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Facility

Vainu Bappu Telescope

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Abstract. The article describes the project of planning, designing and constructing a large optical telescope in India. The historical background covering observational efforts since the middle of the nineteenth century to the post-Indpendence developments has been brought out. Following a Scientific Committee's recommendations, set up after the Second World War, preparation for developments of observational astronomy had started; the tortuous course of planning, preparation and development of technical abilities etc have been described. Various aspects of the project, beginning from site selection, establishment of the optical laboratory, liaison with different laboratories and manufacturing firms for design and fabrication of the telescope mount and the critical control system have been covered. A brief description on the telescope parameters and its auxiliary equipment is given. Some details of the operational problems encountered during fabrication and installation of the telescope and a critical review of its performance are discussed.

Key words : large telescope fabrication

1. Introduction

Astronomical studies using modern telescopes were pursued at the government observatory in Madras since the middle of the nineteenth century. The largest telescope used there was an 8 inch refractor, manufactured by Troughton & Simms, which was installed around 1865[1]. Around 1890, a larger telescope of 20 inch aperture, manufactured by Grubb was procured and installed in an observatory at Poona by K. D. Naegamvala; this telescope was in operation till 1912, when the observatory was closed down, and instruments transferred to Kodaikanal Observatory[2].

Although the community of professional astronomers was small, the need for a larger instrument was keenly felt, and some indigenous efforts to manufacture such instruments were made. Notable among those endeavours was the project undertaken by H.P. Waran of Madras to construct a 24 inch optical telescope in the late forties; the telescope, however, could not be completed due to lack of funds[3]. The largest telescope used at that time was the 15 inch refractor of Howard Grubb make at the Nizamiah Observatory, Hyderabad[4].

In 1945, the Government of India appointed a committee of scientists to examine and recommend steps for development of astronomical studies in the country[5]. The committee was headed by M. N. Saha, and its report contained recommendations for starting a central observatory with at least one large telescope. This coincided with the political independence of the country, which boosted the ambitions of the Indian scientists. They hoped to establish a telescope of 100 inch class, which was till then the largest telescope in the world. A. K. Das, Director of the Kodaikanal Observatory, accordingly proposed the procurement of a large telescope and suitable budgetary provision was included in the proposals for the first five year plan of the Kodaikanal Observatory. Subsequently, the proposals had to be pruned leaving the acquisition of the telescope for a future date.

The night time observing conditions at Kodaikanal Observatory were far from satisfactory, and a search program for new sites started in the fifties. In keeping with the importance of Ujjain in ancient Indian efforts in astronomical sciences, this area was first subjected to a close examination. Night time observing conditions were monitored along with meteorological parameters at the station for a few years; but no persistent efforts appear to have followed.

In April 1960, M. K. Vainu Bappu took over the Directorship of the Kodaikanal Observatory. Soon afterwards, in a meeting of the Standing Advisory Board for Astronomy (SABA), he put forth an important proposal. He suggested that a search for the site for the proposed central observatory be made in the extreme southern part of India; for, with a location close to the equator, one would have access to almost the entire sky and that would be a major advantage for any observatory. He was prophetic, as years later in 1987, when the first naked eye supernova appeared after a gap of four centuries, it was located in the Large Magellanic Cloud in the deep southern sky. Among the observatories in India, only the Vainu Bappu Observatory at Kavalur could carry out detailed photometric and spectroscopic observations of this rare phenomenon. Bappu had other points of arguments also in his favour. A move to start a few southern observatories by European & US scientists has started hotting up; Bappu had definite ideas of studies of several interesting objects located in the southern sky from the new observatory. SABA agreed to this proposal and asked Bappu to go ahead with his search.

The site search party commenced its first expedition in 1962. The team covered all possible hill sites from Kanyakumari to Tirupati-Tirumalai hills. They carried a portable telescope and stopped at several places for a night or two and monitored seeing qualities there and ultimately zeroed down to a spot in the Javadi hills, deep in the midst of a reserve forest of sandalwood trees. The nearest village, just a cluster of mud-built huts, was about a kilometer away; the site derived its name from this small village, Kavalur.

Bappu arrived at his choice from several serendipitous observations. The site is in the form of a hill, surrounded by a ring of still higher hills, beyond a horse-shoe shaped deeply wooded valley. The orography favoured formation of trapped air surrounding the observatory site, and the deeply wooded valley providing little insolation heating of the lower layers produced a relatively stable atmosphere. Bappu's idea was supported by the local forest ranger, who reported regular formation of low ground fogs in the surrounding valley on winter mornings. Such a condition is conducive to good seeing, which was confirmed from observations in later years. Several times in the nights, the seeing better than 1 arc second was recorded by the observers here. The renowned astrophysicist B. J. Bok had described the seeing at Kavalur as excellent[6].

2. Preliminary developments

(a) Acquisition of the one-meter Zeiss telescope

Owing to urgent necessity of solar instrumentation at Kodaikanal for the ensuing programs of the International Geophysical Year, no funds for the large telescope could be allocated in the first two five year Plans. With the hopes of getting some funds during the III five year Plan, Bappu had been busy collecting details of a medium sized telescope; he chose a one-meter telescope offered by Carl Zeiss of Jena, East Germany. Subsequently he could get funds for the same in the Third Plan. A firm order for the telescope could be placed in 1965 and the instrument was delivered in March 1969. It was decided to locate the telescope at the new site, but the construction of the dome and tower could not be completed before 1971. The UP State Observatory at Naini Tal had also ordered an identical instrument which was also delivered by the firm simultaneously. The installation team came towards the end of 1971, and the UPSO telescope was installed by December 1971; then the German engineers came to Kavalur in January 1972 and completed the installation work by May. With the availability of these two telescopes, respectable observational facilities were created in India, which started producing observational results of international standard. Bappu's choice of Kavalur bore fruits; within a very short time, during an occultation event, a discovery was made of a thin atmosphere of Ganymade, a satellite of Jupiter[7].

Bappu did not give up his dream of acquiring a telescope of 100 inch class; he continued his efforts in that direction even when the one meter telescope was being installed. He later convinced the Governing Council of the newly created Indian Institute of Astrophysics about the necessity and urgency of a large optical telescope.

(b) Building up of optical capability

It was realised quite early that a large telescope would be possible only if it could be built indigenously. A critical component of this venture would be the preparation of the optical elements. A telescope of 100 inch class would obviously have to be of reflector type, as refractors larger than one meter aperture are beyond the capability of even present day optical technology. Bappu decided to upgrade the small optical shop which existed at the Kodaikanal Observatory, with the aim of grinding and figuring large reflecting surfaces needed in astronomical instrumentation. A. P. Jayarajan, a scientist in the Kodaikanal observatory, who had only a general science background but had exceptional experimental aptitude was picked up to develop this unique facility. A beginning was made with small optics of about 8 inch (20 cm) in diameter, and the first instrument, a 20/15 cm Schmidt camera was fabricated during late 1964. Taking advantage of the mechanical fabrication facilities that existed at the Kodaikanal Observatory, a glass grinding machine capable of taking blanks up to 36 inch (90 cm) in diameter was constructed. In the meantime, Bappu had ordered and procured several glass blanks of sizes up to 50 inch (127 cm) in diameter; one of them, a 24 inch (60 cm) diameter blank, was ground and figured as a spherical concave mirror, to serve later as the collimator/camera of the Coudé spectrograph at the focus of the Zeiss one meter telescope. The perfect figure of the mirror was demonstrated to the Union Minister Dr Karan Singh, when he visited the Observatory in 1968. A real image of a hanging key was projected in air at the entrance of the laboratory; the image was so realistic that the Minister tried to pick it up. Though it may not indicate the degree of perfectness of optical imaging, the capability of handling large optical surfaces was amply demonstrated.

By 1970, the optical shop was already firmly established. It had produced the optics required for the Eclipse Expedition to Mexico and several other auxiliary imaging systems at Kodaikanal. A 15" (38 cm) aperture Cassegrain telescope was fabricated utilising an old telescope mount[8]; this telescope was the first research telescope installed at Kavalur, and is functional even to this date.

(c) Establishment of the Indian Institute of Astrophysics

In April 1971, the Astrophysical Observatory at Kodaikanal was transformed into a research Institute and named as Indian Institute of Astrophysics (IIA). The new Governing Council, chaired by the eminent experimental physicist, M. G. K. Menon, decided to shift the laboratories to Bangalore, for easy interaction with other scientific groups. Pending construction of a regular building of the optical workshop in the new campus at Koramangala, the laboratories functioned in the premises of the Raman Research Institute since March 1973 for about two years. In November 1975, the optical shop was shifted to the Koramangala site and remained in a temporary shed for another year; finally in early 1977 it was moved into its present location. By that time Bappu had committed himself for getting the optics for the large telescope totally fabricated in this laboratory.

