Progress on the 3.5 m "New Technology Telescope" (NTT)

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Almost two years have gone by since the first article on the NTT written by my former colleague Wolfgang Richter appeared in the *Messenger* (1).

In spite of the disruption due to the move from Geneva to Garching and the loss at that time of *all* the mechanics staff who had worked on ESO telescopes, we can, I think, be satisfied with the progress made. Quite fundamental to this progress is, of course, the funding. This depended on the entry of Switzerland and Italy (announced in the *Messenger* No. 27 and 28 respectively) into ESO. We in the NTT team are particularly happy about these events, for otherwise the NTT could not have become a "real" project with a "real" budget. The approved budget is about DM 24 million (1982), including transport and contingency, which is less than one third of the budget of the existing ESO 3.6 m telescope at La Silla (about DM 68 million – 1974).

How is it possible to aim to build a telescope of about the same aperture only 12 years later than the start of the 3.6 m, at less than one third the price? The answer is the application of new technology which should not only give the reduced price but also *improved* quality and performance.

The principal new technology features are the following:

1. *Weight reduction:* This can only be achieved by lightening the primary mirror since its weight escalates by a chain reaction going through the whole system.

2. *Altazimuth mounting:* This is the oldest form of telescope mounting whose comeback is due to modern electronics which enables 2-axis tracking. The advantages mechanically and spacewise from the symmetry to gravity are self-evident. The advantages in cost and compactness far outweigh, in our view, the disadvantages of the field rotation and the zenith singular point with the accompanying telescope and field inversions.

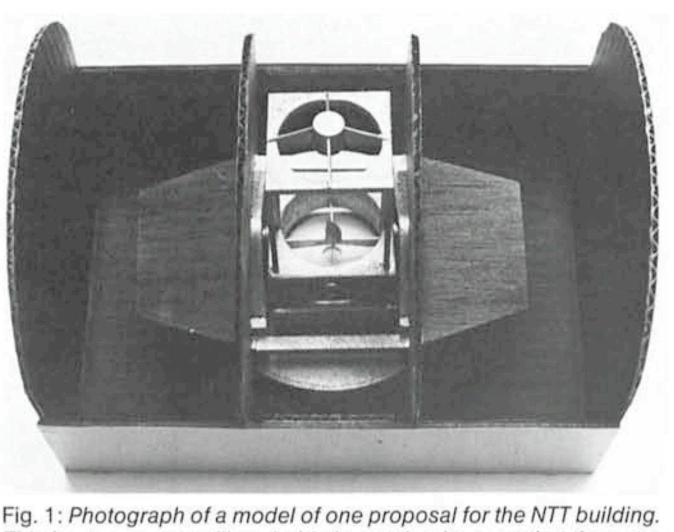

Fig. 1: *Photograph of a model of one proposal for the NTT building. This basic concept will probably be retained except that the outer walls in the direction of the altitude axis will be circular in section instead of flat with quarter spheres above them.*

