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RESEARCH ARTICLE

At the ends of the line: How the Airy Transit Circle was gradually overshadowed by the Greenwich Prime Meridian

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Argument
The Greenwich Prime Meridian is one of the iconic features of the Royal Museums Greenwich. Visitors to the Museum even queue up to pose with one leg on either side of the Line. Yet, the Airy Transit Circle, the instrument that defined the meridian, is almost always excluded from these photographs. This paper examines how the instrument has become hidden in plain sight within the stories of Greenwich Time and Greenwich Meridian, as well as within the public imagination, by providing an analysis of the instrument's transformation from a working astronomical instrument to a museum object. The paper highlights the gradual decoupling of the instrument from narratives of Time and Longitude, which resulted in the Line's popularity overshadowing the instrument that defined it. By doing so, the paper aims at showing the symbiotic relationship between the materiality of the instrument and the meridian line that it defined. Approaching the instrument through the lenses of object biographies, the paper raises the question of whether the life of the instrument came to an end once operations with it were terminated. The analysis of the Transit Circle's life reveals that it reached its end multiple times, which shifts the emphasis away from a single and ultimate end of scientific objects to a process of gradual downfall, during which they can "end" several times. In addition, through the object biography approach, the Transit Circle no longer appears as a dead object reaching an afterlife within a museum setting. Instead, the approach demonstrates that, though the instrument can still be restored to an operational order, doubts about its accuracy, and its relevancy to today's astronomical methods, have led the instrument to be considered obsolete, transforming it into a museum object on display.

Keywords: History of astronomy; observatories; scientific instruments; Royal Observatory Greenwich; object biographies; Prime Meridian

Introduction

At the International Meridian Conference of 1884, twenty-two nations agreed to adopt the Greenwich Meridian as the International Prime Meridian. The second resolution of the conference stated that the Prime Meridian was going to be defined by the line passing through "the centre of the transit instrument at the Observatory of Greenwich" (Howse 1980, 139). This transit instrument was the Airy Transit Circle (Fig. 1). The wording of the resolution emphasized the symbiotic relationship characteristic of transit instruments and the meridian lines that were defined through their use. For instance, in the case of the Greenwich Meridians, every time a new transit instrument was installed at the Royal Observatory at Greenwich, the meridian was "shifted" to cross through the center of the new instrument (Stott 1985, 134). Despite this, while the Greenwich Meridian became a famous international symbol, the Airy Transit Circle that defined it received less public attention. This paper brings the spotlight back to the instrument itself by demonstrating its inseparability from the historical Prime Meridian. By doing so, it raises

Figure 1. The Airy Transit Circle on display at the Royal Observatory, Greenwich. © National Maritime Museum, Greenwich, London.

a new question about the relationship between the two entities, namely: what happens to a meridian line when the life of the transit instrument that defines it ends? And how does the end of a transit instrument affect the "afterlife" of a meridian line?

The main protagonist of this article is the instrument that defined the Prime Meridian: the Airy Transit Circle. This instrument belongs to the family of meridian instruments. Such instruments are used to determine the vertical angle of a celestial body (declination) and the exact time when it crosses the local meridian (right ascension). Such measurements give the position (or coordinates) of a celestial body, which help in locating and identifying them. The measurements made with the Airy Transit Circle were used for several other purposes too: as the basis for astronomical tables (such as the annually published *Greenwich Observations*) that recorded data about the motions of celestial bodies, as data for the *Nautical Almanac* to aid in the navigation of ships, as establishing geographical reference points for cartographers, and as the basis for the time signal distributed at local, national and global levels (Morus 2000; Rooney & Nye 2009; Ishibashi 2020). The Airy Transit Circle thus served as the starting point for producing time and space for the British Empire.

The instrument was named after George Airy (Fig. 2), who was Astronomer Royal and director of the Royal Observatory at Greenwich between 1835 and 1881 (Satterthwaite 2001). Because he was also the designer of the instrument, it embodied the characteristic features of his management of the Observatory as a factory (Schaffer 1988; Smith 1991). Simon Newcomb, for example, noted that the large size of the instrument and its sturdy materiality resembled that of the heavy machinery found in factories rather than that of a precision instrument (Newcomb 1903, 298). At the

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Figure 2. Portrait of George Biddell Airy by John Collier, dated 1883. © National Maritime Museum, Greenwich, London, Airy Collection.

same time, however, it also reflected the precision of eminent mathematical instrument makers such as Edward Troughton and William Simms, who graduated the divided circle of the instrument (the component used for determining the altitude and declination of a celestial body) (Chapman 1995). Finally, the Airy Transit Circle incorporated the use of galvanic currents for transmitting and recording observations (Satterthwaite 2001, 110-112). To achieve this, Airy designed a chronograph necessary for completing the galvanic recording system and implemented it into the everyday routine of the Observatory, paving the way for the dissemination of the chronograph's use at other observatories as well (Lamy & Soulu 2015, 80-86).

