CONTRIBUTIONS to SCIENCE, **5** (2): 141–146 (2009)
Institut d'Estudis Catalans, Barcelona
DOI: 10.2436/20.7010.01.69 ISSN: 1575-6343
www.cat-science.cat

Science in Western Islam. Circulation of knowledge in the Mediterranean

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Resum. La Mediterrània ha estat gresol de la circulació d'ideas i persones des de fa mil·lennis. Durant l'edat mitjana, però, el moviment més rellevant va ser, tal vegada, el que es va produir entre l'Orient (Maixriq) i l'Occident (Magrib) islàmics. Els viatges d'estudis, íntimament units a les prescripcions religioses, varen convertir els científics musulmans en membres especialment actius en la difusió dels coneixements i dels avenços que s'anaven adquirint a la capital de l'imperi, Bagdad. Lluny de ser mers «transportistes» de la ciència, el nivell cultural assolit durant l'edat d'or abbassí els va convertir en un dels clímaxs intellectuals de la història. Al principi, tot i restar en un discret segon pla, els científics del nord d'Àfrica i, especialment, els científics d'al-Andalus varen tenir un paper essencial en la transmissió de la ciència oriental cap a una Europa que en va recollir el testimoni. Per això l'aportació de la cultura araboislàmica és un esglaó sense el qual és impossible entendre la ciència posterior. Els camps conreats foren diversos: medicina, agronomia, òptica... però l'àmbit que presidí la ciència fou, sens dubte, l'astronomia (relacionada, al seu torn, amb les matemàtiques i la geografia). Els noms dels astrònoms més rellevants (des d'al-Khwarizmi fins a Azarquiel) i les fites que varen assolir justifiquen que fossin coneguts per un públic ampli. Malgrat tot, continuen essent uns grans desconeguts.

Paraules clau: història de la ciència ·astronomia àrab · Al-Andalus · circulació de coneixements · Islam

Summary. Since thousands of years ago, the Mediterranean Sea has been a melting pot for the circulation of ideas and, indeed, of people. However, during the Middle Ages, the most notable of these movements was surely that between the Islamic East (Mashriq) and West (Maghreb). In expeditions taken to study abroad, Muslims scientists became especially active participants in the diffusion of knowledge as well as the advances that were being amassed in the capital of the empire, Baghdad. Moreover, these journeys were intimately linked to religious precepts. Far from being mere "carriers" of science, the cultural achievements of Muslim scientists during the Abbasid Golden Age would mark them as members of history's intellectual elite. Although initially discretely out of the limelight, the scientists of North Africa–and especially those of Al-Andalus–played an essential role in the transmission of Eastern science to Europe, where the torch would be taken up. For this reason, it is impossible to understand the further development of science without recognizing the stepping-stone that was the Arab-Islamic contribution. Diverse disciplines were cultivated, including medicine, agronomy, and optics, but undoubtedly the reigning field was astronomy (related, in turn, to mathematics and geography). The most relevant names in astronomy (from al-Khwarizmi to Ibn al-Zarqalluh) and the milestones their bearers achieved should be reason enough to have guaranteed their lasting fame. And yet, they remain largely unheard of.

Keywords: history of science · Arab astronomy · Al-Andalus · circulation of knowledge · Islam

Prelude

The history of science is a fundamental element in constructing a full understanding of the history of society. Furthermore, we must keep in mind that the globalization of ideas has occurred since ancient times, such that an appreciation of who we are is impossible without a proper analysis of all the input we have received thus far. Therefore, it is crucial that we stop and reflect upon the advancement of science in Western Islam, as it will provide us with a broader and clearer vision of our own culture

Based on the Distinguished Lecture given by the author at the Institute for Catalan Studies, Barcelona, on 18 November, 2009. Mònica Rius is President of the Catalan Society for the History of Science and Technology.

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[1]. Particularly, it will demonstrate that we, too, are heirs of the Arab cultural legacy [8].

Within an Islamic context, the "sciences" par excellence are those related to religion whereas the "sciences" discussed here were given the appellation *'ulūm al-awā'il,* meaning "the sciences of the ancients," in recognition of their inheritance from previous cultures. In any case, within the expression *al-'ilmu nūr* (science is light), for example, we can grasp the extent to which the search for knowledge is an element of prestige within Islamic culture. Thus, we find ourselves in an environment where study is emphasized and, accordingly, where results will be readily forthcoming.

