Chapter One

EINSTEIN AND THE WORLD COMMUNITY OF PHYSICISTS AND ASTRONOMERS

Einstein Enters the World Stage

Einstein introduced his theory of relativity into a world that was changing dramatically. Scientific research and technological development were increasingly seen as valuable resources for nations. While applied research went on in industry, most basic physics research around the world was done in academic institutions. The normal path for professional advancement was to find a job as a professor. In Germany, a student who succeeded in obtaining an academic post had "arrived": "The professor had reason to be proud of himself. He had outdistanced most of his fellow graduate students. His 10,000 marks a year placed him in the upper bourgeoisie: in Prussia, for example, less than 1 percent of the population had incomes in excess of 9,500 marks in 1900." German-speaking Europe was the place to be for physics, and Berlin was the center of the physics universe. The leading countries worldwide were the United States, Germany, the United Kingdom, and France. These "big four" had the largest number of academic physicists, the highest total expenditure on academic physics, and produced the largest number of physics papers in leading journals. Though America had the greatest quantity, Germany led the world in quality and prestige. Being published in a German-language physics journal meant that your work would be read widely and by the best physicists in the world. German-speaking universities were spread all over Europe, from Switzerland to eastern Europe as far as Russia, and also in South America. Theoretical physics, which was Einstein's specialty, was a relatively new subdiscipline within physics. The center of gravity for theoretical physics was in German-speaking Europe. Germany led the world's nations in number of university chairs in theoretical physics. The Netherlands had the highest concentration of theoretical chairs per physics post. In the United Kingdom, and even more so in the United States, experimental physics was more common. In the United States, theoretical physicists were rare.[1]

Einstein was completely unknown when he came up with his theory of relativity.[2] He was a junior patent clerk in German-speaking Switzerland when he published his first article on relativity in 1905 at the age of twenty-six. His theory was revolutionary. Since the age of sixteen, he had been wondering about the nature of light and what the world would look like from the vantage point of a light beam. His intuition told him that it was not possible to travel at the speed of light, because no one had ever observed what he expected a person riding a light beam would see. Nor did theory predict it. Einstein knew that uniform motion (constant speed in a straight line) should not affect the laws of mechanics. We experience this principle when we sit in a moving car—it feels the same as if we were stationary. Without looking out the window, we can't tell the difference between moving at uniform speed and sitting at rest. No experiment that we perform in the car will tell us whether we are moving or are at rest. Observers in different states of uniform motion can assume they are at rest and the laws of mechanics will still hold true. This is the principle of relativity. Einstein elevated this principle for all physics, including electrodynamics and optics. All observers in uniform motion can assume they are at rest. No optical or electrodynamics experiment that we perform will tell us whether we are moving or not, including measuring the speed of light. Everyone gets the same answer.

The consequences of this simple statement are startling. Einstein showed that all observers agree on a certain combination of space and time measurements, but not on specific lengths and time intervals. Someone moving past you at high speed will tell you your meter stick is shorter than theirs, and you will measure their meter stick as shorter than yours by the same amount. The extent of the contraction depends on your relative speed. Their clock will run slower than yours, but they will tell you your clock is running slower than theirs. Yet you will both agree when you each measure the speed of light. If you measure the speed of light emitted by the headlight on a speeding train from the ground, you will get the same value as a person standing on the train. The reason you agree is that your meter sticks and clocks measure different lengths and times.

Einstein's theory yielded the same equations that Dutch physicist Hendrik Antoon Lorentz had derived using different concepts. Physicists had hypothesized the existence of a luminiferous ether to account for how light waves propagate. They believed that light comprises undulations in an otherwise invisible ether, which permeates all of space. Lorentz had developed an electron theory to explain why it is impossible to measure Earth's motion through the ether. His idea was that objects compress as they move through the resisting medium. He came up with the same formula for length contraction that Einstein got. Moving lengths contract in the direction they move, the amount of contraction being greater the faster the speed. Einstein's theory captured the fact that each observer sees the other length as contracted. His theory eliminated the need to interpret the contraction physically. The ether became superfluous. It also predicted other consequences that Lorentz's electron theory did not. Only Einstein's theory derived the time effect: moving clocks run slow. He also showed that observers do not agree on simultaneity of events. Two simultaneous events for one observer might not be simultaneous for another. Einstein also showed that if two clocks are synchronous at the same place, and one moves at high speed on a closed path, ending up at the same starting point, the two clocks will no longer be synchronous. The traveling clock will have slowed down relative to the stationary one during the journey.

Einstein submitted his relativity article to the prestigious journal *Annalen der Physik*, published in Berlin. The coeditor, Max Planck, who was responsible for theoretical articles, saw its merit and published it.[3] At first, Einstein's paper elicited discussion only in Germany. The French ignored it as if it had never appeared. The British took some time to react to it, and then they misunderstood and reinterpreted it in terms of a mechanical, luminiferous ether. The Americans also ignored it for awhile, but then most physicists reacted strongly against it for not being practical.[4] The Göttingen mathematician Hermann Minkowski caught physicists' attention with his four-dimensional space-time formulation of Einstein's theory. At a lecture in 1908, Minkowski coined the term "space-time" and made the grand statement: "Henceforth space on its own and time on its own will decline into mere shadows, and only a kind of union between the two will preserve its independence." His formalism involved a four-dimensional space-time in which he treated time as the fourth dimension. This geometrical interpretation made it easy to calculate consequences of Einstein's theory. Yet it also encouraged physicists and mathematicians to conceptualize an absolute four-dimensional world. This notion runs counter to Einstein's entire approach, which was to eliminate the concept of absolute space, a "container" in which objects in the world reside. Einstein did not like Minkowski's formalism, thinking that the elegant mathematics confused the physics. He would later change his mind as he grappled to generalize his theory to accelerated motion.[5]

Einstein's 1905 relativity paper was third in a series of four outstanding papers he published that year. The first was a "revolutionary" paper on light quanta and the second a paper on Brownian motion. His fourth contribution was a supplement to his relativity paper, in which he derived the equivalence of matter and energy as expressed in the now-famous formula $E = mc^2$.[6] Within a couple of years, Einstein was corresponding with the leading physicists in Germany. They were shocked when they discovered that he was a lowly patent clerk and not an eminent professor. In September 1907, Einstein received a letter from the publisher of the prestigious firm of Teubner in Leipzig stating "my presses will always be at your disposal in case you have any literary plans." Several publishers approached him to write a popular account of relativity. Einstein replied: "I cannot imagine how this topic could be made accessible to broad circles. Comprehension of the subject demands a certain schooling in abstract thought, which most people do not acquire because they have no need of it."[7] This reticence to popularize his theory would haunt him, and others, for decades. Together with its unfamiliar notions of space and time, relativity's lack of accessibility to the layperson would contribute to the myth that Einstein's theory is incomprehensible.

