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BM 76488 – a Babylonian Compendium about Conjunctions and Other Planetary Phenomena

Summary

This paper discusses the cuneiform tablet BM 76488, which partly preserves a hitherto unknown Babylonian compendium about planetary phenomena. In several of the preserved sections, periods are assigned to pairs of planets – a topic not attested elsewhere in Mesopotamian astral science. The analysis presented here suggests that some of the periods describe the empirical behavior of planetary conjunctions.

Keywords: Babylonian astronomy; planets; synodic phenomena; conjunctions; periods.

Dieser Beitrag beschäftigt sich mit der Keilschrifttafel BM 76488, auf der ein bisher unbekanntes babylonisches Handbuch zu Planetenphänomenen teilweise erhalten ist. In mehreren der erhaltenen Sektionen werden Perioden zu Planetenpaaren zugeordnet – ein Thema, das an keiner anderen Stelle in der mesopotamischen Sternkunde belegt ist. In der präsentierten Analyse wird vorgeschlagen, dass einige der Perioden das empirisch erfasste Verhalten von Planetenkonjunktionen beschreiben.

Keywords: Babylonische Astronomie; Planeten; Synodische Phänomene; Konjunktionen; Perioden.

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The fragment BM 76488 (measures: 9.2 × 7.6 × 2.2–3.2 cm) preserves the upper part of the obverse and the lower part of the reverse of a tablet (Figs. 1–2).[1] The obverse is heavily eroded and very difficult to read. The lower part of the obverse is partly blackened, presumably as a result of burning. On the reverse the surface is in a better condition, except for two damaged spots in column ii. The provenance of the tablet cannot be established with certainty. The remains of a colophon on the reverse do not preserve a date, place or name of a scribe. The tablet belongs to the Sippar collection of the British Museum, where it was registered on 18 January 1883 (accession number: 83-1-18, 1858).[2] This lot comprises five cases of tablets that were excavated unscientifically by Hormuzd Rassam and his coworkers in Babylon, Sippar (Abu Habba), Borsippa (Birs Nimrud), as well as one or more Assyrian sites.[3] Several features allow us to narrow down the provenance and date of the tablet. Since it is inscribed in Babylonian cuneiform, an Assyrian origin is unlikely. Moreover, its cushion-like shape would be unusual for Babylon, which speaks in favor of Sippar or Borsippa. A precise date cannot be determined, since the colophon does not mention one, nor does the text report any datable phenomena. According to the colophon, the tablet was copied from a wooden board (inlaid with wax). Orthographical and terminological features suggest that the tablet and the original text date between about 500 and 300 BCE. In particular, the occasional use of the Late Babylonian variant of the numeral 9 (rev. ii 9′, 22′) suggests that the tablet was written after about 450 BCE, while the use of *waṣābu* (DAḪ) for addition, instead of the synonymous *ṭepû* (TAB), suggests that the original was written before the Seleucid era (300 BCE).[4]

1 Transliteration and translation

1.1 Obverse

§1	(1)	IGI *u* ŠU$_2$ *ša*$_2$ ^{d}SAG.ME.GAR *ana* ⸢IGI.LA$_2$-*ka* MU *ana* MU *ša*$_2$ x-*ka* xxx.MEŠ TA x⸣ IGI *u* ŠU$_2$ ⸢x⸣ [xx]	In order for ⸢you to see⸣ the appearance and setting of Jupiter, ⸢year by year: …⸣ the appearance and setting ⸢…⸣ […]
	(2)	⸢xxx⸣-*ṣi* *ina* MU-*ka* *ina* 1⸢5 xx BE x⸣ [xxx] ⸢xxx *lu-maš* xx⸣ 30 ŠE$^{?}$ ⸢x DU x⸣	⸢…⸣ … in your year in 1⸢5 …⸣ […] ⸢… constellation (?) …⸣ 30 … ⸢…⸣

1 An earlier version of this paper was presented at the workshop *The Antikythera Mechanism: Science and Innovation in the Ancient World*, Leiden, 17–21 June 2013.

2 The tablet is listed in the third volume of the catalog of the Sippar collection (Leichty, Finkelstein, and Walker 1988, 63).

3 For the collection 83-1-18 see Leichty 1986, xxxiv; Leichty, Finkelstein, and Walker 1988, xii.

4 There are two instances of the word *lumāšu*, 'zodiacal sign' or 'constellation', in damaged or badly understood passages (obv. 2; rev. i 12′). If the former

Fig. 1 BM 76488 Obverse.

	(3)	⸢xx⸣ ^{d}UTU ⸢10 + x *u_4*⸣-*mu ana* ⸢UGU x DAḪ⸣ 17 *u_4-mu ana* ⸢UGU x DAḪ [xxx] ⸢EN$^{?}$⸣ 12 MU.MEŠ ⸢xx⸣ *qaq-qar*.ME ⸢x⸣	⸢…⸣ the Sun, ⸢10 + x days you add⸣ to ⸢…⸣, 17 days you add to ⸢…⸣ […] ⸢until$^{?}$⸣ 12 years, …, positions ⸢…⸣
	(4)	⸢xx *ina* NIM xxxxxx IM xxx *ina* xxxxx⸣ DAL 17 ⸢*u_4-mu* x *ki-i* xx⸣ DAL 13 *u_4-mu* LA$_2$ ⸢x⸣	⸢… in … wind … in …⸣ … 17 ⸢days … when …⸣ … 13 days lacking ⸢…⸣
§2	(5)	⸢xx⸣ IGI ⸢MU.MEŠ xxxxxxxxxxxxxxxx xxxxxxxxx⸣-*tu_4* ŠID-*ma* KI ⸢xxxxx⸣	⸢…⸣ appearance(?) ⸢years …⸣ … you compute, and … ⸢…⸣
	(6)	[xxx] ⸢xxxxxxxxxxx⸣ IGI *u* ⸢xx⸣ [xxxx] A ⸢xxx⸣ 26 ⸢xxxx⸣	[…] ⸢…⸣ appearance and ⸢…⸣ […] … ⸢…⸣ 26 ⸢…⸣

translation is correct, which is entirely uncertain, this would suggest a date after about 400 BCE.

