LAMOST project and its current status

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ABSTRACT

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) is a quasi-meridian reflecting Schmidt telescope with a clear aperture of 4-meter, a focal length of 20-meter and a field of view of 5-degree, dedicated for spectroscopic sky survey. The telescope will be located at the Xinglong Station of National Astronomical Observatory, China, as a national facility open to the astronomical community. The project was planned to be completed in 2004, with its budget of RMB 235 millions yuan (about 28 M$). The project is well in progress, with various sub-systems and their parts in critical reviews or kick-out for manufacturing early or late. Here we report the current status of the project generally. Other authors in this conference will describe details for individual parts of the project.

Keywords: Astronomical telescope, Active optics, Multi-fiber spectroscopy

1. INTRODUCTION

1.1 Scientific Background and Objectives

As a result of many years' efforts, Chinese astronomical community has laid down a solid astronomical observational foundation, which is figured by the 2.16-m and 1.56-m optical telescopes, the 1.2-m infrared telescope, the solar magnetic field and multi-channel telescope, the 13.7-m millimeter wave radio telescope, the meter wave aperture synthesis array and the VLBI stations. It widened and deepened astronomical researches in this country, and raised the standing of Chinese astronomy in the world.

For further progress, Chinese astronomical community, analyzing the developing tendency of contemporary astronomy and astrophysics, and the status of Chinese astronomy, in consideration of the needs and possibility of the present social development in China, proposed the "Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST)" as one big-science project. This project aims at the wide field astronomy and astrophysics, and seizes the valuable opportunity to open up the optical spectroscopic observation in large scale; it realizes a breakthrough in combining large aperture with wide field of view in optical telescope by using original concepts and ingenious design.

The optical spectrum contains abundant physical information of distant celestial objects, and acquiring spectra of a large number of celestial objects is desperately needed in astronomy, which touches various cutting-edge researches of contemporary astronomy and astrophysics. However, among tens of billions various celestial objects recorded by imaging survey, only a very small part has been observed spectroscopically. As the telescope of the highest spectrum acquiring rate, LAMOST will break through the "bottleneck" of spectroscopic observation in astronomy, becoming the most powerful spectroscopic survey telescope for researches of wide field and large sample astronomy. The spectroscopic survey carried out by LAMOST of tens of millions of galaxies and others will make substantial contribution to the study of extra-galactic astrophysics and cosmology, such as galaxies, quasars and the large-scale structure of the universe. Its spectroscopic survey of large number of stars will make substantial contribution to the study of stellar astrophysics and the Galaxy. Its spectroscopic survey combining with the surveys in other wavebands, such as radio, infrared, X-ray and γ-ray will make substantial contribution to the cross-identification of multi-waveband

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of celestial objects. This new telescope will let Chinese astronomy in 21st century have an outstanding contribution in wide field spectroscopy, and in the field of large scale and large sample astronomy and astrophysics, whether extra-galactic or galactic.

1.2. Configuration and Main Parameters

LAMOST is a meridian reflecting Schmidt telescope with a clear aperture of 4-meter, a focal length of 20-meter and a field of view of 5-degree. It is laid down on the ground with its optical axis fixed in the meridian plane, as shown in the Figure 1. It consists of a reflecting Schmidt corrector M_A at the northern end, a spherical primary mirror M_B at the southern end and a focal plane in between. Both the primary mirror and the focal plane are fixed on their ground bases, and the reflecting corrector, as a coelostat, tracks the motion of celestial objects. Celestial objects are observed around their meridian passages. The light collected is reflected from M_A to M_B, and then reflected by M_B and forms image of the observed sky on the focal plane. The light of individual objects is fed into the front ends of 4000 optical fibers accurately positioned on the focal plane, and then transferred into the 16 spectrographs fixed in the room underneath, to be dispersed into spectra and recorded on CCD detectors, respectively and simultaneously.

The southern part of the telescope is higher than the other end, with its optical axis tilted by an angle of 25° to the horizon for the sky coverage. The declination of observable sky area ranges from -10° to +90°. The primary mirror has a size of 6.67m×6.05m with a radius of curvature of 40m, which consists of 37 hexagonal spherical submirrors, each of them having a diagonal of 1.1m and a thickness of 75mm. The reflecting corrector is located at the center of curvature of the primary mirror, and its size is 5.72m×4.40m, which consists of 24 hexagonal plane submirrors, each of them having a diagonal of 1.1m and a thickness of 25mm. The clear aperture of the telescope is around 4m that would become a little larger or smaller depending on the declination of the sky to be observed. Its focal length is 20m, with the focal ratio of 5 correspondingly. The large focal plane of 1.75m in diameter, corresponding to the 5° field of view, should accommodate up to 4000 optical fibers. The fiber positioning mechanism is to place these optical fibers precisely to their pre-determined positions on the focal plane in a relatively short time.

