Setting the scene for Gaia and LAMOST
Proceedings IAU Symposium No. 298, 2013
S. Feltzing, G. Zhao, N. A. Walton & P. A. Whitelock, eds.

doi:10.1017/S1743921313006467

LAMOST Experiment on Galactic Understanding and Exploration: An overview

Licai Deng

National Astronomical Observatories, Chinese Academy of Sciences
20A Datun Road, Beijing 100012, China
email: `licai@bao.ac.cn`

Abstract. The LAMOST survey of the Galaxy, otherwise named LEGUE (LAMOST Experiment for Galactic Understanding and Exploration) started in October 2012. In this talk, I will give an overview of the science plan and the current status of the survey.

---

1. Introduction

LAMOST (Large sky Area Multi-Object fiber Spectroscopic Telescope) is a Chinese national scientific research facility, which is also named Guo Shou Jing Telescope (GSJT) to honor the famous ancient Chinese astronomer from the Yuan Dynasty. The detailed optical design and layout can be found in Cui *et al.* (2012). The system had successfully passed commissioning of almost two years, with all the design goals for all components verified by the pilot survey in the 2011–2012 observing season. The pilot survey ended in June 2012, and an early data release (EDR) of LAMOST containing over 640,000 spectra of stars and galaxies has been online for public access since August 2012. The science mission began in October 2012. The survey contains two main parts: the LAMOST Extra-GAlactic Survey (LEGAS), and the LAMOST Experiment for Galactic Understanding and Exploration (LEGUE) survey of the Milky Way stellar structure. Because of the special horizontal reflecting Schmidt design of the optics, the GSJT has a field of view as large as 20 square degrees, and has at the same time a large effective aperture that varies from 3.6 to 4.9 meters in diameter (depending on the direction it is pointing to). The unique design of LAMOST enables the possibility to take 4000 spectra in a single exposure to a limiting magnitude as faint as $r = 19$ at resolution $R = 1800$ (enhanced from $R = 1000$ by implementing 2/3 slit width), which is equivalent to the design aim of $r = 20$ for the resolution R = 500. This telescope therefore has a great potential to efficiently survey a large volume of space for stars and galaxies.

Lots of progress has been made in the past few years in tuning the performance of LAMOST systems, including fiber positioning, dome seeing control, and optical alignments of spectrographs on the hardware side; and calibrations, data pipelines and data archiving on the software side. As demonstrated by two years of technical commissioning and one year of pilot survey, the system is now approaching its design performance. Although under a number of restrictions (discussed below), LAMOST has already been routinely producing useful spectra of objects brighter than $r = 17.5$, and can successfully observe targets as faint as $r = 20$ in the very best cases (and even fainter for emission line objects). A large spectral data set has been collected during the commissioning and the pilot survey. Although limited by survey depth and sky coverage, a number of early science researches based on LAMOST data have been conducted, and most of the results were published in international top level journals. This makes LAMOST and its survey data eventually known in the community. The scientific results from LAMOST commissioning data include a search for metal poor stars (Li *et al.* 2010), the discovery of new quasars (Huo *et al.* 2010; Wu *et al.* 2010a,b) and planetary nebulae (Yuan *et al.* 2010), and mapping of the 2D stellar population pattern of the M31 disk (Zou *et al.* 2011), etc. As presented by a literature survey in Zhao *et al.* (2012, fig. 1), the publications related with LAMOST were mostly technical papers, only a small number of publications (< 10) were directly based on data taken by LAMOST. After the EDR (Luo *et al.* 2012), dozens of papers appear on ADS, among which over 10 papers were published in peer reviewed international journals, in less than one year. The production includes discovery type papers (QSOs: Huo *et al.* 2013, Wu *et al.* 2012; WD: Zhao *et al.* 2013; M-dwarfs: Yi *et al.* 2013 submitted), stellar classification and statistics type papers (WD: Zhang *et al.* 2013), stellar and Galactic properties type papers (RRLyr: Yang *et al.* 2013; ISM: Yuan *et al.* 2013), and Survey data mining technics (Jiang *et al.* 2013; Wei *et al.* 2013). In this meeting, more talks and posters will show the science cases that were made possible by LAMOST data (see the contributions of Liu, Smith, Yuan, and many poster papers in this volume). In this paper, a sketch of the system will be given in order for the community to understand better what has been going on and what will be available from LAMSOT. The instrument and data flow are characterized in the following section.

2. The LAMOST Project Technical Description

The novel design of the LAMOST system has been known to the community through presentations at different conferences in the past years. For the current volume, showing the characteristic of LAMOST will make it convenient for readers to understand the survey better. GSJT provides a combination of a large aperture, large field-of-view telescope feeding a highly-multiplexed spectroscopic system. However, these capabilities also impose some significant observing constraints that must be carefully considered when designing the survey for the Galaxy and the extra-galactic objects. These constraints are outlined below.

