CHAPTER FIVE

A Carpet for the Computing Room

"Arcturus" is his other name—
I'd rather call him "Star."
It's very mean of Science
To go and interfere!

Emily Dickinson, Poem (1859)

"I WAS SURPRISED to find how quickly one could acquire the stolidity of the soldier," wrote a computer at the Naval Observatory.[1] The observatory, from its hill on the northern bank of the Potomac River, had an unobstructed view of Confederate territory. Directly across the water sat the plantation of General Robert E. Lee, abandoned by its owner and occupied by Union troops. The navy insisted that the computers and astronomers, most of them civilians, be trained as an artillery crew. The staff dutifully reported to the ballistics range at the Washington Navy Yard, where they learned how to charge and fire a cannon. They spent a day sending shells into the opposing riverbank before they returned to their telescopes and computing desks. None of them remarked that the arc of a cannon trajectory bore a mathematical similarity to the path of a comet, and, of course, none of them was quite ready to fire a gun in anger.[2]

The war permeated Washington, D.C., filling the streets with uniformed troops and the anxious gossip of distance campaigns. Only once was the city the site of an actual battle. That skirmish was fought on the northern border of Washington, a substantial ride from the solitary cannon that had been deployed at the Naval Observatory. Taken as a whole, the Civil War had little direct impact upon the practice of organized computation, even though it reordered American society, revolutionized American government, and profoundly touched the lives of the computers themselves. For the major American computing offices, the rooms found at the Naval Observatory, the Nautical Almanac, and the Coast Survey, the war was a plague that passed over their institutions, leaving them little changed. Individual computers had to make their choice "twixt that darkness and the light," in the words of a contemporary poem, but the computing floors could operate as they did before the war.[3]

Only the computers of the Coast Survey served in battle. The survey's

12. Coast Survey Office. Computing rooms are on the top floor

computing division was actually the oldest computing office in the country. It had been formed in 1843, the year that the survey was reformed and reorganized. The division hired "gentlemen in private life," as a report described them, "to repeat the important calculations of the survey."[4] Each summer, the surveyors would disperse to the field to create triangulation surveys, a large network of triangles that connected major landmarks and navigation points along the coast. Inevitably, after the trigonometry and longitude calculations were done, the triangles would fail to align perfectly. Some sides would be too short; others would be too long. Angles would not close, and lines would cross at the wrong place. The surveyors would correct these failures by modifying their numbers, taking a small bit from one side, adding a little to an angle, rounding numbers until all the triangles matched. The Coast Survey computers in Washington duplicated the process of survey adjustment and provided a means of evaluating the judgment of the original surveyors. If the two sets of computations were sufficiently close, then the director would accept the original survey. If they did not agree, then the computers would be asked to prepare a third set of adjusted calculations.[5]

After the war began, some of the survey computers volunteered for advance survey teams. These teams prepared maps for the Union army and charts for the navy, but this work could not be called organized computation.[6] The majority of these field calculations were quite simple, a quick determination of longitude or adjustment of a triangulation point. The computers usually handled the numbers simply, writing the results in a dirty notebook or on a piece of scrap paper.[7] As the historian Hunter Dupree observed about most science of the Civil War, "experimentation was largely done on the spot, when the men were actually confronted with specific and pressing problems."[8]

For those who remained behind, the Coast Survey computing floor became a haven for scientists unwilling to take up arms. The head of the office, a German immigrant named Charles Schott (1826–1901), "did not find military life congenial" and paid a substitute to take his place in a Northern regiment.[9] The son of Benjamin Peirce, Charles Saunders Peirce (1839–1914), joined the office as a way of avoiding the draft. "I perfectly dread [military service]," he wrote the director of the survey; "I should feel that I was ended and thrown away for nothing."[10] In the computing office, he joined Schott in doing a mix of civilian and military computations. They did engineering calculations for the fortifications of Washington and analyzed the trajectories of new army cannons.[11]

