JHA, xiii (1982)

THE ISAAC NEWTON TELESCOPE

F. GRAHAM SMITH, Nuffield Radio Astronomy Laboratories, and
J. DUDLEY, Royal Greenwich Observatory

The Isaac Newton Telescope (INT) was in operation at the Royal Greenwich Observatory, Herstmonceux, from 1967 to 1979, when it was dismantled and refurbished for operation at the Roque de los Muchachos Observatory on La Palma, Canary Islands. The first conception, in 1946, expressed the determination of British astronomers to retain a leading position in observational astronomy, a position which they had progressively lost over the previous half century. There was enthusiastic support for the concept, and funds were made available almost immediately. Unfortunately, for various reasons, the design and building of the telescope were painfully slow processes, occupying twenty-one years. There can be no serious doubt that the telescope, during the twelve years of its operation at Herstmonceux, did indeed act as a centre for the revival of astrophysical research in the UK; it is, however, arguable that there were comparatively few scientific successes directly attributable to the telescope. This paper attempts to place the INT and its scientific work in the context of the development of observational astronomy in the UK.

The voluminous correspondence between the main promoters of the project over the twenty-one years reveals a story with considerable interest to present-day organisers of comparable projects; in particular it shows many sharp contrasts with the history of the La Palma project, which includes the design and building of two new optical telescopes as well as the improvement and removal of the INT to the very much better site. An understanding of this contrast comes from the evident differences between the states of British astronomy at the two epochs: it will be a recurrent theme in this short history that the designers were severely handicapped by the very condition that the telescope itself eventually helped to cure, namely the almost total lack of an essential team comprising both experienced observers and telescope designers.

British Astronomy before 1946

The historical foundation of British observational astronomy rests primarily on two telescope builders: Herschel and Rosse. Of these the more successful in terms of observational results was Sir William Herschel (1738–1822): he discovered the planet Uranus in March 1781, and conducted a masterly survey of the heavens with his "twenty-foot" telescope (the mirror, made of speculum metal, was 18 inches in diameter). The third Earl of Rosse in 1845 constructed a mirror 6ft in diameter, and his telescope revealed the spiral structure of some of the nebulae. These two men were each able to devote their genius and their energy single-mindedly to the creation of an instrument which they themselves were to use for their own clearly foreseen purposes. They were determined and resourceful men.

The initiative in large telescopes passed to the USA with the opening of the 60-inch on Mount Wilson in 1908. Observing conditions there are vastly superior

0021-8286/82/1301-0001 $2·00

to those anywhere in Britain, both in respect of atmospheric transparency and "good seeing", *i.e.* comparative freedom from atmospheric diffraction. The 100-inch on Mount Wilson and later the 200-inch and the 48-inch Schmidt on Palomar Mountain sealed the American supremacy. In Britain only the Radcliffe Observatory, whose valuable Oxford site was vacated in 1935, was financially able to plan a new large telescope, the 74-inch; this came into operation in Pretoria as late as 1948 only because the war years intervened.

During these years of observational doldrums the Royal Observatory at Greenwich was controlled by the Admiralty, through a Board of Visitors; its main tasks were concerned with navigation, positional astronomy, and solar and magnetic observations. There was little connection with any university research, and the astrophysical research which developed notably under Woolley was not required by the Admiralty, although it was not actually discouraged. The Admiralty is said to have classed the Transit Circle among the "useful telescopes", while the Yapp 36-inch equatorial which was equipped for spectrographic observations was classed among the "others". It was, after all, the purpose of the Observatory to serve and improve navigation, not to engage in astrophysics. The move to Herstmonceux in the post-war years did, however, offer possibilities of improved observing conditions: the choice of Herstmonceux as a good site was made on general meteorological grounds and especially on the basis of total sunshine hours, which usually gives an indication also of the available hours for night observations.

Post-war Research

In 1943, when the end of the war could first be dimly perceived, Professor P. M. S. Blackett and Sir Ralph Fowler wrote to the Council of the Royal Society pointing out the need to encourage and organise scientific research in the post-war years. The Royal Society responded by commissioning reports on various sciences, emphasising the need to encourage fundamental research in contrast to the applied research which was expected to grow naturally out of the wartime scientific effort. These reports were published in 1944; they did not include astronomy, but there was a note that a special committee had been set up to examine the needs of post-war astronomy. In fact this committee met first on 27 July 1945 and again on 1 June 1946; its members were H. Spencer Jones, P. M. S. Blackett, W. M. H. Greaves, E. M. Lindsay, H. H. Plaskett and F. J. M. Stratton.

The Royal Society Committee remarked that British astronomers were mainly using instruments dating from the 1880s, and recommended that telescopes should be provided both in Britain and in the Southern Hemisphere for the general use of all astronomers, both in the universities and in the two Royal Observatories. The telescopes were to be, in order of priority:

(i) a conventional large reflector, diameter 72 to 100 inches, suitable for spectroscopy, to be installed in Britain;

(ii) a wide-angle camera of the Schmidt type, to be installed in the Southern Hemisphere;

(iii) another Schmidt, to be installed in Britain.

These recommendations were adopted by the Council of the Royal Society on 13 June 1946. They seem in retrospect to have been appropriate and well-founded: more so than appear to have been the subsequent decisions of the Board of Management, to which this history will soon turn.

A separate initiative was taken at about the same time by Professor H. H. Plaskett, Director of the Oxford University Observatory, and Harold Spencer Jones, the Astronomer Royal. In letters dated 13 March 1945 (H.H.P. to H.S.J.)[1] and 19 March 1945 (H.S.J. to H.H.P.)[2] they discuss the desirability of an expression of post-war needs by the Council of the Royal Astronomical Society, reinforcing the initiative already taken by the Royal Society. The Council considered this on 14 June 1946 and the two Secretaries (W. H. McCrea and D. H. Sadler) submitted a memorandum to the Royal Society,[3] asking for assistance in obtaining Government funding. This memorandum again recommended the construction of a large telescope in Britain, but it was more equivocal about the design, introducing the possibility that the large telescope might itself be a Schmidt. Unfortunately the equivocation on this point was to continue for many years.

