Pointing model for LAMOST experiment set

Hai Wang*, Yuanxing Zhao
National Astronomical Observatories / Nanjing Institute of Astronomical Optics & Technology, Chinese Academy of Sciences
188 Bancang Street, Nanjing 210042, P.R. China

ABSTRACT

LAMOST experiment set is a special reflecting Schmidt telescope set up at the camps of NIAOT (Nanjing Institute of Astronomical Optics & Technology). It's optical configuration and tracking formulas are given. The difference between LAMOST experiment set and general alt-azimuth telescope is analyzed. The method for getting pointing error data from ST-7 CCD image is discussed. A TPOINT like approach for the pointing model was chosen. The procedure for the development of the model is described. As result we got 4.35" rms accuracies.

Keywords: Pointing model, telescope, LAMOST

1. INTRODUCTION

The LAMOST experiment set was built to verifying active optics and friction driving technology that will be applied in LAMOST telescope. The experiment set consists of three parts: Schmidt corrector mirror (Ma), focal plane mechanism and spherical main mirror (Mb). The optical axis is horizontal with Ma at south, Mb at north and focal plane in the middle. The distance between the Ma and Mb is 40 meters. The focal plane mechanism and Mb are stationary on the foundation. The tracking movement of observed object is depended on the rotation of Ma that is like a 1 meter aperture alt-azimuth telescope (Fig.1). A truss structure with a platform supports the Shack-Hartmann wave front sensor and ST-7 CCD at the focal plane. For simplicity and reduce the cost, there is no optical rotator to take care of effects of telescope field rotation. Because the focus length is 20 meters, the field of view for the wave front sensor is so small that it needs high tracking and pointing accuracy. But the ST-7 camera is equipped with a 3.5x focal reducer giving a field of view of 4.14′ x 2.76′ on a 756x510 number of pixels(pixel dims. 9x9μ)

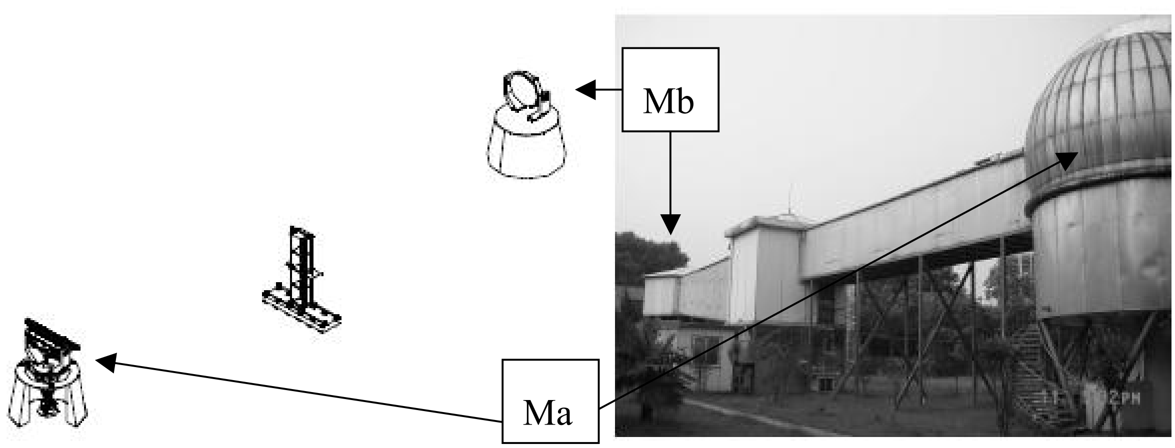

Fig. 1 The experiment set

1

2. TRACKING FORMULAS

[1]*haiwang@niaot.ac.cn; phone 86 25 8548 2259; fax 86 25 8540 5562

Ground-based and Airborne Telescopes, edited by Larry M. Stepp, Proc. of SPIE
Vol. 6267, 62673A, (2006) · 0277-786X/06/$15 · doi: 10.1117/12.670107

The biggest difference between Ma and general alt-azimuth telescope is that Ma reflects incidence light to stationary Mb. There is no blind area in the zenith and elsewhere. But in reality the image quality will degrade if incidence angle is more than 65 degree. The max tracking speed is less than 35 ″/sec and the Ma altitude angle only changes less 1 degree in one and half hour after or before the transit of star. These can be calculated according to its special tracking formula.

