Science on Stage in Early Modern Spain

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1 From Mesopotamia to Madrid: The Legacy of Ancient and Medieval Science in Early Modern Spain[1]

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Introduction: From Abentumet to Albumasar

Lope de Vega's *La desdichada Estefanía* (*Unfortunate Stephanie*, 1604) dramatizes the legend of Estefanía Alonso "la desdichada" (d. 1180), the illegitimate daughter of Alfonso VII of León who was killed by her husband Castro for what he thought was infidelity. The misunderstanding comes about when Estefanía's slave Isabel, a "cautiva de la frontera" (captive from the frontier, i.e., of Muslim background) (l. 593; Kennedy, *Lope* 112), disguises herself as her mistress and receives Castro's rival Fortunio (*Fortune*), who sleeps with her believing she is Estefanía. Castro, hearing rumours of betrayal, pursues the disguised Isabel, who takes refuge by hiding under Estefanía's bed, where her mistress is asleep with Castro's baby. Castro bursts into the bedroom and, in a fit of blind rage, kills his wife before she ever learns of the rumours of her infamy, after which Isabel emerges and confesses her deception.

This complex plot involves disguise, mistaken identity, and "passing" – numerous scenes depict Christians disguised as Muslims and vice versa – and dramatizes a palpable anxiety, expressed in terms of seduction and sexual honour, over the easy confusion of the foreign with the domestic, Muslim with Christian. Significantly, the main story of false identities and misplaced jealousies takes place against the backdrop of the imminent Almohad invasion of the peninsula (1147), with part of the plot unfolding in Morocco, where Castro and Fortunio meet for a duel. In a scene just after Isabel speaks of her captive origins and confesses her secret love for Fortunio, an astrologer named "Albumasar" secretly predicts the future conquest of the Almoravids in al-Andalus by the lowly "Abdelmón," a figure representing ʿAbd al-Mu'min al-Kūmī (d. 1163), the first caliph to succeed the Almohad founder, Ibn Tumart. Albumasar introduces himself by referring to his fame as a well-known astrologer in both North Africa and Iberia:

> ¿Sabes que astrólogo soy,
> no sólo en Fez y Marruecos
> conozido, donde estoy;
> mas que a España, con los ecos
> de mi fama, nombre doy?

> Did you know that I am an astrologer, not only well known here in Fez and Morocco, but also giving fame to Spain with the echoes of my name?

Abdelmón replies:

> Sé que si alguno ha naçido
> Que sepa esa inçierta çiençia,
> Tú solo en el mundo has sido,
> Porque la antigua esperiencia
> Has puesto en eterno oluido.
> Sé que de esferas, planetas,
> Cielos y otros movimientos,
> Sabes las causas secretas,
> Y que nuestros nacimientos
> Por su ascendiente interpretas. (ll. 690–704; Kennedy, *Lope* 116–17)

> I know that if anyone has been born who knows that uncertain science, you alone in the world are he, because you have cast ancient knowledge into oblivion. I know that you know the secret causes of the spheres, planets, heavens, and other movements, and that you interpret our births by their ascendant.

In studying this episode, Frederick de Armas points out that Lope followed an earlier version of this story told by thirteenth-century King Alfonso X in his *History of Spain* (*Estoria de España*) (De Armas, "El rey" 123), in which Albumasar's name is Abentumet. "Se leuanto en los alaraues un moro que dizien Abentumet, et era un sabio en la astronomia, que es el saber de las estrellas, et era muy sabio en las naturas otrossi" (There arose among the Arabs a moor called Abentumet, who was an expert in astronomy, the knowledge of the stars, and who

was an expert in natural sciences also) (Alfonso, *Primera* 2:658). Alfonso himself indicates, moreover, that his own source was "el arçobispo don Rodrigo que lo dize en la su estoria" (the Archbishop Rodrigo, who tells it in his history), i.e., the history of Spain *On the Things of Spain* (*De rebus hispaniae*) by thirteenth-century archbishop of Toledo Rodrigo Jiménez de Rada (d. 1247), who told this story in almost identical terms in Latin, describing the Muslim astronomer as "homo in astronomia et naturalibus ualde doctus" (a man very learned in astronomy and natural [sciences]) (*De rebus*, 7.10, 231).[2] It is not a surprise to find Lope's source in Alfonso's *Estoria*, not only because of the *Estoria's* wide distribution in manuscript and print and in the revised version of Florián Ocampo (*Los cinco primeros libros de la coronica general*, 1553), but also because it served as a source used by Lope's acquaintance, Jesuit Juan de Mariana, who also tells a nearly identical story in his own *Historiae de rebus hispaniae* (1592) (507).

The value of tracing this history goes beyond that of simply identifying Lope's sources; it intimates a larger story of the reception – in turns enthusiastic and agonistic – of ancient and medieval science in early modern Iberia. While the name Abentumet is a calque of Ibn Tumart, Albumasar, as De Armas notes, is the Latinate name of Abū Maʿshar al-Balkhī (d. 886 CE), a scholar from Balkh in Khorasan (present-day northern Iran and Afghanistan). He became one of the most renowned astronomers in the Abbasid court of Baghdad in the ninth century, its moment of greatest splendour. Just as the Moorish captive Isabel found her way into the arms of Fortunio by taking on the guise of her Christian mistress Estefanía, so Arabic texts like Abū Maʿshar's found their way into Christian hands by taking on new guises through translation into Latin and Romance. The fact that writers from Jiménez de Rada to Lope depict this astrologer figure (Abentumet/Albumasar) as "learned" (*doctus*/*sabio*) underscores the reputation that Muslim intellectuals had throughout the Middle Ages and well into the seventeenth century as paragons of astronomical and scientific learning. Although Albumasar's appearance as a character in twelfth-century Morocco is anachronistic, the fact that he is cast as an internationally renowned expert ("no sólo en Fez y Marruecos conozido ... mas que a España, con los ecos de mi fama, nombre doy") attests to his enduring relevance as a symbol of scientific investigation even nine centuries after his death and thousands of kilometers from his home. Albumasar actually appeared in at least two other plays by Lope de Vega ("El primer rey de Castilla" and, granting his authorship, "La difunta pleiteada") as well as in numerous other contemporary plays, including the 1615 English work "Albumazar" by Thomas Tomkis (Halsted, "The Attitude" 217). "Albumasar" appears with regularity in the abundant astrological publications of the sixteenth century, more than any authors other than Ptolemy and Aristotle, and his name even came to be listed in the Inquisition's list of forbidden books and authors (Lanuza-Navarro, "La astrología" 307–8). The enduring popularity of the figure of Abū al-Maʿshar, from the work of Jiménez de Rada and Alfonso in the thirteenth century to Mariana in the sixteenth and Lope and others in the seventeenth is a testament to the Arabic role in the growth of scientific knowledge in Iberia. As Albumasar tells Abdelmón, "Rey de África serás, / A España con gente irás" (You will be king of Africa; you will go to Spain with men) (ll. 745–6; Kennedy, *Lope* 118).

Yet the logic of literary flourishes such as Lope's transformation of Ibn Tumart into Abū al-Maʿshar evokes an even longer historical chain of transmission and influence, one that stretches back even before Abū al-Maʿshar to the Greek, Egyptian, and Babylonian traditions on which his science was based. Using Lope's scene as a starting point, this chapter will limn the approximate contours of that chain by giving a broad overview of the history of science and technology from its beginnings alongside the birth of writing in ancient Mesopotamia to its growth in the ancient Mediterranean, and from there to its flourishing in the medieval Islamicate world and its transmission into the world of Latin Christendom through the translations and institutions of medieval Iberia. This brief (and necessarily schematic) overview will emphasize the point – not an original one but one that is often forgotten or overlooked, and thus deserving of repetition – that the growth of science in early modern Europe relied on a long precedent of scientific exploration in the ancient and medieval worlds, a reliance in which Spain played a preponderant role. The dynamic dramatization of science and technology on Spain's Golden Age stage is a logical culmination of the unique history of engagement with ancient science in medieval Iberia.

Science in Sumer?

