The European Very Large Telescope Project

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Astronomy is now approaching a new turning point in the long history of the development of instrumentation. The gradual evolution of astronomical detectors from the human eye to photographic plates and then to photoelectric detectors has now reached the stage when high resolution two-dimensional detectors with nearly 100 per cent efficiency are either available or will soon be available for all spectral wavelengths from the optical ultraviolet to the deep infrared. Coating technology which makes it possible to limit the light losses on optical surfaces is also rapidly advancing. Nearly perfect coatings are available throughout the infrared and optical regions. Soon it will no longer be possible to upgrade the efficiency of existing telescopes by relatively inexpensive improvements in detector or instrumentation technology. Additional sensitivity will then be gained only by increasing the aperture.

By the late 1970s, the larger astronomical institutions had realised this approaching need and had initiated studies on the construction of giant telescopes in the 10 – 25 m range. The initial blooming of innovative ideas was followed by a period of costing, of search for funding, and of risk assessment.

The effective work on a 16 m telescope the "VERY LARGE TELESCOPE" project was begun at ESO in 1984. The preliminary studies took about four years and the ESO Council finally approved the project on 8 December, 1987.

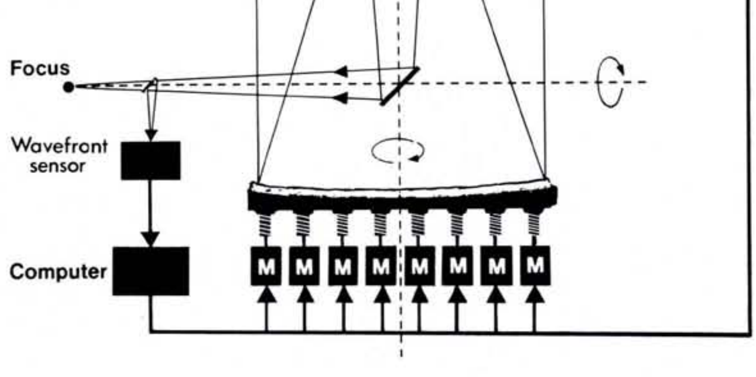
Telescope Concept and Mirror Technology

Mirror technologies which could become available in the next 10 years will not allow us to exceed the size above 8 to 10 metres. Larger apertures can therefore only be obtained through the combination of several mirrors, and the 16 m aperture of the ESO VLT results from the combination of four mirrors of 8 m each. Rather than mount the four mirrors in the same structure, it has been decided to build an array of four independent 8 m telescopes and to recombine the beams at a fixed external location.

This provides considerable flexibility in the construction and operation of the telescopes and offers the possibility of using the array in an interferometric mode. Interferometric techniques that have been mainly developed for radio astronomy are still in their infancy in the optical range. Much progress is however expected in the next decade and interferometry could become a major mode of operation of the VLT in the years 2000.

The 8 m diameter mirrors of the VLT will, for weight and cost reasons, be thin meniscuses, only 200 mm thick. They could be made of fused silica or Zerodur, a zero expansion glass ceramic material which can be spin cast by pouring the liquid glass into a rotating concave mould. The curvature of the mould and the rotation velocity are chosen to give the required shape. A fused silica meniscus can be obtained by fusing together pre-manufactured hexagons of 1 to 2 m size and then slumping the flat disc thus obtained at a high temperature to the desired curvature. Both techniques: Zerodur spin casting and assembling fused silica blocks have been used so far to produce mirrors of up to 4 m diameter.

Fig. 1 — Principle of active optics. An image of a star is analysed by a wavefront sensor; the computer determines the variation of forces to be applied at the back of the mirror to obtain a perfect image; the secondary mirror is used to correct focus and tracking errors. Phase errors generated by the atmosphere can also be corrected with a similar scheme but, because the correction band pass would be much higher, it is necessary to use a small deformable mirror instead of the primary.



Active Optics

Such a thin mirror is very flexible and to maintain the mirror figure to the required accuracy of a fraction of a wavelength it is necessary to use an active support, the principle of which is shown in Fig. 1.

The support of each 8 m mirror will consist of about 150 computer controlled actuators. The distribution of forces at the back of the mirror will then be continuously adjusted in order to provide the sharpest image. In addition, tracking errors, which can be generated by wind buffeting or errors of the drive system will be corrected by the secondary mirror.