Plaskett was at this time President of the RAS, and he took the opportunity to deliver an Address to the Society on 8 February 1946 on the need for large telescopes.[4] This Address, and the chronology outlined above, make it clear that Plaskett was the originator of the scheme: indeed, he is referred to in later correspondence as "the Father of the Telescope". He argued cogently for a telescope of sufficient size to give a large scale on photographic plates, and reviewed the possibilities for wide-field telescopes. He advocated a Schmidt, with corrector plate 49 inches in diameter, using a 74-inch primary mirror. With a focal ratio f/4, the overall tube length would be 33 feet, and the field would be 7°.

Plaskett in his Address discusses how this telescope could be modified for use in spectroscopy. The difficulty is that the Schmidt design uses a glass corrector plate, a transmission element which has a smaller aperture than the primary mirror and which would absorb ultraviolet light. Without the plate, the spherical primary would produce very poorly focused images, almost an arc minute across: with it, light would be lost in the reduced aperture and spectroscopy could not extend to the important short wavelengths. A partial solution to the problem would be to use a corrector plate of the full 74-inch diameter. This and other proposals were to become the preoccupation of the designers for several years afterwards.

The Naming of the Telescope

The tercentenary of Isaac Newton's birth fell on 25 December 1942, and celebrations were postponed until after the war. The inspiration of naming the proposed telescope after the inventor of the reflecting telescope came from Sydney Chapman.[5] The proposal, which was included in the Royal Astronomical Society's Memorandum, was originally for the name to be applied to a complete observatory, including particularly a Schmidt telescope: there are many early references to the Isaac Newton Observatory rather than the Isaac Newton Telescope. The Council of the Royal Society on 13 June 1946[6] resolved to apply to the Treasury for funds for the Observatory, which was to be built at

Herstmonceux. The application would be for a large telescope, about 84 inches in diameter, with two Schmidt telescopes, one being for the Southern Hemisphere; the annual maintenance cost was estimated at £4000.

In July Sir Alfred Egerton, Secretary of the Royal Society, obtained a favourable response from the Treasury[7] and the President announced on 15 July that the Chancellor of the Exchequer had agreed in principle to provide the money necessary to build a 100-inch telescope. On 17 July Spencer Jones informed the Admiralty of the proposal to site the new Observatory at Herstmonceux.[8] The Treasury funds were to be provided in two halves, one direct and the other through the Admiralty, which would have financial control. The Astronomer Royal was to be in charge of the Observatory, which was to be made available to all British astronomers. A new Board of Management would be responsible for the design, construction and operation of the Observatory; this new Board would report to the Board of Visitors.[9]

Dual-purpose Telescope Designs

Plaskett's Presidential Address to the RAS, and an organised discussion at the RAS ordinary meeting on 14 July 1946,[10] revealed a demand for several different kinds of observations, which might not all be available on the same large telescope. Photography over a wide field, about 2° in diameter, was advocated particularly by Spencer Jones, for use in astrometry and photometry.[11] Spectrometry, on the other hand, only requires good images on axis: W. M. H. Greaves, Astronomer Royal for Scotland, was anxious that a wide-field design should not detract from spectrometry by reducing the effective telescope aperture or interposing corrector plates and lenses in the light path.[12] The early design work was aimed at resolving the difficulty by making the telescope a convertible dual-purpose instrument.

A very wide field of view is obtained in a Schmidt telescope, which uses a spherical primary and a corrector plate covering the whole aperture. The corrector is placed at the centre of curvature, twice as far from the primary as the focus, so that the telescope tube must be made unusually long. Furthermore, the useful aperture is smaller than the primary mirror itself. Without the corrector plate, the on-axis image would be spoiled by spherical aberration, which might, however, be removed by a specially figured secondary mirror. A different approach to the problem, by J. G. Baker in the USA,[13] involved a parabolic primary with a corrector plate near the focal plane which gave a shorter telescope but a smaller improvement in the field of view for direct photography. These were recognised to be only two examples of a series of systems which would give a wide field in one configuration and a near-perfect on-axis image in the other. The development of these designs offered a challenge which was eagerly taken up by the optics school of Bristol University.[14]

One of the recommendations of the Royal Society was that a new Institute of Applied Optics should be set up at Bristol, both for the design and the manufacture of advanced optical systems.[15] This idea was not taken up by the University, which wanted neither to embark on the commercial production of a long series of telescopes nor to equip a unit for producing only one, with no guarantee of other commissions to follow. Advice on design was nevertheless freely given, originally by C. R. Burch, and soon afterwards by E. H. Linfoot, who also recruited the help of C. G. Wynne, at that time employed by Wray (Optics) Ltd. This was Wynne's introduction to astronomical optics, a subject to which he has made many notable contributions, including prime focus corrector lenses and a design for a 1-metre dual purpose telescope for La Palma.[16] Out of the many design suggestions made by these three consultants emerged a Schmidt, with spherical primary focal ratio f/3·8, convertible to on-axis use by removing the corrector plate and using a Gregorian secondary mirror figured to correct for the spherical aberration of the primary. The Schmidt field of view would be 2°, and the effective aperture would be 90 inches. The field in the spectroscopic mode would, however, be only about 10 arc seconds, and the alignment of the secondary mirror needed to be very precise. This scheme, involving a telescope tube more than 50 feet long, formed the basis for all design work for the next eight years: its abandonment in 1955 in favour of a conventional paraboloid Cassegrain telescope was a crucial point in the history of the telescope.

The Design Developed

In contrast with the design procedure for most optical telescopes, such as the recent work for La Palma, it must be realised that the British astronomers who were involved had little experience to draw upon, and were at the same time ambitious to regain a front-line position by building a very large telescope of novel design. The same enthusiasm which had produced the funds for a 100-inch rather than a 72-inch telescope was now deployed in exploring ingenious schemes for overcoming the difficulties of the dual purpose design. The unfortunate result was a dissipation of scarce effort, and a series of delays that frustrated the original determination of Plaskett and Spencer Jones to have the telescope built and operating as quickly as possible.

