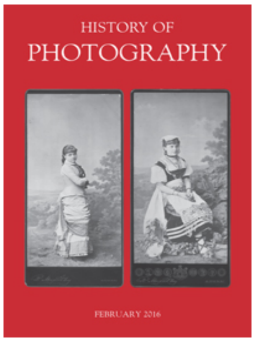

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Aud Sissel Hoel

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Measuring the Heavens: Charles S. Peirce and Astronomical Photography

Aud Sissel Hoel

Taking its point of departure from the current digitisation of the Harvard Astronomical Plate Collection, this article follows the plates back to the time when the status of photography as a research tool for astronomers was still to be established. It focuses on Charles S. Peirce, who, while employed by the US Coast Survey, made astronomical observations and contributed to the deliberation over visual and photographic methods. Particular attention is paid to Peirce's involvement in early explorations of photography's potential as a measurement tool. The guiding assumption is that approaching photography as a tool, rather than as a sign or representation, offers new inroads into the old problem of photography's revealing powers and its capacity to serve as a means of discovery in science. Drawing on Peirce's scientific practice as an alternative resource for theory construction, this article contributes to the ongoing efforts to conceptualise the productive or generative dimension of photographic methods. It concludes by pointing to the diagrammatic notion of evidence developed late in Peirce's philosophical career, proposing that photography be reconceived as a diagrammatic tool.

Keywords: *John Adams Whipple (1822–91), Jules Janssen (1824–1907), Joseph Winlock (1826–75), Charles Wolf (1827–1918), Charles S. Peirce (1839–1914), astronomical photography, photometry, solar eclipse, scientific observation, measurement, photographic evidence, mechanical objectivity, indexicality, diagrams*

Down a set of corkscrew stairs, in the crammed basement of a historic building on Observatory Hill in Cambridge, Massachusetts, a handful of people are busily engaged in photographing, cleaning, and scanning old glass photographic plates of stars. Their task seems overwhelming; three floors of the building are lined with rows of filing cabinets brimming over with more than half a million dry plate negatives. The plate collection, which spans a century of celestial photography from 1885 to 1989,[1] is currently being digitised – not for museum purposes, but in order to come alive again as a resource for present-day astronomical research. The one-hundred-year coverage allows astronomers to study temporal variations in the universe, and the digital access to the old views of the sky has already started to yield new discoveries.[2] This remarkable fact prompts the guiding question of this article: what is it about photography that allows scientists to make new discoveries by way of photographic views taken up to more than a hundred years ago?

The ongoing digitisation of the Harvard Astronomical Plate Collection speaks directly to the main concern of this article: the revealing powers of photographic methods and their potential to serve as research tools or as means of discovery in science. The current use of the dry plate negatives indicates certain characteristics

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Email for correspondence:
aud.sissel.hoel@ntnu.no

1 – The collection has a gap from approximately 1953 to 1968, referred to as the 'Menzel Gap' after the director Donald Howard Menzel (1901–76), who temporarily halted the plate-making operations in order to reduce costs.

2 – See the project *DASCH – Digital Access to a Sky Century @ Harvard*, available at http://dasch.rc.fas.harvard.edu/project.php (accessed 25 January 2016).

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that call for further elucidation. First, photographic methods afford comparability across time and space; they transcend the limited scale of individual observers situated firmly in the here and now. Second, they involve a peculiar repeatability – peculiar because what they repeat is not strictly speaking 'the same': what today's astronomers are able to see and detect by way of the plates is not the same as astronomers saw and detected at the time the astronomical views were taken. The latter characteristic connects with a third – namely, that the revealing powers of photographic methods transcend the intentions and uses envisioned by the people who devised the instruments and produced the photographs. Taking its point of departure from the current digitisation and use of the Harvard Astronomical Plate Collection, this article explores the problem of photography's revealing powers by following the plates back to the time when the status of photography as a research tool for astronomers was yet to be established. In this context, the choice of the term 'tool' is no coincidence. What I hope to show is that approaching photography as a tool, rather than as a sign or representation, offers new inroads into the old problem of photography's realism.

Contemporary researchers on science and technology emphasise the non-neutral roles of technologies in scientific practices,[3] and along with these, the interventional, transformative, and co-constitutive roles of instruments and tools in knowledge.[4] Likewise, historians and philosophers of science accentuate the ways that objects of knowledge are not simply given but gradually discerned and fixated in specialised and mediated instrumental settings.[5] Following these lines of thought, conceiving photography as a tool implies that photography, like all scientific instruments, plays an active role in the process of discovery. In the words of Josh Ellenbogen, who offers a revisionist analysis of the scientific practice of Étienne-Jules Marey, 'visualization, as it generates data on events, *does something* with the data that helps discover law'.[6] Ellenbogen's point is that photography, as put to use by Marey, acquired a productive or generative role and, hence, 'ceased to function as a reproductive technology'.[7] This article contributes to the ongoing efforts to conceptualise the productive or generative dimension of photographic methods, which is not sufficiently accounted for by the notions commonly evoked when the evidential status or scientific value of photographic methods are to be explained.

Peirce and Photographic Evidence

Photography has, since its inception, been claimed to be 'special'. Early advocates of the new method celebrated it for its almost mathematical precision and for the way that it putatively ridded the image-making process of human intermediaries. The potential of the new method to serve as a useful tool for scientists was recognised from the beginning, including for 'physicists and astronomers', for whom, as predicted by François Arago (later director of the Paris Observatory), the new method would become a 'highly valuable means of investigation'.[8] Later in the nineteenth century, photography became, as pointed out by Lorraine Daston and Peter Galison, closely associated with the scientific ideal of mechanical objectivity.[9]

In recent years, Charles S. Peirce has become an authority frequently referred to in explanations of photography's special nature. In visual studies, Peirce is cast as a philosopher of visual and non-linguistic signs, and the reference to his distinction between iconic, indexical, and symbolic signs is now a textbook commonplace. Photographs are commonly characterised in terms of their indexical quality, which is understood to distinguish them from other kinds of images, including digital images. It is, above all, the conviction that photographs have a special, mechanically guaranteed indexical bond to reality that continues to fuel scholarly as well as common-sense ideas about photography's superior evidential capacity. However, if the aim is to bolster beliefs in photography's realism, the

3 – See for example Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network-Theory*, Oxford: Oxford University Press 2005; and *Representation in Scientific Practice Revisited*, ed. Catelijne Coopmans, Janet Vertesi, Michael Lynch, and Steve Woolgar, Cambridge, MA: MIT Press 2014.

4 – Ian Hacking, *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science*, Cambridge: Cambridge University Press 1983; Don Ihde, *Expanding Hermeneutics: Visualism in Science*, Evanston, IL: Northwestern University Press 1998; and Peter-Paul Verbeek, *What Things Do: Philosophical Reflections on Technology, Agency, and Design*, University Park: Pennsylvania State University Press 2005.

5 – See for example Bas C. van Fraassen, *Scientific Representation*, Oxford: Clarendon Press 2008; and Peter Galison 'Images of Self', in *Things That Talk: Object Lessons from Art and Science*, ed. Lorraine Daston, New York: Zone 2004, 257–94.

6 – Josh Ellenbogen, 'Camera and Mind', *Representations*, 101:1 (Winter 2008), 99; original emphasis. See also Josh Ellenbogen, *Reasoned and Unreasoned Images: The Photography of Bertillon, Galton, and Marey*, University Park: Pennsylvania State University Press 2008.

7 – Ellenbogen, 'Camera and Mind', 88.

8 – François Arago, *Comptes rendus*, VIII (1839), 6.

9 – Lorraine Daston and Peter Galison, 'The Image of Objectivity', *Representations*, 40 (Autumn 1992), 81–128. See also Lorraine Daston and Peter Galison, *Objectivity*, New York: Zone Books 2007.

common reference to Peirce is somewhat ironic because, as François Brunet has pointed out, Peirce was not convinced about photography's value as a scientific instrument. Despite the scattered references to photographs, he never aimed to develop a theory of photography. His views on the topic add up to a critique of photographic evidence rather than a defence of it.[10] Further, as I have noted elsewhere,[11] Peirce did not share the scientific ideals that prevailed among his materialist and positivist contemporaries. For him, 'truth' could never be reduced to brute compulsion or conformity to fact – that is, to 'secondness', the kind of dyadic relation associated with the index. Peirce saw 'facts' as products of our intellectual involvement. To accommodate this, he developed a notion of truth based in mediated connections or 'thirdness'.

All this notwithstanding, there are still good reasons to explore Peirce's philosophy as a source for theory construction in photography. For example, when it comes to understanding the revealing powers of photographic methods, there are untapped resources in Peirce's professional experience with photography and other observational methods while he worked for the US Coast Survey. Starting from Peirce's scientific practice, rather than from his classifications of signs, offers a very different perspective on the problem of photography's realism. Pioneering studies in this regard have been carried out by Brunet.[12] This article follows up by undertaking a more detailed analysis of Peirce's involvement in astronomical observation. It concludes by pointing to another untapped resource: the diagrammatic notion of evidence developed late in Peirce's philosophical career, proposing that photography be reconceived as a diagrammatic tool.

