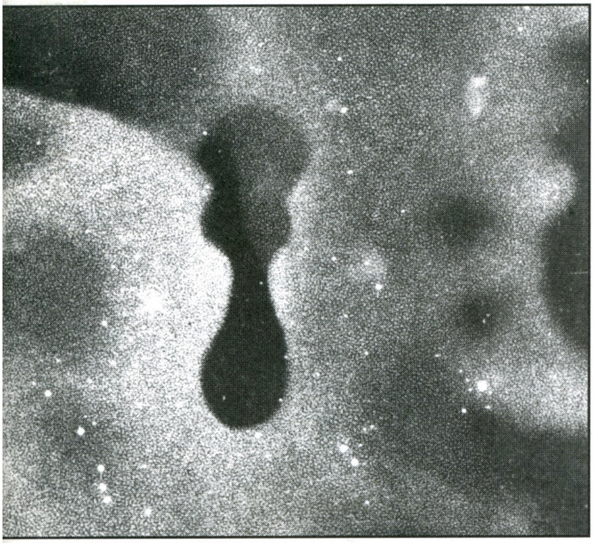
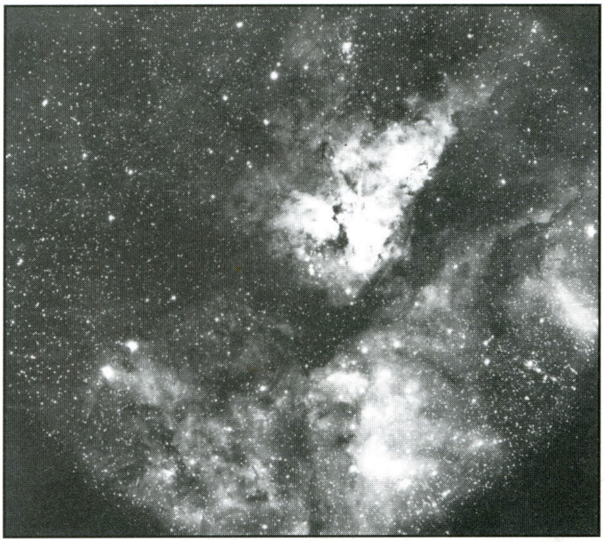
Journal of Astronomical History and Heritage





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JAH² is published twice-yearly, in June and December, and features review papers, research papers, short communications, correspondence, book reviews, and Ruth Freitag's history of astronomy bibliographies. Papers on all aspects of astronomical history are considered, including studies which place the evolution of astronomy in political, economic, and cultural contexts. Papers on astronomical heritage may deal with historic telescopes and observatories, conservation projects (including the conversion of historic observatories into museums of astronomy), and historical or industrial archaeological investigations of astronomical sites and buildings. All papers are refereed prior to publication. There are no page charges and authors receive 25 offprints of their paper free of costs.

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Chicago's Dearborn Observatory: a study in survival

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Abstract
The Dearborn Observatory, located on the Old University of Chicago campus from 1863 until 1888, was America's most promising astronomical facility when it was founded. Established by the Chicago Astronomical Society and directed by one of the country's most gifted astronomers, it boasted the largest telescope in the world and virtually unlimited operating funds. The Great Chicago Fire of 1871 destroyed its funding and demolished its research programme. Only via the sale of time signals and the heroic efforts of two amateur astronomers did the Dearborn Observatory survive.

Key words: *Dearborn Observatory, S W Burnham, refractor, meridian circle, timekeeping*

1 INTRODUCTION

Early in the nineteenth century Americans initiated their still-continuing love affair with astronomy. Observatories were established in major cities, some of them under the aegis of well-to-do amateurs, others closely linked to the college or university in their locale. In 1856 one contemporary historian of astronomy described twenty-five observatories, no more than three of which were situated west of the Alleghenies (Loomis, 1856). By 1902, 142 facilities scattered throughout the United States were in operation, most asserting a focus on research rather than just the instruction of students (Miller, 1970:117).

Directing a facility, especially one focused on research, is an enormously complex challenge. In *Dollars for Research* Miller (1970) documents the situation in nineteenth-century America, and the means by which scientists working in a variety of disciplines garnered resources. This country's astronomers were quite successful in finding patrons willing to establish, equip, and eventually upgrade their astronomical observatories; however, acquiring annual operating funds was a common, constant worry.

Chicago's Dearborn Observatory, conceived during the height of the Civil War and brought into operation early in the Reconstruction era, began as one of the country's most promising research facilities. Within five years it was the prototypical impoverished institution, unable to support a director, much less maintain its major telescopes and ancillary equipment. Dearborn Observatory remained in these dire straits for the next fifteen years, after which it relocated to Northwestern University's campus in Evanston. What is remarkable is that during much of its time in Chicago, the Observatory contributed significantly to the country's growing reputation in astronomy, a result almost as remarkable as its very survival.

2 PROPOSING A CITY TIME SERVICE

Nineteenth-century Americans managed their lives in a more leisurely manner than we do today. Yet, they, too, were time-conscious. Most had learned, some through bitter experience, that the passenger trains running on the country's burgeoning railway lines brooked no tardiness. So when in 1869 May 'J.C.D.' wrote to the editors of the *Chicago Tribune* urging the establishment of a precise source for city time, his words found a receptive audience among readers (J.C.D., 1869).

J.C.D., most likely Chicago Board of Trade president John C Dore, supported his proposal via a mixture of fiction and fact. He began with the remarkable assertion that the city's residents "... have no regular standard by which to regulate time-pieces." Surely he was aware that Giles Brothers & Company, a prominent jewellery firm located at 142 Lake Street, was City Timekeeper, and that it had been providing the official time without charge to the city government for the past four years, all the while supplying that same Chicago time to the railroads. Indeed, J.C.D. may even have known that for two decades the Common Council had been budgeting funds to pay various clockmakers and jewellers to determine the correct time for the bell ringers, subsequently having these expert timekeepers maintain the city-market clocks.

J.C.D. wanted "... the champion city...", as he termed it, to have an authoritative public signal equal to New York City's. There a time ball had been erected, one which fell exactly at noon every day upon receipt of a signal telegraphed from the Dudley Observatory in Albany, 150 miles away. He proposed that a similar device be erected at the top of a prominent Chicago building – either the Court House or a commercial one at the corner of LaSalle and Lake – and that the drop signal come via telegraph from the Dearborn Observatory, then located slightly more than three miles from the city's commercial centre. Perhaps J.C.D. was unaware that New York City's time ball, erected in the spring of 1860, operated for no more than a few months (Bartky, 2000:71). But even having that knowledge would probably not have deterred this civic booster.

As for current time errors, J.C.D. claimed that "... every regulator in each of our watch-dealer stores ... has [a] different time, varying from fifteen to forty-five seconds, and in some instances one or two minutes ..." Given such modest differences, it was well that an anonymous writer using the imaginative pseudonym, 'Time', rushed to his aid a week later with further evidence ('Time', 1869). "Time within two blocks of the Court House varies to day [sic] from five to ten minutes." he wrote in the *Tribune*, reinforcing his data with the impossible-to-judge comparison, "There is scarcely a jewelry firm or railroad in this city, whose time agrees with any other." A clever advocate, 'Time' certainly understood the value of ignoring the obvious question, "How closely need public clocks agree?" Further, this letter writer ended his list of timekeeping lapses with the observation that when the Court House bell announced noon, "... the time of one of the leading jewelers in the city, only across the street from the Court House, stands [at] 8 minutes of 12.", thereby implying that poor timekeeping might also be linked to the municipal government's own bell ringers.

In the matter of civic pride, 'Time' was J.C.D.'s equal. "Now this [sorry state of affairs] should not be in a city of the business and importance and public spirit of Chicago." he declared. "Millions of dollars worth of business is decided by the Court House time ... and the City authorities should see to it that time is correct." Fully supporting J.C.D.'s time-ball proposal, 'Time' urged the additional purchase of a marine chronometer so that the city's bells would be struck accurately at all times, ending his public communication with a challenge to the city authorities. "Chicago Time in every part of the city should agree, and with these suggestions carried into effect, it would agree." And so began a campaign to have the Dearborn Observatory determine Chicago's official time, an idea thrust upon its leadership. Fortunately, they made the most of it.

3 THE CHICAGO ASTRONOMICAL SOCIETY

Dearborn Observatory was a recent addition to the city's expanding suite of cultural assets. At the moment of J.C.D.'s proposal, it was rather a surprising choice for city timekeeper, for its efforts were focused entirely on advancing the science of astronomy.

In late 1862 a group of Chicago's business and social leaders met and concluded that astronomy should be a part of their interests. They discussed the acquisition of a telescope in order to view the heavens, and decided to purchase the finest instrument they could locate. They also took steps to organize a group of like-interested citizens, a process which led to the incorporation of the Chicago Astronomical Society (Illinois House of Representatives, 1867).

3.1 The World's Largest Refractor

Almost at once the Chicagoans learned of what was then the largest telescope lens in the world: an 18½-inch (47 cm) aperture achromat that had been figured in the shop of Alvan Clark & Sons, Cambridgeport, Massachusetts. Completed in the autumn of 1862, the Civil War was preventing the firm from shipping it to astronomer and University of Mississippi chancellor Frederick A P Barnard, who had ordered it (Osterbrock and Briggs, 1999). Now the Clarks were hoping to sell the lens to Harvard College's Cambridge Observatory. However, negotiations regarding price were dragging, for the Observatory did not have the funds for its purchase in-hand.

Already this telescope objective was famous among the world's astronomers. While testing it on the evening of 1862 January 31, Alvan Graham Clark, younger son of the firm's founder and also a distinguished optician and instrument-maker, discovered the 'dark companion' of Sirius, a long-postulated, but hitherto unseen star that was affecting the brighter star's motion (Bond, 1862). Thus not only did the lens surpass in size those mounted in the world's largest telescopes, at Pulkova Observatory in Russia and at Harvard College's observatory in Cambridge, Massachusetts, but this demonstration of its resolving power catapulted the firm into the front ranks of the world's telescope-makers, where it remained for many decades. The following January, France's Academy of Sciences awarded its Lalande Prize to Alvan Graham Clark for his discovery (Warner and Ariail, 1995:35-38).

3.1.1 The Telescope Comes to Chicago

Back in Illinois, the Chicagoans made ready their plans. Lawyer and civic leader Thomas Hoyne (Figure 1), the nascent Chicago Astronomical Society's eventual secretary, left the city on Thursday, 1863 January 20, arriving in Boston on Saturday morning. It was well that he went directly to the Clark firm, for news of the Chicagoans' interest had preceded him. As Hoyne (1874:7-8) subsequently recounted

> On arriving there, he [Hoyne] found himself in time to intercept – and he did certainly interfere, by the merest accident, with an arrangement for the transfer of the Glass to the Cambridge Observatory which had been pending since the spring before [1862], but was now being hurried to a consummation, on account of our Chicago movement.

Hoyne learned that the senior Clark had just left to meet with Observatory director George P Bond and a group of would-be donors residing in Boston. On seeing the telescope lens stored in its wooden box, Hoyne asked one of the younger Clarks the firm's price and terms. Immediately, and without any hesitation, the Chicagoan agreed to it, and proffered the first instalment of $1,500.

Offer in hand, young Clark and Hoyne sought out and met with a greatly disappointed senior Clark, who wanted his magnificent lens close by. After much discussion, Alvan Clark agreed that the Chicagoans were the first to make a definite offer, and at the price quoted to the University of Mississippi. Thanks to Hoyne's acumen, the finest telescope objective in the world was coming to Chicago. The editors of the *American Journal of Science and Arts* offered their congratulations, noting that this first step implied significant additional funding, "... of which Chicago lacks neither the spirit nor the means." (Silliman, 1863).

3.1.2 Housing the Great Refractor

Having purchased the lens for $11,187 (about $150,000 today), the Chicagoans contracted for a suitable telescope mount; Clark agreed to design and fabricate one for an additional $7,000. Deciding the observatory's location was scarcely a problem. In addition to being a founder of the Chicago Academy of Sciences and the Chicago Historical Society, lawyer, banker and insurance company president J Young Scammon (Figure 2) was also a trustee of the University of Chicago (Demise of Mr. Scammon, 1890; Scammon, Jonathan Young, 1999). The civic leader provided the entire $30,000 needed to erect a building on the University's campus at 3400 South Cottage Grove Avenue.[1]

Figure 1. Thomas Hoyne (1817-1883), *c.* 1868 (Courtesy: The Chicago Public Library).

Now officially termed the Old University of Chicago, the campus occupied ten acres of land donated in 1856 by Chicagoan and famous political leader Stephen A Douglas. Already on the grounds in 1863 was one wing of a planned building, its erection having forced the Board of Trustees to mortgage the site. After the Chicago Astronomical Society's acquisition of the telescope, the Board, wanting to provide a memorial to the now-deceased Senator Douglas, voted "that steps be immediately taken for the completion of the main building of the University the *erection of which has become indispensable to the proposed Observatory.*", with emphasis probably supplied by historian T W Goodspeed to indicate a well-founded scepticism. So Douglas Hall (Figure 3) was erected at a cost of nearly $125,000, plunging the school deeper into debt and creating a burden from which it never recovered (Goodspeed, 1916:15-18).

Prior to approving the observatory building's design, the Society sent William W Boyington, an important early Chicago architect,[2] to the East Coast to visit observatories. During his trip Boyington received advice from astronomers at Harvard College and Dudley Observatories, as well as from telescope-maker Alvan Clark (The [Dearborn] Astronomical Observatory, 1863). His final design, one constrained by location, was a tower structure linked to Douglas Hall, with the telescope's pedestal mounting supported on a massive, tapered, masonry column that reached eighty-two feet into the air, the column isolated from the exterior structure. The top of the revolving hemispherical dome, thirty-five feet in diameter and mounted on the exterior structure, was ninety-six feet above the ground. Providing stability for the supporting column required the driving of over one hundred oak pilings into the site's sandy soil, on top of which a twenty-seven-foot diameter, ten-foot-thick concrete foundation was poured (Andreas, 1884:516; Koenitzer, 1927:42, 72).

Figure 2 J Young Scammon (1812-1890), *c.* 1868 (after *Biographical Sketches*, 1868: facing 25; Courtesy: The Newberry Library, Chicago).

In naming the observatory (Figure 4), donor Scammon honoured the memory of his late wife, Mary Ann Haven Dearborn – a famous name in Chicago, for Fort Dearborn had been named for one of her relatives. Scammon, by far the most significant individual in the Chicago Astronomical Society, served as its president for twenty years. The organization attracted other donor-members by offering viewing rights on the telescope in exchange for monetary support of the endeavour.

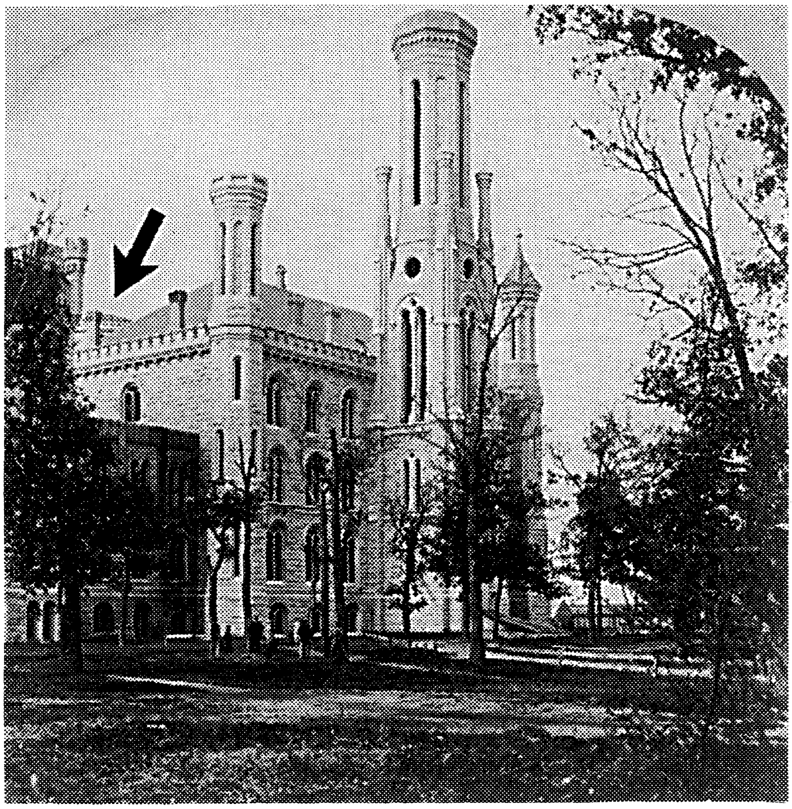

Figure 3. Douglas Hall of the Old University of Chicago, late-1860s, from a stereograph by John Carbutt. The top of the Dearborn Observatory's first dome is visible (see arrow) behind the building (Library of Congress, LC-USZ62-58571. An 1880s view, including the first wing, is in Goodspeed, 1916:facing 14).

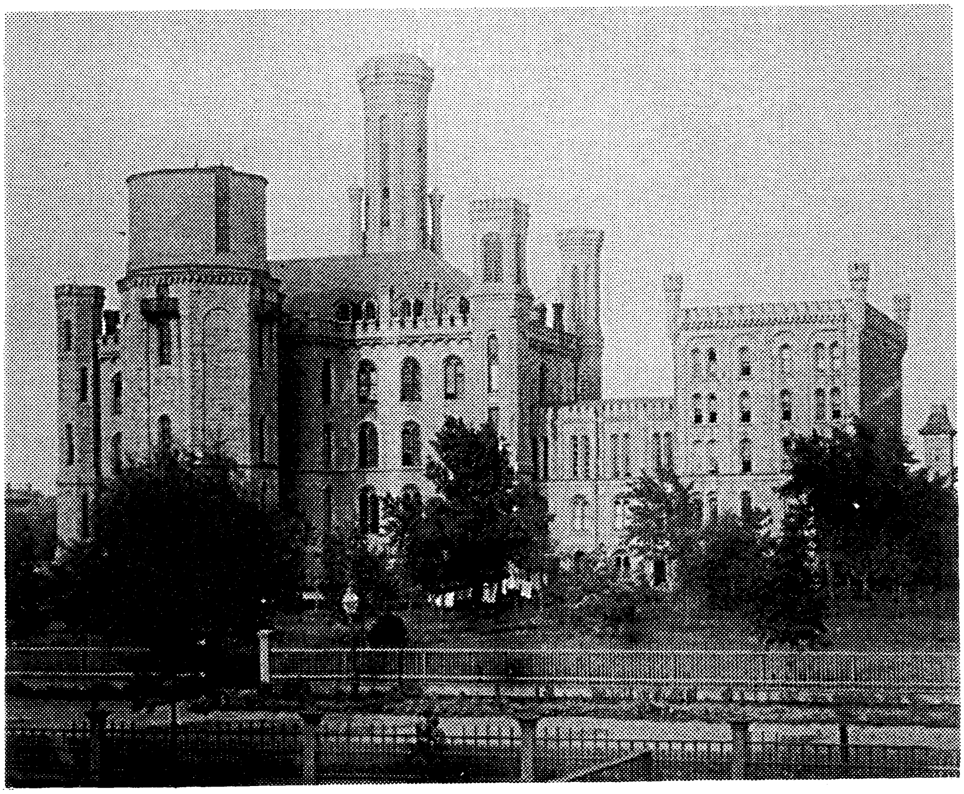

Figure 4. Dearborn Observatory tower at the rear of Douglas Hall (after CAS, 1882:frontispiece. A 'sanitized' version of this image is in Fox, 1915:facing 4).

3.2 The Dearborn Observatory's First Director

With the building finished and the Clark telescope waiting to be installed, the Chicago Astronomical Society turned to the question of an Observatory director. Here, too, they were enormously successful, for Truman Henry Safford (Figure 5), acting director of the Harvard College Observatory since George P Bond's death in 1865, was available. He had just been rejected for the permanent position by Harvard's president and a faculty faction anxious to place its own candidate in the directorship (Rothenberg, 1974:115-117). Safford's years of experience, an impressive list of publications and recognized gifts as an astronomer made him the perfect choice for what was becoming the most advanced astronomical facility in the United States. Late in 1865 December, he accepted the Society's offer to become director of the Dearborn Observatory and professor of Astronomy at the University of Chicago. During the negotiations, Safford proposed the acquisition of a meridian circle – a telescope constrained to view only a north-south arc of the sky and used both for the determination of stellar positions and precise observatory time.

Figure 5. Truman Henry Safford (1836-1901), *c.* 1877 (Courtesy: Williams College Archives).

On Safford's arrival early the next year, the Society placed an order with the German firm of Repsold & Son, Hamburg, for a second major telescope: a 6-inch (15.2 cm) aperture meridian instrument equipped with 40-inch (1 m) diameter graduated circles. Former mayor and successful businessman Walter Gurnee gave $5,000 toward its eventual $7,400 cost, so the telescope was named the Gurnee Meridian Circle

The 18½-inch primary telescope, with its equatorial mounting and clock drive allowing the observation and tracking of objects in any sector of the sky, arrived in March (Colbert, 1866a, 1866b, 1866c, 1916:477). Installed by the Clark firm, it was ready for use on 1866 April 16 (Figure 6).[3] In July Alvan Clark received an honorary Master of Arts degree from the University of Chicago for his accomplishments (Warner and Ariail, 1995:20, 88-89). In order to begin work at the frontiers of astronomy, the Society had invested nearly $60,000 in buildings and equipment.

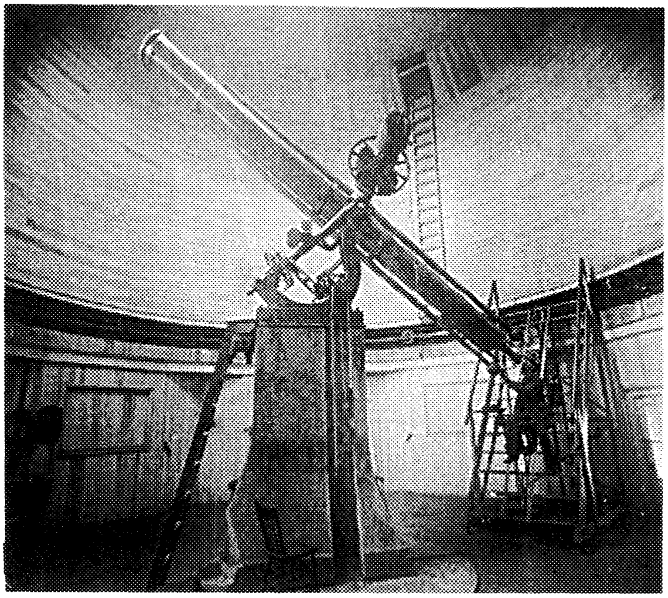

Figure 6a. Dearborn Observatory's 18½-inch refractor at the Chicago site; the seated observer is G W Hough (after CAS, 1882:facing 52).

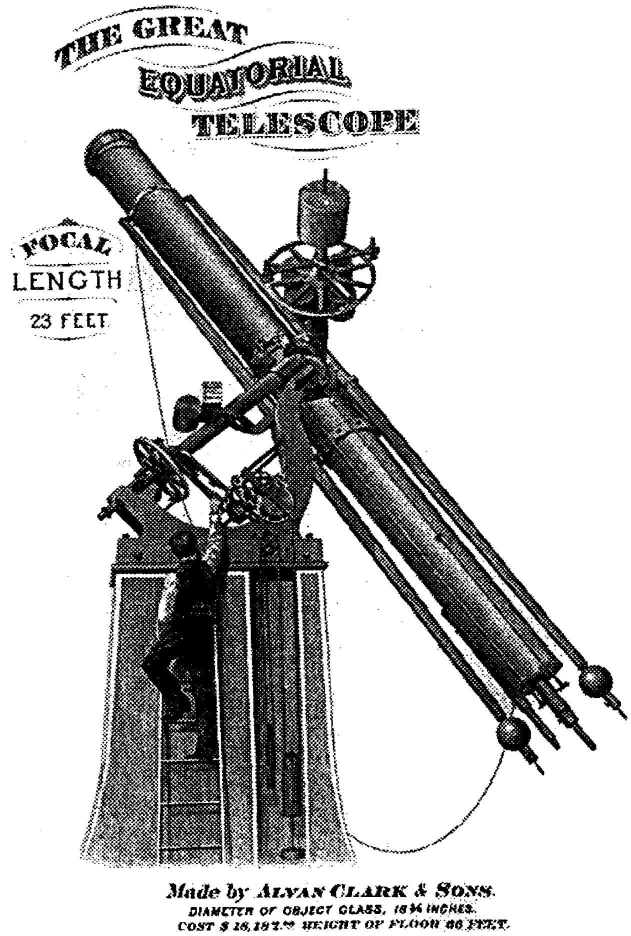

Figure 6b. Detail from a Life Member certificate of the Chicago Astronomical Society (see Figure 10, below). An identical image, without surrounding text, is in Andreas, 1884:516.

Safford, whose salary was paid by Scammon, embarked on a programme of observing nebulae with the equatorial. However, the design of the revolving dome was faulty, and within a short while keeping its opening in front of the equatorial became a major effort. The problem worsened and Safford's observing programme was crippled, with the astronomer able to observe only a narrow, fixed slice of the night sky. Thus when the Gurnee Meridian Circle arrived in 1868 and was mounted between two massive brick piers inside a small transit house some yards west of the main observatory tower (Figures 7 and 8), Safford immediately shifted his research efforts. Early in 1869 he embarked on a multi-year, multi-national co-operative effort of precision measurements of stellar positions, his responsibility a particular zone of the sky (Safford, 1869a).

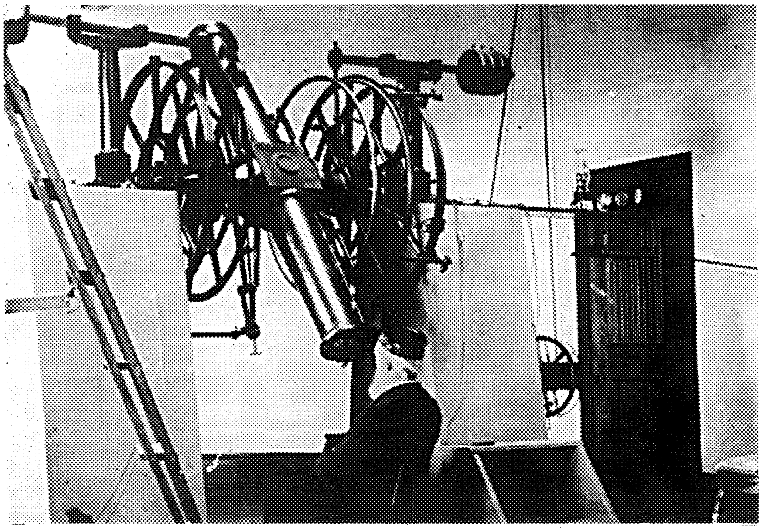

Figure 7. Gurnee Meridian Circle, photograph taken after Dearborn Observatory's relocation to Northwestern University; the observer is G W Hough (Courtesy: Northwestern University Archives). The transit instrument was removed in 1957 ([History of the] Dearborn Observatory, 1985:4).

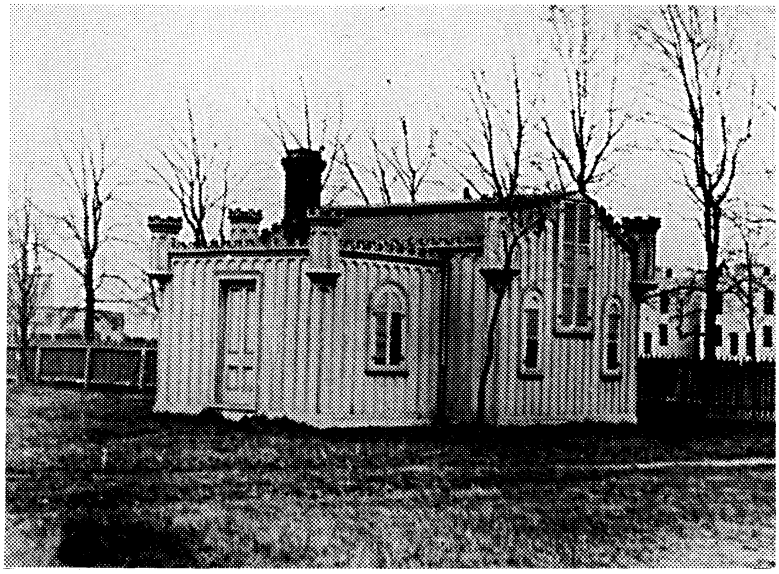

Figure 8. Transit house on grounds of the Old University of Chicago (after Koenitzer, 1927:75; Courtesy: University of Chicago Archives).

3.3 Considering a Time Service

There is no evidence that the Chicago Astronomical Society's leaders or Dearborn's director were considering the distribution of time to the general public when J.C.D.'s appeal for an authoritative source of city time appeared in the *Tribune*. In their research, astronomers use sidereal time, a system of highly-precise timekeeping not based on the public's mean solar time. Of course sidereal time can be converted to mean time; however, the two letter-writers were arguing for the distribution of mean time every day and that meant that a second astronomical-grade clock had to be purchased. And if the Dearborn Observatory was expected to guarantee the accuracy of its transmitted signal – a not-unexpected requirement – then staff would have to compare the mean-time clock frequently against the in-house sidereal standard, thereby committing large blocks of the observatory's most precious resource – those clear nights suitable for observing – to a programme of measuring transits of so-called clock stars. In contrast to a research activity, where one observes clock stars for modest periods before and after a cluster of stellar observations, such a programme would have to be on-going and, given the nature of contractual obligations, have priority. Certainly Safford, who had been at the Harvard College Observatory during the years it provided mean-time signals to Boston, was quite aware of the difficulty in maintaining a contractual service, a service that did not advance the field of astronomy one whit (Bartky, 2000:57-58, 75-76).

At that moment no more than five of the country's half-a-hundred observatories were providing public time in their locales. Of these, only the U.S. Naval Observatory was engaged in a strong programme of astronomical research, and its time service was the result of a long-standing directive from the Secretary of the Navy to provide Washingtonians with a daily time signal (Bartky and Dick, 1981, 1999). Undoubtedly the idea of taking over a local jeweller's function, one that simply did not require accuracies at the state of the art, carried scant appeal for a research-oriented astronomer, no matter how many public-clock discrepancies existed.

