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► **To cite this version:**

Bernard R Goldstein, José Chabás. New evidence on Abraham Zacut's astronomical tables. *Archive for History of Exact Sciences*, 2018, 72 (1), pp.21-62. 10.1007/s00407-017-0199-2 . hal-02552941

**HAL Id: hal-02552941**

**<https://hal.science/hal-02552941>**

Submitted on 23 Apr 2020

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## New evidence on Abraham Zacut's astronomical tables\*

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### I. Introduction

In recent years, the astronomical activity of Abraham bar Samuel bar Abraham Zacut, the celebrated Jewish scholar (born in Salamanca, Spain, 1452; died in Jerusalem, 1514),<sup>1</sup> has been the object of various studies. In particular, the tables contained in his lengthy astronomical treatise written in Hebrew with canons and tables, *ha-H<.>ibbur ha-Gadol* (*The Great Composition*) composed in 1478, and the *Almanach Perpetuum* first published in 1496, consisting of a summary of the tables of the *H<.>ibbur*, have been examined and analyzed (Chabás and Goldstein 2000). The epoch for these two sets is 1473. The main result is that his tables for the Sun, the Moon, and the planets are based on the Parisian Alfonsine Tables, whereas other tables, related to calendrical matters and syzygies, depend on the existing Jewish astronomical tradition in Spain and Southern France. At the time of the expulsion in 1492, Zacut left Spain for Portugal and then moved from Portugal to North Africa in 1496 or 1497, eventually settling in Jerusalem in 1513.

In our monograph published in 2000 we numbered each of the tables of the *H<.>ibbur* and the *Almanach Perpetuum* to which we assigned the sigla “HG” and “AP”, respectively. In this paper we focus on other tables compiled by Abraham Zacut, found in a number of manuscripts and fragments in Hebrew. We also describe in detail a commentary in Latin on a set of tables that can now be confidently assigned to Zacut. Some of these tables differ substantially from those in the *H<.>ibbur* and the *Almanach Perpetuum*; others are based on them with changes in presentation, precision, epoch, number of entries, etc.; and still others correspond exactly to Zacut's tables for 1473, HG and AP. Despite the overall variety of these tables, all those compiled by Zacut reflect a combination of the Jewish tradition and the use of the Alfonsine tables, with no exception, so that he stands as one of the main diffusers of Alfonsine astronomy into Jewish communities in the Middle East.

In Part II we present a text in a Latin manuscript in Cambridge describing the *Tabule verificate*, a set of tables reckoned for the meridian of Salamanca and discussed in our monograph on Zacut (Chabás and Goldstein 2000, pp. 23–36). The date of the epoch, noon of the day preceding January 1, 1461, kept us from considering Zacut, who was not even nine years old at that date, as the author of this set. However, the Cambridge manuscript leaves no doubt that Abraham Zacut is the author of the tables described in it. Moreover, several tables in the *Tabule verificate* appear in the *H<.>ibbur*, as well as in the *Almanach Perpetuum*, although with epoch 1473, and were later also used by Zacut in his Tables of 1513, as will be shown below. The tables in the *Tabule verificate* have been given a number, preceded by the siglum “TV”. Of course, as is most often the case, the epoch used in a set of tables does not represent the date when the tables were compiled. The fact that several tables among the *Tabule verificate* have more entries than those in the *H<.>ibbur* makes it plausible that the *Tabule verificate* were compiled after the *H<.>ibbur*. But the reason for choosing this epoch for the *Tabule verificate* is unknown.

Part III concerns the Tables of 1513, a set compiled by Zacut in Jerusalem with canons, written in Hebrew. The tables are arranged for the Hebrew calendar and deal exclusively with the determination of syzygies and the computation of solar and lunar eclipses. For purposes of identification, we have numbered each table, preceded by the siglum “JM”. In the Tables of 1513 there are two epochs: for dates in the Hebrew calendar the epoch is sunset preceding the civil day in the Julian calendar that began at

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\* This research has been undertaken in the frame work of ALFA, a European Research Council project (Consolidator grant 2016 agreement no. 723085) funded for 2017-2022.

<sup>1</sup> For the date of Zacut's death, see David 1992, p. 82.

midnight, whereas for astronomical purposes the epoch is taken as noon preceding this sunset. For the transcription of the Tables of 1513 four manuscripts have been used; an additional manuscript provided a copy of the canons.<sup>2</sup> One of these manuscripts (MS A) contains additional tables, which are addressed separately in Part IV, where each table is preceded by the siglum “MA”. Some of these tables are arranged for epoch 1473, and are directly linked to those in the *H<.>ibbur*, but two others are computed for epoch 1501 (still for Salamanca, as is the case for the tables with epoch 1473). It seems plausible that, while he was in North Africa, Zacut composed a set of tables with epoch 1501, although the only traces we have found are related to these two tables. However, there is also an anonymous table of new moons with this epoch, extant in a different manuscript, which was probably composed by Zacut (Goldstein 2013). Finally, Part V presents tables by Zacut found in fragments from the Cairo Geniza. Each Geniza fragment containing tables is preceded by the siglum “GZ”. For the equivalence of the tables in the different sets, see Table A. It is clear from it that the various sets of tables overlap and that all of them are properly attributed to Zacut.

In the course of some 35 years (from 1478 to 1513), Zacut produced a series of astronomical tables that depended on both the medieval Hebrew tradition in astronomy and the Parisian Alfonsine Tables. As has been shown elsewhere, these tables had a significant impact on subsequent astronomers working in Hebrew, Latin, and Arabic (Chabás and Goldstein 2000, pp. 161–171; Samsó 2004).

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<sup>2</sup> These manuscripts and fragments of Zacut’s tables preserved in the Cairo Geniza were identified and described in Goldstein 1981.

Table A: Concordance

HG	TV	AP	JM	MA	GZ
4	9*	5	10	11	1, 5
5		6			4
10	5*	9		5**	2
12	11	11			
15	10	12		3**	
16	12	14			
17	17	13			
19	15	15	11		1
20	16	16	12		1, 4
	14	18	13		1
	13		14		
64			1		
			2		
			3		
			4		4
			5		4
			6		
	8		7		1, 4
	7		8		1, 4, 5
			9		1, 4, 5
			15		1, 4, 5
				1	
				2	
				4	1, 2
				6	
				7	
				8	
				9	1
				10	
				12	4, 5

\* The year begins in January rather than in March, as in HG.

\*\* The epoch is 1501, rather than 1473.

## II. The *Tabule verificate* of Abraham Zacut

Cambridge, Trinity College, MS O.3.13, is a thick 16th-century manuscript containing canons in Latin associated with different sets of astronomical tables, but not including tables. Among the texts are canons attributed to Abraham Zacut (7v–10v), Jacob ben David Bonjorn (21r–26v), and Nicholaus Polonius (74v–80v), as well as the canons to the Parisian Alfonsine Tables, beginning *Tempus est mensura...* by John of Saxony. Our focus is on the text attributed to Abraham Zacut, which is otherwise unknown.

Folio 7v opens with “Canons to the tables for conjunctions and oppositions, as well as eclipses compiled by Abraham, the Jew”, immediately followed by the incipit *Dixit Abraam filius samuelis filii abrae zecud...* There is no doubt that, at least for the scribe, Abraham bar Samuel bar Abraham Zacut is the author of the text. Shortly thereafter, the text indicates that the tables described in the text follow *rabbi isaac auencid* (Isaac ben Sid) “who composed the tables of King Alfonso of Toledo” (see Chabás and Goldstein 2003, pp. 4, 136–138). This is one of the very few references to an astronomer in the text.

The treatise in the Cambridge manuscript is divided into two parts: “The first contains true conjunctions and oppositions...” and “The second contains computations of solar and lunar eclipses.” The first table mentioned is for mean conjunctions and covers 76 years, “corresponding to 4 revolutions”. The text adds precise information for characterizing the table: the beginning of any year is noon of the day preceding the first day of January, the table begins in 1461, and the computations were arranged for Christian years. This is indeed a succinct description of the first table in the *Tabule verificate* (TV 1), found in Madrid, MS 3385, 104r: see Table TV 1. The title of this table refers to “elongation”, which has to be understood as the period of time between the beginning of each year and the first mean conjunction, and “elongation” is exactly the term used in the description in the Cambridge manuscript. As shown in Chabás and Goldstein 2000, pp. 24–25, the entry for year 1 corresponds to noon of the day preceding January 1, 1461, and was computed for Salamanca. The table adds a value for 77 years: 18d 14;41h.

Table TV 1: Yearly “elongation” at mean conjunction (excerpt)

Year	Days	Hours	Year
1	18	8;49	76
2	29	0; 1	75
...			
76	6	23;31	1

The Cambridge text then gives the longitude of Salamanca: 25;46° from the western limit, and 2<sup>2</sup>/<sub>3</sub>h and about 1/8h distant from Jerusalem, whose longitude is 67;30° from the western limit. Indeed, 25;46° is the longitude of Salamanca used by Zacut in his other tables, and 67;30° is a standard value for the longitude of Jerusalem (Chabás and Goldstein 2000, p. 155). Note that 2<sup>2</sup>/<sub>3</sub>h + 1/8h = 2;47,30h = 41;52,30° which, when added to 25;46°, yields 67;38,30° ≈ 67;30°. The agreement is not perfect because 25;46° and 67;30° are exact numbers, whereas 2<sup>2</sup>/<sub>3</sub>h and 1/8h are approximate.

Following the explanation of the yearly table for mean conjunctions, the text mentions a table for full months and a table for leap years, and explicitly gives the value of the mean synodic month (29d 12;44h) as well as half of it (14d 18;22h). The *Tabule verificate* for Salamanca have such a table (TV 2 in Madrid, MS 3385, 104r), consisting of two monthly subtables for ordinary and leap years: see Table TV 2. Note that the first entry in both subtables (1d 11;16h) is found by subtracting the mean synodic month from the 31 days, corresponding to January.

Table TV 2: Monthly “elongation” at mean conjunction (excerpts)

Month	Days	Hours	Month	Days	Hours
Jan.	1	11;16	Jan.	1	11;16
Feb.	29	11;16	Feb.	0	22;32

...  
 Dic. 10 5;12                      Dic. 11 25;12

---

Next, a table is mentioned for computing the weekday at the beginning of each year, based on a period of 28 years, called *maior revolutio solis*. This refers to TV 3 in Madrid, MS 3385, 104r, for 28 years, where the entry for year 1 is [day] 7, that is, Saturday. A few lines below we are told to add 5;52h after a revolution of 76 years, in order to find the time of syzygy after a period of 76 Julian years. This is exactly the first entry in TV 4 in Madrid, MS 3385, 104v: see Table TV 4. We note that 5;52h is obtained by subtracting the entries corresponding to years 77 and 1 in TV 1, above: 18d 14;41° and 18d 8;49°, respectively.

Table TV 4: Time of syzygies after 76-year cycles (excerpt)

Cycles	Days	Hours
1	0	5;52
2	0	11;44
...		
26	33	7;20

After considering the time at mean syzygies, the text turns to the lunar position, and refers to a table for lunar anomaly for 180 years. Indeed, this is actually TV 5 (Madrid, MS 3385, 104v–105r), giving the mean motion in lunar anomaly in a period of 180 years: see Table TV 5. The entry for 1 year corresponds to noon of the day preceding Jan. 1, 1461, and can be recomputed with any set of Parisian Alfonsine Tables (Chabás and Goldstein 2000, p. 26). The table adds a value for 181 years, 7s 7;50°. Now, the text explains that one has to add 2;20° after each revolution; indeed, this is the value obtained by subtracting the entry for 1 year from the entry for 181 years in TV 5, and it appears in one of the subtables of TV 5. It is worth noting that a similar table for the mean motion in lunar anomaly, also for a period of 180 years, is found in the *H<.>ibbur* (HG 10) and in the *Almanach Perpetuum* (AP 9), but beginning on March 1, 1473: Chabás and Goldstein 2000, pp. 60, 115–116.

