Unisia (P-ISSN 0215-1421 E-ISSN 2829-1573)
2024, Vol. 42, No. 1, 57-86
https://doi.org/10.20885/unisia.vol42.iss1.art3

Re-Evaluating the Development of the Islamic Sciences: The Case Against the Classical Narrative and the Myth of Decline

Adam Lucas

School of Humanities and Social Inquiry, Faculty of Arts, Social Sciences and Humanities, University of Wollongong, Australia

ABSTRACT

Eurocentric myths about Western scientific and technological superiority persist in popular culture and some scholarly circles. A prevalent myth suggests that Islamic contributions to modern science were primarily the transmission of ancient Greek and Roman knowledge to medieval and early modern Europe. A less extreme version posits significant contributions during Islam's "Golden Age," followed by a decline between the late eleventh and late fourteenth centuries. This paper challenges these narratives, presenting recent scholarship that demonstrates continuous major advances in astronomy, physics, mathematics, and medicine by Islamic scholars throughout the late Middle Ages and into the early modern period. The study underscores the inadequacy of the classical narrative, which claims that Islamic scientific activity declined after an initial period of prosperity. Historians of science from Neugebauer, Kennedy and Swerdlow to Saliba, Ragep and Mozaffari have provided evidence that Islamic scholars not only preserved ancient knowledge but also made original contributions that influenced later European developments. This includes advancements in fields such as astronomy, where figures like Nasir al-Din al-Tusi and Ibn al-Shatir developed models later utilized by Copernicus. The paper also highlights continued progress in medicine and mathematics, with scholars like Al-Razi and Ibn Sina making lasting impacts on European scientific thought. The article argues for a re-evaluation of the role of Islamic sciences, emphasizing that many significant contributions remain understudied due to a lack of accessible manuscript sources. By debunking the myth of decline, the paper calls for recognition of the dynamic and sustained intellectual activity within Islamic cultures, which continued to produce influential scientific work well into the early modern era.

Keywords

astronomy; classical narrative; Islamic sciences; knowledge transmission; mathematics; medicine; myth of decline

ARTICLE HISTORY

Received: May 3, 2022
Revised: June 12, 2024
Accepted: June 12, 2024
Published: June 27, 2024

Contact: Adam Lucas alucas@uow.edu.au

Citation: Lucas, A. (2024). Re-Evaluating the Development of the Islamic Sciences: The Case Against the Classical Narrative and the Myth of Decline. *Unisia, 42*(1), 57-86. https://doi.org/10.20885/unisia.vol42.iss1.art3

INTRODUCTION

> 'There is infinitely more mental initiative in Muslim historiography and philology than in their obsequious refurbishing of ancient science.'

The quote above from the Austrian historian and Arabist, Gustave von Grunebaum (1909-1972) is emblematic of one of the more persistent of the Eurocentric myths about Western scientific and technological superiority and exceptionalism. According to this myth, the contribution of Islamic cultures to the development of modern science and technology was primarily based in their diffusion of ancient Greek and Roman knowledge to medieval and early modern Europe with little or no modification. Islamic scholars simply preserved the intellectual legacies of the Greeks and Romans in Arabic, and subsequently transmitted to European scholars significant tranches of classical knowledge that had been lost to Europe after the collapse of the Roman Empire (Saliba, 2007). The most extreme version of the myth holds that astronomy and mathematics stagnated after the death of Claudius Ptolemy (83-c.168 CE) and were not reawakened until the time of Nicolaus Copernicus (1473-1543). The less extreme version argues that although Islamic scholars made important contributions to the development of medicine, astronomy and mathematics during the so-called 'Golden Age' of Islam, there was a significant decline in the quality and quantity of those contributions sometime between the late eleventh and late fourteenth centuries.

Although there has clearly been a substantial body of scholarship available to Muslim scholars in languages other than English, French and German which has demonstrated the fallacy of these different versions of Islamic intellectual stagnation, most of that scholarship has not been translated for the benefit of Western scholars. Developments over the last forty years in the history and sociology of science and technology have, however, been witness to a major reevaluation of the contribution of non-Western cultures more generally to scientific and technical traditions in the West. A significant body of this scholarship has involved debunking nationalist, rationalist, and Eurocentric myths about the history of science and technology. During that time, specialists in the Islamic sciences from diverse cultural backgrounds have published several dozen important books and articles in English which have sought to demonstrate the important contributions of Islamic scholars to the development of pre-modern science and technology. Their research has exposed the extent to which a number of long-held prejudices and inaccurate assumptions about the development of the Islamic sciences need to be fundamentally re-evaluated, especially by those who claim to champion the exceptional status of the Western canon. In the process of doing so, it has also demonstrated that key developments in modern science and technology need to be fundamentally revised, especially in relation to astronomy, chemistry, mathematics, mechanics, and medicine.

This paper attempts to provide colleagues who are not familiar with the relevant research with some idea of the various grounds for criticizing what George Saliba has called 'the classical narrative' and the associated myth of Islamic decline (Saliba, 2007). Because it is only intended to provide an overview of the work of some of the more prominent historians who have contributed to this research in the English language over the last century, along with brief descriptions of the important work published by Islamic natural philosophers and scholars from the medieval and early modern periods, it makes no pretence to provide any original research on the relevant topics. Nor does it purport to give any particular insight into the depth and breadth of recent Islamic scholarship on these topics in languages other than English. I claim no special expertise on the topic of the development of the Islamic sciences, nor am I familiar with most of the work of scholars writing about the history of the Islamic sciences which is not published in English. However, as a professional historian I have maintained an abiding interest in the general topic and have some familiarity with the work of those who have dedicated their academic careers to it.

Because my professional training has been in the post-Kuhnian contextualist tradition in the history of science (Schuster, 1979, 2016), as well as historiographical developments informed by the sociology of scientific knowledge (e.g. Applebaum, 2003; Burns, 2001), I use the term 'Islamic sciences' to denote the different historical trajectories and theoretical and methodological development of Islamic medicine, astronomy, mathematics, physics, chemistry, geography, timekeeping and cartography outlined in this discussion. My general intention is to introduce readers to the work of several scholars with extensive knowledge of the topics discussed.

My own research in the history of premodern technology has drawn attention to the extensive contributions of Islamic cultures to the development of medieval machine technology. Those contributions include the conveyance of ancient Egyptian, Roman and Chinese innovations to the Mediterranean and northern Europe in the use of water- and wind-power for a wide range of civic, agricultural, and industrial uses, as well as developments that were undoubtedly autochthonic in origin (Lucas, 2006). This article is an attempt to draw the attention of my English-, Arabic-, Turkish- and Persian-speaking colleagues – as well as others whose first language is not English and whose disciplinary interests lie outside history – to the rich heritage of the Islamic sciences. Methodologically, my paper follows the conventions of a review essay.

The article begins with a brief outline of twentieth- and twenty-first century academics writing mainly in the English language who sought to provide informed evaluations of early Islamic scholarship to the development of the sciences and technology. This is followed by an overview of the classical narrative, along with the accompanying myth of Islamic decline which supposedly led to the stagnation of natural philosophy and the exact sciences under Islam. It goes on to describe the development of research by Western scholars going back to the late 1950s which has noted uncanny resemblances between advances in medieval Islamic astronomy and models of planetary motion developed by Copernicus, and how an understanding of the work of Al-Ghazalī (1058-1111) and Ibn Khaldūn (1332-1406) provides important insights into the development of the Islamic sciences during the period of putative 'decline'. It then provides an outline of important but overlooked contributions in astronomy by individuals such as Ali Qūshjī (d. 1474), 'Abd al-'Alī al-Bīrjandī (d. 1525 or 1526), Shams al-Dīn al- Khafrī (fl. 1525) and Fatḥ al-Dīn al-Qaysī (d. 1258). Evidence for continued Islamic developments in medicine by Ibn al-Nafīs (d. 1288) and Manṣūr ibn Muḥammad ibn Aḥmad ibn Yūsuf ibn Ilyās (fl. late 14th c.), and in mathematics by Al-Qurashi (d. 1184), and al-Marrākushī (1256-c. 1321), round out the discussion. Space precludes a discussion of Islamic contributions to the development of chemistry and mechanics. The paper concludes with some general observations about the wealth of material that is yet to be studied by historians working on these topics.

A Century of Scholarly Efforts to Recuperate the Contribution of the Islamic Sciences and Technology to the Modern Period

Amongst the more prominent of the early twentieth-century Western scholars who wrote appreciatively of the legacy of the Islamic sciences and technology were the medievalist Charles Homer Haskins (1870-1937), the historian of medicine Max Meyerhof (1874-1945) and the historian of science George Sarton (1884-1956). However, as I will indicate in more detail below, it was not until Otto Neugebauer (1899-1990) and Edward S. Kennedy (1912-2009) began delving more deeply into Islamic contributions to late medieval astronomy that the significance of those contributions started to become more clearly evident (Kennedy, 1966, 1983, 1984, 1998; Neugebauer, 1945, e.g. 1969, 1975, 1983). Their students and successors Noel Swerdlow, Willy Hartner, Abdelhamid Sabra, Jan P. Hogendijk, George Saliba and Jamil Ragep advanced those studies to a considerable degree (e.g. Hartner, 1969, 1973, 1975; Hogendijk, 2002, 2004, 2005; Hogendijk & Sabra, 2003; Ragep, 1987, 2001b, 2001a, 2005, 2007, 2009, 2016; Sabra, 1984, 1987, 1989, 1996; Saliba, 1979, 1995, 1999, 2000, 2002, 2007, 2009; Swerdlow, 1973, 2017; Swerdlow & Neugebauer, 1984). Together with the work of Régis Morelon, Roshdi Rashed, Julio Samsó, Robert Morrison, David A. King, and S. Mohammad Mozaffari, there is now a large body of detailed research on Islamic astronomy, cosmology, geography, cartography, mathematics and the science of timekeeping which demonstrates major advances and improvements on classical learning by scholars working under Islamic rule (Chemla et al., 1986; King, 1999, 2004, 2005, 2007, 2011; e.g. Morelon, 1994, 2000; Morrison, 2014a, 2014b; Mozaffari, 2013, 2016, 2017, 2018, 2019; Rashed, 2014; Rashed & Morelon, 1996; Samsó, 2018).

