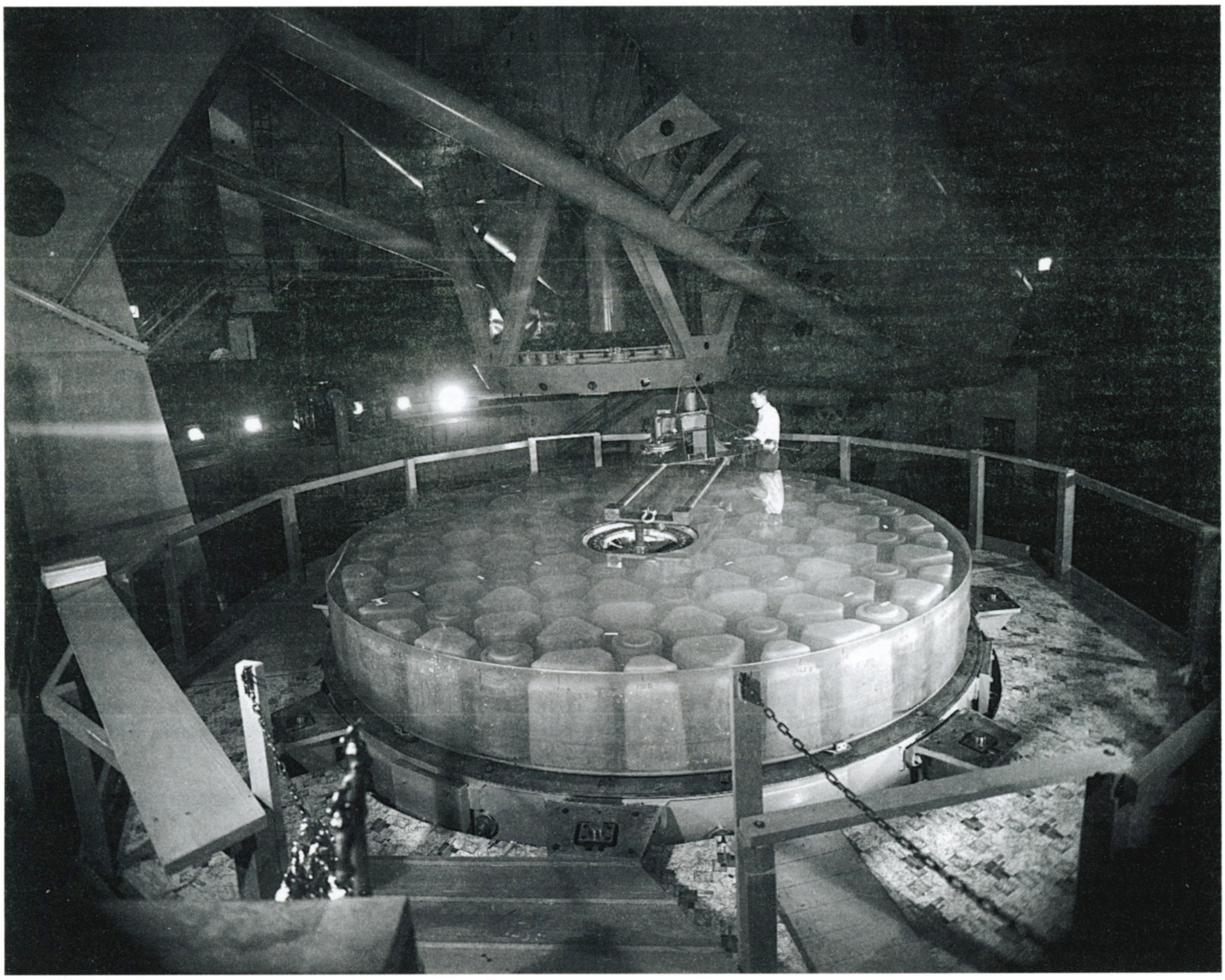
Journal of Astronomical History and Heritage



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Cover: Don Hendrix polishing the 200-inch primary mirror in the dome at Palomar, 1947-8. (Courtesy of the Huntington Library) See pages 7-8.

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Don Hendrix, master Mount Wilson and Palomar Observatories optician

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Abstract
Don O Hendrix, with at most a high-school education and no previous experience in optics, became an outstanding astronomical optician at Mount Wilson Observatory. He started making Schmidt-camera optics for spectrographs there in 1932, and ultimately made them for all the stellar and nebular spectrographs used at the prime, Newtonian, Cassegrain, and coudé foci of the 60-inch, 100-inch, and Palomar Hale 200-inch telescopes. He completed figuring and polishing the primary 200-inch mirror, and also the Lick Observatory 120-inch primary mirror. Mount Wilson and Palomar Observatory designers Theodore Dunham Jr., Rudolph Minkowski, and Ira S Bowen led the way for many years in developing fast, effective astronomical spectrographs, based on Hendrix's skills.

Keywords: *coudé spectrographs, large reflecting telescopes, Schmidt cameras, spectrographs*

1 INTRODUCTION

Don O Hendrix (Figure 1) was the great Pasadena optician who completed the 200-inch primary mirror of the Hale telescope, ground, polished, and figured all its secondaries, and in addition made the optics for the 48-inch Palomar Observatory Schmidt telescope. He also made the optics for the 120-inch Lick Observatory Shane reflecting telescope, and for all the Schmidt cameras used in the spectrographs of the 60-inch and 100-inch reflectors, and of the Hale telescope up to the time of his death in 1961. In all, he made more than fifteen times as many sets of Schmidt optics as Bernhard Schmidt himself made. Hendrix was the undisputed master of Schmidt optics in the world, from Schmidt's death in 1935 until his own death in 1961. Ira S Bowen, the Director of Mount Wilson and Palomar Observatories (henceforth MW&PO), who was noted for his level-headed taciturnity and was never given to fulsome praise, wrote that Hendrix had developed an "... extraordinary skill in hand figuring of large, non-spherical surfaces required in many modern optical designs ..." and that the high efficiency optical equipment in place at the observatories at the time of Hendrix's death was due in large part to his skill and ingenuity (Bowen, 1962a:45).

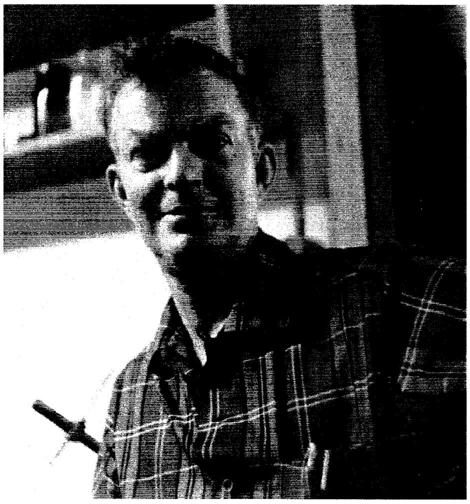

Figure 1. Don Hendrix *c.* 1948–1949, about when he finished the 200-in. Hale telescope primary mirror. (Author's Collection)

2 BIRTH, YOUTH, AND EDUCATION

Hendrix, christened Don Osgood Hendricks, was born in Fort Worth, Texas on 1905 February 6. His father and mother, Frank O. and Julia Ralls Hendricks, born in Hendricks County, Indiana, and Ralls County, Missouri, respectively, were descendants of pioneers, and when their home in Fort Worth burned down, they loaded their children in their car and headed west across the desert to Southern California in 1921. Frank Hendricks had been a bank clerk and later a telegrapher in Texas; according to family legend he shortened his 'handle' to Hendrix to save a few letters in tapping it out in Morse code, and later legally adopted that short form as his family name. They settled in the then largely rural area north of Los Angeles and Glendale, near the villages of La Cañada, La Crescenta, and Montrose, and for some years his parents operated a little country store at a crossroads called Verdugo Junction. Don had completed grade school and two years of high school in Texas; he took his final two years at a high school somewhere in this area. (He wrote on a security clearance form during World War II that it was at Glendale High School, but there is no record of him there now under either the name Hendrix or Hendricks.) Again according to family stories, he rode a horse to and from school.

3 THE MOUNT WILSON OPTICAL SHOP

After graduation, presumably in 1923, Hendrix got a job installing radios (then a fairly new consumer device) and radio transmitters in the Pasadena-Glendale area, working for the Hancock Music Co. Evidently he was quick to learn, skillful, and hard working, as he certainly was later at the Mount Wilson Observatory (henceforth MWO) optical shop. In 1929 he married Phyllis Louise Butcher of La Crescenta. But during the Great Depression the Hancock Music Co. fell on hard times, and eventually went bankrupt, probably in 1931. For several weeks Hendrix and some of the other employees worked without pay, in a desperate attempt to save their jobs, but they could not keep it up very long. Hendrix heard of a temporary job opening at MWO, went there and was hired. Marcus Brown, who had started on the MWO staff as a truck driver, had shifted to an apprentice-level job in its optical shop at 813 Santa Barbara St. in Pasadena in

1928 to learn the optician's trade. In 1929 Brown was transferred to the California Institute of Technology (Caltech) payroll, as one of the first members of the group that would build the 200-inch telescope (Adams, 1929a), and in 1931 he was moved to its campus to head the optical work on the big mirror (Woodbury, 1963:273-82). Walter S Adams, the MWO Director, soon had a new apprentice, Norman Deewes, all lined up to take the job, but at the last moment he was offered a scholarship to go to college, and decided to accept it instead. Within a week Hendrix got his chance through his father's old-boy network. Frank Hendricks (as he was then known at MWO) had been hired as a temporary truck driver there in 1929 in place of one of the regular employees who was too ill to work for many months (Adams, 1929b), and quickly became one of the gang with the other support staff employees. Through them he learned of the unexpected opening in the optical shop and told his son about it. Don Hendrix walked in, applied for the job (which Adams was anxious to fill quickly as the budget was about to be closed), made a good impression, was hired, and began work on 1931 April 22 at a salary of $110 a month. His qualifications were that he was "... known to our opticians, and ha[d] some slight experience in optical work." (Adams, 1931a). That was how Hendrix found his niche during the worst part of the Great Depression, through a series of lucky breaks, and how MWO found its great optician. He did so well right from the start that after little more than two months on the job he received a raise to $125 a month (Adams, 1931b).

The head optician at MWO when Hendrix started was W L Kinney; he and his assistant optician, John S Dalton, had begun work at Santa Barbara Street under George Willis Ritchey more than two decades earlier, when the 60-inch reflector was nearing completion, and they had both worked on the 100-inch as well. They were experts in making the prisms, lenses, and mirrors that went into the spectrographs, photometers, and other optical devices built in the MWO instrument shop. Both of them knew all about cleaning, replacing, and resilvering optics in existing instruments, and about keeping all the telescopes on the mountain (including the solar telescopes) in tip-top optical shape. Hendrix, a taciturn perfectionist, must have learned the skills of his new trade well with them as his teachers. An early photograph, probably taken in 1932 or 1933, shows him working at a gang optical machine, simultaneously grinding four small lenses (Figure 2). That was just about when the little world of astronomical optics began to change dramatically.

4 SCHMIDT CAMERAS

On 1931 October 1, Walter Baade, the 38-year-old German astronomer who had been the top staff member at Hamburg Observatory, joined the Mount Wilson group of observational astronomers. With him he brought the 'secret' of the very new Schmidt camera, invented only the previous year by his older friend, the morose, one-armed optician Bernhard Schmidt. In 1929 Baade and Schmidt had spent four months together, on a long sea voyage to the Philippine Islands, preparing for and observing a total solar eclipse, and then returning to Germany. Baade, an enthusiastic, talkative scientist, had told Schmidt over and over again of the need for a fast, wide-field reflecting telescope. The Hamburg 40-inch reflector, the largest research telescope in Europe, and the 60-inch and 100-inch telescopes he was soon to use at Mount Wilson, have paraboloidal mirrors, which produce perfect, achromatic stellar images on axis. But they are afflicted with coma, an inherent aberration of that type of mirror, which degrades the images away from the axis, and thus cannot provide a single good exposure of a wide field of stars such as a star cloud, the extended region around a globular cluster, or a nearby galaxy. The faster the focal ratio of a reflector, the worse this coma aberration is, as Baade and all astronomers knew. Soon after their arrival back at Hamburg, Schmidt had already conceived the basic idea for his wide-field system, and was making his first "... coma-free reflecting telescope ..." as he called it (Osterbrock, 1994:7-8). The heart of it was a thin glass, aspherically-figured 'corrector plate', placed at the centre of curvature of a *spherical* mirror (which has *no* coma or astigmatism with the stop at that position). By the end of 1930 he had finished his first successful Schmidt camera, a 14-inch aperture, f/1.75 system (Schmidt, 1932).

Figure 2. Don Hendrix at the Mount Wilson Observatory optical shop in the early 1930s. (Courtesy of the Huntington Library)

It was this 'secret' that Baade brought with him to America. In fact it had already been published earlier that year in a brief paragraph in the Hamburg Observatory annual report for 1930 (Schorr, 1931). But as soon as Baade arrived at the MWO offices to begin work on 1931 October 1 he told the astronomers there about the wonderful new wide-field camera. Probably he had a print of the photograph of a star field in Cygnus with him, which Schmidt had taken with his new camera, and the tiny, coma-free star images on it provided a very convincing sample of what the new system could do. Soon Baade found himself talking with John A Anderson, the Mount Wilson instrumental physicist whom George Ellery Hale had placed in charge of the Palomar 200-inch project as executive officer. Although Schmidt's conceptual breakthrough was completely unexpected by traditional optical-design experts like Anderson, once he heard the basic idea he grasped it immediately and could fill in the details quickly. On October 5, just five days after Baade's arrival, Anderson wrote to Hale to tell him of the brilliant new idea, which he knew would "interest" him, meaning that they would have to have a Schmidt camera at Palomar (Anderson, 1931). They did get one five years later, an 18-inch, f/2 Schmidt built on the Caltech campus, but our concern in this paper is with the optics Don Hendrix made in the MWO optical shop and elsewhere.

5 HENDRIX'S SCHMIDT CAMERAS

Anderson and all the other instrumentally-oriented astronomers at MWO realized that Schmidt cameras would be ideal for spectroscopy. The chief requirements for a good spectrograph are that it have a large-aperture, optically fast camera that can produce sharp images over a wide range of wavelengths. These are exactly the properties of a Schmidt, while the lens cameras then in use, if they were fast, were built around thick, heavy lenses which absorbed large fractions of the light passing through them, and had bad chromatic aberrations. Soon Sinclair Smith, a young member of the MWO staff, designed a nebular spectrograph to be used at the Cassegrain focus of the 60-inch (or of the 100-inch, where it later was used). It was a prism instrument, as all the Mount Wilson nebular spectrographs then were, with a 2-inch, f/1 Schmidt camera. Both the prism and the corrector plate were quartz, and the collimator was an off-axis, aluminized, paraboloidal mirror, so the spectrograph transmitted ultraviolet light down to λ3000, the atmospheric cut-off. This was another advantage of a Schmidt over conventional lens-spectrographs of that time. A disadvantage is that the focal surface is spherical, not flat; Smith apparently used film pressed over a mandril of the correct curvature mounted at the focal point inside the camera. He described the new spectrograph as being completed and tested in the laboratory in an oral paper he gave in 1934 December, and by 1935 he was getting spectra of M 32 and other elliptical galaxies with it. The images were excellent, Smith (1934, 1935, 1936) reported.

Very probably Hendrix made the optics for this first Schmidt camera used at MWO. In their research papers astronomers did not then name the technicians who had provided their instruments, and the MWO annual reports written by Walter S Adams, the Director, described new spectrographs briefly as they were constructed but seldom revealed who had built what. Kinney had retired on 1931 July 31, leaving Dalton as the senior optician and Hendrix as his assistant, the only two men in the optical shop. Adams did mention some of the jobs Dalton carried out, all of them traditional mirrors, prisms, and lenses. Probably the young, eager Hendrix was the optician who was assigned to learn how to produce the Schmidt optics from the start. He completed his first Schmidt camera, a small, relatively long focal-ratio instrument, in 1932, but nothing was published about it and it was evidently an experiment and learning experience for him. Harold A Lower, an amateur telescope-maker who later, with his father, Charles A Lower constructed an early Schmidt, wrote that Hendrix had shown him the camera and photographs taken with it in the spring of 1933 (Lower, 1939). Hendrix had described Schmidt cameras and the methods he used for making them in a talk to an amateur telescope-makers' group in Riverside, California, earlier that spring (Anon, 1936; Christie, 1939a, 1939b). Its founding president, H Page Bailey, a dentist by profession and a dedicated amateur telescope-maker, is often credited with having constructed the first Schmidt camera in America in 1932, an 8-inch aperture, f/2.4 instrument, but no statement seems ever to have been published about photographs taken with it (Smiley, 1938). Bailey had met Anderson in the summer of 1931 and had shown him and Russell Porter the impressive 15-inch Cassegrain reflector he had made (Lindsay, 1931; Cook, 2001). They looked it over again in the spring of 1932 at Bailey's observatory in Riverside, California (Ingalls, 1932). Between these two visits, Anderson and Porter had also met him at San Bernardino Valley College in mid or late 1931 October, to inspect the 16-inch telescope he had built for it (Anon, 1931). Bailey almost certainly learned of the Schmidt principle from Anderson after Baade's arrival in Pasadena, probably at their meeting in October. Very likely Anderson had sent Hendrix to speak to the group in 1933 at Bailey's request. Certainly just a few years later Hendrix was widely known as the person who had made all the MWO Schmidts. It seems clear that Dalton was content to continue with the older lens optics in which he was so experienced.

Also in 1934, Theodore Dunham Jr., a MWO high-dispersion spectroscopist and instrumentalist, designed the first coudé spectrograph for the 100-inch to use a Schmidt camera. It was built around an excellent 4⅜ × 5½-inch aluminized pyrex plane grating ruled at Robert W Wood's laboratory at Johns Hopkins University. The Schmidt camera optics, with a 4.3-inch aperture and 31-inch focal length, were made at least in part by Dunham himself. A key point in his design was that it was an "off-axis Schmidt," with the plateholder outside the collimated light beam from the grating to the spherical mirror (Dunham, 1934a). This is achieved by making the corrector plate for a camera with a diameter more than twice as large as the beam diameter, and then cutting a circular, off-axis segment from it to use in the spectrograph. Dunham used this instrument experimentally in 1934-5, but in 1936 it was rebuilt to incorporate a better set of optics, made by Hendrix, with a 32-inch focal length, and put in use in that form in 1937 (Figure 3).

Figure 3. Don Hendrix, Melvin Johnson, Ralph Dietz, and Theodore Dunham Jr. (left to right) in the optical shop, about 1938. (Courtesy of the Huntington Library)

Hendrix also very probably made the two other Schmidt cameras, with much shorter focal ratios, which were used only very briefly at the 100-inch coudé spectrograph. One was a 2.8-inch, f/1.8 system intended for use at either the Cassegrain or coudé focus. With it at the coudé in 1934 Dunham or one of the other Mount Wilson astronomers recorded the spectrum of Antares to λ11000 with one of the very slow infrared photographic emulsions then in use, but no result of this experiment seems to have been published. The other was an extremely fast 4.1-inch, f/0.57 Schmidt camera, completed in 1934-5, which was evidently a failure, for no results with it were reported (Dunham, 1934b). Henry Norris Russell, the famous Princeton theoretical astrophysicist who had close ties with MWO, described this f/0.57 as still "under construction" in the spring of 1935 (Russell, 1935). The higher-order aberrations grow rapidly as focal ratio becomes faster, and probably that was the problem. The coudé focus was much more suited to longer focal-length cameras, to provide high dispersion, high-resolution spectrograms. Hendrix made the optics for two more such cameras, one an off-axis Schmidt with 73-inch focal length, the other a 114-inch focal-length spherical mirror with no corrector plate at all. Both were used at the 100-inch coudé, which meant the beam was approximately five inches in diameter. At such a slow focal ratio, spherical aberration is negligible compared with the grain size in the photographic plates then in use. Hence there was no glass in the light path at all, and the 114-inch camera was effective right down to the atmospheric cut-off (Adams, 1941). The plate-holders for these coudé cameras were curved to hold the narrow photographic plates used in them to fit the focal surface.

Rudolph Minkowski, who came to Mount Wilson in 1935, first as a visitor, later a staff member, designed a nebular-type spectrograph to be used at the Cassegrain focus of either of the two large reflectors. It was built around a 2-inch, f/3 Schmidt, made by Hendrix and first used by Baade and Minkowski in 1936 at the 60-inch to obtain spectra of Comet Peltier. This spectrograph, like those at the coudé, had an off-axis paraboloidal mirror collimator (the long focal ratio of the Cassegrain, f/16, made this design attractive) and two prisms (highly efficient plane gratings were still almost unobtainable). It used film in a curved plateholder (Baade and Minkowski, 1936).

These small nebular spectrographs were faster, covered a much wider range of wavelengths, and produced superior images to the Rayton-lens spectrographs then being used by Milton Humason to obtain the red shifts of faint, distant galaxies. He had taken spectrograms of M 32 and a few other elliptical galaxies with Smith's f/1 instrument, and had seen how good they were, but he wanted an even faster spectrograph (Humason, 1936). The f/0.57 conventional Schmidt had not worked out. In this situation Dunham designed a 2-inch, f/0.67 "thick-mirror Schmidt," in which the spherical mirror is on the back surface of a piece of glass, whose front surface, or face, is plane. Light passes through the corrector plate, continues in air to the face of the thick mirror, continues through the glass to the spherical mirror, and is reflected back to the focal surface at the face of the glass. Because the light path ends in the glass, the convergence of the rays produces a shorter focal length than in the equivalent "air Schmidt". Hendrix made this thick-mirror Schmidt, which was in use by 1939 at the Cassegrain focus with the nebular spectrograph which Minkowski had designed (Hendrix, 1939).

Dunham, a great advocate of Schmidt cameras in spectroscopy, was a scion of a wealthy New York family. As a result he had the income of a non-profit family foundation, the Fund for Astrophysical Research, to use to finance instruments and projects which he considered worthwhile (Dunham, 1938, 1940). He made an arrangement with Adams under which the Fund would buy raw materials (chiefly glass disks) and at times pay one or two opticians to work in the MWO optical shop under Hendrix's supervision. He would spend some of his time on Dunham's Fund projects and MWO would provide the work space and the tools; in exchange the Fund's opticians would spend part of their time working on MWO projects with him. Ralph Dietz worked with Hendrix under this arrangement beginning in 1938 February, and probably helped with the 73-inch coudé camera, as he certainly did with the 114-inch.

During 1937–1938 Hendrix also completed the optics for an f/1, 3-inch aperture air Schmidt, as they came to be called to distinguish them from the thick-mirror systems. It was used in the nebular spectrograph, stopped down to f/1.5, with a field-flattening lens just in front of the photographic plate (Minkowski, 1944). That same year he also finished the optics for an f/1, 9-inch aperture air Schmidt. It probably was intended for an instrument Dunham hoped to build, for there is no further record of it in the MWO annual reports.

By 1938 Hendrix was recognized throughout the astronomical world as an outstanding optician, who could make any kind of a mirror, lens, prism, and especially, Schmidt camera. Their corrector plates, with aspherical surfaces, were considered extremely difficult to make, but somehow he had mastered them. He had the right combination of intelligence, manual dexterity, concentration, desire, drive, and ability to learn from each job he did. Frequent testing of the corrector plate as he proceeded with figuring it was part of his technique, but he had also learned to extrapolate just how far to go before testing again, pushing the job forward but always staying in control of it. In 1938, John Strong, one of the physicists who had developed the process of aluminizing glass mirrors by deposition in a vacuum, published his authoritative book, *Procedures in Experimental Physics.* He had written most of it himself, with three chapters by other physicists on their specialties included in it. One other chapter, sixty-four pages long, on laboratory optical work, was based almost entirely on Hendrix's procedures, as he described them to Strong. It is the best source for learning the techniques Hendrix used, and in particular the last few pages of the chapter describe the methods he employed to make Schmidt corrector plates (Strong, 1938:29-92).

In the fall of 1937, when Richard S Perkin was founding his new optical company which became so famous after World War II as Perkin-Elmer, he tried to hire Hendrix away from MWO to become his head optician. Frank E Ross, the astronomer who was the top telescope and astronomical camera designer of that time, considered Hendrix far superior to the other optical workers of that day, Robert Lundin and J W Fecker, and thought that if Hendrix took the job, Perkin-Elmer would quickly become the best supplier of astronomical optics in America. But Adams knew he could not afford to lose him, and in Ross's phrase, "came across with the goods", a big salary raise (at least in the MWO frame of reference), and Hendrix stayed in Pasadena (Perkin, 1937; Ross, 1937).

6 THE SCHMIDT CAMERA ARTICLE

Then in 1939 Hendrix and William H Christie (Figure 4) published an article in the *Scientific American* on applications of the "Schmidt principle" in optical design, describing and illustrating many variants of Schmidt cameras. Christie, born in England like Hendrix's wife, was a Mount Wilson staff astronomer; and their two families were close friends. Most of the ideas and all of the descriptions of how the optics could be made came from Hendrix, while Christie organized the material and wrote the text (Hendrix and Christie, 1939). It included an excellent, large-format nearly full-page figure showing twenty-two different types or layouts of Schmidt cameras and spectrographs built around them. The article contained a wealth of practical details on making Schmidt corrector plates, and included a description of how to test an entire system in auto-collimation, or by scanning a pentaprism across it with another viewing telescope, if a large flat was not available (see Wilson, 1999:87-89).

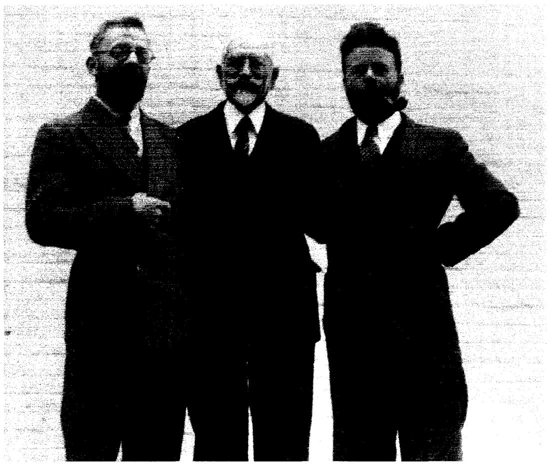

Figure 4. William H Christie (left), MWO staff astronomer and Don Hendrix's co-author, with Ferdinand Ellerman (centre) and Olin C Wilson (right), the three 'beards' of the MWO staff in 1939 (Courtesy of the Huntington Library)

Their article created a minor *furor* in the telescope-making community, for Hendrix and Christie began by describing Schmidt's "great invention," and then went on to say that although several articles had been written about Schmidt cameras since then, "... little that is new has been included in these discussion." Naturally, the authors of those articles were not pleased. One of them, Charles H Smiley, Professor of Astronomy at Brown University, wrote a hot letter to Albert G Ingalls, Associate Editor of the magazine, complaining that the article did not do justice to earlier workers in the field, and demanding to publish a "criticism" of it (Smiley, 1939a). Smiley sent a copy of his letter to Christie, who replied more politely but firmly denying the Professor's comments. Christie admitted that their opening statement was "... a little misleading as it stands ...", but insisted that what they had meant was that according to Baade, Schmidt had independently conceived of the variants such as the thick-mirror Schmidt before anyone else, but had not published them. Christie closed by saying that he had shown Smiley's letter to several other MWO staff members, and they had all agreed that he was right and his critic was wrong (Christie, 1939a)! This comment exemplified perfectly the MWO attitude of that time: that it was the seat of all astronomical knowledge. Smiley's main points were that MWO astronomers had been working on Schmidt cameras since 1932 but had not revealed until then any of the details which would help others get into the game too, and that Hendrix and Christie had not referred to published papers by others, and in particular had not given the analytic formula that specifies the shape of the aspherical corrector plate, then still regarded as quite esoteric (Smiley, 1939b, 1939c). Both were justified, if overstated, complaints, and although what they had written was not a scientific research paper, but rather an illustrated, semi-technical article addressed to amateur telescope makers. Hendrix and Smiley should at least have referred to the quite detailed theoretical analysis by Bengt Strömgren that had been published four years earlier (Strömgren, 1935). But it was in German and they probably realized that even if the *Scientific American* editor had not cut out the reference, few of the amateur opticians would have been able to lay their hands on a copy of it, much less read and understand it. Ingalls ultimately published a shortened criticism as Smiley rewrote it (Smiley, 1939d), and Christie's measured response to it (Christie, 1939b) in later issues of *Scientific American.*

James G Baker, just beginning his career as an outstanding optical designer at Harvard, also wrote to *Scientific American*, correcting a few minor errors in the theoretical details of the treatment of the thick-mirror and solid mirror Schmidt cameras in Hendrix and Christie's article. Baker warned amateur readers of the magazine that making the optics of any Schmidt was a very difficult process, and then went on to describe in fairly technical language the design of the advanced cameras he was then working on (Baker, 1939). Christie had been "bewildered" by the vehemence of Smiley's attack and still thought that his criticisms were groundless (Christie, 1939c). This episode undoubtedly heightened Hendrix's reluctance to go public, and he apparently never wrote another popular article, with or without co-authors.

However, over the years this one article he had written was widely read by amateur and professional opticians for the copious information it contained, particularly after it was reprinted in *Amateur Telescope Making (Book Three)*, a collection of "... contributions to amateur precision optics for advanced amateurs and professionals." (Ingalls, 1961:354-365). Unfortunately not all large-telescope project managers studied and understood it, for the pentaprism test described in it (which is applicable to any reflecting telescope) was not used on the Hubble Space Telescope before it was launched in 1990. If it had been, it would have revealed immediately the spherical aberration, which could have been corrected on the ground rather than later, and much more expensively, in space (Wilson, 1999).

7 THE PALOMAR 48-INCH SCHMIDT TELESCOPE

In 1939 Hendrix began his biggest job up to then, the 72-inch diameter spherical mirror for the 48-inch, f/2.5 Palomar Observatory Schmidt camera. It was the big telescope that Anderson had foreseen for Palomar back in 1931, when he wrote Hale immediately after learning about Schmidt's new concept from Baade. The Mount Wilson astronomers, led by Hubble, had recommended strongly that a "big Schmidt" be built, to find and locate accurately the faint stars, nebulae, galaxies, and clusters of galaxies on which the "big eye," with its great light-collecting power but limited field, could then be used (Hubble, 1937a, 1937b; Mason, 1937). The Palomar 18-inch Schmidt had proved the principle. With the Caltech optical shop fully engaged in shaping the 200-inch primary mirror, Hendrix began making the 48-inch optics in the MWO shop (Figure 5). Dietz assisted him, and they completed the spherical primary mirror in five months during 1939-40. Hendrix then began work on the 48-inch corrector plate but soon laid it aside as the MWO shop, and much of its scientific staff, began shifting to defence and then wartime technical development work.

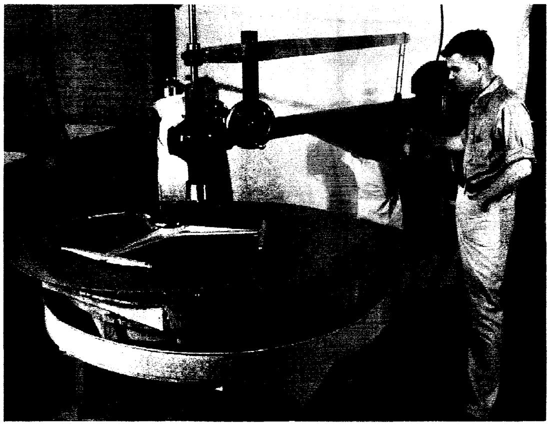

Figure 5. Don Hendrix *c.* 1938 doing preliminary work on a corrector plate for the 48-inch Schmidt telescope. (Courtesy of the Huntington Library)

8 WORLD WAR II

The Trustees of the Carnegie Institution of Washington, which owned and operated MWO, and particularly their President, Vannevar Bush, were strongly committed to the Allied cause in World War II. Especially after the fall of France in 1940, they realized that the United States would soon be at war with Nazi Germany. They began converting their scientific resources from research to weapons development programs. Bush became President Franklin D. Roosevelt's personal scientific adviser, and the tsar of American science during the war. Optics were especially important, particularly telescopes and prisms for range finders, and cameras for aerial photography. Hendrix became a technical consultant and teacher, who travelled to several large optical factories, including the Frankfort Arsenal in Philadelphia and the Spencer Lens Co. in Buffalo, to help them improve their manufacturing and testing techniques. Later he went to Wright Field in Ohio, and to Matagordo Air Base in Texas to see gunnery sights he had helped develop at MWO in use, or to find ways to improve them. Dalton retired in 1942 October, and Hendrix succeeded him as the head of the optical shop. In reality, by then he had been the Mount Wilson optician for years.

In that shop Hendrix, among his many other wartime activities, made several experimental Schmidt cameras, as part of development projects. Dunham became head of the optical instruments section of the Office of Scientific Research and Development, with headquarters in Washington. He was often travelling between military and university research centres, while simultaneously trying to supervise Hendrix's work back in Pasadena. Only fragmentary records are available from that period, but they show that the Mount Wilson optician made at least one 12-inch, f/1 air Schmidt and two Cassegrain Schmidt systems. The first of these Cassegrains was an f/2.5, 12-inch aperture system. It was called an f/3.4 in some reports, because the partial blocking of the primary mirror by the secondary reduced the effective light-collecting area to that of an unobstructed 8.8-inch aperture (Dunham, 1945). Hendrix tested this Cassegrain camera at Mount Wilson, photographing stars and distant mountain peaks, in 1943 March. At that time, with the limited computing power available, it was sometimes quicker to try out new designs experimentally than by long calculations. Computer programs of today suggest that the variation of spherical aberration with wavelength, occurring in the corrector plate, was severe.

A later design, which is documented, was a smaller, f/1, 3-inch thick-mirror Cassegrain, which was called a "night camera." (Anon, 1943). It was not completed and tested until 1945. Both these cameras had their two spherical mirrors, and hence their focal surfaces as well, concentric. There was no compelling reason to use a Schmidt camera for aerial photography except at night, for the Ross-type lenses, with designs improved by James G Baker at Harvard, working at about f/7 with an accessible, flat, focal surface, were more convenient. Those cameras used long rolls of film, which were much easier to handle and process than the circular cut films required in the Schmidts. However, the "snooperscopes" and "sniperscopes" developed during the war, essentially infrared telescopes working with image converters to provide upright visual images for individual soldiers at night, were mass-produced, molded-plastic Cassegrain Schmidts. The cameras Hendrix made at MWO may have helped their designers perfect them (figure 6).

9 AFTER THE WAR

After the war ended in 1945, Bowen succeeded Adams as Director of what soon became Mount Wilson and Palomar Observatories, operated as a unit with organizationally separate CIW and Caltech staffs sharing all the telescopes. An expert in optics, Bowen was an ideal choice, who had all the know-how to push the 200-inch to completion. It had been in mothballs during the war, but work on it resumed on the Caltech campus under Anderson with Marcus Brown as chief optician. Both had been working on the project from the beginning and were getting on in years, Anderson already having passed the retirement age. Bowen decided that he and Hendrix would take over from them as soon as the 200-inch mirror was brought to a satisfactory figure and was ready to be moved to the observatory on Palomar, where the final touch-ups and testing would be done in the dome.

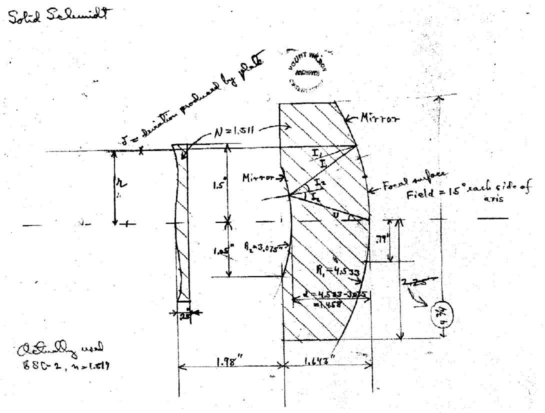

Figure 6. Optical drawing used by Hendrix to make the Cassegrain two-mirror, thick-mirror Schmidt camera. Note that the convex secondary mirror, with 1.05-inch radius, blocks a large part of the area of the concave, 1.5-inch radius primary. (Courtesy of the Huntington Library)

In the meantime, Hendrix went back to work on the 48-inch corrector plate. Dietz had left for the Caltech rocket project, which spun off the Naval Ordnance Test Station at China Lake, in the California desert, after the war. Floyd Day, a night assistant at Mount Wilson since 1941-2, transferred to the optical shop and helped Hendrix with this job. It was delicate work, because the large glass disk was thin and flexible, but the final product was excellent. The Caltech mechanical shop constructed the streamlined tube and mounting, and the completed optics were tested in the telescope in 1948 September. Frank Ross had designed a field-flattening lens to be used in it if necessary, but it proved possible to use large 14 × 14 inch glass plates, specially made only 1 mm thick, which would bend over a mandrill without breaking. They covered a field about 6°.5 square. Only very minor adjustments were necessary, and by 1949 January the 48-inch Schmidt (Figure 7) was in full operation (Harrington, 1952; Minkowski and Abell, 1963; Ross, 1940).