Nevertheless, with city time now a public issue, the Dearborn Observatory director had to consider it. No doubt Safford discussed the situation with the directors of the Chicago Astronomical Society; he probably also consulted with Elias Colbert (Figure 9), one of the Society's most enthusiastic members and also a *Chicago Tribune* editor. Safford probably did not speak with those running the railroads in Chicago, for in mid-July railway superintendents and others petitioned the city's Common Council for "... the establishment of a system whereby the correct time shall be furnished to the people, by means of a telegraphic connection of the city clock with the Dearborn Observatory."

Included in the railroads' petition were the purchase and installation of slave-clock dials at the city's rail depots, which would be kept in synchrony within fractions of a second via electrical pulses from a master clock placed at some central location in the city. This timekeeper would also control the striking of the hours on the Court House bell. The petition closed with an appeal for the appointment of a specific watchmaker as City Timekeeper (Chicago Common Council, 1869; A Prayer for Standard Time, 1869).

4 SETTING THE STAGE FOR PUBLIC TIMEKEEPING[4]

After reporting the submission of the railroads' appeal to the city government, the *Chicago Tribune* printed two editorials, both probably written by Elias Colbert (1869a, 1869b). The first dismissed J.C.D.'s proposal for an Observatory-controlled time ball, arguing that such a device was unsuitable since it was used to calibrate marine chronometers on ocean-going ships. The editorial did not mention a time ball's second use: to provide a daily, authoritative signal for the general public.

In the second editorial, the writer supported the idea of establishing a standard time for Chicago, but opposed the use of public funds to purchase the timekeepers. Moreover, he claimed that time accurate to within five seconds was sufficient for all business purposes. He noted that authoritative time meeting that level of quality could be obtained at modest cost via a twice-weekly signal, either telegraphed or brought to the city by chronometer, from the Dearborn Observatory. He (Colbert) also declared that the Observatory's astronomers were "... the most suitable person[s] to entrust with the regulation of the city time."; that is, one of them should be, *de facto,* City Timekeeper.

Figure 9. Elias Colbert (1829-1921) (Courtesy: Chicago Historical Society).

4.1 Enter the Dearborn Observatory

The very next day the *Tribune* printed a letter from Safford (1869b), in which the astronomer asserted that the Dearborn Observatory was ready and willing "... to undertake the regulation of the principal clocks in the city to uniform standard time ..." To do so, however, would require some sort of compensation, for he and his assistants – Safford's students – were completely engaged in a scientific programme and could not be spared even to undertake this worthy public service.

The astronomer went on to describe the great advantages of electrically-regulated clocks and to explain how easy it would be to connect an automatic bell striker to a central public clock. A fair distribution of costs among the interested groups –"... the municipality, the general public, and railway and other corporations. " – was certainly feasible, Safford concluded, reiterating the importance of assuring time uniformity throughout the city.

Having laid to rest both competing proposals, all that remained was to assure the proper fee for the Dearborn Observatory. A month later the Common Council received Safford's proposal, submitted on behalf of the Chicago Astronomical Society. Dearborn Observatory time signals would actually save the city money, he argued, for the Society was requesting only $1,000 a year for a time service, while the combined annual salaries of the watchmen assigned to strike the hours on the Court House bell totalled $1,800. (Ignored, of course, was the primary service these city employees provided). Safford also promised no additional municipal costs, for the $1,500 needed for the equipment – a central clock and strikers – would be raised by a private appeal for funds (Chicago Common Council, 1869-1870).

4.2 The Common Council Manoeuvres

Since the Society's proposal already had been endorsed by the city's Board of Fire and Police Commissioners, Common Council approval appeared certain. However, its formal submission came too late in the legislative process, and the matter was held over. It was not until mid-April in 1870 that the new Council's members approved a resolution supporting the funding request, and the Society launched its public appeal for funds to purchase equipment.

Giles Brothers, seeing itself about to be superseded as the city's official timekeeper, battled to retain its position. In August the firm presented a petition, signed by a number of Chicago businesses and individuals, offering to place an astronomical-grade timekeeper – one varying no more than five seconds a month – in the rotunda of the Court House. The clock would be equipped with electro-mechanical devices for striking the City Hall bell every hour and driving subsidiary dials in city offices. Offered at a price of two thousand dollars, Giles Brothers promised to maintain it " ... free of expense to the city."

The municipal authorities now faced a delicate choice: to approve a one-time capital expenditure of two thousand dollars to pay for a clock, or to authorize an annual expenditure of one thousand dollars for accurate time signals. The Council referred the Giles Brothers' proposal to its Committee on Finance.

Learning of the jewellery firm's petition, Chicago Astronomical Society officials immediately accelerated their canvassing for equipment funds. Simultaneously the Society's secretary informed the city's Board of Public Works of their continuing interest in providing Dearborn Observatory time to the city.

Almost at once, the Board of Public Works declared that "It would greatly add to the usefulness of this [time standard] project if there should be erected ... large dials showing the correct time at all hours." The Board then informed the Common Council's Committee on Finance of the negotiations currently underway with the Chicago Astronomical Society. The Committee responded with a recommendation to the Common Council that Giles Brothers' petition be tabled. The jewellery firm's manoeuvre had failed (Chicago Common Council, 1869-1870).

In November the Common Council passed an ordinance directing that illuminated clock dials be erected on the cupola of the Court House, at a cost not to exceed $2,000. Chicagoans would have the city's true time all day and all night, but that luxury came with a price: $3,500 in capital costs, and $1,000 annually (Chicago Common Council, 1869-70; Ranney, 1869:284-291).

5 CONSTRUCTING CHICAGO'S PUBLIC-TIME SYSTEM

Over the next ten months the many actions needed to bring Dearborn Observatory's time to the heart of the city were completed. E B Chandler, the city's Fire Alarm Telegraph superintendent, designed an electrically-controlled bell-striking mechanism, and then oversaw its construction and placement in the cupola of the Court House. In addition he had wires run to connect the striker directly to his office (What O'Clock, 1871). A pendulum-regulated clock capable of automatically transmitting hour signals was placed there and checked daily by observatory astronomers. Adjusted to conform to the time defined by the Dearborn Observatory meridian, this master clock's display was approximately four seconds faster than the official time at the Court House, a constant difference that scarcely mattered to any citizen. Starting in mid-January of 1871, hours were struck on the Court House bell (What the Dearborn Observatory is Doing, 1871).

In mid-February a sidereal-time clock made by E. Howard & Co. arrived at the Dearborn Observatory and was placed in service. In June the Common Council appropriated three thousand dollars to cover Observatory operating expenses and the city's share of the Court House clock. Also that summer a Howard tower clock, purchased by the Chicago Astronomical Society, was installed in the cupola of the Court House and set to time. In early October the Dearborn Observatory received its first payment from the appropriation for City Time. (Still to come were the four, large-diameter, gas-illuminated clock dials which had been ordered from England. At that moment they were on a train bound for Chicago).

6 DISASTER STRIKES

More than two years had passed since J.C.D. and 'Time' had proposed that Dearborn Observatory provide time for Chicago's citizens; its leaders had responded. Apparently the next phase in Dearborn's plan was to set up a system of synchronized clocks for Chicago railroad depots and businesses linked by wires to its new activity. Safford had already described such an installation.

The Great Chicago Fire of 1871 October ruined everything. Although Dearborn Observatory remained untouched by the conflagration, the Chicago Astronomical Society was devastated. All Society records were lost, considerable assets of its primary benefactor, J Young Scammon, burned to the ground, and his insurance company was bankrupted by the magnitude of its fire losses. Owing enormous sums, Scammon could no longer pay the director's salary. Safford became a wandering astronomer, employed by the federal government in its Western boundary surveys. Although Scammon himself remained ever-hopeful of economic recovery, Safford's career at the Dearborn Observatory was over. Receiving an official leave of absence two-and-a-half years later (Safford, 1874), the astronomer eventually resigned as director and accepted a professorship in astronomy at Williams College (Elliott, 1979:225).

6.1 First Attempts at Recovery

With the Chicago Astronomical Society now destitute, with its primary telescope unable to function, and with no astronomer available to continue the stellar observing programme with the Gurnee Meridian Circle, Elias Colbert became the force driving the Dearborn Observatory's endeavours (Andreas, 1886:428). This committed amateur astronomer, who had been elected Assistant Director during the Society's time-service negotiations with the city of Chicago prior to the Great Fire, continued working full-time at the *Chicago Tribune*, and taught Safford's courses in astronomy at the University of Chicago. In articles and editorials, Colbert cajoled and pleaded, reminding readers that the Society's Dearborn Observatory remained one of Chicago's great cultural assets.

Results were painfully slow in coming. The Panic of 1873, followed by the Chicago Fire of 1874, crushed any hope of attracting monies that could be used to create an endowment. Nonetheless, Colbert's tactics succeeded in attracting members (Figure 10); their annual dues allowed the Society to accumulate funds in anticipation of repairing the observatory dome, whose failure had made Dearborn's primary telescope almost useless.

6.2 Competition for Time Services

In early 1874 June, a new issue arose. Chicago's Western Electric Manufacturing Company, then at 220 Kinzie Street and having strong ties to the Western Union Telegraph Company, began to experiment with the distribution of time. Already producing and selling fire alarms, telegraph equipment, and other electrical instruments, Western Electric was contemplating the installation of an advanced system of electrically-regulated clocks throughout the city. Needing a source of precise time, it was receiving the daily signal transmitted by the Allegheny Observatory, a university facility across the river from Pittsburgh and over 450 miles from Chicago. These experiments had the unintended consequence of restarting the Dearborn Observatory's mothballed time service, for by the end of the month Western Electric was receiving time from Chicago's observatory (Hamblet, 1874).

Figure 10. Life Member certificate of the Chicago Astronomical Society, early 1900s(?), 16¾ by 11¾ inches. The central figure is J Young Scammon (From the collections of Northwestern University Archives).

Undoubtedly the company's switch to a local time-giver was the result of Colbert's vigorous efforts to find sources of income for the Society's near-moribund Observatory. Colbert continued along this path, and in late 1875 the Chicago Astronomical Society arranged with Western Electric to have Dearborn Observatory time signals automatically transmitted every minute to various organizations, including the Chicago Board of Trade, several area railroads, Giles Brothers and other city jewellers, Western Union, and the Elgin Watch Company factory outside the city. Negotiations over the next several months led in 1876 May to the Chicago Astronomical Society signing a five-year time-service contract with Western Electric, for which Dearborn Observatory received five hundred dollars annually for its signals (CAS, 1876:42, 44-45).

6.3 Enter Burnham

Elias Colbert, who had been appointed Acting Director at the time of Safford's leave of absence, was also anxious to restore Dearborn Observatory to its proper place in the field of astronomy. An opportunity to do so came in 1873. Sherburne Wesley Burnham (Figure 11), an amateur astronomer who resided a few blocks from Dearborn, was starting to become known in the professional community for his catalogues of hitherto-unknown double stars. To Colbert's great chagrin, Burnham was discovering these visual binaries with a 6-inch (15.2cm) Clark telescope mounted in his own backyard. In a May editorial alerting readers to Burnham's accomplishments, the *Chicago Tribune* editor warned that the 18½-inch refractor was "... now rusting in the Dearborn Observatory." and, further, that "The dome that protects it from the rain is also an efficient protector from observation.... It is simply a disgrace to the city," scolded Colbert (1873), "that the Dearborn telescope should remain in its present condition."

Figure 11. Sherburne Wesley Burnham (1838-1921), *ca.* 1884 (after Fraser, 1889:301; Courtesy: Mary Lee Shane Archives of the Lick Observatory, University of California-Santa Cruz).

Burnham, a full-time court reporter by profession, possessed extremely keen eyesight. He was also an efficient observer, able to quickly check his sightings against prior findings. And he was resourceful, as his success with his own modest equipment already demonstrated. Invited to use the Society's library and the Dearborn's near-immobile telescope, Burnham (1874:382-384) discovered his 188th companion star on 1873 December 22.

6.3.1 Management Conflict Erupts

Over the next months, Burnham made further discoveries; his fame, and that of the Dearborn Observatory's 18½-inch refractor, spread. Then in 1875, thanks to Colbert's success in garnering funds, a new dome was constructed and installed; once again the telescope could be pointed at will to any sector of the sky. In mid-September 1876 Burnham became Acting Director of the Dearborn Observatory – an unpaid appointment proposed by Colbert, who resigned his own unpaid directorship.

Unfortunately, Burnham's observational programme came into direct conflict with the pledges – viewing rights on the primary instrument – made by Colbert to those who had given funds to the Society. Accordingly, on 1877 April 11 Burnham was removed from the directorship and denied the use of the Society's telescope. Embarrassing publicity followed (Burnham, 1877:31; Fraser, 1889:305-306). One of the country's important science journals, noting that "For many years this large instrument ... has lain idle ...", when it ought to have been "... steadily doing service in astronomy, such service as no other instrument can do.", called on "... friends of science in Chicago ..." to take action to aid Burnham (Silliman, 1877). On July 22 the part-time astronomer was once again observing with the Dearborn refractor, continuing his remarkable string of discoveries of double stars, but sharing telescope time with member-visitors. Placing Colbert in charge of the facility again, Chicago Astronomical Society officers monitored the uneasy peace between their indispensable fund-raiser and Burnham, the now-world-famous observer (CAS, 1877:4-5). Burnham's efforts over the next four years, carried out with the now-functioning telescope, restored Dearborn Observatory's scientific reputation. His subsequent career at the Washburn, Lick, and Yerkes Observatories is well known to historians of astronomy (Ashbrook, 1970; Barnard, 1921; Burnham, 1900:vii-xii; Frost, 1921).

6.4 Enter Hough

The Chicago Astronomical Society's policy of having its equipment used to further the study of astronomy continued. George Washington Hough (Figure 12), who had been director of the Dudley Observatory for a number of years, came to the Chicago area in 1874 to establish a scientific equipment manufacturing enterprise in Riverside (present-day Belvidere). Some years later he, and one or two other astronomers from Midwestern colleges, began observing with the Dearborn's primary instrument (Andreas, 1886:429). In 1879 May, after Colbert's resignation, Hough became the full-time director of the Dearborn Observatory. The position remained an unpaid one.

Figure 12. George Washington Hough (1836-1909), *c.* 1882 (Courtesy: Mary Lee Shane Archives of the Lick Observatory, University of California-Santa Cruz).

Hough revived the Dearborn Observatory's research programme while Colbert continued writing editorials and manœuvring behind the scenes. In 1881 January the newspaperman's efforts finally paid off: the city of Chicago renewed its long-dormant time-service contract with the Chicago Astronomical Society. Dearborn Observatory began by sending a daily signal to the Fire Alarm Telegraph Office. Then with the purchase of transmitting clocks, it extended its service to continuous transmissions. The municipal government agreed to pay $2,000 a year for this 'Time Service of the City of Chicago'.

7 PATHWAYS TO A SECOND DISASTER

The future looked bright. The Dearborn Observatory had survived, its reputation had been restored, and once again the Chicago Astronomical Society was able to pay the salary of a full-time astronomer. Even a programme of facility rehabilitation and modernization appeared feasible. Unfortunately, it was a false dawn. Still lacking an endowment, Dearborn remained dependent on income from its time-service contracts.

Several disturbing signs already lurked on the horizon. In 1880, the Western Electric Manufacturing Company, which owned the clock used to transmit the observatory's time signals, refused to renew its annual contract with the Chicago Astronomical Society. While continuing to purchase Dearborn's authoritative Chicago time, it hinted that in the future it might be acquiring its primary signals from another source: either Allegheny or the U.S. Naval Observatory. The latter's daily noon signal had been available nationally since 1877 via the wires of Western Union, with the telegraph giant quoting an annual fee of three hundred dollars to receive them in Chicago. The Chicago Astronomical Society began exploring the possibility of serving private customers directly.

7.1 The University of Chicago Falters

The University of Chicago's plight added to the general uncertainty surrounding the Observatory's future. Heavily in debt, with its mortgage holder threatening foreclosure, the University's property included the tower building housing the Dearborn Observatory's primary telescope. Legal actions commenced in 1881 June.

7.2 The City of Chicago Adopts Standard Railway Time

Timekeeping itself began to change, adding yet another concern. On 1883 November 18, almost all of North America's railroads changed to Standard Railway Time, a voluntary system of operating times designed by and for the industry (Bartky, 1989). Replacing a myriad of unrelated railroad times were five separate times, each differing from its neighbouring one by exactly one hour. (Although of no real interest to the continent's railway companies, the new set of operating times had been deliberately linked to the time defined by the meridian instrument situated on the grounds of the Royal Observatory at Greenwich, England). Companies whose rail operations were centred in and around Chicago, and which were using Chicago time, were asked to adopt Central Railway Time, six hours earlier than Greenwich meridian time. Most of the thirty-six affected railway companies switched on that November Sunday. The holdouts expressed the fear that Chicago commuters would miss trains, since the city's time differed by more than nine minutes from the new time.

On Monday Chicago's City Council received, and immediately accepted, the Mayor's proposal for the city to adopt the railroads' new time. With the city's legal time now identical to Central Railway Time, the holdout railway companies switched to the new operating time. For the Dearborn Observatory, changing its authoritative time signals to conform to the new public time was a simple enough task: the mean-time transmitting clock was stopped for nine minutes, thirty-three and seven-tenths seconds and then restarted.

Throughout the country, more and more municipalities continued the necessary process of making Standard Railway Time a legal one for public purposes. The creation of America's time zones had begun.

The Central Railway Time that Dearborn was now transmitting was exactly one hour earlier than the time signals that both Allegheny and the Naval Observatories were transmitting. Significantly, the daily noon signal from Washington was being received in Chicago at exactly eleven o'clock; to use it to regulate a clock there no longer required minute and second adjustments. No one understood the implications of this country-wide simplification in time distribution better than the engineers at Western Union and Western Electric, and a rapidly growing group of electrical inventors.

7.3 New Timekeeping Technologies

Timekeeping technology was already changing. In the 1870s, after decades of trials and failures, a reliable, battery-driven clock synchronizer was finally demonstrated. Now, weight- and spring-powered clocks could be set to time and then kept in close synchrony even when they were hundreds of miles apart. Railroad and telegraph companies showed great interest in the development, the former because the displays on station clocks would differ by no more than a few seconds when synchronized periodically, the latter because the line of telegraph needed to send the synchronizing pulses had to be dedicated to that purpose no more than a very few minutes every hour, thereby leaving the wire available for transmitting telegrams.

A second advance in timekeeping technology made the wider distribution of time signals from some central source an even more profitable opportunity. In the fall of 1884 Chester H Pond, a well-known electrical inventor, received a patent for a clock whose mainspring was wound once every hour via a long-lasting, internal battery. This invention of a 'self-winding' clock meant that large companies, once their timekeepers were installed and set to time, would not have to employ people to wind them every week. And if such clocks were also synchronized hourly via a line of telegraph, then time displays would always be the same throughout the enterprise.

In 1885, tests of a bank of fifty clocks equipped with synchronizers began, using a Western Union line in Chicago (Bartky, 2000:172). Also early that year Western Electric removed its clocks from the Dearborn Observatory, and terminated its annual payment to the Chicago Astronomical Society. Scrambling to borrow another timekeeper in order to replace its lost income, Dearborn Observatory began offering Chicago time directly to private customers (CAS, 1885:194, 201; Western Notes, 1885). Only a tiny handful of firms signed up for the service.

7.4 Questions of Ownership

The Chicago Astronomical Society was facing even graver difficulties. The court decisions in the bankruptcy of the University of Chicago had brought into question the ownership of the Dearborn Observatory itself. The tower building had been University property since 1863, but not until 1886 did the courts recognize that the telescopes, clocks, library and associated equipment within the structure belonged to the Chicago Astronomical Society. Society records document the gratitude owed to lawyers Thomas Hoyne, who died before the final decision was announced, and J Young Scammon, for their years of effort to gain a favourable decision in the courts. But the victory was bittersweet; all understood that the Dearborn Observatory's remaining days on the University's campus were numbered (CAS, 1887:3-5).

8 EXIT THE DEARBORN OBSERVATORY

Early in 1888 the inevitable move from the Cottage Grove Avenue site began; the telescopes were dismantled and the ancillary equipment placed in storage. In March, the city of Chicago terminated its $2,000 annual contract and began purchasing its time from Western Union – at a cost of three hundred dollars per year. Despite the large annual saving, the selection of another time purveyor could not have come any sooner: the directors who negotiated the Society's contract in 1881 were influential Chicagoans, and the Dearborn Observatory was an important cultural asset. Only with the Observatory's relocation to Northwestern University in Evanston (Fox, 1915:9-13; Hough, 1889b, 1889c) did the telegraph company have any chance to win Chicago's business – no matter what it charged.

A rather tragicomical footnote to this final anecdote must be mentioned. Hough, who had relocated the Gurnee Meridian Circle to temporary quarters in Evanston while an observatory building on Northwestern's campus was being constructed, tried to retain Dearborn's other Chicago time-service customers: two banks and one jewellery store (Hough, 1888:276-278). Placing a mean-time transmitting clock at the offices of the *Chicago Tribune*, he and Colbert had a telegraph wire brought in and commenced the transmission of time signals; occasional stellar observations made in Evanston checked the transmitting clock's display of Chicago time. The following April this observatory time service was discontinued, Hough (1889a:285) deeming it "... unprofitable...", as it surely must have been. Throughout Chicago, public time was now the responsibility of the Western Union Telegraph Company, with the primary synchronizing signal – noon at the 75th meridian (Washington time) – arriving every day at its city office.

9 THE ELDERS OF CHICAGO'S DEARBORN OBSERVATORY

Despite the loss of a significant cultural resource, Chicagoans can be proud of the stewardship of the Dearborn Observatory by these nineteenth-century citizens, of whom four must be cited. First is Thomas Hoyne, whose negotiating skills created the opportunity. Next is J Young Scammon, on whose retirement as president of the Chicago Astronomical Society it was noted:

> Whenever a history of Chicago shall be written in which justice shall be done to those who have made our city what it is, then will the name J.Y. Scammon be found to occupy an honored place in the records of those whose benefactions have contributed most to the growth and prosperity of the city and its institutions. (Hough, 1882:20).

Third is court reporter and amateur astronomer S W Burnham, who brought fame to the near-useless Observatory during its darkest days. And fourth on the list is *Chicago Tribune* editor and amateur astronomer Elias Colbert, the now-forgotten fund-raiser, who prevented the institution's collapse by marketing its Chicago time.

10 ACKNOWLEDGMENTS

I am indebted to Donald Osterbrock, Lick Observatory, who read an early draft of this article and urged the inclusion of S W Burnham; doing so led to the discovery of contemporary images of the Dearborn Observatory's telescopes. Deborah Warner, National Museum of American History, supplied a number of citations to Alvan Clark & Sons. University of Chicago Archivist Daniel Meyer provided most useful guidance as well as a fascinating framework for the discussion of the Old University of Chicago given here. Allen Streicker and Patrick Quinn, Northwestern University Archives; Morag Walsh, The Chicago Public Library Archives; John Powell, The Newberry Library; and Sylvia Kennick Brown, Williams College Archives, were of great assistance in locating images in their respective collections. Steven Dick, U.S. Naval Observatory, provided insightful comments on my earlier draft. Once again I am indebted beyond measure to Elizabeth Bartky for her unswerving support.

11 NOTES

1 This location is sometimes confused with Douglas Park, on the city's West Side. Close to the Dearborn Observatory's original site is the Stephen A. Douglas Tomb State Memorial Park, with its monument to 'The Little Giant.'

2 The Chicago Water Tower, completed in 1869, was also designed by Boyington. One of the few structures to survive in the path taken by the Great Chicago Fire of 1871, arguably it is the city's most beloved landmark.

3 Another contemporary image of the refractor at the Chicago site is in Burnham (1900:facing xii); Osterbrock (2000) has shown that the observer here is Burnham himself and dates the photograph as not later than 1883-1884. The Northwestern University Archives holds an extensive collection of photographs taken around 1894, at the time G W Hough modified the telescope's driving mechanism. Alvan Clark & Sons' mahogany mounting tube was replaced in 1911 and is on permanent display at the Adler Planetarium and Astronomy Museum in Chicago.

4 A portion of this section and the next are excerpted from *Selling the True Time* (Bartky, 2000:78-83), with the permission of the publishers, Stanford University Press. Copyright 2000 by the Board of Trustees of the Leland Stanford Junior University.

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Recollections of life as a student and a young astronomer in Germany in the 1920s

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Introduction

The author of this essay, Hermann Alexander Brück (Figure 1), Emeritus Professor of Astronomy at the University of Edinburgh and former Astronomer Royal for Scotland, died on 4 March 2000 in his 95th year. He was the last of his generation of astronomers in both Germany and Britain, and among the oldest members, if not the oldest, of the Royal Astronomical Society and of the Astronomische Gesellschaft.

Hermann Brück was born in Berlin in 1905 and, as he recounts below, received his education at the Universities of Kiel, Bonn and Munich in 1924-1928. To the end of his life he looked back on his student days in Munich as the most profitable and exciting he ever experienced. From Munich he began his astronomical career at the Potsdam Astrophysical Observatory. These, too, were happy days, destined, however, to be blighted within a few years by the rise of Nazism.

In 1936 Brück left Germany, and obtained a temporary Research Assistantship at the Vatican Observatory. From there he went a year later to Cambridge, rising to the rank of John Couch Adams Astronomer and Assistant Director of the Observatory. In 1947, in response to an invitation from Eamon de Valera, then Taoiseach (Prime Minister) of Ireland, he moved to Dublin where he undertook the task of re-founding the defunct Dunsink Observatory under the auspices of the Dublin Institute for Advanced Studies. He moved from Dublin to the Royal Observatory Edinburgh in 1957, taking up the combined post of Astronomer Royal for Scotland and Regius Professor of Astronomy in the University of Edinburgh. He retired in 1975 at the age of 70.

Always interested in history, he occupied himself in his retirement with various historical projects. These included writing the histories of the Royal Observatory Edinburgh *(The Story of Astronomy in Edinburgh,* Edinburgh 1983) and of the earlier Dun Echt Observatory in Aberdeenshire (Lord Crawford's Observatory at Dun Echt 1872-1892, *Vistas in Astronomy* **35,** 1992) as well as a record of his own years at Dunsink Observatory (in Patrick A Wayman's *Dunsink Observatory 1785-1985,* Dublin 1987). A brief account of his student years in Germany was also published in 1987 (Rajkumari Williamson (ed.) *The Making of Physicists,* Bristol 1987). He also wrote (with M T Brück) a biography of one of his predecessors, Charles Piazzi Smyth, *(The Peripatetic Astronomer,* Bristol 1988) and contributed articles to biographical dictionaries.

This paper is an edited extract from reminiscences which he wrote for his family. I have omitted the more personal parts, leaving the account of his education and early years as an astronomer in Germany, which after an interval of over 70 years is, I believe, already of some historical interest. I have also added some footnotes.

All the photographs in this paper are from H A Brück's collection, and were reproduced by Photo Labs, Royal Observatory Edinburgh.

Key words: *Astronomv in the 1920s; Kiel University; Bonn University; Munich University; Potsdam Observatory; Einstein Tower*

1 Early Years

I was born in 1905 in Berlin into a military family. My father, a Captain in the XX Corps of the 9th German Army, was killed in action in the first battle of Lodz in the second half of November 1914. I was an only child, and from then brought up by my mother on her own. I have vivid recollections of the hardships of the First World War, and of the Spartacus Revolution in 1919 which I witnessed on the streets of the city.

Figure 1. H A Brück in 1929

My earliest introduction to astronomy came about by chance. Confined to bed with some minor illness, I was given a book to keep me amused. It was J J von Littrow's famous *Wunder des Himmels,* edited and brought up to date by Professor Paul Guthnick of Berlin and published in 1910. I still possess my copy of that book which sparked off my lifelong enthusiasm. Another, much smaller but very charming book by J H Fabre, the great French entomologist, called *Der Sternenhimmel* reinforced my ardour. I later obtained a small telescope, and used to look at the Moon from my window, long after my bedtime.

There was great popular interest in science at that period, thanks to the spread of the ideas of relativity which Einstein himself had first talked about publicly in a lecture he gave in June 1915 at the Popular Observatory at Berlin-Treptow. I began to read all the scientific books I could find, either purchased or borrowed from the 'Preussische Staatsbibiothek' in Unter den Linden, for which I obtained a Reader's ticket on the recommendation of the Director (Headmaster) of my Gymnasium.

2 School

At the age of 14 I started my five-year secondary education at the Kaiserin Augusta Gymnasium in Berlin-Charlottenburg, a Grammar school which, though specializing in the Classics, had also excellent teachers in science. The most outstanding of these was the master who taught both Greek and German to the 'Prima', the final two years at school. He was a firm believer in the unique value of a classical education. We read with him a great deal of Homer, Plato, and Thucidides, and the Greek dramatists Aeschylus, Sophocles, and Euripides whom he placed first among the six greatest poets in history, the other three being Dante, Shakespeare, and Goethe. I am happy to say that I am still able to read my Greek classics with pleasure. The other great teacher whom I was fortunate enough to have at school gave us a four-year course in mathematics and physics. In mathematics he took us up to number theory, analytical and spherical geometry and the calculus, including differential equations. His physics classes gave us a taste of the newly-emerging field of atomic theory.

I left the Gymnasium in March 1924 having done well in my 'Abitur', the German equivalent of the schools final examination, with top marks in mathematics, physics – and 'Turnen' (athletics). My good results dispensed me from oral examinations, and my certificate stated that I was about to enter university to study 'mathematics and science'. The golden gates of a future in astronomy were open!

My mother had long objected to my wanting to pursue astronomy as a career, which seemed to her to offer no firm prospects. By the time I left school, however, she had been persuaded by one of my uncles that I should be allowed to follow my inclination – on condition that if my studies at university did not work out, I would agree to take up a 'more sensible' profession like law or medicine.

