A TALE OF THREE TELESCOPES: THE JOHN A. BRASHEAR COMPANY AND ITS 46-cm OBJECTIVE OF 1893

Richard Taibi
7002 Coolridge Drive, Temple Hills, Maryland 20748, USA.
Email: rjtaibi@hotmail.com

Abstract: This is a history of a 46-cm objective lens used in three refracting telescopes. It was designed and figured by Charles S. Hastings and James B. McDowell respectively, employed by the John A. Brashear Company. In the past, its fabrication had been attributed to John A. Brashear alone. The lens, mounted in two different telescopes, had two periods of scientific use in the United States during the nineteenth and twentieth centuries, with Percival Lowell (1894–1895) and the Flower Observatory (1896–1954), respectively. On 1 July 2019, the lens began a third use in New Zealand.

Keywords: John A. Brashear, Charles S. Hastings, James B. McDowell, Objective Lenses, Percival Lowell, Flower Observatory, New Zealand

1 INTRODUCTION

This is the history of a 126-year-old medium-sized objective lens that has had an eventful and and intriguing history. John A. Brashear, a steel factory millwright who aspired to produce astronomical optics of exquisite quality, formed an eponymous company ca. 1881 to accomplish his goal. As the company's production orders increased Brashear's son-in-law, James B. McDowell figured more of those optics and became the firm's chief optician. Soon observatory customers' sophisticated requirements necessitated hiring a consultant who had specialized in geometrical optics: Charles S. Hastings of Yale University.

The Brashear Company's design and fabrication team, Hastings and McDowell, was given the assignment of creating a 46-cm objective lens that would showcase American mastery of astronomical optics for the 1893 World's Columbian Exposition in Chicago. After the Exposition, John Brashear leased the objective to Percival Lowell to observe the 1894–1895 Martian opposition. Immediately after Lowell's use, the University of Pennsylvania bought the objective, in a mounting by Warner and Swasey, for its Flower Observatory west of Philadelphia, Pennsylvania. From 1896 to 1954, the Brashear/ Warner and Swasey refractor was used principally for double star studies. In 1954, the telescope was dismantled; it was in storage until the early twenty-first century when the lens again was placed in a mounting for use at a dark sky reserve in New Zealand.

2 BIOGRAPHICAL SKETCHES OF PRINCIPAL JOHN A. BRASHEAR COMPANY PERSONNEL

The essential figures of the company's history are John A. Brashear, founder of his company, James B. McDowell, the principal optician, and Charles S. Hastings, consultant designer of the company's largest optical products.

2.1 John A. Brashear

Figure 1 is a portrait of Brashear in late life. John Brashear's family entered North America in 1658 when forebears named 'Brasseur' landed in the Virginia colony. They had emigrated from France with the Huguenots. In that same year they moved to Calvert County, Maryland and settled there for more than a hundred years Over time the spelling of the family's name changed and in 1713 it had become Brashear. In 1775 John's great grandfather, Otho Brashear emigrated from Maryland with two brothers named Brown to a site in western Pennsylvania where they founded a village they named Brownsville, site of John's birth in 1840. John's father, Basil Brown Brashear (1817–1890), was a saddlemaker who suffered episodes of illness throughout his life. John knew little about the maternal side of his family's origins. His mother, Julia Smith Brashear (1819–1910) taught school before she married 'Brown' Brashear and she continued to do so to support the family during his illnesses.

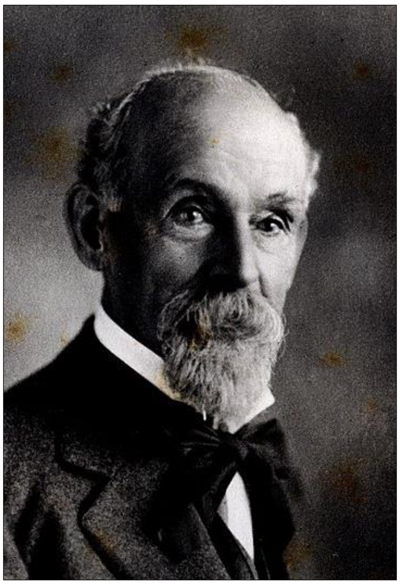

Figure 1: John A. Brashear (1840–1920) in late life (Wikimedia).

John Alfred Brashear was the eldest of seven children consisting of five boys and two girls. As a youngster he and a sister were needed to help his mother with washing and ironing all family members' clothes; in so doing he was introduced to a lifelong pattern of helping and serving others.

John's maternal grandfather, Nathaniel Smith was the hereditary and inspirational source of his lifelong passion for astronomy. Smith had been enthralled by the 1833 Leonid meteor storm and the Great Comet of 1843; he regaled his grandson with stories of those extraordinary experiences. Smith also studied astronomy using Thomas Dick's books. When John was eight years old, Smith taught him the constellations and when he learned that an itinerant who sold telescopic views of the heavens was to visit Brownsville, he paid for 9-year-old John to see the Moon and Saturn. Seventy years later, Brashear reminisced:

> … the scenery on the moon and the rings of Saturn impressed me deeply … the entrancing beauty of that first sight has never been forgotten. (Scaife, 1924: 8).

However, the boy noticed that the telescopic images were distorted by what he, as an adult would learn were striae in its lenses. As impressed as he had been, he soon found himself "… dreaming dreams of the day when I should make a telescope better than …" the stargazer's. (Scaife, 1924: 12).

Nathaniel Smith was a rural polymath. Brashear recalled, that his grandfather "… was an all-around mechanic, inventor …" (Scaife, 1924: 3). John attributed his own success in mechanical work and the use of tools to Smith's teachings; as a teen he assisted Smith in making an electric engine, a Morse telegraph instrument, a gyroscope, and an operational daguerreotype apparatus.

After John's early unsatisfactory experiences as a preacher, a printer and salesman, John's father determined his 16-year old son's career by apprenticing him as a pattern-maker in an engine factory which supplied local companies building steamboats. The teenager flourished in this work and his enthusiasm was noticed by the master mechanics; Brashear said that they "… were kind to me and I had every opportunity given me to do high-class work." (Scaife, 1924: 14). His hard work ethic was appreciated by the works' owners; it was acknowledged by preferential treatment like assisting management on paydays and being taught mechanical drawing. They also showed their partiality when,

> … later on in my apprenticeship, I was frequently called on to assist in putting the completed engines on the boats for which they were made. (Scaife, 1924: 14).

This task required physical endurance and skillful use of tools as well; the exercise of these personal qualities were to become hallmarks of Brashear's mechanical career.

Brashear completed his apprenticeship in 1859 at age 19. He was employed for the next two years building engines for Louisville, Kentucky's water works. Then he returned to Brownsville at the declaration of the Civil War in 1861. He spent the war years as a steel mill mechanic and ultimately was placed in charge of the mill's machinery.

While serving as his church's choir leader, he met the church's young Sunday school teacher, Phoebe Stewart (1843–1910) and they married in 1862. Although the couple was devoted to each other they were childless. Undeterred, they adopted a girl, Effie, and later a boy, Harry. Harry died in his teens, but Effie lived to marry James B. McDowell (1860–1923) in 1880. McDowell was a glass factory apprentice who later became Brashear's employee (Scaife, 1924) in the John A. Brashear Company and also the firm's master optician (Plaskett, 1924).

When the Brownsville steel mill suffered a work stoppage in 1867, John found a millwright's position in South Pittsburgh and the young couple moved there. Four years later, Brashear was able to turn a calamity for his employer into an opportunity for advancement. A devastating fire in December 1871 destroyed large portions of the mill and ruined its antiquated machinery. He was asked to rebuild the mill with new machinery and accomplished the task by May 1872. When work was completed the factory ran "… with not a hitch in the new engines, boilers, mills, shears, etc." (Scaife, 1924: 26). He was rewarded with a pay raise and with what became typical of Brashear's relationships with industrialists, he found that "… they took me into their confidence in many matters, and I was a welcome visitor in their homes." (Scaife, 1924: 25). Brashear consistently showed allegiance to employers' interests and as a result he earned their gratitude and their patronage which enabled him to transcend his working class origins.

That $300 pay raise in 1872 provided enough to allow the couple to build their first house in South Side, Pittsburgh. Soon after moving in, they decided "… to build a little shop and commence the construction of a telescope …" (Scaife, 1924: 31). They ordered optical glass in 1872, but Brashear admitted that "I was absolutely ignorant of the various processes used in lens-making…"; however, by trial and error, he learned to cut the glass squares into circles and to

> … roughly compute the curves, although I knew nothing about a study of the index of refraction or dispersion of the glass. (Scaife, 1924: 33).

