngest academicians ever in China.

Pan will have to scale new heights to succeed in space. The quantum-mechanical principles themselves are straightforward—at least to the researchers. The key hurdle will be the exquisitely precise timing necessary to allow two ground receivers to measure the quantum state of entangled pairs at exactly the same moment. "That's very demanding," says Zeilinger, whose group will use receivers across Europe to tune in to China's spacecraft. For only a few minutes at a time, he says, stations in Europe and China can simultaneously view the satellite. "The satellite will be flying very fast. The distance

is huge. We have to make sure the quantum signal can be transferred to the right point," adds Pan, whose team is devising the payload here at a new branch campus of his university. If all goes well, Pan envisions a network of satellites that would function as repeater stations for global coverage. Although China's quantum spacecraft is a civilian project, military programs have a keen interest in unbreakable encrypted communications; U.S. efforts in satellite-based quantum communication appear to be classified. Even if a government agency ran the system, civilian information would be impervious to eavesdropping. "The satellite owner can only allow you or not allow you to communicate. Once they allow you, they cannot see the message. There is no way," Pan says. That may reassure Bank of America—but the Pentagon may not welcome a Chinese quantum-cryptography capability with open arms.

from the rocket, the spacecraft's thrusters failed to execute a burn properly, stranding it and its piggybacked companion in low Earth orbit. Over the next several days, controllers at the Lavochkin Association in Moscow, which designed Fobos-Grunt, attempted to communicate with the spacecraft to set it back on course, but to no avail. Fobos-Grunt plunged back through the atmosphere on 15 January, broke apart, and disappeared over the Pacific Ocean. "It was very disappointing. A really big blow for our science," Wu says.

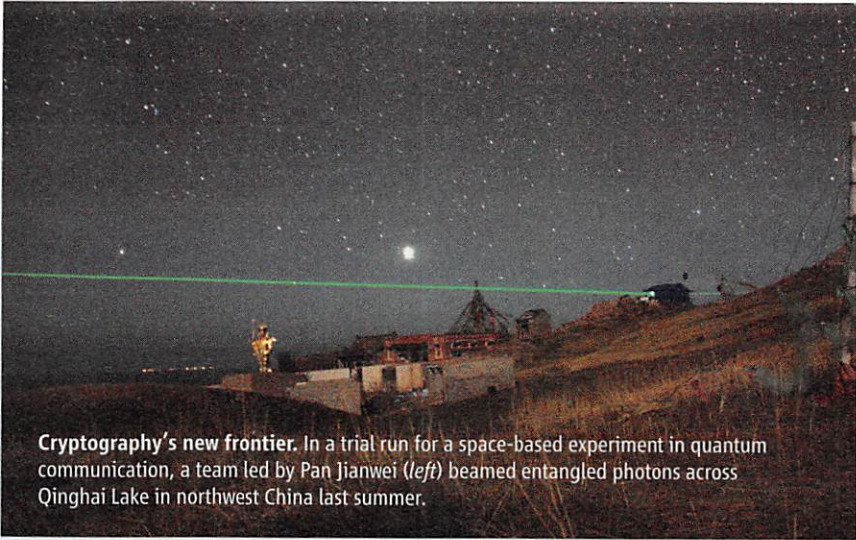
Wu's chagrin may prove short-lived. In the months before the Fobos-Grunt disaster, China had already begun drafting blueprints for a space science program that, it hopes, will

make the country stand out not just for aeronautical engineering but for discoveries in space science, as well.

