

# LATEST NEWS ON INSTRUMENTATION

## The University of Hawaii Adaptive Optics System

A new type of adaptive optics system is currently being developed at the Institute for Astronomy, University of Hawaii (UH). Whereas the COME-ON and COME-ON+ systems are based on technologies developed for defense applications, the UH system is based on the novel concept of "wavefront curvature sensing and compensation" [1]. It is expected to provide similar performance with a simpler and more cost effective technology. It is planned to operate with faint natural reference sources and is optimized for astronomical applications. This development is currently supported by a 3-year NSF grant. Here we briefly describe the system and present the results of conclusive tests performed at the CFH telescope.

An adaptive optics system consists of a wavefront sensor, a deformable mirror, and a control system. Here is a brief description of these three components in the UH system. For further details we refer the reader to the literature [2-7]

Whereas current AO wavefront sensors measure local wavefront slope errors, the UH sensor detects local wavefront curvature (Laplacian) errors together with radial slope errors at the pupil edge. This also gives a complete set of information to reconstruct the aberrated wavefront. It is done by simply comparing the illumination in two oppositely defocused pupil images. A vibrating membrane mirror is used to switch from one image to another at a 7 KHz rate. An array of photodetectors is used to record the illumination. Any wavefront error produces a modulation of the illumination which translates into modulated electric signals. These signals are demodulated and used to control a deformable mirror. The technique has now been

successfully tested both in the laboratory and at the telescope with a low sensitivity detector array (photodiodes). A new array of very high sensitivity detectors (photon counting avalanche photodiodes) is being built for stellar applications.

The UH system also uses an unconventional type of deformable mirror called bimorph. In most systems local wavefront errors are compensated by locally deforming a thin mirror. A bimorph mirror consists of a pair of piezoelectric wafers glued together. It compensates local wavefront curvature errors by local bends similar to the bending of a bimetallic plate with temperature. Because it directly compensates wavefront curvature errors, a bimorph mirror is well matched to a wavefront curvature sensor. Although proposed in the seventies, this mirror technology has only recently been developed by Onera (France) through a contract with Laserdot, the company which made the COME-ON and COME-ON+ mirror [8,9]. The electrode pattern was designed at the University of Hawaii and optimized for atmospheric compensation. Laserdot recently succeeded to produce a bimorph mirror of good optical quality. It has been tested at UH, producing spectacular results on laboratory generated seeing. Unfortunately it was later damaged by an arc between two electrodes.

The UH control system consists of an array of analog lock-in amplifiers providing demodulated signals with parallel outputs. Analog-to-digital (A/D) converters are used to provide inputs to a 20 MHz 386 PC-type computer. A digital matrix multiplication provides the output signals necessary to control the deformable mirror. The signals are converted back to analog voltages and amplified before application to the mirror electrodes. A 500 Hz sampling rate has recently been achieved, which is more than adequate to control the wavefront on a 3.6 m telescope (the COME-ON+ system is planned to work at a 400

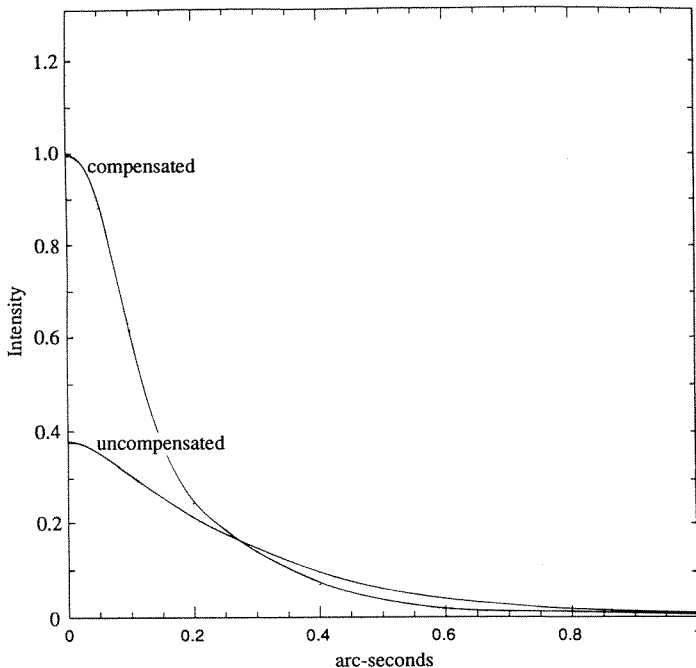


Figure 7: Stellar images profiles recorded in April 91. The tip/tilt error signals were sensitive to coma.

