The Lick Observatory: Building the Foundation of Astrophysics

Gordon L. Houston

Abstract. The emerging science of astrophysics began in the early nineteenth Century. Astronomy leading up to this moment was based on empirical observations and astrometry. Two distinct observational techniques changed astronomy and society forever: spectroscopy and astrophotography. These became the basic tools and instruments for the new science of astrophysics. The building of the Lick Observatory is an underappreciated event that impacted astronomy and astrophysics. Prior to this, astrophysics had three limitations: the instruments, the building, and the staff of astronomers. The building of the Lick Observatory changed all three and as a result built a solid foundation for the growth of modern astrophysics.

Short History of the Lick Observatory

Completed in 1888, the Lick Observatory (see Fig. 1), was named after the first benefactor to dedicate his estate to a scientific pursuit, James Lick.

Fig. 1. The Lick Observatory, entrance and the dome for the 36" Lick Refractor, with author Gordon Houston, prior to attending the Astronomical Society of the Pacific Annual Meeting. Taken 11 September 2009.

Gordon L. Houston, 'The Lick Observatory: Building the Foundation of Astrophysics', *Culture and Cosmos,* Vol. 27 no. 1, Spring/Summer 2023, pp. 261-274.
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The money was dedicated in his original Deed of Trust of 1874; it was fourteen years in the making. In 1876, James Lick died before the first stage of construction had begun. He was interred at the base of the telescope pier, at the appropriate stage of construction in early 1887, see Fig. 2.[1] The Great Lick 36" Refractor saw its first light on 3 January 1888. The observatory was completed and turned over to the University of California on 1 June 1888.[2]

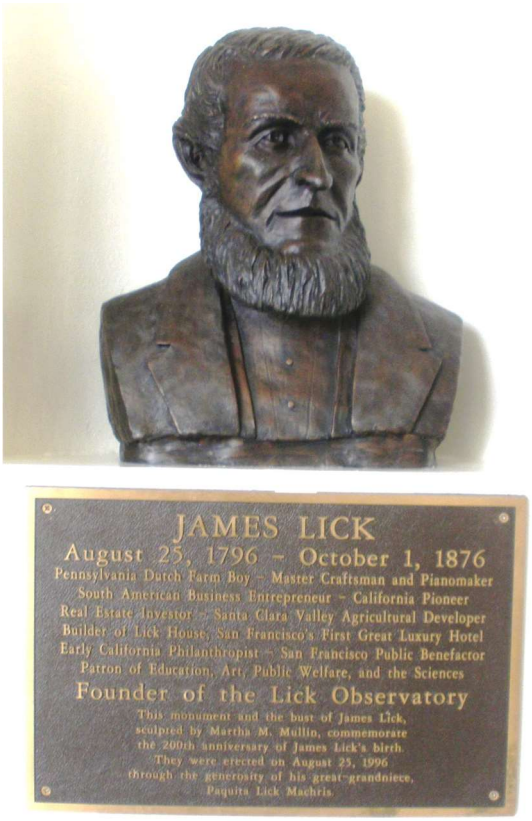

Fig. 2. James Lick bust, Lick Observatory. Date taken, 11 September 2009 by Gordon Houston.

[1] Donald E. Osterbrock, John R. Gustafson, and W. J. Shiloh Unruh, *Eye on the Sky, Lick Observatory's First Century* (Berkeley, CA: University of California Press, 1988), p.53.
[2] Kevin Krisciunas, *Astronomical Centers of the World* (Cambridge; Cambridge University Press, 1988). p.142.

Simon Newcomb, the leading astronomer in America in the late 1800s, and Edward Holden, the first Lick Observatory director, were instrumental in the planning stages. There were considerable issues involving the Lick Trust which are beyond the scope of this paper. The three main characteristics that Newcomb and Holden had significant input on were the site location and building, the instrument or telescope, and the initial staff. Site selection for the Lick Observatory was the first in the world to be undertaken with a goal of finding a location with favourable atmospheric conditions, what is known as astronomical 'seeing'.[3] After several locations were passed over, Mt Hamilton was chosen, but only after Newcomb and Holden had hired a noted double star observer, Sherburne W. Burnham.[4] He spent several months on top of Mt Hamilton and his report to the trustees – Newcomb, Holden, and Alvan Clark – made their decision very easy.[5] Burnham's report and the process of site selection became a standard for all future research observatories in the world.

