<CT>Introduction: Observatory Techniques in Nineteenth-Century Science and Society

<CAU>David Aubin, Charlotte Bigg, and H. Otto Sibum

<EPI>Observatories—Temples of the most sublime of the sciences, . . . mysterious sanctuaries where, in the silent night and away from the busy hum of men, philosophers are in intimate communication with the innumerable worlds which people the Universe.

—Amédée Guillemin (1864).[1]</EPI>

<EPI>The fact is that when an astronomer goes into his observatory for his night's work he finds it usually convenient to leave all the ecstatic and most of the poetic portions of his constitution outside.

—Robert Ball (1892).[2]</EPI>

<EPI>The object of the Observatory is the accurate and systematic observation of the heavenly bodies, for the advancement of Astronomical Science; co-operation in Geodetic and Nautical Surveys; meteorological and magnetic investigations, and the improvement of Tables useful in Navigation.

—William. C. Bond (1894). [3]</EPI>

<P1>What is an observatory? The term conjures up images of a neoclassical monument surrounded by delightful gardens, a makeshift camp on a desolate beach, a wooden shack on a university campus, or a refuge on an icy mountaintop; a place where astronomers scrutinize faraway stars through gigantic and delicate telescopes, calculating and recording their motions on endless series of folio volumes. There, celestial mechanics and nautical almanacs are elaborated, reference clocks and maps are kept, and magnetic surveys and colonial expeditions are planned and coordinated. There, more or less distinguished audiences gather to hear lectures on the history of the universe and the progress of science.

The observatory is all of this and much more. This book is a first attempt at surveying the observatory's multiple roles in nineteenth-century scientific, economic, and cultural life.

Without pretending to be exhaustive, we want to highlight the range of activities carried out in the observatory in the hope to stimulate further investigation. The observatory, we argue here, was essential in ensuring the growing social and cultural significance of the mathematical, physical, and cosmological sciences in the nineteenth century. It was simultaneously indispensable in constructing elements of the modern western state and society—among others, European colonial expansion and the emergence of a public enthusiastic about scientific and technological developments.

Most nineteenth-century observatories were concerned with both the heavens and the earth. Astronomy of course played a prominent part in observatories: it was their main purpose and, for all involved, the model of what science should be. But astronomy belonged to a larger group of sciences that we refer to as "observatory sciences." Just as historians have recently attempted to characterize the "laboratory sciences" or the "field sciences," we want to focus on another emerging family of nineteenth-century sciences that includes, besides astronomy, cartography, geodesy, meteorology, and to an extent physics and statistics. While universities and academies tended to split science along disciplinary lines, a number of pursuits coexisted at the observatory, and we make a first attempt to investigate them as a coherent whole.

In the course of the nineteenth century, according to one estimate, the number of astronomical observatories worldwide rose from fewer than three dozen to more than two hundred—and this excludes the observatories devoted to meteorology, geomagnetism, geodesy, navigation, or statistics.[4] From Göttingen to Königsberg, from Brussels to St. Petersburg, from Rio de Janeiro to Petchaburi (Thailand), the endowment of expensive observatories became an inescapable requirement for any modern state intent on preserving its political independence and securing its integration into the world-system (figure 1).[5] Observatories were dear to modern states not only for the different services they rendered—

most obviously in domains connected with the control and administration of space, cartography, geodesy, and navigation—but also for ideological purposes. Simultaneously, observatories were a central focus for expressing public curiosity about science and enthusiasm for it.

<figure 1 near here>

The picture of the observatory that we paint here therefore moves away from conventional representations of the solitary astronomer at his eyepiece. We present the observatory as a specific space of scientific practice and as an essential element in a number of industrial, technological, and military undertakings, in many ways a pillar of the state (figure 2). The observatory was both, and the frequent public and official celebrations of the observatory and of the observer accordingly emphasized both the abstract and remote character of the science they produced and its very material utility. In all its manifestations, the observatory united heavenly with earthly concerns.

<figure 2 near here >

This diverse set of practices ought to be considered together because they share two fundamental unifying characteristics: they are observatory sciences in that both occupy the space of the observatory and, more fundamentally, because they are based on a set of common techniques. In the following, we explain what we mean by observatory techniques and show some of the ways they were employed.

<A>Observatory Techniques

<P1>The exuberant juxtaposition of activities at the observatory might at first seem bewildering. A nineteenth-century guidebook documents this coexistence of worlds at the Paris Observatory: “The Observatory . . . is a most curious piece of architecture, having in it neither wood nor iron; it is not a large building, but has fine appearance; . . . it is vaulted throughout, and a geometrical staircase, having a vacuity of 170 feet deep, merits particular

notice. There is a circular universal chart upon the pavement of one of the apartments. By means of mechanical arrangements *of* the roof and cupola open, and every night, the weather permitting, astronomical observations are taken. M. Arago, the most celebrated astronomer of France, lectures here, where there is every facility, and every instrument to be found requisite to the promotion of the science of astronomy; there are two pluvia-meters, for ascertaining the quantity of rain that falls in Paris during a year. There is a general map of France, containing 182 sheets, a marble statue of Cassini (the author of the *work*).”[6] Etymology suggests that an observatory is a place dedicated to observation; and indeed, astronomy was traditionally considered the most accomplished observation-based science. In particular, celestial mechanics long provided a model for systematizing scientific observations by using mathematics. For the astronomer Pierre-Simon Laplace, “the only way to know nature is to question it through observation and computation.”[7]

But while they constantly insisted on the importance of observation in the pursuit of scientific truths, scientists and philosophers widely differed on what they meant by it. The *encyclopédistes* defined observation as “the attention of the mind [*l’esprit*] turned toward the objects offered by Nature.” As opposed to experimentation, which could only teach investigators about artificial circumstances, observation was construed as the nonintrusive, albeit methodical, process of perceiving and recording that was the true basis of science. With the rise of the laboratory sciences, observation took on new connotations and often came to be portrayed as a somewhat weaker and overhauled counterpoint to the interventionist methods of the new experimental sciences. Though experimentation now often replaced observation as the idealized methodological foundation of science, laboratory scientists continued to regard the practice of observation as central to experimental work. The value placed by laboratory scientists on the “mechanical objectivity” guaranteed by self-recording apparatuses appears in this light as an appropriation of earlier discourses on scientific observation within a new, experimentalist framework; and underlines the continuing ambivalence of the experimental sciences toward observation. Conversely the observatory sciences' avowed adherence to the observation ideal cannot hide their eminently interventionist ethos; one need only mention land surveying or navigation. Far from being a stable, self-evident, universal category, "observation" is a situated set of practices, methods, and ideals whose complex history remains to be written.[8]

The observatory plays a central role in the history of observation as a practice, method, and value. But to understand this history we need to look beyond the individual astronomer. Observing is a socially and culturally determined experience; the astronomer "looks (schauen) with his own eyes, but sees (sehen) with the eyes of the collective."[9] And conversely, what goes on in the observatory contributes to change in the wider experience of observation. We therefore want to broaden the focus to include the material and conceptual environment of scientists working in the observatory, the cultural and economic constraints to which they are subjected, and the significance of their work in this wider context.

