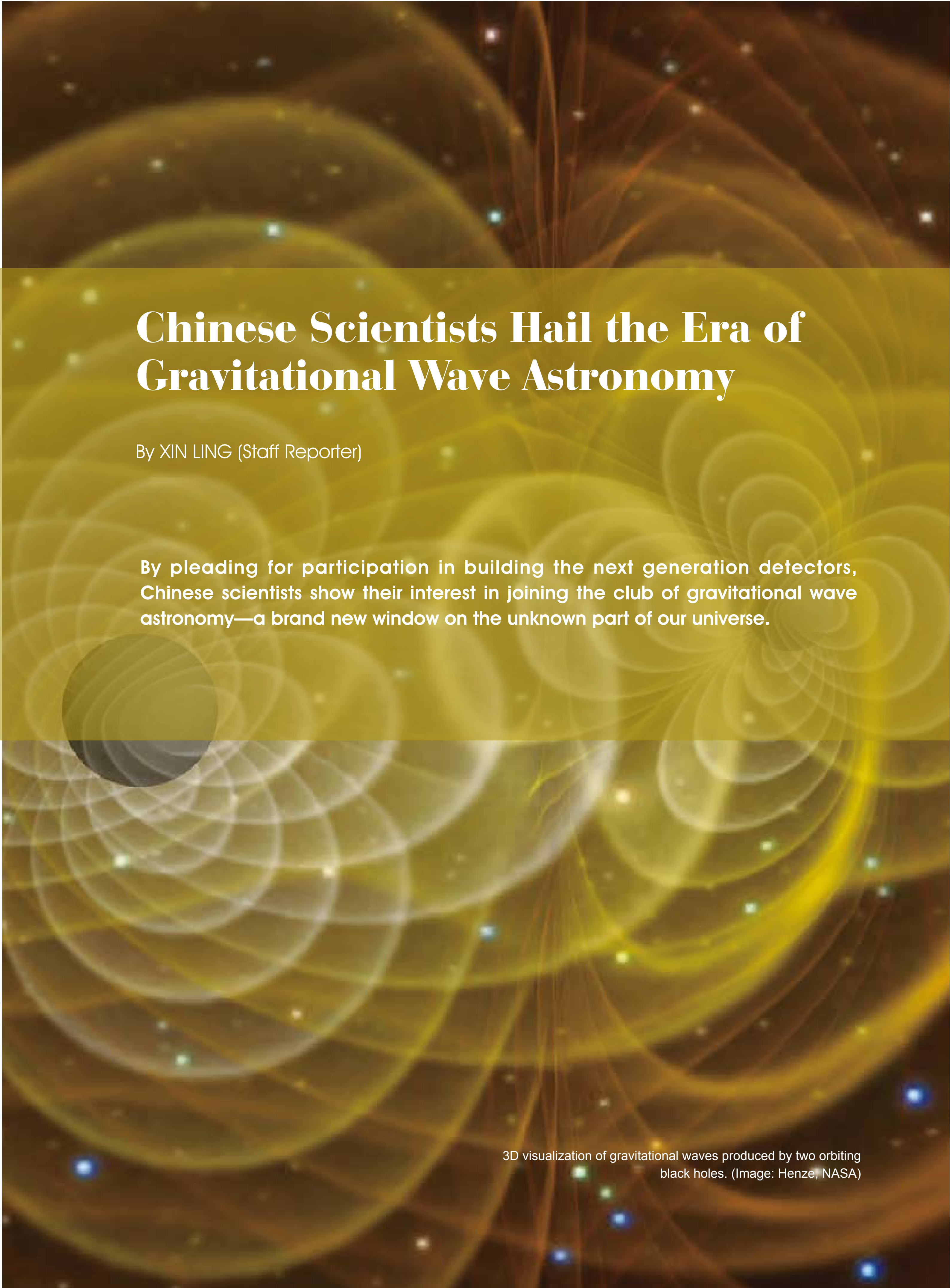
Chinese Scientists Hail the Era of Gravitational Wave Astronomy

By XIN LING (Staff Reporter)

By pleading for participation in building the next generation detectors, Chinese scientists show their interest in joining the club of gravitational wave astronomy—a brand new window on the unknown part of our universe.



