# Low-order AO system in LAMOST

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## ABSTRACT

The large sky area multi-object fiber spectroscopic telescope (LAMOST) is a special reflecting Schmidt telescope with its main optical axis on the meridian plane tilted by an angle of 25º to the horizontal. The clear aperture is 4m, working in optical band. The light path is 60m long when working in observing mode and it will be doubled if work in auto-collimation mode. So the image quality is affected clearly by the ground seeing and the dome seeing. In order to improve the seeing condition of the long light path, we enclosed the spherical primary and the focus unit in a tunnel enclosure and cooled the tunnel. This is an effective but passive method. Corresponding experiments and simulations show the main part of the aberrations caused by the ground seeing and dome seeing is slowly changed low order items such as tip-tilt, defocus, astigmatism, coma and spherical aberration. Thus we plan to develop the low-order AO system based on the low-cost 37channel OKO deformable mirror for the telescope to better the ground seeing and the dome seeing, not aimed to reach diffraction limited image. This work is being carried on now.

**Keywords**: LAMOST, ground seeing, low-order aberration, deformable mirror

## 1. INTRODUCTION

LAMOST is a special reflecting Schmidt telescope with its main optical axis on the meridian plane tilted by an angle of 25º to the horizontal[1], shown in Fig.1. The clear aperture is 4m. The whole system includes three parts: reflecting Schmidt corrector Ma, composed of 24 hexagonal planar sub-mirrors at the northern end; spherical mirror Mb, composed of 37 hexagonal spherical sub-mirrors with the curvature radius of 40m at the southern end, which is fixed on

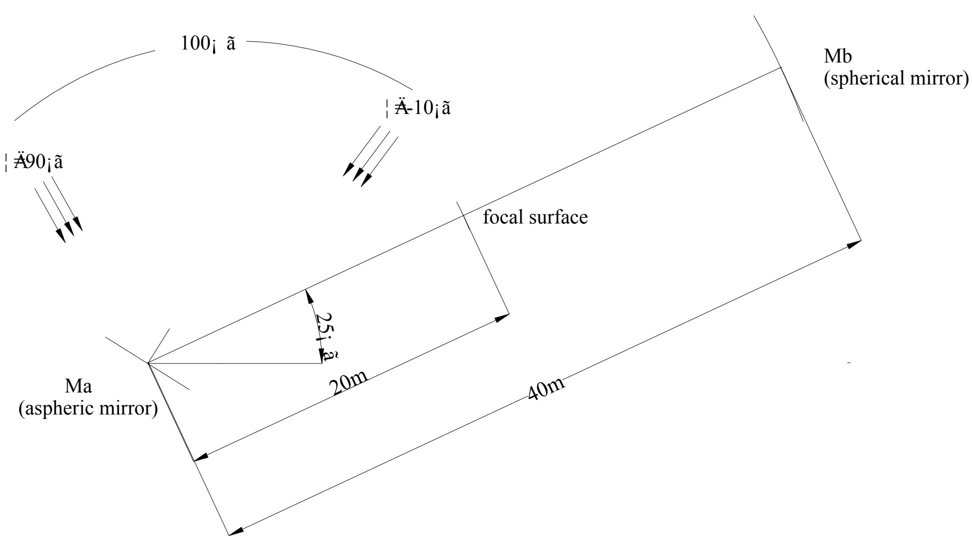


Fig. 1. Diagram of LAMOST

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the foundation; and focal plane with a linear diameter of 1.75m in between, which provides the foundation for placing 4000 optical fibers on the focal surface, also fixed on its ground bases. This configuration breaks through the traditional design mode and leaves out the long tube of traditional Schmidt telescope. An alt-azimuth mounting is adopted for Ma to do the tracking, and the thin mirror active optics technology is used for Ma too to eliminate the third-order spherical aberration of Mb. The project will be finished at the end of 2007. The telescope will be mounted on XingLong Station, BeiJing, where the seeing is about 2″ . The light path is 60m long when working in observing mode as shown in Fig.1. and it will be doubled (120m) if work in auto-collimation mode, as shown in Fig.2, for simplicity the optical axes is made to be horizontal. Thus we can see the image quality is affected clearly by the ground seeing and the dome seeing due to the long light path.

