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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).

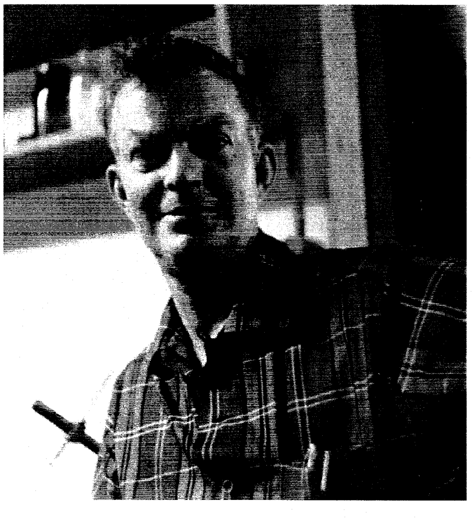

Figure 1. Don Hendrix *c.* 1948–1949, about when he finished the 200-in. Hale telescope primary mirror. (Author's Collection)

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).

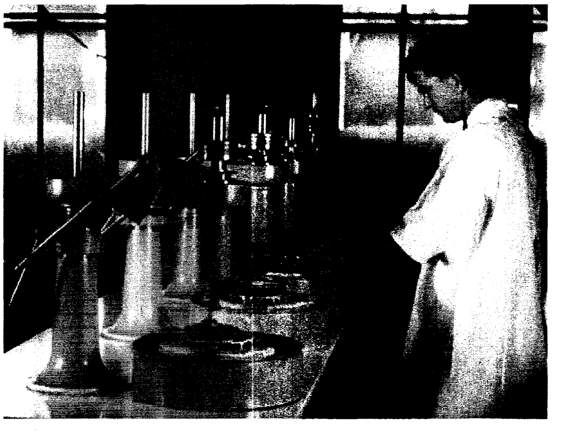

Figure 2. Don Hendrix at the Mount Wilson Observatory optical shop in the early 1930s. (Courtesy of the Huntington Library)

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).

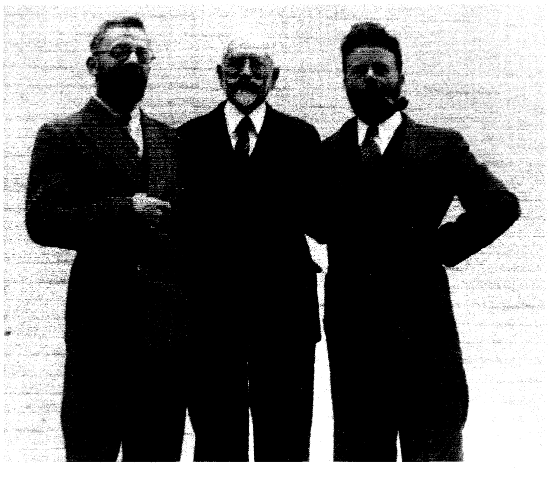

Figure 4. William H Christie (left), MWO staff astronomer and Don Hendrix's co-author, with Ferdinand Ellerman (centre) and Olin C Wilson (right), the three 'beards' of the MWO staff in 1939 (Courtesy of the Huntington Library)

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.

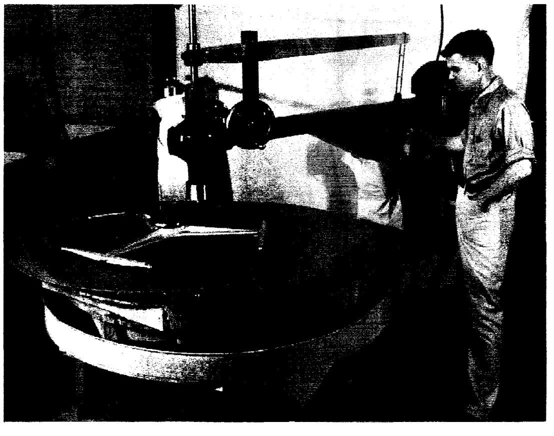

Figure 5. Don Hendrix *c.* 1938 doing preliminary work on a corrector plate for the 48-inch Schmidt telescope. (Courtesy of the Huntington Library)

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.

