Optical telescopes in India

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Fabrication and use of optical telescopes for astronomical observations in India have been reviewed. Evolution of telescopes, their optics, mounting and drive system leading to large aperture instruments of today has been described. Limitations of ground-based observations in spectral coverage and degradation of images have been discussed. The article describes all existing telescope installations in India and various efforts made in the country in fabrication of telescopes for astronomical use. A brief account of the project by which the 2.34 metre telescope was constructed is given. Some of the proposals for future telescopes are mentioned.

1 Introduction

Combination of lenses to produce angular magnifications of images of distant bodies is reported to have been tried by several early inventors, before the seventeenth century; but the credit of inventing the first practical system is usually given to Hans Lippershay of the Netherlands in 1608. Shortly afterwards, Galileo used the telescope for astronomical observations and brought about a revolution in science. The efforts for improving the performance of this new instrument were continued throughout the 17th and 18th centuries, as a result of which many forms of telescopic combination of lenses and mirrors were invented. The sizes of telescope apertures also increased over the years so that by the end of the 18th century, a reflecting telescope with a 48″ diameter primary mirror was in operation. These telescopes provided the means of collecting light from celestial sources over large apertures and created bright images in its focal plane, which could be conveniently magnified and viewed. The device was found so useful in astronomical observations, that its use became totally unavoidable in astronomy. The era of pre-telescope astronomy passed into history.

In India, the earliest reference to the use of an astronomical telescope was in 1651, by an Englishman Jeremiah Shekerley at Surat[1]. More notable efforts were the observations by Father Richaud, a French jesuit priest at Pondicherry in 1689, when he discovered a comet, and also the double nature of the southern star Alpha Centauri by using a telescope[2]. Recent revelations indicate that Maharaja Sawai Jai Singh had also used telescopes in his observations at some of his observatories. But the credit for starting regular use of telescopes at an observatory in India must go to William Petrie in Madras around 1786. This observatory, later adopted by the East India Company in course of time, added telescopes of respectable apertures to their observing equipment. At the end of the nineteenth century, barring a few small observatories in some educational institutions, the Madras observatory was the only professional institution carrying on astronomical observations through telescopes.

Changes had come in two major steps during the present century; during the first decade, two new observatories equipped with new telescopes and instruments were set up. They are the Solar Physics Observatory at Kodaikanal and the Nizamiah Observatory at Begumpet, Hyderabad. The second step came after independence, when the five year development plans were undertaken. New telescopes and other instruments were added to the arsenal of old scientific instruments in the existing observatories and new institutions for astronomical research were created. The present article will mainly deal with the events and developments during this latter period.

2 Optical Telescopes: the Prime Tool of Astronomers

2.1 Optics

The primary function of an astronomical telescope is to collect light from celestial sources and concentrate the same to form bright images. The real images formed in the focal plane can either be directly recorded on photographic plates or by photoelectric detectors, or analysed by focal plane instruments, e.g. spectrographs, polarimeters, etc. Except in cases of small telescopes, and contrary to the popular belief, the images are rarely seen through magnifying eyepieces. The image formation can be done by utilising the refractive or reflective properties of optical elements, and on this basis, the telescopes are divided into two classes, reflectors and refractors.

During the course of evolution of telescopes, both types had held upperhand sometime or other. Galileo's telescopes were of refractor type, where the main objective was a single lens. As the size and magnification of the instrument increased, it was noticed that light of different colours does not follow the same ray path through the refracting elements, as a result of which different images of different colours are superposed in the final focal plane. This made the edges coloured besides spoiling the quality of images. A method of avoiding this defect was invented by Hall in England around 1730 in the form of achromatic lens combination and perfected later by John Dolland in 1757.

In the meanwhile, the idea of using reflection properties of polished surfaces in image formation was tried by a few scientists. The earliest attempt was by James Gregory in 1663, who advanced a scheme of using a concave paraboloid primary mirror and another concave ellipsoid secondary to produce images free from chromatic and spherical aberrations. Owing to limitations in producing perfect geometrical surfaces at that time, the Gregorian idea could not be realised. The first practical reflecting telescope was built by Isaac Newton in 1668, where he introduced a new idea of flat secondary mirror at 45° to the primary axis. Such an arrangement brought the observing point to one side of the telescope tube which is known as the Newtonian focus.

In the present day telescopes, another design is commonly used which originated at about the same time. In 1672 a Frenchman, N. Cassegrain, proposed a combination of a concave paraboloidal primary and convex hyperboloidal secondary, which would produce a magnified image through a central hole in the primary. A modification of this scheme proposed around 1930 by George Ritchey and Henri Chretien provided a much wider aberration-free field; the modification comprises of an under-corrected primary paraboloid and over-corrected secondary hyperboloid. Another modification of the Cassegrain arrangement is introduction of 45° flat mirror bringing the focal plane to one side of the tube. The arrangement was proposed by James Nasmyth and is known by that name.

The advantage of Nasmyth focus is that the beam may be brought out through the declination axis where heavy focal plane instruments may be located. A still more convenient location for heavy complex focal plane instruments is at the Coude focus, which is formed by a special long focus secondary and set of plane mirrors taking the beam through both of declination and polar axes. This focal plane is usually brought to a fixed point on the observing floor. Some of these arrangements are illustrated in Fig. 1.

There had been considerable changes in the choice of optical materials over the ages. Lenses had been made out of glass, but the precise control of the refractive properties came much later. The achromatic combinations demanded more than one type of glass, and the way for graded optical properties and design of imaging system utilizing such varieties opened up. The peak of excellence of large refracting telescope objectives was achieved in the late nineteenth century by a few groups in Europe and the United States. It was one family of opticians, that of Alvan Clark in the US, who produced the largest achromatic objectives in the world existing today, viz. the 40 inch telescope at Yerkes Observatory near Chicago, and the 36" Lick refractor at Mt Hamilton near San Fransisco.

