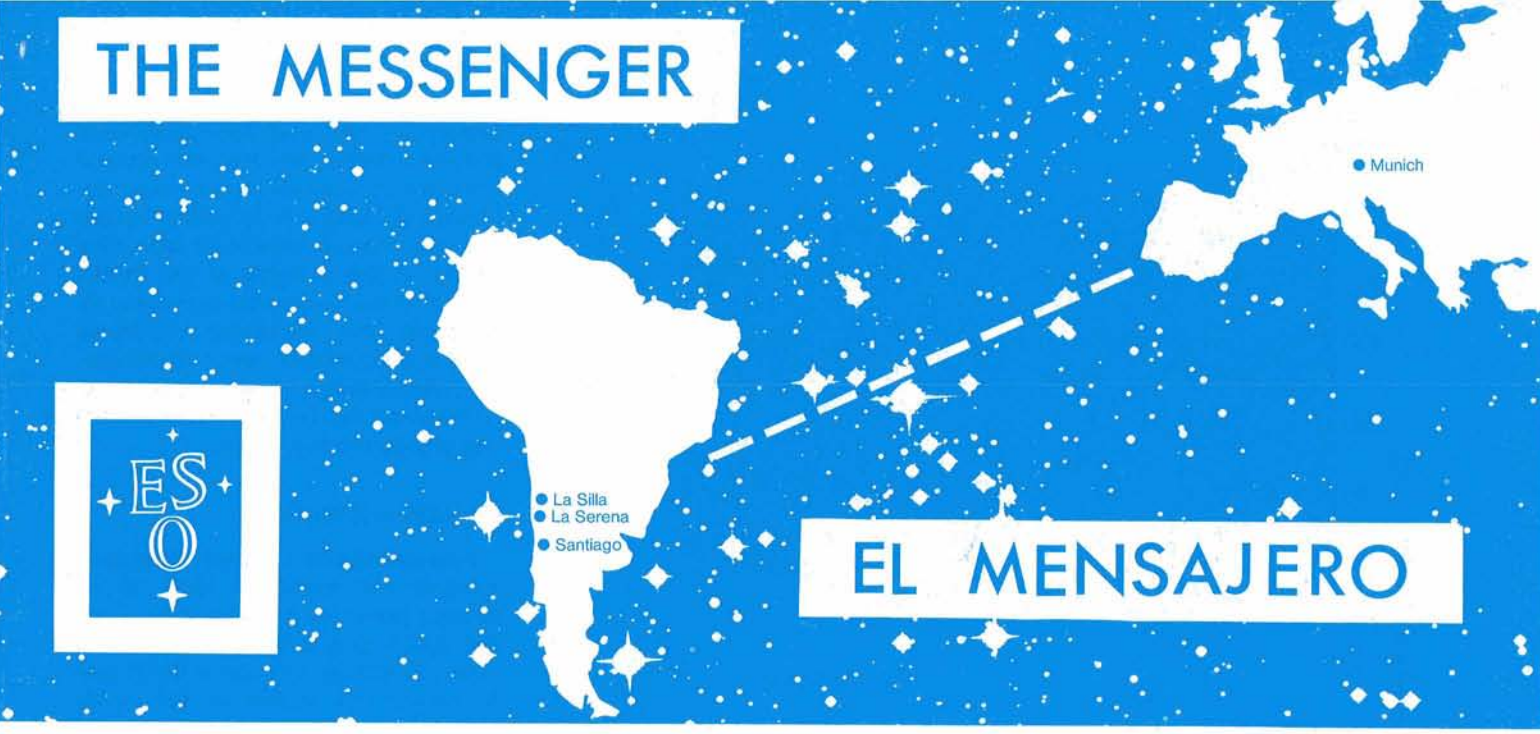
THE MESSENGER

EL MENSAJERO



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Successful Tests of Adaptive Optics

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An old dream of ground-based astronomers has finally come true, thanks to the joint development of a new technique in astronomical imaging – called *adaptive optics* –, by ESO and Observatoire de Paris, ONERA (Office National d'Etudes et de Recherches Aérospatiales), LASERDOT (formerly CGE) in France.

It has been demonstrated that this technique effectively eliminates the adverse influence of atmospheric turbulence on images of astronomical objects, yielding images almost as sharp as if the telescope were situated in space.

Why Adaptive Optics?

Ever since the invention of the telescope in the early 17th century; astronomers have had to accept that the quality of astronomical images obtained with ground-based instruments is severely limited by a factor which is beyond their control, that is the turbulence in the Earth's atmosphere.

