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The Scientific and Historical Value of Annotations on Astronomical Photographic Plates

Sara J. Schechner
Harvard University, USA

David Sliski
University of Pennsylvania, USA

Abstract

The application of photography to astronomy was a critical step in the development of astrophysics at the end of the nineteenth century. Using custom-built photographic telescopes and objective prisms, astronomers took images of the sky on glass plates during a 100-year period from many observing stations around the globe. After each plate was developed, astronomers and their assistants studied and annotated the plates as they made astrometric, photometric, and spectroscopic measurements, counted galaxies, observed stellar variability, tracked meteors, and calculated the ephemerides of asteroids and comets. In this paper, the authors assess the importance of the plate annotations for future scientific, historical, and educational programmes. Unfortunately, many of these interesting annotations are now being erased when grime is removed from the plates before they are digitized to make the photometric data available for time-domain astrophysics. To see what professional astronomers and historians think about this situation, the authors conducted a survey. This paper captures the lively discussion on the pros and cons of the removal of plate markings, how best to document them if they must be cleaned off, and what to do with plates whose annotations are deemed too valuable to be erased. Three appendices (please visit Supplementary Material, available online) offer professional guidance on the best practices for handling and cleaning the plates, photographing any annotations, and rehousing them.

Keywords

Observatory, photography, telescopes, glass plates, archives, annotations, preservation, Harvard College Observatory, Digital Access to a Sky Century at Harvard

Corresponding author:
Sara J. Schechner, Collection of Historical Scientific Instruments, Harvard University, Science Center 370, 1 Oxford Street, Cambridge, MA 02138, USA.
Email: schechn@fas.harvard.edu

The Digital Access to a Sky Century at Harvard (DASCH), a multiyear undertaking of the Harvard College Observatory (HCO), is digitizing the world's largest collection of glass-plate photographs captured of the sky between 1885 and 1993 with observing stations in Massachusetts, USA, Peru, South Africa, and elsewhere around the globe. The purpose of the ambitious project involving more than 500,000 plates is to make the rich trove of data held in the Harvard Astronomical Plate Stacks accessible for time-domain astrophysics. About 20% of these plates have historically significant markings related to the work of the HCO on topics such as stellar variability, proper motion, galaxy dynamics, cosmology, meteors, and the ephemerides of minor planets, asteroids, and comets. Names associated with the research performed with the plates include Edward Pickering, Williamina Fleming, Annie Jump Cannon, Henrietta Leavitt, Harlow Shapley, Fred Whipple, and others. Historically significant writing is also found on the plate jackets.[1] (See Figures 1 and 2.)

In May 2013, Harvard professor Jonathan Grindlay, Robert Treat Paine Professor of Practical Astronomy and the lead scientist of DASCH, called a meeting to discuss the preservation of the photographic glass plates that were being scanned. Present at this meeting were Harvard museum curators, librarians, photographic conservators, historians of science, scientists, and the DASCH staff.[2]

One of the major issues discussed without conclusion was what to do with the annotations marked on the non-emulsion side of glass plates. The scientists argued that grime and annotations obscured the scientific data (i.e. the positions and brightness of celestial objects) that they hoped to preserve and make accessible by creating a digital file of each astronomical photograph. Therefore, project protocols called for a two-step process. A technician took a photograph of the annotations on the plate and its jacket. Then each plate was cleaned with razor blades, an ethanol/water (40/60) solution, and microfiber cloths in order to remove smudges and India ink annotations from the non-emulsion side before the plate was scanned. The historians, librarians, and conservators were worried that the solvents applied by hand on each plate and then wiped off with towels, and those to be employed with stainless-steel wire brushes in an automated plate washing machine (still in the works) might accidentally damage the emulsion or scratch the glass.[3] They were also concerned that the cleaning of the plates before scanning was an irreversible process whereby valuable historical and scientific data possibly contained in the annotations would be lost. They asked about the quality and format of the photographs of annotations, and made recommendations to increase resolution, optimize lighting, calibrate colour, change file type, and improve the photography station. After the meeting, the conservators and photographer submitted reports on best practices for plate handling and photography to DASCH.[4] Updated versions of the reports are appended to this paper for the benefit of others working with photographic plates.

The 2013 meeting, prompted specific questions:

1. To what degree do the annotations on the plates and their paper jackets have historical value?
2. How should they be documented?
3. Are photographs of the annotated plates and jackets sufficient substitutes for the real artefacts for research? If yes, what resolution and image quality would satisfy researchers?

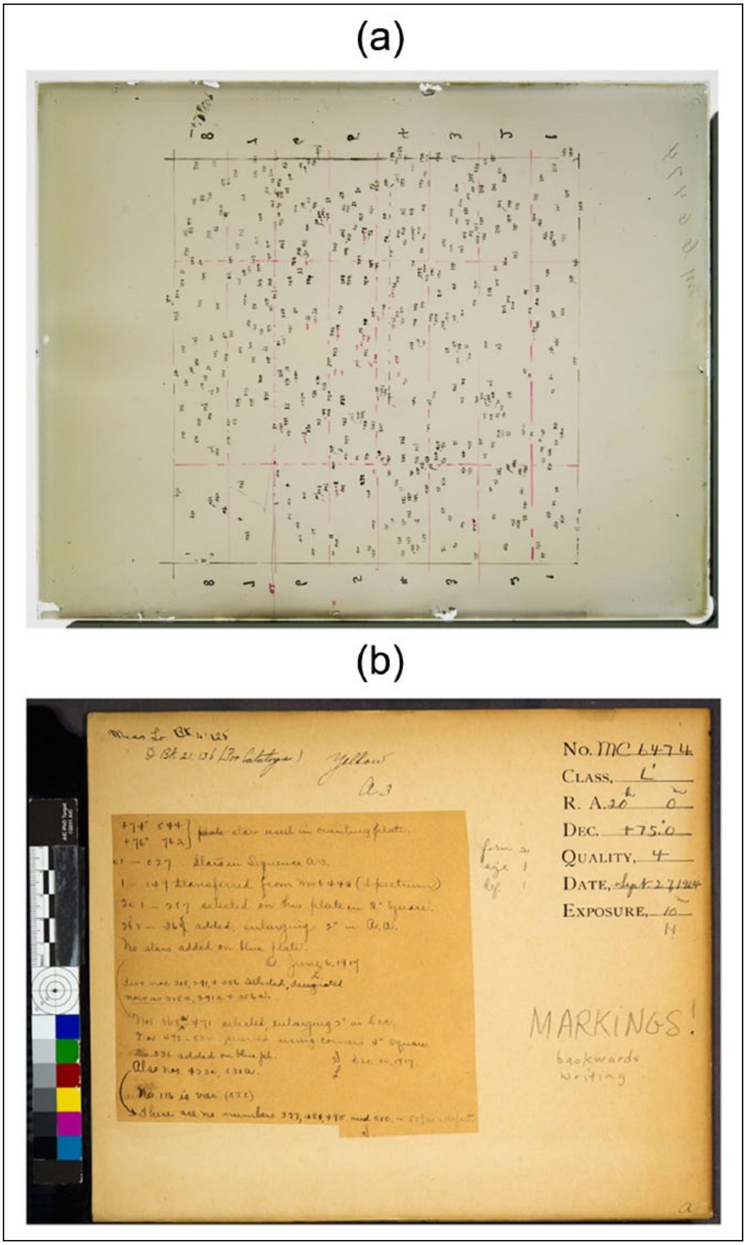

Figure 1. Plate MC6474 (a) and its jacket (b) illustrate the process of compiling a catalog of stars from multiple plates that were sensitive to different portions of the spectrum. This yellow-sensitive plate was exposed on 27 September 1914 and compared to a blue-sensitive plate. As the work progressed through the end of 1917, different women at the observatory annotated the jacket. They include "L" (Evelyn Leland), "S," and "AJC" (Annie Jump Cannon). The plate annotations are unusual in being written backwards on the plain side in order to be read directly from the emulsion side. Photographic plate taken with the 16-inch Metcalf telescope in Cambridge, MA, with its protective sleeve. Courtesy of the Harvard College Observatory Plate Stacks.

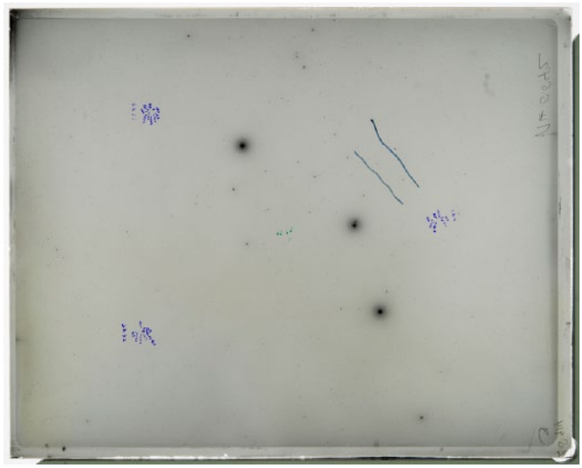

Figure 2. A meteor streaked across the sky when plate RH8842 was exposed on 16-17 May 1939. Fred L. Whipple took note of it on May 26, drawing lines on either side of its visible path on the plate. Without these annotations, it would be hard to locate the meteor on the plate, much less know that any astronomer took an interest in it. Photographic plate RH8842 was taken with a 3-inch Ross-Fecker patrol telescope at Oak Ridge Observatory, Harvard, MA. Courtesy of the Harvard College Observatory Plate Stacks.

4. Should the original plates and jackets be preserved after digitization?
5. Should any annotated plates be set aside uncleaned in order to illustrate the work of specific researchers, their methods, research subjects, and major discoveries? If so, which ones and how many?

