Preparing first light of LAMOST

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ABSTRACT

Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) is an innovative telescope project with both large aperture (effective in 4 meters) and wide field of view (5 degrees) to achieve the large scale spectroscopic survey observation. It is a horizontal meridian reflecting Schmidt configuration realized by an active deformable Schmidt plate. For achieving such an ambitious project with limited budget, both its primary mirror (6.67m X 6.05m) and Schmidt plate (5.74m X 4.4m) are segmented. LAMOST project is expected to be completed before the end of 2008. The assembly and test of whole telescope and 16 spectrographs with 4000 optical fibers in its focal plane is going to be finished in August of 2008. With just its partial aperture, more than 200 optical fibers and one spectrograph, the scientific commissioning has been done and some preliminary results have been obtained. This paper introduces the progress of LAMOST project during 2007 and 2008, and presents the achievement in its technology which is also useful for the future extremely large telescopes.

Keywords: Large astronomical telescope, Wide field of view, Active optics, Segmented mirror, Multi-fiber spectroscopy survey

1. INTRODUCTION

LAMOST is a Chinese national large scientific project. It was proposed formally in 1996, and approved by Chinese Government in 1997. The preliminary design and the detail design were finished in 1999 and 2001 respectively. The construction was started in 2001 and will be completed in 2008. The characteristics of LAMOST are: (1) It is a meridian reflecting Schmidt telescope with an active correcting plate; (2) With both wide field of view (5 degrees) and large aperture (effective in 4 meters); (3) There are 4000 optical fibers on the focal surface for obtaining 4000 spectra. LAMOST is going to be operated mainly for spectroscopic survey. With its 1.5 hours average exposure time, and 0.5nm spectral resolution, the 20.5 magnitude objects could be observed in LAMOST spectroscopic survey. Since 4000 spectra of objects could be obtained during one observation, LAMOST will have the highest spectrum acquiring rate for the wide field and large sample astronomy.

The spectroscopic survey carried out by LAMOST of tens of millions of galaxies, stars and others will make substantial contribution to the study of extra-galactic astrophysics and cosmology, such as galaxies formation and evolution 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 structure and evolution of our 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 of celestial objects.

To achieve the large aperture with wide field of view, the main innovations of LAMOST[1, 2] are:

(1) The meridian reflecting Schmidt telescope configuration resolved the difficulties to get large transparent lens and to build a very long tube of Schmidt telescope with large aperture;

(2) Applying active optics to get variable aspheric surface during observation to realize the optical system which could not realized by the conventional way.

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Another main technical innovation in LAMOST is for positioning of 4000 optical fibers[3, 4]. Partitioning the focal surface into small areas and control all fibers by parallel control method to let 4000 optical fibers on the required position in short time before each observation.

Since limited budget of the LAMOST project, both the reflecting Schmidt plate and the primary mirror have to be segmented. This reduced the cost obviously, but introduced the technical challenges in the active optics and the risk in the project. The Technical challenges in active optics are as following:

- A combination of segmented mirror active optics and thin deformable mirror active optics in one mirror;
- Two large segmented mirrors needed to be actively controlled in the same time in the telescope;
- The deformable sub-mirrors are hexagonal;
- Wave front sensing on a variable aperture during change the observing sky area and tracking.

The technical challenges have been overcome based on the researches and experiments in the early stage[5, 6], and continuator in recent years[7, 8], and demonstrated in the "small system" test on site in last year. Some innovations come out during resolving these technical challenges, such as pre-calibration method[9, 10] to obtain the forces and displacements for force and displacement actuators of each hexagonal sub-mirror simultaneously etc.

2. PROGRESS OF SUBSYSTEMS

There are 8 sub-systems in LAMOST project: optics, active optics and mirror support, mounting and tracking, telescope control, instruments (including fibers & fiber positioning, spectrographs, CCDs), enclosure, observatory control & data processing, input catalogs & survey strategy. In last two years, all sub-systems have get into the final stage, completed all manufacturing and started installation on site. The following are progress in main subsystems

Ma is a 5.72m×4.40m reflecting Schmidt plate, which consists of 24 hexagonal plane sub-mirrors. Each sub-mirror has a diagonal of 1.1m and a thickness of 25mm. Most Ma sub-mirror blanks are SITALL from LZOS, Russia and some are VO2 from Xinhu Glasswork, Shanghai, China. All Ma sub-mirrors were polished in NIAOT in Nanjing, China, and finished in Oct. 2006. The average surface accuracy after polishing is 12.45nm in RMS with the first 8 Zernike modes subtracted, where the minimum is 8.02nm and maximum is 18.1nm. Every Ma sub-mirror assembly (sub-mirror with its complete active support system) has been tested in laboratory in NIAOT before integrated on the telescope at Xinglong site.