Tracing the history of scientific thought requires an initial decision about what "science" (> Lat. *scientia*, "knowledge") is and how it may be distinguished from other forms of knowledge of and engagement with the world. I will define science as the abstract notion of a communal attempt to organize and theoretically systematize knowledge of

the physical world, involving a shared methodology or technique, an advance in technological knowledge and use, and some kind of testing that includes the control of variables and the repetition of results. On this broad basis, one might note that all of these factors accompanied the birth of agriculture, and it might therefore conceivably be proposed that some form of proto-scientific thinking – a first step towards thinking systematically about the physical world of cause and effect – roughly corresponded to the Neolithic Revolution that marked the transition from a hunter-gatherer lifestyle to a settled society in the hilly flanks of the Fertile Crescent, approximately 10,000 to 12,000 years ago. From this perspective, one might also say that the earliest foundations of scientific inquiry – although obviously far different from modern ideas of science – preceded written language itself, which is first attested in the pictographic and cuneiform tablets of the second half of the fourth millennium BCE in Sumer (Mesopotamia) and shortly after in Egyptian hieroglyphics. Later parallel (and independent) developments in China, India, and Mesoamerica might also qualify as evidence of this early mode of thought that necessarily accompanied human settlement.

To be sure, not all would agree that such developments qualify as steps towards *scientia*, and many in the history of science impugn the attempt to characterize certain knowledge as "science" – even in a loose way – before the concept in its modern usage came into being in the eighteenth century. Historian David Wootan, for example, asserts categorically that "Modern science was invented between 1572, when Tycho Brahe saw a nova, or new star, and 1704, when Newton published his *Opticks*" (*Invention*, 1). Although he concedes that "there were systems of knowledge we call 'sciences' before 1572," he follows Karl Popper's model in defining true scientific knowledge as that which, even if correct, is always potentially "falsifiable" and never fully verifiable (Popper, *Logic* 20). Science must be, by definition, anti-metaphysical – empirical and logical and not mythical or dogmatic. From this perspective, any use of the term "science" to characterize empirical knowledge before the Enlightenment is illegitimate because such knowledge, it is reasoned, was not sought purely for itself but instead served another purpose (such as predicting the future, understanding the gods, etc.).

For Wootan, moreover, "true science" must be "prepared to question every long-established certainty … in light of new evidence" (*Invention* 1–2). Yet as Thomas Kuhn poignantly argued over fifty years ago, "in science … novelty emerges only with difficulty, manifested by resistance, against a background provided by expectation … Normal science (is) a pursuit not directed to novelties and tending at first to suppress them" (*The Structure* 64). While the assumptions of pre-modern learning about the physical world were the result of a world view fundamentally at odds with our own – astronomy necessarily went hand in hand with astrology, chemistry with alchemy, mechanics with magic – that incommensurability does not in itself disqualify such learning as unscientific, even though it does not meet modern standards. As Kuhn notes, science can only function by rejecting all that falls outside of its operational paradigm (103), including earlier knowledge now disproved or rejected, yet that rejection does not in itself constitute a defining proof of what science actually is. Scientists rely on the contextual and partly arbitrary bias of their operational paradigm in order to function, and thus science must advance through the revolutions that accompany "paradigm shifts" and not simply grow with the incremental accretion of knowledge.

Yet to summarize the history of science as a narrative of birth, growth, and transmission – whether one begins in the year 10,000 BCE or 1572 CE – is necessarily to construct an artificial teleology, what Herbert Butterfield calls a "Whig interpretation of history," which he defines as "a scheme of general history which is bound to converge beautifully upon the present" (*The Whig* 11). Such a diachronic history of science – whether told as accretion or revolution – is factitious and flawed by design, for the many communities that have contributed to scientific knowledge in the past do not pertain to any single tradition and do not present a single chain of causation and accumulation of knowledge. As Bruno Latour insists, we must distinguish between individual sciences and the notion of "science" itself, which he defines as "the politicization of the sciences through epistemology" (*Politics* 10). Nevertheless, despite its flaws and its implicit Eurocentrism, such a history of "science" writ large, understood as an artificial composite of individual sciences all relying on a common epistemology and metaphysic, can, with caveats, also be heuristically useful as an approach towards a richer and more nuanced contextualization of early modern learning. Taking such perspectives into account, it is clear that any treatment of the history of science, especially one that traces transmission of knowledge over time, must navigate between the Scylla of "Whig history" and the Charybdis of paradigm bias by resisting the impulse to equate all influence with progress and by provisionally including in the definition of science all systematic and empirical engagement with the world, regardless of the religious or cultural assumptions about the nature of existence held by its practitioners.

Although the Neolithic Revolution may be an absurdly early point to begin the story of science, I have proposed it only as a way to exemplify the point that foundational narratives are cultural fictions, not empirical facts, whose points of beginning are held to be appropriate only within a certain operational paradigm. If the invention of agriculture is not a sufficient watershed in the birth of scientific thinking as defined by a modern perspective, the invention of writing (first in Sumer, and subsequently – and independently – in Egypt, China, and Mesoamerica) may well be, because it offered a technology of information storage that cognitive scientist Merlin Donald has called the first "externalization of symbolic memory" (*Origins* 363). Although seemingly first employed in Mesopotamia for explicitly bureaucratic and administrative (rather than aesthetic or religious) functions (Cooper, "Babylonian" 72), it was a precondition for the growth of Babylonian mathematics and celestial observations. Its decisive influence is analogous to the eventual impact that the *mechanization* of writing (after Gutenberg's metallurgical advances in the casting of moveable metal type for the printing press, ca. 1440) had upon the dissemination of astronomic observations and the resulting theories, and the growth of science more generally, in the sixteenth century, or to the impact of electronic computing on research since World War II.[3] Throughout the history of science, advances in technology have proceeded in tandem with advances in knowledge.

Many of the Sumerian advances in technology were mechanical – the use of the wheel, the stone arch, irrigation, and the plow, etc. – and certainly many of these relied not simply on methodology but also on writing and numeric calculation. The Sumerians developed the ability to compute place value in a base 60 number system, from which derived the division of hours into sixty minutes, of minutes into sixty seconds, of circles into 360 degrees, of years into approximately 360 days, etc. This advanced mathematical notation, which was inherited by the Akkadians (who ruled Mesopotamia from the second half of the third millennium) and Babylonians (in the first half of the second millennium) facilitated complex geometric and algebraic calculations including a rudimentary version of the Pythagorean Theorem and the accurate sexagesimal representation of the square root of two, accurate to six decimal digits (van der Waerden, "Mathematics" 667–71). The notion of place value allowed the later introduction of a placeholder for zero (although it was not used for mathematical calculation). Such knowledge formed the base of Mesopotamian architectural advances (such as ziggurats and domed ceilings) and more importantly supported an advanced culture of astronomical observation and data recording. Between 1200 and 1000 BCE, Babylonian astronomers, making use of earlier knowledge and observations, compiled the first known star catalogues. These included not only names of scores of stars and recordings of their movements, but also constellation names that would be used in later astrological theories. Some of these (the scorpion, the lion, the bull, etc.) would be used in Greece in the fourth century BCE, forming the basis of some familiar astrological names (Scorpio, Leo, Taurus, etc.). The Babylonians recorded thousands of omens both celestial (e.g., future eclipses) and astrological (e.g., future misfortunes and disasters) based on astronomical data recorded over centuries (Rochberg, *The Heavenly* 4–5).

At the same time, the exploration of the physical world in ancient Babylonia was roughly contemporary with a parallel tradition of astronomy and applied engineering in Egypt. Unlike the base 60 system of the Babylonians, the Egyptians employed a more familiar decimal system, although without a place-value logic and, like the Greeks after them, without the use of a zero, even as a placeholder. While arithmetic calculations used a cumbersome system of doubling and addition, basic geometrical principles were approximated, including a rough estimate of the value of pi (different from but approximately equal to that used in Babylonia), basic Pythagorean triples for laying out right triangles, and a set of number pairs whose ratios approximate the Golden Ratio (in which the ratio of two of these numbers is equal to that of their sum to the larger number), already in use in the design of the Great Pyramid of Giza in the twenty-fifth century BCE. These geometrical advances were, like those of the Babylonians, principally for astronomical/astrological purposes, charting the stars and measuring the calendars in order to regulate agriculture in the Nile valley. When Lope's Albumasar predicts the future kingship of Abdelmón, he is, in a way, carrying on an astrological tradition stretching back millennia, all the way to the astronomical and astrological traditions of ancient Mesopotamia and Egypt.

