

The Rise and Fall of Astrophotography

Dr. Joseph S. Tenn

Department of Physics and Astronomy
Sonoma State University
Rohnert Park, California

HONORABLE MENTION

HUGHES GRIFFITH OBSERVER CONTEST
1987

Dr. Joe Tenn's carefully crafted articles seem to be able to win a prize in the annual Hughes Aircraft Company Science Writing Contest any time he chooses to enter, and his students have occasionally won prizes, too. This heartens our outlook on higher education in America and provides interesting and unusual material for readers of this magazine. His last article, "Simon Newcomb, a Famous and Forgotten American Astronomer," appeared in the November, 1987, issue of the *Griffith Observer*, almost two years ago. It was saddled with several errors imposed by the editor, not the author, and we hope this time we have given Dr. Tenn's most recent contribution more reliable preparation for print. His attention this time is fixed on the development of astrophotography.

On the occasion of the January, 1987, American Astronomical Society meeting in Pasadena, visiting astronomers were invited to tour the Palomar Observatory. The five-meter telescope, towering five stories above us, looked as imposing as ever, although it had been in operation nearly four decades and was no longer the world's largest.

The real surprise, to this visitor at least, was that the telescope is no longer used for photography. Most of the darkrooms have been converted to other purposes. According to the superintendent, it has been at least three years since the last photograph was taken for research purposes with the Hale telescope. A call to Eugene Harlan at the Lick Observatory brought similar news. Photography was scheduled at the three-meter Shane telescope for only three nights in 1986.

At these and other large telescopes, information is now recorded with charge-coupled devices (CCDs) and other electronic devices and transferred into computers in digital form. The astronomer of a few years ago descended from the mountain with the night's results visible on a glass photographic plate; today's astronomer brings back magnetic tape containing billions of bits which only a computer can read.

The reign of astrophotography was a short one. Little more than a century has elapsed since

the first serious uses of chemical emulsions for professional research. Less than fifty years earlier the first crude experiments suggested the possibility that astronomical information might be recorded photographically.

Daguerreotypes

Astronomers were involved with photography from its beginning. It was the French astronomer Francois Arago who made the first public announcement of the invention of the daguerreotype on January 7, 1839. Within the month, the great British astronomer, chemist, and mathematician John Herschel had duplicated the process and made a photograph of his father's 40-foot telescope.

Louis Daguerre, building partly on the work of amateur lithographer Joseph-Nicephore de Niepce, had found a way to fix an image on an iodized silver plate. Workers in Britain and France had been trying for years to preserve images with silver salts, long known to be sensitive to light. Drawings, leaves, and other objects had been silhouetted on paper, leather, or metal coated with solutions, but when the images were exposed to more light, they faded away. Daguerre had found that bathing the exposed plate in mercury vapor caused the shiny mercury to coat the portion of the plate which had been affected by light. A salt solution washed away the remaining silver iodide,

The GRIFFITH OBSERVER (ISSN 0195-3982) is a publication of the Griffith Observatory, which is operated by the Board of Recreation and Park Commissioners of the City of Los Angeles. established in 1937, the OBSERVER strives to present astronomy and related subjects in such a manner as to stimulate and maintain an enduring interest in the physical sciences. All submitted articles and observational results will be considered for publication in an effort to encourage an active and progressive participation in the subject.

Editor-in-Chief: Dr. E. C. Krupp
Contributing Editor: John Mosley
Circulation Editor: Barbara Hoekendorf
Published monthly — © 1989 Griffith Observatory
Observatory program information: (213) 664-1191
Observatory offices: (213) 664-1181
Sky Report: (213) 663-8171

U.S. subscriptions — \$12.00 for one year
2800 East Observatory Road, Los Angeles, California 90027
Application to mail at second class rate is pending at Los Angeles, CA
Printed by the Los Angeles City Printing Services

and a metallic "daguerreotype" retained the image.

In France, Arago immediately foretold the future of photography in astronomy: It would be used to preserve images, of course, and also for photometry (the measurement of brightness) and spectroscopy. This last proposal was especially prescient, as it was still two decades before Kirchhoff and Bunsen would show the significance of Fraunhofer's dark lines in the spectrum of the sun.