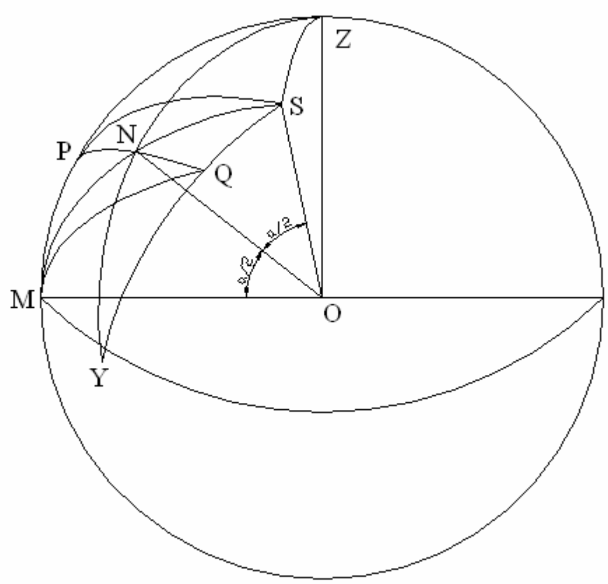

Fig. 2 Celestial Sphere

In Fig. 2, the point Z is the zenith, P is the north pole, M is celestial sphere projection of Mb and also the north point of the horizon, S is star, ON is view line of Ma, N is middle point of arc MS, the angle MON = SON, the arc MN = SN, so S is reflected to M and P to Q, Z to Y. The angle PSQ is the rotation angle γ of the focal plane and equals PMQ. When the hour angle H and declination δ of star are known, the azimuth a , zenith z and γ of Ma can be calculated by following equations derived according to the spherical trigonometry. φ is the site latitude.

$$
\begin{aligned}
&\cos MS = \cos\phi \sin\delta - \sin\phi \cos\delta \cos H \\
&\sin ZMS = \frac{\cos\delta \sin H}{\sin MS} \\
&\cos z = \sin MN \cos ZMS \\
&\sin a = \frac{\cos\delta \sin H}{2\cos MN \sin z} \\
&\sin\gamma = (\cos\phi + \sin\phi \tan MN \cos ZMS)\sin H
\end{aligned}
\tag{1}
$$

When the azimuth a and zenith z of Ma are known, the hour angle H and declination δ of star can be calculated by another set of equations.

$$
\begin{aligned}
&\cos MS = 2\sin z \cos A \sin z \cos A - 1 \\
&\cos ZS = \sin 2z \cos A
\end{aligned}
$$

$$\tan MZS = \frac{\sin z \sin z \sin 2a}{\cos MS}$$
$$\sin\delta = \sin\phi\cos ZS + \cos\phi\cos MS \qquad (2)$$
$$\tan H = \frac{-\cos\phi\sin ZS\sin MZS}{\cos ZS - \sin\phi\sin\delta}$$

3.POINTING MODEL

3.1 Relation between image deviation and needed correction

A real telescope is imperfect in a variety of respects. Its readouts may be offset; the components of the mounting may be out of alignment; the tube may bend under its own weight; the azimuth axis may not point to the zenith. The aim of pointing model is to correct those imperfection by apply correction to the telescope readouts or star coordinate.
For setting up pointing model error data at different sky area must be gotten at first. For this experiment set ST-7 CCD from SBIG company is good enough to take image and guiding, but it's difficult to judge if the star is at center of view field by eye and it takes about twenty seconds to get a new image because of data transfer from CCD to PC. So we decided store star image and encoder readouts of Ma at same moment, then get image deviation by analyze CCD image, finally calculate needed correction applied by Ma. As result we found an interesting fact that is different from general telescope.
Different star coordinates are calculated according to above formulas and showed in bellow figure 3, when the azimuth a and zenith z of Ma are at different position.

