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ASTRONOMY IN THE MEDIEVAL SPANISH JEWISH COMMUNITY

Spain was unusual in the Middle Ages as a meeting ground for Muslims, Christians, and Jews. In particular, it is now customary to look back to a 'Golden Age' of Jewish culture from the tenth to the twelfth centuries, partly under Muslim domination and partly under Christian domination, although in that period the Jewish community faced real crises. Nevertheless, the Jewish elite was more integrated into the dominant culture in Spain than anywhere else in the Middle Ages. Indeed, Samuel Ibn Nagrela (d. 1056) became vizier of Granada and led a Muslim army and, as *nagid* (head of the Jewish community), he was a patron of learning in addition to being a scholar and poet in his own right—in general, his actions and interests paralleled those of a model Muslim ruler, making due allowances for the minority status of Jews.[1] For these elite Jews to serve in the government under Muslim rule, they had to be thoroughly conversant with the secular aspects of Muslim culture such as Arabic literature, philosophy, and science. But the mark of this elite was also to excel in matters of Jewish culture, particularly Hebrew poetry. And this Hebrew poetry was modeled after Arabic poetry in rhyme, meter, and theme, but using the Hebrew Bible as the store of images rather than the pre-Islamic poetry used by Muslims.[2] The result for the Jewish community was a creative assimilation of aspects of a foreign culture that is quite impressive.

The reconquest of Muslim Spain by the Christians began in earnest with the capture of Toledo in 1085, leading to the entry of fanatical Muslims from North Africa who were, in general, hostile to the Jewish community. By the middle of the twelfth century, most Spanish Jews were living in areas dominated by Christians, and by the middle of the thirteenth century, most of Spain (with the exception of Granada) had come under Christian control.

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[1] For a history of the Jews in Muslim Spain, see E. Ashtor, *The Jews of Moslem Spain*, 3 vols., Philadelphia 1973-84. For Samuel Ibn Nagrela as the model for Spanish Jews, see G. D. Cohen, *The Book of Tradition*, Philadelphia 1967, 269 ff.

[2] A. Schippers, *Spanish Hebrew Poetry and the Arabic Literary Tradition*, Leiden 1994. For a Hebrew poem from eleventh century Spain with an astronomical theme, see R. Loewe, 'Ibn Gabirol's Treatment of Sources in the *Kether malkuth*', in *Studies in Jewish Religious and Intellectual History Presented to Alexander Altmann*, eds. S. Stein and R. Loewe, Tuscaloosa 1979, 183-94.

But Spanish Muslim culture cast a long shadow, and it affected the Jewish community until the expulsion in 1492.

The twelfth century

The medieval Hebrew tradition in astronomy began in Christian Spain in the twelfth century with Abraham Bar Ḥiyya who mainly summarized Arabic astronomical texts. Bar Ḥiyya was soon followed by Abraham Ibn Ezra, and together they laid the foundation for this Hebrew tradition that spread far beyond the Iberian peninsula. To be sure, one should also consider Maimonides a product of twelfth century Spain despite the fact that most of his works were written in Egypt, for he spent his formative years there, and refers to discussions of astronomy by Muslim scholars in Spain.

Bar Ḥiyya's astronomy is much indebted to al-Battānī (d. 929), an astronomer at Raqqa on the upper Euphrates (now in Syria). Al-Battānī produced a set of astronomical tables, called a *zīj* in Arabic, that in turn was based on Ptolemy's tables with some modifications. However, Bar Ḥiyya transformed those tables of planetary motion for the Jewish calendar, rather than the Seleucid calendar used in the original. Bar Ḥiyya's introduction to the tables appeared in a separate treatise, *The Book on the Calculation of the Planetary Motions*, and it too is heavily dependent on al-Battānī's work.[3] In fact, al-Battānī gave a rather good account of Ptolemaic astronomy, and so Bar Ḥiyya chose well. In any event, from that time on, a reader of Hebrew had reliable access to the basics of planetary motion. Levi ben Gerson (d. 1344), the most original medieval astronomer to write in Hebrew, repeatedly mentions the tables of al-Battānī as representing Ptolemaic theory even though they had not been translated as such before his time into Hebrew and there is no persuasive evidence that Levi read Arabic. Therefore, I assume that Levi is referring to Bar Ḥiyya's version of these tables even though Bar Ḥiyya himself did not call attention to his dependence on al-Battānī.[4]

Bar Ḥiyya also engaged in messianic speculation in his 'Scroll of the Revealer' (*Megillat ha-megalleh*), depending largely on an interpretation of

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[3] Abraham Bar Ḥiyya, *La obra Séfer Ḥeshbon mahlekot ha-kokabim de R. Abraham Bar Ḥiyya ha-Bargeloni*, ed. J. M. Millás, Barcelona 1959.