This uncle, Karl Kisskalt, a distinguished medical man, had been appointed in 1912 to the Chair of Bacteriology and Public Health in the University of Königsberg, from where he moved to a similar Chair in the University of Kiel five years later. His support had not been given without thought. He considered it wise that my mathematical and scientific ability ought first to be tested properly by a suitable academic in his University. Accordingly, Professor Toeplitz, the distinguished Kiel mathematician, gave me a grilling, and seemed to find me suitable. After this, my uncle arranged for me to visit the University Observatory. I was fortunate to meet there Professor Carl Wirtz, a remarkable scientist, who at that time was engaged in a study of the radial velocities of galaxies which V M Slipher had measured at Lick Observatory. Few though they were, these showed a linear relation between radial velocity and magnitude which indicated an increase of radial velocity with distance. Wirtz attempted to relate his findings to Willem de Sitter's relativistic model of the world, and he presented me with a copy of his paper on the subject in *the Astronomische Nachrichten* which preceded Hubble's work on the same problem by several years[1]. It was my first meeting with a real astronomer, and my first encounter with astronomical research. I still regret that Wirtz's paper, the first astronomical reprint to be given to me, got lost in the course of my later wanderings.

When it came to deciding on a university, the choice was already made. I matriculated in Kiel in May 1924 for the summer semester. In Germany, the academic year is divided into two semesters, not three terms as in Britain. In my time, also, it was not unusual to attend more than one university; in my own case I spent my first three semesters in three different universities – Kiel, Munich, and Bonn, before finally settling for Munich, from where I eventually graduated. I still possess my certificates from all these universities.

3 Kiel 1924

I took four courses of study in Kiel – two in mathematics by Professors Toeplich and Hasse; one not very inspiring course in experimental physics by Professor Dieterici who was also Rector of the University; and the fourth in inorganic chemistry by Professor Diels. The last was outstanding and memorable. Diels was to receive the Nobel Prize for Chemistry in 1950. There were also occasional lectures from Professor Wirtz.

It must be admitted that I did not profit much academically from my semester at Kiel. This however was largely my own fault. I had joined the Corps Saxonia, one of the elite student clubs in the University. To belong to the Corps brought considerable prestige but was a huge distraction from studies. The Corps clubhouse became the centre of most of our activities. We met there several times a week at parties where considerable quantities of beer were consumed. Fencing played a leading role in our lives, requiring compulsory training in the early morning, the aim being to qualify to take part in duels ('Mensuren'). I much enjoyed fencing, but did not reach beyond the rank of 'Fuchs' or Junior member before I left the University.

Though life was pleasant, I became concerned at the inordinate amount of time and effort demanded by membership of the Corps and realized that I was in danger of getting away from my original purpose. After a lot of thought I decided at the end of the semester to resign from the Corps, leave Kiel, and get down to some real work at some other university.

4 Munich 1924-25

I chose Munich. On the academic side Munich had on its staff the distinguished astronomer, Professor Hugo von Seeliger, internationally known for his work on the structure of the stellar system. Unfortunately he fell ill and died in December 1924 before I had a chance to benefit from his lectures. In that same winter Munich was ravaged by an epidemic of influenza which killed two members of staff in the University's Department of Astronomy. It was not a propitious time for an enthusiastic would-be student of astronomy. As a result I concentrated on mathematics, taking the lectures of Professors Perron and Harthog, the former quite superb. There were also good courses on relativity theory by Professor Graetz and on the history of the determination of time by Professor Zinner, who was to become Germany's leading historian of astronomy.

Outside the University I practised skiing in the Bavarian Alps, and during that semester bought from the famous Sporthaus Schuster a pair of beautiful Norwegian hickory skis which served me well over the years and which now, seventy years later, stand propped against a wall in my home.

5 Bonn 1925

In the Spring of 1925 my uncle accepted a newly-established Chair of Bacteriology at the University of Bonn. For family reasons, it was decided that I should join my aunt and uncle there. In fact, I was to spend the remainder of my student days with them, first in Bonn and then in Munich, where my uncle, shortly after taking up the Bonn appointment, was invited to and accepted the prestigious Chair of Bacteriology and Public Health which he was to occupy for the rest of his academic life.

My time at the University of Bonn, though destined to be of only one semester's duration, was rewarding. I enrolled in April 1925 to read mathematics, physics and astronomy. The lectures on mathematics by Professors Beck (theory of functions) and J O Müller (Calculus), turned out to be excellent. Equally profitable was an intensive course on spectroscopy given by Professor H Konen, collaborator with H Kayser in the production of the *Handbuch der Spektroscopie,* that great standard work on the subject. The course included – for the first time in my university experience – a lot of laboratory work, including molecular spectroscopy under Dr Mecke.

Of particular appeal to me at Bonn, with its renowned history in that field, was the astronomy course. This course, on 'The Theory and Practice of Astronomical Instruments', was shared by Professor Küstner and Extraordinarius Professor Mönnichmeyer. Küstner was the undisputed Dean in the field of positional astronomy in Germany at the end of the 19th century. His fame rested on the discovery in 1888 at the Berlin Observatory of the variation in latitude or minute oscillations of the position of the Pole. The possible mobility of the Earth's axis of rotation had been suggested theoretically already in the 18th century by Leonhard Euler. but its very small effect had not been found until Küstner detected it in his meridian circle observations of the latitude of Berlin. Aiming at all times at the highest precision in observations of star positions, Küstner had been able to reduce probable errors from Bessel's value of 0″.7 to 0″.27.

These had been remarkable achievements, but by my day as a student, Küstner's eagerly awaited lectures had lost their brilliance. However, it was a privilege to have heard and known him.

On the practical side, we students received excellent instruction from Professor Mönnichmeyer who took us three times a week to Argelander's old observatory and put us through an intensive course in the use of astronomical instruments. The aim was to ascertain what degree of precision could be reached in the case of each of a range of instruments of increasing complexity, starting with portable instruments such as sextants and repeating circles, advancing to transit circles and theodolites, and reaching, finally, the meridian circle. We learned how to determine geographical position by the method of lunar distances – a method, popular with sailors in earlier times, which provided an interesting problem in computation as well as observation.

Among my happy recollections of Bonn in that summer semester of 1925 is the song of the hosts of nightingales on the tree-lined Poppelsdorfer Allee which we heard on our way home from a night's observing at the Old Observatory. A special student friend in the astronomy class was Max Delbrück, son of the famous historian Hans Delbrück, whose home was not far from ours in Berlin-Grünewald, though I had not known him previously. So much were we seen together as we walked to and from the Observatory that we were dubbed 'Delbrück and his echo' – Delbrück and Brück. As recounted in his biography[2], Delbrück was deeply disappointed with the old classical astronomy he encountered at Bonn, and left in search of the new physics at Göttingen. His subsequent brilliant career in atomic physics, biophysics, and genetics which led to a Nobel Prize in medicine in 1969, is legendary. Our paths, unfortunately, never crossed after we left Bonn.

At the end of the semester, with my uncle and aunt, I returned to Munich.

6 MUNICH 1925-28

The time from my matriculation at Munich in the winter semester 1925-26 to my graduation in the summer of 1928 was the most enjoyable and the most fruitful period of my student years. The Chair of Astronomy had been filled by Seeliger's successor, Professor Alexander Wilkens who had come to Munich from the University of Breslau. His field was classical celestial mechanics, in particular the theory of perturbations of planetary orbits. He was a firm believer in the superiority of the French work in that field. His lectures were based on the heavy tomes of F Tisserand's *Mécanique Céleste* and Henri Poincaré's *Methodes Nouvelles.* He despised German textbooks: "Throw the lot out of the window!" – but accepted *Die Mechanik des Himmels* by the Swedish C V L Charlier and F R Moulton's *Periodic Orbits,* published in 1920.

Wilkens' difficult subject did not attract more than a half a dozen students to his lectures, of whom I was one of the most attentive. Thanks to the excellent lectures in mathematics from Professors Caratheodory (analytical mechanics) and Perron (algebra), I made rapid progress in Wilkens' courses. In fact, I got on so well that he held out the prospect to me of being able to gain an early doctorate with a problem on periodic perturbations of minor planets.

My attitude to astronomy changed dramatically, however, in my second semester (summer 1926) when I experienced the lectures of Professor Arnold Sommerfeld. Sommerfeld (Figure 2) was the most brilliant university teacher I ever met. His lectures were models of clarity, and beautifully delivered. He would fill the two large blackboards in his lovely handwriting with never a mistake. Though I found myself at the wrong end of his 6-semester course on theoretical physics, I was able to keep up quite well with his lectures even in my first semester – partial differential equations of physics – introduced with a discussion of Fourier's work. Sommerfeld himself – and the subject matter of his lectures – aroused my immense enthusiasm and the wish to make theoretical physics rather than astronomy my main field of study. Mathematics and astronomy would then be my secondary subjects.

Figure 2. Arnold Sommerfeld circa 1928

Professor Wilkens, though disappointed with my change of direction, accepted my new views. I continued attending his lectures on celestial mechanics for a full two years, and took part regularly in his astronomical colloquia at the Observatory. I also attended the astrophysics lectures of Professor Zinner, and, in my last semester, listened to a remarkable course on the physics of the Sun by Professor Robert Emden, of 'Gaskugeln' fame. As with astronomy, I kept up my mathematics courses throughout, quite particularly the brilliant lectures of Caratheodory.

In order to learn more about experimental physics, I took the intensive lecture and laboratory course of Professor Wilhelm Wien and his assistants. Wien, famous chiefly for the law of black-body radiation enunciated in 1893 which bears his name, was greatly revered – and not a little feared – by his students. Out of interest I also went from time to time to Munich's Technical University to listen to the entertaining lectures of Sommerfeld's friend J Zenneck, the Professor of Physics there, which were accompanied by demonstrations, including, I recall, the firing of rifles!

As Sommerfeld's course progressed I became particularly intrigued by his lectures on the new quantum and wave mechanics. I exerted myself to the full to be accepted into his seminar (or study group) where the marvellous new developments in physics were kept under constant discussion. It was at Sommerfeld's seminar that Werner Heisenberg, then professor in Leipzig, first spoke about his uncertainty principle (1927), when I was already a member and had the good fortune to be present.

To become a member of the seminar one had to demonstrate one's suitability by giving a critical presentation of a recent scientific paper. The task set for me was to discuss a paper by Erwin Schrödinger with the formidable title 'Quantizierzung als Eigenwertproblem, Störungstheorie und Anwendung auf den Starkeffekt der Balmerlinien' which had just appeared in Volume 80 of the *Annalen der Physik.* I was given six weeks to prepare my talk. It is no exaggeration to say that never in all my life did I work as hard day and night as I did on that occasion! However, my talk went well, and I was formally accepted as a member of Sommerfeld's Seminar. Twenty years later, when Professor Schrödinger and I were colleagues at the Dublin Institute for Advanced Studies, we laughed heartily as I recalled my ordeal of 1926.

Having joined the seminar I was taken on by Sommerfeld as a candidate for a doctorate. The first problem proposed to me for research turned out to be incapable of solution. Another was found for me by Sommerfeld, in conjunction with his assistant Albrecht Unsöld, which I was able to solve in due course and which formed the substance of my doctoral thesis. Unsöld, though a few months younger than I, had already obtained his doctorate under Sommerfeld and was now his assistant. He and I became close friends and remained so throughout our lifetimes. Unsöld, recognised as one of the world's leading astrophysicists, moved from Munich a few years later and spent almost his entire academic life thereafter in the University of Kiel[3].

A delightful aspect of becoming a student of Sommerfeld's was the opportunity of getting to know him on the ski slopes. He was an expert skier, and had a Hutte or cabin in the mountains at Bayerische Zell where his assistants and senior students, as well as occasional foreign visitors – ten or so people altogether – would be invited to spend weekends. Albrecht Unsöld and I were among those thus privileged. Professor Zenneck, Sommerfeld's great friend and fellow ski-ing enthusiast, often came as well. Sommerfeld's technician from his crystallography Department was usually there too: his wife – the only lady in the company – an excellent cook, fed us splendidly in true Bavarian manner. In those days we carried our skis on our shoulders, and trudged all the way up the icy track – a far cry from today's ski-lifts. These weekends in the mountains were among the highlights of my student days.

I myself was also keen on mountaineering, and in summer spent most weekends rock climbing in the mountains of the Wilder Kaiser in the Tirol east of Kufstein, either alone or with the Munich Alpine club.

I completed my thesis – on a problem concerned with the wave-mechanical calculations of the forces which keep ions apart in salt crystals, afterwards published in a paper in *Zeitschrift für Physik* – in good time. The thesis was accepted, and I was put forward for oral examination in theoretical and experimental physics, and in mathematics and astronomy. I had four examiners – Sommerfeld and Wien for physics, Tietze for mathematics, and Wilkens for astronomy. Wien had a reputation as a severe examiner: even Heisenberg's grade had been marred by his questioning In my case he was, indeed, the only examiner to prove awkward, with his disconcerting habit of whistling while waiting for answers. However, I survived: I was in fact the very last person to be examined by Wien who died soon afterwards at the early age of 61.

On 24 July 1928 I graduated Doctor of Philosophy 'magna cum laude' at the University of Munich.

On my 85th birthday, in 1990, it gave me great pleasure to receive from the Rector of the University of Munich a duplicate certificate of my D.Phil. degree.

7 THE EINSTEIN INSTITUTE

I owe the next step in my career to my Professor, Sommerfeld. Sommerfeld took a great interest in the work of A S Eddington whose *Internal Constitution of the Stars* had appeared in 1926. He suggested that, with my love of astronomy, my path ought to be in this new astrophysics – the path also chosen by Unsöld for his life's work. The leading astronomical institution in Germany was the Astrophysical Observatory in Potsdam where in 1924 an entirely new Department, the Einstein Institute[4], had been established on forward-looking lines. Sommerfeld considered that this Institute would be a good place for me to work, and upon his recommendation to its Director Erwin Finlay Freundlich[5], I was awarded a research grant (what one would now call a Research Fellowship) to work there shortly after leaving Munich. Albrecht Unsöld was also to spend some time as a visiting researcher there.

The Astrophysical Observatory at Potsdam had come into being in the 1870s, one of the very first observatories in the world to be devoted specifically to the 'new astronomy' of the time. It acquired under its first Director, H J Vogel, international eminence for work on stellar spectroscopy and the radial velocities of stars. The large site encompassed several buildings and staff residences. The main building was surmounted by three domes housing refractors of modest size. Later in the nineteenth century another separate dome was built for the photographic refractor used for the international Carte du Ciel project. A substantial addition to the Observatory was a 31/20-inch photographic/visual refractor acquired in 1899 and mounted in a huge new separate dome on the south side of the main building (Figure 3). However, by the time this 'Great Potsdam Refractor' was built, the usefulness of large refractors had all but passed. This fact, combined with the instrument's inadequate performance and the poor seeing conditions at the site, prevented this large telescope from being used for any serious programme of research.

It was only in the 1920s that a move was made to up-date the instrumental facilities of the Potsdam Astrophysical Observatory. This was largely thanks to the efforts of Freundlich who had joined the staff in 1920 as an 'Observator', having previously been assistant at the Berlin Observatory at Berlin-Babelsberg. Freundlich's special interest was in the observational tests of Einstein's Theory of Relativity. In the case of the first test – the motion of the perihelion of the orbit of the planet Mercury – Einstein's theory had proved clearly superior to Newton's. The second test involved the redshift of the lines in the spectrum of the Sun caused by the gravitational attraction of the Sun's mass on its light. The third was the deflection by the Sun of the light of stars close to the Sun's limb, an effect observable at times of total solar eclipse.

Karl Schwarzchild, the eminent successor of Vogel as Director of the Potsdam Observatory, had already tried, in 1913, to detect relativistic redshifts in the solar spectrum, but found his equipment inadequate for the task. Freundlich recognized the need, if this observation was to be made, for a telescope of long focal length coupled with a spectrograph of high resolution – along the lines of the large tower telescope at Mount Wilson Observatory in California. Freundlich's project would be costly, but he had the backing of leading scientists such as Planck, Nernst, and von Laue, who were greatly interested in the experiment, since Eddington and his team of English observers appeared to have successfully demonstrated the deflection of light in accordance with Einstein's predictions at the Sun's limb during the total eclipse of May 1919. Major financial support for Freundlich came from German industrialists, particularly from the concern IG Farben whose President, Carl Bosch, industrial chemist and Nobel Laureate, was prepared to take a close interest in the matter.

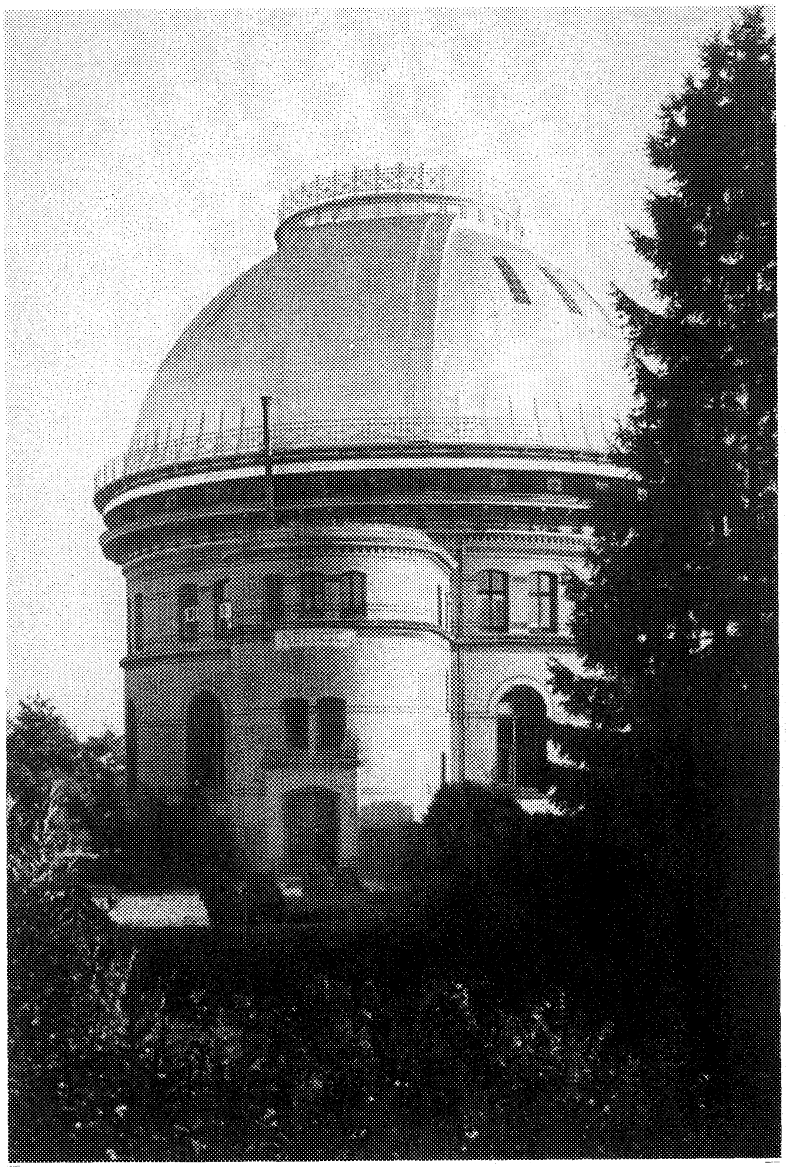

Figure 3. The Great Refractor Building

The actual design of the building, known as the Einstein Turm (or Tower) (Figure 4), on a site to the south of the Great Refractor, was entrusted to the famous modern architect Felix Mendelsohn, who co-operated closely with the firm of Carl Zeiss Jena which was responsible for supplying the optical equipment. The instrument used two mirrors of a coelostat (Figure 5) to send the Sun's light vertically down on to a lens of 60-cm aperture and focal length 14.5 metres. The solar beam, turned into a horizontal direction by an auxiliary mirror, was then thrown into a large prism or grating spectrograph with a collimator of 12 metres focal length (Figure 6). The whole installation was successfully completed at the end of 1924. The Einstein Tower was acclaimed as a truly modern and effective instrument which would lead to significant advances in the field of relativity theory and of solar physics in general.

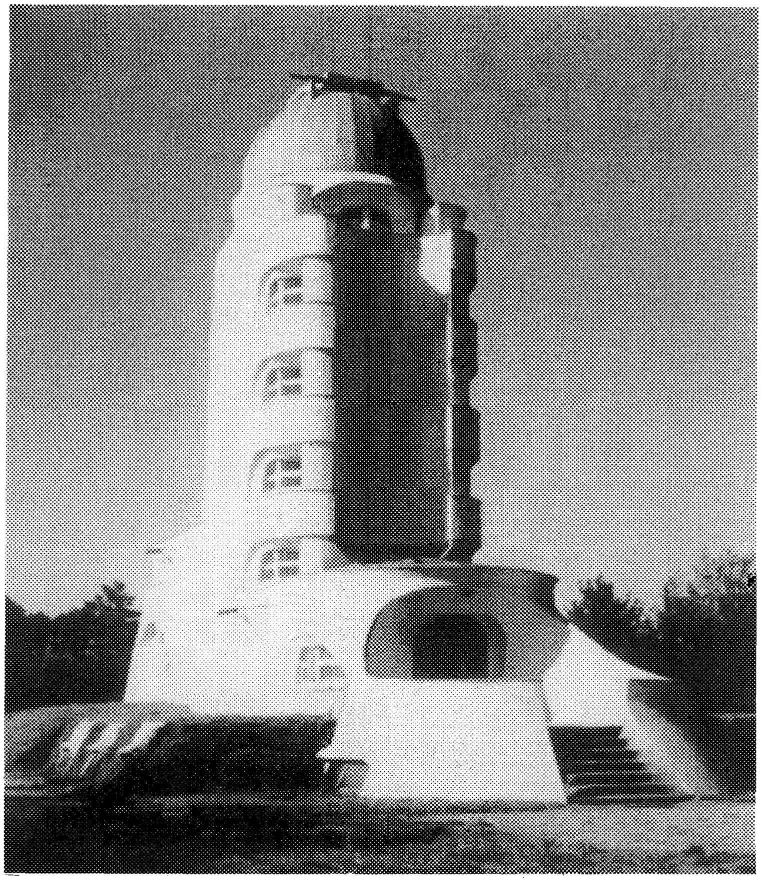

Figure 4. The Einstein Tower

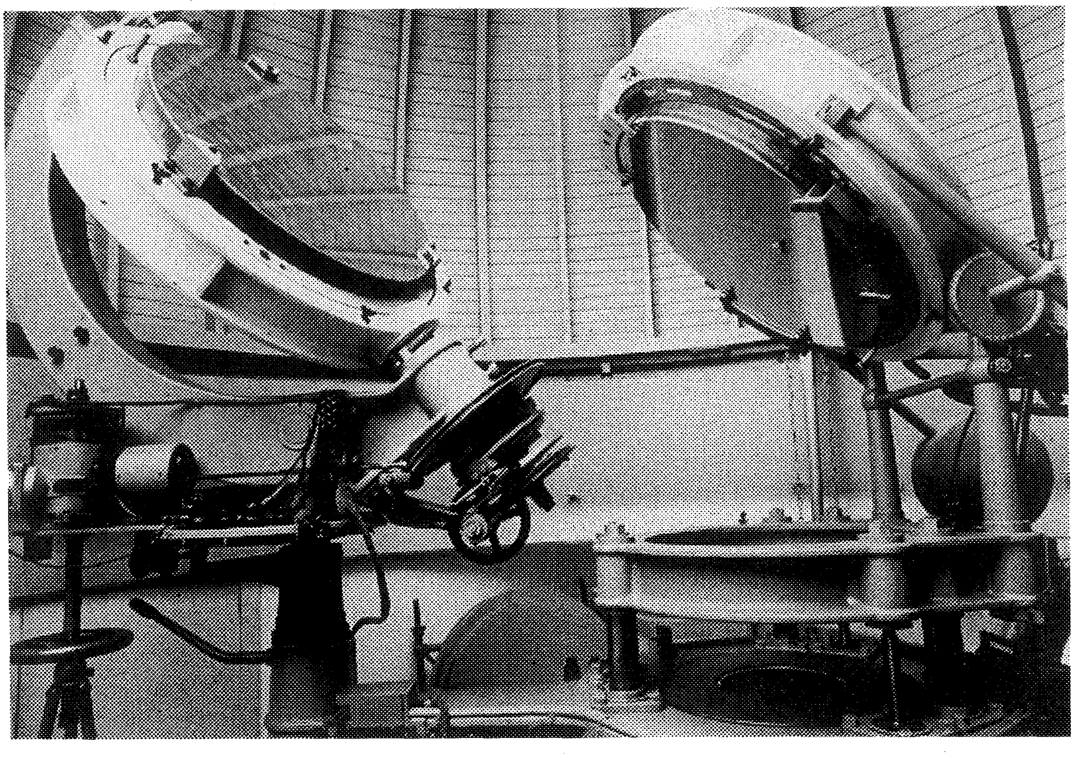

Figure 5. The coelostat at the Einstein Tower

On my arrival in Potsdam I was very kindly received by Professor Freundlich and his scientific staff – Drs Harald von Klüber[6] and Karl Wurm, and his technical assistant Fraulein G. Schröder (see Figure 7). Klüber then introduced me to the Director of the Astrophysical Observatory, Professor Hans Ludendorff. The Einstein Institute was officially a department of the Astrophysical Observatory, in which Freundlich was, formally, no more than one of the Observatory's senior astronomers or 'Hauptobservatoren'. Freundlich, however, had been fairly successful in making himself independent of the Director. I soon became aware that personal relations between him and Ludendorff were cool, and that the Observatory staff, or part of it, was divided into two 'camps', with allegiances to one or other of these men. This feud passed over my head, however, and throughout my years at Potsdam, first at the Einstein Tower and then on the main Observatory staff, I fortunately experienced no friction from that source and was on good terms with astronomers on both sides.

Figure 6. The solar spectrograph at the Einstein Tower

When I first arrived at the Einstein Turm I found Freundlich and Klüber busy preparing for an expedition to Sumatra where they planned to observe the total eclipse of the Sun of 9 May 1929. Freundlich had earlier taken part in an eclipse expedition organized from Hamburg Observatory to the Crimea in 1914, which was hampered by poor weather. On this occasion Freundlich and Klüber's intention was to carry out the relativity test by observing, with new and specially-constructed equipment, the deflection of starlight at the limb of the Sun. Klüber had his hands full, adjusting a double horizontal camera which, fed by a coelostat, was to produce images of the Sun of 8-cm diameter on a photographic plate. The results of this successful expedition gave a light deflection of $2''.24$, appreciably larger, even after doing a new reduction, than the theoretical value of $1''.75$. The discussion of what the true value of this quantity ought to be was to preoccupy Freundlich for the rest of his life and put him at odds with mainstream relativists.

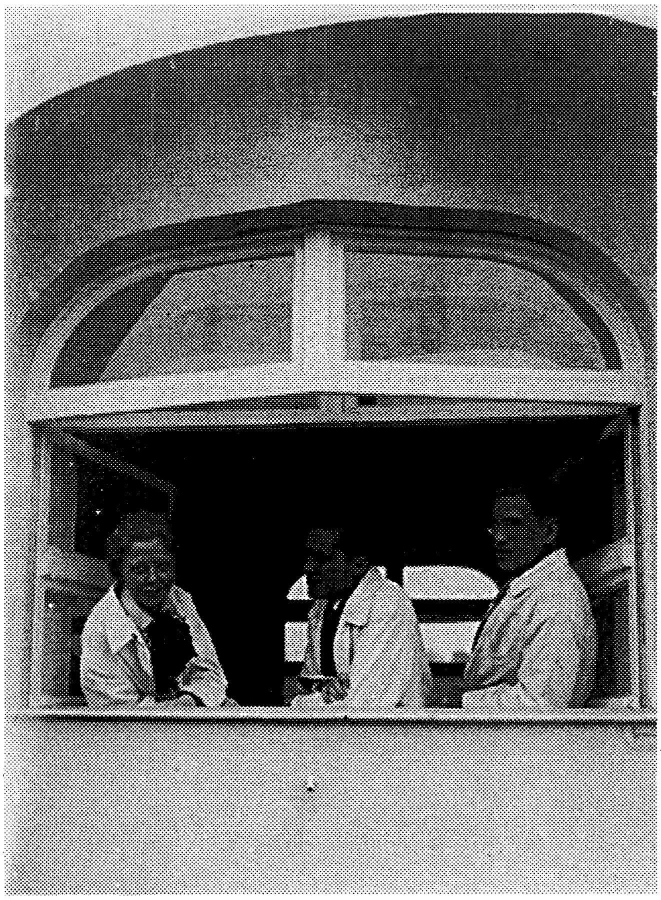

Figure 7. Fraulein Schröder, Karl Warm and H A Brück at the Einstein Tower

My first duty at the Einstein Turm was to familiarize myself with the spectroscopic equipment and with the operation of the 'Dreh-system' constructed by C Zeiss which allowed the light of two different regions of the Sun to be thrown simultaneously onto the slit of the spectroscope. The purpose was to search for redshift of lines in the solar spectrum as predicted by the Theory of General Relativity. Analysis of the observations showed that the method was not powerful enough to detect the redshift. However, they showed a change in wavelengths of Fraunhofer lines along a solar radius and established the so-called 'limb effect' for which no theoretical explanation could be found. The results were published in a joint paper with Freundlich and A von Brunn, who had joined us from Danzig (Gdansk). The same unexplained effect was later confirmed by Miss M G Adam at Oxford.

Meantime Wurm, the third member of our team, used the solar spectrograph for laboratory spectroscopy. He had an electric furnace to produce narrow iron comparison lines, and also did some molecular spectroscopy.

In addition to the solar work in the Einstein Turm I had the opportunity of being involved with Professor H. Schüler in laboratory spectroscopic studies of hyperfine structure in spectral lines for the determination of nuclear moments, a field in which he was the leading expert. This resulted in a number of papers in the *Zeitschrift für Physik*. Schüler, who did not belong to the regular Potsdam staff but had a grant from the Kaiser Wilhelm Institute, had his laboratory in one of the rooms in the Great Refractor building. It was there that I first met Derek Jackson FRS, the Oxford spectroscopist with whom I was to collaborate for a time in the 1950s[7].