The Board of Management first met on 23 July 1947.[17] It consisted of the Directors of the Oxford University Observatory (Plaskett) and the Cambridge Solar Physics Observatory (Stratton), and four representatives each of the Royal Society and the Royal Astronomical Society. From the start it appears that Spencer Jones was expected to act, in modern terminology, as Project Scientist and as Project Manager. He was also Chairman of the Board. Separate sub-committees were appointed at the first meeting to study servo control and automatic guiding: later committees were charged with optical design for the telescope and for spectrographs, while yet another committee dealt with mechanical design. The seeds of trouble had been planted; the harvest was reaped in 1955, when Blackett, on rejoining the Board after some years, remarked "I find a complete impasse of judgement among astronomers".[18]

The crucial issue of the dual-purpose design was, however, faced squarely in the first three Board meetings. At the third, on 12 December 1947, Blackett referred to the original Royal Society recommendation for separate 100-inch and Schmidt telescopes, and both Greaves and R. O. Redman were opposed to the dual-purpose design.[19] It was judged, nevertheless, that the chances of obtaining separate funds for a smaller Schmidt were too slim, and it was agreed to adopt the dual-purpose design. The main design difficulty was seen as mechanical: the Gregorian secondary had to be kept in position very accurately at all attitudes of the telescope tube. Some means of compensating for gravitational deflection was needed; the Board decided, following a suggestion by Blackett, to consult Barnes Wallis, already famous for his unconventional design work on aircraft frames.

Barnes Wallis was asked to propose a means of stiffening a telescope tube 50 feet long so that it would deflect less than five-thousandths of an inch between vertical and horizontal attitudes. He at once showed that this could only be achieved by some form of compensation, and proposed a thermal control in which heated or cooled fluids were circulated through tubular elements of the structure. His report[20] was circulated to members of the Board who did not react decisively. It was also seen by Burch, who wrote to Spencer Jones in February 1948:[21]

> I have read Mr. Wallis' report with interest and admiration. and I am bound to admit the thermal compensation scheme ought to work. But I find myself coming more and more to the conclusion that the sensible thing is to drop the idea of the 100″ Schmidt-Cassegrain with spheric primary and aspheric secondary for spectroscopy: to cater for the spectroscopy with a straight 100″ Cassegrain, either paraboloid-hyperboloid or Ritchey–Chrétien, and press for a 40″ (say) Schmidt-Cass on its own merits.
>
> The combined system I agree could probably be made to work. But not by a Committee! What it needs is a fanatic, burning with the desire to devote if need be ten solid years to it, and nothing but it. Produce the fanatic, and I'll reconsider my conclusion.

A later version of the compensation proposal depended on pressurised oil within hollow structural members. The inspiration for this may have come from Sir John Carroll who proposed to Spencer Jones (8 April 1948)[22] that hydraulic jacks would be better than the thermal system. Wallis later supervised a study of flexure control for the INT in the Department of Civil Engineering of Birmingham University, under Professor Redshaw.[23]

Progress was therefore placed in the hands of consultants and committees. Nothing was lost by this, as the availability of glass for the mirror and corrector plate was not yet established. The optical design was in fact decided on at the fifth meeting, on 27 June 1949,[24] on the assumption that the mechanical design difficulties could be solved. This was a rash assumption: the flexure problem, and indeed the whole mounting design, remained unsolved up to 1955.

The Mirror and the Corrector Plate

Although the capability of producing suitable glass disks for the mirror existed only in USA, it was naturally felt desirable to encourage British manufacturers to develop the necessary techniques. A possibility of export orders provided some encouragement: Australia, Egypt and India all wanted large telescopes, and the widespread war-time destruction of observatories in USSR seemed to offer another market.[25] The Soviet Academy of Sciences were in fact planning to place a contract for a 74-inch telescope with Grubb Parsons; they contemplated following the INT design and increasing the diameter to 100 inches.[26]

With this encouragement the Pilkington glass works started work on new annealing tanks, intended for large disks of borosilicate glass. They eventually produced a series of 72-inch disks, which were used successfully in telescopes in Egypt and Australia. But before they reached the full size for the INT a suitable disk became available from the USA as an outright gift, and the Pilkington development came to a halt.

In 1936 the Corning glass works cast a 98-inch disk as a trial for the 200-inch mirror subsequently used for the Hale Telescope on Palomar Mountain. At this time the McMath Observatory in Michigan was planning to build a large telescope, and the disk was purchased for this by the McGregor Trust, an independent foundation led by Judge Hulbert. The telescope was never built, because of financial difficulties, and the disk lay unused in Michigan.

The first indication that this mirror blank might be available came through a visit by Dr A. M. Uttley, of the Telecommunications Research Establishment in Great Malvern. During a visit to USA in 1948 he had been asked by the Board to look at telescope control systems and autoguiders, on which he was an expert.[27] He had in fact installed a prototype electronic autoguider on a 13-inch astrographic telescope at Greenwich as part of his research on radar systems. While he was at Michigan, the Director, Dr Leo Goldberg, showed him the disk and indicated that it could be bought very cheaply for the INT.[28] Uttley recalls that the cost would have been about £5000.[29] It was clearly not on the open market, and the offer was a generous gesture of goodwill. Discussions between Goldberg and Spencer Jones at the IAU General Assembly in Zurich over the difficulty of finding even a comparatively small sum in foreign currency led to an offer from Judge Hulbert of the outright gift of the disk.[30] It was shipped on the SS *Maidan*, and arrived in Britain on 5 August 1949.

There were many anxious moments in the grinding and polishing of the primary mirror. Borosilicate glass was used because of its comparatively low thermal expansion coefficient, but it is difficult to pour in large uniform pieces. When Grubb Parsons ground off the two faces, allowing a look inside, the disk was seen to contain extensive striae, surrounded by systems of small cracks. Corning Glass, and J. A. Anderson who supervised the work on the 200-inch mirror, gave the reassuring advice that their glass had similar defects which had nevertheless not prejudiced the success of the mirror. The grinding of the hollow face of the 98-inch mirror began. Linfoot reported that the system of cracks had "the glittering appearance of a crystallised icthyosaurus preserved in aspic".[31] As the stresses close to the striae were relieved by grinding, so the cracks spread, and work was stopped in May 1951 for further consultations with the American opticians. A badly cracked piece of the same glass, dating from 1936, and optically worked for tests in the Mount Wilson Observatory, was re-examined and found not to have changed with the passage of time. It seemed that if fracture could be avoided during figuring, it was unlikely to occur later. A cautious re-start was authorised, and the spherical surface was figured successfully in 1954.

