A Revision of the Star Tables in the Mumtaḥan Zīj[1]

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Abstract: The table of 24 stars in one of the two extant manuscripts of the *Mumtaḥan zīj* is the earliest non-Ptolemaic star table in medieval Middle Eastern astronomy. Dated to 829 AD, it is a fruit of the two systematic observational programs carried out by a group of astronomers in Baghdad and Damascus in the early ninth century. In this study, the accuracy of this table is examined, showing the existence of an obvious systematic negative error in the longitude values. The manuscripts also contain another table of 18 stars, all of which also appear in the first table, in which the longitudes are updated for 1011 AD. This table is further updated for 1231 AD in the *Īlkhānī zīj*, the official product of the observational programs in the Maragha observatory, northwestern Iran, in the 1260s, where it is ascribed to Ibn al-A'lam (d. 985 AD). In this paper, some verifiable and convincing proofs are provided for the hypothesis that the second Mumtaḥan star table is quite probably a refinement of the first table made by Ibn al-A'lam on the basis of a few stellar observations by himself dated to about 976 AD. Firm evidence for one of these observations, namely of Regulus (α Leo), is provided by his younger contemporary Ibn Yūnus (d. 1009 AD).

Keywords: Medieval Astronomy, Islamic Astronomy, Middle East, *Mumtaḥan Zīj*, Star Table, Yaḥyā b. Abī Manṣūr, Ibn al-A'lam, *Īlkhānī Zīj*, Ibn Yūnus

1. Introduction

The *Mumtaḥan zīj* (*Verified zīj*) is the official work reflecting the principal achievements of the observational programs carried out by Yaḥyā b. Abī Manṣūr, Khālid b. 'Abd al-Malik al-Marwarūdhī, Sanad b. 'Alī and 'Alī b. 'Īsā al-Ḥarranī[2] during the

1. I extend my sincerest thanks to Profs. Paul Kunitzsch (Germany), John Steele, Dennis Duke (United States of America), Benno van Dalen (Germany), and Glen Van Brummelen (Canada) for their kind help, encouragements, useful criticisms, and suggestions.

2. On the astronomers considered in this article, reliable information can be found, e.g., in *DSB*, *NDSB*, *BEA*, EI_2, Sezgin 1978, and Rosenfeld and İhsanoğlu 2003. For the Islamic astronomical

reign and on the order of al-Ma'mūn (786–833 AD, seventh ʿAbbāsid caliph from 813 to 833 AD) in the *Shammāsiyya* quarter of Baghdad and in the monastery Murrān near Damascus during 829–832 AD.[3] It has come down to us only in two manuscripts, none of which represents this work in its original form. Rather, they are mixed with later amendments, additions, and so on. These two recensions are El Escorial, MS árabe 927 (hereafter denoted by the siglum "E") and Leipzig, Universitätsbibliothek, MS Vollers 821 (afterwards indicated by "L"). Both manuscripts go back to the same recension of the *Mumtaḥan zīj* presumably compiled in the second half of the tenth century. It is of particular interest to our present study that some of Ibn al-Aʿlam's parameter values were included in both manuscripts.[4]

Concerning Ibn al-Aʿlam's contributions to medieval Islamic astronomy, it merits mentioning that although his *ʿAḍudī zīj* is now lost, a portion of its content and some of its tables are preserved in later Islamic works, from which its underlying parameters can be deduced and this work can be reconstructed to a good degree.[5] Ibn al-Aʿlam appears to be the earliest medieval astronomer who was engaged in the derivation of the fundamental parameters of the Ptolemaic planetary models. He measured new values for the eccentricity of Saturn (3;2), Jupiter (2;54),[6] and Mer-

tables mentioned in this article, see Kennedy 1956; King, Samsó, and Goldstein 2001. A new and more complete survey is in preparation by B. van Dalen.

3. On these astronomical activities, see Sayılı [1960] 1988, chapter 2, a brief summary of which is given in Charette 2006, p. 125. On the solar observations carried out in them, see Mozaffari 2013, esp. Part 1, pp. 322, 326, 327–329, Part 2, pp. 403–408. On the values measured for the obliquity of the ecliptic and the equinox times, see Bīrūnī 1967, pp. 60–64; Bīrūnī 1954–1956, Vol. 1, p. 363–364, Vol. 2, p. 640, nos. 9–13; also, Kennedy 1973, pp. 32–39. On the solar noon-altitudes, see Said and Stephenson 1995, esp. pp. 122, 125. On the instruments constructed in the two observational locations, see Bīrūnī 1954–1956, Vol. 1, p. 363, Vol. 2, pp. 637, 778; also, Mozaffari and Zotti 2015 for new light on an instrument called "circle" which was used by Yaḥyā in Baghdad. About the *Mumtaḥan zīj*, especially, see Vernet 1956 and the relevant articles collected in Kennedy 1983, and on its manuscripts, van Dalen 2004a. For its planetary latitude tables, see Viladrich 1988. Its star tables, which is the main focus of the present paper, was first edited in Vernet 1956, which is full of errors in reading the *abjad* numerals, and then in Girke 1988, which was never published; also, for the latest concluding remarks about them, see Kunitzsch 2003.

4. See van Dalen 2004a, p. 11.

5. See Kennedy 1977; Mercier 1989; see also van Dalen 2004b, esp. p. 22, n. 7.

6. Ibn al-Aʿlam's tables of the equation of centre of these two superior planets are preserved in Kamālī's *Ashrafī zīj* (written in Shiraz about the turn of the fourteenth century). The table for Saturn's equation of centre is on f. 233v in MS P and is displaced with a minimum tabular value of

cury (3;35).[7] He has also unprecedented values for the solar eccentricity and the radius of the lunar epicycle.[8]

In what follows, we will first, in section 2, introduce the two star tables preserved in the two extant manuscripts of the *Mumtaḥan zīj* and other early Islamic stellar tables that are pertinent to it (see Table 1).Then, we will address two intrinsically interconnected questions; the first is: Why have six stars in the first table of the *Mumtaḥan zīj* not been included in the second table? And the second is: Why did al-Ṭūsī and the other Maragha astronomers engaged in compiling the *Īlkhānī zīj* attribute the second star table of the *Mumtaḥan zīj* to Ibn al-A'lam? In section 3, we will analyze the Mumtaḥan star tables by recomputing the given coordinates; in section 3.1, the first question will be dealt in depth, and section 3.2 will be devoted to a quantitative analysis of the ecliptical coordinates given in these star tables. In section 4, we will discuss the second

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0;12° (for arguments 76°–81°) and a maximum value of 11;48° (for arguments 253°–258°). The table for Jupiter's equation of centre is on f. 234r in MS P and is also displaced with minimum 0;28° (for arguments 72°–78°) and maximum 11;32° (for arguments 246°–252°) (on the displaced equation tables, a term coined by the late Prof. E.S. Kennedy, see Kennedy 1977; also, see Chabás and Goldstein 2013 and the references mentioned therein). Accordingly, the maximum equations of centre of Saturn and Jupiter are derived, respectively, as 5;48° and 5;32°. The modern values for the geocentric eccentricity of the two planets in Ibn al-A'lam's time are, respectively, equal to 3;26 and 2;48 (see Mozaffari 2014a, p. 26). It should be noted that none of his values for the eccentricity of the two superior planets is more accurate than Ptolemy's. That no new table for the equation of centre of Mars is associated with Ibn al-A'lam gives the impression that he probably had not measured a new value for its eccentricity. Note that the geocentric eccentricity of Mars has nearly remained constant, about Ptolemy's value 6;0, during the past two millennia, which may explain why Ibn al-A'lam did not reach a new value for it (see Mozaffari 2014a, Figure 5 on p. 29). Ibn al-A'lam's value for the eccentricity of Saturn was used in the *zījes* of three Western Islamic astronomers (see Samsó and Millás 1998, p. 273).

7. Ibn al-A'lam's table of the equation of centre of Mercury is preserved in Kamālī's *Ashrafī Zīj*, f. 237r: the maximum equation of centre in this table is equal to 3;40° (for arguments 99°–101°). It should be noted that his value for the eccentricity of this planet is more exact than Ptolemy's values 3;0, 2;45, 2;30, as found in the *Almagest*, *Planetary Hypotheses*, and *Canobic Inscription* (*Almagest* IX.8,9: Toomer 1984, p. 459; Goldstein 1967, p. 19; Jones 2005, pp. 69, 86–87); the true value during the past two millennia has been about 3;50 (note that for the eccentricity of Mercury, we consider here half of the distance between the Earth and the center of the hypocycle in Ptolemy's complicated model for this planet, on the circumference of which the centre of its deferent revolves).

8. See Mozaffari 2013, Part 1: pp. 326, 330, Part 2: pp. 393, 397; Mozaffari 2014b, p. 105.

question, and will put forward a hypothesis which seems satisfactory to a considerable degree in order to explain why the Maragha astronomers attributed the second star table from the *Mumtaḥan zīj* to Ibn al-Aʿlam.