While the instrument was initially considered a mechanical marvel (Belteki 2020), after 1884 its public perception focused more on its role in defining the International Prime Meridian (Maunder 1900). Despite this role, by the late 1920s systematic errors were identified in the data produced with it, which led to a decrease in the regularity of its use. The last official observation with it was made in 1954, and a few years later it began to be displayed, in its original position at the observatory, as a museum object.

The primary, crucial difference between the Airy Transit Circle and other transit circles was its size. During the early nineteenth century, the new methods of producing object glasses allowed for increased optical power without the need to increase the overall size of telescopes (Jackson 2000). As a result, many instrument makers began decreasing the overall size of transit circles, which also allowed for their easier reversibility (to counter instrumental errors) (Martin 1949). Rather than relying on instrument makers, Airy decided to design the instrument himself.

Although his design was not popular, it was copied by at least two other observatories: the Royal Observatory at the Cape of Good Hope, and the Coimbra Observatory in Portugal. The circle at Coimbra Observatory was of a much smaller size, but adopted the same illuminating method as the one used in the Airy Transit Circle (Bonifacio et al. 2009). It arrived to Coimbra in 1855, but had a relatively short lifespan, and was replaced in 1879 with another transit circle made by Repsold.

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The transit circle of the Royal Observatory at the Cape of Good Hope was almost identical to the one at Greenwich. Installed in 1854, it remained in use until 1947. However, this instrument faced criticism for its systematic errors. In addition, when David Gill became the director of the Cape Observatory, he reported that the "instrument itself was barked with dust and congealed oil" (Warner 1979, 86). Gill then began a long campaign the replace the Cape Transit Circle with one of a newer design. He was ultimately successful in convincing the Admiralty, and was granted the funds for designing and constructing the new Reversible Transit Circle (Warner 1979, 100). Even though the new instrument was installed in 1901, the old one continued to be used until 1947, when it was no longer considered "worthy of redemption" anymore, and consequently "sold as scrap metal" in 1950 (Warner 1979, 120). As these three comparative examples show, instruments may share many similarities throughout their lives, and yet face different fates once they fall out of use.

Despite being the instrument that was used to define it, the presence of the Airy Transit Circle has been relatively muted in previous histories of the Greenwich Meridian. The historical scholarship has focused mostly on the techniques that defined longitude, rather than on the transit instruments themselves. Derek Howse (1980) provided the most detailed description of the astronomical work at the Observatory, including how the Greenwich Meridian was produced, but his work only dedicated a few sentences to the Airy Transit Circle itself. *Finding Longitude* by Rebekah Higgitt and Richard Dunn (2014) showed the long history of the changing techniques and instruments used to define longitude, but made no reference to the Airy Transit Circle. Rebekah Higgitt and Graham Dolan (2010) examined how "the Line" was represented at the Observatory after 1884, but offered little explanation about the parallel life of the instrument defining it.

Charles Withers (2017) highlighted the geo-political concerns that the adoption of an international meridian entailed, and Michael Kershaw (2019) discussed the transition from transit instruments to wireless techniques for the astronomical determination of longitude during the twentieth century. A shared feature of these two works is the relatively little attention given to the materiality and the reliability of the transit instruments that were used for determining meridians. For instance, Withers (2017) discussed the "Prime Meridian's afterlife" (13), and made a case for the Prime Meridian itself as an object of study (14-20), but only mentioned the Airy Transit Circle once, and only to note the discrepancy between the current measurement of the Greenwich Meridian being east of the instrument (272). In light of this, the aim of this paper is to shift the attention away from the Line, and to focus on the materiality of the astronomical instrument that was used to produce it. The article aims to demonstrate how changes to the materiality of the instrument affected the meridian, and how the life of the instrument was intertwined with the life of the Line.

To reconstruct the history of the end of the instrument, the article draws upon the "object biographies" approach. Appadurai (1986) and Kopytoff (1986, 67), who originated the approach, highlighted the social life of things, where things only gain meaning (and effectively "a life") within a social context. Lorraine Daston (2004) argued for letting the materiality of things tell their own stories, in order to highlight objects as active participants of history (Wise and Wise 2004). However, a central problem of the approach has remained the need to define what constitutes the *life* of an object (Dannehl 2009). In light of this, the approach has been criticized for anthropomorphizing things (Soderqvist & Bencard 2010) and for ventriloquizing the voices of objects (Ritchie 2018).

Taking different paths toward understanding the lives of objects, Alberti (2005; 2011) focused on the afterlife of "animals-as-objects" displayed at museums, while Werrett (2013) highlighted how objects and things are often recycled into new assemblages. Previous scholarship has also focused on the end of the lives of scientific and astronomical instruments in particular. Both Deborah Warner (1995) and Liba Taub (2018) implied that instruments lose their status as scientific instruments once they stop functioning. An example to this would be the telescope of James South, which was broken up into pieces and sold off as scrap metal once South considered it an instrument that did not function as expected (Hoskin 1989). As mentioned above, the Transit Circle of the Royal Observatory at the Cape of Good Hope encountered a similar fate.

