The LEGUE disk targets for LAMOST's pilot survey *

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Abstract We describe the target selection algorithm for the low latitude disk portion of the LAMOST Pilot Survey, which aims to test systems in preparation for the LAMOST spectroscopic survey. We use the PPMXL astrometric catalog, which provides positions, proper motions, B/R/I magnitudes (mostly) from USNO-B and J/H/Ks from the Two Micron All Sky Survey (2MASS) as well. We chose eight plates along the Galactic plane, in the region $0^{\circ} < \alpha < 67^{\circ}$ and $42^{\circ} < \delta < 59^{\circ}$, which cover 22 known open clusters with a range of ages. Adjacent plates may have some small overlapping area. Each plate covers an area of 2.5° in radius, with its central star (for the Shack-Hartmann guider) brighter than 8th magnitude. For each plate, we create an input catalog in the magnitude range 11.3 < I_{mag} < 16.3 and B_{mag} available from PPMXL. The stars are selected to satisfy the requirements of the fiber positioning system and have a uniform distribution in the I vs. B - I color-magnitude diagram. Our final input catalog consists of 12 000 objects on each of eight plates that are observable during the winter observing season from the Xinglong Station of the National Astronomical Observatory of China.

Key words: disk: Milky Way — stars: spectroscopy — survey: pilot

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1 INTRODUCTION

The Guo Shou Jing Telescope (GSJT, formerly called the Large sky Area Multi-Objet fiber Spectroscopic Telescope — LAMOST) is a 4 meter telescope with 4000 fibers in the focal plane (Cui et al. 2012). The telescope is located at the Xinglong Station, located 114 km to the east north east (ENE) of Beijing and operated by the National Astronomical Observatories of China. Currently, a pilot survey is running on the telescope, in preparation for a full spectroscopic survey, which is expected to begin in late 2012. The survey has the potential to significantly increase our understanding of the substructures in the Galactic stellar spheroid and disk components through measurements of radial velocities, metallicities and effective temperatures for millions of stars (Deng et al. 2012).

Here, we describe a low latitude disk survey concentrating on open clusters, which is being conducted as part of the LAMOST Pilot Survey. The pilot survey mainly aims to test the LAMOST system, in preparation for the planned major survey. The pilot survey targets fainter objects on dark nights (Yang et al. 2012; Carlin et al. 2012), and brighter objects when the Moon is bright or the atmosphere has low transparency (Zhang et al. 2012). The footprint of the bright night disk survey is shown in Figure 1 overlaid on a starcount map from SDSS photometry. The magenta part is the disk survey region centered at $b = 0^{\circ}$, which will be discussed in this paper.

One of the primary science objectives of the LAMOST disk survey is to investigate the structure of the thin/thick disks of the Galaxy, including the chemical abundance as a function of position within the disk and the extinction in the disk. In the main survey, we expect to cover 300 open clusters in the low Galactic latitude region, and obtain stellar radial velocities as well as abundance information for stars as faint as $r = 16^{m}$ in the cluster fields. This will be the largest spectroscopic data set for studying the properties of Galactic open clusters, including the structure, dynamics, and evolution of the disk as probed by open clusters (Chen et al. 2003; Ahumada et al. 2011).

Some of the expected scientific outputs from the disk pilot survey include:

- significant improvements in essential parameter measurements of the targeted open clusters, using kinematic membership information and homogeneous abundance data.
- a database of spectroscopically confirmed cluster members in the outer parts of the clusters, that will provide good targets for detecting or verifying possible tidal tails of these stellar clusters.
- a large sample of young stellar objects across the surveyed area, which will provide important clues to properties of large-scale star formation and the history of Galactic star formation as well as information on the 3D extinction in the Galactic plane.



Fig. 1 The footprint of the bright night disk survey in equatorial coordinates overlaid on a starcount map from SDSS photometry. The magenta disk survey region is centered on the Galactic plane and the yellow circular areas are eight plates that were chosen for the pilot survey.

- tens of thousands of spectra of bright disk stars that can be used to characterize the chemistry and kinematics of the thin disk.

The open clusters are particularly important to the survey, since some of the well characterized open clusters provide important "standards" for a range of stellar types that can be used to calibrate the LAMOST observations and the data-processing pipeline.