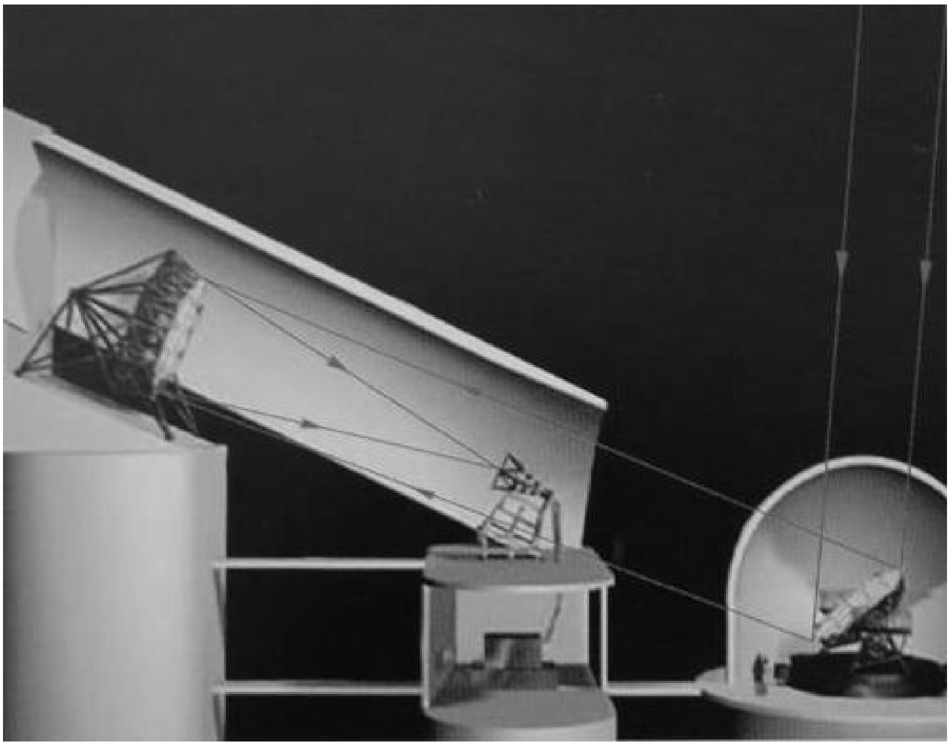


Fig. 1 LAMOST overview

1.3. General Situation of the Project

The LAMOST project has its management under National Astronomical Observatories (hereafter NAOC) with its project office in the headquarter of NAOC, and its main workforce distributed in the Nanjing Institute of Astronomical Optics and Technology /NAOC in Nanjing, the Beijing part of NAOC and in the University of Science and Technology of China in Hefei. The project has its board and scientific and technical committee as usual.

The project proposal was reviewed in 1996, and listed as one of "The National Mega-Science Facilities Program". The feasibility study was reviewed in 1997, and the project started to be funded at the end of the same year. The preliminary design was reviewed in 1998. The project has been in progress, with various sub-systems and their parts in critical reviews or kick-out for manufacturing early or late since then.

The telescope will be located at the Xinglong Station of NAOC as a national facility, which will be open to the astronomical community. The project was planned to be completed in 2004, with its budget of RMB 235 millions Yuan (about 28 M$).

2. NEW CONCEPTS AND KEY TECHNOLOGIES

LAMOST is a novel telescope with some new concepts and new technologies[2] especially in the following three aspects:

(a) Large field of view with large aperture

For a conventional Schmidt telescope with a wide field of view, it is very difficult to make its transmission corrector large, meanwhile for a reflecting telescope with a large aperture, its field of view is smaller. With the new concepts and design, LAMOST is expected to be a most powerful astronomical instrument in combining a large clear aperture (4 m) and a wide field of view (5°).

(b) Obtaining a variable large aspheric mirror surface by combining active optics technologies in both of segmented mirror and thin deformable mirror

The active optics technique for segmented thin mirrors will be applied to the reflecting Schmidt corrector. Combining both the thin mirror and segmented mirror active optics, it not only controls the aspherical shape of the corrector to correct the spherical aberration of the primary mirror, but also controls the co-focus of all 24 submirrors. This system gives excellent image quality within the 5° field of view, with the largest image of 1.77 arcseconds only on the edge of the field of view.