2. The Mumtaḥan star tables

Two star tables are explicitly associated with the *Mumtaḥan zīj* (Table 1).[9] The first and, in all likelihood, original table contains ecliptical coordinates of 24 stars together with their declinations and degrees of transit (i.e., the points on the ecliptic that transit the meridian simultaneously with the stars). The longitudes are for (presumably, the beginning of) the year 214 Hijra (hereafter H), whose beginning was 18 Bahman (the 11th Persian month) 197 Yazdigird (Y) or 11 March 829.[10] The stars are arranged in the order of increasing longitude, except for α Aur (no. 10) and α Cen (no. 24). This table can only be found in MS E. In its heading, we are told that the ecliptical coordinates are according to both the *Shammāsī* and Damascene observations. In the second table, the ecliptical coordinates of 18 out of these stars are listed for the year 380 Y (whose beginning was 14 March 1011). These are accompanied by their declinations, transit degrees, their half diurnal arcs and the versed sines of these arcs, their meridian altitudes and the sines of these altitudes, and the longitudes of the points on the ecliptic which rise simultaneously with these stars and the oblique ascensions of these longitudes.[11] The longitudes in the second table were updated from the first table by adding an increment of 2;36°, which seems to be the result of adopting the value ψ = 1°/70 Persian years for the rate of precession ((380 – 198)/70 = 2;36°).[12] There are four exceptions, namely θ Eri, α CMa, α Aql, and β Peg (nos. 1, 11, 20, 23, denoted by asterisks in

9. See van Dalen 2004a, pp. 27–28.

10. *Mumtaḥan zīj*, E: p. 188.

11. *Mumtaḥan zīj*, E: pp. 189–190 and L: ff. 31v, 153r. The values for the declination, degree of transit, and right ascensions of some of the stars in the *Mumtaḥan zīj* have been published and discussed in connection with a treatise by Ḥabash on the Universal Plate in Charette and Schmidl 2001, pp. 139–140, 143–144; albeit, no attempt was made there to identify the stars, and nothing was said about the severe difficulties with their identifications, which we shall address presently. See also King 2004–2005, Vol. 1, pp. 143–144.

12. Note that the annual precessional motion in the *Mumtaḥan zīj* (E: p. 187) is equal to 0;0,54,44,20° per *Arabic* year, which is approximately equal to 1° in 66 *Arabic* (*not* Persian) years. On the probable Indian origin of this value, see Pingree 1964, p. 138; 1972, p. 29; 1976, p. 113.

Table 1, Col. V), for which the differences in longitude are larger than 2;36°. No plausible scribal errors in the *abjad* numerals can be suggested in order to account for these deviations. The other difference between the two tables is in the order of the stars: in the first table, θ Eri appears in the first row, but in the second, in the very last row; moreover, in the second, α Ori (no. 9) comes before β Ori (no. 7).

The *Īlkhānī zīj*, written and compiled by Naṣīr al-Dīn al-Ṭūsī and his team at the Maragha observatory (northwestern Iran, *ca.* 1260–1320 AD), includes a comparative star table with ecliptical coordinates according to Ptolemy, Ibn al-A'lam, and Ibn Yūnus for the same 18 bright stars found in the second *Mumtaḥan* table as well as the ecliptical coordinates of 16 stars (the same 18 stars except for θ Eri and β Per) observed by the Maragha astronomers in the 1260s. The epoch of longitudes in this table is the beginning of 601 Y (18 January 1232), i.e. about thirty years before the founding of the Maragha observatory.[13] The columns ascribed to Ibn al-A'lam in this table in fact go back substantially to the *Mumtaḥan*

13. *Īlkhānī zīj*, P: f. 56v, T: f. 100r, M1: f. 100v, M2: f. 86v, C: p. 195. The comparative star table in the *Īlkhānī zīj* was first brought to light in the early modern period, more than three centuries ago, by Edward Bernard in the *Philosophical Transactions of the Royal Society*; see Bernard 1684, p. 571. This article reflects a peculiarity of the time when astronomical data from preceding centuries were not regarded as purely historical materials, but as part of the scientific literature of the day. Bernard apparently made use of some manuscripts of the *Īlkhānī zīj* preserved in Oxford. The epochs Bernard takes for the star tables of Ibn al-A'lam, Ibn Yūnus, and al-Ṭūsī (respectively, 980, 996, and 1233 AD) are all erroneous, but his reading of the *abjad* numerals are notably precise. This work was followed by Knobel 1875–1877, pp. 8–9, 11, 21–22. An excerpt of the comparative star table of the *Īlkhānī zīj* was published by the late Prof. E.S. Kennedy (1956, p. 170, although with a few mistakes; e.g., the coordinates for θ Eri associated with the Maragha astronomers are in fact for β Cas). It should be noted that the longitudes in the column devoted to Ptolemy in the comparative star table of the *Īlkhānī zīj* were updated from the *Almagest* star catalogue by adding a precessional motion of 16;45°, which is in agreement with a precessional rate of 1°/66 Egyptian/Persian years. Ibn Yūnus's star table is not contained in the extant manuscripts of his *Ḥākimī zīj*, but has been preserved in the Cairo manuscript of Muḥyī al-Dīn al-Maghribī's first *zīj* written at Maragha, the *'Umdat al-ḥāsib* (M: f. 142v; an excerpt of this table was published in King 2004–2005, Vol. 1, p. 31), and in Abu'l-'Uqūl's *Mukhtār zīj* (L: ff. 92v–93r), written in Yemen *ca.* 1300 AD (on Abu'l-'Uqūl, see King 2004–2005, Vol. 1, *passim*). These preserved tables include the ecliptical coordinates of, respectively, 59 and 62 stars for the end of 400 Y (7 March 1032). Ibn Yūnus's longitudes of the 18 stars were converted to the epoch of the *Īlkhānī zīj* by adding an increment of 2;51°, which is again in conformity with a precessional rate of $1°/70^{y}$ ((601–401)/70 ≈ 2;51°). A detailed analysis of Ibn Yūnus's star table is in preparation by the present author. The comparative star table of the *Īlkhānī zīj* is discussed in detail in Mozaffari 2016.

tradition, because the ecliptical coordinates of the 18 stars were evidently derived from the second star table in the *Mumtaḥan zīj*. The differences in longitude between the two amounts to 3;9°, which is again consistent with the rate of precession $\psi = 1°/70^y$ ((601–380)/70 = 3;9,26° ≈ 3;9°).

Consider Table 1: In the case of four stars (nos. 1, 18, 21, and 24), the latitudes are equal to Ptolemy's values. Surprisingly, for two of these (nos. 21 and 24, which have not been included in the second table), the longitudes appear to have been updated from the *Almagest* by adding a precessional value of 10;15°. This impression is enhanced by inspecting al-Farghānī's and Ḥabash's star tables (see below and Table 1), which are based on the first Mumtaḥan star table. Another scribal error can be detected in the latitude of α CrB (no. 16) in the first table (which has not been included in the second table either), where +45;6° should be replaced by +44;6°, because it can be found in both al-Farghānī's and Ḥabash's tables, as well as being consistent with the values given for the declination and degree of transit of this star (see Table 2).

The latitudes in the two tables are in agreement with each other, except in two cases: for Rasalhague (α Oph; no. 18), the first table has +35;0°, but the second gives +36;0° (the first value seems a scribal error). And for Altair (α Aql; no. 20), the first table has +29;12° but the second gives +29;14°, which is quite probably a simple scribal error that can also be found in the columns ascribed to Ibn al-A'lam in the comparative star table in the *Īlkhānī zīj*.

As shown in Table 1, the first Mumtaḥan star table was commonly adapted in later works connected to the Baghdad astronomical circle in the early Islamic period and thereafter.[14] For instance, in his work on the astrolabe, *al-Kāmil fī ṣan'at al-aṣṭurlāb* (*The Complete Work on the Fabrication of the Astrolabe*), al-Farghānī in-

14. The Mumtaḥan table has also exercised some influence on Byzantine and late medieval European sources; e.g., in a Greek MS preserved in the Vatican library as Vat. Gr. 1056, which is a copy of a twelfth-century codex, there are some star tables which have been updated from the Mumtaḥan table: the table on ff. 30v/continued on 33r contains 29 stars whose longitudes for 1155–6 AD are 5° larger than those in the *Mumtaḥan zīj* and whose latitudes are the same. The table on f. 31r is for 1160–61 AD with the longitudes in the previous table augmented by 0;5°; we are told that this is taken from the three sources Χεκέμ (obviously Ibn Yūnus's *Ḥākimī zīj*; however, in reality, the table has nothing to do with Ibn Yūnus's own non-Ptolemaic star table), Κουσιάϱ (Kūshyār b. Labbān), and the Egyptians. The adopted rate of precession is the Mumtaḥan value $1°/66^y$. See Pingree 1964, pp. 138–139; Kunitzsch 1970 (I thank Prof. Kunitzsch for bringing this to my attention and supplying me with plenty of useful notes).

cludes a table of 25 stars, 23 of which are also included in the first Mumtaḥan star table.[15] He excludes *al-nāṭiḥ* (α Ari; no. 3) and, instead, adds *'urqūb al-rāmī* (β Sgr; no. 25) and *suhayl* (α Car; no. 26). For 20 stars, he adds 0;15° to the longitudes in the first Mumtaḥan table in order to update it for the beginning of 225 Y (i.e.,11 Dhi'l-ḥijja 241 H or 21 April 856), but for θ Eri, α PsA, α Cen and β Sgr, he rather adds 11;12° to Ptolemy's values. For the longitude of α Car, he has 89;15°, 12;45° more than the value given in the *Almagest* star catalogue.

