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ASTRONOMICAL DATING OF BABYLON I AND UR III

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We undertake a comprehensive effort to establish the absolute chronology of the First Dynasty of Babylon and of Ur III by reexamining the Venus Tablet data and by cross-checking with extensive contemporary month-length data. The presently available evidence heavily favors the Long Chronology, with Ammisaduqa year 1 beginning in -1701 = 1702 B.C.; the most likely beginning for Amarsin year 1 is -2093.

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1. Introduction

The only items known to us that relate historical dates of the first half of the second and of the late third millennium B.C. to astronomical events are:

(1) Some Venus observations from the time of Ammiṣaduqa;

(2) Some lunar eclipse omina;

(3) Month-lengths as recorded in contemporary economic-administrative texts.

Both (1) and (2) are contained in tablets of the astrological series *Enuma Anu Enlil*, and are available only in late and possibly corrupt versions. Clearly, being contemporary, the month-lengths (3) should provide the most reliable data for astronomical dating purposes.

Perhaps also some cultic offerings to planetary gods (principally Inanna-Ishtar-Venus) might be linked to planetary phenomena, and if so, they might become a very important second source of contemporary astronomical information (cf. Falkenstein (1965), p.52; Sauren (1970), with a very critical review by Hunger (1973/74)).

The astronomical dating problem now consists in the identification of all dates lying inside the historically acceptable range that are compatible with astronomy. The task is largely a statistical one: we must assess the accuracy of the observations and judge the quality of the agreement between calculations and observations, and if there are several compatible solutions, we must assess the relative strength of evidence favoring each particular solution.

The last comprehensive attempt to fix Old Babylonian chronology by astronomical means has been that by Langdon, Fotheringham and Schoch (1928), in their book *The Venus Tablets of Ammizaduga*, henceforth cited LFS.

In the time since, the historically admissible range of solutions has been shifted several centuries; there has been a new edition of the Venus Tablet by Reiner and Pingree, *The Venus Tablet of Ammiṣaduqa*, Bibliotheca Mesopotamica Vol. 2,1 (1975), henceforth cited RP; we have many more attested intercalary months and month-lengths; and last, but not least, computers have taken out much of the drudgery of extensive astronomical calculations.

Aided by hindsight, we can identify the principal weak spots of LFS as follows. First, lacking computers, Fotheringham had to ignore most of the statistical aspects (e.g. questions about the accuracy of the observations and of the mathematical models used for calculating visibility conditions). Therefore, as already Otto Neugebauer (1929) had pointed out, it was not clear whether the good agreement LFS had obtained for the month-lengths with their 'Solution II' was any better than the best agreement to be expected among five randomly picked wrong chronologies. Second, and even worse, it now turns out that so many of the intercalations used by LFS are questionable and possibly wrong that their comparison of observed and calculated month-lengths is almost meaningless.

In spite of this criticism, the approach used by LFS is sound, and it appears worthwhile to undertake a new and better equipped attack along similar lines.

In view of the low trustworthiness of the Venus data, one would prefer to work with the contemporary month-lengths alone, but unfortunately, the presently available material does not suffice to pick a unique date from more than a few dozen alternatives -- the true chronology will not stick out if there are too many possibilities to choose from. So we adopt the following strategy that plays one data set against the other and thus allows us to cross-check both:

- First, narrow the choices down to those compatible with the Venus data.
- Then check the Venus chronologies against the month-length data from Ammisaduqa's reign, and hopefully narrow the choices down to one.
- Check with month-lengths from segments of consecutive years with reasonably complete intercalations (the late years of Ammiditana, the late years of Hammurapi, and the early years of Samsuiluna).
- The Ur III chronology is fixed within about 10 years relative to Babylon I. Check and fix more precisely with the aid of the month-lengths.
- Finally, check also the eclipse material.

This strategy turned out to be reasonably successful, and our findings can be summarized as follows.

The so-called Long Chronology (Ammisaduqa year 1 = -1701 = 1702 B.C.*) fits well, both with regard to the Venus and the month-length data from Ammisaduqa's and Ammiditana's reign; the quality of the fit is even better than that obtained for reliably dated Late Babylonian control material. The Middle and Short Chronologies (i.e. -1645, -1637, -1581) agree so poorly that they must be ruled out. Among the 20 Venus chronologies investigated (ranging from Ammisaduqa year 1 = -1976 to -1362), -1701 gives the best fit. There is one other astronomically feasible choice, the 'supershort' chronology -1517, but the fit is poorer, so that the odds are about 15 to 1 in favor of -1701.

Reckoning backwards, we obtain that Hammurapi reigned from 1848 B.C. to 1806 B.C.. The Hammurapi-Samsuiluna month-length evidence is not conclusive, but it also favors the Long Chronology.

