Journal of Astronomical History and heritage 7(2):85-94 2004

Investigations of the interstellar medium at Washburn Observatory, 1930–58

David S Liebl*
University of Wisconsin - College of Engineering, 432 North Lake Street, Rm. 311, Madison, Wisconsin 53706, USA
E-mail: liebl@epd.engr.wisc.edu

Christopher Fluke
Centre for Astrophysics and Supercomputing, Swinburne University of Technology, PO Box 218, Victoria 3122, Australia
E-mail: cfluke@swin.edu.au

Abstract
Between 1930 and 1958, the Washburn Observatory of the University of Wisconsin-Madison was home to pioneering photometric research into the interstellar medium by Joel Stebbins and Albert Whitford. Between 1933 and 1941, Stebbins and Whitford published seminal research on the photometry of stellar reddening, using the Washburn 15-inch refractor and the 60- and 100-inch reflectors at Mount Wilson Observatory.

Many factors were responsible for the Washburn Observatory's pre-eminence in this area. This paper reviews their research on interstellar dust during the years 1922–58, the observational technology and scientific methods that were developed at the Washburn Observatory during that time and the scientific discoveries that originated there. We discuss the factors that enabled Washburn Observatory to become a leader in photometry during the first half of the twentieth century. We also draw on the recollections of past and present Washburn Observatory scientists[1] to understand how Washburn's standing led to a subsequent programme of research into the interstellar medium at the University of Wisconsin-Madison. The resulting portrayal of Washburn Observatory provides insights into the evolution of astronomical research in America, from the beginning of the twentieth century until today.

Keywords: *photometry, reddening, Stebbins, University of Wisconsin, Whitford*

* To whom correspondence should be addressed.

1 INTRODUCTION

Washburn Observatory was established in 1884, serving as the primary astronomical research facility for the University of Wisconsin-Madison (UW) until the construction of the UW-Pine Bluff Observatory in 1958. Joel Stebbins was Washburn Observatory's Director from 1922 to 1948. During this time, Stebbins and faculty members Albert E Whitford (Washburn Director 1948–58) and Charles M Huffer were responsible for greatly advancing astronomical photoelectric photometry, and our understanding of the effect of the interstellar medium (ISM) on the measurement of starlight.

During Stebbins' tenure, Washburn Observatory was unusual among American astronomical facilities. In addition to having smaller than average staff[2], the facility was dedicated solely to photoelectric photometry, and had a long-term programme of research concentrating on two topics: eclipsing variable stars and stellar reddening. These characteristics caused us to ask how Stebbins, Whitford, and Huffer came to lead the field of photoelectric photometry, especially in the face of competition from more generously-funded, staffed, and equipped observatories (e.g. the nearby University of Chicago-Yerkes Observatory). We chose to examine how these early observations of reddening grew into a long-standing research programme at the University of Wisconsin on the nature of the interstellar medium.

No comprehensive history of the Washburn Observatory has been written, and this paper does not attempt to fill that need. Several shorter publications cover the Observatory's early history (Holden, 1881) or are popular accounts written to commemorate anniversaries and other special events (Bless, 1978; Greenstein, 1948; Huffer and Flather, 1959; Osterbrock, 2003a, 2003c; Shane, 1941; Stebbins, 1940, 1958; Whitford, 1953a). In this paper we review the early history of Washburn Observatory, Joel Stebbins' early career, and his rôle in the development of photoelectric photometry. We describe the problem of interstellar reddening and how the research conducted by Stebbins and Whitford contributed to our current understanding. In conclusion, we discuss how Washburn achieved its leadership in photometry, and its place in the evolution of American astronomy.

2 EARLY HISTORY OF WASHBURN OBSERVATORY

During the late nineteenth century, astronomical observatories in the United States were predominantly associated with educational or government institutions like Harvard, University of Michigan, or the U.S. Naval Observatory (Lankford, 1997). Unlike Europe, there were few American astronomical facilities owned and operated by wealthy amateurs (e.g. Percival Lowell's observatory founded in Flagstaff in 1894), and these were often donated to public institutions (e.g. George Ellery Hale's Kenwood Observatory founded in Chicago in 1888). For the University of Wisconsin, an astronomical observatory was considered to be a necessary part of the academic resources of a 'Great University', and instruction in astronomy was considered part of the basic science curriculum taught along with the related fields of mathematics and navigation.

In 1876 the Wisconsin Legislature authorized the allocation of $3,000 for "... astronomical work and instruction in astronomy so soon as a complete and well-equipped observatory shall be given the University on its own grounds without cost to the State ..." (Bless, 1978:1). Rising to this challenge in 1878, former Governor Cadwallader C Washburn used $65,000 of his own money to build and equip the eponymous observatory atop a hill overlooking Lake Mendota (Figure 1). In keeping with the high aspirations of the University, the Observatory was equipped with a world class telescope—the 15.6-inch aperture Clark refractor, the third largest such instrument in America at that time.

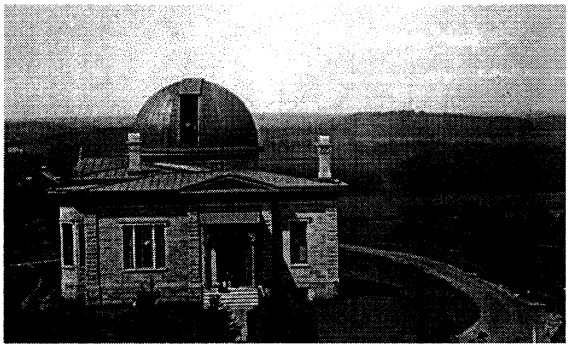

Figure 1. Washburn Observatory *c.* 1880. The open land behind the Observatory was completely urbanized by 1958 (Courtesy: Wisconsin State Historical Society).

The research carried out at Washburn Observatory during this early period was exclusively observational astronomy, with an emphasis on the measurement of the position of stars and the separation of double stars. During the years prior to 1922, Washburn Observatory had three directors: James C Watson from 1878 to1880, Edward S Holden from 1881 to 1885, and George C Comstock from 1887 to 1922. The stature of these men was such that when the newly-formed Lick Observatory was searching for a director, first Watson (who died shortly thereafter) and then Holden were approached. Holden's acceptance in 1885 was the beginning of a long relationship between the Wisconsin and Californian institutions (Osterbrock, 1976; see also Osterbrock, 2003b).

3 JOEL STEBBINS' EARLY CAREER

Joel Stebbins received his undergraduate degree from his home University of Nebraska in 1899, before moving to Madison to study with G C Comstock. Comstock's research had made him one of the pre-eminent astronomical teachers of his day (Whitesell, 2003), a founder of the American Astronomical Society, Wisconsin's first member of the National Academy of Science, and an influential rôle model for the new UW-Astronomy graduate student (Stebbins, 1939). Comstock's regard for Stebbins' ability was so great that he recommended that he complete his degree at Lick Observatory on Mount Hamilton, California, because of its greater research opportunities (Whitford, 1978).