[4] See B. R. Goldstein, 'A New Set of Fourteenth Century Planetary Observations', *Proceedings of the American Philosophical Society* 132 (1988), 371-99, esp. 388, 390, 392. Later in the fourteenth century, Immanuel ben Jacob Bonfils of Tarascon produced a Hebrew version of al-Battānī's tables for epoch 1340: see, e.g., Munich, Staatsbibliothek, MS Heb. 386, fol. 8b-38b, especially fol. 16a, where the heading is: 'table for the mean motion of Saturn according to al-Battānī by R. Immanuel ben Jacob'. Other copies of these tables are found in Munich, Staatsbibliothek, MS Heb. 343, fol. 180b-201b; and in New York, Jewish Theological Seminary of America, MS 2597, fol. 45a-73b.

the Book of Daniel. But in the fifth part of the book he based his messianic speculation on the conjunction Saturn and Jupiter to take place in 1345, about two centuries after his own time. This tradition of astrological eschatology, with its emphasis on the Saturn-Jupiter conjunction of 1345, was later invoked by several Jewish scholars, and then appropriated (and reinterpreted) by scholars in Latin Christendom beginning in the mid-fourteenth century, and continuing for several centuries thereafter. Among its notable proponents was Pierre d'Ailly (d. 1420) who associated the coming of the Antichrist with a Saturn-Jupiter conjunction.[5] Maimonides scorned such astrological eschatology, but Bar Ḥiyya defended it as consistent with his interpretation of the Book of Daniel. In a letter to Judah ben Barzillai, the rabbinical leader of Barcelona at the time, Bar Ḥiyya argued that the Talmudic rabbis accepted astrology, and that it is justified to use the rules of astrology for all that relates to the world as well as to each individual in it. To get around astrological fatalism, he adds that 'the righteous of Israel—unlike the other nations—can nullify the decrees of the motions of the planets from upon them through their righteous deeds and their prayers'.[6] One may see in this remark an echo of the Talmudic dictum: 'There is no planet (*mazzal*: or zodiacal sign) [that rules] over Israel'.[7]

Abraham Ibn Ezra (d. 1167) was a prolific scholar who wrote in Hebrew on a variety of subjects, and is perhaps best known for his Biblical commentaries.[8] Yet he was one of the foremost transmitters of Arabic scientific knowledge to the West for both Jews and Christians. Moreover, he had access to Islamic astronomical treatises that are no longer extant, and this has helped in the reconstruction of early Islamic astronomy. Among such works translated by Ibn Ezra that do not survive in the original Arabic are Ibn al-Muthannā's *Commentary on the Astronomical Tables of al-Khwārizmī* and Māshā'allāh's *Book on Eclipses*. Al-Khwārizmī's treatise (early ninth century) is a very important witness for the early stages of

[5] J. P. Boudet, 'Simon de Phares et les rapports entre astrologie et prophétie à la fin du moyen âge', *Mélanges de l'École Française de Rome* 102 (1990), 617-48, esp. 638.

[6] R. C. Kiener, 'The Status of Astrology in the Early Kabbalah from the Sefer Yeṣirah to the Zohar', *Proceedings of the Second International Conference on the History of Jewish Mysticism*, Jerusalem 1987, 6:1*-42*, esp. 19*.

[7] 'Eyn mazzal le-Yisrael': see, e.g., Babylonian Talmud, Shabbat 156a. In Maimonides, *The Guide of the Perplexed*, ii.10, transl. S. Pines, Chicago 1963, 269 f, it is noted that the term *mazzal* in Rabbinic texts can mean 'planet' as well as 'zodiacal sign'. For Maimonides's rejection of astrological history, see his 'Epistle to Yemen', I. Twersky, *A Maimonides Reader*, New York 1972, 452 ff.

[8] Much of the material here about Ibn Ezra derives from my article, B. R. Goldstein, 'Astronomy and Astrology in the Works of Abraham Ibn Ezra', *Arabic Sciences and Philosophy* 6 (1996), 9-21, where additional references may be found. See also *Rabbi Abraham Ibn Ezra: Studies in the Writings of a Twelfth-Century Jewish Polymath*, eds. I. Twersky and J. M. Harris, Cambridge Mass. 1993.

Islamic astronomy in the late eighth and early ninth centuries. But the problems concerning the history of this treatise are considerable because the original Arabic only survives in a Latin translation by Adelard of Bath (early twelfth century) of an Arabic version made in Spain by Maslama al-Majrīṭī (ca. 1000). Moreover, Ibn al-Muthannā's *Commentary* (tenth century) is lost in the original Arabic and only survives in Hebrew and in Latin. Finally, there are two Hebrew versions of this commentary: the one by Ibn Ezra which is short and incomplete, and another longer one which is anonymous.[9] Ibn Ezra also wrote a treatise, *De rationibus tabularum*, that is extant only in Latin. But he probably composed it in Hebrew, which would mean that the Latin is simply an anonymous translation. This text includes many paraphrases drawn from Ibn Ezra's translation of Ibn al-Muthannā's treatise and, in the treatment of trigonometry, it is explicitly based on the Indian tradition as reported in Ibn al-Muthannā's commentary.[10]

Māshā'allāh's *Book on Eclipses* is an astrological text that includes a discussion of the natures of the zodiacal signs as well as of an astrological theory of world history. We learn from various sources that Māshā'allāh was Jewish, but it is not apparent in any of his surviving works. Ibn Ezra clearly indicates in various treatises that he accepted the astrological theory of world history based on conjunctions of Saturn and Jupiter that played an important role in the works of Māshā'allāh (d. 815), among others. Here we are told:

> Māshā'allāh said: I have already said that great things take place on account of a great conjunction of the outer planets. Some of these conjunctions indicate great events, for a conjunction of Jupiter and Saturn is a great conjunction and indicates great events. To recognize the event, note the hour of the conjunction, the ascendant, and (the position of) the planets. Know: if the (planetary) ruler of the horoscopic diagram is benevolent, it is an indication of good and the improvement of times, but if it is malevolent, it is an indication of evil, destruction, drought, famine, and war.[11]

In a previous passage, Māshā'allāh said that a great conjunction is an indication of the rising of prophets and seers.[12]

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[9] B. R. Goldstein, *Ibn al-Muthannā's Commentary on the Astronomical Tables of al-Khwārizmī*, New Haven 1967; B. R. Goldstein, 'The Hebrew Astronomical Tradition: New Sources', *Isis* 72 (1981), 237-51, esp. 250.