10 THE 200-INCH AND ITS SPECTROGRAPHS

A huge tractor-trailer outfit hauled the 200-inch primary mirror up the mountain road to Palomar in 1947 November. Hendrix aluminized it in the dome after several unsuccessful attempts, each leading to more powerful vacuum pumps, and Anderson, Bowen, Brown, Hendrix, Russell Porter, and others saw first light through the telescope in December, just before Christmas. The images revealed many problems in the mounting and support system, which Bowen and engineer Bruce Rule solved one by one. In 1948 June the telescope, almost finished, was dedicated twice, once before the Caltech, Rockefeller Foundation, and Carnegie Institution officials, and then again a week later before the American Astronomical Society, assembled for its summer meeting on the floor of the dome. The telescope was named for George Ellery Hale, to commemorate the man who had made it a reality but had not lived to see it completed. Then Hendrix, assisted by Melvin Johnson, who had worked at the Caltech optical shop until it closed down and he transferred to MWO, began the final touch-ups of the mirror, guided by Hartmann-screen exposures on stars, which Bowen interpreted. Hendrix worked with a small polishing machine mounted on a carriage pivoted at the centre of the mirror, whose outer end rode on the edge of the mirror. Bowen finally pronounced the mirror satisfactory in 1949 September, and regular observations during the dark of the Moon began in November. Final Hartmann tests taken in the winter showed no further improvements could be made, and the telescope went into full operation (Bowen, 1950, 1960a). It was the high point of Hendrix's career (Figure 8). Then he began making Schmidt cameras for spectrographs again.

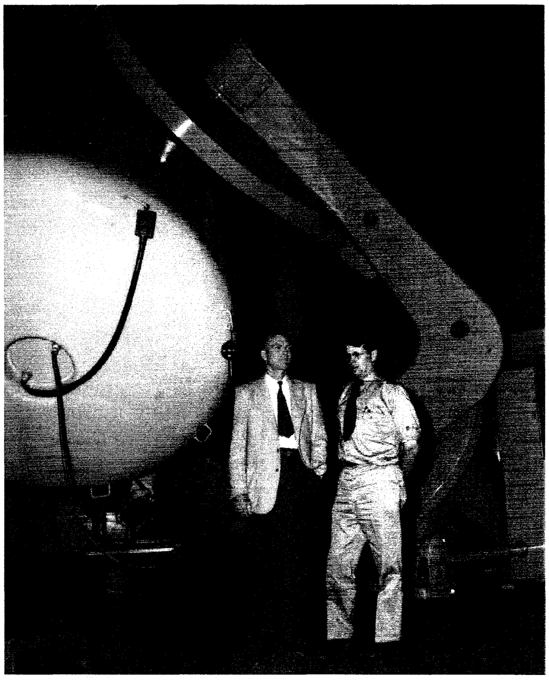

Figure 7. Don Hendrix (left) and Byron Hill, Palomar Observatory mountain superintendent (right), at the dedication of the 48-inch Schmidt telescope in 1949 June. (Courtesy of the Huntington Library)

After Smith's untimely death in 1938, Minkowski had taken over designing the MWO nebular spectrographs. He considered adopting a "solid-block" design, with the corrector plate figured on the face of the same piece of glass which had the spherical mirror on its other end, but concluded it was too difficult to make, and that the "not easily accessible" focus (in the middle of the piece of glass) would make it too difficult to use (Minkowski, 1944). Hendrix may have tried to make one or more of these solid-block Schmidts experimentally in the 1940s, but if so no record has turned up. He had conceived a variant of this design, a folded solid Schmidt with a single internal reflection which brought the focus to the surface of a prism-shaped "solid triangle," but whether he ever made one of these is not known either (Hendrix and Christie, 1939).

The first Schmidt camera Hendrix did make for the new Hale telescope was part of a nebular spectrograph Minkowski had designed to be used at the prime focus. Although the telescope had been planned and built with a Cassegrain focus, and in the 1930s Anderson and Smith had designed prism spectrographs for use there, both Bowen and Minkowski favoured the prime-focus cage, which had been designed primarily for direct photography. There were no extra reflections, with resulting light losses, there at the prime focus. The camera Hendrix made for the Hale prime focus was a 3-inch aperture, f/0.47 thick-mirror system. It was based on the new concept Bowen had introduced, with a "twice-through" corrector plate mounted just a few millimetres in front of the grating, so that the light beam from the collimator passed through it once on the way to the grating, and then was reflected and diffracted back through it toward the spherical mirror. This design saved space in the spectrograph, and insured that no light would be lost at either end of the spectrum. The figure on the corrector plate was reduced by about half compared with that of an equivalent once-through plate (Bowen, 1952a). Humason began using this spectrograph as soon as it was completed in its original form with two light flint glass prisms as the dispersing element in 1950 to obtain redshifts of faint, distant galaxies, and it proved to be a great success (Humason, 1951). But soon highly efficient, "blazed" reflection gratings ruled in the Mount Wilson grating laboratory, on a machine developed by Harold Babcock and greatly improved by his son Horace were available and preferable to prisms, especially for the yellow, red, and near-infrared spectral regions. In 1952 a new spectrograph, designed by Minkowski, using the same optics but with a grating replacing the prisms, went into service. It was even faster than the prism version, and with five different gratings eventually available, it was much more flexible (Humason, Mayall, and Sandage, 1956:99). Later that same year Hendrix made a longer focal-length camera of the same thick-mirror, twice-through design, a 3-inch, f/0.95 system for higher-resolution spectroscopy (Bowen, 1952a).

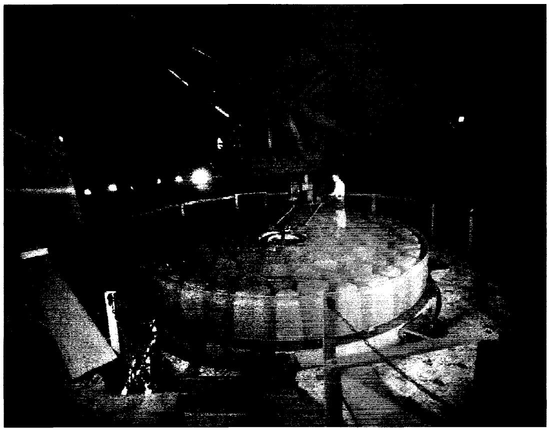

Figure 8. Don Hendrix polishing the 200-inch primary mirror in the dome at Palomar, 1947-8. (Courtesy of the Huntington Library)

Bowen, an optics expert and long-time laboratory spectroscopist, designed the coudé spectrograph for the 200-inch himself. It was built around four identical 5½ × 7-inch gratings, ruled at MWO, mounted in a 2 × 2 array, providing the large beam size necessary to take full advantage of the large 200-in primary mirror. The collimator, an off-axis paraboloid, produced a 12-inch diameter beam. Hendrix made the longest, 144-inch focal-length camera first, an f/12 spherical mirror used, like the 114-inch focal-length camera of the 100-inch coudé, with no corrector plate. He, with Day and Johnson (both of whom assisted him on all these cameras), finished it in 1950 also. In 1951 they completed and put into use three more Schmidt cameras for the coudé, of 72-inch, 36-inch, and 18-inch focal lengths respectively, each an air Schmidt with a twice through corrector plate. All four of these spectrographs had plateholders which bent special thin glass plates to the right curvature. The shortest camera had an aplanatic sphere, as Bowen called it, or in the astronomers' more graphic terms, an "eyeball lens," in the converging beam of the 18-inch, shortening it to an f/0.7, 8.4-inch focal length, and also flattening the field. It was the last to be finished, and did not get into full operation until 1952 (Bowen, 1952b). This coudé spectrograph and the five Schmidt cameras Hendrix and his assistants had made for it provided much of the data astronomers obtained on the abundances of the elements in stars of all types during the next ten or fifteen years, exploring the consequences of nuclear reactions in stellar interiors, just as Bowen had foreseen when he became Director in 1946. In a later excellent review article Bowen described some of the methods Hendrix had used in the 1950s to make these and other later Schmidt camera optics (Bowen, 1960b).

11 THE MOUNT WILSON SPECTROGRAPHS

After the 200-inch, Bowen turned his attention, and Hendrix's, to the Mount Wilson telescopes, first to the 60-inch, by then much used for spectroscopy by Carnegie postdocs, Caltech grad students, and visiting astronomers from other observatories with smaller telescopes (if any) at poorer sites. The oldest spectrographs on Mount Wilson, prism instruments with ancient lens cameras, had all gravitated to the 60-inch. To replace them, and to provide more efficient observing opportunities, Bowen designed an "all-purpose" (called by the astronomers "people's") spectrograph which was left permanently mounted at the folded-Cassegrain focus. It had a two-mirror Cassegrain collimator, several interchangeable 4-inch gratings, and three twice-through corrector-plate Schmidt cameras, with focal lengths of 16-inch, 8-inch, and 4-inch, corresponding to focal ratios f/4. f/2, and f/1 respectively. A rotatable turret in the spectrograph held three gratings, two of them standard, with the third slot available for special gratings needed by specific observers. The whole system was designed so that an astronomer could quickly and easily switch gratings or cameras to whatever combination best suited his or her research problem. Hendrix, with Day and Johnson's help, provided the optics for this spectrograph and the three Schmidt cameras, which went into operation in 1955 (Bowen, 1957).

Next Bowen and Hendrix updated the coudé spectrograph of the 100-inch reflector, also heavily used by postdocs and visitors, as well as by the MW&PO staff members. The long-focus cameras designed and built in the days of Dunham and Adams were still excellent, but there were no fast, lower-dispersion cameras available for use there. The off-axis Schmidt cameras Dunham had favoured were not appropriate for faster focal ratios, because their corrector plates would have the higher-order aberrations inherent in the even larger aperture systems of which they represented only a part. Hence Bowen designed two Schmidt cameras with twice-through corrector plates, as at the 200-inch coudé. By now the 100-inch spectrograph had a 6-inch off-axis paraboloidal collimator mirror, and four interchangeable gratings for use with it. Hendrix made the optics for these two new cameras, with focal lengths 16-inch and 8-inch respectively, corresponding to focal ratios of f/2.7 and f/1.3. The twice-through feature meant that the depths of the figures of these corrector plates were smaller (by a factor about two) than they would have been in conventional Schmidt cameras, and thus presented no problems for Hendrix in making them. These two cameras for the 100-inch coudé spectrograph were the last two Schmidts Hendrix made for MW&PO (Bowen, 1962b).

12 SCHMIDT CAMERAS FOR OTHER OBSERVATORIES

Few if any American observatories had optical technicians of their own, and both Adams and Bowen allowed Hendrix to do small jobs for selected outside institutions, which he carried out in his own time at his small home shop, just as Ritchey had done decades earlier under Hale. The first Schmidt camera optics that Hendrix made in this way were for the 82-inch McDonald Observatory reflector. In 1936-7 its director, Otto Struve, had ordered and obtained small f/2 and f/1 Schmidt cameras for its Cassegrain-focus prism spectrograph from Carl H Nicholson of Du Quoin, Illinois, an amateur telescope-maker associated with the Adler Planetarium in Chicago (Struve, 1937; Struve and Roach, 1936). Later Struve also ordered an even faster f/0.5 air Schmidt from Arthur DeVany of Davenport, Iowa, another amateur telescope-maker and optician who was eager for paying jobs (Struve, 1939). However he was unable to complete it successfully (Struve, 1946a). Ross, the astronomer and optical-design expert who had been a Yerkes Observatory faculty member before he transferred to the 200-inch project, then recommended to Struve that he ask Hendrix to make this fast Schmidt instead (Struve, 1938a).

Just at that time young Horace Babcock, who had done his Ph.D. thesis at Lick Observatory on nebular spectroscopy, was joining the McDonald Observatory staff, and planned to continue that line of research with the 82-inch reflector. He had used a fast prism and lens-camera spectrograph at the prime focus of the Crossley reflector at Lick, and as a visitor at MWO had also observed with Smith's original quartz-prism spectrograph with its f/1 Schmidt camera at the Cassegrain focus of the 60-inch telescope (Babcock, 1939; Babcock and Johnson, 1941). Probably at his suggestion, or Ross's, and no doubt with confirming advice from Adams, Struve decided to have a fast grating spectrograph built for the prime focus of the 82-inch, and to use the fastest Schmidt camera in it instead of in the Cassegrain-focus spectrograph. Babcock's father, Harold Babcock, was in charge of the grating ruling-machine at MWO, and was able to provide a good blazed grating for the McDonald spectrograph. Struve placed the order for a 2-inch, f/0.65 thick-mirror Schmidt with Hendrix (who favoured this design and focal ratio) in 1938 (Struve, 1938b). He finished the optics for it in 1940-1, and Carl Ridell began making the spectrograph in the Yerkes mechanical shop (Struve, 1946b). However before it was completed, Babcock left McDonald for war-time service on the Caltech rocket project in Pasadena in 1941-42, and after the war ended he found a new job at MW&PO (Struve, 1946a, 1946b). Hence not until 1948 did Thornton Page of Yerkes and McDonald Observatories put the spectrograph together (its paraboloidal collimator mirror also made at Yerkes), with the help of long-distance advice from Hendrix (see Kuiper, 1948). Page immediately began using the new spectrograph with a new blazed Bausch & Lomb grating for nebular spectroscopy with the 82-inch McDonald telescope. With it he first demonstrated that the red [N II] emission lines are relatively strong in comparison with Hα in diffuse nebulae (Page, 1948). Then he turned to galaxies, especially 'double' (or interacting) spirals and ellipticals, and showed that these same red [N II] and Hα lines are strong in many of them, and ideal for measuring their radial velocities (Page, 1952).

In 1949 Andrew McKellar, of the Dominion Astrophysical Observatory in Canada, corresponded with Hendrix about his making a Schmidt camera for its Cassegrain spectrograph, but nothing ever came of it (McKellar, 1949). Probably an important factor was that Hendrix was then fully occupied with making optics for the Hale telescope spectrographs. However in another case, probably in the mid-1950s, he did make the optics for a 10-inch, f/2 Schmidt telescope on his own time for a Southern California amateur, Ted Haberman, who built the mounting, drive, and plateholders for it himself (Zwicky, 1956). Probably there were other similar Schmidt camera optics which Hendrix made in the 1950s for which no records have turned up thus far.

13 THE LICK OBSERVATORY REFLECTOR AND SPECTROGRAPHS

Hendrix's biggest outside job was as a consultant to Lick Observatory when it built its 120-inch reflector, the second largest in the world when it was completed in 1959. Soon after the California legislature appropriated the funds to build it, Lick Director C Donald Shane asked Bowen to let Hendrix take leave to make the optics for the telescope. With the 200-inch in operation in 1949, Bowen and CIW President Bush were willing to release him part-time after 1951 January 1, when the Palomar coudé spectrograph was scheduled to be completed (Bowen, 1949; Scherer, 1949). Hendrix travelled back and forth between Pasadena and Mount Hamilton, where he ground and polished the 120-inch primary mirror in the dome building. Johnson worked with him on this project, as did Howard Cowan, who came from Southern California with Hendrix (whom he knew well) and was hired on the Lick staff as an optician. Hendrix trained him there and in the MW&PO optical shop, where Cowan went for several long stays (Cowan, 1959). He then in turn helped to train Donald Loomis, later the chief optician at Kitt Peak National Observatory, who was hired by the nascent "National Astronomical Observatory" to work with Cowan at Lick and learn from him (Shane, 1955, 1958). Presumably Hendrix had been asked to teach Loomis (whom he had not picked himself), but declined. In any case they both worked as Hendrix's assistants whenever he was at Mount Hamilton.

The 120-inch, like almost all large telescopes, took longer to complete than anyone had originally estimated, but the main problems were all mechanical, not optical. Hendrix, who signed on as a consultant in 1951, began grinding and polishing the primary mirror in 1953, in the optical shop built under the dome for the telescope on Mount Hamilton (Shane, 1953). He began the figuring in 1955 (Figure 9), and he and Cowan finished it in 1958-9, guided by Hartmann test plates taken, measured, and reduced by Nicholas Mayall and Stanislavs Vasilevskis each time the primary mirror was put back in the telescope (Shane, 1958). Albert Whitford, the new Director, pronounced it completed in 1959, and it went into regularly scheduled operation in 1960 March (Whitford, 1959, 1960).

Figure 9. Don Hendrix cleaning a spot on the Lick Observatory 120-inch primary mirror, 1959. (Courtesy of Mary Lea Shane Archives of the Lick Observatory)

George Herbig, of the Lick faculty, had designed a coudé spectrograph for the 120-inch, which Hendrix and his assistants began working on long before the primary mirror had received its final figure and polishing. They completed the 6.5-inch paraboloidal collimator mirror, and the spherical mirrors for the two longest cameras, one of 120-inch focal length, an f/24 (which did not need a corrector plate), and the other of 80-inch focal length, in 1954. They finished the spherical mirrors for the shortest, 20-inch camera in 1955-6, and for the 40-inch in 1957-8, and then did the corrector plates for the three which needed them in 1959 and 1960. These three cameras were all conventional, once-through, air Schmidts (Whitford, 1959, 1960). Like almost all of Hendrix's cameras, they were immediate successes.

14 CONCLUSION

Hendrix probably would have made the optics for a Schmidt camera for the prime-focus spectrograph of the big Lick reflector next, but by then he was in poor health. He was a hard-driving perfectionist all his life, and did not like to "waste time" with aspiring would-be opticians, nor have outsiders watch him at work and question him about what he was doing. His sole hobbies seem to have been bow-and-arrow and rifle target shooting and hunting, in which Day and Johnson joined him. Some at MW&PO wondered if that was how they got their jobs in the optical shop in the first place, but they certainly became skilled opticians under his tutelage. Hendrix was a heavy smoker, probably from boyhood, and it is hard to imagine that he got much exercise except when stalking a deer. He suffered a heart attack in the 1950s, was hospitalized, and recovered, but he continued smoking and from then on never seemed completely well. By then he was a consultant involved in helping plan several large telescopes, including an 80-inch reflector for Kitt Peak National Observatory and a large astrometric reflector for the U. S. Naval Observatory station in Flagstaff. Death caught up with him on 1961 December 26, in the guise of an internal haemorrhage which began while he and his wife were returning to their home in Pasadena from a Christmas visit with their son Robb's family in West Covina. Hendrix was only 56 years old. His death was a great shock to all who knew him, and a serious loss not only for MW&PO but for astronomy as well. Bowen wrote that many of the instruments at MW&PO "... were only possible because of Don's unusual ingenuity and skill." Bowen feared it would be impossible to find anyone who could really replace Hendrix, and missed him as a friend on whom he could always depend for sound advice on optical problems (Bowen, 1961). The optics for the two big reflectors, the 48-inch Schmidt telescope, and the many Schmidt cameras used in spectrographs, remain his monuments.

15 ACKNOWLEDGEMENTS

This paper is dedicated to the memory of Robb Hendrix, who helped me greatly by providing information on many facets of his father's personal life. Robb himself died in Pasadena on 2000 October 7, just a few days before I delivered a preliminary, oral form of this paper at a meeting of the Antique Telescope Society in Flagstaff. I am also indebted to James G Baker, Aden Meinel, Harland Epps, and Daniel J Schroeder, who over the years have all advised me on many questions concerning astronomical optics, especially Schmidt cameras. The first three of them all knew Don Hendrix (as I did, when I was a young astronomer at MW&PO), and shared their memories of him and of his work with me. Thomas R Cave, Don Davidson, Marlow Marrs, and Paul Roques were also most helpful in e-mail and telephone communications and interviews on various phases of Hendrix's work. George H Herbig sent me, at my request, his insightful memories of Hendrix's optical work at Lick Observatory, just as the late Albert E Whitford and Stanislavs Vasilevskis had earlier given me their thoughts in many informal conversations. Anthony Cook, Kenneth Lum and Thomas R Williams kindly gave me useful information from their own history of astronomy research, and Dan Lewis and Steven Turner located very valuable source material for this paper at the Henry Huntington Library in San Marino, California and the National Museum of American History in Washington, D.C., respectively.

In addition to the papers and books referenced below, I used as background material for this paper many manuscript letters, reports, and other materials in the Mount Wilson Observatory Collection in the Huntington Library, in the Mary Lea Shane Archives of the Lick Observatory, University of California Santa Cruz Library, and in the Yerkes Observatory Archives. I am most grateful to them and to their

respective curators, Dan Lewis, Dorothy Schaumberg, and Judy Bausch, for their kind and effective help in locating these documents. I am particularly grateful to The Huntington Library, which holds the copyright, for permission to reproduce Figures 2 through 8.

An earlier, shorter version of this paper was published in the *Journal of the Antique Telescope Society* in 2001 under a somewhat different title. I have revised, corrected, and added significantly to that earlier article for publication here, and I appreciate the permission of Peter Abrahams, current President of that Society, to use the material from it here.

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The following abbreviations are used:

AIP = Albert G. Ingalls Papers, National Museum of American History, Smithsonian Institution, Washington.

IBP = Ira S. Bowen Papers, Henry Huntington Library, San Marino.

MSA = Mary Lea Shane Archives of the Lick Observatory, University of California, Santa Cruz.

OSP = Optical Shop Papers, Mount Wilson Observatory Collection, Huntington Library, San Marino.

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Donald E Osterbrock is a research astronomer, now retired, and an historian of astronomy, particularly of the history of observational astrophysics in the big-telescope era in America. Recently-published books are *Yerkes Observatory 1892-1950: The Birth, Near Death, and Resurrection of a Scientific Research Institution* and *Walter Baade, A Life in Astrophysics.*

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Airy's zenith telescopes and "the birth-star of modern astronomy"

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Abstract
When Sir George Airy (1801–91) became the seventh Astronomer Royal in 1835, the Royal Observatory at Greenwich already had a long history of zenith observations for monitoring aberration and nutation, and providing a zenith-point for the meridional instruments.

Continuing this programme, Airy designed two very successful instruments. His Reflex Zenith Tube succeeded where earlier instruments had failed, and his reflex principle was developed to provide the most successful zenith instruments over more than a century. His zenithal Water Telescope, developed for a specific experiment, was equally successful. The design and construction, operating procedures, and programmes carried out with these instruments are described.

Keywords: *zenith instruments, Greenwich Observatory, positional astronomy.*

1 INTRODUCTION

As Airy entered his second decade at Greenwich, having completed the massive re-reduction of all the Greenwich positional observations of the Moon and planets from the period 1750–1830, he turned his attention to the Observatory's positional instruments. Whilst the existing instruments were in good order, they had already been in use for more than three decades at a time of rapid development in positional astronomy, and Airy foresaw a need to extend his observing capability to fainter objects (not least because of the fast-growing numbers of minor planets), and also to achieve greater accuracy. This study resulted in a suite of four major new instruments which all entered service between 1847 and 1854, comprising three specialist telescopes and a chronograph. All were designed, and their construction supervized, by Airy himself. They would prove to have a combined useful life of 313 years, and the designs of two of them would remain influential for more than a century.

One of these instruments, the Reflex Zenith Tube, was an example of Airy's remarkable ability to select the best method of achieving a particular end, where many others had failed. Its performance eventually proved to be of such a high standard that it was hastily brought back into service after its intended retirement, and also provided the basis for a new generation of zenith instruments.

2 HISTORICAL BACKGROUND

By the beginning of the seventeenth century support was growing in favour of the heliocentric universe proposed by Copernicus half a century earlier, against the geocentric system still strictly advocated by the ecclesiastical authorities. An early supporter was Galileo, whose telescopic discovery of the phases of Venus and the satellites of Jupiter were demonstrations of the validity of the Copernican system. Galileo realized that if the annual parallax of a star could be measured it would effectively prove the Earth to be in motion. In 1632 he suggested a possible method of doing this in his *Dialogue Concerning the Two Chief World Systems.* By observing the parallactic angle between one star and another close by, the observation would be freed from the effects of atmospheric refraction. There is however no record of Galileo having attempted this himself.

As support for the Copernican system increased, the immediate need to observe stellar parallaxes in order to demonstrate the Earth's motion waned, but it was later realized that they would provide a means of directly measuring stellar distances. Early efforts were however doomed to failure, the stars being much farther away than the early observers imagined, and instruments would be needed capable of measuring parallactic angles to a fraction of one second of arc.

2.1 Early Observations

The first serious attempt to measure a stellar parallax was made by Robert Hooke in 1669. Hooke realised that the effect of atmospheric refraction is zero at the zenith, and that a second-magnitude star, γ Draconis, transited almost zenithally in London. Hooke had a telescope of 36 feet (10.97 m) focal length, and realizing that it would be necessary for it to remain stationary through months of observation he mounted it vertically within his rooms at Gresham College, London. Unfortunately his observations were terminated by illness and damage to the telescope lens, but as Hoskin (1997) has written, the construction of a telescope designed to measure the position of one single star, and that only when the star was near the zenith, was a brilliant conception at a time when telescopic astronomy was still in its infancy. Hooke did obtain a value of 27″ for the supposed parallax of γ Draconis, but this was not confirmed by other observers. Furthermore, Flamsteed and others had reported unexplained annual variations in the declination of Polaris over a range of some 40 arc-seconds.

This led Flamsteed, newly appointed as the first Astronomer Royal, to construct a zenith telescope in about 1676. This consisted of an objective nominally of 90 feet focal length, mounted horizontally at the top of a well at Greenwich, the eyepiece assembly being suspended beneath it as a plumb-bob, thus automatically establishing the vertical. There is only one recorded observation, on 1679 July 30: "Ego in puteo subterraneo transitum observavi lucidae in capite Draconis" [I, in the underground well, observed the star in the head of Draco], cited in Baily (1835:lix). There is no record of Flamsteed's well being specially dug, it is more probable that he made use of an existing well associated with Greenwich

Castle [formerly known as 'Mirefleur'] which formerly stood on the site. Its exact location was in some doubt for many years, but was established by Airy in 1840; the upper 25 feet of the shaft were excavated in 1965. The well is shown in use as a telescope in a contemporary engraving by Francis Place (see Howse 1975, Figures 52, 53). Flamsteed's limited use of it may be explained by the unpleasant conditions, or by the poor quality of the object glass (by Borel of Paris) which still survives. It was presented to The Royal Society in 1737 by James Hodgson, an assistant to Flamsteed at Greenwich who married his niece and inherited some of his property; in the Society's records it is described as "that which Mr Flamsteed designed to have used in the well at the Observatory at Greenwich, but was prevented by the damp of the place" (Weld 1848, vol.I, p. 255). The lens, now in the care of the Science Museum, London, was examined and tested at Greenwich in 1955 where it was found to be of very poor quality. It is a very thin plano-convex lens, 9¾ inches (24.8 cm) in diameter and 0.36 inches (9 mm) thick at the centre, and the focal length was found to be 87 feet 5 inches (26.64 m) in sodium light (Hunter & Martin, 1956).

2.2 Observations by Molyneux and Bradley

The next significant attempt was made by the amateur astronomer Samuel Molyneux, using a zenith sector of 24 feet (7.3 m) radius by George Graham, one of the leading instrument-makers of the day. This instrument, built into the fabric of Molyneux's home in Kew, south-west London, was not a fixed telescope, but one pivoted at the top and therefore able to move in the meridian plane through a small arc north or south of the zenith, the motion being controlled by a micrometer screw and measured against a graduated arc. The vertical was established by a plumb-line. Molyneux was assisted in his observations by James Bradley, later to become the third Astronomer Royal. Observations of γ Draconis between 1725 December 3 and 12 had showed no change in the star's zenith distance (ZD), but observing again on December 17 Bradley found it had moved, and in a direction opposite to that predicted by the Earth's motion. During the next twelve months the displacement varied over a range of about $40''$. This variation was not accounted for by either parallax or atmospheric refraction. Bradley decided that an instrument was required which could observe more stars, and commissioned from Graham a new zenith sector of 12½ feet (3.8 m) radius, which was erected at his aunt's home in Wanstead, Essex in 1727. The new instrument had a range of zenith distance of ±6°.25. Bradley found that each star traced out an apparent path whose size was related to its declination. He suspected that the annual movement was related to the Earth's motion, and in 1728 realized the cause. It was an effect of relative velocity, arising from the Earth's orbital motion and the finite velocity of light, which had been determined by Römer in 1675. Bradley had discovered the aberration of light. This explained the observed motions, but correcting for it did not reveal a measurable parallax due to the stars' great distances. Further observations with the same instrument did however enable Bradley to announce the discovery of nutation in 1748.

2.3 New Instruments Introduced by Pond

The story now moves back to Greenwich. After Bradley became Astronomer Royal in 1742 his zenith sector was purchased for the Royal Observatory, where it is still preserved, and continued to be used. Towards the end of his term of office Nevil Maskelyne had commissioned a mural circle to replace the quadrants which had been used for zenith distance determinations for more than half a century; it was installed in 1812. His successor as Astronomer Royal, John Pond, was very experienced in positional observation before his arrival at Greenwich in 1811. It had now become clear that the traditional plumb-line could no longer provide a sufficiently accurate zenith-point for ZD observations. Initially the mural circle was used differentially, using the direction of the pole (determined from observations of circumpolar stars) as a reference. In 1812 Pond installed a 9½-foot 'zenith micrometer' on the circle pier to provide the zenith-point. This was in effect a Newtonian reflector mounted as a zenith tube, but was never used successfully. In 1816 he replaced it with an 8-foot achromatic zenith telescope. The use of an achromatic object-glass was clearly a step forward, but no recorded observations exist. In any case, by 1822 Pond realized that the zenith-point could be determined using the mural circle itself, by combining observations of stars made directly and by reflection in a trough of mercury. This required the combination of observations made on different days, however, and in 1824 a second circle was erected so that the observations could be made directly and by reflection at the same transit.

Meanwhile, Pond's final zenith instrument was nearing completion. Originally intended to provide accurate zenith-point determinations, it had been commissioned in 1819 and a room constructed for it at the north-west corner of Flamsteed House, on the site once occupied by Halley's original transit instrument. After disputes and delays the 25-foot 'Great Zenith Tube', having an object-glass of 5 inches (12.7 cm) aperture and 24 feet 6 inches (7.47 m) focal length, was finally erected in 1831. It was found to be very unsatisfactory, largely due to the effect of convective air currents in its tall, narrow enclosure. The roof was replaced in 1834 in an unsuccessful attempt to cure the problem. The instrument was to prove yet another failure, but perhaps its greatest contribution was to engage the interest of the one person most capable of devising a solution to the problem.

2.4 Improvements by Airy

From his taking office in 1835 it is clear that Airy was anxious to get Pond's Zenith Tube into good order. In his very first report to the Board of Visitors he remarks:

> The Zenith Tube deserves particularly to be noted at present. I have reason to think that much of the difficulty of seeing stars well defined, &c. arose from the passage of currents of unequally-heated air near to the object-glass: possibly however a part might arise from defects of the object-glass ... With respect to the mechanical construction, it is in my opinion seriously defective.[1]

A year later he reports that the acting parts of the instrument have been completely remodelled, new micrometers fitted, and regular observations were about to commence[2]. Further modifications were reported in 1840. Although the instrument was designed to permit rotation of the telescope through 180°, this operation took a minimum of fifteen minutes and so direct and reversed observations at the same culmination were not possible. Airy makes an important statement in 1842:

> An inspection of the results of the Zenith Tube observations has convinced me that it will never be possible to obtain results quite satisfactory unless the double observation (in opposite or reversed positions of the instrument) can be made at one transit. I have therefore made some small alterations in its mounting for facilitating rapid observation (the principal novelty, as regards the observation, being that two wires are provided, one for the observation of γ Draconis in each position), and it is found that the double observation can be made without the smallest difficulty.[3]

In the following annual report Airy records that the results of the observations were more consistent since the change[4], but only four years later he is expressing doubts whether there is any advantage in the continued use of the instrument, "the irregularities of result ... exceeding those of the mural circles"[5]. The following year he reports that the final observation was made on 1848 May 1 and the instrument dismounted[6]. The major cause of the irregularities was no doubt the unsuitability of the room, and Airy refers in the same report to the expressed opinion of several members of the Board that the instrument should be remounted elsewhere[7]. He clearly had no intention of abandoning the observing programme, however, and records that a principle for a new instrument "first occurred to me in the spring of 1848 and was first described in a short Address to the Visitors"[8]. A month later, "if it be the object of the Visitors to obtain a continuous series of accurate observations of γ Draconis (a thing to which, in my opinion, too great importance cannot be attached), and to adopt … a new construction", he submitted a proposal for a new form of zenith telescope[9]. Airy was clearly convinced of the importance of continuing observations of γ Draconis, which he was later to describe as "the birth-star of modern astronomy" (Airy 1872:cxix).

3 GAMMA DRACONIS

This star (HD164058) had now been an object of interest to English observers for 180 years. Also known as *Eltanin* (the Head of the Dragon), it appears to have been significant in ancient Egypt also, its rising *c.* 3500 BC being aligned with the central passages of the temples of Hathor at Denderah and of Mut at Thebes (Allen, 1963:208). It is an orange giant at a distance of 31 parsecs, equivalent to a parallax of only 0″.025, hence the inability of Hooke and his successors to measure it. Its position, for the epoch 2000.0, is α 17^h 56^m 36.2^s, δ +51° 29′ 20″. Its declination, being very similar to the latitude of Greenwich (51° 28′ 38″.2N), and its relative brightness (visual magnitude 2.23) combined to establish its importance as 'the zenith star'. In Flamsteed's time it transited about 4′ north of the zenith, in Airy's time about 2′ north. With an annual proper motion of 0″.024 in an approximately south-west direction, its ZD at 2000.0 was 42″ north. Due to aberration its declination varies during the year over a range of ±40″.1, reaching its most northerly culmination in mid-September and its southernmost in mid-March. These figures demonstrate the accuracy Bradley had achieved with Molyneux's instrument in 1725.

4 AIRY'S REFLEX ZENITH TUBE

Airy's proposal for the new instrument, as set out in his report to the Board of Visitors in 1848, embodied the reflex principle that was to found a dynasty of highly-successful zenith instruments:

> Let the micrometer be placed close to the object-glass, the frame of the micrometer being firmly connected with the object-glass cell, and a reflecting eyepiece being used with no material tube passing over the object-glass: and let a basin of quicksilver be placed below the object-glass, but in no mechanical connexion with it, at a distance equal to half the focal length of the object-glass. Such an instrument would at least be free from all uncertainties of twist of plumb-line, viscosity of water, attachment of upper plumb-line microscope, attachment of lower plumb-line microscope, and the observations connected with them: and might be expected, as a result of this extreme simplicity, to give accurate results.[9]

Construction of the new instrument was delayed, pending a decision whether it should re-use the object-glass of the old Zenith Tube, or that of Pond's ten-foot Transit Instrument, which was about to be superseded by Airy's new Transit Circle. Airy did demonstrate the detailed construction of the proposed instrument at the Visitation in 1849 June, however, in the form of a model. He comments that:

> … the Visitors will remember, that the micrometer and the object-glass are united, and that the only way of putting the telescope in focus is by altering the distance between the object-glass and the surface of the quicksilver. After careful consideration, I have determined on doing this by a vertical motion of the tube in which the object-glass is mounted; the weight of the tube, &c. being supported by a counterpoise, and the motion being effected by rack and pinion, with a clamp-screw for fixing when in the proper position.[10]

Airy further proposed "that the Observer should remain fixed in position while the object-glass and micrometer are reversed, his face being turned either to the East or to the West, in order that his hand may conveniently reach the micrometer head". He proposed that two wires be used, for observing the star in the two positions of the micrometer, and chose the object-glass from the old transit instrument. The optical arrangement of the instrument is shown schematically in Figure 1.

4.1 Design and Construction

This comparatively small instrument bears all the hallmarks of Airy's design principles. As in the case of the Altazimuth and the Transit Circle, stability was ensured by the use of iron castings, on which the optical and measuring parts were mounted. Manufacture of the instrument was entrusted to Airy's trusted collaborator William Simms (1793–1860) of Troughton & Simms, who was at the same time responsible for making the optical and precision-measuring parts of the Transit Circle.

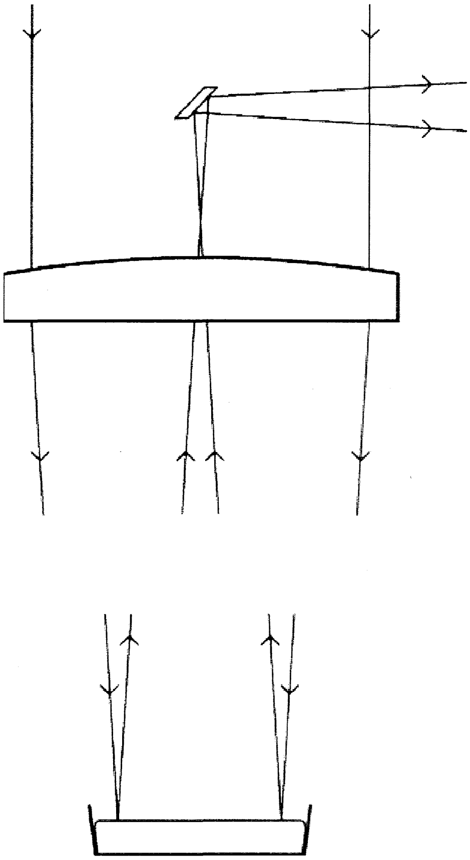


Figure 1. The optical arrangement of the Reflex Zenith Tube (middle section omitted).

Airy published a detailed description of the Reflex Zenith Tube (RZT), including four plates of detailed drawings (Airy, 1855). This account includes an extended statement of the optical principles and method of use of the instrument, and also the procedures used to determine the corrections to the micrometer readings to compensate for any slight inclination of the optical axis from the true vertical. Sectional drawings from Airy's description, showing the general construction of the instrument, are reproduced in Figure 2. The account concludes with a summary of the measures made to determine the constants of adjustment. A brief account of the instrument is given by Howse (1975:67–9).

4.1.1 Component Parts

The main parts of the instrument consist of three modules: (i) an outer tube on a pedestal base; (ii) an inner tube which can slide vertically within the outer tube and be clamped at the desired position, to which structures supporting the eyepiece tube and the diagonal reflector are attached and having a recessed and flanged upper end; (iii) the rotary, which sits in the recessed upper end of the inner tube and carries the object-glass and micrometer assembly. The exterior parts are shown in Figure 3.