Imports

Classical legacy. The state of science in Al-Andalus during the 7th–9th centuries was characterized mainly by the combination of a Latin substratum, as evidenced by the persistence of the Isidorian influence, and Arab tradition. *Etymologiae*, by Isidore of Seville, was one of the key writings through which the first Arabs to arrive on the Peninsula–generally with little schooling–would have access to part of the Latin legacy. Additionally, the adoption of certain astrological methods must be mentioned. For example, 'Abd al-Wāḥid b. Isḥāq al-Ḍabbī (fl. 788–860) [13], the first Andalusian astrologer whose name we know of, seemed to have had access to Latin sources related to the "system of the crosses," which formed the basis of his famous *urjūza* [2]. This latter work, in turn, was conserved in the Alphonsian version of the "Book of the Crosses" (13th century) [11].

Pre-Islamic legacy. Before acquiring a state-based structure, science had been historically related to the army (which counted doctors and astrologers in its ranks). In this initial phase, the conquerors themselves were mythical characters with a multitude of virtues, among others, the possession of extensive scientific knowledge or, at the very least, its practical application. 'Uqba b. Nāfi', the conqueror of North Africa, was able to determine the orientation of the Qiblah through divine revelation. Thanks to his charisma, Kairouan–the city he founded and that was intended to become the capital of the new province–was freed of snakes and scorpions. This same legend is also found attributed to Ḥanash al-Ṣan'ānī, one of the conquerors of Al-Andalus and founder of the first mosque in Zaragoza.

If one is to examine the Arab scientific tradition, then one must first discuss the *anwā'* system. Arabs of the pre-Islamic era had quite an efficient understanding of the sky. It served in orienting them during their night-time caravan journeys through the desert, as well as in predicting meteorological phenomena. Furthermore, they were able to establish relationships between the heliacal risings and the acronychal settings of stars, on the one hand, and certain weather patterns, on the other, in such a way that the appearance of a specific star was related to a distinct phenomenon, such as rain or wind. Later, this *anwā'* system fused with that of the lunar mansions, according to which the moon "slept" in one of its houses every night until finally completing the monthly cycle. With its characteristic miscellany of content (information about winds, navigation, the cycle of the seasons, the science related to the Islamic cult, etc.), the books of the *anwā'* were fairly successful and were a genre cultivated in Al-Andalus and Maghreb for centuries. One of the most paradigmatic examples is the *Calendar of Córdoba* written by 'Arīb b. Sa'īd and Rabī' b. Zayd in 973.

From the beginning, the Islamic West would live with *savoir faire* (a research-driven science) as well as *savoir savant* (an applied science). Due to their intrinsic characteristics, agriculture, astrology, and medicine are the fields that have drawn the most attention. The first two have already been briefly mentioned, but attention should also be paid to the third. The troops that reached the Iberian Peninsula were made up of an amalgam of Arabs from distinct backgrounds and of Berbers recruited in North Africa [6]. These armies were not solely made up of men since they were accompanied by their families. Among the many tasks taken on by the women, nursing was of particular importance. In addition to their role as midwives, sources inform us that some of the women became especially skilled in treating and curing wounds incurred during war.

The Abbasid East. The emirate age in Al-Andalus (9th–10th centuries) coincided with the Abbasid Caliphate of Baghdad and represents an era of major Eastern influence. Despite political rivalry, the emirs encouraged the Andalusians to journey to the East to search out books. Indeed, travel was a part of the requirements of being Muslim, since its adherents were obliged to make the pilgrimage to Mecca. A Medieval version of today's exchange students, the Andalusians–especially those of the period of the emirs–took advantage of their travels in order to broaden their studies by sitting in on lessons given by the most prestigious teachers.

The Abbasid Caliphs, especially al-Ma'mūn (813–833), promoted science in specific centers, such as the *Bayt al-Ḥikma* (House of Wisdom), where translations of all kinds were carried out. There, authors including Pythagoras, Plato, Aristotle, Euclid, and Hippocrates were translated into Arabic. Among the scientists working in Baghdad at that time was *al-Khwārizmī* (ca. 800–ca. 850). His importance and key role in history is manifested in the scientific terminology related to his name or to the titles of his works. *Guarisme* (a Catalan word meaning "numeral") and "algorithm" are derived from his name, while "algebra" comes from *al-jabr*, the first part of the title of his book *Al-jabr wa-l-muqābala*, specifically dedicated to solving equations.

