Great strides of China’s space programmes

By Jane Qiu

While China’s almost flawless space endeavours—such as its space lab Tiangong-2, launched last year, and the 2012 mission that sent a rover to the surface of the Moon—have long impressed the world, space-science missions were not among its priorities until recently. The situation improved in 2011 when the Chinese Academy of Sciences won government support for a 10-year Strategic Pioneering Programme on Space Science—with a total budget of nearly 1 billion dollars. Since then, China has launched satellites to probe dark matter, detect black holes and conduct quantum experiments from space. This year will see the launch of an astronomy satellite and a highly anticipated mission to bring back rocks from the Moon.

In a forum chaired by National Science Review’s Executive Associate Editor Mu-ming Poo, space scientists discussed different types of Chinese space programmes, the science missions already launched or in development, the importance and challenges of international collaboration, and the uncertain future of the country’s space-science development.

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CHINESE SPACE SCIENCE: NEW KID ON THE BLOCK

Poo: China’s space endeavour has come a long way since its debut satellite Dongfanghong-1 broadcast ‘The East is Red’ from space in 1970. How many types of space programme does China have now?

Wu: China has three types of space programmes: manned space mission (such as the space station and the manned mission to the Moon), deep-space exploration (such as lunar and Mars exploration) and space-science programmes. Before the launching of the Strategic Pioneering Programme on Space Science 6 years ago, China’s only dedicated science missions were Double Star, which is a collaborating project with the European Space Agency (ESA) to study magnetic storms from 2003 to 2007, and the Mars probe Yinhuo-1 as part of the Russian Photos-Grunt mission (though the mother rocket failed to leave Earth’s orbit and plunged into the Pacific Ocean in 2011).

Li: Until recently, China focused mainly on space technology and on developing satellites that have direct application values, such as Earth observation, communication, navigation, weather forecast and environment monitoring. It has just started to pay more attention to space science. It’s a new kid on the block.

Wu: Similar to other countries, our budgets come from the tax payers, so there must be procedures in place to ensure that the...
money is properly spent. There are mainly two criteria for mission selection. One is that they will have to have major scientific breakthroughs. Two projects—the dark-matter and quantum satellites—belong to this category.

The other criteria is that the missions will help build capacity on a large scale. Even if the progress may not be groundbreaking, we will have lots of discoveries in many areas, can train a whole generation of space scientists and produce many high-quality papers. Astronomy satellites capable of observing celestial objects at broad wavelengths—such as the Hard X-ray Modulation Telescope (HXMT)—fall into this category. So are those designed to study space weather, which have also direct application values, and to carry out microgravity experiments, such as the Shijian-10 capsule.

**Poo:** What are the latest developments in space-science missions?

**J. Wang:** Shijian-10 successfully returned to Earth in April 2016 after having carried out microgravity and life-science experiments in space. We launched the Dark Matter Particle Explorer (DAMPE) in December 2015 and the Quantum Experiments at Space Scale (QUESS)—the first such satellite in the world—last August. Tiangong-2, the second orbiting lab launched last September, carried out 14 experiments—including POLAR, which was designed to see whether the photons from γ-ray bursts are polarized.

The key to boost international collaboration—and China’s role in space science—is to boost our originality of ideas and our technological capability.

— **Yifang Wang**

**Y. Wang:** I’ve been involved in particle-physics experiments in space since 1990s, including the US$2-billion dark-matter experiment using Alpha Magnetic Spectrometer (AMS) attached to the International Space Station. I can see a clear trajectory of China’s space-science development: we’ve progressed from an early phase of following and learning to a stage now where we are on a par with our European and US counterparts. I’m confident we will be a world leader in the foreseeable future.

**Poo:** What’s happening in the coming years?

**Li:** There will be 30 space missions in 2017, a record-breaking number in China’s space history. Some of the highlights include: the launch of our first astronomy satellite HXMT this June, the docking of a new module Tianzhou-1 with Tiangong-2 and the sample-return mission by Chang’e-5 at the end of the year.