[10] Abraham Ibn Ezra, *El libro de los fundamentos de las Tablas astronómicas de R. Abraham Ibn Ezra*, J. M. Millás, Madrid 1947; J. D. North, *Richard of Wallingford*, 3 vols., Oxford 1976, 2:266. In J. D. North, *Horoscopes and History*, London 1986, 23 ff, there is a detailed analysis of a method for domification that is first described in several works by Ibn Ezra, including *Fundamentos de las Tablas*.

[11] B. R. Goldstein, 'The Book on Eclipses of Māshā'allāh', *Physis* 6 (1964), 205-13, esp. 212.

[12] Goldstein, 'The Book on Eclipses', 211.

Since Ibn Ezra was one of the first scholars to write on scientific subjects in Hebrew, he had to invent or adapt many Hebrew terms to represent the technical terminology of Arabic. Some of his coinages were accepted by later Hebrew authors, while many others were not. As an example of a mixed reception, there is the case of Ibn Ezra's introducing the term *maḥberet* for conjunction (of the Sun and the Moon and, more generally for two, or more, celestial bodies). This innovation was accepted by some later writers, but others followed Ibn Gabirol and Abraham Bar Ḥiyya who used for this phenomenon either *deviqah* or *dibbuq* (both of which are derived forms from the same root in Hebrew).[13]

The aid of a Jewish collaborator who knew Arabic in a translation from Arabic into Latin by a Christian is reported on a number of occasions, presumably because some Christian translators had a deficient knowledge of Arabic. One well known example of this procedure is mentioned in the preface to the Latin version of Avicenna's *De anima* (between 1152 and 1156), under the patronage of the archbishop of Toledo. The Jew, looking at the Arabic text, read it aloud, word by word, in the 'vulgar' language (presumably, Castilian), and the Christian translator simultaneously wrote down a Latin version of what he had heard. The name of the Jew is given as Avendauth who has been identified as Abraham Ibn Daud, a noted Jewish philosopher living in Toledo at the time. It seems that Gerard of Cremona (d. 1187), one of the most prolific translators in Spain of scientific texts from Arabic into Latin, proceeded in much the same way, but took advantage of the services of a Mozarab (i.e., a Christian who had adopted Arabic culture) called Galip, rather than of a Jew. This procedure must have been fairly common in Spain, for Abraham Ibn Ezra assumed (without any evidence) that a Jew served as intermediary in a translation from Sanskrit into Arabic in the eighth century.[14]

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[13] The best study of medieval Hebrew mathematical and astronomical terminology is G. B. Sarfatti, *Mathematical Terminology in Hebrew Scientific Literature of the Middle Ages* [in Hebrew and English], Jerusalem 1968. See also S. Gandz, *Studies in Hebrew Astronomy and Mathematics*, New York 1970, 127 ff; and J. Klatzkin, *Thesaurus philosophicus linguae hebraicae et veteris et recentioris*, New York 1968.

[14] M.-T. d'Alverny, 'Les traductions à deux interprètes, d'arabe en langue vernaculaire et de langue vernaculaire en latin', *Traduction et traducteurs au Moyen Age: Actes du colloque international du CNRS*, 26-28 mai 1986, ed. G. Contamine, Paris 1989, 193-206; Goldstein, *Ibn al-Muthannā's Commentary*, 148; D. Pingree, 'The Fragments of the Works of Yaᶜqūb Ibn Ṭāriq', *Journal of Near Eastern Studies* 27 (1968), 97-125, esp. 101.

The thirteenth and fourteenth centuries

By far the most important impact of Jews on European astronomy came about from the work of astronomers under the patronage of Alfonso X of Castile (reigned: 1252-1284) whose goal seems to have been to provide his astronomers with a working library for their discipline without having to consult other treatises. In particular, the Alfonsine tables were the most widely used astronomical tables in Europe from the fourteenth to the end of the 16th centuries. The instructions for these tables survive in a Castilian version, but the tables themselves are only extant in a Latin adaptation produced by a group of Christian scholars in Paris in the 1320s. The authors of the Castilian version, as indicated in the prologue, were both Jews, Isaac ben Sid and Judah ben Moses. The prologue also indicates that the king served as patron, and that the tables were compiled at his command. The king did so, we are told, because of discrepancies between observations and computations based on the tables of al-Zarqāllu (eleventh century), and decided that the only way to correct them was to make a series of new observations. Some of these observations are reported in *Yesod ᶜOlam* by Isaac Israeli of Toledo (fl. 1310), with the prefatory remark: 'I examined [the calculations of] three eclipses, which Rabbi Isaac *ha-Ḥazzan* b. Sid (or Sayyid) prepared and arranged in the city of Toledo at the command of the king don Alfonso, (...) and [I saw them] in his own handwriting'.[15] There were other astronomers involved at the court, both Jewish and Christian, who produced a set of treatises called the *Libros del Saber de Astronomía*, and most of these works involved at least one Jewish scholar.