The telescopes have conventional alt-azimuthal mounts with the elevation axis above the primary. This has been

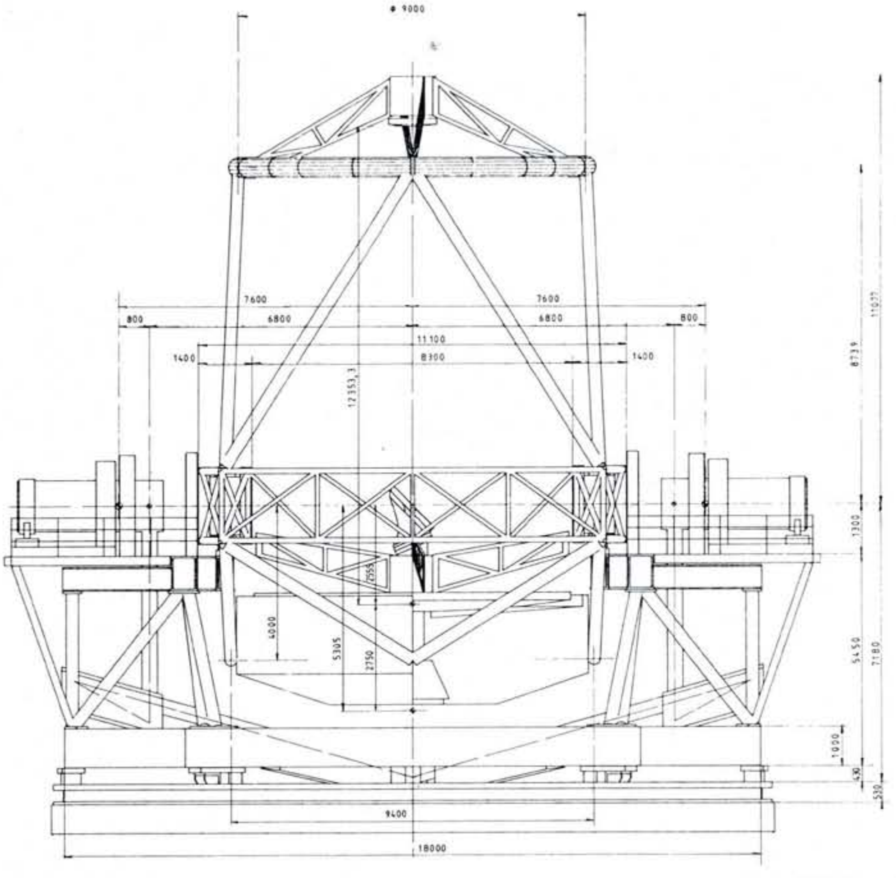


Fig. 2 — 8 m telescope structure. Because of the fast F-ratio of the primary mirror (F/1.8) and the compactness of the Alt-Azimuth mount, the overall dimensions will be similar to those of a 3.5 m classical telescope based on equatorial mounts.

found to provide the lightest structure and the minimum building size.

Mechanical Structure

The telescope structure, Fig. 2, comprises a framework with an optimized stiffness to mass ratio, the lowest eigenfrequency of which is close to 10 Hz. The "tube" has a mass of 110 tons and the total moving mass is 230 tons. The drives may be based on directly coupled motors, a solution which seems extremely attractive from the performance point of view. In the design presently investigated, the elevation would be set using two motors, 2.4 m in diameter, each with a peak consumption of about 6 kW (the mean would be 10 to 50% of peak depending on the wind torque). The azimuth control would be through four quasi linear motors four metres long positioned round a circle 10 m diameter. The total peak power would be only 6.4 kW thanks to the large diameter. All motors would have to be water cooled. Despite its potential advantages, it remains to be established whether the cost of a direct drive solution is acceptable and adequate solutions can be found to the problems of heat dissipation, and of electromagnetic interference produced by the high power switching amplifiers.

Beam Combination/Interferometry

Recombining the beams of the four telescopes is essential in order to take advantage of the full collecting power of the VLT.

There are two combining modes: incoherent and interferometric.

