*RevMexAA (Serie de Conferencias)*, **19**, 59–62 (2003)

# EFFICIENCY OF LOW-ORDER ADAPTIVE CORRECTION FOR THE SAN PEDRO MÁRTIR OBSERVATORY: EXPERIMENTAL RESULTS

V. V. Voitsekhovich and V. G. Orlov

Instituto de Astronomía, UNAM, México D.F., México

RESUMEN

Se presenta la eficiencia estimada de un sistema astronómico adaptivo de bajo orden basado en datos experimentales obtenidos en el Observatorio Astronómico Nacional en San Pedro Mártir usando una prueba de Hartmann dinámica. El resultado demuestra que para la banda $V$ la corrección adaptiva de bajo orden permite una mejora útil en las imágenes observadas. Para la banda $K$, aún con la más sencilla de las correcciones de tipo "tip-tilt" se logra una mejora considerable en la calidad de la imagen.

ABSTRACT

The efficiency of low-order adaptive astronomical systems is estimated on the basis of experimental data obtained at San Pedro Martir observatory with dynamic Hartmann test. The estimation is performed for the 1.5 m telescope. The results show that for the $V$-band the low-order adaptive correction provides a good improvement in observed images, while for the K-band even the simplest tip/tilt correction gives a very noticeable improvement in the image quality.

*Key Words:* **ATMOSPHERIC EFFECTS — INSTRUMENTATION: ADAPTIVE OPTICS — TURBULENCE**



## 1. INTRODUCTION

Adaptive systems are being increasingly used in astronomy. Advanced adaptive systems with a high-order correction allow nearly diffraction-limited images to be obtained. However, such advanced systems have some disadvantages:

- The higher the order of correction, the more light the system needs;
- the cost of the system increases drastically with the order of correction;
- the complexity of the system maintenance.

Along with this, a relatively simple and cheap low-order adaptive system can be useful for many types of astronomical observations at small and middle-sized telescopes. In this paper we present the results related to the efficiency of low-order adaptive systems. Our estimates of the goal efficiency is based on the experimental data obtained with a Dynamic Hartmann System named *Rapid*. The observations were carried out at the San Pedro Mártir Observatory (Mexico) on the 1.5-m telescope during the site testing campaign of May 2000.

## 2. EXPERIMENTAL EQUIPMENT

The observations were carried out with the Dynamic Hartmann system (*Rapid*), which allows for the measurement of the spatio-temporal structure of turbulence-induced phase distortions at the telescope aperture. We present below a short description of the equipment while the details can be found in Voitsekhovich et. al. (2000).

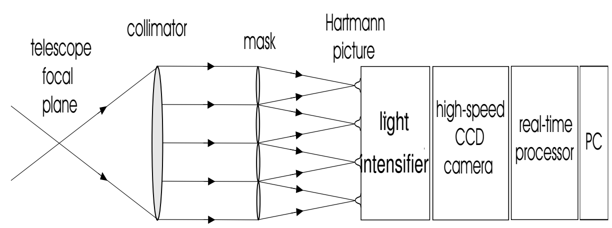


Fig. 1. Scheme of experimental equipment.

The experimental scheme of the *Rapid* equipment is shown in Fig. 1.

The phase distortion at the telescope aperture is mapped at the Hartmann mask. The Hartmann mask consists of 48 lenses. Each of the mask lenses produces a Hartmann spot at the mask focal plane. The offset of a Hartmann spot from its equilibrium position is proportional to the local wavefront tip/tilt at the corresponding zone of the telescope aperture. A set of Hartmann spots at the mask focal plane forms a Hartmann image from which the phase at the telescope aperture can be retrieved.

The Hartmann picture is projected on the en-

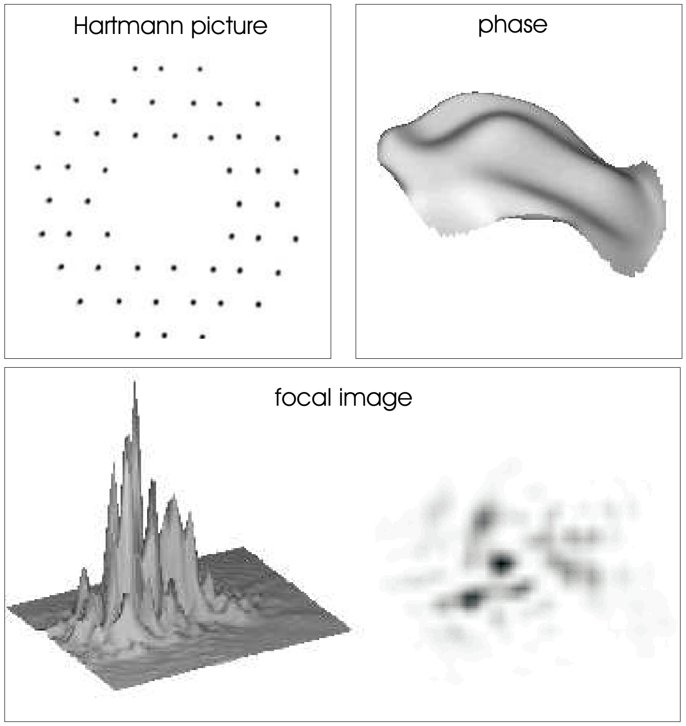


Fig. 2. Experimental data example (a single frame). Top left panel: Example of Hartmann picture. Top right panel: Example of reconstructed phase. Bottom: Example of point-spread function ($V$-band, 0.55 m$\mu$).

trance of the light intensifier which amplifies the picture intensity and sends it to the entrance of the CCD camera. The CCD-camera is a high-speed camera that allows frame recording speeds of 25, 50, 100, 200 frames $s^{-1}$.