3. Proposal for the large telescope

Eversince the late sixties, Bappu had been pressing for funds to start the large telescope project; but the parent department, India Meteorological Department, was evading the responsibility on the plea that such a project be taken up in the new set up, which Govt of India was considering since mid sixties. The Governing Council took charge of the Institute in April 1971; in September 1971 during the 3rd meeting of the Governing Council, Bappu put up a proposal for the project. The principal themes advanced by him for the telescope were: (i) the study of spiral structure of our Galaxy, specially in the relatively unexplored portions visible in the southern hemisphere covering the near galactic plane from Puppis to Carina and Centaurus; (ii) the study of stellar chromospheres principally by the methods of stellar spectroscopy; (iii) the study of the morphological aspects of external galaxies, the study of chemical composition parameters in these aggregates and their bearing on stellar evolution. The Council after a prolonged discussion agreed in principle, and suggested that he should come up with a detailed project report covering all aspects of the proposed activities. The Council decided that the large telescope would be a national facility available to all Indian astronomers. In 1972 the Institute ordered for the necessary mirror blanks, and initiated steps to engage a firm for consultancy.

Enquiries for the mirror blank were sent to several glass and ceramic manufacturers of the world. Of these, Corning Glass Works of the US quoted $ 200,000 for a 2.5 m Cervit blank of a newly developed ceramic material with a very low thermal expansion coefficient. At the then existing rate of exchange, the price amounted to about Rs 17 lakhs. On the other hand, Schott's Glaswerk in Federal Republic Germany offered slightly smaller size mirror blank of a similar material at DM 100,000/- which amounted to Rs 5 lakhs. This, it was learnt, was possible only because two more blanks of the same size and type were being cast, resulting in the overhead cost being shared by the other two groups. It was decided to accept the offer from Schott; the size of the blank was 93" (236 cm) in diameter, the size of the telescope aperture was thus fixed. It was a conventional thick blank with a diameter to thickness ratio of 6. The blank was received in May 1974, and stored in a temporary hut at Kavalur.

The next step was to decide on the mounting. Various designs of mounting were followed in the large telescopes of the world; all had their respective merits and demerits. Bappu had worked out some tentative designs, but it was felt that it would be wise to consult some experienced engineers before freezing the design.

In December 1974, Tata Consulting Engineers, Bombay were chosen for this task. The firm had past experience in the design and fabrication of the Ooty Radio Telescope and Arvi Steerable Dish. It may also be mentioned that earlier S. Jagannathan, a senior executive of this firm, had some discussions with Bappu at Kodaikanal. At that time he was accompanied by an engineer, Hunter, from a Canadian firm Dilworth, Secord, Meagher & Associates, who had earlier designed a large optical telescope for Canada. The initial offer for this consultancy job came from the Tata, Dilworth, Secord, Meagher & Associates, but later, the Canadian collaborators pulled out and the project was completed by the Indian counterparts, Tata Consulting Engineers (TCE).

In 1975 beginning, Bappu accompanied by D. P. Panchal of TCE, went round some of the large telescope installations in USA, and had detailed discussions with their engineers. Enormous help and goodwill exhibited by some of the US scientists at this stage deserve special mention. Harlan Smith of the University of Texas at Austin, who was a close personal friend of Bappu, not only supplied the complete duplicate set of drawings for the 107 inch Mc Donald Observatory telescope and several other design details, but also provided constant help and advice during the entire course of fabrication of the telescope.

On return from this trip, a long consultation meeting was held in the TCE's office in Bombay, where besides Bappu, Jayarajan and Bhattacharyya from IIA participated. All aspects of the optics, mount, control and ancilliary systems were discussed. The overall design of the telescope was frozen in this meeting: The telescope would have an f/3.25 primary focus, f/13 Cassegrain and f/43.25 Coude foci. The mount would be equatorial with an open yoke and a horse-shoe bearing in the north, and driven by spur-gears with optical encoders on its axes (figure 1). An on-line computer would generate the control signals and at the same time process the observational data. The telescope would be installed in a tower, above the turbulent boundary layers which hover close to the ground. With these basic features, a concept report was submitted by the TCE in

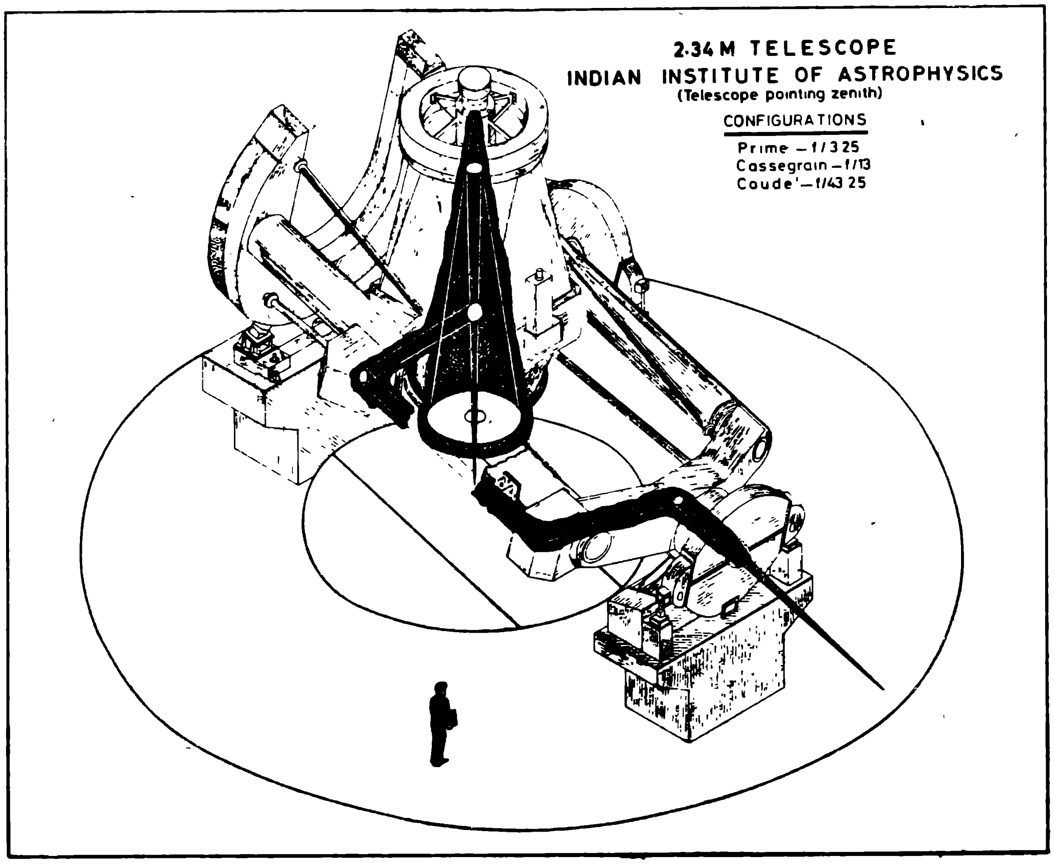

Figure 1. 2.34 m telescope configurations.

November 1976. The green signal for fabrication of the large optical telescope was finally received thirty one years after Saha Committee made its recommendations.

4. The telescope project

After accepting the concept report submitted by the TCE, the Council formed a Project Management Board (PMB) consisting of expert members from different disciplines. M. K. V. Bappu (Chair), J. C. Bhattacharyya, D. Easwara Das (Vikram Sarabhai Space Center), C. M. Govers (Bhabha Atomic Research Center), N. V. G. Sarma (Raman Research Institute) and S. C. Tapde formed this committee. Tapde, a young engineer, who had already acquired a long experience by his association with the Arvi communication satellite system and antenna building projects, was appointed as the Project Manager and he became the Secretary to PMB. Full financial and executive powers were vested with this Board. K. G. Unnikrishnan Nair, an active observer, was inducted into the team to assist the Project Manager. Later on, in 1982 following the sudden death of Bappu, Council appointed Bhattacharyya as the Chairman and Ch. V. Sastry (IIA) as a new member.

The final site for installation of the telescope was still to be chosen. Although the Kavalur Observatory had been functioning for more than ten years, as judged earlier, the location offered not a very high number of cloud free nights; Bappu wanted to install the large telescope in a site which offered good 'seeing' conditions in southern part of India. Bappu had already started this search in 1973 itself. He, along with a team of young assistants, went north of Bangalore, covering Chickmagalur, Belgaum, Panchghani, Mahabaleswar, Aurangabad area and finally to Pachmarhi, staying and observing seeing conditions at each place for a few nights. A report covering the expedition was brought out and submitted to the Council. It was noticed that as one moves north, the improvement in the number of clear hours was very gradual, with increasing loss of access to southern skies. He felt that the southern location of the telescope was still preferable; in his report, he clearly indicated that in future when the question of locating a still larger telescope is taken up, some of these sites might be seriously considered.