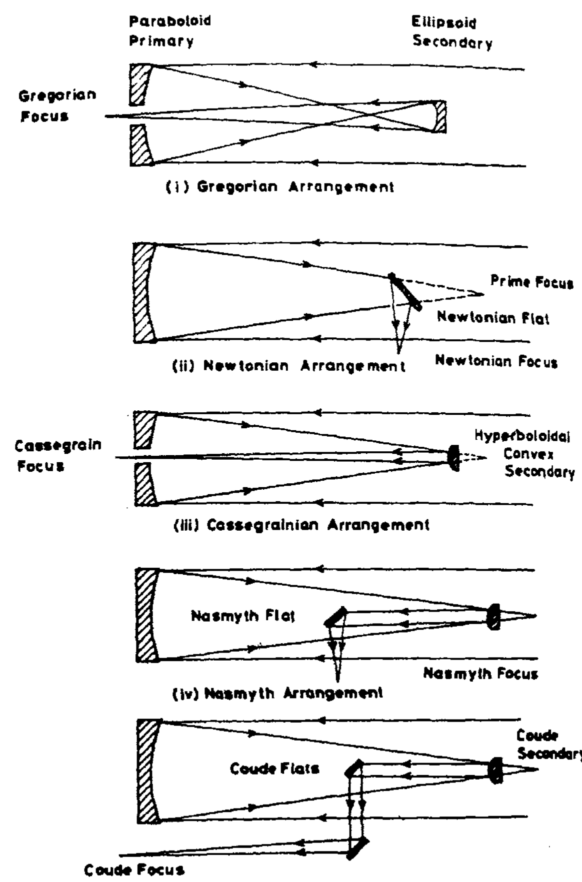

Fig. 1—Variations in reflector telescopes

A similar evolution of mirror materials can also be seen in the history of telescopes. The earliest reflectors used to be made out of metal; an alloy of copper and tin with addition of small quantities of arsenic appeared to meet the requirements. Other variations were proposed, including one of pure platinum which was never built, and several metal-alloy mirror telescopes constructed. Ideas of metal coated glass mirrors were tried but proved impractical until a method in chemical laboratory developed by Justus von Liebig in 1856 changed the situation. He developed a chemical method of depositing metallic silver on glass, and the technique was employed by several telescope makers. One of them, Henry Draper, successfully completed a silver fronted glass mirror reflector telescope in 1862. The new design was so successful that others all over the world started following it; the era of metal mirrors was over.

In the beginning, ordinary soda glass was used as the mirror substrate. This material has relatively large thermal expansion coefficient; this property coupled with poor thermal conduction produced distortions in the finely figured optical reflecting surface. Later when low expansion glass was developed that became the standard material for mirror blanks. A natural substance, quartz, was found to have still better thermal properties, but the problems involved in melting natural quartz and casting them into blanks was indeed formidable. Only a few decades ago, a new ceramic material was developed which shows virtually zero expansion properties around room temperatures. Two glass manufacturing organizations in the world, i.e. M/s Corning Glass Works, USA and M/s Schott Glaswerk of FRG have marketed these mirror blanks under the trade names 'Cervit' and 'Zerodur' respectively. Almost all modern telescopes fabricated in recent years have used these materials for their mirrors.

Besides these two main types of telescopes, a third variety, of a hybrid nature has come up for use in astronomical observations. The most common form of telescopes of this type was invented in 1920s by Bernhard Schmidt; and is known as Schmidt telescope or Schmidt camera. This telescope has a large spherical concave primary mirror, preceded by a large thin corrector lens at its centre of curvature. This has unusually wide field of view, and is generally used for sky survey observations, where large areas of the sky are required to be covered.

2.2 Mounts

For small telescopes, no special problems of mounting the optical elements are encountered; but with increasing apertures, these assume roles of prime importance. The elements are required to be held in perfect alignment and separation, and the entire assembly need to be moved to compensate for the earth's rotation. Many forms of mounts were designed and tried; some of them having proved more convenient have survived and got modified with the addition of modern technological developments. Brief descriptions of some of the components of telescope mounts are given in this section.

The main optics, the refracting objective or the reflecting mirors are held in a structure known as the tube. For refracting elements, or small reflecting telescopes, this, indeed, is a cylindrical tube, from which the optical components are suspended by means of rings, flanges, spiders or similar structures. The tube is held by a set of bearings arranged in a line perpendicular to the tube axis and passing through the centre of mass. This is called the declination axis because the