In general, the Civil War cannons did not inspire much organized computation. Though the armies and navies of Europe were starting to deploy steel guns with rifled barrels, the forces of both the Northern and Southern states used less accurate, smoothbore cannons. Shells fired by these guns rarely followed the trajectories predicted by mathematical ballistics, and so most ordnance officers needed only figures that showed the approximate range of their shots. The only real mathematical ballistics of the war was done at the experimental battery in the Washington Navy Yard, the same place where the Naval Observatory computers had learned the basic gunnery drill. The battery's gun placement was a long, low building that faced the river. A flag on a small cupola warned nearby ships when the gunners were preparing to shoot. Its staff fired thirty to fifty shots a week across the water, rattling the windows of local houses and reminding the nearby members of Congress that the country was at war. From these shots, the officers estimated the trajectories of the weapons. Most of the computations were done by a single officer, John Dahlgren (1809–1870), who was more interested in estimating the stress on gun barrels than in predicting the flight of shells.[12]

The war produced three new scientific institutions within the federal government, though none of the three had any immediate influence upon the practice of organized computing. The first organization, the Naval Inventions Board, included both Dahlgren and Charles Henry Davis. It reviewed proposals for new weapons that had been submitted to the Union navy, but it conducted no research of its own and produced no computation beyond the simple figures that the board members scratched on proposals. The second institution, the National Academy of Sciences, also listed Davis and Dahlgren among its first members. This group, modeled on the Académie des Sciences in France and the Royal Society in England, was intended to organize the nation's scientists and advise the government "upon any subject of science or art."[13] The French Académie had been an active supporter of organized computation, as it published the *Connaissance des Temps*, but its American counterpart undertook no such activity during the Civil War. The early years of the institution were disrupted by controversies over the selection of the first members. The National Academy of Sciences undertook only a little research during the war, none involving large calculations.[14]

The last new scientific institution of the war was a civilian organization, the Department of Agriculture. Congress, no longer checked by Southern members fearing the expansion of government institutions, formed the new department to promote agricultural production. The department's leader, who shared the name Isaac Newton (1837–1884) with the seventeenth-century mathematician, wanted the new agency to start a new program of scientific computation, one that would gather and analyze statistics of agricultural output and consumption. "Too much cannot be said in favor of agricultural statistics," he wrote. They reveal "the great laws of supply and demand, of tillage and barter, thus enabling both [farmer and merchant] to work out a safe and healthy prosperity."[15] In spite of his enthusiasm, the department was unable to start a comprehensive statistical program during the conflict.[16]

Though the war may have produced no immediate changes in the division of computational labor, its relics slowly transformed scientific calculation. At the war's end, the landscape was littered with thousands of miles of new telegraph wires. These wires followed the armies, Northern and Southern, as they marched across the countryside. They allowed Abraham Lincoln to second-guess his generals in the field and Jefferson Davis to follow the Confederate incursions into Pennsylvania; commanders used them to coordinate the divisions of their armies. After the war's end, these lines were available for a national effort to collect and process weather statistics.

Before the construction of the telegraph, the study of the weather had been a frustrating affair. Though an individual scientist could collect weather data, such numbers were of limited use unless they could be put in the context of a region or a continent. Without a full picture, a researcher might mistake a small squall for a major front, a local wind pattern for the great movement of the atmosphere. In the 1840s, the U.S. Navy and the new Smithsonian Institution had attempted to collect weather data along the northern length of the Atlantic coast. They had recruited four hundred volunteers, including Maria Mitchell's father, given them printed data forms, and created a standard ritual for collecting data. The observers had recorded wind, temperature, and precipitation at fixed times during the day and placed the completed forms in the U.S. mail. Workers at the Smithsonian had sorted the forms and forwarded the data to Lafayette College in Pennsylvania, where a staff of computers summarized the results.[17]

The joint navy/Smithsonian meteorological project was a modest success at best. As weeks passed before the data reached Washington, the results could only be used for historical study and not for forecasting. Perhaps more troubling was a lack of discipline in the system. The volunteers were told to gather data at specific times, but in fact they recorded the numbers when it was convenient for them or perhaps did not record the data at all. The scientists in Washington could not be sure that their summaries represented an accurate picture of the weather at any specific time and day. During the 1850s, the director of the Smithsonian proposed using the telegraph as a means of collecting data more quickly and imposing more discipline on the volunteers. He wrote to several telegraph companies, requesting that they "allow [the Smithsonian], at a certain period of the day, the use of their wires for the transmission of meteorological intelligence."[18] Getting the telegraph companies to cooperate on a such a large project proved to be almost as difficult as collecting the weather data. Most of the telegraph companies owned only a single line or perhaps a small collection of lines that fanned outward from a central office. Generally, these companies were only willing to transmit the data at night, a restriction that still allowed the Smithsonian to gather and transmit their data in a day's time. By the late 1850s, the telegraph lines were sending so much data to Washington that the Smithsonian hired a staff of "expert computers" to process it all.[19]

