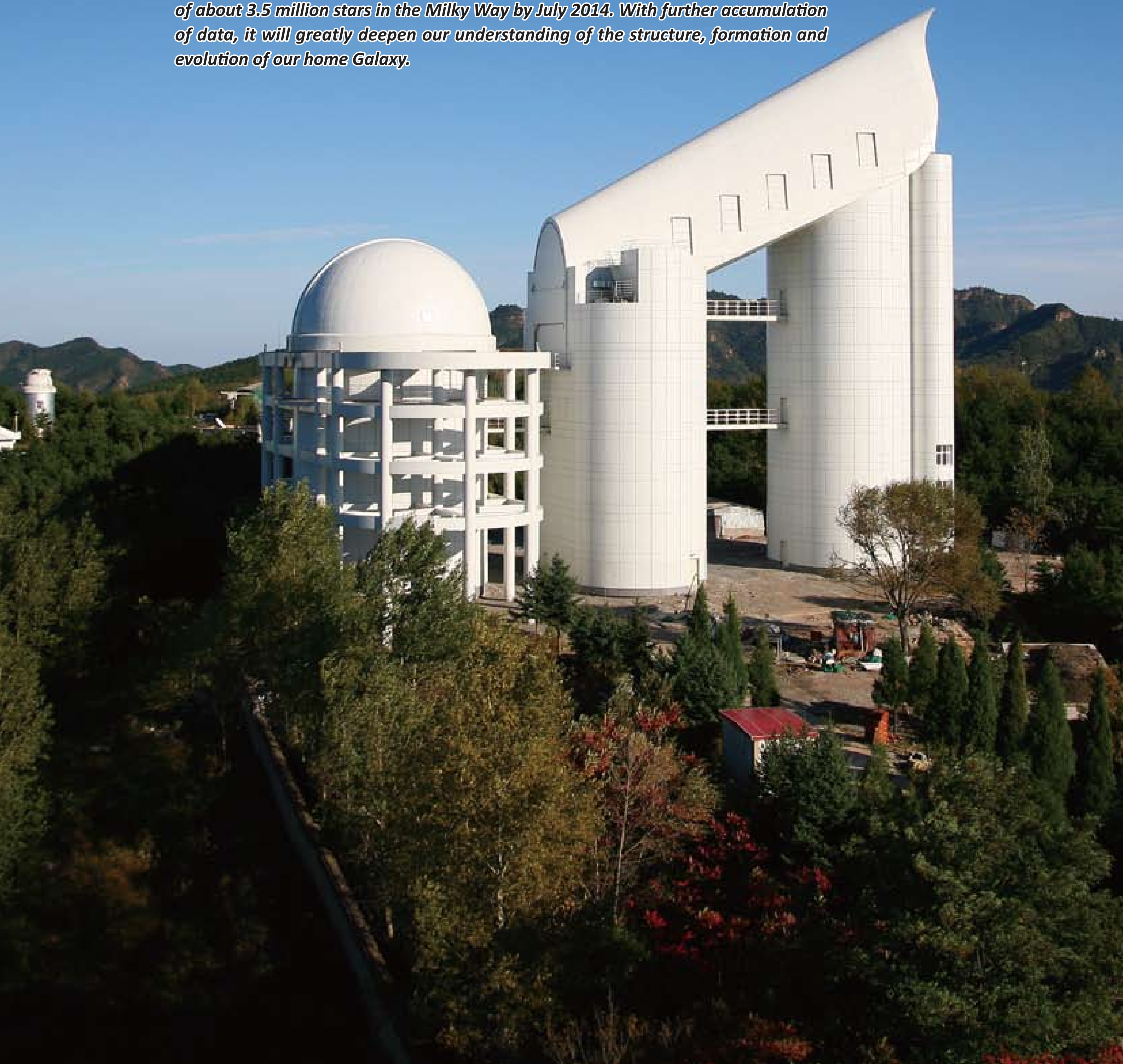
# China's Spectrum Factory Gathers Momentum

By XIN Ling (Staff Reporter)

***Only one year of pilot survey followed by two years of spectroscopic survey, LAMOST — China's first world-class telescope — had already acquired the spectra of about 3.5 million stars in the Milky Way by July 2014. With further accumulation of data, it will greatly deepen our understanding of the structure, formation and evolution of our home Galaxy.***



"My biggest wish is to see LAMOST get more and better spectra", ZHAO Yongheng told many people when the telescope was officially put into operation in September 2012.