$$a = (-80:10:80)$$
$$z = (0:10:90)'$$

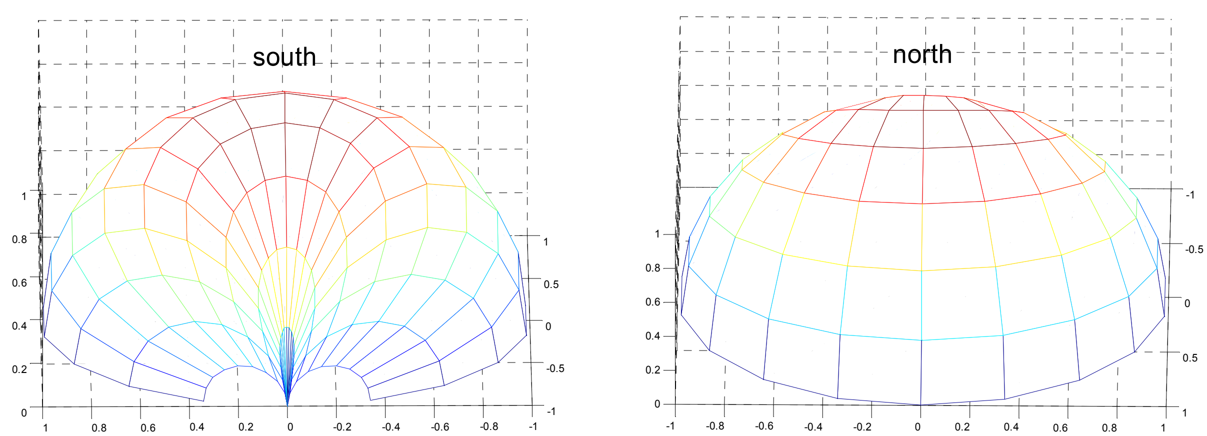

Fig. 3 Distribution map of star

In fig. 3 left map is viewed from south, right from north. The longitude is correspondent with same azimuth and different zenith of Ma, the latitude is correspondent with same zenith and different azimuth of Ma. It's clear that the arc length of different longitude is different. When the azimuth of Ma is 0 degree, the arc length of longitude is big circle. When the azimuth of Ma is 90 degree, the arc length of longitude is zero. So is latitude. In fact no light can be reflected to Mb by Ma when the azimuth of Ma is 90 degree or the zenith of Ma is 0 degree. It can be imagined that same deviation on CCD image means different correction when Ma at different position. We naturally want to know the relation of the deviation on CCD image to correction of Ma.
Assume that star is at center of CCD image, Ma moves a few arc seconds in the azimuth or altitude axis, the deviation of star from center on CCD image can be calculated according to above formulas and showed in bellow figure 4. Because there is no optical rotator, coordinate rotation must be calculated by bellow formulas.

$$Xc = x \cdot \cos\gamma - y \cdot \sin\gamma$$
$$Yc = x \cdot \sin\gamma + y \cdot \cos\gamma \quad (3)$$

In above formulas γ is rotation angle of view field, Xc and Yc are CCD coordinates after rotation. The azimuth a and zenith z of Ma are