Until now, most other science missions have languished as mere proposals. Although the first two spacecraft launched under China's lunar exploration program—Chang'e 1 in 2007 and Chang'e 2 in 2010—carried scientific instruments, they "were more for prestige and engineering than for science," Wu says. After mapping future landing sites, Chang'e 2 is now en route for a flyby of 4179 Toutatis, a potentially hazardous asteroid that will whiz close to Earth at the end of the year. Chang'e 3, scheduled for launch in 2013, will be the first spacecraft to make

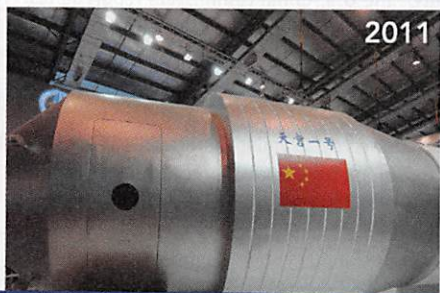
a soft landing on the moon since the Soviet Union's Luna mission in 1976. It will roll out a rover that will analyze soil samples and set up an extreme ultraviolet telescope—the first astronomical observatory on the moon. Some officials have talked of a crewed lunar landing after 2020, but that adventure is not set in stone. The rationale for such a mission, Qi says, "is being hotly debated."

Heralding a new era for space science, on 3 May 2011, Wu announced that CAS will undertake five scientific missions in the coming years (*Science*, 20 May 2011, p. 904). CAS has budgeted \$554 million over 5 years for the missions and established NSSC last year to oversee the burgeoning program.



Cryptography's new frontier. In a trial run for a space-based experiment in quantum communication, a team led by Pan Jianwei (*left*) beamed entangled photons across Qinghai Lake in northwest China last summer.

—R.S.



2011

Tiangong module is the first step toward the space station.



2011

Yinghuo-1 is destroyed aboard the doomed Fobos-Grunt Mars probe (*pictured*).



2012

Shenzhou 9 heralds an era of sustained presence in space.

Run by the Army for the Army?

BEIJING—Early in the morning on 11 January 2007, China fired a missile topped with a kinetic kill vehicle at a spacecraft in low Earth orbit, smashing it to smithereens. The shot did not ignite a conflict, as the target, an aging weather satellite, was China's own. But Fengyun-1C's obliteration sent a message. A few months earlier, the United States had unveiled a space policy pledging to "deny, if necessary, adversaries the use of space capabilities hostile to U.S. national interests." China's antisatellite (ASAT) test showed that two could play at that game.

Although the People's Liberation Army (PLA) runs China's space program, leaders here have long maintained that the nation's aspirations are benign. "China always adheres to the use of outer space for peaceful purposes, and opposes weaponization or any arms race in outer space," states a white paper released last December by China's State Council. A top diplomat reiterated that theme earlier this month at a conclave of the United Nations Committee on the Peaceful Uses of Outer Space. Helping to shape that perception are an ambitious slate of space science experiments planned over the next decade (see main text, p. 1630), and this month's Shenzhou 9 mission, which featured China's first docking of spacecraft with astronauts aboard.

But other aspects of China's space program keep the Pentagon's top brass up at night. Last year, in its annual report to Congress on China's military program, the U.S. Department of Defense asserted that "PLA strategists regard the ability to utilize space and deny adversaries access to space as central to enabling modern, informatized warfare." PLA writings, the report notes, "emphasize the necessity of 'destroying, damaging, and interfering with the enemy's reconnaissance ... and communications satellites,' suggesting that such systems, as well as navigation and early warning satellites, could be among initial targets of attack to 'blind and deafen the enemy.'"

The direct-ascent ASAT test was a visible exercise in muscle-flexing. With much less fanfare, China is developing a number of other kinetic kill weapons and directed-energy technologies such as lasers and high-powered microwave beams to knock out spacecraft, the Pentagon says. China, it notes, can also jam common satellite communication bands and GPS receivers. "Barring effective countermeasures, the PLA's ability to complicate U.S. access to space assets is likely to grow over the next 10-15 years," states an April report from the U.S.-China Economic and Security Review Commission.

China's ultimate intention for its growing constellation of space-based sensors and transmitters is unclear. The network could be purely defensive, and it will have civilian applications in Earth observation and navigation. "A threat consists of both capabilities and intentions," says Mark Stokes, executive director of the Project 2049 Institute, a think tank in Arlington, Virginia, and author of the commission's report. "Beijing's intentions remain ambiguous."

Dual-use data. Last December, China launched its 10th Beidou navigation satellite, bringing the system online for commercial customers and giving its military a source of GPS information it can control.