Peirce and the Harvard College Observatory

While today Charles S. Peirce is mostly known as a philosopher, logician, or semiotician, in his own time he was primarily recognised as a mathematician and scientist. In the course of his employment by the US Coast Survey, he made important contributions to cartography, astronomy, mathematical physics, geodesy, as well as metrology.[13] Beyond that, he contributed to chemistry, philology, and the new experimental psychology.[14] As a young man, Peirce worked as a 'computer' for the Coast Survey,[15] gaining experience in theoretical astronomy. From 1867 he conducted astronomical observations for the Harvard College Observatory, then directed by Joseph Winlock.[16]

The first successful daguerreotype of an extra-terrestrial object – the moon – was taken by John William Draper as early as 1840.[17] Still, it would take another fifty years, and considerable amounts of experimentation, before photography was generally accepted as a legitimate tool in astronomical research, the scientific status of photographic observations being actively negotiated and disputed along the way. At Harvard College Observatory, astronomers were experimenting with photography long before Edward C. Pickering, director of the Observatory from 1877 to 1919, embarked on his ambitious project of making a photographic survey of the entire sky, whose results make up the bulk of the current plate collection. The first attempts were made in 1848 under the direction of William Cranch Bond, and subsequently under the direction of his son, George Phillips Bond. With the assistance of Boston's leading daguerreotypist John Adams Whipple, successful impressions of the moon and the star Vega were obtained.[18] The latter were the first daguerreotypes of a star (apart from the sun), something that put the Observatory at the forefront of celestial photography.[19] Despite meagre funding for this kind of work, experimenting with photographic methods continued under Winlock, director of the Observatory from 1866 to his unexpected death in 1875.

This article enters the story by zeroing in on the solar eclipse of 1869. My reasons for choosing this particular event are not motivated by its being the 'first' of anything (successful daguerreotypes of a total eclipse of the sun were taken already in 1851[20]); nor does the eclipse of 1869 mark a watershed in the history of

10 – François Brunet, 'Visual Semiotics versus Pragmaticism: Peirce and Photography', in *Peirce's Doctrine of Signs*, ed. Vincent M. Colapietro and Thomas M. Olshewsky, Berlin: Mouton de Gruyter 1996, 307.

11 – Aud Sissel Hoel, 'Lines of Sight: Peirce on Diagrammatic Abstraction', in *Das bildnerische Denken: Charles S. Peirce*, ed. Franz Engel, Moritz Queisner, and Tullio Viola, Berlin: Akademie 2012, 253–71.

12 – Brunet, 'Visual Semiotics'. See also, François Brunet, *La naissance de l'idée de photographie*, Paris: Presses Universitaires de France 2012, 307–10; and Mirjam Wittmann, 'Fremder Onkel: Charles S. Peirce und die Fotografie', in *Das bildnerische Denken*, ed. Engel, Queisner, and Viola, 303–22.

13 – Victor F. Lenzen, 'Charles S. Peirce as Astronomer', in *Studies in the Philosophy of Charles Sanders Peirce*, ed. Edward C. Moore and Richard S. Robin, second series, Amherst: The University of Massachusetts Press 1964, 33–50.

14 – For an account of Peirce's contribution to experimental psychology, see Thomas C. Cadwallader, 'Peirce as an Experimental Psychologist', *Transactions of the Charles S. Peirce Society*, 11:3 (1975), 167–86.

15 – The term 'computer' means 'one who computes'. Before electronic computers, the term referred, in the astronomical context, to a person performing complex and often tedious calculations.

16 – Lenzen, 'Charles S. Peirce as Astronomer', 33–37.

17 – For a discussion of John William Draper's photographic experiments, see Sarah Kate Gillespie, 'John William Draper and the Reception of Early Scientific Photography', *History of Photography*, 36:3 (August 2012), 241–54.

18 – Dorrit Hoffleit, *Some Firsts in Astronomical Photography*, Cambridge, MA: Harvard College Observatory 1950, 7 and 24.

19 – *Harvard College Observatory: The First Century – A Review of the Past and a Preview of the Future*, Cambridge, MA: Harvard College Observatory 1946, 12.

20 – Hoffleit, *Some Firsts*, 18.

astronomical photography, such as for example the Great Comet of 1882.[21] I choose this entry-point because it marks a juncture where the historical and conceptual concerns of this article intersect: Winlock's idea of what constituted a 'good' photograph in the astronomical context went beyond, as he put it, 'making pictures'. Instead, he set out to explore photography's potential as a measurement tool. For this purpose, Winlock devised a micrometre for measuring photographs of the sun, and – of particular interest to historians and theorists of photography – he employed Peirce to discuss and evaluate the scientific value of the eclipse photographs.

21 – See John Lankford, 'The Impact of Photography on Astronomy', in *The General History of Astronomy*, Vol. 4: *Astrophysics and Twentieth-Century Astronomy to 1950: Part A*, ed. Owen Gingerich, Cambridge: Cambridge University Press 1984, 23–25.

Photographing the Solar Eclipse of 1869 at Shelbyville, Kentucky

In the very first issue of *Nature*, Norman Lockyer, founder and editor of the new journal and himself a prominent scientist and astronomer, commented on the recent event that had taken place on the American continent: 'Certainly, never before was an eclipsed sun so thoroughly tortured with all the instruments of Science'.[22] Photography was listed among the instruments used. As Lockyer reports, several hundred photographs were taken of the eclipse. Personally, Lockyer was most interested in the spectroscopic observations, and what these could tell about the chemical composition of the red flames or prominences visible along the edge of the moon during totality. The eclipse photographs were

22 – J. Norman Lockyer, 'The Recent Total Eclipse of the Sun', *Nature* (4 November 1869), 15.

Figure 1. John Adams Whipple, *Harvard Observatory Team, Photographing Eclipse*, albumen silver print, 1869. National Portrait Gallery, Smithsonian Institution; gift from Larry J. West.

remarked upon only in passing and praised for their 'perfection of finish'.[23] It becomes clear from this comment that, while Lockyer recognised the revelatory function of spectroscopy, he understood the photographs primarily as 'pictures' in the sense of representations that gave nothing but a general idea of the appearance of the eclipse. Winlock, however, who was in charge of one of the observing parties, had ambitions to develop a method of photographic observation that probed deeper than mere appearances.

Winlock's team of observers was one of the expedition parties dispatched by the US Coast Survey, in cooperation with the Harvard College Observatory (figure 1).[24] Peirce, who had been employed intermittently by the Coast Survey since 1859, was also part of the team. Among the solar phenomena observed by Winlock's party, particular attention was accorded to examining the spectrum of the prominences and the shape of the corona. Before 1869 it was already established that the prominences were appendages to the sun consisting primarily of incandescent hydrogen. However, it remained to be investigated whether there were other constituents whose light was too feeble to be observed except during a total solar eclipse. Spectroscopic observations were conducted by Winlock at the party's main observing station at Shelbyville, Kentucky, and by Peirce at the eclipse station at Bardstown, also in Kentucky. In his report, Winlock claims that the result of his own spectroscopic observations was 'to establish beyond a doubt that magnesium was a constituent of the prominences'.[25] When it comes to the shape of the corona, nothing was established previous to 1869.[26] One of Winlock's main objectives, therefore, was to secure a 'good photograph' of it.[27]

The photographic observations were conducted at Shelbyville under the direct supervision of Winlock, in collaboration with Whipple, the renowned Boston photographer, and further assisted by George B. Clark (of Alvan Clark & Sons, the famous maker of optics), the photographer John Prendergast, and John W. Williams, a photographer from Shelbyville.[28] The telescope used for taking photographs was a small equatorial with an aperture of five and a half inches, a focal length of seven and a half feet, and a driving-clock of good quality. The photographic telescope was also equipped with a chronograph, which recorded the time of each exposure. Eighty photographs were obtained during the progress of the eclipse (figure 2), of which seven were taken during totality. 'One of these', Winlock reports, 'with an exposure of forty seconds, gives a most satisfactory picture of the corona' (figure 3).[29] Even if Winlock here refers to the photograph of the corona as a 'picture', it is clear that he understood it to have a revelatory function:

> I immediately recognized in this the fact that the corona was less in extent near the extremities of the sun's axis, and largest in the line of the equator. I have reason to think that this picture gives nearly all of the corona which can with certainty be considered as belonging to the sun.[30]

As pointed out by Winlock, previous to 1869 most written and pictorial descriptions of the corona had suggested a circular shape. Beyond this, the accounts varied so much as to remain inconclusive. However, a photograph of the corona taken by the Italian astronomer Father Secchi in Spain during the 1860 eclipse suggested a more peculiar shape. But whether this shape was a permanent feature of the corona, or merely a transient phenomenon, could not be confirmed until the operation was repeated. In 1870, when Winlock made another expedition to observe a solar eclipse, stationed this time at Jerez de la Frontera in the south of Spain, he took the opportunity to repeat the operation yet again. Upon comparing the 1869 and 1870 photographs, he was further convinced that the peculiar shape was a permanent feature,[31] and hence that the corona was beyond doubt an appendage of the sun.[32] For Winlock, then, a photograph taken singly did not prove much. Repetition and comparability were required for results to be reasonably conclusive.