Meanwhile, instruments that broke down, but were then repaired pose another theoretical question: should their repaired forms be considered as part of their original lives? Answering yes to that question, Simon Schaffer argued for showing "shards and fragments alongside glamorous devices" (2011, 707). This would mean that, despite the material modifications made to an instrument, it continues "living" its life as the same instrument even as part of new assemblages. Finally, repairing, recycling and merging instruments together raises the question of whether we should consider different parts of an instrument to have their own lives. For instance, can the object glass of a telescope be considered to have its own life if it is reused in another telescope?

From these questions we can infer that there are various ways in which objects, things, and instruments can arrive at the end of their lives. In addition, because objects can be repurposed in different social contexts, the end of their lives can happen multiple times. This article examines how the Airy Transit Circle has come to the end(s) of its life, and how ending the life of the instrument affected the representation of the Greenwich Meridian.

The many ends of the Airy Transit Circle

As outlined in the previous section, pinpointing the end of the life of the Airy Transit Circle depends on how we define its end. Focusing on instances of breakdowns and major repairs highlights the instances of temporary ends. There were very few of these occurrences, as the instrument underwent constant maintenance. The main maintenance of the instrument was undertaken every Monday, when the telescope tube was lifted and turned around on its East-West axis while the various moving parts of the instrument were lubricated. This task was so important that when John Green (the person responsible for carrying out the regular Monday maintenance) asked for a week's leave, Airy requested that he start it after he had finished with the Monday maintenance and to return by next week as not to miss the essential task (Belteki 2019, 163). Similarly, when the astronomical assistant of the Royal Observatory at the Cape of Good Hope visited Greenwich, it was Green who was asked to demonstrate how to care for the instrument. Besides Green, the Chief/First Assistant of the Observatory was asked by Airy to provide monthly reports on the state of the instruments. Smaller problems with the instrument (e.g. making squeaking noises and requiring cleaning) were noted in these reports, though almost none of these minor problems were mentioned in Airy's annual reports on the state of the Observatory (Belteki 2017). Green's specialized task and the reports on the state of the instruments show that the maintenance of the Airy Transit Circle was considered an essential task, designed to avoid the instrument reaching a state of disrepair, and therefore its end.

This critical attention to maintenance as a crucial task did not, however, prevent the instrument from suffering occasional major breakdowns. For instance, in 1864 the chains holding up the East-West axis of the telescope tube broke, and operations with it had to be halted until repairs were carried out (Airy 1865, 7). Similarly, when the wires in the eyepiece of the telescope broke, observations had to be discontinued until they were replaced.[1] Such cases of repair practices demonstrate that the life of this instrument required maintenance by its users, without which the instrument's life would have come to an end. In addition, such cases highlight the life of an instrument as characterized by a series of operational and non-operational states (Baker 2012). This is important in highlighting that the life of an instrument does not end simply because it breaks. Instead, it continues in a non-operational state, in which its users decide whether to repair it or not.

[1]See entry for 6 February 1863 in Astronomer Royal Journal 1862-1876, RGO 6/26. For a note describing the incident see RGO 6/171 14.

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It is important to note that the Airy Transit Circle was considered a precision instrument. As a result, it was used by constantly measuring its instrumental errors (Evans 2012). This was due to the instrument responding to even the slightest of environmental changes and interactions with its users. Robert Main (the First Assistant of the Observatory from 1835 to 1860) highlighted this feature of meridian instruments by noting how even the breath of the observer could alter the measurements shown by an instrument (Main 1863, 23). The Transit Circle's first official description highlighted similar aspects of the instrument. Almost a quarter of the entire description was devoted to an explanation of how the instrumental errors were measured, and how they were applied to observations (Airy 1854, 17-23). Consequently, when the astronomical data was published in the Greenwich Observations, tables of instrumental errors were provided to help astronomers calculate the measured position of celestial bodies. In this light, the instrument was useful and reliable, but it was never perfect. Instead, as a precision instrument, its high quality rested on the extent to which its imperfections were made visible.

Such a design and approach towards working with astronomical instruments highlighted the hierarchy imposed by astronomers on instrument makers during the nineteenth century. The German astronomer Friedrich Bessel stated that "every instrument … is made twice, once in the workshop of the artisan, in brass and steel, and then again by the astronomer on paper, by means of the list of necessary corrections which he derives by his investigation" (Pannekoek 1961, 325). Similarly, John Herschel stated that "though we are entitled to look for wonders at the hands of scientific artists, we are not to expect miracles" (Herschel, 1849, 76-77). Instead, he emphasized that the instrumental errors can be overcome through the work of the astronomers who directed their attention "to the detection and compensation of [instrumental and observational] errors, either by annihilating, or by taking account of, and allowing for them" (ibid.). In relation to the end of the life of instruments, such quotes demonstrate that imperfections of instruments were not synonymous with their ends. Instead, the end of the credibility of a precision instrument arrived when its errors were identified as systematic, too large to account for, or when the material parts displaying the results were no longer useable.