Uncertainty is not surprising, considering that China from the start has blurred the lines between its military and civilian space activities. Soon after the Tiananmen Square crackdown in 1989, the United States imposed sanctions on the export of dual-use technologies to China. A decade later, the International Traffic in Arms Regulations effectively barred U.S. entities from using Chinese launch vehicles. Those were heavy blows for China's space program. "Space is 95% dual use," says Dean Cheng, a China space expert with the Heritage Foundation in Washington, D.C. "Any improvement in space technology can have military

implications." In a report last April assessing U.S. space export policy, the U.S. Defense and State departments concluded that "China's civilian and military space industry are fused together such that reasonable regulators must consider the high likelihood that space-related items and technology will be diverted from a civil use and applied to military programs."

The U.S. government has compiled a lengthy dossier on attempts, some successful and others foiled, to acquire restricted technologies for China's space program. According to the space export report, recent cases include theft or diversion of space

launch technical data, military-grade accelerometers, microwave amplifiers with radar applications, thermal insulation blankets for satellites, and carbon-fiber material for rockets and spacecraft. The report asserts that China's maturing space program "was often able to accomplish this progress by exploiting foreign technologies and items, especially those from the United States."

That conclusion may be too harsh. By most accounts, China's space program has depended on homegrown ingenuity far more than foreign technology. "We applied our own intelligence to solve our own problems," says Qi Faren, former chief designer of the Shenzhou spacecraft. "I'm not under the impression that they have relied on technology theft to advance their space program writ large," Cheng says.

Over the years, a once purely military effort has drawn more heavily on universities and civilian institutes. "The networks linking China's defense R&D community and traditionally civilian universities appear to be expanding significantly," the U.S.-China commission report states. It flags work in military optoelectronics R&D at Sichuan University in Chengdu, development of kinetic kill vehicle components at Zhejiang University in Hangzhou, and research on passive stealth coatings for reentry vehicles at Nanjing University.

With the 2007 ASAT test followed by a similar exercise in 2010, China raised the stakes in the Pacific. China paid a price for its 2007 use of firepower, which chilled relations between the Chinese and U.S. space programs and drew opprobrium over the roughly 3000 shards of Fengyun-1C that force the International Space Station to occasionally carry out evasive maneuvers. But other nations have been put on notice: In the future battlefield of space, China may speak softly, but it carries a big stick.

—R.S.

Astrophysics is set to take center stage. First off the blocks should be the Hard X-ray Modulation Telescope (HXMT), conceived nearly 20 years ago to observe black holes, neutron stars, and other objects based on their x-ray and gamma ray emissions. HXMT, China's first astronomy satellite, could be launched as early as 2014 and will be the first of three instruments in China's Black Hole Probe Program. Another mission incubating for years that now has a green light is KuaFu, a Sino-Canadian mission to study the sun's influence on space weather. Russia may join KuaFu, pegged for a 2015 launch along with Shijian 10, a spacecraft that will study the effects of strong radiation and microgravity on organisms and materials.

Work is also progressing on two later launches. One is the lead probe in China's Dark Matter Detection Program. The spacecraft, being designed by CAS's Purple Mountain Observatory in Nanjing, aims to register gamma rays generated when dark-matter particles annihilate each other. The fifth mission in the works, the Quantum Science Satellite, is designed to transmit entangled photons between a spacecraft and receiving stations on Earth (see p. 1632). Success would mark a first step in secure intercontinental quantum communication.

Four more missions that have passed preliminary reviews would considerably build up China's clout in spaceborne astrophysics. The goal is to get them launched in the next 5-year plan, beginning in 2016. One is the X-ray Timing and Polarization (XTP) telescope, conceived by CAS's Institute of High Energy Physics. As the lead facility in the planned Diagnostics of Astro-Oscillations Program, XTP would be "a much more powerful mission that goes far beyond HXMT," says Zhang, the project's leader. XTP would have a larger collection area and powerful mirrors to collect more photons—and thus observe fainter objects and

scrutinize them in greater detail, he says. Astrophysicists around the world have been clamoring for just such a telescope, but early last year NASA and ESA canceled plans for an International X-ray Observatory, and a scaled-down version called Athena lost out to a Jupiter probe in an ESA competition which concluded last month.