To convey some idea of the level of collaboration, we are told in *The Book of the Fixed Stars* that the king himself was engaged in the revision of this work. The text was first translated by Judah ben Moses Kohen and Guillén Arremón Daspa in 1256, but was later revised in 1276 by the same Judah, another Jewish scholar, Samuel, and two Italians, with the active participation of the king. Most of these scholars were engaged in translations from Arabic into Castilian, while some produced new texts, the most important of which was the *Alfonsine Tables*. One of the Jewish collaborators, known as Abraham *alfaquim*, i.e., the physician, translated two texts from Arabic directly into Castilian: *The Book on the Configuration of the World* by Ibn al-Haytham (eleventh century), and the *Escala de*

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[15] N. Roth, 'Jewish Collaborators in Alfonso's Scientific Work', *Emperor of Culture: Alfonso X the Learned of Castile and His Thirteenth Century Renaissance*, ed. R. I. Burns, Philadelphia 1990, 59-71, esp. 67. See Isaac Israeli, *Yesod ᶜOlam*, part iv, chap. 7 (*Liber Jesod Olam, seu Fundamentum Mundi*, eds. B. Goldberg, and L. Rosenkranz, 2 vols., Berlin 1846-48, vol. 1, part iv, p. iv); J. D. North, 'The Alfonsine Tables in England', *Prismata*, eds. Y. Maeyama and W. G. Saltzer, Wiesbaden 1977, 269-301, esp. 270.

Mahoma (the original is lost, but it is preserved in Latin and French translations from the Castilian). Moreover, at the request of King Alfonso, this Abraham revised the Castilian version of the *Azafeha* by al-Zarqãllu that had previously been translated by the Christian scholar, Fernando of Toledo. Abraham *alfaquim* has now been identified as Abraham Ben Waqãr, a member of an eminent Jewish family of scholars and courtiers who, along with his brother Isaac, attended Sancho IV, the successor to Alfonso X, at his deathbed. He and his brother were praised for their knowledge of medicine in a poem by Todros ha-Levi (d. ca. 1306). Moreover, Todros credited Abraham with the ability to foretell the future (*maggid* ᶜ*atidot*), which may be an allusion his skill as an astrologer.[16] Alfonso was also interested in astrology for, even before becoming king, he had acquired an Arabic manuscript of the *Lapidary* and, as we read in the prologue to the Castilian version:

> [Alfonso] obtained it in Toledo from a Jew who held it hidden, who neither wished to make use of it himself nor that any other should profit therefrom. And when he had this book in his possession, he caused another Jew, who was his physician, to read it and he was called Jehuda Mosca *el menor* and he was learned in the art of astrology, and knew and understood well both Arabic and Latin. And when through this Jew his physician he understood the value and great profit which was in the book, he commanded him to translate it from Arabic into the Castillian language, so that men might better understand it and how to profit more from it. And one Garcia Pérez his clerk aided in this translation. He was also learned in the art of astrology.[17]

John of Lignères was one of the Parisian scholars responsible for the Latin version of the Alfonsine tables, and in a somewhat earlier work, a set of astronomical tables composed in 1322, he singled out three earlier astronomers for praise: al-Battānī, al-Zarqãllu, and Abraham Benthegar. John added that the introduction (or 'canons') to Abraham's astronomical tables had not yet been translated from Hebrew, 'although it seems to me from what I have heard that they are the best of all, with the exception of those of al-Battānī'.[18] The name Abraham Benthegar may be a corruption of Abraham Ben Waqãr despite the linguistic problems with that identification, but Abraham Ben Waqãr is not known to have composed any astronomical

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[16] D. Yellin, *Gan hammeshalim we-haḥidoth: Diwan of Don son of Yehuda abu-el-*ᶜ*Afiah*, Jerusalem 1934, 84. Abraham alfaquim was identified as Abraham ben Waqãr by E. S. Procter, 'The Scientific Works of the Court of Alfonso X of Castille', *Modern Language Review* 40 (1945), 12-29, esp. 23.

[17] Procter, 'Alfonso X of Castille', 19. See also D. Romano, 'Le opere scientifiche di Alfonso X e l'intervento degli ebrei', *Oriente e occidente nel medioevo: filosofia e scienza, Atti dei Convegni* 13 (1971), 677-710.

[18] M.-M. Saby, 'Les canons de Jean de Lignères sur les tables astronomiques de 1321', unpublished thesis: Ecole Nationale des Chartes, Paris 1987. A summary appeared in *Ecole Nationale des Chartes: Positions des thèses*, 1987, 183-90.

works in Hebrew. Nevertheless, the fact that John of Lignères, one of the main collaborators in the Parisian Latin version of the Alfonsine tables, praised a Hebrew text that he had not read, is surely evidence of the high esteem of Jewish astronomers at the time. Al-Battānī was a famous astronomer whose astronomical tables had a great influence in Spain, and al-Zarqāllu was the most prominent Spanish-Muslim astronomer whose influence was felt in subsequent generations. Thus, Abraham Benthegar is placed in very good company.