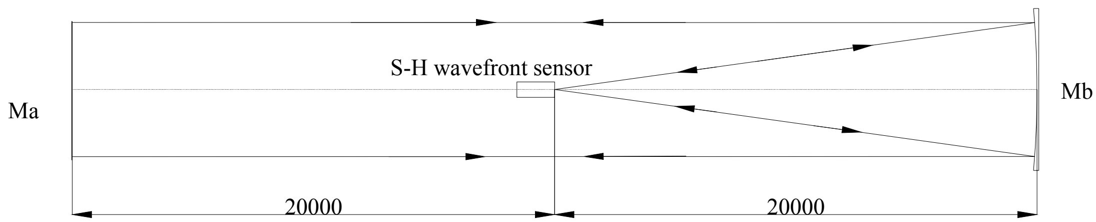



Fig. 2. The optical diagram of auto-collimation mode

In our outdoor active optics experiment system which is a unit LAMOST only with one corrector segment and one primary segment, in order to improve the seeing condition, we enclosed the spherical primary and the focus unit in a tunnel enclosure and cooled the tunnel[2], as shown In Fig. 3 and Fig.4.

Fig.3. The initial outdoor unit active optics setup for LAMOST

Fig. 4. The unit active optics setup with enclosure and cooling system

In our experiments, we collect many frames once, normally 500 frames for centroid determination when reconstruct the wave front. And in this way, we get close-loop result of 80% of the light energy encircled in 1 arcsecond under seeing conditions about 2-3arcsecond. But from the respect of the positioning error of our designed Shack-Hartmann (S-H) wave front sensor (WFS), it can reach 1/50 pixel in lab, but in our outdoor experiment the positioning error only about 1/10 pixel. Thus we can see, seeing in the light path still has clear effect.

According to the reference[3,4], the local air is slowly changed in temporal frequency, and the produced phase distortion is also low-order aberrations such as tip-tilt, defocus, astigmatism, coma and spherical aberration, refer to Fig. 5. This coincides with our experiment. So we want to develop the low order adaptive system to lower the influence of the light path seeing.

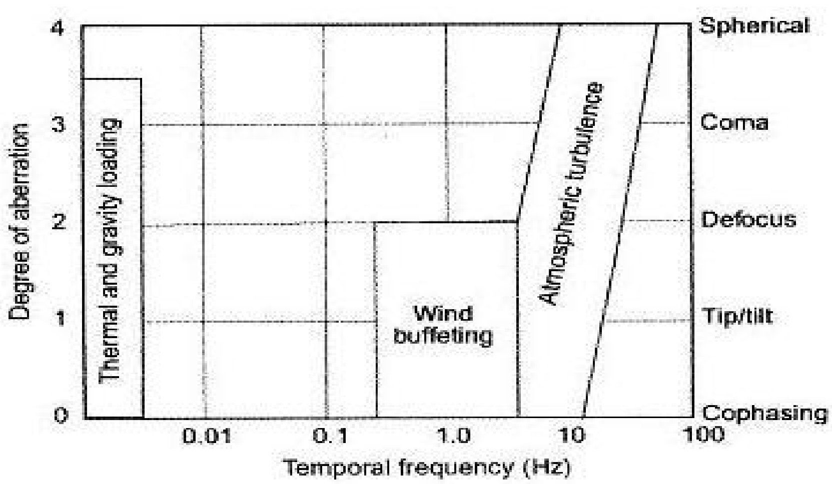



Fig.5. Effects compensated by active and adaptive optics

## 2. PRELIMINARY DESIGN OF THE LOW-ORDER ADAPTIVE OPTICS

According to the LAMOST design specifications, this telescope will work in 390-900nm and 80% energy will encircle in 2 arcsecond. The telescope itself is not designed for high resolution imaging at the current stage, and the low-order AO system is used to better the seeing condition in the long light path, thus partially improve the image quality. Based on our designed S-H WFS for the unit LAMOST experimental setup, we get the close-loop wave front of the auto-collimation correction before and after dome opening, deducted the tilt, defocus, astigmatism, coma and till spherical aberrations in turn, we get the following results, see table.1. The sampling interval is 200ms.