XTP would study x-ray emissions from matter spiraling into a black hole, or x-ray signatures of frame-dragging generated, for instance, as a spinning black hole tugs at spacetime. "We'll look at the physics of extreme conditions," Zhang says. For now, XTP is a purely Chinese mis-

"Although our spacecraft may not be the best, we successfully made it by ourselves."

—QI FAREN,
SHENZHOU CHIEF
DESIGNER



whose effective diameter is the maximum distance between the instruments. They would follow in the footsteps of Japan, which operated a space-based array from 1997 to 2002, and Russia, which is now testing its Spektr-R radio telescope launched last year.

China's proposed array would initially consist of two long-millimeter-wavelength antennas, each 10 meters wide. Key challenges include getting the space antennas to work with high pointing accuracy and having enough bandwidth to transmit scientific data, says Hong Xiaoyu, director of the Shanghai Astronomical Observatory, which is designing the system and is open to international collaboration. The top priority would be to map the fine structure of supermassive black holes that inhabit the center of galaxies and their accretion disks, which are believed to be the power source for

active galactic nuclei. Ten years after the first array, Hong says, his team hopes to launch millimeter-wave antennas. Longer baselines and shorter wavelengths produce a higher resolution of radio sources.

China also hopes to blaze a trail in interplanetary physics. NSSC is designing a solar probe that would receive a gravity assist from Jupiter, which would send it into a highly inclined orbit above and below the ecliptic plane, the line of sight between Earth and the sun. Only one previous satellite has followed a similar orbit: Ulysses, an ESA-U.S. probe launched in 1990 that measured a steady weakening of the solar wind and helped pinpoint sources of gamma ray bursts. NSSC's Solar Polar Orbit Radio Telescope (SPORT) would be the first to gaze down or up at coronal mass ejections streaming from the sun. Besides probing the properties of the solar wind and coronal mass ejections, Wu says, SPORT's spectacular bird's-eye view should improve forecasts of space weather.

The fourth new mission to pass mus-

China's Space Astronomy Takes Flight

Black Hole Probe Program

- Hard X-ray Modulation Telescope (HXMT)
- Space Variable Objects Monitor satellite
- Gamma-ray Burst Polarization (POLAR) experiment (aboard Tiangong)

Diagnostics of Astro-Oscillations Program

- X-ray Timing and Polarization (XTP) satellite

Portraits of Astrophysical Objects Program

- Space Very Long Baseline Interferometer (VLBI) telescope array

Dark Matter Detection Program

- Dark Matter Detection Satellite
- High Energy Cosmic Radiation Detection Facility (aboard space station)

Solar Physics Program

- KuaFu
- Solar Polar Orbit Radio Telescope (SPORT)
- Space Solar Telescope

sion. But China is exploring teaming up with Germany, which is contemplating a scaled-down Athena called Gravitas. A big attraction for China is that Germany could equip a joint probe with a much more advanced mirror; restrictions on the sale of high-tech equipment to China would force Zhang's team to commission an inferior Chinese-made mirror.

As the centerpiece of the Portraits of Astrophysical Objects Program, China intends to invest its long-standing expertise in VLBI in new space radio telescopes. Its current VLBI network consists of four large, ground-based dishes; three times a year, two of its dishes team up with the European VLBI Network for monthlong observation runs. China's plan calls for spacecraft that would operate in tandem or as arrays with ground dishes, mimicking a huge radio telescope

"When I look at astronomy textbooks, none of the discoveries were made by people working in China."