Contributions

Astronomy. The arrival of Islam in the West did not mean a decline in the study of the skies. On the contrary, Islam is a religion with an enormous amount of astronomic content. The field of astronomy related to religion (*mīqāt*) is quite extensive, considering that four of the five pillars of Islam are linked to astronomy (actually, all of them except for the profession of faith, the *shahāda*). The orientation of the Qiblah, the determination of prayer times, and the visibility of the moon, for example, are indispensable elements of day-to-day Muslim life. This does

not mean that Islam is exclusively a religion of scholars: the Koran specifically insists that religion pose no difficulties so that one cannot excuse oneself from it out of ignorance. The uniting of these two aspirations–the pursuit of those guiding astronomical principles that are compatible with the will of popularization–gave rise to a new tendency, popular astronomy, which became widely adopted. The *faqih* Ibn Ḥabīb (d. 852), in his *Kitāb al-Nujūm,* championed Arab scientific tradition and, in adhering to the Koran, made it extremely clear what limitations existed in analyzing the firmament: the stars could be studied to guide the way, but not to carry out astrological calculations.

In Al-Andalus, the consequence of political decadence–a by-product of the decentralization implied by the caliphate system–was the proliferation of scientists dispersed throughout the *taifas*. Among the most famous of these was Maslama al-Majrīṭī, considered to be the first truly Andalusian mathematician and scholar. Maslama represents the maturity of Andalusian astronomy for a variety of reasons, first and foremost for his founding of a real school that lasted over three generations. Among his direct disciples, Ibn al-Samḥ (d. 1035) and Ibn al-Ṣaffār (d. 1035), two significant authors who achieved a high level of popularity, also in the rest of Europe, stand out because their works on the construction and use of the astrolabe were translated into Latin. As for the contributions made by Maslama, it should be noted that he correctly predicted the conjunction of Saturn and Jupiter that was to take place in 1006/1007 and that would cause a great number of disasters, among them a change of dynasty. Maslama made use of important Eastern works that had already reached Al-Andalus, such as the *Sindhind*, by al-Khwārizmī, for which he authored a revision as did Ibn al-Ṣaffār and Ibn al-Samḥ.

Among the most important scientists in Al-Andalus was Ibn al-Zarqalluh, also known as Azarquiel (d. 1100) [3], who amassed the work that came out of the school of Maslama and expanded upon it. He deserves historical recognition for his labors as a theoretical astronomer as well as his for his efforts as a designer of new scientific instruments (Fig. 1).

Ibn al-Zarqalluh went about studying the lunar and solar models, the length of the sidereal year, the eccentricity corresponding to the model of Mercury or Venus, and many other questions. In order to carry out his studies, he made diverse and lasting astronomical observations. In addition, illustrations of his instruments were preserved and later incorporated in the *Libros del Saber de Astronomía*, compiled under the direction of Alfonso X the Wise (1221–1284) [4] (Fig. 2).

Ibn al-Zarqalluh distinguished between instruments used to observe shadow as projected upon a gnomon (such as the solar quadrants) and instruments used to directly observe the position of the sun and stars (such as the celestial sphere, the astrolabe, or the armillary sphere). He developed both types of instruments in original ways, especially the equatorium and the saphaea [7] (Fig. 3).

The motivation behind the saphaea was that Ibn al-Zarqalluh was trying to improve the astrolabe. While inarguably the most widely employed instrument, the astrolabe had the disadvantage of requiring a specific plate for each latitude. If the plate corresponding to the latitude of interest was not available, the instrument was no longer useful or, at the very least, its measurements were inexact. This deficit led the Andalusians to design instruments with universal plates, such as the saphaea *zarqāliyya*, or its contemporary, the universal plate of ʻAlī b. Khalaf. The importance of these instruments includes the fact that they are the first documentation of the use of meridian stereographic projection. Later, in Nasrid Granada, Ḥusayn b. Aḥ mad Ibn Bāṣo (m. 1315) [5] developed his own universal plate, building on the Andalusian tradition but also on the many contributions that had arrived from the East.

As Al-Andalus lost ground politically and academically, Maghreb became the focal point, although during this period many astronomers compiled tables (*zij)* derived from the Andalusian tradition [12]. The likely reason for the continued Andalusian influence was that the most renowned of the Maghreb astronomers, Ibn Isḥāq al-Tūnisī (fl. ca. 1193–1222), was an inheritor of the Azarchelian tradition. However, observations carried out during the 14th and 15th centuries by individuals such as Ibn ʻAzzūz al–Qusanṭīnī (m. 1354) resulted in the eventual abandonment of the calculations of Ibn al-Zarqalluh, as these astronomers determined their own numerical values for the planetary positions and the obliquity of the ecliptic.