The war disrupted the Smithsonian weather project. When the collection of weather data was resumed in 1870, it was under the control of the Army Signal Corps, which controlled many of the telegraph lines that had been built during the conflict. The Signal Corps devised a system to collect weather data three times a day; at midnight, 11:00 AM, and 4:00 PM. The observers recorded their data in a coded form and telegraphed their results to Washington.[20] Data moved toward the capital as if it were water coursing through the tributaries of a river. It flowed from farms and villages, joining other data en route and pausing at regional offices to wait for an open moment on the lines that stretched toward Washington. In general, the rising flood of data took about three hours to reach the central office of the Signal Corps.[21]

The Signal Corps created a small computing staff that processed all of the weather data in intensive two-hour shifts. Computers worked at stand-up desks, where they recorded the information on preprinted forms and blank weather maps. Each computer was responsible for only part of the data. One handled temperature, another wind, a third precipitation. They reported to their stations just as the data began to emerge from the telegraph room. Young boys carried the paper from the telegraph to a single clerk, who read each telegram aloud, translating the symbols into placenames, amounts of precipitation, and percentages of humidity. As they heard their numbers being read, the computers would add the figures to their summaries and mark their maps. After the clerk had read the last telegram, the computers required only a few minutes to complete their calculations. The "work is done as fast as the translator can dictate," reported the director of the office, "so that within an hour all the telegraphic reports are received and within the same hour all the translating and map making is done."[22]

At first appearance, the Signal Corps computers had little in common with observatory or almanac staffs. They worked in short bursts of effort, in contrast to the sustained efforts of the astronomical computing offices, and handled calculations far simpler than the process of reducing data or preparing an ephemeris. Yet the staff of the Signal Corps was building upon ideas that had been first seen in observatories. Astronomers had seen the telegraph as a means of coordinating scientific effort across large distances. The principles of electric telegraphy had been first demonstrated by the German astronomer Carl Friedrich Gauss in the 1830s. The staff of the U.S. Naval Observatory had witnessed the first test of an American telegraph in 1844.[23] The second message to travel from Washington to Baltimore in that demonstration of the telegraph, the message that followed the famous invocation from the Hebrew scriptures, "What hath God wrought!" was a question concerning astronomical research: "What is your time?"[24] A difference in time corresponded to a difference in longitude, which was often expressed in values of hours rather than in the modern unit of degrees. (In some sense, we retain this old scale of longitude when we talk about Los Angeles as three hours off New York or Iowa as an hour ahead of Colorado.) The telegraph promised the ability to make measurements of longitude that were accurate to within one hundred feet. A *Nautical Almanac* computer devised a way to make such measurements with equipment no more sophisticated than a pair of standard pendulum clocks.[25] At the Harvard Observatory, the staff attempted to extract the possible accuracy for its telegraphic measurements by installing a telegraph switch panel in its basement and placing telegraph keys on its observing chair.[26]

At the Computing Division of the Coast Survey, the end of the war brought new rigor to the adjustment calculations. For many years, the surveyors had known that the adjustments could be handled mathematically, without any appeal to the judgment of computers, by a method called least squares. Using least squares, a computer could find the minimal number of adjustments that would make all the angles meet and all the sides be the proper length. The method of least squares had been developed by the same Carl Friedrich Gauss who had demonstrated the telegraph. Though many scholars have concluded that Gauss did not invent the method, they do acknowledge that most English-speaking astronomers learned the method of least squares from Gauss's book *Theoria Motus Corporum Coelestium in Sectionibus Conicis Solem Ambientium.*[27] The fact that this book was written in Latin was a hindrance to many American computers. Increasingly, the classical languages of Latin, Hebrew, and Greek were being dropped by the nation's colleges and replaced with modern languages, notably German. During the 1850s, Davis had concluded that his computers needed an English edition of the book and had undertaken the translation himself. He had finished the manuscript just before he departed the almanac to take command of a ship in the Caribbean.[28]