In Section 2, we describe the footprint of the survey as well as the catalog from which the targets were selected. In Section 3, we describe the selection of spectroscopic targets, including selection in color and magnitude, the effects of blending in a crowded field, and the properties of the selected spectroscopic targets. Finally, in Section 4 we summarize the paper.

2 FOOTPRINT AND INPUT CATALOG

For the pilot survey of the disk, we have chosen eight plates along the Galactic plane that are nearly uniformly distributed in Galactic longitude, and in a range of right ascension and declination that will make them easily observable with GSJT. The telescope's design favors observations with $-10^{\circ} < \delta < 60^{\circ}$; lower declinations are unobservable, and the effective aperture and image quality of the telescope decreases rapidly at declinations above $\delta = 60^{\circ}$. Since the observations should be taken near the meridian, it is important to spread the target fields out in Galactic longitude so that there are targets available at all right ascensions. The part of the sky observed is $0^{\circ} < \alpha < 67^{\circ}$ and $42^{\circ} < \delta < 59^{\circ}$. Adjacent plates may slightly overlap. Each plate covers an area of 2.5° in radius, with its central star (for the Shack-Hartmann guider) brighter than $V = 8^{\rm m}$. It is a requirement that each field observed by LAMOST have a bright star in the center so that the shape of the mirrors can be actively adjusted to focus stellar images in the focal plane.

We were able to select fields that cover 22 previously identified star clusters.

Table 1 shows the selected open clusters within coverage of the designed disk pilot survey plates. The angular distance between the cluster center and the plate center is less than two degrees in all cases. We also list the parameters (Dias et al. 2002; WEBDA¹) for each cluster, including (if available) cluster name, the position, reddening and distance, the average proper motion and radial velocity, an estimation of the cluster's age and the corresponding number of the survey plate. Some of the clusters have been poorly studied and we expect to obtain their kinematic and chemical information for the first time from the pilot survey database.

Individual stellar targets are selected from the PPMXL astrometric catalog (Roeser et al. 2010), which includes positions, proper motions, rough *BRI* magnitudes, and *JHK*s magnitudes from 2MASS. PPMXL is a full sky catalog of positions, proper motions, 2MASS and optical photometry of 900 million stars and galaxies, aiming to be complete for the brightest stars down to about $V = 20^{\text{m}}$. It is the result of a re-reduction of USNO-B1 observations, supplemented with 2MASS and ICRS results. PPMXL is currently the largest collection of ICRS proper motions with typical errors ranging from 4 mas yr⁻¹ to more than 10 mas yr⁻¹, depending on the object's observational history.

In PPMXL, the photometric information from USNO-B1.0 is listed, as well as the NIR photometry from 2MASS when available. The B, R, I magnitudes in the USNO B1.0 magnitude system are rather crude, and there are discrepancies in the magnitude system from field to field and from early to late epochs. However, PPMXL is the only source that provides photometry in optical bands for low galactic latitude targets, which is necessary as an input catalog for our pilot survey of the disk.

Figure 2 shows the number density of stars in one of our plate regions, centered at ($\alpha = 5.1421^{\circ}$, $\delta = 56.5569^{\circ}$; $l = 118.6619^{\circ}$, $b = -6.0655^{\circ}$). The PPMXL catalog lists 2.2×10^5 point objects in this area. On average there are over 11 000 targets per square degree in this low Galactic latitude region, complete in magnitude to $I \sim 16.3^{\text{m}}$.

¹ http://www.univie.ac.at/webda/



Fig.2 The star number density of PPMXL in one of our plate regions, centered at $(RA = 5.1421^{\circ}, Dec = 56.5569^{\circ})$. A total of 2.2×10^{5} targets are included. The color bar on the right shows different number density scales in units of 10^{4} stars mag⁻².