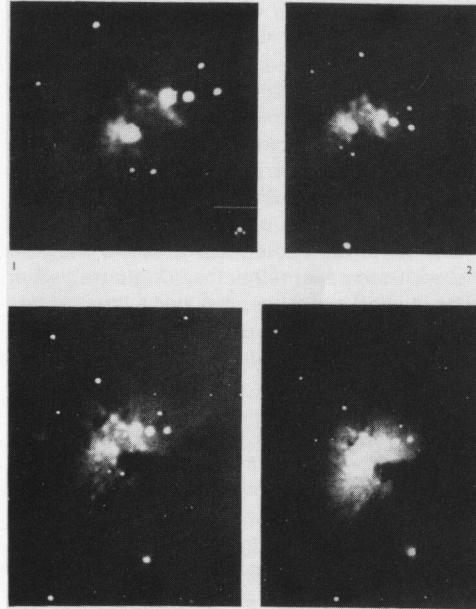
In England, Herschel showed that sodium thiosulphate is a much better fixer than salt, coined the terms "positive" and "negative," and was one of the first to call the new process "photography." He and his friends, notably William Henry Fox Talbot, made many improvements in the process.

The first astronomical photograph, however, was made in America. After the details of Daguerre's process were revealed, again by Arago, a number of amateurs began experimenting. John William Draper, professor of medicine at New York University and an experienced experimenter with both light and chemistry, quickly improved the sensitivity of the process. By March, 1840, he had the first image of the moon to show any details. Exposure time was twenty minutes. Within three years he was using photography to discover new spectral lines in the infrared and ultraviolet.

Other Americans joined in. In 1847, Harvard College Observatory acquired one of the two largest telescopes in the world, the 15-inch Great Refractor, made in Munich and twin to the instrument at Pulkovo, Russia. With the aid of professional photographer John A. Whipple, Harvard astronomers William and George Bond made the first photograph of a star on July 16, 1850. It took a 100-second exposure to get that image of Vega. That same year they made daguerreotypes of the moon so good that they were awarded a prize medal at the Crystal Palace exposition in London.

The following year they obtained the first photograph of a planet. Much to their surprise they found that Jupiter, which receives only one twenty-seventh as much sunlight as the moon, requires about the same exposure. They had discovered that the giant planet is much more reflective than the earth's satellite.

In the meantime, the French physicists Leon Foucault and Louis Flzeau, under the urging of



*As astronomers grew more experienced and skilled with photography, photographs of celestial objects improved and showed more detail. Here is a sequence of photographs of the Orion nebula, recorded on gelatin dry plates. The first (upper left) was taken by Henry Draper on 30 September 1880. The picture required 51 minutes of exposure. On 11 March 1881, Draper's 104-minute exposure with the same telescope — his 11-inch refractor — provided the image in the upper right. More nebulosity and more stars have been captured on the plate. Henry Draper continued to work at this business, and the photograph in the lower left was taken by him on 14 March 1882. This time he exposed the plate for 131 minutes. The last picture of this set was taken by William H. Pickering, on 28 August 1889, with the 13-inch refractor at the temporary station of Harvard Observatory on Mount Wilson. We begin to see the Orion nebula we know from pictures. (illustration courtesy Dr. Gerard de Vaucouleurs, *Astronomical Photography: From the Daguerreotype to the Electron Camera*)*

the ubiquitous Arago, had made daguerreotypes of the sun adequate to reveal sunspots though not yet good enough to show limb darkening. Here the problem was too much light. Early daguerreotypes of the sun were all overexposed until sufficiently fast shutters were developed. As early as 1847, John Herschel was calling upon astronomers to photograph the sun daily and to make systematic studies of sunspots.

Perhaps the last significant achievement made with daguerreotypes was the first photograph of a solar eclipse, made by the professional photographer Berkowski with the Konigsberg heliometer on July 28, 1851. Prominences and the inner corona could be seen. That same eclipse saw Italian astronomer Angelo Secchi, using both daguerreotypes and the silver chloride process invented by Fox Talbot, finally prove the existence of limb darkening. Called the calotype or photogenic process, the new method used paper rather than Daguerre's silver plate. A short exposure produced a latent image which could be developed later. A major advantage over the daguerreotype was that copies could be made.

The Wet Plate Era

Both processes were made obsolete by the wet collodion method introduced in 1851. Following a suggestion by the Frenchman G. Le Gray, the English sculptor Frederick Scott Archer invented the wet collodion process. Now glass negatives could preserve as much detail as daguerreotypes and could be used to make any number of prints. The prints could even be enlarged.