Incorporated with the site selection was the design of the observatory building, which was mainly done by Edward Holden with advice from Simon Newcomb. It had to adequately house the instrument in the mountaintop environment, and include a well-stocked library for research and writing. Holden was a voracious writer and went on to establish the Astronomical Society of the Pacific and the Publications of the ASP.[6]

The Lick 36" refractor was the largest refractor in the world at the time of its completion. However, there was considerable debate over whether to build a refractor or a reflector. Newcomb travelled to Europe to survey the astronomy community about which type of telescope to build. The Scottish astronomer David Gill recommended a reflector, indicating that it would produce far more accurate and precise measurements. Newcomb had been in charge of the largest refractor in the world, the 26" Naval Observatory refractor.[7] The main issue that led to selecting a refractor was the state of manufacturing at the time. Many refractors existed in the world but reflectors still had not overcome inherent manufacturing issues such as the mirror coatings.[8]

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[3] Osterbrock et. al., *Eye on the Sky*, p.36.
[4] Osterbrock et. al., *Eye on the Sky*, p.35.
[5] Krisciunas, *Astro Centers of the World*, p.141.
[6] Katherine Bracher, 'A Centennial History of the Astronomical Society of the Pacific', *Mercury, The Journal of the Astronomical Society of the Pacific* XVIII, no. 5 (September/October 1989): pp.7–8.
[7] Osterbrock et. al., *Eye on the Sky*, p.19.
[8] Osterbrock et. al., *Eye on the Sky*, p.22.

Edward Holden had a goal of becoming the first director of the Lick Observatory early in the planning stages. He took steps to ensure this would happen. He went from military service to a professor at the Naval Observatory, assisting Simon Newcomb. He had such high energy and enthusiasm that Newcomb invited him in on the initial discussions of the construction of Lick Observatory. Later, he took the Director's position at the Washburn Observatory of the University of Wisconsin, as a career building step.[9]

Holden's experiences at both observatories gave him insight into the astronomical community and the skills of various astronomers. He recruited a highly talented and skilled initial staff, which included S.W. Burnham, E.E. Barnard, James E. Keeler, and John M. Schaeberle. W.W. Campbell was hired and took over the work of James E. Keeler, who left in 1891 to become the director at the Allegheny Observatory.[10] Detailed biographical sketches of each astronomer and their lasting impact on astronomy and astrophysics are given below.

Astronomical Research Before Lick

Astronomy before the building of the Lick Observatory was dominated by wealthy amateurs. Two factors drove this, the first being the cost of astronomical telescopes, and second, the lack of formal astronomical education. Telescopes of even modest size were out of the financial reach of the average person, so only wealthy people had the resources to acquire quality telescopes. These amateur astronomers mainly performed empirical observation of celestial objects, which included astrometry, the measurement of star positions. In the case of educational institutions, they had the financial resources for observatories with larger instruments, but these were located near the host institution and therefore had poor atmospheric and light conditions.

Astrometry was the astronomical practice dating back to the first cultures who observed the celestial sphere. The development of the telescope made these measurements much more precise, but still did not provide information on the physical nature of the stars and the fuzzy areas in the sky. The emergence of spectroscopy and the development of astronomical photographic methods began to change the science of astronomy. The building of the Lick Observatory brought all the pieces together, making a significant impact on astrophysics, albeit one that has been overshadowed and forgotten over time.

[9] Osterbrock et. al., *Eye on the Sky*, p.50.
[10] Krisciunas, *Astro Centers of the World*, p.143.

Development of Spectroscopy

The following is a timeline of the development of spectroscopy, condensed from Crowe.[11]