There have been a number of attempts to synthesise this scholarship and present it to a general readership over the last forty years. For example, Donald Hill and Ahmad al-Hassan have published general surveys of Islamic technology in the 1980s and 1990s (Al-Ḥasan & Hill, 1994; Hill, 1998), while Emilie Savage-Smith and her collaborators have more recently published several surveys of Islamic medicine, cartography and geography (Greppin et al., 1999; Pormann & Savage-Smith, 2007; Rapoport & Savage-Smith, 2014; Savage-Smith, 2013). Other general surveys include Rashed & Morelon's *Encyclopedia of the History of Arabic Science* (1996), Hogendijk & Sabra's edited collection, *The Enterprise of Science in Islam* (2003), Saliba's *Islamic Science and the Making of the European Renaissance* (2007), Selin's *Encyclopedia of the History of Science, Technology and Medicine in Non-Western Cultures* (2008), and the edited collection by Rahman et al., *The unity of science in the Arabic tradition: Science, logic, epistemology and their interactions* (2008). Taking a somewhat broader approach, a book and edited collection by Bala, *The Dialogue of Civilizations in the Birth of Modern Science* (2006) and *Asia, Europe and the Emergence of Modern Science* (2012) are dedicated to drawing the attention of historians of science to the contributions of non-Western cultures more generally to the development of the contemporary sciences and to debunking Eurocentric views of their origins (cf. Langermann, 2018). Finally, the Institute for the History of Arabic-Islamic Science in Germany has published more than 100 volumes to date in its series *Islamic Mathematics and Astronomy* (Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 2021). The series consists of reprints of the vast majority of all the published research in Arabic and Western languages on both topics that appeared before 1960.

The Classical Narrative and the Myth of Islamic Decline

The development of a contemporary research program in the history of the Islamic sciences has required of those who wish to study it extensive knowledge of a wide geographic area and several different languages. Because it also involves the formation of a number of scientific disciplines and technical practices, a significant amount of training and experience is required to master the source material and adequately interpret it. Because of the difficulties associated with working on such material, it has necessarily restricted the number of scholars who can pursue this topic

(Savage-Smith, 1988). However, that also makes it a relatively straightforward matter to outline how the contribution of the Islamic sciences to the modern period has been represented in western scholarly circles over the last two centuries.

The earliest and most influential narrative to emerge concerning the role of Islam in the development of modern science was that it played only a kind of handmaiden role in that development, despite some early improvements. According to its proponents, the translation of Greek and Persian science during the early Abbasid period (ca. 750-900) instigated a brief flowering of the Islamic sciences, which was soon extinguished by religious opposition. This supposedly occurred around the same time that much of the relevant knowledge had been transmitted to Latin Christendom. The subsequent 'twelfth-century Renaissance' saw European scholars develop their own scientific ideas without further recourse to Islamic texts or commentaries (Haskins, 1927). Although Saliba has argued that most proponents of the 'classical narrative' placed the decline of the Islamic sciences in the eleventh century, as we will see below, there has been some divergence over the relevant dates among the scholars concerned. Nevertheless, Saliba's (2007) general outline of the narrative and its shortcomings remains largely accurate.

Initially propagated by the first generation of European historians of science during the 'long nineteenth century', amongst the earliest of its exponents was the classical economist Adam Smith (1723-1790). In his posthumously published 'The History of Astronomy' (1869, p. 354), Smith argued that:

> "For, though the munificence of the Abassides, the second race of the Caliphs, is said to have supplied the Arabian astronomers with larger and better instruments than any that were known to Ptolemy and Hipparchus, the study of the sciences seems, in that mighty empire, to have been either of too short, or too interrupted a continuance, to allow them to make any considerable correction in the doctrines of those old mathematicians … They were still, therefore, too much enslaved to those systems, to dare to depart from them, when those confusions which shook, and at last overturned the peaceful throne of the Caliphs, banished the study of the sciences from that empire. They had, however, before this, made some considerable improvements: they had measured the obliquity of the Ecliptic, with more accuracy than had been done before."

Less accommodating was the distinguished French physicist, philosopher and historian Pierre Duhem (1861-1916), who described 'the wise men of Mohammedanism' as 'completely destitute of all originality'. In one particularly derogatory passage in his 'History of Physics' entry for *The Catholic Encyclopaedia*, Duhem (1911) asserted that:

> "The revelations of Greek thought on the nature of the exterior world ended with the 'Almagest,' [by Ptolemy] which appeared about A.D. 145, and then began the decline of ancient learning. Those of its works that escaped the fires kindled by Mohammedan warriors were subjected to the barren interpretations of Mussulman commentors and, like parched seed, awaited the time when Latin Christianity would furnish a favourable soil in which they could once more flourish and bring forth fruit."

Unlike Smith, Duhem was prepared to give no credit to Islamic scholars in the development of the sciences. Nevertheless, the idea that there was a decline in scientific learning under Islamic rule was already being propounded by Smith in the 1780s.

Similar views to Smith's were expressed by orientalists throughout the nineteenth and early twentieth centuries. Most simply assumed that cultural deterioration had occurred throughout Islam during the latter half of the Middle Ages. For example, the influential French philologist, Ernest Renan (1823-1892), argued that those Muslims who were his contemporaries have 'the deepest contempt for education, for science, for all that constitutes the European spirit'. He nevertheless acknowledged that there had been a time when astronomy and algebra 'underwent remarkable developments' during the first 500 years of Islam's diffusion, and that there were also 'astonishing results' in chemistry. However, from roughly 1275, Renan argued, 'the Muslim countries plunge into the saddest intellectual decay' after 'philosophy is abolished in Muslim countries' (Renan, 1883).

The minimization of Islam's contributions to the sciences by prominent European intellectuals such as Smith, Duhem and Renan were somewhat corrected in historical assessments from the 1920s and '30s by William Dampier (1867-1952), Charles Homer Haskins (1870-1937), Max Meyerhof (1874-1945) and George Sarton (1884-1956). But these more favourable assessments were similarly tempered with the observation that although Islamic scholarship had flowered between the eighth and eleventh centuries (the so-called 'Golden Age' of the Islamic sciences), it had suffered a marked decline between the late eleventh century and the late thirteenth century.

The second generation of western orientalists drew on the work of the aforementioned historians of science to construct very similar stories about the contributions of Islamic scholars to mathematics, medicine, natural philosophy and the development of technology. For example, although Islamic scholars were 'manifestly impeded by the acceptance of authority' with respect to the natural sciences, von Grunebaum cited Sarton and Haskins to concede that they had 'clearly surpassed their Greek masters' with respect to optics, and had 'added important observations of fact' with respect to medicine and astronomy (von Grunebaum, 1924, pp. 336, 338). However, he goes on to argue that Islam failed to 'put natural resources to such use as would ensure progressive control of the physical conditions of life. Inventions, discoveries, and improvements might be accepted but hardly ever were searched for' (von Grunebaum, 1924, p. 343). His conclusion was that (von Grunebaum, 1924, p. 344):

> "Islam has never shown that overflowing abundance of ideas, that boundless fertility that is the greatness of the Greeks, nor did it spend itself in exuberant advance to unknown shores regardless of the havoc such advance might wreak on the present possession, as is the way of the West. Islam does not reach to the stars."

While none of the early advocates of Islamic decline provided any compelling evidence to back up their claims, they did propose some reasons as to why this decline had occurred. For example, the ophthalmologist, translator and historian of medicine, Max Meyerhof, proposed at least two different theories. At the end of a paper outlining the contents of a medical philosophical treatise by the Nestorian Christian physician, Abu Sa'id Ubaid Allah ibn Bakhtyashu (a.k.a. Ubaid-Allah, 940–1058), he concludes that the Greek philosophical tradition was 'well understood and taught' in the middle of the eleventh century, but 'very soon the decay set in, and about the year 1100 AD orthodox scholasticism was already victorious in the Islamic world and led to the scientific stagnation which prevailed during the rest of the Middle Ages' (Meyerhof, 1928).

Meyerhof subsequently offers a very different account in a book chapter for *The Legacy of Islam* titled 'Science and Medicine' published in 1932 which both contradicts his earlier explanation and is internally incoherent (cf. Abdalla, 2004). First of all, he suggests that Islamic science began to decline around 1100 because of the negative influence of the popular Sufi jurist and polymath, Abū Hāmid al-Ghazalī (1058-1111). However, as will be explained in more detail below, al-Ghazalī was a critic of Aristotelianism and certainly not an advocate of 'orthodox scholasticism'. Later in the same chapter, Meyerhof tells us that Islamic science experienced a 'standstill' (rather than a decline) in the twelfth century, and that there was 'a further deterioration of the general standard' in medical scholarship from the beginning of the fourteenth century due to the detrimental effect of 'magical and superstitious practices' (Meyerhof, 1931).

