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Astronomy and Ancient Chronology

Peter J. Huber, Klosters

1 The available astronomical evidence.

The currently available astronomical evidence relevant for the absolute chronology of the late third and early second millennium BC has five independent parts:

(a) OB Venus data (b) OB month-lengths	linked to Ammiṣaduqa year 1
	⇕ about 400 years
(c) Ur III month-lengths (d) Ur III eclipses	linked to Amar-Sin year 1
	⇕ about 287 years
(e) Akkad eclipses	linked to Sargon year 1

None of them is fully trustworthy. The Venus data (a) are corrupted through a long scribal tradition and it is not *a priori* obvious that they represent genuine observations from the time of Ammiṣaduqa. The month-length data (b) and (c) are noisy. If they have the same statistical structure as their Neo-Babylonian counterparts (which is not proven), a correct chronology induces an agreement rate of merely 67% between calculated and observed 30-day months. This is uncomfortably close to the agreement rate 53% pertaining to a randomly chosen wrong chronology, and for establishing absolute dates on the basis of month-lengths alone one would need between 250 and 300 precisely spaced month-lengths (i.e. several decades of data, which may have lacunas, but with perfectly known intercalations). The eclipses (d) and (e) are from the omen series Enuma Anu Enlil, and it is not clear to what extent such omens contain genuine eclipse observations, or merely learned systematization. Also the identification of the apodoses with historical events is uncertain (e.g. whether the omen EAE 20-III pertains to the death of Šulgi or of some other king). Around 2000 BC, eclipse times are subject to clocktime errors of give or take about one hour, caused by the irregular rotation of the earth. Moreover, the year counts establishing the distances between the First Dynasty of Babylon, the Third Dynasty of Ur, and the Akkad dynasty, may have unsuspectedly large uncertainties.

The only way to check astronomical consistency of the evidence is by trying, that is: by attempting to fit chronologies to the data. The best fitting chronology is not necessarily the correct one, but if some chronologies can be fitted coherently, then this supports validity of the data.

Note. This paper is based on investigations reported more fully in Huber (1982, 1999-2000, 2000).

2 The Venus data.

Despite Huber *et al.* (1982), much confusion still exists about the Venus tablet and its astronomical significance, and Gurzadyan's treatment in Gasche *et al.* (1998) has added only further obfuscation. A critique and refutation of Gurzadyan's treatment provides an excellent opportunity to elaborate on the problems posed by the text, and to explain what can be gleaned from it.

Certain aspects of the Venus data are chronologically insensitive. For example, the durations of invisibility depend mainly on the common longitude of the sun and the planet at the time of conjunction, in other words on the season, and one gets a good agreement once every eight years. It seems that Gurzadyan had zeroed in on such aspects. What is chronologically sensitive are the dates of events relative to the lunar month: they shift four days every eight years, and thus Venus events are in step with the months only about once every 56 or 64 years. However, it is not possible to argue in a simple-minded fashion in terms of such Venus periods (8, 56, or 64 years). Some astronomically feasible Venus chronologies are spaced 35 years (e.g. -1517 and -1482), and it is necessary to check compatibility by explicit computation. — In order to avoid too much repetition, I shall play some variations on the themes treated in Huber *et al.* (1982); for a change, I shall argue with discrepancies expressed in days (which is slightly more intuitive) rather than in *arcus visionis* values.

I am following the text established by Reiner and Pingree (1975, to be quoted RP), see their Table IV, with minor and mostly inessential deviations. An exception is my treatment of years 8-9, see below. I use the mnemonic abbreviations WS, ER, ES, WR for Western Setting, Eastern Rising, and so on. From the number of internal inconsistencies (between dates of disappearance and reappearance and the stated duration of invisibility), of discrepancies between duplicates and of astronomical impossibilities, I once guessed that at least 20%, maybe 40%, of the numbers contained in that text are grossly wrong – or as I prefer to express it: that between 60% and 80% appear to be in order. They must have been corrupted by copying errors during the long period between the creation of the original text and the writing of the surviving manuscripts. Many of the corrupted passages are signalled by impossible durations of invisibility. Since several (but not all) of the impossible durations are consistent with the dates of disappearance and reappearence given in the text, I conclude that the Venus tablet goes back to an original text containing dates, including year names, but no durations of invisibility/visibility, and that the latter were added only after the text already had considerably deteriorated. In the tables below, dates supposed to be corrupt are marked by a star, and conjectural emendations are given in parentheses. Brief justifications for starring or for emending follow. The preliminary screening is primarily based on astronomically impossible durations of invisibility: at inferior conjunction (Venus between Sun and Earth) the expected duration ranges from about 1 to 19 days; at superior conjunction (Venus behind Sun), from about about 55 to 75 days. For more details, see Huber *et al.* (1982).

Inferior conjunction. In year 14, the invisibility is at least a month too long, comparison with year 6, a Venus period earlier, suggests that the date of WS is wrong. Year 19 is incompatible with the 8-year Venus period and the events 8 and 16 years earlier. The 7d invisibility of the years 8, 13 and 21 may reflect an ancient restoration of a broken text, based on a schematic insert included in the Venus text. This insert ("Section II" of RP, p.24) gives unrealistic constant durations of invisibility of 7 days at inferior and of 3 months at superior conjunction. In these 7d pairs at least one member date agrees poorly either with the 8-year period or with modern calculation. If we want to avoid biasing chronological conclusions, we should exclude complete pairs, preferably all three.

Superior conjunction. The 5m 16d invisibility of year 12 is much too long; both ES and WR appear to be wrong. In year 13, the stated invisibility is much too short, perhaps one should emend XI 21 into XII 21, but also the reading 21 (or 11?) is in doubt. The events of year 18 are missing on the tablets; Weir once proposed to restore them from a textual variant for year 5, but even though his conjecture agrees well with calculation, I shall disregard it as insufficiently founded. In year 16, the main text has XII 15 ES, 3m 9d invisibility, III 25 WR. The invisibility is about a month too long, Pingree (in RP p. 21 bottom) restores the text from duplicates as XII 25 ES, 2m 9d invisibility, III 4 WR. In year 20 the text has WR on VI 24, but gives an interval 2m 6d, corresponding to VI 1, and we accept the latter as a conjectural emendation.

The WR on 9 III 11 and the WS on 9 XII 11 are fairly secure emendations, based on the following considerations. In the years 8-9 the text is garbled and one event is missing (Venus sets twice in a row, without rising in between). The date III 11 for WS is impossible (it roughly corresponds to the date expected for WR), and the stated invisibility of 9m 4d is nonsense (from year 1, a Venus period earlier, one would expect about 4d). I conjecture that an early version of the text, before the durations of invisibility were added, once had the sequence:

8 XII 25 ES – Year of the Golden Throne – 9 III 11 [WR, 9 XII 11] WS, 9 XII 15 ER.

A scribe copying the text would have skipped from the first number 11 to the next number 11, omitting the passage in square brackets.

