A New Set of Fourteenth Century Planetary Observations

BERNARD R. GOLDSTEIN

University of Pittsburgh

I. INTRODUCTION

Ever since antiquity astronomy has consisted of both theory and observation, but these two components have often received different treatments in the original sources. In the medieval period we find many texts that present theories (even new theories) for the motions of the Sun, the Moon, and the planets; and other texts that describe instruments (some newly invented) for making observations. Moreover, medieval scholars carefully read various works that survived from antiquity, notably Ptolemy's *Almagest*, and these treatises served as a guide for the scientific study of astronomy. In particular, Ptolemy described methods for determining the planetary models (or parts of them) from sets of dated observations, and he gave numerous examples (including many based on observations he himself made) which take up a major portion of his *magnus opus*. In this respect, however, the vast majority of his successors did not follow him, for we find surprisingly few planetary observations in the medieval astronomical corpus. (A similar paucity of observations of the Sun, the Moon, and eclipses has also been noted.)[1] Indeed, in most astronomical tables compiled in the Middle Ages observations play no role, and it can be demonstrated that the tabular entries are largely based on earlier astronomical theories.[2]

The *Astronomy* of Levi ben Gerson (d. 1344) is, therefore, unusual for recording 45 observations he made of planetary longitudes and latitudes

---

[1] Ibn Yūnus' astronomical tables contain the most extensive set of observational reports, both of eclipses and of planets (Caussin 1804). Al-Bīrūnī mentions many observations in his *Taḥdīd*, but planetary observations are not included there (Ali 1967; cf. Kennedy 1973). Recently some additional reports in Arabic have come to light: Saliba 1983 and 1985; King and Gingerich 1982. Levi's eclipse observations (as well as some others) are discussed in Goldstein 1979, and his solar observations are to be found in Chapters 56 and 57 of his *Astronomy* (unpublished).

[2] See Kennedy 1956 for a survey of Islamic astronomical tables.

PROCEEDINGS OF THE AMERICAN PHILOSOPHICAL SOCIETY, VOL. 132, NO. 4, 1988

that are presented here for the first time. The original Hebrew text has 136 chapters and, for the four chapters containing these observations, only two Hebrew manuscript copies survive.[3] In the fourteenth century Latin version only one of these chapters, chapter 109, is preserved. This study is based on an unpublished edition I made of the Hebrew text of these chapters: chapter 109 contains reports of 9 observations of Saturn, chapter 113 contains reports of 17 observations of Jupiter, chapter 117 contains reports of 8 observations of Mars, and chapter 122 contains reports of 11 observations of planetary latitudes.

Levi's *Astronomy* deals with a wide range of topics including astronomical instruments, trigonometry, the relationship of astronomy to physics, astronomical models, methods for deriving parameters for models, and tables for solar and lunar motions as well as eclipses. Levi's solar and lunar theories are both based on his own observations and, in the case of the lunar theory, he claims greater success than Ptolemy achieved.[4] For the planets Levi's text is incomplete: some chapters are partially preserved and some are not preserved at all. Preliminary to the description of the model for each outer planet is a chapter containing relevant observations and some remarks on their relationship to Ptolemy's theory as perfected by al-Battānī. Similarly, preceding the chapter on planetary latitude theory is a chapter containing relevant observations. It is unusual for a medieval astronomer to prefer depending on his own observations rather than those of the ancients.[5] In Levi's subsequent chapters on planetary distances we find values for the ratio of maximum to minimum distances for each planet, and this suggests that he succeeded in finding planetary models to his own satisfaction using what he calls "heuristic reasoning."[6] A preliminary study of Chapter 110 concerning Saturn's model indicates that it is of the same type as Levi's lunar model, i.e., Levi makes no use of epicycles, and he uses equants and "reflections" of angles.[7] His main task was to adapt Ptolemy's parameters to his models, allowing for the possibility that Ptolemy's parameters may have to be modified to account for his observations. The only parameter changed in the chapters presented here is the longitude of apogee,[8] and Levi has rejected Ptolemy's claim that the planetary apogees are fixed with respect to the fixed stars, as Levi tells in chapter 19 (Goldstein 1985a, p. 113).

---

[3] For a discussion of the manuscripts of Levi's *Astronomy*, see Goldstein 1974, pp. 74ff. For the manuscripts used here, see Section II, below. Chapter 104 was to have contained observations of Venus, but only the first 4 lines of that chapter are extant in MS Q (165b) and even they are omitted in MS P. Chapter 107 announces Levi's intention of making observations of Mercury, but only 5 lines at the beginning of this chapter are extant; see Q:175a, P;206b (where the text is less complete). For the first 20 chapters of Levi's *Astronomy*, see Goldstein 1985a.

[4] On Levi's lunar theory, see Goldstein 1974, pp. 53ff.

[5] Cf. Kennedy 1956; and Hartner 1969.

[6] See Goldstein 1986 where the term "heuristic reasoning" is also discussed (cf. 46:18 and 113:19, below).

[7] See Goldstein 1974, p. 56 (where reflection takes place about point *L* in the figure).

[8] More precisely, it is the motions of the planetary apogees that are stated which, in turn, are based on new determinations of these apogees. Concerning Mars, Levi tells us that it is appropriate to change the eccentricity (117:12).

To give a sense of Levi's attitude to Ptolemy and his reasons for deviating from the results of his predecessor, I also present a translation of Chapter 46 from Levi's *Astronomy*, based on the Hebrew manuscripts. Levi indicates his reluctance to depart from the ancients, but felt compelled to do so because of the evidence he found. At the same time he rejects the alternatives proposed by al-Biṭrūjī (twelveth century, Spain) for they "are strongly contradicted both by observation and reason" (chap. 46:3).[9] From the colophon in the manuscripts we learn that this book (or at least a draft of it) was completed in 1328,[10] but here we learn that "many observations in this treatise were made after the completion of this book" (chap. 46:39). Indeed, Levi's planetary observations range form 1325 to 1340.

The data are summarized in Tables 1 to 7. In Table 1, I assign to each observation a sequential number in chronological order to facilitate references to the text and the other tables. The remaining columns contain the julian day number for noon of the date of the observation, a reference to the text by chapter and sentence number, the date and time of the observation, and the objects observed.

From Table 1, it is clear that no observations of Mercury are cited (see n. 3; cf. Goldstein 1985a, p. 111), and that only 4 fixed stars are mentioned: Aldebaran (α Tau), Regulus, Spica, and γ Leo. One occultation, or near occultation, of Jupiter by Venus is reported (No. 44). Moreover, there are 5 pairs of observations taken on the same day: Nos. 1 and 2, 4 and 5, 24 and 25, 27 and 28, 34 and 35. The years of greatest observational activity in this table are: 1325 (5 observations), 1328 (11 observations), 1335 (7 observations), and 1339 (8 observations). Note that for Levi the year began on 1 Mar, and so dates in January and February are given 2 year numbers, e.g., No. 8: 8 Jan 1327/8 (for Levi this took place in 1327, but in our reckoning it was in 1328). Observation No. 2 took place at about sunrise, and this may mean that the text is defective. Moreover, Observation No. 23 took place only shortly after noon and Observation No. 45 took place at 3;30^h after noon at which times the Sun would be shining brightly.

Tables 2, 3, and 4, display the data for the 11 observations of Saturn, the 20 observations of Jupiter and the 13 observations of Mars, respectively, keyed to the observation numbers in Table 1. Column 1 shows the number of days since the first cited observation (e.g., for Saturn, No. 2) rounded to the nearest 1/2 day (or 3/4 day): the entries were derived from the julian day numbers and the times in Table 1. Columns 2 and 3 display the values in the text for observed and computed longitudes respectively: note the close agreement in most cases. The exceptions are: Saturn, Nos. 7, 27; Jupiter, Nos. 9, 19; and Mars, Nos. 17, 28. In all these cases, Levi's observed longitudes are in much better agreement with the modern values (see Table 5) than his computed values based on al-Battānī. Moreover, these are precisely

---

9 On al-Biṭrūjī, see Goldstein 1971. Numbers separated by a colon here refer to chapter and sentence in the translation.

10 Cf. Goldstein 1974, p. 30.

TABLE 1

A Summary of Levi Ben Gerson's Planetary Observations

No.	Julian Day No.		Text	Date and Time				Observed
1	2205	273	113:50	16 Sep	1325,	$6;30^h$	bef. noon	Jupiter with Aldebaran
2	2205	273	109:28	16 Sep	1325,	6	bef. noon	Saturn with Aldebaran
3	2205	284	109:31	27 Sep	1325,	6;30	bef. noon	Saturn with Aldebaran
4	2205	300	109:34	13 Oct	1325,	6	bef. noon	Saturn
5	2205	300	113:53	13 Oct	1325,	6	bef. noon	Jupiter
6[a]	2205	896	113:56	1 Jun	1327,	8	aft. noon	Jupiter
7	2206	107	109:7	29 Dec	1327,	10	aft. noon	Saturn
8	2206	117	113:59	8 Jan	1327/8,	5	bef. noon	Jupiter
9	2206	172	113:7	3 Mar	1328,	7	aft. noon	Jupiter
10	2206	231	113:62	1 May	1328,	8	aft. noon	Jupiter
11	2206	235	117:37	5 May	1328,	8	bef. noon	Mars and Venus
12	2206	277	113:65	16 Jun	1328,	8	aft. noon	Jupiter
13[b]	2206	341	122:12	19 Aug	1328,	8	bef. noon	Venus passed Saturn
14	2206	385	122:15	2 Oct	1328,	6	bef. noon	Venus passed Jupiter
15	2206	419	117:22	5 Nov	1328,	12	aft. noon	Mars with Aldebaran
16	2206	421	113:31	7 Nov	1328,	6	bef. noon	Jupiter with Spica
17	2206	442	117:5	28 Nov	1328,	6	aft. noon	Mars with Aldebaran
18	2206	467	113:34	23 Dec	1328,	5	bef. noon	Jupiter
19	2206	959	113:10	29 Apr	1330,	8	aft. noon	Jupiter
20	2207	352	122:31	27 May	1331,	8	aft. noon	Mars with Regulus
21	2208	042	122:26	16 Apr	1333,	7	aft. noon	Mars with Regulus
22	2208	122	122:22	5 Jul	1333,	8	aft. noon	Mars and Saturn
23[c]	2208	428	122:4	7 May	1334			Venus and the Moon
24	2208	578	122:34	4 Oct	1334,	3	bef. sunrise	Mars with Regulus and γ Leo
25	2208	578	117:34	4 Oct	1334,	8	bef. noon	Mars with Regulus
26	2208	615	122:2	10 Nov	1334,	1;30	bef. sunrise	Venus with Spica
27	2208	753	109:10	28 Mar	1335,	9	aft. noon	Saturn
28	2208	753	117:8	28 Mar	1335,	9	aft. noon	Mars with Regulus
29[d]	2208	853	122:38	[6 Jul]	1335,	1	aft. sunset	Mars with Spica
30	2208	867	109:37	20 Jul	1335,	8	aft. noon	Saturn
31	2208	872	113:38	25 Jul	1335,	8;30	bef. noon	Jupiter
32	2208	909	109:39	31 Aug	1335,	8	aft. noon	Saturn
33	2208	913	113:41	4 Sep	1335,	8	bef. noon	Jupiter
34	2210	027	113:68	22 Sep	1338,	8	bef. noon	Jupiter
35	2210	027	117:25	22 Sep	1338,	7	bef. noon	Mars with Regulus
36	2210	084	117:28	18 Nov	1338,	7	bef. noon	Mars
37	2210	135	113:71	8 Jan	1338/9,	7	aft. noon	Jupiter
38	2210	137	117:31	10 Jan	1338/9,	8	bef. noon	Mars
39[e]	2210	150	113:74	23 Jan	1338/9			Jupiter
40[e]	2210	153	113:77	26 Jan	1338/9			Jupiter
41[e]	2210	157	113:80	30 Jan	1338/9			Jupiter
42	2210	210	109:42	24 Mar	1339,	8	bef. noon	Saturn
43	2210	256	109:45	9 May	1339,	12	aft. noon	Saturn
44	2210	398	122:9	28 Sep	1339,	2	bef. sunrise	Venus and Jupiter
45	2210	698	122:18	24 Jul	1340,	3;30	aft. noon	Venus and Jupiter