It was precisely the credibility of the data produced by the Transit Circle that brought the instrument close to its end for the first time. Towards the end of the 1850s, Albert Marth began criticizing the processes that were implemented for the reduction of the observations made with the instrument (Marth 1860; Belteki 2019, 244-253).[2] By attacking the calculating processes, Marth was not questioning the materiality of the instrument, but rather the processes that governed the data it produced. In doing so, he attacked the Airy's organization of the observing procedures and his new system of Observatory governance (Schaffer 1988; Smith 1991). Marth's criticism also highlighted possible further sources of errors from which the instrument suffered, thereby attacking the credibility of the data produced with the instrument, and consequently the production process that defined space and time for the British Empire. Though Airy downplayed the importance of this criticism, it still prompted him to write a more than 30-page long, point by point refutation of Marth's paper to the members of the Board of Visitors overseeing the work of the Observatory (an unprecedented occurrence under Airy's directorship).[3] Despite facing criticisms of its materiality and use soon after its installation, the Transit Circle continued to be used and hailed as a reliable instrument by the astronomical community. However, "the Marthiad episode" (as it was labelled by Airy's friend, William Henry Smyth) demonstrated that

[2]Albert Marth was a German astronomer who worked for various British astronomers and observatories throughout his career. His work criticizing the Airy Transit Circle was rejected for publication twice by the Royal Astronomical Society (upon personal intervention by Airy), and was ultimately published in 1860 within the international astronomical journal *Astronomische Nachrichten*. After the paper's publication, Airy maintained a lifelong resentment against Marth.

[3]Airy's original draft of the response still survives. It can be found within the Cambridge University Library: Royal Greenwich Observatory Archives, Papers of George Airy, RGO 6/13 272-305, 13 September 1860.

questioning the reliability of the instrument and the credibility of the data it produced had the potential to bring the instrument to its end.

We can also measure the end of the instrument by looking at the number of observations that were carried out with it. Fortunately, such data is available for historians of science, since each observation was published in the Greenwich Observations, and also summarized in the Annual Reports of the Astronomer Royal.[4] These numbers show that observations fell dramatically on three occasions: 1906, 1919, and 1942. The dip in the numbers in 1906 was due to two reasons. First, regular observations with the Transit Circle to create the Second Nine-year Catalogue of Stars, which previously had required additional observations on a daily basis, were completed. Part of this catalogue was intended to provide reference data for the larger international Carte du Ciel project that began in 1887. With the observations finished, the use of the instrument became less frequent. The second reason for the dip in the number of observations related to the materiality of the instrument. The Annual Report for 1906 notes that the object glass of the Transit Circle required repolishing that year, but, the optician in charge of the task being absent, regular observations were interrupted for two months (Christie 1906, K5-K9). In brief, the year 1906 is a useful example for demonstrating two of the reasons that can lead an instrument to come to a temporary end: either because its materiality requires alteration (e.g., repolishing of object glass) or because it is no longer required to be used for its previously intended purpose (e.g., observations for a catalogue finished).

The year 1919 highlighted a different reason for the large fall in the numbers. As a consequence of the war, the number of employees of the Observatory significantly decreased, which led to a reduction in the number of observations. In addition, the year witnessed exceptionally bad weather, which further limited the number of possible observations (Dyson 1922, F6). This example shows that the operations of an instrument can further depend on environmental forces (e.g. weather) and on the availability of qualified members of staff. Thereby, we observe that the readiness of the materiality of an instrument for use does not mean that it is being used. Even though the materiality of the Transit Circle was in good order, extra-material factors had the potential to bring about the end of its life.

With all these possible avenues for an instrument to reach the end of its life, we can now examine what happened when such problems accumulate over time. From the 1920s onward, systematic errors were gradually identified in the data produced by the Transit Circle, and the responsibility of making observations for time service was consequently transferred to another instrument in 1927 (Gething 1954, 415). When this happened, the instrument lost one of the functions that had been assigned to it since 1851. In the following years, the quality of important parts of the instrument, such as the object glass and the divided circle, began to decay. By 1931, the object glass was badly stained, and considered to be too thin for further repolishing. This was one of the reasons that the Observatory sought the support of the Admiralty for funding a new transit circle to take over the work of the Airy Transit Circle (Dyson 1932, F16-F17). By 1936, a new transit circle (the Reversible Transit Circle) was installed at Greenwich, which gradually reduced the number of observations made with the Airy Transit Circle. Two years later, the poor state of the object glass of the Airy Transit Circle was once again highlighted, with the additional note on the impossibility of repolishing it further. The decaying state of the instrument's divided circle, used for measuring the altitude of celestial bodies, was similarly noted. Years of regular cleaning had eroded the graduations on the divided circle's surface, to the point where many of the divisions became unreadable. Even though the circle was re-graduated as part of a larger repair operation, the collective number of accumulated problems (i.e. systematic errors, stained and thin object glass, and the installation of a new transit circle) provided justification for abandoning the Transit Circle's regular use (Spencer Jones 1951, F38-F39). Yet, the same report