Table TV 5: Mean motion in lunar anomaly (excerpt)

Years	(s)	(°)	Years
1	7	10;10	180
2	10	8;43	179
...			
180	3	26; 2	1

Next there are explanations regarding the solar anomaly, mentioning a table for 76 years. The first subtable in TV 6 (Madrid, MS 3385, 105v) is for the mean motion in solar anomaly, and it is based on a

cycle of 76 years. The others display entries for months, days, and hours: see Table TV 6. The text confirms that this table was computed for 1461, and indeed the first entry in TV 6 corresponds to noon of the day preceding Jan. 1, when using any version of Parisian Alfonsine Tables.

Table TV 6: Mean motion in solar anomaly (excerpt)

Years	(s)	(°)	Years
1	6	18;26	76
2	6	18; 1	75
...			
76	6	17;23	1

The following lines in the text refer to a table to correct the lunar anomaly, consisting of two columns (time and minutes of proportion). As expected, this description corresponds to TV 7 (Madrid, MS 3385, 106 r–v): see Table TV 7. As shown in Chabás and Goldstein 2000, pp. 28–29, these two columns derive from Nicholas de Heybech’s table for finding the time from mean to true syzygy. The first column (time) corresponds to Heybech’s col. IV and the second column (minutes of proportion), to the complement in 60 of Heybech’s col. III.

Table TV 7: Correction of lunar anomaly (excerpt)

Argum.	(h)	(min)
1	0;11	60
2	0;22	60
...		
30	4;59	56
...		
90	9;40	30
...		
180	0; 0	0

Then comes a description of a table to correct solar anomaly, also consisting of two columns (time and minutes of proportion), and it clearly corresponds to TV 8 (Madrid, MS 3385, 107 r–v): see Table TV 8. Again, as shown in Chabás and Goldstein 2000, p. 29, these two columns derive from Nicholas de Heybech’s table for finding the time from mean to true syzygy. The first column (time) corresponds to the difference between Heybech’s columns I and II and the second column (minutes of proportion) is the same as Heybech’s col. II.

Table TV 8: Correction of solar anomaly (excerpt)

Argum.	(h)	(min)
--------	-----	-------

---

1	0; 4	1
2	0; 8	2
...		
30	1;49	30
...		
90	3;46	61
...		
180	0; 0	0

---

On folio 8v of the Cambridge manuscript it is noted that a certain Stephanus made a severe mistake (“erravit gravissime”) in the tables “he compiled for conjunctions and oppositions at the horizon of Salamanca, where opposite 3s 1° of solar argument he wrote 4;47h (...) in that place the solar equation in the tables of King Alfonso is 2;10<sup>o</sup>”. We are not aware of any Stephanus in Salamanca at the time and we do not know the contents of his tables, but the “severe mistake” by Stephanus may result from confusing the entry for 91° in TV 8 (3;46h) and the corresponding value in Nicholas de Heybech’s column I (4;47h), which is the sum of 3;46h and 61 minutes, as shown in TV 8.

Concerning the table for the equation of time, the text explains that the argument is the day number in a given month and that the entries are displayed in minutes of an hour. The format described is very uncommon, but it is the same as that of TV 9 (Madrid, MS 3385, 108r). However, the format differs from those in the tables for the same purpose, JM 10 and MA 11, where the argument is the solar longitude rather than the day in a year. In the excerpt of TV 9 shown here, only the first and last two rows are displayed, together with the values of relative maxima and minima: see Table TV 9. The same table, beginning in March, with a few slightly different entries, is found in the *H<.>ibbur* (HG 4) and in the *Almanach Perpetuum* (AP 5): Chabás and Goldstein 2000, pp. 56, 108.

Table TV 9: Equation of time (excerpt)

---

	Jan	Feb	...	Apr	...	Jul	...	Oct	...
1	6	0		16		14		29	
2	5	0		16		14		29	
...									
6		0							
...									
12						12			
...									
20	0					12		32	
...									
22	0					12		32	
...									
24	0					12		32	
...									
26	0					12			
...									
30	0	0		23		13		31	



31    0    0            0            13            31

---

The text then refers to a table for the solar elongation from the lunar node for 56 years, and explicitly indicates that it begins at noon of the day preceding the first day of March 1461. These are exactly the characteristics of TV 10 (Madrid, MS 3385, 108r–109r), displaying the differences between the longitude of the Sun and the lunar ascending node in a period of 56 years: see Table TV 10. The value for 57 years is also indicated, 8s 6;37°. Recomputation for Salamanca with the Parisian Alfonsine Tables confirms that the first entry was computed for the day preceding March 1, 1461, in contrast to other tables that begin in January 1461. The text also mentions that after one revolution, 3;32° has to be added. This value can be derived by subtracting the entry for 1 year from the entry for 57 years in TV 10, but it also appears as the entry for one revolution in one of the subtables associated with TV 10. Still other subtables display entries for the days in a year, the hours in a day, and the minutes in an hour. A similar table for the distance of the Sun from the lunar node, also for a period of 56 years, is found in the *H<.>ibbur* (HG 15) and in the *Almanach Perpetuum* (AP 12), but beginning on March 1, 1473: Chabás and Goldstein 2000, pp. 62, 118.

Table TV 10: Yearly solar elongation from the lunar node (excerpt)

---

Year	(s)	(°)	Year
1	8	3; 5	56
2	8	22;21	55
...			
56	7	17;33	1

---

There follows a reference to a table for the “true” motion of the lunar nodes, which seems to be TV 11 (Madrid, MS 3385, 109r): see Table TV 11. The value for 57 years, 3s 13;10°, is also given. The difference between the entries for year 57 and year 1 is 3;7°, and this is precisely the value appearing in the manuscript that has to be subtracted to find the position of the lunar node after a revolution of 56 years. A similar table for the mean motion of the lunar node is found in the *H<.>ibbur* (HG 12) and in the *Almanach Perpetuum* (AP 11), but beginning on March 1, 1473 and valid for a period of 93 years: Chabás and Goldstein 2000, pp. 60, 117.

Table TV 11: “True” motion of the lunar node (excerpt)

---

Year	(s)	(°)	Year
1	3	16;17	56
2	2	26;57	55
...			
56	4	2;29	1

---

The second part of the treatise, on eclipses, begins at the bottom of f. 9r. The first table mentioned is for parallax, and we are told that it consists in 7 parts. The latitude of Salamanca for which the table is valid is given as 41;19°. This corresponds to the table presented in 7 subtables, labeled TV 12, found in

Madrid, MS 3385, 109v–110r, of which we only reproduce the subtable for the sign of Cancer: see Table TV 12. This table calls for a comment on its units. The columns headed “Time” and “Long.” are equivalent and related by a factor,  $0;32,56^\circ/\text{h}$ ; they represent the component in longitude of parallax given in hours and minutes, and in minutes of arc, respectively. The use of units of time for parallax in longitude is not frequent. The column headed “Lat.” is the component of parallax in latitude, in minutes of arc. The same table, but for scribal errors, is found in the *H<.>ibbur* (HG 16) and in the *Almanach Perpetuum* (AP 14): Chabás and Goldstein 2000, pp. 62, 122–124. We know of very few astronomers who used hours and minutes for the component in longitude: Levi ben Gerson, Bonjorn, Ben Verga, and Peurbach (Chabás and Goldstein 2012, p. 132).

Table TV 12: Parallax for Salamanca (Cancer)

Hour	Time	Long.	Lat.
7;30	1;13	40	38
7, 0	1;13	40	38
6	1;15	41	37
5	1;20	44	34
4	1;20	44	29
3	1;12	40	25
2	0;53	29	20
1	0;31	17	17
0	0; 0	0	16
1	0;31	17	17
2	0;53	29	20
3	1;12	40	25
4	1;20	44	29
5	1;20	44	34
6	1;15	41	37
7; 0	1;13	40	38
7;30	1;13	40	38

The text does not mention the table for the eclipsed fraction of the solar and lunar disks, TV 13, found in Madrid, MS 3385, 110r–111v: Chabás and Goldstein 2000, p. 32.

Table TV 13: Eclipse fraction

Digits diam.	Sun (dig.)	Moon (dig.)
1	0;22	0;30
2	1; 0	1;10
3	1;50	2;50
4	2;40	3;10
5	3;20	4;20
6	4;40	5;50

7	5;50	6;42
8	7; 0	8; 0
9	8;30	9;10
10	9;40	10;20
11	10;50	11;20
12	12; 0	12; 0

---

The next table considered in the text is called *latitudinis lune precise*. This is the same terminology as that used in TV 14 (Madrid, MS 3385, 110v), referring to a table to convert the argument of lunar latitude into latitude in the vicinity of the lunar nodes, where an eclipse is possible, with an inclination of the lunar orb of 4;29°: Chabás and Goldstein 2000, p. 32. The argument is given at intervals of 0;15°, from 11s 24° to 0s 17° and from 5s 13° to 6s 6°. Moreover, the text explicitly gives these values as the limits for solar eclipse visibility, and adds that they are valid for observers in geographical latitudes in the range from 24° to 48°. A further precision is given: for the middle of the 5th climate the limits are 5s 13;21° – 6s 2;38° and 11s 27;22° – 0s 16;39°: see Table TV 14. A similar table is found in the *Almanach Perpetuum* (AP 18), where the entries are displayed at intervals of 0;30°, rather than 0;15°: Chabás and Goldstein 2000, pp. 130–131. We note that the *Almanach Perpetuum* also has a table for latitude based on a maximum value of 5°, whereas the *H<.>ibbur* has only one table, based on 5°.

Table TV 14: Precise lunar latitude (excerpt)

Arg. latitude		Latitude	Arg. latitude	
0s	5s	(°)	6s	11s
0;15	29;45	0; 1,12	0;15	29;45
0;30	29;30	0; 2,21	0;30	29;30
...				
6; 0	24; 0	0;28,11	6; 0	24; 0
6;15	23;45	0;29,21		
...				
17; 0	13; 0	1;18,48		

---

Next is a discussion of a table for the solar eclipses *in longitudine media*, where it is remarked that this table follows [the opinion of] Poel (*sequtus sum poel*), that is Jacob ben David Bonjorn, also known as Jacob Po'el in Hebrew texts. Among the tables in the *Tabule verificate*, there is one for solar eclipses at mean distance, TV 15 (Madrid, MS 3385, 110v), which may be derived from Bonjorn's tables (Chabás and Goldstein 2000, pp. 126–127): see Table TV 15. The argument, in minutes, is the “visible latitude”, that is, the difference between latitude and parallax in latitude, and it is given at intervals of 0;0,30° from 0;0,0° to 0;22,0° and at intervals of 0;0,15° from 0;22,0° to 0;28,15°. The central column is for the eclipsed part of the solar diameter, in digits and minutes of a digit, and the third column is for the half-duration of the eclipse, in minutes of time. A similar table, but with intervals of 1° of the argument, is found in the *H<.>ibbur* (HG 19) and in the *Almanach Perpetuum* (AP 15): Chabás and Goldstein 2000, pp. 62, 125–127.

Table TV 15: Solar eclipses at mean distance (excerpt)

---

Argum. ( $^{\circ}$ )	Eclipsed Part (dig)	Half- duration (min)
0; 0	11;47	55
0;30	11;34	55
1; 0	11;22	55
...		
28; 0	0; 9	3; 0
28;15	0; 0	0;30
28;23	0; 0	0; 0

---

There follows a precise description of a table for lunar eclipses at mean distance in 5 columns (also using the term *spatium*). It matches perfectly TV 16 (Madrid, MS 3385, 111r-v): Chabás and Goldstein 2000, p. 33. With regard to lunar eclipses, the text indicates that the possibility of a lunar eclipse is restricted to the intervals 11s 18 $^{\circ}$  – 0s 12 $^{\circ}$  and 5s 18 $^{\circ}$  – 6s 12 $^{\circ}$  of the argument of lunar latitude, in agreement with the limits in TV 16. Bonjorn has a similar table, with the same format and limits, but with fewer entries, for the argument of latitude is displayed at intervals of 0;30 $^{\circ}$ , rather than at 0;5 $^{\circ}$  as is the case here. Bonjorn's table was reproduced by Zacut in his *H<.>ibbur* (HG 20) and it is also found in the *Almanach Perpetuum* (AP 16): Chabás and Goldstein 2000, pp. 62, 127–128.

