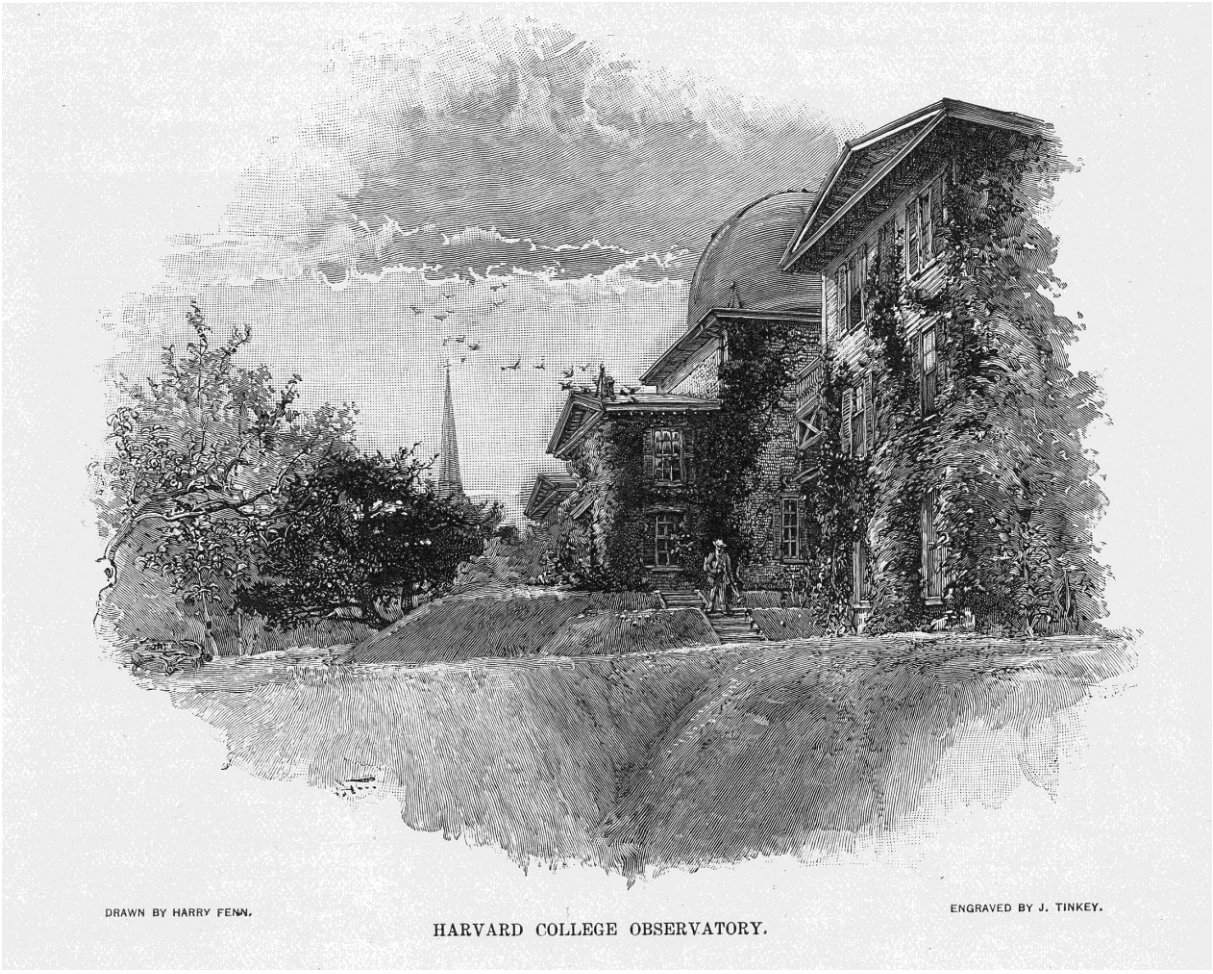
The Antiquarian Astronomer

Journal of the Society for the History of Astronomy



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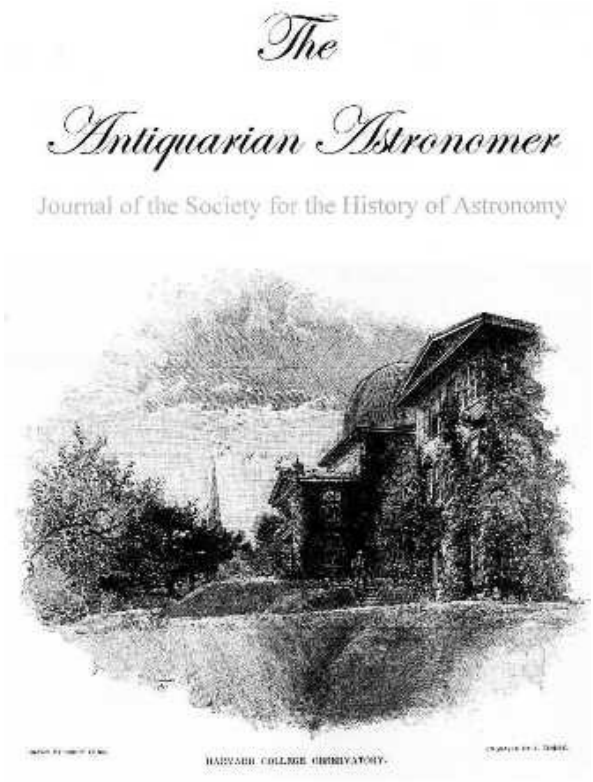
The Cover illustration:

A GREAT MODERN OBSERVATORY

***The Century Magazine*, June 1897, p. 299**

Our cover illustration first appeared in an article by Mabel Todd Loomis titled 'A Great Modern Observatory' in *The Century Magazine*, June 1897. Forty years after Horace P. Tuttle arrived at the Harvard Observatory; this was perhaps the only vantage point preserving the illusion that little has changed. As always the Sun has risen and the astronomer begins his stroll homeward, alone in thoughts of last night's work. But how that work has evolved! In 1897 the Great Equatorial still rests under its massive copper dome, but no longer is it Harvard's principle instrument, and no longer does it measure astrometric positions. Under the directorship of E.C. Pickering, it has been given over to 'the new astronomy', the measurement of physical properties of the heavenly bodies: analyzing the light of variable stars and of the moons of Jupiter. The East balcony no longer supports an astronomer and comet seeker, and four years earlier a massive fireproof addition houses the *seventy thousand* photographic plates of stellar spectra and photographic magnitudes produced in that past decade that 'may take the place of the sky itself'. The new Bruce photographic telescope has been photographing southern stars from 20,000 feet at Arequipa, Peru; no other observatory could claim dual-hemi-sphere programmes 'harmonious' under one director.

'This conjunction of photography with the study of stars obliterates the favourite popular vision of the typical astronomer, up all hours with eye constantly at a great "optic tube"', wrote Mrs. Loomis. 'If the atmosphere be lower than freezing, or even a New England zero, romantic imagination insists that his heart must be amply warmed by his heavenly enthusiasm. But the elimination of personality makes the records of astronomy indisputable, and renders its pursuit more practical, not to say more comfortable…'



Now a full century past Mabel Loomis, we desire to return to the romantic and personal era of visual astronomy at the Harvard College Observatory, to put our own eye to the optic tube.