Besides Kavalur, Bappu had chosen two more alternative sites: one in the Baba Budan hills of Karnataka and the second in the Horsely hills in Andhra Pradesh. Two teams were sent to these sites to conduct comparative observations for one full season. In the quality of sky transparency and seeing, no significant difference was found between the three stations; considering the advantage of a well established infrastructure already existing at Kavalur and on the basis of good 'seeing' condition, this site was recommended for location of the large telescope. The Council appointed a committee for evaluating the site survey report. It consisted of K. R. Ramanathan (Chair), K. D. Abhyankar, M. K. V. Bappu, V. Radhakrishnan, Y. P. Rao and G. Swarup; they recommended accepting the survey report. In November 1976 the IIA Council thus approved that the 93 inch telescope be located at Kavalur.

For preparation of the site for the new telescope, an additional 60 acre forest land adjacent to the existing observatory was acquired. The land was cleared of shrubs and roads were laid connecting the proposed installation site; provision was made for locating the power house with standby generators and a small mechanical workshop which were considered absolutely essential for the project. The increased demand for water necessitated augmenting the existing system of water supply by digging additional wells and arranging for the pumping system to the new areas.

With the site finalised, the TCE started giving detailed civil works drawings. A construction firm from Madras, Subramaniam & Co was awarded the contract for civil works. The responsibility for supervision of construction was shouldered by the Civil Engineering Division of the Department of Space (DOS). From the Institute, N. Selvavinayagam coordinated the construction work along with Tapde. The rotating dome of the telescope calls for another type of structural expertise; the contract for fabrication and installation of this item was awarded to Vikhroli Metal Fabricators (VMF), Bombay. But there were so many factors deciding a smooth trouble free operation of the giant structure that the original design submitted by the TCE had to undergo many modifications, during and after installation of the dome.

The construction work started in 1978. Special care was taken to provide separate foundation for the telescope piers and the tower resting on the bed rock so that vibrations of the tower and dome are not transmitted to the telescope. The proposed installation of an on-line computer, air conditioning of critical areas, elaborate hydraulic system etc necessitated providing ducts for air, coolant and power at various points in the building, detailed layouts for which had to be provided at this stage itself. The giant 250 ton dome atop the building was required to smoothly rotate to match the telescope position; special attention to this requirement was paid while constructing the circular track.

The rotating part of the dome structure was assembled in the VMF's works at Bombay; after testing the entire assembly the parts were dismantled and carried over to Kavalur by road. For installation, several elaborate arrangements had to be made; a derrik crane with a reach of about 50 meters, carrying pieces weighing up to 10 tons to appropriate places high above ground, had to be employed. The pieces were welded there *in situ* to form the skeletal structure of the dome; cladding was provided with 2 mm thick mild steel sheets welded on to the frame. Slabs of glass wool was fitted underneath to provide necessary thermal insulation, with anodized aluminium panels giving clean smooth finish to the inner shell of this giant structure. It rested on a circular track on the outer wall of the dome with six active and twentyeight idling trucks carrying the load. Two giant sliding shutters were mounted on this, which move on another set of straight tangential tracks fixed on the dome frame. Viewed from distance, the dome, covered with super white titanium dioxide paint, with its cat-walk painted in red, appears as a gigantic decorated pearl atop the dark green canopy of the sandalwood forest.

5. Optical grinding

The new optical shop at Koramangala, Bangalore campus earmarked a separate area for grinding, polishing and figuring the 93 inch primary mirror. A 75 ft vertical concrete tower had been built on top of this, so that periodic testing of the surface could be carried out without the necessity of removing the mirror from the grinding table. Arrangements for testing set ups at different heights were incorporated in the tower.

Besides the old 36 inch grinding machine built at Kodaikanal, a bigger and more versatile machine was installed in this workshop. It could handle blanks up to 50 inches in diameter, and indeed, several elements for the secondary optics of the large telescope were fabricated on these machines. But none of them could handle a mirror of 93 inch (236 cm) diameter; it was, therefore, required to build a new grinding machine for this job. But, for that purpose, an optimum design had to be worked out. Strict specifications for its performance had to be laid down; range of speeds, vibrations, manouverability of the tools, mirror supports etc had to conform to the requirement. The TCE was persuaded, and entrusted with another contract to provide detailed design for such a machine.

Fabrication of this machine was entrusted to a machine-tool manufacturing firm in Ahmedabad — Laxmi Vijay Brass & Iron Works. Some vital components had to be imported, but the bulk of the machine could be manufactured in India meeting the specifications laid down. By that time, Bappu inducted A. K. Saxena into the Optics team to work on the aspect of testing and aluminizing. By May 1979, the grinding machine was installed at the optical shop of Bangalore. The mirror blank was transported from Kavalur and loaded on the machine on December 19, 1979.

The first task was to drill the Cassegrain hole on the primary mirror. This was done by using a special trepanning tool, a 30 inch (75 cm) diameter mild steel cylindrical shell rotating around its axis; the abrasive used was coarse grain carborandum powder mixed with water. The trepanning was done from the bottom side of the mirror and was stopped when about 7 cm more remained; the idea was that the subsequent profile generating operation would remove this layer without distorting the surface. The gap created by the trepanning operation was filled up by araldite and plaster of paris — a rigid yet removable adhesive, so that the grinding operations do not produce zones around edges of Cassegrain hole. The blank was turned upside down to bring up the profile generating surface (figure 2); it was then accurately centered on the grinding table. The next grinding operation was scooping out a rough spherical surface; for this a rotating diamond tool at a very high speed was used. The tool was mounted on the cross arm of the tool carrier, the vertical feed being controlled by a sliding arm moving over a profile template. About half-a-ton of the material had to be scooped out. Several problems, *e.g.* overheating of the bearings etc. had to be encountered which were solved by the optics team. The operation was over in about three months, producing a rough spherical concave surface of appropriate curvature.

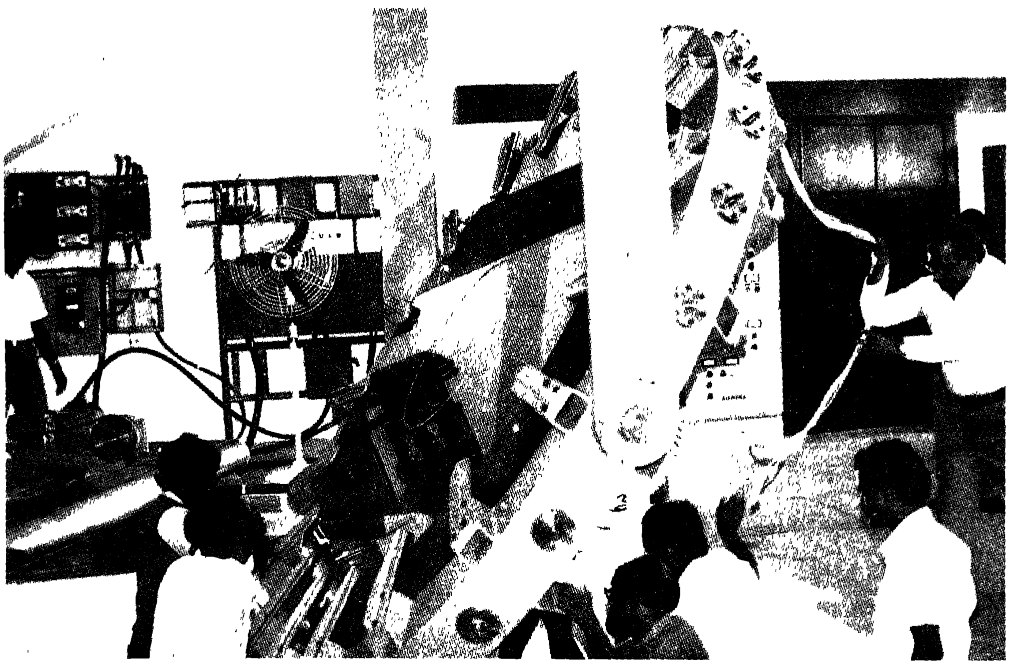

Figure 2. 2.34 m primary mirror being turned down for figuring.

The next step was smoothening the mirror surface. Special composite tools were prepared with glass pieces stuck to a bitumen base on a wooden framework and using gradually finer grades of carborandum powder in the form of a slurry. The uneven surface left out after the scooping by diamond wheels could be ground down to a smooth spherical concave shape. At this stage, the glass studded tools were taken off, and replaced by pitch tools. These are formed by overlaying a large cast aluminium dish with a layer of optical pitch — a mixture of bitumen bees-wax and rosin blended together by melting. Abrasive material used in this operation was finely powdered carborandum mixed with water. After this, the abrasive mixture was changed to powdered cerium oxide which produced a polished surface. The spherical concave surface thus formed usually has small departures from a perfect sphere, and these can only be detected by optical tests. The operation by which these are detected and gradually removed is known as 'figuring'. This is an extremely slow operation. It is often said that in grinding mirrors the first 90% of work takes only 10% of time, the remaining 10% takes the remaining 90% of time. In the case of the 93 inch primary mirror, the operation began in December 1979, rough grinding by diamond wheel was over within three months; glass and pitch tool smoothening was completed in December 1980 and polished surface for the first test was available in August 1981. The finished mirror could be delivered only in September 1985.