Table 1. Aberration deduction results of the close-loop wave front

| | Unit: μm | Before dome opening Seeing 2.92" | | | After dome opening Seeing 4.36" | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| a | PV<br>RMS | 1.242<br>0.249 | 1.01<br>0.223 | 1.103<br>0.263 | 1.257<br>0.216 | 1.188<br>0.264 | 1.406<br>0.307 |
| b | PV<br>RMS | 1.216<br>0.243 | 0.910<br>0.216 | 1.100<br>0.243 | 1.161<br>0.201 | 1.066<br>0.208 | 1.439<br>0.263 |
| c | PV<br>RMS | 1.212<br>0.244 | 0.961<br>0.199 | 1.055<br>0.232 | 1.144<br>0.200 | 1.060<br>0.209 | 1.439<br>0.263 |
| d | PV<br>RMS | 0.829<br>0.182 | 0.831<br>0.168 | 0.818<br>0.178 | 1.041<br>0.191 | 0.659<br>0.143 | 0.769<br>0.148 |
| e | PV<br>RMS | 0.786<br>0.170 | 0.724<br>0.155 | 0.758<br>0.159 | 0.988<br>0.173 | 0.532<br>0.115 | 0.635<br>0.107 |
| f | PV<br>RMS | 0.712<br>0.123 | 0.683<br>0.097 | 0.684<br>0.107 | 0.666<br>0.132 | 0.581<br>0.111 | 0.576<br>0.107 |

Note : a: full wave front;
b: deduct tip-tilt;
c : deduct tip-tilt and defocus;
d: deduct tip-tilt, defocus, astigmatism;
e: deduct tip-tilt, defocus, astigmatism, and coma;
f: deduct tip-tilt, defocus, astigmatism, coma, and spherical aberration.

Considering the accuracy of S-H wave front sensor and the deformable mirror's correction accuracy, we don't deduct the wave front when rms less than 150nm. The above datum show the low-order AO system with tip-tilt, defocus, astigmatism, coma and spherical aberration correction ability can satisfy the requirement. From the datum, we can also see the ground seeing is some different from the high layer Kolmogorov atmospheric turbulence in which the tip-tilt item will occupy about 87% of the wave front variance[3], and the tip-tilt mirror is necessary. This difference is partially due to the low turbulence sensitivity of our measurement S-H WFS in the active optics experiment setup. But one thing we can make sure is the ground seeing is slowly changed in temporal frequency and the generated wave front variance can be characterized as low-order aberrations. The related experiment is keeping on.

Based on our designed S-H WFS for unit active optics experiment setup, our first step is to design the low-order AO system for the outdoor active optics experiment system which has a clear aperture of 1.1m, the preliminary design is shown as Fig.6., in which component 1(collimating imager, which images the entrance pupil on deformable mirror) and 8 (field lens) are commonly used in both the unit active optics S-H WFS and the AO S-H WFS. When we succeed in the unit experiment, we will continue with our second step to develop a low-order AO system for the whole LAMOST. We investigated the deformable mirrors of OKO Technology, and determined to buy their 37channel piezoelectric deformable mirror (PDM) as our corrector which has 8microns deflection range and can achieve about 0.3mrad tip-tilt correction. In our experiment the average tip-tilt is less than 0.1mrad, so the tip-tilt mirror is not necessary in our system. We are designing the corresponding optical parts as indicated in Fig. 6. with red block.