$$a = \pm 20 + (-50:10:50)/3600$$
$$z = 60 + (-40:10:40)/3600$$

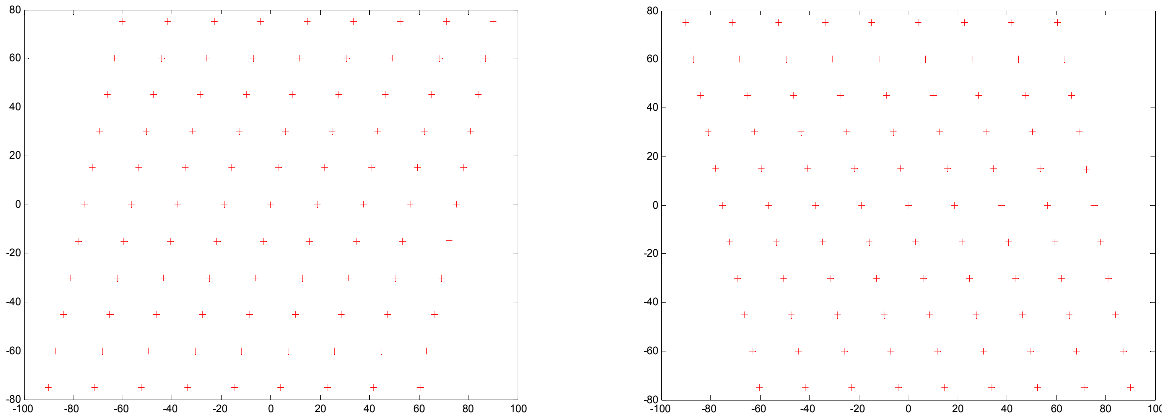

Fig. 4 CCD dot map

In fig. 4 left is dot map when a is negative (after transit), right is symmetric map when a is positive, horizontal row is correspondent with same azimuth and different zenith of Ma, the inclined column is correspondent with same zenith and different azimuth of Ma. The difference between two contiguous columns is same, so is row. The below relations between the deviation on CCD image and correction of Ma are found after checking other position of Ma.

$$delta\_Y = 2 \cdot delta\_a \cdot \sin^2 z$$
$$delta\_X = 2 \cdot delta\_z \cdot \cos a \quad (4)$$

The inclined angle ω between column and row of fig. 4 can be calculated by following formula.

$$\cos\omega = \frac{-\cos z \sin a}{\sqrt{1-\cos^2 z \cos^2 a}}$$

It's clear that the inclined angle ω depends on position of Ma and the correction applied by Ma must be calculated by following formulas.

$$delta\_a = \frac{delta\_Y}{2 \cdot \sin^2 z}$$
$$delta\_z = \frac{delta\_X}{2 \cdot \cos a} - \frac{delta\_a}{\tan\omega} \quad (5)$$

3.2 Basic pointing model

Although the famous TPOINT analysis software written by Patrick Wallace has been applied widely in the world, it can't be used directly in our telescope because of our special optical configuration. But the thinking included in the TPOINT is great. The general approach taken by TPOINT is that as far as possible the telescope model should describe real effects (geometrical misalignments, well understood flexures, etc.), and empirical functions should be used only to mop up any remain systematical errors. This method was chosen to develop our pointing model also.
Ma contains only a piece of Schmidt corrector mirror and dozens of force actuators on back of mirror, so the tube of Ma is short and there is almost no tube flexure. Six basic terms are considered firstly and the pointing model is as follows.

$$ca = IA + CA\sec e + NPAE\tan e + AN\tan e\sin a - AW\tan e\cos a$$
$$ce = IE + AN\cos e + AW\sin a$$

In above formulas the meaning of each parameter is as follows.

Table 1. Meaning of model parameters

a	Position of Ma azimuth axis
e	Position of Ma elevation axis
IA	Azimuth axis index error
IE	Elevation axis index error
CA	Collimation error
NPAE	a/e nonperpendicularity
AN	Azimuth axis north-south misalignment
AW	Azimuth axis west-east misalignment

The pointing error that is the distance d from star image to center of view field can be calculated approximately by following equation.

$$\begin{aligned}&\Delta z = -\Delta e\\ &d = 2\cdot\sqrt{(\Delta a\cdot\sin^2 z)^2 + (\Delta z\cdot\cos a)^2}\\ &PSD = \sqrt{\frac{\sum_{i=1}^{n} d_i^2}{n-p}}\end{aligned} \tag{6}$$

In above equations Δa and Δe are residual of pointing model after least squares estimates, n is samples size, p is number of parameters for model and PSD is population standard deviation.