23 – Ibid., 15.

24 – Other parties were stationed in Tennessee, Illinois, Iowa, and Alaska.

25 – Joseph Winlock, *Annals of the Astronomical Observatory of Harvard College*, vol. VIII, Cambridge, MA: Press of John Wilson and Son 1876, part I, 59.

26 – For a detailed account of the practices of drawing and photographing the corona in the 1860s and 1870s, see Alex Soojung-Kim Pang, *Empire and the Sun: Victorian Solar Eclipse Expeditions*, Stanford: Stanford University Press 2002, chapter 4.

27 – Winlock, *Annals*, vol. VIII, part I, 59.

28 – Whipple describes the division of labour as follows: 'Mr. George Clark operated the mechanical parts of the photographic telescope. Our Mr. J. Pendegrast [sic] coated the plates. Mr. Williams, photographer, of Shelbyville, developed'. Report by John Adams Whipple quoted in 'Photographing the Eclipse in America', *The Illustrated Photographer* (22 October 1869), 495.

29 – Report by Joseph Winlock in *Report of the Superintendent of the United States Coast Survey Showing the progress of the Survey during the Year 1869*, Washington, DC: Government Printing Office 1872, 125.

30 – Ibid., 124–25.

31 – On both photographs the corona has the same characteristic form, 'extending farthest from the sun at four points between the solar poles and equator, while its extent was particularly small about the poles'. Winlock, *Annals*, vol. VIII, part I, 61.

32 – Ibid., 58 and 60.

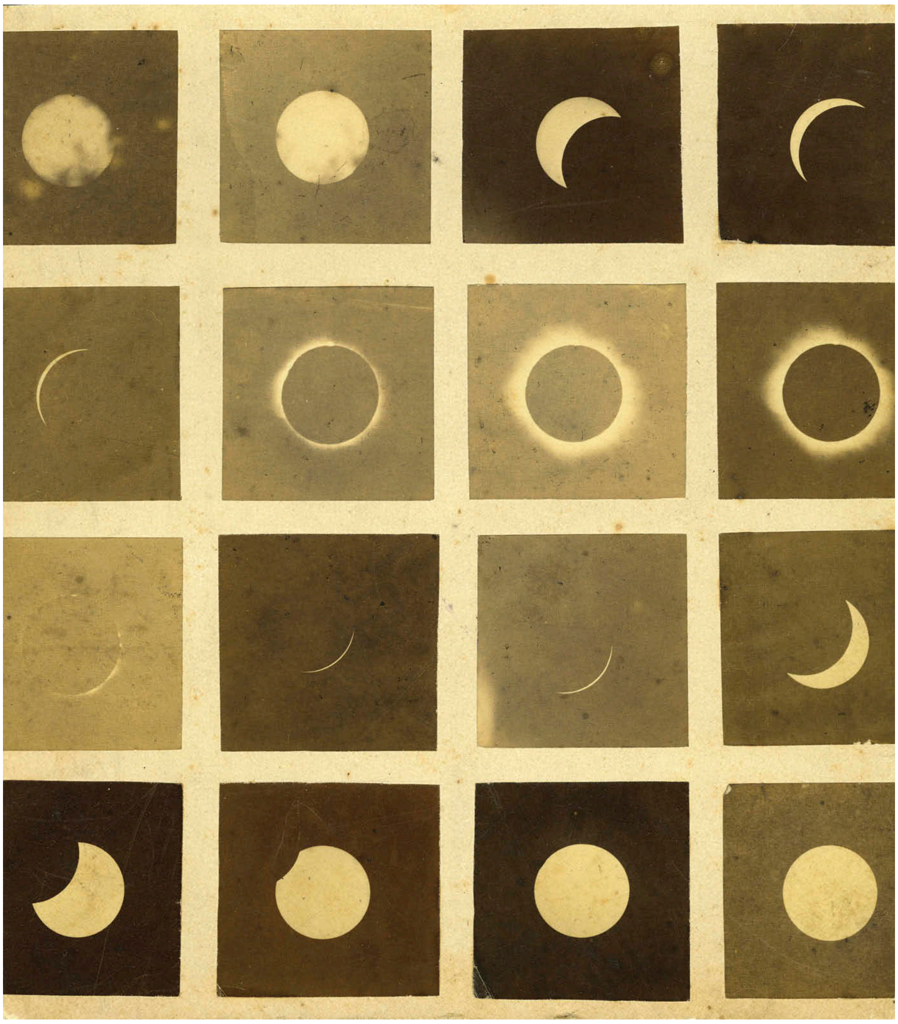

Figure 2. Views of various phases of the solar eclipse, albumen prints, 1869. Shelby County Public Library; gift from Peggy and Alwin Miller.

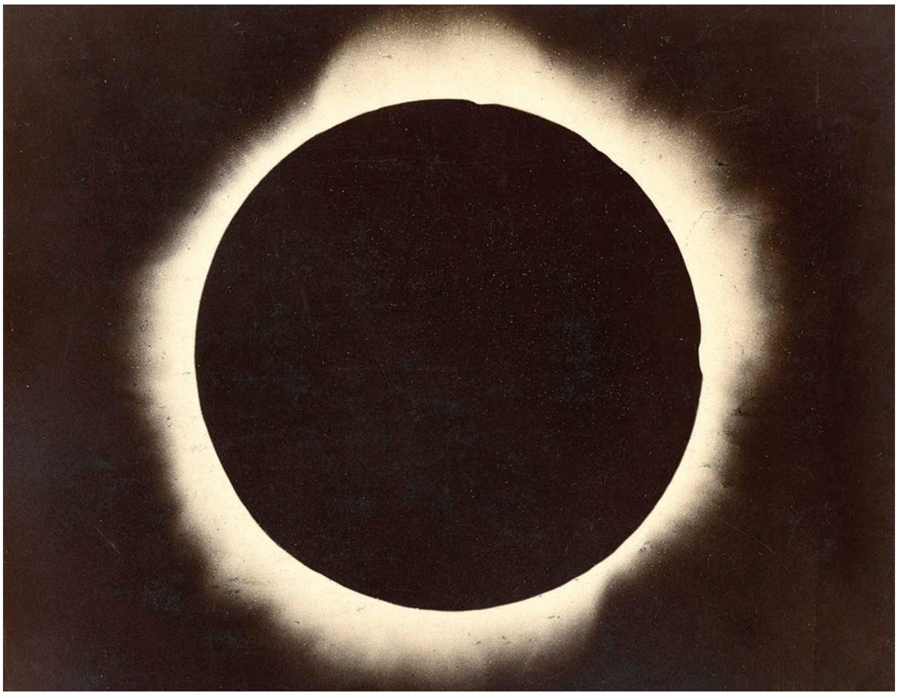

Figure 3. John Adams Whipple, *Solar corona at eclipse, Shelbyville, Kentucky August 7 1869*, photographic print, 1869. Institute of Astronomy Library, University of Cambridge, United Kingdom.

The method adopted by Winlock for photographing the solar eclipse of 1869 was to take the photographs at the focus of the telescope's receiving lens. In so doing, he rejected the method of enlarging the image by an eyepiece before exposure, which was adopted by Warren De La Rue when he photographed the 1860 eclipse in Spain.[33] Winlock had two objections to the enlargement method. First, he thought that the passage of light through the lenses of the eyepiece would enfeeble the fainter parts of the corona and hence prevent a satisfactory image of it. Second, and even more interestingly with a view to this article's concern with photography as a measurement tool, he thought that taking the photograph beyond an eyepiece would distort the image 'to an extent which it is difficult to determine accurately', and hence that it would increase 'the difficulty of providing a fixed line of reference for such measurements as I wished to have made of the photographs I might obtain'.[34] Hence, the main deficiency of the enlargement method was not so much that it led to distortions, but that the distortions involved could not be properly calculated.

33 – Winlock, *Report of the Superintendent 1869*, 124; and Winlock, *Annals*, vol. VIII, part I, 37.

34 – Winlock, *Annals*, vol. VIII, part I, 37.

A further argument for not enlarging the image was that this would make the resulting photographs better suited for measuring with a micrometre. Along with the long-exposure photographs of the corona, Winlock directed the production of a series of instantaneous photographs of the partial phases of the eclipse (figure 4). The motivation for making these photographs was 'to ascertain the degree of accuracy with which they could be measured when taken in this way'.[35] The photographs of partial phases were also made in preparation for the 1874 transit of Venus. The intention was 'to make the measures in such a way that the distances between the centers of the sun and moon, or the sun and Venus, would be obtained free from the effects of photographic irradiation'.[36] Since the camera had remained undisturbed throughout the progress of the eclipse, a comparison of plates showing partial and total views would enable the calculation of position-angles with 'all the accuracy attainable in a diagram of the proportions of these plates'.[37] Notice here that Winlock introduced the term 'diagram' while discussing accurate calculation on the basis of photographic views.