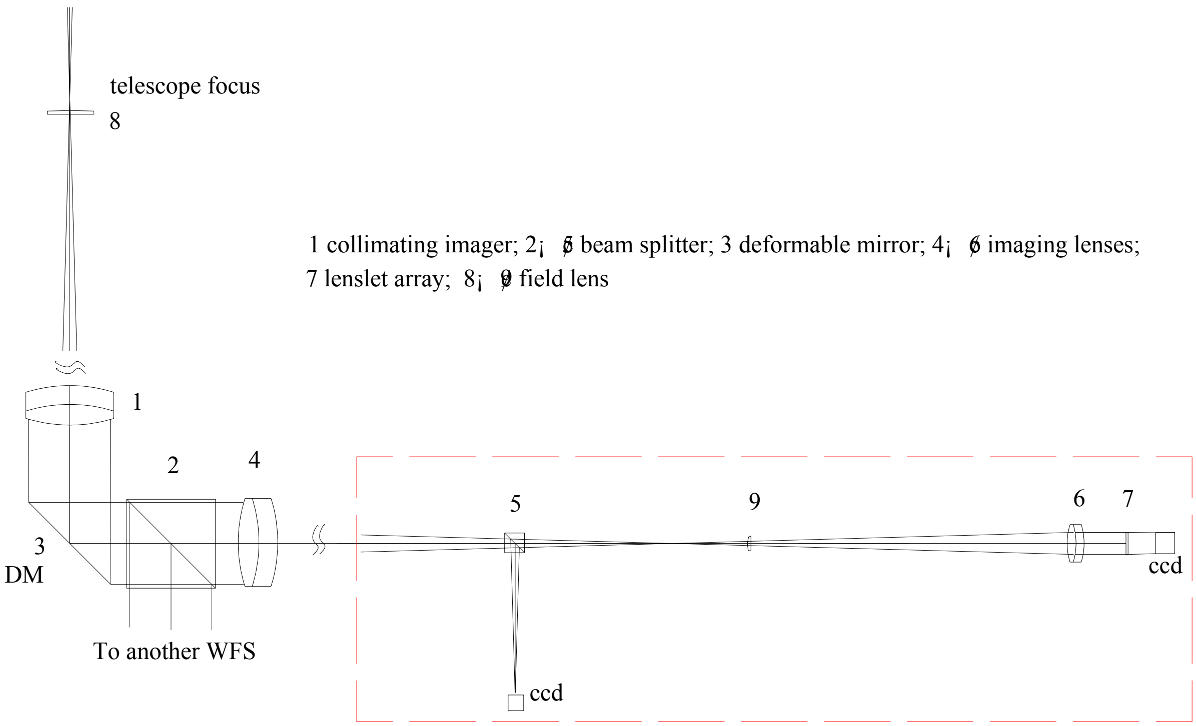



Fig.6. Diagram of low-order AO preliminary designed for the unit LAMOST

## 3. 37 CHANNEL PIEZOELECTRIC DEFORMABLE MIRROR FOR OUR LOW-ORDER AO SYSTEM

The view of OKO 37 channel piezoelectric deformable mirror[5] and the geometry of the mirror's actuators are presented in Fig. 7.

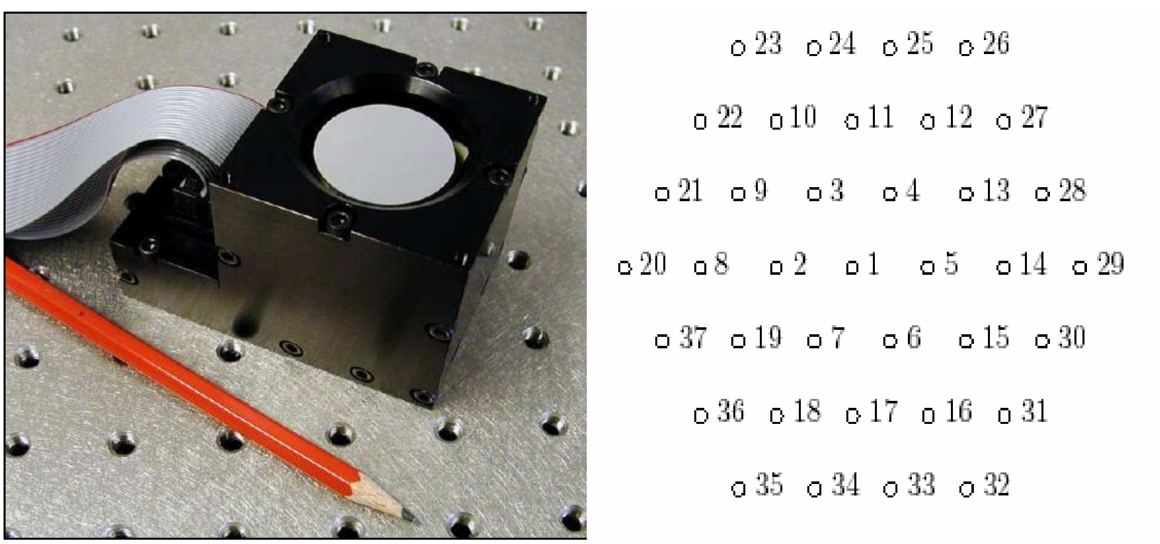



Fig.7. The view of OKO 37ch PDM and geometry of the mirror actuators

The technical parameters of this mirror are listed in Table. 2.

Table.2 Technical parameters of the 37ch PDM

| Parameter | value |
|---|---|
| Aperture shape | Circular 30mm in diameter |
| Mirror coating | metal |
| Actuator voltages | 0 + 400V(with respect to the ground elctrode) |
| Number of electrodes | 37 |
| Actuator capacitance | 5nF |
| Frequency range | 0….2kHz mirror itself |
| Maximum stroke | 8μ m at +400V |
| Actuator pitch | 4.3mm |

The mirror itself has quick respond time and large dynamic range to satisfy our application. The generated low-order mode of zernike aberrations up to [4,4] are shown in Fig. 8.