To tackle the complex technical space that was the observatory, we find it useful to focus on what we call "observatory techniques." We take the whole set of physical, methodological, and social techniques rooted in the observatory as our focus of inquiry. Techniques, according to Marcel Mauss, are "a set of generally and primarily manual, organized and traditional, motions and acts concurring to reach a known goal."[10] What we call observatory techniques included the set of practices required to perform successfully at the telescope eyepiece: the calibration, manipulation, and coordination of precision instruments for making observations and taking measurements. They embraced methods of data acquisition, reduction, tabulation, and conservation, along with complex mathematical analyses (error analysis and celestial mechanics). They also included various techniques for producing maps, drawings, and photographs, but also of material, numerical, and textual—

indeed poetic—representations of the heavens and the earth that ultimately shaped the way the world, society, and science itself could be construed. Finally, these techniques incorporated the social management of personnel within the observatory as well as international collaborations.

The techniques we examine here were developed inside and outside observatories—by instrument makers in their workshops, navy officers on ships, civil engineers in the field, and physicists in their cabinets. But in the observatory they were uniquely assembled to form a coherent system. Thereby these techniques helped define a space of knowledge: the observatory. The distinction between place and space was introduced by Michel de Certeau in The Practice of Everyday Life.[11] Place is understood geometrically, in the sense that two things cannot be in the same place at the same time. Space, on the other hand, is a "practiced place." It is "actuated by the ensemble of movements deployed within it," determined by historical subjects, by the users of place. Thus the streets geometrically defined by urban planners are transformed into space by walkers. The physical, geometrical, and geographical way in which Certeau has understood places owes much to the work of observatories in the eighteenth and nineteenth centuries. Technologies closely associated with observatories had a major impact in reconfiguring understandings of space and time whose measurement was changed by theodolites and high-precision clocks, while telegraphy and photography helped transform the way they were culturally experienced.[12] But, more fundamentally, Certeau helps us to consider how observatory scientists created a knowledge space that transcended the boundaries of the observatory.

The observatory techniques as we conceive them reveal the perpetually reengineered cohesion of the observatory sciences. They formed a consistent foundation to a unified science of the heavens and the earth practiced by observatory scientists in the first part of the nineteenth century and later publicized in widely popular works such as François Arago's

Popular Astronomy and Alexander von Humboldt's Cosmos. Humboldt's presentation of his scientific travels is revealing. He insisted on precision and examined the entire terrestrial globe with intense scrutiny. He envisioned the earth as a celestial body to be measured with theodolites and weighed with pendulums, a gigantic magnet whose field could be accurately determined by the sophisticated instruments designed by his friend Carl Friedrich Gauss. Humboldt saw the earth as a thermodynamic system, which could be studied using the tools of geography, chemistry, and statistics, and as a meteorological system whose precise empirical study could be furthered by using the geomathematical isotherms he had invented. As much a stimulus to as an outcome of the scientific practices deployed by the observatory scientists of his day, Humboldt located the unity of science in the necessary connection between the various forms and phenomena of nature, and he eschewed hierarchies among the sciences.

The unity of science was an important concern for nineteenth-century scientists. But one should always remember that the unity of science has been construed in a variety of ways. Some argued, as Auguste Comte did in his Traité philosophique d'astronomie populaire (1844), that a single way of knowing united the sciences. Others, like the director of the Roman College Observatory, Angelo Secchi (as Massimo Mazzotti recalls here), later preferred to found the unity of science on a unique abstract principle such as the conservation of energy, as would later become the norm. As John Tresch shows in this book, Humboldt's unity rested more on the complex interaction between active instruments and trained users than on abstract principles. Even if by 1900 most of the observatory sciences had evolved beyond recognition and in some cases had broken away from the astronomical observatory, Humboldt's vision continued to inspire to discourses on the unity of science, not least in the popular science narratives of the last decades of the century (Ole Molvig, Charlotte Bigg).[13]

<A>A Science of Precision

<P1>Early on astronomers had insisted on the precision of their measurements and computations. The transformation of industrial and scientific cultures in the nineteenth century has been traced in part to the rise of “the values of precision.”[14] Laboratories in universities and industries have traditionally been seen as central locations in this process. The observatory may have been as important, if only because a number of these values already pervaded observatory culture by the end of the eighteenth century. Many fundamental experiments—Léon Foucault’s speed-of-light measurements or Gauss’s electromagnetic experiments, to name just two—were carried out in observatories. “The most precise observations,” Gauss assured his sponsors in 1833, “can be expected only of those mathematicians who are familiar with the finest means of observation, namely the practical astronomer.”[15] At the heart of the observatory’s material culture lay a family of scientific instruments; most, though by no means all, were optical. The telescopes, polariscopes, spectroscopes, magnetometers, clocks, and thermometers populating the observatory expressed the concern of their users—to achieve the highest possible level of precision in the (mostly quantitative) measurement of natural phenomena. Astronomy was the first precision science.[16]

<figure 3 near here >

Take the telescope (figure 3). The construction of this high-precision optical instrument required skilled labor on the part of artisans able not only to etch fine, evenly distributed lines on a brass circle but also to polish glass blanks into aberration-free lenses. These skills were developed in close collaboration with astronomers: standards for making circles were kept at the observatory, and the optical laws for producing achromatic lenses were derived from experiments often conducted by observatory physicists.[17] In observatories, telescopes were often set up on stone pillars to isolate them from vibrations; they rotated along an axis precisely oriented with respect to the meridian. Telescopic observation relied on precise routines, such as the eye-and-ear method: the observer listened to the tick of a sidereal clock (another high-precision instrument), noting on paper slips the exact time when a star passed above a metallic thread in the telescope’s ocular. Mastering this procedure required a long apprenticeship. And what could not be disciplined by training was quantified. The systematic differences in observers’ measurements of the same object were identified and investigated both mathematically and experimentally by astronomers early in the nineteenth century. This knowledge was condensed into the so-called personal equation, which gave each observer’s deviation from the average (correct) measurement.[18] Finally, as Simon Schaffer explains here, the consignment of observatory measurements and their subsequent treatment was a highly ritualized operation. Raw data had to be “reduced,” that is, reconciled by taking into account such factors as the time of the night, the longitude and latitude of the observatory, the position of the earth, and even meteorological conditions which affected the refraction index of the atmosphere. Numbers were produced in vast quantities in the observatory and subjected to extensive manipulations before being carefully preserved for posterity in well-kept archives and long rows of beautifully bound volumes. The computing room and the library were essential components of all large observatories (figure 2).

“Every instrument,” Friedrich Bessel wrote, “is made twice: once in the workshop of the maker out of brass and steel, and a second time by the astronomer on paper.”[19] In the observatory, instruments were submitted to intense scrutiny. The observatory was a workshop where a wide range of technological devices—optical instruments, electrical apparatuses for telegraphy, clocks—were developed, tested, calibrated, and put to extensive use. This was done in association with instrument makers whose workshops were usually close to the observatory, frequently their main customer.[20] Conversely, instrument makers’ workshops in the nineteenth century were sometimes used as observatories, where observations were made on instruments rather than stars. Instrumentenkunde, the art of studying the properties of instruments to design better ones, became characteristic of much nineteenth-century experimental physics. At times physicists have seemed to have paid more attention to their instruments than to the natural phenomena they purportedly studied.[21] Concern with instrumentation was certainly shared by observatory scientists from the early 1800s and remained a structuring element of the interaction between physics and astronomy well into the last decades of the century, as Richard Staley shows in his discussion of Michelson's ether-drift experiments.

