The ESO Optics Group and some Recent Achievements

R. N. Wilson

DEVELOPMENT OF THE OPTICS GROUP

The ESO Optics Group was formed in March 1973. The need was already pressing at that time with many problems connected with the optical tolerancing and testing of the 3.6 m telescope requiring urgent attention. Also required was a major optical design effort on prime focus correctors and ancillary optics for the adapters (interface units between astronomer and telescope providing viewing, guiding, focusing and other facilities). The auxiliary instrumentation programme, then in its initial phases, also placed heavy demands—not only for optical design, but also on basic layout determined by the astronomical/optical interface.

It became evident very early that the founder member of the OG, Ray Wilson, could not cope alone with this large and increasing volume of work. The first extension of the OG was Francis Franza, a technical assistant in mechanics, who joined us in January 1973. His first major task was the opto-mechanical layout of the prime focus and Cassegrain adapters in collaboration with the (then) coordinator, Bernth Malm.

At the end of 1973 an extremely powerful optical design programme, ACCOS V, was purchased from the USA. This was put into use with the CERN CDC 7600 computer and rapidly proved a most powerful and efficient tool. However, a full-time optical designer was required to exploit it. In September 1974, Maurice Le Luyer, one of France's most experienced optical designers, joined the OG. He took over responsibility for the whole optical design and computer side of the OG operations. The most urgent tasks were the computation of the adapter optics and the prime focus correctors.

The decision had been taken in late 1972 to build an optics laboratory next door to the mechanics assembly hall. It was the group leader's philosophy from the start that optical *manufacture* was not a sensible field of activity for ESO, since there is ample manufacturing capacity available in industry. The role of the laboratory was thus to be principally optical assembly and testing. To take charge of the Optics Laboratory, equip it and assume responsibilities in the mounting load of work in auxiliary instrumentation, Daniel Enard was engaged in February 1975. At the same time Guy Ratier joined the OG for a year, on leave from the Pic-du-Midi Observatory. Guy's main task was to advance the design of a coudé spectrometer as well as assisting with the adapters and with certain specialized problems connected with the 3.6 m telescope.

Until this year, it had been impossible for the OG to take any significant interest in existing equipment in Chile—the manpower simply did not permit it. However, contact was established by a visit by Ratier in 1975 and by Enard and Wilson in February 1976. The major purpose of the latter visit was to prepare the way for the installation and test phase of the optics of the 3.6 m telescope. A fruit of this contact has been the decision to engage an optical engineer for La Silla. Max Lizot will be joining the Operations Group in August 1976. He will not be a formal member of our OG but will maintain very close liaison with us to the mutual benefit, we are confident, of both ESO-Geneva and ESO-La Silla. To complete the basic manpower of the OG, an optical technician will be engaged within the next few weeks. His work will be the assembly and test of equipment in the Optics Laboratory.

SOME RECENT ACHIEVEMENTS

1. Telescope Optics

The end of the current year should mark the end of an era for the OG in which the requirements of the 3.6 m telescope have dominated our activities.

Several man-years of capacity have been devoted to the *adapters* alone in one way or another. The *simplified prime focus adapter*, designed round the Gascoigne plate corrector, has recently been assembled and adjusted and has now left for Chile. It is an essential element in the initial prime focus use of the telescope. A major effort of assembly, adjustment and test will take place over the next few months on the *Cassegrain adapter*, for which the optics was recently delivered. A prime focus *adapter for the triplet corrector* is under development.

After considerable design analysis, it was decided to equip the telescope with two types of prime focus corrector. (It should be remembered that the naked primary of our quasi-Ritchey-Chrétien telescope does not yield a corrected image without corrector.) The first type is called the *Gascoigne plate (GP)* and provides a field of about 0°25 with a single aspheric plate. Two such plates have been manufactured, one optimized for the red spectral region and one for the blue. These ESO plates are among the first to be made: the manufacture is difficult and its success depends on a rigorous test procedure. A special optical system for this test was developed in the OG. The GPs should provide maximum efficiency correctors with particularly good ghost-image performance. Combined with an electronographic image tube (Spectracon), they should give maximum penetration into space for photographic work. The *triplet* correctors (again a "red" and "blue" one) are currently being manufactured and will be available for integration into the adapter towards the end of this year. They will provide a field of 1° with rather stronger ghost images and will be used with classic photographic plates (or perhaps film) where a larger field is useful. *Doublet* correctors, giving intermediate characteristics, have also been calculated, but it is felt that the others cover sufficiently our present requirements.