The outer tube is of very solid construction and has an exterior pair of iron strengthening rings. The inner tube is provided with an interior pair of strengthening rings, and carries a counterbalancing stirrup arm with adjustable weight. A rack provides for vertical motion of the tube, activated by a pinion mounted on the outer tube and accessed through a slot; a clamping screw is also provided. Attached to its southern side is the upper end of a brass rod terminated with a wooden float in the mercury trough, to facilitate focussing. The arm attached to its eastern side to support the eyepiece, and the pair of arms on the west which support the diagonal reflector, are cranked in order to provide clearance for the rotary.

The eyepiece is constructed in two parts to avoid obscuration of the instrument's field of view, and has four optical components. The diagonal reflector is in the form of a 45° prism, whose lower surface is also figured to form the third lens. The fourth lens is mounted just below. The other part of the eyepiece comprises a horizontal tube, supported clear of the telescope aperture and containing the first and second lenses. In order to ensure that the observations of γ Draconis are made centrally in the field of the object-glass, the wire-frame and eyepiece diagonal are offset from the centre of the object-glass by an amount equivalent to the zenith distance of the star.

The rotary is equipped with handles and end-stops to facilitate the 180° rotation between observations. The object-glass is the achromatic objective by Peter Dollond, formerly used in the Troughton Ten-foot Transit Instrument from 1816-50; its aperture is 5 inches (12.7 cm) and its focal length 9 feet 8 inches (2.9 m). The micrometer assembly is attached to the object-glass cell, and hence rotates with it. A spirit level is provided on the cell, with a scale to measure any slight inclination of the optical axis from the vertical. The rotary (with handles), the eyepiece and the prism reflector can be seen in Figure 4.

There are two extraneous assemblies, (i) the mercury trough (described by Airy as the "quicksilver trough") and (ii) the field-illumination apparatus. The trough has two chambers, connected by a curved passage (Z) in the base of the trough, one to provide the horizontal reflecting surface (Y), and a smaller one (X) carrying the float used in adjusting the focus (see Figure 2). Airy points out in his description that "the surface of the quicksilver in Y may be made perfectly clean; the quicksilver being all poured from Y to X through Z, in such a manner as to carry the dirt with it, and being returned in such a manner that the upper stratum of the quicksilver in X never descends so low as the passage Z"[11]. The field-illumination apparatus comprises an inclined elliptic annular reflector, mounted above the mercury surface to direct the light from a gas lamp up the main tube, the brightness of the field being controlled by tilting the reflector with the control rod provided (see Figure 2).

4.1.2 Micrometer and Wire-frame

In his detailed proposal for the instrument Airy suggested a major detail of construction which would greatly facilitate the double observation:

> I propose to use a more complex micrometer; not a double micrometer in the ordinary sense, but an apparatus in which a micrometer A carries every part of a micrometer B; that A be read before beginning; that the first bisection be made by B; and that without altering or reading B the second

bisection be made by A, and that both be then read. This apparatus would possess two great advantages, viz., that no reading would be necessary between the observations, and the same hand would be used in both bisections; while the two observations would still be made upon two wires fixed to the same metallic frame, and no weakness, or new liability to friction, would be introduced.[12]

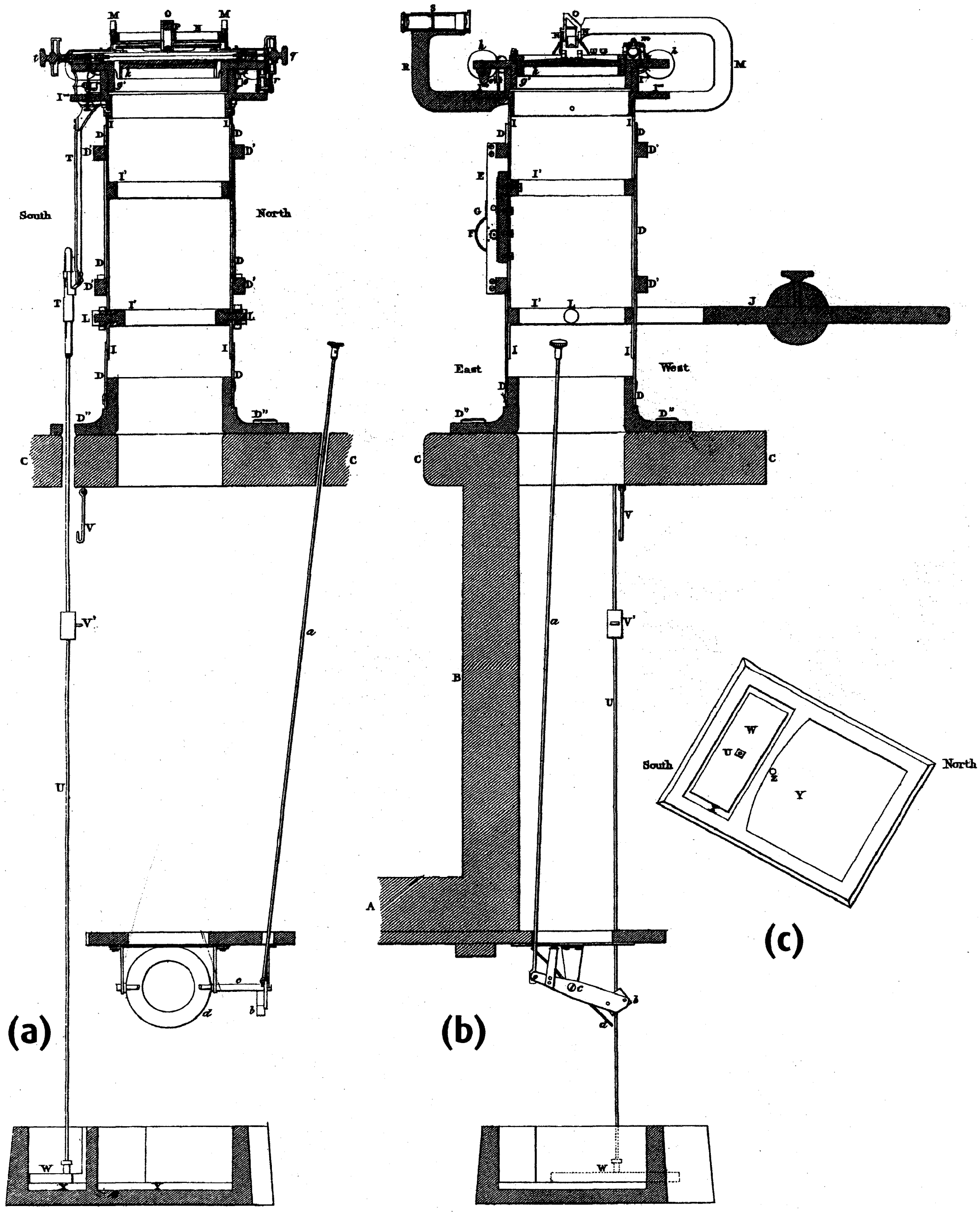


Figure 2. Vertical sections of the RZT, from Airy's description; (a) viewed from the east, (b) viewed from the north; (c) plan of the mercury trough (after Airy, 1855:plate I).

This passage demonstrates how thoroughly Airy had considered the procedure to be adopted in using the instrument, which was still only in the design stage. It is noteworthy too that Airy was concerned with the design and construction of both this instrument and his revolutionary and complex Transit Circle[13] at the same time, further evidence of his rare combination of supreme astronomical and engineering talents. The principle of the double micrometer is shown in schematic form in Figure 5. The values of one revolution of the micrometer screws expressed in arc, as re-determined in 1902 at the start of the latitude programme (see below), were 16″.79 for micrometer A and 16″.60 for B.

The micrometer wire-frame carries two wires, called 15 and 16, separated by a distance equivalent to approximately twice the ZD of γ Draconis; these being centred in the field, if wire 15 is positioned on the image of the star in one position, a small adjustment will bring the other into coincidence with it in the reversed position. Wires 15 and 16 were the central pair of a series of thirty mounted on the frame, to provide pairs for the observation of other stars culminating at greater distances from the zenith. This provision was little used for many years, but was to prove essential to the success of the instrument in the latter phase of its working life. Although referred to as 'wires', as in all the positional instruments of the time they were in fact spider webs.

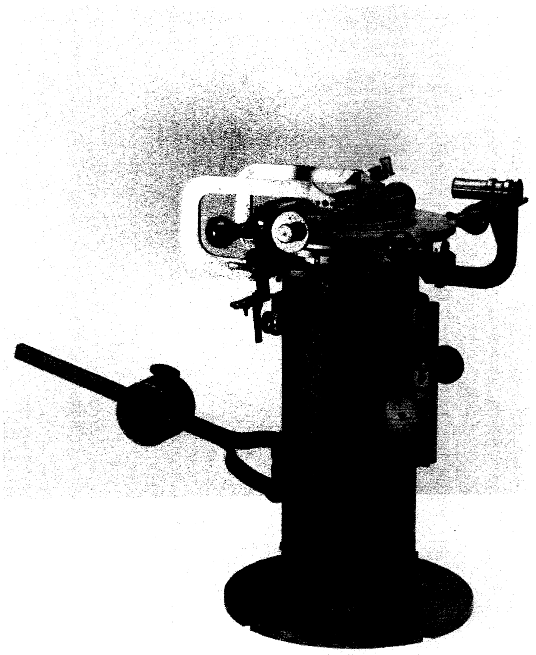


Figure 3. The RZT, photographed from the south-east.

In normal use the wires were oriented east–west, to make ZD measures as the star transited the meridian; the values of the wire intervals could be determined very easily, by rotating the instrument through 90° so that the wires were parallel to the meridian and timing the transit of the star across each wire in turn.

The micrometer wire-frame carries two wires, called 15 and 16, separated by a distance equivalent to approximately twice the ZD of γ Draconis; these being centred in the field, if wire 15 is positioned on the image of the star in one position, a small adjustment will bring the other into coincidence with it in the reversed position. Wires 15 and 16 were the central pair of a series of thirty mounted on the frame, to provide pairs for the observation of other stars culminating at greater distances from the zenith. This provision was little used for many years, but was to prove essential to the success of the instrument in the latter phase of its working life. Although referred to as 'wires', as in all the positional instruments of the time they were in fact spider webs.

In normal use the wires were oriented east–west, to make ZD measures as the star transited the meridian; the values of the wire intervals could be determined very easily, by rotating the instrument through 90° so that the wires were parallel to the meridian and timing the transit of the star across each wire in turn.

4.1.3 Installation and Early Mounting Problems

Airy initially housed the new instrument by adapting a small room off the north-east corner of the former circle room, now extended southward to accommodate the new Transit Circle. The walls were raised, and a flap-shutter mounted in the roof. The RZT was erected, and initial determinations of the instrumental constants carried out, in the autumn of 1851. The mercury trough was mounted on a brick pier built over an old stove flue, but despite detaching it from all nearby structures it was found that the mercury surface was disturbed by frequent tremors. The brick pier was taken down and the trough mounted upon a bed of sand, but the disturbance persisted. Use of the instrument was also interrupted by an unfortunate accident when in November the wire-frame was removed for some broken wires to be replaced. Subsequent failure to record γ Draconis, which at the time transited in daylight, did not at first arouse suspicion. In the following spring, however, Airy returned from a visit abroad to find that night transits were also being lost, and found on investigation that when the wires were replaced the prism had been put back incorrectly. It was immediately corrected, but many possible observations had been lost and poor weather had also added to the problem.

By 1854 Airy had concluded that the tremors in the mercury surface were incurable, "proximity to the entrance gate rendering it liable to perpetual jars, and the hardness of the brickwork upon which its sand-bed is founded tending to propagate the tremors"[14]. He therefore proposed to construct a new building, "in the angle between the passage behind the Astronomer Royal's Room and the south projection of the Transit Circle room", that is adjoining the south-western corner of the ATC room. There was some delay, but the new RZT building was completed and the instrument moved at the end of 1855. On moving the instrument Airy modified it in the light of these experiences, by shortening the main tube and mounting it on a raised table. This provided easier access to the mercury trough, and the instrument was no longer standing on the same floor as the observer. The published account (Airy, 1855) describes the instrument in this revised form.

Before moving the RZT, Airy carried out some tests at the new site by erecting a collimating telescope vertically above the mercury trough, to examine the reflected image of its wires. The results were not pleasing:

> "A well was dug below to various depths, finally to the depth of ten feet below the surface, or seven feet below the deepest foundation; and stages were erected from time to time for support of the quicksilver trough, always resting on the bottom of the well without touching the sides. The tremor was not in the smallest degree diminished. Besides the great disturbances, causing the wire-comb of the Collimator to disappear, when a door was shut in any part of the Observatory, or when a person

walked within many yards, there was a constant tremor which usually made the wire invisible. The experience of this investigation justifies me in believing that no practicable depth of trench prevents the propagation of tremor when the soil is like that of Greenwich Hill, a gravel, in all places very hard, and in some, cemented to the consistency of rock."[15]

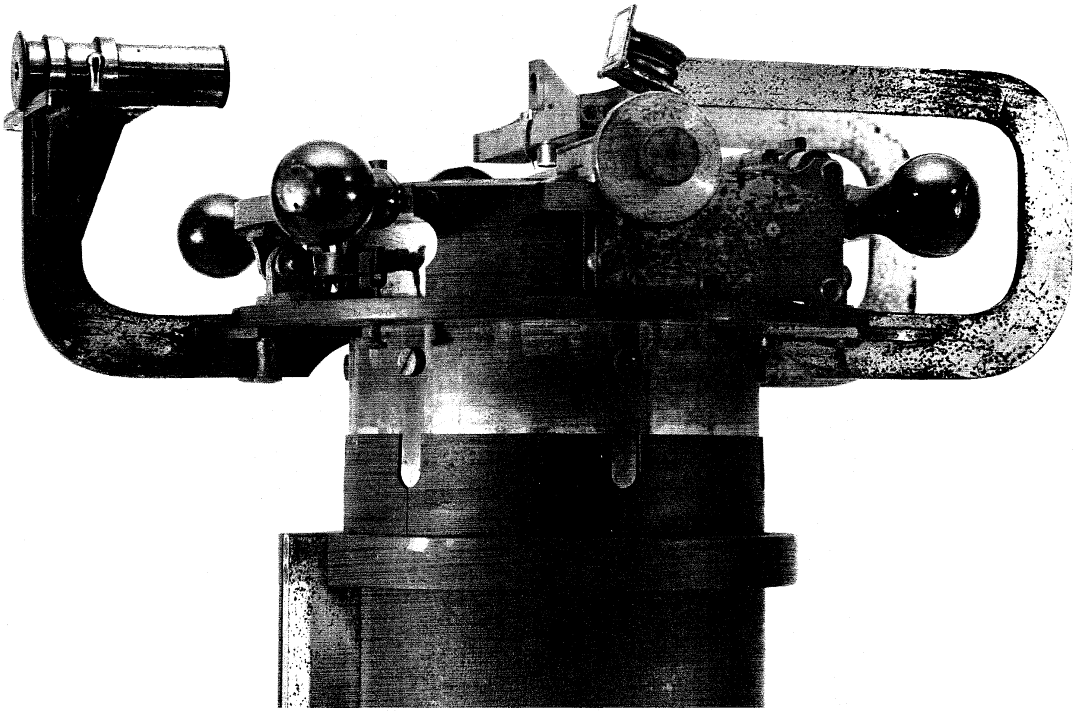


Figure 4. The upper part of the RZT, showing the reflecting prism and eyepiece above the rotary which carries the object-glass and microscope assembly.

Airy then adopted a plan which "was in some measure tried at the Paris Observatory, and was again urged by Sir John Herschel"[16], mounting the mercury trough on a stage suspended on strips of "vulcanized caoutchouc" [rubber]; after some adjustment the system worked, "leaving the image practically almost perfect". The following year Airy was able to report "the construction has been perfectly successful; the tremors are absolutely destroyed, and the star has been observed at all times of night and day. It so happened that it was observed on the very day on which it passed with the sun"[17], although "Frequent attention is necessary to correct the stretching of the straps of vulcanized caoutchouc".[18] Another problem in the tall, narrow room, described as "a little room of a most curious shape" (Maunder, 1900:304), was inadequate ventilation. This was cured by changing to an opening window: "The image of the star, since a free passage of air was allowed from the window, is almost always very good"[19]. Thus Airy had finally freed the observations of γ Draconis from the damaging effects of air currents on zenith observations which had plagued him since his arrival at Greenwich 22 years earlier.

5 OBSERVATIONS WITH THE RZT

5.1 Observing Programmes

5.1.1 The Original Programme, 1851–99

For almost half a century the RZT was used for its original purpose of determining the zenith distance of γ Draconis in order to monitor aberration and nutation, and to provide a reference zenith-point for the other meridian instruments. When it commenced operation in 1851 the mural circles hitherto used for the ZD observations of the Sun, Moon, planets, and stars had been superseded by Airy's Transit Circle, but like them the ATC was equipped with the means of observing stars both direct and by reflection, thus providing its own determined zenith-point. Airy was however very conscious of the fact that no instrument, however well engineered, can be entirely free from small errors of adjustment, and that these must be determined as accurately and frequently as possible and appropriate corrections made to the observations. He was clearly aware of the value of maintaining an independent means of determining the zenith point, using a simpler form of instrument which was not subject to those instrumental errors varying with the instrument's attitude which were an unavoidable complication in transit-circle observations, for example errors of collimation, level, azimuth, and flexure (see Satterthwaite, 2001). The RZT therefore continued to be used for this purpose until long after Airy's retirement.

Examination of the observations over several decades had revealed some unaccountable anomalies, however, and in the period 1882–86 ZD measures of the star were temporarily suspended and a long series of tests was carried out in an endeavour to relate these anomalies to thermal effects. A new focussing rod with a scale reading to 1/200 inch was fitted, and transits of γ Draconis, and occasionally 9 Aurigae, were observed over all 30 wires to determine variations in the scale value corresponding to different temperatures and slight variations in the focal length.[20] Unfortunately, analysis of these observations did not lead to a useful correlation. Normal ZD observations were resumed in 1886 April[21]. By the end of the century the Transit Circle was performing with such accuracy and its instrumental errors were so well determined that the need for an independent check was reduced, and because of the increased pressure on observers due to the programme of observations for a new Ten Year Catalogue, observations with the RZT were suspended at the end of 1899[22].

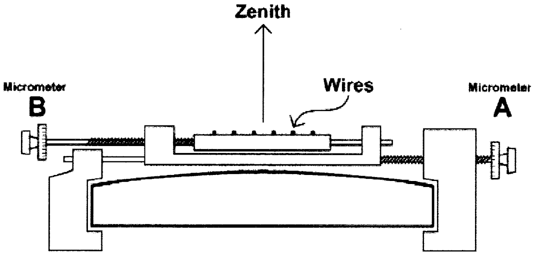


Figure 5. The principle of Airy's double micrometer, mounted on the OG-cell.

5.1.2 A New Programme, 1902–11

In the eighteenth century Euler had predicted that the axis of rotation of a body such as the Earth would not necessarily coincide with its axis of symmetry, in which case the latter would precess around the former which maintains a fixed direction in space. This would result in a wandering of the geographical pole around the pole of rotation, and consequently a variation in measured latitudes. The phenomenon was first observed by Küstner as a variation in the latitude of Berlin between 1886 and 1888. In a more extended analysis it was shown by Chandler (1891) that this would explain the anomalous results obtained with the RZT, which was therefore well suited to the task of monitoring the variation, and in 1902 "It was in consequence decided to resume the observations of γ Draconis without delay, and to observe such other stars as passed near enough to the zenith, and were sufficiently bright"[22].

The provision for observing other stars which Airy had built in, little used hitherto, now became an important feature of the instrument. The first list of stars observed indicates its range of brightness and ZD:

Star	Magnitude	ZD (′)
Piazzi XIII.296	6.3	+3.5
9 Aurigae	5.5	0.0
Groombridge 1017	6.9	–0.4
Groombridge 1024	6.2	–0.6
γ Draconis	2.2	–1.4
Lalande 14549	6.6	–2.7
ι Bootis	5.3	–19.7
5 Canum Venaticorum	5.0	–36.7

It was found that stars could be observed with good definition down to magnitude 7.0 and up to 50′ north or south of the zenith; a considerable number of stars were therefore added to the list, and more than 9600 observations were made before the RZT was finally retired. The observations from the period 1906–09 were discussed by Eddington and "On the whole a fair agreement is shown with the results of the International Latitude determinations published by Professor Albrecht".[23] It appeared however that the instrument could no longer give the accuracy required in latitude work, and that the time had come when a new instrument was required. The RZT made its last observation on 1911 August 24, and was superseded by the Cookson Floating Zenith Tube, on loan from the Cambridge Observatory. This was a conventional 6½-inch, f/10 Cooke photographic refractor, supported vertically in an iron frame which floated in an annular trough of mercury, thus permitting rotation about the vertical. Airy's reflex principle was no longer used, but would soon make a triumphant return (see section 8 below).

5.2 Methods of Observation

The normal procedure was to start with micrometer A at the observer's right hand: (i) Read and record micrometer B; (ii) as star enters the field set wire 15 on its image using micrometer A; (iii) immediately reverse the instrument and set wire 16 on the star using micrometer B; (iv) read both micrometers and record; (v) read spirit level and record. The observer faced west during the observation, using his right hand to make the micrometer settings. His field of view is shown diagrammatically in Figure 6. (Note that the apparent path of the star is affected by telescopic inversion and by reflection at the prism).

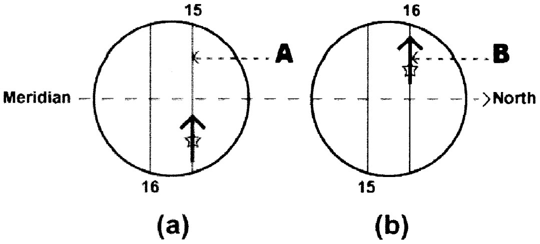


Figure 6. The observer's field of view, (a) before transit, micrometer A to the right, wire 15 set on the star; (b) after transit, instrument rotated 180°, micrometer B to the right, wire 16 set on star.

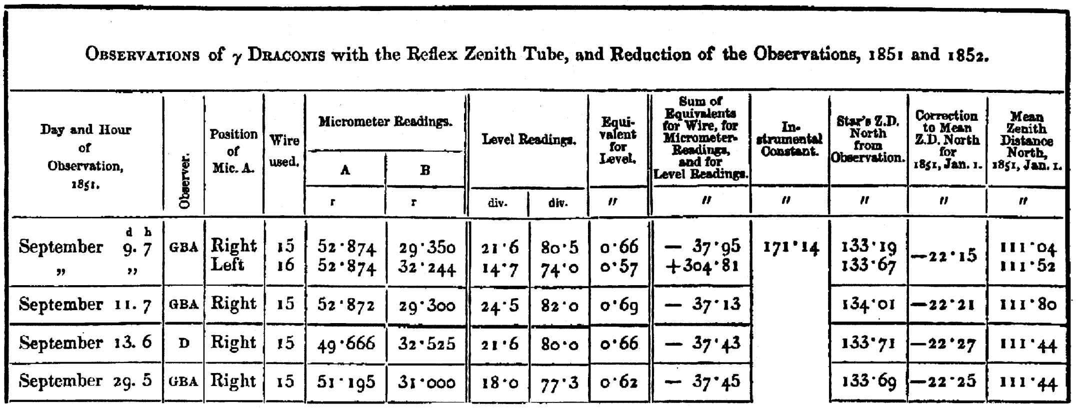
Reduction of the observations is carried out by combining the micrometer settings with the known separation of wires 15 and 16: first observation, reading of A + first reading of B; second observation, reading of A + second reading of B + separation of wires. A further correction is made for any slight inclination of the object-glass indicated by the spirit level. For stars further from the zenith a similar procedure was adopted, using the most convenient pair of wires, for example wires 11 and 20.

Although the complete observation required two bisections at the same transit, this was occasionally prevented, for example by passing cloud. As with other forms of positional work, however, for observations made regularly with the same instrument over a long period of time, the instrumental adjustments and variations become so well known that with care some value can be extracted even from a single observation.

Observing duties with the RZT were normally undertaken by the Transit Circle observers. The proximity of the RZT to the ATC was convenient, enabling the duty observer with the latter to make the observation of γ Draconis when its culmination occurred during his watch, absenting himself from the major instrument for only a very few minutes. One of the most experienced observers writes that "an exercise in agility, occasionally performed, was the observation of γ Draconis ... with the Transit Circle and with the Reflex Zenith Tube by one and the same observer at the same culmination. The star passed through the field of view of the latter telescope in less than forty seconds, and this interval could just be spared from the larger instrument, situated about five yards to the east, still leaving time for a planned symmetrical transit observation to be made." (Witchell, 1952). This account clearly relates to the RZT in its original position, but access to its later position was only slightly less convenient and would not have precluded repetition of the feat.

5.3 First and Last Observations, and Statistics

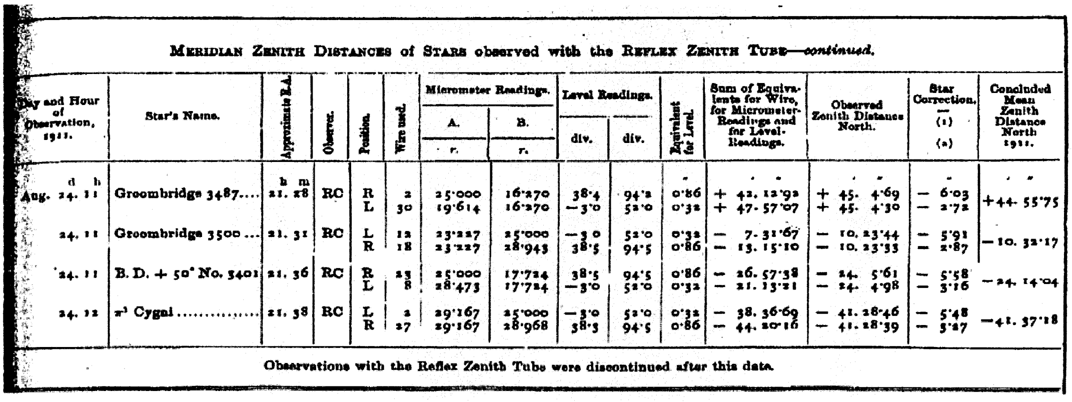
The first observation of γ Draconis was made by Airy himself on 1851 September 9 (see Figure 7). The last observation, at the end of the latitude programme, was made by R T Cullen on 1911 August 24 (Fig. 8).



Observations of γ Draconis with the Reflex Zenith Tube, and Reduction of the Observations, 1851 and 1852.

Day and Hour of Observation, 1851.	Observer.	Position of Mic. A.	Wire used.	Micrometer Readings.		Level Readings.		Equivalent for Level.	Sum of Equivalents for Wire, for Micrometer-Readings, and for Level Readings.	Instrumental Constant.	Star's Z.D. North from Observation.	Correction to Mean Z.D. North for 1851, Jan. 1.	Mean Zenith Distance North, 1851, Jan. 1.
				A	B								
d h				r	r	div.	div.	"	"	"	"	"	"
September 9. 7	GBA	Right	15	52·874	29·350	21·6	80·5	0·66	− 37·95	171·14	133·19	−22·15	111·04
" "		Left	16	52·874	32·244	14·7	74·0	0·57	+304·81		133·67		111·52
September 11. 7	GBA	Right	15	52·872	29·300	24·5	82·0	0·69	− 37·13		134·01	−22·21	111·80
September 13. 6	D	Right	15	49·666	32·525	21·6	80·0	0·66	− 37·43		133·71	−22·27	111·44
September 29. 5	GBA	Right	15	51·195	31·000	18·0	77·3	0·62	− 37·45		133·69	−22·25	111·44

Figure 7. The first observations with the RZT. [Observers: GBA – G.B.Airy, D – E.Dunkin] (after *Greenwich Observations 1851*).



Meridian Zenith Distances of Stars observed with the Reflex Zenith Tube—*continued.*

Day and Hour of Observation, 1911.	Star's Name.	Approximate R.A.	Observer.	Position.	Wire used.	Micrometer Readings.		Level Readings.		Equivalent for Level.	Sum of Equivalents for Wire, for Micrometer-Readings and for Level-Readings.	Observed Zenith Distance North.	Star Correction. — (1) (2)	Concluded Mean Zenith Distance North 1911.
						A.	B.							
d h		h m				r.	r.	div.	div.	"	' "	' "	"	' "
Aug. 24. 11	Groombridge 3487....	21. 28	RC	R	2	25·000	16·270	38·4	94·2	0·86	+ 42. 12·92	+ 45. 4·69	− 6·03	+44. 55·75
				L	30	19·614	16·270	−3·0	52·0	0·32	+ 47. 57·07	+ 45. 4·30	− 2·72	
24. 11	Groombridge 3500 ...	21. 31	RC	L	12	23·227	25·000	−3·0	52·0	0·32	− 7. 31·67	− 10. 23·44	− 5·91	−10. 32·17
				R	18	23·227	28·943	38·5	94·5	0·86	− 13. 15·10	− 10. 23·33	− 2·87	
24. 11	B. D. + 50° No. 3401	21. 36	RC	R	23	25·000	17·724	38·5	94·5	0·86	− 26. 57·38	− 24. 5·61	− 5·58	−24. 14·04
				L	8	28·473	17·724	−3·0	52·0	0·32	− 21. 13·21	− 24. 4·98	− 3·16	
24. 12	π¹ Cygni	21. 38	RC	L	2	29·167	25·000	−3·0	52·0	0·32	− 38. 36·69	− 41. 28·46	− 5·48	−41. 37·18
				R	27	29·167	28·968	38·3	94·5	0·86	− 44. 20·16	− 41. 28·39	− 5·27	

Observations with the Reflex Zenith Tube were discontinued after this date.

Figure 8. The final observations with the RZT. [Observer: RC – R T Cullen] (after *Greenwich Observations 1911*).

The total number of published observations with the instrument is 11,844, more than 95% being double measures. Observations of γ Draconis during the period 1851–99 totalled 2051. Observations of all stars in the latitude variation programme, 1902–11, totalled 9793, approximately 660 of which were of γ Draconis; thus nearly 2500 observations of this star were made with the RZT during its working life.

6 AIRY'S WATER TELESCOPE

In the 1860s Hoch, Klinkerfues, and others, investigating the effects of the wave theory of light, pointed out that the passage of a ray through a refracting medium such as a telescope objective might affect the apparent value of aberration. To test this theory Klinkerfues had inserted a tube filled with turpentine in the telescope tube of a transit instrument and observed the transits of two groups of stars whose position suggested that the effect of aberration should be close to maximum and minimum respectively. His observations were not conclusive, but suggested that the theory might well be correct. This was clearly of concern to Airy:

> The question of dependence of the measurable amount of sidereal aberration upon the thickness of glass or other transparent material in the telescope (a question which involves, theoretically, one of the most delicate points in the Undulatory Theory of Light) has lately been agitated on the Continent with much earnestness. I have calculated the curvatures of the lenses of crown and flint glass (the flint being exterior) for correcting spherical and chromatic aberration in a telescope whose tube is filled with water ... I have not finally decided whether to rely on Zenith-distances of γ Draconis or on right-ascensions of Polaris. In any form the experiment will probably be troublesome.[24]

6.1 Design and Construction

Airy decided to use γ Draconis. He drew up a design for a vertical telescope and entrusted its construction to Troughton & Simms, this time in the care of the younger William Simms (1817–1907), nephew of Airy's former collaborator who had died in 1860. The new instrument was completed in 1870 and mounted in a building on 'the South Ground' of the Observatory, which had previously housed an instrument used by Struve as part of the Pulkowa–Altona–Greenwich longitude determination. Airy subsequently published an account of the instrument (Airy, 1872), including a detailed description, with drawings, of its design and construction. Figure 9(a), from Airy's description, shows a vertical section through the whole instrument, seen from the east. The telescope is shown after 90° rotation, that is mid-way between its two observing positions. Note the gas lamp (*I*) for field illumination via the inclined mirror (*Y*). Figure 9(b) is a section through the telescope alone; note the elbow eyepiece at the foot of the telescope.

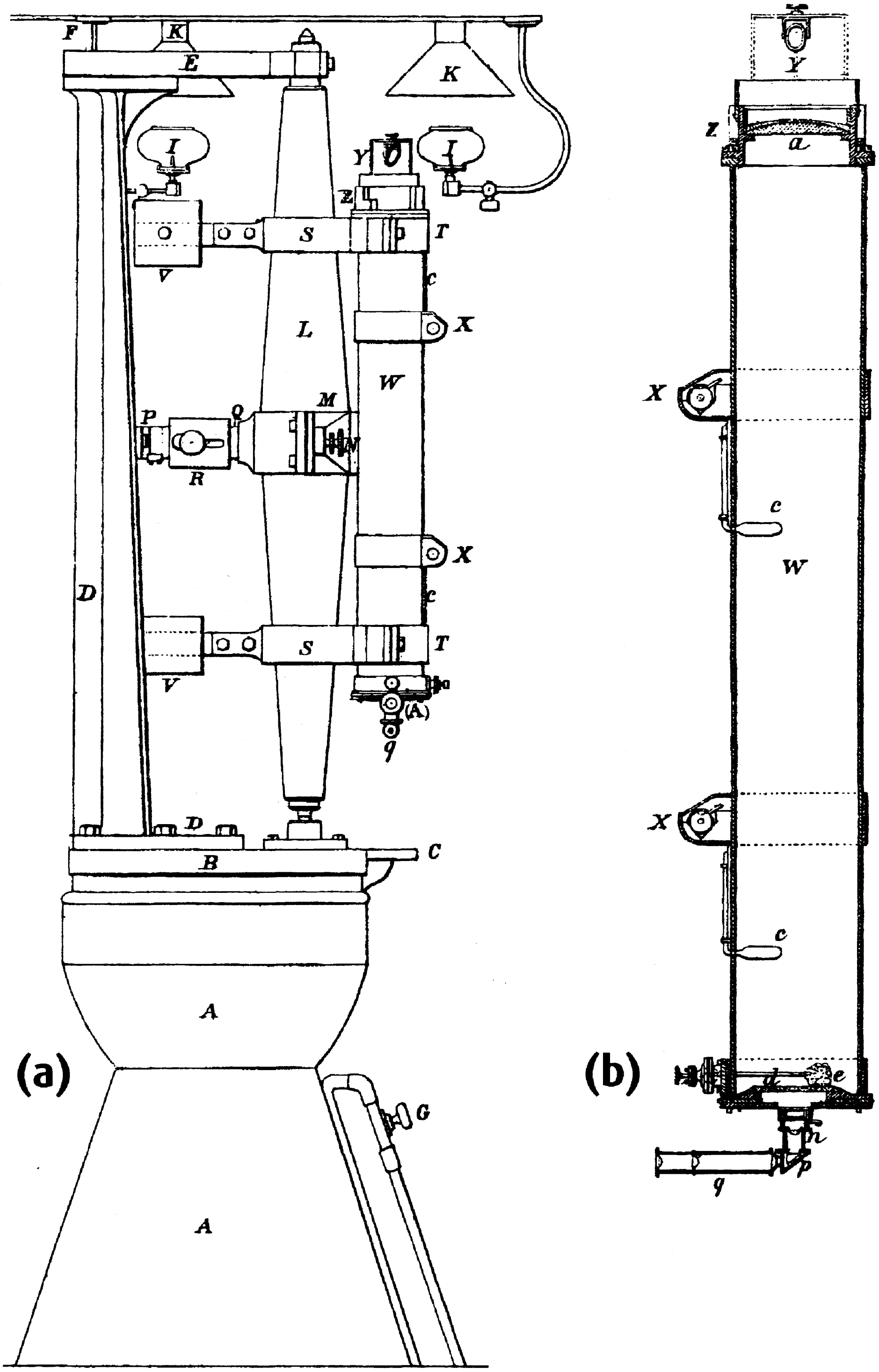


Figure 9. The Water Telescope, from Airy's description. (a) Vertical section from the east, showing instrument mid-way between its observing positions; (b) section through the telescope alone (after *Greenwich Observations 1871*).

6.1.1 Component Parts

The instrument comprised a telescope clamped and parallel to a vertical axis, about which the whole could be rotated. The axis is of bi-conical construction, supported at top and bottom by substantial bearings built into a massive iron frame.

The objective Airy had designed was of a most unusual form. In his account of the instrument he gives full details of the calculations he had carried out in order to produce a lens capable of functioning normally in very abnormal conditions. The result was a two-element achromatic lens, free from spherical aberration, of 3 inches (7.5 cm) aperture and 36 inches (91.4 cm) focal length. Unusually the outer component is the flint glass element, to avoid direct contact with the water; the radii of curvature of its surfaces are 9.0 inches (22.9 cm) and 5.3 inches (13.5 cm). The inner component is a crown glass meniscus, radii 5.3 inches (13.5 cm) and 50.0 inches (1.27 m); the meniscus is cemented into the cell with a watertight cement.

A plane-parallel plate of crown glass closed the lower end of the tube. Provision was made for filling and draining the tube, the water column when full measured 35.3 inches (90.2 cm). Mounted below the bottom plate is the eyepiece, an elbow construction with a 45° prism and four lenses, one in the short vertical tube and three in the longer horizontal arm. The eyepiece can be rotated in its mount, so that the observer, sitting on the north side of the instrument and facing south, can make both observations. The construction of the instrument required "several unusual arrangements; amongst others, the means of cleaning the lower plate glass from mud, and of cleaning the internal surface of the object-glass from bubbles"[25]. The former was achieved by means of a sponge carried on a rod passing through the ball of a ball and socket joint. The tube was "so completely filled with water that there is a slight upwards-pressure against the object-glass. It is apparently impossible to prevent air bubbles from accumulating ... but a bent tube is inserted through [the filling aperture] and the bubbles are sucked out by a slight action of the observer's mouth."[26]

Figure 10 shows the instrument from the south-east, with the telescope in one of its observing positions south of the vertical axis. Note the two large spirit-levels mounted on the telescope tube, and the arms bearing adjustable end-stops for the 180° rotation. The eyepiece is not fitted.