[a] The time reported here is specified as 8^h after *apparent* noon (113:56), and I understand Levi to mean apparent noon in all cases where he refers to noon.

[b] MS P: 7^h before noon. The data are not sufficiently precise to decide which time is to be considered the preferred reading in the text.

[c] In the text, the time is given by the solar altitude to the west of 62;24° for geographical latitude 44° (Levi's value for the latitude of Orange): see Comments on Table 7.

[d] No date in the year 1335 is reported in the text, but by computing when Mars was about in conjunction with Spica, we arrive at 6 July (see Table 6): note that using this date leads to agreement with the mean arguments in Table 4, columns 4 and 5.

TABLE 2

Saturn*

No.	1 Δd	2 λ(obs.)	3 λ(comp.)	4 $\bar{\kappa}$	5 $\bar{\alpha}$
2	0[d]	87;58°	88;15,40°	184; 6°	101;43°
3	11	88; 4	88;28,33	184;26	112;10
				[184;28]	[112;12]
4	27	88; 1	88;20,58	—	—
				[185; 0]	[127;25]
7	834½	113;36	112;48,31	212;45	178;35
				[212; 3]	[176;17]
13	1068			—	—
				[219;53]	[38;37]
22	2849½		177;30,57	—	—
				[279;34]	[284;53]
27	3480½	204;21	202;46	300;30	176;34
				[300;42]	[175;41]
30	3594½	201;13	200;58	304; 2	284;11
				[304;31]	[284;14]
32	3636½	204;38,34	204;27,15	305;44	324;17
				[305;55]	[324;13]
42	4937	252;29	252; 9,27	349;22	122;15
				[349;29]	[122;30]
43	4983¾	251;20,48	250;51,39	350;56	166;50
				[351; 3]	[167; 0]

Notes

No. 7, Col. 3: 112;48,31° (109:8), 112;20,1° (109:18), 113;5° (109:22).
Col. 4: 212° (109:18°), 216;45° (109:9).
No. 22, Col. 3: 117;30,57° (P), 117;30,51° (Q).
No. 27, Col. 4: 300;30° (109:20), 305;15° (109:12).
No. 30, Col. 3: 200;58° (P), 200;57° (Q).
Col. 4: 304;2° (P), 304;3° (Q).

*Numbers enclosed in square brackets have been recomputed by the method described in the Introduction; all other numbers in Columns 2-5 appear in Levi's text. In the notes, numbers in parentheses refer to chapter and sentence, e.g., 109:8 refers to chapter 109, sentence 8.

the observations on which Levi based his corrections to al-Battānī's parameters, as we learn in chapters 109, 113, and 117.

Columns 4 and 5 display text values for the mean argument of center ($\bar{\kappa}$) and the mean anomaly ($\bar{\alpha}$). Below each of them (except for the first entry) is a value I have computed to check on the textual readings. These values were derived as follows:

$$\bar{\kappa} = \bar{\kappa}_0 + \mu_1 \cdot \Delta d \tag{1}$$
$$\bar{\alpha} = \bar{\alpha}_0 + \mu_2 \cdot \Delta d \tag{2}$$

where $\bar{\kappa}_0$ and $\bar{\alpha}_0$ refer to the values in the text for the earliest of Levi's observations (e.g., Saturn, No. 2), μ_1 and μ_2 refer to the mean motions in longitude and anomaly derived from al-Battānī's tables, and Δd refers to the

TABLE 3

Jupiter*

No.	1 Δd	2 λ(obs.)	3 λ(comp.)	4 $\bar{\kappa}$	5 $\bar{\alpha}$
1	0^{d}	98 °	97;59, 3°	260;28°	101;11°
5	27	99;33	99;33,21	262;40	125;32
				[262;43]	[125;33]
6	623½	129; 2	128;59,28	312;16	304
				[312;18]	[303;54]
8	844	162; 3	162; 5,46	330;36	143
				[330;38]	[142;54]
9	899½	156; 5	158;13,52	339;14!	191!
				[335;15]	[193; 0]
10	958½	153	152;56, 3	340; 7	246;20
				[340; 9]	[246;15]
12	1004½	157;12	157; 7,10	343;56	288;15
				[343;59]	[287;46]
14	1112			—	—
				[352;55]	[24;47]
16	1148	185;32	185;20	359;51!	57;18
				[355;55]	[57;16]
18	1194	191;35,10	191;24	—	—
				[359;44]	[98;47]
19	1686½	217; 2	219;15,59	—	—
				[40;40]	[183;17]
31	3599	34;10	34;19,30	21;22!	108;13!
				[199;40]	[109;21]
33	3640	34;28	34;38,18	204;49!	145;35!
				[203; 5]	[146;21]
34	4754	130;46	130;44,54	295;28	71;42
				[295;41]	[71;45]
37	4862½	133;28	133;24	304;32	169;44
				[304;43]	[169;41]
39	4877	131;29	131;24	—	183;32
				[305;55]	[182;46]
40	4880	131;15	131;10,46	306; 3	185;20
				[306;10]	[185;28]
41	4884	130;39	130;38,10	—	—
				[306;30]	[189; 5]
44	5125			326;49	46;32
				[326;32]	[46;35]
45	5425½			—	—
				[351;31]	[317;47]

Notes

No. 6, Col. 2: 129;2° (Q), 129;52° (P).
Col. 4: 312;16° (P), 312;8° (Q).
No. 12, Col. 3: 157;7,10° (P), 157;7,11° (Q).
No. 33, Col. 2: 34;28° (P), 34;27° (Q).
No. 34, Col. 3: 130;44,54° (P), 130;44,50° (Q).

*Numbers enclosed in square brackets have been recomputed by the method described in the Introduction; all other numbers in Colums 2-5 appear in Levi's text.

TABLE 4

Mars*

No.	1 Δd	2 λ(obs.)	3 λ(comp.)	4 κ̄	5 ᾱ
11	0ᵈ	353;52,30°	354;10°	181;53°	95;13°
15	184¾	81;31	81;37,22	278;38 [278;42]	180;20,25 [180;30]
17	207½	73;37	75;56,46	291;25 [290;38]	190; 5,27 [191; 0]
20	1117½			— [47;32]	— [251; 2]
21	1807½			— [49; 9]	— [209;31]
22	1887½		177;32,26	89;59 [91; 5]	246;21,15 [246;27]
24	2343			— [329;47]	— [96;42]
25	2343	140;45	140;38	329;40 [329;47]	96;29 [96;42]
28	2518½	175;23	176;28,44	62;31 [61;46]	176;51 [177;42]
29	[2618]½			114;10 [114;10]	223;47 [223;52]
35	3792	158;58	158;54	9; 2 [9;11]	45;20 [45;31]
36	3849	194;45	194;39,37	39;10 [39; 3]	71;34 [71;50]
38	3902	227; 1,40	226;55,35	66;32 [66;49]	96; 4 [96;18]

Notes
No. 36, Col. 2: 194;45° (P), 194;48° (Q).

