Southern LAMOST for all sky spectroscopic survey

Xiangqun Cui[*1,5], Shou-guan Wang[2], Ding-qiang Su[3,5], Yongheng Zhao[2], Ya-nan Wang[1], Yaoquan Chu[4], Guoping Li[1,5]

1 National Astronomical Observatories/Nanjing Institute of Astronomical Optics and Technology Chinese Academy of Sciences, 188 Bancang Street, Nanjing 210042, P. R. China

2 National Astronomical Observatories, Chinese Academy Sciences, Bejing, 100012, P.R. China

3 Department of Astronomy, Nanjing University, 22 Hankou Road, Nanjing 210093, P. R. China

4 University of Science and Technology of China, 96 Jinzhai Road, Hefei 230026, P. R. China

5 Key Laboratory of Astronomical Optics & Technology, Nanjing Institute of Astronomical Optics & Technology, Chinese Academy of Sciences, Nanjing 210042, China

ABSTRACT

The all sky spectoscopic survey is very important both in extra-galactic and Galactic studies. The Large-Sky-Area Multi-object Fiber Spectroscopic Telescope (LAMOST) has successfully completed its engineering work and inaugurated in October of 2008. Now it is in the commissioning stage. In pursuit of the all sky spectroscopic survey, a southern LAMOST is proposed. Tecnically, the Southern LAMOST will be mainly a copy of present LAMOST in Xinglong, China, which is located at about latitute +40 degrees. Modifications are to be made for much better image quality and thinner optical fibers to match with the better seeing condition in the Southern site. There will be 6000 or 8000 optical fibers used on the focal surface to get the highest spectrum acquiring rate, and will be equipted with about 12 to 16 spectrographs with 24 to 32 CCD cameras. Southern LAMOST is going to be built by international collaboration.

Keywords: Wide field telescope, Spectroscopic observation, All sky survey, Multi-fiber spectroscopy, Active optics, Reflecting Schmidt system, Segmented mirror.

1. INTRODUCTION

Abundant physical information about remote celestial bodies is contained in their optical spectra. The optical spectra of enormous amount of celestial bodies are critical in astronomical research of wide field of view and large samples that concerns various frontiers in astronomy and astrophysics. Up to now, however, among the tens of billions of all kinds of celestial bodies recorded by imaging surveys, only a very little part (about one ten thousandth) has gotten their spectra. Prof. Shou-guan Wang, in early of 1990's, suggested to Chinese astronomical community to put their effort in large scale spectroscopic survey, and together with Prof. Ding-qiang Su to proposed the innovative active reflecting Schmidt telescope — Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) [1-3]. The overall concept and key technical innovations[4-6] makes it a unique astronomical instrument in combining a large aperture with a wide field of view. For such a special telescope optical system, we name it Wang-Su reflecting Schmidt system.

LAMOST is composed of a segmented active reflecting corrector of 5.72m x 4.40m and a segmented primary mirror of 6.67m x 6.05m. The available large focal surface accommodates up to 4000 fibers[7], by which the collected light of distant and faint celestial objects down to 20.5 magnitudes is fed into the spectrographs [8], promising a very high spectrum acquiring rate of several ten-thousands of spectra per night.

On October 16, 2008, inauguration ceremony of LAMOST (The Large Sky Area Multi-Object Fiber Spectroscopic Telescope) was held on Xinglong Observing Station of National Astronomical Observatories of China. The completion of LAMOST at Xinglong is shown that the technical challenges especially the active optics and optical fiber positioning system have been successfully overcome and telescope technologies have been developed and step forward

[*] xcui@niaot.ac.cn; phone 86 25 85482202; fax 86 25 85405562

Ground-based and Airborne Telescopes III, edited by Larry M. Stepp, Roberto Gilmozzi, Helen J. Hall
Proc. of SPIE Vol. 7733, 77330B · © 2010 SPIE · CCC code: 0277-786X/10/$18 · doi: 10.1117/12.856700

dramatically in China [9, 10]. LAMOST is the one that possesses the capability of highest spectrum acquiring rate in the world. After the commission period, it will begin the first annal spectroscopic survey project. The expected millions of spectra acquired can be used to do research on large scale structure of Universe, structure and evolution of the Galaxy, and so on. Some early scientific papers for observing dada from the engineering commissioning stage have been published or accepted [11-15].