A statistical analysis shows that the agreement of the -1701 solution not only is the best one, but that it is also significantly better than what we would expect for the best among a certain number of randomly chosen wrong chronologies. The significance level depends on how wide we choose the admissible historical range and is of the order of 1% to 5%. This gives an *a posteriori* vindication of the validity of the Venus Tablet data – if the set of chronologies selected on the basis of the Venus data had not contained the correct one, we should not have obtained such a good agreement.

The Ur III data also favor the long chronology: between -2213 and -1890, the best fit for Amarsin year 1 is -2093, while reckoning back from the long chronology gives -2100 plus or minus a few years. There is no good match for the supershort chronology.

Among the authors, specific responsibilities were distributed as follows. Neo- and Late Babylonian data: Sachs; OB data: Stol; Ur III data: Whiting; data analysis: Huber. Leichty, Walker and van Driel contributed a substantial amount of NB and OB data; Walker also collated many British Museum texts. The investigation profited greatly from discussions and correspondence with many colleagues. Special thanks are due to Claus Wilcke, who carefully read an early draft and offered many helpful suggestions. The data analysis on the computer was in part supported by NSF Grant MCS-79-08685 and ONR Contract N00014-79-C-0512.

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* There is a one year difference between the astronomical and the historical year count (there is no year 0 in the historical numbering, 1 B.C. is followed by 1 A.D.).

2. Astronomical theory and calculations

The calculations were based throughout on the theories and parameters used in P.V.Neugebauer's *Astronomische Chronologie* (cited PVN) and in Tuckerman's (1962, 1964) and Goldstine's (1973) tables. The computer programs were written by Huber, originally for a CDC-6500, and later adapted to a VAX-11/780.

The principal difficulty and challenge of historical astronomy resides in our insufficient knowledge of the so-called secular terms. They reflect the changes in the rotation of the earth and in the motion of the moon caused by tidal friction (and perhaps some other causes). The effects are sizeable: if we were to use the present rate of rotation for our calculations, instead of taking the changes into account, the slowing down of the earth's rotation would, by the middle of the first millennium B.C., lead to a clocktime difference of about six hours between the actual and the calculated time of day. Unfortunately, the changes are somewhat irregular, and not known with high accuracy.

The most recent treatment of the problem of the secular terms is Paul Muller's thesis (1975). Muller's estimated standard errors of his estimates of the secular terms in the rotation of the earth correspond to a clocktime error of ±0.9 hours in the year -2100, and the errors in the lunar longitude correspond to ±0.5° (which arc is traveled by the moon in 0.9 hours). These errors are correlated in such a way that they partially cancel each other when lunar phenomena are concerned (the main reason for this is that these secular terms were estimated from lunisolar phenomena, namely historical solar eclipses). Therefore, I roughly estimate that the total, combined error should lie below the equivalent of 0.1 days or 1.3° in lunar longitude for the year -2100. By abuse of language, we shall in the following refer to the combined effects of the errors in the secular terms simply as the 'clocktime error'.

Despite the somewhat antiquated astronomical theories, the elements used by PVN are reputed to be very nearly the best possible ones, so the above estimate for the magnitude of the clocktime error should apply also to them. Indeed, if I understand Muller's corrections properly, then the mean longitudes for the year -2100 differ by −0.24° (moon) and −0.07° (sun), when they are calculated according to PVN-Tuckerman or Muller, respectively. This translates into a clocktime difference of about 20 minutes.

The Venus theory of PVN-Tuckerman is quite accurate; according to Stephenson and Houlden (1981), by the year -600 the maximum error in geocentric longitude is only about 0.05°. If we assume that the error increases quadratically with time, it still is only about 0.1° by -1700, which is negligible for our purposes. Moreover, Venus phenomena are quite insensitive to clocktime errors -- first and last visibility observations are affected by observational errors of one day or more, and any clocktime error smaller than 0.5 days simply is too small to become noticeable with the kind of OB observations we have.

Month-lengths on the other hand are quite sensitive to clocktime errors. Under ideal weather conditions and zero clocktime errors, the computed and the observed first visibility coincide in about 95% of the cases (cf. Section 5.2), and the computed and the observed month-lengths thus agree in about 90% of the cases. A rough calculation shows that a clocktime error of 0.1 days under otherwise ideal conditions would raise the probability of missing the observed crescent from about 5% to about 10%, and the probability of missing the month-length from 10% to about 20%. A clocktime error twice as big (0.2 days) would raise the corresponding probabilities to about 20% and 36% respectively, and would probably render futile any attempt at astronomical dating with the less-than-ideal month-lengths recorded in non-astronomical texts.

Checking the Venus chronologies against the month-length data thus may also help to confirm whether calculated month-lengths are sufficiently accurate so that they can be used for dating purposes in the early second millennium B.C.

3. The calendar

The Babylonian day began at sunset, and, at least in principle, the month began with the first visibility of the lunar crescent after the new moon.

Under ideal weather conditions, the intervals between two first sightings of the crescent vary irregularly between 29, 30 and occasionally 31 days. According to calculations for the latitude of Babylon, among 1000 months there will be about 471 intervals of 29 days, 528 of 30 days and 1 of 31 days.