*Numbers enclosed in square brackets in Columns 4 and 5 have been recomputed by the method described in the Introduction; all other numbers in Columns 2-5 appear in Levi's text.

entry in column 1. From the close agreement of text and computation one can see that Levi's parameters for μ_1 and μ_2 do not differ greatly from those of al-Battānī. An exclamation point following an entry in the table indicates those cases where text and computation do not agree closely. The values I used for μ_1 were taken from Kennedy (1956, p. 156) that he derived from the astronomical tables of al-Battānī:

Saturn: 0; 2, 0,35,51,48, 3°/ᵈ
Jupiter: 0; 4,59,16,55,54,57
Mars: 0;31,26,40,15,11,13
Sun: 0;59, 8,20,46,56,14

To find the mean motions in anomaly, μ_2, I subtracted al-Battānī's mean planetary motions in longitude from his mean solar motion, with the following results:

Saturn: 0;57, 7,44,55, 8,11°/d
Jupiter: 0;54, 9, 3,51, 1,17
Mars: 0;27,41,40,31,45, 1

Table 5 displays a comparison of Levi's observed planetary longitudes with modern computed values. I have used a computer program supplied to me by Professor Peter Huber that is based on Tuckerman (1964) with some modifications and corrections. This program can correct the lunar positions for parallax, and computes the times of rising, culmination, and setting for the Sun, the Moon, and the planets, as well as the positions of these bodies in various coordinate systems, where all times are expressed in Universal

TABLE 5

Observed Longitudes Compared With Modern Computed Longitudes

	1	2	3	4	5	6
No.	Date and Time: UT	App. Noon, Orange: UT	Text λ(Obs).	Modern λ(Comp.)	Diff. (3) − (4)	Planet
1	16 Sep 1325, 5.05^h	11.55^h	98.00°	97.92°	.08°	Jupiter
2	16 Sep 1325, 5.55	11.55	87.97	88.21	−.24	Saturn
3	27 Sep 1325, 4.99	11.49	88.07	88.44	−.37	Saturn
4	13 Oct 1325, 5.43	11.43	88.02	88.37	−.35	Saturn
5	13 Oct 1325, 5.43	11.43	99.55	99.61	−.06	Jupiter
6	1 Jun 1327, 19.64	11.64	129.03	128.88	.15	Jupiter
7	29 Dec 1327, 21.80	11.80	113.60	113.92	−.32	Saturn
8	8 Jan 1328, 6.87	11.87	162.05	161.94	.11	Jupiter
9	3 Mar 1328, 18.85	11.85	156.08	155.79	.29	Jupiter
10	1 May 1328, 19.60	11.60	153.00	152.70	.30	Jupiter
11	5 May 1328, 3.60	11.60	353.88	352.72	1.14	Mars
12	16 Jun 1328, 19.69	11.69	157.20	156.96	.24	Jupiter
15	5 Nov 1328, 23.44	11.44	81.52	81.13	.39	Mars
16	7 Nov 1328, 5.44	11.44	185.53	185.25	.28	Jupiter
17	28 Nov 1328, 17.56	11.56	73.63	73.14	.48	Mars
18	23 Dec 1328, 6.76	11.76	191.59	191.40	.19	Jupiter
19	29 Apr 1330, 19.61	11.61	217.03	216.63	.40	Jupiter
25	4 Oct 1334, 3.46	11.46	140.75	140.62	.13	Mars
27	28 Mar 1335, 20.72	11.72	204.35	204.63	−.28	Saturn
28	28 Mar 1335, 20.72	11.72	175.38	175.34	.04	Mars
30	20 Jul 1335, 19.77	11.77	201.22	201.52	−.30	Saturn
31	25 Jul 1325, 3.26	11.76	34.17	34.15	.02	Jupiter
32	31 Aug 1335, 19.63	11.63	204.64	204.87	−.23	Saturn
33	4 Sep 1335, 3.61	11.61	34.47	34.48	−.01	Jupiter
34	22 Sep 1338, 3.51	11.51	130.77	130.59	.18	Jupiter
35	22 Sep 1338, 4.51	11.51	158.97	159.04	−.07	Mars
36	18 Nov 1338, 4.49	11.49	194.75	194.77	−.02	Mars
37	8 Jan 1339, 18.87	11.87	133.47	133.29	.18	Jupiter
38	10 Jan 1339, 3.88	11.88	227.03	227.26	−.23	Mars
39	23 Jan 1339, [6.11][a]	11.93	131.48	131.42	.06	Jupiter
40	26 Jan 1339, [6.06][a]	11.93	131.25	131.02	.23	Jupiter
41	30 Jan 1339, [5.97][a]	11.94	130.65	130.50	.15	Jupiter
42	24 Mar 1339, 3.75	11.75	252.48	253.14	−.66	Saturn
43	9 May 1339, 23.60	11.60	251.35	250.95	.40	Saturn

Notes
[a] No time is indicated in the text; the time here is 1^h before sunrise.

Time (UT). For purposes of comparison I have converted the longitudes in the text to decimal notation, and the times in the text to Universal Time, using the values produced by the program to define apparent noon (i.e., when the Sun culminates, or crosses the observer's meridian), sunrise, and sunset for Orange (4;48° E, 44;8° N: mod.), where Levi lived. The observations listed in this table are only those for which the text reports a longitude (see Tables 2, 3, and 4). The differences listed in column 5 are positive in 21 cases and negative in 13 cases. Only two of Levi's observed longitudes differ from the corresponding modern values by more than 1/2°: No. 11 (Mars) where the difference is 1.14°, and No. 42 (Saturn) where the difference is − 0.66°.

Table 6 displays the observations, with the times converted to UT, again keyed to the observation numbers in Table 1, in which fixed stars are mentioned. The longitudes of these fixed stars are not given in the chapters under discussion, but the observed longitude of Aldebaran appears in Chapter 61 as 60;15,57° for 3 Oct 1335 (mod. 60;30°). According to Levi, al-Battānī's value for that date is 60;38°, i.e., 0;22° greater than Levi's observed value (see Goldstein 1975, p. 36). In Levi's star list of 1325, the longitude of Aldebaran is 60;30° (based on al-Battānī's entry in his star catalogue increased by 6;40° for precession), and in 10 years the precession at 1° in 66 years (al-Battānī's value) would amount to 0;9°, implying a longitude for Aldebaran in 1335 of 60;39° in close agreement with Levi's text (cf. Goldstein 1985b, pp. 199ff). We may then determine Levi's longitudes for the three other fixed stars cited here by him because he informs us that "the longitude of [one] fixed star tells us the longitudes of the remaining fixed stars whose longitudes are inscribed in the tables, for we can compute [their longitudes] according to Ptolemy's values for the distance in [longitude] from this star to [each of] them" (chap. 16:31, Goldstein 1985a, p. 104). Thus we take al-Battānī's longitudes increased by 6;26° (= 6;40° + 0;8° − 0;22°) for the precession from al-Battānī's epoch, 880 A.D., to 1335. Al-Battānī's longitude for Regulus is 134;0° which implies that Levi's value for 1335 would be 140;26° (mod. 140;36°). Similarly, Levi's value for γ Leo in 1335 would be 139;46° (= 133;20° + 6;26°: mod. 140;16°), and for Spica it would be 194;16° (= 187;50° + 6;26°: mod. 194;34°). From Table 6 it is clear that none of the observations with Aldebaran involved a conjunction. The numbers enclosed in square brackets have been computed using Professor Huber's program.

Table 7 displays observations of two planets at the same time: all but No. 11 are at, or near, conjunction. Observation No. 23 presents a problem that is discussed in the Comments on Table 7. Again, the times have been converted to UT, and the numbers enclosed in square brackets have been computed using Professor Huber's program.

No instruments are named explicitly, but the Jacob Staff was clearly used in Observation No. 23 (see the Comments on Table 7). The lack of an instrument is indicated in 122:27, "I estimated that Mars was about 0;36° to the north of Regulus but we did not measure it with the observational

TABLE 6

Observations With Fixed Stars*

No.				Long.	Lat.
	Aldebaran: Observed Planetary Longitudes				
1.	16 Sep 1325,	5.05^h UT	Jupiter:	98; 0°	
2.	16 Sep 1325,	5.55 UT	Saturn:	87;58	
3.	27 Sep 1325,	4.99 UT	Saturn:	88; 4	
15.	5 Nov 1328,	23.44 UT	Mars:	81;31	
17.	28 Nov 1328,	17.56 UT	Mars:	73;37	
	Regulus: Observed Planetary Longitudes; and Differences in Latitudes				
20.[a]	27 May 1331,	19.63^h UT,	in conjunction with Mars:	[140;25°	1;19°]
	Diff. in lat.: (Mars − Regulus) = 0;47°				
21.[a]	16 Apr 1333,	18.64 UT,	in conjunction with Mars:	[140;18	2;10]
	Diff. in lat.: (Mars − Regulus) = 0;36°				
24.[b]	4 Oct 1334,	2.93 UT,	in alignment with (γ Leo and) Mars:	[140;37	1;26]
	Diff. in lat.: (Mars − Regulus) = 1/8 (γ Leo − Regulus)				
25.	4 Oct 1334,	3.46 UT,	[in conjunction] with Mars:	140;45	
28.	28 Mar 1335,	20.72 UT,	with Mars:	175;23	
35.	22 Sep 1338,	4.51 UT,	with Mars:	158;58	
	Spica: Observed Planetary Longitudes; and Differences in Latitudes				
16.	7 Nov 1328,	5.44^h UT,	with Jupiter:	185;32°	
26.[c]	10 Nov 1334,	5.26 UT,	in conjunction with Venus:	[193;44	1;59°]
	Diff. in lat.: (Venus − Spica) = 3;59°				
29.[c]	6 Jul 1335,	20.26 UT,	in conjunction with Mars:	[195; 0	−0;31]
	Diff. in lat.: (Mars − Spica) = 1;30°				

*Longitudes and latitudes enclosed in square brackets have been derived by modern computation (see Introduction).

[a] Levi's Observation No. 20 implies a latitude for Regulus of 0;32° and Observation No. 21 implies a latitude for Regulus of 1;34°. To make them consistent, perhaps we should emend the difference in latitude in No. 21 to read 1;36° (instead of 0;36°). However, both al-Battānī and Ptolemy give the latitude of Regulus as 0;10° (cf. Nallino 1903-07, vol. 2:159), while the modern value for Levi's epoch is 0;26°.