In order to answer these questions, Professor Jonathan Grindlay, asked Dr Sara Schechner, curator of Harvard's Collection of Historical Scientific Instruments, past chair of the Historical Astronomy Division (HAD) of the American Astronomical Society (AAS), and a founding member of the AAS Working Group on the Preservation of Astronomical Heritage (WGPAH), to conduct a survey of the history-of-astronomy community. Schechner invited David Sliski, then a DASCH curatorial assistant, to collaborate, since he had raised concerns about plate handling, organized the advisory meeting, and helped to implement many of the changes suggested by museum professionals. This report summarizes the findings of that survey. Illustrations of annotated plates and their jackets are included in order to assist readers in understanding what such plates look like.

Method of the survey

The survey was qualitative with 25 people responding in writing to a questionnaire that was distributed via email to WGPAH, HAD, HASTRO-L (a history of astronomy listserv), and personal correspondents. Prior to the survey, members of WGPAH and HAD were less likely to be strangers to the challenges of preserving astronomical photographs and archival records, since these organizations had been instrumental in organizing meetings and publications on the topic.[5] Subscribers to HASTRO-L, on the other hand, are drawn from a wider population than HAD's and WGPAH's professional astronomers, and they would have been less familiar with the survey topic. A total of 80 percent of the respondents were astronomers, many of whom had worked with photographic plates in their research. The remaining 20 percent were professional historians of science.

Although the response rate was small for a survey circulated to several hundred individuals, the respondents were distinguished scientists and historians. Most replies were public insofar as they were sent to discussion lists where all subscribers could read them and openly engage with them. The result was a lively discussion, which this report strives to capture in the fashion of oral histories by having many quotations.

Summary of findings

All respondents agreed that the annotations on the plates and jackets had scientific, historical, and educational value, and the preponderance rated this value as very high. Most believed that preservation of this scientific and historical value could be accomplished adequately by photography, provided that the images were of very high quality (as defined below). All agreed that some plates should be set aside without removing the annotations as samples of the historical methods, the work of key individuals, and important discoveries.

Discussion of particular questions

Do plate and jacket markings have any historical or scientific value?

The answer was a resounding yes, and respondents stated many reasons why. The best digest was offered by David DeVorkin, Senior Curator at the Smithsonian National Air and Space Museum: the annotations, he said, were "incontrovertible proof that something was done in a certain way, without the possibility of some equivalent of 'Photoshopping,' either conscious or inadvertent."[6]

Only one respondent, Bradley Schaefer, who described himself as "both a heavy user of the Harvard plates (and other plate collections) and a person who has done a lot of history work," claimed that he had "never come across any annotation that was of any astrophysical … [or] historical use at all." But after reading the discussion on HASTRO-L, he agreed that other researchers have found utility, writing "*I* have never found the plate annotations helpful, but Wayne Osborn's email trumps my lack of utility, because *he* has found a variety of uses for them."[7] While acknowledging that some historical and representative plate annotations should be saved, Schaefer maintained that most annotations would never be of utility to astronomers or historians. (Wayne Osborn of Yerkes Observatory, to whom Schaefer referred, has been a scientific user of astronomical photographic plates and a major advocate for their preservation.[8])

Schaefer is to be credited with voicing an opinion held strongly by others, but there were also many respondents at the opposite pole. The latter believed so intensely in the value of the markings that they contended that any removal of these would be detrimental to future research, both historical and scientific. Arguing for the historical importance, Barry Madore, a senior researcher at the Observatories of the Carnegie Institution for Science,

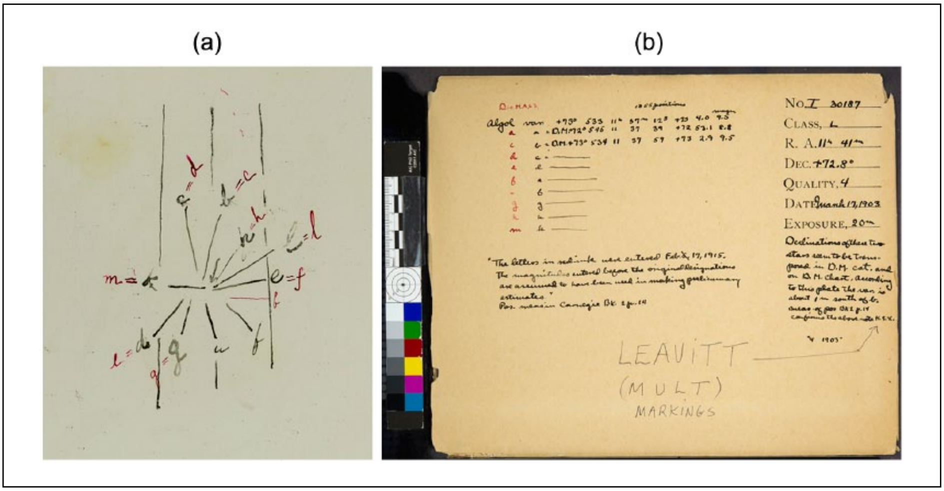

Figure 3. Exposed on 17 March 1903, plate I30187 (a) and its jacket (b) illustrate Henrietta Swan Leavitt's method for discovering variable stars. She marked the star of interest—Zeta Draconis—with an arrow, and labeled nearby stars with letters *a* through *k* in black ink so that their magnitudes could be compared. Zeta Draconis proved to be an Algol-type eclipsing binary star. After Henry Norris Russell and Harlow Shapley used the light curve of the star to determine the orbital parameters of the binary system in 1914, Leavitt returned to the plate to reassign letters in red ink to the comparison stars. Photographic plate taken with the 8-inch Draper telescope in Cambridge, MA (detail) with protective sleeve. Courtesy of the Harvard College Observatory Plate Stacks.

said that "unless a strong scientific case can be made for scrubbing any given plate, the over-riding default should be to preserve the historical record. There is probably more value in the history than in the developed grains." Wendy Freedman, now at the University of Chicago, but then director of the Carnegie Observatories, concurred "that removing markings is to be avoided given the historical nature of these markings." Jay Pasachoff, director of the Hopkins Observatory at Williams College, wrote, "Just as I wouldn't scrub off Edwin Hubble's handwriting, I would say that the handwriting of Henrietta Leavitt, Williamina Fleming, and others shouldn't be scrubbed off," but added that they should "at least be separately scanned."[9] (See Figure 3 for a plate related to Leavitt's work.)

Arguing on behalf of the scientific importance of markings were astronomers such as William Liller, R.W. Willson Professor of Applied Astronomy at Harvard (1961–1983), who had spent many hours in the Harvard plate stacks in the 1970s identifying x-ray sources and studying their historical behaviour, as well as noting quasi-stellar objects, novae, supernovae, and the occasional asteroid or comet of interest. Liller made this "fervent plea":

> I herewith submit that in the vast majority of cases, the ever-so-tiny little "vee" marks or circles on the glass plates were put there in indelible ink by highly diligent inspectors who had a clear understanding that at some time in the future, someone might just want to measure precisely the position or brightness of the object of interest. Ergo, meticulous care was almost certainly taken

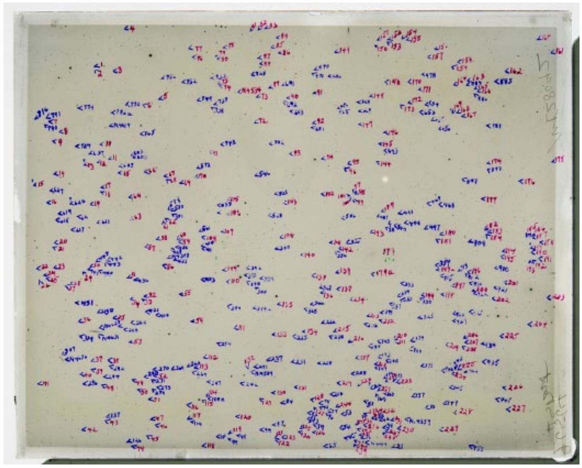

Figure 4. Annotations in diverse colors of ink mark the 'fuzzy' objects that could be galaxies of different sorts. Although the photographic plate MC28092 was taken on 25-26 January 1936 with Harvard's 16-inch Metcalf telescope at Oak Ridge Observatory, its jacket indicates that the plate was later examined for Seyfert galaxies, which were not described until 1943. Harlow Shapley and his team used the 16-inch Metcalf in conjunction with the 24-inch Bruce telescope in the southern hemisphere to identify more than 500,000 new galaxies. Courtesy of the Harvard College Observatory Plate Stacks.

> not to let the ink mark encroach on, or even come close to the image. And so my strong recommendation would be not to "scrub off" these marks.[10]

See Figure 4 for an example of such plate markings.

Even those who took the opposite stance – that is, that all plates should be cleaned – still conceded that the markings might prove worthwhile to document. Vladimir Strelnitski, the retiring director of Maria Mitchell Observatory on Nantucket, recalled discussions on the matter at the international meeting at the Pisgah Astronomical Research Institute (PARI) in Rosman, North Carolina in November 2007:[11]

> Some people expressed a strong belief that the old markings on the plates may be useful, and thus they should be copied before cleaning the plate. It was too late an advice for MMO: the scanning had been finished by then.

His frank opinion was that the old markings "may present some interest (mostly historical) only in very rare cases." Therefore, their preservation should be decided case by case in big scanning projects where there was pressure to get things done as quickly as possible.[12] Strelnitski's colleague at the Maria Mitchell Association, and formerly the Executive Officer for the AAS (1979–1995), Peter Boyce only half agreed: "I would not save any of the plate markings – as long as they are photographed sufficiently well."[13]

Indeed some respondents expressed curiosity and dismay about missed opportunities arising from cases of "lost" annotations. Virginia Trimble, an astrophysicist and historian of astronomy at the University of California Irvine, and Lee Robbins, Head Librarian of the Astronomy and Astrophysics Library of the University of Toronto and co-author with Wayne Osborn of a plate census and reports on plate preservation, both shared the story of Harlow Shapley and Milton Humason. Humason's connections to astronomy started as a mule driver hauling supplies up Mount Wilson for the construction of the 100-inch telescope. When it was complete in 1917, he was hired as a janitor and a couple of years later became a member of the scientific staff. Shapley was on the mountain at the same time, and offered to let the budding astronomer have a look at his M31 plates with a blink comparator. After a few weeks of studying the plates, Humason returned with several objects marked and asked if they might be Cepheid variables. According to Humason, Shapley said he must be mistaken; everyone knows those variables cannot be Cepheids because the Andromeda nebula is part of our galaxy and any Cepheid in it would be brighter. He then took out his handkerchief and rubbed out Humason's marks. If the story is credible – as Shapley later admitted – Shapley erased an opportunity for recognizing the extragalactic nature of the spiral nebula 4 to 5 years before Hubble did. He also erased our chance to check Humason's story.[14]

What kind of research might be done from annotations in the future?