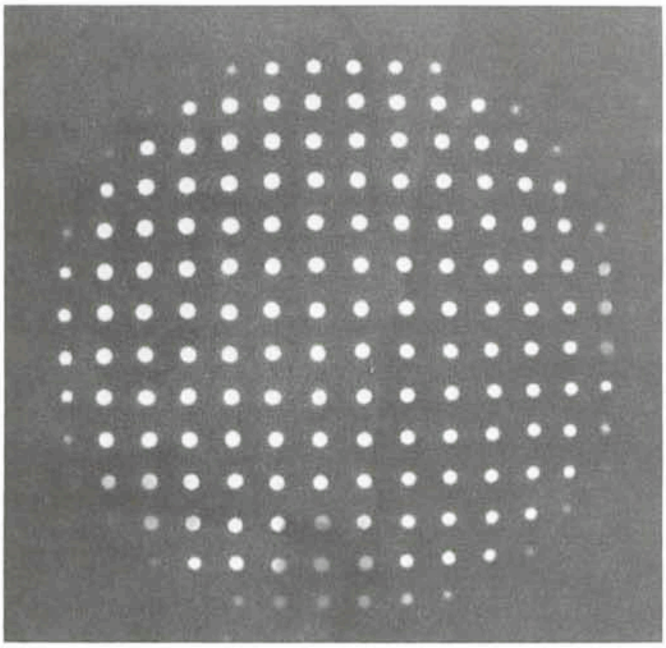

Fig. 1. Hartmann plate for f/5 paraboloid of 600 mm diameter tested at centre of curvature.

2. Testing and Adjustment of Telescopes and Other Optics

Telescopes are very expensive instruments. The quality demands placed on the manufacturer of the optics are considerably more severe than those customary before the last war. Such quality is only possible or verifiable with highly sophisticated test procedures. The standards of test and adjustment in *maintenance* must be correspondingly high, otherwise the heavy economic investment in potential quality is wasted in astronomical practice.

The expected performance of the 3.6 m telescope on the basis of existing test material has been analysed in great detail. In particular, the prime mirror support system has been the subject of a careful analysis which suggests that the telescope should, even with the least favourable interpretation, be well within the specification. The final quality will be known before the end of this year. A comprehensive adjustment and test schedule has been planned, based on visual and photographic tests but above all on *Hartmann testing* with a 2-dimensional screen. This rigorous test procedure, pioneered in its general 2-dimensional form at Lick, Kitt Peak and the Optical Sciences Center in Tucson, provides a means of analysing telescope quality in scope and precision quite impossible in the pre-computer era. A basic programme kindly supplied by Kitt Peak has been considerably extended to give comprehensive analysis of the different possible errors which can affect the image due to manufacturing irregularities in the mirror surfaces or distortions of cells or the tube. This development is certainly one of the most important undertaken by the OG. Apart from the computer side, it requires sophisticated plate-measuring equipment with computerized output. Such facilities exist in the Sky-Atlas Laboratory in Geneva and similar developments have been undertaken by ESO-Chile for plate measurements at La Silla. Trial Hartmann tests have been performed on the 1 m telescope of the Pic-du-Midi and on the ESO 1 m photometric telescope. Routine Hartmann testing should have a major impact in future in maintaining high optical quality of all ESO telescopes.

An analogous programme development which is also of great significance allows the *computer analysis of interferograms*. Such interferograms provide one of the best methods of establishing the quality of optical elements and systems. Such analysis has already been of great value in assessing the quality of the Gascoigne plate correctors and of parabolic mirrors destined for use in holographic grating production.

It is not possible in a general article like this to go into details of Hartmann or interferometric testing. However, it is instructive to see what a typical Hartmann plate and interferogram look like and what computer analysis produces. Figure 1 shows a Hartmann plate exposed for an f/5 parabolic mirror, tested in auto-collimation at its centre of curvature. A screen containing a set of holes in a rectangular mesh arrangement is placed in front of the mirror and a photographic plate placed *near*, but not *at*, the pinhole image at the centre of curvature. If the mirror were a perfect *sphere*, the image would be perfect and the Hartmann plate produced would be a perfect reproduction on a small scale of the screen. Aberration of the image produces distortions of the positions of the spots. In this case, the major barrel-type distortion does not correspond to errors of the mirror, but to aberration produced by its desired parabolic form. If the spot coordinates are measured with an accurate measuring machine, a sophisticated computer programme can analyse the errors in terms of a defined polynomial with a statistical or higher order residual. After removing the term corresponding to the parabolic form,