[b] In the text, the time is given as 3^h before sunrise and this corresponds to 2.93^h UT (= 5.93^h UT − 3^h). According to modern computation, at the time of the observation, the longitude of Mars (140;37°) was close to that of Regulus (140;35°) and that of γ Leo (140;15°). According to al-Battānī (cf. Nallino 1903-07, pp. 158-59), the latitude of Regulus is 0;10° and the latitude of γ Leo is 8;30° but, according to modern computation for Levi's epoch, the latitudes of these two stars were 0;26° and 8;47°, respectively. Since the latitude of Mars was 1;26°, the difference between its latitude and that of Regulus was 1;0° which is indeed about 1/8 of the difference in latitude between the two stars:

$$8;47° - 0;26° = 8;21°$$

and

$$8;21°/8 = 1;3°.$$

[c] Levi's Observation No. 26 implies a latitude for Spica of −2°, and Observation No. 29 implies a latitude for Spica of −2;1°. According to Ptolemy and al-Battānī, the latitude of Spica is −2° (cf. Nallino 1903-07, vol. 2:160), while the modern value for Levi's epoch is also −2°.

instrument." This passage suggests that normally Levi did use an instrument, presumably the Jacob Staff that he invented for this purpose and which he described in chapters 6 and 7 (see Goldstein 1985a, pp. 51ff, and 143ff). In chapter 7, Levi notes that crosspieces of different sizes can be fitted

TABLE 7

Observations Of Two Planets At The Same Time*

No.				Long.	Lat.
11.	5 May 1328,	3.60h UT,	Mars:	353;52,30°	
	with Venus:			[6;23]	
13.	19 Aug 1328,	3.69 UT,	Saturn:	[124;43	0;33°]
	behind Venus:			[125; 2	0;22]
	Diff. in lat.: (Saturn − Venus) = 0;20°				
14.	2 Oct 1326,	5.47 UT	Jupiter		1;10
				[178;11	1; 8]
	behind Venus:			[179;19	1;31]
	Diff. in lat.: (Venus − Jupiter) = 0;10°				
22.	5 Jul 1333,	19.75 UT,	Mars:	[177;38	0;18]
	(comp.)				(0;11)
	in conjunction with Saturn:			[177;55	2;21]
	(comp.)				(2;5,15)
	Diff. in lat.: (Saturn − Mars) = 2;3,33°				
23.[a]	7 May 1334,	12.48 UT,	Venus		1; 9
				[99;22	2;59]
	(comp.)				(2; 0)
	(comp./Ptolemy)				(3; 8,58)
	in conjunction with the Moon:				3;39,20
				[99;16	4;14]
	Diff. in lat: (Moon − Venus) ≈2;31°				
44.[b]	28 Sep 1339,	3.80 UT,	Jupiter:	[156;47	0;59]
	(comp.)				(0;45,20)
	occulted by Venus:			[156;47	1; 3]
	(comp.)				(0;20,11)
	Diff. in lat.: (Venus − Jupiter) ≈ 0°				
45.	24 Jul 1340,	15.26 UT,	Jupiter:	[166;59	1;10]
	in conjunction with Venus:			[166;51	0;53]
	Diff. in lat.: (Jupiter − Venus) = 0;10° to 0;15°				

*Longitudes and latitudes enclosed in square brackets have been derived by modern computation (see Introduction); latitudes enclosed in parentheses are computed values that appear in Levi's text; other longitudes, latitudes, and differences in latitude are observed values that appear in Levi's text.

[a] The time shown here, 12.48h UT, corresponds to the moment when the solar altitude in Orange to the west was 62;24° (122:4); apparent noon took place at 11.60h UT (i.e., 0;53h earlier), and true conjunction took place at 12.75h UT. The observed latitude for Venus here is far from the modern value, but Levi's report is internally consistent and I see no simple way to account for his error. From 122:5 we learn that Levi used a Jacob Staff to make his observation: the ratio of (half) the crosspiece to its distance from the eye was 3 to 124. The corresponding angle is the arctan of 3/124 or 1;23° which, when doubled, yields 2;46° for the distance from Venus to the farther edge of the Moon. We then subtract 0;15° for the lunar radius and this results in 2;31° for the distance from Venus to the center of the Moon. If we subtract 2;31° from 3;39;20° (the observed apparent lunar latitude), the result is 1;8,20° for the latitude of Venus, in good agreement with the value in the text of 1;9°, but in poor agreement with the modern value of 2;59°. It is somewhat ironic that Ptolemy's value for the latitude of Venus, which Levi wishes to correct, comes much closer to the modern value. For the Moon, the modern values here have been corrected for parallax.

[b] This observation was made in Avignon (4;48° E, 43;56° N: mod.): cf. 122:9. From the modern data it appears that a near occultation did take place.

to the staff to facilitate observations of diverse angular separations between the two stars or planets (Goldstein 1985a, p. 147). In chapter 3, Levi notes that the most appropriate kind of observation for correcting errors in previous theories is that of a true conjunction, for no instrument is required (Goldstein 1985a, pp. 27-28). Finally, in chapter 16, he tells us that, "We cannot make observations of the planets without first knowing the positions of the fixed stars with which they are observed. But there is great uncertainty concerning their positions that arises from the proliferation of opinions we found among our predecessors concerning the motion of the eighth sphere [i.e., precession]" (Goldstein 1985a, p. 102). On Levi's determination of precession, see Goldstein 1975.

One of the purposes of chapter 109 is to determine the apogee of Saturn. Indeed, we are told that on the basis of these observations the apogee of Saturn has progressed 27;16° in the 1200 years since Ptolemy (109:50), and this agrees with the value cited in chapter 19, namely, 1° in 44 Julian years (cf. Goldstein 1985a, p. 113). Ptolemy's value for Saturn's apogee in his own time (137 A.D.: cf. Toomer 1984, p.340–91) was 233° (Sco 23°: *Almagest* XI.7, trans. Toomer, p. 541). If we add 27;16° to this amount, the sum is 260;16°, and this should be Levi's value for Saturn's apogee. However, Levi does not explicitly cite Ptolemy's value nor his own value for Saturn's apogee, and different methods of computing his value lead to different results. In 109:49-50 we are told that the increase in Saturn's apogee from that required by al-Battānī is 8;53° (cf. 109:26-27). In al-Battānī's text Saturn's apogee is 244;28 for A.D. 880 (Nallino 1903-07, vol. 2:114; cf. vol. 1:72). From 880 to 1337 is 457 years and, at 1° per 66 years for precession according to al-Battānī, Saturn's apogee would be at 251;23° (= 244;28° + 6;55°) for 1337. If we add 8;53° to that value, we arrive at 260;16°, and this agrees exactly with our previous computation.

However, if we compute Saturn's apogee from the entries in Table 2, columns 3, 4, and 5, we arrive at a little more than 257°. In these computations I used Levi's arguments in columns 4 and 5, entering them in al-Battānī's tables of correction:

$$\lambda(\text{comp.}) = \lambda_A + \bar{\kappa} + c(\bar{\kappa},\bar{\alpha}) \tag{3}$$

where λ(comp.) is taken from column 3, $\bar{\kappa}$ from column 4, $\bar{\alpha}$ from column 5, and $c(\bar{\kappa}, \bar{\alpha})$ from al-Battānī's tables (cf. Neugebauer 1957, pp. 201f): λ_A is the longitude of the apogee that is sought. I checked Nos. 2, 3, 30, 32, and 43, and the resulting values for Saturn's apogee were about 257;12°. If we subtract 27;16° from it, we find that Saturn's apogee for Ptolemy's time should have been about 230°. Now the sentence in which Ptolemy states Saturn's apogee is: "since we showed that in our time [Saturn's] apogee was at Sco 23°, *at the observation in question* [−228 Mar 1] *it must have had a longitude of Sco* 19⅓°" (italics added: *Almagest* XI.7, trans. Toomer, p. 541). It is a simple textual error for a reader or copyist to skip from the first occurrence of "Sco" to the second one, leaving out the intervening words. Moreover, the Hebrew would have read "Sco 19;20°" rather than "Sco 19⅓°," in which case the value could easily be misread as "Sco 19;50°" because of the similarity of the letters for "20" and "50." For the moment, the discrepancy between these two methods of computing Levi's value for Saturn's apogee remains a puzzle. Perhaps it is relevant to note that Levi initially decided to add 5;53° to Saturn's apogee to account for the first two observations he discussed (Nos. 7 and 27), and then found that he had to add an additional 3° to account for other observations (109:26-27). Is this how the discrepancy between 257;12° and 260;16° arose?

For Jupiter there is no problem comparable to that for Saturn. I compute the longitude of its apogee for Levi's time from Observation Nos. 1, 6, 10, and 40 to be about 181;15°, using the same method described above for Saturn. Ptolemy's value for this parameter in his own time is 161° (*Almagest* XI.3, trans. Toomer, p. 522), and so the motion in 1200 years was 20;15°, or 1° in about 59¼ years. Levi's parameter for the motion of Jupiter's apogee is 1° in about 60 Julian years (Goldstein 1985a, p. 113) which corresponds to a total motion of 20° in 1200 years. Levi tells us that he had to increase Jupiter's apogee by 2° over that derived from al-Battānī (113:25,29), whose value for A.D. 880 is 164;28° (Nallino 1903-07, vol. 2:114). Al-Battānī's value is certainly corrupt, for the precession in the interval from A.D. 137 to A.D. 880 at 1° in 66 years amounts to 11;15°. But if we take the precession from Ptolemy's time to that of Levi, i.e., 1200 years, at the rate of 1° in 66 years, it amounts to 18;11°. Now if we add this amount to Ptolemy's value we get 179;11° and, if we add another 2° (as Levi's text tells us to do), we arrrive at 181;11°, in close agreement with the value for Jupiter's apogee derived from the data in Table 3.

For Mars, I compute the longitude of its apogee for Levi's time from Observation Nos. 11, 15, 35, 36, and 38, to be about 134°, using the same method described above for Saturn. Ptolemy's value for this parameter in his own time is 115;30° (*Almagest* XI.9, trans. Toomer, p. 502), and so the motion of Mars' apogee was about 18;30° in 1200 years or 1° in about 65 years. Levi's value for the motion of Mars' apogee is 1° in about 66 Julian years (Goldstein 1985a, p. 113), which corresponds to a total motion of 18;11° in 1200 years.

As Levi remarks, the motion of Saturn's apogee is close to the value he assigns to the motion of the solar apogee (109:50).[11] Moreover, the motion of Mars' apogee is close to the value he assigns to precession, i.e., the motion of the fixed stars, of 1° in about 67 years (Goldstein 1975, p. 36). For Ptolemy, the solar apogee is fixed tropically, and the planetary apogees are fixed sidereally: clearly Levi did not agree with Ptolemy on this point, and each apogee is given its own proper motion. On the discovery of the proper motion of the solar apogee by al-Zarqāllu (Spain, 11th century), see Toomer 1969.

---

[11] Levi's parameter for the motion of the solar apogee is 1° in about 43 ⅔ years: cf. Goldstein 1974, p. 94.

