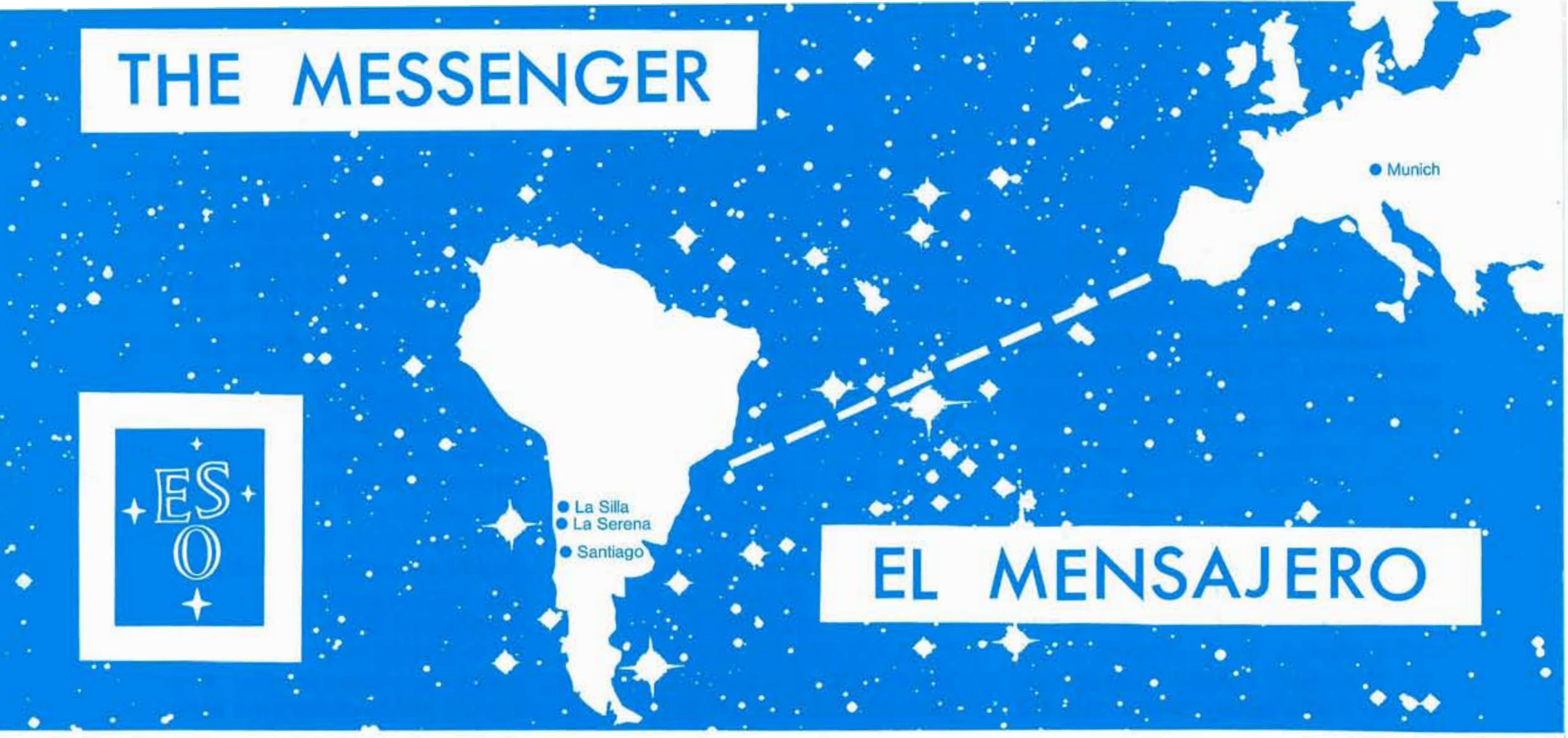
THE MESSENGER

EL MENSAJERO



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"First Light" in the NTT

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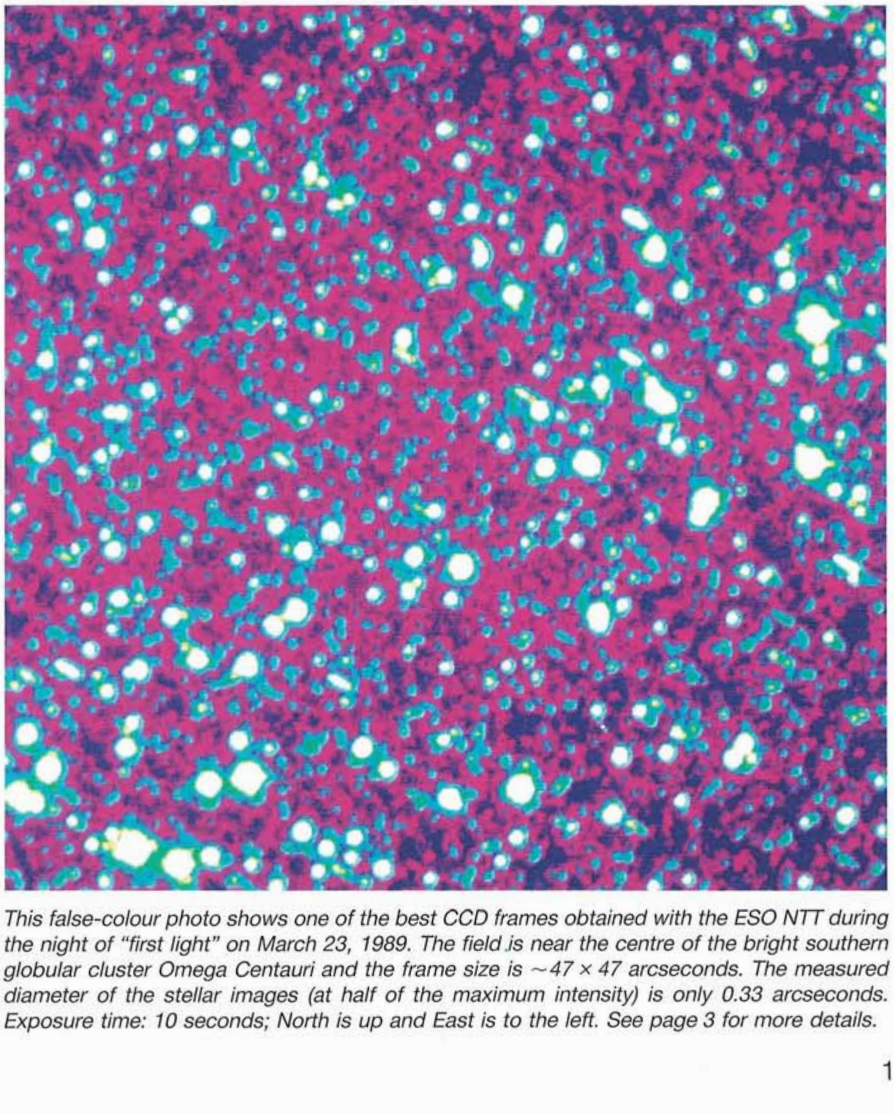
On the night 22–23 March 1989, "First Light" was achieved in the NTT in the sense that the first direct images of astronomical objects were produced with the optics in an optimized state near the zenith position.

The fact that the quality of these images turned out to be the best ever recorded in ground-based astronomy certainly made it the most memorable event in the ESO career of the author and his colleagues whose work on the NTT had led to this remarkable success.

But this result did not drop out of the sky! Many years of hard work by a small group of dedicated colleagues were necessary to achieve it. The principal new technology feature of the NTT was its Active Optics control system, the background and principles of which were described in *The Messenger* No. 53 (September 1988), page 1. The other new technology feature of fundamental importance for the optical quality was the design of the building. Although its basic concept is the same as that of the MMT (a building rotating with the alt-az mounted telescope), the new features were crucial, particularly the opening of the telescope area on both sides to allow maximum natural ventilation. These two new technology features, together with the excellent work of Carl Zeiss in figuring the optics, were the key to the image quality achieved at First Light.