The observatory helped to further the culture of precision that transformed scientific practices in the nineteenth century. The "crusade" by Humboldt to survey the Earth's magnetic field is an example of how observatory techniques were adopted for electromagnetic research. In 1828 Humboldt built a small magnetic observatory in Berlin and initiated a program of coordinated observation at various locations at prearranged times. This required a precise knowledge of time and of the geographical locations, each of which was determined by astronomical means. Gauss, then director of the Göttingen Observatory, took a major part in this survey. Mathematical equations had previously been used to account for electromagnetic phenomena, but Gauss may have been the first to quantify them.[22] Characteristically for an astronomer, he gave thorough descriptions of the instruments he had taken from the observatory panoply and adapted to geomagnetic surveys. His addition of a telescope to Gambey's dip magnetometer allowed the scientist to observe the needle at a distance and avoid its disturbance though air currents and bodily heat (figure 4). With his bifilar magnetometer, Gauss claimed that "the horizontal part of the earth's magnetic field can now be observed as precisely as the stars in the sky."[23]

<figure 4 near here>

Even the physical laboratory borrowed from the observatory. Before large physical laboratories were established in the 1860s and 1870s, it was common to speak of “physical observatories.”[24] Recognizing the need for a specially designed environment for his experiments, Gauss had an iron-free building set up on the grounds of the astronomical observatory. This was one of the first modern physics laboratories. In Germany, his collaborator Wilhelm Weber wrote to Edward Sabine, “until now there existed only collections of physical instruments without permanent facilities for their use; there were no physical laboratories or observatories.”[25] Notwithstanding, the astronomical observatory continued to be an important setting for conceiving and performing crucial experiments in optics, magnetism, and physiology.

<A>Managing Numbers: Statistics

<P1>In observatories a wide array of mathematical skills were fostered and developed. The observatory sciences were heir to the eighteenth-century “mixed mathematics,” sciences such as astronomy, music, optics, and mechanics in which mathematics figured prominently.[26] In the hands of observatory scientists from Leonhard Euler, Alexis Clairault, Jean Le Rond d’Alembert, later Laplace and Joseph Lagrange, and to Louis-Augustin Cauchy and Henri Poincaré, the celebrated three-body problem stimulated the development of mathematical analysis. The division of computing labor was first carried out in close collaboration with the Bureau of Longitudes, much as a team ked by Gaspard Prony computed logarithmic tables during the French Revolution. It has also been argued that Gauss’s work on non-Euclidean geometry was related to his geodetic work.[27] We will illustrate the complex relationship between mathematics and observatory techniques by taking the example of statistics.

In the early nineteenth century statistics was defined as “all that can contribute to give an exact idea of an empire, enlighten the competent administrator, and train the true statesman.”[28] By 1900 statistical science had been quantified and tied to probability theory, and this was in part the work of astronomers. As Simon Schaffer emphasizes, the astronomer’s unique ability to manage numbers in vast quantities had wide-ranging implications. In his discussion of early-nineteenth-century Sweden, Sven Widmalm shows how geodetic and statistical surveys were linked to coordinated efforts for mobilizing the nation as a whole for war purposes. Drawing attention to techniques for managing numbers throws new light on the participation of observatory scientists in mathematizing the social sciences.

“Quantification,” according to Theodore Porter, “is a social technology.”[29] But the techniques used by statisticians to gather, tabulate, and manipulate data with the goal of making them universally comparable bear close resemblance to those designed by observatory scientists. Authors of almanacs had long recognized this when they published ephemeredes, meteorological, and statistical data side by side.[30] The evolution of statistics might indeed be compared to the development of longitude determinations for navigation, as discussed by Guy Boistel. In both cases the conflicts between expert quantifiers in the observatory and actors on the field relying on traditional techniques led to a continual conceptual and social adjustment.

Observatory scientists were among the first scientists to face the “avalanche of printed numbers” studied by Ian Hacking for the social sciences.[31] Astronomers pioneered probabilistic and statistical tools for analyzing and assessing the significance of their data. Laplace compiled comet statistics and attempted to evaluate the number of observations necessary to ascertain the influence of the moon on the Parisian weather.[32] Astronomers such as Laplace, Gauss, Francis Baily, John Herschel, and Adolphe Quetelet developed principles of probability theory to deal with the most intricate astronomical questions. It is therefore hardly a surprise to find that observatory scientists often paid close attention to statistics and contributed significantly to their development in the nineteenth century. As an example one might mention the Annuaire du Bureau des Longitudes for 1869, in which statistical demography occupies a large place, alongside astronomical, geographical, meteorological, and physical data and memoirs (figures 5–6).

<figures 5, 6 near here>

Quetelet, the director of the Brussels Observatory, developed his social theory of the "average man" on the basis of a formal analogy with astronomy: "In my opinion, statistics must therefore tread the same path as the sciences of observation."[33] Among historians of statistics, the analogy has been debated at length and caused some uneasiness, owing to the perceived epistemological rift between Laplacian determinism and the notion of statistical causation in mathematical statistics.[34] But Quetelet might be most appropriately described as an observatory scientist intent on adapting the techniques he had learned in the observatory to understand and control social phenomena.

Developed largely for observatory purposes, Gauss's and Laplace's theory of errors is justly famous for having set the foundations for Quetelet's mathematical statistics. Error theory has been compared to the technologies of mechanical objectivity: "like photography, [it] was a strategy for eliminating interference by subjects."[35] Stéphane Callens has noticed that in elaborating his theory of errors, Gauss seemed more concerned with the order inherent in the mathematical analysis of celestial motions than with natural order.[36]

Again, it is no surprise to find that in France statistical institutions were often called observatories. In Hard Times Charles Dickens had already imagined such a space, "a stern room, with a deadly statistical clock in it, which measured every second with a beat like a rap upon a coffin-lid." "As if an astronomical observatory should be made without any windows, and the astronomer within should arrange the starry universe solely by pen, ink, and paper, so Mr. Gradgrind, in his Observatory (and there are many like it), had no need to cast an eye upon the teeming myriads of human beings around him, but could settle all their destinies on a slate, and wipe out all their tears with one dirty little bit of sponge.”[37] Martina Schiavon’s and Sven Widmalm’s contributions detail how geodetic surveys led to the militarization of observatory techniques. Writing to Sabine, Weber explained: “One finally increasingly recognizes the importance that the education of exact observers of nature has for science and for practical life. So far only astronomy has offered an opportunity . . . for the education of exact observers.”[38] By 1900 the number of “exact observers” of society and nature had skyrocketed; the significance of observatory techniques in this process remains to be established. This does not imply that the circulation of observatory techniques between different communities was always straightforward. Guy Boistel’s close study of nautical astronomy shows that the transfer of techniques from the astronomer to the seafarer was always a contested affair in which each community tried to extend its acknowledged domain of expertise at the expense of the other.