It is possible that two of these observations may have been used to determine the distance in longitude of a fixed star from the Sun, using Venus as an intermediary. Ptolemy found such a distance using the Moon as intermediary (*Almagest* VII.2, trans. Toomer, p. 238), taking into account both the lunar motion and the change in lunar parallax in the time between the first observation before sunset and the second observation after sunset (the first yields the distance from the Sun to the Moon, while the second yields the distance from the Moon to a fixed star). In chapter 16, Levi reports Ptolemy's procedure (Goldstein 1985a, p. 102), and offers another method that involves the observation of a fixed star during a lunar eclipse (Goldstein 1985a, p. 187; for an example of Levi's use of this second method, see Goldstein 1975, p. 36). The use of Venus as the intermediary instead of the Moon was introduced by Bernhard Walther (d. 1504), and this procedure has the advantages that Venus' motion is much simpler than that of the Moon, and its parallax can be ignored (Beaver 1970, p. 41). Now Levi's observations of Venus with the Sun on 7 May 1334 (No. 23), and of Venus with Spica on 10 Nov 1334 (No. 26) would serve this purpose, provided he had confidence in determining the motions of the Sun and of Venus in the interval from the first observation to the second. Such a procedure is not described in any passage I have found in the extant chapters of Levi's *Astronomy*, but he may have considered it.

II. Translation

In the translation, I have reported all numerical variants in the manuscripts: in a few cases some uncertainty may remain because of the similar shapes of some pairs of letters in the Hebrew alphabet that are used for writing numerals, but most such questions have been resolved by means of internal consistency or computation according to the instructions in the text. Sentence numbers have been added in square brackets as an editorial device to facilitate subsequent references, e.g., 109:2 refers to chapter 109, sentence 2. Also, observation numbers, arranged in chronological order, are added to the translation in square brackets.

The Hebrew manuscripts are identified as:
P: Paris, Bibliothèque Nationale, heb. 724
Q: Paris, Bibliothèque Nationale, heb. 725

Table 8 indicates the locations of chapters 46, 109, 113, 117, and 122 in these manuscripts by folio and line number.

Table 8

Chapter	P	Q
46	88a:30– 89b:6	65b:9 – 66b:3
109	208a:1 –209a:3	178b:1 –179a:32
113	214a:1 –215b:2	186b:1 –187b:24
117	221b:1 –222a:22	194a:1 –195b:2
122	235b:31–236b:19	207a:15–207b:31

CHAPTER 46. In this chapter we direct the community of scholars not to hasten to dissent from the views of the ancients except after much investigation and careful scrutiny.

[1] We will not hide [the lesson to be drawn from] what has happened to us in this art [i.e., astronomy], for it may help to direct [the research of] those who succeed us: they should not hasten to dissent from the views of ancients, particularly when these views have been accepted by generation after generation of scholars over a long period of time. [2] This is certainly the case in this science, for the community of investigators has followed the opinion of Ptolemy for about 1200 years. [3] We have not found any trained scholar in this discipline who disputed his principles except for the author of the *New Astronomy* [Lat.: Alpetragio, i.e., al-Biṭrūjī] whose opinions, however, are strongly contradicted both by observation and reason, as we have already explained.

[4] But when deciding to dissent from the teachings of the ancients, one should do so with extreme care and scrutiny, deviating from these teachings as little as possible. [5] It is appropriate because they [i.e., the ancients] were lovers of truth and endeavored to approach it as closely as possible even when their principles prevented them from reaching it entirely. [6] Therefore, Ptolemy devised all those strategems and postulated all those strange features (*zaruyot*) in order that the planetary models he proposed be arranged so as to make the computation of the planetary paths according to his principles come as close as possible to the truth. [7] Therefore, we first tried to solve some of the difficulties raised against him by our predecessors with respect to his postulates concerning eccentric spheres and epicycles, seeking to find observational evidence to establish his hypotheses. [8] Indeed, the reason for which we invented the aforementioned instrument was to determine the amount of the eccentricity. [9] When we investigated this matter for the Moon and found that the model could not possibly be as Ptolemy had postulated, we took pains to investigate alternative possibilities for the models of the celestial bodies until we discovered [a model] according to which the motions [of these bodies] conform to observational evidence.

[10] Our intense love for the opinions of the ancients led us at first to rely upon the opinion of Ptolemy as perfected by al-Battānī concerning the motion of the fixed stars, the motion of the apogee, the [mean] motion in longitude for each planet, and the [mean] motion in anomaly [for each planet]. [11] One should accept these parameters as accurate because the hypotheses postulated by Ptolemy [and accepted by al-Battānī] do not disturb the results derived from comparing their observations with those of their predecessors who came long before them. [12] But their principles did interfere and prevent them from establishing the true corrections [for the planetary motions]. [113] Nevertheless, we were at first led to depend on the opinions of the ancients in this matter, for at that time we had not yet obtained observations by which we could determine the mean position of the Sun which is indispensable for finding the parameters for these motions, as is clear with a little reflection on what has been said above. [14] When we

investigated the positions of the planets by observation in this way, we encountered confusion and disorder which led us to deny some of Ptolemy's principles underlying the maximum planetary corrections. [15] We decided that the principles of his models constrained him to set forth the corrections in this way. [16] Consequently, we sought to produce a model for each planet consistent with the positions that we observed even if that entailed a slight deviation from the values for the maximum planetary corrections postulated by Ptolemy.

[17] We were so eager to achieve this [discovery of the true planetary models], even before completing all the observations appropriate to be undertaken by someone whose goal is a perfect investigation in this art [of astronomy], because we feared that, should we perish, this wonderful science concerning the truly existing planetary models that we had already attained in a general way would perish too, before we had a chance to complete the particular details for each planet. [18] We worked very hard on this using heuristic reasoning (*heqqeshim taḥbuliim*) until we discovered a model that fit all the observations we had already made and many others undertaken thereafter. [19] But then, when we were pleased with what we had found, we made other observations that deviated greatly from the calculation according to the model we have found for that planet. [20] Yet we still could not accept a model from which would follow Ptolemy's corrections for the inclination of the diameters at 0° anomaly for the reason mentioned in Chapter 36 of this Section. [21] This also led us far from the correct amount, especially for Mars at 0° anomaly.

[22] After working diligently on the matter and considering many models for each planet, we discovered that most of the errors found by observation must be ascribed to the planetary positions, the mean motions in longitude, the positions of the apogees, and the positions of the fixed stars that we had accepted from the ancients. [23] We realized that it was possible for the ancients to err a little because the verification of these parameters requires an extraordinarily long time interval, especially for the motions of the apogee and of the fixed stars, which to this day have only reached a small fraction of a revolution. [24] Determining [*lit.*: equating] the [mean] motion in longitude for each planet may also have introduced an error in [the calculations of] the ancients. [25] The determination of this motion for each planet requires that, when it is observed, its position in the ecliptic be found with the greatest possible accuracy and, after a long interval of time, when it is observed again, its position in the ecliptic again be found with the greatest possible accuracy. [26] If the planet was at the same distance from its apogee for both observations such that its position in anomaly was the same for both observations, we may then determine the true amount of that planet's [mean] motion in longitude. [27] Otherwise, there remains some doubt in the calculation [of the mean motion in longitude], for the motion in longitude will be mingled with the apparent motion due to one or the other correction, or both corrections. [28] Their attempt to distinguish one motion from the other was certainly very difficult, for they did not determine the

true correction for each place even if it is possible that they succeeded in determining the maximum corrections. [29] Furthermore, the observations of the ancients reported by Ptolemy clearly contain non-negligible approximations.

[30] It seems more plausible to us to accept that the ancients erred than to think that Ptolemy set forth principles concerning the planetary maximum corrections at variance with observational evidence, especially with regard to the corrections due to the motion in anomaly which can be perceived in a very short time interval, not much longer than a year. [31] It is impossible to imagine that someone who so precisely set up these corrections in this wonderful way for the sake of which he postulated those strange features (*zaruyot*) in order to achieve the closest possible agreement with observational evidence, that he be incapable of setting forth the amounts of these maximum corrections [due to the motion in anomaly] without deviating perceptibly from their true amounts, all the more so considering that he repeated the observations of these corrections each year. [32] This is what led us to postulate the inclination of the diameters for the motion in anomaly at 0° anomaly as Ptolemy had postulated it, for otherwise the gates of investigation of the model appropriate for each planet would have closed before us. [33] This also led us to investigate the procedures and arrangements (*sedarim*) that allow one to determine the planet's position in longitude, the position of the planet's apogee, and its position in anomaly.

[34] Previously we directed our attention as much as was required to the determination of the positions of the fixed stars. [35] This was possible after we had determined the mean position of the Sun, as indicated above, for otherwise it is not possible to bring this inquiry to perfection, as has already been explained. [36] This also led us at first to accept the views of the ancients concerning the positions of the fixed stars, the apogees for each planet, as well as the positions in longitude and anomaly, as we already mentioned, for we did not determine the position of the mean Sun perfectly until the year 1335 according to the Christian reckoning, as we will explain, God willing, in the chapter on the Sun. [37] Much before that time this book was already completed, and this led us to investigate the model for each planet separately according to our ability, not our will; nevertheless, we wish to direct those who come after us to complete what is missing in our treatment of the postulates for each of the planetary models such that it will conform to the observational evidence, because we did not have [all] the necessary observations at our disposal. [38] Subsequently, when our eyes were opened by [further] observations and we obtained [what was required for] a more perfect statement of the matter, we went over the contents of this book and perfected whatever needed perfecting. [39] Therefore, you will find many observations in this treatise that we made after the completion of this book.

[End Chapter 46]

CHAPTER 109. [1] We will illustrate some of the great confusion in the reckoning of the motion of Saturn, i.e., that we found it very far from the place where we were supposed to see it according to the reckoning of Ptolemy as perfected by al-Battānī. [2] Moreover, we noticed impossible confusion in its position which was related entirely to the motions in longitude, for we do not see uniform motion in diverse places of the deferent. [3] This is a result of an error in his computation of the apogee. [4] This follows from what we saw on one side of the deferent, namely the side on which there is an increment, for as it approaches more closely to the apogee we observe a greater increment in its place. [5] Thus it follows that the position of the apogee is greater than what al-Battānī took for it. [6] Since Ptolemy based this on observations at acronychal rising [*lit*.: the ends of the night], it is proper, when we wish to equate (*lehashvot*) this reckoning, that we take those observations which are near 180° in anomaly.

[Observation 7]

[7] We observed Saturn in the year 1327 of the Christian era, 10 hours after noon on the 29th of December, and we found it at Cancer 23;36°. [8] According to the reckoning which we mentioned, it should have been at Cancer 22;48,31°, i.e., according to the model of Ptolemy as perfected by al-Battānī. [9] When we computed the mean position of the Sun in our observation according to the method we explained, the distance from its apogee in the reckoning of al-Battānī was 216;45°, and its motion in anomaly was 178;35°.