3D visualization of gravitational waves produced by two orbiting black holes. (Image: Henze, NASA)

When young physicist David Blair started his postdoctoral research at Stanford University in the spring of 1973, he noticed some signs on the wall of the corridor. "GRD for Christmas", the signs read. GRD means gravitational radiation detection. "That must be the goal of our project," he said to himself, "to make the detector work and detect gravitational waves in ten months' time." He did not talk to anyone about it, and worked extremely hard. As it came towards November, he was getting so tired from work that he went to his boss, saying: "I know we are supposed to be detecting gravitational waves for Christmas, but can I have a week's holiday?" His boss replied, "Oh sure, but don't worry about those signs. They have been there since last year!"

This April, when the story was retold by Blair, now a white-bearded professor, to a room full of students and researchers from around the world who gathered here at the Kavli Institute of Theoretical Physics, Chinese Academy of Sciences (CAS) in Beijing for a workshop on gravitational wave astronomy, he could not help but burst into laughter with his audience. "I just couldn't believe that forty years later, we are still looking everywhere for those waves," there was plenty of self-mockery in his voice.

Empty-handed as scientists like Blair are after decades of untiring hunt, they now have every reason to believe that success is just in sight. Great news brought to Beijing by David Reitze, Blair's colleague and friend who is now leading the Laser Interferometer Gravitational-Wave Observatory (LIGO) in the U.S.: the world's largest detecting facility has just completed a major upgrade and is ready to try out its immense power. Ten times more sensitive than its previous version, the so-called Advanced LIGO will very likely catch one of those mysterious waves before the decade is out.

Coming into the spotlight at the workshop are not only the existing projects like LIGO, but also China's role to play in the future. Although China still does not have a single detector of its own by far, the scientists started long ago thinking about what and how they could do to catch up with the world. Their strategy is to join hands with foreign colleagues to build the next generation detectors. With China's ever growing ambition in fundamental research, its part in the upcoming gravitational wave astronomy era will be anything but an onlooker.

"Darkness before Dawn"

Often described as "cosmic ripples", gravitational waves are generated by accelerating masses that bend space-time. They propagate at the speed of light, carry energy, and are supposed to be ubiquitous. However, in reality, they are almost nowhere to find because they are inconceivably weak. Only those originating from the most violent phenomena in the universe are possible to catch: like the coalescence of super massive black holes, black hole mergers, the birth and interaction of binary neutron stars, or the Big Bang itself. That's why gravitational waves were envisaged by Albert Einstein a century ago but remain one of his few untested, key predictions to date.

These waves not only convey direct information about the motion of the massive celestial bodies—how they move, twirl, and collide, but may make a powerful tool to examine dark matter, dark energy and even cosmic formation. Once they are observed, the significance goes far beyond the verification of Einstein's theory itself. It will open a completely new window on the part of the universe that electromagnetic waves will never enable us to see.

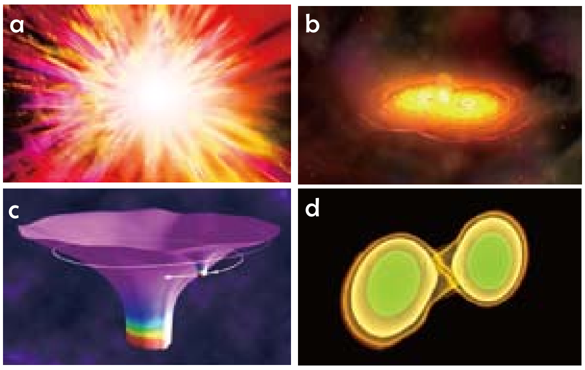
The detection of gravitational waves calls for a facility so sensitive that it could detect a change in distance between the Earth and the Sun smaller than the size of an atom. The first detectors scientists ever built were bulky, cooled metal bars that never really got close to any detection but blazed a trail for their dogged followers. The second and current generation of technology is called interferometers. They use the minuscule phase shift of laser light that move back and forth between hanging mirrors to sense gravitational waves, while ruling out all kinds of disturbing factors including seismic noises, radiation pressure and thermal noises.

As an all-time flagship project sponsored by the National Science Foundation, LIGO consists of twin interferometer observatories, one located in Livingston, Louisiana and the other in Hanford, Washington which use L-shaped ultra high vacuum systems with 4km long arms to directly detect gravitational waves. With efforts led by generations of scientists from Caltech and MIT, LIGO had finished its technology upgrade by March 2015, and the entire international scientific community is waiting anxiously to witness it deliver a milestone discovery in history.

The world is finally on the verge of catching a wave, Reitze said. Advanced LIGO, which was a complete rebuild of Initial LIGO except for its vacuum system, will be operational in September, and run for three months before it is shut down to be tuned toward designed sensitivity. Its sensitivity is tenfold that of Initial LIGO, meaning the possibility of catching a wave expands by 1,000 times in space.