In 1907, Einstein agreed to write a comprehensive review article on relativity for Johannes Stark's *Yearbook of Radioactivity and Electronics*. Entitled "On the Relativity Principle and the Conclusions Drawn from It," Einstein's paper went beyond his 1905 papers and introduced for the first time his attempt to incorporate gravitation into his relativity framework. "Now I am concerned with another relativity-theory reflection on the law of gravitation, by which I hope to explain the still unexplained secular changes in the perihelion distance of Mercury . . . but so far it doesn't seem to work out."[8]

In 1909 Einstein finally left the Patent Office to become extraordinary professor of theoretical physics at the University of Zurich. He did not get the post easily. First, there was no position for a theoretical physicist. Second, the physics professor, his former teacher Alfred Kleiner, had another candidate in mind, Swiss-born Friedrich Adler. These two obstacles were cleared when Adler, who had been a close friend of Einstein's at school years earlier, himself suggested Einstein, and when Kleiner was elected rector of the university and promptly created the new post. Einstein then had to demonstrate to Kleiner that he could teach. He failed at first, but then redeemed himself. The Zurich faculty voted on the matter and picked Einstein. Luckily, the faculty recognized that he was a rising star and recommended him despite his Semitic origins. Kleiner noted that "about the personal character of Dr. Einstein nothing but the best reports are made by all who know him." Personally, he was "unhesitatingly prepared to have him as a colleague in my immediate proximity." The dean added to the faculty's recommendation:

> The above remarks by our colleague Kleiner, based as they are on many years of personal contact, were the more valuable to the commission, and indeed to the department as a whole, as Herr Dr. Einstein is an Israelite, and as the Israelites are credited among scholars with a variety of disagreeable character traits, such as importunateness, impertinence, a shopkeeper's mind in their understanding of their academic position, etc., and in numerous cases with some justification. On the other hand, it may be said that among the Israelites, too, there are men without even a trace of these unpleasant characteristics and that it would therefore not be appropriate to disqualify a man merely because he happens to be a Jew. After all, even among non-Jewish scientists

> there are occasionally people who, with regard to a mercantile understanding of their academic profession, display attitudes which one is otherwise accustomed to regard as specifically "Jewish." Neither the commission, nor the department as a whole, therefore thought it compatible with its dignity to write "anti-Semitism" as a principle on its banner, and the information which our colleague Herr Kleiner was able to furnish on Herr Dr. Einstein has put our minds completely at rest.[9]

The Directorate of Education still wanted Adler. By good fortune, Adler gallantly took himself out of the running and Einstein got the job.

Einstein's reputation in German-speaking Europe grew quickly. In 1910 news from Czechoslovakia that he had been nominated for a full professorship at the German university in Prague prompted Zurich University to raise his salary. An attractive offer from Prague eventually came, however, and Einstein moved his family in April 1911. It was during his stay in Prague that Einstein would return to his deliberations about relativity and gravitation. This work would bring the young genius into contact with the world of astronomy.

The Astronomy Community

The greatest number of astronomers were in the same "big four" countries as for physics. The United States and Germany had the largest communities, followed by France and the United Kingdom, closely followed by Russia, with Italy not far behind. A distinctive feature of the world astronomical community was that it had a larger institutional base than physics. The basic home of the observational astronomer was the observatory. In each country one found many men and women who were not attached to universities and colleges. State-supported institutions mandated to provide time service and astronomical data useful for civilian needs were also important centers of basic research. They often housed leading astronomers. Theoreticians, too, were often outside of academia. Nautical-almanac departments of the navy and geodetic institutes employed computers and higher-grade celestial mechanics specialists. In addition to these state-supported institutions, private observatories funded by individuals with an interest in astronomy were common. Philanthropic foundations dedicated to financing scientific research also initiated and financed observatories. The most notable in this period were the Carnegie Institution and the Rockefeller Foundation in the United States. In addition to astronomers working in these research observatories and institutions, there were those at colleges and universities. For them, the job structure was similar to that of their physicist colleagues, with the observatory being analogous to the physics research institute or laboratory.[10]

The top position in any observatory was the directorship. In academically affiliated places, the director usually held the astronomy chair. Centers weak in astronomy often had one of the mathematics or physics professors run the observatory. The director decided the research program, allowing his staff lesser or greater freedom in following their own interests. Instrumental facilities played a key role in determining what a director might or might not do. One needed a good refractor for double-star work.[11] Large reflectors were necessary for nebular photography. Climate also played a role. Spectroscopy required less atmospheric transparency than photometry. Observatories located in poorer climates, or near large cities, concentrated on stellar radial velocities and other spectroscopic work.[12] Within these constraints, the director could do what he wished, but he usually had to make compromises along the way. For example, Heber D. Curtis, who played an important role in the relativity story, took the director's position at Allegheny Observatory in Pittsburgh after spending years at Lick Observatory on Mount Hamilton in California. The mountain observatory had offered a clear sky perfect for nebular photography. Less than a month after taking up his new post, he wrote to his former chief at Lick, William Wallace Campbell: "This place for several years has been just a parallax machine, without much chance for individual work. Am planning to reduce the program, very gradually, and without destroying the value of unfinished work, to about six-tenths of its present scope, so that everyone can have some time for himself. But it will long remain, I think, one of the things we can do here."[13] A year later Curtis had changed his tune:

> My first year here seems mainly to have been spent in finding out the things that I cant [*sic*] do here, and there are quite a lot of them . . . the California combination of instruments *plus* climate is a hard one to beat. Parallax and photometry we can do here to great advantage, however. But not photoelectric photometry, I fear. I have naturally had "in the back of my head" various plans for changing the character of the work here, but am gradually coming round to the conviction that what we are doing is not only the thing we can do best, but also the field most needed today.[14]

The parallax program was a very heavy one: "Like the old yarn of the man who 'caught' the bear, it is something which we cant let go even in part as yet without losing the value of much which has been done here in the past." Curtis estimated that it would be "a year or so yet" before he could reduce the work to the 60 percent level that was his goal.