[Observation 27]

[10] Moreover, we observed Saturn in the year 1335 about 9 hours after noon on the 28th of March, and we found it at Libra 24; 21°. [11] According to the computation of al-Battānī for correcting the mean Sun, as we understand it, it should have been at [Libra] 22;46°. [12] At that time [Saturn] was 305;15° from its apogee, and its motion in anomaly was 176;34°.

[13] The excess in the first observation, as compared with computation, was about 0;47,29°, while in the second observation it was 1;35°. [14] It is clear that the discrepancy (*ḥilluf*) between the two excesses is related of necessity to the error in the longitude of the apogee. [15] This difference is 0;47,31° and we found, according to the tables of Ptolemy, that an error of 1° in the observation on the 28th of March makes an impression in the position of the apogee of 0;4°, while an error of 1° in the observation on the 29th of December makes an impression in the position of the apogee of 0;6°. [16] Therefore, we divide this excess by the sum of these two impressions, namely 0;10°, and there results 4;45° to be added to the position of the apogee. [17] It has already been made clear that now the error will agree for these two observations.

[18] Thus Saturn, by this assumption, was observed on the 29th of December when it was 212° [Q: 62°] beyond apogee and, since every degree of the error in the position of the apogee produces an impression in this position of 0;6°, it is clear that Saturn should have been in Cancer 22;20,1°. [19] The excess over what was observed is 1;15,59°.

[20] For the observation on the 28th of March, according to this assumption, [Saturn] was 300;30° beyond the apogee. [21] Each degree of the error in the position of the apogee makes an impression in this place of 0;4°. [22] Therefore, it is clear that the position of Saturn should have been Cancer 23;5° so that the excess, between the observed position and this, is 1;16° which agrees with the previous result. [23] Therefore, it is necessary to add to the position of Saturn in longitude 1;15° [Q: 1;16°] except for the correction added to these two observations, on account of the deficiency of this amount in anomaly, which is about 0;8°. [24] Moreover, it is necessary to add about 1;8° to the motion in longitude. [25] Since this amount is appropriate, we also add [it] to the position of the apogee to account for the corrections in the aforementioned sphere. [26] It is clear that we must add 5;53° to the position of Saturn's apogee in order for these two observations to agree. [27] When we examined [Q *adds:* the rest of the] observations in this way both at apogee and perigee, we found another confusion for which it is necessary to add to the position of apogee about 3°[a].

[Observation 2]

[28] This conclusion resulted from our observation of 1325 of the Christian era, 6 hours before noon on the 16th of September: at that time we saw Saturn with α Tau (*ᶜain ha-shor*), and its longitude was Gemini 27;58°. [29] According to the reckoning by Ptolemy's model, it should have been at Gemini 28;15,40°. [30] At that time [Saturn] was 184;6° from its apogee, and its motion in anomaly was 101;43°.

[Observation 3]

[31] Moreover, we observed Saturn with a α Tau in the aforementioned year, 6½ hours before noon on the 27th of September, and we found it at Gemini 28;4°[b]. [32] According to the aforementioned reckoning, it should have been at Gemini 28;28,33°. [33] At that time [Saturn] was 184;26° from its apogee, and its motion in anomaly was 112;10°.

[Observation 4]

[34] Moreover, we observed Saturn in the aforementioned year, 6 hours before noon of the 13th of October: we found it at Gemini 28;1°[b]. [35] According to the aforementioned reckoning, it should have been at Gemini 28;20,58°. As you will see, when we repeated the observation in this place, the observed potition was less than expected according to the aforementioned reckoning, while the opposite was true for the observation near the apogee.

[Observation 30]

[37] Thus, in the year 1335, 8 hours after noon of the 20th of July, we saw Saturn at Libra 21;13°[b]. [38] According to the aformentioned reckoning it

---

a. *Marginal note.* L[evi] s[aid]: If we add to the position of the apogee another 3°, it will agree, approximately, with this observation.

b. *Marginal note.* L[evi] s[aid]: Moreover, this will agree approximately if we add an additional 3° to the apogee.

should have been at Libra 20;58° [Q: 20;57°]; at that time Saturn was 304;2° [Q: 304;3°] from its apogee, and its motion in anomaly was 284;11°.

[Observation 32]

[39] Moreover, in this year, on the 31st of August 8 hours after noon, we found Saturn at Libra 24:38,34[ob]. [40] According to the aforementioned reckoning, it should have been at Libra 24;27,15°. [41] At that time [Saturn] was 305;44° from its apogee, and its motion in anomaly was 324;17°.

[Observation 42]

[42] We observed Saturn in the year 1339, about 8 hours before noon on the 24th of March: we found it at Sagittarius 12;29°. [43] According to the aforementioned reckoning by Ptolemy's model, it should have been at Sagittarius 12;9,27°. [44] At that time [Saturn] was 349;22° from its apogee, and its motion in anomaly was 122;15°.

[Observation 43]

[45] We observed Saturn in that year about 12 hours after noon on the 9th of May: we found it at about Sagittarius 11;20,48°. [46] According to the aforementioned reckoning, it should have been at Sagittarius 10;51,39°. [47] At that time [Saturn] was 350;56° from its apogee, and its motion in anomaly was 166;50°.

[48] When we examined these observations that took place near the apogee and near the perigee, we saw from them, according to the previously mentioned principles, that this error [in the positions of Saturn] may be ascribed to the error in the apogee, and that all of them will agree, approximately, if we add 3° to the position of the apogee. [49] Since this is so, it is clear that it is appropriate to increase the apogee which follows from the reckoning of al-Battānī by about 8;53°. [50] Its motion *(mahalakh)* in about twelve centuries is thus 27;16°, and this agrees approximately, with the motion of the solar apogee, for we found that it had moved about 27;30° in twelve centuries, i.e. the interval between the observations of Ptolemy and our observations.

[51] From our observations of Saturn at mean distances, we found that the correction for the inclination of the diameters does not agree with Ptolemy's model, and it is among the subjects of our current research. Nevertheless, here we shall assume Ptolemy's model for the corrections, for thereby we shall be directed to perfect the model to agree with our sense perception.

[End Chapter 109]

CHAPTER 113. [1] There seems to be much confusion concerning the true motion of Jupiter, for we found it far from where it ought to have been according to Ptolemy's model, even as computed with al-Battānī's [tables] which are more accurate. [2] Moreover, we saw that this confusion cannot be entirely ascribed to the error in the motion in longitude for which reason we always saw Jupiter at less than where it should have been according to the reckoning which we mentioned. [3] But we also found that whenever Jupiter approached the perigee of the orb of apogee, there appeared in it a greater observed diminution. [4] Thus it would seem that the position of the apogee is greater than where al-Battānī put it. [5] Ptolemy based this reckoning on observations at acronychal risings. [6] Therefore, when we wish to equate *(lehashvot)* this reckoning, we ought to take these observations at 180° of anomaly: we took two such observations.

[Observation 9]

[7] The first observation: we observed Jupiter with Regulus in the year 1328 of the Christian era, 7 hours after noon on the 3rd of March, and we found it at Virgo 6;5°. [8] According to al-Battānī's reckoning for the longitude of Jupiter and the position of its apogee, together with our mean position for the Sun, it should have been at Virgo 8;13,52°. [9] At that time, according to the aforementioned reckoning, [Jupiter] was 339;14° from its apogee, and its anomaly was 191°.

[Observation 19]

[10] The second observation: we observed Jupiter with Spica *(simak al-ᶜazal)* in the year 1330, 8 hours after noon on the 29th of April, and we found it at Scorpio 7;2°. [11] According to the aforementioned reckoning, it should have been at Scorpio 9;15,59°.

[12] In these two observations, as well as in all the rest of the observations that we made of Jupiter, we found that the observed [position] was less than it should have been according to this reckoning. [13] Therefore, we know that the position of Jupiter in longitude was assumed to be greater than what it should be. [14] In this case, it would seem most likely that this amount of error can only be ascribed to an error in the planet's motion [MSS *read:* place] in longitude, or to the position of the apogee, or to both of them. [15] In fact, we must ascribe this error to both causes, for we found the distance between observation and computation greater in the observation on the 29th of April than in the observation on the 3rd of March. [16] We know that part of this error is related to the error in computing the distance of the planet from its apogee, and that will be explained more completely from the observations at apogee and perigee, for they yield an increment to the computed position of Jupiter's apogee of about 2°, as we will explain. [17] The excess of computation over observation in the observation on the 3rd of March is 2;8,52°, and the excess of computation over observation in the observation on the 29th of April is 2;13,59°. [18] It is clear with a little reflection that the distance of the planet from its apogee must be less than what it was in the computation by some amount in order to agree with these two observations.

[19] First we shall investigate by means of heuristic reasoning what impression a diminution of 1° in longitude would make in each of these observations. [20] We found that according to Ptolemy's model, a diminution of 1° in longitude implies a diminution in the observation on the 3rd of March of about 1;7,50°. [21] When we divide this into the diminution of this observation, namely, 2;8,52°, the result is 1;53;59°. [22] But in the observation on the 29th of April, a diminution of 1° in longitude implies a diminution of 1;9°. [23] When we divide this into the diminution in the observation, namely 2;13,59°, the result is 1;56,30° [P: 1;57,30°]. [24] This implies a

diminution in the position of Jupiter in longitude of about 1;54° at the very least. [25] But this does not [yield complete] agreement, for it is clear from the observations of Jupiter that we made at apogee and perigee that we must increase the position of the apogee by about 2°. [26] This will increase the position for the 3rd of March by about 0;12,20°, and for the 29th of April by about 0;9,52°. [27] Further, it is necessary to diminish the longitude by appropriate amounts for the two observations. [28] Thus, for the observation on the 3rd of March, one should subtract 2;14,54° [Q: 2;4,54°] and for the observation on the 29th of April 2;5,5°. [29] This implies that we should subtract about 2;5° from the longitude of Jupiter, and add 2° to the position of the apogee, as compared with what follows from the reckoning of al-Battānī.

[30] This was verified by many observations at apogee and perigee as well as at intermediate positions: all of them agreed very well with this reckoning, the remaining small discrepancy being due to the approximation in Ptolemy's reckoning, or to the approximation in the taking of the observation, resulting either from the thickness of the air, or from the approximation [in the measurement (?)] in the observation.