The Basic ("Passive") Alignment of the Optics

The final stage for the NTT optics started in November 1988. The mechanics of the telescope had been



This false-colour photo shows one of the best CCD frames obtained with the ESO NTT during the night of "first light" on March 23, 1989. The field is near the centre of the bright southern globular cluster Omega Centauri and the frame size is ~47 × 47 arcseconds. The measured diameter of the stellar images (at half of the maximum intensity) is only 0.33 arcseconds. Exposure time: 10 seconds; North is up and East is to the left. See page 3 for more details.

assembled under the supervision of Gerardo Ihle. To him and his colleagues in Chile we owe, also for much help later, a deep sense of gratitude. The optical alignment procedure and the handling of all the elements involved, required the definition and procurement of a considerable number of mounting and handling devices. This was planned and defined by Francis Franza and Paul Giordano last autumn and manufactured with the help of Rainer Grote. Francis and Paul then spent 6 weeks from the beginning of November, without intermission, preparing this material for the following alignment mission. This included the mounting of the prime mirror supports and their testing with Lothar Noethe. As an example of the sort of auxiliary material involved, one can cite the temporary "bridge" over M3 which serves for its mounting but also as support for one of the sighting telescopes used in the alignment.

Then followed a second mission from 10 January, also of 6 weeks without any intermission, for the basic (passive) alignment of the optics of the NTT, carried out by Francis Franza, Paul Giordano and Ray Wilson. The procedure for this alignment was laid down by the above on the basis of a standard procedure used by them on a number of La Silla telescopes, notably the 3.6 m, the Danish 1.54 m, the CAT and, in its final stages, for the MPIA 2.2 m. The NTT alignment procedure was a more refined and complete form, taking account of its alt-az mount and double Nasmyth focus. If one considers certain inevitable problems of control of the telescope, this alignment programme, comprising 56 individual technical steps, represented the absolute maximum achievable in 6 weeks of continuous work. In fact, without the absolutely excellent support from the La Silla colleagues in electronics, mechanics and optics, it would not have been possible in the time. In particular, the continuous superb support of the mechanical workshop must be emphasized as playing a key role in the completion of the heavy work load. This general procedure included the aluminization of the three mirrors, carried out under the supervision of Paul Giordano who has many years of experience in this field. Of course, the biggest task here was the primary aluminization, above all because of the delicate handling procedure involved.

The individual steps of the alignment procedure can be grouped in the following work packages:

- Optical identification of the ALT-axis (basic reference line for the whole alignment).
- Optical identification of the AZ-axis.
- Optical identification of OPT, the line defined as the optical axis of the telescope and which is perpendicular to ALT and traverses the intersection point of ALT and AZ.
- Reduction of the angular error between OPT and AZ and the intersection (coplanarity) error in the knot point of AZ relative to ALT.
- Adjustment of M3 bearing axis to be coincident in angle and position with OPT.
- Mount M2, centre it to OPT, set it perpendicular to OPT and align the focus movement to OPT.
- Remove M1 dummy (counterweight), mount M1 cell (without M1) and centre M1 cell to OPT.
- Insert M3, adjust its tilt in both planes and place its reflecting surface on the intersection of ALT with OPT.
- Mount M1, adjust tilt of the M1 cell to eliminate decentring coma on a natural star ("*Technical* First Light").

The last step above is the final one in the *passive* alignment. In fact, it could not be completed at that stage as the image analyser (our off-line test system called "ANTARES") was not yet available at that time with a CCD detector. At that stage, therefore, no attempt was made to adjust the M1 cell but about ⅔ of the considerable coma (which was normal and expected at this stage without adjustment of the M1 cell) was corrected by a visual inspection of the defocused image and by using the full range available of the M2 x-y movement for fine coma correction. "Technical First Light" was celebrated on 15 February with an image on TV of Jupiter, with modest seeing and at a zenith distance of about 50°.

The Final Effort: Trimming the NTT Optics to the Limit

The final stage of the setting up and optimization of the optics near the zenith was accomplished by the above team and Lothar Noethe in a 16-day mission ending on 23 March. Lothar played the central role as the person responsible for the entire software and image analysis side, following up the work on the 1 m experiment and the acceptance of the optics at the manufacturers, Carl Zeiss.