**Wu:** China has approved five new space-science missions as part of the 13th five-year plan till 2020. These include the Solar Wind Magnetosphere Ionosphere Link Explorer (SMILE)—the first joint mission with the ESA to study space weather—Magnetosphere, Ionosphere and Thermosphere (MIT), the Einstein Probe (a wide-field X-ray telescope), Water Cycle Observation Mission (WCOM) and the Advanced Space-borne Solar Observatory (ASO-S), China’s first solar exploration satellite.

We’re also preparing for future missions beyond 2020. These include High-Energy Cosmic Radiation Detection Facility (HERD) —a cutting-edge dark-matter probe that will attach to China’s space station which will be launched in 2023—the X-ray Timing and Polarisation (XTP) satellite (for probing the black hole), the Solar Polar Orbit Telescope (SPORT), Search for Terrestrial Exo-Planets (STEP) and a Space Millimetre-wavelength VLBI Array (S-VLBI) probe.

**Poo:** It’s all very exciting. How has it been going regarding the QUESS, DAMPE and POLAR? What are you trying to achieve?

**J. Wang:** QUESS is dedicated to basic research—rather than a quantum-communication satellite as some people think. Its main goal is to test fundamental principles of quantum mechanics in space. We know that several particles can be generated in ways such that the quantum state of each particle cannot be measured independently of the others, even when the particles are separated by a large distance—a phenomenon known as quantum entangling. We have proved that this can be achieved on Earth over 1000 kilometres through air, the world record. The mission’s primary goal is to test if quantum entangling can stretch between Earth and the satellite.

Only if this is the case can we begin to think about quantum transmission, also known as quantum-key distribution, between QUESS and a ground station. If all goes well, the project could move towards applications of quantum communication after the construction of the space station is completed, possibly in 2023. We’re already ahead of the game. China is likely to be a world leader in this area of research in the coming decades.

**Zhang:** A unique feature of DAMPE is that it has a large detection area and can survey the sky at energies much higher than existing detectors such as AMS, which is attached to the International Space Station. DAMPE is able to observe a large volume of cosmic rays and differentiate whether they come from sources other than dark matter, such as pulsars. It’s working very well and we’ve got some encouraging results. POLAR is also going very well. It has exceeded our expectation in some aspects. Our goal was to probe γ-ray bursts, which we did. We also detected solar flares. More surprisingly, we got clear signals of pulsars even though we didn’t realize the instrument would have such capacity.

**DEEP-SPACE EXPLORATION AND MANNED MISSIONS**

**Poo:** How is China doing in its deep-space exploration programmes?

**Li:** Since China’s lunar-exploration programme kicked off a decade ago—with the launch of Chang’e-1—we have achieved many technological breakthroughs. We managed to orbit around the Moon in 2007 and land a rover on its surface in 2013. These missions have also resulted in significant scientific discoveries. Later on this year, Chang’e-5 will try to bring lunar rocks
back to the Earth. Another probe will be sent up next year to make a soft landing on the far side of the Moon.

Poo: Are we playing catching-up to a large degree?

Li: Indeed. Since 1960 s, the US and Russian have explored the Moon in a detailed and systematic way, including six manned missions, more than 100 probes and nearly 400 kilograms of lunar rocks. In the past decade, China has launched only three lunar probes. The point is not about repeating what other countries have achieved for the sake of it. It’s more about long-term capacity building in terms of both engineering and scientific capability, which can’t be achieved over a handful of missions. This is absolutely essential before we could attempt more audacious missions—such as next year’s mission to land on the far side of the Moon, which, if successful, would be the first in the world.

Poo: What are we trying to achieve in deep-space exploration?

Li: It’s difficult to pinpoint specific scientific goals in space exploration. The over-arching goal is discovery but we often don’t know what’s out there or what we will find. But, based on the history of space exploration, we always get lots of surprises when we send probes to places people have never been before and in ways that have never been tried. The key is really to be daringly innovative. This is why we want to explore the far side and the polar regions of the Moon—where nobody has been before.

