First tip/tilt correction with the Palomar 200" adaptive optics system

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ABSTRACT

During the nights of 18-22 March 1998, the Palomar 200" adaptive optics (AO) breathed its first breathe of life, closing lock on a natural guide star for the first time. We present telescope results obtained during the initial closed-loop tip/tilt tests of the AO system at the 5m Hale Telescope on Palomar Mountain. Furthermore, we report on the first light results of the Palomar High Angular Resolution Observer (PHARO). Early tip/tilt correction results demonstrate a factor of ~1.3 improvement in peak infrared irradiance for several second exposures. The facility AO and PHARO systems are scheduled for a series of engineering runs throughout 1998. Initial closure of the 241 actuator high order natural guide star (NGS) adaptive loop is expected this summer.

Keywords: Adaptive optics, infrared instrumentation, large telescope instrumentation

1. INTRODUCTION

The Palomar 200" AO system[1] is a facility instrument designed and constructed by Jet Propulsion Laboratory for the has been undergoing integration and testing since February 1997. During the nights of 18-21 March 1998, initial closed loop tests of the AO system were conducted using the 5m diameter Hale Telescope at Palomar Mountain. This observing run also marked first light for the Palomar High Angular Resolution Observer (PHARO), a dedicated near-IR science camera optimized for use with the AO system[2]. Designed for near-IR imaging, spectroscopy, and coronagraphy, PHARO is undergoing continued integration and test at Cornell University.

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2. ENGINEERING RESULTS

2.1 Optomechanical tests

In June 1997, flexure measurements were performed to evaluate the impact of overall and non-common path (NCP) mechanical flexure between the science arm and WFS arm of the AO instrument[3]. Based on these measurements, several mechanical modifications were made to the relay optical mounts to improve their mechanical rigidity. The instrument flexure was remeasured during the March engineering run, when we could evaluate the effect of the PHARO camera and mount (approximately 250 lbs) on the AO bench, and determine the total image motion at the PHARO focal plane. The overall flexure during a 15 degree motion from zenith was found to be reduced from 1.5 to 1.0 arcsec and the NCP flexure reduced from 200 to 150 milliarcsec. While the overall flexure will be monitored and corrected during closed-loop operation, the NCP flexure remains unacceptably high compared to our science goal of 10mas NCP motion during a 1 hour exposure. This reinforces our belief that a separate metrology scheme will be required to meet our performance goal[4].

2.2 Deformable mirror actuator gains

This engineering run also marked our first experience operating our 349/241 actuator deformable Xinetics, Inc. mirror[5] at low temperatures. According to Xinetics specifications, the poled-PMN electrostrictive actuator is strongly temperature dependent. The actuator gain (as represented by the material strain vs. voltage curve) is expected to increase by as much as 80% at 4C, compared to 24C. Preliminary analysis of our measurements during the run are largely consistent with these values, although individual actuators were seen to exceed 100% gain increase (at 4C on the mountain compared to 20C in our laboratory at JPL). Due to excessive vibration in the Cass cage environment (see 2.3 below), we were unable to obtain quantitative results for each individual actuator. Furthermore, there was insufficient time to perform careful hysteresis measurements. However, we feel the hysteresis performance of the mirror with temperature is also approximately consistent with Xinetics predictions (~2% at 20C, ~10% at 4C). Our estimation of hysteresis is also consistent with that previously measured for a 37-element PMN mirror by Acton[6], although our data indicate larger changes in actuator gain.

2.3 Vibration coupling

Although the Palomar 200" AO system includes a phase shifting interferometer used to interrogate the alignment of the system and of the deformable mirror surface, we were unable to take advantage of this feature while the instrument was bolted onto the Cass ring because of excessive vibration. Although it was not possible to estimate the magnitude of OPD variations induced into our phase shifting interferometer, the magnitude was sufficient to render our phase unwrapping algorithm impotent. After some investigation, we determined that the source of vibration was, in fact, a beating of the frequencies of two cooling fans within our VME chassis housed in one of our electronics racks, mounted to the Cass cage itself. Although we have subsequently addressed these vibration problems, we are also currently investigating more robust phase unwrapping algorithms for use in the telescope environment.

3. TELESCOPE RESULTS

3.1 PHARO first light

The observing run in March 1998 also produced "first light" for PHARO, the system's near-infrared science camera. The mechanical integration on the AO bench yielded no unexpected problems and the optical alignment required very little time thanks to PHARO's built-in pupil-imaging mode. The operation at the telescope has shown that all observing modes work properly. The internal flexure of the camera optics within the dewar is less than one pixel within 30 degrees of zenith. Our test results showed no vignetting but one faint ghost reflection (~ 10" away), probably caused by the dichroic beam-splitter in front of the camera. Image distortion and sensitivity are in very good agreement with the theoretical expectations[2]. The detector read noise at the telescope was about 15 electrons in correlated double sampling mode. PHARO is controlled via a graphical user interface (GUI) which provides several online image diagnostic tools; our first run has shown that the GUI is very convenient and simple to use, even for observers unfamiliar with the camera control. In the near future, we plan to install a cosmetically improved science grade array detector, complete the set of spectral filters and grisms, implement ore sophisticated array readout modes, and make further improvements to the control software.