LAMOST, or the Large Sky Area Multi-Object Fiber Spectroscopic Telescope, is a 4 m aperture, 5 degree field of view and 4,000 optical fiber telescope developed by China for Galactic and extragalactic surveys. As an astrophysicist and veteran of the LAMOST group, Zhao was as excited as his fellows who had devoted over a decade to the making of their brainchild. However, now that he was appointed executive deputy director of the LAMOST Operation and Development Center, he could not help feeling some pressure on top of that excitement. For all its out-of-this-world design and technique, will LAMOST finally present the best performance to the long-awaiting audience?

Since then, Zhao and his coworkers at the National Astronomical Observatories in Beijing and the Xinglong Observing Station, where LAMOST is located, have been working closely to make their wish come true. Every morning, a daily observation plan is sent from Beijing to Xinglong. When night falls, LAMOST opens its eye to carry out the plan. Each spectrum collected is automatically broken down by software into raw data. The next dawn, these raw data will be transmitted back to Beijing for further processing and creating data products that can be used by astronomers. Such routine operation goes on every clear night from September to the next June, when weather in Xinglong becomes unfavorable for observation. Then engineers will give LAMOST a thorough checkup and put it to rest until the next observing season.

"This is how our spectra factory works," Zhao was obviously proud to be the "factory manager".

Two years have passed, and their efforts paid off. LAMOST's achievement went beyond expectations. By July 2014, it had produced the spectra of up to 3.5 million stars in the Galaxy, much ahead of schedule with its first five-year plan (2012-2017) which aims to collect five million spectra in all.

"The number of spectra obtained by LAMOST is already an order of magnitude larger than previous surveys," said Heidi Newberg, a leading astrophysicist from the Rensselaer Polytechnic Institute at Troy, New York, USA and head of the PLUS ("Participants in LAMOST, US") group.

## Ambitious survey of the Milky Way

Abstract as it may seem, the spectrum is like a star's fingerprint. It tells much about the star's story: its size, temperature, velocity, chemical composition, etc. Such information helps not only to map the structure of a galaxy, but also to find out how the galaxy has formed and evolved.

For the hundreds of billions of stars in the Milky Way, it is difficult for earthly telescopes to catch them one by one, especially those dark and remote ones. Before LAMOST, although there had been several star samplings, none of them was systematically conducted over continuous skies. Now, for the first time, LAMOST is obtaining a large-scale, well-distributed and consistent sample.

"What we are doing with LAMOST is an unprecedently detailed 'census' in the Galaxy. Our sample will be big and fair enough for various researches, from statistical analysis to making new discoveries," Zhao explained.

According to Newberg, the LAMOST survey is significantly more ambitious than the previous Sloan Extension for Galactic Understanding and Exploration (SEGUE), of which she is a founding participant, and the Radial Velocity Experiment (RAVE).

"SEGUE observed 349,000 unique stars sparsely sampled across higher latitudes in the northern hemisphere. RAVE observed 574,630 stellar spectra in the higher latitude region of the southern hemisphere. By comparison, LAMOST has already obtained spectra from more than three million stars in the northern hemisphere, and the area of sky surveyed is largely complementary to both previous surveys," she pointed out.

The LAMOST spectrum factory is not only productive but efficient. According to LUO Ali, Zhao's colleague and head of the Data Processing Division under the LAMOST Operation and Development Center, 60% to 70% of the data are of good quality.

"At the moment, our data are open to all domestic users and their overseas collaborators. In December 2014, about 1.7 million spectra will be released for the first time to the world," Luo revealed.

## Great science in the making

Sharp tools make good work. So far, the analyses of LAMOST spectra have already led to some exciting discoveries. For instance, an international team recently used evidence from LAMOST to unravel a rare hypervelocity star.

"Hypervelocity stars are produced around the supermassive black hole at the center of the Galaxy. They carry information about their birth place, and can be a useful probe to our Milky Way Galaxy on a range of scales," introduced ZHENG Zheng, an associate professor in physics and astronomy from the University of Utah who is the lead author of the study.

Hypervelocity stars are rare, so a large survey like

An astrophysicist-artist's conception of a hypervelocity star speeding away from the visible part of a spiral galaxy like our Milky Way and into the invisible halo of mysterious "dark matter" that surrounds the galaxy's visible portions. University of Utah researcher Zheng Zheng and colleagues in the U.S. and China discovered the closest bright hypervelocity star yet found. (Photo Credit: Ben Bromley, University of Utah)

LAMOST is needed to find them. With the first year's data, Zheng and his colleagues discovered the first hypervelocity star — LAMOST-HVS 1 — from the LAMOST survey. It has a mass about nine times that of the Sun, with a distance of 40,000 light years from the Earth.

"Among all the hypervelocity stars discovered so far, LAMOST-HVS 1 is the nearest and the second brightest, which provides us a good opportunity for followup study to learn about the star better," Zheng said. "And as the LAMOST survey continues, we expect to discover tens of hypervelocity stars of all kinds."