It is not entirely clear how the Babylonians dealt with sightings delayed by poor weather, and they need not have done it in the same way at different places and in different times.

The evidence available so far indicates that each month had at most 30 days, and that the 30th day could be cut short by the appearance of the moon. Thus, day 30 sometimes would run its full course from sunset to sunset, and sometimes it would last only about an hour, from sunset to the appearance of the lunar crescent, upon which event the first day of the next month would begin. The technical terms in Akkadian are *šullumum* and *turrum* respectively: the Moongod either 'completes' the day, or he 'turns it back'. The interpretations of these technical terms in AHW (p.1145 and p.1334) are not entirely correct. As far as we know, day 30 would always be followed by day 1; the few apparent attestations of a 31st day seem to be misreadings (of 30-lá-1, i.e. 29, or the like).

In accordance with this, the Late Babylonian astronomical texts consistently indicate the month-length by stating whether the moon became visible on 'day 30' or on 'day 1'. These same texts systematically, and often tacitly, substitute very accurate predictions when crescent observations had been missed because of poor weather.

Earlier times would not have the astronomical know-how to make accurate predictions (mathematical astronomy was invented only about 500 B.C.). A Neo-Assyrian letter contains the interesting statement: 'When I first observed the crescent of the moon on the 30th day, it was already high, too high to be the crescent of the 30th. Its position was like that of the 2nd day. So, if it suits the king, my lord, the king should wait for the report of Assur before fixing the date.' (Parpola, LAS No. 119). Presumably, the situation behind this letter is that a month earlier one had missed a crescent observation because of poor weather and had started the month a day late. Because of this, the moon now was very high when it became visible on day 30, and the author of the letter suspects that it should have been visible already on the day before, if the weather had not been bad again. When the letter was written, day 1 had already begun, and since the report from Assur would need some time to arrive, 'fixing' the date presumably means that the king would decree to skip a date early in the month and have, say, day 3 follow immediately upon day 1.

There are reports of unusually early appearances of the moon, for example Thompson RMA No. 58 mentions an appearance on the 28th day. Presumably, such an early appearance would automatically and immediately turn around the date to day 1 of the next month, but it is also possible that one would allow the month to complete the 29th day.

There can be no doubt that in Neo- and Late Babylonian times the day began at sunset. But there may have been regional differences. For example, the Neo-Assyrian letter LAS No. 1 seems to exploit a difference between the astrological beginning of the day (at sunset) and the civil beginning (at a later point, say midnight); however, as Parpola (personal communication) points out, this interpretation hinges on the reading of the slightly damaged number 15 in Rev. line 18.

The Babylonian year began somewhere near spring equinox. Fotheringham (LFS, p.69ff.) argued on the basis of contracts for the delivery of dates and of barley, mostly from the reign of Hammurapi, that his Solution II (Ammiṣaduqa year 1 = -1920) agreed best with the seasons. We find it convenient to characterize the beginning of the year by the longitude of sun and moon at the New Year syzygy* (the new moon immediately preceding Nisan 1). For Fotheringham's Solution II, the Ammiṣaduqa New Year syzygy longitudes fluctuate around a median value of 16°, and accordingly, the OB year would on the average begin about two weeks after spring equinox.

But this argument is precarious. In particular, it assumes that there have been no climatic shifts between OB and present times, and that the average beginning of the year stayed the same between Hammurapi and Ammiṣaduqa.

It is evident from the very irregular pattern of intercalations that there must have been large fluctuations in the beginning of the year. We note that if a New Year syzygy happens to fall at 0° (i.e. at equinox), then the syzygy 12 or 13 months later falls at 350° or 18°, that is, about 10 days before, or 18 days after the spring equinox, respectively. Expressed differently, an ordinary year decreases the longitude by 10°, an intercalary year increases it by 18°. In OB times, two consecutive intercalary years are no rarity, and there is at least one quadruplet of intercalary years (namely Hammurapi years 32, 33, 34 and 35, see the Appendix, Section 2). Ammiṣaduqa's reign contains runs of 4 and of 5 consecutive regular years (namely years 6 to 9, and 14 to 18 respectively). In other words, in Hammurapi's reign the beginning of the year once was moved by 4×18° = 72°, or about 2.5 months, and in Ammiṣaduqa's time, it once was allowed to lapse by 5×10° ≈ 52°.

Unless we either have *complete* lists of intercalations, or are able to date several reigns absolutely by astronomical means, we have no way of knowing even whether the aimed-for beginning of the year stayed the same from one king to the next. An investigation of the beginning of the year in Neo- and Late Babylonian times proves instructive; the principal reference and source is Parker and Dubberstein, *Babylonian Chronology*, 3rd edition, Brown University Press (1956), henceforth cited PD^3, complemented by Goldstine's tables.