Table TV 16: Lunar eclipses at mean distance (excerpt)

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Argum. of latitude 0s 6s 5s 11s ( $^{\circ}$ )	Eclipsed part (dig)	Half- duration (h)	Half- totality (min)
12; 0	18; 0	0; 0	0; 0
11;55	18; 5	0;10	0; 5
11;50	18;10	0;19	0;10
...			
11; 0	19; 0	1;58	0;43
...			
6; 0	24; 0	12; 2	1;35
5;55	24; 5	12;12	1;35
...			
0;10	29;50	23;51	1;49
0; 5	29;55	24; 2	1;49
0; 0	30; 0	24;12	1;49

---

Next, a table for the *expansio luminarum* is briefly mentioned. This term refers to the eclipsed fraction of the solar and lunar disks. The same term is used in the headings of TV 13 (Madrid, MS 3385, 110r, 111v): Chabás and Goldstein 2000, p. 32. In fact, there are two tables in the *Tabule verificate* for this purpose: a standard one, already found in *Almagest* VI.8, and another, with the same format, but with the argument displayed at intervals of 0;18° (there are no entries in the column for *expansio lune* in Madrid, MS 3385, 111v).

The first three lines on f. 10v of the Cambridge manuscript, beginning “ctiones” and ending “luminarium” are not the continuation of the text at the end of f. 10r, and all three of them have the indications “va” in the left margin, and “cat” in the right margin.

Finally, the text also mentions a “tabella” to correct eclipses, where the argument is lunar anomaly, and it corresponds to TV 17 (Madrid, MS 3385, 111v): Chabás and Goldstein 2000, pp. 33–34. This table derives from Ptolemy’s *Handy Tables*, and it is closely related to a table in the *H<.>ibbur* (HG 17) and in the *Almanach Perpetuum* (AP 13) used for the equation of eclipses: Chabás and Goldstein 2000, pp. 33–34, 118–122.

Table TV 17: Correction of Eclipses (excerpt)

Lunar anomaly (°)		<i>Expansio solis</i>	Lunar anomaly (°)	
(°)	(°)		(°)	(°)
0s 0	0s 0	0; 6, 0	6s 0	6s 0
0s 2	11s 28	0; 5,59	6s 2	5s 28
0s 4	11s 26	0; 5,58	6s 4	5s 26
...				
1s 0	11s 0	0; 5, 0	7s 2*	5s 0
...				
2s 0	10s 0	0; 3, 0	8s 2*	4s 0
...				
2s 26	9s 4	0; 1, 1	8s 28*	3s 4
2s 28	9s 2	0; 1, 0	9s 0*	3s 2
3s 0	0s 0**	0; 0, 0	—	3s 0

\* The entry 6s 6° is missing in this column, and the remaining entries in it have thus been shifted upwards one place.

\*\* Instead of 9s 0°.

We conclude that beyond all doubt the text in Cambridge, Trinity College, MS O.3.13, 7v–10v, provides a detailed description of the *Tabule verificate* for Salamanca, extant in Madrid, Biblioteca Nacional, MS 3385, 104r–113r. According to the text itself, the author is Abraham Zacut. Moreover, several of these tables appear in Zacut’s *H<.>ibbur*, as well as in the *Almanach Perpetuum*, and use the same technical terminology, but there are two significant differences between the *Tabule verificate* and tables in other works by Zacut: the epoch here is January 1 or March 1, 1461, and a few tables have a significantly higher number of entries, for they use shorter intervals in the arguments.

### III. Tables of 1513

For these tables we have used the following manuscripts:

MS A. New York, Jewish Theological Seminary of America [JTSA], MS 2636.

MS B. New York, JTSA, MS 2574.

MS C. New York, JTSA, MS 2567.

MS M. London, Montefiore Library, MS 426.

MS S. London, Sassoon, MS 799.<sup>3</sup> Canons only.

As stated at the beginning of the canons, Zacut compiled this set of tables in Jerusalem in 5273 (= 1513)<sup>4</sup>. The tables in MS B are taken to be the base text of the Tables of 1513, with two other copies, MSS C and M. There are a few additional tables in each manuscript that are not discussed here. MS A is a special case: some of the tables in this manuscript agree with those in Zacut's Tables of 1513; others, however, need to be treated separately (see Part IV). The tables have been assigned numbers here that differ from those in the manuscripts, which are mutually inconsistent. In the headings for the tables in MS A the author's name is given as "R. Abraham Zacut, may his memory be for a blessing". In MS M his name is given as "R. Abraham Zacuto, may his memory be for a blessing". Zacut's name does not appear in the headings for the tables in MSS B and C.

It is likely that disciples of H<.>ayyim Vital (d. 1620) were prominent among the copyists of Zacut's Tables of 1513. While Vital is best known as a successor to the Kabbalist, Isaac Luria (d. 1572), he was also interested in alchemy and astronomy (Levy 1990, p. 35). Indeed, part I of his treatise on astronomy was published in 1866 by his Kabbalist followers, and in it Vital referred to Zacut's parallax table for Jerusalem (Vital 1866, 49a; cf. Steinschneider 1964, p. 202, and Steinschneider 2014, p. 40; see Table JM 15, below). Moreover, in MS M we are told that the texts on folios 1a to 74b (including Zacut's tables) were copied from a manuscript in the hand of Vital.<sup>5</sup>

For the canons we have consulted MSS B and S and, in one case a Geniza fragment (see n. 4). In the transcription of each table the witnesses in the various manuscripts are listed in the heading. The canons include several worked examples which help the reader understand how to compute various quantities. There is also a worked example for the solar eclipse of August 20, 1514. Curiously, the solar eclipse of March 7, 1513, which was nearly total in Jerusalem, is given very little attention. Tables JM 7, JM 8, and JM 9 have been analyzed previously (Goldstein and Chabás 2008). In the notes for each table, we indicate if it has a counterpart in other sets of tables by Zacut.

In contrast to his tables in the *H<.>ibbur* and the *Almanach Perpetuum* with epoch 1473 and mean motions for years and months in the Julian calendar, Zacut's Tables of 1513 are arranged for the Hebrew calendar with its 19-year cycles, years of Creation, and Hebrew months. These tables are restricted to the motions of the Sun and Moon with an emphasis on conjunctions and oppositions, and can be used for computing the circumstances of solar eclipses for Jerusalem and the circumstances of lunar eclipses.

Table of contents:

Table JM 1. Mean conjunctions in 19-year cycles.

Table JM 2. Solar positions in complete 19-year cycles.

Table JM 3. True solar positions at mean conjunction.

Table JM 4. Table for the anomaly of the Moon and the mean motion of the Moon, according to Ptolemy, in 19-year cycles, years, and months.

Table JM 5. Table for the argument of latitude at the time of mean conjunction in 19-year cycles.

Table JM 6. Table of the true argument of latitude at mean conjunction for each year in a 19-year cycle.

<sup>3</sup> MS S has page numbers and not folio numbers; hence, for example, S 10 means page 10 in MS S.

<sup>4</sup> MS S 1. The beginning of the canons is missing in MS B, but it is preserved on the first page of the Geniza fragment, Paris, Alliance Israélite Universelle, MS VIII.E.60 (there are no tables in this fragment).

<sup>5</sup> We are most grateful to Y. Tzvi Langermann for his assistance in deciphering the notes in MS M, 1a and 74b.

Table JM 7. First correction. Table for correcting the Sun when the Moon is at perigee of its epicycle in hours and minutes.

Table JM 8. Second correction. Table for correcting the lunar anomaly in hours and minutes.

Table JM 9. Third correction. Table for correcting the solar center and the lunar anomaly, to be added to the value at the perigee of the lunar epicycle.

Table JM 10. Equation of time.

Table JM 11. Table for solar eclipses at mean distance.

Table JM 12. Table for lunar eclipses at mean distance according to the opinion of R. Jacob Po'el.

Table JM 13. Table for finding lunar latitude from the argument of latitude.

Table JM 14. Area digits.

Table JM 15. Parallax for Jerusalem.

Table JM 1. B 3a.

Heading. Table for finding mean conjunction, arranged by the scribe Jacob Mizrah<.>i

Years of creation	Cycles	Weekdays, hours, parts	Complete embolismic [years] in a cycle [E]	Complete [years in a] cycle	Weekdays, hours, parts	Months of the year	Weekdays, hours, parts
5264	278	(5)d 5h 859p	2	1	(4)d 8h 876p	Heshvan	(1)d 12h 793p
5283	279	(7)d 22h 374p	3 E	2	(1)d 17h 672p	Kislev	(3)d 1h 506p
5302	280	(3)d 14h 969p	4	3	(7)d 15h 181p	Tevet	(4)d 14h 219p
...				...		...	
			11 E	10	(6)d 6h 339p		
				...			
			1	19	(0)d 0h 0p	Elul	(2)d 20h 83p
						Embolismic year	
						Adar II	(2)d 4h 438p
						Nisan	(3)d 17h 151p
						...	
						Elul	(4)d 8h 876p

Notes.

1. We use Neugebauer's convention for the weekday, putting the day number in parentheses, e.g., Sunday is (1)d: cf. Neugebauer 1956, p. 115.

2. The length of a mean synodic month in the Hebrew calendar is 29d 12h 793p [= 29d 12;44,3,20h = 29;31,50,8,20d] = 1d 12h 793p (mod 7), where 1080p = 1h. The mean synodic month in the Parisian Alfonsine Tables is 29;31,50,7,37,27,8,25d  $\approx$  29;31,50,8d: Chabás and Goldstein 2003, p. 270.

3. The radix for the era of Creation is (2)d 5h 204p. [i.e., Monday, 5h 204p after sunset]: Neugebauer 1956, p. 116.

4. The accumulated time in 235 mean synodic months [= 19 years] is (2)d 16h 595p (mod 7), and this is the line-by-line difference in the column for the 19-year cycles. Cf. Zacut's Table HG 64: Chabás and Goldstein 2000, pp. 77–80.

5. To find the entry for 278 cycles, we add the radix for Creation and the accumulated time in 277 19-year cycles: (2) 5h 204p + 277 · [(2)d 16h 595p]. The result is (5)d 5h 859p (mod 7), as in the text.



6. To compute a mean conjunction, add the entries for the current number of 19-year cycles, for complete years in a 19-year cycle, and for the current month. The result is the time of the mean conjunction preceding day 1 of the current month in weekday number, hours, and parts of an hour.

7. Worked example (B 2b, S 10):

I sought the mean conjunction of the new year of 5274 of the Creation, that is 10 years have elapsed in cycle 278. The entry for cycle 278 is (5)d 5h 859p, and opposite 10 years is (6)d 6h 339p. I added them together and the result is (11)d 11h 1198p [with S; B: 1195], where 1080p equals 1h. There remain 118p. I added 1h to 11h and the result is 12h. I subtracted 7d from (11)d and the result is (4)d. Thus the mean conjunction takes place (4)d 12h 118p from the beginning of the night [6 pm] or, in the morning of (4)d [Wednesday] 118p after sunrise, or counting from the [previous noon on Tuesday] add 6h, and the result is 18h 118p after noon on (3)d [Tuesday].

We recompute the mean conjunction in the worked example with the Parisian Alfonsine Tables, taking the difference in time from Jerusalem (longitude  $67;30^\circ$ ) to Toledo (longitude  $28;30^\circ$ ) to be  $2;36h$  ( $= 39^\circ = 67;30^\circ - 28;30^\circ$ ), based on Zacut's values for these longitude: see Cantera 1931, pp. 363, 365. The time of mean conjunction in the worked example is  $18h 118p = 18;6,33h$  after noon (Jerusalem) on Tuesday, Aug. 30, 1513 (for Tishri 1, 5274, began at 6 pm. Aug. 31, 1513, Wed.). We subtract  $2;36h$  from  $18;6,33h$  and the result is  $15;30,33h$ . The mean longitudes of the Sun and Moon on Aug. 30, 1513,  $15;30,33h$  after noon (Toledo) according to the Parisian Alfonsine were  $168;37^\circ$  and  $169;21^\circ$ , respectively. Clearly, according to the Parisian Alfonsine Tables mean conjunction took place a little earlier (about  $1;30h$ ), for the mean longitudes of the Sun and the Moon on Aug. 30, 1513,  $14h$  after noon were  $168;34^\circ$  and  $168;32^\circ$ , respectively. In other words, there is a systematic difference in the times of mean conjunction of about  $1;30h$  between Zacut's computation for Jerusalem, using the traditional methods of the Hebrew calendar, and computation with the Parisian Alfonsine Tables. Given the separate origins of the two procedures, exact agreement is not to be expected. As we shall see, for the time of mean conjunctions and oppositions Zacut's Tables of 1513 depend on the entries in Table JM 1, that is, for computations of longitudes Zacut used the Parisian Alfonsine Tables, entering with the times derived from Table JM 1.