The only drawback was that the plates had to be prepared immediately before use. A dangerous solution of guncotton in alcohol and ether was painted on the glass and saturated with silver salts.

It was sensitive to light until it dried, a matter of ten minutes or so. The wet collodion was the first method sensitive enough for short exposures of sunlit terrestrial scenes. It gave us the Civil War photographs of Mathew Brady and the celebrated portraits by Julia Margaret Cameron.

In astronomy the new method caught on quickly. George Bond at Harvard, using a new driving clock built by Alvan Clark and Sons and encouraged by the "fast" new plates, resumed astrophotography. He pioneered the photographic measurement of stellar positions (astrometry) and magnitudes (photometry).

It is difficult to recall how tedious astronomy was at that time. Astronomers painstakingly measured stellar positions with transits and meridian circles. They drew maps of star fields and nebulae, and they estimated magnitudes by eye. No wonder it was difficult to tell whether a nebula had really changed since the making of a previous sketch decades earlier. The variability of certain stars was known, but

estimates of fractions of a magnitude made by different observers or by the same observer at different times were always suspect. Now photographs provided an unbiased permanent record which could be compared with later photographs or measured under a microscope at leisure.

In England, the wealthy amateur Warren de la Rue, inspired by the Harvard photographs, built a 13-inch reflector and began photographing the moon in 1852. By the 1860s excellent lunar photographs were almost common. New Yorkers Henry Draper (son of John William) and Lewis Rutherfurd contributed some of the best. De la Rue even took advantage of the moon's libration to make stereoscopic pictures which showed the mountains and craters in three dimensions.

Staked to a new specially-designed instrument by the Royal Society, de la Rue photographed the sun daily from 1858 to 1872 (after which the Royal Greenwich Observatory took up the task). Within a few years there were statistical studies of sunspot activity. It seemed miraculous at the time that a photograph made in a fraction of a second could record more detail than a skilled observer sketching at the telescope for hours.

Perhaps de la Rue's greatest triumph occurred at the July 18, 1860, eclipse, for which he took his heliometer to Spain. His photographs provided conclusive evidence that the prominences were part of the sun and not the moon's atmosphere. There was even a huge prominence in the photographs which could not be seen by eye. Physicist Michael Faraday exclaimed, "Photography could therefore render evident to us phenomena of the sun which the human eye could not discern."¹

It was during this period that photography began to cause changes in telescopes. Professional astronomers used only refractors, but de la Rue and other amateurs were achieving good results with reflecting telescopes. The achromaticity of the reflector compensated for its difficulty of use. Early astrophotographers who used refractors began adding additional lenses so as to bring the shorter wavelengths to a focus at the plate holder. The short blue and violet waves were found to have a stronger effect on the emulsion than the longer yellow and red rays. Rutherfurd was one of the first to so adapt his refractor. He also built one of the first measuring machines in order to measure relative positions

of stars on his photographs. By 1865 he predicted that it would be possible to map the sky with photography as soon as more sensitive emulsions could be developed. He lent his 11½-inch lens to Benjamin A. Gould for use in a photographic survey of the southern sky to be made from Cordoba, Argentina.

Rutherford made the first photograph of "rice grains" on the surface of the sun in 1871. His photographs of the sun's spectrum won wide praise.

The other prominent New York amateur, Henry Draper, scored one notable first in the wet-plate era: In 1872, he obtained the first photograph of the spectrum of a star (Vega) to show absorption lines.

There were failures, too. Photographs of the transit of Venus in 1874 failed to allow an accurate determination of the times of contact, data which were essential for use of the event to determine the distance of the sun. Many professional astronomers were still convinced that a skilled observer's eye was better than a camera at the end of a telescope.

The Gelatin Dry Plate

The 1870s saw the final revolution. While dry collodion had been around for a few years, it had never achieved adequate sensitivity for astronomical use. Now chemists developed dry emulsions of silver bromide dissolved in gelatin and found ways to increase their speed. In 1879, George Eastman built the first machine to coat glass plates with the new emulsions automatically. The man who would found Eastman Kodak had begun the era of mass photography.