When their first lens was completed in 1875, the Brashears' 13-cm doublet was "… barely corrected …" in spherical aberration (Scaife, 1924: 34); but it allowed a view of Saturn that Brashear declared to be better than the view of Saturn in the itinerant astronomer's telescope (ibid.). He had achieved the goal he had set years before, to make a better telescope. Nevertheless, in 1876 Brashear asked Samuel Pierpont Langley (1834–1906), Director of nearby Allegheny Observatory, to inspect the lens and give advice to improve his work. Langley was impressed with the Brashears' first effort and loaned John a copy of Henry Draper's (1837–1882) book about making a silver-on-glass reflector telescope.

The Brashears' next effort, in 1877 was to grind a 30-cm mirror using techniques John had learned after he devoured the instructions in Draper's book (Scaife, 1924). John labored on the mirror after a long work day, sometimes after two days in a row, at the steel mill. But with Phoebe as his partner in optical work he made steady progress; he acknowledged, "… it could not have been done without the deep and abiding interest of my wife." (Scaife, 1924: 47). In one crucial event, it was her encouragement and rough grinding of a second 30-cm disk that rescued John from depression when the original mirror cracked. The second mirror was a success and its results in a star test were so good that Langley, Frank Washington Very (1852–1927) and George Ellery Hale (1868–1938) were able to use it in their research projects.

Heartened by their success, Brashear placed an advertisement in *Scientific American* magazine offering silvered mirrors, eyepieces and zenith diagonals for purchase by amateurs. It was greeted by hundreds of requests (Scaife, 1924). However John's routine of evening optical work after mill labor ultimately exhausted him. In 1881 he collapsed and a physician diagnosed him with a "… nervous breakdown from overwork." (Scaife, 1924: 66). His health crisis precipitated a family conference about John leaving the mill to pursue private business. Effie and her husband James McDowell agreed to pool financial resources with John and Phoebe to begin an optical business venture; thus the John A. Brashear Company was born.

In July 1881 Langley introduced Brashear to William Thaw, Sr. (1818–1889) a philanthropist who had been impressed by Samuel Langley's reports about the quality of Brashear's work. After inspecting his small workshop and home and meeting Phoebe, Thaw asked Brashear to write a proposal for a larger workshop with necessary machinery. Thaw paid all costs, equal to 76,000 USD in 2018, for the new factory and their remaining house debt without requiring any repayment. By December 1881 machinery was installed in the new shop and Brashear added McDowell and George Klages, a mechanic, to the factory's staff. By 1885, Brashear's staff of five had more contracts than they could fill and Brashear faced a predicament of how to expand his factory to fill them. Once again Thaw furnished the money and land for a two-story facility at no cost to Brashear. Thaw explained his philanthropic motivation as "… my appropriations to your enterprises are primarily contributions to original research in science." (Scaife, 1924: 93).

By the mid-1880s, James McDowell was responsible for figuring the larger objective lenses and mirrors the firm fabricated under Brashear's general supervision (Plaskett, 1924). Orders for optical products began to increase from scientists. The optical physicist Charles S. Hastings (1848–1932) had asked McDowell to polish prism surfaces to exacting tolerances. The results were so good that Hastings brought the company to the attention of Henry A. Rowland (1848–1901), physicist inventor of a diffraction grating ruling machine. McDowell was able to polish a 1/5th light wave speculum surface on metal plates that Rowland used in his gratings. Impressed, Rowland offered the Brashear firm a "… business arrangement for supplying these gratings to scientists …" that continued for decades. Brashear wrote that "… several thousand of these plates were made at our shop." (Scaife, 1924: 75–76).

In 1887, Brashear was proud to announce that Charles Hastings

> … proposed to join forces with us and calculate the curves of any objectives for which we might receive orders … we readily accepted his proposition … to his masterly knowledge of mathematical optics … is due the successful making of perhaps half a hundred of the larger telescope objectives. (Scaife, 1924: 85–86).

Given that Hastings joined the Brashear Company in 1887, it can be assumed that he designed the 46-cm lens that is the topic of this paper. It was fabricated in 1893.

Brashear's social relationships with Pittsburgh philanthropists were crucial to the establishment of a Pittsburgh astronomical institution. In 1894 Brashear was elected Chairman of the Allegheny Observatory Committee of what is now the University of Pittsburgh. He led the Committee in fundraising, but by 1905 it had not raised enough money to complete a new observatory. Brashear visited his friend Henry Clay Frick (1849–1919), Chairman of Carnegie Steel

Company, who agreed to pay one-half of the observatory's remaining costs if Brashear could raise the other half by 15 October 1905. Brashear met the deadline and the observatory was completed in 1912 in time to be dedicated and presented to the University during an August meeting of the American Astronomical Society's predecessor organization. Frank Schlesinger (1871–1943), Director of the Allegheny Observatory from 1905 until 1920, summarized Brashear's importance to the Pittsburgh community:

> I have never seen elsewhere or at any other time the parallel of Brashear's part in the life of Pittsburgh during the past 15 years. He enjoyed the confidence of men of every stamp. He was the clearing house for all kinds of projects: charitable, educational, scientific, literary, and musical. (Schlesinger, 1920: 377).

Brashear continued in like fashion for the remainder of his life. However, in what might have been his final major optical work, Brashear performed the rough grinding and preliminary polishing of the 1.83-m Dominion Observatory mirror from 1914 to 1915 (Plaskett, 1924).

John Brashear died on 8 April 1920, ten years after his wife, Phoebe.

2.2 James B. McDowell

McDowell was born in County Down, Ireland on 2 December 1860. At age seven, his mother brought him and his sisters to the United States of America where they settled on the South Side of Pittsburgh. He married Effie, John and Phoebe Brashear's adopted daughter, on 25 March 1880. In addition to regular work with a local glass-maker, he spent some evenings working in his father-in-law's small optical workshop. He soon developed skill (Scaife, 1924) figuring glass into lenses and mirrors for astronomical telescopes, and he joined the Brashear Company in 1882. McDowell accepted more of the optical work when John Brashear became increasingly engaged in public speaking and civic and educational projects in the Pittsburgh area:

> Probably only a few of the many customers of the Brashear Co. realized that the beautiful quality of their optical instruments was due to the skill, not of the head of the firm but of his son-in-law and partner. (Plaskett, 1924: 186).

Specifically on that issue, Plaskett (1924: 187) reported,

> … the only other large ... objective figured by Mr. McDowell of which I have any special knowledge was an 18-inch [46-cm] used for a time by Percival Lowell …

Plaskett noted (1924: 187) that "Mc Dowell was justly proud of the quality of this objective …"

McDowell was credited with taking great care in fashioning the Brashear Company's lenses, mirrors and optical components and he did not stint time and expense if they were needed to create quality optics. McDowell's death on 28 November 1923 was attributed to too many prolonged work sessions requiring intense concentration for delicate work on large glass surfaces. At the time of his death he had recently completed work on a 66-cm objective for Yale University and was in the final stages of polishing a 69-cm lens for the University of Michigan. McDowell's largest project was the 1.83-m mirror for Dominion Observatory at Victoria, British Columbia completed in 1918 (Plaskett, 1924).

2.3 Charles Sheldon Hastings

Charles Hastings was born at Clinton, New York, USA, on 27 November 1848. Several paternal forebears were physicians, as was his father. When Charles was six years old the family moved to Hartford, Connecticut where he attended public schools. He earned a Bachelor's degree and later a Doctorate in June 1873 from Yale University's Sheffield Scientific School. He pursued postgraduate work in Germany where he studied with H.L.F. von Helmholtz and attended G.R. Kirchhoff's lectures on optics.

In 1876 Hastings was invited to join the faculty of Johns Hopkins University where he rose to the rank of Associate Professor of Physics in 1883. After a 20,000 km trip to observe a solar eclipse in 1883, he accepted a new position, Professor of Physics, at the Sheffield School (Uhler, 1938). He remained there until he retired in 1915 (Schlesinger, 1932).

At John Brashear's invitation in 1887, Hastings joined the Brashear Company as a consulting optical designer. That began what Uhler (1938: 277) termed the 'Brashear-Hastings-McDowell Association'. Schlesinger recalled (1932: 151) that "… these three men remained associates until the death of Brashear in 1920 and that of McDowell in 1923." During their work together, Hastings and McDowell became good friends (see Figure 2) and Plaskett (1924: 192) recalled hearing McDowell speak with "… enthusiasm about the optical … ability and the personal qualities of his great friend."