The frequent presence of visiting scientists such as Jackson was one of the attractions of working at Potsdam. Freundlich made a practice of welcoming researchers from abroad as well as from Germany: the British cosmologist E A Milne was one of those whom I got to know in Potsdam, where he spent many months working with Freundlich.

Part of the activity at the Einstein Institute was the excellent colloquia. I heard Jan Oort speak about the rotation of the Galaxy at one of the colloquia. It was there, too, that I met the Danish astronomer Elis Stromgren and his son Bengt, Bart Bok from the Netherlands, and many others.

A regular participant at the colloquia was the spectroscopist Walter Grotrian, who was a member both of the main Astrophysical Observatory and of the Science Faculty at Berlin University. Grotrian introduced me into the illustrious circle of M von Laue's Physics Colloquium at the University in which speakers reported on recent published researches to an audience including no fewer than five Nobel Laureates. I was pleased to be allowed to speak; my topic was a paper by Otto Struve concerning the Stark Effect in stellar spectra. Einstein used to turn up at the Physics Colloquium. As a very junior member, I cannot claim to have known him personally, except in so far as his waving at me from his sailing boat on the lake at Potsdam when I was out in my own little dinghy. Einstein was a member of the Board of the Einstein Institute but rarely took part; in fact I do not recall ever having seen him there.

Klüber and – soon after my arrival – I myself, had the use of simple living-cum-sleeping rooms in the Great Refractor. It meant that I could stay on the Hill during the week, and at weekends go home to Berlin which could be reached easily on the S-Bahn (fast train) which connected the city with Potsdam. There was also in the same building a large room where the younger members of staff and guests could have lunch, brought up in covered metal containers from a restaurant in Potsdam. The communal lunch, eaten under the gaze of a large portrait of Sir William Huggins, provided a pleasant opportunity for conversation and social contact. I recall discussions about French literature with Wurm who was an ardent fan of Balzac and possessed all his works in the original. At lunchtime also, we could enjoy walks in the surrounding forests or play tennis in the Observatory grounds.

8 THE ASTROPHYSICAL OBSERVATORY

After two years at the Einstein Turm I was offered a permanent post on the staff of the Astrophysical Observatory, occasioned by the appointment of Friedrich Becker to a Chair at Bonn. The programme which I took over from Becker (who became a very special friend) – and into which he initiated me before he left – was the Potsdam Spektral Durchmusterung, the spectral classification of southern hemisphere stars from objective prism spectra on photographic plates taken at the Potsdam Observatory's station at La Paz, Bolivia. The purpose of the programme was to extend classification to fainter stars than were included in Harvard's Henry Draper Catalogue which reached magnitude 8 or 9. The region of sky involved covered 91 of Kapteyn's Selected Areas, observed with a 30-cm astrograph which operated for this single purpose from 1926 until 1929. Becker had spent a long time in La Paz obtaining these spectra. Rolf Müller, astronomer son of Ludendorff's predecessor, was also absent in South America when I first came to Potsdam.

My work consisted in examining the objective prism spectra, which had a dispersion of 180 Å per mm, in a stereocomparator, assigning to each star a spectral type and measuring the star's position and magnitude from the companion direct vision plate in the comparator. The project was regarded as a major piece of astronomical research. Visitors to the Observatory were often brought along to watch the work in progress: I remember Herzsprung being surprised at my being able to classify spectra as faint as 13 magnitude. A necessary task was to compare our classification with the Harvard system: they agreed well so that the Potsdam results could be readily converted to the HD system. My share in this enterprise (24 of the Selected Areas) was published by the Astrophysical Observatory in 1935.

A companion Spectraldurchmusterung for the northern sky was being carried out at the Hamburg-Bergadorf Observatory, using plates obtained at that Observatory, under the direction of Arnold Schwassmann, and I travelled to Hamburg more than once to consult with him and to compare and maintain standards. In Hamburg I met, among others, Bernhard Schmidt, the designer of the Schmidt telescope.

Though the spectral classification programme was my principal duty, I was left plenty of time for other research according to my own inclination. I obtained objective prism spectra of very faint objects with the Observatory's 12-inch Schmidt camera – acquired before my time and attached to the old Carte du Ciel refractor – with a prism giving a dispersion of 150 Å per mm. The refractor itself was not in use, but the burdensome work of the international Carte du Ciel programme, initiated in 1887, was still going on under Dr Münch. In fact it was never completed.

My post at the Observatory brought the bonus of very pleasant living quarters, a 'bachelor pad', in the Assistants' house (Figure 8). Herr Strobusch, the head of the Observatory's workshop had an apartment in the same house. My other neighbour was Wilhelm Becker, younger brother of Friedrich, appointed somewhat later.[8]

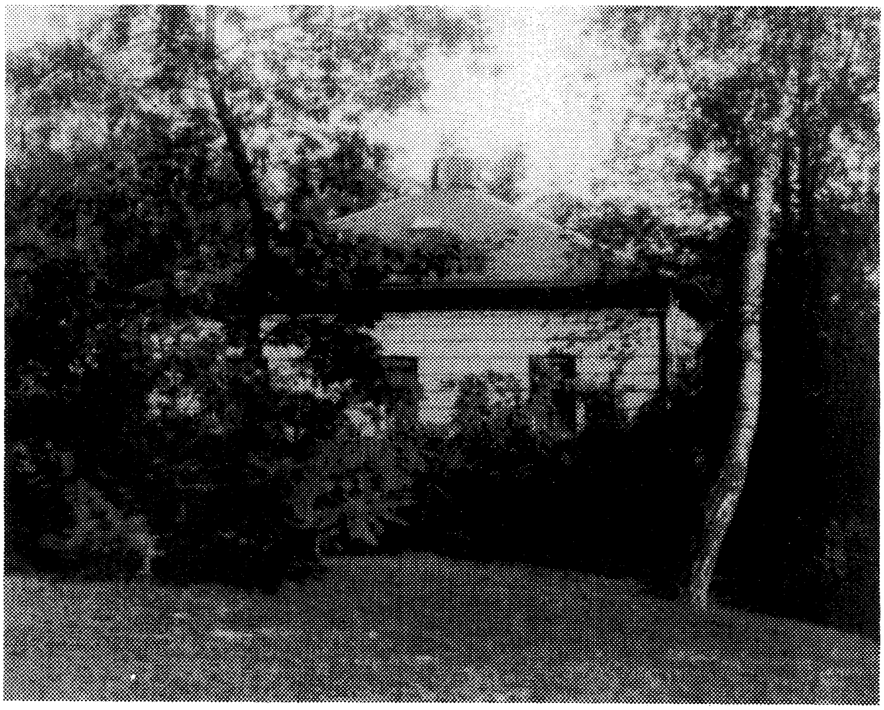

Figure 8. The Assistants' House at the Potsdam Observatory

The senior members of the staff – as in all large observatories in that era – had official residences in the grounds. Professor Ludendorff, his second-in-command Professor Eberhard, and Professor (Baron) von der Pahlen occupied single houses. Drs Grotrian and Hassenstein lived in the large house originally built for Vogel, now divided into two apartments. Including their families, there was therefore quite a sizeable community.

I greatly admired Professor Ludendorff as a scientist. He was also very kind to me on a personal level, and welcomed me into his family for social occasions.[9] I was equally welcome in the home of Baron von der Pahlen where I met many of the Russian emigré circle, and also in the Grotrians'.

Outside Potsdam I met many other astronomers at meetings arranged by Professor Hans Kienle in Göttingen where they were engaged in a pioneering programme in stellar spectrophotometry. I took a great interest in this work which I discussed in a review article in the Supplement Volume of the *Handbuch der Astrophvsik,* edited jointly by Ludendorff and Eberhard. I also had an interesting friend in Robert Henseling, a serious amateur astronomer with whom I co-edited the magazine *Die Sterne* (which still flourishes), a most agreeable task.

During my time there were also meetings of the Astronomische Gesellschaft (The German Astronomical Society) which I attended, in Bern and in Göttingen. The latter, in 1933, was the first at which certain members appeared in Nazi uniform.

Up to that time, life as a young astronomer in Germany was idyllic.

Notes

1 W C Seitter and H W Duerbeck have made a study of Wirtz's work: see references in Freitag, R.S., 2000. Recent publications relating to the history of astronomy. *Journal of Astronomical History and Heritage*, **3**:59-85.

2 Fisher, E.P. and Lipson, C., 1987. *Thinking about Science.* Norton, New York.

3 Albrecht Unsöld (1905-1995) was a welcome visitor in Scotland. He received a D.Sc. degree *honoris causa* from the University of Edinburgh in 1971, and in 1975 delivered an address at a farewell function for H Brück's retirement. He also had links with Professor D Walter Stibbs at the University of St. Andrews.

4 The fascinating scientific and human history of the Einstein Turm has been recorded by Professor Klaus Hentschel of the University of Göttingen in: Hentschel, Klaus, 1992. *Der Einstein Turm*. Spektrum Akademischer Verlag Heidelberg; Hentschel, Klaus (tr. Hentschel, Ann M.), 1997. *The Einstein Tower*. Stanford University Press, Stanford.

5 E F Freundlich (1855-1964) was obliged to leave Germany in 1933. He was eventually appointed to a Chair of Astronomy in the University of St. Andrews, Scotland.

6 H von Klüber (1901-1978) moved to Cambridge in 1949.

7 D A Jackson (1906-1982). Obituary: *Biographical Memoirs of Fellows of the Royal Society*, **29**:269-296 (1983).

8 Steinlin, U., 1982. *Extraprint of the Astronomical Institute of Basel.* This publication records a celebration of Wilhelm Becker's 75th Birthday in July 1982 in Basel, with greetings from former colleagues including his brother Friedrich, A Unsöld, H Brück and others.

9 Ludendorff (1873-1941) died during the Second World War. H Brück, then living in Britain, wrote his Obituary Notice in *Monthly Notices of the Royal Astronomical Society*, **102**:78-79 (1942).

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Nineteenth-century longitude determinations in the Great Lakes region: government-university collaborations

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Abstract
The longitude problem – determining geographic position with precision on land or at sea – was one of the greatest scientific problems of all time. Yet, this fascinating history was virtually forgotten until 1993 when William J H Andrewes at Harvard University organized an international symposium and Dava Sobel wrote her best-selling book *Longitude* (1995). But, this recent attention stopped short of chronicling the important contributions made by nineteenth-century astronomical observatories in determining the longitude across America. University observatories collaborated on longitude determinations with government agencies such as the United States Lake Survey to enable them to perform accurate surveys of land and coastal areas. This research provides the historical context of nineteenth-century longitude determinations in America. Specific examples and details are drawn from Great Lakes longitude determinations performed through collaborations between the U. S. Lake Survey and academic astronomers at the Hudson Observatory at Western Reserve College, Harvard College Observatory, Hamilton College Observatory, and the University of Michigan Detroit Observatory.

Key words: *longitude, telegraph, United States Lake Survey, United States Coast Survey, Detroit Observatory*

1 INTRODUCTION

In 1993, Harvard University hosted an international symposium on longitude, which was attended by 500 people from seventeen countries (Andrewes, 1996). This event refocused attention on one of the greatest scientific challenges of all time – the longitude problem. It also prompted Dava Sobel to write her *New York Times* best-selling book, *Longitude* (1995), which makes accessible to the layperson the fascinating history of the longitude problem in all its scientific detail.

In the concluding remarks at the Harvard symposium, one of the speakers provided a stunning demonstration of the advancement of scientific technology over the last 150 years. He pulled out a pocket-sized Global Positioning System (GPS) instrument, and after the push of a button, announced the exact latitude and longitude of the position he occupied at the podium. It was not always this easy. The longitude problem challenged the most eminent scientists from the very beginnings of navigation at sea until the 1870s, by which time longitude was as easily determined as latitude, facilitated by the electric telegraph, the chronograph, and other scientific advancements.

By the twentieth century, the history of the longitude problem had become obscure. The Harvard symposium placed the longitude problem once again in the international spotlight, but it stopped short of chronicling the important contributions made by nineteenth-century astronomical observatories in determining longitude across America. It was nineteenth-century longitude determinations that permitted accurate surveys of land and coastal areas.

The discovery by the author in 1996 of 164 chronograph data sheets at the University of Michigan, spanning the years 1860-1901, provided invaluable primary source material and triggered a great curiosity that led to this in-depth examination of nineteenth-century longitude determinations in the Great Lakes region (Figure 1). The chronograph data sheets contain meridian circle telescope observations and clock signals recorded at the University of Michigan Detroit Observatory,[1] located in Ann Arbor. The collection appears to be complete, beginning with the earliest chronograph data sheets created in 1860 when the University of Michigan purchased its first chronograph, and ending in 1901, at which point the chronograph likely become antiquated, falling out of use.

Figure 1. Great Lakes Region circa 1823 by F Lucas, Jr., Baltimore, Maryland, B T Welch, engraver (Courtesy: William L. Clements Library, University of Michigan).

This research presents the historical context of nineteenth-century longitude determinations, and the specific details of Great Lakes longitude determinations made between 1858 and 1869 by the United States Lake Survey in collaboration with academic observatories. University and college participation included the observatories at Western Reserve College in Hudson, Ohio; Hamilton College in Clinton, New York; Harvard College in Cambridge, Massachusetts; and the University of Michigan in Ann Arbor.

2 THE LONGITUDE PROBLEM

The British Parliament established a prize in 1714 of £20,000, to be awarded to the person who could solve the longitude problem. Longitude and latitude are the critical co-ordinates of descriptive geography, which are needed to determine position on land or at sea. Longitude became a great concern to England and other European countries that relied on ships to transport people and goods, because without an accurate means of determining longitude at sea, many vessels went off course and experienced costly delays or were tragically lost. Determination of latitude was easily performed using a sextant or other instrument to measure the angle between the horizon and the Sun or the pole star, thereby establishing the ship's distance from the equator. Determination of longitude, however, was a far greater challenge.

It was expected that an astronomer would solve the longitude problem, largely because astronomical science was employed for related determinations, such as latitude. But, it was actually a clock-maker named John Harrison who was the successful contestant, although he struggled for decades before his invention received the recognition it deserved. Harrison developed a marine timekeeper, a very reliable clock capable of maintaining an accurate rate at sea by its ability to compensate for the pitch and roll of the ship, dramatic changes in temperature and humidity, and other challenging environmental conditions that other clocks could not withstand. Although Harrison spent 40 years obsessing and doing battle to have his invention officially recognized, his fourth marine timekeeper, which he completed in 1759, was eventually awarded the coveted prize. Harrison's precise timekeeper led to the development of the marine chronometer, which revolutionized navigation around the globe.

3 A NATIONAL OBSERVATORY

Astronomy was considered to be the science of the elite in the early decades of Colonial America. Many prominent men, and some women, owned telescopes and pursued astronomy primarily as a hobby. President John Quincy Adams' interest in astronomy manifested itself as a personal resolve to remove the control of time from nature, as determined by the sundial and the almanac, and place it under the control of educated scientists and the government. But, his idea was ridiculed, and his phrase "light-houses of the skies" was used to mock his efforts to establish a national observatory, because the United States Coast Survey was the priority in the 1820s. The uncharted US shoreline was treacherous, claiming many vessels, lives, and valuable goods. A comprehensive survey of the coast was needed to provide accurate charts for safe navigation.

Yet, Adams continued to press for a national observatory. He cautioned against reliance on European observatories, which numbered in excess of 130, and said "... are we not cutting ourselves off from the means of returning light for light, while we have neither observatory nor observer upon our half of the globe, and the earth revolves in perpetual darkness to our unsearching eyes?" (Jones and Boyd, 1971:36). In Adams' view, "There is not one study in the whole circle of the sciences more useful to the race of man upon earth, or more suited to the dignity of his destination as a being endowed with reason, and born to immortality, than the science of the stars... The history of Astronomy has been, in all ages, the history of Genius and Industry, in their blazing light and untiring toil, patronized by power." (*Centenary of the Cincinnati Observatory*, 1944:27).

Nearly two decades passed before Adams' vision for a national observatory was achieved. Small steps helped to clear the way for progress. One early step was the creation of a small astronomical observatory known as the dépôt of charts and instruments. The dépôt was quietly set up by Lieutenant Charles Wilkes of the Coast Survey near Capitol Hill in Washington in the early 1830s, and used primarily to rate chronometers for the Navy's fleet of ships. Astronomy had, therein, gained a higher national priority because of its utility to the Coast Survey.

West Point Observatory was established in 1839, and the following year, Sears C Walker opened the Philadelphia High School Observatory. In 1843, Ormsby M Mitchel opened the Cincinnati Observatory. At Mitchel's invitation, John Quincy

Adams, despite his advancing age and fragile health, made the long journey to Cincinnati to lay the cornerstone at the building's dedication. He would not miss this opportunity to celebrate the "... perseverance to accomplish what [he had] promised." (*Centenary of the Cincinnati Observatory*, 1944:20). Finally, in 1844, a National (Naval) Observatory was established at Washington, just four years before Adams died. Academic observatories began to appear, as well, including Williams College (1836), Western Reserve College (1838), and Harvard College (1839).

4 THE UNITED STATES COAST SURVEY

By 1847, the United States Coast Survey reported in the astronomical journal *Sidereal Messenger* that it had achieved resounding success:

> Within the last five years, a complete revolution has taken place in our country. The great experiment of inducing the people generally, to contribute for the erection and support of institutions devoted to pure science, has been successfully tried, and the results have attracted the notice, and secured the high commendation of foreigners, who once believed such results impossible. (Mitchel, 1848:55).

Prior to the creation of the Coast Survey, charts of the shores and harbours of North America were undertaken by J F W Des Barres, His Majesty's Surveyor-General for the Colonies. Then in 1806, Ferdinand R Hassler proposed a complete navigational survey based upon a uniform system. Hassler, a native of Switzerland who had studied geodesy under the most eminent European scientists, began his career in Switzerland with the triangulation of the Canton of Berne. This prepared him well for his appointment by Thomas Jefferson in 1807 as the inaugural Superintendent of the Coast Survey. Hassler's charge was to chart the nation's coasts and its land formations for the safe navigation of ships. At that time, on average, three hundred vessels were annually wrecked along the Atlantic Coast (The Coast Survey, 1879:520). If a ship captain's determination of longitude was off by even one second, this was significant: at the equator, one degree of longitude is equivalent to about 111 kilometres (exactly 60 nautical miles), so, one second of longitude is equal to about 1.85 kilometres (exactly 1 nautical mile). Over the course of a lengthy transatlantic passage, a ship could find itself seriously off course. Navigation and surveying required great precision.

Unfortunately, the War of 1812 and other factors caused a lapse in the Coast Survey's surveying efforts. The Coast Survey work recommenced in 1832. During the period of neglect, the distinguished civilian hydrographers, Edmund W Blunt and his son, of New York, provided information to ensure the safe navigation of ships (Loomis, 1879:507).[2] Civilians continued to make observations for the government after the Coast Survey was fully operational. William Mitchell and "his assistant," (who was, no doubt, his daughter, Maria Mitchell, who now figures prominently in the history of astronomy), made important observations of Moon culminations and meridian transits at Nantucket, Massachusetts (Davis, 1851:11). From 1832 onward, the Coast Survey was active in making contributions to science, including studies of magnetism and sea currents. Ferdinand Hassler died in 1843 and was succeeded by Alexander Dallas Bache, a great grandson of Benjamin Franklin and nephew of Vice President of the United States Alexander Dallas.

Explorations of the South Seas were launched in 1838, led by Lieutenant Wilkes. These explorations refocused attention on the utility of astronomical observations. The heavens co-operated, too, by captivating public attention with spectacular displays of meteor showers and awesome comets – their long tails blazing across the sky. Comets were heralded by the educated as opportunities to expand knowledge, but some were superstitious that comets might be "... forerunner(s) of pestilence, famine, or some other dreadful calamity." (Watson, 1861:vii). Gradually, astronomy became more accessible by the general public, and with this change, came a wider acceptance of astronomical science (Bruce, 1987:101).

5 LAND SURVEYS

Knowledge of astronomy was brought to America by the first explorers, because astronomical methods were essential to navigation. Astronomical methods also had utility to the early surveyors. The burgeoning emigrant population prompted territories to initiate public surveys so that the land could be sold. In the Michigan Territory, a public survey began in 1815.

Cartographers and surveyors needed accurate co-ordinates to create geographical and navigational maps, yet no reliable means existed to accurately determine the longitude. In recognition of the problem, Congress adopted in 1785 the Governmental Land Surveys' system of dividing land, called the "Rectangular System." Following this plan, an arbitrary line was established in the Michigan Territory in 1815 to serve as the principal meridian line. It extended due north from the mouth of the Auglaize River, a branch of the Maumee River in Ohio, to St. Mary's Falls at the northern point in the Upper Peninsula. A baseline was also established, located to intersect the meridian line along the northern boundary of Wayne County, running due west across the Michigan Territory as the northern boundary of a line of other counties, across to Lake Michigan (Figure 2). These co-ordinates served as the points of reference for all future triangulation surveys of Michigan. Comparable meridian lines and baselines were established for other states and territories.

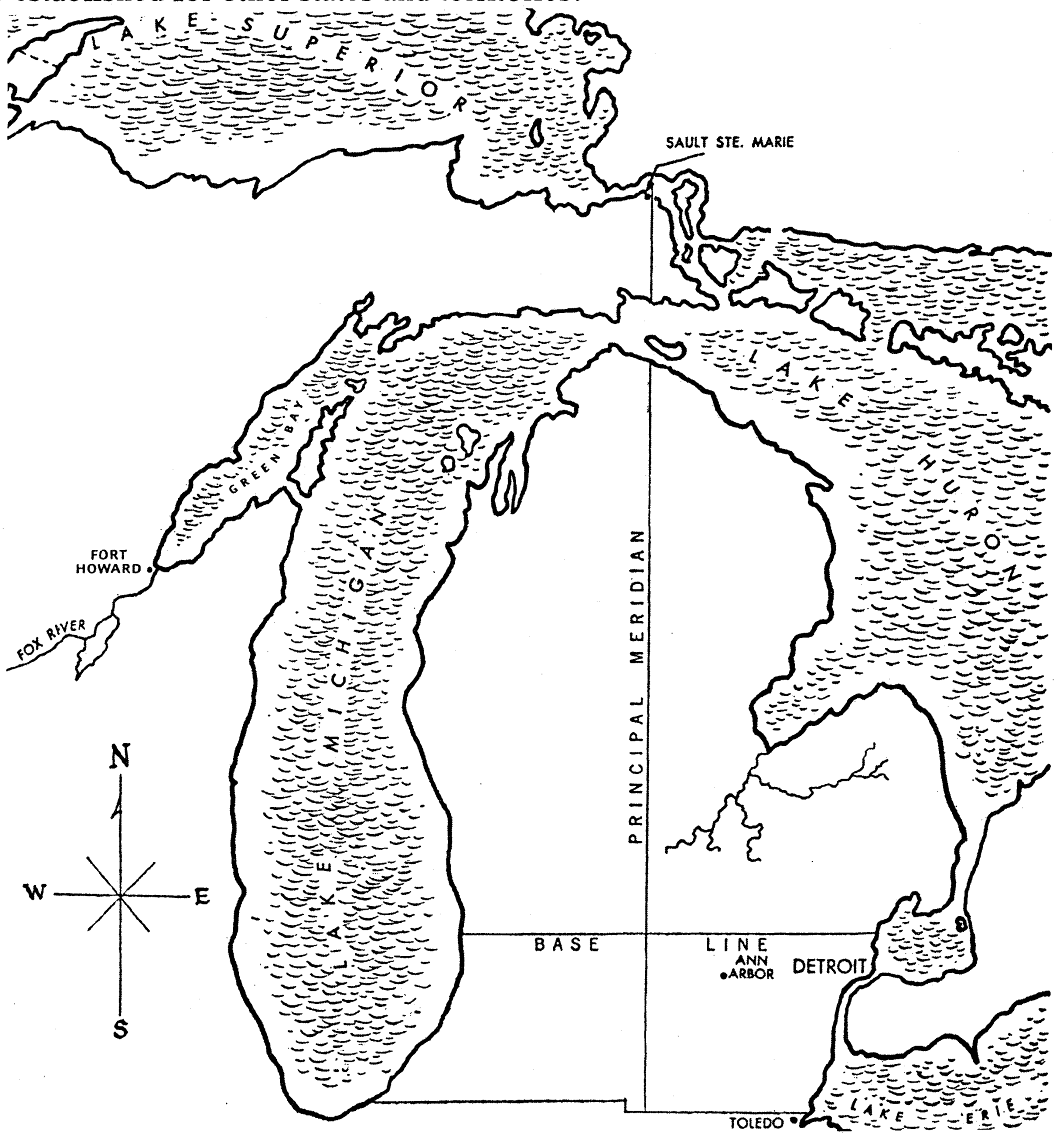


Figure 2. Baseline and meridian line established for Michigan in 1815 (adapted from Bald, 1954:152).

As railroads and canals were established across the United States, and the land became settled, the need for accurate land surveys became more critical. Precision land surveying was very important to railroads in acquiring land to lay down track. Without proper surveys, property disputes could subsequently arise, with serious consequences if tracks had to be moved. When the need arose to string wires across the country for the electric telegraph, the clear stretches along railway beds served admirably.

Early surveys were often grossly inaccurate, in some cases misrepresenting the position of cities by 4.8 kilometres (3 miles) or more, owing to the imperfection of the instruments used, the presence of iron deposits that interfered with compass readings, and the "... ignorance, carelessness and dishonesty ..." of some surveyors (Farmer, 1901:302). The solar compass (Figure 3), which was invented by William Austin Burt[3] of Michigan (see Burt, 1844), was patented on 1835 February 25. It helped to alleviate the interference of iron ore deposits on the accuracy of the compass needle. The solar compass, through the ingenious use of the Sun's rays to determine the exact position of a north-south line, made it possible to conduct accurate surveys in areas where the presence of minerals made the conventional compass useless. Geologist Bela Hubbard said of his use of the solar compass for surveys of Michigan's Upper Peninsula in 1845:

> This accuracy has been attained by the exclusive use, by all the parties, of "Burt's Solar Compass," an instrument too well known to need more than a bare allusion, but the great value of which has been more than fully confirmed during the surveys of the past season.... It seems difficult to imagine how the lands could have been run with the ordinary compass. (Burt, 1985:70).

Sir John Herschel commended the invention in 1851 after it had been perfected the previous year. The solar compass was also recognized in 1851 with a medal from the Franklin Institute and a prize medal at the Great Exposition at the Crystal Palace in London.

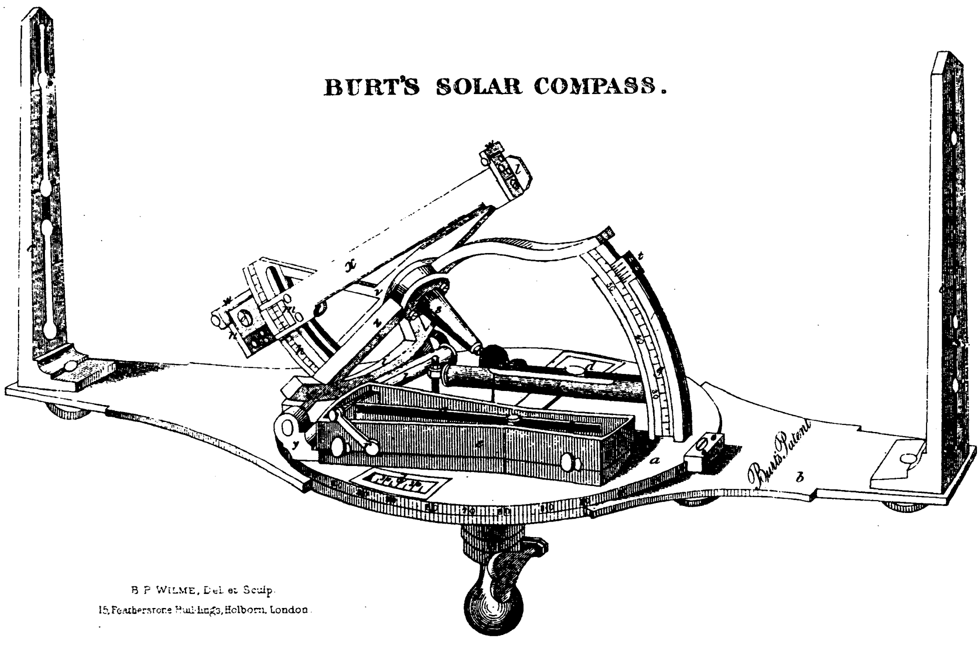


Figure 3. Burt's solar compass was invented in Michigan in 1835 (after Tuttle, 1873:517).

Even with the benefit of the solar compass, surveying work was exceptionally difficult and dangerous, pushing men to the limits of their endurance. In 1847, with a solar compass in hand, Henry Wiltse, a U.S. Topographical Engineer, led his surveying party through the Lake Superior territory in Wisconsin. He later recounted the details of the challenges and privation:

> ... the men were 'packed' with the utmost limit of their strength, and yet each member of the party was restricted to the clothes upon his back, and a single blanket, that they might be able to carry the greatest amount of provision, which was made to consist of pork and flour alone.... During four successive weeks there was not a dry garment in the party, day or night. The work was done in the long hot days of June and July. Consider a situation like the above, connected with the dreadful swamps through which we waded, and the great extent of windfalls [trees prostrated by the wind] over which we clambered; the deep and rapid creeks and rivers that we crossed, all at their highest stage of water; that we were constantly surrounded, and as constantly excoriated by swarms, or rather clouds of musquitoes [sic.], and other still more troublesome insects; and, consider further, that we were all the while confined to a line, and, consequently, had no choice of ground; that we were forced to follow that line wherever and through whatever it chanced to carry us, and you can form some idea of our peculiar, if not suffering, situation. (State Historical Society of Wisconsin, **IV**:1859:362).

It was important to get the job done correctly the first time, because neither man nor beast would willingly volunteer to repeat such an arduous ordeal.

6 LONGITUDE DETERMINATIONS IN AMERICA BEFORE THE TELEGAPH

The establishment of baselines and meridian lines made it possible to conduct land surveys by triangulation, but the use of arbitrary lines held limited value in the absence of accurate longitude. Prior to the electric telegraph, explorers, cartographers and agencies such as the United States Coast Survey and United States Lake Survey employed various astronomical methods to determine longitude, even though they recognized that the methods were imprecise. Methods of determining longitude included observations of eclipses of Jupiter's satellites, instantaneous signals, celestial phenomena, and lunar distances.