Table JM 2. B 4a.

Heading. Table for the position of the Sun in complete cycles [of 19 years]

Cycles of the Creation		Cycles	
Beginning of Creation	5s 14;21°		
20	5s 15;56	1	0s 0; 5°
40	5s 17;31	2	0s 0;10
60	5s 19; 6	3	0s 0;15
80	5s 20;41	4	0s 0;19
...			...
260	6s 4;57		...
...		17	0s 1;21
...			...
380	6s 14;27	20	0s 1;35

Note.

1. The mean motion derived from the entry for 20 cycles is 0;59,8,19,37,...°/d, as in the Parisian Alfonsine Tables (Chabás and Goldstein 2012, p. 57).

Table JM 3. B 4b-5a. M 53b.

Heading. Table for finding the true position of the Sun at mean conjunction [M adds: in a cycle of 19 years]

Years in a cycle	Tishri	Heshvan	Kislev	Tevet	Shevat	...	Elul
1	0s 0; 0°	0s 29;29°	1s 29;27°	2s 29;40°	3s 29;50°		10s 20;33°
2	11s 19;18	0s 18;34	1s 18;22	2s 18;31	3s 18;44		10s 10; 2
3	11s 8;36	0s 7;41	1s 7;18 <sup>a</sup>	2s 7;20	3s 7;35 <sup>a</sup>		10s 28; 2
4	11s 26;54	0s 26;19	1s 26;15	2s 26;27	3s 26;37		10s 17;31
5	11s 16;13	0s 15;25	1s 15;10	2s 15;18	3s 15;32		10s 7; 5
...							
11	11s 10;11	0s 9;15	1s 8;55	2s 8;58	3s 16;13		10s 29;34
...							
19	11s 11;40	0s 10;48	1s 10;28	2s 10;34	3s 10;48 <sup>b</sup>		11s 1; 4

a. M: 3s 7;35; B: 3s 17;35.

b. M: 3s 10;48; B: 3s 10;52.

Notes.

1. The entries in this table cover 235 consecutive months in a 19-year cycle, and they are for finding the true position of the Sun at the time of mean conjunction preceding the beginning of the month. An entry in this table is to be added to those that are appropriate in Table JM 2.

2. Worked example for the conjunction of Tishri 5274 (B 3b, S 11):

Find the entry for cycle 277 and then for Tishri year 11. The entry for 260 complete cycles is 6s 4;57° [see Table JM 2] and for 17 complete cycles it is 0s 1;21° [see Table JM 2]. The entry for Tishri year 11 is 11s 10;11° [see Table JM 3]. I added them together and the result is 17s 16;29° = 5s 16;29° [= 166;29°].

Recomputation with the Parisian Alfonsine Tables for Tuesday, Aug. 30, 1513, 14 hours after noon (see Table JM 1, n. 7), Toledo time (mean conjunction) yields 166;28° for the true Sun, in very good agreement with the text.

Table JM 4. B 6a. A 65b. C 64b. M 55a.

Heading. B and C: Table for the lunar anomaly and mean motion according to Ptolemy in cycles [of 19 years], and complete months

The headings in A and M add:

(1) Tables of the late R. Abraham Zacut [M: Zacuto].

(2) Radix for mean [lunar motion] at the time of the Creation 5[s] 16;25°; radix for the anomaly: 8[s] 16;30°.

Anomaly	Complete cycles of Creation	Mean motion	Anomaly	Years in the cycle	Mean motion
10s 6;57°	1	0s 0; 5°	10s 9;48 <sup>oh</sup>	1	11s 19;17°
8s 13;55	2	0s 0;10	8s 19;36	2	11s 8;34
6s 20;52 <sup>a</sup>	3	0s 0;15	7s 25;13	3	11s 26;57
4s 27;49	4	0s 0;19	6s 5; 1	4	11s 16;14 <sup>j</sup>
3s 4;46	5	0s 0;24		...	
	...		9s 25;27	10	11s 10; 8
11s 18;41	7	0s 0;34		...	
	...		10s 6;55 <sup>i</sup>	19	0s 0; 5
6s 9;33	10	0s 0;48 <sup>f</sup>			
0s 19; 4 <sup>b</sup>	20	0s 1;35			
1s 8;12	40	0s 3;10			
	...			Months	
3s 5;30 <sup>c</sup>	100	0s 7;56 <sup>g</sup>	0s 25;49	1	0s 29; 6 <sup>k</sup>
6s 11; 0	200	0s 15;52	1s 21;38	2	1s 28;13
1s 28;45	250	6s 6;24		...	
0s 5;40 <sup>d</sup>	251	—	10s 9;48	12	11s 19;17
10s 28;49 <sup>e</sup>	270	—	11s 5;37	13	0s 18;23
8s 24;17	278	—	6s 12;55	half-month	6s 14;33
7s 1;15	279	—			
5s 8;12	280	—			
11s 17;45	290	—			
5s 27;18	300	—			
	...				
9s 20;48	400	—			
8s 22;11	520	—			

a. B, C, and M: 6s 20;52; A: 6s 20;22.

b. A and M: 0s 19;4; B and C: 0s 19;6.

c. A, C, and M; 3s 5;40; B: 4s 5;30.

d. A and M: 0s 5;40; B: 0s 8;40; C: 0s 5;42.

e. A and B: 10s 28;49; C: 2s 28;49; M: 10s 28;39.

f. A, B, and M: 0s 0;48; C: 0s 0;47.

g. B, C, and M: 0s 7;56; A: 0s 7;26.

h. B, C and M: 10s 9;48; A: 10s 9;47.

i. B and M: 10s 6;55; C: 10s 7;55; A illegible.

j. A, B, and M: 11s 16;14; C: 11s 16;54.

k. Corrected from 0s 29;15 in B and M; A: 0s 29;15; C: 0s 20;15.

#### Notes.

1. Despite the heading which suggests that the mean motions were taken from Ptolemy, in fact they were taken from the Parisian Alfonsine Tables, truncated to sexagesimal thirds.
2. In addition to the copy of this table on A 65b, there are similar tables for the Hebrew calendar on A 95a (anomaly only), and A 95b and M 68b (mean motion only). Most of the corresponding entries are the same as in Table JM 4.
3. The lunar mean motion in longitude computed from the Parisian Alfonsine Tables for 19y or 235 mean synodic months is  $254 \cdot 360^\circ + 0;4,53^\circ (= 13;10,35,1^\circ/d \cdot 235 \cdot 29;31,50,8,20d)$ , or approximately  $0;5^\circ$ , in agreement with the entry in Table JM 4 for 1 cycle.
4. The lunar mean motion in anomaly computed from the Parisian Alfonsine Tables for 19y or 235 mean synodic months is  $251 \cdot 360^\circ + 306;56,55^\circ (= 13;3,53,57^\circ/d \cdot 235 \cdot 29;31,50,8,20d)$ , or approximately  $306;57^\circ$ , in agreement with the entry in Table JM 4 for 1 cycle.
5. Worked example for lunar anomaly (B 5b, S 12):

If you wish to find the lunar anomaly at mean conjunction for Tishri [5274], enter 270 cycles and find 10s 28;39°; then enter 7 cycles and find 11s 18;41°, and opposite 10 years 9s 25;27°; the sum is 8s 12;47° [With S; B: 8s 12;41°].

According to the Parisian Alfonsine Tables for the mean conjunction of Tishri 5274 at the time derived from Table JM 1 (with a time difference between Toledo and Jerusalem of 2;36h), that is, for Aug. 30, 1513, 15;30h after noon (Toledo), the lunar anomaly was 253;34° (text 252;47°). So, the computation using the time of conjunction, based on the traditional Hebrew calendar does not produce agreement. On the other hand, at 14h after noon, the mean longitude of the Sun was 168;34° and that of the Moon was 168;32° (that is, 14h after mean noon is the time of mean conjunction according to the Parisian Alfonsine Tables), and the lunar anomaly was 252;45°, in close agreement with Table JM 4 (252;47°). Hence, Zacut found the lunar anomaly for mean conjunction at the time computed with the Parisian Alfonsine Tables, not at the time according to the traditional Hebrew calendar.

Table JM 5. B 7a. A 65a. M 54b.

Heading. Table [A and M add: for finding] the true [B om.: true] argument of latitude at the time of mean conjunction or opposition [i.e., the elongation of the mean Sun from the lunar node] in complete [19-year] cycles; after 48 complete cycles add  $3;9^{\circ}$  [M adds: from one cycle to the next cycle (add)  $7;34^{\circ}$ ]

Cycles	
Beginning of Creation <sup>a</sup>	8s 7;29°
49	8s 10;38
97	8s 13;47
145	8s 16;56
193	8s 20; 5
241	8s 23;14
242	9s 0;48
243 <sup>b</sup>	9s 8;22
...	
277	5s 25;38
278 <sup>c</sup>	6s 3;12
...	
300 <sup>d</sup>	11s 19;37
...	

- a. This row is in A and M; missing in B.
- b. In A, from here on the number of cycles is generally written in Arabic decimal numerals, rather than in Hebrew alphanumeric notation that is used elsewhere.
- c. B and M: 278; A has 277 in Hebrew alphanumeric notation and 278 in Arabic decimal numerals.
- d. B and M: 300; A: 301 in Arabic decimal numerals.

#### Notes.

1. The terminology in the heading is unusual: in fact, in Table JM 5 Zacut lists the elongation of the mean Sun from the lunar node, which is not what is generally meant “the argument of latitude”, that is, the elongation of the Moon from the lunar node: cf. *Almagest* V.4 (Toomer 1984, pp. 183–187); and John of Saxony’s canons to the Parisian Alfonsine Tables (Pouille 1984, p. 74). See the heading in Table MA 3.
2. The amount to be added in 48 cycles from the creation to cycle 49 is  $3;9^{\circ}$ , as indicated in the heading, and this applies to the rest of the table as well. The amount to be added for 1 cycle is  $7;34^{\circ}$ , which is consistent with the amount to be added in 48 cycles: if we divide  $363;9^{\circ}$  by 48, the result is  $7;33,56^{\circ} \approx 7;34^{\circ}$ .
3. The daily increment in the elongation of the mean Sun from the lunar node can be derived from this table as follows. In 19 years there are 235 mean synodic months of  $29;31,50,8,20d$ , and in this time the elongation exceeds 20 returns in longitude by  $7;33,56^{\circ}$ . Then the daily increment in the elongation is  $(20 \cdot 360^{\circ} + 7;33,56^{\circ}) / (235 \cdot 29;31,50,8,20d) = 1;2,18,57,43, \dots^{\circ}/d$ . In the Parisian Alfonsine Tables the daily mean motion of the Sun is  $0;59,8,19,37, \dots^{\circ}/d$ , and the daily mean motion of the lunar node is  $0;3,10,38,7, \dots^{\circ}/d$ ; hence, the daily elongation of the mean Sun from the lunar node is  $1;2,18,57,44, \dots^{\circ}/d$ , which is very close to the value derived from Table JM 5.

Table JM 6. B 7b–8a. C 64a. M 54a.