<A>Observing with “Science’s Eye”: Networks

<P1>Statistical enterprises relied on extensive data-gathering networks that were of central importance in the history of nineteenth-century observatories. Twice in the space of one year in 1853, Quetelet welcomed delegates from western nations to the first international congresses on navigation and on statistics in Brussels. This experience inspired him to dream up “the vastest observation system ever conceived by the human mind: to cover the whole globe, in all its accessible parts, with a vast network of observers . . . so that science’s eye remains ceaselessly open, so to speak, to all that happens on the surface of our planet.”[39] Networks have been a favorite metaphor for the way science works outside of controlled environments and in relation to political power.[40] One origin of this metaphor, and indeed the model that inspired late-nineteenth-century and twentieth-century technoscientific and imperial networks, was the observatory. This book sheds light on our contemporary

understanding of science by examining another typical observatory technique: the construction and maintenance of extensive networks in which observatories were key nodes.

Observatory scientists indeed were at the forefront of scientific networking. In 1800 an international group of astronomers led by Franz Xaver von Zach had set up the Vereinigte Astronomische Gesellschaft to look for what they thought was a missing planet between Mars and Jupiter. They established an early international vehicle for communication by publishing regular observations in Zach's Monatliche Correspondenz (1800–14) and Heinrich Christian Schumacher's Astronomische Nachrichten (from 1821).[41] In the case of geomagnetic campaigns, observatory instruments and techniques were designed at the same time as the networks in which they functioned.[42] In his chapter on Humboldt's metaphysics, John Tresch argues that the wide range of instruments and their users formed a "republic." They existed only as parts of coextensive networks that had to be organized both socially and technologically.

A case in point is meteorology (figure 6).[43] Observatories traditionally measured, centralized, and published data about the weather. When systematic surveys were first envisioned under Napoleon I, they were designed on the basis of exemplary observatory techniques—instrumental technologies and tabulating techniques. In meteorogical surveys, Jean-Baptiste Lamarck specified, "careful, detailed, simultaneous and comparable observations" should be tabulated in standard ways, and all the tables thereby produced should be reunited in a central site where they would be examined and compared.[44]

<figure 6 near here>

Observatory networks were specially crafted to integrate particular techniques. Observatories collected local data in standardized ways and centralized them at a few selected, carefully regulated centers. The meteorological networks established by the Paris Observatory director Urbain-Jean Le Verrier in France, the Admiral FritzRoy in Britain, and the Smithsonian Institution in the United States were grafted to telegraphic lines in just that way, while the director of the U.S. Naval Observatory, Matthew Fountaine Maury, compiled naval logbooks by the thousands. To take their place in the network, observers had to be disciplined or the observations had to be mechanized, as Massimo Mazzotti shows with regard to Secchi's meteograph. Extracting numbers from precision instrumentation, tabulating them, and making forecasts and theories on that basis followed the model provided by astronomy, not metaphorically but by mobilizing the very techniques that defined observatories. No wonder meteorological stations came to be called observatories!

While meteorological networks replaced traditional qualitative assessments of the weather with quantified data wired telegraphically to, and compiled in, a central node, observatory scientists used similar resources for the precise measurement of the earth. Geodesists who relied on what topographical information they could gather from peasants in the fields or notables in the villages they visited to select their observation sites transformed local knowledge about the landscape into standardized astronomical coordinates, as Sven Widmalm and Martina Schiavon show. Observatories also established time distribution networks, supplying public clocks with standard time set to the Greenwich meridian (Ole Molvig). Thanks to photography, even astronomical data could be dispatched in a worldwide network of observers and analyzers of plates.[45]

Observatories were key sites for the technological networks of nineteenth-century industrial nations. Standards of measurement such as the yard and meter were defined by observatory scientists and safeguarded in observatories. As astronomers had long realized, universal standards are an absolute requirement for communication within a distributed network of observers. Gauss's introduction of absolute units in electromagnetism was said to have "extraordinary significance for physics."[46] The observatory was an acknowledged site of technical expertise where a broad range of technologies, clocks, electrical devices, thermometers, and computing machines were calibrated and subjected to stringent testing. In the United States they were even deemed essential to business, in part because they provided time—“An accurate knowledge of time is important to all business men, but especially to banking.”[47]

Not all networks are equivalent, however. In his discussion of the Russian Central Observatory in Pulkovo, Simon Werrett shows that the center can sometimes stand in for the whole network. In this case the network’s pragmatic function of extending control over Russian territory was overshadowed by the czar’s desire to represent this network theatrically. Similarly, both Theresa Levitt and John Tresch reveal that different conceptions of the autonomy of individual participants (whether observers or instruments) in collective networks of observation could be a potential source of conflict. Indeed, all the contributions to this book in one way or another emphasize the utterly political nature of the observatory scientists’ networking activities.

<A>Observatory Techniques on the World Stage

<P1>“Outside the scientific services,” George Orwell noted in Burmese Days, “there is no particular need for a British official in India to do his job competently.”[48] Historians are increasingly becoming aware of the importance of scientific institutions for imperialistic enterprises. It is hardly worth insisting that observatory techniques—and not just the techniques of medicine and natural history that are most often studied by historians of colonial science—also proved indispensable in the constitution of large overseas empires. Navigation and cartography, as Guy Boistel recalls here, motivated the establishment of the Paris and Greenwich observatories: “it is in such institutions that science became part of the infrastructure of the modern state.”[49] In the eighteenth century the longitude problem structured many of the scientific and technological questions raised in the academy, the observatory, and the workshop, and at the highest level of government. In the following

century the grafting of permanent or makeshift observatories in conquered territory went hand in hand with extensive efforts in cartography, geodesy, hydrography, and meteorology in service to the discovery, conquest, and settlement of new colonies. A precise study of observatory techniques in empires is bound to produce a more comprehensive picture of the resources needed for imperialistic pursuits (figure 7). In his study of the Paramatta Observatory in Australia, Simon Schaffer shows the overlap between observatory techniques of number crunching and the techniques of colonial administration.

<figure 7 near here >

The colonial project transplanted the metropolitan situation into foreign lands. And of course local complexities in turn had a crucial impact on the science itself—on the knowledge it accumulated and the way it was organized socially, as well as on its political significance. By expanding observatory techniques and networks and taking them into new territories (geographic and social), imperialistic projects sometimes overstretched both techniques and networks. These challenges provided opportunities for overhauling techniques and networks and served to enhance the global prestige of observatory techniques.

The participation of observatory scientists in imperial projects also had important consequences for the metropolis. In the nineteenth century, as Alex Pang has shown in his study of eclipse expeditions, astronomers came to rely on imperial structures to extend the range of their observations.[50] As David Aubin and Simon Schaffer discuss in this volume, such enterprises in turn could have a profound impact on the astronomical science carried out in British and French central observatories.