6.1.2 Micrometer and Wire-frame

Mounted immediately below the plane glass window, the micrometer is of the same double construction used by Airy in the RZT. The wire-frame is carried by micrometer B, the supports for which are on the slide of micrometer A. There are 26 parallel wires, at intervals equivalent to about 250″. The fixed plate of the micrometer bears a system of crossed wires for reference. The value of one revolution of the micrometer was equivalent to 73″.77 for micrometer A and 73″.89 for B. The double micrometer and elbow eyepiece assembly are shown in Figure 11, from Airy's account.

7 OBSERVATIONS WITH THE WATER TELESCOPE

Observations of the ZD of γ Draconis were made "only at the times when aberration produces its greatest effect in north-polar-distance."[27]

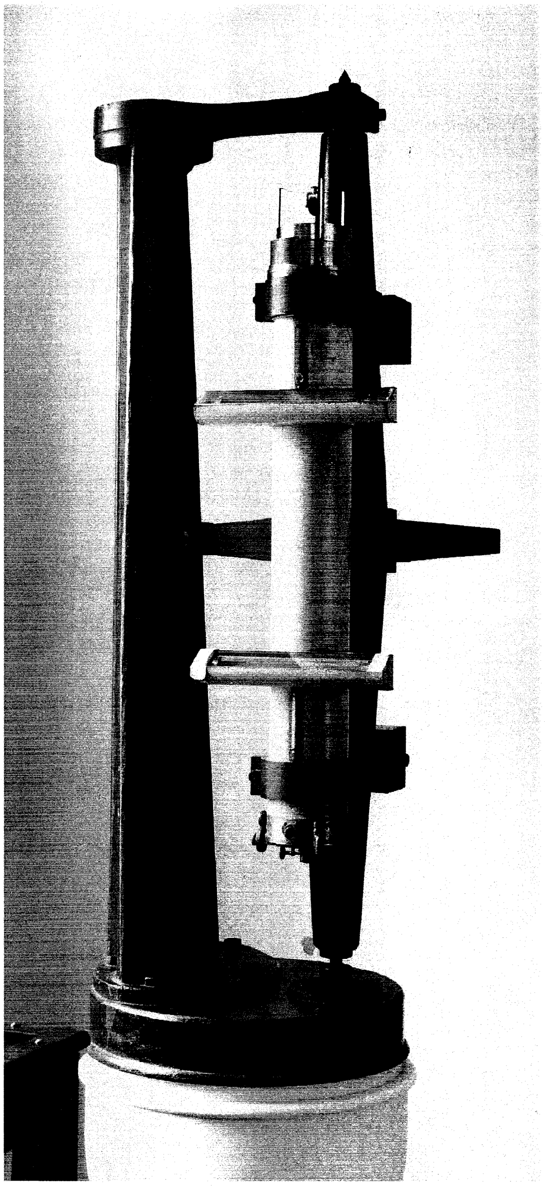


Figure 10. The Water Telescope in one of its observing positions, south of the vertical axis.

7.1 Method of Observation

This is essentially similar to that with the RZT, (see 5.2 above). Some impression of the observer's situation, and the pressures upon him, may be gained from extracts in Airy's own description:

> He reads micrometer (A), enters the reading in his book, places the instrument [at the first observing position] and reads the levels ... he turns the eyepiece to a convenient position, and, when the star has arrived near to the center of the field, he bisects it with the proper wire by the screw (B). Without leaving his place, and without reading the micrometer, he rapidly rotates the instrument [to the second observing position] and makes another bisection of the star ... by the screw (A). Then he reads the two levels. Finally, he brings the instrument to a convenient position, and takes the new readings of (A) and (B). Thus every element for a complete double determination in reversed positions of the instrument is obtained, by observations of the star occupying only a few seconds of time.[28]

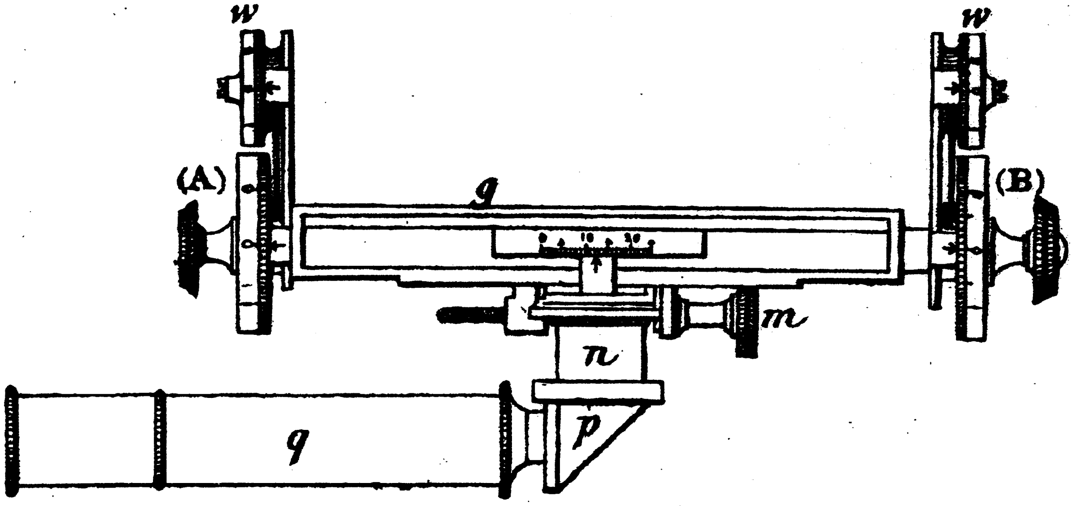


Figure 11.The double microscope and micrometer assembly of the Water Telescope (after *Greenwich Observations 1871*).

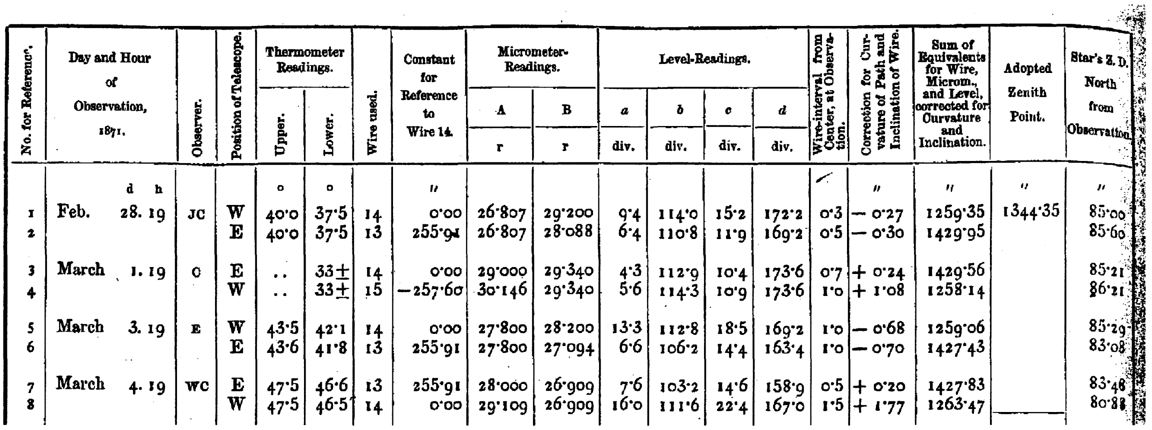
Reductions of the observations are similar to those for the RZT.

7.2 First and Last Observations, and Statistics

The first published observation was made on 1871 February 28 by J Carpenter (see Figure 12), and the last by G S Criswick on 1872 October 7. In 1871 Airy was able to record:

> "The new Water-Telescope has been got into working order, and performs most satisfactorily." He continues "As the astronomical latitude of the place of observation is not known, the bearing of these observations on the question of aberration cannot be certainly pronounced until the autumn observations shall have been made; but supposing the geodetic latitude to be accordant with the astronomical latitude, the result for aberration appears to be sensibly the same as with ordinary telescopes.[29] At the Annual Visitation in 1872 June he records "With the view of making its results less dependent on level-values, it has been carefully adjusted to verticality."[30] Finally, in 1874 June, he reports "The Water-Telescope was dismounted in August last, the observations with it having been brought to a satisfactory termination.[31]

In its short life the instrument was used for 51 double and 5 single observations of the zenith star. It is a mark of Airy's belief in the value of the experiment that he devoted so much effort and resources to the design and construction of an instrument for a single experiment, which could be achieved with so few observations over such a short time. He finally reports "The observations of γ Draconis with the Water-Telescope, made in the autumn of 1871, and the spring of 1872, are reduced" and concludes that the observations "absolutely negative the idea of any effect being produced on the constant of aberration by the amount of refracting medium traversed by the light."[32] Thus Airy, in little more than two years, had devised the means, constructed the instrument and made and reduced the observations necessary to solve a problem which had exercised the minds of numerous contemporaries for over a decade.



No. for Reference.	Day and Hour of Observation, 1871.	Observer.	Position of Telescope.	Thermometer Readings.		Wire used.	Constant for Reference to Wire 14.	Micrometer-Readings.		Level-Readings.				Wire-interval from Center, at Observation.	Correction for Curvature of Path and Inclination of Wire.	Sum of Equivalents for Wire, Microm., and Level, corrected for Curvature and Inclination.	Adopted Zenith Point.	Star's Z.D. North from Observation.
				Upper.	Lower.			A	B	a	b	c	d					
								r	r	div.	div.	div.	div.					
	d h			°	°		"							′	"	"	"	"
1	Feb. 28. 19	JC	W	40·0	37·5	14	0·00	26·807	29·200	9·4	114·0	15·2	172·2	0·3	− 0·27	1259·35	1344·35	85·00
2			E	40·0	37·5	13	255·91	26·807	28·088	6·4	110·8	11·9	169·2	0·5	− 0·30	1429·95		85·60
3	March 1. 19	C	E	..	33±	14	0·00	29·000	29·340	4·3	112·9	10·4	173·6	0·7	+ 0·24	1429·56		85·21
4			W	..	33±	15	−257·60	30·146	29·340	5·6	114·3	10·9	173·6	1·0	+ 1·08	1258·14		86·21
5	March 3. 19	E	W	43·5	42·1	14	0·00	27·800	28·200	13·3	112·8	18·5	169·2	1·0	− 0·68	1259·06		85·29
6			E	43·6	41·8	13	255·91	27·800	27·094	6·6	106·2	14·4	163·4	1·0	− 0·70	1427·43		83·08
7	March 4. 19	WC	E	47·5	46·6	13	255·91	28·000	26·909	7·6	103·2	14·6	158·9	0·5	+ 0·20	1427·83		83·48
8			W	47·5	46·5	14	0·00	29·109	26·909	16·0	111·6	22·4	167·0	1·5	+ 1·77	1263·47		80·88

Figure 12. The first observations with the Water Telescope. [Observers: JC – J.Carpenter; C – G.S.Criswick; E – W.Ellis; WC – W.H.M.Christie].

8 CONCLUSION

Both the Reflex Zenith Tube and the Water Telescope still exist, in the care of the National Maritime Museum. Though no longer on permanent display, the RZT is in good order and was displayed in a temporary exhibition on Airy's life and work at the Royal Observatory during 2001.

Throughout his long term of office as Astronomer Royal (1835–81) Airy carried out observations of γ Draconis, continuing the interest shown by all his predecessors. Like Hooke, they all realized their good fortune in being able to observe a reasonably bright star passing almost exactly through the local zenith, with the consequent freedom from the loss of positional accuracy arising from the effects of atmospheric refraction. It was Airy, however, who finally devised instruments capable of realizing the full potential of the method. His design of the RZT was not just an improvement on the zenith instrument he had inherited and struggled with for so long, but was an entirely new concept that eventually provided the means of proving the existence of latitude variation, hitherto only a theoretical concept. His Water Telescope was the only effective instrument to disprove the possibility that the aberration of light might seriously affect positional observations. Only Bradley before him, with the discovery of aberration and nutation, had achieved comparable success with zenith instruments.

Airy's reflex design, using the normal to the horizontal surface of a dish of mercury to establish the vertical, combined with rotation of the instrument so that the quantity 'double ZD' could be measured, was the forerunner of a series of important instruments. The reflex principle was not used by Cookson in the design of the (photographic) Floating Zenith Tube which replaced the RZT at Greenwich, but it was used in the development of a photographic zenith instrument by F E Ross for the U.S. Naval Observatory in Washington. The prototype was used in Gaithersburg, Maryland from 1911 to 1914, before being installed in Washington in 1915.

A much more highly developed version, with many innovative refinements, was designed by D S Perfect for the Royal Greenwich Observatory. The Photographic Zenith Tube (PZT) was constructed by Grubb, Parsons & Co. and installed at Herstmonceux, Sussex, in 1955. It was used to determine the time of transit of fundamental stars which culminated close to the zenith, as well as to measure their ZD as with Airy's instrument. With an aperture of 25 cm, a large number of faint stars could be observed. Its operating sequence was entirely automatic, and initiated by remote control from a separate building so that there were no effects due to the body heat of an observer in the instrument pavilion.

In addition to monitoring latitude variation, the transit timings were used in the control of the time service; the PZT proved to be the most accurate telescope ever used for this purpose. Several similar instruments were set up at observatories around the world. Three-quarters of a century after Airy's death, instruments developed from his design were still in use for observations to a precision of which he could only have dreamed. They were a fitting memorial to the scientific and engineering genius of a remarkable man.

9 ACKNOWLEDGEMENTS

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Figures 3, 4, and 11 are reproduced by courtesy of the National Maritime Museum.

10 NOTES

Frequent reference is made to the annual *Reports of the Astronomer Royal* to the Board of Visitors of the Royal Observatory, a series begun by Airy on his taking office in 1835 and continued until the Board of Visitors ceased to exist in 1965. References to this valuable source are cited in the form *ARR18xx*.

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Porters, watchmen, and the crime of William Sayers: the non-scientific staff of the Royal Observatory, Greenwich, in Victorian times

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Abstract
A careful study of the detailed archives of the Victorian Royal Observatory makes it possible to build up a picture of the employment and working conditions not only of the astronomical staff who worked at Greenwich, but also of the labourers, watchmen, and gate porters. Indeed, the archives open up a window on to how the Observatory was run on a daily basis: how its non-scientific staff were recruited and paid, and what were their terms of employment. They also say a great deal about how Sir George Biddell Airy[1] directed and controlled every aspect of the Observatory's life. Yet while Airy was a strict employer, he emerges as a man who was undoubtedly fair-minded and sometimes even generous to his non-scientific work force. A study of the Observatory staff files also reveals the relationship between the Observatory labouring staff and the Airy family's domestic servants. And of especial interest is the robbery committed by William Sayers, the Airy family footman in 1868, bringing to light as it does Sir George and Lady Richarda Airy's views on crime and its social causes and consequences, the prison rehabilitation service in 1868, and their opinions on the reform of offenders. Though this paper is not about astronomy as such, it illuminates a fascinating interface where the world of astronomical science met and worked alongside the world of ordinary Victorian people within the walls of one of the nineteenth century's most illustrious astronomical institutions.

Keywords: *Airy, Greenwich Observatory, labourers, watchmen, porters, Sayers.*

1 INTRODUCTION

The Victorian archives of the Royal Observatory, Greenwich, are a mine of primary historical information in so many ways. Of course, there is the straightforward astronomy, but because Sir George Biddell Airy, who was Astronomer Royal between 1835 and 1881, kept a gelatine imprint copy of every scrap of paper which the Observatory generated, there is in addition a vast archive of social history. I have been working on a biography of Sir George for many years, and feel that I have not only come to know the Astronomer Royal very well, but have also been able to follow the appointments, careers, retirements and deaths of several dozen other people who worked for the Royal Observatory over forty-six years. These people, moreover, included not just members of the astronomical and scientific personnel, but of the ancillary and service staff as well.

And especially invaluable in these researches has been the generous loan from the present-day Airy family of well over a thousand individual private documents, which have made it possible for me to come to know Sir George and his wife Lady Richarda Airy 'at home', as it were, along with their children, wider family, and friends. And especially interesting has been the emergence of a whole 'below stairs' or servants' world at the Royal Observatory. Indeed, the people who lived in this world, and who, in Victorian terms, occupied places a good few rungs lower down the social ladder than even the lowliest scientific Assistants (after all, the Assistants themselves had their own domestic servants), emerge as real figures in their own right from the vast archive of documents that pertain to the daily running of the Royal Observatory – documents which would, in almost all other institutions, have been used as fire-kindling one hundred years ago.

2 G B AIRY AND HIS 'LABOURERS'

In addition to its astronomical Assistants, the Royal Observatory employed a small staff of men – usually three or four at any one time – who seem to have been given the generic title of 'Labourers'. These would include lodge porters, handymen, night-watchmen, and such: individuals who, in addition to maintaining the basic physical security of a walled and gated Government establishment, were also required to carry coal and candles to keep the offices in which the astronomers worked warm and illuminated, remove rubbish, sweep the floors, and do simple maintenance.

And as well as this official Observatory staff, there were those who were employed by the Airy family as their own servants, but whose comings and goings, because they were private as opposed to Government servants, were less well recorded, yet who still left an historical trace. These would no doubt have included a cook, various maids, and at least one manservant, a footman, which office, as we shall discover presently, was held in 1868 by one William Sayers. At any time, therefore, there were probably about six or eight official and domestic 'Servants' and 'Labourers' working within the walls of the Royal Observatory.

But no Admiralty labourers actually *lived* within the Observatory grounds, and while the Airy family might (there is no solid record) have had some 'live-in' servants within their private residence in Flamsteed House, we know that Sayers the footman lived in digs in Prior Street, Greenwich (Airy, 1868b). Living in one's own digs, even if half a mile away, was usually preferred by a servant to living in the attic of their employer's house, for being in digs meant that a servant had a life of his or her own, once the long working day ended. One could then go for a walk, visit a pub, or keep a tryst with a sweetheart in a way that was impossible when the beady eyes of the master and mistress were always on one.

Yet while Airy was a high-principled and in some ways a strict employer, he was no martinet. Indeed, the abundant Observatory documents relating both to the scientific and to the labouring staffs make it clear that if an employee was honest, loyal, and thorough, then the Astronomer Royal would be a firm friend in time of need. Sick pay would be negotiated if the man fell ill, or pensions or gratuities extracted out of the Admiralty for men who were deemed in need of retirement.

Airy himself (Figure 1) was an immensely scrupulous and hard-working scientific servant of Her Majesty's Government, but he was no workaholic. He fiercely guarded his own personal space and, as numerous records make clear, he regarded the time which he spent in the domestic parts of the Astronomer Royal's residence with his family as utterly sacrosanct. And so were family holidays away from Greenwich, spent either at the Airy family cottage at Playford, Suffolk, travelling on the Continent, or at a rented house in the Airys' beloved Lake District. Airy and his family were always away from Greenwich for at least six or eight weeks a year. He regarded it as essential to get off the premises to really relax, and he also allowed the Astronomical Assistants between two and six weeks' annual holidays, although I have found no references to servants' holidays beyond single day treats (Airy, 1875). Sir George, indeed, was a family man to his fingertips, whose love-affair with his wife Richarda (Figure 2) lasted a lifetime, and whose relationship with his children was remarkably warm, affectionate, and humorous. In Airy's view, relaxation was a crucial counterpoise to work, and his approach to astronomy was rigorously professional. For unlike many of the wealthy Victorian Grand Amateurs, for whom astronomy was a driving passion (see Chapman, 1998), Airy regarded it as a *job*: a fascinating and a high-status job, but not what he wanted to do in the evenings or while on holiday.

These attitudes cast a lot of light on Airy's own relationship with both his scientific and labouring staffs. Although he respected a man's right to his off-duty time, and while imposing strict and meticulous working practices upon all aspects of the Observatory's life, he nonetheless realized that when an astronomical shift was over, or forty years' service had been duly clocked up, a man had a right to do his own thing unhindered by thoughts of work.

Many, though not all, of the men who became porters, watchmen, or labourers at the Observatory were ex-ratings from the Royal Navy, who had been recommended to Airy by the supervizing Lieutenant at the Royal Naval Hospital down the hill who managed the activities of those able-bodied ex-sailors who were young and fit enough to work. On one occasion, however, a man who had been a former domestic servant with the Airy family strove to better himself by seeking Admiralty employment, clearly as a result of Airy's original support. James Payne, who may have been an ex-sailor when coming to work for the Airy family, had left Airy's domestic employ about 1861 to become an Admiralty Storehouseman. In 1872 March, however, Payne was seeking promotion to Storehouseman, First Class, and wrote to Airy for his support. As usual, Airy was willing to pull out all the stops when it came to helping a thoroughly reliable man to better himself, and the Astronomer Royal sent a letter of recommendation to G J Shaw Lefevre, M.P. (Airy, 1872b). And while it seems, from the letter which Airy later sent to Payne, that a more Senior Storehouseman had in fact received the promotion (the Navy at this period always promoted on seniority), Airy (1872c) made it plain to his old servant that this was in no way an adverse reflection on Payne's capabilities. One wonders whether Payne ever did receive a subsequent promotion in his shore-based job.

Figure 1. George Biddell Airy in 1853. (After the Enid Airy Collection with thanks to the Airy Family.)

Yet while a good number of the labouring and portering staff at the Victorian Observatory were ex-navy men, one must remember that the Greenwich pensioners were by no means all old men, for when Britain had the biggest navy in the world, even in peacetime, the ravages of tropical disease, damaged joints, hernias, and occasional battle injuries[2] meant that there was an endless stream of relatively young men retiring from the Service who in one way or another could become recipients of pensions from Greenwich Hospital. And a good many of them became sufficiently recovered to pick fights in local pubs, consort with Greenwich's small army of prostitutes, and cause various kinds of trouble in the town. And some of the more reliable ended up working for Airy.

It was the rule, however, that a Naval Hospital Pensioner had to sleep at least one night per week in the Hospital, usually Saturday, though at the very beginning of his tenure as Astronomer Royal in 1838

July, Airy asked Lieutenant Rivers if John Williams, the Gate Porter, could be excused this duty (Airy, 1838). Williams was allowed this residential absence from the Hospital on condition, so Lieutenant Rivers specified, that "... he shows his legs to his Boatswain once a week ...", and thereby maintains his official presence on the pensioners' muster (Rivers, 1838).

Working as a Labourer at the Royal Observatory was quite well paid for unskilled work, and while the sums of money paid to individuals for a day's, a week's, or a year's wages, as recorded in the Observatory accounts, seemed to vary considerably, one must remember that some of these men could well have been in receipt of some kind of Navy pensions as well. And when the word got around that a Gate Porter's or a Labourer's job was going up at the Observatory, a cluster of written applications would often be sent to the Astronomer Royal, and these clusters of documents are still preserved in the Observatory archives.

3 EMPLOYMENT, PAYMENT, AND RETIREMENT

On 1853 February 26 Joseph Gale, the 71-year-old Observatory Night Watchman (who does not seem to have been pensioned off) died in office. Though he was only paid 12/6 a week (so Airy informed J Briggs, the Accountant General of the Royal Navy – see Airy, 1853a), his relatives or friends still saw it as fitting to have a batch of embossed, black-edged, and finely-printed funeral cards produced to record his passing, one of which still survives in the Observatory archives (Gale, 1853). Then the job applications started to come in. One came from an ex-policeman who had served in 'R' Division of what was probably the Greenwich Constabulary (Common, 1853), and who promised fine character-references, while another was from Michael Sheeky or Sheehy, the Observatory Gate Porter, on behalf of his brother, whom he describes as a "... proper Steady man 45 Years of age Five feet nine and Strong." (Sheeky, 1853). But the job went to Thomas Smallwood, who, in his application sent from his home in Upper George Street, Greenwich, described himself as a 'Shoemaker' (Smallwood, 1853). Like many 'respectable' working people whose letters are preserved in the Greenwich archives, Smallwood had been taught to write a fine copperplate hand, but his penmanship was better than his spelling and his grammar. For their 12/6 a week, Gale and Smallwood were only on duty from 11 p.m. to 5 a.m. each day, with overtime pay if they were needed to work longer. They had to make their rounds once an hour, clock on, and do odd jobs during the night (Airy, 1853b). Whether Smallwood came to work at Greenwich via a prior service as a naval rating before taking up shoemaking is not clear, but as he does not seem to have had any explicit connection with the Naval Hospital, it is quite possible that he was a civilian. Self-employed shoe-repairing could, after all, be an unpredictable occupation, and it is not unlikely that Smallwood continued to do some shoe-mending by day, while working six hours a night as an Observatory Watchman for some reliable money.

Thomas Smallwood had been 51 years of age when appointed in 1853 March, and twenty years later, in 1873 August, he wrote to the Astronomer Royal, "Sir, I regret to say that my strength does not improve and i fear that i shall never to do my duty again ...", and must retire (Smallwood, 1873). Since he had been a good and loyal servant, Airy immediately swung into action in an attempt to secure a pension for Smallwood, and wrote to the Secretary of the Admiralty on the subject. Unfortunately, however, Smallwood did not hold an established post covered by the Navy Estimates, but was a long-term casual servant, paid out of the Observatory's petty cash fund, and did not, therefore, qualify for an official pension. But Airy fought back for Smallwood, arguing that he had been entrusted with various 'confidential duties' over the years and had always behaved impeccably: indeed, said Airy, his long service "... seems to have a moral claim somewhat analogous to that of a Warrant Officer." (Airy, 1873b). In fact, Airy went on to fight his elderly Gate Porter's pension claim up through the bureaucratic echelons of the Admiralty, until in 1873 September a compromise was reached. For while bureaucratic precedent would not allow pensions to be paid to casual employees, the Admiralty relented under the force of Airy's bombardment, and agreed to pay a lump-sum gratuity of £20, or 6 months' wages, to Smallwood (Accountant ..., 1873).

Figure 2. Lady Richarda Airy. (After the Enid Airy Collection with thanks to the Airy Family.)

Then a week later, on September 19, poor Thomas Smallwood suddenly died. Airy now became determined that the gratuity should go to Rebecca Anne Smallwood, his widow, and the documentary saga of Smallwood's financial recompense was brought to a successful conclusion when Thomas Smallwood junior wrote to the Astronomer Royal on 1873 October 25, to record the eventual arrival of the gratuity to his mother, and to thank Airy (Figure 3) for the trouble he had taken on his father's behalf.

The success Airy had had in getting a gratuity for Smallwood was probably due, in part, to the previous approaches he had made to the Lords Commissioner of Admiralty to obtain pensions and gratuities for Greenwich porters and labourers, not all of which had been fruitful. Ten years earlier, however, another valued old retainer, Michael Sheeky, had felt the shades of infirmity and age closing about him. For in 1863 September, Sheeky had written to Airy in a good clear hand:

> Master to my Grief i present this note to you i find myself since Midsummer in constant pains and i am afraid to Remain any longer you assisted me last winter but my helth [?] [or help] was wanting i dread the wet and cold And i know i could not do what i have done ser i have been faithfull to my Employment and your directions i Kept Strictly in your absence the Same as when you were at the at [*sic*] home you were just to me and may the lord Reward you and your family M^{e}. Sheeky.

The preserved documents pertaining to Sheeky's career at the Observatory prove that he really was as good as his word in terms of loyalty and reliability. Sheeky was also an old sailor, for 12 years before, in 1851, Airy had written to the redoubtable Lieutenant Rivers to get Sheeky excused the necessary muster rolls at the Hospital.

When Sheeky had become too ill to continue his gate porter duties, however, Airy secured the services of another Greenwich pensioner, Edward Wellman, as his stand-in (Airy, 1863c), and entered into correspondence with Edward Hilditch, the Medical Inspector of the Royal Naval Hospital. Sheeky, so Hilditch informed Airy, had a nephritic (kidney) condition, and while the general prognosis was good, the elderly gate porter was best retired from further service (Airy, 1864a).

Once the Naval Hospital medical authorities had confirmed that Sheeky could no longer return to work, Airy set about obtaining financial support from the Admiralty. What is truly amazing, however, is the amount of sheer dogged energy that the Astronomer Royal – who in 1864 was himself 63 years old – was willing to devote to securing economic assistance for loyal yet humble labourers earning a few shillings a week. For whenever Airy waded in to obtain a pension or a gratuity for an old servant, it was on the top administrative brass of the Admiralty or War Office that he always set his sights. Airy did not trouble to present a case for a broken old retainer by working his way through labyrinths of middle-management red tape, through senior clerks and managers who dealt in shillings and half-sovereigns: no, he always went for the top. Letters demanding weekly shillings for Sheeky ended up on the desks of Lord Clarence Paget, Mr Whiffen (Accountant General of the Navy), Mr Romaine, and other nautical and armed forces administrative luminaries (Airy, 1864b, 1864c, 1864d).

Airy was not just concerned, moreover, with obtaining some sort of economic security for loyal servants who had become too old or too ill to work. He was also anxious about the working demands which could be placed upon those still in harness. Portering at the Royal Observatory, indeed, could be a gruelling job in winter, and as Airy reminded Mr Lethbridge, of the Royal Naval Hospital, in 1841, it was the Observatory Porter's job to go to the Hospital gate to meet the Admiralty Messenger, which duty sometimes required the man to stand waiting for a whole hour, in all weathers, " ... and this, I think, would be sufficient to kill even a young man." (Airy, 1841). Airy requested the Admiralty to erect a shelter in which porters could wait, out of the weather. And elsewhere in Airy's correspondence with the Admiralty, he chivvies the Commissioners and their officials to supply good overcoats, sturdy boots, and similar protective garments to Observatory labouring staff whose duties often exposed them to the full fury of the elements. In 1863, for instance, Airy complained to Admiral Sir Stephen Lushington that the Gate Porter (probably Michael Sheeky) was worried about what seems to have been some new regulation likely to deprive him of the gold-laced coat and hat of his rank, and "The old man feels deeply the denial of the costume which he has borne many years." And what is more, Airy felt that a less ornate dress for the Porter would also damage the dignity of the Observatory (Airy, 1863a).

It is also clear that the Observatory Gate Porter's job was not without its physical dangers from stone-throwing roughs, especially on Saturdays and Sundays when large crowds surged through Greenwich Park, and in the socially-troubled 1840s particularly, Airy exchanged several letters on the matter of Gate Porter and Park security with the Superintendent of Greenwich Police, in the light of the new powers implicit within the Metropolitan Police Act of 1839 (Airy, 1840–1843).

Figure 3. Sir George Airy in 1873. (After the Enid Airy Collection with thanks to the Airy Family.)

Although we now live in a very different social and economic world from that of the people of mid-Victorian Britain, and we take it for granted that public employers have a duty, and a state welfare system exists, to provide a safety-net for the old, the sick and vulnerable, it is hard to imagine modern-day persons of the standing of Airy and the Accountant to Her Majesty's Navy discussing the merits of the case of, let us say, a part-time cleaner or security man who had become too ill to work. And one wonders how exasperated Mr Whiffen or Lord Clarence Paget felt when yet another demand for a two-shillings-a-week pension fell upon their desks. But what this body of correspondence obviously conveys to us is that Airy would do his best to see justice done to the 'little people' who had served him well. And over his five decades at Greenwich, there were quite a few of them.

On the other hand, it should not in any way be assumed that Airy believed servants had an automatic right to job security or pensions. He was too much of a member of the Victorian middle class to believe that the 'lower orders' had any rights to paid idleness or disobedience, and always insisted to the Admiralty that, as the Director of the Royal Observatory, all powers of patronage and promotion over the staff, both astronomical and labouring, should rest entirely in his hands. And when in 1863 March James Stride, the Observatory labourer and gardener, wrote to the Astronomer Royal for pecuniary assistance with his necessary retirement "... without being troublesome to the Parish as he has no other sorse [*sic*] for his subsistence ..." (Stride, 1863), Airy was measured in his ensuing letter to Lord Clarence Paget (Airy, 1863b).

For as the senior Observatory servant, with twenty-one years' service, Stride occupied an Established Post, and had a formal claim to a pension. And in all fairness, Airy fully backed Stride's claim, whose 'rheumatic gout' had rendered him unfit for further work. But Airy, one suspects, had never been fully happy with Stride, not because he was not a dutiful and loyal worker, but because he had been appointed over Airy's head, and seemingly without his approval, by the Admiralty. Indeed, at the time of Stride's appointment, 1842 August 22 (Herbert, 1842), Airy had complained most forcefully to the Hon. Sidney Herbert, Secretary for War, insisting that *no one*, not even a labourer, should be appointed to the Observatory staff without the Astronomer Royal's full permission. And one senses that poor Herbert was taken aback from the way in which he apologized profusely to Airy for the oversight, while assuring Airy that Stride was a good man. And as if further attempting to smooth the Astronomer Royal's ruffled feathers, even the eminent Sir John Barrow, Secretary to the Admiralty Board, wrote a letter to Airy backing up Herbert's statement and emphasizing that Stride was naturally expected to be "... in absolute submission to your directions ..." (Barrow, 1842). Airy was always forthright in reminding their Lordships who was boss whenever the Queen's Navy crossed the threshold of the Royal Observatory.

Due largely to Airy's backing, James Stride got a handsome pension of £16-9-8 a year, which in 1864 Stride requested to have paid to an address at Lower Woodford, near Salisbury, Wiltshire (Airy, 1863d). Had James Stride run away to sea when a young man, perhaps as a way of escaping the tedium and poverty of an agricultural labourer's life, and after leaving the navy and working at the Royal Observatory for twenty-one years, then returned to his Wiltshire roots, grey-haired and worn out? It would be interesting to know more about his life, and if there are any members of the Stride family still living at Lower Woodford today.

Yet the upshot of the Stride affair in 1863 was to remind Lord Clarence Paget that the post of Labourer at the Observatory should no longer be an Established one, but a post held by a direct appointee of the Astronomer Royal, and paid by means of a weekly wage from an Observatory cash fund. In this way, the Astronomer Royal maintained total control over his staff, and reserved to himself the right to recommend a pension for a man on that individual's own merits and not by an established right.

And no doubt one reason why Airy was so concerned with holding all authority in his own hands in matters of staffing was that he knew what a roguish bunch old sailors could be. One also suspects that, as a civilian and an ex-Cambridge don of a distinctly high-minded cast when it came to social probity, he was less tolerant of the fiddles and dodges of former Navy ratings than would have been Sir John Barrow, Lieutenant Rivers, or the other ex-officers with whom he had dealings. Unlike Lord Nelson, George Biddell Airy was not conveniently blind in one eye, and his earnest, civilian full-sightedness probably made him much less willing to put up with those acts of drunkenness, swearing, or petty indiscipline that a retired battleship captain would have left studiously unnoticed.

When Henry Liffen replaced Stride as labourer and gardener in 1864 January, he had a referee, a Blackheath market gardener, who described him as "... Sober and Honnest and abel." (Sexton, 1863). Liffen seems to have been a competent horticulturist (there is no evidence that he was an ex-sailor), providing flowers, sweeping passageways, and even, in 1864 July, tending beehives in the Airy family's private garden. Yet when he was found to have been absent without leave on the afternoon of 1872 February 19, Airy hit the roof, instructing the Chief Assistant and future Astronomer Royal William Christie that "... I fine him 2/6^{d}. *Please remember this when you pay him his quarter's stipend* and let this stand *on the face of his receipt* as a deduction for absence without leave." (Airy, 1872a). Rather harsh, one feels, for the first recorded misdemeanour in eight years of service, for Liffen was being fined a whole day's wages for half a day's absence. Airy was also adamant in reminding Christie, in 1873 May, when the elderly Liffen was retiring, that the rules of employment for labourers had now changed and, unlike his predecessor Stride, Liffen would not be receiving a pension. I have not been able to discover whether or not he received a lump-sum gratuity (Airy, 1873a).

But if Liffen's absence was capable of arousing Airy's sense of righteous indignation, and costing the poor man a day's wages, it was nothing compared to some of the antics of which some Observatory servants had earlier been found guilty.

On 1867 December 23, for instance, the Gate Porter (probably Richard Tuddenham) had enquired whether, during his long night watches, his wife might be allowed to join him for company, over Christmas, for example (see Stone, 1867). Airy, and his current Chief Assistant, Edmund Stone, corresponded about the possibility, until Airy decided against it, for fear of creating a precedent whereby night workers at the Observatory felt that their wives or friends could regularly keep them company (Airy, 1867). Whatever transpired over the next few months is not clear, but in early 1868 August, Mrs Tuddenham turned up at the Observatory gates and created such a scene that she had to be threatened with police intervention if she did not shut up and go away. Tuddenham himself was threatened with dismissal if he failed to control his wife's outbursts and keep her away from the Observatory, and on 1868 August 5, Stone, at Airy's behest, wrote to the lady in question threatening her husband with a week's notice or the sack if she came near the Observatory again (Stone, 1868a).

Ructions had also broken out at the Observatory in 1861 January, when Airy and his family had been absent at their cottage at Playford in Suffolk. It seems that a man called Shadbolt, accompanied by his two small children, had turned up at the Astronomer Royal's private residence in Flamsteed House, claiming to be Airy's old Cambridge servant. Innocently enough, a housemaid had admitted Shadbolt, no doubt to the Servants' Hall, but when challenged by Airy's current head manservant, Green, he became abusive. He appeared to be demanding some sort of place in the current domestic entourage of the Airy family. The police had to be summoned, as a result of which Shadbolt's behaviour was deemed sufficiently extreme to warrant an examination by the police doctor, who pronounced him "... out of his senses ...", and had him committed to the workhouse (Stone, 1861).

But as, according to his 'Journal', the Airy family did not return to the Observatory from their five-week Christmas and New Year holiday at Playford until 1868 January 30, Airy's personal involvement with the Shadbolt affair seems to have been entirely by correspondence with the Chief Assistant (Airy, 1868a). No authentic independent record survives regarding Shadbolt's claim to have been Airy's old Cambridge servant.