The gelatin dry plate appeared truly wonderful to astronomers. It was fast! A brightly-lit terrestrial scene required a 30-minute exposure on the daguerreotype of 1840; it took ten seconds with the wet collodion plate. Now it could be photographed in 1/15 of a second. It was convenient, too. No longer did the astronomer need a chemical laboratory in the observatory. The new plate could be prepared in advance, stored for lengthy periods, and, unlike its quickly-drying predecessor, exposed for hours.

Again the amateurs led the way. In 1880, Henry Draper made the first photographs of the Orion nebula. He used his 11-inch Clark refractor, specially focused for photography, rather than his homemade 28-inch reflector for this work,

but the most important tool was the driving clock. He built seven clocks before achieving one which could keep an object in the center of the field for an hour. In the remaining year and a half of his life he surpassed that first photo several times, but his work was soon made obsolete by the superb photographs of Andrew Common.

Another of the wealthy English amateurs who contributed so much to nineteenth century science, Common built a number of reflectors, including one 36 inches in diameter which is still in use.²

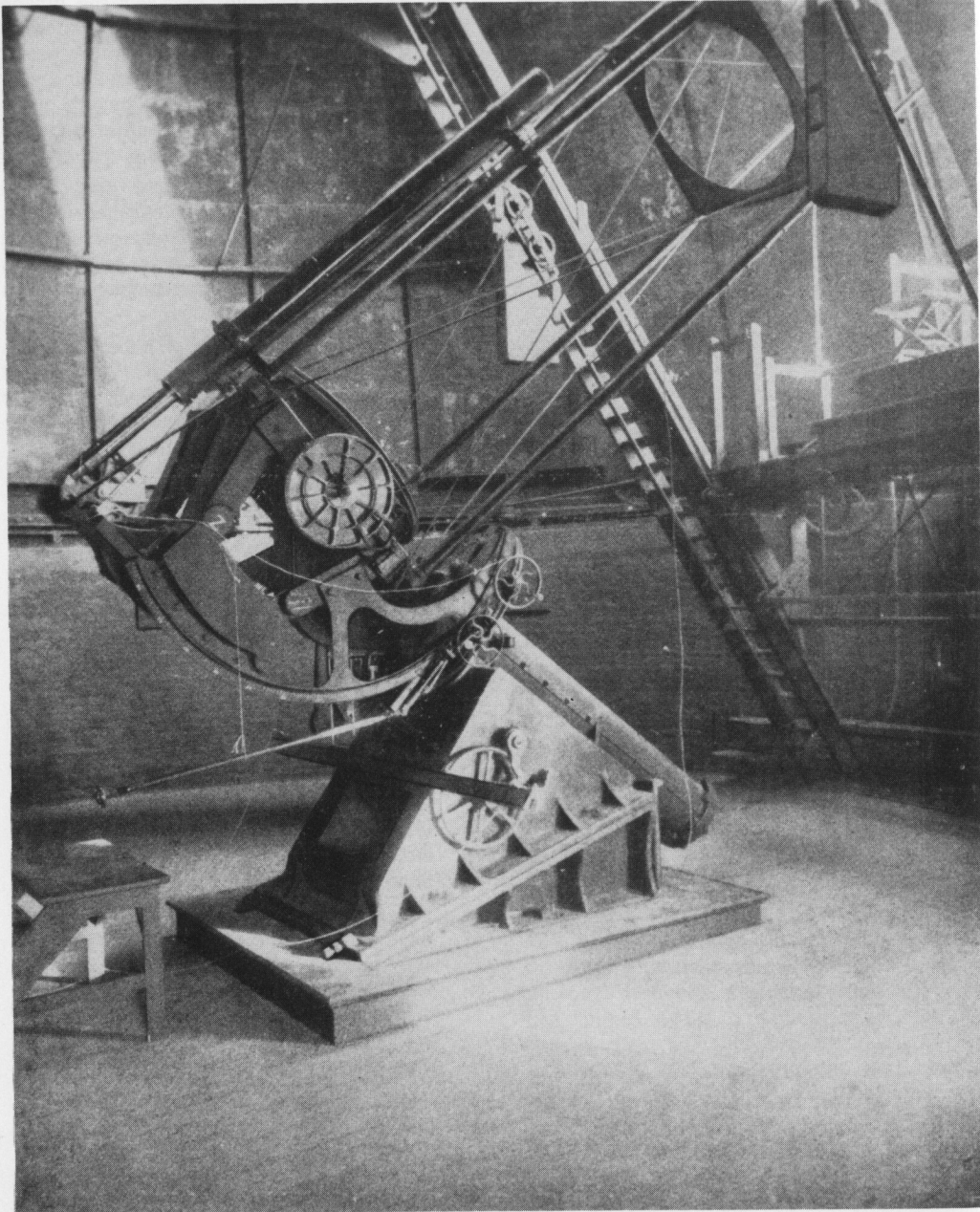
His photographs of the Orion nebula won him the Gold Medal of the Royal Astronomical Society in 1884. That year David Gill, Her Majesty's Astronomer at the Cape of Good Hope, pointed out the significance of this work:

No hand of man has tampered with these pictures. They have a value on this account which gives them a distinct and separate claim to confidence above any work in which the hand of fallible man has had a part.

The standpoint of science is so different from that of art. A picture which is a mere copy of nature, in which we do not recognise somewhat of the soul of the artist, is nothing in an artistic point of view; but in a scientific point of view the more absolutely that the individuality of the artist is suppressed, and the more absolutely a rigid representation of nature is obtained, the better.

Here is a volume compiled by one of the most energetic and able of American astronomers — Prof. Holden. It contains faithful reproductions of all the available drawings that have been made by astronomers of this wonderful nebula of Orion from the year 1838 to recent times.

If now we were to suppose one hundred years to elapse, and no further observation of the nebula of Orion to be made in the interval; if in some extraordinary way all previous observations were lost, but that astronomers were offered the choice of recovering this photograph of Mr. Common's or of losing it and preserving all the previous observations of the nebula recorded in Prof. Holden's book — how would the choice lie? I venture



A.A. Common, well known for his superior astrophotography in the 1880s, also built this 36-inch reflector, which is now installed at Lick Observatory on Mount Hamilton, California. The telescope was built in 1879. Andrew Crossley purchased it from Common in 1885 and donated it to Lick in 1895, seven years after the Observatory had opened. Here it is shown at Lick Observatory before a new mount was constructed for it in 1905. Last year, by the way, was the one hundredth anniversary of the founding of Lick Observatory, whose contributions in astrophotography and its successors have been considerable. (Publications of Lick Observatory, Vol.. VIII, 1908, p. 16)

to say that the decision would be — Give us Mr. Common's photograph.³

The last of the great amateur pioneers of astronomy was the Englishman Isaac Roberts. His twenty-inch f/5 silver-on-glass reflector was completed in 1885. He abandoned his plan to make photographic charts of the entire northern sky when the professionals began work on it. "But other fields for photographic work are open with ample room for all who choose to labour in them," he noted, and he went on to make a systematic survey of nebulae and star clusters. On October 1, 1888, his three-hour exposure of the great nebula in Andromeda revealed its spiral structure for the first time. His beautiful 1893 book, *A Selection of Photographs of Stars, Star-Clusters and Nebulae, together with information concerning the instruments and the Methods employed in the pursuit of Celestial Photography*, contains in its preface

The photographs portray portions of the Starry Heavens in a form at all times available for study and identically as they appear to an observer aided by a powerful telescope and clear sky for observing.

Absent are the atmospheric tremors, the cold observatory, the interrupting clouds, the straining of the eyes, the numbing of the limbs, the errors in recording observations, and the many hardships incurred by our predecessors, of glorious memory, in their attempts to see and fathom the ILLIMITABLE BEYOND.

Another volume of his magnificent photographs was published many years later by his widow, the San Francisco-born Paris Observatory astronomer, Dorothea Klumpke-Roberts.⁴

The Professional Era

By the mid-1880s, the professionals were taking over. David Gill observed a "splendid" comet in 1882. He reported later

At the Royal Observatory, Cape of Good Hope, we were not at the time engaged in photographic operations. Several photographers in the Cape Colony found it possible to obtain impressions of the comet, but they were unable to secure pictures of scientific value, because they were unprovided with means to follow the

diurnal motion. I had no available camera belonging to the observatory, and no experience in the development of modern dry plates. In these circumstances, I applied to Mr. Allis, a skillful photographer in my neighborhood, who eagerly consented to cooperate with me in the work. I arranged means to attach his camera to the stand of an equatorial telescope, and the telescope itself was employed to follow the nucleus of the comet accurately during the whole time of exposure by the aid of the driving clock and with small corrections given by hand.

