Scientific Writings from the Ancient and Medieval World

THE BABYLONIAN ASTRONOMICAL COMPENDIUM MUL.APIN

Hermann Hunger and John Steele

ROUTLEDGE

The Babylonian Astronomical Compendium MUL.APIN

MUL.APIN is the earliest surviving general work on astronomy in which a wide range of theoretical and practical information relating to the Sun, Moon, stars, and planets is presented. Hermann Hunger and John Steele have done us all an immense service in providing this up-to-date edition and accessible, yet accurate translation of a document of central importance for our understanding of the history of Mesopotamian astronomy, and more broadly of all pre-telescopic astronomy.

Alexander Jones, Institute for the Study of the Ancient World, New York University, USA

MUL.APIN, written sometime before the eighth century BC, was the most widely copied astronomical text in ancient Mesopotamia: a compendium including information such as star lists, descriptions of planetary phases, mathematical schemes for the length of day and night, a discussion of the luni-solar calendar and rules for intercalation, and a short collection of celestial omens. This book contains an introductory essay, followed by a new edition of the text and a facing-page transliteration and English translation. Finally, the book contains a new and detailed commentary on the text. This is a fascinating study, and an important resource for anyone interested in the history of astronomy.

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Preface

Fragments of the Babylonian astronomical compendium known as MUL.APIN were first identified over one hundred years ago, but it was not until 1989 that a complete edition, with translation and study of the text, was published by H. Hunger and D. Pingree under the title *MUL.APIN: An Astronomical Compendium in Cuneiform*, Archiv für Orientforschung Beiheft 24 (Horn: Berger & Söhne, 1989). In the years since the publication of that volume, several new fragments of MUL.APIN have been identified. In addition, the publication of editions and studies of other works of early Babylonian astronomy that relate to MUL.APIN, as well as detailed studies of certain sections of MUL.APIN itself, has led to advances in our understanding of the text and its contents. With the earlier edition now being out of print, the time seems right to present an updated edition and translation of MUL.APIN, accompanied by a new study of its contents. The new edition incorporates several tablets of MUL.APIN that have been published since the 1989 edition, as well as a few previously unpublished tablets identified by ourselves.

Our work in both establishing the text of MUL.APIN and understanding its contents owes a large debt to the efforts of several scholars over the past century, in particular F. X. Kugler, E. Weidner, J. Schaumberger, B. L. van der Waerden, and D. Pingree. We also wish to record our sincere thanks to J. C. Fincke, who shared with us her article containing editions of several newly identified fragments and very generously provided us with photographs of all of the relevant tablets in the British Museum. She also drew H. Hunger's attention to a procedure for drawing copies of tablets from photos, which was developed by C. Wunsch and which is used for the copies in this book. We are grateful to St. Maul and A. Hätinen, who gave us access to tablets from Assur ahead of their publication. Previously unpublished tablets in the British Museum are published here by permission of the Trustees of the British Museum.

Abbreviations

CAD	The Assyrian Dictionary of the Oriental Institute of the University of Chicago (Chicago: Oriental Institute)
CT	Cuneiform texts from Babylonian tablets etc. in the British Museum (London: British Museum)
LBAT	Late Babylonian astronomical and related texts copied by T. G. Pinches and J. N. Strassmaier, prepared for publication by A. J. Sachs with the co-operation of J. Schaumberger (Providence: Brown University Press)

Introduction

The text known as MUL.APIN was the most widely copied work in the astral sciences written in ancient Mesopotamia.[1] It was composed sometime before the end of the eighth century BC, and copies of it have been found at many sites throughout Assyria and Babylonia, dating from the late Neo-Assyrian (eighth to seventh century BC) down to the Seleucid (third to first century BC) periods. In addition to being widely copied, MUL.APIN was clearly read and used by scholars throughout these periods: it is one of only a very few works of astral science identified by name in other cuneiform texts and provided the foundation for many later texts of what we term 'schematic astronomy'.[2] It is no exaggeration to say, therefore, that MUL.APIN was the most important work of early Babylonian astronomy.

Our knowledge of Mesopotamian astral science is based upon more than 5,000 cuneiform tablets containing texts ranging from collections of celestial omens, to reports of dated astronomical observations, to procedures for calculating astronomical phenomena. These tablets fall into two main groups: (1) tablets from the Neo-Assyrian period – dating to the late eighth and early seventh century BC and written either in Assyrian or Babylonian script – which mainly come from the last Assyrian capital, Nineveh, with small numbers having been found at the earlier capitals of Assur and Kalhu, all of which are in the Assyrian heartland, and at the site of the city of Huzirina in Anatolia, on the periphery of the Assyrian empire; and (2) tablets from Babylonia, ranging in date from the eighth century BC to the first century AD, mostly from the city of Babylon, but with a substantial number from Uruk in southern Babylonia, and a handful of tablets from other Babylonian cities. These sources show a thriving and multifaceted astronomical tradition that included the careful and regular observation of astronomical phenomena, the development of methods to predict those same phenomena, and the interpretation

1 The term 'astral sciences' is a catch-all to refer to scholarly activity that falls under the modern categories of astronomy, astrology and celestial divination, cosmology, and certain aspects of meteorology. For simplicity, we often use the term 'astronomy' in place of the longer 'astral sciences', with the understanding that astrology and celestial divination are part of astronomy.

2 Steele (in press a).

of astronomical phenomena through celestial omens and other systems of astrology, as well as texts such as MUL.APIN that provide schemes describing recurring astronomical events.