Meyerhof was neither the first nor the last to attribute Al-Ghazalī's influential book, *Tahāfut al-Falāsifa* (*The Incoherence of the Philosophers*) with having mobilized an anti-scientific backlash throughout the Islamic world in the latter half of the Middle Ages. The supposed chilling effect of al-Ghazalī's work on the continued development of Islamic science is one of the most frequently invoked causal factors cited by Islamic decline theorists. However, this view is based on a misunderstanding of al-Ghazalī's aims and the content of his book, which are primarily directed at denouncing Plato and

Aristotle and the influence of pagan Greek philosophy on the development of natural philosophy in Islam. Despite al-Ghazalī's antipathy toward the Greeks, he expressed strong support for observational and logical forms of demonstration and mathematical forms of proof, neither of which could be accurately described as 'anti-scientific' stances nor any form of 'orthodox scholasticism' (Marmura, 2000). Al-Ghazalī's stance reflects one position in a long-running debate among Islamic scholars who sought to differentiate on both theological and philosophical grounds practical mathematics and logical demonstration from the more 'abstract' forms of reasoning associated with Greek natural philosophy, which included astrology, physics, and metaphysics (Ragep, 2001b, 2001a).

Whereas Meyerhof placed the beginning of the decline as occurring in the twelfth century and accelerating in the early fourteenth century, his fellow historian of science George Sarton argued that it took place after the fourteenth century, when Arabic learning was 'smothered by theological obscurantism and by superstitions'. According to Sarton (1966, pp. 92–93), it 'fell into a kind of sluggishness and despondency which made further progress impossible' as Muslim political power decreased. On the positive side, Sarton (1966, p. 87) largely attributed what he called 'the miracle of Arabic science' to 'the catalyzation of Arabic vigor and earnestness and of Islamic faith by Persian curiosity and sophistication'. He went on to argue in his essay 'Islamic Science' that, 'Some historians have tried to pooh-pooh those immense achievements by claiming that there was nothing original in them and that the Arabs were nothing but copy-cats. Such a judgement is all wrong' (Sarton, 1966, p. 88). He then provides evidence for why it is wrong, and at the end of his article details how scholarship in the field can be further advanced.

As we will see in the section to follow, Sarton's upbeat suggestions for further research in the mid-1950s and his outline of the rich untapped manuscript sources to be mined were pursued by a number of younger scholars of the next generation. Although those scholars have seriously questioned the claims and evidential basis for Islamic decline, a number of their contemporaries continued to repeat it in one form or another in several influential books.

For example, the eminent American historian of science David Lindberg echoes the views of many of the previously cited decline theorists in his widely read and critically acclaimed *The Beginnings of Western Science: The European Scientific Tradition in Philosophical, Religious, and Institutional Context, Prehistory to A.D. 1450*. He wrote that, 'during the thirteenth and fourteenth centuries, Islamic science went into decline; by the fifteenth century little was left' (Lindberg, 2007, p. 180). To his credit, Lindberg was not offering a monocausal explanation for this decline, arguing instead that opposition to scientific activity from conservative religious forces was only one of three factors which he drew on to account for the 'decline'. The other two factors were a restriction of scientific focus to less important questions following the 'naturalization of Islamic science', and ongoing military conflict after 1100 between warring Islamic states and factions as well as external enemies (Lindberg, 2007, pp. 180–182). Nevertheless, as Ragep (2009) has noted in his review of Lindberg's revised version of the book, the latter's account of the role of Islam in Europe's intellectual heritage remained somewhat threadbare.

American sociologist Toby Huff's *The Rise of Early Modern Science, Islam, China and the West* (2017) similarly located the period of supposed Islamic decline at the end of the thirteenth century. He extends the causal nexus for his account to encompass a mixture of religious, legal, cultural and institutional factors. Most recently, Sylvain Gouguenheim (2008) has sought to reinvigorate Duhem's account of Islam's role in the history of science in his *Aristote au Mont Saint-Michel: Les racines grecques de l'Europe chrétienne*. Although he did not directly name any of the revisionist historians of science cited in the introduction, Gouguenheim rejects what he describes as the prevailing view nowadays that 'Arabic learning' was responsible for rescuing Europe from the 'Dark Ages'.

Given that Duhem's and Gouguenheim's positions are untenable and inconsistent with the evidence, we should also extend some scepticism toward the proponents of Islamic decline. They broadly agree that there were major advances in Islamic medicine, astronomy and mathematics during the first 500 years of Muslim rule. However, their general reliance on the supposed absence of evidence does not support the conclusion that such evidence is absent. Indeed, there is now a substantial body of evidence to indicate there was no decline in the quality or quantity of research into the sciences by Islamic scholars from roughly 1100 onwards.

According to Mohammed Abdalla, the most well-informed defender of what he calls 'the decline theory' concerning the development of the Islamic sciences was the historian of science, Abdelhamid Sabra (1924-2013). He argues that although Sabra forcefully argued against Duhem that Islamic cultures did not just passively preserve and transmit ancient Greek sources, but actively modified and improved on them, Sabra nevertheless accepted that a decline did take place. However, it would appear that Abdalla overlooked some of Sabra's more recent scholarship, which acknowledged that there was no overall decline, and that whatever decline did take place did not occur across the totality of Islamic civilization (Hogendijk & Sabra, 2003). Indeed, Abdalla makes the point in his book, *Islamic Science: The Myth of the Decline Theory*, that 'Sabra's suggestion that not all centres of scientific activity in the Islamic Empire [sic] were always in the same phase of development at the same time' was central to Ibn Khaldūn's (1332-1406) analysis of the fate of the Islamic sciences in the Middle Ages (Abdalla, 2008, p. 129).

In his famous work of universal history, *Muqaddimah* (known as the *Prolegomena* in Europe), first published in 1377, Ibn Khaldūn argued that when the lands of the Maghrib (the present-day countries of Morocco, Tunisia, Libya and Algeria) and Islamic Spain fell into social and economic decline, scientific instruction ceased to be cultivated in the west of the Islamic Empire. But even though scientific activity eventually disappeared in the west of the Empire and ceased to be cultivated in the cities of Baghdad, Basra and al-Kufa (as they likewise fell into ruin), science was transplanted from these early centres of scholarship to other parts of what are now Iraq and the Central Asian republics. It was also conveyed to Cairo and adjacent centres, wherein scientific activities continued to develop and prosper. Ibn Khaldūn directly connected this activity to the level of civilized development in each region and the extent to which a sedentary culture had been established and was subsequently maintained. According to Ibn Khaldūn, both factors contribute to the vibrancy and diversity of the crafts, including scientific instruction. In other words, different parts of Islamic civilization experienced different rates of growth and decline, depending on local religious influences, the priorities of political and religious leaders, and the extent to which armed conflict undermined stability, security and prosperity in particular regions (cf. Abdalla, 2008, pp. 28–30).

Abdalla has pointed out that although copies of Ibn Khaldūn's manuscript were held in European libraries as early as the seventeenth century, the *Muqaddimah* was not translated into French until 1862 and into English and Portuguese until 1958 (Abdalla, 2004). While this may explain why Ibn Khaldūn's insights into the mixed fortunes of Islamic scientific development remained largely unknown to Western scholars until quite recently, the fact that both Arnold Toynbee and George Sarton held him in the highest regard suggests that it is more likely that the full implications of his insights concerning the shifting centres of Islamic intellectual life were not fully grasped by Western scholars (Grant, 2008).

One of the basic assumptions underlying contemporary contextualist historiographical approaches is that scholarly standards, conventions, and expectations differ from one time period, culture, and discipline to another. Ibn Khaldūn's account is therefore not only remarkably modern but remarkably accurate, because contemporary historians of Islamic science have come to much the same conclusion. Contrary to the arguments of proponents of the decline theory, there was no overall reduction in the quality or quantity of research being produced in the Islamic caliphates and empires. What *did* happen was a shift in emphasis to different scientific practices, along with a shift in the location of the intellectual centres of that activity, and in the grounds for justifying engagement with different branches of the sciences as broadly construed.

The negative assessments of Islamic scholars' contributions to the development of the sciences and natural philosophy during the second half of the Middle Ages have been challenged on a number of fronts. For example, the historian of medieval science, Edward Grant, has recently argued that 'from around 1100 to 1500, sciences such as optics, astronomy, mechanics, mathematics, and medicine reached a higher state in Islam than in the medieval West (Grant, 2008).[1] According to Jan P. Hogendijk and Abdelhamid Sabra writing in 2003, 'the Islamic tradition in the exact sciences continued well into the nineteenth century, and abundant source material is available in the form of unpublished manuscripts in Arabic, Persian, and other languages in libraries all over the world' (Hogendijk & Sabra, 2003, p. vii).

The most detailed argument in support of these claims is contained in George Saliba's *Islamic Science and the Making of the European Renaissance* (2007). In that book, he argues that the catalyst for the development of the sciences in early Islam was the administrative reforms of 'Abd al-Malik (r. 685-705) which installed Arabs throughout the government bureaucracy and standardized the coinage. The non-Arab bureaucrats who had previously largely monopolized government posts due to their knowledge of the elementary sciences and their linguistic and scientific skills suddenly found their jobs and livelihoods threatened.

In order to be able to compete with the new occupants of the dīwān, and go back to monopolize the high positions of government, members of these communities of [non-Arab] bureaucrats had to make use of their knowledge of both the Greek language and the elementary sciences that they used in the dīwān, and try to educate themselves or their children in the more advanced sciences, to which their elementary sciences referred for higher precision and sophistication (Saliba, 2007, pp. 60–61).

The non-Arab bureaucrats 'resorted to higher specialization through the translation of the more advanced sciences' which enabled them 'to gain an edge on the new competition' and thereby secure for themselves 'a new monopoly at the higher echelons of government' (Saliba, 2007, pp. 60–61, 65). According to Saliba, the genesis of a scientific tradition in Islam was made possible by three factors: a cadre of non-Muslim scholars with some scientific training, a bureaucratic culture that incorporated a reward system which promoted the sciences, and an external support structure in the

---

[1] Readers are directed to Grant's paper which discusses how ancient Greek natural philosophy was received, transmitted and critiqued by Islamic and Christian theologians, including the status of natural philosophy within Islamic societies based on the tripartite division of intellectual inquiry that privileged Islamic law and theology above those scholars 'who used Greek philosophy to interpret and defend the Muslim religion', and the *falasifa*, 'who followed rational Greek thought, especially the thought of Aristotle' (Grant, 2008).

form of state patronage that gave the sciences a socially sanctioned way to carry out their various tasks.