In the first part of the timespan in question (-747 to -625), the intercalations are incompletely known, but the eclipse texts in LBAT (A. Sachs, *Late Babylonian Astronomical and Related Texts*, Brown University Press (1955)), # 1413 to # 1417, allow us to fix the beginning of 14 years. Attested intercalations are indicated by the letters A or U, as in PD^3.

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* ***Syzygy*** is a collective term for new and full moons. More precisely, at the new moon syzygy, the moon has the same longitude as the sun, at the full moon syzygy, the longitudes differ by 180°. Longitudes are counted in the ecliptic, that is in the great circle traveled by the sun, from the vernal equinox (0°) to the summer solstice (90°), the autumn equinox (180°) and the winter solstice (270°).

Source	Year	New Year Syzygy
LBAT 1413	-747	335°
LBAT 1413	-746U	325
LBAT 1413	-745	343
LBAT 1414 Obv.I	-730	356
LBAT 1414 Obv.II	-712A	338
LBAT 1414 Obv II	-711	356
LBAT 1415 Obv.I	-701	337
LBAT 1414 Obv.III	-694	349
LBAT 1417 Obv.II	-667	351
LBAT 1415 Obv.III	-665U	359
LBAT 1415 Obv.III	-664	17
LBAT 1417,LBAT 1416 Obv.III	-650U	343
LBAT 1417,LBAT 1416 Obv.III	-649	1
LBAT 1417 Obv.IV	-631	343

Table 3.1. New Year syzygies fixed by eclipse texts.

The median of these longitudes is 346°, which agrees almost exactly with the repeated assertion of the astronomical compendium MUL.APIN that puts the spring equinox on Nisan 15.

From the first year of Nabopolassar (-624) on, the intercalations in PD^3 appear to be complete and reliable (except that the second Ululu in the year -606 should be shifted to the year -607, see Neugebauer-Sachs (1967), p.198).

Shortly after -500, the 19-year intercalary cycle was introduced, and from there on, the beginning of the year was (at least in principle) tightly constricted to the range 358° to 25°, with a median value of 12°. Apart from negligibly small fluctuations from one 19-year cycle to the next, there is a slight secular drift: by the year 0, these three longitudes have increased by 2° each. In -384, an intercalary month was inserted prematurely, so that the following year started with 31°. Note that the longitudes for ordinary years (8° to 25°) and for intercalary years (358° to 7°) do not overlap, and that the lone year with a second Ululu in the 19-year cycle has the earliest beginning (358°).

Thus, the evidence can be summarized in the following Table 3.2 (the years between -624 and -500 were somewhat arbitrarily subdivided into groups of 15 to 19 years when forming ranges and medians).

	Solar longitude at New Year syzygy	
Years	median	range
-747 to -631	346°	325 to 17°
-624 to -610	354	342 to 12
-609 to -595	3	348 to 15
-594 to -576	13	353 to 30
-575 to -557	9	342 to 24
-556 to -538	11	353 to 27
-537 to -519	5	344 to 20
-518 to -500	9	354 to 21
-499 onward	12	358 to 25

Table 3.2. Solar longitude at New Year syzygy.

Thus, between the 8th and the 5th century, the beginning of the year moved by 26°, or almost a month, from about 346° to 12°. While the data are not reliable enough to state so with certainty, it looks as if this shift is due to a discontinuous change made during Nabopolassar's reign.

Because of the large fluctuations and other uncertainties, we should allow a rather wide range for the average beginning of the OB year. Somewhat arbitrarily, we propose to accept chronologies as feasible if they lead to median longitudes in the range between 325° and 45°, that is, if they either lie in the total range (325° to 31°) of the Neobabylonian values, or if they do not deviate more than one month from Fotheringham's average of 16°. But extreme values should be regarded with suspicion.

4. Venus

4.1. Venus phenomena and their recurrence

The motion of Venus is the most regular among the planets in the solar system. During each synodic period (about 20 months) Venus becomes invisible twice: once when it passes between the earth and the sun (inferior conjunction), once when it passes behind the sun (superior conjunction), see Figure 4.1. First and last visibilities repeat themselves fairly accurately after 5 synodic periods or 8 years, more precisely, after 99 synodic months minus 4 days. After 7 or 8 such cycles, the 4-day deficits accumulate to a full month. Thus, after 56 or 64 years (692 or 791 months), Venus phenomena are again in step with the lunar months, but now they fall about two weeks earlier with regard to the solar year.

The duration of the stretches of invisibility is essentially determined by the common longitude of Venus and the sun at conjunction, that is, by its date in the solar year. At inferior conjunction, Venus remains invisible between about 1 day (at longitude L=320°) and about 19 days (L=160°), while at superior conjunction, the duration of invisibility is between 55 days (L=285°) and 70 days (L=55°). Of course, these durations are subject to statistical fluctuations of a few days. For details, see in particular van der Waerden (1943).