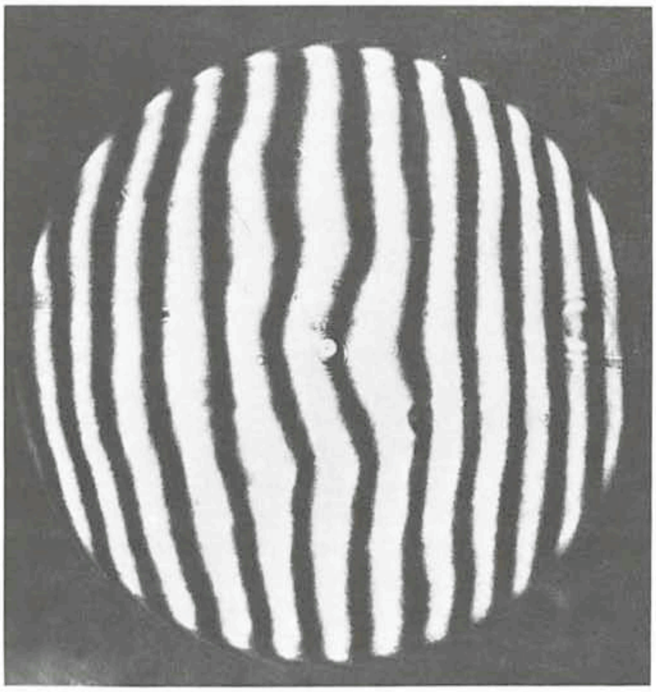

Fig. 2. Interferogram of same f/5 paraboloid tested at centre of curvature with compensating lens to remove spherical aberration.

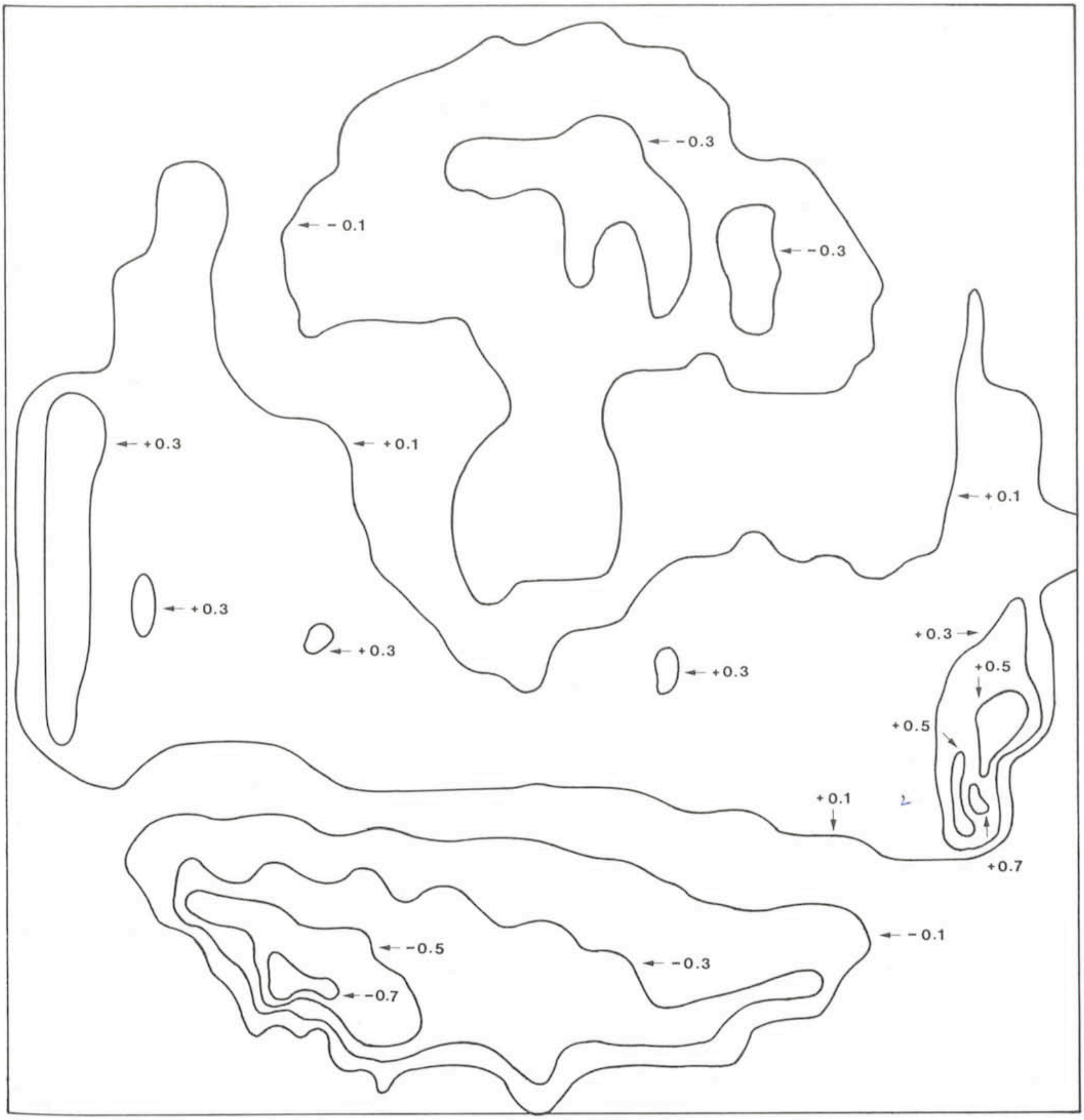

Fig. 3. Wavefront corresponding to the interferogram and produced from computer analysis. The contour lines represent the error from a perfect wavefront in wavelengths as units.

the analysis reveals in this case that the most serious error is astigmatism of about 0.75 λ (λ = wavelength of light 500 nm).