Science and scientists

At this point, science must be placed within its social context in order to appreciate the relationships between science and power, science and the economy, and the procedures of scientific dissemination.

Patronage. To reach their level of scientific development, the Andalusians required financial and political backing [10], and in fact, the emirs, caliphates, and kings of the *taifas* were great pa-

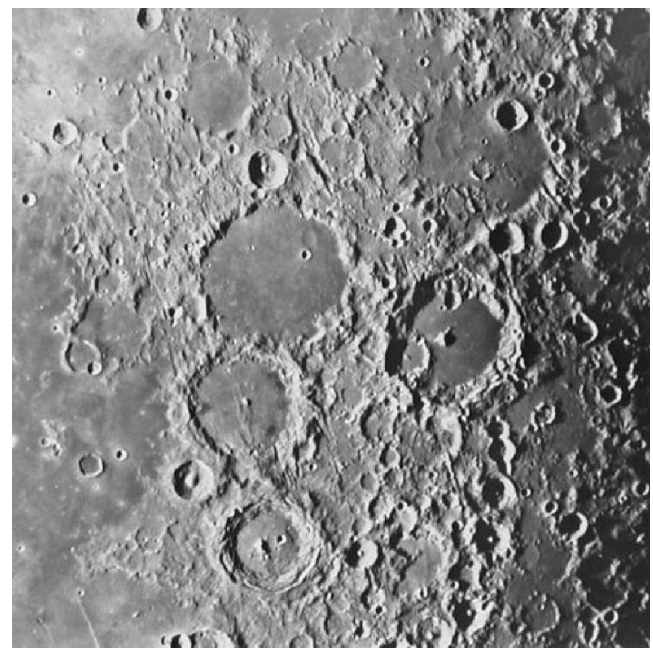

Fig. 1. One of the craters on the moon located in section 33 is named after was Ibn al-Zarqalluh, also known as Azarquiel.

trons. As such, they were also responsible for the "scientific politics" that became a part of every era. The sources richest in information are historical chronicles and biographical dictionaries–the latter genre having been highly embraced–but this means that the record is reduced to the circle of the courts. Be that as it may, those who ruled had a predilection for three activities: mathematics, medicine, and astronomy. The first was so indispensible to calculations related to the division of inheritances that a specialized vocation was born, the *faraḍī*. Medical skill, naturally, was essential to protecting the health of the ruler himself, as well as that of his family and the elite class. Finally, astronomy was related to astrology, which was practiced throughout the entire history of Al-Andalus in a more or less open fashion.

Nevertheless, for historians, precisely establishing the extent of this patronage is difficult for various reasons. On a great number of occasions, the sources of information qualify members of the court who simply had knowledge of medicine or mathematics as "patrons" or "mathematicians." Furthermore, it has been determined that some scientists had to carry out other lines of work (for example, practicing judicature) in order to bring in income; this would explain why many Andalusian "scientists" did not leave behind any written legacy. Finally, there were a small number of scientists who were able to live exclusively from their studies. In any case, the unpredictability of the rewards or punishments awarded by the sovereign formed a part of the relationship between him and his subjects.

Science and power. An example of the close-knit relationship between science and power [9] is evidenced by the emirate of ʻAbd al-Raḥmān II (821–852), where scientific studies were of the utmost importance if one was to develop a successful career in the court. Individuals such as Ibn al-Shamir and Ibn Firnās prospered in this environment, as they earned salaries as both poets and as astrologers. The emir himself had studied astronomy and enjoyed testing his astrologers. The competition amongst the astronomers could be fierce, to the extent that some would end up being sentenced to prison after being betrayed by a colleague (Ziryāb, for example, who betrayed Ibn al-Shamir). The commoners' lack of comprehension towards scientific practices could also become dangerous. The alchemy experiments carried out by Ibn Firnās were the cause of his being condemned for witchcraft by his neighbors.

Astrologers also played a politically important role since they could notably back some political candidates over others. In turn, this positioning could be very favorable in helping to win over the trust of the future emir or caliph. The successful ruler hoped to govern with as much exactitude as possible, and thus, before going to war, was eager to know whether he had any chance of winning it. The issue would become controversial depending on any changes in religious orthodoxy. What at the beginning of the 9th century was legal, was no longer so one hundred years later because theologians specialized in Islamic religion were promoting a Corpus Juris that was much more narrowly interpreted and specific. During the caliphate, when Eastern religious trends would already have reached Al-Andalus, the caliphs were subjected to pressure from the jurisconsults who, in turn, were supported by the popular masses, a scenario highly different from that during the period of the emirs.