1. 1666 - Isaac Newton passed light through a prism, seeing an array of colours, i.e., the spectrum.
2. 1800 - William Herschel measured temperature changes at different points of the spectrum, discovering infrared radiation.
3. 1801 - J.W. Ritter discovers the extreme blue end of the spectrum, or ultraviolet radiation.
4. 1828 - Josef Fraunhofer describes 500 dark lines in the solar spectrum; light from planets and moons have the same dark lines. He discusses bright line spectra, which may correlate with the dark lines. He develops the diffraction grating, used instead of a prism for dispersing the light.
5. 1859 - Wilhelm Bunsen and Gustav Robert Kirchoff establish spectrum analysis on a rigorous basis. Kirchoff publishes a study of the chemical constitution of the Sun.
6. 1864 - Sir William Huggins uses a spectroscope with a telescope, showing that some nebulae are glowing gases as they produce bright line spectra, which indicates they are composed of gas at a very high temperature.
7. 1872 - Henry Draper makes the first spectrograph of a star, a photograph of the star's spectrum.
8. 1890 - Publication of the first Henry Draper Catalogue of 10,000 spectra in 7 spectral types: A, B, F, G, K, M, and N.
9. 1888 to 1891 - James E. Keeler designs a spectroscope to be used with the Lick Refractor, a combination superior to any spectroscopy to date.[12]

Development of Astrophotography

1. 1850 to 1876 - A variety of methods are used in various observatories.
2. 1871 - The introduction of dry plate astrophotography, a significant technological leap from other methods being employed.[13]
3. 1876 - Sir William Huggins uses the dry plate method to record spectra.
4. 1888 to 1890 - James E. Keeler uses the 36" Crossley Reflector for astrophotography, making a large reflector necessary for observatories.[14]

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[11] Michael J. Crowe, *Modern Theories of the Universe, From Herschel to Hubble* (New York: Dover Publications,1994), pp.179–83.

[12] Osterbrock, *Eye on the Sky*, p.72.

[13] Edward Emerson Barnard, 'The Development of Photography in Astronomy', *Science, New Series* 8, no. 194 (1898): p.345.

[14] Osterbrock, *Eye on the Sky*, p.127; Krisciunas, *Astro Centers of the World*, p.151.

Site Selection and Architecture

The Lick Observatory was the first mountaintop observatory, the site being selected for its optimum atmospheric 'seeing' conditions. Newcomb and Holden employed S.W. Burnham, an expert double star observer to do a site evaluation. He met Alvan Clark in 1869, who was visiting Chicago, and ordered a 6" Clark refractor.[15] Burnham discovered over 400 new double stars, so he became a well-known 'amateur astronomer'. He started using the 18.5" Dearborn refractor in Chicago, the largest in the world in the 1860's. Burnham had spent weekends at the Washburn Observatory, with Holden as director, for better observing conditions.[16] He spent two months on Mt Hamilton observing and his report convinced the Lick Trustees, Newcomb, and Holden that the site was suitable (see Fig. 3).

Fig. 3. The Lick Observatory atop of Mt Hamilton. Date taken, 11 September 2009 by Gordon Houston.

Mt Hamilton is at an elevation of 4250 feet and is the tallest peak in the region, so views were unobstructed and meant less atmosphere to observe

[15] Osterbrock, *Eye on the Sky*, pp. 35–36.

[16] Peter Susalla and James Lattis, *Wisconsin at the Frontiers of Astronomy: A History of Innovation and Exploration* (Madison, WI: University of Wisconsin-Madison, Wisconsin Blue Book, 2009-2010), p.13.

through. The location was above the thermal layer, providing excellent 'seeing'. Burnham reported excellent observing conditions on 49 out of 60 nights due to low humidity. The number of clear nights meant substantially more observing could be accomplished. Thus, more could be accomplished by a small staff compared to some of the big observatories in the east.[17] The bedrock or 'trap' rock provided stable footing for the telescopes. If only everyone had listened to Isaac Newton, when he made the following recommendation:

> Telescopes... cannot be formed so as to take away that confusion of rays which arises from the tremors of the atmosphere. The only remedy is a most serene and quiet air, such as may perhaps be found on the tops of the highest mountains above the grosser clouds.[18]

The Instruments

The Lick 36" Refractor (see Fig. 4), was the largest refracting telescope in the world when completed.