‘A large chunk of glass’:

The 98-inch mirror of the Isaac Newton Telescope, 1945-1959

Lee T. Macdonald

Deputy Director of the British Astronomical

Association Historical Section

The Isaac Newton Telescope (INT) was completed in 1967 at Herstmonceux in southern England, headquarters of the Royal Greenwich Observatory, and was used there by professional astronomers for twelve years before being dismantled and moved to La Palma in the Canary Islands, where it remains a working telescope to this day. When it was moved to La Palma, the telescope was fitted with a new primary mirror. The original mirror, which was used throughout the Herstmonceux years, was obtained as a gift in the late 1940s from the University of Michigan in the United States. This paper records the troubled early history of this mirror and how it was nearly abandoned more than once, and tries to set its history in the political and economic context of mid-twentieth-century Britain as well as the history of astronomy.

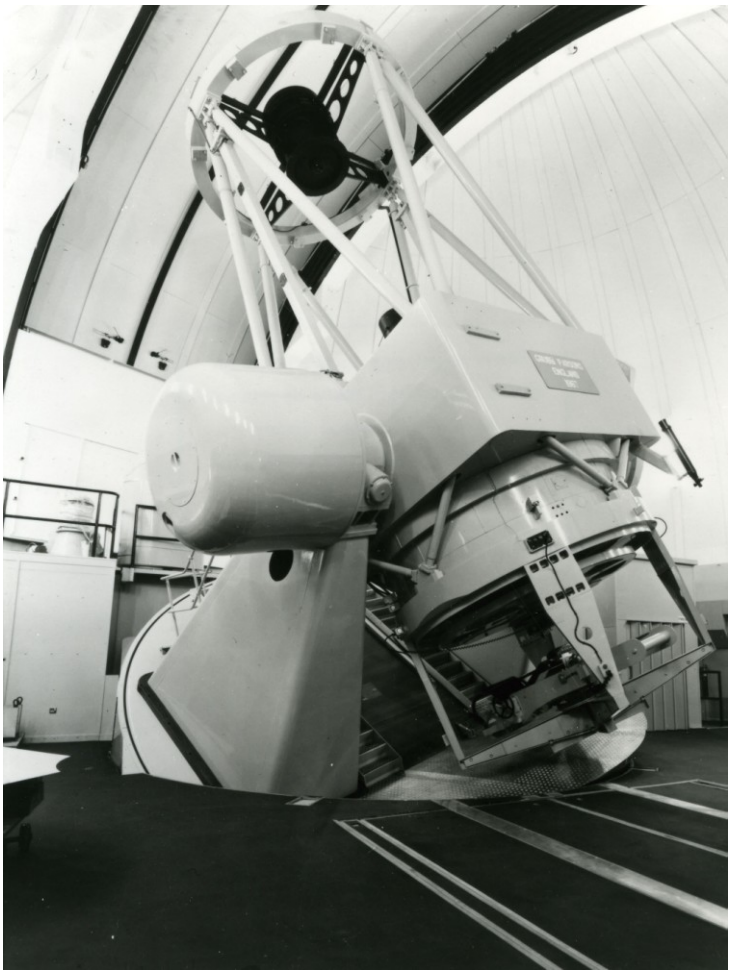


Fig. 1 The Isaac Newton Telescope at Herstmonceux.
By courtesy of the Royal Astronomical Society.

The Isaac Newton Telescope was conceived and funded in 1946, in honour of the tercentenary of the birth of Sir Isaac Newton, which fell in January 1943 (December 1942 according to the Old Style calendar) but the celebrations for which had been postponed because of the Second World War. At the time, no large telescope to complete with the great reflectors of the western United States yet existed in the British Isles, and the idea was to build a large, world-class telescope to which all British professional astronomers would have access. Very early on in the telescope's history, it was decided to build it at Herstmonceux Castle in Sussex, the post-war site of the Royal Observatory (from 1948 known as the 'Royal Greenwich Observatory, Herstmonceux'). On its completion in 1967, it was the largest telescope in Western Europe. But the INT remained at Herstmonceux for just twelve years before it was dismantled and eventually rebuilt on La Palma in the Canary Islands. Herstmonceux, a few miles from the south coast of England, proved to be a very poor observing site for so large a telescope, and its productivity in terms of research results was meagre.[1]

Fig. 2 The INT being dismantled for refurbishment by Grubb Parsons prior to its removal to La Palma.
By courtesy of George Wilkins.

How the INT came to be built at what seems, with hindsight, to be an obviously unsuitable location for a large optical telescope, and why it took some twenty-one years to build, has been discussed elsewhere – by Smith and Dudley and, more recently and in more detail, by the present author.[2] But as yet there has been no detailed account of the history of the telescope's 98-inch mirror, the glass disc, or 'blank' which was of American origin and which was soon found to be of doubtful optical quality. When the INT was re-erected at La Palma, it was equipped with a new mirror, and the original mirror, with its reflective coating removed, is now on public display at the Herstmonceux Science Centre. As we shall see, concerns about the mirror's quality more than once came close to fundamentally changing the course of the whole INT project – indeed, in one sense, they actually did so, in that the original mirror had a focal ratio of f/3, very fast for Cassegrain telescopes of the day, causing the present-day INT on La Palma, which has the same tube as the Herstmonceux instrument, to have the same compact f/ratio. Here I shall describe the history of the original 98-inch mirror, examining how it came to be obtained from the United States and the reasons for the various decisions made regarding it. I shall also contend that some of the decisions around a piece of glass of this size and cost were not just astronomical or technical but had economic and political ramifications as well.

Fig. 3 INT Mirror Close Up: The original 98-inch Isaac Newton Telescope mirror, now on display at the Herstmonceux Science Centre. The reflective surface has been re-moved, allowing us to see into the glass. A number of flaws in the glass can be discerned in this photograph, though the large gash at the top is more likely to be subsequent damage.
By courtesy of the author in March 2008.

The historical context of large mirrors

By the 1940s, large reflecting telescopes had a long pedigree in the British Isles. Their original pioneer was William Herschel (1738-1822), who, in addition to discovering Uranus, built the largest reflecting telescopes of his day and used them (principally one of 18.7 inches' aperture, the so-called 'large twenty-foot' telescope) to try to determine the properties of

the vast numbers of nebulae he discovered and to work out the size and structure of the stellar universe. Others, such as his son John Herschel (1791-1871) and Lord Rosse (1800-1867) followed in his footsteps. But until the early twentieth century, most astronomers continued to prefer refractors. Until the advent of silver-on-glass mirrors in the 1850s, the only material from which a satisfactory telescope mirror could be made was speculum metal, which was difficult to work, especially in larger sizes, and prone to tarnishing once completed. For several decades after silver-on-glass mirrors became available, the refractor remained the instrument of choice for most professional observatories, because nineteenth-century astronomy was overwhelmingly a science of positional measurement. Refractors, with their precision mountings and accurately-aligned optics, were eminently suited for this purpose. Large reflectors, on the other hand, were difficult to mount adequately and could not be used for the precision observations that professional astronomers wanted to undertake.