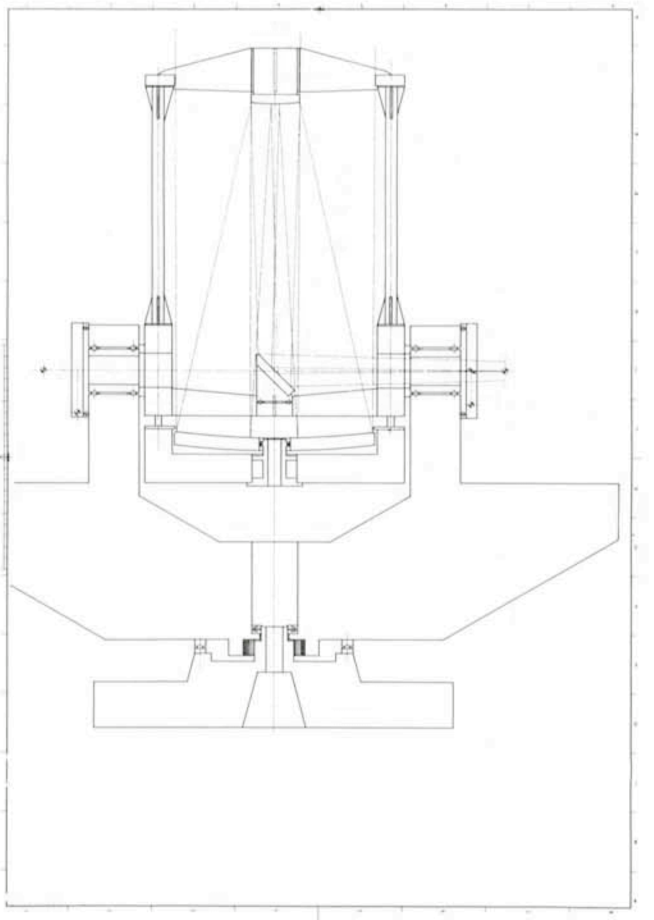

Fig. 2: *Basic geometry of the NTT (schematic).*

3. *A unique type of focus:* Multi-focus (universal) telescopes are very expensive and the gains have often proved illusory because of maintenance and operating complications. After much discussion, the choice was made for a *Nasmyth*-type focus with 2 principal fixed stations on the altitude axis. The principal motivation for the Nasmyth choice was the maintenance and operating simplicity of a light tube undisturbed by instrument weight or exchanges at the upper or lower ends. Prime focus direct imagery can be effectively replaced with a reduced field by focal reducer solutions. No IR wobbling secondary is envisaged, but the single secondary and Nasmyth mirror mounts will be designed to be as "clean" as possible.

In general, the existence of the ESO 3.6 m telescope as a general-purpose instrument available in parallel favours a more specialized design for the NTT.

4. *A compact building without a classical dome:* Our basic model here is the MMT building on Mt. Hopkins which undoubtedly represents a major advance in telescope technology. Fig. 1 shows a photograph of a single model we have prepared for a possible rotating building, but this will certainly still be modified. At what height the rotation would take place is also still open. At present we are considering as the most probable final form the following:

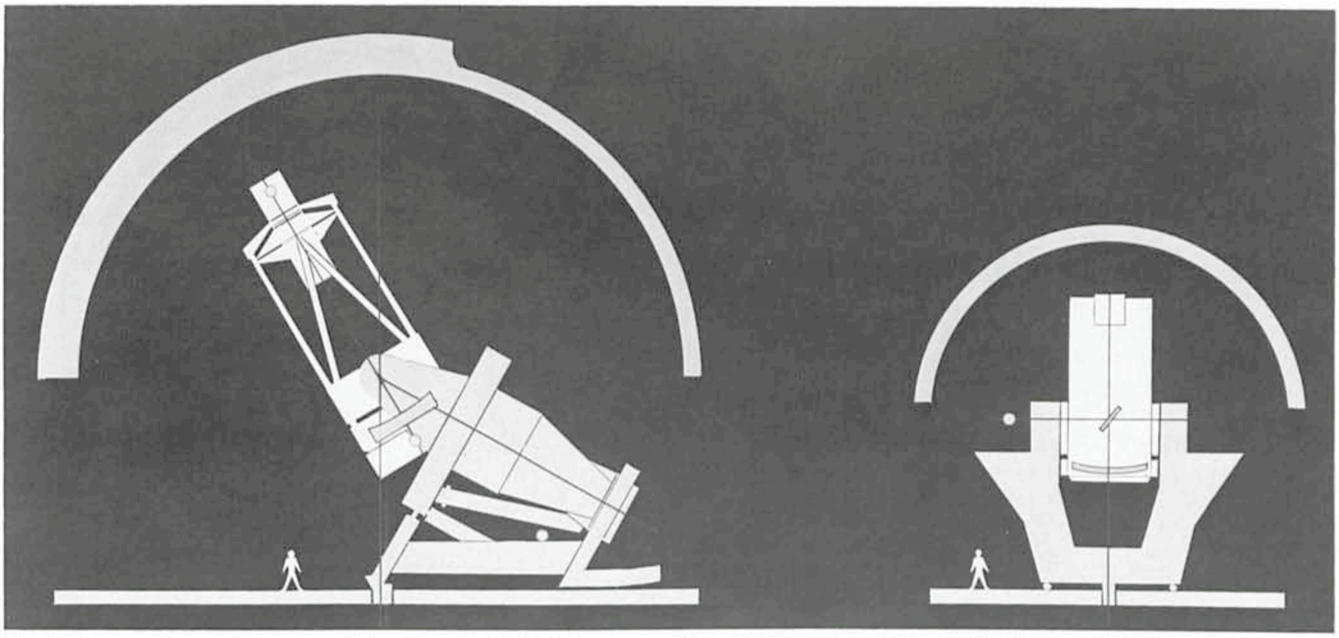

Fig. 3: *Comparison of "sweep circles" for the ESO 3.6m conventional telescope and the NTT, showing the compactness of the latter in comparison.*

- One starts with a cylindrical building with a hemispherical dome as was illustrated in ref. (1).
- This is cut in half vertically. Between the two halves a piece of square section is added, covered by a half-cylinder.
- The telescope is placed in the square section and the protecting half-cylinder consists essentially of windscreens. In this way, flexibility exists between maximum ventilation (windscreens fully open) and maximum wind protection (windscreens closed to leave a horizontal slit width similar to the telescope aperture).
- The quarter-sphere dome elements on each side of the half-cylinder are separated off by an insulated wall and house the instruments.