2.1. *General layout*

LAMOST is a reflecting Schmidt telescope with its optical axis fixed along the north-south meridian (Su *et al.* 1998; Cui *et al.* 2010). Both the Schmidt plate and the primary mirror are segmented. The Schmidt plate (“Mirror A”) is made of 24 sub-mirrors, and the primary (“Mirror B”) of 37 segments, each of which is in a hexagon shape with 1.1 meters in diagonal dimension. Both mirrors are controlled by active optics. Mirror A is made of thin flat glass that can be deformed to a Schmidt plate surface in real time (Su & Cui 2004).

The focal surface is circular with a diameter of 1.75 meters ($\sim 5°$); 4000 fibers are almost evenly distributed on it. Each of the fibers is driven by 2 motors in 2 degrees of freedom. A Shack-Hartmann system is located in the center of the field of view to enable active mirror deformation. Guiding is provided by 4 guide CCD cameras placed about halfway out from the center of the field; these cameras monitor shifts in the positions of relatively bright stars during the exposures. The guide stars are also used to measure seeing (based on the FWHM of stars on the images) during the exposure for each plate.

The dome for LAMOST has 3 towers aligned in a North-South direction, hosting Mirror A, the focal surface and instruments, and Mirror B, respectively. Mirror A has a transitional dome which can be opened completely. The focal surface and Mirror B towers are connected by a tube structure. The layout of the system and a sketch of the optical path are shown in Fig. 1.

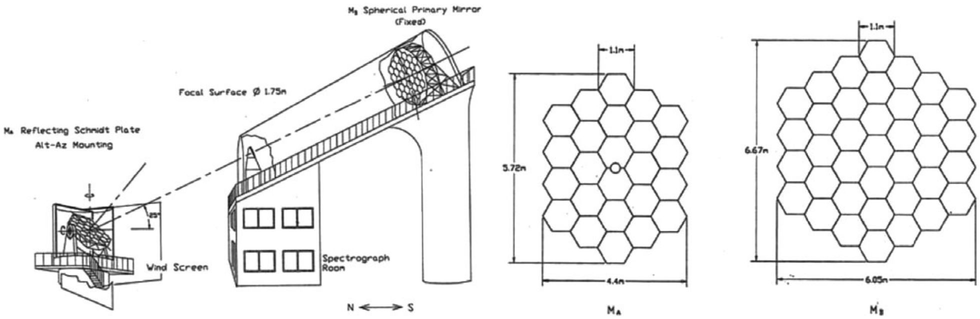

Figure 1. The left panel shows a layout of the LAMOST system and light path. The right panel shows the sketch of the two segmented mirrors, the left one is the Schmidt plate with AO, the right one is the spherical primary. The scales are indicated (courtesy Shou-guan Wang, Ding-qiang Su, Yao-quan Chu, Xiangqun Cui and Ya-nan Wang, in LAMOST documentation archive).

2.2. *Pointing*

The telescope can be pointed in declination from $-10°$ to $90°$. However, for $\delta > 60°$, the effective aperture decreases, thus the limit magnitude of the spectrum becomes shallower. By $\delta = 90°$, 30% of the light in the center of the field is lost and the image quality in the outer parts of the field is degraded such that one might not be able to use the fibers that are more than 1.5 degrees from the center of the focal surface (eliminating 64% of the science fibers). At all declinations, 20% of the light is lost at the edges of the field of view due to vignetting. For this reason, our survey footprint is limited to $\delta < 60°$.

The telescope can be pointed about 2 hours (at $\delta \sim 30°$) in each direction from the meridian, though the exact limits need to be verified by direct observations. Since we typically need 1.5 hours of exposure time for each pointing, there are very strong constraints on the right ascension that can be targeted at any given time. When planning the survey, we must ensure that there are always fields available at each accessible right ascension. It is beneficial to have more targets prepared than finally can be observed in the length of the survey, since we will not be able to plan for the exact number of hours available at each right ascension due to the weather.

2.3. *Weather*

The weather at the site is extremely seasonal. For a detailed discussion of the site conditions, please refer to Yao *et al.* (2012). The weather statistics by day of the year (fig. 1 in Yao *et al.* 2012) were taken from observing logs recorded in the past years from the BATC (Beijing-Arizona-Taipei-Connecticut) multi-color photometric survey experiment, which operates at the same site. The figure shows that observing conditions in June, July, and August will give us very little opportunity to observe at right ascensions between 16h and 22h. The part of the sky for which we will have the greatest number of observations is between 2h and 8h, when the fields near the Galactic anticenter are available.

2.4. *Fiber Spacing*

The fibers used by LAMOST have a scale of 3.3 arcseconds on the focal surface. The spectroscopic fiber centers are about 4.47 arcminutes apart (the dots on the right panel of Fig. 2), and each fiber can be moved a maximum of 3 arcminutes from its central position (Xing *et al.* 1998). The left panel in Fig. 2 illustrates how the fibers are operated. Each fiber is driven by a fiber robot made with two motors, which can place the fiber head to any point within a radius of 17.5 mm, with a forbidden range of 8mm around the mounting position. The right panel in Fig. 2 shows how neighboring fibers can be placed. There are two possibilities to avoid fiber collisions, as demonstrated in the plot. Areas labeled "A" can be reached by two fibers, while regions marked "B" are within reach of three fibers. These conditions actually define the closest pair or trio of targets that can be observed, and place fairly strong constraints on the uniformity of the targets over the field of view. For example, if an open cluster (OC) is $20'$ in diameter, we can place at most about 50 fibers on stars within the cluster's diameter, and those must be fairly uniformly distributed over the cluster area. We can select less than 20 targets in the vicinity of a globular cluster (GC) with tidal radius of $10'$. It will be also difficult to do completely filled surveys of any area of the sky. Many programs might benefit from combining observations to overcome fiber spacing limitations.