Since LAMOST located on the northern hemisphere (latitude 40.4 degrees), its spectroscopic survey covers only partial sky area (declination from -10 to 90 degrees). However, it is very important that all sky spectroscopic survey to promote the research on the hot topics in astrophysics, and the quality of Xinglong station as an astronomical site could only be ranked as "median". Therefore, we propose to construct one "LAMOST South" on one of the best sites in southern hemisphere. The telescope configuration of LAMOST South mainly will be a copy of the present, but could be modified, such as the different tilt axis angle or vertical configuration of LAMOST which we considered at the early stage of proposal, depends on the site and image quality requirements, and some detail designs could be modified too from the lesson learned during construction of LAMOST. Based on the experience to construct LAMOST, LAMOST South can be constructed within 4 -5 years and with budget of about $60M.

The spectroscopic survey carried out by the LAMOST South will be complement (and exceeding in many ways) of surveys by LAMOST in China. With two LAMOSTs, spectroscopic survey could cover all sky. LAMOST South will do spectroscopic survey for tens of millions of galaxies and millions of quasars, which will benefit the study of extra-galactic astrophysics and cosmology, such as: (1) Studies of large-scale structure of universe; (2) Baryon Acoustics Oscillations => Dark energy; (3) Formation and evolution of galaxies; (4) AGN physics; (5) Accurately measure luminosity functions & star-formation rate densities with redshift & environment; (6) Detailed studies of local low-luminosity galaxies. For Spectroscopic survey for structure and evolution of the Galaxy, such as: (1)Discovery of spheroid substructure; (2) Constrain Galactic potential and dark matter; (3) Search for extremely metal poor stars; (4) Identify smooth component of spheroid; (5) Structure of thin/thick disks, including chemical abundance and kinematics; (6) Search for hypervelocity stars; (7) Survey OB stars and 3D extinction in Galaxy; (8) Globular cluster environments; (9) Properties of open clusters; (10) Complete census of young stellar objects across the Galactic plane.

2. SPECIAL CONSIDERATION

2.1 Optical system

LAMOST North at Xinglong Station is with a variable aperture between 3.6m to 4.9m depending on its point sky area during the observation. Its optical axis is tilted by an angle of 25° to the horizon from south to north for the sky coverage. The declination (δ) of observable sky area ranges from -10° to +90°. LAMOST North is with a field of view in 5 degrees for the declination -10° to +60°, and 3 degrees for +60° to +90°. With F ratio 5, the diameter of the focal plate is 1.75m. The 4000 optical fibers are fixed and controlled by 4000 positioning units on the focal plate. The image quality of the telescope optical system depends on the field of view and the incident angle which is variable for different sky area and tracking time. For estimation, it is easier to take an average 4m aperture and without taken account about the tracking. One can see from Table 1 the worst image quality for pointing at the meridian plane is at edge of the field of view while telescope is pointing to sky area at +90°. Since the site seeing at Xinglong is about 2 arc seconds on average, and the optical fibers are with diameter in 3.3 arc seconds, the image quality of LAMOST North is good enough to fit the observing condition.

Table 1 Image quality (80% energy encircled in arc seconds) of LAMOST North

FOV (2w) / δ (°)	1°	3°	5°
-10	0.048	0.142	0.250
0	0.073	0.221	0.390
10	0.102	0.304	0.534
20	0.131	0.398	0.689
30	0.162	0.500	0.861
40	0.198	0.611	1.055
50	0.239	0.735	1.279
60	0.286	0.876	1.547
70	0.342	1.043	
80	0.409	1.262	
90	0.493	1.550	

Considering the site for LAMOST South, such as Chile, the seeing condition will be much better than Xinglong, to gain from the benefit, we need also better image quality and adopting thinner optical fibers. There are two ways to get better image quality in LAMOST: (1) reduce the incident angle of the telescope optical system, that is to say, to increase the tilt angle of the optical axis in meridian plane; (2) to adopt smaller field of view while enough objects on the focal surface still could be got.