To summarize the process of purging and emending, we note that the text originally covered 13 synodic periods of Venus, or 52 individual dates of disappearence and appearance. We disregard the conjectural restoration of year 18; this leaves us with 50 dates. Among them, we have marked 12 as probably corrupt (without making any chronological assumptions!). Thus, 38 useable dates remain; of them, 4 are fairly secure conjectural emendations (again made without making any assumptions about the chronology!).

Inferior conjunction					Text
	WS		ER		invis
1 XI	15	XI	18		3
3 VI	23	VII	13		20
5 II	2	II	18		18(!)
6 VIII	28	IX	1		3
8 IV	25*	V	2*		7
9 (XII	11)	XII	15		9m(!)4d
11 VI	26	VI2	7		12
13 II	5*	II	12*		7
14 VII	10*	VIII	27		1m 17d
16 IV	5	IV	20		15
17 XII	10	XII	14		4
19 VI2	1*	VI2	17*		16
21 I	27*	II	3*		7(!)

-1549		calculated			obs-calc	
WS		ER		invis	WS	ER
XI	3	XI	3	0	12	15
VI	10	VI	28	18	13	15
I	15	I	21	6	16	26
VIII	8	VIII	15	7	20	15
III	27	IV	12	14	27*	19*
XI	28	XI	29	1	13	16
VI	6	VI	24	18	20	13
I	12	I	17	5	23*	25*
VIII	4	VIII	12	8	-24*	15
III	24	IV	7	13	11	13
XI	24	XI	25	1	15	18
VI2	3	VI2	21	18	-2*	-4*
I	7	I	13	6	20*	19*

Starred: probably corrupt. In parentheses: conjectural restorations.

Table 2.1. Observed and calculated disappearances and appearances of Venus, and differences between observation and calculation in days.

In Tables 2.1 and 2.2, calculated events correspond to the first day with *arcus visionis* values: WS ≤ 5.2°, ER ≥ 5.7°, ES ≤ 6.2°, WR ≥ 6.3° (i.e. settings are taken to be the first day of invisibility). These limits were chosen in view of the comments in Huber *et al*. (1982), p.14: the first two values are Schoch's limits, the other two were slightly raised against his 6°, to improve the agreement with the LB data. The same limits must very nearly be true also for the OB material. This can be seen from the row with the medians in Table 2.2: if the limits are correct, then for each chronology, the difference between the two values theoretically ought to be 0. At superior conjunction, the agreement can be improved slightly by lengthening the duration of invisibility on each side by 1 day. This would amount to raising the visibility limits by another 0.2°, but this is well within statistical uncertainty. Note that at inferior conjunction, the *arcus visionis* changes between 0.6° and 1.6° per day, at superior conjunction between 0.1° and 0.3° per day. Note also that the Babylonian day begins at sunset, so for example the calculated invisibility of 0 days (= difference between the dates of WS and ER) in the first line of Table 2.1 means that on the evening of XI 2 Venus was still marginally visible; the next morning (also XI 2) and evening (XI 3, WS) it was invisible; on the following morning (also XI 3, ER) it became visible again (note that it could not be seen for almost 36 hours).

An inspection of Table 2.1 shows that for Ammiṣaduqa year 1 = -1549 (the Gasche-Gurzadyan chronology) there is a systematic offset of about half a lunar month between calculations and observations. For example in the first line of Table 2.1, Venus events that are calculated to occur just after new moon, in reality are observed just after full moon, and so on (this argument clearly is independent of the intercalations). If we take the midpoint of the calculated short invisibility at inferior conjunction (where the planet cannot be seen by a naked-eye observer under any circumstances), then we find that it systematically fails to fall inside the observed interval of invisibility, except in the years 14 and 19, where the textual dates are corrupt. Since Venus events shift about 4 days in the lunar calendar for each 8-year Venus period, one would have to move by 4 Venus periods, or 32 years, either forward to the Supershort chronology -1517 or backward to the Short Chronology -1581, in order to get the events in step with the lunar month.

In Table 2.2, the observed dates and the differences between observed and calculated dates are presented in more compact form for both inferior and superior conjunctions and for all of the main Venus chronologies. It is evident that for the unstarred dates, apart from the Gasche-Gurzadyan chronology -1549, the differences between the observed and the calculated dates are small, with very few exceptions. Even the larger among the differences are still small enough that they could have been caused indifferently by scribal errors, by bad weather, or by a wrong chronology. On the other hand, most of the starred items are grossly deviant, and if we should try to reconcile at least some of them with any chronology, we would lose the good agreement with the majority.

Smallness here must be interpreted in comparison to Late Babylonian control material. Among the LB Venus observations accessible to me, between 85% and 90% of the observed dates fall within ±2 days of the calculated dates at inferior conjunction, and within ±6 days at superior conjunction; there are occasional deviations of up to 11 days. The LB values are somewhat biased toward good weather conditions (dates marked in the LB texts as “not observed” had been excluded by me). We do not know whether the OB observers followed the same observational conventions, and what they did in case of bad weather (probably they just substituted an educated guess, like their LB colleagues). But in any case, if one disregards the starred numbers in the tables, most of the remaining discrepancies between observations and calculations are reassuringly small and comparable to those in the LB material. In my opinion they are too small for artificial data of antique manufacture before Ptolemy’s time. For example, they compare favorably to the differences between modern calculation and Venus tables of LB mathematical astronomy, such as ACT 410.

Inferior conjunction			obs - calc											
Text			-1701		-1645		-1637		-1581		-1549		-1517	
WS	ER	invis	WS	ER	WS	ER	WS	ER	WS	ER	WS	ER	WS	ER
1 XI 15	XI 18	3	-1	0	-4	-2	0	2	-4	-1	12	15	-1	1
3 VI 23	VII 13	20	-7	-1	-6	-3	-1	0	-1	0	13	15	-1	1
5 II 2	II 18	18(!)	3	7	0	5	4	10	1	9	16	26	2	13
6 VIII 28	IX 1	3	-1	1	-1	-2	2	1	2	-1	20	15	8	2
8 IV 25*	V 2*	7	18*	8*	13*	4*	17*	9*	14*	6*	27*	19*	14*	7*
9 (XII 11)	XII 15	9m(!)4d	-1	0	-4	-1	1	4	-3	0	13	16	-2	1
11 VI 26	VI2 7	12	1	-4	2	-6	5	-2	4	-3	20	13	6	-1
13 II 5*	II 12*	7	10*	6*	7*	4*	11*	9*	7*	7*	23*	25*	8*	11*
14 VII 10*	VIII 27	1m 17d	-44*	0	-45*	-2	-41*	2	-40*	1	-24*	15	-35*	1
16 IV 5	IV 20	15	2	1	-3	-3	1	1	-3	-2	11	13	-3	-1
17 XII 10	XII 14	4	2	4	0	3	3	6	0	3	15	18	0	3
19 VI2 1*	VI2 17*	16	-20*	-19*	-20*	-21*	-15*	-17*	-16*	-19*	-2*	-4*	-15*	-16*
21 I 27*	II 3*	7(!)	7*	0*	3*	0*	8*	3*	3*	3*	20*	19*	5*	7*
		median:	0	0	-2	-2	1.5	2	-0.5	0	14.5	15	-0.5	1