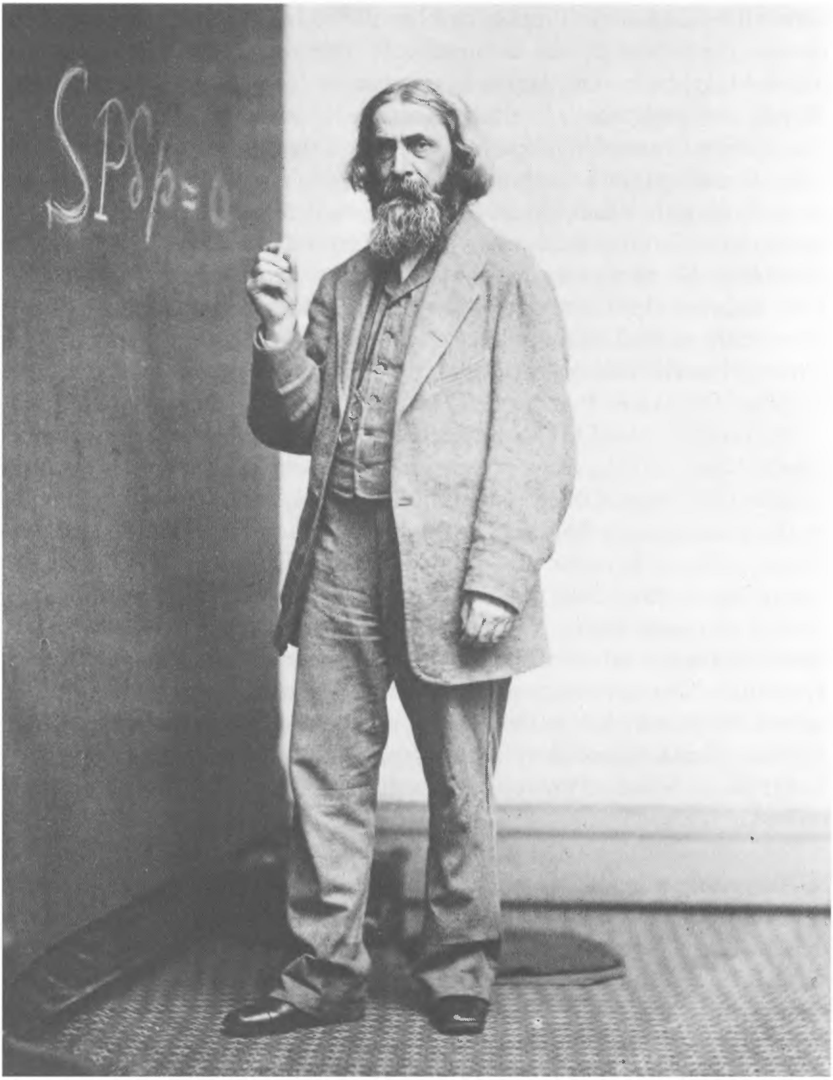
Prior to the war, the method of least squares was not widely used in the survey office because the calculations were long and arduous. It was much simpler to adjust the values by instinct and trust the judgment of the computers. The calculations for least squares required two steps. First, the computer had to prepare what were called "condition equations" or "normal equations." A typical problem would adjust twenty-five values in a survey spread over two or three square miles. In all, there might be two or three hundred measurements that had been made by the surveyors that had to be reduced into twenty-five condition equations, one for each of the values being adjusted. The second step disassembles the condition equations in a messy series of calculations. The process can be compared to the job of disassembling a steel-frame building, moving it to a new site, and reconstructing it in a slightly different shape. As the building is reassembled in its new form, each girder needs to be adjusted with a cut or an extension. Like the process of moving a building, least squares computations required detailed record keeping. Any mistake in either the records or the arithmetic required the computer to begin the process again.[29] The English translation of *Theoria Motus Corporum* did much to promote the method of least squares, but it described a plan for the computations that was slow and redundant. A computer knowing only the plans described by Gauss would resist any large problem.[30] In the United States, the method became widely used only after a Coast Survey computer named Myrrick Doolittle (1830–1911) developed a more efficient means of doing the calculations.

Doolittle was yet another student of Benjamin Peirce, though he had come to Peirce later in life. He had been born in Vermont and lacked the time or the money or the inclination to attend college. Proving to be a natural teacher, he had begun his career by instructing the children of friends and neighbors. At the age of 26, he accepted a position at the New Jersey Normal College and remained there until the onset of the war.[31] Deciding that it was time for him to get a degree, he enrolled at Antioch College in Ohio. Antioch was a small religious college that embraced the abolitionist cause with all the fervor of the age. He studied at the college for two years and was awarded a bachelor's degree in 1862. That summer Doolittle volunteered for an Ohio regiment in the Union army, only to find "his physical condition preventing enlistment."[32] He remained at the college for one more year as a mathematics instructor and then left to join Peirce at Harvard.