If we put LAMOST South at a site with latitude φ = -30°, pending the choice of sky coverage of the instrument agreed on by the cooperation partners, here , as an example, change the tilt angle of the optical axis in meridian plane to 60° , taking the observing sky area as covering from declination -90° to 0°, and taking a field of view in 5 degrees for the declination -60° to 0°, and 3 degrees for -90° to -60° (Fig. 1). Table 2 lists the preliminary calculation results of the image quality of the optical system for LAMOST South, and Fig. 2 shows the spot diagram for two worse sky areas.

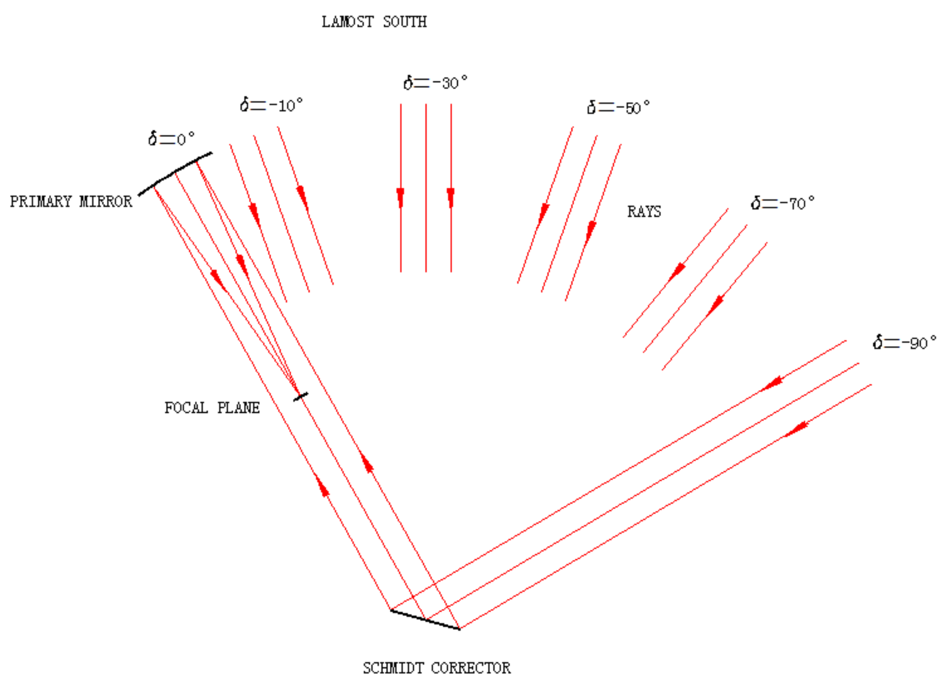
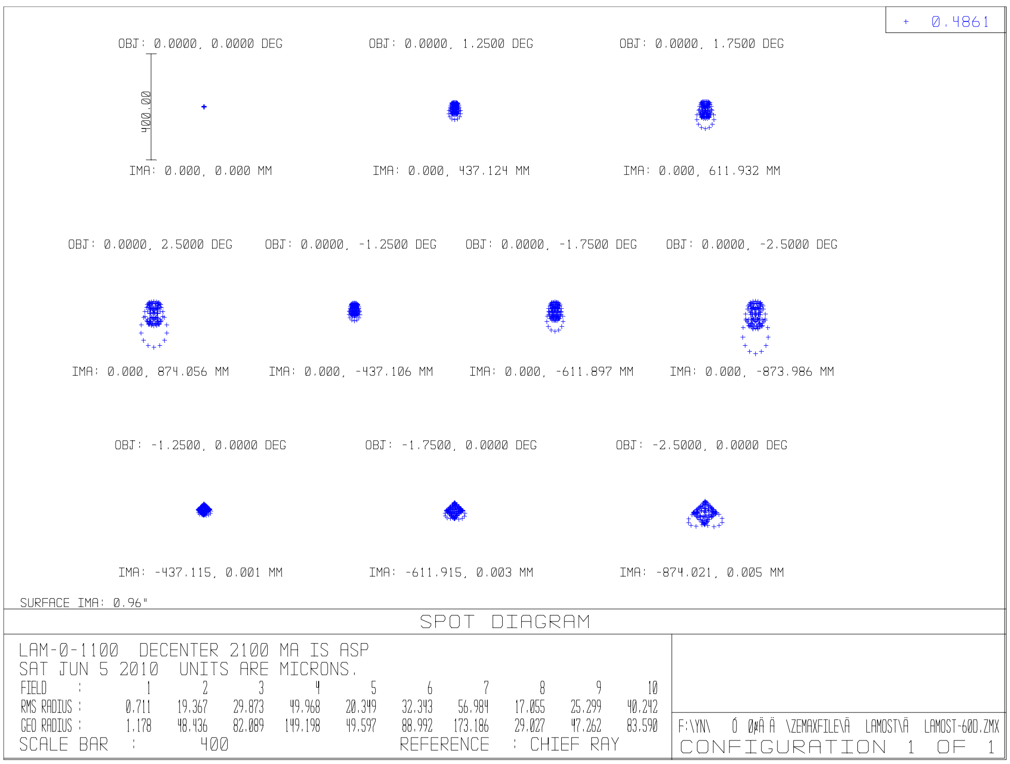