[Observation 16]

[31] We observed Jupiter with Spica in the year 1328 of the Christian era, 6 hours before noon on the 7th of November, and we found Jupiter at Libra 5;32°. [32] According to the aforementioned reckoning, it should have been at Libra 5;20°. [33] At that time [Jupiter] was 359;51° from apogee, excluding the increment of 2°; while its anomaly was 57;18°.

[Observation 18]

[34] In that year, 5 hours before noon on the 23rd of December, we found Jupiter at Libra 11;35,10°. [35] According to the aforementioned reckoning, it should have been at Libra 11;24°. [36] The observed position was greater than the computed position by about 0;11°, and this agrees with increment of 2° in the position of the apogee.

[37] The observations near perigee also confirm this increment of about 2° to the position of the apogee.

[Observation 31]

[38] In the year 1335 of the Christian era, 8½ hours before noon on the 25th of July [P: June], we found Jupiter at about Taurus 4;10°. [39] According to the aforementioned reckoning, it should have been at Taurus 4;19,30°. [40] At that time [Jupiter] was 21;22° [Read: 201;22°] from its apogee, and its anomaly was 108;13°.

[Observation 33]

[41] In that year, 8 hours before noon, on the 4th of September, we saw Jupiter at Taurus 4;28° [Q: 4;27°]. [42] According to the aforementioned reckoning, it should have been at Taurus 4;38,18°. [43] At that time [Jupiter] was 204;49° [Q: 24;49°] from its apogee, and its anomaly was 145;35°.

[44] All these observations confirm very nearly the increment of 2° in the position of the apogee. [45] We found from observations near perigee, on one side of the orb of apogee, that the increment in the position of the

apogee was even greater than this amount, and so it would seem that the correction near perigee is smaller than [the correction near apogee]. [46] But these observations were taken with the Moon and we are not sure that they are free from error, for we have not yet examined the lunar observations closely enough to depend on the veracity of the correction to its motion at all places on the orb of apogee: this is a matter that we are currently pursuing. [47] Therefore we fix the apogee at 2° more than previously assumed. [48] We leave the rest [as it was] until the truth becomes clear to us by means of these observations, God willing. [49] We will show that many observations are in agreement, very nearly, with the reckoning on which we have decided.

[Observation 1]

[50] We observed Jupiter with α Tau in the year 1325 of the Christian era, $6^1/_2$ hours before noon on the 16th of September, and we found it at Cancer 8°. [51] According to the reckoning on which we decided because of the aforementioned observations, it should have been at Cancer 7;59,3°, and this agrees very nearly. [52] At that time [Jupiter] was 260;28° from its apogee, and its anomaly was 101;11°.

[Observation 5]

[53] On the 13th of October of that year, 6 hours before noon, we saw Jupiter at Cancer 9;33°. [54] According to the aforementioned reckoning, it should have been at Cancer 9;33,21°. [55] At that time [Jupiter] was 262;40° from its apogee, and its anomaly was 125;32°.

[Observation 6]

[56] In the year 1327, 8 hours after apparent noon on the first of June, we saw Jupiter at Leo 9;2° [P: 9;52°]. [57] According to the aforementioned reckoning, it should have been at Leo 8;59,28°. [58] At that time [Jupiter] was 312;16° [Q: 312;8°] from apogee, and its anomaly was 304°.

[Observation 8]

[59] In that year, 5 hours before noon on the 8th of January, we saw Jupiter at Virgo 12;3°. [60] According to the aforementioned reckoning, it should have been at Virgo 12;5,46°. [61] At that time [Jupiter] was 330;36° from its apogee, and its anomaly was 143°.

[Observation 10]

[62] In the year 1328, 8 hours after noon on that 1st of May, we saw Jupiter at Virgo 3°. [63] According to the aforementioned reckoning, it should have been at Virgo 2;56,3°. [64] At that time [Jupiter] was 340;7° from its apogee, and its anomaly was 246;20°.

[Observation 12]

[65] In that year, 8 hours after noon on the 16th of June, we saw Jupiter at Virgo 7;12°. [66] According to the aforementioned reckoning, it should have been at Virgo 7;7,10° [Q: 7;7,11°]. [67] At that time, [Jupiter] was 343;56° from its apogee, and its anomaly was 288;15°.

[Observaiton 34]

[68] In the year 1338, 8 hours before noon on the 22nd of September, we saw Jupiter at Leo 10;46°. [69] According to our reckoning, it should have

been at Leo 10;44,54° [Q: 10;44,50°]. [70] At that time, [Jupiter] was 295;28° from its apogee, and its anomaly was 71;42°.

[Observation 37]

[71] In that year, on the 8th of January, 7 hours after noon, we saw Jupiter at Leo 13;28° [Q: 3;28°]. [72] According to the aforementioned reckoning, it should have been at Leo 13;24°. [73] [Jupiter] was 304;32° from its apogee, and its anomaly was 169;44°.

[Observation 39]

[74] On the 23rd of January we saw Jupiter at Leo 11;29°. [75] According to the aforementioned reckoning, it should have been at Leo 11;24°. [76] At that time its anomaly was 183;32°.

[Observation 40]

[77] On the 26th [P: 27th] of January, we saw Jupiter at Leo 11;15°. [78] According to the aforementioned reckoning, it should have been at Leo 11;10,46°. [79] At that time [Jupiter] was 306;3° from its apogee, and its anomaly was 185;20°.

[Observation 41]

[80] On the 30th of January, we saw Jupiter at Leo 10;39°. [81] According to the aforementioned reckoning, it should have been at Leo 10;38,10°.

[82] We found other observations that disagreed with Ptolemy's model, and it seemed to us that the absence of agreement was due to the correction for the inclination of the diameters that does not agree with Ptolemy's model. [83] We measured some of them and they agreed with our model, and [that agreement] was best at 150° of anomaly before or after [the apogee]. [84] In our model for Jupiter, we accept the amounts of the corrections that Ptolemy determined for this planet for, from them, we will be led the [true] corrections, very nearly, with much investigation of the observations.

[End Chapter 113]

CHAPTER 117. [1] We see much confusion concerning the true motion of Mars, so much so that we find it does not conform to Ptolemy's principles for the corrections. [2] Part of [the reason why] it is distant from the correct [model] seems to be that it agrees with what follows from our model despite the [partial] agreement with his principles. [3] Our first opinion was to accept his model, and this led us to a more appropriate determination of the amount of the correction. [4] But to equate the motions in longitude and apogee, we have to consider observations, to which we were led by Ptolemy, that will allow us to find the position of the apogee and the position of the mean planet: these observations take place at acronychal risings.

[Observation 17]

[5] We say that we observed Mars with α Tau in the year 1328 of the Christian era, 6 hours after noon on the 28th of November: we found it at Gemini 13;37°. [6] But according to the reckoning of al-Battānī, it should have been at Gemini 15;56,46°. [7] At that time, [Mars] was 291;25° from its apogee, and its motion in anomaly was 190;5,27°.

[Observation 28]

[8] We observed Mars again, with Regulus, in the year 1335 of the Chris-

tian era, 9 hours after noon on the 28th of March: we found it at Virgo 25;23°. [9] But according to the reckoning of al-Battānī, it should have been at Virgo 26;28,44° [Q: 25;28,44°]. [10] At that time [Mars] was 62;31° from its apogee, and its motion in anomaly was 176;51°. [11] The computation in both cases yielded a result greater than the observation, namely in the first case 2;19,46°, and in the second case 1;5,44°.

[12] It is clear to us from many observations that to change the position of the apogee is not sufficient for, with a little investigation together with our preceding remarks, it is clear that these discrepancies can only be accounted for by correcting the eccentricity which is larger than it ought to be. [13] This correction had to be added in the first observation, whereas in the second observation it had to be subtracted. [14] Since this error is about equal in both these observations where the distances from the apogee were about equal, we will divide the 1;14°, the excess of the first observation over the second, into two halves, and the result is 0;37°. [15] There remains the increment due to the error in computing the motion in longitude in both of these observations, namely 1;42,44°. [16] The diminution from the longitudes of 1/2° gives the impression in the first observation, according to Ptolemy's model, of 1;10,15° as the diminution in the true position of the planet. [17] It is appropriate, by proportion, that there is a diminution from the longitude there on account of the 1;42,44° of about 0;44°, and the diminution from the longitude of 1/2° gives the impression in the second observation of a diminution in the true position of the planet of 1;7,16°. [18] Therefore, it is appropriate, by proportion, that we subtract about 0;46° from the longitude there on account of the 1;42;44°: this is clear from the tables of Ptolemy. [19] Therefore, it is appropriate to subtract about 0;45° from the longitude to equate this discrepancy. [20] It is appropriate for you to know that we repeated the second observation many times around that time and all these observations agreed closely with what we have recorded. [21] Moreover, we found that many other observations agreed closely with what we have recorded.

[Observation 15]

[22] We observed Mars with α Tau in the year 1328 [Q: 1327] according to the Christian reckoning, 12 hours after noon on the 5th of November, and we found it at Gemini 21;31°. [23] At that time, according to our computation, [Mars] was 278;38° [Q: 275;38°] from its apogee, and its motion in anomaly was 180;20,25°. [24] According to Ptolemy's model, it should have been at Gemini 21;37,22°.

[Observation 35]

[25] Moreover, we observed Mars with Regulus in the year 1338 of the Christian era, 7 hours before noon on the 22nd of September: we found it at Virgo 8;58°. [26] At that time, according to our reckoning, [Mars] was 9;2° from its apogee, and its motion in anomaly was 45;20°. [27] According to Ptolemy's model, it should have been at Virgo 8;54°; 9;4° from its apogee, and 45;18° in anomaly.

[Observation 36]

[28] In the aforementioned year, 7 hours before noon on the 18th of

November, we found Mars at Libra 14;45° [Q: 14;48°]. [29] According to the reckoning with Ptolemy's model, which we have mentioned, it should have been at Libra 14;39,37°. [30] At that time [Mars] was 39;10° from its apogee, and its motion in anomaly was 71;34°.

[Observation 38]

[31] In the aforementioned year, 8 hours before noon on the 10th of January we found Mars at Scorpio 17;1,40°. [32] According to the reckoning with Ptolemy's model, it should have been at Scorpio 16;55,35°. [33] At that time Mars was 66;32° from its apogee, and its motion in anomaly was 96;4°.