We have no record of Doolittle's life in Cambridge. Given the nature of his mathematical interests, it seems likely that he spent some time in the Nautical Almanac Office with the computers, but he stayed less than twelve months with Peirce. In 1864, he left Massachusetts without completing a degree in order to join his wife, Lucy Doolittle, who was working in Washington, D.C. She was a volunteer with the Sanitary Commission, a precursor of the Red Cross.[33] With the help of Benjamin Peirce, Doolittle took a job at the Naval Observatory as an assistant observer. He found the observatory work "wearying," as the job required him to record the positions of stars by night and to reduce observations by day. Deciding that he wanted to live a less taxing life, he resigned his position and took a job at the Patent Office examining the applications for patents on steam boilers.[34]

During Doolittle's time at the Patent Office, Benjamin Peirce came to Washington as the director of the Coast Survey. Peirce surprised both his friends and his detractors by proving to be a competent manager. He demonstrated that he could schedule survey crews, approve new projects, draft budgets, and work with members of Congress. He also found time among the demands of his official duties to conduct mathematical research. He returned to the classical problem of mathematical astronomy, the three-body problem, and developed a new way to compute the motion of the moon. He requested that the Computing Division prepare a table of the moon's position from his equations, but this work had to be suspended "for want of a sufficient and adequate force of computers." He was able to complete the tables only when he convinced the secretary of the navy to allocate an extra $2,000 to pay the salaries of three new computers.[35]

Peirce also experimented with a new form of arithmetic which used only two symbols, 0 and 1, instead of the ten digits of decimal arithmetic. Eventually named "binary arithmetic," it would be the basis of electronic



13. Benjamin Peirce, director of Coast Survey Office

computing machines, though such machines were seventy-five years in the future and beyond the vision of Benjamin Peirce. "I have no such extravagant thought as that of a substitute for our decimal system," he wrote, though he believed that it might be interesting to compute "some of the fundamental numbers of science by a new arithmetic for the purpose of comparison and verification."[36]

In 1873, Peirce offered Doolittle an appointment as a computer. According to his family, this appointment brought Doolittle "into his life's work."[37] He quickly came to dominate the Computing Division, though he never became its formal leader. He was not a mathematician after the manner of Benjamin Peirce or even Charles Henry Davis, but he had an innate grasp of calculation and was able to produce concise, simple computing plans. In 1874, he turned his attention to the calculation of least squares. He did nothing to the method itself, but he found a simpler procedure for handling the computations. He reduced the redundancies in Gauss's procedure, dropping calculations that were handled in other ways. The result was a plan that was more orderly and more efficient. In effect, he found a way of taking down the girders and reassembling them with the fewest steps. "The results reached appear very satisfactory," reported the director of the computing floor.[38] The technique became the standard method of computation at the Coast Survey. It removed the old judgments from survey adjustment and the old "gentlemen in private life" from the computing floor.

In the two decades that followed the end of the Civil War, women began to find a place in the computing rooms. Just as their male counterparts were no longer educated gentlemen, these women were not Maria Mitchells or Nicole-Reine Lepautes, the talented daughters of loving fathers or the intelligent friends of sympathetic men. They were workers, desk laborers, who were earning their way in this world with their skill at numbers. In many ways, they were similar to the female office workers, who were increasingly common in the nation's cities. Before the war, offices were closed to women, except for those well-nurtured daughters, loyal helpmates, or resilient widows. The war had opened government offices to women, as the federal agencies needed more clerical workers than they could draw from the dwindling pool of male labor. Many of these first female clerks were, in fact, war widows, women who had married in the first exciting days of the conflict and lost their husbands on some hallowed battlefield in Tennessee or Virginia. These women earned a meager salary from the government that often had to support children and mothers in addition to the worker herself.[39]

Women began finding employment with private companies after the war ended in 1865. The nature of business had expanded with the war, had become more complex, and now required central office staffs to coordinate production. Business skills were taught at high schools, a new innovation in public education. These skills were similar to those needed by human computers, though clerks did not need to understand the calculus of Newton. Both clerks and computers were subordinate to a professional staff, both were paid a small wage, and both handled routine work. By 1875, one out of six hundred office workers was female, and within a decade, women would fill one out of fifty office jobs.[40]