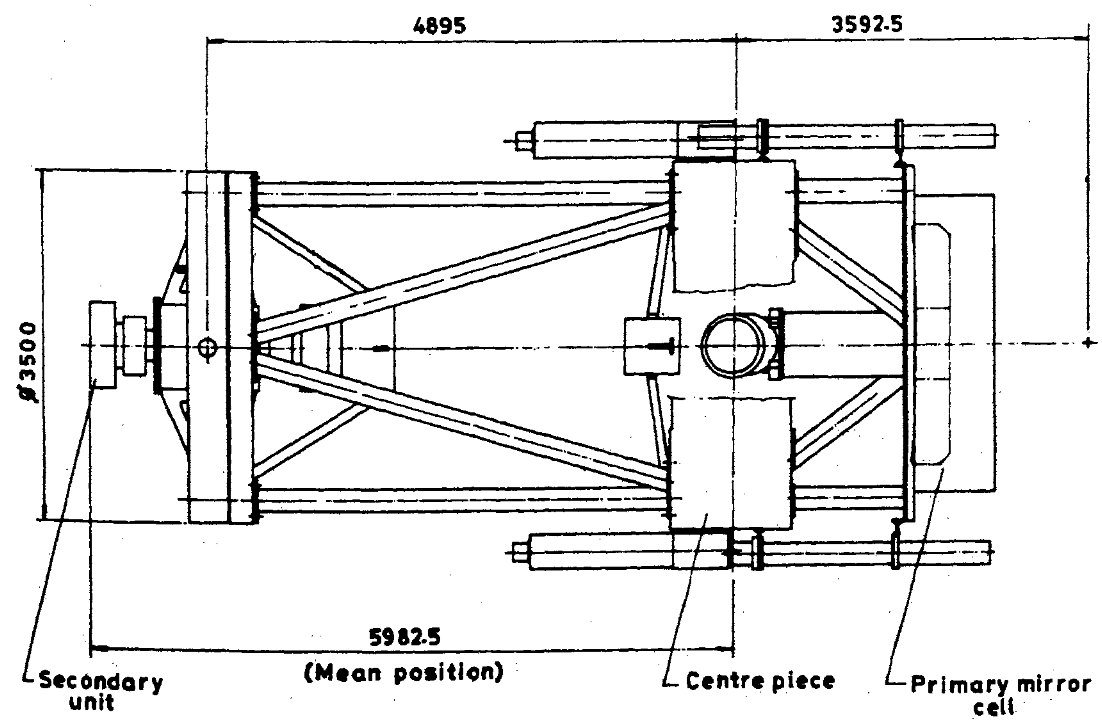

Fig. 2—Serrurier truss of 234 cm telescope

tube can be rotated around it to point to different declinations on the celestial sphere.

In large telescopes, use of a closed tube is not only unnecessary but also undesirable. Such an arrangement results in huge increase in the weight of the mount, together with large thermal inertia, which causes localised hot zones, and thermal convection currents within the telescope volume. The result of these effects in the stability of the images are usually disastrous, and need be avoided at all costs. This objective is achieved by replacing the tube with a skeletal structure, technically known as the 'Serrurier truss' (Fig. 2). This is a light structure providing the necessary rigidity for the heavy optical elements to stay in place and also providing surfaces to fix the declination bearings.

The declination bearings allow swivelling of the telescope tube in the north-south direction; it is necessary to have another degree of movement in the east-west direction. This is provided by another set of bearings called the 'polar-bearings'. There are several alternative designs for movements around this polar axis. The most common of them is called the 'equatorial mounting' where the polar axis is kept aligned parallel to the earth's rotation axis. In one of its simplest form, and in low latitude stations as in India, a sturdy axle is held between two bearings on two piers. The

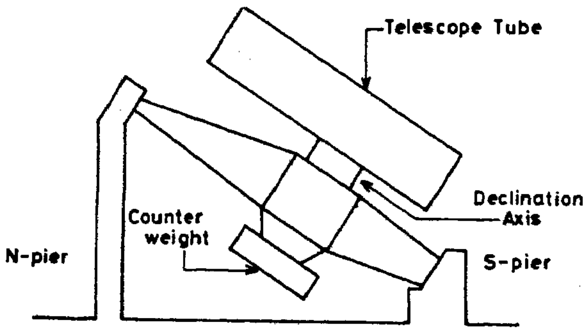

Fig. 3(a)—Sketch of the English mount

Fig. 3(b)—Photograph of 102 cm Zeiss telescope

axle has a clear orthogonal hole in the centre through which the declination axis attached to the tube passes through; the tube weight is balanced by a heavy counterweight on the opposite side of the polar axis. This is an asymmetrical mounting, and is known as the English mount. A sketch of the arrangement is shown in Fig. 3(a). A photograph of the 102 cm Zeiss telescope at the Vainu Bappu Observatory, Kavalur employing the same mount is shown in Fig. 3(b).

The asymmetrical mounting necessitates the employment of a heavy counterweight, which puts additional problems on the bearings and movements. To avoid the use of counterweights, symmetrical yoke design is sometimes employed. But this design restricts pointing the telescope towards the polar regions. To steer around this difficulty a novel design was adopted for the Palomar 5 metre telescope mount. The north side of the yoke was opened out and attached to a huge horse-shoe like structure, whose surface was specially ground to provide a smooth bearing surface. This design was adopted by the Indian scientists for the 234 cm optical telescope at Kavalur.

There are several other forms of mounts which have been adopted for advantages in particular latitudes or the type of foci used. At not too low latitude locations, symmetrical open fork or asymmetric open polar axis mountings have been used. These are generally suitable for medium sized telescopes; for large telescopes the engineering cost considerations force designers to adopt non-equatorial type mountings. The most economical of them is the alt-azimuth type mountings, where a combination of a vertical and a horizontal axis is used. In these mountings, movements around both the axes are needed for tracking even fixed stars. The movements needed are non-uniform and require the use of computers. There are other disdavantages also; the focal plane field rotates with the movement of the telescope. This necessitates, for photographic experiments, that the camera also be rotated in synchronism with movements. In, the pre-computer days this was a difficult task, but has become considerably easy in recent years.

A different type of mounting is used in solar telescopes; these telescopes need very large focal ratios, thereby increasing the focal lengths and consequently the lengths of the telescope tubes. It is impracticable to have a very long tube kept pointing at the sun. A system of moving mirrors, called coelostats or sideros tats are used which keep the beam fixed with respect to a stationary telescope tube. The loss of light by multiple reflections at the coelostat mirrors can be tolerated. But there are other disadvantages due to this method. The instrumental polarization and scattered background becomes unacceptable for certain types of experiments. Modern solar telescopes, are therefore, employing new designs, where ingenious ideas in optical configuration, mounting and drive are being used.

2.3 Drives

Besides proper mounting of telescope optics it is essential to drive the telescope for its proper functioning. For pointing to different parts of the sky, fast motions (~ 1°/s) are employed in medium and large telescopes, the technical name of the operation is 'slewing'. After finding the field, it becomes necessary to set the telescope precisely on the object. This is done by viewing the field through a magnifier and moving the telescope at a slow rate; it is impractical to use the slewing fast motion to do this 'setting'. Typical value of setting speed used is about 1′/s. After setting the telescope, minor corrections may be necessary, which are provided in 'guiding' motions, which may be a few arc seconds per second of time. All these motions are in addition to the 'tracking' rate, which becomes necessary for compensating for earth's rotation and is about 15 arc seconds per second around the polar axis. In equatorial mountings, no declination motions are needed for tracking the fixed stars. For solar system objects, additional motions are usually provided at guide speeds around both axes.