6.1 Jupiter's Satellites

Longitude could be determined in the field and at sea by observing eclipses of Jupiter's satellites. The time of the exact instant of disappearance and reappearance of each satellite could be checked against an ephemeris to calculate the difference between local time and the Greenwich time provided in the ephemeris. Complicated mathematical reductions were also needed. This method required clear skies, the proper equipment, and a significant investment of time, the combination of which was difficult for early explorers to achieve in the field. Even with the best equipment and conditions, the method was imprecise. Eclipses of Jupiter's satellites were an uncertain measure due to the considerable size of the satellites and their tendency to disappear and reappear gradually rather than instantaneously.

Meriwether Lewis, for the 1803 Lewis and Clark expedition through the Louisiana Territory to the Pacific Coast, carried the best chronometer available at the time. But, timekeepers were not yet sufficiently reliable, and the rigours, the elements, and the temperature extremes to which Lewis' chronometer was subjected during his journey rendered the timepiece inadequate for precision longitude determinations. Ships at sea typically carried several chronometers for comparative purposes, the time of which they regularly checked using astronomical instruments. In contrast, Lewis was able to carry only one timepiece and portable astronomical equipment, and there was little time for extensive observations and complicated mathematical reductions.

6.2 Instantaneous Signals

Several experimental means were used in the early nineteenth century to determine distances and positions by sending instantaneous signals. In 1843, as part of the Canadian survey of the Bay of Fundy, under the direction of Captain H W Bayfield of the British Royal Navy, rockets were detonated to determine times and positions. The ship *Columbia* in Bedford Basin set off rockets that were observed by the *Gulinare* in Halifax Harbour, a distance of 40 kilometres (25 miles) (Thomson, 1966:189). The United States Lake Survey used rockets and also employed "powder-flashing" in longitude work done at Lake Superior. The flash from ignited gunpowder could be observed from a distance of about 18 kilometres (30 miles) (Comstock, 1882:28). Signals were given from distance intervals of about 1.2 kilometres (2 miles) by means of a "delicate wand" or flag during daylight hours (Davis, 1851:11). Sunlight reflected off a small mirror, or heliotrope,[4] could be seen at distances up to 280 kilometres (175 miles) under the right conditions. Interestingly, mirrors were also used to telegraph messages using Morse code signals (Comstock, 1882:18). Morse code signals were also exchanged between ships within 0.3 kilometres (½ mile) of one another (Maver, 1904). One ship struck a hammer against a bell positioned below water level, while a second ship received the signal by listening through an ear piece attached to a trumpet-shaped tube that extended below the water (Figure 4). At night, a lamp was used to project a beam of light through a perforated board, which was visible at a considerable distance (Davis, 1879:514, 520). The various instantaneous signals used in establishing distances and positions were thought to provide a high degree of accuracy, though their utility was limited to short distances.

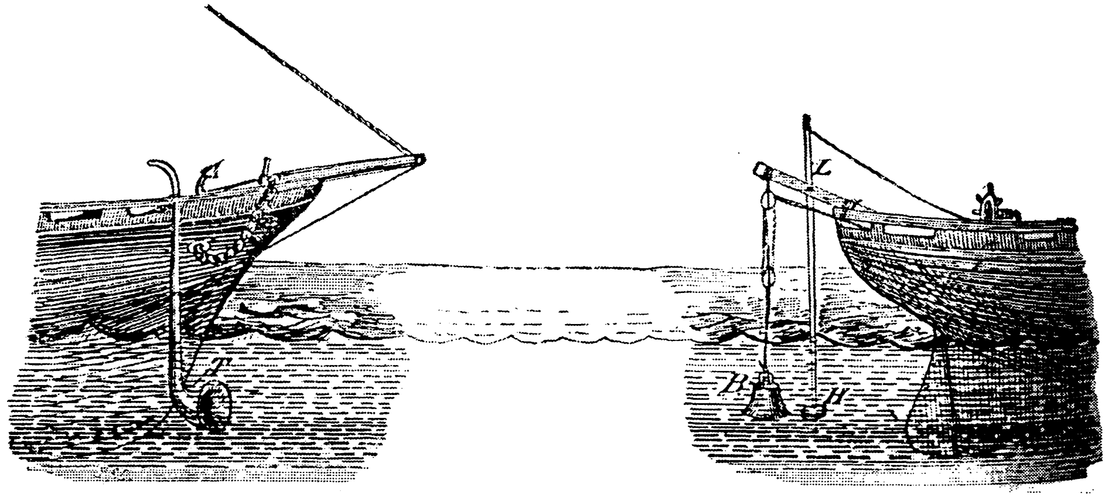


Figure 4. Ships communicated by sending Morse code signals underwater. Sound was produced by the stroke of a hammer (*H*) against a bell (*B*) and received by ear through a trumpet (*T*) which was placed below the water line (after Maver, 1904:286).

6.3 Celestial Phenomena

Longitude determinations were sometimes performed through observation of instantaneous celestial phenomena such as shooting stars or bursting meteors; solar and lunar eclipses; and occultations of the stars and planets by the Moon. Such phenomena were visible at the same absolute moment by observers positioned anywhere across the globe, although the local time of observation varied by location. Each hour of difference in local time corresponded to a 15-degree difference in longitude. But, these observational methods held flaws. Meteor events were difficult to identify at remote stations. Solar and lunar eclipse observations tended to be inaccurate due to the imperfect definition of Earth's shadow. And, occultations of stars and planets by the Moon were troublesome because the Moon's parallax is not absolute for all observers – it can vary depending upon the observer's location. These methods required numerous, repeated observations in order to reduce the amount of error (Chauvenet, 1891, I:314-420; Loomis, 1879:305-343; Olmstead, 1854:124).

6.4 Method of Lunar Distances

The method of lunar distances served for several centuries as the most reliable means of measuring longitude. The method was first introduced in 1514 by Johann Werner of Nuremberg, and was refined over subsequent centuries. Longitude and time are rooted together with Earth's rotation on its axis, so that the difference in longitude between two positions can be found by comparing the local time of these two points. Timepieces were not accurate enough on land nor at sea to serve reliably in longitude determinations. Werner and others observed that the Moon's motion serves as a sort of clock, with the Moon being the hand of the clock and the Sun, stars and planets being the markers on the dial. In the course of a year, as Earth revolves around the Sun and the Moon around Earth, the angular distance between the Moon and selected stars varies with the passage of time. Furthermore, the angular distance between the Moon and the Sun varies in the course of a lunar month, as the Moon progresses through its phases. These factors make the changing lunar distance a useful measure of time. Yet, what appears to be simple in principle is mathematically complex. The calculations must make allowance for atmospheric refraction and for lunar parallax, because observations are made from Earth's surface rather than from Earth's centre. Further, the accuracy needed for longitude measurements requires an instrument of great precision, an accurate star catalogue, and accurate predictions several years in advance of the motion of the Sun, Moon, and stars. Publication of an annual ephemeris (almanac) based on the Greenwich meridian, which commenced in 1767, simplified the process of deducing Greenwich time (Howse 1996:150-161; Chauvenet, 1891, I:393-395). The method of lunar distances gradually fell out of use as chronometers became more accurate on land and at sea.

7 CAMBRIDGE, MASSACHUSETTS: 'THE AMERICAN GREENWICH'

By the early 1840s, several observatories were established in America. The Harvard College Observatory, established in 1839, was located in Cambridge, Massachusetts, and was often referred in the USA to during the nineteenth-century as the 'Cambridge Observatory'. It was situated close to Boston's shipping port, which was convenient for chronometric expeditions between American and England. William C Bond, director of the Harvard College Observatory, had an office for his chronometer business, Wm. Bond & Son, located near Boston harbour, from which he established a direct telegraph connection to the Harvard observatory clock. This telegraph connection eliminated the need to transport chronometers overland from Boston harbour to the observatory at Cambridge, thus avoiding any possibility of error the journey might have introduced (Gould, 1869:3).

As early as 1845, the Harvard College Observatory was regarded as "... the best determined position in America ..." from which the longitude of all other principal positions in the United States was determined (Bailey, 1931:104). Over the course of many years, Bond determined the longitude of his Observatory through repeated observations of eclipses, transits, occultations, and Moon culminations. His longitude was recognized in 1845 for its reliability by the American and British Commissions leading the Survey of the Northeastern Boundary. Bond's longitude determinations proved so accurate that only slight modifications were later needed to correct for data obtained on subsequent chronometer expeditions, and from eventual telegraph and radio longitude determinations.

During the summer of 1849, the longitude of Harvard College Observatory was repeatedly checked using chronometers carried aboard ships that crossed the Atlantic Ocean between England and Boston. Initially, chronometers carried aboard the Cunard line of steamers were utilized for this purpose (Davis, 1851:27). When this commercial means was determined to have reached the limits of its accuracy, chronometers were specially prepared and rated by Bond for the purpose of determining the longitude.

Bond's chronometric expeditions culminated in 1855 with six transatlantic voyages carrying as many as fifty-two chronometers together aboard ship between Cambridge, Massachusetts and Liverpool under the care of Sydney Coolidge, a volunteer assistant at the Harvard College Observatory (Gould, 1869:5; Bailey, 1931:51). Coolidge also made the requisite transit observations both at Cambridge and Liverpool. Coolidge, who was the grandson of Thomas Jefferson, served the Harvard College Observatory without pay from 1853 until 1860, at which time he joined the Civil War effort.[5] The mean rate of the clocks Coolidge transported from Europe was used to check the distance between Cambridge, Massachusetts and the Liverpool observatory, the longitude of which from Greenwich was precisely known. It was this rigorous series of voyages between England and Boston that earned international confidence in Bond's longitude.

Cambridge thus became the zero-point of longitude on the American continent. The longitude of locations in America was thereafter determined based upon the longitude of Cambridge, Massachusetts, which came to be considered the 'Greenwich of America'. Longitude was expressed in terms of distance west from Greenwich, or west from Cambridge, to which was added the distance between Cambridge and Greenwich. Gradually, observatories across the United States determined their distance from Cambridge, thereby establishing their longitude.

By the early 1850s, longitude determinations of fixed points extended from the Atlantic Coast to the eastern outskirts of the Midwest. Longitude was established between Cambridge and New York (1848), Philadelphia (1849), and Washington (1849). In 1849, the Philadelphia High School Observatory and the Hudson Observatory at Western Reserve College in Hudson, Ohio, collaborated to determine longitudes, a venture that established the first accurate co-ordinates from which territorial and local surveys of the mid-western United States could be referenced. The observatory at Seaton Station, located at Washington, collaborated on the longitude with Savannah, Georgia, in 1851, and with Roslyn Station, near Petersburgh, Virginia, and Charleston, South Carolina, in 1852. Seaton Station and Savannah then connected with the observatory at Amherst College in Massachusetts in 1850 and 1851 respectively. About the same time, a connection established between Washington and the Cincinnati Observatory served as an important step in determining the distance between Washington and New Orleans (André and Angot, 1877:31; Davis, 1851:27; Loomis, 1874; Loomis, 1879:310; Nourse, 1874). These established points of longitude were, over time, linked to other observatories across the country, with the chain eventually extending all the way from the Atlantic Coast to San Francisco. These reference points for longitude were critical elements in the accuracy of North American maps and charts.

8 THE ELECTRIC TELEGRAPH AND CHRONOGRAPH

The conception by Samuel F B Morse of the electric telegraph in 1832 proved to revolutionize the determination of longitude by eliminating much of the error inherent in existing methods. Morse made his first demonstration of the electric telegraph in 1835 at the University of the City of New York, where he was on the faculty. Fellow faculty member, Henry P Tappan, who became the first president of the University of Michigan in 1852, witnessed Morse's practical demonstration of the telegraph with a small group of others.

Controversy over the identity of *the* true inventor was commonplace during this era of scientific discovery, and Morse's discovery was not exempt; his invention of the electric telegraph was hotly disputed. Testimonials were the principal basis for the settlement of such controversies. In 1868, Morse called upon Tappan to write a letter verifying what he had observed regarding Morse's invention. On 1868 February 14, Tappan wrote to his wife while he was away in Berlin to share a transcript of his letter in support of Morse. His letter captures his excitement about scientific discovery, and his thrill in being associated with the men responsible for great inventions:

> It is curious that the painter Fulton should be father of Steam Navigation, and indeed also of Railroads, for the propulsion of vessels on water led to the propulsion of locomotives on land, by steam: and the painter Morse the father of the Electro-magnetic Telegraph. What a change these two inventions have made in the world! How they have carried forward the centuries! And they both owe their inventions to American painters! (Tappan, 1868).

Morse was eventually successful in his lengthy succession of lawsuits, receiving a large fortune in royalties. His invention of the electric telegraph revolutionized the entire world to a degree comparable to the invention of the printing press 400 years earlier (Dibner 1964:1).

The electric telegraph made it possible to connect clocks at observatories located a considerable distance apart. The clocks could then be compared, taking into account the transmission time of a signal over the telegraph wire – the fraction of a second it took the current to pass over the distance between one station and another. The electric telegraph method, when combined with the use of an electric chronograph, made it possible to record with great precision the timing of star transits. Although credit for the invention of the chronograph is debated, between John Locke of Cincinnati, Ohio, and William C Bond of Harvard College Observatory, it was Bond who greatly improved the instrument. His invention of the 'spring-governor' employed a pendulum and a flywheel to ensure uniformity in the revolution of the cylinder (Bailey 1927:38-39). For this invention, Bond was awarded a gold medal at the Crystal Palace Exposition in London in 1851.

The chronograph consisted of a brass cylinder covered with paper, and a pen electrically controlled by a galvanic battery (Figure 5). The cylinder rotated by means of weight-driven clockwork at the rate of one revolution per sidereal minute. Each sheet could record up to two hours of work. Electrical wires were utilized to connect the chronograph to an astronomical clock. Each swing of the clock's pendulum broke the electric current, thereby jogging the pen to record the seconds on the paper in exact

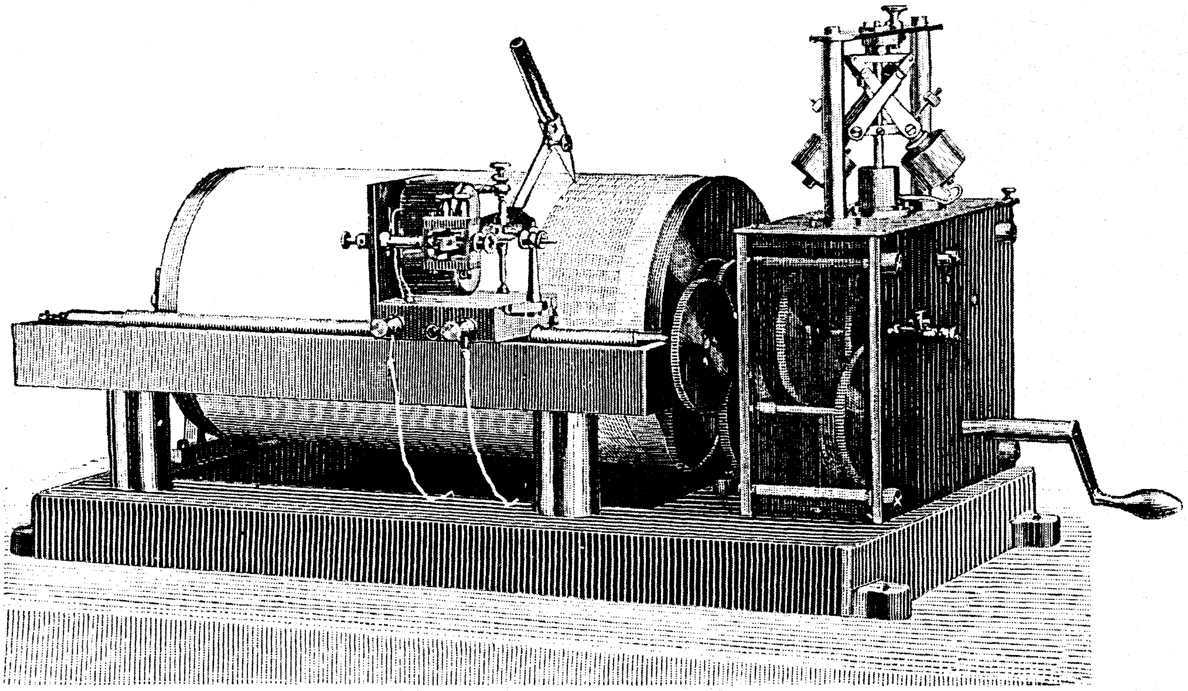


Figure 5. Electric chronograph showing the pen in the process of inscribing data on paper attached to the revolving drum (after Ambronn, 1899:1049).

coincidence with the beats of the clock. The observer, looking through a meridian circle telescope, recorded the transit of a star by pressing a key at the exact instant the star crossed the various wires in the reticle of the meridian circle's eyepiece (see Figure 6). In this way, the precise timing of the passage of a star could be ascertained.

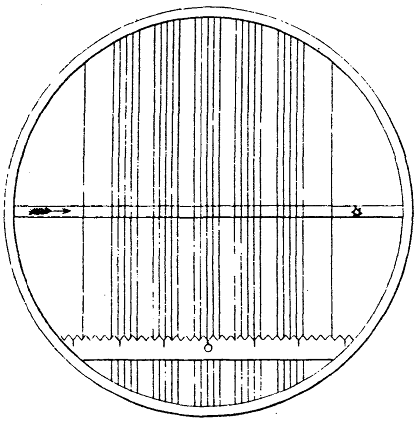


Figure 6. Reticle of a meridian circle telescope showing spider lines, or wires, and micrometer (after Chauvenet, 1891, II:Plate 1, Figure 1).

By comparing data recorded on the chronographs, the distance between two observatories could be determined. If the longitude of one observatory was already known, the longitude of the other could be calculated by determining the distance between it and the known longitude. Sears C Walker of the United States Coast Survey originally suggested this method of determining longitude, utilizing star signals and a chronograph attached to a galvanic circuit to record astronomical observations (Chauvenet, 1891, I:342). The method's growing reputation for great accuracy caught the attention of Alexander Dallas Bache, Superintendent of the Coast Survey, who soon called the chronographic method into use. Walker's method came to be known as the 'American method'. Observers at two stations a distance east and west of each other noted the meridian passage of stars and recorded the time of transit using the clock at the eastern most station. Data from the recorded times of transit were reduced to determine the equivalent distance, thereby arriving at the distance between stations.

Even though Walker's American method of determining longitude had been in use for a decade, in 1858 Captain George C Meade, who had charge of the United States Lake Survey from 1857 to 1861, suggested a change to C A Young of the Hudson Observatory at Western Reserve College in Hudson, Ohio. Young found Meade's modification to be innovative, and the results virtually free of error. Instead of utilizing only one clock at the eastern most observatory to record the time of a star's transit, Meade suggested that two clocks be utilized, one at each observatory (Meade, 1913:211-212).

The electric telegraph was used extensively within Europe to determine the longitude of various locations. In the United States, connections were made between the Harvard College Observatory and other nearby observatories, because the Harvard College Observatory had already determined its distance from the prime meridian at Greenwich. Gradually, connections between observatories were made, from the East Coast to the South, and to the Midwest. An automatic repeater was introduced around 1860, which enabled transmission of telegraph signals beyond the previous limit of about 480 kilometres (300 miles) (Coe, 1993:78-79). The following year, a transcontinental telegraph line was completed, permitting telegraph communication from the Atlantic all the way to the Pacific Coast. As the telegraph stretched across the country, longitude determinations followed shortly behind, by way of St. Louis, Missouri, and Salt Lake City, Utah, to San Francisco, California.

9 THE ATLANTIC CABLE

Another great technological challenge of the mid-nineteenth century was to connect Europe and America by telegraph. Telegraph lines were omnipresent across the United States and Europe. Yet, bodies of water continued to present obstacles to communication. In 1842, Morse devised a means of laying telegraph lines underwater. He spanned New York harbour using a copper wire insulated with hemp soaked in tar pitch and coated with indiarubber (Bright, 1903:16). Ezra Cornell got involved three years later when he laid a cable across the Hudson River to connect Fort Lee with New York. This early technology did not withstand the harsh conditions to which it was subjected, such as ice floes in winter. Experiments with different materials, such as gutta-percha, and various construction techniques were ongoing. The prototypes of the cable grew stronger with each improvement that was introduced.

The great momentum of the spread of telegraphic technology brought with it a widespread desire for international communication. It became clear that a transatlantic telegraph cable was needed. It would be a monumental undertaking. Interest in a transatlantic cable was extensive, and nineteenth-century ambition seemed to have no boundaries. Beyond the utility of determining the longitude, a submarine cable across the Atlantic would connect the continents for personal and business communications, effectively reducing communication time by weeks. In thinking about a transatlantic telegraph cable, there were many unknowns. Would an electric signal travel over such a great distance, and at such depth? What was the terrain of the ocean bed? No soundings had yet been taken of the ocean floor, and the ability to lay a submarine cable depended entirely on the terrain. Perhaps the most challenging question of all was, how would such an undertaking be financed?

New Yorkers Cyrus W Field and Peter Cooper stepped forward to provide the leadership and financial backing that, with the assistance of many others, carried the project forward. World geography determined the route, extending over land and sea from New York to Newfoundland, and across the ocean to Valentia, Ireland. Successful submarine telegraph lines had already been run in Europe across the English Channel in 1851, and between Corsica and La Spezia, Italy, in 1854. Then, on 1857 July 16, the first telegraphic cable was laid across the Detroit River in Michigan. To achieve the durability needed for such a feat, a cable identical to the Atlantic cable prototype was obtained (Figure 7). The Detroit River cable was considered by some to be "... the first really successful submarine telegraph cable laid in any waters." (Farmer, 1884:884-885). These early prototypes helped to guide the refinement of the submarine cable, the construction of which was improved as deficiencies were noted in testing.

The process of laying the Atlantic cable was fraught with problems and setbacks. The first expedition in 1857, and a subsequent attempt in 1858, both failed. But, a

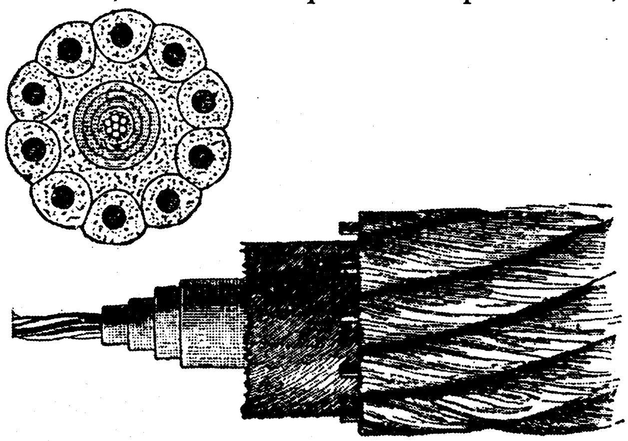


Figure 7. Anatomy of the Atlantic Cable (after Bright, 1903:52)

second attempt in 1858 met with success in August of that year. The nation rejoiced, and Field's hometown, New York City, was the centre of jubilation. Franz Brünnow, director of the Detroit Observatory at the University of Michigan, wrote to George P Bond at the Harvard College Observatory:

> ... as the Atlantic Telegraph is an established fact now, I suppose the Cambridge observatory [Harvard College Observatory] will be the first to make use of it for a more accurate determination of the longitude, if it should ever work well enough for that purpose. (Brünnow, 1858).

Brünnow's scepticism was prescient, because in October, the telegraph signal became weak, and then faded completely. An investigation determined that high voltages had ruined the cable. This was a major disaster, but Field and others were undaunted. Only 732 messages had been communicated over the Atlantic telegraph in 1858 (Abbott, 1934:96), but the great utility of these communications motivated Field and others to make another attempt. The next five years were spent in the total reconstruction of the plans. Field was convinced he could make it work, but in 1865, another attempt failed when the cable broke.

The year before, a separate plan was put into motion to explore the possibility of an overland telegraph that would connect America with Europe by way of San Francisco and the Yukon Territory (known then as Russian America). By this route, the underwater portion of the telegraph cable, across Bering Strait from the Yukon Territory to Russia, would be a distance of only about 65 kilometres (40 miles). The Western Union Telegraph Company provided the capital for the project, and the Smithsonian Institution was called upon to identify a leader for an exploratory mission. Robert Kennicott, an explorer and naturalist from Chicago, was recruited. He had already explored the remote regions of Hudson Bay, and was well prepared for the "... hardship, privation, and isolation." of arctic journeys (Dall, 1895:123), but died during the mission. Other scientists, such as William H Dall, Mark W Harrington, and Marcus Baker,[6] carried on the work, including Kennicott's natural features inventory and collection of animal, plant, and geological specimens.

In 1866 September, there was great jubilation when the two lost ends of the 1865 Atlantic cable were recovered and successfully spliced. The Atlantic Cable was finally complete! Many distinguished officials attended a banquet in Cyrus Field's honour to recognize this great achievement. Congress granted Field a gold medal for his dedication and persistence over the nearly thirteen years of the project. When word of the success of the Atlantic Cable reached Alaska in late 1867 July, the Alaskan telegraph expedition was abandoned. But, the Alaska expedition had generated great interest in the region, and this was one of several factors that influenced the American government to purchase the Alaska territory.

10 UNITED STATES LAKE SURVEY

The idea to undertake a survey of the Great Lakes region was first suggested in 1831 at a meeting held in Detroit, Michigan, but ten years passed before the United States Lake Survey was created in 1841 by act of Congress. The Lake Survey's mission was to prepare charts and take soundings of the north and north-western lakes. Explorers and fur traders had identified a wealth of natural resources in the interior regions of this territory, such as iron ore, coal, limestone, lumber, copper, and other products. The Great Lakes were the principal means of accessing the interior of the continent, but in order to safely enter these waters, navigators needed a reliable source of accurate charts (Unites States Lake Survey, 1939). Accurate charts would enable commerce to proceed in safety.

After a few years at Buffalo, New York, the Lake Survey office relocated in 1845 to Detroit in a building at the corner of Wayne and Congress Streets (Farmer, 1884:918; United States Lake Survey, 1939:1-2, 34). In 1857, Detroit merchant John Hull made available to the Lake Survey at no cost a vacant lot on Washington Avenue near Grand River Avenue. No doubt, Hull found the arrangement advantageous to his business because he alone provided the supplies needed for the Lake Survey's lengthy surveying excursions. A wooden building was erected on this site and equipped for astronomical and magnetic observations (Comstock, 1882:11). Then, in 1865, the Lake Survey relocated to permanent headquarters in Detroit at the junction of Grand River Avenue and Park Place.

Parties of surveyors, up to 200 men in number, were deployed at Detroit from May through October. They had two steamers at their disposal to take soundings of the lakes from the shore to a point 16 kilometres (10 miles) out. The data they collected were used to ascertain the depth of the lakes, and to note any obstructions such as reefs and shoals. Rowboats were used to explore the shoreline, and shore parties travelled inland to survey the terrain. Teams of three men used triangulation methods to determine the accurate location of prominent objects and places on land. During the winter months, data were computed and transcribed for publication, and charts were drafted and engraved. By 1883, the Coast Survey annually sold 6,400 charts (Farmer, 1884:918).

Captain Meade, who had charge of the Lake Survey from 1857 to 1861, was a gifted scientist. His abilities were so admired by Joseph Henry, Secretary of the Smithsonian Institution, that Henry tried to dissuade Meade from taking a military leadership position during the Civil War, fearing that Meade's considerable scientific talents would be lost to the war effort. Henry's pleas were unsuccessful in retaining Meade in his scientific capacity. As history reveals, Meade left the Lake Survey in 1861 when called to duty by General McClellan, whereupon he took command of a reserves group in Pennsylvania. In 1863, he became a national hero by winning the Battle of Gettysburg.

11 GREAT LAKES LONGITUDE DETERMINATIONS

Between 1858 and 1869, numerous university observatories collaborated with the United States Lake Survey on longitude determinations in the Great Lakes region, including the observatories at Harvard College, Western Reserve College, Hamilton College, and the University of Michigan. These invaluable collaborations greatly contributed to the accuracy of navigational charts, maps, and land surveys of the Great Lakes region.

11.1 Sand Point, Saginaw Bay, Michigan, 1858

Captain Meade of the Lake Survey collaborated with academic astronomers in 1858 on the determination of the longitude of Sand Point at Saginaw Bay, Michigan. Topographical engineer Lieutenant Turnbull and assistant James Carr collected observational data of the Moon and Moon culminating stars, and these data were then sent by Meade to George P Bond at the Harvard College Observatory to perform the complicated mathematical reductions (Meade, 1858:4).

11.2 Ann Arbor, Michigan, 1858

It was in 1858 March that the longitude of Ann Arbor, Michigan, was first determined, by Franz F E Brünnow (Figure 8), the director of the University of Michigan's Detroit Observatory, from occultations of the *Pleiades* (Brünnow, 1861:17). Brünnow reported in the scholarly journal he created and edited, *Astronomical Notices*, that he determined the longitude of Ann Arbor to be $26^h\ 4^m\ 0^s$ west from Washington. This was done with the assistance of George P Bond, who provided observations made on 1858 March 19 of occultations of the *Pleiades* (Brünnow, 1861:1).

Henry P Tappan, the University of Michigan's first president, recruited Brünnow from Berlin in 1854 to be the inaugural director of Tappan's new observatory.

Figure 8. Franz F E Brünnow (1821-1891), inaugural Director of the University of Michigan Detroit Observatory, 1854-1864 (Courtesy: Bentley Historical Library, University of Michigan).

Brünnow was the favorite student and acclaimed assistant of the renowned astronomer Johann Encke of the Berlin Observatory. While in Berlin, Tappan asked Brünnow to inspect the 6-inch meridian circle telescope (Figure 9) he had ordered from the firm of Pistor & Martins of Berlin and also the astronomical clock ordered from M Tiede of Berlin, before they were shipped to America. Brünnow had greatly admired the meridian circle, and it later occurred to Tappan that the astronomer might wish to follow the telescope to America.