5. *A systematic closed loop active optics concept providing automatic opto-mechanical maintenance:* This is closely linked to the weight reduction aspect of Point 1 above. It is a natural technological response to the higher flexibility of thinner mirrors. The aim, which seems perfectly feasible, is to achieve *always* effectively diffraction-limited performance: the telescope monitors its own optical quality and corrects itself as required. The principles are discussed in detail in refs. (2), (3), (4).

6. *Atmospheric seeing correction:* This is far more difficult than the correction of the quasi-stable telescope errors of Point 5. It is hoped to make a start on image motion correction as has been reported by Angel (5). Because of the limitations of the isoplanatic angle (that angle over which the "seeing" function remains sensibly constant, which is about 2 arcmin for image motion and only about 10 arcsec for the highest seeing frequencies), it is better to deal with the essentially different aspects of active optics of Points 5 and 6 by different technical approaches.

7. *Remote control:* We consider this an essential feature of a telescope which bears the name NTT. It is a highly emotive subject among astronomers because it implies a radical change in their professional life style. But we believe that nothing can bring bigger gains in efficiency, provided it is carried through all aspects of operation and scheduling.

8. *"Maintenance-friendly" electronics:* Future telescopes will all be totally dependent on electronics for all their functions. The stable configuration of the NTT should be a big asset in assuring good reliability; but it is also essential that breakdowns can be rapidly resolved by systematic diagnostics and module replacements.

9. *Instrumentation:* "Carousel" or transverse carriages for a variety of instruments can be logically applied to a building of the type envisaged. However, to keep changes to an absolute minimum, 3 basic instruments are at present planned for the NTT:
- A long-slit spectrograph for the visible (standard instrument at one Nasmyth focus),
- IRSPEC, the IR spectrograph currently under development for the 3.6 m telescope (standard instrument at the other Nasmyth focus),
- Direct imaging by a focal reducer and CCD camera of a 30 arcmin field.

By the time the NTT is operating, fiber optics coupling may also play a major role.

The above general characteristics have led to the following design features for the optics of the NTT:
- Prime focal ratio f/2.2.
- Secondary (Nasmyth) focal ratio f/11.
- Ritchey-Chrétien configuration. This gives optimum field correction for the mirror system. This field (30 arcmin) is not only useful astronomically but essential for the offset guide star choice, since this is used not only for auto-guiding but also auto-focusing and auto-image-correction.
- The basic concept provides for a primary blank of meniscus form of aspect ratio 1:15.

Fig. 2 shows (schematically) the basic geometry of the telescope and Fig. 3 the immense reduction of building and dome size compared with the present ESO 3.6 m telescope. For the latter, the circle above the telescope effectively represents the dome whereas for the NTT it is simply the "sweep circle".

Particular attention is being given to the *pointing* accuracy of the NTT. In view of the considerable mechanical simplification of the altaz mount, the specification for the *absolute pointing accuracy (including initialization) is 1 arcsec rms.* If this is reliably achieved, the operating comfort in the optical as well as IR regions will be a major asset.

The auto-guider will be of the same type of TV system used most successfully on our 3.6 m telescope (6). The auto-focusing and auto-image-correction will get its information from an image analyser using the SHACK modification (7) of the Hartmann method with a CCD as on-line detector. The active optics control is simply a systematic on-line application of methods we have been using routinely for the past six years to test and analyse off-line the image quality of telescopes both at La Silla and in other observatories. The method is based on a least squares polynomial analysis of the wavefront to determine the terms like decentering coma, astigmatism and spherical aberration which are amenable to correction by intervention in the telescope, and was first used with great success on our ESO 3.6 m telescope (8), (3). In the NTT, the image analyser will feed the polynomial coefficients to the computer which calculates the centering change (for the coma) or primary support force changes (other errors) to correct the image. Details are given in ref. (4) and the scheme is shown schematically in Fig. 4.

Thus the "brain" of the NTT is the image analyser with its computer and the "heart" is the active primary support and secondary mirror control. All normal correction operations will take place without any disturbance to the observation–indeed the observer will be unaware they are happening.