The first essential step was to get the image analysis working. This was rapidly achieved with no significant problems. Gaetano Andreoni of La Silla became an invaluable member of our team and worked with us the whole time.

The image analysis confirmed immediately the amount of decentring coma we had expected from the previous mission. The Coma3 (decentring coma) coefficient was evaluated from the mean of many measurements as about 12,800 nm or *4.5 arcsec* with zero correction (central position), of the x-y movement of M2. Using the calibration value given by Bernard Delabre from the optical design of the telescope, it could be deduced that the M1 cell had to be tilted by about *2 arcmin* to correct this large coma. This is a measure of the extreme sensitivity of passive telescopes to decentring coma, since this is a quite small angle and well within the mechanical tolerances of the telescope. A maximum of 2,5 mm had to be machined off the flexion bar feet holding the M1 cell in order to achieve this tilt. The biggest problem was to interpret the physical orientation of the coma in the telescope: an error here would have meant the whole operation of lowering the cell and machining the flexion bars would have to be repeated! It was therefore with a feeling of great relief that we saw the confirmation of the orientation when the first image analysis showed that the coma had been reduced to less than one tenth of its original value.

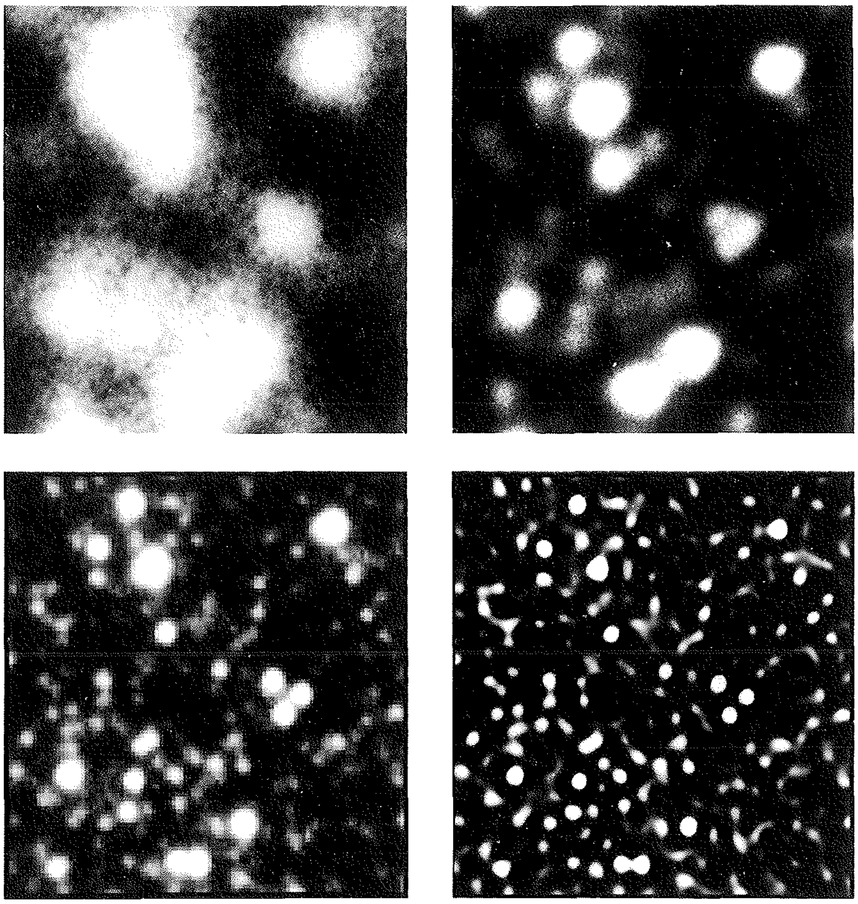
This formally completed the *passive* adjustment of the telescope. It remained to optimize its performance in the zenith by the dc active optics correction, i.e. the correction of residual fixed errors.