Heading. Table of the true argument of latitude at [each] mean conjunction [C adds: and opposition] for [each year in] a 19-year cycle [i.e., the elongation of the true Sun from the lunar node]

Year of the cycle	Tishri	Heshvan <sup>a</sup>	Kislev	Tevet	...	Elul
1	0s 0; 0°	1s 1; 3°	2s 2;35°	3s 4;22°		11s 7;46°
2	0s 8; 4	1s 8;54	2s 10;16	3s 11;59		11s 16; 1
3	0s 16; 8 <sup>b</sup>	1s 16;47 <sup>c</sup>	2s 17;58	3s 19;34 <sup>d</sup>		0s 24;20
4	1s 24;43	2s 25;45	3s 27;15	4s 29; 1		1s 2;35
5	2s 2;51	3s 3;37	4s 4;56	5s 6;38		1s 10;55
...						
11	5s 22;32	6s 23;10	7s 24;24	8s 26; 1		6s 0;41
...						
19	10s 28; 3	11s 29;32	1s 0;46	2s 2;26		11s 7; 0

a. B and M: Heshvan; C: Marheshvan.

b. B and C: 8; M: 18.

c. C and M: 47; B: 48.

d. C and M: 34; B: 33.

Notes.

1. The columns are headed by month names from Tishri to Elul, and there are 19 rows. In 7 of the 19 years there is an intercalary month, Adar II. This table is to be used together with the table JM 5, for finding the elongation of the true position of the Sun from the lunar ascending node, which is here called “the true argument of latitude”, at the time of the mean conjunction of each month in a 19-year cycle. As indicated in the notes to Table JM 5, Zacut’s terminology is unusual, for the argument of latitude generally refers to the elongation of the Moon from the lunar node.

2. Worked example for the argument of latitude (B 6b, S 13):

To find the argument of latitude for the conjunction of Tishri, [of the year] above [5274], I entered cycle 278 even though it is not complete and opposite it is 6s 3;12° [see Table JM 5]. I entered the month Tishri of year 11 of the cycle and opposite it is 5s 22;32° [as in the table, and MS S; MS B: 5s 23;32°]. I added them together and the true argument of latitude is 11s 25;44° [= 355;44°].

3. To recompute this value for the argument of latitude, we must first find the time of mean conjunction, and then compute the elongation of the true position of the Sun from the ascending node for that time. And we also need to convert the time in Jerusalem, used by Zacut, to the time in Toledo, used in the Parisian Alfonsine Tables. The difference in longitude between Toledo and Jerusalem is 39° or 2;36h (see Table JM 1, n. 7).

The time in Jerusalem is first given in hours after the beginning of the day, evening epoch, i.e., 6 pm of the day preceding the date given in tables for converting dates from the Hebrew calendar to the Julian calendar. And then Zacut converts the time from evening epoch to noon epoch earlier on the same day, by adding 6h.

4. We now offer a recomputation of the worked example. Tishri 1, 5274 AM (year 11 of 19-year cycle 278) = Sept. 1, 1513 (Thursday, beginning 6 pm Wednesday, August 31). According to the worked

example for Table JM 1, mean conjunction preceding Tishri 1, 5274 AM took place on Tuesday, Aug. 30, 1513, 18;6,33h [B 12b: 18;6½h] after noon Jerusalem time, corresponding to about 15;30 hours after noon on Aug. 30, 1513, Toledo time, or 15;41h after noon, Salamanca time. Indeed, 0;11h represents the time difference between Toledo and Salamanca, corresponding to 2;44°: Chabás and Goldstein 2000, p. 103. The longitudes according to the Parisian Alfonsine Tables for Aug. 30, 1513, 15;41h, are: (1) mean solar longitude 168;38°; (2) true solar longitude 166;32° (3) node 170;48°; and (4) elongation of the true Sun from the ascending node 355;44°, in exact agreement with the worked example for Table JM 6.

This result for Salamanca is confirmed by the entries in the *Tabule verificate*, TV 10: “Table for the solar elongation from the lunar node” (Chabás and Goldstein 2000, pp. 29–30). Entry for 1513, 169;13°; entry for August 30, 185;51°; entry for 15;41h, 0;40°; sum 355;44°, in exact agreement with the worked example for Table JM 6.



Table JM 7. B 8b. C 65a. A 66a. M 55b.

Heading. First correction: Table for the correction of the Sun [A and M: center of the Sun] when the Moon is at the perigee of its epicycle, in hours and minutes.

Subtract					
Degrees	3s	4s	...	8s	Degrees
1	0; 4h	1;53h		1;54h	29
2	0; 8	1;57		1;50	28
3	0;12	2; 0		1;47	27
4	0;16	2; 3		1;43	26
5	0;19	2; 6		1;39	25
...					...
10	0;38	2;22		1;20	20
...					...
15	0;56	2;36		1; 1	15
...					...
20	1;15	2;49		0;42	10
...					...
25	1;32	3; 1		0;21	5
...					...
30	1;50	3;14		0; 0	0
	2s	1s	...	9s	
Add					

Notes.

1. There are no variants in the entries.

2. This is the first of three tables for determining the time from mean to true conjunction, based on Nicholaus de Heybech's table: see Tables JM 8 and JM 9 (below). For discussion of this table, see Goldstein and Chabás 2008, pp. 350–351. For similar tables, see TV 7 and TV 8: Chabás and Goldstein 2000, pp. 28–29.

Table JM 8. B 9a. C 65b. A 66b. M 56a.

Heading. Second Correction. Table for the correction of lunar anomaly, in hours and minutes

A adds: Table of the late R. Abraham Zacut

M adds: Tables of the late R. Abraham Zacuto

Add						
Degrees	0s	1s	2s	...	5s	Degrees
0	0; 0h	4;59h	8;32h		4;43h	30
1	0;11	5; 8	8;37		4;34	29
2	0;22	5;17	8;42		4;25	28
3	0;33	5;26	8;46 <sup>a</sup>		4;16	27
4	0;43	5;35	8;51		4; 7	26
5	0;53	5;44	8;55		3;58	25
...						...
10	1;44	6;23	9;12		3;13	20
...						...
15	2;36	7; 1	9;27		2;25	15
...						...
20	3;25	7;34	9;36		1;39 <sup>a</sup>	10
...						...
25	4;13	8; 4	9;42		0;50	5
...						...
30	4;59	8;32	9;42		0; 0	0
	11s	10s	9s	...	6s	
Subtract						

a. A, C, and M: 8;46; B: 8;42.

b. B, C, and M: 1;39; A: 1;59.

Note.

1. This table is for the second of three correction tables for the time from mean to true syzygy, based on the table of Nicholaus de Heybech. For discussion of this table, see Goldstein and Chabás 2008, pp. 351–352.

Table JM 9. B 9b. C 66a. M 56b. A 67a.

Heading. Third correction: Table for correcting the solar center and the [lunar] anomaly for all values of the degrees of the Moon in all signs of the anomaly, and it is to be added to [the value at] the perigee of the [lunar] epicycle; a combined [*meh<.>uberret*] table [that is, a double argument table]  
 [A adds: Table of the late R. Abraham Zacut]

		subtract									
		Solar center									
Lunar anomaly		3s 0° (min.)	3s 15° (min.)	4s 0° (min.)	4s 15° (min.)	...	6s 0° (min.)	6s 15° (min.)	...	8s 15° (min.)	9s 0° (min.)
0s 0°	12s 0°	0	15	29	41		60	58		16	0
0s 10	11s 20	0	15	29	40		59	57		15	0
0s 20	11s 10	0	14	28 <sup>a</sup>	40		58	56		15	0
1s 0	11s 0	0	14	28	39		56	55		15 <sup>b</sup>	0
...											
3s 0	9s 0	0	8	16	23		33	32		9	0
3s 10	8s 20	0	7	14	20		28	27		8 <sup>c</sup>	0
3s 20	8s 10	0	6	11	16		23	22		7	0
...											
5s 20	6s 10	0	0	0	1		1	1		1	0
6s 0	6s 0	0	0	0	0		0	0		0	0
		3s 0°	2s 15°	2s 0°	1s 15°	...	0s 0°	11s 15°	...	9s 15°	9s 0°
		add									

a. A, B, and M: 28; C: 29.

b. A, B, and C: 15; M: 9.

c. A, B, and M: 8; C: 5.

Notes.

1. The headings for the columns specify “minutes of an hour”.

2. This is the third table for correcting the time from mean to true syzygy (see tables JM 7 and JM 8, above). For discussion of this table, see Goldstein and Chabás 2008, pp. 352–354.

Table JM 10. B 10a. C 66b. M57a. A 67b.

Heading. Table for correcting the days and the nights, always to be added [i.e., the equation of time]

degrees	Ari	Tau	Gem	Cnc	Leo	Vir	Lib	Scor	...	Psc
	min	min	min	min	min	min	min	min		min
0	8	18	22	17	12	15	24	31		1
2	9	19	22	17	12	16	25	31		1
4	10 <sup>a</sup>	19	22	17 <sup>b</sup>	12	16	25	31		1
6	10	20	22	16	12	17	26	32		2
8	11	20	22	16	12	17 <sup>c</sup>	27	32		2
10	12	21	21	15	12	18	27	32		3
...										
20	15	22	20	14	13	21	30	30		6
...										
30	18	22	17	12	15	24	31	28		9

a. C, M, and A: 10; B: 11.

b. C, M, and A: 17; B: 16.

c. C, M, and A: 17; B: 18.

Notes.

1. Another table for the equation of time is found in Table MA 11 with intervals of 10°; the entries do not agree with those in Table JM 10.

2. The maximum is 0;32h at Scor 6° to Scor 10°; the minimum is 0;0h at Aqr 12° to 26°. Cf. Zacut's table for the equation of time in his tables for 1473, where the argument is the day of the year (Chabás and Goldstein 2000, p. 108); see also TV 9. The entries in Table JM 10 agree with those for the equation of time in the *zij* of al-Battānī, the Toledan Tables, and the Parisian Alfonsine Tables (all three of which have the same entries), except that here they are given in minutes of time whereas in the other sets of tables they are given in degrees, where 1° = 0;4h. For example, the maximum value in Table JM 10 is 0;32h which corresponds to 7;54° in the aforementioned sets of tables (Chabás and Goldstein 2012, pp. 37–41).

Tables JM 11. B 10b. M 59b. A 71a.

Heading. Table for a solar eclipse at mean distance

Minutes of apparent latitude	Eclipsed part of the solar diameter in digits and minutes	Half-duration of the eclipse (min)
0	11;46	55
1	11;22	55
2	10;57	55
3	10;32	55
4	10; 7	55
5	9;42	54
6	9;17	54
...		
27	0;32	13
28	0; 7 <sup>a</sup>	3
29	0; 0	0

a. B and M: 7; A: 3.

Note.

1. Table JM 11 for solar eclipses is the same as Table TV 15, but for the interval in the argument (Chabás and Goldstein 2000, pp. 32–33). In Table TV 15 the argument is given at intervals of half a minute in contrast to Table JM 11 where the argument is given at intervals of one minute. Table AP 15 has the same intervals as Table JM 11 and the same entries, but for variant readings (see Table AP 15A in Chabás and Goldstein 2000, p. 125). For another copy, see Table HG 19 (Chabás and Goldstein 2000, p. 62).

Table JM 12. B 10b. M 59b. A 71a.

Heading: Table for lunar eclipses at mean distance according to the opinion of R. Jacob Po<sup>e</sup>el

Argument of latitude		The eclipsed part of the lunar diameter	Half-duration of the eclipse	Minutes of half totality
0s/6s	5s/11s			
12; 0°	18; 0°	0; 0d	0; 0h	0
11;30	18;30	0;59	0;31	0
11; 0	19; 0	1;58	0;43	0
10;30	19;30	2;58	0;53 <sup>a</sup>	0
10; 0	20; 0	3;58	1; 1	0
9;30	20;30	4;58	1; 7	0
9; 0	21; 0	5;58	1;12	0
8;30	21;30	6;59	1;17	0
...				
5;30	24;30	13; 2	1;37 <sup>b</sup>	22
...				
1; 0	29; 0	22;10	1;49	55
0;30	29;30	23;10	1;49	55
0; 0	30; 0	24;12	1;49	55

a. M and A: 53; B: 43.

b. B and A: 37; M: 36.

Notes.

1. On B 10b this table is divided into two parts: the first part displays entries from 12;0°/18;0° to 5;30°/24;30°, and the second part is upside down and displays entries from 5;0°/ 25;0° to 0;0°/30;0°.

2. The reference to Jacob ben David Po<sup>e</sup>el (fourteenth century: otherwise known as Bonjorn) is also in the heading to Table HG 20 (Chabás and Goldstein 2000, p. 62). Zacut's source for this table was Bonjorn's corresponding table, which he copied (Chabás 1992, p. 251). On Bonjorn's contributions to astronomy, see Chabás 1991.