2.5. *Wavelength Coverage and Spectral Resolutions*

Sixteen spectrographs are used in the system, each fed with the dispersed light from 250 fibers (Zhu *et al.* 2006; Zhu *et al.* 2010). The "native" resolution of the default LAMOST grating setup is $R \approx 1000$, which yields spectral wavelength coverage of $3700 < \lambda < 9100$ Å. The resolution can be increased by placing a slit of fixed width in front of the fiber heads (e.g., a slit of half the fiber width yields $R \approx 2000$ while retaining the same wave length coverage). The survey will also include an $R = 5000$ mode, which will yield two pieces of the spectra that are 350 Å wide, one in the red and the other in the blue. The blue wavelength coverage is centered around 5300 Å, to sample more metal lines, including the prominent $Mg\ b$ (5175 Å) triplet. The red segment covers the spectral range 8400–8750 Å, sampling the CaII triplet, Fe I, Ti I, and other lines, which are ideal for measuring the radial velocity (RV) and [Fe/H]. This $R = 5000$ mode wavelength coverage and dispersion are similar to that of the RAVE experiment. The $R = 2000$ (half slit width) spectra will be similar in quality to the longer exposure SEGUE spectra, with RVs and metallicities determined to $\sim$7 km s^{-1} and 0.3 dex, respectively. The accuracies in measuring RV and [Fe/H] at $R = 5000$ are expected to be 1 km/s and 0.1 dex, respectively.

In the past few years since acceptance in 2009, LAMOST has tested different resolutions by tuning the slit width, with the goal of having adequate resolution stellar spectra to accurately measure [Fe/H] (and possibly [α/Fe]), without sacrificing too much light by placing a narrow slit in front of the fiber aperture. Considering all the possible science goals of the project, a consensus has been reached in the community to use only a fixed slit width of 2/3 the fiber diameter for the survey when R1000 gratings are mounted. This will give a spectral resolution of $R \approx 1800$ around g band (similar to that of SDSS) instead of 1000 when no slit is used. This result in only about 22% loss of light (compared to 40% when a half width slit is used) will achieve a reasonable resolution. For the high resolution mode when R5000 gratings are used, no slit will be used in order to retain as many of the incoming photons as possible.

2.6. *Observing Constraints*

The LEGUE survey is designed to serve the science objectives, subject to the constraints of the telescope system (Zhao *et al.* 2012). Since the telescope is constrained to operate within 2 hours of the meridian, and a typical exposure set of three 30-min exposures takes about two hours to observe, there is a very small range of right ascension that can be observed at any given time. This fact combining with the weather patterns (see Yao *et al.* 2012) means that the telescope will have very little observing time towards the Galactic center, since the Galactic center is observable only in the summer when it is

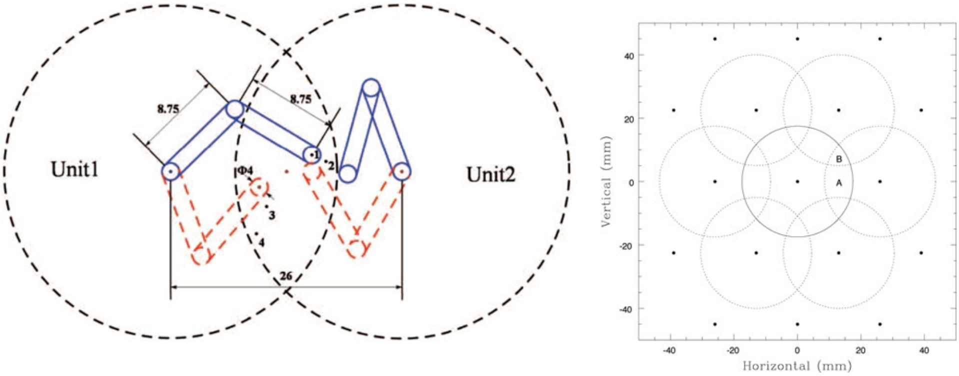

Figure 2. The left panel: A plot showing the minimum separation of two targets on which two fibers can be positioned. The right panel: The distribution of fibers on the focal surface. The distance between any two fiber centers is 26mm (or 4.47 arcmin). There are two kinds of areas where fiber collision may happen, labeled "A" and "B" respectively. These areas actually give the possibility to measure objects in pairs (in "A") or triples (in "B") at a single shot.

almost always too humid to observe. Most of the available clear weather will be when the Galactic anticenter is up in the winter months.