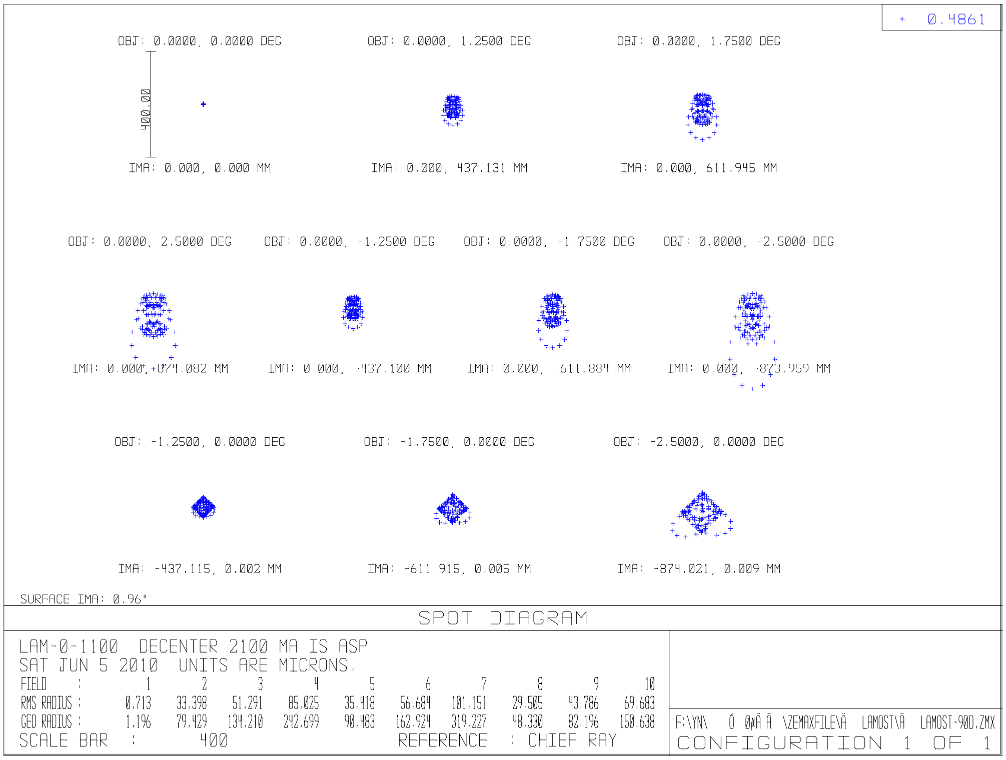
Fig. 1 The sky coverage of LAMOST South with the optical axis tilted in 60 degrees

Table 2 Image quality of LAMOST South (80% and 90% energy encircled, in arc seconds)

