First light on the 127-element adaptive optical system for 1.8-m telescope

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A 127-element adaptive optical system has been developed and integrated into a 1.8-m astronomical telescope in September 2009. In addition, the first light on a high-resolution imaging for stars has been achieved (September 23, 2009). In this letter, a 127-element adaptive optical system for 1.8-m telescope is described briefly. Moreover, star observation results in the first run are reported. Results show that the angular resolution of the system after adaptive optics correction can attain 0.1 arcsec, which approaches the diffraction limit of 1.8-m telescope at 700–900 nm band.

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For large ground-based astronomical telescopes, adaptive optics (AO) technique[1−14] can be used to correct the distortion induced by atmospheric turbulence and the optical aberration of the telescopes. After correction, the quality of the image remains limited by the size of the telescope aperture. For astronomical observations, the aberrations occur near the end of the optical path, both in Earth's atmosphere and in the telescope itself. If uncorrected, these aberrations cause the image of a star to spread into a "seeing disk", which may be 10–100 times larger than the diffraction limit of the telescope itself. This results in angular resolution degradation and greatly reduces peak intensity. An AO system measures this phase disturbance and compensates in real time, restoring the image quality to a useful fraction of the diffraction-limited capability of the telescope. In 1996, a 21-element AO system[2,3] was built and installed on the 2.16-m telescope of the Beijing Astronomical Observatory for high-resolution observation in K band. A 61-element adaptive optical system in the 1.2-m telescope of Yunnan Astronomical Observatory was built for observation with a visible wave range in 2000[4,5]. This system was upgraded and operated in May 2004[6,7]. A 127-element adaptive optical system has been developed[8], and was integrated into the 1.8-m astronomical telescope installed at the Yunan observatory in LiJiang in September 2009. The first light on high-resolution imaging for the stars was achieved on September 23, 2009. In this letter, we briefly introduce the 127-element adaptive optics system and present the first result of high-resolution imaging for the stars.

The 1.8-m telescope is a classical Cassegrain optical system with two optical focuses: Coude and Nasmyth (Fig. 1). The primary mirror of the 1.8-m telescope is $F/1.5$ parabolic and its clear diameter is 1760 mm. The parameters of the Coude optical system are shown in Table 1.

The light from the 1.8-m telescope was reflected by the primary, secondary, and tertiary mirrors, as well as the five reflective mirrors in the Coude room wherein the 127-element adaptive optical system was installed (Fig. 2).

In the Coude room, the telescope optics output was deflected by a pick-off mirror into AO system, where it was compensated for both tilt and high-order disturbances induced by atmospheric turbulence and telescope optics. When the pick-off mirror is removed, the telescope optics output can be directed to other systems. A He-Ne laser source was used to calibrate the AO system.

In the AO system, the telescope output was collimated to match the pupil of the tip-tilt mirror and the 127-element deformable mirror using relay optics with four reflective mirrors. We used second relay optics, also with four reflective mirrors, to reduce the beam size to match the pupil of the lens array of Hartmann-Shack (H-S)

Table 1. Parameters of the Conde Optical System

F Number	$F/90$
Field of View (FOV)	$> \Phi 3$ arcmin
Obstruct Ratio	<0.2

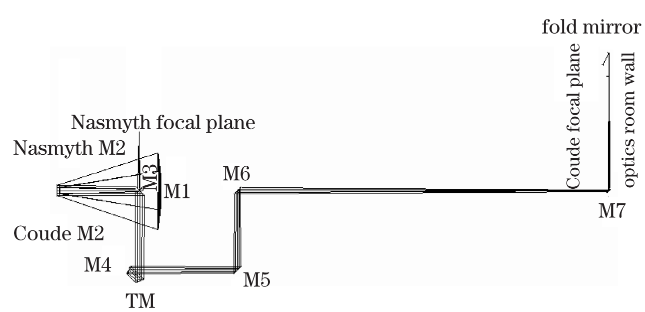

Fig. 1. 1.8-m telescope optical system. TM: tip-tilt mirror, M: mirror.