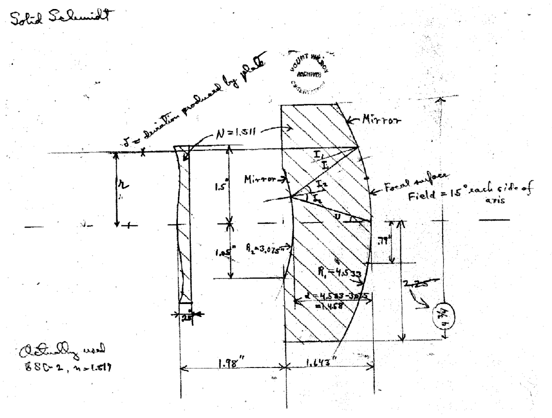

Figure 6. Optical drawing used by Hendrix to make the Cassegrain two-mirror, thick-mirror Schmidt camera. Note that the convex secondary mirror, with 1.05-inch radius, blocks a large part of the area of the concave, 1.5-inch radius primary. (Courtesy of the Huntington Library)

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.

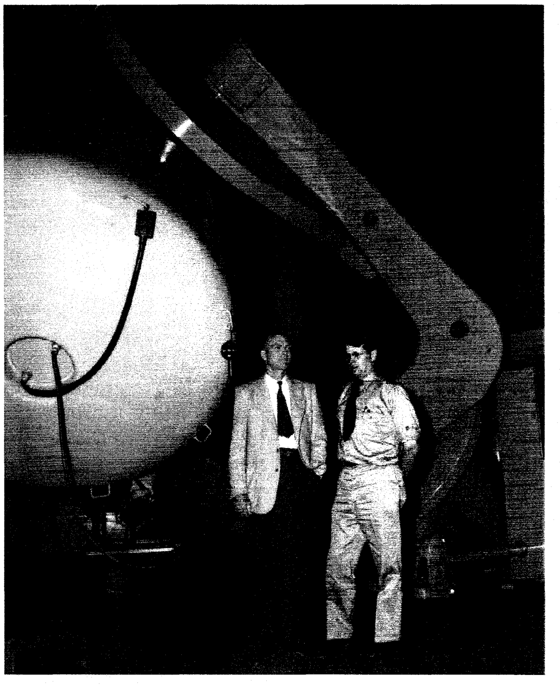

Figure 7. Don Hendrix (left) and Byron Hill, Palomar Observatory mountain superintendent (right), at the dedication of the 48-inch Schmidt telescope in 1949 June. (Courtesy of the Huntington Library)

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).

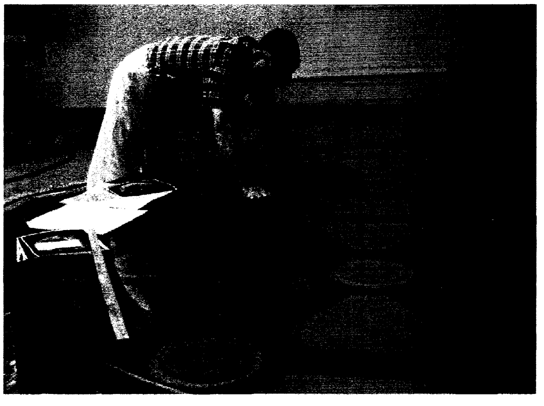

Figure 9. Don Hendrix cleaning a spot on the Lick Observatory 120-inch primary mirror, 1959. (Courtesy of Mary Lea Shane Archives of the Lick Observatory)

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.

16 REFERENCES

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.

WAP = Walter S. Adams Papers, Henry Huntington Library Papers, San Marino.

Adams, W.S., 1929a. Letter to W.M. Gilbert, dated January 16. In WAP.

Adams, W.S., 1929. Letter to W.M. Gilbert, dated August 10. In WAP.

Adams, W.S., 1931a. Letters to J.C. Merriam, dated April 6 and 21. In WAP.