Superior conjunction			obs - calc											
Text			-1701		-1645		-1637		-1581		-1549		-1517	
ES	WR	invis	ES	WR	ES	WR	ES	WR	ES	WR	ES	WR	ES	WR
2 VIII 11	X 19	2m 8d	-6	3	-9	-1	-6	3	-7	-1	9	15	-4	0
4 IV 2	VI 3	2m 1d	-5	-10	-4	-8	1	4	4	-2	23	15	13	0
5 IX 25	XI 29	2m 4d	3	1	-2	-3	1	1	-3	-1	10	13	-5	0
7 V 21	VIII 2	2m 11d	-3	-1	-6	-3	-2	0	-5	-3	12	14	-3	1
8 XII 25	(III 11)		-2	-2	-4	-3	-1	0	-5	-2	8	12	-8	-2
10 VIII 10	X 16	2m 6d	-3	4	-7	0	-2	4	-4	0	12	15	0	1
12 I 9*	VI 25*	5m 16d	-52*	45*	-51*	48*	-46*	52*	-43*	53*	-24*	69*	-35*	57*
13 X 21	XI 21*	15d(!)	3	-33*	-3	-36*	1	-33*	-3	-35*	10	-21*	-5	-35*
15 V 20	VIII 5	2m 15d	-1	5	-3	3	1	8	-2	5	15	21	1	8
16 XII (25)	III 4	2m 9d	1	-4	-1	-7	2	-4	-1	-6	12	9	-4	-5
18 (IX 12*)	(XI 16*)	(2m 4d)	2*	7*	0*	4*	4*	8*	2*	4*	18*	20*	5*	4*
20 III 25	VI (1)	2m 6d	-4	-4	-1	-2	4	3	8	4	27	20	15	7
21 X 28	XII 28	2m	14	7	8	3	11	7	6	4	20	20	6	6
		median:	-2	0	-3	-2.5	1	2	-3	-1	12	15	-3	0.5

Starred: probably corrupt. In parentheses: conjectural restorations.

Table 2.2. Differences between observation and calculation. The medians are calculated excluding the starred items.

In the past, I have experimented with various degrees of data cleaning, from no purging (i.e. keeping all 50 data items, and letting robust statistical methods take it from there), to moderate purging (keeping 38 items, like here), to throwing out also most conjectures and all of years 19-21 (keeping 31 items; the number 38 in the header of Table 2.1 of Huber (1999-2000) is an error for 31). The statistical results and conclusions are remarkably little affected, except that purging tends to sharpen them (cf. Huber *et al.* (1982), p. 21). In particular, by excluding years 19-21 (i.e. Section III of the text, condemned by Reiner and Pingree), we exclude four positive values for superior conjunction in the -1581 column and thereby make that column even more lopsidedly negative. This erodes some of the statistical support for the -1581 chronology and changes its credit rating from moderately good to poor.

Reiner and Pingree rightly warn about the risks involved in the use of certain parts of the Venus tablet for dating (RP p. 23). However, if anybody is qualified to judge such matters, then I am (I have made my career as a statistician by dealing with contaminated and otherwise corrupted data, and with data analysis; cf. Huber (1981)), and I have come to a much more favorable assessment of the situation than Reiner and Pingree. Clearly, the Venus tablet data are badly contaminated, and one must be careful. Fortunately, a fairly large fraction (about 20%) of the data can be recognized as being corrupted without prejudging the chronology, and robust methods should be fully able to handle the rest. In particular, there can be hardly any doubt that the omens traditionally attributed to the years 1-17 are consecutive. Those of the years 1-8 and 9-17 show an exactly parallel statistical behavior across different chronologies, that is, they show the behavior to be expected from consecutive data, cf. Table 4.3a of Huber *et al.* (1982), and it would be exceedingly difficult to find a different home for the second half of them without destroying this parallelism. My conclusions can be summarized as:

(1) *There is hardly any doubt that the Venus Tablet contains a hard core of genuine, consecutive observations. They must have extended at least over the years 1 to 17 (with a corrupted passage in years 8-9). Whether the physically separate and rather corrupt Section III is a continuation for years 19 to 21 (skipping year 18) is undecidable. All this holds independently of the attribution of the observations to Ammiṣaduqa's reign.*

(2) *The Venus chronology proposed by Gasche-Gurzadyan (Ammiṣaduqa year 1 = -1549) has no basis in the Venus Tablet; it fact, it is flatly contradicted by it. The nearest compatible chronologies are 32 years earlier (-1581) or 32 years later (-1517), respectively.*

3 Confirming the attribution to Ammiṣaduqa.

Even if the Venus Tablet almost certainly has a genuine observational kernel, it may or may not record observations from the time of Ammiṣaduqa. To follow an orderly judicial procedure, we need at least a second, independent source of evidence, confirming the attribution (which was based on the name of Ammiṣaduqa's year 8, "Year of the Golden Throne", occurring in the corrupt passage between years 8 and 9 of the tablet). The OB month-lengths permit such an independent confirmation.

Between the years -1976 and -1362, at most 20 chronologies give a more or less acceptable agreement with the Venus text (the list of Table 3.1 is over-inclusive, for example -1538 is too far out of season to be chronologically feasible). We have two mutually exclusive possibilities:

either: (I) one of the 20 is correct,
or: (II) none of them is correct.

It is possible to use the month-length data (b) to test (I) and (II) against each other. Statistical tests always are styled to reject a hypothesis, and the tests may have three possible outcomes:

- reject (I) — and accept (II) by implication,
- reject (II) — and accept (I) by implication,
- the tests are inconclusive.

In our case, the tests reject (II): for one of the chronologies (-1701) the month-lengths agree significantly better with calculation than what one would expect from the best among 20 randomly chosen wrong chronologies. The significance level is about 5%, that is, the probability of wrongly rejecting (II) is about 5%.

