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Active Optics
on the
Nordic Optical Telescope

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1. Introduction

The Nordic Optical Telescope (NOT) is located on Roque de los Muchachos, La Palma. The telescope was designed and constructed in 1984-89. It is a modern telescope with an alt/az mounting and a co-rotating building [1], [2], [3]. The telescope has been in regular operation since 1990 and delivers observations of high image quality.

The primary mirror of the Nordic Optical Telescope has a diameter of 2.56 m and the focal ratio F/2. The mirror has an aspect ratio of 13.5 and, thus, is thin and lends itself well to active control. The mirror was figured at the optical laboratory of the Turku University. The 80% energy concentration diameter of the telescope in passive mode after alignment of the primary and secondary has been measured to 0.34" using stars.

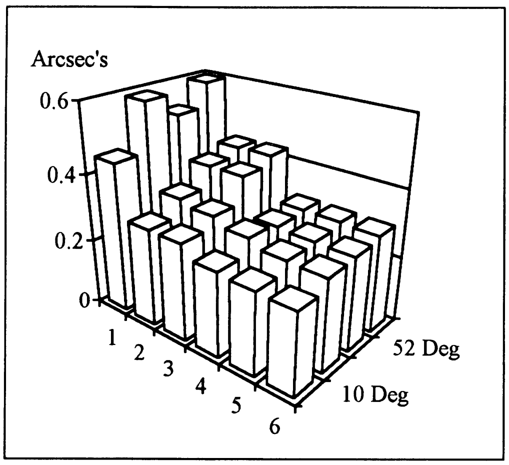

Figure 1. Diameter of 80% energy concentration at the NOT for various zenith distances. Legend: 1: Raw data, 2: Coma removed in post-processing, 3: Spherical aberration removed 4: Astigmatism removed, 5: Triangular coma removed, 6: Quadratic astigmatism removed.

Figure 1 shows the variation in image quality as a function of zenith distance for the not optimally aligned telescope. It can be seen that the image quality can be improved by removing low-order aberrations. Thus an active optics system is justified since it will be capable of compensating for such aberrations and maintaining the telescope optics well aligned.

2. Principle of Operation

The active optics system serves the purpose of removing aberrations originating from the telescope itself. Such aberrations occur at low temporal frequencies.

In principle, an active optics system functions as shown in Figure 2. The optical quality of the telescope is monitored using a wavefront sensor. The alignment of the secondary and the shape of the primary are adjusted in closed-loop operation. The active optics system has two purposes:

a) Assure telescope alignment. Usually, the major source of aberrations in modern telescopes is decentering coma from misalignment of the primary and the secondary. An alignment of the secondary has a large effect on image quality.

b) Remove low-order aberrations. As can be seen from Figure 1, good image quality can be achieved by merely compensating for low-order aberrations. Since these can be represented as linerar combinations of low order mirror eigenmodes, deformation of the primary in its low order modes is a simple measure that highly improves image quality.

Obviously, compensation for aberrations can be achieved by means of fast updates on the basis of an on-line wavefront sensor. However, there is evidence

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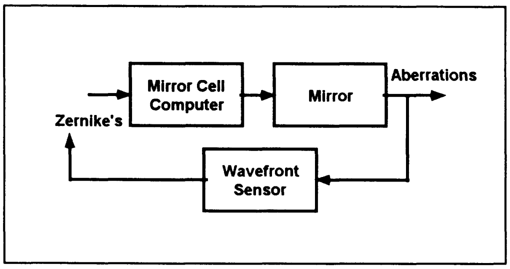

Figure 2. Operating principle of an active optics system.

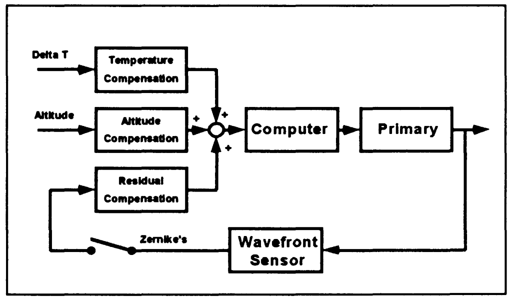

Figure 3. Principle of operation foreseen for the active optics of the Nordic Optical Telescope.

that good image quality can be maintained applying only occasional updates, provided that correction of altitude dependence is accomplished using calibration tables in the computer.