The Night of "First Light"

Apart from one effect, the image analysis had brought no surprises. This one effect was a residual of axi-symmetric (spherical) aberration which was some five times larger than the maximum we had expected. Variations of this value could be explained by a hot-air bubble effect on the primary, but a fixed residual of about 0.5 arcsec remained. This exceeded the passive specification. Because its correction absorbed a much larger part of our total active dynamic range than we expected, it proved most convenient to correct using the "natural mode", a system of modal formulation suggested by Noethe and Schneermann for the VLT. In this way, this aberration as well as the other fairly small residuals *were all reduced to values within one tenth of an arcsec, including the residue of coma.* This required the averaging of ten or more measurements. We were helped by the fact that, during the nights leading up to "First Light" on 22–23 March, the external seeing was extremely good.

On 20 March we could already announce that *the "INTRINSIC QUALITY" of the telescope optics (80 % of the light of a star concentrated in about 0.15 arcsec) had already been reached.* This dc modulation of the M1 active support was then introduced into the springs provided and remains now as a fixed

A Revolution in Ground-based Direct-imaging Resolution



These four images illustrate the importance of improving the resolution of astronomical images. They demonstrate the great potential of the ESO New Technology Telescope (NTT), in terms of finer details and fainter limiting magnitude, as compared to other telescopes.

The field shown is near the centre of the bright southern globular cluster ω Centauri. It measures 12 × 12 arcseconds and covers about 1/16 of the area of a CCD frame, obtained with the NTT on the night of "First Light", see the picture on page 1.

The first (upper left) picture is an enlargement of a photographic plate obtained in 1984 with the ESO Schmidt telescope under seeing conditions mediocre by La Silla standards (~ 2 arcsec). The exposure time was 10 min on unsensitized, blue-sensitive IIIa-J emulsion behind a GG 495 filter (spectral range 500 – 540 nm). The original image scale is 67.5 arcsec/mm; i.e. the field shown corresponds to 0.18 × 0.18 mm on the original 30 × 30 cm plate. In other words, about 2.6 million fields of this size are contained on the Schmidt plate.

Next (upper right) follows an excellent photographic plate obtained at the Cassegrain focus of the ESO 3.6 m telescope in 1977. The exposure lasted 6 min 15 sec and the seeing was ~ 1 arcsecond. The emulsion was IIIa-J and no filter was used (spectral range 300–540 nm). The image scale is 7.2 arcsec/mm; on the original 6 × 6 cm plate this field measures 1.7 × 1.7 mm.

A 10 sec unfiltered CCD exposure was made with the NTT at the moment of "First Light" on March 23, 1989; a small part of it is shown here in two versions. The first (lower left) is the "raw" 100 × 100 pixel image (pixel size 0.123 arcseconds). The Full Width at Half Maximum (FWHM), as measured directly on the stellar images in the frame is 0.33 arcseconds. To this value, the NTT optics contributed perhaps 0.15 arcseconds, so that the actual, atmospherically induced seeing may have been better than 0.3 arcseconds, a spectacular value, even by La Silla standards.

At the lower right, the same frame is shown after "sharpening" by advanced image processing. For this, the frame was subjected to deconvolution with a point spread function, which was empirically constructed from 50 profiles of uncontaminated stellar images and at the same time resampled at 1/5 of the pixel size in both directions. The FWHM is now improved to 0.18 arcseconds; the stellar images are noticeably sharper and faint stars are much better visible. To facilitate the comparison, the intensity scale is the same in both NTT frames.

The image processing was made by Dietrich Baade at the ESO MIDAS facility in Garching with an algorithm developed by Leon Lucy. About 3 hours VAX 8600 CPU time was needed to perform 20 iterations; this time can of course be significantly reduced with other computers, optimized for "number-crunching".

The improvement in resolution is dramatic, as illustrated for instance by the triple star, just right of the field centre. The distance between the two components which are closest to each other, is only 0.79 arcseconds. The Schmidt picture does not indicate any multiplicity, the 3.6 m barely resolves the system, while the NTT shows the three components, well detached from each other. Note also the resolution of the double system near the lower border, here the distance is 0.59 arcseconds.