(c) Spectroscopy with thousands of parallel controllable fibers on partitioned focal surface

The large focal plane of 1.75m in diameter, corresponding to the 5° field of view, should accommodate up to 4000 optical fibers, making LAMOST the telescope of the highest spectrum acquiring rate. The fiber positioning mechanism is to place these optical fibers precisely to their pre-determined positions on the focal plane with 4000 small regions in a relatively short time. The parallel controllable fiber positioning promises simultaneously moving the fibers in their own small regions and fine adjusting.

3. CURRENT STATUS AND PROGRESS

The project has divided into eight systems, that is: optics, active optics and mirror support, mounting and tracking, telescope control, instruments, enclosure, observation control and data processing, input catalogs and survey strategy. They are now mostly in detail design and start manufacturing.

3.1.Optics

The primary mirror M_B has a size of 6.67m×6.05m with a radius of curvature of 40m, which consists of 37 hexagonal spherical sub-mirrors, each of them having a diagonal of 1.1m and a thickness of 75mm. To fit the image quality, the requirement for surface error of each sub-mirror is PTV 150nm and RMS 20nm. The critical point is the consistency of the large radius of curvature of all sub-mirrors~~,~~ within 1.5mm, causing the difficulty with manufacturing and testing. The glass blanks is of Schott Zerodur, with the first batch available already. JSC LZOS has been chosen for M_B figuring and polishing recently. The first batch of finished sub-mirrors is scheduled to be available next summer and all 40 sub-mirrors including 3 spares are to be ready afterwards.

The reflecting corrector M_A has a size of 5.72m×4.40m, which consists of 24 hexagonal plane sub-mirrors, each of them having a diagonal of 1.1m and a thickness of 25mm. The manufacturing requirements for surface error of M_A are PTV 550nm and RMS 140nm before the active correction, and PTV 150nm and RMS 20nm after the active correction. The glass blanks is of glass ceramic V02 from the Shanghai Xinhu Glass Work with the first batch delivered. The plane sub-mirrors will be figuring and polishing on the continuous polishing machine of 3.6-m in the Mirror Laboratory of Nanjing Astronomical Optics and Technology Institute.

3.2. Active Optics and Mirror Supports

(a) Active optics[2-5]

The active optical system is the most challenging part of the project. It is not only a combination of segmented mirror active optics and thin deformable mirror active optics on the reflecting corrector $M_{A,}$ but also has two large segmented mirrors needed to be actively controlled in the same time in the telescope. To control the aspherical surface shape of each sub-mirror of M_A, total of 39 support points including 30 force actuators are going to be used for each sub-mirror. The force actuator consists of a load cell, spring, ball or normal lead screw and a step motor, which is controlled in open or close loop by a computer in real time with 1.5 minutes interval. For maintaining the co-focus of both M_A and M_B, there are 3 displacement actuators in each sub-mirror cell for tip-tilt adjusting. For M_A the displacement actuators will be controlled in real time with 1.5 minutes interval together with force actuators. For M_B the displacement actuators will be controlled with much longer interval, because it mainly corrects the thermal deformation of mirror and its support. Two Shack-Hartmann wave front sensors are going to be used in LAMOST. One will be put at focus of the telescope to get wave front information of the M_A for correcting the surface shape and tip-tilt of each sub-mirror. Another one will be located at the center of curvature of M_B that is at the center of M_A.

Two experiments have been done in laboratory for segmented mirror and thin deformable mirror active optics respectively between 1994 and 1998. To approach the real application and optimize the design, an outdoor experiment with full scale but unit optical components started in spring of 2001in Nanjing (Fig.2). The experiment has not got ideal results yet, but many problems have been discovered and been modifying, for example, support system of very thin mirror M_A, force actuators, Shack-Hartmann wave front sensor, accurate tracking of the alt-azimuth mounting and seeing due to air turbulence in the enclosure. It is expected to get some results and make decision for the specification and detail design of the active support system and wave front sensors soon in this year.

The Shack-Hartmann sensors could not measure seven sub-mirrors in the center area of M_B and two sub-mirrors in the center area of M_A, which are blocked by the focal plane. As compensation, displacement sensors are going to be used at least on those sub-mirrors. The choice, on which kind of displacement sensors are going to be adopted, will be made around the end of this year and the beginning of next year.