MUL.APIN contains a concise and generally well-organized collection of astronomical material covering all of the main topics we know to have been the subject of Babylonian astronomical concern in the second and early first millennium BC: lists of stars, the calendar, the synodic phases of the planets, the variation in the duration of visibility of the Moon and the length of day and night, the length of a shadow cast by a gnomon at different times of day throughout the year, and celestial omens. Copies of the work were often written in a two-tablet series, although the break between the two tablets was not fixed. Tablets containing the whole of the work on one tablet are also known, and it is possible that copies that extended over three tablets existed. The work is remarkably stable, with relatively few differences between the preserved copies.[3] This stands in contrast to another widely copied work of the astral sciences, the compendium of celestial omens *Enūma Anu Enlil*, which exhibits considerable variation, even to the extent of different traditions of the numbering of tablets between different cities.[4]

Modern scholarship on MUL.APIN began with the publication of a copy of BM 86378, a well-preserved manuscript for Tablet I, by King (1912: pls. 1–8). The publication of this copy led quickly to the publication of editions and studies of the tablet by Kugler (1913: 1ff.), Weidner (1915: 35ff. and 141ff.) and Bezold et al. (1913). Weidner (1923) identified and published further manuscripts of MUL.APIN, including sources that preserved parts of Tablet II. A full edition of the whole of MUL.APIN, accompanied by a short astronomical commentary, was finally published by Hunger and Pingree (1989). Since then, several new sources have been identified by Horowitz (1989–1990), Fincke (2014, 2017), Hätinen (forthcoming), and ourselves. The edition presented here is based upon all sources known to us as of September 2017.

In referring to lines within MUL.APIN, we follow the division of the work into two tablets adopted by Hunger and Pingree in their edition of 1989, with the exception of three additional lines in II Gap A. This line numbering is based upon two of the best-preserved sources, our source A (BM 86378) and source HH (VAT 9412+11279). It should be pointed out again, however, that this line numbering is essentially arbitrary. In particular, the division between 'Tablet I' and 'Tablet II' adopted here is a modern convention, only partly reflected in the ancient sources, and so it is unwise to form conclusions about the composition or structure of the work based upon this division.

3 For a study of the differences between the manuscripts that were published in Hunger and Pingree (1989), see Hobson (2012: 47–61). Most differences can be ascribed to simple scribal errors (especially in numbers) or minor orthographic variations.

4 Fincke (2001).

Structure and content of MUL.APIN

The preserved copies of MUL.APIN divide the text into sections that are separated from one another by horizontal rulings. In many cases, two or more sections can be grouped together to form large units of text that are subdivided into smaller parts. These larger units often contain one or more sections that contain factual statements, such as the names of stars or constellations, followed by a section containing a summary of the preceding sections: for example, giving the number of stars in the list, or a short mathematical procedure that draws upon the data given in the earlier section. We can therefore distinguish between larger units of text, which we will call ‘sections’, and the ‘subsections’ that make up this larger unit. No distinction is made between the appearance of the horizontal rulings that are used to separate sections and subsections. However, some general trends can be seen within sections. For example, sections often begin by giving lists of what can be thought of as astronomical data, such as the names of stars, the dates on which stellar phenomena occur, the intervals between the synodic phenomena of the planets, and the duration of visibility of the Moon and the length of night. Entries in these lists are usually indicated using the DIŠ sign (a single vertical wedge), which we translate using the symbol ¶.[5] Generally, entries in a list are given on separate lines, unless they are too long, in which case they extend on to a second line, or all the entries in the list are very short, in which case two entries are given per line, sometimes both marked with the DIŠ sign and arranged into two mini-columns, at other times simply following one another, without a separating DIŠ sign. Following a list of data, we often find one or more subsections that either summarize the preceding data or give a short procedure related to that data. These subsections can often be differentiated from the data subsections by the absence of the DIŠ sign at the beginning. Most of these procedures are not intended to tell the reader how to use the preceding data but instead to provide a justification for the data itself.

The basic contents of MUL.APIN can be summarized as follows:

I i 1 – I ii 35: Three lists of stars in the paths of Enlil, Anu, and Ea. These three paths divide the sky into northern, middle and southerly ranges of declination.

I ii 36 – I iii 12: A list of dates in the 360-day schematic calendar on which selected stars become visible for the first time (known as first visibility or heliacal rising).

I iii 13 – I iii 33: A list of stars which rise as other stars set.

I iii 34 – I iii 48: A list of the number of days between the rising (first visibility) of two stars.

5 The role of the DIŠ sign is discussed in detail by Watson and Horowitz (2011).

I iii 49 – I iv 9: A brief discussion of the culmination (*ziqpu*) of stars and a list of *ziqpu* stars.

I iv 10 – I iv 30: A list of dates in the 360-day schematic calendar on which one star culminates when another star rises at its first visibility.

I iv 31 – II i 8: A list of stars through which the Moon passes each month (i.e. the zodiacal constellations), followed by statements that the Sun and the planets move through the same path that the Moon travels.

II i 9 – II i 43: Statements concerning the motion of the Sun to the north and south and the change in the length of daylight. The dates of the solstices and equinoxes are placed on the 15th of Months I, IV, VII, and X in the 360-day schematic calendar.

II i 44 – II i 67: Statements of the duration of the visibility and invisibility periods of the five planets.

II i 68 – II Gap A 7: A brief discussion of the four seasons, which path the Sun is in during those seasons, and their characteristic weather. The seasons are set such that the solstices and equinoxes fall in their middle.

II Gap A 8 – II ii 20: An intercalation scheme governed by the date of conjunction of the Moon with the Pleiades and by the date of the first visibility of certain stars, followed by a mathematical explanation of the consequences of there being one intercalary month every three years.

II ii 21 – II ii 42: A mathematical scheme for the length of a shadow cast by a gnomon on the dates of the solstices and equinoxes.

II ii 43 – II iii 15: A mathematical scheme for the length of night and the daily change in the duration of visibility of the Moon.

II iii 16 – II iv 12: A short collection of celestial omens.

The macro structure of MUL.APIN largely follows a logical structure. The text begins by introducing the main stars of the night sky, before dividing these stars into three overlapping groups: stars for which the date of first visibility is given; stars whose culminations are to be used; and the zodiacal constellations through which the Moon, Sun, and the five planets pass. The latter two of these groups of stars are named according to their characteristics: the *ziqpu* ('culminating') stars (MUL^{meš} šá ziq-pi), and the stars that stand in the path of the Moon (DINGIR/MUL^{meš} ša i-na KASKAL ^{d}Sin GUB^{meš}). With the exception of the list of stars in the path of the Moon, the lists of stars are followed by further lists in which additional statements about some of these stars are given that tie phenomena of the stars either to one another or into a calendrical framework. The second half of MUL.APIN moves away from a concern with stars to present material relating to the calendar, the synodic phases of the planets, mathematical schemes for the length of shadow cast by a gnomon, the length of night, and the daily variation in the duration of visibility of the Moon. Finally, a small group of celestial omens is given at the end of the text. Although still following a broadly logical order, this second half of the work is not as well ordered as the first part. In particular, it is unclear why the section concerning the synodic phases of the planets appears between two sections that concern the calendar. It is tempting to see the planetary material as having become displaced from its original position, which may have been immediately following the statements that the planets travel the same path as the Moon; however, this may simply reflect a modern bias in what we think would make a logical order, rather than what made sense for the author of the text. On the whole, however, later sections of the composition build upon or rely upon data introduced earlier in the text.