...In forwarding copies of these photographs to the Royal Society of London and to the Paris Academy of Sciences, I drew particular attention to the large number of stars shown upon the plate, and insisted upon the importance of the means thus offered to photograph comparatively large areas of the sky and thus rapidly make charts of the entire heavens.⁵

Gill became one of the most important advocates of systematic use of photography for cataloging the sky. By 1885, he had acquired funding from the Royal Society and begun a photographic survey of the southern sky. He soon joined in other innovations: International collaboration and the separation of observation from plate reduction. Groningen astronomer J. C. Kapteyn, lacking a telescope and hampered by the perennial clouds of the Netherlands, volunteered to establish a laboratory and to measure Gill's plates. Working thousands of miles from the observatory, Kapteyn went on to become one of the world's most prominent astronomers. Soon others, notably a talented group of women at Harvard, were making contributions to astronomy without spending nights at the telescope.

In France, the brothers Paul and Prosper Henry were taking astrophotography a giant step further. They had been mapping the sky in the old fashioned way, painstakingly plotting points for each star along the ecliptic when, in 1880, they came to the Milky Way. *Quelle horreur!* There were too many stars. They decided to photograph the field instead. Expert opticians, they built a 6-inch telescope corrected for photography and began experimenting. The results were so spectacular that the director of the Paris Observatory, Admiral Ernest B. Mouchez, wrote,

I was so astonished with the exceptional beauty of this debut and with its extreme importance to the future of astronomy, that despite some administrative difficulties I had no hesitation in accepting their proposal to have a large 33-cm (13.4-inch) photographic instrument built immediately.⁶

By the mid-eighties, they were producing photographs so sharp that the smallest stars on their plates were 0.03 mm (equal to 2 seconds of arc) in diameter. They could photograph stars down to the 12th magnitude in two minutes and could reach 16th magnitude with long exposures. One of their photographs could chart more stars than a visual observer could plot in several years. The Henrys found the first nebula to be discovered by photography: The nebulosity surrounding some of the stars in the Pleiades. They also identified more than two thousand stars in that cluster once known as the "Seven Sisters." It was decided that the greatest contribution they could make to astronomy would be to leave their successors such excellent photographs of the entire sky.

This was too big a project for one observatory. With the support of Gill, Mouchez called an international conference. Fifty-eight astronomers from sixteen countries gathered in Paris on April 16, 1887, to discuss astrophotography and the cooperative production of a *Carte du Ciel* ("Map of the Sky") to leave to posterity. Eighteen observatories agreed to build photographic refractors identical to that of the Henrys and each to photograph and catalog a section of the sky. For cataloging purposes each photograph would involve three exposures, of 20 seconds, three minutes, and six minutes, all on the same plate, slightly displaced for each exposure. This would ensure the elimination of the false identification of plate defects or dust as stars. The plates for the maps would require lengthy exposures. An international committee was set up to supervise this work and to ensure uniformity. The committee was an important precursor to the International Astronomical Union, established after the First World War.

The project was long, tedious, and expensive. Some of the southern observatories withdrew and were replaced by others. The catalog was not completed until 1964, and portions of the map were never finished. None of the American observatories chose to take part. They went on to do more important work instead. According

to historian John Lankford, "the growth of astrophysics in the United States may have been stimulated as a consequence of nonparticipation in the *Carte du Ciel* while, at least to a degree, astrophysical research in Europe may have been retarded because the *Carte* absorbed funds and engrossed staff time that otherwise might have been allocated to astrophysics."⁷

It cannot be said that all astronomers greeted the new methods with enthusiasm. Many worried that the photographic plate would interpose a new source of error between the sky and the final result of the observation. When Edward Holden, director of the soon to-be-completed Lick Observatory, wrote a glowing magazine article, "Photography the Servant of Astronomy," in 1886, he forecast wonderful results. "We can hand down to our successors a picture of the sky, locked in a box."⁸

The director of the McCormick Observatory at the University of Virginia responded with "Photographers versus Old Fashioned Astronomers." Ormond Stone was obviously hurt:

One would infer, I think, that there is no longer any use for that venerated, but now to-pass-away, class of individuals hereafter to be known as "old fashioned astronomers," and that hereafter observers skilled in the use of the meridian circle and the micrometer, will bear about the same relation to astronomical photographers as did the astronomers who lived before the invention of the telescope to the Herschels and the Struves of later date.⁹

Meanwhile Edward C. Pickering at Harvard had begun using photography to record the spectra of hundreds of thousands of stars for the Henry Draper Memorial. By the mid-1890s he had procured a new telescope (the Bruce) and begun the famous sky survey which would be so valuable to astronomers of the twentieth century. At Lick Observatory, Holden's successor, James Edward Keeler, took Common's 36-inch reflector (called the Crossley in honor of its donor) and made such spectacular photographs of nebulae and star clusters that professionals the world over turned to reflectors for good. The twentieth century saw steady advances in the sensitivity and fineness of grain of photographic emulsions. A team at Eastman Kodak, headed by C. E. Kenneth Mees, devoted its efforts to producing better and better



James Edward Keeler obtained a stunning photograph of the Orion nebula on 16 November 1898, with the 36-inch Crossley Reflector at Lick Observatory. Pictures like this inspired more than one generation of astronomers. Their visual impact was exceeded only by the novelty of color, when it came from Palomar and appeared in National Geographic Magazine in 1959. (Publications of Lick Observatory, Volume VIII, 1908, frontispiece)

emulsions for astronomers' use. It is unlikely that Kodak made a profit from the astronomers, but the company's research efforts may well have paid off elsewhere. In recent years some of the greatest improvements have come from Alex G. Smith and his colleagues at the University of Florida's Rosemary Hill Observatory. But while these advances were being made, astrophotography was already being superseded by the rapidly advancing field of electro-optics. As early as 1906, Joel Stebbins at the University of Illinois was experimenting with devices which converted light into an electric current. Stebbins as a student had been asked by a professional astronomer, "Are you going to be a real astronomer or just one of these newfangled photographers?"¹⁰ Instead, as he put it later, "...the whole field of photographic research was skipped, and we jumped directly from visual to photoelectric methods."¹¹

How he got started is best told by Stebbins himself:

The (visual) photometric program went along well enough for a couple of years until we got a bride in our household, and then things began to happen. Not enjoying the long evenings alone, she found that if she came to the observatory and acted as recorder, she could get me home earlier. She wrote down the numbers as the observer called them, but after some nights of recording a hundred readings to get just one magnitude, she said it was pretty slow business. I responded that someday we would do all this by electricity. That was a fatal remark. Thereafter she would often prod me with the question: "When are you going to change to electricity?"¹²

Stebbins and a physicist colleague began experimenting with selenium cells. The first was too insensitive to detect Jupiter, but at least it picked up the moon. Improvements, such as accidentally dropping the cell and finding that smaller cells worked better, followed. Soon a chilled cell could record stars of the second magnitude. First at Illinois, and then for many years at the University of Wisconsin, Stebbins and his co-workers, most notably Albert E. Whitford, developed photoelectric photometry. The selenium cell gave way to better photoelectric cells. The electrometer was replaced by

vacuum tube amplification, and later by the photomultiplier tube.

Electronic scanners were developed which could be used to obtain digital spectra. Astronomers became accustomed to digital images transmitted back to earth from television-like cameras in space. In the early 1970s, scientists at Bell Laboratories invented solid state devices based on charge coupling. In 1976, University of Arizona astronomers made the first astronomical pictures with CCDs. The devices can record as much as 70 percent of the light which falls on them. The comparable figure for the best chemical emulsions is about 4 percent.

Now each month's magazines bring spectacular new images of the sky made with CCDs. New telescopes, including both the Hubble Space Telescope and half a dozen ground-based ones described at that recent American Astronomical Society meeting, are planned from the start to use the phenomenal new detectors. Just a century after photography replaced visual astronomy at major observatories, it has yielded to a newer and better technology.