Recent postcolonial studies have shown that traditional dichotomies that form the basis for nineteenth-century colonial rhetoric—Occidental and Oriental, civilized and primitive, scientific and superstitious—were constantly “crossed and hybridized.” Claims about progress, civilizing missions, and rationality were blatantly negated by the practices of exploitation in the colonies. The historian Gyan Prakash has explained that the “contortions of the discourse were endemic to colonialism not because of the colonizer’s bad faith but due to the functioning of colonial power as a form of transaction and translation between incommensurable cultures and positions.”[51] The boundary between Orient and Occident is blurred further when one considers the political uses made of astronomical events, such as the eclipse in Thailand in 1868 discussed by Aubin. His analysis shows that the pragmatic and ideological uses of the eclipse were very similar in the European and Southeast Asian contexts.

<A>Representations: Instruments, Images, and Imagination

<P1>A final example of observatory technique is representation.[52] The observatory was a representation factory in three main overlapping senses. Observatory scientists were primarily concerned with developing imaging technologies. Part of their job was to process raw data and construct elaborate—and socially potent—representations of the cosmos in various forms (maps, tables, equations, narratives, and pictures). A true “laboratory of visuality,” the observatory was a favorite site for reconfiguring the visual experience in the nineteenth century charted by cultural historians.[53] Recent studies have shown that seeing is a culturally determined act, shaped by deliberate strategies and by more diffuse but nevertheless powerful forces. Particular architectures (e.g. the panopticon or the urban perspective) discipline the sight as well as individual and communal behavior. New visual technologies influenced nineteenth-century aesthetics, giving rise to discourses surrounding the objectivizing techniques of mechanically rendered images, especially photography.

From the mid-nineteenth century onward, optical technologies became ubiquitous in modern western societies—in the observatory, the laboratory, and the scientific field, in the theater, in the museum, and at the exhibition, in public institutions, and at the factory. Optical instruments have contributed to transforming the nature and practice of representation, and thereby have created new ways of seeing the world and society. Optical devices, such as stereoscopes, spectroscopes, photographic cameras and all sorts of deforming lenses and motion apparatus, became as widespread as opera glasses. They were to be found on the streets, in fun fairs, and at exhibitions and were purchased by an increasingly wide range of customers (figures 50, 53).

Optical instruments helped to bring skills, techniques, and technologies to a wider public. The significance of the observatory in the elaboration, circulation, and adoption of the material techniques that partly conditioned the nineteenth-century reconfiguration of vision has been insufficiently discussed in the historical literature. All optical devices were characterized by shared hardware (screws, divided circles, prisms, lenses, etc.) and shared methods of producing and interpreting evidence, all of which were important concerns of the observatory. These devices have mostly been considered in isolation from each other, obscuring their common origin.[54] Popular optical devices were often produced by successor workshops of observatory suppliers. The Soleil-Duboscq-Pellin dynasty, a major supplier of the Paris Observatory throughout the century, also produced projection apparatuses for popular use.[55]

As the preeminent locus of expertise and innovation in optics, the observatory closely interacted with instrument makers in the development of optical technologies. Makers sought to put their instruments to extensive use in the observatory before city planners and social reformers would turn them into actual or emblematic tools for disciplining space and society. Astronomers and makers were concerned with the nature of light and vision, and of error and illusion in perception, as well as the theory and practice of optical arrangements. As Richard Staley and Martina Schiavon show, the observatory, as a repository of expertise, was a source of advice to surveyors, armies, navies, and scientists from other fields, but also to artists, popular lecturers, and showmen who all relied on optical observatory techniques.

New technologies transformed science as well. Astronomers and historians have discussed the impact that new instrument technology had on the emergence of astrophysics in the late nineteenth century by examining the role of the photographic camera and particularly the spectroscope (Richard Staley and Massimo Mazzotti).[56] By transforming the means of observation available to astronomers, these instruments led them to new questions, such as the chemical constitution of celestial bodies, which could not previously be answered satisfactorily. Astronomers were quick to realize that such investigations had a wide popular appeal in particular because of their connection to the question of the plurality of inhabited worlds.[57]

Early spectroscopists decisively contributed to transforming into displays of political and scientific power the optical instruments that they used in the observatory, in the laboratory, and on overseas scientific expeditions. A site for popularizing science, the observatory pioneered many optical techniques which later made their way to fun fairs, exhibitions, and theater halls. Ole Molvig and Charlotte Bigg discuss some of the innovative mechanisms developed by astronomers and popularizers to convey their narratives, which were often closely patterned on scientific devices. The emergence of the concept of the “public” in the second half of the nineteenth century is related to the optical techniques of projection, of photography as a widespread amateur pursuit, and of both combined to create a large press industry. From the mid-nineteenth century this set of techniques was instrumental in launching a broad-based popular science that produced representations of astronomical knowledge, along with visions of society and of science’s place within it.

Representation therefore should also be taken in the extended sense, for the observatory produced not only representation techniques but also powerful representations of science (see figure 8).[58] Central observatories, with imposing architecture and ancient traditions, occupied a privileged place in the life of the city.[59] They had always served representative purposes for their patrons, whether as symbols of a monarch’s enlightened power (Simon Werrett), a nation’s industrial and scientific excellence (Ole Molvig), or republican progressive values (Theresa Levitt). They were accordingly expected to be the site of soirées and visits by dignitaries, state representatives, and the wider public: treating visitors to evening lectures, tours, or peeks through telescopes were important duties for professional astronomers. Public participation could take different forms, from an impromptu, late-night visit to Pulkovo by the czar, who turned up with guests after a dinner party, to Arago’s deliberately democratic lectures to the Parisian population on astronomy.

<figure 8 here>

As several contributions to this volume show, cultural and political representation was central to observatory practices, that is, the question of who is entitled to represent science and simultaneously to offer a vision of the polity to be expressed by popular scientific representations. The observatory was a theater in which the state, science, and empire were displayed. There cosmological narratives were crafted and delivered, thematizing the place of man in the universe, the conquest of new territories and populations, and scientific and technological progress. Theresa Levitt and John Tresch demonstrate that cosmological narratives first voiced in fashionable public lectures put forward a vision of how science and the state could work together in the conquest and administration of societies, territories, and nature. Charlotte Bigg explains that as the different observatory sciences grew apart in the late nineteenth century, the unity of science was reaffirmed in grand narratives wedding positional astronomy with meteorology, physics, astrophysics, and geology. Cosmic stories flowing out of the observatory acquired a level of authority that put them on par with competing theological and evolutionary worldviews.

Tensions could arise from the observatory’s dual role: emblematic and pragmatic. Simon Werrett shows that Pulkovo functioned as a pristine showcase for the imagined order of the Russian observatory sciences and the Russian Empire, while the actual networks withered away. Similar tensions between scientific and representational work existed at the Greenwich and Paris Observatories. Yet both were equally important aspects of observatory life. As Ole Molvig argues in this volume, with its cosmic theater, popular observatory, and museum, the Urania was an essential piece in the political economy of Berlin science. His story helps us to understand better why public and private funds were made available for the Berlin Observatory and the laboratories of the Physikalisch-Technische Reichsanstalt, and also what work was carried out there.[60]

In their public exertions, observatory scientists could meet with opposition, even hostility. Their narratives were criticized as being unacceptable for political or religious reasons; they had to meet the challenges raised by the natural sciences and by debates triggered by geology, evolutionary theory, or paleoanthropology. The astronomers' power to broadcast their cosmologies was also resented by competitors on the popular-science market. A growing number of popular lecturers expressed worldviews alternative to those put forward by established scientists (Charlotte Bigg), a sign of the utterly political nature of the observatory's public activities. In various outlets, popular science often pictured scientific power as a benevolent force at the very moment when many in the lower classes were left aside by technological change. Cosmological narratives provided forceful arguments in an ongoing negotiation between different social groups about the nature of science, the world, and society.