The wave front correction is performed in a series of iterations[6]. If the residual aberration $\phi_n$ at the n-th iteration corresponds to the set of actuator signals $X_n$, then the actuator signals at the next step $X_{n+1}$ will be determined by

$$X_{n+1} = X_n - g \cdot A^{-1}\phi_n \tag{1}$$

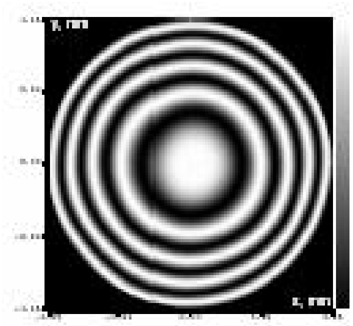
Where $g$ is the feedback coefficient with value in the range $(0,1]$, $A$ is the influence matrix of the mirror, $A^{-1}$ is its pseudo-inverse given by

$$A^{-1} = VS^{-1}U^T \tag{2}$$

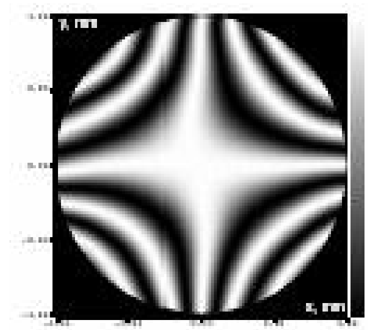
U, S and V are the singular value decomposition (SVD) of A which is $A = USV^T$. The columns of the matrix U make up orthonormal set of the mirror deformations(modes), and the values of the diagonal matrix S represent the gains of these modes. Discarding those modes having small singular values may improve controllability of the AO system.

For atmospheric turbulence with Kolmogorov's statistics, compensated by a 37-channel piezoelectric deformable mirror, the rms residual aberrations (correction error of the deformable mirror) will be about 9% with respect to rms value of the initial aberrations, calculated with the same method described in reference[7].

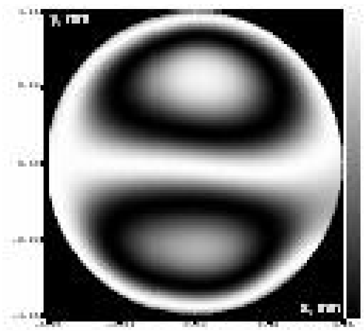
Together with Dell Inspiron 6000 and the CCD of Basler A602f, the close-loop frequency can reach 30HZ, which is totally satisfy our application.



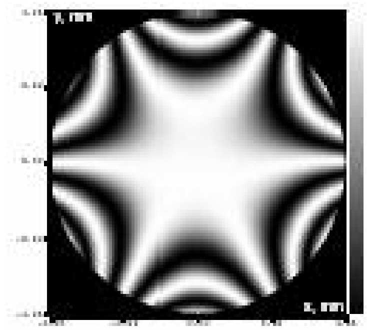
Zernike term[2,0], amplitude 2 μm



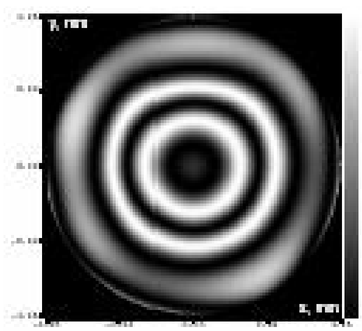
Zernike term[2,2], amplitude 2 μm



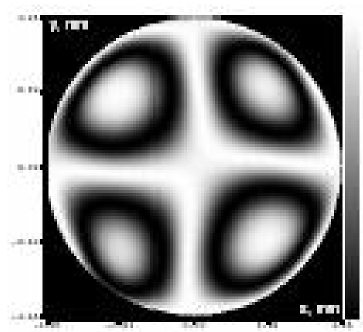
Zernike term[3,1], amplitude 1 μm



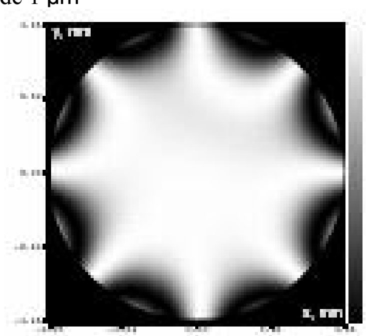
Zernike term[3,3], amplitude 2 μm



Zernike term[4,0], amplitude 1 μm



Zernike term[4,2], amplitude 1 μm



Zernike term[4,4], amplitude 1 μm

Fig.8. Zernike aberrations generated by 37ch PDM

## 4. CONCLUSION

Due to the long light path of LAMOST, the image quality is clearly affected by the ground seeing. Though we adopted some methods to better light path seeing, they are passive in usage. Now we are designing the low-order adaptive optics based on the low-cost OKO 37 channel piezoelectric deformable mirror to lower the ground seeing influence. We'll get the unit test result at the end of this year.

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