The supply of the corrector plate was also beset with uncertainties. Detailed optical designs vacillated between a full-size plate 98 inches in diameter, which could be left in place for most spectrographic work, and a more economical 80-inch plate which would be removable. The thickness would ideally be about 2 inches. Two suppliers were known: Schott-Genoschen in Germany offered plates in UBK7, a glass transmitting ultraviolet light, but without sufficiently close specification on uniformity of refractive index, which is vitally important in a large transmission element. At the same time Pilkington Glass offered a sheet of "stirred white plate", which promised to be more uniform but was only 1-inch thick.[32] On 30 March 1951 the Board agreed to order the plate from Schott.[33] The Admiralty demurred over the question of foreign exchange, and despite a reiteration by the Board on 15 December 1954, this time with financial approval from the Admiralty and the Treasury, the Schott order seems never to have been placed. At the same meeting the Board decided to buy the Pilkington plate also, as an insurance. This plate was delivered, but never worked optically as a Schmidt corrector. It is now a museum piece at the RGO.

The 1955 Crisis

Among Redman's notes of Board meetings there is a manuscript remark "This telescope will never get built by a large Board".[34] We have already noted the absence of a proper project management, and the heavy reliance on the personal work of Spencer Jones. Between 1951 and 1954 very little was achieved, apart from the figuring of the mirror. Spencer Jones himself was occupied with the building for the Equatorial Group of telescopes at Herstmonceux, and there was no one to supervise the committee work and the designers at Grubb Parsons.

In October 1954 the individual Board members wrote to Spencer Jones calling for a meeting of the Board which had met only once since 30 March 1951;[35] even at this one meeting on 26 February 1954 there was little or no progress to report.[36] The tenth meeting was accordingly held on 17 November 1954. Plaskett and several other members advocated giving responsibility for progress to a small Executive Committee;[37] this was set up, with wide powers to act, at the next meeting on 15 December 1954.[38] Redman was Chairman, with Plaskett and R. d'E. Atkinson (of the RGO) as the only other members. The Committee acted immediately; there were dramatic changes to follow shortly.

The Executive Committee was to produce a report on the telescope project for the next meeting of the Board, which was held on 8 July 1955.[39] The main difficulty in writing the report was that Redman did not merely complain of the previous lack of progress: he believed strongly that the Board was actually moving in the wrong direction. The report had three parts. The first was unanimous, consisting of the facts on the dual-purpose design. The second was a minority report by Redman, who argued against any dual purpose telescope: he would instead support either a Schmidt or the conventional Cassegrain paraboloid, preferring the latter because of the increasing importance of spectroscopy. The third part by Atkinson combined a defence of the dual system with an attempt to reconcile the two different viewpoints.

Redman had not been acting impetuously or without consultation. Sisson (Grubb Parsons) had set out for the Executive Committee the difficulties in the accepted scheme: there was no certainty about the supply and figuring of the corrector plate, or of the figuring of the Gregorian secondary and the unusually large flat mirror for the coudé focus, while the length of the telescope tube and the off-set fork mounting all constituted new departures which were probably feasible individually but which together made up a formidable task. Greaves continued to argue for the conventional Cassegrain. But now there was a new opinion to be sought: Woolley was due to succeed Spencer Jones as Astronomer Royal at the end of 1955.

Dr R. v. d. R. Woolley was at the Mount Stromlo Observatory in Canberra, and by coincidence he was involved in the construction and testing of a 50-inch telescope with a Gregorian secondary. This was made to work well, but the experience ensured that the inherent difficulties of the INT design were easily appreciated by him. He wrote to Redman on 16 May 1955 expressing his sympathy with Redman's worries, and asking whether the advocates of the Schmidt could really put forward an adequate astronomical programme.[40] "Merely re-photographing the sky with a 100-inch instead of a 72-inch seems a bit dim."[41] (Atkinson remarked to Plaskett[42] "one might as well put a Palomar plate in an enlarger!".) However, Woolley reserved judgement until his arrival at Herstmonceux.

The Board considered the Report of the Executive Committee at its twelfth meeting on 8 July 1955. Redman was not present: he was overseas on an eclipse expedition. The Board thought that it was too late to turn back and agreed unanimously (apart from Blackett, who abstained) to proceed with the dual-purpose design. Woolley was, however, to be consulted at an informal meeting during the IAU General Assembly in Dublin, when the decision could be confirmed as final.[43]

The Board met for the thirteenth time on 5 March 1956 with Woolley as Chairman.[44] He reported the informal meeting in Dublin, and stated baldly that he could not take on the responsibility for the dual-purpose telescope. He wanted the Board to reform the Executive Committee and to re-affirm the controlling position of the Director of the RGO. And he proposed that the telescope should be a conventional Cassegrain paraboloid. The Board agreed.

The new Executive Committee consisted of Woolley, Blackett, Plaskett and Redman. It was to work out designs and specifications to place before the Admiralty, who would place contracts to get the telescope built.[45]

The Cassegrain Paraboloid Design

From 1955 the design process was fairly straightforward. There was a serious delay in 1958 when the Admiralty and the Treasury stopped all expenditure for a year because of a national financial crisis. The order for the telescope was placed in December 1959. Even allowing for this late start, the completion in 1967 still may seem slow progress; part of this was due to a change of responsibility from the Navy Works Department to the Ministry of Public Building and Works in 1964,[46] which led to a delay in the completion of the telescope building. There was also a major change in organisation in April 1965, when the Science Research Council took over the RGO and the INT from the Admiralty.