The assertion that the list contains the true chronology with a reasonably low probability of error gives us sufficient confidence into the chronological trustworthiness of the Venus text that we dare to assign relative probabilities to the 20 candidate chronologies. The results are listed in Table 3.1. Note that -1701 takes the lion's share of the combined probabilities (87% on the basis of the month-lengths alone, 93% on total evidence), followed by -1517 (6%), while all others together share the remaining 1%.

The month-length data also allow to settle another point. In the case of the middle chronologies the median discrepancies between observed and calculated Venus dates (cf. Table 2.2) show an interesting pattern: For -1645, all four events on average are observed about 2 days earlier than calculated, for -1637 about 2 days later. A statistical sign test, based on the early/late counts, rejects the middle chronologies on the 1% level (Huber *et al.* (1982), p.21). This is a strong argument against the correctness of the middle chronologies. The month-lengths now furnish a second, independent source of evidence, reinforcing that conclusion by allotting very low probabilities to these chronologies (see Table 3.1).

YEAR	VENUS		MONTH-LENGTHS							TOTAL
	Ammiṣaduqa (31 obs.)		Ammiṣaduqa (21 months)		Ammiditana (13 months)		Hammurapi-Samsuiluna (54 months)		com-bined	
	w	p_{Vs}	m	p_{As}	m	p_{Ad}	m	p_{HS}	p_{ml}	p_{tot}
-1976	1.58	.057	10	.018	6	.019	21	.043	.0015	.0005
-1920	-2.93	.003	13	.003	6	.017	23	.026	.0001	$<10^{-5}$
-1912	3.63	.0003	10	.018	6	.017	22	.031	.0010	$<10^{-5}$
-1856	-0.33	.189	14	.002	6	.023	25	.011	$<10^{-4}$	$<10^{-4}$
-1800	-4.65	$<10^{-5}$	10	.018	8	.009	25	.005	$<10^{-4}$	$<10^{-8}$
-1792	2.31	.014	7	.112	3	.106	24	.008	.0093	.0007
-1736	-1.84	.037	9	.034	6	.023	20	.077	.0059	.0012
-1765	-2.39	.011	7	.112	5	.032	23	.016	.0057	.0004
-1757	2.28	.015	9	.034	4	.058	21	.043	.0083	.0007
-1701	-0.18	.196	6	.205	1	.306	19	.139	.8674	.9282
-1645	-4.84	$<10^{-5}$	13	.003	5	.032	23	.014	.0001	$<10^{-8}$
-1637	2.84	.004	12	.006	8	.005	22	.038	.0001	$<10^{-5}$
-1581	-2.26	.016	12	.006	5	.030	24	.009	.0001	$<10^{-5}$
-1525	-5.41	$<10^{-7}$	9	.034	9	.004	24	.014	.0002	$<10^{-10}$
-1517	-0.02	.199	6	.205	4	.065	21	.045	.0590	.0642
-1538	3.62	.0003	13	.002	4	.054	24	.014	.0002	$<10^{-6}$
-1482	1.56	.059	7	.112	3	.096	25	.005	.0051	.0016
-1426	-2.99	.002	11	.010	4	.054	21	.070	.0038	$<10^{-4}$
-1418	4.29	$<10^{-4}$	8	.061	6	.019	18	.251	.0297	$<10^{-5}$
-1362	0.10	.198	12	.006	5	.030	19	.144	.0023	.0025

Table 3.1. Relative likelihoods of the Venus chronologies.

- First column: year 1 of Ammiṣaduqa. Note that there are several, somewhat overlapping cycles with alternating 8- and 56-year spacings.
- Second column: w is a robust, normalized measure of how much the tablet dates are collectively shifted relative to the calculated dates; negative values are early, positive values late. For a correct chronology, one would expect these numbers to be approximately normally distributed, with mean 0 and standard error 1; values exceeding 2.6 are unlikely to occur. p_{Vs} gives relative likelihoods of the different chronologies, calculated on the basis of these w. The calculations are based on a purged data set, retaining 31 of a total of 50 values.
- The next columns summarize the month-length data; for example, from Ammiṣaduqa's reign, there are 21 months with 30 days, taken from economic texts, and for the -1701 chronology, m=6 of them disagree with calculation, resulting in a relative likelihood of 0.205 for that chronology.
- The final two columns give likelihoods first for the combined month-lengths, and then for Venus data plus month-lengths. The likelihoods are normed such that the numbers in each column add up to 1.

4 The Ur III evidence: month-lengths and eclipses.

A comparison of month-lengths from economic/administrative texts (mostly texts dated on day 30) with calculation gives the following best fits:

Number	Date	LNY	Misses	Probability
-14185	-2147MAR 1	323.3	93	0.0019
-14061	-2137MAR11	332.2	93	0.0019
-13764	-2113MAR16	337.4	93	0.0019
-13725	-2110MAY10	30.3	93	0.0019
-13516	-2093APR 3	354.9	83	0.3054
-13431	-2086FEB15	310.0	88	0.0208
-13392	-2083APR11	3.7	91	0.0048
-13294	-2075MAR15	337.0	89	0.0126
-13183	-2066MAR 5	328.0	92	0.0030
-13082	-2058MAY 5	26.4	93	0.0019
-12886	-2042MAR11	333.1	91	0.0048
-12860	-2040APR16	8.6	89	0.0126
-12847	-2039MAY 5	26.1	92	0.0030
-12823	-2037APR14	5.6	90	0.0077
-12762	-2032MAR19	341.9	93	0.0019
-12651	-2023MAR10	332.8	91	0.0048
-12638	-2022MAR29	350.7	92	0.0030
-12627	-2021FEB17	311.6	89	0.0126
-12625	-2021APR16	8.4	92	0.0030
-12614	-2020MAR 7	329.9	84	0.1745
-12514	-2012APR 6	359.6	93	0.0019
-12429	-2005FEB20	314.6	83	0.3054
-12154	-1983MAY16	36.9	89	0.0126
-12132	-1981FEB25	320.0	91	0.0048
-12106	-1979APR 2	355.7	93	0.0019
-11996	-1970FEB22	317.9	92	0.0030
-11884	-1961MAR15	337.6	89	0.0126
-11760	-1951MAR23	346.5	89	0.0126
-11551	-1934FEB14	310.3	87	0.0348
-11463	-1927MAR29	351.7	92	0.0030
-11426	-1924MAR25	348.1	92	0.0030
-11217	-1907FEB16	311.9	88	0.0208

Table 4.1. Best Ur III month-length alignments (228 months). Given are the Goldstein number of the New Year syzygy of Amar-Sin year 1, its date in the Julian Calendar, the corresponding solar/lunar longitude, the score (i.e. the number of “misses”, or mismatches, between the observed and the calculated month-lengths), and the relative likelihoods of the chronologies (standardized so that they sum to 1 in the above table). Shown are all dates between -2150 and -1900, with longitudes between 310° and 50°, and scores not exceeding 93.