Adams, W.S., 1931b. Letters to W, M. Gilbert, April 9, May 11 and July 11. In WAP.

Adams, W.S., 1941. Some results with the coudé spectrograph of the Mount Wilson Observatory. *Astrophysical Journal*, **93**:11-23.

Anderson, J.A., 1931. Letter to G. E. Hale, dated October 5. In George Ellery Hale Papers, Microfilm Edition, Reel 5.

Anon, 1931. Newspaper article in the *San Bernardino Valley College* newspaper, October 30.

Anon, 1936. An invitation to a superastrofestivity affair. *The Pacific Stargazer*, January issue. (This is the first and only issue of this newsletter of the Citrus Belt Astronomical Association, a predecessor of the Riverside Astronomical Society of today.)

Anon, 1943. Undated working drawing of thick-mirror Cassegrain Schmidt camera, 3-in aperture, 3-in effective focal length. In WAP.

Baade, W., and Minkowski, R., 1936. The spectrum of Comet Peltier (1936a). *Publications of the Astronomical Society of the Pacific*, **48**:277-278.

Babcock, H.W., 1939. Rotation of the Andromeda Nebula. *Lick Observatory Bulletin*, **19**:41-51.

Babcock, H.W., and Johnson, J.J., 1941. A spectrophotometric study of the light of the night sky. *Astrophysical Journal*, **94**:271-278.

Baker, J.G., 1939. Two letter to the editor of Telescoptics. *Scientific American*, **161**:314, 317, and 376-377.

Bowen, I.S., 1949. Letter to D. O. Hendrix, dated October 5. In IBP.

Bowen, I.S., 1950. Final adjustments and tests of the Hale telescope. *Publications of the Astronomical Society of the Pacific*, **62**:91-97.

Bowen, I.S., 1952a. The spectrographic equipment of the 200-inch Hale telescope. *Astrophysical Journal*, **116**:1-7.

Bowen, I.S. 1952b. Optical problems at the Palomar Observatory. *Journal of the Optical Society of America*, **42**:795-800.

Bowen, I.S., 1957. Instrumentation at the Mount Wilson and Palomar Observatories. *Publications of the Astronomical Society of the Pacific*, **69**: 377-384.

Bowen, I.S., 1960a. The 200-inch Hale telescope. In G.P. Kuiper and B.M. Middlehurst (eds.). *Telescopes*. University of Chicago Press, Chicago. Pp. 1-15.

Bowen, I.S., 1960b. Schmidt cameras. In G.P. Kuiper and B.M. Middlehurst (eds.). *Telescopes*. University of Chicago Press, Chicago. Pp. 43-61.

Bowen, I.S., 1961. Letter to Phyllis (Mrs. D.O.) Hendrix, dated December 27. In IBP.

Bowen, I.S., 1962a. Report of the Director of the Mount Wilson Observatory [for 1961–62]. *Carnegie Institution of Washington*, **61**:3-50.

Bowen, I.S., 1962b. Spectrographs. In W.A. Hiltner (ed.). *Astronomical Techniques*. University of Chicago Press, Chicago. Pp. 34-62.

Christie, W.H., 1939a Letter to C.S. Smiley, dated June 24. In AIP.

Christie, W.H., 1939b. Letter to the editor of Telescoptics. *Scientific American*, **161**:252-253.

Christie, W.H., 1939c. Letters to A. G. Ingalls, dated July 6 and 10. In AIP.

Cook, A., 2001. H. Page Bailey: A pioneering telescope maker. *Sky & Telescope*. **101**:130-131 (March issue).

Cowan, H., 1959. Manuscript Optical Shop Annual Report for 1958–1959. In MSA.

Dunham, T., Jr., 1934a. The use of Schmidt cameras in plane-grating spectrographs. *Physical Review*, **46**: 326.

Dunham, T., Jr., 1934b. Schmidt spectrograph cameras. *Publications of the* American *Astronomical Society*, **8**: 110-111.

Dunham, T., Jr., 1938. The construction and performance of stellar spectrographs. *Publication of the Astronomical Society of the Pacific*, **50**: 220-221.