For a long time it was thought impossible to avoid this natural limit. Now, for the first time, this old problem has been demonstrably solved.

A Break-through in Optical Technology

In a major technological breakthrough in ground-based astronomy the VLT Adaptive Optics Prototype System (also referred to as Come-On) has now proved its ability to overcome this natural barrier during a series of successful tests in the period 12–23 October 1989. They were performed at the coudé focus of the 1.52-m telescope at the Observatoire de Haute-Provence (OHP), France.

The extensive tests showed that it was possible to effectively "neutralize" the atmospherically induced smearing of a stellar image by a closed-loop correction system. In this way stellar images were obtained at infrared wavelengths whose sharpness was only limited by the telescope aperture, i.e. diffraction limited images.

On each of the ten nights, infrared exposures were made of about 10 bright stars ranging from the visible magnitude 0.7 to 4.7 (including Capella, Deneb, Betelgeuse, γ^1 And, and others). The

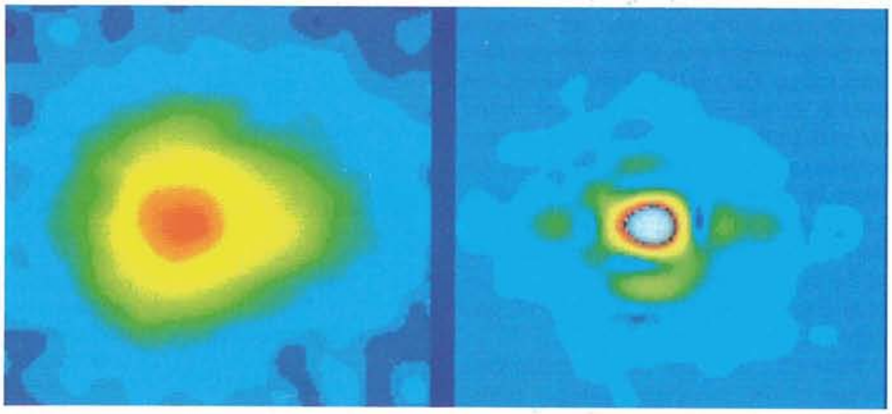

Figure 1: *Imaging of Deneb in the K-Band without and with adaptive feedback loop activated. The image diameter shrinks from 1.0 arcsec to 0.37 arcsec which is the diffraction limit in the K-Band (2.2 μm).*