Later Jewish astronomers knew the Alfonsine tables through the Latin version produced in Paris, and that version was translated into Hebrew by Moses ben Abraham de Nîmes in Avignon in 1460. Of interest is that Moses was aware that some of the tables were added after the Alfonsine tables were originally compiled: 'The translator said: this table together with the eight tables that follow do not belong to Alfonso, but they were added to fulfill a need and to be useful', and 'The translator said: here end the tables of King Alfonso with all the supplementary tables that the Christians added to make them complete so that the astronomer will not need any other tables'. Several of these supplementary tables appear in the *editio princeps* of the Latin version (published by Ratdolt in 1483), but they are not designated as supplementary there.[19] So readers of Moses's Hebrew version had access to information, ultimately derived from the Latin manuscripts, that was not generally available to readers of the *editio princeps*. Recently, an anonymous Hebrew version of the Alfonsine tables has been found—it seems to derive from late fifteenth century Spain, and one of the epochs in it is 1473.[20]

Jewish scholars served at several royal courts, but none had the impact of the astronomers who served Alfonso X. For example, Jacob b. Abba Mari Anaṭoli was a physician and philosopher who, in the 1230s, served Emperor Frederick II at his court in Naples, where he assisted in translations from Arabic into Latin by Michael Scot that played a role in a political dispute with the pope.[21] Jacob translated a number of Arabic treatises into Hebrew,

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[19] B. R. Goldstein, 'Solar and Lunar Velocities in the Alfonsine Tables', *Historia Mathematica* 7 (1980), 134-40, esp. 137 f; *Alfontii regis castellae illustrissimi Caelestium motuum tabulae*, Venice 1483; E. Poulle, *Les tables alphonsines avec les canons de Jean de Saxe*, Paris 1984. See also North 'Alfonsine Tables in England', and J. D. North, 'Just whose were the Alfonsine Tables?' *From Baghdad to Barcelona: Studies in the Islamic Exact Science in Honour of Prof. Juan Vernet*, eds. J. Casulleras and J. Samsó, 2 vols., Barcelona 1996, 1: 453-75.

[20] St. Petersburg, Rossiiskaia akademiia nauk, MS Heb. C-076, fol. 31a-54a. Another version of the Alfonsine tables in Hebrew is preserved in Milan, Ambrosiana, MS Heb. X-193 Sup. The handwriting in this Hebrew manuscript is Italian, and it probably dates from the late fifteenth century.

[21] Cf. G. Freudenthal, 'Maimonides's *Guide of the Perplexed* and the Transmission of the Mathematical Tract "On Two Asymptote Lines" in the Arabic, Latin and Hebrew Traditions', *Vivarium* 26 (1988), 113-40, esp. 122, 128; G. Freudenthal, 'Les sciences dans les

including Averroes's *Epitome of the Almagest* (of which the original Arabic is lost) and Ptolemy's *Almagest*. Jacob also reports on conversations with the Emperor and with Michael Scot on scientific and philosophical issues. For example, concerning a passage in Maimonides's *Guide of the Perplexed*, ii.26, related to Job 37:6, Jacob tells us that 'our master, the Emperor Frederick, explained the reason why the term "snow" was used to designate prime matter (...)'.[22]

The conditions of Jewish life in Spain deteriorated in the course of the fourteenth century, and a series of riots, beginning in Seville in 1391, resulted in the conversion of a significant number of Jews. The period of instability lasted for a long time, and many Jews fled to other countries. One such refugee was probably Isaac al-Ḥadib, the Spaniard, who was active in Sicily in 1396 but, as far as I know, al-Ḥadib does not say why he left Spain. In his astronomical tables written in Hebrew, he mentions Muslim and Jewish predecessors, and a Hebrew commentary on these tables was written in the 16th century in Egypt by Abraham Gascon.[23] He also composed a text describing an equatorium, which he called 'The Precious Instrument' (*Keli ḥemda*), whose purpose was to replace the use of tables for calculating planetary positions by an instrument that only requires the turning of dials. The tradition of making such instruments began in the Islamic world some centuries earlier, and the variety of ways to construct such equatoria, all of which represented the Ptolemaic planetary models, is quite astonishing. Al-Ḥadib begins his treatise as follows:

> To find the true positions of the seven planets [the five planets plus the Sun and the Moon] (...) involves difficulty and effort in the (use of) all the different kinds of tables that have been composed for these purposes that cannot be avoided. (...) Moreover, errors affect the results (...) because of the multitude of operations, sometimes to be added and sometimes to be subtracted. The person computing the (planetary) position may add when he was supposed to subtract, and vice versa. (...) Many tried to construct instruments to simplify this as was done for the Sun [on the back of] the astrolabe (...) But these instruments came with lengthy instructions and could only be used with great difficulty. (Such is the case) with the instrument ascribed to al-Zarqāllu and others (ascribed) to Christian scholars. (...) In the year 5156 [= 1396 A.D.] in Syracuse on the island of Sicily (...) I invented an instrument that is easy to construct and it is accurate to a degree [of longitude]. The astrologers rely on

communautés juives médiévales de Provence: leur appropriation, leur rôle', *Revue des études juives* 152 (1993), 29-136, esp. 50.

[22] C. Sirat, 'Les traducteurs juifs à la cour des rois de Sicile et de Naples', *Traduction et traducteurs au Moyen Age: Actes du colloque international du CNRS, 26-28 mai 1986*, ed. G. Contamine, Paris 1989, 169-91, esp. 172.

[23] Goldstein, 'The Hebrew Astronomical Tradition', 240.