Comstock and Stebbins were to stay in close communication over the coming years, and Stebbins' lasting respect and admiration for his early mentor is evident in his Biographical Memoir of Comstock (Stebbins, 1939). Comstock advised him on his choice of a faculty position at the University of Illinois (Stebbins, 1984; 1957), and his eventual move to Washburn Observatory (Lankford, 1997). By the time Stebbins left Illinois 1922, he had been the recipient of the Rumford Medal, the Draper Medal, had served as Secretary of the American Astronomical Society, was a member of the Organizing Committee of the International Astronomical Union, and had been elected to the National Academy of Sciences. Most importantly, however, he had helped transform photoelectric photometry from an experimental technique into a powerful tool for the measurement of starlight.

4 PHOTOELECTRIC PHOTOMETRY IN THE EARLY TWENTIETH CENTURY

As early as 1897, Washburn Observatory was an active site of photometric research, where G C Comstock was using atmospheric diffraction to pioneer the determination of the effective wavelength of stars (Stebbins, 1939; Weaver, 1946). Comstock employed a wire grating over the aperture of the 15-inch refractor to create diffraction images of a star. He then measured the energy distribution of the resulting spectrum, using a filar micrometer to gauge the separation of the visually-brightest diffraction lines on either side of the primary image, and transformed these measurements into effective visual wavelengths for the star. We can speculate that Comstock's early experience with the photometry of stars, especially his development of this innovative measurement technique, would predispose him toward the talents of his later protégé, Joel Stebbins.

Meanwhile in Europe, the need for a quantitative measurement of starlight had led to the development of the pyrheliometer, bolometer, radiometer, and the first electric photometer by George Minchin in 1892. Minchin's photovoltaic selenium photocell, while able to detect starlight, was not successfully adopted by other European astronomers (Stebbins, 1940). Fifteen years later, Stebbins and F C Brown at the University of Illinois (Hearnshaw, 1996), adapting a selenium photoconductive cell, made the first astronomical photoelectric measurements of the phases of the Moon (Stebbins, 1957).

Photoelectric photometry is distinct from visual or photographic photometry, in that the photon creates a transient electrical effect as it falls upon the detector. The main advantages of the photoelectric cells used by Stebbins were the linear response (number of incident photons directly proportional to the number detected over an extended range) and improved reproducibility compared to other photometric methods of the time. By 1910, Stebbins had used photoelectric photometry to describe the light curve of the variable star Algol, with an accuracy unobtainable by the visual or photographic methods of the day (Stebbins, 1910). This work not only established the existence of Algol's bright eclipsing companion star, but showed the utility of photoelectric photometry for astronomical measurement, and the skill of Stebbins as an observer. Stebbins had enough confidence in the value of his own work that he began promoting photoelectric photometry beyond academic publications (Stebbins, 1914, 1915). At the same time, he continued to improve upon the technology, leading to increases in the sensitivity (signal to noise ratio) of the cells.

When the Swiss physicist Joseph Kunz joined the Illinois faculty in 1911, he brought with him the latest European technology, the Elster and Geitel potassium hydride photoelectric cell. This photoemissive cell had increased sensitivity to light, and more rapid recovery time than the selenium cell, which allowed for more frequent observations and reduced error (Stebbins), 1915). Stebbins was quick to recognize the potential application of the new cell to astronomy. Travelling to Berlin during the 1912-13 academic year, he met with Paul Guthnick and Hans Rosenberg who were beginning their own experiments with the new technology (see Greenstein, 1948; Huffer, 1955). By 1916, Kunz and Stebbins had developed the potassium photoelectric cell to the point where they were publishing accounts of its manufacture, and the application of the 'Kunz cells' to astronomy (Kunz and Stebbins, 1916). Stebbins had even taken his new photometer to the Lick Observatory to study the eclipsing binary β Lyra using the 12-inch refractor (Svec, 1992).[3]

One has only to read the accounts by Stebbins' contemporaries and students (DeVorkin, 1977a; Greenstein, 1948; Kron, 1996; Shane, 191; Whitford, 1978) to realize that he as an astute professional, and a meticulous observer, who could focus his energy and interet over long periods of time to achieve an objective unseen by others. As C D Shane (1941:10) put it on the occasion of Stebbins' receipt of the Bruce Medal in 1941, Stebbins was "...an investigator who, starting with most modest resources in a nearly virgin field, has developed methods, and discovered and extended their application, until now the field deserves to be ranked among the most important in astronomical research."

5 PHOTOELECTIC PHOTOMETRY AT WASHBURN OBSERVATORY

When Joel Stebbins came to the University of Wisconsin in 1922 as Director of the Washburn Observatory, his development of the photoelectric photometric technique using the Illinois 12-inch refractor had improved sensitivity from magnitude 3 to magnitude 6, and he provided measurements with an accuracy in the range of thousandths of a magnitude (Stebbins, 1921). At Wisconsin, Stebbins took the bold step of converting the Washburn 15-inch refractor from a visual instrument to a dedicated photoelectric photometer, making it the first such instrument at a major American observatory, and it would remain the only such instrument for another dozen years (Whitford, 1978).

Continuing with his photometric studies of eclipsing variable stars, Stebbins soon employed C M Huffer as both a photometrist and instructor in the University's newly-formed undergraduate course on astronomy (Taylor, 1877). In 1932, Albert Whitford (then a UW graduate student in physics) developed a single-stage thermionic (Pilotron FP-54 vacuum tube) amplifier that greatly improved the signal-to-noise ratio of the Washburn photoelectric photometer. By enclosing the photoelectric cell and amplifier components in an evacuated casing, Whitford was able to further reduce noise, increasing the sensitivity of the instrument from about magnitude 7.7 to magnitude 9.6 (Whitford, 1932).

Following the example of his own mentor, G C Comstock (Jaell, 1995), Stebbins arranged for a two-year post-doctoral fellowship for Whitord at Mt. Wilson Observatory in 1933. This had the dual effect of piquing the young physicist's interest in observational astronomy, and placing Washburn's photoelectric photometer (complete with photometrist) in the midst of the thriving California astronomical community (Whitford, 1986). Shortly thereafter, Whitford joined Washburn Observatory as a researcher, continuing to improve the efficiency of the photoelectric equipment while gaining experience in astronomical research.

The relationship between these three researchers seems to have been moulded early on. Stebbins, as Director, set the research agenda and managed the facility. Huffer, (who had been a student of Stbbins' prior to a tour of duty at Lick's Chilean observatory) was primarily a photometrist and instructor, responsible for making accurate and systematic measurements for Stebbins' observing programmes, and teaching undergraduate students (DeVorkin, 1977b). Whitford served as the electronic specialist, designing and constantly improving the photoelectric equipment (DeVorkin, 1978).