Figure 4.2 shows the duration of invisibility of Venus, depending on the longitude at conjunction, after van der Waerden. The durations for superior conjunction were slightly raised (by 3 days) to account for the schematic 30-day months used in the Venus Tablet, for the change of date at sunset, and for the fact that van der Waerden gives the times between the visibility limits (which tend to be slightly shorter than the actual times). There is some (meager) empirical evidence from the LB observations that for solar longitudes between 150° and 270° the *arcus visionis* may be somewhat higher (around 1°), thus, in this range of longitudes, the duration of invisibility at superior conjunction should be about 5-10 days longer on the average. For inferior conjunctions, the effect is smaller (1 to 2 days).

The numbers in Figure 4.2 refer to the invisibilities of the Venus Tablet; they correspond to the numbering of the disappearances in Table 4.2 below, and they are positioned at the points corresponding to the calculated longitude of the conjunction for the -1701 chronology and the durations of invisibility given by the Venus Tablet. Questionable entries are enclosed in parentheses. See in particular Section 4.3.1.

After a few 56 or 64 year periods, the phenomena are shifted to different seasons and also get out of step with regard to the duration of invisibility, but then another cycle sets in.

Following a procedure going back to Ptolemy, the theoretical conditions for visibility of Venus in the evening or morning sky are found by calculating the negative altitude h of the sun at the moment when the planet passes through the mathematical horizon (see Fig. 4.3).

Usually, the planet will not be visible when it passes through the horizon, because of atmospheric extinction, but if the so-called *arcus visionis* h exceeds some critical value h_0, the planet should be visible at some intermediate time between sunset and setting of the planet in the evening, or between rising of the planet and sunrise in the morning.

Since the critical value h_0 was not accurately known, and the random fluctuations even less well, it is necessary to examine the Late Babylonian Venus observations.

4.2. The Late Babylonian Venus observations

From the texts published in LBAT (and some photographs of unpublished tablets) a total of about 100 observations of first and last visibilities of Venus could be culled, ranging in time between the years -461 and -73. The problem with these observations is that they are too good in the sense that most texts do not give the observations as they were observed, but as they should have been observed. That is, they are already corrected for the vagaries of the atmospheric conditions. For instance, based on the high position of Venus, or on its measured duration of shining on day x, the Babylonian observer would conclude that under normal conditions the planet should already have been visible on day $x-1$ or $x-2$. Some texts give regularly, some occasionally, two observations: an 'outer' one, often with a measured duration of shining, and an 'inner' one (by these two terms I distinguish the events according to their closeness to the conjunction with the sun). In many cases, the 'inner' one seems to be not a genuine observation, but rather an educated guess of the observer. Occasionally, and in some texts regularly, only a unique observation is given. The 'inner' and the 'unique' observations show the same statistical behavior, while the 'outer' ones differ substantially (cf. Table 4.1). This agrees with the fact that the summary sections of the LB astronomical diaries only retain the 'inner' observations, after giving both 'outer' and 'inner' ones in the main text a few lines earlier. Even if we carefully weed out dates that are accompanied by the remark 'nu pap', 'I did not watch', our data unavoidably will be biased toward the ideal values.

Within the time span of our LB observations (-461 to -73), there seem to be changes in the practice of observing or of reporting the observations, and there are differences between the treatment of first and last visibilities. The following excerpts were chosen to illustrate some of the features just described.

Last visibility. Early texts give a unique date; later texts give two dates, the first one with a measured duration of shining. For example (LBAT **1237, 110 S.E.): du$_6$ 15 9 ***na šá*** dele-bat, ***in*** 19 dele-bat ***ina*** šú ***ina*** rín šú 'Month VII 15: 36 minutes shining of Venus (***na*** is abbreviation for ***namirtu***, and refers to the time between sunset and setting of the planet). On about the 19th Venus set in the west in Libra.' Very late texts give a unique date, without duration of shining. Did this arise from a decay of observational practice?

First visibility. Early texts usually give two (or three) dates. For example (LBAT 1387, Artaxerxes I., year 2): dir-še 30 13 nu igi. 1 ***ina*** šú ***ina*** lu šú. 6 ***ina*** nim ***ina*** lu igi nim. ***ina*** 4 ***ki*** 5 igi. 'Month XII$_2$ 30 (i.e. the lunar crescent appeared on the 30th day of the preceding month XII, and thus XII had only 29 days; this is the standard convention to indicate month-lengths in these texts), 13 (time degrees, i.e. 52 minutes between sunset and moonset), not seen (!! i.e. the preceding items are not observations, but calculations; according to modern calculation, the moon should indeed have been visible, but with marginal visibility conditions, $\Delta h = 0.2$, see Section 5.1.). On the 1st, in the west, in Aries (Venus) set. On the 6th, in the east, in Aries, it appeared, high, it appeared on about (***ina***) the 4th or 5th.' Later texts add a duration of shining. For example (LBAT 375, 144 S.E.): gu$_4$ 30 ge$_6$ 15 15 dir an za, si šár du. ge$_6$ 16 16 dir an za si šár du. 17 si du. ... ... 18 dele-bat ***ina*** nim ***ina*** til múl-múl igi, kur nim-*a*, 9,30 ***na-su***, ***in*** 15 igi. 'Month II 30 (i.e. the preceding month had 29 days). The night of the 15th and the 15th, clouds captured (? if za is abbreviation for *sabtat*) the sky, north ... (wind) blew. The night of the 16th and the 16th, clouds captured(?) the sky, north ... (wind) blew. On the 17th, north (wind) blew. ... (some lunar observations on the night of the 18th) ... On the 18th Venus appeared in the east in the end of Taurus, brilliant and high, 38 minutes was its shining, it appeared on about the 15th.' In this case, bad weather evidently interfered with the observations.