Each frame recorded by the CCD-camera is transmitted to a real-time processor for preliminary data reduction. This consists of two real-time functions: the calculation of Hartmann spot offsets and their recording to the fast memory. The equipment allows to accumulate long data sets (up to 40000 frames) as only the spot offsets are recorded.

## 3. DATA EXAMPLE

The dynamic Hartman data were obtained with the 1.5 m telescope at the National Astronomical Observatory on San Pedro Mártir, Baja California, Mexico. The obtained Hartmann picture offsets were recorded at 50 frames $s^{-1}$.

An example of a single Hartmann picture can be seen in Fig. 2 (top left panel). Analyzing this picture, one can notice that the spot centers are shifted with respect to their equilibrium positions. The equilibrium position for each spot is calculated by averaging the spot coordinates over all the frames. The spot offsets corresponding to the current frame are calculated as the difference between the current spot coordinates (image centroid coordinates) and the corresponding equilibrium coordinates.

The phase at the aperture is reconstructed for each frame using a least-square fit of the offsets to the gradients of Zernike polynomials (Noll, 1976). The reconstruction procedure is described in detail in Voitsekhovich (1998). An example of the reconstructed phase is shown in Fig. 2 (top right panel).

Making use of Fourier transforms, one can calculate the point spread function (PSF) corresponding to the reconstructed phase. An example of PSF is shown in the bottom panels of Fig. 2. As one can notice, this PSF shows typical features observed in short-exposure images.

## 4. EFFICIENCY OF ADAPTIVE CORRECTION

During the May 2000 Site Testing Campaign we observed for three nights with *Rapid*, and obtained 50 data sets. In order to estimate the efficiency of low-order adaptive correction, we have chosen one typical data set (taken on 19 May 2000) from all the available data.

The goal efficiency can be considered to be an improvement in the long-exposure PSF. In this paper we compare the long-exposure PSFs for three cases:

San Pedro Mártir: Astronomical Site Evaluation (México, D. F. and Ensenada, B. C., México, April 3-4, 2003)
Editors: Irene Cruz-González, Remy Avila & Mauricio Tapia

San Pedro Mártir: Astronomical Site Evaluation (México, D. F. and Ensenada, B. C., México, April 3-4, 2003)
Editors: Irene Cruz-González, Remy Avila & Mauricio Tapia

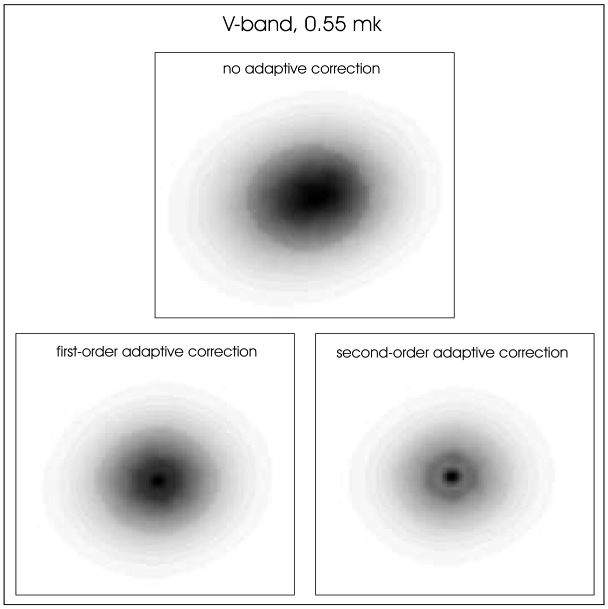


Fig. 3. Long-exposure PSF ($V$-band).

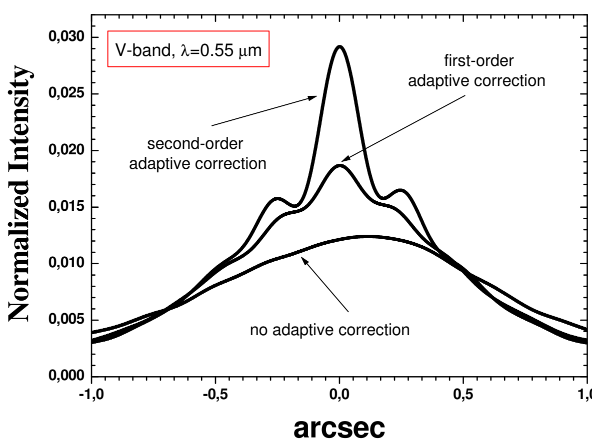


Fig. 4. Long-exposure PSF central cut intensity in the $V$-band, normalized to the maximum intensity of the diffraction-limited PSF.