Previous studies of MUL.APIN have tended to assume that the work is a compilation of texts, at least some of which may have been considerably earlier in date than MUL.APIN itself.[6] Although this is possible, several arguments count against this conclusion. First, the astronomical data throughout MUL.APIN are remarkably consistent between sections.[7] We would not necessarily expect that, if the work was put together from already existing texts, all of those texts would reflect a unified body of astronomical knowledge. Second, we know of no examples of earlier texts that contain exact parallels to sections of MUL.APIN. It seems more likely, therefore, that the whole of MUL.APIN was composed at a single moment in time, by a single author. This author certainly drew on earlier knowledge to produce his text, but did not simply edit together existing textual material. In composing MUL.APIN, the author attempted to produce a single, concise text that covered all of the topics of concern in the astronomy of the period.

As discussed by Watson and Horowitz (2011), the macro structure of MUL.APIN reflects not only an increasing complexity of topic as we move through the work, from simple star lists at the beginning to mathematical schemes and procedures for the length of the shadow cast by a gnomon and the daily change in the duration of lunar visibility towards the end, but also a parallel increasing complexity in the conceptual framework and language of the material. For example, we move from simple spatial relationships between two objects (e.g. one star in front of another) to more complex, abstract spatial relationships (e.g. the cardinal directions), and from third person statements to second person procedures in which the reader is instructed to do something, not just read the text. Watson and Horowitz further argue that this ordering of topics in MUL.APIN reflects the history of Babylonian astronomical activity, beginning with listing stars and moving

6 For example, Hunger and Pingree (1989: 9).

7 Indeed, there is only one clear contradiction within the text: in the list of dates of the first visibilities of stars in I ii 36 – I iii 12, the stars Eridu and the Raven are stated to have their first visibility on the 10th of Month VI, and the star ŠU.PA to have its first visibility on the 15th of Month VI. However, in the list of stars that culminate at the moment of the first visibility of another star, Eridu and ŠU.PA are said to have their first visibilities together on the 15th of Month VI (the first visibility of the Raven is not mentioned).

on to procedures for calculating intercalations and astronomical phenomena. We find this conclusion problematical, however, first because it assumes that science progresses in a direct, positive direction, from less accurate to more accurate, and from listing to procedures; second, because it does not fit in very well with what we know of the history of early Babylonian astronomy where, for example, numerical schemes that model the variation in the length of day and night are known from roughly the same time period as the earliest star lists; and third, because it projects on to the ancient scribe who composed MUL.APIN a modern concern with placing things in historical sequence. In our opinion, the ordering of topics within MUL.APIN can be better explained by the needs of the text itself. For example, the intercalation rules in II Gap A 8 – II ii 20 rely upon the list of dates of the rising of stars in I ii 36 – I iii 12.

Basic concepts and methods

Stars and constellations

The Babylonian night sky was populated by a large number of celestial objects that were designated by the Akkadian word *kakkabu*, normally translated into English as ‘star’; *kakkabu*, however, is used to refer to a large range of celestial objects, rather than just single fixed stars. In addition to individual fixed stars, *kakkabu* could be used to refer to a constellation, a group of stars that constitute part of a constellation, or a planet, as well as transitory objects such as comets and meteors. Within MUL.APIN, *kakkabu* usually refers to individual stars, groups of stars, or constellations. Unless otherwise noted, we follow the convention of the text in referring to all of these as ‘stars’.

By the time of the composition of MUL.APIN, a large number of constellations had been constructed by the fixed stars being grouped into patterns that were then identified with and named after a variety of human (or divine) figures, animals, and objects. These constellations appear in various lists, omen texts, and literary works. Some of the constellations are described in the preserved examples of what have been termed ‘uranology texts’, which give prose descriptions of the constellations.[8] Although the uranology texts clearly post-date the composition of MUL.APIN, there is no reason to suppose that the images of the constellations changed significantly over time.

Individual stars and small groups of stars were often identified as parts of constellations. For example, in addition to naming the Scorpion, MUL.APIN refers to two other stars that are part of the Scorpion: the Chest of the Scorpion and the Horn of the Scorpion. In this example, the stars are named by reference to the larger constellation. Sometimes, stars or small star groups could have individual names and also be part of a larger constellation. For example, within the Stag are two stars or star groups: the Vole, a group of scintillating stars that stand in the Stag’s chest, and the Deleter, a bright red star that stands in its kidney. Cases

8 Beaulieu, Frahm, Horowitz, and Steele (2018).

such as these may suggest that, at some point in Mesopotamian history, there was a process of combining or overlaying on one another two or more traditions of constellations. Such a process may also explain what seem to be alternative traditions of how some star names, which were written using logograms, were read by the Babylonian scholars. For example, the name of the star written ^{mul}UD.KA.DUḪ.A was sometimes read as the Akkadian word *nimru*, 'panther', but in a uranology text this constellation is described as being a clothed human figure with two faces, almost certainly reflecting a literal Sumerian reading of the star name as the 'Demon with the gaping mouth'. Similarly, the star name written ^{mul}EN.TE.NA.BAR.ḪUM was sometimes read as the Akkadian word *ḫabaṣirānu*, 'mouse-like', but in the uranology text it is again said to be a human figure.

Several attempts have been made over the past 120 years to identify Babylonian stars and constellations with their modern equivalents. Only those stars that are used in Late Babylonian observational texts can be identified with certainty; the identity of many other stars and constellations can be guessed at with greater or lesser confidence, based upon their position relative to other stars and constellations, similarities in the names of the stars with those known from Greek and later sources, and visual analogues helped by the descriptive statements found in texts. Recent summaries of possible identifications, including some that are quite speculative, can be found in Hunger and Pingree (1999: 271–277) and Kurtik (2007). We deliberately avoid the question of star identifications in the present work.