Observatory directors varied in how much autonomy they gave to their staff. Depending on the size of the institution, there could be several different levels of seniority below the top job. In the United States the most senior were called "astronomer" or "associate astronomer," depending on how sophisticated a pay scale was needed. In Germany, these senior staff were called "Hauptobservator," in the United Kingdom "chief assistant," and in France "astronome" or "astronome adjoint." In large observatories, senior staff were in charge of one instrument and/or one of the main research programs. Within guidelines set down by the director, they had free reign on what research they chose to carry out. In smaller institutions, these ranks were rarely filled, as the director usually required an assistant before he could afford a research colleague. Middle ranks were filled by "assistant astronomer" (U.S.), "observator" (Germany), "second assistant" (U.K.) and "aide-astronome" (France). In most observatories, particularly the thriving research centers, seniority and pay scale were the only practical differences between senior and middle ranks. At the lowest rung of the observatory hierarchy one finds the "assistants" ("Hilfsarbeiter" in German and sometimes "third assistant" in larger U.K. establishments), "computers," aids, mechanics, and secretaries. The assistant might perform a host of tasks such as routine night observing, preparing lists of stars or other objects to include in one of the research programs, developing photographic plates, and measuring plates. The computer might determine orbits based on series of photographs of comets, asteroids or planets, measure and tabulate positions of spectral lines, or calculate stellar parallaxes. In major observatories, a large staff of computers might be hired with a chief computer in charge. In small observatories, a director and one or two assistants might comprise the entire staff. Assistants might in reality do the work of an astronomer at larger places, depending on the director's disposition.

Even at major observatories primarily dedicated to research, assistants might have a great deal of latitude in their work. Heber Curtis, referring almost two decades later to his first years as an assistant on the staff of Lick Observatory, claimed "about the only difference between an Assistant and an Astronomer at that hot-bed of research is that the latter is older and draws a bigger salary."[15] Not all assistants were as lucky. As we shall see, Erwin Freundlich, a young assistant at the Royal Observatory in Berlin, ran into difficulties with his director, Hermann Struve. Freundlich wanted to conduct observational tests of Einstein's theory, whereas Struve wanted to keep him occupied on routine observational and computational tasks.[16]

The Astrophysics Revolution

The latter part of the nineteenth century ushered in two new technologies—photography and spectroscopy. For the first time since humans began to observe the heavens, astronomers could study the motions and physics

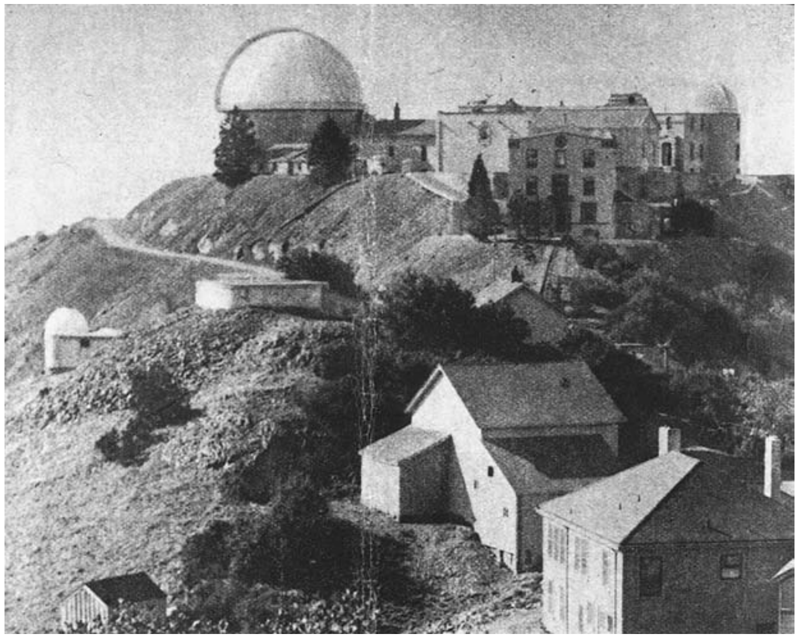

Figure 1.1. Lick Observatory on the summit of Mount Hamilton, California, near San Jose, ca. 1923. The large dome houses the 36-in refractor. (Courtesy Mary Lea Shane Archives of the Lick Observatory, University Library, University of California-Santa Cruz.)

of stars. The spectroscope allowed astronomers to study the stars' chemical composition and their velocities in the line of sight. Photography provided permanent recording of images that astronomers could measure and analyze in detail. These dramatic changes marked the beginnings of a shift away from the older tradition of positional astronomy toward study of the physics of celestial objects. A new field of research—astrophysics—was born.[17]

As the fledgling discipline began to flourish about the turn of the century, the American astronomical community took a leadership role. American astronomical journals began to appear, stemming the tide of American papers flowing across the Atlantic for publication in European journals. The Americans designed and built new research observatories and applied advanced technology to astrophysical problems with great vigor. Four major observatories devoted to astrophysical research went into operation around this time—Lick Observatory in northern California (fig. 1.1); Lowell Observatory near Flagstaff, Arizona; Yerkes Observatory in Williams Bay near Chicago; and Mount Wilson Observatory in southern California (fig. 1.2). All of them were privately funded.

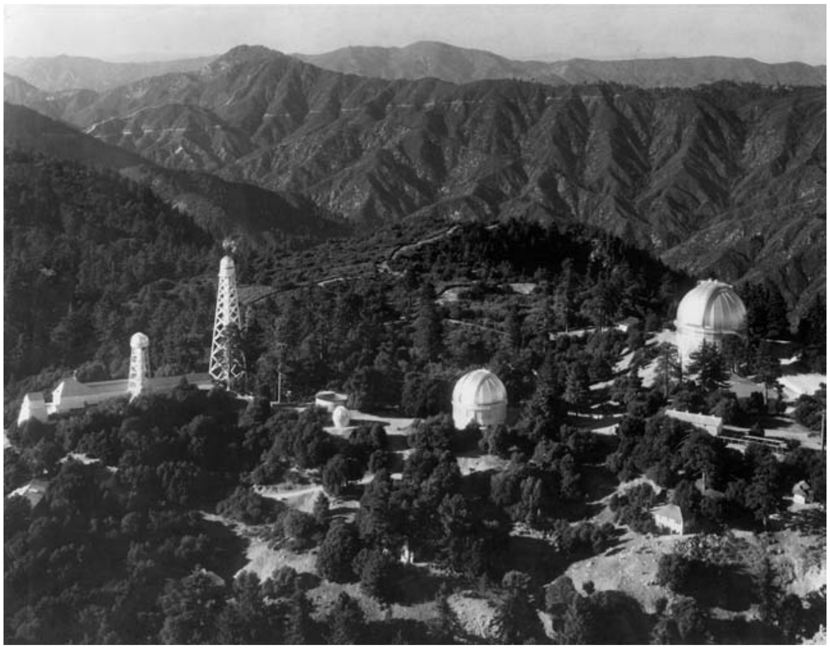

Figure 1.2. Mount Wilson Observatory in the San Gabriel Mountains outside Pasadena, California, 1931. *Left to right*: horizontal Snow telescope, 60-foot solar tower, 150-foot solar tower, 60-inch telescope dome, 50-foot interferometer building, and dome of the Hooker 100-in telescope. The first telescope put into operation was the Snow telescope completed in 1905 and used by George Hale. The 60-ft solar tower was erected in 1908; the 60-in telescope was completed in 1909; the 150-ft solar tower was completed in 1912; and the Hooker 100-in telescope was tested successfully in 1917. (Courtesy Carnegie Institution of Washington.)