After the development of the thermionic amplifier, the technological improvements to photoelectric photometry continued. While none would have the same dramatic effect on sensitivity as Whitford's innovation, the Washburn group was quick to explore and exploit new tools. In 1929, the caesium oxide (developed over silver) photocell was introduced. This new material increased the wavelength response range to 3,500-10,000Å (Whitford, 1986), as compared to the Kunz cell's range of 3,500-5,800Å (Stebbins and Huffer, 1934). This permitted photoelectric measurements at red wavelengths, allowing for the development of the six-colour photometry method (see Section 7.3 below), and the measurement of extended objects such as nebulae (Stebbins and Whitford, 1943).

In 1937, Gerald Kron and Albert Whitford used the new RCA photomultiplier tube to create an automatic telescope guider for the Mt. Wilson 60-inch telescope. Kron had completed an M.S. in Mechanical Engineering at UW in 1934, when he obtained a position at Washburn Observatory helping to maintain the photoelectric equipment in Whitford's absence (DeVorkin, 1978). In 1935, Kron accompanied Stebbins on a summer observing session at Mt. Wilson, where he worked with Whitford as a research assistant. As he had for Whitford, Stebbins recommended Kron for a doctoral research programme, this time at Lick Observatory (Jarrell, 1995). Kron successfully received his Ph.D. in 1938, and became a leading photometrist, creating another strong link between the Wisconsin and California astronomers.

6 THE PROBLEM OF INTERSTELLAR REDDENING

In 1930, Lick Observatory's Robert Trumpler noted that, "For more than a century astronomers have interested themselves in the question: Is interstellar space perfectly transparent, or does light suffer an appreciable modification or loss of intensity when passing through the enormous spaces which separate us from the more remote celestial objects?" (Trumpler, 1930b:214). The inability to obtain a factor for the 'extinction' of starlight, that could be applied to measurements of stars at different distances and positions, posed serious problems for the study of astrophysics at the beginning of the twentieth century.

While considerable thought and observation had been expended on this problem, no agreement had been reached into the cause of this reddening (or, colour excess) of starlight. Perhaps most fundamental was the need to accurately measure astronomical distances. Several investigators, including J C

Kapetyn, P J van Rhijn, and H Shapley, had based estimates of the size of our Galaxy on data that proved to be erroneous because it did not account for reddening from interstellar dust (Oort, 1972). Also, multiple-wavelength observations of starlight and stellar spectra used to understand the evolution of stars were uncertain if dust was selectively obscuring some wavelengths and not others.

Trumpler's approach to resolving this problem was to use two methods to estimate the distances of open clusters of stars at differing galactic latitudes. The first method estimated 'photometric distances' from the apparent magnitude and spectral type of the stars in each cluster. For the second method, he reasoned that clusters at similar stages of evolution (i.e., total number of stars and central cluster density) should have the same linear diameter. While the photometric estimate could be affected by absorption of starlight, the dimensional method would not be. Assuming a 1:1 correlation between the two methods (in the absence of absorption), he demonstrated that the correlation that was observed did indeed result from absorption. He also found that open clusters near the plane of the galaxy suffered more from extinction by the ISM, indicating that the obscuring material was more concentrated there (Trumpler, 1930a, 1930b, 1930c).

Trumpler's proposal that interstellar dust caused reddening of the light from stars along the plane of our Galaxy was a turning point for research at Washburn Observatory. In 1930, Stebbins was visiting Lick Observatory, where Trumpler suggested that the observed reddening effect could be measured more precisely with the Washburn photoelectric photometer (Jarrell, 1995; Stebbins and Huffer, 1933, 1934). Stebbins immediately embarked on a programme of research into the properties of the ISM that was to occupy Washburn Observatory for the next two decades.

7 RESEARCH INTO DUST AT WASHBURN OBSERVATORY

Over the years 1933–41, Stebbins, Huffer, and Whitford published seminal research on the photometry of stellar reddening, using the Washburn 15-inch refractor and the 60- and 100-inch reflectors at Mount Wilson Observatory. UW Professor Emeritus John Mathis (pers. comm. to David S Liebl, 2002) sums up the advantage Washburn Observatory held over other observatories at this time:

> Studying dust extinction from photography was pretty marginal because plates were difficult to calibrate quantitatively, and the reddening of starlight is only obvious when there is large extinction. By contrast, photoelectric photometry is rather quantitative. So Stebbins and Whitford, and almost only they, could study the effects of extinction in stars that were lightly or moderately reddened.

Their measurements provided a precise confirmation of Trumpler's hypothesis. Indeed, when the Washburn data were used to correct Harlow Shapley's estimate of the size of our Galaxy, Stebbins is said to have remarked "We have shrunk the Universe." (DeVorkin, 1977b).

Stebbins was careful to mention the many difficulties that arose while attempting to take accurate photometric measurements for these studies. Problems with the equipment included: inconsistent sensitivity of individual cells, problems with cell voltage control, and frequent difficulties with the electrometer. He also emphasized the importance of good astronomical seeing conditions, and favourable winds to drive off the wintertime coal smoke! Stebbins (1928:18) ends on a typically-droll note by noting that "This dismal picture is brightened somewhat by the knowledge that conditions are worse elsewhere."

Washburn Observatory research on interstellar dust can be organized under the following headings: Photometry of O and B Stars; Photometry of Globular Clusters; Six-colour Photometry of Stars; and the Law of Interstellar Reddening. Each of these is discussed below.

7.1 Photometry of O and B Stars

O and B type stars were chosen by Stebbins for study because of their high intrinsic luminosities, and because they are among the most distant stars for a given apparent magnitude. This helped to compensate for the limited light-gathering power of the Washburn refractor, and provided the greatest contrast with un-reddened stars of known apparent magnitude. Beginning with a list (provided by Trumpler) of B stars likely to show the effects of reddening, Stebbins and Huffer soon expanded their list of programme stars to include all B0-B5 type stars in the Henry Draper Catalog north of Dec -15° and m_v >7.5 (producing a data set of about 700 stars). This allowed them to make comparisons between stars at similar galactic latitudes, and increase the sample number in areas where reddening seemed to be most pronounced. This list eventually grew to a total of 1,332 stars with the addition of observations made by Stebbins at Mt. Wilson Observatory using the Kunz cell and Whitford's thermionic amplifier, mounted on the 60- and 100-inch reflectors (Stebbins and Huffer, 1933, 1934; Stebbins, *et al.*, 1939, 1940, 1941)

To obtain a colour index (the ratio of the brightness of a star at more than one wavelength), two calibrated filters (4,200Å and 4,700Å) were used to measure 100 standard stars situated above the plane of the galaxy. These stars were assumed to be free of significant reddening, and were termed 'normal stars'. Then, over 144 nights between 1930 and 1932, measurements were taken for the first set of 700 stars. The colour excess for these stars was determined by subtracting the colour index of a 'normal star' from the colour index of the programme star.