The earliest form of drive was manual; a couple of handwheels could be turned for pointing the telescope at any desired direction. It was William Lassel in the1840s who introduced the idea of turning the handwheel in synchronisation with loud ticks from a pendulum clock. It was not long before gravity driven clocks took over. In course of time, the synchronous motors replaced clocks; further developments saw quartz controlled oscillators generating stable alternating current source for driving the motors. Latest in the field to come are dc torque motors, driven by amplifiers, whose inputs are provided by precision shaft encoders and digital electronic circuits.

Some problems remain untouched by these improvements. This is due to the fact that only angular movements around the axes are controlled through these; there always remain small errors in the actual pointing of the optical system. The errors arise because of refraction in our atmosphere, flexure in the telescope tube and support, non-orthogonally of the two axes and errors in alignment of the telescope polar axis with earth's rotational axis. Efforts to tackle these problems have been directed in two ways: active guiding and computer control.

In active guiding, the simplest arrangement is to rigidly attach another small guiding telescope with a photoelectric device which produce error signals whenever the telescope goes off the target. Amplified error signals can be made to correct movements of the telescope in two orthogonal axes. This arrangement has two major drawbacks. First, unless the object is bright, or at least has a bright star nearby to be used for guiding, the error signal is noisy and not effective in controlling the telescope. Secondly, at very high magnifications there appears differential flexure between the guide and the main telescope, so that the guiding is imperfect. The second defect has been sought to be corrected in many telescopes by borrowing light from the main telescope beam for guiding purposes, but the first defect needed a more drastic approach.

The new approach is to guide the telescope by computer control. Basically the arrangement is that of a closed loop servo-control through precision shaft encoders and stabilized clock pulses; this provided the first order drive. Then by using the system, the entire sky is mapped by observing standard stars and noting their deviations from the instrument coordinates. These errors are interpolated, and corrections for appropriate pointings and movements generated in an on-line computer. The main advantage of this system is that no bright source is needed for guiding the telescope; in today's frontiers of astronomy very often we come across problems dealing with sources which are too faint for normal observations. Only such a computer-controlled telescope will be capable of bringing out results in such experiments. The best example for such an observational triumph is the discovery of the optical component of the Vela pulsar, by the Anglo Australian Telescope[3]. The object sought was three magnitudes fainter than the normal sky limit; the telescope was required to be guided on a blank spot for 6hrs while incoming trickle of photons were detected and sorted out in memory bins on a computer. At the end of the experiment, it could be seen that the light from this invisible source had pulsated in rough synchronsim with the radio pulses received from it.

For ground-based optical telescopes, this represents the latest technique employed; for space-borne instruments, advantage of better visibility is taken advantage of, and pointing is achieved by active star sensing. The Hubble Space Telescope, a 2.4 metre aperture orbiting optical telescope, has provisions for precise pointing by following the method of active star tracking.

2.4 Limitations of Ground-Based Optical Telescopes

Telescopes located on the earth's surface have several limitations; some of them may be minimised by new experimental techniques, while others can be eliminated only by locating the instruments in space. Some of the major limitations are described below.

The first limitation is due to absorption of light in the earth's atmosphere. The entire visible band between 400 mμ to 700 mμ wavelength is free from molecular absorption except for a few isolated lines. In the near ultraviolet, the atmosphere turns opaque at $\lambda < 320$ mμ, while in the infrared, absorption due to moisture, CO_2 and O_3 appears heavy over extended bands. There are semi-transparent windows up to 5 μm, where the optical telescopes can be used with suitable detectors.

Even in the transparent visible band some loss of light is inevitable due to scattering and absorption by air molecules and aerosols. This is measured by extinction coefficient, which is an index derived from loss of light from standard stars at different altitudes. Extinction in near ultraviolet and blue region of the spectra is comparatively higher even in good locations; they may exceed 0.5 magnitude per unit airmass. Extinctions in visual yellow and red regions are lower; a typical value of 0.1 to 0.3 m/airmass is common. In transparent bands of IR, values as low as 0.03-0.05 m/airmass are encountered. All these result in diminution of the intensity of images; the extent of diminution increasing with zenith angle.

The second limitation of the telescope is in the field of imaging. In any case, the images formed are diffraction limited, but even that limit is beyond reach of earth-based telescopes. To quote a figure, the diffraction limited Airy disc of a star image should be 0.1 arcsec diameter in a telescope of one metre aperture; but in actual practice, one gets a blurred unsteady image of 1 arc dia. or even larger. The effect is known as atmospheric seeing and is created due to turbulence in the layers above. One of the major factors considered at the time of choosing a new observatory site is the quality of seeing experienced there. The resolution of any telescope will considerably improve if installed outside our atmospheric envelope.

Still a third limitation one has to put up with is due to scattering of light in our atmosphere. This results in creating a strong halo around bright objects, thereby drowning any faint fine features which would otherwise, have been detectable. An extreme example is the total masking of solar chromosphere and corona by the strong scattered light of photosphere; there are many examples of faint features remaining undetectable in the telescopic images. In ground-based solar coronagraphs, locations are sought on higher mountain peaks, where rarefied air helps to reduce atmospheric scattering.

Full capability of optical telescopes is achievable only outside earth's atmospheric envelope, and that is the reason why a new experiment of establishing an orbiting optical telescope in space has been launched. The Hubble Space Telescope will be put in operation sometime this year 1989. This is expected to provide diffraction limited images almost totally free from scattering, and with a spectral response which will be limited by detector characteristics only.

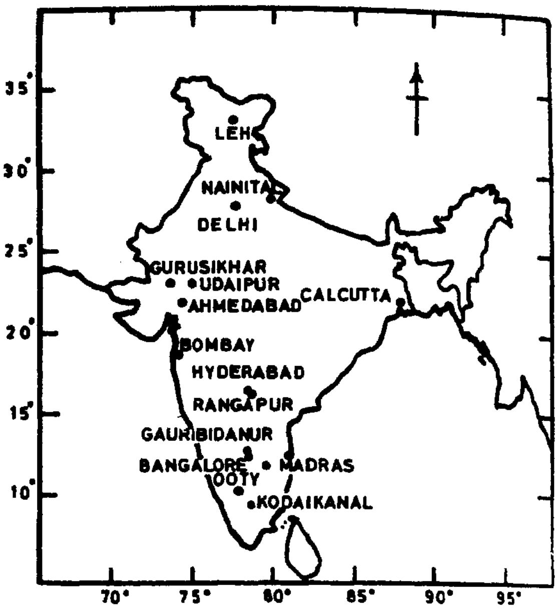

Fig. 4—Distribution of optical telescopes in India

3 Existing Optical Telescopes in India

Distribution of optical telescopes in India is shown in Fig. 4. Small telescopes without focal plane instruments installed in various schools and colleges are not included here. Brief descriptions of the telescopes and their associated instrumentation are given in the following paragraphs.