Hastings was co-author of *A Text Book of General Physics for the Use of Colleges and Scientific Schools* (Hastings and Beach, 1898) and sole author of *New Methods in Geometrical Optics with Special Reference to the Design of Centered Optical Systems* (Hastings, 1927). The latter book

> … was essentially a compilation of results which its author had accumulated during his life-long experience as consultant and theor-

ist for the John A. Brashear Optical Co. (Uhler, 1938: 282).

Hastings was elected to the National Academy of Science in 1889. He also belonged to the American Association for the Advancement of Science. He married in 1878; the couple had one daughter who married and had four children, three girls and a boy. Hastings died 31 January 1932 in Greenwich, Connecticut.

3 THE BRASHEAR COMPANY'S 46-cm OBJECTIVE

Manufacturers of locomotives and cannons, fine art painters, and makers of scientific apparatus all looked forward to displaying their best work at the World's Columbian Exposition which welcomed the public from 1 May to 30 October 1893 in Chicago. Forty-six nations publicized their contributions to the world's fund of knowledge and demonstrated the best features of their cultures. The Exposition was an exciting opportunity to proclaim American prowess in telescope manufacture. One large telescope mounting that was displayed would soon point the Yerkes Observatory's 1.02-m refractor to any point above its Wisconsin horizon and follow celestial objects flawlessly. The Exposition was a golden opportunity that John Brashear (1892) did not want to miss; he wanted to show the world an example of American optical excellence that his factory could produce.

Brashear's preparations to produce a masterpiece probably began in early 1892 when it is considered that the completed achromat would have to be display-ready and shipped to Chicago by 1 May 1893. Brashear ordered a set of 46-cm diameter crown and flint glass blanks from the world's most skillful glass manufacturer, Mantois of Paris (*Report of Committee on Awards of the World's Columbian Commission,* 1901). No historical information was available about the blanks' cost but one estimate (Bart Fried, pers. comm., 2019) was 2,500 USD in 1892, the equivalent of 71,000 USD in 2018.

No specific details about the optical properties of the crown and flint blanks or the firm's fabrication methods exist, beyond the generalities in the *Report*:

> The constants of the various wave lengths entering into the [design] problem were determined with very great accuracy, and the curves were computed from these constants so as to eliminate spherical aberration and give the very best possible color correction to the objective. Fortunately the density of the glass was very nearly equal throughout, so that a spherical figure to each surface was produced by [Brashear's] methods of polishing and 'figuring' and, as a consequence, the objective came out exactly as it was computed. (*Report*, 1901: 941–942).

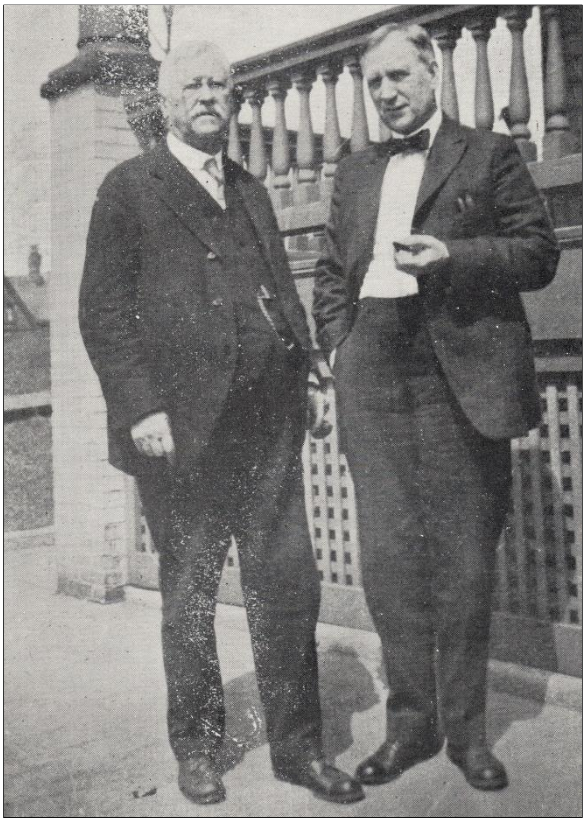

Figure 2: Charles S. Hastings (on left) and James B. McDowell circa 1920 (after Plaskett, 1924: Plate IV).

It is clearer from the fore-going biographical sketches that Charles Hastings was the lenses' designer and James McDowell was the principal optician responsible for completing the achromat. Assuming Hastings was the lens' designer, he likely used a refractometer and methods he described in a paper he wrote "… for the purpose of discussing the theory of the astronomical objective." (Hastings, 1878: 275).

The Brashear opticians' practice was to test an achromat's quality by examining the image the lens produced of an actual star. Such tests were conducted at night outside the factory, using a tube assembly mounted on a large test stand as shown in Figure 3.

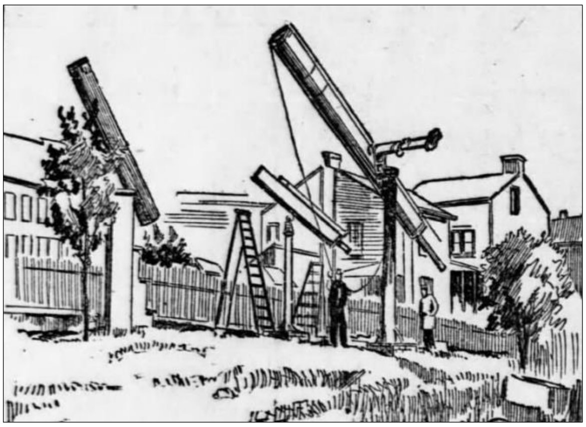

Figure 3: Objective lens test stands outside the Brashear shop in 1891 (after Stofeil, 1891).

Figure 4: Brashear's 46-cm objective before installation in the restored New Zealand telescope. (courtesy: Adrian Ashford Collection).

Figure 4 shows the assembled finished achromat. It had an 8-m focal length (Brashear, 1894), resulting in an f/17.4 focal ratio. When it was mounted in a steel tube and on a stable mounting it proved to be a very capable performer. Charles L. Doolittle (1843–1919), the Flower Observatory's second Director, reported that

> The Equatorial has been employed in a series of observations of double stars. About 500 such measurements have been obtained. This work furnishes one of the severest tests of optical performance which can be applied. The result has been highly satisfactory though occasions have been somewhat rare when atmospheric conditions allowed the instrument to exhibit its full power. (Doolittle 1897: 144).

This objective has been used in telescopes at two observatories and at the time of writing, in July 2019, it has just begun a third use. The first telescope was one made by Alvan Clark and Sons and was used by Percival Lowell and his assistants from 1894 to 1895. The objective's second use, by the Flower Observatory staff, from 1896 to 1954, was in a tube and on a mounting manufactured by Warner and Swasey. The objective lens' third and present avatar is in the Warner and Swasey telescope's tube and mounting which has been modified for use in New Zealand.

In order to place the 46-cm achromat in context among its peers, two tables have been compiled; one to illustrate how its diameter ranked among the epoch's observatory instruments and the second table to show where it stood in the Brashear Company's history. Table 1 compares the Brashear lens to other objectives of the late nineteenth century. Inspection of the table reveals that larger objectives were fabricated by several other optical firms years before the Brashear Company produced its 46-cm lens. Listed in Table 2 are large objective lenses and mirrors the Brashear Company fabricated after 1888. Inspection of that list discloses that the 46-cm achromat was superseded in diameter by nine more optics made after it. However, production of the 46-cm lens marked the Brashear Company's entrance into the observatory-class objective market.

4 LOWELL OBSERVATORY AND THE 46-cm BRASHEAR/CLARK TELESCOPE

4.1 Introduction

American astronomer William Henry Pickering (1858–1938; Figure 5) had disregarded his older brother Edward's orders. Edward Charles Pickering (1846–1919) was the determined Director of Harvard College Observatory (HCO). Edward's goal was to pursue spectrographic in-

Table 1: Observatory refractors in operation by the end of 1893, and having objectives at least as large as the Brashear Company's 46-cm (after Hollis, 1898; 1914).