	(7)	⸢xxxxxxxxxxxxx⸣ [xxxxxxxxxx] ⸢xx⸣ *ki-i* ŠU$_2$ ⸢xx⸣ [xxxxxxx]	⸢…⸣ […] ⸢…⸣ when setting(?) ⸢…⸣ […]
	(8)	⸢xx KA 30 50 IB$_2$.ME.A GAR⸣-*an* ⸢xxxxx⸣ [xxxxx] ⸢x 20 x 20 xx⸣ [xxx]	⸢… 30 50 you put down as a prediction. …⸣ […] ⸢… 20 … 20 …⸣ […]
§3	(9)	⸢IGI *u* ŠU$_2$⸣ *ša*$_2$ ^{d}*dil-bat ana* ⸢xxxxxxxx⸣ [xxxx] ⸢1.30 BI xxxxx⸣ [xx]	In order for you to […] ⸢the appearance and setting⸣ of Venus ⸢…⸣ […] ⸢1.30 …⸣ […]
	(10)	2 *u*$_4$-*mu* ⸢TA⸣ IGI 2 U$_4$ ⸢xxx⸣ [xxxxxx xxx] 30 20 IB$_2$.ME.A GAR-*an*	2 days ⸢from the appearance, 2 days ⸢…⸣ […] 30 20 you put down as a prediction.
	(11)	4 *u*$_4$-*mu* TA IGI ⸢5$^{?}$ *u*$_4$-*mu* x⸣ [xxxxxx] ⸢xxx IB$_2$.ME.A GAR-*an* xx⸣ [xx]	4 days from the appearance, ⸢5$^{?}$ days …⸣ […] ⸢… you put down as a prediction. …⸣ […]
	(12)	⸢x⸣ *u*$_4$-*mu* TA IGI 8 *u*$_4$-⸢*mu* xx⸣ [xxxxx] ⸢xxx IB$_2$.ME.A GAR-*an* x⸣ [xx]	⸢…⸣ days from the appearance, 8 ⸢days …⸣ […] ⸢… you put down as a prediction. …⸣ […]
	(13)	⸢xxxx⸣ *ina* 8 ⸢MU.MEŠ *ki*⸣-*i* 3 ⸢x⸣ [xxx] ⸢x MU x TA⸣ IGI *ana* ŠU$_2$ IB$_2$.⸢ME.A⸣ [GAR-*an* xx]	⸢…⸣ in 8 ⸢years when⸣ 3 ⸢…⸣ […] ⸢year … from⸣ appearance to setting you [put down] as a ⸢prediction⸣. […]
	(14)	⸢xxx 5 xxx⸣ *ina* 56 ME ⸢2 xx MU xx⸣ [xx] ⸢x⸣ [xxxxxx]	⸢… 5 …⸣ in 56 days ⸢2 … year …⸣ […] 2 ⸢…⸣ […]
§4	(15)	⸢xxxxxxxxxx⸣ [xxxxxx] 30 ⸢xxx A xxx⸣ [xxxx]	⸢…⸣ […] 30 ⸢…⸣ […]
	(16)	[xx] *ina* ⸢UGU xxxxxxxxxxxx⸣ [xxxx]	[…] in ⸢…⸣ […]
	(17)	[xx] ⸢x⸣ 1.20 ⸢xxx BE xxxxxx⸣ [xxxx]	[…] ⸢…⸣ 1.20 ⸢…⸣ […]
	(18)	[xx] ⸢MU.MEŠ *ki-i* xxxxxxx⸣ [xxxxx]	[…] ⸢years when …⸣ […]
	(19)	[xx] ⸢xxxxx ½-*šu*$_2$ xxxxx⸣ [xxxxxxx]	[…] ⸢… half of it …⸣ […]
	(20)	[xx] ⸢xxx AN *ana* MU-*ka* xx⸣ [xxxxxx xxxxxx]	[…] ⸢… to your year …⸣ […]
§5	(21)	[xxxxxxx] ⸢xxxxxxxxxx⸣ [xxxxxxxx]	[…] ⸢…⸣ […]

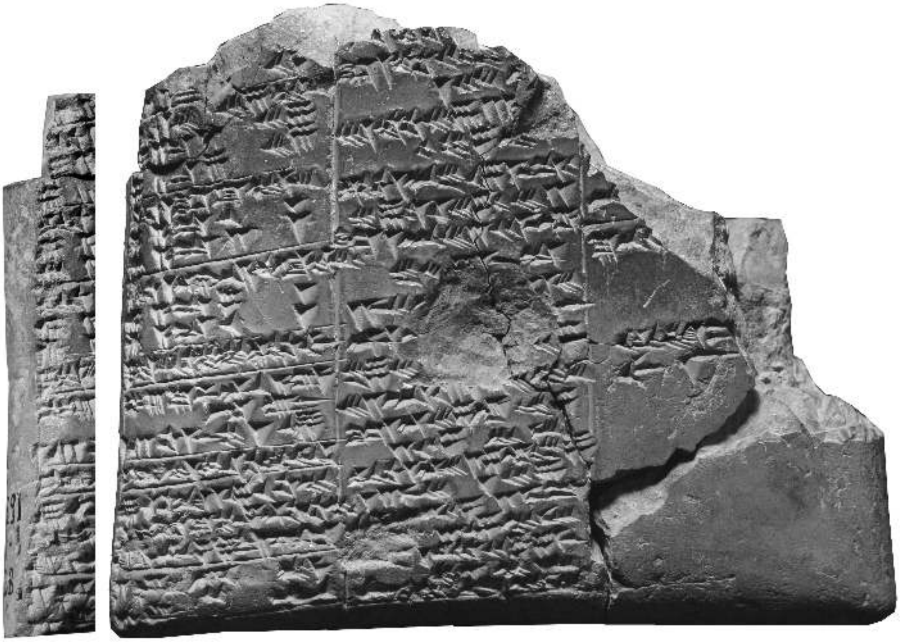

Fig. 2 BM 76488 Reverse.