Table 1 Properties of Open Clusters in the Disk's Pilot Survey Ar	rea
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Name	RA (h m s)	Dec (d m s)	l (°)	b (°)	Ebv	Dist (pc)	$\begin{array}{c} \mu_{\alpha}\cos\delta\\ ({\rm mas}{\rm yr}^{-1}) \end{array}$	$(\max^{\mu_{\delta}} yr^{-1})$	Rv (km s ⁻¹)	Age (Gyr)	Plate Nr.
ASCC 2	0 19 51.6	55 42 36	118.46	-6.89	0.10	1200	-0.91	-3.94		0.676	1
Stock 21	0 29 49.2	57 55 12	120.05	-4.83	0.40	1100	-0.12	-1.52		0.525	1
ASCC 3	0 31 8.4	55 16 48	120.02	-7.48	0.17	1700	-1.92	-1.25	-37.00	0.079	1
King 2	0 50 60.0	58 10 48	122.87	-4.69	0.31	5750				5.023	2
IC 1590	0 52 48.0	56 37 48	123.12	-6.24	0.32	2384	-1.36	-1.34	-37.50	0.007	2
ASCC 5	0 57 57.6	55 50 24	123.85	-7.02	0.25	1500	-3.10	-2.91	-43.00	0.011	2
NGC 657	1 43 20.9	55 50 24	130.22	-6.30							3
ASCC 6	1 47 13.2	57 43 48	130.34	-4.34	0.30	1200	-1.02	-1.18	-20.00	0.148	3
NGC 743	1 58 37.0	60 9 36	131.20	-1.63							4
ASCC 7	1 58 55.2	58 58 12	131.54	-2.77	0.50	2000	-0.57	-3.08	-49.00	0.023	4
Stock 2	2 14 24.0	59 16 12	133.36	-1.92	0.34	380	16.22	-13.39	-2.85	0.148	4
NGC 869	2 19 4.8	57 8 60	134.63	-3.72	0.48	2079	-0.49	-0.90	-39.82	0.019	4
Basel 10	2 19 28.1	58 17 60	134.30	-2.62	0.77	1944	1.47	0.35		0.041	4
ASCC 8	2 20 49.2	59 36 36	134.02	-1.33	0.55	2200	-1.24	0.57	-42.09	0.006	4
NGC 884	2 22 1.2	57 8 24	135.01	-3.60	0.56	2345	-0.84	-0.23	-38.14	0.013	4
Trumpler 2	2 36 54.0	55 55 12	137.37	-3.97	0.32	649	1.40	-5.57	-39.00	0.085	5
Czernik 12	2 39 12.0	54 55 12	138.08	-4.75							5
NGC 1220	3 11 40.1	53 20 24	143.04	-3.96	0.70	1800				0.060	6
King 5	3 14 36.0	52 43 12	143.74	-4.27		1900			-52.00	0.759	6
Czernik 15	3 23 12.0	52 15 0	145.10	-3.97							6
King 7	3 59 0.0	51 47 60	149.77	-1.02	1.25	2200				0.661	7
Berkeley 11	4 20 36.0	44 55 12	157.08	-3.64	0.95	2200	1.45	-2.37		0.110	8

3 TARGET SELECTION AND INPUT CATALOG DESIGN

3.1 Target Selection Process

For each of our selected plates, we must create an input catalog with about three times as many stars as can be observed, from which the fiber assignment software will select the actual targets. Since

GSJT contains 200 fibers per square degree in the focal plane, we select 600 stars deg⁻² in the input catalog. We explain here how we select stars with $11.3 < I_{mag} < 16.3$ and derive the available B_{mag} from PPMXL. Additionally, targets are selected to favor open cluster members, satisfy the requirements of the fiber positioning system, and maintain a uniform distribution in I and B - I color-magnitude space.

Our target selection algorithm is as follows:

- For every LAMOST survey field, we construct input catalogs of a bright subset of the PPMXL catalog with $11.3 < I_{\text{mag}} < 14.3$ and a faint subset with $14.3 < I_{\text{mag}} < 16.3$.
- To prevent contamination of spectra by nearby stars (the blending effect, see discussion in the next section), we eliminate all stars that have a similar brightness or a brighter neighbor within 5". Note that the LAMOST fiber diameter is 3.3" and the typical seeing in the Xinglong station is around 2" to 3".
- To prevent local overdensity for fiber allocation, we set 6" as the minimum spatial distance for all selected stars in the following steps.
- We eliminate very high proper motion objects; the proper motion limit is PM<100 mas yr⁻¹. Note that the typical mean observation epochs for PPMXL sources were during the 1970s or 1980s.
- Highest priority is assigned to cluster members, whenever membership information is available in Kharchenko's catalog (Kharchenko et al. 2005). Membership in this catalog is estimated from the proper motion of individual stars in the region of the cluster.
- For the remainder of the targets, we perform uniform sampling in color-magnitude space (B I vs. I) by randomly selecting stars on the color-magnitude diagram (CMD). For instance, for the bright subset of Plate 1 we set the magnitude range as $11.3^{\text{m}} < I < 14.3^{\text{m}}$ and color range as $-1.5^{\text{m}} < (B I) < 4.5^{\text{m}}$ which includes a total of about 36000 stars. First we generate a random point in the $(B I) \sim I$ space, then, within a search radius of 0.03 mag (roughly the average distance in the color-magnitude space), select the object closest to the random point as our sample star. In addition, all the selected stars will satisfy the spatial distance limit of 6". The iteration ends up with a bright sub-catalog of 12 000 stars ready for the fiber assignment software to select the actual targets. Here we note that the magnitude from PPMXL is rather crude.