Astronomical Advances in the Islamic Sciences: The Copernican Connection

With respect to the history of astronomy, even those scholars who have argued for Islamic decline accept that major advances were made during the early period. Islamic scholars refined and revised observational astronomy using new instruments and improved methods of calculation that were developed in the many new observatories set up in what are now Iraq and Iran from the early ninth century onward. Islamic astronomers were highly critical of the legacy of Ptolemy, and many of these criticisms and their alternative solutions particularly those of Nasīr al-Dīn al-Tūsī (d. 1274), Mu'ayyad al-Din al-'Urdi (d. 1266), Qotb al-Din Shirazi (1236-1311) and Ibn al-Shātir (1304-1375), were known in European scholarly circles by the early fifteenth century.

The work of Neugebauer, Kennedy, Swerdlow, Hartner, Morelon, Sabra, Saliba, Morrison, Ragep, King and Mozaffari has been instrumental in advancing our understanding of how the work of Islamic scholars laid the foundations for Renaissance developments in astronomy that ultimately led to the Copernican Revolution. Based on the extensive research that has been undertaken by these and other scholars in recent years, it is clear that Islamic astronomy continued to flourish after the eleventh century in Persia, Egypt, Syria and elsewhere, and that major advances continued to be made by Islamic astronomers up until the late fifteenth century and possibly later.

Perhaps most notably, three generations of historians of science have been pointing out remarkable similarities between the findings of Islamic astronomers and those of Copernicus and some of his Renaissance contemporaries since the late 1950s. The three most striking similarities between the work of Islamic astronomers and similar findings by Copernicus are the basis for criticising Ptolemy's equant device, the alternative models proposed, and the arguments for the earth's rotation.

Otto Neugebauer, the well-known Austrian-American mathematician and historian of science, made a number of important observations in the late 1950s about the evident links between Islamic astronomers' models of planetary motion and those of Copernicus. For example, he noted that 'the same method for the correction of Ptolemy's lunar model was used about 200 years before Copernicus by the Damascene astronomer and *muwaqqit*, Ibn al- Shātir' (Neugebauer, 1957, p. 197). In the same year, Victor Roberts (who was a student of the Arabist and historian of science, Edward S. Kennedy) noted that al-Shātir's lunar theory in his *Kitāb Nihāyat as-Sūl fi Taṣḥīḥ al-Uṣūl* ('A Text of Final Inquiry in Amending the Elements') is 'identical with that of Copernicus' 'except for trivial differences in parameters' (Roberts, 1957). Two years later, Kennedy and Roberts went somewhat further by observing that Copernicus's solar, lunar and planetary models were identical to those of al-Shātir from more than a century earlier (Kennedy & Roberts, 1959). Kennedy and Roberts later confirmed these findings and other resemblances between the work of Copernicus, al-Shātir and other Islamic astronomers in the Marāgha school (Kennedy, 1966; King, 2010; Roberts, 1966; Saliba, 2002).

In 1973, Neugebauer's student and colleague, Noel Swerdlow, published a paper likewise noting Copernicus' model for Mercury and the other planets was identical to those of al-Shātir (Swerdlow 1973). Swerdlow argued that Copernicus could not have been fully aware of the significance of the model for Mercury he was describing because al-Shātir's model (and earlier Ptolemaic models) correctly predicted the largest orbit of Mercury (i.e. point at which Mercury was closest to the Earth) occurred twice, when the centre of the epicycle was at 120 degrees on either side of the apogee. Copernicus, however, incorrectly noted that the largest orbit of Mercury happened at quadrature, when the centre of the epicycle was at 90 degrees from the apogee. Swerdlow concluded the model could not have been Copernicus' own invention, as he would have fully understood its significance had it been his, and would not have made such a fundamental error. Copernicus must therefore have copied his Mercury model and that of the other planets from another source, and ultimately from al-Shātir (Swerdlow, 1973).

It should be noted that Neugebauer also recognised that the Persian natural philosopher and astronomer, Nasīr al-Dīn al-Tūsī (1201-1274), had introduced in the mid-thirteenth century a general solution to the problem of generating linear motion from a combination of circular motions (known as 'Tūsī's Proof' or the 'Tūsī Couple') that was precisely the same solution used by Copernicus in *De revolutionibus* III, 4 (Neugebauer, 1957, pp. 203, 207; cf. Kennedy, 1966). At the time, Neugebauer could only point to the fact that Tūsī's work and that of other Arabic astronomers was common knowledge in Italy by the 1500s (cf. Saliba, 2002, 2007, p. 167 f.).

Building on Neugebauer's work, Willy Hartner published another paper in 1973 that demonstrated the alphabetic designators for the essential geometric points used by Tūsī in his cosmological work, *Tadhkira* from c. 1260–1261, were replicated by Copernicus in *De revolutionibus*. Hartner suggested Copernicus must therefore have known about Tūsī's work when he was in Italy, but had it translated or explained to him by a third party, because as far as we know, Copernicus was not an Arabic speaker, and Tūsī's text was never translated into Latin (Hartner 1973). More recently, George Saliba has found substantial evidence of Islamic scientific manuscripts being conveyed to Renaissance Europe in the mid-1500s. This included a copy of Tūsī's *Tadhkira* that was part of the library of Copernicus's younger contemporary, Guillaume Postel (1510-1581), who was a French astronomer, linguist, and Kabbalist (Saliba, 2007, p. 217).[2]

Like Neugebauer and Hartner, Swerdlow was unable to determine what the sources of transmission for these models might have been. He nevertheless concluded that there were five main sources for Copernicus's planetary theory: Ptolemy's *Almagest*, Georg Peurbach and Regiomontanus's *Epitome of the Almagest*, Peurbach's *Theoricae novae planetarum*, the *Alphonsine Tables* (compiled in Toledo from local and Islamic astronomical observations at the order of King Alfonso X of Castile in the mid-thirteenth century) and the work of the Marāgha astronomers, which included Ṭūsī (Swerdlow 1973: 425-426; cf. Swerdlow 2017). A decade later, Swerdlow and Neugebauer suggested a specific pathway of transmission for Ṭūsī's lunar model to Europe via the Greek polymath, Gregory Chioniades (Swerdlow & Neugebauer 1984: 47, 295).

A number of other scholars have tried to determine possible sources and pathways of transmission of Islamic astronomical knowledge to early modern Europe over the last few decades. Most recently, Robert Morrison has argued that the Jewish scholar, Moses Galeano, was a likely source of knowledge concerning Islamic astronomy for European astronomers in the early sixteenth century, and in particular, the work of Ibn al-Shāṭir. Galeano spent several years in the Veneto from 1497 to 1502, a period which overlaps with Copernicus's time studying medicine at the University of Padua. Morrison points out that 'Galeano brought with him knowledge of scientific theories that appeared not only in Copernicus's work, but also in the homocentric astronomy (where each celestial body maintained a fixed distance from a static earth) of Giovanni Battista Amico (d. 1538) and Girolamo Fracastoro (d. 1553), two other astronomers writing at the University of Padua' (Morrison, 2014a).

Morrison concludes that while direct connections between Galeano and these European astronomers cannot be definitively established, Jewish scholarly informants like Galeano were most likely the sources of knowledge of later Islamic astronomers via established scholarly networks connecting Europe, Crete and the Ottoman Empire. The overwhelming parallels between al-Shāṭir's and Copernicus's models and the evidence for Islamic knowledge transmission to Europe via Jewish scholarly networks strongly suggest that independent invention is unlikely.

Morrison's conclusion on this point has been given further weight by Jamil Ragep and his co-author Sajjad Nikfahm-Khubravan who have examined the development of Copernicus's Mercury model between the publication of *Commentariolus* and *De*

---

[2] In his earlier book, *A History of Arabic Astronomy* (1995), Saliba also drew attention to a passage in Ṭūsī's work that discusses whether Venus orbits the earth or the sun in response to observations by two other astronomers that they had observed Venus crossing the face of the sun at both extremes of its epicycle. Ṭūsī argues that 'This disproves the fact that they were in the same sphere as the sun, with the sun as their center' (Saliba, 1995, p. 149).

Revolutionibus (Nikfahm-Khubravan & Ragep, 2019). They show how Copernicus not only had direct access to al-Shātir's work, he had to modify al-Shātir's models with their 'heliocentric bias' to conform to what they call a 'quasi-homocentricity' in the *Commentariolus*, and that by the time of *De revolutionibus*, he had mastered the details of the Mercury model and corrected his earlier errors concerning the reproduction of Ptolemy's elongations at the trines of Mercury's orbit.

Building on the insights of Neugebauer et al., Ragep has also demonstrated the relevance of the Ottoman astronomer Ali Qūshjī (d. 1474) to understanding how Copernicus transformed a geocentric system into a heliocentric one via the apparent vehicle of Regiomontanus's *Epitome of the Almagest* (Ragep, 2005). Part of Ragep's argument centres on the efforts of later Islamic astronomers to divorce the practice of astronomy from Greek forms of natural philosophical theorizing (Ragep, 2001b). This involved debates about the appropriate domain and limits of natural philosophy and theoretical speculation in relation to observable phenomena in the heavens and the mathematical representation of their movements. One pole of the debate was famously represented by Ibn Rushd (1126-1198), known in the West as Averroes, who was particularly critical of the lack of conformity of Ptolemy's astronomical models to physical reality: 'To assert the existence of an eccentric sphere or an epicyclic sphere is contrary to nature … The astronomy of our time offers no truth, but only agrees with the calculations and not with what exists' (quoted in Gingerich, 1986). Ali Qūshjī's position provides an instructive counterpoint to Averroes' realist position, which led his predecessor to reject eccentric deferents for a strictly concentric model of the universe.