The calendar

The Babylonian calendar used throughout the second and first millennia BC was a luni-solar calendar in which the 12 months of the year were defined by the first visibility of the new moon crescent, and the year was kept in line with the seasons by the addition of a thirteenth month slightly more often than once every three years.[9] The Babylonian day began at sunset. In the evening that would begin the thirtieth day, a watch was kept for the new moon. If the new crescent moon was seen, then the day that was just beginning would be renamed as the first day of the new month. However, if it was not seen, that day would remain as the thirtieth day of the current month, and a new month would begin the following evening, irrespective of whether the Moon was seen or not on that day. Thus, months had either 29 or 30 days, and the beginning of the month would not be delayed because bad weather prevented the Moon being seen on the thirty-first evening.

The Babylonian year began in the spring. Because 12 lunar months are about 11 days shorter than the solar year, the first day of the first month of a year will move earlier relative to the equinox (or, put another way, the date of the equinox will move later in the Babylonian calendar) by about 11 days per year, until an intercalation is performed by the addition of an extra month, which will then move the beginning of the next year forward by about 19 days (11 days back

9 It is likely that, for about one hundred years in the late second millennium BC, the Assyrian calendar was purely lunar without intercalation. See recently Bloch (2012) and Jeffers (2017).

plus 30 days forward) relative to the equinox. Thus, in a properly intercalated calendar, the beginning of the year falls within a range of about 30 days relative to the equinox (and relative to a purely solar calendar such as ours). Early in the first millennium, the new year took place before or around the time of the vernal equinox, but, presumably by intention, the beginning of the year was allowed to gradually slip to after the equinox by the beginning of the fifth century BC, after which it was kept stable.[10] The 12 months of the Babylonian calendar are:

Month I	Nisannu
Month II	Ajjaru
Month III	Simanu
Month IV	Du'uzu
Month V	Abu
Month VI	Ululu
Month VII	Tešritu
Month VIII	Araḫsamnu
Month IX	Kislimu
Month X	Ṭebetu
Month XI	Šabaṭu
Month XII	Addaru

Owing to the difficulty of making calendar-based calculations when months can be either 29 or 30 days in length and there may be either 12 or 13 months in a year, from as early as the late third millennium BC, a simplified 'schematic' calendar was often used in both astronomical and non-astronomical (e.g. economic) calculations.[11] In the schematic calendar, months are assumed to always contain 30 days, and the year to contain 12 months, making a total of 360 days in a year. It is important to stress that the schematic 360-day year never replaced the luni-solar calendar as a true calendar used in everyday life. Instead, the schematic calendar existed purely as a simplification of the true calendar, both to make calculation easier and to provide a fixed framework to place events (in our case, astronomical phenomena) in a schematic fashion. The schematic calendar already appeared in an astronomical context in texts that date to the Old Babylonian period, well before the composition of MUL.APIN. In those texts, the solstices and equinoxes are placed on the 15th days of Months III, VI, IX, and XII. In MUL.APIN and texts that follow it, however, the solstices and equinoxes are placed one month later, on the 15th of Months I, IV, VII, and X. The reason for this one-month shift in the dates of the solstices and equinoxes between the Old Babylonian and later texts is unknown. The schematic calendar is used extensively throughout MUL.APIN, in contrast to the true luni-solar calendar, which only appears in the context of intercalation rules.

10 Britton (2007).
11 For a summary of the use of the schematic calendar, see Brack-Bernsen (2007).

Numbers and quantities

The commonest types of number found in MUL.APIN are what are called 'quantities', that is, concrete numbers accompanied by a metrological unit that unambiguously represent the magnitude of a measurable item. Three types of quantity with their associated metrologies appear in MUL.APIN: intervals of time, weights, and lengths. Time intervals of less than a day are measured in bēru (DANNA), UŠ and NINDA, where there are 12 bēru in a day, 30 UŠ in a bēru, and 60 NINDA in an UŠ:

	12		30		60	
Day	↔	bēru	↔	UŠ	↔	NINDA

Weights are expressed in minas (MA.NA) and shekels (GÍN), where there are 60 shekels in a mina:

	60	
mina	↔	shekel

Lengths are expressed in cubits (KÙŠ).

The second type of number found in MUL.APIN is written using the floating-point sexagesimal place value system. In this system, each place is a factor of 60 larger than the place that follows it, but there is no indication of absolute magnitude. In our translation, we separate sexagesimal places using a comma. A number such as 23,5,56 can therefore be understood as $(23 \times 60^2) + (5 \times 60) + 56$ or $(23 \times 60) + 5 + (56 \times 60^{-1})$, or any multiple of 60 greater or smaller. In our commentary, we sometimes indicate the implied magnitude of a sexagesimal number by using a semicolon between integers and fractions.

In MUL.APIN, the floating-point sexagesimal place value system only appears within procedures as part of a calculation, never in the presentation of a piece of data. This is in accord with the use of the sexagesimal place value system within Babylonian mathematics, where it is used as an intermediary stage in performing calculations, but the initial problem and the final result are given as quantities with units.

Zigzag functions

A common mathematical tool employed in MUL.APIN, and within Babylonian astronomy more generally, is the zigzag function. Zigzag functions are used to model periodic variations by means of linear increases and decreases between maximum and minimum values in uniform steps. For example, the scheme for the variation in the time interval from sunrise to the rising moon on the fifteenth day of the month over the course of the year presented in II ii 43 – iii 12 follows a zigzag function, with a minimum value of 8 UŠ and a maximum value of 16 UŠ:

Month I	12 UŠ
Month II	10 UŠ 40 NINDA
Month III	9 UŠ 20 NINDA
Month IV	8 UŠ
Month V	9 UŠ 20 NINDA
Month VI	10 UŠ 40 NINDA
Month VII	12 UŠ
Month VIII	13 UŠ 20 NINDA
Month IX	14 UŠ 40 NINDA
Month X	16 UŠ
Month XI	14 UŠ 40 NINDA
Month XII	13 UŠ 20 NINDA