The source from which they are most likely to receive gravitational waves is a binary neutron star coalescence, Reitze predicted. And once operating at designed sensitivity, Advanced LIGO would theoretically be able to see around ten such events each year. “I’m an optimist. If the universe is kind, we could see gravitational waves in two to three years,” Reitze claimed.

Blair agreed that the detection is probably three years away “or less”. Compared with years ago when people built detectors just to “hope for the waves to come”, today, there is a clear prediction of the signals: how many are out there, and what sensitivity the devices have to have. “We are about in a situation of the Large Hadron Collider, which had had a clear prediction to detect the Higgs boson before it really did,” he noted.



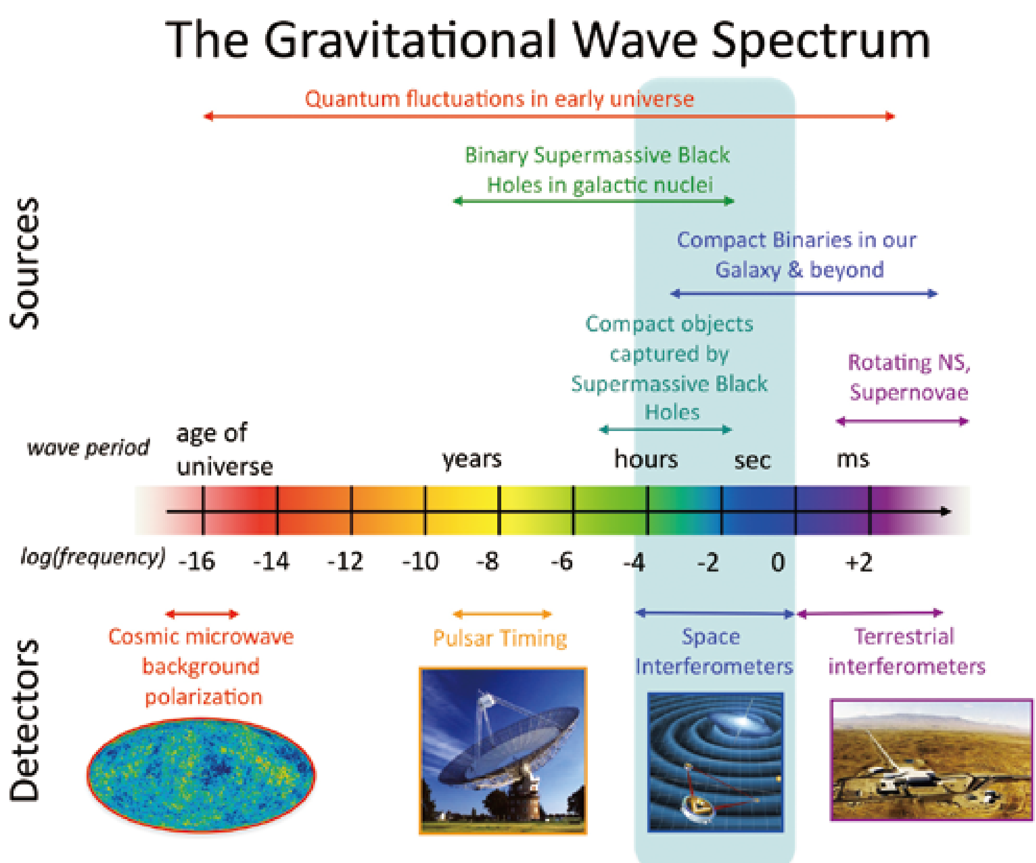
Various sources of gravitational waves: (a) the Big Bang; (b) supermassive black hole coalescence; (c) black holes feeding on smaller objects; (d) merging pairs of neutron stars.

A Ground-based Detector for China? A China-Australia Joint Proposal

Strictly speaking, China is not a latecomer in gravitational wave detection. Domestic study started in the late 1970s, a decade after Joseph Weber invented the first copper bar detector at the University of Maryland, College Park. A group at Sun Yat-sen University in Guangzhou was actively developing similar devices, but then their leading scientist died from a laboratory accident and the research just petered out.

“China lagged behind when the world began to develop interferometers,” observed ZHU Zonghong, dean of the astronomy department of Beijing Normal University and a co-organizer of the workshop.