1.2 Reverse

Column i

§6′	(−1′)	[x *ana* x 24 MU.MEŠ]	[… to … 24 years.]
	(0′)	[x A.RA$_2$ x 24]	[… times … is 24.]
	(1′)	⸢x⸣ A.RA$_2$ [x] 2⸢4⸣	⸢…⸣ times […] is 2⸢4⸣.
§7′	(2′)	⸢$^{\text{d}}$⸣UTU *ana sin* 36 MU.⸢MEŠ⸣	Sun to Moon 36 years.
	(3′)	⸢18⸣ A.RA$_2$ ⸢2⸣ 36	⸢18⸣ times ⸢2⸣ is 36.
	(4′)	6 A.RA$_2$ 6 36	6 times 6 is 36.
§8′	(5′)	GU$_4$.UD *ana* GENNA 1-*šu* MU.MEŠ	Mercury to Saturn 60 years.
	(6′)	6 A.RA$_2$ 10 1	6 times 10 is 1,0.
	(7′)	30 A.RA$_2$ 2 1	30 times 2 is 1,0.

§9′	(8′)	GU$_4$.UD *ana* ^{d}*ṣal-bat-a-nu* 1-*šu* MU.MEŠ	Mercury to Mars 60 years.
	(9′)	15 A.RA$_2$ 4 1	15 times 4 is 1,0.
	(10′)	6 A.RA$_2$ 10 1	6 times 10 is 1,0.
§10′	(11′)	7 MU.MEŠ 10 *u*$_4$-*mu* DAḪ GU$_4$.UD IGI	7 years 10 days you add, Mercury appears.
§11′	(12′)	*bi-rit lu-maš* AN *u* ILLU	Inside a constellation (?): rain and flood,
	(13′)	*ina* NIGIN$_2$-*u*$_2$	when it is surrounded (?).
	(14′)	1.12 *u*$_4$-*me* ŠE 1 18	1.12 days … 1 18.
§12′	(15′)	DU$_3$-⸢*uš*$^{?}$⸣ MU *ana* MU : 11 *u*$_4$-⸢*mu*⸣ IGI *u* ŠU$_2$	Procedure. Year by year: 11 days, appearance and setting.
§13′	(16′)	19 11 UD NE 1 15 10 *u*$_4$-*mu*	19 11 … 1 15 10 days.
	(17′)	⸢*ki-i*⸣ TA DIB BU GAR AN UD 10 *u*$_4$-*mu*	⸢When⸣ from … 10 days.
	(18′)	⸢KIMIN x⸣-*ti* GAR 8 KASKAL.2 ⸢GUR UŠ⸣	⸢Ditto …⸣ … 8 … ⸢it turns back the path, becomes stationary⸣.
§14′	(19′)	2-*u*$_2$ DAL EDIN	Second, … open country.
	(20′)	3-*u*$_2$ BAD SUKUD	Third, … high ground.

Column ii

§15′	(1′)	⸢*dil-bat ana* MUL$_2$.BABBAR⸣ [xx]	⸢Venus to Jupiter⸣ […]
§16′	(2′)	GENNA *ana* MUL$_2$.BABBAR 20 : ⸢50$^{?}$⸣ [ME DU$^{?}$]	Saturn to Jupiter 20 : ⸢50$^{?}$⸣ [days the *deficit* (?)]
	(3′)	1.29 ⸢MU⸣.[MEŠ xx]	1,29 ⸢years⸣ […]
§17′	(4′)	*sin ana* MUL$_2$.BABBAR 36 2 ME [x]	Moon to Jupiter 36, 2 days […]
	(5′)	: 54 ⸢MU.MEŠ⸣ [xx]	: 54 ⸢years⸣ […]

§18′	(6′)	GU$_4$.UD *ana dil-bat* 40 15 ME DU :	Mercury to Venus 40, 15 days the *deficit*:
	(7′)	49 U$_4$ 11 34 : 32	49 days 11 34 : 32
§19′	(8′)	GENNA *ana dil-bat* 32 20 ME DIRI	Saturn to Venus 32, 20 days the excess.
	(9′)	59 ⸢*6*$^?$ ME⸣ DU	59, ⸢*6*$^?$ days⸣ the *deficit*.
	(10′)	1-*me* 20 ⸢MU⸣.[MEŠ x] ⸢x⸣ 1.30	120 ⸢years⸣ […] ⸢…⸣ 1.30.
§20′	(11′)	AN *ana* ⸢*dil*$^?$⸣-[*bat* xxx] LA$_2$	Mars to ⸢Ve⸣[nus …] lacking,
	(12′)	48 ⸢30⸣ [xxx] 24	48 ⸢30⸣ […] 24
	(13′)	32 *dil-bat* ⸢1.12 xx⸣.30 MU.MEŠ	32, Venus,⸢1,12 …⸣.30 years.
§21′	(14′)	GENNA *ana* AN 30 5 DIRI : 45	Saturn to Mars 30; 5 the excess : 45,
	(15′)	2.24 MU.MEŠ	2,24 years.
§22′	(16′)	GU$_4$.UD *ana* AN 32 5 DIRI : 48	Mercury to Mars 32, 5 the excess : 48,
	(17′)	1.2 ME 30 1.36	1,2 days 30 1,36.
§23′	(18′)	⸢*šamaš*$_2$(20) *ana* AN⸣ 2.24 2 ME DU	⸢Sun to Mars⸣ 2,24, 2 days the *deficit*.
	(19′)	[xx] 2.15 MU.MEŠ	[…] 2,15 years.
§24′	(20′)	⸢GENNA$^?$⸣ *ana* GU$_4$.UD 27 5 ME	⸢Saturn$^?$⸣ to Mercury 27, 5 days,
	(21′)	52 MU.MEŠ	52 years.
§25′	(22′)	⸢*sin*$^?$ *ana*$^?$ GU$_4$.UD$^?$⸣ 19 MU.MEŠ	⸢Moon$^?$ to Mercury$^?$⸣ 19 years.