The interferogram (Fig. 2) is of the same mirror, but with the important difference that the aberration caused by the parabolic form has been removed by a compensating lens. The error in straightness of the fringes thus represents the manufacturing errors directly. The astigmatism is only obvious to the practised eye, but the central "hole" in the wavefront is very evident.

Figure 3 shows a contour map of the wavefront compared with a perfect sphere. This is part of the output from the computer analysis. In this case, the map was deduced from the interferogram, but an analogous map can be obtained from the Hartmann plate. This map shows clearly the basic "saddle" form corresponding to astigmatism.

3. Optics Laboratory

Telescope testing is perhaps the most important application, but many such Hartmann plates and interferograms will be produced, as with the paraboloid discussed above, in our own Optics Laboratory shown in Figure 4. Apart from normal small equipment of optical benches, light sources, etc., the main equipment consists of a Matra "Acofam" Optical

Test Bench, which permits detailed analysis of lens systems, a heavy optical bench in stone, a Laser Unequal Path Interferometer and a photometer. The photo also shows a HP 2100 computer of the sort which will be used for the controls of the 3.6 m telescope and for Hartmann analysis.

4. Auxiliary Instrumentation for the 3.6 m Telescope

A word should now be said about recent work on auxiliary instrumentation, without which the utility of the telescope would be very limited. We make no attempt here to list or discuss the instrumentation programme in general (such an article will appear in a future issue), but mention only those projects on which the OG has worked.

A conceptual design has been worked out for a *coudé echelle spectrometer,* and this has been approved by the Review Team advising on the project. The detailed design study will be pursued as soon as the 3.6 m initiation phase is complete. Similarly, a conceptual design for a *Cassegrain echelle spectrograph* has been prepared for discussion in the appropriate Review Team. Optical design work is under way on a *focal reducer* for the prime focus of the 3.6 m telescope. The optics of the *coudé auxiliary telescope (CAT)* will be tendered within the next few weeks. A *coma device* (a device devised by A. Behr for testing the centering of telescopes) is in an advanced state of manufacture.

Depending on priorities, pressure on development capacity and availability of suitable products from industry, it may be in ESO's interest to buy a complete instrument. In the case of an instrument in which optics assumes a dominant role, the definition and processing of the contract followed by acceptance and testing, form a part of our work which should not be underestimated. An example is the *Boller and Chivens spectrograph* which has just been delivered for immediate use at the Cassegrain focus of the 3.6 m telescope as soon as this focus becomes available.

5. Other ESO Equipment

Coming now to the general support side of the Observatory's other equipment apart from the 3.6 m telescope, the development of a novel *off-set guiding system for the 1 m Schmidt telescope* should be mentioned. This will permit off-set guiding even with the objective prism. The optical design is complete and its manufacture should be possible soon. Preliminary work has also been completed for ordering a new "blue" Schmidt plate which should make the Schmidt telescope more effective in the blue spectral region. Other projects actively being pursued are improvements in the *Zeiss camera* (TV guiding on the 1.5 m telescope) and the *Echelec spectrograph.*

6. Other Observatories and Institutes

Finally, the OG has fruitful contacts with observatories and institutes of the member states. These include assistance and advice (usually in both directions) with the Pic-du-Midi and OHP in France, with Danish observatories (e.g. supply of a focal reducer), cooperation on optics with ESA in the working group of a Space Astrometry project, and supply of optics for holographic grating production for Göttingen Observatory. Last but not least, our "sister" organization in Geneva, CERN, has built a prototype of the Cerenkov Counter optical system proposed by the OG. We have also assisted them in the manufacturing contracts for eight such systems which are in course of delivery. The result seems very promising and should be of major importance in the CERN research programmes.

In this article we have made no attempt to cover in any depth any of our activities, but rather to give an idea how numerous they are. We hope you will be indulgent if we have had no time yet for *your* problem. We hope we can tackle it soon!

Fig. 4. ESO Optics Laboratory. At the right the ACOFAM test bench; left foreground the stone bench with interferometer; centre background HP 2100 computer.