In view of the poor transmission of the OB data, it is difficult to find out according to which convention the OB astronomers would report their observations. It seems, however, that it is closer to the 'inner' than to the 'outer' observations.

The investigation is reported in more detail in Huber (1977). The texts yield the following collection of *arcus visionis* values on the reported days of first/last visibility in the morning/evening.

'Inner' and 'unique' observations

	WS (22)	WS-1 (22)	ER (23)	ES (21)	ES-1 (21)	WR (26)
2.	08					
3.	136889	6	2			
4.	002679	1377	6	68	9	
5.	333469	01444568	5677788	06888999	0289	2347889
6.		234589	012488	13345688	00011355589	0112444455578
7.	1	58	125	134	01357	123459
8.	8		0138			
9.			1			
10.		3				

'Outer'observations

	WS (8)	ER (19)	ES (8)	WR (11)
5.				678
6.	4		2	789
7.	016	2468	0024888	22359
8.	44	0002222356		
9.	7	249		
10.	5	4		
11.		1		

Table 4.1. Stem-and-leaf display of Late Babylonian *arcus visionis* values of Venus (in parenthesis: number of observations).

We use the common abbreviations WS, ER, ES, WR for Western Setting, Eastern Rising, Eastern Setting, and Western Rising. Table 4.1 summarizes the Late Babylonian *arcus visionis* values in a very compact fashion, in the form of so-called stem-and-leaf displays. They are to be read as follows. To the left of the first vertical line, the integral part of h is given, to the right, the first decimal digit. For instance, the upper left hand corner of the table conveys that there are two 'inner' WS-observations with h between 2.0 and 2.9, namely 2.0 and 2.8, and there are six values between 3.0 and 3.9, namely 3.1, 3.3, 3.6, 3.8, 3.8, 3.9. Figure 4.4 shows the same data graphically; the boxes give the median and the two quartiles, and the whiskers extend to the extreme values (except that some putative outliers are marked by stars).

The *arcus visionis* values for WS, where the daily changes are very large (0.6 to 1.6 degrees), are surprisingly low, much lower than the values for the other three events, but the values of the preceding day (WS-1) are in the right neighborhood. I therefore conjecture that the events WS (and ES) do not denote the day of last visibility, but the day of first invisibility. Incidentally, the terminology of the schematic section of the OB Venus Tablet suggests that the same convention holds also there.

From Table 4.1 one obtains the following median values for the *arcus visionis* (i.e. one-half of the 'inner' observations falls below, one-half above this value):

	WS	WS-1	ER	ES	ES-1	WR
Median	4.4	5.5	6.1	6.1	6.3	6.4
Median minus 1/2 daily change		5.0	5.6		6.2	6.3
Schoch's limit	5.2		5.7	6.0		6.0

Schoch's limit, which is traditionally used to calculate theoretical visibility conditions (the planet is supposed to be visible if the *arcus visionis* exceeds the limit), should be compared not to the median, but to the median minus one-half of the daily change, and then turns out to be surprisingly accurate: it is essentially exact for inferior conjunctions, and it may tend to be too optimistic (by about one day) for superior conjunctions.

4.3. The Old Babylonian Venus observations

Apart from minimal changes (to be mentioned below) we followed the text established by E. Reiner and D. Pingree, *The Venus Tablet of Ammisaduqa*, Bibliotheca Mesopotamica, Vol. 2,1 (1975). We quote this edition as RP.

4.3.1. Data screening

To avoid possible misunderstandings, I must present the analysis of these very poor data in considerable detail. As a rule, apparent gross errors and conjectural emendations were included in the astronomical calculations, but otherwise treated like missing values and excluded from statistical tests. However, I struggled with the Venus Tablet data long enough so that the treatment is not wholly consistent between calculations I did seven years ago (i.e. before RP) or more recently.

The text contains dates of 49 distinct phenomena; if it ever was complete, it covered 52. The data set is the worst I ever have encountered as a statistician. From the number of internal inconsistencies (between dates of disappearance and reappearance and the stated duration of invisibility) and of discrepancies between duplicates, one may guess that at least 20% to 40% of the dates must be grossly wrong. This entails that we must perform some data screening to eliminate the clearly wrong values, and then we must employ statistical techniques that are robust (insensitive to the presence of a moderate number of gross errors).