Only one temporary deviation in design needs to be recorded. Linfoot was consulted about the photographic field available in the parabolic design, and advocated a small departure from the exact parabolic form of the primary with a corresponding extra figuring on the secondary mirror, taking the combination part way towards the Ritchey–Chrétien configuration. Woolley acquiesced, and his account[47] of the telescope in the *Quarterly journal of the RAS* in 1962 includes this change. Unfortunately the prime focus image is bound to suffer from such a change; the central image was enlarged to 1·1 arc seconds by the consequent spherical aberration. Woolley considered for a while adding a full-size corrector plate, in the manner of the Baker schemes proposed in 1946, but instead he agreed in 1964 that the primary mirror should revert to a pure paraboloid.[48] The description and illustrations of the telescope in his 1962 article are otherwise close to the final realisation.

There was one significant change to the prime focus corrector towards the end of the construction phase. The original contract specified a Ross 3-element corrector, as proposed by Grubb Parsons. This would provide image diameters of one arc second over a 20 arc minute field. Wynne had recently designed a greatly improved 4-element corrector, giving ½ arc second images over a 40 arc minute field. The new design was adopted in August 1968, even though the glass blanks for the smaller corrector had already been purchased.

Perhaps the most remarkable aspect of this second phase of design and construction, from 1955 onwards, was the very small involvement of the astronomical community. Only Redman was deeply concerned; not only did he take a leading part in committee work, but he continued to contribute valuable ideas about such matters as building designs and dome ventilation. There was, however, one occasion when the INT became the subject of a rather more open debate. This was the Eighth Herstmonceux Conference of 1964, when there was a discussion on observational programmes for the telescope.

At this Conference P. B. Fellgett presented a paper on the design of large telescopes in general[49] which attempted an analysis of the rate at which information was obtained by telescopes with various angular fields and various apertures. He pointed out that the angular field and most other details of the telescope configuration were unimportant for on-axis work; however, he placed great emphasis on imaging over a wide field, which can indeed provide a large amount of information. He argued that a much smaller telescope providing good field imaging should have been built, and suggested that the Cassegrain design adopted for the INT represented a disaster for British astronomy. His argument was immediately countered by other observers, who pointed out that quantity of information was not the right criterion. R. F. Griffin put it simply thus: "One of the advantages of a big telescope is that it can see fainter objects than a small one, not that it gathers data about things already known."[50]

This debate obviously should have taken place earlier. However, it is instructive to look at the photograph of the members of the Conference;[51] a new generation of astronomers was appearing, and the analysis of future needs and methods of observational astronomy from that time onward was conducted in a very different atmosphere from that of the early days of the INT.

The official opening of the INT by HM The Queen took place on 1 December 1967. It was a joyful occasion despite the long delay in completion of the telescope, which only became available for use by university astronomers in the last quarter of 1968. The opening was, however, very nearly postponed because of a last minute technical hitch. A safety inspection of the building revealed that it was insulated throughout by thick slabs of polystyrene foam, which had only recently been found to be a serious fire hazard; furthermore, there was no external fire escape. The ceremony was almost called off because the local fire brigade did not have a long enough escape ladder. The nearest available, as it turned out, was in Cheshire: this one was therefore driven down to Herstmonceux and discreetly tucked away behind the other telescope buildings to provide the essential safety cover. After the opening the polystyrene was cut out and partly replaced with fireproof material.

The Operation and Performance of the INT

The INT operated continuously from December 1967 to March 1979 with remarkably few mechanical troubles and with only short periods out of action for routine maintenance. Re-aluminising the primary mirror at approximately six-month intervals was notably efficient: only one night of observing was lost on each occasion. An assessment of the scientific success of the telescope is, however, more complex and more controversial.

The whole of the observing time was allocated by a panel of astronomers, most of whom were themselves users of the INT and most of whom were from universities. The panel reported to the Astronomy Space and Radio Board of the Science Research Council. The Royal Greenwich Observatory staff had no special status or privileges in relation to observing time: the RGO did, however, undertake the responsibility of maintaining the telescope and providing night assistants. The total staff required for day-to-day running of the telescope was equivalent to seven full-time.

There was initially no instrumentation provided with the telescope apart from photographic plateholders for the prime and Cassegrain focal stations. A photographic spectrograph was moved from the Yapp telescope for use at the Cassegrain: it was replaced in 1968 by a new photographic spectrograph which was designed and built at the RGO. Over 500 spectra were obtained in the first six months with this instrument. A further RGO spectrograph, the ITS, was brought into use in 1970. This used an image tube intensifier; although the spectrograph was successful, the new image tubes were very unreliable and observers often preferred to use the older photographic instrument. Between them these two spectrographs were the mainstay of many of the later observing programmes both of the RGO and of visiting astronomers. A coudé spectrograph was designed and built by RGO staff: the optical design was shown to be entirely satisfactory, but the poor thermal conditions in the coudé room only allowed comparatively short exposures under stable conditions, and few observations were made with it.

Two other instruments were later added for general use, the McMullan camera and the "People's Photometer". Both were designed and constructed at the RGO.

Woolley had consistently pointed out the need for an uninterrupted year of commissioning work on the telescope, but eventually yielded to pressure and allowed the first observers to be allocated time in the last quarter of 1968. Visiting astronomers either used the RGO instruments or brought their own to the telescope. A considerable part of the telescope time was devoted to new and untried instruments, which encouraged university groups interested in the development of instruments but which did not consistently provide astronomical results. Applications for telescope time represented an over-subscription by a factor of three for the first few years; this factor only fell to near unity as the end of the twelve-year run was approaching.

Observing practices during these twelve years did not, therefore, conform to the original proposals and expectations of the Board of Management in several important ways. The many discussions on the use of wide-field photography were reflected only in a desultory use of Cassegrain photography during the first year and none thereafter. Prime focus photography was, however, regularly in use after the corrector lens was installed in July 1969. The emphasis on coudé spectroscopy was somewhat dampened by the poor performance of the spectrograph, but the whole emphasis changed to Cassegrain spectroscopy, providing medium spectral resolution on relatively faint objects. An even greater emphasis on Cassegrain spectroscopy can be seen at the Anglo-Australian Telescope, and the instrumentation plans for the La Palma telescopes show that the trend is likely to continue.