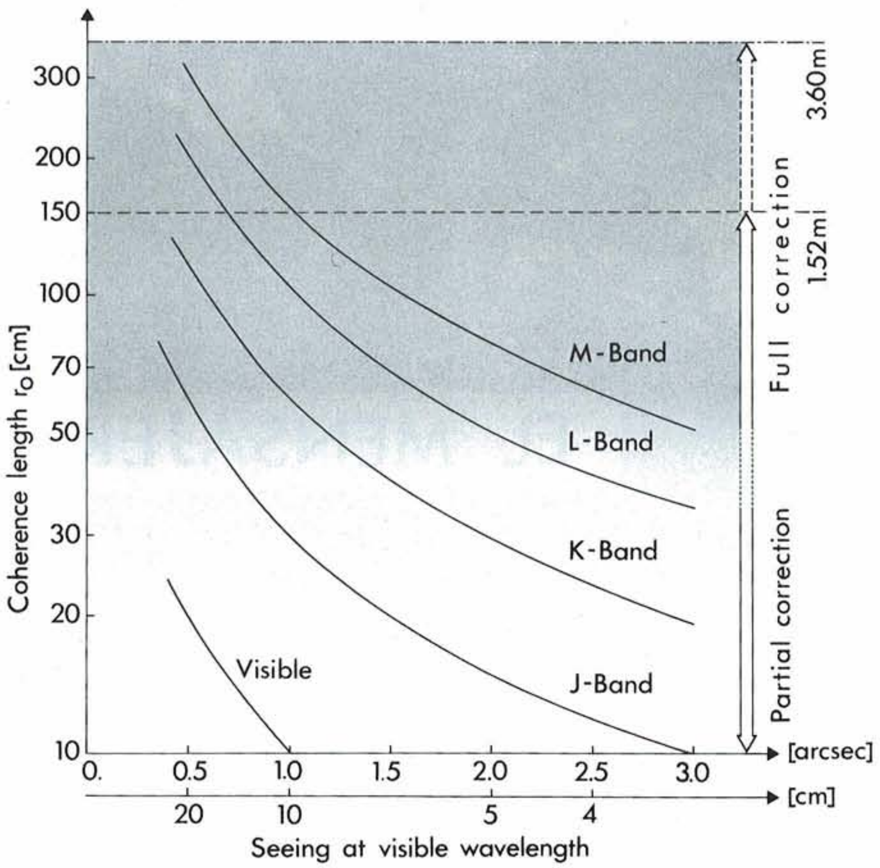

Figure 2: *The application range of this prototype adaptive system is marked as the shaded zone in the diagram for different wavelengths bands (Visible, J-, K-, L-, and M-band). The coherence length r_0 for the various wavelengths is plotted as a function of the seeing disk diameter at visible wavelength. When r_0 exceeds approximately 40 cm, which corresponds to the mean actuator spacing on the deformable mirror, then full correction is obtained. Below this value only partial correction is possible. When r_0 reaches the diameter of the telescope, then the telescope is only limited by its optical quality and adaptive optics is not required.*

infrared images have been taken in the J, H, K, L, and M bands. Several integrations were made through each filter without the adaptive feed-back, immediately followed by an equal number with the device activated. Depending on the brightness of the observed star, each exposure lasted between 10 and 100 seconds. At this time the prototype system is not optimized in light efficiency. For wavelengths of 3.5 μm and longer, the diffraction limit was always reached, irrespective of the atmospheric turbulence. During the observations, the seeing in the visible wavelength band ranged from 0.7 arcsec to 2.5 arcsec with equivalent seeing cell sizes (coherence lengths) r_0 of 14 to 4 cm. During the phases with better seeing, diffraction limited imaging was even reached at 2.2 μm (0.3 arcseconds) and a noticeable improvement was seen at 1.2 μm. Figure 1 shows an example.

Figure 2 displays the application range of this prototype system under various seeing conditions. The diagram shows for the 4 infrared wavelengths ranges the relation between the image size in the visible and the coherence length r_0 at infrared wavelengths. This adaptive optics prototype system is capable to fully correct the atmospheric turbulence if the seeing conditions are such that the coherence length r_0 in the infrared range is larger than 30 to 50 cm. 30 to 50 cm corresponds to the mean actuator spacing on the deformable mirror. If the operation falls in an r_0 range below this value, the correction is only partial. Are the application conditions above the dashed line, then no improvement can be achieved, because the telescope (in case it is of perfect quality and well aligned) is by itself diffraction limited. A first analysis of the results confirmed the theoretical expectations. Whenever the observing conditions were in the operation range of the system, perfect image quality was reached, as demonstrated by the well-known Airy ring around the star image.

How Does it Work?

Adaptive Optics is based on an optical/electronic feed-back loop. In its physical principles it is equivalent to *active optics* as it is applied in the ESO New Technology Telescope (NTT) (see *Messenger* Nos. 53 and 56). But for the compensation of the atmospheric turbulence, the system has to correct much faster than in the active case and therefore the wavefront correction cannot be done by the primary mirror. Therefore,

Figure 3: *The adaptive system at the coudé focus of the 1.52-m telescope at OHP.*

TABLE: Technical Data.

Deformable mirror:	19 piezoelectric actuators +/− 7.5 micrometre stroke
Tip/tilt mirror:	gimbal mount piezoelectric actuators
Wavefront sensor:	Shack-Hartmann principle 5 × 5 and 10 × 10 subapertures 100 × 100 intensified Reticon detector built-in reference source additional field selection mirror
Wavefront computer:	dedicated electronics host computer based on Motorola 68020
Control algorithm:	modal correction scheme mirror eigenmodes
Camera:	32 × 32 InSb array camera (SAT detector) additional chopping mirror

Figure 4: *The control panel of the adaptive prototype system. The large rack in the upper left contains the wavefront computer. It is based on dedicated processors for a fast wavefront analysis.*

the optical system must include an additional, small deformable mirror which can change its surface profile fast enough in a way that exactly compensates for the distortions of the wavefront after it has passed through the atmosphere.

In the present prototype system the mirror surface is deformed by 19 piezoelectric actuators. The information about how to deform the mirror comes from a wavefront sensor which allows to measure the shape of the distorted light wavefront sampled in 5 by 5 sub-apertures. It requires a very fast and powerful computer to calculate how the actuators located behind the deformable mirror have to push and pull the mirror surface. Figures 3, 4, and 5 show the system installed at the coudé focus of the 1.52-m telescope, its control panel, and a close-up view of the opto-mechanics and its principle. The main data of the prototype system are given in the Table. The major components of this system and the system in the laboratory has been described earlier in *Messenger* Nos. 52 and 57.