3.1 Solar Telescopes

The biggest solar telescope available in the country is the Kodaikanal solar tunnel telescope installed in 1959. This is of fixed-tube type fed by a 3 mirror coelostat system [Fig. 5(a)]. The optics is mounted on isolated concrete platforms in an underground tunnel [Fig. 5(b)], which also houses a long solar spectrograph. The spectrograph can produce extreme high dispersions with high resolution; a typical value of 10 mm per Å with a resolving power of a few times 10^5.

Other telescopes for solar imaging are associated with spectroheliographs, and one at Kodaikanal with a spectrohelioscope. The associated devices are fixed-tube instruments fed by coelostat or siderostat systems. The photoheliograph employs a pointing-tube telescope. The coronagraph, where use of coelostat mirrors are forbidden, also employs this design; the objective of the coronagraph telescope is a specially selected single lens with extremely low scattering properties.

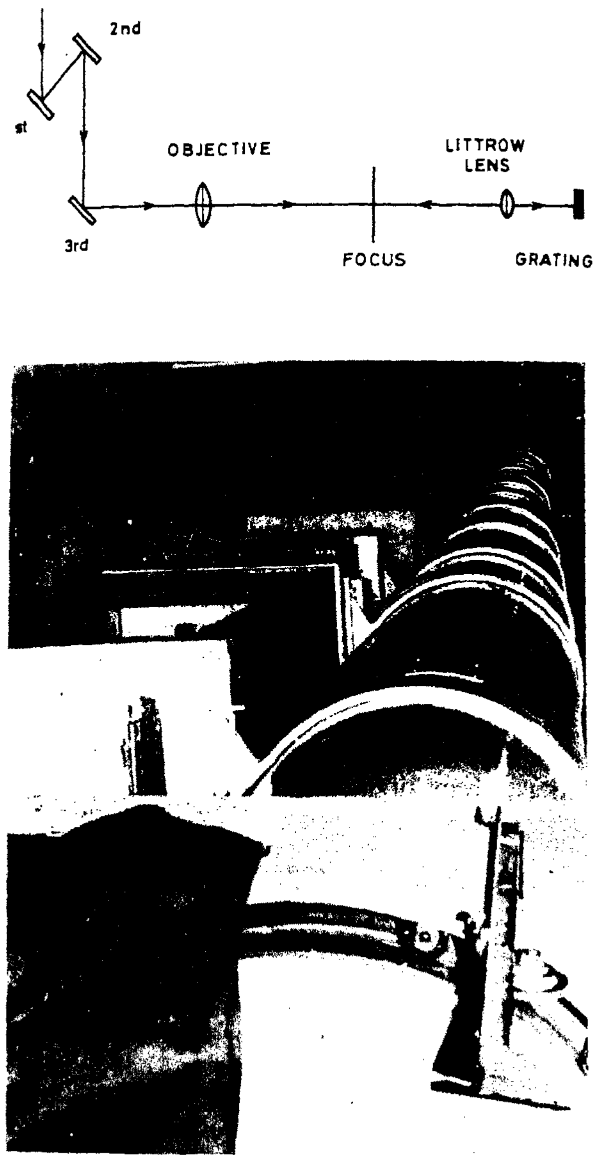

Fig. 5—(a) Ray path in Kodaikanal solar telescope and spectrograph; (b) Photograph of the underground tunnel in which the optical system is mounted

Another 'pointing tube' design has been used in the Udaipur Solar Observatory's 12 feet Spar telescope. The telescope aperture is rather small, but in the site on an island surrounded by the waters of the lake, the seeing quality is excellent. This enables the telescope to image fine details without much blurring.

A third solar observing facility is at the UP State Observatory, Nainital. Here the telescope uses reflection optics, in off-axis skew Cassegrain arrangement, and employs the same in solar spectroscopy experiments. Sunlight is collected through a locally fabricated 46 cm coelostat, and the objective illuminated by this beam[4].

3.2 Telescopes for Night Observations

Old telescopes—The oldest night telescope in the country, still in use, is the 'Madras 8 inch Equatorial now installed at the Kodaikanal Obervatory. It has refracting optics and obtained from M/s Troughton & Simms of England in 1865. At present, it has a photoelectric photometer at its focus, and has been mainly employed for photometry of variable stars and comets.

The next oldest telescope in use is a Grubb-Parsons Cassegrain telescope of 52 cm aperture. This was employed in photometric and spectroscopic observations at Kodaikanal until 1978, when it was shifted to Kavalur. Over the years 1986-88, it was installed in a temporary observing station at Leh in Ladhak, where photometric observations were carried out with the help of this telescope. The telescope was originally obtained by Prof. K D Naegamvala in 1890s for Poona Observatory, and subsequently transferred to Kodaikanal in 1912.

Another old telescope still in use is the 38 cm (15 in) Grubb refractor of the Nizamiah Observatory at Begumpet, Hyderabad. In recent times, considerable work in photoelectric photometry has been done with this telescope. Owing to deterioration of environmental conditions, observational work on this telescope has remained suspended over the past few years, and plans are afoot to shift it to a new location in the Osmania University campus.

The old 8″ Cooke astrograph with a 10″ guide telescope used in the international Carte du Ciel program (1912-1934) is now installed at the Japal-Rangapur Observatory of the Osmania University. It was extensively employed in the Comet Halley Observation Program of 1985-86.