At the heart of international collaboration is mutual trust... [which] is built up gradually over time—through many small-sale grassroots collaboration over many years.

— Ji Wu

Poo: China’s next destination is Mars. What’s the plan?

Li: A Mars mission is being planned for 2020 with the Long March-5 heavy-lifting rocket. It will place a spacecraft to orbit the red planet for one Martian year (687 Earth days) or longer. Seven payloads aboard the spacecraft will measure various aspects of the Martian surface and atmosphere. Meanwhile, another probe would land on a flat patch of land near the equator. If successful, a six-wheeled, solar-powered rover will be released to roam the Martian surface for at least three Martian months—probing the ground with radar, performing chemical and mineral analyses on the soil, and looking for signs of life. The risk involved cannot be underestimated. Last October, a lander of ESA’s ExoMars mission failed a soft-landing attempt.

Poo: How about China’s manned space missions?

Zhang: There are three stages in China’s manned missions. The first is to send astronauts to space, which has been achieved several times since 2003. The second is to set up a space lab, which is what Tiangong-2 is about. Over a dozen scientific experiments and engineering tests have been conducted there and the two astronauts returned to Earth safely after a 30-day mission—the longest flight by Chinese astronauts to date. Tiangong-2 is designed with a lifespan of two years.

The final stage is the space station. Its construction will begin next year and the first module will be launched around 2020. The space station, while much bigger and more complex than Tiangong-2, will still be much smaller than the International Space Station, with a designed lifespan of 10 years. It will have several modules, where astronauts can live and work for several months at a time, carrying out maintenance work and conducting scientific experiments in and outside the station. Several instruments, such as the dark-matter probe HERD, will be attached to the station. There is also a plan to launch an astronomy satellite that will fly in the same orbit. This would allow easy access if maintenance is necessary.

APPLICATIONS OF SPACE PROGRAMMES

Poo: Space programmes have implications for civilian and military applications. Is that something that is highly regarded when missions are evaluated?

Wu: The key criteria for selecting space-science missions is scientific breakthroughs—rather than application values. We’d need to develop the necessary technologies to achieve what we want to achieve. For instance, the DAMPE payload weighs 1.4 tonnes, nearly three-quarters of the entire satellite. This high ratio is a significant achievement from a technological point of view. How this kind of technological know-how can be applied in other areas is not our concern and beyond our control—which I think is the case in every country.

In any case, the application side is totally independent of space-science programmes. China, for instance, has invested heavily on civilian applications for a long time. It launches about 20 application satellites a year in areas such as meteorology, oceanography, environmental monitoring, navigation and global positioning.

J. Wang: I agree. Scientific breakthroughs must be the primary concern of our space-science missions. But if promising practical values come out of the missions, then we should also push for more rapid applications so people can benefit. This would help secure long-term support if the government see that frontier science are relevant to people’s lives. If the quantum experiments in space go well, for instance, we could push for its applications in quantum communication. It should also be possible to develop follow-up application satellites by leveraging results from space-science missions.

INTERNATIONAL COLLABORATION IN SPACE PROGRAMMES

Poo: Space programmes are very costly. Can China do it alone? To what extent are we collaborating with other nations?

Wu: International collaboration is absolutely essential because the resources of individual countries are limited. No single country can do it alone. China is expanding its scope of international collaboration and is open to all nations. But the situation has been impossible with the US since it passed a law in 2011 that explicitly prohibits NASA to have any bilateral
collaboration with China. In 2013, Chinese scientists were even banned to attend an academic conference on NASA’s Kepler space telescope programme—a decision that was revoked due to international outcry.