In 1875, Anna Winlock (1857–1904) approached the Harvard Observatory and asked if she might be employed in calculation. Winlock was the eldest daughter of Joseph Winlock, the director of the Harvard Observatory and the former superintendent of the Nautical Almanac. Joseph Winlock had unexpectedly succumbed to a brief illness, leaving behind a widow and five children with no obvious means of support. The officers of Harvard had been kind and gracious. They had given Mrs. Winlock a decent interval to vacate the house on the observatory grounds and had helped her to find a new home in Cambridge.[41] Once they felt that the new widow was settled, they ceased all financial support of the family.[42]

It fell to Anna Winlock, the eldest child at eighteen years of age, to sustain the family. Winlock had been close to her father in much the same way that Maria Mitchell had been close to William Mitchell. She had watched him work at the almanac office and learned from his example the rudiments of mathematical astronomy. When Anna Winlock was twelve years old, she had been her father's companion on an expedition to view an eclipse of the sun. The party left Cambridge and traveled southwest to Kentucky in order to make its camp. The young girl was probably included because the trip passed through the country of her father's birth. Along the way, the senior Winlock introduced his daughter to his various cousins and sisters and aunts. Nonetheless, the expedition was a time with the astronomers, an opportunity to prepare instruments and observe an eclipse.[43]

Joseph Winlock had left the Harvard Observatory volumes of unreduced observations, a decade of numbers in a useless state. The interim director complained that he could not process the data, as "the condition of the funds is an objection to hiring anyone."[44] At this point, Anna Winlock presented herself to the observatory and offered to reduce the observations. Harvard was able to offer her twenty-five cents an hour to do the computations. Winlock found the conditions acceptable and took the position.[45] In less than a year, she was joined at the observatory by three other women. The first was Selina Bond, the daughter of her father's predecessor. Like Winlock, Bond stood in need of a steady income, as her father's fortune had been squandered through the actions of a "rascally trustee." The second, Rhoda Saunders, was the graduate of a local high school who had been recommended to the observatory by the Harvard president. The last was probably the relative of an assistant astronomer.[46]

By 1880, the Harvard Observatory employed a complete staff of female computers. The director who hired this staff, Edward C. Pickering (1846–1919), is often considered progressive and liberal for employing

14. Computing room of the Harvard Observatory

women. He was called a "true Victorian gentleman in his attitude towards women and to everyone, men and women alike," by one of his computers.[47] Pickering worked closely with a female benefactor, Mrs. Anna Palmer Draper, to finance the activities of the observatory, and he encouraged an assistant to teach mathematical astronomy at Radcliffe College, the new women's school affiliated with Harvard.[48] Yet Pickering was motivated as much by economy as by altruism. "To attain the greatest efficiency," he wrote, "a skillful observer should never be obliged to spend time on what could be done equally well by an assistant at a much lower salary."[49] The salary he offered to the women was half the prevailing rate for calculation. "[The Harvard] computers are largely women," complained the director of the Naval Observatory in Washington, "who can be got to work for next to nothing."[50]

"Pickering's Harem," as the group would occasionally be called, served as an uncomfortable example to the government computing agencies.[51] When the secretary of the navy asked why the Naval Observatory could not reduce its expenses for computation, as the Harvard Observatory had done, he was met with a defensive reply from the superintendent. He claimed that the Naval Observatory paid "its employees at exactly the same (or in some cases less) rate as in other branches of the

Government Service," deftly deflecting the issue of hiring women. Shifting to a more aggressive position, he argued, "To charge extravagance against the Observatory because its employees are paid according to a rate fixed by law for the public service at large is clearly disingenuous and tending to mislead."[52] The Naval Observatory would not hire a female computer until 1901.[53] The Coast Survey and the Nautical Almanac, who had benefited from the labors of Maria Mitchell, were slightly more progressive and hired their second female computers in 1893. However, the Nautical Almanac was self-conscious about this action and identified its new employee as a man.[54]

The Harvard Observatory has left an unusual document that suggests the daily routine of its computing staff and the challenges faced by the female computers. This document is a musical parody, entitled the *Observatory Pinafore*, based on W. S. Gilbert and Arthur Sullivan's operetta *H. M. S. Pinafore*. The parody was written by a junior astronomer, Winslow Upton (1853–1914), and so reflects the point of view of the astronomers, not the computers. It shows the women struggling with their work, confronting astronomers with problems, and working in an environment that would constrain their role or even deny that they were part of a scientific endeavor.

