

The "dedication" of the MMT (to whom or to what it was dedicated I was unable to discover) provided an opportunity for assessing the role of the various novel techniques which are under investigation for the construction of large optical telescopes. The MMT consists of six telescopes on the same mount, arranged so that their separate images of an on-axis object can be combined at a common focus. At this focus the combined image may be recorded directly, giving a photograph over a rather small field of view; alternatively, a spectrograph may be used for the on-axis object. In either case the available modes of operation are restricted, but in these limited modes the collecting power of the six telescopes may be effectively combined. The MMT is not a general purpose instrument; it is intended for certain limited but important types of observation.

The development of large optical telescopes is now seen to be dividing into two streams. The more conventional telescopes are appropriate for a wide variety of tasks, and the requirements for versatility and adaptability are powerful influences on their design. They are, however, expensive, and it is becoming clear that economic forces will constrain the sizes of these telescopes within the range below about 5 metres in diameter. The new approach is to admit a restriction of the modes of operation, and design for a larger effective collecting area which can be applied to a particular kind of observation.

Size alone is not, of course, the sole measure of the usefulness or even the sensitivity of a telescope. The argument for size is mainly concerned with collecting area. At optical wavelengths angular resolution is limited by atmospheric diffraction ("seeing") rather than by diffraction at the aperture, so that a 10 centimetre and a 10 metre telescope would usually give stellar images of about the same size. The larger telescope, however, puts more light into the image and thereby increases the contrast between the image and the background. To some extent the difference in collecting area could be compensated for by an increase in observation time, but the light-gathering power of the larger telescope may eventually be essential for detecting the faintest objects in a reasonable observation time. (At infra-red wavelengths large apertures may additionally provide useful improvements in angular resolution; if large optical telescopes can be made sufficiently versatile to include infra-red observations, this is a separate argument leading to large size.)

The practical usefulness of large telescopes, even when their use is confined to a single focus, relies on a proper match between telescope and auxiliary instruments. Telescopes in which the design is based on an increased diameter of a single aperture tend to operate with smaller focal ratios, since large telescope lengths are expensive and inconvenient. But small focal ratios give small fields of view, and the advantage of photographing a large field of view in one exposure may be lost. Telescopes in which separate elements form separate images, which are subsequently combined on the slit of a spectrograph, do not give the full advantage of the whole light-gathering power in this mode; indeed, the combination of the separate beams in any mode of operation is technically difficult and often inefficient.

Single Apertures and Arrays

The main requirement of new designs is a large collecting area. For some purposes it is immaterial if this area is distributed among several different telescopes, whose output can be added after detection. This is the equivalent of using a single telescope with a long integration time. An array of single telescopes may offer advantages of cost savings as compared with a single large telescope of equivalent collecting area, but it also has obvious disadvantages of complexity. Whatever geometrical arrangement may ultimately be used, it is evident that the individual elements of any array will be made as large as economically possible so as to minimise this complexity. A balance of advantages will determine the actual size, but any proposal for an array will seek to use large unconventional apertures in much the same way as any proposal to build only a single aperture.

There is, therefore, a thrust towards investigations of large reflector telescopes in which the ultimate purposes may vary but in which the general aim is to construct reflectors with collecting areas larger than those of the conventional reflectors. There are several ways in which this might be achieved.

Techniques for Large Reflectors

Conventional telescopes use monolithic primary mirrors with ratios of diameter to thickness ranging from 6 (AAT) to 14 (UKIRT). Support systems which preserve the shape of such mirrors at all angles of tilt are readily available for sizes up to about 5 metres and focal ratios about 3 and above. These comparatively thick mirrors require heavy support structures, which add to the total cost of the telescope, and it would clearly be advantageous to use a single large thin

mirror, say 10 to 20 cm thick. Techniques are not yet available for the manufacture, handling and support of such mirrors, but there is little doubt that such thin mirrors could be made and used with diameters up to 5 or 6 metres. Beyond this size it may be necessary to fabricate and figure the mirror at the telescope site, which may not be practicable. Design efforts therefore are mainly directed towards the use of multiple smaller mirror elements, either in the form of multiple telescopes, i.e. the multiple mirror concept, or towards a segmented mirror, in which a single reflector surface is made up of tessellated separate sections. The segmented mirror offers the advantages of the single reflector, i.e. versatility and simplicity, while the multiple mirror concept allows the use of a short focal length, with its considerable cost savings in the mounting and the dome.