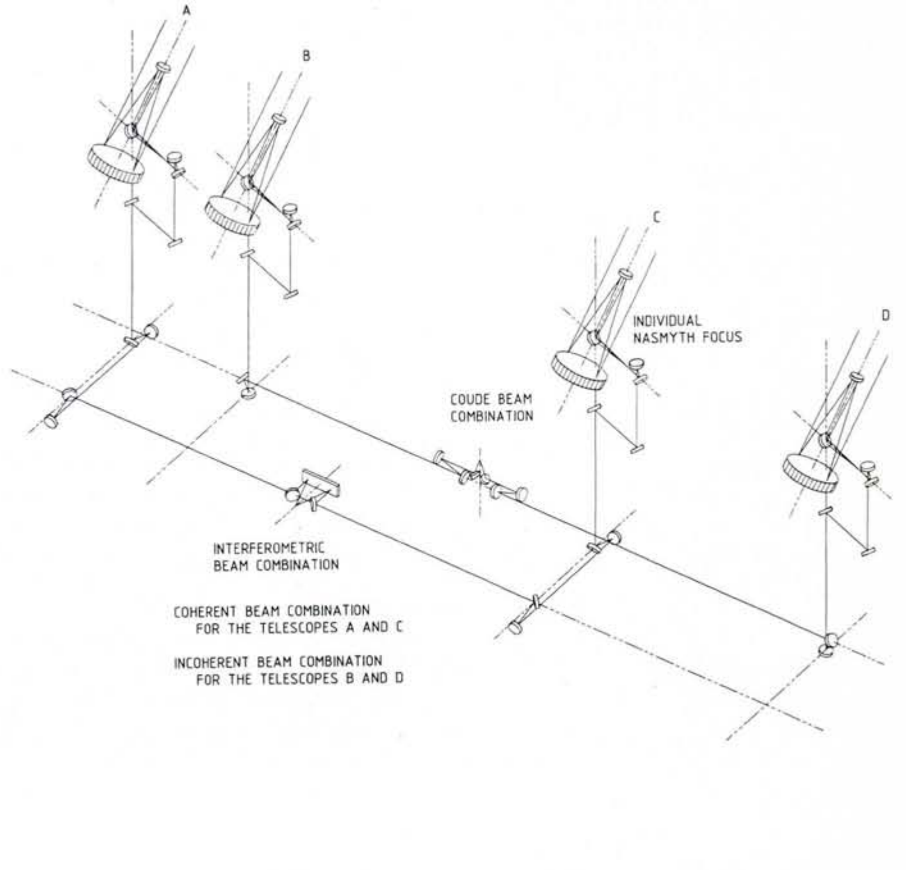
i) Incoherent Combination

The four beams are combined in the centre of the array without any correction for path length differences. This combined focus will be mainly used for spectroscopy in the visible and near IR. Several mirrors will be necessary and high efficiency coatings will be mandatory. Such coatings with efficiency of 99% or more exist but are limited in bandpass to less than one octave which implies that several sets of mirrors will have to be used to cover the full spectral range. Fig. 3 shows the principle of the beam combination.

ii) Interferometric Combination

Interferometry or more generally aperture synthesis is a well know technique in radioastronomy. The linear array concept of the VLT offers a unique possibility for astronomical observations with very high angular resolution by operating the telescopes as an infrared and /or

Fig. 3 — Optical scheme of the VLT. On each 8 m telescope the third mirror deviates the telescope beam to one of the two 'Nasmyth' stations located on each side of the elevation axis. For Coudé operation, the beam is picked up by a movable mirror at the Nasmyth focus and relayed either to the individual Coudé focus or to the combined focus where the full 16 m aperture is available. The beams can also be recombined for interferometry, in which case their relative phase difference has to be compensated by variable optical delay lines.



visible long-baseline interferometer. In the proposed, compact linear array configuration with a baseline of 104 m between the centres of the most extreme telescopes, resolutions up to approximately 45 milliarcsec at 20 µm wavelength and approximately 0.75 milliarcsec in the blue could be reached.

Interferometry with two or more telescopes is only at its beginning, but its potentials have been well demonstrated by recent measurements with small existing prototypes. Interferometry requires the phasing of the VLT unit telescopes. This sets much tighter specifications on the mechanics and optics, than if the four telescopes would only be incoherently combined.

Obtaining images or spectra at the diffraction limit from the ground, either with a single large pupil or with two or more smaller pupils, suffers basically from the fluctuations of the index of refraction of the atmosphere. In the interferometric mode, the full gain of the 8 m single apertures of the VLT is, however, only obatined, if adaptive optics is applied for a real-time partial or full phase compensation of the degradations due to atmospheric turbulence. Adaptive optics basically consists of a wavefront analyser associated with a correcting device, usually a deformable mirror driven by a very fast computer.