For many years, Australian and Chinese scientists have been working together on gravitational waves through joint conferences, student exchanges and postgraduate training. This time, the five-week workshop offered them a wonderful chance to discuss about future collaboration,



The gravitational wave spectrum, sources and detectors. (Credit: NASA)

David Blair is a forerunner of Australia-China cooperation in gravitational wave research.

especially in the field of experimental research.

And their dream is big.

"We are exploring the possibility of building a pair of ground-based detectors, one in China and one in Australia, which could see three times further into the space than Advanced LIGO," revealed Blair, who is from West Australian University and a forerunner of Australia-China cooperation in the field.

According to him, there are many ways to improve the sensitivity of a detector: making longer "arms", using better optical and control technologies and so on. For instance, they are looking into a new technique called "optical squeezing" which can change the property of light and is pioneered by a group of researchers from the CAS Institute of Physics. They are also considering replacing amorphous coating layers with pure crystal coating for detector mirrors to reduce unwanted vibration, a technology under development in several institutions across the world including the CAS Institute of Semiconductors.

The detectors may cost "a few hundred million dollars" and take "six to ten years" to build if approved, Blair told *BCAS*.

ZHU, however, seemed to hold reservations about the twin detector blueprint. "As for building ground-based detectors, I think China has a positive lesson to learn from its neighbor Japan. Japan started out 20 years ago from a 10-meter small detector, and then they built a 300m one to catch up with the world. Now they are pioneering with KAGRA and quasi third-generation technology. This step-by-step mode will help China accumulate talents and key technologies before it achieves something big."

Yun-Kau Lau from the CAS Institute of Mathematics doubted the need for a ground-based detector in China at all. "Australia has good reasons to own a big detector given its geographical uniqueness in the southern hemisphere. But I don't see why China really needs one." An efficient way, as he suggested, might be Asian-Pacific countries including China, Korea and Australia jointly develop related technologies and co-build a detector in the southern hemisphere.

Space-borne Detection? European Space Agency Lures China to Be a Part

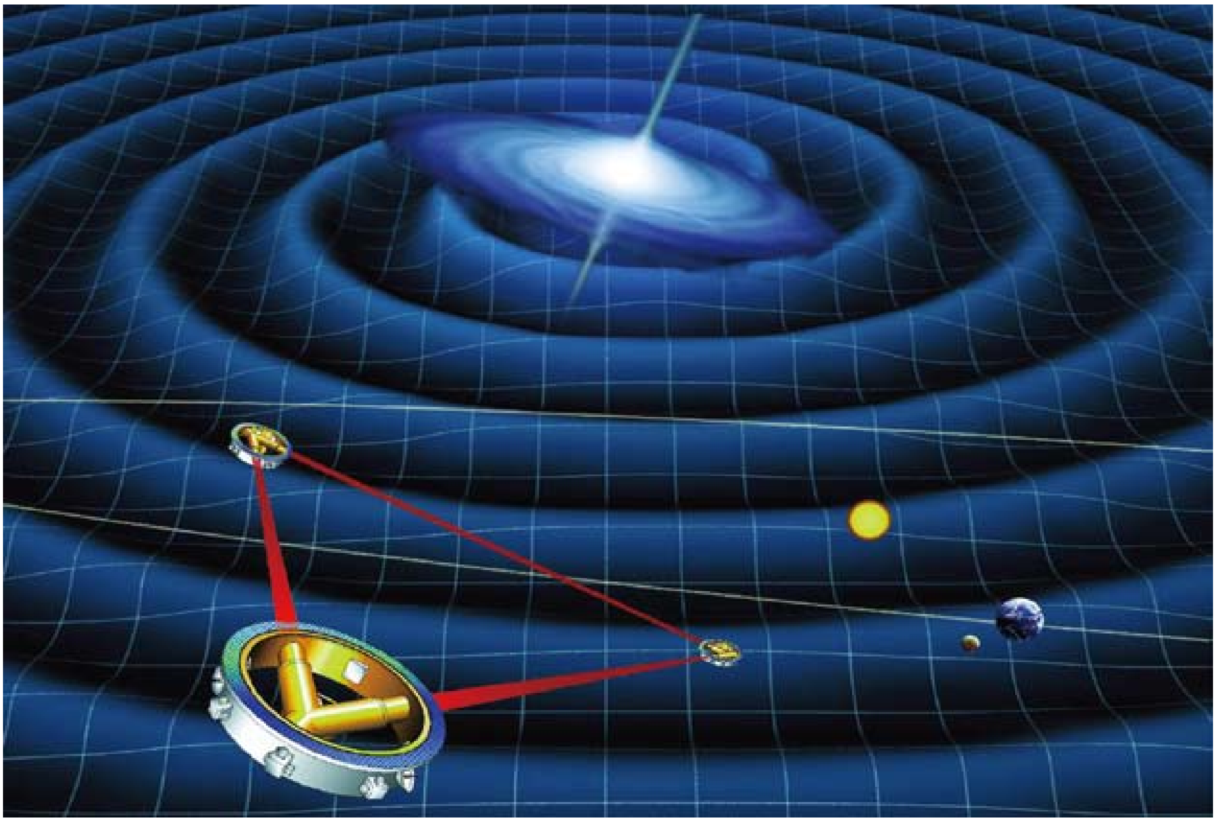
The Laser Interferometer Space Antenna (LISA) mission was proposed by the European Space Agency (ESA) in the late 1970s to detect gravitational waves from space. According to its original design, LISA comprises a constellation of three spacecraft, which are arranged in an equilateral triangle, each arm being five million kilometers long. With lasers from each spacecraft to each other spacecraft forming two independent interferometers, LISA will travel along a solar orbit trailing the Earth, measure differential changes in the length of the arms, and sense gravitational waves that are produced by compact binary systems or supermassive black hole mergers.