(b) Mirror supports[6-8]

The mirror supports consists of two separate parts, the support system of M_A, the Schmidt correcting plate, and the support system of M_B, the main spherical mirror. Both are main truss structures with 24 and 37 sub-mirror cells respectively, and they are now in process of the detail design and the final structure analysis.

So far, the modification design and further optimization of the M_A cell has been finished. A pilot M_A sub-mirror cell has been also designed and calculated, and will be accomplished for delivering to manufacturer. Displacement actuator has been preliminarily chosen and relevant structure has been considered and reviewed together with sub-mirror cell design. Dynamic calculation of the whole M_A support system is also underway.

(a) Overview

(b) Schmidt plate with its alt-az mounting and active support system

Fig. 2 Outdoor experiment for active optics

As to the progress in the support system of $M_{B,}$ presently, the pilot sub-cell of Mb, a whiffletree style axial support system and a center lateral support system have been chosen. It is in process of machining, and related testing configuration is laid out and designed. The setup is ready for testing. The main support structure of M_B has been modified with the final structure analysis.

3.3. Mounting and Tracking[9, 10]

It is a special alt-azimuth mounting system tracking in the direction of the normal line of the tracking mirror like coelostat, and the tracking path mainly around the meridian surface that means the tracking speed is very low and smooth. The focal plane mechanism will take the task of tracking in rotation to compensate the image rotation.

The detail design of the alt-az mounting and tracking system have been reviewed and modified. It is ready for manufacturing all big parts of the structure and oil hydraulic pads. The companies, which can manufacture the big structure and oil hydraulic system, have been preliminarily chosen. The tape encoder supplied by HEIDENHAIN Co. in German will be used as the angle measuring device. The quality of mount, the moment of inertia, the deformation and so on have already been defined. The detail design will be finished soon.

The focal structure is related with many sub-systems, such as fiber positioning, Shack-Hartmann wave front sensor and CCD guiding for telescope tracking. So the detail design of this part will be a little late than others. It is expected to be finished in the first half of next year. The focal mechanism will take the task of focusing and tilt adjusting of the focal plane for the image quality also.

3.4. Telescope Control[11-13]

The telescope control is going to call for bid soon in this year.

Some parts of the system have been developing since 2000: (a) The control system in high hierarchy has passed the review in July 2001 on the level-0 simulator. Development of level-1 simulator for control system now has been proceeding steadily. (b) The development of GPS based timescale synchronization system has been completed, and passed the review in July 2002. The system is able to establish timescale with accuracy of 1 ms on the real time distributed control system of the telescope. (c) The development of QNX based real time distributed database system has seen its completion, and has passed the review in July 2002. Three servo loops, namely current loop, velocity loop and position loop, have been adopted for azimuth axis tracking in outdoor experiment system. Improvement for the tracking control is in progress.

In the active optics control of the outdoor experiment system, 52 sets of force actuators are commanded to control the mirror shape by a computer. The range of manipulating force has reached ± 100N with accuracy of RMS$\leq$50mN. Currently test with 37 sets of force actuators distributed on a LAN controlled by 5 smart controllers is under way. The actuator control strategy is based on so called distributed-and-centralized mode.

Refer to displacement actuator control test, the test for single unit displacement actuator has been done, and multi-unit test is being conducted.

3.5. Instruments

(a) The Low Resolution Spectrographs (LRSs)[14, 15]

LAMOST planed for first light will use 16 Low Resolution Spectrographs each fed by 250 fibers. Each spectrograph has a red and a blue channel by a dichroic separator. Which are designed to meet the scientific requirements: spectral resolution element of 0.5-1.0 nm for galaxy radshift survey and of 0.25 nm for stellar spectroscopic survey, both with spectral coverage is 370 - 900nm.

Fundamental desired capabilities and design alternatives were reviewed in the end of 2000. At that time, two alternative designs, one based on plane reflective grating and another based on aspherical grating[16, 17], were recommended. A prototype of LRS will use aspherical grating. Figure 3 is the schematic of LRS.

Combining the scientific requirements with the technical constraints and cost consideration, its final design is of all-Schmidt system with aspherical reflecting gratings as the dispersing element and corrector for aberration. The 130mm long fiber slit holds 250 fibers send the light to a f/4 spherical collimator of aperture 220x454 mm. A dichroic plate of 220x290 mm divides the beam into red and blue. The blue grating of 220x228 mm with 720 line/mm covers 370-590 nm with the center wavelength of 480 nm, and the red grating of the same size with 480 line/mm covers 570-900 nm with the center wavelength of 735 nm. Both cameras with f/1.5 are Schmidt systems with inner focus. A flattener also acts as the window of CCD detector. The image quality is RMS 12-30 micrometer in diameter.