FOV (2w) / δ (°)	3° EE80	3° EE90	5° EE80	5° EE90
0	0.05	0.10	0.06	0.10
-10	0.11	0.12	0.19	0.21
-20	0.19	0.21	0.33	0.37
-30	0.28	0.30	0.48	0.53
-40	0.37	0.40	0.64	0.71
-50	0.47	0.50	0.80	0.90
-60	0.57	0.62	0.98	1.10
-70	0.68	0.74		
-80	0.82	0.88		
-90	0.98	1.05		



δ= -60°



δ= -90°

Fig. 2 The spot diagram of LAMOST South for optical axis tilt in 60 degrees

From above preliminary calculations, one could see that the better image quality could reach with the higher tilt angle of the optical axis and even the same field of view of LAMOST.

2.2 Atmospheric dispersion correction

There is no correction on atmospheric dispersion in LAMOST North since it is very difficult to realize. The way we have thought about to correct the atmospheric dispersion is to put a small correct lens on the front end of each optical fiber. The difficult thing is how to hold the corrector lens in front end of each fiber, and without rotation during fiber positioning. Considering the maximum atmospheric dispersion is about the same as site seeing at Xinglong, and just for the extreme sky area, the correction was gave up. Now, for LAMOST South, we are thinking about to correct the atmospheric dispersion with a special way. For example, we just correct the atmospheric dispersion for the sky area from declination -90° to -60° by putting at some prism strips in front of the focal surface. The calculation and analysis on this method has been done, and shown the possibility (the paper on this special atmospheric dispersion corrector is going to be published as soon as possible). In this way, we believe that the image quality of the LAMOST South should be about twice better than LAMOST North. Also a half diameter of the optical fiber could be applied in. Therefore, the limited observing magnitude should be higher.

2.3 Tracking

From Fig.1, one can find that in the sky areas of $-10° \le \delta \le 0°$, celestial objects could not be observed during a period around the meridian plane because the tube of LAMOST will obstruct them. At present, we are considering preliminarily that for this small part of sky coverage, the alt-azimuth mounting of the reflecting Schmidt corrector will stop the observation for a while during such a period and tracking just before and after the meridian.

2.4 Positioning of optical fibers

In LAMOST North, 4000 fiber positioning units are installed on the focal surface of 1.75 m in diameter. But actually during each observation, tens of thousands celestial objects can be observed in such wide field of view. If smaller optical fiber positioning units are adopted, there will be about 6000 to 8000 fibers to be used for spectroscopic observation in different sky area and different field of view.

In order to make the optical fiber aiming at the celestial object more easily and quickly, a pre-collimation method will be introduced. The method is that before the observation, firstly an acquiring optical fiber (Fig. 3) will point to the observed celestial object or a brighter object nearby; it will only take very short exposure time for all the acquiring fibers to image the celestial objects on one CCD. After multiple exposures, the acquiring optical fibers will aim at the targets accurately, and then the optical fibers for spectroscopic observations will be moved precisely to focus on the observed objects based on the distance L between the two kinds of optical fibers. Various errors caused by the thermal deformation of the focal plate, the variation and asymmetry of the scale size on the focal surface and so on, will result in the shifting of the origin position of optical fibers. This pre-collimation method can greatly simplify the measuring and modifying these errors before the observations.