The mirror surface figuring operation commenced in September 1981, the first interferogram being taken in September 1981. This new method for qualitative evaluation of the surface more precisely was developed by Saxena in the Institute's laboratory in Bangalore[10]. It had the advantage of detecting small asymmetric zones, which might escape unnoticed in the conventional wire-tests. The first step was to figure the mirror surface as a sphere, and then produce smoothly varying radii of curvature from centre outwards. A variety of tools and short grinding operations were needed to achieve this objective. A sequence of daily correction and testing, formed a routine at the optical shop. Periodical interferograms were taken (figure 3), analysed by A. K. Saxena and J. P. Lancelot and the findings of daily wire-tests confirmed with the computations thereon.

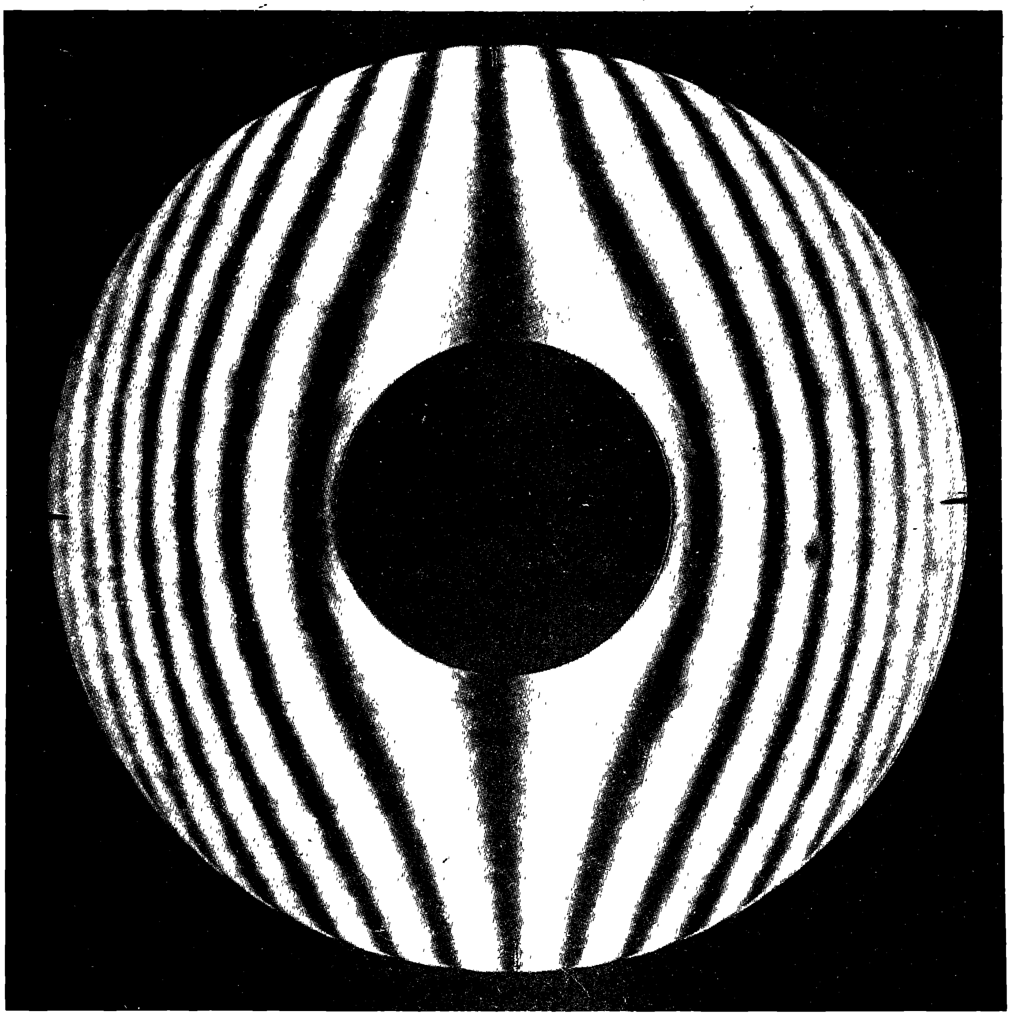

Figure 3. Interferogram of 2.34 m primary mirror.

The project received a severe set back at this stage. Bappu, who was closely monitoring the optical work, suddenly and unexpectedly passed away. He left for a short assignment abroad, underwent a cardiac bypass operation in August 1982 in Munich, Germany and never returned home. By his long experience, Bappu had acquired a thorough knowledge about testing of optical surfaces, and he was expected to supervise the delicate testing of the finished mirrors; with his sudden departure, the optics group was left to fend for themselves. But in the meantime, the two scientists leading the figuring and testing groups, Jayarajan and Saxena, had developed considerable expertise and confidence in their respective fields. They went ahead with their programs accepting the challenge. Except for seeking the advice from Don Loomis, an optical expert from Custom Optics, Tucson, USA, who visited the laboratory in late 1984, towards the final stages of figuring operation, no other help was needed for completion of the optics. The primary mirror could be produced with better accuracy than what was originally aimed at. A three element Wynne corrector system for producing a corrected wide field at the prime focus, as well as other auxiliary optics for the Cassegrain focus to be set up later, were completed by the group led by Saxena[11]; while Jayarajan concentrated on the final figuring of the primary mirror.

6. Mount design and fabrication

The concept report had visualised a two pier mount with a yoke open in the north ending in a giant horse-shoe bearing. The specifications of the horse-shoe were rather stringent; the bearing surface should be a part of a sphere 6.5 meter diameter ground finished with undulations not exceeding 75 microns at any place. This was essential as this surface would have to closely mate with two hydraulic pads. Several other parts of the mount had similar strict specifications. Before floating the tender the PMB decided on deputing a team to have face to face discussions with the leading heavy engineering workshops in the country. The team found that although facilities for producing these parts meeting the specifications exist at several places, the final results would depend on the skill and experience of engineering teams in handling precision work.

In response to the limited tender sent to four heavy engineering firms, three quotations were received. They were from: (i) Larsen & Tubro, Bombay, (ii) Walchandnagar Industries Ltd, Walchandnagar near Pune and (iii) K.C.P. Ltd, Madras, all private sector organizations. The only public sector undertaking which responded was Heavy Engineering Corporation, Ranchi; it repeatedly requested for extra time for submitting its quotation. After agreeing to two requests for postponement, the PMB finally decided not to wait anymore. After carefully studying the three quotations, it was decided to accept Walchandnagar Industries Ltd's (WIL) offer, which was approved by the Council of the Institute in September 1979. Necessary purchase order was released for commencement of the work on the mount.

The fabrication work being a task of unique nature, many hardships were encountered from the beginning : the level of tolerances acceptable for many components was very strict, and hence high rate of rejections ensued. The PMB sought and obtained the services of two experienced engineers from VSSC, Thiruvanathapuram, and they were stationed at the works. The Project Manager, Tapde, was assisted by K. M. Subbaraman, who had to make several trips to WIL for monitoring the progress. Often the fabrication process had to be stopped, for want of clarifications from TCE. The original target time for completion was 27 months, which had to be extended several times. The WIL had apparently underestimated the complexity of the task, and started incurring cost overruns. They appealed to the IIA for a revison in their prices quoted earlier, which could not be immediately agreed to. The impasse was avoided by mutually agreeing that at the end of the completion of the telescope, any cost overrun which may be assigned to unusually complex nature of the job, would be examined by a competent committee, and considered for appropriate compensation. Ultimately, the WIL could successfully complete the work during mid 1984; the telescope mount was ceremonially handed over to the Chairman of the Governing Council of the Institute, M. G. K. Menon, Scientific Advisor to Prime Minister, on July 8, 1984 at Walchandnagar in the august presence of late Vasant Dada Patil, Chief Minister of Maharashtra. After that, it was disassembled and part by part transported to Kavalur by road, a thousand kilometers away.

The final installation of the mount at Kavalur was an extremely difficult job, calling for elaborate planning and ingenius improvisations. This was very efficiently executed by the Project Manager, with the able support provided by B. R. Madhava Rao. The site was away from civilization, and space inside the dome severely restricted, making the precision assembly job very inconvenient. A series of assembly platforms, lifting tackles and support arrangements had to be improvised, and delicate step by step movements were planned in advance. About a hundred workers of varying skills worked there for more than six months, and they could successfully tackle the task in May 1985 with the unstinted help and support provided by the full team of observatory staff, in general, and the technicians, in particular.

7. The control system

(a) Requirements

The movements of any modern telescope are required to be very precise for optimum performance. Also, for most of the faint objects, it is necessary to be able to point the telescope blindly through its coordinate indicators. In the design of the control system for the telescope such requirements were kept in mind. For this purpose, it was planned to incorporate a computer in its driving and pointing control work.