Ali Qūshjī was associated with the Samarqand court of Ulugh Beg, a grandson of Tamerlane (1336-1405), and in later life worked as an astronomer, mathematician and professor in various courts and institutions in Central Asia and Persia, gaining renown and influence for centuries via his writings and students. Two of his unorthodox positions, seemingly influenced by his teachers from the Samarqand School, were that astronomy should rid itself of its dependence on Aristotelian physics, and that the Earth's rotation is a possibility because the question of its motion cannot be determined by observation (Ragep, 2001a, 2001b).

Qūshjī argued that although astronomical models may be calculating devices that do not precisely document observable reality they are nevertheless a source of wonder, because of their correspondence with the phenomena they are recording. Unlike some of his Islamic predecessors and European successors, however, he did not propose an instrumentalist compromise between Aristotelian physics, Ptolemaic astronomy and observable reality. Ragep points out that in his rejection of the metaphysical assumption that human beings can know true reality, Qūshjī is making a more sophisticated point: 'that the correspondence between our human constructions and external reality is itself a source of wonder … one could glorify God with science; one could not glorify God with conventions' (Ragep, 2001a).

Debates amongst Islamic scholars about the accuracy and representational status of mathematical models in astronomy continued well into the sixteenth century and beyond. Ragep points out that 'Abd al-'Alī al-Bīrjandī (d. 1525 or 1526) was a contemporary of Copernicus who produced several major astronomical works, including commentaries regarding the earth's motion. Against Qūshjī, he also defended the use in astronomy of both natural philosophy and metaphysics (Ragep, 2001a). By way of contrast, another contemporary of Copernicus, Shams al-Dīn al-Khafrī (fl. 1525) produced 'four mathematically equivalent Mercury models without taking a position on which one was the real model' (Morrison, 2014b). What Duhem was to later call instrumentalist versus realist debates concerning the truth status of mathematical astronomy had been going on amongst Islamic scholars for some time before they became a preoccupation amongst European scholars.

David A. King has shown how a significant proportion of the scholarship undertaken in mathematics, astronomy and natural philosophy occurred within the institutional context of the mosque. He argues that this evidence 'makes nonsense of the popular notion that religion inevitably impedes scientific progress, for in this case the requirements of the former actually inspired the progress of the latter for centuries' (King, 2004, p. xvii). King's work documents how Islamic astronomers and mathematicians during the Middle Ages solved problems arising from Islamic daily practices, such as the direction of Mecca and reforms of the religious calendar, using astronomical observations and theory as well as mathematical methods (King, 2004, 2005). In the process, he has shown how some astronomical instruments that supposedly originated in Europe actually originated in the Islamic world several centuries earlier (King, 2003, 2005). He has also clearly demonstrated that Islamic mathematicians were producing extraordinarily sophisticated tables for astronomical time-keeping in Egypt, Syria, and Turkey between the eleventh and the eighteenth centuries, precisely during the period that the supposed decline in Islamic sciences is supposed to have begun (King, 1986).

Medical Advances in the Islamic Sciences: Eclipsed and Overlooked

Islamic achievements in medicine and mathematics are two of the few areas of scientific scholarship that proponents of the classical narrative have been generally willing to accept, and even praise. With regard to medicine, it is well known and widely accepted that Muslim and non-Muslim scholars translated into Arabic the complete Hippocratic corpus, as well as the pharmacological and medical works of Pedanius

Dioscorides (c. 40-90 CE), Claudius Galen (129-199/217 CE) and various Hellenic medical authorities. They also recorded and adapted Indian and Chinese medical practices.

Many Greco-Roman and Byzantine medical works were rewritten, summarized and systematized to make them more comprehensible, accessible and teachable in the medical schools attached to the great hospitals that were founded in major Islamic cities such as Baghdad and Damascus. Islamic medical scholars developed theoretical discussions of symptoms and causes, and frequently provided examples of how to apply specific knowledge to practical cases. According to Emilie Savage-Smith, they 'also added an extensive pharmacology, more elaborate notions of medical pathology, knowledge of certain diseases and disorders, new therapies, and some new surgical techniques and instrumentation' (Savage-Smith, 2013).

The Persian physician, alchemist, chemist and philosopher, al-Razi (864 or 865 – 925 or 935 CE) and his fellow Persian, the physician, mathematician and astronomer, Ibn Sīnā, better known to Westerners as Avicenna (c. 980-1037) were the two most notable Islamic medical scholars of the pre-modern period. Ironically, it was the very success of Al-Razi and Ibn Sīnā as medical authorities in late medieval and early modern Europe which tended to 'crowd out' the visibility of Islamic medical scholars from the later Middle Ages. Their renown among Westerners subsequently reinforced perceptions that nothing of value had been produced by Islamic medical scholars after 1100.

Abū Bakr Muḥammad ibn Zakariyyāʾ Al-Razi (864 or 865 – 925 or 935 CE), commonly known as Al-Razi (or Rhazes in early modern Europe), is widely recognized as an early proponent of experimental medicine and one of the greatest clinicians to have ever lived (Adamson, 2021; Iskandar, 2008; Meyerhof, 1935). His work had a profound influence on the medical curriculum of Western universities. He was a pioneer in what we now call paediatrics, obstetrics, ophthalmology, and psychology, as well as the use of alcohol as an antiseptic and mercury as a purgative. He also wrote on grammar, logic, and astronomy (Fakhry, 2004).

The *al-Kitab al-Hawi fi'l tibb* (*The Virtuous Life* or *The Comprehensive Book on Medicine* in European translation) is a monumental posthumous compilation of Al-Razi's working notebooks in the form of a medical encyclopaedia. First translated into Latin in 1279, *al-Hawi* was printed in numerous editions from 1486. It remained one of the most extensive (and expensive) medical works by a single author until the nineteenth century (Adamson, 2021; Savage-Smith, 2013). Other medical treatises by al-Razi that remained in wide circulation throughout Europe until the nineteenth century dealt with infectious diseases, anatomy, renal diseases, and pharmacology (Adamson, 2021; Ansari, 1976). He was highly critical of religion, denied the existence of miracles, and accepted an atomic theory similar to that of Democritus. He also 'believed that the sciences continually progressed because scientists build upon the knowledge they inherit from their predecessors' (Grant, 2008, p. 517).

Ibn Sīnā (c. 980-1037), commonly known as Avicenna in the West, was even more famous and prolific than his predecessor. Fusing the Aristotelian tradition with the Neoplatonic idea of emanation, he wrote extensively on physics (McGinnis, 2020) and metaphysics (Lizzini, 2020). However, his fame in the West rested primarily on his medical compendium, *al-Qanun fi al-Tibb* (*The Canon of Medicine*) and a scientific and philosophical encyclopaedia called *Kitab al-Shifa'* (*The Book of Healing*) that covered topics as diverse as astronomy, logic and metaphysics, as well as fields of research that we would now describe as chemistry, the earth sciences, psychology and philosophy of science (McGinnis, 2020).

Ibn Sīnā's *Canon of Medicine* was used as a standard medical textbook in the universities of Europe until the eighteenth century. It provided an overview of contemporary medical knowledge in the Islamic world, and although it is largely based on the teachings of Galen and Hippocrates, it also includes medical practices developed by Persian, Chinese and Indian physicians, all of which is interpreted from within an Aristotelian natural philosophical framework. The book dealt with the contagious nature of various diseases, and described a variety of skin complaints, sexually transmitted diseases, disorders of the internal and external organs, and various psychological and pathological disorders, along with a detailed pharmacology and guide for preparing compound drugs. It also served as a concise reference work that was easier to use (and digest) than Galen's twenty-volume medical corpus (McGinnis, 2010; Savage-Smith, 2002, 2013).

Islamic medical scholarship continued to flourish in Syria and Egypt until the late fourteenth century and in Persia throughout the sixteenth and seventeenth centuries. Ophthalmology was one of the specializations in which medieval Islamic scholars demonstrated a number of innovations and original insights. This included the removal of cataracts and the development of an intricate surgical procedure to treat a previously unrecognized complication of trachoma (Savage-Smith, 2013). The twelfth and thirteenth centuries witnessed a proliferation of Islamic treatises published on ophthalmology, including a manual describing the treatment of 124 eye conditions by the Egyptian physician, Fatḥ al-Dīn al-Qaysī (d. 1258), and another comprehensive manual composed by the Syrian Khalīfah ibn Abī al-Maḥāsin al-Ḥalabī. The latter manual contains a substantial quantity of original material, 'including diagrammatic charts of ophthalmological instruments and the first recorded instance of the use of a magnet to remove a foreign object from the eye – in this case a piece of a needle that had broken while couching a cataractous eye' (Savage-Smith, 2013, pp. 151–152). A third treatise produced in the thirteenth century by Abū Zakarīyā' Yaḥyá ib Abī al-Rajā' contains a lengthy (and unusual) geometrical explanation of vision, as well as illustrations of various instruments and a diagrammatic quarter section of an eye represented along two different planes (Savage-Smith, 2013).

In the field of anatomy, Islamic medical literature was largely conservative until the end of the fourteenth century, when it began generating a specialized body of literature that appears to have had some European influence. Sections on anatomy feature in all the major medieval Arabic and Persian medical encyclopedias 'describing the bones, muscles, nerves, arteries, veins, and the compound organs, which included the eye, the liver, the heart, and the brain, as well as chapters on embryological theories' (Savage-Smith, 2013, p. 154). It was not, however, until the publication by Mansūr ibn Muhammad ibn Ahmad ibn Yūsuf ibn Ilyās (fl. late 14th c.) of his *Anatomy* sometime between 1394 and 1409 that we see anatomical illustrations of the entire body. Each of the five chapters on the bodily 'systems' associated with the bones, nerves, muscles, veins and arteries is appended by a full-page diagram featuring many labels (Savage-Smith, 2013).