At the time of starting the UP State Observatory, a few telescopes were imported, largest of them being a 52 cm reflector made by Cox Hargreaves and Thomson of UK. Others are 15 cm, $f/15$ reflector (Cooke), 25 cm, $f/15$ refractor (Cooke) and 38 cm, $f/15$ reflector.

More recent telescopes of foreign make—In the late 1960s three optical telescopes of larger than one metre aperture were purchased from foreign manufacturers and installed in three observatories. These are:

1 122 cm reflector at Japal-Rangapur Observatory
2 104 cm reflector at UP State Observatory
3 102 cm reflector at Kavalur Observatory

The 122 cm telescope was manufactured by J W Fecker & Co, USA, and has a Nasmyth focus and provisions for a wide field Baker corrector and a Coude focus. The other two telescopes are made by M/s Carl-Zeiss, Jena of German Democratic Republic, and are both called as 'one metre telescopes'. The aperture sizes notified by the two observatories, are decided according to their own criteria, although the two telescopes are identical, except for slight differences in mountings to suit different latitudes at the two sites. Both the telescopes have $f/13$ Ritchey-Chretien foci and $f/30$ Coude foci, with several optical attachments which considerably augment their capabilities.

Panjabi University, Patiala obtained a 60 cm aperture Carl-Zeiss Cassegrain reflector in mid-seventies; after some delay the telescope has now been installed in a dome in the university campus.

When demands for observational time on telescopes grew, and the existing observatiories could not meet all demands, several scientific groups imported portable 14" telescopes from abroad. These are almost invariably of Celestron-14 model, which has partially hybrid optics in Schmidt Cassegrain combination. Three very active groups who resorted to this scheme are (i) the Physical Research Laboratory working at Gurusikhar, (ii) the Positional Astronomy Centre, Calcutta, with temporary observatories away from the city and (iii) the ISRO satellite group at Bangalore. They have carried out, in recent years, very interesting observations using these modest aperture telescopes.

Telescopes fabricated in India—Efforts to fabricate astronomical telescopes in India can be traced back to the early years of this century, when S K Dhar and Brothers of Hooghly started making small reflectors[5]. Many other small enterpreneurs and amateur groups made valiant efforts to rig up a respectable size telescope in later years. Largest mirror for such a project was a 24" paraboloid which was started by H P Waran of Madras, but could not be completed due to lack of funds.

Concerted efforts to design and fabricate astronomical telescopes were started in several institutions after independence. One such endeavour was by P K Kichlu of Delhi University in late fifties; his efforts were ultimately taken over by a company who produced several small telescopes. But more determined efforts were channelled by M K V Bappu (at Kodaikanal) who employed greater resources he could command as the Director of the observatory, in developing indigenous telescope making capabilities. A P Jayarajan took up the challenge of developing optical shop facilities, and their first telescope, a 20 cm Schmidt with .5 cm corrector plate was put into use in 1965. This was followed by a 38 cm Cassegrain telescope, whose optics was completed and fitted on an old telescope mount available at Kodaikanal. This telescope is being used regularly at the Vainu Bappu Observatory, Kavalur eversince 1968.

The next project taken up by the Kodaikanal team was a 76 cm Cassegrain telescope in the early seventies. In this venture, the entire telescope complete with the mount and drive was planned to be fabricated. Although the primary mirror was completed without much difficulty, the fabrication of the mount posed unforeseen problems. Ultimately a modified design was finally successful in 1980, and the telescope was employed in an occultation experiment in April 1981. Still many problems connected with backlash in the gear system, erratic drive, distortion due to stresses in the mirror cell, etc. remained, which were removed one by one. The telescope was equipped with a modern electronic drive and coordinate display system, and is being used for regular observations from 1986.

The next large telescope project undertaken by the team was the 234 cm telescope; a detailed account of the project is given in the next section. For this project, a fairly large design engineering group was set up at the Indian Institute of Astrophysics, Bangalore. Between the items required for completion of the large telescope, the team led by S C Tapde drew up detailed designs for a 40 cm Cassegrain telescope, and had it fabricated. The optics was ground and figured by a team led by A K Saxena of the organization. The telescope was completed in 1983, and had a very successful run at Kavalur during the Indian Halley Observation Program, 1985-86. The telescope was manufactured under a joint program sponsored by UGC-ISRO-IIA, and was earmarked for installation at the Indian Institute of Science, Bangalore.

One more research type telescope was completed by this group, and this is a 60 cm/45 cm Schmidt at Kavalur. The optics was completed by Saxena and a yoke type mount modified for this telescope. The mount was originally fabricated at Kodaikanal, for the International Mars Observations of 1969-71. At that time, a $f/140$ focus Cassegrain optics of 60 cm aperture was lent by Lowell Observatory Flagstaff, Arizona, and installed on this mount and drive. The Schmidt telescope was employed for Comet Halley Observations 1985-86; on completion of that project, another one of searching for new solar system objects was launched, and at the present time, continuing.

In the mid-sixties, the UP State Observatory imported the optics and tube for a 56 cm reflector telescope, and made the mounting and drive assembly for the same in the observatory's workshops. This appears to be the first major mount and drive fabricated in the country in recent times. The first complete optical telescope with optics, mounting, drive, dome and building was done by the scientists and engineers of IIA in 1980, when the 76 cm Cassegrain telescope became operational at Kavalur.

Besides these two institutions engaged in researches in astronomy and astrophysics, the activity of telescope making has been taken over by a few small entrepreneurs in India. Among them, two firms appear very active as judged from their advertisements and exhibits. They are M/s P Devadas of Madras and M/s Tejraj & Sons of Bombay. They have successfully produced reflecting telescopes complete in all respects and supplied these instruments to some scientific and educational institutions.

The only attempt to produce astronomical refracting telescopes on a mass scale appears to be a project undertaken during 1984-85, under active support from the Department of Science & Technology, Government of India. The original optical design of this 75 mm refractor was done by IIA and the mechanical mount by IISc, both from Bangalore. The work of mass production was later taken over by CSIO, Chandigarh, who made modifications in design to suit production technology, and over a thousand pieces of the telescope finally produced by the Punjab State Electronics Corporation. All the products came to market just before appearance of Comet Halley and the entire stock was sold out. Although demands are still high, no serious efforts have been made to bring forth fresh models of such telescopes.