Mb is a 6.67m×6.05m spherical mirror 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. The Mb sub-mirror blanks are ZERODUR from SCHOTT. The LZOS took the contract for grinding and polishing of all Mb sub-mirrors. LZOS finished polishing all Mb sub-mirrors in Sep. 2006, with the average surface accuracy 15nm in RMS and consistency of the curvature radius less then 1.5mm. Every Mb sub-mirror assembly has been tested in NIAOT before integrated on the telescope at Xinglong site.

Active system including 816 force actuators and 72 displacement actuators for Ma, 111 displacement actuators for Mb, Shack-Hartmann wavefront sensors for Ma and Mb respectively, and their control system. All these components are ready in the early of this year for complete the whole system.

Mounting and tracking system of Ma and focal plane have been installed completely in 2006 and tested in 2007 within the "small system". Telescope control system for pointing and tracking is carried out by CSP from France. Enclosure and building for telescope is completed in 2006 and 2007 respectively, with cooling and ventilation system.

Focal plane instruments are including 130km fibers with a diameter of 320micron, 4000 fiber positioning units, 16 low/medium, and 32 4kX4K CCD cameras. The fiber positioning units is a parallel control system to control 4000 fiber positioning units with 8000 step motors. University of Science and Technology of China is developed the technology and the all 4000 fiber positioning units will be completed in June of this year. The 16 spectrographs with resolution 1000/2000 for low with wave band 370-590nm in blue and 570-900nm in red, and 5000/10000 for medium with wave band 510nm-540nm in blue, and 830nm-890nm in red. The first spectrographs completed in NIAOT in 2006, and all 16 will be completed in August, 2008. The total 32 CCD detectors are with E2V 4096X4096 pixel scientific CCD sensors which have been delivered in 2006. The complete 32 CCD cameras are going to be completed in LAMOST laboratory in Beijing in July, 2008.

Software for automatic observation & data processing for large sky area spectroscopic survey have been carried out and progress obviously by the observatory control & data processing group and input catalogs & survey strategy group in headquarters of National Astronomical Observatories in Beijing and University of Science and Technology of China together.

3. TEST WITH "SMALL SYSTEM"

Take advantage of LAMOST is an integrated parallel system in general, a test for whole key parts has been taken in the first half years of 2007 with just a partial optical aperture including 6 sub-mirrors and Ma, 9 sub-mirrors of Mb (Fig. 1), a small focal plane with 250 fibers (Fig. 5), 1 spectrograph with 2 CCD cameras (Fig. 6). The small system is about a 2m LAMOST but with a complete telescope mounting and tracking system, a complete control software system.

The test with "small system" completed in June, 2007. The testing results are showed in Fig. 2-4 is the test for telescope. With the close loop control by active optical system, the 9 sub-mirrors of Mb can be focused in 80% energy encircled in 0.5 arc seconds (Fig. 2). For whole optical system with both Ma and Mb, during tracking a star for more than one and a half hours, the image quality controlled by the close loop active optics control is within 80% energy encircled in 1.2 arc seconds[11] (see Fig. 3). In Figure 4, it showed the star images in FWHM 2 arc seconds from one of the four guiding CCDs located at the 3° field of view on the focal surface during test observation.