Dunham, T., Jr., 1940. The use of a spherical mirror camera in the coudé spectrograph of the 100-inch telescope. *Publications of the American Astronomical Society*, **10**: 49.

Dunham, T., Jr., 1945. Two-mirror Schmidt camera for aerial photography. *Final Report, Section 16.1 Report No. 104, O.S.R.D. No. 5644*

Harrington, R.G., 1952. The 48-inch Schmidt-type telescope of the Palomar Observatory. *Publications of the Astronomical Society of the Pacific*, **64**:275-281.

Hendrix, D.O., 1939. An extremely fast Schmidt camera. *Publications of the Astronomical Society of the Pacific*, **51**:158-159.

Hendrix, D.O., and Christie, W.H., 1939. Some applications of the Schmidt principle in optical design. *Scientific American*, **161**:118-123.

Hubble, E., 1937a. The role of an auxiliary telescope in research with the 200-inch reflector. Memorandum dated May 12. In Rockefeller Archive Center, Tarrytown, New York.

Hubble, E. 1937b. Undated letter [~June 2] to [M.] Mason. In Bruce Rule Papers, California Institute of Technology Archives, Pasadena.

Humason, M.L., 1936. The apparent radial velocities of 100 extra-galactic nebulae. *Astrophysical Journal*, **83**:10-22.

Humason, M.L., 1951. Apparent velocities of extragalactic nebulae in four faint clusters. *Publications of the Astronomical Society of the Pacific*, **63**:232-233.

Humason, M.L., Mayall, N.U. and Sandage, A.R., 1956. Redshifts and magnitudes of extragalactic nebulae. *Astronomical Journal*, **61**:97-162.

Ingalls, A.G., 1932. The amateur astronomer. *Scientific American*, **146**:308-309.

Ingalls, A.G. (ed.), 1961. *Amateur Telescope Making (Book Three)*. Scientific American, New York.

Kuiper, G.P., 1948. Yerkes Observatory and McDonald Observatory [Annual Report for 1947-1948]. *Astronomical Journal*, **54**:70-76.

Lindsay, F.B., 1931. A new mounting and housing for a telescope. *Popular Astronomy*, **34**:497-500.

Lower, H.A., 1939. Undated note to A.G. Ingalls, probably written about July 1. In margins of copy of letter Christie 1939a. In AIP.

Mason, M., 1937. Letter to R.B. Fosdick, dated June 2. In Bruce Rule Papers, California Institute of Technology Archives, Pasadena.

McKellar, A., 1949. Letter to D.O. Hendrix, dated September 14. In OSP.

Minkowski, R., 1944. Schmidt systems as spectrograph cameras. *Journal of the Optical Society of America*, **34**:89-92.

Minkowski, R. and Abell, G.O., 1963. The National Geographic Society Palomar Observatory sky survey. In K.Aa. Strand (ed.). *Basic Astronomical Data*. University of Chicago Press, Chicago. Pp.481-487.

Osterbrock, D.E., 1994. Getting the picture: wide-field astronomical photography from Barnard to the achromatic Schmidt. *Journal for the History of Astronomy*, **25**:1-14.

Page, T.L., 1948. The purity of interstellar Hα. *Astrophysical Journal*, **108**:157-158.

Page, T.L., 1952. Radial velocities and masses of double galaxies. *Astrophysical Journal*, **116**:63-80.

Perkin, R.S., 1937. Letter to W.H. Wright, dated October 25. In MSA.

Ross, F.E., 1937. Letters to W.H. Wright, dated October 20 and 27, and November 3. In MSA.

Ross, F.E., 1940. The 48-inch Schmidt telescope of the Astrophysical Observatory of the California Institute of Technology. *Astrophysical Journal*, **92**:400-407.

Russell, H.N., 1935. The newer telescope. *Scientific American*, **154**:294-295.

Scherer, P., 1949. Letter to I.S. Bowen, dated September 14. In IBP.