Growth in Greece

Despite such beginnings, it is customary to identify the "true" origins of modern science in Greece, when pre-Socratic philosophers of the sixth and fifth centuries BCE first began systematically to pose questions about the natural world in purely physical terms. Thales of Miletus (d. 546 BCE, western Anatolia) is considered to be the founder of Greek geometry, having noted that the angles of the base of an isosceles triangle are equal, and that the ratios of line segments created by crossing two intersecting lines and two parallel lines are exactly proportional. He also postulated a unity of physical matter as based on one substance, water, and his ideas directly influenced Aristotle's theories of matter and the nature of the universe (Graham, *The Texts* 17–18; Longrigg, "Thales" 297).

Although we know very little about Pythagoras (d. 496 BCE, on nearby Samos) and his followers, numerous ideas (such as the Pythagorean theorem or a cosmology of perfectly spherical orbits of the sun, moon, and five planets around a central fire) are associated with the Pythagoreans, mostly without textual evidence (Graham, *The Texts* 905–6; Von Fritz, "Pythagoras" 224). Other postulates can be more certainly associated with contemporary pre-Socratics, such as Heraclitus (d. 475 BCE), positing the universe as flux guided by unchanging laws (Graham, *The Texts*, 135), Empedocles (d. 430 BCE), theorizing four elements to the universe, earth, air, fire, and water (326–7), and Democritus (d. 370 BCE) and his teacher Leucippus, posing an atomic theory of the universe as made up of tiny, indivisible pieces that formed the building blocks of all matter (516).[4] The reflection on the cosmos in physical terms as a world ordered by constants and physical laws similarly guided the medical ideas of Hippocrates (fl. second half of the fifth century BCE) and the natural philosophy of Theophrastus (d. 287 BCE).

Undoubtedly the most scientifically influential insights were the cosmological, biological, and metaphysical theories developed by Aristotle in his vast oeuvre. One fundamental aspect in which he is often distinguished from his teacher Plato is in the epistemological value he concedes to analytical reasoning on the basis of perceptible things. Whereas Plato (*Republic* 479e) argues that, "those who view many beautiful things but do not see the beautiful itself … have opinions about all things, but know nothing of the things they opine" (*Collected* 719–20), Aristotle (*Metaphysics* 13.1080a) rejects the independent existence of "forms" in themselves. "It might be thought impossible that substance and that whose substance it is should exist apart; how, therefore, could the Ideas, being substances of things, exist apart?" (*Complete* 1:1707). Although his logical method was more aimed at metaphysical questions – beyond sensory perception – than at empirical observations, in subsequent centuries it came to provide, when coupled with his rejection of the independent existence of forms, a foundation for deductive analysis of facts gained through empirical observation.

While it is misleading to see Aristotle as an exclusively "empirical" thinker (Owen, "Aristotle" 252), there is no question that Aristotle's rejection of forms as independently knowable and his assertion (*Metaphysics* 1.992a) that "philosophy seeks the cause of perceptible things" (Aristotle, *The Complete* 2:1568) came to have profound implications for the study of the physical world in later centuries.

Apart from the definitive influence of his *Organon* (the six works on logic) on later philosophy, his influence on later scientific thought stemmed from his defence of the logical organization of knowledge, as well as his theory of the four causes (material, formal, efficient, and final), and more generally his organization of "sciences" (*epistēmai*) into categories. His taxonomies of knowledge are reflected in the different foci of his works. His *Physics, Meteorology,* and *On the Heavens* were all influential on later investigations in astronomy. His books on animals, on movement and respiration, and on birth, death, and change (such as *On Generation and Perishing*) were foundational for the later development of life sciences. Above all, his exposition on deductive reasoning in the *Posterior Analytics* was determinative for the establishment of a logical method of investigation.[5] His works were the subject of commentaries both in antiquity and, in translation, throughout the Middle Ages.

Yet for all of the originality of presocratic and Classical Greek scientific thought, it is important to view it in the wider context of the ancient world. This implies, on the one hand, recognizing the many parallel discoveries in the East, both India and China, whose interaction with Greek science is uncertain (and is still being debated), and on the other, considering the notable parallels between Babylonian mathematics and astronomy and those that developed in Egypt and Greece.[6] While it is not impossible that some of the Presocratics in western Anatolia came into contact with Egyptian or even Babylonian ideas – Herodotus (*Histories* 2.109, in *The Persian* 399) and Aristotle (*Metaphysics* 1.981b, in *The Complete* 1:1553) themselves claim as much – the period when such a transfer of knowledge is most probable is in the Hellenistic period (i.e., from the death of Alexander the Great in 323 BCE until the death of Cleopatra upon Roman conquest of the Ptolemaic Kingdom in Egypt in 30 BCE), or in the Roman period that followed. It was in these centuries that Alexandria became a preeminent intellectual centre, boasting a vast library of sources from diverse regions of Eurasia and supporting research in many areas.

The dynamic culture of Hellenistic Alexandria supported the work of a few key thinkers who, together with Aristotle, would prove to be the most influential over the subsequent two millennia. Euclid of Alexandria (d. 265 BCE) developed the geometrical ideas of the Pythagoreans by extending the Aristotelian methodology of deduction in measurement and calculation. His *Elements* would become the most influential book in mathematics until the Enlightenment. Hellenistic mathematicians such as Archimedes of Syracuse (d. 212 BCE), although perhaps best known for developing numerous mechanical innovations (such as the hydraulic screw and water clock), made important advances in the measurement of the volume and area of irregular shapes and objects, including the use of "infinitesimals" to calculate area along a curve, thus anticipating methods of integral calculus formalized by Newton and Leibniz (Clagett, "Archimedes" 229).

Greek scientific thought was partly preserved by the Romans, and various Latin works of the Roman period that were read and copied in the Latin Middle Ages drew from Greek scientific texts. Lucretius (d. ca. 94 BCE) built on Democratus and Empedocles to develop his own theory of "atoms." Pliny the Elder (d. 79 CE) drew heavily from Aristotle and Theophrastus in writing his natural history. Greek sources provided a basis for Roman advances in technology and mechanics, from metallurgy and mining to hydraulics and engineering to agriculture and cartography. Yet it was the Greek intellectuals in the Western Roman Empire that produced the scientific writing destined to be the most canonical in subsequent centuries. Dioscorides (d. 70 CE), a physician from Cilicia in Asia Minor, travelled around the eastern Mediterranean and elsewhere gathering samples and information to produce his *De materia medica*, a pharmacological guide to plants and medicines. Copied and translated extensively, it circulated in Greek, Latin, and Arabic and remained a standard reference book for fifteen centuries (Riddle, "Dioscorides" 121). The writings of the Greek physician Galen (d. ca. 200 CE), who moved from western Anatolia to Alexandria to Italy, were profoundly influential in medicine well into the early modern period. Galen further advanced anatomical knowledge through the dissection of animals (but not humans). He made reference to earlier Greek anatomists such as Herophilus (d. ca. 260 BCE) and Erasistratus (d. ca. 240 BCE), who were among the only figures to dissect and vivisect the human body before the late Middle Ages – using criminals condemned to death as subjects. Galen also developed the teachings of Hippocrates to propose physiological theories concerning the nervous system, the circulatory system, and the theory of four bodily humors (blood, yellow bile, black bile, phlegm), which formed the basis of medieval medical theory (Kudlien, "Galen" 231–3).

Galen's long legacy was matched only by his contemporary Ptolemy (d. ca. 170 CE), who became a definitive source for all medieval and early modern astronomy. Working in Roman Alexandria, Ptolemy wrote studies on cartography, music, optics, astronomy, and astrology. His greatest influence came in the *Mathēmatikē Syntaxis* (better known by its Arabic-derived title *Almagest*, a transliteration of the Greek for "the greatest"), the first and only comprehensive treaty on astronomy from the ancient Greek world. Based on the cosmology of Aristotle and Hipparchus (d. 120 BCE), the likely inventor of the astrolabe, Ptolemy's *Almagest* systematized a model of the universe that would be definitive throughout the Middle Ages. Ptolemy described the orbit of the planets, sun, and moon around the earth, drawing directly in some cases from Babylonian observations (Aaboe, *Episodes* 62–5). Besides including a star catalogue and a description of the movement and properties of each celestial body, including the fixed stars, it introduced the quadrant (for celestial measurement determined by estimating altitude and angle) and extended and formalized the theory of epicycles (small circles made by the planets and stars centred on the path of their larger orbit) in order to explain the problem of apparent retrograde motion observed from earth. The geocentric model proposed by Ptolemy remained the dominant model until Copernicus replaced it with a heliocentric model in the sixteenth century CE (Toomer, "Ptolemy" 202). When Abdelmón tells Albumasar "la antigua esperiencia / has puesto en eterno oluido," he is referring to the long legacy of ancient Greek science, a legacy preserved and extended in the medieval Islamicate world.

