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Preface: The LAMOST Galactic surveys and early results

Xiao-Wei Liu[1], Gang Zhao[2] and Jin-Liang Hou[3]

[1] Department of Astronomy, Peking University, Beijing 100871, China; *x.liu@pku.edu.cn*
[2] Key Laboratory of Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China
[3] Key Laboratory of Galaxies and Cosmology, Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030, China

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Abstract By the time of this writing, the ongoing LAMOST Galactic surveys have collected approximately 4.5 million stellar spectra with signal-to-noise ratios better than 10 per pixel. This special issue is devoted to early results from the surveys, mostly based on the LAMOST Data Release 1 (DR1; Luo et al., this volume) that contains data secured by May 2013, the end of the first year of regular surveys, although a few studies have made use of data collected in the second year of regular surveys. LAMOST DR1 was released to the Chinese astronomical community and international partners in August 2013 and made public to the whole world in March 2015. Here we briefly review the scope and motivation, data reduction and release, as well as early results of the surveys. As the project advances, one can expect that these surveys will yield an exquisite description of the distribution, kinematics and chemistry of Galactic stellar populations, especially those within a few kpc of the Sun, a robust measurement of the local dark matter density, and, consequently, shed light on how our Galaxy, and other galaxies in general, form and evolve.

Key words: Telescope: LAMOST — Milky Way: general — Spectroscopy: survey

1 LAMOST GALACTIC SURVEYS

Understanding how galaxies form and evolve remains one of the most challenging problems of modern astrophysics. The Milky Way, our host galaxy, is the only grand design (barred) spiral galaxy in which the individual constituent stars can be resolved and studied in multi-dimensional phase space (three-dimensional positions and velocities) as well as chemical compositions and ages. Thus it offers a unique opportunity to unravel the underlying physical and astrophysical processes that govern galaxy formation and evolution (e.g. Rix & Bovy 2013). For this purpose, it is necessary to build large statistically complete samples of Galactic stars that include all types and evolutionary stages with accurate measurements of distances, proper motions, radial velocities, atmospheric parameters (effective temperature, surface gravity and metallicity) and ages. However, given the enormous technical challenges, systematic large scale spectroscopic surveys that sample significant volumes of the major structural components of the Milky Way (the central bulge, bar, thin and thick disks and halo) have not been possible until recently.

LAMOST (also called the Guo Shou Jing Telescope; Cui et al. 2012) is an innovative, quasi-meridian reflecting Schmidt telescope with an effective light-collecting aperture of ~ 4 m. Equipped with 4000 robotic optical fibers distributed over a field of view that is 5 deg in diameter, it currently offers the world's highest spectral acquisition rate. It is thus ideal for carrying out, for the first time, systematic spectroscopic surveys of large numbers of Galactic stars, drawn from a significant volume of the disk, the defining structure of the Galaxy, and from the halo (Zhao et al. 2012; Deng et al. 2012; Liu et al. 2014). After a two-year commissioning phase and one-year pilot survey, the LAMOST regular surveys were initiated in October 2012, aiming to collect at least seven million stellar spectra with signal-to-noise ratios (SNRs) better than 10 per pixel in five years. Stars with all colors have been targeted, which are randomly drawn from color-magnitude diagrams. Depending on their magnitudes, stars are targeted with Bright, Medium and Faint plates, with limiting magnitudes set at $14.0 \lesssim r \lesssim 16.3$, $16.3 \lesssim r \lesssim 17.8$ and $17.8 \lesssim r \lesssim 18.5$ mag, respectively. Constrained by observing conditions at the site, only a very restricted number of Faint plates will get observed. Eventually, bright and grey lunar nights will be used to observe Very Bright plates, targeting stars brighter than $r \lesssim 14.0$ mag. The simple yet non-trivial target selection algorithm has the advantage that, with due considerations of the various selection effects introduced in different stages of observation and data reduction, the underlying stellar populations can be recovered from the observed spectroscopic samples. This target selection strategy also opens up a huge parameter space for new discoveries, as rare objects with extreme colors get preferentially targeted (cf. Yuan et al. 2015a).

The main scientific goals of the surveys include: (1) To collect optical spectra for statistically complete samples totaling at least 7 million Galactic stars drawn from the thin and thick disks and halo, and determine their basic parameters (radial velocity, effective temperature, surface gravity and metallicity); (2) To map out in detail the distributions of stars and the interstellar medium in multi-dimensional phase space (three dimensional position and velocity) as well as chemical composition and age for significant portions of the Galactic disk and halo. This will allow researchers to unravel the star formation and chemical enrichment history of the disk and better understand the effects of secular evolution on the disk structure and related properties; (3) To estimate the contributions of mergers and accretions to the Galactic stellar spheroid, and search for possible phase-space substructures in it; (4) To delineate the gravitational potential and matter distribution of the Galaxy, and measure the local dark matter density in the solar neighborhood; (5) To identify and study objects of special interest with multi-wavelength data, such as extremely metal-poor stars, hypervelocity stars, white dwarf binaries, etc.

