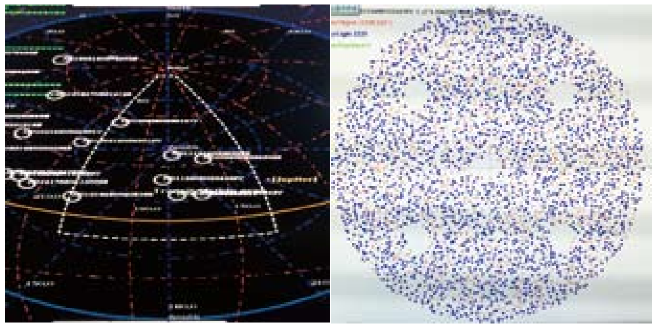
Against All Odds

Unfavorable weather conditions, poor seeing, change in science missions — despite these adversities, LAMOST people persevere and innovate, while unfolding a new chapter of Galactic astronomy.

By XIN Ling (Staff Reporter)



It was early May in the Yanshan mountains 160 kilometers northeast of Beijing, when night began to fall upon the Xinglong Observation Station. As usual, SHI Jianrong closed his curtain, grabbed his flashlight, and hurried out of the dorm. Under a full moon, the hills were resting in tranquil beauty; not far away, the town of Xinglong was glowing in flickering lights. He looked up at the sky: the forecast just warned a huge cloud was approaching from the west. He frowned.

It took him less than two minutes to nimbly cross the woods and get to the office building, which was dwarfed by the ten-story-high Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) standing next to it in mysterious majesty. Trotting up to the second floor, he opened the door of the control room. It was bright and busy inside: his colleagues from the National Astronomical Observatories were making final preparations for tonight's observation.

On the big screen it read: temperature 14.6°C, humidity 12.1%, maximum speed of wind 6.7m/s. The sky was clear, and it seemed a nice night to shoot the stars, except for one fact — the moon was shining. By lighting up the sky, it blunted LAMOST's sharpness to see fainter objects.

Observation began around eight, after SHI picked a relatively luminous target area for his team to start with. To acquire high-quality spectra, the light must be collected and transferred all the way down the pipeline with minimum loss and maximum precision. LAMOST was born for such missions: with unique technologies, its reflecting mirror can deform continuously to track the motion of celestial bodies, while up to 4,000 optical fibers are designed to position themselves quickly and accurately according to the locations of stars.

Everyone in the control room was a good hand on the assembly line of the LAMOST spectrum factory. First, they sent instructions to the system for a preliminary positioning of the optical fibers. Then the two mirrors, both of which are segmented, automatically adjusted themselves to function integrally and straighten the light paths. Then, a central star and four guiding stars were used to pinpoint the final positions of the fibers. With all this done, the CCD cameras connected to the spectrographs would click three times, and the spectra of thousands of stars just came fresh out of the oven.

"Exposure completed." With a familiar voice prompt echoing across the room, SHI sighed with some relief. One and a half hours' work yielded more than 1,200 spectra — not record-breaking but still uplifting for Xinglong's May, a time when frequent wind, sandstorm and rain will halt the telescope anytime.

Actually, those spectra were their only prize of the night. The cloud arrived as expected, blocked LAMOST's sight and would not leave. Waiting in vain for it to disperse, SHI dismissed his men and called it a day at 1 am.

Speaking of weather, not many people would see

Xinglong as a paradise for stargazing.

"The Xinglong station is located in an area which is not blessed with large numbers of perfectly clear nights," said Timothy Beers, an astrophysicist from the University of Notre Dame, U.S. "The local weather is not consistently good. As a result, only a portion of the available time for observing can be used. At other times, there are just too many clouds to work through."

When LAMOST was completed, scientists were expecting some 250 clear nights per year. But "with worsening air pollution and light pollution, the number has dropped to 150," SHI lamented.