The number of astronomical telescopes completed in India is not large, but the low figure does not reflect the capability in the country for producing good optics. Many large reflecting surfaces were completed for special scientific instrumentation. Large collimators and camera mirrors have been produced and incorporated in spectrographs; optics for high precision laboratory testings have been prepared. Any reasonable demand for accuracy can be met with our existing methods and techniques.

4 234 cm Telescope Project of IIA

This project of building up of a large optical telescope was an extremely ambitious one, considering that the work involved several advanced branches of technology and such a task has not been attempted before. Towering challenges were foreseen in individual items of work; some of them are given below:

(i) The primary mirror surface would be required to be figured with an accuracy of $\sim \lambda/10$, and this figure maintained at all orientations of the telescope.

(ii) The design and fabrication of the mount should be generally self-compensating to avoid nonlinear errors in pointing.

(iii) The drive should be smooth and accurate to a few arc seconds in long exposures.

(iv) Provisions for use of modern solid-state array detectors and on-line image processing to be provided.

(v) The entire telescope assembly weighing well over 100 tons, as well as the rotating dome weighing twice as much will have to be transported to the isolated place and got erected there.

Obviously, this called for an all out endeavour dealing simultaneously with many technical and engineering problems. The challenge was taken up by Dr M K V Bappu and a green signal for the project was given in 1973.

The first requirement was to freeze the size of the proposed telescope. The recommendation for such a telescope was first given in a 1945-46 report of a committee, chaired by Prof. M N Saha. Later, elaborating on the report, Dr A K Das had put the desired size at around 100". In 1973, when global inquiries for the availability of mirror blanks were floated, M/s Schotts Glaswerk of FRG quoted an unusually low price (~Rs 5 lakhs) for a 93" diameter Zerodur blank, which was being produced at that time as ordered by other telescope manufacturers. Since the blank would be available in less than a year's time, it was decided to accept the offer. The size of the proposed telescope was thereby frozen to 236 cm or 93".

As the next step, activities in two directions were simultaneously started. First, a suitable site for installation of the completed telescope needed to be decided. Almost a decade ago, the site at Kavalur was selected for installation of the Zeiss one-metre telescope; the site had the characteristics of excellent seeing at times, but an average number of cloud free nights. Bappu decided that the utility of the 93" telescope will be more from an extreme southern location in India, from where greater access to the southern skies will be available. Accordingly, besides Kavalur, two more sites were chosen in southern India, at Horshly hills near Madanapalle in Andhra Pradesh, and at Sagunagiri in the Baba Budan hills of Karnataka. After two years of testing, it was found that the alternate sites do not offer any additional points of advantage; the number of clear nights or the quality of seeing are almost the same at the three places. Kavalur had the advantage of an established observatory, and a much better logistic support which would be needed for installation of the big telescope.

The second activity was identifying an engineering team to draw up the consolidated design of this instrument involving optical, mechanical and electronic systems. Around 1970, a representative of a Canadian engineering team, M/s Dilworth, Secord, Meagher and Associates had approached Dr Bappu offering their services in the design of a large optical telescope. The firm at that time, was negotiating with M/s Tata Consulting Engineers, Bombay, for a collaboration in large fabrication consultancy. Although the initial offer was made in the name of the joint company, actual design work was done totally by its Indian counterpart M/s Tata Consulting Engineers. The concept re-

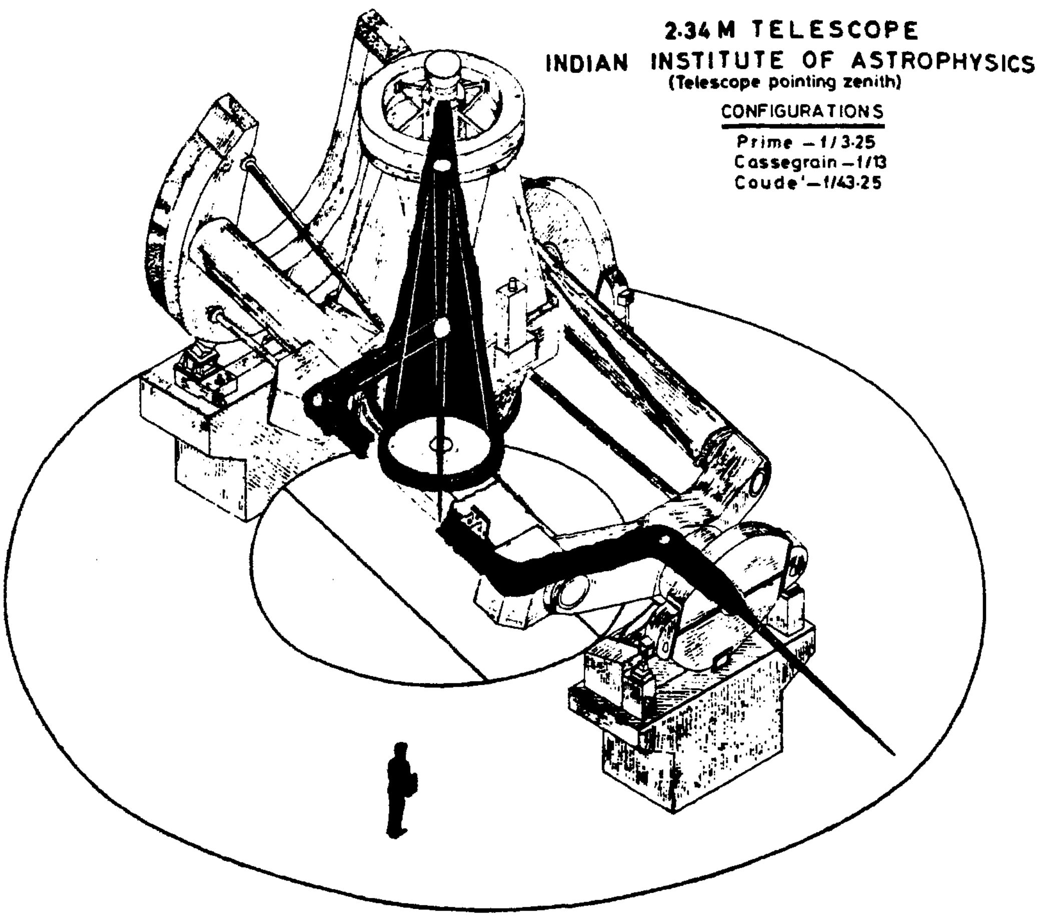

Fig. 6—Sketch of the proposed optical system

port of a 93″ aperture optical reflector telescope was submitted by the firm in Nov. 1976. A sketch of the proposed optical system is shown in Fig. 6.