[4]From 1839 onward, the *Annual Report of the Astronomer Royal to the Board of Visitors* can be found as an appendix to every volume of the *Greenwich Observations*.

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stated that due to the instrument's historical value and its close connection to the Prime Meridian, the instrument would remain at its present site (Ibid.). This decision ended the life of the instrument as a working scientific instrument, reframing it as a historical object. In other words, its significance was no longer derived from its potential contributions to future observation programs, but from what it had achieved throughout its history.

On 12 September 1940, observations with the Transit Circle came to an end (Spencer Jones 1953, E3). Despite this, the ongoing war nevertheless had a major impact on its life. During a bombing of the Observatory, the building that housed the instrument was damaged and resulted in minor damage to the instrument itself. Fortunately, this did not lead to its destruction and the minor damage to the instrument was soon repaired. However, many other astronomical instruments around the world were destroyed in similar bombings. Among these were the large instruments of the Pulkovo Observatory, which, like Greenwich, devoted part of its research program to positional astronomy. When German troops began their advance towards Leningrad, the staff moved the optical parts of the telescopes and the smaller equipment to another location (Herbig 1945, 197).

Taking the necessary precautions proved to be a good preventive measure. During the siege of Leningrad, the German front lines were set up less than a mile away from the Pulkovo Observatory, which resulted in the heavy bombardment of the Observatory buildings and in the inevitable destruction of the instruments, mountings, and tools that remained there. Among these were the meridian instruments used for an ongoing observing program to create a catalogue of 2,957 geodetic stars (Mikhailov 1955, 31).

Due to the cessation of work at Pulkovo, it was decided to continue Pulkovo's observation program with the participation of foreign observatories. Among these observatories was the Royal Observatory, Greenwich, which offered to revitalize its retired Airy Transit Circle. After the instrument was restored to an operational state, regular observations with it began again, and continued even after the war until 1954 (Spencer Jones 1954, E3-E4).

This story of the Transit Circle highlights the fact that the end of a scientific instrument can occur multiple times, rather than being restricted to a single event. In this light, as long as the individuals responsible for the instrument are willing to continue with its maintenance, repair, and refurbishment, a scientific instrument can continue to avoid reaching its end. Moreover, the story shows that the instrument was considered to have reached the end of its life only in comparison to the other instruments available to the astronomical community. In this sense, the instrument itself did not end, but rather, its use was halted by the community. In addition, as highlighted by one of the Annual Reports of the Astronomer Royal, the instrument's function was transformed from that of a scientific instrument to that of a historical object. According to such an approach, while the life of the Transit Circle as a scientific instrument ended, it continued to exist as a museum object.

The end of the instrument, the end of the Line?

The most renowned contribution of the Airy Transit Circle remains its association with the International Prime Meridian. Unlike the Equator, there is not a single Prime Meridian defined by the shape of the Earth. Instead, meridian lines can be established at any local position. The major obstacle in establishing such a line is defining it when there are very few points of reference available to the observer.

The history of astronomy and navigation are defined by the search for methods and techniques for the ever more precise measurement of longitude. Meridian instruments (such as the Airy Transit Circle) emerged as key tools within astronomy to make astronomical observations connected to local longitudes. These instruments not only measured the declination and the time of transit of celestial bodies, but also contributed by defining, with ever more precision, the meridian

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lines. In this sense, meridian lines and meridian instruments have always had symbiotic relationships: a line is required to set up the instrument, but then the instrument is used to define the line with greater precision. Through such an approach, the materiality of the instrument is inseparable from any of the abstract or material representations of the line. As a result, any history of a meridian is part of the biography of the instrument that defined it, and the politics of the instrument has an impact of the history of the line.

This approach to the relationship between instrument and meridian is actively present within histories of observatories and current displays at museums. Howse's history of the Royal Observatory, Greenwich, for example, emphasizes that whenever a new transit instrument was installed, the Greenwich Meridian was accordingly shifted (Howse 1980). Similarly, observatory buildings themselves were built with the intention to be the very instruments defining the meridian. For example, one of the major historical features of the Paris Observatory is the Meridian Room, where the meridian line on the floor was used to measure the local transits of the Sun. Despite this, histories of the measuring of longitude and time have tended to de-emphasize the concerns about the materiality of the instruments, which downplays the importance of the symbiotic relationship. By contrast, this paper argues that the symbiotic relationship between the Airy Transit Circle and the Greenwich Meridian was a defining feature of the instrument's life.