35 – Winlock, *Report of the Superintendent 1869*, 125.

36 – Ibid.

37 – Report by Joseph Winlock in *Report of the Superintendent of the United States Coast Survey Showing the Progress of the Survey during the Year 1870*, Washington, DC: Government Printing Office 1875, 138.

After the 1869 eclipse, Winlock continued his quest for increased comparability and repeatability. He proposed that telescopes used for photography should have a single fixed lens of long focus. At the Observatory, he tested out different methods for providing a line of reference for measuring photographs.[38] For the approaching transit of Venus, Winlock recommended a combination of a stationary plane mirror and a fixed long-focus lens. He advised against the use of a heliostat along the same lines as he advised against the use of an eyepiece to enlarge the image: whereas a properly adjusted stationary plane mirror would allow any distortion ensuing from the movement of the image to be accurately computed, the irregular running of a heliostat would leave such distortions to mere guesswork.[39]

38 – For a detailed description of these methods, see Winlock, *Annals*, vol. VIII, part I, 40.

39 – Ibid., 36.

Peirce's Evaluation of the Eclipse Photographs

In order to further investigate the applicability of his method to eclipses and transits, Winlock employed Peirce – who was renowned for his mathematical skills – to device a method for measuring the eclipse photographs and evaluate their usefulness. In order to measure the photographs (glass plate negatives) of the partial phases of the eclipse, Peirce made use of a large micrometre produced by Alvan Clark & Sons in accordance with Winlock's directions. The micrometre was based on principles adopted by Warren De La Rue. In the *Annals* of the Harvard College Observatory its mode of operation is described as follows:

> The photograph is viewed through a microscope fixed to the stand which supports the whole instrument. A plate sliding between guides fixed upon this stand carries a second plate sliding at right angles to the first. This second plate supports a vertical

Figure 4. Samples of the original glass plate negatives, showing the partial phases of the eclipse, 1869. © Harvard College Observatory. Image copyright protected and not to be reproduced without prior written permission.

axis provided with a position circle, above which is a frame carrying the photograph to be measured, and sufficiently movable by screws to allow the photographs to be properly centered under the microscope.[40]

Peirce started out with some preliminary measures in order to test the perpendicularity of the photographic plates with respect to the optical axis of the telescope. The results of these initial calculations were discouraging. 'The tilt was often considerable, but had no fixed character'.[41] This meant that, since the variations in tilt were of an irregular nature, they could not be accurately computed. Further, since the measurements were inadequate due to the lack of photographic achromatism (that is, distortions of the lens which blur the outlines), Peirce was also prevented from making a proper calculation of the tilt of individual plates. He chose to proceed, therefore, as if there were no tilt.[42] The next step was to correct the measurements made of the limbs of the sun and moon for simple refraction and differential refraction.[43] Assuming that the limbs of the sun and moon, as corrected for refraction, were circles, he sought to determine their respective radius vectors. Again the results were unsatisfactory. The blur at the outlines of the limbs caused problems. Upon further calculation, Peirce found that 'the values of the moon's radius, and consequently of the distance of the sun and moon, were quite uncertain'.[44] This finding threw cold water on Winlock's ambition to calculate distances on the basis of photographic observations. Peirce also found that the radii of the sun and moon, as given by the photographs, were much too small, owing to achromatism caused by the presence of the corona. Hence, since there seemed to be no way to determine the radii of the sun and moon with sufficient accuracy, Peirce was led to the conclusion that photographs measured in this way were 'practically of little value for eclipses'.[45]

But Peirce was not the only one to measure and discuss photographs of the partial phases of the 1869 eclipse. Shortly before the eclipse, it was decided that photographic observations should also be made by another expedition party sent out by the US Coast Survey. This party, which was stationed at Springfield, Illinois, was headed by Charles A. Schott of the Coast Survey. The telescope used for the Springfield photographs was an equatorially mounted refractor with an aperture of four inches and a focal length of about six feet. The photographer James Wallace Black of Boston, who operated the photographic apparatus, secured 178 sharply defined pictures of partial phases and six during totality. As in Shelbyville, the Springfield photographs were taken at the focus of the object-lens, as advised by Winlock.[46] Schott conducted the subsequent measuring and discussion of the Springfield glass plate negatives. To ensure 'uniformity of treatment for the better comparison of partial and final results', the Springfield photographs were submitted to the same measuring method as developed by Peirce.[47]

The Springfield photographs turned out to suffer from the same problems as described by Peirce. In addition to these, Schott found that the photographic plates could only be subjected to low degrees of magnification (about 10 power), owing to 'the imperfect definition of the edge of the film of the collodion'.[48] Upon comparing his results with Peirce's measurements of the Shelbyville photographs, Schott found them to agree 'within their probable errors'.[49] However, despite the fact that the evaluation of the Springfield plates exposed shortcomings of the same nature as those exposed by Peirce, Schott did not draw the conclusion that photography was unfit for measuring purposes. Instead, and in anticipation of the coming transit of Venus, Schott ends his report with practical advice about how the shortcomings could be addressed.[50]

Peirce's Photometric Observations

Schott's report on the measurements of the eclipse photographs is prefaced by a note from the superintendent of the Coast Survey, Benjamin Peirce (Charles S.

40 – Ibid., 42; there are also further technical details not quoted here.

41 – Charles S. Peirce, 'Report on the Results of the Reduction of the Measures of the Photographs of the Partial Phases of the Eclipse of August 7, 1869, Taken at Shelbyville, Kentucky, under the Direction of Professor Winlock', in *Report of the Superintendent 1869*, 183.

42 – Ibid.

43 – Simple refraction is the change in the apparent position of astronomical objects owing to light changing direction in its passage through the earth's atmosphere. Differential refraction is the change in the apparent position of astronomical objects, relative to each other, due to refraction.

44 – Peirce, 'Report on the Results of the Reduction', 184.

45 – Ibid.

46 – Benjamin Peirce in *Report of the Superintendent 1869*, 40; and Charles A. Schott, 'Observations at Springfield, Illinois', in *Report of the Superintendent 1869*, 147–48.

47 – Schott, 'Observations at Springfield', 153.

48 – Charles A. Schott, 'Report on the Results of the Micrometric Measures of Photographic Pictures of the Solar Eclipse, of August 7, 1869, Taken at Springfield, Illinois', in *Report of the Superintendent 1869*, 186.

49 – Ibid., 197.

50 – For example, the perpendicularity of the plates with reference to the optical axis of the telescope could be ensured mechanically. The distortions resulting from the unequal contraction of the collodion film could be resolved by placing, at the focus of the object-lens, a system of ruled parallel equidistant lines, crossing each other at right angles. Schott, 'Report on the Results of the Micrometric Measures', 197.

Peirce's father), who praises the report for its profound discussion of the new photographic methods of observation. According to the superintendent, Schott's measurements demonstrate the decided superiority of photographic observations over observations made with 'eye and ear'.[51] This comment is symptomatic of the increasing frustration at the time about the defectiveness of traditional visual methods of observation, and the hope invested by an increasing number of astronomers in photography as a means of surmounting the shortcomings of vision. It was widely admitted that the observations of the previous transit of Venus, in 1769, had produced highly discordant results. The differences in observations were a source of embarrassment to the astronomical community, and while some astronomers blamed the instruments, others blamed the nervous system or the use of unskilled observers.[52] Charles S. Peirce contributed to the deliberation over visual methods of observation, both in his scientific practice and theoretically.

Of special interest is a series of photometric observations that Peirce conducted between 1872 and 1875. The aims of these observations were to determine the brightness or magnitude of a selected group of stars by way of a photometer, and compare the results of these observations with existing star catalogues. In astronomy, the term 'magnitude' refers to the degree of brightness of a star (or other celestial body) expressed on a numerical scale, where lower numbers mean greater brightness. Traditionally, as in Ptolemy's star catalogue, the brightest stars as seen by the naked eye were of the first magnitude and the faintest ones of the sixth.[53] As pointed out by Peirce, subsequent observers had continued to use this method of indicating brightness.