3. Table JM 12 for lunar eclipses is the same as Table AP 16 and Table HG 20, but for variant readings (Chabás and Goldstein 2000, p. 127; cf. Cantera 1935, p. 136). The same table is also found in Table TV 16 but, in contrast to the other copies where the argument is at intervals of 0;30°, here the argument is at intervals of 0;5° (Chabás and Goldstein 2000, p. 33).

Table JM 13. B 11a. A 69a. M 59a.

Heading: Table for solar eclipses

A and M add: Tables of R. Abraham Zacut [M: Zacuto]

Arg. of lat. north	Exact lunar latitude	Arg. of lat. south
0s // 5s		6s // 11s
0; 0°// 0; 0°	0; 0, 0°	0; 0°// 0; 0°
0;30 //29;30	0; 2,21	0;30 //29;30
1; 0 //29; 0	0; 4,42 <sup>a</sup>	1; 0 //29; 0
1;30 //28;30	0; 7, 3 <sup>b</sup>	1;30 //28;30
...		...
6; 0 //24; 0	0;28,11 <sup>c</sup>	6; 0 //24; 0
...		
17; 0 //13; 0	1;18,48 <sup>d</sup>	

a. A and M: 0;4,42; B: 0;30,42.

b. A and M: 0;7,3; B: 0;7,6.

c. A and M: 0;28,11; B: 0;28,12.

d. A and M: 1;18,48; B: 1;16,48.

Notes.

1. The expression for the argument of latitude (here meaning the elongation of the Moon from the lunar node)  $h\langle.\rangle oq\ ha\text{-}merh\langle.\rangle av$  is the same expression used in Tables JM 5 and JM 6 for the elongation of the Sun from the lunar node.

2. Table JM 13 is a table for finding lunar latitude from the argument of latitude, where the maximum value of the lunar latitude is  $4;30^\circ$ . The argument is given at intervals of  $0;30^\circ$ . Levi ben Gerson's corresponding table (Goldstein 1974, p. 212, col. VI) has entries at intervals of  $1^\circ$ : the entries common to Levi's table and those here agree.

3. TV 14 is the same table with the same limits ( $17;0^\circ$  for northern argument of latitude and  $6;0^\circ$  for southern) but the entries are given at intervals of  $0;15^\circ$ . The entries common to TV 14 and those here agree.

4. Table JM 13 is intermediate between Levi's table and TV 14, as far as precision is concerned.

Table JM 14. B 11a. MS A 69a. M 59a.

Heading: The eclipsed part of the surface of the luminaries [i.e., area digits of eclipse]

Digits of the diameter	Surface of the Sun	Surface of the Moon
1	0;22	0;30
2	1; 0	1;10
3	1;50	2; 5
4	2;40	3;10
...		
12	12; 0	12; 0

Note.

1. Table JM 14, as indicated in Chabás and Goldstein 2012, pp. 174–175, is a table for the area digits of eclipse in the tradition of al-Battānī, not in what has been called the “common tradition”. In TV 13 the entry for the area digits of the Moon corresponding to 3 linear digits is 2;50 (rather than 2;5 in Table JM 14, which agrees with al-Battānī: Nallino 1903–1907, 2:89).



Table JM 15. B 11b–12a. A 69b–70b. C 67a–68a. M 57b–58b.

Heading. Table for parallax for the latitude of Jerusalem, 32°, and longest daylight 14;16h

Cancer 3[s] <sup>a</sup>			
hours	corr. for the time	par. in long.	par. in lat.
7; 8	1;20h	44'	32'
7; 0	1;20	44	32
6	1;22	45	31
5	1;26	47 <sup>d</sup>	28
4	1;24	46	22
3	1;14	41	18
2	0;54	30	13
1	0;31	17	10
Noon	0; 0 midheaven	0	8
1	0;31	17	10
2	0;54	30	13
3	1;14 <sup>b</sup>	41	18
4	1;24	46	22
5	1;26	47 <sup>d</sup>	28
6	1;22	45	31
7; 0	1;20 <sup>c</sup>	44	32
7; 8	1;20	44	32
Cancer 3[s] <sup>a</sup>			

- a. C: 3; MS B: 4; A and M: om.  
 b. A and M: 1;14; B and C: 0;14.  
 c. A, C, and M: 1;20; B: 1;22.  
 d. A, and M: 47; B and C: 46.

Notes.

1. The heading is missing in B.
2. In addition to the subtable for Cancer displayed here, there are subtables for all the other zodiacal signs.
3. There are two columns for parallax in longitude, the first is expressed in time, and the second (equivalently) in minutes of a degree of longitude. The entry for time can be computed from the entry in longitude divided by about 0;32,56°/h, the hourly lunar velocity, e.g., 1;20h = 44/32;56 (see the entries for 7;8h). The inclusion of a column for time in parallax tables is characteristic of followers of Levi ben Gerson (Chabás and Goldstein 2012, pp. 132–133). As far we know, Zacut was the only other astronomer to present a table where the parallax in longitude is given both in time and in degrees (Chabás and Goldstein 2000, pp. 31–32 [TV 12], 122–124 [AP 14], both for Salamanca).

#### IV. Additional tables in MS A

Two mean motion tables are based on the Julian calendar with epoch 1473, the epoch of Zacut's *Almanach Perpetuum* (MA 1, MA 2); two are based on the Julian calendar with epoch 1501 (MA 3, MA 5); and one depends on the Hebrew calendar (MA 4). These two tables with epoch 1473 are not found in

Zacut's *Almanach Perpetuum*, but they are closely related to them and to the *Tabule verificate*, which are also due to Zacut (see Part I, above). The tables for epoch 1501 are certainly by Zacut, and they are still computed for Salamanca, even though in 1501 Zacut was living in North Africa. Table MA 4 is based on the Hebrew calendar and recasts the same information found in Tables MA 2 and MA 3 for the Julian calendar. The mean motion tables were all derived from the Parisian Alfonsine Tables. There are no surprises in the remaining tables, but it is of interest that Table MA 8 has an unusual presentation. A peculiar feature of this manuscript is that several tables appear more than once; we have no explanation for this. In MS M there are copies of two of these additional tables (see Tables MA 3, MA 4); and in MS C there is a copy of one of these tables (see Table MA 12).

#### Table of Contents:

- MA 1. Mean motions of the planets for each year up to 32 Julian years, epoch 1473.
- MA 2. True ascending node for 32 consecutive Julian years, epoch 1473.
- MA 3. Table of the motion of the true Sun from the ascending node, and table of the lunar ascending node in 56 Julian years, epoch 1501.
- MA 4. Table of the ascending node in the Hebrew calendar: after each cycle of 48 times 19 years subtract  $0;40^\circ$ .
- MA 5. Table for the solar center and the lunar anomaly for 76 Julian years, epoch 1501.
- MA 6. Table for the corrections of center for the five planets and the Moon.
- MA 7. Table for the corrections of anomaly for the five planets and the Moon.
- MA 8. Double argument table for correcting the lunar position.
- MA 9. Table for the solar declination and lunar latitude.
- MA 10. Table of the stationary points for each planet.
- MA 11. Table for the equation of time.
- MA 12. True lunar anomaly in days after syzygy.

Table MA 1. A 84a-b and A 59a, 60a

Heading. [Mean motions of the planets for each year up to 32 years]

	mean	mean	...	[mean]	...	[mean]	[mean]
	Sun: after 32 years add 0s 0;14,8°	Saturn: after 32 years add 1s 1;30,35°		Venus: after 32 years add 0s 5;50,9°		Moon: after 32 years add 9s 15;42,2°	Lunar anomaly: after 32 years add 2s 3;35,6°
years	apogee 3s 0;56, 0°	apogee 8s 12;54, 0°		apogee 3s 0;56, 0°		—	—
1	11s 17;19,32°	2s 25;31, 3°		2s 14;12, 4°		0s 2;32,25°	9s 24;51, 0°
2	11s 17; 5,11	3s 7;44,38		9s 29;13,45		4s 11;55,28	0s 23;34, 0
3	11s 16;50,50	3s 19;58,13		5s 14;15,26		8s 21;18,31	3s 22;17, 0
4	11s 17;21,18	4s 20;13,48		0s 29;54, 7		1s 13;52, 9	7s 4; 4, 0
...							
32	11s 17;47, 0	3s 14;48, 7		7s 5; 0,28		5s 8;51,26	8s 29;43, 0

Notes.

1. The same table appears in MS A twice, with no heading.

2. There are subtables for Julian months, beginning with March (A 61a, 85a); for days (A 62a, 63a, 85b, 88a); and for hours (A 63b–64a, 88b–89a).

2. To confirm the values of the apogees and the entries for year 1 in Table MA 1 we recompute them according to the Parisian Alfonsine Tables for Feb. 28, 1473, 0;1h after noon, and obtain the following results, in agreement with the text:

	Apogees	mean motion
Sun	90;56°	347;19°
Saturn	252;54	85;31
...		
Venus, anomaly	90;56	74;12
...		
Moon	—	2;32
Lunar anomaly	—	294;51

3. To confirm the increments after 32 years at the head of the columns in Table MA 1, we compute the values according to the Parisian Alfonsine Tables for Feb. 28, 1505, 0;1h after noon, and obtain the following results, in agreement with the text:

	mean motion	Increment after 32 years (1505 – 1473)
Sun	347;33°	0;14°
Saturn	117; 2	31;31
...		
Venus, anomaly	80; 2	5;50

...		
Moon	288;15	285;43
Lunar anomaly	358;26	63;35

4. It follows from notes 2 and 3 that the mean motions and the apogees are the same as those in the Parisian Alfonsine Tables.

Table MA 2. A 89a, 63b.

Subtable 1. Heading. [True ascending node for 32 consecutive years, and true ascending node in days]

True ascending node	After 32 years <sup>a</sup> , add 3s 11;4 <sup>o</sup>	True ascending node in days	
years		days	
1	7s 24;11 <sup>o</sup>	1	11s 29;57 <sup>o</sup>
2	7s 4;52	2	11s 29;54
3	6s 15;32 <sup>b</sup>	3	11s 29;50
4	5s 26; 9 <sup>c</sup>	4	11s 29;47
5	5s 6;49	5	11s 29;44
...		...	
...		30	11s 28;25
32	11s 24;35		

a. A 89a adds: of the Moon.

b. With A 63b and Zacut 1496, 62r; A 89a: 5s 15;32.

c. With A 63b and Zacut 1496, 62r; A 89a: 6s 26;9.

Notes.

1. There is no heading in A 89a or in A 63b.

2. According to the Parisian Alfonsine Tables, the longitude of the lunar node on Feb. 28, 1473 was 7s 24;11,27<sup>o</sup>, in full agreement with the entry in this table for year 1, and on Feb. 28, 1505, it was 33s;15,41<sup>o</sup>, or 101;4,14<sup>o</sup> greater than 32 years earlier, in agreement with the value at the head of the column.

3. Table AP 11 (= HG 12) is a similar table for 93 years, where the first 32 entries agree with those here (Chabás and Goldstein 2000, p. 117; Zacut 1496, 62r). Table TV 11 lists the longitudes of the ascending node for 56 years, where the first entry corresponds to the day preceding March 1, 1461 (Chabás and Goldstein 2000, p. 30).

4. The entry for day 1 is 11s 29;57<sup>o</sup>, the complement in 360<sup>o</sup> of the motion of the lunar ascending node in a day. Hence, the expression “true ascending node” refers to the complement in 360<sup>o</sup>. See Table AP 11 (Chabás and Goldstein 2000, p. 117), where the same terminology is employed, and the same entries are given for years (1 to 32, of the 93 years in AP 11), months, and days. Since the motion of the ascending node is retrograde, it was often displayed with increasing longitude, and an instruction in the canons to subtract the tabulated value from 360<sup>o</sup>.

Subtable 2. Heading. True ascending node in months

months	
March	11s 28;22 <sup>o</sup>
April	11s 26;46
May	11s 25; 8
...	
February	11s 10;40

Note.

1. The subtables for months and days appear again on A 93a, with no variants.

Table MA 3. A 92b, M69a; A 91b–92a, 93a.