Because Mirror B (the downward facing Schmidt primary) is fixed, the effective collecting area of the telescope and the quality of the point spread function depend on the hour angle and declination of the observations. The largest collecting area and smallest point-spread function (PSF) are when Mirror A (the Schmidt corrector) and Mirror B are nearly aligned at $\delta = -10°$. However, at very low declinations the air mass is huge, so there is high atmospheric extinction and distortion. Thus, considering all factors, the optimal image quality is to be found at around $20° < \delta < 30°$.

At declinations above $\delta = 60°$, the PSF at the edge of the focal plane becomes so large that observations are restricted to a 3° field of view instead of the full 5° field of view. Because the fiber positions are nearly fixed, we lose 64% of the fibers as well as 64% of the field of view. The best observing conditions are expected in a declination range of $10° < \delta < 50°$ and within two hours of the meridian, with the additional constraint that for $10° < \delta < 20°$ the observations are within 1.5 hours of the meridian. Within this range, there will be a reasonable consistency of observations and a PSF that puts most of the light inside the fibers. Outside of this range, the performance is largely unknown, and in many cases could be substantially worse than this recommended operating region.

The fibers are positioned with robotic arms that operate within $3.15'$ of their nominal positions, which are about $4.7'$ apart. The survey targets must be fairly evenly distributed on the sky; at most seven fibers can be placed within any circular sky area with radius of about $3.15'$. If an OC is $20'$ in diameter, we can place at most about 50 fibers on stars within the cluster's diameter, and those must be fairly uniformly distributed over the cluster area. We can select fewer than 20 targets in the vicinity of a GC with tidal radius of $10'$. In addition to limiting our ability to sample stars in clusters, the uniformity constraints of the fiber positioning system make it difficult to do completely filled surveys of any area of the sky.

2.7. *A brief description of the data reduction procedure*

LAMOST data are processed by data pipelines written specifically for the LAMOST Spectral Survey (Zhao 2000). The data flow in the software chain is outlined here: raw data after observations will be transferred from the site to the data center at NAOC through a dedicated fiber connection on a daily basis. A cluster of 16 multi-processor workstations is used for 2D and 1D reduction pipelines. Tests during commissioning time have shown that the computing power is sufficient for the workload.

The LAMOST 2D pipeline follows the regular steps of the SDSS spectro2d pipeline (Stoughton *et al.* 2002), but is different in many details. Twilight flat-fields taken each observing day are used to get the trace of each fiber spectrum. All the spectra from the same night are extracted using the same trace function, minor shifts are made to align individual frames, and then the spectra are flat-field corrected. Hg/Cd and Ne/Ar arc lamp spectra are extracted to determine the dispersion function of each fiber, with strong sky emission lines also included to further fix the wavelength solution. About 20 sky fibers are allocated in each (250-fiber) spectrograph. After wavelength calibration, spectra from these sky fibers are combined into one super-sky spectrum. The super sky spectrum is scaled to best fit the sky spectrum in each fiber, then this scaled sky spectrum is subtracted from each fiber. Five F-type subdwarfs are observed in each spectrograph to provide flux calibration. Flux corrected spectra from different exposures taken on the same night are combined to improve the signal to noise ratio. The whole processing CPU time for one observation (three 30-min exposures for all 4000 fibers) from tracing to flux calibration takes about 90 minutes.

The 1D pipeline is similar to the SDSS SpecBS pipeline (Aihara *et al.* 2011). The extracted spectra are first classified into 3 different categories (i.e., stars, galaxies, and QSOs) by a comparison of the observed spectra with templates. The RV and redshift are then calculated. After that, each object in each category is further processed to determine the spectral subclass. Galaxies are classified into subclasses AGN, STAR_FORMING, STARBURST, BROADLINE and Normal, then the velocity dispersion of each galaxy is calculated by the synthetic stellar population method. Stars are classified into different spectral classes by matching to spectral templates. The RV of each stellar spectrum is determined by cross-correlation with the ELODIE (Baranne *et al.* 1996) stellar spectral library. The final classification and redshift is written into the fits header of the spectrum. The whole procedure for 1D pipeline to reduce spectra of one observation (4000 fibers) takes about one CPU hour.

Since both the pipeline and the hardware need further refinement, each spectrum is examined by eye to ensure the quality. Those spectra with obvious problems are rejected. After visual inspection, spectra of sufficient quality are released to the public (i.e., those who have been authorized for data access).

With the data collected during the pilot survey, we are beginning to be able to assess the performance of LAMOST in survey operations. At its best, LAMOST can deliver data at a quality comparable to SDSS. The pilot survey is concluded in June 2012, and the data analysis indicated that, although in the best conditions (very rare at the site) the system can go down to $r = 19$ (Zhao *et al.* 2012), the survey will be most optimal to go no fainter than $r = 18$ in current performance. Fig. 3 shows sample spectra of stars with magnitudes near the limit accepted for the survey. The stellar parameters are given in inlet of each spectrum. In typical site conditions, LAMOST is able to observe stars at this magnitude limit and get optimal S/N ratio that meet scientific requirements.