Like Friedrich W. A. Argelander before him, Peirce set himself the task of reforming the scale of magnitudes, but this time with the aid of a photometer. Taking inspiration from Fechner's psychophysical law,[54] which he held to be approximately true, Peirce sought to fix the scale of star magnitudes 'by making the ratio of light between successive magnitudes equal'.[55] Further, in order to render the scales of the previous naked-eye observers comparable, he reduced them to his own scale. Interestingly, however, he could not accomplish this by comparing single stars directly, since every scale contained 'great irregularities' that usually were 'of more consequence than the mean discrepancy between two scales'.[56] Peirce, therefore, reduced the scales of different observers into one by using 'instead of numbers themselves [...] a certain function of them'.[57] Likewise, in his original observations, Peirce did not undertake comparisons on the basis of singular readings of the light of stars. The stars to be observed were divided into groups. A night of observations consisted of comparing the stars from two of these groups with the photometer star. Every star was observed one after another; and the sequence was repeated four times, giving four readings for each star.[58] The subsequent comparisons, however, were statistical in nature, calculating the mean values of individual stars and groups of stars. In this way, Peirce's photometric star catalogue became the first to contain calculated magnitudes.[59]

Despite its ingeniousness, Peirce's method of reducing the scales of different observers to one was no safeguard against errors. Peirce himself was the first to admit this. Like his discussion of the eclipse photographs, the report that documents his photometric research is replete with concerns about possible sources of error. One set of concerns, already touched upon, relates to irregularities of the scales of magnitudes and the problems of comparing them. Two other sets of concerns, which I will now turn to, relate to the observational instrument and the observer, respectively.

The instrument used by Peirce for his photometric observations was a photometer, purchased by the Harvard College Observatory in 1872 and constructed after the design of the German astronomer Johann Karl Friedrich Zöllner (figure 5). The principle of the Zöllner photometer is described in the

51 – Remark by Benjamin Peirce in Schott, 'Report on the Results of the Micrometric Measures', 186.

52 – Jimena Canales, 'Photogenic Venus: The "Cinematic Turn" and Its Alternatives in Nineteenth-Century France', *Isis*, 93:4 (December 2002), 587 and 592.

53 – The scale of magnitudes is also called 'visual magnitude' or 'apparent magnitude', because it measures the brightness of the celestial object as seen from earth.

54 – Fechner's psychophysical law states that subjective sensation (say, perceived brightness) is proportional to the logarithm of the intensity of the physical stimulus (say, light).

55 – Charles S. Peirce, *Photometric Researches: Made in the Years 1872–1875*, Annals of the Astronomical Observatory of Harvard College, vol. IX, Leipzig: Wilhelm Engelmann 1878, 7.

56 – Ibid., 8.

57 – Ibid., 9.

58 – Ibid., 103–04.

59 – This claim was made by the astronomer Walter Hassenstein in his 'Visuelle Photometrie', *Handbuch der Astrophysik* (1929–36), quoted in Lenzen, 'Charles S. Peirce as Astronomer', 40.

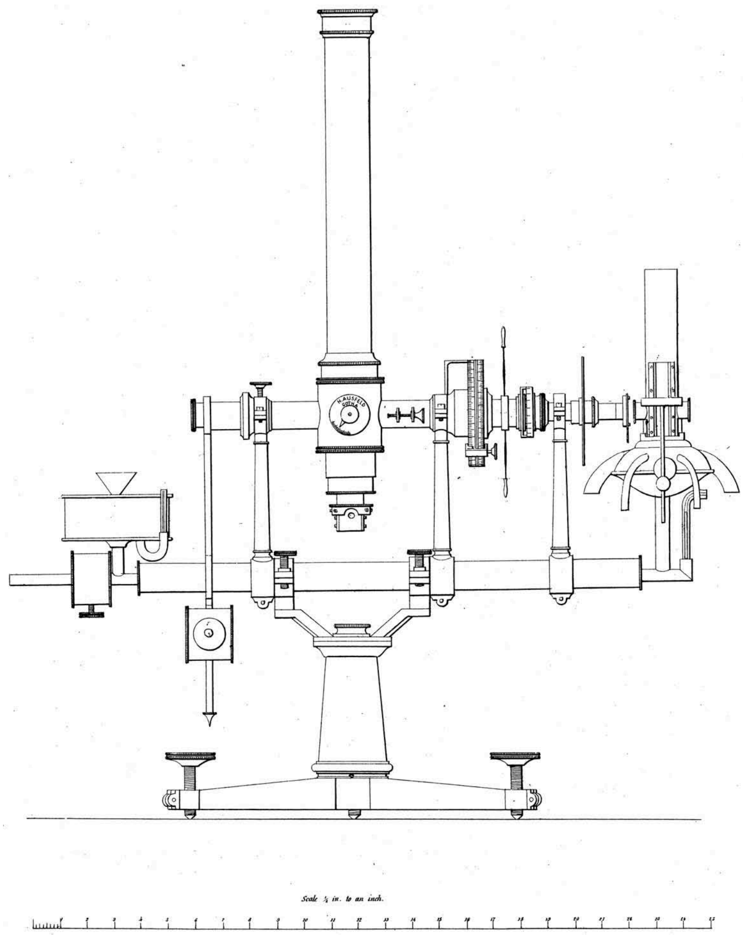

Figure 5. Zöllner photometer. Illustration from Charles S. Peirce, ‘Photometric Researches: Made in the Years 1872–1875’, *Annals of the Astronomical Observatory of Harvard College*, Volume IX, Leipzig: Wilhelm Engelmann, 1878 plate 184.1. © Harvard College Observatory.

Annals as ‘the reduction, by a set of Nicol’s prisms, of the light of an artificial star, which may thus be brought to a degree of brightness apparently equal to that of a natural star, the image of which also appears in the field of the observing telescope’.[60] The photometer was also equipped with a quartz plate, which made it possible to vary the colour of the artificial photometer star, and, hence, to match the apparent colours of the stars as well as their brightness. In practice, however, the task of visually comparing the photometer star with the real star was anything but easy. Peirce’s observations with the photometer were beset with problems – some practical, others more deeply principled.

Peirce’s photometric observations were conducted in five periods and at four different locations in the USA: at Cambridge, Hoosac Mountain, and Northampton in Massachusetts, and at Washington, District of Columbia. In most cases, the instrument was placed inside a little round observatory (figure 6), designed specifically for the purpose and which could easily be disassembled and moved from place to place.[61] The observations were made in all kinds of weather conditions, which sometimes affected the results. Even if he did make some observations of the colours of stars, he soon had to stop because the colour of the kerosene lamp varied too much, and because the instrument had to be refocused each time the colour-circle had been used. In Peirce’s opinion, a better design of the photometer would have been to leave the brightness of the artificial star fixed and instead vary the light of the real star: ‘In that way, we should compare the stars of different colors at a fixed relation to one another’.[62] The kerosene lamp caused much headache beyond the readings of colour. The lamp, which Peirce characterised as a ‘poor affair’, had to be kept clean and well filled and its wick neatly trimmed. It was easily blown by the wind and on occasions even blown out. The Nicol’s prisms were a further cause of concern. Upon its way to the eyepiece, the light from the kerosene lamp passed

60 – *Annals*, vol. VIII, part I, 43.

61 – Peirce, *Photometric Researches*, 102–03.

62 – Ibid., 89.

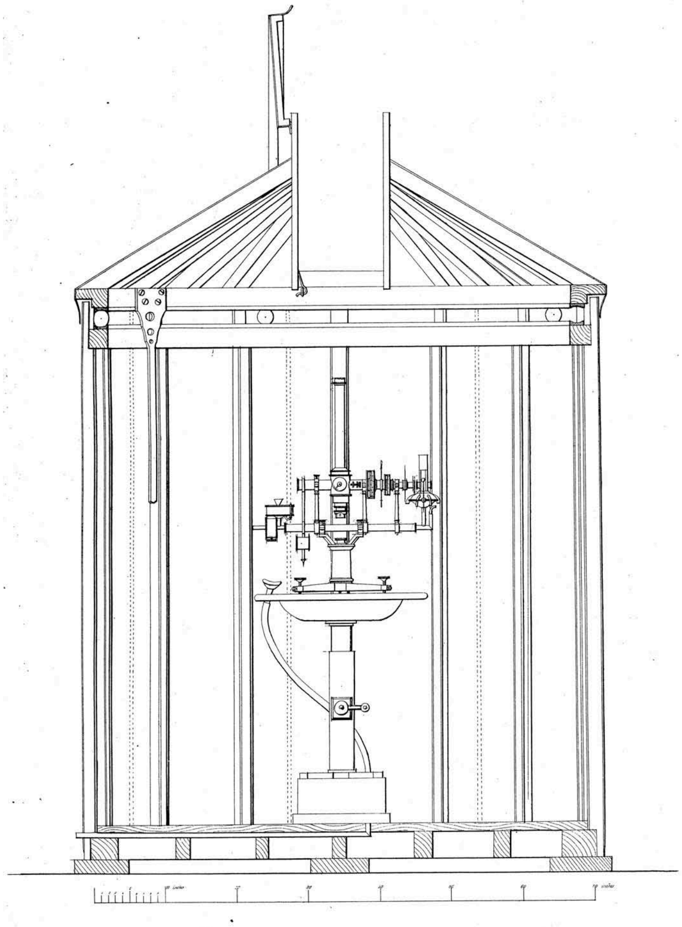

Figure 6. Photometer observatory. Illustration from Charles S. Peirce, 'Photometric Researches: Made in the Years 1872–1875', *Annals of the Astronomical Observatory of Harvard College*, Volume IX, Leipzig: Wilhelm Engelmann, 1878, plate 184.3. © Harvard College Observatory.

