UCRL-JC-121185 Rev 1
PREPRINT
CONF-9510218--3

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S. S. Olivier, J. An, K. Avicola, H. D. Bissinger
J. M. Brase, H. W. Friedman, D. T. Gavel
B. Macintosh, C. E. Max, J. T. Salmon, K, E. Waltjen

This paper was prepared for submittal to the
Optical Society of America Adaptive Optics '95
Garching, Germany
October 2-6, 1995

November 8, 1995

Lawrence Livermore National Laboratory

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INITIAL RESULTS FROM THE LICK OBSERVATORY LASER GUIDE STAR ADAPTIVE OPTICS SYSTEM

Scot S. Olivier, Jong An, Kenneth Avicola, Horst D. Bissinger,
James M. Brase, Herbert W. Friedman, Donald T. Gavel,
Bruce Macintosh, Claire E. Max, J. Thaddeus Salmon, Kenneth E. Waltjen

Lawrence Livermore National Laboratory

ABSTRACT

Results are presented from the initial tests of the sodium-layer laser guide star adaptive optics system developed for the 3 m Shane telescope at Lick Observatory. These results include the first continuous wavefront phase correction using a sodium-layer laser guide star.

1. INTRODUCTION

An adaptive optics and sodium-layer laser guide star system has been built by Lawrence Livermore National Laboratory (LLNL) for the 3 m Shane telescope at Lick Observatory, located on Mt. Hamilton near San Jose, California. The goal of this project is first, to demonstrate the feasibility of using these systems for astronomical imaging, and second, to collaborate with University of California astronomers to conduct forefront research in high-resolution IR astronomy.

2. ADAPTIVE OPTICS SYSTEM DESCRIPTION

Details of the adaptive optics system have been published previously.[1,2,3] This prototype system is mounted at the f/17 Cassegrain focus of the 3 m telescope.

The deformable mirror, built by LLNL, has 127 actuators arranged in a triangular pattern. In the current configuration, 61 of the actuators are actively controlled.

The Shack-Hartmann wavefront sensor has 37 subapertures in the clear aperture of the telescope. The subapertures have a diameter of 50 cm mapped to the telescope primary mirror, and are also arranged in a triangular pattern to match the deformable mirror actuators. The wavefront sensor camera, built by Adaptive Optics Associates, has a 1.2 kHz maximum frame rate, and uses a 64×64 CCD, built by Lincoln Laboratory, with 11 e^- read noise.

The wavefront control computer is an 80 Mflop Mercury VME system with 4 I860 processors. When the control loop is operated at a sampling rate of 500 Hz, 53% of the input phase disturbance is corrected during each cycle time. This includes the effects of camera integration and readout time as well as the compute time and the transfer time to the deformable mirror drivers.

A separate tip-tilt sensor is necessary when the wavefront sensing is performed using the laser guide star. The tip-tilt sensor uses four photon-counting avalanche photo-diodes operated as a quad cell.

3. NATURAL GUIDE STAR ADAPTIVE OPTICS TEST RESULTS

The control loop performance for bright natural guide stars is shown in Figure 1. With a sampling rate of 500 Hz, a closed-loop bandwidth of 30 Hz is achieved. The phase power rejection is 14 dB, corresponding to a factor of 25 reduction in the wavefront phase variance

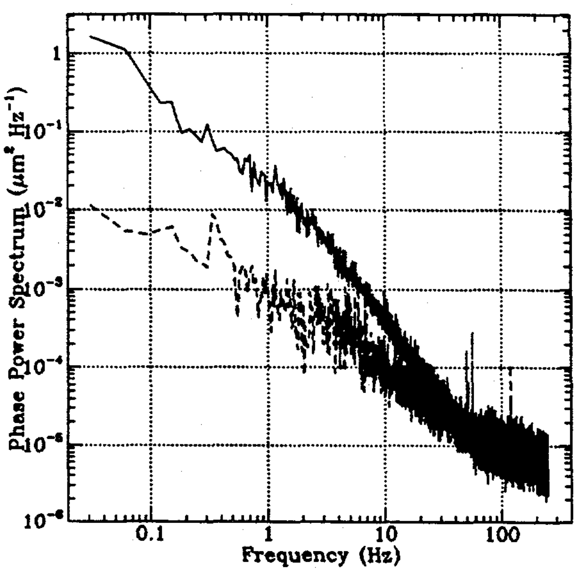

Figure 1 -- Wavefront phase power spectra from Nu Cygnus with and without adaptive optics compensation. These data were obtained during an engineering test of the Lick adaptive optics system on the 3 m Shane telescope, Sep. 8, 1995.

The phase power rejection is relatively insensitive to the atmospheric power spectrum. For the particular atmospheric power spectrum shown in Figure 1, the coherence length and frequency at 0.55 μm were $r_0 = 14$ cm and $f_0 = 4$ Hz. The residual closed-loop servo error was 80 nm. In addition, there was a residual fitting error of 130 nm.

These residual errors should have allowed imaging with a Strehl ratio of 0.8 at 2.2 μm. The highest Strehl ratio achieved during this run was 0.1. The calibration error was measured to be 240 nm at 1.3 µm. This leaves a residual error of 450 nm unaccounted for in order to match the measured Strehl ratio. This remaining error is likely to be due to drifts in the calibration due to internal flexure, as well as chromatic aberration in the camera optics.