The combination of advanced equipment and excellent observing conditions thrust the Pacific observatories into the forefront of astrophysical research. Percival Lowell founded his observatory in Flagstaff because of the excellent "seeing" in the desert climate (figs. 1.3a,b). The astronomer Vesto Melvin Slipher utilized the favorable observing conditions, advanced technology, and his ingenuity to pioneer spectroscopy of faint nebula with the Lowell 24-inch refractor (fig. 1.4). Lowell was primarily interested in planetary work, especially observations of Mars, though he allowed Slipher to spend half his time on his own interests. In 1909, Lowell assigned Slipher the task of photographing spectra of spiral nebulae in the hope of learning more about the origin of our solar system. At the time, he and many other astronomers believed that nebulae were in our own Milky Way stellar system and were birthplaces of stars. By 1912, Slipher was able to photograph the spectrum of the Andromeda

Figure 1.3a. Lowell Observatory near Flagstaff, Arizona. Dome housing the 24-inch Clark refractor. (Courtesy Lowell Observatory.)

nebula, an object so faint that no one had succeeded before him. The spectrum showed a remarkable displacement of lines toward the red. The redshift was larger than for any other object, indicating an enormous velocity of recession. Slipher got the first good plate of the spectrum, showing displacement of spectral lines, in August 1912, three years after he first took up the problem. The exposure took nine hours on a single night.[18] Slipher shifted his work to other spirals, dominating the field for years until a 100-inch reflecting telescope went into operation at Mount Wilson. Slipher's work revolutionized nebular spectroscopy and opened an avenue of research that led directly to the discovery of the expanding universe. He took over the observatory directorship after Lowell's death.

William Wallace Campbell had been appointed to the Lick Observatory staff in 1891, where he had use of the Lick 36-inch refracting telescope (fig. 1.5a,b). The Lick instrument was then the largest of its kind in the world and later second only to the 40-inch refractor of the Yerkes Observatory.[19] Campbell designed a new and powerful spectrograph for use with the 36-inch. With it he set new standards of precision in stellar spectroscopy.[20] When Lick director James Keeler died suddenly and unexpectedly at the turn of the century, the Lick trustees consulted twelve leading astronomers for advice about a successor. They all chose Campbell.[21] As director of Lick Observatory, Campbell embarked on a systematic pro-

Figure 1.3b. Percival Lowell observing at the 24-inch Clark telescope. (Courtesy Lowell Observatory.)

gram to determine radial velocities of stars brighter than a specified value. His goal was to determine statistically the structure of the stellar system and the Sun's motion through it. With financial assistance from Darius Ogden Mills, a friend of the observatory who had financed Campbell's spectrograph, the new Lick director had a second spectrograph built. He set it up at a station in Chile, so that the southern part of the sky could be included in his massive observing program.[22]

In 1911, the year that astronomers first learned of Einstein's gravitational light-bending prediction, Campbell published preliminary results

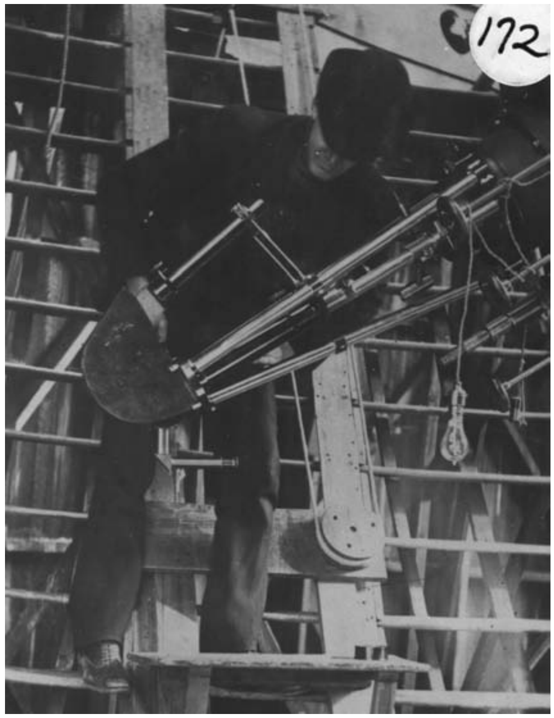

Figure 1.4. Vesto Melvin Slipher observing with the Brashear spectrograph mounted on the 24-inch telescope. (Courtesy Lowell Observatory.)

of the Lick radial velocity program. His paper caused a stir. Campbell showed that there was a systematic shift in spectra of certain types of stars. If interpreted as a velocity, these shifts meant that the stars were receding from the Sun by as much as 4 km per second. The cause of this so-called K-term became an important research topic. More than a decade later, Campbell's K-term would be interpreted and misinterpreted in terms of Einstein's general theory of relativity.[23] Campbell's accurate and systematic program on radial velocities inspired many other observatory directors to put similar programs on their research agendas. Campbell's technical and organizational experience in the area put him in demand as a consultant, and his reputation and that of his observatory spread rapidly.

Campbell was also a champion for science and a strong American scientific community. He was an experienced fund-raiser and organizer, continually looking for ways to fund science. Consider the circular letter he sent in 1915 to Western scientists as president of the American Association for the Advancement of Science:

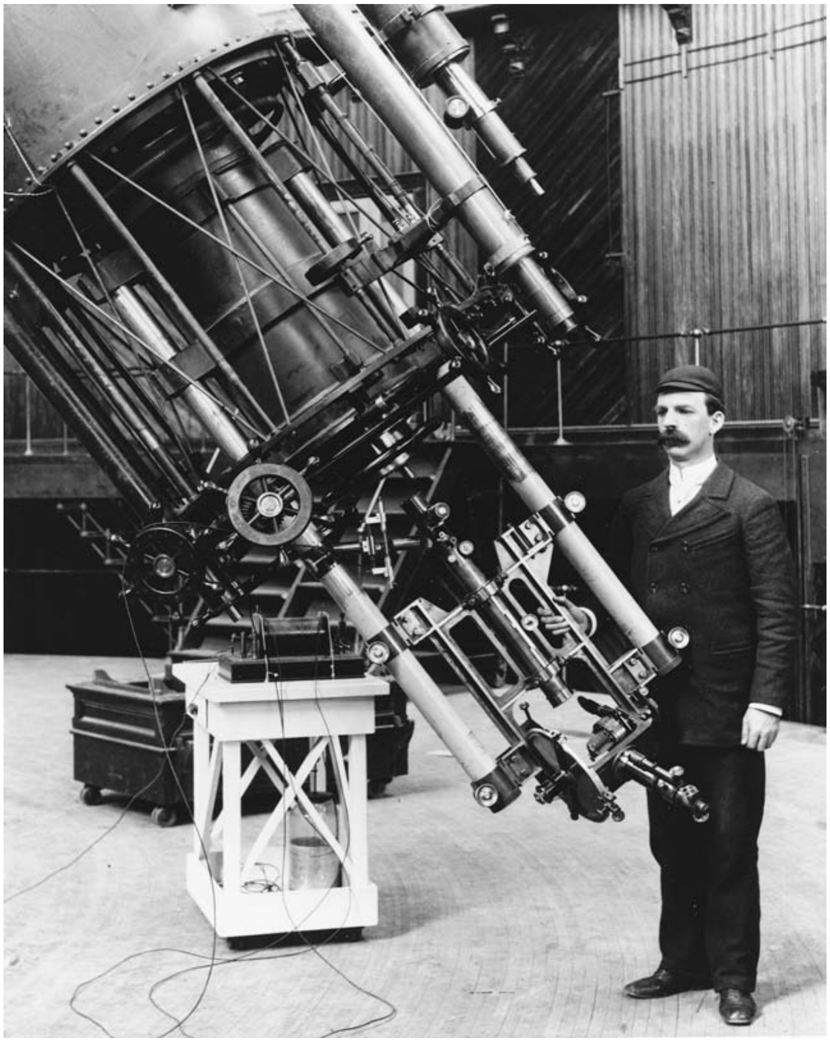

Figure 1.5a. William Wallace Campbell in 1893 at the eye end of the Lick 36-inch refractor. (Courtesy of the Mary Lea Shane Archives of the Lick Observatory, University Library, University of California–Santa Cruz.)

The Pacific Division of the American Association for the Advancement of Science desires to form a card catalogue of the men and women in the Pacific region who would assist, or at least take a friendly interest, in the advancement and dissemination of knowledge. . . . Our present want is especially a list of those who are trustees or supporters of educational institutions, art galleries, museums, libraries, etc.; of physicians, attorneys, merchants, and

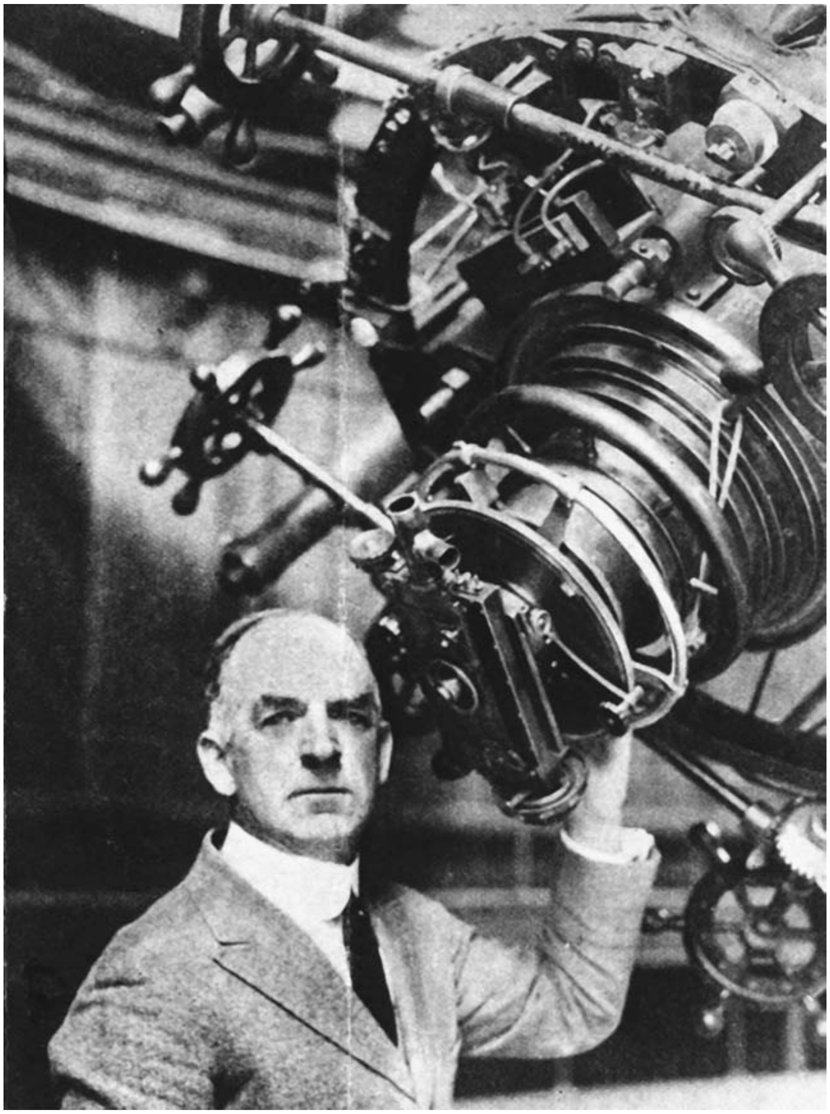

Figure 1.5b. Campbell thirty years later, at the same telescope, several months before he announced results of eclipse observations made in Australia in 1922. (Courtesy of the Mary Lea Shane Archives of the Lick Observatory, University Library, University of California–Santa Cruz.)

> other leading citizens who take a personal interest in the intellectual advancement of their communities; and of persons who have a special interest in some branch of science. Would you be willing to form such a list for your own region, but letting it include addresses in any part of your state? We need to know full names and post office addresses, titles, occupations or professions, and we should be glad to have a line describing their leading interest or service.[24]

This combination of organizational ability and attention to the wider support of science led the University of California to ask Campbell to be president in 1922. The National Academy of Sciences made the same request after he had retired some eight years later.[25] For the first two decades of the twentieth century and more, Campbell directed research at Lick Observatory with characteristic acumen.