Other new techniques in driving and control of the telescope were also employed. Conventional method of tracking is by using a large worm wheel around its polar axis and driving it by means of a worm screw coupled to a synchronous motor through a gear box. The inherent back lash is usually tackled by a preloading arrangement by hanging weights. The Zeiss one metre telescope at Kavalur has this type of drive and has been satisfactorily working for years. However, fabrication of the large worm wheel is an ultra-precision mechanical job, and was avoided in some new drive systems. The new arrangement requires ordinary spur bull gears which are driven by a pair of d.c. motors working against each other through gear boxes; the speed of drive being controlled through a servo loop fed by position information from precision shaft encoders which are available commercially. The precision needed for the fabrication is thus transferred to the shaft encoders, which are produced with ample accuracies needed for modern telescope drives. Such systems are more easily manouvered through modern cascaded control loops/systems.

(b) Design

It was originally expected that the TCE would be able to provide the complete design of the control system, but soon it was realised that their level of expertise in this field was not high enough to produce the ultra precision system needed for the telescope. It was therefore decided in 1979 to approach the most experienced control system team in the country, *viz.* Reactor Control Division of the Bhabha Atomic Research Centre, Bombay. The group was led by the legendary control system scientist, late S. N. Seshadri, who had earlier rendered his expert advice and help in several heavy control projects, besides designing many control systems of atomic reactors. He readily accepted the challenge and a collaboration plan was drawn up where the scientists and engineers of both IIA and BARC would work as a team. The IIA team was led by J. C. Bhattachayya, assisted by A. K. Pati and a team of engineers from IIA electronics laboratory. Although large scale migration during the project affected the team's composition, very important roles were played by V. Chinnappan, P. Santhanam, C. Viswanath, S. Sadasivam and T. S. Raghu. R. Srinivasan, who joined the IIA group at a critical stage in 1985, took overall charge of the electrical system installation. The BARC team was also affected by migration, but the roles played by Messrs B. N. Karkera, B. M. Kundgolkar, R. S. Pithwa and S. S. Kane were major ones.

The complete control panels of the telescope were designed and fabricated at the BARC workshops, and installed in a special cabin on the observing floor. Banks of power supply modules were similarly designed and fabricated at BARC workshops and installed in the large telescope building. Elaborate cabling connecting different components and control elements were carried out; a total length of about 10 kms of cables had to be used for interconnections inside the building alone.

After the installation of the telescope mount and the primary mirror, extended tuning and adjustments of the control system had to be carried out. Along with the mechanical balancing for all movements, the gains and feedbacks in all servo loops were critically adjusted and set. Countless problems originating from vibrations, inadequate electrical shielding and component defects were sorted out by a team of scientists and engineers. The roles played by K. K. Scaria, R. Srinivasan, V. Chinnappan, and a large number of technicians from IIA during this period deserve special mention. Among them special praise must be made for the contributions made by F. Gabriel, A. Mani and K. S. Subramanian, who led important technical groups during execution of many difficult jobs. The team achieved smooth controlled operation of the telescope. R. Sivashanmugam, Officer-in-charge of the Kavalur Observatory, played an important role in the entire project for logistic help and liaison work.

(c) The on-line computer

Originally an on-line computer was envisaged in order to compute on-linear corrections to the telescope drive, but as the telescope work progressed, revolutionary changes in the detector technology came along. The new imaging detector, Charge Coupled Device (CCD) was proved to be extremely sensitive and capable of reaching much fainter magnitude with the same aperture sizes. It became imperative that the new telescope should be equipped with CCD detectors; but such arrangements demanded fairly powerful computers, so the original idea of having a PDP-11 type computer was modified and a VAX 11/780 computer system with several image processing peripherals was acquired. A. K. Pati and J. C. Bhattacharyya shouldered the responsibility of acquiring the VAX system through Computer Maintenance Corporation. The control computations could be done in the interrupt mode, and image processing operations would take the bulk of computer time. K. K. Ghosh who had past experience in the VAX system, was inducted in the system operations. Several image processing software packages were added to the system later. The on-line operations were started in 1988 by V. Chinnappan and R. Srinivasan.

8. The supporting facilities

Besides development of roads and ensuring adequate electric power supply at the site, several auxiliary facilities had to be provided for proper functioning of the telescope. These are described in the following sections:

(i) The air conditioning plant

The control electronics and the computer system needed controlled temperature and humidity for smooth operation; an elaborate air conditioning system had to be employed for this purpose. Actually the specification for operation of the VAX computer system was so rigid that a totally separate A/C plant was required to be set up. All heavy compressors for the plants were located at the ground floor level on separate foundations, lest the vibrations would disturb the piers and observing conditions. The generated heat in the two systems had to be dissipated far away from the telescope building, for which purpose separate cooling towers were installed connected by long underground pipes. The cooled air was delivered to the enclosures containing electronic systems through elaborate duct, and coolant carrying pipes were provided in the building. Total power requirement for air conditioning is about 30 KW for which separate electrical cables had to be laid from the power house.

(ii) The Cassegrain platform

For access to the Cassegrain focal plane from all orientations of the telescope, and for locating heavy focal plane instruments, a separate hydraulic platform system has been installed. This consists of three separate platforms which are sections of a 10 meter circle at the centre of the observing floor which can be individually raised or lowered through a range of 3 meters above the floor level. The load carrying capacity of individual platforms is, however, restricted to about 250 kg, requiring really heavy equipment to be located somewhere else on the floor; but this enables observers with moderately heavy equipment to do experiment close to the Cassegrain focal plane. The platforms can be operated from the main control console, as well as through a hand set switch on the platform itself; there are provisions for protecting the telescope mount by infrared proximity sensors against accidential hits with the platform.

(iii) The prime cage access ports

The prime focus of the telescope has been extensively used in observational programs; although most of the operations now are remote operated, earlier period saw observers climbing on to the prime cage. Even now for setting and making preliminary adjustments to the prime focus equipment, access to the prime cage is essential. For this purpose, three access stations have been located on the dome, which can be reached through ladders, and from there foldable cantilever bridges provide access to the prime cage. Use of both the telescope drive and dome rotation are essential for this operation. A ride on the prime cage from port to zenith to observe celestial objects is a privilege. After observing a few objects, the pilot-turned Prime Minister, late Rajiv Gandhi, complimented the engineers for the smooth operation of the telescope.

(iv) Material handling equipment

Many components of the large telescope are heavy, and cannot be handled without elaborate arrangements, Some of them, *e.g.* the mirrors, require periodic realuminization, necessitating them to be removed from the telescope and fitting them back. A ten-ton gantry crane had therefore to be fixed on the rotating dome for handling these components. However, for removing and refitting the primary mirror another elaborate lifting trolley with sets of hydraulic jacks had to be arranged. When fully loaded, this trolley weighs close to ten tonnes, which is too much as a point load for the observing floor, hence the operating procedure calls for laying a temporary rail track for the trolley.

(v) Aluminizing equipment

All mirrors in the telescope need periodic recoating, and for this purpose a giant aluminizing equipment had to be located on the ground floor of the telescope building. The internal dimensions of the vacuum chamber are such that the primary mirror along with the dolly can easily be accommodated. In fact, it can hold even slightly larger mirrors, up to 2.8 m in diameter. The chamber can be evacuated down to 10^{-6} mm of Hg, at which pressure the mean free path is of the order of the dimensions of the chamber. A set of aluminium vapour guns are located in an auxiliary frame in the chamber, which can be fired in any desired sequence. There are provisions for discharge cleaning of the surface to be aluminised. All control systems have been brought out to an external panel; surface monitoring can be done visually through some port windows in the chamber.

The plant has been designed by the Technical Physics Division of the BARC, Bombay and fabricated by the Indo-Burma Petroleum Co. Ltd. D. V. Deshpande, S. R. Gowariker and A. S. Raja Rao of the division were deeply involved in the design and fabrication of the equipment with Saxena and his team in IIA complementing during the commissioning phase.

(vi) Hydraulic bearing support system

The main bearings of the telescope are of the hydraulic pad type, where a thinfilm of hydraulic fluid carries all the load of the telescope mount. As part of the bearing surface is exposed to the atmosphere, extreme care is needed to keep the bearing fluid clean and under pressure; this is achieved by a filtering and pumping system located in the floor below. Smooth operation of this equipment is essential for proper functioning of the telescope. One of the safety interlocks in the drive system is controlled by a monitor watching the oil pressure; too low a pressure automatically shuts off the system.

The hydraulic pads were manufactured by FAG Precision Bearings Ltd fitting the profile of the horse shoe bearing surface. For this purpose an additional section of the toroid was attached in the gap of the horse shoe so that the entire circular bearing surface could be generated and finished in one setting at the WIL works. The additional piece was detached after this operation and sent to FAG in Germany for figuring the pad surface. It was shipped direct to WIL works, where it was installed by the FAG engineers. Subsequent dismantling and setting up at Kavalur was, however, done by the WIL engineers.