Besides its application to interferometry, adaptive optics is of great significance for any single telescope since it may provide tremendous gains in efficiency and spatial resolution.

Ideally, the telescope would become diffraction limited. In practice adaptive optics may compensate up to 70% of the atmospheric effects which already would provide a tremendous improvement.

Building

Traditional telescopes are protected from the environment, and in particular from the wind, by hemispherical domes. These are closed during the day and highly insulated in order to prevent the massive structures heating up. Most modern domes have an active thermal regulation which maintains the average night-time temperature. During the night however, the temperature outside drifts and because of the relatively small aperture, which is barely larger than the light beam, the temperatures inside and outside are never in equilibrium. This is the source of convective eddies which tend to deteriorate the image quality.

Another drawback of classical domes is their high cost. This explains why recent telescopes have buildings tailored around the telescope and rotating with it. They are largely open to ensure a good ventilation, which in turn exposes the telescopes more to wind gusts. More rigid mounts and adjustable wind barriers can help overcome this difficulty.

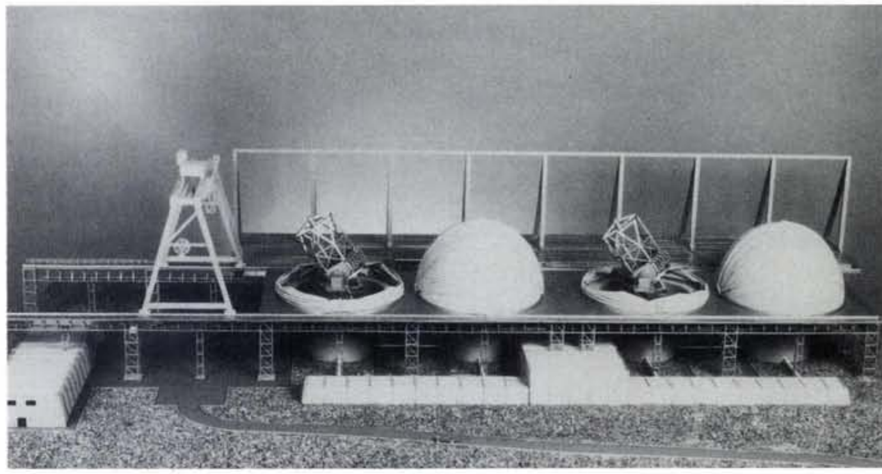


Fig. 4 — A model of the array concept. The four 8 m telescopes are aligned in order to face the prevailing wind and to provide several base lines for interferometry. They partly operate in the open air and are covered by light inflatable shelters during the day. A fixed wind screen allows observing even under strong winds.

An even more radical approach is envisaged for the VLT. It is proposed to operate the telescope in the quasi-open air and to solve the difficult question of sensitivity to wind by means of very stiff drives and a fine correction of tracking errors with an active secondary mirror.

Though operating in the open air, the telescopes need physical and thermal protection during day-time and bad weather periods. An innovative concept of an inflatable dome is envisaged for the VLT.

The dome consists of spherical segments made of a double wall nylon-reinforced plastic fabric arranged in two symmetric quarters of a sphere. The fabric is supported by an articulated steel structure. After closing, the dome and the double wall space are independently inflated. The strength and stability are directly related to the inflation pressure, which may vary from 3 – 30 mbar according to the acting wind load. The double wall provides effectively a necessary protection and a good thermal insulation. The two fabrics are aluminized on their inner surfaces.

No matter how elegant this principle, it would be too novel to be applied immediately to the largest telescope in spite of the fact that there is already valuable experience on inflated radomes. For this reason a half-scale model about 15 m diameter has been built. It is installed at the ESO observatory of La Silla and will be studied for a couple of years before a final decision is taken.

Fig. 4 shows a model of the VLT concept with a fixed wind screen to reduce the wind on the telescope structure.