It was intended that the bright and faint datasets would be sent to fiber assignment separately, and two pointings (one brighter and one fainter) would be done at each position. Instead, the two lists were merged before fiber assignment for the pilot survey, and in some cases a second or third pointing was constructed (with many repeated sources).

3.2 Blending in a Crowded Field

For a fiber fed multiobject spectroscopic telescope such as GSJT, blending, which can be defined as at least two objects being captured by a fiber in an exposure, must be taken into account when the telescope targets crowded fields (e.g. the Galactic disk or open clusters).

LAMOST uses 4000 fibers on the 1.75-meter-diameter focal plane; each fiber has an aperture of 3.3 arcsec. When a fiber is targeting an object, some flux contributed by its neighboring objects may also be recorded. Hence, the final processed spectrum could be very strange if it is contaminated by the blended objects. In order to investigate the probability of blending in the LEGUE disk survey, we perform a simple simulation.

We assume that 1) all objects in the simulation are point sources; 2) the range of the brightness of the objects covers 10 < m < 18 mag, with the fainter objects being ignored; 3) we only "observe" objects brighter than 16 mag, and only the objects between 16 and 18 mag contribute to the blending; 4) the luminosity function is studied using a catalog of SDSS photometry and it can be approximately

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Fig. 3 The simulation of the blending within a fiber aperture. The X-axis on bottom is the density of the simulated objects with m < 18 mag, while on top is the density of the objects with m < 16 mag corresponding to the bottom X-axis. The luminosity function is assumed to be $A(m) \sim \exp(0.5m)$, which is approximately estimated from SDSS photometry. The dotted, dashed and solid lines with triangles, rectangles and circles show the probability of more than 10% of the flux of the blended objects being in the fiber aperture when fibers are assigned to all objects with m < 16 mag given the dome seeing being 2, 3, and 4 arcsec, respectively. The error is estimated from a Monte Carlo approach.

fitted by $A(m) \sim \exp(0.5m)$; and 5) the PSF is a Gaussian, in which σ is smaller than the dome seeing by a factor of 2.35.

In the simulation we consider a circular, one square degree region filled with uniformly distributed objects (down to 18 mag). The density is from 2500 to 25000 stars deg⁻², which is the typical density range in the outer disk and open clusters. Then we assign fibers to all objects with m < 16 mag given the dome seeing. For each fiber we calculate the ratio of the total flux from the neighboring objects (only those located within 3×seeing are considered) to that from the target in the fiber aperture. If the ratio is higher than 10%, we mark this fiber as a significantly blended fiber. Note that the sky flux is ignored in the calculation. The fraction of the significantly blended fibers in the field is defined as the probability of the blending.

We did the simulation for the seeing of 2'', 3'' and 4''. The results are shown in Figure 3. We find that the probability of more than 10% of the flux of the blended objects being in the fiber aperture increases linearly with the density of the objects. Moreover, the bigger the seeing the higher the probability of the blending. For instance, in the central region of an open cluster, in which the density can be around 10 000 per square degree, the LAMOST spectra will suffer significant blending in about 0.7% of the spectra on each plate, given a seeing of 2''. It increases to 1% and 1.3% when the seeing is increased to 3'' and 4'', respectively. It is worthy to note that in practice even fainter neighboring objects, e.g. objects with strong emission lines, the outskirt of a neighboring galaxy, nearby emission nebulae etc., may also contribute to the flux. This limit will constrain the target



Fig. 4 *Left*: the color-magnitude distribution of selected targets as a bright subset $(11.3 < I_{mag} < 14.3)$ for plate1, satisfying requirement for SSS fiber-assignment; *Right*: spatial distribution of selected stars. Red *: OC members, red triangle: plate center (*color online*).