(vii) Voltage and frequency control system

The operation of the VAX computer system demanded not only a strict control of the power supply voltage, but also the frequency, which could not be obtained from the mains supply. The functioning of the disc memory drive would be seriously hampered by the fluctuations in supply frequency, and in case of sudden surge/stoppage of supply, the disc pack would crash, resulting in a total break down. To avoid such eventualities, a controlled motor-generator system has been installed to supply the power for running the computer. The output voltage and frequency are being monitored by precision sensors, and suitable feed backs control both these parameters. The system was originally designed and supplied by a local electrical equipment manufacturing firm, but needed extensive modifications by IIA's electronics laboratory engineers.

The entire telescope facility required a peak power load of 200 KW, and a separate high tension connection to the observatory had to be obtained. A bank of standby diesel generating sets providing full back up has also been installed. The main supply has been routed through a bank of servo-controlled stabilizers to protect the installation from large fluctuations of the supply voltage.

9. The final installation and first light

Completion of all fabrication activities converged around the middle of 1985. The mechanical mount was installed; the control system was tested with a dummy primary mirror; the last figuring operation on the primary mirror was carried out in May 1985. In July, the mirror was packed with extreme care and transported to Kavalur, accompanied by escort vehicles. It received the final cleaning and was loaded into the aluminising chamber. The test aluminising was conducted, and after the operation was successful, the final coating was given on July 26, 1985. Pending finalisation of the arrangements for mirror loading, the finished primary was stored in the chamber under partial vacuum.

It is instructive to give a brief account of the primary mirror installation. The telescope mount was first positioned with the tube pointing to the zenith and locked in this position. Special props and supports provided along with the mount were fixed so that when heavy components are detached, the unbalanced mechanical system does not crash and get damaged. The rail track was then laid on the observing floor to enable the mirror loading trolley to be positioned directly beneath the mirror cell. The trolley, which was stored in the ground floor, was then brought up by using the ten ton gantry crane fitted to the dome, placed on the track, and wheeled to the bottom of the telescope. The hydraulic jacks on the trolley were then raised to take the load of the mirror cell with the primary mirror. The bolts holding the mirror cell to the tube were then removed and jacks slowly lowered. The trolley could then be moved away from beneath the telescope, where the crane could pick up the mirror and transfer into the mirror transfer ring. This could not be done without further raising the 4-ton mirror from the support pads; and for this purpose a manually operated screw jack pad system had been provided in the mirror trolley. In the raised position the carrying ring could be slipped around the mirror and gripped from the side by screwing in a series of grip pads. Thus secured, the dummy mirror could be lifted and lowered on a trolley in the ground floor, from where it was whisked away to a platform outside the building to serve as an exhibit for visitors.

The aluminising chamber was then opened and the lid with the mirror attached was wheeled on the track beneath the ring hanging from the dome crane. The ring was then slipped round the mirror and the side gripping pads were tightened. The ring was next raised to the observing floor and the mirror was lowered on to the empty cell lying on the mirror trolley. The trolley was then moved to the bottom of the telescope and the mirror cell was raised by the hydraulic jacks to fit into the telescope tube; and then bolts were tightened as before. The reverse sequence of operations of removing the mirror trolley, the temporary tracks on the observing floor and the telescope props and locks completed the operations.

It should be kept in mind that every time the mirror was required to be aluminised, the entire sequence of operations had to be followed. Without these facilities, it would have been impossible to install and maintain the telescope.

The entire sequence of these operations was carried out by a young team of engineers and technicians led by Saxena. It is difficult to convey any idea of the delicateness and intricacies involved in the operation; any slight mishap in the lifting tackle could have resulted in scratches, or even total loss of the mirror necessitating a few years of rework. All participants of the project team anxiously watched the operations with baited breath.

It was planned right from the beginning that the telescope operations should be introduced in phases. In the first phase, only the prime focus would be made operational with a camera and a photometer, which were to be specially designed and fabricated. For obtaining a respectable field, a three-element Wynne corrector system was designed and constructed, which gave a coma free field of about 20 arc minutes. The telescope was finally ready for 'first light' on the night of October 31. Jayarajan, who had spent last five years in producing and perfecting the primary mirror, was chosen for the first peep through the telescope. He was also expected to satisfy himself that supporting pads for the mirror were adequate, which would ensure the quality of the surface. This, he was happy to certify.

The first photography through the telescope was taken by Bhattacharyya on the night of November 2, 1985. The Pleiades cluster was snapped in a couple of seconds; although the brighter members were over exposed, the fainter ones in the field proved the excellent quality of the primary mirror.

On January 6, 1986, in a simple ceremony, late Rajiv Gandhi, the then Prime Minister of India, christened the newly commissioned telescope as Vainu Bappu Telescope, in memory of the person who was instrumental for its creation. The entire Kavalur observatory was also renamed after its founder; it is now known as the 'Vainu Bappu Observatory' (figures 4 and 5). A few months later, the council dedicated this telescope as National Facility.

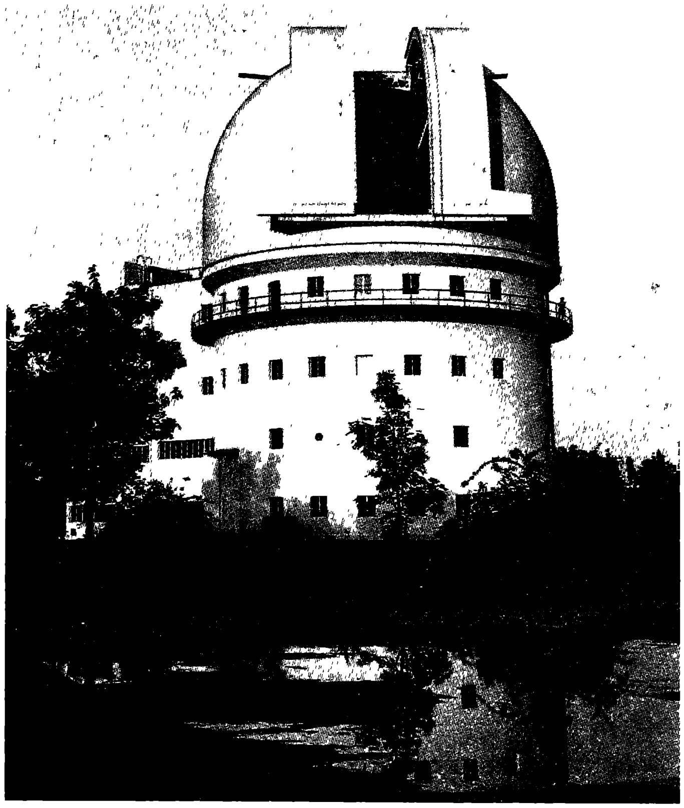

Figure 4. Vainu Bappu Telescope building with dome.

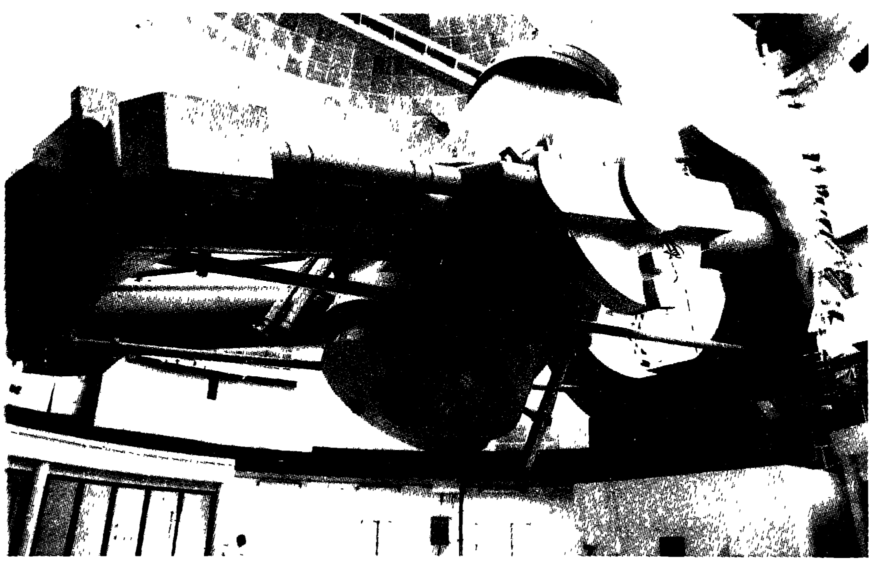

Figure 5. Vainu Bappu Telescope.

10. Later developments

The first few months' observations consisted of photographing faint galactic and extragalactic objects with the prime focus camera by K. K. Scaria (figure 6). During this period, occasional malfunctioning of the drive system was encountered. The defects, which were due to a variety of causes, were traced and appropriate corrective actions taken by R. Srinivasan and his team[12].

The CCD camera was first introduced at the prime focus in 1986; later in February 1987, a group of scientists from TIFR used their CCD system for study of faint extra galactic objects[13]. In 1988, a regular CCD camera started operating at the prime focus, and images could be monitored on the TV screen in the control console.