4.DATA ANALYSIS

Pointing observations were performed in October 2004. The preliminary data analysis based on basic six terms pointing model, which used 55 stars, gave an rms residual error of 4.6 arc sec. The rms pointing accuracy before correction was 17.9 arc sec. The 4.6 arc sec result that was calculated directly from residuals with formula (6) can be verified by another method. Because star coordinate can be calculated with formula (2) so we can get two pairs of coordinate (h1, δ1) and (h2, δ2) according to Ma original position plus original error and original position plus pointing model correction. Assume star (h2, δ2) is at center of view field, the deviation between star (h1, δ1) and star (h2, δ2) can be calculated accounting for tangent plane projecting and view field rotation.

Table 2. Estimates of model parameters and t-value

Name	*Estimate*	*Standard Variance*	*T Test*
IA	-174.3	40.9	-2.2
IE	19.6	4.7	19.3
CA	158.6	49.7	1.4
NPAE	19.7	29.9	0.5
AN	-23.5	4.8	-22.0
AW	56.2	2.5	197.5

According to data in table 2 three parameters IA, CA and NPAE are abnormal.

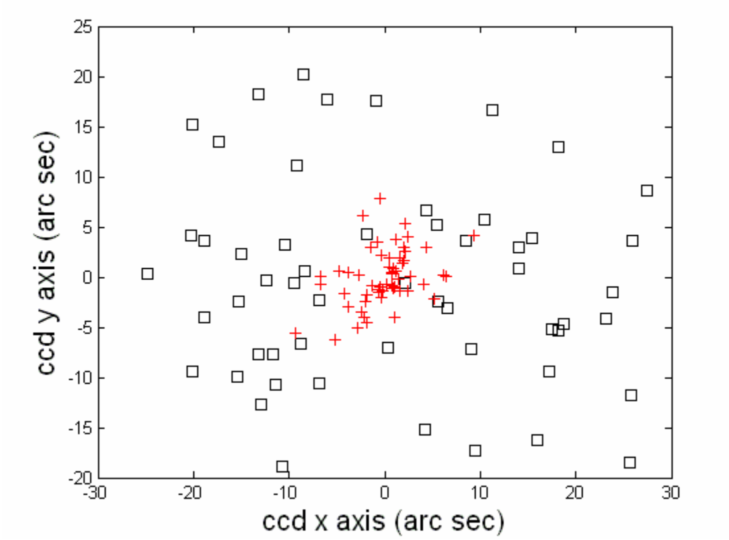

Fig. 5 residual and original error data tested on October 15, 2004

In fig. 5 square expresses original error data and cross for residuals after correction by pointing model.