We must emphasize that the correct alignment does not necessarily have the lowest number of mismatches. Though, it is reasonably certain that it will show up in the above table. If the same miss-rate as in the Late Babylonian control material applies (50 out of 153), the probability that the correct alignment has 93 or fewer misses and therefore shows up in the above table, is about 99%. If, for example, ΔT is off by 1 hour, this probability still is about 95%. We should search the table for a year 1 of Amar-Sin such that the Simānu eclipse (EAE 20-III), supposedly presaging the death of Šulgi (who died at the end of month X or beginning of month XI), occurs in the preceding year, and is followed 42 years later by an eclipse matching the Addaru eclipse (EAE 21-XII), supposedly presaging the destruction of Ur at the end of the reign of Ibbi-Sin. It turns out that the eclipse of -2094 July 25 is the only one preceding a year in Table 4.1. Gratifyingly, it even precedes the year with the best score (83 misses), and moreover it is followed 42 years later by the eclipse of -2052 April 13, matching the omen of EAE 21-XII. The only other pair of eclipses matching the omens and spaced by 42 years occurs in the years (-2018, -1976).

Tablet 20, Month III.
If an eclipse occurs on the 14th day of Simānu, and the god in his eclipse becomes dark on the side east above, and clears on the side west below. .... (The eclipse) “pulls out” (*issuh*) the first watch and touches the middle watch (so Recension A; B has: “equalizes” (*imšul*) the first watch). .... The king of Ur, his son will wrong him, and the son who wronged his father, Šamaš will catch him. He will die in the mourning place of his father. The son of the king who was not named for the kingship will seize the throne.

```
-2200 ≤ DATE ≤ -1850, 2 ≤ M ≤ 5
0.6 ≤ Beg , 1.6 ≤ End ≤ 2.6
40 ≤ Entry ≤ 140, 220 ≤ Exit ≤ 320
--------------------------------------
 DATE       M   D  Beg End  Angles Magn
-2188AUG13  5.0 14 1.0 2.0   63 282 1.21
-2174MAY12  2.1 14 0.8 1.8  108 282 1.80
-2149JUL 4  3.7 14 0.6 1.9  115 263 1.32
-2094JUL25  4.5 13 1.1 2.3   74 285 1.32
-2018JUN26  3.5 15 1.0 2.1   79 305 1.07
-2007MAY25  2.5 13 1.3 2.4  129 254 0.96
-2001JUL18  4.2 15 1.3 2.4  116 249 1.08
-1936JUL18  4.3 14 0.9 1.9   47 295 0.75
-1914MAY18  2.3 15 1.5 2.6   92 295 1.47
-1907JUN28  3.6 14 1.5 2.5  126 255 1.04
-1860JUN19  3.3 15 0.6 1.7   68 297 1.04
-1853JUL31  4.7 14 1.4 2.3  123 231 0.73
Gurzadyan:
-1953JUN27  3.6 14 0.3 1.5  104 256 1.39
```

Tablet 21, Month XII.
If an eclipse occurs on the 14th day of Addaru, and it begins in the south and clears in the north; it begins in the evening watch and clears in the morning watch. You observe his eclipse and bear in mind the south. The prediction is given for the king of the world: The destruction of Ur. [........ will be] destroyed, variant: an order to destroy its city walls will be given. While the barley is being heaped up, the devastation of the city and its environs (will occur).

```
-2200 ≤ DATE ≤ -1850, 11 ≤ M or M ≤ 2
0.6 ≤ Beg ≤ 2.4, 2.6 ≤ End ≤ 4.4
80 ≤ Entry, 260 ≤ Exit
--------------------------------------
 DATE       M   D  Beg End  Angles Magn
-2106MAR12 12.2 13 2.4 3.2 143 272 1.00
-2062MAY 4  1.8 14 1.5 2.6 105 287 1.78
-2052APR13  1.2 13 1.8 2.6 159 260 0.63
-2030FEB11 11.2 15 2.3 3.2 131 270 1.14
-2015APR24  1.6 13 2.4 3.4 120 297 1.84
-1976MAR15 12.2 15 1.8 2.7 150 267 0.82
-1975MAR 4 11.9 14 2.0 2.9 106 307 1.47
-1968APR15  1.2 15 2.2 3.2 109 287 1.84
-1928FEB23 11.6 13 2.1 2.9 110 276 1.63
-1900FEB14 11.3 14 2.1 2.9 140 263 0.94
-1881FEB14 11.3 15 1.9 2.7 103 300 1.58
-1874MAR27 12.7 14 1.9 2.8 106 290 1.82
Gurzadyan:
-1911MAR16 12.3 13 1.3 2.0   66 328 0.58
```

The search criteria are listed at the beginnings of the eclipse lists. The approximate month number M is calculated from the solar/lunar longitude at the new moon preceding the eclipse, assuming that the year begins approximately at the vernal equinox (e.g. if this longitude is between 345° and 15°, then M is between 1.0 and 2.0, etc.). Because of haphazard intercalations, deviations of up to plus/minus 1.5 months can be expected. D is the day of the eclipse in the Babylonian month. It was disregarded in the searches — it seems to be affected by ancient systematization, EAE 20 lets all eclipses begin on day 14. Begin and end are expressed in watches of the night and decimal fractions (1.0 = beginning of the first watch, 3.5 = middle of the third watch, etc.). Entrance and exit angles range from North=0°, East=90°, South=180°, to West=270°. Magnitude values greater than 1 indicate a total eclipse. The search criteria for the eclipse timings were expanded by 0.4 watches to account for uncertainties in ΔT.

