CONF-9607118--2
UCRL-JC-123528
PREPRINT

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This paper was prepared for submittal to the
1996 Adaptive Optics Topical Meeting
Maui, Hawaii
July 8-12, 1996

March 8, 1996

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Introduction

In this paper, we present a conceptual design for a general-purpose adaptive optics (AO) system, usable with all Cassegrain facility instruments on the 3 meter Shane telescope at the University of California's Lick Observatory located on Mt. Hamilton near San Jose, California. The overall design goal for this system is to take the sodium-layer laser guide star adaptive optics technology out of the demonstration stage and to build a user-friendly astronomical tool. The emphasis will be on ease of calibration, improved stability and operational simplicity in order to allow the system to be run routinely by observatory staff.

A prototype adaptive optics system[1,2,3,4] and a 20 watt sodium-layer laser guide star system[5,6,7] have already been built at Lawrence Livermore National Laboratory (LLNL) for use at Lick Observatory. The design presented in this paper is for a next-generation adaptive optics system that extends the capabilities of the prototype system into the visible with more degrees of freedom. When coupled with a laser guide star system that is upgraded to a power matching the new adaptive optics system, the combined system will produce diffraction-limited images for near-IR cameras. Atmospheric correction at wavelengths of 0.6 - 1 mm will significantly increase the throughput of the most heavily used facility instrument at Lick, the Kast Spectrograph, and will allow it to operate with smaller slit widths and deeper limiting magnitudes.

Description of existing prototype Lick AO system

The engineering tests of the prototype AO system using natural reference stars began at Lick Observatory on the 1 meter Nickel telescope in the Fall of 1993 [2] and on the 3 meter Shane telescope in the Fall of 1994. [3] The same prototype system also has served as the testbed for sodium-layer laser guide star adaptive optics experiments at Lick Observatory. [4] The prototype AO system has provided us with valuable experience in design and engineering of the optical and control systems, specifically in alignment, calibration and operation of adaptive optics on astronomical telescopes.

The prototype AO system uses a Hartmann wavefront sensor, with a triangular array of 37 subapertures in the clear aperture of the 3 meter telescope. Subapertures have a diameter of 43.6 cm mapped onto the telescope primary. Images from the hex-shaped lenslets are recorded using a high-quantum-efficiency CCD camera built by Adaptive Optics Associates using a Lincoln Laboratory 64x64 chip with 27x27 μm pixels.

The deformable mirror is LLNL built with a triangular array of 127 electrostrictive lead magnesium niobate (PMN) actuators. Currently, 61 actuators are actively controlled and 66 are kept fixed since they lie outside the clear aperture of the telescope.

The tip-tilt system uses a set of four photon-counting avalanche photodiodes operated as a quad cell, and a small (2.5 cm) tip-tilt mirror.

The entire prototype AO system is taken apart for transportation to and from the LLNL for each observing run. Assembly, realignment and calibration requires almost 16 hours before initial observations can begin. The Lick laser guide star is based on the sodium resonance principle[8] and generates the guide star at 589 nm. The laser guide star system, including the dye pump, diagnostic and control electronics, beam expanding telescope and FAA-certified safety system, is already mounted to the 3 meter telescope.

The laser was first propagated to the mesosphere in May 1995 and the first guide star characterized in July 1995. The photon return signal is ≈ 0.2 photons/cm^2/msec at the top of the telescope which corresponds to a ninth magnitude visible star. This signal is adequate for the present prototype AO system but inadequate for the new proposed 349 actuator deformable mirror. For the latter, a laser power of roughly 50 W is needed to maintain a sufficient signal level.

Conceptual design of new adaptive optics user instrument

The new Lick adaptive optics user instrument is intended to be an evolutionary extension of the prototype AO system in the sense that many aspects of the optical design, calibration techniques, and control system design will be carried over. Significant upgrades will be made in several specific areas. Three of these areas are addressed in the conceptual design described in this paper:

1) the opto-mechanical structure will be larger and more robust and permanently mounted on the telescope;
2) the number of controlled degrees of freedom will be increased to 349;
3) a telescope simulator and turbulence generator (turbulator) will be installed in order to allow calibration and operational testing of the system during day time hours.

Additional upgrades will be made in the areas of supervisory control and user interface software.

The goal of these upgrades is to produce a robust user-friendly AO system able to provide significant image improvement down to optical wavelengths, and to be used with a wide variety of infra-red and visible cameras and spectrographs. In addition the astronomer will have the ability to refuse the AO capability and use the same interface as before. This can be done by removing the tertiary and the last AO turning mirror. Figure 1 shows the conceptual opto-mechanical layout of the new Lick adaptive optics user instrument.