The results of this work clearly showed a correlation between colour excess and galactic latitude, concentrated along the median plane of the galaxy. Stebbins and Huffer (1934:258) concluded that the distribution of the reddening effect was "... quite irregular or spotted in nature ... [and] considering the Galaxy as a spiral nebula, the distribution of the observed B-stars suggests a clear space or lane inclined about 40° to a radius from the center." Figure 2 (reproduced from Stebbins, 1940) shows the distribution of reddened B-stars (colour excess (E) >0.16) in relation to the Galactic plane.

7.2 Photometry of Globular Clusters

Alongside the observations of O and B stars using the Mt. Wilson 100-inch telescope, Stebbins and Whitford measured the reddening of globular clusters over a range of galactic latitudes using the Mt. Wilson 100-inch reflector (Stebbins, 1933; Stebbins and Whitford, 1936). Globular clusters were of interest because their intrinsic luminosities and their great distance (as compared to individual stars in the plane of the Galaxy), provided a means of comparing Galactic absorption with absorption in intergalactic space. Stebbins and Whitford continued to use the same method for measuring the globular clusters as used for the O and B stars. However, they chose to use the colour excess of stars in the vicinity of each cluster as their standard, and centred the diaphragm of the large reflector on the core of the cluster to measure its colour index. They typically made six measurements of a single cluster, alternating filters and interspersing the sky background.

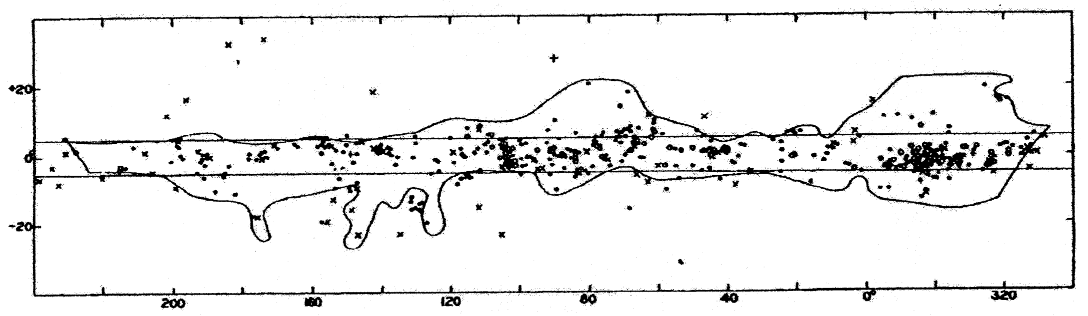

Figure 2. Distribution of reddened B stars along the Galactic plane (after Stebbins, 1940:242; reproduced courtesy of the Editors of the Astronomical Society of the Pacific).

In all, sixty-eight globular clusters visible from the latitude of Mt. Wilson were measured. Once again they found that objects near the plane of the Galaxy were reddened in comparison to those at high Galactic latitudes (Figure 3). Comparing their results to Trumpler's estimate of the diameter of the Galaxy based on open clusters (10,000 parsecs) and Harlow Shapley's estimate based on Cephied variables (80,000 parsecs), they concluded that the Galaxy was probably 30,000 parsecs in diameter (Stebbins and Huffer, 1934). Their correction of these distance measurements for the extinction by interstellar dust once again demonstrated the utility of the more quantitative photoelectric method, and it helped to secure the Wisconsin astronomers' growing reputation for precision photometry.

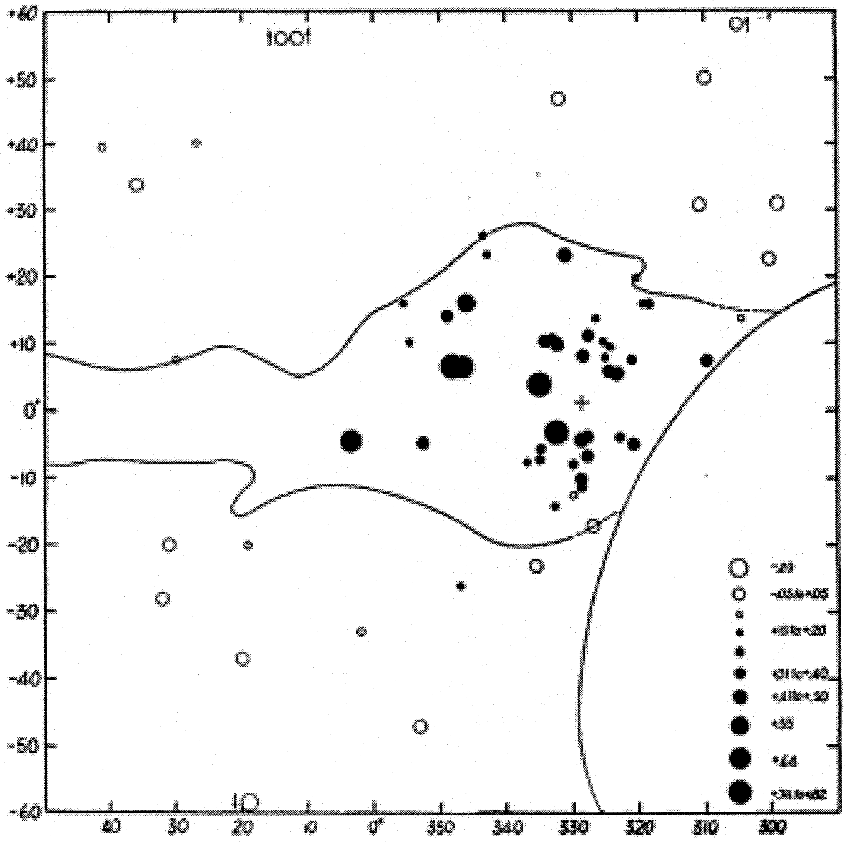

Figure 3. The colours of globular clusters (in Galactic co-ordinates) (after Stebbins and Whitford, 1936:145).

Table 1. Absorption at different wavelengths (after Stebbins and Whitford, 1943: 32).

Filters	U	V	B	G	R	I	I_1	I_2
λ	3530	4220	4880	5700	7190	10,300	12,500	∞
1/λ	2.83	2.37	2.05	1.75	1.39	0.97	0.80	0.00

7.3 Six-colour Photometry of Stars

The availability of the caesium oxide photocell, with its expanded wavelength response (3,530–10,300Å), made it possible for the Washburn group to explore spectrophotometric measurements. Their first approach was an attempt to measure stellar spectra directly using a dispersing prism on the Mt. Wilson 100-inch reflector. However, difficulties with maintaining the wavelength calibration of the instrument (Whitford, 1958) led to the adoption of a more reproducible approach (i.e., expanding the range of filter photometry from two to six colours).