This symbiotic relationship was regularly represented in articles about the Observatory that appeared in periodicals during the nineteenth and early twentieth century. One of the most popular nineteenth-century accounts of the Observatory was written by Edwin Dunkin (Fig. 3). He was employed at the Observatory for 36 years (1838-1884), gradually climbing from the lowest ranking computer to the role of Chief Assistant. He was also one of the members of staff responsible for making observations with the Transit Circle and determining its errors. Therefore, he had firsthand experience of how the instrument was used on a daily basis. His description of the Transit Circle emphasized the close relation between the instrument and the line by writing that "the middle wire in the eye-piece of the telescope is the meridian line from which arcs of longitudes on British maps are reckoned. In illustration, we may notice that one half of the observing room is in the eastern hemisphere, and the other half is in the western" (Dunkin 1862, 23). According to this description, the line was not an independent or separate entity, but one that resided within the materiality of the Transit Circle.

Dunkin was not alone in describing the relationship between the line and the Transit Circle in this manner. James Carpenter, another member of the Observatory staff, noted the same relationship in a similar way:

> In its [the telescope's] focus is placed an extremely fine vertical line, - in reality, a fragment of spider's web. Now, to whatever point of the heavens we direct this telescope, bearing in mind that it can only move in a vertical direction, the spider line represents the astronomical meridian at that point. The virtual meridian of Greenwich is therefore really no more than half-an-inch of cobweb. (Carpenter 1866, 252)

As we see in this quote, Carpenter's description can be characterized as even more embedded within the materiality of the Transit Circle and its components than Dunkin's description was. For Carpenter, the line and the instrument, as well as their histories, were entangled and inseparable from each other. In fact, taking Carpenter's approach even further, every time the middle crosshair or the spider's web broke in the eye-piece, the observer broke not only the instrument, but the Greenwich Meridian too. Similarly, when instrument makers replaced the wires, they not only repaired the instrument, but also inserted a new Greenwich Meridian.

This type of representation gradually began to fade after the Greenwich Meridian was "selected" as the Prime Meridian in 1884. Instead, the line was thought of as an almost independent entity, going beyond the limits of the Transit Circle. A good example of this is Walter Maunder's history of the Observatory. Like Dunkin and Carpenter, Maunder was a member

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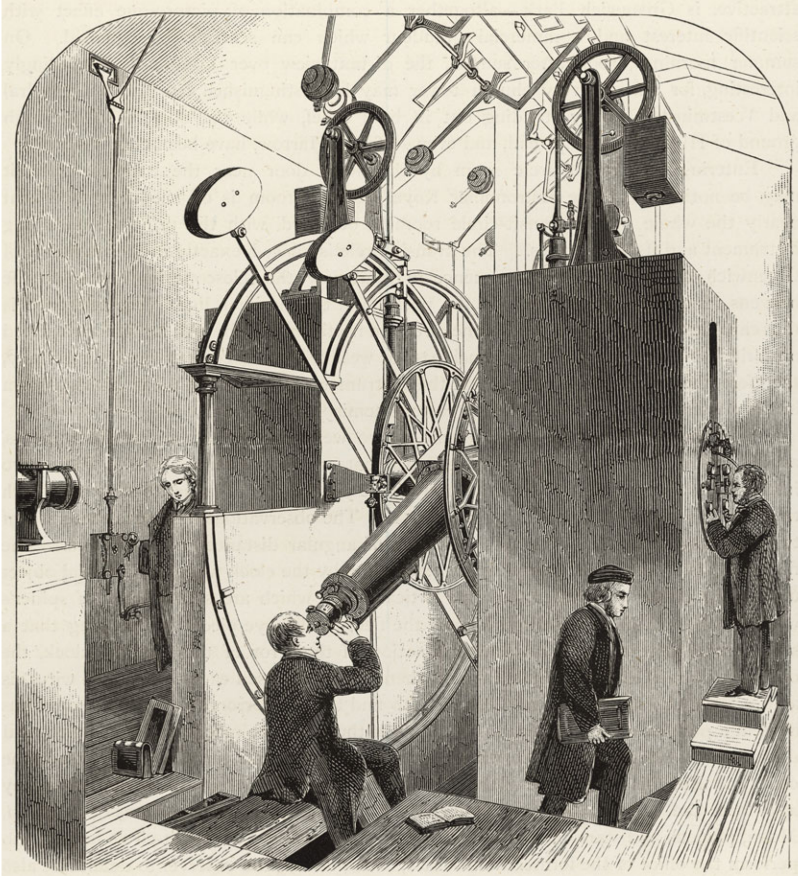

Figure 3. Illustration of the Airy Transit Circle used in Edwin Dunkin's book *The Midnight Sky* (1891) © National Maritime Museum, Greenwich, London.

of the Observatory staff. His description of the relationship between the instrument and the Transit Circle differs from theirs in linking it to the "optical axis" and other instruments resting on the continuation of the line, rather than to the middle wire in the eyepiece: "the optical axis of this telescope marks 'Longitude Nought,' which is further continued by a pair of telescopes [i.e. collimators], one to the north of it, the other to the south" (Maunder 1900, 148). In Maunder's description, the line was no longer thought to be confined to the instrument itself, but was instead an entity that went beyond its limits and encompassed whatever was placed on it (e.g. collimators).