Segmented Mirrors

The problem with a segmented paraboloid is that the outer segments must be figured as "off-axis paraboloids"; no practical technique exists for this. One possibility under investigation at Kitt Peak National Observatory (KPNO) is to deform mechanically a thin segment in such a way that a spherical figure on the stressed segment would become an off-axis paraboloid when the stress is relieved. KPNO has applied to the National Science Foundation for support for a programme which might eventually lead to a 7-metre diameter telescope, in which the central 4 metres would consist of a conventional but thin parabolic element, with an extension over a further $1\frac{1}{2}$ metres radius made up of separate petals. These petals must be figured as off-axis paraboloids.

A different approach is to accept that only spherical surfaces can be constructed out of segmented mirrors, and to use a suitable secondary reflector to compensate for the serious spherical aberration that must be involved. The Crimean Astrophysical Observatory has constructed a small prototype from seven 40cm elements, and now propose a version 25 metres in diameter. This is called ET-25. The primary mirror would be constructed from 500 separate elements each 1.1 metre diameter, and it would have a primary focal length of 55 metres. The correcting secondary would be a single element 6 metres in diameter, non-spherical but with axial symmetry. Here the difficulty is to contain the focal length to a reasonable size since the smaller the focal ratio the more difficult it is to correct for spherical aberration, and the larger must be the correcting secondary. The ET-25 would be a monumentally large telescope; the 2000 tons of moving parts would be partly floated in water tanks, leaving hydrostatic bearings to provide the precision bearings both in altitude and azimuth. Only the Nasmyth focus would be used.

Foreseeable Developments

No development of multiple-mirror or segmented telescopes is at present funded. The MMT itself is not completely working, as the laser alignment system has not been installed and tested. Nevertheless the concept could clearly be extended to a telescope using, say, six mirrors each 4 metres in diameter, giving the equivalent of a single aperture almost 10 metres in diameter. This would be a very demanding engineering project, and is unlikely to be attempted until the MMT has been fully tested.

Segmented mirrors may become useful if the figuring of off-axis paraboloids becomes possible. The choice of focal ratio will then be determined partly by the difficulty of figuring, which will lead to large focal ratios, and partly by the cost of the telescope dome, which increases rapidly with increasing focal ratio.

In either approach it will be essential to design for a restricted mode of operation. The acceptability of such a restriction obviously depends on the range of observing opportunities otherwise available to the astronomers who might use the telescope.

The Importance of Site Quality

Discussions of the possibilities of constructing larger telescope apertures are concentrated on the need to obtain spectra of faint point-like objects. The sensitivity of a telescope for this purpose is generally proportional to the diameter of the aperture, and inversely proportional to the diameter of the star image (the "seeing" disc). It is therefore as important to build on a good site as it is to build a large diameter, and it is also important to avoid bad seeing due to conditions in the telescope dome. The problems of dome seeing worsen as sizes increase, but no account of this has been taken in the more speculative plans for large telescopes.

Implications for the 4.2-metre telescope

The specification of the 4.2-metre telescope covers a full range of functions, and includes the ability to switch easily between apparatus installed at different focal stations. The specification arises from the needs of astronomers who have practically no other means of observing in the northern hemisphere with a large optical telescope. Any revision of the 4.2-metre project must take these urgent needs into account: it would be a very serious step, for example, to reduce the specified performance by making the

telescope more specialised. At the same time it is clear that new ideas are being generated which will eventually lead to larger telescopes for special purposes, and it is proper to ask if these new ideas should in any way affect the design of the 4.2-metre telescope.

Given that any move to reduce the specified performance should be resisted, the only question to be addressed is the possibility of constructing a telescope with equal or greater performance at a lower cost. The performance must include a very good pointing accuracy and very good optics, to take full advantage of the site on La Palma, and there is therefore little or nothing to be saved on the telescope mounting, drive and control system. If a thinner mirror were available at no extra cost, some reduction in weight would be possible, provided that sufficient stiffness could be maintained. A larger diameter might be obtainable at no extra cost if such mirrors were available.

The conclusion must be that there is at this time no serious proposal for methods of building a larger telescope, and that if such a proposal were to be made during the next few years it would inevitably involve an unacceptable reduction in the specified performance. The 4.2-metre telescope should be built according to the present design.

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On the occasion of the recent inauguration of the Canadian-French-Hawaiian Telescope some basic properties were published which it is interesting to compare with those for the proposed La Palma 4.2 metre telescope.

	<u>CFHT</u>	<u>LP 4.2m</u>
Mirror diameter	3.66m	4.22m
Mirror thickness	0.60m	0.56m
Mirror mass	14	17
Mass of tube	105t	90t
Mass of mounting	145t	140t
Total mass including base	325t	240t
Dome diameter	32m	31.5m
Height of building to top of dome	38m	39.5m