Between 1943 and 1956, Stebbins, Whitford, and Kron used both the 60-inch Mt. Wilson reflector and the 36-inch Crossley reflector at Mt. Hamilton to obtain six-colour photometric measurements of 409 stars of types B, A, F, G, K, and M (Stebbins and Whitford, 1943, 1945, 1947; Stebbins and Kron, 1956). The increased spectral range of the six-colour system allowed them to more accurately discriminate among the spectra of different types of stars, and the observed effects of interstellar dust. This provided the raw data for calculations of wavelength-specific extinction, and led to the development of a law of interstellar reddening.

7.4 The Law of Interstellar Reddening

The development of a wavelength-specific interstellar absorption curve that could be applied to astronomical observations was an important goal for the Washburn Observatory scientists (Stebbins, *et al.*, 1940; Whitford, 1948, 1961). From 1930 through the 1940s, measurement of the colour excess of stars, star clusters, and galaxies remained the main research activity of the Washburn faculty.

In addition to the study of stellar luminosities, the six-colour approach proved to be an especially powerful tool for measuring the wavelength-dependence of interstellar absorption. Early in the course of their investigation, Stebbins and Whitford used measurements from thirty O and B type stars to explore the selective absorption of the ISM over the range of their photometric system. The results (Table 1) clearly show the wavelength dependency of the absorbing material for each filter. Here, for the first time, they attempted to extrapolate the absorption curve deeper into the infrared region (I_1 and I_2 are beyond the cut-off of the I filter), estimating the zero point of the curve.

The Washburn group found a simple inverse (1/λ) relationship between the absorption of light and wavelength. Compare this to Rayleigh scattering (typical of the scattering of incident light by atmospheric molecules), which is inversely proportional to the fourth power of wavelength ($1/\lambda^4$). While the group put forward an initial hypothesis describing a "... law of space reddening ..." (Stebbins and Whitford, 1943:25), it was Whitford (1958) who took this information and developed from it a systematic description of interstellar reddening in his landmark paper "The law of interstellar reddening."

By 1940, Stebbins, Whitford and Huffer had evaluated the distribution of interstellar absorption by mapping the colour excess of O and B stars within 2,000 parsecs of the Sun against the galactic latitude of the stars. While they were able to measure a strong absorption effect near the galactic plane, they failed to observe a distance-absorption relationship that would allow them to determine reddening caused by a homogeneous ISM. Whitford questioned whether the properties of the ISM (either density or composition) were sufficiently uniform to be able to apply a general law of reddening along any given line of sight.

Whitford also recognized that their six-colour measurements of O and B type stars could not stand alone as evidence for a relationship between total and selective absorption (Whitford, 1953b). To resolve this, he correlated the Washburn estimates of colour excess with data that had been obtained from other researchers using spectrophotometric methods (i.e., J Borgman, L Divan, J Dufay, J J Nassau and W W Morgan, P J van Rhijn, and C Schalén), and with data acquired using a new photoelectric scanning spectrograph developed at Wisconsin by Arthur Code (Figure 4). Earlier work (Whitford 1948) using a lead sulphide photoconductive cell with deeper infrared response (2.4 μ), had also indicated that the zero point of the coefficient curve might not be a simple linear extension of the measured values. Figure 5 shows these slopes diverging at 2μ. In addition, Whitford (1958:201) hints at preliminary indications of "... anomalies in the ultraviolet portion of the reddening curve ...", an effect that was soon to direct attention towards the first astronomical observations made from above the Earth's atmosphere.

8 WASHBURN AFTER THE STEBBINS ERA

Joel Stebbins retired in 1948, with Albert Whitford succeeding him as Director. Under Whitford, the Observatory was transformed from an independent scientific facility into an academic department within the UW-College of Letters and Science. It also expanded to include a fully-fledged graduate programme in astronomy, after having graduated only four Ph.D. students (J D R Bahng, O J Eggen, T E Houck, and C M Huffer) in the previous seventy-five years (Osterbrock, 2000a).

Nineteen fifty-eight stands as a milestone in the history of Washburn Observatory. Albert Whitford stepped down to take up the Directorship of Lick Observatory, and Arthur Code returned to Madison from Caltech to begin his own ten-year stint as Director. Whitford had recommended Code for the Washburn Directorship because of Code's experience with Washburn's photometric instrumentation, just as Stebbins had recommended Whitford for the post (D Osterbrock, private communication).

It was Code (with Robert Bless) who would expand Whitford's work on the interstellar extinction curve into the ultraviolet region of the spectrum using satellite-based observatories. John Mathis joined the group to study the nature of interstellar grains, and was followed by Blair Savage who conducted research into the physical properties of the ISM. When Joel Stebbins returned to Madison in 1958 to dedicate the new Pine Bluff Observatory and its 36-inch Cassegrain reflector, it marked the beginning of a new chapter in astronomical research at the University of Wisconsin-Madison.

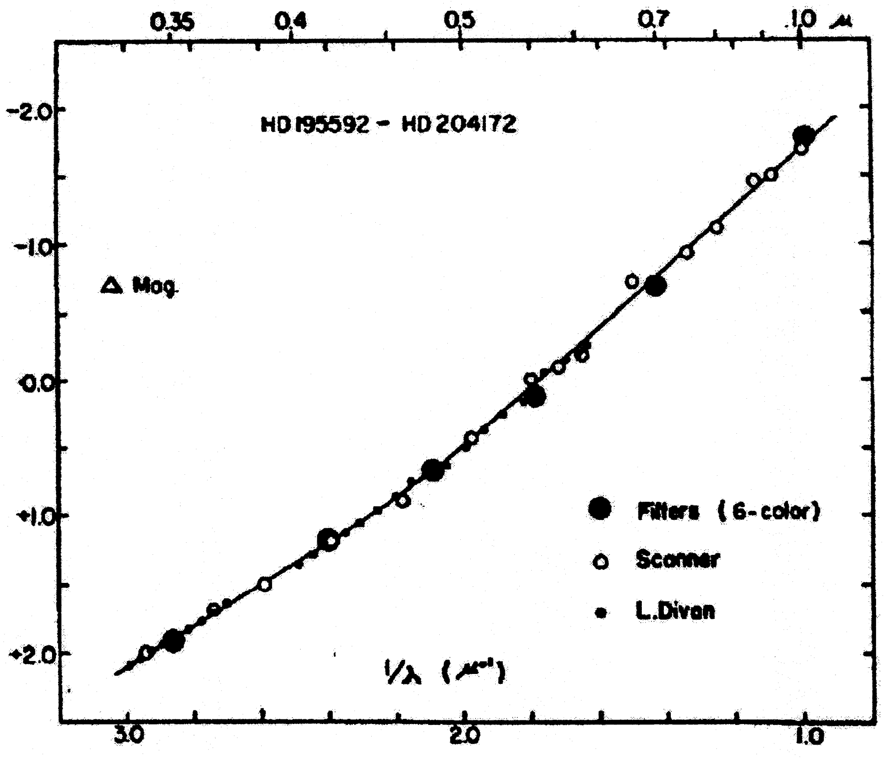

Figure 4. Monochromatic magnitude differences between a reddened star and a normal star, as observed by three methods (after Whitford,1958:203).