—ZHANG SHUANG-NAN,
INSTITUTE OF HIGH ENERGY
PHYSICS, BEIJING



CREDIT: (TOP AND BOTTOM) ZHANG DONGDONG

eppendorf



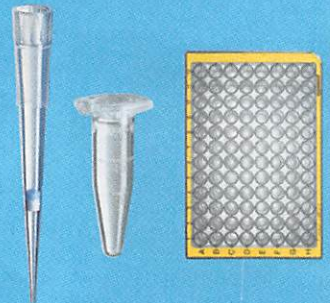
Absolute Certainty

It's your sample

Experience peace of mind with Eppendorf consumables in guaranteed quality and order your free sample on www.eppendorf.com/consumables

Don't leave your results to chance:

- > Unique features to make every day routines faster and easier
- > Minimized risk of chemical leaching from our consumables
- > Purity grades tailored to even the highest requirements



www.eppendorf.com

eppendorf® is a registered trademark of Eppendorf AG, Hamburg, Germany.
All rights reserved, including graphics and images. Copyright © 2012 by Eppendorf AG.

ter is MIT, named for the magnetosphere, ionosphere, and thermosphere. The four-spacecraft cluster, another NSSC brainchild, would attempt to shed light on how electrons and other energetic particles flow between those regions of space.

To maintain the momentum of China's suddenly vibrant space science program, NSSC is about to call for proposals for another slate of missions—up to three more, Wu says—that would be funded after 2015. Unlike in Europe or the United States, the price tag won't be a showstopper. "In China, the decision process may be slow, but once a mission is approved, it will go," Zhang says. "We haven't had a mission canceled because of the budget."

They do face one big impediment: limited interactions with colleagues abroad, especially those from the United States. "If scientists from NASA come to China for a conference, they cannot talk with Chinese scientists one-to-one," Wu says. "It reminds me of our Cultural Revolution," he says, when science in China was largely suppressed. The NSSC and the U.S. National Academies are discussing ways to catalyze discussions between space scientists in the two countries. One tantalizing conversation starter may be China's long-term space astronomy plan, which envisions putting telescope arrays on the moon after 2035.

A lasting legacy

Shenzhou 9's success opens a new realm for Chinese scientists. The ability to perform docking maneuvers in space will allow China to ferry equipment to Tiangong 1 and add up to two more modules. Research on Tiangong involves closer coordination with the space program's military masters. Two years ago, CAS founded the Technology and Engineering Center for Space Utilization here to manage scientific payloads for Tiangong and the planned space station. The army-run China Manned Space Engineering Office has barred foreign correspondents from interviewing center staff. However, scientists elsewhere in CAS and at universities who are designing the experiments were able to speak with *Science*.

A bevy of experiments are now being readied for Tiangong, including an atomic clock, a materials science furnace, and a plant tissue culture apparatus. Astrophysicists also have reason to cheer. Among the approved projects, China and Switzerland are teaming up on POLAR, a gamma ray

450-ton International Space Station, China's space station should host high-powered science. China Manned Space Engineering Office is expected to approve the first payloads from among dozens of contenders early next year. Among those vying for space are a suite of astronomy experiments called

the Cosmic Lighthouse Program. One of two proposed large instruments is the High Energy Cosmic Radiation Detection Facility to study dark matter and cosmic rays.

The other instrument would allow China to play a major role in the coming era of large-scale astronomical surveys—and possibly help unravel the nature of dark energy. China's wide-field optical telescope would complement planned instruments elsewhere, such as the Large Synoptic Survey Telescope (LSST), an 8.4-meter dish to be built in Chile that could see first light in 2018. But LSST will not be able to detect infrared or near-ultraviolet waves from cosmic sources, which are absorbed in the upper atmosphere, and its resolution,