Towards the end of the nineteenth century, the development of spectroscopy and photography and, related to this, the rise of astrophysics that continued Herschel's enquiries as to what stars and nebulae actually are, as opposed to merely measuring their positions, helped to turn astronomers towards large reflectors. Cutting-edge astrophysics demanded large telescopes, as the stars and nebulae examined in these studies were often very faint, especially when their properties were studied with spectrographs, which spread out the light of an already faint object into a spectrum. Principally, it was the work of astronomers in the clear skies of the western United States that convinced the astronomical community of the potential of big reflectors. Refractors had reached their practical size limit with the completion of the Yerkes 40-inch in 1897, since refractors beyond a certain size suffered excessive light loss due to the thickness of the glass of their objective lenses and distortion due to the weight of the lenses. At the same time, optical and engineering pioneers such as George Ritchey in the United States and Howard Grubb in Ireland had solved many of the problems associated with mounting large reflectors and had turned them into precision instruments.

But even in the 1940s, making a mirror with a diameter of 98 inches was no mean feat. In order for it to be ground to a satisfactory optical figure, the glass in a telescope mirror needs to be as free as possible from defects such as air bubbles and striae (streaks of glass of different density from their surroundings). This is difficult to achieve in a very large mirror, where a huge amount of molten glass has to be poured into the casting mould very quickly. When the blank for the 100-inch Hooker telescope was delivered in 1908, it was initially pronounced a failure, stimulating the St. Gobain glassworks in Paris to cast a second disc at their own expense, although eventually the original disc was used and performed satisfactorily. The giant 200-inch blank for the Hale Telescope on Mount Palomar was only successfully cast on a second attempt. Casting and annealing the blank for the 74-inch Radcliffe reflector in South Africa failed twice before a satisfactory mirror was produced, leading to serious delays in the project.[3] It is in this context that we need to consider the history of the 98-inch Isaac Newton Telescope mirror.

The Idea of a large British telescope

Although in 1946 the British government approved funding for a 100-inch telescope, the earliest correspondence on the subject reveals that astronomers originally wanted a somewhat smaller instrument. The idea of what would become known as the Isaac Newton Telescope grew out of a committee set up by the Royal Society to assess the requirements of post-war astronomy. Consisting of just four members – Sir Harold Spencer Jones (Astronomer Royal), Harry Plaskett (Savilian Professor of Astronomy at Oxford), and Arthur Milne (Oxford) and Henry Plummer (Oxford then Dunsink and Woolwich) – the committee met for the first time on 27 July 1945 (when hostilities with Japan were not yet concluded). Its report noted 'a complete lack of equipment of large light-gathering power'. While it acknowledged that the British climate 'does not justify the erection of instruments of the largest size', it believed 'that a reflector of 60-inch aperture at a selected site in the south of England could be effectively used for special observations which are not possible with the largest existing telescopes in this country'.[4]

The case for the telescope was first publicly aired by Plaskett in February 1946, in his address as President of the Royal Astronomical Society. Plaskett advocated 'an f/4 Schmidt telescope with an aperture of 49-74 inches'– that is, with a front corrector plate of 49 inches' aperture and a 74-inch primary mirror. The Schmidt corrector plate was to be removable, so that when the Moon was up, making the sky too bright for Schmidt photography, the telescope could be used in a Cassegrain optical configuration for spectroscopy of individual objects, thus giving two telescopes in one.[5] In response to Plaskett's speech, the RAS formed a committee to consider whether his proposal for a large telescope in Britain was advisable, and, if so, how to get the approval of the Society as a whole and how to go about applying for funding.

The committee – which was chaired by Plaskett – proposed that the RAS apply for a government grant for the telescope through the Council of the Royal Society, then a key body in approving funding applications for scientific research. The final proposal submitted by the RAS called for 'a sum of the order of £100,000 to build a reflecting telescope of at least 72 inches aperture'.[6] The jump in size of the proposed instrument from 60 to 72 or 74 inches may have owed much to the fact that Harry Plaskett was the son of Canadian astronomer John S. Plaskett, who had designed and built the 72-inch reflector for the Dominion Astrophysical Observatory at Victoria, British Colum- bia. Plaskett Junior may have instinctively considered 72 inches as an ideal aperture for a large telescope. 74 inches was also the size of the Radcliffe Observatory's flagship telescope, which by this time had been set up in South Africa, but whose mirror would not be delivered until 1948.

I have described elsewhere how, in the spring of 1946, it was decided to name the new telescope after Sir Isaac Newton and thus the proposal was rushed through to the Treasury so that funding for the project could be announced at the Newton tercentenary celebrations in July of that year.[7] On 1 June, the Royal Society Committee on Post-War Needs in Astronomy met for the second time and 'took into consideration' the RAS application, which had been submitted to the Royal Society in time for its Council meeting on 16 May. It is in the minutes of this meeting that we find the first reference to a proposal for a 100-inch telescope. The committee decided that the top priority among 'the minimum needs of British astronomy' was 'one large reflector for spectroscopy in this country, of at least 72″ aperture and preferably 100″'.[8] Six days after the meeting, Spencer Jones wrote to the Secretary of the Royal Society, stating the new telescope should have an aperture 'appreciably larger' than the Radcliffe 74-inch because the shorter clear periods in Britain necessitated shorter exposure times.[9] The Royal Society's original proposal to the Treasury suggested building an 84-inch telescope, saying that the 72-inch size suggested by the RAS was 'very much the minimum size'. The proposal estimated that an 84-inch would cost around £150,000 – mid-way between a 72-inch (£100,000) and a 100-inch (£200,000).[10] But all subsequent documents refer to a 100-inch telescope. On 8 July, Sir Alan Barlow, Second Secretary to the Treasury, wrote to the Chancellor of the Exchequer, Hugh Dalton, repeating Spencer Jones's argument that Britain's frequently cloudy skies demanded shorter exposure times, and therefore a larger telescope, with which: 'much time can be saved and work can proceed more continuously. I feel, after discussing the matter with the Astronomer Royal, that the extra cost of the 100″ lens [*sic*] is worthwhile if we are to try and recover our former pre-eminence in astronomy'.[11] An article written shortly afterwards for *The Observatory* by Donald Sadler, Superintendent of the Nautical Almanac Office and therefore a senior member of staff at the Royal Observatory, confirms that a discussion took place between Barlow and Spencer Jones, in which the latter emphasised 'the marked inferiority of the United Kingdom' in the matter of large telescopes and 'developed the case so forcibly that Sir Alan Barlow agreed to advise the Chancellor that provision should be made for the construction of a telescope of 100 inches' aperture'.[12] The Chancellor agreed to fund the project the same day, and four days later Barlow wrote to Egerton at the Royal Society (copying his letter to Spencer Jones), saying that 'the Chancellor of the Exchequer is prepared to ask Parliament to provide money for the purchase of a 100-inch telescope'.[13]

Thus Britain was committed to moving into the uncharted waters of constructing a telescope on a par with the largest operational telescope in the world – the most important element of which was a mirror of 100 inches diameter.

Obtaining the Glass Blank

The design and construction of the telescope was overseen by a 'Board of Management', whose Chairman was the Astronomer Royal, Sir Harold Spencer.