[Observation 25]

[34] We observed Mars with Regulus in the year 1334 of the Christian era, 8 hours before noon on the 4th of October, and we found it at Leo 20;45°. [35] According to our reckoning with Ptolemy's model, it should have been at Leo 20;38°. [36] At that time [Mars] was 329;40° from its apogee, and its motion in anomaly was 96;29°.

[Observation 11]

[37] In the year 1328 of the Christian era, 8 hours before noon on the 5th of May, we observed Mars with Venus: we found it, from our computation of Venus's [longitude], at Pisces 23;52,30°. [38] According to Ptolemy's model, it should have been at Pisces 24;10°. [39] At that time [Mars] was 181;53° from its apogee, and its motion in anomaly was 95;13°, and this agrees very nearly. [40] These observations, as you will see, agree very nearly with what we have discussed, and we made many other observations that agree with this reckoning. [41] But we have found other observations that were very far from this reckoning, at apogee, at perigee, and at mean positions, namely, we have observed . . .[a]

[42] . . . except that we ought first to suppose the model according to Ptolemy's principles with regard to the amounts of the corrections from which, God willing, we will be led [to approve] what was approximate in his reckoning.

[End Chapter 117]

CHAPTER 122. [1] It is now appropriate to mention observations of the inclinations of the planets.

[Observation 26]

[2] We observed Venus with Spica in the year 1334 of the Christian era, on the 10th day of November, one and a half hours before sunrise: we saw Venus 3:59° to the north of Spica. [3] At that time Venus was 143;55° from its apogee; its anomaly was 249;53°; its latitude, according to the reckoning of Ptolemy, was 1;36,7° to the north, but we observed its latitude as 1;59° to the north, for we reckon the latitude *(merḥav)* of Spica as 2° to the south, in agreement with Ptolemy.

[Observation 23]

[4] In that year [1334], on the 7th of May, we observed Venus with the

a. Here both P and Q have a blank space of more than a page.

center of the Moon when the altitude *(govah)* of the Sun to the west was 62;24° in the horizon where the pole culminates at 44°. [5] Its center had already reached the longitude of the center of the Moon, very nearly; Venus appeared to the south of the Moon, 3° on the crosspiece (*luaḥ*) at a distance (*merḥaq*) of 124°, including the entire diameter of the Moon. [6] Therefore, its apparent latitude was 1;9°, and the apparent latitude of the Moon was 3;39,20° to the north [P mg.: the latitude *(roḥav)* of Venus was then 2° to the north]. [7] According to Ptolemy's model, the latitude of Venus was 3;8,58° to the north. [8] At that time Venus was 319;50° from its apogee, and its anomaly was 134;45°.

[Observation 44]

[9] In the year 1339 of the Christian era, on the 28th of September, about 2 hours before sunrise of the aforementioned day, in the city of Avignon, Venus occulted *(histir)* Jupiter, to the appearance of the eye. [10] At that time the latitude of Venus, according to the tables, was 0;20,11° to the north, while the latitude of Jupiter was 0;45,20° to the north. [11] At that time Venus was 101;15° from its apogee, and its anomaly was 269;6,4°; while Jupiter was 326;49° from its apogee, and its anomaly was 46;32°.

[Observation 13]

[12] In the year 1328 of the Christian era, on the 19th of August, about 8 hours [P: 7 hours] before noon, Venus was south of Saturn by about 0;20°, and then Venus passed him by. [13] At that time the latitude of Venus, according to the tables was [blank space in MSS]; and the latitude of Saturn, according to the tables, was [blank space in MSS]. [14] At that time Venus was [blank space in MSS] from its apogee, and its anomaly was [blank space in MSS].

[Observation 14]

[15] In the same year, on the 2nd of October, 6 hours before noon, we saw Venus pass about 0;10° to the north of Jupiter whose latitude at the time as 1;10°. [16] At that time the latitude of Venus, according to the tables, was [blank space in MSS]; while the latitude of Jupiter was [blank space in MSS]. [17] At that time Venus was [blank space in MSS] from its apogee, and its anomaly was [blank space in MSS]; while Jupiter was [blank space in MSS] from its apogee, and its anomaly was [blank space in MSS].

[Observation 45]

[18] In the year 1340 of the Christian era, on the 24th of July, about three and and a half hours after noon, Venus overtook Jupiter to the appearance of the eye. [19] I estimated that Jupiter was between a sixth and a quarter of a degree north of Venus. [20] At that time the latitude of Venus, according to the tables was [blank space in the MSS]; while the latitude of Jupiter was [blank space in the MSS]. [21] At that time Venus was [blank space in the MSS] from its apogee, and its anomaly was [blank space in the MSS]; while Jupiter was [blank space in the MSS] from its apogee, and its anomaly was [blank space in the MSS].

[Observation 22]

[22] In the year 1333 of the Christian era, on the 5th day of July, about 8

hours after noon, we saw Mars in latitude [*read*: conjunction] with Saturn, but about 2;3,33° south of him. [23] The longitude of Mars according to our reckoning was Virgo 27;32,26°, and of Saturn Virgo 27;30,57° [Q: 27;30,51°]. [24] According to the tables, the latitude of Mars was 0;11° to the north, whereas the latitude of Saturn was 2;5,15° to the north. [25] At that time Mars was 89;59° from its apogee, and its anomaly was 246;21,15°; whereas Saturn was [blank space in the MSS] from its apogee, and its anomaly was [blank space in the MSS].

[Observation 21]

[26] In that year, on the 16th day of April, about 7 hours after noon, we saw Mars in conjunction in longitude, approximately, with Regulus. [27] I estimated that Mars was about 0;36° to the north of Regulus but we did not measure it with the observational instrument *(keli ha-mabaṭ)*. [28] Therefore, we have not depended very much on the latitude taken from this observation. [29] According to the tables, its latitude was [blank space in the MSS]. [30] At that time Mars was [blank space in the MSS] from its apogee, while its anomaly was [blank space in MSS].

[Observation 20]

[31] In the year 1331 of the Christian era, on the 27th of May, about 8 hours after noon, we saw Mars in conjunction in longitude, approximately, with Regulus. [32] The apparent distance in latitude between them was 0;47°. [33] At that time Mars was [blank space in the MSS] from its apogee, and its anomaly was [blank space in the MSS].

[Observation 24]

[34] In the year 1334 of the Christian era, on the 4th of October, about 3 hours before sunrise, Mars was on a straight line with Regulus, and the star that was in its degree [i.e. γ Leo]. [35] I estimated the latitude between Mars and Regulus as about 1/8 of the distance between Regulus and that star. [36] At that time the latitude of Mars, according to the tables, was [blank space in the MSS]. [37] At that time [Mars] was [blank space in the MSS] from its apogee, and its anomaly was [blank space in the MSS].

[Observation 29]

[38] In the year 1335 of the Christian era, about one hour after sunset, we saw Mars 1;30° to the north of Spica. [39] According to the tables, [Mars'] latitude was about 0;23° to the south. [40] If this were correct, the latitude of Spica would be 1;53° to the south. [41] But we found its latitude from our own observations greater than 2;30° [to the south] when we observed it in conjunction in longitude with the Moon. At that time Mars was 114;10° from its apogee, and its anomaly was 223;47° [P: 253;47°].

[End Chapter 122][a]

Acknowledgments

I am most grateful to Professor Peter J. Huber (Harvard University) for making his program for computing planetary positions available to me, and

---

a. There is a blank space in both P and Q before the beginning of Chapter 123, and this suggests that some of Chapter 122 has been lost.

to Dr. John P. Britton (Yale University) and Dr. Brian Marsden (Smithsonian Astrophysical Observatory) for their assistance in computing star positions. Dr. Gad Freudenthal (CNRS, Paris) kindly provided a number of suggestions for the translation of Chapter 46 of Levi's *Astronomy*. This study was supported by a research grant from the National Endowment for the Humanities.

References

ALI, J. 1967. *al-Bīrūnī's Taḥdīd al-Amākin*. Beirut.

Almagest. See Toomer 1984.

BEAVER, D. 1970. "Bernard Walther: Innovator in Astronomical Observation," *Journal for the History of Astronomy* 1:39-43.

CAUSSIN DE PERCEVAL 1804. "Le livre de la grande table Hakémite," *Notices et Extraits des Manuscrits de la Bibliothèque Nationale* 7:16-240.

GOLDSTEIN, B. R. 1971. *Al-Biṭrūjī: On the Principles of Astronomy*. New Haven.

———1974. *Levi ben Gerson's Astronomical Tables*. Hamden CT.

———1975. "Levi ben Gerson's Analysis of Precession," *Journal for the History of Astronomy* 6:31-41.

———1979. "Medieval Observations of Solar and Lunar Eclipses," *Archives Internationales d'Histoire des Sciences* 29:101-156.

———1985a. *The Astronomy of Levi ben Gerson (1288-1344)*. New York.

———1985b. "Star Lists in Hebrew," *Centaurus* 28:185-208.

———1986. "Levi ben Gerson's Theory of Planetary Distances," *Centaurus* 29:272-313.

HARTNER, W. 1969. "Naṣīr al-Dīn al-Ṭūsī's Lunar Theory," *Physis* 11:287-304.

KENNEDY, E. S. "A Survey of Islamic Astronomical Tables," *Transactions of the American Philosophical Society* NS 46.

———1973. *A Commentary upon Bīrūnī's Kitāb Taḥdīd al-Amākin*. Beirut.

KING, D. A., AND GINGERICH, O. 1982. "Some Astronomical Observations from Thirteenth-Century Egypt," *Journal for the History of Astronomy* 13:121-128.

NALLINO, C. A. 1903-07. *Al-Battānī sive Albatenii Opus astronomicum*. 2 vols. Milan.

NEUGEBAUER, O. 1957. *The Exact Sciences in Antiquity*. Providence.

SALIBA, G. 1983. "An Observational Notebook of a Thirteenth Century Astronomer," *Isis* 74:388-401.

———1985. "Solar Observations at the Maragha Observatory before 1275," *Journal for the History of Astronomy* 16:113-122.

TOOMER, G. J. 1969. "The Solar Theory of al-Zarqāl," *Centaurus* 14:306-336.

———1984. *Ptolemy's Almagest*. New York.

TUCKERMAN, B. 1964. *Planetary, Lunar, and Solar Positions A.D. 2 to A.D. 1649*. Philadelphia.