3. LEGUE: the plan and science goals

LEGUE is going to survey a large volume (in both sky coverage and depth) for the structure of the Galactic halo and disk in five years started in October 2012. The revealed structure will inform our models of star formation, the formation history of the Galaxy, and the structure of the gravitational potential, including the central black hole and

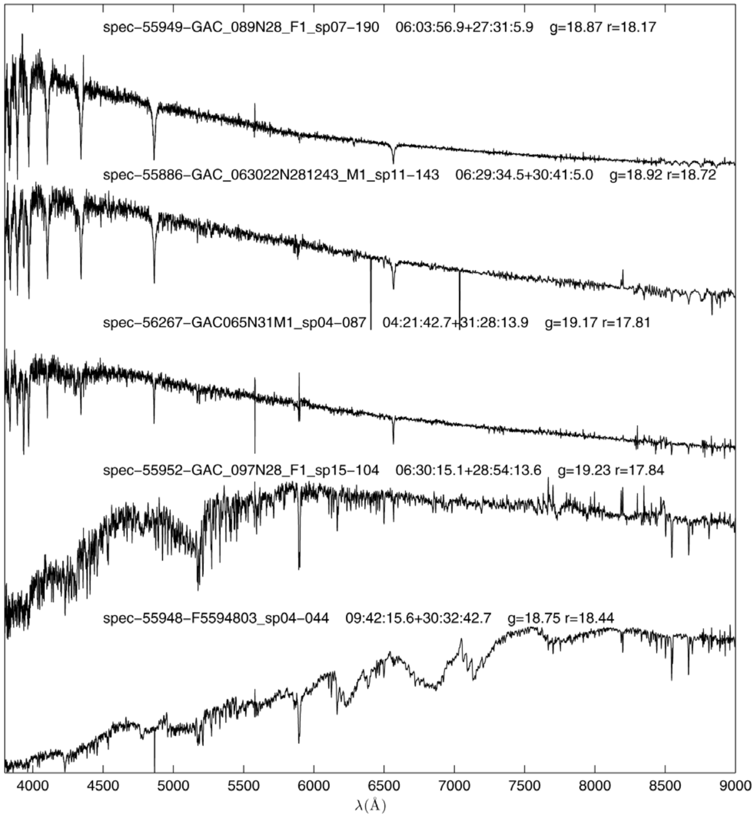

Figure 3. The LAMOST sample spectra for faint stars ($r \geqslant 17.8$) fainter than the survey's limiting magnitude, all with high S/N. The temperature goes down from top to bottom (late-A to M-dwarf), covering a large range of stellar parameters. The magnitudes in SDSS system are indicated in each of the spectra. The vertical axis is flux in random units, the horizontal axis is wavelength in angstrom.

(sub)structure of the dark matter component. The total five-year Galactic structure survey plan presented here includes spectra at least 5 millions of stars down to $r < 17.8$, plus about the same amount of spectra of stars brighter than $r = 14$, based on the real statistics of the pilot and the first year of the regular survey. Compared with previously estimates (Zhao *et al.* 2012, Deng *et al.* 2012), such an expectation is more realistic.

The LEGUE survey is divided into three parts: the spheroid, the disk, and the anticenter. The spheroid survey covers $|b| > 20°$; the anticenter survey covers Galactic latitude $|b| \leqslant 30°$, and longitude $150° \leqslant l \leqslant 210°$; and an extended disk survey covers as much of the low latitude sky ($|b| \leqslant 20°$) as is available from Xinglong Station; the $20° \leqslant l \leqslant 80°$ region of the disk will be poorly sampled due to a limited number of clear nights in summer (see Yao *et al.* 2012 for more on site conditions). Each of these portions of the survey has somewhat different target selection algorithms, which will be similar to the target selection algorithms implemented in the pilot survey, and described in companion papers (Carlin *et al.* 2012, Yang *et al.* 2012, Zhang *et al.* 2012, Chen *et al.* 2012).

Based on the data of a huge number of stars from the LAMOST spectroscopic survey, stellar kinematics can be calculated and the metallicity distribution function in the Galaxy will be obtained. This will allow us to systematically investigate the space density, Galactocentric rotation velocity and velocity ellipsoid, and chemical abundance of stars as a function of position in the Galaxy. All these studies will provide important constraints on the present models of the Galactic structure, formation history, kinematical and dynamical evolution, chemical evolution, and the dark matter distribution in the Milky Way.

The primary science drivers of the LAMOST Galactic structure survey are:

(*a*) Search for extremely metal poor stars in the Galactic spheroid;

(*b*) Kinematic features and chemical abundances of the thin/thick disk stars, with the goal of deriving the mass distribution (including the dark matter mass), the dynamical and chemical evolution, the structure and the origin of the Galactic disks;

(*c*) A thorough analysis of the disk/spheroid interface near the Galactic anticenter, with the goal of determining whether previously identified anticenter structures are tidal debris, or whether they are part disk structures;

(*d*) Discovery of stellar moving groups that may be associated with dwarf galaxies, and follow-up observations of known streams and substructures in the Galactic spheroid;

(*e*) Survey of the properties of Galactic OCs, including the structure, dynamics and evolution of the disk as probed by OCs;

(*f*) Search for hypervelocity stars and determination of their creation mechanism;

(*g*) Survey the OB stars in the Galaxy, tracing the 3D extinction in the Galactic plane;

(*h*) A complete census of young stellar objects across the Galactic Plane, which provides important clues to the studies of large-scale star formation and the history of Galactic star formation.