Lens Diameter (cm)	Optical Company	Observatory	Location	Telescope Manufacturer	Date of Manufacture
91	Clark	Lick	Mt Hamilton, California, USA	Warner and Swasey	1888
83	Henry	Meudon	Paris, France	Gauthier	1891
77	Henry	Nice	Nice, France	Gautier	1886
76	Clark	Pulkovo	St. Petersburg, Russia	Repsold	1885
69	Grubb	Vienna	Vienna, Austria	Grubb	1878
66	Clark	U.S. Naval	Washington DC, USA	Warner and Swasey	1871
66	Clark	McCormick	Charlottesville, Virginia, USA	Clark	1883
63	Cook	Newall	Gateshead, England	Cooke	1862
60	Henry Bros.	Meudon	Paris, France	Gautier	1889
58	Clark	Halstead	Princeton, New Jersey, USA	Clark	1881
51	Merz	Manila	Manila, Philippines	Merz	1892
49	Merz	Strasbourg	Strasbourg, France	Repsold	1880
47	Clark	Dearborn	Evanston, Illinois, USA	Clark	1863
46	Henry	La Plata	La Plata, Argentina	Gautier	1890
46	Brashear	Lowell	Flagstaff, Arizona, USA	Clark	1893

Table 2: Large optics manufactured by the John A. Brashear Company, 1888–1925 (after Plaskett, 1924: 188; Scaife, 1924: 245).

Year	Aperture (cm)	Telescope	Observatory	Location
1893	46	Refractor	Lowell Observatory and later Flower Observatory	Flagstaff, Arizona, USA and Upper Darby, Pennsylvania, USA
1902	93	Reflector	Lick Observatory Southern Station	Santiago, Chile
1905	76	Reflector	Allegheny Observatory	Pittsburgh, Pennsylvania, USA
1907	95	parabolic mirror	Detroit Observatory	Ann Arbor, Michigan, USA
1911	61	Objective	Swarthmore College	Swarthmore, Pennsylvania, USA
1914	51	Refractor	Chabot Observatory	Oakland, California, USA
1914	76	Thaw Refractor	Allegheny Observatory	Pittsburgh, Pennsylvania, USA
1918	1.83	Reflector	Dominion Astrophysical Observatory	Victoria, British Columbia, Canada
1924	69	Objective	Lamont-Hussey Observatory	Bloemfontein, South Africa
1925	66	Objective	Yale University's Southern Station	Johannesburg, South Africa

vestigations of the stars. Edward had sent William to Arequipa, Peru, in 1890 because most of the stars seen from Peru were below New England's southern horizon and they could not be monitored from Cambridge, Massachusetts, home of the HCO. William's assignment was to photograph the spectra of stars in the southern sky. If William had followed his brother's dictates, HCO would have had the entire southern sky's stellar spectra as well as the northern ones that HCO had captured from Cambridge. Instead of honoring his assignment, William had become captivated by an Italian astronomer's startling claims of straight line markings on the surface of Mars. Giovanni Schiaparelli (1835–1910) observed the lines using a relatively small refractor, one with an objective 22-cm in diameter. In Peru, William had the use of a 33-cm refractor that Edward had sent there. William was irresistibly drawn to follow up Schiaparelli's reports, especially since the Italian's eyesight was reputed to be failing and he could no longer proceed with his work. In addition, William had a larger refractor than Schiaparelli's and so he expected to see the lines even more clearly. In fact, in the clear Peruvian mountain air, William found dark markings which he interpreted to be hundred-kilometers-wide 'lakes.' By 1893, Edward grew tired of his brother's misuse of the Arequipa expedition's funds and he directed William to return to Cambridge (Strauss, 1994). We can easily imagine William's chagrin at having to abandon the pursuit of the alleged Martian features.

When William returned to Cambridge he began to explore funding for a new telescope and observatory in order to continue his Martian investigations. In fact, he had contacted John Brashear in November and December of 1893 saying that he planned to buy the 46-cm lens with a loan from Andrew Carnegie, the steel magnate. William was so intent on acquiring that lens that his first letter to Brashear was dated two days following the close of the Columbian Exposition (Strauss 1994: 45, 46, fn21). And if the Pittsburg magnate failed him, William had

Figure 5: William Henry Pickering (https://en.wikipedia.org/wiki/William_Henry_Pickering#/media/File:Pickering_William_Henry_02598v.jpg).

more prospects. His family was well connected with wealthy Bostonians and he was in the midst of exploring their willingness to help him when he began conversations with Percival Lowell (1855–1916: Figure 6) in January 1894. By late January Lowell and Pickering had agreed upon an observatory project that was to be paid for by Lowell's fortune and constructed with the benefit of Pickering's experience in setting up a large observatory structure and telescope at Arequipa (Martz, 1938; Strauss, 1994).

Figure 6: Percival Lawrence Lowell (https://en.wikipedia.org/wiki/Percival_Lowell#/media/File:Percival_Lowell_1900s2.jpg).

4.2 Lowell, Douglass, Pickering and Mars in 1894

Lowell was a member of a wealthy Boston family that had made a fortune by milling cotton; in addition Lowell was a canny investor and had accumulated his own wealth (Hoyt, 1996). From 1883 to 1893, he had made several trips to Japan and became enthralled with Japan's culture and language which he quickly mastered. To nineteenth century Americans, Japan was an exotic, little-known country that had only since 1854 admitted Americans. The country's resistance to American curiosity made it irresistible to Lowell who insisted on mastering its culture and describing it to his fellow countrymen in a series of four books (ibid.). It may have been Lowell's curiosity about exotic and distant foreign places that years later would make the planet Mars inescapably intriguing. For, Lowell, exploring the red planet would be a greater thrill than dwelling in Japan had been.

Figure 7: Andrew Ellicott Douglass counting tree-rings (https://en.wikipedia.org/wiki/A._E._Douglass#/media/File:A._E._Douglass.jpg).

The groundwork for collaboration on Martian observation between Lowell and William Pickering had actually been developing for a few years. Their interest in Mars dated back to 1890 when they had first discussed Martian research. In addition, Lowell showed an enduring interest in William's Martian sketches; in 1892 he asked Edward Pickering to share William's Arequipa drawings (Strauss, 1994). So, by 1894 Lowell and Pickering were predisposed to consider each other fellow enthusiasts and logical partners to conduct a Martian investigation.

By January 1894 anyone who wanted to build a new observatory dedicated to investigating Mars faced a time crunch: the Earth would be nearest to Mars, at its opposition in October. Numerous logistical and construction problems needed to be overcome in a short period of time. However the team was primed to act quickly; Lowell already had a research program formulated and Pickering may have been the only man in the United States with recent experience in establishing an astronomical outpost on the frontier. Even so, the men needed to act decisively and quickly.

On 24 January 1894, Pickering informed Brashear that Lowell would soon be writing him for the purpose of leasing the 46-cm objective lens (*Annals of the Lowell Observatory, Volume 1*, 1898; Strauss, 1994). While arrangements between the two men proceeded, Lowell sent Andrew E. Douglass (1867–1962; Figure 7), a HCO associate of William Pickering's and a veteran of Arequipa too, to perform a survey of geographical sites for the observatory. Based upon Douglass' findings, Lowell decided on 16 April that his observatory should be built at Flagstaff, Arizona Territory. A week later, on 23 April, Douglass had ground broken just west of Flagstaff to begin building the observatory (Putnam, 1994).

Meanwhile, in the East Brashear and Lowell finalized their agreement about the 46-cm lens for Lowell's proposed telescope. Lowell Observatory's Archives contain a typewritten lease statement written by Brashear and addressed to Lowell. The lease's terms stated that it was to last from 1 May 1894 to 1 May 1895, for which, Lowell would pay 500USD (15,000 in 2018 USD) in advance. In the event that another customer wanted to buy Brashear's objective while Lowell used it, Brashear promised Lowell the prior right to buy it for 6,000 USD (181,000 USD in 2018) (Brashear, 1894a). Lowell (1894) sent Brashear a check for $500 on 3 May 1894.

Back at Flagstaff, Douglass now the observatory's construction supervisor, prodded work to proceed at breakneck speed and it is no surprise he later wrote: "The time occupied in building the dome and in mounting the 18-inch [46-cm] telescope was unusually short." (Douglass, 1895: 395). William Pickering arrived with the objective lens on 20 May 1894 (Putnam, 1994) only seventeen days after Lowell's money reached Brashear. When the lens arrived, waiting for it was a steel tube and equatorial mounting made by Alvan Clark and Sons.