Campbell's opposite number at Mount Wilson, George Ellery Hale, was scientific entrepreneur par excellence (fig. 1.6). Hale, more than any one person, contributed to the advancement and institutionalization of astrophysics research in the United States. He was the driving force behind Yerkes and Mount Wilson. After graduation from M.I.T. in 1890, he built his own 12-inch telescope at home and set up Kenwood Observatory, which he ran for six years. In August 1894, while associate professor of astrophysics at the University of Chicago, he started the *Astrophysical Journal*. He was also one of the founding members of the American Astronomical and Astrophysical Society.[26] Hale was among the first American astronomers to dedicate himself single-mindedly to astrophysical research as opposed to the older positional astronomy. As a boy he had the opportunity to help George Washington Hough, director of the Dearborn Observatory in Evanston, Illinois, with time determination. Though he loved doing it at the time, he decided then that such work could never satisfy him. "The reason lay in the fact that I was born an experimentalist, and I was bound to find the way for combining physics and chemistry with astronomy."[27]

After founding Yerkes Observatory and making it one of the world's leading astrophysics observatories, Hale was drawn to the clear skies out West. He established the Mount Wilson Solar Observatory at Mount Wilson in southern California and became its first director. As soon as research began at Mount Wilson, the world's astronomers were amazed at the technical advances. In 1908 Walter Sydney Adams published remarkable results from a spectroscopic investigation of the Sun's rotation. Cape of Good Hope astronomer Jacob Halm congratulated Hale on Adams's paper; but, he admitted, "while reading it I could not suppress a feeling of sadness at the astounding fact that he could do on one plate what took me a whole year's troublesome visual observations."[28] Hale's vision was

Figure 1.6. Astronomer George Ellery Hale operating his spectroheliograph, which he used to study magnetic fields in sunspots. (Courtesy Carnegie Institution of Washington.)

to establish the world's leading center for research, including the observatory, a physical laboratory, and leading theoreticians nearby. He was instrumental in creating the California Institute of Technology to provide a first-rate education and research institution that would complement the work of the observatory.[29]

While the Americans were developing a strong capability in astrophysics research, the leading European countries were by no means insignificant in comparison. Some of the most influential early pioneers in astrophysics were British. During the first decade of the twentieth century, the largest proportion of observatories engaged in astrophysical work was in Britain. Solar physics particularly interested British astronomers. More solar research occurred in Britain than in the other leading European countries and the United States. Germany, too, had a strong commitment to astrophysics and to research in general. On the eve of the First World War, Edward Charles Pickering, director of Harvard College Observatory, could boast that "the United States has attained an enviable position in the newer departments of astronomy," meaning astrophysics. Yet he wondered whether the American lead could be maintained. He noted, "In Europe, especially in Germany, observatories and instruments of the highest grade are now being constructed, the government furnishing appliances with the most liberal hand."[30]

The outbreak of World War I and subsequent years of international chaos drastically changed the situation. After the war, Germany was thrown into a financial crisis that severely affected resources for scientific research. William F. Meggers of the Bureau of Standards in Washington traveled in Europe for four months during the summer of 1921. He visited scientists in England, Holland, France, Germany, Austria, Switzerland, and Italy. He observed that German and Austrian scientists were in a bad situation. The Germans could not afford subscriptions to foreign scientific journals. In many cases they were reticent to try, because of resentments due to the war. Inflation was crippling Austria, reducing the University of Vienna's annual appropriation for its physics institute to one-sixtieth of its 1914 level, or "less than 15 shillings in British money!"[31] In the fall of 1923 a concerned Meggers wrote Heinrich Kayser in Bonn asking incredulously whether what he had been reading in U.S. newspapers about the German mark was true or whether it was a joke. Meggers had been "so positive that your country would survive that I bet on marks when they were 3 for 1 cent and now they are 1,000,000 for 2 cents."[32]

With the economic situation as bad as it was, Germany could not compete on the international scene. Scientific isolation from allied countries exacerbated the situation. French astronomers adamantly opposed having any association with German colleagues. Though the British were less single-minded about the issue, the general feeling among European astronomers was to exclude Germany from the International Astronomical Union, which the allied countries created after the war.[33] The American position was equally anti-German. Unlike some of their transatlantic colleagues, the Americans did not want to extend the ban to neutrals and urged that they be admitted to the union as early as possible. At the Brussels meeting of the International Council in July 1919, the neutrals were invited to membership.[34] Germany was another story. At Campbell's initiation,[35] the board of directors of the Astronomical Society of the Pacific removed the Berlin Observatory from a list of six nominating observatories for the society's Bruce Medal. They substituted the National Observatory of the Argentine Republic at Cordoba.[36] In spring 1922 Joel Stebbins, secretary of the American Astronomical Society, canvassed members on the issue of renewed relations with the Germans. Out of twenty-nine respondents, nine were opposed and twenty were for renewal, "but more or less with reservations to the extent that we should not do anything to offend the French and Belgians."[37] The British, as winners, did not suffer as much as the Central Powers; and, due to their physical isolation from the continent, not as much as their French allies. The United States came out ahead of the Europeans in general. In astronomy their strong position before the war turned to world leadership after it.

European Brains and American Money

In 1905, the same year that Einstein published his first article on relativity, Hale successfully launched the International Union for Solar Research. Its fourth conference took place at Mount Wilson in August and September of 1910. About one hundred astronomers attended the event, many of whom were from Europe. One of the principal decisions that emerged from the sessions was to extend the union to incorporate stellar astrophysics.[38] Among the festivities was a tour of the observatory, where Hale had established a sophisticated laboratory for spectroscopic research as part of the installation. The guests included Karl Schwarzschild, the dynamic director of the Astrophysical Observatory in Potsdam; Heinrich Kayser of Bonn; and a young German spectroscopist, Heinrich Konen. Konen was on an extended visit to U.S. observatories and laboratories as part of a traditional *Studienreise*, or study travel year. He submitted a report of his trip, which included the following assessment of American astrophysics and physics: "One ought not to be deceived by well meaning articles in the newspapers which repeat the old view that Americans have money and institutes but no researchers or ideas. Perhaps this is still true in other fields, but in astrophysics and physics it has been out of date for a long time, and implies a fatal error. The Americans possess both, men and ideas, money and instruments; and they apply them with reckless energy."[39] The European perception of America as the nouveau riche of science persisted in Britain as well as Germany. In February 1911, the president of the Royal Astronomical Society used the phrase "British brains and American money" when referring to lunar tables calculated by Ernest W. Brown, a British-born theoretical astronomer who had crossed the Atlantic to take a position at Yale. Ironically, he was arguing for more support for the older astronomical discipline of astrodynamics, which he felt was being neglected in favor of the newer fields of astrometry and astrophysics.[40]

On his *Studienreise*, Konen had perceived the strength of the American astrophysics community. Men like Hale had organized it into an extremely interdisciplinary group. Spectroscopists and other physicists interacted with the astronomers. Everyone tried to solve problems that bore directly or indirectly on astrophysical questions. The physicists Konen met in this milieu were largely practical men whose contact with practitioners from other disciplines generated exciting new lines of research. Most of them were not theoretical physicists. In fact, the Europeans were not far off in their assessment of the Americans' theoretical abilities. Hale, Campbell, and others trying to build up the research community in America were keenly aware of their deficiencies in theory.