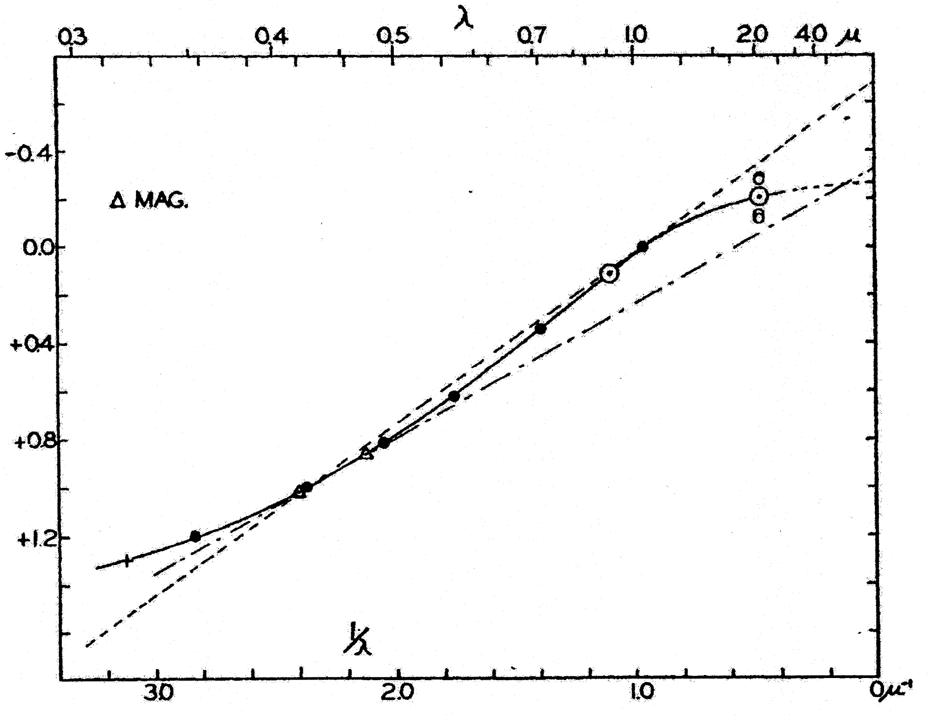

Figure 5. Mean interstellar absorption curve from four pairs of stars, reduced to V – I = 1.00m (after Whitford, 1948:105). Filled circles are six-colour observations; small open circles are individual lead sulphide observations, with large open circles showing the means; and the cross is the silver-filter observation of one pair only. The triangles show the baseline of the C1 colours.

9 DISCUSSION

As we have seen, a number of factors contributed to Washburn Observatory's pre-eminence in photoelectric photometry. Certainly, Stebbins' persistent pursuit of the development and application of photoelectric photometric technology and techniques was responsible for the Washburn Observatory's outstanding contributions. While other astronomers were quick to adopt photographic techniques for recording starlight, adoption of the photoelectric technique was less rapid. Stebbins was keenly aware of George Minchin's earlier failure to successfully promote the selenium photo-voltaic cell as an astronomical tool (Stebbins, 1940). While Stebbins' early measurement of the period of Algol convinced the scientific community of the value of photoelectric photometry, his tireless advocacy of photoelectric photometry, both within the discipline and with the interested public (Stebbins, 1934a, 1934b, 1935, 1948), did much to promote acceptance of the new technique.

The application of electrical and electronic technology to astronomy was in its infancy during these years. That Stebbins would recruit a physics graduate student (Whitford) to maintain and improve his photoelectric apparatus underscores this point. When Stebbins and Whitford first took the new photometer and thermionic amplifier to Mt. Wilson they found that no one there had a good grasp of the principles of its operation (Whitford, 1986). The ongoing refinement of photoelectric equipment and technique required skills and experience that were, to some extent, self-reinforcing. This meant that the Washburn faculty would naturally come to lead other observatories.

Specialized skill was also required to make consistently-accurate photoelectric measurements of starlight under demanding conditions. The photometrist was required to manually observe and record many observations over the course of the night, with equipment that was often challenging to use. Not only did the photometrist need to be intimately familiar with idiosyncrasies in the equipment, but judgment (based on experience) was needed to evaluate the quality of each measurement taken. This degree of experience would have been difficult to obtain anywhere else than at Washburn Observatory, with its dedicated photoelectric photometer.

Photoelectric cells were difficult to make, and more difficult to make well. Stebbins clearly valued his long-term relationship with Kunz, which afforded him access to the most sensitive and stable cells coming from Kunz's laboratory. He was even careful to cite the number of the specific cell used for a set of measurements, and transported the best cells to California when working with the Lick and Mt. Wilson telescopes. The general lack of availability of highly sensitive cells, combined with cell-to-cell inconsistency, may have discouraged other astronomers from employing the technique. This problem would only be resolved when 'off the shelf' photomultiplier tubes became available following World War II. Retired Lick Observatory Director, Donald Osterbrock (pers. comm. to David S Liebl, 2002) adds:

> The Kunz cells first, and the amplifier afterward, were much better than any other astronomers had, and enabled them [Stebbins and Whitford] to go far ahead of all the visual and photographic photometrists who were still grinding out marginal results with outdated techniques. It wasn't the telescope or the site [Madison], but because their results were so good, and their contacts too (Whitford had been at Caltech and Mt. Wilson Observatory 2 years) that they could go to the big telescopes to get data on faint stars, clusters and galaxies.

It is reasonable to conclude that it was the persistence, ingenuity, equipment, technique, and accumulated expertise of the Washburn group that put them, and kept them, at the forefront of American photoelectric photometry.

Washburn Observatory during these years serves as an interesting case study of the changing character of American astronomical research in the early twentieth century. Donald Osterbrock's comment (ibid.) about the Stebbins' era is telling in this respect: "Astronomy departments did not have research programs back then, especially ones as small as UW's. Astronomers did the research they were most interested in, and could do with the equipment they had."

We have seen how Comstock and Stebbins directed the research at Washburn, following their own interests with the assistance of a few staff. The Observatory was nominally independent of the academy at UW, and although Comstock and Stebbins did teach (and even this responsibility was delegated, in part, by Stebbins to Huffer), Washburn was primarily a research facility. As we have seen, the astronomy programme at Wisconsin did not have a graduate degree programme as such until Albert Whitford began the process of integrating it into the College of Letters and Science after Stebbins' retirement.