Column iii

§26′	(1′)	⸢x⸣ [xxxxxxxxx]	⸢…⸣ […]
	(2′)	*ina* ⸢20$^?$⸣ [xxxxxxxxx]	In ⸢20$^?$⸣ […]
	(3′)	UDU.IDIM ⸢x⸣ [xxxxxxx]	planet ⸢…⸣ […]
Col.	(4′)	*ul-tu* ⸢^{giš}⸣[DA xxxxxxx]	[copied] from a ⸢wooden⸣ [board …]
	(5′)	IGI.LA$_2$ [xxxxxxx]	checked […]

2 Philological remarks

2.1 Obverse

(1) IGI *u* ŠU$_2$: the context implies that IGI and ŠU$_2$ denote the synodic phenomena of first appearance (IGI) and last appearance (ŠU$_2$). Their Akkadian readings are probably *nanmurtu*(IGI), 'appearance' and *rabû*(ŠU$_2$), 'setting', respectively.[5]

ana amārika(IGI.LA$_2$-*ka*), 'In order for you to see', is a common introductory phrase of Late Babylonian astronomical procedure texts.[6]

(3) DAḪ = *waṣābu*, 'to add' (lit.: 'to append').

(4) DAL (or RI?): interpretation unclear.

(8) IB$_2$.ME.A: this logogram, which also appears in obv. 10–12, is not mentioned in the dictionaries and sign lists. It is probably a variant spelling of *qību*(ME.A), 'prediction'. This is suggested by similar logograms in which a verbal root is preceded by the (pseudo-Sumerian) prefix IB$_2$, e.g. IB$_2$.TAG$_4$ = *riḫtu*, 'remainder'.[7]

2.2 Reverse

Column i

(12′) *birīt* = 'in between; inside' (prep.). *lumāšu* = 'constellation; zodiacal sign'. Perhaps a reference to a planet (Mercury?) standing inside a constellation and hence being surrounded by it (see 13′).

(13′) NIGIN$_2$-*u*$_2$: the phonetic complement suggests *lamû* G inf., 'to surround; be surrounded'.

(14′) The interpretation of this phrase remains unclear.

(16′) 19: the old version of the numeral 9 is used here.

(17′) GAR AN UD: even though the signs are clear, their correct reading is not obvious. Neither *ša*$_2$ ^{d}UTU, 'of the Sun', nor GAR-*an* UD, 'you put down …' appears to yield a meaningful sentence.

(18′) The damaged sign following KIMIN might be KAL or DIRI.

(19′) DAL: due to the numerous possible readings of this sign the interpretation remains unclear. EDIN = *ṣēru*, 'open country'.

5 For an overview of the synodic phenomena of the planets see Ossendrijver 2012, 58.

6 Ossendrijver 2012, 36.

7 CAD, Vol. 14, R, 337b.

(20′) BAD: due to the numerous possible readings the interpretation remains unclear. SUKUD = *mēlû*, 'height.'

Column ii

(6′) DU: this is the first of several instances where DU appears to signify the subtractive nature of the correction to the date, as opposed to DIRI ('to exceed'), which signifies an additive correction (see rev. ii 8′, 14′, 16′). A very preliminary, pragmatic translation 'deficit' has been adopted for all of these instances. The Akkadian reading of DU (or GUB) is not clear – perhaps a form of *alāku*, 'to go,' or *izuzzu*, 'to stand.' This usage of DU is not attested elsewhere in the astronomical corpus as far as known. A subtractive number of days to be applied to the date of an astronomical phenomenon is usually marked by LA_2 = *maṭû*, 'to be lacking' (thus in BM 41004 rev.) or its D stem, *muṭṭû*, 'to diminish' (thus in BM 45728 rev. 6).

(7′) 49: the old version of the numeral 9 is used here. UD: reading uncertain; everywhere else in the text 'day' is written *u_4-mu* or ME.

(8′) DIRI: probably to be read itter, 3 m. sg. pres. of *(w)atāru* G, 'exceeds,' or the cognate noun *atartu*, 'excess.'

(9′) ⌜*6*?⌝: the upper three wedges are preserved, which implies a number between 4 and 9 (old version).

(17′) 1 2 ME 30: the correct reading of these signs is not clear. The initial 1 might also be read ana, 'to,' and ME might be *ūmu*, 'day,' or ME, 'hundred.' None of these options appears to yield a plausible interpretation.

(18′) ⌜*šamaš*$_2$(20) *ana* AN⌝: only the upper parts are preserved.

(22′) ⌜*sin*? *ana* GU_4.UD?⌝: *sin*(30) might also be *šamaš*$_2$(20).

Column iii

(1′) x: perhaps *ina*, 'in.'

(3′) UDU.IDIM: either the word 'planet' or the determinative preceding the name of a planet. UDU.IDIM is followed by two damaged winkelhakens, perhaps part of MUL_2.BABBAR, 'Jupiter,' or a number 20 or 30. Note however that *šamaš*$_2$(20), 'Sun' and *sin*(30), 'Moon,' are never preceded by the determinative for planet.