2 DATA REDUCTION AND RELEASE

By May 2015, three years into the regular surveys, approximately 4.5 million stellar spectra with SNRs better than 10 had been collected. Spectra processed with the LAMOST 1D- and 2D pipelines were then analyzed with the LAMOST Stellar Parameter Pipeline (LASP) to determine basic parameters, including radial velocity, effective temperature, surface gravity and metallicity (Luo et al. 2015, this volume). Processed 1D spectra and deduced stellar parameters have been released to the Chinese astronomical community and international partners for scientific analyses on a regular basis, typically once per season. Major data releases are made available on a yearly basis. They are then made public to the whole world approximately one and half years later.

The LAMOST Data Release 1 (DR1; Luo et al. 2015, this volume) was released to the Chinese astronomical community and international partners in August 2013 and then made public to the worldwide community in March 2015. This release contains 1.72 million stellar spectra with $\mathrm{SNRs} \geq 10$ collected by May 2013, the end of the first-year of regular surveys, and stellar parameters were determined from 1.08 million of them with LASP. LASP has been developed by the LAMOST Operation and Development Center at National Astronomical Observatories, Chinese Academy of Sciences, which administers LAMOST and manages the surveys. LASP determines stellar parameters by template matching with the ELODIE spectral library (Prugniel & Soubiran 2001; Prugniel et al. 2007).

In conjunction with LASP, another pipeline, the LAMOST Stellar Parameter Pipeline at Peking University (LSP3; Xiang et al. 2015b), has been developed and applied to the LAMOST Spectroscopic Survey of the Galactic Anticenter (LSS-GAC; Liu et al. 2014). LSP3 determines stellar atmospheric parameters by template matching with the MILES spectral library (Sánchez-Blázquez et al. 2006; Falcón-Barroso et al. 2011). In addition to the basic stellar parameters, other quantities of interest, such as values of extinction and distance to individual stars and their orbital parameters, have been determined using a variety of techniques and published as value-added catalogs (Yuan et al. 2015a).

Hitherto, restricted by the wavelength coverage of the ELODIE and MILES template spectra, which only go up 6800 Å and 7400 Å, respectively, both LASP and LSP3 are unable to deliver stellar atmospheric parameters for a significant fraction (about one third) of the quality spectra collected. This is either because the stars are heavily reddened by interstellar dust grains and thus have very low SNR in the blue part of the spectrum, or they simply exhibit an intrinsic red color (indicating a very late spectral type). To overcome this problem, a major observational campaign is currently under way to extend the wavelength coverage of the MILES template spectra to 9000 Å (Wang et al. 2015, in preparation). This campaign will also improve the parameter coverage and homogeneity of the MILES library by observing additional template stars. In addition, algorithms that can determine the α-element to iron as well as carbon to iron abundance ratios have been developed and tested (Han et al. 2015, in preparation). We expect that in the next major data release, those abundance ratios, crucial for studying the nature and origin of the Galactic thick disk, will be available.

3 EARLY RESULTS

The first results from LAMOST observations were published in 2010 using commissioning data (Yuan et al. 2010; Huo et al. 2010; Li et al. 2010; Wu et al. 2010a,b), which reported the identifications of dozens of planetary nebulae in M31, and candidates of metal-poor stars and background quasars in fields in the vicinity of M31 and in other fields. Another work on the kinematics and stellar population of M31 was published in 2011 (Zou et al. 2011). The release of data collected in the pilot survey launched in October 2011 (Luo et al. 2012) resulted in a number of papers on topics ranging from the identifications of white dwarf-main sequence binaries (Ren et al. 2013), DA white dwarfs (Zhang et al. 2013, Zhao et al. 2013), a catalog of M dwarfs (Yi et al. 2014), and a spectroscopic study of H I lines in the spectra of RR Lyrae stars (Yang et al. 2014) to kinematic substructures in the Galactic disk (Carlin et al. 2013) and the stellar velocity distribution in the solar neighborhood (Xia et al. 2015), as well as additional identifications of several hundred background quasars in fields in the vicinity of M31 (Huo et al. 2013), a spectroscopic study of a radio-loud quasar (Shi et al. 2014a), a search for double-peaked, narrow emission line galaxies (Shi et al. 2014b), and the identification of dual active galactic nuclei (Huang et al. 2014).