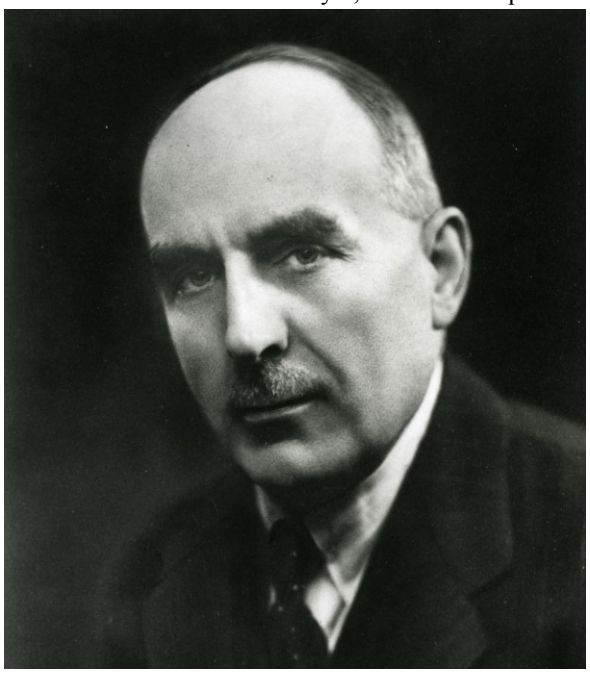


Fig. 4 Sir Harold Spencer Jones, Astronomer Royal from 1933 to 1955 and Chairman of the Isaac Newton Telescope Board of Management until his retirement in 1955.
By courtesy the Royal Astronomical Society.

Jones. Responsibility for directing the project thus lay with Spencer Jones until his retirement in 1955. Also on the Board were the Astronomer Royal for Scotland (William Greaves until 1955, Hermann Brück from 1957), the directors of the Oxford and Cam- bridge University Observatories (Harry Plaskett and Roderick Redman respectively), and four representatives each from the Royal Society and the RAS.

Glass companies in Britain capable of producing a 100-inch disc to the required specifications were very few and far between in the 1940s. Economic problems caused by the war meant that buying a disc from the United States would involve a very unfavourable dollar exchange rate, and the government was determined to avoid spending US currency wherever possible. Initially, Spencer Jones thought of using a *metal* mirror, an idea harking back to the eighteenth- and nineteenth-century reflectors of the Herschels and Lord Rosse, on the grounds that:-

> A metal mirror would have the advantage of high thermal conductivity and it could probably be cast to approximately the correct spherical shape required before parabolising. ... A metal mirror would, of course, avoid the long annealing process which is essential for any type of glass mirror.[14]

Quite why an Astronomer Royal of the 1940s seriously considered a metal mirror is not clear, although it should be said that the idea may not be quite as ludicrous as it sounds, as some researchers around this time were looking into alternatives to glass for making telescope mirrors.[15] The idea seems never to have been followed up, though as late as March 1947 Spencer Jones was writing that the 'possibility of making a metal mirror should not be ruled out'.[16]

During 1947 the decision was made to use a conventional glass disc. In February of that year, Civil Servant Sir Charles Wright of the Royal Navy Scientific Service wrote to Sir Alan Barlow at the Treasury, enclosing a letter from the Pilkington Brothers glass-making firm of St Helens, Lancashire, which said that 'we feel very strongly that this disc should be made in this country and this is our chief reason for considering its manufacture'.[17] Wright, having visited Pilkington, had no doubt of their ability to do the job, and added that 'I hate the idea of having to go to America for a large chunk of glass'.[18] This corresponded exactly with the views of the Treasury, anxious as they were to avoid spending American currency: 'We should, of course, be strongly adverse to sanctioning dollar expenditure unless it was quite clear that it was impossible for the work to be done in this country'.[19] George Sisson, Managing Director of Grubb Parsons, the famous firm which had made many large telescopes for observatories across the British Empire and beyond and was a strong candidate for contracts to build the INT, was also enthusiastic about Pilkington making the disc:-

> It appears that Pilkington Brothers have the necessary melting facilities, and factory space directly available for manufacturing large discs. They intend to proceed in any case with the production of some small discs in low expansion glass which they would like to submit to us for our comments.
>
> ... It does seem to me that the existence of a source of supply for large discs in this country would be an excellent thing, from the point of view of national prestige, and I have no doubt that a number of discs will be required, some of which will certainly be glass.[20]

At its inaugural meeting in July 1947, the Board of Management agreed to enter negotiations with Pilkington with a view to them casting a 100-inch disc.[21] At the third Board meeting, held in December 1947, it was announced that Pilkington had cast several discs, including one of 74-inch diameter, as experiments, and that they had given March 1949 as a preliminary date for casting the 100-inch.[22] At the meeting of 11 May 1948 it was announced that Pilkington had accepted a contract to make the disc for a new 74-inch telescope for Australia (the 74-inch at Mount Stromlo Observatory, completed in 1955).[23] However, a contract was not placed for the 100-inch disc. This was partly because at this stage, the Board were still arguing as to the optical design of the new telescope. At the December 1947 meeting, the Board had agreed to take up Plaskett's suggestion of a dual-purpose Schmidt and Cassegrain telescope, but the exact details still had to be worked out. Quite apart from this, however, a new development occurred very soon after the May 1948 meeting.

Just thirteen days after this meeting, Albert Uttley of the Telecommunications Research Establishment at Great Malvern, Worcestershire, who was on an offic ial visit to the United States on behalf of the Ministry of Supply, wrote to Spencer Jones from the British Joint Services Mission in Washington D.C. At the inaugural Board meeting, Uttley had been co-opted to two sub-committees set up by the Board to discuss control and servo mechanisms for the telescope. One of these committees, aware of his planned visit to the United States, asked if funding could be obtained to extend his visit so that he might investigate the telescope guiding systems at several American observatories, and his extended trip was later approved.[24] Now, on 24 May, Uttley wrote to tell Spencer Jones that during a recent trip to the University of Michigan at Ann Arbor, he had learned that they had 'a 97″ disc which they are willing to sell'. The disc had original-

ly been cast in 1935 by the Corning Glass Company of New York (who had also made the 200-inch blank for Mount Palomar and the 74-inch Radcliffe blank) for a telescope for the University of Michigan, but the telescope had never been built, because the Great Depression had halted the project and it was never restarted. The unused mirror blank had been returned to the telescope's original sponsors, the McGregor Fund (a private foundation based in Michigan), in December 1947. Uttley reported that he had inspected the disc, which was being offered for sale together with a blank for a secondary mirror and the central glass 'plug' for the primary, for $25,000. It proved to be 97 $^{5}/_{8}$ inches across (so nearer 98 inches than 97) and 'everyone considers the disc to be a very good one' – that is, it did not have too many internal bubles.[25] In his reply to Uttley, Spencer Jones said that he had known about the plans for this telescope since 1931, when he had discussed them with the then director of Michigan University Observatory, Heber Curtis, and had heard that the disc was for sale 'some time ago'. He now asked Uttley whether the offer of the disc was made in expectation of a reply.[26] Uttley then received a letter from Leo Goldberg, the current head of astronomy at the University of Michigan, bearing the news that:-

> In the event that the Astronomers of Great Britain should wish to employ the 98″ disc for the proposed Newton Telescope we now feel reasonably certain that McGregor Fund would want to make an outright gift of the mirror blanks.