The work began simultaneously on many fronts. Civil works for the tower and concrete telescope piers were entrusted to the Engineering Division of the Department of Space; the Optics Laboratory building at Bangalore was completed by CPWD. Design of a suitable optical grinding machine was completed by TCE, and the machine was constructed by The Laxmi Vijay Brass & Iron Works, Ahmedabad. The rotating dome contract was awarded to M/s Vikhroli Metal Fabricators of Bombay, who did a commendable job of erection of the 250 ton mammoth structure on top of a 15 metre tower at the isolated location of Kavalur surrounded by dense forests. A VAX 11/780 computer system with COMTAL image processing facilities was installed in the tower close to the telescope. Environmental control was needed for housing the computer system as well as some of the control electronics which were provided by elaborate air conditioning system. For access to the Cassegrain focus of the telescope, a 8 metre hydraulic platform was needed, that was provided by a Hyderabad firm. For meeting all the electrical power requirements, a 400 kW sub-station with standby diesel generator sets was established; a small mechanical workshop for meeting the requirements of maintenance and new instrumentation was also set up. A 2.8 metre vacuum chamber for aluminizing the mirrors was also installed at the base of the tower. These and many other electrical and material handling equipment had to be completed before the installation of the telescope.

The task of fabricating the optics was shouldered by a dedicated team at IIA; AP Jayarajan assumed the leadership for this job. The 5-ton ceramic blank was subjected to rough grinding by diamond wheels, trepanning for the Cassegrain hole, and then a series of fine grinding and polishing operations using glass and pitch tools with different grades of carborundum and finally cerium oxide. The optical surface was first figured as a sphere of appropriate curvature, then the slow process of parabolization started. Besides the conventional wire test, a new interferometric method of testing was developed in the laboratories and applied in this iterative process[6].

Simultaneously, on smaller machines in the optical shop, other components of telescope optics were got ready. For figuring the Cassegrain secondary, a large handle sphere of 127 cm diameter was fabricated; most of the latter programs including the aluminization of the mirrors were executed by Saxena.

Responsibility of rigging up of the mechanical structure lay on Tapde, who was also the manager of the entire project. The mechanical team, which included the design engineers from TCE, had visited all possible large workshops in the country to study the feasibility of having these fabricated. However, when quotations were invited only three private firms had come forward, and one of them, M/s Walchandnagar Industries Limited were awarded the contract. They had also grossly underestimated the difficulties in this special fabrication, and the completion was delayed by more than three years.

Originally it was expected that the consulting engineers will give detailed specifications for the control and electronics, including the computer interfacing. It was, however, found that they did not possess the in-house technical competence for this special job, and had to heavily depend on IIA and other laboratories to provide solutions to numerous small problems arising out of the design and execution process. IIA took over this responsibility and went ahead in the design and fabrication of these systems. They sought and obtained help and guidance from the Reactor Control Division of BARC in heavy servo control jobs. Late Mr S N Seshadri and his team not only designed the control servo system, but had the console fabricated and installed at Kavalur. Scientists and engineers of the two organizations worked together as a team and completed the installation of the complex system.

It is unfortunate that the originator of the project, Dr M K V Bappu could not see the fulfilment of his dream; for in August 1982, he passed away. The telescope was, however, completed and became operational in October 1985. On 6th January 1986, in a simple brief ceremony, Shri Rajiv Gandhi, the Prime Minister of India, named the telescope after Vainu Bappu.

The Vainu Bappu Telescope is the present largest optical telescope in the country with its 234 cm primary mirror. It even surpasses the 188 cm telescope at the Tokyo Observatory, which was the largest telescope in Asia until October 1985. The telescope has several features which distinguishes this among the advanced telescopes of the world today. For example, with the new CCD camera at its prime focus with the image procesing facility on the VAX 11/780 computer, it is capable of reaching faint objects in the far reaches of the universe, which has hitherto been the monopoly of large telescopes abroad.

5 Future of Large Telescopes in India

Although no projects aiming to set up a still larger optical telescope in the country are currently being pursued, a few ideas have been voiced. The most advanced among them is the 4 metre telescope project proposed by the Uttar Pradesh State Government. A concept report has already been prepared in which two alternative mount configurations have been suggested. The question of preparation of the optics has been left open, so are a few other vital points. The biggest problem appears to be the availability of finances. At one time, the UP state Government appeared very keen to totally finance the project; their enthusiasm seems to have ebbed down, recently.

A few other proposals have been made in various forums. A 2.4 metre infrared telescope has been suggested for the proposed high altitude observatory near Leh, in Ladhak; the telescope may be totally built in India. A twin telescope interferometer has been suggested for location in a suitable site; individual telescope may be of apertures less than 2.4 metre—the maximum size optics which can be totally fabricated within the country with the help of existing equipment. Still a third proposal visualises a 6-7 metre aperture telescope, where only the optics need be imported and the rest of the structures done in India.

In the field of solar instrumentation, a new design vacuum telescope has been proposed[7]. This will have, besides a domeless design, modern components, e.g. active mirrors and adaptive mirrors to compensate for the atmospheric-seeing disturbances. The location of this telescope has not been decided, and also, full financial support not promised yet. Development of several sub-systems of this telescope however, is being attempted.

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