Since the light is better concentrated on the detector, the higher resolution also leads to fainter limiting magnitudes. The 10 second NTT exposure reaches about magnitude 20. A simple extrapolation then predicts that a limiting magnitude well beyond 27 mag may be reached with the NTT within a reasonable exposure time. The actually achievable value will of course also depend on other factors, like the sky background and the accuracy of the tracking.

correction. The *passive* correction of coma had been so accurate that the final *active* correction established only required x, y movements of 0.176 mm and 0.031 mm respectively, only tiny fractions of the nominal range available of ± 5 mm. Although the relatively large value of spherical aberration originally found has been actively fully corrected and therefore does not finally worry us, it is still important to understand its origin. This will be investigated further.

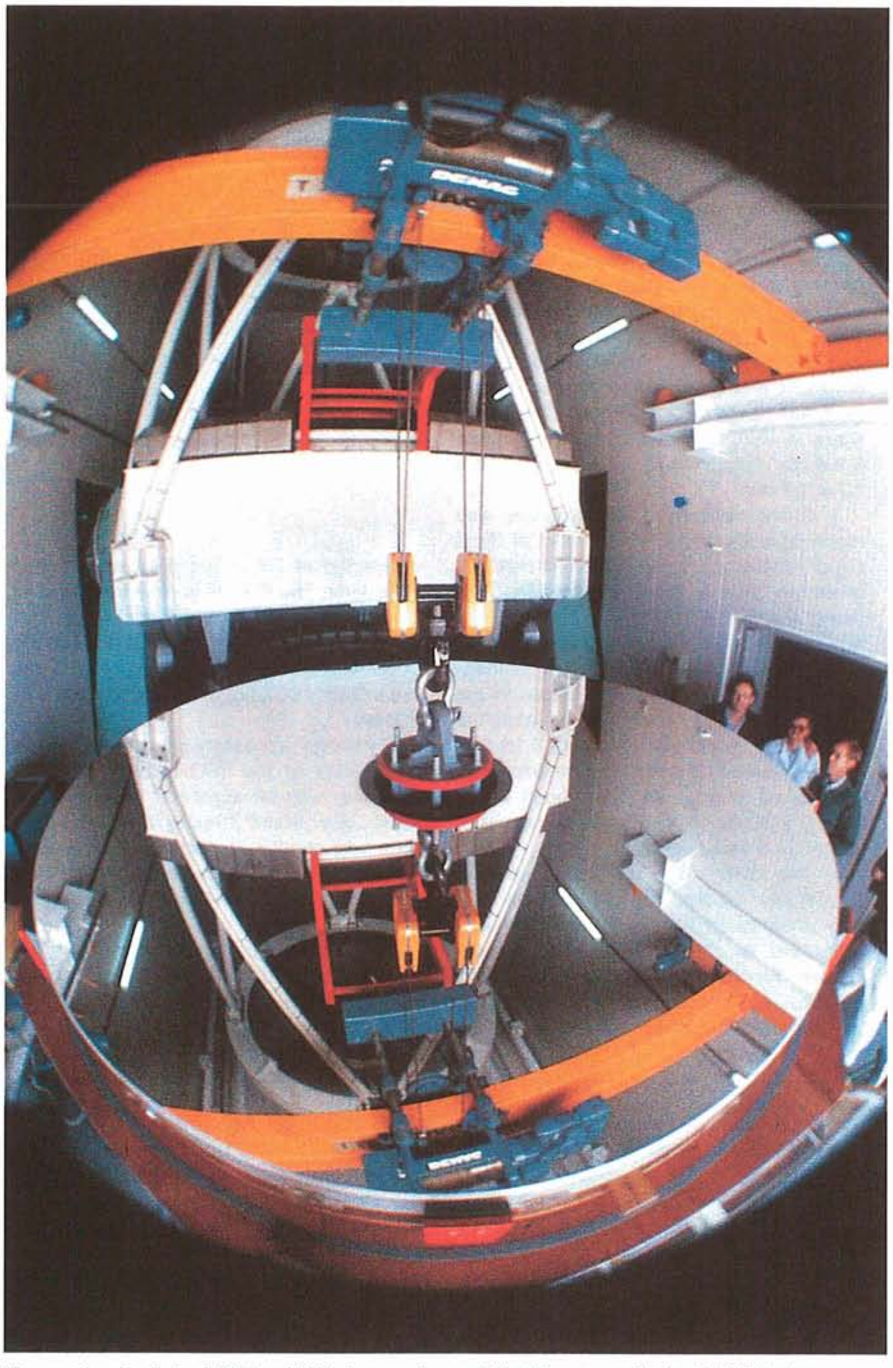
The CCD of the image analyser was dismounted and set up via a 45° mirror directly in the telescope focus. On the evening of 22 March we were ready for "First Light" in the true sense of the first astronomical images with the optimized optical system. The field available with direct imaging on the CCD was only *47 arcsec,* so account had to be taken of this in selecting objects. A further important parameter was the exposure time. A true judgement of the quality of the telescope image always requires an exposure time which integrates out the external seeing. With very good seeing,