The experience of INT observers has been coloured by the change of emphasis from the comparatively simple photographic programmes envisaged in the early planning days to the more sophisticated and demanding observations of modern astrophysics. Long exposures, which are often needed for spectroscopy of faint objects, are hard to obtain in poor climatic conditions; an observation of a star transit, or a photograph of a field of bright stars, can be fitted into a short break in cloudy conditions. The records show an average of 1250 clear hours per annum over the years 1973–78, about half those to be expected on a good site. But only 63 nights per year could be classed as completely clear, and therefore suitable for long exposures. Of the total observing time, about two-thirds was actually used for astronomical observations. Variable sky clarity, which was fairly frequent, made it difficult to judge exposure times correctly, and some considerable time was thereby wasted.

The nightly reports from observers included their estimates of the seeing conditions, *i.e.* of the image diameter. The median value was about 3 arc seconds, about twice the median value expected from a good site. Sky brightness conditions were also comparatively poor: the lights of the nearby town Eastbourne had a serious effect, forcing observers to make more exposures so as to cancel out stray light and improve signal-to-noise ratios.

The difficulties of weather, poor seeing and sky brightness conspired to make the observing procedures very inefficient. Compared to operation on an excellent site such as La Palma, the output of spectroscopic data would be expected to be reduced by a factor of at least six. There was a further difficulty: the large demand for telescope time led the allocation panel to assign time in short stretches, so that there were instrument changes required on the telescope on average at only three-day intervals. As any observer knows, considerably longer runs without instrument changes are needed to ensure consistent, well-calibrated observations, even in a good climate. Many observers returned to their universities without even seeing the dome opened to the sky.

After the first year or two of operation, original scientific papers based on INT observations appeared at the rate of about ten per year.

The Move to La Palma

The events leading to the setting up of an overseas observing station in the Northern Hemisphere, and the choice of the Roque de los Muchachos Observatory on La Palma as the site, have been recorded elsewhere.[52] Although the original plans called for three new telescopes, it was soon realised that it was unreasonable to expect the Science Research Council to provide funds for the construction and running of a new 2·5-metre telescope while the INT remained at Herstmonceux. The decision to move it was taken in principle in 1974,[53] and the last observations at Herstmonceux were made in May 1979.

The removal to La Palma was intended to involve as little alteration to the telescope as was reasonably possible. There were, however, two vitally important factors. Obviously, first, the polar axis of the telescope needed to be farther from the vertical to allow for the 23° change in latitude: the maximum zenith angle of the telescope should be preserved in this change, giving access to more southerly declinations than previously. The second factor was the greatly improved seeing conditions for which the La Palma site had mainly been chosen.

It was rare for stellar images to be as small as 1 arc second in diameter at Herstmonceux. Indeed, Woolley discouraged investigations into the refractive effect of warm air inside telescope domes, such as that of the 36-inch Yapp reflector, on the fatalistic assumption that most of the bad seeing originated outside. He preferred the inside of the dome to be slightly warmer than the outside,[54] presumably to avoid condensation on the telescope. He did not want a heavily insulated dome, and was prepared to relax the requirement proposed by Grubb Parsons that the air temperature in the closed dome should not rise by more than 5°F during a normal sunny day.[55]

A totally different attitude was obviously appropriate and indeed essential on La Palma, where seeing better than 1 arc second was expected for about half the observing time. The most important change was to obtain a new primary mirror, using the new glass ceramic material which has a very low coefficient of thermal expansion. A suitable disk of Zerodur purchased from Schott was figured successfully by Grubb Parsons: it actually gives a full aperture of 100 inches in contrast to the useful aperture of only 96 inches in the previous configuration. 'Dome seeing' troubles have been thoroughly investigated, and it is expected that they have been completely avoided by a thorough system of dome insulation and ventilation. There is no need to keep the dome interior warm: on La Palma the relative humidity is normally so low that it is even allowable to keep the primary mirror cooler than the ambient night air by local refrigeration.

The re-mounting of the telescope for latitude 28°N could have been achieved by tilting the 'polar' axis up to the vertical and rebuilding the drive systems. This would have given the 'alt-azimuth' mounting, which has been adopted for the new 4·2-metre telescope. This mounting scheme was actually considered seriously in 1946, when R. d'E. Atkinson, Chief Assistant at the RGO, proposed it complete with a 'master equatorial' control.[56] A similar master equatorial system was patented by B. N. Wallis, and an improved version, patented by Sisson, was used in the 210ft Parkes and the 150ft Algonquin radio telescopes. Modern alt-azimuth mounts achieve a suitable control through a computer system: this could have been applied to the INT, but the necessary revision of the drive systems was eventually found to be too expensive.

The most obvious changes in the INT on La Palma are in its instrumentation and mode of operation. Observers will not ride on the telescope; there will be no prime focus cage, which has been replaced by a fully automated camera and instrument mounting. Modern instruments mainly use photoelectric detectors instead of photographic plates: observers will operate from within a control room, with full benefit of television and automatic guiding. Again, it is interesting to look back to the late 1940s, when Uttley and Atkinson were discussing autoguiders which would keep the telescope pointed correctly at a star at the edge of the field of view.[57] Autoguiders have not been much needed at Herstmonceux, but they will be essential on La Palma to take full advantage of the smaller images given by the better seeing.

The coudé spectrograph at Herstmonceux was a failure. The optical system was properly designed, but there were serious difficulties with temperature gradients and fluctuations in the coudé room. The Navy Works Department did indicate that this was likely, because one wall of the room was exposed on the outside to sunlight and varying air temperatures,[58] but Woolley and the Board were not ready to undertake the spectrograph design and decided to leave the room completely empty, adding appropriate insulation later. Unfortunately, this did not cure the problem, as the spectrograph was nearly vertical and the room developed a variable horizontal stratification. In the La Palma building the coudé room accordingly extends horizontally, and the walls are very well insulated.

All these changes to the specification of the INT and its instruments have been extensively discussed by the British astronomical community and agreed by the Science Research Council. The implementation of the whole La Palma scheme was put into the hands of the Royal Greenwich Observatory, whose prime function was clearly seen as the provision of observing facilities for the whole British community. A project team nineteen strong, including both engineers and astronomers, backed by considerable resources of instrument designers and mechanical and electronic engineers, was devoted to the task. It was no longer necessary for the Director to act as Project Scientist, Project Manager, Chairman of the Board, and in practically every other capacity as seems to have been expected of Spencer Jones.