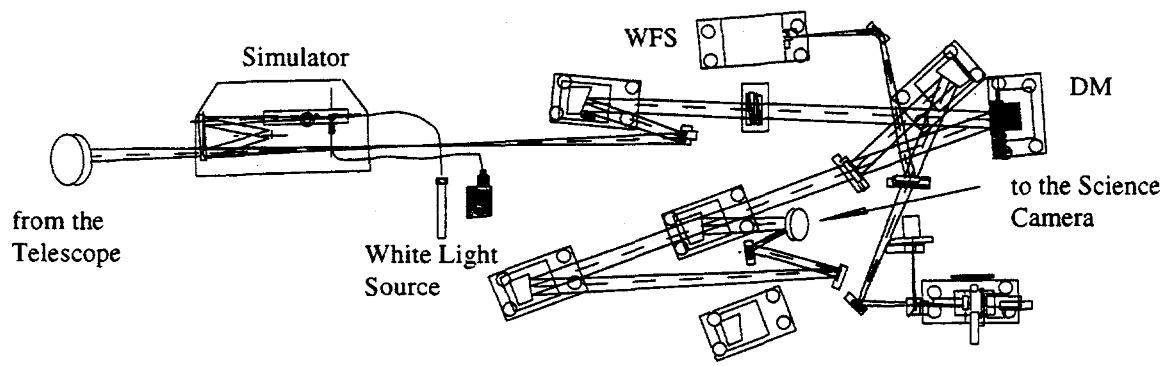

Figure 1 - preliminary layout of the Lick adaptive optics package

Light from the telescope tertiary mirror enters from the side and hits a turning mirror, the tip-tilt mirror, an off-axis parabolic collimating mirror, the 349-actuator deformable mirror, a broadband (450-600nm) dichroic beamsplitter, then an off-axis parabolic focusing mirror, to the science camera.

The reflected light from the dichroic beamsplitter is focused by an off-axis parabolic focusing mirror, a narrow band (589nm) dichroic beamsplitter reflects the sodium wavelengths to the wavefront sensor and transmits the rest of the light to the tip-tilt sensor and an image sharpening camera.

Wavelengths greater than 0.6 μm pass through the first dichroic beam splitter to the science camera leg. This consists of the focusing off-axis parabolic mirror and two turning mirrors which send the beam to the science instrument. The focusing off-axis mirror can be switched in order to change the f-number of the output beam from the nominal f/17 to any different f-number that is better suited to a specific science instrument. For instance the high-resolution IR camera currently being built by Prof. James Graham (UC Berkeley) currently requires an f/30 cone for optimal performance.

Figure 2 shows how the Lick adaptive optics user instrument will be mounted to the 3 meter Shane telescope. The AO system will be essentially transparent to the science instrument, in the sense that the f/17 output beam will have the same back focal length and output pupil position that the science instrument would see if it were mounted directly at the Cassegrain focus of the telescope.

The AO system will be based on a 349-actuator deformable mirror. The optical components (active and passive) will be be increased in size in order to match the larger deformable mirror.

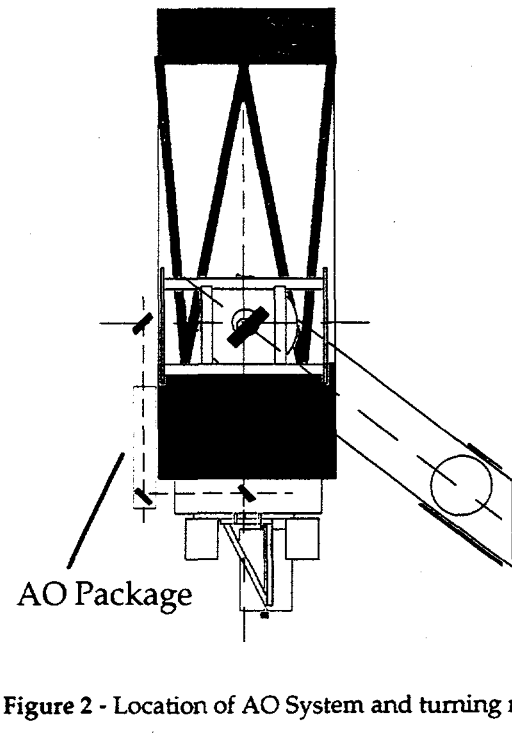

Figure 2 - Location of AO System and turning mirrors

To accomplish the transition to the routine use of adaptive optics laser guide stars systems in astronomical research, we will incorporate daytime alignment and calibration tools, and a user interface which will make it possible for the system to be calibrated and operated on a routine basis by only one or two people.

The Lick Observatory has important advantages as a development environment for this project. The laser (together with its FAA and environmental approvals) exists there today. The observatory is located within an hour and a half of UC Santa Cruz, UC Berkeley, and LLNL. It is easily accessible to astronomy faculty, engineering staff, and students.

Available astronomical instrumentation and performance enhancement

Available instruments include the following. First, a near-infrared camera is being designed by Prof. James Graham of UC Berkeley, and will be built by Infrared Laboratories of Tucson. The camera will have a plate scale of 0.07 arc sec per pixel, matched to the diffraction limit of the 3 m telescope. The camera will be built around a 256x256 pixel NICMOS III array, sensitive from 1 to 2.5μm.

Second, Lick Observatory's LIRC-2 near-IR camera with a 0.13 arc sec pixel scale, is available for use in applications where slightly lower spatial resolution is optimum.

Third, the primary visible-light instrument will be the Kast Cassegrain spectrograph. The Kast is a two-channel device with a short-wavelength "blue" section and a longer-wavelength "red" section. Only the red section sensitive from 4000 to 11000 angstroms would be relevant to adaptive optics work. It uses gratings as dispersive elements, with resolution ranging from 4.6 to 1.2 Å per pixel with a 400x1200 pixel CCD and a plate scale of 0.78 arc sec per pixel.

Many scientific projects are not feasible under typical Lick Observatory seeing of 1 arc sec or greater, and will benefit from the routine availability of adaptive optics. Adaptive optics (AO) provides several advantages over normal seeing for optical and near infrared imaging and spectroscopy. The diffraction-limited core of the point spread function resulting from AO translates directly into an improved detection threshold for stellar objects, by increasing the contrast between object and background sky. AO provides a larger dynamic range for studies of faint objects near brighter neighbors. AO offers improved spatial resolution for detailed morphology studies, and even when there is only the beginning of a diffraction-limited core, AO can increase the signal to noise ratio for spectroscopy by allowing use of a smaller slit which admits less sky background.

Acknowledgements

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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