The same 24 stars of the first star table in the *Mumtaḥan zīj* appear in MS Istanbul, Yeni Cami, no. 784/2 of Ḥabash al-Ḥāsib's *Zīj al-Dimashqī*.[16] In MS Berlin, Ahlwardt, no. 5750 of Ḥabash's *Zīj* (which is an amalgam of later recensions and dates to *ca*. 1300 AD), like al-Farghānī's table, *al-nāṭiḥ* (α Ari; no. 3) has been excluded, and the two stars β Sgr (no. 25) and α Car (no. 26) have been added. In other words, this table includes all 25 stars from al-Farghānī's table. Five further stars are appended to this table; four of these are new, but α Cyg is repeated under its alternative name, i.e., *dhanab al-dajāja*, "bird's tail" (nos. 22 and 29).[17] The longitudes were updated for the year 304 H (whose beginning was 1 Tīr, the fourth Persian month, 285 Y or 5 July 916) by adding 1;17° to the Mumtaḥan longitudes, or 1;2° to al-Farghānī's ones. Of course, it can be clearly seen that the compiler of this table had access to and, indeed, made use of both the first Mumtaḥan star table and al-Farghānī's one for the following reasons. On the one hand, for three of the four stars whose longitudes in al-Farghānī's table were updated from the *Almagest* (i.e., θ Eri, α Cen and β Sgr), the author of the star table surviving in Ḥabash's *zīj* updated the longitudes from the *Almagest* by adding 12;14° (i.e., 1;2° more than al-Farghānī's

15. The table has been edited first in Destombes 1958, p. 309, and then in Lorch 2005, pp. 125–127. It is worth noting that in his 400-chapter *Kitāb al-'Amal bi'l-asṭurlāb* (*Book on the Use of the Astrolabe*), al-Ṣūfī makes use of al-Farghānī's star table, although with a new set of values for the latitudes of the 24 stars, which are neither identical with those in the *Almagest*, nor with those in the first Mumtaḥan star table (al-Ṣūfī 1995, pp. 121–123, which is transcribed from MS Istanbul, Topkapı Sarayı, Ahmet III, no. 3509, dated to the 13th century; Kunitzsch 1990, pp. 156–157, 162–166). It should be noted that these latitude values are erroneous to a degree that makes it improbable that they are related to new observations; rather, it seems that what has come down to us is nothing more than *abjad* numerals badly distorted in the process of copying and transmission.

16. See Debarnot 1987, pp. 56–57.

17. Ḥabash, B: ff. 62r–v. See King 2004–2005, Vol. 1, pp. 142–143 for other functions of spherical astronomy embedded in this table; the only two differences with respect to the first Mumtaḥan star table are the addition of the right ascensions of transit degrees and the cosines of the declination; Kunitzsch 2003, p. 348.

value), but for α PsA, he added 1;17° to the Mumtaḥan longitude; as a result, the longitude of this star is only 0;20° more than that in al-Farghānī's table. On the other hand, for α Car, which is not included in the Mumtaḥan star tables, the author of the star table extant in Ḥabash's *zīj* simply added 1;2° to the corresponding value in al-Farghānī's table. There are five cases of deviation from either the increment 1;17° or 1;2° (nos. 10, 12, 13, 25, and 26); of course, these are trivial, and may quite probably be considered scribal errors in the alphanumerics (see apparatus to Table 1). For the five additional stars (nos. 27–31), the differences in longitude between the star table in Ḥabash's *zīj* and the corresponding values in the *Almagest* star catalogue run from 11;44° to 12;27°. Therefore, it can be said that al-Farghānī's and the early tenth century star table embedded in Ḥabash's *Zīj* overall contain six stars (nos. 26–31) whose longitudes show a clear relation neither to the Mumtaḥan table, nor to the *Almagest* star catalogue. It is hard to judge whether these longitudes were the results of new observations, since the latitudes of these added stars in both al-Farghānī and Ḥabash's tables were entirely borrowed from Ptolemy's star catalogue.

Al-Farghānī's increment of 0;15° for updating the Mumtaḥan star table is simply the result of applying the Ptolemaic value ψ = 1°/100 Persian years for the rate of precession to the time interval of 225 – 200 = 25 years between his and the Mumtaḥan star table.[18] Al-Farghānī claims that he reached this value by means of an observation of *al-'ayyūq* (Capella, α Aur) in 225 Y (856–7 AD). In that year, he measured the longitude of this star as 65;20° and then compared it with the corresponding value in the first Mumtaḥan star table ((65;20°–65;5°)/25 = 1°/100^{y}).[19] Al-Farghānī's value for the longitude of Capella is in error by about –0;35°, which is tolerable within its context, especially, with regard to the mean absolute error of 0;37° in the longitudes in the first Mumtaḥan star table, as we shall see later (the longitude of Capella in the first Mumtaḥan star table is in error by –0;27°; see Table 2).

There is a severe difficulty with the value of 1;17° that the author of the star table in Ḥabash's *Zīj* utilized for the longitudinal increment between 214 H and 304 H, because it is only in accordance with a rate of precession ψ = 1°/70 *Arabic* years.[20] For the three stars related to the *Almagest* star catalogue (i.e.,

18. In this way, he has committed an error in considering the era of the Mumtaḥan table as 200 Y, instead of 198 Y, for which the increment would be slightly over 0;16°.

19. Lorch 2005, pp. 12–13.

20. However, in MS B of Ḥabash's *Zīj*, the annual rate of precession is given as 0;0,52,56° (Ḥabash, B: f. 28v) which is equal to 1° in 68 Arabic (or 66 Persian) years. In MS Istanbul, the rate

nos. 1, 24, and 25) as well as for α Car (no. 26), he unreasonably applied the difference between his and al-Farghānī's values for the longitudinal increment after the epoch of the first Mumtaḥan star table (i.e., 1;17° – 0;15° = 1;2°) to the longitudes in al-Farghānī's star table. In other words, it can be said that according to the author of the star table preserved in Ḥabash's *zīj*, all of the stars, except for α PsA, traveled over one degree in $60^1/_4$ Persian years or about 62 Arabic years after the epoch of al-Farghānī's table; such a strange result is, indeed, the consequence of working with a mélange of the traditions of stellar astronomy (Ptolemaic and Mumtaḥan) and various values for the rate of precession ($1°/70^y$ and $1°/100^y$).

As noted earlier, in the column for Ibn al-A'lam in the comparative star table in the *Īlkhānī zīj*, the ecliptical coordinates of the 18 stars were derived from the second star table of the *Mumtaḥan zīj* by adding a value of 3;9° to their longitudes. The only difference between the *Īlkhānī zīj* and the second star table of the *Mumtaḥan zīj* is that the former tabulates the value –39;4° for the latitude of Sirius (α CMa) for Ibn al-A'lam, whereas both star tables of the *Mumtaḥan zīj* have –39;20°. A possible explanation for this difference is the plausible scribal confusion of the *abjad* numerals 20 ک and 4 د. Since this error is found in all manuscripts of the *Īlkhānī zīj* that I consulted, it appears to have taken place at the time of compilation of this *zīj*, due to miscopying or a faulty prototype.

3. An analysis of the Mumtaḥan star tables

In Table 2, we compare the values for the latitude, longitude, declination, and transit degree of the 24 stars in the first Mumtaḥan star table with the recomputed values for the declination and transit degree given within brackets as well

of precession is the same as in the *Mumtaḥan zīj*; see note 12, above (Debarnot 1987, p. 57). But, according to Ibn Yūnus' account, the value 1° in 70 *Persian* years appeared in Ḥabash's *zīj*, which is in agreement with what Ibn al-A'lam found later (L: pp. 107–108; Caussin, pp. 151, 155). I have no explanation for this mélange of values for the rate of precession associated with Ḥabash other than assuming that one applied incorrectly the rate of 1° in 70 *Persian* years to the time interval of 90 *Arabic* years between 304 and 214 H. Also, note that the year 304 can by no means be assumed to be in the Yazdigird era, simply because the interval of 304 – 198 = 106 years cannot be put in relation to the increment of 1;7° by applying any of the three abovementioned values for the rate of precession.

as with the true modern values for the latitude, longitude, and declination at the time indicated in bold case.[21] The values for the declination and degree of transit allow us to control the ecliptical coordinates and to identify some further scribal errors in the *abjad* numerals, which are mentioned in the apparatus of Table 2.

As stated earlier, an important question we are here confronted with is why al-Ṭūsī and the other Maragha astronomers engaged in compiling the *Īlkhānī zīj* attributed the second star table of the *Mumtaḥan zīj* to Ibn al-Aʿlam. In my opinion, the answer to this possibly very complicated question cannot be addressed until another question has been settled properly: Why have six stars in the first table of the *Mumtaḥan zīj* not been included in its second table? In order to investigate this question, it will be useful to take a deeper look at the ecliptical coordinates of the 24 stars in the first star table of the *Mumtaḥan zīj*.