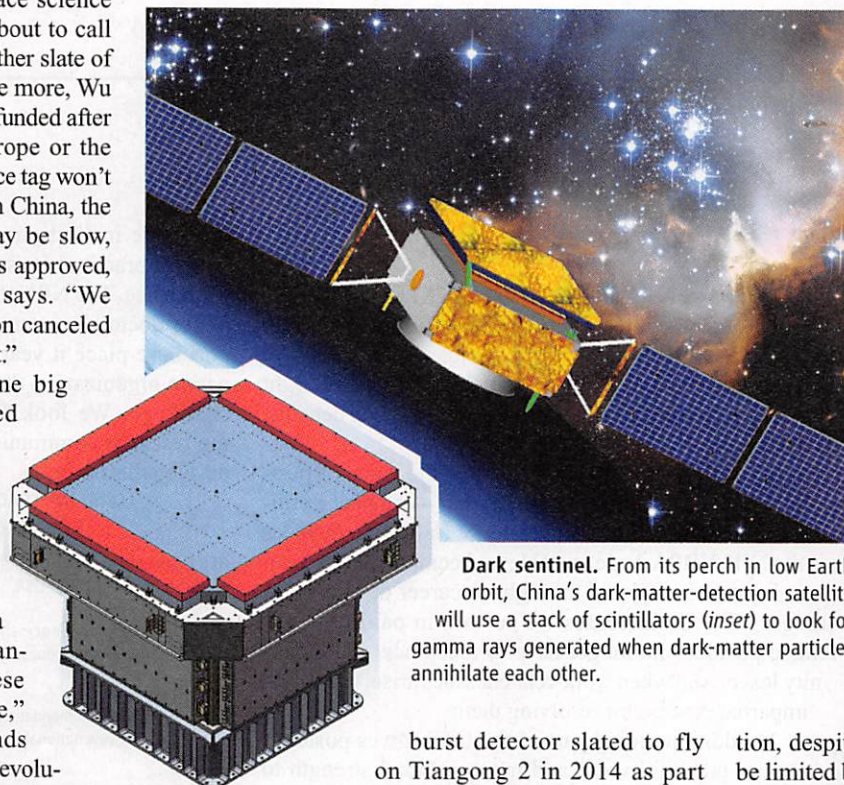
despite Chile's superb conditions, will be limited by atmospheric turbulence.

China's as-yet-unnamed mission also won't look in the infrared, as it is not possible to import astronomy-grade infrared detectors. Chinese industrial-grade detectors "don't have the needed performance," says team member Zhan Hu, a cosmologist here at the National Astronomical Observatory of China. But China's space station survey, he says, will complement other efforts with its high angular resolution and multiple bands covering optical and near-ultraviolet wavelengths. One challenge to mounting any telescope on a space station is that the station will rotate as it orbits. To keep a fixed gaze, the telescope must counterrotate. That job will be farmed out to optomechanical engineers. "They'll do the heavy lifting," Zhan says.

If the survey mission passes muster, Zhan is confident that Chinese scientists will have new knowledge to contribute to science. "With surveys, you always find something unexpected," he says. "Current physics cannot explain dark energy. We have an opportunity to discover some revolutionary physics."

—RICHARD STONE

With reporting by Bu Kai and Zhang Dongdong.



Dark sentinel. From its perch in low Earth orbit, China's dark-matter-detection satellite will use a stack of scintillators (*inset*) to look for gamma rays generated when dark-matter particles annihilate each other.

burst detector slated to fly on Tiangong 2 in 2014 as part of the Black Hole Probe Program. It will be the only dedicated instrument in space for measuring gamma ray polarization, which should help scientists determine the structure of a gamma ray jet's magnetic field, Zhang says. That, in turn, may shed light on the origin of gamma ray bursts. One hypothesis is that they are unleashed when a massive star collapses at the end of its life; another is that they are generated when neutron stars or black holes merge. "Each model predicts a different structure of the magnetic field," Zhang says.

Scientists here may never have had such a wealth of opportunities if China had been invited to join the 16-nation International Space Station. "China didn't have to make Tiangong if we could participate. But we were blocked out," Qi says. Tiangong is a steppingstone to a 60-ton space station that China announced last December that it would build by 2020.

Although a pipsqueak compared with the

Online

sciencemag.org

Podcast interview with author Richard Stone (http://scim.ag/pod_6089).

Podcast interview with author Richard Stone (http://scim.ag/pod_6089).



LETTERS

edited by Jennifer Sills

Postdocs: The Power of Unions

AS A POSTDOC AT THE UNIVERSITY OF CALIFORNIA–SANTA CRUZ AND PRESIDENT OF UAW LOCAL 5810, the union that represents over 6000 postdocs at the University of California, I read with interest A. I. Leshner's Editorial on the need for a broad-scale effort to standardize and improve the postdoc experience ("Standards for postdoc training," 20 April, p. 276). Leshner is right that many postdocs face numerous challenges, including limited job security, varying benefits, visa and immigration issues, and pay that fails to reflect our contributions.