The cosmos was contested territory. Who could legitimately speak <u>about</u>, or <u>for</u>, the cosmos was a matter of debate. Both Aubin's and Schaffer's contributions to this volume track the conflicts between various clans intent on asserting their rights to speak for the heavens and—ultimately—for science and modernity. Both further show that numerical, literary, pictorial, and political representations of science cannot be dissociated from knowledge production and scientific practice. Just as we have argued that imperialistic enterprises cannot be confined to the periphery of the history of nineteenth-century science, several chapters suggest that it would be a mistake to view popularization as sitting on the margins of the history of science. In contrast to the view that scientific results are stabilized first in the professional observatory and only then shown to the public, Tresch, Levitt, and Bigg insist that interactions with the public must be counted among the elements that structure scientific pursuits.

<A>In Conclusion

<P1>How then to account for the strong tension between the ubiquity of observatory techniques in modern society and the prevalent image of astronomy as an ethereal pursuit? By the end of the nineteenth century state-of-the-art astronomical observatories were no longer urban monuments but structures on remote mountaintops. Astronomy seemed to have been symbolically cut off from earthly concerns, to the point where its prominent social position seemed inconsistent with its object of study, even to major scientists such as Poincaré: "Governments and parliaments must find that astronomy is one of the sciences which cost most dear: the least instrument cost hundreds of thousands of dollars, the least observatory costs millions; each eclipse carries with it supplementary appropriations. And all that for stars which are so far away, which are complete strangers to our electoral contests, and in all probability will never take any part in them."[61] This tension can be accounted for by the increased specialization of the observatory users during this period. A need for specialization was felt by an increasingly diversified pool of users adopting observatory techniques. Geodesists and meteorologists in particular deserted the astronomical observatory to found disciplines of their own. In the early twentieth century the observatory more narrowly focused on positional astronomy and astrophysics.[62]

Nevertheless, the observatory and its personnel continued fulfilling a social function into the twentieth century. In times of emergency as in times of peace, observatory techniques—the manipulation of optical instruments, precision measurement, number management, social organization—continued being vital.[63] During the First World War observatory scientists were called upon to perform a great variety of services ranging from active duty on the front to technical and scientific war work.

The observatory was no longer the main site where the reliability of these techniques was put to the test—it was now only one among a wide range of institutions. Bureaus of standards safeguarded metrological units; meteorological stations were established independently of astronomical observatories; large laboratories for physics and psychology investigated the laws of nature and of sensory perception on which observatory practices depended; national statistical bureaus and the international institutes of statistics compiled data and turned their science into a thoroughly mathematical branch; popular astronomy was organized in learned societies where professional astronomers often played no more than figurative roles; separate institutions were set up for popularizing science; photography and soon cinema were by and large turned into forms of art or reporting, losing touch with their scientific origins.

Still, as the techniques fostered in the observatory continued to spread, there were potent reasons to maintain observatories as safe havens for astronomy. Untainted by lowly collusion with industry, war, and politics, the astronomical observatory, more than any other scientific institution, was seen to embody the ideals of disinterested science. Laplace used astronomy to define the omniscient intelligence that human rationality, striving toward the truth, must approach: “The human mind offers, in the perfection which it has been able to give to astronomy, a feeble idea of this intelligence.”[64] This was the view that Arago sought to popularize. His friend Honoré de Balzac portrayed astronomers as paragons of precision and lawful order.[65] In the last third of the century professional popularizers, poets, and novelists turned astronomy into an endless source of romantic bewilderment. But one wonders whether most professional astronomers, spellbound by their numbers, mathematics, and instruments, were not out of touch with the world. From the misanthropic Palmyrin Rosette, handcuffed by his companions in an effort to force him to rejoin the earth in Jules Verne's Off a Comet! (Hector Servadac) to Professor Phostle, the crazed scientist who shocked Tintin by predicting the end of the world in Hergé's Shooting Star (L'étoile mystérieuse), the astronomer had become the lunatic described by Anatole France (figure 10): "Engulfed in the celestial spaces he knew not what occurred upon the surface of the earth."[66]

<figure 10 near here>

Steven Shapin has argued that seclusion is the seed of error.[67] In Thomas Hardy's Two on a Tower, the nightly solitude of the astronomer—especially if troubled by the presence of a married woman—looked suspicious. Set up on mountains, astronomical observatories escaped direct public scrutiny, but the knowledge that they produced retained an aura of certainty, perhaps because their personnel seemed to have so little to do with mundane concerns. The very idea of pure science depended on preserving this untainted site of knowledge production.

Forced to acknowledge that navigation alone provided enough justification for the support of observatories, Poincaré nonetheless insisted that astronomy was valuable in its own right, because it taught philosophical lessons about the proper place of human beings in the universe and provided a methodological guide to the conduct of science: "it is useful because it is grand; that is what we should say."[68]

<A>Notes

1. Amédée Guillemin, The Heavens: An Illustrated Handbook of Popular Astronomy, 2nd edn, ed. J. Norman Lockyer (London: Richard Bentley, 1866), 485.

2. Robert Ball, In Starry Realms (London: Isbister, 1892), 99. We are grateful to Simon Schaffer for suggesting this reference.

3. W. C. Bond to Josiah Quincy, 11 October 1849, quoted in Carlene E. Stephens, "Astronomy as Public Utility: The Bond Years at the Harvard College Observatory," Journal for the History of Astronomy 21 (1990): 21–35, 29.

4. See the data provided by Dieter B. Herrmann in "An Exponential Law for the Establishment of Observatories in the Nineteenth Century," Journal for the History of Astronomy 4 (1973): 57–58; Herrmann, The History of Astronomy from Herschel to Hertzsprung, 179. On the multiplication of observatories see Bigourdan, Histoire de l'astronomie d'observation et des observatoires en France; Hahn, "Les observatoires en France au XVIII^{e} siècle"; Howse, "The Greenwich List of Observatories"; Steven J. Dick, "National Observatories: An Overview," Journal for the History of Astronomy 22 (1991): 1–4; and Dick, "Pulkovo Observatory and the National Observatory Movement."

5. On the American observatory movement see Steven J. Dick, "National Observatories: An Overview," Journal for the History of Astronomy 22 (1991): 1–4; Dick, "Pulkovo Observatory and the National Observatory Movement"; Craig Howard White, "Natural Law and National Science: The 'Star of Empire' in Manifest Destiny and the American Observatory Movement," Prospects: An Annual of American Cultural Studies 20 (1995): 119–60; and Marlana Portolano, "John Quincy Adams's Rhetorical Crusade for Astronomy," Isis 91 (2000): 480–503.