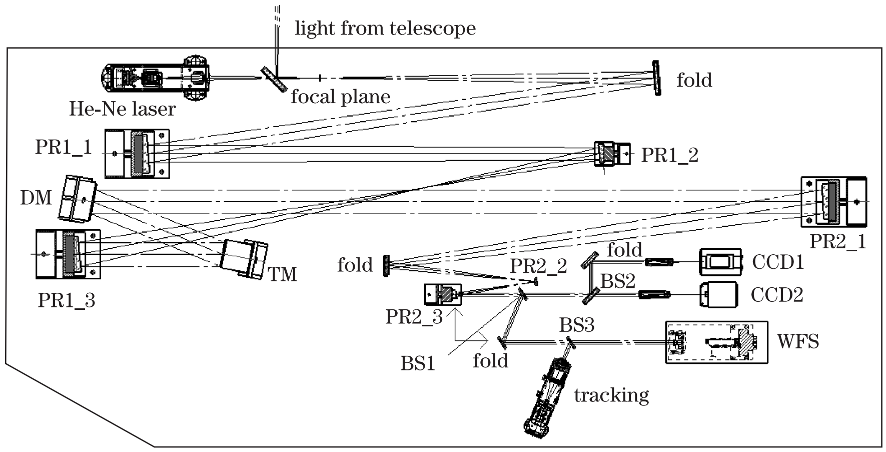

Fig. 2. Optical configuration of the 127-element adaptive optical system. PR: puiple relay optics, DM: deformable, BS: beam split mirror, WFS: wavefront sensor, CCD: charge-coupled device.

Table 2. Main Specification of the AO System

Number of Actuators of the Deformable Mirror	127
Lens Array of the H-S Wavefront Sensor	13×13, Square
Frame Rate of the H-S Wavefront Sensor	500, 1000, and 2000 Hz Selectable
High Resolution I-Band Imaging	700–900 nm
Imaging FOV	27×27 arcsec

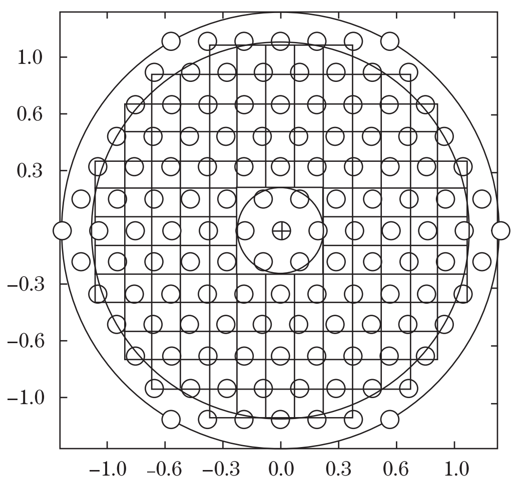

Fig. 3. Arrangement of the actuators of the deformable mirror and the sub-aperatures of the wavefront sensor.

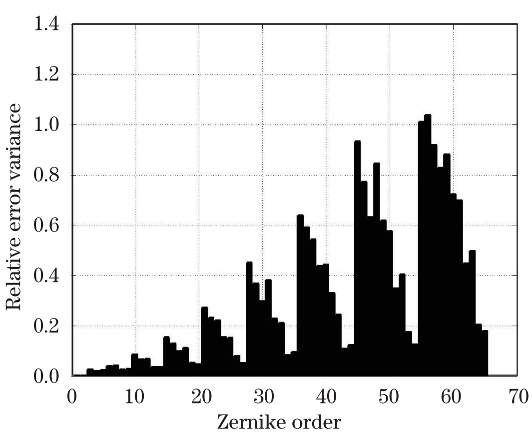

Fig. 4. Relative RMS error of the Zernike aberrations.

wavefront sensor. The beam was split by a dichroic mirror into two parts. Reflective light from 400 to 700 nm was guided to the H-S wavefront and tracking sensors. Transmitted light from 700 to 1700 nm was directed to the high-resolution imaging system, where the light was divided by another dichroic mirror into two beams for I- and J-band imaging.

The AO system has two operating modes: the natural-guide-star mode, wherein the tip-tilt mirror is controlled by the average slope from the H-S wavefront sensor to correct the tilt disturbance, and the laser-guide-star mode, which uses the Na beacon. A very narrow band filter with a central wavelength of 589 nm was designed to transmit the Na beacon light to the H-S wavefront sensor and reflect the visible beam from the natural star to the tracking sensor.