A typical image of a randomly chosen field of the Milky Way will contain stars at many distances from local disk to distant halo, and may also contain groups of stars of a variety of origins. While these groups are well mixed and indistinguishable from multi-color imaging alone, the addition of kinematic information and spectroscopic stellar atmospheric parameter information ([Fe/H], $T_{\rm eff}$, log g, [α/Fe]) make possible the identification of a common origin for groups of stars. If one has a large enough kinematic sample, such as that proposed here for LAMOST, one can start to trace the origin and build up of the Galaxy itself and explore the role that individual bursts of star formation at different times played in the assembly of the thick disk and halo. This is a study that can only be done with spectra of hundreds of thousands to millions of stars.

It was a tremendous asset of the SDSS imaging survey that it covered a large ($>$ 8000deg^2) region contiguously, with no significant holes in area. One of the benefits is that this allowed clear unambiguous discovery of faint long streams tracing around our Galaxy; e.g., the Grillmair and Dionatos 63-degree stream (Grillmair & Dionatos 2006), and the Orphan Stream (Belokurov *et al.* 2006), among others. Without a large contiguous picture it would be difficult if not impossible to piece together the very low contrast density enhancements that make up these faint structures. Since LAMOST can cover a similar large area spectroscopically, one could look for kinematic streams in RV and position which are contiguous across the sky, and connect pieces of structures which would otherwise not be possible to unambiguously associate with each other.

As a spectroscopic survey in between SDSS and Gaia for the Milky Way, LEGUE bares a great promise. However, there is also a number of restrictions preventing the survey from following up above mentioned discoveries, and revealing the uncovered structures of the Galaxy in phase space as originally designed. The main hurdle for LEGUE survey to cover above list of science goals is the limiting magnitude (currently r = 17.8). In the meantime, new opportunities also emerge: exploring the bulk of Galactic stellar disk which was not studied by former surveys including SDSS/SEGUE. In order to do that, a high quality photometry catalog covering the low galactic latitudes is required. PanSTARRS 1(PS1) provides a 3PI sky coverage with very similar photometry system as

SDSS (Magnier, Schlafly & Finkbeiner *et al* 2013). The team of Galactic research joined LEGUE by providing a one epoch catalog down to $r = 19$ in g,r, and i bands. Combining the publicly available UCAC4 with PS1, we can have a full input catalog covering a very broad range in magnitude ($12 < r < 19$) for target selection. Target selection will follow the algorithm for LEGUE (Carlin *et al.* 2012, Yang *et al.* 2012, Zhang *et al.* 2012) based on such an input catalog, and will be applied to the spheroid and disk parts (the anticenter will follow a separate selection, see Liu's contribution in this volume).

4. Spheroid, Disk, and Anticenter Components

The LEGUE spectroscopic survey covers three major sky regions. Each region requests its own magnitude range, target selection, and signal-to-noise requirement. The spheroid science, analog to SEGUE survey, requires faint targets deep in the halo. The anticenter survey, taking advantage of the fact that the majority of the good weather at Xinglong is in the winter months when the Galactic anticenter is high in the sky, will obtain a large sample of spectra in this interesting part of the Galaxy. The disk survey aims at bright stars when the moon is bright, particularly the member stars in OCs. In the disk, there are sufficient stars to populate the LAMOST fibers even at bright magnitude limits.

4.1. *Spheroid Survey*

We will perform a spectroscopic survey of at least 2.5 million stars selected from combined UCAC4 and PS1 (g, r, i) photometry catalogs with $|b| > 20°$, at a density of 320 stars per square degree (2 visits to the same pointing) or higher, over two contiguous areas: the north and the south Galactic caps, covering more than 5000 square degrees of sky. In the north Galactic cap, brighter stars will be observed when the weather is not pristine and the footprints of the disk/anticenter surveys are not visible in the sky. At least 90% of the survey plates will be in this contiguous area, and at least 90% of the science fibers on each plate will be assigned based on a set of uniform survey criteria, using r, $(g - r)$, and $(r - i)$. Using these criteria, we can target essentially all blue O, B, A, and WD stars, and a statistically significant fraction of F turnoff, K giant, M giant, and high latitude stars with $0.1 < (g - r) < 1.0$.

Because we cannot observe all possible targets, we will employ weighted random sampling to select stars from all possible spectral types and classes (see Carlin *et al.* 2012). There will not be separate individual selection criteria for each type of star, as was used in SEGUE I. The target selection algorithm will be similar to the spheroid target selection algorithms used for the pilot survey (Zhang *et al.* 2012; Yang *et al.* 2012). It will still be complicated to calculate the fraction of spectra observed for any given color, magnitude, and position on the sky, because the fraction of stars being observed depends on the stars' number density and how many times that part of the sky was observed; in higher density regions and the first plate observed in a given part of the sky, a higher fraction of the spectra will be relatively rare objects in less populated regions of color and magnitude.