"Space-borne detection is like putting the detector in an excellent vacuum. As it is free of earthly noises, the measurement accuracy can be improved by at least four orders of magnitude," said HU Wenrui, founding director of the National Microgravity Laboratory at the CAS Institute of Mechanics, who has been a firm advocate for space-based gravitational wave detection in China.

Widely seen as a landmark project in fundamental physics, LISA went through a major change in 2011 when one of its two initial partners, the United States space agency NASA who had promised to share half of the two-billion budget, decided to back out. Since then, the project has been revised and scaled down to what is now known as the Evolved LISA (eLISA).

Then about three years ago, some chief scientists from ESA visited HU's office in Beijing. They wondered if China was interested in getting involved in eLISA. "A great chance and a great challenge", HU thought.

Fortunately, CAS leadership and the China National Space Administration showed strong support to the idea. The next step is for Chinese and European scientists to draft a joint recommendation letter, hand it in to respective agencies, and kick off official negotiations as soon as



The original design of LISA. Three spacecraft will be placed in orbits to form a triangular formation with center 20° behind the Earth and side length five million km (the figure is not to scale). (Credit: NASA)

possibleaccording to HU.

China, who may contribute instruments up to 20% worth of the total eLISA investment, is actively preparing itself for major technical challenges. For instance, it is now developing a satellite for gravity field measurement, and the devices to be equipped on this satellite are very similar to those for eLISA.

"eLISA is going to be the most advanced satellite China has ever participated in building. Its tentative launch time is 2034, so we still have time," HU said.

While there is no question about the scientific significance of eLISA, its technology can be really demanding. In space, just like on the Earth, there will always be a battle against noises: solar radiation pressure, noises from the spacecraft themselves, etc. For China, the engineering aspect could be a pitfall, Lau warned.

As for which instruments China might be contributing, Lau's answer was "not a whole lot". One possibility is the optical telescope.

Lau also expressed his concern for China's future in the eLISA project. NASA is likely to return if LISA Pathfinder—the European probe to test key technologies for eLISA which is scheduled for launch this coming November—turns out to be a success. "It's going to be complicated, you know," he hinted. "So about eLISA… we have a good start, but there is a long way to go."

China's BICEP Experiment? Tracing Primordial Waves from the Third Pole

Besides direct detection, there is also an indirect way to prove the existence of gravitational waves, by looking at how they impacted the behavior of particles like photons right after the Big Bang, which dramatically heated up and expanded the universe from no more than a few centimeters to over 80 billion light years, leaving radiation everywhere during the cooling process.

Comparing the effect of gravitational waves on photons to that of sea waves on ships, ZHANG Xinmin from the CAS Institute of High Energy Physics depicted the simple rationale of looking for primordial gravitational waves from cosmic microwave background (CMB). "When sea waves arrive, the ships not only bump up and down, but they also pitch and spin," he said. Similarly, by measuring the polarization of CMB, there is a good chance to interpret the

Ali Observatory in western Tibet is operated by the National Astronomical Observatories, Chinese Academy of Sciences. (Credit: NAOC)

earliest gravity propagation which contributed to making the universe the way it looks today.