Brilliance in Baghdad

In 391 CE, Coptic Pope Theophilus of Alexandria clamped down on all pagan temples in his city, including the famous temple of Serapis (the Serapheum), and at some point around this time or a few decades after, the remaining centres of study were largely abandoned. When, less than two decades later in 410, Rome itself fell to the Visigoths, scientific learning was interrupted, although not entirely wiped out. Commentaries on earlier works survive from the fifth century, although less remains from the sixth and seventh centuries. In Latin Europe, education in the seven liberal arts, which in the early Middle Ages took

place almost exclusively in monasteries, was divided into the *Trivium* (grammar, rhetoric, dialectic) and the *Quadrivium* (arithmetic, geometry, astronomy, and music), and thus a rudimentary attention was given to scientific subjects, although increasingly without the support of key Greek texts. While there is some material from places, such as Ravenna, attesting to an ongoing critical engagement with some ancient authorities on medicine and philosophy, the extent of learning in many places was greatly diminished by the late sixth century. Although some practical texts such as Hippocrates and Galen's *Method of Healing* or copies of Dioscorides did continue to circulate, "the resources for the maintenance of an active intellectual tradition of medicine were also diminishing" (Nutton, "Medicine" 84). Most critically lacking was the majority of the Aristotelian corpus, and much other speculative Greek scientific thought was also absent, or at least not widely available. What was transmitted included Boethius's translation of Porphyry's (d. ca. 305 CE) commentary on Aristotle's *Categories* known as the *Isagoge*, and Isidore of Seville's (d. 636) *Etymologies*, which seems to have drawn most of its information from Roman writers and encyclopedists only distantly informed by Aristotle and other Greek scientific texts (Pliny, Varro, Solinus, Boethius) (Isidore, *Etymologies* 11–17). Isidore's capacious work was critically important for the preservation of ancient Latin sources, but his eclectic summaries did not provide enough sound information or theoretical reflection to support systematic exploration of the physical world (Sharpe, "Isidore" 28).

Yet the rise and spread of Islam in the seventh century led to the preservation and renewal of that ancient tradition, expanding the intellectual legacy of the ancient Greek world to an unprecedented degree. Although translation between Greek and Arabic for bureaucratic or diplomatic purposes was not uncommon in the first century of Islam, the Umayyad Caliphate (662–750) was not distinguished for its patronage of scientific learning and seems to have produced few translations of Greek scientific material (Gutas, *Greek* 23–4; Morrison, "Islamic" 116). However, the founding of Baghdad in 762 as a new capital after the Abbasid overthrow of the Umayyads in 750 set the scene for a proliferation of translating activity and intellectual exploration. This was in part due to the geographical location of the newly founded capital, which was strategically chosen to symbolize the union of the Arab caliphate with the political tradition of the Sasanian Persian empire. The second Abbasid Caliph al Manṣūr (d. 775) adopted the core values of Sasanian political ideology, which represented itself as the intellectual heir of all the other civilizations that had gathered learning from all corners into its borders, by patronizing translation and supporting the development of astrology and astronomy, mainly for political prognostications (Gutas, *Greek* 34–35; Ragep, "Islamic" 35). Among the first translations were pre-Islamic Zoroastrian astrological texts. This core focus on astrology naturally led to a robust interest in astronomical research in the subsequent century.

In the wake of this founding ideology, a string of Abbasid caliphs in the ninth century, especially Harūn al-Rashīd (d. 809), al-Ma'mūn (d. 833), and their successors, officially patronized an intensive translation effort designed to gather into Arabic versions all learning of value. An important factor determining translation activity was the availability of texts, and caliphs sought copies to expand their libraries, which seem to have housed, at least under later caliphs, works of a very wide variety, from Greek classics of every sort acquired from Byzantium, to texts of Sanskrit, Paḥlavi (Middle Persian), Syriac, Coptic, and even possibly Ethiopian and Ḥimyaric (Yemenite) origin (Gutas, *Greek* 57–9). Many translators came from Nestorian and Syrian Christian backgrounds, and also included Muslims, Zoroastrian Persians, Sabians (Ḥarranian star worshippers), and Jews. Yaḥyā ibn al-Bātrīq (early ninth century) made some of the first Arabic translations of Hippocrates and Galen, as well as Ptolemy's *Tetrabiblos* (on astronomy) and Aristotelian books on zoology (Goodman, "The Translation" 480–1).

Among the most famous and influential translators was the Nestorian Christian Ḥunayn ibn Isḥāq (d. 873), who worked as chief court physician in the caliphate of al-Mutawakkil, writing original works of medicine and natural philosophy and translating into Arabic scores of works of astronomy, medicine, mathematics, magic, and philosophy from Pahlavi, Greek, and Syriac versions (Goodman, "The Translation" 487–8). His translations included, among many others, works of Euclid, Ptolemy, Hippocrates, and above all, Galen. The latter was translated into Arabic on the basis of Syriac versions formerly made from Greek originals in the sixth century by the Monophysite Christian priest and physician Sergius of Rēsh'aynā (d. 536) (Iskander, "Hunayn" 235). Ḥunayn's use of Syriac material prepared by earlier Christians points to the important role of Christian activity in the Sinai peninsula and the Levant in late antiquity in providing a precedent for the later Arabic translation movement in Baghdad, although as Gutas points out, "before the "'Abbāsids, relatively few secular Greek works had been translated into Syriac ... the bulk of the Greek scientific and philosophical works were translated into Syriac as part of the 'Abbāsid translation movement during the ninth century" (Greek Thought 22).

In this context, Ḥunayn's medical texts were influential in the development of medicine in the Islamicate world, making Galen's vast oeuvre available in Arabic and influencing later polymath physicians such as the alchemist al-Rāzī (d. 925), Aristotelian philosopher Ibn Sīnā (d. 1037), and medical historian Ibn Abī Uṣaybi'a (d. 1270). His disciples also continued to produce translations after him, including, in stages, virtually the entire Aristotelian corpus as well as Aristotle's later commentators including Prophyry and Alexander of Aphrodisias (fl. ca. 200 CE). Another notable translator in Baghdad was the pagan intellectual Thābit ibn Qurrah (d. 901), who revised Ibn Isḥāq's translations of Euclid and Ptolemy and disseminated teachings of Pythagoras and Archimedes. Over the course of a century and a half, in a process of knowledge transfer whose scale had no comparison in prior human history and remains unique today, scores of scholars translated and composed thousands of works on all known subjects of learning. Baghdad thus became a uniquely advanced centre of scientific knowledge, one that not only amassed learning from elsewhere, but that critiqued Greek sources and advanced scientific thought in unique ways (Saliba, *Islamic* 25).

The translations included work from all known scientific branches, but most attention was paid to mathematics/geometry, medicine, and, because of its political ramifications, astronomy/astrology. The initial approach followed the tradition received from Indian astronomy via Sanskrit sources and Persian translations, and one of the earliest translations/adaptations of this sort were the Sanskrit astronomical tables *Siddhānta* (*Sindhind*) by Ibn Ḥabīb al-Fazārī (d. 806). Following this tradition, scholars prepared similar astronomical handbooks (*azyāj*, sing. *zīj*) that included tables of star data, and most famous among these was the original work *Zīj al-Sindhind* of al-Khwārizmī (d. after 847) (Toomer, "al-Khwārizmī" 360). He wrote numerous works of astronomy and mathematics, and was especially distinguished for introducing mathematical notation and "Hindu numerals," the partial basis for modern "Arabic" numeral notation today. This system of Indian reckoning and observation cultivated by al-Khwārizmī and applied by Abū Ma'shar and others coexisted in Baghdad with the Greek tradition. This was reflected above all in works by al-Battānī (d. 929), whose tables helped disseminate Ptolemy's geocentric model of the solar system. Further east, in Isfahan, the rival Buyid empire also patronized astronomical investigation, producing work such as the *Book of Fixed Stars* (*Kitāb ṣuwar al-kawākib*) of ʿAbd al-Raḥmān al-Ṣūfī (d. 986), which drew from Eastern traditions and also expanded the Ptolemaic charting of the stars with more careful measurements.