Fig. 5 Left: the color-magnitude distribution of selected targets as a faint subset $(14.3 < I_{mag} < 16.3)$ for Plate-1, satisfying requirement for SSS fiber-assignment; *Right*: spatial distribution of selected stars. Red triangle: plate center (*color online*).

selection for the disk survey to either avoid very crowded regions or accept the fact that there would be a few percent of blended spectra and later develop a pipeline to address this issue.

3.3 Sample Plate for the Disk Portion of the Pilot Survey

As an example of the outputs from the target selection process, Figure 4 shows the color-magnitude distribution of selected targets as a bright subset (left panel) $(11.5 < I_{mag} < 14.3)$ for Plate 1 and the spatial distribution (right panel) of selected stars. It can be seen that our uniform selection in color-magnitude space favors bluer as well as brighter objects in the input catalog. There are two open clusters well within the field of view of Plate 1 (centered at RA= 5.1421° , Dec= 56.5569°): ASCC 2 and ASCC 3. We assign highest priority to members (87 stars) of these clusters (membership information from Kharchenko et al. 2005). Here the output of our selection algorithm largely achieved the basic goal for target selection from field disk stars: we would like to sample a larger

fraction of the rarer stars than the less rare, and a larger fraction of the interesting cases than the less interesting ones.

In this plate, we expect to observe all 87 open cluster member stars which can be used to calibrate the spectral quality and stellar parameters, especially the radial velocity and metallicity.

Figure 5 shows the color-magnitude distribution of targets in a faint subset (left panel) (14.3 < $I_{\rm mag}$ < 16.3) and the corresponding spatial distribution (right panel) of selected stars. Since the magnitude limit in Kharchenko's catalog (Kharchenko et al. 2005) is brighter than $V \sim 14^{\rm m}$, there is no membership information available for this faint subset. In the future, we will use astrometric catalogs (like PPMXL and UCAC3) to determine cluster membership to a deeper magnitude limit from proper motion.

4 SUMMARY

We have described the target selection algorithm for eight low latitude, bright plates that are planned to be observed during the LAMOST Pilot Survey. Stars from 22 open clusters will be observed on these plates. To date, five plates have been successfully observed, and the data reductions and quality assessment are being conducted. This portion of the Pilot Survey is in preparation for a larger survey that will cover 300 Galactic open clusters.

The highest priority targets on these plates are known or suspected members of Galactic open clusters. Other disk stars in the $11.3 < I_{mag} < 16.3$ range were uniformly selected over I and B-I color-magnitude phase space. Very high proper motion objects are not targeted. Positions, proper motions, and magnitudes are taken from the PPMXL catalog.

The spectra observed in this disk portion of the LAMOST Pilot Survey will be used to study Galactic open clusters, to investigate young stellar objects and to study the chemistry and kinematics of disk stars. The stars in open clusters will be important calibrators for the main spectroscopic survey.

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References

Ahumada, A. V., Bragaglia, A., Tosi, M., & Marconi, G. 2011, in Revista Mexicana de Astronomiay Astrofísica Conference Series, 40, 265

Carlin, J. L., Lépine, S., Newberg, H. J., et al. 2012, RAA (Research in Astronomy and Astrophysics), 12, 755 Chen, L., Hou, J. L., & Wang, J. J. 2003, AJ, 125, 1397

Cui, X. Q., Zhao, Y. H., & Chu, Y. Q., et al. 2012, RAA (Research in Astronomy and Astrophysics), submitted Deng, L., Newberg, H. J., Liu, C., et al. 2012, RAA (Research in Astronomy and Astrophysics), 12, 735

Dias, W. S., Alessi, B. S., Moitinho, A., & Lépine, J. R. D. 2002, A&A, 389, 871

Kharchenko, N. V., Piskunov, A. E., Röser, S., Schilbach, E., & Scholz, R.-D. 2005, A&A, 438, 1163

Monet, D. G., Levine, S. E., Canzian, B., et al. 2003, AJ, 125, 984

Roeser, S., Demleitner, M., & Schilbach, E. 2010, AJ, 139, 2440

Skrutskie, M. F., Cutri, R. M., Stiening, R., et al. 2006, AJ, 131, 1163

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

Zhang, Y., Carlin, J., Liu, C., et al. 2012, RAA (Research in Astronomy and Astrophysics), 12, 792