In Germany, a research team led by Norbert Christlieb at the Center for Astronomy, Heidelberg University is using LAMOST data to search for the oldest stars in our Galaxy, in order to understand how the chemical elements have formed during the Big Bang, and in successive generations of stars after that.

"It's still too early to talk about important discoveries, but LAMOST data that we have analyzed have clearly demonstrated that searching for these kinds of stars is very efficient with LAMOST," Christlieb told *BCAS*.

Timothy Beers, who is Notre Dame Chair in Astrophysics from the University of Notre Dame, USA, has been working with LAMOST scientists to refine the selection criteria for stellar targets and develop software pipelines for the determination of stellar parameters.

"The followup spectroscopic analysis of the most interesting stars has only just begun. My expectation is that LAMOST will discover many carbon-enhanced metal-poor stars, which include a subset of the objects that will constrain the nature of the very first stars to be formed in the Universe," Beers predicted.

LIU Xiaowei, a stellar physics expert and acting director of the Kavli Institute for Astronomy and Astrophysics at Peking University, is one of the first to use LAMOST for observation and research after its construction was completed. His research has been focused on galactic formation and evolution.

Since September 2012, Liu's team has been working on the LAMOST Spectroscopic Survey of the Galactic Anti-Center (LSS-GAC) program. As a major component of the LAMOST Experiment for Galactic Understanding and Exploration (LEGUE), LSS-GAC aims at revealing the true multidimensional structure and the formation and evolution history of the Galaxy.

"The formation and evolution of galaxies is a very challenging issue for astrophysicists in the 21st century," Liu said. "Galaxies are the building blocks of the universe. However, our knowledge of the Milky Way is not yet as complete and precise as our knowledge of the universe."

Liu's study won strong support from the Chinese Ministry of Science and Technology. He is now chairing a major project on "Galactic Studies and Multi-waveband Object Identification with the LAMOST", which is a synergy of 30 leading astronomers from domestic universities and research institutions. The budget of the project is 25 million yuan.

Zhao is one of the 30 scientists involved in Liu's project. "From the 320 million yuan worth of telescope to the generous research grants, the Chinese government shows unparalleled support to the development of astronomy in China," commented Zhao. Zhao is also participating in another two top-level research programs based on LAMOST Galactic surveys, one sponsored by the National Natural Science Foundation of China and the other by the Chinese Academy of Sciences, both launched in 2014.


A LAMOST-PLUS Workshop was held in Nanchong, China on May 21-22, 2012 to assess the data obtained during the six months of LAMOST Pilot Survey. Among the participants was Prof. Heidi Newberg (first row, middle), head of the PLUS group.

## Prospects and Challenges

LAMOST's strong debut has filled Zhao with confidence. He estimated that if everything goes on well, by June 2017, LAMOST will at least harvest six million spectra of stars living in the northern hemisphere's sky.

Concerning work after the first five-year observation, Zhao said that new scientific goals depend on more data accumulation, but the focus of the telescope will generally be on Galactic surveys.

Scientists have blueprinted a colorful tomorrow for LAMOST. "LAMOST is a technical platform that needs constant improvement. In five to ten years, it may need more optical fibers to see more efficiently, say 5,000 or 6,000 — this is already under discussion. Another five years ahead, maybe a more advanced spectrograph is necessary. Or maybe we will try to replace the spectrograph with an imager and transform LAMOST into an imaging surveyor," Zhao envisioned.

Teamwork is the key to LAMOST data processing, which is led by Prof. LUO Ali.

Meanwhile, Zhao and his colleagues are also pushing forward the construction of an identical twin of LAMOST in Chile, which will run similar large-scale Galactic surveys into the skies of the southern hemisphere.

As for the handicaps for these exciting plans, Zhao considered funding issues to be much tougher than technical barriers. No matter it's a second LAMOST or a more advanced LAMOST, "the main problem will be money".

In LUO Ali's eyes, the biggest challenge comes from talent drain. Many of his students choose to work for big IT companies after they graduate, and the reason partly rests with "the existing salary and evaluation systems".

Although LAMOST still faces a number of difficulties, as some overseas experts have pointed out, including data calibration, improvement of the seeing and the establishment of a more efficient collaboration mechanism, the telescope carries the expectations of astronomers from around the world. Just as Newberg indicated, when the Sloan Digital Sky Survey (SDSS) began 15 years ago, people had a very simple picture of the structure of the Milky Way's halo. SDSS showed that the halo actually contained considerable substructure. "We seem to be in a similar position today in finding that the Milky Way's disk is far more complicated than the simple one or two components, distributed spatially as a double exponential. LAMOST has the potential to bring us to a better understanding of this structure, of which our Sun is a part."

And as its name indicates, LAMOST was born to make history.