3 Commentary

The preserved portions of the text can be divided into four distinct parts, here labeled I (§§1–5), II (§§6′–9′), III (§§10′–14′) and IV (§§15′–26′). Taken together they constitute some sort of compendium about planetary phenomena. The colophon may hint at this, since it contains the word or determinative 'planet' (rev. iii 3′), but this may also be the catchline of another, related tablet. The different parts were compiled without much effort to produce a consistent terminology. For instance, Mars is called AN as well as ^{d}*ṣal-bat-a-nu*, and Jupiter is called ^{d}SAG.ME.GAR as well as MUL_2.BABBAR. Generally speaking, the terminology of the text is very similar to that of the Late Babylonian non-mathematical astronomical and astrological procedures. In particular one may mention BM 41004 and BM 45728,[8] two compendia about planetary phenomena from Babylon, and TU 11,[9] a compendium from Seleucid Uruk with Goal-Year procedures mainly concerned with the Moon. Throughout this paper, several references will be made to these compendia in order to interpret certain passages. Certain isolated passages from the text are known from other Late Babylonian astronomical tablets (see below). However, no duplicates of the text, or of any of its parts, have been identified. In particular, the reverse deals mainly with planetary conjunctions, a topic that is not addressed in any previously published Babylonian astronomical procedure text.[10]

Part I occupies the entire obverse of the fragment. Unlike the reverse, this side of the fragment is not subdivided into columns. Due to the strong erosion, not much can be read in part I. It appears that all four partly preserved sections are concerned with the prediction of the synodic phenomena of the planets, i.e. their first and last appearances, stations, and oppositions. One or more instances of the word 'prediction' (obv. 8–13), a period expressed in years (obv. 2, 3), a number of days that is 'lacking' (obv. 4) and the instruction '(you add) to your year' (obv. 20) are clear references to the so-called Goal-Year method. This method is based on the empirical fact that many of the planetary and lunar phenomena that were observed by Babylonian astronomers repeat in a future year – the Goal Year – near the same celestial position and calendar date as in the year that precedes it by a characteristic period which is different for each planet.[11] In addition to the periods, which are expressed in years, the Goal-Year method involves small additive or subtractive corrections to the dates, which are expressed in days. Apart from synodic phenomena, the Goal-Year method was also used for predicting when a planet would pass by one of the so-called Normal Stars, a group of reference stars. For some planets

8 BM 41004: Brack-Bernsen and Hunger 2005/2006; BM 45728: Britton 2002.

9 Brack-Bernsen and Hunger 2002.

10 However, a tablet from Babylon (Hunger, Sachs, and Steele 2001, No. 58) with reports of conjunctions between the Moon and Mars and between the Moon and Saturn for the period 423–400 BCE confirms that Babylonian astronomers were collecting empirical data on planetary conjunctions.

11 For the Goal-Year method cf. Brack-Bernsen and Hunger 2002; Hunger and Sachs 2006; Gray and Steele 2008; Gray and Steele 2009; Steele 2011.

a different period was used for these star passages. Furthermore, even if the same basic period was used for both types of phenomena, the corrections to be applied to the date are usually different. Also note that the Goal Year periods and the corrections are to be understood in relation to the Babylonian luni-solar calendar. That is, the whole number of years by which a Goal Year period was labeled by the Babylonian astronomers is always to be understood as a shorthand for a whole number of calendar months, and the correction in days is to be added to or subtracted from that number of months.

As in the Goal Year procedures BM 41004 and BM 45728, some of these corrections appear to be mentioned in part I. Section 1 begins with instructions for Jupiter, but an additive correction of +17 days mentioned in obv. 3 is not attested for that planet.[12] However, it is consistent with the expected correction associated with the 12-year period for Jupiter's synodic phenomena (see Tab. 1). That period is not known to be a Goal Year period that was actually used, but it is in fact mentioned in obv. 3. It is also explicitly assigned to Jupiter in a Seleucid astrological procedure text.[13] The planets dealt with in §2 remain unidentified, but the following section (§3) clearly deals with Venus. In obv. 13 its standard 8-year Goal Year period is mentioned. This is followed by some instruction concerning the interval between Venus's first appearance and its last visibility as morning or evening star. Some of the corrections (2 days in obv. 10, 4 days in obv. 11) might be connected to the 8-year period (compare Tab. 1).

Parts II–IV are written on the reverse, which is divided into three columns. In both parts II and IV each procedure mentions two planets and an associated period expressed in years, sometimes also other data pertaining to these planets. Part II consists of four identically structured procedures. Each of them contains three statements, the first of which is of the type 'planet 1 to planet 2: *p* years.' It appears that in part I planet 1 is repeated in subsequent sections while planet 2 varies from section to section. All preserved values of *p* are 'pleasant' numbers, being multiples of 12. Furthermore, the values of *p* in §§7′–9′ can all interpreted as the sums of known Goal-Year periods of the involved planets. The 36 years that are assigned to the Sun and the Moon (§7′) can be interpreted as 18 + 18 years, twice the saros period, the standard Goal-Year period for lunar and solar eclipses (Tab. 1). In §8′, the 60 years that are assigned to Mercury and Saturn equal 1 + 59, where 59 years is the standard Goal-Year period for Saturn and 1 year is a valid, although unattested Goal-Year period for Mercury (Tab. 1). The 60 years assigned to Mercury and Mars in §9′ equals 13 + 47, where 47 years is the standard Goal-Year period

12 The standard Goal Year periods for Jupiter are 71 years (for synodic phenomena) and 83 years (for star passages); the associated corrections are of the order +1 d and +5 d, respectively (Gray and Steele 2008; Steele 2011).