Respondents envisioned many general scientific and historical reasons to consult the annotations of photographic plates and their jackets. In addition to the obvious point that the jackets record essential information regarding exposure dates, times, equatorial position of the plate centre, and plate number, the principal reasons were as follows:

- As proof of who had taken, read, or examined the plate.
- To confirm a result.
- To disclose whether reference stars or other objects were misidentified.
- To see if markings somehow influenced or corrupted the data.
- To understand what choices were made that led to a particular result.
- To recognize a first discovery.
- To derive cultural patterns and practices in observing.

The annotations were often compared to book marginalia insofar as they might help scholars to understand who had read what, why they had read it, and what their conclusions were.[15] One surprise of the survey was that most reasons given *not* to erase plate markings were scientific rather than historical. Although all of the stated reasons have great potential, historical value, only the last item on the list above – to derive cultural patterns and practices in observing – is exclusively a historical reason.[16]

Have plate markings been useful for research and education in the past?

The DASCH principal investigator, Jonathan Grindlay, had challenged the authors to provide examples of specific cases in which plate markings had been useful or necessary in the past. The survey passed this challenge along in the form of questions, "Has anyone done such research with marked plates in the recent past? If so, which plates were important for their work?" For clarity, the responses, itemized below, are divided into two categories – historical and educational uses and scientific uses. This list is representative and should not be construed as all-inclusive. Readers of this report will, no doubt, recall other instances.

Historical and educational uses. The principal historical or educational motives to examine marked plates were to understand or illustrate the work of astronomers and to generate public admiration for the discipline. The plates cited most for such programmes were of three varieties: (1) plates on which famous discoveries were marked, (2) plates that illustrated a scientific method, or (3) plates showing a step taken by a particular astronomer in the course of research. Here are some instances:

1. The famous Mount Wilson plate on which Edwin Hubble marked his first discovery of a Cepheid variable in the Andromeda nebula (M31), establishing beyond a doubt that the M31 was a galaxy outside of our own. This plate is featured in the astronomy textbook of Jay Pasachoff and on the Carnegie Observatories website.[17] To wash away a marking such as this would be tantamount to erasing annotations in copies of Copernicus's *De Revolutionibus*, several people said.[18]
2. The discovery plates of Miranda and Nereid (the satellites of Uranus and Neptune, respectively), taken by Gerard Kuiper in 1948 and 1949 at McDonald Observatory, which have these objects marked.[19]
3. The HCO discovery plate for the Sculptor dwarf galaxy – photographed in 1932 with the Bruce 24-inch doublet telescope, then in Bloemfontein, South Africa – shows not only the galaxy discovered in 1938, but also observatory methods of working with the plate. Over 2000 galaxies are marked in ink and numbers in circles refer to magnitude standards on the plate. The plate markings are published by Gingerich.[20] (Figure 5 shows such a heavily annotated galaxy plate.)
4. An HCO plate showing a portion of the sky near Sagittarius and Scorpius with 39 globular clusters circled is published in Harlow Shapley's autobiography.[21]
5. Plates of M101 and M33 that Adriaan van Maanen measured and marked between 1915 and 1923, showing the direction and magnitude of the rotation of the spiral nebulae, are illustrated in Robert Smith's history of the debate over the size and nature of the universe.[22] Van Maanen's conclusions on the speed of rotation were accepted by Harlow Shapley as proof that nebulae were within the Milky Way, while they were rejected as erroneous by Heber Curtis because he believed the spiral nebulae were extragalactic and comparable in size to the Milky Way. If they rotated as fast as van Maanen calculated from the plates, the spiral arms would be moving faster than the speed of light. Examination of van Maanen's marked plates has aided astronomers and historians to understand better where his errors originated. (Figure 6 shows a spiral galaxy's orientation being measured.)
6. An HCO galaxy plate, prints made from plate spectra, and a log book of Annie Jump Cannon are on public display in *Time, Life, and Matter: Science in Cambridge*, a permanent exhibition of the Harvard Collection of Historical

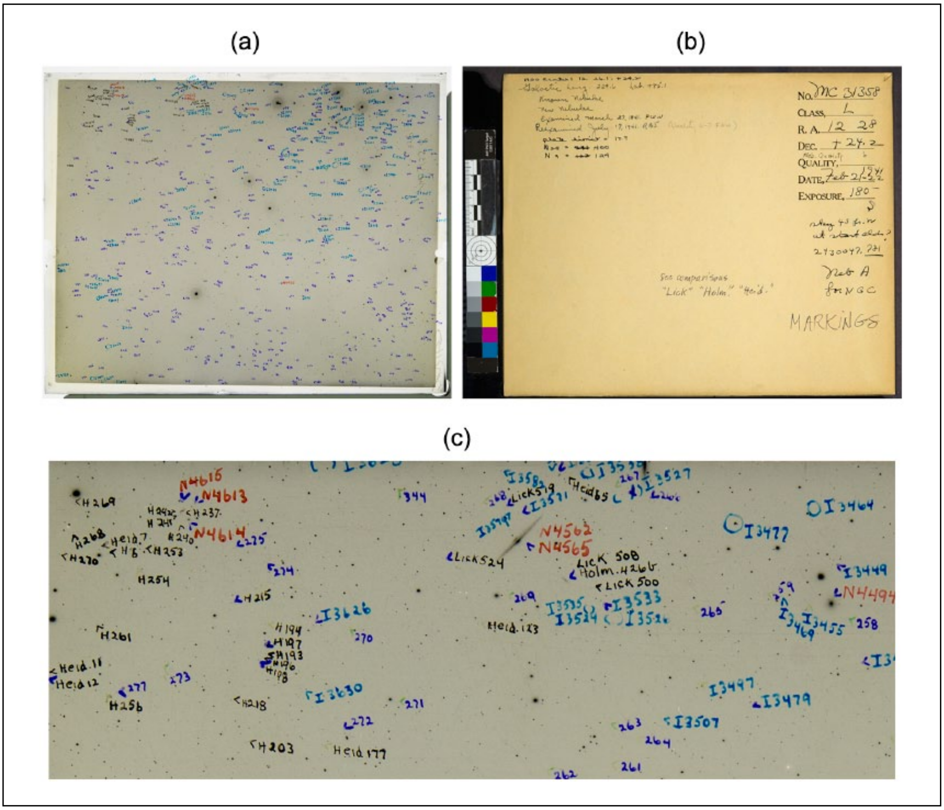

Figure 5. Marked in five colors of ink by at least three individuals, plate MC31358, shown here (a) with its protective jacket (b), is an example of layered annotations representing work over several years. Taken on 21-22 February 1941, the plate was studied a month later by Frances Woodworth Wright who marked the 'fuzzy' objects on it with green arrows and two shades of blue ink. These included Index Catalogue (IC) objects. On July 17 another observer, "RBJ", reexamined the plate and likely added the labels in red ink for New General Catalogue (NGC) objects. The detail (c) of the upper portion of the plate is also filled with notes in black ink, which designate objects according to deep sky surveys by Erik Holmberg and the Lick and Heidelberg observatories. These may be the work of a third observer after 1950. Galaxies such as NGC 4565, a tilted spiral galaxy (seen near the upper center of the detail) were studied in the 1930s-1950s in order to determine their shapes, how they rotated, and their dynamical interactions with other galaxies. Photographic plate MC31358 taken with the 16-inch Metcalf telescope at Oak Ridge Observatory (full plate and detail) with its jacket. Courtesy of the Harvard College Observatory Plate Stacks.

Scientific Instruments. In the exhibition, they illustrate the pioneering research methods and scientific life at HCO during the Pickering era.[23]

7. The discovery plate for Pluto taken on 23 January 1930 at the Lowell Observatory is on display in an exhibition, *Exploring the Planets*, at the National Air and Space Museum.[24]

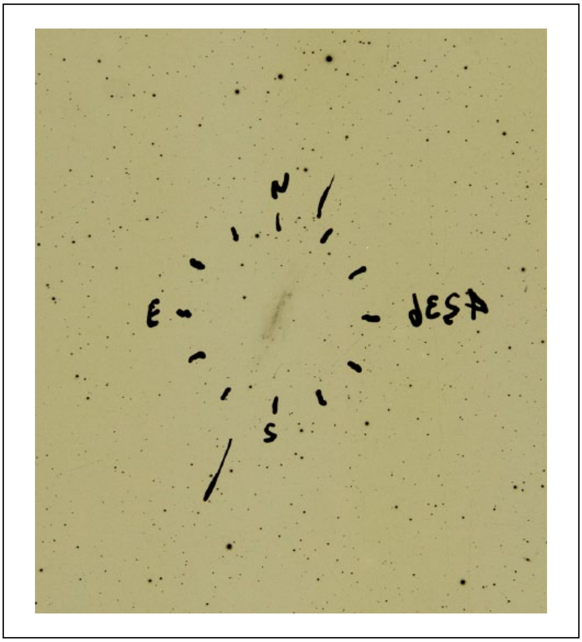

Figure 6. The markings on plate MA8246, exposed on April 6-7, 1940, draw attention to NGC 4236 and its orientation in the sky. Edwin Hubble had classified this nebula as a Sc Spiral Galaxy in his famous 1926 paper, which divided extra-galactic nebula into a sequence of "island universes" based on their structure. At the time, Harlow Shapley had opposed the idea of galaxies beyond the Milky Way, but this 1940 photographic plate offers evidence of Harvard College Observatory's continued interest in galaxy distribution under Shapley's leadership. Photographic plate taken with the 12-inch Metcalf telescope at Oak Ridge Observatory, Harvard, MA (detail). Courtesy of the Harvard College Observatory Plate Stacks.