Maunder's book was the last major popular description of the Observatory produced by one of its former members of staff, but discussions about the symbiotic relationship between the line and the instrument re-emerged once the Airy Transit Circle was turned into a museum object. The guidebooks produced by the National Maritime Museum (the institution that ultimately took over the Royal Observatory at Greenwich) and by members of its curatorial team presented mixed interpretations of the instrument-meridian relationship. In the first guide to the Observatory as a museum, Philip Laurie noted that "the Transit Circle performed its duties for more than a century and still stands defining the Prime Meridian" (Laurie 1960, 16). By doing so, Laurie continued to connect the materiality of the instrument to the Prime Meridian. Frank Carr, the

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Figure 4. Two tourists on the Meridian Line, Greenwich, circa 1931 © National Maritime Museum, Greenwich, London.

director of the National Maritime Museum, maintained this emphasis on the material connection by stating that the "prime meridian has been the centre wire in the Airy transit circle" (Carr 1965, 14).

The next guidebook to the Observatory marked a small shift away from the materiality of the instrument towards a more abstract presence of the line. This guidebook defined the Prime Meridian as the "longitudinal centre line of this instrument [i.e. the Airy Transit Circle]" (National Maritime Museum 1969, 12), rather than as an item within the materiality of the instrument itself. A contemporary article by Derek Howse similarly highlighted this abstract definition of the Prime Meridian as "a meridian passing through the centre of Airy's Transit Circle" (Howse 1970, 208). This was a definition that preserved the wording of the resolution at the 1884 Washington Conference, where the instrument was chosen to define the Prime Meridian ("the meridian passing through the centre of the transit instrument at the Observatory of Greenwich"), and a definition that Howse reused in his book on the history of the Observatory (Howse 1980, xiv).

Basil Greenhill's guide to the National Maritime Museum continued the material link between the instrument and the Prime Meridian, by characterizing "the Line" as being defined by the "optical axis" of the Transit Circle (Greenhill 1982, 110). Kristen Lippincott went even further by describing "the crosshairs of the great Transit Circle telescope" as the entity that defined Longitude Zero (Lippincott 1994, 2). As these examples show, the history of the Greenwich Meridian has been connected to the materiality of the Airy Transit Circle. Despite this, however, the imagination of the public remains captured by standing on both sides "the Line" rather than by taking photos of the line with the instrument (Fig. 4). It is this engagement with the product of a "dead instrument" that raises the question: why is the product not considered "dead" too? Or, perhaps it is? Perhaps the line defined by the instrument has also reached its end?

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Walter Maunder's popular book about the Observatory was also important for noting that the Greenwich Meridian was not always marked by the Airy Transit Circle. Instead, the Greenwich Meridian moved to the East by a few yards every time a new meridian instrument was set up inside a different room of the Observatory. Such an approach emphasizes both the close material links and the tangibility of the Line.

This movement of the line has served as the focus of historical research over the past decades. The issue gained further interest in 2015, when international news outlets noted the publication of a scientific paper that described how the Greenwich Meridian moved with the development of global positioning systems (Malys et al. 2015). Since then, Michael Kershaw demonstrated how the emergence of wireless technologies contributed to the gradual transition from measurements made with a single instrument to incorporating simultaneous measurements made with multiple instruments at different locations (Kershaw 2019).

The availability of simultaneous measurements contested the need to refer the observations back to the Greenwich Meridian as defined solely by the Airy Transit Circle. Kershaw argued that the simultaneous observations used to establish a universal standard of time resulted in the shift from the meridian defined by the Transit Circle to a "fictitious zero of longitude" that was calculated to be just a few meters east of the Greenwich Meridian (Ibid., 236). This was a crucial moment in the life of the Transit Circle, since it separated the materiality of the instrument from its product (the line) for the first time. In this sense, redefining the measurement of the Prime Meridian marked the end of the line as defined by the Airy Transit Circle. It is important to note here that this coincided with the gradual downfall of the credibility of the Airy Transit Circle. Only a year before the establishment of the fictitious meridian, the measurements of time service observations had been moved from the Transit Circle to another instrument due to the systematic errors being identified within the data provided by the Transit Circle.