3.1. The six problematic stars

A closer inspection reveals that five of the six stars that have not been included in the second Mumtaḥan star table cannot be readily identified due to confusion in their names, their coordinates, or both of them together, as shall be scrutinized in detail below. We treat each case separately (see Tables 1 and 2):

No. 3. The name *al-nāṭiḥ* refers to α Ari. The longitude 22;40° for this star as given in the first Mumtaḥan table is in relatively fair agreement with the corresponding true modern value for the longitude of α Ari at the time, but the value +22;0° for its latitude is severely in error, because a latitude of 22;0° and a longitude of 22;40° point to a "vacant" place (to an unaided eye) in the constellation Andromeda. Furthermore, neither the declination nor the degree of transit of this star recomputed from its tabulated ecliptical coordinates is in agreement with those in the table. It is noteworthy that, for example, a change of this star's latitude to 9;50° (i.e., assuming a scribal error 9;50 ط ن → 22;0 0 كب) produces exactly the tabular value for the declination, but not a value for the transit degree in fair agreement with the tabulated one. It might have

21. For the recomputation, we used the value 23;35° for the obliquity of the ecliptic, which is the upper limit of the values for the obliquity of the ecliptic observed in the Ma'mūnic observations.

been for these difficulties that this star is absent from all the other star tables based upon the first Mumtaḥan star table.

No. 5. According to the Arabic folk star nomenclature, *kaff al-jadhmā'* is identical with α Cet, a southern star. However, all coordinates for this star in the table are in fair agreement with α Per. In his *Kitāb Ṣuwar al-kawākib al-thābita* (*Book On the constellations of the fixed stars*), al-Ṣūfī attributes this confusion to the "authors of the *zījes*".[22]

No. 8. The name *al-nathra* was used for M44, an open cluster in the constellation Cancer with a slight northern latitude of about 1.5°. But, the ecliptical coordinates that the *Mumtaḥan zīj* gives for no. 8 are evidently *not* for *al-nathra*, but for one of the three stars on the belt of Orion. Significantly, this is corrected in al-Farghānī and Ḥabash's tables, where *al-nathra* is replaced by *surrat al-jawzā'*, the "navel/middle of Orion", i.e., ε Ori, which is referred to in Ptolemy and al-Ṣūfī's works as the "middle of the three stars on the [Orion's] belt".[23]

No. 21. The latitude of α PsA in the first Mumtaḥan star table is equal to Ptolemy's, which is in error by more than 2°. Moreover, that the longitude of this star in al-Farghānī's table, as already stated, appears to have been directly updated from the *Almagest* gives a strong impression that its longitude in the first Mumtaḥan table might also have been based upon Ptolemy's value. However, it should be mentioned that the longitudinal difference of 10;15° between the two is equal to the corresponding difference in the longitude for α Tau (no. 6), while the formal value for the precessional increment of the stellar longitudes in the interval of time between Ptolemy and the *Mumtaḥan zīj* was taken equal to the longitudinal difference for α Leo (i.e., 10;30°).[24] Moreover, both tabulated values for the declination and degree of transit are severely in error in comparison with those recomputed from the tabular

22. AL-ṢŪFĪ 1954, p. 260; AL-ṬŪSĪ's translation, p. 235; see also KUNITZSCH 1970, p. 286. This can also be found in Ibn Yūnus's star table, where the coordinates λ = 48;33° and β = 30;0°, indeed, point to α Per (true values at the time: 48;37° and +30;1°). See AL-MAGHRIBĪ, *'Umdat*, M: fol. 142v; ABU'L-'UQŪL, L: f. 92v.

23. AL-ṢŪFĪ 1954, pp. 267/272; AL-ṬŪSĪ's translation, pp. 241/245; see also KUNITZSCH 1970, p. 287. The name *surrat al-jawzā'* can also be found in Ibn Yūnus's star table, where the coordinates λ = 69;43° and β = –24;25° for 1032 AD are indeed for ε Ori (true values at the time: 69;58° and –24;38°).

24. See also DEBARNOT 1987, p. 57.

values for this star's ecliptical coordinates; the declination value of 13;0° 0 يج may be assumed (of course, very unlikely) a scribal error for 37;30 لز ل, but even so, a large deviation of 7;42° in the degree of transit of this star is severely incompatible with other values in the tables, and so remains inexplicable.[25]

No. 24. This star is not correctly included in the Mumtaḥan table by increasing longitude, since the table evidently lists the stars in the order of increasing longitude; nevertheless, it also occupies the same position in both copies of Ḥabash's *Zīj* as well as in al-Farghānī's table. Its name refers to α Cen. All the star tables of the Mumtaḥan astronomers, al-Farghānī, and Ḥabash, suffer from a common scribal error in the *Almagest* tradition, where the number of the zodiacal sign of the longitude of this star was wrongly written down as 6, instead of 7 (6s 8;20°, instead of 7s 8;20°, ز →و).[26]. Moreover, with a true declination of about –55.5° at the time of the Mumtaḥan observations, the star culminated in Baghdad at an altitude of slightly more than 1°, and in Damascus at an altitude of less than 1°.[27] It is then obvious that al-Mamūnic astronomers could not actually observe this star, but had to update its longitude from the *Almagest*. This was already noticed by al-Ṣūfī; in the prologue of his *magnum opus*, he notices the scribal error in some copies of the *Almagest*, adds his precessional increment of 12;42° to Ptolemy's *correct* value 7s 8;20 = 218;30° for the longitude of this star, and set forth his quite probably sound impression that the Mumtaḥan astronomers had added 10;15° to the incorrect value 6s 8;20° = 188;20° for the longitude of α Cen.[28] Therefore, similar to no. 21, all information at our disposal reinforces the idea that the longitude of this star was updated from the *Almagest*. As can be seen in Tables 1 and 2, the value for the latitude of this star is also given for its declination; even more surprisingly, the value 199;32° for the degree of transit of this star is equal to the value al-Farghānī gives for its longitude,[29] which does not seem to be a

25. Cf. Charette and Schmidl 2001, p. 143.

26. See Lorch 2005, p. 129, and the references mentioned therein.

27. al-Ṣūfī (1954, p. 329; al-Ṭūsī's translation, p. 296), mentions that in all places, the altitude of the star is less than that of *Suhayl* (α Car, with a declination of –52.5° at the time).

28. al-Ṣūfī 1954, pp. 6–7; al-Ṭūsī's translation, p. 7. It is then curious that this error can also be found in al-Ṭūsī's *Taḥrīr al-majisṭī* (*Exposition of the* Almagest), P1: p. 262, P2: f. 77v, P3: f. 100v, B: f. 105r.

29. This has already been noted in Lorch 2005, p. 129.

simple coincidence, since this value differs by more than 23° from the degree of transit recomputed from its ecliptical coordinates. I cannot currently explain how this value entered from al-Farghānī's to the Mumtaḥan star table.

In the case of no. 16, the difficulty is not as severe as the above five cases, and so this star can safely be taken to be α CrB. However, it is evident that the author of the supposed second star table of the *Mumtaḥan zīj* used the erroneous value +45;6° (rather than the correct +44;6°) for the latitude of this star. The latter, and correct, value for the latitude results very closely in the tabular values for the declination (i.e., +31;5°) and degree of transit (i.e., 223;4°), as indicated in Table 2. But, the former, and incorrect, value results in the value +31;58° for the declination and 223;36° for the degree of transit. Therefore, it is quite probable that the author of the second Mumtaḥan star table recognized some difficulties here, which are merely arising from a simple scribal error in the *abjad* numeral for the latitude of this star, as noticed in the apparatus to Table 1.

Besides the six problematic stars discussed above, there is a difficulty with θ Eri (no. 1), whose longitude is approximately as erroneous as Ptolemy's (+3;24°, comparable with Ptolemy's error of +3;5°), and whose latitude is also equal to that in the *Almagest*. One may thus have some qualms about whether the Mumtaḥan astronomers actually observed this star. Rather, it seems that the longitude of this star is related, in one way or another, to Ptolemy. The fact that for the longitude of this star, both al-Farghānī's table and that in Ḥabash's *Zīj* are overtly dependent upon the *Almagest* weighs this possibility. However, it deserves noting that if the difference of 10;30° in longitude of α Leo between the Mumtaḥan table and the *Almagest* star catalogue was used as the precessional increment in order to update the longitude of θ Eri from the *Almagest* star catalogue, its longitude for 214 H would amount to 10;40°, and if the corresponding difference of 10;15° in longitude of α Tau was employed for this purpose, its longitude would be equal to 10;25°; none of them is in accordance with the tabular value for the longitude of θ Eri.

3.2. Errors in the stellar coordinates

Excluding the six problematic stars, the mean absolute error in the latitude of the remaining 18 stars is about 13.2′ (Ptolemy: 18.5′). As we have seen in the preceding section, the six problematic stars may be reliably identified by recomputing their declinations and degrees of transit as given in the Mumtaḥan table and correcting several large scribal errors. We exclude two remaining outliers in the latitude values (i.e., nos. 21 and 24). With the four additional stars, the average error in the absolute latitude values amounts to about 13.0′ (Ptolemy: 15.9′). The maximum error is found for α Ori (–34′) and the minimum deviation for α Aur, α CMa, and α Sco (only ± 1′). The errors are randomly distributed, and no special pattern in them can be detected (see Figure 1).

Also in our examination of the accuracy of the longitudes of the Mumtaḥan stars, only two of 24 stars, i.e., θ Eri (no. 1) and α Cen (no. 24) should be excluded for two obvious reasons: these stars′ longitudes have unusually large errors, and, as mentioned earlier, there is reasonable uncertainty about whether they were actually observed in al-Ma’mūnic astronomical programs. The mean absolute error in the longitudes of the remaining 22 stars is about 36.9′ (Ptolemy: 69.5′) and in those of 17 stars common in both Mumtaḥan tables (excluding θ Eri) is 38.5′. The smallest error is found for α Lyr (only +2′), and the maximum error for β Ori and α Aql (~ –1°). A noteworthy characteristic of the table is the existence of a systematic error in the longitudes, because only the error in the longitude of α Lyr is *positive*, while all other errors are *negative*, falling in the range from –0.5° to –1°, with only two exceptions, α CMa and α PsA, with errors of, respectively, –8′ and –10′. The errors are exhibited in Figure 2.