The *Observatory Pinafore* must be one of the first parodies of Gilbert and Sullivan's opera, a show that has been adapted and modified many times. Winslow Upton probably saw the original *H. M. S. Pinafore* during its American premier in November 1878. This production, unauthorized by Gilbert and Sullivan, debuted in the old Boston Museum of Art six months after the show opened in London. Upton acquired a copy of the vocal score and wrote his observatory version nine months later "during four rainy days of an August vacation in Vermont."[55] He replaced the opening chorus of sailors, who tell of their shipboard life, with a chorus of computers, who sing:

> We work from morn till night
> For computing is our duty;
> We're faithful and polite.
> And our record book's a beauty;
> With Crelle and Gauss, Chauvenet and Peirce,
> We labor hard all day;
> We add, subtract, multiply and divide,
> And we never have time to play.[56]

The song is in the same spirit as the original and suggests that Upton is going to follow Gilbert and Sullivan's original plot. In *H. M. S. Pinafore*, a young sailor is in love with the daughter of his captain. Prevented from marrying by the social gulf between them, the two spend much of the opera planning to elope. "Love levels all ranks," says one character, "but not so much as that." The show is filled with trios and dances, a silly song by a pompous bass singer, a touching lover's lament for the soprano, and a rousing chorus expressing English superiority. Near the end, one character announces, much to everyone's surprise, that the captain and the young sailor were switched at birth, an announcement that immediately elevates the sailor and allows him to wed his love. The other characters gleefully ignore the logical problems with this solution, notably that the young sailor is now old enough to be the father of his bride, and sing a rousing recap of the songs.

Upton could have chosen to adapt Gilbert's plot to the Harvard Observatory. He might have decided to have a young female computer, perhaps a recent graduate of Cambridge Girls' High School, fall in love with an assistant astronomer who is a member of a prominent Beacon Hill family. After two acts of rewritten dances, solos, and choruses, we might discover that there was a mix-up in the two families which, after an extended lawsuit, reverses the fortunes of the two young people and allows them to marry. However, Upton did not follow this approach, as he was not interested in exploring the relations between men and women. Instead, he chose to explore the love between a young man and his science, the love that a junior astronomer had for his position at the Harvard Observatory.

In the *Observatory Pinafore*, Upton recasts the female love interest as a young male astronomer, though he retains the female name "Josephine" from the original.[57] The male Josephine is about to lose his position at Harvard. With no other positions available, he intends to take a job at an inferior private observatory in Rhode Island. Upton expresses nothing but scorn for the Rhode Island observatory. It is the hobby of a wealthy businessman, and hence it is tainted, less virtuous than the Harvard facility. The script portrays the businessman and the director of his observatory as vain and stupid. "I'm very proud of my degree," sings the Rhode Island astronomer, "For it shows that I'm a man of extraordinary sense."[58] As the plot moves through its paces, the Josephine astronomer bemoans his departure from Harvard and eventually finds a way to demonstrate his astronomical skill by repairing a telescope. When he fixes the device, his value is recognized, and he is allowed to remain in Cambridge.

The only computer identified by name in the *Observatory Pinafore* is Rhoda Saunders. She may have been chosen because of her role in the observatory, because she was a friend of Winslow Upton, or because she possessed the best voice among the female employees. The script suggests that she was strong and confident of her skills. In a scene which has no parallel in the original Gilbert and Sullivan play, she defends her work to an agitated assistant astronomer. "Oh! Oh! Oh! Oh! Oh! It's all wrong! A fearful mistake!" exclaims the astronomer, who has just been looking at a sheet of reduced data. When the figures are identified as the work of Saunders, she quickly affirms, "I don't believe it's wrong."[59] The observer eventually calms down and agrees with her. As the script was intended to entertain the staff of the Harvard Observatory, this scene is probably an exaggerated version of a real event, though it gives us no real assessment of Saunders's character. She may have been strong and outgoing or quiet and retiring. Even if it could give us a fuller picture of Saunders, it would be of little use, for the scene is one of the last times that a computer appears in the original script. By the end of the first act, the female computers all but disappear from the show.