4. LASER GUIDE STAR SYSTEM DESCRIPTION

Details of the laser are published elsewhere.[4,5] Three frequency-doubled 65 W YAG lasers are located in a room beneath the floor of the 3 m Shane telescope dome. Also located in this room, is the waveform generator, consisting of the dye master oscillator laser, the phase modulator and wavelength controls.

Fiber optics carry the YAG pump light and the dye master oscillator light to a dye preamplifier laser and a dye power amplifier laser, which are mounted on the side of the 3 m telescope. Also mounted on the telescope are a beam control and diagnostics package and a 30 cm refractive launch telescope and safety system.

5. LASER GUIDE STAR SYSTEM TEST RESULTS

The highest power achieved out of the dye power amplifier on the 3 m Shane telescope has been 20 W. The pulse full width at half maximum is 100 ns, and the pulse repetition rate is 11 kHz. The laser typically operates at about 15 W, and the lowest operating power has been 13 W.

The size of the guide star produced in the mesospheric sodium layer by the laser guide star system has been measured to be 1.8 arc seconds for a 10 second exposure. The seeing during this measurement was 1.3 arc seconds, so the laser guide star size was consistent with the seeing given that the laser light must go through the atmosphere twice. The diffraction-limited size of the guide star in the sodium layer is 0.6 arc seconds, so the laser guide star should get as small as 1.0 arc seconds for long exposures in 0.5 arc second seeing.

The return signal from the laser guide star has been measured to be between 0.16 and 0.26 photons cm^{-2} ms^{-1} for an output power of 15 W. This corresponds to a V magnitude of 9.0 to 9.5. The return flux is consistent with model predictions. The variability in the return flux may be due to drift in the laser frequency which is not yet actively stabilized.

6. LASER GUIDE STAR ADAPTIVE OPTICS TEST RESULTS

The laser guide star is focused on the wavefront sensor by moving the entire wavefront sensor assembly back 15 mm to the 90 km focal position. The Rayleigh scatter is blocked by a field stop in the focal plane just before the wavefront sensor collimating lens.

The initial results for the control loop performance using the laser guide star are shown in Figure 2. With a sampling rate of 55 Hz, a closed-loop bandwidth of 3 Hz was achieved. The phase power rejection was 6 dB corresponding to a factor of 4 reduction in the wavefront phase variance.

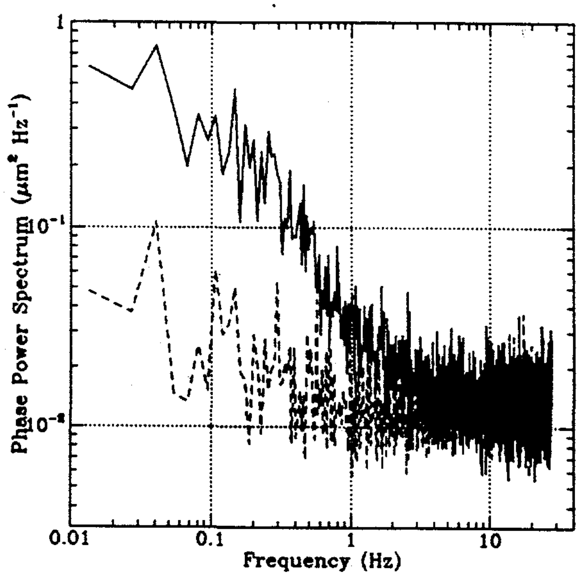

Figure 2 -- Wavefront phase power spectra from the sodium-layer laser guide star with and without adaptive optics compensation. These data were obtained during an engineering test of the Lick laser guide star adaptive optics system on the 3 m Shane telescope, Sep. 13, 1995.

For the atmospheric power spectrum shown in Figure 2, the coherence length and frequency at 0.55 μm were $r_0 = 14$ cm and $f_0 = 4$ Hz. The residual closed-loop servo error was 200 nm. In addition, there was a residual fitting error of 130 nm.

These residual errors should have allowed imaging with a Strehl ratio of 0.6 at 2.2 μm. During these tests, the actual images were not improved. This was evidently due to changes in the wavefront reference calibration caused by the movement of the wavefront sensor to the laser guide star focal position, along with the calibration errors already discussed for natural guide stars. In the future, recalibrating at the laser guide star focal position should allow image improvement at the expected level.

7. SUMMARY

A prototype adaptive optics system has been installed and tested on the 3 m Shane telescope at Lick Observatory. The adaptive optics system performance, using bright natural guide stars, is consistent with expectations based on theory.

A sodium-layer laser guide star system has also been installed and tested on the Shane telescope. Operating at 15 W, the laser system produces a 9th magnitude guide star with seeing-limited size at 589 nm.

Using the laser guide star, the adaptive optics system has reduced the wavefront phase variance on scales above 50 cm by a factor of 4. These results represent the first continuous wavefront phase correction using a sodium-layer laser guide star.

Assuming tip-tilt is removed using a natural guide star, the measured control loop performance should produce images with a Strehl ratio of 0.4 at 2.2 μm in 1 arc second seeing. Additional calibration procedures must be implemented in order to achieve these results with the prototype Lick adaptive optics system.

8. ACKNOWLEDGMENTS

Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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