13 TU 20, rev. 2 (Hunger 1976). This period is not used as a Goal Year period. It is close to Jupiter's sidereal period (11.86 yr).

for the star passages of Mars and 13 years is a valid, but non-standard Goal-Year period for Mercury's synodic phenomena which is mentioned in BM 41004 rev. 16. In §6′ the names of the planets are not preserved. It seems likely that planet 1 is the Sun, since this is also the case in §7′. Hence 24 years might be interpreted as 18 + 6 years. However, a Goal-Year period of 6 years is not attested, so the identification of the planets in §6′ remains unclear.

From an astronomical point of view, the Goal-Year periods of two different planets do not add up to a meaningful period for conjunctions between these planets (cf. below). Hence there must have been other considerations, presumably astrological or numerological, that motivated the pairwise addition of these periods. The fact that all values of p are 'pleasant' numbers may be seen as confirmation of a numerological motivation. Furthermore, each procedure continues with two representations of p as the product of two numbers, i.e. $p = q \cdot r$. No obvious astronomical significance can be attached to the values of q and r, except in §7′, where $r = 18$ (rev. i 3) can be interpreted as the saros period.

After §9′, column i continues with part III, which consists of five short procedures (§§10′–14′) that do not appear to have much in common. Part III deviates from parts II and IV in that the procedures are not concerned with pairs of planets, but with single planets, or other astronomical, astrological or, perhaps, lexical topics. In §10′ a period of 7 years and an additive correction of 10 days are assigned to Mercury. The formulation of this rule is entirely analogous to the Goal-Year procedures in BM 41004 (rev.) and BM 45728 (rev.). Each procedure mentions a period measured in years and a correction expressed in days. As mentioned, they are to be understood in relation to the Babylonian luni-solar calendar. That is, the 7 years actually stands for 86 months, the closest whole number of months corresponding to 7 years, and 10 days is the correction that must be added to this number of months. This is a valid Goal-Year rule for Mercury (Tab. 1), which is not attested elsewhere as far as known. The correction of +10 days is close to the value of +9 days obtained from a modern computation.

The meaning of §11′ is largely unclear. The terms 'rain and flood' are often mentioned together in astronomical diaries and in certain astrological texts concerned with weather prediction.[14] The significance of the numbers in rev. i 13′–14′ is also not clear; perhaps they represent a period for these phenomena.

In §12′ we are again on solid ground, since this procedure mentions the well-known interval of approximately 11 days by which the solar year exceeds 12 synodic months. This parameter, known by the modern term yearly epact, is mentioned or implied in numerous Babylonian astronomical texts. In an ordinary year of twelve months, i.e.

14 See Hunger 1976; Sachs and Hunger 1988; Brack-Bernsen and Hunger 2002.

planet	phenomena	nr. of elementary periods	years	months (m) +days (d)	BM 76488	
Moon, Sun	synodic	223 P_{syn}	18.030	223 m	18 yr	§7′
	synodic	669 P_{syn}	54.089	669 m	54 yr	§17′
Mercury	synodic	3 P_{syn}	0.9515	12 m – 7 d	1 yr	§8′
	synodic	22 P_{syn}	6.9780	86 m + 9 d	7 yr +10 d	§10′
	synodic	41 P_{syn}	13.005	161 m – 5 d	13 yr	§9′
	synodic	164 P_{syn}	52.018	643 m +11 d	52 yr	§24′
Venus	synodic	5 P_{syn}	7.993	99 m – 5 d	8 yr [… d]	§3
	star passages	13 P_{sid}	7.997	99 m – 2 d	8 yr [… d]	§3
	synodic	20 P_{syn}	31.973	395 m +13 d	32 [yr]	§20′
	synodic	30 P_{syn}	47.960	593 m +10 d	48 [yr]	§20′?
	synodic	75 P_{syn}	119.899	1484 m –29 d	120 yr	§19′
Mars	star passages	25 P_{sid}	47.020	581 m +17 d	47 yr […d]	§9′
Jupiter	synodic	11 P_{syn}	12.013	148 m +17 d	12 yr +17 d?	§1
Saturn	synodic	57 P_{syn}	59.003	730 m – 6 d	59 yr – 6 d	§8′, §19′
	synodic	86 P_{syn}	89.022	1101 m – 1 d	89 yr [… d]	§16′
	synodic	142 P_{syn}	146.990	1118 m + 2 d	144 yr (error for 147 yr?)	§21′?

Tab. 1 Goal-Year type periods for synodic phenomena and Normal Star passages: modern data and BM 76488.

a year without intercalation, the dates of all stellar phenomena, i.e. heliacal risings ('appearances') and settings ('disappearances'), are shifted by this amount. Hence §12′ is probably concerned with stellar, not planetary phenomena.

Section 13′ is difficult to interpret and the correct reading of some signs could not be established. It seems to be concerned with a period, a correction expressed in days, the Sun and certain planetary phenomena, including retrograde motion and stations (rev. i 18′). Section 14′ contains two short, numbered statements that appear to be lexical glosses. Their meaning remains opaque and it is not clear to which of the preceding statements, if any, they are connected.

After a break of unknown length column ii continues with part IV which contains at least ten sections, each concerned with a pair of planets (§§15′–26′). The sequence of the pairs of planets is different from part II, since planet 2 is repeated in subsequent sections while planet 1 varies from section to section. Each pair of planets occurs only once. They may be divided into five distinct types: (1) conjunctions with the Moon (§§17′, 25′); (2) conjunctions with the Sun (§23′); (3) conjunctions between two inner planets (Mercury and Venus) (§18′), (4) conjunctions between an inner planet and an outer planet (Mars, Jupiter, or Saturn) (§§15′, 19′, 20′, 22′, 24′); (5) conjunctions between two outer planets (§§16′, 21′). In every section, the statement 'planet 1 to planet 2' is followed by a period measured in years and a correction for the date analogous to the one in §10′. With some exceptions, these periods are not attested elsewhere, as far as known. Unlike the periods from part II, they may have been derived from astronomical observations. At least some of them are empirically meaningful values of the mean time between one or more *clusters* of conjunctions of the involved planets; for a modern derivation see Appendix A, i.e. Section 4 of this article. Note that for conjunctions of type 4 the mean periods for conjunctions are expected to coincide with Goal-Year type periods of the outer planet, for type 2 with those of the planet. The most interesting periods are therefore those for conjunctions of types 1, 3, and 5, since they should differ from the Goal-Year periods for individual planets. Sometimes one or two additional periods are mentioned after the period for conjunctions. Some of these other periods are identifiable as Goal-Year periods for one of the involved planets – usually the planet that is mentioned in first position. Other aspects of the procedures in parts IV still defy interpretation.