Lowell Observatory Archivist Lauren Amundson opined (pers. comm., 2017) that Douglass had engaged two brothers, local mechanical jacks-of-all-trades, named Godfrey and Stanley Sykes, to attach the lens to the tube. As shown in Figure 8, the Clark mounting held a second refractor too, one with a 30-cm Clark objective; so the 46-cm telescope and the smaller one were both poised to probe Mars' mysterious surface features (Putnam, 1994). Lowell wrote

(1898) in the observatory's *Annals* that formal Martian observations by Douglass and Pickering began on 22 May 1894; Lowell did not leave for Flagstaff until 28 May (Putnam, 1994). May's observations were made with the 30-cm telescope; 'first light' with the 46-cm telescope was reserved for Lowell who did not arrive in Flagstaff until 1 June 1894 (Pickering, 1898).

Lowell believed that visual inspection of Mars was all that he needed to confirm his hypothesis that life existed there; his records reveal no use of photographic or spectroscopic observations. Instead, Lowell paid particular attention to the telescope's eyepieces. These were crucial tools which permitted him to capitalize on all the resolving power and light grasp of the Brashear objective. And so, Brashear had made special efforts to optimize Lowell's observational experience. One example was a reshaped eyepiece barrel to eliminate frustration when changing eyepieces. Without it an image that was sharp in one eyepiece would be fuzzy in the next one and observers wasted time refocusing the telescope. To eliminate this aggravation, Lowell asked (1894a) Brashear to shape each of the eyepieces' metal barrels, i.e to 'parfocalize' them.

Lowell (ibid.) also had asked for a broad range of eyepieces and Brashear provided them; the list of magnifications was 112, 320, 420, 440, 617, 862, 1305 and 3522 times. In addition, he asked for two more high-powered eyepieces that yielded magnifications of 673 and 1114. Lowell (1898) also agreed to Brashear's recommendation for an eyepiece that gave a magnification of 158 times. Despite all those options, in practice he, Douglass and Pickering discovered that they were typically using 440 and 617 power when they examined Mars. Lowell (1898: 5) found that using "… a thin piece of ochre glass placed in front of the eyepiece as a rule [was] conducive to detection of detail." Douglass' preference was not to use a colored glass filter, and Pickering used both methods when he believed the conditions waranted (ibid.).

The three astronomers recorded their visual impressions by sketching Mars' features. Before the advent of sensitive photographic emulsions drawings were the rule for this purpose. A drawing's fidelity to reality is highly dependent on a number of idiosyncratic factors, e.g. artistic ability, the viewer's eyesight, sensitivity to color, visual defects like astigmatism, expectations of what would be seen and perhaps other physiological and psychological idiosyncrasies. The human eye-brain-hand system was prone to errors, yet in the late nineteenth century drawing was widely considered the best means available to record what an eyewitness saw. Lowell (1898b: 79) defended validity of his team's drawings by arguing that,

> For the substantiation of changes on the planet's surface, it is … of paramount importance that the drawings to be compared should all have been made by the same person at the same telescope under … nearly … the same atmospheric conditions …

In other words, Lowell believed it was possible to control observational error by insisting upon a rigid method: compare drawings made by the same observer, using the same telescope, with a similar atmosphere at two different dates; then, any changes recorded were due to changes on the planet.

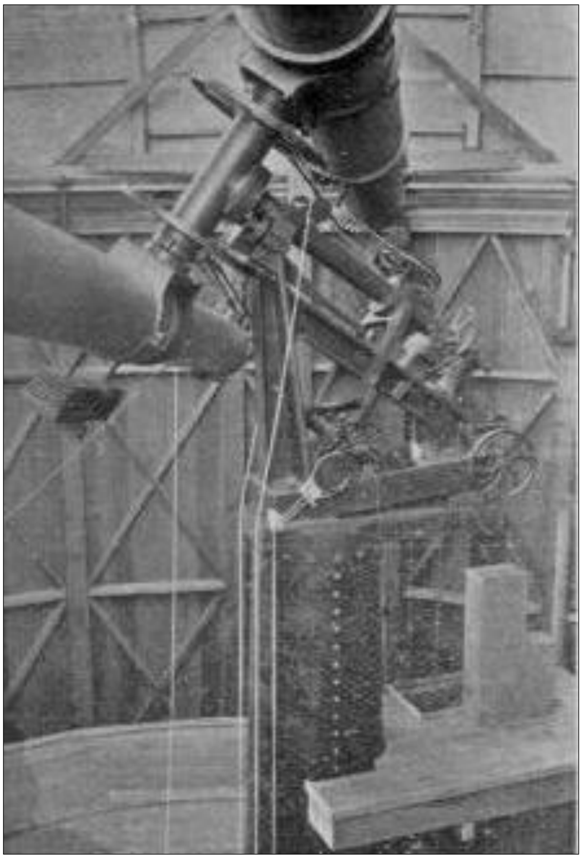

Figure 8: The 46-cm Brashear/ Alvan Clark telescope and smaller Clark together on the same mounting during Percival Lowell observations at Lowell Observatory in 1894–1895 (after Douglass, 1895: Plate XXVIII, Figure 2).

Lowell and his associates had considered using photography to record Martian appearances and the 30-cm refractor mounted in parallel to the Clark telescope was to be used for that purpose. However, Douglass (1895: 397) reported that as late as 30 January 1895, "… we have spent little time at this work." Douglass did not report why efforts were neglected. That was unfortunate because, if a clear photographic image had been obtained, it would have provided objective support for claims of straight canals that Lowell had made based upon visual observations alone.

Douglass (1895: 399) went on to report, "The original plan of observation was to follow the development of the seasons … and record them chiefly by means of drawings." He mentioned a particular Martian feature that the team hoped to see in October 1894 when Mars and Earth were closest together and when detail on Mars' surface would have been more easily seen:

> The doubling of canals on Mars has of course been a subject of special interest to us. Through October and November [1894] Mr. Lowell gave this his special attention and in November saw a number of double canals … Mr. Lowell saw them double only in the best seeing, 8 or 10 on a scale of 10 [being best], and then they appeared like railroad tracks, straight and closely parallel. (Douglass, 1895: 401).

Lowell had hoped to dispel criticisms that he had seen what he hoped to see, by pointing out that the Flagstaff sky was especially clear and tranquil and therefore his claims should be accepted as an actual state of Martian geography and were not illusory.

William Pickering was particularly interested in optical accessories that would allow him to examine Mars spectroscopically and in polarized light. He hoped those means would confirm that features on Mars' surface indicated evidence of life or even the prerequisites for it. Brashear was advised by astrophysicist James Keeler (1857–1900) to make highly refractive prisms for the spectroscope. Following that recommendation, two were made; one was "… a 60 degree prism of glass and a similar one of quartz." (Douglass, 1895: 395) These were "… mounted in a somewhat different way so as to give the highest range [of the spectrum] for the investigation of the chlorophyll band …" (Brashear, 1894b: 2–3). But despite these preparations, no use of a spectroscope was reported during the 1894–1895 season.

To exploit another observational approach, Brashear's staff made a "… polariscope of the Airy pattern, which can be placed between the eyepiece and the eye." (Douglass, 1895: 395). Its purpose was to reveal the presence of liquid water. On one occasion, 4 June 1894, Pickering found one Martian locale with "… clear traces of polarization … this would naturally be the case if it were water." However, as he continued to look for these telltale signs of water, he was less convinced that they were common (Pickering, 1894: 554–555).

Nevertheless, a persistent progression of certain Martian features convinced Lowell that there was wholesale transportation of water from the southern polar ice cap through straight canals to irrigate areas of vegetation in the northern parts of Mars. His examination of Mars from 1 June 1894 until 3 April 1895, his last observation with the Brashear objective, showed Lowell what he perceived to be a Martian Engineer-mediated sequence of events:

> When we consider this chain of changes, beginning with the melting of the south polar *snow* cap and ending with the darkening of the northern canals, we see, first that water almost certainly be the [explanation] in the matter, and secondly, that the phenomena must be due … to its indirect effects in causing vegetation to sprout (Lowell, 1898b: 84).

Ultimately, Lowell would come to believe that Martian engineers were responsible for creating canals as a means of water transport. One of Lowell's biographers wrote:

> Percival Lowell evolved his formal theory of the probable existence of intelligent life on Mars within two months after observations were begun … and after he himself had observed the planet for barely a month through the [46-cm] telescope. (Hoyt, 1996: 68).