Future Plans

This prototype system will soon be installed at the ESO 3.6-m telescope at La Silla. The encouraging results represent a first, major step on the way towards an adaptive system for the 16-m Very Large Telescope (VLT). An upgrade of the deformable mirror to approximately 50 actuators, a wavefront sensor with 10 by 10 sub-apertures, and an even faster computer system will be the next step. Such a system could then be designed and built for the NTT.

The new technology makes it possible to achieve the theoretical limits for optical imaging in the infrared wavelength range by means of a medium-sized telescope. Further developments will aim at perfecting the technique for larger telescopes and at shorter wavelengths. Not only will present-day telescopes benefit,

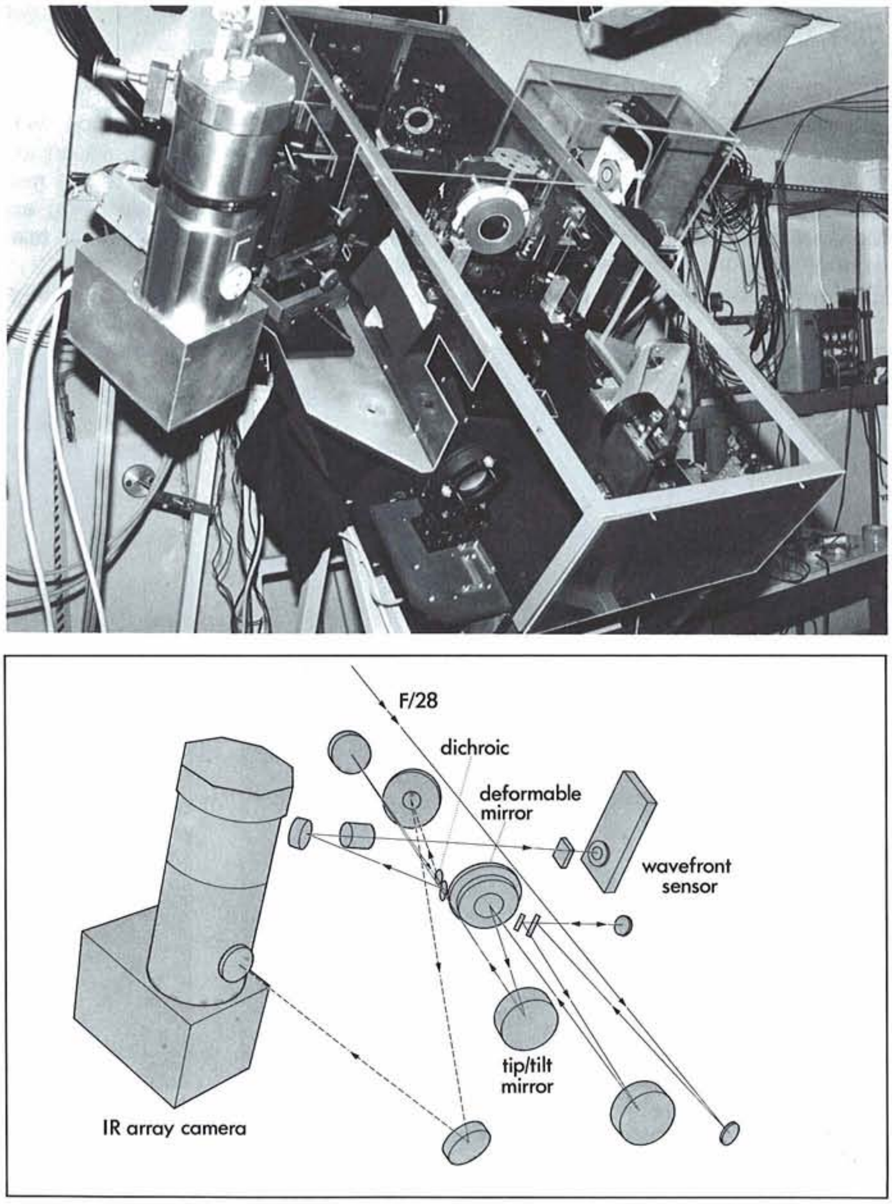

Figure 5: *Close-up view of the adaptive system (upper) and schematics of the optical lay-out (lower). The F/28 beam enters from the top, a focal reducer changes the ratio to F/8 (for the ESO 3.6-m telescope), and an off-axis parabola in front of the deformable mirror collimates the beam. After the deformable mirror, the beam is reflected at a gimbal mounted mirror for tilt correction and then a second off-axis parabola refocusses it. The infrared and visible part are separated by a dichroic mirror. The infrared part is relayed to the IR array camera, while the visible part is reflected to the wavefront sensor.* ▶

but this technique will revolutionize the exploitation of the next-generation telescopes, such as the ESO VLT, and, in many cases, compete with observations carried out by telescopes deployed in space.