Finally, it may be mentioned that the Mumtaḥan astronomers accomplished the computation of the declinations and degrees of transit in their star table with a good accuracy, except for some of the six problematic stars (nos. 3, 21, 24).

4. The relation between the second Mumtaḥan star table and Ibn al-A‘lam

Now, we are at a rather secure position to examine our main problem and work out a hypothesis about the reason behind the attribution of the second table to Ibn al-A‘lam by the Maragha astronomers. The considerations set forth in section 3.1 could by no means remain hidden to the eyes of a competent astronomer having a sufficient knowledge of the bright stars which were continuously in use in his everyday professional life (e.g., in timekeeping). As we have seen in section 2, al-Farghānī and the anonymous updater of the first Mumtaḥan star table in the early tenth century as incorporated in the recension of Ḥabash’s *zīj* recognized the problem with the identification of star no. 8 in the first Mumtaḥan table. A while after the middle of this century, due to al-Ṣūfī's elaborate work on the fixed stars, the misunderstandings in the identification of the stars —which were mainly owing to the mixture of the pagan Arabs' folk star lore and Ptolemy's astronomical tradition— had been resolved to the degree that a comprehensive knowledge of these two distinctive systems had been acquired.[30] There can be little doubt that since then, every skilful learned astronomer could easily distinguish the glaring errors and cases of confusion in the Mumtaḥan star table, and so could decide to discard the six problematic stars in this table and keep the rest. Accordingly, it is not unlikely that the second Mumtaḥan star table is a contribution made by Ibn al-A'lam, as we are told in the *Īlkhānī zīj*.

The further evidence supporting this hypothesis is as follows:

(i) As the comprehensive study of B. van Dalen shows, both recensions of the *Mumtaḥan zīj* that have come down to us are inextricably entwined with materials obviously related to Ibn al-A'lam.[31]

(ii) Through Ibn Yūnus's report of Ibn al-A'lam's observation of Regulus in 365 H/344–5 Y/ 975–6 AD,[32] we know that the latter found a value of 135;6° for the longitude of this star (the true value at the time is about 135;37°). Comparing this with the longitude of 133;0° for 198 Y in the *Mumtaḥan zīj* results exactly in the value 1° in 70 Persian years for the rate of precession: (135;6–133;0)/(345–198) = $0;0,51,26^{\circ/y} = 1^{\circ}/70^{y}$, which Ibn Yūnus credits to Ibn al-A'lam (note that Ibn Yūnus thought that this value was originally used by Ḥabash and then also by Ibn al-A'lam).[33] It should be noted that the value

30. It is worth noting on the side how difficult the identification of the stars must have been to the early Islamic astronomers; this can evidentially be seen in al-Ṣūfī's 400-chapter book on the application of the astrolabe (see note 15, above), a work written in the earliest stage of the author's scholarly career, when he had not yet acquired a sufficient knowledge of the fixed stars (according to KUNITZSCH 1990, pp. 155–156). For example, al-Ṣūfī mentions the meridian altitude of α Cen (no. 24 in Table 1), one of our six problematic stars, as 10° in his birthplace Rayy (a city just to the south of modern Tehran; latitude ~ 35.5°), while with a declination of ~ –56° at the time it was permanently invisible in this city (AL-ṢŪFĪ 1995, p. 347; KUNITZSCH 1990, p. 165).

31. See van Dalen 2004a, *passim*.

32. IBN YŪNUS, *Zīj*, L: pp. 106–108; CAUSSIN 1804, pp. 143–155. Ibn Yūnus gives there an invaluable, detailed list of the observations of Regulus by his Islamic predecessors in order to derive the constant of precession.

33. Yet in HARTNER 1955, p. 134, and even later in GRASSHOFF 1990, p. 20, the precessional rate $\psi = 1^{\circ}/70^{y}$ is exclusively attributed to al-Ṭūsī. As noted earlier, Ibn Yūnus's attribution of this value to Ḥabash cannot be verified with regard to the extant manuscripts of his *Zīj* (see note 20, above).

135;6° for the longitude of Regulus is exactly equal to the value in the second star table reduced to Ibn al-A'lam's time by taking the precessional rate ψ = 1°/70^y, because 135;36° – (380 – 345)/70 ≡ 135;6°. Ibn al-A'lam might then have prepared his star table for 345 Y, 380 Y, or any other date simply by adding the increment computed on the basis of ψ = 1°/70^y to the longitudes in the Mumtaḥan star table. This was a routine operation in compiling star tables in *zījes*; for instance, al-Battānī and Muḥyī al-Dīn al-Maghribī derived the value 1° in 66 Persian years for the rate of precession on the basis of their own observations, and then applied it to a number of the stars in the *Almagest* catalogue in order to convert their longitudes to their own times.[34]

(iii) As we have seen, the difference in the longitudes of the four stars θ Eri, α CMa, α Aql, and β Peg (nos. 1, 11, 20, 23) are not in agreement with the increment of 2;36° between the two Mumtaḥan star tables. The differences run from +0;5° (in the case of α CMa) to +0;55° (in the case of α Aql). None of them, as noted earlier, can be explained as a probable scribal mistake in the *abjad* numerals. The question we are here confronted with is: Who was responsible for the observation of these stars about the turn of the eleventh century? Let us examine the errors in the longitudes in the second star table, especially by considering the "new" values for these four stars. The longitude values for Ibn al-A'lam's time can be derived from the second Mumtaḥan star table simply by subtracting 0;30° from its longitudes (note that the epoch of the second table, 380 Y, is 35 years ahead of the time of Ibn al-A'lam's observation of Regulus, and thus 35/70 = 0.5°). In the case of the abovementioned fours stars, we also convert their longitudes from the first table by simply adding 2;6°. The results are compared with the true modern values at the time. For the four stars, we have:

	I	*II*	*III*	*Differences*	
	1st Table + 2;6°	*2nd Table – 0;30°*	*Modern value for 976 AD*	*I – III*	*II – III*
θ Eri	12;16°	13; 3°	8;50°	+3;26°	+4;13°
α CMa	89;56	90; 1	89;59	–0; 3	+0; 2
α Aql	286;24	287;19	287;21	–0;57	–0; 2
β Peg	344;26	344;35	345; 6	–0;40	–0;31

34. *Zīj al-Ṣābi'*, chapter 51: Nallino [1899–1907] 1969, Vol. 3, pp. 187–190.

It is significant that the longitude of α Aql in the first Mumtaḥan star table suffers from a large error of about –1°, but in the new value in the second table, the error is almost zero. As we have seen earlier, θ Eri is a problematic star in early Islamic star tables and its longitude was usually updated directly from the *Almagest* (Table 1). Moreover, this star does not come in the second Mumtaḥan table in the order of increasing longitude, but appears in the very last row; consequently, it might very well be considered a later addition. In any event, the much too large longitude 13;33° in the second Mumtaḥan star table appears to have been updated from the *Almagest* star catalogue by taking the precessional rate $\psi = 1°/66^{y}$.[35]

We illustrate the errors in the second star table reduced to Ibn al-A'lam's time along with those in the first table (for 829 AD) in Figure 3, respectively by the solid and hollow circles (the outlying value for θ Eri is excluded). The numbers along the horizontal axis are those assigned to the stars in Tables 1 and 2, i.e. basically in the order of increasing longitudes. The mean absolute error in the longitude of the 17 stars in the second table is 30.7′, which is about 8′ less than the mean absolute error in the longitudes of the same stars in the first table.

Although possibly not conclusive, the combined evidence enhances the belief that the second star table preserved in the extant recensions of the *Mumtaḥan zīj*, is, in fact, Ibn al-A'lam's star list, as we are told in the *Īlkhānī zīj*. A probable scenario is that Ibn al-A'lam polished the Mumtaḥan star table by (1) removing the six unidentifiable, disputable stars in it, as explained earlier, (2) observing the longitudes of the three stars α CMa, α Aql, and β Peg anew, and (3) adding an increment computed from his own value 1° in 70 Persian years for the constant of precession to the longitudes of the remaining 14 stars. It should be emphasized that Ibn al-A'lam did not detect the fact that the updated longitudes were less than the true values for his time. Of course, this does not come as a surprise, since his observed values for the longitudes of α Leo and β Peg suffer from an error of –0;31° as well. According to Ibn Yūnus's account, Ibn al-A'lam derived his value $1°/70^{y}$ for the rate of precession by comparing his observation(s) of Regulus dated to 976 AD and the longitude of this star in the *Mumtaḥan zīj*. The above argument shows that this may indeed have

35. The time interval between the *Almagest* star catalogue, 885 Nabonassar, and 380 Y/ 1759 Nabonassar equals 874 years, and thus the increment of the longitude amounts to about 13;15°, which added to the Ptolemaic longitude of 0;10° yields 13;25°, which is not far from the value 13;33° in the second Mumtaḥan star table.

happened, although its verification requires Ibn al-A'lam's original *zīj* to be found, a work which has long been lost with seemingly no hope to discover its original.[36]