Figure 4. Cartoon of Sir G B Airy about to punish an unknown astronomer giving some indication of the way in which some people probably regarded him. The cartoon appears in one of the 1874 British transit of Venus notebooks. (Courtesy RAS Library.)

While the manservant named Green who dealt with the abusive Shadbolt in 1861 January could well have been the same Green whom Airy had spoken of as suffering from paralysis in 1859 August (Airy, 1859), he is unlikely to have been the Edward Green who suffered summary dismissal in 1850 January. For Edward Green the Gate Porter had been guilty of a most reprehensible crime in Airy's eyes: "Dismissed Edward Green who has been Gate Porter many years, as it appeared that he lodged two prostitutes in his house." (Airy, 1850). In Airy's eyes, such conduct by the once-trusted ex-sailor was a breach of that trust, and a clear indication that Green was willing to associate himself with bad characters. Perhaps one reason why Michael Sheeky turned out to be a veritable model Gate Porter and devoted servant to Airy is because in 1850 he succeeded to Green's job, from a less well-paid one, and fully understood the dire consequences of getting into the Astronomer Royal's bad books.

4 THE CRIME OF WILLIAM SAYERS

One incident which took place at the Royal Observatory during the summer of 1868 provides some valuable insights into the social assumptions and practices of Victorian England. This was a case of criminal misconduct by an Airy family servant. In 1868 July, Edwin Dunkin, the Second Astronomical Assistant and third in command after the Astronomer Royal, who was responsible for the custody of the Observatory petty cash account during the holiday absence of the First Assistant Edmund Stone, discovered the safe unlocked and £8 missing (Dunkin, 1868). Soon afterwards, Airy found that two £5 notes, his personal property, had disappeared from a private drawer in his own study (Airy, 1868c). An investigation was immediately set in motion which tells us much about how suspicions were formulated and the process of detection commenced.

Scrupulous in all things, the Astronomer Royal was soon able to provide the two detectives from Greenwich Police Station assigned to the case with the serial numbers of the missing bank notes. Such notes, after all, were valuable items of wealth in 1868, and Airy clearly wrote down their serial numbers as a routine matter of security. He then supplied the police with the names and addresses of three Observatory servants, Messrs Smallwood, Liffen, and Tuddenham, who were the institution's current porter, watchman and labourer, as possible suspects (Airy, 1868b). All three of these men possessed an intimate knowledge of the routine of the Observatory, while their coal-carrying, candle-lighting, and related duties also took them into the Astronomer Royal's residence in Flamsteed House, as well as the Observatory offices, where they would have had access to Airy's private study. It is interesting to note, however, that in none of the documents surrounding this theft did Airy express any suspicions regarding members of the scientific staff of the Observatory who, as gentlemen, he would have regarded as honourable.

It was also at this time, in early 1868 August, that Mrs Tuddenham caused that riotous disturbance at the Observatory gates which almost cost her husband his job, and one wonders if her fury had been triggered by a routine police visit to their house, in search of Airy's missing £5 notes. Quite likely, the three Royal Observatory servants felt angry and embittered about having their names and addresses given to the police as obvious suspects (Stone, 1868b). It was, after all, the Victorian upper and middle classes who saw the 'Bobbies' as their protectors and friends, whereas the poor not infrequently regarded them as petty tyrants who used the authority of their uniform to reinforce a harsh pecking order within the working class.

The numbered notes were soon traced, however, to one William Sayers, who had for the last three years been employed not by the Observatory, but by the Airy family, as a footman and manservant. What is more, the twenty-one-year-old servant had recently contracted what the Astronomer Royal considered to be an unwise marriage to a flighty wife, and was living in a one-room bedsit in Prior Street, Greenwich. Sayers was caught in the act of passing one of the missing £5 notes, which led to his arrest and speedy confession. Being a footman, he had easy access to his master's private apartments, including his duplicate set of Observatory safe keys (*Standard*, 1868). One presumes that the person who was changing the banknote for Sayers became suspicious because in their private capacity young domestic servants would rarely ever have handled sums of money in such high denominations. There is no surviving record of Sayers's actual salary, though on 1868 July 31 and August 8 there are references to him having received £3-10-0 wages, but with no indication of the period covered by the sum (Airy, 1868d). A footman's wage could vary considerably depending on age and height, and whether he had an imposing appearance. A second footman of 5ft 6in stature could expect only £22 or so a year, but an experienced six-footer would receive between £32 and £40 per annum—not to mention tips (Dawes, 1989:127).

The Sayers robbery in itself would have been of little historical significance but for the incidents which followed the culprit's arrest at the end of 1868 July. These incidents cast some light on the relationships within the Airy household, as well as the Astronomer Royal's overall attitudes towards crime and its social remedies.

In late July, Mrs Sayers, the mother of the thief, sent a simple, undated letter to Lady Richarda Airy, in which she implored the Astronomer Royal's wife to assist her son and, if possible, help to reduce the pending prison sentence (Mrs Sayers, 1868). Though Richarda's reply does not survive – one presumes that she did not take gelatine copies of her correspondence – it is clear that she spoke up on her former servant's behalf, for when a report of the trial was published in the *Standard* newspaper on August 5, her mitigating statement was cited. Lady Airy's plea was sufficiently strong, indeed, to have Sayers's sentence reduced from six to four months' hard labour (*Standard*, 1868).

The imprisonment of Sayers did not conclude the involvement of both the Airys in the affair, and the correspondence which was to follow illuminates both Sir George's attitude towards criminals and also introduces us to an interesting aspect of the mid-Victorian prisoner rehabilitation service.

Towards the end of 1868 October, as Sayers was coming to the end of his four-month sentence, Airy received a letter from the Revd W Fraser, Chaplain of Maidstone gaol, where Sayers was serving his sentence. The Revd Mr Fraser made two requests of Airy: firstly, that he might provide character references for Sayers to help him obtain work on his release; and secondly, that he would grant the ex-convict a sum of money to help him manage in the period between release and employment (Fraser, 1868).

Airy expressed his willingness to supply the ex-convict with a testimonial to help him obtain honest employment, but he was not willing to contribute money to his personal upkeep. On the other hand, the Astronomer Royal was glad to enclose a £5 cheque to put into the general prisoners' fund for the gaol (Airy, 1868g). While reluctant to give personal financial aid to the man who had robbed him, Airy did not object to helping prisoners in general. Indeed, this response was entirely in keeping with Airy's general character. For as we have seen, he was always happy to promote the interests of the honest and deserving labouring poor, while at the same time believing that the shiftless and the guilty should be punished. Even so, as a humane man, Airy saw it as his duty as a gentleman to help the unfortunate – even those who had been caught and were now paying their dues. Hence the £5 cheque.

The correspondence with the Revd Mr Fraser, moreover, along with that which he had exchanged with the Superintendent of the Greenwich Police Station, became a vehicle by which Airy came to outline his opinions on the criminal character, with particular reference to that of William Sayers.

Sayers represented a dangerous type, Airy argued, not because of any conspicuous wickedness in itself, but because he was "... weak and sharp, a most dangerous association." His sharpness and cunning were not mischievous in themselves, but because he was a weak character, he was an ideal "... tool of accomplished thieves ...", and would be manipulated by greater rogues (Airy, 1868e). Airy was of the opinion that such associations lay behind the robbery.

The Astronomer Royal then suggested a prognosis for the future career of Sayers, which was congruent with the prevailing nineteenth-century theories of criminal types. Unless placed under a proper reforming discipline and kept out of bad company he would degenerate, and meet one of two ends. Either he would be egged on by his accomplices to commit increasingly serious crimes, or he would become insane and die in a mad-house. Sayers's "... countenance ought to be well marked and registered ..." for future public reference, asserts Airy (Airy, 1868g), though one wonders how a man possessing such a conspicuously criminal physiognomy had ever been employed by the Airy family in the first place! Was Airy being wise after the event?

The shock of four months' hard labour, and possibly the kindly ministrations of the Revd Mr Fraser, certainly seem to have brought about a profound contrition in Sayers. Early in December, shortly after Sayers's release, Mrs Richarda Airy received a letter from one Revd Mr Scott of Greenwich, an Evangelical missionary who worked with discharged prisoners. He said that Sayers was a reformed man, with a "... Christian Character ...", who most dearly wished to meet Mrs Airy and beg her forgiveness (Scott, 1868). Scott asked if such a meeting could be arranged.

One presumes that Sayers was not granted the requested audience, however, although he took every opportunity of catching the Astronomer Royal's lady as she came and went. Sayers came to waiting at the Observatory gates, on the public park side, in the hope of seeing her, and generally "... lurking about in the neighbourhood.", as Airy complained to the Revd Mr Fraser (Airy, 1868h). Airy issued strict instructions to the Observatory gate porters not to admit Sayers under any circumstances, and to summon the Park Police if he became difficult.

Meeting with no success in securing a personal interview, the languishing Sayers decided to send a letter to Mrs Airy. Addressing her as 'Madham', and with many of the ungrammatical terms of servant-talk parodied in the *Punch* cartoons of the period, Sayers begged her forgiveness, beseeched her to prevail upon her husband to give him a chance of "... getting me on through this life ... ", and even offered to pay back the stolen money.

Sayers's letter to Richarda Airy was undated, but was filed in a sequence dating from early 1869 (Sayers, n.d.). It cannot be denied, however, that Sayers set about the reform of his character and way of life with commendable earnestness, securing a job at the 'Crystal Palace', Deptford, on Airy's recommendation, and winning the warm approval of George Harrison, the Landlord (Harrison, 1868), six months later when he applied for an upper servant's place in the household of one Colonel Lowry Cole.

Airy sent a cautiously-worded letter to Colonel Cole at the end of 1869 October, mentioning Sayers's criminal record, but also emphasising his skills as a manservant. Of particular interest was the postscript which Airy added to this letter, which leads one to suspect that the Astronomer Royal had revised his theories about the inherent criminality of Sayers. His offence, Airy now argues, had been performed "... under the strong temptation of providing for an imprudent marriage, and ... he would be heartily glad to have an opportunity of recovering his character." As the file on William Sayers closes with this letter, one assumes that he got the job with Colonel Cole, and that the reformed man did indeed "... recover his character ... " instead of ending his days either on the gallows or in the predicted criminal mad-house.

The documents relating to Sayers are of significance, amongst other things, for the light they cast on the character of Mrs Airy, and for their indication that it was clearly known amongst servants, and even their parents, that she was capable of mitigating her husband's rigour. Nowhere in the documents, nor in the newspaper articles relating to the trial, is there any reference to Airy himself being appealed to as a potential fount of mercy. Quite apart from the obvious fact that he personally was £10, and the Observatory £8, worse off because of the incident, his naturally legalistic way of thinking inclined him to place justice above leniency when a trusted underling went astray. Richarda Airy, however, obviously possessed a reputation for kindness and generosity, so it was naturally through her that pleas for mercy were conveyed. And it is reassuring to know that under her influence the Astronomer Royal was capable of changing his mind.

5. CONCLUDING REMARKS

Whether Victorian prison chaplains and rescue missionaries generally went to such lengths to aid discharged convicts as did the Revds Mr Fraser and Mr Scott, or whether Airy was approached because of his high social position, would be impossible to ascertain without a wider archival knowledge of the Victorian penal system. Yet, irrespective of precedents or motives, Airy's subsequent actions were of crucial importance in giving to William Sayers the fresh start which he so earnestly desired. The Royal Observatory staff archives open up a remarkable window into the way in which two great social groups, the working and the upper middle classes, viewed each other across that gulf of wealth and culture which was a fact of life in Victorian England. But perhaps most of all, they show that George Biddell Airy, while in no way a 'soft touch', was nonetheless a man of conscience with clear ideas of social justice, and that it was well known amongst the working people of Greenwich that Lady Richarda knew how to soften justice with mercy.

6 NOTE

1. 1 George Biddell Airy and his wife Richarda are generally referred to by the titles 'Sir George' and 'Lady' Airy in this paper. Airy did not actually accept a knighthood until 1872 July (Order of the Bath), though he had been offered the rank of knight in 1835, 1847, and 1863, turning down the offer on these occasions on the grounds of the relative modesty of his financial circumstances.
2. Navarino, the last great naval battle fought under sail by British men-o'-war against the Turkish and Egyptian fleets, had been as recent as 1827.

THE LATE SIR GEORGE BIDDELL AIRY, ASTRONOMER ROYAL. (From a Photograph by John Watkins.)
(See page [illegible].)

Daily Graphic Jan 6. 1892.

Figure 5. The late Sir George Bibbell Airy, Astronomer Royal. (From a Photograph by John Watkins.) Illustration accompanied an obituary in the *Daily Graphic* of 1892 January 6. (After the Enid Airy Collection with thanks to the Airy Family.)

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An astronomer calls: extracts from the diaries of Charles Piazzi Smyth

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Abstract
Charles Piazzi Smyth, who for forty-two years in the nineteenth century was Astronomer Royal for Scotland, was an indefatigable traveller who visited many observatories, amateur and professional, at home and abroad, during his years of office. An imaginative, artistic if somewhat eccentric character, he kept informal diaries in which he recorded his day to day experiences and impressions, personal as well as scientific. His reactions to people and places could be prejudiced, but were always interesting. The purpose of assembling these extracts is not so much to throw light on their author, whose story has already been told, as to provide glimpses of what life was like for working astronomers at that time, and of the extent of their collaboration and mutual support.

Keywords: *French astronomy, German astronomy, Italian astronomy, Lassell, Huggins.*

1 INTRODUCTION

The astronomical community – as is evident from the activities of the Inter-Union Commission for the History of Astronomy (see *ICHA Newsletters*, 2001 & 2002) – increasingly urges the importance of preserving archives including written documents of every kind, and encourages efforts to find and list them. Established observatories usually have their archives of formal papers, but private material such as letters and diaries, with their often uninhibited comments, are also of potential value and interest.

An example of such material are the copious diaries of Charles Piazzi Smyth (1819-1900) (Brück and Brück, 1988) which are preserved in the archives of the Royal Observatory Edinburgh (Brück, 1988). Piazzi Smyth (Figure 1) – who chose to attach his second forename to his surname in this manner – began his career as a young man of 16 at the Royal Observatory Cape of Good Hope. Ten years later he was appointed Professor of Astronomy at the University of Edinburgh and Astronomer Royal for Scotland, a post he held for forty-two years until his retirement.

He was a man of many talents. As an astronomer, he extolled the superiority of high altitudes for astronomical observation and conducted a pioneering site-testing expedition to Tenerife in 1856. He was also a gifted artist (Warner, 1983) who left behind many beautiful watercolours of scenes and meteorological phenomena, and liked to adorn his diaries with sketches of people and places. He had a great interest in mechanical things, and was a skilful experimenter. He was unfortunately not well-supported financially in his Edinburgh post, and in practice he carried out his research in solar and laboratory spectroscopy using his own equipment and at his own expense. He performed much of his solar work in favourable climates abroad. He published delightful book-length accounts of some of his travels, in Tenerife, Russia and Egypt (Piazzi Smyth, 1858, 1862, 1867) but notes made on other journeys remain largely unpublished. It is from these that the following extracts have been taken. I have selected in particular some accounts of visits to observatories and his meetings with well-known astronomers. From his marriage in 1855 December he was accompanied everywhere by his wife Jessie (Figure 2).

Figure 1. Charles Piazzi Smyth (Courtesy Royal Observatory Edinburgh)

2 PARIS 1855

[Piazzi Smyth was one of the British contingent at the Paris Universal Exhibition of 1855. He naturally could not be in Paris without visiting the Paris Observatory under its renowned director Urban J Le Verrier (1811-77). Le Verrier's part in the discovery of the planet Neptune in 1846 had caused a certain amount of envy in England where John Couch Adams had also predicted the unknown planet's position but had failed to have it observed. Le Verrier already had the reputation of being somewhat arrogant; and perhaps Piazzi Smyth was rather too pressing.]

2.1 Paris Observatory

"*11 May*. Le Verrier rather ugly and French in looks, except the colour of his hair which is lighter than flaxen. Wife dark hair, good looking and sensible; one boy about 8, girl about 3, playing about; nurse or poor relation in room working with needle and attending to children. Room richly filled up, but at end, though looking unlike it by reason of green silk curtains and coverlets, a bed. A small fire in the room, acceptable as evening was wet. Le Verrier, rather cool and Airy [a pun on the name of the Astronomer Royal, G B Airy] in manner, stood before the fire part of the time, went to sleep part of the time, attended to the children part of the time, and read the paper, paying little attention to the guest of his invitation. Conversed with Mme Le Verrier who speaks English rather better than her husband; she was, however, not quite well, had toothache. Her great admiration of Paris, as over London, still greater of the Emperor L Nap[oleon]. NB had never been in the Louvre.

"After a great length of time a little tea brought in, nothing to eat with it, but eau-de-vie offered which refused. After tea L[e Verrier] brightened up a little and with his wife and boy formed material for a pleasing picture. He was speaking of the importance of a good deal of sleep, 7 hours at least, also plenty of recreation and long demission of astronomical labour. He could not do anything on any other plan. But he allowed that each man must find out the particular plan which will suit him best; and the plans of two men may be very different though the ends be the same. I asked him presently to show me something of the Observatory, which he did." [Next pages missing]

Figure 2. Jessie Piazzi Smyth (Courtesy Royal Observatory Edinburgh)

3 MALTA 1864

[In 1864 Piazzi Smyth and his wife made a private expedition to Egypt to survey the Great Pyramid. Piazzi Smyth had fallen under the spell of a strange theory that the Pyramid had been designed under divine guidance in Old Testament days, and that its dimensions were marked out in units of the Biblical sacred cubit. That cubit was alleged to be linked with the physical dimensions of the Earth and with the British unit of length, the inch. The matter involved the debate on whether Britain should replace its ancient system of weights and measures by the French metric system, then being widely adopted in Continental countries.

Piazzi Smyth's preoccupation with the mystical Pyramid became an obsession, which coloured his thinking for the rest of his life. It could prove an embarrassment in social intercourse, as is evident from the rather cool reception he got from William Lassell whom he visited in Malta when the steamer called there on its way to Alexandria. The wealthy English amateur William Lassell (1799-1880) was one of the great makers of speculum reflectors, who built a 24-inch instrument, the world's largest to be equatorially mounted, and later a 48-inch. He spent two periods in Malta, the second with the 48-inch in 1861-5, which is when the Smyths visited him. His principal discoveries were of planetary satellites (Chapman, 1989). His assistant Albert Marth (1828-98) observed nebulae. Marth, a German, was a university educated professional astronomer who spent most of his life in England as assistant to wealthy amateur astronomers but had offended the British establishment by publishing a critical account of astronomy at Greenwich in 1860 (see Chapman, 1998)]

3.1 Lassell's Observatory, Valetta

"*2 December*. Valetta. Pass through Palau Gardens. Trees growing well in courts, Norfolk Island pine, oleander, pomegranate, oranges and a plant with its branches tipped with red leaves looking like bright red flowers. Down again on opposite side of ridge through streets where two modern English ladies can hardly pass with their hoops. Note the Maltese lace with the Maltese crosses worked therein; at last reach quarantine harbour, looks blue, bright but very lovely compared with the other. On opposite shore, see Mr Lassell's telescope, white and twin tower like. Take a boat and on landing find it on top of a bare ridge within a walled enclosure, a few houses and a few small streets in the way, all blazing yellow. Walled enclosure looks expensive and solid. Knock at small private-looking door, where is only a small keyhole, clearly an astronomer's night latch key. Man appears, half English, half Maltese; admits party and goes off with letters and cards to Mrs Lassell at the house, some half a mile off. We are then seated in the workshop which runs all along one side of the enclosure, guess length of room 70 feet, part being given to a steam-engine room; the engine shaft entering the other bigger room and capable of being connected with the polishing machinery which appears made in excellent engineering style; but cumbersome of course for mirrors 4 feet in diameter. Lathes, benches, work tables and side shelves with tools innumerable and rafter space stored away with all sorts of bar-iron and wooden planking.

"Mr Lassell presently comes in from Valetta; recognises and begins explaining. Mrs Lassell and daughters from the house, who carry off Jessie and Miss Stanley [their travelling companion] there, and Mr Lassell again explains that everything there within, including that enclosure, was put by himself. Steam engine and workshop, of course, for he cannot polish the speculum without steam engine. (At this point, amongst the bundles of iron bars, ask him for a piece of one, 1 foot long, for material for making a standard rule for the Pyramid. He did not seem at first well inclined to part with anything but a scrap upon the floor straight on one side and cut into an arc on the other; but finally directed his man to file off a foot from a large double bar of this iron, about 20 foot long, which I thanked him for).

"Then to telescope again; 4 foot mirror, 40 feet long, his old Liverpool construction of Polar axis. Motion in AR given by a man turning an endless screw 1 inch in a second agreeably with motion of pendulum which he sees just before him. This rather wet; and this first screw and its handle have a large flywheel to equalise the man's efforts. The first second's worm acts on the endless screw of AR circle only through train of wheels and pinions. Tube of telescope novel in being open, formed of longitudinal laths of iron bar traced with rings; Mr L. says it decidedly performs better than the solid tube and eliminates most of the twirling and twitching of stars' images. Observer brought to end of telescope by a tower which has 3 separate observing stories one above the other and can be advanced to and from centre and all round centre on a great circular stage and railway.

"At this point came up his assistant Mr Marth, the German, with a paper of places for the next few nights of the 4 modern satellites of Uranus, for without the plans compiled beforehand it is very difficult to say which are satellites and which are small stars in certain parts of the sky. Consider Mr L. has settled the non-existence of 4 out of Sir W. Herschel's 6 satellites of Uranus, for 2 of the modern 4 will not answer to any of the old 6. Negative discovery seems all that has crowned Mr L.'s vast labour. He has found no new satellite of Neptune or Uranus and no rings; apparently nothing planetary. Obs[ervations] of nebulae going on also.

"This result apparently unsatisfactory in face of such appalling works, engineering and architectural i.e. appalling to anyone who has not the means (money) and whose hobby it is not. Seems to have had a depressing and rigidifying effect on Mr L. Wonder, with all his old deference to Mr Airy that he takes for an assistant Mr Marth, the German whose only great work hitherto has been his reputedly evil attack on Mr Airy and the Greenwich observations.... But with all this assistance, no discovery yet.

"Went down to the house with Mr Lassell; really a splendid house, for size of halls, rooms and staircases, paved with stone and 20 feet high (the rooms). All had a very good luncheon or early dinner and family were very kind. Took notes of precession in RA and NPD for α Draconis and ε Tauri [significant stars to be observed in Egypt]. Mr Lassell only stiffer and stiffer and when at last Pyd [pyramid] and standard measures were introduced by Jessie he declared that <u>he</u> could not see any possible method by which the proportion of the Earth's diameter on any scale could be ascertained! And that was given out in a manner implying that it would be a waste of time for anyone to be occupying himself with any questions thereanent.

"So left them at 2.15 p.m., glad to have seen them and obliged to them, but with a something, somewhere, wanting in mental satisfaction."

4 GERMANY 1869

[Piazzi Smyth was promised funds for a modern equatorial telescope, and went to Germany to consult the great Munich opticians, Steinheil and Merz. The train brought the travellers through Bonn, where they stopped for several days. They visited the Observatory at Bonn, made famous by Friedrich Wilhelm Argelander (1799-1875), compiler of the *Bonner Durchmusterung*, a massive catalogue giving the positions and magnitudes of some 32,000 stars down to ninth magnitude. Piazzi Smyth was also anxious to meet Johann Heinrich Mädler (1791-1874), one-time Director of Dorpat Observatory in Estonia (Eelsalu, 1999), now retired in Bonn: he was the author of the theory of the "Central Sun" in 1846, no longer accepted, which proposed that the Milky Way system rotated around a central point situated near Alcyone in the Pleiades. The idea appealed to Piazzi Smyth, who believed that the Pleiades played a special role in the dating of the Great Pyramid.

The Director of the Royal Observatory at Bogenhausen near Munich, Johann von Lamont (1805-79), was a versatile astronomer and expert on terrestrial magnetism and magnetic instrumentation.]

4.1 Bonn

"*13 May*. Golden Star Hotel in market place good and clean. Bonn clean and large for its 25,000 inhabitants; the houses very roomy and spacious; streets wide; trees umbrageous, public gardens frequent ... University buildings very extensive; museum of plaster casts very extensive; also a museum of Fatherland, chiefly Roman remains. Gardens remarkable for proof of little wind; long delicate leaves, flowers untouched by wind. Horse chestnuts white, also a pink one – splendid; also a creeper with blue flowers, convolvulus etc. etc. Frequent book and engraving shops.

"Sent out forenoon letter and pamphlets to Dr Mädler and to Argelander. A beautifully written letter from Dr Mädler. Called on him afterwards at Hofgartenstrasse 3, a house strangely decorated towards top with German medieval dragons in the plaster. He and Mrs M. are living here, pensioned apparently from Russia. He old and failed; she cheerful and pleasant – with half drawingroom filled with magnificent plants. Both enter kindly into the notion of Pyramid and Alcyone – both have suffered from or felt jealousies of astronomers as to his views on Alcyone.

"Call afterwards on Argelander at the Observatory. A huge building looming far and wide with one great dome and 4 small ones in a large garden delightfully adorned with plants. Doors, windows, halls, rooms, magnificently large, but not much money going to keep them up. Personal establishment only Argelander and an assistant Salem who was at Aden observing an eclipse last summer; and a son-in-law more a friend than an assistant. The instruments, a meridian circle with 4 inch object glass, and a 6 inch heliometer equatorial. The meridian circle good; has two circles and two sets of microscopes on arms to each pier though only one used at a time; has meridian collimators looking through central hole of telescope; they pride themselves much on the collimator error determination being accurate and no difference of 1.0″. Their clock arrangements poor and simple as of old. Heliometer equatorial very dirty and rusty because they say that they cannot keep out the wet from shutters and windows. It is a brother instrument to Bessel's. Mounted on wooden stand.

They complain of the clock motion being imperfect, and say that Otto Struve also does, now; and well they may, looking at the ridiculously small size of the balls.

"As compared with Edin[burgh] Equat[orial] it is fearfully strong and heavy. The pillar of mahogany beams 6 inches square, the hours circle small in radius but with spokes 1 inch square of solid cast brass and a rim of 2 or 3 inches in the side. The wooden tube like the mast of a ship; the metal filings at the ends most massive.

"Argelander has no opinion at all of Steinheil's instrumental work though the first of his optical work, his object glasses long in focal length but very perfect, more so perhaps than Merz's.

"Argelander taken up almost exclusively with cataloguing stars; with his mer[idian] circle he can just see to 9th. An old, kindly looking, finished style petit old gentleman, but not likely to go far out of his way for anyone. Gave me a portion volume on proper motion stars."

4.2 A Day with the Mädlers

"*14 May*. Took over to Mädlers by request a statement about Alcyone and Pyramid. At 12, to the Mädlers for an excursion; and they do it well, Mrs M being the active one. 1st class tickets to Godesberg, a few miles east of Bonn. ... Enter Table d'hôte room, only ⅓ of tables filled on account of the early season. We [are] guests of Mädlers. Dinner begins very well but presently Dr Mädler taken almost with fainting; led away; sees a doctor and after a rest of an hour is all right again and can return.

"Dr Mädler is 85 years old; has been married about 25 years; is a Berliner. She a Hanoverian and has seen much of the English and [was] partly in the train of a daughter of George 3rd [King of England, then also of Hanover]. He has been at Dorpat 25 years until the last three years. Was a well known astronomer and good friend of William Struve when in Germany – but on going to Dorpat, W. S[truve] wishes to take command of him but Mädler said No! he could do his own work in his own way. This gave mortal offence and there has been a war between the Struves and Mädler ever since. They have respect for W. Struve but none for Otto S. who they insist is living only on the fame of his father and having let the books of Pulkova get into confusion."

4.3 Observatory at Bogenhausen

"*20 May*. [Munich]. In the afternoon, the N[atural] History Museum being closed went through drizzling rain to the Observatory intending only to leave a letter and parcels to announce a visit next day. Passed river; passed a large stalactite rookery; passed rows of some peasant houses; passed along roads, muddy and lined with larch poplars; enter a village SE of city; enquired at a country post office and found ourselves on the road to the Observatory. What a road to a Royal establishment! A track barely marked out by wheels of a few shingle stones, and fresh ploughed ground on one side, the observatory's wooden fence on the other. Observatory inside, a queer-looking one storied plebeian place, spite of two small domes and one large one separate; these are true domes, not the Pulkova drums.

"We tread through the wet track more wondering than ever. As we turn the western corner the road track disappears under grass – alas, how long since the wheels of a patronising government have passed this way! A wooden fence all along, small and tumble down, as of backwoods. Presently a gate lodge, the man intent on his own affairs outside; we enter and walk through wet grass towards a dilapidated one stor[e]y building – half a dozen rabbits almost dispute the way with us. We approach the door and read a printed notice that admittance to see the instruments is given on two days of this week. Ring; and a woman servant appears who on receiving the letter and parcel for Dr Lamont insists on our entering. Enter accordingly into a dusty study, tables and chairs piled with papers and books and bits of telescopic apparatus; glass cases with reels of wire, insulated coils, bits of other instruments.

"Presently appears the Astronomer, Dr Lamont – serenely smiling, a philosophical old man, say 70 years, thin, acute, but kindly with close cropped head and shaven face, a dressing gown of dark colour and short fur worn inside, and a shirt perfectly innocent of both collar and starch, and nothing more visible! Heavens! Here is a philosopher at last. He speaks English admirably and pleasantly, and discusses for two hours and then takes us into the observatory – first into the workshops, then into the observing room. What a scene! Why, there is every possible variation of every known astronomical instrument – and unknown also, one might say, through all the range of optical, mechanical and electrical – and all designed, made too, by himself on slender means, furnished by Reichenbach or Fraunhofer – but such short plans and quick cuts to get high accuracy as these geniuses never knew. Registration hourly magnetical and meteorological is going on on all sides, with museums of old barometers, thermometers, clocks, early examples of heliometers, magnetometers etc. as have since become famous – dusty, oxidised, many of them; but evidently new work going on amongst them in every department almost of physics. A new zone-star observing instrument capable of observing or recording 4 stars per minute to 0.01 min. of RA, 0.1 of D and 0.1 of mag[nitude], of wood and iron and glass most bravely moving on knife-edges recording all three things electrically – a transit circle with reading microscopes magnifying 200 times, a second circle inside the first for getting mean of dec[lination]; but a totally different arrangement made on the plan for aiding zone observation by a single reading microscope.

"Never was an astronomer so independent of what the opticians chose to supply to him; never was an observatory so full of all sorts of things that none but the master could move about safely in it. Never were more star places observed by one man, more than 100,000 owe their records to him. Scientific, and theoretically mathematical to a high degree, here is a man who for practical astronomy is practical above all others – not only in using instruments for observation but designing and making them in every possible manner; and that, not by large funds, but by the help of young men selected for genius of the proper kind by him. He does not like to have as assistants educated astronomers.

"And who is this Dr Lamont? A Scottish boy, born in Braemar and at 13 carried away (probably from poor and Gaelic speaking peasants by the priests) and spending the rest of his life in Bavaria. Almost as in bitterness of memory of another land, he said Bavaria was a country where no man ever died for want of food. He knew a Scotchman who could not speak a word of German but lived in Bavaria because he loved the country and the people."

5 ITALY 1872

[On a tour of the Mediterranean, the Smyths travelled from Liverpool, arriving in Palermo, Sicily, after a 12-day voyage. Piazzi Smyth who had successfully observed the spectrum of the *aurora borealis* in Edinburgh during the recent high sunspot maximum planned to observe the zodiacal light from the low latitude of Sicily in order to compare its spectrum with that of the aurora. It had been suggested that the two phenomena had the same spectrum. Piazzi Smyth believed otherwise.

Palermo Observatory was the home of Piazzi Smyth's illustrious godfather Giuseppe Piazzi, discoverer of the first asteroid in 1801. The current Director was Gaetano Cacciatore (1814-89), whose father was Piazzi's successor. His assistant was Pietro Tacchini (1838-1905), future successor of Angelo Secchi in Rome. The Italian astronomers, notably those in Palermo, were leading experts in solar spectroscopy and in eclipse observations. They used a visual spectroscope for systematic observing of prominences, something that Piazzi Smyth had never seen before. By chance, a blue sun was observed in Palermo on the day the Smyths arrived. The Palermo astronomers were extraordinarily helpful, collaborating with Piazzi Smyth evening after evening over a period of four weeks and introducing the visitors to scientists in other Departments of the University. Only a selection of the diary entries are given here.

The Smyths' contact in Palermo was an old friend Colonel Henry Yule, a geographer and well-known author of a *Life of Marco Polo*, who had lived long in the East before retiring to Sicily.

The Smyths' cruise continued, calling at Trieste and Venice. From Venice they went to Padua with an introduction from Tacchini to the acting Director of the observatory, Professor Guiseppe Lorenzoni (1843-1914) (Pigatto and Zanini, 2001), who was later to succeed Giovanni Santini (1787-1877) as Director.]

5.1 Palermo

"*Sunday 10 March*. Palermo Bay. A blue-white sun in an ominously watery looking sky. Messenger from Col Yule boards ship early; then the Colonel, looking like Marco Polo himself. With few words he contrives to get the ship's officer to send us and baggage off before anyone else, and before breakfast; then through the shipping moored end-on to mole. ...

"*12 March*. At 9 p.m. with Miss Yule to the observatory to see M. Cacciatore. Ascend to top of Palace by broad flight of low stairs generally constructed in marble; pass under a long verandah with glass ornaments and groves of shrubs to M. Cacciatore, finding him with a brother and brother-in-law, the former bearing the name of Piazzi and the latter holding a foundation situation called after Piazzi. He speaks French, the others not. Room abundantly decorated but with paintings mostly very bad. He then takes us upstairs and along gallery after gallery floored and lined with marble all along. Shows two paintings and one bust of Piazzi, then shows the Ramsden alt-azimuth under a dome with white marble pillars beneath, and then to the new meridian circle room (Piston and Martin's), Equatorial by Merz (9.5 inch object glass), chronograph room, Secchi's grand meteorograph etc etc. – each room with the name in golden letters outside. Instruments in good state of preservation and cleanliness, and are generally kept under linen covers. Spectroscope is direct vision from Leipsic: no makers in Palermo.

"Return to Hotel at 11 p.m.; many shops still open.

"*20 March*. By cab to the Observatory. Saw S[ignor] Cacciatore and S. Tacchini. Spoke to former chiefly on meteorology, and to the latter on spectroscopy. Former to copy out for me the Met[eorological] journal for the first two weeks of March as descriptive of storm on SS Kedar [experienced on the voyage]. Touching the blue sun, he says that that came from dust in the atmosphere, for dust fell that day on the roof of the Observatory and was gathered up: he gave us a specimen. S. Tacchini similarly gave me a specimen from Genoa, collected similarly in 1870.

"On speaking of spectrum of zodiacal light. Signor T. has not observed it himself but speaks as though all Italian astronomers were sure the aurora, zodiacal light and solar corona gave one and the same spectrum line, and he gave me two papers and a mss page to prove the same [by Secchi and other Italian astronomers].

"*22 March*. At the Observatory 9.30. Sig. Cacciatoro receives us urbanely. The dust on the roof of the observatory was caught on the morning of the 10th but might have fallen the previous night or day, but not the previous 3 days because the wind was so strong ... he supposes the dust came from Africa.

"To observatory to see Signor Tacchini. Spectroscope attached to the end of 9 inch equatorial. Two black curtains fitted up temporarily for eye end to move between and also [to shield] from sun. No clock work; used RA and dec[lination] handles combined with Sp[ectroscope's] own circle of position. Slit is used very narrow – solar prominence seen thus, in narrowest sections as it passes slit. ... Sp[ectroscope] only for mapping shapes and sizes or red prominences. Tacchini observes sunspots by projection on screen and fixes angles and draws circle on a board with circles of position and radii. Has observed Saturn [in the same way] and drawn it accurately ...

"At 9 p.m. return by invitation to observatory to look through equatorial. Tacchini works; Cacciatore looks on. Moon three quarters full ... Jupiter not very well defined, and from power 150 and its small disk Tacchini with a short sharp pencil puts in details on a circle drawn on paper 6 inches in diameter. The central zone is certainly rosy. I could not pretend to see all that he put down. ... He showed the Linnhe crater as a nebulous white spot on Mare Serenitatis.

"Jessie complains of the cold at the observatory, overwalks herself for warmth in returning and falls ill again.

"*24 March, Sunday*. Professors Cacciatore and Tacchini send enquiries after Jessie. ...

"Says Senator Professor Cannizzoni at Col Yule's

party: What is the matter with Mrs Piazzi Smyth?
Col Y: She has overfatigued herself and brought on a slight fever. She was actually twice at the observatory in the course of one day.
"Sen.P.C.: (with utmost astonishment) What has a donna to do at an Observatory!
"*28 March.* Dejeuner at Observatory chez Signor Cacciatore. S. Tacchini in company. Neatly set out in room looking to Monreale and mountains. Eggs, bread, French wines and water, salt beef, bread butter and Marsala wine. Larks spitted on silver skewers like cupid's darts and the skin of a fowl or turkey stuffed with forcemeat. Coffee and tea. The tea in a silver coffee pot and the coffee in a china teapot.
"Visit equatorial. Tacchini works hard at prominences. We then unpack spectroscope and show its action with lamp spectrum and choose a window looking west.
"7.15 p.m. to Observatory for Z[odiacal] L[ight] observations.
"*1 April.* At R. Observatory Palermo with Signor Cacciatore. Z Light appears well in west; sky clear of almost every particle of cloud. ZL best seen without, rather than with, gathering objective and without telescope, or with prisms, collimator and slit only. [observations continue until 8.25] (Figure 3*)*.