It should be emphasized that this screening is independent of chronological assumptions. We already noted that Venus phenomena show an approximate 8-year periodicity. About 80% of the preserved dates more or less match this periodicity, while some 20% (most of the dates marked B in Table 4.2) are wildly off the mark, and presumably are gross scribal errors. The remaining 80% may still contain some less gross scribal and observational errors (e.g. caused by poor weather conditions). Among them, we shall throw out groups which seem to be affected by a common pattern of errors, for example the entire last section of the text, which seems to be more corrupt than the rest.

				-1701	-1645	-1637	-1581
1	WS	1 XI 15	G I	5.54	10.31	3.71	9.98
2	ER	1 XI 18	G I	5.88	4.33	8.13	4.88
3	ES	2 VIII 11	G I	7.78	8.42	7.56	7.72
4	WR	2 X 19	G I	7.17	6.26	7.12	6.17
5	WS	3 VI 23	G I	9.65	8.79	5.78	5.73
6	ER	3 VII 13	G I	4.46	1.69	7.28	5.91
7	ES	4 IV 2	G I	6.98	6.68	6.03	5.70
8	WR	4 VI 3	G I	5.22	5.43	5.89	6.07
9	WS	5 II 2	G I	-0.37	4.77	-1.89	3.04
10	ER	5 II 18	B	11.45	9.70	12.24	11.46
11	ES	5 IX 25	G I	5.41	6.54	5.81	7.00
12	WR	5 XI 29	G I	6.65	5.50	6.65	6.08
13	WS	6 VIII 28	G I	5.25	6.20	2.09	2.95
14	ER	6 IX 1	G I	7.59	3.28	8.09	5.59
15	ES	7 V 21	G I	6.94	7.66	6.55	7.29
16	WR	7 VIII 2	G I	6.26	5.86	6.43	5.94
17	WS	8 IV 25	B	-13.99	-10.46	-15.39	-13.40
18	ER	8 V 2	B	17.46	11.86	16.49	12.14
19	ES	8 XII 25	G I	6.42	6.76	6.27	7.14
20	WR	9 III 11	C	6.06	5.64	6.42	5.89
21	WS	9 XII 11	G I	6.68	9.89	3.30	9.55
22	ER	9 XII 15	G I	6.27	5.54	9.35	6.19
23	ES	10 VIII 10	G I	6.92	7.81	6.70	7.10
24	WR	10 X 16	G I	7.51	6.32	7.45	6.47
25	WS	11 VI 26	G I	4.50	3.70	0.96	1.51
26	ER	11 VI$_2$ 8	M I	1.96	-0.80	4.83	3.43
27	ES	12 I 9	B	11.21	10.86	10.38	10.66
28	WR	12 VI 25	B	12.52	11.85	12.34	11.93

					-1701	-1645	-1637	-1581
29	WS	13 II 5	B		-11.30	-6.58	-12.99	-6.90
30	ER	13 II 12	M		10.25	8.73	11.38	10.22
31	ES	13 X 21	G	I	5.43	6.83	5.83	7.01
32	WR	13 XI 21	B		-2.48	-3.47	-2.36	-2.71
	WR	13 XII 21	C		5.36	4.49	5.37	4.81
33	WS	14 VII 10	B		34.57	29.63	28.96	24.33
34	ER	14 VIII 27	G	I	6.62	3.69	10.00	7.72
35	ES	15 V 20	G	I	6.32	6.80	5.94	6.47
36	WR	15 VIII 5	G	I	7.58	6.97	7.78	7.18
37	WS	16 IV 5	G	I	2.59	8.01	3.46	8.51
38	ER	16 IV 20	G	I	7.45	2.04	7.53	3.75
39	ES	16 XII 15	M	I	7.35	7.98	7.44	8.45
	ES	16 XII 25	C		5.98	6.27	5.78	6.38
40	WR	17 III 25	M		9.33	9.36	10.01	10.02
	WR	17 III 4	C		5.50	4.71	5.53	4.91
41	WS	17 XII 10	G	I	1.52	4.86	-0.24	4.61
42	ER	17 XII 14	M	I	8.92	8.50	11.38	9.54
43	ES	18 IX 12	C		5.54	6.20	5.09	5.51
44	WR	18 XI 16	C		8.39	7.45	8.59	7.54
45	WS	19 VI$_2$ 1	B		15.48	15.41	13.56	14.97
46	ER	19 VI$_2$ 17	B		-22.90	-24.71	-19.10	-21.19
47	ES	20 III 25	G		6.70	6.28	5.63	5.33
48	WR	20 VI 24	M		8.46	8.55	9.06	9.40
	WR	20 VI 1	C		5.96	6.11	6.67	6.94
49	WS	21 I 27	B		-5.71	-0.73	-7.41	-1.03
50	ER	21 II 3	G		6.11	5.74	8.12	7.68
51	ES	21 X 28	M		3.17	4.17	3.50	4.65
52	WR	21 XII 28	M		8.39	7.26	8.40	7.57

Table 4.2. The Venus Tablet data.