1. PSF without adaptive correction.
2. PSF for first-order adaptive correction (tit/tilt corrected).
3. PSF for second-order adaptive correction (tip/tilt, defocus, and astigmatism corrected).

In order to show how the goal efficiency depends on the wavelength, the tests are performed for both the $V$-band (0.55 $\mu$m) and the $K$-band (2.2 $\mu$m).

Figure 3 shows images of the PSF for the $V$-band

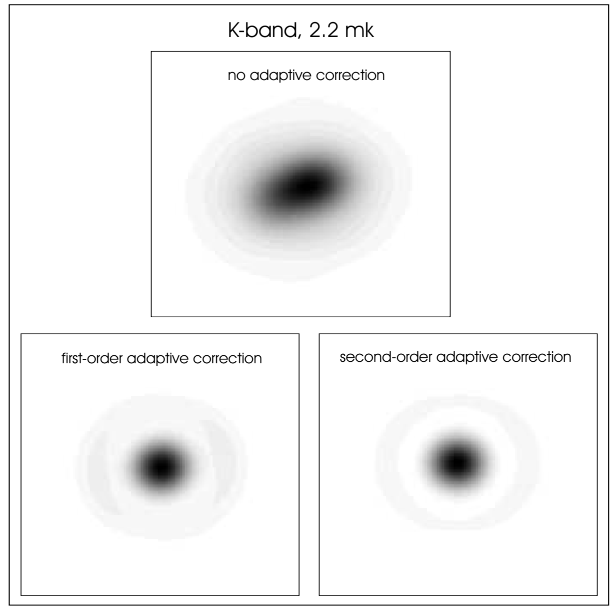


Fig. 5. Long-exposure PSF ($K$-band).

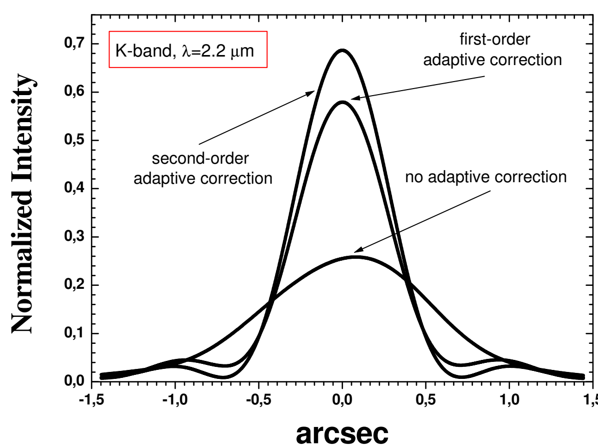


Fig. 6. Long-exposure PSF central cut intensity in the $K$-band, normalized to the maximum intensity of the diffraction-limited PSF.

in the three cases, while Fig. 4 shows the central cuts of the corresponding PSF. Note that in Fig. 4 the cuts are normalized by the maximum intensity of diffraction-limited PSF for the 1.5 m telescope. Similar PSFs for the $K$-band are shown in Figs. 5 and 6.

As one can see from Figs. 3 and 4, for the $V$-band the low-order adaptive correction provides a good improvement in the observed images. As for the $K$-band, even the simplest tip/tilt correction (first-order correction) gives a very noticeable improvement in image quality making it near to diffraction-limited.

## 5. CONCLUSIONS

We estimated the efficiency of the low-order adaptive correction based on experimental data obtained with a dynamic Hartmann test. The estimation has been done for the 1.5 m telescope located at the San Pedro Mártir Observatory (Mexico). The results show that for the $V$-band the low-order adaptive correction could provide a reasonable improvement in the long-exposure images, while for the $K$-band even the simplest tip/tilt correction gives a very noticeable improvement in image quality, close to diffraction-limited.

We are grateful to Dr. L. Georguiev for useful discussion. This work received support from Consejo Nacional de Ciencia y Tecnología, (CONACYT, Mexico), grants E9507-1020 and 34517-E.

## REFERENCES

Noll R. J., 1976, J. Opt. Soc. Am., 66, 207.

Voitsekhovich V. V., Ankudinov S. N., Mantsvetov A. A., Savolanen V. E., Konoplev S. V., Perespelov A. V., Tsytsulin A. K., Nikitin V. V., Dolgov D. G., 2000, Journal of Optical Technology, 67, 7898.

Voitsekhovich V. V., 1996, J. Opt. Soc. Am. A., 8, 1749.

Valerii Voitsekhovich, Valeri Orlov: Instituto de Astronomía, Universidad Nacional Autónoma de México, Ciudad Universitaria, Apartado Postal 70-264, 04510 México, D. F., México (voisteko,orlov@astroscu.unam.mx).

San Pedro Mártir: Astronomical Site Evaluation (México, D. F. and Ensenada, B. C., México, April 3-4, 2003)
Editors: Irene Cruz-González, Remy Avila & Mauricio Tapia