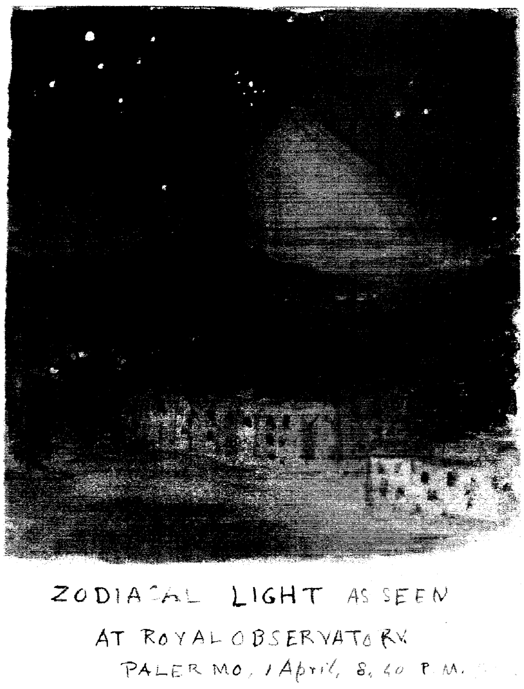

Figure 3. The "brilliant zodiacal light" at Palermo, 1872 April, sketched by Charles Piazzi Smyth.

"*3 April.* 7 p.m. to Observatory. Present, Signor Cacciatore and Tacchini.
"Begin arrangements in plenty of time by twilight.... from 7.15 to 8.50 good view of ZL.
"[They all record what they see, independently].
"[Tacchini] will write to Gasperi, Donati and others and confer with them. He is in a fix. ... But now I show him that all three spectra are different. ZL spectrum like any old residual twilight spectrum and also like sp[ectrum] of starlit sky or starshine. And why not? If ZL is the united glare of millions of meteors shining by reflected solar light as I have always maintained.
"*5 April.* ... In spectroscope Jessie declares ZL spectrum as different from aurora spectrum as night from day.
"*7 April.* Brilliant zodiacal light now abundantly past Pleiades. Orion Nebula very bright.
"Two dozen casks of Marsala ordered through Col Yule."

5.2 Padua

"*24 April.* Venice to Padua by rail. Visit to Observatory at Padua, top of lofty old tower, 120 feet high. Santini, Director, 90 years old and absent (author of *Elementi in Astronomia* 1830 and *Teorica degli Stamenti Ottici* 1828). Telescope counterpoised from flexure in a Reichenbach Meridian Circle by Stark, Vienna. Lorentzini, the Acting Director, shows his equatorial and spectroscope. Small equatorial (4 inches), smaller dome. Sliding black cloth curtains tube. Telescope tube has silver scale and vernier to focus exactly for clear vision at any given part of the spectrum, as C, D3 or F, to see red prominences at those places distinctly at once. Telescope eyepiece carries perforated plate; turning the open slit with length along spectrum you see where you are; turning at right angles you have a good view of the required line and get rid of much needless light. Screw near C moves telescope to bring any part of the line on to the slit.

"Anemometer of Alexandria optician for registering both velocity and direction on one piece of clock-moved paper. Direction given by vane; velocity cup well of 4 feet, 5″ cup. Chain from direction vane turns; horizontal axis with great sharp-edged worm. Clock moves a sling of paper under it. Velocity wheel winds up weight and lets it fall after completing every turn....

"Universal instrument by Repsold of Hamburg. Like Pulkova instrument but with microscope to both upper and lower circles; counterpoise; method of reversing.... Lorenzino took this instrument and equatorial to Sicily for eclipse [of 1870]. A pleasant quiet diffident man. He presents us with photos and conducts us over Padua. University has 44 professors, 1480 students.
"(NB Hotel charges 3 lire for bottle of Asti Bianco which is sold at a shop a few doors down the street for 0.8 lire; profit without trouble mainly 400 percent, if tourists will go on permitting it.)"

6 PARIS 1875

[Piazzi Smyth and his wife were in Paris to visit instrument-makers and to order his solar spectroscope from his favourite optician, Salleron, with whom he had several meetings. They afterwards paid another visit to Le Verrier, now in his sixties, at the Observatory. Since their last meeting with him, he had been obliged to resign following trouble with his staff, but was reinstated in 1873.]

6.1 Paris Observatory

"*7 July.* Noon to Observatory Difficulty of finding Le Verrier anywhere. He comes at last from a bath. Extensive well-planted and shady gardens behind observatory. Numerous domes on observatory, high up, and also about the garden. He begins to show us the new reflecting Equatorial in progress; is called off by a telegram and appoints 8 p.m.

"8 p.m. At Observatoire. The only building in Paris not inscribed with Liberté, Egalité, Fraternité, but simply Observatoire. Madame and M. Le Verrier seated on the terrace of the observatory. Presently Mr [H.C.] Russell of the Sydney Observatory announced. A herculean build of a man, of good natured rather stolid look, M. L[e Verrier] takes us to see the new reflecting equatorial again. Lightning storm coming on. After awhile he takes us 'to see the observatory' but only shows us some old instruments in a sort of hall. Return to Mme Le Verrier and Jessie; they are now inside house, and Mme L. much alarmed at the lightning closes first the door, then the window curtains. When we say that we have not yet seen the active instruments of the Observatory she gets her husband up again to show them to me, Mr R[ussell] and Jessie though M.L. does not much like that. He shows us only the transit circle. Boasts of it much over the Greenwich one; affects great acquaintance with instruments; sits down on the step of the basement and cannot get up without assistance. I find out for myself the portable collimators, reflectors *a la* Foucault. Great storm of lightning and rain. Afterwards we are all left to find our way home without any refreshments or assistance.

"*9 July*. Le Verrier made a grand speech at the Institute about the weather – 1st to explain how the Observatory had predicted dry weather just before the great inundation in the south of France took place; and 2nd to say that now all the probabilities were for fine weather. That was on Wednesday at 3 p.m. At 9 p.m. that evening came the great thunderstorm of our visit."

7 FRANCE 1876

[The Smyths came back to Paris a year later to collect the spectroscope from Salleron. It was not quite ready so they follow Salleron's suggestion that they should visit the observatories of Toulouse and Marseilles while they waited. The Director at Toulouse was the eminent mathematician François Felix Tisserand (1845-96), appointed in 1873, who later became a Professor in Paris and the author of *Traité de Méchanique Céleste*. The observatory at Marseilles was founded by Le Verrier, originally as a branch of Paris Observatory, its situation chosen as suitable for linking France geodetically with Algeria. Eduard Jean Marie Stephan (1837–1923) was put in charge, and was in due course named Director. The Observatory's programme was to observe comets, asteroids and nebulae. Stephan's name is well-known to posterity for his discovery of the group of nebulae known as Stephan's quintet. Stephan's assistant in the same programme was Henri-Joseph Perrotin (1845–1904). Piazzi Smyth became deaf in later years; presumably that is why his questions to Tisserand were written down and why Stephan wrote on the blackboard.

Back in Paris, having called briefly on E .D Marié Davy at his meteorological observatory, they visit Pierre Jules César Jannsen (1824–1907), solar spectroscopist and eclipse observer, famous as the first to observe solar prominences outside an eclipse by the use of a spectroscope on the day after the total eclipse in India in August 1868. Jannsen was much concerned with the spectrum of Earth's atmosphere, and with distinguishing lines of terrestrial origin in the solar spectrum. He also investigated the spectrum of water vapour in the atmosphere. Piazzi Smyth, who had tried the same experiment, was anxious to elicit details of Jannsen's observations, but without much success. Jannsen was the first Director of the solar observatory at Meudon in 1876, but at the time of the Smyths' visit was still in his private observatory in Montmartre.]

7.1 Toulouse

"*20 May*. Walk to Observatory, up the Alleé L Napoleon, now Allée Lafayette, cross railway and then up another street going up hill … Observatory in a large garden enclosure with lodge gate at entrance. Large and roomy building. M. Tisserand the astronomer a little smiling sailor-like man, great upon his experience in Japan at Venus transit [1874]. The first assistant, M. Perrrotin, has discovered 3 new planetoids. The work of the observatory is essentially extra-meridian; they have a large meridian room, with several openings and a number of instruments under them, but old: Lalande's great quadrant, Ramsden's Transit etc. The planet discoveries were made with objective 7″, f[ocal] l[length] 100″, mounted so as to have eyepiece at centre, both movements given by pivots and handles, both circles have white divisions on black ground; can be read from a constant seat, no clockwork, no illumination of field or of wires; wires very thick showing dark on starlit sky. Planet discovery consists in checking star maps against sky. Instrument by Eichen.

"The great reflector is in a dome in the garden; said garden full of battle bones, and large portion collected in one place. Garden flourishing, roses and jessamine in flower, gooseberries and currants in fruit; vines promising.

"*21 May*, Sunday. List of 15 questions [regarding observatory and university duties] in readiness for M. Tisserand on visit to Observatory; answered that night. 8 - 8.30 p.m. walk to observatory. Steep hill. M. Tisserand obliging and merry as ever. He got 2 observations of Jupiter's satellites in the early hours of this morning. Had been spending his Sunday in preparing a mathematical-astronomical lecture to be given tomorrow at 8 a.m. in the university and was ready for a night's work now. He answered my questions; then with addition of M. Perrotin we enter the Reflector Dome in garden. They begin showing Venus, though it was low; no clamping; no clockwork; with power of 170. Very brilliant, very white and well defined but accompanied by ghost … Next looked at Vega. No finding by setting of circles but only by pointing along tube (needs 2 men to turn dome). Companion to Vega surprisingly distinct. Nebula (annular) in Lyra a great triumph, so brilliant in so dark a field yet nebular in texture. [Observed] Jupiter [and] Polaris.

"What birds are these whose songs come in at the open shutter from the garden? asks Jessie. Nightingales, responds M. Tisserand; and so it is, they abound in this obs[ervatory] of dead men's bones. Most complaisant doorkeeper shows us half-way down the hill and we proceed, the fair and the shows and the cafés are still at 11 p.m. in full swing; a rotating system of wooden horses and carriage is in great request among men and women and children of all degrees. They revolve most quickly and most smoothly: an example to the dome revolvings of an observatory. A horse turning in a small circle inside seems to do it all."

7.2 Marseilles

"*26 May*. Walk up a long street, continuation of Rue de Noailles. Tramway and perfectly open carriages for coolness. By broken ground we reach the Observatory which has no regular direct road yet, nor any distinct fence around it, nor any astronomer's house, nor any distinct observatory but a large number of detached buildings of all sizes and shapes. In the first of these surmounted by a cup anemometer and wind vanes on tall poles, we are shown into a very dark room out of the blinding sunlight, and presently M. Stephan appears – a very little man, middle aged – say 35 – prim, neatly got up in his dress; rather precise and severe in his manner but amiable and obliging withal. A follower of M. Le Verrier; this observatory founded by M. Le Verrier as Toulouse by M. Delaunay. This Observatory useful to M Le V. for longitude with Algeria and other parts. Three assistants here with a computing room for themselves and the Director with a room as big for himself alone. A concierge man, too, cap in hand to Director, and many workmen about the place. M. Stephan takes us first to the Great Telescope in its own building: a drum dome. Mirror back all naked and exposed, very green glass and supported merely by a bar of wood across a central pad. Thickness at edges 2.75″ at centre 5″ nearly. Silvering 18 months old; should be renewed every 12 months; is done by M. Stephan All the means at hand, rope rings for slinging mirror upside down ... Chair entirely novel and good. At top of wall under dome and level with the telescope centre is a circular fixed platform ascended by fixed side stair.

"Great telescope employed yesterday on nebula; its diagonal prism small. On either side of diagonal prism of telescope are two little prisms like ears, placed in reversed way; these receive light from the illuminating lamp at opposite side of tube to reflector which sends it back and illuminates the field. Clock motion found not quite strong enough, though said to be good otherwise. Whole instrument made under Foucault by Eichen when in Secretan's service.

"A large equatorial is next shown, under drum dome also; objective 10″ splendidly complete instrument and such a chair – rolling around on wheels and pinions and slides for movement to and from centre and up and down. The instrument's clockwork – Foucault's fan fly, and said to work well in all temperatures and to hold star bisected [for] many minutes. Field dark with light wires. Micrometers with enormous box of frames of micr[oscope] but no movement of eyepiece; therefore only to ensure truth of motion over small space. Eichen is a prime mechanician to some astronomers.

"*27 May*. Mme Stephan to call on Jessie tomorrow. He apparently is really impressed by the Great Pyramid, the only great astronomer we have met who is. He visited the G Pyramid on his return from the Indian eclipse.

"7.15. Out to Observatory in closed fiacre. Conversation on definition of telescope. M. Jannsen had not found definition on Himalayas better than on Indian Plains. I quite agree that that might have been so, though on Teneriffe result was different. M. Stephan writes on blackboard splendidly to explain himself. Adjourn to telescope ... Look at stars; rain begins; back by carriage.

"*29 May* p.m. Observatory again. Venus shown, fairly defined crescent but with great patch of violet colour from residual chromatics. Star shown on meridian with Foucault's fly regulator or clockwork: it sometimes keeps bisected for long, sometimes varies and then some accident is found to have occurred to clock screw. ... Therefore leave equatorial and go to telescope. While chair of equatorial with all its wheelworks turns out to be adapted only for observing at low altitudes – the bridge chair for reflector to be specially adapted for zenith or near zenith work, or on the meridian; for meridian sweeping nothing could be better. But said chair ... is too heavy and slow to move. Attendant has very hard work, and astronomer could do nothing without him. M. Stephan has arranged a long series of double stars in order from 0.3″ to 16″, also clusters and nebulae to be looked at; but they would have occupied a week night and day; and as sky though clear has bad definition we look only at 1 or 2 of each. Want of clockwork a nuisance; also want of focussing screws. ...

"The setting of D[eclination] circle is all done by [light of a] hand-lamp. The instrument however is very awkward and its chair is too far out of meridian. [other difficulties with instrument] But M. Stephan abounds in amiability and devotion."

7.3 Jannsen at Montmartre

"*3 June*. Back at Grand Hotel, Paris

"*4 June*. Attentive and polite letter from M. Marié Davy, also from M. Jannsen.

"*5 June*. At noon start our long drive to Observatoire de Montsouris ... open country 2-3 miles out though within the fortifications. Marié Davy, stout, round-faced, flat-headed, abundantly grey-haired man. His observatory a relic of the exhibition of 1867, a sort of Alhambra palace affair. His experiments in meteorology numerous and praiseworthy, dealing with the chemistry of meteorology and agriculture as well. ...

"Long drive in search of M. Jannsen after 9 p.m. Rue Labbat, beyond Montmartre, found at last ... home with a garden. House modest in size and character, and the old woman servant evidently has expected us and shows us straight in to the salon i.e. a small room more like a study and with one gentleman and two lady visitors besides us. M. Mme and Mlle Jannsen sitting conversing. Jessie gets on well with Mme Jannsen, I tolerably well with M. J.; the gentleman visitor wants to know about Teneriffe. When the visitors leave at 11 p.m., then M. Jannsen begins on my points, gives me some [photographic] plates and pamphlets but is very obscure as to any drawings either in ms. or print of any spectrum of the vapour of water shown by a steam tube against gas-light only. What he shows are old things already printed on telluric lines in the Sun, and even if his chief plate of those was, as he seemed to say, sunlight through a steam tube against sunlight without steam, it is a little bit of the steam lines only, viz., from D to C cut off sharply and artificially at either end. He was only positive and clear on this, that a length of 36 feet of steam tube shows nothing, 100 [feet] a little, 250 feet grandly, and in his new observatory he will have 350 feet. But otherwise the spectrum of the vapour of water is as unsatisfactory as ever; there is no existing drawing of it pure and simple.

"Returned 1 a.m."

8 LONDON 1876

[William Huggins (1824–1910), one of the pioneers of astrophysics, began his spectroscopy of stars in 1863 and soared to fame as the first to observe the emission line spectra of certain nebulae and of a nova (Hearnshaw, 1986: *passim*). Though an amateur, he had on loan from the Royal Society new modern instruments, erected at his private observatory in Tulse Hill, London, in 1871. His clever wife Margaret whom he married in 1875 became his collaborator in photographic stellar spectroscopy which they pursued for a further quarter of a century. The Hugginses' artistic lifestyle was recorded by many visitors. The dog Kepler was also famous. The glass door panels mentioned by Piazzi Smyth are preserved in the Whitin Observatory, Wellesley College, USA.]

8.1 Tulse Hill

"*19 June*. Off to Huggins.

"Far out among Clapham's bowery roads and gardens, a long way, too, from railway station; a small house, small garden in front, large behind, small rooms and long and narrow staircases, but all filled to overflowing with the most exaggerated ideas of medieval furniture: the painted glass at door however reproducing with the group from the Bayeux Tapestry isti mirent at the comet; a sun with red prominences and a nebula, and their respective spectra. Fernery and palm-house, though small, grandly successful. The dogs, the big yellow mastiff Kepler and the little barky black terrier Tycho Brahe. Access through house to the observatory dome, carpeted floor, and large, with space for laboratory as well as driving clock, ... induction coil etc. ... He has much liking for his old pieces of apparatus and making up things himself, and was once beyond everyone else in sp[ectroscopy]. But now, even with Mrs H.'s assistance, he must see that others do not pass him in refinements of mechanics."

9 CONCLUDING REMARKS

Besides providing some charming vignettes of individual astronomers, Piazzi Smyth's informal on-the-spot impressions highlight how very hard the professional astronomers of the nineteenth century worked when observatory staff numbered no more than two or three – for example Tisserand at Toulouse and Stephan at Marseilles. They also show – as at Palermo where astronomers stinted neither time nor energy in facilitating their foreign colleague's experiment – how much personal encounters mattered before the days of conferences and instant communication.

10 ACKNOWLEDGEMENTS

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Was the supernova of AD1054 reported in European history?

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Abstract
The bright supernova of AD 1054, which produced the Crab Nebula, was extensively reported in East Asia and there is also a brief Arabic reference. Whether the star was recorded in European history has long been a matter of debate. In this paper we investigate in some detail purported European accounts of the supernova. We conclude that none of these are viable. The new star probably escaped notice in Europe because at the time astronomical knowledge was generally very limited.

Keywords: *calendar; chronicles, Crab Nebula, Europe, history, Moon, supernova*

1 INTRODUCTION

The stellar outburst which occurred in AD 1054 is without doubt the most well-known of all historical supernovae. At optical wavelengths, its remnant – discovered by John Bevis in 1731 – is by far the brightest supernova remnant. This object, listed as the first entry in the catalogue of spurious 'comets' by Charles Messier, was named the 'Crab Nebula' by Lord Rosse in 1844. The Crab Nebula was identified as the remnant of the supernova of AD 1054 as long ago as 1921 (by Knut Lundmark). Radio waves were detected from the object in 1949 and the discovery of a pulsar within it in 1968 attracted tremendous interest internationally.

The supernova explosion in AD 1054 was widely reported as a bright 'guest star' in China and was also noted in Japan. Yet only a single record of the star from outside East Asia is *definitely* known; an Arabic work cites an observation which probably originated from Constantinople. In recent years, several possible sightings recorded in European literature have been proposed. In this paper we discuss these suggestions in some detail.

2 HISTORICAL SUPERNOVAE

On the available historical evidence, only five galactic supernovae have been observed over the last 1500 years. These events occurred in the years AD 1006, 1054, 1181, 1572, and 1604 – and thus were all prior to the telescopic era (Stephenson and Green, 2002). Each of these temporary stars was observed by Chinese and other East Asian astronomers (either in Japan or Korea) and many important records are preserved today. Only records of the earliest two events (AD 1006 and 1054) have so far been identified in Arabic literature. The two most recent outbursts occurred after the Renaissance and both supernovae were extensively observed by European astronomers, notably Tycho Brahe (in AD 1572) and Johannes Kepler (in AD 1604).

Of the three medieval supernovae, the most brilliant appeared in Lupus in AD 1006. This was indeed a spectacular object, attaining a magnitude of around –7.5 (Winkler *et al.*, 2003), and remaining visible for at least three years. Several European chronicles contain reports of this star, which also attracted widespread attention in the Arab world (Goldstein, 1965; Stephenson and Green 2002). By contrast, there seems little doubt that the relatively faint supernova of AD 1181, which was located in Cassiopeia, was not noticed outside East Asia. Its peak apparent magnitude was probably close to zero and – although the star was circumpolar – it was lost to view after six months.

One of the Chinese accounts of the supernova of AD 1054 relates that it was visible in the daytime for twenty-three days. As this star was well placed for visibility before dawn, its position would be relatively easy to locate after the Sun had risen. Hence the apparent magnitude of the star at maximum may be estimated as around –3.5 or –4. The supernova, which appeared in the (Western) constellation of Taurus, remained visible for twenty-one months. Before considering the question of European observations, we need first to summarize what is known about the appearance and location of the star, as derived from East Asian sources. The material in Section 3, below, is largely based on the investigation of Stephenson and Green (2002), to which the reader is referred.

3 EAST ASIAN OBSERVATIONS OF THE SUPERNOVA OF AD 1054

The supernova of AD 1054 was carefully recorded in China, and a brief but important report is also preserved from Japan. As quoted in both the *Songshi* and the *Wenxian Tongkao*, Chinese astronomers first detected the supernova on the day *jichou*, in the fifth lunar month of the first year of the Zhihe reign period; the equivalent Julian date is AD 1054 July 4. The date of last reported sighting (as also noted in China) corresponds to AD 1056 April 6. Conjunction with the Sun is not mentioned in the extant records, but these are no more than summaries of what were originally extensive observations.

Both Chinese and Japanese sources describe the supernova as a 'guest star' (*kexing*); this was the usual term for a strange star-like object, although the expression was occasionally applied to comets. No motion over the twenty-one months of visibility is mentioned in any of the preserved East Asian accounts. This rules out any possibility that the object might have been a comet. Comets seldom remain visible to the unaided eye for more than six months. Further, in twenty-one months both the orbital motion of a comet and that of the Earth – which would have completed nearly two orbits around the Sun – would have resulted in a marked change in relative position.

In China, the new star of AD 1054 was reported (in the *Song Huiyao*) to be "... visible in the daytime, like Venus", and it remained a daylight object for twenty-three days. As the visibility of the star – already some 35 degrees to the west of the Sun on July 4 – would improve with the passing days, any fading would be purely an intrinsic feature. The position of the supernova was described by both Chinese and Japanese astronomers as very close to the Chinese constellation *Tianguan*, which is represented on East Asian celestial charts as a single star. By considering reported positional measurements of *Tianguan*, and also computing the circumstances of planetary conjunctions with this star, it can be conclusively shown to be identical with ζ Tau, a somewhat isolated 3rd magnitude star. The specific positional terms used in both Chinese and Japanese records imply that the supernova appeared less than about 1 degree from ζ Tau. The Crab Nebula is 1.1 degrees from ζ Tau, whose RA and dec. at the epoch AD 1054 were 04^{h} 41^{m}.6 and +20°.0 respectively.

A Japanese record in the *Meigetsuki* – compiled nearly two centuries after the event – asserts that the supernova appeared "... after the middle ten-day period of the fourth lunar month in the second year of the Tenki reign period." As the middle ten-day period was equivalent to AD 1054 May 20–29, the indicated date evidently was soon after May 29. Apart from the fact that the star was in conjunction with the Sun on May 28, such an early date is in conflict with additional details in the same entry which state that the guest star was visible in the east "... at the (double) hour *chou* [i.e. 1–3 a.m.]." Since sunrise would occur around 4.50 a.m., the star must have been already considerably to the west of the Sun when it was first noticed. If we read *fifth* lunar month instead of *fourth* in the *Meigetsuki* record – as was first suggested by Duyvendak (1942) – ζ Tau would then be rising more than two hours before the Sun; this is in close accord with observation. The equivalent date of first sighting would thus be soon after June 28, and hence in reasonable accord with the Chinese discovery date. In this context, we may note that the brilliant supernova of AD 1006 was independently detected on the same day by both Chinese and Japanese astronomers, while for the much fainter supernova of AD 1181 discovery in China and Japan occurred only one day apart.

An independent record in the *Qidan Guozhi* from the Liao kingdom in northern China notes both the occurrence of a guest star near Mao (the Pleiades) and a solar eclipse at some unspecified time before the death of King Xingcong – who died on AD 1055 August 28. The guest star almost certainly was the supernova. However, there is nothing in the text to suggest that star and eclipse occurred at the same time; they were both regarded as important astrological events preceding the death of the King. Hence a definite date for the observation of the supernova cannot be deduced from the Liao record.

To the unaided eye, the appearance of the supernova of AD 1054 would be merely that of an unusually bright star. Chinese astronomers noted that "... it had pointed rays on all sides ..."; this was presumably due to distortion within the eye of light from a bright point source. The various records indicate that the other historical supernovae (AD 1006, 1181, 1572, and 1604) all showed similar features.

In summary, if we are to identify any European records of the supernova, we need to consider references to a bright star-like object, probably seen in the northern summer of AD 1054. Both Chinese and Japanese records indicate that the supernova was visible in the eastern sky before dawn. Although the star was located in the constellation of Taurus it would actually be in the zodiacal sign Gemini; the longitude of ζ Tau was then 71°.6, almost in the middle of the range covered by Gemini (60–90°).

4 AN ARABIC RECORD

Brecher *et al.* (1978) were the first authors to provide firm evidence that the supernova of AD 1054 was observed outside East Asia. In a thirteenth century Arabic text – a biographical encyclopaedia of physicians – they discovered a brief reference to a new star seen in or near AD 1054. In this work, entitled '*Uyūn al-Anbā*' and compiled by Ibn Abī Uṣaybi'a around AD 1242, an intriguing report by Al-Mukhtār Ibn Buṭlān is quoted:

> I, Ibn Abī Uṣaybi'a, have copied the following from an account in his [Ibn Buṭlān's] own hand. He says: 'One of the well-known epidemics of our time is that which occurred when the spectacular (*athari*) star (*kawkab*) appeared in Gemini in the year AH 446 [AD 1054 April 12 – 1055 April 1]. In the autumn of that year fourteen thousand people were buried ... in Constantinople ... As this spectacular star appeared in the sign of Gemini which is the ascendant of Egypt, it caused the epidemic to break out in Fusṭāṭ [old Cairo] when the Nile was low, at the time of its appearance in the year AH 445 [AD 1053 April 23 – 1054 April 11] (trans. Brecher *et al.*, 1978).

In AD 1054, Ibn Buṭlān, a Christian physician, was living in Constantinople, having only recently moved there from Cairo. There is some confusion in the text over the year when the star was said to appear – that is whether it was seen in AH 445 or 446. However, the fact that the star was located in the zodiacal sign Gemini strongly supports its identification with the supernova. The description by Ibn Buṭlān represents the only known Arabic account of the AD 1054 supernova. Since at the time Ibn Buṭlān was domiciled at Constantinople (the capital of the Byzantine Empire), it may be presumed that the new star was seen from here. However, there is a possibility that the observation was made instead at Cairo, which also features in his report.

5. RECORDS OF THE AD 1006 SUPERNOVA IN EUROPEAN HISTORY

Before considering possible European reports of the supernova of AD 1054, it is helpful to briefly cite the known records from Europe of its much more brilliant predecessor, the supernova of AD 1006. Although this star was in a very southerly declination (–38°), there are several important European accounts (Goldstein, 1965; Stephenson and Green, 2002). The most detailed report is to be found in the *Annales Sangallenses*, the chronicle of the monastery of St. Gallen. This text only specifies the year of occurrence, but describes the supernova as "... a new star (*stella nova*) of unusual size ... glittering in aspect and dazzling the eyes ..." The account adds that the star was seen for three months and that its shape was often distorted, probably due to atmospheric turbulence; the meridian altitude of the supernova at St. Gallen was less than five degrees, so that the star would barely skim the mountainous southern horizon.

A further description – in the *Annales Beneventani*, from Benevento in Southern Italy – again only cites the year (i.e. 1006) and merely relates that "... a very bright star (*stella clarissima*) gleamed forth." Several further European reports describe the object as a "comet", usually without further details. However, the account from Metz in southern France is more specific: "A comet with horrid appearance was seen in the southern part of the sky, emitting flames this way and that ..." (*Alpertus de Diversitate Temporum*). Because of the extremely low meridian altitude of the supernova at Metz (some three degrees), the allusion to flames probably results from atmospheric turbulence, as at St. Gallen.

By comparison, the supernova of AD 1054 (at declination +21°), was extremely well-placed for northern observers. Hence references to the effects of atmospheric distortion are unlikely. We might expect European accounts to mention little more than the appearance of a bright star.

6 POSSIBLE RECORDS IN EUROPEAN LITERATURE

The question whether the new star of AD 1054 was reported in specifically European literature has attracted a number of investigators. Several authors – notably Dall'Olmo (1980), Williams (1981), Guidoboni *et al.* (1992), McCarthy & Breen (1997) and Collins *et al.* (1999) – have proposed references to the star in European chronicles.

Three suggested European sightings of the AD 1054 supernova relate to the appearance of an unidentified bright star near the crescent Moon. However, in two of these instances it is necessary to assume a substantial error in the recorded date. In three further examples, a variety of unusual phenomena are described, sometimes in the form of visions. Curiously, all of the inferred dates of observation are several weeks before the star was first sighted in China, despite the fact that none of the supposed European observers were astronomers. It is difficult to avoid the impression that some of the modern authors cited above were anxious to demonstrate European priority on this occasion.

In this context, it should be emphasized that dating errors in contemporary medieval European chronicles are surprisingly rare. This is evident from a study of the eclipse observations cited in such works; for eclipses, of course, the precise date of occurrence can be verified by modern computation. One of us (Stephenson, 1997) investigated numerous records of total and near-total solar eclipses as reported in European annals between AD 733 and 1544. In as many as forty-eight instances, an explicit date (year, month and day) is given on the Julian calendar. Comparison with the computed dates of these events reveals that forty-two of these forty-eight dates prove to be exactly correct. Of the remaining six records, there are three examples of errors of only one or two days and a further three cases where the year is one year in error but both month and day are correct. This survey should provide a useful reference by which to assess potential European records of the AD 1054 supernova. In particular, if it proves necessary to assume serious dating errors in interpreting purported accounts of the supernova, adequate justification for amending the recorded date is necessary. Caution needs to be exercised in order to avoid playing some sort of 'identification game'.

7 INFERRED CLOSE APPROACHES OF THE MOON TO THE SUPERNOVA

Because the Crab Nebula lies only 1.5 degrees to the south of the ecliptic, occasional close approaches of the Moon to the supernova would perhaps occur during its long period of visibility to the unaided eye. Such an event might well have drawn attention to the new star. The possibility of such a conjunction has attracted the attention of various authors (Dall'Olmo, 1980; Williams, 1981; and Collins *et al.*, 1999).

However – as detailed below – the results of computation are not encouraging during the (northern) late spring and early summer of AD 1054 (i.e. in the months leading up to discovery in China on July 4). We compute that from the point of view of Central Europe (approximate latitude 45° N, longitude 10° E), during the months of April, May and June in AD 1054 the Moon would not be seen to pass within about five degrees (i.e. ten times the apparent lunar diameter) of the supernova. For comparison, the daily mean motion of the Moon is some 13 degrees.

At the epoch J2000, the RA and declination of the centroid of the Crab Nebula are: $05^h\ 34^m\ 31^s$, +22° 01′.0. Reducing to the mean epoch AD 1054.5, the equivalent longitude and latitude are 70°.91 and –1°.42. In April of AD 1054, the closest visible approach of the Moon to the supernova would take place after dusk on the evening of April 13; the Moon and star would then be as much as 5°.7 apart. At that time, the Moon (phase 0.10) would be 38 degrees E of the Sun. A month later, at dusk on May 11, the minimum visible separation would be 5°.1; the Moon would then be a very thin crescent (phase 0.03), some 20 degrees to the E of the Sun. By the next conjunction, on June 8, the supernova would be a little to the west of the Sun; at dawn on this date, the Moon would be 4°.9 from the star. However, the slender crescent – elongation only seven degrees to the W of the Sun – would then be invisible.

Continuing into the summer of AD 1054, the next conjunction between the Moon and the supernova visible in Europe would occur before dawn on July 5. The Moon (phase 0.11) would be 39 degrees W of the Sun. On this occasion, the minimum visible separation would be 2°.8; as seen from Central Europe, the spacing between Moon and star would still be more than five lunar apparent diameters. Before dawn on August 2, the Moon and supernova would be as much as 6°.1 apart, while in the early hours of August 28, the separation would be 2°.6. It is with these various figures in mind that we may assess proposed conjunctions of the Moon with the supernova.

7.1 A close conjunction recorded in the *Cronaca Rampona*

In a summary table, Newton (1972:690) drew attention to what he described as a "Bright light within the circle of the Moon" in the year AD 1058. This event was recorded in a fifteenth century Bologna chronicle, the *Cronaca Rampona*, compiled around AD 1476. Newton himself did not dispute the recorded year. However, this report was subsequently investigated by Williams (1981), who proposed that – despite various chronological problems – it represented a sighting of the supernova of AD 1054. Although criticized by Breen and McCarthy (1995), Williams' suggestion was taken up by Collins *et al.* (1999).

We have translated the appropriate entry in the *Cronaca Rampona* as follows:

> In the year of Christ 1058 [i.e. Ml8], (Pope) Stephen IX was enthroned on the 28th day of the 9th month ... (Also) in the year of Christ 1058 [i.e. Ml8], Henry III had reigned for 49 [i.e. x19] years. He first came to Rome in the month of May. At this time there was famine and death over the whole Earth. He occupied the Tiburtine state for three days in the month of June ... At this time a very bright star entered into the circle of the new Moon on the 13 Kalends at the beginning of the night (*stella clarissima in circuitu prime lune ingressa est, 13 Kalendas in nocte initio*).

From Williams (1981), combinations of Roman and Indo-Arabic numerals – as found in the above record – were quite common in the fifteenth century, but highly unlikely in the eleventh century. Hence these instances must represent editing by the fifteenth century compiler. It is clear from the neighbouring entries in the chronicle that the compiler indeed intended the year when the "very bright star" appeared to be AD 1058, as there are immediately prior entries in the chronicle sequentially under the years 1046 [Mxl6], 1049 [Mxl9], 1051 [Mli], 1055 [Mlv] and 1056 [Ml6].

The chronology of the above text presents several serious problems – see also Breen and McCarthy (1995). First of all, it is well established that Stephen IX became Pope on AD 1057 August 2. Further, Henry III died on AD 1056 October 5 after a reign of only seventeen or eighteen years (depending on whether exclusive or inclusive counting is used). Henry became King of Germany in AD 1039. He is known to have made two separate visits to Italy. The earlier of these was in the autumn and winter of AD 1046 when he was crowned Holy Roman Emperor. The latter visit occurred in 1056, and it seems that this is the occasion mentioned in the chronicle. There is thus evidence of several major dating errors in this short passage, written more than four centuries after the events described. Hence there must be a strong element of speculation in any attempt to derive the date when the "very bright star" appeared.

Williams (1981) felt that it was "... almost impossible to make astronomical sense ..." of the phrase *stella clarissima in circuitu prime lune ingressa est*. However, in medieval Latin the term *circuitus* can mean "circle" (Latham, 1965:86). Reference to a further medieval Italian text – see below – indicates that *prime lune* may be understood to mean 'new Moon', as also proposed by Breen and McCarthy (1995). Hence we infer an occultation of a bright celestial body by the young crescent Moon in the early evening.

Unfortunately, even the month when the event took place is not specified; the star was seen "on the 13 Kalends" of an unspecified month. In most months, 13 Kalends corresponds to either the 19th or 20th day of the preceding month; for example 13 Kalends April is equivalent to March 20. However, 13 Kalends March would be either February 17 or 18. Breen and McCarthy (ibid.) point out that at no time in AD 1054 did the new Moon fall "... anywhere near the 13 Kalends of any month." They further remark: "Indeed, not between the dates October 20 (13 Kalends November) 1050 and through to May 20 (13 Kalends June) 1056 did the Kalends coincide with a *prima luna.*" In particular, the first lunar month of AD 1054 began on January 12 (4 Ides January) while the last full lunar month began on December 3 (5 Nones December).

In view of the wide variety of chronological problems associated with this fifteenth century text, it would seem scarcely justifiable to associate "the very bright star" with the supernova of AD 1054. Even if an alteration of the date by several years could indeed be shown to be acceptable, the fact that no close conjunction of the Moon with the supernova was visible on any evening in April, May or June of AD 1054 would seem to invalidate any attempt to suggest that the *Cronaca Rampona* implies discovery of the star in Europe before it was sighted in China.

Instead, we feel that there is a real possibility that the "bright star" mentioned in the *Cronaca Rampona* was the planet Venus. Although several medieval European annalists had an appreciable interest in astronomical matters, it is apparent from a study of their writings that in general their knowledge of the night sky – in common with many educated non-scientists today – was very basic. Probably very few people of that time would be able to identify the planets (Stephenson and Green, 2002).

In the summary table by Newton (1972:690) mentioned above, he also noted that a similar astronomical report to that in the *Cronaca Rampona* is found under the year AD 1086 in another Italian chronicle, the *Annales Cavenses*. We have consulted a copy of the *Annales Cavenses*, the Latin chronicle of the monastery of La Cava in Southern Italy, as published in volume III of the well-known series *Monumenta Gemaniae Historica, Scriptores*. The appropriate entry may be translated as follows:

> 1086. On the 13 Kalends of March [i.e. February 17] at the beginning of the night a very bright star entered into the circle of the new Moon (*13 Kal. Martii incipiente nocte stella clarissima in circulum lunae primae ingressa est*).