For astronomical observation, a business which more or less runs at the mercy of weather gods, site selection seems vital. For instance, the Sloan Digital Sky Survey (SDSS) telescope, LAMOST's predecessor in large-scale sky survey, sits at the Apache Point Observatory in southwestern U.S. with 65% clear nights; not to mention those first-rate sites which have 75-80% of their nights clear, like some places in Chile and Hawaii.

"Winter is the best season for us," said WU Yuzhong, SHI's coworker. On a lucky winter night, they can do as many as ten sky areas by working 13 hours nonstop. However, starting from April, the observing conditions deteriorate dramatically. "Take this year for example. For February, our total observation time was like 200 hours, but for April it was less than 60."

To make things worse, LAMOST is now turning to darker skies which basically require longer exposure duration. "The time needed for each exposure can triple from 10 to 30 minutes", SHI noted. It means that the number of skies to be observed may reduce considerably.

Five million spectra is the goal LAMOST people set for themselves for the first five years of survey (2012-17). Thanks to technical innovations and their diligence, this goal had been almost secured by the summer of 2015, which is two years ahead of schedule. That is to say, if LAMOST is able to maintain its annual productivity of 1.1 million spectra, then towards the end of 2017, it will contribute to the world more than seven million spectra of stars in the Milky Way. It is a feat to be achieved nowhere else on Earth — by setting up an unprecedentedly large database, it will greatly enhance our understanding of the formation and evolvement of the Milky Way.

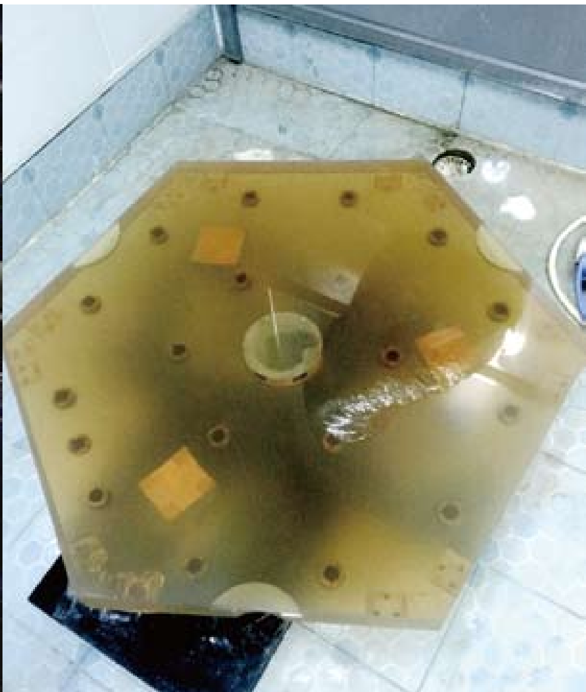
The clouds, however, is not the only reason to have plagued LAMOST with poor seeing right after it was constructed.

For instance, scientists found that the temperature gap in and out of the body tube was another important factor. "A slightest airflow spreads out and dims the light," said ZHAO Yongheng, chief scientist of the LAMOST project. So they installed an overall cooling system to make sure that during the day, the in-tube temperature is maintained at the exact outdoor temperature at which LAMOST starts to work that night.

It is not uncommon for the temperature to drop below minus 20 degrees in Xinglong during winter. Commissioning all day long in a fridge-like telescope, the engineers had to do a lot of push-ups to stay unfrozen. "Those were our hardest days," recalled ZHANG Yong and LI Yeping from the Nanjing Institute of Astronomical Optics and Technology, who have been engaged in the building and maintenance of LAMOST for over a decade.

Besides a constant effort to improve seeing, ZHANG's group has another ongoing challenge to address: the disassembling and assembling of mirrors for their annual recoating.

"Each segment of the primary mirror is 150 kilograms heavy and worth over a million yuan. Their



safety is my top priority," ZHANG said. "We can't afford any mistakes to happen."

This year, both the primary mirror and the correcting mirror, which together involve 61 pieces of 1.1m-wide hexagonal sub-mirrors, need to go through the recoating process. And to minimize the impact on observation, the pace is kept at one sub-mirror per day, which is very time consuming.