The terminology of the omen texts is open to dispute. The terms “above” (AN.TA) and “below” (KI.TA) are only used in EAE 20; in Recension A, all eclipses begin AN.TA and end KI.TA (there are a few inversions in Rec. B, maybe scribal errors affecting an expression no longer understood?). Gasche *et al.* (1998) take this to mean above or below the horizon (p. 74, note 296), which is clearly incorrect: an eclipse beginning in the first watch cannot possibly end below the horizon. I conjecture that these terms are redundant and refer to the leading and trailing edge of the lunar disk, in rough analogy to their use in OB grammatical texts to denote prefixes and postfixes. The word *imšul,* from *mašālu* “to make, or be, equal” admits several interpretations: does the eclipse equal the first watch, or does it divide it into two equal halves? The verb *nasāhu* “to pull out” can mean “to excerpt” (a text), or “to take off” (on a voyage, by pulling out the tent poles): does the eclipse “take out” the entire first watch, or does it “take off” during the first watch? The one thing we can be reasonably certain is that according to Rec. A, the Simānu eclipse extends a little into the second watch (thus the ancient astronomer should have seen enough of the early phases of the eclipse in the first watch to know the entrance angle, cf. Hunger (1992), Report 316, for a case where he did not). With the literal interpretations of *issuh* and *imšul* just suggested (but not with Rochberg’s) it is possible to interpret the two recensions as to contain different descriptions of the *same* eclipse; this eclipse then must have been very nearly coextensive with the first watch. Incidentally, the first watch of the night begins at sunset, thus for the Simānu eclipse at approximately 19:04 local time (not at a fixed 18.00, as assumed by Gasche *et al.* (1998)).

The identification of the Addaru eclipse with -2052 April 13 admittedly is unsatisfactory, since its duration (0.8 watches) is too short to last from the first to the last watch. There might be a scribal error. Though, we know now that LB time measurements of long time intervals (e.g.

between sunset and the beginning of an eclipse) were affected by standard errors of about 15%, so the difference might perhaps be explained as a timing error.

Both of Gurzadyan's eclipses begin and end much too early, the entrance angle of the Addaru eclipse does not match (north-east instead of south), and its duration is even shorter than that of the -2052 eclipse. The emphatic claim that these two eclipses "perfectly fit", and "fit the ancient descriptions at a higher confidence level" (Gasche *et al.*, p.75) thus is a gross misrepresentation, the contrary is true.

In short: the two Ur eclipses do not support the Gasche-Gurzadyan chronology.

5 The Akkad eclipses.

If we use Sollberger's relative chronology (Sollberger 1954-56) to count back from Amar-Sin year 1 = -2093, we obtain Sargon year 1 = -2380, and an amazing coincidence of ominous eclipses: there are 9 major lunar eclipses preceding a change of reign in the dynasty of Akkad, and all are matched by an omen pertaining to Akkad! A comparable coincidence occurs again 54 years later, with Sargon year 1 = -2326. Historically, this second alternative may be more attractive: it shortens to distance between Šarkališarri and Ur-Nammu from 80 years to one generation, and it squeezes out the Guti dynasty (making the last Akkad king Šu-DURUL, Utuhegal as king of Uruk, and Ur-Nammu as governor of Ur, all contemporaries). But afterwards, good matches are rare; the only chronology between Sargon 1 = -2311 and -2102 for which one can find eclipses with matching protases and apodoses for all three omens 20-I, 21-I and 21-VI, occurs for Sargon year 1 = -2250. For that chronology there are 7 major eclipses preceding a change of reign, but only 3 of them are matched by an omen (namely the transitions Maništusu — Naramsin — Šarkališarri). Excerpts of the relevant parts of the omens follow (see Rochberg-Halton (1988) for the complete texts):

> **Tablet 20, Month I.** ... the god in his eclipse becomes dark on the side south above, and clears on the side north below.... If in his *šurinnu* Venus [enters within him], the son of the king will enter the throne (var.: house) of his father. .... The king of Agade will die .... The god who in his eclipse began the last watch, delayed 1/3 (variant: 2/3) of the watch, and set while eclipsed ...
>
> **Tablet 21, Month I.**... it begins in the south and [clears in ....]; it begins in the evening watch and clears in the middle watch. ... The king of Akkad will die....

> **Tablet 21, Month VI.**... it begins in the north and clears in the south, variant: east; it begins in the evening watch and clears in the middle watch. ... The prediction is given for the king of Akkad... If an eclipse occurs on the 15th day: the son of the king will kill his father and take the throne.
>
> **Tablet 21, Month VIII.**... it begins in the north and clears in the south, var[iant: ....]; it begins in the middle watch and clears in the morning watch, variant: when it (i.e. the sun) rises. ... The prediction is given for the king of the world: Either the king will die, or a large army will fall, or a large army will revolt.
>
> **Tablet 18, Month XI.** If an eclipse occurs in Šabaṭu in the morning watch, the king of Amurru, var. a great king (and) the king of Guti [will experience] bad luck. ...If the eclipse occurs on the 15th of Šabaṭu, the land [...] and famin[e ...]; the king of Akkad will die and the untrue son of the king [will seize the throne(?)].

The box below displays the alignment of reigns and eclipses for the chronology equating Sargon year 1 with -2326. For further details see Huber (1999-2000). Note that two large lunar eclipses can occur in months I and VI of the same year only if there is an intercalation in between (specifically, a month I.2).

Sargon						**-2326**		
Rimuš (son of Sargon)						**-2270**		
Maništusu (elder brother of R.)						**-2261**		
	DATE	M	D	Beg	End	Angles		Magn
20-I	-2247APR10	1.0	13	3.0	3.9	84	313	1.05
21-VI	-2247OCT 4	6.7	15	1.6	2.6	84	239	1.43
Naramsin (son of Maništusu)						**-2246**		
20-I	-2210APR21	1.4	13	3.3	4.3	119	277	1.52
	Venus rises during totality							
21-VI	-2210OCT15	7.1	15	0.8	1.7	45	279	0.95
Šarkališarri (son of Naramsin)						**-2209**		
21-VIII	-2185DEC 7	8.9	14	2.1	2.9	97	226	1.01
Igigi, Nanum, Imi, Elulu						**-2184**		
20-I	-2182APR12	1.1	14	3.4	4.3	143	276	1.10
21-VI	-2182OCT 5	6.8	14	1.2	2.2	38	262	1.10
Dudu						**-2181**		
18-XI	-2160FEB 9	11.1	13	2.8	3.6	126	273	1.28
Šu-DURUL (son of Dudu)						**-2160**		
21-I	-2146MAY 3	1.8	15	1.1	2.0	150	265	0.83
end of dynasty						**-2146**		

6 Transition Akkad - Guti - Uruk - Ur.

The omen EAE 21-IV is commonly associated with the victory of Utuhegal over the Guti king Tirigan (cf. *Cambridge Ancient History*, 3rd Ed., Vol. I, Part 2, p. 462):

> **Tablet 21, Month IV.** If an eclipse occurs on the 14th day of Du'ūzu, and it begins in the west and clears in the south, variant: north; it begins in the evening watch and clears in

> the middle watch. You observe his eclipse and bear in mind the west. The prediction is given for the king of Guti: The downfall of Guti in battle. The land will be totally laid waste.