Goldberg added that he would be glad to discuss the matter with Spencer Jones at that summer's General Assembly of the International Astronomical Union, of which Spencer Jones was President.[27] Thus the offer of a mirror going free dates from 14 June 1948, not 6 September as stated by Smith and Dudley.[28] That Spencer Jones was aware of Michigan's offer of a free mirror blank is evidenced by his letter to Barlow at the Treasury of 23 June, in which he said that 'Michigan have now offered a 98″ disc for free'. The cost of a disc made by Pilkington, by contrast, was likely to be between £8,000 and £10,000. He was now asking the Treasury whether he should accept this offer, in view of the fact that Pilkington, although not yet formally contracted, were under a 'definite understanding' that they would be casting the mirror blank.[29] Rather predictably, the Treasury responded:-

> All that we would say officially would be that it is a pity to spend £10,000 of the taxpayers' hard won money if you can get the same thing for nothing and secondly, that we should welcome anything which prompted friendly relations with the USA. ... I take it that with Treasury consent you could find other good uses for the £10,000.[30]

After the IAU meeting, Spencer Jones wrote to Judge Henry Hulbert, President of the McGregor Fund, saying that the completed disc on offer would save much time in building the telescope, the only difficulty being the need to avoid dollar expenditure:-

> Dr Goldberg told me that he thought the McGregor Trustees would be prepared to dispose of the 98½-inch disk on favourable terms. I have referred to the difficulties about dollar exchange, arising from the difficult economic position to which we have been reduced by the heavy cost of the recent war, because we may have to decline an advantageous offer and it might otherwise seem ungrateful to have to do so.[31]

Spencer Jones wrote this letter nearly three months *after* Goldberg's 14 June offer of an 'outright gift', yet he made no mention of this, and just dropped hints about 'favourable terms'. Clearly Spencer Jones was angling for Goldberg's offer, which would involve no dollar expenditure.

Hulbert did not reply until February 1949, due to having suffering a stroke. His reply, when it came, read: 'It was the unanimous decision of the Board of Trustees that McGregor Fund make an outright gift of the 97½-inch disk to the Royal Greenwich Observatory, and I am very happy indeed to convey this message to you.'[32] The gift was announced in *The Times* on May 17, in a short article placed modestly near the bottom of page 4, between an announcement of discussions between Churchill and Attlee on defence and Princess Margaret's visit to Buenos Aires.[33] Spencer Jones announced it to the Board of Management at its meeting on 27 June, but the minutes make no mention of his correspondence with Uttley and Goldberg, instead giving the impression that it was a gift out of the blue. We do not know if the negotia tions between the various parties leading to the gift were ever mentioned at this meeting.

Fred Hoyle has accused Spencer Jones, in print, of putting the Michigan people in a situation from which they 'could not refuse to make the gift', leading to one astronomer giving him the nickname 'Scrounger-Jones'.[34] But there is no evidence for this in the correspondence: Uttley seems to have been surprised by the offer. But did Spencer Jones, who had been aware of the existence of the disc 'for some time', and had known about the proposed telescope since 1931, send Uttley to Michigan in the hope of getting the disc on favourable terms? Uttley was definitely in the United States on official Ministry of Supply business, and all the documentary evidence says that his visit was ex-

tended so that he could investigate guiding systems for telescopes, not look for a second-hand mirror blank. A letter from Uttley to Spencer Jones dated December 1947 encloses his proposed American itinerary, which does not mention Michigan.[35] A series of letters of introduction for Uttley from Spencer Jones, written on 11 March 1948, does not include one to Michigan.[36] Spencer Jones did write such a letter to Goldberg on 16 March, but it mentions only telescope guiding systems, not mirror blanks![37] The possibility remains that at some time between 11 and 16 March, Spencer Jones became aware, or remembered, that a 98-inch disc was for sale, and then wrote to Goldberg, with the real aim of getting Uttley to inspect the disc. But there is no evidence for this.

Grinding the mirror

The 98-inch disc, plus the blanks for the secondary and the central plug, was transported to Britain by ship and unloaded on 8 August 1949.[38] Transporting the glass from the United States cost £186 7s 9d; this was all it cost the British taxpayer to obtain it.[39] Three organisations were considered for the contract to grind the mirror: Grubb Parsons, Cox, Hargreaves and Thompson and Bristol University. Grubb Parsons was judged to be the only firm capable of doing the job, because Cox, Hargreaves and Thompson lacked experience in making large optics and Bristol University would require a large outlay of money to get started. Also, not giving the contract to Grubb Parsons 'would be a big blow to their prestige'.[40] At the Board meeting of 10 March 1950, it was agreed that the Admiralty should be asked to place the contract with Grubb Par- sons, and the disc was duly delivered to the firm's Newcastle works on 6 April.[41]

As early as 18 April, Sisson was reporting that both surfaces of the disc contained cracks, and by the end of 1950 it was clear that these problems had become serious.[42] On 20 December, optical designer E. H. Linfoot visited Grubb Parsons to inspect progress in grinding the mirror. The most serious flaws in the glass appeared to be 'certain ropey cords of glassy material differing in constitution from the main mass of the disc'. Some of these 'cords' had cracks around them, caused by their different expansion properties from the rest of the glass. The most badly affected surface was the side which had been uppermost in the casting mould, where some cracks met the surface and there were numerous air bubbles. The lower surface showed no such cracks, but here 'the worst cord of all undulated to within 1.9 inches of the surface, presenting with its fractures the glittering appearance of a crystallised ichthyosaurus preserved in aspic'. It was agreed that the reflecting surface should be ground from the lower side, where there were no cracks and fewer air bubbles, and even after grinding 'there should still be nearly one inch of good glass between the "ichthyosaurus" and the surface'.[43]

Grinding began on 30 March 1951, using diamond milling. On 6 April, the operator broke into the 'ichthyosaurus' cord, which the diamond milling process had caused to form 'an extensive crack system... The original extension of the crack system amounted to some 18″'.[44] The opticians were not optimistic about the prospects for the disc; by 13 April they had 'reached the conclusion that if the glass was to be successfully figured it must be in a stable condition and it appeared unlikely that a disc which would not stand normal milling operations would make a satisfactory mirror for long term use in a telescope'.[45] On 12 June, following advice from Ira Bowen, Director of the Mount Wilson and Palomar Observatories – who had helped to design the optical system of the 200-inch telescope – they stopped the diamond milling work and resumed grinding the mirror with conventional abrasive techniques, because the latter caused less strain on the glass and so was less likely to introduce cracks.[46] The grinding was a long process. In November 1952, Sisson reported that even during conventional grinding, new cracks had appeared in the surface, and it was now necessary to grind for a further depth of nearly 1/8 inch.[47] Work was only completed in 1954. At the Board meeting held in February of that year, Redman reported that he had visited Grubb Parsons and believed that 'the mirror promised well... The firm had done a good job with a very moderate piece of glass...'.[48] By 9 August, the mirror had been successfully ground to a spherical surface, the type of surface required by the dual-purpose design at that point.[49]

The dual-purpose design meant that the mirror was ground to a focal ratio of f/3, and the telescope remained an f/3 instrument when it was finally built as a conventional Cassegrain in 1967. Fred Hoyle later claimed in his memoirs that the telescope's compact f/ratio was caused by the fact that 'the disk was so full of bubbles and striations that, to figure it at all, a lot of glass had to be taken out of the middle. ... leading to an unusually short focal length'.[50] This is an oversimplification. It is certainly true, as we have seen, that the blank was 'full of bubbles and striations', but these were not the original reason for the telescope's short focal length. Rather, the f/ratio was 'selected with the duplex telescope in mind', as Roderick Redman noted during deliberations over the optical design in 1955.[51] This was why, in Hoyle's characteristically blunt words, '...the plate scale was poor, the tube length was short, and the dome housing the INT was

small, which explains why the unfortunate Sir Isaac's memorial telescope is a little runt of an instrument.'[52] Although he later became a member of the Board of Management, in the earlier years of the project it is likely that he had only second-hand knowledge of the problems with the mirror. It is true, however, that when it was eventually decided to build a conventional Cassegrain telescope instead of a dual-purpose instrument, the cracks in the disc committed Grubb Parsons to leaving the mirror at f/3. As Spencer Jones's successor as Astronomer Royal, Richard Woolley, wrote, 'the makers are unwilling to change it to f5, as there are cracks which they think will develop if they take off ¾-inch of glass. My suggestion is that they parabolise it without altering the focus much – which they think they can do'.[53]

