LASER GUIDE STAR ADAPTIVE OPTICS ON THE 1.5 METER TELESCOPE AT THE STARFIRE OPTICAL RANGE

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Abstract.

The Starfire Optical Range 1.5 m telescope is equipped with a 241 actuator adpative optics system operating at visible wavelengths. The system can use either natural or laser guide star beacons for sensing wavefront distortions induced by atmospheric turbulence. This paper describes the main parameters of the system and presents a few examples of experimental results. The best results are Strehl ratios of 0.64 (star beacon) and 0.48 (laser beacon), both having full-width-half-maximum point spread functions of 0.13 arc second (0.88 μm).

Key words: adaptive optics – laser guide star – atmospheric compensation

1. Introduction

Adaptive optics is one approach to compensate wavefront distortions induced by atmospheric turbulence. Rayleigh scattering of focused laser light can be used to generate artificial beacons for telescopes operating at high D/r_0 and/or that require a high degree of correction (Strehl ratios of >0.5). Results reported here were obtained using a laser beacon at an average range of 10 km.

2. Hardware Description

The details of the experimental hardware are described in the reference and only briefly summarized here. These experiments were performed on the 1.5 m telescope at the Starfire Optical Range (SOR) operated by the Air Force Phillips Laboratory near Albuquerque, NM. The telescope is located on a 12 m pier inside a conventional hemispherical dome and the adaptive optics set-up is in a temperature controlled coudé room. A quartz window isolates the coudé room air from the ventillated pier.

The main elements of the system are the deformable mirror, a two-axis tilt mirror, a two channel Shack–Hartmann camera to sense either star beacons or laser beacons, a full-aperture tilt sensor, the beacon laser, an aperture sharing element for injecting the laser into the coudé feed of the telescope, and processing and control electronics located immediately above the coudé room on the second floor of the observatory. Table 1 summarizes the key parameters. The copper vapor laser shares the full aperture of the telescope in order to minimize the laser beam divergence and create a beacon whose angular size is set by atmospheric seeing. The combination of a polarizing beam splitter and quarter-wave plate provide a very efficient duplexer—coupling the outgoing beam into the telescope and allowing the return light to reach the wavefront sensor.

We have recently retrofitted the wavefront sensor camera with an unintensified 64x64 pixel array fabricated by MIT Lincoln Laboratory. This array has 82% quantum efficiency at 0.6 μm and a read noise of ~12 electrons at 1667 frames per

J.G. Robertson and W.J. Tango (eds.), Very High Angular Resolution Imaging, 293–295.

TABLE I

Laser Guide Star Experiment Parameters

Parameter	Value
Telescope	1.5 m aperture, AZ-EL gimbals
Laser	copper vapor, ~200 watts avg pwr
Laser wavelengths	0.5106 and 0.5782 μm, equal power, full aperture
Pulse format	5000 pulses/sec, 50 ns pulse width
Backscatter range	10 km ±1.2 km range gate
Wavefront sensor	Shack–Hartmann, gated, intensified CCD array
Subapertures	9.2 cm square, 208 total, 16 across the 1.5m aperture
Optics transmission	30% Transmit; 25% Receive
Laser signal	40 primary photo electrons per pulse per subaperture
Pulses per meas.	3, each return integrated 16 μsec, 1667 frames/sec
Deformable mirror	low voltage, continuous facesheet on individual actuators
Number of actuators	241 independent, 305 with slaves, 7 mm spacing
Act./subapt. geometry	actuators registered at the corners of subapertures
Closed loop bandwidth	143 Hz maximum
Imaging wavelengths	0.88 ±0.05 μm, or 0.65–0.8 μm
Camera resolution	0.023 arc second per pixel
Camera filed of view	one arc minute maximum

second. We have demonstrated closed loop adaptive optics operation using this new array at 800 Hz sample rate using an $m_V = 5.3$ star beacon.

We use a 14x14 pixel CCD array for the full aperture tilt sensor (fast guider or tracker). A processor computes the centroid of the natural guide star image and commands a two-axis steering mirror to keep the image centered on the array. The CCD array is quite noisy (160 electrons per pixel) and the tilt correction loop provides image stabilization to 0.02 arc second for stars brighter than first magnitude but only ~0.1 arc second for sixth magnitude stars at bandwidths of 50-75 Hz. Tilt correction is the limiting factor in system performance for long exposure images of faint objects. We plan to upgrade the track sensor using a quieter CCD array and a fiber optic coupled 4x4 array of silicon avalanche photodiode photon counters.