Subtable 1. A 92b (1). M 69a.

Heading. Table of the true motion of the Sun from the ascending node, and the lunar ascending node in 56 years

years	Arg. of lat.	Asc. node		years	Arg. of lat.	Asc. node
1	9s 27; 2°	1s 22;37°		29	3s 28;48°	7s 21; 4°
2	10s 16; 7	1s 3;18		30	4s 17;52	7s 1;45
3	11s 5;13	0s 13;58		31	5s 6;28	6s 12;25
...				...		
28	3s 9;45	8s 10;24		56	9s 11;30	2s 8;50

Notes.

1. The years in column 1 are years in the Julian calendar.
2. Column 2 lists the elongation of the true Sun from the ascending node which, as we learn from the heading of the subtable 2, is what Zacut called the true argument of latitude.
3. Similar tables for the elongation of the true Sun from the node in 56 years appear in AP 12 (epoch Feb. 28, 1473), TV 10, and HG 15 (Chabás and Goldstein 2000, pp. 29–30, 62, 118–119).
4. Column 3 lists the positions of the true lunar node for Julian years; the same information is given in Table MA 2.
5. Although the epoch of this table is not specified, it is Feb. 28, 1501, 28 years after 1473, the epoch of Zacut's *H<.>ibbur*, that is, the first entry in column 2 of this table, 9s 27;2°, is the same as the entry for year 29 in AP 12, where year 29 in AP 12 is 1501. The entries for the ascending node also agree with the Parisian Alfonsine Tables. There is one other table with epoch 1501: see Table MA 5, below.

Subtable 2. A 92b (2).

Heading. [Table for] the [true] motion of the Sun in argument of latitude in hours

Entries from 1h (0;3°) to 24h (1;2°). However, in Subtable 3, the entry for 1 day is 1;3°; for the underlying parameter, see Subtable 3, note 1.

Subtable 3. A 91b–92a.

Heading. Table for the true motion of the Sun from the ascending node, and this is the true argument of latitude

Days	March 0s	April 1[s]	...	Feb. 11s
1	1; 3°	3; 8		20;36°
2	2; 5	4; 4		21;41
3	3; 8	5;12		22;45
...				

29	[1s] [0]; 4	2s 1;39		0s 20; 8
30	[1]; 5	2;40		0; 0
31	[2]; 7	0; 0		0; 0

Notes.

1. The daily motion in this “elongation” with the parameters of the Parisian Alfonsine Tables is  $0;59,8,19^{\circ}/d + 0;3,10,38^{\circ}/d = 1;2,18,57^{\circ}/d$ . The entry for Feb. 29 (= day 366) is then  $366 \cdot 1;2,18,57^{\circ}/d = 360 + 20;7,36^{\circ} \approx 20;8^{\circ}$ , as in the table. Other entries, however, were not accurately computed.

Subtable 4. A 93a (1)

Heading. [Motion of] the ascending node in months [beginning with March]

Subtable 5. A 93a (2)

Heading. [Motion of] the ascending node in days [from 1 to 30]



Table MA 4. A 94b–95a. M 67b–68a.

Subtable 1. A 94b, M 67b. Heading: Table of the ascending node: [after] each cycle of 48 [times 19 years] subtract  $0;40^\circ$

M adds: Tables of the late Abraham Zacuto

Beginning of cycles	
Beginning of Creation	2s 23;12°
49	2s 22;32
97	2s 21;52
145	2s 21;12
193	2s 20;32
241	2s 19;52
242	2s 27;21
243	3s 4;50
244	3s 12;19
245	3s 19;48
246	3s 27;18
...	
306	6s 26;27
307	7s 3;56

Notes.

1. The years in the first column are years in the Hebrew calendar. The entries are at intervals of 48 cycles from the Creation to cycle 241, and then at intervals of 1 cycle from cycle 241 to 307.

2. For 1 cycle of 19 years, the line-by-line difference is  $7;29^\circ$  or  $7;30^\circ$ . For 48 cycles of 19 years the line-by-line difference is  $0;40^\circ$ , as indicated in the heading; hence,  $359;20^\circ/48 = 7;29,10^\circ$ . With the parameter in the Parisian Alfonsine Tables for the daily motion of the node,  $0;3,10,38,7,14,\dots^\circ/d$ , the motion in a 19-year cycle is  $367;29,10^\circ (= 7;29,10^\circ)$ , which is the value derived from the entries in this table.

3. There is another table in the same manuscript for the motion of the node in Julian years: see Table MA 3 (A 92b).

Subtable 2. A 95a (1). M 68a.

Heading. [Table of the ascending node]<sup>a</sup>

Years of a cycle	Ascending node for years of a cycle	Months	Ascending node for months	Days	Ascending node for days
1	0s 18;46 <sup>o</sup>	1	0s 1;34 <sup>o</sup>	1	0s 0; 3 <sup>o</sup>
2	1s 7;32	2	0s 3; 8	3	0s 0; 9
...		...		5	0s 0;16
...		...		...	
...		11	0s 17;13	...	
...		12	0s 18;46 <sup>b</sup>	...	
19	0s 7;29			...	
				29	0s 1;31
				30	0s 1;35

a. There is no heading for this table in A; the heading in M is only: Tables of the late Abraham Zacuto.

b. Read: 18;46 (MSS: 18;19).

Note.

1. The years in column 1 are years in a cycle of 19 years in the Hebrew calendar; the numbered months refer to the months in the Hebrew calendar.

Table MA 5. A 93a–94a.

Subtable 1. A 93b. Heading. Table for the solar center and the lunar anomaly for 76 years

			AP 9	
years	center	anomaly	years	anomaly
1	8s 16;20°	11s 20;30°	29	11s 20;30°
2	8s 16; 5	2s 19;13	...	
3	8s 15;50	5s 17;26		
4	8s 16;35	8s 29;43		
5	8s 16;20	11s 28;27		
6	8s 16; 5	2s 27;10		
7	8s 15;50	5s 25;22		
8	8s 16;35	9s 7;39		
9	8s 16;20	0s 6;23		
10	8s 16; 5	3s 5; 6		
...			...	
65 <sup>a</sup>	8s 16;16	3s 27;40	93	3s 27;40
--	8s 16; 1	6s 26;23	94	6s 26;23
66	8s 15;46	9s 25; 6	95	9s 25; 6
67	8s 16;31 <sup>b</sup>	1s 6;53	96	1s 5;53
...				
74	8s 15;45	10s 11; 0	103	10s 11; 0
75	8s 16;30	1s 22;47	104	1s 22;47
76	8s 16;15	4s 21;31	105	4s 21;31
77	8s 16;– <sup>b</sup>	–	106	7s 20;14

a. After year 65, the year numbers have been shifted one row down.

b. Read: 8s 16;0 (MS: 8s 16).

#### Notes.

1. The entries for the solar center have been checked with TV 6, and those for the lunar anomaly with TV 5 (= AP 9): see Chabás and Goldstein 2000, pp. 26–28, 115–116. According to the Parisian Alfonsine Tables, on Feb. 28, 1501, noon, Salamanca, the solar center was 256;20°, which agrees with the entry in this table, and the lunar anomaly was 350;29°, which is very close to the entry in this table. The entries in Table AP 9 are displayed here for comparison with those in Table MA 5.

2. Year 1 in this table is year 29 in AP 9 (= 1473 + 28) = 1501, that is, the difference between the corresponding entries in the column for years is 28.

3. The entries in TV 6 begin with noon of the day preceding Jan. 1, 1461 (6s 18;11°) and were all computed using the Parisian Alfonsine Tables (Chabás and Goldstein 2000, p. 26); the first entry for the solar center in this table corresponds to the entry in TV 6 for year 41, that is, 1501. According to TV 6, for January and February one should add 1s 28;9° in a non-leap year, which is the case for 1501. Adding 6s 18;11° to 1s 28;9° results in 8s 16;20°, which is exactly the entry for year 1, understood here as noon of the day preceding March 1, 1501.

4. There is one other table in MS A with epoch 1501: see Table MA 3, above. An anonymous table for New Moons for a period of 76 years, beginning in 1501, is probably also due to Zacut: see Goldstein 2013. We are not aware of any other tables with this epoch.

Subtables 2 and 3. A 93a (not transcribed). These subtables with the same format as subtable 1 are for months beginning in March (although in the column headed “months” all the entries are blank); and for minutes of an hour at intervals of 5 minutes.

Subtables 4 and 5. A 94a (not transcribed). These subtables with the same format as subtable 1 are for days of the month from 1 to 30; and for hours from 1 to 24.

Table MA 6. A 89b.

Heading. Table for the corrections of center and the minutes of proportion (excerpt)

Center	Sun and Venus		Saturn	...	Moon	
	corr.	min. of prop.	corr.		corr.	min. of prop.
0s 0°	0; 0°	60 far	0; 0		0; 0	0 near
...						
3s 0°	2;10	2	6;31			
3s 5°	2;10	6				
...						
3s 25°					13; 9	40
...						

Notes.

1. The columns for Jupiter, Mars, and Mercury have not been transcribed.
2. The argument is at 5° intervals for 0s 0° to 6s 0° and for 6s 0° to 12s 0°.
3. Saturn and Jupiter have no column for minutes of proportion.
4. For the Moon, the argument, here called “center”, is the double elongation. Zacut has accepted the terminology of the Parisian Alfonsine Tables, where col. 3 is labeled *aequatio centri* (Ratdolt 1483, e4r–e6v).
5. The entries for all the planets agree with the corresponding entries in the Parisian Alfonsine Tables, although in some cases there is a difference of 0;1°.

Table MA 7. A 90a–b.

Heading. Table for the corrections of the anomalies (excerpt)

anomaly	Saturn			...	Venus			...	Moon	
	farthest	mean	closest		farthest	mean	closest		correction for anomaly <sup>a</sup>	closest <sup>b</sup>
0s 5°	0; 2°	0;30°	0; 2°		0; 1°	2; 6°	0; 1°		0;24°	0;12°
0s 10	0; 3	1; 0	0; 4		0; 2	4;11	0; 3		0;47	0;24
...										
3s 0									4;55	2;37
3s 5	0;20	6;13	0;24						4;56	2;38
3s 10									4;55	2;39
3s 15									4;51	2;40
...										
4s 15					1;10	45;59	1;15			
...										

- a. In the Parisian Alfonsine Tables this column is headed *Aequatio argumenti*, with precision to seconds.
- b. In the Parisian Alfonsine Tables this column is headed *Diversitas 45iametric*.

Notes.

1. Displayed here are the first two entries in each column plus the maximum corrections for anomaly at mean distance for Saturn and Venus, and the maximum entries for the Moon. Those for Jupiter, Mars, and Mercury have been omitted, but they have the same structure and agree in the same way with the corresponding entries in the Parisian Alfonsine Tables.
2. Some of the headings for the columns have been displaced, but the entries are all in their proper order.
3. The headings, farthest, mean, and closest, refer to the distance of the epicycle from the observer: cf. *Almagest*, V.8 and XI.11 (Toomer 1984, pp. 238, 549–553) and the Parisian Alfonsine Tables (Ratdolt 1483, e4r–g5v), where the corrections for both anomaly and center appear in columns in the same table for each planet.
4. The argument is at 5°-intervals of anomaly from 0s 5° to 6s 0° and from 6s 0° to 11s 25°. The agreement with the Parisian Alfonsine Tables is very good, although some corresponding entries differ by 0;1°.

Table MA 8. A 86a.

Heading: Table for correcting the lunar anomaly in degrees and minutes

anomaly	signs of the center						
	0[s] 0	1[s] 0	2[s] 0	3[s] 0	4[s] 0	5[s] 0	6[s] 0
0s 0°	0; 0°	0; 0°	0; 0°	0; 0°			0; 0°
0s 5	0;24	0;24	0;27	0;30			0;36
0s 10	0;47	0;48	0;52	0;59			1;11
0s 15	1;11	1;13	1;18	1;28			1;46
...							
1s 0	2;17	2;20	2;30	2;52	3; 6	3;21	3;27
...							
2s 0	4; 5	4;11	4;30	5; 6	5;31	5;58	6; 8
2s 5	4;18	4;24	4;44	5;23			6;28
...							
3s 0	4;55	5; 3	5;26	6;13	6;45	7;19	7;32
3s 5	<b>4;56</b>	5; 4	5;27	6;15			<b>7;34</b>
3s 10	4;55	5; 3	5;27	6;14			<b>7;34</b>
3s 15	4;51	4;59	5;23	6;11			7;31
...							
4s 0				5;42			
...							
5s 0				3;27			
...							
5s 25	0;29	0;30	0;33	0;38			1;48

Notes.