through a number of lenses, diaphragms, and prisms, as well as the quartz plate and a reflecting glass plate, striking altogether twenty-eight surfaces. The Nicol's prisms that came with the instruments, however, could not be put in position and had to be replaced. The malfunctions of the kerosene lamp and the Nicol's prisms notwithstanding, the most serious errors afflicting Peirce's photometric observations were due to the use of diaphragms or caps on the telescope's object lens. Since the photometer star had to be reduced in light to match the real star, the observation of particularly bright stars required a cap with a smaller aperture. These caps, Peirce found, 'seldom or never produced their theoretical effects'.[63] Again, Peirce blamed the design of the instrument, which altered the photometer star to match the real star. Higher accuracy would have been obtained if instead 'the real star had been brought to a fixed standard'.[64]

In his report on his photometric research, Peirce also discusses sources of error that relate to the observer and to the observer's handling of the instrument. He mentions, for example, the difficulties he had of putting his eye straight to the telescope. The telescope was constantly changing directions and Peirce had to have a table constructed that allowed him to rest his arm so as to keep it steady. He also worried about the eyes becoming fatigued in an unequal manner by the varying lights, compromising the comparison of the photometer star with the real star.[65] Another source of error concerned the different susceptibility of the eye to different colours. In addition to the general tendency of observers to determine stars as too bright, light of different colour is perceived differently at different degrees of brightness. 'For if a red and a blue light which appear equally bright are both doubled in brightness [...], they will no longer appear equally bright, but the red will appear the brighter'.[66] Further discrepancies are introduced when stars of different colours are observed 'by different observers or under different

63 – Ibid., 97.

64 – Ibid., 102.

65 – Ibid.

66 – Ibid., 6.

atmospheric circumstances or with telescopes of different power'.[67] Observers may also differ in 'mental subdivision', and even assuming that all observers make no errors in estimating brightness, discrepancies may be introduced because they divide magnitudes differently.[68]

67 – Ibid.

68 – Ibid., 9 and 167.

Peirce's Theory of Errors

For Peirce, the insistence on a fixed standard is connected with the idea of calculated observational values, and ultimately with his notion of truth in science. The connection is seen more clearly if we consider Peirce's theoretical work, such as 'On the Theory of Errors in Observations' (1875), where he brings probability to bear on the problem of induction.[69] In this text, where Peirce sets out to discuss the limitations of the method of least squares, he defines knowledge as consisting of 'nothing but average numbers'.[70] The reason he gives for this is that knowledge derives from induction and hypothesis. He sets out the general nature of induction as follows: 'From a bag of mixed black and white beans I take out a handful, and count the number of black and the number of white beans, and I assume that the black and white are nearly in the same ratio throughout the bag'. This assumption, Peirce maintains, is a valid inference, because '[i]f I am in error in this conclusion, it is an error which a repetition of the same process must tend to rectify'.[71] This procedure, however, teaches us nothing about the colour of any particular bean, only about the approximate general ratio between black and white beans. 'This is the only knowledge we ever have, a knowledge of what assumption to make in the particular case in order to do the best in the long run'.[72]

69 – Lenzen, 'Charles S. Peirce as Astronomer', 33.

70 – Charles S. Peirce, 'On the Theory of Errors in Observations' (1875), in *Report of the Superintendent 1870*, 201.

71 – Ibid.

72 – Ibid., 202.

This pragmatic approach to knowledge has implications for the theory of observations. First, it implies that what observation gives us to know is not a mere number expressing the value of the unknown quantity, but a function expressing the probable or mean value. It further implies that the precision of an observation is not something that belongs to a single observation; it is, rather, a statistical quantity that belongs to an infinite series of observations.[73] Thus, in Peirce's view, knowledge is never a punctual affair but an open-ended process that stretches out over time. Errors resulting from accidental variations, therefore, will tend to be rectified in the long run through numerous repetitions of the same process. Yet for a procedure to be regarded as an instance of the same process, and for an observation to count as a member of the same series of observations, the standard of measurement needs to be left fixed.

73 – There is an interesting link from this discussion of average numbers to the composite photographs invented by Sir Francis Galton in the 1880s. For thought-provoking discussions of Peirce's understanding of composite photographs, see Christopher Hookway, '"...a sort of composite photograph": Pragmatism, Ideas, and Schematism', *Transactions of the Charles S. Peirce Society*, 38:1–2 (2002), 29–45; and Chiara Ambrosio, 'Composite Photographs and the Quest for Generality: Themes from Peirce and Galton' (forthcoming in *Critical Inquiry*).

Peirce's investigations of errors in observation included a number of experiments designed to explore the effects of individual differences. The problem of individual differences in observation, which caused much worry among Peirce's scientific contemporaries, was usually ascribed to physiological differences or lack of training. In observations and measurements, the differences played out as variations in reaction time and were referred to as 'personal error', or, as in astronomy, as 'personal equation'.[74] The goal of Peirce's experiments was to record the time it took subjects to answer various kinds of signals. The results showed that, while the personal equation was more or less stable across numerous observations, the range of errors continued to decrease as long as the experiment lasted. He ends his text, therefore, by recommending 'transit-observers [to] be kept in constant training by means of some observations of an artificial event which can be repeated with rapidity'.[75] Peirce was not alone in affirming the value of training, and artificial transit machines for stabilising the reaction times of observers were built by the Russians, Germans, English, and Americans as part of the preparations for the transit of Venus in 1874.[76] All the same, the disciplinary regimes for training observers were not enough to dispel the general distrust in visual methods of observations, and the upcoming transit saw a broad, international mobilisation in favour of the new photographic methods.

74 – For detailed accounts of personal equation, see Simon Schaffer, 'Astronomers Mark Time: Discipline and the Personal Equation', *Science in Context*, 2:1 (1988), 115–45; and Jimena Canales, *A Tenth of a Second: A History*, Chicago: University of Chicago Press 2009. See also Jessica Ratcliff, *The Transit of Venus Enterprise in Victorian Britain*, London: Pickering & Chatto 2008, 84–86.

75 – Peirce, 'Theory of Errors', 212.

76 – For discussions of the use of transit machines and model training, see Canales, 'Photogenic Venus', 594–96; and Jessica Ratcliff, 'Models, Metaphors, and the Transit of Venus in Victorian Britain', *Cahiers François Viète*, 11–12 (2007), 63–82.

Eye versus Photograph

The 1874 transit of Venus was regarded by the international astronomical community as a unique opportunity to obtain a more precise value of the solar parallax, and hence to calculate the mean distance between the earth and the sun.[77] The use of Venus transits to calculate the solar parallax was first proposed by the English astronomer Edmond Halley (1656–1742).[78] The precision of the method, which involved triangulation, crucially depended on an exact timing of Venus's apparent contact with the sun's limb. Further, as the observations of the 1769 transit had made painfully clear, observers differed in their timing of contacts. During the 1874 transit, photographic methods were used to eliminate differences in observation. The astronomical community was devastated to learn, however, that the observational results were still discordant, and that the photographic methods had led to no significant improvement in determining the value of the solar parallax.[79]

In the period leading up to the 1874 transit of Venus, observations made by eye and ear were critically compared with observations made by photographic methods. The French astronomer Hervé Faye of the Paris Observatory, for example, favoured photography on the grounds that the automated procedure putatively suppressed human intervention: 'The observer does not intervene at all with his nervous agitation, his anxieties, his preoccupations, his impatience, [or with] the illusions of his senses and of his nervous system'.[80] In Faye's view, the preferred method would be to take many photographic imprints at short and regular intervals, an idea that was picked up by the French astronomer Jules Janssen, who developed a method referred to as the 'photographic revolver'.[81] However, as evidenced by the 1874 transit, suppressing the observer by adopting a method where, in the words of Faye, 'everything is automatic' did not suffice to solve the problem of discordant observations.

As a consequence of the failed attempt to obtain a more precise value of the solar parallax through photographic means, sentiments turned against photography. An international congress set up to plan the 1882 transit decided against the use of photographic methods.[82] Janssen, however, insisted that the failures were due to the circumstances – to the images being obtained under unfavourable conditions – and not to the essence of the photographic method. In his view, photographs of celestial phenomena were much to be preferred to drawings. A representation by human hand, he maintained, could not compete with 'the image of a star as drawn by the star itself'.[83] Thus, like Faye, Janssen expressed his adherence to the scientific ideal of mechanical objectivity.