This operating principle has been chosen for the NOT. See Figure 3. Whenever good image quality is particularly important, the observer has the option to align and adjust the optical system using active optics. Between these updates, compensation is performed by the computer using calibration tables on the basis of altitude angle and, possibly, primary mirror temperature.

3. Mirror Support System

The primary mirror can be deformed by adjusting the load forces in 45 metallic bellows supporting the mirror axially. The bellows are each connected to a pressure regulator. The 45 pressure regulators are controlled by a Motorola 68030 computer in a VME system. Three load cells serve as fixed points and define the position of the mirror. The signals from the load cells are used for the common-mode control of the support forces of the bellows. The load cell forces are kept close to zero by the control system.

4. Wavefront Sensor

The wavefront sensor is of the Hartmann-Korhonen type [4], [5]. A Hartmann screen is placed at an image of the entrance pupil. A CCD is placed so close to the focus that the Hartmann dots interfere. Positions of the interference dots are computed and from these, the wavefront can be determined. The computer outputs the five lowest-order quasi-Zernike coefficients for the aberrated wavefront. The layout of the wavefront sensor is shown in Figure 4.

5. Control Algorithms

The lowest eigenmodes of the primary mirror have been determined using the finite element program Algor. Subsequently, it has been determined how the Zernike polynomial can be best expanded in these low-order modal shapes. Correction for astigmatism,

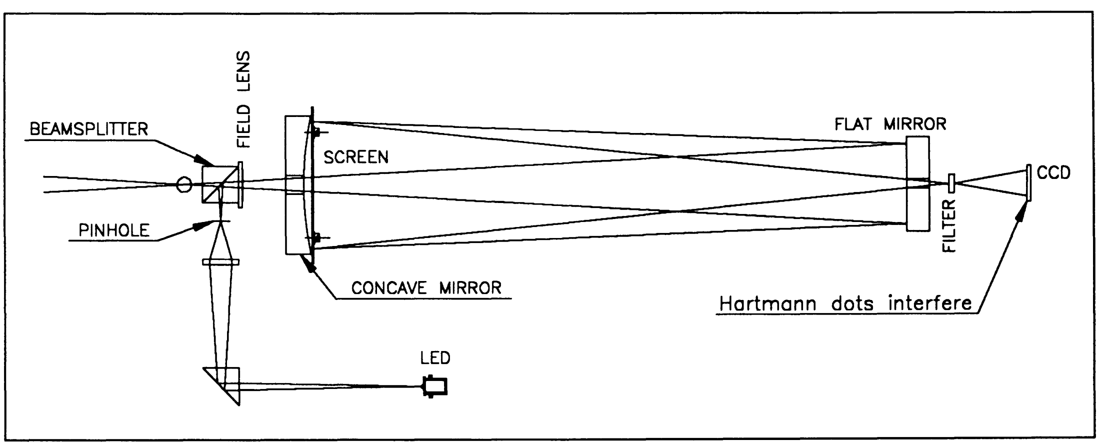

Figure 4. Wavefront sensor for the active optics of the NOT.

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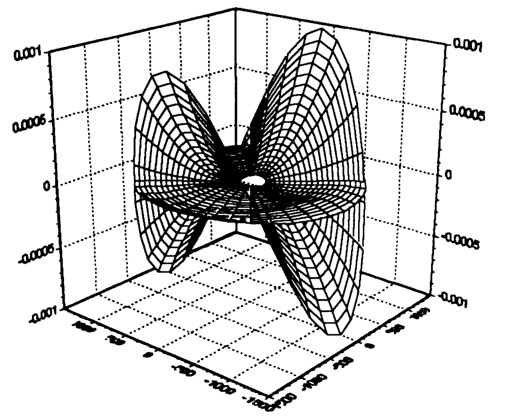

Figure 5. Correction for astigmatism using two eigenmodes of the primary. The highly curved surface shows the original aberration (1 micron) and the flat surface the residual aberration after correction.

spherical aberration, triangular coma, and quadratic astigmatism is done using the six lowest order eigenmodes of the primary mirror. Correction for coma is done by translating the secondary transversely.