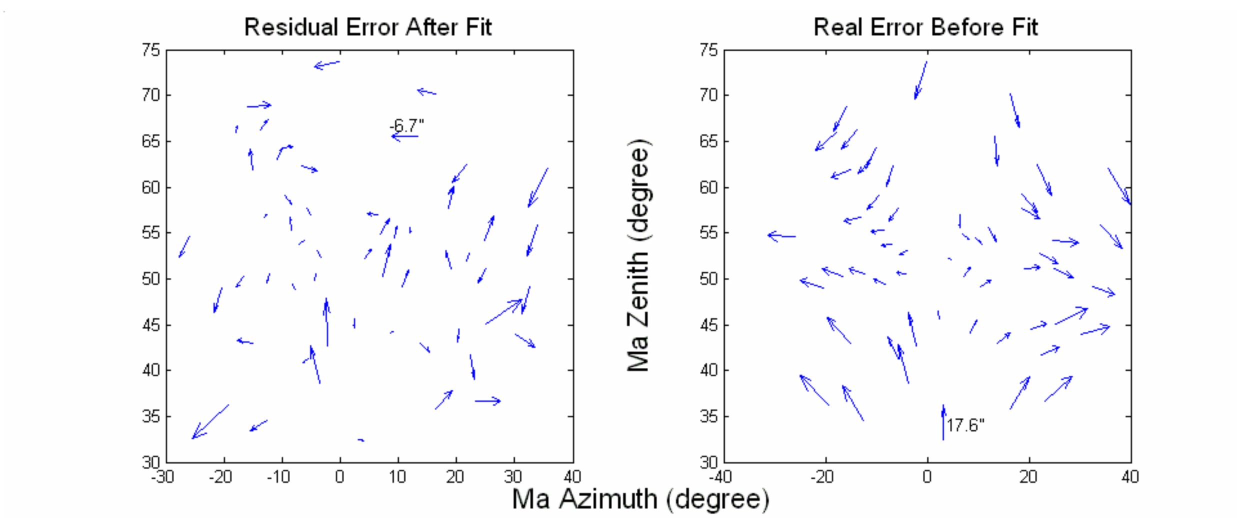

Fig. 6 Error vector before and after fit

In fig. 6 error vector means deviation on ccd image, arrow length means deviation size and arrow origin is position of Ma. Regular pattern can be seen from right real error map and disappears on left residual error map. Residuals are disorderly and not well distributed.