The intense research in Greek astronomy and various branches of the Aristotelian corpus supported advances in technology as well as theory. Astronomers in Baghdad and beyond thus made critical improvements of Greek astronomical tools, principal among which was the Ptolemaic astrolabe. Al-Farghānī, working in the ninth-century Caliphate of Baghdad, describes the first construction of an astrolabe in Islamic lands a century before (Morrison, "Islamic" 116). Also developed were the sundial and the Ptolemaic quadrant, used for measuring the inclined position of celestial bodies and deriving information based on these calculations, such as calendric data and latitudinal position. The transfer of such technology in the form of the circulation of scientific instruments exemplifies in concrete terms how ancient Greek scientific learning was appropriated and developed by Muslim scientists, from whom it was later passed to Latin Christendom (Rodríguez-Arribas et al., *Astrolabes*).

Throughout the Islamicate world, astronomical learning was also regularly used for prognostication. Even a century before al-Ṣūfī, Abū Maʿshar – also Persian – worked in the Baghdad caliphate where he not only compiled his own *zīj* tables, but also wrote extensively on the application of that Hindu-Persian astronomical tradition, combined with Aristotelian cosmology, for astrological interpretations and predictions (Pingree, "Abū" 236). Later polymaths such as Ibn Sīnā and the astronomer al-Bīrūnī (d. ca. 1048) were highly critical of astrology (Morrison, "Islamic" 126), debating aspects of Aristotle's theories (without discarding his categories) and tackling not only astronomical questions such as the weight of celestial bodies, but also metaphysical questions such as the possibility of a void or the eternity of the universe (Dallal, "Early Islam" 124). Despite these later criticisms, Abū Maʿshar's fame as an astrologer spread widely, especially in Latin translation, making his name known "not only in Fez and Marrakech" and other centres of the Islamicate world, "but also in Spain," reaching all the way to Lope de Vega in the seventeenth century.

The translation activity continued in Baghdad for well over a century, but by the second half of the tenth century, its activities waned. In competition with both the Abbasid Caliphate in Baghdad and the Fatimid Caliphate in Cairo, the young caliphate of Cordoba sought to promote learning and science by expanding libraries and patronizing

the copying and study of numerous works of Greek and Arabic science. In the middle of the century, Byzantine Emperor Constantine VII sent the Greek-speaking monk Nicholas to Córdoba at the request of the first caliph ʿAbd al-Raḥmān III (d. 961), along with a Greek copy of Dioscorides's *De materia medica*. Nicholas collaborated with the caliph's Jewish vizier Ḥasday ibn Shaprūṭ (d. 975) and the local scholar Ibn Juljul (d. ca. 994), who produced a new updated translation into Arabic (Vernet, "Ibn Juljul" 187). The greatest expansion took place under the rule of the next caliph, Al-Ḥakam II (d. 976), who not only made important expansions to the Great Mosque of Cordoba, still standing today, and the completed construction of the palatial city of Medinat al-Zaḥra, now in ruins, but also assembled a vast library of materials gathered from across the Islamicate world. As it was destroyed after the fall of the caliphate in 1031, no certain evidence of its size is known, but chroniclers of the period have claimed it contained some 400,000 volumes. Although modern historians, based on reports of an author-title catalogue list of some forty-four volumes, estimate that the number probably did not exceed 40,000 (Sánchez-Moliní Sáez, "Las bibliotecas" 87–9), the library was undoubtedly immense for the period. It certainly contained, along with numerous private libraries of the caliphate, many of the most important works translated in Baghdad in the previous century.

Medicine in al-Andalus reached an advanced degree of sophistication, and a number of figures from the caliphate and subsequent reigns of the Almoravids and Almohads are recognized as some of the most important physicians of the medieval Muslim world. Al-Zahrāwī (d. 1013) was the leading surgeon in the caliphate (Hamarneh, "Al-Zahrāwī" 584). His compendious encyclopedia of surgical practice, which bears the droll title *The Book the Arrangements of Medical Knowledge for One who is Unable to Compile One for Himself* (or for short, *Kitāb al-Taṣrīf, Book of Arrangements*), became a standard reference text for centuries. Other Andalusī scholars continued to contribute to an advanced medical culture in Iberia into the thirteenth century. These included Ibn Zuhr (d. 1162) of Seville – a pioneer in medical experimentation with animals who claims in his *Book of the Facilitation of Therapeutics and Diet* (*Kitāb al-Taysīr fī al-Mudāwāh wa-l-Tadbīr*) that he demonstrated the safety of a tracheotomy by performing one on a goat (Catahier, "Ear" 523) – the Muslim Aristotelian philosopher Ibn Rushd (d. 1195) – who wrote commentaries on Galen, Ibn Sīnā, and Aristotle's *Physics* and *Metaphysics* – and the Jewish Aristotelian Moses Maimonides (d. 1204). All of these later physicians seem indebted to Al-Zahrāwī's approach to surgery.

The greatest scientific scholar under al-Ḥakam II's caliphate was the mathematician and astronomer Maslama al-Majrīṭī (d. 1007), who not only improved on the existing translation of Ptolemy's *Almagest*, but also translated and updated the *zīj* of al-Khwārizmī and translated Ptolemy's *Planispherium* (Pingree, "The Indian," 246; Vernet, "Al-Majrīṭī," 39). He also introduced to al-Andalus the voluminous encyclopedia of scientific, philosophical, and religious knowledge known as the *Epistles of the Brethern of Purity* (*Rasā'il Ikhwān al-Ṣafā*), compiled in Iraq in the previous century and drawing heavily on Greek sources and theories. Al-Majrīṭī was one of the most pivotal figures in the transfer of the scientific learning in Baghdad to the caliphate of Córdoba (Samsó, *La ciencia* 84–93). When Lope's Abdelmón tells Albumasar, "si alguno ha naçido/ que sepa esa inçierta çiençia, / tú solo en el mundo has sido," he underscores the unique role of the medieval Islamicate world as the heir and keeper of the wealth of Greek science.

Translation in Toledo

When Lope's Albumasar predicts the future kingship of Abdelmón, he is speaking about 'Abd al-Mu'min's rise as leader of the Almohads in the middle of the twelfth century. It was during these very years that numerous works of Greek and Arabic science were translated into Latin in and around the city of Toledo, which had been captured from the Taifa king al-Ma'mūn of Toledo in 1085. As a Taifa kingdom, it had been an active centre of scientific learning in the eleventh century, housing abundant resources and books. Influential magistrate Ṣā'id al-Andalusī (d. 1070) brought intellectuals to the Toledan kingdom in order to promote scientific learning there, especially in medicine and astronomy. Vizier to King Ma'mūn of Toledo, the pharmacologist Ibn Wāfid (d. 1074) wrote on medicine as well as alchemy. Most significant in the kingdom was al-Zarqālī (d. ca. 1100), one of the most important Muslim astronomers from al-Andalus in any period. Beyond improving on the design of the astrolabe – examples of his instruments survive today – he produced the *Toledan Tables*, a *zīj* that translated and improved on the tables of al-Khwārizmī and al-Majrīṭī and combined Indian and Greek astronomical models (Vernet, *Lo que* 203–4).

The taking of Toledo by the Christians opened a channel by which the accumulated intellectual wealth of the Islamicate world could begin to flow into Latin Christendom. Before this decisive event, such learning had only trickled into Christian circles in a few limited instances. In 976, monks at the Riojan monastery of San Martín de Albelda produced the compilation of works known as the *Codex Vigilanus*, which contains the first Western Christian record of writing Hindu-Arabic numerals (without zero) (see figure 1.1), a system that Gerbert de Aurillac (d. 1003, later Pope Sylvester II) also encountered in Catalonia a few decades later (Vernet, *Historia* 73–4). A century later, Jewish convert Petrus Alfonsi of Huesca produced the first Latin version of Khwārizmī's *zīj*, which was then improved and re-translated by his student Adelard of Bath (d. ca. 1152). Adelard also translated al-Khwārizmī's book on Hindu reckoning as *Algoritmi de numero Indorum* (Al-Khwārizmī's book on Numbers of the Indians), thus giving "Arabic" numerals their definitive form in the Latin West (and thus rendering al-Khwārizmī's name for the first time in the form it is known to us today, i.e., as the words *Algorithm* and, in Spanish, *guarismo*, "digit") (Clagett, "Adelard" 63). As David King has noted, Hindu-Arabic numerals such as those adopted from Khwārizmī "are neither Hindu nor Arabic … but they would better be called Hispano-Indian numerals, because whilst the Arabic forms for the numerals passed through Spain they were modified by Europeans … Our numeral forms are ultimately derived from these, with new input from the forms introduced into Europe in the 12th century by means of a Latin translation of al-Khwarizmi" (*The Ciphers* 310).