Each month, the time interval decreases by 1 UŠ 20 NINDA, until it reaches the minimum (*m*) of 8 UŠ, after which it increases by the same increment until it reaches the maximum (*M*) of 16 UŠ, after which it decreases again, so that the whole sequence begins again after 12 months. We refer to the increase per step as the difference (*d*) of the zigzag function. In this example, it takes 12 steps, or 12 months, to complete a full cycle of the sequence and return both to the same value and the same direction of increasing or decreasing values. Twelve months therefore constitute the *period* of the function (the interval in time after which the function repeats), and 12 steps constitute the function's *number period* (the number of steps after which the function repeats). In many zigzag functions used in later mathematical astronomy, the two periods are not equal: in such cases, the period of the function is not an integer; the function will not hit the minimum and maximum values in each cycle, because the difference between the minimum and maximum values is not an integer multiple of the function's difference *d*; and the number period will be significantly larger than the period, because it takes many cycles of increasing and decreasing values before the return to the same value. However, in MUL.APIN and other texts of early astronomy, the period and the number period are always equal, and the function reaches the maximum and minimum each cycle.

The place of MUL.APIN within Babylonian astral science

MUL.APIN is part of an astronomical tradition in Babylonia that stretches back to the early second millennium BC. Our knowledge of the earlier periods of Babylonian astral science, however, is largely dependent upon cuneiform tablets that were written in the eighth century BC or later. Although the content of these sources broadly accords with those of the few astronomical tablets preserved from earlier times, it is far from certain whether they provide us with an accurate picture of astronomical activity in the second and early first millennia BC. Put simply, the texts that are available to us are those that someone in the Neo-Assyrian and later periods considered worth copying, and therefore reflect the interests and biases of these late scribes. It is possible, for example, that whole other aspects of astronomical practice – for example, making and recording astronomical observations – existed but were not transmitted down into the late period. Thus, any characterizations of early Babylonian astronomy must remain tentative and preliminary.

Despite these words of caution, it is possible to identify several themes within early Babylonian astral science: the use of simple numerical schemes to model the variation of the length of day and night; the grouping of stars into three 'paths' associated with the gods Enlil, Anu, and Ea; the development of collections of celestial omens; and the use of the 360-day schematic calendar. Numerical schemes for the length of day and night are known from an Old Babylonian (early second millennium BC) tablet, BM 17175+17284,[12] the so-called 'Three Stars Each' texts,[13] the oldest known example of which dates to the twelfth century BC, and the fourteenth tablet of the celestial omen series *Enūma Anu Enlil*.[14] These schemes all assume a linear variation in the length of day and night between extremes in the ratio of 2:1, with the solstices and equinoxes placed in the middle of Months III, VI, IX, and XII of the schematic calendar. *Enūma Anu Enlil* tablet 14 also includes a scheme for the variation in the duration of visibility of the Moon over the course of a schematic equinoctial month: it assumes that the daily change in the Moon's visibility is equal to one-fifteenth of the length of night. The Three Stars Each texts contain lists of twelve stars in each of the three paths. Three stars, one from each path, are assigned to a month in the schematic calendar. These months are probably to be understood as the month in which the star makes its first appearance before sunrise (first visibility). Some of these texts add sections listing stars that rise and set simultaneously. Tablet 51 of *Enūma Anu Enlil* contains omens that utilize the lists of stars in the Three Stars Each texts.[15] Omens from a wide range of other types of celestial phenomenon, including the appearance of the Moon, lunar and solar eclipses, the appearance of the Sun, planetary phenomena, and metrological phenomena, are listed in other tablets of *Enūma Anu Enlil* – a large composition written on about seventy tablets – and its predecessors.[16]

All of the types of material contained in the texts just described are found in MUL.APIN as well: numerical schemes for the length of daylight and the duration of visibility of the Moon, star lists, and celestial omens. Furthermore, MUL.APIN and this other material share several basic principles such as the centrality of the schematic calendar and basic parameters, such as the 2:1 ratio for the length of the longest to the shortest day and the factor of one-fifteenth connecting the length of night and the daily change in the duration of visibility of the Moon. MUL.APIN goes further than this other material, however, by adding additional topics such as intercalation and the length of shadow cast by a gnomon, and by providing more precise information such as exact dates for the first appearance of stars, rather

12 Hunger and Pingree (1989: 163–164).
13 Horowitz (2014).
14 Al-Rawi and George (1991–1992).
15 Reiner and Pingree (1981).
16 For a survey of *Enūma Anu Enlil* and related material, see Koch-Westenholz (1995).

than simply the month in which this was expected to occur. Furthermore, there is one crucial difference between MUL.APIN and the Three Stars Each, *Enūma Anu Enlil* Tablet 14 and BM 17175+17284: MUL.APIN places the solstices and equinoxes in the middle of Months I, IV, VII, and X, whereas these other texts place them one month earlier. These two factors, the greater scope and precision of MUL.APIN and the change in the placement of the solstices and equinoxes in the schematic calendar, suggest, although do not prove, that MUL.APIN was composed later than these other texts.

MUL.APIN, the Three Stars Each, *Enūma Anu Enlil*, and similar texts present a fairly coherent picture of early Babylonian astronomy. These texts are all primarily descriptive rather than offering procedures for making astronomical calculations or recording accounts of specific observations. They present an overarching, largely self-consistent description of the universe that is mathematically ordered around the 360-day schematic calendar. Although based in part upon knowledge of observed astronomical phenomena, this description is not primarily empirical, and it is highly unlikely that observations were made specifically in order to produce this description. Rather, accumulated knowledge of simple astronomical phenomena that are easily seen without particular observations were combined with basic mathematical models such as the schematic calendar and the zigzag function, resulting in a description of the universe that, although based in astronomical reality, is simplified and schematized in order to produce a coherent model. One consequence of this simplification is that some parts of the resulting model are not very accurate. The clearest example of this inaccuracy is the 2:1 ratio for the length of longest to shortest day, which is a gross exaggeration for the latitude of either Babylonia or Assyria. Mathematical simplicity and the coherence between different parts of the overall description of the universe seem to have been given priority over accuracy here.[17] Furthermore, some of the gross inaccuracies in MUL.APIN may have been less important to the text's composer and reader than we tend to project on to them. Although the 2:1 ratio may be particularly bad, the function for the duration of visibility of the Moon that is derived from it, which may have been more important to the Babylonians, is not as bad.