**Poo:** But didn’t China participate in international space programmes before?

**Y. Wang:** Indeed. That was before the law was passed when the China–US relation was much better. For instance, scientists at Chinese Academy of Sciences’ Institute of Electronic Engineering were involved in the design and construction of the dark-matter detector AMS, which was launched in 2011 and is now attached to the International Space Station. The international team initially planned to use superconducting magnet to detect cosmic rays [high-energy particles that reach Earth from space] but switched to permanent magnet less than six months before the scheduled launch, partly to extend the detector’s lifespan while preserving its sensitivity.

Collaborating with Samuel Ting of the Massachusetts Institute of Technology in Cambridge, Chinese scientists had an important role in terms of the design, testing and manufacturing of this core component. In its fifth year running, AMS is expected to function until 2024 when the International Space Station retires. It would have lasted for no more three years if superconducting magnets were used. From this perspective, China’s contribution to AMS is significant.

A main issue is that there is no single agency in China to coordinate different space programmes, … and neither is there long-term strategic planning and funding commitments.

— Shuangnan Zhang

**Li:** This was really a win–win situation. Things are very different now. NASA’s hands are tied because of the law. But many of its researchers and administrators—at all levels—are very keen to work with China. The agency sends a delegation to China every other year, when it visits key institutions such as the China National Space Administration and the National Astronomical Observatories, and organizes small-scale academic exchanges. There are some collaborations between individual scientists on, for instance, the analyses of data from the lunar programmes, but nothing official or major.

**Zhang:** NASA certainly keeps a close eye on what China is doing. I just learned that scientists from two NASA institutions—the Goddard and Marshall Space Flight Centres—plan to jointly propose a programme that is conceptually very similar to our black-hole and neutron-star probe eXTP. Since 2011, we’ve been working in China and with our European colleagues from 16 countries as well as individual US scientists on a few technological huddles, which must be overcome before the project can be officially approved. Now scientists from NASA are trying to get our European partners to join their project instead if they succeed in securing the fund. It’s a shame NASA scientists have to compete with us like this. I really wish we could all work together—especially both the Goddard and Marshall centres are world leaders on high-energy physics and we have a lot to offer as well.

**Poo:** How about our collaboration with other countries?

**Li:** ESA is our key collaboration partner and our relationship is going from strength to strength. We’ve been working together in the past two decades. Between 2003–2007, for instance, we teamed up to study magnetic storms in China’s very first space-science mission Double Star. Our European partners in countries like Italy, Poland and Switzerland have important contributions to DAMPE, POLAR and HXMT. There will be ESA payloads in the upcoming Chang’e-4 mission. We also have lots of collaboration on data analyses.

**Wu:** It’s through these relatively small-scale collaborations that we have got to know each other and build trust—which is critical. Now CAS and ESA have selected a joint mission called SMILE to study space weather. We came up with the idea and drafted the guidelines together. We are working so intimately together that each agency will contribute half of the satellite and half of the payloads.

**Y. Wang:** Many European institutions are also very much interested in our next-generation dark-matter probe HERD. I suspect their contribution should constitute at least 50% in terms of fund and payloads. When the International Space Station retires in 2024, European and US scientists will be interested in working with us on our space station, which, if all goes well, will be up and running by 2023. I think the key to boost international collaboration—and China’s role in space science—is to boost our originality of ideas and our technological capability. If we are strong, we don’t need to worry about being unable to find world-class scientists to work with. It’s a matter of shuidaoqucheng (‘the channel forms naturally when water arrives”).

**Zhang:** Indeed. The US may even soften its stance at that stage because it would realize that it’s at its own loss not to work with China. Already, NASA is very much interested in the SMILE mission and may funnel its contribution, which could be hardware or scientists, through ESA. So the mission may end up being a China–ESA partnership with US participation. It’d be a good starting point.

**Wu:** At the heart of international collaboration is mutual trust. There is a deep sense of mistrust between China and the US, which will not disappear until people start working together. The US law that bans bilateral collaboration between the two nations can only make things worse. Trust is built up gradually over time—through many small-scale grassroots collaborations over many years. This is what has happened between China and ESA. This is why we have now reached the stage to work so closely together on SMILE. If it works out, we will be confident to have much larger-scale collaboration on more audacious projects. This serves everybody and our common humanity. Nobody wants to see the Cold War repeating itself.
FORMIDABLE CHALLENGES AHEAD

Poo: What are the main challenges for space science in China?