11.3 Hudson, Ohio ↔ Detroit, Michigan, 1858

Shortly after Meade's appointment as head of the Lake Survey, he was eager to determine the longitude of the Lake Survey's base of operations at Detroit by means of the telegraphic method, because of the method's proven accuracy. To achieve this, he needed to collaborate with an observatory whose longitude was well established by the telegraphic method. Meade desired to undertake this work in 1857, but the instruments required for the observations did not arrive in time. In 1858, with the new instruments in place, he was ready. The closest observatory with a well-established longitude determined by the telegraphic method was the Hudson Observatory at Western Reserve College in Hudson, Ohio. Astronomer Elias Loomis, who founded the Hudson Observatory in 1838, established its longitude in 1849 by telegraphic connection with Philadelphia.

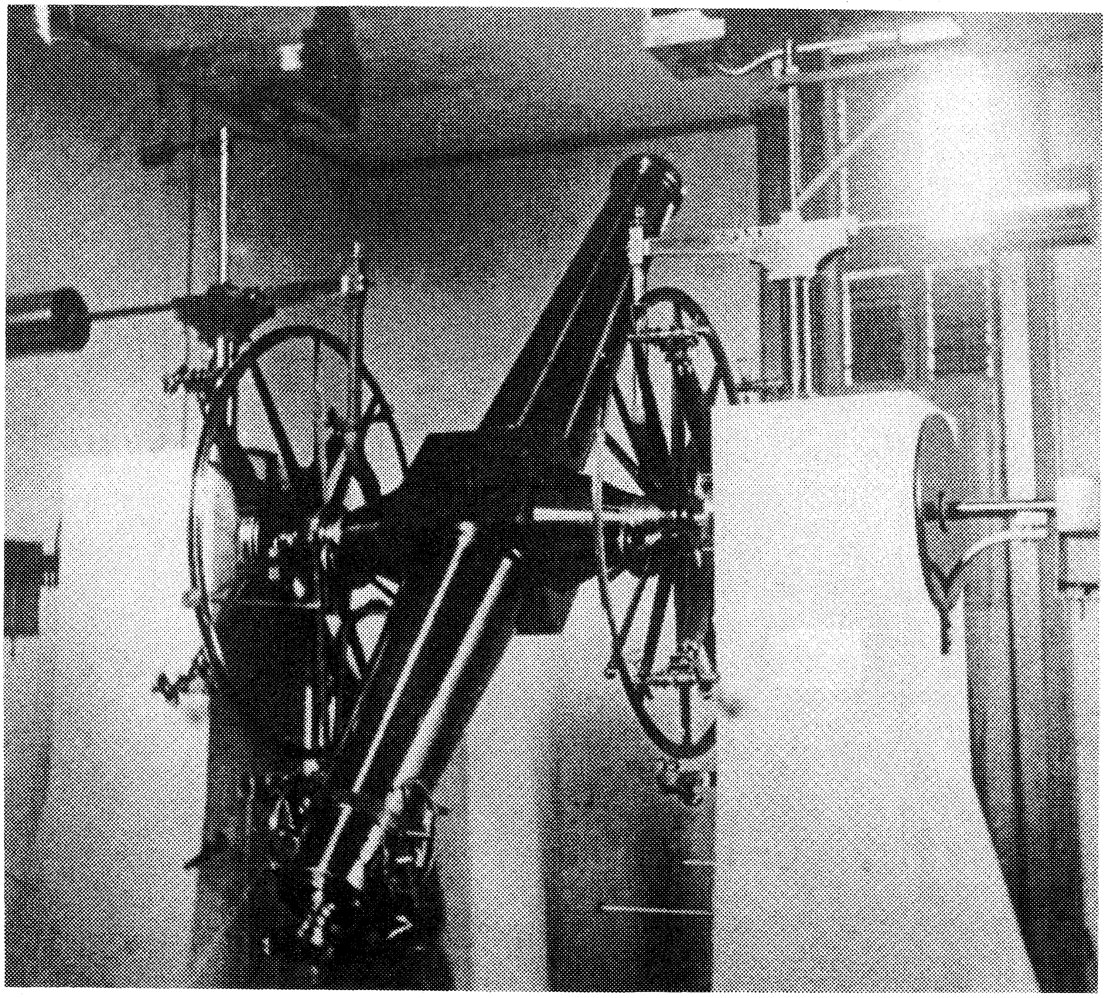


Figure 9. Meridian circle telescope at the University of Michigan Detroit Observatory, made in 1854 by Pistor & Martins of Berlin. Astronomical clock by M Tiede of Berlin is mounted on the limestone clock pier (behind the left circle) (Courtesy: Bentley Historical Library, University of Michigan).

In preparation for the 1858 longitude determination between Hudson, Ohio and Detroit, an arrangement was made with Anson Stager of the Western Telegraph Company for free, uninterrupted use of the telegraph wire after 9 p.m., when it was less busy. Turnbull, the observer in Detroit, recorded his observations using a chronograph, and C A Young at Western Reserve College used a Morse register.[7] The transits of particular stars and their local times were recorded at both stations, and the longitude of Detroit was then determined from reductions of these data. To complete the process, Turnbull easily determined the latitude of Detroit through a series of observations over seven evenings in 1859 April and May using a zenith telescope (Comstock, 1882:11). Meade thus obtained the first accurate determinations of longitude and latitude for Detroit, which would be invaluable to him in establishing survey triangulations in the Great Lakes region.

11.4 Ann Arbor, Michigan ↔ Detroit, Michigan, 1860

In 1860 May, Lieutenant O M Poe of the Lake Survey contacted James C Watson (see Figure 10), Brünnow's assistant at the University of Michigan Detroit Observatory, who had charge of the Observatory during Brünnow's one-year absence as Associate Director of the Dudley Observatory in Albany, New York. Poe desired to check the accuracy of the longitude of the Lake Survey observatory at Detroit, and Watson agreed to help. The method used by Watson and Poe was an exchange of arbitrary signals over the telegraph wire – a method less accurate than use of an electric telegraph and a chronograph. Yet, it was the only method available to Watson in 1860, because the University of Michigan did not yet have a chronograph as part of its astronomical equipment, nor was there a direct telegraph connection to the Detroit Observatory at Ann Arbor.

On the evening of 1860 May 26, Watson was ready as darkness approached. Notebook in hand, he wrote "The weather having cleared up just before dark the following observations were made with the meridian circle." (University of Michigan

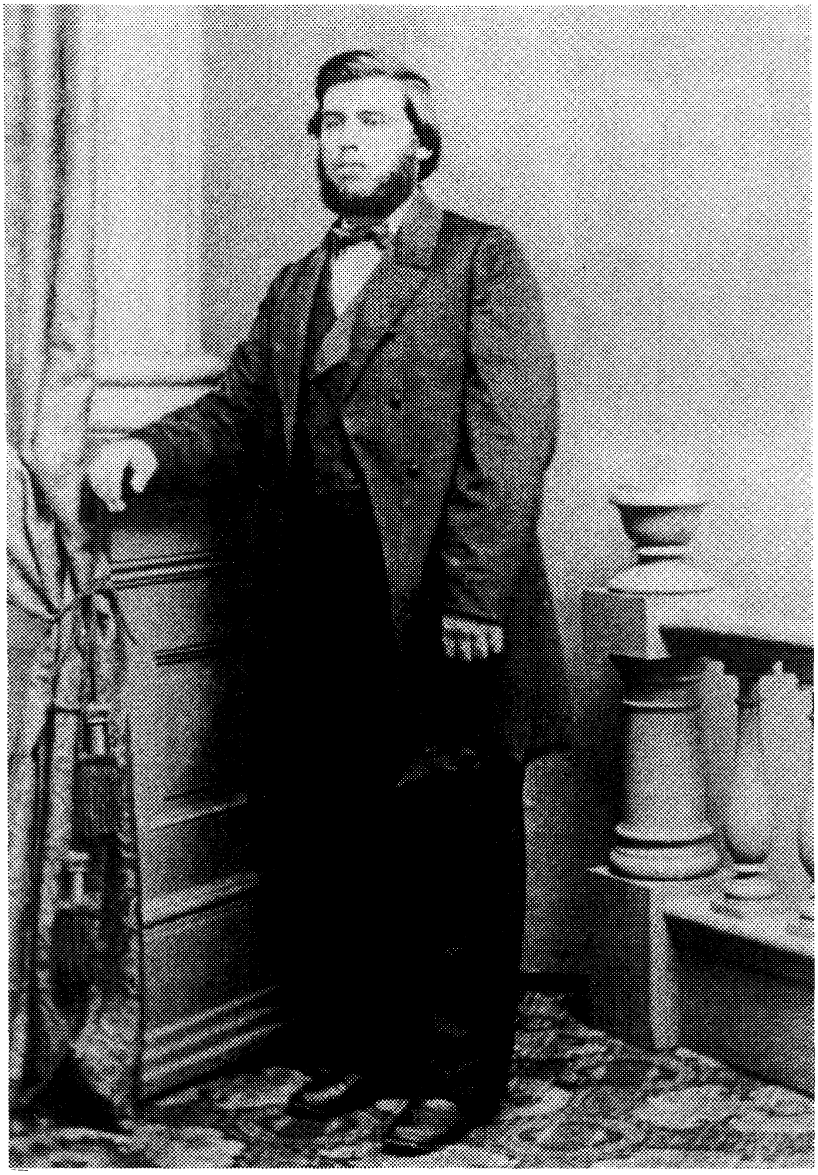


Figure 10. James C Watson (1838-1880), educated at the University of Michigan Detroit Observatory, and director from 1864-1879 (Courtesy: Bentley Historical Library, University of Michigan).

Observatory Records, Box 12). The temperature was 18.4°C (65°F) outside and 19.5°C (67°F) inside the east wing of the Observatory, which held an 1854 Pistor & Martins meridian circle telescope. The barometric pressure registered 97.826 kilopascals (28.888 inches of mercury).

Beginning at 11:38:35.5 p.m., Watson made observations of the stars Leonis, Ursae Majoris, and Virginis, noting the time of transit over the wires of the meridian circle telescope's reticle. He recorded the following in his logbook:

Leonis				
11^h	38^m	$35^s.5$		
		49.4		
		3.4		
		17.7		
		32.0		
		45.8		
11	39	59.7		
Ursae Majoris				
11^h	45^m	$13^s.6$	}	
		37.3	}	last three wires
11	46	0.5	}	
Virginis				
12^h	9^m	$26^s.5$		
		39.8		
		53.4		
	10	7.2		
		20.8		
		34.4		
12	10	47.8		

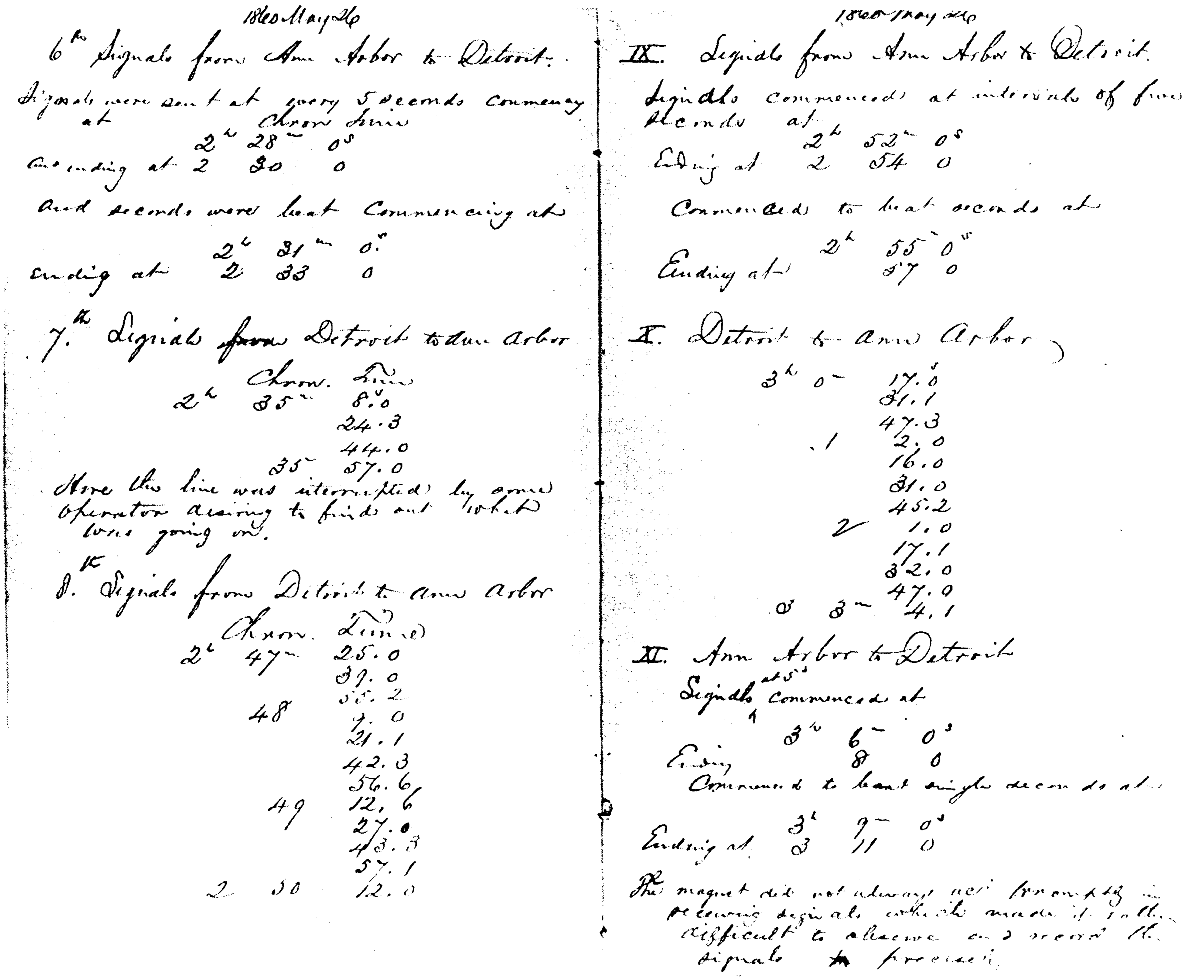
He then checked the alignment of the meridian circle telescope using the spirit level, with the telescope's clamp set at the East.

Next, Watson determined the correct local time using data from his observations. He found that his chronometer was 9 minutes 36.5 seconds fast compared with the Observatory's clock, and he recorded this in his notebook for later use in making his reductions. He then transported the chronometer on foot with great care to the local telegraph office, which was situated at the Michigan Central Railway depot, just 0.4 kilometres (¼ mile) north-west of the Observatory. There, he received signals by telegraph from Poe in Detroit. Signals were exchanged back and forth fifteen times in all. Watson tapped out the time at intervals of five seconds for one minute, then every second for the final minute.

During the second transmission of signals from Detroit, Watson noted that "Here the line was interrupted by some [telegraph] operator desiring to find out what was going on." (see Figure 11) (University of Michigan Observatory Records, Box 12). The odd repetitions of tapping out the seconds would certainly have seemed out of the ordinary to a telegraph operator accustomed to hearing Morse code signals. The interruption caused a few minutes delay, but Poe and Watson were able to complete the exchange of signals at 3:38 a.m., whereupon Watson returned to the Observatory with his chronometer in hand. He arrived back at the Observatory at 4:10 a.m. and immediately compared the chronometer with the Observatory clock. The error was 0.7 seconds, which he noted in his logbook.

Unfortunately, the Lake Survey's efforts in working with Watson to determine the longitude were not rewarded. Meade of the Lake Survey found that the results were not "... entirely satisfactory ..." (Comstock, 1882:11), and Tappan later revealed the true nature of the problem:

> Mr. Watson had entire charge of the Observatory, during Dr. Brünnow's absence of one year in Albany. Nothing was accomplished at the Observatory during this year. And in the spring, when the Lake Survey made signals of the time to him, by telegraph, for the purpose of determining the longitude, he failed to make the requisite observations for the correction of his time, and they were compelled to wait some two or three weeks for the reductions. (Tappan, 1915:1145).


1860 May 26

6th Signals from Ann Arbor to Detroit.

Signals were sent at every 5 seconds commencing at Chron. time
2h 28m 0s
ending at 2 30 0

And seconds were beat commencing at
2h 31m 0s
ending at 2 33 0

7th Signals from Detroit to Ann Arbor
Chron. time
2h 35m 8.0
24.3
44.0
35m 57.0
Here the line was interrupted by some operator desiring to find out what was going on.

8th Signal from Detroit to Ann Arbor
Chron. time
2h 47m 25.0
39.0
55.2
48 9.0
21.1
42.3
56.6
49 12.6
27.0
43.3
57.1
2 50 12.0

1860 May 26

IX. Signals from Ann Arbor to Detroit
Signals commenced at intervals of five seconds at
2h 52m 0s
Ending at 2 54 0

Commenced to beat seconds at
2h 55m 0s
Ending at 57 0

X. Detroit to Ann Arbor
3h 0m 17.0
31.1
47.3
1 2.0
16.0
31.0
45.2
2 1.0
17.1
32.0
47.0
3 3m 4.1

XI. Ann Arbor to Detroit
Signals commenced at
3h 6m 0s
Ending 8 0
Commenced to beat single seconds at
3h 9m 0s
Ending at 3 11 0

The magnet did not always act promptly in receiving signals which made it rather difficult to observe and record the signals at present.

Figure 11. Page from James C Watson's logbook dated 1860 May 26 showing his notes from an attempt to determine the longitude of Detroit (Courtesy: Bentley Historical Library, University of Michigan).

11.5 Ann Arbor, Michigan ↔ Detroit, Michigan, 1861

When Brünnow resigned from the Dudley Observatory in 1860 to return to his director position in Ann Arbor, he obtained approval from the University of Michigan Board of Regents to purchase a chronograph, made by Wm. Bond & Son. The chronograph was shipped to Ann Arbor, but was delayed in transit. Brünnow wrote to George P Bond in October that "The chronograph has not arrived yet probably on account of the crowded state of the [Erie] Canal." (Brünnow, 1860a). It finally reached Ann Arbor in November.

Brünnow learned a great deal about the processes involved in timekeeping and determination of longitude during the year he spent at the Dudley Observatory. He participated in putting a time service into operation in Albany, and he worked in co-operation with the Harvard College Observatory in 1860 to determine the longitude of the Dudley Observatory (Brünnow, 1860b). Upon his return to Ann Arbor later that year, he also pursued the establishment of a time service in Michigan, enlisting the assistance of George Bond's father, William C Bond, director of Harvard College

Observatory. The Bonds provided the time for the City of Boston, so when the citizens of Detroit asked Brünnow to investigate the feasibility of establishing a time service for Detroit, he naturally sought guidance from the Bonds. Once the Ann Arbor time service was in place,[8] the time was telegraphed from Ann Arbor to Detroit and other cities in the region. Jeweller Martin S Smith displayed the time on a large clock mounted outside his store in downtown Detroit, by which passers-by could set their timepieces. Ships in the Detroit harbour could set their chronometers by a time ball mounted atop Smith's building (Figure 12), which was dropped daily at precisely noon.

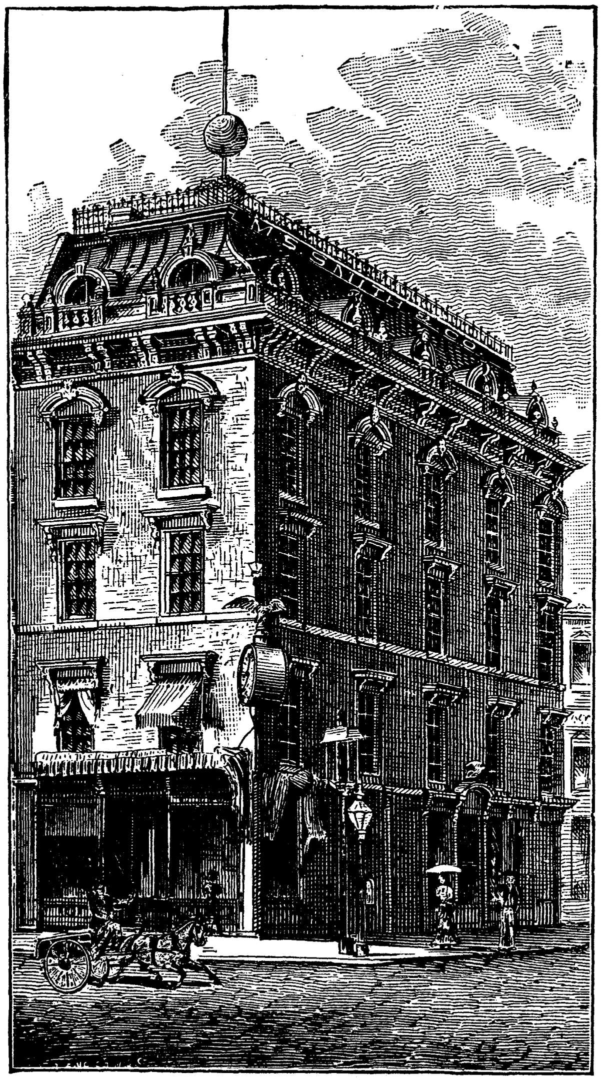


Figure 12. Time provided by the University of Michigan Detroit Observatory was communicated to the city of Detroit using a time ball and clock at Smith's Jewelry Store (after Farmer, 1884:363)

It was the installation of a telegraph line that connected the Detroit Observatory with the nearby Michigan Central Railroad depot, and possession of a chronograph, that made it possible for Brünnow to collaborate with the United States Lake Survey to determine longitude by the telegraphic method. On 1860 October 1, Brünnow wrote to George P Bond that a telegraph connection was established between the Observatory in Ann Arbor and the Lake Survey at Detroit (Brünnow, 1860a). Meade of the Lake Survey proposed to Brünnow that they work together to determine the precise longitude of Detroit, and Brünnow eagerly accepted.

In preparation for the collaboration with the Lake Survey, Brünnow made some preliminary observations of Ursa Minor and Hydra on 1861 March 18, 19, and 21. The

Lake Survey's observer, James Carr, made similar observations from the Lake Survey's observatory in Detroit. The official observations commenced on April 2 and April 10, of Hydra, and the work was concluded with observations on May 1, 20, and 21, of Virgo, and other stars. Poe assisted Carr at the Lake Survey's observatory at Detroit. This collaboration between Brünnow and the Lake Survey resulted in the establishment of Detroit as the fundamental reference point for all positional determinations made by the Lake Survey in the Great Lakes region.

Following the observations, as a final step in the process, Brünnow and Carr determined their personal equation on 1861 June 6 and 7 using the Pistor & Martins meridian circle telescope in Ann Arbor. It was often the case that two observers with the same level of experience and ability would differ in their reflex timing when recording data on a chronograph. The rate of difference was nearly the same for all stars observed, and this constant difference was explained as "... a discordance between the eye and ear." (Chauvenet, 1891, II:189). Therefore, when two astronomers worked together on observations of the same stars from different locations, it was necessary to know and adjust for the rate of this difference, which was referred to as their "personal equation."

Personal equations could be determined using several different methods. One method called for an observer to lie on the observer's couch of the meridian circle telescope, look into the eyepiece, and note the time of transit of a particular star as it passed over the first three or four wires of the reticle. The second observer would then quickly slip into place on the couch to observe the same star as it crossed the remaining wires. Data for a dozen stars over the course of an hour were recorded, and the difference of the mean results for the two observers was their personal equation. The act of changing places on the couch was awkward, and could adversely affect the accuracy of the personal equation. An alternate method was sometimes used to obviate this factor. Each observer independently determined the clock correction by observing fundamental stars, and the difference of these corrections, both reduced for clock rate to the same point of reference, was the personal equation. A third method employed a refracting telescope fitted with a micrometer. Stars were observed and noted as they crossed over the wires of the micrometer (Loomis, 1879:80-82).

11.6 Ann Arbor, Michigan ↔ Clinton, New York, 1861

In 1861, Brünnow arranged a collaboration with fellow German astronomer C H F Peters of the Hamilton College Observatory in Clinton, New York (near Utica) to determine the longitude. With a telegraph cable now in place across the Detroit River, and a telegraphic connection established between Ann Arbor and Detroit, it was possible to connect directly with a distant observatory. By comparing the local time difference between Clinton and Ann Arbor, using data transmitted by the telegraph and recorded on chronographs, the distance between the two observatories could be calculated. In 1859, Peters had determined the longitude of his observatory by connecting by telegraph with the observatory at Harvard College. The known longitude at Clinton would enable Brünnow to include in his longitude calculation not only the distance between Ann Arbor and Clinton, but also the previously determined distances between Clinton and Cambridge, Massachusetts and between Cambridge and Greenwich – all the way to the prime meridian.

The establishment of a telegraph connection between Ann Arbor and Clinton was greatly complicated by the Civil War. Telegraph lines were in constant use throughout the night, yet the superintendents of the New York Central Railroad and the Western Telegraph Company allowed the two astronomers, Brünnow and Peters, the use of one wire for two nights, after midnight (Brünnow, 1861:17-18).

The first connection between the Detroit Observatory and Hamilton College Observatory was made on 1861 June 29. The mean time clock at Hamilton College and the sidereal clock at Ann Arbor were transmitted over the telegraph line, with 126 beats of the two clocks recorded on two chronographs (see Figure 13). A second successful telegraph connection was established on July 3. The data they gathered were corrected for error in the precision of the clocks, in collimation and azimuth using the method of least squares, and in level as determined by the spirit level on the meridian circle. The result was a successful determination of the longitude of the Ann Arbor meridian circle, set at $50^m24^s.21 \pm 0.047$ west of Cambridge or $5^h34^m54^s.87$ west of Greenwich. Brünnow (1861:17-18) published the details of this longitude determination in *Astronomical Notices*. This longitude was later corrected to $5^h34^m55^s.27$ west of Greenwich after the value for the Harvard College Observatory's longitude was corrected using the telegraphic method once the Atlantic Cable was operational. Brünnow also determined the latitude of the Detroit Observatory, the value of which was extremely close to the present-day accepted value (University of Michigan, 1951:447).

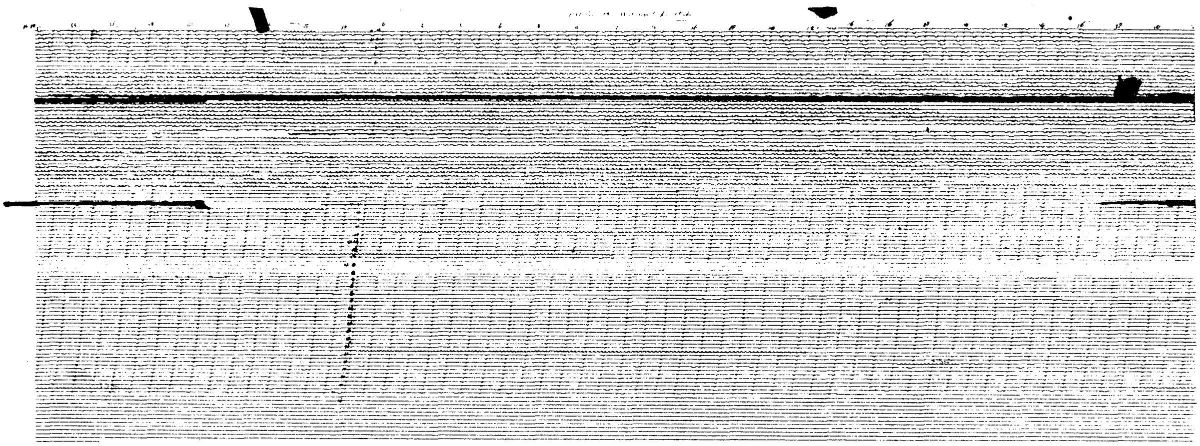


Figure 13. Chronograph sheet dated 1861 June 29 recorded the beats of the clock at Hamilton College Observatory as received at the University of Michigan Detroit Observatory by telegraphic connection. These data were used to determine the longitude of Ann Arbor, Michigan (Courtesy: University of Michigan Detroit Observatory Collection).

11.7 Ann Arbor, Michigan ↔ Green Bay, Wisconsin, 1864

In 1864, the Lake Survey called again upon the services of James C Watson, who was newly appointed as the director of the University of Michigan Detroit Observatory upon Brünnow's resignation and return to Europe. The Lake Survey needed Watson's assistance to determine the longitude of Fort Howard, Wisconsin located at the head of Green Bay. Carr, Assistant Engineer for the Lake Survey, had previously determined the latitude of Fort Howard in 1862, based on seven nights of observations of 30 pairs of stars with a Würdemann transit telescope (Comstock, 1882:627). For the 1864 longitude determination, Lake Survey observers General Raynolds and S W Robinson were at their observatory in Detroit, and C A Young was positioned at Fort Howard. Watson made intermediate observations at Ann Arbor while Orlando B Wheeler,[9] who received his training from Brünnow and Watson at the University of Michigan, observed at Chicago. Each station was equipped with a transit telescope, clock, and chronograph. Watson's observations began on 1864 May 7, with observations of *Polaris*, and continued on July 4, 5, 9, 10, 11, 12, 18, 19, 25, and 29, concluding on July 30.

11.8 Ann Arbor, Michigan ↔ Cambridge, Massachusetts, 1869

In 1869, Watson at Ann Arbor and Samuel P Langley at the Allegheny Observatory in Pittsburgh, Pennsylvania, were invited by the United States Coast Survey to connect by telegraph with the Harvard College Observatory for the purpose of re-verifying the longitude. This effort took place during the Coast Survey's effort to determine longitude between Cambridge, Massachusetts, and San Francisco by way of Omaha, Nebraska, and Salt Lake City, Utah. The exchange of signals between Cambridge and Ann Arbor took place on three nights between 1869 March 15 and March 21, with observers A T Mosman and F Blake stationed in Cambridge and Watson in Ann Arbor. This collaboration was apparently never completed. Langley travelled to Cambridge to determine his personal equation with observer Blake at Harvard, but the Coast Survey report implies that Watson never made the trip to determine his personal equation (United States Coast Survey, 1872:15).