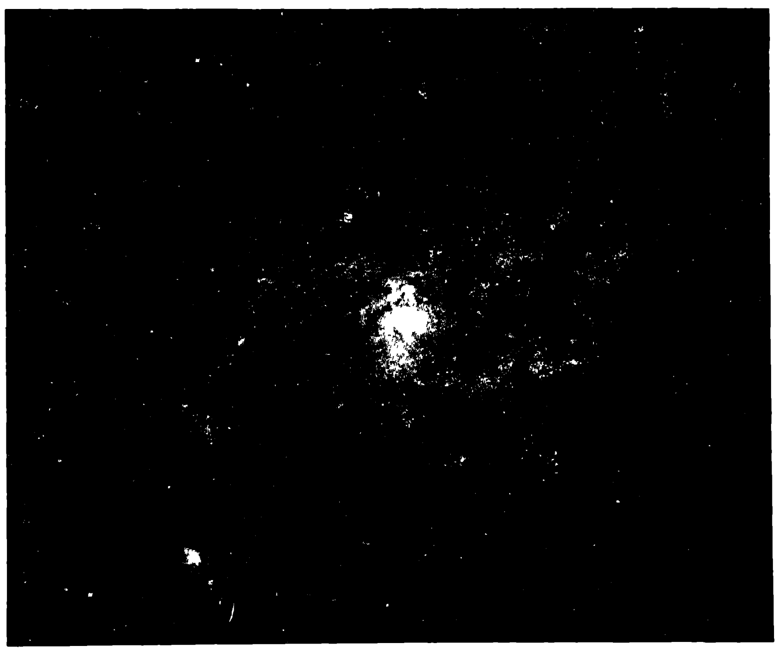

Figure 6. M 33 photographed through the Vainu Bappu Telescope.

The next phase of operation of the telescope in the Cassegrain mode was somewhat delayed following an accident during the installation of the prime focus. Due to failure of a lifting tackle, the Cassegrain and Coude secondary, while being removed, crashed on the observing floor and was extensively damaged. A careful review of the situation was conducted, and it was decided to remake this with a modified design. B. Mallikanadh, who was responsible for the design of the mount, was entrusted with this task. He had left the TCE after completion of the project and was doing independent consultancy work. A new cage was fabricated by M/s Vani Machine Tools, Hyderabad, based on his modified design. The cage was thoroughly tested at the IIA laboratories in Bangalore, where extensive electrical control elements were incorporated. The secondary optics were already completed, and the final installation and adjustment of Cassegrain system were carried out on the telescope at Kavalur. The roles played by R. Srinivasan, B. R. Madhava Rao and A. K. Saxena, the respective heads of the electronics, mechanical and optical laboratories of the Institute in this operation revealed a high degree of competence and confidence gained in making the large telescope.

The installation of the Cassegrain focus was complēted in November 1989[14] and a modified Boller & Chivens Spectrograph obtained from the Anglo-Australian Observatory was installed. The figure and mounting of the Cassegrain secondary was of the expected standard and seeing-limited images could be easily obtained. By using the CCD equipment, it became possible to scan the images. Figure 7 shows such a scan on the binary Gamma Leonis with two components separated by 4".3. Some modifications are still needed for optimal performance of the spectrograph at the Cassegrain focus, which are being attended to.

Meanwhile, several steps leading to fully automatic guiding of the telescope were taken; an intensifier-CCD camera system was acquired, and installed in an off-set arrangement at the Cassegrain focus. For prime focus photometer operation, an optical arrangement for guiding on the field through a CCD camera was developed [15]. In order to determine mechanical corrections of the telescope pointing, coordinates of several bright stars all over the sky were determined and indications on the console compared. This information was stored in the computer memory, and used for pointing the telescope blindly to any desired spot[16].

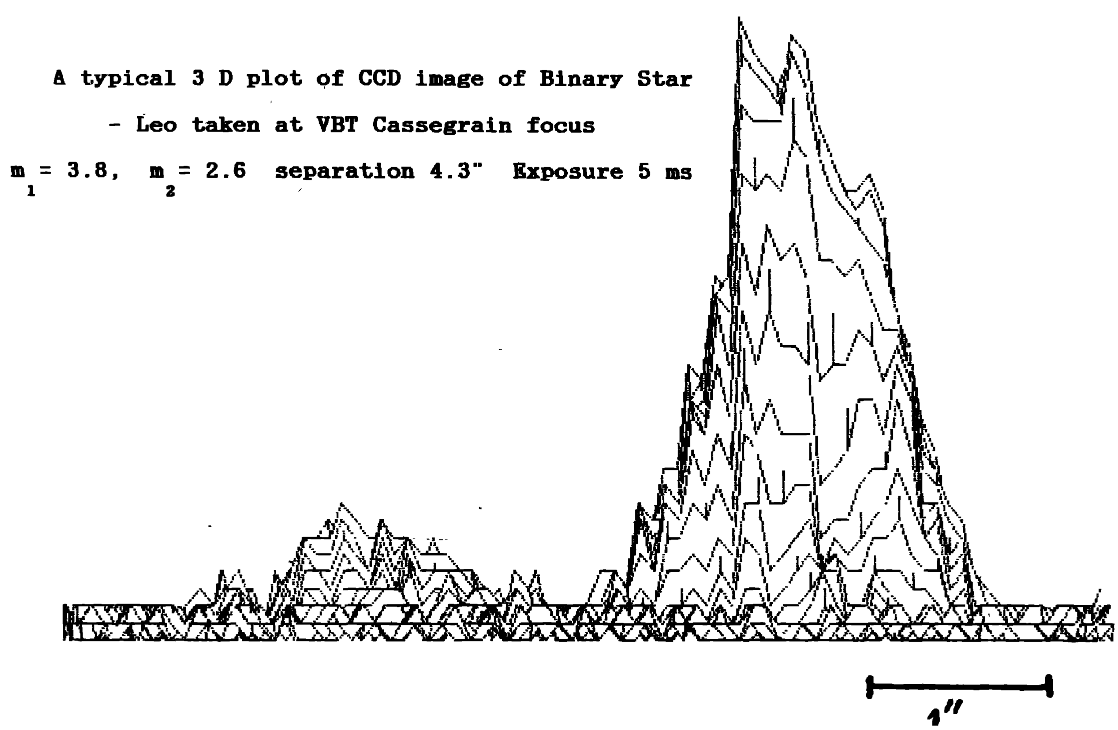

Figure 7. 3-D plot of CCD image of Gamma Leonis.

Vital statistics of the telescope

The idea for acquiring a large optical telescope had been in the minds of scientists about twenty five years before Bappu took the plunge in the early seventies; at least ten years of preparatory work had gone into this effort. For getting the green signal from the financial angle, another five years had passed. November 1976 can be taken as the beginning of the project, when the concept report by TCE received the approval of the Institute's Council. Two major activities were taken up in late 1979 and executed almost simultaneously during mid 1985 : the fabrication of the mechanical mount and the actual time for fabrication and installation was thus about six years.

The funds received for the project were a part of a research scheme of the IIA's five year plans. The expenses for personnel and equipment for pure observational and theoretical research work were met from this scheme. Barring these items of work, the total expenditure incurred for the entire observational facility, including buildings, VAX computer system, auxiliary equipment etc. was around Rupees six crores. It is difficult to estimate the cost of such a system, if imported; it would have been certainly higher than this figure. Besides, what we would have totally missed is the development of a modern scientific instrument making capability in the country which has been used in several national projects of scientific research since then. Further, this activity have created enough confidence in the minds of the Indian astronomers to plan building much bigger telescopes.

The Vainu Bappu Telescope (VBT) is the largest optical telescope at present in Asia; in the Asia-Pacific region, except for the Anglo-Australian Telescope at Siding Springs, Australia, and a bank of super large reflectors on Mauna Kea, Hawaii, no other observatory in this region has optical telescopes of this size. Table 1 summarizes the details of these telescopes installed as of 1989 in different observatories all over the world.

An explanatory note regarding the size of the telescope aperture appears necessary here as in different contexts apparently inconsistent figures have been quoted. The zerodur blank obtained from Schott's Glaswerk was 2360 mm dia, but it had a bevelled edge on the front side, reducing the available surface for mirror generation. Initially it was estimated that an aperture of 2340 mm will be available. This was the size estimated for the primary aperture during the execution of the entire project. When the mirror was completed and installed the clear aperture size was accurately measured and found to be 2322 mm. In common parlance, this is known as the 90 inch telescope which is now replaced by the abbreviation VBT.

In this project originally, a provision was made for an f/43.25 Coude focus; in the figure showing the optical layout, it may be seen that this calls for six reflections, and all necessary components were fabricated. Subsequently, the development of optical fibres rendered such elaborate schemes redundant; one can divert the star-light from the prime focal plane to a stationary large spectrograph through bundles of optical fibres with much less attenuation than what could be obtained after multiple reflections. Accordingly experiments are being conducted to rig up such devices at the optical laboratory in Bangalore, while installation of the Coude focus has been kept in abeyance.