4.2. *Anticenter Survey*

The anticenter survey will cover the region of $150° < l < 210°$ and $-30° < b < 30°$, sampling a significant volume of the thin/thick disks as well as the halo. We will use the Xuyi photometric survey to select target stars, aiming for an even coverage across multidimensional $r, (g-r), (r-i)$ color-magnitude space as well as in spatial distribution on the sky whenever possible, to minimize selection biases. It is planed to survey an average of 1000 stars per square degree for $|b| > 2.5°$ and twice that for lower Galactic latitudes. In total, approximately 3.7 million stars in the ∼3600 square degree region will be surveyed. Both faint and bright stars will be targeted according to weather conditions (see Liu 2013 for details, in this volume). There is significant overlap between the disk survey and the bright portion of the anticenter survey. There is also significant overlap between the faint portion of anticenter survey and the spheroid survey.

4.3. *Disk Survey*

We define the disk survey as the Low Galactic Latitude Survey, which will observe as much of the disk with $-20° < b < 20°$ as can be covered from Xinglong, given the latitude and weather constraints, and making sure to include all known OCs in this region (see Chen *et al.* 2012 for an overview of the disk survey). The region for $150° \leqslant l \leqslant 210°$ will be merged with the Galactic anticenter survey, for which the input catalog will be selected from the Xuyi photometric survey. If Xuyi survey is not available in a particular region of the sky, then targets will be selected from a combination of UCAC4, PS1 and 2MASS. Note that from Xinglong station, the $20° \leqslant l \leqslant 80°$ region of the disk will be poorly sampled, due to a limited number of clear nights in summer.

We will perform a spectroscopic survey of at least 3 million $r < 16$ Galactic disk stars. The total region of sky available to survey is about 6000 square degrees. We would expect that 1000 objects per square degree (requiring five visits to each field) will be finally observed. This means the survey will only cover half of the footprint. Weather will dictate that the area near the anticenter will get good coverage. The highest priority targets will be OCs' members; the remainder of the fibers will be placed on stars using a weighted random sampling of optical color and proper motion.

5. Policies

The Chinese national funding agencies provided full coverage of construction and operations for the facility and the science missions, with a hope that such a tremendous effort will be rewarded by scientific output. Therefore, the entire Chinese astronomical community is automatically involved in research based on the survey data. In order to maximize science output of the facility, international collaboration has been highly encouraged since the beginning of the project. The project has benefitted greatly from the contributions of the international community, including reviews of the project and science planning for the survey, and with expertise provided individuals and groups. The National Astronomical Observatories, Chinese Academy of Sciences, are responsible for running the facility and its science operations. The operation center, assigned by the Chinese Academy of Sciences, has published the policies for data access and publications based on the survey database. For those who will be interested in using LAMOST spectral survey data for their research, there are a number of ways to participate, as outlined by the data policy and publication policy. Please visit our website for more information: http://www.lamost.org.

LAMOST data will be classified into 3 main types: raw data (target, flat and calibration images), 1D spectra (raw data after processing and extraction by the 2D pipeline) and object catalogs (parameters produced from the 1D pipeline processing). Auxiliary data, including weather condition sensors and guiding camera images, etc., will also be archived for further data quality assessments. LAMOST data releases will contain 1D spectra and object catalogs. Data collected for the survey will have an 18-month proprietary period, and then the data will be publicly available. For a detailed description of the LAMOST data, please check the official data policy on the LAMOST homepage To maximize the science impact of LEGUE and other data products from LAMOST, the operation center is inclined to a more open data access.

Acknowledgement

Thanks NSFC for support from grants Nos. 10573022, 10973015 and 11061120454. Thanks to all members in LEGUE science working group and colleagues in LAMOST operation center.

References

Aihara, H., Allende Prieto, C., An, D., *et al.* 2011, ApJS, 193, 29

Baranne, A., Queloz, D., Mayor, M., *et al.* 1996, A&AS, 119, 373

Belokurov, V., Zucker, D. B., Evans, N. W., *et al.* 2006, ApJ, 642L, 137

Carlin, J. L., Lépine, S., Newberg, H. J., *et al.* 2012, RAA(Research in Astronomy and Astrophys), 12, 775

Chen, L., Hou, J., *et al.* 2012, RAA(Research in Astronomy and Astrophys), 12, 805

Cui, X.-Q., Su, D.-Q., Li, G.-P., *et al.* 2010, in Society of Photo-Optical Instrumentation Engineers(SPIE) Conference Series, 7733, Ground-based and Airborne Telescopes III, eds. L. M. Stepp, R. Gilmozzi, & H. J. Hall, 773309-1-8

Cui, X. Q., Zhao, Y. H., Chu, Y. Q., *et al.* 2012, RAA(Research in Astronomy and Astrophys), 12, 1197

Deng, L., Newberg, H. J., Liu, C., *et al.* 2012, RAA(Research in Astronomy and Astrophysics), 12, 735

Grillmair, C. J. & Dionatos, O. 2006 ApJ, 643L, 17

Huo, Z.-Y., Liu, X.-W., Yuan, H.-B., *et al.* 2010, RAA(Research in Astronomy and Astrophysics), 10, 612