The descriptive nature of MUL.APIN and other astronomical texts from the early period and the seeming inaccuracy of some of the contents lead to the question of what these texts were for. This question has no single answer: the texts almost certainly had a different function when they were written to the role they played in the late first millennium, for example. Two diametrically opposing views of how to understand the purpose of early Babylonian astronomy have been put forward in recent years. Brown (2000) has argued that MUL.APIN, the Three Stars Each, and other early texts present a model for an 'ideal' universe against which reality can be judged, with agreement being a positive omen and disagreement a negative omen. Brown's argument draws support from the story of the formation of the heavens in the Babylonian creation epic *Enūma Eliš*. The fifth tablet of this epic describes a universe that is created with a repeating order founded around a

17 Brown (2000).

30-day month and a 12-month year, exactly the schematic calendar used in early astronomical texts. Furthermore, *Enūma Eliš* makes a direct allusion to the Three Stars Each texts. Brown's argument is further supported by evidence from reports of divinatory practice that, for example, show that 29-day months were often considered unfavourable, whereas 30-day months were favourable. In Brown's interpretation, MUL.APIN was not intended to be used (and was not used) to calculate astronomical phenomena in the context of making astronomical predictions, but rather to provide an ideal that could be compared with observed reality purely for divinatory purposes. Brack-Bernsen (2005), however, argues that MUL.APIN was intended from its creation to be used to make astronomical (in the modern sense) predictions. In her view, the schemes that use the 360-day calendar provide a simple way to calculate phenomena that can then be adjusted to fit the actual luni-solar calendar by the two calendars being tied together through the dates of phenomena such as the solstices and equinoxes. Contrary to Brown's view, these two interpretations need not be mutually exclusive: the schemes found in MUL.APIN may have been used both to provide an ideal against which to judge reality for divinatory purposes and to simplify the calculation of astronomical phenomena by using schemes based upon the simple schematic calendar and nice numerical values for key parameters. Furthermore, it is quite possible that different readers of the text read it in different ways and used it for different purposes.

Our earliest sources for MUL.APIN date to the Neo-Assyrian period. A large number of tablets containing astronomical and astrological material are known from the last Assyrian capital of Nineveh, the earlier capitals of Assur and Kalhu, and other Assyrian cities, including Huzirina in Anatolia. In addition to MUL.APIN, these texts include works that can be thought of as standard reference works, such as copies of the celestial omen series *Enūma Anu Enlil* and other related omen material and commentaries, the Three Stars Each texts, and a variety of different star lists. There are also texts that are the result of astronomical and astrological practice, in particular, a large number of letters and reports sent by scholars to the kings Esarhaddon and Assurbanipal that concern the ominous interpretation of observed celestial phenomena. MUL.APIN was clearly already a well-known standard text by this period: it is referred to by name in a list of compositions (perhaps a library catalogue; K 12000d) and is mentioned as among the texts being copied for the king's library in a letter sent by the scholar Akkullanu to the king (Parpola 1993: No. 62). Passages from MUL.APIN are quoted in a handful of letters and reports (Hunger 1992: No. 507; Parpola 1993: No. 362), including one that identifies MUL.APIN as the source of the quotation (Parpola 1993: No. 62). A long quotation from MUL.APIN I iv 1–3 also appears at the head of a list of the distances between *ziqpu* stars (K 9794 and its late duplicate AO 6478).[18] Also from this period, we find excerpt texts that quote

18 The passage is lost on K 9794 but preserved on the duplicate AO 6478 from Seleucid Uruk. So far as they are preserved, the two tablets are exact duplicates, even in layout, and so there is no reason to believe that this passage was not found on K 9794.

whole sections from MUL.APIN: our sources NN and UU (see Table of sources), both from Assur, excerpt, respectively, the sections containing the scheme for the length of night and the duration of visibility of the Moon (II ii 43 – iii 12) and the intercalation scheme (II Gap A 8 – ii 6, although UU is broken at the beginning and so begins at II Gap A 13, and it ends unexpectedly at II ii 4 rather than at II ii 6). A later Babylonian excerpt, source M from Nippur, contains the list of the dates of first appearances of stars (I ii 36 – I iii 12; M is broken at the beginning and preserves only line I ii 42 onwards). These excerpt texts seem to extract from MUL.APIN the parts that are of most practical use, namely those that have to do with intercalation and the visibility of the Moon. Evidence from letters sent by scholars to the king show that one consideration in deciding if an intercalation was necessary was whether the first appearance of stars occurred at their expected time. Some of these letters quote visibility dates from I ii 36 – iii 12, and these dates were themselves used in the intercalation scheme described at II Gap A 8 – ii 6. The excerpt texts, therefore, provided ready access to those parts of MUL.APIN that were most commonly needed by the scholars. They also provide a strong indication that at least parts of MUL.APIN did indeed have a practical use and were not used only for divination.

Despite the existence of many other texts containing lists of stars that circulated during the Neo-Assyrian period, the repertoire of stars presented in MUL.APIN seems to have taken on a special status. For example, the uranology texts draw exclusively upon the constellations contained in MUL.APIN, and often quote from MUL.APIN their descriptions.[19] This again points to the central place held by MUL.APIN in early Mesopotamian astronomy.

Sources from Babylon and, to a lesser extent, Uruk and other cities show that extensive astronomical activity was undertaken in Babylonia from the latter part of the eighth century BC onwards. Babylonian astronomy quickly developed into a multifaceted endeavour that included the precise and systematic observation of individual celestial phenomena; the development and application of methods for the prediction of future phenomena by applying lunar and planetary periods to past observations; the construction of systems of mathematical astronomy that allowed certain lunar and planetary phenomena to be calculated using purely numerical methods, without direct empirical input; and new forms of astrology, including numerical schemes associating calendar dates with medical ingredients and cultic sites and systems of personal astrology. These new types of astronomy and astrology led to the production of new genres of astronomical texts, such as the Astronomical Diaries, which contain reports of night-by-night observations of certain celestial phenomena; Goal-Year Texts, which assemble observational data for predicting future astronomical phenomena; Almanacs and Normal Star Almanacs, which contain the results of these predictions; tables containing astronomical data calculated using the various systems of mathematical astronomy and

19 Beaulieu, Frahm, Horowitz, and Steele (2018).

procedure texts that explain how to make these predictions; and horoscopes that contain astronomical data for around the date of birth of an individual.