Under the leadership of the Archbishop of Toledo Raimundo de Sauvetat (d. 1152) and then continuing after his death, the city of Toledo was transformed into a hub of Latin translating activity.[7] Among the dozen or more active translators working around Toledo or in its cathedral, three major figures were Domingo Gundisalvo (d. 1184), archdeacon of Segovia, the Italian Gerard of Cremona (d. 1187), and "Johannes Hispalenses" (often confused with others of a similar name in this period). Gundisalvo translated al-Fārābī's *On the Division of the Sciences* (*Kitāb Iḥṣā' al-'ulūm*), numerous commentaries on Aristotle by Ibn Sīnā, as well as the *Fons Vitae* of Iberian Jewish Neoplatonist Ibn Gabirol (Kren, "Gundissalinus" 592). Gerard of Cremona translated Aristotle's books on physics, the *Almagest* of Ptolemy, as well as works of Euclid, Archimedes, Hippocrates, Galen, Ibn Sīnā, al-Khwārizmī, and al-Zarqālī. Significant among his many translations was the critique of Ptolemy written by Jābir ibn Aflaḥ of Seville (d. 1160), the *Correction of the Almagest* (*Iṣlāḥ al-Majisṭi*) (Lemay, "Gerard" 176–88). Johannes Hispalenses, besides his numerous translations of astronomical studies, also rendered the astrological work by Abū Ma'shar and collaborated with Gerard to translate al-Faraghānī's *Compendium of the Science of the Stars* (*Jawāmi' 'ilm*

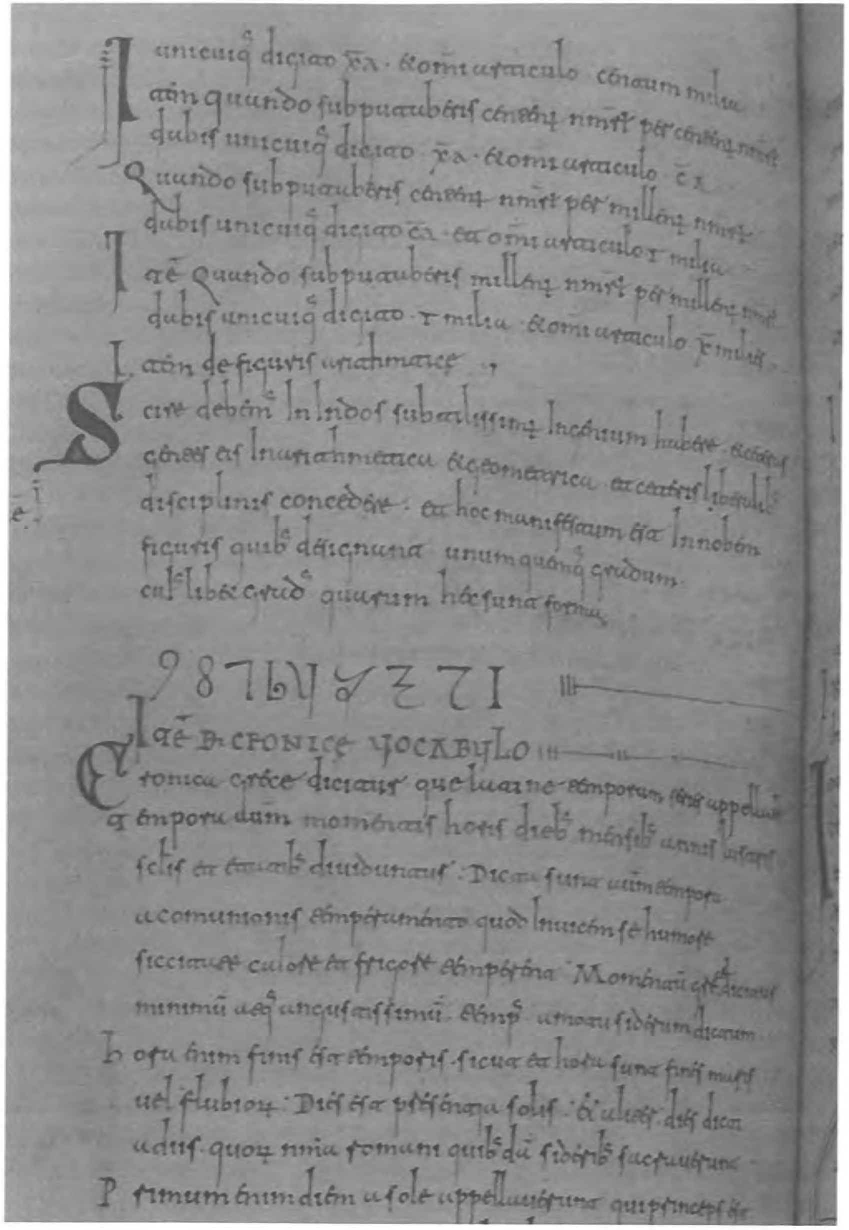

Figure 1.1 Biblioteca de El Escorial, Ms. D-I-2, fol. 12v (detail).

al-nujūm), which would later be translated into Romance (Vernet, *Lo que* 198). Other translators, such as Robert of Ketton (d. 1160), best known for his Latin Qur'ān translation, also rendered al-Battānī. Herman of Carinthia (d. ca. 1160), who collaborated with Robert on his anti-Islamic translations, also translated or re-translated works of Ptolemy, Euclid, Abū Ma'shar, and al-Khwārizmī, among others.

The flurry of translating activity in twelfth-century Toledo laid the groundwork for further translations in the thirteenth century, both in and beyond the Iberian Peninsula, both to Latin and to Hebrew. For example, Mark of Toledo not only undertook a second Latin Qur'ān translation at Rodrigo Jiménez de Rada's behest, but he also translated Hippocrates and several of Ibn Isḥāq's versions of Galen. Michael Scot (d. ca. 1235), working first under Rodrigo's patronage in Toledo and later in the Sicilian court of Frederick II (d. 1250), continued translating works of Arabic science, including Biṭrūjī's astronomical work, Aristotle's writing on animals as well as commentaries by Ibn Sīnā and Ibn Rushd on Aristotle's natural philosophy (Pick, *Conflict* 79–80, 94–5). Leonardo Pisano, better known as Fibonacci (d. ca. 1240), dedicated the final version of his *Book of Calculation* (*Liber abaci*) to Michael in gratitude for his corrections. The work, based on Euclid and al-Khwārizmī, revolutionized European mathematics and disseminated the Hindu-Arabic numeral system (which he calls *figure indorum*), including the zero, "quod arabice zephirum appelatur" ("which in Arabic is called *zephirum*," thus transliterating the Arabic *ṣifr* rather than translating the concept as *nihil*) (Pisano, *Fibonacci's*, 618 n. 1). Roger Bacon (d. ca. 1292), in Oxford and Paris, made extensive use of translations of Aristotle and Islamic commentators and scientists in his *Opus maius*, a compendious critique of scholastic thought that laid out a coherent methodology for scientific reflection and experimentation and proposed important educational reforms for European universities (Crombie and North, "Bacon" 378).

A similar and related wave of translation took place in Jewish communities of Iberia and Provence. Abraham Ibn Ezra (d. ca. 1167) translated Arabic work on astronomy and astrology, incorporating it into an extensive original corpus of works in Hebrew and Latin. Another figure providing a link between Latin and Hebrew sources was the mysterious Provençal convert (who later returned to Judaism) nicknamed Do'eg ha-Edomi (fl. ca. 1200). He produced numerous Hebrew versions of many recently produced Latin versions of Arabic medical texts.[8] The thirteenth century was transformative for scientific thought in Jewish culture. Samuel Ibn Tibbon (d. ca. 1230), the translator of Maimonides's philosophy, also translated into Hebrew Arabic commentaries on Galen and Averroes and Ibn Baṭrīq's versions of Aristotle's *Meteorology*. His son Moses ibn Tibbon (d. ca. 1274), translated various medical works by Maimonides as well as portions of Galen, Euclid, Ibn Isḥāq, Ibn Rushd, and others (*Zonta*, "Medieval" 30–4). The Hebrew translation movement, which can only be superficially mentioned here, overlapped with and supported the Latin translation movement in significant ways, providing translators and disseminating texts.