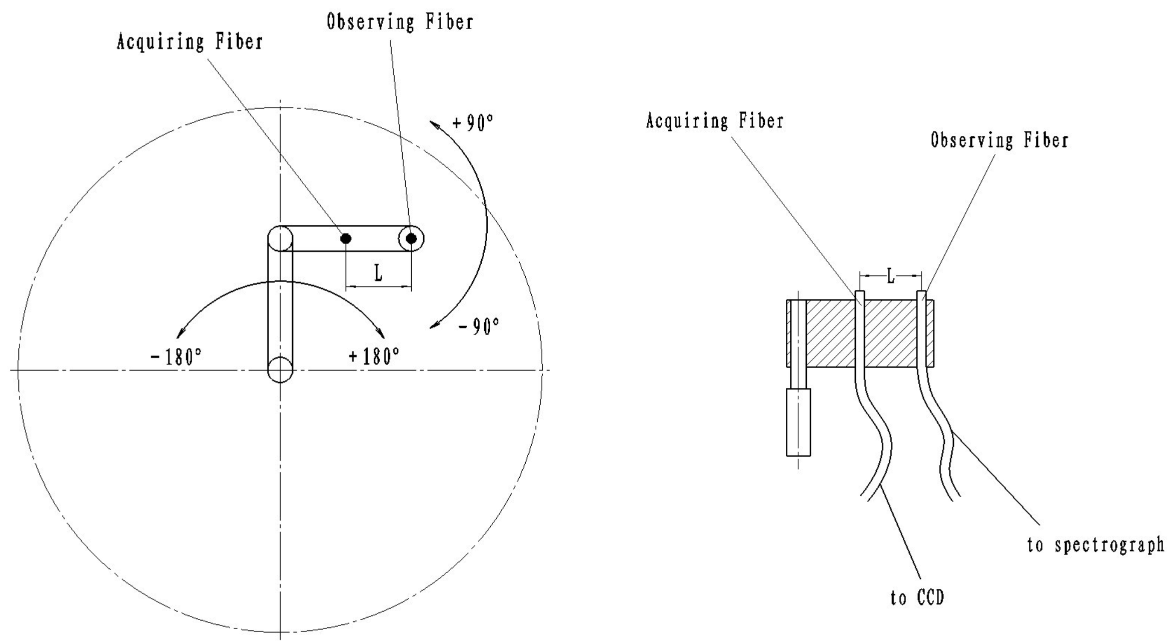


Fig. 3 Fiber positioning units to which acquiring optical fibers are added

3. CONCLUSION AND PRELIMINARY CONFIGURATION

According to the above consideration, the preliminary parameters of LAMOST South are listed in the Table 3. LAMOST South is going to be built via international collaboration. The final parameters are going to be decided with more detail study and discussion with our international partners. We call on that the institutions of international astronomical society could be concerned with the construction of. All issues about LAMOST South could be determined by one cooperation committee which is build up by those institutions involved.

Table 3 The parameters of LAMOST and LAMOST South

	LAMOST	LAMOST South
Aperture	3.6-4.9m	Average > 4m
Field of view	5 degrees	3 - 5 degrees
Site seeing (FWHM)	2 arcsec	< 1 arcsec
Image quality (d_{80})	< 2 arcsec	< 1 arcsec
Fiber number	4000	6000- 8000
Diameter of fibers	3.3 arcsec	1.6 arcsec
Spectrographs / CCDs	16 / 32	8 /16 or 16/32

ACKNOWLEDGMENTS

We thank Dr. Su Lin, Ms Genrong Liu very much for their help on prepare this paper.

REFERENCES

[1] Wang, S.-G., Su, D-Q., and Hu, Q.-Q., “Two telescope configurations for China”, SPIE, 2199, Advanced Technology Optical Telescopes V, ed. by L. M. Stepp, 341–351(1994).

[2] Wang, S.-G., Su, D.-Q., Chu, Y.-Q., Cui, X.-Q., and Wang, Y.-N., “Special Configuration of a Very Large Schmidt Telescope for Extensive Astronomical Spectroscopic Observation”, Applied Optics, 35, 5155 (1996).

[3] Su, D.-Q., Cui, X.-Q., Wang, Y.-N., and Yao, Z.-Q., “Large Sky Area Multi-object Fiber Spectroscopic Telescope (LAMOST) and its key technology”, Proc. SPIE, 3352, 76-90 (1998).

[4] Su, D.-Q., Cao, C.-X., and Liang, M., “Some new ideas of the optical system of large telescopes”, Proc. SPIE, 628, 498-503(1986).

[5] Su, D.-Q., and Cui, X.-Q., “Active Optics in LAMOST”, Chin. J. Astron. Astrophys, 4(1), 1-9 (2004).

[6] Cui, X.-Q., Su, D.-Q., Li, G.-P., Yao, Z.-Q., Zhang, Z.-C., Li, Y.-P., Zhang, Y., Wang, Y., Xu, X.-Q., and Wang, H., “ Experiment system of LAMOST active optics ”, Proc. SPIE, 5489, 974-985 (2004).