8. Saturn's moon Phoebe, the first moon to be discovered photographically, was found by William H. Pickering in March 1899 by comparing four plates (A3230, A3227, A3228, and A3233) taken on 16–18 August 1898 with the Bruce 24-inch doublet telescope at the HCO station in Arequipa, Peru. In describing the method used to make the discovery, Edward C. Pickering noted that "in planning the Bruce photographic telescope, a search for distant and faint satellites was regarded as an important part of its work, and accordingly, plates for this purpose were taken at Arequipa."[25]
9. The HCO discovery plate for Comet Bappu–Bok–Newkirk (C/1949 N1) – J3064, photographed by the 24-33-inch Jewett Schmidt telescope on 2 July 1949 – was located by Indian astronomer, Amar Sharma of Nikaya Observatory, Bangalore, for his profile of the late Indian astrophysicist M. K. Vainu Bappu in *Biographies of Worldwide Comet Discoverers*. Images of the marked plate and its jacket have also been published by R. C. Kapoor, and another mistakenly described as the discovery plate but taken on a successive day has been published by Denis Buczynski.[26]

The story of the Comet Bappu–Bok–Newkirk plate is instructive for its historical value and as a demonstration of the usefulness of the markings. Observing for the first time at Oak Ridge Station of the HCO, Harvard graduate student M. K. Vainu Bappu exposed a photographic plate for 55 minutes with the 24-33-inch Jewett Schmidt telescope near dawn on 2 July 1949. Rather than send the plate back to Cambridge for processing, Bart Bok, his professor, suggested that Bappu develop it himself to see what his own plate looked like. When it came out of the fixing bath, Bappu announced eagerly that he was going to look for comets! “Ha, ha,” Bok chuckled. “Everyone looks for comets.” While the plate was being examined by Bok and Bappu, an undergraduate, Gordon A. Newkirk, Jr stopped by and was invited to see the good quality of the photograph. Looking at the plate through the binocular microscope, Newkirk exclaimed, “Hey, that looks like the trail of an asteroid or something!” Bok took another look and stated, “That is no asteroid – that is a hairy comet.” Two more Jewett plates taken by Bok and Bappu the next night confirmed the discovery.[27]

Harlow Shapley, director of the observatory, announced the new comet,[28] but barely 10 days after the discovery, Bappu received a stern letter from the Government of Hyderabad, his sponsor, telling him to stop playing around with comets and get to work on “photoelectric photometry of eclipsing variables.” Fred Whipple, chairman of Harvard’s Department of Astronomy pushed back, writing in Bappu’s defence to the Indian Embassy in Washington, DC, that this was the first occasion in his memory in which a foreign government had seen itself fit to criticize the educational methods of the Astronomy Department of Harvard University. He pointed out that the discovery was accidental to the photographic work that was essential to Bappu’s training as a graduate student:

> For him to have failed to note this unusual object on his photographic plates would have been a sin of scientific omission; to have failed to announce the discovery would have been a serious neglect of his duty to the scientific world.[29]

Whipple continued,

> Our policy of education for graduate students in Astronomy includes thorough background training in classical and positional astronomy, in stellar astronomy, in cosmogony and in modern astrophysics. We will not grant the degree of Doctor of Philosophy to a student who does not have a well-rounded background in all of these areas. If it is actually true that the Hyderabad Government wishes Mr. Bappu to study “Photoelectric Photometry of Eclipsing Variables” and nothing else in his graduate work, they have certainly erred in sending him to Harvard University. We would be glad to assist him in such a narrow study, if necessary, but we could not grant the degree of Doctor of Philosophy in Astronomy on that basis alone.

> Our experience has shown that independence of mind, a broad background in mathematics and the physical sciences and freedom in choosing research problems are essential to a physical scientist who is to produce creative work.

Whipple closed his letter by saying,

> Mr. Bappu is doing excellent work as a graduate student. … I feel personally that it is a great mistake for him to be handicapped psychologically by ill-founded reprimands that should be directed, if at all, to those who have assumed the responsibility for his graduate education.

So here we have a photographic plate at the centre of a great story about a young graduate student who would later be seen as the "father of modern Indian astronomy." It is a story of youthful exuberance and optimism, serendipitous discovery, instructional methods and educational philosophy, scientific news, and the meddling of foreign powers. It is a story involving Bok, Shapley, Whipple, Bappu, and Newkirk – all exceptional astronomers.

The whereabouts of this discovery plate were unknown for years to the Indian astronomical community until Amar Sharma was guided by William Liller to the Harvard plate stacks. Liller, who had been a good friend of Bappu in their student days, observed that if the plate were marked – and the mark saved – it would be a simple matter to find the plate and the comet on it. Without markings, Sharma would have had to find, look up, or calculate the comet's position, make a finding chart at the appropriate scale, and then match it with the plate images.[30] As it turned out, there has been confusion in the literature with two different plates published as the discovery plate. The source of this mistake appears to be the fact that the discovery plate was cleaned and the comet no longer marked (except for a note on the plate jacket), while plates taken on successive nights to confirm the discovery were still marked when a researcher sought them out.[31]

Scientific uses. Astronomers who have used photographic plates in their research offered many scientific reasons to preserve the markings on plates and their jackets. From their own experiences, they cited:

1. Notations used to identify objects unambiguously in cases where only approximate positions were given in the literature (e.g. plate notations used to re-identify some "lost" variable stars).[32]
2. Notations used to identify the plate referenced in an article only by its date (e.g. "The earliest plate showing the object was taken July 9, 1919 …," Solon Bailey describing a particular nova as an "extra-ordinary object" on Harvard photographs "examined by Miss H.S. Leavitt and Miss D.W. Block.")[33]
3. Notations used to identify instrumentation employed when there is no locatable log book and the envelope has no writing, but it is written in the border of the plate image (e.g. early plates at Yerkes with annotations like "M2, 40-inch telescope 1900 Sept 12 8:10 – 11:10." More specifically, a request to identity the telescope used for three Yerkes plates of the Sun, which were lent to Greenwich Observatory in 1939. The information is now needed for a revision of the Greenwich sunspot observations).[34]
4. Notations used to confirm a result or to question an earlier finding (e.g. plates reviewed in order to evaluate the reference frames and stars used by previous investigators, whose parallax measurements disagree with a modern value).[35] The reexamination and measurement of van Maanen's plates of spiral nebulae by modern astronomers is a good example of this.

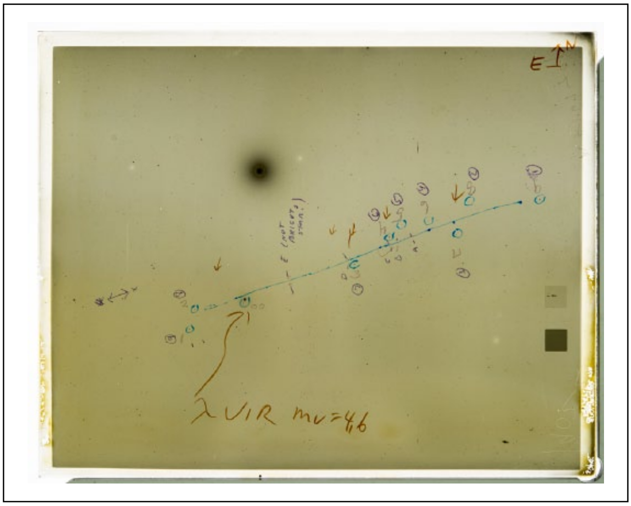

Figure 7. An observer on 8 April 1920 has marked plate MC16749 along the ecliptic in an effort to track a solar system object, most likely a recently discovered minor planet. The bright object in the field is Saturn. Photographic plate MC16749 exposed with the 16-inch Metcalf telescope in Cambridge, MA. Courtesy of the Harvard College Observatory Plate Stacks.

5. Notations used to find a minor planet and calculate its orbit (e.g. William Liller's and Lola Chaison's work on Minor Planet (2060) Chiron, whose image was found marked in indelible ink on Harvard plates taken in 1943, 1941, and 1897).[36] (See Figure 7 for a plate illustrating minor planet work.)
6. Notations used to "debug" the New General Catalogue (NGC) and the Index Catalogue (IC) of nebulae (e.g. Harold Corwin's use of HCO plates listed in the *Harvard Annals*, vol. 60).[37]
7. Notations used to identify the plate itself when separated from its envelope.[38]

Respondents suggested that the digital library known as the SAO/NASA (Smithsonian Astrophysical Observatory/National Aeronautics and Space Administration) Astrophysics Data System (ADS) be searched in order to come up with a starting list of key HCO plates that might merit special attention and preservation with markings intact.

Can digital images replace the real thing?

The point of this question was to gauge what if anything was lost when the plate was cleaned as part of the DASCH project. Would a digital image of an annotated glass-plate photograph be just as good for the scientific, historical, and educational uses enumerated above as the undisturbed physical plate in its original marked state?