The entry point is astronomically impossible (no lunar eclipse can begin in the west) and must be disregarded. The only matching eclipse in the first half of the 22nd century occurs in -2159:

```
 DATE       M   D  Beg End  Angles Magn
-2159JUL24  4.4 15 1.8 3.0 105 232 0.98
```

Initially, I had thought that this was a near fatal blow to the proposed Ur III chronology (Amar-Sin 1 = -2093), because in that chronology, the year -2159 falls after the end of the reign of Utuhegal of Uruk and corresponds to the first year of his successor Ur-Nammu in Ur. Then I was informed (by W. Hallo and C. Wilcke), that Ur-Nammu initially was governor of Ur, installed there by his brother(?) Utuhegal, and that he took over the kingship only several years later (presumably after Utuhegal's accidental death by drowning). Finally, it even turned out that a year from the time of Ur-Nammu bears the name "Year Gutium was destroyed" (see Sigrist and Damerow (1997), Ur-Nammu year k). Presumably, the reign of Utuhegal as king in Uruk and the governorship of Ur-Nammu in Ur began more or less simultaneously, and the king lists include the years of Ur-Nammu's governorship in his year count.

The following omen may refer to the transition of power from Utuhegal to Ur-Nammu:

> **Tablet 20, Month IV.** If an eclipse occurs on the 14th day of Du'ūzu, and the god in his eclipse becomes dark on the side east above, and clears on the side south below. .... The eclipse equalizes the first watch .... In Du'ūzu (the eclipse occurs) not at its calculated time (i.e. prematurely?). .... The king who ruled will die. .... The prediction is given for Ur. .... The grandson, descendant of the king (or: of a king), will seize the throne. .... The king together with his clan will be killed.

Note that the dynasty founder Ur-Nammu is the the only Ur III king who was not the son of his predecessor. A matching eclipse occurs in -2149:

```
 DATE       M   D  Beg End  Angles Magn
-2149JUL 4  3.7 14 0.6 1.9 115 263 1.32
```

For further details see Huber (1999-2000).

7 Summary conclusions.

The precise version of the Gasche chronology (Ammiṣaduqa year 1 = -1549, fall of Babylon 51 years later) is not supported by the astronomical evidence, contrary to the claims made by Gasche *et al.* (1998). It is flatly contradicted by the Venus text, the nearest compatible Venus dates being -1581 and -1517, see Section 2. Also the eclipses do not support it, see Section 4.

A set of long chronologies gives a coherent, near-perfect fit for all five components (a) to (e) of the astrononomical evidence:

Sargon year 1 = -2380 or -2326
Amar-Sin year 1 = -2093
Ammiṣaduqa year 1 = -1701
Fall of Babylon = -1650

All ominous lunar eclipses of EAE 20 and 21 concerning changes of reign in Akkad or Ur find a reasonably convincing seat in this chronological framework (except EAE 20-II, which does not match any eclipse whatsoever between -2200 and -1850). Of the 9 large lunar eclipses preceding a change of reign in the dynasty of Akkad, all can be accounted for by 5 different omens, see Section 5. The overall, coherent fit is so good that it must be taken seriously; it cannot be disregarded simply because it disagrees with the (by necessity chronologically softer) archaeological evidence.

On the other hand, it does not seem to be possible to fit a substantially shorter chronology without doing violence to at least two of the five parts of the astronomical evidence. In particular, the best fitting short chronology I could find is:

				Quality of fit
(a)	Venus Tablet:	Ammiṣaduqa year 1 =	-1581	good(?)
(b)	OB months:			no fit
(c)	Ur III months:	Amar-Sin year 1 =	-1979 -1981 -1983	all so-so
(d)	Ur III eclipses:			no fit
(e)	Akkad eclipses:	Sargon year 1 =	-2250	so-so

Note that with Sargon year 1 = -2250, which gives the best fit for the Akkad eclipses between -2311 and -2102, only 3 of the 7 major lunar eclipses preceding a change of reign in the dynasty of Akkad are accounted for. The principal support for short chronologies thus rests on the Venus tablet evidence, and even that is eroded, if we follow the advice of Reiner and Pingree and throw out Section III of the Venus tablet (cf. the comments on data cleaning, made in Section 2).

In other words: the best “short” fit is unconvincingly poor, and therefore the combined astronomical evidence, far from supporting it, argues against a short chronology. In my opinion, tree-ring data from a single site (see Kuniholm *et al.* (1996)) are not strong enough to overcome this, and I do not think that the conflict can be resolved without additional evidence. But it might be worthwhile to re-check history once more, and in particular establish limits of plausibility also for *upward* shifts. What range of chronologies is compatible/incompatible with the various components of the full historical evidence, including for example the Hittite generation count?

Incidentally, a preliminary check of the newly found solar eclipse in the Mari eponym chronicle, mentioned by Veenhof at the Ghent Colloquium, seems to indicate that it is chronologically inconclusive by being able to give convincing matches with too many chronologies. Among them are the Long (Ammiṣaduqa year 1 = -1701), both Middle ones (-1645, -1637), the Short (-1581) as well as the Gasche (-1549). However, it appears to exclude the Supershort chronology (-1517).

8 Appendix: Accuracy of astronomical programs and tables.

We now have a substantial body of completely different astronomical programs and tables, partly based on analytical expansions, partly on brute force numerical integration. In addition, we have a large body of ancient naked-eye observations. The results of various comparisons can be summarized as follows:

- **There are no problems with the celestial mechanics of modern programs** (Bretagnon, Chapront, Meeus, ...): for the historical periods in question, they are more accurate than ancient visual observations.
- **There are minor problems with empirical visual parameters:**
  systematic errors of about 2 minutes in rising and setting times, 5 minutes in beginning and end of lunar eclipses and of totality, and random effects about twice as large.

- **There are some problems with lunar orbital acceleration:**
  now resolved, thanks to lunar laser ranging. The correct value is in the range of -25.8" to -26"/cy^2 (the value -23.8946 used in the commercially available 1991 version of the Chapront programs is much too low).
- **There are major problems with the irregular rotation of the earth.**
  The problems are in the difference $\Delta T = ET-UT$ between Ephemeris Time ET (the uniform time scale used in celestial mechanics) and Universal Time UT (based on the rotation of of the earth, roughly equivalent to Greenwich Mean Time) and its extrapolation beyond -500. At present, most approaches are directly or indirectly based on Stephenson and Morrison, 1982 and 1984:

  (StM82) $\Delta T = ET-UT = 32.5\, t^2$ sec, with t measured in centuries since 1800 AD
  (based on Babylonian eclipse observations).

  (StM84) $\Delta T = 25.5\, t^2$ sec, between 948 AD and 1600 AD,
  $\Delta T = 1360 + 320\, t + 44.3\, t^2$ sec, between 390 BC and 948 AD
  (interpolatory spline fit to Babylonian and Arabic observations).