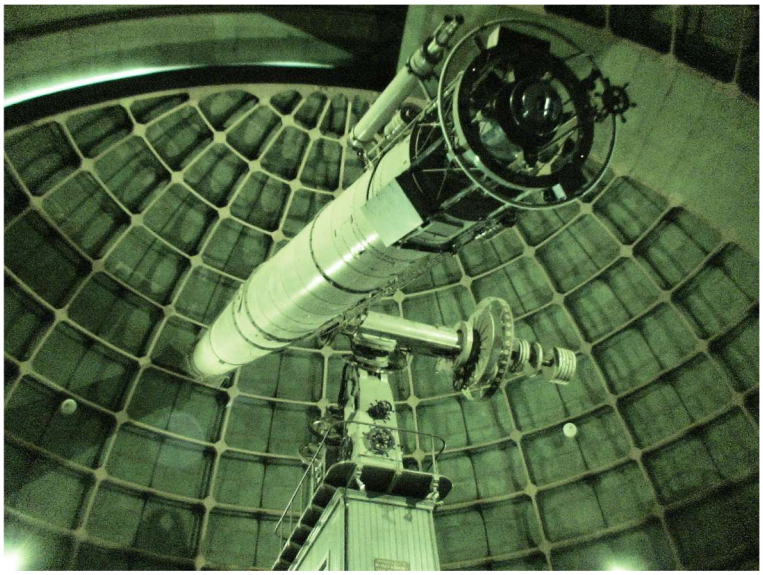

Fig. 4. The Lick 36" Refractor. Date taken, 11 September 2009 by Gordon Houston.

[17] H. F. Newall,' Notes on Visits to Some American Observatories', *The Observer* 14, no. 174, (1891): p.155.

[18] Sir Isaac Newton, in his *Opticks*, 1730.

It proved that larger instruments coupled with superior cameras and spectroscopes produced superior science results. There were larger reflecting telescopes than the Crossley Reflector (see Fig. 5) but when paired with astrophotography, it set a standard that all observatories adhere to today.

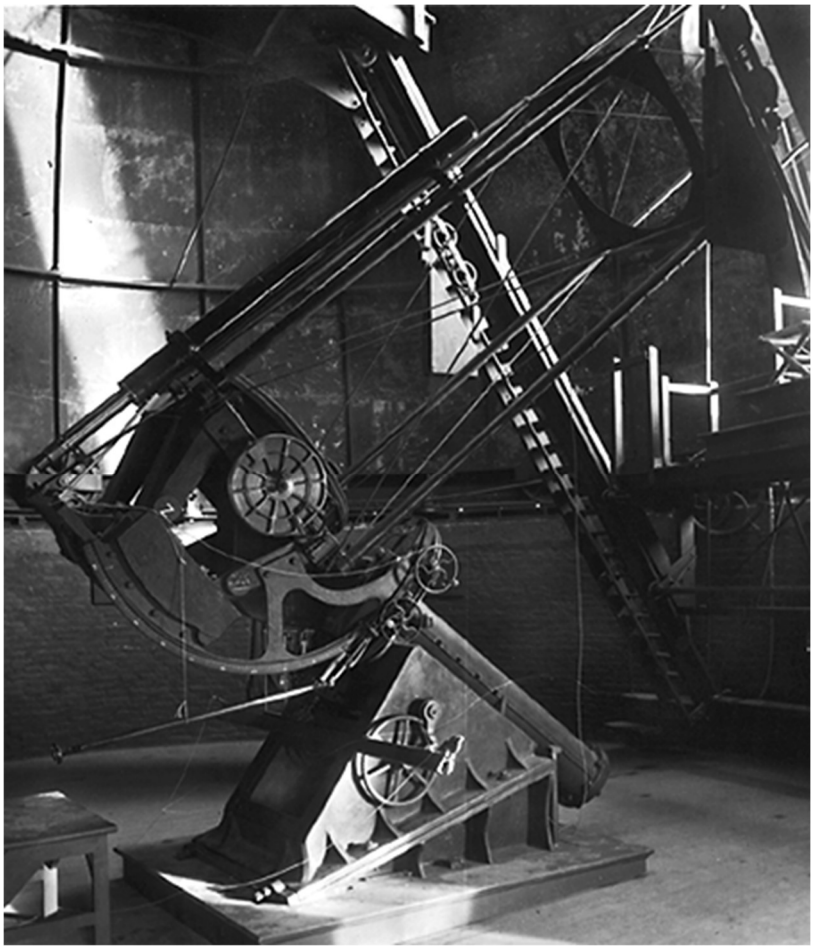

Fig. 5. The Crossley Reflector. Photo: UC Observatories Mary Lea Shane Archives.