Wu: China began to invest in space science only six years ago, and the investment constitutes less than 5% of the total budget in aeronautics and space programmes—far from enough compared to 10–50% in the US, EU, Japan and Russia.

Zhang: Indeed. The recent missions, such as QUESS and DAMPE, have attracted a lot of attention worldwide. But we face rather formidable challenges. A main issue is that there is no single agency in China, equivalent of NASA in the US or ESA in Europe, to coordinate different space programmes, and neither is there long-term strategic planning and funding commitments. At the moment, three independent government agencies oversee different space programmes with limited overlap: the State Administration for Science, Technology and Industry for National Defence takes care of deep-space exploration, the China Manned Space Engineering Office is in charge of manned space programmes and the Chinese Academy of Sciences leads space-science missions.

At CAS, we’re moving forward on a mission-by-mission basis. We’ve just managed to secure some funding for the next five years, but nobody knows what will happen afterwards. We are in a constant state of zhaobubaoxi (‘not knowing where the next meal will come from’). Both NASA and ESA have long-term funding commitments—it’s a matter of which missions they want to invest in. In China, we don’t know if there will still be funding for space science at the end of this funding cycle in five years’ time. That’s the difference. And this does no good to attracting talented people to the field.

Li: Indeed. We got lots of data from various space programmes, but lack high-quality people to analyse them. Neither is there sufficient support for this kind of research. China’s science ministry and National Natural Science Foundation should have stable funding to support basic research in space science. This will help long-term capacity building. In Europe and the US, many teams have been working on space-science projects systematically for decades. We need to work with them and learn from them. At the same time, we should start boosting the quality of our own researchers in China, which may be a more effective and sustainable approach in the long run than getting a small number of high flyers from the West.

J. Wang: Another challenge is to better integrate scientific goals and engineering designs. Historically, meeting technological challenges has been the main focus of China’s manned space programmes and deep-space exploration. The goals have been to send the probes up and get some sorts of data, but what those data could tell us scientifically was often not carefully thought out. There were incidences in which engineers were not clear at an early stage what scientists wanted to achieve and then it was too late to make changes, largely compromising the effectiveness of the missions.

This must be changed in the future. Engineers and scientists should work closely together from the very beginning. And engineering designs should be catered towards scientific goals. This is the only way that we can make the most out of space missions scientifically. I think this is also partly why the quantum satellite has been so successful—scientists and engineers spent years doing testing and experiments together on the gourd long before the project got a go-ahead.

Poo: In terms of talent pools, what sorts of people do you need?

Li: Space science, which is basically sciences in space, is a big melting pot and needs people from all sorts of training—including engineering, astronomy, physics, mathematics, chemistry, material science, biology and geology. Anybody with a scientific training can come and work on space science. It’s crucial to provide long-term support and a conducive environment and to give young people the freedom to pursue their passion.

"It’s crucial to provide long-term support and a conducive environment and to give young people the freedom to pursue their passion."

— Chunlai Li

J. Wang: I’d like to make three points. First, we need a group of people with imagination because original ideas are the key driving force. Second, there should be relatively stable engineering teams. Space science is quite different from laboratory-based experiments, which scientists can do it alone. In space science, engineering capability is the prerequisite, so having a stable, experienced and highly committed engineering team is crucial. This requires long-term government support. Finally, long-term government support is critical for the healthy development of space science. The lack of funding security is a main obstacle to attracting and retaining talented people.

Wu: I’d like to take this opportunity to appeal to the international community not to be too sensitive to our space-science programmes. China is a new kid on the block. We’re just starting out. Our investment in space science is actually very small compared to major space powers. We have a long long way to go to get anywhere near the level of developed countries. But China has the potential to make a significant contribution to the knowledge about our universe.

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