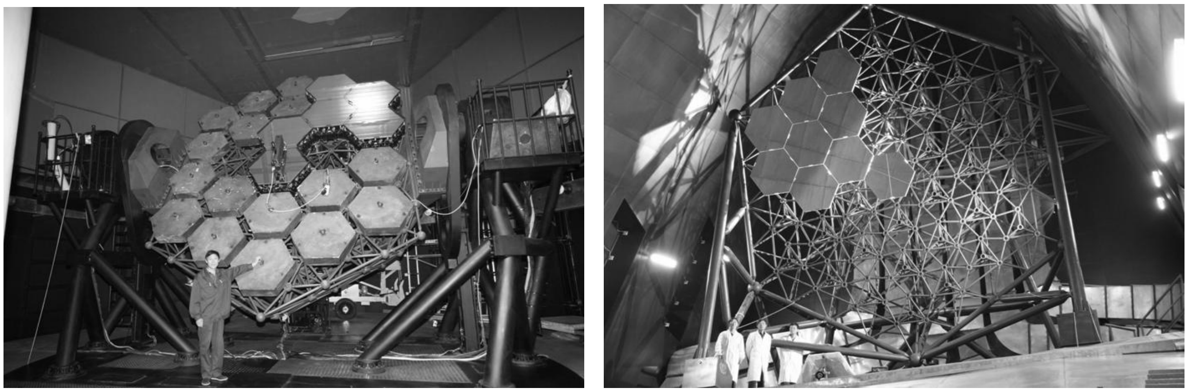
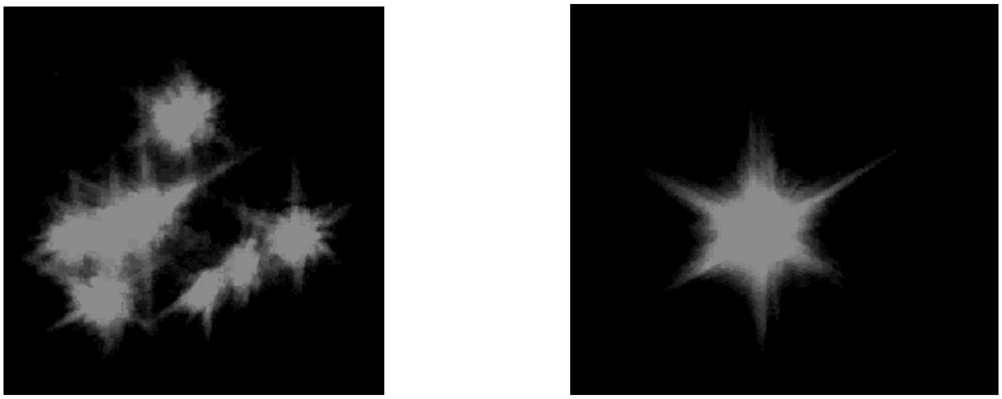


Fig.1. "Small system" with a quarter of segments on Ma and Mb



(a) (b)

Fig.2. 9 sub-mirrors of Mb in active co-focus: (a) before and (b) after active correction

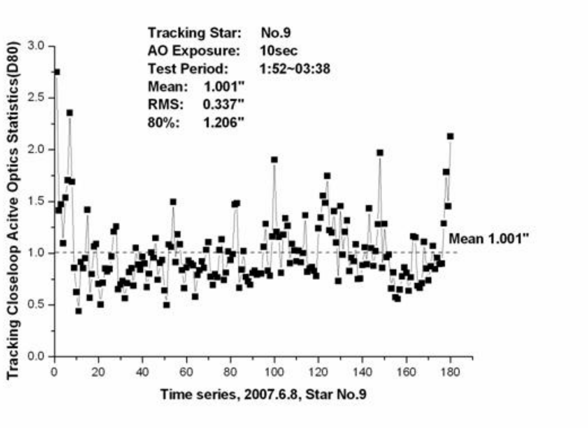


Fig.3. Statistic image results of close loop active control during tracking a star in 106 minutes

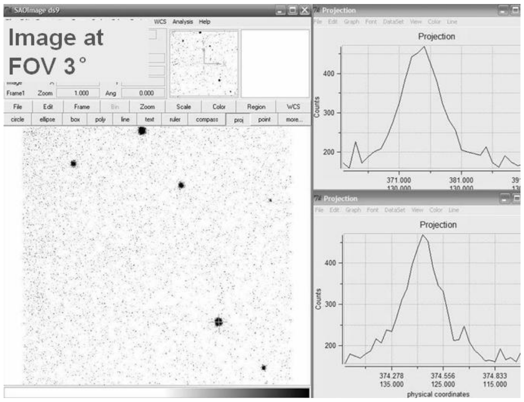


Fig.4 Image quality from CCD camera on FOV 3° during active correction control in test observation