George Ellery Hale asked the astronomical community the best telescope to build prior to constructing the Wilson Observatory. Edward James Pickering of the Harvard College Observatory said: ‘The work of Keeler

and the 36-inch Crossley Reflector... made the large reflector a necessity for any serious work in an observatory'.[19]

The Staff

The final aspect of lasting significance of the building of the Lick Observatory was the assembling of a professional staff to be dedicated to astronomical research. It was the staff whose education, experience, and individual expertise enabled Lick Observatory to have such an impact on the new science of astrophysics. The original staff included Edward S. Holden, James E. Keeler, Burnham, Barnard, and Schaeberle, and assistant astronomer Hill. W.W. Campbell joined the Lick staff in 1891 when Keeler resigned. The following sketches of each detail the impact of a highly qualified observatory staff.

Edward S. Holden

The first director of the Lick Observatory, Holden, designed it along with Simon Newcomb. He recruited the first staff of astronomers with each having skills in complimentary areas of astronomical research. He wrote constantly, much of which was published for the general public. In this regard he substantially heightened the awareness of astronomy.[20] He pioneered lunar astrophotography with the Lick Refractor. His most lasting legacy, one of which is still a major contributor to the science and education of astronomy today, was the formation of the Astronomical Society of the Pacific. All of the staff astronomers were charter members.[21]

Holden's interest in astronomy started early, as a cousin by marriage, George Bond, was Director of the Harvard College Observatory. He first attended Washington University Academy, where he studied astronomy and mathematics. He then received an appointment to West Point and after a year of active duty, he resigned and became a professor of mathematics in the U.S. Navy, assigned to the Naval Observatory, working for Simon

[19] Edward Singleton Holden, 'Mountain Observatories', *Publications of the Astronomical Society of the Pacific* 5 (1889): p.101.
[20] F.J. Neubauer, 'A Short History of the Lick Observatory', *Popular Astronomy*. LVIII, no. 7, (1950): p.319
[21] Andrew Fraknoi, 'Celebrating the Astronomical Society of the Pacific's 120th Anniversary: Some Glimpses from our Past', *Astronomy Beat* 15 (29 January 2009): ASP, p.1.

Newcomb.[22] Simon Newcomb was the leading American astronomer of the time.[23] As discussions began about the possibility of the Lick Observatory, he decided that from then on he would do everything to become the first director. He left the Naval Observatory to become the Director of the Washburn Observatory at the University of Wisconsin. Washburn had a 15" refractor, which was a large step down from the 26" refractor he had used at the Naval Observatory, but he was in charge and directed the science efforts.

As the first Director, Holden was responsible for assembling what was the most talented staff of astronomers of the day. The original staff included Holden, Burnham, Schaeberle, Keeler, and Barnard.[24] In describing the staff, Newcomb said they 'immediately became well known in astronomy, owing to the excellence of their work'.

His military background was a double-edged sword. He had great discipline and organizational skills, but his people management skills were lacking, and that led to the departure of two of the key astronomers, Burnham and Barnard. Fortunately, he was able recruit new staff astronomers who were equally talented in astronomical research. The tensions amongst the staff continued and Holden was dismissed as Director in 1897.[25]

James E. Keeler

Keeler was the only trained and educated astrophysicist of the initial staff, having a degree in physics and astronomy from John Hopkins University.[26] He was considered the outstanding astrophysicist of the late nineteenth Century. He was an expert visual observer and a pioneer in spectroscopy.[27] He left on good terms with Director Holden, and went on to become the director at the Allegheny Observatory in 1891.[28] He replaced Samuel

[22] Peter Wlasuk, 'Edward Singleton Holden', in *Biographical Encyclopedia of Astronomers*, eds T. Hockey, V. Trimble and T.R. Williams (New York: Springer Science+Business Media, LLC., 2007), pp.518–19.
[23] Osterbrock et. al., *Eye on the Sky*, p.70.
[24] Osterbrock et. al., *Eye on the Sky*, p.68.
[25] Osterbrock et. al., *Eye on the Sky*, p.105.
[26] Glenn Walsh, 'James Edward Keeler', in *Biographical Encyclopedia of Astronomers*, eds T. Hockey, V. Trimble and T.R. Williams (New York: Springer Science+Business Media, LLC., 2007), pp.616–18.
[27] Donald E. Osterbrock, 'James E. Keeler, Pioneer Astrophysicist', *Physics Today* (February 1979): pp.40–47.
[28] William Wallace Campbell, 'James Edward Keeler', *Astrophysical Journal* XII, no. 12 (1900): p.243.