An Overall Assessment

The history of the INT from the first proposal to the end of observations at Herstmonceux must be seen in relation to the development of astronomy in Britain during the same period. It is illuminating to look first at the records of the Royal Society Committee on Post-War Needs in Astronomy, 27 July 1945.[59] The main concern of this committee was the very small total number of astronomers revealed by a questionnaire which was sent to all observatories in the UK.[60] Only fifteen staff posts could be identified with an income over £600 per annum; these would correspond to "qualified scientists and engineers", or QSEs in modern parlance. The Royal Observatories were not regarded as scientific establishments; the RGO pay and conditions of service were determined by the Admiralty. The Committee recommended improvements in these matters, and also the establishment of one Research Studentship, and two Travelling Fellowships to enable staff to observe overseas. This was the Dark Age of British astronomy.

From the start, the INT was intended to be a national telescope. This was re-affirmed on many occasions: during the crisis of 1955 Greaves wrote to

Redman, "The avowed aim of the INT was that it should be shared by UK observatories".[61] This was a new pattern, which has now been followed by the Science Research Council in respect of all the RGO telescopes, and all the overseas telescopes. Admittedly it is a policy which leads to considerable discussion and sometimes delay: Spencer Jones wrote to the Secretary to the Board of Visitors (Jowsey) on 28 October 1955, "If the telescope were for the sole use of this Observatory the design would have been settled long ago and estimates could have been obtained. But the telescope is for the use of all the observatories in the UK; they do not all want the same thing."[62] The decision-making processes in the Science Research Council's committees sometimes seem slow and cumbersome, but they are evidently a considerable improvement: Spencer Jones goes on to say, "The Board of Management . . . is in my opinion not a satisfactory body for discussing and deciding upon a design".[63]

The siting of the telescope in Britain was seen as essential if the universities were to be seriously involved.[64] Not all astronomers agreed: Thackeray, writing to Redman from the Radcliffe Observatory, where the southern sky was available, stated: "The INT should now go to the Southern Hemisphere. The next generation will deplore the shortsightedness of the preference over more favoured sites in the south."[65] The argument had its parallel in the pre-war years: the Radcliffe Observatory closed in Oxford in 1935, and there were deep divisions about the proposal to reconstruct it overseas. Lindemann, in particular, is said to have opposed such a move.[66] However, all those actually involved in the INT decision agreed that there was no real alternative. Even Redman, who was a strong advocate of the south, said: "Astronomers . . . acquiesce, because the choice is between a new instrument in a bad situation or no instrument at all."[67]

On the delays and discouragements of the long years of design and construction one can only sympathise with Redman, who wrote to Woolley: "I have myself spent a lot of time over this telescope, much of it combating crazy ideas which should never have been seriously considered, and have absolutely nothing to show for it."[68] We must add, however, that Redman played a most constructive rôle throughout, and went on to play an even more important and influential part in the establishment of the Anglo-Australian Telescope. Even Woolley at one period despaired:[69] when the Admiralty cut off funds in 1958 he asked Grubb Parsons for a quotation for a straightforward 74-inch telescope. Earlier he had cast envious eyes on the Egyptian 74-inch, ready for shipment to Helwan and temporarily held up by political difficulties: he informed the Hydrographer (Rear-Admiral Collins) of this, and advised him that it could be working at Herstmonceux within eighteen months.

The final judgement must concern the effect that the INT had on British astronomy. During its building and operation there was a transformation, which can be ascribed to a multiplicity of causes, such as the growth of radio astronomy and space research, the growth of university research generally and the formation of the Science Research Council. Whatever the causes, there can be no doubt that the INT is linked to them, as it was in the eyes of the Advisory Council on Scientific Policy where it was said of astrophysics in the UK: "Recent years have seen the beginning of an improvement. Thanks in part to the institution of vacation courses for undergraduates at the Royal Observatory, Herstmonceux, more first-class young men are being attracted, and the completion of the

Isaac Newton Telescope at Herstmonceux scheduled for 1965 is expected to bring a great improvement in observational facilities."[70] The INT, and after it the Anglo-Australian Telescope, the UK Schmidt which was eventually built in Australia, the UK Infrared Telescope on Hawaii, and now the new telescopes on La Palma, bear witness that the improvement did indeed take place.

Appendix: Estimates and final cost of the INT

Expenditure on the INT first appears in vote 6 of the Navy Estimates for 1949–50. These include the sum of £3,000 for preliminary work on the telescope. A note of explanation is also given:

> The Isaac Newton Telescope will be erected at Herstmonceux. . . . Capital costs which will be spread over a number of years, are borne directly on Navy Votes but one half is recoverable from a Grant-in-aid from Class IV, vote 10 of the Civil Estimates. [This later became vote 11.] Maintenance costs will be borne wholly on Navy Votes.

Class IV of the Civil Estimates is given over to grants for science and the arts. The 1949–50 estimate was for £1,500. The total cost at this time was estimated at £315,000.

The Naval Estimate rose slowly but steadily over the years until by 1955–56 it was £11,850. Then in 1956–57 it jumped sharply to £51,700 with a corresponding increase in the Civil Estimates to £25,800 to be spent mainly on building work. This increase coincides exactly with Woolley's appointment as Astronomer Royal and his setting up of a new Executive Committee following the 1955 crisis. In 1957–58 the figure dropped to £30,000, expenditure of which slipped, and nothing was included in the 1958–59 Estimate which merely includes the remark "work postponed". After this the Estimate remained around the £20,500 mark.

The Monthly Financial/Progress Report on Science Research Council Projects issued by the Ministry of Public Buildings and Works (MPBW) gives a more detailed breakdown of large items of expenditure from 1965, when SRC took over responsibility for the telescope, until August 1967 when the civil works and telescope erection were complete. At this time it only remained to instal the primary mirror and align the various optical components.

In August 1965 the MPBW reported to SRC the following estimates for the items within their responsibility:

Building (F. G. Minter Ltd)	£257,000
Dome (Grubb Parsons Ltd)	£161,000
Aluminising Plant (contract not yet let)	£34,000

In addition the MPBW fee on the whole project was expected to be £90,400.