To address these issues, Leshner unfortunately fails to recognize how the voice of postdocs themselves—through the democratic process of collective bargaining—can play a critical role. The contract that the UAW has negotiated with the University of California includes a minimum salary scale that matches the NIH/NRSA scale, a stable and comprehensive benefits plan, more job security, and the right to career development resources. With the increases we've won in paid time off, female postdocs no longer have to face uncertain maternity leave. And when work-related issues arise, there is an impartial process for resolving them.

In addition, being part of the UAW gives postdocs a more powerful voice and more political strength to advocate for issues such as science funding, progressive immigration reform, and gender equality in the academy.

When postdocs have an equal say in determining our working conditions, our quality of life improves, which in turn improves the quality of research. Our union welcomes the opportunity to work with the Committee on Science, Engineering, and Public Policy (COSEPUP) and all other interested parties for the good of postdocs and for the good of society.

NEAL SWEENEY

Department of Molecular, Cell and Developmental Biology, University of California-Santa Cruz, Santa Cruz, CA 95064, USA; UAW Local 5810, Berkeley, CA 94704, USA. E-mail: president@uaw5810.org

Speaking with one voice. Postdoc unions can negotiate better benefits for their members.



Postdocs: NPA's Success

THE NATIONAL POSTDOCTORAL ASSOCIATION (NPA) applauds the recent Editorial by A. I. Leshner calling for the scientific community to commit to providing quality postdoctoral experiences ("Standards for postdoc training," 20 April, p. 276). The NPA is ideally positioned to take up Leshner's call to action: In its first decade of existence, the NPA has laid the groundwork for the standards, norms, and expectations required to deliver an optimal postdoctoral experience.

The NPA's Recommendations for Postdoctoral Policies and Practices (1) have been adopted widely by research institutions and funding agencies. Due in large part to the NPA's efforts, the number of postdoc offices on record has increased from less than 25 in 2001 to more than 135 today. The NPA provides online toolkits and conducts site visits to help institutions establish postdoc offices as well as postdoc associations. In answer to Leshner's call to action, the NPA Board of Directors has undertaken an initiative to develop a national certification program to

recognize institutions that are implementing best practices for supporting the postdoc experience. The NPA's track record, expertise in postdoctoral matters, and established support base place it years ahead of any alternative organization that might take on this challenge. We look forward to engaging the research community at all levels as we develop this program.

LORRAINE TRACEY,* MAHADEO SUKHAI,
STACY L. GELHAUS, DAVID TAYLOR

NPA Board of Directors, National Postdoctoral Association, Washington, DC 20005, USA.

*To whom correspondence should be addressed. E-mail: Lorraine@nationalpostdoc.org

Reference

1. NPA, NPA Recommendations for Postdoctoral Policies and Practices (www.nationalpostdoc.org/recommendations).

Turing in Context

IN HIS PERSPECTIVE "BEYOND TURING'S machines" (13 April, p. 163), A. Hodges claims that in 1945 Turing "used his wartime technological knowledge to design a first digital computer." He also suggests that Turing's work of 1936 laid the foundation for encoding "all known processes," going "far beyond the vision of others at the time." These statements implicitly diminish the earlier work of Kurt Gödel and Konrad Zuse. In 1931, Gödel used the integers to design a universal language capable of encoding arbitrary computations and general algorithms that could prove theorems (1). This allowed him to identify the fundamental limits of math and provability. Turing and his adviser Alonzo Church later merely reformulated Gödel's work in an elegant way. Furthermore, Zuse's 1936 patent application Z23139/GMD Nr. 005/021 already described a concrete general computer, as opposed to a purely mathematical construct. By 1941, Zuse had physically built the first working universal digital machine, years ahead of anybody else [e.g., (2, 3)]. Thus, unlike Turing, he not only had

CREDIT: ISTOCKPHOTO.COM