This quote emphasizes how much Lowell's theory was due to mindset as much as due to visual observation. We know Lowell's conclusions were erroneous because we are the fortunate inheritors of 126 more years of critical spectrographic, orbiting satellite, and robotic surface rovers' observations made by many investigators who succeeded Lowell. Vanderbilt University astronomer David Weintraub (2018) has documented how measurements of water abundance, considered the *sine qua non* for life, have steadily decreased over the decades since Lowell's time. Yet, some astronomers have detected sufficient water that prompt them to believe life there may exist. Nevertheless, most aqueous assessments of Mars make it seem unlikely that any, especially intelligent, life exists on it. If those accumulated data guide our perceptions of the Martian surface, we think of it as being desolate, cold and dry; in particular, the accumulated data and its interpretation persuades us that no intelligent life can exist upon it.

Today, with the benefit of satellite imaging we know that changes in the color, shape, and positions of dark areas on Mars are due to fierce Martian winds that move its reddish sand to alternately reveal and obscure darker portions of the planet's surface. New knowledge has revamped our mindset about Mars and so even though it may look like Mars did in 1894, in our minds it is not the same planet Lowell 'saw.' Without today's accumulated knowledge, Lowell's preconceptions about water's presence led to a theory about why he saw color changes on the planet. Put another way, Lowell had projected[1] his biases onto the ambiguous features of the Martian disc.

5 FLOWER OBSERVATORY AND THE 46-cm BRASHEAR/WARNER & SWASEY TELESCOPE

5.1 Introduction

After it had served Lowell's purpose, the Brashear firm's lens was returned to it just before Lowell's lease term expired in May 1895 (Lowell, 1898a; Schindler, 2016). The lens did not languish in Pittsburgh for very long; as Brashear wrote (1896) to a friend, "The [46-cm] I loaned Lowell was sold to the University of Pennsylvania …" because the University had made plans to use it at an observatory site west of Philadelphia.

In the summer of 1895 the University of Pennsylvania began developing an observatory site at a farm bequeathed by Reese Wall Flower. It was to have an observatory built upon a campus that included a director's residence and a second building for small telescopes to be used in geodetic research (Doolittle, 1896). Warner and Swasey attached the 46-cm objective lens to a steel tube and mounted it upon a large equatorial mounting. By 12 November 1896, John Brashear and Worcester Warner had finished installing the entire 'equatorial' inside the Flower Observatory building (Brashear, 1896). Figure 9 shows the completed telescope as it appeared circa 1912. University of Pennsylvania records are unclear about the instrument's cost because it was combined with the Observatory buildings'; the total for both was 12,797 USD (Financial Statement, 1896), a sum that in 2018 was the equivalent of 395,000 USD.[2]

Six months after installation, on 12 May 1897 the Observatory was formally opened in a gala ceremony at which Simon Newcomb (1835–1909) gave an address. Newcomb was one of the foremost American astronomers and internationally respected mathematical astronomers of his day. It was a curious footnote to the Observatory's history that its first Director, Ezra Otis Kendall (1816–1899) was not present at the dedication. He died 18 months after that occasion and did not apparently play any role in the Observatory's functioning during his short tenure in the Director's post (Koch, 2010).

However other Flower Observatory staff had not waited for a formal dedication to begin using the Brashear/Warner and Swasey telescope. Eric Doolittle (1870–1920), son of the second Observatory Director, Charles Leander Doolittle (1843–1919) used the 46-cm equatorial to measure separations and angular relationships between the two components of 500 double stars before the ceremonial opening (Doolittle, 1897). The Brashear lens had been idle for only nineteen months between its last imaging of Mars in Arizona and the start of splitting double stars in Pennsylvania. The telescope's pre-dedication use began what was to be a 58-year career, from 1896 to 1954, of active astronomical research by many Flower Observatory astronomers.

The Flower Professors of Astronomy, 1896–1954, who did double duty as the Observatory's Directors, held a vastly different philosophy about astronomical science than did Percival Lowell. All of them, their Department of Astronomy colleagues, and their graduate student assistants all construed an astronomer's duty to be the methodical performance of meticulous and pre-

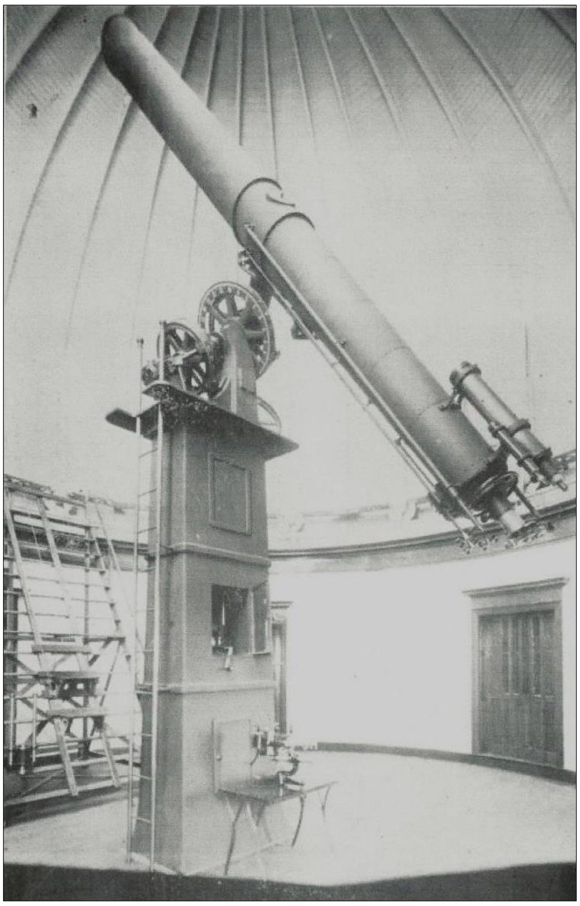

Figure 9: Flower Observatory's 46-cm Brashear/Warner and Swasey telescope ca. 1912 (after Doolittle and Doolittle, 1912: Plate following 1: x)

cise measurements and their compilation for eventual publication. During the Flower refractor's lifetime this meant recording measurements of double stars and magnitude estimates of variable stars. None of these astronomers expected that what they saw through the telescope would confirm unconventional theories about planets or stars. They did not expect to revolutionize astronomical science; they merely kept track of what they saw. 'Saw' was the appropriate verb for most of Flower's existence; the astronomers made visual studies, they did not use photography to record observations. Only a few years before the Observatory was closed

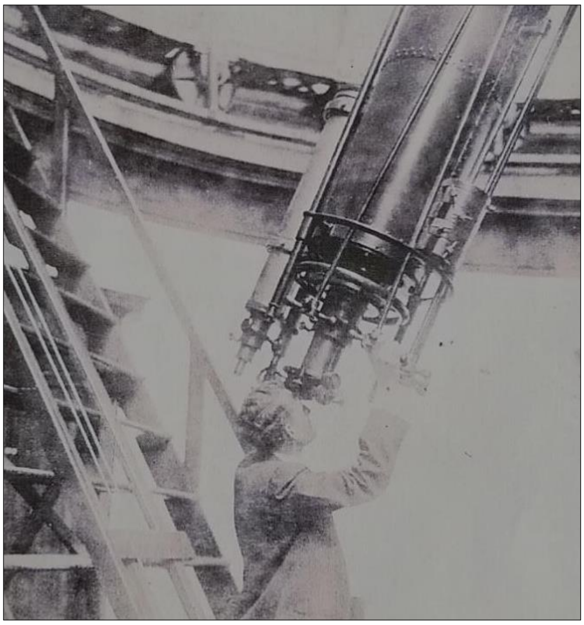

Figure 10: Professor Eric Doolittle at the filar micrometer eyepiece of the 46-cm refractor at Flower Observatory in 1914 (after Billings, 1959: 73).

did staff members develop an electronic means of measuring the brightness of stars. And only once, on its inauguration day in 1897, was the refractor used spectroscopically; on that occasion, a Brashear spectroscope was mounted on it to impress hundreds of attendees with the Sun's spectrum (Koch, 2010).

5.2 Double Star Astronomy

William Herschel (1738–1822) was one of the earliest astronomers to study double stars systematically (Tenn, 2013). In 1802, Herschel coined the term 'binary star' to designate pairs of stars that orbit each other over periods of years and were not mere line-of-sight couples. In 1803 he published a paper in which he presented observational evidence that six pairs whose positions he had measured over 25 years had actually orbited each other. His 1802 and 1803 papers, as well as two earlier ones (1782; 1785) were the earliest double star catalogs. Younger astronomers continued to follow Herschel's stellar specialty including several Flower Observatory astronomers who carried on the discipline of binary measurement and catalog publication.