Given these extensive developments in Babylonian astronomy, it might be expected that MUL.APIN would have become redundant. The simple schemes modelling celestial phenomena, which relied upon the 360-day schematic calendar, would have quickly been seen to be crude and inaccurate once precise observations were systematically made and recorded, and the newly developed systems of mathematical astronomy were both more ambitious and more accurate than anything that could be achieved using the type of astronomy found in MUL.APIN. However, MUL.APIN continued to be copied and quoted until at least the last couple of centuries BC. Roughly half of the known sources for MUL.APIN are Late Babylonian, and quotations of the list of the dates of first visibilities of stars (I ii 36 – I iii 12), the statement concerning the daily change in which stars are visible (I iii 49 – I iii 50), and the statement that intercalation once every three years means that there are the equivalent of 10 extra days per year (II ii 13 – II ii 17) are known from other Late Babylonian astronomical texts.

MUL.APIN was not just copied, however, which could have implied that it survived only out of an antiquarian interest: new texts that drew directly from the astronomy of MUL.APIN were composed as well. These new texts continued the tradition of schematic astronomy, founded on the 360-day schematic year and the basic principles and parameters used in MUL.APIN, and include further expansions of the scheme for the length of shadow cast by a gnomon,[20] the lunar visibility scheme,[21] and the list of the dates of the first appearances of stars. Perhaps most surprisingly, a detailed mathematical scheme that gives the culmination of positions at or at specified distanced behind *ziqpu* stars at sunrise and sunset was developed, based upon the schematic calendar and the MUL.APIN scheme for the length of daylight. Remarkably, this scheme was then combined with the newly developed concept of the zodiac as a way of dividing the path of the Sun, Moon and planets into twelve equal parts to produce a so-called 'rising time scheme' that correlates the time it takes for a zodiacal sign to rise across the horizon with the range of distances behind *ziqpu* stars that culminate over the same time period.[22] This example shows that the astronomy of MUL.APIN remained part of a living tradition that existed alongside, and on occasions interacted with, the (what to us may seem incompatible) new developments in Babylonian astronomy during the last eight centuries BC.[23]

The continued importance of MUL.APIN in the late period is further demonstrated by a recently identified composition, partially preserved in at least two copies, that seems to rework sections of MUL.APIN, expanding on the

20 Steele (2013).
21 Brack-Bernsen and Hunger (2002: 72–75).
22 Steele (2017).
23 Steele (in press a).

information presented in the text and rewriting it in a deliberately different form.[24] Only a small fraction of the work can be reconstructed at present, but the preserved parts expand upon the list of dates in the schematic calendar of the first visibilities of stars in MUL.APIN I ii 36 – iii 12, the discussion of intercalation in II ii 13–17, and the scheme for the duration of lunar visibility in II ii 43 – II iii 15. Interestingly, the composition seems to parallel the overall structure of MUL.APIN, highlighting its direct relationship with the earlier text.

MUL.APIN holds an important place in the history of Babylonian astronomy. For the scholars of the Neo-Assyrian period onwards, the text represented the culmination of 'early' Babylonian astronomy, presenting a complete and self-consistent model of the celestial world. But, far from representing the end of this 'early' tradition of astronomy, MUL.APIN then became the foundation for later developments in schematic astronomy that existed alongside other types of astronomy in Babylonia.

Date and place of composition

The history of the composition of MUL.APIN – who composed it, when, and where – unfortunately remains uncertain. The earliest preserved copies date to the early seventh century BC: the colophon of source HH says that this tablet, which comes from Assur, was written in the eponym year of Sennacherib, corresponding to 687 BC, and the other Assur sources come from archives that date to around the same time. Similarly, archival context implies that the tablets from Nineveh were copied within a couple of decades of the middle of the seventh century BC, and that the tablets from Huzirina were written towards the end of the eighth century or during the first three-quarters of the seventh century BC.[25] The wide distribution of copies of the text and the fact that it was a composition that was referred to by name in other tablets from this period, however, suggest that MUL.APIN was not a new text at this time. It seems reasonable to suppose, therefore, the MUL. APIN could not have been composed any later than about 750 BC. How much earlier, however, is difficult to establish. The only firm piece of evidence placing a constraint on the age of MUL.APIN is the mention of the Kassites in line II ii 20, which places a *terminus post quem* for its composition in the middle of the second millennium BC when the Kassites gained control of Babylonia. Thus, the text could, in principle, have been composed any time between the middle of the second millennium and the end of the first quarter of the first millennium BC.

Two approaches have been used by earlier scholars to attempt to place narrower constraints upon the date of composition of MUL.APIN. Pingree,[26] Watson and

24 The work is partially preserved on BM 36315+37517, BM 36382, BM 37175, and BM 37200 and will be published in due course by J. M. Steele. For a description of these texts and a preliminary analysis, see Steele (in press a).

25 Pedersén (1995).

26 Reiner and Pingree (1981: 72–75) and Hunger and Pingree (1989: 11).

Horowitz,[27] and others have argued that it is possible to reconstruct a sequence of texts containing star lists, beginning with the Old Babylonian 'Prayer to the Gods of the Night', through the Three Stars Each texts (one of which is preserved on a tablet from the twelfth century BC), to MUL.APIN, with increasing accuracy in the sequence of first appearances of the stars. These authors therefore conclude that MUL.APIN was almost certainly written after the twelfth century. Although this conclusion is attractive, and very likely correct, there are methodological problems with this approach to dating. First, it assumes that a text that is astronomically more accurate is necessarily later than one that is less accurate. But this need not have been the case: accuracy in the modern sense may not have been the primary motivation underlying any of these lists. Second, the existence of a copy of the Three Stars Each text dating to the twelfth century BC does not imply that the Three Stars Each text was composed at that time: it is possible that the tablet contains a copy of a much earlier text.