6. Francis Hervé, How to Enjoy Paris in 1842, Intended to Serve as a Companion and Monitor Indicating All That Is Useful and Interesting in the French Metropolis: Containing Historical, Political, Commercial, Artistical, Theatrical and Statistical Information, as Also a Description of the Manners and Customs of the Parisians of the Present Day, with Instructions for the

Stranger in Respect to Economy, and Advice as to His General Proceeding with the French (Paris: Amyot, 1842), 185–86.

7. Laplace, Exposition du système du monde, 6th edn (Paris: Bachelier, 1835), 207. In a recent biography Laplace is shown to have been in many ways the last savant of the Enlightenment. Hahn, Pierre Simon Laplace.

8. See however Marie-Noëlle Bourguet, “Landscape with Numbers: Natural History, Travel and Instruments in the Late Eighteenth and Early Nineteenth Century Centuries,” Instruments, Travel, and Science, ed. Bourguet, Licoppe, and Sibum, 96–125. In his study of observation logbooks in eighteenth-century France, Nicolas Lesté-Lasserre has recently shown this noninterventionist ethos to be a very partial view of the observational practices of the period. See Lesté-Lasserre, “Le journal d’observations astronomiques au XVIII^{e} siècle.” On mechanical objectivity see Daston and Galison, “The Image of Objectivity.”

9. Fleck, “Schauen, sehen, wissen,” 154.

10. Mauss, “Les techniques et la technologie,” 252. For a historiographical discussion of “techniques” in the history of science and technology see Dominique Pestre and Yves Cohen, “Présentation,” Annales HSS, nos. 4–5 (July–October 1998), 721–44; and Sibum, “Narrating by Numbers.”

11. Certeau, The Practice of Everyday Life, 91–130. For the historiography of space in science studies see e.g. Hannaway, “Laboratory Design and the Aim of Science”; Shapin, “The House of Experiment in Seventeenth-Century England”; Ophir and Shapin, “The Place of Knowledge”; David N. Livingstone, “The Spaces of Knowledge: Contributions towards a Historical Geography of Science,” Environment and Planning D: Society and Space 13 (1995): 5–34; Crosbie Smith and Jon Agar, eds., Making Space for Science: Territorial Themes in the Shaping of Knowledge (Houndmills: Macmillan, 1998); and Peter Galison and Emily Thompson, eds., The Architecture of Science (Cambridge: MIT Press, 1999).

12. On cultural changes in notions of time and space see Kern, The Culture of Time and Space, and the more technically informed Bartky, Selling True Time.

13. On this issue see also Peter Galison and David J. Stump, eds., The Disunity of Science: Boundaries, Contexts, and Power (Stanford: Stanford University Press, 1996).

14. Wise, The Values of Precision.

15. Gauss to Göttingen University curator, 29 January 1833, quoted in Jungnickel and McCormmach, Intellectual Mastery of Nature, 1:64.

16. Historians of astronomy can be counted among those who have pioneered the exploration of nontheoretical issues in the history of science, in particular paying considerable attention to instruments of high precision and their makers. See for example Henry C. King, The History of the Telescope (Mineola, N.Y.: Dover 2003 [1955]); and Chapman, Dividing the Circle.

17. See e.g. Jackson, Spectrum of Belief.

18. On the "personal equation," which has given rise to extensive literature, see Schaffer, "Astronomers Mark Time"; Canales, "Exit the Frog," and her contribution to the History of Venus Transits Conference in Paris, 4 June 2004 (forthcoming in Cahiers François Viète); Schmidgen, "Time and Noise." On the social organization of an observatory see Smith, "A National Observatory Transformed."

19. Friedrich Wilhelm Bessel, Populäre Vorlesungen über wissenschaftliche Gegenstände, ed. H. C. Schumacher (Hamburg: Perthes-Besser und Mauke, 1848), 432. We are grateful to Simon Schaffer for this reference.

20. On instrument makers see Turner, Nineteenth-Century Scientific Instruments; and Bennett, The Divided Circle. See also Paolo Brenni's series "19th-Century French Scientific Instrument Makers" in the Bulletin of the Scientific Instrument Society, in particular "I: H.-P. Gambey," 38 (1993): 11–3; "III: Lerebours et Secretan," 40 (1993): 3–6; "XI: The Brunners and Paul Gautier," 49 (1996): 3–8; "XII: Louis Clément François Breguet and Antoine Louis

Breguet," 50 (1996): 19–24; and "XIII: Soleil, Duboscq, and Their Successors," 51 (1996): 7–16.

21. Dörries, "Balances, Spectroscopes, and the Reflexive Nature of Experiment"; Blondel, "Electrical Instruments in Nineteenth Century France, between Makers and Users"; Blondel, "Les physiciens français et l'électricité industrielle à la fin du XIX^{e} siècle"; Jackson, Spectrum of Belief; Bigg, "Behind the Lines"; and Terry Shinn and Bernward Joerges, eds., Instrumentation between Science, State, and Industry (Dordrecht: Klüwer Academic, 2001).

22. Darrigol, Electrodynamics from Ampère to Einstein.

23. Gauss to Olbers, 2 September 1837, in Briefwechsel zwischen C. F, Gauss und H. W. M. Olbers (Hildesheim: Georg Olms, 1976), 2:649. See also David Aubin, "Astronomical Precision in the Laboratory: The Role of Observatory Techniques in the History of the Physical Sciences," Grundsätze über die Anlage neuer Sternwarten, by Borheck, 31–36; Fabien Locher, "The Observatory, the Land-Based Ship and the Crusades: Earth Sciences in the European Context, 1830–50," British Journal for the History of Science 40, no. 4 (2007): 491–504.

24. Aubin, "Orchestrating Observatory, Laboratory, and Field."

25. Weber to Sabine, 20 February 1845, quoted in Jungnickel and McCormmach, Intellectual Mastery of Nature, 1:77. Our emphasis.

26. Gary I. Brown, "The Evolution of the Term Mixed Mathematics," Journal of the History of Ideas 52 (1991): 81–102.

27. Ernst Breitenberger, "Gauss's Geodesy and the Axioms of Parallels," Archive for History of Exact Sciences 31 (1984): 273–89. Ivor Grattan-Guinness, "Work for the Hairdressers: The Production of de Prony's Logarithmic and Trigonometric Tables," Annals of the History of Computing 12, no. 3 (1990): 177–85. D. Aubin, "Observatory Mathematics in the Nineteenth

Century," Oxford Handbook for the History of Mathematics, ed. Eleanor Robson & Jacquelin Stedall (Oxford: Oxford University Press), 273-298.

28. D. F. Donnant, Théorie élémentaire de la statistique (Paris: Valade, 1805), xii.

29. Porter, Trust in Numbers, 49.

30. Perkins, Visions of the Future. See Marie-Noëlle Bourguet, "Décrire, compter, calculer : The Debate over Statistics during the Napoleonic Period," The Probabilistic Revolution, ed. Lorenz Krüger, Lorraine J. Daston, and Michael Heildeberger (Cambridge: MIT Press, 1989), 1:305–16.

31. Ian Hacking, "Biopower and the Avalanche of Printed Numbers," Humanities in Society 5 (1982): 279–95; Hacking, The Taming of Chance.