Schmidt, B., 1932. Ein lichtstarkes komafreies Spiegelsystem. *Mitteilungen der Hamburger Sternwarte in Bergedorf*, **7**:15-18.

Schorr, R. 1931. Hamburg-Bergedorf [Observatory report for 1930]. *Vierteljahresschrift der Astronomischen Gesellschaft*, **66**:164-183.

Shane, C.D., 1953. Lick Observatory [Triennial Report for 1950–1953]. *Astronomical Journal*, **58**:245-253.

Shane, C.D., 1955. Lick Observatory [Annual Report for 1954–1955]. *Astronomical Journal*, **60**:282-286.

Shane, C.D., 1958. Lick Observatory [Annual Report for 1957–1958]. *Astronomical Journal*, **63**:361-365.

Smiley, C.H., 1938. The remarkable Schmidt camera. *Griffith Observer*, **2**:92, 95.

Smiley, C.H., 1939a. Letter to A. G. Ingalls, dated June 20. In AIP.

Smiley, C.H., 1939b. Letter to A. G. Ingalls, dated June 23. In AIP.

Smiley, C.H., 1939c. Letter to W. H. Christie, dated June 26. In AIP.

Smiley, C.H., 1939d. Letter to the editor of Telescoptics. *Scientific American*, **161**:188-189.

Smith, S., 1934. An f/1 quartz spectrograph. *Physical Review*, **47**:257.

Smith, S., 1935. Some notes on the structure of elliptical galaxies. *Astrophysical Journal*, **82**:192-201.

Smith, S., 1936. The mass of the Virgo cluster. *Astrophysical Journal*, **83**:23-30.

Strömgren, B., 1935. Die Schmidsche Spiegelteleskop. *Vierteljahrsschrift der Astronomischen Gesellschaft*, **69**:65-86.

Strong, J., in collaboration with Neher, H.V., Whitford, A.E., Cartwright, C.H., and Hayward, R., 1938. *Procedures in Experimental Physics*. Prentice Hall, Englewood Cliffs.

Struve, O., and Roach, F.E., 1936. Reflection nebulae. *Astrophysical Journal*, **84**:219-228.

Struve O., 1937. A new slit spectrograph for diffuse galactic nebulae. *Astrophysical Journal*, **86**:613-619.

Struve O., 1938a. Letter to F.E. Ross, dated November 7. In OSP.

Struve O., 1938b. Letter to D.O. Hendrix, dated December 5. In OSP.

Struve O., 1939. Yerkes Observatory and McDonald Observatory [Annual Report for 1938–1939]. *Publications of the American Astronomical Society*, **9**:298-306.

Struve O., 1946a. Yerkes Observatory and McDonald Observatory [Annual Report for 1939–1940]. *Publications of the American Astronomical Society*, **10**:102-110.

Struve O., 1946b. Yerkes Observatory and McDonald Observatory [Annual Report for 1940–1941]. *Publications of the American Astronomical Society*, **10**:201-211.

Whitford, A.E., 1959. Lick Observatory [Annual Report for 1958–1959]. *Astronomical Journal*, **64**:290-298.

Whitford, A.E., 1960. Lick Observatory [Annual Report for 1959–1960]. *Astronomical Journal*, **65**:531-536.

Wilson, R.N., 1990. "Matching error" (spherical aberration) in the Hubble Space Telescope (HST): some technical comments. *ESO Messenger*, **61**:22-24.

Wilson, R.N., 1999. *Reflecting Telescope Optics II*. Springer, Berlin.

Woodbury, D.O., 1963. *The Glass Giant of Palomar*. Dodd, Mead, Co., New York.

Zwicky, F., 1956. Letter to C.D. Shane and E.F. Carpenter, dated October 5. In MSA.

In addition to the listed references, I have also used the Annual Reports of the Director of Mount Wilson Observatory, or later, of Mount Wilson and Palomar Observatories from 1929-30 to 1963-4, by W S Adams through 1946-7, and by I S Bowen after that, published in successive volumes of the *CIW Year Books*. They contain useful nuggets of information about many, but not all, of the Schmidt cameras Hendrix built there.

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