In §§15′, 16′, and 17′, planet 2 is Jupiter, while planet 1 is successively equal to Venus, Saturn, and the Moon. In §15′ the period is not preserved. In §16′ two numbers are partly preserved, but the units are not. However, the common structure underlying each of the procedures §§15′–25′ suggests that the first number, 20, is the period measured in years, while the second one, probably 50, is the correction expressed in days. A period of 20 years is not attested elsewhere in the cuneiform literature in connection with Saturn or Jupiter. It cannot be interpreted as a sum of Goal-Year periods for these planets as was done in §§6′–9′. However, 20 years is a correct mean period for successive conjunctions between these planets (Tab. 2). It is in fact the shortest possible period for conjunctions between these planets, comprising one elementary period (P_{co} in Tab. 3). As shown in Tab. 2, it can be expressed as 247 months, the closest whole number of months corresponding to 20 years, and a subtractive correction of 41 days. This suggests that the damaged number 50 (rev. ii 2′) was followed by a subtractive marker, probably DU, because that logogram appears to be used in this function throughout §§15′–25′ (see the philological remarks). Rev. ii 3′ mentions a period of 89 years, but the correction in days

pair of planets	nr. of (clusters of) conjunctions	years	months, days	shift in longitude	BM 76488	
Venus – Jupiter	11	12.013	148 m +17 d	+5°	[...]	§15′
Saturn – Jupiter	1	19.858	247 m −41 d	−117°	20 [yr]	§16′
Moon – Jupiter	478	35.982	445 m + 2 d	+12°	36 [yr +]2 d	§17′
Mercury – Venus	?	?	?	?	40 [yr] −15 d	§18′
Saturn – Venus	31	32.089	396 m +27 d	+32°	32 [yr] +20 d	§19′
Mars – Venus	8	17.082	211 m + 8 d	+29.5°	[...]	§20′?
Saturn – Mars	15	30.135	372 m +21 d	+5°	30 [yr] + 5 d	§21′
Mercury – Mars	15	32.030	396 m + 5 d	+11°	32 [yr] + 5 d	§22′
Saturn – Mercury	26	26.914	334 m −33 d	−31°	27 [yr −]5 d	§24′
Moon – Mercury	235	19.000	235 m	+0.2°	19 yr	§25′

Tab. 2 Mean time between multiple conjunctions: modern data and BM 76488.

is missing. This is a valid Goal-Year period for Saturn that can be construed as 30 + 59 years, the sum of two Goal-Year periods for this planet, both of which are mentioned in BM 41004 rev. 13–14, while 59 years is also mentioned in BM 45728 rev. 13.

Returning to §15′, it can be assumed that the missing period is some multiple of the mean period for successive clusters of conjunctions between Venus and Jupiter (P_{co} in Tab. 3). This multiple was probably chosen in such a way that a close return to the same date and celestial position is achieved. We cannot be sure which period is to be restored, but a plausible one would be 12 years (see Tab. 2).

In §17′ planet 1 is the Moon. The period of 36 years is a correct value for the mean duration of 478 conjunctions between the Moon and Jupiter. This multiple may have been selected because it yields a very close return of the date as well as the celestial position (Tab. 2). The second period, 54 years (rev. ii 5′), is not followed by a correction for the date. It corresponds to another well-known Goal-Year period for the Moon, namely 669 months = 3 saros periods. Since a synodic period for the Moon always consists of a whole number of months, the absence of a correction expressed in days is expected.

In §§18′–20′ planet 2 is Venus, while planet 1 is set to Mercury, Saturn, and Mars, respectively. In §18′ a period of 40 years and a subtractive correction of 15 days follows the statement 'Mercury to Venus'. This period is not attested elsewhere. Its origin and justification remain unclear for the moment. The next line contains several numerals and, perhaps, the word 'day'. The interpretation remains unclear. The interval of 49 days could not be identified.

In §19′ a period of 32 years and an additive correction of 20 days are assigned to conjunctions between Saturn and Venus. This correction agrees quite well with the expected value (Tab. 2). The 32-year period does not produce a particularly close return to the same date and ecliptical longitude, but neither does any shorter period. A period of 10 conjunctions = 29.36 years does produce a much closer return of the ecliptical longitude (shift: $-1°$), but the remainder of 0.36 years yields a very large correction for the dates of about $+4.5$ months. The next two lines mention two further periods, the first of which, 59 years, is the standard Goal-Year period for Saturn (Tab. 1). The associated correction of -6 days is also mentioned in BM 41001 rev. 13. The second period, 120 years (rev. ii 10′), is not attested elsewhere. It might be interpreted as a Goal-Year period for Venus (Tab. 1). The expected subtractive correction may have been written in the gap. The meaning of the other numbers is not clear.

Section 20′ deals with Mars and Venus, but the period is broken away (rev. ii 11′). A plausible period that might have been mentioned here is 17 years corresponding to 8 conjunctions (Tab. 2). The number 48 (rev. ii 12′) can be readily interpreted as a Goal-Year period of Venus (Tab. 1). The meaning of the other numbers in that line is not clear. The third and final line of §20′ mentions another valid Goal-Year period of Venus (32 years) and two damaged numbers whose significance is not clear.