Science and economy. Yet scientific practice was not merely a pastime of the palace. Some scientists helped improve Andalusian technology (as exemplified by improvements in irrigation) and thus its economy. Ibn Firnās, a many-faceted individual, contributed to the development of glass production. It should be noted that this industry was expanding in a climate of economic prosperity, in which the court stopped using wooden cups in a desire to acquire the most sophisticated glassware. Indeed, Al-Gazāl practiced "scientific espionage" since, upon returning from the embassy that he ran in Byzantium, he introduced a variant of the fig and, possibly, helped in expanding the silk industry.

Exports and new imports

The declining influence of Al-Andalus led to the transfer of Muslim centers of science into Christian hands. Thus, in time, Toledo would no longer be inhabited by astronomers from the School of Maslama or even by Ibn al-Zarqalluh himself; instead, it gradually converted into a hub of scientific translation under the command of Alfonso X the Wise. However, in the 10th century, Catalonia had already taken in a Mozarab population that had emigrated up from the south and that would prove to be essential to the diffusion of Andalusian science. Lupitus Barchinonensis, archdeacon of Barcelona, was one of the first translators of scientific Arab writings into Latin and, although there is no record of it, he may have counted on the collaboration of a Mozarab monk. Gerbert of Aurillac (945–1033), who would later be named Pope Sylvester II, asked Lupitus for a copy of one of his translations on astrology, *De utilitatibus astrolabii.* Gerbert also asked bishop Miró de Bonfill of Girona to make a copy of *De multiplicatione et divisione numerorum a Joseph Hispano editum* available to him, one of the paths through which Arabic numerals advanced into Europe. Manuscript 225 from the abbey of Ripoll, consisting of writings on a level much more advanced than those found in other Catalan monastic libraries, is perhaps the first miscellany of scientific translation from Arab into Latin. Therefore, the circulation of knowledge did not begin with the decadence of Al-Andalus, but coincided with its splendor.

The Toledan 12th century would be responsible for making known the Arab versions of names which up to that point were known for their Latinized versions, such as Averrois (Abu-al-Walid Muhammad ibn-Ahmad ibn-Muhammad ibn-Rushd), Albategnius (Abu Abdallah Muhammad ibn Jabir ibn Sinan ar-Raqqi al-Harrani as-Sabi al-Batani), and Abulcasis (Abu al-Qasim Khalaf ibn al-Abbas Al-Zahrawi). Translations also began to be made into Romance languages, such as those made by John of Seville into Castilian Spanish. In terms of original materials, it was not only Andalusian science that was translated, but also essentially everything that arrived from the East. This enormous effort can almost entirely be attributed to one name: Gerard of Cremona, who translated nearly all of the major works of Arab science into Latin.