> the astrolabe (...) and there is no doubt that the approximation with the astrolabe is far greater than that found in this instrument.[24]

Al-Ḥadib then goes on to explain the construction and use of his instrument. After an extensive search of Hebrew manuscripts, I found only five such instruments described in Hebrew, and there does not seem to be any surviving example. Two of them are ascribed to a certain Joseph ha-Parsi who is otherwise unknown. The first is called 'The golden instrument' (*Keli paz*), composed in Seville in 1439, and the second is called 'The instrument of exile' (*Keli golah*), composed by the same author in 1444 in Bologna, Italy. So it seems that this is also a case of a Spanish refugee. From another such text it is clear that the 'market' for equatoria was probably driven by practitioners of astrological medicine who needed to find planetary positions in order to cast horoscopes, but whose mathematical skills may have been limited.[25]

The fifteenth century

The two outstanding Jewish astronomers in the Iberian peninsula during the fifteenth century were Judah ben Verga, and Abraham Zacut. Ben Verga was active in the 1450s and 60s and is associated with Lisbon (Portugal) where he made some astronomical observations. He also composed astronomical tables that have recently been identified by Tzvi Langermann.[26] Abraham Zacut was born in Salamanca (Spain), probably in 1452, and left Spain at the time of the expulsion in 1492. He wrote a lengthy astronomical treatise with both an introduction and tables, entitled: *The Great Composition* (*ha-Ḥibbur ha-gadol*), and the epoch of the tables is the year 1473. Zacut finished his work around 1478, and three years later the treatise was translated from Hebrew into Castilian, with the help of Zacut himself, by Juan de Salaya, who had previously held the chair of astronomy at the University of Salamanca. The tables were printed in Latin in Leiria (Portugal) in 1496,

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[24] B. R. Goldstein, 'Descriptions of Astronomical Instruments in Hebrew', *Essays in Honor of E. S. Kennedy*, eds. D. A. King and G. Saliba, *Annals of the New York Academy of Sciences* 500 (1987), 105-41, esp. 128.

[25] P. Barker and B. R. Goldstein, 'The Role of Comets in the Copernican Revolution', *Studies in the History and Philosophy of Science* 19 (1988), 299-319, esp. 311 n 24; Goldstein 'Descriptions of Astronomical Instruments', 119 f; B. R. Goldstein, 'Scientific Traditions in Late Medieval Jewish Communities', *Les Juifs au regard de l'histoire: Mélanges en l'honneur de M. Bernhard Blumenkranz*, ed. G. Dahan, Paris 1985, 235-47, esp. 239.

[26] The canons of Ben Verga's tables are preserved in St. Petersburg, Rossiiskaia akademiia nauk, MS Heb. C-076, fol. 57a-65a; and the tables in Paris, Bibliothèque Nationale, MS Heb. 1085, fol. 86b-98a, and Oxford, Bodleian Library, MS Heb. Nb. 2044, fol. 222b-236b. For other works by Ben Verga, see M. Steinschneider, *Mathematik bei den Juden*, 2nd edn., Hildesheim 1964, 196.

with an introduction in Latin in some copies and in Castilian in others. The colophon at the end of this printed text tells us that Joseph Vizinus was the translator (and d'Ortas the printer), but the introduction, with instructions for using the tables, in Latin (or Castilian) is sufficiently different from the corresponding Hebrew text to be considered a distinct work.[27]

It has been suggested that Zacut was a professor at the University of Salamanca, but this is clearly contradicted by the list of professors of astronomy in his lifetime. Alternatively, it has been suggested that he was a student at the University of Salamanca. Both claims are based on the same passage in the preface to the Latin version published in 1496 (but not in the Castilian variant) for which there is no Hebrew counterpart. According to this preface, the text is dedicated to an unnamed 'presbyter' of Salamanca, usually taken to be the bishop of Salamanca who died in 1480 and is supposed to have been Zacut's patron. But this preface was taken, almost word-for-word, from a dedication to a bishop in Hungary by Regiomontanus in his *Tabulae directionem* that was published in 1490, and the insertion of that dedication into the Latin version of Zacut's tables was most probably due to Vizinus, 'the translator', or possibly to d'Ortas, the printer.[28] Zacut's Hebrew text does not allude to this bishop at all, and Juan de Salaya's translation in 1481 does not do so either. Moreover, the introduction to Zacut's tables in Hebrew is clearly addressed to a Jewish audience, rather than to a Christian patron.[29] In short, there is no longer any credible evidence for a formal association of Zacut with the University of Salamanca.

The tables themselves are quite extensive, and Zacut based them primarily on the Alfonsine tables, the tables of Jacob Poël, and the tables of Judah ben Asher (d. 1391), the great grandson of the famous Rabbi of Toledo, Asher ben Yeḥiel (d. ca. 1328). The tables of Judah ben Asher have

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[27] Zacut, *Tabule tabularum celestium motuum astronomici zacuti*, Leiria 1496; for the Hebrew canons: Oxford, Bodleian Library, MS Opp. 8° 42; and for the Hebrew canons and tables: Lyon, Bibliothèque Municipale, MS Heb. 14; Munich, Staatsbibliothek, MS Heb. 109; and Warsaw, Żydowski Instytut Historyczny, MS Heb. 245. The most important studies of Zacut's astronomical works are F. Cantera Burgos, 'El judío salmantino Abraham Zacut', *Revista de la Academia de Ciencias de Madrid* 27 (1931), 63-398; and F. Cantera Burgos, *Abraham Zacut*, Madrid 1935. See also B. R. Goldstein, 'Abraham Zacut and the Medieval Hebrew Astronomical Tradition', *Journal for the History of Astronomy* 29 (1998), 177-86.