Savage-Smith notes that a major breakthrough in human anatomy that has not been widely recognized by Western scholars is the description of the movement of blood via the pulmonary transit provided by the Syrian physician Ibn al-Nafīs (d. 1288) in his critical commentary on Ibn Sīnā's *Canon of Medicine*, completed in 1242. The relevant passage explicitly states that blood from the right ventricle must pass through the lungs and not through a passage connecting the ventricles, as Galen had incorrectly maintained. Al- Nafīs' formulation of the 'lesser' circulation predates by three centuries those made by Michael Servetus (d. 1553) and Realdo Colombo (d. 1559). Although this commentary on Ibn Sīnā's anatomy was not as widely known among Islamic physicians as his other work, Savage-Smith records two fourteenth-century Arab physicians and a sixteenth-century Persian physician who were aware of it, with the latter writing two anatomical treatises based on it (Savage-Smith, 2013).

It should therefore be clear from this brief exposition that Islamic medical knowledge and practices in ophthalmology and anatomy continued well into the era that 'the decline' is supposed to have taken place, and once again demonstrate the threadbare evidential basis for such claims.

Mathematical Advances in the Islamic Sciences: A Rich and Enduring Legacy

The contributions of Islamic scholars to the development of modern mathematics are considerable and significant. Not only were they responsible for creating the modern numeric system and algebra, they also invented trigonometry and algorithms. These advances were recognized and valued by European scholars of the late medieval and early modern periods and were subsequently widely disseminated. Some were produced during the so-called 'Golden Age', but many continued to be made in later centuries. As in medicine and astronomy, innovative and important work continued to be produced by Islamic scholars and practitioners far beyond the supposed point of their collective intellectual decline.

It is widely accepted that the Arabic numeric system was transmitted to the West in the second half of the eleventh century. However, the means by which the system was transmitted is not widely known or discussed. It occurred through the vehicle of a Latin translation of the first part of Muhammad ibn Mūsā al-Khwārizmī's (c. 780 – c. 850) *Kitāb al-Jamʿ wa-l-tafrīq bihisāb al-Hind* (*The Book of Addition and Subtraction According to the Hindu Calculation*). Al-Khwārizmī's seminal work in arithmetic and algebra helped shape the development of mathematics in Europe until the late sixteenth century. The term 'algebra' is derived from the Arabic word *al-jabr* and is taken from the title of another of al-Khwārizmī's books (Djebbar, 2013).

The development of trigonometry was driven by Habash al-Hasib al-Marwazi (c. 764-c. 864), Abū al-Wafā' Būzjānī (940-998), and Abu Rayhan Biruni (973-1048) during the so-called 'Golden Age'. However, the much later Persian mathematician, Ghiyāth al-Dīn Jamshīd al-Kāshī (c. 1380-1429), is notable for having made an accurate calculation of π, rediscovering the decimal fraction, and devising techniques of computation that remained unparalleled until recently. Similarly, the development of geometry was driven by Thābit ibn Qurra (836-901) and Omar Khayyám (1048-1131) during the so-called 'Golden Age', but was considerably advanced by the already noted (and much later) Nasīr al-Dīn al-Tūsī (1201-1274).

The work of Islamic mathematicians in the Maghrib after 1100 lends further weight to the argument against decline. In Ahmed Djebbar's 1995 paper, 'On mathematical activity in North Africa since the ninth century', he outlines the work of Abul-Qasim al-Qurashī of Bougie (d. 1184), al- Hassār (fl. 12th c.), Ibn al-Yāsamīn (d. 1204), Ibn Mun'im (d. 1228) and Ibn al-Bannā al-Marrākushī (1256-1321). Al-Qurashī (d. 1184) is notable for his original work in algebra, having written a widely read commentary on the work of the great Egyptian mathematician, Abu Kamil (d. 930), which introduced new ways of classifying al-Khwārizmī's six canonical equations and their demonstrations. He also invented a widely appreciated new method of inheritance which was 'based on the decomposition of the numbers in prime factors in order to reduce the fractions that intervene in the distribution of a given inheritance to the same denominator' (Djebbar, 1995, p. 12).

Although very little is known about Al-Hassār, one of the two of his surviving books is notable for preserving the western Islamic tradition of calculation, introducing the format of fractional expression that Fibonacci (c. 1270 - c. 1250) first conveyed to

European audiences in the thirteenth century (i.e., where the numerator and denominator are represented with Arabic numerals and separated by a horizontal bar: the vinculum, which is used to denote that the symbols in a mathematical expression should be grouped together in some way). It is also the only known Maghribian work of calculation to have been widely circulated in southern Europe via a Hebrew translation by Moses Ibn Tibbon from 1271 (Djebbar, 1995, pp. 12–14).

The black Berber, Ibn al-Yāsamīn (d. 1204), is notable for having written the oldest book on the objects and operations of algebra, enabling the writing and solution of equations and the abstract manipulation of polynomials. Ibn Mun'im (d. 1228) is notable for having been one of the greatest exponents of geometry and number theory of his time. His work included discussions of figurate numbers, the determination of amicable numbers, and combinatorial propositions and trends (Djebbar, 1995, pp. 15–16).

Ibn al-Bannā al-Marrākushī (1256-c. 1321) was one of the last great innovators in Islamic mathematics and was widely read and commented on. Producing over 80 works during his lifetime, he appears to have originated algebraic symbolism, and demonstrated for the first time the formula of factorials, giving the combinations of n letters of a given alphabet taken p at a time (without utilising the arithmetic triangle), as well as partially establishing the relations between polygonal numbers and combinations, and the sums of certain progressions of whole numbers. However, this was a high point in mathematical activity under Islam, and although it continued in the Maghrib in the latter half of the fourteenth and fifteenth centuries, its quality was not as high as the earlier period, lending weight to Ibn Khaldūn's earlier cited observations (Djebbar, 1995, pp. 17–19; cf. Rashed, 2014).

CONCLUSION

This brief survey of recent advances in historical scholarship on the Islamic sciences provides ample evidence of the sophistication and diversity of the scientific research being undertaken throughout Islamic societies until well into the sixteenth century and subsequently. Clearly, this evidence provides a clear refutation of every aspect and version of the decline theory as propounded by all those scholars who have ever articulated such views. It should be a cause of considerable concern for all of us that major advances in the sciences and technology by Islamic scholars continue to be ignored in virtually every Western cultural context in which they should, in fact, figure far more prominently. It is also arguable that the rise of Islamophobia in Europe, the Americas and Oceania in recent years can be directly attributed to the indefensible omission of the Islamic cultural heritage from Western education systems.

Not only does the research I have outlined in this paper demonstrate that major advances in Islamic scientific scholarship continued to be made until well into the early modern period, it also demonstrates that religious considerations and politics did not always oppose the practice of the sciences under Islam, but in many cases constructively engaged with them and contributed to their development. Furthermore, as Ragep has noted, 'Since the vast majority of texts written during this late period in the history of Islamic science have yet to be studied (much less published), many exciting surprises might well be anticipated' (Ragep, 2001a).

In providing this brief survey, my hope is that it might inspire a younger generation of historians from Arabic, Turkish, Persian and other non-English-speaking backgrounds to consider pursuing some of the research avenues opened up by the scholarship outlined above. In the process, these younger scholars may well uncover more valuable insights that will help better inform those of us from English-speaking backgrounds about the significant contributions made by Islamic scholars to the development of the contemporary sciences, and thereby engender more respect and tolerance for the culture that produced them.

Author Contributions

Conceptualization: A.L.; Data curation: A.L.; Formal analysis: A.L.; Funding acquisition: A.L.; Investigation: A.L.; Methodology: A.L.; Project administration: A.L.; Resources: A.L.; Software: A.L.; Supervision: A.L.; Validation: A.L.; Visualization: A.L.; Writing – original draft: A.L.; Writing – review & editing: A.L. Author has read and agreed to the published version of the manuscript.

Funding

This study received no direct funding from any of the institutions.

Institutional Review Board Statement

The study did not require any ethical approval.

Informed Consent Statement

Informed consent was not required for this study.

Data Availability Statement

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to institution's policy.

Acknowledgments

The author thanks School of Humanities and Social Inquiry, Faculty of Arts, Social Sciences and Humanities, University of Wollongong, Australia for administrative support for the research on which this article was based.

Conflicts of Interest

The author declares no conflicts of interest.

REFERENCES

Abdalla, M. (2004). The fate of islamic science between the Eleventh and Sixteenth Centuries: A comprehensive review of scholarship from Ibn Khaldun to the present. *Humanomics*, *20*(3), 26–57. https://doi.org/10.1108/eb018895

Abdalla, M. (2008). *Islamic science: The Myth of the decline theory*. VDM Verlag.

Adamson, P. (2021). Abu Bakr al-Razi. In E. N. Zalta & U. Nodelman (Eds.), *The Stanford encyclopedia of philosophy*. Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/sum2025/entries/abu-bakr-al-razi/

Al-Ḥasan, A. Y., & Hill, D. R. (1994). *Islamic technology: An illustrated history* (Repr). Cambridge Univ. Pr. [u.a.].

Ansari, A. S. B. (1976). Abu Bakr Muhammad Ibn Yahya Al-Razi: Universal scholar and scientist. *Islamic Studies*, *15*(3), 155–166. https://www.jstor.org/stable/20847003

Applebaum, W. (2003). *Encyclopedia of the scientific revolution: From Copernicus to Newton*. Routledge. https://doi.org/10.4324/9780203801864

Bala, A. (2006). *The Dialogue of civilizations in the birth of modern science*. Palgrave Macmillan US. https://doi.org/10.1057/9780230601215

Bala, A. (Ed.). (2012). *Asia, Europe, and the emergence of modern science*. Palgrave Macmillan US. https://doi.org/10.1057/9781137031730

Burns, W. E. (2001). *The Scientific revolution: An encyclopedia*. ABC-CLIO.