Despite this awareness of the Greek originals of many well-known texts, the influence of Islamic commentators and scientists continued to be felt in European centres of learning for centuries. Latin versions of Ibn Isḥāq's *Introduction to Medicine* and Ibn Sīnā's *Canon of Medicine* long remained standard medical textbooks in Europe (Pormann and Savage-Smith, *Islamic* 164). Printings of Gerard of Cremona's versions of Euclid's *Elements* and Ptolemy's *Almagest* were widely available in the sixteenth century. Raphael included Ibn Rushd among the scholars of antiquity in his fresco *The School of Athens* (1509–11), commissioned by Pope Julius II to decorate the Apostolic Palace in the Vatican. There is no clearer testament to the legacy of Islamic science and philosophy in the growth of European learning than the survival of Latin versions of dozens of Arabic and Hebrew names, including Johannitus (Ḥunayn ibn Isḥāq), Azophi (al-Ṣūfī), Algoritmi (Al-Khwārizmī), Alfraganus (Al-Faraghānī), Avicenna (Ibn Sīnā), Albategnius (Al-Battānī), Azarquiel (al-Zarqālī), Abulcasis (Al-Zahrāwī), Abenzoar (Ibn Zuhr), Averroes (Ibn Rushd), Alhazen (Ibn Haythām), Haly Abenragel (Ibn Abī Rijāl), Gebir (Ibn Aflaḥ), and many others, not to mention, of course, Albumasar himself.

In Christian culture, this process of translating Arabic texts in the twelfth and thirteenth centuries in collaboration with Jewish scholars culminated during the reign of King Alfonso X of Castile (d. 1284), the younger first cousin of Frederick II of Sicily. Alfonso was the first king of the expanded kingdom of Castile after the decisive military victories against the Almohads by his father Fernando III, including the conquest of Cordoba (1236) and Seville (1248). After his father's death in 1252, Alfonso sought to match his father's legacy of military conquest with activity in the cultural sphere, dedicating the abundant resources of his Crown to support the translation of Arabic works still left untranslated, including works of astronomy and astrology, magic, wisdom literature, and Islamic legends. Rather than ordering translations into Latin, he made the radical choice to commission translations into Castilian, thus solidifying the role of the vernacular in scientific and philosophical

learning in the Peninsula. Through his patronage of over a dozen translations from Arabic, as well as his oversight of original historiographical, legal, and poetic compositions, he had a more decisive impact on the intellectual culture of Christian Iberia than any other medieval sovereign.

Virtually all of his translation projects, including his book on games (*Libro de ajedrez, dados, y tablas*) or falconry (*Libro que es fecho de las animalias que caçan*, or *Libro de Moamín*) could serve to exemplify the trajectory of transmission from antiquity that began in the Abbasid Caliphate and continued in Toledo. Like the translation movement in Baghdad, the *translatio studii* he sponsored was at the same time a *translatio imperii* that aimed largely to establish his political prestige. Even before his reign began, he commissioned the translation of the widely popular mirror for princes *Kalīla wa-Dimna* (*Calila e Digna*), itself the eighth-century Arabic translation of a frame-tale collection that had originated as the Sanskrit *Panchatantra*.

Yet his primary interest was less in abstract political theorizing than in *Realpolitik*, which for him meant, as it had in the Sassanid Empire and early Abbasid Caliphate, seeking an advantage through political prognostication. Thus, the most abundant of his translations – and eventually, the most scientifically significant – were astronomical and astrological works. In 1254, two years after his reign began, he commissioned the Jewish translator Yehudah Moshe ha-Cohen to complete *Libro conplido en los iudizios de las estrellas*, a translation of the *Distinguished Book of Judgments of the Stars* (*Kitab al-bāriʿ fī aḥkām an-nujūm*) by Ibn Abī al-Rijāl (d. ca. 1063), Tunisian court astrologer in Kayrawān. It was, in all likelihood, the same translator, working with a team of Jewish scholars that also included Isaac ibn Sid (Rabiçag), whom Alfonso commissioned to render into Castilian a string of other astrological works (Fernández, *Arte* 59–72). These included the *Book of Crosses* (*Libro de las cruzes*), on astrological conjunctions, attributed to one ʿUbayd Allāh, possibly ʿUbayd Allāh al-Istījī, an astrologer from Cuenca in the eleventh century (Samsó, "Astrología"; Fernández, *Arte* 75); the *Picatrix*, a translation of the Arabic book of divinatory magic *Goal of the Sage* (*Ghāyat al-ḥakīm*), of uncertain authorship but erroneously attributed to al-Majrīṭī (Fernández, *Arte* 291); and the collection of Pseudo-Aristotelian astrological and talismanic lore about stones known as the *Lapidario*, which was expanded near the end of Alfonso's reign with tables known as *Libro de las formas e imágenes que están en los cielos*, or *Tablas del Lapidario* (Fernández, *Arte* 138, 283). Like Albumasar, Alfonso sought through these translations to interpret "nuestros nacimientos / Por su ascendiente."

For Alfonso and his contemporaries, this astrological, magical, and legendary material was not categorically different from other works that today seem like true scientific astronomical treatises. For example, Alfonso ordered the translations of the *zīj* of al-Battānī (*Los canones de Albateni*), the *Kitāb fī hay'at al-'ālam* (*De configuratione mundi*) by Ibn Haythām (Samsó, "El original árabe"), al-Ṣūfī's *Book of Fixed Stars*, which formed the basis of his *Libro de la ochava esfera*. This work makes up the first part of the larger *Book of Astronomical Knowledge* (*Libro del saber de astronomía* [or *astrología*]), which is the only surviving piece out of three large astronomical compilations ordered by Alfonso. The second part of the *Libro del saber* includes various shorter treatises on astronomical instruments (the quadrant, the astrolabe, various clocks, etc.) (Chabás, "Las ciencias" 70–5; Fernández, *Arte* 225). As Samsó has shown, some of these works were faithful translations, while others included original material to varying degrees ("Las ciencias" 560; "Al-Bīrūnī"). Without a doubt, the most influential of Alfonso's scientific projects was the compilation of his own *zīj* tables, based on the *Toledan Tables* of al-Zarqālī (Thomas). The *Alfonsine Tables* expanded these and corrected many observations, blending astronomical observations from the Indian tradition of al-Khwārazmī and al-Majrīṭī with the Ptolemaic tradition of al-Battānī and al-Zarqālī (Chabás, "Aspects" 27).

Alfonso's translations were used in the fourteenth and fifteenth centuries, and thus were also logically among some of the earliest printed books on astronomy and astrology. His *Libro complido* was translated into Latin in Alfonso's court (and later into Judeo-Portuguese, Hebrew, and other languages), and was printed in Venice in 1485 (*Praeclarissimus liber completus in judiciis astrorum*), even earlier than the first printing of Abū Ma'shar in Latin (*De magnis coniunctionibus*, Augsburg, 1489). Alfonso's tables were translated into Latin in the 1320s in Paris, and this version displaced the Latin versions of al-Majrīṭī made by Adelard of Bath. After being printed in Venice in 1483, Alfonso's tables became the most widely known astronomical tables in Europe (Chabás "Aspects" 32–3). The Jewish scholar Abraham Zacuto (d. ca. 1515) made direct use of the *Alfonsine Tables* in his Hebrew writing as well as in the Latin work based on this, the *Almanach Perpetuum* (1496), which proved extremely important in astronomical thought in the early sixteenth century. (Chabás, "Las ciencias" 87–90). Copernicus's personal annotated copy of the 1492 printing of Alfonso's tables, along with Gerard of Cremona's translations of Ptolemy (Venice 1515) and of Ibn Aflaḥ's corrections (Nurenberg 1534) all still survive today (Czartoryski, "The Library") (see figure 1.2).