All respondents affirmed that the primary function of the photographic plates, and their reason for being preserved so long, was that they were scientific evidence in time-domain studies. Many understood that a consequence of the ongoing nature of the scientific mission was the erasure of markings – with few exceptions – in order to produce the highest quality digital images of the star fields.[39] But since erasure was irreversible, there were caveats: the photographs of the markings had to be of high fidelity to the originals. The reproduction quality should be checked before any washing was done. The resolution of the digital images should be no less than 600 ppi, and the images should be shot in "raw" and preserved as tiffs with care taken to colour balance the image, something that is not trivial to achieve.[40] If these conditions were met, this group of respondents thought that photographs of annotations would be an adequate substitute for the original marked plate for most scientific and historical purposes. One respondent with extensive museum and archival experience, David DeVorkin, went further to recommend strongly that 600 ppi prints should be made on acid-free paper and deposited with copies of the annotated envelopes in a suitable archive.[41] DASCH's Jonathan Grindlay agreed that "this would be nice, and historically appropriate," but pointed out that there has been no National Science Foundation (NSF) funding to replace even a fraction of the acidic envelopes in deplorable condition, much less to make prints on archival paper, and DASCH has been unsuccessful so far in finding funds from other sources.[42]

A second group of respondents contended that the annotated plates should be scanned, then cleaned, and scanned again, in place of image capture by direct camera photography. "Scanning the markings is a necessity," one wrote, "especially if the image embedded in the emulsion can also be shown in the scan."[43] According to Jonathan Grindlay, this would not be practical. The annotations on the glass side would not be in focus with the stars on the emulsion side. Instead, DASCH has promised to enable the superposition of the in-focus, high-resolution photograph of the original plate on the scanned image of the cleaned plate. This would "be a far more useful historical resource than the original plate, since it would then include all the modern processing (photometry and astrometry) of each and every object." It would enable the photographic sequence stars used by the original investigators to be checked, systematically, for the first time.[44] Regrettably, this promise remains to be fulfilled.

Although cleaning of the plates seemed unstoppable, and photographs, the only records of annotations that would survive going forward, Jay Pasachoff asked whether it had been shown empirically that the accuracy of the scanning was higher if the plates were cleaned first: "If not, then there is no real gain in the wiping, and the non-wiping method would win overwhelmingly." He proposed an experiment of taking an uncleaned, unimportant plate and scanning it three times: first, as is; second after marking it with ink; and third, after cleaning it. Any differences in quality would then be evident.[45] The authors note that no such experiment has yet been published.

Alistair Kwan, a historian of science then at the University of Rochester, offered another reason to pause and reflect. Photographs do not reveal as much information as the eyes can in examining an original document. Palaeographers and physically oriented bibliographers will examine ink thickness, density, texturing of the inky surface, a strain on the substrate, hand writing, fingerprints, and even dirt for clues. These details are only caught by photography if the photographer sets out to capture them with raked lighting, filters, and bracketed exposures. All this is time consuming. It is easier for the specialist to examine the original document in order to see its true scale, how it reads at different angles, what properties the medium has, and how reflection and parallax may aid the object handler in better understanding it.[46]

Although most respondents tolerated the erasure of markings, one group remained very unhappy about it, because no photograph would be equivalent. Some took umbrage at the whole idea of "scrubbing" off any potentially useful annotations. "Could you find a word other than 'scrubbed'?" one astronomer wrote,

> To me this conjures up images of Brillo Pads and Bon Ami ("hasn't scratched yet") . . . . I have visions of Pickering's and Shapley's heroines rolling around in their respective graves sensing that the ink marks left from all those hours and hours of labor might be expunged forever. Like footprints in the sands of time, I suppose.[47]

There were three particular situations in which all respondents agreed that a photograph could not substitute for a marked plate. The first was exhibition. Even respondents who would have washed every plate conceded that those with intact, original annotations would be best for exhibition purposes.[48] The second case was fundraising: "Originals are good for inspiring donors and the general public, and hence for generating funding and other kinds of support. There are memories to be evoked, and great heritage value."[49] The third was calibration and reference. Samples of different types of marked plates should be saved in order to enable researchers to assess the representativeness of the digital images.

How many plates should be saved uncleaned?

Although respondents disagreed on the number of annotated plates that were worth preserving in their original state, there was consensus that sampling would be adequate. The samples should include the following:

- Plates illustrating different types of celestial photography, methodology, and annotations on the non-emulsion side (e.g. Figure 8).
- Plates with different coloured inks, along with information about the individuals associated with the inks and their reasons for using the distinct colours. It was also recommended that sample pens, if they survive, should be kept even if they are dried out. Ink differences might be sorted out using chromatography or mass spectrometry.[50]
- Plates that helped establish the variable nature of quasi-stellar objects.[51]
- Plates of the Large and Small Magellanic Clouds with Cepheid variables marked by Henrietta Leavitt.[52]
- Plates marked by Williamina Fleming and other important users, especially the women of HCO.
- Plates used by Harlow Shapley, Adelaide Ames, and others, who studied the large scale distribution of galaxies in the 1920s–1930s.[53]
- Key discovery plates.

Respondents were also concerned about the plate jackets, writing that care should be taken to digitize them as well. If plate rehousing was necessary, then as many as possible

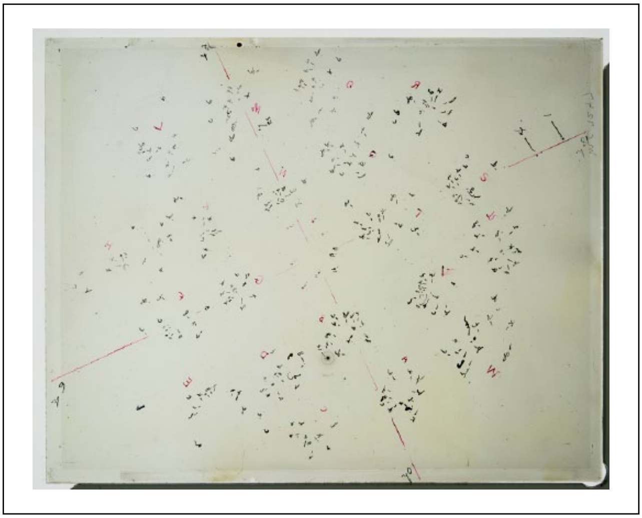

Figure 8. E.C. Pickering's new method of using a North Polar Sequence as a standard for photometric work is exemplified by markings on plate MC7247. For this project, he enlisted Henrietta Swan Leavitt to determine the magnitudes of a sequence of stars photographed near the North Pole. When stars of unknown brightness were later photographed on the same plate as stars in the North Polar Sequence, their magnitudes could be determined. Photographic plates with a North Polar Sequence also enabled the astronomers to rate the quality of the night for photometric work. Photographic plate MC7247 taken with the 16-inch Metcalf telescope in Cambridge, MA on 16 December 1914. Courtesy of the Harvard College Observatory Plate Stacks.

of the old jackets should be preserved and archived. Particular attention should be paid to the physical preservation of jackets with markings made by historically significant individuals. At least one or two jackets should be kept for each person involved in the programme.[54] If the intent was to throw any jackets away, a number of respondents offered to store them at their home institutions or recommended that they be sold or auctioned off as a fundraiser.[55]

What should be done with the scanned plates?

It was universally agreed by respondents that no matter how exquisite the current imaging equipment is, it can produce "only an observation of an observation."[56] Therefore, the original plates should always be preserved somewhere as a backup, or to look for diffuse veiling (e.g. a very faint supernova light-echo), which the digitizing software may have removed during processing. Saved plates could also be reimaged in the future as new technology or new ways of interrogating the data become available.[57] The DASCH team completely agreed, and noted that it has been refiling the barcoded plates in their original cabinets after scanning.

The best place to preserve the photographic plates, respondents concurred, was at the institution that created them, since it would presumably have a sense of the historical importance, and it would keep the plates near the log books and working notes associated with them. If housing at the originating observatory or university were not possible, the plates should be stored at a regional or national plate archive.[58]

Wayne Osborn, the author of a census of North American plate collections and a tireless campaigner for their protection, preferred to have "an established plate repository, with several of these scattered around the country and specializing in plates of certain types." For example, there could be a repository for patrol plates of planetary features, a repository for plates of the Sun and solar eclipses, a repository for slit spectra, a repository for wide-field direct plates, and so forth. Each repository should have at least one specialist responsible for the plates who would be able to respond knowledgeably to questions about them. "A problem with repositories," Osborn pointed out,

> is that the metadata needed to utilize the plates is often located in notebooks and log books at the observatory or the campus library at which the plates were taken. Sending the plates to a distant repository likely means separating them from the log books.

This problem could be solved, however, by having images of the log book pages available online, readily searchable, and linked somehow to the plate images.[59]

Who would fund the programmes of plate preservation and storage? Since the plates exist as astronomical data, the responsibility for their care and maintenance resides with the astronomical community, not with historians.[60]

Most respondents agreed, however, that some photographic plates deemed to have high historical value could be loaned or transferred to museums for display purposes or historical preservation in their collections. Nonetheless, Elizabeth Griffin, an astrophysicist at the Dominion Astrophysical Observatory and Chair of the International Astronomical Union (IAU) Task Force for the Preservation and Digitization of Photographic Plates, observed that she "would not recommend separating parts of any high-quality collection for museum status unless the owners of the digital records are happy to allow it."[61]

Philosophical points raised

Respondents to the survey were very thoughtful and raised some interesting philosophical issues. Even those with strong opinions recognized that "there may be no clear-cut answers," but only disparate visions of preferred practices, the outcome of which "must perforce be conditioned by limited resources."[62]

Elizabeth Griffin spoke for many astronomers in voicing concerns about drawing a line between old things and historical things. Griffin asked, "What is it that transforms an artefact into something of heritage value? Is it historic just because it is old?" She noted that many of the people who had made the telescopic observations and plate markings were just doing their jobs, and that there was nothing magical about the way they did it. Could it be that the passage of years had mysteriously hallowed their work? "We would not so readily attribute the same sanctity to data observed last night by our contemporaries." Griffin suspected that the decisions were "more emotional than objectively scientific," and that rarity played a part.[63] To this, a historian would reply that the decisions were not based simply on age or rarity or emotion, but on ways in which the markings showed us how business was done then. Moreover, the boundary between historic and non-historic is not a rigid one drawn between dichotomies, nor does scientific objectivity (whatever that may be then or now) play a part in making the distinction. The essence that makes an object historical is fluid and varies in the context in which it is seen and interpreted.[64]

In selecting plates to preserve uncleaned, how do we know when "hand-written marks or annotations are seriously scientific or only somewhat casual?"[65] Historians would concede that it is difficult to ascribe motivations to past actors on the basis of the tangible remains of their actions alone. Nonetheless, the difficulty in figuring this out does not make it impossible to do so; there may be other documents and objects that shed light on the motivation for and importance of particular markings. Moreover, the historical value of any particular item may have little to do with whether it was created in a casual or calculated manner.