[7] Xing, X.-Z., Zhai, C. Du, H.-S., Li, W.-M., Hu, H.-Z., et al. “ Parallel controllable optical fiber positioning system for LAMOST ”, Proc. SPIE, 3352, 839-849 (1998).

[8] Zhu, Y.-T., Hu, Z.-W., Zhang, Q.-F., Wang, L., Wang, J.-N., “A multipurpose fiber-fed VPHG spectrograph for LAMOST”, Proc.SPIE, 6269, 62690M-1-9 (2006).

[9] Cui, X.-Q., “Preparing the first light of LAMOST”, Proc. SPIE, 7012, 701204-1-7 (2008).

[10] Cui, X.-Q., Su, D.-Q., Li, G.-P., Wang, Y.-N., Liu, G.-R., Zhang, Y., and Li, Y.-P., “The optical performance of LAMOST telescope”, Proc. SPIE paper No. 7733-5 in the proceedings of this symposium, (2010).

[11] Yuan, H.-B., Liu, X.-W., Huo, Z.-Y., Zhang, H.-H., Zhao, Y.-H., Chen, J.-J., Bai, Z.-R., Zhang, H.-T., Zhang, H.-W., García-Benito, R., Xiang, M.-S., Yan, H.-L., Ren, J.-J., Sun, S.-W., Zhang, Y., Li, Y.-P., Lu, Q.-S., Wang, Y., Ni, J.-J., and Wang, H., "New planetary nebulae in the outskirts of the Andromeda Galaxy discovered with the Guoshoujing Telescope (LAMOST)", Research in Astronomy & Astrophysics, 10(7), 599-611(2010).

[12] Huo, Z.-Y., Liu, X.-W., Yuan, H.-B., Zhang, H.-H., Zhao, Y.-H., Chen, J.-J., Bai, Z.-R., Zhang, H.-T., Zhang, H.-W., García-Benito, R., Xiang, M.-S., Yan, H.-L., Ren, J.-J., Sun, S.-W., Zhang, Y., Li, Y.-P., Lu, Q.-S., Wang, Y., Ni, J.-J., and Wang, H., "New background quasars in the vicinity of the Andromeda Galaxy discovered with the Guoshoujing Telescope (LAMOST)", Research in Astronomy & Astrophysics, 10(7), 612-620 (2010).

[13] Wu, X.-B., Chen, Z.-Y., Jia, Z.-D., Zuo, W.-W., Zhao, Y.-H., Luo, A.-L., Bai, Z.-R., Chen, J.-J., Zhang, H.-T., Yan, H.-L., Ren, J.-J., Sun, S.-W., Wu, H., Zhang, Y., Li, Y.-P. Lu, Q.-S., Wang, Y., Ni, J.-J., Wang, H., Kong, X. and Shen, S.-Y., "A very bright i = 16.44 quasar in the 'redshift desert' discovered by LAMOST", arXiv:1005.5499, Accepted by Research in Astronomy & Astrophysics (2010).

[14] Wu, X.-B., Jia, Z.-D., Chen, Z.-Y., Zuo, W.-W., Zhao, Y.-H., Luo, A.-L., Bai, Z.-R., Chen, J.-J., Zhang, H.-T., Yan, H.-L., Ren, J.-J., Sun, S.-W., Wu, H., Zhang, Y., Li, Y.-P. Lu, Q.-S., Wang, Y., Ni, J.-J., Wang, H., Kong, X. and Shen, S.-Y., "Eight new quasars discovered by LAMOST in one extragalactic field", arXiv:1006.0143, Accepted by Research in Astronomy & Astrophysics (2010).

[15] Li, H.-N., Zhao, G., Christlieb, N., Luo, A.-L., Zhao, J.-K., Zhao, Y.-H., Chen, J.-J., and Bai, Z.-R. "Test Observation on Searching for Metal-Poor Stars with LAMOST", Accepted by Research in Astronomy & Astrophysics, 1-8(2010).