Huo, Z.-Y., Liu, X.-W., Xiang, M.-S., *et al.* 2013, AJ, 145, 159

Jiang, B., Luo, A.-L., Zhao, Y.-H., & Wei, P. 2013, MNRAS, 430, 986

Li, H.-N., Zhao, G., Christlieb, N., *et al.* 2010, RAA(Research in Astronomy and Astrophysics), 10, 753

Luo, A.-L., Zhang, H.-T., Zhao, Y.-H., *et al.* 2012, RAA(Research in Astronomy and Astrophysics), 12, 1243

Magnier, E. A., Schlafly, E., Finkbeiner, D., *et al.* 2013, ApJS, 205, 20

Stoughton, C., Lupton, R. H., Bernardi, M., *et al.* 2002, AJ, 123, 485

Su, D.-Q. & Cui, X.-Q. 2004, ChJAA(Chin. J. Astron. Astrophys), 4, 1

Su, D.-Q., Cui, X., Wang, Y., & Yao, Z. 1998, in Society of Photo-Optical Instrumentation Engineers(SPIE) Conference Series, 3352, ed. L. M. Stepp, 76

Wei, P., Luo, A.-L., Li, Y.-B., *et al.* 2013, MNRAS, 431, 1800

Wu, X.-B., Chen, Z.-Y., Jia, Z.-D., *et al.* 2010a, RAA(Research in Astronomy and Astrophysics), 10, 737

Wu, X.-B., Jia, Z.-D., Chen, Z.-Y., *et al.* 2010b, RAA(Research in Astronomy and Astrophysics), 10, 745

Wu, X.-B., Zuo, W.-W., Yang, Q., *et al.* 2012, RAA(Research in Astronomy and Astrophysics), 12, 1185

Xing, X., Zhai, C., Du, H., *et al.* 1998, in Society of Photo-Optical Instrumentation Engineers(SPIE) Conference Series, 3352, ed. L. M. Stepp, 839

Yang, F., Carlin, J. L., Liu, C., *et al.* 2012, RAA(Research in Astronomy and Astrophysics), 12, 781

Yang, F., Deng, L., Liu, C., *et al.* 2013, New Astron., in press

Yao, S., Liu, C., Zhang, H.-T., *et al.* 2012, RAA(Research in Astronomy and Astrophysics), 12, 772

Yi, Z., Luo, A., Song, Y., *et al.* AJ, submitted

Yuan, H.-B., Liu, X.-W., Huo, Z.-Y., *et al.* 2010, RAA(Research in Astronomy and Astrophysics), 10, 599

Yuan H.-B., Liu, X.-W., & Xiang, M.-S. 2013, MNRAS, 430, 2188

Zhao, Y. 2000, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, 4010, ed. P. J. Quinn, 290

Zhao, G., Zhao, Y.-H., Chu, Y.-Q., *et al.* 2012, RAA(Research in Astronomy and Astrophysics), 12, 723

Zhao, J.-K., Luo, A., Oswalt, T. D., & Zhao, G. 2013, AJ, 145, 169

Zhang, Y.-Y., Carlin, J. L., Yang, F., *et al.* 2012, RAA(Research in Astronomy and Astrophysics), 12, 792

Zhang, Y.-Y., Deng, L., Liu, C., *et al.* 2013, AJ, in press

Zhu, Y., Hu, Z., Zhang, Q., *et al.* 2006, in Society of Photo-Optical Instrumentation Engineers(SPIE) Conference Series, 6269, 20

Zhu, Y., Hu, Z., Wang, L., *et al.* 2010, Scientia Sinica Phys, Mech & Astron, 40, 1

Zou, H., Yang, Y.-B., Zhang, T.-M., *et al.* 2011, RAA(Research in Astronomy and Astrophysics), 11, 1093

Discussion

Hans-Walter Rix: Is the goal to cover the full solid angle of the three areas?

Licai Deng: yes.

Hans-Walter Rix: How will this solid angle be filled, as the survey goes on? Sparsely sampling the full area, or billing up a growing contiguous area?

Licai Deng: As the progress is mainly constrained by observing time available, the areas (in R.A.) with more observing time will be covered better. All the areas will be observed on a growing contiguous basis whenever possible.

Xiaowei Liu: This is a comment. The internal errors of LAMOST RV measurement from multiple observations is about 3 km/s, very similar to SDSS. Comparison of RV of LAMOST and SDSS common objects shows a scatter of about 7 km/s, only slightly higher than expected.

Licai Deng: The figure I quoted is from our binary statistical analysis using LAMOST data only, but we have done the same thing for SDSS data which turned out to be better than LAMOST. It is good to know that the errors in LAMOST RV is similar to SDSS in your measurements. We will look into the difference and do a double check.

Piercarlo Bonifacio: What is the factor limiting the accuracy of RV?

Licai Deng: The accuracy I mentioned is from repeated observations with time span over one day. If other physical factors, such as those due to binaries and pulsating stars, are taken out, we end up with an error of RV measurements. The lines are measured by fix aperture sampling, 2D sampling has been tested which gives better RV. However, it is computing power consuming, and will not be used in the pipeline.