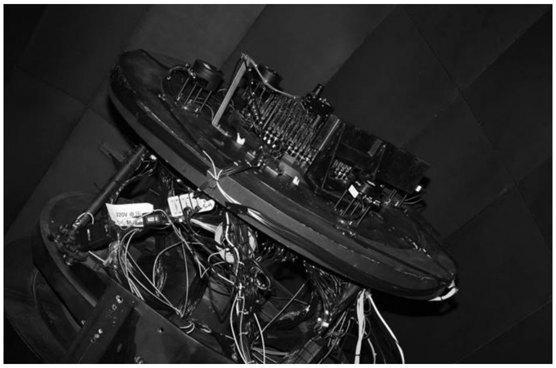


Fig.5. 250 optical fibers and positioning units

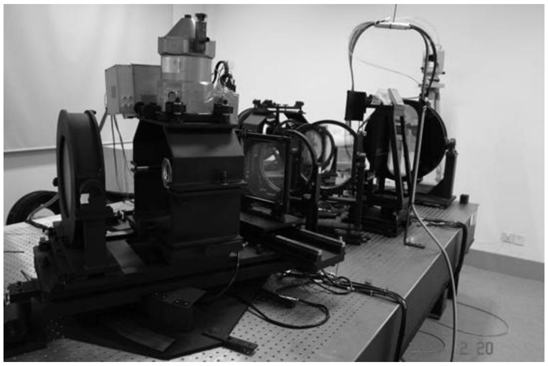


Fig.6. The first spectrograph

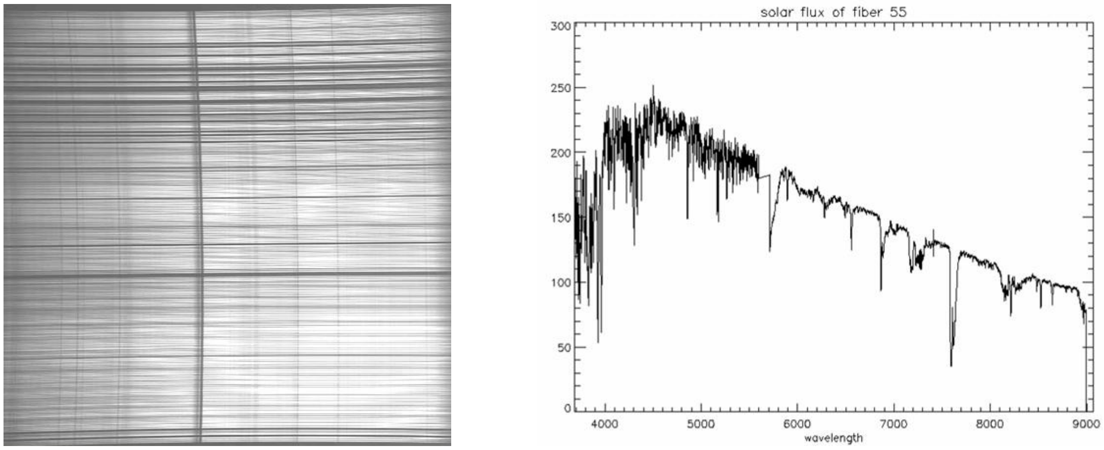


Fig.7. Spectra of sky light in day (15:00 May 25, 2007)

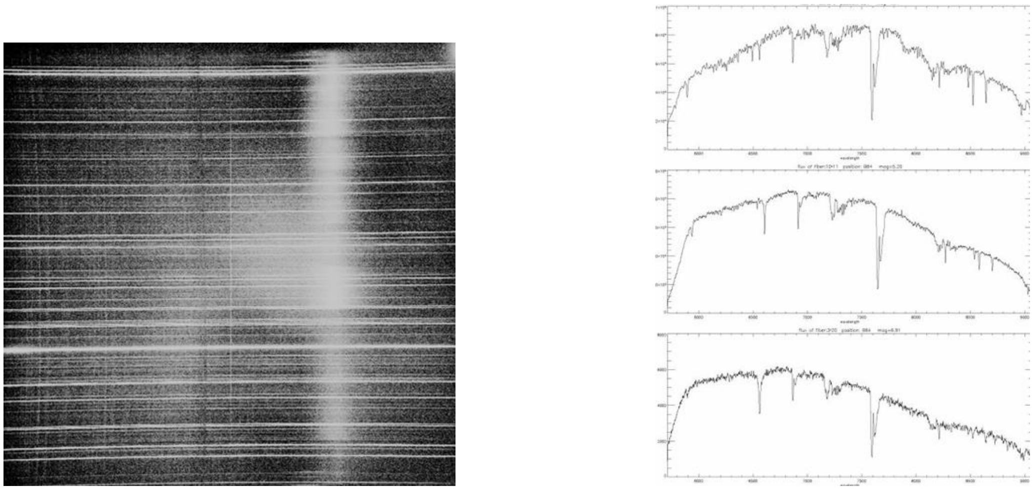


Fig.8. 120 spectra of stars (3:00 June 18, 2007, Cloudy, 1800s Exp)

The observational tests of the small system is including sky light (Fig. 7) and bright stars observation (Fig. 8). To test the whole system in spectroscopic observation, by distributed the selected stars on the fibers automatically, first spectrum got on the 30 May, 2007, and some more and more were got in the following June, but with cloudy weather during that season. With 30 minutes exposure time except blocked fibers in 250 optical fibers, 207 spectra have been observed during the next test around the end of 2007.