Considering this long saga of problems with the disc, it is tempting to speculate as to whether the Michigan astronomers offered it to Spencer Jones at a knockdown price, and then for nothing, because they secretly wanted to get rid of it, knowing all along that it was not good enough to be used in a telescope. That the Americans had long known the disc to be problematic is confirmed by a letter from George McCauley of Corning, who had originally cast this disc, as well as the 200-inch one for Mount Palomar and the 74-inch Radcliffe. The letter, sent before the mirror even arrived in Britain, stated that it had originally been cast in a new type of low-expansion glass, and warned Spencer Jones of 'undesirable features' in the glass, including 'cracks, parallel with and normal to striae whose expansion is obviously different from the main body of the glass'. McCauley did, however, note that the successful 200-inch Palomar mirror, which was made from the same glass and using the same technique as the Michigan 98-inch, showed the same 'undesirable features', but they had had no effect on the success of the 200-inch, 'nor was there observed any severe extension of the checks [sic] due to grinding operations'.[54] But we do not know how serious the flaws in the 200-inch disc were compared to those in the 98-inch. In any case, short of examining the records of the Michigan observatory, it is impossible to know whether they were indeed trying to rid themselves of a 'white elephant'.

The Woolley Era

Richard Woolley became Astronomer Royal, and therefore director of the INT project, in January 1956. Evidence in Woolley's papers in the RGO Archives reveals that even before his announcement in March of that year to abandon the dual-purpose telescope design, he was also having serious thoughts about abandoning the problematic 98-inch mirror.[55] As early as 12 January, George Sisson at Grubb Parsons wrote to him, saying: 'Many thanks for your kind reception on Tuesday. I will set in hand enquiries about the 100-inch disc and some design work for early submission to you for discussion'.[56] Just four days later, Sisson wrote that he had talked to Lawrence Pilkington, of Pilkington Brothers, the firm who had been first choice to cast the mirror blank before the donation of the 98-inch disc, who had said that he 'thought he could cast a 100-inch mirror disc of excellent quality'.[57] So just days after Woolley took over as Astronomer Royal, he was making moves about a replacement disc. It is likely that Sisson met Woolley at Herstmonceux a few days before these letters and informed him about the cracks in the disc. Even more likely, through his contacts with British and overseas astronomers, Woolley was aware of the problems with the 98-inch blank before he took up his post, maybe years before. As Director of Mount Stromlo Observatory from 1939 until 1955, he was well-connected with the international astronomical scene, and in particular, his time at Mount Wilson Obser vatory under a Commonwealth Fund Fellowship from 1929 to 1931 would have acquainted him well with leading American astronomers who had experience of building and using very large telescopes.

Fig. 5 Sir Richard van der Riet Woolley, Astronomer Royal from 1956 to 1971. As Chairman of the Isaac Newton Telescope Board of Management from 1956, he saw the project through to its completion in 1967.
By courtesy the Royal Astronomical Society.

Woolley does not seem to have immediately followed these enquiries up, but on 16 March he received another letter from Sisson, this time to say that Cairo University in Egypt had indicated that they were unable to decide on a site for their new 74-inch telescope, which Grubb Parsons had already built and which was in packing cases in England, and that they were thinking of terminating their contract for the telescope. This raised the interesting possibility that a ready-made 74-inch telescope might be available for the RGO, which would reduce the urgency of building the 98-inch.[58] Woolley suggested this to his immediate superior, Hydrographer of the Navy Commodore Kenneth Collins, emphasising that the building of the INT could proceed 'at leisure – or at least not under the desperate pressure of having no major telescope in England'.[59] Collins's response, however, was that the idea was 'unlikely to succeed in the present financial climate', and that unless the price of the 98-inch telescope could be reduced by some £250,000, 'to try to get two telescopes out of the Treasury in lieu of one, will be harder than getting water out of a stone'.[60] In addition, the 74-inch mirror was not without its own difficulties. Sisson reported that it had:

> a crack extending some distance round the edge and penetrating an inch or so into the substance of the glass. ... In the event we were able to make a perfectly good mirror out of the blank and no difficulties whatever were experienced in connection with the crack, which is indeed far less serious than the condition of the 98-inch disc.[61]

It is clear from this that Sisson still had serious concerns about the 98-inch mirror, which would explain his enthusiasm for starting afresh with a new 100-inch blank. In the event, the Egyptians decided not to release the telescope, apparently with national prestige in mind.[62] Woolley ruefully reported to Collins at the Admiralty:-

> It looks as if we shall after all be prevented from carrying out "operation Farouk" by the attitude of the Egyptians. I regret this very much, as it offered such a splendid opportunity for getting my crew, so to speak, some first-class sea-going experience.[63]

It is interesting to speculate what might have happened had the RGO got the 74-inch. As Woolley noted, the RGO would have had a large telescope right away. Experience with it might possibly have led the RGO to reconsider the wisdom of building a large telescope at Herstmonceux, before they were committed to building the INT there. But as events turned out, 1956 was not a good year to buy a telescope from Egypt. The British government's fury at Nasser's nationalisation of the Suez Canal the following July might have made acquiring a telescope from Egypt highly embarrassing, and it could even have been used as a political bargaining tool in the ensuing Suez Crisis.

Woolley then reverted to the enquiries he had begun in January about making a new mirror, but although he again expressed an interest in obtaining a 100-inch disc, he also seriously considered the possibility of building a 74-inch telescope, not in addition to, but instead of, a 100-inch. Just a week after hearing that the Egyptian telescope was not available, Woolley asked Sisson: 'How much would you charge, and what delivery could you give, for a brand new 74-inch?'[64] By 1956 Grubb Parsons had built three 74-inch reflectors in addition to the Egyptian: the Radcliffe, the Mount Stromlo and the David Dunlap Observatory 74-inch at Toronto Canada. All these 74-inch telescopes had a very similar design, and Woolley, the prime mover behind the building of the Mount Stromlo 74-inch, would have been well aware that Grubb Parsons could easily have turned out a 'standard issue' 74-inch telescope from existing blueprints.[65] There is a note of desperation in his phrase 'how much would you charge', as if he wanted a telescope as soon as possible and was not prepared to waste time on a piece of glass that might turn out to be a failure. Sisson replied, quoting a price of £141,000 and a possible completion date of early 1960. He also mentioned enquiries he had made of Pilkington, the German firm Schott and Corning in the United States, but noted that these enquiries had so far come to very little. He said that it was 'proving difficult to get anything at all definite out of Pilkington Brothers'; that Schott were unable to make a disc more than 15 inches thick (Grubb Parsons wanted a thickness of at least 17 inches); and that he had not heard back from Corning.[66] Sisson remained enthusiastic about building a 74-inch telescope: 'It would, of course, be much more straight forward [than a 100-inch] and eliminate a lot of unknowns'.[67] But on 23 April, Woolley wrote: 'Now that "operation Farouk" is off we must simply go ahead with the 98-inch Isaac Newton proposals'.[68] So Woolley dropped the idea of building a new 74-inch or 100-inch instead of the 98-inch sometime between 11 and 23 April 1956.