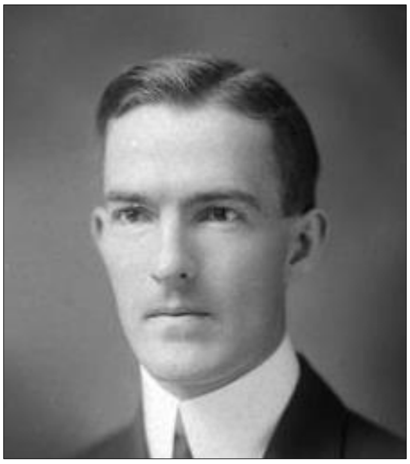

Figure 11: Charles Pollard Olivier in 1914 (https://en.wikipedia.org/wiki/Charles_Pollard_Olivier#/media/File:Charles_Pollard_Olivier.jpg).

Throughout all Flower Observatory Directors' regimes all routine monitoring of cataloged binaries was accomplished with the use of a filar micrometer. Figure 10 shows third Observatory Director Eric Doolittle as he used one. This device contains fixed and moveable wires and all are seen with the target stars in the telescope's image (Koch, 2010). The micrometer's wires were moved by turning 'screws,' small knobs that controlled them. Moving the wires allowed the astronomer to measure the separation between a double's components and the position angle of the stars.[3] The purpose of the measurements was to record where the component stars were located relative to one another. With the passage of time, changes in the stars' positions might prompt a future astronomer to recompute the orbit to see if the result confirmed an earlier computation.

A sense of what this work was like is clear from its description by Charles P. Olivier (1884–1975; Figure 11), the Observatory's fourth Director, who reported the tedious procedures he used to measure a binary star's position angle and separation:

> The writer usually makes four independent settings in position angle and four for double distance, which adds up to 12 in all. In angle, he has of late found it more accurate to place his wire *perpendicular* to the line joining the two components, rather than by trying to bisect them. (Olivier, 1937: 127).

Olivier added that one such routine was inadequate for the reliability he wanted and that "… published results depend on from two to at most four or five separate nights' work. Three is the more usual number."

One a graduate student, Raymond H. Wilson, Jr. (1911–1989) modified the Observatory's filar micrometer with a device he called an interferometer. He described this device and its benefits as,

> … an auxiliary tube fitted into the filar micrometer of the Flower Observatory [46-cm telescope]. A double slit aperture forming the interferometer was supported two feet inside the focus of the telescope. The position angle of the slits could be read from the micrometer circle. From readings of position angles of minimum fringe visibility have resulted many accurate measures in position angle and distance of 44 double stars between 0″.1 and 0″.6 in distance and down to

> magnitude 7.5 in brightness. The interferometer more than doubles the resolving power of the telescope and greatly reduces the inconvenience of poor seeing. Its defects are a waste of light and susceptibility to errors caused by atmospheric dispersion. (Wilson, 1936: 65).

Neither Wilson nor any other Flower Observatory astronomer used the modified micrometer device after Wilson completed his 1936 dissertation, but he did describe it in a longer paper some years later (Wilson, 1941).

Double star work required the steadiest and clearest air for the closest pairs to be monitored systematically. Even as early as 1897, Flower Observatory's Director complained that atmospheric conditions frequently interfered with the full effectiveness of Brashear's objective (Doolittle, 1897). Atmospheric quality steadily deteriorated as time went on because of expanding business and housing construction that encroached on the Observatory's location in Upper Darby. By 1932, Olivier complained (1932: 4) about an

> … immense increase in electrical illumination of both streets and buildings … we now suffer from being practically in the city (of Philadelphia).

Olivier explained that poor transparency and seeing conditions forced him and his staff to limit telescopic magnification to 212 times, on most occasions, and to only 423 times on the best nights. Use of such low magnifications, 5 and 9 times per cm of telescope objective, meant that component stars did not appear very far apart and errors due to eyestrain could more easily be made when using the micrometer.

However when air conditions were excelent, astronomers found the 46-cm objective performed extremely well, sometimes slightly surpassing the Dawes' Limit. For the Brashear objective, the test would be components of a double star that were 0″.25 apart. Yet in 1901, Eric Doolittle (1901: 1–2) found that

> … on nearly perfect nights … it has been found possible to clearly separate stars whose distance is little if any greater than 0″.21 or 0″.22 which is well within the theoretical separating power of a lens of (this) aperture.

Doolittle (ibid.) also reported that, the lens allowed him to make "… good measures on stars the magnitudes of which Burnham estimates as 13-14."[4]

The Brashear/Warner and Swasey telescope was kept busy monitoring, measuring and remeasuring double stars from 1 January 1897 (the earliest published report) until late 1953 or possibly early 1954. The work continued during the administrations of three Directors: Charles Doolittle (Figure 12), his son Eric, and Charles Olivier. During his Directorship, Olivier made every effort to increase his roster of staff members who monitored double stars, and during the period from September 1930 to June 1931 he reported that he had five observers who were using the 46-cm refractor. Of the years 1929 to 1932, he wrote: "… double stars have taken up 90% of the time spent on observations …" (Olivier, 1932: 4). Eric Doolittle and Olivier published the results of their staffs' night-time labors in a series of nine volumes of *University of Pennsylvania Publications* (Doolittle, 1901; 1905; 1907; 1912; 1923; and Olivier, 1932; 1939; 1949; 1957). The total number of stars Flower Observatory astronomers had monitored and measured over nearly six decades totaled 10,591.

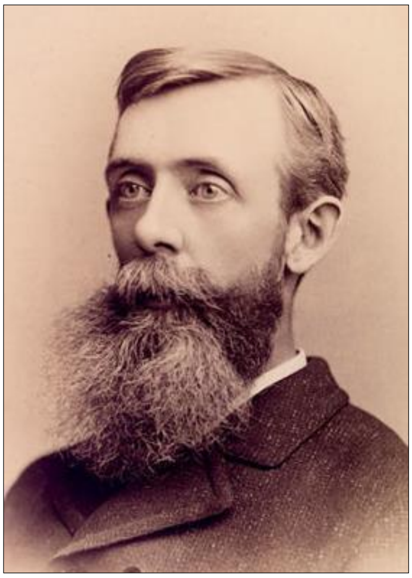

Figure 12: Charles Leander Doolittle (https://www.wikitree.com/photo/jpg/Doolittle-1368).

5.3 Photometry of Variable Stars

Soon after he became the Flower Observatory's Director in late 1928, Charles Olivier added a new research program to the Observatory's tradition of double star studies: stellar photometry.

The visual photometer used with the 46-cm objective was a wedge photometer that had been in use since the 1880s. Measurements were made by positioning the telescope so that a star shone through a wedge-shaped piece of tinted glass located at the eyepiece. The observer moved the glass so that the star shone through progressively thicker (therefore darker) zones of it and when the star disappeared, the place on the wedge where it vanished marked how bright it had been (Pickering, 1882).

Olivier was an expert in using type of photometer, and had practiced with one beginning in 1901 when he was a 17 year old Assistant to Ormond Stone, Director of the University of Virginia's observatory (Olivier, 1967). Since he was now responsible for determining the Observatory's research priorities, Olivier assigned his staff to use the Brashear/Warner and Swasey telescope and wedge photometer to monitor variable stars. Even with this new duty, double star work occupied most of the staff's observing time and it was not until 1940 that a lengthy report was made using the staff's photometric results. That monograph detailed brightness estimates for 284 variable stars and many more non-variable comparison stars in the sky regions surrounding them (see Olivier, 1940).

Until about 1947 the human retina was the only receptor that received the 46-cm lens' focused light. Earlier users of the lens, from Lowell to Olivier and his staff, all used visual means to inspect celestial objects and made judgements about them or measurements of them. Furthermore, their brains were the only data processors of the light beaming through the telescope, but that all changed in the late 1940s when William Blitzstein (1920–1999) and Israel M. Levitt (1908–2004) used a 1P21 photomultiplier tube and d.c. amplifier to make a photoelectric photometer (Levitt and Blitzstein, 1947; cf. Koch, 2010). For his dissertation, Levitt (1949) used this photoelectric system to correlate visually determined star magnitudes with photon counts. Then, the counts were used to determine magnitude fluctuations of ZZ Cassiopeiae.

5.4 Lunar and Planetary Observations During the 1940s

Late in the Observatory's history, a 'rogue' telescopic project was carried on with the Brashear lens. Walter H. Haas (1917–2015) was a Graduate Assistant to Olivier in the mid-1940s but in addition to required variable star assignments Haas found time to pursue a personal astronomical project: lunar and planetary studies.