The continuity of interest between the Directors, combined with Washburn's standing as a dedicated photoelectric photometry observatory, likely served to support the consistency in mission and approach to astronomy that we see over this period. In each case (Stebbins, Whitford, and Code), the new Director was a former student and/or colleague, who shared the vision and skills of his mentor. While it might be difficult to argue that Comstock and Code had much in common, one can easily trace their lineage as scientists through Stebbins and Whitford.

While Washburn Observatory between 1922 and 1958 might seem quite different from modern astronomy as characterized by the 'Big Science' of the post-Cold War period, some things have not changed. Stebbins excelled in his rôle as a mentor for talented young astronomers (e.g. Gerald Kron), first helping to place them at prestigious institutions and then collaborating with them. Establishing and maintaining productive collaborations with other astronomers was also a high priority, along with service to the institutions that supported astronomy in America (Stebbins, 1931; Whitford, 1972). Perhaps it is most accurate to describe Washburn Observatory during this time as a case study of astronomy in transition, from the era of the solitary observer to that of the highly co-ordinated and directed research programme.

We end with these final word of inspiration for future astronomers from Joel Stebbins (1958: 449), expounded at the dedication of the University of Wisconsin's Pine Bluff Observatory: "It is a far reach from the simple methods of astronomical observation in 1878 to the rather complicated procedures of today, but whatever the direction that research takes at Washburn Observatory, we can be sure that its value will be limited only by the imagination and energy of its staff."

10 ACKNOWLEDGMENTS

The authors wish to express their gratitude to Professors Arthur Code, John Mathis, Donald Osterbrock, and Blair Savage for taking time to share their recollections and perspectives on the early days of the Washburn Observatory. We also thank the University of Wisconsin-Archives for providing access to the personal and professional papers of Joel Stebbins; the University of Wisconsin-Oral History Project; the American Institute of Physics – Sources for the History of Modern Astrophysics Project; and finally to the Wisconsin State Historical Society, the University of Wisconsin Astronomy Department, the Astronomical Society of the Pacific, and the American Astronomical Society for permission to reproduce Figures 1, 2, 3, and 4-6 respectively.

11 NOTES

1. During the fall of 2002, one of us (DSL) established a dialog about the Stebbins years with the following Washburn Observatory scientists: Arthur Code (1951–56, 1958–68), Donald Osterbrock (1958–73), John Mathis (1959–), and Blair Savage (1968–). Quotations in the text by these individuals are taken from the author's interview notes or the subject's correspondence.
2. Lankford (1977) Table 11.5 shows that staffing in American observatories averaged four individuals during 1931.
3. Other accounts of Stebbins' photometric work at Illinois include: DeVorkin (1985); Huffer (1955); Stebbins (1914, 1915, 1940, 1950, 1957).

12 REFERENCES

Bless, R.C. 1978. *Washburn Observatory 1878-1978.* University of Wisconsin, Madison.

DeVorkin, D.H. 1977a. A.E. Whitford: Oral History Interview (transcript), Institute of Physics-Center for History of Physics, College Park.

DeVorkin, D.H. 1977b. Charles M. Huffer: Oral History Interview (transcript), Institute of Physics-Center for History of Physics, College Park.

DeVorkin, D.H. 1978. Gerald Kron: Oral History Interview (transcript), Institute of Physics-Center for History of Physics, College Park.

DeVorkin, D.H. 1985. Electronics in astronomy: early applications of the photoelectric cell and photomultiplier for studies of point-source celestial phenomena. *Proceedings of the Institute of Electrical and Electronic Engineers*, **73**:1205-1220.

Greenstein, J.L. 1948. The seventieth anniversary of Professor Joel Stebbins and of the Washburn Observatory. *Popular Astronomy*, **56**:283-299.

Hearnshaw, J.B., 1996. *The Measurement of Starlight.* Cambridge University Press, Cambridge.

Holden, E.S. 1881. Washburn Observatory. *Publications of the Washburn Observatory*, **1**:5-37.

Huffer, C.M. 1955. The development of photo-electric photometry. *Vistas in Astronomy*, **1**:491-498.

Huffer, C.M., and Flather, E. 1959. The Washburn Observatory 1878-1959. *Transactions of the Wisconsin Academy of Science, Arts and Letters*, **48**:249-259.

Jarrell, R. 1995. A.E. Whitford: Directorship of Lick Observatory 1958-1968, (interview transcript), U.C. Santa Cruz Regional History Project, Santa Cruz.

Kron, G.E. 1966. Joel Stebbins 1878-1966. *Publications of the Astronomical Society of the Pacific*, **78**:214-222.

Kunz, J., and Stebbins, J. 1916. On the construction of sensitive photoelectric cells. *Physical Review*, **7**:62-65.

Lankford, J. 1997. *American Astronomy: Community Careers and Power, 1859-1940.* University of Chicago Press, Chicago.

Oort, J.H. 1972. The development of our insight into the structure of the Galaxy between 1920 and 1940. *Annals of the New York Academy of Science*, **198**:255-266.

Osterbrock, D.E. 1976. The California-Wisconsin Axis in American astronomy. *Wisconsin Academy Reviews*, **23**:2-8.

Osterbrock, D.E. 2000. A fortunate life in astronomy. *Annual Review of Astronomy and Astrophysics*, **38**:1-33.

Osterbrock, D.E. 2003a. From Comstock to Stebbins to Whitford: UW Astronomy from 1886 to 1958: From the Nearest Stars to the Most Distant Galaxies, (transcript of remarks made at American Association of Physics Teachers meeting, August 25, Madison, provided by the author).

Osterbrock, D.E., 2003b. The California-Michigan axis in American astroonmy. *Journal of Astronomical History and Heritage*, **6**:120-136.

Osterbrock, D.E. 2003c. Through Thick and Thin With Art Code: From Wisconsin to Caltech and Back Again-And Beyond!, (transcript of remarks made at A. Code's 80th Birthday Dinner, provided by the author).

Shane, C.D. 1941. Address of the Retiring President of the Society in awarding the Bruce Gold Medal to Dr. Joel Stebbins. *Publications of the Astronomical Society of the Pacific*, **53**:5-11.

Stebbins, J. 1910. The measurement of light of stars with a selenium photometer, with an application to the variations of Algol. *Astrophysical Journal*, **32**:185-214.

Stebbins, J. 1914. The electrical measurement of starlight. *Scientific American*, **111**:408, 415.

Stebbins, J. 1915. The electric photometry of stars. *Science* (New Series), **41**:809-813.

Stebbins, J. 1921. A photo-electric study of Algol. *Astrophysical Journal*, **53**:105-120.