In §§21′–23′ planet 2 is Mars, while planet 1 is set to Saturn, Mercury, and the Sun, respectively. In §21′ a period of 30 years is assigned to Saturn and Mars. This is a valid mean period for conjunctions between these planets (Tab. 2). In fact, it corresponds to the smallest possible multiple of the basic period for conjunctions between these planets, $P_{\mathrm{co}} = 2.0$ years, that yields a reasonably close return to the same ecliptical longitude. However, the reported correction of $+5$ days differs significantly from the expected value of about $+21$ d.[15] The significance of the number 45 is unclear. The period of 144 years mentioned in the next line (rev. ii 15′) is neither a Goal-Year period of Saturn, nor of Mars. Note however that 147 years are a valid non-standard Goal-Year period of Saturn which is attested in BM 41001, rev. 15 (see also Tab. 2).

In §22′ a period of 32 years is assigned to Mercury and Mars. This is a valid period for conjunctions between these planets. The correction of $+5$ days agrees with the expected value (Tab. 2). The meaning of the other statements is not clear (cf. the philological remarks).

The period of 144 years assigned to the Sun and Mars in §23′ is problematic. Since planet 1 is the Sun, the mean periods for conjunctions should equal a Goal-Year type

15 Its magnitude does agree with the expected shift along the ecliptic measured in degrees, but it seems unlikely that the correction has this deviating meaning here.

period of Mars, but 144 years is not one of them. The period of 135 years (rev. ii 19′) remains unidentified; as far as known it is not a valid Goal-Year period of any planet.

In §§24′–25′ and presumably also in the missing first section of column iii, planet 2 is Mercury. In §24′, 27 years is assigned to Saturn and Mercury, a valid mean period for conjunctions between these planets (Tab. 2). In the next line (rev. ii 21′) a period of 52 years is mentioned. This is a valid Goal-Year period for Mercury (Tab. 1). The associated correction for the date is omitted. In §25′ planet 1 is probably the Moon. The period of 19 years is a valid mean period for conjunctions between the Moon and Mercury (Tab. 2).

In part IV planet 2 was successively equal to Jupiter, Venus, Mars, and Mercury. This leaves out Saturn, the Moon and the Sun as possible candidates for planet 2 in the sections that are missing in column iii between §25′ and §26′. It can be assumed that planet 1 was chosen in such a way that no pair of planets is repeated.

4 Appendix A: mean periods for planetary conjunctions

Two planets are said to be in conjunction when they have the same ecliptical longitude for the observer. Since this event is affected by the varying velocities of both planets, the time between successive conjunctions is not constant. However, a mean period, say P_{co}, can be derived from the sidereal periods of the involved planets by assuming that they move along the ecliptic at their mean velocity:

$$P_{co} = \frac{P_1 P_2}{|P_2 - P_1|}.$$

Here P_1 and P_2 are suitably chosen sidereal periods of planets 1 and 2, respectively. For the Moon and the outer planets (Mars, Jupiter, Saturn), the actual sidereal periods are to be used here. For the inner planets (Mercury, Venus) the appropriate sidereal period is that of the Sun (1 year), i.e. the motion of these planets with respect to the mean Sun is ignored. Hence the formula does not work for conjunctions between Mercury and Venus, because the denominator vanishes in that case $(P_1 = P_2 = 1\,\mathrm{yr})$, but cf. below. The resulting values of P_{co} and the associated mean displacements along the ecliptic are compiled in Tab. 3. By computing 360°/shift one can assess how many conjunctions are needed for a close return to the same ecliptical longitude. The resulting periods, converted to mean synodic months and a correction expressed in days, may then be compared with the periods mentioned in the text (Tab. 2).

Note that the time between two actual, individual conjunctions is subject to variation and can differ significantly from the values of P_{co} thus computed. Moreover, all

	Mercury		Venus		Mars		Jupiter		Saturn	
	P_{co} [yr]	shift	P_{co} [yr]	shift	P_{co} [yr]	shift	P_{co} [yr]	shift	P_{co} [yr]	shift
Moon	0.0809	+29.1°	0.0809	+29.1°	0.0779	+14.9°	0.0753	+2.28°	0.0750	+0.92°
Mercury			*0.90*	*–36°*	2.1353	+48.7°	1.0921	+33.1°	1.0351	+12.7°
Venus					2.1353	+48.7°	1.0921	+33.1°	1.0351	+12.7°
Mars							2.2354	+67.8°	2.0090	+24.6°
Jupiter									19.858	–117°

Tab. 3 Mean periods and mean longitudinal shifts for planetary conjunctions (modern values).

five planets (Mercury, Venus, Mars, Jupiter, and Saturn) experience retrogradations, i.e. they occasionally change their direction of motion along the ecliptic. As a result, several conjunctions may occur in rapid succession within a single interval P_{co}. Hence P_{co} represents the mean time between successive clusters of conjunctions rather than individual conjunctions. A modern table with computed conjunctions published by Meeus reveals that up to five conjunctions may form a single cluster in the case of Mercury and Venus or Mercury and Mars.[16] For other conjunctions involving Mercury, Venus, Mars, Jupiter or Saturn up to three conjunctions may form a single cluster. The only exception is the Moon, which moves much more rapidly than the planets, so that it never experiences more than one conjunction within the interval P_{co}. The correctness of the results for P_{co} in Tab. 3 is confirmed by the data in the tables of Meeus.[17] As mentioned, the approach followed here does not work for conjunctions between Mercury and Venus. The tables of Meeus reveal that the mean time between successive clusters of conjunctions between these planets is 0.90 yr. That number and the associated mean longitudinal shift are shown in italics in Tab. 3.

16 Meeus 1995, 39–46.

17 Meeus 1995, 39–46.

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