12 CONCLUSION: THE UTILITY OF SCIENCE

Through collaborations with government agencies, university observatories in America played an instrumental role in determining longitude so that land and coastal areas could be accurately surveyed. They formed similarly useful collaborations with private enterprise. The observatories provided precise astronomical time to ensure the safe navigation of ships, passage of trains, transportation of goods and passengers, and synchronous closing of financial markets. They created inventions such as the electric telegraph and chronograph. They implemented technologies such as W C Bond's chronometric expeditions. And, they introduced innovations in scientific instrument and telescope design and optics. To a large extent, the early observatories in this country owed their very existence to the utility of applied astronomical science.

As an example, the creation of the University of Michigan Detroit Observatory was made possible through collaboration with private enterprise. Henry N Walker, a prominent businessman from Detroit, was in the audience the day that University of Michigan president Henry P Tappan delivered his inaugural address in 1852. At the conclusion of Tappan's speech, Walker stepped forward to offer his assistance in raising funds to construct an observatory. Walker, who had significant interests in banking and in the railroad business, identified with Tappan's stated position that scientific endeavours have both a scholarly and an applied value. Tappan said:

> ... can we truly be called a nation, if we cannot posses within ourselves the sources of a literary, scientific, and artistic life as well as of a political and commercial? (Tappan, 1852:16).

Perhaps Walker took particular note when Tappan said:

> We aim not merely to equal, but even to surpass the old nations of the world, in our manufactures, our steamboats, and our railroads. We level the forests in a day, lay down our tracks, and startle the old world with the sounds of our engines.... [We lay] substantial railroads in every direction ... Let us make men as well as houses and railroads. Let us have eternal thoughts circulating among us as well as gold and silver. (Tappan, 1852:51).

Tappan formed a successful collaboration with Walker to raise funds to create the Detroit Observatory. It was a magical matching of applied and basic science interests: Tappan would have his observatory for astronomical instruction and research, and Walker would benefit from the timekeeping a meridian circle telescope and a trained astronomer would provide. Correct time would help keep Walker's trains on schedule and avoid collisions, and financial markets would close at the same time, thereby eliminating any possibility of inappropriate financial gain by one entity over another. The valuable collaboration between the University of Michigan and the citizens of Detroit was so important to the creation of Tappan's new observatory that he named it after the city of its major benefactors (see Whitesell, 1998).

The timekeeping service academic observatories performed for national and local government, and for private enterprise, helped to sustain the observatories. The private observatories generally collected revenue for providing a time service, and most public observatories, including the Detroit Observatory, provided the service at no cost, although this free service no doubt influenced the level of appropriations made by State governments to public universities.

By the 1870s, the national sentiment was that "Astronomers, by their accurate determinations of the places of the sun, the moon, and the stars, [had] given prosperity to commerce and boundless wealth to [the] commercial cities." (Loomis, 1874:52).

The same nineteenth-century tenets continue to apply in the twenty-first century through collaborations formed between universities, the government, and private enterprise. The transfer of technologies developed by universities provides many technical, medical, scientific, and other useful advances to society, and sustenance to the economy. Basic science continues to demonstrate its utility in practical applications – such as in the development of the Global Positioning System (GPS) that can determine longitude with the press of a button – and in ways we have yet to imagine.

13 ACKNOWLEDGEMENTS

I am grateful to Dennis G Baker of the University of Michigan's Atmospheric, Oceanic, and Space Sciences Department, who saved historical weather records from being discarded in the 1980s, and then gave them to the author in 1996. Found co-mingled with these records were the chronograph data sheets used in this research. I am indebted to William J H Andrewes for his comments on a draft of this paper. I thank Brenda G Corbin of the U.S. Naval Observatory and Steve Quillen of the National Oceanic and Atmospheric Administration for reference assistance, and the Bentley Historical Library and the William L. Clements Library at the University of Michigan for permission to use images from their collections.

14 NOTES

1 The 1854 Detroit Observatory at the University of Michigan in Ann Arbor was named to honour its principal benefactors from the City of Detroit (and should not to be confused with the United States Lake Survey observatory at Detroit).

2 Edmund Blunt Jr. became Ferdinand Hassler's first assistant in 1832.

3 William A Burt also invented Burt's Typographer, the first typewriter, in 1828.

4 Johann F C Gauss of the Göttingen Observatory, Germany, invented the heliotrope, a small, round mirror the size of a silver dollar, which was used to reflect the Sun's rays a great distance.

5 Sydney Coolidge was killed during the Civil War at the Battle of Chickamagua in 1863 (Jones 1971:117).

6 Mark W Harrington was director of the University of Michigan Detroit Observatory from 1879 to 1891, after which he became the inaugural chief of the U.S. Weather Bureau. His interest in meteorology was developed in Alaska. Marcus Baker graduated from the University of Michigan in 1861. He became a noted cartographer, founding member of the National Geographic Society, and Assistant Secretary of the Carnegie Institution.

7 The Morse register held a fillet of paper that reeled off at a uniform velocity by means of wheels moved by a weight. A pen, which was connected to the armature of an electro-magnet powered by a galvanic battery, recorded data on the paper.

8 The exact date the time service commenced at the Detroit Observatory is not known. The first documented date that confirms a time service was in operation is 1863.

9 Orlando B Wheeler graduated from the University of Michigan in 1861.

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Buenaventura Suárez SJ: the pioneer astronomer of Paraguay

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Abstract
Father Suárez was a self-made astronomer in colonial Paraguay during the first half of eighteenth century. He constructed some scientific instruments, obtained data from his own astronomical observations, and made his own computations. He wrote to other scientists around the world, and published a book, *Lunario de un Siglo*, which was well received in Europe. Copies of this work are elusive today.

Key words: *Father Buenaventura Suárez, SJ,* Lunario de un Siglo*, latitude and longitude determinations, Paraguayan astronomy*

1 INTRODUCTION

San Cosme y San Damián (or San Cosme, for short) was one of the thirty communities set up by the Jesuits for Guarani Indians in the Great Province of Paraguay in South America. It is situated just north of the Paraná River, which marks the Paraguay-Argentina border (see Figure 1). San Cosme was founded in 1632, but in less than a century its location was changed at least three times as a result of attacks by Portuguese bandits originating from nearby Brazil (Furlong, 1978).

San Cosme's main claim to fame is that it was the home of Paraguay's first astronomer, the missionary priest Father Buenaventura Suárez, SJ (see Troche-Boggino, 1997, 1998). Born in Santa Fé (Argentina) on 1678 September 3, Suárez studied for the priesthood in Córdoba (also in Argentina), and then was based at San Cosme from 1703 until 1747. He then moved to Santa Maria, Argentina, were he died on 1750 August 23.

Apart from his astronomical achievements, little has been documented about Suárez's personal life, and no portrait of him has been located. However, he is known to have been a very amiable and prudent man, and not at all eccentric. He was very knowledgeable about medicinal herbs, and developed a method of preparing chocolate in a land where cocoa was not well known. He also made mirrors, organs, and bells, and advised local artisans in the art of picture-painting and icon-making (Furlong, 1978).

Father Suárez was the first native-born astronomer in southern South America, and was a contemporary of such famous 'Old World' astronomical figures as Bradley, Halley, and Newton (Figure 2). His southern hemisphere work predated that of La Caille at the Cape of Good Hope (see Evans, 1988), yet virtually nothing has been written about him (partly, one suspects, because of the paucity of relevant documentation). This little paper, which is based in part upon the account of Suárez provided in Spanish by Furlong (1978:597-606), summarizes what little we know about his pioneering astronomical achievements in Paraguay over a forty-year period during the eighteenth century.

2 SUÁREZ'S INSTRUMENTS AND ASTRONOMICAL OBSERVATIONS

With the help of local Indian artisans Father Suárez personally built several astronomical instruments. These included telescopes; at very least one sundial; a

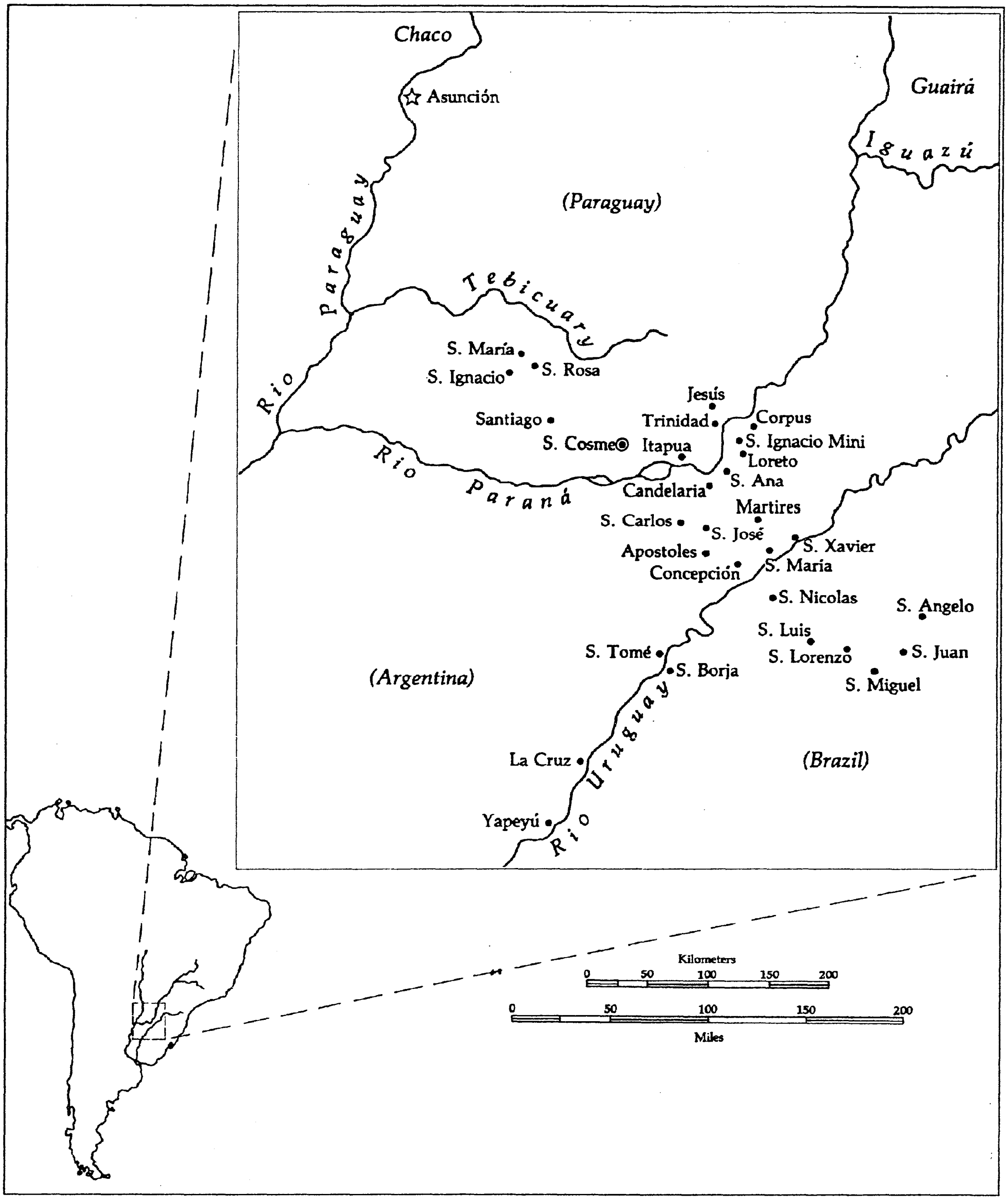

Figure 1. Jesuit towns of Paraguay, 1607-1767 (after McNaspy and Blanch, 1982:17).

quadrant (marked with degrees, subdivided into minutes); and a pendulum clock (Suárez, 1752; Furlong, 1978). Solar observations made with the quadrant were used to regulate the clock.

There is firm documentation that prior to 1739 Suárez made eight different refracting telescopes, or 'long view glasses', each featuring two convex lenses polished from local crystalline rocks. The lengths of these instruments are listed as 8, 10, 13, 14, 16, 18, 20, and 23 feet (ibid.), indicating that they were simple Galilean refractors of long focal length reminiscent – but on a much smaller scale – of those 'long telescopes' made during the previous century by Hevelius and others (e.g. see King, 1979:52-53). For them to have functioned at all, Suárez must have fashioned some form of simple supports for his telescopes.

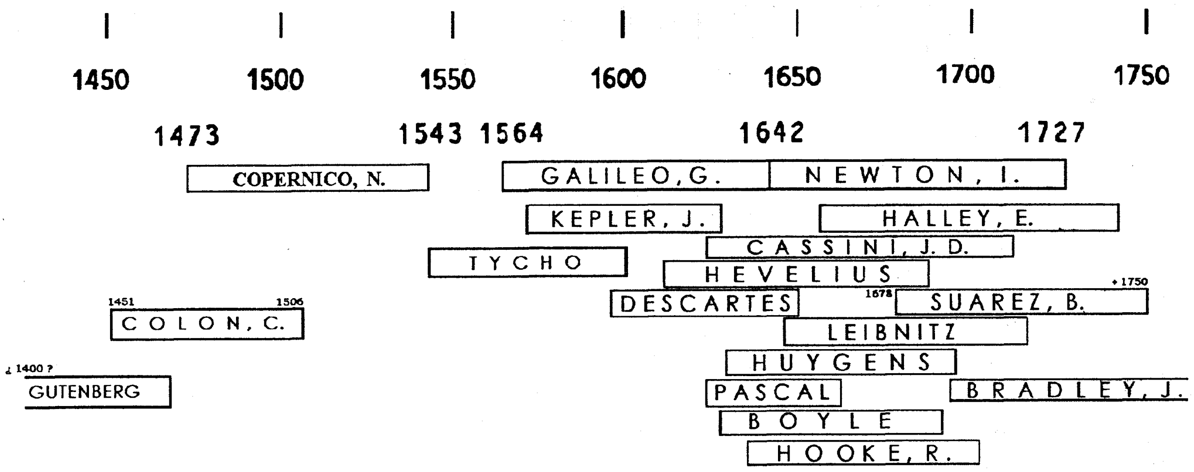

Figure 2. The life-spans of Fr. Suárez and other astronomers and scientists, 1450-1750. Detail from a poster presented at IAU Colloquium 162, London, 1996

Suárez (1752) employed his two smallest telescopes to record solar and lunar eclipses, and between 1726 and 1739 he used his six largest telescopes and the astronomical clock to record 147 eclipses of the Jovian satellites. Prior to 1739 Suárez (ibid.) also observed some comets, but precisely which ones is not specified. Marsden and Williams (1999) reveal that just eight different comets were reported world-wide between 1703 and 1739 (inclusive), and these are listed below in Table 1. However, as the final column in this table indicates, not all of these comets were prominent naked eye objects when viewed from San Cosme (A Gilmore, pers. comm., November 2000).

Table 1. Comets, 1703-1739

Comet	Perihelion Time	Old Designation	Visibility
C/1706 F1	1706 January 30.706	1706	Marginally naked eye
C/1707 W1	1707 December 12.488	1707	Naked eye
C/1718 B1	1718 January 15.406	1718	Naked eye
C/1723 T1	1723 September 28.128	1723	Naked eye
C/1729 P1	1729 June 16.648	1729	Telescopic
C/1733 K1	1733 May 6.159	1733	Naked eye
C/1737 C1	1737 January 30.847	1737 I	Naked eye
C/1739 K1	1739 June 17.916	1739	Marginally naked eye

By the early 1740s the Jesuit provincial heads had come to recognize Father Suárez's genius, and they decided to provide him with two professionally-made telescopes (of unspecified manufacture) and two 'Martirion' (Martineau?) clocks. All of these instruments were imported from England, and arrived in 1743 (Furlong, 1978). The telescopes had focal lengths of 8.25 and 16.5 feet, and judging by other telescopes in this size range available in Europe at this time (e.g. see Howse, 1986; King, 1979) were most likely refractors rather than reflectors. Collectively they cost 36,000 pesos, while the clocks were even more expensive at 62,400 pesos (Furlong, 1978). With these new instruments, Suárez was able to substantially improve the accuracy of his Jovian satellite observations.

During his time in Paraguay Father Suárez determined the longitude and latitude of San Cosme, and he then used these as datum points from which to establish the co-ordinates of all of the other local Jesuit mission towns (Furlong, 1978:303). It would appear that he used Galilean satellite observations to establish the longitudes.

Although there is no evidence that Suárez published any of his astronomical observations in scientific journals, he did correspond with other scientists – including

Celsius at Uppsala, de Peralta at Lima, Grammatici at Amberg, l'Isle at St. Petersburgh, and Koegler at Peking – and exchanged observations with them (Furlong, 1978).

3 THE BOOK *LUNARIO DE UN SIGLO*

Father Suárez may not have published any research papers about his on-going astronomical work, but he did publish a book, *Lunario de un Siglo* (literary, *Lunar Calendar for a Century*), based upon his own observations and the astronomical writings of Hipparchus, Copernicus, Reinaldo, Mulerio, Petacio, Billi, de l'Isle, and de la Hire.[1] Although all the necessary calculations were completed in 1739, *Lunario de un Siglo* did not appear until 1743 or 1744. The first edition came out in Europe (city unknown) of which no copies are extant, and the book was subsequently reprinted in Lisbon (Portugal) in 1748, Barcelona (Spain) in 1752 (see Figure 3), Quito (Ecuador) in 1759 and in Corrientes (Argentina) in 1856 (Furlong, 1978). It is of interest to note that three of these reprints were published posthumously and that the last two originated from South America.

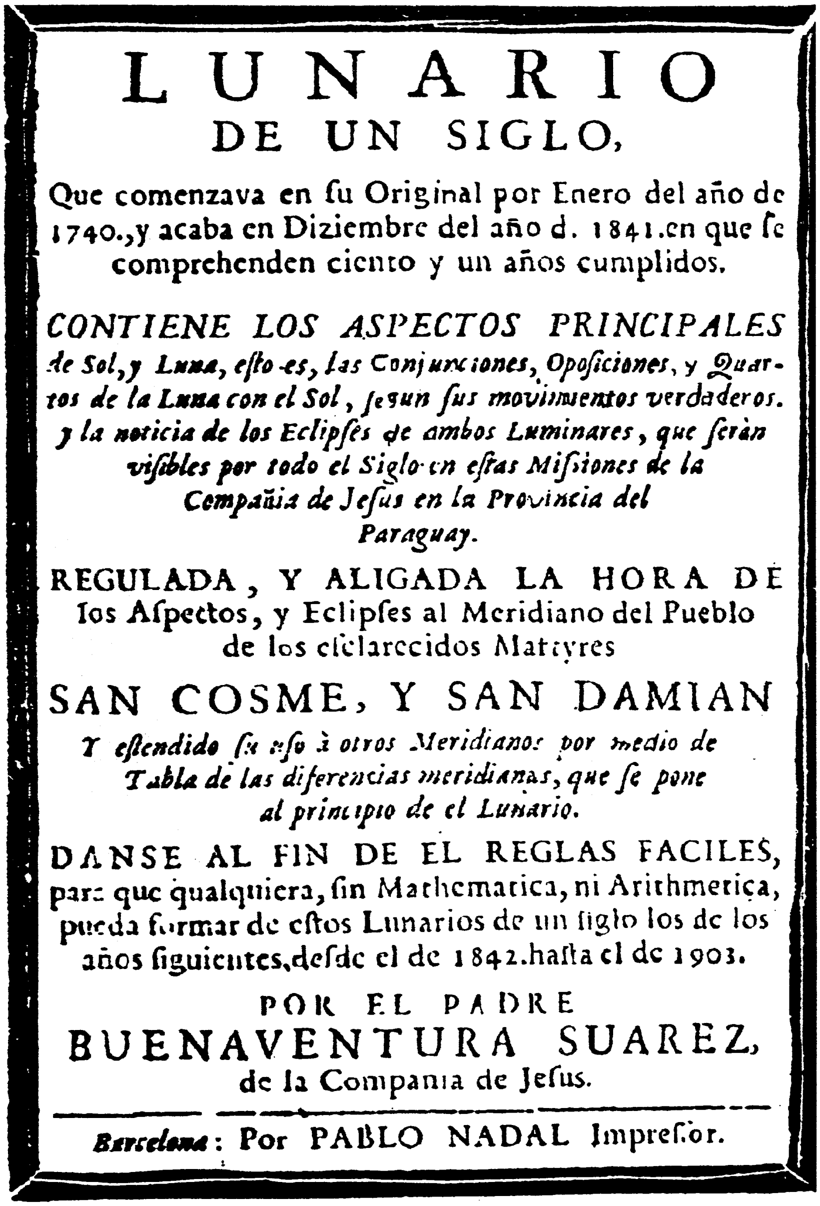
LUNARIO
DE UN SIGLO,
Que comenzava en ſu Original por Enero del año de 1740.,y acaba en Diziembre del año d. 1841.en que ſe comprehenden ciento y un años cumplidos.
CONTIENE LOS ASPECTOS PRINCIPALES de Sol,y Luna, eſto es, las Conjunciones, Opoſiciones, y Quartos de la Luna con el Sol, ſegun ſus movimientos verdaderos. y la noticia de los Eclipſes de ambos Luminares, que ſeràn viſibles por todo el Siglo en eſtas Miſsiones de la Compañia de Jeſus en la Provincia del Paraguay.
REGULADA, Y ALIGADA LA HORA DE los Aſpectos, y Eclipſes al Meridiano del Pueblo de los eſclarecidos Martyres
SAN COSME, Y SAN DAMIAN
Y eſtendido ſu uſo à otros Meridianos por medio de Tabla de las diferencias meridianas, que ſe pone al principio de el Lunario.
DANSE AL FIN DE EL REGLAS FACILES, para que qualquiera, ſin Mathematica, ni Arithmetica, pueda formar de eſtos Lunarios de un ſiglo los de los años ſiguientes,deſde el de 1842.haſta el de 1903.
POR EL PADRE
BUENAVENTURA SUAREZ,
de la Compania de Jeſus.
Barcelona: Por PABLO NADAL Impreſſor.

Figure 3. Title page of the 1752 Barcelona edition of *Lunario de un Siglo* (after Furlong, 1978:602).

Lunario de un Siglo is a kind of astronomical calendar for one century (covering the period 1740 January to 1841 December), and contains the dates of phases of the Moon, solar and lunar eclipses visible from Jesuit towns, and church festivals. Also listed are the longitudes (in hours and minutes relative to San Cosme) and latitudes of seventy different towns and cities around the world. Suárez also gives rules for the extension of the data in *Lunario de un Siglo* from 1842 through to 1903. When it was first published this proved a very useful book, and consequently it was well received in Europe.

4 THE LEGACY

By order of King Carlos III, Jesuit priests and brothers were expelled from Spain and all of its colonies about 1767. San Cosme had 3,356 inhabitants at this time, and as with other Jesuit communities in Paraguay its population declined. The passage of the years and military actions also took their toll, and now all that remain on the sites of many of the original communities are ruins and some sculptures (see McNaspy and Blanch, 1982).

San Cosme fared somewhat better and today is a little town of about 4,000 inhabitants. All of Father Suárez's astronomical instruments have been lost, but a sundial at San Cosme has survived (Figure 4) and is attributed to him (Servin, 1988). Meanwhile, his church, house and, a number of associated buildings have been reconstructed, all serving as a testament to this exceptional man.

Figure 4. The surviving Suárez sundial at San Cosme y Dámian (Troche-Boggino Collection).

5 CONCLUDING REMARKS

Father Buenaventura Suárez was South America's first native-born astronomer, and was a remarkable man. Despite his isolated situation, he constructed a number of scientific instruments (including eight different telescopes and an astronomical clock), and used the telescopes to observe comets, solar and lunar eclipses, and Jovian satellite phenomena. Some of these observations served to provide the latitudes and longitudes of the thirty little Jesuit communities in the Great Province of Paraguay. Suárez also wrote a book, *Lunario de un Siglo*, which was well received in Europe and South America and went through four reprints.

Suárez is recognized as Paraguay's earliest astronomer and he is also well know to Argentine astronomers (who consider him *their* first astronomer), yet little has been done to document and publicize his achievements.[2] This little paper provides a useful start, but a much more detailed account is warranted. The challenge in conducting such a study will be to access Jesuit and other archival repositories in Europe and locate letters and other records written by, or about, Suárez.

6 ACKNOWLEDGEMENTS

I am grateful to A Gilmore (Mount John University Observatory, New Zealand) and Dr B Servin (President of Asociación de Aficionados a la Astronomía, Asunción) for supplying information relevant to this study, and to Dr W Orchiston (Anglo-Australian Observatory, Sydney) for comments on the original version of this paper.

7 NOTES

1 De la Hire provided a basic table that Suárez used for his eclipse computations.

2 However, Dr Jaime Garcia (Director of the Instituto Copernico, Argentina, and a leading member of the Liga Latinoamericana de Astronomía) is also taking an interest in Suárez, while Dr B Servin has actively promoted Suárez's memory here in Paraguay.

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History of Astronomy at the 2000 General Assembly of the International Astronomical Union

Sessions organized by Commission 41 (History of Astronomy) featured on three different days at the 24th General Assembly (GA) of the International Astronomical Union, held in Manchester, England.

1 JOINT DISCUSSION 6: APPLIED HISTORICAL ASTRONOMY

JD 6 ran throughout Friday, August 11. Also participating were Commissions 4 (Ephemerides), 19 (Rotation of the Earth) and 20 (Positions and Motions of Minor Planets, Comets and Satellites), and supporting were Division I (Fundamental Astronomy), Division II (The Sun and Heliosphere), and Division III (Planetary System Sciences).

The session was chaired by S Dick and F R Stephenson, and was attended by more than 100 people. They heard papers on: "Babylonian observations" (D Brown), "East Asian observations" (F R Stephenson), "Southern Hemisphere observations" (W Orchiston), "Practical astronomy in Indo-Persian sources" (S M R Ansari), "Early observations and modern ephemerides" (E M Standish), "Secular variation of planetary orbital elements" (Y B Kolensik), "Ancient eclipses and the Earth's rotation" (L V Morrison), "Earth orientation since AD 1600" (D D McCarthy), "Creating modern cometary models using ancient Chinese data" (D K Yeomans), "Historical variability of the interplanetary complex" (M E Bailey), "Early telescopic sunspot records" (D V Hoyt), "Recorded long-period comet fluxes as an indicator of historic astronomical activity" (D W Hughes), "Scientific interpretation of historical auroral records (D M Willis), and "Remnants of historical supernovae" (D A Green). A final overview was given by W T Sullivan.

Poster papers included: "Exiguus: The Father of the Christian Era" (M Stavinschi), "History of cometary exploration at Kyiv University" (K I Churyumov), "Akademische Sternkarten, Berlin 1830-59" (D Jones), "History of Astronomy in Ukraine" (A Korsun), and "Sunspot records: 1853-1996" (J M Brooke *et al.*).

2 SPECIAL SESSION: INVENTORY AND PRESERVATION OF ASTRONOMICAL ARCHIVES, RECORDS, AND ARTIFACTS

The inventory and preservation of archives has been a long-standing concern of Commission 4, and a Special Session was arranged for the morning of Wednesday August 16. One of the purposes of this session was to serve as input to the Working Group on Archives reactivated at this meeting (see 3.7 below), by gaining insight into what is being done in individual countries, where progress is being made thanks to individual and institutional efforts. At the same time, the session was part of an initiative by the International Union of History and Philosophy of Science to encourage preservation and inventory of scientific archives in general.

The session was chaired by S Dick, and was attended by about 50 people. They heard papers on: "The inventory of IAU archives, and the ESO archives" (A Blaauw), "Royal Astronomical Society library and archives" (P Hingley), "Norman Lockyer Observatory archives" (G Wilkins), "'Alidade' and the iconographic base for astronomical archives preserved in France" (S Débarbat and J-P Cressent), "German archives" (W Dick), "Status of the Euler edition and archives" (A Verdun), "Russian archives" (A Gurshtein), "Preservation and digitization of observatory publications" (B Corbin and D Coletti); "Inventory and preservation of archives and historic instruments in Australia and New Zealand" (W Orchiston), "The Nha Il-Seong

Museum of Astronomy" (I-S Nha), and "Archives in India" (S M R Ansari). At the last minute, T Nakamura was unable to attend the GA, but his paper on "Astronomical Archives in Japan" was summarized by I Hasegawa.

A Blaauw pointed out that his inventory of IAU archives (published in 1999) covers only the years 1919-1970, and that efforts should be made to insure that the IAU archives since 1970 are also preserved and inventoried. This problem should be taken up by the Working Group on Archives, as should the general problem of building on this session to insure the world-wide preservation and inventory of archives.

3 BUSINESS MEETING OF C41

3.1 General

Commission President, S Dick, called the meeting to order on August 15. W Orchiston and W Dick were appointed Secretaries for the session, and S Débarbat returning officer for the elections, with C Sterken assisting. Of the members on the Organizing Committee, W Dick, A Gurshtein, I-S Nha, W Orchiston and W Sullivan were present, as well as Vice President F R Stephenson and Immediate Past President S M R Ansari; E Proverbio and X Zezong were unable to attend; 24 others were in attendance and apologies were received from B Warner and R Haynes. A moment of silence was observed for members deceased since the last GA, including Olaf Pedersen (1997 December 3), Helen Wright (1997 October 23), Derek Howse (1998 July 28), and Heino Eelsalu (1998 July 26).

3.2 Presidential Report

President Dick reported on highlights of the last triennium. In order to facilitate communication between members, a Commission WEB Site was set up (thanks largely to the efforts of W Dick), and the President issued six *Newsletters* to Commission members and others.

Following up on recommendations at the last GA, the Commission sponsored IAU Colloquium 178 on "Polar Motion: Historical and Scientific Problems", which was held in Cagliari, Sardinia, on 1999 September 27-30. At the time of this GA, the 641-page Proceedings, edited by S Dick, D McCarthy, and B Luzum, had just appeared as Volume 208 in the Astronomical Society of the Pacific's Conference Series.

In conjunction with the U.S. Naval Observatory, the Commission sponsored an around-the-world time ball drop on New Year's Eve to usher in the year 2000, involving 20 sites in eight countries on six continents. The event will be repeated for the beginning of the new millennium on 2001 January.

President Dick invited W Orchiston to report on the new *Journal of Astronomical History and Heritage*, which he and J Perdrix successfully launched following the Kyoto GA. As at 2000 June, five issues had appeared.