Chemla, K., Morelon, R., & Allard, A. (1986). La tradition Arabe de Diophante d'Alexandrie: À propos de quatre livres des Arithmétiques perdus en Grec retrouvés en Arabe [The Arabic tradition of Diophantus of Alexandria: on four books of Arithmetic lost in Greek but found in Arabic]. *L'antiquité classique*, *55*(1), 351–375. https://doi.org/10.3406/antiq.1986.2193

Djebbar, A. (1995). On mathematical activities in North Africa since the 9th century. First part: Mathematics in the medieval Maghreb. *AMUCHMA Newsletter*, *15*, 3–42. https://www.researchgate.net/publication/293107783_On_mathematical_activities_in_North_Africa_since_the_9th_century_First_part_mathematics_in_the_medieval_Maghreb

Djebbar, A. (2013). *Al-Khwârizmî – L'algèbre et le calcul indien*. ACL-les Éditions du Kangourou.

Duhem, P. (1911). History of physics. In *The Catholic Encyclopedia*. Robert Appleton Company. https://www.newadvent.org/cathen/12047a.htm

Fakhry, M. (2004). *A history of Islamic philosophy* (3rd ed.). Columbia University Press.

Gingerich, O. (1986). Islamic astronomy. *Scientific American*, *254*(4), 74–83. https://www.jstor.org/stable/24975932

Gouguenheim, S. (2008). *Aristote au mont Saint-Michel: Les racines Grecques de l'Europe Chrétienne [Aristotle at Mont Saint-Michel: The Greek roots of Christian Europe]*. Seuil.

Grant, E. (2008). The Fate of Ancient Greek natural philosophy in the Middle Ages: Islam and Western Christianity. *The Review of Metaphysics*, *61*(3), 503–526. https://www.jstor.org/stable/20130975

Greppin, J. A. C., Savage-Smith, E., & Gueriguian, J. L. (Eds.). (1999). *The diffusion of Greco-Roman medicine into the Middle East and the Caucasus*. Caravan Books.

Hartner, W. (1969). Nasir al-Din al-Tusi's lunar theory. *Physis*, *11*, 287–304.

Hartner, W. (1973). Copernicus, the man, the work and its history. *Proceedings of the American Philosophical Society*, *117*, 413–422.

Hartner, W. (1975). The Islamic astronomical background to Nicholas Copernicus. In O. Gingerich & J. Dobrzycki (Eds.), *Tudia Copernicana XI11 (Colloquia Copernicana 111)* (pp. 7–16). Ossolineum.

Haskins, C. H. (1927). *The Renaissance of the Twelfth Century*. Harvard University Press.

Hill, D. R. (1998). *Studies in medieval Islamic technology*: *From Philo to al-Jazarī, from Alexandria to Diyār Bakr*. Ashgate.

Hogendijk, J. P. (2002). Two Editions of Ibn al-Haytham's Completion of the Conics. *Historia Mathematica*, *29*(3), 247–265. https://doi.org/10.1006/hmat.2002.2352

Hogendijk, J. P. (2004). Ideals and realities in Ibn al-Haytham's mathematical oeuvre. *Early Science and Medicine*, *9*(1), 37–43. https://doi.org/10.1163/1573382041153160

Hogendijk, J. P. (2005). Applied mathematics in Eleventh Century Al-Andalus: Ibn Mucadh al-Jayyan and his computation of astrological houses and aspects. *Centaurus*, *47*(2), 87–114. https://doi.org/10.1111/j.1600-0498.2005.470201.x

Hogendijk, J. P., & Sabra, A. I. (Eds.). (2003). *The Enterprise of science in Islam*: *New perspectives*. The MIT Press.

Huff, T. E. (2017). *The Rise of early modern science*: *Islam, China, and the West* (3rd ed.). Cambridge University Press.

Institut für Geschichte der Arabisch-Islamischen Wissenschaften. (2021, August 21). *Islamic mathematics and astronomy* [HTML]. Goethe-Universität. https://www.uni-frankfurt.de/58972120/ISLAMIC_MATHEMATICS_AND_ASTRONOMY

Iskandar, A. Z. (2008). Al-Rāzī. In H. Selin (Ed.), *Encyclopaedia of the history of science, technology, and medicine in Non-Western cultures* (pp. 155–156). Springer Netherlands. https://doi.org/10.1007/978-1-4020-4425-0_9326

Kennedy, E. S. (1966). Late Medieval planetary theory. *Isis*, *57*(3), 365–378. https://doi.org/10.1086/350144

Kennedy, E. S. (1983). *Studies in the exact Islamic sciences*. Syracuse University Press.

Kennedy, E. S. (1984). Two Persian astronomical treatises by Nasr al-Din al Tusi. *Centaurus*, *27*(2), 109–120. https://doi.org/10.1111/j.1600-0498.1984.tb00763.x

Kennedy, E. S. (1998). *Astronomy and astrology in the Medieval Islamic World* (1st ed). Taylor & Francis Group.

Kennedy, E. S., & Roberts, V. (1959). The Planetary theory of Ibn al-Shāṭir. *Isis*, *50*(3), 227–235. https://doi.org/10.1086/348774

King, D. A. (1986). *Islamic mathematical astronomy*. Variorum Reprints.

King, D. A. (1999). *World-maps for finding the direction and distance to Mecca*: *Innovation and tradition in Islamic science*. Brill. https://doi.org/10.1163/9789004450738

King, D. A. (2003). 14th-Century England or 9th-Century Baghdad? New insights on the elusive astronomical instrument called navicula de venetiis. *Centaurus*, *45*(1–4), 204–226. https://doi.org/10.1111/j.1600-0498.2003.450117.x

King, D. A. (2004). *In synchrony with the heavens, Voluume 1 Call of the Muezzin (Studies I-IX)*. Brill.

King, D. A. (2005). *In synchrony with the heavens, Volume 2 Instruments of mass calculation (Studies X-XVIII)*. Brill.

King, D. A. (2007). *Astrolabes and angels, epigrams and enigmas*: *From Regiomontanus' acrostic for Cardinal Bessarion to Piero della Francesca's flagellation of Christ*. Franz Steiner Verlag.

King, D. A. (2010). Edward Stewart Kennedy (1912–2009). *Journal for the History of Astronomy*, *41*(1), 117–119. https://doi.org/10.1177/002182861004100106

King, D. A. (2011). *Astrolabes from medieval Europe*. Ashgate Variorum.

Langermann, Y. T. (2018). Babylonian and Indian wisdoms in Islamicate culture. *Oriens*, *46*(3–4), 435–475. https://doi.org/10.1163/18778372-04603004

Lindberg, D. C. (2007). *The Beginnings of Western science*: *The European scientific tradition in philosophical, religious, and institutional context, Prehistory to A.D. 1450* (2nd ed.). University of Chicago Press.

Lizzini, O. (2020). Ibn Sina's metaphysics. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy*. Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/fall2021/entries/ibn-sina-metaphysics/

Lucas, A. (2006). *Wind, water, work*: *Ancient and medieval milling technology*. Brill. https://doi.org/10.1163/9789047417224

Marmura, M. E. (2000). Translator's introduction (M. E. Marmura, Trans.). In A. H. M. al-Ghazali, *The Incoherence of the philosophers* (2nd ed., pp. xv–xxvii). Brigham Young University.

McGinnis, J. (2010). *Avicenna*. Oxford University Press.

McGinnis, J. (2020). Ibn Sina's natural philosophy. In E. N. Zalta & U. Nodelman (Eds.), *The Stanford Encyclopedia of Philosophy*. Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/spr2025/entries/ibn-sina-natural/

Meyerhof, M. (1928). An Arabic compendium of medico-philosophical definitions. *Isis*, *10*(2), 340–349. https://doi.org/10.1086/346327

Meyerhof, M. (1931). Science and medicine. In T. Arnold & A. Guillaume (Eds.), *The Legacy Of Islam* (pp. 311–355). Oxford University Press.

Meyerhof, M. (1935). Thirty-three clinical observations by Rhazes (Circa 900 A.D.). *Isis*, *23*(2), 321–372. https://doi.org/10.1086/346968

Morelon, R. (1994). Ṯābit B. Qurra and Arab astronomy in the 9th Century. *Arabic Sciences and Philosophy*, *4*(1), 111–139. https://doi.org/10.1017/S0957423900001879

Morelon, R. (2000). Ibn al-Haytham et ses arguments cosmologiques [Ibn al-Haytham and his cosmological arguments]. *Épistémologiques*, *1*(1–2), 101. https://doi.org/10.11606/issn.1982-3568.epistemologiques.2000.105067

Morrison, R. (2014a). A scholarly intermediary between the Ottoman Empire and Renaissance Europe. *Isis*, *105*(1), 32–57. https://doi.org/10.1086/675550

Morrison, R. (2014b). What was the purpose of astronomy in Ījī's Kitāb al-Mawāqif fī ʿIlm al-Kalām? In J. Pfeiffer (Ed.), *Politics, patronage and the transmission of knowledge in 13th—15th Century Tabriz* (pp. 201–229). Brill. https://doi.org/10.1163/9789004262577_009

Mozaffari, S. M. (2013). Limitations of methods: The accuracy of the values measured for the earth's/sun's orbital elements in the Middle East, A.D. 800–1500, Part 1. *Journal for the History of Astronomy*, *44*(3), 313–336. https://doi.org/10.1177/002182861304400305

Mozaffari, S. M. (2016). Planetary latitudes in medieval Islamic astronomy: An analysis of the non-Ptolemaic latitude parameter values in the Maragha and Samarqand astronomical traditions. *Archive for History of Exact Sciences*, *70*(5), 513–541. https://doi.org/10.1007/s00407-015-0172-x

Mozaffari, S. M. (2017). Holding or breaking with Ptolemy's generalization: Considerations about the motion of the planetary apsidal lines in medieval Islamic astronomy. *Science in Context*, *30*(1), 1–32. https://doi.org/10.1017/S0269889717000011

Mozaffari, S. M. (2018). An analysis of medieval solar theories. *Archive for History of Exact Sciences*, *72*(2), 191–243. https://doi.org/10.1007/s00407-018-0207-1

Mozaffari, S. M. (2019). The orbital elements of venus in Medieval Islamic astronomy: Interaction between traditions and the accuracy of observations. *Journal for the History of Astronomy*, *50*(1), 46–81. https://doi.org/10.1177/0021828618808877

Neugebauer, O. (1945). The History of Ancient astronomy problems and methods. *Journal of Near Eastern Studies*, *4*(1), 1–38. https://doi.org/10.1086/370729

Neugebauer, O. (1957). *The exact sciences in antiquity*. Brown University Press.