What Kershaw and other historians demonstrated was that "Greenwich Meridian" was a term used to denote what were actually multiple successive meridians, derived from observations made at the Royal Observatory, Greenwich. Through this approach, the Line never ended, but always moved. By contrast, approaching the history of the line through astronomical instruments demonstrates that the different meridians were dependent upon the specific astronomical instruments that determined them. As a result, a meridian line appears to reach the end of its life every time the operations with the specific instrument that defined it are halted. In other words, we can interpret meridian lines reaching the ends of their lives in two different ways: either as the same line reaching the end of its life multiple times (whenever a new instrument is installed) or as multiple meridians reaching the separate ends of their lives (with each instrument giving birth to a different line).

The way in which the historical Greenwich Meridian is displayed today at the Royal Museums Greenwich successfully mixes the two approaches (Fig. 5). The line that crosses the courtyard (and over which the iconic photos are taken) marks the Greenwich Meridian as determined by the Airy Transit Circle. Therefore, it is a representation of the Line that was selected at the 1884 International Meridian Conference, as opposed to the exact location of the Prime Meridian in use today. The connection between the Transit Circle and the Line is made as clear as possible through the arrangement of the site. The representation of the Line across the Observatory courtyard not only leads directly to the Transit Circle Room where the Airy Transit Circle still stands today, but the northern wall of the same room is partially transparent in order to give the visitors the ability to visually connect the instrument and the line. Yet, despite these attempts to make the connection between the two entities, photos of the line very rarely feature the Transit Circle in their backgrounds. They are more likely to show the view of London from the top of the hill or the shoes of visitors. The reason for this can be traced back to its practical origins, namely the relatively large size of the instrument in comparison to the room that houses it. Returning to Maunder's description of the Observatory once again, the presentation of the Airy Transit

Figure 5. Illuminated Meridian Line at night, Royal Observatory, Greenwich (1994) © National Maritime Museum, Greenwich, London.

Circle appears as a problem that has been present ever since its installation: "this room is not well adapted for representation by artist or photographer" (Maunder 1900, 147).

Conclusion

This paper used the example of the Airy Transit Circle as a vehicle through which to examine the various ways in which scientific instruments can end. It situated this problem within the "biographical approach" to objects, showing how the different definitions used for the life of an object can lead to different interpretations of what entails the end of an object's life. By using examples from the history of astronomy, the first part of the paper identified several different ways in which astronomical and scientific instruments can reach their ends. One important finding of the paper is that, depending on what definition of life is being used by researchers, instruments can be understood to have a single ultimate end to their lives, or they can arrive at various ends that gradually transform them into different objects (or become parts of new assemblages). This framework was applied to analyze the downfall of the Airy Transit Circle, in order to demonstrate the various ways in which that instrument can be considered to have ended. The Airy Transit Circle is a useful example because its downfall has been very well documented, highlighting a variety of issues associated with the end of instruments: issues of credibility, material decay, broken and replaced parts, and being surpassed by newer, more precise instruments. In addition, since the use of the instrument was halted at one point, but then resumed a year later, it provided a unique example of how and why instruments can be "reborn." Finally, since it continues to function as an object displayed at a museum, this instrument raises further questions about whether its current state should be considered part of its life or its afterlife.

Focusing on the end of scientific instruments brings up the crucial question of how their ends affect the lives of entities that they produce. Since the Airy Transit Circle was used to define the International Prime Meridian, it serves as a great example through which to consider the symbiotic relationship between the instrument and its product. The paper demonstrated that such a symbiotic relationship was highlighted in publications by the astronomical assistants prior to the Greenwich Meridian being chosen as the Prime Meridian. However, in publications after 1884, the Prime Meridian began to be seen as a distinct entity. Once the instrument was turned into a museum object, guidebooks produced about the Observatory began to highlight once again the close connection between the Airy Transit Circle and the Line. Most often, this was achieved by making the crosshair of the telescope the material basis for the line. Despite these efforts, the difficulties of making the instrument visible, while placing increased emphasis on extending the material representation of the Prime Meridian across the Observatory's courtyard, made the instrument almost disappear from the public's general understanding of the Prime Meridian. Since the Prime Meridian functioned both as a symbol for the British Empire and as a scientific standard, detaching its life in the public imagination from the Airy Transit Circle served as a useful tool in maintaining credibility in the Line despite the downfall of the instrument that had defined it.

While recent works on the history and politics of the Prime Meridian have demonstrated how scientific techniques and geopolitical preferences influenced the rise and fall of new meridians, they have not yet linked this to a close analysis of the materiality of the instruments that determined them. This paper attempted to create an even closer link between the two regularly intersecting approaches and to demonstrate how creating a closer link can inform both research directions. By investigating how scientific instruments end, we are able to gain new insights into how instruments and their products are decoupled, and how the downfall of instruments can influence the credibility of the data they produce.

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