ANTARES at the NTT Nasmyth focus; F. Franza and P. Giordano (right) (Photo Ph. Dierickx).

In the NTT control room at the moment of "First Light": R. Wilson (right), L. Noethe (at terminal) and R. Gaetano (foreground).

15 seconds may be sufficient, normally 30 seconds is required as a minimum. On the other hand, the telescope tracking was – inevitably – not yet optimized. Krister Wirenstrand had provided us with excellent support in getting the tracking to a level which was quite sufficient for our image analyses (about 1 arcsec drift in 60 s) but the requirements for direct imaging with very good seeing are far more stringent. Of course, at 21.00 hours we did not know what seeing we would have that night, but the very good seeing of previous nights, as measured by the seeing monitor at Vizcachas, 5 km away, had raised our expectations: it had often given values of 0.7 arcsec, sometimes lower.

Globular clusters were agreed to be the most favourable objects, both from their density of stars and ease of identification, as the pointing model was still in a relatively early stage of development (e.g. no precession correction working). Philippe Dierickx, who had joined us a few days before from Garching, and the author made up a list of possible objects fairly near the zenith from the amateur catalogues of Norton and Burnham. It should be emphasized that the telescope optics had only been optimized *near the zenith* at this stage. The performance at zenith distances of 60° had also been investigated and the quality measured was still 80% energy within about 0.5 arcsec at that inclination, without any supplementary correction. This is a better quality than any other telescope on La Silla at this zenith distance, even after optimum adjustment, but we are certain we can achieve effectively the same quality with the NTT at 60° as near the zenith, i.e. 80% energy within 0.2 arcsec. However, this will require a minor modification of the axial fixed points of the M1 support, so the optimization for the inclined telescope will only take place in July-August. For this reason, it was desirable to limit the



The newly aluminized 3.58 m NTT mirror arrives at the telescope. Photo: H.-M. Hahn.

zenith distance to a maximum of 30°, preferably less. However, *field rotation errors* were worse near the zenith. So it was clear that, at this stage of technical progress on the telescope, there were severe constraints on the position and brightness of suitable objects.

Excellent Seeing!

It soon became clear we were going to have a night of excellent external seeing. By 22.00 hours 0.7 arcsec was reported by Vizcachas (see the article by M. Sarazin on page 8). A number of excellent pictures of various objects were taken. Towards 23.00 hours Vizcachas reported the extraordinary seeing value of *about 0.4 arcsec!* It was already clear that we were privileged to have a night for our First Light of quite exceptional seeing. We were greatly assisted and encouraged by the presence and active help of two astronomers, Jorge Melnick and Sandro D'Odorico, to whom we extend our thanks. The author suggested that we go to the globular cluster *ω Centauri* to get a rich field of stars in a well-known object. The first exposure of 10 s without filter with zenith distance 23° was analysed by Jorge and found to give a FWHM of an arbitrarily chosen star of 0.44 arcsec! An atmosphere of great excitement prevailed: Jorge queried whether the pixel size (23 μm) and telescope scale (187 μm/arcsec) could really be correct? They were! An exposure of the same field in ω Centauri of 60 s was made, using a filter. Jorge deduced FWHM values for 5 stars between 0.42 and 0.36 arcsec! Field rotation effects (slight ellipticity at the upper left, less at the lower right on the screen) were apparent. So it was decided to reduce the exposure for the next picture to *30 s* with a zenith distance of about 18° (the minimum). The seeing was given by Vizcachas as 0.5 arcsec. Jorge measured one image of *0.35 arcsec,* others of 0.39 and 0.42 and expressed his amazement. Clearly, the dome seeing was negligible: a gentle and steady wind blew across the telescope, through the building fully open on both sides.