Recoating enhances the mirrors' reflecting power and the overall performance of the telescope, according to LI Fengyun, head of the coating lab who has been working at the Xinglong station for more than thirty years. "For LAMOST, the reduction of reflectivity is not too bad, only around 2-3% each year," she revealed. "But we take every opportunity to improve efficiency."

From decoating each sub-mirror to coating it first with a 300nm-thick aluminum film and then with a 15nm protection film, LI handles her work with great caution and expertise. In 2013, her team set a record by finishing recoating all 61 sub-mirrors within seven weeks' time.

LI is also responsible for cleaning the fiber surfaces, 4,000 of them in all which are densely dotted over the 1.75m-wide focal surface, to ensure the light pathways are not blocked by dust. Examining the fibers one by one with a microscope, she will clear up those with "more than ten specks of dust" using cotton buds soaked with certain alcohol/ether mixture. "From recoating to fiber cleaning, dust is my biggest enemy," she said.

Thanks to all these efforts, after three years of operation, LAMOST is now running at its design performance, ready to nourish more and better science coming along the way.

When it comes to science, the seemingly unlucky debut of LAMOST turned out to be a blessing in disguise.

LAMOST was originally designed for extragalactic survey and cosmological studies, above all of its other scientific goals. However, before its pilot survey kicked off in 2011, the SDSS project had already completed a ten-year observation of over a million galaxies beyond the Milky Way. This made LAMOST a late-comer in the field with nothing much to do. Haunted by the seeing problem at the same time, it almost fell into a dilemma.

At some point, Chinese scientists decided to re-anchor LAMOST to Galactic exploration, the second but more practical option on its science list.

And Galactic survey was very difficult before LAMOST. Simply the number of stars in the Milky Way — 200 billion of them in all — would overwhelm the most productive telescopes at that time. When LAMOST weighed in with a 4m aperture and 4,000 optical fibers, it greatly advanced observation efficiency and made statistically-significant sampling of the Galaxy possible for the first time in history.

"Getting a big and uniform sample is the key to Galactic study. For a huge stellar community like the Galaxy, the more spectra we obtain, the better," said FU Jianning, a stellar physicist from Beijing Normal University.

According to Beers, the full LAMOST Galactic survey is expected to contain 10 million stellar spectra. "This total sample will be about 20 times larger than that obtained by Sloan, and is certain to contain numerous stars of great interest for high-resolution spectroscopic studies with other telescopes. It will also provide key constraints on the kinematics of the recognized stellar populations in the Galaxy, including the thin/thick disk system and the inner/outer halo population," he said.

Using LAMOST data, Chinese researchers have already discovered a number of special stars, such as hypervelocity stars which may indicate the whereabouts of the black hole in the center of our Milky Way, and metal-poor stars that could shed light on the Galactic scenarios after the Big Bang.

While providing domestic astronomers with unrivalled research opportunities, LAMOST is also actively contributing to the world through data sharing and international collaboration. In March 2015, 2.2 million spectra which LAMOST obtained during its first year of survey (2012-13) were released to the world. This number alone has exceeded the entire amount of stellar spectra acquired by all previous surveys combined.

LAMOST was made in China but for the world.

As the most powerful spectrum collector on Earth, LAMOST has proved to be extremely helpful when combined with space-based astronomical missions like NASA's Kepler satellite.

"While providing continuous and high-precision photometry of thousands of stars, Kepler's light-curves themselves do not give information about the physical parameters of its target stars, such as the effective temperature, surface gravity, metallicity and projected rotational velocity, which are fundamental for astrophysics studies," explained FU, who is also co-chair of the LAMOST-Kepler project.

It is almost a mission impossible for traditional telescope systems to observe the 150, 000 Kepler targets, most of which are rather faint, in an efficient way. When a global consortium was launched between 2009 and 2010 using 33 ground-based telescopes in 23 nations to observe the Kepler field, it ended up collecting only the spectra of about 500 stars all together.