The above terminology is remarkably similar to that in the *Cronaca Rampona* account. Additionally, the day of the month (the 13 Kalends) is the same. The recorded date of the conjunction in the *Annales Cavenses* corresponds to AD 1086 February 17. We compute that on this same evening, the Moon would be a very thin crescent (phase 0.022), only 17 degrees to the east of the Sun. Taking the latitude and longitude of La Cava as 40°.7 N and 14°.7 E respectively, we compute that at dusk (local time 6 p.m.) on February 17, the topocentric co-ordinates of the Moon were: longitude = 350°.86 and latitude = –1°.45. Comparing with the computed planetary co-ordinates for all five bright planets, we note that Venus (longitude = 350°.94, latitude = –1°.24) was very close to the Moon at that time; the planet would actually be occulted for more than half an hour. There is thus excellent accord between observation and computation, and hence confirmation of the accuracy of our interpretation of the terminology in the text. In particular, there is no need to invoke any new star to explain the report.

Newton (1972:690) also notes that ten years after the above event the *Annales Cavenses* also records a very bright star in "... the circle of the Moon ..." at the time of a lunar eclipse. A translation of this entry is as follows:

> 1096. The Moon, aged 12 days, was obscured when the sky was clear, and a very bright star came into the circle of the Moon (*stella clarissima venit in circulum lunae*) on the 8 Ides August.

The equivalent date is AD 1096 August 6. Computation reveals that on this same evening the Moon was indeed eclipsed. The total phase began at sunset and ended a little after 10.30 p.m. At mid-eclipse, the topocentric lunar co-ordinates were: longitude = 320°.22, and latitude = –0°.68. Further, we note that the planet Jupiter (longitude = 322°.70, latitude = –1°.32) was then only about three degrees away from the Moon. About two hours after midnight, the edge of the Moon would pass within one degree of Jupiter; although not an occultation, these circumstances would be in tolerable accord with the record.

We have so far been unable to identify any close conjunction of the Moon with the bright planets Venus or Jupiter which would satisfy the record in the *Cronaca Rampona*. However, the combination of dating errors in the text may well prove prohibitive.

7.2 A close conjunction recorded in the *Chronicon* of Jacobus Malvecius

Dall'Olmo (1980) drew attention to a bright star in another fifteenth century chronicle – compiled by Jacobus Malvecius between AD 1412 and 1461. The appropriate entry may be translated as follows:

> And in those days a star of immense brilliance appeared within the circle of the Moon around the first days of its separation from the Sun (*Et diebus illis stella fulgoris immensi intra circulum lunae apparuit circa dies primos post ipsius separatione a sole*).

The date is not specified directly, but Dall'Olmo notes that at much the same time Malvecius records an earthquake at Brescia in Northern Italy – on a date corresponding to AD 1064 Apr 11. Dall'Olmo "... was inclined to relate this record to the Crab explosion ...", but he gave no satisfactory grounds for amending the date by ten years. He merely suggested that such a discrepancy might have occurred due to a copying error or a very rough date in the original manuscript.

As we have shown, no close approach of the Moon to the supernova of AD 1054 was visible in Europe during the northern spring and summer of that year, which nullifies Dall'Olmo's suggestion. As an alternative, we have investigated the possibility of an occultation of Venus or Jupiter by the Moon during the spring of AD 1054, but no such event was then visible in Europe. However, just what the chronicler meant by "in those days" is unclear.

7.3 A possible close conjunction recorded in the Armenian chronicles

Collins *et al.* (1999) drew attention to a paper by I S Astapovich published in 1974 which noted a possible conjunction of the Moon with a star in the spring of AD 1054, as reported in the Armenian chronicles. These chronicles, covering the period from the ninth to the seventeenth centuries, were compiled by an annalist named Matendaram. Collins *et al.* point out that in 1969, Astapovich, in a joint paper with E E Tumanian, had considered that the appropriate AD 1054 entry merely alluded to some bright meteors. However, in his subsequent paper Astapovich had revised both his interpretation and the presumed date of the event. According to Collins *et al.*, Astapovich gave an amended translation as follows:

> 1054 of the New Era was the fifth of the reign of Leo IXth. That year on the Moon's disc a star has appeared. It happened on the 14th May in the first part of the night.

Leo IX was enthroned as Pope in 1049 February. We have ourselves not seen either of the papers by Astapovich or the entry in the Armenian chronicles. Collins *et al.* calculated that the Moon and Crab Nebula were in conjunction on May 11 and suggested that possibly the supernova was first noticed in Armenia on the night of May 14 and that the phrase translated "Moon's disc" can possibly be rendered as "circuit of the Moon", etc. Although they emphasise that "... support for this hypothesis is unlikely to be found without a reanalysis of the original chronicle, which is unavailable to us...", Collins *et al.* still included the report as a "... possible supernova sighting ..." in Table 1 of their paper.

As in the other examples cited above, an alternative inference is that the Armenian record alludes to a close approach of the Moon to one of the brighter planets. We compute that as seen from Armenia (approximate latitude = 40° N, longitude = 45° E), on the stated evening of May 14 the Moon was in conjunction with Jupiter, although the two objects were some three degrees apart. It seems very plausible that this is the event referred to in the text, although renewed examination of the entry in the Armenian chronicles is desirable.

In summary, none of the three records discussed in this Section provides satisfactory evidence that the AD 1054 supernova was reported in European literature.

8 OTHER CELESTIAL PHENOMENA MENTIONED IN EUROPEAN LITERATURE

Collins *et al.* (1999) have followed Guidoboni *et al.* (1992) in linking two other celestial phenomena mentioned in European writings with the supernova of AD 1054. In both of these accounts the events are associated with the death of Pope Leo IX, which occurred on April 19 (13 Kalends May) in that year. In a brief discussion (Stephenson and Green, 2002:141), we inadvertently attributed the remarks by Collins *et al.* to Breen and McCarthy (1995). We would like to place on record our sincere apologies to both sets of authors. In fact, Breen and McCarthy are very critical of any links between the recorded events at the death of Leo and the supernova.

One of the celestial phenomena considered by Guidoboni *et al.* (1992) and Collins *et al.* (1999) is described in the *Tractus de ecclesia S. Petri Aldenburgensi* as follows:

> On the 18th Kalends May [AD 1054 April 14], the second day of the week [Monday] at about midday, his soul happily departed. And in the same hour of its departure from his body, not only in Rome, where his body lay, but furthermore over the whole Earth a circle of extraordinary brightness appeared in the sky to men for the space of about half an hour (*verum etiam in toto orbe terrarum circulus eximiae claritatis hominibus apparuit in caelo per spatium fere mediae horae*).

We note that April 14 was a Thursday, not a Monday. As Breen and McCarthy point out, there is a double error in the text; Pope Leo IX died on Tuesday April 19. The term *circulus* usually refers to a circle or ring. Either of these renderings, together with the very short duration of this daytime phenomenon (only about half an hour), suggests that it was a solar halo. The remark that the event was seen over the whole Earth may be understood simply as hyperbole. As we see it, there is nothing in this record to suggest the identification of the *circulus* as a new star, briefly seen in the middle of the day.

Guidoboni *et al.* (1992) and subsequently Collins *et al.* (1999) also considered a reference in a work by Libuinus entitled *De obitu Leonis*. This account describes how at the very time the Pope died, a certain man by the name of Alpertus "... saw as it were the path by which his soul was escorted by the angels to Heaven adorned with shining vestments and gleaming with countless lamps." (*quasi stratam palliis fulgentibus adornatam et innumeris coruscantem lampadibus*).

The description by Alpertus seems more in the nature of a mystical vision than an observation meriting astronomical interpretation. Collins *et al.* note that in the evening Jupiter, Venus, Mars, and Mercury – as well as the bright stars of Orion – were all visible at the same time in the western sky. If the supernova had already appeared by then (April 19) it would add to the spectacle. However, in our view, if an astronomical explanation is at all viable, a vivid auroral display might better fit the phenomenon described. Nevertheless, we note that according to the *Tractus de ecclesia S. Petri Aldenburgensi* – cited above – Pope Leo IX died around midday. A purely literal, pragmatic interpretation of the description in the *De obitu Leonis* may well be futile.

McCarthy and Breen (1997) have discussed in detail a supposed allusion to the AD 1054 supernova in the *Irish Annals* on a date equivalent to 1054 April 24. They translate the item as follows:

> A round tower of fire was seen at Ros Ela on the Sunday of the feast of St George [AD 1054 April 24] for the space of five hours of the day, and innumerable black birds passing into and out of it, and one great bird in the midst thereof ...

This obscure account clearly has a mystical basis. Despite McCarthy and Breen's detailed visibility computations, they affirm that "... it will never be possible to prove conclusively that they [the occurrences described] refer to an observation of the supernova of 1054." In purely physical terms, the phenomenon, which was only visible on a single day, would appear to be of substantial angular size. Rather than relating to a star, it is arguable that a solar halo display (by day) or an aurora (by night) is perhaps more likely. However, such a naive materialistic interpretation may well be inappropriate.

9 CONCLUSION

In total, we have discussed six alleged sightings of the supernova of AD 1054, all of which were said to have occurred between April 19 and May 20 – and thus several weeks before the discovery date in China.

In three instances an object identified as a star was seen in the vicinity of the Moon. However, in two of these cases a substantial error in the date must be assumed. We have emphasized that medieval annalists would probably not be able to distinguish between a bright star and a planet and we have noted that in all three examples the observation may well refer to a close conjunction of the Moon with either Venus or Jupiter.

In a further three instances, the phenomenon described is of a more cryptic character and is thus very difficult to qualify in physical terms. In particular there is little to suggest that a star-like object forms the basis of the report.

In summary, it is our firm view that there is no convincing evidence that the supernova of AD 1054 is reported in extant European literature. We further regard any suggestion that the supernova was sighted significantly before its discovery in China as without foundation.

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Examination of early Chinese records of solar eclipses

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Abstract
The earliest Chinese historical text that contains systematic records of solar eclipses is the *Spring and Autumn Annals*. In historical periods before the Spring and Autumn period (i.e. the Xia, Shang and Western Zhou Dynasties), solar eclipse records are vague and sporadic. Although numerous scholars have investigated these records in the past two thousand years, it has been rather difficult for them to reach final conclusions. With recent advancements both in astronomical computation and in historic chronology, there has been significant progress in the study of the alleged early Chinese records of solar eclipses. These records include the reference to the solar eclipse of the Three Miao and of Zhongkang in the legends of the Xia dynasty, the expressions such as "three flames ate the Sun", "the Sun and the Moon were eclipsed" and "the Sun was zhi" in the oracle-bone inscriptions of the Shang Dynasty, and the passages of "the sky became extremely dark", "the day dawned twice" and "the Sun was eclipsed" in the literature of the Zhou Dynasty.

Keywords: history of astronomy, solar eclipse, ancient astronomical records, early Chinese history

1 INTRODUCTION

Among various early Chinese astronomical records, that of the solar eclipse (henceforth simply referred to as 'eclipse') was the most complete one and occupied a special position. This was not only because an eclipse, especially a total one, was so spectacular that people were frightened, but also because it was a warning to the Emperor – for the Sun was the symbol of the Emperor according to traditional astrological theories. When an eclipse occurred, the Emperor would normally eat vegetarian meals, avoid the main palace, perform rituals to rescue the Sun, and, sometimes, issue imperial edict to take the blame on himself. Moreover, in order to compile and issue reliable calendars (which was one of the most important governmental affairs during the imperial times), eclipses had to be observed regularly, because they could verify the accuracy of the calendars. Therefore, systematic observing and recording of eclipses, although part of feudalist superstitious rites, was required for scientific research into the calendar during imperial times in China.

The extant systematic early Chinese records of eclipses are from the Spring and Autumn period (770–476 BC). In the *Spring and Autumn Annals*, the history of the state Lu, thirty-seven eclipses are recorded. The loss of eclipse records from the Warring States period (475–221 BC) and the Qin Dynasty (221–206 BC) is severe. From the Western Han Dynasty (206 BC – AD 23) to the end of the Ming Dynasty (AD 1368–1644), however, such records are complete. Their format, which is rather simple and regular, is as follows: on a certain sexagesimal date of a certain month of a certain year, the Sun was eclipsed. Generally, there is not much information in these records. By the Qing Dynasty (AD 1644–1911), the eclipse records are not only complete, but also include details of the magnitudes and the times of the eclipses. However, studies have shown that these data were predications rather than actual records of observations.

The eclipse records before the Spring and Autumn period – so-called early Chinese eclipse records – are vague and sporadic. In the study of these records, there are problems such as how to understand and interpret the original texts and how to determine whether they are eclipse records and, if so, what kinds of eclipses were recorded. Furthermore, the questions of how to narrow down the chronological period for a particular eclipse record and what method of astronomical computing to adopt are two common problems in this field.

The problem of determining the chronological period for an early Chinese eclipse record is caused by the lack of clear temporal information in these records. In an early eclipse record, if there were a specific date that could be converted to a precise corresponding Gregorian calendar date, it would be a very simple matter to identify the eclipse listed in the record. Unfortunately, the fact is that these early records normally do not contain specific dates; in a record, there may only be a king's name, or a month number and a date without the king's name. Even if a king's name appears in such a record, it is still rather difficult to narrow down the chronological period for the record, because the generally-accepted earliest precisely-determined date in Chinese history is 841 BC. The length of the reign of each king before that date remains undetermined. As a result, even if a record contains the year of a king, there is no way to directly convert that year to the corresponding year in the Gregorian calendar. As a matter of fact, the main purpose of the study of these early eclipse records has been to establish specific absolute dates for early Chinese history.

Of course, an historian may put forward a general chronological period for an eclipse, based on historical and/or archaeological evidence he or she deems credible. But because eclipses are periodic and repetitive, during this general period a number of eclipses may be possible candidates for such a record. In order to narrow down the period for an event, researchers have to find as much information as possible, such as the date, time and magnitude of the eclipse, and so forth, from relevant records. Such data can serve as the basis for the historian to pinpoint the actual date of an eclipse, but they are often vague, even contradictory. Accordingly, for a particular eclipse, this may result in suggested dates that vary wildly. This is the main cause for divergent results in the study of early Chinese eclipse records.

Recent progress with regard to the dating of early Chinese eclipse records is documented in the report of the Xia-Shang-Zhou Chronology Project, which was published in 2000 (Expert Group…, 2000). In this report, there is a chronological table that provides specific dates for each king of the Western Zhou and Late Shang Dynasties, and approximate starting years for the Xia and Early Shang Dynasties. These dates are the result of a long-term co-operate investigation involving many different disciplines, only one of which was astronomy. This report is undoubtedly an important reference for those wishing to study early Chinese eclipse records.

There is great uncertainty in calculating the details of early eclipses, because of the problem of applying modern astronomical computing method-ology to eclipses that occurred thousands of years ago. The main source of error originates from $\dot{n}$ and c, which are both coefficients of square terms for time. Accordingly, the error increases rapidly when the eclipse is distant from the present, which makes the region where a total eclipse could be seen move in an east-west direction. Currently, the error of parameter c is about ±3, which would lead to a movement of ±5 degrees in longitude of the region where a total eclipse could be observed at the beginning of the first century AD. Such movement would increase to ±20 degrees in the twentieth century BC, which certainly affects the occurrence and magnitude of an eclipse in an extreme way. It is only in the past 20 years that this problem has been given due attention by scholars.

The effect of parameter $\dot{n}$ is similar to that of parameter c, and the general relation between them can be expressed as $0.92\Delta\dot{n} = \Delta c$ (Stephenson and Morrison, 1995). In ILE (Improved Lunar Ephemeris), which is based on the Brown Theory and has been adopted in the field of astronomy for a long time, $\dot{n}$ and c are specified as –22.44 and 29.95, respectively. These two values are generally used in eclipse cannons (e.g. Mucke and Meeus, 1983) and in software used for computing eclipses. In recent years, there has been remarkable progress both in determining $\dot{n}$ by various modern methods and in studying c through early astronomical records. In the study of early astronomical records, the value of $\dot{n}$ and that of c are specified as –26 and 30 (or 31), respectively (Liu, 1994; Pang *et al.*, 2002; Stephenson and Morrison, 1995; Zhang and Han, 1995). Obviously, the range from 28 to 34 for c is worth discussing.

2 ECLIPSES OF THE XIA DYNASTY

The contemporary written records of the Xia Dynasty (ca. 2070–1600 BC) have not yet been discovered. Most events of the Xia Dynasty known today are from texts compiled in the Eastern Zhou (770–221 BC) and Western Han Dynasties. Before the Eastern Zhou, how those events were transmitted remains unknown. Therefore, both the clarity and reliability of alleged eclipse records of the Xia Dynasty are not satisfactory at all. It is understandable that at that time, people may have been unable to accurately describe and classify eclipses. As a result, although an eclipse might cause great chaos among people, this astronomical phenomenon would not be recorded specifically as an eclipse. The situation for early eclipse records in other countries was similar.

2.1 The Alleged Eclipse of the Three Miao

The three Miao were a group of people who lived at the beginning of the Xia Dynasty. It is said that there was an eclipse related to the rebellion of these people. The reference to this alleged eclipse in the "Against Aggressive Warfare" chapter of the *Mozi* reads as follows:

> In ancient times, the three Miao tribes rebelled massively. Heaven ordered them to be killed. The demoniac Sun rose at night. It rained blood in three mornings. A dragon appeared in the temple. Dogs cried in the markets. In summer, there were floods, and earth cracked until water gushed forth. The five grains mutated. The people were thus greatly frightened. Gaoyang thus issued an order in the Dark Palace. Yu himself held the auspicious command from the heaven to attack the Miao.

This event is cited in other texts as well: it is mentioned in the *Kaiyuan zhanjing* that "… the Sun rose at night." In the *Miaochao zi*, it is recorded that "… the three Miao rebelled massively, the demoniac Sun rose at night." According to these texts, this event occurred before the great Yu founded the Xia Dynasty.

Pang (1996) has proposed that both "… the Sun rose at night" and "… the demoniac Sun rose at night" refer to the phenomenon of a double dusk. When a total or near-total eclipse takes place around sunset, it suddenly becomes dark; several minutes later, when the total eclipse is over it becomes bright, and then becomes dark again (like what normally happens at dusk). If ancient people regarded the first darkness caused by the eclipse as natural dusk, the bright sky immediately after would be the unusual appearance of the Sun at night. If Pang's interpretation is accepted, it would be possible, by way of calculating the date of that eclipse, to determine an absolute date for the era of the great Yu, an important point in Chinese history.

Pang (ibid.) further claims that this eclipse and sixteen other solar and lunar eclipses in early Chinese records provide the skeleton of the chronology from 841 BC back to the start of the Xia Dynasty. Moreover, these early records of solar and lunar eclipses corroborate each other, thus providing important data for research into the long-term change of the Earth's rotation.

Based on the *Bamboo Annals*, Nivison and Pang (1990) have suggested that Yu's reign during the Xia Dynasty dated between 1914 to 1907 BC. During that period, from the region of the three Miao (which is to the south of the Yangtze River, to the west of Lake Poyang and to the east of the Hengshan Mountains) there was indeed an eclipse that could have caused the 'double dusk' phenomenon. It was an annular eclipse with the greatest magnitude of 0.97–0.99, and it occurred on 1912 September 24 BC, which was the third year of Yu.

Liu Ciyuan (2001) points out that, if "the Sun rose at night" is identifiable as a solar eclipse, it could be an eclipse that caused either a double dusk or a double dawn. As a result, it is essential to research the eclipse over an even longer period and to take the uncertainty of the various parameters into serious consideration. By adopting an approach similar to that used when researching the double dawn—which will be explained below—and taking a larger range for *c* (say from 28 to 35), Liu found six possible double dusk eclipses and five possible double dawn eclipses between 2250 BC and 1850 BC. Since the Xia-Shang-Zhou Chronology Project has chosen 2070 BC as the starting year of the Xia Dynasty (i.e. the year when Yu ascended the throne), the total eclipse of 2072 April 29 BC should be the most possible one. When the range for *c* is 30–33, this was a total eclipse that occurred from the region of the Three Miao at sunset.

It must be acknowledged that the argument that treats "the Sun rose at night" as the reference to an eclipse is rather weak. First of all, all the unusual events mentioned in the *Mozi* could not have happened on the same day. The original text does not specify whether or not the Sun rose at night only once. If it indeed happened more than once, it could not possibly be an eclipse. Second, the reliability of the event is a big question; to any reasonable person, the notion that it rained blood for three mornings and that a dragon appeared in a temple could not possibly be true. How can one be certain that "the Sun rose at night"? Even if one accepts that the quotation is a reference of an eclipse around sunset at dusk, it is not clear in the original text that it was visible from the region of the Three Miao or from the capital of Gaoyang. As a result, there is no firm basis for identifying the eclipse as one visible from the region of the Three Miao, as Pang (1996) did. It seems likely that "the Sun rose at night" in the *Mozi* and other later texts is not a reference to an eclipse.

2.2 The Eclipse of Zhongkang

Zhongkang was the fourth King of the Xia Dynasty. In the "The Punitive Expedition of Yin" chapter of the *Book of Documents*, there is the following passage that may be regarded as a reference to an eclipse:

> On the first day of the last month of autumn, the sun and the moon did not meet harmoniously in Fang. The blind *musicians* beat their drums; the inferior officers and common people bustled and ran about. He and Ho, however, as if they were mere personators of the dead in their offices, heard nothing and knew nothing; — so stupidly went they astray from their duty in the matter of the heavenly appearances, and rendering themselves liable to the death appointed by the former kings. (Legge 1893a: 165-166)

The extant version of this chapter was found in the Eastern Jin Dynasty (317–420). As a result, its authenticity has been suspected to be false. On the other hand, similar passages are found in earlier texts such as *Zuozhuan* (see the text of the seventeenth year of Zhao Gong) and the "Basic Annals of the Xia Dynasty" chapter of the *Records of the Historian*.

This event is specifically recorded as an eclipse in the 'modern text' *Bamboo Annals*:

> In his first year, which was ke-ch'ow (26th of cycle, = BC 1951), when the emperor came to the throne, he dwelt in Chin-sin. In his 5th year, in the autumn, in the 9th month, on the day kang-seuh (47th of cycle), which was the first day of the month, there was an eclipse of the sun, when he ordered the prince of Yin to lead the imperial forces to punish He and Ho. (Legge 1893a: 119)

Its content is very clear; this passage includes the date, month, and year of the eclipse. However, the 'modern text' *Bamboo Annals* and the dates given in it are generally regarded as a forgery. It is very likely that these dates have something to do with the calculation of Yixing in the Tang Dynasty (618–907).

In the "The Punitive Expedition of Yin" chapter, the appearance of *shuo*, 'the first day of the month,' *chen*, 'the Sun and the Moon meet,' the dereliction of duty by Xi He (an astronomical officer), and the chaos caused by the frightening astronomical phenomenon make people relate that event to a total eclipse. As a matter of fact, the *Zuozhuan* already relates it to an eclipse, so it has been a tradition to regard the passage as a reference to an eclipse with a great magnitude.

There are, however, some problems with the record of this eclipse. According to the "The Punitive Expedition of Yin" chapter of the *Book of documents*, it occurred in the third month of autumn. According to the *Zuozhuan*, it took place in the fourth month in summer. Obviously, these are not the same, and the eclipse could not have happened both in the fourth month in summer and in the last month of autumn. Unfortunately, there is no way to determine which one is correct—if in fact one of them is.

Also, although the sentence "the Sun and the Moon did not meet harmoniously in Fang" is often interpreted to mean that the eclipse occurred in Fang, a constellation, it is actually rather difficult to give a satisfactory explanation for this meaning. Wu Shouxian (1998) suggests that it could possibly refer to the co-occurrence of an eclipse and a comet because the character of negative fu and that for a comet were so similar that the character was possibly changed to that of negative fu during transmission.

Since the "The Punitive Expedition of Yin" chapter was once regarded as a chapter of the *Book of Documents*, the most important Chinese classical text, a great amount of research has been conducted on this chapter (e.g. see *Commentaries to the Thirteen Chinese Classics*). On the other hand, there has been research that aims to establish the date of Zhongkang reign by dating the eclipse. Based on the Dayan calendar (see the "Treatise on Calendar" chapter of the *New History of the Tang*), Yixing of the Tang Dynasty calculated the date of this eclipse. He reached the following conclusion: it occurred on *gengxu* (day 47), the first day of the ninth month of year *guisi*, which was the fifth year of Zhongkang's reign, at the second degree of the Fang. This date corresponds to 2128 October 13 BC in the western calendar. The same conclusion was reached by Guo Shoujing of the Yuan Dynasty (1279–1368), although his calculation was based on the Shoushi calendar (see the "Treatise on Calendar" chapter of the *History of the Yuan*). Li Tianjing of the late Ming Dynasty and Yan Ruoqu of the Qing Dynasty also conducted research on the Zhongkang eclipse with similar approaches. After western knowledge was introduced to the east in the late Ming Dynasty, ancient Chinese classics were introduced to the west as well. Many western and Japanese scholars also carried out research on this eclipse, and their methods of calculation were far superior to those of the early Chinese scholars. For a comprehensive review of these researches, readers are referred to Chen Zungui (1984).

In recent decades, as a result of improvements in and popularization of astronomical computing methods pertaining to eclipses, new calculations have shown that some previous research findings are no longer tenable. Pang's (1987) calculation has the Zhongkang eclipse occurring on 1876 October 16 BC, and this result is in agreement with his historical date for the eclipse of the Three Miao. In addition, it is recorded in the *Xiaojing gouming jue*, an astrological book from the Han Dynasty, that there was a conjunction of five planets in the era of the great Yu. Such a rare event occurred on 1953 February BC, and this date is in agreement with Pang's dates for Zhongkang and the great Yu as well. Saito Kuniji (1992) has carried out a thorough analysis and correction of ancient texts such as the *Bamboo Annals*. He puts the first year of Zhongkang's reign in the period 1921–1881 BC. According to his calculations, there was an annular eclipse visible from the region of Luoyang on 1912 September 24 BC.

Li Yong's (1999) research and reconstruction of the calculation methods used for Guo Shoujing's Shoushi calendar confirm that there would indeed have been an eclipse on the date given by Yixing and Guo Shoujing, but its magnitude would have been very small, which does not match the situation described in the ancient texts. Furthermore, this partial eclipse would not have been visible from anywhere in China.

Wu Shouxian (2000) has prepared a comprehensive and detailed review and analysis of previous studies, and he lists thirteen different dates in regard to the Zhongkang eclipse. Using modern methods, his calculations clarify some misunderstandings resulting from errors and mistakes made by earlier computers. After thoroughly analyzing relevant texts and the astronomical background of those early events, he researched eclipses that were observable from China over a period of three centuries. During the chronological period associated with the Zhongkang eclipse and the Xia-Shang-Zhou Chronology Project (Expert Group ..., 2000), he proposes 2043, 2019, 1970 and 1961 BC as four possible dates for this event.

Since the reference to the Zhongkang eclipse is recorded in the *Zuozhuan*, one of the earliest Chinese historical texts, it is likely a credible eclipse record. But the information about this eclipse in later texts is neither certain nor complete. As a result, it is still very difficult to calculate the absolute date of this eclipse.

3 ECLIPSES OF THE SHANG DYNASTY

As recently as one hundred years ago, the Shang Dynasty, just like the Xia dynasty, was regarded as legendary. The discovery of oracle-bone inscriptions at Yinxu confirms many historical facts of the Shang, such as the genealogy of the Shang royal house, recorded in early Chinese texts. This has not only solved the controversy of the existence of the Shang Dynasty, but has also dated the inscriptions to the Shang. Based upon the five clear records of lunar eclipses in the Bin-group inscriptions, we are almost certain that there were records of frequent observations of solar eclipses in late Shang as well, although records of solar eclipses identified so far are much less clear than those of lunar eclipses.

3.1 The Alleged Eclipse of the "Three Flames Ate the Sun"

Jiaguwen heji 11506, a plastron of the Bin-group inscriptions of Shang King Wuding, bears a phrase that was translated as "Three flames ate the Sun and there was a big star" by Dong Zuobin. Dong regarded the phrase as a reference to an eclipse. Liu Chaoyang (1945) held the same opinion, and his interpretation of the phrase was as follows: at the dawn of *yimao* (day 52), it was foggy. Three flames ate the Sun, and a big star could be seen. To him, it obviously recorded the phenomenon of an eclipse. The flames actually referred to solar prominences. Later, Liu Chaoyang (1953) dated this eclipse to 1302 June 5 BC, a *bingchen* (day 53) day, and identified the big star as Mercury. Xu Zhentao (1995) identifies this eclipse with the total eclipse at 11:00 a.m. on 1250 March 4 BC, also a *bingchen* day, which was visible from Anyang. If the phrase indeed is a reference to an eclipse, as they claim, it is still difficult to accept these two opinions because the two eclipses they selected happened on *bingchen* rather than *yimao*, as recorded on *Jiaguwen heji* 11506.

Chou and Pang (a talk at International Symposium on Xia Culture, University of California, Los Angeles, 1990) have conducted a detailed examination of the inscription and researched it. They transcribed several characters of the inscription's verification a little differently from Dong Zoubin. Accordingly, they translate the verification as:

> The king made prognostication and said, there would be no disaster and rain. From *yimao* to the early morning of next day, three flames ate the Sun, a big star appeared.

Such a change will avoid the difficulty of identifying the eclipse with *bingchen* (53) rather than *yimao* (52). Pang's (2002) calculation equates this eclipse to that of 1302 June 5 BC, which occurred at 10:45 (Anyang local time). The total eclipse lasted six minutes and twenty seconds. Based on this, he further deduces that contemporary $\Delta T = 7.3 \pm 0.3$ hours.

It must be pointed out that the change made by Chou and Pang (1990) is only an unsubstantiated opinion and is not well supported by paleographical evidence. As a result, it is unfortunate that Chou and Pang's (1990) conclusion seems baseless.

Because of the rarity of a total eclipse, and because of the claim that the inscription in question was the first record in Chinese history of solar prominences, a solar eclipse and the accompanying appearance of a star, this inscription has been assigned paramount importance. Since such an interpretation of the inscription was put forward by Dong and Liu, it has been followed by a great number of scholars, both inside and outside China. To some extend, the opinion seems to be the final conclusion and the inscription is generally regarded as a world record, set by the Chinese.

Different interpretations, however, have existed ever since the very beginning of discussions about the inscription. Yang Shuda read the character *xing*, 'star,' as *qing*, 'sunny.' This interpretation is supported by the context of the inscription. Yan Yiping (1989) demonstrated that the phrase *shiri*, 'to eat the Sun,' actually was a noun of time and had nothing to do with a solar eclipse. Most recently, Li Xueqin's (1999:17) new textual research lends further support to Yang Shuda's interpretation.

According to Yang and Li's interpretation, there is no expression such as "three flames ate the Sun and a big star was seen" on *Jiaguwen heji* 11506. This completely discredits the opinion that the inscription is an eclipse record. Because inscriptional evidence shows the expression *shiri* to be a time noun in the Yin oracle-bone inscriptions (see, for example, *tunnan* 42, 624 and 2666), the inscription on *Jiaguwen heji* 11506 must be excluded from eclipse records.

3.2 The Alleged Eclipse of the So-called "The Sun and the Moon Were Eclipsed"

The sentence "The Sun and the Moon were eclipsed" appears on *Jiaguwen heji* 33694, a scapula of the Li-group inscriptions (Figure 1). Relevant inscriptions can be translated as follows:

> Divining on *guiyou* (day 10), tested: The Sun and the Moon were eclipsed, it was auspicious. Divining on *guiyou*, tested: The Sun and the Moon were eclipsed, it was not auspicious.

As to what astronomical phenomenon these two inscriptions actually refer, there are the following options:

1) A solar or lunar eclipse occurred. Because there was a lunar or solar eclipse not long ago, the Shang divined whether it was auspicious or inauspicious.
2) A lunar eclipse occurred in the daytime on *guiyou*, i.e. the Moon rose with eclipse.
3) The day was as dark as night because of the eclipse.
4) A solar eclipse occurred at dusk on *guiyou*. The followers of options 3 and 4 read the character yue, 'the Moon', as xi, 'night'. The commonality among the above opinions is that there was a solar or lunar eclipse on day *guiyou*. Accordingly, its date can be calculated.
5) The inscriptional sentence "the Sun and the Moon were eclipsed" is equivalent to "the Sun and the Moon became dark and were eclipsed" in the "Treatise on Astronomy" chapter of the *History of the Han*.
6) These two inscriptions were divining whether a solar and a lunar eclipse would occur.

According to these last two options, there was no solar and lunar eclipse that actually occurred on *guiyou*. As a result, there is no base for any calculations. But this still leaves four other options.

Figure 1. Oracle bone: the Sun and Moon were eclipsed

Based on the assumption that a solar eclipse and a lunar eclipse did actually occur in succession, Chen Zungui (1984) has made the following calculations. If the lunar eclipse occurred on *guiyou* or one or two days before *guiyou* and the solar eclipse happened before this lunar eclipse, the inscriptions could possibly refer to the total solar eclipse of 1230 July 18 BC and a later lunar eclipse. If the solar eclipse happened on *guiyou* or one or two days before *guiyou* and the lunar eclipse was before this solar eclipse, the inscription would possibly refer to either the lunar eclipse of 1230 May 11 BC and the solar eclipse of 1230 May 26 (*guiyou*) BC or the lunar eclipse of 1222 August 3 BC and the solar eclipse of 1222 August 18 (*gengwu*) BC. Chen has cited Dong Zuobin's opinion: that the two inscriptions are records of the lunar eclipse of 1217 May 11 BC and the solar eclipse of 1217 May 26 (*guiyou*) BC.

Xu Zhentao (1995) supports the third option above. According to his calculation, the eclipse was the total solar eclipse, which had a magnitude of 0.92 at 17:00 (Anyang local time) on 1176 BC August 19 (*guiyou*).

Li Xueqin (1999:67) analyzes the contexts of these inscriptions, and argues that the character ri, 'the Sun', and yue, 'the Moon', actually consist of the character ming, 'dawn'. As a result, he interprets them as a reference to an eclipse at dawn. He further provides the following information for the calculation of the eclipse: 1) it occurred in a month when there was a disastrous locust plague; 2) its sexagesimal date was *guiyou*; 3) it happened at sunrise; 4) it was obviously visible from Anyang; and 5) its absolute date was later, but not much later, than those lunar eclipses of the reign of Wuding (i.e. this eclipse would have been in the reign of Zugeng).

Based on the above conditions set by Li Xueqin for this eclipse, Zhang Peiyu (1999) examined eclipses visible from Anyang in the early morning, and dating between 1500 and 1000 BC. He found only one eclipse that met these requirements, and it occurred around 7 o'clock a.m. on 1269 August 27 BC, with a greatest magnitude of 0.65.

Zhang also made calculations relating to the various interpretations listed above. On the basis of his calculations regarding the five lunar eclipses in the Bin-group inscriptions, he presents the following results:

1) If those two inscriptions indeed refer to consecutive solar and lunar eclipses, they may be records of the lunar eclipse of 1171 November 6 BC and the solar eclipse of 1171 November 21 (*guiyou*) BC. In this case, the lunar eclipse happened before the solar eclipse. They may also be records of the solar eclipse of 1183 January 12 BC and the lunar eclipse of 1183 January 21 (*guiyou*) BC. In this case, the solar eclipse occurred earlier than the lunar eclipse and it meets the requirement that the Sun set with eclipse.
2) If they mean there was a solar eclipse and the day became dark, they may be a record of the total eclipse, visible from Anyang, on 1176 August 19 (*guiyou*) BC.

While the conditions set by Li Xueqin are helpful for the selection of an eclipse for the two inscriptions, he really needs to provide more inscriptional evidence to substantiate them. From the point of view of paleography, Hu Houxuan (1986: 35-36) reviewed previous studies about the two inscriptions and analyzed the two inscriptions themselves. He was correct in pointing out that the symbol for *xi* was not written the same as *yue* in these two inscriptions and that the meaning of *xi* is 'night' in the oracle bone inscriptions. Since a solar eclipse that occurs at night cannot be seen, the phrase "the Sun and the Moon were eclipsed" could not be read as "the Sun was eclipsed at night." As a result, option four is no longer tenable. Moreover, Hu's (1986: 36) analysis of its context was correct when he stated that "The phrase gui-you zhen ri yue you shi is a charge, not a verification, and therefore it is definitely not the record of an actual event." So the two inscriptions might have something to do with an eclipse, but they are not true eclipse records.

The following is another Li-group inscription: "Tested: the Sun was eclipsed." Obviously, the sentence "the Sun was eclipsed" is the predictive claim rather than verification of the inscription. For the same reasons stated by Hu (1986), it is not a legitimate eclipse record.

3.3 The Alleged Eclipse of "the Sun Was *Zhi*"

In the Li-group inscriptions, there are several examples of the phrase "the Sun was *zhi*." One in particular on *Jiaguwen heji* 33710 reads as follows: "On *xinsi* (day 18) tested: the Sun was *zhi*; perhaps, (we will) report to Father Ding." There are three more examples whose dates of divination are *yichou* (day 2), *gengchen* (day 17), and *yisi* (day 42), respectively. The divinatory date of *Jiaguwen heji* 33699 is not legible although Peng (2002) transcribes it as *wuzi* (day 25). The divinatory dates of other examples are lost.

The majority of scholars in the fields of oracle-bone inscriptions and early Chinese astronomy agree that the expression "the Sun was *zhi*" refers to an important astronomical phenomenon, but whether it means that the Sun was eclipsed remains an open question.

It was Guo Moruo who first noted that the pronunciations of the characters *zhi* and *shi*, 'eclipse', were similar and that word *zhi* could be used as a loan word for *shi*. Accordingly, Guo regarded the phrase "the Sun was *zhi*" as reference of eclipse. Chen Mengjia thought that *zhi* might refer to a sunspot or spots. Furthermore, it has been proposed that the phrase may imply that the colour of the Sun changes to red. With the discovery of phrase "the Moon was *zhi*" in the oracle-bone inscriptions, Chen Mengjia's opinion is no longer tenable, because there is no 'moonspot' (or spots).