Shortly afterwards, the pictures taken were transferred to Garching via the satellite link, blocking the computer. There was telephone communication and mutual jubilation at the astonishing results. Our colleagues in Garching were working intensively to process the images, confirming our results. A wonderful spirit of a total team prevailed, separated by 12,000 km in two groups, all rejoicing at the remarkable proof of success of the NTT right from the start at first light.

Some final comments about the quality of these images should be made. With our image analyser and the force sensors on the M1 support, we had complete proof two nights before that the quality of the telescope optics themselves was better than 80% energy in 0.2 arcsec. On the night of first light we knew also from the force measurements that the quality was slightly inferior due to excess loads on the fixed points. This gives a slight triangular effect in the images which can be detected in the deconvolution of the images by Dietrich Baade. Nevertheless, it is unlikely that the quality of the optics was worse than 80% in 0.20 arcsec. *The slight ellipticity of the star images is entirely due to tracking errors (constant over the field) or associated field rotation errors (variable over the field).* It will require a lot more work on the tracking before it is within its specification of 0.1 arcsec rms with 15 min or more integration time. Until this is achieved, tracking errors will be the limitation of the optical quality achievable near the zenith. Also, we repeat, the inclined optical performance has still to be optimized. So, much technical work has still to be done to get the NTT fully within its extremely stringent specification.

A New Era

The real surprise of the First Light pictures was the extraordinary external seeing and the proof that, without optimization of the thermal conditions in the building and telescope, the dome seeing was effectively zero. This finally proved the point we have always made: that it is worth pursuing the goal of virtually diffraction limited quality of the optics (now readily achievable and *maintainable* with active optics) and optimized conditions for dome seeing because the real limits of external seeing have hardly been known or explorable in the past. A new era can start with the NTT and other telescopes using its principles, in which an image quality can be obtained which penetrates into the domain of space optics – but at costs of only a fraction of 1% of those of space optics!

Finally, our grateful thanks again to all those colleagues on La Silla and Garching who helped us achieve these results.

. . . and the View from Garching

During the early weeks of 1989, news about progress with the NTT at La Silla kept circulating through the ESO Headquarters in Garching. Whenever a staff member arrived from La Silla, he was immediately and persistently questioned by colleagues about the latest status. How happy we were to learn in February about the fine results reported by the optical group during the final trimming of the NTT optics!

By mid-March we knew that the great moment was rapidly approaching. A Telefax from Ray Wilson informed us that the predicted optical quality was being achieved and that the night of "First Light" was imminent. We talked about the first astronomical pictures and how they would look, and we tried to forget that, even above La Silla, clouds might eventually spoil our hopes.

A Memorable Morning

On March 22, two days before Good Friday, we received the details about the NTT performance, which Ray Wilson has described above. We also learned that during the coming night the first attempt would be made to have "First Light". Would it be possible to obtain reasonably good images and would it perhaps also be possible to transmit them in near-real time to Garching via the permanent satellite link? And quite apart from the astronomical/technological significance of these first images, should we try to inform the world immediately about this important event or should we rather plan a Press Release for the week after?

In the evening that day, we decided to proceed as optimists and to prepare ourselves for the best. Some of the staff members agreed to be on call in the early morning hours. Massimo Tarenghi, Manager of the NTT project, said that he would already be in the Remote Observing Room at 2 o'clock in the morning, i.e. when the night fell at La Silla; the time difference was 5 hours.

Sure enough, there he was, speaking on the telephone with Lothar Noethe in the NTT control room on La Silla, when I arrived just after 3 o'clock. I sensed something unusual in the way they excitedly spoke to each other and then I