It merits here to marginally mention a note about Ibn al-A'lam's measurement of the rate of precession. We have seen above how Ibn al-A'lam reached his own figure of 1°/70^y. His value for the longitude of Regulus is in error by about –0;31° and that in the first Mumtaḥan star table (Table 2, no. 13) is –0;35° off. This relatively small difference of +0;4°is principally responsible for Ibn al-A'lam's derivation of a slightly larger value, 1°/70^y, than the true figure of 1°/71.6^y for the rate of precession.[37] Ibn al-A'lam's value is the most accurate of the values observed for the rate of precession throughout the first millennium AD. Of course, one cannot neglect that the derivation of such a precise value was somewhat of a matter of chance and coincidence, because the errors committed both by the Mumtaḥan astronomers and Ibn al-A'lam in the measurement of the longitude of Regulus are of the same sign and nearly of the same order, so that they neutralize each other to a considerable degree. In addition, the error of +0;4° is distributed over the relatively long period of 147 years between the two. It deserves noting that Ibn al-A'lam's value is not the best medieval estimation; Ibn Yūnus's value of 1° in 70$^1/_4$ years has a better accuracy,[38] and Muḥyī al-Dīn al-Maghribī's value of 1°/72 Persian years, which has been applied in his first *zīj* prepared in Damascus, the *Tāj al-Azyāj* (*Crown of the zījes*), provides the best medieval approximation to the true value of 1°/71.6^y (however, later, after joining the Maragha team, he derived the value 1°/66^y).[39]

36. The hypothesis posited here is passingly mentioned as a conjecture in Kunitzsch 2003, p. 349.

37. The true difference in longitude of Regulus between 198 Y and 345 Y amounts to 2;2°: 2;3° due to precession and –0;1° due to Regulus's sizable negative proper motion. Taking this into account, the total error in the longitudinal difference of Regulus between the Mumtaḥan observers and Ibn al-A'lam would be equal to 0;3°. This value produces an error of +0;0,1,13$^{°/y}$ in the annual rate of precession in the intervening 147 years, namely instead of the true rate 1°/71.6^y ≈ 0;0,50,17$^{°/y}$, one arrives at 0;0,51,30$^{°/y}$ ≈ 1°/70^y.

38. It merits noting that Bīrūnī compares the two values reported for the longitude of Regulus by Hipparchus, 119;50°, in 761 years before the Yazdigird era/129 BC (*Almagest* VII.2: Toomer 1984, p. 328; Pedersen 1974, p. 415, no. 46) and by Abu al-Wafā' of Būzjān, 135.5°, in 343 Y/974–975 AD, and derives from them a rate of precession equal to 1° in 70 years and 4 months, which is close to the value adopted by Ibn Yūnus (Bīrūnī 1954–1956, Vol. 2, pp. 676–677).

39. Dorce 2002–2003, p. 198; 2003, pp. 111, 180. The value 1°/72^y can be found in the *Barcelona Tables* (*ca.* 1381) and also was independently measured in Italy or France in 1306 (as documented in a codex preserved in Vienna, no. 5311, f. 137r; see Goldstein 1994, pp. 193, 196–197; for the star tables in this manuscript, see Kunitzsch 1986). Muḥyī al-Dīn reached the

Ibn al-A'lam's Muslim predecessors were not, of course, so fortunate in the derivation of precessional motion; as we have seen earlier, al-Farghānī measured the value 65;20° for the longitude of Capella, which is about –0;35° in error for his time (856–7 AD), which is nearly equal to the error committed by Ibn al-A'lam in the measurement of the longitude of Regulus. Al-Farghānī compared his value 65;20° with the corresponding value in the first Mumtaḥan star table, which has an error of –0;27°. The true values for the longitude of Capella at the times of the Mumtaḥan observers and al-Farghānī, as given to a precision of minutes of arc, are equal to, respectively, 65;32° (Table 2, no. 10) and 65;55°. With these values, one could achieve, at best, a value of about $1°/70^y$ (i.e., $0;23°/27^y \approx 0;0,51^{°/y}$) for the rate of precession. But, because of the existence of an error of –0;8° in the longitudinal difference of Capella between the values measured by the Mumtaḥan observers and al-Farghānī and, especially, due to the narrow time span of 27 years between the two, an error of $-0;0,18^{°/y}$ ($\approx -0;8°/\ 27^y$) occurs in the annual precessional motion. Thus, this error results in a very low estimation of $0;0,51^{°/y}–0;0,18^{°/y} = 0;0,33^{°/y} \approx 1°/100^y$ for the rate of precession, and thus, leads to the confirmation of Ptolemy's estimation.

5. Discussion and conclusion

In this paper, we have dealt in detail with the most likely first attempt made in the Middle East in the medieval period to measure systematically the ecliptical coordinates of a group of 24 stars (mostly bright, from the first to the third magnitude), carried out by the Mumtaḥan team of observers in Baghdad and Damascus in the first half of the ninth century. In the surviving manuscripts of the *Mumtaḥan zīj*, two tables of 24 and 18 stars are preserved, the first for 829 AD and the second, an update of the first, for 1011 AD. The first goal of this research was to address the two questions: Why are six stars from the first table absent from the second? And why did the astronomers working in the Maragha observatory in the latter half of the thirteenth century attribute the second table to Ibn al-A'lam, an astronomer who flourished in the latter half of the tenth century? We have shown

value $1°/66^y$ in Maragha by making the observations of eight bright stars and then comparing his own derived longitudes with Ptolemy's; the procedure is explained in detail in his *Talkhīṣ* VII.1–2: ff. 111r–115r.

that because of some difficulties with either the names or the coordinates given for those six stars, their identification is problematic. Then, presenting some pieces of evidence, we have worked out a hypothesis that the second star table is probably the work of Ibn al-A'lam, resulting from his measurement of the rate of precession as $1°/70^{y}$ — which, according to Ibn Yūnus's account, was done by comparing his value for the longitude of Regulus, measured in 975–6 AD, and the corresponding value measured by the Mumtaḥan astronomers —and a few corrections made by him in the longitudes of the stars α CMa, α Aql, and β Peg.

Furthermore, we have evaluated the errors in the ecliptical coordinates given for the stars in the Mumtaḥan star tables. The result was that in the latitude values, the Mumtaḥan astronomers attained a better degree of precision (with a mean absolute error of about 13′ and the errors distributed randomly) in comparison with Ptolemy (with a mean absolute error of about 18.5′). But in the longitudes we have observed a negative systematic error, a feature also found in Ptolemy's star catalogue in the *Almagest*. We are not told how the Mumtaḥan astronomers made their stellar observations, and thus the source of this systematic error, which can be a deficiency in the instrument(s) and/or a defect in the solar theory used (like in the case of Ptolemy's star catalogue), is unknown to us. The solar tables in the surviving recensions of the *Mumtaḥan zīj* do not show a negative systematic error that could be the cause of the errors in the stellar longitudes. We have computed the solar true longitudes at noon on the basis of the parameters of the *Mumtaḥan zīj* for a period of 8000 days beginning with 1 January 820[40] and have compared the results with modern values. The agreement is surprisingly good, with errors ranging from –1.8′ to +3.1′, a mean error of 0.4′ (with standard deviation $\sigma =$ 1.0′) and a mean absolute error of 0.9′ (see Figure 4). It should also be noted that from the recorded observations in the secondary sources we know that the Mumtaḥan astronomers made their solar observations in the period from 829 to 832 AD. So, if the stellar observations were also made in this period, they may have had to make use of a preliminary version of their solar theory (possibly prepared by Yaḥya before his death in 830 AD) or an earlier theory.[41]

40. It was done with the aid of Prof. Benno van Dalen's very useful program Historical Horoscopes.

41. It should be noted that also in Ptolemy's *Almagest* the epoch of the star catalogue (137 AD, the beginning of the reign of emperor Antoninus) preceded the time at which Ptolemy completed his solar theory. See, e.g., Evans 1987, Part 2, p. 241.

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Nos.		Star	Latitude	Longitude					
				I	II	III	IV	V	VI
				Ptolemy	Mumtaḥan First Table (*214 H*)	Al-Farghānī (*225 Y*) *II + 0;15°*	Ḥabash (*304 H*) *II + 1;17°*	Mumtaḥan Second Table (*380 Y*) *II + 2;36°*	Īlkhānī zīj (*601 Y*) *V + 3;9°*
*1	*ākhir al-nahr*	θ Eri	−53;30° [Pt.]	0;10°	10;10°	11;22° [= I + 11;12]	12;24° [= I + 12;14]	13;33° *	16;42°
*2	*kaff al-khaḍīb*	β Cas	+51;45	7;50	18;24	18;39	19;41	21; 0	24; 9
3	*al-nāṭiḥ*	α Ari ?	***+22***; 0†	10;40	20;40	——	——	——	——
*4	*ra's al-ghūl*	β Per	+22;45	29;40	39;1̲6†	39;31	40;33	41;52	45;01
5	*kaff al-jadhmā'*	α Cet ? α Per	+30; 8†	34;50	45;1̲5†	45;30	46;32	——	——
*6	*al-dabarān*	α Tau	− 5;15	42;40	52;55	53;10	54;12	55;31	58;40†
*7	*rijl al-jawzā'*	β Ori	−31; 4†	49;50	59;30	59;45	60;47	62; 6	65;15
8	*al-nathra / surrat al-jawzā'* †	M 44 ? ε Ori	−24;25	57;20	66;24	66;39	67;41	——	——
*9	*yad al-jawzā'*	α Ori	−16;45	62; 0	71;36	71;50	72;53	74;12	77;21
*10	*al-'ayyūq*	α Aur	+22;50	55; 0	65; 5	65;20	66;2***6*** [...;22̲]†	67;41	70;50
*11	*[al-shi'rā] al-yamāniya*	α CMa	−39;20†	77;40	87;50	88; 5	89; 7	90;31*	93;40