[28] Regiomontanus, *Tabulae directionum*, Augsburg 1490, fol. a2^r-a3^r; Zacut, *Tabule tabularum celestium motuum*, fol. 2^r-2^v. This similarity was first noted in B. Cohn's review of '*Almanach perpetuum coelestium motuum* (*radix 1473*) (...) Reproduction facsimilé, Edition 1496, (...) München 1915', in *Vierteljahrsschrift der Astronomischen Gesellschaft* 25 (1917), 102-23, esp. 106; and later in E. Zinner, *Regiomontanus: his life and work*, transl. E. Brown, Amsterdam 1990, 121, but was not mentioned in Cantera, *Abraham Zacut* (see esp. 21 ff).

[29] For the Hebrew text of the introduction with German translation, see B. Cohn, *Der Almanach perpetuum des Abraham Zacuto*, Schriften der wissenschaftlichen Gesellschaft in Strassburg, 32. Heft, Strassburg 1918; for a Spanish translation, see Cantera 'El judío salmantino Abraham Zacut', 239 ff.

recently been identified by Tzvi Langermann in a Vatican Hebrew manuscript, and they are of considerable interest in their own right.[30] One set of tables in Zacut's *magnum opus* may serve as an example of the extent and quality of his achievement. There is a table, described in chapter 3 of the Hebrew text and in chapter 4 of the printed Latin edition, for the daily true positions of the Moon at noon in Salamanca for each day in a cycle of 31 years beginning on March 1, 1473; this table has 11,325 entries given to minutes of arc. The cycle of 31 years is one that was discovered by Jacob Poël and used in his tables for true conjunctions and oppositions of the Sun and the Moon computed for Perpignan for a period of 31 years, beginning in 1361; Jacob Poël had fewer than 750 lunar positions to compute.[31] In his introduction Zacut credits Jacob Poël for this cycle, but the entries in Zacut's table were computed with the Alfonsine tables and, with them, a recomputation of all the entries for March 1473 shows no discrepancy greater than a minute of arc.[32] The only other table preserved in a Hebrew text comparable to Zacut's lunar table, with 11,325 entries, is found in the Vatican Hebrew manuscript that has the tables of Judah ben Asher.[33] I am not aware of such extensive tables of daily lunar positions in either Arabic or Latin.

Zacut's arrival in Portugal in 1492 did not go unnoticed by the royal court at the time when astronomical principles were being introduced into navigation, though historians may have exaggerated his role.[34] But the

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[30] Y. T. Langermann, '*Sefer Ḥuqqot Shamayim* by R. Judah ben Asher', *Kiryat Sefer* 58 (1983), 622-23 [in Hebrew]. The canons begin, 'And this belongs to Judah (...)': Vatican, Bibliotheca Apostolica, MS Heb. 384, fol. 284a. From the rest of the canons, and Zacut's references to them, it is clear that this Judah is Judah ben Asher who died in 1391, and not the son of Asher ben Yeḥiel who bore the same name and died in 1349. On the various members of this family, see A. Freimann, 'Die Ascheriden (1267-1391)', *Jahrbuch der Jüdisch-Literarischen Gesellschaft* 13 (1920), 142-254.

[31] On Jacob Poël (Jacob Bonjorn), see J. Chabás, 'The astronomical tables of Jacob ben David Bonjorn', *Archive for History of Exact Sciences* 42 (1991), 279-314; and J. Chabás, *L'astronomia de Jacob ben David Bonjorn*, Barcelona 1992. New evidence for the occurrence of this 31-year cycle in Arabic has just come to light: see J. Samsó, 'Andalusian Astronomy in 14th Century Fez: al-Zīj al-Muwāfiq of Ibn ᶜAzzūz al-Qusanṭīnī', *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften* 11 (1997), 73-110, esp. 86 ff.

[32] See J. Chabás and B. R. Goldstein 'Abraham Zacut and Iberian Astronomy in the Late fifteenth Century' [in preparation].

[33] Vatican, Bibliotheca Apostolica, MS Heb. 384, fol. 347a-359a. Unfortunately, there are no dates in this table which makes it rather difficult to recompute its entries.

[34] Cantera, *Abraham Zacut*, 33 ff. The only early Portuguese historian who mentions Zacut's role in navigation is Gaspar Correa (d. 1583?), and it is difficult to assess his reliability since he was not a direct witness to the events when Zacut was in Portugal: see J. Bensaude, *Histoire de la science nautique portugaise: résumé*, Geneva 1917, 74-78. Correa wrote his *Lendas da India* in Goa, India, between 1529 and 1561 and claims that he gathered his information from the sailors of Vasco da Gama: J. Bensaude, *L'astronomie nautique au Portugal*, Berne 1912, reprint ed. Amsterdam 1967, 133.