The active primary support is a "soft", force-based system which is a natural development of the principle of the astatic lever, the commonest form of support in conventional telescopes. Hydraulic systems are also being considered but it is not easy to improve on the simple mechanical lever system first applied by Wm. Lassell in 1841 (9). Our consultant, Dr. Schwesinger, who also designed the novel primary cell of our CAT telescope (10), has designed an axial support with 78 supports and a special push-pull radial support which gives *passively* the same quality as our 3.6 m telescope specification, although the NTT primary mirror has an aspect ratio 2 ½ times thinner.

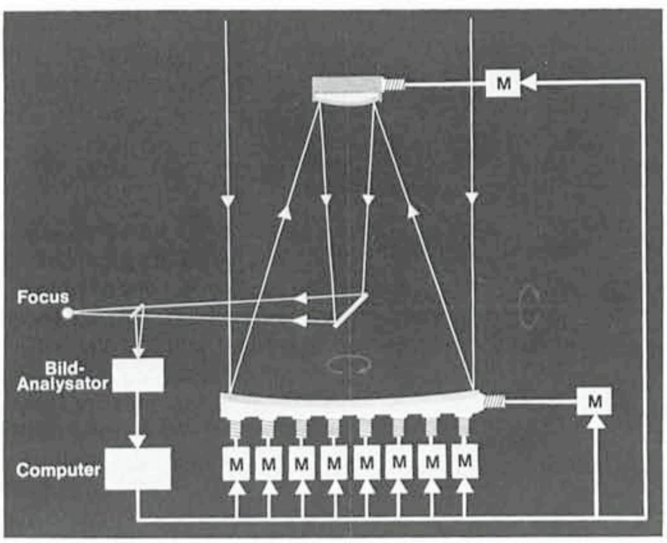

Fig. 4: *Principle of closed-loop active optics control for automatic opto-mechanical maintenance.*

A fundamental aspect of any new technology telescope is the choice of material for the primary mirror. Speculum metal was used from the invention of the reflector by Newton and Cassegrain about 1670 until about 1860 when silvering of glass was invented by Foucault and Liebig. "Normal" glass was replaced by low expansion borosilicate glass in the 1930s and this in turn by fused silica in the 1950s and 1960s, and then by zero expansion glass ceramic in the 1970s. In conventional, passive telescopes, the gain from zero or nearly-zero expansion was immense, though it has often led to carelessness with heat sources resulting in poor "dome-seeing".

Thinner mirrors and active optics make a critical look at this whole technical area necessary. If the thermal capacity and wall thickness of low expansion glasses can be reduced in light-weighted ("egg-crate") structures then this much cheaper material becomes very interesting, as Angel has shown (11). Also the dome seeing aspects are better than with solid zero-expansion blanks. Similarly, metal in solid or structured form re-assumes great interest, since modest warping can be corrected actively and its internal thermal time constant is vastly better than that of any glass. If Sir William Herschel's 20 foot focus speculum had not been pretty good, the foundations of the NGC catalogue would not have been laid! Our recent SHACK-Hartmann tests of the Merate 1.37 m metal mirror (pure aluminium) telescope in Italy have revealed optical performance no different after 14 years of use from many normal "glass" mirror telescopes. There is a modest amount of astigmatism (1.1 λ) which may come from warping but could equally have been there originally or be induced by the primary or secondary mounts. If the decentering coma and this astigmatism were corrected, this telescope would give 1 arcsec images (diameter for 80 % energy concentration).

For the NTT a two pronged approach is therefore foreseen: a "glass" type mirror still to be chosen when complete offers are available, and an aluminium mirror if this latter can be procured.

Since the entry of Italy in May, the NTT has entered the "engineering" phase.

This must be so, as the completion date for "first light" is scheduled to be 1. 1. 1987, a hard schedule for a telescope involving new technology. The project staff in the "Telescope Group" currently consists of 4 people, soon to be expanded to 6. This staff has to deal with other problems as well, so there is no possibility, in general, to do in-house detailed design. Only the conceptual design will be done in-house apart from certain areas like the primary cell.

The NTT is seen as an excellent test bench for the VLT (Very Large Telescope) project which should soon be defined. Work on the NTT and on projects like the Texas 7.6 m (12) indicate that extension to 8 m dimensions with monolithic primaries should be perfectly feasible.

ESO has two exciting telescope projects. We must do our utmost to ensure that our observatory is equipped with telescopes as advanced and efficient as those anywhere in the world. It is our belief that the NTT will fulfil this aim.

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