(Continued)

*12 *[al-shi'rā] al-sha'āmiya*	α CMi	–16; 0†	89;10	99; 0	99;15	100; ***2*** [...;17]†	101;36	104;45†
*13 *qalb al-asad*	α Leo	+ 0;15	122;30	133; 0	133;15	134;1***6*** [...;17]†	135;36	138;45
*14 *[al-simāk] al-a'zal*	α Vir	– 2; 6	176;40	186;48	187; 3	188; 5	189;24	192;33
*15 *[al-simāk] al-rāmiḥ*	α Boo	+31;12	178;20	187;10	187;25	188;27	189;46	192;55
16 *[munīr] al-fakka*	α CrB	+44; 6†	194;40	205; 6	205;21	206;23	——	——
*17 *qalb al-'aqrab*	α Sco	– 4;24†	222;40	232;55	233;10	234;12	235;31	238;40
*18 *ra's al-ḥawwā'*	α Oph	+36; 0† [Pt.]	234;50	245;18	245;33	246;35	247;54	251; 2
*19 *[al-nasr] al-wāqi'*	α Lyr	+61;45	257;20	269; 0	269;15	270;17	271;36	274;45
*20 *[al-nasr] al-ṭā'ir*	α Aql	+29;12†	273;50	284;18	284;33	285;35	287;49*	290;58
21 *fam al-ḥūt*	α PsA ?	–23; 0 [Pt.]	307; 0	317;15 [= I + 10;15?]	318;12* [= I + 11;12]	318;32	——	——
*22 *al-ridf*	α Cyg	+59;36	309;10	318;24	318;39	319;41	321; 0	324; 9
*23 *mankib al-faras*	β Peg	+31;10	332;10	342;20	342;35	343;37	345; 5*	348;14
24 *rijl qanṭūrıs*	α Cen ?	–41;10 [Pt.]	218;20	***198***;35† [228;35 = I + 10;15 ?]	***199***;32† [229;32 = I + 11;12]	***200***;34 [230;34 = I + 12;14]†	——	——
25 *'urqūb al-rāmī*	β Sgr	–23; 0 [Pt.]	257;40	——	268;52 [= I + 11;12]	269;5***7*** [...;54 = I + 12;14] †	——	——
26 *suhayl*	α Car	–75; 0 [Pt.]	77;10	——	89;55 [= I + 12;45]	90;***17*** [...;57 = III + 1; 2] †	——	——

(Continued)

27	*rafīq al-suhā*	ζ UMa	+55;40 [Pt.]	138; 0	——	——	149;48 [= I + 11;48]	——	——
28	*dhanab al-asad*	β Leo	+11;50† [Pt.]	144;30	——	——	156;17 [= I + 11;47]	——	——
29	*dhanab al-dajāja*	α Cyg	+60; 0 [Pt.]	309;10	——	——	321; 6 [= I + 11;56]	——	——
30	*'unuq al-ḥayya* †	ϰ Ser	+37;15 [Pt.]	201;20	——	——	213;47 [= I + 12;27]	——	——
31	*'unuq al-shujā'* †	α Hya	−20;30 [Pt.]	120; 0	——	——	131;44 [= I + 11;44]	——	——

Table 1: Two star tables of the *Mumtaḥan zīj* and its later adoptions.

Notes:
[Pt.] denotes a Ptolemaic value.
Names: 2. First Table has only *al-khaḍīb*. // 5. First Table has only *al-jadhmā'*. // 8. The name *al-nathra* appears in the first star table in the *Mumtaḥan zīj*, which is replaced by *surrat al-jawzā'* in Ḥabash's. // 27. Ḥabash's text reads *raqīq* (رقيق), instead of *rafīq* (رفيق), "companion/associate". The Arabs called the star Alcor (80 UMa), which is very close to Mizar (ζ UMa), as *Suhā'*, and thus ζ UMa is named here the "companion of *Suhā*". This name, however, is not mentioned by al-Ṣūfī. // 30,31. In both cases, the text reads *'ayn* (عين), "eye", instead of *'unuq* (عنق), "neck". Especially, in the case of no. 30, the latitude of the star as is in the *Almagest* agrees with ϰ Ser, but it should be noted that according to both Ptolemy and al-Ṣūfī, this star is in the "mouth" of Serpens, not in its "neck".

Latitude: 3. 9;…? See the discussion in this paper and Table 2. // 5. al-Farghānī has +30;***10*** (maybe, a scribal error: ح → ى). // 7. *Īlkhānī zīj*, C: …;***7*** (a scribal error: د → ز), T: …;***20*** (د → ک). // 11. *Īlkhānī zīj*: …;***4*** (a scribal error: ک → د). // 12. *Īlkhānī zīj*, C: ***5***;0. // 16. Both Mumtaḥan tables have +4***5***;6, but al-Farghānī and Ḥabash have correctly +44;6 which is in good agreement with tabular values for the star's declination and transit degree; see Table 2. // 17. Al-Farghānī: –4;2***5*** (کد → که); *Īlkhānī zīj*, C: 4;***34*** (کد → لد), M1: ***13***;24 (د → یج). // 18. First Table: +3***5***;0. Note that the value +36;0 both is equal to the value in the *Almagest* and is in agreement with the true value for the latitude of the star. // 20. Second Table and *Īlkhānī zīj*: +29;1***4*** (a scribal error). // 28. Ḥabash: ***+51;7*** (likewise, a scribal error: یا ن → نا ز , since in the *Almagest*, the latitude of the star is indeed 11;50°).

Longitude: 4. First Table gives 39;***3***6 which seems a scribal error, and should be 39;16 which is in accordance with al-Farghānī (39;16 + 0;15 = 39;31), Ḥabash (39;16 + 1;17 = 40;33), and second Table (39;16 + 2;36 = 41;52). However, it should be noted that the value 39;36° is closer to the true value for the longitude of β Per at the time (39;53°). // 5. First Table: 45;***3***5 (similar to no. 4). However, if we assume that by the wrong name *kaff al-jadhmā'*, the Mumtaḥan astronomers had, in reality, α Per in mind (see our discussion in this paper and Table 2), it should again be noted that the value 45;35° is closer to the true value for the longitude of α Per at the time (45;48°). // 6. *Īlkhānī zīj*, P, M2: …;4***2***. // 10,12,13,25,26. Ḥabash: the differences may plausibly be explained by taking the probable errors in writing down the alphanumerics: کب → کو , یز → ب , یز → یو , نز → ند, and نز → یز, respectively. // 12. *Īlkhānī zīj*, C: 10***6***; …, T: 10***5***;… (ید → یه/یو).

Nos.	Star	Latitude	Longitude	Declination	Transit Degree
*1 *ākhir al-nahr*	θ Eri	−53;30° **−53;49**	10;10° **6;46**	——	——
*2 *kaff al-khaḍīb*	β Cas	+51;45 **+51;13**	18;24 **18;54**	+52;51° [+52;56] **+52;43**	346; 5° [345;55]
3 *al-nāṭiḥ*	α Ari	+22; 0 [+9; 50] **+ 9;56**	20;40 **21;19**	+17;12 [+28;19] [+17;12] **+17;33**	14;13 [10;41] [16;30]
*4 *ra's al-ghūl*	β Per	+22;45 **+22;18**	39;16 **39;53**	+36; 0 [+36; 1] **+35;49**	30; 9 [30;10]
5 *kaff al-jadhmā'*	 α Cet α Per	+30; 8 **−12;40** **+30; 0**	45;15 **27;59** **45;48**	+44;54 [+44;54]† **− 1; 1** **+44;58**	32;59 [32;59]
*6 *al-dabarān*	α Tau	− 5;15 **− 5;33**	52;55 **53;27**	+13;30 [+13;32]† **+13;23**	54;15 [54;16]†
*7 *rijl al-jawzā'*	β Ori	−31; 4 **−31;17**	59;30 **60;30**	−10;16 [−10;14] **−10;16**	65;45 [65;43]
8 *al-nathra surrat al-jawzā'*	 M 44 ε Ori	−24;25 **~ +1.5** **−24;40**	66;24 ~ 111 67; 8	− 2;37 [−2;35] **− 2;43**	70;14 [70;14]
*9 *yad al-jawzā'*	α Ori	−16;45 **−16;11**	71;36 **72;26**	+ 5;40 [+5;42] **+ 6;22**	73;41 [73;43]

(Continued)