This simple notion becomes very complicated when it comes to technical realization, because earthly bound, the signals are extremely feeble while unwanted noises too strong. Although scientists have remarkably increased the number and sensitivity of ground-based detectors over the past two decades, in 2014, the reported detection of primordial waves by the Background Imaging of Cosmic Extragalactic Polarization (BICEP)-II experiment in Antarctica turned out to be unreliable due to the trick of cosmic dust.

Inspired by BICEP, however, ZHANG is actively pushing forward a similar experiment in China with his former student and now collaborator SU Meng from the Harvard-Smithsonian Center for Astrophysics. "The necessity to see the northern half of the sky puts us in a good position to weigh in," he said with excitement.

And Ali Plateau in southwestern Tibet will be an ideal site, he told *BCAS*. At 5,100 meters above sea level, Ali is naturally endowed with high altitude, stable air and dry weather, which is vital for astronomical observation and CMB observation. The relatively developed local infrastructure including a well constructed airport, transmission lines and highways is "a big plus", SU added.

"Our goal is to grow Ali into an international collaboration like the Daya Bay neutrino experiment, where China plays a leading role," ZHANG was ambitious. By far, he has successfully connected with leading scientists from Harvard University, University of Chicago and Taiwan. Canada and Europe may join later, too. Meanwhile, many domestic institutions will be involved, including the National Astronomical Observatories, the CAS Purple Mountain Observatory and Southwest University.

Once the idea gets the green light from the Chinese government, China will provide scientific design and US partners will install their telescopes with the state-of-the-art microwave technologies in Tibet.

The project features great scientific significance as well as achievability, said ZHANG and SU. For instance, it is not going to be as expensive as the other proposed detectors, with a budget of only eight million US dollars (50 million yuan), and hopefully research results will come out within five years' time.

ZHANG insisted that time has finally come for China to get its own data and have its say on gravitational wave research.

"At least this is a chance for us to 'make mistakes' (like BICEP-II), which otherwise we would never be able to do."

Challenges vs. Dreams

In her award-winning book Einstein's Unfinished Symphony, Marcia Bartusiak envisioned a fascinating landscape for astronomers and physicists alike brought forth by gravitational wave astronomy. "I figured that the era had passed when a science writer could chronicle the advent of an entirely new astronomy, where the heavens were a blank slate ready to be filled in. But gravity wave astronomy, I came to realize, now offered me that opportunity," she wrote.

Just as former LIGO director Barry Barish put it, Advanced LIGO will be "the beginning, not the end, of the story". For China, the game has just begun, too.

When the Five-hundred-meter Aperture Spherical Telescope (FAST) is completed in the southwest China in 2016, it will become the country's first facility to directly detect gravitational waves, by means of pulsar timing. But for a detector dedicated to gravitational wave study which need to be developed from scratch, it probably won't be operational until 2025 or 2030.

According to Barish, China has been making a very conscious effort in recent years, and once gravitational waves are detected, the Chinese will be very well positioned to build the next detectors and work in gravitational wave astronomy.

But it does not come for free, he said. If China starts to develop its own smaller scale interferometer and encourage more international collaborations, it could be prepared to do something very soon.

Before everything, China needs to train hundreds of scientists and engineers who can work on the state-of-the-art technologies that are involved in building such detectors. "Accumulating experience and expertise always takes time, and it's not just a problem of money", reminded Michel Boer, an astrophysicist from CNRS and co-investigator of the China-France Space Variable Objects Monitor (SVOM) project, which is designed to detect gamma ray bursts and gravitational waves.

"The most important thing now is to cultivate a critical mass of talents and an efficient system in China," Lau echoed. The fact is, from the LAMOST telescope to FAST and SKA, the Chinese astronomical circle has been struggling with talent shortage for quite a few years.

The judgment and confidence of the domestic scientific community is important, too. "Sometimes I'm saddened by the thought that China may not really get down to gravitational waves until Westerners detect them, just like many other scientific opportunities we have missed," ZHU mourned. He insisted that gravitational wave astronomy will be one of the most frontier disciplines in science that's worth pursuing, and the earlier it gets started, the better.

At present, ZHU is actively preparing for the opening of a Gravitational Wave and Cosmology Lab at his department, which will probably become the first lab in China dedicated to the study of gravitational waves. It will feature internationalized and interdisciplinary talents from astronomy, physics, mathematics and information technology, and focus on data analysis and the pre-research of key technologies needed to build medium-sized detectors.

"China could be a world leader in gravitational wave physics. You've got to dream big. You've got to go for it," Reitze urged.