The contracts for the telescope and for the primary mirror were handed over to MPBW by the Navy Department in November 1965. The original contracts were for £321,000 and £29,000 respectively, but the addition of some items, and cost increases of £32,000, had brought the total to £390,624. The estimated total project cost at this time was therefore £916,300.

The final cost was given by MPBW in August 1967 as £956,600.

REFERENCES

1. RGO file: History of the INT.
2. *Ibid.*
3. Published in *Monthly notices of the Royal Astronomical Society*, cvii (1947), 11–15.
4. "Address on astronomical telescopes" by H. H. Plaskett, *ibid.*, cvi (1946), 80–94.
5. See ref. 3, p. 11.
6. Royal Society Council Meeting, 13 June 1946, minute 6.
7. RGO file: History of the INT.
8. *Ibid.*
9. "Second memorandum, 1946 September 3", *Monthly notices of the Royal Astronomical Society*, cvii (1947), 15–19.
10. Reported in *Observatory*, lxvi (1946), 308–17.
11. *Ibid.*, 310–12.
12. Report on Observing Programmes for 100-inch Reflector, by W. M. H. Greave, R. O. Redman papers (RGO) box 1 [*c.* 1947].
13. INT Board of Management Meeting, 10 October 1947.
14. Spencer Jones to Hydrographer, 4 January 1948, RGO file C12 1946–55.
15. Royal Society, Post-war Needs in Astronomy Committee Meeting, 1 June 1946, minute 3.
16. C. F. W. Harmer and C. G. Wynne, "A simple wide-field Cassegrain telescope", *Monthly notices of the Royal Astronomical Society*, clxxvii (1976), pp. 25P–30P.
17. INT Board of Management Meeting, 23 July 1947.
18. Blackett to Barker, 20 May 1955, RGO file C12 1946–55.
19. INT Board of Management Meeting, 12 December 1947.
20. Flexible and Inflexible Structure [a manuscript report] by Dr B. N. Wallis [with a covering letter 2 February 1948], RGO, INT Additional papers.
21. RGO, INT Additional papers.
22. Carroll to Spencer Jones, 11 May 1948, RGO file C12 1946–55.
23. Wallis to Spencer Jones, 13 May 1952, *ibid.*
24. INT Board of Management Meeting, 27 June 1949.
25. Correspondence in RGO file C12 1946–55 Section R *and* INT Board of Management Meeting 10 October 1947.
26. Shajn and Vavilov to Spencer Jones, 14 June 1948, RGO file C12 1946–55.
27. Report on Discussions with American Astronomers on the Proposed Isaac Newton Telescope, by A. Uttley, TRE Memo N/A/8 [9 August 1948].
28. Uttley to Spencer Jones, 24 May 1958, RGO file: History of the INT.
29. Private communication with the authors.
30. Spencer Jones to Hulbert, 6 September 1948, RGO file: History of the INT.
31. Linfoot to Spencer Jones, 30 December 1950, R. O. Redman papers (RGO) box 1.
32. Messrs Pilkington to Spencer Jones, 28 April 1950, RGO file C12 1946–55.
33. INT Board of Management Meeting, 30 March 1951.
34. INT Board of Management Executive Committee Reports, etc. [1955], R. O. Redman papers (RGO) box 1.
35. Plaskett to Redman, 21 October 1954, R. O. Redman papers (RGO) box 1.
36. INT Board of Management Meeting, 26 February 1954.
37. *Ibid.*, 17 November 1954.
38. *Ibid.*, 15 December 1954.
39. *Ibid.*, 8 July 1955.
40. Woolley to Redman, 16 May 1955, R. O. Redman papers (RGO) box 2.
41. *Ibid.*
42. Atkinson to Plaskett, 1 February 1955, RGO file C12 1946–55.
43. INT Board of Management Meeting, 8 July 1955.
44. INT Board of Management Meeting, 5 March 1956.
45. *Ibid.*, 5 March 1956.
46. *Ibid.*, 5 June 1964.
47. R. v. d. R. Woolley, "The Isaac Newton Telescope", *Quarterly journal of the Royal Astronomical Society*, iii (1962), 249–58.
48. INT Board of Management Meeting, 5 June 1964.

49. P. B. Fellgett, "Possible programmes for the Isaac Newton Telescope", *Observatory*, lxxxiv (1964), 216–19.
50. In the report of the Eighth Herstmonceux Conference, *ibid.*, 169–90, p. 188.
51. *Ibid.*, plate VI.
52. F. Graham Smith, "The new observatory on La Palma", *Quarterly journal of the Royal Astronomical Society*, xxii (1981), 254–65.
53. Science Research Council Meeting, 20 November 1974 *and* Northern Hemisphere Observatory Planning Committee Meeting, 27 November 1974, minute 164.1.
54. Navy Works Department Meeting, 1 December 1961, RGO file C12 1960–66.
55. Woolley to Allcock, 14 December 1961, RGO file C12 1960–66.
56. Atkinson to Hartree, 21 August 1946, RGO file C12 1946–55.
57. Correspondence to and from Atkinson, Uttley and others, 1947–48, RGO file C12 1946–55.
58. See ref. 54.
59. RGO file: History of the INT.
60. *Ibid.*
61. Greaves to Redman, 8 February 1955, R. O. Redman papers (RGO) box 2.
62. Spencer Jones to Jowsey, 28 October 1955, RGO file C12 1946–55.
63. *Ibid.*
64. See ref. 4.
65. Quoted by Redman, February 1955, R. O. Redman papers (RGO) box 2.
66. *Radcliffe Observatory 1772–1972*, by A. D. Thackeray (Radcliffe Trust, London, 1972), 19.
67. R. O. Redman, "Post-war astronomy", *Observatory*, lxvi (1945), 153–9, p. 157.
68. Redman to Woolley, 28 May 1958, RGO file C12 1956–59.
69. Woolley to Redman, 9 October 1958 *and* Plaskett to Woolley, 16 October 1958, R. O. Redman papers (RGO) box 2. Memo by Woolley, October 1958, RGO file C12 1956–59.
70. SP(60) 25, 30 March 1960.