Table 1. Large optical telescopes all over the world (as of 1989 December)

Telescopes/Institution	Location	Dimeter (m)	(in)	Date completed	Composition of mirror
Soviet Special Astrophysical Obs.: BTA (Large Altazimuth Tel.)	Caucasus, U.S.S.R.	6.0	236	1976	Pyrex
Palomar Obs. : Hale Telescope	Palomar Mtn., California	5.0	200	1948	Pyrex
Whipple Obs.: Multiple Mirror Tel.	Mt. Hopkins, Arizona	4.6	176	1949	Fused Silica
Roque do los Muchachos Obs.: Herschel Tel. (U.K.)	Canary Islands, Spain	4.2	165	(1986)	Cer-Vit
Cerro Tololo Inter-American Obs.	Cerro Tololo, Chile	4.0	156	1975	Cer-Vit
Anglo-Australian Telescope (AAT)	Siding Spring, Australia	3.9	153	1975	Cer-Vit
Kitt Peak National Obs.: Mayall Refl.	Kitt Peak, Arizona	3.8	150	1974	Fused Quartz
United Kingdom Infrared Tel. (UKIRT)	Mauna Kea, Hawaii	3.8	150	1979	Cer-Vit
European Southern Observatory (ESO)	La Silla, Chile	3.6	142	1976	Fused Silica
Canada-France-Hawaii Tel. (CFHT)	Mauna Kea, Hawaii	3.6	140	1979	Cer-Vit
German-Spanish Astronomical Center	Calar Alto, Spain	3.5	138	(1983)	Zerodur
NASA Infrared Telescope Facility (IRTF)	Mauna Kea, Hawaii	3.0	120	1979	Cer-Vit
Lick Observatory : Shane Telescope	Mt. Hamilton, California	3 0	120	1959	Pyrex
McDonald Observatory	Mt. Locke, Texas	2.7	107	1968	Fused Silica
Crimean Astrophysical Obs.: Shajn Tel	Crimea, U.S.S.R.	2.6	102	1976	Pyrex
Byurakan Observatory	Armenia, U.S.S.R.	2.6	102	1976	Pyrex
Las Campanas Obs.: Irene du Pont Tel.	Cerro Las Companas, Chile	2.5	101	1977	Fused Silica
Roque de los Muchachos Obs.: Issac Newton Telescope	Canary Islands, Spain	2.5	101	1982	Zerodur
Mt. Wilson Obs.: Hooker Tel.	Mt. Wilson, California	2.5	100	1917	Plate glass
Space Telescope (ST)	Earth Orbit	2.4	94	(1985)	U.L.E. Honeycomb
Wyoming Infrared Obs.	Jelm Mtn., Wyoming	2.3	92	1977	Cer-Vit
Vainu Bappu Telescope	Kavalur, India	2.3	92	1985	Zerodur
Steward Obs.	Kitt Peak, Arizona	2.3	90	1969	Fused Quartz
Mt. Stromlo and Siding Spring Obs	Siding Spring, Australia	2.2	88	(1983)	Cer-Vit
University of Hawaii	Mauna Kea, Hawaii	2 2	88	1970	Fused Silica
German-Spanish Astronomical Center	Calar Alto, Spain	2.2	88	1979	Zerodur

12. A critical review

A large telescope as visualised more than forty years ago by the Indian scientists has become a reality during the last decade. Several refinements are still being attempted, which is a feature of all active telescopes, and will continue as long as the observational groups demand. Still a time has come for looking back to what has been achieved and where we have failed, so that we do not repeat the same mistakes in future.

Let us look at the positive side first. The surface of the primary mirror is of excellent quality; we have compared this with the characteristics of the Zeiss one meter mirror and found that the VBT mirror has a better figure. This is amply illustrated by the interferograms and computations thereof which indicate that 70% of the energy is concentrated in the image plane within radius of 0.3 arc sec and 80% within 0.6 arc sec. On some clear still moments at the VBT, star images of 1 arc sec could be obtained. This certainly testifies the capabilities of the Institute in fabricating the large mirrors with finesse and also speaks high of the man — Vainu Bappu — who had tremendous confidence in the indigenous mirror fabrication.

The movements of the telescope mount are very smooth and almost silent. This could be possible because of excellent design, choice of bearings, and fabrication of various delicate components, paricularly the horse-shoe surface. This feature extends promise towards achieving a perfect tracking and pointing system when fully automated soon. The present blind pointing accuracy is about 10 arc seconds which is sufficient for most of the applications, but, for experiments involving objects beyond normal limits of detection, a better performance is desirable. These qualities helped the performance of the telescope. This was demonstrated to the Research Advisory Committee for Instrumentation during its visit to Kavalur in March 1989 when a 23rd magnitude object could be detected at the prime focus CCD by a 15 min exposure.

As against these positive qualities, we have several features which should have been considered more carefully. The location of so many power dissipating components in the building has resulted in warm updraughts and spoilt the seeing quality. In the adjoining 40 inch telescope building 'seeing' better than 0".7 arc sec was often observed, whereas the avarage 'seeing' in the VBT was about 1".5. Vigorous attempts to improve the situation are on; but the lesson we have learnt is that, for future projects, the heat producing components should be located as far away from the telescope as possible.

The dome is too large and massive for the size of the telescope, making it impossible to move faster without generating annoying vibrations. In fact, this being the first major telescope project, the designers appear to have been a bit too cautious and over-designed some components. Also, for the size of the telescope aperture, the mount is too massive which with proper foresight could bave been optimised for better performance and cost.

Criticism regarding the choice of Kavalur as the location of the telescope has been voiced by a few, as the number of cloud-free nights are limited. It is however not realised that this aspect had been carefully considered before deciding on this location; Kavalur has many advantages over other sites in India and this telescope was located with a view to investigate specific problems in present day astrophysics[17].

The question of creating a much larger facility in India is presently engaging the attention of astronomers. The emphasis there is on locating the new telescope at the best available site in the country ensuring performance to the highest possible level. It is hoped that the experiences gained in creating the VBT facility by various groups would help our new efforts in successfully achieving the proposed objective.

13. Epilogue

A project of this magnitude and complexity involving latest developments in scientific instrumentation cannot be expected to be successfully achieved without unstinted help and

support of many scientists and organizations. We have named some of them during our description of the project; besides them, several names deserve mention in this chronicle.

All members of the IIA's Governing Council were intimately involved. It will be superfluous to mention the role of Prof. M. G. K. Menon, Chairman of the Governing Council since beginning, and his keen interest and help to the project. It is perhaps difficult to imagine the financial crunch the IIA and the PMB had to face in the late seventies and early eighties. The extra requirement had often to be met from by delaying other developmental projects of IIA, and funds, thus, saved were utilised for essential expenses of the telescope facility. But both the Governing Council and the parent departments (earlier the Ministry of Tourism and Civil Aviation and later the Department of Science & Technology) had always tried to help the project, by agreeing to the adjustments proposed by the PMB, and sanctioning additional funds as far as possible. But for their coopration, the telescope would have definitely been delayed with consequent rise in the cost. Prof. S. Ramaseshan and Prof. G. Swarup, both member of the IIA Governing Council during the first two terms, made several contributions and helped in the formation of the Project Management Board. After the passing away of Vainu Bappu, Dr N. A. Narasimham evinced keen interest in the project and in this connection he made several trips to Walchandnager, Banglore and Kavalur. Dr R. Ramanna, Director, BARC, who was also incidentally a member of the IIA's Council during early seventies, gave his unstinted support when the help of his organization was sought. Dr P. Dastidar, Director of Reactor Group, had always given priority to the requirement of the project over many other jobs in BARC; several other scientists from his organization *e.g.* M/s Mahendru, Natarajan spent their time towards attaining the objectives of the project.

Prof. S. Dhawan, Chairman of the Space Commission and the Chief Engineers of the Civil Engineering Division of the Department of Space *viz.* Mr Satyanarayana and later Mr R. D. John and their colleagues rendered invaluable help in executing various parts of the project. Dr M. R. Srinivasan, Head of the PPED/DAE and Dr S. R. Valluri, Director, National Aeronautical Laboratory came to the Institute's help several times by giving suitable advice in technical and on procedural matters.

The TCE team involved in the project consisting of M/s D. P. Panchal, B. Mallikanadh, J. D. Krupakar and A. M. Dubashi had spent their utmost effort in making the project a spectacular success. Prof. Ramesh of IIT, Bombay and Dr A. R. Acharya of VSSC, Thiruvananthapuram rendered valuable help in the dynamical analysis of the mount and servo loop problems. Special thanks were due to Dr W. C. Livingston of Kitt Peak National Observatory, Tucson, USA, who arranged for the visit of the optics expert, Mr Don Loomis, and responded to many other requests during the telescope fabrication. The two top bosses of the WIL, M/s Vinod Doshi and Chakor Doshi displayed more enthusiasm beyond their business interests during the fabrication of the mount and installation of the telescope. All these factors were of vital importance in our pioneer endeavours of building the first large optical telescope in India. The entire project team and a good section of the IIA personnel played a big role in this project.

Acknowledgement

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