Though Upton changed the gender of the female romantic lead and gave most of her songs to a man, he was not such a fool as to give the best soprano song to a male voice. He assigns the lover's lament, the song "Sorry her lot," to Rhoda Saunders and uses it to express some of the frustrations of the computers. In the original opera, this song is one of the points where Arthur Sullivan's music transcends the comedy of Gilbert's words and expresses a few moments of honest human emotion. It is stately, with a delicate melody that falls from high notes to low. In *H. M. S. Pinafore,* the falling melody is a fall of resignation, a recognition that love may be eternal but that courtship and marriage are governed by the conventions of society. "Weary the heart that bows the head," she sings in the last verse, "When love is alive and hope is dead."

Upton's version of the aria nearly matches the language of the original. It is his best writing in the entire script. Saunders, the computer who had held her own against the charges of an assistant observer, sings of repetition, tedium, and self-doubt.

> Sorry her lot, who adds not well;
> Dull is the mind that checks but vainly;
> Sad are the sighs that own the spell
> Symboled by frowns that speak too plainly.[60]

To those unversed in arithmetic, computing was indeed a difficult task, but Saunders was a good computer and served at the observatory for thirteen years. She, as well as the entire staff, had known the times when fatigue made any mental labor difficult. Under such circumstances, computers could barely add a column of figures and would make error after error in the simplest of calculations. Upton underscores the problem of fatigue by contrasting the computers, who work during the day, against the observers, who work at night.

Happy the hour when sets the sun;
Sweet is the night to earth's poor daughters,
Who sweetly may sleep when labor is done,
Unlike their brother astronomers.[61]

The sweet sleep is only a brief respite from their days of toil. Upton reinforces the tedium of the work through the chorus:

Heavy the sorrow that bows the head
When fingers are tender and the ink is red.[62]

The computers used red ink to correct their mistakes. A page of red figures meant the day had been hard and frustrating.

Once the song is finished, Saunders has only a few more lines in the script about mistakes and red ink before her role is finished and she leaves the stage. Just before she departs, there is a brief exchange that suggests the anxieties created by the presence of women at the observatory. The Rhode Island astronomer asks Pickering about the size of the computing staff. Pickering replies that it is "quite large—most enough for a good dance in spare hours." After hearing this, the other astronomer exclaims, "Do you allow, sir, your assistants to dance? Physicians tell me it is promotive of inaccuracy in computation." To modern sensibilities, this response is a quaint remnant of Victorian superstition, but it actually expresses a deep anxiety of the times. No one was entirely confident that men and women who were unrelated by family ties could work together in offices without being influenced by physical attraction. Taken at face value, the script suggests that E. C. Pickering may not have thought about this question, for the observatory captain responds, "Indeed! I was not aware of that."[63] However, it seems likely that Upton is being ironic, for Pickering was comfortable with the presence of women in his observatory, while the leaders of the Naval Observatory and the Nautical Almanac were not.

In 1880, shortly after Winslow Upton had finished the *Observatory Pinafore*, the director of the real Harvard Observatory, E. C. Pickering, announced that "a handsome carpet has also been purchased for the Computing Room in the east wing."[64] It was a pleasant addition to the room, for it deadened excess noise and provided a layer of insulation against the frozen ground of the Massachusetts winter. Pickering undoubtedly purchased it with all goodwill, yet the carpet was also a symbol of divided labor, of tasks for men and women. The literature of the time talks of separate spheres for the two genders, a metaphor that borrows from the classical model of astronomy. The sphere of Mars encircles the sphere of Venus, but both spin on the same axis. Men could move freely through the observatory, even into the telescope room, "a dark and dingy place," Upton tells us, "all clattered up and smelling strong of oil."[65] The women had their computing room, with its desks and its carpet.

The Harvard Observatory marks the end of experiments with dividing the labor of computation. Subsequent computing offices draw their models, consciously or unconsciously, from the laboratories that were founded before 1880. The Harvard Observatory also marks the end of astronomy as the dominant force in scientific calculation. Indeed, the *Observatory Pinafore* makes it clear that orbits and positions are no longer the most interesting part of astronomical research. Upton's writing transforms the rousing chorus of British superiority at the end of the play into a song of praise for a photometer, an instrument that measures the brightness of stars.[66]