Stebbins, J. 1928. Photoelectric photometry of stars: instruments and methods. *Publications of the Washburn Observatory*, **15**(1):5-18.

Stebbins, J. 1931. The photo-electric photometer of the Yerkes Observatory. *Astrophysical Journal*, **74**:289-297.

Stebbins, J. 1933. Absorption and space reddening in the Galaxy as shown by the colours of globular clusters. *Proceedings of the National Academy of Sciences*, **19**:222-228.

Stebbins, J. 1934a. The dark Galaxy. *Scientific Monthly*, **39**:129-143.

Stebbins, J. 1934b. Dust Between the Stars, (radio transcript), University of Wisconsin Archives, Madison.

Stebbins, J. 1935. Dust between the stars. *Scientific Monthly*, **40**:270-272.

Stebbins, J. 1939. George Cary Comstock 1855-1934. In *National Academy of Sciences of the United States of America: Biographical Memoirs*, **20**:161-182.

Stebbins, J. 1940. The electrical photometry of stars. In *Symposium on the Photoelectric Cell in Astrophysical Research.* Publications of the Astronomical Society of the Pacific, Seattle (Conference Volume 52). Pp. 235-243.

Stebbins, J. 1948. Starlight by photocell. In *The New Astronomy. A Scieintific American Book.* Simon and Schuster, New York. Pp. 219-228.

Stebbins, J. 1950. The electrical photometry of stars and nebulae. *Monthly Notices of the Royal Astronomical Society*, **110**:416-428.

Stebbins, J. 1957. Early photometry at Illinois. *Publications of the Astronomical Society of the Pacific*, **69**:506-510.

Stebbins, J. 1958. The Washburn Observatory 1878-1958. *Publications of the Astronomical Society of the Pacific*, **70**:437-449.

Stebbins, J. 1984. Personnel and professional papers 1902-1984. University of Wisconsin-Madison Archives, Madison.

Stebbins, J., and Huffer, C.M. 1933. Absorption and space reddening in the Galaxy from the colours of B-stars. *Proceedings of the National Academy of Sciences*, **19**:597-604.

Stebbins, J., and Huffer, C.M. 1934. Space reddening in the Galaxy from the colours of 733 B-stars. *Publications of the Washburn Observatory*, **15**(21):217-259.

Stebbins, J., and Kron, G.E. 1956. Six colour photometry of stars VII. The colours of 409 stars of different spectral types. *Astrophysical Journal*, **123**:440-457.

Stebbins, J., and Whitford, A.E. 1936. Absorption and space reddening in the Galaxy from the colours of globular clusters. *Astrophysical Journal*, **84**:132-157.

Stebbins, J., and Whitford, A.E. 1943. Six colour photometry of stars I. The law of space reddening from the colours of O and B stars. *Astrophysical Journal*, **98**:20-32.

Stebbins, J., and Whitford, A.E. 1945. Six colour photometry of stars III. The colours of 238 stars of different spectral types. *Astrophysical Journal*, **102**:318-346.

Stebbins, J., and Whitford, A.E. 1947. Six colour photometry of stars V. Infrared radiation from the region of the Galactic Center. *Astrophysical Journal*, **106**:235-242.

Stebbins, J., Huffer, C.M., and Whitford, A.E., 1939. Space reddening in the Galaxy. *Astrophysical Journal*, **90**:209-229.

Stebbins, J., Huffer, C.M., and Whitford, A.E., 1940. The mean coefficient of selective absorption in the Galaxy. *Astrophysical Journal*, **92**:193-199.

Stebbins, J., Huffer, C.M., and Whitford, A.E. 1941. Selective absorption in space near the Sun. *Astrophysical Journal*, **94**:215-225.

Svec, M.T. 1992. The birth of electronic astronomy. *Sky and Telescope*, **83**(5):496-499.

Taylor, D, 1977. Charles M. Huffer: Oral History Project Interview, (audio tape), University of Wisconsin-Archives, Madison

Trumpler, R.J. 1930a. Preliminary results on the distances, dimensions and space distribution of open star clusters. *Lick Observatory Bulletin*, **14**(420):154-158.

Trumpler, R.J. 1930b. Absorption of light in the Galactic system. *Publications of the Astronomical Society of the Pacific*, **42**:214-227.

Trumpler, R.J. 1930c. Spectrophotometric measures of inter-stellar light absorption. *Publications of the Astronomical Society of the Pacific*, **42**:267-274.

Weaver, H.F. 1946. The development of astronomical photometry. *Popular Astronomy*, **54**:212-230, 287-299, 339-351, 389-404, 451-464, 504-526.

Whitesell, P.S., 2003. Detroit Observatory: nineteenth century training ground for astronomers. *Journal of Astronomical History and Heritage*, **6**:69-106.

Whitford, A.E. 1932. The application of a thermionic amplifier to the photometry of stars. *Astrophysical Journal*, **76**:213-223.

Whitford, A.E. 1948. An extension of the interstellar absorption curve. *Astrophysical Journal*, **107**:102-105.

Whitford, A.E. 1953a. Washburn Observatory. *Astronomical Journal*, **56**:172.

Whitford, A.E. 1953b. Limits of sensitivity and precision attainable by photoelectric methods: critical summary and comparison of various techniques. In F. B. Wood (ed.). *Astronomical Photoelectric Photometry.* American Association for the Advancement of Science, Washington. Pp. 126-141.

Whitford, A.E. 1958. The law of interstellar reddening. *Astronomical Journal*, **63**:201-207.

Whitford, A.E. 1961. The distance to the Galactic Center from the photometry of objects in the nuclear region. *Publications of the Astronomical Society of the Pacific*, **73**:94-100.

Whitford, A.E. 1972. Astronomy and astronomers at the mountain observatories. *Annals of the New York Academy of Science*, **198**:202-210.

Whitford, A.E. 1978. Joel Stebbins: July 30, 1878-March 16, 1966. In *National Academy of Sciences of the United States of America: Biographical Memoirs*, **49**:293-316.

Whitford, A.E. 1986. A half-century of astronomy. *Annual Review of Astronomy and Astrophysics*, **24**:1-22.

David S. Liebl is on the faculty of the University of Wisconsin-Madison, Department of Engineering Professional Development. An amateur astronomer, his first view of the planets was as a child through the Washburn Observatory Clark refractor. He recently was awarded a Masters of Science-Astronomy by Swinburne University of Technology in Melbourne, Australia.

Dr Christopher Fluke is an astronomer with the Centre for Astrophysics and Supercomputing at Swinburne University of Technology in Melbourne, Australia. He has helped develop a virtual reality system for astronomy education, including writing, producing, and directing several short 3D movies about the Universe. He also teaches an Internet-based astronomy history course for Swinburne Astronomy Online.