The 0.5 nm monochromatic image of the fiber core of 320 micrometer is about 120 micrometer in diameter. The spectral resolution element of 0.5 nm can be sampled with 4 -5 pixels even with the biggest available CCD pixels. It could meet easily lower resolution observation for fainter objects by more binning readout. And it can meet the 0.25 nm resolution observations by setting a slit of 160 micrometers width after the fiber slit on the expense of some loss of light, which is tolerable due to the brighter targets for the stellar spectroscopic survey.

A prototype of LRS is to be finished and tested in 2003. Its optics and mechanical parts are under manufacturing. The aspheric gratings are to be provided by LOOM, OMHP (Observatoire Astronomique de Marseille-Provence) through the cooperation. And the sub-master is in preparation using active optics, guided by Professor G. Lemaitre

CCD detector system is being designed in the Detector Laboratory of NAOC. We are searching the probable supplier for the large amount of the chips.

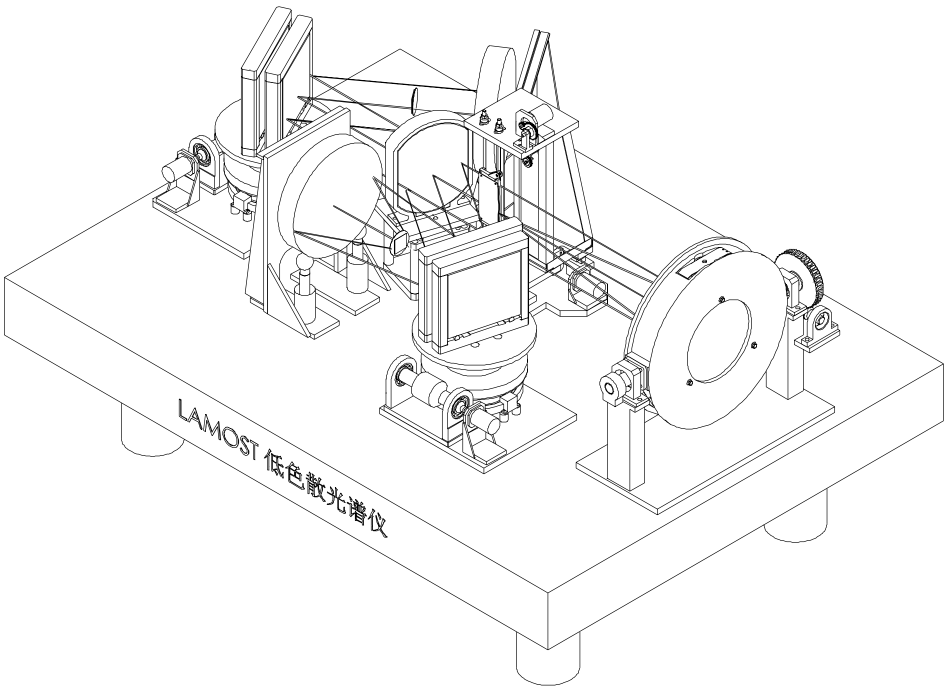


Fig. 3 Low Resolution Spectrograph

(b) Fiber Positioning

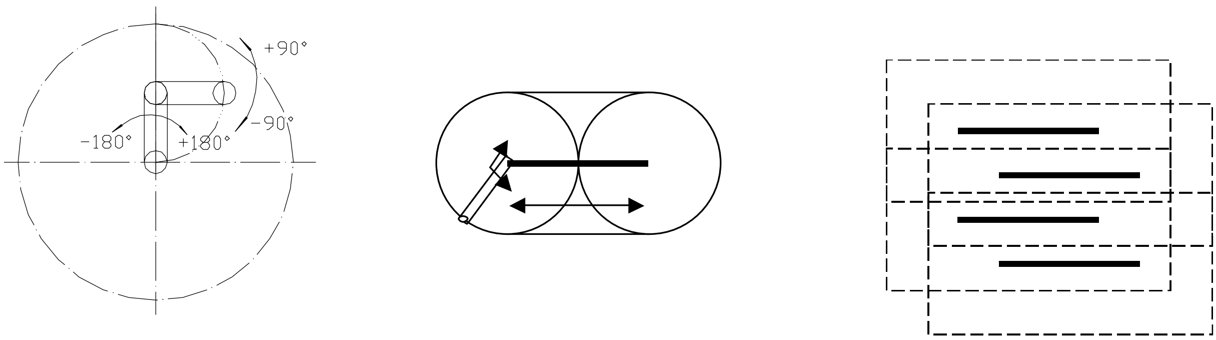
To realize the accurate positioning of thousands of fibers in a short period, the parallel control concept by partitioning the focal surface into thousands of small regions to fit in with thousands fibers is a novel approach. In every small region, computer can control two motors for one or several fibers, which are with the coordinates of stellar objects from catalog. Since this concept proposed in 1994, many fiber-positioning systems have been proposed or developed. Now there are three different types of fiber positioning system have been in tested and developmented in China:

- The focal plane is divided into 4000 small regions for 4000 fibers with the distance of 26 mm between any two neighboring fibers. Each fiber is mounted on a double arm rotating mechanism, and its position is controlled in one small region with a diameter of 35 mm. There are two step motors for control rotations of two arms respectively. It is developed in University of Science and Technology of China in Hefei[18 - 20] (Fig. 4(a)).

- Same as (1), except every fiber positioning mechanism is controlled to move in polar coordinate system with one rotation arm in the region with a diameter of 40 mm. It is developed in Institute of Optics and Fine Mechanics in Changchun.

- Fig. 4(b) and Fig.4(c) showed a schematic drawing of the third design for positioning of 4000 fibers. There are four fibers of one set mounted on one positioning mechanism, which could be moved in linear plus rotational directions in an area of 1200mm^2. The distance between sets is 50 mm. It is developed in Institute of Automation in Shenyang.

At present, prototypes of those three designs with multi-fiber units have been built in laboratories, and are going to be tested on 2.16m telescope in Xinlong Station in this summer.



(a) (b) (c)

Fig.4 Schematic drawings of optical fiber positioning

3.6. Enclosure[21, 22]

LAMOST enclosure is very special because of its 40 meters long “tube” (optical path is 60 m) and the special tracking mode of the reflecting Schmidt plate. The most important and critical problems in the enclosure are the seeing in and out of the enclosure, and the wind buffeting protection for those very thin sub-mirrors of M_A. To keep a good enough seeing several methods are going to be adopted:

The dome of M_A will be open completely but with wind screen (or wall) during observation;

The enclosure of M_B will be ventilated naturally or by exhaust fan;

The wall and floor of the enclosure need to be cool during daytime;

Distributed temperature sensors on enclosure will be used to monitor the temperature gradient and feed back it to the temperature control system.

Some experiments on enclosure seeing have been done with the outdoor experiment system for the active optics in Nanjing. By experiment and analysis of wind tunnel testing and numerical simulation in 1999 and 2000, the preliminarily design of the enclosure is finished. Further optimization and detail design should be done soon after the call for bid.

3.7. Observation Control and Data Processing[23-26]

Observatory Control System deals with the telescope control system, instrument control system and both of data processing and input catalogs and survey strategy to do observation. Its version 1.1 software has been completed, and the version 1.2 is being developed.

Data Processing System is divided into near-line one located in the telescope buildings and off-line one located in the observatory headquarter.

On the Data Processing System, the simulation of the LAMOST raw data has been done. The prototype of data processing software for 2-d spectral data is being developed. Many works on the spectral analysis software has been done, such as spectral classification of objects, measurement of spectral lines and determination of redshifts. A storage system of 5.5TB and databases of multi-wavelength sky survey have been built. Work of Virtual Observatory techniques are being studied to incorporate in.

3. 8. Input Catalogs and Survey Strategy.

The source of the survey targets will be the SDSS released catalog with excellent photometry and astrometry for the 10000 square degrees of the Northern Galactic Cap, which is more than enough for the requirements of the LAMOST input catalogs. And the important DSS-II with other imaging surveys is being studied for the other sky region which the telescope can access.

The guiding star catalog will be GSC2.0.

A software package called "SSS (Survey Strategy System)" is necessarily needed to make the surveys effectively by compile the observation plan from input catalogs of various time intervals, ranging from night to longer period. A group at University of Science and Technology of China has finished its first version.

4. SUMMARY

The LAMOST project is really a great challenge for us due to its innovative idea and its ambitious aim and last but not least, with limited sources. However, it is going forward steadily.

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