32. Stephen M. Stigler, "Napoleonic Statistics: The Work of Laplace," Biometrika 62 (1975): 503–17; O. B. Sheynin, "On the History of Statistical Methods in Astronomy," Archives for History of Exact Sciences 29 (1984): 151–99.

33. Adolphe Quetelet, Recherches statistiques sur le Royaume des Pays-Bas (Brussels: Hayez, 1829), iv.

34. Stephen M. Stiegler, "Adolphe Quetelet: Statistician, Scientists, Builder of Intellectual Institutions," Actualité et universalité de la pensée scientifique d'Adolphe Quetelet: actes du colloque organisé à l'occasion du bicentenaire de sa naissance, Palais des Académies, 24–25 octobre 1996 (Brussels: Académie Royale des Sciences, 1997), 51. See also Porter, The Rise of Statistical Thinking, 47ff.

35. Porter, Trust in Numbers, 201.

36. Stéphane Callens, Les maîtres de l'erreur: mesure et probabilité au XIX^{e} siècle (Paris: Presses Universitaires de France, 1997), 60. On the history of statistics and its relation to astronomy see also Alain Desrosières, The Politics of Large Numbers: A History of Statistical Reasoning, trans. Camille Naish (Cambridge: Harvard University Press, 1998); and Michel

Armatte, “Histoire du modèle linéaire: formes et usages en statistique et économétrie jusqu’en 1945” (doctoral thesis, EHESS, Paris, 1995). On error theory see also Martina Schiavon’s contribution to this volume.

37. Dickens, Hard Times, chapter 15. We thank Simon Schaffer for this reference. See also his contribution to this volume for further discussion of the same episode.

38. Weber to Sabine, 20 February 1845, quoted in Jungnickel and McCormmach, Intellectual Mastery of Nature, 1:77.

39. Adolphe Quetelet, Sciences mathématiques et physiques au commencement du XIX^{e} siècle (Brussels: C. Muquardt, 1867), 23.

40. Latour, Science in Action.

41. On the history of collective organization in astronomy see, for Germany, Jürgen Hamel, “H. C. Schumacher: Zentrum der internationalen Kommunikation in der Astronomie und Mittler zwischen Dänemark und Deutschland,” and Gudrun Wolfschmidt, “Internationalität von der VAG (1800) bis zur Astronomischen Gesellschaft,” Acta Historia Astronomiae 14, 89–120, 182–203; and Dieter B. Herrmann, “Das Astronomentreffen im Jahre 1798 auf dem Seeberg bei Gotha,” Archive for the History of Exact Sciences 6 (1969–70): 326–44. For the United States see Lankford with Slavings, American Astronomy, and DeVorkin, Henry Norris Russell.

42. Cawood, “Terrestrial Magnetism and the Development of International Collaboration in the Early Nineteenth Century”; and Cawood “The Magnetic Crusade.”

43. On the history of meteorology see Fleming, Meteorology in America; Anderson, Predicting the Weather; and Locher, “Le nombre et le temps.”

44. Jean-Baptiste Lamarck, Annuaire météorologique pour l’an XI de l’ère de la République française 4 (1804): 153.

45. Bigg, “Photography and the Labour History of Astronomy.”

46. Ernst Dorn, “Anmerkungen” to C. F. Gauss’s Die Intensität der erdmagnetischen Kraft auf absolutes Maass zurückgeführt (Leipzig: Engelmann, 1894), 50, quoted in Jungnickel and McCormmach, Intellectual Mastery of Nature, 1:71. On standards in observatories see e.g. Frängsmyr, Heilbron, and Rider, eds., The Quantifying Spirit in the 18th Century; Schaffer, “Metrology, Metrication and Victorian Values”; and Alder, The Measure of All Things.

47. Elias Loomis, “Astronomical Observatories in the United States,” Harper’s New Monthly Magazine 13 (1856), 25–52, at 51–52.

48. George Orwell, Burmese Days (San Diego: Harcourt Brace, 1962 [1934]), chapter 5, 68.

49. Michael S. Mahoney, “Charting the Globe and Tracking the Heavens: Navigation and the Sciences in the Early Modern Era,” The Heirs of Archimedes: Science and the Art of War through the Age of the Enlightenment, ed. Brett D. Steele and Tamara Dorland (Cambridge: MIT Press, 2005), 221–30, at 228. On longitude see Howse, Greenwich Time and the Discovery of the Longitude; Andrewes, The Quest for Longitude; Boistel, “L’Astronomie nautique au XVIII^{e} siècle en France”; and Jullien, ed., Le calcul des longitudes.

50. Pang, Empire and the Sun.

51. Both quotes from Gyan Prakash, ed., After Colonialism: Imperial Histories and Postcolonial Displacements (Princeton: Princeton University Press, 1995), 3. Specifically on observatory techniques see Raj, Relocating Modern Science; and Pratt, Imperial Eyes.

52. On representation in observatory sciences see Levitt, “The Shadow of Enlightenment.”

53. Benjamin, “The Work of Art in the Age of Mechanical Reproduction”; Foucault, Discipline and Punish; Crary, Techniques of the Observer; Daston and Galison, “The Image of Objectivity”; Schivelbush, The Railway Journey; and Schivelbush, Disenchanted Night. On the role of the observatory sciences see Schaffer, “On Astronomical Drawing”; and Canales, “Photogenic Venus.”

54. See Bigg, “Behind the Lines.”

55. Mauss: “un mécanicien de précision opère des visées, lit des verniers, qui, autrefois, étaient le privilège des astronomes.” “Les techniques et la technologie,” 254.

56. Hentschel, Mapping the Spectrum; Bigg and Staubermann, eds., “Spectroscopic Histories”; Bigg, “Behind the Lines.”

57. Crowe, The Extraterrestrial Life Debate.

58. The history of popular science in the nineteenth century has mostly focused on natural history at the expense of the observatory sciences, despite the prominence of cosmological themes and the enthusiasm for optical instruments in such forums as museums, international exhibitions, and conversaziones. Among recent publications see Secord, Victorian Sensation; and Daum, Wissenschaftspopularisierung im 19. Jahrhundert.

59. Laurie, “The Board of Visitors of the Royal Observatory”; and Aubin, “The Fading Star of the Paris Observatory in the Nineteenth Century.”

60. Cahan, An Institute for an Empire.

61. Poincaré, The Value of Science, 84.

62. See Dominique Pestre, “The Moral and Political Economy of French Scientists in the First Half of the Twentieth Century,” History and Technology 13 (1997): 241–48.

63. See Schiavon, “Des savants-officiers entre science, armée, état et industrie de précision.”

64. P.-S. Laplace, A Philosophical Essay on Probabilities, trans. Frederick W. Truscott and Frederick L. Emory (New York: Dover, 1951), 4.

65. See Le Père Goriot, Eugénie Grandet, and Mémoires de deux jeunes mariées, chapter 25.

66. Anatole France, L’île des pingouins (Paris, 1908).

67. Steven Shapin, “‘The Mind Is Its Own Place’: Science and Solitude in Seventeenth-Century England,” Science in Context 4 (1991): 191–218.

68. Poincaré, The Value of Science, 115.