Early published results from LAMOST DR1 include the identification of a hypervelocity star (Zheng et al. 2014) and the identifications of several extremely metal-poor stars (Li et al. 2015b), metallicity estimates for *Kepler* stars (Dong et al. 2014), studies of binarity in Galactic FGK field stars as a function of effective temperature and metallicity (Gao et al. 2014; Yuan et al. 2015b), the detection of a new moving group in the halo (Zhao et al. 2014), a re-estimation of the local standard of rest (Huang et al. 2015a), a catalog of white dwarf-main sequence binaries (Ren et al. 2014), the luminosity, mass functions and formation rate of DA white dwarfs (Rebassa-Mansergas et al. 2015), kinematics and activities of M dwarfs (Yi et al. 2015), a large number of Am star candidates (Hou et al. 2015), and a new stellar spectral classification template library for the LAMOST 1D pipeline (Wei et al. 2014).

This special issue presents another 22 articles. Most of them are based on the LAMOST DR1, although a few of them have made use of data from DR2 which was released to the Chinese astronomical community and international partners in December 2014, and will be publicly available to all interested researchers in July 2016. These papers cover a lot of ground, from data reduction and release, stellar parameter determination and comparison, to search and identification of objects of special interest, catalogs of special classes of objects, and kinematics and chemistry of the Galactic disk based on carefully defined large samples of stars.

Luo et al. (2015) present and describe the first public data release of the LAMOST spectroscopic surveys. It presents an overview of the surveys, the performance of the telescope and instruments, describes in detail the process of data reduction and stellar parameter determination, the data products and caveats, and provides instructions for data access and usage. A study comparing stellar parameters yielded by the LAMOST and APOGEE (Majewski et al. 2015, in preparation) surveys is presented by Chen et al. (2015b). Taking advantage of the huge number of spectra collected by LAMOST, Liu et al. (2015) build loci of spectral line indices of MK spectral classes and use the results to classify LAMOST spectra with an SVM-based algorithm.

Efforts have been made to build catalogs of specific classes of objects, such as M dwarfs (Guo et al. 2015), M giants (Zhong et al. 2015), red clump stars (Wan et al. 2015), and candidate members of open clusters (Zhang et al. 2015a). Those samples will be very useful for probing the kinematics and chemistry of the Galactic disk and halo, near and far. Using a sample of nearly 0.3 million main-sequence turn-off stars with robust distance and age measurements, the largest assembled hitherto, Xiang et al. (2015a) present measurements of the radial and vertical gradients of stellar metallicity in the Milky Way's outer disk, and find that both exhibit strong spatial variations as well as temporal evolution, suggesting that the disk may have experienced a two-phase buildup history. The disk's radial and vertical metallicity gradients have also been measured by Huang et al. (2015b) using a sample of over 70 000 red clump stars with 5%–10% distance accuracy. Using a sample of about 0.57 million FGK dwarfs, Sun et al. (2015) present a detailed three-dimensional map of stellar bulk motions within 2 kpc of the Sun, revealing spatially coherent, kpc-scale stellar flows. Bending- and breathing-modes as well as higher-order perturbations, such as breaks and ripples, are clearly visible.

Several contributions report the identifications of objects of special interest, including luminous infrared galaxies (Lam et al. 2015), E+A galaxy candidates (Yang et al. 2015), background quasars in fields in the vicinity of M31 and M33 (Huo et al. 2015), globular clusters in M31 and M33 (Chen et al. 2015a), an r-process element strongly enhanced extremely metal-poor star (Li et al. 2015a), magnesium-poor stars (Xing et al. 2015), Be stars (Lin et al. 2015), symbiotic stars (Li et al. 2015c), and low-mass hypervelocity star candidates (Li et al. 2015d). Finally, Zhao et al. (2015a) present measurements of a chromospheric activity index for a huge sample of about 120 000 FGK stars and examine their variations with height from the Galactic plane and with stellar age. A study investigating the evolutionary stages and disk properties of over two hundred young stellar objects across the Perseus cloud is presented by Zhang et al. (2015b). Zhao et al. (2015b) report the identifications of nine phase-space overdensities, including six halo stream candidates.

To summarize, the LAMOST Galactic surveys have made solid progress in observation and data reduction and have begun to produce rich results. With the imminent release of early data from *Gaia* (Perryman et al. 2001), which will provide parallaxes and proper motions with unprecedented accuracy for essentially all LAMOST Galactic targets, this huge LAMOST spectral data set, already the world largest by a large margin, will surely become ever more authoritative in tackling some forefront problems in Galactic studies. We are entering an exciting era in Galactic astronomy. More interesting results are on their way. All interested researchers from the worldwide astronomical community are most welcome to take full advantage of this invaluable asset.

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