Site

The present ESO site at La Silla is one of the world's better telescope sites for seeing. Although the atmospheric water vapour is rather high, there are also periods with less than 2 mm precipitable water. The site was chosen almost 25 years ago on the basis of the then valid criteria which included, apart from astronomical considerations, questions like availability of water, nearness to a reasonably large city, etc. In view of the magnitude of the VLT investment, it is not clear that these last criteria should have the same weight today and a new search has been made to see if substantially better sites exist, without excluding from consideration ease of operation, infrastructure needs, or the personal comfort of the staff.

Studies have been mainly concentrated on a coastal region of Northern Chile, which seems to offer an outstanding climate, but space on the available summits is limited. Cerro Paranal — located about 150 km south of Antofagasta, a few kilometres from the coast, and at 2650 m elevation — has been monitored for more than three years and appears an excellent candidate. On the basis of presently available data, Paranal appears to be superior to any known site in the world for cloudless nights and is also extremely dry. It is a serious candidate for the VLT.

Schedule

The present plans foresee that the first telescope could be ready in 1995 and the project could be completed by the year 2000. An extensive instrumentation programme will be developed in collaboration with national astronomical institutes.

EPS Workshops

New achievements in physics not only satisfy our scientific curiosity, but can have often important technical and economic consequences. This new scheme of EPS Workshops strengthens the links between academic research and industrial development in Europe by bringing together competent representatives of both sides in special fields, where a broad collaboration is desired.

"Magneto-optical Recording" is such a characteristic field, where the creative hybridization between materials research and technical ingenuity is a decisive factor for economic success in a very competitive international market. The goal is to reach much faster, better and denser storage of information by replacing the usual combination of magnetic layers and inductive heads by modern optical devices, such as lasers, interacting with magneto-optically active magnetic materials.

Light is refracted and absorbed by matter through its interaction with the electrons present. In ferromagnetized materials, the magnetic electrons spin and rotate around parallel axes so that the optical properties are different for light waves of different polarity; a ferromagnet brought between two crossed polarizers may look dark or bright depending on the angle of its magnetization with respect to the light beam. This effect can be used for reading by a polarized laser beam the binary information stored in a magnetic tape or disk much faster and more conveniently than by small induction coils which usually need to fly at tremendous speed for very small distances over the surface. The advantages in terms of density, precision and quality of using magneto-optical techniques for recording are evident to anyone who has listened to a modern compact disk player.

The industrial realisation however of such magneto-optical devices requires the development of not only advanced optical and electronic apparatus, but also new magnetic materials, which combine the physical properties desired with a large magneto-optical activity. For this task one needs much more fundamental knowledge about the chemistry, electronic structure, magnetism and optics of magnetic alloys and compounds than can be found in the present literature.

"SQUID" are in a rather different economic category at the present time, but to exploit the potential of these low temperature quantum devices a similar meld of science and different technologies is needed and the close cooperation between academie and industry.

SQUID is an acronym for Superconducting Quantum Interference Device. Its working principle is based on flux quantization and the Josephson effect. Practically, SQUIDs are very sensitive magnetometers, working at a temperature as low as that required by the superconducting materials of which they are made. Using an inductive coupled coil, such devices can also be used as low impedance, high sensitivity ammeters. There are basically two kinds, the RF SQUID and the DC SQUID, but even if their working principles are very different, their behaviour from the point of view of the user is much the same.

For frequencies lower than about 100 MHz there is no other amplifier with such a high sensitivity to energy changes. In fact their sensitivity, *i.e.* the minimum magnetic energy detectable for unit bandwidth, is usually expressed in units of the Planck constant. Often such a device is near to the limit imposed for an amplifier by quantum mechanics and is one of the few that explicitly makes use of quantum mechanics.

In many fundamental physics experiments the SQUID is the only device that can give the sensitivity required. On the other hand, the need for low temperature and special low noise, linearizing electronics excludes its use in many applications.

The Future of Magneto-Optical Recording

Bad Honnef, 2-4 November 1987

Themes

The workshop was devoted to discussions of basic research in magneto-optics and research and development on magneto-optical recording in Europe. Some 50 people from 11 countries participated, half of whom were from industrial R & D laboratories. Of the 13 papers presented again half were from industrial R & D laboratories and half from governmental and university research laboratories.

Without going into the detail of the special presentations* we summarize here the final discussion which reflects the essential goal of the workshop: To assess the status of magneto-optical recording in Europe, compared with that in Japan and the USA.

* A limited number of copies of the presentations are available from the EPS Secretariat, price SFR 50.–.