Many newer programs use a variant of (StM84) as a default for all dates before 948 AD.

My recommendation:

- For interpolation between -390 and +1600: use (StM84).
- For Neo- and Late-Babylonian times both (StM82) and (StM84) are OK.
- For extrapolation beyond -500: use (StM82), not the default (StM84)!

A statististical analysis and stochastic modeling of the Length-of-Day process shows that in the range of 1 year to 2700 years it can be excellently modeled by a Brownian motion with drift (Huber 2000). For the uncertainties in the extrapolation of ΔT, caused by irregular fluctuations in the length of day, one obtains the following standard errors:

by -1000:	10 minutes
by -1500:	30 minutes
by -2000:	60 minutes

Graphically, the extrapolation error can be represented as follows:

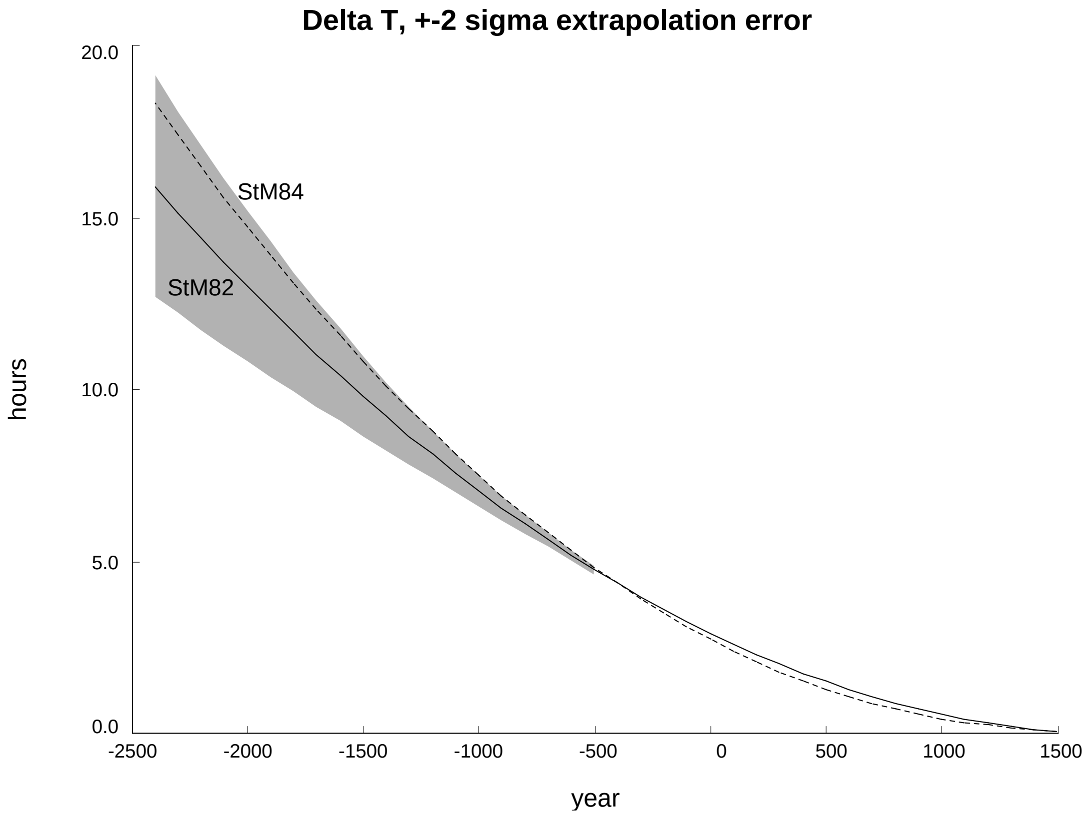

Figure 8.1. Extrapolation of ΔT, with ±2σ limits for the estimated extrapolation error. Note that the dashed curve (StM84) is a modification of (StM82), devised to simultaneously accommodate not only modern time observations (around 1600AD), and Babylonian observations (centered around 390BC), but also Arabic observations (centered at 948AD), whose average deviates about 8 minutes from (StM82).

9 Bibliography.

Gasche, H., Armstrong, J. A., Cole, S. W., and Gurzadyan, V. G. (1998). *Dating the Fall of Babylon.* University of Ghent and the Oriental Institute of the University of Chicago.

Huber, P. J., Sachs, A., Stol, M., Whiting, R. M., Leichty, E., Walker, C. B. F. and vanDriel, G. (1982). Astronomical Dating of Babylon I and Ur III. *Occasional Papers on the Near East,* Vol. 1, Issue 4. Malibu: Undena Publications.

Huber, P. J. (1981). *Robust Statistics.* Wiley, New York.

Huber, P. J.(1999-2000). Astronomical Dating of Ur III and Akkad. *Archiv für Orientforschung.*

Huber, P. J. (2000). Modeling the Length of Day and Extrapolating the Rotation of the Earth. In: *Astronomical Amusements, Papers in Honor of Jean Meeus*, ed. F Bònoli, S. De Meis and A. Panaino. IsIAO, Milano.

Hunger, H. (1992). *Astrological Reports to Assyrian Kings*. State Archives of Assyria, VIII. Helsinki University Press.

Kuniholm, P. I., Kromer, B., Manning, S. W., Newton, M., Latini, C. E., Bruce, M. J. (1996). Anatolian tree rings and the absolute chronology of the eastern Mediterranean, 2220-718 BC. *Nature,* Vol. 381, 780-783.

Morrison, L. V. and Stephenson, F. R. (1982). Secular and Decade Fluctuations in the Earth’s Rotation: 700 BC - AD 1978. In: W. Fricke and G. Teleki (eds.), *Sun and Planetary System,* 173-178. Dordrecht, Holland: D. Reidel Publishing Company.

Reiner, E., and Pingree, D. (1975). *The Venus Tablet of Ammiṣaduqa*. Bibliotheca Mesopotamica 2,1. Malibu, CA.

Rochberg-Halton, F. (1988). Aspect of Babylonian Celestial Divination: The Lunar Eclipse Tablets of Enuma Anu Enlil. *Archiv für Orientforschung,* Beiheft 22.

Sigrist, M., and Damerow, P. (1997). *Mesopotamian Year Names*. (Web site: www.mpiwg-berlin.mpg.de/Yearnames/HTML).

Sollberger, E. (1954-56). Sur la chronologie des rois d'Ur et quelques problemes connexes. *Archiv für Orientforschung* 17, 10-48.

Stephenson, F. R. and Morrison, L. V. (1984). Long-term changes in the rotation of the Earth: 700 B.C. to A.D. 1980. *Philosophical Transactions Royal Society London* A 313, 47-70.