37-element solar adaptive optics for 26-cm solar fine structure telescope at Yunnan Astronomical Observatory

Changhui Rao (饶长辉)[1,2], Lei Zhu (朱 磊)[1,2*], Xuejun Rao (饶学军)[1,2], Chunlin Guan (官春林)[1,2], Donghong Chen (陈东红)[1,2], Jun Lin (林 隽)[3], and Zizhong Liu (刘子忠)[3]

[1]*Key Laboratory on Adaptive Optics, Chinese Academy of Sciences, Chengdu 610209, China*

[2]*Laboratory on Adaptive Optics, Institute of Optics and Electronics, Chinese Academy of Sciences, Chengdu 610209, China*

[3]*Yunnan Astronomical Observatory, National Astronomical Observatories, Chinese Academy of Sciences, Kunming 650011, China*

**E-mail: neil_chu1980@yahoo.com.cn*

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A 37-element solar adaptive optics (AO) system was built and installed at the 26-cm solar fine structure telescope of Yunnan Astronomical Observatory. The AO system is composed of a fine tracking loop with a tip/tilt mirror and a correlation tracker, a high-order correction loop with a 37-element deformable mirror, a correlating Shack-Hartmann wavefront sensor based on the absolute difference algorithm, and a real time controller. The system was completed on Sep. 28, 2009 and was used to obtain AO-corrected high-resolution solar images. The contrast and resolution of the images are clearly improved after wavefront correction by AO. To the best of out knowledge, this system is the first solar AO system in China.

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Images with a spatial resolution of around 70–100 km in the solar photosphere (about 0.1 arcsec) are crucial for solving the fundamental space problem of magnetic microstructure, which requires solar observations with spatial resolutions better than 0.1 arcsec; this has given rise to the need for a solar telescope equipped with an aperture of a few meters in size and adaptive optics (AO)[1−3]. Compared with nighttime AO, solar AO is presented with more complex challenges, such as the time variations of day viewing, the use of visible wavelengths for observation by solar astronomers, and the solar wavefront sensor, which must be designed to work on low-contrast, extended, and time-varying objects, such as solar granulation[4].

AO has become an indispensable tool for ground-based solar telescopes to obtain high-resolution solar images. In 2002, we successfully designed a tilt-correction AO system for the 43-cm solar telescope of Nanjing University[5,6] to demonstrate the feasibility of current technology and acquire experience in building AO for meter-class solar telescopes. The development of the system began in Aug. 2008, and was completed in Sep. 2009. In this letter, we present the main characteristics and experimental results of this process. An overview of the system, including the layout and parameters, is given. The experimental results, such as images with or without AO using sunspots and solar granulation as the beacons, are presented.

The 26-cm solar fine structure telescope was built in the 1980s. The field of view (FOV) of the telescope is 6 arcmin, and its spatial resolution is about 2 arcsec. It is located on Phoenix Hill, Kunming, Yunnan. The optical setup of the telescope is divided into two classes, one for observing the photosphere and the other for the chromosphere. The AO system was installed in the optical path of the chromosphere.

Figure 1 shows the optical layout of the AO system, which works in visible spectral range. The light from the sun passes through a vacuum primary collimator that reshapes the telescope pupil to be 27.5 mm in diameter. After passing through a pre-filter (λ=550 μm), the beam is reflected by a tip/tilt mirror (TTM) of 27.5 mm in diameter. The relay optics in front of the deformable mirror (DM) resizes the pupil and makes the beam on the DM approximately circular in shape with a diameter of about 40 mm. Then, the beam reflected by the DM is collimated to a circle of 6 mm in diameter and split into three channels. The first is fed into the correlation tracker channel, the second is fed into the correlating Shack-Hartmann wavefront sensor (WFS) channel, and the third is fed into the imaging channel.

The AO system is composed of a fine tracking loop with a TTM and a correlation tracker, a high-order correction loop with a 37-element DM, a correlating Shack-Hartmann WFS based on the absolute difference algorithm[7−9], and a real time controller. The main parameters of the system are as follows.

Fine tracking loop: FOV of live image: $19.2'' \times 19.2''$; FOV of reference image: $9.6'' \times 9.6''$; Frame rate of camera: approximately 3000 fps; Tilt range of TTM: $\pm 3'$; Resonant frequency of TTM: approximately 800 Hz.

High-order correction loop: Geometry of subapertures: 6×6; FOV per subapertures: $16'' \times 16''$; Frame rate of camera: approximately 1600 fps; Number of DM actuators: 37; Stroke: ± 2 μm.

The integration of the 37-element AO system into the solar telescope was completed on Sep. 28, 2009. Figure 2 shows the images recorded using sunspots as the beacon and a short exposure time (20 ms) with and without AO after dark and flat field processing. Figure 3 presents the images obtained on Oct. 27, 2009 using solar granulation as the beacon (exposure time=20 ms).