Langley, with whom he had done astrophysical research, when Langley stepped down as director of the Allegheny. Keeler returned to the Lick Observatory as the second Director in 1898, after Edward Holden.

His spectroscopy work with the 36" Lick Refractor, measuring the radial velocity of three stars, produced results comparable to modern-day measurements. He determined the chief nebular line at the wavelength of λ5007, the radial velocities of the Orion nebula, and he identified the forbidden' lines in nebulae, called nebulium at the time.[29] He discovered the change in wavelengths of the nebular lines, which he attributed to the Doppler Effect and the different speeds of gas in the nebulae. He also realized that there were four distinct spectral lines in nebula which were not common to stellar spectra.[30] This may have been the first observational evidence of the nature of the spiral nebulae.

Keeler's photography with the Crossly Reflector was maybe the most important, causing a shift from refractors to reflectors, thereby changing astrophysics research forever. His photographs of the 'nebulae' revealed uncatalogued objects in great numbers, and he discovered that over half were in the form of spirals. Keeler described this as the 'law of spiralty'.[31] He estimated as many as 120,000 if he had photographed the whole sky.[32]

Keeler was a big influence on George E. Hale, with whom he co-founded The Astrophysical Journal, still the flagship journal of professional astrophysics. He was also a founding member of the Astronomical Society of the Pacific and the American Astronomical Society, being elected as a member of the first permanent Council.[33] Keeler has been described as the outstanding American astrophysicist of his generation.[34]

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[29] J. H. Moore, 'Fifty Years of Research at the Lick Observatory', *Publications of the Astronomical Society of the Pacific* 50, no. 296 (1938): p.193.
[30] Osterbrock, 'James E. Keeler', pp.40–47.
[31] Agnes M. Clerke, *Problems in Astrophysics* (London: Adam and Charles Black, 1903), p.177.
[32] Marcia Bartusiak, *Archives of the Universe* (New York: Random House, 2008), p.418.
[33] David DeVorkin, *The American Astronomical Society First Century* (Washington, DC: The American Astronomical Society, 1999), p.48.
[34] Donald E. Osterbrock, 'Contributions of James E. Keeler to Planetary Research', Abstract 13.03 AAS Annual Meeting 1981, p.815.

Edward Emerson (E.E.) Barnard

Having bought a 5" refractor at the age of 20, E. E. Barnard was a self-taught astronomer who had sharp visual observational skills. That same year, he met Simon Newcomb, who was attending a science conference in Nashville, Tennessee, and who told him to be grounded in mathematics. Prior to coming to the Lick Observatory, he had worked in a photography shop for seventeen years, starting from the age of nine. This built a broad basis for his expert astrophotography.[35]

Barnard was one of the most prolific discovers of comets in the 19th Century.[36] He discovered the first comet by photography with the Lick Refractor. His photographs of the structure and rapid changes of comets from night to night demonstrated the advantages of the wide-angle lens in astrophotography, which is considered to be his most notable contribution to astronomy.[37] He discovered the fifth moon of Jupiter with the Lick Refractor, the first to be discovered since Galileo discovered the first four.[38]

However, he is most noted for his photography of the Milky Way, which was started while he was at the Lick Observatory, and which is considered the best celestial photography up to that time. He had also discovered the dark extended interstellar absorption regions in the Milky Way, which later became classified as Barnard dark nebulae.[39] He left Lick in 1895, mainly due to a conflict with Director Holden, and joined George E. Hale at the Yerkes, completing a dark Nebulae catalogue. At Yerkes, he mentored Edwin Hubble in astrophotography using the 24" reflector.[40]

Sherburne W. Burnham

Residing in Chicago, Burnham was an amateur astronomer and expert double star observer. In 1876, he became the acting director of the

[35] Edwin B. Frost, 'Edward Emerson Barnard', *Astrophysical Journal* LVIII, no 1 (July 1923): p.2.
[36] William Sheehan,' Edward Emerson Barnard', in *Biographical Encyclopedia of Astronomers*, eds T. Hockey, V. Trimble, and T.R. Williams (New York: Springer Science+Business Media, LLC., 2007), pp.96–98.
[37] Moore, 'Fifty Years of Research at the Lick Observatory', p.192.
[38] Osterbrock, *Eye on the Sky*, pp.80–81.
[39] Sheehan, 'Edward Emerson Barnard', pp.96–98.
[40] *Yerkesweb*, Yerkes Observatory homepage, http://astro.uchicago.edu/yerkes/, [accessed 2 April 2010].