Indeed, the routine nature of an activity may be good reason to preserve evidence of it. One astronomer reminisced,

> It was not uncommon to write on plates. I did so when I observed spectra photographically. Quite often we wrote in pencil on the emulsion *before* exposing, for purposes of identification, so as to render it indelible after developing. We might also put ink blobs to indicate (to ourselves or an assistant) the wavelengths at which the intensity calibrations should be traced, or arrows to remind ourselves (or an assistant) which was the spectral region of particular interest.

Her conclusion was, "Markings like that have no historic value, and should be erased."[66] In contrast, a historian of astronomy finds such information priceless in understanding scientific practices, even if the work is mundane to its practitioners. What we have here is tacit knowledge revealed. The recent book, *Observing by Hand* by Omar Nasim makes this point forcefully. The unpublished sketches and annotations of nebulae found in astronomers' personal observing notebooks reveal how the observers shaped and constituted celestial phenomena and the processes they employed in the production of scientific knowledge.[67] Certainly, not every such marked plate need be protected, nor should they all be dismissed out of hand.

"When all is said and done, we must also not lose sight between the two opposing properties: the objective and subjective," Griffin wrote,

> A photographic plate is an objective observation, but the marks which were added afterwards may only be someone's opinion, guide or aid, and are definitely subjective. The scientific process depends on retaining the objective and keeping a clear boundary between it and the subjective.[68]

Here, Griffin called our attention to a much debated conundrum at the heart of investigations into the natural world for thousands of years – i.e. the boundaries between objectivity and subjectivity in empirical science. And she showed us that the humble astronomical photographic plate sits at that boundary. Philosophers and historians of science would say that subjectivity enters the story before the plate is exposed, developed, and read. The decision to photograph that part of the sky with that instrument and wavelength sensitivity is already coloured by human thought and culture.[69] Taken to the logical conclusion, there are no unvarnished facts. But of course, scientists, as a matter of practice and practicality, believe that they work in a world where their observations can and should be objective and not influenced by their beliefs.

Concluding thoughts

The results of the survey show that many eminent astronomers and historians firmly believe that annotations on the photographic plates and their jackets have significant scientific, historical, and educational value. As authors, we agree. We endorse the preservation of as many markings as possible. In cases where current scientific needs can only be met with the permanent removal of annotations, we urge scientists to have technicians photograph or scan the plates and jackets using high-resolution, colour-balanced protocols and archiving procedures. To assist observatories and plate repositories facing this daunting task, we append to this paper the procedural recommendations of conservators, photographers, and archivists on plate handling, cleaning, photography, and rejacketing.

We would also like to point out that the arguments raised in this paper are pertinent in other disciplines and areas within the academy. This is not just a story about astronomy and its photographic data.

First, there is a growing body of work by historians on the history of note-taking and annotations. This scholarship examines notes not just for clues of the development of a particular writer's thoughts, but also to understand collective practices that have defined professions, occupations, audiences, cultural groups, times and places, and purposes. The content and material culture of notes can show us how ideas and data are shaped and transmitted, organized and preserved, solidified, disputed, and repudiated.[70] Closely associated with note-taking are drawings, sketches, maps, arrows, circles, and assorted visual languages. Scholars have begun to examine these markings too, and see in them further evidence of annotations focusing one's attention and memory, and being intimately entangled with observation, interpretation, and objectivity.[71] In the words of Lorraine Daston, by looking, writing, and drawing, nature is "made intelligible by being made legible."[72]

Second, there is a substantial body of literature that discusses the history and problematic nature of scientific photography, showing that it has never been as isolated and objective as its early proponents claimed. In the nineteenth century, scientists welcomed the camera for its "mechanical objectivity," even as they worried about the instability of photographic methods, chemical emulsions, and their sensitivity to light and colour. It mattered how photographic plates were prepared, developed, and stored. For instance, as collodion-process wet plates dried, their emulsions could warp and buckle, producing distortions in the image, making them unreliable for precise measurements. The choice of photographic lenses, apertures, and focal lengths also affected the resultant image's flatness, scale, and exposure time. Astronomers debated the pros and cons of daguerreotypes, wet plates, and the new gelatine dry plates in advance of their national expeditions to observe the Transit of Venus in 1874. In practice, scientific photography by different individuals of the same subject – whether a Transit of Venus, a solar eclipse, or a horse race – could be as different as written reports or drawings of observations, leading historians and philosophers to ask if it might be better to talk about "making" rather than "taking" a photograph. Indeed, recent scholarship has shown that skill, taste, social class, gender, politics, and belief undermine the objective and evidentiary claims of photographs.[73]

If it is a fallacy to claim that photographs are witnesses of reality unmediated by human agency, then why should we treat them as different from written sources? We can ask the same questions about how they were made, to whom they circulated, and what meanings they had to those who examined them. We must conclude, therefore, that astronomical photographs should not be privileged over their annotations, jacket manuscripts, and associated log books. All must be studied together, if historians of science are to have a complete picture of the way astronomers actually used photography in their work.

Finally, what seems to be at stake here is the nature of the archive and the power of its diverse constituents. The erasure of plate markings would certainly be a loss to historians but also to scientists, as the results of this survey show. The driving force for such erasure today is a narrowly focused interpretation of the needs of long-time-domain astronomers. But why should this group be permitted to act on a judgment that will irreversibly alter the state of the archives for everyone else? Who gets to decide? Indeed, even if altering the artefacts seems unproblematic now, should we let our lack of imagination foreclose prospects of their use in the future? We may not yet have "invented the technologies or articulated the conceptual frameworks that might reveal what is latent in them today," one respondent remarked:[74] "We cannot say today how science and history might develop tomorrow."

Notes on Contributors

Sara J. Schechner is the David P. Wheatland Curator of the Collection of Historical Scientific Instruments, Harvard University. Her latest book is *Tangible Things: Making History through Objects* (OUP, 2015). David Sliski was part of the Digital Access to a Sky Century at Harvard (DASCH) team from 2011 to 2014. He is currently a graduate student in the Department of Physics and Astronomy at the University of Pennsylvania.

Supplementary material

In three appendices to this article (available in the online edition of the journal), we offer professional guidance on the best practices for handling and cleaning the plates, photographing any annotations, and rehousing them.

Notes

1. J. Grindlay, S. Tang, R. Simcoe, S. Laycock, E. Los, D. Mink, A. Doane, and G. Champine, "DASCH to Measure (and Preserve) the Harvard Plates: Opening the ~100-Year Time Domain Astronomy Window," in W. Osborn and L. Robbins (eds), *Preserving Astronomy's Photographic Legacy: Current State and the Future of North American Astronomical Plates*, ASP Conference Series, ccccx (San Francisco: Astronomical Society of the Pacific, 2009), pp. 101–110 (ADS Bibcode: 2009ASPC..410..101G); C. Clabby, "A New Looking Glass: Historic Harvard Plates [Interview with Jonathan Grindlay]," *American Scientist*, 101, 2013, pp. 142–3, <http://www.americanscientist.org/issues/pub/a-new-looking-glass-historic-harvard-plates>.

See also *DASCH: Digital Access to a Sky Century @ Harvard* at <http://dasch.rc.fas.harvard.edu/project.php>, and the Smithsonian Astrophysical Observatory Telescope Data Center, "The Harvard College Observatory Astronomical Plate Stacks," <http://tdc-www.harvard.edu/plates/>.

2. "A meeting on the Digital Access to a Sky Century at Harvard (DASCH) project and the preservation of the largest astronomical glass plate collection in the world," *Harvard College Observatory*, 14 May 2013. Representing the DASCH team were Dr Jonathan Grindlay, Robert T. Paine Professor of Practical Astronomy, DASCH principal investigator; Alison Doane, Curator of Astronomical Photographs at the Harvard College Observatory; Edward Los, software engineer; Robert Simco, hardware engineer; Jaime Pepper, curatorial assistant; and David Sliski, curatorial assistant. Consultants invited from the Collection of Historical Scientific Instruments (CHSI), Harvard University included Dr Jean-François Gauvin, Director of Administration; Dr Sara Schechner, David P. Wheatland Curator; Martha Richardson, Collection Manager; and Samantha Van Gerbig, CHSI photographer and senior curatorial technician. Consultants from the Harvard Library were Dr Frenziska Frey, Malloy-Rabinowitz Preservation Librarian, and Head of Preservation and Digital Imaging Services; William Comstock, Head of Imaging Services; Andrea Goethals, Manager of Digital Preservation and Repository Services; Brenda Bernier, James Needham Chief Conservator and Head of the Weissman Preservation Center; Elena Bulat, Photograph Conservator for Special Collections; Anabelle Chabauty, intern at the Weissman Preservation Center; and Jacqueline Ford, imaging assistant at the Wolbach Library. Others included Dr Owen Gingerich, Professor Emeritus of Astronomy and the History of Science, Harvard University; Dr Elizabeth Griffin, Dominion Astrophysical Observatory, Chair of the IAU Task Force for the Preservation and Digitization of Photographic Plates; and Dr Jay Pasachoff, Field Memorial Professor of Astronomy and Director of the Hopkins Observatory at Williams College, Chair of the Historical Astronomy Division of the American Astronomical Society.
3. In correspondence with the authors, 29 December 2014, Jonathan Grindlay claimed that

   testing of the wire-brush cleaning method required to remove ~100y old India ink revealed it is physically impossible for a stainless steel wire brush to scratch glass, for the obvious reason that the hardness index of glass exceeds (significantly) that of steel!