The issue of whether to go ahead with the 98-inch disc resurfaced in 1958, while funding for the project was temporarily brought to a halt by a period of financial difficulties caused by the Suez Crisis. Referring to a letter sent to him by Woolley on 9 March of that year (which was not found in the file), Sisson replied that 'there is no doubt that a 74″ similar to Mount Stromlo would cost very considerably less than a 98″ as planned'.[69] Then, a month later, Sisson made a

dramatic announcement. The 74-inch mirror for the instrument that Woolley had wanted to acquire from the Egyptian government had been sent back to Grubb Parsons for re-grinding, due to optical defects. Re-grinding had caused a 'massive crack in the lower half of the glass running from edge to edge almost across a diameter. This crack developed directly out of one of the existing cracks around the edge'. The mirror was now unusable, and Sisson admitted that it had caused him to 'think again about the dangers of touching the 98″. My original reluctance to risk changing the F. ratio now looks to be more reasonable than it first appeared.... it does seem possible to have a disc in a condition such that quite a small amount of working will trigger off a major crack system, all of which is perhaps as terrifying to us as to the Astronomer'[70] Woolley continued to favour abandoning the 98-inch and instead building a 74-inch telescope, which, moreover was cheaper and so more likely to be funded in the current stringent economic climate. Woolley said that with the approval of Redman and Plaskett, he would 'try to find out from the highest possible level whether there is any chance that we would get the 74-inch where we would not get the 98-inch. My own feeling is that the 74-inch is a major telescope and that it would be fully worth-while to open possibilities of some very good work'.[71] Redman replied in favour of going for a 74-inch: he remarked that an instrument of this size was 'now a very humdrum kind of telescope and will bring us no prestige. But we have lost so much face over this affair already that I doubt whether that matters'.[72] Plaskett concurred as well, although he cautioned that size did mean prestige in the non-astronomical world, and that support might be hard to get from the Royal Society for a 74-inch telescope. He also said that:-

> we are apparently already not in very good odour with Goldberg because no use has been made of his gift of the 98-inch disc. ... If we reject the 98-inch disc altogether, the name of British astronomy will probably stink in the not uninfluential circle of Goldberg and his astronomical friends. In the long run this will not matter, because by then they and we shall be dead, but in our life times some pretty valuable American astronomical concessions might be lost to us through the hostility of Goldberg and McMath.[73]

But Plaskett considered that there was an 'overwhelmingly strong' case for abandoning the 98-inch telescope and building a 74-inch instead. He suggested that Woolley write to Goldberg to advise him 'frankly' of the position he was in and why he wanted to opt for a 74-inch.[74]

Woolley appears never to have done this. Three months later, the Treasury announced that funding for the INT had been reinstated.[75] When the Board of Ma nagement reconvened the following April, Woolley told its members that they should be 'fully aware of the state of the present disk and the extent to which the cracks might matter before making any decision on replacing it or not'. Sisson was invited to this meeting, and he warned that the cost of a new disc would be at least ten per cent of the total cost of the telescope, and thought that the cracks in the 98-inch disc, 'although annoying, would not prove detrimental. Final figuring would confirm this one way or the other and this work would take about a year'. It was unanimously agreed that Grubb Parsons should have the contract for the final grinding of the mirror.[76]

Attending this meeting as a representative of the RAS was Fred Hoyle, who had recently been elected to the Plumian Professorship of Astronomy at Cambridge. Three days after the meeting, he wrote to Woolley:

> At Wednesday's Board meeting it seemed to me that, in spite of Sisson's reassurances, the position regarding the 98″ mirror is not really satisfactory. I would have said this much more strongly at the time but for your predecessor's [Spencer Jones] presence!

Hoyle advised that, because it might be necessary to purchase a new blank in the end, contingency funds should be incorporated in the contract proposal.[77] Woolley reassured Hoyle that his acquaintances at Mount Wilson had advised him not to worry about the cracks, and that 'I think what is proposed is right – that Grubb's should regrind and measure the cracks to see if they extend'.[78] In any case, by this time moves had been made towards the actual building of the telescope. On 16 April, Grubb Parsons had sent a formal tender for the construction of the instrument – including figuring the 98-inch mirror – to the Admiralty, and on 4 May Woolley confirmed to the Hydrographer that the tender was satisfactory.[79] Seven months later, the Admiralty awarded a contract to Grubb Parsons to build the telescope and deliver it to Herstmonceux.[80]

One more serious attempt to make Woolley think again about the mirror was made in 1960, and I have described this in more detail elsewhere, as it was embedded in a more general attempt by the Cambridge astronomer Ray Lyttleton and, very likely, his colleague Fred Hoyle, to make the government and the RGO reconsider the decision to build the telescope at Herstmonceux.[81] One prong of the attack came via the Cambridge historian and wartime intelligence of-

ficer Harry Hinsley, who, in a letter to the Admiralty wrote that the 'piece of glass' for the telescope was 'of questionable quality'.[82] The letter was forwarded to Woolley by the Hydrographer of the Navy. On the quality of the glass blank, Woolley replied: 'I went into this question very carefully with Mr. Sisson and I do not believe that anybody at Cambridge knows more about it than Sisson does'– artfully glossing over both Sisson's and his own grave doubts as to the suitability of the disc, and the fact that they had made enquiries about getting a new one![83] Woolley was now fully committed to the 98-inch disc and was not to be moved. The mirror was finally finished in April 1966, and Sisson seems to have been delighted with its quality.[84] The completed Isaac Newton Telescope was formally opened by H.M. The Queen on 1 December 1967.

Conclusion

For all its troubled history, and its only twelve years of service before being replaced, it would be very wrong to write off the 98-inch INT mirror as a failure. Early in its period of use, astronomers using the INT with the Michigan mirror installed made a discovery at the cutting edge of astrophysical research. In the summer and autumn of 1971, Paul Murdin and B. Louise Webster discovered a possible black hole orbiting the 9th-magnitude star HD 226868 in Cygnus, which was in the same position as the X-ray source Cygnus X-1.[85] Grubb Parsons had indeed 'do ne a good job with a very moderate piece of glass'.[86]

The flaws in the mirror blank did have one major consequence for the design of the telescope. As we have seen, the original dual-purpose design called for an f/3 mirror instead of the f/5 focal ratio normally used in large Cassegrain reflectors of this period. hen it was decided to build an ordinary Cassegrain instead of a duplex instrument, the flaws in the mirror blank discouraged the astronomers and opticians from changing it to an f/5. But it was due to its original design, not the faulty mirror, that the INT had an f/3 mirror in the first place. The cracks in the mirror merely committed the RGO to leaving it as an f/3 telescope – in the words of Fred Hoyle, 'a little runt of an instrument'.[87]

We have Spencer Jones's own admission that he had known since 1931 about plans for a large Michigan University telescope, and that in 1948 he knew that the mirror blank was lying unused in Michigan. But there is no evidence that he sent Albert Uttley to Michigan as an agent to obtain it, let alone that he knew that the disc was available at no charge. The British government, before it heard about the Michigan offer, had actually wanted the disc to be British made, and as they had already pledged £100,000 to build the INT, Spencer Jones could easily have afforded to spend £10,000 on a mirror made by Pilkington. Spencer Jones's motive for accepting Michigan's offer seems to have been to save taxpayers' money, which is what the Treasury mandarins in Whitehall wanted him to do. It is true that the government were also keen, where possible, to strengthen relations with the United States; in the late 1940s, the war-torn economies of Europe, including Great Britain, were desperate for American financial aid, and so Barlow was probably being sincere when he said that 'we should welcome anything which prompted friendly relations with the USA'.[88] Even so, much of the blame for obtaining what eventually proved to be a flawed disc must lie with the parsimony and hypocrisy of the Treasury, who, for all their talk of buying British, had no problem with 'having to go to America for a large chunk of glass' when it was available for nothing.