Dearborn Observatory, working without pay.[41] In the early 1880s he spent weekends at the Washburn Observatory in Madison, Wisconsin, to take advantage of the clear skies. Edward S. Holden was the director of the Washburn Observatory at that time. Burnham owned a 6" Alvan Clark & Sons refractor, made by the same company that figured the lens on the 40" Lick Refractor. He was employed to do the site evaluation at Mt Hamilton. His report to the Lick Trustees is an essential guide of site evaluation for all future observatories.

He was hired by James Holden and he continued his double star observations at Lick. His relationship with Director Holden became strained, so in 1892 he returned to Chicago as clerk for the U.S. District Court until 1902.[42]

He continued to visit the Dearborn Observatory and was appointed professor of astronomy at the University of Chicago, pending the opening of the Yerkes Observatory. He continued his double star observations, creating an extensive double star catalogue. Many of these observations were of short period doubles, leading to an early understanding of the masses of stars.[43]

John M. Schaeberle

Schaeberle was a civil engineer schooled at the University of Michigan. He excelled at visual observations and was adept at making instruments. His main duty was meridian circle observations, but was instrumental in designing the 40-foot Schaeberle Camera.[44] The camera was used to photograph the corona of the Sun during several solar eclipse expeditions, which were the best photographs of the corona ever produced. Solar physics was new astrophysics at the time, so the impact on his observations was very significant for the time. He discovered and observed the second ever white dwarf, the companion of the star Procyon, with the first being Sirius B discovered by Alvan Clark.[45]

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[41] Unknown, *Dearborn Observatory Pamphlet* (Evanston, IL: Northwestern University, 2017), p.4.
[42] Sheehan, 'Edward Emerson Barnard', pp.96–98.
[43] Sheehan, Edward Emerson Barnard, pp.96–98.
[44] Patricia S. Whitesell, 'John Martin Schaeberle', in *Biographical Encyclopedia of Astronomers*, eds T. Hockey, V. Trimble, and T.R. Williams (New York: Springer Science+Business Media, LLC., 2007), pp.1015–017.
[45] Whitesell, 'John Martin Schaeberle', p.1016.

W. W. Campbell

Campbell was an engineer, educated at the University of Michigan, who studied astronomy under Professor John M. Schaeberle. He learned spectroscopy from James Keeler while volunteering at the Lick during the summer of 1890. Director Holden took notice of his hard work, and he was hired permanently when Keeler left to become the director at the Alleghany Observatory. Campbell took over the spectroscopy work of Keeler. He found visual spectroscopy limiting and designed the Mills Spectrograph. He became the world's leading spectroscopist, surpassing all others, including Keeler himself.[46] Most notable was his observation of variable radial velocities, which led to the discovery of spectroscopic binaries.

Campbell became the third Director of the Lick Observatory when James Keeler passed away. Lick continued with the spectroscopic work. As Director of the Lick Observatory, he created a southern hemisphere observatory with a second Mills spectrograph. During his tenure as Director of Lick, the most complete set of radial velocities ever produced was created, which included 339 spectroscopic binaries.[47]

Conclusions

The building of the Lick Observatory was a significant moment in astronomy, advancing the new science of astrophysics in a way that is under-appreciated today. Pioneering work was done that set the standard for astrophysics research that still influences researchers today. Lick Observatory showed that advanced instruments used with large telescopes produced excellent science. The selection and placement of the Lick Observatory produced more science in a shorter period of time, with a small staff than had been ever produced before. As a testament to this, the Lick Observatory is still a significant research observatory, whereas most observatories built before the Lick are only historical facilities.

[46] Joseph S. Tenn, 'William Wallace Campbell', in *Biographical Encyclopedia of Astronomers*, eds T. Hockey, V. Trimble, and T.R. Williams (New York: Springer Science+Business Media, LLC., 2007), pp.195–97.

[47] Moore,' Fifty Years of Research at the Lick Observatory', p.196.