   He plans to publish these results. Bart Fried, Principal, All Glass International LLC, Forest Hills, NY pointed out, however, that surface hardness and scratch resistance are not the same thing, that there are diverse tests to measure each of these, and that Grindlay's claim does not take into account any particulates in the grime that will be pushed around by steel brushes. Bart Fried to the authors, 20 July 2015.

4. The 2013 reports reiterated advice given 6–12 months earlier by the professional staff of the Collection of Historical Scientific Instruments and the Weissman Preservation Center at Harvard to DASCH: (1) S. Van Gerbig, "Comments on the HCO DASCH Plate Scanning Project," 31 May 2012; a 10-page report of best practices in museums and archives for plate handling, cleaning, lighting, colour balancing, image capture, and metadata, submitted by the CHSI photographer and endorsed by Jean-François Gauvin and Sara Schechner, respectively the CHSI administrative director and curator. (2) D. Sliski, "Advice from a Meeting with Brenda Bernier, Paul M. & Harriet L. Weissman Senior Photograph Conservator, and Elena Bulat, Photograph Conservator of the Weissman Preservation Center, Harvard Library, January 25th 2013," DASCH project notes, January 2013.

5. For example, see W. Osborn and L. Robbins, *Census of Astronomical Photographic Plates in North America: Final Report* (Washington: American Astronomical Society Working Group on the Preservation of Astronomical Heritage, 2008), <https://aas.org/files/census-report-final.pdf>. A *Workshop on Developing a Plan for Preserving Astronomy's Archival Records* was held on 18–19 April 2012 at the offices of the American Institute of Physics, College Park, MD, USA. It was organized by the AAS Working Group on the Preservation of Astronomical Heritage (WGPAH) and co-sponsored by the American Astronomical Society and the American Institute of Physics with support from the National Science Foundation. The report of the meeting, *Preserving Astronomy's North American Heritage Records* is published online by WGPAH, <https://aas.org/files/wgpah_april_2012_workshop_report.pdf>.
6. David DeVorkin, email to the AAS Working Group on the Preservation of Astronomical Heritage (WGPAH), 9 June 2013. DeVorkin expressed his own opinion and not that of the Smithsonian Institution.
7. Brad Schaefer to HASTRO-L, 7 June 2013; and Brad Schaefer to David Sliski, 18 June 2013.
8. See Osborn and Robbins, *Census of Astronomical Photographic Plates* (Note 5); and W. Osborn, A. Accomazzi, M. Castelaz, J.D. Cline, K. Cudworth, and R.E. Griffin, "Making Archival Data Available for Research in the Next Decade and beyond," in W.Osborn and L.Robbins (eds) *Preserving Astronomy's Photographic Legacy: Current State and the Future of North American Astronomical Plates*, ASP Conference Series, ccccx (San Francisco: Astronomical Society of the Pacific, 2009), pp. 160–5 (ADS Bibcode: 2009ASPC..410..160O).
9. Email exchange between Jay Pasachoff, Wendy Freedman, Barry Madore, and Sara Schechner, 28 May 2013.
10. William Liller to Sara Schechner and Jonathan Grindlay, 19 June 2013.
11. Sponsored by the National Science Foundation, the PARI workshop on 1–3 November 2007 brought together individuals responsible for observatory plate collections to discuss ways to prevent old plates from being discarded or stored under poor conditions. For recommendations stemming from the workshop, see W. Osborn and L. Robbins, "The Workshop on a National Plan for Preserving Astronomical Photographic Data," and M.W. Castelaz, "The Astronomical Photographic Data Archive at the Pisgah Astronomical Research Institute," in W. Osborn and L. Robbins (eds) *Preserving Astronomy's Photographic Legacy: Current State and the Future of North American Astronomical Plates*, ASP Conference Series, vol. ccccx (San Francisco: Astronomical Society of the Pacific, 2009), pp. 33–78 (ADS Bibcodes: 2009ASPC..410…33O and 2009ASPC..410…70C).
12. Vladimir Strelnitski to David Sliski, 12 June 2013.
13. Peter Boyce to Sara Schechner, Joe Tenn, and Jonathan Grindlay, 9 June 2013.
14. Virginia Trimble to WGPAH, 6 June 2013; Lee Robbins to Sara Schechner, 10 June 2013; R. Kolb, "Be careful what you rub out," 504th Convocation Address, University of Chicago, 27 August 2010, <https://convocation.uchicago.edu/sites/convocation.uchicago.edu/files/uploads/504th%20-%20Rocky%20Kolb.pdf>; A. Sandage, *Centennial History of the Carnegie Institution of Washington, vol. i: The Mount Wilson Observatory* (Cambridge: Cambridge University Press, 2004), pp. 495–8. According to R.W. Smith, *The Expanding Universe: Astronomy's "Great Debate," 1900-1931* (Cambridge: Cambridge University Press, 1982), p. 144, Owen Gingerich asked Shapley about the story in the early 1970s, and he replied it might be true.
15. Anna Sudaric Hillier to Sara Schechner, 10 June 2013; email exchange between Jay Pasachoff, Wendy Freedman, Barry Madore, and Sara Schechner, 28 May 2013.
16. Woodruff T. Sullivan, III to Sara Schechner, 24 December 2014.

17. The plate is H335H, the Hooker 100-inch telescope plate 335 by Hubble. J. Pasachoff and A. Filippenko, *The Cosmos: Astronomy in the New Millennium*, 4th ed. (Cambridge: Cambridge University Press, 2013), fig. 16-6; Carnegie Observatories, "Hubble's Famous M31 VAR! Plate," <https://obs.carnegiescience.edu/PAST/m31var>.
18. Virginia Trimble to WGPAH, 6 June 2013; Jay Pasachoff, Wendy Freedman, Barry Madore, and Sara Schechner, email exchange, 28 May 2013.
19. Wayne Osborn to HASTRO-L, 7 June 2013.
20. O. Gingerich, "Through Rugged Ways to the Galaxies," *Journal for the History of Astronomy*, 21, 1990, pp. 77–88.
21. H. Shapley, *Through Rugged Ways to the Stars* (New York: Charles Scribner's Sons, 1969).
22. Smith, *The Expanding Universe* (Note 14), pp. 33, 102.
23. S.J. Schechner, curator, *Time, Life, and Matter: Science in Cambridge*, an exhibition in the Putnam Gallery of the Collection of Historical Scientific Instruments, Harvard University, 2005-present.
24. Smithsonian National Air and Space Museum, "Exploring the Planets / Discovery / Discovering New Planets," <https://airandspace.si.edu/exhibitions/exploring-the-planets/online/discovery/disc_planets.html>.
25. E.C. Pickering, "A New Satellite of Saturn," *Harvard College Observatory Circular*, no. 43, 10 April 1899, reprinted in *Astrophysical Journal*, 9, 1899, pp. 274–6 (ADS Bibcode: 1899ApJ…..9..274P). See also E.C. Pickering, "A New Satellite of Saturn," *Harvard College Observatory Bulletin*, no. 49, manuscript dated 17 March 1899 (ADS Bibcode: 1899BHarO..49….1P); E.C. Pickering, "A New Satellite of Saturn," *Astronomical Journal*, 20(458), 1899, p. 13 (ADS Bibcode: 1899AJ…..20…13P).
26. R.C. Kapoor, "Comet Bappu-Bok-Newkirk: The Only Comet with an Indian's Name to It," *Current Science (Bangalore)*, 105(1), 2013, pp. 116–21, <http://www.currentscience.ac.in/Volumes/105/01/0116.pdf> (accessed 8 December 2014). D. Buczynski, "C/1949 N1 Bappu-Bok-Newkirk," *British Astronomical Association Comet Gallery*, 26 August 2013, <http://britastro.org/gallery_image/2595>. Buczynski published plate J3068, taken 3 July 1949, which is mistakenly described as the discovery plate. J3068 has the comet and reference stars marked clearly in red ink, whereas the discovery plate J3064 no longer has the comet marked, making it very hard to find. This illustrates the confusion that may arise when annotations have been cleaned off.
27. "Harvard Tyro Finds Comet," *The Christian Science Monitor*, 6 July 1949, <http://search.proquest.com.ezp-prod1.hul.harvard.edu/docview/508082730?accountid=11311> (accessed 8 December 2014); Kapoor, "Comet Bappu-Bok-Newkirk" (Note 26).
28. H. Shapley, "New Comet" and "Comet Bappu-Bok-Newkirk," Harvard College Observatory Announcement Cards 1006-1008, 5, 8, and 11 July 1949, John G. Wolbach Library, Harvard-Smithsonian Center for Astrophysics.
29. Fred L. Whipple, letter, 26 July 1949, quoted in full in Kapoor "Comet Bappu-Bok-Newkirk," (Note 26), p. 118.
30. William Liller in email to Sara Schechner and Jonathan Grindlay, 19 June 2013; A. Sharma, "Tracing the Photographic Plate of Comet Bappu-Bok-Newkirk," *Current Science (Bangalore)*, 105(3), 2013, pp. 295–6, *Academic Search Premier*, EBSCO*host* (accessed 9 December 2014). Grindlay hopes that DASCH's high-resolution, colour-corrected photographic image of each plate and its barcoding system will make the process of identification and location in the Plate Stacks easier than it has been previously.
31. Cf. Kapoor, "Comet Bappu-Bok-Newkirk" (Note 26) and Buczynski, "C/1949 N1 Bappu-Bok-Newkirk" (Note 26).