President Dick reported that for this GA he and F R Stephenson had organized Joint Discussion 6 (Applied Historical Astronomy) and the Special Session on "Inventory and Preservation of Astronomical Archives, Records and Artifacts".

During the triennium, Commission members continued to carry out research and publish, and highlights of their work are given in the IAU Transactions.

3.3 Election of Officers, New Members, and Consultants

The following officers were elected for the 2000-2003 triennium:

President:	Professor F Richard Stephenson (UK)
Vice-President:	Professor Alex Gurshtein (Russia)
Immediate Past President:	Dr Steven Dick (USA)
Organizing Committee:	Dr Wolfgang Dick (Germany)

Professor Rajesh Kochhar (India)
Dr Tsuko Nakamura (Japan)
Professor Il-Seong Nha (Korea)
Dr Wayne Orchiston (Australia)
Professor Woodruff T Sullivan (USA)
Professor Brian Warner (S. Africa)

The following new members of the Commission were approved: P Brosche (Germany), M Brück (Scotland), M Chen (China PR), I Chinnici (Italy), B Corbin (USA), T de Jong, H W Duerbeck (Germany), D Green (USA), W-Y Han (Korea), J Hearnshaw (New Zealand), A Heck (France), B Hidayat (Indonesia), M Hirai (Japan), N D Huan (Vietnam), S Hyung (Korea), B Jovanovic (Yugoslavia), F Launay (France), E-H Lee (Korea), K Locher (Switzerland), T Nakamura (Japan), B Pettersen (Norway), T Rafferty (USA), C Ruggles (UK), L Schmadel (Germany), B Soonthornthum (Thailand), H Steinle (Germany), C Sterken (Belgium), W Tobin (New Zealand), A Verdun (Switzerland), H Yamaoka (Japan), G Wilkins (UK), and E Zsoldos (Hungary).

New consultants elected were: J P Cressent (France), L Dalong (China), K-D Herbst (Germany), P Hingley (UK), R Mercier (UK), M Nam (Korea), S R Sarma (India), G Satterthwaite (UK), W Sheehan (USA), and J M Steele (UK). Consultants re-elected were J A Bennett (UK), K Bracher (USA), J Evans (USA), R Freitag (USA), A Jones (USA), E S Kennedy (USA), D A King (Germany), S McCluskey (USA), V N Sharma (India), B G Sidharth (India), J Tenn (USA), B van Dalen (Germany), T R Williams (USA), Y Włodarzcyk (Poland), and M Yano (Japan).

Total membership of the Commission, including new members, stands at 179, plus 27 consultants.

3.4 Resolutions

On behalf of A Batten, S Dick presented a report relating to the preservation of the sites involved in measuring the Struve arc of the meridian, and their designation as World Heritage Sites, following up a resolution passed at The Hague GA in 1994. The meeting asked S Dick to convey its thanks to A Batten for his continuing efforts.

S Dick also reminded members of the long-standing IAU resolution on the preservation and inventory of archives; the Special Session at this GA was meant to regain momentum on this resolution.

Two new Commission resolutions were then unanimously approved by the meeting:

1) *Recognizing* the historical importance of previous transits of Venus and the numerous transit of Venus expeditions mounted by many countries, and *noting* the rarity of the upcoming transits of 2004 and 2012, Commission 41 *recommends* that the sites of the previous transit of Venus expeditions be inventoried, marked and preserved, as well as instrumentation and documents associated with these expeditions.

2) *Considering* the importance of the contribution of the International Latitude Service to the study of polar motion, Commission 41 *recommends* that concerted efforts be made to preserve the buildings and instruments associated with the observatories of the International Latitude Service and predecessor observatories especially the associated geodetic monuments or pillars. (This resolution derived from IAU Colloquium 178 on "Polar Motion: Historical and Scientific Problems").

3.5 The History of Astronomy Programme at the 2003 General Assembly in Sydney

There was general agreement that Commission 41 should seek to be involved in at least one Symposium at the Sydney GA; that it should be the chief sponsor of a Joint Discussion; and that it should hold a range of business, science, and special meetings, some of which should focus on specific subjects, perhaps related to the new Working Groups (see below). It was noted that the transits of Venus would be a particularly timely subject.

3.6 C41 and the IUHPS

For many years Commission 41 has been deemed a "Joint Commission" of the IAU and International Union of History and Philosophy of Science, and it was agreed that the two International Unions should continue to co-operate for the benefit of both historians (who predominate in the IUHPS) and astronomers (who predominate in the IAU).

S M R Ansari noted that the IUHPS will meet in Mexico City between 2001 July 8 and 14, and that the programme includes a session on "Astronomical Heritage of non-European Cultural Areas".

3.7 Formation of Commission Working Groups

The meeting decided to establish four C41 Working Groups:

Archives (Dr Suzanne Débarbat, France)
Astronomical Chronology (Professor Alex Gurshtein, Russia)
Historical Instruments (Professor Il-Seong Nha, Korea)
Transits of Venus (Dr Wayne Orchiston, Australia)

The name and national affiliation of the chairperson of each WG is given above in brackets. Each WG will have a clearly-defined programme of work leading up to the next GA.

3.8 Status of Commission 41

C41 is a Commission that is not attached to any Division. By unanimous vote, the meeting reaffirmed the following statement from the Kyoto GA:

> "History of astronomy is a discipline that overarches the entire field of study of the IAU, and therefore should not be confined to one Division. We wish to remain a separate Commission until such time as we can become a separate History of Astronomy Division."

3.9 Vote of Thanks

On behalf of Commission members, W Orchiston moved a vote of thanks to S Dick for his sterling efforts as C41 President during the last three years.

Steven J Dick and
Wayne Orchiston

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Reviews

The Star of Bethlehem: an Astronomer's View, by Mark Kidger, (Princeton University Press, Princeton, New Jersey, 1999), xi + 306 pp., ISBN 0 691 05823 7, £14.50, US$22.95, cloth, 222 × 147 mm.

The Star of Bethlehem: the Legacy of the Magi, by Michael R Molnar, (Rutgers University Press, New Brunswick, New Jersey, 1999), xvi + 187 pp., ISBN 0 8135 2701 5, £23.50, US$25.00, cloth, 222 × 147 mm.

Now when Jesus was born in Bethlehem of Judaea in the days of Herod the king, behold, wise men from the east came to Jerusalem.
Saying, Where is he that is born King of the Jews? for we saw his star in the east, and are come to worship him.
And when Herod the king heard it, he was troubled, and all Jerusalem with him.
And gathering together all the chief priests and scribes of the people, he inquired of them where the Christ should be born.
And they said unto him, In Bethlehem of Judaea: for thus it is written by the prophet,
And thou Bethlehem, land of Judah, Art in no wise least among the princes of Judah: For out of thee shall come forth a governor, Which shall be shepherd of my people Israel.
Then Herod privily called the wise men, and learned of them carefully what time the star appeared.
And he sent them to Bethlehem, and said, Go and search out carefully concerning the young child; and when ye have found *him*, bring me word, that I also may come and worship him.
And they, having heard the king, went their way; and lo, the star, which they saw in the east, went before them, till it came and stood over where the young child was.

Matthew II:1-9

The above few verses from Matthew's gospel are the only mention of the Star of Bethlehem in the New Testament. Similarly, all the other references to it in ancient sources are thought to derive from Matthew rather than being independent accounts (but see below). Of the four gospels of the New Testament only Matthew and Luke mention the birth of Christ. Those of Mark and John begin with Christ's adult ministry, following the usual classical tradition which attached little importance to childhood. Further, Luke and Matthew give different accounts of Christ's birth: briefly, Luke has the shepherds and angels, Matthew the Magi and the star. The familiar plot of countless nativity plays is a conflation of these two accounts. The Greek word originally used in Matthew's account is Anglicized as 'Magi'. The singular was 'magos', which is usually taken to mean a learned astrologer and diviner, probably also with a priestly rôle, who acted as adviser to princes and rulers. 'Wise men' is as good a rendering into English as any. The Magi are usually assumed to have travelled from Babylonia or Persia. The tradition that they were themselves kings is an interpolation by the early Church, which disapproved of astrology. Nowhere in Matthew is the number of the Magi mentioned; the idea that there were three is also a later invention and estimates of the numbers have ranged from two to fourteen at various times.

None of the gospels are eyewitness accounts of the events they describe. The author of Matthew's gospel is usually thought to be a Christianized Jew living in Antioch around AD 85. At least three possible types of explanation have been proposed for his story of the star: that it was a fabrication, a supernatural event, or a report of an astronomical phenomenon. Biblical scholars usually, though not universally, prefer the first alternative and consider the account a 'Midrash', a story concocted for allegorical and instructional purposes, and usually involving a prophecy being fulfilled (Paffenroth, 1993; Stevens, 2000). Such stories are a common feature of Jewish religious writing. In the present case the prophecy of Balaam (Numbers XXIV:17) is probably the passage being alluded to:

There shall come forth a star out of Jacob,
And a sceptre shall rise out of Israel:

Despite this inauspicious background there have been numerous attempts to find an astronomical phenomenon which could have been the basis of the star in Matthew's account. Indeed, the appearance of articles on this topic in newspapers and popular astronomy magazines during December is almost an annual event. This enterprise is usually considered to have begun with Kepler and his observation of a `new star' in 1604, though he regarded the Magi's star as a supernatural event with no conventional astronomical explanation. In 1979 Freitag was able to list over three hundred books and articles about the Star of Bethlehem and their production has continued unabated since. This corpus represents a remarkable ratio of exegesis over the scant source material. Two new books on the topic have appeared relatively recently: *The Star of Bethlehem: an Astronomer's View* by Mark Kidger and *The Star of Bethlehem: the Legacy of the Magi/* by Michael R Molnar. Both are aimed at the general public rather than a more specialized audience.

Mark Kidger is an astronomer working at the Instituto de Astrofisica de Canarias, Tenerife. He also writes and broadcasts on popular astronomy in both English and Spanish. His book is a review and synthesis of the various explanations that have been proposed for the Star of Bethlehem. It is very much in the same tradition as Hughes' *The Star of Bethlehem Mystery* (1979), but with the benefit of an additional twenty years of scholarship. It covers the history and background to the Star of Bethlehem story and describes the usual suspects: planets, planetary conjunctions, comets, meteors, novae, and supernovae. For each type of candidate a brief description of modern astronomical understanding of the phenomenon is given, together with a discussion of how well it fits the Star of Bethlehem story. Kidger concludes with a tentative suggestion that the Star of Bethlehem was a previous eruption of the nova DO Aquilae in 5 BC, following a series of planetary conjunctions over the preceding couple of years.

Kidger seems surer of the astronomy than the historical background to the story (in mitigation it should be recalled that his book is subtitled 'an Astronomer's View'). There are a few historical oddities and Chapter 7 on the civilisations of ancient Mesopotamia and their astronomy is idiosyncratic. Conversely, the descriptions of the modern understanding of the various astronomical phenomena are well done, and given that the book is aimed at a lay audience, using the Star of Bethlehem story as a vehicle for this material is perhaps no bad thing. The author has not been well-served by his publishers: the book would have benefited from better editing and the suggestions for further reading for Chapters 8 to 10 appear to have been omitted.

Michael Molnar was an astronomer and physicist at Rutgers University. He now works on commercial Internet software and is also an amateur numismatist. It was this interest in ancient coinage which provided the initial impetus for his ideas about the Star of Bethlehem. In 1991 he bought a coin minted in Antioch around AD 6 which showed a ram looking backwards at a star. The ram seems likely to represent the constellation of Aries which, within the precepts of the astrology of classical antiquity, was associated with the Jews and Judaea.

Molnar's book starts, like Kidger's (and Hughes'), by discussing the account of the star in Matthew, what is known of the origin of Matthew's gospel, other early Christian writers and the historical background to the story. He briefly covers the various explanations that have been proposed in the past: comets, novae, etc., only to find them wanting in one or more respect. He then describes his own explanation for the Star of Bethlehem, which is the main purpose of the book.

Like many good ideas, Molnar's insight is obvious in retrospect. It is that the Star of Bethlehem story should be interpreted in terms of the astral science and precepts of the time, rather than according to modern ideas. Modern explanations of the Star of Bethlehem have tended to propose bright, spectacular, events which are immediately obvious. Conversely, the Magi were astrologers and the importance of astrological events depended not on their brightness, but rather on the positions of the planets within the signs and houses of the zodiac and the orientation of both the planets and the zodiac with respect to the horizon.

Molnar taught himself astrology as it was practised in classical times (a singularly thankless task which involves mastering difficult and arcane material of little apparent usefulness). He then found that around 17 April 5 BC the positions of the planets combined to yield an extremely strong portent indicating the birth of a powerful King of the Jews. He interprets this alignment as coinciding with the birth of Christ and hence being the origin of the Star of Bethlehem story. He also finds that though the original Greek of Matthew's account of the star has a literal meaning (which is how it is usually translated) many of the phrases were also technical terms in Greek astrology, and the passage makes better sense if it is translated in this light. Molnar's approach also provides a simple explanation to a long-standing puzzle about Matthew's account: why, though the Magi recognized the star, no-one in Jerusalem or Judaea appeared to notice it. Jewish religious tradition disapproved of astrology and it was not practised in Jewish communities (Deuteronomy XVIII:9-14).

Molnar's book is a significant contribution to elucidating the origin of the Star of Bethlehem story and seems a better explanation than those proposed previously. For anyone who does not wish to read the entire book he has published a paper giving a more succinct account of his ideas (Molnar 1995). He also believes that he has uncovered evidence for the Star of Bethlehem independent of the account in Matthew (Molnar 1999). The book itself is well produced and though intended for the layman is nonetheless well endowed with footnotes and references for further reading. In addition to providing a new explanation for the Star of Bethlehem the book also acts as a primer for the astrology of classical antiquity. Indeed, I thought that by concentrating on a single astrological event it nicely complemented the most recent overview of this subject, Barton's *Ancient Astrology* (1994).

There is, however, a conundrum at the heart of any astronomical explanation of the Star of Bethlehem: whether the event proposed coincided with the birth of Christ by chance or by supernatural intervention. This problem takes an extreme form in Molnar's theory, where it apparently requires astrology's arbitrarily invented rules to work. The problem does not arise if the story of the star is a fabrication. It is, however, possible to reconcile Molnar's ideas with the story being a Midrash. Recall that the author of Matthew appears to be a Christianized Jew living in Antioch, which was a Hellenized city where both astrology and the Stoic philosophy often associated with it were well established. Though the author seems unlikely to have been versed in astrology himself, he may well have known of portents predicting the birth of a Jewish Messiah around the time of the birth of Christ, and simply incorporated elements of these into his narrative. Remember that he was writing in a cultural context where the Emperor Augustus had skilfully used an auspicious horoscope as propaganda to legitimize his rule. This possibility removes the necessity for the astrological portents to actually correspond to the date of Christ's birth. The true explanation of the origin of the Star of Bethlehem story will probably never be definitively established, but in the meantime Molnar's explanation seems the most convincing available.

Acknowledgements
I am grateful to Mr P A L Chapman-Rietschi for useful discussions, though he would not necessarily concur with all the opinions expressed in this review.

Clive Davenhall

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Science in Translation: Movements of Knowledge through Cultures and Time, by Scott L Montgomery (The University of Chicago Press, Chicago & London, 2000); xii + 326 pp. US$28.00 £18.00, cloth-only, 152 × 228 mm.

Lingua franca, a universal language of strict scientific discourse, is the unapproachable dream of present-day scientists. It existed for a while among medieval Europeans in the form of commonly-approved Latin but did not survive for good. Alas, it was the great astronomer Galileo who blew up this short-living frangible accord. He appealed to the larger audience and that is why he preferred to argue in the conventional Italian street-jargon. The bad example was too infectious.

History of science upholds a few problems of extraordinary significance, which seem to lay on a surface of mainstream and, therefore, have to be carefully examined but actually are not scalpelled and analysed by a devoted and experienced specialist. Among those are problems of production, accumulation, and dissemination of scientific knowledge due to translations from one certain language into another. These problems are a far cry of proper understanding and too many various aspects of them are false and mythological. Some novel avenues concerning those problems are highlighted in the innovative and informative scholarly book *Science in Translation: Movements of Knowledge through Cultures and Time*. Having been a part-time technical translator and qualified science writer for more than a decade, the author, a consulting geologist, is a first-hand referee for many topics he is in touch with. As a result, his original book is of genuine attractiveness for anyone who is interested in the broad scopes of history of science and especially history of Earth sciences and astronomy. There are some important conclusions in this study.

The book is composed of an introduction and three loose, weakly-connected parts. The first part envelopes more than half of the book's volume. It contains four chapters and would be the most engaging division for a practitioner in the history of astronomy. Mainly, it is committed to the translations from oriental languages to the Middle Age's Latin. In this part, the author treats particularly such issues as the creation of an intellectual environment and the transformation of the medieval Universe. He is also tracking the transfer of astronomical knowledge from the Greeks to the Near East and India. Without actual astronomical background, the author basically features the problems of interpretation of the genuine texts and the social-cultural context of such activity.

In this first part the author successfully disregards the old, long-lasting and popular myth about the direct impact of classical Hellenistic and Roman civilizations on the Western world. With solid facts in his hands, he convincingly demonstrates that the real influence seeped through from the eastern countries and such languages as Syriac, Persian, and Arabic. This is a serious setback for one of the founding misconceptions of the Western culture. The author is scrupulous in investigating the circumstances that brought those different societies into scientific interconnections.

The second part embraces only two chapters and is dedicated to the non-Western world, especially Japan. There are many interesting historical highlights in this part, which, as a rule, remain unknown to Western readers. Among the most exciting features is the strong case of the formation of scientific terminology in Japanese from the sixteenth through the twentieth century.

Finally, the third part contains a single chapter and exhibits the problems of modern scientific translation. The bibliography of the book stands out in richness and variety. It contains about 500 titles not only in English, but also in some other European languages.

Meanwhile, it is improper to evaluate this valuable book as homogeneous and focused. Its positive and negative aspects are mixed up. I do hesitate to name it a monolith monograph that exhausts the matters under consideration. In reality, it looks more like a collection of well-done essays, or case studies, each of them being deep and entertaining, that offers a lot of significant specifics. But in some essential respects the book is limited and lacks the general conceptual vision of the problems. Overall, there is no doubt that this detail-rich book will be of vivid interest for various audiences.

Alexander A. Gurshtein

Archives of the International Astronomical Union. Inventory for the Years 1919-1970, by A. Blaauw (International Astronomical Union, Paris, 1999), xiv + 42 pp., paperback, 234 × 165 mm.

The International Astronomical Union (*Union Astronomique Internationale*) is the premier international body for professional astronomers and was founded in 1919. Currently, there are over 8200 members from more than 65 different countries, and through its Symposia, Colloquia and triennial General Assemblies the IAU plays a leading role in highlighting major developments in astronomy.

In 1994, Professor Adriaan Blaauw, a former President of the IAU, performed a major service to astronomy by producing his masterly *History of the IAU. The Birth and First Half-Century of the International Astronomical Union* (Kluwer, Dordrecht, pp. xx +296), and he has now followed this up with a complementary booklet dealing specifically with the archives of the Union, a topic covered in a mere three-and-a-half pages in his *History*.

In 57 pages, *Archives of the International Astronomical Union* ... provides potted biographies of successive General Secretaries of the Union through to 1970, and lists documents relating to their terms of office. Of greatest interest are 'Correspondence' files pertaining to general matters, restructuring of the IAU, Commissions, Working Groups, the organization of Symposia and General Assemblies, and publications, but there is also material on IAU finances and international astro-politics – particularly during the so-called cold war period. Another entry that particularly caught my eye was a folder titled "Astronomically Underdeveloped Countries/UNESCO involvement".

For those wishing to research aspects of IAU history, Blaauw's booklet will be an invaluable resources (along with his earlier *History of the IAU* ...), and it also refers to important source material for those investigating such distinguished astronomers as A Fowler, J H Oort, P Th Oosterhoff, D H Sadler, and F J M Stratton, all of whom served two or more sessions as IAU General Secretary.

Wayne Orchiston

A Far Off Vision: a Cornishman at Greenwich Observatory, 'Auto-Biographical Notes' by Edwin Dunkin. Transcribed, Edited and with an Introduction by P D Hingley &

T C Daniel [an edition of Royal Astronomical Society Additional Manuscript no. 55], (Royal Institution of Cornwall, 1999), 218 pp., ISBN 1 898166 73 0, spiral bound, £20.00, 241 × 165 mm.

Edwin Dunkin was a remarkable man. During 46 years service on the staff of the Royal Observatory at Greenwich he rose through the entire progression of ranks, from temporary computer to Chief Assistant – a record that was not equalled for a hundred years. As Chief Assistant for the last three years of his service he was deputy to the eighth Astronomer Royal, William Christie, but as this book makes clear he was the most trusted of assistants to that very demanding taskmaster, Sir George Airy.

Dunkin wrote this volume of 'auto-biographical notes' in June and July 1894 as a septuagenarian suffering from chronic deafness, "content to pass the remainder of my days in the enjoyment of comparative quietness and peace ..." In his Preface he states that the notes "were not written, nor are they intended, for publication", but should be kept private and preserved as a simple family record. His widow and son clearly honoured this intention; nothing more is known of the whereabouts of the manuscript volume until its discovery in a Southend garage in 1970, and its acquisition by the Royal Astronomical Society in November of that year. Its pages depict in detail the professional life of an astronomer at Greenwich during its nineteenth-century heyday – but they give us so much more. The social background, the pleasure Dunkin gained from personal contacts both within and outside his professional life, and especially those related to his Cornish roots, paint a much broader picture of both the man and his times. Consequently this volume is a major contribution to the historiography of science and Victorian social history, and one can only share the Editors' hopes that a century on "Dunkin ... would have excused our venturing to publish his private memoirs".

Dunkin and his younger brother Richard were the sons of William Dunkin, who had been employed as a computer for the Nautical Almanac Office for almost 30 years until his death at the age of 57. He had not wished his sons to follow in this profession, but following his early demise it was necessary for the brothers, then aged 17 and 15, to obtain gainful employment. Through the good offices of a family friend and the Superintendent of the NAO, they were appointed in 1839 as temporary computers at the Royal Observatory to work on Airy's re-reduction of the lunar and planetary observations made there in the years 1750–1830. The younger brother remained in this work for nine years, and then obtained a permanent position on the staff of the NAO where he served until his retirement.

Edwin Dunkin was however destined for higher things. After two years Airy appointed him an assistant in the newly-formed Magnetic and Meteorological Department, where he was engaged in the two-hourly programme of magnetic readings, thus adding familiarity with instruments to his computing experience. His real ambition was to work in the astronomical department, and he continued to extend and develop his astronomical knowledge to this end. When a vacancy arose in 1845 he was thus very well qualified, and had also gained Airy's trust and confidence, and was promoted to the established grade of Junior Assistant at the age of 24.

From here he never looked back. He observed regularly with the mural circle and was in charge of the reductions of the circle observations, and after six months he transferred to similar duties with the transit instrument. He was thus uniquely qualified to work with the new positional instruments then being constructed to Airy's designs. When the first of these – the Altazimuth instrument designed to obtain off-meridian positions of the Moon – was commissioned in 1847 Dunkin was appointed superintendent of the instrument, despite being the most junior of the Assistants at the time.

When Airy's great Transit Circle was completed in 1850, to replace the mural circle and transit instrument from the end of that year, Dunkin was additionally given responsibility for the determination of its instrumental errors, micrometer scale values, etc., and was one of the team of regular observers with both instruments. The book also records numerous expeditions, to carry out astronomical and geophysical work and longitude determinations, which were entrusted to Dunkin's supervision, and many other illuminating aspects of his life too numerous to list here. He was promoted Senior Assistant in 1856, and replaced Christie as Chief Assistant on Airy's retirement in 1881. He retired in 1884, being then President of the RAS which he had previously served as both Secretary and Vice President. He was elected a Fellow of the Royal Society in 1876, and became President of the Royal Institution of Cornwall in 1889. He died in 1898.

The Editors have done a fine job of organizing the text for publication, and have contributed not only a valuable and detailed introduction, but also extensive and valuable commentary in the form of fully-referenced footnotes. They are to be congratulated, as are the Royal Institution of Cornwall for undertaking the publication of a book which can not only be read with pleasure, but which is also a valuable source for historical and sociological research. Having extended this well-earned praise it pains the reviewer to have to close on a negative note. The book is nicely printed, on good quality paper, but as a reference volume it is ruined by the inexplicable and inexcusable decision to issue it with a spiral wire binding. Surely at the price – or not much more – something more permanent could have been managed? One can only hope that librarians at least will be willing to expend some of their limited resources on rebinding a work which should remain on their shelves in perpetuity in usable condition.

Gilbert E Satterthwaite

300 Jahre Astronomie in Berlin und Potsdam, edited by Wolfgang Dick and Klaus Fritze (Harri Deutsch Verlag, Frankfurt am Main, 2000), 252 pp., 20 figures, chronological survey, bibliography, name and subject indices, DM32.00, 210 × 148 mm.

Three hundred years ago, the Brandenburg Elector Friedrich III (who one year later elected himself Frederick I, King of Prussia) decided to found an Academy of Sciences and an Observatory in Berlin. In the same year, Gottfried Kirch was hired as the first astronomer of the academy, and a calendar patent was issued. The tercentenary of these three events motivated the historian of astronomy, Wolfgang R Dick in Potsdam, and the Babelsberg astronomer Klaus Fritze, to publish an anthology of studies on the interesting history of astronomy and astrophysics in Berlin, Potsdam, and their environs.

The longest contribution in the volume is Wolfgang Dick's 30-page introduction, a very carefully-researched survey of the developments, centred mostly around institutions such as the old and new Berlin observatories (the latter was designed by the world-known architect Karl Friedrich Schinkel, but unfortunately was destroyed around 1913 after the astronomers had moved to Babelsberg on the outskirts of Berlin), the Potsdam Astrophysical Observatory (founded in 1874) or the Einstein Tower (built between 1921 and 1924). His remarks about several less well-known institutes and organizations are also very useful, one example being the Astronomische Rechen-Institut. It was founded in 1874, becoming fully independent of the Observatory in 1896.

The prominent Berlin instrument makers, Pistor & Martins, who had constructed the Berlin/Babelsberg Meridian Circle, as well as many other *optici* and *mechanici* in Berlin are also thematized by Jörg Zaun in two contributions to this volume. The post-war history and relatively-recent work at the Astrophysikalische Institut Potsdam and at the Einstein Tower are covered in brief papers by Peter Notni, Jürgen Staude, Axel Hofmann, and Klaus Fritze.

In order to provide some background on the cultural meaning of calendars like the one issued in Berlin since 1700, Jürgen Hamel has contributed – in the reviewer's opinion – the most interesting paper on astronomical calendars as a source of information and *Bildung*. Basing his analysis upon a broad survey of the contents of such calendars between 1455 and 1830, we meet a motley thematic assortment of political agitation, astrological prognostication, serious popularization of scientific ideas, and general entertainment.

Annette Vogt contributed a prosopographical study of female astronomers in Berlin and Potsdam, based upon her screening of all female Ph.D. candidates at the Friedrich-Wilhelms-Universität in Berlin between 1899 and 1945. Her two case studies are Margarete Güssow and Gertrud Kobe, both of whom were active around 1933 when the Nazis came to power. Whereas the former joined the Nazi party and other NS organizations early on in March 1933 and seems to have played a rather dubious role as an informant in the following years, the latter rejected all compromise and had to leave the meteorological institute of the university in 1938. Paradoxically, she had no trouble finding employment at the Marine Observatory in Wilhelmshaven. After 1945 Gertrud Kobe could return to the university institute and even fulfilled the functions of a substitute director from 1948 on, but she only eventually got a tenured lecturing position in 1960. Both Annette Vogt's paper and Klaus-Dieter Herbst's contribution on the biography of Gottfried Kirch are rife with new material and really further the ongoing historical research.

Some of the other contributions are more like summaries of institutional history, but nevertheless very useful, especially if used in conjunction with the very good indexes of persons and institutions compiled at the end of the text, and the extensive bibliography of 350 texts pertaining to the theme of the book. Only one rather poor paper on world view and philosophy of science in the oeuvre of Hans Kienle should, in the reviewer's opinion, not have been included in this anthology which altogether is another welcome addition to the flourishing series *Acta Historica Astronomiae*.

Klaus Hentschel

Aiming For The Stars, by Tom D Crouch (Melbourne University Press, Melbourne, 2000), xiii + 338 pp., ISBN 0 522 84885 0,AU$45.00,cloth.

Originally a publication of the Smithsonian Institution and written by the senior curator of aeronautics of the National Air and Space Museum of the USA, this books is a top quality description of the American space programme with the appropriate sidelines into the USSR/Russian space programmes where they competed with or ran parallel to the US efforts.

The first half of the book describes all the events (right from Johannes Kepler of 1571) that led to the first American manned space flights, highlighting very strongly the involvement of Von Braun and his German colleagues. It provides a good feel of those hectic times of the real space race. The discussion then goes through the lunar programme and Skylab, and on to the Space Shuttle, stopping virtually at the time that the International Space Station becomes the dominant feature.

In all, one chapter (perhaps too little) is devoted to the other aspects of the US space effort: the planetary missions, the scientific missions, to the extent that these were conducted by the US government.

One of the more curious anecdotes that sprinkle the book, was the effort by Buzz Aldrin to see if he could get his feet on the Moon before Armstrong, by suggesting that 'the commander should remain on board of the LM, at least for a time, to handle potential emergencies'. We all know the result. The book has few photos but that does not distract from the contents.

One irritating thing, for an Australian, occurs right on page 2 when the author provides a summary of spaceports but excludes Woomera, Australia, even though he includes Brazil that has not yet had a successful space launch from its spaceport. But, apart from that, this is a highly recommended book. Just in time for Christmas.

Jos Heyman

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Cover illustrations show a series of images of the η Carinae area beginning with a drawing by John Herschel published in 1847, a black and white photograph taken by Ben Gascoigne with the MSSSO 40-inch reflector at Siding Spring, a colour photograph taken by David Malin with the AAO 150-inch at Siding Spring, and a view taken with the Hubble Space Telescope, courtesy J Morse (U. CO), K Davidson (U. MN), and NASA.