*10	*al-'ayyūq*	α Aur	+22;50 **+22;51**	65; 5 **65;32**	+43;36 [+43;38] **+43;45**	59;47 [59;46]†
*11	[*al-shi'rā*] *al-yamāniya*	α CMa	−39;20 **−39;21**	87;50 **87;58**	−15;48 [−15;46] **−15;46**	88;31 [88;24] 88;22
*12	[*al-shi'rā*] *al-sha'āmiya*	α CMi	−16; 0 **−15;47**	99; 0 **99;40**	+ 7;17 [+7;19]† **+ 7;29**	98; 0 [98;0]
*13	*qalb al-asad*	α Leo	+ 0;15 **+ 0;25**	133; 0 **133;35**	+17;14 [+17;15]† **+17;15**	133; 5 [133;4]
*14	[*al-simāk*] *al-a'zal*	α Vir	− 2; 6 **− 1;58**	186;48 **187;33**	− 4;38 [−4;38] **− 4;49**	185;53 [185;53]
*15	[*al-simāk*] *al-rāmiḥ*	α Boo	+31;12 **+31;32**	187;10 **187;54**	+25;37 [+25;36] **+25;37**	201;25 [201;25]
16	[*munīr*] *al-fakka*	α CrB	+44; 6 **+44;27**	205; 6 **205;49**	+31; 5 [+31;4] **+31; 9**	223; 4 [223;6]
*17	*qalb al-'aqrab*	α Sco	− 4;24 **− 4;25**	232;55 **233;27**	−22;50 [−22;52]† **−23; 1**	231;44 [231;43]
*18	*ra's al-hawwā'*	α Oph	+36; 0 **+36; 4**	245;18 **246; 5**	+14;11 [+14;11] **+14; 6**	251;10 [251;10]
*19	[*al-nasr*] *al-wāqi'*	α Lyr	+61;45 **+61;47**	269; 0 **268;58**	+38;12 [+38;10] **+38;12**	269;24 [269;27]
*20	[*al-nasr*] *al-ṭā'ir*	α Aql	+29;12 **+29;21**	284;18 **285;17**	+ 6;36 [+6;14] **+ 6;28**	281;31 [281;31]

(Continued)

21	*fam al-ḥūt*	α PsA	−23; 0 **−20;59**	317;15 **317;25**	−13; 0 [−37;27] **−35;31**	318;24 [326;6]
*22	*al-ridf*	α Cyg	+59;36 **+59;58**	318;24 **319;15**	+41; 2 [+41;0] **+41;30**	298; 0 [297;58]
*23	*mankib al-faras*	β Peg	+31;10 **+31; 7**	342;20 **343; 4**	+21;45 [21;44] **+21;57**	329;14 [329;13]
24	*rijl qanṭūris*	α Cen	−41;10 **−42;26**	198;35 **224; 4**	**−41;10** [−44;22] **−55;28**	**199;32** [176;12]

Table 2: The Mumtaḥan first star list: recomputation and comparison with true values.

Notes:

Declinations: 5. Text: *45*;54 (a probable scribal error: مد → مه). // 6. Text: *53*;30 (a clear scribal error: يج → نج). // 12. Text: *50*;17 (a scribal error: ز → ن). // 13. Text: *14*;14 (a clear scribal error: يز → يد). // 17. Text: *24*;50 (a probable scribal error: كب → كد).

Transit Degrees: 6. Text: 54;*55* (a scribal error: يه → نه). // 10. Text: *8*9;47 (a clear scribal error: ب كط مز → ا كط مز).

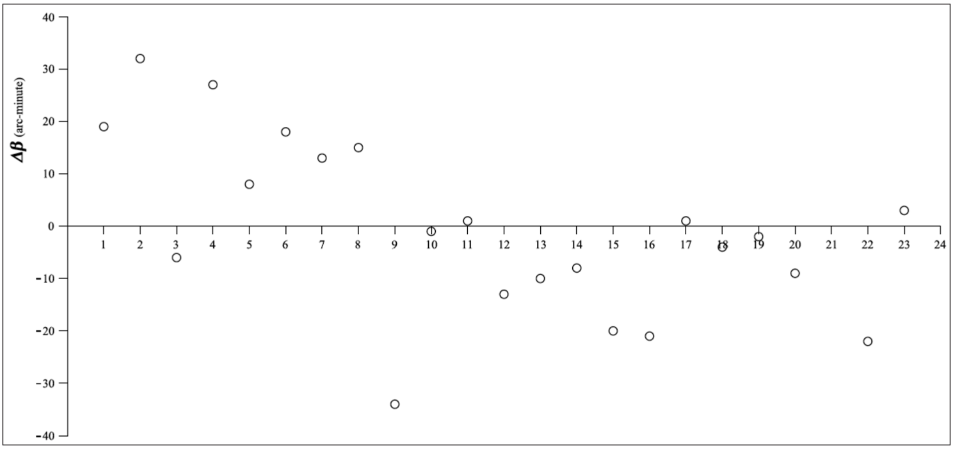

FIGURE 1: Errors in latitude in the Mumtaḥan star table (excluding outliers, nos. 21, α PsA, and 24, α Cen).

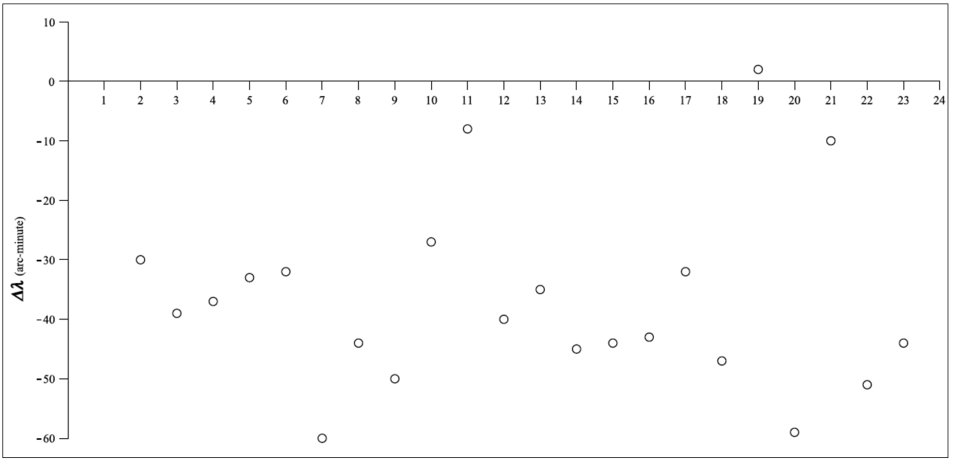

FIGURE 2: Errors in longitude in the Mumtaḥan star table (excluding outliers, nos. 1, θ Eri, and 24, α Cen).

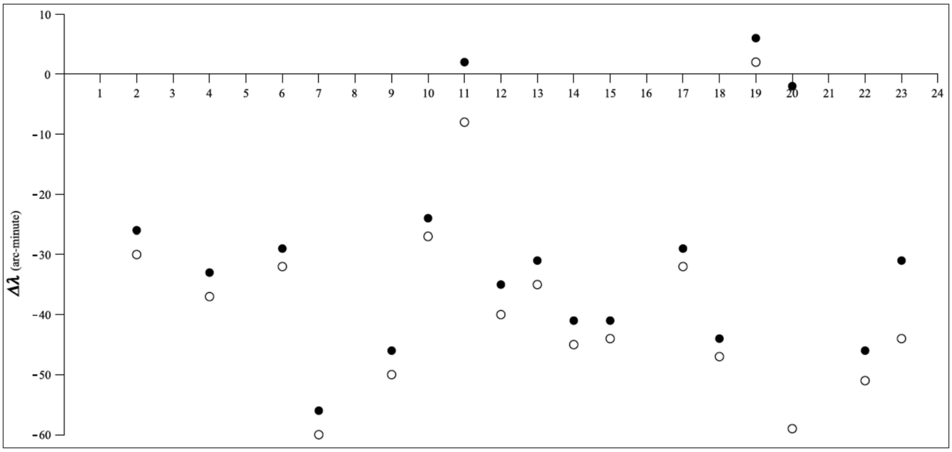

FIGURE 3: Errors in longitude for 17 stars common in both Mumtaḥan star tables.

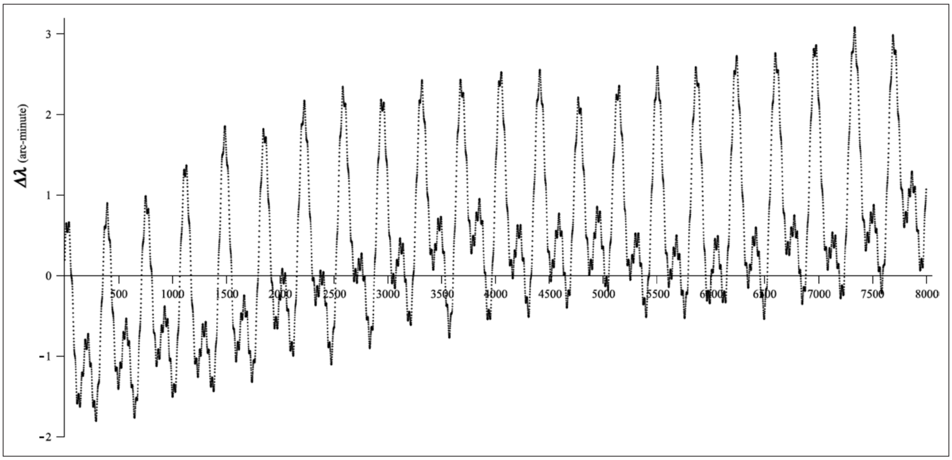

FIGURE 4: Errors in the solar longitudes computed on the basis of the solar theory in the *Mumtaḥan zīj* in a period of 8000 days starting from 1 January 820.