His fascination required him to pursue observational opportunities at unusual times of day. For example, on 30 April 1944 he documented a mid-afternoon occultation of Jupiter by the Moon (Haas, 1944). Using the Flower Observatory refractor his planetary observations yielded publishable results; for instance, during WWII, he systematically monitored Jupiter during two successive apparitions (Haas, 1945; 1946). Haas' observations were the last recorded ones, since Lowell used the 46-cm Brashear lens for intensive planetary studies.

Haas' advocacy for and pursuit of Solar System observations ultimately found expression in his establishment of the Association of Lunar and Planetary Observers in 1947.

5.5 The End of Observational Astronomy at Flower Observatory

It could be said that the Brashear lens had its 'last light' at Pennsylvania in late 1953 when Observatory staff ended their study of variable star EZ Aquilae (Olivier, 1961).

The Observatory's closure had been coming for at least 30 years. There were two reasons: deteriorating sky quality at the observatory and the University of Pennsylvania's desire to sell the Observatory campus for cash. Flower Observatory astronomer-historian Robert Koch reported (2010: 83–85) that the University of Pennsylvania was offered money for its Observatory property beginning about 1922, and in 1949 it was offered a sum that today would equal 811,000 USD. Eventually a decision was made "… to sell the property and plan for a new station …" The University sold the property on 12 August 1954 after the telescope had been disassembled. The Brashear objective went into storage on 30 June 1954.

6 TRANSFER OF THE 46-cm BRASHEAR/ WARNER & SWASEY TELESCOPE TO NEW ZEALAND

6.1 Introduction

The separated Warner and Swasey telescope and Brashear objective have had a precarious history since mid-1954. However their misadventures have had a happy ending when the two were reunited and mounted in April 2019 and the complete telescope was opened to the public on 1 July at a rural dark sky site in New Zealand.

Robert Koch wrote (2010: 116) that as early as "… 1951 and before 1955 it had been decided that the Flower refractor would not be erected at [a] new (Pennsylvania) site." A University of Pennsylvania News Bureau release (1964) was frank about why this decision was made: funds were not available for the expensive task of renovating the 46-cm telescope, constructing a building and making a new dome. As a result, the instrument was placed in storage at the New Bolton Center, the University's veterinary medical unit at Kennett Square, Pennsylvania (Wood, 1963). Lack of money to resume its scientific work was to be the telescope's persistent nemesis for the next 65 years.

In December 1962 the fifth Flower Observatory Director, Frank Bradshaw Wood (1915–1997) made arrangements with New Zealand's University of Canterbury to establish a jointly operated Southern Hemisphere observatory (ibid.). In anticipation of relocating the 46-cm Brashear/ Warner and Swasey telescope to New Zealand, Frank Maine Bateson (1910–2007), a veteran New Zealand variable star observer and University of Pennsylvania Research Associate spent three years making careful night-sky site surveys throughout New Zealand (see Bateson, 1964). As a result, in June 1963 1,067-m high Mount John, located in an isolated region of the South Island of New Zealand, was selected as the site for what would become Mount John University Observatory (Wood, 1963).

Because the refractor was destined for New Zealand, funding was found for its complete renovation and this was entrusted to the Wilmot Fleming Engineering Company. By September 1963 the telescope was refurbished and the mounting's drive mechanism had been reconfigured for operation in the southern hemisphere (Size, 1963). It was then loaded aboard a merchant ship and by October 1963 it had arrived in New Zealand (Wood, 1963).

However progress stopped following delivery. Ominously, a University of Pennsylvania news release (1965) reported: "UPenn has sent a (46-cm) refractor telescope to the observatory, where it is being stored until a structure can be built to house it …" Lack of funding was again a problem; and in particular, construction of a new observatory was an expensive proposition. The telescope remained in shipping crates at Mount John Observatory while the Brashear objective was stored at the University of Canterbury's campus in Christchurch. That state of affairs lasted until 1990 when the University offered Christchurch's Yaldhurst Museum of Transport and Science possession of the telescope (but not ownership) if it would provide an observatory for the telescope. Contrary to everyone's hopes, expense doomed this plan too. The telescope had legally become the property of the University of Canterbury, but since there was no new prospect for its resurrection, it remained in storage at Yaldhurst for the ensuing 25 years (Ashford, 2016).

6.2 A New Home under Dark Starry Skies

In 2015 an astronomical tourism business, Earth and Sky operating out of Lake Tekapo at the foot of Mount John offered the telescope a new lease on life. Earth and Sky proposed that the telescope should be the main attraction, among other astronomical and local museum displays at an Astronomy Village Centre on the shore of the lake. The telescope's University of Canterbury curator, Professor John Hearnshaw (pers. comm., 2017) arranged for Earth and Sky to acquire it from the University and in September 2015 the stored telescope was trucked from Yaldhurst to Fairlie, a town 30 minutes away from the Lake. There it was taken to an engineering workshop to once again be restored to operating and display condition.

Volunteer technician Ade Ashford (2016) had first-hand experience with Warner and Swasey's craftsmanship when he helped with the renewal work. Ashford assisted in removing the telescope tube's protective paint applied before shipment in 1963. He praised the luster of the telescope's massive brass focusing mechanism as well as the beauty of a mahogany-and-brass handrail attached to the instrument. Warner and Swasey did not merely manufacture a telescope; they sculpted parts of it. Figure 13 shows the massive Warner and Swasey equatorial mounting as it appeared after renovation.

The Royal Astronomical Society of New Zealand's 20 July 2019 *e-Newsletter* reprinted an article from *The Timaru Herald* newspaper that informed readers of a long-awaited event. Dark Sky Project (formerly Earth and Sky) and a Ngai Tahu Maori tourism organization had combined resources to make it possible for the telescope's remounting and operation in an observatory. The two organizations had funded a 1140-m^2 building with "… a dome [that] houses the 125-year-old [*sic*] Brashear Telescope which stands up to nine metres …" high. The building and dome are sited on the shore of Lake Tekapo that is located in the Aoraki/Mt. Cook Mackenzie International Dark Sky Reserve, which was so designated by the International Dark Sky Association. The complex was opened to the public on 1 July 2019 after being blessed by local Maori councils and presented to the public by Dame Patsy Reddy, Governor-General of New Zealand.

The *Timaru Herald* article included an image of the renovated Brashear New Zealand telescope. Tourists who visit it will see an esthetically impressive instrument and will have a treat in store for them when they look through Lake Tekapo's refurbished refractor!

7 NOTES

1. 'Projected' in this article is defined as a non-pathological psychological phenomenon in which an observer confronted with a novel, confusing or ambiguous image labels it based upon his or her own life experiences. Seeing Mars telescopically through a turbulent atmosphere is such an uncertain visual experience. A cogent example of this type of projection is G.V. Schiaparelli's response to glimpsing straight lines between darker Martian areas that earlier observers had labeled as 'seas.' His undergraduate training had been as a hydraulic engineer and he called the lines 'canali,' Italian for 'channels' or 'canals' which is logical for a man whose occupational task it would have been to direct water from one location to another. Whenever we ask ourselves 'What was it I

Figure 13: The refurbished Warner and Swasey equatorial mounting in New Zealand (courtesy: Adrian Ashford collection).

just saw?' our minds project our curriculum vitae upon it in an effort to 'explain' it. Excellent discussions of the perceptual challenges inherent in visual Martian observations and that prompted projection are Sheehan (1988; 2015).

2. For this paper I used the following site: https://www.measuringworth.com/uscompare/relativevalue.php. The 'real price' value of a commodity was used for this estimate. All conversions of dollar amounts were made using this website.
3. An illustration of the view through a filar micrometer with the arrangement of the wires used to make an observation is shown in Russell, et al. (1927: 679).
4. 'Burnham' referred to Sherburne Wesley Burnham (1838–1921), who was an expert American double star observer, and compiler of earlier astronomers' double star catalogs (Burnham, 1906).

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Dr Richard Taibi is an independent scholar and a retired clinical psychologist based in Maryland, USA. For the past 35 years he has contributed visual meteor observations to the American Meteor Society and the International Meteor Organization. He has also contributed observations to the International Occultation Timing Association. During the last 20 years, Richard's historical research interests have been American astronomy and biographies of its professional and amateur astronomers. For the last 15 years he has served as an advisor to the American Meteor Society regarding its history. Richard's book, *Charles Olivier and the Rise of Meteor Science*, was published by Springer in 2017.