A scientific-technical paper, describing the first adaptive optics results, is expected to appear soon in *Astronomy & Astrophysics*.

Acknowledgements

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Astronomical Observations With the NTT During Commissioning

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It was with particular pleasure and emotion that I received the first astronomical images obtained with the NTT from Chile. As the NTT Project Manager it was satisfying to see that the work of many – both inside and outside ESO – had converged to produce an instrument whose performance was even better than expected. As an astronomer it was fascinating to see new details of objects which are being explored by many of us with other telescopes but at lower resolution.

The illustrations of 4 images (Figures 1–4) are spectacular examples of the possibilities of the new telescope.

It is important to understand the value and limits of these observations obtained during the commissioning phase of the NTT which represents a complex and delicate period for a new telescope.

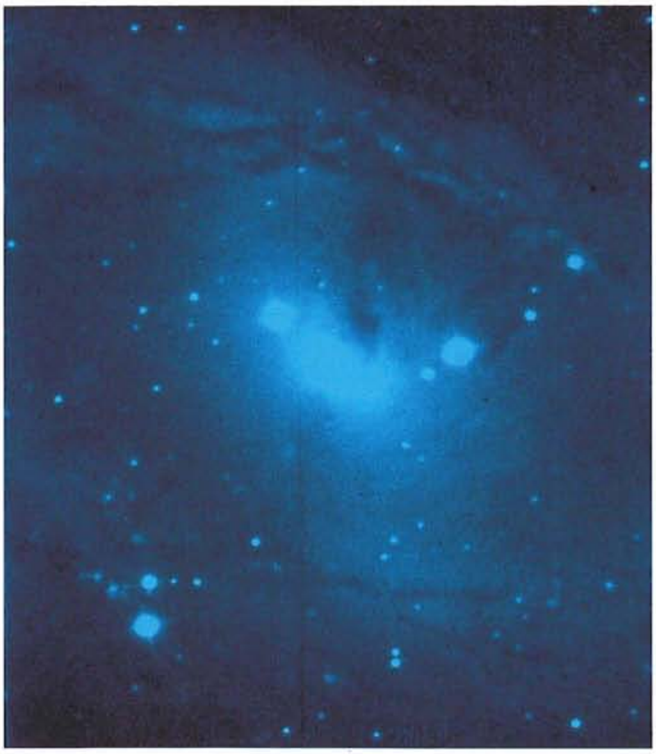

Figure 1: *NGC 6300. The short exposure of only 30 seconds of this SB galaxy shows dust features in the inner part and on the nucleus that resemble the horse head in the Orion nebula. Seeing is 0.7 arcsec.*

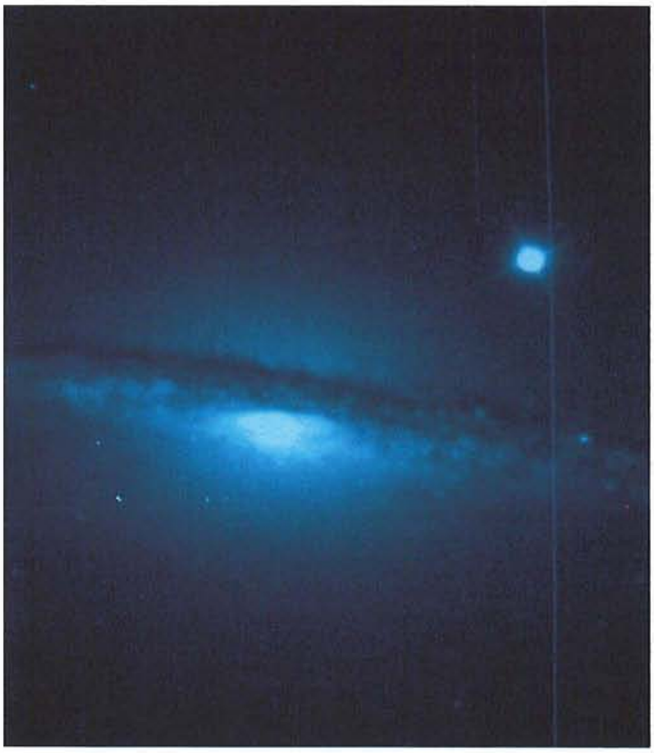

Figure 2: *NGC 681. An edge-on dust spiral.*