As an example, Figure 5 shows how astigmatism can be corrected using only two minimum energy modes.

The theoretically achievable wavefront errors after correction, related to the original errors, are shown in the following table:

Coma	0%
Astigmatism	2.3%
Spherical Aberration	6.3%
Triangular Coma	13%
Quadratic Astigmatism	6.3%

6. Preliminary Tests

The active optics of the NOT is presently being installed and only preliminary results are available. The initial tests were concerned with introduction of artificial aberrations and verification that these occurred as foreseen.

Figure 6 shows results from such a test. The wavefront of the undisturbed telescope was recorded. Thereafter, two microns of astigmatism were imposed onto the otherwise passive primary. A new wavefront was recorded and the initial one subtracted from it. The change of the wavefront was expanded into a quasi-

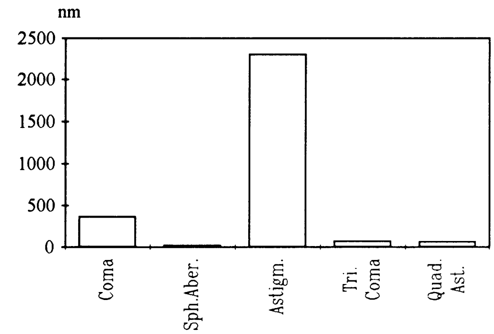

Figure 6. Aberrations measured after introduction of 1 micron of astigmatism on the otherwise passive mirror.

Zernike polynomial. The magnitudes of the lowest order aberrations determined in this way are shown in Figure 6. Apart from astigmatism, it can be seen that 400 nm of coma has appeared, largely due to a change in altitude during observations.

Figure 7 shows similar results related to spherical aberration. Also here, a minor amount of coma has turned up.

7. Further Work

It is intended to test the active optics system further during technical time in August and September 1992. Also, a cross-check of the wavefront sensor with another type of wavefront sensor would be of interest to study the aspect of measurement noise.

Thereafter, it is intended to streamline the software to make it more user-friendly and, thus, to provide local staff and visiting astronomers with a valuable tool for achieving excellent image quality.

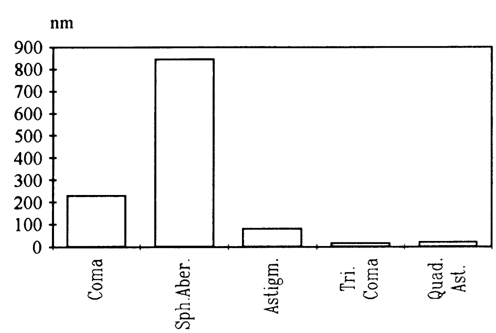

Figure 7. Aberrations after introduction of 1 micron of spherical aberration.

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8. Acknowledgments

The wavefront sensor was designed optically by Tapio Korhonen from the Turku Observatory in Finland. Software for the wavefront sensor was written by Timo Lappalainen from Opteon Oy in Turku.

9. References

[1] Ardeberg, Arne: Some properties of the Nordic Optical Telescope. Report from the Nordic Optical Telescope Scientific Association, November 1989.

[2] Ardeberg, Arne and T. Andersen: Low Turbulence-high performance. Proc. SPIE vol. 1236, p 543-558, 1990.

[3] Ardeberg, Arne and T. Andersen: VLT Design implications of the Nordic Optical Telescope. Proc. on the ESO conference on Very Large Telescopes and their Instrumentation. Garching, 21-24 March 1988.

[4] Korhonen, Tapio: Interferometric method for optical testing and wavefront error sensing, Proc. SPIE 444, p.249-252, 1984.

[5] Korhonen, Tapio & Timo Lappalainen: Interferometric wavefront sensor for the NOT. Notnews no. 4, July 1991.

[6] Owner-Petersen, Mette & Ole Brix Larsen: Active Optics on the Nordic Optical Telescope. Mirror Control Algorithms. Technical report from the Nordic Optical Telescope Scientific Association. December 1991.

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