3. Results

Our efforts to date have been directed toward evaluating the system performance using bright stars to measure point spread functions, modulation transfer functions, and Strehl ratios.

Figure 1 is indicative of the performance of the system. The average Strehl ratio of 15 measurements resulted in a value of 0.57 ±0.05 for star beacon compensation and 0.38±0.08 for laser beacon compensation. This figure illustrates rather dramatically the potential of adaptive optics. The compensated images have nearly the same peak intensity as the uncompensated image for only one-hundredth the exposure time.

Figure 2a shows cross secions of 10 ms exposure images of laser beacon and nat-

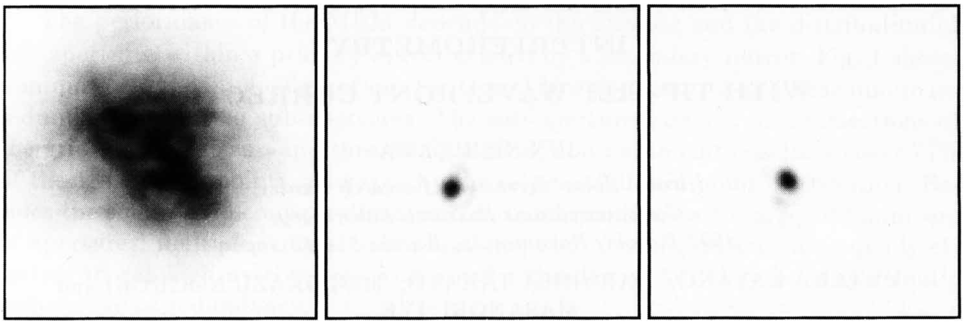

Fig. 1. Comparison of one second exposure tilt only corrected stellar image (left) and 10 ms exposure higher-order compensated images using the star as a beacon (center) and a laser beacon (right). Full-width-half-maximum image sizes are 1.8, 0.13, and 0.13 arc sec, Strehl ratios are ~0.02, 0.59, and 0.48. The fields are 2.9 arc sec square and the imaging wavelength is 0.88 ±0.5 μm. The higher order adaptive optics was operating at a closed loop bandwidth of 105 Hz, the Greenwood frequency was ~35 Hz and r_0 was approximately 8 cm (0.5 μm at zenith).

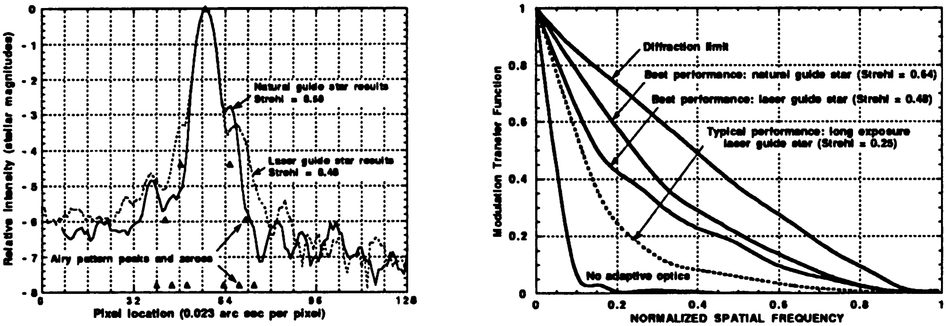

Fig. 2. (a) Point spread function of the system for short exposures. (b) Modulation transfer function of the system for short and long exposures. The performance is degraded at long exposures due to indequate full aperture tilt correction.

ural star beacon compensated images—esentially the point spread function of the system. Figure 2b is the modulation transfer function of the system derived from short and long exposure images. Note there is significant response at high spatial frequencies—permitting the use of image enhancement schemes such as deconvolution.

References

Fugate, R.Q. *et al.*, "Two generations of laser guide star adaptive optics experiments at the Starfire Optical Range," submitted to *JOSA A*, feature issue on Atmospheric Compensation, 1993.