32. W. Osborn and O.F. Mills, “The Ross Variable Stars Revisited. I.” *Journal of the American Association of Variable Star Observers*, 39(2), 2011, p. 186 (ADS Bibcode: 2011JAVSO..39..186O) and “The Ross Variable Stars Revisited. II.” *Journal of the American Association of Variable Star Observers*, 40(2), 2012, pp. 929–40 (ADS Bibcode: 2012JAVSO..40..929O). Another example of the use of plate and envelope notations was a case where a particular star was found to have high proper motion, but the comparison stars were in a variable star study. In a note to the authors, 29 December 2014, Grindlay responded,

    Now the precise RA, Dec positions of each object resolved on each plate are produced by the DASCH scans – complete with proper motion corrections applied. And the photographic images of the original plate make it just as clear how these objects relate to the historical record, but now with far better positions and corrections to compare with other historic or current/modern studies.

33. S.I. Bailey, *Harvard College Observatory Bulletin*, no. 680, p. 1919 (ADS Bibcode: 1919BHarO.680….1B); Wayne Osborn did find the key Harvard plate referenced in the article. See G. Luberda and W. Osborn, “New Light Curve for the 1909 Outburst of RT Serpentis,” *Journal of the American Association of Variable Star Observers*, 40(2), 2012, pp. 887–93 (ADS Bibcode: 012JAVSO..40..887L).
34. Wayne Osborn to WGPAH, 6 June 2013: “We identified the telescope by locating three plates taken on the known dates for which the notation ‘returned from Greenwich Observatory 1939’ was on the plate jacket.” Wayne Osborne to Sara Schechner, 19 December 2014.
35. Jennifer Bartlett to WGPAH, 23 August 2014; Peter Broughton to HASTRO-L, 7 June 2013: “There are surely situations where an astronomer has unwittingly misidentified a star on a plate and subsequent researchers would find this misidentification helpful in re-examining the astronomer’s analysis.”
36. William Liller to Sara Schechner and Jonathan Grindlay, 19 June 2013:

    Discovered by C.T. Kowal in 1977, its [Chiron’s] orbit, later calculated by B.G. Marsden to be mainly between those of Saturn and Uranus, was only crudely known until yours truly with Lola Chaison found its image on Harvard plates taken in 1943, 1941 and 1897. The 1941 image was found on one of those absolutely magnificent 14″ x 17″ Bruce astrograph 3-hour exposures; it was located roughly a half degree from its guesstimated position. The image, short and faint, was, in fact, marked (in indelible ink) because the plate inspector thought it was that of a faint distant galaxy seen edge-on. (As I remember, there were more than a thousand images marked on that plate.) One can imagine the difficulty in relocating that image if all the marks were scrubbed off.

    See C.T. Kowal, W. Liller, and B.G. Marsden, “The Discovery and Orbit of /2060/ Chiron,” in R.L. Duncombe (ed.), *Dynamics of the Solar System*, IAU Symposium Series No. 81 (Dordrecht: D. Reidel Publishing Co., 1979), pp. 245–50 (ADS Bibcode: 1979IAUS…81..245K).

37. A list of HCO plate numbers on which IC objects were found is in the *Harvard Annals*, lx, 152–3, 178. A few additional plates with asteroid trails noted are on pp. 176–7. Harold Corwin wrote that this debugging has been a “hobby” of his for over forty years:

    Many IC objects were discovered on Harvard plates taken in the 1890s and early 1900s. … A few of the IC objects have not been found on subsequent plates: Are these missing objects plate defects, or possibly unresolved multiple star images? Perhaps their positions were simply recorded incorrectly. The [annotated] plates may help provide answers. (Harold Corwin to Sara Schechner, 22 August 2013)

38. Wayne Osborne to Sara Schechner, 19 December 2014, citing his experience at Yerkes.
39. Elizabeth Griffin to WGPAH, 7 June 2013; Jennifer Bartlett to WGPAH, 23 August 2013; and Tom Corbin to Sara Schechner, 12 June 2013.
40. Van Gerbig, "Comments on the HCO DASCH Plate Scanning Project" (Note 4); Sliski, "Advice from a Meeting" (Note 4); David DeVorkin to WGPAH, 9 June 2013; Elizabeth Griffin to WGPAH, 7 June 2013; Tom Corbin to Sara Schechner, 12 June 2013.
41. David DeVorkin to WGPAH, 9 June 2013.
42. Jonathan Grindlay to Sara Schechner and David Sliski, 29 December 2014.
43. Jim Lattis to David Sliski and Sara Schechner, 7 June 2013; Harold Corwin to Sara Schechner, 22 August 2013; David Dudek to Sara Schechner, 10 June 2013.
44. Jonathan Grindlay to Sara Schechner and David Sliski, 29 December 2014.
45. Jay Pasachoff to Sara Schechner and David Sliski, 5 January 2015. When asked by the authors, Jonathan Grindlay of DASCH said that he had plans to publish the results of such an experiment sometime in the future.
46. Alistair Kwan to HASTRO-L, 7 June 2013. This has also been the experience of the curator and photographer at the Collection of Historical Scientific Instruments, Harvard University.
47. William Liller to Sara Schechner and Jonathan Grindlay, 19 June 2013.
48. Wayne Osborn to WGPAH and HASTRO-L, 6–7 June 2013; David DeVorkin to WGPAH, 9 June 2013; and many others.
49. Alistair Kwan to HASTRO-L, 7 June 2013.
50. Alistair Kwan to HASTRO-L, 7 June 2013.
51. David DeVorkin to WGPAH, 9 June 2013.
52. Jay Pasachoff, Brad Schaefer, and many respondents mentioned these.
53. Harold Corwin to Sara Schechner, 22 August 2013.
54. Tom Corbin to Sara Schechner, 12 June 2013; William Liller to Sara Schechner and Jonathan Grindlay, 19 June 2013.
55. Virginia Trimble to WGPAH, 10 June 2013; Jay Pasachoff to Sara Schechner, 7 June 2013; David Dudek to Sara Schechner, 10 June 2013; Adam Hughes to Sara Schechner, 10 June 2013.
56. Elizabeth Griffin to WGPAH, 7 June 2013.
57. Elizabeth Griffin, Wayne Osborn, Jennifer Bartlett, Virginia Trimble, and other members of the WGPAH made this point in emails circulated 6–7 June and 23 August 2013.
58. Elizabeth Griffin, David DeVorkin, Jennifer Bartlett, and Wayne Osborn to WGPAH, 6–9 June and 23 August 2013.
59. Wayne Osborn to WGPAH and HASTRO-L, 6–7 June 2013.
60. David DeVorkin to WGPAH, 9 June 2013.
61. Elizabeth Griffin to WGPAH, 7 June 2013.
62. Elizabeth Griffin to WGPAH, 7 June 2013.
63. Elizabeth Griffin to WGPAH, 7 June 2013. (The first quotation is paraphrased for clarity.)
64. See L. Ulrich, I. Gaskell, S. J. Schechner, and S. A. Carter, *Tangible Things: Making History through Objects* (New York: Oxford University Press, 2015); L. Wittgenstein, *Philosophical Investigations*, 3rd ed. (New York: Pearson, 1958).
65. Elizabeth Griffin to WGPAH, 7 June 2013.
66. Elizabeth Griffin to WGPAH, 7 June 2013.
67. O.W. Nasim, *Observing by Hand: Sketching the Nebulae in the Nineteenth Century* (Chicago: University of Chicago Press, 2014).

68. Elizabeth Griffin to WGPAH, 7 June 2013.
69. See J. Ratcliff, *The Transit of Venus Enterprise in Victorian Britain* (London: Pickering & Chatto, 2008); J. Ratcliff, "Models, Metaphors and the Transit of Venus in Victorian Britain," *Cahiers François Viète*, 11–12, 2007, pp. 63–82; and A.Soojung-Kim Pang, *Empire and the Sun: Victorian Solar Eclipse Expeditions* (Stanford: Stanford University Press, 2002), chap. 4: "Drawing and Photographing the Corona."
70. A. Blair, "Note Taking as an Art of Transmission," *Critical Inquiry*, 31(1), 2004, pp. 85–107; A. Blair, "Humanist Methods in Natural Philosophy: The Commonplace Book," *Journal of the History of Ideas*, 53, 1992, pp. 541–51; A. Blair and R. Yeo (eds), "Special Issue: Note-Taking in Early Modern Europe," *Intellectual History Review*, 20(3), 2010, pp. 301–433; A. Blair, "Student Manuscripts and the Textbook," in E. Campi, S.de Angelis, A.-S. Goeing and A. Grafton (eds), *Scholarly Knowledge: Textbooks in Early Modern Europe* (Geneva: Droz, 2008), pp. 39–73; L. Daston, "Taking Note(s)," *Isis*, 95, 2004, pp. 443–8; M.R. Canfield (ed.), *Field Notes on Science and Nature* (Cambridge: Harvard University Press, 2011); F.L. Holmes, J. Renn, and H.-J. Rheinberger (eds), *Reworking the Bench: Research Notebooks in the History of Science* (Dordrecht: Kluwer, 2003); R. Yeo, "Notebooks as Memory Aids: Precepts and Practices in Early Modern England," *Memory Studies*, 1, 2008, pp. 115–36. See also the conference at the Radcliffe Institute for Advanced Study, *Take Note* (2012), <http://www.radcliffe.harvard.edu/event/2012-take-note-conference>.
71. Nasim, *Observing by Hand* (Note 67); M.J.S. Rudwick, "The Emergence of a Visual Language for Geological Science, 1760–1840," *History of Science*, 15, 1976, pp. 149–95.
72. Daston, "Taking Note(s)" (Note 70), p. 446.
73. J. Tucker, *Nature Exposed: Photography as Eyewitness in Victorian Science* (Baltimore: The Johns Hopkins University Press, 2006); J. Tucker (ed.), "Special Issue: Photography and Historical Interpretation," *History and Theory*, 48(4), 2009, 1–168; L. Daston and P. Galison, *Objectivity* (New York: Zone Books, 2007); and Ratcliff, *Transit of Venus Enterprise* (Note 69).
74. Omar Nasim to Sara Schechner, 20 July 2015.