However, the views expressed by Janssen were more complex than this. Beyond making 'faithful images' of celestial phenomena, photography had the potential of providing 'even more important services' to astronomy – namely, as a 'means of discovering facts that escape investigation by our optical instruments'.[84] The realisation that the photographic plate could 'see' more and other than the human eye was dramatically demonstrated by a series of photographic plates of a comet made by the Scottish astronomer David Gill of the Royal Observatory at the Cape of Good Hope in 1882. Because of exceptionally long exposure times, the plates revealed stars that had never been seen before by any method.[85] The excitement stirred by Gill's plates contributed to shifting the sentiments yet again, leading eventually to one of the most ambitious photographic projects ever undertaken: the 'Carte du Ciel' project, which was announced by the 1887 international astronomical conference in Paris, and which cemented photography's status as a research tool in astronomy.[86]

While both Faye and Janssen proclaimed the superiority of photographic observation over visual or 'direct' observation, a more nuanced view of the respective merits of the two methods was offered by another French astronomer, Charles Wolf. According to Wolf, the two methods complemented each other by

77 – Obtaining a reliable figure for this distance was of key importance to astronomers, since it served as the fundamental constant setting the dimensions of the solar system, and by extension the universe.
78 – Ratcliff, *Transit of Venus Enterprise*, 9–12.

79 – Ibid., 60–65 and 138–40.

80 – M. Faye, 'Le prochain passage de Vénus sur le soleil', *La Revue Scientifique de la France et de l'étranger, Revue des cours scientifiques* (2nd series, 4th year), 16 (17 October 1874), 366: 'L'observateur n'y intervient pour rien avec ses agitations nerveuses, ses anxiétés, ses préoccupations, son impatience, les illusions de ses sens et de son système nerveux'.
81 – For details about this method, see Monique Sicard, 'Passage de Vénus: Le Revolver photographique de Jules Janssen', *Études photographiques*, 4 (May 1998), 44–63; and Canales, 'Photogenic Venus'.
82 – Lankford, 'Impact of Photography', 22.

83 – Jules Janssen, 'La photographie céleste', *Revue Scientifique*, 2 (14 January 1888), 34: 'l'image d'un astre tracée par l'astre lui-même'.
84 – Jules Janssen, 'Sur la constitution de la surface solaire et sur la Photographie envisagée comme moyen de découverte en Astronomie physique', *Comptes rendus des séances de l'Académie des sciences*, 85 (31 December 1877), 1250: 'La Photographie céleste entre actuellement dans une voie nouvelle. Jusqu'ici cet art n'avait été envisagé dans ses applications à l'Astronomie que comme un moyen d'obtenir des phénomènes, des images fidèles et indépendantes de toute intervention de la main humaine. Aujourd'hui, la Photographie est en état de rendre des services encore plus importants et devient un moyen de découvrir des faits qui échappent à l'investigation par nos instruments d'optique'.
85 – Lankford, 'Impact of Photography', 25.
86 – For a detailed discussion of the 'Carte du Ciel' project, see Geoff Barker, '"Carte du Ciel": Sydney Observatory's Role in the International Project to Photograph the Heavens', *History of Photography*, 33:4 (November 2009), 346–53.

revealing different aspects of the sky: 'The eye makes us see stars that the photograph seems incapable of reproducing, or reproduces with a very different relative brightness. [...] The photograph, on the other hand, may reveal the existence of stars that are invisible to the naked eye'.[87] Even more interesting is Wolf's remark that, while the human visual organ always remains the same, the sensibility of the 'artificial retina' is subject to change: 'It could be that a layer of collodion might see and make visible a sky different to that which is imprinted on a layer of gelatine bromide', which, again, would differ from the sky seen and made visible by 'the photography of the future'. [88] The point I want to make here is that photographic observations did not simply replace visual observations in the sense of providing more accurate inscriptions of what might otherwise have been observed directly. Instead they revealed, in the words of Janssen, 'a new world'.[89]

87 – Charles Wolf, 'Sur la comparaison des résultats de l'observation astronomique directe avec ceux de l'inscription photographique', *Comptes rendus des séances de l'Académie des sciences*, 102 (1 May 1886), 477: 'L'œil nous fait voir des astres que la Photographie paraît être impuissante à reproduire, ou reproduit avec un éclat relatif très différent. [...] Par contre, la Photographie peut nous révéler l'existence d'astres invisibles à l'œil nu'.

88 – Ibid.: 'La couche sensible de la plaque photographique est une rétine différente de celle de l'œil humain; mais, en outre, cette rétine artificielle change de sensibilité lorsque sa nature vient à changer. Il se peut qu'une couche de collodion voie et fasse voir un ciel autre que celui qui impressionne une couche de gélatinobromure. La Carte du ciel obtenue aujourd'hui par la Photographie est autre que celle que donne l'observation directe, et elle est autre aussi que celle que donnera, dans vingt ans, la Photographie de l'avenir, dont les procédés seront certainement différents des nôtres. L'œil humain, au contraire, est un organe toujours le même, dont les observations sont en tout temps comparables entre elles'.

89 – Janssen, 'Sur la constitution', 1252.

Thus understood, Gill's photographic plates did not simply reproduce the (already) visible. Rather, they made visible the (hitherto) invisible, allowing astronomers to see the (hitherto) unseen. Each in their own way, Winlock, Janssen, and Wolf came close to realising that photography, when put to use as a research tool in astronomy, no longer functioned as a mere reproductive tool. As a tool of discovery, photography takes on an active role. Each photographic method delineates the phenomena under scrutiny in a characteristic manner, establishing a field of possible determinations that do not translate directly into the delineations and determinations provided by other methods. Today's scholars are increasingly acknowledging the productive or generative roles played by the apparatuses of science, and with these the inner connections between scientific instrument and object of knowledge.

A comment by Peter Galison reads like an echo of Wolf, confirming the latter's prediction about future photographic methods revealing new and different aspects of the sky:

> [M]easuring instruments and the objects they study often enter together: scan the heavens through a radio telescope, and the sky-scape lights up one way; look through an optical scope, and very different elements become its major features.[90]

90 – Galison, 'Images of Self', 275.

When we move from one method to the next, there is a change of venue – a new 'space' of possible entities opens up, and along with that, new patterns for discerning and comparing phenomena. Thus conceived, there is no competition between eye and photograph.[91] Instead, photographic apparatuses are understood to amplify and transform vision in various productive ways, forming hybrid and distributed observational systems.

91 – A similar point is made by Joel Snyder in relation to the photographic work of Étienne Jules Marey. See Snyder, 'Visualization and Visibility', in *Picturing Science Producing Art*, ed. Caroline A. Jones and Peter Galison, New York and London: Routledge 1998, 379–97.

Concluding Discussion: Photography as a Diagrammatic Tool

As we have seen, Joseph Winlock wanted to go beyond mere appearances by exploring photography's potential as a measurement tool. During the solar eclipse of 1869, he sought to photograph the eclipse in a way that ensured the comparability of the partial and total views. Since the camera had remained in the same position during the entire eclipse, he assumed that the position-angles could be calculated with accuracy. Here and elsewhere, Winlock drew a distinction between images that served pictorial functions and images that served revelatory or scientific functions, characterising the latter as 'diagrams' or, as in a report where he discusses a series of astronomical engravings executed by the French artist Étienne Léopold Trouvelot, as 'maps'. According to Winlock, a 'map' is distinguished from a 'picture' by providing a systematic grasp of the relative positions of the object in question (in this case, a nebula).[92] A map, therefore, is 'accurate' in the sense of displaying the object's features in a systematic manner – that is, as from a fixed or unchanging point of view – ensuring the comparability of the features relative to each other.

92 – *Annals*, vol. VIII, part II, 7.

In contemporary discourse, photographs are commonly regarded as hybrid signs or, in Peircean terms, as indexical icons. The indexical quality is further associated with the mechanical origin of photographs. It would be tempting, perhaps, to assign the pictorial function to the iconic aspect and the revelatory function to the indexical aspect. However, this division of labour does not hold up to closer scrutiny. As transpires from the negotiations surrounding the adoption of photography as a research tool in astronomy, the mechanical origin alone did not suffice to ensure the scientific value of the photographic views. Nor was the mechanical origin necessary, because even drawings could be used for measurement purposes provided that they were made in a systematic way.[93] The key to the scientific value, for Winlock, and even more so for Peirce, was the fixed or unchanging point of view.

93 – Ibid., 6–7. The systematic nature of the views could be secured, for example, by camera obscura projections or by some kind of grid system, ensuring an accurate portrayal of the relative positions of the parts of the object being observed.

Interestingly, when reflecting upon his photographic experiments, Winlock seemed to make a distinction between 'good' and 'bad' distortions. Bad distortions were distortions that could not be properly calculated, and that, for this reason, were left to mere guesswork. It was precisely to avoid bad distortions that Winlock recommended the use of stationary plane mirrors and fixed long-focus lenses and advised against the use of the enlargement method and heliostats. Likewise, when reflecting upon his photometric research, Peirce complained about the design of the Zöllner photometer on the grounds that it failed to bring the observed stars to a fixed standard. Both Winlock and Peirce, then, seemed to realise that observational instruments impose a standard on the observed phenomena, and that systematic determination and comparison depend on the fixed relation established by this standard. Wolf, on his side, went even further by realising that each photographic method imposed a different standard, and that, depending on the method used, a different sky would come into view. While preparing for the 1874 transit, the astronomical community seemed oblivious to all this. Failing to standardise their methods, the photographic observations produced discordant results.