The arrangement of the actuators of the deformable mirror and the sub-aperatures of the wavefront sensor is presented in Fig. 3. Figure 4 shows the relative root-mean-square (RMS) error defined as the ratio of residual RMS error to the original RMS error for the individual Zernike aberrations with this AO system. It further shows that the 127-element AO system can be used efficiently to correct the top 35 orders Zernike aberrations.

In its first run in 2009, the AO system worked in the natural-guide-star mode and the imaging band ranged from 700 to 900 nm. The main specifications of the AO system are shown in Table 2.

The developed 127-element AO system was integrated into the 1.8-m astronomical telescope in September 2009. The first light on the high-resolution imaging for the stars was achieved on September 23, 2009. Figure 5 presents the open- and closed-loop star images of the 127-element AO system in the first run. The sampling frequency was 1000 Hz. The imaging wavelength of the star was I band.

The open- and closed-loop images of the binary star

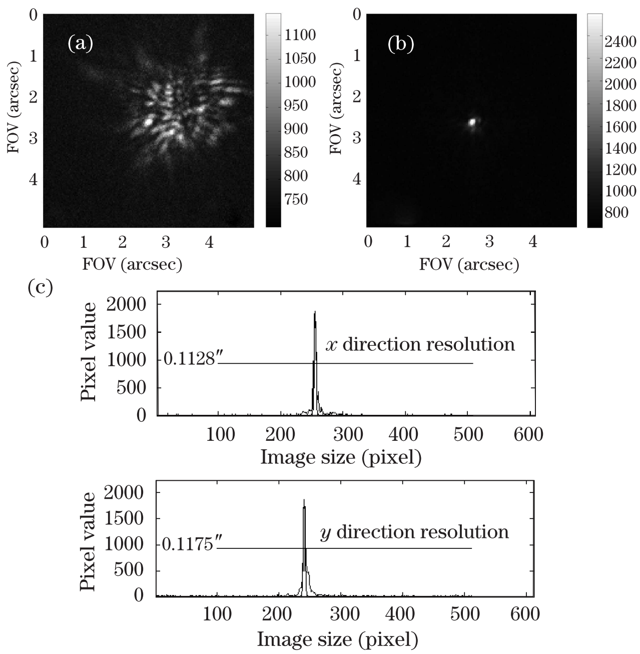

Fig. 5. (a) Open- and (b) closed-loop star images of the 127-element AO system; (c) two-dimensional section of the closed-coop image.

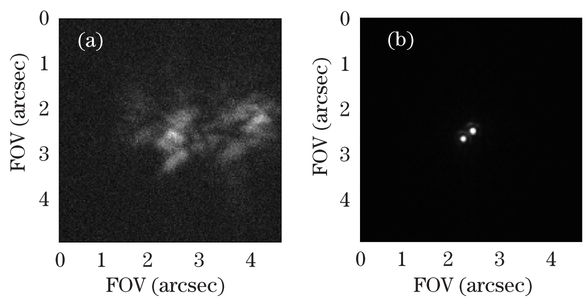

Fig. 6. (a) Open- and (b) closed-loop images of the binary star WDS BU 989 on October 21, 2009. The magnitude is 4.1. The angular separation is 0.245 arcsec.

WDS BU 989 on October 21, 2009 are shown in Fig. 6. The images had a magnitude of 4.1 and an angular separation of 0.245 arcsec. The full-width at half-maximum (FWHM) of the star image with AO was approximately 0.1 arcsec, which approached the diffraction limit of the 1.8-m telescope at 700–900-nm band.

The star observation results illustrated that the AO system can be used to correct the aberration induced by the atmosphere turbulence efficiently. The resolution of the closed-loop image attained the diffraction limit of the system.

In conclusion, a 127-element adaptive optical system has been developed and integrated into the 1.8-m astronomical telescope in September 2009. The first light on the high-resolution imaging for the stars was achieved on September 23, 2009. The star observation results show that the AO system can be used to correct the aberration induced by the atmosphere turbulence efficiently. The resolution of the closed-loop image attains the diffraction limit of the system.

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