1. This is a double argument table for finding the lunar equation as a function of true anomaly and center, where center refers to the double elongation of the Moon from the Sun. The maximum entries for 0° of double elongation (4;56°) and 180° of double elongation (7;34°) agree with the corresponding values in the Parisian Alfonsine Tables: cf. Ratdolt 1483, e4r–e6v.

2. To compute an entry according to the Parisian Alfonsine Tables, let  $c(\alpha, \kappa)$  be an entry in the table, where  $\alpha$  is the true anomaly,  $\kappa$  is the double elongation,  $c_3(\kappa)$  is the entry in column 3,  $c_5(\alpha)$  the entry in column 5, and  $c_6(\alpha)$  the entry in column 6 in the Parisian Alfonsine Tables for correcting lunar positions. Then

$$c(\alpha, \kappa) = c_6(\alpha) + c_3(\kappa) \cdot c_5(\alpha).$$

For 60° of anomaly, this formula becomes

$$c(60^\circ, \kappa) = 4;5^\circ + c_3(\kappa) \cdot 2;3^\circ.$$

Then

$$c(60^\circ, 0^\circ) = 4; 5^\circ (= \text{Text})$$

$$\begin{aligned}
c(60^\circ, 30^\circ) &= 4;11^\circ \text{ (= Text)} \\
c(60^\circ, 60^\circ) &= 4;30^\circ \text{ (= Text)} \\
c(60^\circ, 90^\circ) &= 4;58^\circ \text{ (Text 5;6)} \\
c(60^\circ, 120^\circ) &= 5;33^\circ \text{ (Text 5;31)} \\
c(60^\circ, 150^\circ) &= 5;58^\circ \text{ (= Text)} \\
c(60^\circ, 180^\circ) &= 6; 8^\circ \text{ (= Text)}
\end{aligned}$$

The discrepancy in the entry for  $90^\circ$  of double elongation is found in the entire column for  $90^\circ$  of double elongation. Since the entries in this column are internally consistent, they must have been computed by a different formula or the same formula with different parameters. Let us consider the formula

$$c(\alpha, 90^\circ) = c_6(\alpha) + 0;30 \cdot c_5(\alpha),$$

where  $c_3(90^\circ)$  is taken to be  $0;30$  (as in the tables of Levi ben Gerson) rather than  $0;26$  (as in the Parisian Alfonsine Tables). Then

$$\begin{aligned}
c(30^\circ, 90^\circ) &= 2;52 \text{ (= Text)} \\
c(60^\circ, 90^\circ) &= 5; 6 \text{ (= Text)} \\
c(90^\circ, 90^\circ) &= 6;13 \text{ (= Text)} \\
c(120^\circ, 90^\circ) &= 5;42 \text{ (= Text)} \\
c(150^\circ, 90^\circ) &= 3;27 \text{ (= Text)}
\end{aligned}$$

We conclude that for computing the entries in the column for  $90^\circ$  of double elongation,  $c_3(90^\circ) = 0;30$  was used rather than  $0;26$  as in the Parisian Alfonsine Tables. This is indeed very strange, but we have no explanation to offer. We note that column 3 in the Parisian Alfonsine Tables, called “minutes of proportion”, is for interpolation; in Levi ben Gerson’s lunar correction table (based on a different model for lunar motion), the corresponding column for interpolation has an entry of  $0;30$  for argument  $90^\circ$  (Goldstein 1974, p. 214, Table 35). It seems that Zacut may have based his computations for the lunar corrections on tables in two different sets.

4. Although there are quite a few double argument tables for the lunar equation (e.g., Jacob ben Makhir’s *Almanac* [Chabás and Goldstein 2018], John of Lignères’s *Tabule magne* [North 1977, p. 283], the Oxford Tables [Chabás and Goldstein 2016], and the tables of Joseph Ibn Waqār [Chabás and Goldstein 2015, p. 607]), we have not found Zacut’s presentation in any previous set of astronomical tables.



Table MA 9. A 91a (1).

Heading. Table of declination; table of lunar latitude

Note.

1. This table is not displayed. The argument of solar declination is at intervals of  $6^\circ$  with a maximum of  $23;33^\circ$  at argument  $90^\circ$ . The argument of lunar latitude is at intervals of  $6^\circ$  with a maximum of  $5;0^\circ$  at argument  $90^\circ$ . These are standard parameters: for the maximum declination of  $23;33^\circ$  in works by Zacut, see Chabás and Goldstein 2000, pp. 104–106 [AP 3]; for the maximum lunar latitude of  $5;0^\circ$ , see Chabás and Goldstein 2000, p. 130 [AP 18]. See also Chabás and Goldstein 2012, pp. 23, 104.

Table MA 10. A 91a (2).

Heading. Table of the stationary points for each planet

center	station of Saturn	station of Jupiter <sup>a</sup>	station of Mars	station of Venus	station of Mercury
	anomaly	anomaly	anomaly	anomaly	anomaly
0s / 0s	3s 22;42°	4s 4; 5°	5s 7;24°	5s 15;49°	4s 27;15°
1s / 11s	3s 22;56	4s 4;17	5s 8;15	5s 16; 1	4s 26;36
2s / 10s	3s 23;28	4s 4;53	5s 10;21	5s 16;30	4s 25;18
3s / 9s	3s 24;11	4s 5;41	5s 13;24	5s 17;10	4s 24;38
4s / 8s	3s 24;50	4s 6;24	5s 16;11	5s 17;45	4s 24;29
5s / 7s	3s 25;19	4s 6;59	5s 18;22	5s 18;10	4s 24;35
6s / 6s	3s 25;30	4s 7;11	5s 19;15	5s 18;21	4s 24;42

a. The entries in this column are vertically displaced; the copyist put the ‘correct’ entries in the margin.

Note.

1. The entries agree with those for first station in the zij of al-Battānī (Nallino 1903–1907, 2:138–139), differing in some cases by  $0;1^\circ$  or  $0;2^\circ$ . Al-Battānī’s table for first stations was included as a column in the tables for the planetary equations in the astronomical tables of Abraham Bar H<.>iyya (Paris, Bibliothèque nationale de France, MS Heb. 1046, 19a–26b).

Table MA 11. A 91a (3).

Heading. Table for correcting the days according to the solar longitude (i.e., the equation of time)

degrees	Ari	Tau	Gem	Cnc	Leo	Vir	Lib	Sco	Sgr	Cap	Aqr	Psc
	min	min	min	min	min	min	min	min	min	min	min	min
10	13	23	24	19	16	21	30	33	25	10	0	3
20	17	24	23	17	17	24	32	32	21	6	0	6
30	20	25	21	16	19	28	33	29	16	2	1	9

Note.

1. This table is similar to Table 10 of the Tables of 1513 which is also for the equation of time, but the entries are different and at different intervals.

2. The maximum is 0;33h at Sco 0° to Sco 10°; the minimum is 0;0h at Aqr 10° to 20°. On the equation of time, see Chabás and Goldstein 2012, pp. 37–41.

Table MA 12. A 68a. C 66b.

Heading. Table for true lunar anomaly in days after conjunction or opposition

Days		Days		Days	
1	0s 16;39°	11	4s 11;32°	21	9s 13;13°
2	1s 3;13 <sup>a</sup>	12	4s 27;14	22	9s 18;44
3	1s 19;26	13	5s 13;35	23	9s 23;37
4	2s 4;50	14	6s 0;10	24	10s 1;39
5	2s 18;20	15	6s 16;50 <sup>b</sup>	25	10s 13;31
...		...		...	
10	3s 27;31	20	9s 4; 0	30	1s 3;40

a. A: 1s 3;13; C: 1s 13;13.

b. A: 6s 16;50; C: 6s 13;50.

Notes.

1. The formula in modern notation for finding the true lunar anomaly is

$$\alpha = \alpha\text{-bar} + c_3(2\eta),$$

where  $\alpha$  is the true lunar anomaly,  $\alpha\text{-bar}$  is the mean lunar anomaly,  $\eta$  is the elongation of the Moon from the Sun, and  $c_3$  is the entry in column 3 for the equation of center in the table for the lunar equations in the Parisian Alfonsine Tables (Ratdolt 1483, e4r–e6v). The daily lunar mean motion is about 13;3,54°/d, and the daily mean motion in elongation is about 12;11,27°/d. For example, for day 10,

$$\begin{aligned}\alpha &= 10 \cdot 13;3,54^\circ + c_3(10 \cdot 12;11,27^\circ) = 130;39^\circ + c_3(243;49^\circ) \\ &= 130;39^\circ - 13;8^\circ = 117;31^\circ\end{aligned}$$

in exact agreement with the text. In some other cases the difference between text and recomputation is 0;1°.

2. This table might be useful for entering double argument tables, where one argument is the true lunar anomaly (see, e.g., Table MA 8). However, we are unaware of a similar table in any other medieval set of astronomical tables.

## V. Fragments of Zacut's astronomical tables in the Cairo Geniza

GZ 1. Cambridge University Library. Ar. 29.175 (6 folios).

1a. Table JM 9.

1b. Table JM 10.

2a–3a (1). Table JM 15.

3a. (2) Table for cycles of 28 years; weekday. (3) “Correction for eclipses”. The argument is the number of the zodiacal sign: for 0s/12s the entry is “5 to be subtracted”, for 3s/9s the entry is 0, for 4s/8s the entry is “2 to be added”, and for 6s the entry is 5 [to be added]. (3) col. 1: Months, beginning in March, and col. 2: weekday. A marginal note on 3a includes the date 5433 A.M. [= 1672 C.E.]

3b. Table JM 13.

- 4a. Tables JM 11 and MA 12.
- 4b. Notes (no tables).
- 5a. Table JM 7.
- 5b. Table JM 8.
- 6a–b. Table MA 4 (cycles, years in a cycle, months).
- 6b. Tables MA 4 (days) and MA 9.

GZ 2. New York, JTSA. ENA NS 11.17 (1 folio, very faint). The date 5261 A.M. [= 1500/1501 C.E.] appears on 1a:1.

- 1a. Table MA 4 (beginning with cycle 243).
- 1b. Table MA 5 (days and hours only).

GZ 3. New York, JTSA. ENA NS 61.20

- 1a. A worked example in the form of a table: for a facsimile and a transcription, see Goldstein 1981, p. 244.

GZ 4. Paris, Alliance Israélite Universelle. VIII.E.4 (12 folios, very faint, the folios were unbound when seen in Paris); some folios were numbered but others were not. In effect, the order of the folios is somewhat uncertain.

- 1a. Table JM 4.
- 1b. Table JM 7.
- 2a. Table JM 8.
- 2b. Table JM 9.
- 3a. (1) too faint; (2) Table MA 12.
- 3b–4b. Table JM 15.
- 5a. Too faint.
- 5b. Table JM 12.
- 6a–b. Text.
- 7a–10b. Poorly preserved. 12 columns with headings for March/Aries to Feb./Pisces, and rows for years from 1 to 136 (34 years on each folio); entries in days, hours, and minutes. The entries (in so far as they are legible) are identical with those in Zacut, Tables HG 5 and AP 6 (Chabás and Goldstein 2000, pp. 56, 109–110): “Entry of the Sun in each zodiacal sign”.
- 11a. Mostly too faint, but a small table has the heading, limits of solar eclipses for Jerusalem, which also appears in the canons of 1513: B 13b, S 17.
- 11b. Table JM 5.
- 12a. Mostly too faint. Headings for the months in the Hebrew calendar.

GZ 5. Paris, Alliance Israélite Universelle. VIII.E.28 (2 folios)

- 1a. Table JM 15 (Cancer and Leo only).
- 1b. (1) Table JM 10; (2) Table MA 12.
- 2a. Table JM 9.
- 2b. Table JM 8.

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