After he took over as Astronomer Royal, Richard Woolley twice seriously considered – indeed, made practical moves towards – abandoning the 98-inch disc, but each time he changed his mind. Whereas Spencer Jones was a traditional positional astronomer, Woolley was an astrophysicist, who had specific research programmes that demanded a large telescope. He therefore wanted the INT to be built without further delay and was not prepared to waste time on a mirror that might not be up to standard when used under the stars. Within days of becoming Astronomer Royal, he enquired about having a new 100-inch blank made. In the spring of 1956, he jumped at the chance of obtaining a ready-made 74-inch telescope from the Egyptian government. When this came to nothing, partly because the Egyptians changed their mind about selling the telescope and partly – again – because of government financial constraints, he asked Grubb Parsons how much they would charge for an off-the-shelf 74-inch. Two years later, while government finances for the INT project were temporarily suspended, Woolley again sounded out the possibility of building a brand-new 74-inch telescope instead of the 98-inch. The reasons for his retreat this time are more complex. Economics may provide part of the explanation again: abandoning the 98-inch project now, after so many years, might well have led to a loss of credibility for optical astronomers in the eyes of the government. Hoyle has claimed that Woolley made just this point in a private conversation, saying that stopping the project now would drastically reduce astronomers' prospects for funding in the future, though Hoyle's account of the INT story contains several major inaccuracies;

including, in this case, the claim that the issue was whether 'to have some sort of a telescope or none', which is clearly not true. [89] Additionally, at the time, Plaskett warned Woolley that it might be difficult to get support from the Royal Society for a 74-inch telescope – the Royal Society being very influential in the allocation of science funding in the days before the Science Research Council was set up in the 1960s. But fear of offending the Americans, who had donated the 98-inch disc, was probably just as important in saving the 98-inch telescope's future. Woolley may have taken to heart Plaskett's warning about offending Leo Goldberg, who, as one of the founding fathers of the Association of Universities for Research in Astronomy (AURA), Vice President of the International Astronomical Union from 1958 to 1964 and, slightly later, Vice President of the American Astronomical Society (1959-1961), indeed moved in a 'not uninfluential circle'.[90] His reaction to the news of the 98-inch disc being discarded might have done a lot of damage to the reputation of British astronomy abroad. Indeed, as early as 1950, Plaskett had written to Spencer Jones, saying that he had recently had some hints from the Americans about Britain's lack of appreciation of the donation, and that Judge Hulbert 'wonders what we are doing with his gift'.[91]

We can also detect in this episode – and, indeed, earlier on in the saga – that large telescopes meant prestige, for governments as well as astronomers. Both Redman and Plaskett alluded to this in their responses to Woolley's suggestion of building a 74-inch telescope instead of the 98-inch: Redman remarked that a 74-inch was 'now a very humdrum kind of telescope and will bring us no prestige', and Plaskett too said that size meant prestige in the non-astronomical world.[92] Prestige may well have been a factor in the decision to build a 100-inch telescope in the first place. Although the British climate was used to justify building a 100-inch telescope instead of a 72-inch, there are grounds for arguing that prestige – national and scientific – was a factor in opting for the larger telescope. 100 inches was the aperture of the largest operational telescope in the world, the Hooker reflector at Mount Wilson (the 200-inch at Mount Palomar was not dedicated until 1948), and the astronomers would have been well aware of this. A British 100-inch telescope would have equalled the famous one at Mount Wilson. According to Sadler, Spencer Jones had explained to Barlow the 'marked inferiority of the United Kingdom' with regards to large telescopes.[93] Plaskett certainly saw a large telescope as a means of keeping the Union Jack at the forefront of astronomy. In his original 1946 speech, Plaskett had expressed the hope that with a central university observatory with its big telescope, 'Britain would once again take its place in the van of astronomical research'.[94] This keeping up with the astronomical Joneses agreed well with the government's own agenda for science at the time. The civil servants, even allowing for the fact that the astronomers made a strong case to them for a 100-inch telescope, created no difficulties when they were asked to support the project. This is perhaps not surprising, because Clement Attlee's Labour government, elected just a year before the decision on the telescope was made, saw science as crucial to Britain's future development. In particular, Sir Alan Barlow was Chairman of a committee on scientists set up by the Attlee government in December 1945, which believed that science was central to the country's future 'if we are to maintain our position in the world and restore and improve our standard of living...'.[95] Barlow strengthened his case for the 100-inch telescope to the Chancellor on the grounds that an instrument of this size was essential for Britain to recover its 'former pre-eminence in astronomy'.[96] Astronomers and political leaders were agreed that a 100-inch telescope would help Britain lead the world in science once more.

We can therefore sum up the saga of the 98-inch Isaac Newton Telescope mirror as a largely political story, with a measure of government bean-counting thrown in. The 98-inch mirror was saved by astronomers' fear of losing funding in the long term and probably by their equally strong desire not to offend the Americans. Scientific and national prestige were at stake in the decision to build a 100-inch telescope in the 1940s, and, later, in Woolley's decisions as to whether to reduce the size of the telescope to 74 inches. But it should be noted that the government's desire to save money where possible, regardless of the cost to science or prestige, was also a factor in the story. The government wanted the prestige that a great telescope offered, but when it came to the test, financial economy took first place. The politics of 'a large chunk of glass' were inextricably infused with the economic troubles of post-war Britain.

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The abbreviation 'RGO' in the notes below refers to papers held in the Royal Greenwich Observatory Archives, Cambridge University Library, Cambridge, UK. The initial number after 'RGO' refers to the papers of a specific astronomer – RGO 9: papers of Harold Spencer Jones, RGO 10: papers of Sir Richard Woolley, RGO 37: papers of Roderick Redman. The number after the stroke (/) indicates a folder number in the papers of the relevant astronomer.

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The Author

Lee Macdonald, BA (Hons.), MA, MPhil, FRAS graduated from Cambridge University in 2008 with an MPhil degree in History, Philosophy and Sociology of Science, Technology and Medicine, and has also done research at the Science Museum in London. This article is based on parts of his Cambridge dissertation on the origins and construction of the Isaac Newton Telescope and includes material that did not make it into the dissertation due to length restrictions. A long-time amateur astronomer, Lee Macdonald is the author of *How to Observe the Sun Safely* (Springer, 2003); a new, revised and expanded version is to be published by Springer in 2012. He is also Deputy Director of the British Astronomical Association Historical Section.

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