The conclusion comes from test of “Small System”:

(1) The whole system is working and all subsystems are reliable, which is including the optical system, the active sub-mirrors support system, the active optics control system, the wavefront sensing, the mounting and tracking system, the optical fiber positioning, spectrograph and CCD cameras.

(2) The method and software to distribute stars on optical fibers are valid.

(3) Efficiency calculated from the observing stellar spectra and sky light spectra showed that the 20.5 magnitude in spectroscopic observation could be reached by full aperture of LAMOST.

During “small system” test, all subsystems within the problems needed to be resolved and modified have been detected. These problems have been processed soon in the next half years of 2007.

After test the “small system”, all of us believe that the success of the“small system”paved the way for complete whole system of LAMOST and get first light in 2008!

4. CURRENT STATES AND FUTURE PLAN

LAMOST building on site has been completed (Fig. 9), and all sub-mirrors of Ma and Mb have been installed and aligned in June (Fig. 10). The 4000 optical fiber positioning system, the 16 spectrographs, and all CCD cameras are going to be ready in two months, so we believe that the first light with 4000 spectra will be see in 2008.

The future plan of LAMOST project is as follows:

- Complete whole system and engineering test before the end of 2008;
- Start the commissioning with complete system in 2009;
- The regular spectroscopic survey in 2010-2015.

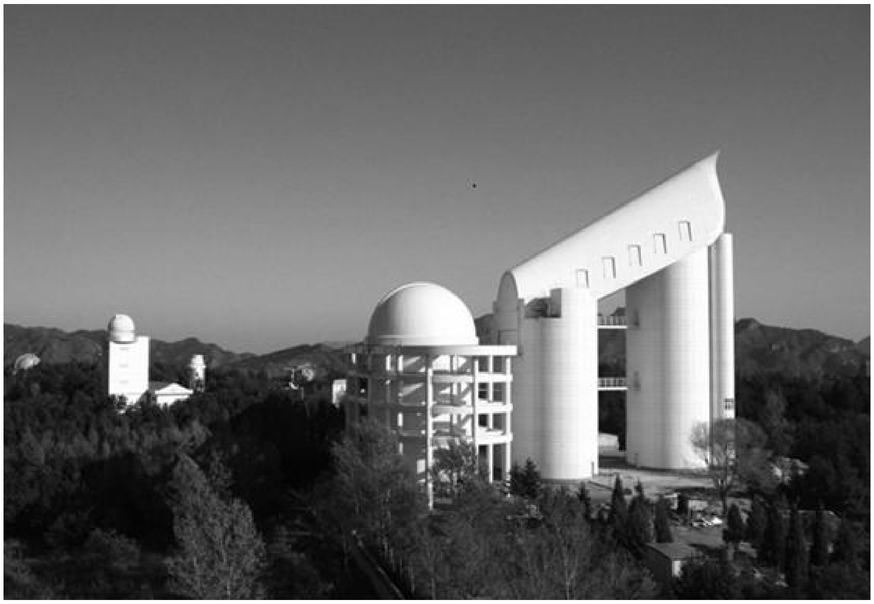


Fig.9. LAMOST on its site (Xinglong)

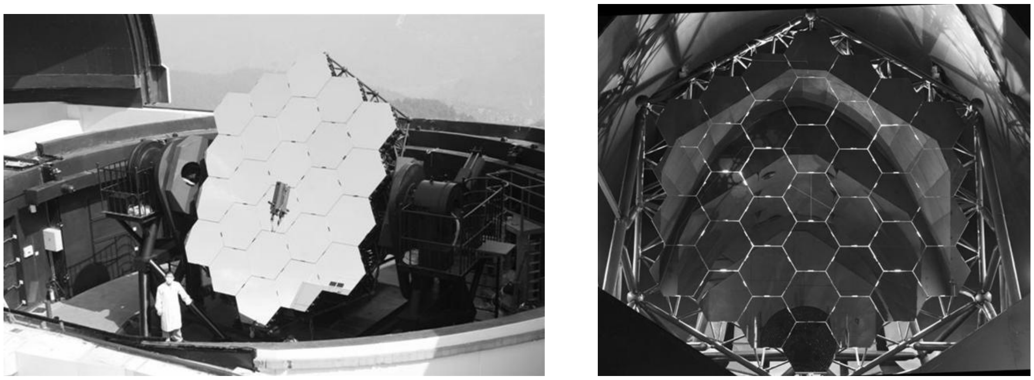


Fig.10 Both mirrors completed installation in June, 2008

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