Li Xueqin (1999:79, 187) has discussed the contexts of these inscriptions. By comparing the meaning of words in relevant inscriptions and building upon recent progress in the field of Chinese paleography, he determines with certainty that the expression "the Sun was zhi" is the expression for a solar eclipse in the oracle bone inscriptions. He further argues that Chen Mengjia's other suggestion (that the phrase might relate to the reddening of the Sun) is also untenable.

Zhang Peiyu (1999) has identified five lunar eclipses in the Bin-group inscriptions with five lunar eclipses that occurred between 1201 BC and 1181 BC. As for the above eclipses in the Li-group inscriptions, he has found only one set of eclipses whose dates are comparable to the dates of the five lunar eclipses: the eclipse on *gengchen* occurred on 1198 October 21 BC, that of *xinsi* on 1172 June 7 BC, and that of *yisi* on 1161 October 31 BC. As for the eclipse of *yichou*, he has not yet identified it with any particular eclipse, because of Li's (1999:187) opinion that the Shang diviner was not certain whether an eclipse had actually happened.

Pang (2002), too, has derived dates for those four eclipses: the eclipse of *yichou* happened on 1226 May 6 BC, that of *gengchen* on 1198 October 21 BC, that of *xinsi* on 1172 June 7 BC, that of *yisi* on 1161 October 31 BC, and that of what he transcribes as *wuzi* on 1163 June 27 BC. Obviously, he expanded the time period in his search for these eclipses.

As shown above, more than six decades after Guo, there is not much progress with regard to the decipherment of the bone inscription *zhi*. Some important questions remain unanswered. For example, if *zhi* indeed is a loan word for *shi*, why is *shi* itself used to refer to an eclipse? Why does *shi* not *zhi* appear in early Chinese records of eclipses? Moreover, the calculations for the alleged eclipse records in this section have not produced satisfactory results, because of two main reasons. First, whether or not these inscriptions are true eclipse records remains an open question, and there is no way to guarantee convincing results. Second, as Hu Houxuan (1986) has pointed out, all these inscriptional phrases "the Sun was *zhi*" appear in charge rather than in verification of these inscriptions and they are thus not records of true events. As a result, there is simply not sufficient information for reliable calculations. Considerably more work needs to be done on determining whether these are in fact true eclipse records.

4 WESTERN ZHOU

In the literature of the Zhou Dynasty, there are two unique astronomical phenomena, that is, the double dawn and the sky becoming extremely dark, that might be caused by eclipses with great magnitude. However, historians of the Western Zhou had failed to realize the occurrence of solar eclipses, possibly because of cloudy weather or because the Sun was hidden behind a mountain. Since the Eastern Zhou, the concept of *shuo*, "new moon," has been clearly established, and the prediction of solar eclipses has begun after the Han Dynasty. As a result, phenomena similar to "the day dawned twice" and "the sky became extremely dark" can easily be recognized as eclipses and they no longer appear in texts. The expression of an eclipse in the *Book of Songs* is very clear, but whether it refers to a specific eclipse still remains an issue. Having said that, thirty-seven eclipse records were found in the *Spring and Autumn Annals*, from which the history of systematic and continuous Chinese eclipses began.

4.1 The "Tian-Da-Yi" Eclipse Record

There is the following passage in the *Bamboo Annals* "ancient text":

> In the nineteenth year of King Zhao, the sky became extremely dark (tian-da-yi). Pheasants and hares were terrified. The King's six armies perished in the Han River.

'Yi' is an ancient character, which means "dark and shadowed" or "dark and windy". Apparently, this "tian-da-yi" event happened when King Zhao led the military campaign against the southern state of Chu. The passage above is cited in other texts such as *Chu Xueji* (Volume 7), *Kaiyuan zhan jing* (Volume 101), and *Taiping yulan* (Volume 907). The military campaign is often mentioned in bronze inscriptions as well, so the reliability of the event is not in question.

The fact is that when a total eclipse reaches its greatest magnitude the sky becomes dark so rapidly that frightened pheasants and hares panic and run about. There may also be a cool wind because the surface of the ground is not heated evenly. Similar situations are often seen in both ancient and modern Chinese and non-Chinese eclipse records. Therefore, "it became extremely dark" is very likely a reference of an eclipse with a great magnitude. As for why it was not recorded as an eclipse, it might be because the sky was overcast that day. At that time, people were unable to determine "new moon day", and needless to say, they could not forecast eclipses. As a result, it did not occur to them that the sky became extremely dark because of an eclipse. This is rather similar to the situation of a double dawn in the first year of King Yi. He Youqi (1989: 119), Takarou Hirasei (1997) and Zhang Wenyu (1998) all point out without further discussion that "it became extremely dark" is a reference to an eclipse.

King Zhao was the fourth king of the Western Zhou Dynasty. The absolute dates of his reign cannot be found in the historical texts, and more than thirty opinions have been proposed thus far. On the other hand, the majority of historians agree that the last year of King Zhao's reign, when the eclipse occurred, was in the period between 1000 and 950 BC (Zhu Fenghan and Zhang Rongming, 1998).

During that period, according to Liu Ciyuan (2002a), there were four eclipses with great magnitude that were visible from central China. They took place in 980 BC (an annular eclipse), 978 BC (a total eclipse), 976 BC (a total eclipse) and 969 BC (an annular eclipse). In his astronomical computations, he adopted the following parameters: $\dot{n} = -26$ and $28<c<33.5$. As for the locations of observation, the following two localities were chosen: Jingchu (nowadays Jingzhou in Hubei Province) and Zongzhou (present day Xi'an).

His analyses show that from the region of Jingchu, it would have been possible to observe three out of the four eclipses. These occurred in 980 BC, 976 BC and 969 BC, and their maximal magnitudes were 0.87, 0.94, and 0.93, respectively. Among these three eclipses, the one in 969 BC was also visible from Zongzhou and its greatest magnitude was 0.90. This eclipse could have possibly caused the sky to become extremely dark, thus frightening pheasants and hares. This was further associated with the death of King Zhao and the loss of his six armies. All of these unusual events made it possible that the record of this eclipse was spread and passed down. As for the eclipse in 978 BC, its magnitude was likely not as great. Moreover, the Sun was very close to the horizon – possibly even below the horizon – when the eclipse reached its greatest magnitude. Therefore, it was impossible for this eclipse to have caused the sky to become extremely dark.

Based on the calendar reconstructed from bronze inscriptions and various other sources, the Xia-Shang-Zhou Chronology Project (Expert Group ..., 2000) selects 995 BC as the first year of King Zhao's reign, and 976 BC as the first year in the reign of his immediate successor, King Mu. Therefore, the nineteenth year of King Zhao's reign should be 977 BC. However, there was no eclipse of great magnitude visible from China in that year; the eclipse in the last year of King Zhao's reign was most likely the one in 976 BC, as Liu Ciyuan (2002a) has shown. This apparent contradiction can be resolved by adjusting the Project's chronological table appropriately. If the reign of King Kang, the king preceding King Zhao, is increased by one year, the reign of King Zhao will be one year later accordingly, which will cause the nineteenth year of King Zhao's reign and the first year of King Mu's reign to be in the same year. Since no bronzes of King Zhao can be used to determine the absolute dates of the chronology of Western Zhou, such an adjustment will not be contradictory to the reconstructed calendar based on extant bronze inscriptions. As a matter of fact, it will not be contradictory to *any* evidence used in the reconstruction of the calendar by the Project team.

It should be noted that according to the adjustment proposed above, King Mu would have changed the designation of the year when he came to the throne. However, this is not a problem since it was allowed by contemporary practices (Chen Meidong, 2000). In fact, according to the Project's chronological table, both King Gong and Gonghe changed the designation of the year when they came to the throne in the Western Zhou Dynasty. Thus, based on astronomical calculations and results of the Xia-Shang-Zhou Chronology Project, the total eclipse of 976 May 31 BC is the best explanation for the record in the "ancient text" *Bamboo Annals* that "the sky became extremely dark in the nineteenth year of King Zhao". When the value of *c* is between 28 and 30, according to Liu's calculation, the greatest magnitude of the eclipse visible from the region of Jingchu was as much as 0.94.

In sum, the notion that the sky became extremely dark in the last year of King Zhao's reign is indeed a record of an eclipse, and it can be identified with the eclipse of 976 May 31 BC.

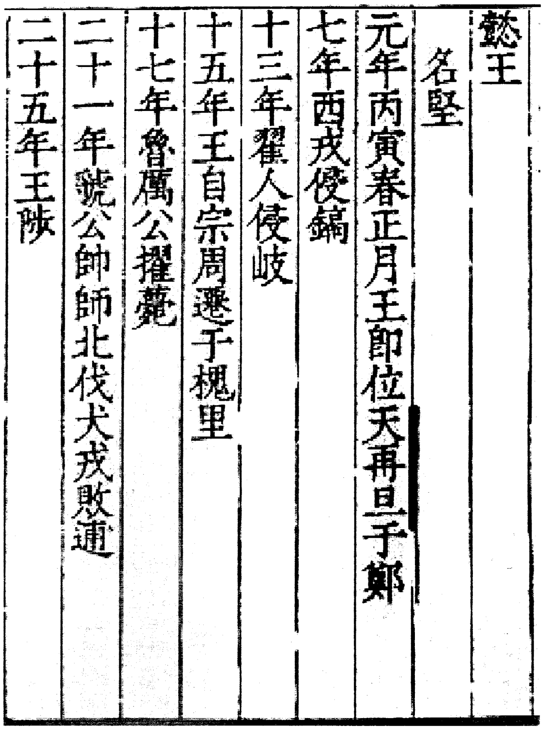
4.2 The "Double Dawn" Eclipse Record

It is recorded in the *Bamboo Annals* that "in the first year of King Yi it dawned twice at Zheng." (Figure 2). Apparently, its literary meaning is that it dawned again after it dawned once, which can be called a 'double dawn'. Zheng, a contemporary place name, was in the vicinity of present day Xi'an city.

The *Bamboo Annals* was discovered in the tomb of King Xiang of Wei of the Warring States during the Western Jin Dynasty. It is an early Chinese historical text which is of paramount importance, but unfortunately has been lost for centuries. However, its record of the double dawn is cited by *Kaiyuan zhan jing* of the Tang Dynasty and *Taiping yu lan* of the Northern Song Dynasty, and appears in other reference books. In the "modern text" *Bamboo Annals*, this event is recorded as:

> In his 1st year, which was *ping-yin* (3d of cycle, = BC 894), when he came to the throne, there were two sun-risings in Ch'ing. (Legge 1893a: 152).

This is the only record of a double dawn in the historical texts, and it is often listed in the entry of "sky changes" or "sky cracks" without any detailed discussion. Liu Chaoyang (1944) was the first scholar who pointed out that it was a change in the brightness of the sky caused by a total eclipse. It thus became possible to determine the date of King Yi by calculating the date of the eclipse. Therefore, this opinion was taken very seriously in the field of Chinese history, and based on the calculation of the eclipse, Liu Chaoyang reached the conclusion that the first year of King Yi's reign was 926 BC.



懿王

名堅

元年丙寅春正月王卽位天再旦于鄭

七年西戎侵鎬

十三年翟人侵岐

十五年王自宗周遷于槐里

十七年魯厲公擢薨

二十一年虢公帥師北伐犬戎敗逋

二十五年王陟

Figure 2. *Bamboo Annals*: double dawn.

Research carried out subsequently has been summarized by Liu Ciyuan (1999). For example, Dong Zuobin has pointed out that the eclipse would need to have occurred around sunrise for it to have caused the phenomenon of a 'double dawn'. Dong proposed that the eclipse was in 966 BC. As for the first year of King Yi's reign, the following alternatives have been proposed: 925 BC, 919 BC, 903 BC and 899 BC. The approach adopted by the majority of historians is this: after determining the date of King Yi's reign on the basis of other chronological data, they selected one eclipse from the cannon of eclipses that was near their date-range for King Yi; but they did not pay much attention to the astronomical calculation of the eclipse. Because of the relatively high frequency of eclipses at this time, this approach has led to different conclusions.

Pang (1988) offers a good explanation of the situation of an eclipse at sunrise. Moreover, he makes use of the most recent astronomical computational methods to revise the calculation of the eclipse. At the end of his investigation, he firmly concluded that the eclipse in 899 BC is the one referred to as the double dawn event during the reign of King Yi.

Stephenson (1992) opposed the opinion that the double dawn was caused by an eclipse for two reasons. First, in his calculations Pang specifies a value of 29.5 for *c*, and gets the result that the eclipse in 899 BC happened at sunrise at Zheng, which meets the requirement of the double dawn record in the *Bamboo Annals*. However, the correct value of *c* was thought by Stephenson to be 44.3, which would mean that the eclipse occurred more that one hour before sunrise at Zheng. As a result, it would be impossible to have seen any change in brightness of the sky that could be associated with a 'double dawn' event. Second, the eclipse in 899 BC was annular, and although its magnitude was not very different from that of a total eclipse, its effect on the human eye would have been quite different. An annular eclipse does not cause the sky to become extremely dark.

After discussing the relevant texts, previous studies and the location of Zheng, Liu Ciyuan (1999a) pointed out that a major shortcoming of the previous studies was the lack of a theoretical explanation and actual observations of the phenomenon. By conducting research into how sky brightness is expressed and the change in the sky brightness at normal sunrise, and by taking astronomical theories on changing sky brightness during an eclipse into consideration, he established a theory of how to calculate the sky brightness during an eclipse at sunrise (Liu Ciyuan, 1999b). He found that the degree of obviousness, or intensity, of the phenomenon of a double dawn at a location is mainly related to the magnitude of the eclipse, the height of the Sun, and the weather.

Given a proper definition of the intensity, all such events can be calculated and illustrated by means of intensity contour maps. The eclipse of 1997 March 9 provided an excellent opportunity to test his theory, and this event was recorded by a network of observers in northern Xinjiang. At eighteen different locations more than sixty observers prepared thirty-five different reports that covered the magnitude of the eclipse, the height of the Sun, and the weather conditions. These reports verified Liu's theoretical calculations. Building on the observations of that eclipse, Liu examined eclipses between 1000 and 840 BC and found that only the eclipse of 899 April 21 BC could have caused a 'double dawn' at Zheng.

After further analysis of the historical background and natural situation of Zheng, Liu (1999c) affirmed that the double dawn in the first year of King Yi at Zheng was a reference to the eclipse of 899 BC. Moreover, astronomical analyses show that, on average, a double dawn at a particular location happens only once in a thousand years. Since the possible range for the first year of King Yi's reign given by historians is about 40 years, the probability of that double dawn occurring at Zheng is only 4 percent. The occurrence of a double dawn with such small a probability thus lends support to the opinion that the recorded double dawn was indeed caused by an eclipse (Liu Ciyuan 2002b).

The excavated bronze Shihu gui is classified as a vassal of King Yi, and it bears a phrase that reads, "On *jiaxu* (day 11), which was *jiwang*, 'after full moon,' of the sixth month of the king's first year." The lunar phase of *jiaxu* of the sixth month of 899 BC in Chinese calendar was exactly jiwang. This is strong collateral evidence for Liu's conclusion (Expert Group ..., 2000). As a result, the identification of 899 BC as the first year of King Yi's reign has been adopted by the Xia-Shang-Zhou Chronology Project as one of the seven datum points in establishing the chronology of the Western Zhou Dynasty.

4.3 The Eclipse Recorded in the *Book of Songs*

A poem in "The Conjunction in the Tenth Month" of the *Book of Songs* includes the following stanzas:

> At the conjunction (of the sun and moon) in the tenth month,
> On the first day of the moon, which was *sin-maou* [i.e. *xinmao*, day 28],
> The sun was eclipsed,
> A thing of very evil omen.
> Then the moon became small,
> And now the sun became small.
> Henceforth the lower people
> Will be in a very deplorable case. (Legge 1893b:320-321).

This poem clearly records that there was an eclipse on *xinmao*, which was the first day of the tenth month, and that there was a lunar eclipse not long ago. Throughout Chinese history, scholars have provided an enormous number of commentaries on this record (e.g. see the *Commentaries to the Thirteen Chinese Classics*).

As for this eclipse, it has been dated to the reign of King Li, King You, or King Ping (for references, see Chen Zungui 1984). Astronomers of different dynasties have tried to use different methods to calculate the date of this eclipse. It is recorded in the *New History of the Tang Dynasty* that Yu Kuang of the Southern Dynasties identified it with the eclipse of 776 BC, the sixth year of King You of the Zhou Dynasty. Yixing, who based his calculation on the Dayan calendar, reached the same conclusion, as did Guo Shoujing (see the "Treatise on Calendar" chapter in the *History of the Yuan Dynasty*). Such a result implies that the calendar used in this poem was the Zhou calendar, which is different from the Xia calendar used in other poems in the *Book of Songs*. This has caused some doubts. Recent calculations show that the eclipse of the sixth year of King You was not visible from central China. Accordingly, the eclipse has been identified with the one in the first year of King You's reign, on 781 June 4 BC, or the one in the thirty-sixth year of King Ping's reign, on 735 November 30 BC.

Chen Zungui (1984) has conducted a detailed review of previous studies. After analyzing relevant texts and the historical background of the poem, he does not believe that the month during which the eclipse occurred, in the first year of King You's reign (i.e. 781 June BC), matches the month recorded in the poem. Nor does he believe that the historical situation in 781 BC matches what was described in the poem. Therefore, he inclines to identify the eclipse with one in 776 BC, the sixth year of King You's reign, and points out that there were two visible lunar eclipses that took place in 776 BC, on February 26 and August 21. Moreover, he claims that astronomical events in the sixth year of King You's reign match very well the situation described in the poem.

Zhang Peiyu (1984) has analyzed all solar eclipses during the two hundred year period from 880 to 680 BC, which corresponds to the reigns of King Li, King Xuan, King You, King Ping, King Huan, and King Zhuang. He has found four eclipses around *xinmao* in the tenth month of the contemporary calendar. They occurred on 833 September 5 BC, 797 October 26 BC, 776 September 6 BC, and 735 November 30 BC, but his calculations showed that the first two eclipses were partial and could not be seen from China. The eclipse of 776 BC (in the sixth year of King You's reign) was only visible to the north, and could not have been seen from the capital of the Zhou. As for the eclipse of 735 BC (in the thirty-sixth year of King Ping's reign), this was observable as a partial eclipse from the capital of Zhou, with a maximum magnitude of 0.80. Moreover, the first month of the year was the third month after the winter solstice, which was very close to the Xia calendar (whose first month was the second month after the winter solstice). Therefore, the eclipse of 735 BC was very likely the one recorded in the poem.

Liu Jinyi (1985) argues that, according to Oppolzer's cannon, if ΔT is changed by 3.5 hours, Xi'an would have been part of the region where the eclipse in the sixth year of King You's reign could have been seen. However, modern research has made it clear that such a drastic change of ΔT is impossible.

Liu Ciyuan and Zhou Xiaolu (2002c) have reviewed the *status quo* and the difficulties associated with historical and astronomical studies about the eclipse in the *Book of Songs*. Based on the progress in astronomical computing achieved in recent decades, they present a comprehensive discussion on astronomical factors relating to the eclipse. They tabulated all eclipses that occurred on *xinmao* days from the eighth century BC to the sixth century BC and all eclipses that happened in the tenth months from the reign of King Li to that of King You. Moreover, they discussed astronomical factors such as the magnitude of each eclipse, its possible range of change caused by the uncertainty of calculating, and associated lunar eclipses, in the hope that such information will be helpful for future research into the meaning and background of the poem in the *Book of Songs*.

Although it is generally accepted that the stanza cited at the beginning of this Section is an eclipse record, its identification is still surrounded by controversy. This may have something to do with the nature of the record. After all, it is a poem, and it could be that some information in that poem is not historically correct.

5 POSTSCRIPT

Early Chinese texts are rather brief and abstruse. In addition, the ability of the ancient Chinese to understand and describe astronomical phenomena was limited. As a result, there is great uncertainty with regard to the so-called early Chinese eclipse records. As a matter of fact, apart from the eclipse record in the *Book of Songs*, none of the records discussed above includes accurate terminology for a solar eclipse. For example, what some records describe is only *similar* to the situation during a solar eclipse, and other records are regarded as references of solar eclipses only because certain scholars have claimed that they *are* eclipse records.

In this paper, we call them early Chinese solar eclipses records simply because they have been used as sources of data in the study of solar eclipses. The aim of this paper has been to examine which of the alleged early Chinese solar eclipse records are reliable eclipse records and which are false.

6 ACKNOWLEDGEMENT

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The C41/ICHA Transits of Venus Working Group. 2: Lord Lindsay's Transit of Venus expedition to Mauritius 1874

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Of the many expeditions that set out from Britain to observe the Transit of Venus in 1874, that organized by Lord (James Ludovic) Lindsay (later Earl of Crawford) from the Dun Echt Observatory in Scotland to the island of Mauritius was unique in certain respects: it was privately funded, and it carried out an independent and in part experimental programme of observation.

Dun Echt Observatory, which functioned from 1872-92 on the country estate of the Crawford family near Aberdeen, was the dream creation of Lindsay, a talented independent astronomer of professional standing. Lindsay's immediate ambition, when he began to plan his observatory in 1872, was to observe the approaching transit of Venus, and preparations for the Transit went hand in hand with the furbishing of the new observatory. He recruited the brilliant and enthusiastic David Gill, and together they set about acquiring a variety of instruments, with particular reference to the needs of the Transit. They decided that their principal instrument for that event should be a heliometer, the favoured instrument of the official German and Russian expeditions. Lindsay's expedition also made provision to contribute by the photographic method, and was equipped with much auxiliary apparatus, including a transit instrument, chronometers, and photographic materials.

The site on Mauritius was provided by a resident of the island, Eduard de Chazal, on his estate of Belmont, sixteen miles from Port Louis (latitude 20° S). The scientific team consisted of Lord Lindsay, David Gill, Ralph Copeland, on leave from Dunsink Observatory, and Lord Lindsay's photographer Henry Davis. A horizontally-mounted telescope of 40 feet focal length was employed to photograph the transit, while Gill was responsible for using the heliometer in the manner adopted by the German astronomers. The transit, on 1874 December 9, was observed according to plan. The data were reduced and pooled with those of the other British expeditions but not separately published. As with other expeditions world-wide, the results were disappointing.

The real significance of the Mauritius expedition lay in Gill's second heliometer programme. It consisted in observing the minor planet Juno, which was in opposition one month previously, on November 5, for the purpose of deriving the solar parallax by the diurnal method. Gill, who had travelled in advance with the bulk of the expedition's equipment, was installed in Mauritius in good time, but the heliometer, which was transported by Lindsay in his yacht, unfortunately arrived late. Gill's observations began only on November 12, continuing until November 30. The span was enough, however, to provide a good result and to establish the method.

The diurnal method of observing the parallax of a planet, and hence of the Sun, had been suggested as far back as 1857 by G B Airy, but had not previously been put into practice. Instead of observing the planet from widely-separated positions on the surface of Earth, the astronomer observes it from the same location after an interval of time, allowing the rotation of Earth to provide the baseline for parallax. This requires to be done when the planet is in opposition, the observations being made in the evening and again in the morning. The idea of using a minor planet for parallax work instead of the nearest planets, Mars and Venus, originated with J G Galle in 1872, who pointed out that a minor planet, though more distant, had the advantage of a star-like appearance, allowing its position to be more precisely determined. He tried the method with the minor planet Flora at its opposition in 1873 October, with the co-operation of a number of observatories throughout the world, including Dun Echt. Gill's procedure was thus original, in that it combined for the first time the diurnal method with the use of a minor planet, and furthermore, used – unusually – the heliometer for the observations. The resulting solar parallax (8″.77) was published in 1877 (Lindsay and Gill, 1877).

The Juno work on Mauritius confirmed the advantages of the diurnal method of parallax determination, and of minor planets for parallax purposes. It also, as far as Gill was concerned, sealed his preference for the heliometer as a positional instrument. It was the springboard for Gill's successful observations of Mars (again with Lindsay's heliometer) at opposition in 1877, and his subsequent important series of collaborative observations of minor planets, leading to improved values of the solar parallax (listed by Hughes, 2001).

An account of Lord Lindsay's Transit of Venus expedition is included in Brück's history of Dun Echt Observatory (Brück, 1992). Lord Lindsay's historic heliometer is preserved at the Royal Observatory Edinburgh.

Lord Lindsay has recorded that the site of the Transit of Venus instruments at Belmont on Mauritius was given by the owner as a gift to the Government for preservation. The present writer does not know if the site is still marked, but would like to draw it to the attention of the Working Group.

The site of the Dun Echt Observatory is marked by an engraved stone, placed there by the 26th Earl of Crawford (formerly Lord Lindsay) in 1892.

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Reviews

Sky and Ocean Joined. The U.S. Naval Observatory 1830–2000, by Steven J. Dick (Cambridge University Press, Cambridge, 2003), xiv + 609 pp., ISBN 0 521 81599 1, hard cover US$130.00, £90.00, 254 × 180 mm.

The U.S. Naval Observatory is one of the great observatories of the world, with a fascinating history – especially for those with a penchant for positional astronomy or time-keeping – and Steven Dick has done us a real service in producing this much-anticipated book. Nor have we been let down, for this book has been all of fifteen years in the making; no hurried slip-shod history, it is a well-researched thorough account of "...the first national observatory of the United States, [and one which is] analogous to the famous observatories at Greenwich and Paris."

Chronologically, the book contains three distinct Parts. The first, titled "The founding era, 1830–65", traces its embryonic beginnings as the Depot of Charts and Instruments in 1830, its evolution to *de facto* observatory status in 1842, and its formal establishment as the U.S. Naval Observatory in 1844. Other chapters in Part I follow its development under Maury's directorship and later (under Gilliss) during the Civil War, while Chapter 3 provides a worthwhile diversion in relating the founding (in 1849) and early years of the Nautical Almanac Office. In his account of the critical 35-year period covered by Part I, Dick brings out the interesting interplay between astronomy, meteorology, hydrology, and navigation, and introduces the military-civilian staffing dichotomy which would rear its ugly head with renewed urgency later in the century.

From a personal perspective, I found Part II, "The golden era, 1866–93", the most captivating section of the book, dealing as it does with solar eclipse and transit of Venus expeditions, and Hall's discovery of Phobos and Deimos. During this era, the USNO "... stood at the pinnacle of the world's astronomical observatories by virtue of its high scientific accomplishment ... [in spite of being] plagued by problems ranging from its bad location at "Foggy Bottom" on the Potomac River to persistent conflict over naval versus civilian control." It was also the era of Simon Newcomb, the doyen of American astronomy, a time when the Observatory's 26-inch Clark refractor ranked – albeit briefly – as the largest telescope of this type in the world, and a period of technological innovation where spectroscopy and photography were brought to the service of astronomy. But the foregoing highlights and high-profile events should not blind us to the fact that routine time-keeping and positional astronomy were the Observatory's "bread-and-butter programs" at this time, as Dick gently reminds us.

With the up-coming 2004 and 2012 transits of Venus increasingly in our thoughts, chapter 7 on "William Harkness and the transits of Venus of 1874 and 1882" has particular poignancy. Astronomers from the USNO played critical roles in both transits, leading observing parties that dispersed to the far reaches of the globe. This followed international controversy about the most appropriate means of observing these rare events, the Americans opting (primarily) for photography and the fixed horizontal photoheliograph. To illustrate the range of preparations that led to a successful transit observing programme, Dick profiles Hobart, one of two Australian stations chosen by the Americans in 1874 (the other was Campbell Town, also in Tasmania – see Orchiston and Buchanan, 1993). Largely as a result of the notorious 'black drop effect' (see Schaefer, 2001) the international results from 1874 were disappointing, placing in jeopardy the American 1882 transit programme. Eventually a much curtailed international operation was approved, again with reliance on photography, and the fact that a meaningful figure for the solar parallax was derived on this occasion is much to the credit of Harkness and his patience and persistence. But once again funding issues prevented the full results being published, and this whole frustrating ordeal is carefully outlined by Dick, along with the fascinating interplay between Harkness and Newcomb as they each jockeyed for supremacy in the solar parallax stakes. History would decree Harkness the sentimental favourite but Newcomb the winner.

The final section of this book deals with "The twentieth century", and at 255 pages is by far the largest of the three Parts. After a chapter about the move from Foggy Bottom to the present site at Observatory Circle, that ever-simmering issue of civilian versus military control, and administrative developments from WWI on, Dick launches into three lengthy thematic chapters about the Observatory's current tripartite obligations: astronomy (with new instrumentation, staff, research programmes, field stations, and discoveries), time-keeping, and navigation. This weighty volume ends with a final chapter titled, simply, "Summary", a bibliographical essay, five appendices (one of which relates to sources) and a detailed and invaluable index.

Despite its length, *Sky and Ocean Joined* is easy reading. It is well-illustrated and well-referenced, and careful editing and proof-reading have made it remarkably free of 'typos' and other errors. I did, however, notice that the locations of the two Tasmanian transit of Venus sites, Hobart and Campbell Town, have been interchanged in figure 7.9, and that one of Dick's own papers about the 1874 transit of Venus expeditions (see Orchiston, Love and Dick, 2000) somehow managed to slip through the net when the page references were assembled. These minor concerns aside, this tome is an historical *tour-de-force*, and I thoroughly recommend it to everyone interested in US astronomical history, positional astronomy, national observatories, naval history, navigation, time-keeping, or the conflict involving civilian and military control of science.

Wayne Orchiston

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Starry Night: Astronomers and Poets Read the Sky, by David H. Levy (Prometheus Books, New York, 2001), 203 pp., ISBN 1 57392 887 9, soft cover, price US$18.00, 184 × 133 mm.

In astronomy the night sky is treated as a subject for dispassionate inquiry. A more universal response, long articulated by artists, and in particular poets, is awe and wonder at the spectacle of the heavens. This artistic response is the subject of *Starry Night*. The author's basic thesis is that the scientific and poetic responses spring from the same underlying creative impulse and are but opposite sides of the same coin. This attitude is perhaps not the usual one, but surely has much to commend it.

Probably wisely, the author largely restricts himself to quoting and discussing poetry written in English. There is a brief mention of astronomical references in the Bible and Chaucer (who, in addition to his better-known works also wrote *A treatise on the Astrolable*), though most of the material dates from Elizabethan times or later. The astronomical allusions in the works of Shakespeare, Tennyson, and Gerard Manley Hopkins are covered in particular depth, as are the astronomical paintings of Van Goth.

Starry Night is not primarily a book on the history of astronomy, though inevitably it contains quite a bit of historical material. It is written for the general reader and the style might not be to the taste of some. There is the occasional blunder (Messier did not catalogue comets, as the author, of all people, well knows), but these do not seriously detract from the whole. The author needs little introduction: he is well known as a comet-hunter and was the co-discoverer, with the Shoemakers, of comet Shoemaker-Levy 9 which impacted Jupiter in 1994. The book is a complete revision and expansion of his earlier *More Things in Heaven and Earth* and the chapter on Gerard Manley Hopkins is adapted from his Thesis.

Some of the poems discussed are well-known, others less so, but part of the book's charm is the opportunity it offers to revisit old friends and make new ones (I've known the couplet: 'Two men looked out through the prison bars / one saw mud, the other stars' since I was a student, but now I've finally learnt its attribution). Other old favourites are absent, but any collection is necessarily personal and selective. The book is an easy read and thoroughly enjoyable. It makes a refreshing change from the technical minutiae of professional astronomy and can be recommended as an introduction to poetry on an astronomical theme.

Clive Davenhall

Historical Supernovae and their Remnants, by F. Richard Stephenson & David A. Green (Oxford University Press, Oxford, 2002), xiv + 252 pp., ISBN 0 19 850766 6, hard cover, £65.00, 240 × 160 mm.

Those of us with a passion for radio astronomy have a special place in our hearts for the discrete source, Taurus-A. One of the first 'radio stars' to be discovered, this was soon associated with the Crab Nebula. Later it assumed even more importance when a pulsar was discovered near the centre of the radio source, and optical and X-ray correlates were subsequently detected. But what makes Taurus-A particularly remarkable is its association with the supernova explosion of AD 1054 that was described in some detail by Chinese and Japanese astronomers. This is one of a mere handful of recorded historic supernovae (Sne).

Stephenson and Green discuss these and other possible historic SNe in their book, *Historical Supernovae and their Remnants*, recently released by Oxford University Press. No simple reincarnation of Clark and Stephenson's *The Historic Supernovae* (1977), this new volume presents additional historical material, and Green has been able to assimilate a wealth of new radio data accumulated over the ensuing quarter-century.

The new book begins with introductory chapters on the historical records and the nature of supernovae, supernova remnants and pulsars, followed by a discussion of whether Flamsteed observed a SN in AD 1680 that is associated with the strong radio source Cas-A, before launching into detailed accounts of the SNe of AD 1604, 1572, 1181, 1054, and 1006. Then follow chapters on possible pre-AD 1000 SNe, reported 'new stars' or 'guest stars' which were not SNe, and "Future prospects". Closing out the book are is a glossary of Chinese astronomical terms, a few pages on modern astronomical terminology, a summary of the SNRs in Green's electronic catalogue (www.mrao.cam.ac.uk/surveys/snrs) and thirteen pages of references for those wishing to pursue this topic in more depth. In a little over 250 pages, Stephenson and Green provide a fascinating mix of historic astronomy and modern astrophysics, and show how historical data can be used to address contemporary astronomical issues.

Historical Supernovae and their Remnants is a *tour-de-force*, and like the Clark and Stephenson predecessor will long remain the standard work in this field. The fascinating interweave of historical, optical, X-ray, and radio data makes for entertaining reading, and the book is well illustrated and is supplied with a useful Index. Despite the high price, this book should be essential reading for all those with an interest in SNe, SNRs, pulsars, Oriental astronomy, or the basics of 'Applied Historical Astronomy'.

Wayne Orchiston

100 Years of Observational Astronomy and Astrophysics. Homage to Miklós Konkoly Thege, edited by Christiaan Sterken & John B. Hearnshaw (Vrije Universiteit, Brussels, 2001), xii + 268, paperback, ISBN 90 805538 3 2, €35.00 & US$30.00, 240 × 155 mm.

This volume derives from a 3-day workshop that was held at Tihany, Hungary, in 1999 August, the second in a series "… dedicated to the rise of observational astrophysics in the nineteenth and early twentieth century …" This particular workshop coincided with the centenary of the Konkoly Observatory, Hungary's national observatory.

Konkoly Observatory's origins can be traced back to the talented and well-endowed amateur astronomer, Miklós Konkoly Thege, and in the lengthy first section of this book ('Astrophysics in Hungary') Balázs documents Konkoly's pioneering observational efforts, the emphasis on variable star photometry after his observatory was taken over by the state in 1899, and later forays into solar and minor planet astronomy. Magda Vargha, Librarian at the Konkoly Observatory from 1965 to 1999 and to whom these Proceedings are dedicated, provides a thought-provoking chapter comparing and contrasting the lives and astronomical achievements of Konkoly and America's Simon Newcomb, "... two great contemporaries of late nineteenth century astronomy ...". This is followed by Wolfschmidt's masterly review of Konkoly's instrumentation, research programmes and his prowess as an organiser of science. Sterken and Zsoldos then provide two short chapters in which they examine early colorimetry at the Konkoly Observatory and Schwab's variable star observations; Illés-Almár discusses possible SL9-like impact features on nineteenth century Jovian drawings by two other Hungarian astronomers; and in a little over three pages Patkós rounds out Part I by briefly examining Konkoly's success in international networking, and commenting on international co-operation in variable star astronomy today. With unbridled optimism, he concludes that "Using the different large data bases now emerging, talented people will find way to make high-level scientific work in the next hundred years of the Konkoly Observatory too." (page 88).

Part II, with four chapters, provides an international perspective by discussing the parallel rise of astrophysics in France, South Africa, and Japan. Takeuti's chapter on Japanese astronomy around 1899 provides a fascinating exposé of the ways in which an Asian nation went about replacing the old traditional system with the 'new astronomy' introduced by the West, while Caplan's account of the Marseilles Observatory highlights the successive achievements and lost opportunities experienced by Stephan, Bourget, and their collaborators between 1860 and 1920. But personally, as a denizen of the Southern Hemisphere I was captivated by Laney's account of the first century at the Royal Observatory, Cape of Good Hope, and its interesting evolution from positional astronomy to astrophysics under the inspired directorship of Sir David Gill.

In the third Part of this book ("Observational Techniques'), Hearnshaw and Staubermann provide a useful observational context for the work at the Konkoly Observatory by describing major worldwide trends in photographic stellar photometry and early astrophotometry, respectively, while in the single chapter representing Part IV, Schnell presents a succession of fascinating thumbnail accounts of the contributions to international astrophysics made by twelve different well-known women astronomers. One of these is that famous chronicler of early astrophysics, Agnes Mary Clerke, who has recently been the subject of a separate detailed study (see Bruck, 2002).

The final section of this book (Part V. Interpretations of Early Observational Data) contains two chapters. A long paper by Duerbeck and Seitter reviewing progress in theoretical and observational cosmology during the first half of the twentieth century, with emphasis on the work of Einstein, de Sitter, Friedman, and Lemaître, is followed by Brosche's 3-page "A footnote on the prehistory of interpretation of stellar colours".

All in all, this reasonably-priced book offers an interesting mix of papers, providing as it does an overview of early astrophysics and observational developments in Hungary and other countries. The chapters are well written and well referenced, and most are well illustrated. I recommend this book to anyone with an interest in the history of astrophysics, or the development of astronomy in Hungary.

Wayne Orchiston

Reference

Bruck, M.T., 2002. *Agnes Mary Clerke and the Rise of Astrophysics*. Cambridge University Press, Cambridge.

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