Theoretical developments such as relativity and quantum mechanics coming out of Germany increasingly motivated these leaders to beef up their strength in modern theoretical physics. They relied on European institutions to give the younger astronomers more physics training. Paul Merrill got his Ph.D. in astronomy from the University of California at Berkeley in 1913. After completing his thesis at Lick Observatory, he landed a job as astronomy instructor at the University of Michigan. Before he left, Campbell had advised him that "a knowledge of the modern developments of Physics" would be of "value to an astronomer." Two years later, Merrill asked Campbell if he should go abroad after the war to study in Europe. Campbell replied:

> My opinion on the importance to an astronomer of a knowledge of the modern developments of physics is stronger now than when you were here. Next academic year might be the time to go abroad to Cambridge, Manchester, Paris, or Germany, provided the war ends within the next few months, but this is not probable; and to plan for residing in Europe while the war is in progress would be folly. Professor Millikan, of the University of Chicago, is a good man in certain phases of modern physics, but you would get so many other advantages through European experience I would advise waiting for conditions there to improve.[41]

Robert Andrews Millikan had been a student of Albert Abraham Michelson, winner of the Nobel Prize for physics in 1907. Michelson's pioneering work in optical interferometry had earned him an international reputation as an experimental physicist of the highest caliber. Millikan, trained in the same tradition, became equally renowned for measuring the elementary electronic charge, experimentally verifying Einstein's quantum formula for the photoelectric effect and measuring Planck's constant.[42] Millikan was a fine experimenter, but he was no theoretician. His friend, physicist Frank B. Jewett, president of the American Institute of Electrical Engineers, presented the Institute's Edison medal to Millikan in 1923, the same year that Millikan received the Nobel Prize in physics. Jewett had sent him a copy of the speech he would be giving at the presentation. At Millikan's request, he deleted the following sentence: "I do not think that Millikan is a great physicist in the sense that we look upon Newton, Kelvin, Helmholtz or JJ Thomson, that is, as a man who has produced or will produce revolutionary ideas." Jewett obviously thought highly of Millikan, but he understood that he was a specific brand of experimentalist. The great theoreticians he had mentioned had come from the United Kingdom and Germany.[43]

In the United Kingdom, mathematicians trained at Cambridge University had a virtual monopoly on physics posts as well as astronomy. The term "wrangler" was given to graduates who obtained first-class degrees in mathematics at Cambridge. "Senior wranglers" came first in the infamous tripos examination. In 1914, the observational astronomer Arthur Hinks complained "the whole trend of policy in Cambridge & England generally . . . is to take astronomical posts as sustenance for mathematicians." Hinks was bitter because he had been passed over in favor of a younger man, Arthur Stanley Eddington (fig. 1.7), to succeed Sir Robert Ball as director of the observatory at Cambridge. Hinks had been chief assistant since 1903. Eddington was an up-and-coming theoretician of exceptional ability. In 1904 he was the youngest senior wrangler in the history of Cambridge and became one of the world's leading theoretical astrophysicists. Hinks was a positional astronomer of the old school and did not like the shift in orientation toward astrophysics. He felt that he rightfully deserved the Cambridge directorship and resigned rather than stay as chief assistant under Eddington. "They must have been mad to imagine that a man who had had the ambition to do what I had been able to do would be content with an inferior position and no fun all his life."[44] In addition to having math virtuosos in astronomy posts in England, one also found theoretical astronomers holding chairs in applied mathematics. For example, James Jeans, who later became one of Britain's leading theoreticians in astronomy, began his career in the early 1900s as a lecturer in mathematics at Trinity College in Cambridge. Not being able to obtain a chair at the college, in 1905 he moved to Princeton University in the United States to take a chair in applied mathematics. Only when the incumbent holding the Stokes chair for mathematics at Christ's College retired could Jeans return to a Cambridge post.[45] Jeans played an important role in the 1920s in the theoretical side of research at Mount Wilson.

Hale was keenly aware of the European strength in theory. He was diligent in maintaining contact with European theorists, who in turn val-

Figure 1.7. Arthur Stanley Eddington, Plumian Professor of Astronomy, University of Cambridge. (Courtesy Niels Bohr Library, AIP.)

ued the observational strengths at Mount Wilson. During the fall of 1917, James Jeans was preparing his book on cosmogony, which became one of the classics in the field. He wrote to Hale for permission to include some Mount Wilson material. "On selecting photographs," he related to his friend, "I am not surprised to find that all the 16 which I should like to have permission to reproduce come without exception from Mount Wilson." Jeans admitted to feeling "a little embarrassed at asking for permission to illustrate my book entirely from Mount Wilson photogs., but venture to do so, as yours are so preeminently the best." About a year later, Hale visited Jeans at his estate at Bex Hill in England. He wrote enthusiastically to his wife: "I had a delightful visit with the Jeans at Bex Hill. You may remember that he was a member of the Princeton faculty some years ago. He is an extremely able mathematical physicist and astronomer—Schuster says Rayleigh compares him with Poincaré. He has recently worked out a theory of stellar evolution and we are cooperating with him in his studies of the nature of spiral nebulae." Four years later Hale made the informal collaboration with his theoretical colleague more official. He offered Jeans a Mount Wilson research associateship for the year 1923.[46]

The perception in America that theoretical expertise in physics must be sought in Europe persisted into the 1920s. It was reinforced in the middle of the decade when developments in quantum theory began to pour out of Germany.[47] The new ideas had important applications to astrophysics. The American theoretical astrophysicist Henry Norris Russell applied himself almost exclusively during this period to using quantum theory to calculate frequencies of spectral lines for chemical elements of astrophysical interest. American spectroscopists were very much dependent on theoreticians from abroad. William F. Meggers, at the Bureau of Standards in Washington, D.C., corresponded regularly with Russell about spectra of new elements. Yet he also kept in close touch with theoreticians like Arnold Sommerfeld in Munich, whom he invited in 1923 to speak at the Bureau on quantum theory and atomic spectra. Sommerfeld later sent Meggers his student, Otto Laporte, to spend some time there. After he left, Meggers thanked Sommerfeld profusely:

> There has been such an avalanche of theoretical developments during the past year from [Wolfgang] Pauli, [Werner] Heisenberg, [Friedrich] Hunt, [Max] Born and [Pasqual] Jordan, [Erwin] Schrödinger, and others that Dr. Laporte has been more than busy keeping himself and others informed. We have depended upon him so much for this information and for its application, that we nicknamed him our Herr Geheimrat, and shall miss him very acutely in the future. Shortly after he came he organized a colloquim [*sic*] which has been maintained mainly by his energy and enthusiasm. All of us derived great benefit from these meetings, and we regret that the leading spirit is gone. Many of us recognize that lack of a permanent employee of Dr. Laporte's type is a serious defect in the organization of our Bureau and I have suggested to our Herr Geheimrat that we will try to get him a permanent appointment as soon as he becomes an American citizen.[48]

By this time (1926) the American astronomy community was so strong that European astronomers were coming to study and work with them more often than the reverse. In many cases, Europeans were coming to the United States solely to use the superior equipment there, particularly the large telescopes. Like Meggers and most other researchers at strong centers of experimental and applied physics, astronomers continually sought contact with European theoreticians.