3.2 Initial tip/tilt closed-loop operation

The AO system successfully performed tip/tilt correction on bright ($m_v < 8$) guide stars, using tip and tilt information measured by the system's Shack-Hartmann wavefront sensor. For these tip/tilt experiments, the wavefront sensor was operated between 50 and 300 Hz sample rates, with the tip/tilt mirror receiving an update signal every fourth frame. Thus the tip/tilt update rate varied from 12.5 to 75 Hz. For reference, our 8" diameter modified Aerotech AOM-8 mount was previously measured in the laboratory to have a fundamental resonance (flopping of the inner gimbal) at approximately 82 Hz. Because of an implementation error, our proportional-integral controller was unstable, but successful operation of a simple proportional controller was achieved.

A good example of the level of image improvement provided by tip/tilt correction alone is shown in Figure 1.

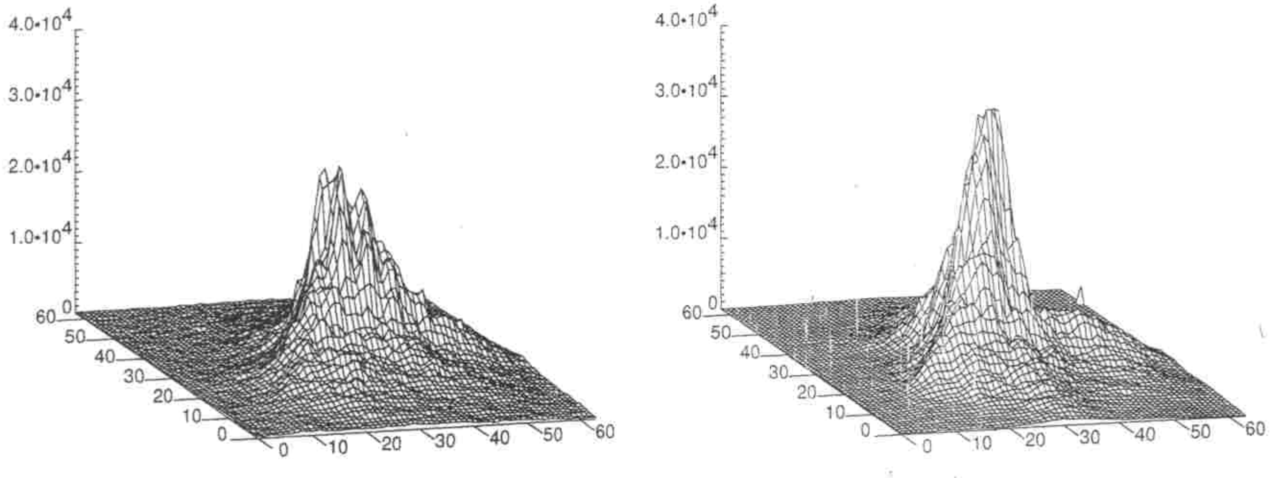

Figure 1. Tip/tilt correction off, FWHM = 0.64 arcsec (left) and on, FWHM = 0.52 (right). Images are of HR5833 at K-band, plate scale = 40 mas/pixel. (Because of different integration times, 3.4 sec for the uncorrected and 5.0 sec for the corrected image, the uncorrected images has been scaled by 5.0/3.4 for this comparison). With this renormalization, the improvement in peak image irradiance is a factor of 1.3 For the corrected image (right), the fast steering mirror was updated at a rate of 75Hz.

Following Martin[7], we estimate the image motion contribution to the long-exposure seeing FWHM as,

$$\alpha_{rms} = 0.603\left(\frac{\lambda}{D}\right)\left(\frac{D}{r_0}\right)^{5/6}$$

where λ is the wavelength of observation, D is the telescope pupil diameter, r_0 is the atmospheric coherence length, and α_{rms} carries units of radians. For $D = 5\text{m}$, $r_0 = 0.70$ meters (estimated from the uncorrected image FWHM = 0.64 arcsec = λ/r_0), and $\lambda = 2.2\ \mu\text{m}$, this equation leads to an estimate of the 2-D rms image motion of 0.28 arcsec. The 1-D error is expected to be a factor of $\sqrt{2}$ less than that or 0.20 arcsec. Assuming the tip/tilt error adds in quadrature to the high order errors, we expect the corrected FWMH to be approximately the square root of $(.64)^2 - (.20)^2$, which equals 0.60 arcsec.

Note that the corrected image FWHM, 0.52 arcsec, is less than this prediction. In fact, the images in Figure 1 represent the best image improvement obtained during the run and probably include a chance improvement in seeing conditions between the two measurments.

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