Neugebauer, O. (1969). *The exact sciences in Antiquity* (2nd ed.). Dover Publications.

Neugebauer, O. (1975). *A History of Ancient mathematical astronomy*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-61910-6

Neugebauer, O. (1983). *Astronomy and history selected essays*. Springer New York. https://doi.org/10.1007/978-1-4612-5559-8

Nikfahm-Khubravan, S., & Ragep, F. J. (2019). The Mercury models of Ibn Al-Šāṭir and Copernicus. *Arabic Sciences and Philosophy*, *29*(1), 1–59. https://doi.org/10.1017/S0957423918000085

Pormann, P., & Savage-Smith, E. (2007). *Medieval Islamic medicine*. Edinburgh University Press. https://doi.org/10.1515/9780748629244

Ragep, F. J. (1987). The Two versions of the Tūsi couple. *Annals of the New York Academy of Sciences*, *500*(1), 329–356. https://doi.org/10.1111/j.1749-6632.1987.tb37210.x

Ragep, F. J. (2001a). Freeing astronomy from philosophy: An aspect of Islamic influence on science. *Osiris*, *16*(1), 49–71. https://doi.org/10.1086/649338

Ragep, F. J. (2001b). Tūsī and Copernicus: The earth's motion in context. *Science in Context*, *14*(1–2), 145–163. https://doi.org/10.1017/S0269889701000060

Ragep, F. J. (2005). ᶜ Alīqushjī and Regiomontanus: Eccentric transformations and Copernican revolutions. *Journal for the History of Astronomy*, *36*(4), 359–371. https://doi.org/10.1177/002182860503600401

Ragep, F. J. (2007). Copernicus and his Islamic predecessors: Some historical remarks. *History of Science*, *45*(1), 65–81. https://doi.org/10.1177/007327530704500103

Ragep, F. J. (2009). David C. Lindberg. *The Beginnings of Western Science: The European Scientific Tradition in Philosophical, Religious, and Institutional Context, Prehistory to a.d. 1450* . Second edition. Xvi + 488 pp., figs., bibl., index. Chicago/London: University of Chicago Press, 2007. $25 (paper). *Isis*, *100*(2), 383–385. https://doi.org/10.1086/605220

Ragep, F. J. (2016). Ibn al-Shāṭir and Copernicus: The Uppsala notes revisited. *Journal for the History of Astronomy*, *47*(4), 395–415. https://doi.org/10.1177/0021828616678508

Rahman, S., Street, T., & Tahiri, H. (Eds.). (2008). *The unity of science in the Arabic tradition: Science, logic, epistemology and their interactions*. Springer Netherlands. https://doi.org/10.1007/978-1-4020-8405-8

Rapoport, Y., & Savage-Smith, E. (Eds.). (2014). *An eleventh-century Egyptian guide to the universe: The Book of curiosities*. Brill.

Rashed, R. (2014). *Classical mathematics from Al-Khwarizmi to Descartes*. Routledge. https://doi.org/10.4324/9781315753867

Rashed, R., & Morelon, R. (1996). *Encyclopedia of the history of Arabic science Volume 3 Technology, alchemy and life sciences* (1st ed.). Routledge. https://doi.org/10.4324/9780203086537

Renan, E. (1883). *Islam and science*. A lecture presented at La Sorbonne on 29 March 1883.

Roberts, V. (1957). The Solar and lunar theory of Ibn ash-Shāṭir: A Pre-Copernican Copernican model. *Isis*, *48*(4), 428–432. https://doi.org/10.1086/348609

Roberts, V. (1966). The Planetary theory of Ibn al-Shatir: Latitudes of the planets. *Isis*, *57*(2), 208–219. https://doi.org/10.1086/350114

Sabra, A. I. (1984). The Andalusian revolt against Ptolemaic astronomy: Averroes and al-Bitruji. In E. Mendelsohn (Ed.), *Transformation and tradition in the sciences: Essays in honor of I. Bernard Cohen* (pp. 233–253). Cambridge University Press.

Sabra, A. I. (1987). The Appropriation and subsequent naturalization of Greek Science in Medieval Islam: A preliminary statement. *History of Science*, *25*(3), 223–243. https://doi.org/10.1177/007327538702500301

Sabra, A. I. (1989). *The Optics Of Ibn Al Haytham, Books I-III, On direct vision*. The Warburg Institute, University of London. http://archive.org/details/A.I.Sabraed.Trans.TheOpticsOfIbnAlHaythamBooksIIIIOnDirectVision.TranslatedWithI

Sabra, A. I. (1996). Situating Arabic science: Locality versus essence. *Isis*, *87*(4), 654–670. https://doi.org/10.1086/357651

Saliba, G. (1979). The First Non-Ptolemaic astronomy at the Maraghah school. *Isis*, *70*(4), 571–576. https://doi.org/10.1086/352344

Saliba, G. (1995). *A History of Arabic astronomy: Planetary theories during the Golden Age of Islam*. NYU Press.

Saliba, G. (1999). Critiques of Ptolemaic astronomy in Islamic Spain. *Al-Qanṭara*, *20*(1), 3. https://doi.org/10.3989/alqantara.1999.v20.i1.449

Saliba, G. (2000). Arabic versus Greek Astronomy: A Debate over the foundations of science. *Perspectives on Science*, *8*(4), 328–341. https://doi.org/10.1162/106361400753373713

Saliba, G. (2002). Greek astronomy and the Medieval Arabic tradition. *American Scientist*, *90*(4), 360. https://doi.org/10.1511/2002.27.850

Saliba, G. (2007). *Islamic science and the making of the European Renaissance*. The MIT Press. https://doi.org/10.7551/mitpress/3981.001.0001

Saliba, G. (2009). Islamic reception of Greek astronomy. *Proceedings of the International Astronomical Union*, *5*(S260), 149–165. https://doi.org/10.1017/S1743921311002237

Samsó, J. (2018). *Astronomy and astrology in al-Andalus and the Maghrib* (2nd ed.). Routledge.

Sarton, G. (1966). 5. Islamic science. In T. C. Young, *Near Eastern Culture and Society* (pp. 83–98). Princeton University Press. https://doi.org/10.1515/9781400886845-007

Savage-Smith, E. (1988). Gleanings from an Arabist's workshop: Current trends in the study of Medieval Islamic science and medicine. *Isis*, *79*(2), 246–266. https://doi.org/10.1086/354701

Savage-Smith, E. (2002). Galen's lost Ophthalmology and the Summaria Alexandrinorum. *Bulletin of the Institute of Classical Studies*, *45*(Supplement_77), 121–138. https://doi.org/10.1111/j.2041-5370.2002.tb02285.x

Savage-Smith, E. (2013). Medicine in Medieval Islam. In D. C. Lindberg & M. H. Shank (Eds.), *The Cambridge history of science*: *Volume 2, Medieval science* (pp. 139–167). Cambridge University Press.

Schuster, J. A. (1979). Kuhn and Lakatos and the history of science: Kuhn and Lakatos revisited. *The British Journal for the History of Science*, *12*(3), 301–317. https://doi.org/10.1017/S0007087400017374

Schuster, J. A. (2016). [Review of *Review of* Thomas Kuhn's Revolutions: A Historical and an Evolutionary Philosophy of Science?, by J. A. Marcum]. *Notre Dame Philosophical Reviews*. https://ndpr.nd.edu/reviews/thomas-kuhns-revolutions-a-historical-and-an-evolutionary-philosophy-of-science/

Selin, H. (Ed.). (2008). *Encyclopaedia of the history of science, technology, and medicine in Non-Western cultures*. Springer Netherlands. https://doi.org/10.1007/978-94-007-3934-5

Smith, A. (1869). *The Essays of Adam Smith* (J. Black & J. Hutton, Eds.). Alex Murray & Son. https://www.gutenberg.org/ebooks/58559

Swerdlow, N. M. (1973). The Derivation and first draft of Copernicus's planetary theory: A translation of the Commentariolus with commentary. *Proceedings of the American Philosophical Society*, *117*(6), 423–512. https://www.jstor.org/stable/986461

Swerdlow, N. M. (2017). Copernicus's derivation of the heliocentric theory from regiomontanus's eccentric models of the second inequality of the superior and inferior planets. *Journal for the History of Astronomy*, *48*(1), 33–61. https://doi.org/10.1177/0021828617691203

Swerdlow, N. M., & Neugebauer, O. (1984). *Mathematical astronomy in Copernicus's De Revolutionibus* (Vol. 10). Springer New York. https://doi.org/10.1007/978-1-4613-8262-1

von Grunebaum, G. E. (1924). *Medieval Islam*: *A study in cultural orientation*. University of Chicago Press.

This page intentionally left blank.