conditions of the Jews in Portugal quickly deteriorated, and Zacut had to emigrate to North Africa after only a few years in Portugal. Zacut composed a new set of astronomical tables when he was in North Africa and another when he reached Jerusalem. The latter tables were arranged for the Jewish calendar in contrast to his earlier tables that were arranged for the Christian calendar. In an unpublished manuscript we learn that at the age of 61, in 1513, Zacut resided in Jerusalem at the academy of Isaac Sholal, the leader (*nagid*) of the Jewish communities in Egypt and Palestine, who brought many Spanish refugee scholars to his academy. Zacut's fame is reflected in subsequent Hebrew astronomical texts such as those by Ḥayyim Vital (d. 1620), the great disciple of the mystic Isaac Luria, and Jacob Mizraḥi (Aleppo, ca. 1685).[35]

Zacut was also interested in messianic speculation, and composed a treatise in 1498 (while in North Africa) in which astrological interpretations of eclipses and planetary conjunctions were prominent. According to his theory, messianic fulfillment would begin in 5264 A.M. (= 1503/4).[36]

Conclusion

We should not be surprised that astronomical observations played only a minor role in the works of medieval Jewish astronomers, despite the great ingenuity and enormous effort displayed in them. The Alfonsine tables might seem to be an exception since we are told that the observations of eclipses motivated the renovation of previous tables. But, in fact, the eclipse tables in the Alfonsine tables were taken over without any modification from a previous set, known as the Toledan tables. It would then seem that the appeal to observations may have been a pretext to get royal support for the enterprise—there are similar cases in the Islamic world.[37] The emphasis in recent literature on observational activity is largely due to modern notions of what a scientist should do; there was no such requirement in the Middle Ages.[38] It was not easy to master the astronomical literature and to contribute

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[35] Goldstein, 'The Hebrew Astronomical Tradition'. Zacut's tables for 1501 and 1513 are only extant in fragments.

[36] M. Beit-Arié and M. Idel, 'Treatise on Eschatology and Astrology by R. Abraham Zacut', *Kiryat Sefer* 54 (1979), 174-94 [in Hebrew].

[37] A. Sayili, *The Observatory in Islam*, Ankara 1960, 204.

[38] Even when a medieval astronomer made observations, they were rarely used to modify a theory. This is the case for the eclipse observations made by Alfonso's astronomers, cited above, and those made in the fourteenth century by John of Murs: see G. Beaujouan, 'Observations et calculs astronomiques de Jean de Murs (1321-1344)', *Proceedings of the XIVth International Congress of the History of Science (Tokyo and Kyoto 1974)*, Tokyo 1975, 2:27-30 (reprinted as Essay VII in G. Beaujouan, *Par raison de nombres: L'art du calcul et les savoirs scientifiques médiévaux*, Aldershot, Hampshire, 1991). More typical is the tradition of

to it, and those who did so were generally admired. Zacut's astronomical work is, in this regard, typical, for he hardly recorded any observations in it.[39] Instead, he devoted considerable ingenuity to making his tables easier to use than those previously available. Similarly, al-Ḥadib was motivated to invent his equatorium in an effort to simplify calculations. Most medieval astronomers shared this perspective on their art although Levi ben Gerson is a major exception to this rule.[40] Moreover, astronomy was valued because it raised the prestige of Jews in the eyes of their Gentile neighbors. Indeed, the study of astronomy was not included in the ban on philosophy enacted in Barcelona in 1305.[41]

Throughout the Middle Ages the Spanish community was the model for Jewish interest in science, and its impact was felt in all parts of the Jewish world. In most cases, we can find the agent, usually a refugee from Spain, who brought scientific texts to communities that previously had little or no scientific tradition. This was true for southern France with the arrival in the twelfth century of the Tibbonids and others,[42] it was true for Sicily at the end of the fourteenth century with the arrival of al-Ḥadib, and it was true for Jerusalem in the 16th century with the arrival of Abraham Zacut. No other Jewish community was able to take on this role after the expulsion in 1492, and Jews did not participate to any great extent in the astronomical revolution from Copernicus to Newton.

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the star list compiled by Ibn al-Kammād (early twelfth century, Spain) which was integrated without any changes into a variety of subsequent texts in Arabic, Hebrew, and Latin: see B. R. Goldstein and J. Chabás, 'Ibn al-Kammād's Star List', *Centaurus* 38 (1996), 317-34; and Samsó, 'Andalusian Astronomy in 14th Century Fez', 107-10.

[39] Cantera, 'El judío salmantino Abraham Zacut', 300. Zacut observed an occulation of Spica by the Moon in 1474, but does not specify the date. Modern computation indicates that such an occultation occurred a little after 22h00 UT, 26 May 1474. [I am grateful to Dr. David Dunham for computing the conditions of this occultation]. A second observation, reported in only one extant manuscript, has recently come to light: see B. R. Goldstein and J. Chabás, 'An Occultation of Venus Observed by Abraham Zacut in 1476', in *Journal for the History of Astronomy* [in press].

[40] See B. R. Goldstein, 'The Physical Astronomy of Levi ben Gerson', *Perspectives on Science* 5 (1997), 1-30, and references in it. Levi made a large number of observations (by medieval standards), and used them to construct and modify theories. For a preliminary discussion of the theoretical and observational interests of al-Maghribī (d. 1283), one of the astronomers at the observatory at Maragha, see G. Saliba, *A History of Arabic Astronomy*, New York 1994, esp. 166 ff.

[41] Y. Baer, *A History of the Jews in Christian Spain*, 2 vols., Philadelphia 1966, 1:301 ff.

[42] Freudenthal 'Les sciences dans les communautés juives médiévales de Provence', 43 ff.

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