The second approach to dating the composition of MUL.APIN has been to try to find the date that best fits some of the astronomical data contained in the composition. Most attempts have used either the list of dates of the first appearances of stars in I ii 36 – I iii 12 or the list of intervals of days between the first appearances of stars in I iii 34 – I iii 48, or both. Because the date of the first appearance of a star is dependent upon its celestial longitude and latitude and upon the geographical latitude of the observer, it should, in principle, be possible to find a date and latitude that provide the best agreement with modern computation. There are three obstacles to finding a correct result, however. First, the dates and the intervals in days given in MUL.APIN are reported using the schematic 360-day calendar, rather than a calendar that uses the true length of the solar year. Second, many of the 'stars' given in these lists are constellations or star groups. Does the first appearance of a constellation refer to the first appearance of one star of the constellation, or the appearance of enough stars to make the constellation readily identifiable, or even the appearance of the complete constellation? And third, can the ancient star names be confidently identified with modern counterparts, ideally without relying upon the list that is being analysed?

The first detailed attempt to date MUL.APIN astronomically was undertaken by van der Waerden (1949). He considered the intervals in days between the first appearances of the first star of a constellation and the first appearance of Sirius, concluding that the best fit was for dates between 1300 and 1000 BC and for an observer at the latitude of Babylon. Using a somewhat different set of identifications of stars, Papke (1978) proposed a much earlier date of around 2300 BC as best fitting the intervals between the first appearances of stars. Such an extremely early date does not seem plausible, however, and many of Papke's assumptions concerning the identification of stars do not hold up to close scrutiny. Reiner and Pingree (1981: 6) attempted to identify the Babylonian constellations visually using the Zeiss planetarium at the Adler Planetarium in Chicago, arriving at the

27 Watson and Horowitz (2011: 3–6).

conclusion that the best fitting date for the various star lists in MUL.APIN is about 1000 BC, and that the observations were made in Nineveh. Reiner and Pingree's approach relies heavily upon their own visual impressions and upon the (untestable) accuracy of the planetarium. More recently, de Jong (2007) has repeated the type of analysis done by van der Waerden, but using more detailed astronomical models of stellar visibility. De Jong concludes that the observations underlying the two lists of MUL.APIN can be dated to about 1300 BC with an uncertainty of about 150 years. He also concludes that the observations were probably made in Babylon, and that Nineveh can be excluded as a possible place of observation.

Although de Jong's analysis is the most convincing yet published, it still suffers from methodological problems that, in our view, cannot be overcome. First, when mapping dates in the text, which are given in the schematic 360-day calendar, on to the solar year, it is necessary either to alter those dates by stretching the 360-day year so that it reaches the length of the solar year (about 365¼ days) or to assume a period of 5¼ 'empty' days somewhere in the year (e.g. at the end). Although the effect of this assumption will be fairly small, it may nevertheless be sufficient to push the derived date too early or late. Second, and more serious, all attempts to use the dates of first appearances and the intervals between them acknowledge that the dates are given only to a precision of 5 days. However, they also tacitly assume that the dates have been obtained by simply rounding the date obtained from observation to the closest 5-day interval, and that the errors caused by such rounding balance out. In our opinion, this assumption is not justifiable on the basis of the available evidence. We do not know what strategies or techniques would have been used by the ancient scholars. Systematic rounding in one direction (e.g. always rounding up rather than rounding down or up to the nearest 5-day interval) would cause a significant bias in the data. Furthermore, it is possible that the dates given in the text were adjusted to make them fit into a scheme, rather than simply rounded, which would certainly bias the data. And finally, too many assumptions need to be made in the identification of stars and the interpretation of what first appearance means when constellations are mentioned.

Our conclusion must therefore be rather unsatisfactory: we simply do not know when MUL.APIN was composed. MUL.APIN's placement of the solstices and equinoxes one month later than in a text we can firmly date to the Old Babylonian period and in *Enūma Anu Enlil* and the Three Stars Each texts suggests that MUL.APIN is a later composition, and the fact that MUL.APIN was well known by the end of the eighth century BC provides a broad constraint on the date of the text, placing it in the late second or early first millennium BC, but no more than that. We lean towards an early first millennium BC date, but purely on impressionistic grounds.

We similarly have no definitive evidence for the place of composition of the text, although there are enough hints in the text to point towards a Babylonian rather than an Assyrian origin. An Assyrian origin would have important consequences for our understanding of scholarly activity in Assyria at this period,[28]

28 George (1991).

which is often downplayed in modern scholarship owing to lack of evidence and a default assumption that assigns scholarly developments to Babylonia when there is no compelling evidence to the contrary. As with establishing its date, the methodological problems with trying to answer the question of where MUL.APIN was composed by means of astronomical analysis are, in our opinion, too great to allow a firm conclusion to be drawn.

Three small pieces of non-astronomical evidence, however, provide modest support for concluding that MUL.APIN was a Babylonian composition. First, the three reigns associated with intercalary months (Šulgi, the Amorites, and the Kassites) in lines II ii 18 – II ii 20 make more sense from a Babylonian perspective than an Assyrian one: Šulgi was an important Sumerian king during the third dynasty of Ur, the Amorites ruled southern Babylonia during the early second millennium BC, and the Kassites ruled Babylonia during the second half of the first millennium BC. None of these kingdoms extended into Assyria. Second, if MUL.APIN was composed in the late second millennium BC in Assyria, as suggested by Pingree, this would almost coincide with the period in Assyrian history when intercalation was not performed in the Assyrian calendar (in contrast to the Babylonian calendar). It would therefore be difficult to understand why several intercalation rules are presented in the work. Finally, there are a few words in the text that are decidedly Babylonian: that is, they would be written differently in the Assyrian dialect:

I ii 29: be-let (Ass. bēlat)
I iii 8 and iii 50: li-la-a-ti (Ass. li-li-a-ti)
I iv 3: immaru (Ass. immuru)
I iv 38: annûtu (Ass. anniūtu)
II iii 36: lidekki (Ass. ludakki)

We therefore lean towards a Babylonian rather than an Assyrian origin for the work.

In conclusion, therefore, it seems likely that MUL.APIN was composed sometime in the late second or (more likely) early first millennium BC in Babylonia.

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