The realisation that different observational methods bring different standards to bear on the observed phenomena breaks with the scientific ideal of mechanical objectivity, which conceives scientific value in terms of non-intervention.[94] When Janssen celebrated the image of a star that was 'drawn by the star itself', his assumption was that the camera, in contrast to the human hand, did not intervene into the phenomenon observed but merely reproduced it in a faithful manner, responding to nothing but 'the reality of things'.[95] Even if Peirce, in his comments on photography, sometimes emphasises a mechanically induced indexical bond to reality,[96] his ideas about truth and evidence do not comply with mechanical objectivity. Truth and evidence for him have to do with necessary reasoning, which cannot be explained in terms of brute compulsion ('secondness'). Thus, to pave the way for an alternative understanding of the revealing powers of photographic methods, I end this article by pointing to Peirce's diagrammatic notion of evidence, which, in sharp contrast to mechanical objectivity, conceives intervention as a prerequisite for discovery in science, and not, as we are accustomed to think, as an obstruction to it. More interesting still, the diagrammatic notion of evidence introduces a new and operational notion of iconicity that, when extended to photography, allows us to rethink photography as a diagrammatic tool.[97]

94 – Daston and Galison, 'Image of Objectivity', 82, 84, 96 and 120–23.

95 – Janssen, 'Sur la constitution', 1250–51: 'à la réalité des choses'.

96 – See for instance Charles S. Peirce, 'What Is a Sign?' (ca. 1894), in *Essential Peirce*, Vol. 2: 1893–1913, ed. Nathan Houser, Bloomington: Indiana University Press 1998, 5–6.

97 – A key source for Peirce's operational notion of iconicity is an unpublished manuscript that is referred to as 'PAP'. See Charles S. Peirce, '(PAP) [Prolegomena for an Apology to Pragmatism]', in *Charles S. Peirce: The New Elements of Mathematics*, vol. IV: *Mathematical Philosophy*, ed. Carolyn Eisele, The Hague: Mouton 1976, 313–30.

According to Peirce, necessary reasoning is characterised by the way that it makes its conclusion evident, in the sense that 'the truth of the conclusion is *perceived*, in all its generality'.[98] He immediately adds that indexes, being based on brute force, are incapable of communicating such evidence, and so are symbols and ordinary icons. It is only diagrams, or as he now puts it 'diagram-icons', that have the capacity literally to show that the consequence follows.[99] In contrast to ordinary icons, which are defined in static terms of resemblance, diagram-icons are defined in dynamic and operational terms. They do not simply depict the (already) visible; they make visible the (hitherto) invisible. Further, they incorporate, in their

98 – Ibid., 317; original emphasis.

99 – Ibid., 318.

very mode of operation, a logical factor, a generative rule of exposition, and hence belong to 'thirdness'. They do not simply resemble their objects; they *make similar* by providing a viewpoint or standard *according to which* phenomena are seen and determined. Peirce's operational take on iconicity resonates with contemporary attempts to conceptualise the 'logos' and 'agency' of images and media.[100] For Peirce, the evidential capacity of diagram-icons has precisely to do with their 'action'. Diagram-icons are forceful devices that reveal their objects by imposing a stable viewpoint or standard according to which the objects in question can be systematically delineated and compared.

100 – W. J. T. Mitchell, *What Do Pictures Want: The Lives and Loves of Images*, Chicago: University of Chicago Press 2005; Gottfried Boehm, *Wie Bilder Sinn erzeugen: Die Macht des Zeigens*, Berlin: Berlin University Press 2007; and Horst Bredekamp, *Theorie des Bildakts: Frankfurter Adorno-Vorlesungen 2007*, Berlin: Suhrkamp 2010.

Peirce's diagrammatic notion of evidence is rich in implications that need unpacking. I will concentrate here on one of these – namely, that the observational instruments of science intervene into the phenomena under scrutiny by providing, so to speak, the infrastructural conditions for their visibility and determinability. We have seen one obvious example of this, the Zöllner photometer, which literally incorporated a standard of comparison: the artificial photometer star. However, since the photometer star had to be adjusted to the real star and not the other way around, the instrument failed to establish a fixed relation, leading to unsystematic or 'bad' distortions that corrupted the comparability of the observed stars. When extended to photography, the diagrammatic approach brings out that photography plays an active role in co-constituting objects and observers, and hence that there is a directionality to photographic mediation that falls outside the purview of the indexical notion of evidence. For, as diagrammatic tools, photographic methods are understood to involve mediated, two-way exchanges with reality.

The diagrammatic approach also goes beyond the indexical notion of evidence in that it no longer seeks assurance in singular reference to existing particulars. As Peirce reminds us, truth differs from material fact, and knowledge can never be reduced to a 'punctual affair'. He demonstrated this in his astronomical practice, by developing star catalogues with calculated magnitudes; and he demonstrated this in theory, by asserting that precision is a statistical quantity that belongs to infinite series of scientific observations and not to single observations. The open-ended process of discerning and fixating the object also reminds us that knowledge has a collective dimension. As Galison and Daston have noted, Peirce sought the kind of knowledge that would overcome the 'vagaries' of individual observers. In scientific observations, the right results could only emerge from the joint efforts of a community of observers.[101] This calls attention to yet another service provided by the observational instruments of science: their coordinating role. Provided that they are properly standardised, the instruments of science allow the repetition of the 'same' line of sight, aligning observers across time and space. For all that, as should be clear from the above discussions, observational instruments are material and hybrid devices that, in the messy situations of real observations, will only approximate their 'theoretical effects'. Nor do the observational instruments fulfil their role as research tools all by themselves. Observational instruments always form part of larger, distributed scientific apparatuses that include human observers, training, paper and inscription processes, scientific theories and concepts, and auxiliary tools.

101 – Peter Galison and Lorraine Daston, 'Scientific Coordination as Ethos and Epistemology', in *Instruments in Art and Science: On the Architectonics of Cultural Boundaries in the 17th Century*, ed. Helmar Schramm, Ludger Schwarte, and Jan Lazardzig, Berlin: Walter de Gruyter 2008, 323–24.

In his efforts to probe deeper than mere appearances, Winlock turned to photographic measurement. However, depending on the approach, 'photographic measurement' can mean different things. One way would be to conceive photographs as faithful reproductions from which measurements can be taken. This was probably Peirce's point of departure at the time he conducted the evaluation of the Shelbyville photographs. An alternative way would be to conceive photography as a measurement technology in its own right, in the sense that each photographic method imposes its own standard for delineating and comparing the phenomena under scrutiny. The latter approach, which draws on Peirce's diagrammatic notion of evidence, reconfigures the relationship between the pictorial and the revelatory as understood by Winlock and other historical actors discussed in this article.

When conceived in terms of an operational notion of iconicity, the pictorial turns into an active relation that provides the conditions for the visibility and determinability of phenomena. Photographic methods do not simply reproduce or mimic a pre-given reality; they make similar in the sense of imposing specific rules for exposing the phenomena of interest, setting the condition for seeing or accessing them. These rules simultaneously serve as standards, specifying the dimensions along which the phenomena can be compared. Thus conceived, picturing and measuring become two sides of the same active process of revealing.

By regarding photographic picturing as a two-way 'measured' relation, the diagrammatic approach accentuates photography's productive dimension, and simultaneously, the affinities between the photographic observational practices of the past and contemporary scientific imaging. This is to say that by acknowledging photography's active role in the process of discovery, the diagrammatic approach puts photography theory on a new track that enables an alternative understanding of the passage from analogue to digital photography. For, with the diagrammatic approach, the transition to the digital era is no longer associated with a loss of photography's evidentiary force. There are two reasons for this. First, photographic evidence is no longer conceived in terms of non-intervention. Photographic methods (including analogue methods) intervene by imposing their own infrastructural conditions for the visibility and determinability of phenomena, each method revealing a different aspect of reality. Second, a key characteristic of diagram-icons is that they yield more information when manipulated in a systematic manner.[102] In the pioneering days of photometry, the plates were subjected to transformations and experimentations in the form of measurements performed by human computers – in the case of the Harvard Astronomical Plate Collection, by a team of highly educated and underpaid women astronomers.[103] The digital environment seems to augment photography's revealing powers and its capacity to serve as a means of discovery in science – as exemplified by the ongoing digitisation of the plate collection, which makes the old photographic views susceptible to calculations and manipulations on a whole new scale. On this occasion, however, the transformations and experimentations are performed by algorithms and pattern-recognition technology, provoking the plates to yield new information about how the position and brightness of stars change over time.

102 – Hence, just as there are 'good' and 'bad' distortions, there are 'good' and 'bad' manipulations – good manipulations furthering the process of discovery rather than obstructing it.

103 – These women astronomers were referred to as the 'Harvard Computers', or, less respectfully, as 'Pickering's Harem'. For a detailed account of one of these women astronomers, see George Johnson, *Miss Leavitt's Stars: The Untold Story of the Woman Who Discovered How to Measure the Universe*, New York and London: W. W. Norton & Company 2005.