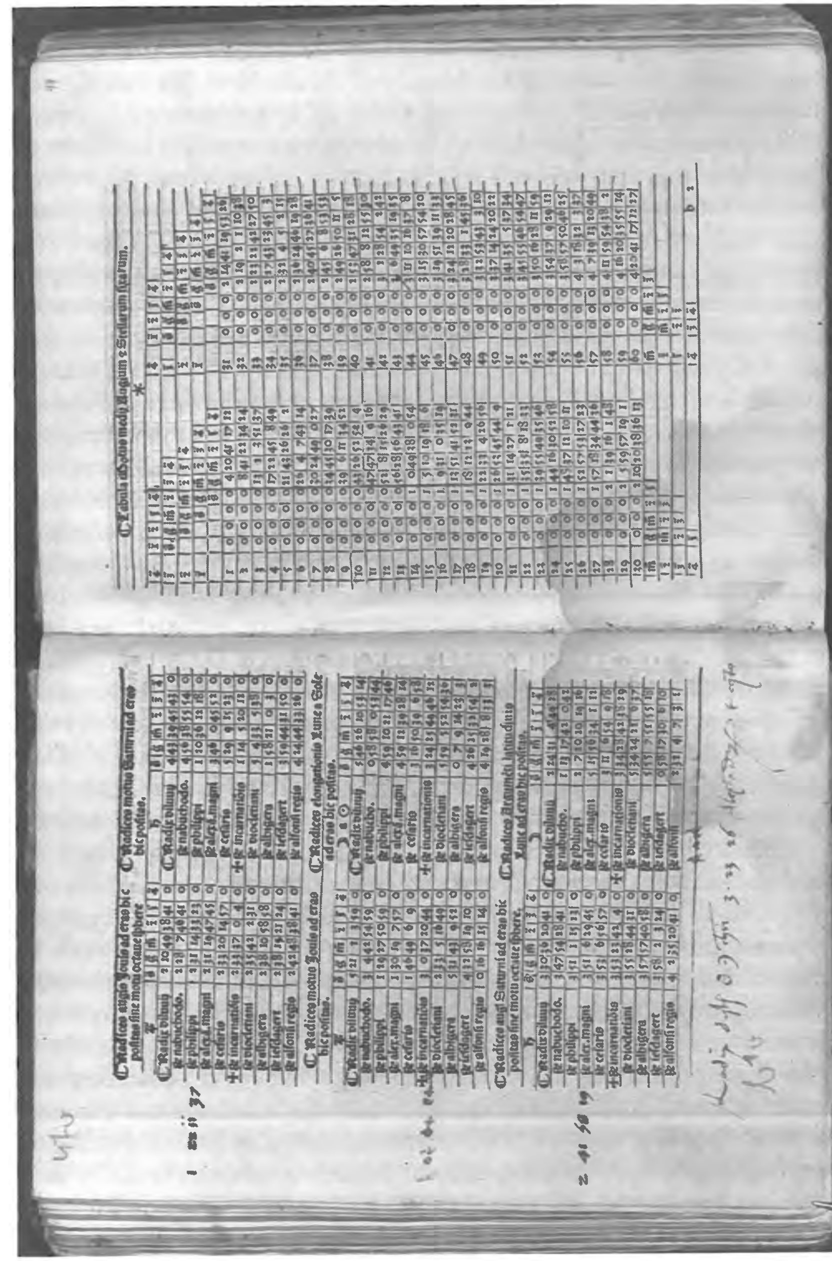

Figure 1.2 Uppsala University Library, Copernicana 4 (1), fols. 47v–48r.

Conclusion: Mise-en-scène in Madrid

When Alfonso recounts in his history of Spain how "Se leuanto en los alaraues un moro ... et era un sabio en la astronomia ... et era muy sabio en las naturas otrossi," he evokes an inveterate tradition of Islamic learning that was still relevant and familiar when, over three centuries later, Lope's Abdelmón tells Albumasar, "de esferas, planetas, / cielos y otros movimientos, / sabes las causas secretas." The scientific advances of the ancient world, from Euclidian geometry to Ptolemaic astronomy to Aristotelian natural sciences, were cultivated in Albumasar's Baghdad, a uniquely fitting site for the rich confluence of diverse streams of ancient learning from the Greek, Persian, Sanskrit, and ancient Egyptian and Mesopotamian worlds. Because of Toledo's own strategic position as the site of the later encounter of Latin and Arabic traditions, it played a decisive role in the reception and transmission of that concentrated knowledge. Because Alfonso X, embracing his role as heir of the twelfth-century translation effort, ruled at a formative moment in which newly translated learning began to be disseminated throughout Europe, the writing he commissioned served as a bridge between medieval and early modern astronomy. Alfonso's influence in astronomy is emblematic of a more general trend: many significant advances of European science – from the Copernican heliocentric model to Kepler's optical theories to Harvey's explanation of the circulation of blood – built in some way on this transmission of knowledge from antiquity to early modernity via Baghdad and Toledo.[9] While the narrative of the history of science as a forward-moving chain of transmission certainly succumbs to a Whig vision of history, the search for first discoveries in modern science without their long historical context falls into the blinding trap of paradigm bias.

The dissemination in the age of printing of Latin translations of Arabic versions of Greek texts naturally came to play a pronounced role in early modern Spanish cultural expression. One need not look far for examples of this legacy. Lope de Vega's use of the prognostications of Albumasar as part of the backdrop for the drama of the captive Isabel passing as her Christian mistress, is only one of a string of meaningful allusions to the legacy of Islamic science in Spain. When he names Ibn Rushd (*La Dorotea* 291) or Ibn Rijāl (554) or Ibn Sīnā (*El Alcalde Mayor*, *La viuda casada y donzella*, *La noche de San Juan*, *El Caballero de Yllescas*, *El mármol de Felisardo*), he evinces a familiarity with their writing and a recognition of their expertise. As he writes in *La hermosura de Angélica*, "Los moros siempre en medicina diestros, / como Avicena y Rasis testifican/ en junta de dotores y maestros, / varios remedios a la muerte aplican" (The moors, always skilled in medicine/ as Ibn Sīnā and Rāzī testify, / together with doctors and teachers, apply various remedies against death.) (*La hermosura* 256). When Lope mistakenly describes the Presocratic Anaximander as "astrólogo de Persia celebrado" (a celebrated Persian astrologer) (*Lo que ha de ser*), or cites (deliberately?) both Avicena and Galen together in Latin (*El acero de Madrid*), or names in the same breath Al-Faraghānī and Ptolemy (*El príncipe perfecto*), he assumes a familiarity with the common Greco-Arabic astronomical heritage that formed the basis of pre-modern science. When he then names, in the next lines, "Alfonso, King of Spain" as an astronomer who made corrections to these Greek and Muslim scholars, he points to the critical role of Iberia in expanding and transmitting that heritage to the early modern world.[10]

The growth of the theatre in this period might itself be explained in part as a result of Spain's particular role in the development of modern scientific thought. It is certainly no coincidence that science and drama, which both flourished in a new and unique way in ancient Greece, should flourish again in parallel fashion in the early modern period. In Alfred North Whitehead's words, "The pilgrim fathers of the scientific imagination as it exists today are the great tragedians of ancient Athens ... their vision of fate, remorseless and indifferent ... is the vision possessed by science" (*Science* 12). The medieval accounting of necessity, sharpened over centuries in the charting of the golden rules of mathematics, the laws of the stars, and the ineluctability of disease and death, gave rise in the early modern period to a new skeptical materialism that involved both a revolutionary understanding of the physical world and an unparalleled insight into the human condition precipitated by that very knowledge. This new vision was marked not only by more intensive scientific learning, but also *pari passu* by a profound intellectual and spiritual crisis – the beginning, in Kuhn's words, of a "paradigm shift" (119) in human thought that has led both to the modern scientific world view and to the post-Cartesian concept of the sovereign self adrift in an alien universe of material forces. Spain's unique position in the history of science also made it a logical place where the first echoes of that crisis, like the "ecos de mi fama" of which Albumasar boasts, resonated forcefully across all areas of Golden Age cultural expression.

NOTES

1 The author is grateful to Aileen Das and Ed Casey for their comments on an earlier draft of this chapter.
2 On Alfonso's use of Rodrigo for this story, see Hazbun, *Narratives*, 52.
3 On the role of the press in the growth of science, see Eisenstein, *The Printing Press*, 453–682.
4 A comprehensive source for pre-Socratic thought is Graham, *The Texts*. See also the corresponding entries in Gillespie et al., eds. *Complete Dictionary of Scientific Biography*.
5 This overview summarizes Lloyd, *Early Greek Science*, 99–124.
6 On the influence of Babylonian science in Greece, see Rochberg, *The Heavenly Writing*.
7 For a coherent list of the major philosophical translations undertaken in Toledo, see Burnett, "Arabic into Latin," 391–400.
8 For a chronological chart of scientific translation into Hebrew, see Zonta, "Medieval."
9 One can compare this history to parallel channels of transmission of ancient science via Baghdad, such as that reaching the Ottomans and Safavids of the seventeenth century. See, for example, Brentjes.
10 All references to plays are drawn from the Teatro Español del Siglo de Oro Database (TESO).

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