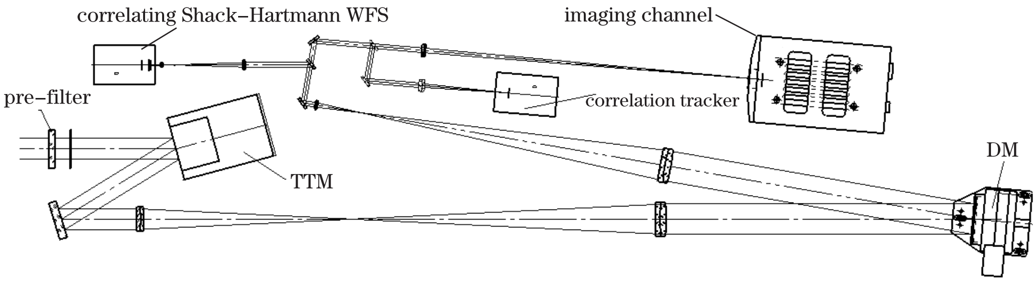

Fig. 1. Optical layout of the AO system.

High-resolution solar images were acquired with the help of AO. The granulation pattern visible in the photosphere and covering the entire surface of the sun was observed. Image contrast increased from about 1% to about 3% when the loop was closed (Fig. 4).

To the best of our knowledge, we have built and successfully tested the 37-element solar AO system for the 26-cm solar fine structure telescope in China for the first time. The design and experimental results of the system are presented. Results show that the contrast and resolution of the images are clearly improved after wavefront correction by AO. A detailed description of the system will be presented in a succeeding letter.

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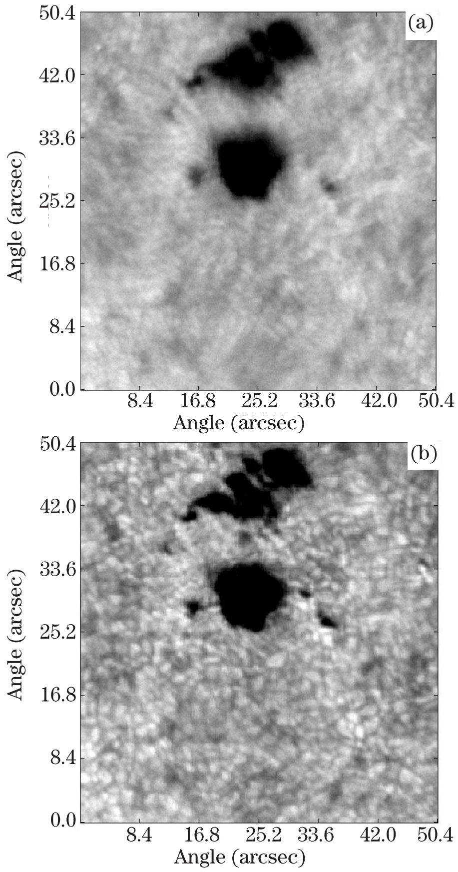

Fig. 2. Images using sunspots as the beacon (a) without and (b) with AO.

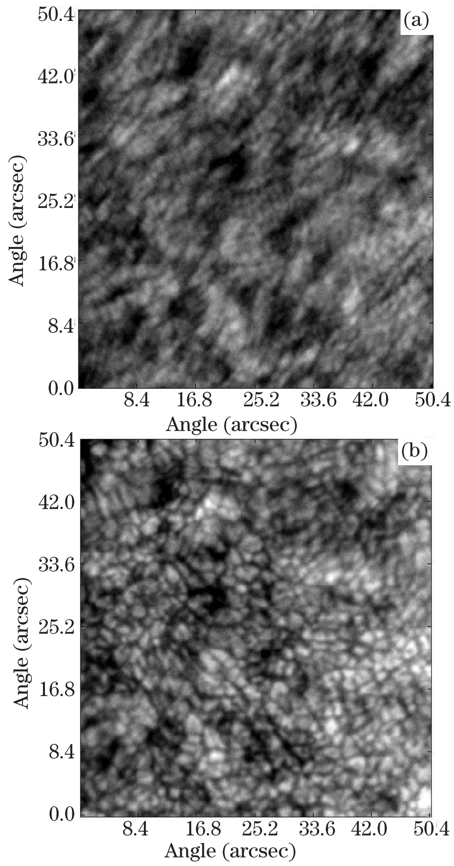

Fig. 3. Images using solar granulation as the beacon (a) without and (b) with AO.

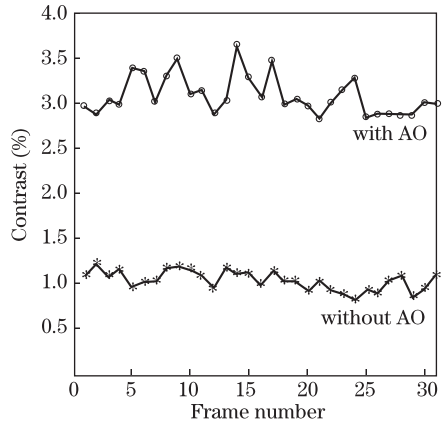

Fig. 4. Image contrast with or without AO (granulation pattern).

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