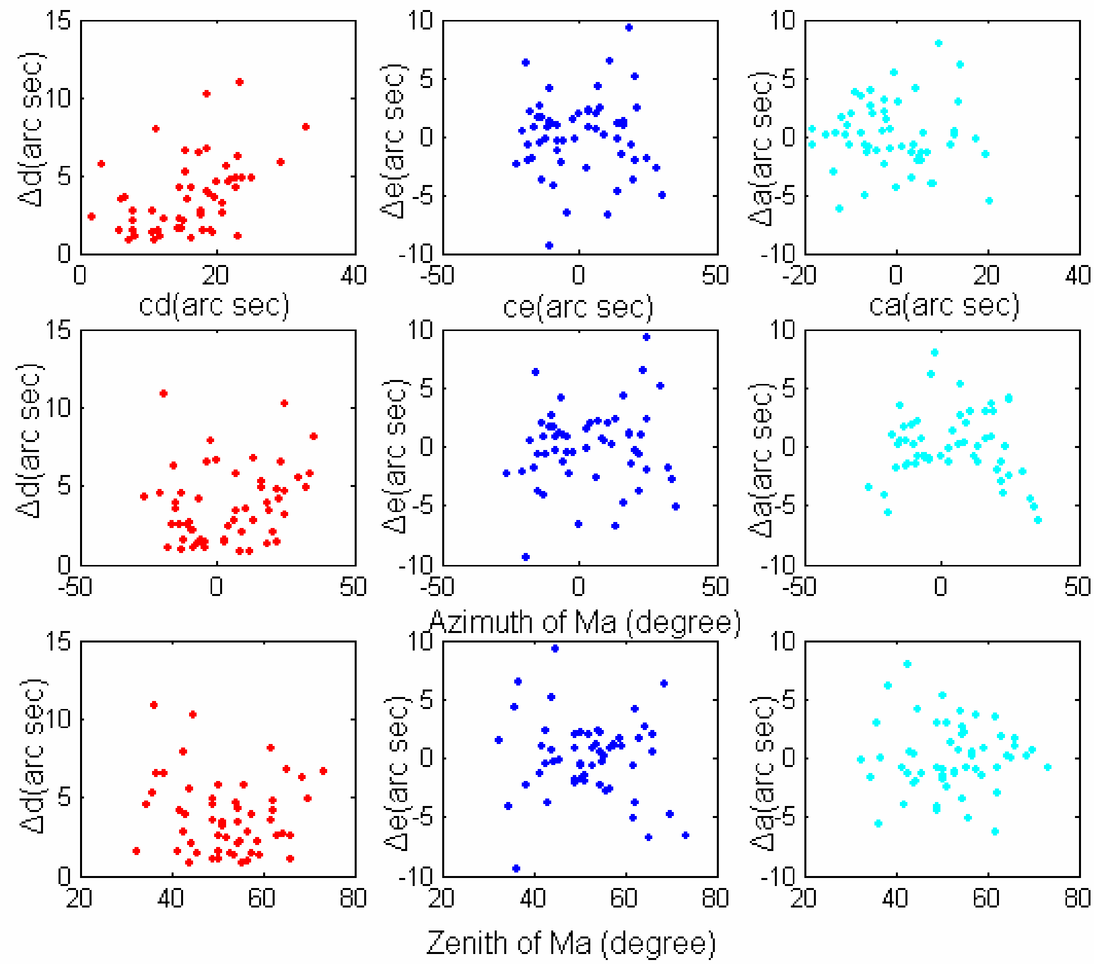

Fig. 7. Residual to different axis

Fig. 7 is a plot of residuals and it's component against different variable. Although the residuals are not well distributed, there is no clear convincing pattern of abnormal behavior. We still believe that there is some inadequacy in the model and that the CCD's axes are not well aligned in azimuth and altitude. Many empirical functions were tried and there was no clear effect. After adding another 4 parameters to basic model 4.35 arc sec rms accuracy was achieved and our model is as follows.

$$ca = 23.8 + 98.3 \cdot \sec e + 27.9 \cdot \tan e - 6.7 \cdot \tan e \cdot \sin a - 58.1 \cdot \tan e \cdot \cos a - 29.7 \cdot \sin a$$
$$- 194.1 \cdot \cos a + 9.5 \cdot \sin 2a \cdot \sec e + 55.5 \cdot \cos 2a \cdot \sec e$$
$$ce = 3.3 - 6.7 \cdot \cos a + 58.1 \cdot \sin a$$

5.CONCLUTION

Although final pointing accuracy is not very good, the method to develop pointing model is right and the pointing model is effective. If we know more about our telescope we'll do better. This experience is also good to the LAMOST and other telescope.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to Yong Zhang, Yeping Li and You Wang for their support in those nights.

REFERENCES

1. Ding-qiang Su, Xiangqun Cui, Ya-nan Wang and Zhengqiu Yao, "Large Sky Area Multi-object Fiber Spectroscopic Telescope (LAMOST) and its key technology", Advanced Technology Optical/IR Telescopes VI, ed. By L. M. Stepp, SPIE Vol. 3352, pp. 76-90, 1998
2. Ding-qiang Su, Ya-nan Wang, "The Tracking Motion of the Large Sky Area Multi-object Fiber Spectroscopic Telescope (LAMOST)", ACTA ASTROPHYSICA SINICA Vol. 17, pp. 315-322, 1997
3. Xiangqun Cui, Ding-qiang Su, Guoping Li, Zhengqiu Yao, Zhengcao Zhang, Yeping Li, Yong Zhang, You Wang, Xinqi Xu, Hai Wang, "Experiment system of LAMOST active optics", Proc. of SPIE VOL. 5489, 2004
4. P. T. Wallace, "TPOINT—Telescope Pointing Analysis System (V. 4.4)", Starlink User Note 100.10
5. P. T. Wallace, K. P. Tritton, "Alignment, pointing accuracy and field rotation of the UK 1.2-m Schmidt telescope", Mon. Not. R. astr. Soc. (1979) 189, 115-122
6. U. Graser, U. Hopp, " Pointing models for the Calar Alto 2.2m and 3.5m telescope", Astron. Astrophys. 251, 737-742 (1991)
7. John O. Rawlings, Sastry G. Pantula, David A. Dickey, "Applied Regression Analysis – A Research Tool", Second edition, Springer-Verlag New York, Inc.
8. Douglas C. Montgomery, George C. Runger, "Applied statistics and probability for engineers", Third edition, John Wiley & Sons, Inc.
9. http://www.jach.hawaii.edu/JCMT/telescope/pointing/