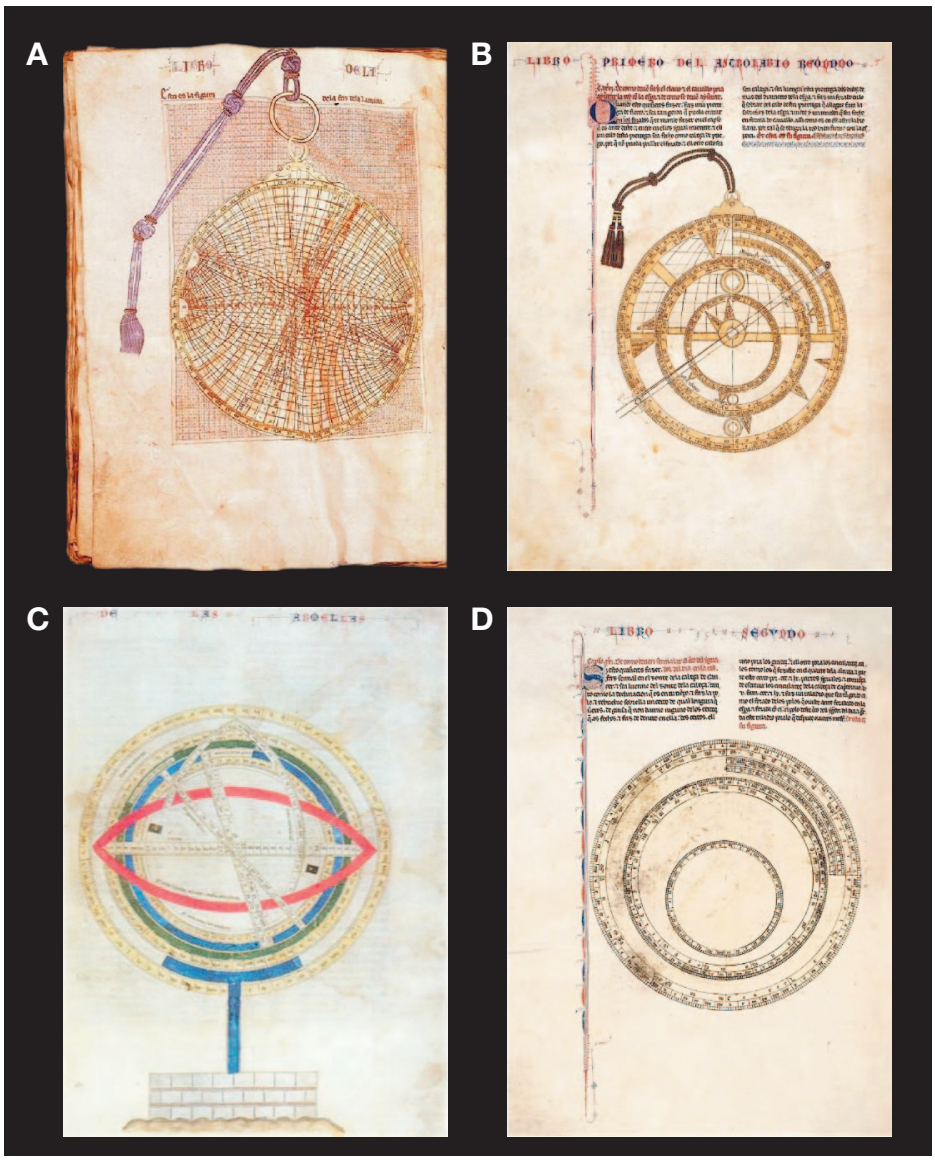

Fig. 2. Illustrations of (**A**) the saphaea *zarqāliyya*, (**B**) the spherical astrolabe, (**C**) the armillary sphere, and (**D**) one of the faces of Azarquiel's equatorium, according to the *Libros del Saber de Astronomía*, compiled under the direction of Alfonso X the Wise (1221–1284), page 112 of the ms. of the Complutense University of Madrid Library.

Fig. 3. Solar quadrant conserved in the archaeological site of Madinat az-Zahra.

Be that as it may, ideas did not circulate in solely one direction. Andalusian science reached the Islamic East just as the destination for Eastern articles was Maghreb (the tables of Ulugh Beg, for example, arrived in the 17th century). However, it seems the circle closed with the first text on Andalusian artillery, written in Tunis between 1630 and 1632 by the Morisco Ibrāhīm b. Gānim Arribas and translated into Arabic in 1638 by another Morisco, Aḥmad b. Qāsim Bejarano Al-Hajari (fl. 1598–1638).

Colophon

While 2009, the International Year of Astronomy, commemorated Galileo's aiming of a telescope at the sky for the first time (1609), interest in the study of the heavens has not been exclusive to any specific country or culture. On the contrary, our current level of knowledge would not have been possible without the work of all those scientists who preceded us. In this sense, Arab-Islamic science is an important stepping-stone. Appreciation of the knowledge acquired through Arab and Islamic contri-

butions is essential in order to obtain a full and coherent picture of the evolution of science. But we must also acknowledge that the science of Al-Andalus and Maghreb, in its quality of being at once both Eastern and Western, represents a meeting point between the East and the West that should not be forgotten.

Notes and references

Notes

[1] For more information on this subject, consult: Vernet J (2006) Lo que Europa debe al Islam de España (reprinting). Acantilado, Barcelona. And J. Samsó J (1992) Las ciencias de los antiguos en Al-Andalus. Mapfre, Madrid

[2] The *urjūza* is an educational poem written in *rajaz* meter. This style of composition is easily memorized and was often used by instructors to impart their "textbooks"

[3] The proof is that one of the craters on the moon located in section 33 bears his name.

[4] Ms. 156 from the library of the Complutense University of Madrid. (The entire book can be consulted on Google Books [http://tiny.cc/9ka2o].)

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