This interplay between observational prowess and theoretical expertise runs like a thread through the story of how American astronomers judged Einstein's theory of relativity. Interaction between astronomers and physicists, Americans and Europeans, scientists and the public, all have a bearing on this basic theme. Relativity came from within the physics discipline, in particular from the German theoretical tradition. The Americans' lead in technological capabilities gave them a major role in relativity testing. The competition between them and the British often highlighted the perceived superiority of the Americans. Yet on the theoretical side, Americans depended on British theorists to explain what the theory was all about. When the public became obsessed with relativity after the war, astronomers had to cope with being cast in the role of expert in a domain that was largely unfamiliar to them.

California Astronomy: The Nation's Leader

The successes of Hale and Campbell at Mount Wilson and Lick made an impression on the international astronomy community. The advantages of good seeing and large telescopes allowed these Western observatories to move quickly to the forefront of astrophysical research. During the war years, British observers noted this fact in their yearly reports of astronomical progress around the world. "The year 1915 is noteworthy for the increase of our knowledge of the motions of the nebulae, and this increase is in the main due to the activity of the Pacific observers." In 1917: "The year is remarkable for an outburst of activity among the astronomers of the Pacific Coast in the recognition of 'novae' in spiral nebulae."[49]

Even in the United States, the California community was an acknowledged leader. Hale's and Campbell's leadership and influence, both nationally and internationally, were important. Clear skies also had a lot to do with it, as Heber Curtis (fig. 1.8) realized after he had left Lick to lead the Allegheny Observatory in Pittsburgh: "Rotten weather, not very cold as yet, but cloudy most of the time. We had a record in October, 23 usable nights in succession, but November and December promise to be likewise

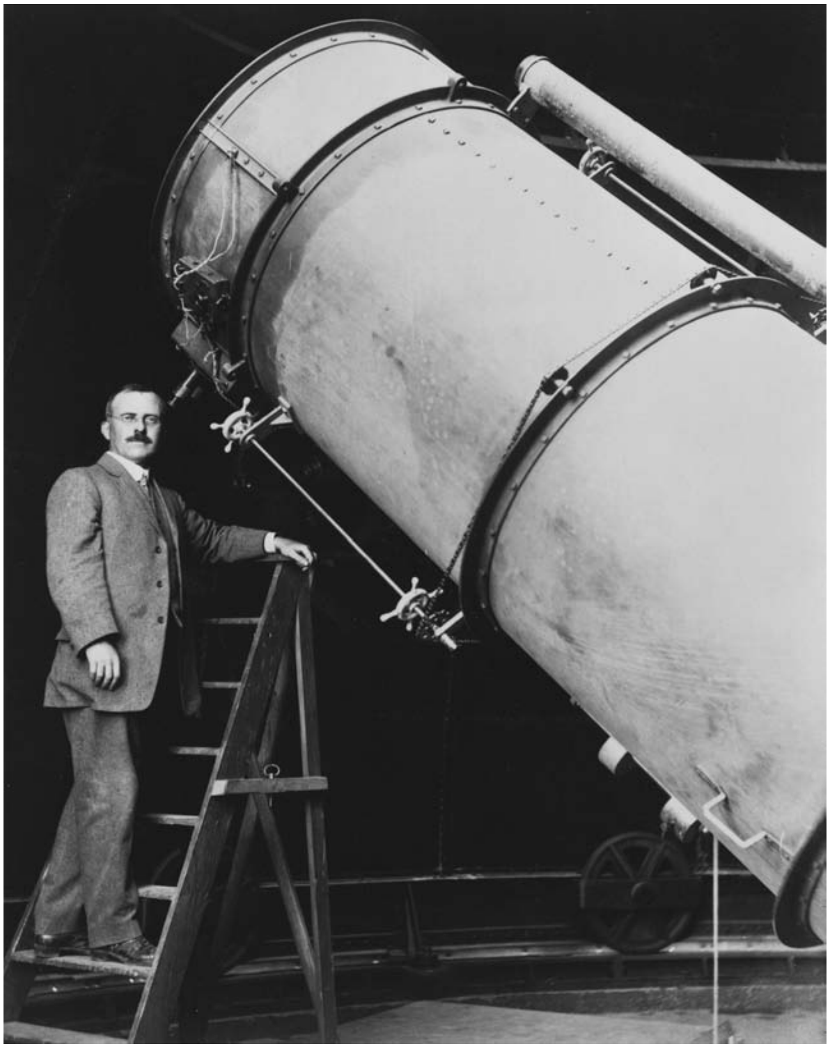

Figure 1.8. Heber Doust Curtis at the Crossley reflector. (Courtesy Mary Lea Shane Archives of the Lick Observatory, University Library, University of California–Santa Cruz.)

records, with the negative sign! I sure would like a good Mount Hamilton night and the use of the Crossley [reflector] once more!"[50]

By the 1920s, the California community was a significant force in educating astronomers. Lick's ties with the University of California at Berkeley ensured that the new generation of astronomers would be schooled in the astrophysics tradition carried on at the two great California observatories. In 1927, over 20 percent of the leading astronomers with doctorate degrees received them in California. Almost three-quarters of these had teaching or research fellowships while they were doing their studies—the highest rate of material support in the country. Students were trained in theoretical astronomy, practical astronomy of position, astrophysics, and modern physics. As part of their degree requirements they could carry out their own investigations at one of the top research observatories in the country, Lick Observatory. Their chances of getting a job after graduating were excellent. A large number of them found positions at Mount Wilson or at Lick. This excellence in astronomical research and education combined to give Pacific astronomy a leading place in the American community. In 1927, over half of the astronomers who were members of the prestigious National Academy of Sciences were located in California or were elected when they lived there.[51]

In the following story, California astronomers emerge as pacesetters in the research and discussion that surrounded Einstein's theory of relativity. Their great strength in observation and relative weakness in theory would have a major impact on how they judged Einstein.