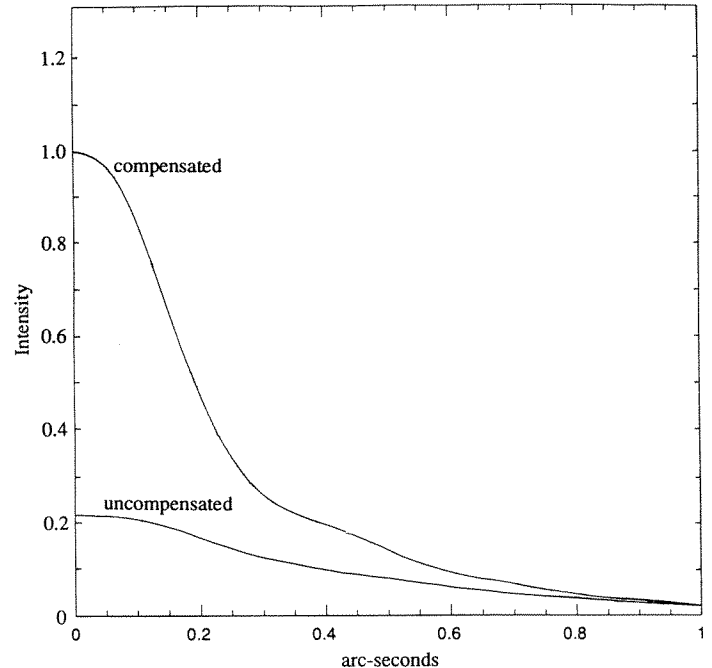


Figure 8: Stellar images profiles recorded in January 92. The tip/tilt error signals were insensitive to coma.

Hz sampling rate). The UH system is highly optimized; although the number of degrees of freedom of the compensation (12) is much smaller than that of conventional systems, the resolution improvement is expected to be comparable.

Although the system has not yet been completed, two engineering runs have already been made at the CFH telescope. The optical set-up fits on a small 3 x 4 ft table installed in the Coudé room. The tests were made on bright stars with the low sensitivity detector used for development purpose (array of silicon diodes). We concentrated most of our efforts in recording the error signals delivered by the wavefront sensor for further statistical analysis purpose. The sensor was also used to control a fast tip/tilt mirror for atmospheric tip/tilt compensation. One minute CCD exposures were taken one immediately after the other with and without the control system.

The figures show photometric profiles of pairs of stellar images recorded with and without compensation at 0.85 $\mu$ m with the telescope aperture stopped down to one meter. In both cases the image full width at half maximum (fwhm) was divided by a factor two. Data shown in Fig. 7 were taken in April 1991. The seeing was very good (0.5" uncompensated image) but the control system was not fully optimized (the tip/tilt signal was affected by random turbulence induced coma errors). Although the compensated image fwhm is 0.25", the gain in central intensity is only by a factor 2.5. Data shown in Fig. 8 were taken in January 1992. The seeing was not as good (0.7" uncompensated image). As a result the compensated image fwhm is only 0.35". Note however the high gain by a factor of about 5 in the central intensity. It is very close to the theoretical maximum gain achievable with tip/tilt compensation only. To our knowledge, this is the first time such a performance has been demonstrated.

These results clearly demonstrate that the image fwhm is not a good performance criterion for compensated images. Experts in the field use a better criterion called the Strehl ratio. It is the ratio of the image central intensity to that of the diffraction-limited image. The absolute Strehl ratio is difficult to estimate on astronomical images but one can easily estimate the Strehl ratio improvement when the control system is on.

During the January run compensated stellar images have also been recorded with a deformable bimorph mirror of low optical quality on temporary loan from ONERA. The full telescope aperture was used in the H band. Owing to the poor quality of the mirror, the Strehl ratio improvement was only by a factor three, but the image fwhm went down to 0.1". A bimorph mirror of good optical quality is expected to be available for the next observing run in July 1992.

A new type of adaptive optics system has been successfully demonstrated. Compared to current systems, it is easier to implement and better adapted to astronomical applications. An array of very sensitive photon counting detectors is now being built. It will enable us to sense the wavefront using natural guide stars as faint as  $m=16$ . A complete working system is expected to be ready for astronomical observations in 1993.

The UH adaptive optics group includes Buzz Graves, Dan McKenna, and Malcolm Northcott. This development effort was made possible thanks to an initial support from ONERA provided by Marc Séchaud. Bimorph mirror technology was developed by Pascal Jagourel at Laserdot.

F. Roddier

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## CFHT AO Bonnette Status

The CFHT AO Bonnette project has reached its cruising speed. Here are some of the specifications for the Bonnette as presented at the 1992 Users' Meeting in Victoria last May. The Bonnette should:

- provide median Strehl Angles  $< 0.2$  arcseconds from 0.5 to 2.3 $\mu$ m
- provide a choice of either high-order or tip/tilt-only image correction
- use modal control to drive the adaptive mirror surface and tip/tilt mirror
- offer the possible use of the science source as the wavefront reference
- feed full-sized instruments (imagers, 2-D spectrographs,...) with 2.5 pixel sampling of the diffraction core for wavelengths longer than 1.5  $\mu$ m.
- provide differential flexures under 5  $\mu$ m/hour of telescope motion
- transmit (excluding the beamsplitter) : from 0.4 to 2.3  $\mu$ m a minimum of 75% at any wavelength, with a mean value of 85%.
- readily switch between the corrected 1.5' field and a straight through uncorrected field 5' in diameter.
- be modular, reliable, user transparent, and be capable of evolution to better adaptive mirrors and wavefront sensors.
- cost  $< \text{U.S. } \$10^6$  on a three year development timetable.

A more detailed description of the Bonnette was given in the previous Bulletin (No 26, 1992 I)

At this stage, the design of the optical layout (wavefront sensing path included) has been completed by Dr. E.H. Richardson of the University of Victoria. The input focal ratio is f/8 and the output f/19.6. In order to keep the number of optical elements to a minimum Dr. Richardson has elected to make use of toroidal elements in the design. Two retractable flat mirrors allow the use of the direct f/8 focus with a field of view of 5