Notes

- 1 Faraday, Michael, "Mr. Warren De la Rue's Photographic Eclipse Results," lecture to the Royal Institution, May 3, 1861. *Royal Institution Library of Science: Astronomy*, vol. 1, p. 30.
- 2 See the articles by Remington Stone in *Sky and Telescope*, October and November, 1979, for the history of this telescope.
- 3 Gill, David, "Recent Researches on the Distances of the Fixed Stars, and some Future Problems in Sidereal Astronomy," lecture to the Royal institution, May 23, 1884. *Royal Institution Library of Science: Astronomy*, vol. 1, p. 227-28.
- 4 See Katherine Bracher's article in *Mercury*, September-October, 1981, for more on Dorothea Klumpke-Roberts, the donor of one of the Astronomical Society of the Pacific's awards.
- 5 Gill, David, "The Applications of Photography in Astronomy," lecture to the Royal institution, June 3, 1884. *Royal Institution Library of Science: Astronomy*, vol. 1, p. 314.
- 6 *Annales du Bureau des Longitudes*, Paris, 1887, p. 777. Quoted in de Vaucouleurs, Gerard, *Astronomical Photography: From the Daguerreotype to the Electron Camera*, p. 49.

- ⁷ Lankford, John, "The Impact of Photography on Astronomy," in Gingerich, Owen, ed., *Astrophysics and Twentieth-century Astronomy to 1950*, The General History of Astronomy, vol. 4A, p.32.
- ⁸ Holden, Edward S., "Photography the Servant of Astronomy," *Overland Monthly*, November, 1886, p. 459.
- ⁹ Stone, Ormond, "Photographers versus Old Fasioned Astronomers," *The Sidereal Messenger*, vol. 6, no. 1, p. 2 (1887).
- ¹⁰ Whitford, Albert, "Joel Stebbins," *Biographical Memoirs of the National Academy of Sciences*, vol. 49, p. 309.
- ¹¹ Stebbins, Joel, "The Washburn Observatory, 1878-1958" *Publications of the Astronomical Society of the Pacific*, vol. 70, p. 442 (1958).
- ¹² Stebbins, Joel, "Early Photometry at Illinois," *Publications of the Astronomical Society of the Pacific*, vol. 69, p. 507 (1957).
- Kristian, Jerome and Blouke, Morley, "Charge Coupled Devices in Astronomy," *Scientific American*, October, 1982, pp. 66-74.
- Lankford, John, "The Impact of Photography on Astronomy," in Gingerlch, Owen, ed., *Astrophysics and Twentieth-century Astronomy to 1950*, The General History of Astronomy, vol. 4A. Cambridge: Cambridge University Press, 1984.
- Mannheim, L. Andrew, "Photography, Technology of," *Encyclopaedia Britannica*, 15th ed., vol. 14, p. 328-346. Chicago: Encyclopedia Brittanlca, Inc., 1980.
- Mees, C. E. Kenneth, "Recent Progress in Astronomlcal Photography," *Annual Report of the Smithsonian Institution*, 1953. Washington, U.S. Govt. Printing Office, 1954, pp 205-218.
- Newhall, Beaumont, "Photography, Art of," *Encyclopaedia Britannica*, 15th ed., vol. 14, p. 306-327. Chicago: Encyclopaedia Britannica, Inc., 1980.
- Norman, Daniel, "The Development of Astronomical Photography," *Osiris*, vol. 5, 1938, pp. 560-94.
- Roberts, Isaac. *A Selection of Photographs of Stars, Star-Clusters and Nebulae*. London: The Universal Press, 1893.
- Royal Institution Library of Science: Astronomy*, vol. 1. Barking, Essex, England: Elsevler Pub. Co., Ltd., 1970.
- de Vaucouleurs, Gerard, *Astronomical Photography: From the Daguerreotype to the Electron Camera*. New York: Macmillan, 1961.

Bibliography

- Abney, William de W. "Photography," *Encyclopaedia Britannica*, 9th ed., vol. 18, p. 821-840, New York: Charles Scribner's Sons, 1885.
- Buttman, Gunther. *The Shadow of the Telescope: A Biography of John Herschel*, tr. Bernard Pagel. New York: Charles Scribner's Sons, 1970.
- Jones, Bessie Zaban, and Boyd, Lyle Gifford. *The Harvard College Observatory: The First Four Directorships, 1839-1919*, Cambridge: Harvard University Press, 1971.
- Keeler, James Edward, "Photographs of Nebulae and Clusters made with the Crossley Reflector," *Publications of the Lick Observatory*, Vol. VIII, Sacramento: California State Printing Office, 1908.

MOVING?

**PLEASE SEND US YOUR NEW ADDRESS
AND OLD ADDRESS, TOO**