LAMOST is exactly what Kepler needs in that respect. When FU first introduced LAMOST to his European coworkers, they were "shocked" to learn about its 4,000 fibers.

So the LAMOST-Kepler project was initiated in 2010. When the first round of survey was concluded in September 2014, LAMOST finished observing the full Kepler sky and reaped 100,000 low-resolution spectra of 80,000 stars.

As FU pointed out, the collaboration between LAMOST and Kepler is highly complementary and mutually beneficial. It has helped LAMOST to check data quality, since its test phase, and confirmed that LAMOST data are quite reliable. As Peter De Cat from the Royal Observatory of Belgium, who chairs the LAMOST-Kepler project, wrote, "our preliminary results has shown that the stellar parameters derived from the LAMOST spectra are in good agreement with those found in the literature based on high-resolution spectroscopy."

With LAMOST-Kepler data, researchers have even detected loopholes in some stellar parameters previously given by Kepler. In particular, the deviation in metallicity measurement is so substantial that it has led them to question the established assumption about how metallicity is related to its likelihood to have one or more planets.

Besides Kepler, the coalition of LAMOST and ESA's Gaia mission, which is scheduled for data release around 2020, is also very promising. "Many of the stars to be observed with LAMOST will have precision distances and proper motions obtained with the Gaia satellite, which, in combination with radial velocities from the LAMOST spectra, will enable measurement of the full space motions of these stars, which is a powerful tool for investigating the assembly history of our Galaxy," Beers predicted.

"I think LAMOST has a very large user community," said LIU Xiaowei, professor at Peking University and one of the first users of LAMOST data. "Anyone who is interested in Galactic study can be its potential user. As a world-class project, LAMOST is very competitive and will continue to be so in the near future. It raised the global awareness of the importance of large-scale sky surveys, and put Galactic study in the forefront of astronomy in the years to come."

Just as LIU pointed out, LAMOST will be a milestone in the history of Chinese astronomy.

By the successful design, construction and operation of such a state-of-the-art telescope, the nation is creating its first astronomical database, feeding its scientists with first-hand data, and cultivating a new generation of optical and observational talents. And to achieve all this, China started "from scratch".

More importantly, LAMOST has built up China's confidence in the field. In the eye of CUI Xiangqun, the telescope's chief engineer, "LAMOST has greatly boosted our morale. It manifested to the world that China has a role to play in astronomy — sometimes even as a pioneer or leader."

LAMOST people are excited to envision their future. One scheme is to move LAMOST, after 2017, to somewhere in the southern hemisphere where observing conditions are much better. "But I think building a twin of LAMOST in the southern hemisphere is more ideal, probably with 6,000 to 8,000 fibers," FU argued. "Meanwhile, there will always be plenty of things for LAMOST to do in Xinglong."

But for the moment, what LAMOST needs is time. "As a basic science, astronomy is not made for any leap-forward kind of research. Instead, it needs time to 'deposit' and 'ferment'," LIU emphasized. With more and more astronomers getting access to LAMOST data, research findings are bound to mushroom.

"The last thing I would worry about is LAMOST's research productivity," ZHAO was confident. Thanks to the support of major funding agencies like the Ministry of Science and Technology, the National Natural Science Foundation of China and the Chinese Academy of Sciences, LAMOST scientists will hopefully not have to worry about their grants in a few years ahead.

Above all, China should first celebrate the realization of such a telescope, they say. "Xinglong may not be the most favorable observing site in China," CUI confessed. "But I'm very grateful that the government finally decided to fund us, and that we managed to build it up at a low cost and high efficiency."

"Like many other telescopes in the world, LAMOST was not born perfect," FU echoed. "But over the years, it has made enormous progresses to improve its seeing and fiber positioning accuracy. LAMOST makes not only an engineering legend, but a future success story of a new Galactic astronomy in the big data era."

As CUI put it, "If we were picky and stubborn about the site back then, LAMOST is probably still a design on paper today, and our technologies and talent team still where they were fifteen years ago. Therefore, I would say, with the existence of LAMOST came all our possibilities."