The data are classified as good (G), mediocre (M), or bad (B), depending on how well they are able to fit at least one chronology fitting the majority of the data; C stands for conjecture, and dates included in the main calculations are marked I. The *arcus visionis* values for the four main chronologies are also given (they formed the basis for the G,M,B-classification).

A detailed description of the screening process follows. The events are identified by their numbers in Table 4.2.

Faulty month-names.

#7,#21 Two nonsensical month-names were emended (VII in IV and III in XII), and the altered dates were retained.

#32 The duration of invisibility between #31-32 is much too short (cf. Section 4.1). A comparison with the sequence of events 8 years earlier, taking the month VI_2 in year 5 into account, suggests that in #32 XI should be changed into XII. But I felt safer deleting this entry, there are too many uncertainties involved here. By the way, I followed Langdon, who 'read 21 on the tablet clearly' (LFS $p.8^{10}$), against RP (which prefers 11, plainly preserved on another manuscript).

Conjectural fill-ins.

#20 The WR is missing, the text puts the WS on III 11, and has a nonsensical invisibility of 9 months 4 days at inferior conjunction. I conjecture that III 11 really was the date of the WR, and that an ancient copyist skipped a line, misled by the same number 11 in the date for the WS. We mark #20 as a conjecture and do not use it in the analysis.

#43-44 These two events were displaced by a schematic insertion, which gives rather unrealistic, constant durations of invisibility of 7 days at inferior, and of 3 months at superior conjunction. Weir (1972, p.27) conjectured that a textual variant for the pair #11-12 might preserve the missing dates for year 18. They are marked as conjectures and are not used in the analysis.

#48 The text has VI 24, with an incompatible interval (2 months 6 days). Reconstructing the date of the WR from the ES and the interval gives VI 1 and a much better fit, but we disregarded it in the analysis.

Impossible durations of invisibility.

#27-28 The interval is impossibly long, so at least one date must be grossly wrong. Since neither fits with any chronology fitting a majority of the data, we drop both.

#33 The interval #33-34 is much too long; a comparison of #13-16 with #33-36 suggests that #33 is the offender, so we drop it.

#39-40 The interval of invisibility (3 months 10 days) is about a month too long. Pingree (RP p.21, bottom) reconstructs the dates XII 25 and III 4, and the latter is indeed attested as a variant. We felt the reconstruction was too conjectural to be used; we dropped #40 and kept #39 with XII 15.

Invisibility 7 days at inferior conjunction.

#17-18, 29-30, 49-50 These three pairs have 7 day invisibility. All three pairs give a poor to impossible fit for at least one of the two events, for any chronology fitting the majority of the data. We conjecture that these dates were interpolated with the help of the schematic 7 day invisibility of the schematic insertion at year 18, mentioned above. The safest procedure is to drop all 6 dates.

Last years.

#45-52 At least 5 of these 8 dates give a poor fit for any chronology fitting the majority of the data. One may wonder whether they belong to Ammiṣaduqa at all. We believe they continue the preceding observations, but are badly garbled. If they would not belong here, it would be difficult to find a home for them. For instance, the most likely candidate for #45-46 is Ammiditana year 32, which however has an attested XII_2, not a VI_2. If the pair #45-46 belongs to Ammiṣaduqa year 19, then the date VI_2 17 is about right for WS (not for ER), so one might perhaps conjecture that here a scribe tried to restore a badly broken text on the basis of the isolated date VI_2 17 and the duration of invisibility, mistaking the former for the date of ER. Anyway, we cannot gain much by keeping this section in, so we may just as well stay on the safe side and drop it entirely.

Other reasons.

#10 This date agrees so poorly with any chronology fitting the majority of the data (it is several days too late) that I decided to drop it, though it may very well be genuine and correspond to an observation delayed by bad weather; cf. the *arcus visionis* values for 'outer' observations in Table 4.1. This is in fact the only item rejected solely because it disagreed with calculation, without being under suspicion for other reasons, like internal inconsistencies, or for belonging to a group showing a suspicious pattern.

This leaves us with 31 of the 49 preserved observations. It would be difficult to screen out more observations without prejudging the chronology.

After establishing a particular chronology we may go back and check also the rest of the data against calculation. If we accept the -1701 solution, it appears that 3 or 4 more dates are wrong: #9, 26, 41 and possibly 39. It would thus seem that two fairly long sections of the tablet, namely #26-33 and #39-52, are almost throughout corrupt, while most of the rest, namely 25 dates (or just barely over 50% of the 49) are in good shape. Four more observations (#30, 42, 47, 50) interspersed in the bad sections are also in good (but perhaps accidental) agreement with calculation.